# Phosphine-Catalyzed Annulation of Designed Enones and Ynones

**ATANU MONDAL**

*A thesis submitted for the partial fulfillment of*
*the degree of Doctor of Philosophy*

Department of Chemical Sciences
Indian Institute of Science Education and Research Mohali
Knowledge City, Sector 81, SAS Nagar, Manauli PO, Mohali, 140306, Punjab, India.

**July 2022**

*Dedicated to*
*those whose motivation*
*paved the way for my progress*

# Declaration

I do hereby declare that the work presented in this thesis titled "***Phosphine-Catalyzed Annulation of Designed Enones and Ynones***" has been carried out by me under the supervision of **Dr. S. S. V. Ramasastry** in the Department of Chemical Sciences, Indian Institute of Science Education and Research (IISER) Mohali, India. This work has not been submitted in part or full for a degree, diploma, or fellowship to any other university or institute. Whenever contributions of others are involved, every effort is made to indicate this clearly with due acknowledgements of collaborative work and discussions. This thesis is a bona fide record of original work done by me, and all sources listed within have been detailed in the bibliography.

**Atanu Mondal**

Date:

Place: IISER Mohali

In my capacity as the supervisor of the candidate's thesis work, I certify that the above statements by the candidate are true to the best of my knowledge.

**Dr. S. S. V. Ramasastry**

*Associate Professor*

*Department of Chemical Sciences*

*Indian Institute of Science Education and Research Mohali*

Date:

Place: IISER Mohali

# Contents

# Acknowledgements

I would like to take this opportunity for acknowledging some very special people who are integral parts of my journey this far.

At the very outset, I want to express my deepest gratitude to my supervisor Dr. S. S. V. Ramasastry, for his inspiring guidance, insightful advice, and constant encouragement throughout the present investigations. I am thankful to him for being supportive in the tough times during my Ph.D. journey and for believing in me to accomplish my work. It was indeed an incredible journey altogether as a Ph.D. student with the ups and downs of organic synthesis. It has been a great privilege and honor to be associated with him.

Besides my supervisor, I am thankful to my doctoral committee members Dr. R. Vijaya Anand and Dr. V. Sugumar, for spending their valuable time and offering valuable suggestions during the yearly assessment of my thesis work.

It is my privilege to thank the present director of IISER Mohali, Prof. Jayaraman Gowrishankar, and former directors of IISER Mohali, Prof. D. P Sarkar and Prof. N. Sathyamurthy, for providing world-class research infrastructures.

I acknowledge the NMR, X-ray, and HRMS facilities of IISER Mohali. I want to thank the convenor of the NMR facility Dr. S. S. V. Ramasastry, for his cooperation. I am grateful to Dr. A. R. Choudhury and Prof. Sanjay Mandal for cooperation in recording X-ray analysis of my samples. Next, I sincerely thank HRMS facility committee members Prof. P. Guptasarma and Dr. S. A. Babu. I am grateful to the current head of the department Dr. Sanjay Singh, and former head of the department Dr. S. A. Babu, and Prof. K. S. Viswanathan and other faculty members of Chemical Sciences for facilitating the use of various departmental instruments and their valuable suggestions.

My extraordinary lab-mates deserve a special thanks for their friendly cooperation and invaluable helps whenever required. I cannot express in words how much fortunate I am to have talented former and current lab members Dr. Seema, Dr. Bishnupada, Dr. Rajendra, Dr. Siddheshwar, Dr. Uttam, Dr. Sonu, Bara, Prashant, Lona, Ketan, Jay Prakash, Dipto, Nirmal, Nisha, Shivam, Shubham, Anwita, Sahil, Komal, Manisha, Jopaul, Shivangi, Pinku, Mrudula, Animesh, Siddhant, Kaushalendra, Raju, Raghu, Dr. Nitul, Dr. Jagdeep, Dr. Vivekanand and Dr. Arshad for maintaining healthy environment and useful discussions in the lab which helped me in learning and understanding various aspects of research. It was really great to work and spend time with all of them as a complete enjoyment package in the busy lab schedule. And I will always relish these memories throughout my life. I wish them great success in every aspect of their life. I thank especially Bishnu Da and Lona (as a perfect friend cum sister) for their

constant support and assistance during this tenure. I am grateful to my co-authors for their contribution to my work. I also thank all the summer trainees and project students who worked on short-time projects in our lab.

It is an excellent privilege to express my sincere regards to all my teachers and lecturers (especially Dr. Tarun Kumar Sarkar, late Dr. Dinabandhu Kundu, Dr. Rajdeep Mukherjee, Mr. Indradeep Bhattacharya, Mr. Sajal Ghosh, and Mr. Sushanta Ghosh), for their direct or indirect support and motivation which have guided me to reach this far.

I am thankful to my friends in IISER Mohali, especially Joydip da, Anamika, Sonam, Arup, and Yogesh for their heartily support throughout my Ph.D. career in IISER Mohali. I also thank Dr. Mayank, Sandeep, and Labhini for helping in crystal recording and analysis. I am grateful to my friend Suman from IIT Ropar for providing extended support by recording the NMR and HRMS data whenever required. I am also thankful to my college and school friends, especially Akash, Sankarsan, Sandip, Jacinta, Jayisha, Avishikta, Sourav, Vivekananda, Anudipa and Saikat, for their care, love and affection throughout my educational journey.

I acknowledge the technical staff's help and support, especially Mr. Triveni and Mr. Balbir, for their timely help with HRMS and NMR data and non-teaching staff, especially Mr. Mangat and Mr. Bahadur, the department of chemical sciences.

I am grateful to IISER Mohali for providing my doctoral fellowship.

As we are going through a global pandemic (COVID-19), I have a special mention to all the health workers, professionals, and researchers fighting at the forefront and risking their lives.

Finally, I would like to express my heartfelt gratitude to my parents for their eternal blessing, unconditional love, unwavering support, and encouragement in accomplishing my dream. I want to thank my elder brother and twin brother for their support and encouragement and for giving me the space to follow my dream. I have a special mention for Senjuti for her support during the final stage of my Ph.D. journey and also opening a new chapter in my life. Any word of gratitude will fall short for them.

**Atanu Mondal**

18 July 2022

## Summary

The art of constructing complex molecular architecture has encouraged the generation of chemists to synthesize such molecules possessing significant biological and medicinal attributes. Inspired by the catalytic systems in nature, chemists looked into imitating biocatalytic processes. This led to the birth of organocatalysis, where small organic molecules bear the minimal functionalities that can activate the substrate and affect the reactions. Organocatalysts are less toxic, readily available, and less sensitive to air and moisture than metal catalysts. There are essentially four types of organocatalysts; Lewis bases, Lewis acids, Brønsted bases, and Brønsted acids. N-heterocyclic carbenes, amines, and phosphines are widely employed in catalysis among the Lewis bases. The use of trivalent phosphines as Lewis base significantly impacts organic synthesis for assembling a large variety of molecular frameworks. However, developing general, efficient, and atom-economic organocatalytic methods involving phosphine as a catalyst remains an emerging research area.

The thesis entitled "*Phosphine-Catalyzed Annulation of Designed Enones and Ynones*" describes the efforts towards the development of novel phosphine-catalyzed intramolecular annulation strategies involving designed enones and ynones to construct medium ring-sized carbocycles. The content of the thesis has been divided into three chapters. A brief introduction is provided in all the chapters, the compounds are sequentially numbered (bold), and references are marked sequentially as superscripts and listed at the end of the thesis.

Our ongoing research interest in developing new organocatalytic methods for synthesizing cyclopenta-and cyclohepta-fused arenes and heteroarenes, we have deviced a few organophosphine catalyzed strategies with designed enones and ynones. The first chapter of the thesis describes a phosphine-catalyzed intramolecular vinylogous aldol reaction of $\alpha$-substituted enones to synthesize various cyclopenta- and cycloheptannulated arenes and (hetero)arenes incorporated with two contiguous stereocenters, one of which is an all-carbon quaternary center, in good yields and diastereoselectivities. Interestingly, this result represents the first phosphine-catalyzed intramolecular vinylogous aldol reaction (IVAR) of $\alpha$-substituted enones. To streamline the scope of this methodology, the IVAR adducts were also elaborated to (i) benzo-fused nine-membered carbocyclic systems in two steps *via* base mediated oxy-Cope rearrangement, (ii) synthesis of functionalized indanes which are analogous to echinolactone D and russujaponol F, (iii) interesting classes of 1,3-dienes, 1,3,5- trienes, and 1-yn-3,5-dienes in two steps through acid-catalyzed fragmentation strategy.

To our knowledge, activated alkynes are unusual substrates for the MBH reaction. Therefore, we are inquisitive about the fate of activated alkynes under the typical MBH set up.

The second chapter of the thesis describes a phosphine-catalyzed intramolecular hydroacylation of activated *α,β*-ynones leading to the formation of 2-arylidine-1,3-indanediones in good yields. To our surprise, this reaction represents the first metal-free and organo-catalytic alternative for the intramolecular hydroacylation of activated ynones. Then, this strategy was extended to synthesize a new class of functionally rich dibenzocycloheptadiones in good yields. Indeed, it was the first report to synthesize fused seven-membered carbocycles *via* an intramolecular hydroacylation of *α,β*-ynones. Further, serendipitous organocatalytic approaches for the synthesis of 3-ethynyl-3-hydroxyindanones involving a *δ'*[C($sp^3$)-*H*]-functionalization, and dibenzo[*a,c*]-cyclooctadiones *via ω'*[C($sp^3$)-*H*] functionalization of *α,β*- ynones have also been described. Intriguing mechanistic details governing these processes were elucidated.

The dibenzocycloheptane moiety is the key core of various bio-active natural products and pharmaceutically relevant compounds and plays a unique role in drug discovery programs. The third chapter of the thesis demonstrates an efficient intramolecular MBH reaction to synthesize chiral dibenzo-fused cycloheptanes. Towards this, a phosphine-catalyzed annulative intramolecular Morita-Baylis-Hillman (IMBH) reaction was developed for constructing dibenzocycloheptanes in good yields. Next, we intended to achieve the synthesis of chiral dibenzocycloheptanes. For this purpose, two complementary strategies were considered, i) the racemic biaryl enone-aldehydes were subjected to asymmetric IMBH conditions involving chiral bifunctional phosphine catalyst in 1,1,1,3,3,3-hexafluoroisopropanol (HFIP) solvent and generated the chiral dibenzocycloheptanes with moderate enantioselectivity but in poor yields. ii) axially chiral biaryl enone-aldehydes were subjected to IMBH condition and delivered the chiral dibenzocycloheptanes possessing two chiral elements, axial and central chirality in excellent yields and enantioselectivity.

# List of Abbreviations

| | |
|---|---|
| Ac | acetyl |
| ACN | acetonitrile |
| aq | aqueous |
| atm | atmospheric |
| BINOL | 1,1′-binaphthalene-2,2′-diol |
| Bn | benzyl |
| Boc | *tert*-butyloxycarbonyl |
| brs | broad singlet |
| $^{n}$Bu | butyl |
| $^{t}$Bu | *tert*-butyl |
| calcd | calculated |
| COD | cyclooctadiene |
| Cy | cyclohexyl |
| d | day(s) |
| d | doublet |
| DABCO | 1,4-diazabicyclo[2.2.2]octane |
| DBU | 1,8-diazabicyclo[5.4.0]undec-7-ene |
| DCE | 1,2-dichloroethane |
| DCM | dichloromethane |
| dd | doublet of a doublet |
| DKR | dynamic kinetic resolution |
| DMAP | 4-dimethylaminopyridine |
| DME | 1,2-dimethoxyethane |
| DMF | *N*,*N*′-dimethyl formamide |
| DMSO | dimethyl sulfoxide |
| Dppp | 1,3-bis(diphenylphosphino)propane |
| dq | doublet of a quartet |
| *dr* | diastereomeric ratio |
| dt | doublet of a triplet |
| *ee* | enantiomeric excess |
| eq | equivalents |
| ESI | electron spray ionization |
| FT-IR | Fourier-transform infrared spectroscopy |

| | |
|---|---|
| *Gem* | geminal |
| h | hour(s) |
| HFIP | 1,1,1,3,3,3-hexafluoroisopropanol |
| HPLC | high-performance liquid chromatography |
| HRMS | high-resolution mass spectrum |
| Hz | Hertz |
| IBX | 2-iodoxybenzoic acid |
| ICD | isocupredine |
| *J* | coupling constant |
| KR | kinetic resolution |
| LDA | lithium diisopropylamide |
| LNMP | lithium N-methylpiperazine |
| m | multiplet |
| mg | milligram(s) |
| MHz | megahertz |
| min | minute(s) |
| mL | milliliter(s) |
| mmol | millimole(s) |
| M.P | melting point |
| MS | molecular sieves |
| m/z | mass/charge |
| NMF | N-methylformamide |
| NMR | nuclear magnetic resonance |
| ppm | parts per million |
| $^{n}$Pr | *n*-propyl |
| $^{i}$Pr | isopropyl |
| *p*-TSA | *para*-toluenesulfonic acid |
| q | quartet |
| rt | room temperature |
| s | singlet |
| sept | septet |
| t | triplet |
| td | triplet of a doublet |

| | |
|---|---|
| *tert* | tertiary |
| THF | tetrahydrofuran |
| TMS | trimethylsilyl |
| TLC | thin layer chromatography |

# Chapter 1

## *Phosphine-Catalyzed Intramolecular Vinylogous Aldol Reaction of α-Substituted Enones*

The art of constructing complex molecular architectures has encouraged the generation of chemists to synthesize such molecules possessing significant biological and medicinal attributes. Inspired by the catalytic systems taking place in nature, chemists looked into imitating biocatalytic processes. This led to the birth of organocatalysis, where small organic molecules bearing minimal functionalities activate the substrate and affect the reactions. Organocatalysts are less toxic, readily available, and less sensitive towards air and moisture than metal catalysts. Helped by intuition and persistence, organocatalysis has emerged as one of the most important frontiers in organic synthetic research and has become a powerful tool in constructing complex molecular skeletons.[1] There are essentially four types of organocatalysts; Lewis bases, Lewis acids, Brønsted bases, and Brønsted acids. Among the Lewis bases, N-heterocyclic carbenes (NHCs), amines, and phosphines are widely employed in catalysis.

The use of trivalent phosphines as Lewis base organocatalysts has a significant impact on organic synthesis.[2] One of the salient features of nucleophilic phosphine catalysis is that tertiary phosphines preferentially attack the activated carbon-carbon multiple bonds to form *β*-phosphonium *α*-carbanion species. The very first report came from Rauhut and Currier in the year 1963, where they demonstrated a tributylphosphine catalyzed dimerization of acrylates.[3] Later, Morita and Hillman reported the first phosphine-catalyzed reaction between aldehydes and activated alkenes to generate *β*-hydroxy carbonyls, commonly known as the Morita-Baylis-Hillman (MBH) reactions.[4] Due to its atom-economic and organocatalytic nature, MBH reaction is one of the most useful C-C bond-forming reactions in organic synthesis.[5]

Cyclopentane and cycloheptane frameworks are abundant in a diverse range of natural products, and bioactive molecules, Figure 1.[6] For example, (–)-hybridalactone is a unique marine eicosanoid isolated from the antibacterial extracts of *Laurencia hybrida*. Coriolin, isolated from *Coriolus consors*, inhibits the growth of *Gram-positive* bacteria *Trichomonas vaginalis* and Yoshida sarcoma cell. Taiwaniaquinol A consists of cyclopentane core, isolated from *Taiwania cryptomerioides*, shows potent cytotoxicity against the epidermoid carcinoma (KB) cancer cell line. Brazilin is one of the important bioactive natural products from *Caesalpinia sappan L*. heartwood, having various biological activities, including antibacterial, anti-inflammatory, anti-allergic, and more.

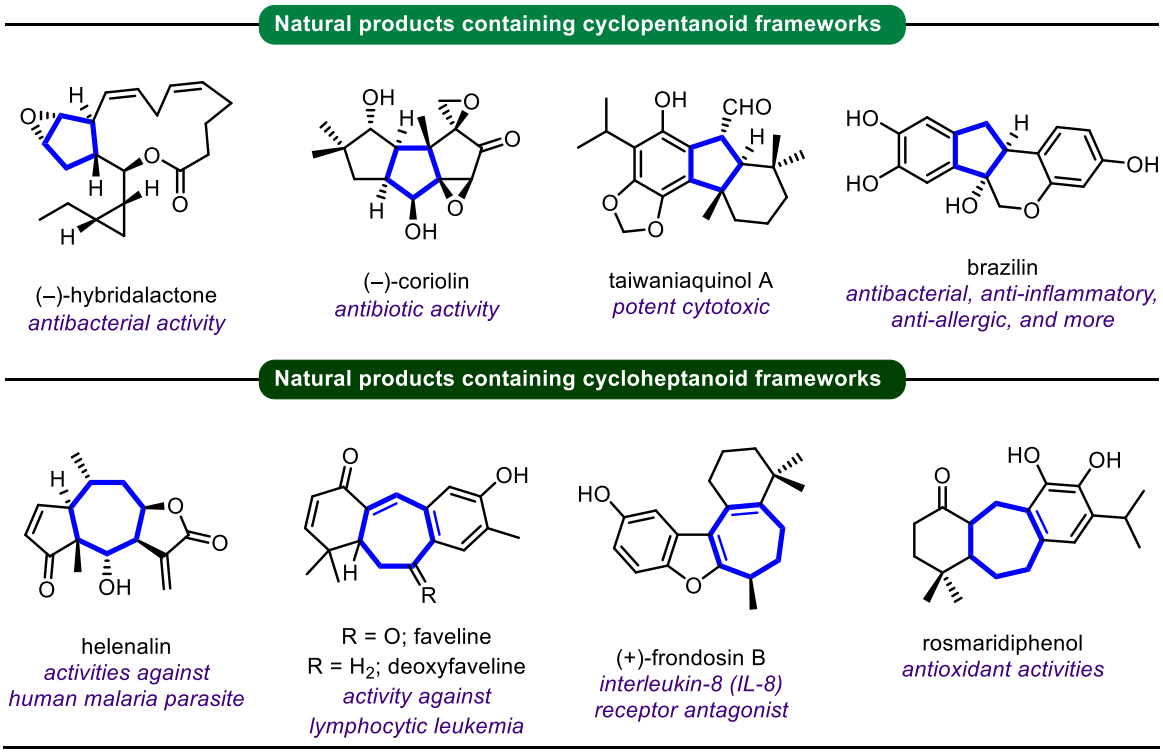
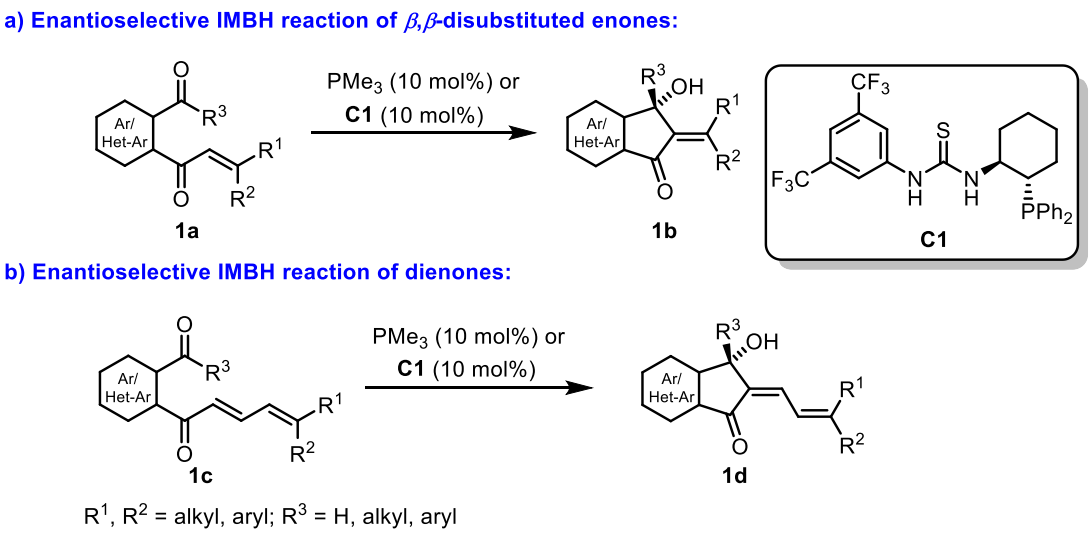



**Figure 1:** Cyclopentane and cycloheptane containing natural products.

Cycloheptane core containing natural products such as Helenalin, a pseudoguaianolide sesquiterpene lactones isolated from *Arnica montana* flowers, exhibits potential activities against the human malaria parasite *Plasmodium falciparum*. Tricyclic benzocycloheptene Faveline, isolated from the bark of *Cnidoscotus phyllacanthus*, was found to show activity against P-338 lymphocytic leukemia. Frondosin B is a tetracyclic terpenoid, acts as an antagonist towards interleukin-8 receptors. Rosmaridiphenol, a icetexane diterpenoid, was isolated from *Rosmarinus officinalis L.* and displays antioxidant activity approaching that of BHT.

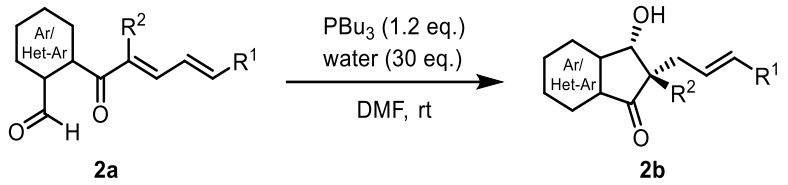
Currently, our research group is focused on developing organophosphine mediated transformations for the synthesis of various useful scaffolds containing fused-cyclopentanes and cycloheptanes.[7] Recently, we have developed a phosphine-catalyzed intramolecular Morita-Baylis-Hillman (IMBH) reaction of sterically and electronically highly demanding $\beta$-mono- and $\beta,\beta$-disubstituted enones **1a** to access cyclopenta[*b*]annulated arenes and heteroarenes **1b**, Scheme 1a.[8] The enantioselective version of it was achieved by using bifunctional catalyst **C1** in combination with HFIP as solvent. In addition, we have also demonstrated an enantioselective organocatalytic IMBH reaction of dienones **1c**, Scheme 1b.[9] This kind of dienones is rarely explored in MBH reaction to synthesize substituted cyclopentanoids **1d**.




**Scheme 1:** Phosphine-catalyzed asymmetric IMBH reactions.

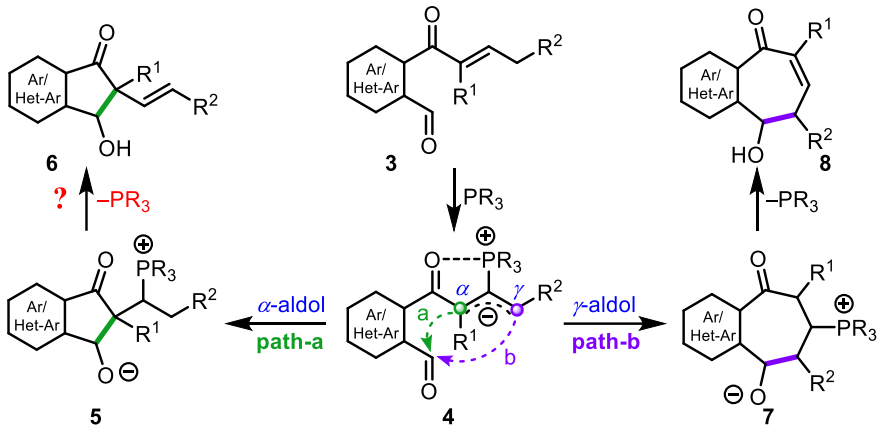
Subsequently, we have shown a phosphine and water promoted diastereoselective intramolecular reductive aldol reaction of $\alpha$-substituted dienone-aldehydes **2a** for the synthesis of cyclopenta-fused arenes and heteroarenes **2b** bearing an all-carbon quaternary centre

(Scheme 2). Interestingly, in this metal-and hydride-free reductive aldol approach, water acts as a terminal oxidant.




**Scheme 2:** Phosphine-mediated reductive aldol reaction of $\alpha$-substituted dienone-aldehydes.

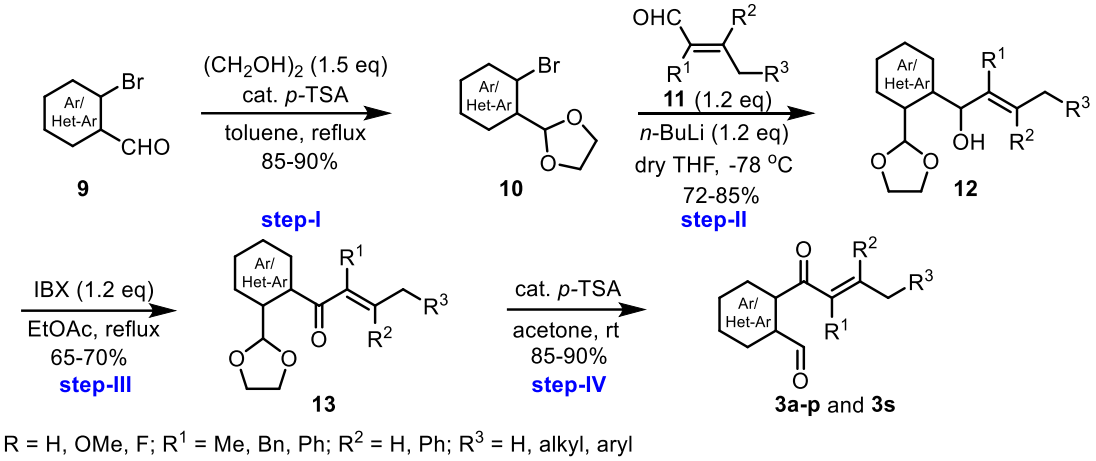
The above-mentioned studies for synthesizing multifunctional cyclopentanoids prompted us to design a new substrate **3** that would lead to a completely different approach to synthesize cyclopentanoids or cycloheptanoids *via* organophosphine catalysis (Scheme 3). We envisioned that the tethered $\alpha$-substituted enone-aldehydes **3** could go through a phospha-Michael addition to generate the zwitterionic species **4**, which could undergo intramolecular aldol reaction *via* path-a ($\alpha$-aldol) leading to fused cyclopentanoids **6**. Although, the ultimate mode of elimination of phosphine for this transformation is not clear at this time. Alternatively, the zwitterionic species **4** can potentially convert to fused cycloheptenones **8** *via* $\gamma$-aldol pathway (path-b).




**Scheme 3:** Our hypothesis towards the phosphine-catalyzed reaction with $\alpha$-substituted enone-aldehydes.

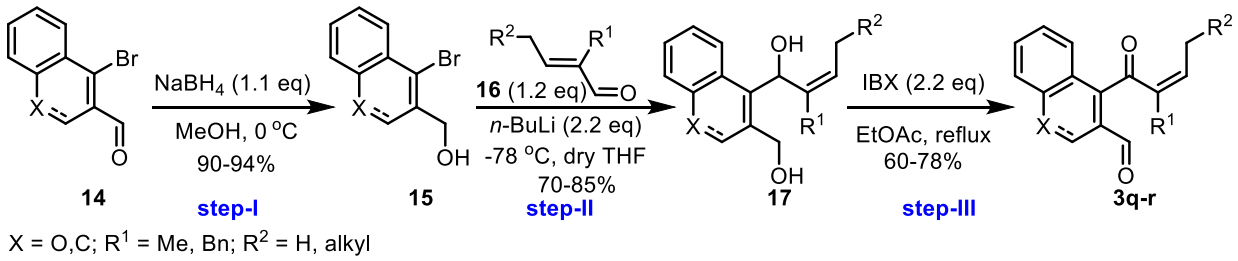
In order to validate the hypothesis presented in Scheme 3, a model substrate **3a-p** and **3s** were synthesized by using a four-step protocol starting from commercially available 2-bromo aldehydes **9** (Scheme 4). The bromo aldehydes **9** were treated with ethylene glycol in the presence of a catalytic amount of *p*-TSA to afford **10**. Direct *n*-butyllithium mediated alkylation of **10** with $\alpha$-substituted enals **11** generated the corresponding alcohols **12**.

Subsequent IBX oxidation and acid catalyzed deprotection of acetal functionality furnished the $\alpha$-substituted enone-aldehydes **3a-p** and **3s**.



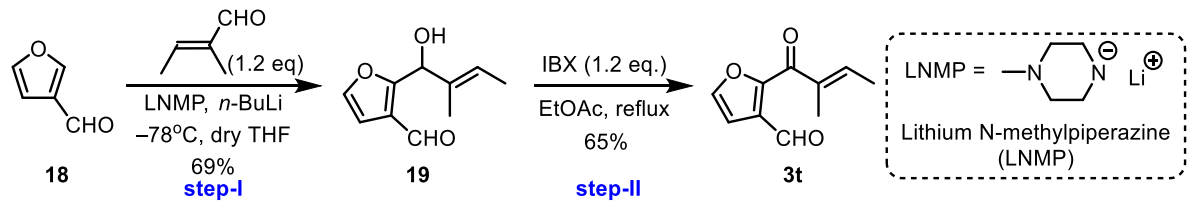

**Scheme 4:** Synthesis of $\alpha$-substituted enone-aldehydes **3a-p** and **3s**.

Naphthalene and chromene based substrates can be accessed easily in a three-step protocol (Scheme 5). The sodium borohydride reduction of bromo aldehydes **14** delivered the respective 2-bromo alcohol **15**. Then, direct *n*-butyllithium mediated alkylation of **15** with $\alpha$-substituted enal **16** generated the diol **17**, which upon IBX oxidation afforded the $\alpha$-substituted enone-aldehydes **3q-r**.



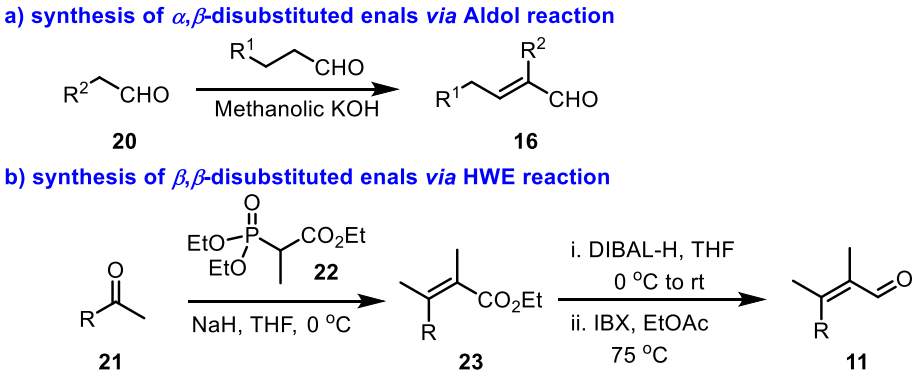

**Scheme 5:** Synthesis of chromene and naphthalene fused $\alpha$-substituted enone-aldehyde **3q-r**.

A two-step protocol was followed for the synthesis of furan-based substrate **3t**, Scheme 6. *In situ* masking of aldehyde functionality by LNMP in furan-3-carboxaldehyde **18** and directed $\alpha$-alkylation afforded **19** and then IBX oxidation furnished the enone-aldehyde **3t**.



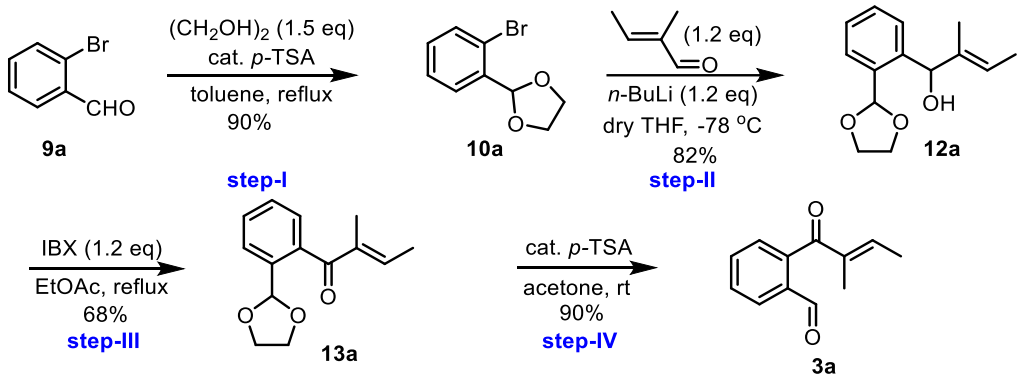

**Scheme 6:** Synthesis of furan based $\alpha$-substituted enone-aldehyde **3t**.

$\alpha$-Substituted enals **16** employed in this study can be accessed from aldehydes **20** by employing classical aldol reaction, Scheme 7a. The $\beta,\beta$-disubstituted enals **11** can be achieved from acetophenone *via* Horner-Wadsworth-Emmons (HWE) reaction, DIBAL-H reduction, and oxidation sequence, Scheme 7b.[10]




**Scheme 7:** Synthesis of $\alpha$-substituted enal **11** and **16**.

We initiated our study by synthesizing the $\alpha,\beta$-dimethyl enone-aldehyde **3a** by following the procedure shown in Scheme 8, starting from commercially available 2-bromo benzaldehyde and tiglic aldehyde.




**Scheme 8:** Synthesis of $\alpha$-substituted enone-aldehyde **3a**.

To validate our hypothesis, the model substrate **3a** was treated with a catalytic amount of $PBu_3$ and it delivered a polar compound with respect to **3a** (based on TLC) with a reasonable yield in a short reaction time, Scheme 9. A careful analysis of the spectral data revealed the exclusive formation of vinylogous aldol product (*via* $\alpha$-aldol) **6a** in a 11:1 diastereomeric ratio, without a trace of the $\gamma$-adduct **8a** (Scheme 3).[11] In the $^1$H-NMR spectrum (see Figure 2), the presence of a two doublets at $\delta$ 5.26 ($J$ = 12.9 Hz) and $\delta$ 5.18 ($J$ = 17.6 Hz) ppm is due to two terminal vinylic protons (C-4 protons), a multiplet at $\delta$ 5.83-5.76 ppm for the vinylic proton

(C-3 proton), a doublet at δ 4.96 ppm ($J$ = 6.5 Hz) due to alcohol connected proton (C-1 proton), and in $^{13}$C-NMR spectrum (see Figure 3), the presence of a downfielded benzylic carbon (C-1) at δ 78.2 ppm, an all-carbon quaternary (C-2) at δ 58.5 ppm, affirmed the formation of 3-hydroxy-2-methyl-2-vinyl-2,3-dihydro-1*H*-inden-1-one **6a**. In the IR spectrum, a broad absorption band at 3432 cm$^{-1}$ for the secondary alcohol and a strong band at 1707 cm$^{-1}$due to the presence of carbonyl further supported the product formation. In the high-resolution mass spectrum, the presence of deprotonated molecular ion peak at $m/z$ 187.0740 $(M–H)^-$ confirmed the structure of **6a**.


**3a** **6a** (*dr* = 11:1)

**Scheme 9:** IVA reaction of $\alpha$-substituted enone-aldehyde **3a**.

The aldol reaction is a cornerstone of synthetic and biosynthetic organic chemistry. It is one of the most predominantly used fundamental carbon–carbon bond-forming reactions leading to the formation of $\beta$-hydroxy carbonyl compounds in the presence of acid or base.[12] The extension of this aldol reaction with $\alpha,\beta$-unsaturated carbonyl compounds as the feedstock of latent enolates against carbonyl electrophile is termed the vinylogous aldol reaction (VAR).[13] It has tremendous applications in polyketide synthesis, which are abundantly present in many natural products and drug molecules. However, the regiochemical issues associated with the vinylogous aldol reaction to achieve a particular VAR product makes this reaction more complex (Scheme 10). The $\alpha,\beta$-unsaturated carbonyl compound **A** generates two enolate species through deprotonation from two potential sites ($\gamma$ and $\alpha$') for enolization, one of which is the thermodynamically favored 'through-conjugated' enolate **B** and another one is the kinetically favored 'cross-conjugated' enolate **C**. **B** can be alkylated at the $\gamma$- or $\alpha$-position to afford the vinylogous aldol product **D** or **E**, respectively. On the other hand, alkylation at the $\alpha'$-position delivers the 'normal' aldol product **F**.

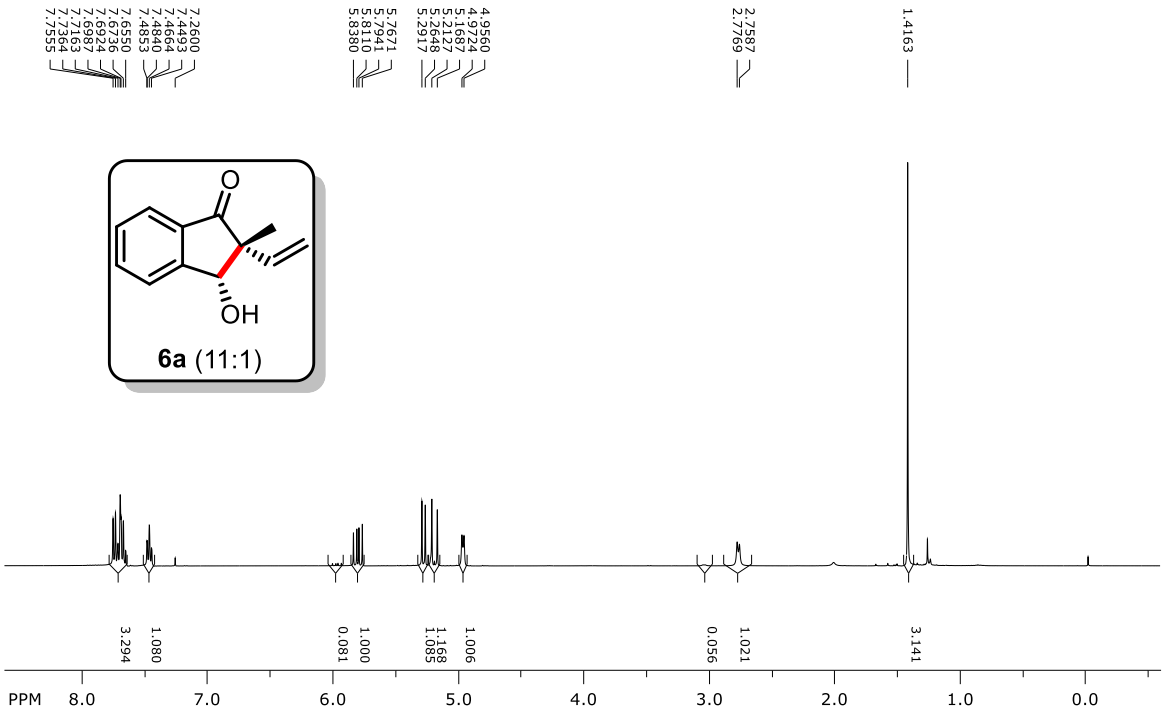



**Figure 2:** $^{1}$H-NMR spectrum of the IVAR product **6a**.

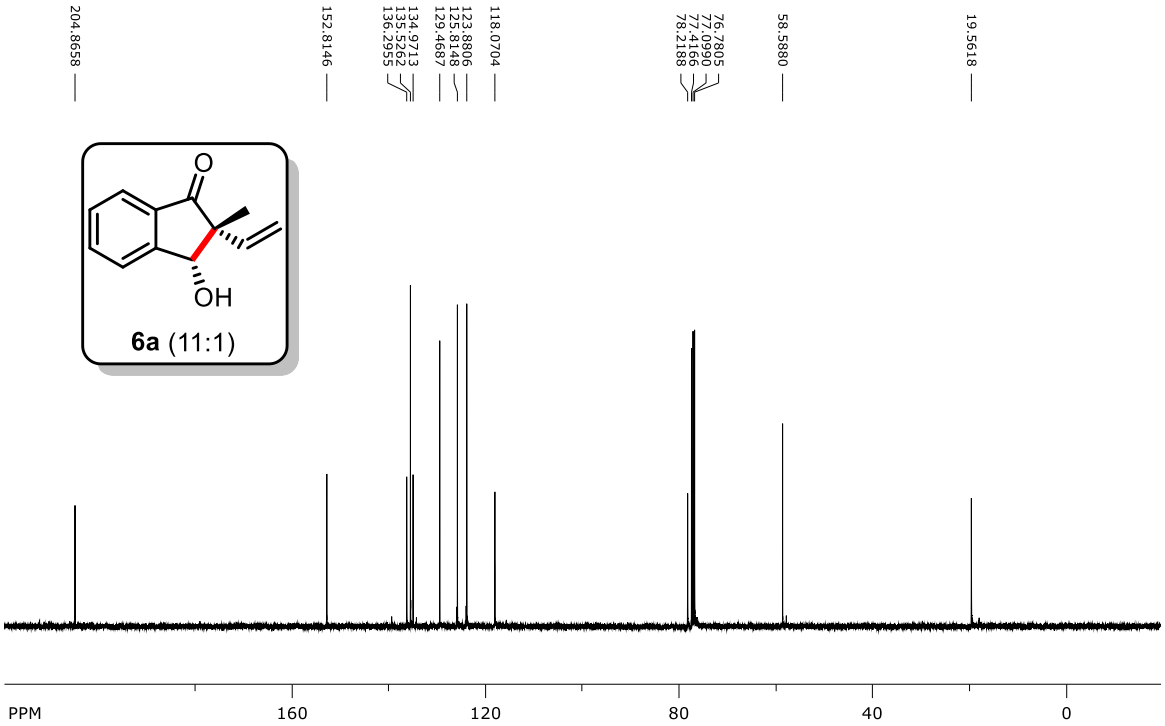
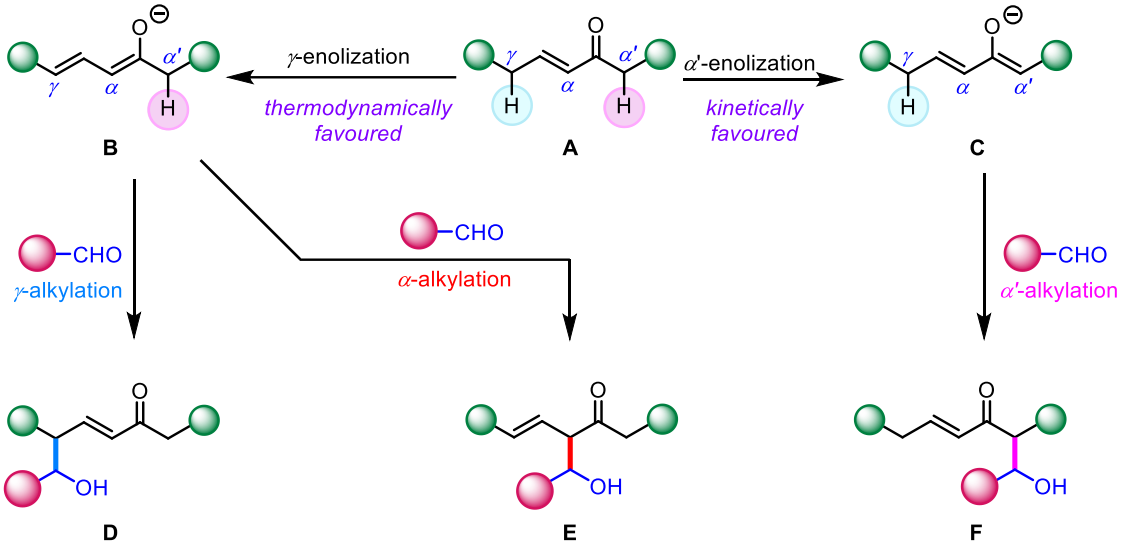
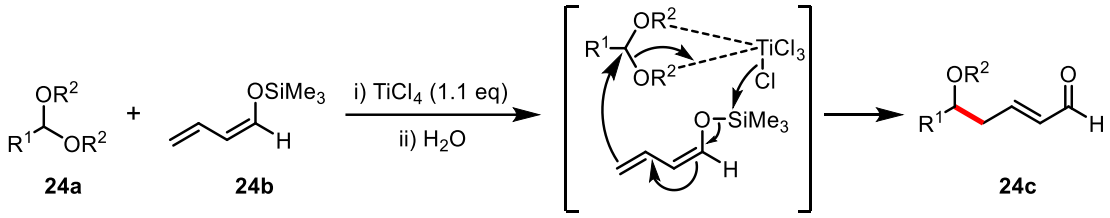



**Figure 3:** $^{13}$C-NMR spectrum of the IVAR product **6a**.



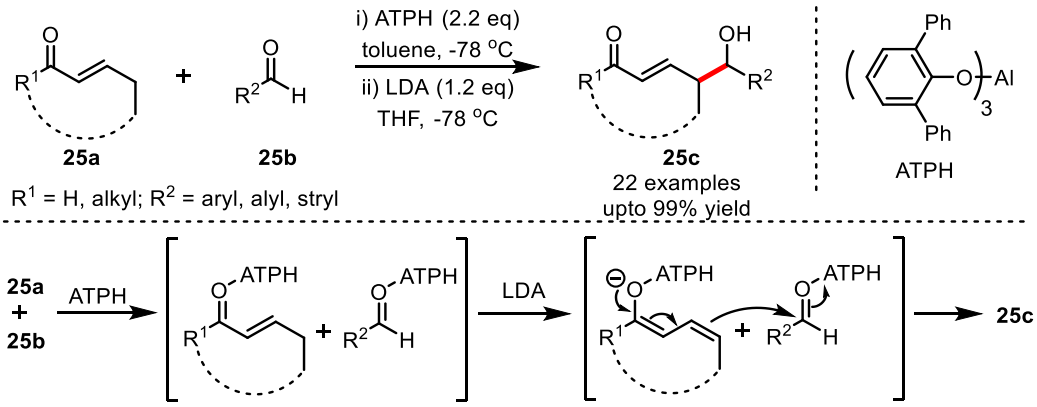

**Scheme 10:** General representation of VAR of $\alpha,\beta$-unsaturated carbonyl compounds.

Hence, in a vinylogous aldol set-up, the generation of 'through-conjugated' dienolate is difficult to achieve. In addition, regulating the site-selective alkylation product ($\alpha$- *vs* $\gamma$-alkylation) is also challenging. The pioneering concept of generating 'through-conjugated' dienolates from $\alpha,\beta$-unsaturated carbonyls *via* sodium ethoxide and subsequent condensation through $\gamma$-position was introduced by R. C. Fuson in 1935.[14] Later, in 1975 Stork demonstrated a synthetic route where enol ethers of symmetric 1,3-diketones generate a kinetic enolate which reacts with aldehyde to obtain the vinylogous aldol product.[15] Parallelly, in the same year, Mukaiyama and Ishida made an ingenious entry into vinylogous aldols where dimethyl acetal **24a** and silyl dienolate **24b** delivered the regiospecific $\gamma$-addition vinylogous aldol product **24c** under activation by $TiCl_4$, Scheme 11.[16] Since then, the vinylogous Mukaiyama reaction has been applied in countless reactions extending the electrophilic or nucleophilic character of a functional group by manifesting the above concept.[17] In spite of the advancement in Mukaiyama aldol reaction, the time-consuming and often laborious formation of the stable silyl dienolates limits its application.[18] However, these methods are still needed to be revised with respect to its generality and highly stereoselectivity, which can be done with a wide range of unactivated substrates. So, the VAR of unmodified enones is always advantageous but less pursued.



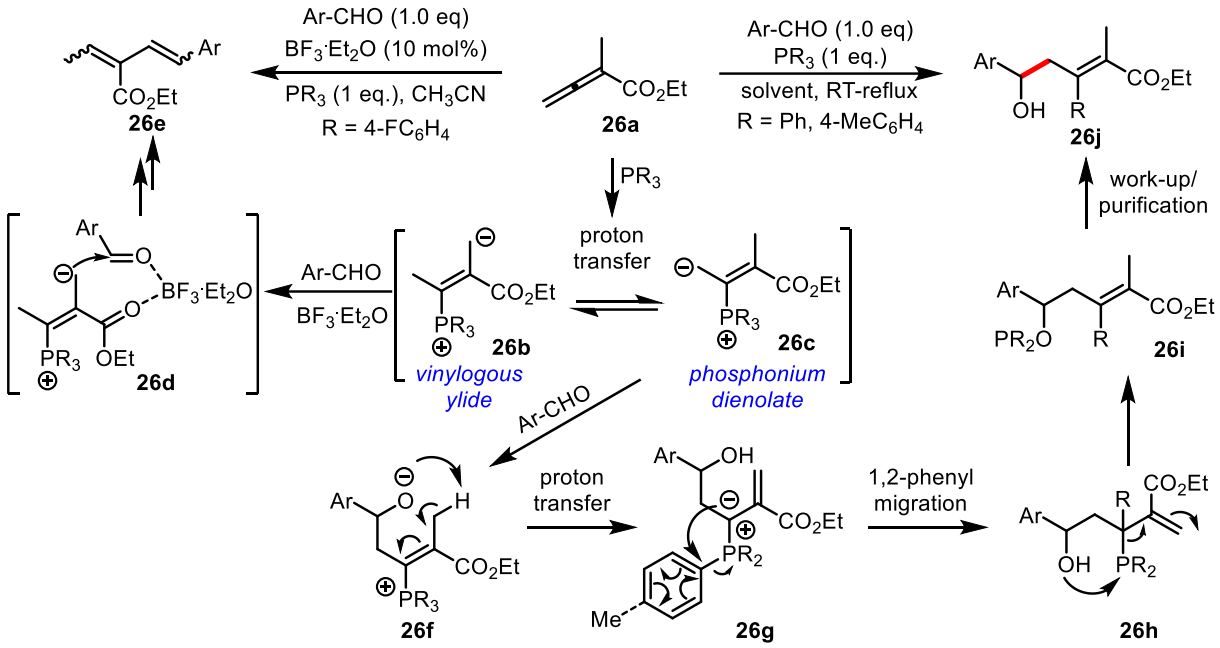

**Scheme 11:** $TiCl_4$ catalyzed vinylogous Mukaiyama reaction.

Towards this, in 1998, Yamamoto and co-workers[19] described a conceptually new direct vinylogous aldol reaction between conjugated carbonyl substrate **25a** and aldehyde **25b** in the presence of a bulky Lewis acid aluminum tris-(2,6-diphenylphenoxide) (ATPH) and LDA to obtain **25c**, Scheme 12. Firstly, **25a** and **25b** form a complex with ATPH and followed by deprotonation by LDA lead to the formation of regiospecific *γ*-addition VAR product **25c** in excellent yield.



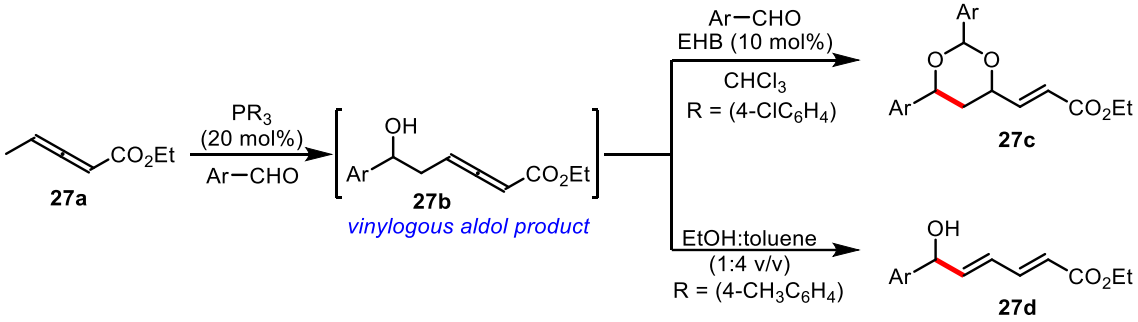

**Scheme 12:** Yamamoto's directed vinylogous aldol reaction using ATPH.

In 2010, Kwon and co-workers[20] reported a phosphine mediated divergent approach for vinylogous Wittig olefination and vinylogous aldol-type reaction involving substituted allenic ester **26a** and various aldehydes, Scheme 13. **26a** and phosphine generated a vinylogous ylide intermediate **26b** which in the presence of Lewis acid and aldehyde furnished the corresponding diene product **26e**. On the other hand, **26a** delivered the *γ*-aldol product **26j** *via* a phosphonium dienolate intermediate **26c** in the absence of Lewis acid. Interestingly, during the formation of **26j** *via* vinylogous aldol reaction, a 1,2-aryl migration from phosphine to carbon occurred in **26g**, which is very rare.



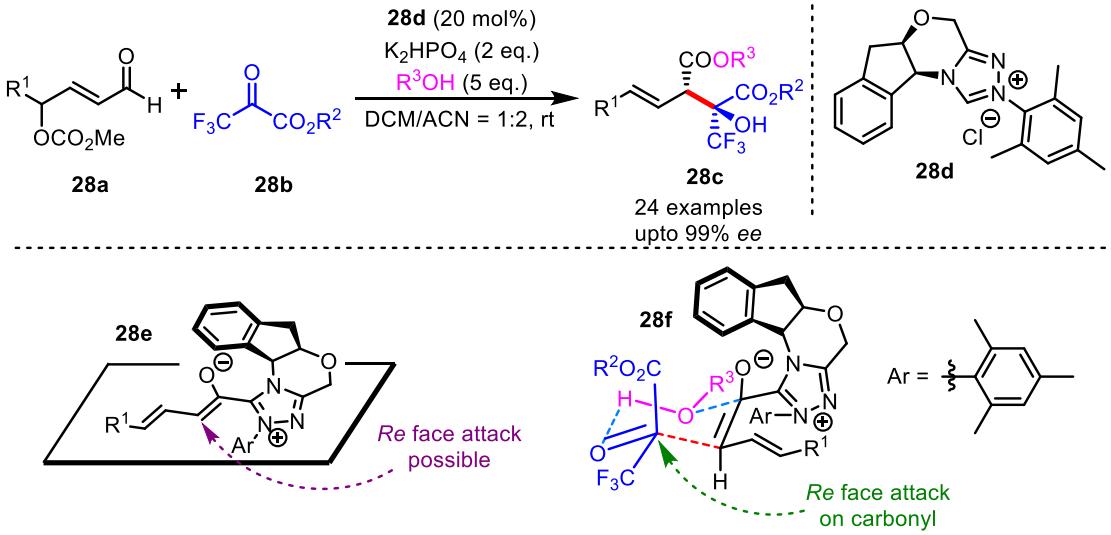

**Scheme 13:** Kwon's phosphine mediated vinylogous aldol/aryl migration reactions.

In 2013, He *et al.*[21] noted a similar phosphine-catalyzed formal vinylogous aldol reaction of *γ*-methyl allenoates **27a** with aldehydes, Scheme 14. Later, the vinylogous aldol intermediate **27b** was utilized for the synthesis of **27c** *via* ketalization/cyclization in the presence of ethyl 4-hydroxybenzoate (EHB) as additive and **27d** *via* isomerization.



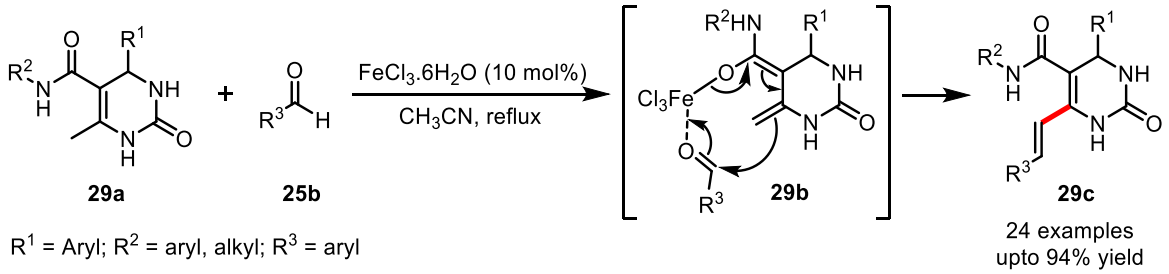

**Scheme 14:** He's phosphine-catalyzed formal vinylogous aldol reaction.

In 2014, Sun *et al.*[22] disclosed an asymmetric vinylogous aldol reaction of **28a** and **28b** catalyzed by N-heterocyclic carbene (NHC), Scheme 15. The precatalyst **28d** would generate the vinylogous NHC-enolate (as depicted in **28e**) with a weak base $K_2HPO_4$. Now, the newly-formed enolate attacks from the *α*-position to the trifluoropyruvate **28b** in presence of suitable nucleophile ($R^3OH$) to furnish **28c** in excellent yields and high enantioselectivity. The absolute stereochemistry of the aldol product **28c** was determined by the proposed six-membered transition state (**28f**).




**Scheme 15:** Sun's NHC-catalyzed asymmetric vinylogous aldol reaction.

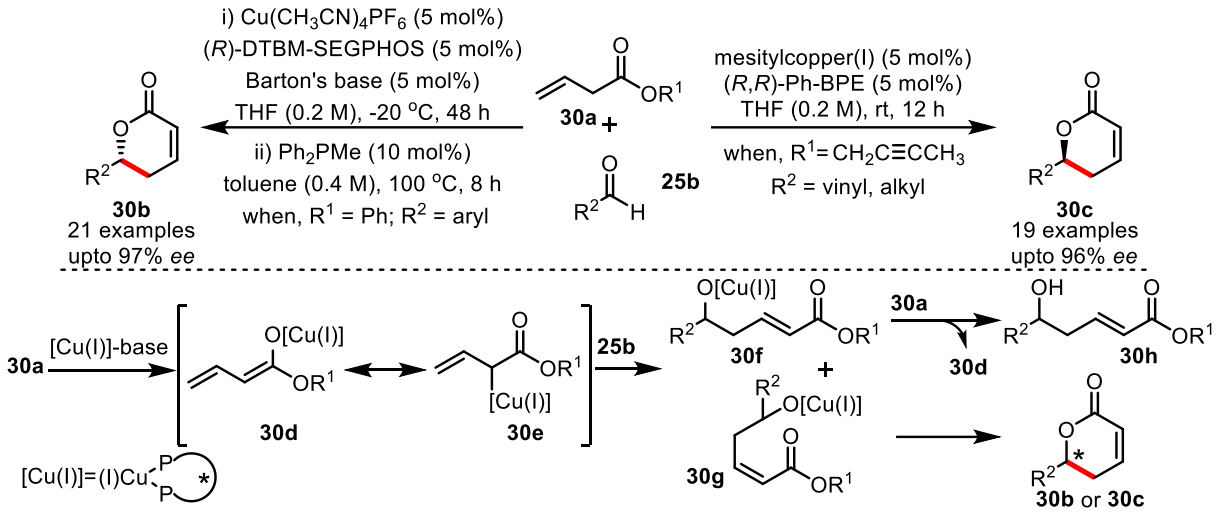
In the same year, Zhang *et al.*[23] developed a $FeCl_3.6H_2O$ catalyzed vinylogous aldol condensation of 5-carboxamide substituted dihydropyrimidin-2(1*H*)-ones (DHMPs) **29a** and aryl aldehyde **25b** to obtain **29c** in excellent yields, Scheme 16. The amide group present in **29a** was realized to be necessary for this transformation. Mechanistically, the presence of iron salt creates a vinylogous conjugate model system **29b** with **29a**. Then, **29b** would attack to the aldehyde **25b** and deliver the aldol condensation product **29c** *via* dehydration.




**Scheme 16:** Zhang's iron-catalyzed vinylogous aldol condensation reaction.

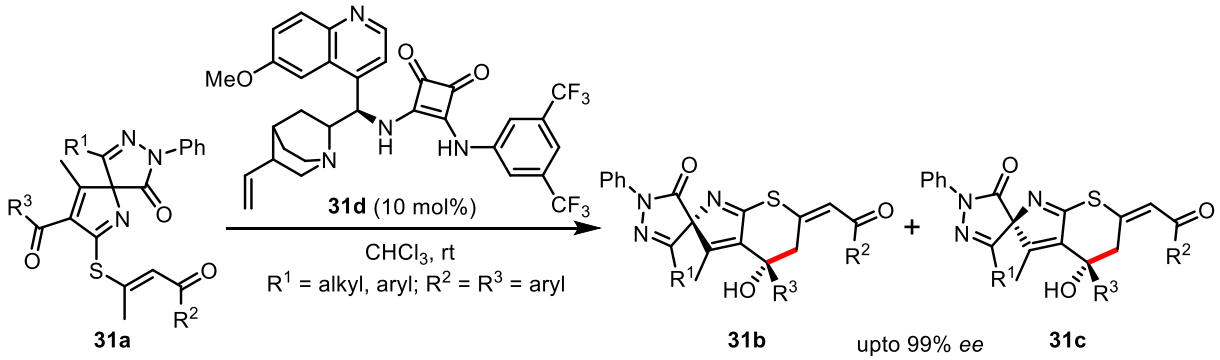
In 2018, Yin and co-workers[24] described a copper-catalyzed direct vinylogous aldol reaction (DVAR) of **30a** and **25b** to synthesize chiral $\alpha,\beta$-unsaturated $\delta$-lactones with moderate to high yields and high enantioselectivity, Scheme 17. Interestingly, using aromatic aldehydes, a one-pot reaction consisting of DVAR along with intermolecular transesterification takes place to generate the lactones **30b**. On the other hand, with aliphatic aldehydes, the DVAR proceeded directly to obtain the lactones **30c**. The reaction proceeds *via* the formation of [Cu]-enolate intermediate (**30d** or **30e**), which in the presence of **25b** generates *trans*- and *cis*-

intermediates **30f** and **30g**, respectively. Next, **30g** delivers the corresponding lactones **30b** and **30c**. Notably, **30f** in the presence of **30a** regenerates **30d** and provides **30h** as minor product.




**Scheme 17:** Yin's copper-catalyzed direct vinylogous aldol reaction.

Recently, Wang *et al.*[25] developed an asymmetric intramolecular vinylogous aldol reaction (IVAR) where **31a** can be converted into spiro[thiopyranopyrrole–pyrazolone] derivatives **31b** and **31c** in excellent yields and high enantioselectivity, catalyzed by quinine squaramide **31d**, Scheme 18. Further studies revealed that the chiral catalyst **31d** was controlling the diastereoselectivity of the reaction and the spiro-centers had no directing effect.




**Scheme 18:** Wang's quinine squaramide-catalyzed asymmetric VAR.

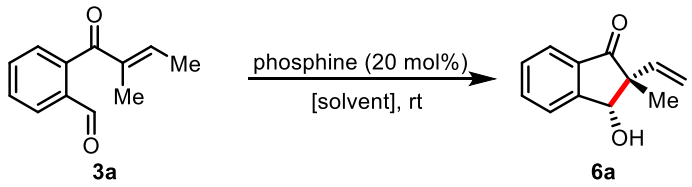
As showcased above, the literature survey disclosed a few important aspects of vinylogous aldol reaction: (i) the tertiary phosphine-catalyzed IVAR of enones is yet to be achieved, (ii) enones possessing $\alpha,\beta$- substitutions are rarely explored, (iii) attack from the $\alpha$-position of the vinylogous enolate is uncommon in VAR.

## *1.1: Results and Discussion*

### *1.1.1: IVAR of α-substituted enone-aldehydes*

Interestingly, our observation described in Scheme 9 represents an unprecedented metal-free and organophosphine-catalyzed intramolecular vinylogous aldol reaction of *α*-substituted enone-aldehydes for the synthesis of 2,2-disubstituted-3-hydroxyindanones (DHIs). After the initial result with the $PBu_3$, a wide variety of phosphines and solvent combinations were investigated to further improve the efficiency of the reaction, and the results are compiled in Table 1. The reaction of **3a** with $PMe_3$ in DMF delivered the expected vinylogous aldol product **6a** in a short reaction time in excellent yield (entry 1). But, when the reaction was carried out with $PCy_3$ and $P(4\text{-}OMeC_6H_4)_3$ in DMF, it delivered the expected product in poor yields (entries 3 and 4), whereas $PPh_3$ was not successful in providing the desired product even after a prolonged reaction time (entry 5). The results also indicated a correlation between the nucleophilicity of the phosphines and the yield. In addition, a brief solvent screening was undertaken (entries 6-11).

**Table 1:** Optimization of reaction parameters




**3a** **6a**

| entry | phosphine | solvent | time (h) | yield (%)[a] |
|---|---|---|---|---|
| 1 | $PMe_3$ | DMF | 1.5 | 87 |
| **2**[b] | **$PBu_3$** | **DMF** | **1.5** | **91** |
| 3 | $PCy_3$ | DMF | 160 | 22 |
| 4 | $P(4\text{-}OMeC_6H_4)_3$ | DMF | 160 | 5 |
| 5 | $PPh_3$ | DMF | 162 | - |
| 6 | $PBu_3$ | toluene | 48 | 57 |
| 7 | $PBu_3$ | DCM | 48 | 62 |
| 8 | $PBu_3$ | DMSO | 5 | 88 |
| 9 | $PBu_3$ | ACN | 6 | 85 |
| 10 | $PBu_3$ | 1,2-DME | 162 | - |
| 11[c] | $PBu_3$ | DMF | 8 | 90 |

All reactions were performed on 0.1 mmol scales. [a] Yields were calculated after silica gel column chromatography. [b] Obtained in 11:1 diastereomeric ratio (*dr*). The *dr* was determined from the crude $^1H$ NMR data. [c] With 10 mol% $PBu_3$.

The polar aprotic solvents[26] such as DMSO and ACN worked well (entries 8 and 9) for the VAR but there was no significant improvement observed concerning the yield and reaction time.

To study the generality of this method, the optimized condition was employed to a wide variety of $\alpha$-substituted enone-aldehydes **3a-t** bearing different steric and electronic features, Table 2. A diverse range of DHIs **6a-t** could be achieved through IVAR in good to excellent yields, and moderate to good diastereoselectivities. Regarding the substituent effect, both aryl and alkyl groups were well-tolerated at $R^1$, $R^2$, and $R^3$ positions. Contrary to our expectation, the presence of electron-withdrawing group (such as -F) on aryl moiety delivered indanones **6c** and **6k** in good yields. Interestingly, the substrates possessing electron-donating groups (such as -OMe) on aromatic backbones showed a considerable influence on the efficiency of the reaction and afforded the respective DHIs (**6d-e, 6g, 6l**) in good yields, Table 2. After realizing the efficacy and facile transformation of $\beta$-monosubstituted enones, the sterically highly demanding $\beta$,$\beta$-disubstituted enones were also demonstrated to produce the DHIs (**6m** and **6n**) in moderate yields and excellent diastereoselectivities. However, slightly high temperatures (60 $^{o}$C) and longer reaction times were required for this transformation. In addition, a class of synthetically challenging spiro indanones (**6o** and **6p**) could be achieved by employing this methodology, which feature in several important bioactive molecules. Pleasingly, the IVAR proceeded even with the substrates bearing naphthalene, chromene and benzothiophene backbones (**6q**, **6r**, and **6s**). The relative stereochemistry of the VAR products was confirmed by the single crystal X-ray diffraction analysis of DHI **6d** and assigned to the other products in analogy, Figure 4.

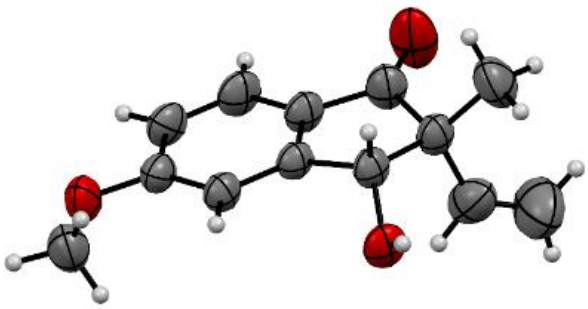
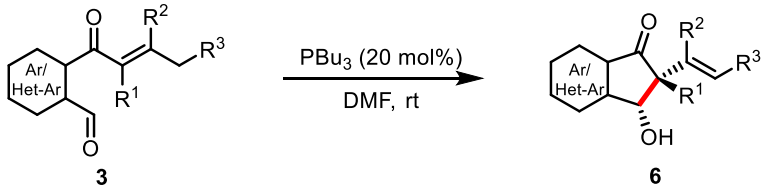


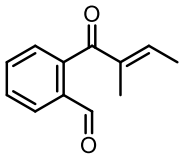
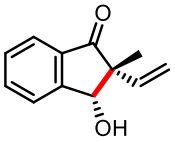
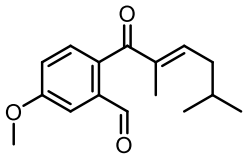
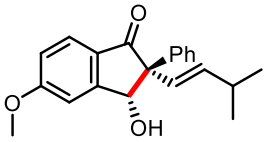
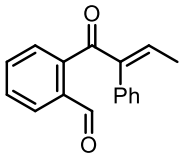
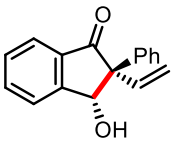
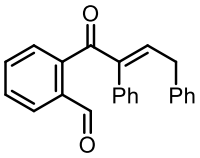
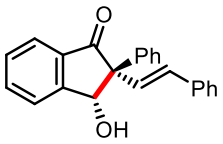
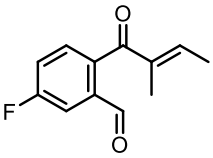
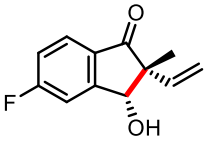
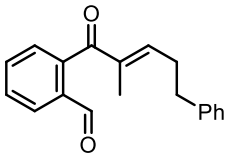
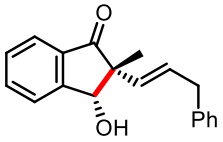
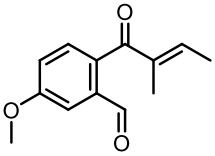
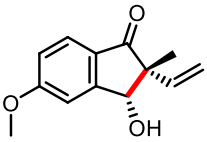
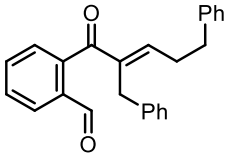
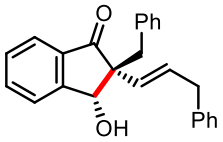
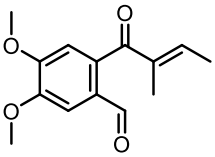
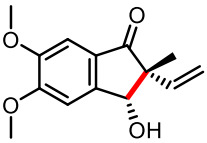
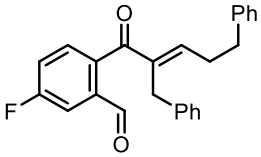
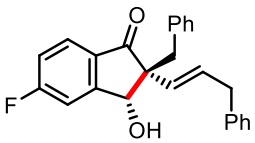
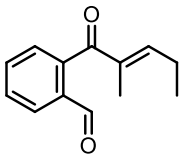
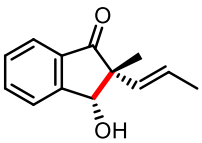
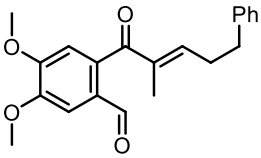
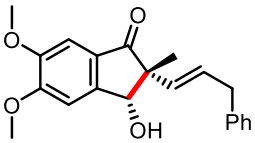
**Figure 4:** ORTEP diagram of DHI **6d**.

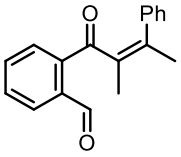
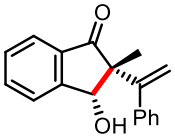
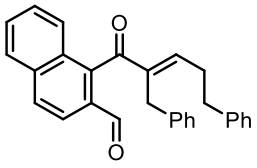
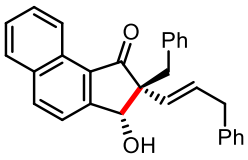
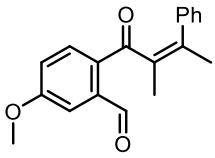
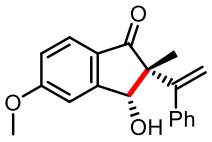
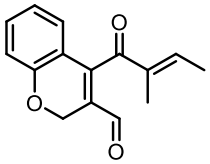
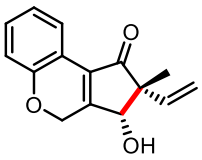
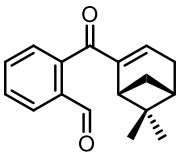
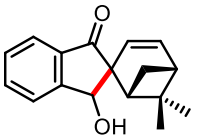
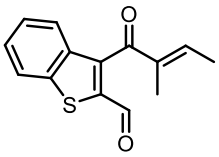
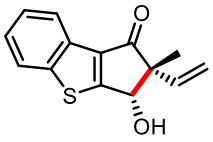
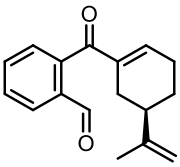
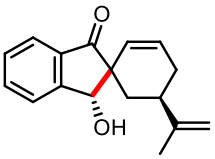
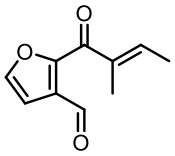
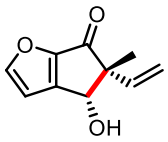
Therefore, this method is realized to be general and robust on a wide range of substrates. However, this method also has limitations as the enone-aldehydes bearing furan backbone **3t** failed to generate the expected product **6t** even after prolonged reaction time.

**Table 2:** Substrate Scope: Annulated cyclopentanoids *via* an intramolecular VAR

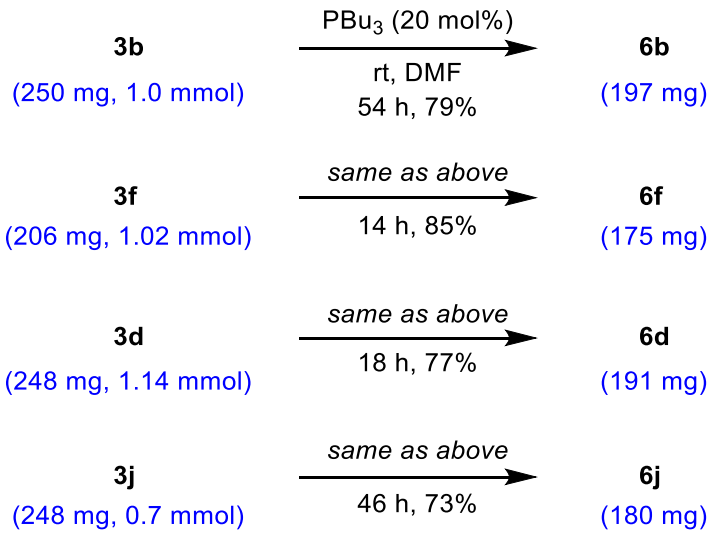



3 6

| entry | substrate | product | entry | substrate | product |
|---|---|---|---|---|---|
| 1 |  **3a** |  **6a**, 91%, 1.5 h, *dr* = 11:1 | 7 |  **3g** |  **6g**, 88%, 36 h, *dr* = 6:1 |
| 2 |  **3b** |  **6b**, 90%, 48 h, *dr* = 3:1 | 8 |  **3h** |  **6h**, 85%, 12 h, *dr* = 10:1 |
| 3 |  **3c** |  **6c**, 80%, 1 h, *dr* = 10:1 | 9 |  **3i** |  **6i**, 88%, 20 h, *dr* = 8:1 |
| 4 |  **3d** |  **6d**, 92%, 6 h, *dr* = 13:1 | 10 |  **3j** |  **6j**, 87%, 40 h, *dr* = 5:1 |
| 5 |  **3e** |  **6e**, 82%, 9 h, *dr* = 8:1 | 11 |  **3k** |  **6k**, 73%, 18 h, *dr* = 12:1 |
| 6 |  **3f** |  **6f**, 89%, 10 h, *dr* = 10:1 | 12 |  **3l** |  **6l**, 82%, 13 h, *dr* = 8:1 |

| entry | substrate | product | entry | substrate | product |
|---|---|---|---|---|---|
| 13 |  **3m** |  **6m**, 58%, 120 h at 60 °C | 17 |  **3q** |  **6q**, 83%, 9 h, *dr* = 19:1 |
| 14 |  **3n** |  **6n**, 62%, 120 h, *dr* = 5:1 at 60 °C | 18 |  **3r** |  **6r**, 82%, 3 h, *dr* = 6:1 |
| 15 |  **3o** |  **6o**, 87%, 50 h, *dr* = 5:1 | 19 |  **3s** |  **6s**, 64%, 24 h, *dr* = 19:1 |
| 16 |  **3p** |  **6p**, 92%, 20 h, *dr* = 4:1 | 20 |  **3t** |  **6t**, 0%, 72 h |

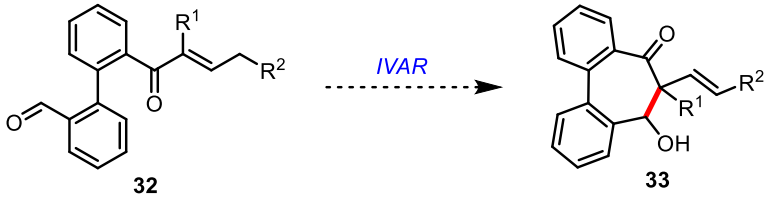
Next, we intended to evaluate the practicality of the method, as described is Scheme 19. Accordingly, four scale-up reactions were carried out under the prototype condition and obtained the respective products in good yields. Although they required relatively longer reaction times when compared with the respective small-scale reactions (See Table 2).




**Scheme 19:** Scale-up reactions.

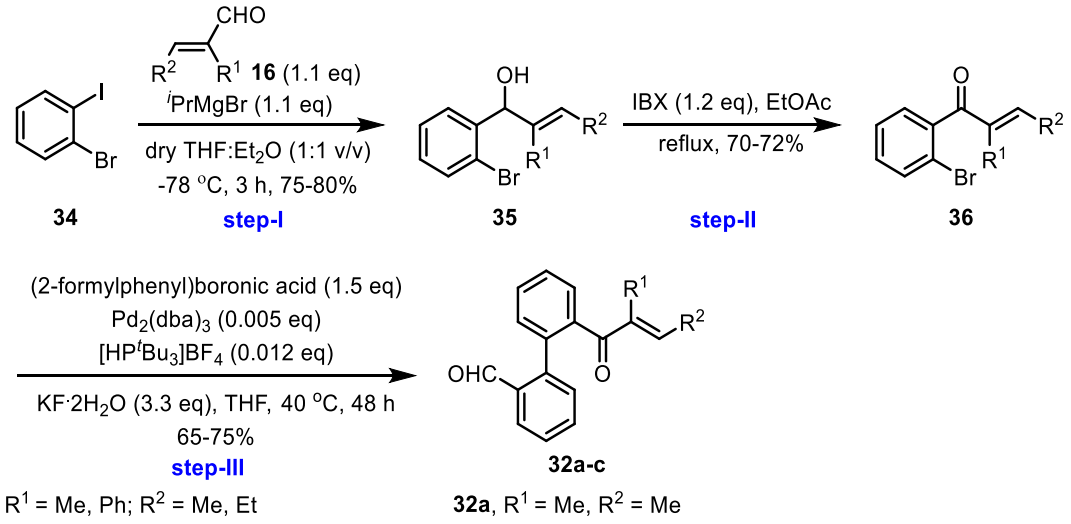
## *1.1.2: IVAR of biaryl enone-aldehydes*

After achieving a practical and efficient IVAR for the synthesis of cyclopentane-fused arenes and heteroarenes, we intended to extend this strategy for the synthesis of cycloheptanes having two contiguous stereogenic centers, one of which is a quaternary carbon[27], Scheme 20. We envisioned that the IVAR of biaryl enone-aldehyde **32** could deliver a new class of functionally rich dibenzocycloheptanones **33**.




**Scheme 20:** Hypothesis of IVAR on biaryl enone-aldehydes **32**.

In order to corroborate our intention towards the synthesis of dibenzocycloheptanones, a model substrate **32a** was synthesized by using a three-step protocol starting from commercially available 2-bromoiodobenzene **34** (Scheme 21). Direct $^{i}$PrMgBr mediated alkylation of **34** with a suitable aldehyde **16** generated the corresponding 2-bromoalcohol **35**. Subsequent IBX oxidation furnished the $\alpha$-substituted 2-bromo enone **36**. Finally, a modified Suzuki coupling between **36** and (2-formylphenyl)boronic acid delivered the expected $\alpha$-substituted biaryl enone-aldehyde **32a**.[28]



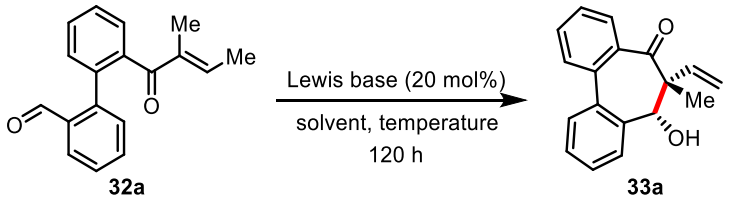

**Scheme 21:** Synthesis of biaryl enone-aldehyde **32a-c**.

Next, the biaryl enone-aldehyde **32a** was subjected to the prototypical condition and isolated the expected dibenzocycloheptanone **33a**, albeit in low yield (entry 1). The structure

of **33a** was confirmed by analyzing the $^{1}$H-NMR and $^{13}$C-NMR spectra of corresponding product (see in Figures 5 and 6). This result prompted us to perform a brief optimization of reaction parameters for the IVAR in biaryl systems. A variety of Lewis bases in combination with different solvents and temperatures were applied for this purpose. There was no significant improvement in yield of the product when different solvents were screened (entries 2-6). A slight increment of yield of the product was observed at elevated temperature with $PBu_3$ catalyst (entry 7). Surprisingly, the change of Lewis base catalyst (such as DBU) at 100 $^{o}$C delivered the expected product in good yield (entry 9).

With this optimized condition in hand, the scope and limitation of the reaction were also examined, Table 4. The biaryl enone-aldehydes having different substitutions at $R^1$ and $R^2$ (**32a-c**) were subjected to the optimized condition (with $PBu_3$ or DBU) and achieved dibenzocycloheptanones **33a-c** with moderate yield and good diastereoselectivity. However, the substrate (**32c**) bearing a phenyl group at the $\alpha$-position failed to generate the expected product **33c**. The relative stereochemistry of the dibenzocycloheptanones is tentatively assigned in analogy to **6**.

**Table 3:** Optimization of reaction parameters




32a 33a

| entry | Lewis base (20 mol%) | solvent | temperature ($^{o}$C) | yield (%) |
|---|---|---|---|---|
| 1 | $PBu_3$ | DMF | rt | 20 |
| 2 | $PBu_3$ | DMSO | rt | 12 |
| 3 | $PBu_3$ | ACN | rt | 18 |
| 4 | $PBu_3$ | toluene | rt | - |
| 5 | $PBu_3$ | 1,2-DCE | rt | - |
| 6 | $PBu_3$ | DMF/HFIP | rt | 20 |
| 7 | $PBu_3$ | DMF | 100 | 30 |
| 8 | DBU | DMF | rt | 27 |
| **9** | **DBU** | **DMF** | **100** | **64** |

All reactions were performed on 0.1 mmol scales. Yields were calculated after silica gel column chromatography.

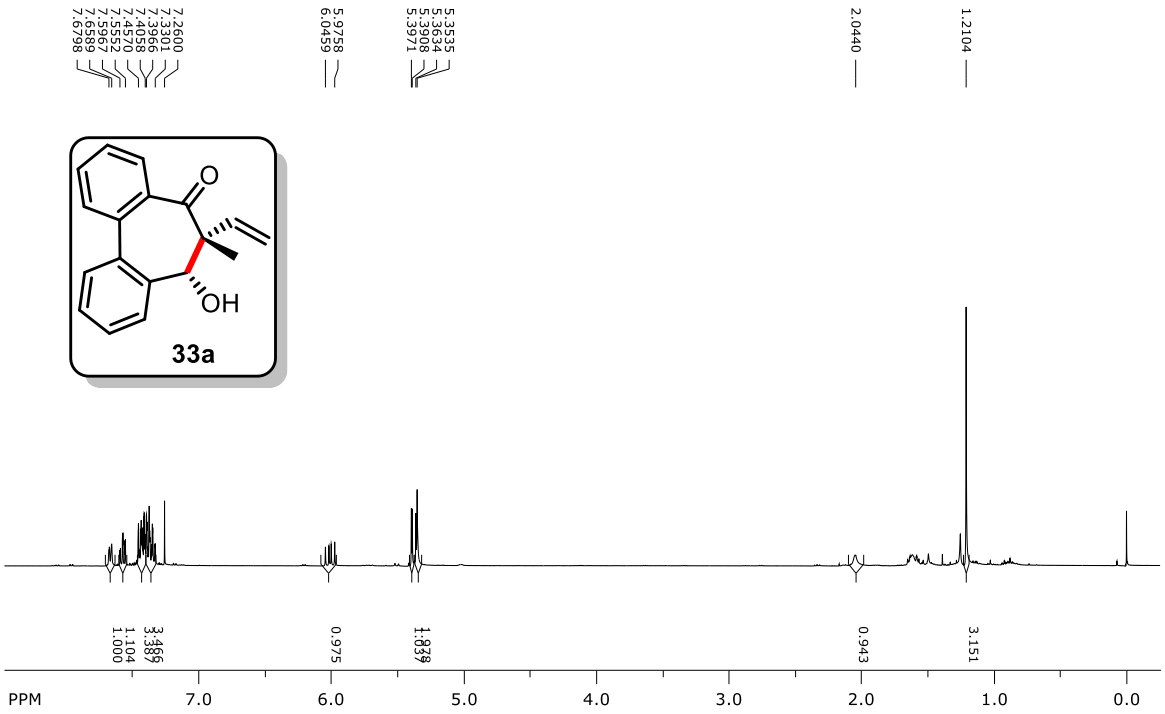



**Figure 5:** $^{1}$H-NMR spectrum of the IVAR product **33a**.

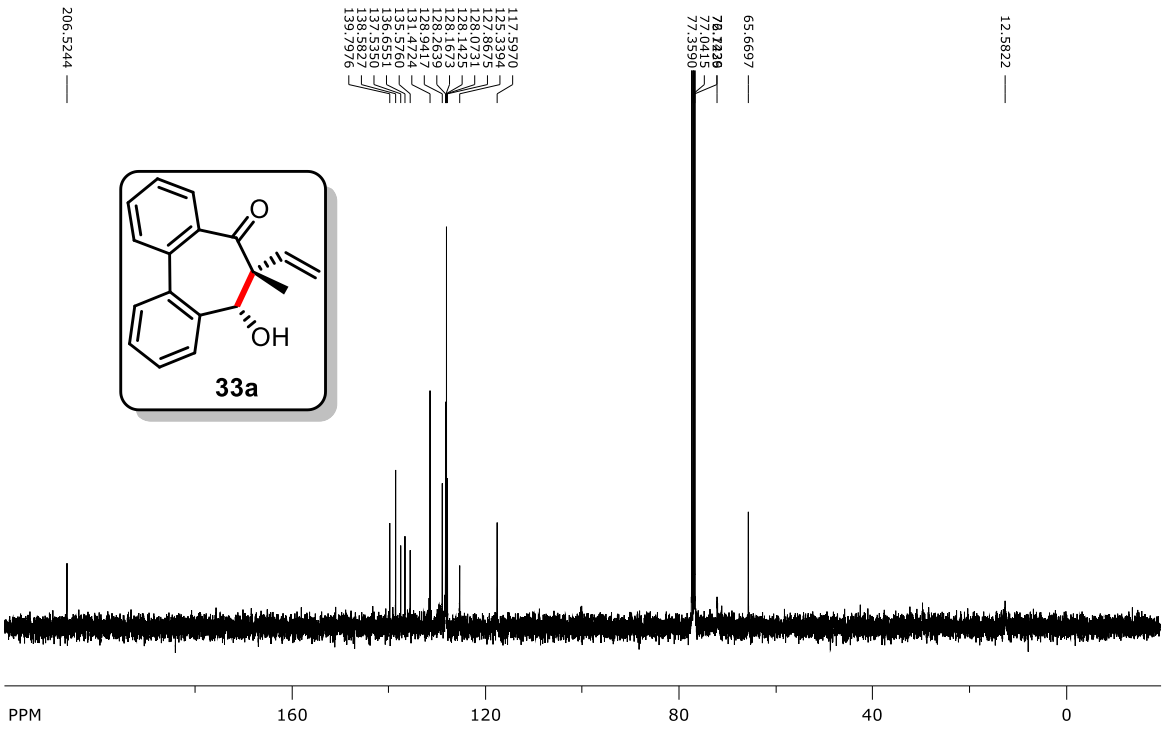
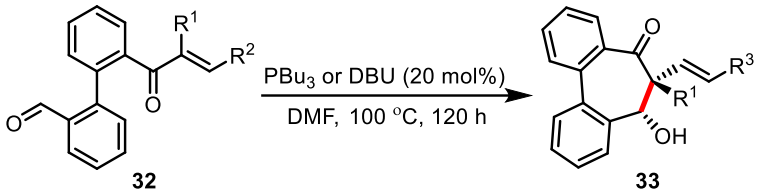
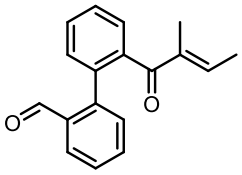
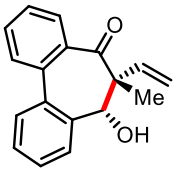
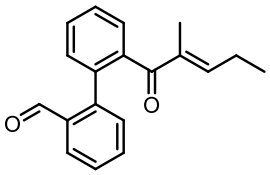
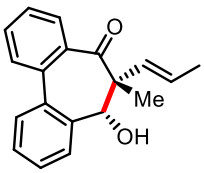
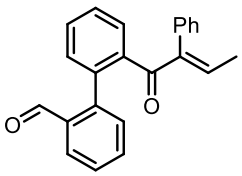
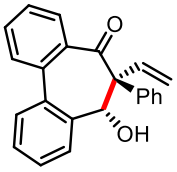



**Figure 6:** $^{13}$C-NMR spectrum of the IVAR product **33a**.

**Table 4:** Substrate Scope: Annulated cycloheptanoids *via* an intramolecular VAR.




**32** **33**

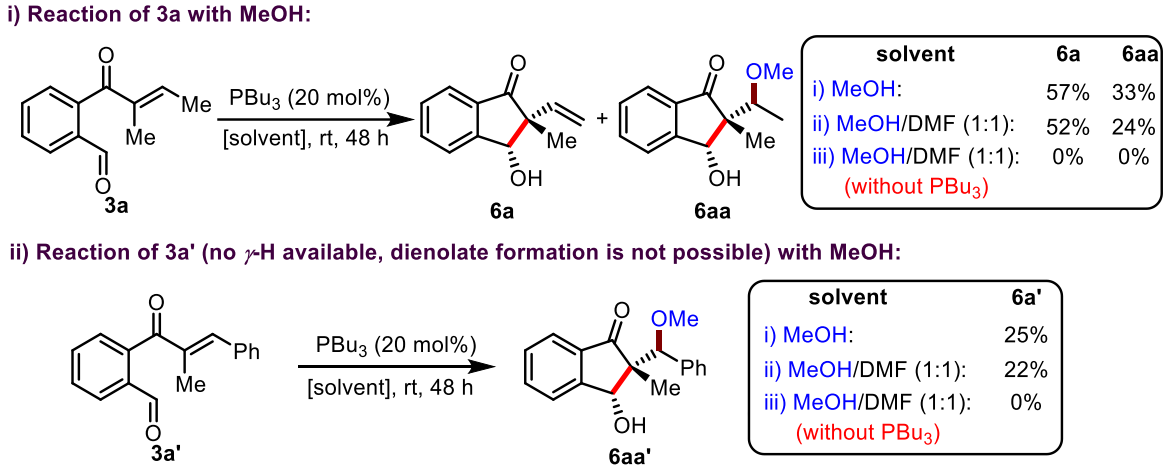
| entry | substrate | product |
|---|---|---|
| 1 |  **32a** |  **33a**, 30% (64%) |
| 2 |  **32b** |  **33b**, 42% (65%), *dr* = 2:1 |
| 3 |  **32c** |  **33c**, 0% |

## *1.2: Mechanistic Insights*

### *1.2.1: Reaction of 3a and 3a' with MeOH*

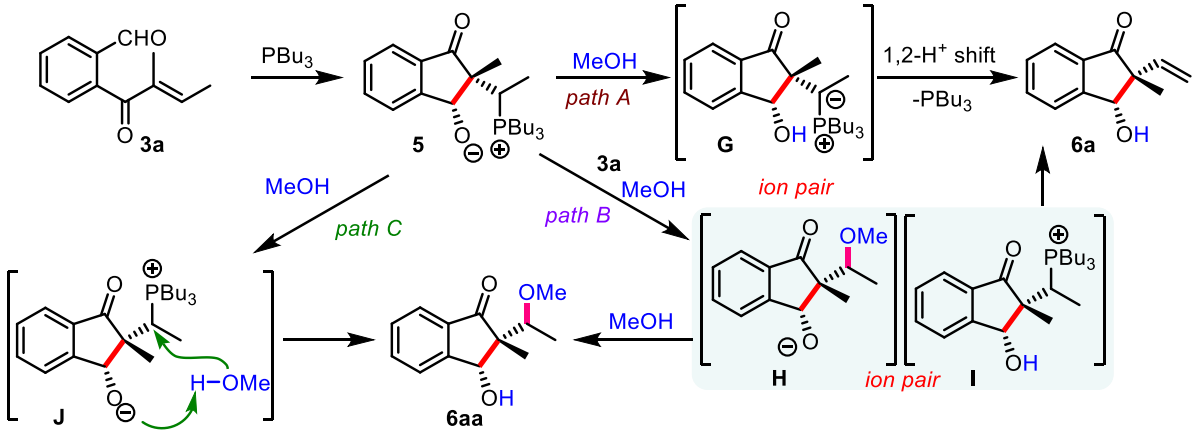
To gain the mechanistic insight about the IVAR, we performed a series of reactions with **3a** to trap the phosphonium ion intermediate with MeOH and the results are summarized in Scheme 22. The reaction of **3a** in (i) MeOH, and (ii) DMF and MeOH with $PBu_3$ as catalyst delivered **6a** and **6aa**. But no product formation was observed in the absence of $PBu_3$-catalyst, Scheme 22. The formation of **6aa** was confirmed by analyzing the spectral data of the corresponding product. In the $^1$H-NMR spectrum (see Figure 7), the presence of a doublet at δ 4.92 ppm ($J$ = 9.0 Hz) due to alcohol connected proton (C-1 proton), a singlet at δ 4.22 ppm due the –OMe group (C-4 position) and in $^{13}$C-NMR spectrum (see Figure 8), the presence of a downfielded benzylic carbon (C-1) at δ 81.0 ppm, another oxygen connected carbon at δ 79.6 ppm (C-4 carbon), methoxy group at δ 56.3 ppm and an all-carbon quaternary (C-2) at δ 55.8 ppm, affirmed the formation of **6aa**. Another enone-aldehyde **3a'** having no γ-hydrogen available, under the same condition resulted in the formation of **6aa'** as an exclusive product as there was no possibility of dienolate formation. For both cases, **6aa** and **6aa'**

formation suggests an initial attack of phosphine to the enone moiety in a Michael fashion over a possible dienolate pathway. It further confirmed the Lewis basic property of phosphines over Brønsted basicity for such transformations.




**Scheme 22:** Trapping of the phosphonium intermediate with MeOH.

A plausible mechanism for the formation of **6aa** is presented in Scheme 23 based on the experimental evidence (as depicted in Scheme 22) and related literature reports.[29] The *α*-substituted enone-aldehyde **3a** undergoes a cascade phospha-Michael addition/aldol reaction to generate the zwitterionic species **5**. Next, in the presence of methanol, **5** can form the ion pair **G**, and elimination of phosphine by the methoxide delivers **6a** (*path A*). On the other hand, the zwitterionic species **5** upon reaction with **3a** and MeOH generates the ion pair **H** and **I** (*path B*). Subsequently, **H** converts to **6aa** by protonation, and **I** generates **6a** *via* phosphine elimination. An alternative mechanism for **6aa** formation can also involve the displacement of phosphine by methoxide, as depicted in **J** (*path C*).




**Scheme 23:** Plausible mechanism for the formation of **6aa**.

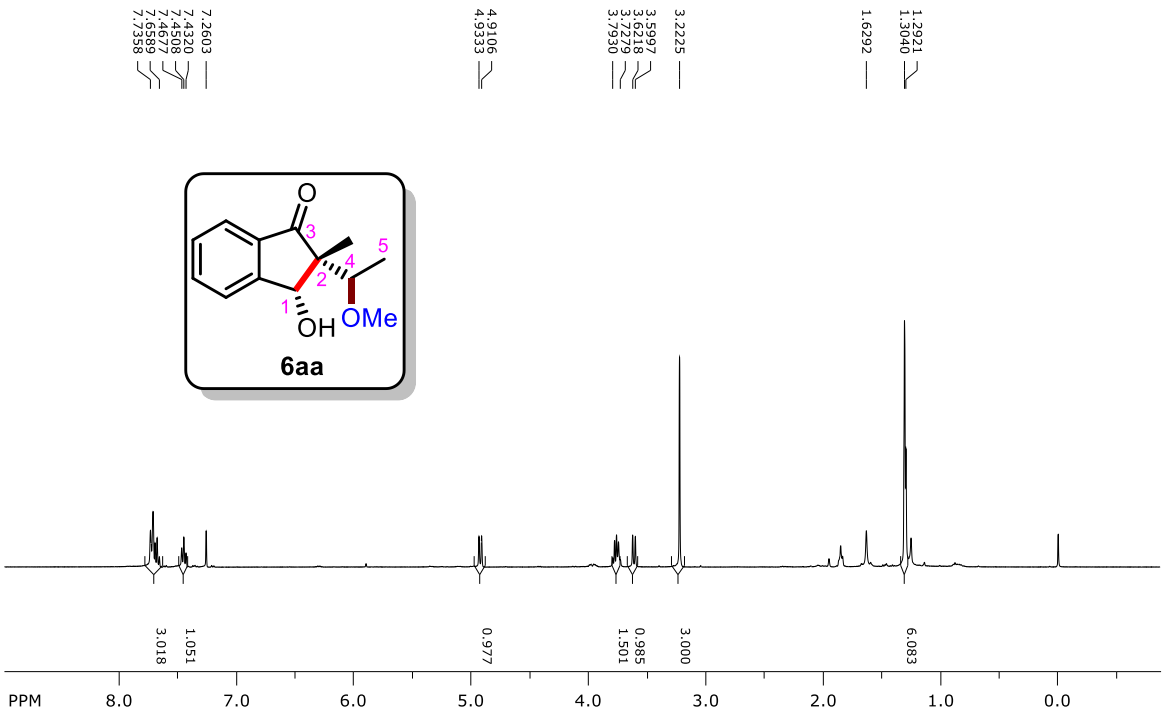



**Figure 7:** $^{1}$H-NMR spectrum of the -OMe added product **6aa**.

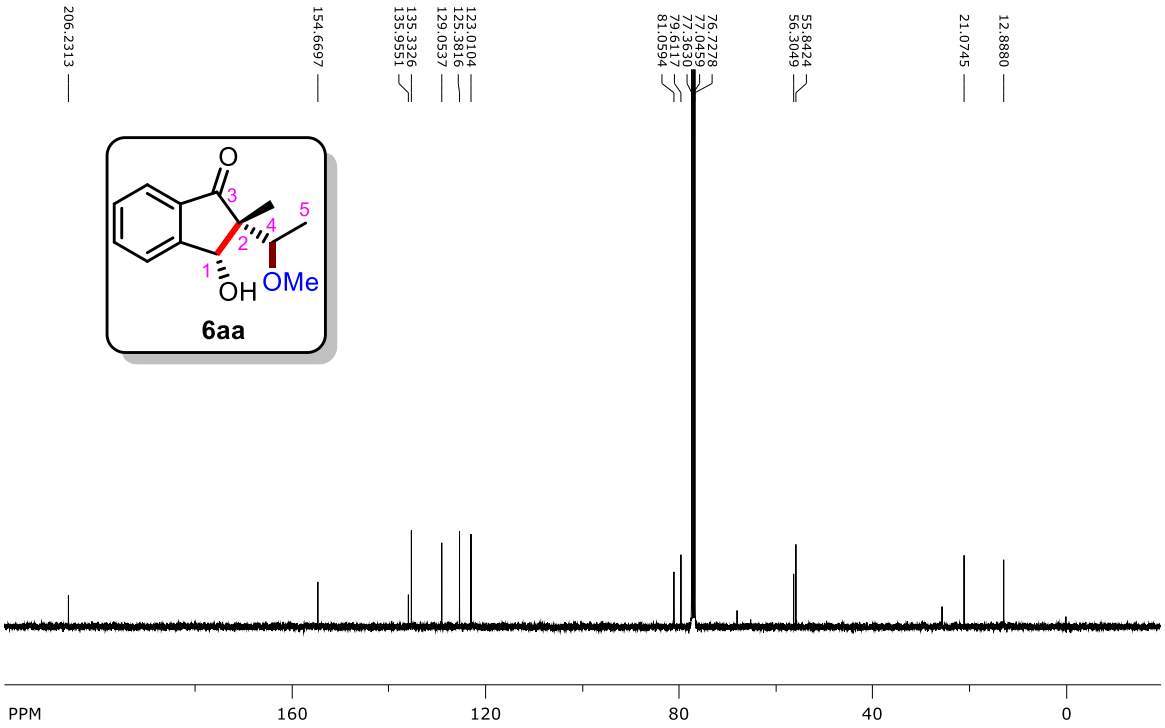
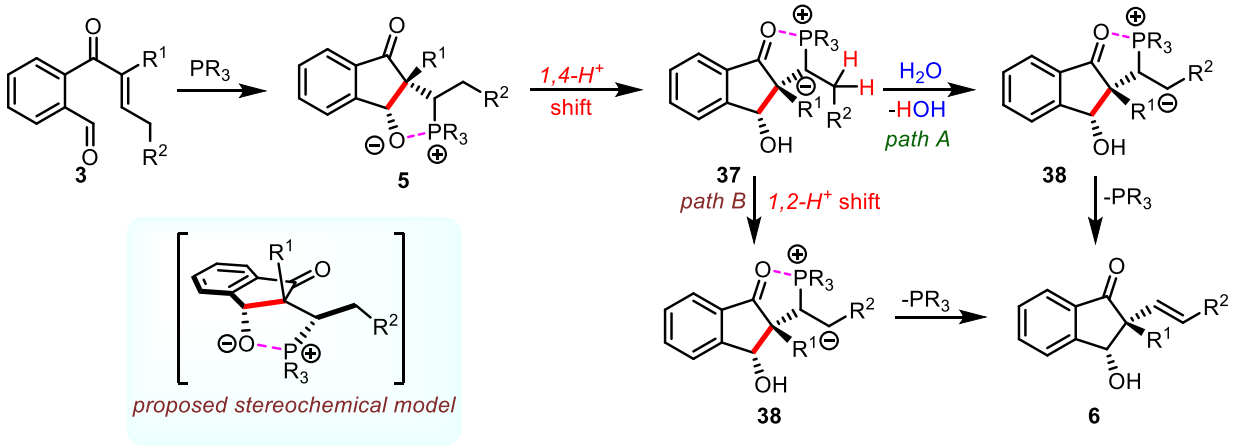



**Figure 8:** $^{13}$C-NMR spectrum of the -OMe added product **6aa**.

### *1.2.1: Plausible mechanism*

Based on the evidence obtained from the control experiments, a plausible mechanism is outlined in Scheme 24. The initial 1,4-phosphine addition to **3** followed by intramolecular aldol reaction, akin to MBH reaction, generates the zwitterionic intermediate **5**. Next, the zwitterionic intermediate **5** undergoes a 1,4-proton shift, leading to the formation of the ylide **37**. Now, **37** can proceed either through $\gamma$-deprotonation assisted by the adventitious hydroxide (*path A*) or *via* 1,2-proton shift (*path B*) to generate the intermediate **38**, which upon elimination of phosphine generates the expected product **6**. In addition, we also proposed a plausible model to explain the stereo-induction at the two consecutive stereocenters as depicted in Scheme 24.




**Scheme 24:** Plausible mechanism for the formation of **6**.

## *1.3: Synthetic utility of IVAR products*

### *1.3.1: Synthesis of benzannulated nine-membered carbocycles*

After successfully establishing the IVAR for synthesizing an array of 2,2-disubstituted-3-hydroxyindanones, we intended to illustrate the synthetic utility of the IVAR products. In this regard, a ring-expansion based on oxy-Cope rearrangement strategy was envisioned to synthesize benzo-fused nine membered carbocycles.[30]

The synthesis of medium-sized carbocycles is one of the most challenging tasks for synthetic chemists, mainly due to their high ring strain. Among them, nine-membered carbocycles are a very important class of structural motif. It not only adopts a single low-energy conformation to relieve its ring strain but exhibits in multiple conformations by pseudo rotation.[31] Many natural products comprising the nine-membered carbocyclic core show diverse biological activities. For example, rubratoxin A was isolated from *Penicillium rubrum* and shows anticancer activity by acting as PP2A-specific inhibitor. Protoxenicin A, was extracted from the soft *Protodendron repens* and exhibits significant cytotoxicity against

different human tumor cell lines. The stilbene oligomer *α*-viniferin, isolated from *Caragana chamlague*, displays inhibition towards acetylcholinesterase (AChE), Figure 9.[32]

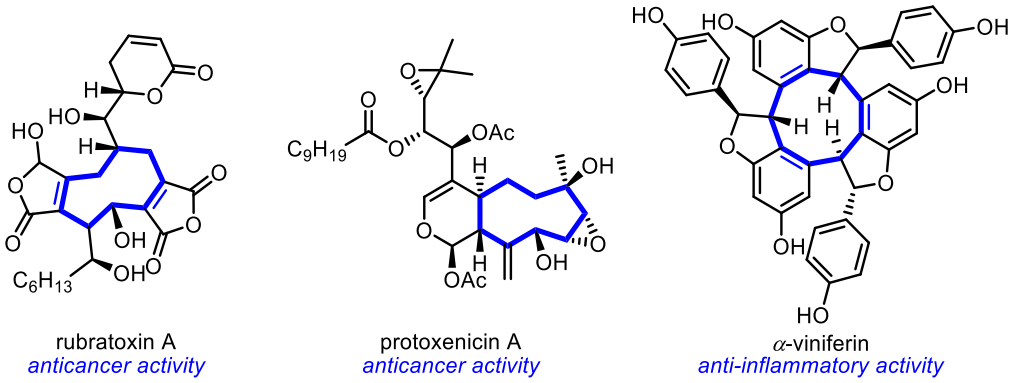
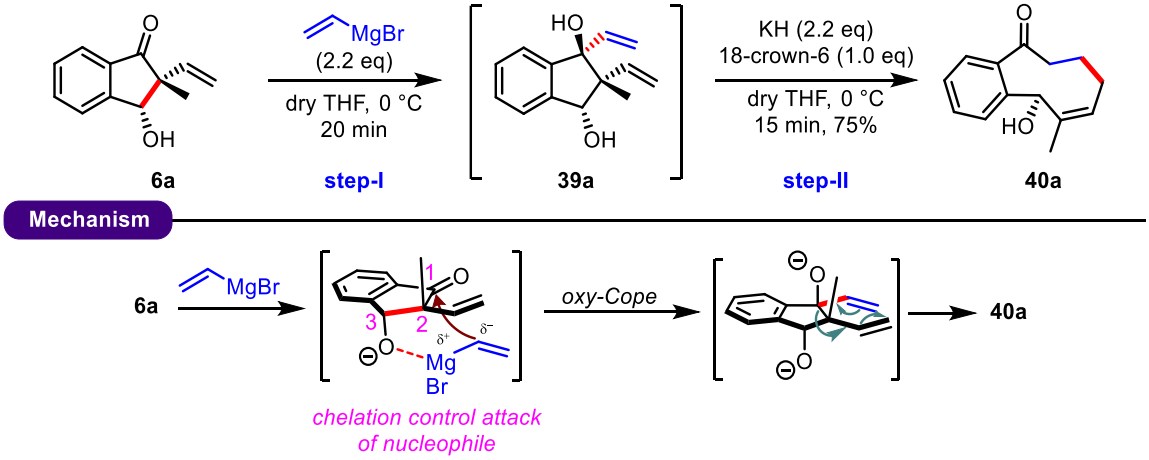



**Figure 9:** Representative natural products having of nine-membered carbocyclic core.

Accordingly, for synthesizing the starting material, **6a** was treated with vinyl Grignard reagent to obtain the allylic *tert*-alcohol **39a**, Scheme 25. Next, **39a** was treated with KH in presence of 18-crown-6 and obtained the expected benzoannulated nine-membered carbocycle **40a** *via* oxy-Cope rearrangement in 75% yield (over two steps). The chelation-controlled and C-3 alkoxide directed addition of vinyl Grignard to **6a**, followed by oxy-Cope rearrangement delivered **40a** as a single isomer. The structure of nine-membered carbocycle **40a** was confirmed by $^{1}$H-NMR and $^{13}$C-NMR analysis (see Figure 11 and 12, respectively). Because the construction of benzo-fused nine-membered carbocycles is very unusual, we have synthesized few other analogues **40a-e** in moderate to good yields, Table 5. The relative stereochemistry was assigned based on the crystal structure of **40b**, Figure 10.




**Scheme 25:** Synthesis of nine-membered carbocycle **40a** with mechanism.

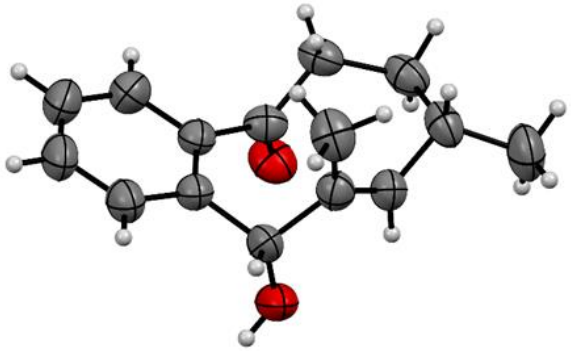
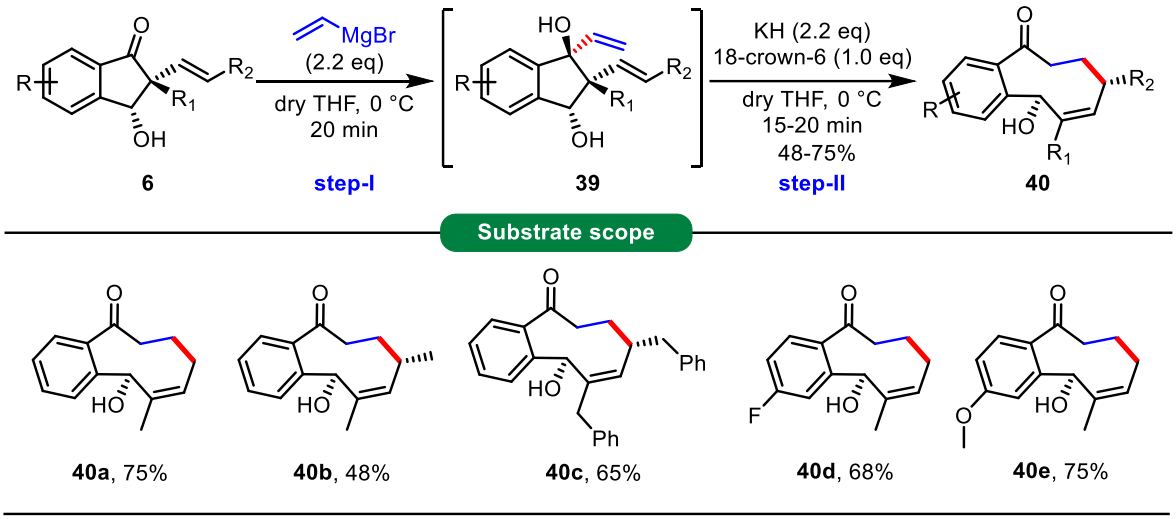


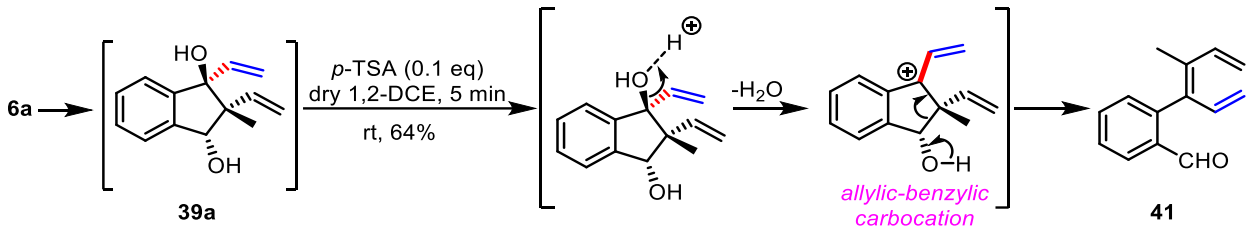
**Figure 10:** ORTEP diagram of nine-membered carbocycle **40b**.

**Table 5:** Synthesis of benzo-fused nine-membered carbocycle analogs **40a-e**.



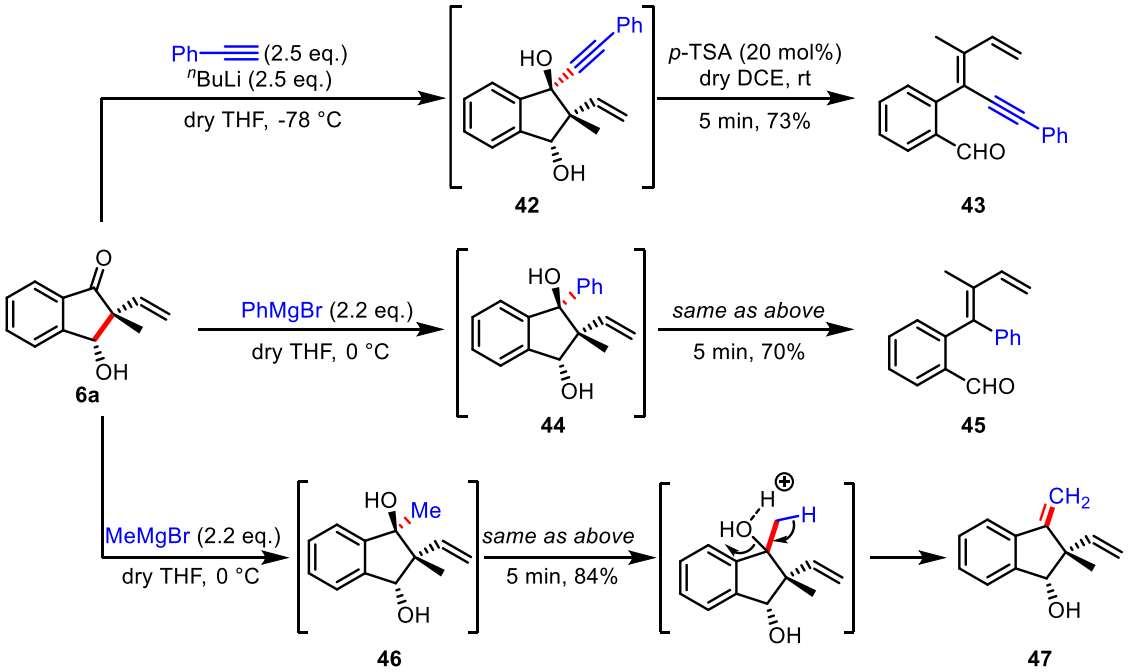

## *1.3.2: Acid-catalyzed ring-opening of IVAR products*

The establishment of a base-promoted strategy for the synthesis of nine-membered carbocycles from structurally unique allylic *tert*-alcohol **39a**, encouraged us to design an acid mediated protocol anticipating the generation of allylic-benzylic carbocationic equivalent which could undergo a structural reorganization to deliver interesting scaffolds. Accordingly, **39a** was treated with a catalytic amount of *p*-TSA at room temperature, Scheme 26. To our surprise, a skeletally unique 2-(4-methylhexa-1,3,5-trien-3-yl)benzaldehyde **41** was isolated in 64% yield. The formation of **41** was explained as depicted in Scheme 26. Indeed, in the presence of a trace amount of *p*-TSA, **39a** rapidly underwent fragmentation *via* allylic-benzylic carbocation to give benzaldehyde **41**. The structure of **41** was confirmed by $^{1}$H-NMR and $^{13}$C-NMR analysis (see Figure 13 and 14, respectively).




**Scheme 26:** Synthesis of 2-(4-methylhexa-1,3,5-trien-3-yl)benzaldehyde **41**.

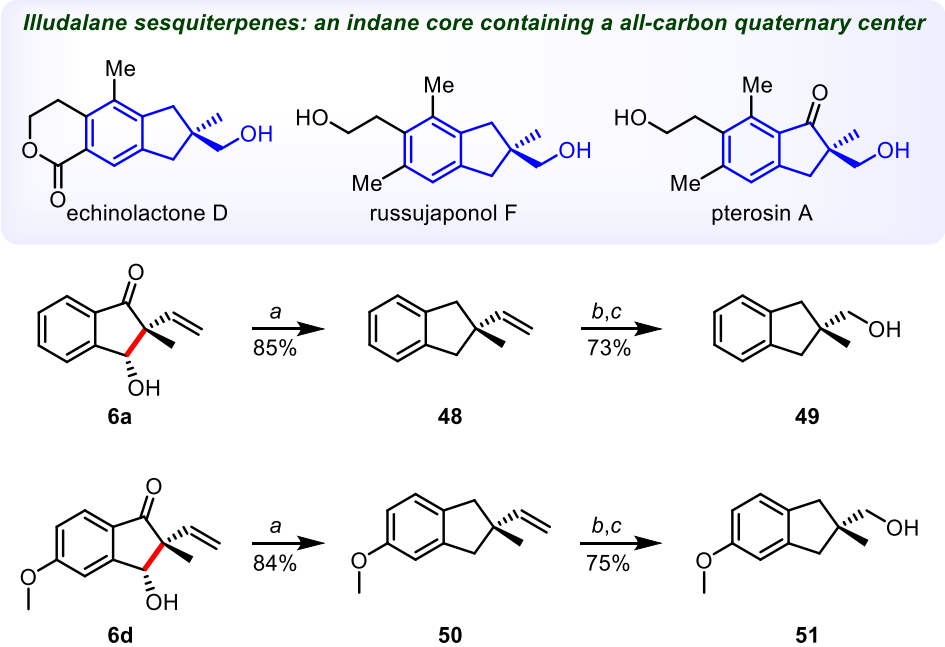
Further studies revealed that the rearrangement is general as long as benzylic-propargylic and bisbenzylic cationic systems are generated. For example, the propargylic *tert*-alcohol **42** delivered 2-(4-methyl-1-phenylhexa-3,5-dien-1-yn-3-yl)benzaldehyde **43**, and the bisbenzylic *tert*-alcohol **44** provided 2-(2-methyl-1-phenylbuta-1,3-dien-1-yl)benzaldehyde **45** in good yields, Scheme 26. But the benzylic *tert*-alcohol **46** produced 2-methyl-3-methylene-2-vinyl-2,3-dihydro-1*H*-inden-1-ol **47** *via* dehydration. Moreover, this kind of skeletal reorganization of indane derivatives is not known so far. It also represents a new entry for synthesizing 1,3,5-trienes, 1-yn-3,5-dienes, 1,3- dienes, and 3-methylene indanols which are otherwise difficult to synthesize.




**Scheme 27:** Synthesis of 1-yn-3,5-dienes, 1,3- dienes, and 3-methylene indanols.

## *1.3.3: Synthesis of Natural Products Analogues*

The synthetic application of this IVAR adducts was demonstrated by preparing the analogues of the bioactive natural products, echinolactone D[33] and russujaponol F[34], Scheme 28. The biological activity of these natural products, such as echinolactone D exhibits antimicrobial activity, and russujaponol F acts as a mild cytotoxic agent. Regarding this, global deoxygenation of **6a** and **6d** was performed with a combination of boron trifluoride etherate and triethylsilane. Then, Osmium tetraoxide catalyzed oxidative cleavage of the vinyl group (in **48** and **50**) followed by the sodium borohydride reduction delivered **49** and **51**, respectively. The structure of indane **49** was confirmed by $^{1}$H-NMR and $^{13}$C-NMR analysis (see Figure 15 and 16, respectively).




*Reagents and conditions:* a) $BF_3.Et_2O$ (5 eq.), $Et_3SiH$ (10 eq.), dry DCM, 0 $^{o}$C, 8 h. b) $OsO_4$ (0.025eq.), $NaIO_4$ (3 eq.), 2,6-lutidine (3 eq.), Dioxane:water (3:1), 8 h. c) $NaBH_4$ (1.5 eq), MeOH, 0 $^{o}$C, 15 min.

**Scheme 28:** Synthesis of natural product analogues **49** and **51**.

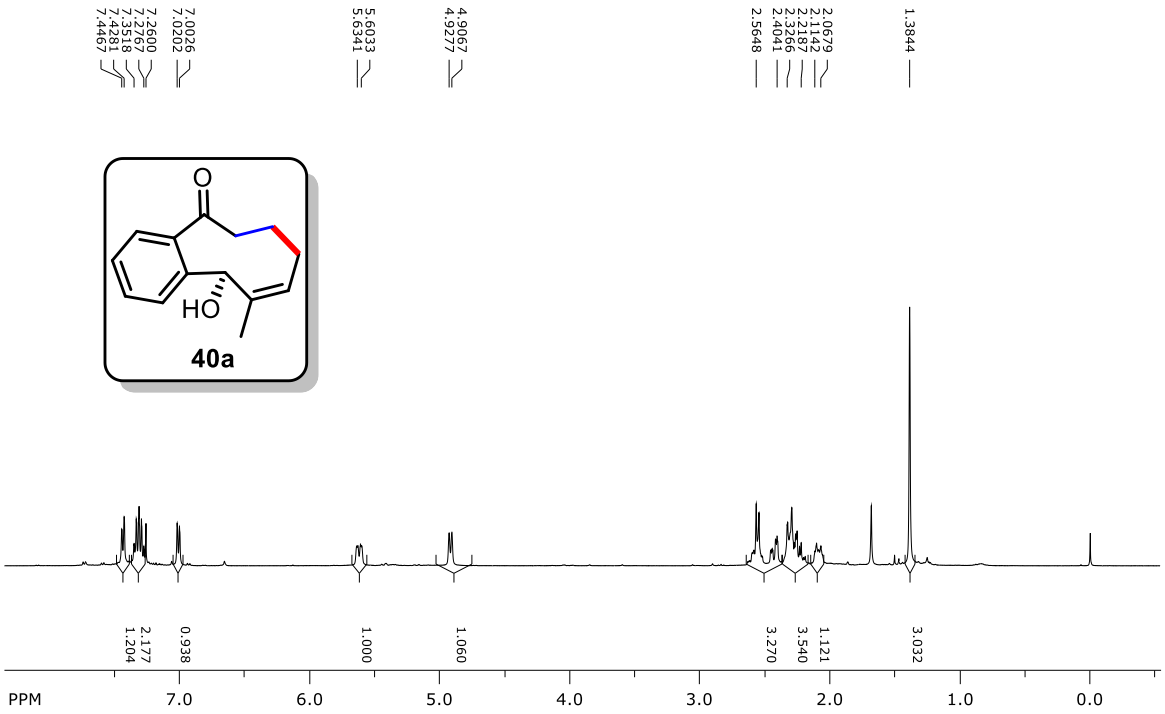



**Figure 11:** $^{1}$H-NMR spectrum of the nine-membered carbocycle **40a**.

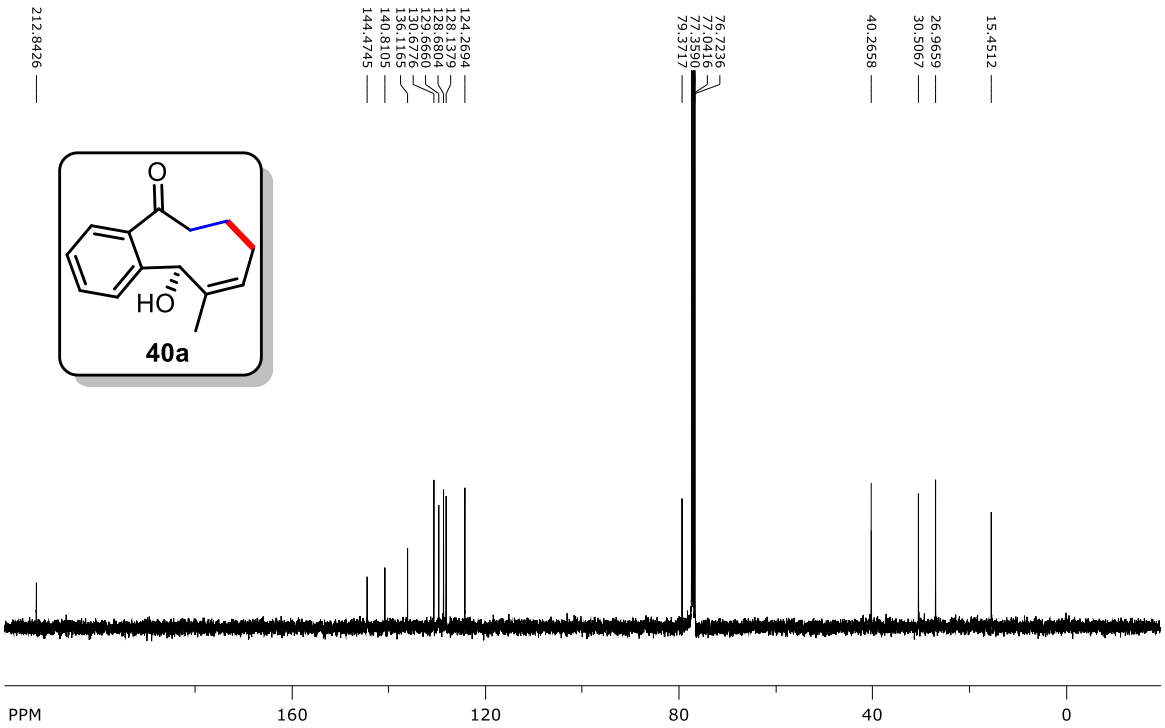



**Figure 12:** $^{13}$C-NMR spectrum of the nine-membered carbocycle **40a**.

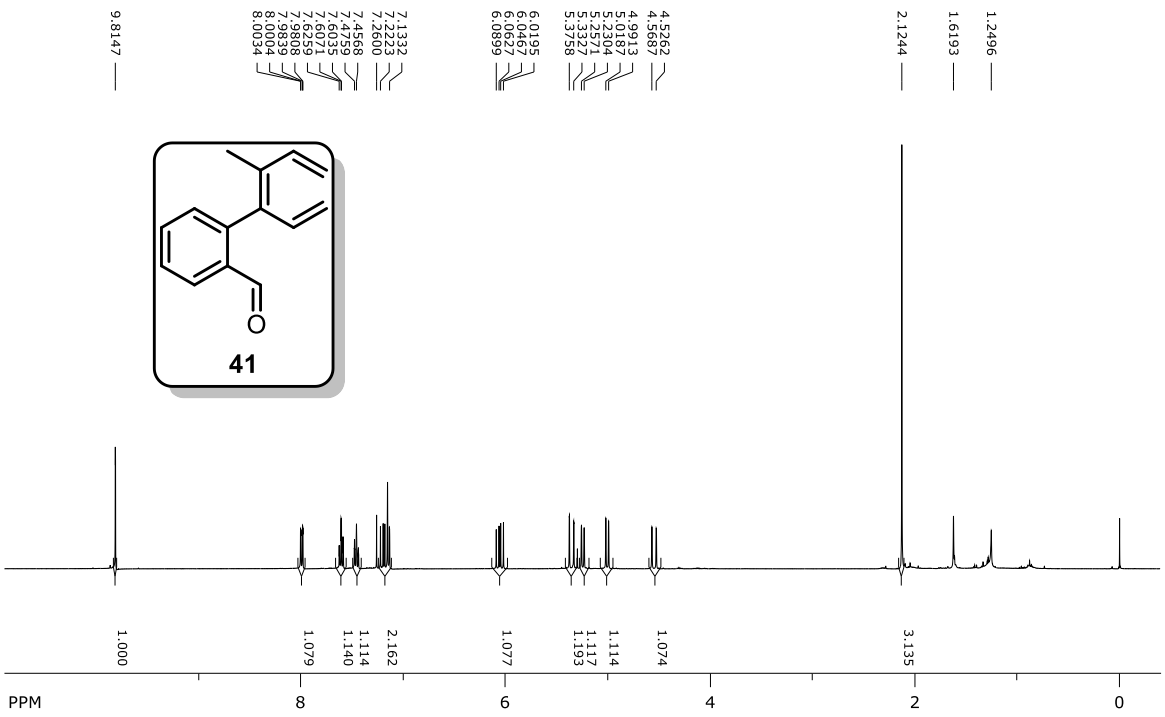



**Figure 13:** $^{1}$H-NMR spectrum of 1,3,5-trienes **41**.

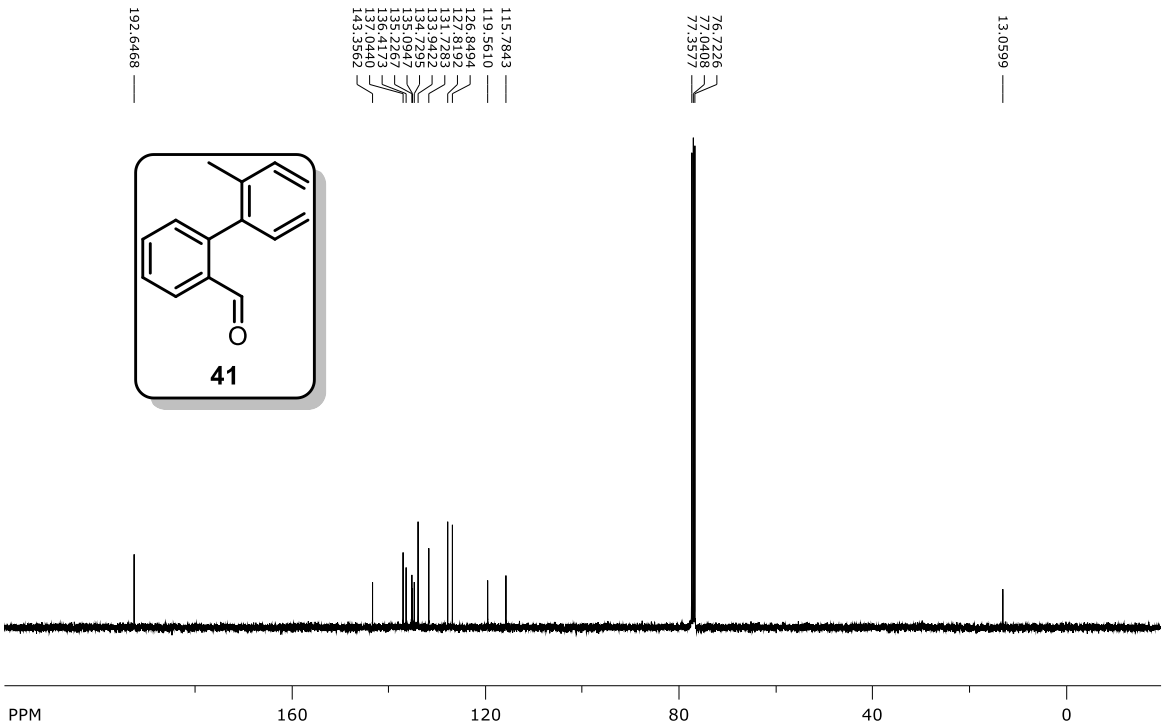



**Figure 14:** $^{13}$C-NMR spectrum of 1,3,5-trienes **41**.

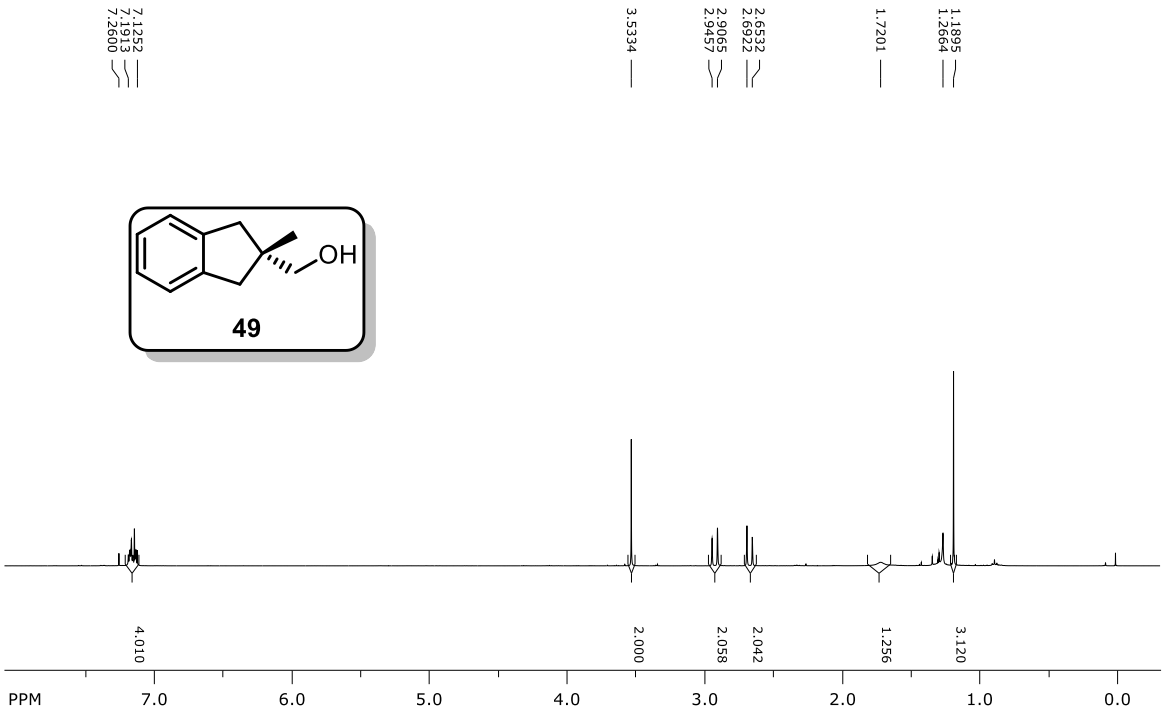



**Figure 15:** $^{1}$H-NMR spectrum of indane **49**.

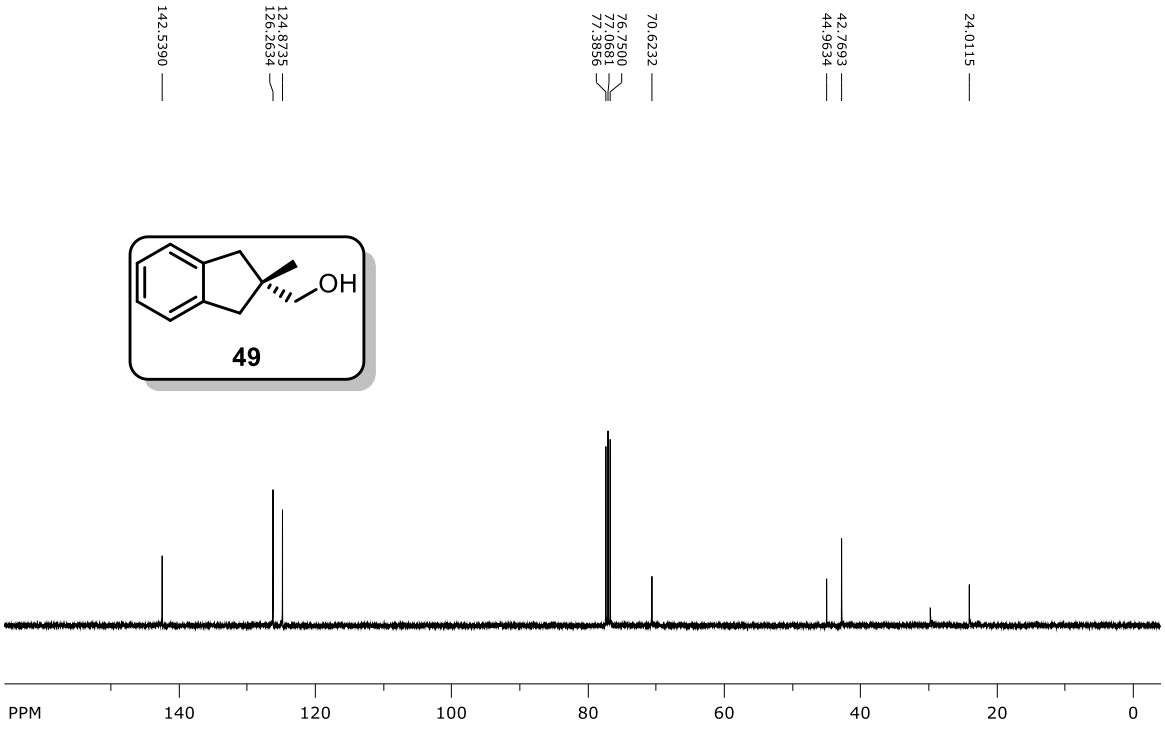



**Figure 16:** $^{13}$C-NMR spectrum of indane **49**.

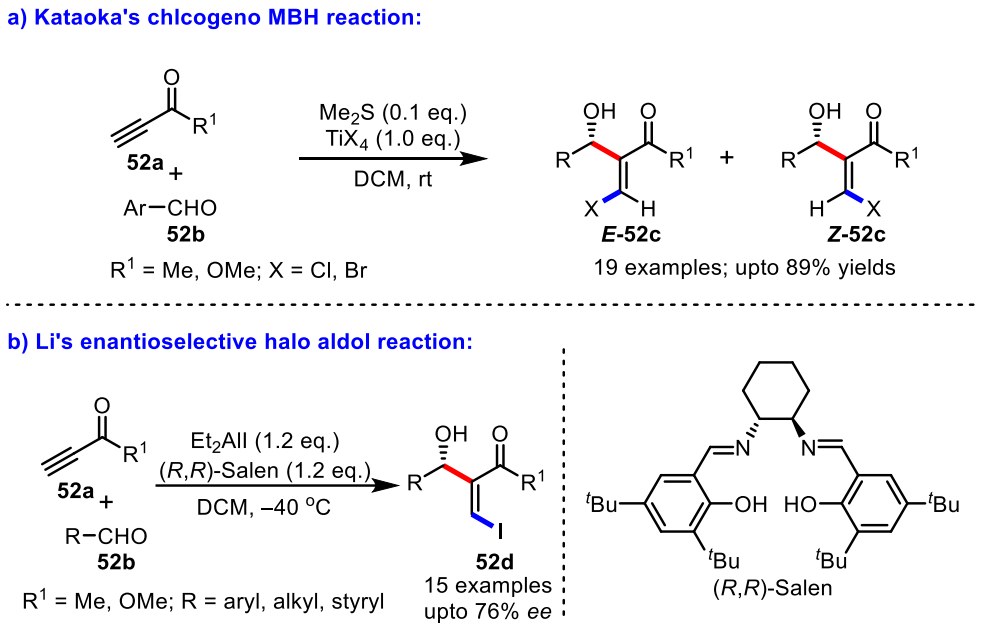
In conclusion, we have established the first phosphine catalyzed IVAR of $\alpha$-substituted enone-aldehydes to synthesize various pentannulated (hetero)arenes possessing two contiguous quaternary and tertiary stereocenters. The DHIs were accessed under extremely mild and moisture insensitive conditions in excellent yields and diastereoselectivities. The concept was also utilized for the synthesis of a new classes of functionally rich dibenzocycloheptanones. The IVAR adducts were converted to benzo-fused nine-membered carbocycles in two steps *via* oxy-Cope rearrangement. A unique acid-catalyzed fragmentation of indane moiety was demonstrated to access interesting classes of 1,3,5-trienes, 1-yn-3,5- dienes, and 1,3-dienes with defined substitution patterns. In addition, the IVAR adducts were transformed to the analogues of echinolactone D and russujaponol F by simple functional group transformations. The generality and practicality of the methodology was carefully evaluated during the course of the study.

# Chapter 2

## *Organophosphine-Catalyzed Intramolecular Hydroacylation of Activated Alkynes*

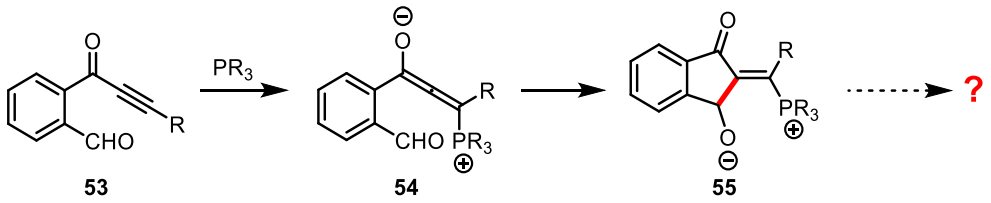
Morita-Baylis-Hillman (MBH) reactions are usually carried out with activated enones having no $\alpha$-substitution and a carbon electrophile in the presence of a nucleophilic catalyst.[4,35] In this regard, we have tactfully utilized activated $\alpha$-substituted enone substrates under a typical MBH condition, and the outcome is an intramolecular vinylogous aldol reaction (described in Chapter 1). After the successful development of the IVAR, we are inquisitive about the fate of activated alkynes under the typical MBH setup. In this context, a handful of reports were known where activated alkynes were being explored during the development of chalcogeno-MBH reaction[36] and halo aldol reaction[37]. Towards this, in 2000, Kataoka *et al.* described a chalcogeno-MBH reaction between an alkyne carboxylic ester or ketone **52a** and aldehyde **52b**

in the presence of a metal-based Lewis acid to obtain *β*-halo MBH adducts **52c**, Scheme 29a.[36a] In his seminal report, Kataoka mentions that "the Baylis−Hillman reaction of active alkynes with aldehydes cannot proceed from the mechanistic viewpoint of the reaction". Later, in 2004, Li and co-workers reported a first enantioselective halo aldol reaction of ethyl propionate **52a** and aldehydes **52b** to synthesize *β*-iodo MBH esters **52d** by using $Et_2AlI$ as halogen source and Lewis acid promoter, Scheme 29b.[37b] The enantioselectivity was achieved by using Jacobsen's chiral cyclohexylsalen ligand, albeit in diminished *ee*.



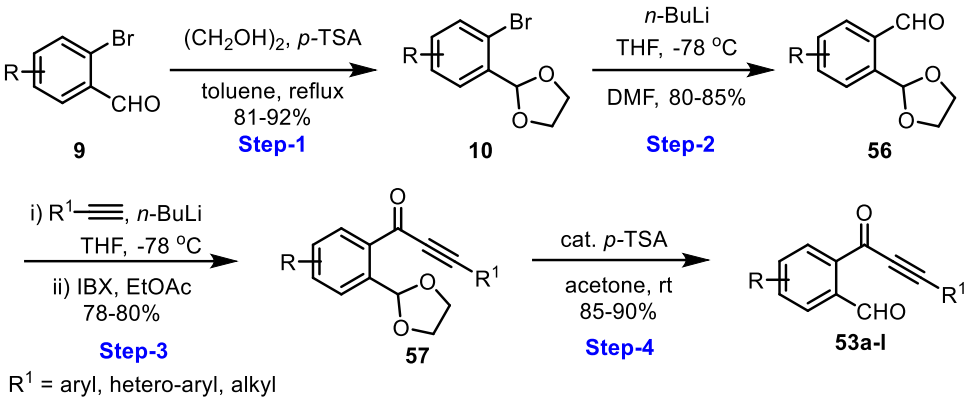

**Scheme 29:** Chalcogeno MBH and halo aldol reaction of ynones.

However, to our surprise, no attempt was ever made to employ activated ynones and aldehydes in the presence of phosphine as a nucleophilic trigger. Towards this, we considered a designed ynone-aldehyde **53** wherein the *α,β*-ynone and aldehyde functionalities were tethered *ortho* to each other for this study. It was envisioned that the zwitterionic intermediate **54** could be generated by the conjugate addition of phosphine to the ynone-aldehyde **53**. Next, it could undergo an intramolecular aldol reaction to generate a zwitterion **55** but the subsequent fate of the reaction was not realized at this time, Scheme 30.



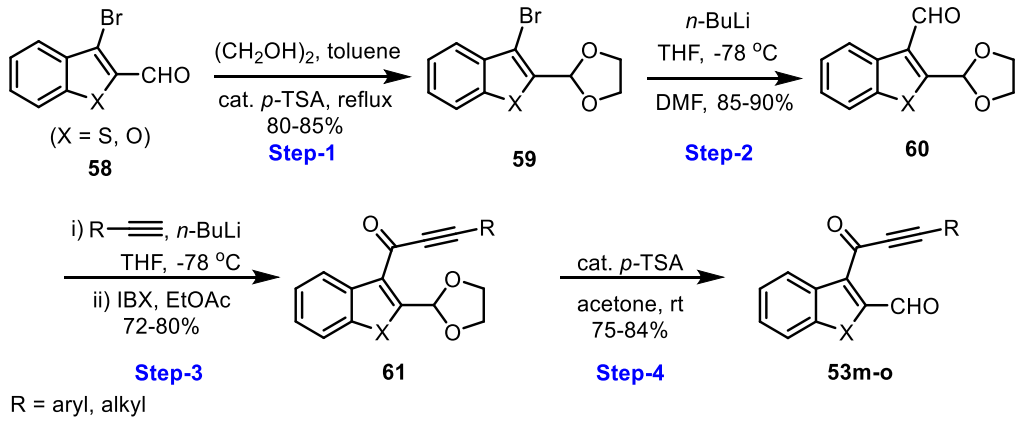

**Scheme 30:** Our hypothesis towards ynone MBH reaction.

In line with this, the ynone-aldehydes **53a-l** can be easily synthesized in four steps starting from commercially available 2-bromo aldehyde **9**, Scheme 31. The bromo aldehyde **9** was subjected to *p*-TSA catalyzed reaction with ethylene glycol to afford **10**. Then, *n*-BuLi mediated formylation, followed by alkylation with substituted alkyne and oxidation with IBX delivered **57**. Finally, acid-catalyzed deprotection of acetal functionality of **57** generated the desired ynone-aldehyde **53a-l**. [38]



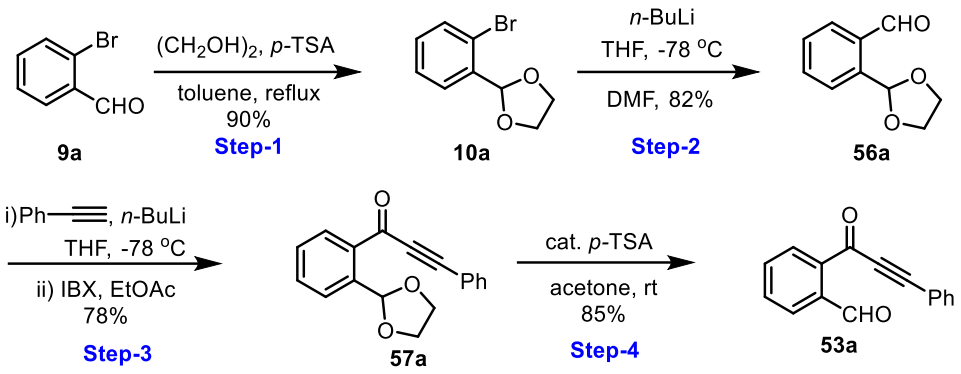

**Scheme 31:** Synthesis of ynone-aldehyde **53a-l**.

Similarly, benzothiophene and benzofuran-based ynone-aldehydes **53m-o** were synthesized, Scheme 32.[38]



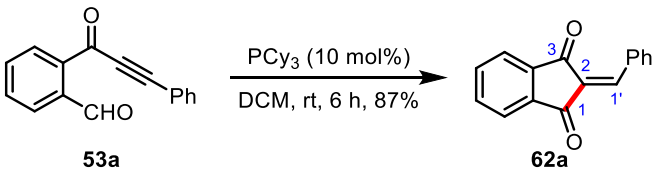

**Scheme 32:** Synthesis of benzothiophene and benzofuran based ynone-aldehydes **53m-o**.

We initiated our study by synthesizing the ynone-aldehyde **53a** by following the procedure shown in Scheme 33, starting from commercially available 2-bromo benzaldehyde and phenyl acetylene.




**Scheme 33:** Synthesis of ynone-aldehyde **53a**.

To validate the hypothesis, our model substrate **53a** was treated with 10 mol% of $PCy_3$ and it delivered a non-polar compound with respect to **53a** in a reasonable yield at room temperature, Scheme 34. To our surprise, a careful analysis of the spectral data revealed the exclusive formation of 2-benzylidine-1,3-indanedione **62a**.[39] This was a phosphine-catalyzed hydroacylative cyclopentannulaation of $\alpha,\beta$-ynones. In the $^1$H-NMR spectrum (see Figure 17), the presence of one singlet at δ 7.90 ppm is due to the $\beta$-proton of carbonyls (C-1' proton), and in $^{13}$C-NMR spectrum (see Figure 18), the presence of two carbonyl peaks at δ 190.3 and 189.0 ppm (C-1 and C-3), affirmed the formation of 2-benzylidine-1,3-indanedione **62a**. This spectral data of **62a** was matched with previously reported literature for further confirmation of the structure.[40]




**Scheme 34:** Phosphine-catalyzed hydroacylative cyclopentannulation of $\alpha,\beta$-ynones.

Some of the noteworthy features associated with the conversion of **53a** to **62a** are (i) this method represents a metal-free (and organocatalytic) alternative for the intramolecular hydroacylation of ynones. In line with this, for the first time $\alpha,\beta$-ynones are employed as substrates in a phosphine-catalyzed hydroacylation process[41], which is indeed a limitation of the existing methods, (ii) it also exemplifies an unusual entry to synthesize fully substituted indanes that present in several bioactive natural products, pharmaceuticals, and organic materials.[42]

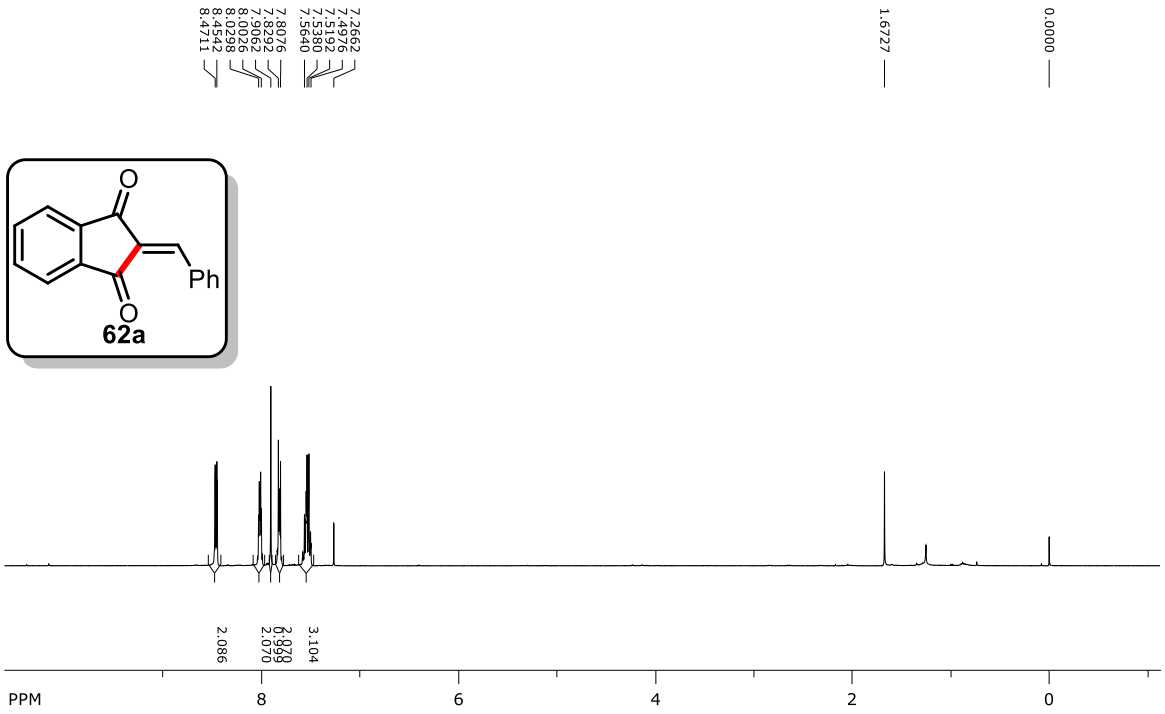



**Figure 17:** $^{1}$H-NMR spectrum of the hydroacylation product **62a**.

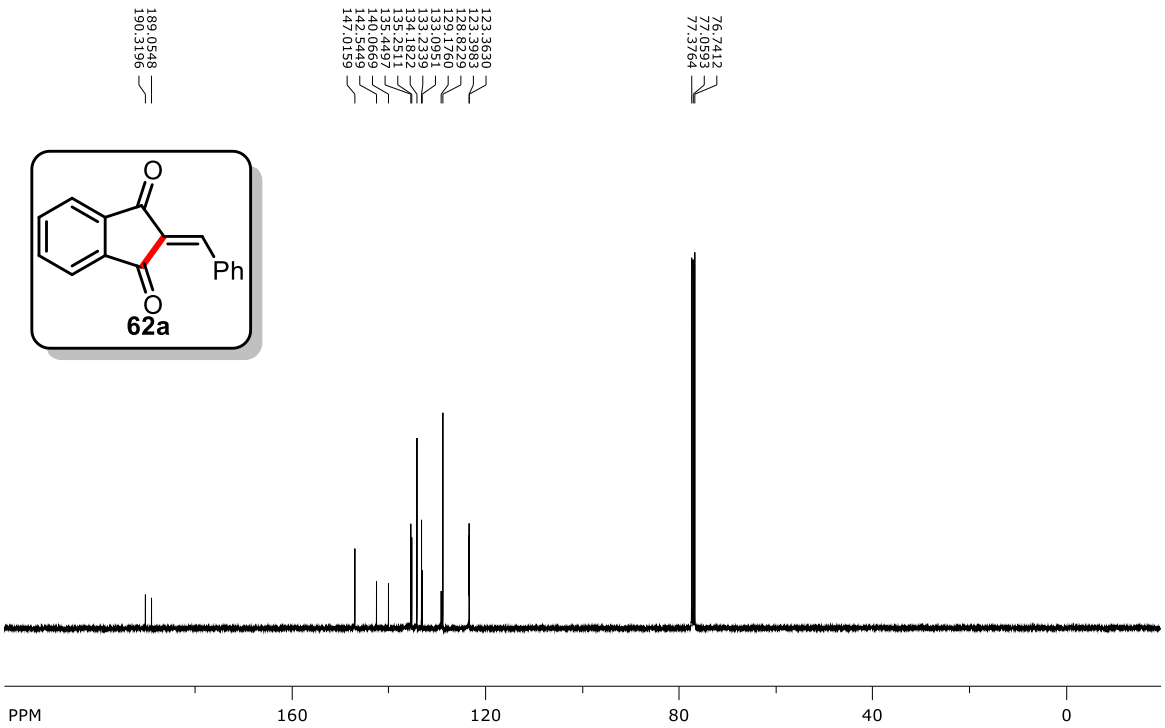
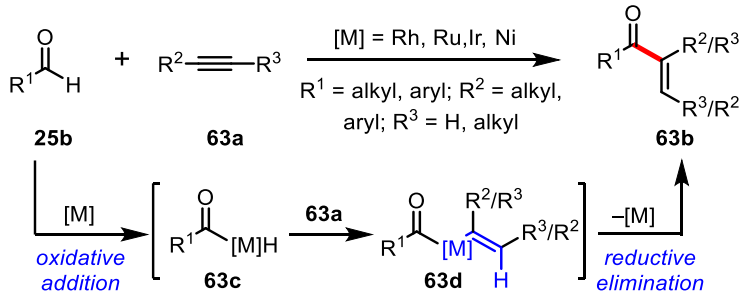



**Figure 18:** $^{13}$C-NMR spectrum of the hydroacylation product **62a**.

In the last few decades, there has been an immense focus on the activation and functionalization of C-H bonds.[43] The methodologies based on the reaction of the C-H bond of a specific functional group and the formation of a new C-C bond with another incoming reagent are essential tools in organic synthesis. In this regard, hydroacylation formally involves the addition of the formal C-H bond of an aldehyde across C-C multiple bonds to generate the corresponding ketone in an atom-economic manner.[44] In 1972, Sakai and co-workers first demonstrated the Rhodium-catalyzed hydroacylation of alkenes to construct cyclopentanes.[45] After that, tremendous advancements were achieved in intra- and intermolecular alkene hydroacylation catalyzed by transition metals[46] and NHCs[47]. Although, the study of alkynes in hydroacylation reactions was gained less attention than their alkene counterparts.

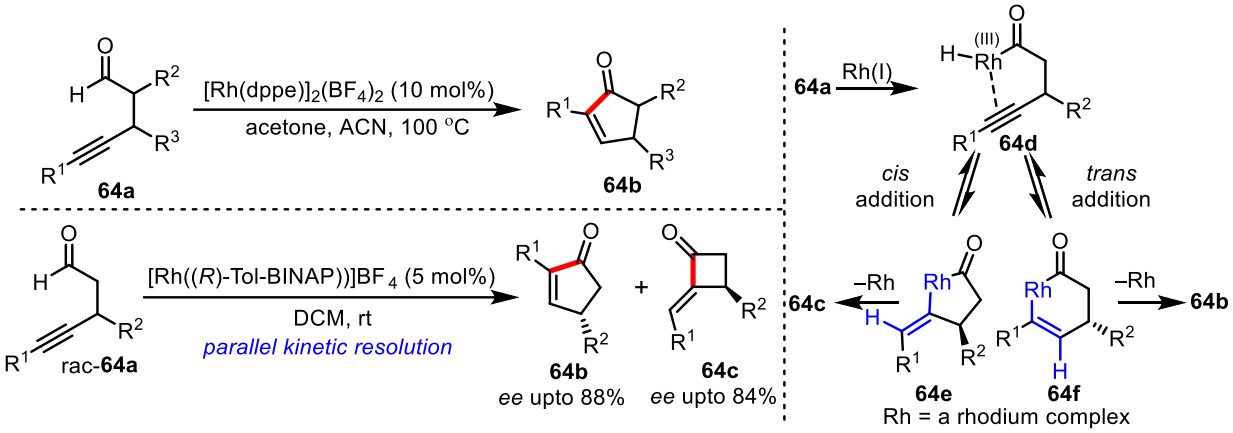
Towards this, in 1990, Seagusa and co-workers[48] first reported a Ni-catalyzed hydroacylation of symmetrical and unsymmetrical alkynes to generate $\alpha,\beta$-enones **63b**, Scheme 35. Later, different metal catalysts[49] ([M] = Rh, Ir, Ru) were also used for this hydroacylation process and rhodium catalysts[50] were realized to be one of the best catalysts for these transformations. A general metal-catalyzed hydroacylation mechanism is shown in Scheme 35. Initially, oxidative addition of strong electron-rich [M] into the C-H bond of aldehyde **25b** forms the [M]-acyl hydride **63c**. The *cis*-addition of [M]-hydride to the alkyne generates **63d** and followed by reductive elimination furnishes the hydroacylation product **63b**.




**Scheme 35:** Metal-catalyzed hydroacylation of alkynes.

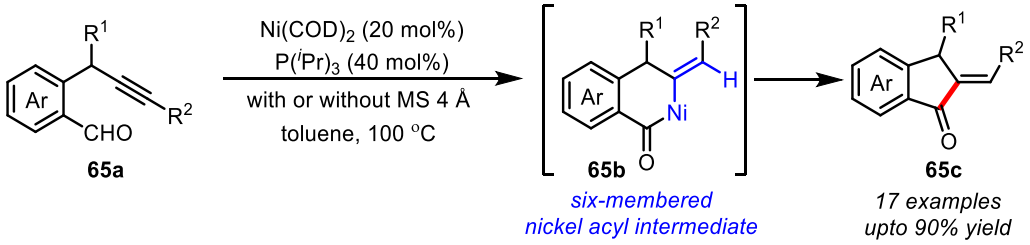
In 2001, Fu and Tanaka[51a] described a Rh-catalyzed intramolecular hydroacylation of **64a** to synthesize cyclopentenone **64b** as an alternative to Pauson-Khand reaction, Scheme 36. Firstly, in presence of Rh(I), **64a** forms a Rh(III) acyl hydride **64d** through oxidative addition to the aldehyde C-H bond. Next, in an unusual step, *trans*-addition of rhodium hydride to the coordinated alkyne to generate a six-membered rhodium metalacyclohexene **64f**. Finally, reductive elimination furnishes the formation of **64b** and regenerates the Rh(I). Later, they illustrated a parallel kinetic resolution of *rac*-**64a** for the formation of enantioenriched cyclopentenones **64b** and cyclobutanones **64c** by a Rh(I)/Tol-BINAP catalyst. Interestingly,

the *cis*- or *trans*-addition of Rh(III) acyl hydride **64d** to the alkyne generates the five or six-membered rhodacyclic intermediate **64e** or **64f**, which reductively eliminates to afford **64c** or **64b**, respectively with good enantiomeric excess.




**Scheme 36:** Fu and Tanaka's Rh-catalyzed hydroacylation of alkynes.

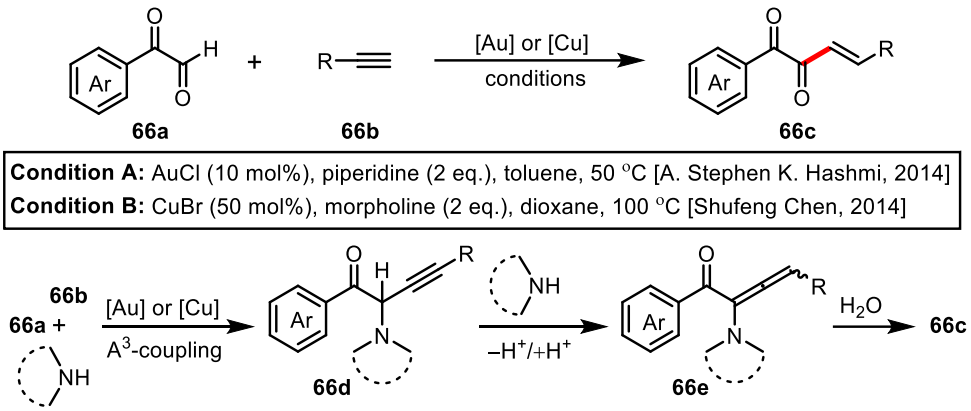
In 2012, Yamamoto *et al.*[52] reported a Ni-catalyzed intramolecular hydroacylation of **65a** for the synthesis of substituted indanones **65c**, Scheme 37. In the presence of $Ni(COD)_2/P(^iPr)_3$ catalyst system, **65a** generates a six-membered nickel acyl intermediate **65b** by the *cis*-addition of Ni-acyl hydride to the alkyne, which after reductive elimination generates the corresponding indanone **65c** with exclusive *E*-selectivity.




**Scheme 37:** Yamamoto's Ni-catalyzed intramolecular hydroacylation of alkynes.

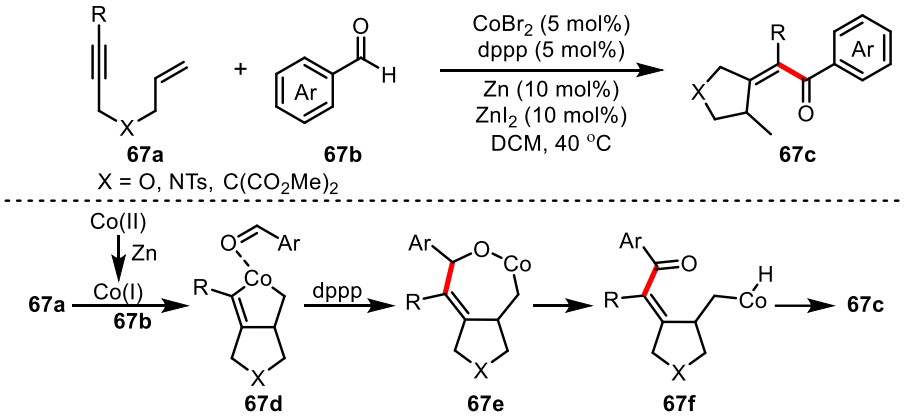
In 2014, Hashmi and co-workers[53] noted a Gold(I) catalyzed reaction of $\alpha$-ketoaldehydes **66a** and terminal alkynes **66b** in the presence of piperidine to deliver 1,2-dicarbonyl-3-enes **66c** and the overall transformation was a formal hydroacylation of alkynes, Scheme 38 (condition A). Later, Chen group[54] also reported the same transformation catalyzed by CuBr and morpholine was used as a base, Scheme 38 (condition B). Initially, a three-component $A^3$-coupling (alkyne-amine-aldehyde-coupling) results in the formation of **66d**. Next, the base can abstract the proton from the $\alpha$-position of carbonyl to generate a conjugated

allenylamine intermediate **66e**. Finally, the hydrolysis of enamine substrate **66e** delivers the final product **66c** with thermodynamically favored *E*-configuration.



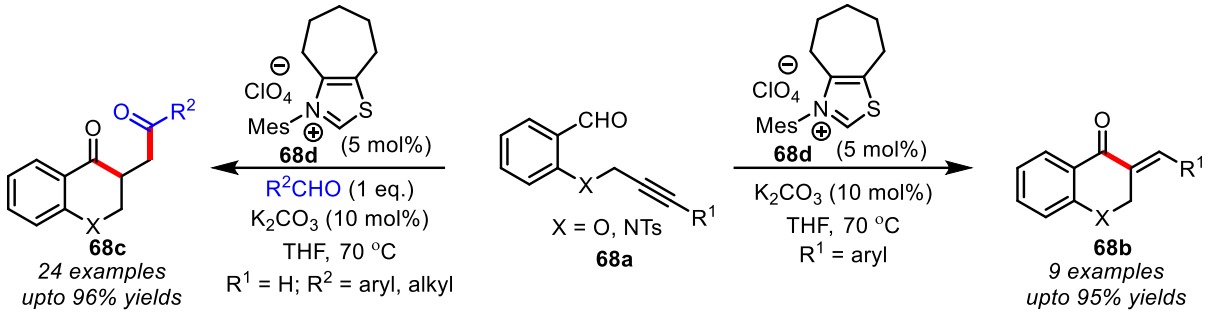

**Scheme 38:** Gold and copper-catalyzed intermolecular hydroacylation of alkynes.

In 2015, Cheng *et al*.[55] reported a cobalt-catalyzed hydroacylative cyclization of enynes **67a** with aldehydes **67b** to access *exo*-cyclic enone **67c**, Scheme 39. **67a** generates a five membered cobaltacycle **67d** which in the presence of ligand dppp forms a bicyclic intermediate **67e** and subsequent *β*-hydride elimination furnishes the formation of product **67c**.



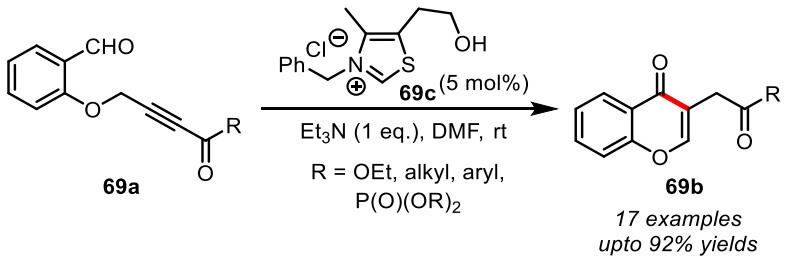

**Scheme 39:** Cheng's cobalt-catalyzed hydroacylative cyclization.

Although, the metal-catalyzed hydroacylation of alkynes are under exploration, only a handful reports are known where organo-catalysts are used for the same. In 2010, Glorius and co-workers[56] disclosed a NHC-organocatalyzed intramolecular hydroacylation of unactivated alkynes. Here, alkyne-aldehyde substrates **68a** in the presence of a NHC catalyst **68d** underwent a hydroacylation process *via* the formation of Breslow intermediate, leading to the formation of *α,β*-unsaturated enones **68b**, Scheme 40. In addition, the presence of an additional aldehyde in the system, the reaction proceeded through a hydroacylation-Stetter cascade catalyzed by NHC to produce **68c** in good to excellent yields.




**Scheme 40:** Glorius's NHC-catalyzed hydroacylation of alkynes.

Similar to this, in 2011, Liu *et al.*[57] described a NHC-catalyzed Stetter type intramolecular hydroacylation of activated alkynes. The alkyne-aldehydes **69a** in the presence of **69c** as catalyst delivered the thermodynamically more stable chromanone **69b** in good to excellent yield at room temperature, Scheme 41. In this context, Shi and co-workers[58] also developed a NHC-catalyzed intramolecular hydroacylation reactions of alkynal phosphonates leading to the synthesis of chromone phosphonates.




**Scheme 41:** Liu's NHC-catalyzed hydroacylation of activated alkynes.

As showcased above, most hydroacylation reactions between alkynes and aldehydes were catalyzed either by transition metals or NHCs. To the best of our knowledge, *α,β*-ynones and organo-phosphines are never utilized for an intermolecular hydroacylation process.

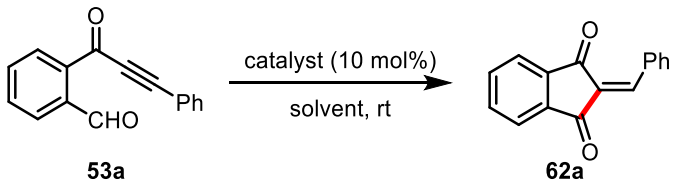
## *2.1: Results and Discussion*

### *2.1.1: Intramolecular hydroacylation of ynone-aldehydes*

To our delight, our observation (described in Scheme 34) represents an unprecedented metal-free and organophosphine-catalyzed intramolecular hydroacylation of activated alkynes leading to the formation of densely functionalized indanes. After having the initial result with $PCy_3$, we were keen to optimize the reaction condition for the hydroacylation process. For this purpose, **53a** was chosen as the model substrate for screening the reaction conditions, and the results were compiled in Table 6. Initially, a wide range of organo-phosphines was

investigated. The reaction of **53a** with $PMe_2Ph$ and $PEtPh_2$ delivered the expected product **62a** with poor to moderate yields (entries 2 and 3). But a marked improvement in yield was observed when the reaction was carried out with $PPh_3$ (entry 4). Further, to improve the efficiency of the reaction, various solvents were screened (ACN, toluene, $CH_3O^tBu$, and 2-methyl–THF) with $PPh_3$ as a catalyst, but the results were discouraging as it failed to improve the yields (entries 5-8). In addition, we also verified the feasibility of performing the reaction under an aqueous medium. **53a** was treated with $PPh_3$ where water-THF combination and brine solution were used as solvent (entries 9 and 10). Interestingly, the reaction generated **62a** in excellent yield in both conditions. Indeed, the best yield of the expected product (93%) was realized when brine solution was employed as solvent. On the other hand, we also screened the reaction with a few N-centered Lewis bases such as DABCO, *β*-isocuperidine (*β*-ICD) which are very well-known catalysts in Baylis-Hillman chemistry (entries 11 and 12). To our surprise, it failed to generate the expected product even after a prolong reaction time. Thus, 10 mol% $PPh_3$ was identified as the catalyst for this hydroacylation process and DCM or brine solution can be used as solvent.

**Table 6:** Optimization of reaction parameters




**53a** **62a**

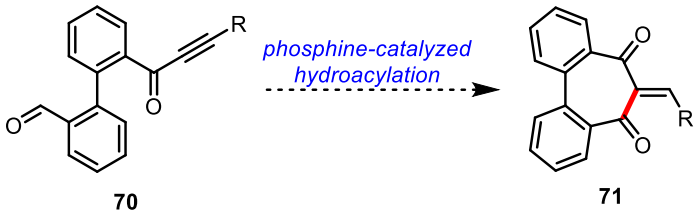
| entry | catalyst | solvent | time (h) | yield (%)[a] |
|---|---|---|---|---|
| 1 | $PCy_3$ | DCM | 6 | 78 |
| 2 | $PMe_2Ph$ | DCM | 8 | 48 |
| 3 | $PEtPh_2$ | DCM | 4 | 72 |
| **4** | **$PPh_3$** | **DCM** | **5** | **92** |
| 5 | $PPh_3$ | ACN | 3 | 76 |
| 6 | $PPh_3$ | toluene | 12 | 82 |
| 7 | $PPh_3$ | $CH_3O^tBu$ | 4 | 70 |
| 8 | $PPh_3$ | 2-Me–THF | 72 | 79 |
| 9 | $PPh_3$ | water:THF (1:1) | 40 | 88 |
| **10** | **$PPh_3$** | **brine** | **8** | **93** |
| 11 | DABCO | DCM | 48 | - |
| 12 | *β*-ICD | DCM | 12 | - |

All reactions were performed on 0.1 mmol scales. [a] Yields were calculated after silica gel column chromatography.

After having the optimized condition in hand, we investigated the substrate scope with various kinds of ynone-aldehydes bearing different electronic features. The results of the study are presented in Table 7. A wide range of 2-alkylidine and 2-arylidine-1,3-indanediones **62a-o** could be rapidly assembled in good to excellent yields. Regarding the substituent effect, as per our expectation, substrates having electron-withdrawing groups (such as -F) in the aryl backbone (**53i-j**) worked nicely under the optimized condition to obtain 1,3-indanediones **62i-j**, Table 7. Whereas, ynones having electron-donating or withdrawing groups **52a-h** have no significant effect on the yields of the reaction while obtaining respective 1,3-indanediones **62a-h**, Table 7. While the reaction was carried out in brine solution, we observed a marginal decrease in yields for the formation of the final product compared to the reaction performed in DCM solvent (**62c-d** and **62i-j**). This observation can be attributed to the miscibility issues associated with the substrates in aqueous media. The ynones with alkyl groups delivered the corresponding indanediones (**53g-h**) in moderate to excellent yields, although in slightly elevated temperature for **53h**, Table 7. Apart from the ynones, enynones-bearing substrates successfully delivered the dienone product (**62l-m**) under the optimized condition in moderate to good yields, Table 7. The generality of the method is also verified with ynones having hetero-aromatic backbone (such as benzothiophene, benzofuran) **53m-o**, which smoothly generates the respective heteroaryl-fused 1,3-cyclopentanediones **62m-o** in good to excellent yields, Table 7.

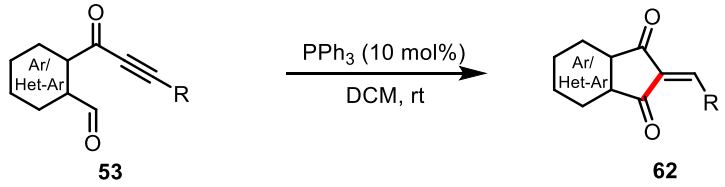
## *2.1.2: Intramolecular hydroacylation of biaryl ynone-aldehydes*

After establishing a general and efficient method for hydroacylative cyclopentannulation of ynone-aldehydes, we planned to extend this concept to a new substrate design **70**, Scheme 42. We anticipated that the designed biaryl ynone-aldehyde **70** under phosphine-catalyzed conditions could generate the dibenzo-fused cycloheptanediones **71**. In the context of metal-catalyzed hydroacylation reactions, Willis opines that the intramolecular reactions to generate rings other than five-membered systems are not trivial as ring closure of these larger rings is generally slower than for five-ring formation.[44d]

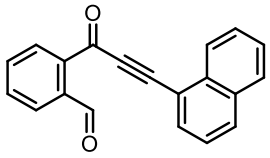
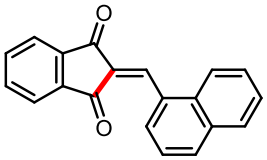
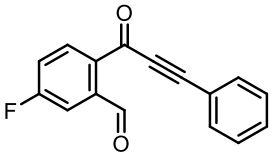
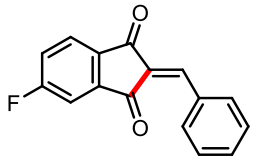
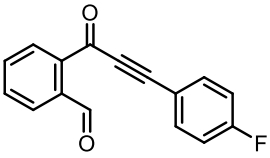
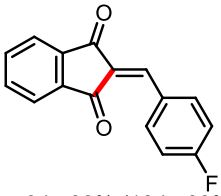
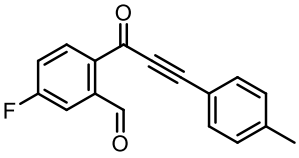
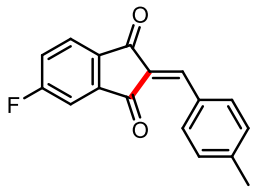
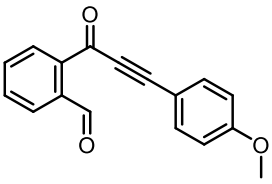
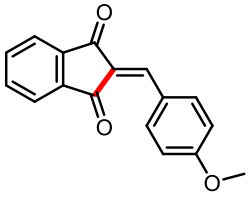
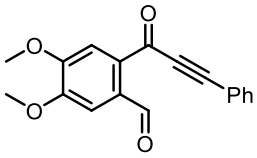
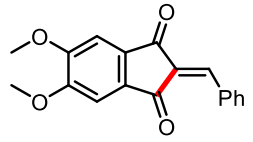
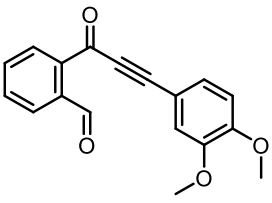
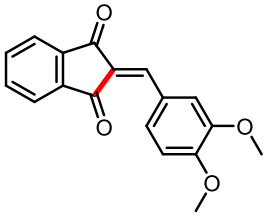
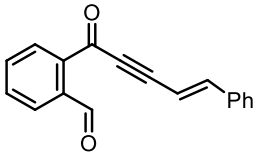
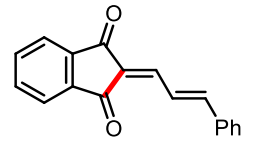
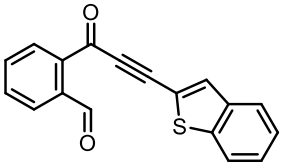
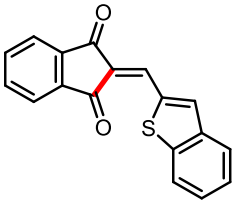
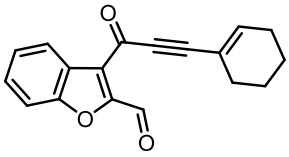
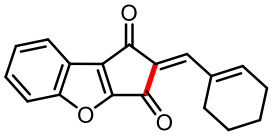
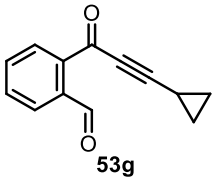
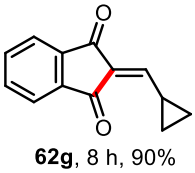
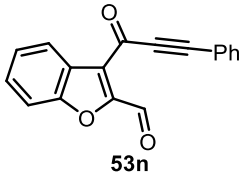
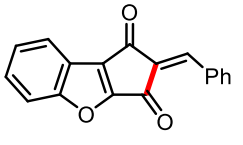
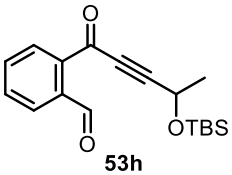
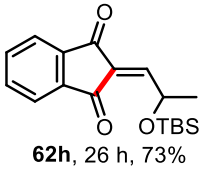
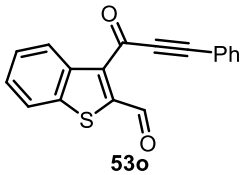
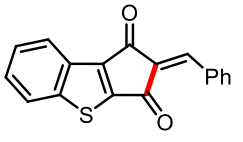



**Scheme 42:** Proposed phosphine-catalyzed hydroacylation of biaryl ynone-aldehydes **70**.

**Table 7:** Substrate Scope: Cyclopentannulated arenes and heteroarenes

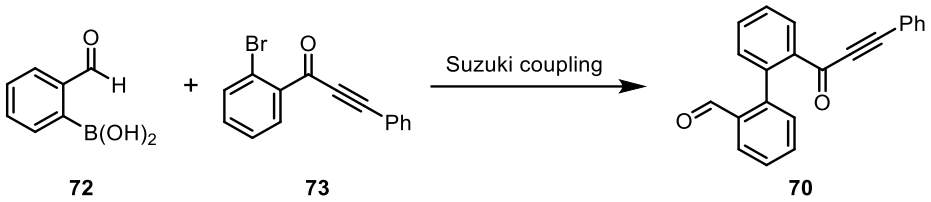



**53** **62**

| entry | substrate | product | entry | substrate | product |
|---|---|---|---|---|---|
| 1 |  **53b** |  **62b**, 6 h, 90% | 8 |  **53i** |  **62i**, 5 h, 95% (12 h, 86%)[a] |
| 2 |  **53c** |  **62c**, 6 h, 88% (12 h, 83%)[a] | 9 |  **53j** |  **62j**, 5 h, 90% (10 h, 82%)[a] |
| 3 |  **53d** |  **62d**, 5 h, 90% (12 h, 81%)[a] | 10 |  **53k** |  **62k**, 8 h, 72% |
| 4 |  **53e** |  **62e**, 10 h, 87% | 11 |  **53l** |  **62l**, 20 h, 72% |
| 5 |  **53f** |  **62f**, 10 h, 91% | 12 |  **53m** |  **62m**, 36 h, 67% |
| 6 |  **53g** |  **62g**, 8 h, 90% | 13 |  **53n** |  **62n**, 24 h, 72% |
| 7[b] |  **53h** |  **62h**, 26 h, 73% | 14 |  **53o** |  **62o**, 10 h, 91% |

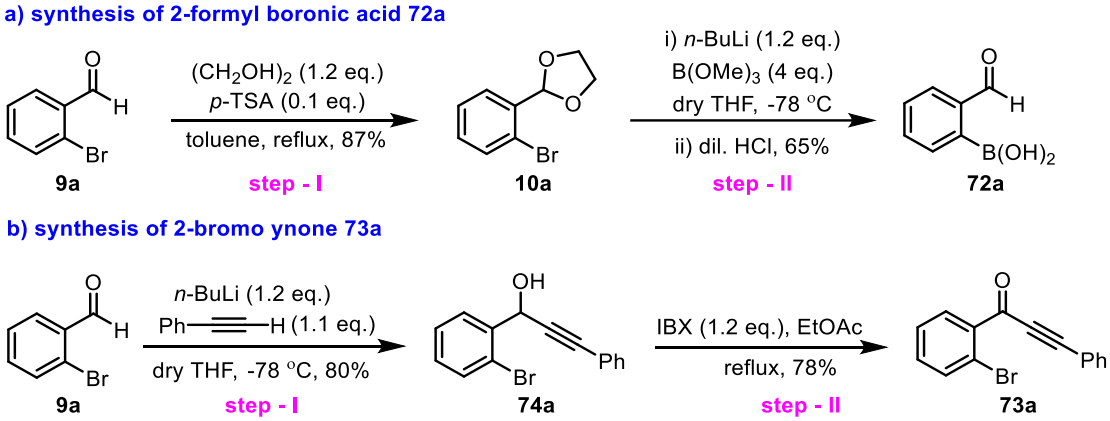
[a] Outcome in brine medium. [b] At 40 °C.

To substantiate our hypothesis presented in Scheme 42, we planned to synthesize the designed substrates **70**. The biaryl ynone aldehyde **70** can be accessed through the Suzuki coupling reaction between 2-formyl boronic acid **72** and 2-bromo ynone **73**, Scheme 43.




**Scheme 43:** Synthesis of biaryl ynone-aldehyde **70**.

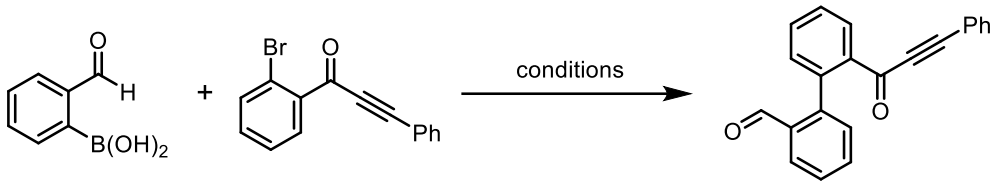
Both coupling partner were synthesized by following a two-step protocol starting from commercially available 2-bromobenzaldehyde **9a**. **9a** was protected with ethylene glycol under acidic medium and subjected to *n*-BuLi mediated borylation to obtain the required 2-formyl boronic acid **72a**, Scheme 44a. Next, *n*-BuLi mediated alkylation of **9a** with phenylacetylene generated the bromo alcohol **74a** which upon IBX oxidation delivered the corresponding 2-bromo ynone **73a**, Scheme 44b.




**Scheme 44:** Synthesis of coupling partner **72a** and **73a**.

Next, we wanted to do a Suzuki coupling reaction between **72a** and **73a** but due to the formation of undesired side products under the reported conditions,[28] a screening of different reaction parameters was taken up and the results are summarized in Table 8. After a brief optimization of reaction parameters, $Pd(PPh_3)_4$ was identified as the catalyst for the coupling process, and DMF or ACN can be used as solvent at 60 °C. Next, the optimized condition was applied for the Suzuki coupling reaction to obtain the required starting material **70a** in excellent yields.

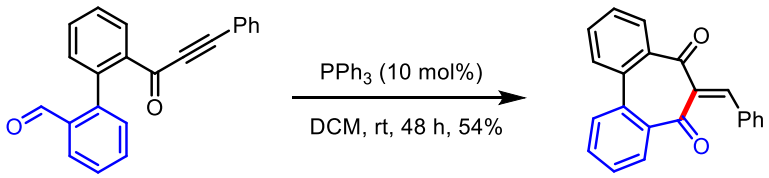
**Table 8:** Optimization table for Suzuki coupling




**72a** **73a** **70a**

| entry | catalyst (0.005 eq.) | co-catalyst (0.012 eq.) | base | solvent | temperature (°C) | water | yield (%) |
|---|---|---|---|---|---|---|---|
| 1 | $Pd_2(dba)_3$ | $[HP(^tBu)_3]BF_4$ | KF (3.3 eq.) | THF | 40 | 3.3 eq. | 49 |
| 2 | $Pd_2(dba)_3$ | $[HP(^tBu)_3]BF_4$ | KF (3.3 eq.) | THF | 40 | 60 eq. | 75 |
| 3 | $Pd_2(dba)_3$ | $[HP(^tBu)_3]BF_4$ | KF (3.3 eq.) | THF | 40 | 100 eq. | 71 |
| 4 | $Pd(PPh_3)_4$ | $[HP(^tBu)_3]BF_4$ | KF (3.3 eq.) | THF | 40 | 60 eq. | 83 |
| 5 | $Pd(PPh_3)_4$ | $[HP(^tBu)_3]BF_4$ | KF (3.3 eq.) | THF | 60 | 60 eq. | 85 |
| 6 | $Pd(PPh_3)_4$ | $[HP(^tBu)_3]BF_4$ | KF (3.3 eq.) | THF | 80 | 60 eq. | 80 |
| 7 | $Pd(PPh_3)_4$ | $[HP(^tBu)_3]BF_4$ | KF (5.0 eq.) | toluene | 60 | 60 eq. | 80 |
| **8** | **$Pd(PPh_3)_4$** | **$[HP(^tBu)_3]BF_4$** | **KF (3.3 eq.)** | **ACN** | **60** | **60 eq.** | **89** |
| **9** | **$Pd(PPh_3)_4$** | **$[HP(^tBu)_3]BF_4$** | **KF (3.3 eq.)** | **DMF** | **60** | **60 eq.** | **91** |

Indeed, gratifyingly, the biaryl ynone-aldehyde **70a** under prototypical conditions (described in Table 7) delivered the desired dibenzo cycloheptanediones **71a** in 54% yield, Scheme 45. The structure of **71a** was confirmed by analyzing the $^1$H-NMR and $^{13}$C-NMR spectra of corresponding product (see Figure 20 and 21).[59] Interestingly, this result represents the first assemblage of fused seven-membered carbocycles *via* an intramolecular hydroacylation of *α*,*β*-ynones.




**70a** **71a**

**Scheme 45:** Initial result of hydroacylation reaction with biaryl ynone-aldehyde **70a**.

Seven-membered carbocyclic moieties are an important structural motif present in several bioactive natural products and pharmaceutically relevant compounds, Figure 19.[60] For example, N-acetylcolchicinol shows good anti-inflammatory activity as compare to structurally similar and more toxic colchicines. Colchibiphenyline and subamol have shown promising anticancer activities by suppressing cell mitosis *via* the inhibition of tubulin assembly. The

phosphate derivative of N-acetylcolchicinol shows potent anti-neoplastic activity and also have undergone clinical trials for renal cell carcinoma and colorectal cancer.

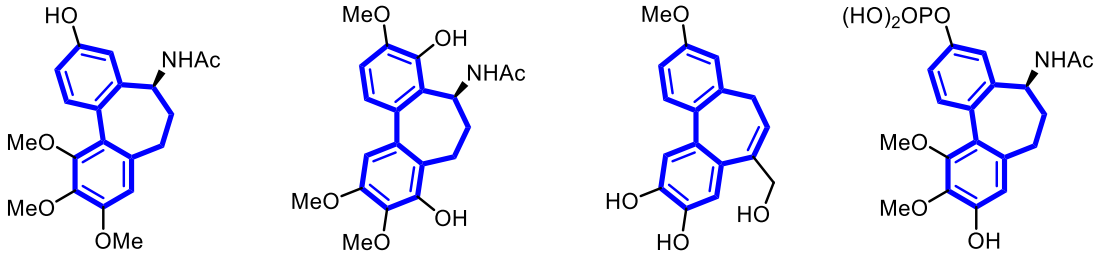
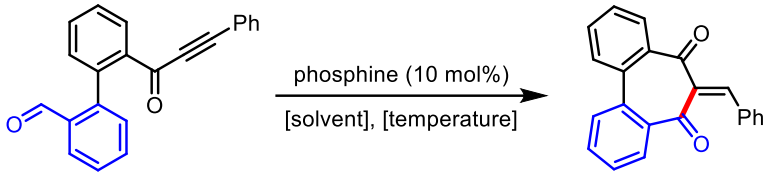



**Figure 19:** Natural products possessing the dibenzocycloheptane motif.

As the initial result with $PPh_3$ was not satisfactory, we performed a brief screening of reaction conditions by considering **70a** as model substrate to improve the yield, Table 9. A wide variety of phosphines in combination with different solvents were screened for the hydroacylation process (entries 1-9). Among them, 10 mol% of $PCy_3$ in toluene at 40 °C delivered the desired product **71a** in 86% yield, and it was realized to be the best condition for this transformation (entry 9).

**Table 9:** Optimization of reaction parameters




**70a** **71a**

| entry | phosphine | solvent | temperature | time (h) | yield (%)[a] |
|---|---|---|---|---|---|
| 1 | $PPh_3$ | DCM | rt | 48 | 54 |
| 2 | $PMe_3$ | toluene | rt | 48 | - |
| 3 | $PCy_3$ | toluene | rt | 9 | 77 |
| 4 | $P(^tBu)_3$ | toluene | rt | 48 | 43 |
| 5 | $PPh_2Et$ | toluene | rt | 48 | - |
| 6 | $PCy_3$ | DCM | rt | 36 | 70 |
| 7 | $PCy_3$ | THF | rt | 9 | - |
| 8 | $PCy_3$ | brine | rt | 48 | - |
| **9** | **$PCy_3$** | **toluene** | **40 °C** | **7** | **86** |

All reactions were performed on 0.1 mmol scales. [a] Yields were calculated after silica gel column chromatography.

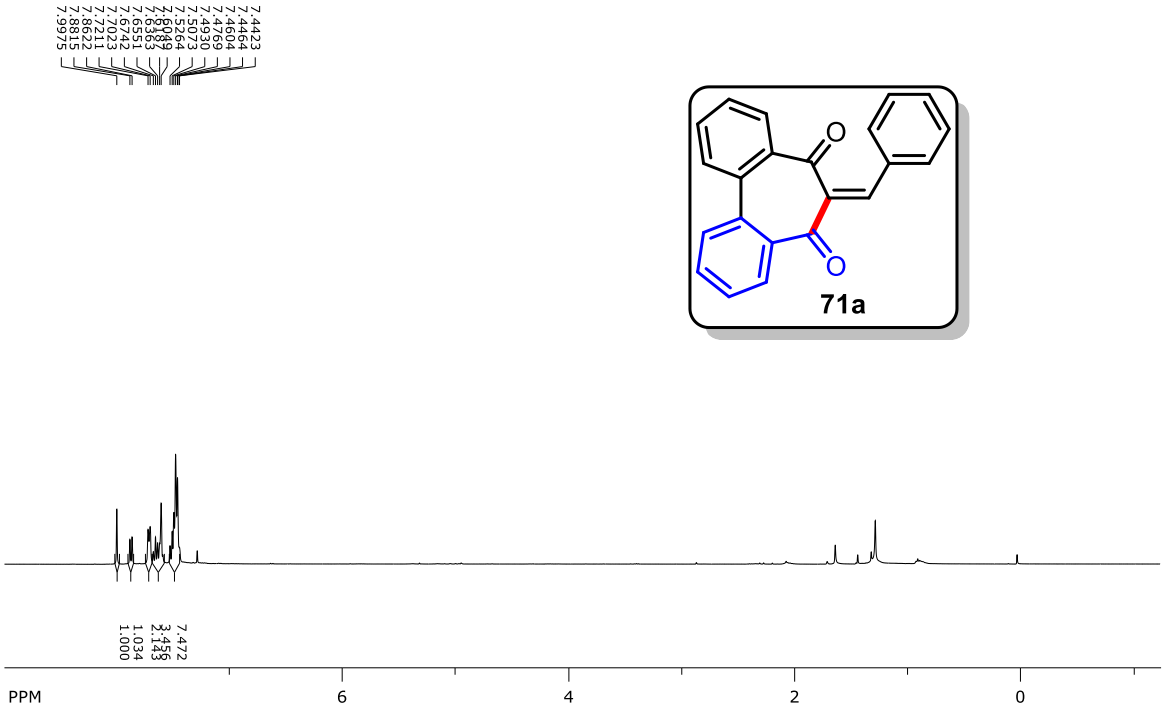



**Figure 20:** $^{1}$H-NMR spectrum of dibenzo-1,3-cycloheptadione **71a**.

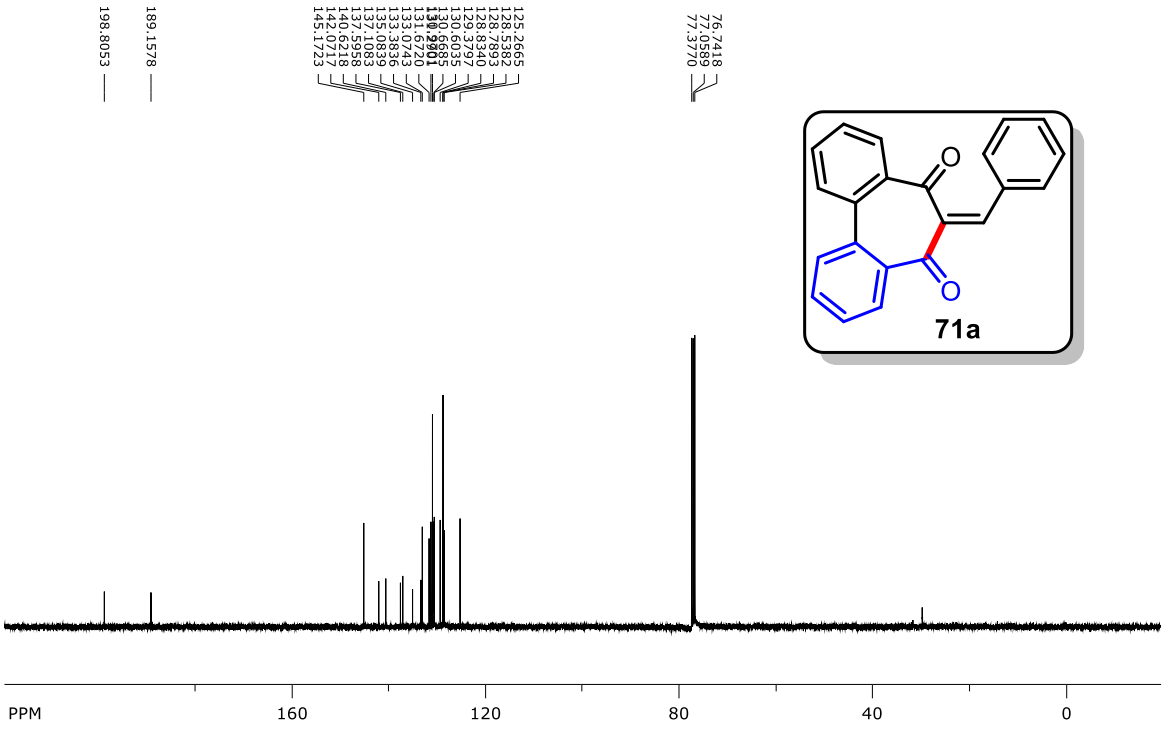



**Figure 21:** $^{13}$C-NMR spectrum of dibenzo-1,3-cycloheptadione **71a**.

With the optimal conditions in hand, we next focused on investigating the substrate scope. Towards this, a diverse range of biarly ynone-aldehydes **70a-l** were synthesized and subjected to the optimized conditions and the results are compiled in Table 10. A wide range ynone-aldehydes **70a-i** having electron-rich, and electron-poor substituents in the backbone or alkyne part were well tolerated under the optimized condition and obtained the desired product **71a-i** in moderate to excellent yields, Table 10. Although, it was observed that electron rich substrates (**70e, 70h** and **70i**) displayed a minor influence on the efficiency of the reaction. Among them, the structure of **71d** was unambiguously confirmed by the x-ray diffraction analysis, Figure 22. Alkyne with alkyl group smoothly furnished the respective cycloheptanedione **71f** in good yield. The enynone substrate **70j** delivered the corresponding cycloheptadienone product **71j** in good yield. On the other hand, **70k** and **70l** on treatment with $PCy_3$ under the optimized conditions resulted in the formation of respective product **71k** and **71l** in moderate to good yield in prolonged reaction time. Here, the requirement of longer reaction time could be attributed to the restricted rotation across the aryl–aryl bond.

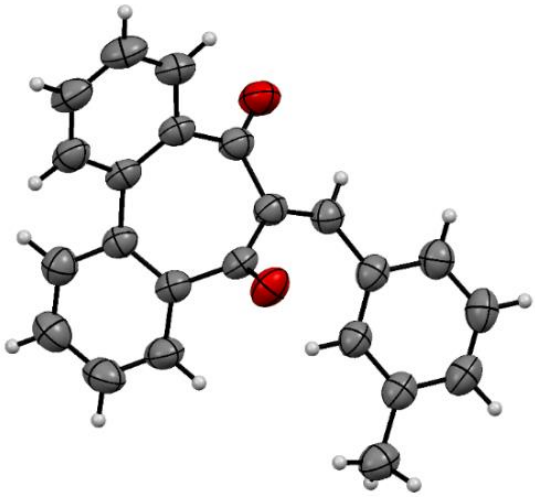
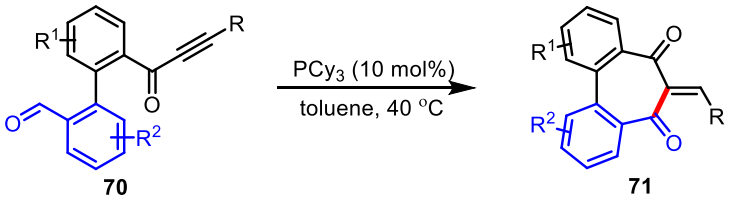


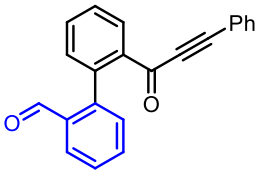
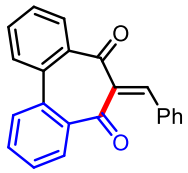
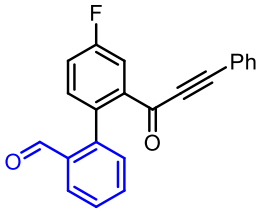
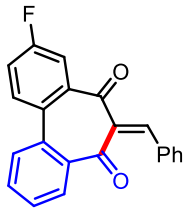
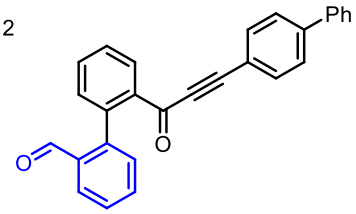
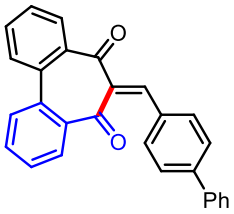
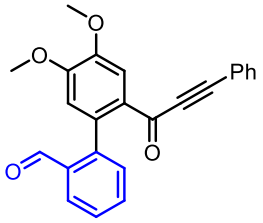
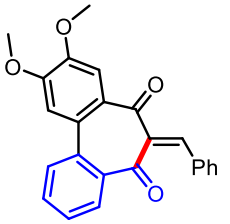
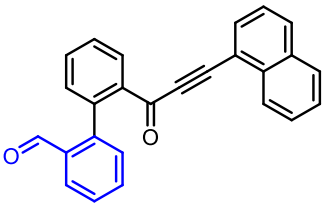
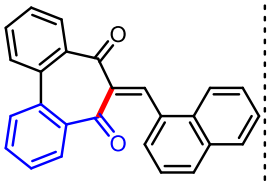
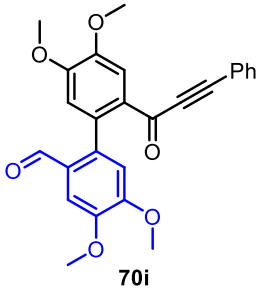
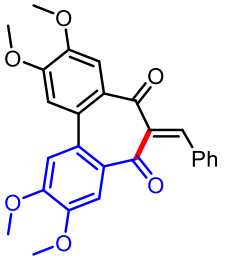
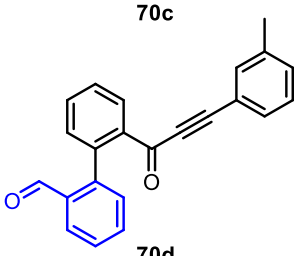
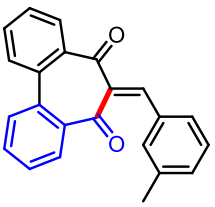
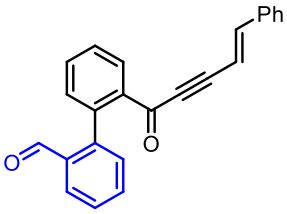
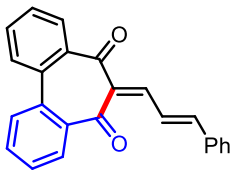
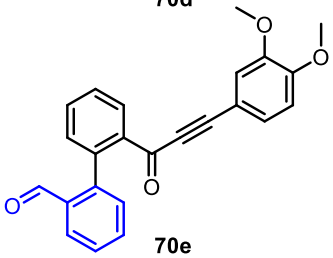
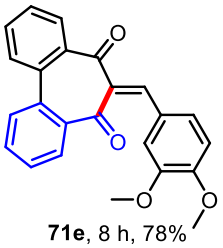
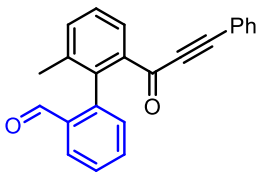
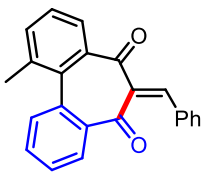
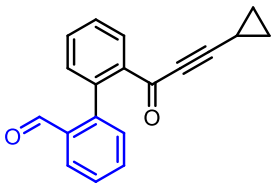
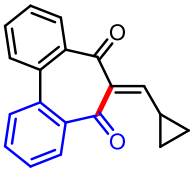
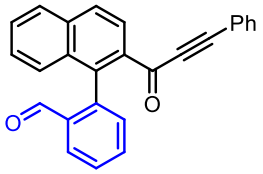
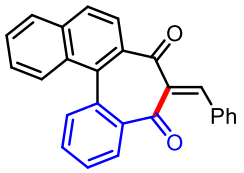
**Figure 22:** ORTEP diagram of dibenzo-fused cycloheptanedione **71d**.

## *2.2: Mechanistic Insights*

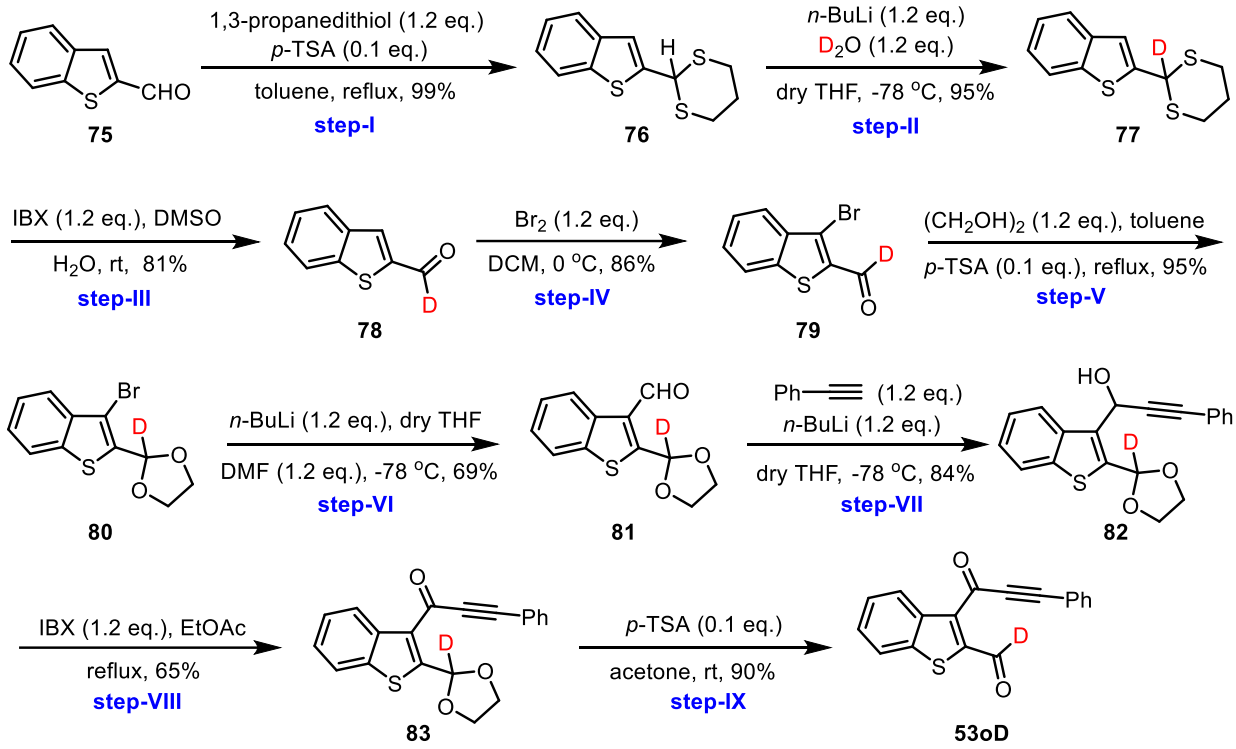
The above-described strategy is highly general and efficient for the synthesis of 1,3-cyclopenta- and cycloheptadiones from its ynone-aldehyde precursor under phosphine-catalyzed conditions. Next, we are curious to gain the mechanistic insights of the phosphine-catalyzed hydroacylation process in a detailed manner. Towards this, we planned a series of isotope labelling experiments and the results were analyzed carefully.

**Table 10:** Substrate Scope: Dibenzo-fused cycloheptanediones




| entry | substrate | product | entry | substrate | product |
|---|---|---|---|---|---|
| 1 |  |  | 7 |  |  |
| | **70a** | **71a**, 7 h, 86% | | **70g** | **71g**, 7 h, 83% (*E*/*Z* 1:1) |
| 2 |  |  | 8 |  |  |
| | **70b** | **71b**, 7 h, 75% | | **70h** | **71h**, 8 h, 86% (*E*/*Z* 5:1) |
| 3 |  |  | 9 |  |  |
| | **70c** | **71c**, 8 h, 74% | | **70i** | **71i**, 8 h, 72% |
| 4 |  |  | 10 |  |  |
| | **70d** | **71d**, 8 h, 86% | | **70j** | **71j**, 18 h, 74% (*E*/*Z* 5:1) |
| 5 |  |  | 11 |  |  |
| | **70e** | **71e**, 8 h, 78% | | **70k** | **71k**, 36 h, 68% (*E*/*Z* 3:1) |
| 6 |  |  | 12 |  |  |
| | **70f** | **71f**, 7 h, 82% | | **70l** | **71l**, 36 h, 73% (*E*/*Z* 2:1) |

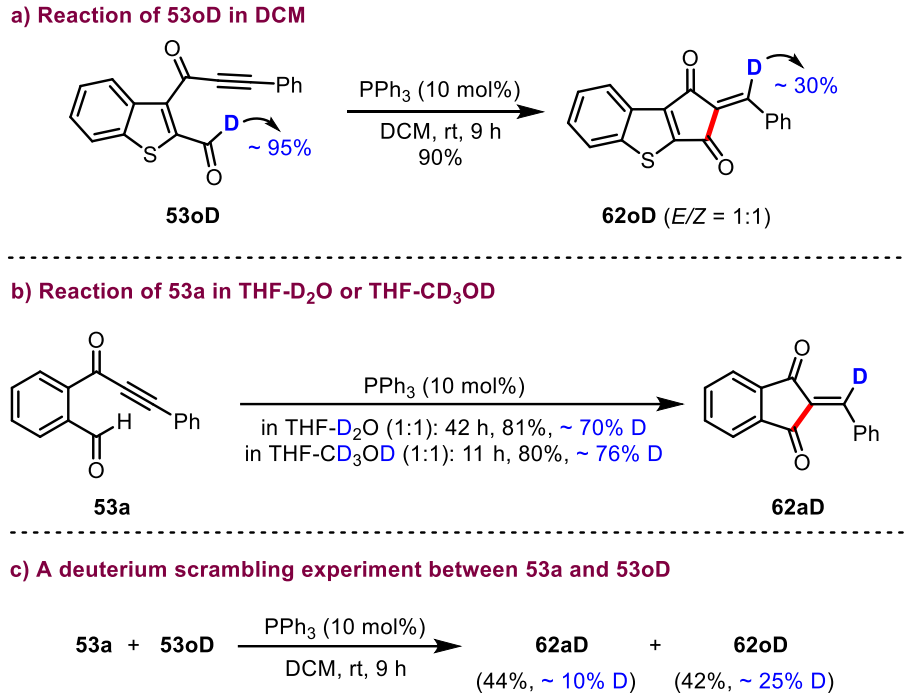
Accordingly, a synthetic route was proposed to access the benzothiophene based ynone **53oD** having deuterated aldehyde functionality, Scheme 46. Benzothiophene-2-carboxaldehyde **75** was treated with 1,3-propanedithiol to obtain the 1,3-dithiane-protected benzothiophene **76**. $^{n}$BuLi mediated proton exchange in the presence of $D_2O$ generated the corresponding deuterated compound **77**. Then, IBX mediated dithiane deprotection of **77** and followed by bromination with $Br_2$ produced the bromo-aldehyde **79**. Again, protection of the aldehyde functionality of **79** with ethylene glycol and subsequent $^{n}$BuLi assisted formylation generated the aldehyde **81**. Further, **81** was subjected to $^{n}$BuLi promoted alkylation with phenylacetylene and followed by IBX oxidation and deprotection with *p*-TSA furnished the desired ynone aldehyde **53oD** with 95% "D"-incorporation.




**Scheme 46:** Synthesis of ynone aldehyde **53oD**.

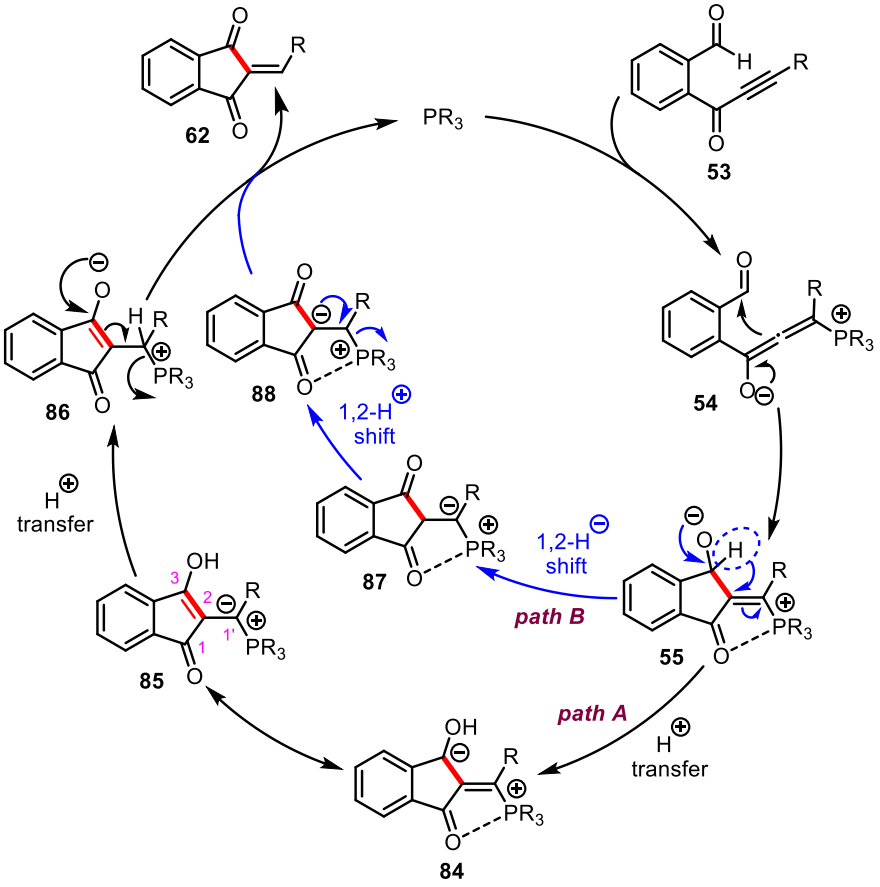
Next, **53oD** was subjected to optimized condition (as described in Table 7) and obtained **62oD** where the extent of "D"-incorporation went down to 30% (Scheme 47a). This result indicated that the transformation of **53oD** to **62oD** at a certain stage may be involving a competing intermolecular protonation pathway, in addition to an intramolecular proton transfer. On the other hand, while **53a** was treated in the presence of deuterated solvents (Scheme 47b), the observed "D"-incorporation in the product **62aD** was 70% in THF−$D_2O$ mixture and 76% in THF−$CD_3OD$, but not 100%. This experiment further supports the hypothesized proton exchange with the solvent environment during the course of the reaction.

In addition, we also performed a deuterium scrambling experiment between **53a** and **53oD**, where the "D"-incorporation in **62aD** and **62oD** were realized to be 10% and 25%, respectively (Scheme 47c). The outcome of this experiment suggested that the aldehydic proton was lost to the solvent medium and re-entered the system through an intermolecular proton transfer step.




**Scheme 47:** Isotope labelling experiments.

Based on the evidence obtained from the above experiments, a plausible mechanism is proposed, Scheme 48. Initial phospha-Micheal addition to the ynone generates the zwitterionic intermediate **54** which subsequently form an another zwitterionic intermediate **55** through an intramolecular aldol reaction. The $\alpha$-proton to alkoxide in **55** is acidic enough to undergo an intermolecular proton transfer *via* path A to generate a vinylogous ylide **84**. The ylide **84** (in resonance with **85**) readily converts to enol **86** by another proton transfer and a subsequent elimination of phosphine furnishes the formation of **62**. On the other hand, **55** can undergo through a 1,2-hydride shift and a subsequent 1,2-proton shift *via* path B to produce **88**, which eventually yields the product **62** while regenerating the catalyst. We also believe that the ylide **85** is responsible for the H/D abstraction from the solvent, which is in line with the experimental observations. Further, the lack of stereoselectivity in products could be attributed to the free rotation across the C2−C1' bond in **85** or **86**. The mechanism of formation of dibenzo cycloheptanediones **71** from biaryl ynone-aldehydes **70** can also be explained in an analogous manner.

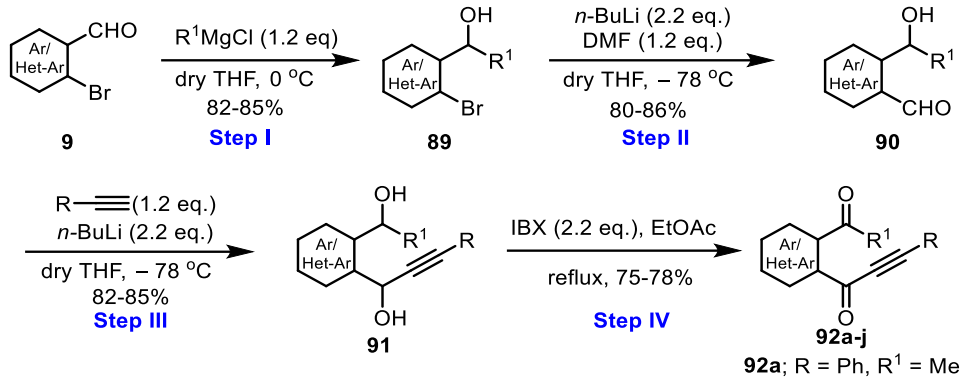



**Scheme 48:** Plausible mechanism of the intramolecular hydroacylation of alkynes.

## *2.3: Reaction with ynone-ketones*

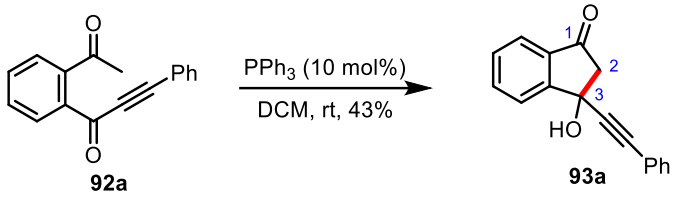
From the mechanism, we have realized that the aldehydic proton plays a crucial role during the reaction. We have anticipated that the replacement of the aldehydic proton with alkyl group may lead to the formation of unexpected products *via* alkyl shift/migration analogous to hydride and proton shift.

Towards this, we planned a four-step protocol to synthesize ynone-acyl substrate **92a-j** and curious to check the fate of the reaction under phosphine condition, Scheme 49. Accordingly, addition of methyl Grignard reagent to 2-bromoaldehyde **9** generated the alcohol **89** which upon reaction with *n*-BuLi/DMF produced the corresponding 2-formyl alcohol **90**. Then *n*-BuLi mediated alkynylation of **90** with suitable alkyne and followed by IBX oxidation afforded the desired keto-ynone **92a-j**.




**Scheme 49:** Synthesis of ynone-ketone **92a-j**.

Next, ynone-ketone substrate **92a** was considered as a model substrate and subjected to the optimized condition (as described in Table 7). Surprisingly, it delivered 3-ethynyl-3-hydroxyindanones **93a** with 43% yield *via* a phosphine-catalyzed intramolecular aldol reaction.[61] The formation of **93a** was confirmed by analyzing the spectral data. The presence of three absorption bands at 3398, 2293, and 1721 $cm^{-1}$ in the IR spectrum due to tertiary alcohol, alkyne and carbonyl group, respectively, indicated the formation of product **93a**. Further, in the $^{1}$H-NMR spectrum (see Figure 25), the presence of a $AB_q$ at δ 3.37 ppm is due to the $-CH_2$ next to carbonyl (C-2 proton), and in the $^{13}$C-NMR spectrum (see Figure 26), the presence of two peaks due to alkyne at δ 85.7 and 89.7 ppm, and a carbonyl peak at δ 201.9 ppm affirmed the formation of 3-ethynyl-3-hydroxyindanones **93a**. A striking feature of this transformation is that it involves an unprecedented organocatalytic *δ′*[C(sp$^3$)-*H*]-functionalization of *α*,*β*-ynones.

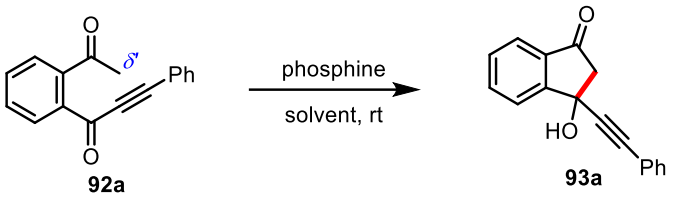



**Scheme 50:** Reaction of ynone-ketone **92a** with $PPh_3$.

As the initial result with $PPh_3$ was not up to the mark, we took **92a** as our model substrate and performed a brief optimization to improve the yield of the reaction. A wide range of phosphines with various solvent combinations was applied during the course of screening (entries 1-12, Table 11). Initial screening with different phosphines revealed that $PBu_3$ was giving a significant improvement in yields (entries 1-6). A subsequent solvent screening was also performed with $PBu_3$ as catalyst (entries 6-11) where polar protic solvents showed

excellent results (entries 8-11). Among them, **92a** in presence of 20 mol% of $PBu_3$ in *tert*-butanol delivered the corresponding product **93a** with 95% yield (entry 16).

**Table 11:** Optimization of reaction conditions



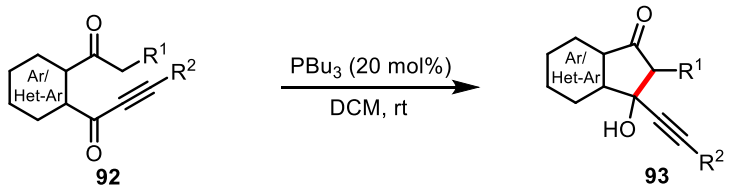

| entry | catalyst (mol%) | solvent | time (h) | yield (%)[a] |
|---|---|---|---|---|
| 1 | $PBu_3$ (20) | toluene | 3 | 44 |
| 2 | $PBu_3$ (100) | toluene | 2 | 48 |
| 3 | $PPh_3$ (20) | toluene | 24 | 25 |
| 4 | $PCy_3$ (20) | toluene | 24 | 21 |
| 5 | $EtPPh_2$ (20) | toluene | 24 | 36 |
| 6 | $PBu_3$ (20) | DCM | 4 | 45 |
| 7 | $PBu_3$ (20) | ACN | 1 | 45 |
| 8 | $PBu_3$ (20) | isopropanol | 1 | 89 |
| 9 | $PBu_3$ (20) | methanol | 1 | 76 |
| 10 | $PBu_3$ (20) | ethanol | 1 | 84 |
| **11** | **$PBu_3$ (20)** | ***tert*-butanol** | **1** | **95** |
| 12 | $PBu_3$ (10) | *tert*-butanol | 24 | 62 |

All reactions were performed on 0.1 mmol scales. [a] Yields were calculated after silica gel column chromatography.

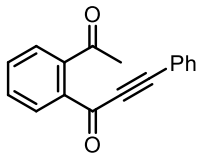
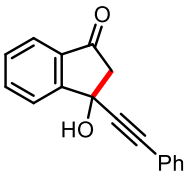
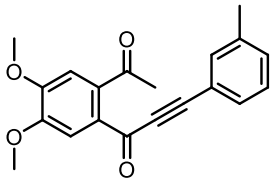
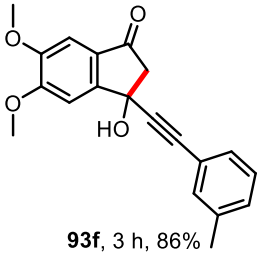
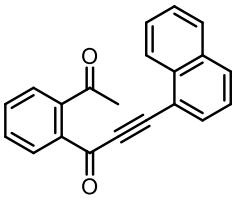
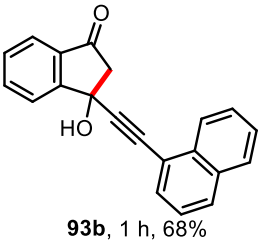
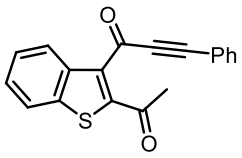
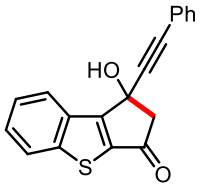
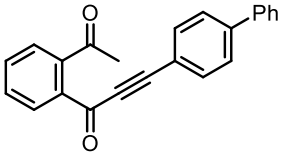
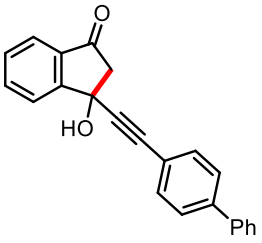
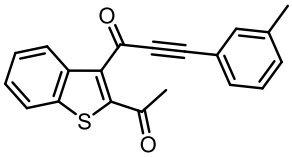
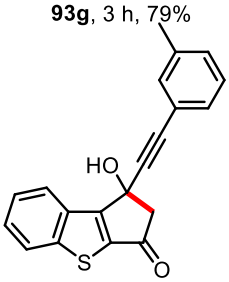
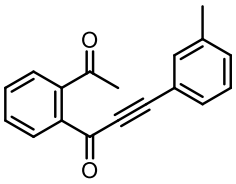
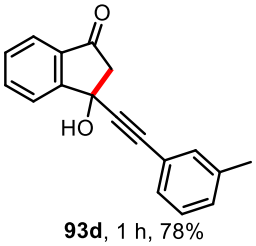
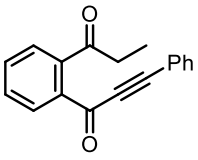
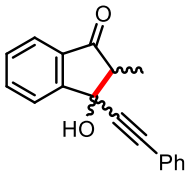
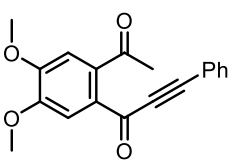
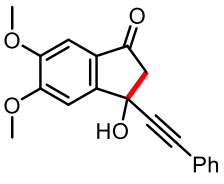
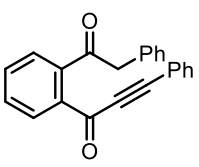
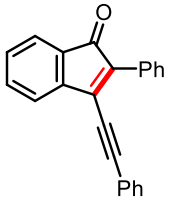
With an interest in expanding the scope of the protocol, a diverse range of ynone-ketone **92a-j** having different electronic features were treated under optimized condition and the results were compiled in Table 12. Substrates having various substitutions at the ynone or in the backbone were well tolerated and obtained the product **92a-f** in 68-95% yield range. Although, the electron-rich substrates (**92e-f**) required a longer time to deliver the expected product **93e-f**. Furthermore, benzothiophene fused 3-ethynyl-3-hydroxyindanones **92g-h** could be easily synthesized by this strategy, which would otherwise require a multistep synthetic route. In addition, $\delta'$-branched ynone-ketone **92i** (when $R^1$ = Me, $R^2$ = Ph) under optimized condition furnished the product **93i** with two contiguous stereogenic centers with 72% yield,

whereas **92j** (when $R^1$ = Ph, $R^2$ = Ph) delivered simply the aldol condensation product **93j** with 80% yield.

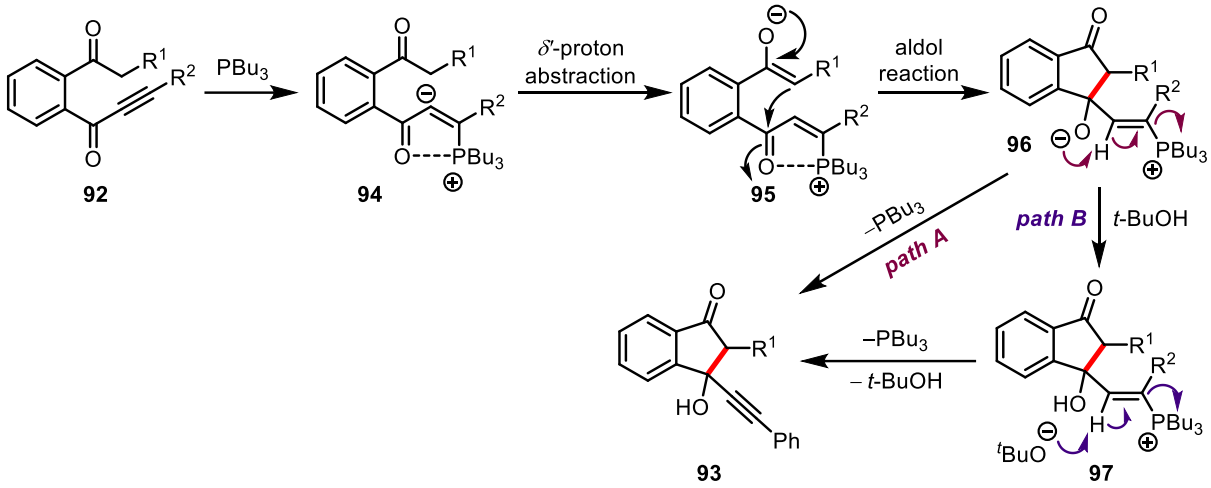
**Table 12:** Substrate Scope: 3-ethynyl-3-hydroxyindanones




**92** **93**

| entry | substrate | product | entry | substrate | product |
|---|---|---|---|---|---|
| 1 |  |  | 6 |  |  |
| | **92a** | **93a**, 1 h, 95% | | **92f** | **93f**, 3 h, 86% |
| 2 |  |  | 7 |  |  |
| | **92b** | **93b**, 1 h, 68% | | **92g** | **93g**, 3 h, 79% |
| 3 |  |  | 8 |  |  |
| | **92c** | **93c**, 1 h, 72% | | **92h** | **93h**, 5 h, 72% |
| 4 |  |  | 9 |  |  |
| | **92d** | **93d**, 1 h, 78% | | **92i** | **93i**, 6 h, 72% (dr = 2:1) |
| 5 |  |  | 10 |  |  |
| | **92e** | **93e**, 3 h, 88% | | **92j** | **93j**, 1 h, 80% |

The formation of **93** from **92** can be explained by the proposed mechanism depicted in Scheme 51. **92** undergoes a phospha-Michael addition and generates zwitterionic intermediate **94**. Next, the *δ'*-proton abstraction of the zwitterion **94** generates an enolate intermediate **95** which proceeds through an intramolecular aldol reaction to provide an alkoxide intermediate **96**. The alkoxide **96** can abstract the vinylic proton (*via* path A) to generate the corresponding product **93**. Alternatively, *in situ* generations of a catalytic amount of *tert*-butoxide (*via* path B) may also deprotonate the vinylic proton in **97** and furnish the product formation **93**.




**Scheme 51:** Mechanism for phosphine-catalyzed aldol reaction.

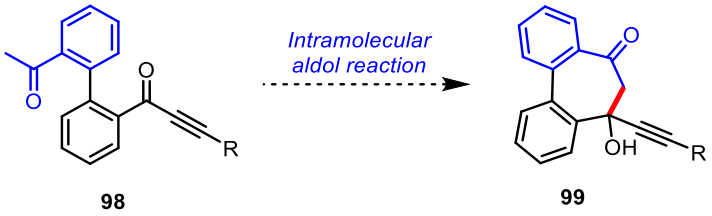
## *2.3.1: Efforts towards asymmetric aldol reaction of ynone-ketones*

After achieving a general and efficient method for synthesizing 3-ethynyl-3-hydroxyindanones from ynone-ketones, we focused on developing an asymmetric organocatalytic version. Towards this, an exhaustive catalyst screening was performed on the keto-ynone **92a** under various conditions and some of the results are presented in Table 13. Despite several efforts to develop an enantioselective version of the aldol reaction, the results were unsatisfactory. We were only able to obtain **93a** in 24% *ee* with the catalyst **C4** in prolonged reaction time with poor yield (Table 13).

## *2.4: Reaction with biaryl ynone-ketones*

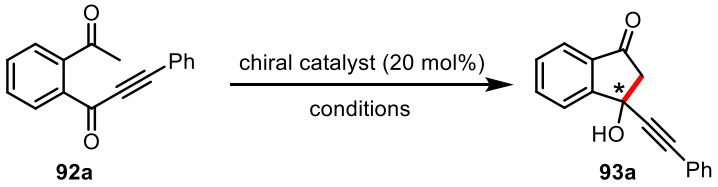
Further, as an extension to this concept described in Table 12, we anticipated the formation of **99** from biaryl ynone-ketone **98** under phosphine catalysis, Scheme 52. To verify our hypothesis, the proposed starting material **98** was synthesized by using a two-step protocol, Scheme 53. 2-bromoynones **73** with different functionality were subjected to standardized Suzuki coupling condition with 2-formylboronic acid to obtain the corresponding

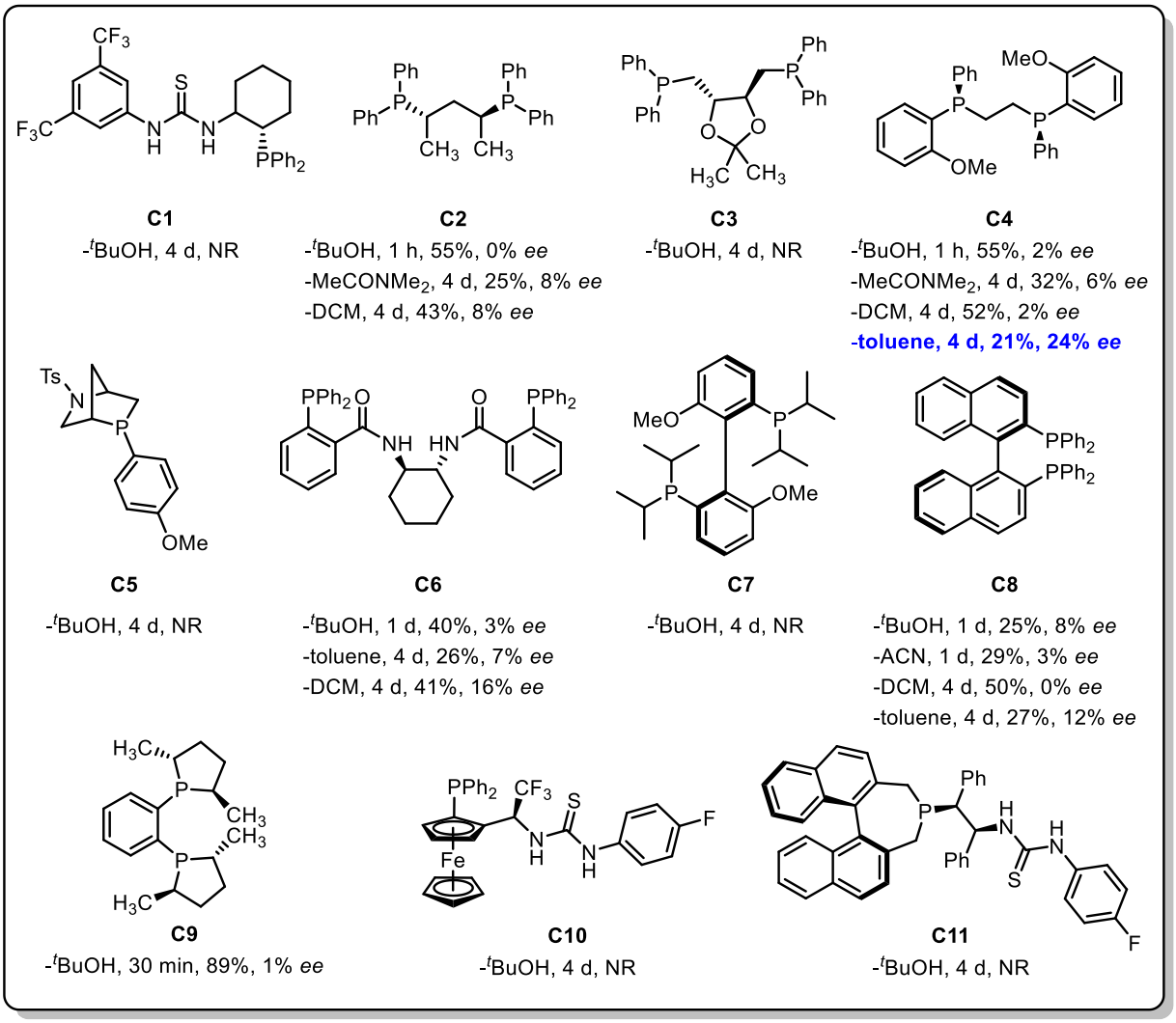
ynone-aldehyde **70**. Methyl Grignard reagent addition to the ynone-aldehyde **70** and followed by IBX oxidation generated the required biaryl ynone-ketone **98**.

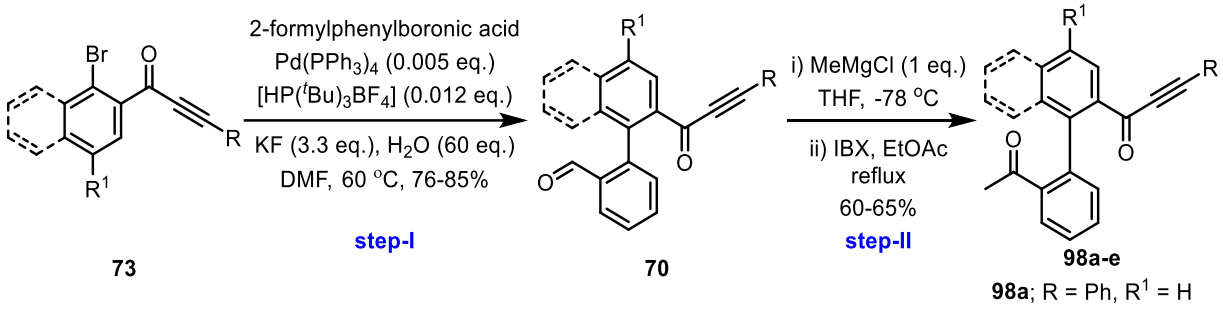



**Scheme 52:** Intramolecular aldol reaction of biaryl ynone-ketones.

**Table 13:** List of chiral catalyst screened

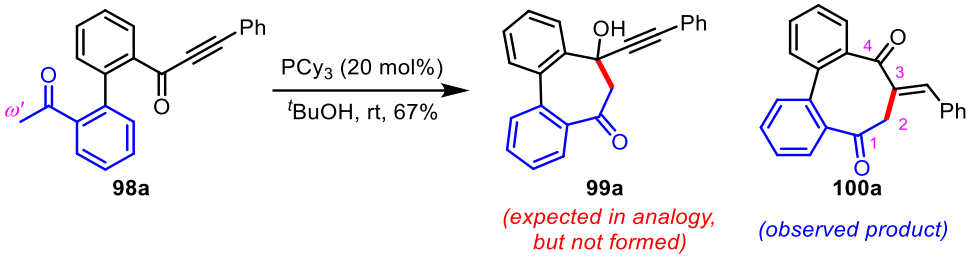





**Scheme 53:** Synthesis of biaryl ynone-ketones **98**.

Accordingly, we synthesized **98a** (R = Ph; $R^1$ = H) as a model substrate and performed a brief optimization with different phosphine catalysts in *tert*-butanol. Among them, $PCy_3$ (20 mol%) delivered a non-polar compound with 67% yield, Scheme 54. To our surprise, a careful analysis of spectral data revealed the sole formation of dibenzo[*a*,*c*]cyclooctadione **100a** without the formation of a trace amount of expected product **99a**. In the $^1$H-NMR spectrum (see Fig. 27), the presence of one $AB_q$ at δ 3.80 ppm is due to the $-CH_2$ next to carbonyl (C-2 proton) and in $^{13}$C-NMR spectrum (see Fig. 28), the presence of two carbonyl peaks at δ 202.8 and 197.7 ppm (C-1 and C-4), affirmed the formation of dibenzo[*a*,*c*]cyclooctadione **100a**. In addition, this method also exemplifies an organo-phosphine catalyzed *ω′*[C(sp$^3$-*H*)]-functionalization of *α*,*β*-ynones.




**Scheme 54:** Reaction of phosphine with biaryl ynone-ketone **98a**.

Natural products consist of eight-membered carbocycles, are a class of structurally intriguing and biologically important molecules such as the famous diterpenes taxol and vinigrol.[62] Among them, natural products having dibenzo-fused cyclooctane motif also exhibit a broad range of biological activities which include cytotoxicity, anti-hepatitis-B activity, inhibition of HIV replication and etc, Figure 23.[63] For example, Kadsurarin has effective inhibitory activity against human type-B hepatitis. Naturally occurring lactones (−)-steganone isolated from *Steganotaenia araliacea*, possess significant activity against P-388 leukemia in mice and human carcinoma of the nasopharynx (KB). Gomisin G isolated from *Kadsura*

*interior*, displays maximum potency in anti-HIV activity and also inhibits the growth of triple-negative breast cancer cell. Isoschizandrin extracted from the fruit of *Schizandra chinesis*, exhibits antiulcer activity in rats.

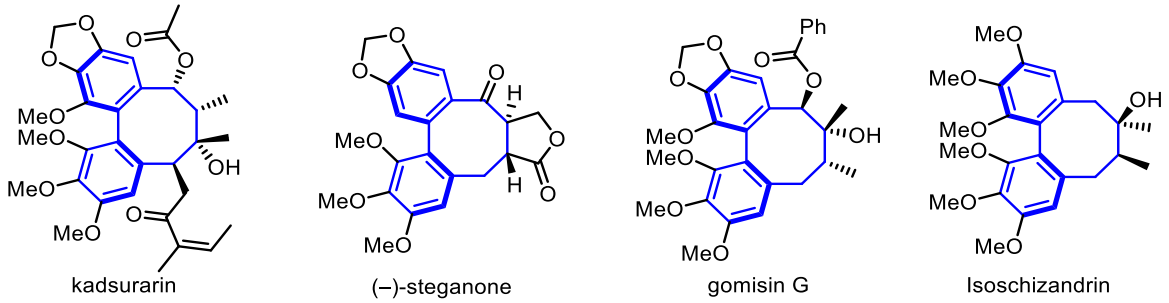
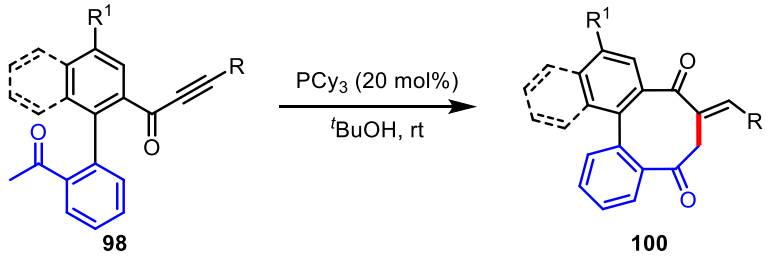
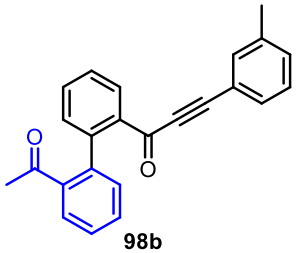
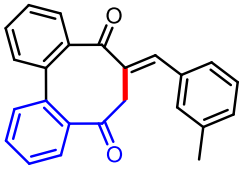
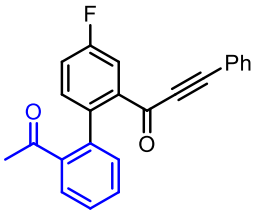
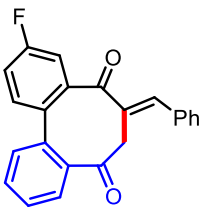
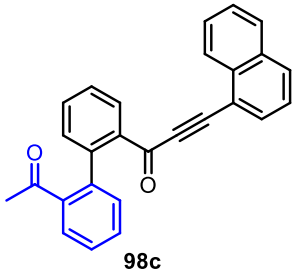
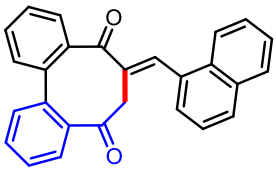
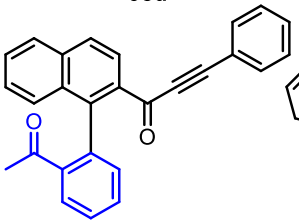
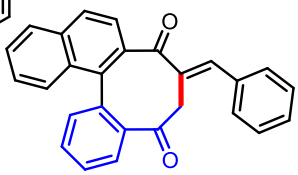



**Figure 23:** Natural product containing dibenzocyclooctane motif.

Since the construction of dibenzocyclooctane rings is challenging, and such a transformation (discussed in Scheme 54) is without precedence, we were interested in synthesizing a few analogues of **100**. Towards this, a variety of biaryl ynone-ketones **98b-e** having different substitutions was subjected to optimized conditions and furnished **100b-e** formation in good to excellent yields, Table 14. Among them, the structure of **100c** was unambiguously confirmed by the X-ray diffraction analysis, Figure 24.

**Table 14:** Substrate Scope: dibenzo[*a*,*c*]cyclooctanediones




| entry | substrate | product | entry | substrate | product |
|---|---|---|---|---|---|
| 1 |  **98b** |  **100b**, 7 h, 65% | 3 |  **98d** |  **100d**, 5 h, 66% |
| 2 |  **98c** |  **100c**, 7 h, 78% | 4 |  **98e** |  **100e**, 5 h, 70% |

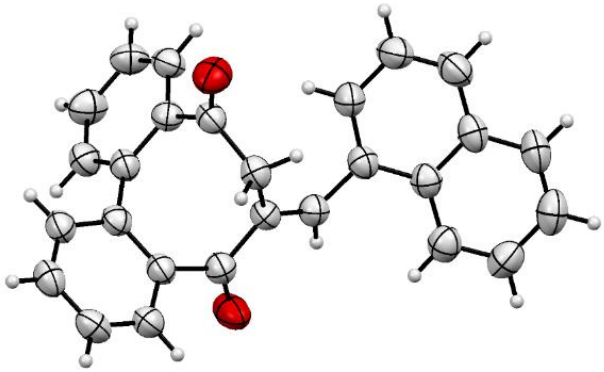
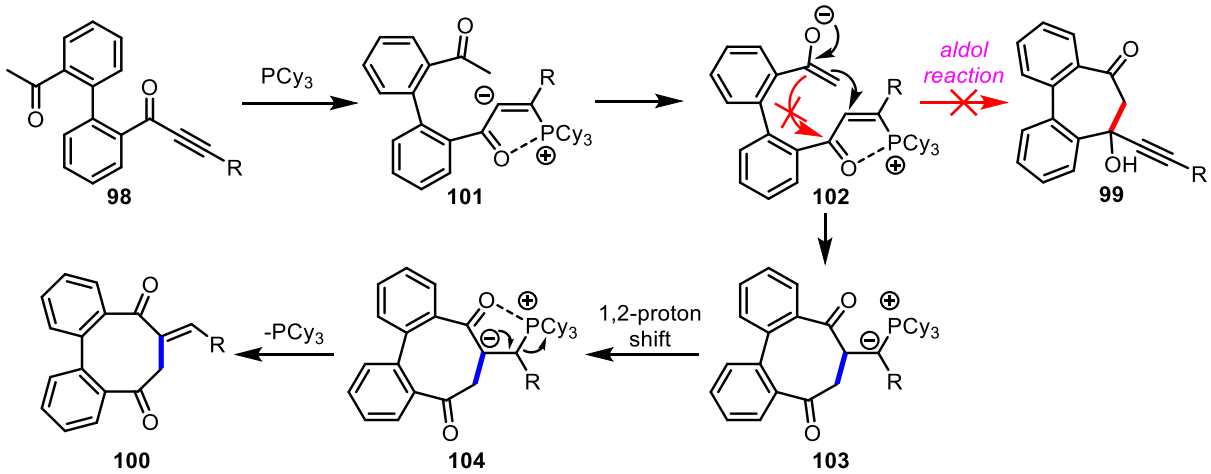


**Figure 24:** ORTEP diagram of **100c**.

Regarding the unprecedented formation of **100** from **98**, a plausible mechanism was proposed, as depicted in Scheme 55. Initially, phosphine attacks **98** in Michael fashion to generate the vinylogous ylide intermediate **101** which abstracts the acidic *ω*'-proton and generates the enolate intermediate **102**. Rather than undergoing an aldol reaction, the enolate **102** cyclizes intramolecularly and furnishes the ylide **103** formation. Further, an evident 1,2-proton shift followed by elimination of phosphine generates **100**. In addition, The P–O interaction depicted in **104** is believed to be responsible for the exclusive formation of *E*-selective products (Scheme 55).




**Scheme 55:** Mechanism for the formation of dibenzocyclooctanediones **100**.

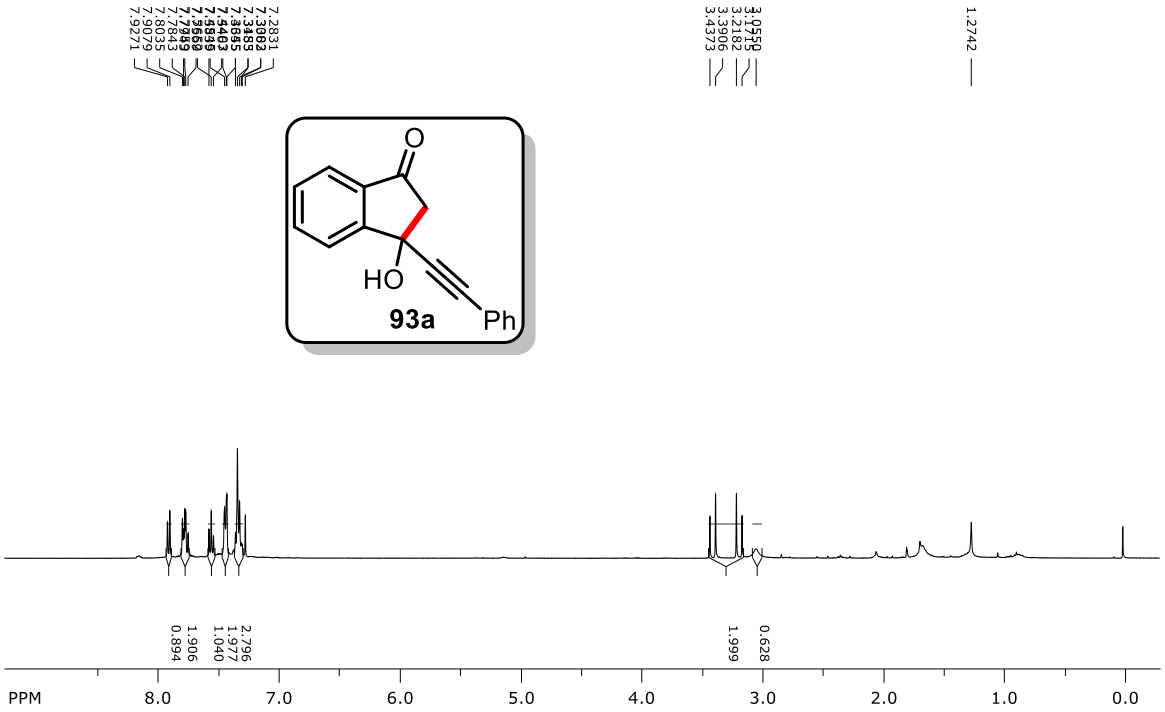



**Figure 25:** $^{1}$H-NMR spectrum of the aldol product **93a**.

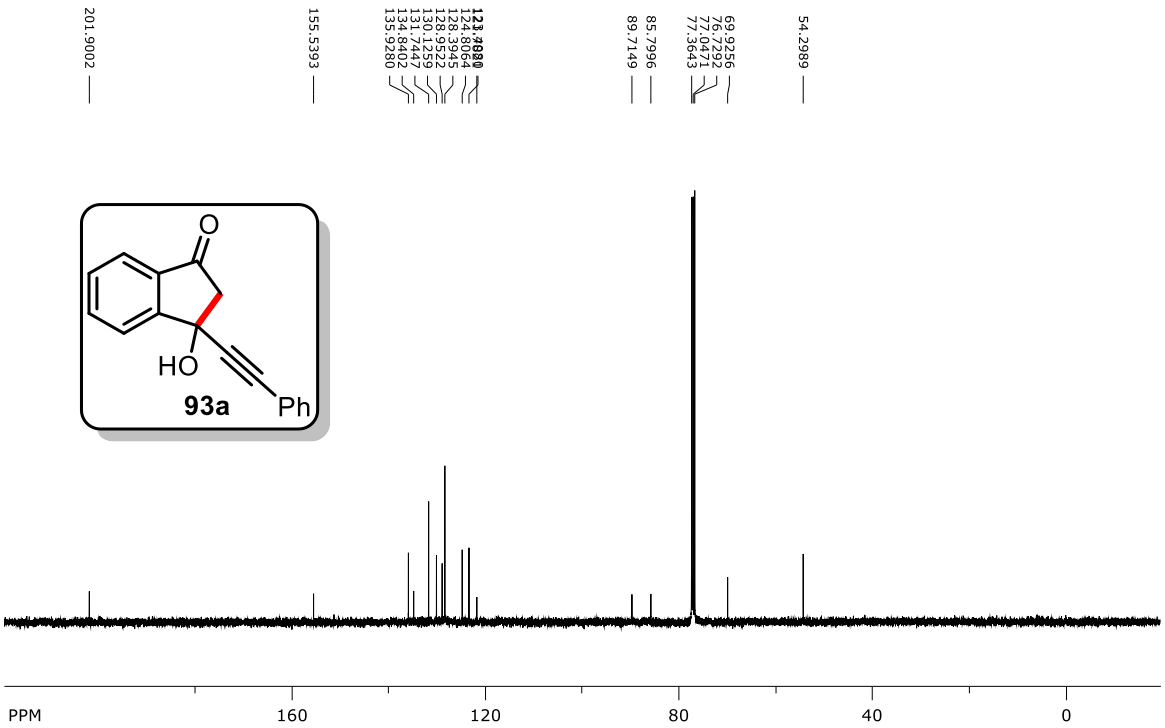



**Figure 26:** $^{13}$C-NMR spectrum of the aldol product **93a**.

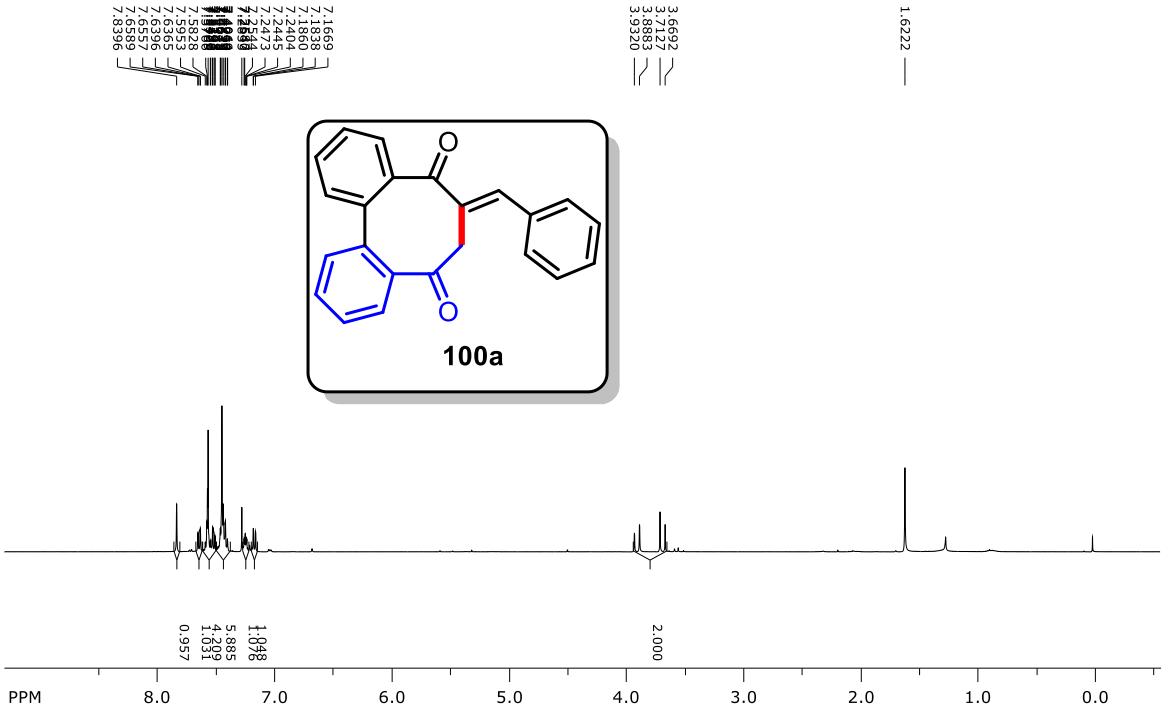



**Figure 27:** $^{1}$H-NMR spectrum of **100a**.

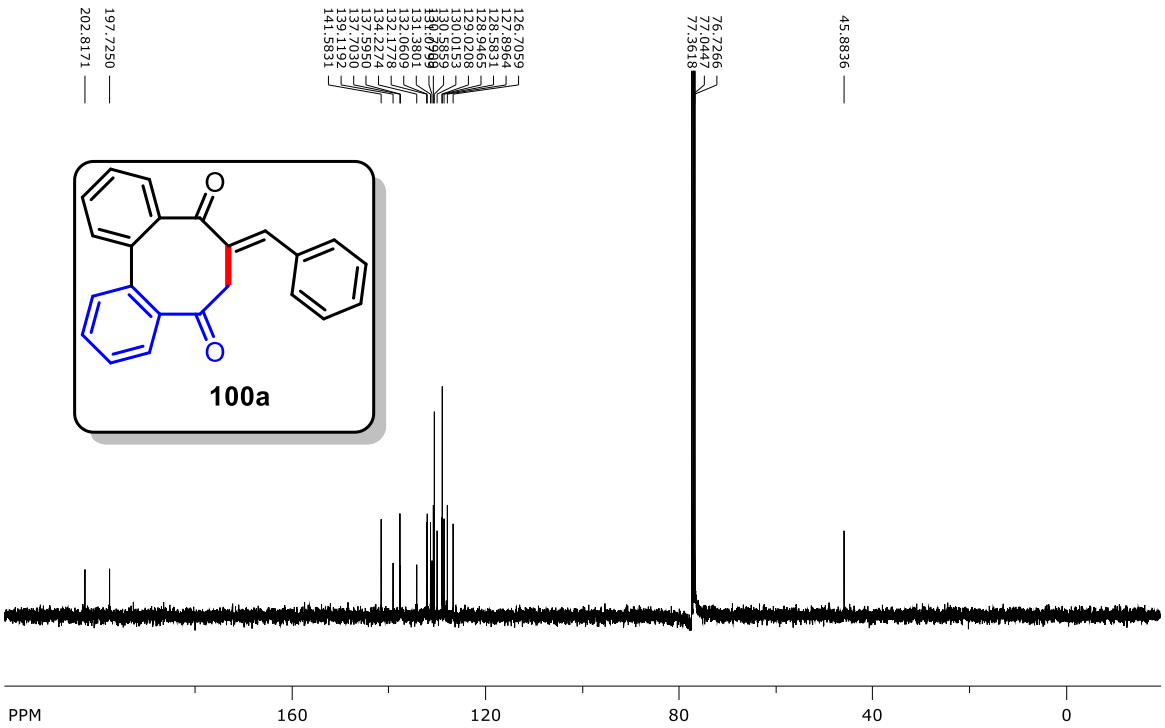



**Figure 28:** $^{13}$C-NMR spectrum of **100a**.

In conclusion, we presented an unprecedented case of phosphine catalyzed Morita-Baylis-Hillman reaction of *α,β*-unsaturated alkynes. Aryl or heteroaryl based ynone-aldehydes under phosphine-catalyzed conditions provide access for the synthesis of 1,3-cyclopentadione fused arenes and heteroarenes. This concept also extended to biaryl ynone-aldehydes for the formation of 1,3-cycloheptanediones. Interestingly, this process represents the first metal-free and organo-catalytic intramolecular hydroacylation of *α,β*-ynones. So, a mild, practically simple and widely applicable strategy was developed that disclosed a rare addition to the organo-catalyzed hydroacylation of activated ynones. We also thoroughly elucidated the mechanism of the reaction to support our observations. Along with that, we accomplished a few serendipitous results with ynone-ketones under phosphine catalysis for the synthesis of cyclopenta-, and octanoids. Aryl or heteroaryl based ynone-ketones under phosphine conditions delivered 3-ethynyl-3-hydroxyindanones *via δ′*[C($sp^3$)-*H*]- functionalization of *α,β*-ynones. This study also demonstrates a phosphine-catalyzed intramolecular aldol reaction of keto-ynones. Later, the efforts to achieve the asymmetric version were also described. In addition, a new phosphine-catalyzed annulation strategy was successfully developed for the synthesis of dibenzo[*a,c*]cyclooctadiones *via ω′*[C($sp^3$)-*H*]- functionalization of *α,β*-ynones.

# Chapter 3

## *Annulative Morita–Baylis–Hillman reaction to synthesize chiral dibenzocycloheptanes*

Having established the phosphine-catalyzed intramolecular reaction of biaryl ynone-aldehydes for the synthesis of cyclopenta-, cyclohepta-, and cyclooctanoids (described in Chapter 2), we are interested in developing an asymmetric annulation strategy to synthesize chiral dibenzo-fused cycloheptanes. The dibenzocycloheptane moiety is the key core of various natural products and pharmaceutically relevant compounds and plays a unique role in drug discovery programs (Figure 29).[60,64] For example, Allocolchicine, isolated from *Colchicum cornigerum,* is active against many cancer cell lines and shows an excellent binding ability to cytoskeletal protein tubulin. Tenuifolin extracted from the stems of *Cinnamomum tenuifolium,* exhibits antiproliferative activity against a human prostate cancer cell line DU145.

Multifloramine isolated from *Colchicum decaisnei* shows significant positive inotropic and negative chronotropic effects on rats. The structurally unique norlignan natural product metasequirin B, and several medicinally important compounds such as cyclopropylallocolchicinoid possess a dibenzocycloheptene unit as the primary molecular architecture. In addition, several medicinally important compounds having dibenzocycloheptane unit as the primary molecular architecture show a diverse pharmaceutical application. They exhibit a wide range of antitumor, antileukemia, antimalaria, and antiplatelet aggregation activities. Owing to the importance of the dibenzocycloheptene motif, the development of general and efficient routes for the synthesis of dibenzocycloheptanes holds a great significance.

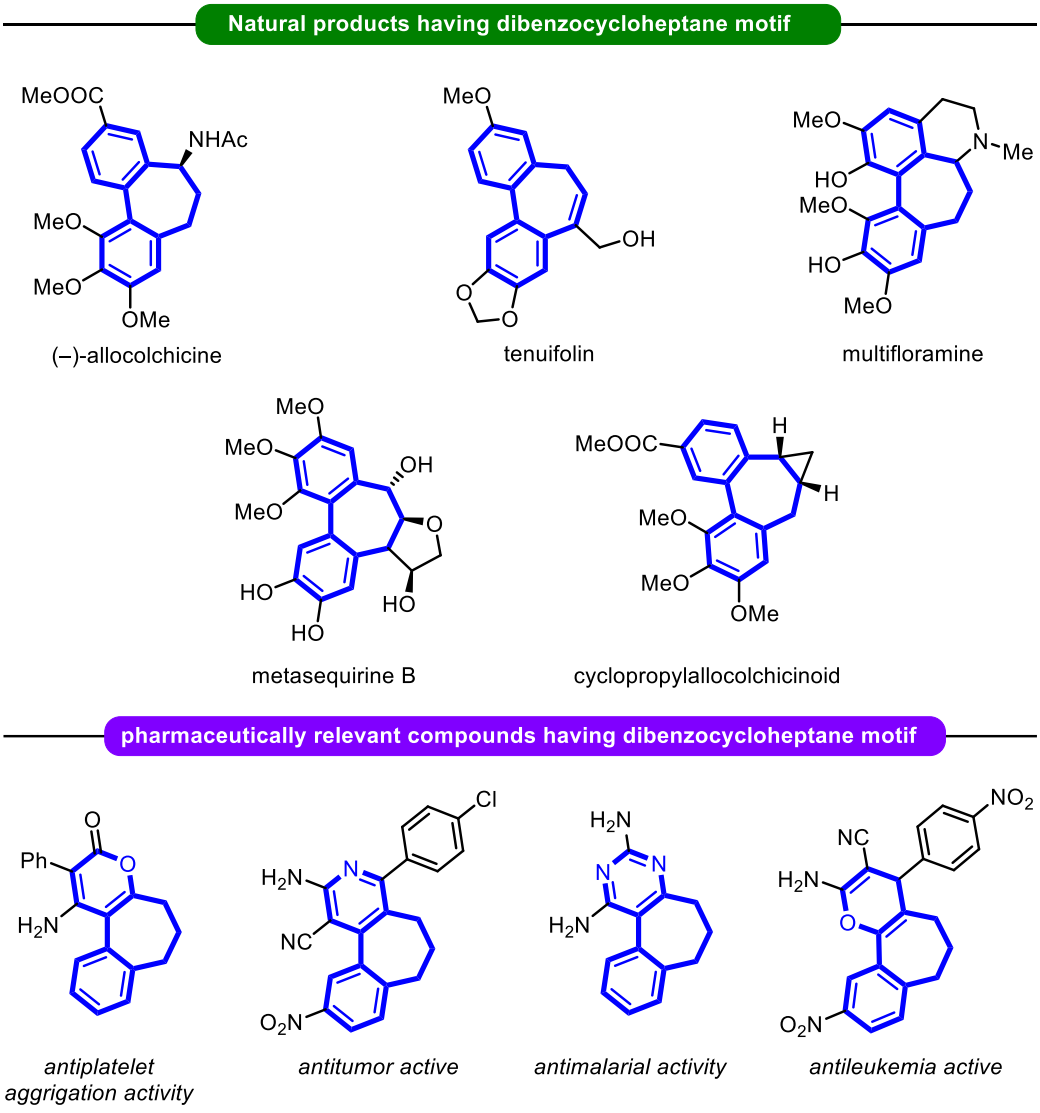



**Figure 29:** Natural products and medicinally important compounds having dibenzocycloheptane motif.

## *3.1: Approaches to synthesize dibenzocycloheptanes*

However, because of inherent transannular and entropic factors, the synthesis of dibenzo-fused cycloheptane (6–7–6 ring systems) skeletons still represents an ongoing challenge to synthetic chemists. In this context, various synthetic methods were known to construct the dibenzo-fused cycloheptanones, Figure 30. These examples majorly include (a) coupling of 1,3-diaryl propanes or propenes (oxidative coupling or cross-coupling), (b) phenanthrol ring expansion, (c) cycloaddition/aromatization, and (d) annulation of functionalized biaryls. Among the synthetic strategies, the coupling of biaryls was a well-established method and on the other hand, annulation of functionalized biaryls was most challenging and less explored.

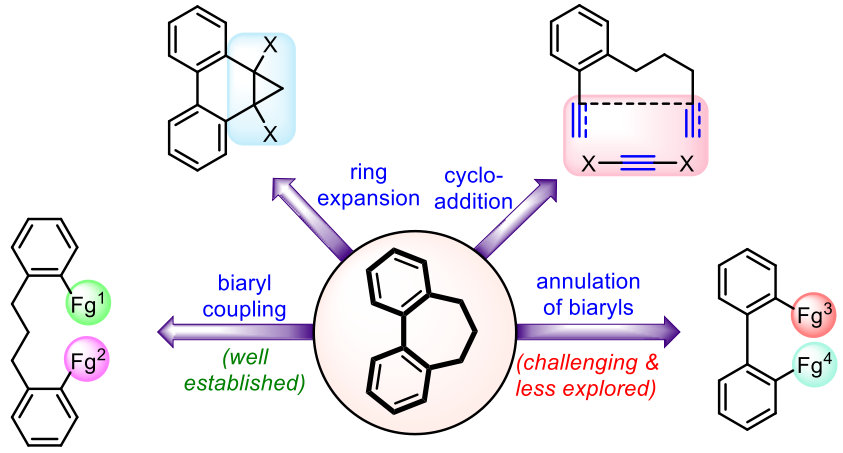
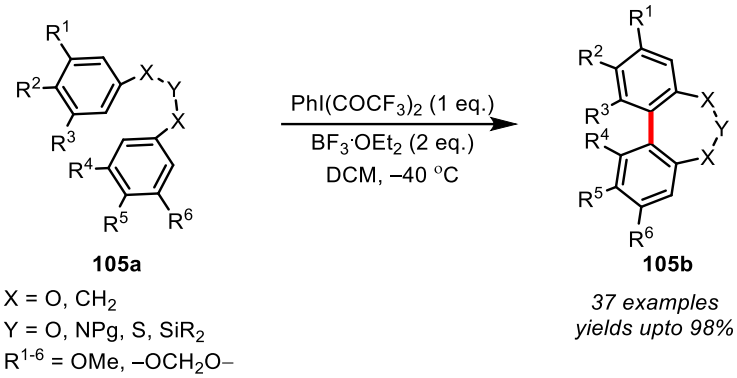



**Figure 30:** Approaches for the synthesis of dibenzocycloheptanes.

## *3.1.a: Coupling of 1,3-diaryl propanes or propenes*

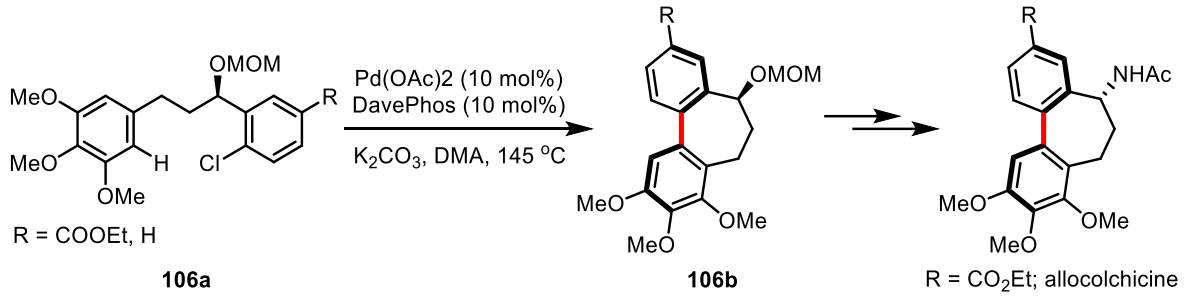
As the dibenzocycloheptane skeleton was the core structure of allocholchicine and other natural products (listed in Figure 29), the biaryl coupling strategy was predominantly used to construct the seven-membered ring as a key step in their total synthesis. Among them, few attractive strategies were discussed to access the challenging 6–7–6 ring systems.

Towards this, in 1998, Kita and co-workers[65] reported an intramolecular oxidative coupling of **105a** to produce seven-membered ring fused biaryls **105b** in the presence of hypervalent iodine reagent, Scheme 56. $BF_3.Et_2O$ activates $PhI(COCF_3)_2$ and reacts with electron-rich substrates **105a** to furnish the formation of biaryl products **105b**. However, the use of (super)stoichiometric amount of strong oxidizing agents was realized to be the foremost drawback of the strategy.



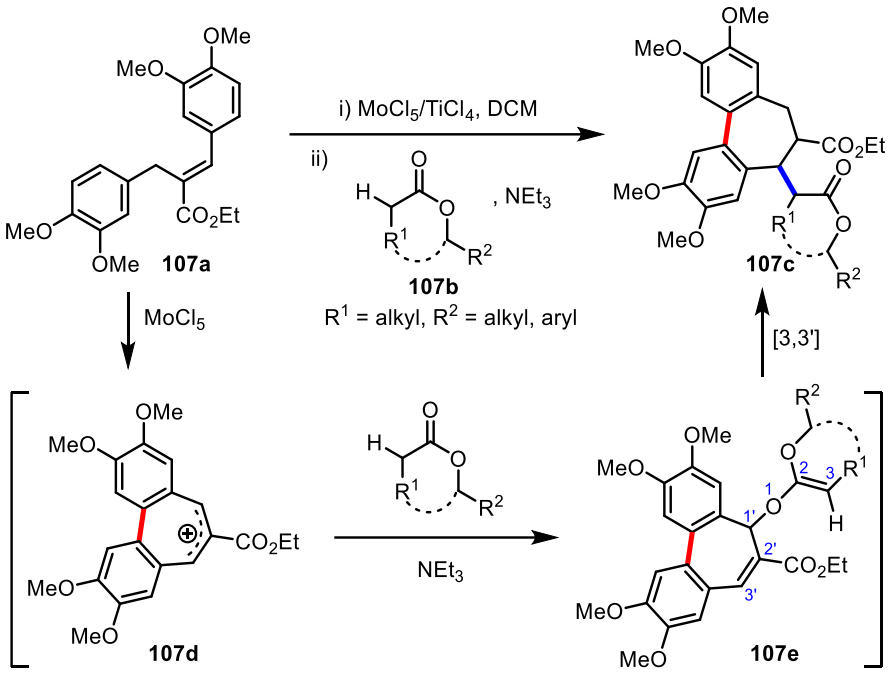

**Scheme 56:** Kita's hypervalent iodine-mediated oxidative coupling.

In 2005, Fagnou and co-workers[66] developed a Pd-catalyzed direct arylation of aryl chloride for the asymmetric synthesis of allocholchicine and its analogues, Scheme 57. 1,3-Diarylpropane **106a** undergoes direct asymmetric arylation in the presence of $Pd(OAc)_2$ and chiral ligand DavePhos to form the biaryl carbon-carbon bond and the seven-membered ring as well in **106b**. Later, this strategy was also employed in the total synthesis of allocholchicine and its analogues.




**Scheme 57:** Fagnou's direct asymmetric arylation of aryl halides.

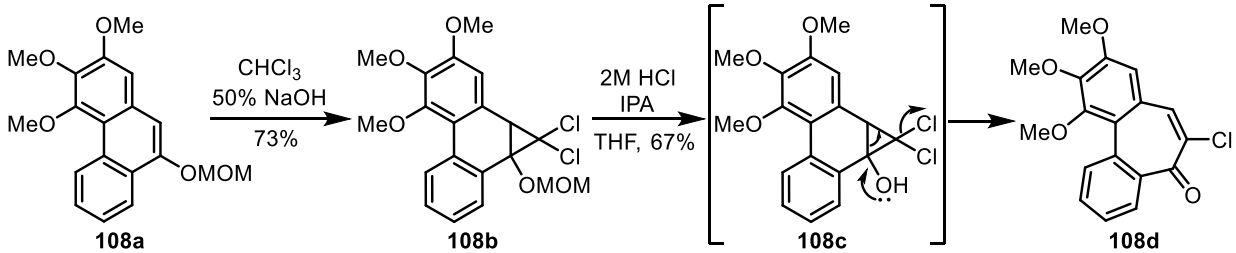
In 2011, Waldvogel *et al.*[67] described a $MoCl_5$ mediated oxidative coupling of 1,3-diaryl propene **107a** for the synthesis of dibenzo[*a*,*c*]cycloheptanes **107c**, Scheme 58. In the domino sequence, **107a** was initially treated with $MoCl_5$ to generate dibezo-fused tropylium cation intermediate **107d**. Next, trapping the reactive intermediate **107d** with **107b** in the presence of $NEt_3$ delivers the intermediate **107e**. Subsequently, **107e** went through a [3,3']-sigmatropic shift to furnish the formation of **107c** in good to excellent yields.




**Scheme 58:** Waldvogel's $MoCl_5$-mediated oxidative coupling.

## 3.1.b: Phenanthrol ring expansion

The ring expansion strategy can be applied to the synthesis of seven-membered carbocycles. In this context, in 2006, DeShong and co-workers[68] introduced an acid-mediated ring expansion of phenanthroline **108a** to dibenzocycloheptenone **108d** *via* cyclopropane ring opening, Scheme 59. **108a** under basic condition formed *gem*-dichloro cyclopropane **108b**. Then, acid-mediated ring-opening of cyclopropane (as shown in intermediate **108c**) delivered the corresponding product **108d**. Later, this method was extended to synthesize different allocholchicinoids.

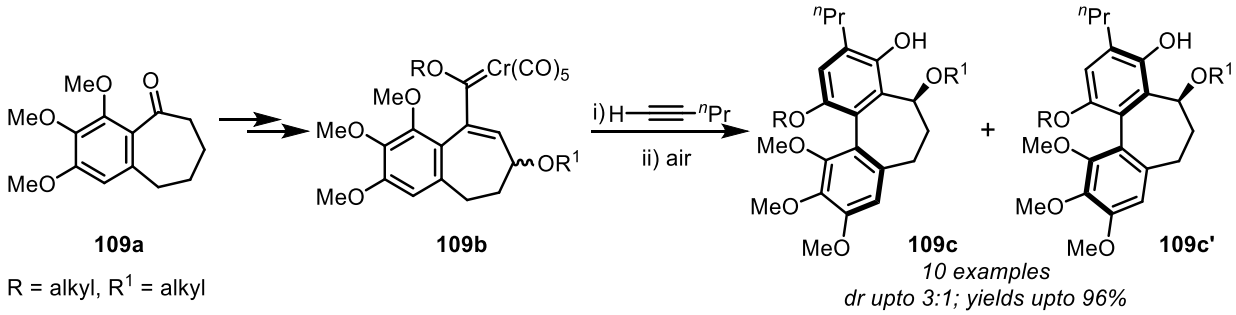



**Scheme 59:** DeShong's phenanthrol ring expansion strategy.

## 3.1.c: Cycloaddition/aromatization

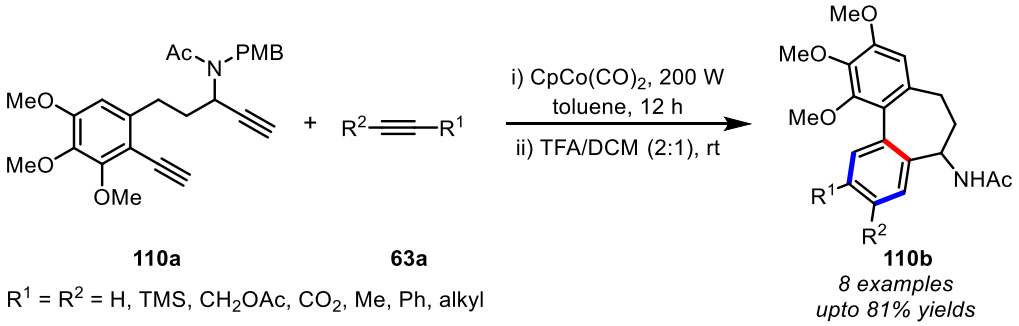
Benzannulation or cycloaddition/aromatization strategies are one of the popular methods to construct dibenzo-fused cycloheptanes. In 2002, Wolff and co-workers[69] reported the synthesis of dibenzo-fused cycloheptanes **109c** from tetrahydrobenzotropone **109a** *via*

benzannulation, Scheme 60. The chromium carbene complex **109b** and alkyne involved in cycloaddition reaction and generated chiral dibenzocycloheptene **109c** or **109c'**. During the atropisomer-selective benzannulation process, the central-to-axial chirality transfer was occurred and respective products were formed in good to excellent yields.




**Scheme 60:** Wolff's atropisomer-selective benzannulation.

In 2017, Ramana and co-workers[70] developed a cobalt-catalyzed [2+2+2]-cyclotrimerization reaction involving tri-alkyne units to synthesize various allocolchicinoids, Scheme 61. Diynes **110a** in presence of 20 mol% $CpCo(CO)_2$ under light (200W bulb) undergo [2+2+2]-cycloaddition reaction with appropriate alkyne **63a** to furnish dibenzocycloheptanes **110b** in good yields. This method was also elaborated to the total synthesis of allocolchicine.

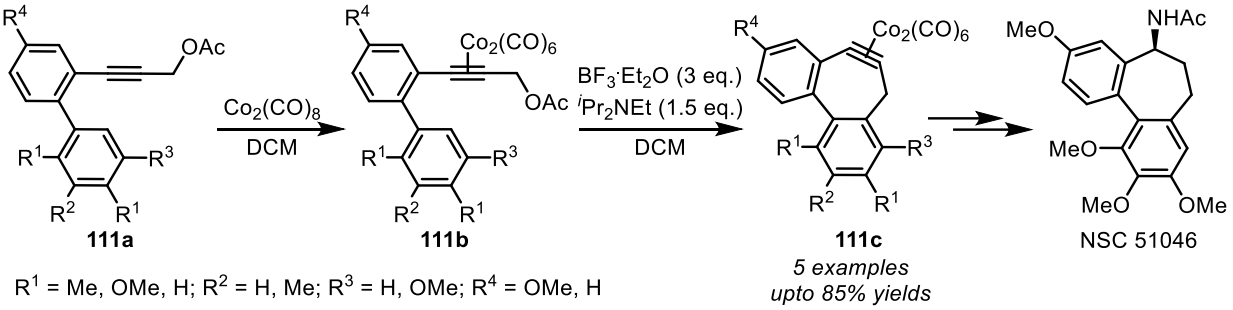



**Scheme 61:** Ramana's cobalt-catalyzed [2+2+2]-cyclotrimerization.

## *3.1.d: Annulation of functionalized biaryls:*

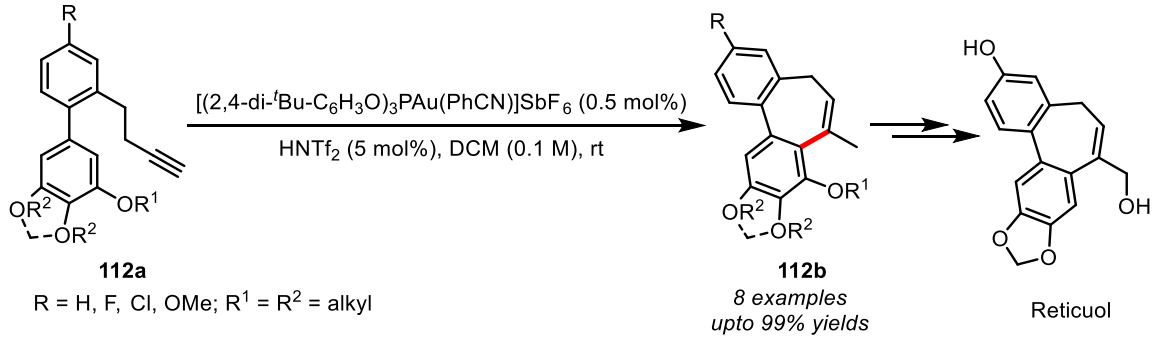
The annulation strategy of functionalized biaryls for the construction of dibenzocycloheptene skeleton received less attention as compared to other available methods. This method offers more flexibility around the biaryl system (unlike the intramolecular coupling strategy, which has geometric and steric constraints) and upon simple manipulation of $Fg^3$ and $Fg^4$ leads to the formation of the cycloheptane ring *via* established strategies. In line with this, in 2007, Green *et al.*[71] reported the synthesis of dibenzocycloheptyne cobalt complex **111c** *via* intramolecular Nicolus reaction of biaryl propargyl acetates **111a**, Scheme 62. **111a**

under the treatment with $Co_2(CO)_8$ generates the corresponding propargyl acetate cobalt complex **111b,** which undergoes Lewis acid-mediated intermolecular Nicolas reaction and furnished **111c** in excellent yields. Later, **111c** with appropriate substitutions can also be converted to enantiopure NSC 51046.



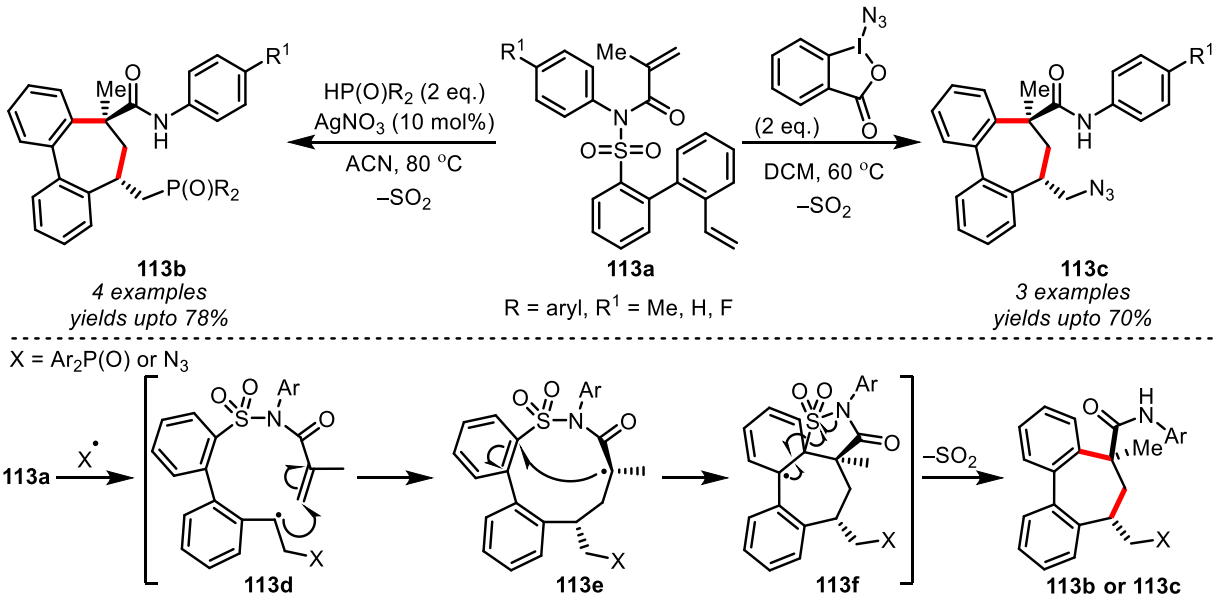

**Scheme 62:** Green's intramolecular Nicolas reaction for the synthesis of NSC 51046.

In 2014, Hashmi and co-workers[72] presented a gold-catalyzed 7-*exo*-dig hydroarylation protocol to synthesize dibenzocycloheptanes, Scheme 63. Biaryl alkyne substrates **112a** upon reaction with the electron-poor gold catalyst $[(2,4\text{-di-}^t\text{Bu-}C_6H_3O)_3PAu(PhCN)]SbF_6$ and in combination with $HNTf_2$, selectively furnished **112b** in excellent yields. This strategy was also utilized for the first total synthesis of reticuol.



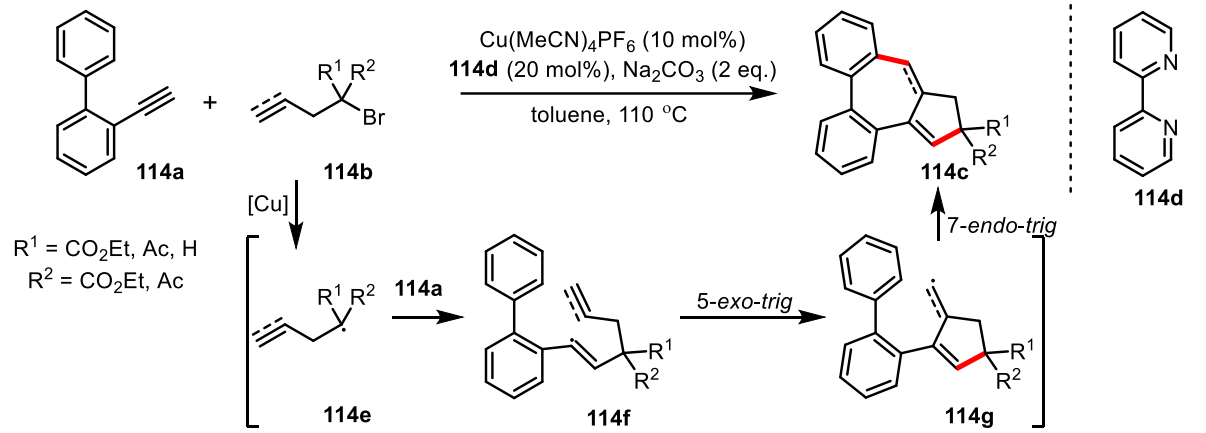

**Scheme 63:** Hashmi's Au-catalyzed intermolecular hydroarylation.

In 2015, Nevado *et al.*[73] reported a divergent cascade radical cyclization of **113a** for the synthesis of phosphonylated dibenzocycloheptanes **113b** and azide substituted dibenzocycloheptanes **113c**, Scheme 64. In the given reaction condition, *in situ* generation of azide and phosphoryl radical reacts with **113a** and forms a radical intermediate **113d** which attacks the enone and delivers **113e** *via* 1,4-aryl migration. Then, rearomatization of **113f** and followed by $SO_2$ elimination, furnished **113b** or **113c** in moderate to good yields.




**Scheme 64:** Nevado's complex radical cyclization.

In 2016, Zhu and co-workers[74] developed a copper-catalyzed cascade annulation between $\alpha$-bromocarbonyls **114b** and biaryl alkyne **114a** for the synthesis of dibenzocycloheptanes **114c**, Scheme 65. In presence of Cu-catalyst, **114b** generates radical intermediate **114e** which then reacts with **114a** to generate **114f**. Subsequently, **114f** undergoes 5-*exo-trig* cyclization to generate **114g** and followed by 7-*endo-trig* cyclization furnishes the formation of **114c**.

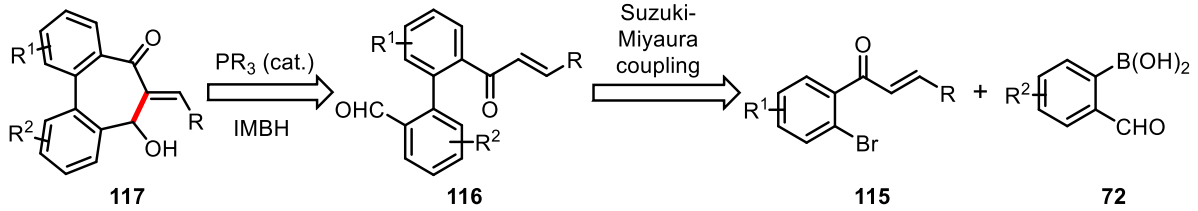



**Scheme 65:** Zhu's copper-catalyzed radical annulation.

As showcased above, most of the strategies leading to the formation of dibenzocyclopentanoids are metal-mediated. Although few metal-free approaches are known, the use of a stoichiometric amount of reagents marks its disadvantage. As an exception, in 2004, Koo reported[75] an example for the synthesis of a seven-membered carbocycle utilizing a

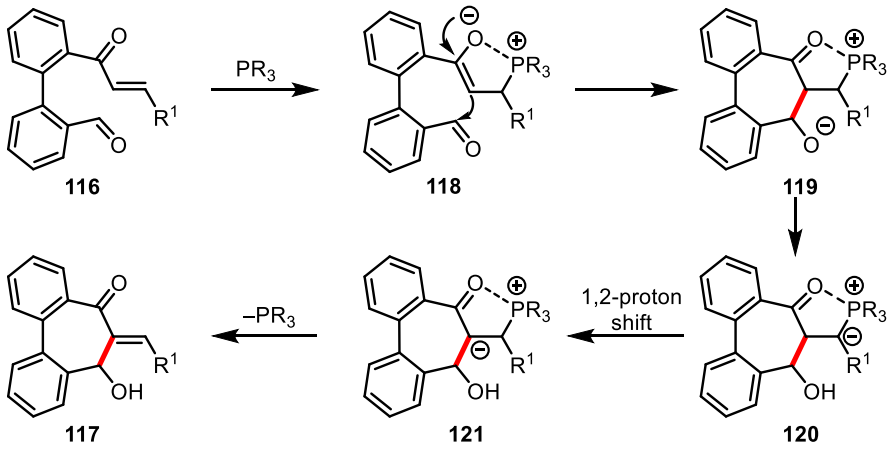
stoichiometric amount of phosphine, but no product formation was observed under catalytic conditions. Therefore, there is a genuine requirement of a metal-free and catalytic strategy for synthesizing dibenzocyclohetanes.

With our experience in phosphine-catalyzed intramolecular annulation reactions[76,7-9] involving ynones and enones (as described in Chapters 1 & 2), we keen to explore the feasibility of developing a catalytic intramolecular Morita–Baylis–Hillman (IMBH) reaction of biaryl enone-aldehydes **116** for the construction of the dibenzocycloheptane moiety **117**, Scheme 66. **116** can be achieved by Suzuki coupling reaction[77] between 2-bromo enone **115** and 2-formylaryl boronic acid **72**.




**Scheme 66:** Our hypothesis for the construction of dibenzocycloheptanes.

In line with this, a phosphine-catalyzed IMBH reaction was envisioned for constructing dibenzocycloheptanes, Scheme 67. It was envisaged that biaryl enone-aldehyde **116** could undergo a phospha-Michael addition followed by an intramolecular aldol reaction to generate zwitterionic intermediate **119**. Subsequently, intramolecular proton shifts and phosphine elimination can lead to the formation of **117**, akin to the MBH reaction.

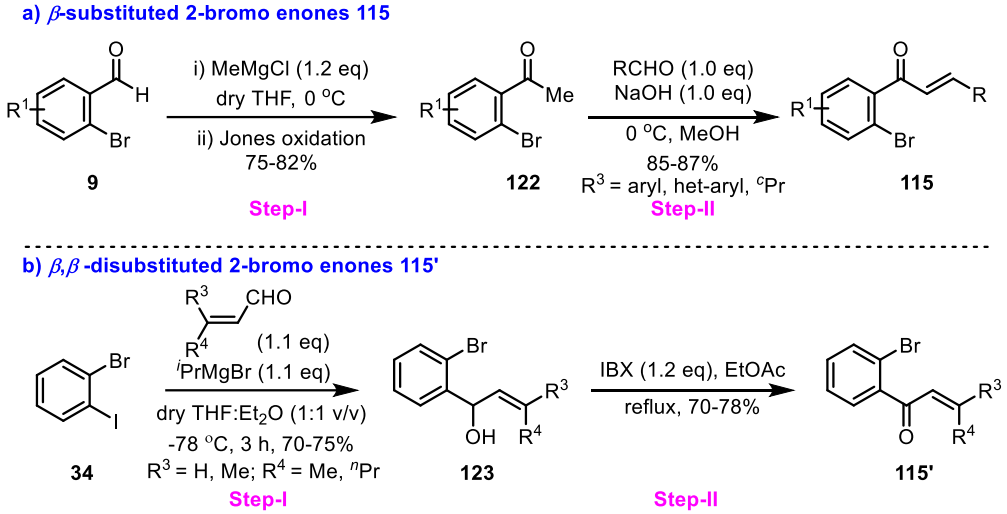



**Scheme 67:** Our hypothesis for phosphine-catalyzed cycloheptannulation.

## *3.2: Results and Discussion*

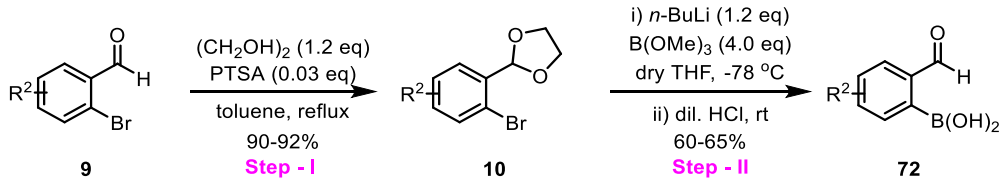
In order to validate the hypothesis presented in the Scheme 66, we commenced synthesizing the substrate **116**. **116** was synthesized by Suzuki-Miyaura coupling reaction

between 2-bromo enones **115** and 2-formylaryl boronic acids **72**. *β*-substituted 2-bromo enones **115** can be easily synthesized by using a two-step protocol starting from commercially available 2-bromoaldehydes **9**, Scheme 68a.[11] **9** was treated with methyl magnesium reagent and followed by Jones oxidation to obtain 2-bromo ketones **122**. Then a base mediated intermolecular aldol reaction between **122** and suitable aldehydes furnished **115**. On the other hand, *β*,*β*-disubstituted 2-bromo enones **115'** were synthesized by using a two-step protocol starting from 2-bromoiodobenzene **34**, Scheme 68b. **34** undergoes $^{i}$PrMgBr mediated alkylation with *β*,*β*-disubstituted enals and followed by IBX oxidation generates the corresponding product **115'**.



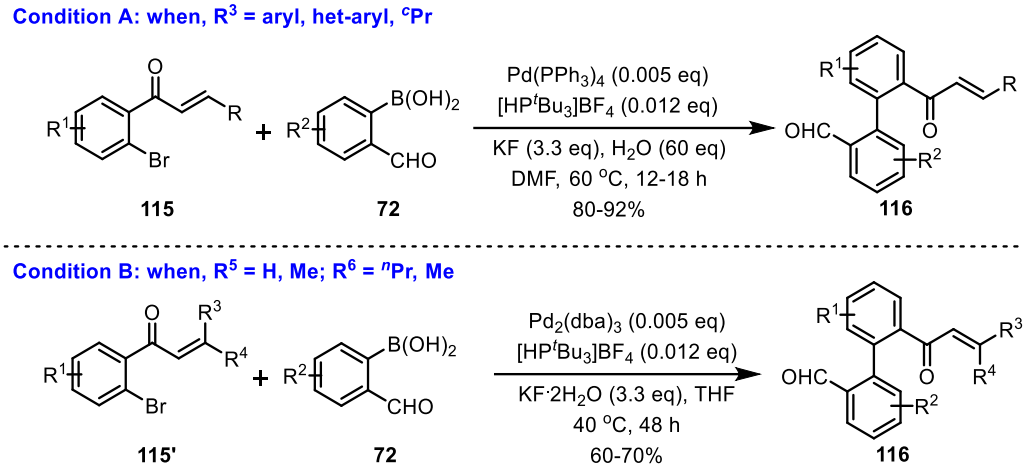

**Scheme 68:** Synthesis of 2-bromo enones **115** and **115'**.

The another coupling partner 2-formylaryl boronic acids **72** can be synthesized by the following strategy mentioned in Scheme 69. The details were already described in Chapter 2 (Scheme 44a).



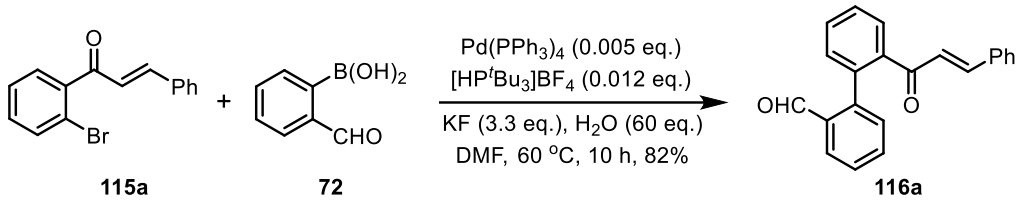

**Scheme 69:** Synthesis of 2-formylaryl boronic acids **72**.

After synthesizing the coupling partners **115** and **72**, the biaryl enone-aldehydes **116** was achieved by the Suzuki-Miyaura coupling reaction between **115** and **72** following the procedures (condition A and B) already described in Chapter 1 (Scheme 21) and Chapter 2 (Table 8).[28,39]




**Scheme 70:** Synthesis of biaryl enone aldehydes **116**.

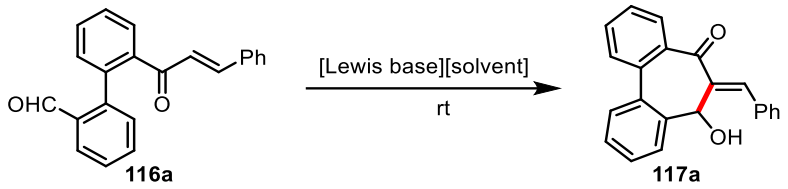
Towards this, we have initiated our study by synthesizing biaryl enone-aldehyde **116a** as the model substrate. Biaryl enone-aldehyde **116a** can be synthesized by the Suzuki coupling reaction between **115a** and **72** following the procedure shown in Scheme 71.[39]




**Scheme 71:** Synthesis of biaryl enone-aldehyde **116a**.

Accordingly, we have initiated our optimization study with biaryl enone-aldehyde **116a** as the model substrate. A wide variety of Lewis bases and solvent combinations were investigated, and the results were compiled in Table 15. Initially, we started our optimization with amine-based catalysts such as DABCO and DBU, which are well-known catalysts for MBH reactions. Unfortunately, DABCO failed to generate the MBH-product **117a**, whereas DBU gave the product with only 16% yield (entries 1–2). Since the results obtained with amine catalysts were poor, we commenced screening various phosphine catalysts for this purpose. All our efforts to obtain **116a** with $PPh_3$, $PPh_2Et$ or $PCy_3$ were unsuccessful (entries 3–6). However, the reaction of **116a** with $PBu_3$ as the catalyst successfully delivered **117a** in excellent yield in a 4:1 mixture of isomers (entry 7).[78] Since MBH reactions are known to be influenced by the nature of the solvent, a brief screening of solvents with $PBu_3$ was performed to ascertain their role. Interestingly, both non-polar and polar solvents, except HFIP provided **117a** in good yields (entries 8–12). Thereby, a catalytic transformation of **116a** to **117a** under efficient and straightforward conditions was established.

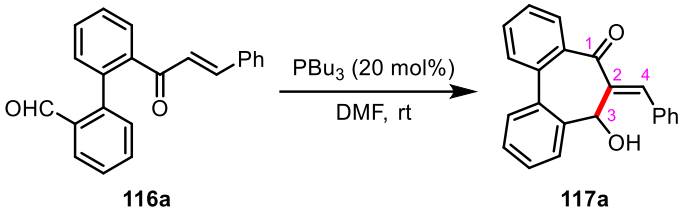
**Table 15:** Optimization of reaction parameters




| entry | catalyst | solvent | time (h) | yield (%)[a] |
|---|---|---|---|---|
| 1 | DABCO | DMF | 15 | - |
| 2 | DBU | DMF | 15 | 16 |
| 3 | $PPh_3$ | ACN | 24 | - |
| 4 | $PPh_3$ | DMF | 24 | - |
| 5 | $PPh_2Et$ | DMF | 24 | - |
| 6 | $PCy_3$ | DMF | 24 | - |
| **7** | **$PBu_3$** | **DMF** | **7** | **85** |
| 8 | $PBu_3$ | DMSO | 7 | 78 |
| 9 | $PBu_3$ | ACN | 15 | 67 |
| 10 | $PBu_3$ | DCM | 31 | 60 |
| 11 | $PBu_3$ | toluene | 28 | 68 |
| 12 | $PBu_3$ | HFIP | 24 | - |

All reactions were performed on 0.1 mmol scales. [a] Yields were calculated after silica gel column chromatography.

The structure of 3-hydroxy-2-arylidine-dibenzocyclohepten-1-ones **117a** was deduced from the spectral data. The presence of two absorption bands in the IR spectrum at 3434 cm-1 due to secondary alcohol and at 1660 cm-1 due to the $\alpha,\beta$-unsaturated ketone indicated the formation of **117a**. In the $^1$H-NMR spectrum (see Figure 32), the presence of a singlet at δ 7.92 ppm due to the $\beta$-proton (C-4), a doublet at δ 5.92 ppm ($J$ = 3.4 Hz) due to the methine proton (C-3), and a doublet of doublet at δ 2.13 ppm ($J$ = 4.6 Hz) due to –OH proton confirmed the formation of **117a**. In the $^{13}$C-NMR spectrum (see Figure 33), a signal at δ 192.8 ppm due to the unsaturated carbonyl (C-1), and a signal at δ 71.5 ppm due to the methine carbon (C-2) further established the structure **117a**. In the high-resolution mass spectrum, the presence of a sodium added molecular ion peak at *m/z* 335.1048 $(M+Na)^+$ further supported the product formation.




**116a** **117a**

**Scheme 72:** Phosphine-catalyzed IMBH reaction of biaryl enone-aldehyde **117a**.

After having the optimized condition in hand, we investigated the substrate scope and generality of the $PBu_3$-catalyzed IMBH reaction leading to the formation of dibenzo cycloheptenones. An array of synthetically challenging 3-hydroxy-2-arylidine-dibenzocyclohepten-1-ones (**117a-z**) could be assembled in good to excellent yields, and the results of this studies are presented in Table 16. Biaryl enone-aldehydes (**116a-z**) with a variety of sterically and electronically diverse substituents on the arene backbones successfully delivered the corresponding products (**117a-z**) in good to excellent yields. Substrates with electron-donating and electron-withdrawing groups across the enone moiety showed only marginal influence on the efficiency of the reaction (**117b–e**, **117g–k**, **117m–s**, **117t–v**). Even the biaryl enone-aldehydes (**116s** and **116x**) with alkyl groups on the enone moiety furnished the corresponding products (**117s** and **117x**) in moderate to good yields in prolonged reaction time. After realizing the extremely facile transformation of *β*-monosubstituted enone-aldehydes (**116a-x**), we considered to explore the sterically encumbered *β*,*β*-disubstituted enone substrates. The reaction of biaryl *β*,*β*-disubstituted enone-aldehyde (**116y**) was found to be sluggish and produced **117y** in 30% yield. This method was also extended to synthesize the benzo-fused benzo[*b*]cyclohepta[*d*]thiophenes **117z**, which are otherwise difficult to access. The molecular structure, including the relative stereochemistry of the dibenzocycloheptenones was assigned based on the X-ray diffraction analysis of **117b** (Figure 31).

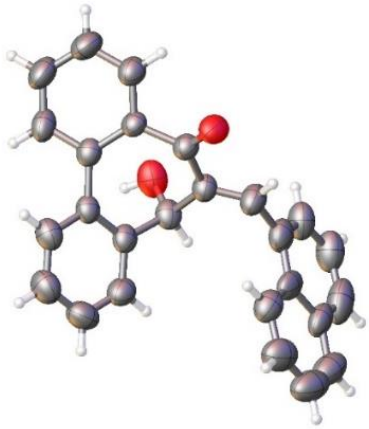


**Figure 31:** ORTEP diagram of dibenzo cycloheptenone **117b**.

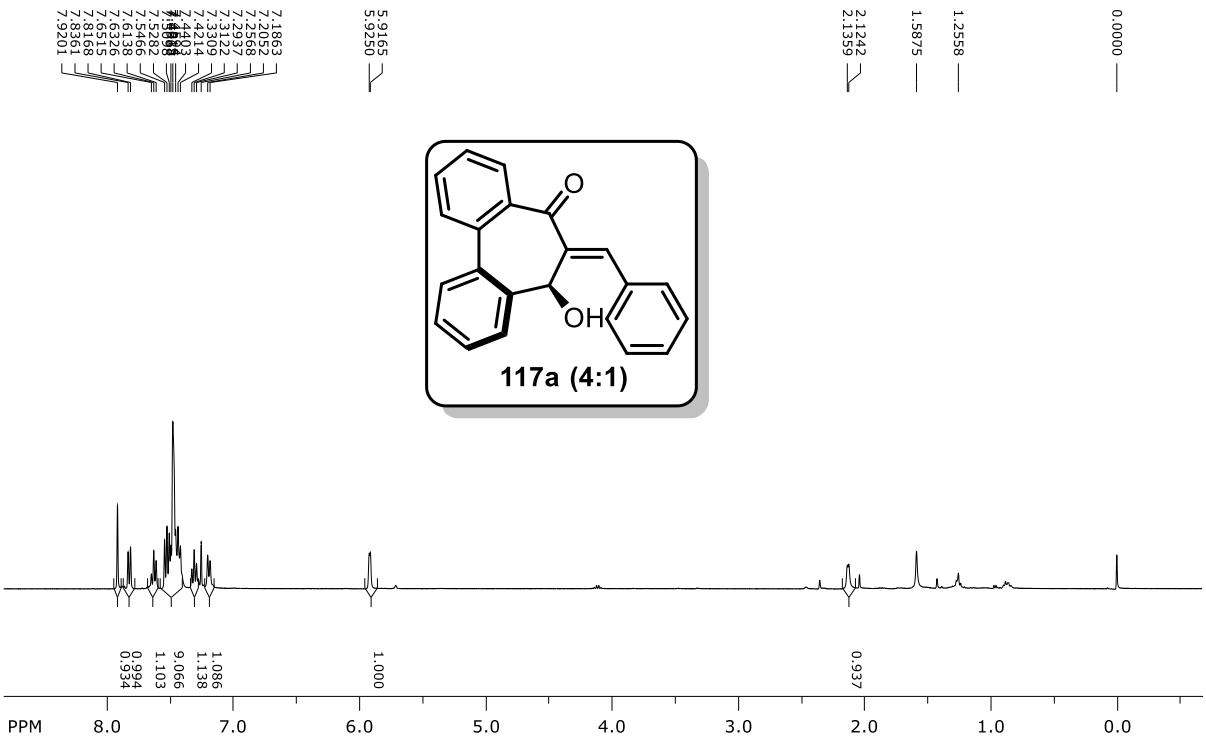



**Figure 32:** $^{1}$H-NMR spectrum of the IMBH product **117a**.

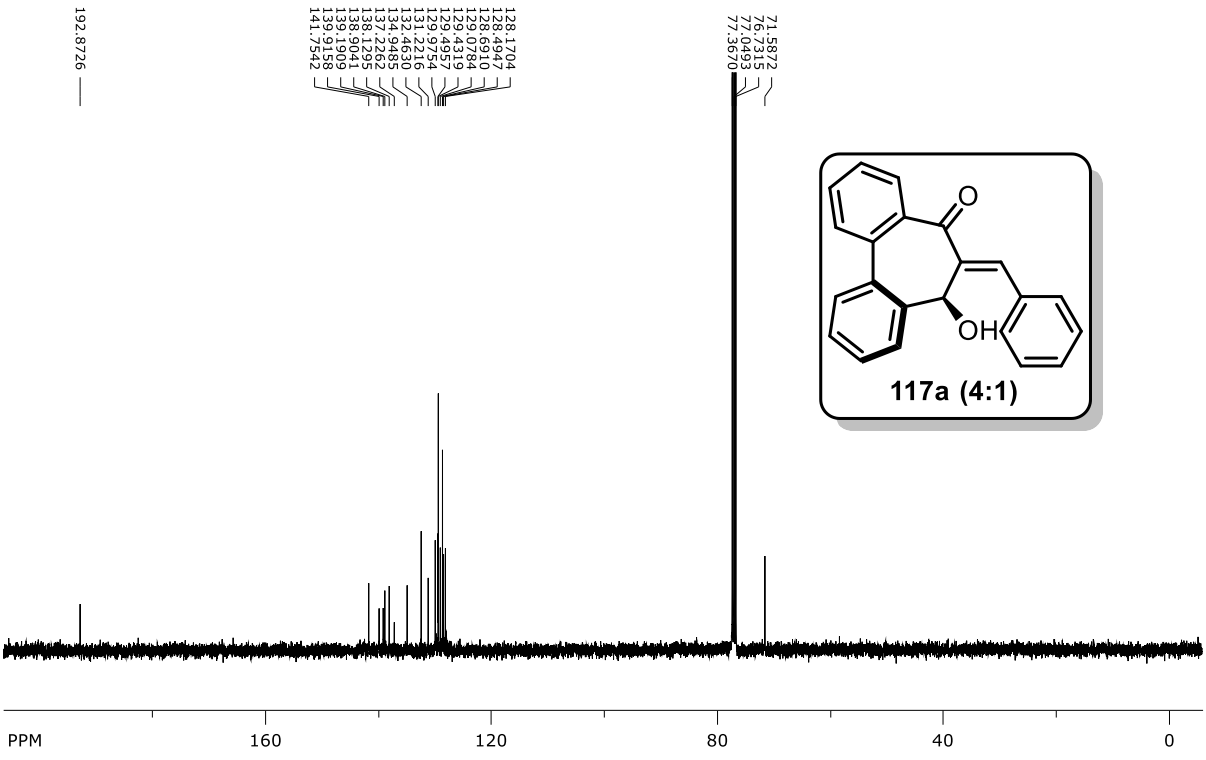
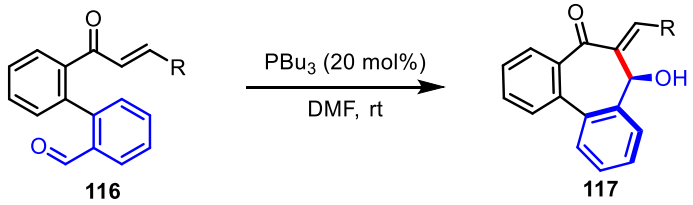
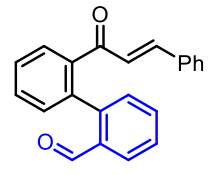
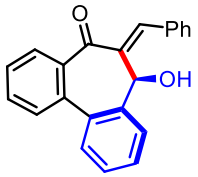
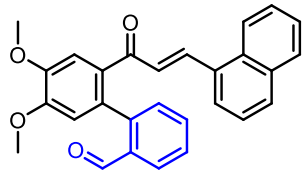
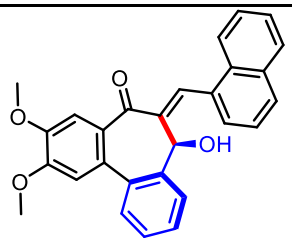
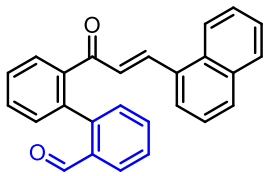
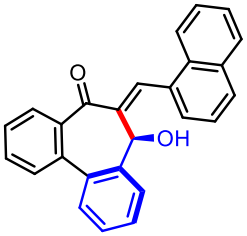
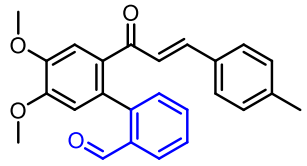
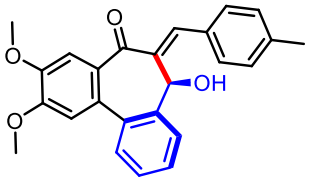
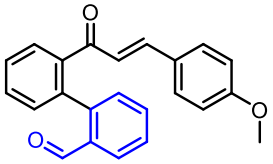
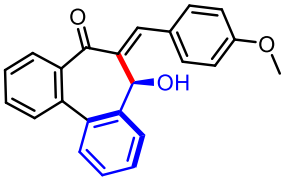
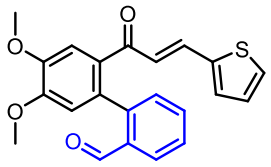
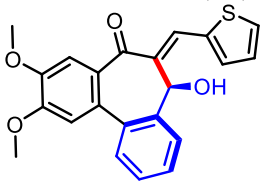
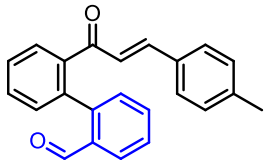
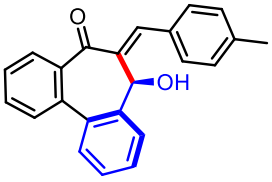
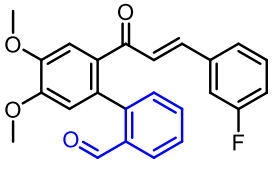
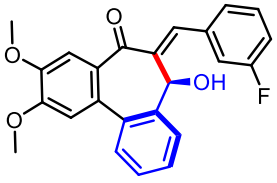
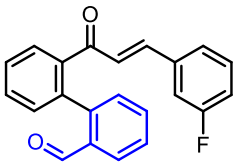
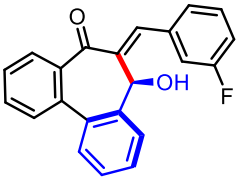
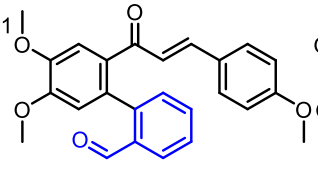
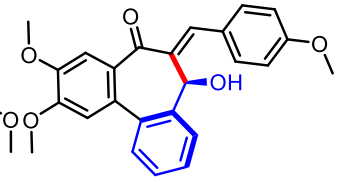
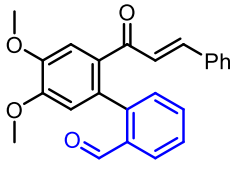
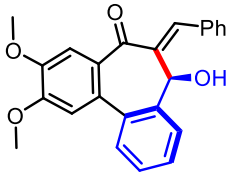
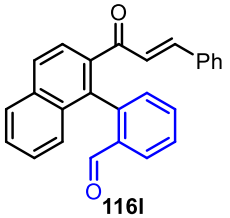
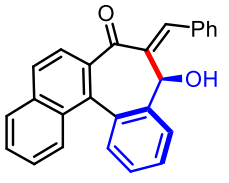
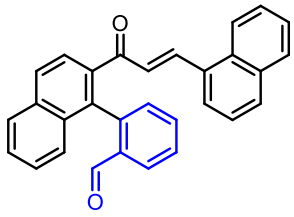
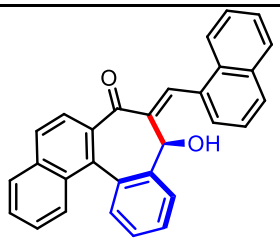
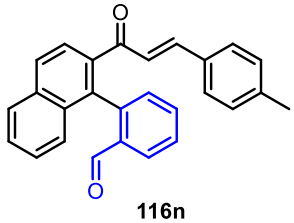
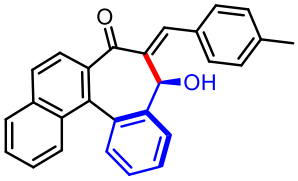
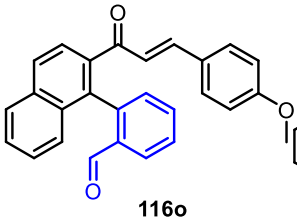
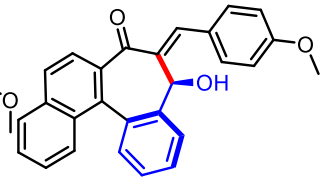
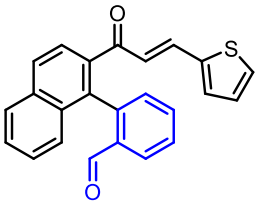
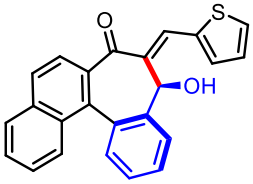
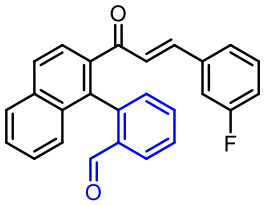
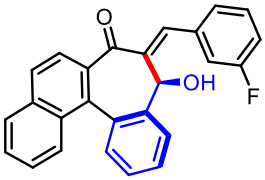
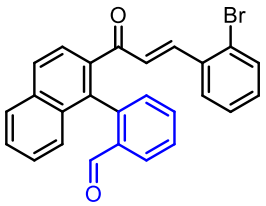
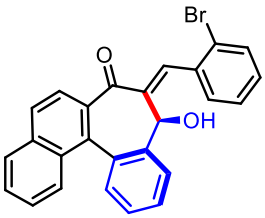
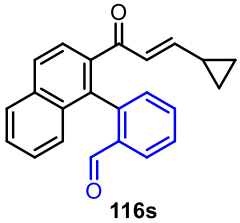
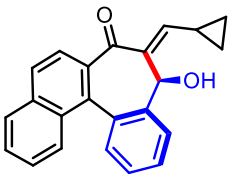
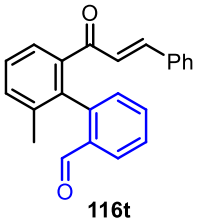
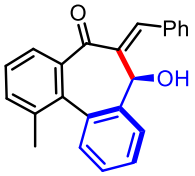
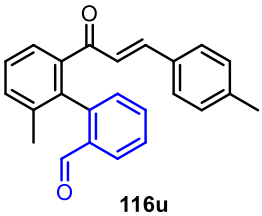
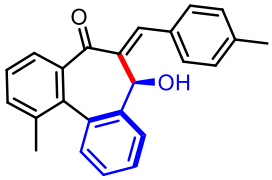
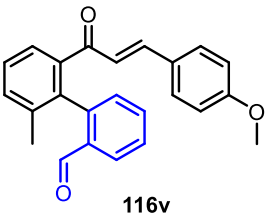
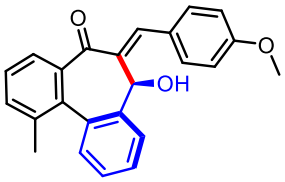
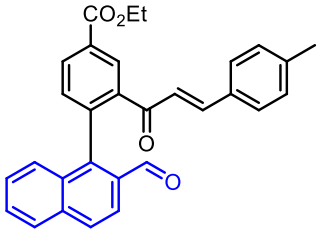
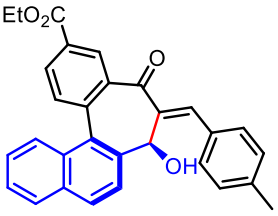
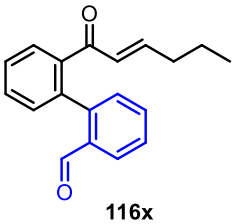
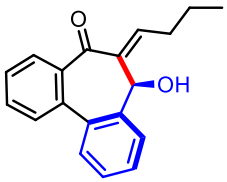
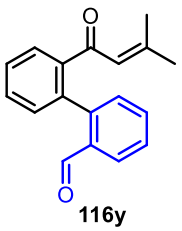
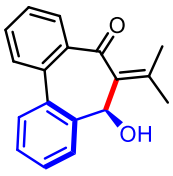
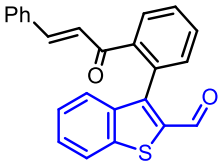
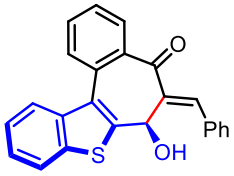



**Figure 33:** $^{13}$C-NMR spectrum of the IMBH product **117a**.

**Table 16:** Substrate Scope: Dibenzo-fused cycloheptenones [a]

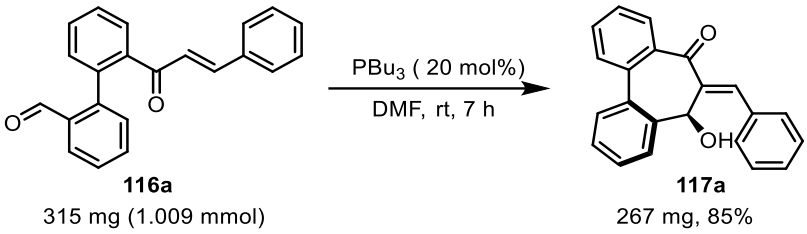



| entry | substrate | product | entry | substrate | product |
|---|---|---|---|---|---|
| 1 |  **116a** |  **117a**, 7 h, 85% (4:1) | 7 |  **116g** |  **117g**, 2 h, 81% (3:1) |
| 2 |  **116b** |  **117b**, 5 h, 81% (4:1) | 8 |  **116h** |  **117h**, 4 h, 83% (5:1) |
| 3 |  **116c** |  **117c**, 4 h, 76% (6:1) | 9 |  **116i** |  **117i**, 6 h, 85% (3:1) |
| 4 |  **116d** |  **117d**, 2 h, 89% (6:1) | 10 |  **116j** |  **117j**, 4 h, 86% (3:1) |
| 5 |  **116e** |  **117e**, 6 h, 72% (7:1) | 11 |  **116k** |  **117k**, 5 h, 85% (4:1) |
| 6 |  **116f** |  **117f**, 5 h, 83% (3:1) | 12 |  **116l** |  **117l**, 7 h, 78% (4:1) |

| entry | substrate | product |
|---|---|---|
| 13 |  **116m** |  **117m**, 6 h, 82% (4:1) |
| 14 |  **116n** |  **117n**, 3 h, 89% (10:1) |
| 15 |  **116o** |  **117o**, 6 h, 75% (3:1) |
| 16 |  **116p** |  **117p**, 5 h, 70% (2:1) |
| 17 |  **116q** |  **117q**, 3 h, 86% (10:1) |
| 18 |  **116r** |  **117r**, 8 h, 90% (3:1) |
| 19 |  **116s** |  **117s**, 4 d, 33% (13:1) |
| 20 |  **116t** |  **117t**, 6 h, 72% (5:1) |
| 21 |  **116u** |  **117u**, 8 h, 84% (7:1) |
| 22 |  **116v** |  **117v**, 9 h, 76% (8:1) |
| 23 |  **116w** |  **117w**, 8 h, 75% (6:1) |
| 24 |  **116x** |  **117x**, 36 h, 67% (4:1) |
| 25 |  **116y** |  [b]**117y**, 48 h, 30% |
| 26 |  **116z** |  **117z**, 8 h, 80% (4:1) |

[a] Isomeric ratios were determined from the crude $^1$H-NMR data. [b] Isomeric ratio could not be deduced from the crude $^1$H-NMR data.

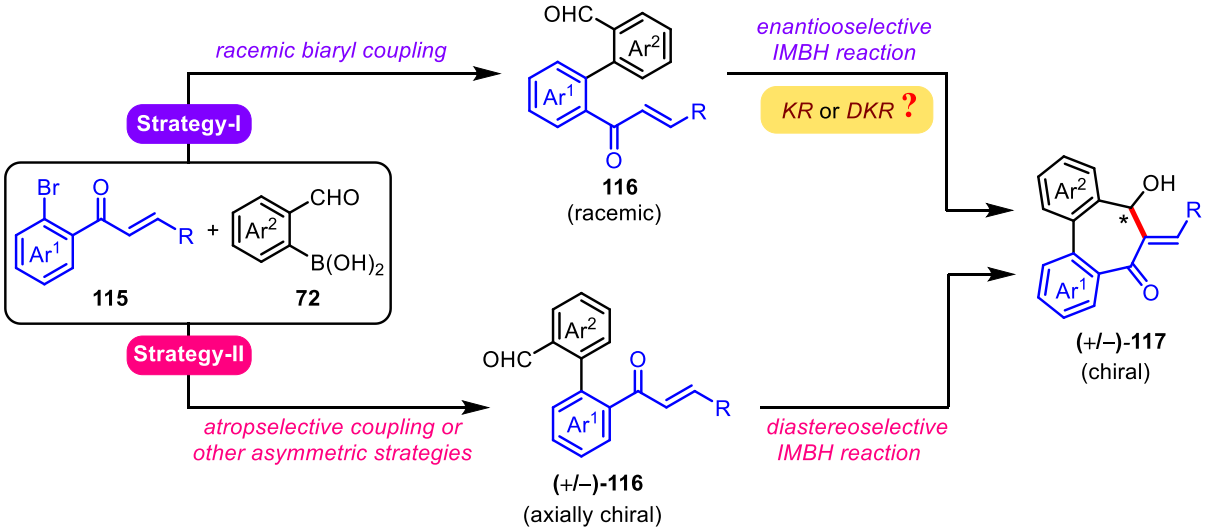
To verify the generality and practicality of the method, a scale-up batch reaction was done with **116a** on 1.0 mmol scales as depicted in Scheme 73. The respective product **117a** was obtained in 85% in 7 h.




**Scheme 73:** The scale-up batch reaction of **116a**.

## *3.3: Development of the synthesis of chiral dibenzo cycloheptenones*

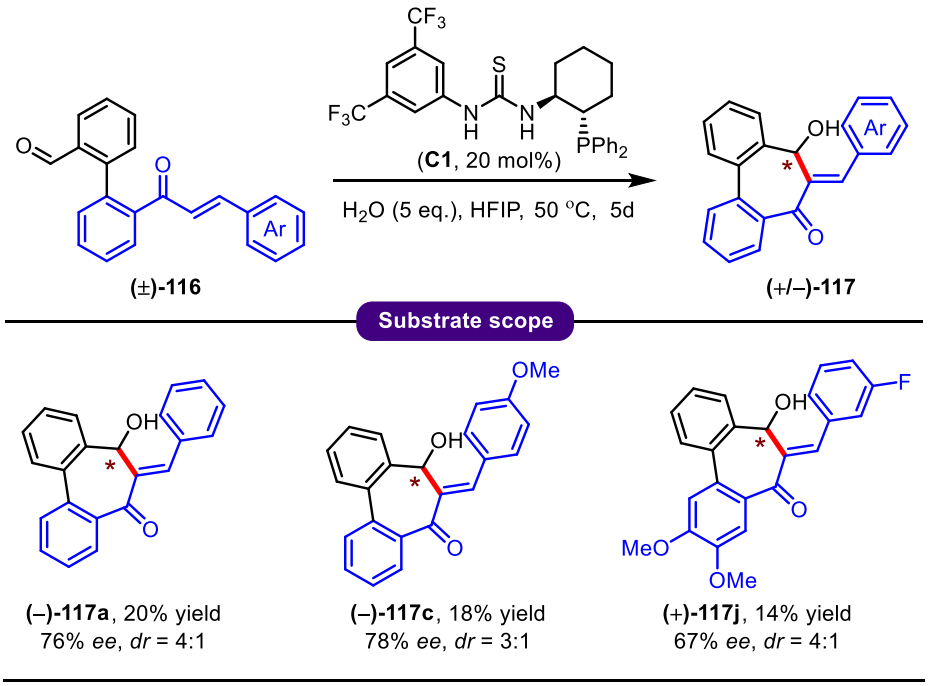
After achieving a general, practical and highly efficient IMBH reaction for the synthesis of racemic dibenzo cycloheptenones, we intended to accomplish the synthesis of chiral dibenzo cycloheptenoness. For this purpose, two complementary strategies were considered, as depicted in Scheme 74. As per the strategy-I, it was expected that the racemic biaryl enone-aldehydes **116** could undergo asymmetric IMBH reaction[35] and provide optically pure dibenzo-cycloheptenones **(+/–)-117**. Depending on the rotational barrier across the C($sp^2$)–C($sp^2$) bond in **116**, it could follow either kinetic resolution (KR) or dynamic kinetic resolution (DKR) to carry out this transformation. On the other hand, as shown in strategy-II, the synthesis of axially chiral enone-aldehyde **(+/–)-116** was planned *via* atroposelective biaryl coupling (or other possible asymmetric strategies).[79] Subsequently, a diastereoselective IMBH reaction of **(+/–)-116** could deliver the desired optically active dibenzocycloheptenones **(+/–)-117**.




**Scheme 74:** Strategies for the synthesis of dibenzocycloheptenones **(+/–)-117**.

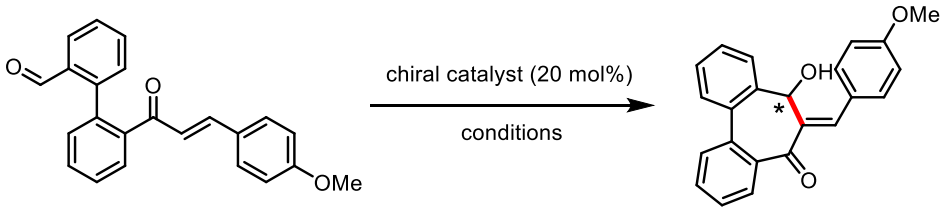
### *3.3.1: Strategy-I: Asymmetric IMBH reaction to synthesize chiral dibenzocycloheptanes*

Since our group extensively worked on the development of asymmetric MBH reaction, we started our screening with racemic **116c** as the model substrate, and applied various chiral phosphines and amines in combination with different solvents. Some of the results are presented in Table 17. The attempts with cinchona based chiral amine (**C12**) was unsuccessful. Among the chiral catalysts, only catalyst **C1** in 1,1,1,3,3,3-hexafluoroisopropanol (HFIP) provided the product **(–)-117c** in good enantioselectivity (90% *ee*), but in poor yield (Table 17). A marginal improvement in the reaction yield was observed when we tried water as an additive at elevated temperature with catalyst **C1.** But the enantioselectivity of the product (78% *ee*) was decreased slightly, Scheme 75. Since the yield of the asymmetric IMBH reaction was poor, indicated that a kinetic resolution process might have taken place during the conversion of **116c** to **(–)-117c**. The racemic **116a** and **116j** were also subjected to the same conditions (see in Scheme 75). Indeed, the respective products, **(–)-117a** and **(+)-117j**, were obtained in 20% and 12% yields and 76% and 67% *ee*, respectively. However, several of our efforts to improve the yield of the asymmetric IMBH reaction were unsuccessful.

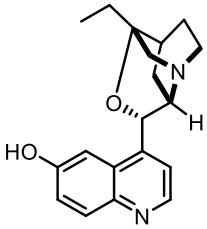



**Scheme 75:** Results of Strategy-I

**Table 17:** Screening of chiral catalysts

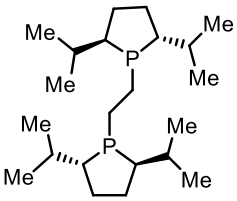



**116c** **(–)-117c**



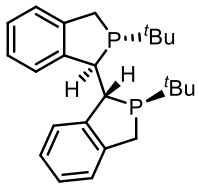
**C12**

- DMF, rt, 8 d: NR
- HFIP, rt, 8 d: NR



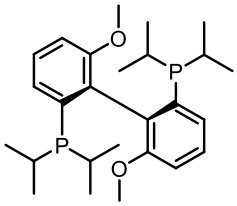
**C13**

- DMF, rt, 8 d: NR
- HFIP, rt, 8 d: NR



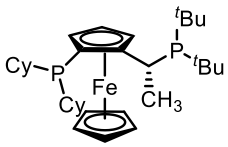
**C14**

- DMF, rt, 8 d: NR
- HFIP, rt, 8 d: NR



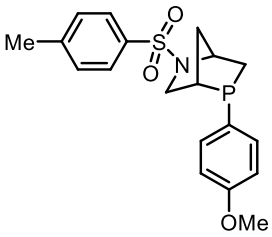
**C7**

- DMF, rt, 8 d: NR
- HFIP, rt, 8 d: NR



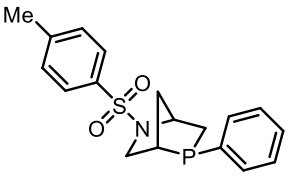
**C15**

- DMF, rt, 8 d: NR
- HFIP, rt, 8 d: NR



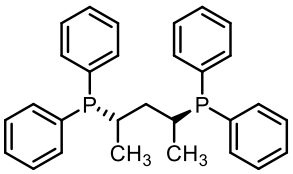
**C16**

- DMF, rt, 8 d: NR
- HFIP, rt, 8 d: trace



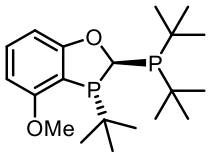
**C5**

- HFIP, rt, 8 d: NR



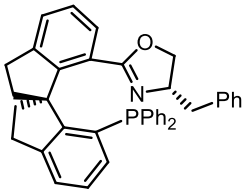
**C2**

- DMF, rt, 8 d: NR
- HFIP, rt, 8 d: NR



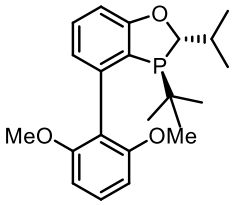
**C17**

- HFIP, rt, 8 d: NR



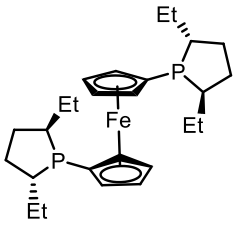
**C18**

- HFIP, rt, 8 d: NR



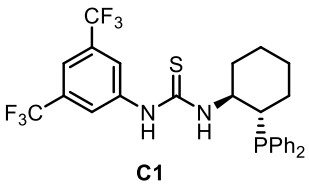
**C19**

- HFIP, rt, 8 d: NR



**C20**

- DMF, rt, 8 d: NR
- HFIP, rt, 8 d: NR



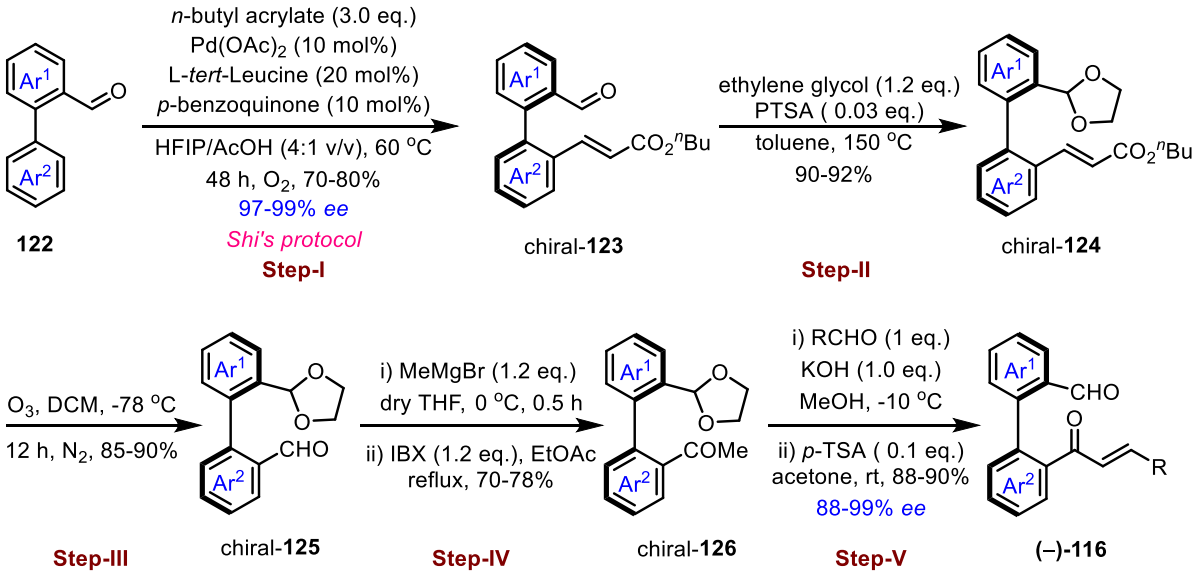
**C1**

- DMF, rt, 8 d: NR
- HFIP, rt, 8 d: 90% *ee*, 8% yield
- HFIP, *p*-nitrophenol (20 mol%), rt, 8 d: NA
- HFIP, BINOL (20 mol%), rt, 8 d: NA
- HFIP:DMF (4:1), rt, 8 d: trace
- HFIP, $Sc(OTf)_3$ (20 mol%), rt, 8 d: NA
- **HFIP, $H_2O$ (5 eq.), 50 °C, 5 d: 78% *ee*, 18% yield, dr = 3:1**

All reactions were performed on 0.1 mmol scales by using DMF (0.5 mL), and HFIP (0.5 mL) as solvent at different temperature and isolated by using silica gel column chromatography.

### *3.3.2: Strategy-II: $PBu_3$-catalyzed IMBH reaction of axially chiral biaryl enone-aldehydes*

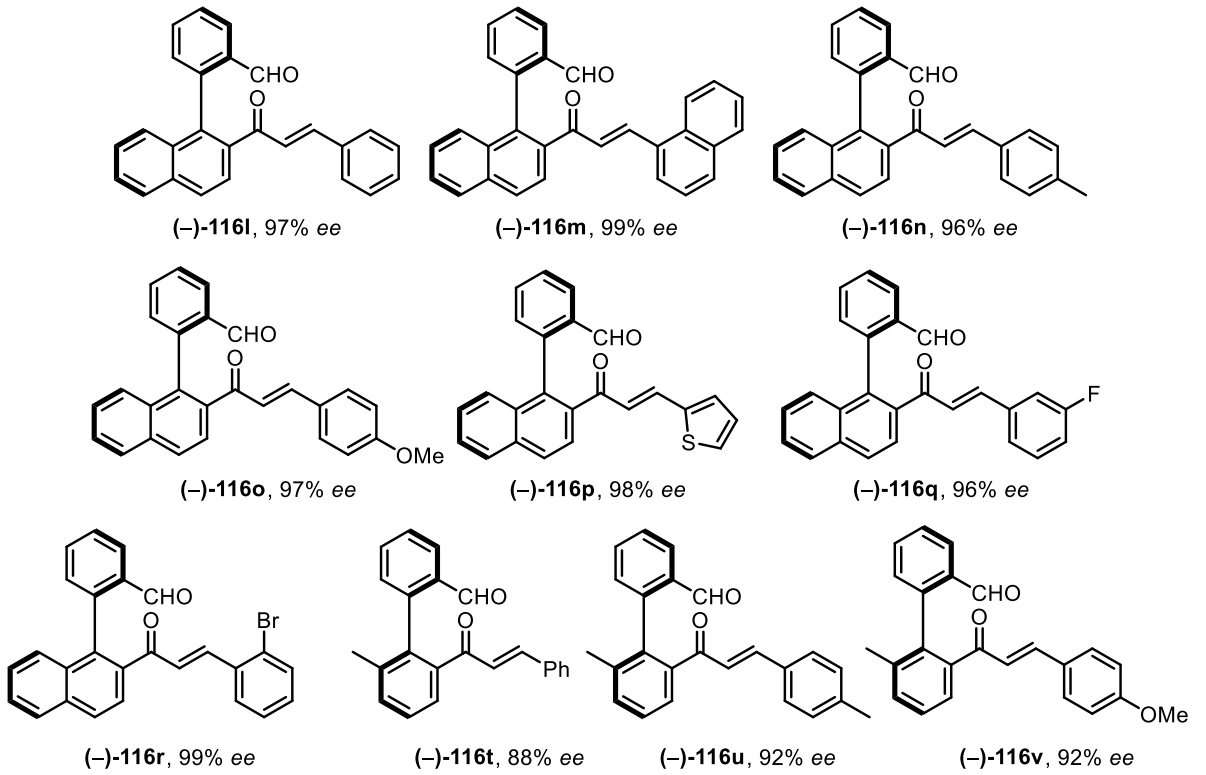
Since the strategy-I was unsuccessful, we opted to explore strategy-II for the synthesis of chiral dibenzocycloheptanes. Towards this, we started the synthesis of axially chiral biaryl enone-aldehydes **(–)-116** by employing Shi's palladium-catalyzed atroposelective C–H olefination protocol as the key step.[80] As depicted in Scheme 76, the chiral biaryl enone-aldehydes **(–)-116** was prepared by following a five-step protocol. Initially, Palladium-catalyzed asymmetric C–H olefination of **122** delivered chiral biaryl enone-ester aldehydes chiral-**123** in excellent enantioselectivity. The reaction of chiral-**123** with ethylene glycol in the presence of a catalytic amount of *p*-TSA afforded chiral-**124**. The ozonolysis reaction of chiral-**124** afforded chiral biaryl aldehydes chiral-**125**, which upon treatment with MeMgBr and subsequent IBX oxidation delivered corresponding ketones chiral-**126**. The aldol condensation reaction of chiral-**126** with appropriate aldehydes under basic conditions and *p*-TSA-catalyzed deprotection of the acetal functional group successfully delivered the desired axially chiral biaryl enone-aldehydes **(–)-116**.




**Scheme 76:** Synthesis of axially chiral biaryl-enone aldehydes **(–)-116**.

A diverse range of axially chiral **(–)-116i-r** and **(–)-116t-v** having electron-donating as well as electron-withdrawing groups across the arene moiety were synthesized with excellent enantiomeric excess and compiled in Table 18.

**Table 18:** Substrate scope: axially chiral **(–)-116i-r** and **(–)-116t-v**



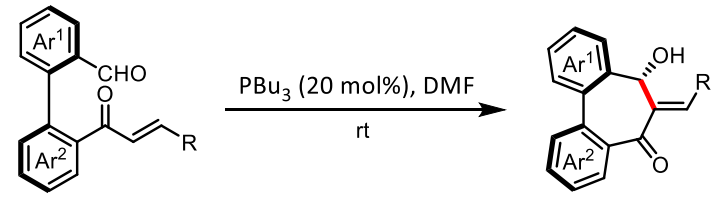

**(–)-116l**, 97% *ee* **(–)-116m**, 99% *ee* **(–)-116n**, 96% *ee*

**(–)-116o**, 97% *ee* **(–)-116p**, 98% *ee* **(–)-116q**, 96% *ee*

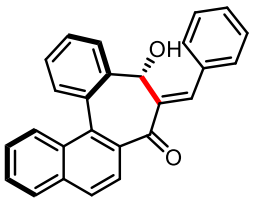
**(–)-116r**, 99% *ee* **(–)-116t**, 88% *ee* **(–)-116u**, 92% *ee* **(–)-116v**, 92% *ee*

Next, axially chiral biaryl enone-aldehydes **(–)-116** were subjected to $PBu_3$-catalyzed IMBH reaction to obtain chiral 3-hydroxy-2-arylidine-dibenzocyclohepten-1-ones **(+/–)-117** in good to excellent yields and the results were compiled in Table 19. Indeed, the axially chiral substrates were converted to a wide range of optically active dibenzocycloheptanes **(+/–)-117l-r** and **(–)-117t-v** possessing two chiral elements, axial and central chirality *via* a phosphine-catalyzed axial-to-central chirality transfer process. Axially chiral biaryl enone-aldehydes with a variety of sterically and electronically diverse substituents on the biaryl backbones or in the arene moiety across the enones, were well-tolerated under the optimized condition and delivered the expected product with almost no loss in enantioselectivity. Arene bearing with heteroaryl substituent such as thiophene across the enone moiety **(–)-116p** furnished the product formation **(–)-117p** in excellent yield. But, the enantiomeric excess of the compound was not determined as it was not resolved in HPLC. The experimentally observed *E*-selectivity across the double bond is in line with the predicted stereochemistry based on the mechanism.

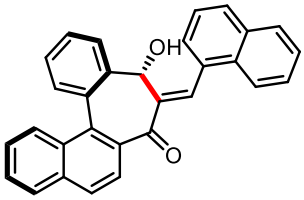
**Table 19:** Substrate scope: Chiral dibenzocycloheptenones



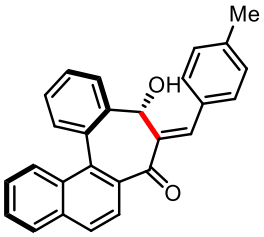

(–)-116 (+/–)-117



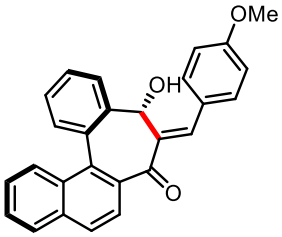

**(–)-117l**, 85%, 8 h
96% *ee* (*E*/*Z* = 4:1)



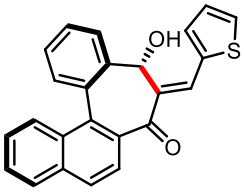

**(+)-117m**, 90%, 14 h
93% *ee* (*E*/*Z* = 4:1)



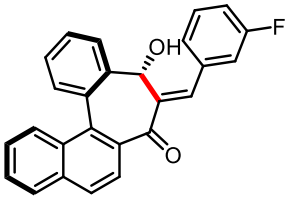

**(–)-117n**, 86%, 8 h
95% *ee* (*E*/*Z* = 3:1)



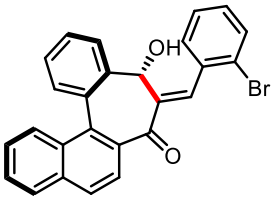

**(–)-117o**, 82%, 12 h
96% *ee* (*E*/*Z* = 3:1)



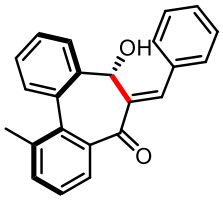

**(–)-117p**, 84%, 10 h
-nd, (*E*/*Z* = 3:1)



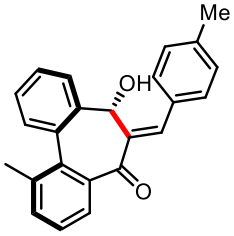

**(+)-117q**, 90%, 4 h
95% *ee* (*E*/*Z* = 5:1)



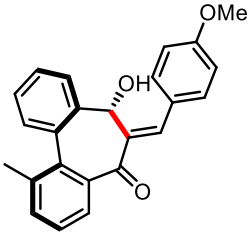

**(+)-117r**, 85%, 8 h
99% *ee* (*E*/*Z* = 3:1)




**(–)-117t**, 75%, 9 h
83% *ee* (*E*/*Z* = 5:1)




**(–)-117u**, 78%, 6 h
86% *ee* (*E*/*Z* = 7:1)

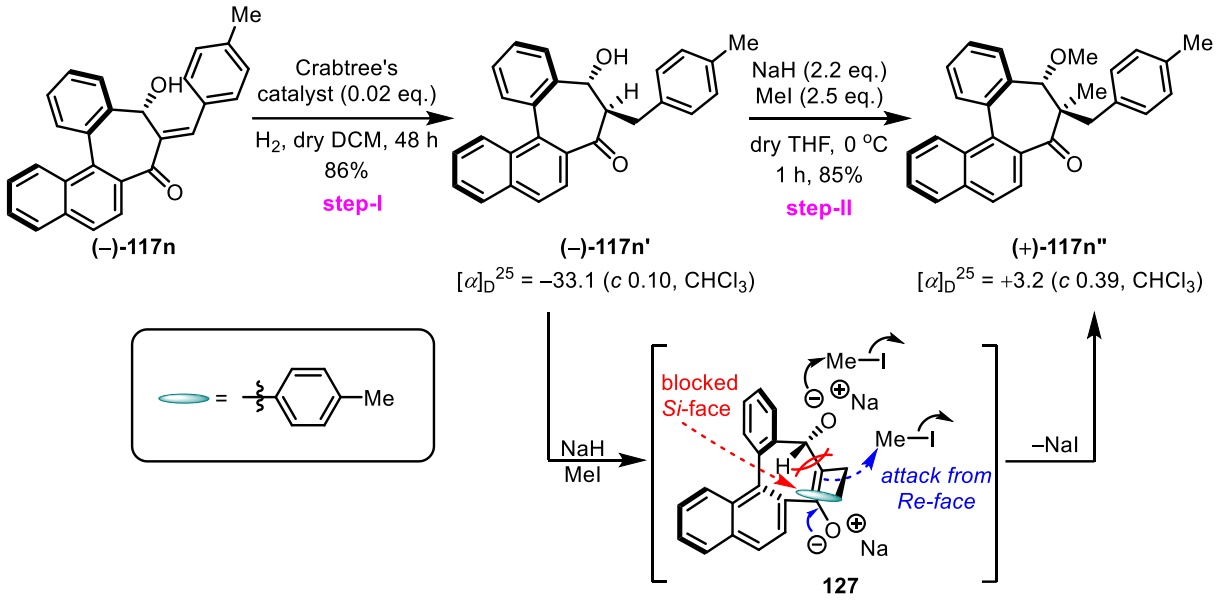



**(–)-117v**, 74%, 10 h
88% *ee* (*E*/*Z* = 10:1)

## *3.4: Determination of relative stereochemistry of (+/–)-117*

To determine the relative stereochemistry of the chiral **(+/–)-117**, a two-step synthetic elaboration of the IMBH-product was performed, as shown in Scheme 77. **(–)-117n** was subjected to hydrogenation using Crabtree's catalyst to obtain **(–)-117n'**. Then alkylation of **(–)-117n'** by methyl iodide, delivered the dialkylation product **(+)-117n"**. Further, the X-ray diffraction analysis of **(+)-117n"** confirmed the relative stereochemistry at the quaternary center, Figure 34. Next, the relative stereochemistry of **(–)-117n** could be easily deduced from the structure of **(+)-117n"**. The relative stereochemistry of the other chiral

dibenzocycloheptanes was also assigned by this analogy. In addition, we proposed a plausible transition state model for the $\alpha$-methylation of the corresponding enolate intermediate **127** as depicted in Scheme 77.




**Scheme 77:** Synthetic elaboration of **(–)-117n** for the determination of relative stereochemistry.

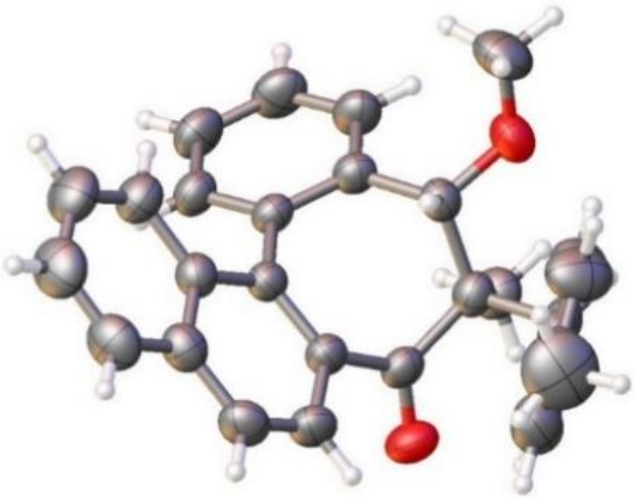


**Figure 34:** ORTEP diagram of **(+)-117n"**.

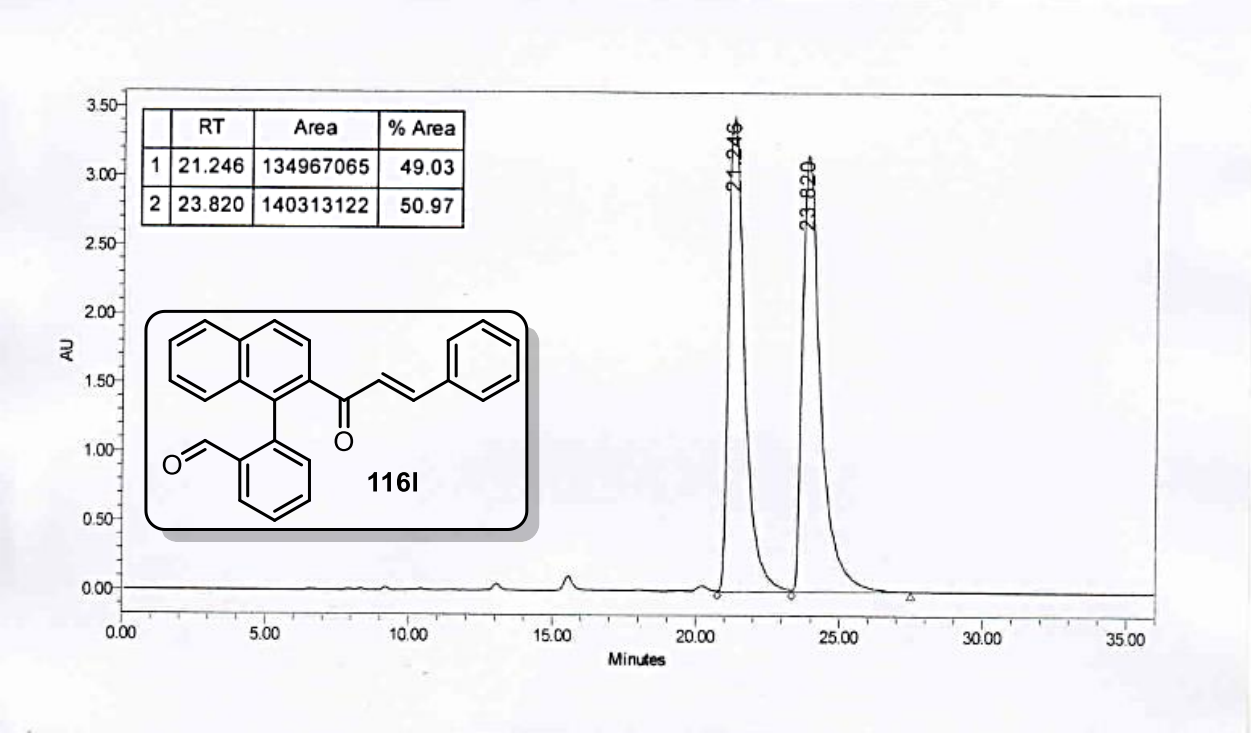



**Figure 35:** HPLC chromatogram of racemic **116l**.

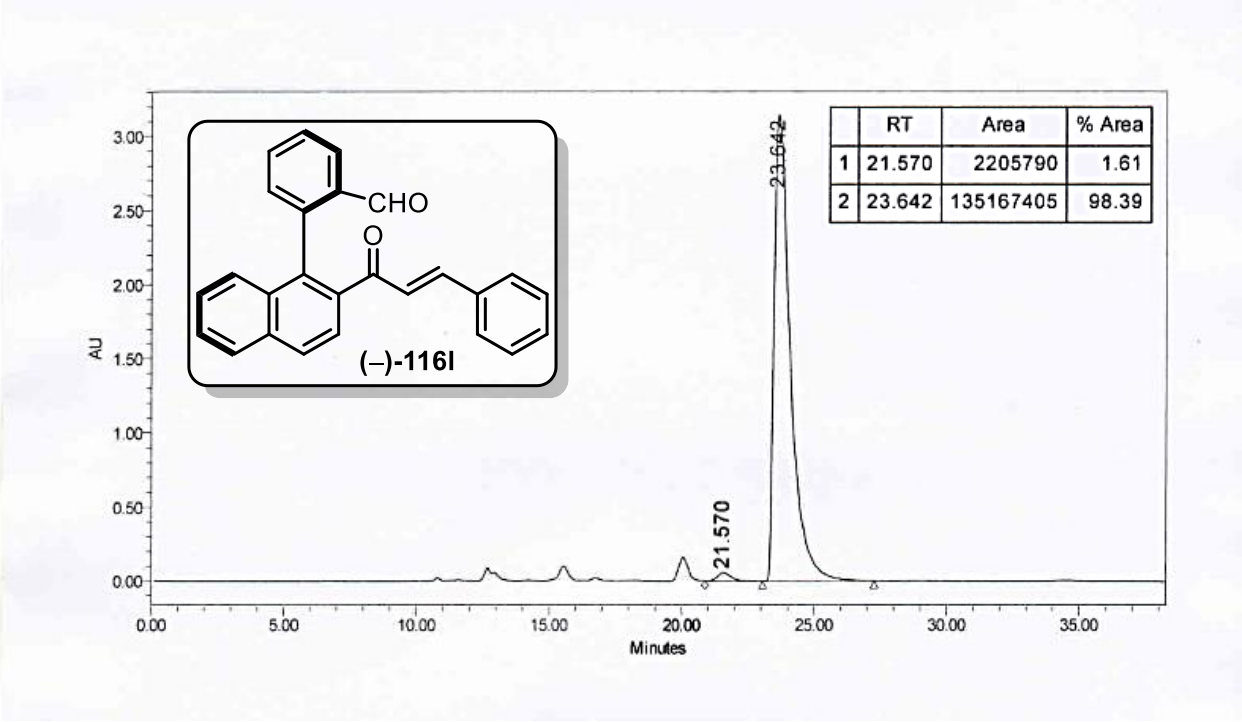



**Figure 36:** HPLC chromatogram of chiral (–)-**116l**.

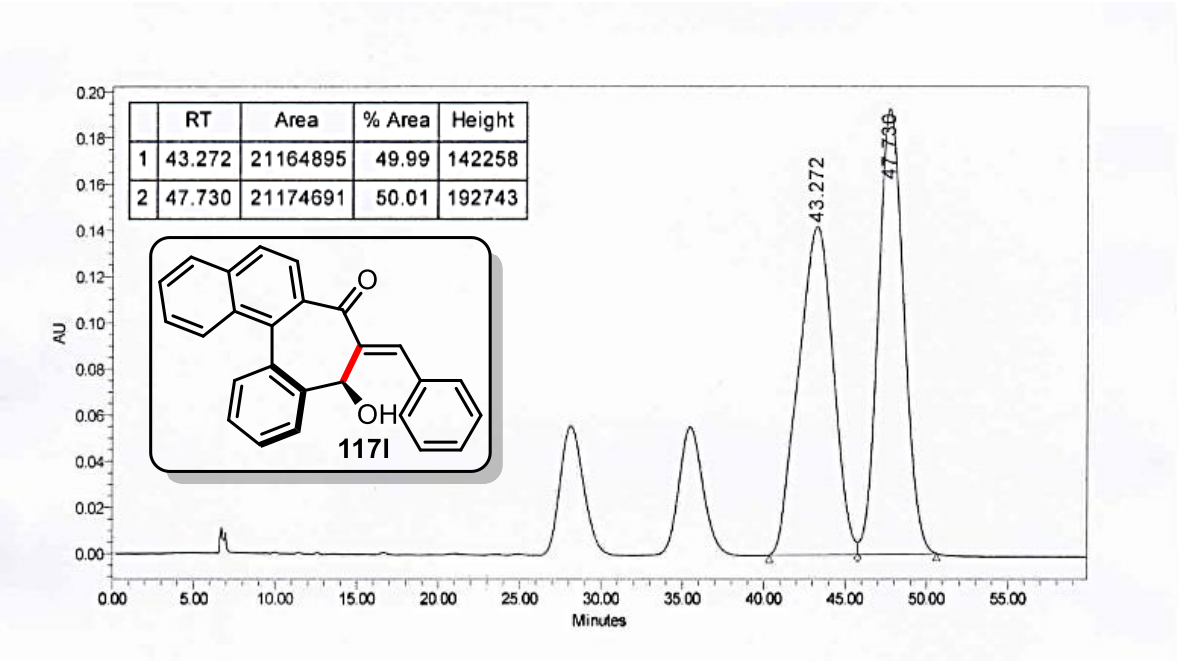



**Figure 37:** HPLC chromatogram of racemic **117l**.

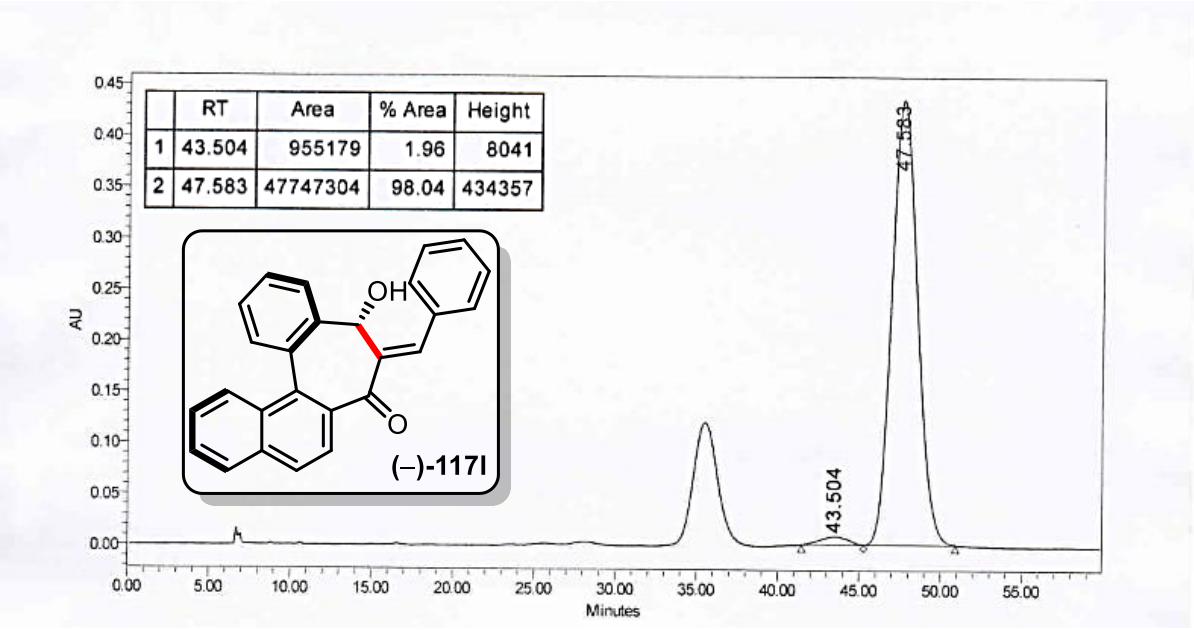



**Figure 38:** HPLC chromatogram of chiral (–)-**117l**.

In conclusion, we have developed first metal-free and organocatalytic approach for the synthesis of dibenzo-fused cycloheptenones. Our efforts towards the development of an asymmetric IMBH reaction for the synthesis of chiral dibenzocycloheptanes were unsuccessful leading to the formation of only kinetically resolved product. Indeed, we could achieve the synthesis of chiral dibenzocycloheptanes *via* a diastereoselective IMBH reaction of axially chiral birayl enone-aldehydes. To our delight, a new annulation strategy to access chiral dibenzocycloheptanes is developed, which is complementary to the known chiral approach. Some of the salient features of this work are: (i) general and broadly applicable, (ii) highly functionalized products that are amenable for further synthetic transformations, (iii) mechanistically straightforward, especially given the MBH reaction is well-established, (iv) simple and practical reaction conditions.

## Conclusions

In conclusion, we demonstrate the first phosphine-catalyzed IVAR of *α*-substituted enones to access various pentannulated (hetero)arenes and dibenzocycloheptanones consisting of two contiguous stereocenters, one of which is an all-carbon quaternary center in good yields and moderate diastereoselectivities. The scope of this work was further extended through elaborations of the IVAR adducts to (i) benzannulated nine-membered carbocyclic systems, (ii) interesting classes of 1,3-dienes, 1,3,5- trienes, and 1-yn-3,5-dienes, and (iii) the analogs of echinolactone D and russujaponol F.

Next, we presented the details of an organophosphine catalyzed MBH-type reaction of activated alkynes. The outcome is an intramolecular hydroacylation of *α*,*β*-ynones to access densely functionalized 1,3-cyclopenta-, cyclohepta-, and cyclooctadione-fused arenes and heteroarenes in good yields. In addition, a phosphine-catalyzed intramolecular aldol reaction of ketoynones *via* *δ′*[C($sp^3$)-*H*]-functionalization was described, and a new annulation event involving a *ω′*[C($sp^3$)-*H*]-functionalization of *α*,*β*-ynones was also discovered. The mechanisms governing these processes have been thoroughly elucidated.

Continued research interest in developing new phosphine-catalyzed strategies led us to develop the first annulative Morita–Baylis–Hillman (MBH) reaction of biaryl enone-aldehydes for the synthesis of highly functionalized dibenzocycloheptanes. Our work towards developing a catalytic enantioselective variant resulted only in kinetically resolved products. Eventually, we synthesized chiral dibenzocycloheptanones by employing the diastereoselective IMBH reaction of chiral biaryl enone-aldehydes in good yield and excellent enantioselectivity.

## Experimental Section

**General experimental methods**: All the reagents, solvents and catalysts employed in this study were procured from Sigma-Aldrich and were used without further purification. For thin-layer chromatography (TLC), silica aluminum foils with fluorescent indicator 254 nm (from Aldrich) were used, and compounds were visualized by irradiation with UV light and/or by treatment with a solution of *p*-anisaldehyde (23 mL), conc. $H_2SO_4$ (35 mL), and acetic acid (10 mL) in ethanol (900 mL) followed by heating. Column chromatography was performed using SD Fine silica gel 60-120 mesh (approximately 15–20 g per 1 g of the crude product). Dry THF was obtained by distillation over sodium and stored over sodium wire. IR spectra were recorded on a Perkin–Elmer FT IR spectrometer as thin films or KBr pellets, as indicated, with $\nu_{max}$ in inverse centimeters. Melting points were recorded on a digital melting point apparatus Stuart SMP30. $^{1}H$ NMR and $^{13}C$ NMR spectra were recorded on a 400 MHz Bruker Biospin Avance III FT-NMR spectrometer. NMR shifts are reported as delta (δ) units in parts per million (ppm) and coupling constants (*J*) are reported in Hertz (Hz). The following abbreviations are utilized to describe peak patterns when appropriate: br=broad, s=singlet, d=doublet, t=triplet, q=quartet and m=multiplet. Proton chemical shifts are given in δ relative to tetramethylsilane (δ 0.00 ppm) in $CDCl_3$ or in $(CD_3)_2SO$ (δ 2.50 ppm) or in $(CD_3)_2CO$ (δ 2.05 ppm). Carbon chemical shifts are internally referenced to the deuterated solvent signals in $CDCl_3$ (δ 77.1 ppm) or in $(CD_3)_2SO$ (δ 39.5 ppm) or in $(CD_3)_2CO$ at δ 29.9 and 206.7. Single crystal X-ray analysis was carried on a Rigaku XtaLAB mini X-ray diffractometer. High resolution mass spectra were recorded on a Waters QTOF mass spectrometer. Optical rotations were recorded on Rudolph APIII/2W instrument. HPLC data was acquired from a Waters machine (model no 515).

### General procedure-1: Synthesis of enone-aldehydes (3a-p and 3s).

**Step-I:** An oven dried 25 mL RB flask was charged with 2- bromobenzaldehydes **9** (1 mmol) in toluene, and ethylene glycol (1.2 mmol) and *p*-TSA (0.1 mmol) were added and the mixture was refluxed at 150 $^{o}C$ by connecting to a Dean-Stark set-up. The reaction continued until **9** disappeared (as monitored by TLC). The reaction mixture was cooled to room temperature and quenched by the addition of triethyl amine. Majority of the volatile components were removed under reduced pressure and the residue was extracted with ethyl acetate (2x3 mL). The organic extracts were combined, dried over anhydrous sodium sulphate and concentrated under reduced pressure. The crude product was purified by silica gel column

chromatography using hexanes/ethyl acetate (9:1) as eluent to afford 2-bromoacetals **10** in 85-90%.

**Step-II:** To a solution of **10** (1.0 mmol) was dissolved in anhydrous THF (5 mL) at –78 $^{o}$C and added *n*-BuLi (1.6 M in hexane, 1.2 mmol). After 45 min, a suitable enone-aldehyde **11** (1.0 mmol) was added at the same temperature and the reaction mixture was stirred for an additional 30 min. The mixture was warmed to room temperature over 30 min. The reaction progress was monitored by TLC. Reaction mixture was quenched with saturated aqueous ammonium chloride solution and extracted with ethyl acetate. The organic extracts were combined, dried over anhydrous sodium sulphate and concentrated. The crude product was purified by silica gel column chromatography using hexane/ethyl acetate (9:1) as eluent to afford the alcohol **12** in 72-85% yield.

**Step-III:** Compound **12** (1.0 mmol) was dissolved in ethyl acetate (10 mL), and IBX (2.2 mmol) was introduced. The resulting reaction mixture was immersed in an oil bath and stirred at 75 °C until compound **12** disappeared as monitored by TLC. The reaction was cooled to room temperature and filtered through Buchner funnel. The filter cake was washed with ethyl acetate (3x2 mL). Organic extracts were combined and worked up using saturated sodium bicarbonate solution to remove excess iodobenzoic acid. The extract was dried over anhydrous sodium sulphate and concentrated under reduced vacuum. The residue was purified by silica gel column chromatography using hexane/ethyl acetate (5:1) as eluent to afford the compound **13** in 65-70% yield.

**Step-IV:** Compound **13** (1.0 mmol) was dissolved in acetone (5 mL) and *p*-TSA (0.1 mmol) was added and stirred at rt until **13** disappeared as monitored by TLC. The reaction mixture was quenched with saturated aqueous sodium bicarbonate solution and extracted with ethyl acetate. The organic extracts were combined, dried over anhydrous sodium sulphate and concentrated. The crude product was purified by silica gel column chromatography using hexane/ethyl acetate (9:1) as eluent to afford compound **3a-p** and **3s** in 85-90% yield.

**General procedure-2: Synthesis of chromene and naphthalene based enone-aldehydes (3q-r).**

**Step-I:** An oven dried 25 mL RB flask was charged with 2-bromo aldehydes **14** (1.0 mmol), 10 mL dry MeOH and placed at 0 $^{o}$C. Sodium borohydride (2.2 mmol) was added portion wise under nitrogen atmosphere and stirred at room temperature until **14** disappeared (monitored by TLC) and quenched by saturated aqueous ammonium chloride. Methanol was

removed under vacuum and extracted using ethyl acetate. All the volatiles were removed under reduced pressure. The crude product was directly purified by silica gel chromatography using hexane/ethyl acetate (5:1) as eluent, to afford **15** in 90-94% yields.

**Step-II:** The compounds **15** under *n*-BuLi mediated alkylation using suitable enal **16** following the general procedure 1, step II to afford diol **17**.

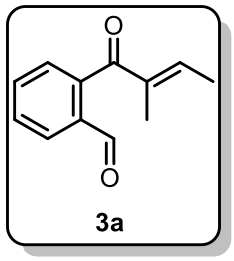
**Step-III:** The diol **17** were oxidized using IBX following the general procedure 1, step III to afford enone-aldehydes **3q-r**.

### General procedure-3: Synthesis of furan based enone-aldehydes (3t).

**Step-I:** An oven dried 25 mL long neck RB flask was charged with a solution of *N*-methylpiperazine (NMP, 1.0 mmol) in THF (5 mL) at −78 °C was added *n*-BuLi (1.6 *M* in hexane, 1.0 mmol). After 15 min, thiophene-3-carboxaldehyde **18** (1.2 mmol) was added and then the reaction mixture was stirred for an additional 30 min. A hexane solution of *n*-BuLi (2.0 mmol) was added and the mixture was stirred for an additional 15 min and then the mixture was warmed to −30 °C in 2 h. The solution was again cooled to −78 °C and tiglic aldehyde (1.5 mmol) was added drop wise over 5 min. The mixture was warmed to room temperature over 30 min. The reaction progress was monitored by TLC. Reaction mixture was quenched with saturated aqueous ammonium chloride solution and extracted with ethyl acetate. The organic extracts were combined, dried over anhydrous sodium sulphate and concentrated. The crude product was purified by silica gel column chromatography using hexane/ethyl acetate (9:1) as eluent to afford the enol-aldehyde **19** in 65% yield.

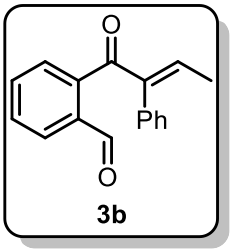
**Step-II:** The enol-aldehyde **19** were oxidized using IBX following the general procedure 1, step III to afford enone-aldehydes **3t**.

### 2-(2-Methylbut-2-enoyl)benzaldehyde (3a).



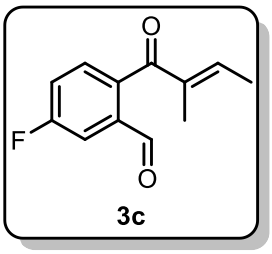

This compound was prepared by following the general procedure-1 and isolated as colorless oil; 200 mg of **13** ($R^1$ = Me, $R^3$ = H) afforded 139 mg of **3a** (86% yield). $R_f$ = 0.5 (hexane/EtOAc = 10/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 2973, 1773, 1700, 1647, 1570, 978, 749. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 9.93 (s, 1H), 7.93 (dd, *J* = 7.2 and 1.1 Hz, 1H), 7.63-7.55 (m, 2H), 7.35-7.33 (m, 1H), 6.25-6.20 (m, 1H), 1.99 (s, 3H), 1.83 (d, *J* = 6.9 Hz, 3H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 198.6, 190.6, 144.5, 142.5, 140.0, 134.6, 133.2, 129.9, 129.6, 128.2, 15.1, 11.0. **HRMS (ESI):** *m/z* calcd for $C_{12}H_{11}O_2$ $(M–H)^+$: 187.0759. Found: 187.0772.

### 2-(2-Phenylbut-2-enoyl)benzaldehyde (3b).



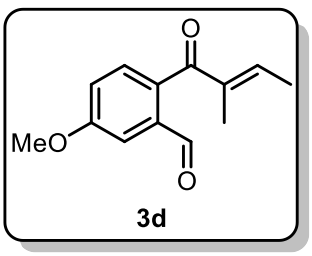

This compound was prepared by following the general procedure-1 and isolated as pale-yellow oil; 200 mg of **13** ($R^1$ = Ph, $R^3$ = H) afforded 153 mg of **3b** (90% yield). $R_f$ = 0.5 (hexane/EtOAc = 10/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 2925, 1699, 1660, 1596, 1244, 748. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 10.0 (s, 1H), 7.93 (d, *J* = 7.5 Hz, 1H), 7.66-7.57 (m, 2H), 7.49-7.42 (m, 3H), 7.36-7.35 (m, 3H), 6.54 (q, *J* = 6.2 Hz, 1H), 1.78 (d, *J* = 7.0 Hz, 3H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 197.4, 190.9, 145.0, 144.8, 142.1, 134.7, 134.5, 133.5, 131.0, 129.99, 129.94 (2C), 128.39, 128.2 (2C), 127.7, 16.1. **HRMS (ESI):** *m/z* calcd for $C_{17}H_{15}O_2$ $(M+H)^+$: 251.1072. Found: 251.1053.

### 5-Fluoro-2-(2-methylbut-2-enoyl)benzaldehyde (3c).




This compound was prepared by following the general procedure-1 and isolated as pale-yellow oil; 200 mg of **13** ($R^1$ = Me, $R^3$ = H) afforded 148 mg of **3c** (90% yield). $R_f$ = 0.5 (hexane/EtOAc = 10/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 3062, 2926, 1701, 1641, 1603, 1490, 1268, 979. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 9.90 (s, 1H), 7.63 (d, *J* = 9.7 Hz, 1H), 7.42-7.39 (m, 1H), 7.33-7.28 (m, 1H), 6.31-6.26 (m, 1H), 1.99 (s, 3H), 1.86 (d, *J* = 7.0 Hz, 3H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 197.2, 189.2 (d, *J* = 1.3 Hz, 1C), 163.2 (d, *J* = 250.8 Hz, 1C), 145.2, 140.0, 138.7 (d, *J* = 3.5 Hz, 1C), 137.2 (d, *J* = 6.4 Hz, 1C), 130.8 (d, *J* = 7.7 Hz, 1C), 120.1 (d, *J* = 22.4 Hz, 1C), 115.6 (d, *J* = 22.4 Hz, 1C), 15.1, 11.1. **$^{19}$F NMR (376.4 MHz, $CDCl_3$):** δ –109.0. **HRMS (ESI):** *m/z* calcd for $C_{12}H_{12}O_2F$ $(M+H)^+$: 207.0821. Found: 207.0813.

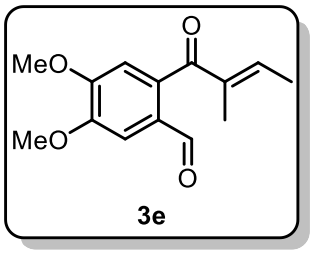
### 5-Methoxy-2-(2-methylbut-2-enoyl)benzaldehyde (3d).




This compound was prepared by following the general procedure-1 and isolated as pale-yellow oil; 200 mg of **13** ($R^1$ = Me, $R^3$ = H) afforded 148 mg of **3d** (89% yield). $R_f$ = 0.3 (hexane/EtOAc = 5/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 2842, 1776, 1696, 1636, 1492, 749. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 9.93 (s, 1H), 7.43 (d, *J* = 2.6 Hz, 1H), 7.35 (d, *J* = 8.4 Hz, 1H), 7.09 (dd, *J* = 8.4 and 2.6 Hz, 1H), 6.33-6.27 (m, 1H), 3.88 (s, 3H), 1.97 (s, 3H), 1.84 (dd, *J* = 6.9 and 0.92 Hz, 3H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 197.9,

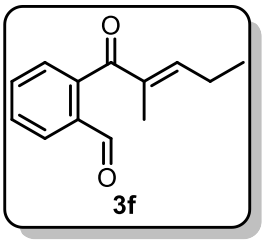
190.5, 160.8, 144.2, 140.1, 137.0, 135.2, 130.7, 119.4, 112.3, 55.7, 15.1, 11.4. **HRMS (ESI):** *m/z* calcd for $C_{13}H_{15}O_3$ $(M+H)^+$: 219.1021. Found: 219.1041.

### 4,5-Dimethoxy-2-(2-methylbut-2-enoyl)benzaldehyde (3e).



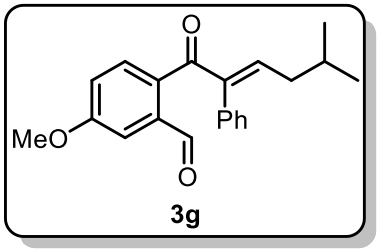

This compound was prepared by following the general procedure-1 and isolated pale-brown oil; 200 mg of **13** ($R^1$ = Me, $R^2$ = H) afforded 151 mg of **3e** (75% yield). $R_f$ = 0.3 (hexane/EtOAc = 5/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 2974, 1754, 1682, 1635, 1022, 784. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 9.80 (s, 1H), 7.44 (s, 1H), 6.83 (s, 1H), 6.34-6.29 (m, 1H), 3.96 (s, 3H), 3.94 (s, 3H), 1.98 (s, 3H), 1.85 (dd, *J* = 6.9 and 0.9 Hz, 3H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 197.9, 189.0, 153.0, 150.0, 145.2, 140.6, 137.8, 128.4, 110.6, 109.5, 56.3, 56.2, 15.2, 11.2. **HRMS (ESI):** *m/z* calcd for $C_{14}H_{17}O_4$ $(M+H)^+$: 249.1127. Found: 249.1109.

### 2-(2-Methylpent-2-enoyl)benzaldehyde (3f).




This compound was prepared by following the general procedure-1 and isolated as colorless oil; 200 mg of **13** ($R^1$ = Me, $R^3$ = Me) afforded 139 mg of **3f** (85% yield). $R_f$ = 0.5 (hexane/EtOAc = 10/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 2961, 1701, 1593, 1570, 1285, 748. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 9.90 (s, 1H), 7.89 (d, *J* = 7.4 Hz, 1H), 7.60-7.52 (m, 2H), 7.32 (d, *J* = 7.2 Hz, 1H), 6.07 (t, *J* = 7.2 Hz, 1H), 2.23-2.16 (m, 2H), 1.94 (s, 3H), 0.91 (t, *J* = 7.6 Hz, 3H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 198.8, 190.6, 151.0, 142.4, 138.3, 134.7, 133.2, 129.9, 129.7, 128.3, 22.6, 12.7, 11.2. **HRMS (ESI):** *m/z* calcd for $C_{13}H_{13}O_2$ $(M-H)^+$: 201.0915. Found: 201.0909.

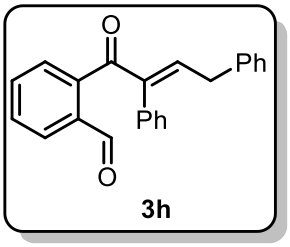
### 5-Methoxy-2-(5-methyl-2-phenylhex-2-enoyl)benzaldehyde (3g).




This compound was prepared by following the general procedure-1 and isolated as pale-yellow oil; 100 mg of **13** ($R^1$ = Ph, $R^3$ = $Me_2CH$) afforded 74 mg of **3g** (85% yield). $R_f$ = 0.3 (hexane/EtOAc = 5/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 2958, 1777, 1700, 1654, 1600, 1025, 748. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 10.12 (s, 1H), 7.51 (d, *J* = 8.4 Hz, 1H), 7.45 (d, *J* = 2.6 Hz, 1H), 7.42-7.39 (m, 2H), 7.35-7.34 (m, 1H), 7.26-7.24 (m, 2H), 7.13 (dd, *J* = 8.4 and 2.6 Hz, 1H), 6.49 (t, *J* = 7.5 Hz,

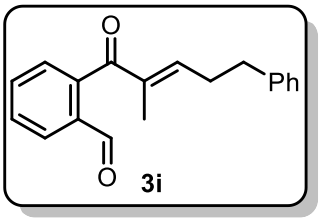
1H), 3.91 (s, 3H), 2.09 (t, *J* = 7.2 Hz, 2H), 1.69-1.64 (m, 1H), 0.84 (s, 3H), 0.82 (s, 3H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 196.5, 190.6, 161.1, 148.3, 144.4, 137.5, 135.2, 134.9, 131.0, 129.7 (2C), 128.2 (2C), 127.6, 119.2, 113.1, 55.7, 38.7, 28.5, 22.4 (2C). **HRMS (ESI):** *m/z* calcd for $C_{21}H_{23}O_3$ $(M+H)^+$: 323.1642. Found: 323.1628.

### 2-(2,4-Diphenylbut-2-enoyl)benzaldehyde (3h).



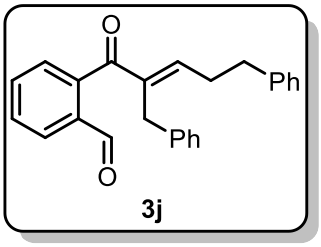

This compound was prepared by following the general procedure-1 and isolated as pale-yellow oil; 80 mg of **13** ($R^1$ = Ph, $R^3$ = Ph) afforded 60 mg of **3h** (85% yield). $R_f$ = 0.5 (hexane/EtOAc = 10/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 3058, 1695, 1597, 1449, 1283, 753. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 10.0 (s, 1H), 7.88-7.86 (m, 1H), 7.63-7.54 (m, 2H), 7.47-7.36 (m, 6H), 7.26-7.22 (m, 2H), 7.19-7.17 (m, 1H), 7.02-6.99 (m, 2H), 6.50 (t, *J* = 7.6 Hz, 1H), 3.47 (d, *J* = 7.6 Hz, 2H). **HRMS (ESI):** *m/z* calcd for $C_{23}H_{17}O_2$ $(M-H)^+$: 325.1229. Found: 325.1225.

### 2-(2-Methyl-5-phenylpent-2-enoyl)benzaldehyde (3i).




This compound was prepared by following the general procedure-1 and isolated as pale-yellow oil; 100 mg of **13** ($R^1$ = Me, $R^3$ = $CH_2Ph$) afforded 77 mg of **3i** (89% yield). $R_f$ = 0.5 (hexane/EtOAc = 10/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 2927, 1775, 1700, 1656, 1600, 1203, 750. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 9.90 (s, 1H), 7.93-7.91 (m, 1H), 7.60-7.57 (m, 2H), 7.28-7.23 (m, 3H), 7.20-7.18 (m, 1H), 7.08-7.06 (m, 2H), 6.12-6.09 (m, 1H), 2.68-2.64 (m, 2H), 2.58-2.52 (m, 2H), 1.93 (s, 3H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 198.7, 190.5, 148.1, 142.4, 140.6, 139.4, 134.7, 133.2, 130.0, 129.7, 128.4 (2C), 128.3 (3C), 126.2, 34.4, 31.0, 11.3. **HRMS (ESI):** *m/z* calcd for $C_{19}H_{19}O_2$ $(M+H)^+$: 279.1385. Found: 279.1364.

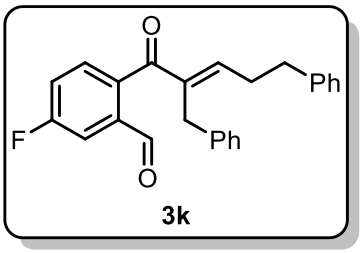
### 2-(2-Benzyl-5-phenylpent-2-enoyl)benzaldehyde (3j).




This compound was prepared by following the general procedure-1 and isolated as pale-yellow oil; 100 mg of **13** ($R^1$ = $CH_2Ph$, $R^3$ = $CH_2Ph$) afforded 75 mg of **3j** (85% yield). $R_f$ = 0.5 (hexane/EtOAc = 10/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 3028, 2928, 1701, 1647, 1598, 1202, 745. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 9.85 (s, 1H), 7.92-

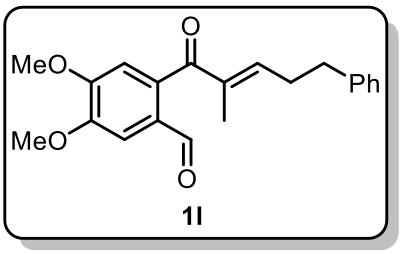
7.90 (m, 1H), 7.56-7.54 (m, 2H), 7.27-7.21 (m, 5H), 7.19-7.16 (m, 4H), 7.02-7.00 (m, 2H), 6.30-6.26 (m, 1H), 3.81 (s, 2H), 2.63-2.61 (m, 4H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 197.9, 190.3, 149.9, 142.4, 142.3, 140.5, 139.3, 134.9, 133.1, 129.9, 129.6, 128.5 (4C), 128.44 (2C), 128.4 (3C), 126.3, 126.1, 34.4, 31.44, 31.4. **HRMS (ESI):** *m/z* calcd for $C_{25}H_{23}O_2$ $(M+H)^+$: 355.1698. Found: 355.1681.

### 2-(2-Benzyl-5-phenylpent-2-enoyl)-5-fluorobenzaldehyde (3k).



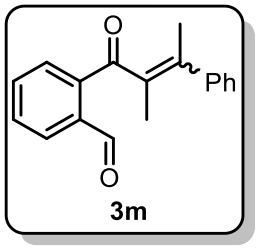

This compound was prepared by following the general procedure-1 and isolated as pale-yellow oil; 100 mg of **13** ($R^1$ = $CH_2Ph$, $R^3$ = $CH_2Ph$) afforded 77 mg of **3k** (86% yield). $R_f$ = 0.5 (hexane/EtOAc = 10/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 3028, 1697, 1653, 1601, 1415, 742. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 9.83 (d, *J* = 2.4 Hz, 1H), 7.64 (dd, *J* = 8.4 and 2.1 Hz, 1H), 7.31-7.28 (m, 4H), 7.27-7.23 (m, 4H), 7.17-7.15 (m, 2H), 7.08-7.06 (m, 2H), 6.34-6.30 (m, 1H), 3.83 (s, 2H), 2.72-2.71 (m, 4H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 196.5, 189.1, 163.3 (d, *J* = 250.0 Hz, 1C), 149.9, 142.4, 140.3, 139.0, 138.4 (d, *J* = 3.5 Hz, 1C), 137.6 (d, *J* = 6.3 Hz, 1C), 131.0 (d, *J* = 7.5 Hz, 1C), 128.61 (2C), 128.6 (3C), 128.3 (4C), 126.3 (d, *J* = 14.8 Hz, 1C), 119.9 (d, *J* = 21.9 Hz, 1C), 115.4 (d, *J* = 22.4 Hz, 1C), 34.4, 31.5, 31.3. **$^{19}$F NMR (376.4 MHz, $CDCl_3$):** δ –108.3. **HRMS (ESI):** *m/z* calcd for $C_{25}H_{21}O_2FNa$ $(M+Na)^+$: 396.1457. Found: 396.1424.

### 4,5-Dimethoxy-2-(2-methyl-5-phenylpent-2-enoyl)benzaldehyde (3l).



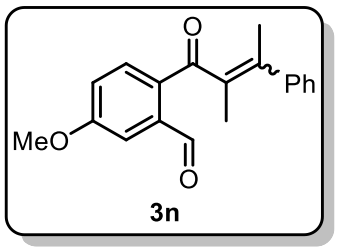

This compound was prepared by following the general procedure-1 and isolated as pale-yellow oil; 200 mg of **13** ($R^1$ = Me, $R^2$ = $CH_2Ph$) afforded 193 mg of **3l** (70% yield). $R_f$ = 0.3 (hexane/EtOAc = 5/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 2937, 1762, 1685, 1636, 1589, 1019, 749. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 9.80 (s, 1H), 7.47 (s, 1H), 7.29-7.28 (m, 2H), 7.22-7.21 (m, 1H), 7.12-7.10 (m, 2H), 6.78 (s, 1H), 6.26-6.22 (m, 1H), 4.00 (s, 3H), 3.91 (s, 3H), 2.73-2.70 (m, 2H), 2.63-2.57 (m, 2H), 1.96 (d, *J* = 1.1 Hz, 3H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 197.9, 189.0, 152.9, 150.0, 148.9, 140.5, 139.9, 137.6, 128.5 (3C), 128.2 (2C), 126.3, 110.6, 109.6, 56.3, 56.2, 34.3, 31.0, 11.5. **HRMS (ESI):** *m/z* calcd for $C_{21}H_{22}O_4$ $(M+Na)^+$: 361.1415. Found: 361.1433.

### 2-(2-Methyl-3-phenylbut-2-enoyl)benzaldehyde (3m).



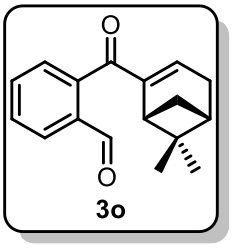

This compound was prepared by following the general procedure-1 and isolated as pale-yellow oil; 100 mg of **13** ($R^1$ = Me, $R^2$ = Ph, $R^3$ = H) afforded 73 mg of **3m** (85% yield). $R_f$ = 0.5 (hexane/EtOAc = 5/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 2916, 1765, 1696, 1593, 1376, 1072, 750. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 10.05 (s, 1H), 7.59-7.57 (m, 1H), 7.37-7.34 (m, 1H), 7.30-7.28 (m, 2H), 7.00-6.95 (m, 3H), 6.93-6.90 (m, 2H), 2.23 (s, 6H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 201.0, 191.6, 145.2, 142.8, 142.7, 135.1, 134.7, 132.0, 130.7, 128.8, 128.2 (2C), 128.0 (2C), 127.7, 127.6, 21.9, 17.5. **HRMS (ESI):** *m/z* calcd for $C_{18}H_{16}O_2Na$ $(M+Na)^+$: 287.1048. Found: 287.1028.

### 5-Methoxy-2-(2-methyl-3-phenylbut-2-enoyl)benzaldehyde (3n).




This compound was prepared by following the general procedure-1 and isolated as pale-yellow oil; 100 mg of **13** ($R^1$ = Me, $R^2$ = Ph, $R^3$ = H) afforded 76 mg of **3n** (87% yield). $R_f$ = 0.5 (hexane/EtOAc = 5/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 2823, 1697, 1597, 1494, 1028, 764. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 10.47 (s, 1H), 7.84 (d, *J* = 8.5 Hz, 1H), 7.45-7.39 (m, 4H), 7.07 (d, *J* = 2.6 Hz, 1H), 6.98-6.96 (m, 2H), 3.92 (s, 3H), 2.19 (s, 3H), 1.94 (s, 3H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 200.3, 192.1, 162.8, 143.0, 142.1, 140.2, 138.0, 134.8, 132.8, 131.6, 128.4 (2C), 127.5 (2C), 118.7, 112.9, 55.8, 22.8, 18.3. **HRMS (ESI):** *m/z* calcd for $C_{19}H_{18}O_3Na$ $(M+Na)^+$: 317.1154. Found: 317.1154.

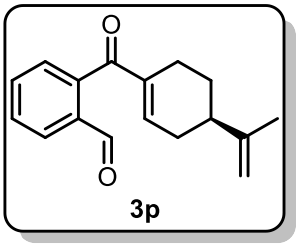
### 2-((1*R*,5*S*)-6,6-Dimethylbicyclo[3.1.1]hept-2-ene-2-carbonyl)benzaldehyde (1p).




This compound was prepared by following the general procedure-1 and isolated as pale-yellow oil; 200 mg of **13** (6,6-Dimethylbicyclo[3.1.1]hept-2-ene) afforded 146 mg of **3o** (86% yield). $R_f$ = 0.5 (hexane/EtOAc = 10/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 2978, 1772, 1700, 1648, 1369, 749. **Optical rotation:** $[\alpha]_D^{25}$ –62.3 (*c* 0.1, $CH_2Cl_2$). **$^1$H NMR (400 MHz, $CDCl_3$):** δ 9.99 (s, 1H), 7.96 (d, *J* = 8.8 Hz, 1H), 7.65-7.57 (m, 2H), 7.42 (d, *J* = 8.6 Hz, 1H), 6.27-6.25 (m, 1H), 3.17 (t, *J* = 5.4 Hz, 1H), 2.59-2.54 (m, 1H), 2.47-2.43 (m, 2H), 2.17 (brs, 1H), 1.39 (s, 3H), 1.16 (d, *J* = 9.2 Hz, 1H), 0.83 (s, 3H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 195.2, 190.5,

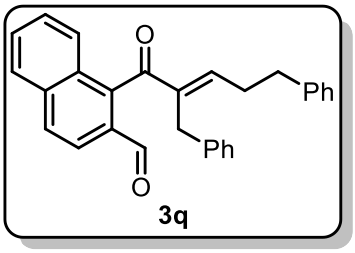
150.7, 143.7, 142.2, 134.8, 133.1, 129.8, 129.4, 128.3, 40.2, 39.8, 37.6, 32.9, 31.1, 25.7, 20.9. **HRMS (ESI):** *m/z* calcd for $C_{17}H_{19}O_2$ $(M+H)^+$: 255.1385. Found: 255.1376.

### (*S*)-2-(4-(Prop-1-en-2-yl)cyclohex-1-ene-1-carbonyl)benzaldehyde (3p).




This compound was prepared by following the general procedure-1 and isolated as pale-yellow oil; 200 mg of **13** (4-(Prop-1-en-2-yl)cyclohex-1-ene) afforded 153 mg of **3p** (90% yield). $R_f$ = 0.5 (hexane/EtOAc = 10/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 2965, 1773, 1700, 1642, 823, 749. **Optical rotation:** $[\alpha]_D^{25}$ –91.4 (*c* 0.1, $CH_2Cl_2$). **$^1$H NMR (400 MHz, $CDCl_3$):** δ 9.95 (s, 1H), 7.94-7.92 (m, 1H), 7.64-7.56 (m, 2H), 7.38-7.36 (m, 1H), 6.39-6.38 (m, 1H), 4.76 (brs, 1H), 4.71 (brs, 1H), 2.76-2.71 (m, 1H), 2.42-2.08 (m, 4H), 2.00-1.94 (m, 1H), 1.74 (s, 3H), 1.57-1.47 (m, 1H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 197.7, 190.6, 148.5, 145.9, 142.3, 140.6, 134.7, 133.3, 129.9, 129.8, 128.2, 109.4, 40.1, 31.6, 26.7, 23.4, 20.6. **HRMS (ESI):** *m/z* calcd for $C_{17}H_{19}O_2$ $(M+H)^+$: 255.1385. Found: 255.1387.

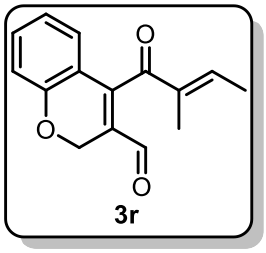
### 1-(2-Benzyl-5-phenylpent-2-enoyl)-2-naphthaldehyde (3q).




This compound was prepared by following the general procedure-2 and isolated as pale-yellow oil; 100 mg of **17** ($R^1$ = $CH_2Ph$, $R^2$ = $CH_2Ph$) afforded 77 mg of **3q** (78% yield). $R_f$ = 0.5 (hexane/EtOAc = 10/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 3028, 2929, 1694, 1661, 1598, 1197, 744. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 9.92 (s, 1H), 7.99 (s, 2H), 7.94 (d, *J* = 8.2 Hz, 1H), 7.67-7.63 (m, 1H), 7.51-7.45 (m, 2H), 7.36-7.33 (m, 2H), 7.29-7.27 (m, 3H), 7.19-7.17 (m, 3H), 6.90-6.87 (m, 2H), 7.31 (t, *J* = 7.0 Hz, 1H), 3.93 (s, 2H), 2.69-2.64 (m, 2H), 2.58-2.55 (m, 2H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 199.1, 190.1, 151.4, 143.7, 143.4, 140.1, 139.1, 135.9, 130.7, 130.5, 129.4, 129.1, 128.6 (6C), 128.4, 128.3, 128.2, 127.6, 126.7, 126.3, 126.2, 122.9, 34.3, 31.7, 31.1. **HRMS (ESI):** *m/z* calcd for $C_{29}H_{25}O_2$ $(M+H)^+$: 405.1855. Found: 405.1841.

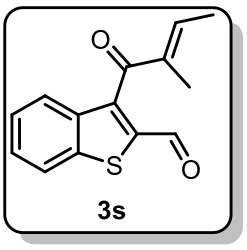
### 4-(2-Methylbut-2-enoyl)-2*H*-chromene-3-carbaldehyde (3r).

This compound was prepared by following the general procedure-2 and isolated as pale-yellow oil; 100 mg of **17** ($R^1$ = Me, $R^2$ = H) afforded 59 mg of **3r** (60% yield). $R_f$ = 0.5 (hexane/EtOAc = 5/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 2928, 1718, 1665, 1602, 1482, 769. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 9.51 (s, 1H), 7.33-7.28 (m, 1H), 6.97-6.89 (m, 3H), 6.81-6.76 (m, 1H), 5.00 (brs,



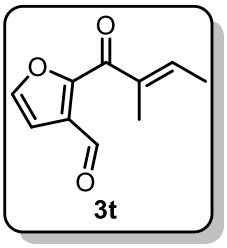

2H), 1.96 (s, 3H), 1.89 (d, *J* = 6.9 Hz, 3H). **$^{13}$C NMR (100 MHz, CDCl$_3$):** δ 196.0, 187.6, 155.5, 149.8, 147.8, 139.9, 133.5, 127.0, 126.9, 122.2, 120.1, 117.1, 62.3, 15.5, 10.2. **HRMS (ESI):** *m/z* calcd for $C_{15}H_{13}O_3$ $(M-H)^+$: 241.0865. Found: 241.0878.

### 3-(2-Methylbut-2-enoyl)benzo[*b*]thiophene-2-carbaldehyde (3s).




This compound was prepared by following the general procedure-1 and isolated as pale-brown oil; 100 mg of **13** afforded 75 mg of **3s** (89% yield). $R_f$ = 0.5 (hexane/EtOAc = 5/1). **IR (thin film, neat):** $\nu_{max}$/cm$^{-1}$ 3057, 2925, 1673, 1513, 1203, 1104, 735. **$^1$H NMR (400 MHz, CDCl$_3$):** δ 9.97 (s, 1H), 7.90 (d, *J* = 8.2 Hz, 1H), 7.74 (d, *J* = 8.2 Hz, 1H), 7.51 (t, *J* = 7.4 Hz, 1H), 7.42 (t, *J* = 7.6 Hz, 1H), 6.56 (q, *J* = 7.0 Hz, 1H), 2.08 (s, 3H), 1.89 (d, *J* = 6.9 Hz, 3H). **$^{13}$C NMR (100 MHz, CDCl$_3$):** δ 193.4, 183.9, 147.3, 144.6, 141.49, 141.42, 141.0, 138.1, 128.5, 125.7, 125.4, 123.1, 15.4, 11.0. **HRMS (ESI):** *m/z* calcd for $C_{14}H_{11}O_2S$ $(M-H)^+$: 243.0480. Found: 243.0494.

### 2-(2-Methylbut-2-enoyl)furan-3-carbaldehyde (3t).

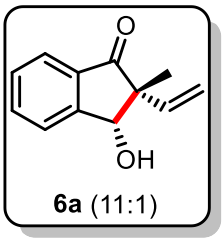



This compound was prepared by following the general procedure-3 and isolated as pale-yellow oil; 100 mg of **19** afforded 64 mg of **3t** (65% yield). $R_f$ = 0.5 (hexane/EtOAc = 5/1). **IR (thin film, neat):** $\nu_{max}$/cm$^{-1}$ 3113, 2929, 1684, 1628, 1570, 785, 761. **$^1$H NMR (400 MHz, CDCl$_3$):** δ 10.28 (s, 1H), 7.45 (s, 1H), 6.89-6.85 (m, 2H), 1.91-1.89 (m, 6H). **$^{13}$C NMR (100 MHz, CDCl$_3$):** δ 187.0, 184.7, 155.4, 144.2, 143.2, 137.1, 130.9, 109.6, 15.1, 11.7. **HRMS (ESI):** *m/z* calcd for $C_{10}H_{11}O_3$ $(M+H)^+$: 179.0708. Found: 179.0699.

### General procedure-4: Synthesis of cyclopenta-fused arenes and heteroarenes *via* IVAR.

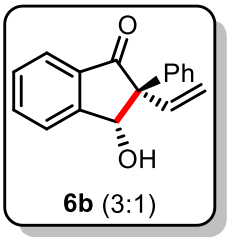
An oven-dried 5 mL glass vial was charged with **3** (1.0 eq, 0.1 mmol), DMF (1.0 mL), and tributylphosphine (0.2 eq, 0.02 mmol) at room temperature (or 60 $^o$C using a heating mantle) and stirred until **3** disappeared as monitored by TLC. Then the reaction mixture was quenched with aqueous $NH_4Cl$ (~1-2 mL) and extracted using ethyl acetate (2x3 mL). The organic extracts were combined and dried over anhydrous sodium sulfate and concentrated. The crude product was purified by silica gel column chromatography using hexane/ethyl acetate as an eluent to afford **6**.

### 3-Hydroxy-2-methyl-2-vinyl-2,3-dihydro-1*H*-inden-1-one (6a).



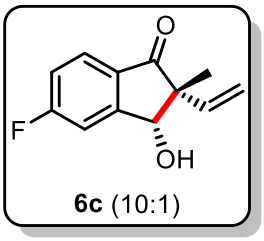

This compound was isolated as colorless viscous oil. Following the general procedure-4, 40 mg of **3a** afforded 36.4 mg of **6a** (91% yield). $R_f$ = 0.3 (hexane/EtOAc = 5/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 3432,2977, 1707, 1631, 1465, 797. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 7.77 (d, *J* = 3.8 Hz, 1H), 7.73-7.70 (m, 2H), 7.50-7.48 (m, 1H), 5.84-5.76 (m, 1H), 5.32 (d, *J* = 10.7 Hz, 1H), 5.25-5.23 (m, 1H), 4.97 (s, 1H), 2.37 (brs, 1H), 1.44 (s, 3H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 205.6, 152.7, 139.3, 135.5, 135.0, 129.5, 125.8, 123.9, 118.3, 78.2, 58.5, 19.5. **HRMS (ESI):** *m/z* calcd for $C_{12}H_{11}O_2$ $(M-H)^-$: 187.0759. Found: 187.0740.

### 3-Hydroxy-2-phenyl-2-vinyl-2,3-dihydro-1*H*-inden-1-one (6b).




This compound was isolated as pale-yellow viscous oil. Following the general procedure-4, 40 mg of **3b** afforded 36.0 mg of **6b** (90% yield). $R_f$ = 0.3 (hexane/EtOAc = 5/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 3427, 3025, 1714, 1604, 1495, 1186, 701. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 7.83 (d, *J* = 7.6 Hz, 1H), 7.73-7.71 (m, 2H), 7.53-7.49 (m, 1H), 7.44-7.43 (m, 2H), 7.35-7.31 (m, 2H), 7.27-7.26 (m, 1H), 6.24-6.17 (m, 1H), 5.53 (d, *J* = 7.9 Hz, 1H), 5.43 (d, *J* = 10.7 Hz, 1H), 5.14 (d, *J* = 17.6 Hz, 1H), 2.62 (d, *J* = 8.2 Hz, 1H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 202.1, 152.5, 140.5, 135.74, 135.70, 135.4, 129.6, 128.6 (2C), 127.7 (2C), 127.2, 125.6, 124.1, 120.5, 78.7, 66.2. **HRMS (ESI):** *m/z* calcd for $C_{17}H_{15}O_2$ $(M+H)^+$: 251.1072. Found: 251.1049.

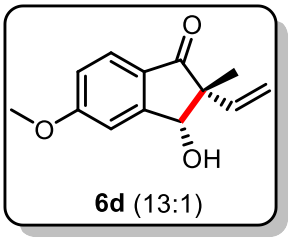
### 5-Fluoro-3-hydroxy-2-methyl-2-vinyl-2,3-dihydro-1*H*-inden-1-one (6c).




This compound was isolated as pale-yellow oil. Following the general procedure-4, 40 mg of **3c** afforded 32.0 mg of **6c** (80% yield). $R_f$ = 0.3 (hexane/EtOAc = 5/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 3432, 2972, 1709, 1605, 1097, 924, 763. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 7.79-7.76 (m, 1H), 7.36 (dd, *J* = 8.0 and 2.0 Hz, 1H), 7.17 (td, *J* = 8.6 and 2.0 Hz, 1H), 5.77 (m, 1H), 5.33 (d, *J* = 10.8 Hz, 1H), 5.21 (d, *J* = 17.5 Hz, 1H), 4.94 (s, 1H), 2.48 (brs, 1H), 1.44 (s, 3H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 202.8, 167.6 (d, *J* = 256.3 Hz, 1C), 155.8 (d, *J* = 9.3 Hz, 1C), 135.9, 131.2 (d, *J* = 1.6 Hz, 1C), 126.4 (d, *J* = 10.1 Hz, 1C), 118.5, 117.7 (d, *J* = 23.8 Hz, 1C), 112.6 (d, *J* = 22.5 Hz, 1C), 77.7 (d, *J* = 1.5 Hz, 1C), 58.9, 19.4. **$^{19}$F NMR**

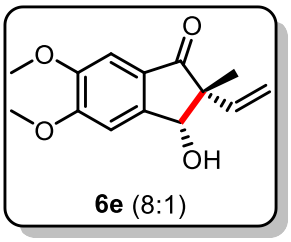
**(376.4 MHz, $CDCl_3$):** δ –100.8. **HRMS (ESI):** *m/z* calcd for $C_{12}H_{12}O_2F$ $(M+H)^+$: 207.0821. Found: 207.0814.

### 3-Hydroxy-5-methoxy-2-methyl-2-vinyl-2,3-dihydro-1*H*-inden-1-one (6d).



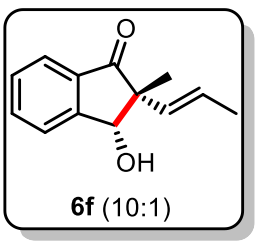

This compound was isolated as colorless solid. Following the general procedure-4, 40 mg of **3d** afforded 36.8 mg of **6d** (92% yield). $R_f$ = 0.3 (hexane/EtOAc = 5/1). M. P = 92-94 °C. **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 3411, 2974, 1700, 1598, 1369, 749. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 7.72 (d, *J* = 8.5 Hz, 1H), 7.16 (d, *J* = 2.1 Hz, 1H), 7.02 (dd, *J* = 8.5 and 2.2 Hz, 1H), 5.84-5.77 (m, 1H), 5.33 (d, *J* = 10.7 Hz, 1H), 5.22 (d, *J* = 17.6 Hz, 1H), 4.93 (d, *J* = 7.0 Hz, 1H), 3.92 (s, 3H), 2.43 (brs, 1H), 1.45 (s, 3H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 202.8, 166.0, 155.8, 136.5, 128.0, 125.7, 118.2, 117.7, 108.5, 78.1, 58.6, 55.8, 19.5. **HRMS (ESI):** *m/z* calcd for $C_{13}H_{15}O_3$ $(M+H)^+$: 219.1021. Found: 219.1013.

### 3-Hydroxy-5,6-dimethoxy-2-methyl-2-vinyl-2,3-dihydro-1*H*-inden-1-one (6e).




This compound was isolated as pale-yellow oil. Following the general procedure-4, 40 mg of **3e** afforded 32.8 mg of **6e** (82% yield). $R_f$ = 0.3 (hexane/EtOAc = 5/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 3452, 2967, 1689, 1592, 1500, 1028, 772. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 7.14 (s, 1H), 7.10 (s, 1H), 5.81-5.74 (m, 1H), 5.26 (dd, *J* = 10.7 and 0.68 Hz, 1H), 5.16 (dd, *J* = 17.5 and 0.7 Hz, 1H), 4.86 (s, 1H), 3.94 (s, 3H), 3.87 (s, 3H), 2.60 (brs, 1H), 1.37 (s, 3H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 203.4, 156.1, 150.8, 148.1, 136.9, 127.7, 117.8, 106.6, 104.1, 78.0, 58.2, 56.3, 56.2, 19.8. **HRMS (ESI):** *m/z* calcd for $C_{14}H_{17}O_4$ $(M+H)^+$: 249.1127. Found: 249.1123.

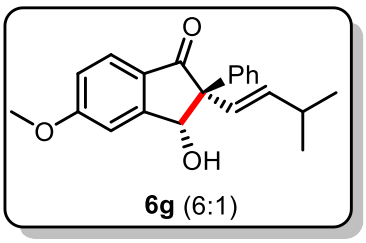
### 3-Hydroxy-2-methyl-2-(prop-1-en-1-yl)-2,3-dihydro-1*H*-inden-1-one (6f).




This compound was isolated as colorless viscous oil. Following the general procedure-4, 40 mg of **3f** afforded 35.6 mg of **6f** (89% yield). $R_f$ = 0.3 (hexane/EtOAc = 5/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 3422, 2925, 1704, 1605, 1466, 1279, 728. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 7.78 (d, *J* = 7.6 Hz, 1H), 7.75-7.68 (m, 2H), 7.52-7.48 (m, 1H), 5.68-5.59 (m, 1H), 5.43-5.38 (m, 1H), 4.93 (d, *J* = 6.8 Hz, 1H), 2.39 (brs, 1H), 1.71-1.69 (m, 3H), 1.44 (s, 3H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 205.2, 152.9, 135.4, 135.0, 129.7, 129.3, 128.8, 125.7, 123.8,

78.2, 57.9, 20.0, 18.5. **HRMS (ESI):** *m/z* calcd for $C_{13}H_{15}O_2$ $(M+H)^+$: 203.1072. Found: 203.1049.

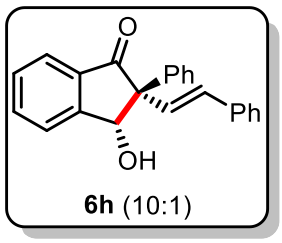
### 3-Hydroxy-5-methoxy-2-(4-methylpent-1-en-1-yl)-2-phenyl-2,3-dihydro-1*H*-inden-1-one (6g).



**6g** (6:1)

This compound was isolated as pale-yellow oil. Following the general procedure-4, 40 mg of **3g** afforded 35.2 mg of **6g** (88% yield). $R_f$ = 0.3 (hexane/EtOAc = 5/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 3447, 3085, 2965, 1701, 1599, 1490, 749. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 7.78 (d, *J* = 8.5 Hz, 1H), 7.47-7.45 (m, 2H), 7.37-7.34 (m, 2H), 7.30-7.25 (m, 2H), 7.21-7.19 (m, 1H), 7.04 (dd, *J* = 8.3 and 2.0 Hz, 1H), 5.77 (dd, *J* = 16.0 and 1.0 Hz, 1H), 5.61-5.55 (m, 1H), 5.44 (d, *J* = 8.2 Hz, 1H), 3.95 (s, 3H), 2.38-2.31 (m, 1H), 1.00 (d, *J* = 6.7 Hz, 3H), 0.96 (d, *J* = 6.7 Hz, 3H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 200.7, 166.0, 155.7, 144.0, 141.7, 128.9, 128.4 (2C), 127.7 (2C), 126.9, 125.9, 124.6, 117.7, 108.4, 78.4, 65.2, 55.8, 31.6, 22.27, 22.25. **HRMS (ESI):** *m/z* calcd for $C_{21}H_{21}O_3$ $(M-H)^+$: 321.1501. Found: 321.1501.

### 3-Hydroxy-2-phenyl-2-(styryl)-2,3-dihydro-1*H*-inden-1-one (6h).

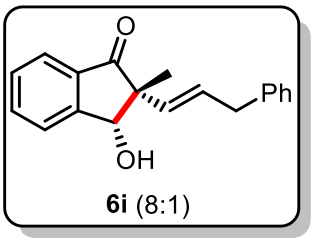


**6h** (10:1)

This compound was isolated as pale-yellow oil. Following the general procedure-4, 40 mg of **3h** afforded 34.0 mg of **6h** (85% yield). $R_f$ = 0.3 (hexane/EtOAc = 5/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 3441, 3056, 2924, 1704, 1603, 1495, 1285, 743. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 7.86 (d, *J* = 7.6 Hz, 1H), 7.76-7.69 (m, 2H), 7.53-7.50 (m, 1H), 7.47-7.45 (m, 2H), 7.36-7.31 (m, 4H), 7.29-7.26 (m, 1H), 7.25-7.19 (m, 3H), 6.62 (d, *J* = 16.4 Hz, 1H), 6.50 (d, *J* = 16.4 Hz, 1H), 5.57 (d, *J* = 7.0 Hz, 1H), 2.59 (d, *J* = 8.4 Hz, 1H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 202.0, 152.4, 141.2, 136.5, 135.7, 135.5, 135.1, 129.7, 128.7 (2C), 128.5 (2C), 127.99, 127.94 (2C), 127.2, 126.9, 126.5 (2C), 125.6, 124.2, 79.2, 65.8. **HRMS (ESI):** *m/z* calcd for $C_{23}H_{19}O_2$ $(M+H)^+$: 327.1385. Found: 327.1373.

### 3-Hydroxy-2-methyl-2-(3-phenylprop-1-en-1-yl)-2,3-dihydro-1*H*-inden-1-one (6i).

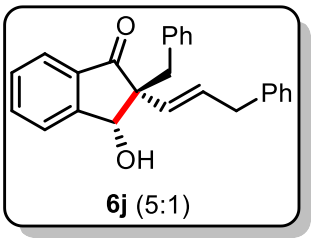
This compound was isolated as pale-yellow oil. Following the general procedure-4, 40 mg of **3i** afforded 35.2 mg of **6i** (88% yield). $R_f$ = 0.3 (hexane/EtOAc = 5/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 3450, 2929, 1767, 1709, 1605, 1287, 747. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 7.80 (d, *J*



**6i** (8:1)

= 7.6 Hz, 1H), 7.76-7.70 (m, 2H), 7.52 (t, *J* = 7.6 Hz, 1H), 7.30-7.27 (m, 2H), 7.22-7.18 (m, 1H), 7.15-7.13 (m, 2H), 5.85-5.78 (m, 1H), 5.53 (d, *J* = 15.8 Hz, 1H), 4.97 (d, *J* = 5.0 Hz, 1H), 3.40 (d, *J* = 6.8 Hz, 2H), 2.17 (brs, 1H), 1.47 (s, 3H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 204.9, 152.7, 139.7, 135.4, 135.0, 133.3, 129.4, 129.2, 128.5 (2C), 128.4 (2C), 126.2, 125.8, 123.9, 78.3, 57.8, 39.2, 20.3. **HRMS (ESI):** *m/z* calcd for $C_{19}H_{17}O_2$ $(M–H)^+$: 277.1228. Found: 277.1205.

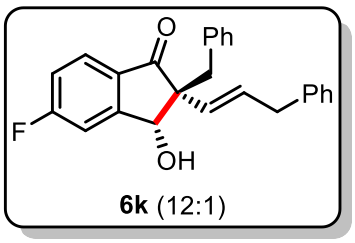
### 2-Benzyl-3-hydroxy-2-(3-phenylprop-1-en-1-yl)-2,3-dihydro-1*H*-inden-1-one (6j).



**6j** (5:1)

This compound was isolated as pale-brown oil. Following the general procedure-4, 40 mg of **3j** afforded 34.8 mg of **6j** (87% yield). $R_f$ = 0.3 (hexane/EtOAc = 5/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 3431, 3029, 2929, 1707, 1604, 1286, 1066, 700. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 7.74 (d, *J* = 7.6 Hz, 1H), 7.62-7.61 (m, 2H), 7.44-7.40 (m, 1H), 7.27-7.24 (m, 2H), 7.21-7.14 (m, 6H), 7.09 (d, *J* = 8.4 Hz, 2H), 5.85-5.78 (m, 1H), 5.62-5.58 (m, 1H), 5.19 (s, 1H), 3.36-3.33 (m, 3H), 3.13 (d, *J* = 13.6 Hz, 1H), 1.95 (brs, 1H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 203.5, 153.0, 139.6, 137.2, 135.35, 135.33, 133.5, 130.4 (2C), 129.1, 129.0, 128.51 (2C), 128.50 (2C), 128.4 (2C), 126.7, 126.2, 125.4, 123.6, 73.9, 62.2, 40.2, 39.4. **HRMS (ESI):** *m/z* calcd for $C_{25}H_{23}O_2$ $(M+H)^+$: 355.1698. Found: 355.1684.

### 2-Benzyl-5-fluoro-3-hydroxy-2-(3-phenylprop-1-en-1-yl)-2,3-dihydro-1*H*-inden-1-one (6k).

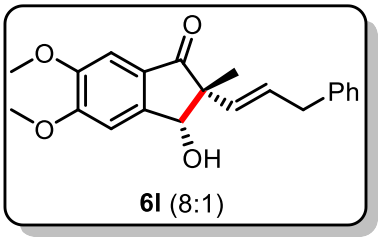


**6k** (12:1)

This compound was isolated as pale-yellow oil. Following the general procedure-4, 40 mg of **3k** afforded 29.2 mg of **6k** (73% yield). $R_f$ = 0.3 (hexane/EtOAc = 5/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 3455, 3029, 1713, 1611, 1331, 751. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 7.78 (dd, *J* = 8.5 and 3.3 Hz, 1H), 7.31-7.28 (m, 3H), 7.26-7.19 (m, 6H), 7.15-7.10 (m, 3H), 5.92-5.84 (m, 1H), 5.67 (d, *J* = 16.0 Hz, 1H), 5.20 (d, *J* = 7.0 Hz, 1H), 3.42-3.37 (m, 3H), 3.17 (d, *J* = 13.6 Hz, 1H), 2.38 (d, *J* = 7.6 Hz, 1H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 201.9, 167.6 (d, *J* = 256.1 Hz, 1C), 156.2 (d, *J* = 9.4 Hz, 1C), 139.6, 137.1, 133.6, 131.6 (d, *J* = 1.9 Hz, 1C), 130.4 (2C), 128.7, 128.56 (4C), 128.52 (2C), 126.8, 126.2, 126.1 (d, *J* = 10.1 Hz, 1C), 117.4 (d, *J* = 23.8 Hz, 1C), 112.4 (d, *J* = 22.5 Hz, 1C),

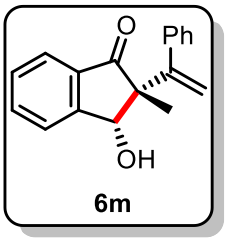
73.4, 62.6, 40.1, 39.4. **$^{19}$F NMR (376.4 MHz, $CDCl_3$):** δ –100.8. **HRMS (ESI):** *m/z* calcd for $C_{25}H_{22}O_2F$ $(M+H)^+$: 373.1604. Found: 373.1592.

### 3-Hydroxy-5,6-dimethoxy-2-methyl-2-(3-phenylprop-1-en-1-yl)-2,3-dihydro-1*H*-inden-1-one (6l).



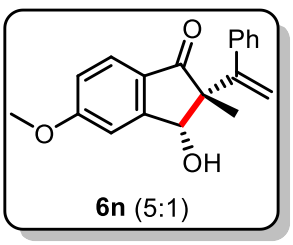

This compound was isolated as pale-yellow oil. Following the general procedure-4, 40 mg of **3l** afforded 32.8 mg of **6l** (82% yield). $R_f$ = 0.3 (hexane/EtOAc = 5/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 3415, 2836, 1700, 1592, 1368, 750. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 7.28-7.24 (m, 2H), 7.19-7.18 (m, 2H), 7.14-7.13 (m, 3H), 5.81-5.74 (m, 1H), 5.50 (d, *J* = 15.8 Hz, 1H), 4.86 (s, 1H), 3.99 (s, 3H), 3.92 (s, 3H), 3.38 (d, *J* = 6.8 Hz, 2H), 2.17 (brs, 1H), 1.42 (s, 3H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 203.6, 156.0, 150.9, 147.9, 139.8, 133.1, 129.9, 128.5 (2C), 128.4 (2C), 127.8, 126.2, 106.6, 104.1, 78.1, 57.5, 56.4, 56.2, 39.2, 20.5. **HRMS (ESI):** *m/z* calcd for $C_{21}H_{22}O_4Na$ $(M+Na)^+$: 361.1433. Found: 361.1415.

### 3-Hydroxy-2-methyl-2-(1-phenylvinyl)-2,3-dihydro-1*H*-inden-1-one (6m).




This compound was isolated as pale-yellow oil. Following the general procedure-4, 40 mg of **3m** afforded 23.2 mg of **6m** (58% yield). $R_f$ = 0.3 (hexane/EtOAc = 5/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 3448, 2923, 1714, 1605, 1285, 892, 703. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 7.83 (d, *J* = 7.6 Hz, 1H), 7.69-7.63 (m, 2H), 7.49 (t, *J* = 7.5 Hz, 1H), 7.21-7.19 (m, 3H), 7.14-7.12 (m, 2H), 5.47-5.44 (m, 2H), 5.29 (s, 1H), 2.28 (brs, 1H), 1.36 (s, 3H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 205.7, 152.8, 149.7, 141.3, 135.4, 134.6, 129.3, 128.3 (2C), 127.7 (2C), 127.3, 125.7, 124.0, 118.2, 76.7, 60.5, 19.0. **HRMS (ESI):** *m/z* calcd for $C_{18}H_{16}O_2Na$ $(M+Na)^+$: 287.1048. Found: 287.1039.

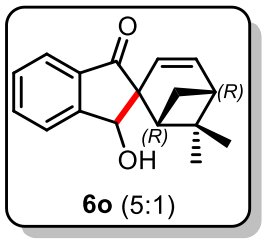
### 3-Hydroxy-5-methoxy-2-methyl-2-(1-phenylvinyl)-2,3-dihydro-1*H*-inden-1-one (6n).




This compound was isolated as pale-yellow oil. Following the general procedure-4, 40 mg of **3n** afforded 24.8 mg of **6n** (62% yield). $R_f$ = 0.3 (hexane/EtOAc = 5/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 3470, 2925, 1706, 1599, 1565, 1443, 1026, 703. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 7.76 (d, *J* = 8.5 Hz, 1H), 7.34-7.27 (m, 1H), 7.20-7.18 (m, 2H), 7.15-

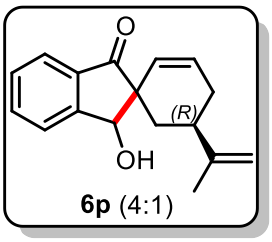
7.12 (m, 2H), 7.05 (d, *J* = 2.0 Hz, 1H), 6.99 (dd, *J* = 8.6 and 2.4 Hz, 1H), 5.45 (s, 1H), 5.42 (s, 1H), 5.22 (s, 1H), 3.86 (s, 3H), 2.42 (brs, 1H), 1.35 (s, 3H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 203.8, 165.9, 155.9, 149.9, 141.4, 128.4, 128.2 (2C), 127.79 (2C), 127.77, 127.3, 125.8, 118.1, 117.6, 108.4, 75.5, 60.6, 19.0. **HRMS (ESI):** *m/z* calcd for $C_{19}H_{17}O_3$ $(M-H)^+$: 293.1178. Found: 293.1175.

### (2*R*,5*R*)-1'-Hydroxy-6,6-dimethylspiro[bicyclo[3.1.1]heptane-2,2'-inden]-3-en-3'(1'*H*)-one (6o).



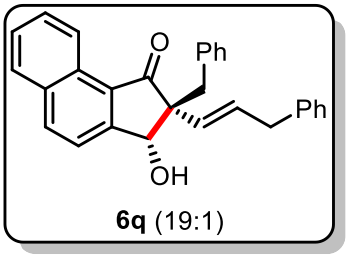

This compound was isolated as pale-yellow oil. Following the general procedure-4, 40 mg of **3o** afforded 34.8 mg of **6o** (87% yield). $R_f$ = 0.3 (hexane/EtOAc = 5/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 3447, 2983, 1701, 1605, 1465, 1154, 764. **Optical rotation:** $[\alpha]_D^{25}$ +110.0 (*c* 0.1, $CH_2Cl_2$). **$^1$H NMR (400 MHz, $CDCl_3$):** δ 7.72 (m, 1H), 7.68-7.66 (m, 2H), 7.50-7.46 (m, 1H), 6.68-6.63 (m, 1H), 5.72-5.70 (m, 1H), 5.12 (s, 1H), 2.30-2.21 (m, 3H), 2.18-2.16 (m, 1H), 1.90-1.83 (m, 1H), 1.34 (s, 3H), 1.19 (s, 3H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 207.2, 152.1, 141.3, 135.27, 135.23, 129.9, 126.7, 124.1, 122.1, 76.8, 62.2, 49.6, 43.4, 42.0, 30.2, 26.9, 23.2. **HRMS (ESI):** *m/z* calcd for $C_{17}H_{19}O_2$ $(M+H)^+$: 255.1385. Found: 255.1367.

### (5*R*)-1'-Hydroxy-5-(prop-1-en-2-yl)spiro[cyclohexane-1,2'-inden]-2-en-3'(1'*H*)-one (6p).



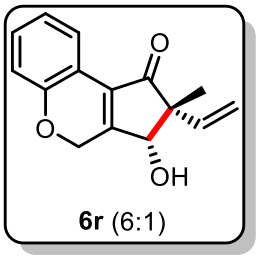

This compound was isolated as pale-yellow oil. Following the general procedure-4, 40 mg of **3p** afforded 36.8 mg of **6p** (92% yield). $R_f$ = 0.3 (hexane/EtOAc = 5/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 3430, 3020, 1706, 1605, 1465, 764, 749. **Optical rotation:** $[\alpha]_D^{25}$ –36.3 (*c* 0.1, $CH_2Cl_2$).**$^1$H NMR (400 MHz, $CDCl_3$):** δ 7.77-7.75 (m, 1H), 7.71-7.69 (m, 2H), 7.49-7.46 (m, 1H), 6.06 (dd, *J* = 10.2 and 3.4 Hz, 1H), 5.42-5.38 (m, 1H), 4.96 (s, 1H), 4.88-4.85 (m, 2H), 2.84-2.80 (m, 1H), 2.28 (brs, 1H), 2.12-2.06 (m, 2H), 1.93-1.87 (m, 1H), 1.79 (s, 3H), 1.74-1.70 (m, 1H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 205.2, 152.6, 146.9, 136.8, 135.3, 134.8, 129.4, 125.8, 123.99, 123.93, 112.0, 78.0, 57.4, 41.8, 27.7, 23.8, 21.3. **HRMS (ESI):** *m/z* calcd for $C_{17}H_{19}O_2$ $(M+H)^+$: 255.1385. Found: 255.1379.

### 2-Benzyl-3-hydroxy-2-(3-phenylprop-1-en-1-yl)-2,3-dihydro-1*H*-cyclopenta[*a*]naphthalen-1-one (6q).



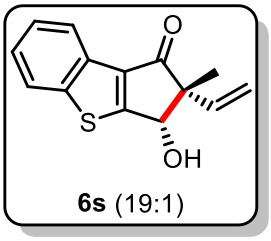

This compound was isolated as pale-yellow oil. Following the general procedure-4, 40 mg of **3q** afforded 33.2 mg of **6q** (83% yield). $R_f$ = 0.3 (hexane/EtOAc = 5/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 3053, 1693, 1576, 1515, 1449, 1078, 701. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 9.12 (d, *J* = 8.3 Hz, 1H), 8.06 (d, *J* = 8.4 Hz, 1H), 7.88 (d, *J* = 8.1 Hz, 1H), 7.71-7.65 (m, 2H), 7.59-7.55 (m, 1H), 7.26-7.13 (m, 8H), 7.09-7.08 (m, 2H), 5.92-5.84 (m, 1H), 5.65 (d, *J* = 15.9 Hz, 1H), 5.26 (s, 1H), 3.42 (d, *J* = 13.6 Hz, 1H), 3.33 (d, *J* = 6.7 Hz, 2H), 3.19 (d, *J* = 13.6 Hz, 1H), 2.10 (brs, 1H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 203.7, 155.4, 139.7, 137.4, 136.4, 133.5, 133.4, 130.4 (2C), 129.8, 129.7, 129.2, 128.7, 128.5 (4C), 128.4 (2C), 128.3, 127.1, 126.6, 126.1, 124.8, 122.1, 73.7, 62.6, 40.3, 39.4. **HRMS (ESI):** *m/z* calcd for $C_{29}H_{25}O_2$ $(M+H)^+$: 405.1855. Found: 405.1866.

### 3-Hydroxy-2-methyl-2-vinyl-2,3-dihydrocyclopenta[*c*]chromen-1(4*H*)-one (6r).




This compound was isolated as pale-yellow oil. Following the general procedure-4, 40 mg of **3r** afforded 32.8 mg of **6r** (82% yield). $R_f$ = 0.3 (hexane/EtOAc = 5/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 3450, 2931, 1719, 1607, 1570, 1261, 750. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 8.01 (d, *J* = 7.6 Hz, 1H), 7.20 (t, *J* = 7.7 Hz, 1H), 6.93 (t, *J* = 7.5 Hz, 1H), 6.86 (d, *J* = 8.1 Hz, 1H), 5.86-5.79 (m, 1H), 5.39-5.28 (m, 3H), 5.24-5.13 (m, 1H), 4.56 (s, 1H), 2.1 (brs, 1H), 1.38 (s, 3H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 202.2, 160.2, 152.9, 136.1, 130.9, 130.7, 125.0, 121.7, 118.6, 116.2, 115.9, 77.7, 65.6, 57.1, 19.8. **HRMS (ESI):** *m/z* calcd for $C_{15}H_{13}O_3$ $(M-H)^+$: 241.0864. Found: 241.0863.

### 3-Hydroxy-2-methyl-2-vinyl-2,3-dihydro-1*H*-benzo[*b*]cyclopenta[*d*]thiophen-1-one (6s).




This compound was isolated as pale-yellow oil. Following the general procedure-4, 40 mg of **3s** afforded 25.6 mg of **6s** (64% yield). $R_f$ = 0.3 (hexane/EtOAc = 5/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 3420, 2963, 1689, 1631, 1561, 1267, 751. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 8.24 (d, *J* = 7.4 Hz, 1H), 7.85 (d, *J* = 7.6 Hz, 1H), 7.49-7.43 (m, 2H), 5.96-5.89 (m, 1H), 5.40-5.28 (m, 2H), 5.15 (s, 1H), 2.64 (brs, 1H), 1.51 (s, 3H). **$^{13}$C NMR (100 MHz,**

**$CDCl_3$):** δ 196.6, 171.3, 145.0, 138.8, 136.5, 131.0, 126.4, 126.1, 124.0, 123.4, 118.7, 76.6, 63.0, 20.2. **HRMS (ESI):** *m/z* calcd for $C_{14}H_{13}O_2S$ $(M+H)^+$: 245.0636. Found: 245.0644.

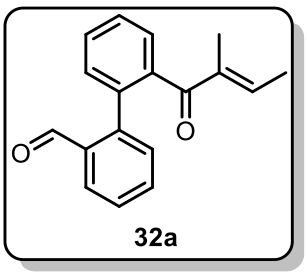
### General procedure-5: Synthesis of biaryl enone-aldehydes 32a-c.

**Step-I:** An oven dried 25 mL long neck RB flask was charged with 2-bromoiodobenzene **34** (1.0 mmol) was dissolved in anhydrous THF:$Et_2O$ (1:1 v/v, 8 mL) at –78 °C and added *i*-PrMgBr (1.6 M in hexane, 1.2 mmol). After 45 min, a suitable enone-aldehyde (1.0 mmol) was added at the same temperature and the reaction mixture was stirred for an additional 30 min. The mixture was warmed to room temperature over 30 min. The reaction progress was monitored by TLC. Reaction mixture was quenched with saturated aqueous ammonium chloride solution and extracted with ethyl acetate. The organic extracts were combined, dried over anhydrous sodium sulphate and concentrated. The crude product was purified by silica gel column chromatography using hexane/ethyl acetate (9:1) as eluent to afford the bromo-enols **35** in 75-80% yield.

**Step-II:** The bromo-enols **35** were oxidized using IBX following the general procedure 1, step III to afford bromo enones **36**.

**Step-III:** The bromo-enones **36** (1.0 mmol), $Pd_2(dba)_3$ (0.005 mmol), $[HP(^tBu)_3]BF_4$ (0.012 mmol), 2-formylphenyl boronic acid (2.0 mmol), and $KF.2H_2O$ (3.3 mmol) were added to a sealed tube. The reaction tube was degassed with nitrogen and then DMF (2.0 mL) was added using a syringe, and the resulting solution was stirred at 40 °C for 48 h. After the reaction was completed (TLC), the reaction was quenched with saturated aq. $NH_4Cl$ solution and extracted using ethyl acetate. The organic extracts were combined dried over anhydrous sodium sulfate and concentrated. The crude product was purified by silica gel column chromatography using hexane/ethyl acetate as eluent to afford biaryl-enone aldehydes **32a-c** in 65-75% yields.

### 2'-(2-Methylbut-2-enoyl)-[1,1'-biphenyl]-2-carbaldehyde (32a).

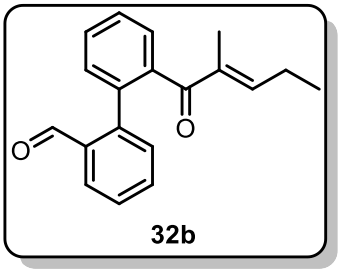


**32a**

This compound was prepared by following the general procedure-5 and isolated as colorless oil; 100 mg of **36** ($R^1$ = Me, $R^2$ = Me) afforded 72 mg of **32a** (65% yield). $R_f$ = 0.5 (hexane/EtOAc = 5/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 2936, 1694, 1639, 1596, 1195, 737. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 9.86 (s, 1H), 7.97 (dd, *J* = 7.7 and 1.1 Hz, 1H), 7.55-7.42 (m, 5H), 7.31-7.29 (m, 1H), 7.19 (d, *J* = 8.4 Hz, 1H), 6.25-6.19 (m, 1H), 1.65 (d, *J* = 6.9 Hz, 3H), 1.59 (s, 3H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 199.5, 191.6, 144.0,

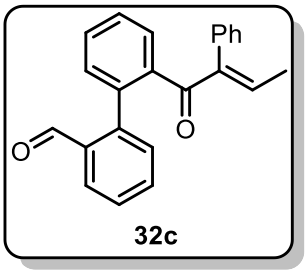
143.3, 140.6, 139.4, 136.4, 133.6, 133.1, 131.2, 130.9, 129.1, 128.2, 128.0, 127.8, 127.6, 14.6, 10.8. **HRMS (ESI):** *m/z* calcd for $C_{18}H_{16}O_2Na$ $(M+Na)^+$: 287.1048. Found: 287.1048.

### 2'-(2-Methylpent-2-enoyl)-[1,1'-biphenyl]-2-carbaldehyde (32b).




This compound was prepared by following the general procedure-5 and isolated as pale-yellow oil; 100 mg of **36** ($R^1$ = Me, $R^2$ = Et) afforded 79 mg of **32b** (72% yield). $R_f$ = 0.5 (hexane/EtOAc = 5/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 2629, 1696, 1648, 1636, 1596, 1260, 757. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 9.89 (s, 1H), 7.98 (d, *J* = 7.7 Hz, 1H), 7.56-7.44 (m, 5H), 7.32-7.29 (m, 1H), 7.21 (d, *J* = 7.6 Hz, 1H), 6.08 (t, *J* = 7.3 Hz, 1H), 2.08-2.00 (m, 2H), 1.60 (s, 3H), 0.84 (t, *J* = 7.5 Hz, 3H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 199.9, 191.6, 149.8, 144.0, 140.6, 137.8, 136.1, 133.6, 133.2, 131.3, 131.0, 129.1, 128.3, 128.0, 127.9, 127.6, 22.3, 12.8, 11.0. **HRMS (ESI):** *m/z* calcd for $C_{19}H_{18}O_2Na$ $(M+Na)^+$: 301.1204. Found: 301.1205.

### 2'-(2-Phenylbut-2-enoyl)-[1,1'-biphenyl]-2-carbaldehyde (32c).



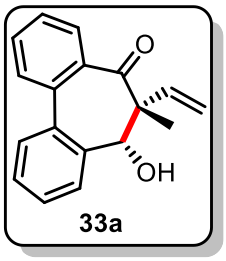

This compound was prepared by following the general procedure-5 and isolated as pale-yellow oil; 100 mg of **36** ($R^1$ = Ph, $R^2$ = Me) afforded 81 mg of **32c** (75% yield). $R_f$ = 0.5 (hexane/EtOAc = 5/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 3057, 2750, 1692, 1651, 1595, 756. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 9.88 (s, 1H), 8.04 (dd, *J* = 7.5 and 1.4 Hz, 1H), 7.63-7.50 (m, 5H), 7.33-7.23 (m, 5H), 6.72-6.70 (m, 2H), 6.53 (q, *J* = 7.0 Hz, 1H), 1.59 (d, *J* = 7.1 Hz, 3H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 198.2, 191.5, 144.8, 144.6, 143.8, 140.7, 136.1, 134.2, 133.7, 133.4, 131.4, 131.3, 129.5 (2C), 129.4, 128.4, 128.3, 128.1, 128.0, 127.9 (2C), 127.5, 15.7. **HRMS (ESI):** *m/z* calcd for $C_{23}H_{18}O_2Na$ $(M+Na)^+$: 349.1204. Found: 349.1188.

### General procedure-6: Synthesis of dibenzocycloheptanones 33 *via* IVAR.

An oven-dried 5 mL glass vial was charged with **32** (1.0 eq, 0.1 mmol), DMF (1.0 mL), and tributylphosphine or DBU (0.2 eq, 0.02 mmol) at 100 $^oC$ (using a heating mantle) and stirred for 5 days. Then the reaction mixture was quenched with aqueous $NH_4Cl$ (~1-2 mL) and extracted using ethyl acetate (2x3 mL). The organic extracts were combined and dried over

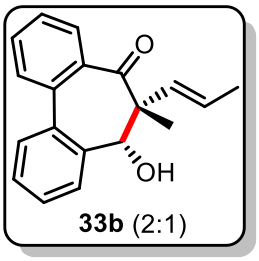
anhydrous sodium sulfate and concentrated. The crude product was purified by silica gel column chromatography using hexane/ethyl acetate (10:1) as an eluent to afford **33**.

### 7-Hydroxy-6-methyl-6-vinyl-6,7-dihydro-5*H*-dibenzo[*a*,*c*][7]annulen-5-one (33a).



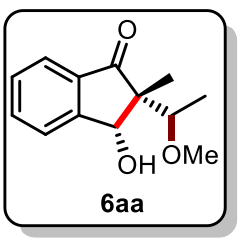

This compound was isolated as pale-yellow oil. Following the general procedure-6, 40 mg of **32a** afforded 12.0 mg of **33a** (30% yield). $R_f$ = 0.3 (hexane/EtOAc = 5/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 3578, 3282, 1650, 1050, 760. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 7.66 (d, *J* = 8.3 Hz, 1H), 7.59-7.55 (m, 1H), 7.45-7.40 (m, 3H), 7.39-7.33 (m, 3H), 6.04-5.97 (m, 1H), 5.39 (d, *J* = 2.5 Hz, 1H), 5.36-5.35 (m, 2H), 2.04 (brs, 1H), 1.21 (s, 3H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 206.5, 139.7, 138.5, 137.5, 136.6, 135.5, 131.4, 128.9, 128.2, 128.1, 128.0 (2C), 127.8, 125.3, 117.5, 72.1, 65.6, 12.6. **HRMS (ESI):** *m/z* calcd for $C_{18}H_{16}O_2Na$ $(M+Na)^+$: 287.1048. Found: 287.1039.

### 7-Hydroxy-6-methyl-6-(prop-1-en-1-yl)-6,7-dihydro-5*H*-dibenzo[*a*,*c*][7]annulen-5-one (33b).




This compound was isolated as pale-yellow oil. Following the general procedure-6, 40 mg of **32b** afforded 16.8 mg of **33b** (42% yield). $R_f$ = 0.3 (hexane/EtOAc = 5/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 3469, 2979, 1685, 1649, 1597, 748. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 7.66 (d, *J* = 7.3 Hz, 1H), 7.58-7.55 (m, 1H), 7.45-7.33 (m, 6H), 5.86-5.77 (m, 1H), 5.63-5.59 (m, 1H), 5.29 (s, 1H), 2.00 (brs, 1H), 1.77 (dd, *J* = 6.4 and 1.5 Hz, 3H), 1.17 (s, 3H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 206.9, 139.9, 137.5, 136.6, 135.5, 131.34, 131.31, 128.8, 128.2, 128.04, 128.03 (2C), 128.01, 127.8, 125.3, 72.4, 64.9, 18.4, 12.9. **HRMS (ESI):** *m/z* calcd for $C_{19}H_{18}O_2Na$ $(M+Na)^+$: 301.1204. Found: 301.1212.

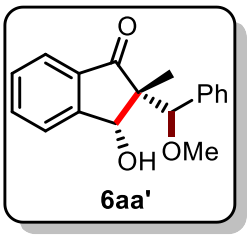
### 3-Hydroxy-2-(1-methoxyethyl)-2-methyl-2,3-dihydro-1*H*-inden-1-one (6aa).




This compound was isolated as colorless viscous oil. Following the general procedure-4, 30 mg of **3a** afforded 11.5 mg of **6aa** (33% yield). $R_f$ = 0.5 (hexane/EtOAc = 5/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 3472, 2926, 1710, 1606, 1282, 1053, 764. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 7.73-7.65 (m, 3H), 7.45 (t, *J* = 6.7 Hz, 1H), 4.92 (d, *J* = 9.0 Hz, 1H), 3.79-3.72 (m, 1H), 3.60 (d, *J* = 8.8 Hz, 1H), 3.22 (s, 3H), 1.30-1.29 (m, 6H). **$^{13}$C NMR (100 MHz,**

**CDCl$_3$):** δ 206.2, 154.6, 135.9, 135.3, 129.0, 125.3, 123.0, 81.0, 79.6, 56.3, 55.8, 21.0, 12.8. **HRMS (ESI):** *m/z* calcd for $C_{13}H_{15}O_3$ $(M-H)^+$: 219.1021. Found: 219.1042.

### 3-Hydroxy-2-(methoxy(phenyl)methyl)-2-methyl-2,3-dihydro-1*H*-inden-1-one (6aa').



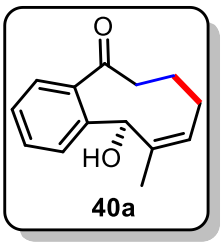

This compound was isolated as pale-yellow oil. Following the general procedure-4, 30 mg of **3a'** afforded 8.4 mg of **6aa'** (25% yield). $R_f$ = 0.5 (hexane/EtOAc = 5/1). **IR (thin film, neat):** $\nu_{max}$/cm$^{-1}$ 3469, 2925, 2824, 1711, 1606, 1454, 1095, 758. **$^1$H NMR (400 MHz, CDCl$_3$):** δ 7.76-7.72 (m, 2H), 7.70-7.66 (m, 1H), 7.47-7.44 (m, 1H), 7.41-7.32 (m, 4H), 7.25-7.23 (m, 1H), 4.98 (s, 1H), 4.60 (s, 1H), 3.39 (brs, 1H), 3.03 (s, 3H), 1.13 (s, 3H). **$^{13}$C NMR (100 MHz, CDCl$_3$):** δ 204.2, 154.2, 136.5, 135.4, 135.1, 129.0 (2C), 128.2, 127.6 (2C), 125.0, 122.9, 87.3, 79.5, 56.6, 56.3, 20.8. **HRMS (ESI):** *m/z* calcd for $C_{18}H_{18}O_3Na$ $(M+Na)^+$: 305.1154. Found: 305.1151.

### General procedure-7: Synthesis of benzannulated nine-membered carbocycles 40a-e.

**Step-I:** An oven-dried 25 mL RB flask was charged with **3** (1.0 mmol) in 10 mL dry THF and placed at 0 °C under $N_2$ atmosphere. Then, vinyl magnesium chloride (1.6 M in THF, 2.2 mmol) was added dropwise at the same temperature and stirred for 20 min. Upon completion, the reaction mixture was quenched with aqueous $NH_4Cl$ (~2-3 mL) and extracted with ethyl acetate (2x5 mL). The organic extracts were combined and dried over anhydrous $Na_2SO_4$, and concentrated under reduced pressure. The crude product was taken to the next step without further purification.

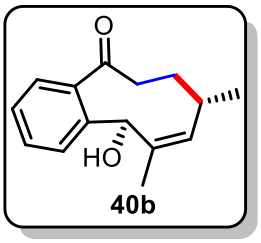
**Step-II:** The crude product **39** was dissolved in 7 mL dry THF and placed at 0 °C under $N_2$ atmosphere. 18-crown-6 (1.0 mmol) and KH (2.2 mmol, 30 wt% dispersion in mineral oil) were added and stirred for 15-20 min at room temperature until the allylic *tert*-alcohol disappeared as monitored by TLC. The mixture was quenched with aqueous $NH_4Cl$ (~2-3 mL) and extracted with ethyl acetate (2x5 mL). The combined organic layers were washed with brine, dried over anhydrous $Na_2SO_4$, and concentrated under reduced pressure. The residue was purified by silica gel column chromatography using hexane/ethyl acetate (10:1) as eluent to afford benzannulated nine-membered carbocycles **40a-e** (yield 48-75%, over 2 steps).

### 11-Hydroxy-10-methyl-6,7,8,11-tetrahydro-5*H*-benzo[9]annulen-5-one (40a).



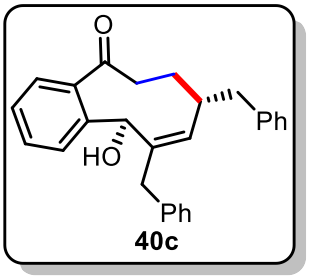

This compound was isolated as colorless oil. Following the general procedure-7, 30 mg of **6a** afforded 25.8 mg of **40a** (75% yield, over two steps). $R_f$ = 0.5 (hexane/EtOAc = 10/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 3406, 2950, 1711, 1680, 1659, 1024, 764. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 7.43 (d, *J* = 7.4 Hz, 1H), 7.35-7.27 (m, 2H), 7.01 (d, *J* = 7.0 Hz, 1H), 5.62 (d, *J* = 12.3 Hz, 1H), 4.91 (d, *J* = 8.4 Hz, 1H), 2.56-2.40 (m, 3H), 2.32-2.21 (m, 3H), 2.11-2.06 (m, 1H), 1.38 (s, 3H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 212.8, 144.4, 140.8, 136.1, 130.6, 129.6, 128.1, 124.2, 79.3, 40.2, 30.5, 26.9, 15.4. **HRMS (ESI):** *m/z* calcd for $C_{14}H_{16}O_2Na$ $(M+Na)^+$: 239.1048. Found: 239.1031.

### 11-Hydroxy-8,10-dimethyl-6,7,8,11-tetrahydro-5*H*-benzo[9]annulen-5-one (40b).




This compound was isolated as colorless solid. Following the general procedure-7, 30 mg of **6f** afforded 16.3 mg of **40b** (48% yield, over two steps). $R_f$ = 0.3 (hexane/EtOAc = 10/1). M. P = 127-129 °C. **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 3424, 2955, 1681, 1455, 1420, 760. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 7.42 (d, *J* = 7.0 Hz, 1H), 7.34-7.27 (m, 2H), 6.99 (d, *J* = 7.0 Hz, 1H), 5.38 (d, *J* = 11.3 Hz, 1H), 4.88 (d, *J* = 6.4 Hz, 1H), 2.61-2.54 (m, 2H), 2.40-2.26 (m, 3H), 2.06-2.03 (m, 1H), 1.39 (s, 3H), 1.13 (d, *J* = 6.2 Hz, 3H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 213.2, 144.4, 140.4, 134.9, 134.4, 130.6, 128.6, 128.1, 124.1, 79.1, 40.4, 39.2, 33.7, 19.2, 16.0. **HRMS (ESI):** *m/z* calcd for $C_{15}H_{18}O_2Na$ $(M+Na)^+$: 253.1204. Found: 253.1195.

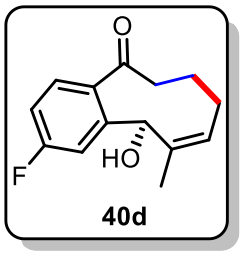
### 8,10-Dibenzyl-11-hydroxy-6,7,8,11-tetrahydro-5*H*-benzo[9]annulen-5-one (40c).




This compound was isolated pale-yellow oil. Following the general procedure-7, 30 mg of **6j** afforded 21.0 mg of **40c** (65% yield, over two steps). $R_f$ = 0.3 (hexane/EtOAc = 10/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 3405, 2924, 1737, 1376, 1217, 758. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 7.38-7.27 (m, 6H), 7.23-7.21 (m, 2H), 7.13-7.04 (m, 4H), 6.51-6.49 (m, 2H), 5.65 (d, *J* = 10.8 Hz, 1H), 4.71 (d, *J* = 5.3 Hz, 1H), 3.54 (d, *J* = 14.4 Hz, 1H), 2.95-2.78 (m, 3H), 2.54-2.44 (m, 4H), 2.36 (d, *J* = 14.4 Hz, 1H), 2.22-2.17 (m, 1H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 212.8, 144.6, 140.9, 140.3, 139.4, 138.4, 133.4, 130.7, 129.0 (2C), 128.8, 128.5 (2C), 128.4 (2C), 128.3 (2C). 128.2, 126.2, 126.0,

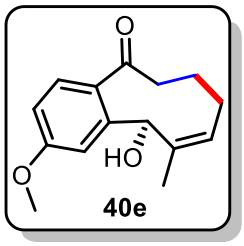
124.3, 76.6, 42.5, 41.0, 40.8, 37.0, 35.2. **HRMS (ESI):** *m/z* calcd for $C_{27}H_{26}O_2Na$ $(M+Na)^+$: 405.1830. Found: 405.1831.

### 2-Fluoro-11-hydroxy-10-methyl-6,7,8,11-tetrahydro-5*H*-benzo[9]annulen-5-one (40d).




This compound was isolated as yellow viscous oil. Following the general procedure-7, 30 mg of **6c** afforded 23.2 mg of **40d** (68% yield, over two steps). $R_f$ = 0.3 (hexane/EtOAc = 10/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 3423, 2934, 1681, 1604, 1583, 1232, 747. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 7.16 (d, *J* = 8.8 Hz, 1H), 6.99-6.97 (m, 2H), 5.63-5.59 (m, 1H), 4.86 (d, *J* = 7.8 Hz, 1H), 2.58-2.51 (m, 2H), 2.43- 2.39 (m, 1H), 2.30-2.18 (m, 3H), 2.11-2.03 (m, 1H), 1.40 (s, 3H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 211.9, 162.06 (d, *J* = 247.8 Hz, 1C), 143.6 (d, *J* = 6.2 Hz, 1C), 140.5 (d, *J* = 3.0 Hz, 1C), 135.6, 130.0, 126.1 (d, *J* = 7.8 Hz, 1C), 117.7 (d, *J* = 21.1 Hz, 1C), 114.7 (d, *J* = 21.0 Hz, 1C), 78.8, 40.4, 30.4, 26.8, 15.3. **$^{19}$F NMR (376.4 MHz, $CDCl_3$):** δ −112.3. **HRMS (ESI):** *m/z* calcd for $C_{14}H_{15}FO_2Na$ $(M+Na)^+$: 257.0954. Found: 257.0951.

### 11-Hydroxy-2-methoxy-10-methyl-6,7,8,11-tetrahydro-5*H*-benzo[9]annulen-5-one (40e).




This compound was isolated as pale-yellow oil. Following the general procedure-7, 30 mg of **6d** afforded 25.5 mg of **40e** (75% yield, over two steps). $R_f$ = 0.3 (hexane/EtOAc = 10/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 3397, 2937, 1712, 1604, 1493, 1272, 742. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 6.95-6.90 (m, 2H), 6.76 (dd, *J* = 8.3 and 2.4 Hz, 1H), 5.58-5.54 (m, 1H), 4.81 (brs, 1H), 3.80 (s, 3H), 2.74 (brs, 1H), 2.54-2.47 (m, 1H), 2.38-2.18 (m, 4H), 2.04 (brs, 1H), 1.37 (s, 3H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 213.1, 159.3, 142.7, 137.0, 136.0, 129.5, 125.5, 116.4, 112.5, 79.4, 55.4, 40.5, 30.5, 26.9, 15.4. **HRMS (ESI):** *m/z* calcd for $C_{15}H_{18}O_3Na$ $(M+Na)^+$: 269.1154. Found: 269.1132.

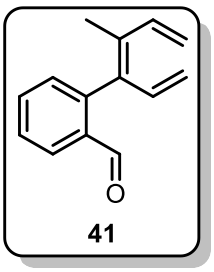
### General procedure-8: Synthesis of 1,3,5-trienes (41), 1-yn-3,5-dienes (43), 1,3-dienes (45) and 3-methylene indanols (47).

**Step-I:** An oven-dried 25 mL RB flask was charged with **6a** (1.0 mmol) in 10 mL dry THF and placed at 0 °C under $N_2$ atmosphere. The RMgX or RLi (2.2 mmol) was added dropwise at the same temperature and stirred until **6a** disappeared as monitored by TLC. Upon completion, the reaction mixture was quenched with aqueous $NH_4Cl$ (~2-3 mL) and extracted

with ethyl acetate (2x5 mL). The organic extracts were combined and dried over anhydrous $Na_2SO_4$, and concentrated under reduced pressure. The crude product was taken to the next step without further purification.

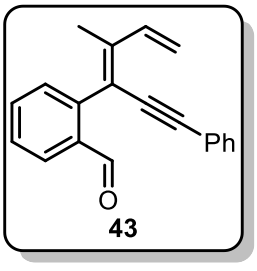
**Step-II:** The crude product was dissolved in 5 mL dry 1,2-DCE and *p*-TSA (0.1 mmol) was added and stirred for 5 min until the allylic *tert*-alcohol disappeared as monitored by TLC. The mixture was quenched with aqueous $NH_4Cl$ (~2-3 mL) and extracted with ethyl acetate (2x5 mL). The combined organic layers were washed with brine, dried over anhydrous $Na_2SO_4$, and concentrated under reduced pressure. The residue was purified by silica gel column chromatography using hexane/ethyl acetate (20:1) as eluent to afford **41**, **43**, **45**, and **47** (yield 64-84%, over 2 steps).

### 2-(4-Methylhexa-1,3,5-trien-3-yl)benzaldehyde (41).




This compound was isolated as colorless oil. Following the general procedure-8, 40 mg of **6a** afforded 26.9 mg of **41** (64% yield, over two steps). $R_f$ = 0.7 (hexane/EtOAc = 20/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 2927, 1697, 1597, 1461, 1197, 771. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 9.81 (s, 1H), 7.99 (dd, *J* = 7.8 and 1.2 Hz, 1H), 7.6 (td, *J* = 7.5 and 1.4 Hz, 1H), 7.45 (t, *J* = 7.6 Hz, 1H), 7.22-7.13 (m, 2H), 6.08-6.01 (m, 1H), 5.35 (d, *J* = 17.2 Hz, 1H), 5.24 (d, *J* = 10.6 Hz, 1H), 5.00 (d, *J* = 10.9 Hz, 1H), 4.54 (d, *J* = 17.0 Hz, 1H), 2.12 (s, 3H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 192.6, 143.3, 137.0, 136.4, 135.2, 135.0, 134.7, 133.9, 131.7, 127.8, 126.8, 119.5, 115.7, 13.0. **HRMS (ESI):** *m/z* calcd for $C_{14}H_{13}O$ $(M–H)^+$: 197.0966. Found: 197.0943.

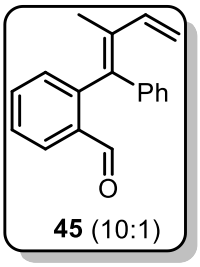
### 2-(4-Methyl-1-phenylhexa-3,5-dien-1-yn-3-yl)benzaldehyde (43).




This compound was isolated as colorless oil. Following the general procedure-8, 40 mg of **6a** afforded 42.2 mg of **43** (73% yield, over two steps). $R_f$ = 0.7 (hexane/EtOAc = 20/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 3062, 2917, 2190, 1694, 1644, 912, 754. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 10.2 (s, 1H), 7.99 (d, *J* = 7.8 Hz, 1H), 7.61 (t, *J* = 7.5 Hz, 1H), 7.47 (t, *J* = 7.6 Hz, 1H), 7.41-7.36 (m, 3H), 7.30-7.29 (m, 3H), 6.32-6.25 (m, 1H), 5.46 (dd, *J* = 17.2 and 0.8 Hz, 1H), 5.16 (d, *J* = 10.8 Hz, 1H), 2.37 (s, 3H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 192.0, 144.3, 142.2, 134.7, 134.2, 134.0, 131.3 (2C), 131.0, 128.5, 128.3

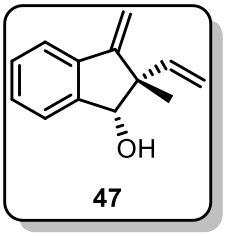
(2C), 128.2, 127.3, 123.1, 118.6, 117.8, 99.0, 90.1, 16.7. **HRMS (ESI):** *m/z* calcd for $C_{20}H_{17}O$ $(M+H)^+$: 273.1279. Found: 273.1263.

### 2-(2-Methyl-1-phenylbuta-1,3-dien-1-yl)benzaldehyde (45).




This compound was isolated as colorless oil. Following the general procedure-8, 40 mg of **6a** afforded 36.9 mg of **45** (70% yield, over two steps). $R_f$ = 0.7 (hexane/EtOAc = 20/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 2923, 1695, 1595, 1433, 1060, 701. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 10.1 (s, 1H), 7.97 (d, *J* = 7.7 Hz, 1H), 7.60-7.56 (m, 1H), 7.43 (t, *J* = 7.6 Hz, 1H), 7.35-7.31 (m, 2H), 7.27-7.23 (m, 2H), 7.19-7.18 (m, 2H), 6.29-6.22 (m, 1H), 5.41 (d, *J* = 17.2 Hz, 1H), 5.12 (d, *J* = 10.9 Hz, 1H), 2.08 (s, 3H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 192.4, 145.9, 141.6, 137.0, 136.8, 135.2, 134.4, 133.8, 131.5, 129.7 (2C), 128.2 (2C), 127.6, 127.3, 127.1, 115.9, 15.6. **HRMS (ESI):** *m/z* calcd for $C_{18}H_{17}O$ $(M+H)^+$: 249.1279. Found: 249.1254.

### 2-Methyl-3-methylene-2-vinyl-2,3-dihydro-1*H*-inden-1-ol (47).




This compound was isolated as pale-yellow viscous oil. Following the general procedure-8, 40 mg of **6a** afforded 33.2 mg of **47** (84% yield, over two steps). $R_f$ = 0.7 (hexane/EtOAc = 20/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 3405, 3079, 2866, 1642, 1585, 1260, 728. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 7.52-7.50 (m, 1H), 7.46-7.44 (m, 1H), 7.33-7.31 (m, 2H), 5.97-5.90 (m, 1H), 5.59 (s, 1H), 5.25-5.21 (m, 2H), 4.99 (s, 1H), 4.79 (s, 1H), 1.92 (brs, 1H), 1.40 (s, 3H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 153.7, 144.3, 140.2, 139.0, 129.1, 128.8, 125.0, 121.1, 115.9, 104.9, 82.3, 54.5, 22.6. **HRMS (ESI):** *m/z* calcd for $C_{13}H_{13}O$ $(M+H)^+$: 185.0996. Found: 185.0938.

### General procedure-9: Synthesis of natural product analogues 49 and 51.

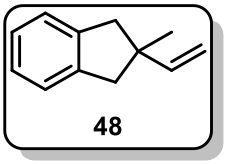
**Step-I:** An oven-dried 25 mL RB flask was charged with **6** (1.0 mmol) in 10 mL dry DCM and placed at 0 °C under $N_2$ atmosphere. Boron trifluoride etherate (5 mmol), and triethylsilane (10 mmol) were added at the same temperature and stirred for 8 h until **6** disappeared as monitored by TLC. Upon completion, the reaction mixture was quenched with aqueous $NH_4Cl$ (~2-3 mL) and extracted with DCM (2x5 mL). The organic extracts were combined and dried over anhydrous $Na_2SO_4$, and concentrated under reduced pressure. The

crude product was purified by silica gel column chromatography using hexane/ethyl acetate (10:1) as an eluent to afford the deoxygenated product **48** or **50** respectively.

**Step-II:** The deoxygenated product **48** or **50** (1 mmol) was then dissolved in 8 mL 1,4-dioxane:water (3:1). 2,6-lutidine (3.0 mmol) and $OsO_4$ (0.025 mmol) were added and stirred for 8 h. The mixture was quenched with aqueous $NaHSO_3$ (~2-3 mL) and extracted with ethyl acetate (2x5 mL). The combined organic layers were washed with brine, dried over anhydrous $Na_2SO_4$, and concentrated under reduced pressure. The crude product was taken to the next step without further purification.

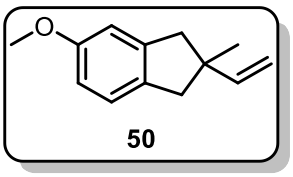
The crude product was dissolved in 5 mL MeOH and placed at 0 $^oC$. $NaBH_4$ (1.5 mmol) was added at the same temperature and stirred for 15 min until the aldehyde was disappeared as monitored by TLC. The mixture was quenched with aqueous $NH_4Cl$ (~2-3 mL) and extracted with ethyl acetate (2x5 mL). The combined organic layers were washed with brine, dried over anhydrous $Na_2SO_4$, and concentrated under reduced pressure. The residue was purified by silica gel column chromatography using hexane/ethyl acetate (5:1) as eluent to afford **49** or **51** respectively (yield 73-75%, over 2 steps).

### 2-Methyl-2-vinyl-2,3-dihydro-1*H*-indene (48).




This compound was isolated as colorless viscous oil. Following the general procedure-9, 50 mg of **6a** afforded 35.7 mg of **48** (85% yield). $R_f$ = 0.7 (hexane/EtOAc = 20/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 2958, 2850, 1650, 1460, 1372, 910, 736. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 7.24-7.17 (m, 4H), 6.12 (dd, *J* = 17.4 and 10.6 Hz, 1H), 5.10 (dd, *J* = 17.3 and 1.2 Hz, 1H), 5.00 (dd, *J* = 10.6 and 1.2 Hz, 1H), 3.04 (d, *J* = 15.4 Hz, 2H), 2.78 (d, *J* = 15.4 Hz, 2H), 1.26 (s, 3H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 147.0, 142.7 (2C), 126.2 (2C), 124.6 (2C), 110.5, 46.08, 46.03 (2C), 25.5. **HRMS (ESI):** *m/z* calcd for $C_{12}H_{13}$ $(M–H)^+$: 157.1017. Found: 157.0974.

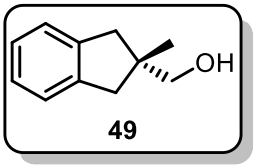
### 5-Methoxy-2-methyl-2-vinyl-2,3-dihydro-1*H*-indene (50).




This compound was isolated as colorless viscous oil. Following the general procedure-9, 50 mg of **6d** afforded 36.2 mg of **50** (84% yield). $R_f$ = 0.5 (hexane/EtOAc = 10/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 2956, 2854, 1495, 1492, 1083, 600. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 7.09 (d, *J* = 8.0 Hz, 1H), 6.78 (brs, 1H), 6.72 (dd, *J* = 8.2 and 2.4 Hz, 1H), 6.09 (dd, *J* = 17.4 and 10.6 Hz, 1H), 5.06 (dd, *J* = 17.4 and 1.2 Hz, 1H), 4.97 (dd, *J* = 10.6 and 1.2 Hz, 1H), 3.80 (s, 3H),

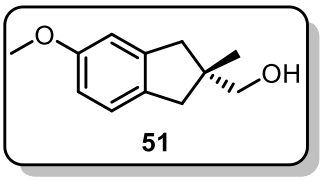
3.00-2.92 (m, 2H), 2.74-2.67 (m, 2H), 1.24 (s, 3H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 158.6, 147.1, 144.2, 137.4, 125.1, 111.8, 110.5, 110.3, 55.3, 46.5, 46.2, 45.1, 25.5. **HRMS (ESI):** *m/z* calcd for $C_{13}H_{17}O$ $(M+H)^+$: 189.1279. Found: 189.1257.

### (2-Methyl-2,3-dihydro-1*H*-inden-2-yl)methanol (49).




This compound was isolated as colorless oil. Following the general procedure-9, 35 mg of **48** afforded 26.1 mg of **49** (73% yield, over two steps). $R_f$ = 0.5 (hexane/EtOAc = 10/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 3480, 2953, 1459, 1186, 1037, 795, 738. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 7.19-7.12 (m, 4H), 3.53 (s, 2H), 2.92 (d, *J* = 15.6 Hz, 2H), 2.67 (d, *J* = 15.6 Hz, 2H), 1.72 (brs, 1H), 1.18 (s, 3H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 142.5 (2C), 126.2 (2C), 124.8 (2C), 70.6, 44.9, 42.7 (2C), 24.0.

### (5-Methoxy-2-methyl-2,3-dihydro-1*H*-inden-2-yl)methanol (51).




This compound was isolated as pale-yellow viscous oil. Following the general procedure-9, 35 mg of **50** afforded 26.8 mg of **51** (75% yield, over two steps). $R_f$ = 0.3 (hexane/EtOAc = 5/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 3497, 2938, 1684, 1601, 1342, 862, 765. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 7.06 (d, *J* = 8.1 Hz, 1H), 6.73 (s, 1H), 6.70-6.68 (m, 1H), 3.77 (s, 3H), 3.51 (s, 2H), 2.91-2.81 (m, 2H), 2.65-2.57 (m, 2H), 1.70 (brs, 1H), 1.17 (s, 3H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 158.6, 144.0, 134.4, 125.3, 112.1, 110.3, 70.6, 54.4, 45.4, 43.0, 41.9, 24.0. **HRMS (ESI):** *m/z* calcd for $C_{12}H_{16}O_2Na$ $(M+Na)^+$: 215.1048. Found: 215.1023.

### General procedure-10: Synthesis of ynone-aldehyde 53a-l.

**Step-I:** The aldehyde functionality of 2-bromobenzaldehydes **9** was carried out using ethylene glycol following the general procedure-1, step-I to afford bromo acetal **10** in 81-92% yields.

**Step-II:** *n*-BuLi mediated formylation of **10** using DMF following the general procedure-1, step-II to afford aldehyde **56** in 80-85% yields.

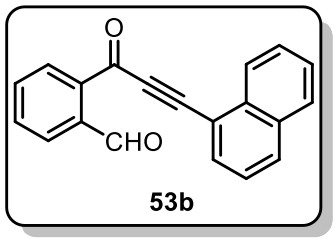
**Step-III:** Alkyne addition to aldehyde **56** and oxidation of corresponding ynol using IBX following the general procedure-1, step-II and III to afford ynone **57** in 78-80% yields (over two-steps).

**Step-IV:** The deprotection of compound **57** using *p*-TSA following the general procedure-1, step-IV to afford ynone-aldehyde **53a-l** in 85-90% yields.

**General procedure-11: Synthesis of benzothiophene- and benzofuran-based ynone-aldehyde 53m-o.**

Benzothiophene- and benzofuran-based ynone-aldehyde **53m-o** were prepared by following the general procedure-10.

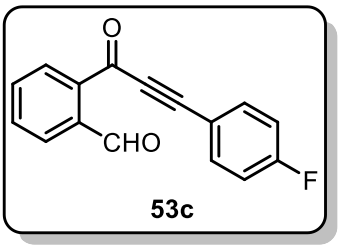
**2-(3-(Naphthalen-1-yl)propioloyl)benzaldehyde (53b).**



**53b**

This compound **53b** was prepared by following the general procedure-10 and was isolated as orange solid. M.P = 90-91 °C. $R_f$ = 0.4 (hexane/EtOAc = 9/1**). IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 2189, 1776, 1695, 1632, 1294, 1220, 986, 774. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 10.63 (s, 1H), 8.46 (d, *J* = 7.3 Hz, 1H), 8.40 (d, *J* = 8.3 Hz, 1H), 8.05-7.98 (m, 3H), 7.95 (d, *J* = 8.1 Hz, 1H), 7.83-7.75 (m, 2H), 7.71-7.67 (m, 1H), 7.62 (t, *J* = 7.4 Hz, 1H), 7.55 (t, *J* = 7.9 Hz, 1H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 192.1, 178.3, 138.7, 137.4, 133.7, 133.6, 133.4, 133.1, 132.9, 132.1, 131.9, 128.7, 128.5, 127.9, 127.1, 125.6, 125.2, 117.1, 92.9, 92.3. **HRMS (ESI):** *m/z* calcd for $C_{20}H_{13}O_2$ $(M+H)^+$: 285.0916. Found: 285.0904.

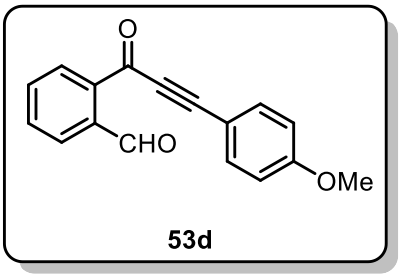
**2-(3-(4-Fluorophenyl)propioloyl)benzaldehyde (53c).**



**53c**

This compound **53c** was prepared following the general procedure-10 and was isolated as pale-yellow solid. M.P = 116-118 °C. $R_f$ = 0.5 (hexane/EtOAc = 4/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 2190, 1688, 1623, 750. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 10.60 (s, 1H), 8.33-8.31 (m, 1H), 7.98-7.95 (m, 1H), 7.79-7.69 (m, 4H), 7.16 (t, *J* = 8.5 Hz, 2H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 192.0, 178.2, 164.3 (d, *J* = 253.3 Hz, 1C), 138.3, 137.4, 135.6 (d, *J* = 9.1 Hz, 2C), 133.5, 132.8, 131.9, 128.5, 116.4 (d, *J* = 22.1 Hz, 2C), 115.7 (d, *J* = 3.2 Hz, 1C), 93.4, 87.5 (d, *J* = 0.9 Hz, 1C). **$^{19}$F NMR (376.5 MHz, $CDCl_3$):** δ -105.0. **HRMS (ESI):** *m/z* calcd for $C_{16}H_{10}FO_2$ $(M+H)^+$: 253.0665. Found: 253.0654.

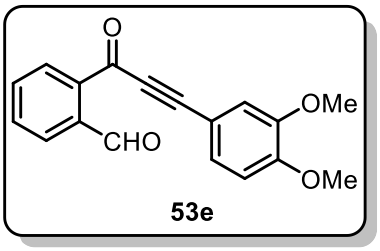
### 2-(3-(4-Methoxyphenyl)propioloyl)benzaldehyde (53d).



**53d**

This compound **53d** was prepared by following the general procedure-10 and was isolated as pale-yellow solid. M.P = 112-114 °C. $R_f$ = 0.5 (hexane/EtOAc = 4/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 2922, 1697, 1624, 1510, 1255. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 10.6 (s, 1H), 8.32 (d, *J* = 7.9 Hz, 1H), 7.96 (dd, *J* = 7.3 and 1.4 Hz, 1H), 7.79-7.71 (m, 2H), 7.66 (d, *J* = 8.7 Hz, 2H), 6.97 (d, *J* = 8.7 Hz, 2H), 3.89 (s, 3H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 192.2, 178.3, 162.2, 138.8, 137.4, 135.4 (2C), 133.2, 132.8, 131.8, 128.4, 114.6 (2C), 111.3, 96.0, 87.9, 55.5. **HRMS (ESI):** *m/z* calcd for $C_{17}H_{13}O_3$ $(M+H)^+$: 265.0865. Found: 265.0854.

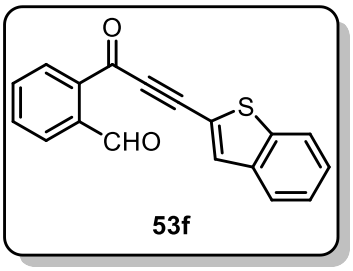
### 2-(3-(3,4-Dimethoxyphenyl)propioloyl)benzaldehyde (53e).



**53e**

This compound **53e** was prepared following the general procedure-10 and was isolated as brown solid. M.P = 137-139 °C. $R_f$ = 0.3 (hexane/EtOAc = 4/1). **IR (thin film, neat):** 2928, 2184, 1694, 1628, 1593, 1514, 1254, 1236, 1138, 1021. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 10.59 (s, 1H), 8.32 (d, *J* = 8.3 Hz, 1H), 7.96 (d, *J* = 7.2 Hz, 1H), 7.79-7.71 (m, 2H), 7.36 (d, *J* = 8.3 Hz, 1H), 7.17 (s, 1H), 6.92 (d, *J* = 8.3 Hz, 1H), 3.97 (s, 3H), 3.94 (s, 3H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 192.2, 178.3, 152.2, 149.0, 138.7, 137.4, 133.2, 132.8, 131.8, 128.4, 128.0, 115.4, 111.3, 111.2, 96.0, 87.7, 56.1, 56.0. **HRMS (ESI):** m/z calcd for $C_{18}H_{15}O_4$ $(M+H)^+$: 295.0970. Found: 295.0957.

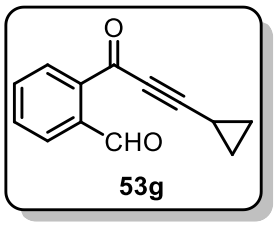
### 2-(3-(Benzo[b]thiophen-2-yl)propioloyl)benzaldehyde (53f).



**53f**

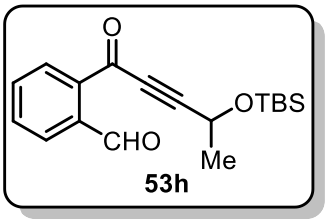
This compound **53f** was prepared following the general procedure-10 and was isolated as yellow solid. M.P = 148-150 °C. $R_f$ = 0.4 (hexane/EtOAc = 9/1**). IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 2923, 2853, 2184, 1694, 1620, 1592, 1269, 987, 738. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 10.56 (s, 1H), 8.32 (d, *J* = 7.4 Hz, 1H), 7.98 (d, *J* = 7.2 Hz, 1H), 7.89-7.85 (m, 3H), 7.82-7.74 (m, 2H), 7.53-7.44 (m, 2H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 192.0, 177.8, 142.0, 138.5, 138.1, 137.5, 134.7, 133.6, 132.9, 132.0, 128.6, 127.2, 125.4, 124.9, 122.3, 119.1, 92.9, 88.2. **HRMS (ESI):** *m/z* calcd for $C_{18}H_{11}O_2S$ $(M+H)^+$: 291.0480. Found: 291.0447.

### 2-(3-Cyclopropylpropioloyl)benzaldehyde (53g).



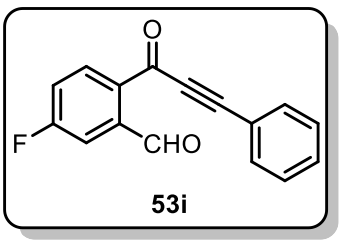

This compound **53g** was prepared following the general procedure-10 and was isolated as pale-yellow oil. $R_f$ = 0.5 (hexane/EtOAc = 9/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 2924, 2209, 1696, 1633, 1266, 916. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 10.51 (s, 1H), 8.19-8.17 (m, 1H), 7.93-7.91 (m, 1H), 7.72-7.69 (m, 2H), 1.59-1.55 (m, 1H), 1.12-1.06 (m, 4H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 192.2, 178.2, 138.7, 137.3, 133.1, 132.7, 131.8, 128.3, 102.9, 76.5, 10.2 (2C), 0.1. **HRMS (ESI):** *m/z* calcd for $C_{13}H_{11}O_2$ $(M+H)^+$: 199.0759. Found: 199.0750.

### 2-(4-((*tert*-Butyldimethylsilyl)oxy)pent-2-ynoyl)benzaldehyde (53h).



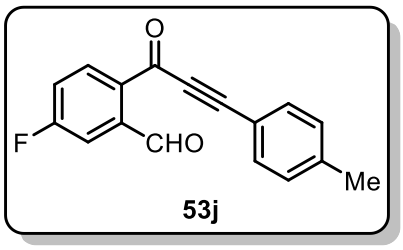

This compound **53h** was prepared following the general procedure-10 and was isolated as yellow oil. $R_f$ = 0.5 (hexane/EtOAc = 9/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 2210, 1699, 1645, 1254, 838. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 10.52 (s, 1H), 8.26-8.22 (m, 1H), 7.95-7.91 (m, 1H), 7.75-7.70 (m, 2H), 4.80 (q, *J* = 6.6 Hz, 1H), 1.58 (d, *J* = 6.6 Hz, 3H), 0.95 (s, 9H), 0.19 (s, 3H), 0.17 (s, 3H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 192.0, 178.2, 137.9, 137.4, 133.4, 132.7, 132.2, 128.4, 97.6, 81.6, 59.0, 25.6(3C), 24.5, 18.1, -4.7, -4.9. **HRMS (ESI):** *m/z* calcd for $C_{18}H_{25}O_3Si$ $(M+H)^+$: 317.1573. Found: 317.1558.

### 4-Fluoro-2-(3-phenylpropioloyl)benzaldehyde (53i).




This compound **53i** was prepared following the general procedure-10 and was isolated as pale-yellow solid. M.P = 82-84 °C. $R_f$ = 0.4 (hexane/EtOAc = 4/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 2195, 1699, 1627, 1580, 755. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 10.6 (s, 1H), 8.41 (dd, *J* = 8.6 and 5.1 Hz, 1H), 7.70 (d, *J* = 7.2 Hz, 2H), 7.63 (dd, *J* = 8.6 and 2.4 Hz, 1H), 7.57-7.53 (m, 1H), 7.48-740 (m, 3H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 190.6, 176.9, 165.4 (d, *J* = 257.2 Hz, 1C), 140.4 (d, *J* = 7.3 Hz, 1C), 135.1 (d, *J* = 8.8 Hz, 1C), 134.5 (d, *J* = 3.4 Hz, 1C), 133.2 (2C), 131.4, 128.8 (2C), 119.5 (d, *J* = 21.9 Hz, 1C), 119.3, 115.7 (d, *J* = 23.3 Hz, 1C), 94.7, 87.3. **$^{19}$F NMR (376.5 MHz, $CDCl_3$):** δ -103.2**. HRMS (ESI):** *m/z* calcd for $C_{16}H_{10}FO_2$ $(M+H)^+$: 253.0665. Found: 253.0653.

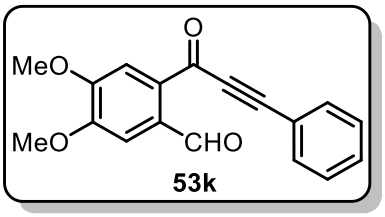
### 4-Fluoro-2-(3-(*p*-tolyl)propioloyl)benzaldehyde (53j).



**53j**

This compound **53j** was prepared following the general procedure-10 and was isolated as pale-yellow solid. M.P = 131-133 °C. $R_f$ = 0.5 (hexane/EtOAc = 4/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 2923, 2195, 1690, 1625, 1580, 755. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 10.5 (s, 1H), 8.40 (dd, *J* = 8.5 and 5.2 Hz, 1H), 7.64-5.59 (m, 3H), 7.43 (*J* = 8.1 and 2.6 Hz, 1H), 7.27 (d, *J* = 7.5 Hz, 2H), 2.45 (s, 3H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 190.7, 176.9, 165.3 (d, *J* = 257.1 Hz, 1C), 142.4, 140.4 (d, *J* = 7.1 Hz, 1C), 135.0 (d, *J* = 8.8 Hz, 1C), 134.8 (d, *J* = 3.0 Hz, 1C), 133.3 (2C), 129.7 (2C), 119.53 (d, *J* = 21.9 Hz, 1C), 116.3, 115.6 (d, *J* = 23.3 Hz, 1C), 95.6, 87.3, 21.9. **$^{19}$F NMR (376.5 MHz, $CDCl_3$):** δ -102.4. **HRMS (ESI):** *m/z* calcd for $C_{17}H_{12}FO_2$ $(M+H)^+$: 267.0821. Found: 267.0809.

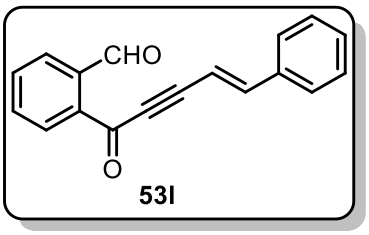
### 4,5-Dimethoxy-2-(3-phenylpropioloyl)benzaldehyde (53k).



**53k**

This compound **53k** was prepared following the general procedure-10 and was isolated as pale-brown solid. M.P = 147-149 °C. $R_f$ = 0.4 (hexane/EtOAc = 4/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 2197, 1680, 1630, 1585, 1519, 1292, 1120. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 10.63 (s, 1H), 7.79 (s, 1H), 7.67 (d, *J* = 7.1 Hz, 2H), 7.55-7.51 (m, 2H), 7.45 (t, *J* = 7.2 Hz, 2H), 4.08 (s, 3H), 4.03 (s, 3H). **$^{13}$C NMR** (100 MHz, $CDCl_3$): δ 191.0, 177.2, 152.7, 152.0, 133.1 (2C), 132.7, 131.7, 131.2, 128.9 (2C), 119.8, 114.0, 109.9, 93.9, 88.0, 56.4, 56.3**. HRMS (ESI):** m/z calcd for $C_{18}H_{15}O_4$ $(M+H)^+$: 295.0970. Found: 295.0956.

### (*E*)-2-(5-Phenylpent-4-en-2-ynoyl)benzaldehyde (53l).

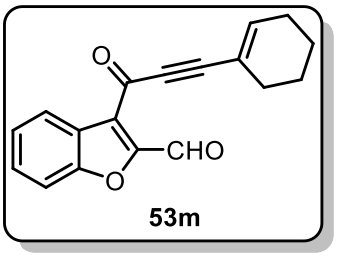


**53l**

This compound **53l** was prepared following the general procedure-10 and was isolated as pale-brown solid. M.P = 64-66 °C. $R_f$ = 0.3 (hexane/EtOAc = 9/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 2924, 2175, 1694, 1631, 1603, 1573, 1284, 1254, 939, 689. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 10.57 (s, 1H), 8.28 (d, *J* = 7.3 Hz, 1H), 7.95 (d, *J* = 7.8 Hz, 1H), 7.78-7.71 (m, 2H), 7.52-7.50 (m, 2H), 7.43-7.39 (m, 5H), 6.41 (d, *J* = 16.3 Hz, 1H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 192.2, 178.2, 149.0, 138.5,

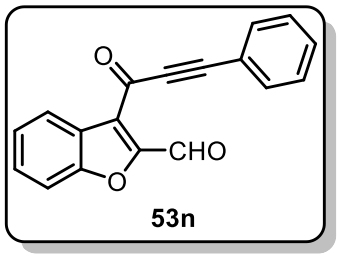
137.4, 134.9, 133.3, 132.8, 131.9, 130.4, 129.0(2C), 128.4, 127.2(2C), 104.8, 94.5, 89.6. **HRMS (ESI):** m/z calcd for $C_{18}H_{13}O_2$ $(M+H)^+$: 261.0916. Found: 261.0905.

### 3-(3-(Cyclohex-1-en-1-yl)propioloyl)benzofuran-2-carbaldehyde (53m).



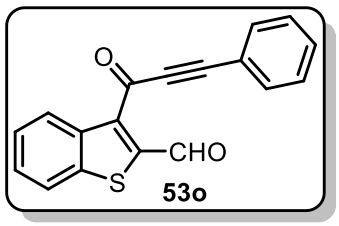

This compound **53m** was prepared following the general procedure-11 and was isolated as pale-yellow semi-solid. $R_f$ = 0.6 (hexane/EtOAc = 7/3). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 2933, 2182, 1682, 1611, 1546, 1446, 1190. **$^1$H NMR (400 MHz, $CDCl_3$):** 10.65 (s, 1H), 8.38 (d, *J* = 7.9 Hz, 1H), 7.67-7.65 (m, 2H), 7.61-7.57 (m, 1H), 7.48 (d, *J* = 7.5 Hz, 1H), 2.31-2.25 (m, 4H), 1.74-1.67 (m, 4H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** 181.0, 171.0, 154.9, 152.6, 145.0, 129.7, 127.3, 125.6, 124.2, 123.9, 118.7, 112.7, 97.1, 88.1, 27.9, 26.4, 21.8, 20.9. **HRMS (ESI):** *m/z* calcd for $C_{18}H_{15}O_3$ $(M+H)^+$: 279.1021. Found: 279.1038.

### 3-(3-Phenylpropioloyl)benzofuran-2-carbaldehyde (53n).




This compound **53n** was prepared following the general procedure-11 and was isolated as pale-yellow solid. M.P = 133-135 °C. $R_f$ = 0.5 (hexane/EtOAc = 8/2). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 2177, 1672, 1608, 1447, 1252, 1164, 1013. **$^1$H NMR (400 MHz, $CDCl_3$):** 10.72 (s, 1H), 8.46 (d, *J* = 7.9 Hz, 1H), 7.74-7.69 (m, 3H), 7.65-7.61 (m, 1H), 7.59-7.55 (m, 1H), 7.53-7.47 (m, 3H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** 180.9, 171.0, 155.0, 152.8, 133.2(2C), 131.7, 129.8, 129.0(2C), 127.1, 125.8, 124.1, 123.7, 119.1, 112.8, 94.6, 89.4. **HRMS (ESI):** *m/z* calcd for $C_{18}H_{11}O_3$ $(M+H)^+$: 275.0708. Found: 275.0721.

### 3-(3-Phenylpropioloyl)benzo[*b*]thiophene-2-carbaldehyde (53o).



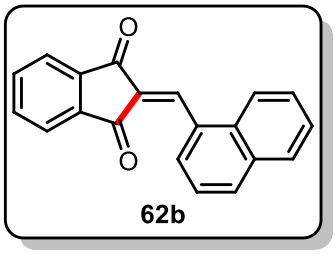

This compound was prepared following the general procedure-11 and was isolated as pale-yellow solid. M.P = 130-132 °C. $R_f$ = 0.5 (hexane/EtOAc = 9/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 2191, 1665**,** 1628, 1495, 1116, 756. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 10.8 (s, 1H), 8.70-8.67 (m, 1H), 7.98-7.96 (m, 1H), 7.69-7.67(m, 2H), 7.61-7.59 (m, 2H), 7.56-7.54 (m, 1H), 7.49-7.45 (m, 2H). **$^{13}$C NMR (100 MHz, $CDCl_3$):**

δ 185.4, 172.0, 148.3, 141.2, 139.6, 137.1, 133.4(2C), 131.7, 128.9(2C), 128.5, 126.5, 126.1, 123.1, 119.2, 95.7, 90.3.

### General procedure-12: Synthesis of 1,3-cyclopentadione-fused arenes and heteroarenes *via* intramolecular hydroacylation reaction

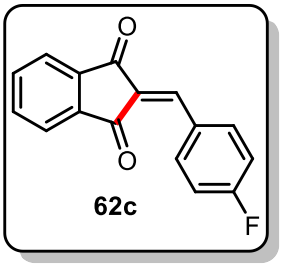
An oven-dried 5 mL glass vial was charged with **53** (1.0 eq, 0.1 mmol), DCM (1.0 mL), and tributylphosphine (0.2 eq, 0.02 mmol) at room temperature and stirred until **53** disappeared as monitored by TLC. Then the reaction was quenched with water and extracted with DCM. The organic extracts were combined, dried over anhydrous sodium sulfate and concentrated. The crude product was purified by silica gel flash chromatography using hexane/ethyl acetate as eluent, to afford **62**.

#### 2-(Naphthalen-1-ylmethylene)-1*H*-indene-1,3(2*H*)-dione (62b).



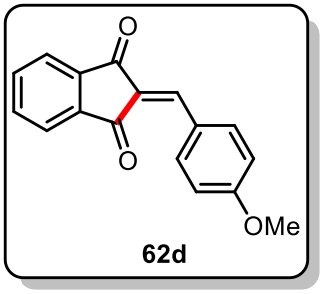

Following the general procedure-12, 20 mg of **53b** afforded 18 mg (90% yield) of **62b** as yellow solid. M.P = 173-174 °C. $R_f$ = 0.4 (hexane/EtOAc = 8/2). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 1693, 1615, 1356, 1226, 770, 728.**$^1$H NMR (400 MHz, $CDCl_3$):** δ 8.82 (s, 1H), 8.78 (d, *J* = 7.3 Hz, 1H), 8.28 (d, *J* = 8.4 Hz, 1H), 8.09-8.06 (m, 2H), 8.04-8.02 (m, 1H), 7.95 (d, *J* = 8.0 Hz, 1H), 7.86-7.84 (m, 2H), 7.68-7.63 (m, 2H), 7.59 (t, *J* = 7.6 Hz, 1H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 190.2, 188.7, 143.1, 142.5, 140.0, 135.4, 135.3, 133.6, 133.5, 132.7, 132.1, 130.0, 129.1, 128.6, 127.6, 126.3, 125.1, 123.6, 123.4(2C). **HRMS (ESI):** *m/z* calcd for: $C_{20}H_{13}O_2$ $(M+H)^+$: 285.0916. Found: 285.0902.

#### 2-(4-Fluorobenzylidene)-1*H*-indene-1,3(2*H*)-dione (62c).




Following the general procedure-12, 20 mg of **53c** afforded 17.6 mg (88% yield) of **62c** as pale-yellow solid. M.P = 179-182 °C. $R_f$ = 0.5 (hexane/EtOAc = 4/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 2917, 1692, 1588, 733. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 8.57-8.54 (m, 2H), 8.04-8.01 (m, 2H), 7.87-7.83 (m, 3H), 7.21 (t, *J* = 8.5 Hz, 2H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 190.2, 189.1, 165.6 (d, *J* = 256.0 Hz), 145.5, 142.4, 140.0, 136.9 (d, *J* = 9.3 Hz, 2C), 135.4, 135.3, 129.6 (d, *J* = 2.9 Hz), 128.6 (d, *J* = 2.3 Hz), 123.4, 123.3, 116.1 (d, *J* = 21.7 Hz, 2C). **$^{19}$F NMR (376.5 MHz, $CDCl_3$):** δ -103.2. **HRMS (ESI):** *m/z* calcd for $C_{16}H_{10}FO_2$ $(M+H)^+$: 253.0665. Found: 253.0656.

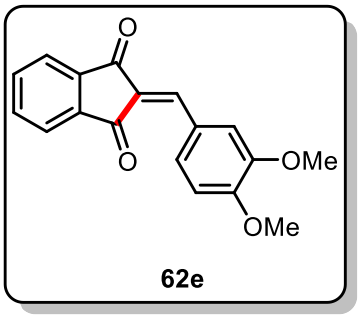
### 2-(4-Methoxybenzylidene)-1*H*-indene-1,3(2*H*)-dione (62d).



**62d**

Following the general procedure-12, 20 mg of **53d** afforded 18 mg (90% yield) of **62d** as pale-yellow solid. M.P = 155-156 °C. $R_f$ = 0.5 (hexane/EtOAc = 4/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 2924, 1684, 1464, 757. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 8.56 (d, *J* = 8.9 Hz, 2H), 8.00-7.98 (m, 2H), 7.86 (s, 1H), 7.81-7.78 (m, 2H), 7.03 (d, *J* = 8.9 Hz, 2H), 3.92 (s, 3H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 191.0, 189.6, 164.1, 147.0, 142.4, 140.0, 137.3(2C), 135.2, 135.0, 126.6, 126.5, 123.2(2C), 114.5(2C), 55.7. **HRMS (ESI):** *m/z* calcd for $C_{17}H_{13}O_3$ $(M+H)^+$: 265.0865. Found: 265.0878.

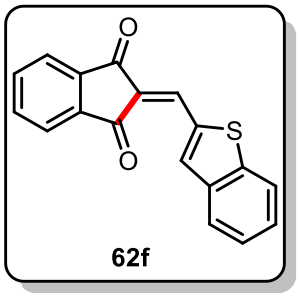
### 2-(3,4-Dimethoxybenzylidene)-1*H*-indene-1,3(2*H*)-dione (62e).



**62e**

Following the general procedure-12, 30 mg of **53e** afforded 26.1 mg (87% yield) of **62e** as yellow solid. M.P = 206-208 °C. $R_f$ = 0.3 (hexane/EtOAc = 4/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 2920, 1703, 1678, 1566, 1517, 1248, 1161, 1145, 739. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 8.87 (s, 1H), 8.00-7.99 (m, 2H), 7.84 (s, 1H), 7.81-7.79 (m, 2H), 7.75 (d, *J* = 8.4 Hz, 1H), 6.97 (d, *J* = 8.4 Hz, 1H), 4.10 (s, 3H), 4.00 (s, 3H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 190.8, 189.8, 154.0, 148.8, 147.5, 142.4, 139.9, 135.1, 134.9, 131.4, 126.9, 126.5, 123.1, 123.0, 115.4, 110.7, 56.1(2C). **HRMS** (ESI): *m/z* calcd for $C_{18}H_{15}O_4$ $(M+H)^+$: 295.0970. Found: 295.0955.

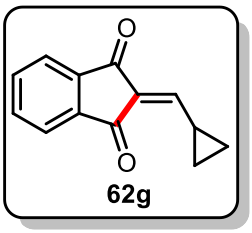
### 2-(Benzo[*b*]thiophen-2-ylmethylene)-1*H*-indene-1,3(2*H*)-dione (62f).



**62f**

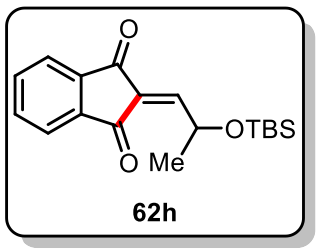
Following the general procedure-12, 20 mg of **53f** afforded 18.2 mg (91% yield) of **62f** as yellow solid. M.P = 213-215 °C. $R_f$ = 0.4 (hexane/EtOAc = 9/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 2921, 2851, 1722, 1687, 1608, 1585, 1356, 731, 722. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 8.30 (s, 1H), 8.08 (s, 1H), 8.04-8.00 (m, 2H), 7.92 (d, *J* = 8.1 Hz, 2H), 7.85-7.80 (m, 2H), 7.51-7.48 (m, 1H), 7.44-7.40 (m, 1H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 190.0, 189.1, 145.7, 142.2, 140.5, 139.0, 138.7, 137.2, 137.0, 135.4, 135.2, 128.0, 126.8, 125.5, 125.2, 123.3, 123.2, 122.7. **HRMS (ESI):** *m/z* calcd for $C_{18}H_{11}O_2S$ $(M+H)^+$: 291.0480. Found: 291.0466.

### 2-(Cyclopropylmethylene)-1*H*-indene-1,3(2*H*)-dione (62g).



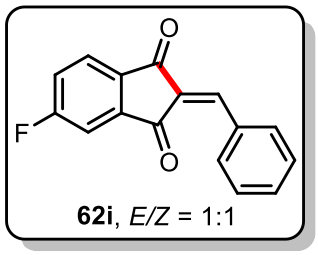

Following the general procedure-12, 20 mg of **53g** afforded 18 mg (90% yield) of **62g** as pale-yellow solid. M.P = 157-160 °C. $R_f$ = 0.5 (hexane/EtOAc = 9/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 2926, 1687, 735. **$^1$H NMR (400 MHz, $CDCl_3$):** 7.97-7.94 (m, 2H), 7.80-7.77 (m, 2H), 6.66 (d, *J* = 11.7 Hz, 1H), 3.33-3.24 (m, 1H), 1.40-1.34 (m, 2H), 1.02-0.98 (m, 2H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 191.1, 189.2, 160.2, 141.9, 139.9, 135.1, 135.0, 129.7, 123.3, 123.0, 14.3, 12.9(2C). **HRMS (ESI):** *m/z* calcd for $C_{13}H_{11}O_2$ $(M+H)^+$: 199.0759. Found: 199.0739.

### 2-(2-((*tert*-Butyldimethylsilyl)oxy)propylidene)-1*H*-indene-1,3(2*H*)-dione (62h).



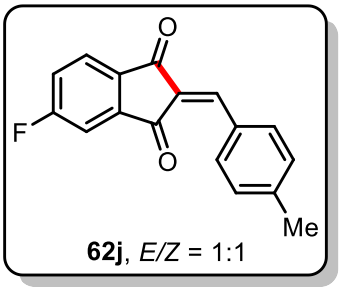

Following the general procedure-12, 100 mg of **53h** afforded 73 mg (73% yield) of **62h** as orange solid. M.P = 42-44 °C. $R_f$ = 0.5 (hexane/EtOAc = 9/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 2956, 2930, 2857, 1737, 1698, 1656, 1348, 737.**$^1$H NMR (400 MHz, $CDCl_3$):** δ 8.02-7.96 (m, 2H), 7.86-7.81 (m, 2H), 7.24 (d, *J* = 7.9 Hz, 1H), 5.81-5.74 (m, 1H), 1.37 (d, *J* = 6.4 Hz, 3H), 0.90 (s, 9H), 0.09 (s, 3H), 0.04 (s, 3H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 189.8, 189.0, 155.8, 141.9, 140.8, 135.54, 135.53, 128.4, 123.5, 123.3, 64.6, 25.7(3C), 23.4, 18.1, -4.6, -4.7. **HRMS (ESI):** *m/z* calcd for: $C_{18}H_{25}O_3Si$ $(M+H)^+$: 317.1573. Found: 317.1560.

### 2-Benzylidene-5-fluoro-1*H*-indene-1,3(2*H*)-dione (62i).




Following the general procedure-12, 30 mg of **53i** afforded 28.5 mg (95% yield) of **62i** as pale-yellow solid. M.P = 172-174 °C. $R_f$ = 0.5 (hexane/EtOAc = 4/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 1678, 1595, 750. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 8.45 (d, *J* = 7.8 Hz, 2H), 8.06-8.02 (m, 1H), 7.906 (s, 1H), 7.65-7.62 (m, 1H), 7.59-7.47 (m, 4H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 189.1, 187.7, 167.2 (d, *J* = 258.1 Hz, 1C), 147.49, 145.2 (d, *J* = 8.9 Hz, 1C), 138.7 (d, *J* = 2.0 Hz, 1C), 134.3 (2C), 133.5, 132.9, 128.9, 128.8(2C), 126.1 (d, *J* = 9.4 Hz, 1C), 123.0 (d, *J* = 23.9 Hz, 1C), 110.1 (d, *J* = 18.2 Hz, 1C). **$^{19}$F NMR (376.5 MHz, $CDCl_3$):** δ -99.2. **HRMS (ESI):** *m/z* calcd for $C_{16}H_{10}FO_2$ $(M+H)^+$: 253.0665. Found: 253.1108.

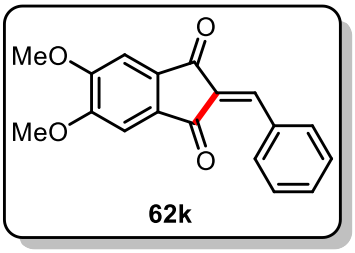
### 5-Fluoro-2-(4-methylbenzylidene)-1*H*-indene-1,3(2*H*)-dione (62j).



**62j**, *E/Z* = 1:1

Following the general procedure-12, 30 mg of **53j** afforded 27 mg (90% yield) of **62j** as pale-yellow solid. M.P = 157-159 °C. $R_f$ = 0.5 (hexane/EtOAc = 4/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 2927, 1676, 1592, 1274, 750. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 8.39 (d, *J* = 7.3 Hz, 2H), 8.05-8.01 (m, 1H), 7.879 (s, 1H), 7.64-7.61 (m, 1H), 7.48 (td, *J* = 8.6 and 2.3 Hz, 1H), 7.34 (d, *J* = 8.0 Hz, 2H), 2.47 (s, 3H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 189.3 (d, *J* = 2.2 Hz, 1C), 188.9, 167.1 (d, *J* = 257.6 Hz, 1C), 147.59, 145.2 (d, *J* = 8.6 Hz, 1C), 145.0, 138.6 (d, *J* = 2.2 Hz, 1C), 134.6(2C), 130.5, 129.7(2C), 128.0, 125.9 (d, *J* = 3.5 Hz, 1C), 122.8 (d, *J* = 23.7 Hz, 1C), 110.0 (d, *J* = 23.1 Hz, 1C), 22.0. **$^{19}$F NMR (376.5 MHz, $CDCl_3$):** δ -99.6. **HRMS (ESI):** *m/z* calcd for $C_{17}H_{12}FO_2$ $(M+H)^+$: 267.0821. Found: 267.0811.

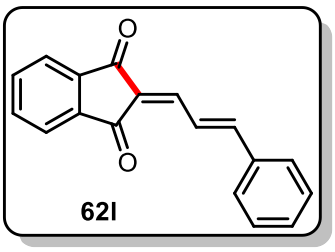
### 2-Benzylidene-5,6-dimethoxy-1*H*-indene-1,3(2*H*)-dione (62k).



**62k**

Following the general procedure-12, 20 mg of **53k** afforded 14.4 mg (72% yield) of **62k** as pale-yellow solid. M.P =188-189 °C. $R_f$ = 0.4 (hexane/EtOAc = 4/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 1717, 1668, 1581, 1497, 1312, 775. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 8.40 (dd, *J* = 7.2 and 1.8 Hz, 2H), 7.72 (s, 1H), 7.52-7.49 (m, 3H), 7.36 (d, *J* = 1.0 Hz, 2H), 4.03 (s, 6H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 189.5, 188.3, 155.6, 155.5, 143.7, 138.0, 135.2, 133.7(2C), 133.2, 132.4, 129.5, 128.6(2C), 103.8, 103.6, 56.74, 56.71. **HRMS (ESI):** *m/z* calcd for: $C_{18}H_{15}O_4$ $(M+H)^+$: 295.0970. Found: 295.0958.

### 2-(3-Phenylallylidene)-1*H*-indene-1,3(2*H*)-dione (62l).

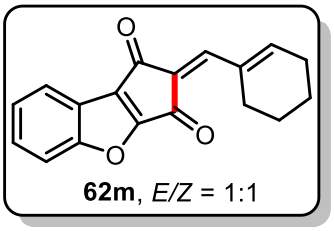


**62l**

Following the general procedure-12, 95 mg of **53l** afforded 68.4 mg (72% yield) of **62l** as yellow solid. M.P = 161-162 °C. $R_f$ = 0.3 (hexane/EtOAc = 9/1**). IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 2924, 1720, 1691, 1611, 1587, 1494, 1368, 1215, 1156, 989, 733. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 8.47 (dd *J* = 15.5 Hz and 12.0 Hz, 1H), 8.01-7.99 (m, 2H), 7.83-7.81 (m, 2H), 7.71-7.66 (m, 3H), 7.48-7.45 (m, 3H), 7.37 (d, *J* = 15.5 Hz, 1H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 190.6, 190.1, 151.2, 144.7, 142.2, 140.8, 135.5,

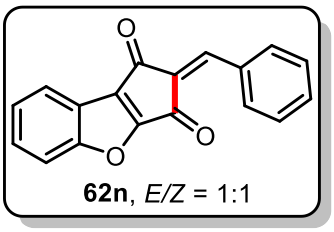
135.2, 135.0, 130.9, 129.0(2C), 128.7(2C), 127.9, 123.6, 123.2, 123.0. **HRMS (ESI):** *m/z* calcd for $C_{18}H_{13}O_2$ $(M+H)^+$: 261.0915. Found: 261.0907.

### 2-(Cyclohex-1-en-1-ylmethylene)-1*H*-cyclopenta[*b*]benzofuran-1,3(2*H*)-dione (62m).



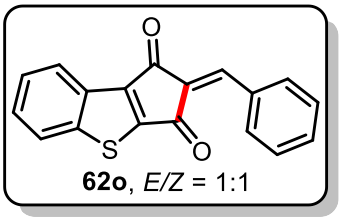

Following the general procedure-12, 22 mg of **53m** afforded 14.7 mg (67% yield) of **62m** as pale-yellow solid. M.P. = 159-161 °C. $R_f$ = 0.6 (hexane/EtOAc = 7/3). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 2926, 1689, 1600, 1409, 1278, 1073. **$^1$H NMR (400 MHz, $CDCl_3$):** 8.43-8.40 (m, 1H), 7.96-7.94 (m, 1H), 7.58-7.56 (m, 2H), 7.21 (s, 1H), 6.81-6.79 (m, 1H), 2.726-2.722 (m, 2H), 2.38-2.35 (m, 2H), 1.74-1.70 (m, 2H), 1.68-1.63 (m, 2H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** 184.9, 182.9, 158.9, 149.1, 148.4, 147.2, 145.9, 136.6, 131.0, 129.1, 128.8, 126.8, 125.9, 123.9, 28.1, 27.8, 22.4, 21.1. **HRMS (ESI):** *m/z* calcd for $C_{18}H_{15}O_3$ $(M+H)^+$: 279.1021. Found: 279.1007.

### 2-Benzylidene-1*H*-cyclopenta[*b*]benzofuran-1,3(2*H*)-dione (62n).




Following the general procedure-12, 25 mg of **53n** afforded 18 mg (72% yield) of **62n** as pale-yellow solid. M.P = 193-195 °C. $R_f$ = 0.5 (hexane/EtOAc = 8/2). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 3060, 1688, 1618, 1439, 1372, 1195. **$^1$H NMR (400 MHz, $CDCl_3$):** 8.31-8.29 (m, 2H), 8.06 (d, *J* = 7.8 Hz, 1H), 7.78 (s, 1H), 7.74-7.71 (m, 1H), 7.63 (t, *J* = 7.8 Hz, 1H), 7.55-7.50 (m, 4H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** 182.1, 178.5, 169.6, 161.6, 143.4, 138.9, 135.8, 133.4(2C), 132.5, 132.3, 130.2, 128.7(2C), 126.2, 123.8, 120.0, 113.7. **HRMS (ESI):** *m/z* calcd for $C_{18}H_{11}O_3$ $(M+H)^+$: 275.0708. Found: 275.0726.

### 2-Benzylidene-1*H*-benzo[*b*]cyclopenta[*d*]thiophene-1,3(2*H*)-dione (62o).



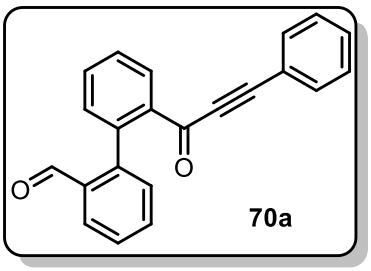

Following the general procedure-12, 20 mg of **53o** afforded 18.2 mg (91% yield) of **62o** as pale-yellow solid. M.P =165-167 °C. $R_f$ = 0.5 (hexane/EtOAc = 9/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 2918, 1729, 1679, 1463, 755. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 8.53-8.48 (m, 1H), 8.40-8.35 (m, 2H), 8.01 (q, *J* = 4.2 Hz, 1H), 7.76 (d, *J* = 10.4 Hz, 1H), 7.64-7.61 (m, 2H), 7.55-7.51 (m, 3H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 189.9, 189.1, 145.7, 142.2, 140.5, 139.1, 138.7, 137.2, 137.0, 135.4, 135.2, 128.0, 126.8,

125.5, 125.2, 123.3, 123.2, 122.7. **HRMS (ESI):** *m/z* calcd for $C_{18}H_{11}O_2S$ $(M+H)^+$: 291.0480. Found: 291.1102.

### General procedure-13: Synthesis of biaryl ynone-aldehydes 70a-l

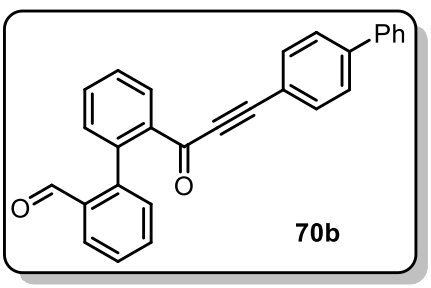
In a sealed tube 2-bromo ynone **73** (1.0 mmol) was dissolved in DMF, and $Pd(PPh_3)_4$ (0.005 mmol), $[HP(^tBu)_3]BF_4$ (0.012 mmol), 2-formyl boronic acid **72** (2.0 mmol), KF (3.3 mmol) and $H_2O$ (60.0 mmol) were added. The reaction tube was degassed with nitrogen using a syringe, and the resulting solution was stirred at 60 °C. The reaction was monitored by TLC until **73** disappeared. Then the reaction was quenched with saturated aq. $NH_4Cl$ solution and extracted using ethyl acetate. The organic extracts were combined dried over anhydrous sodium sulfate and concentrated. The crude product was purified by silica gel column chromatography using hexane/ethyl acetate as eluent to afford biaryl-ynone aldehydes **70**.

#### 2'-(3-Phenylpropioloyl)-[1,1'-biphenyl]-2-carbaldehyde (70a).




This compound **70a** was prepared by following the general procedure-13 and was isolated as pale-yellow viscous oil. $R_f$ = 0.5 (Hexane/EtOAc = 9/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 3061, 2846, 2750, 2195, 1694, 1644, 1594, 1204, 757. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 9.22 (s, 1H), 8.27 (dd, *J* = 7.1 and 1.0 Hz, 1H), 8.02 (d, *J* = 7.7 Hz, 1H), 7.67-7.60 (m, 3H), 7.50 (t, *J* = 7.6, 1H), 7.46-7.43 (m, 3H), 7.37-7.30 (m, 4H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 191.6, 178.6, 144.2, 138.8, 137.1, 134.0, 133.4, 132.9(2C), 132.3, 132.2, 131.4, 130.8, 130.7, 128.5(2C), 128.4, 128.1, 128.0, 119.8, 93.9, 88.1. **HRMS (ESI):** *m/z* calcd for $C_{22}H_{15}O_2$ $(M+H)^+$: 311.1072. Found: 311.1056.

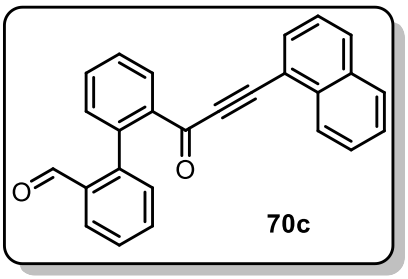
#### 2'-(3-([1,1'-Biphenyl]-4-yl)propioloyl)-[1,1'-biphenyl]-2-carbaldehyde (70b).




This compound **70b** was prepared by following the general procedure-13 and was isolated as yellow oil. $R_f$ = 0.5 (Hexane/EtOAc = 9/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 2924, 2853, 2192, 1693, 1641, 1598, 1300, 1004, 762, 696. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 9.94 (s, 1H), 8.29 (d, *J* = 7.4 Hz, 1H), 8.04 (d, *J* = 7.7 Hz, 1H), 7.66-7.59 (m, 7H), 7.53-7.46 (m, 5H), 7.43-7.39 (m, 1H), 7.34 (t, *J* = 7.4 Hz, 2H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 191.6, 178.6, 144.3, 143.5, 139.7, 138.8, 137.2, 134.0, 133.5(2C), 133.4, 132.3,

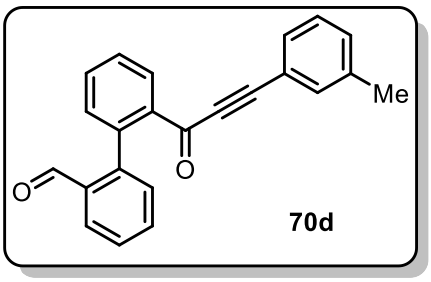
132.2, 131.3, 130.9, 129.0(2C), 128.4, 128.2, 128.0, 127.19(2C), 127.13(3C), 118.5, 94.0, 88.9. **HRMS (ESI):** *m/z* calcd for $C_{28}H_{18}O_2Na$ $(M+Na)^+$: 409.1204. Found: 409.1223.

### 2'-(3-(Naphthalen-1-yl)propioloyl)-[1,1'-biphenyl]-2-carbaldehyde (70c).



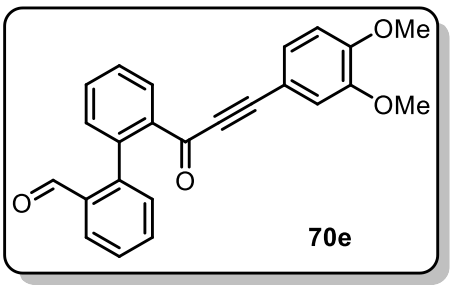

This compound **70c** was prepared by following the general procedure-13 and was isolated as yellow oil. $R_f$ = 0.5 (Hexane/EtOAc = 9/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 3059, 2957, 2923, 2850, 2194, 1693, 1640, 1594, 1296, 1009. **$^1$H NMR (400 MHz, $(CD_3)_2SO$):** δ 9.82 (s, 1H), 8.36-8.34 (m, 1H), 8.15 (d, *J* = 8.2 Hz, 1H), 8.06-8.04 (m, 2H), 7.91 (dd, *J* = 7.7 and 1.1 Hz, 1H), 7.85 (dd, *J* = 7.1 and 1.0 Hz, 1H), 7.81-7.73 (m, 2H), 7.72-7.62 (m, 3H), 7.61-7.53 (m, 2H), 7.45-7.43 (m, 1H), 7.38 (dd, *J* = 7.6 and 0.7 Hz, 1H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 191.6, 178.6, 144.3, 138.8, 137.3, 134.3, 134.0, 133.8, 133.4, 132.5, 132.3, 132.2, 131.3, 130.9, 128.4, 128.3, 128.23(2C), 128.21, 128.08, 128.07, 127.8, 127.0, 117.0, 94.5, 88.5. **HRMS (ESI):** *m/z* calcd for $C_{26}H_{16}O_2Na$ $(M+Na)^+$: 383.1048. Found: 383.1031.

### 2'-(3-(*m*-Tolyl)propioloyl)-[1,1'-biphenyl]-2-carbaldehyde (70d).



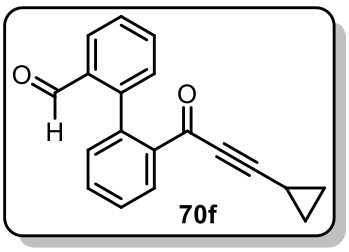

This compound **70d** was prepared by following the general procedure-13 and was isolated as pale-yellow viscous oil. $R_f$ = 0.5 (Hexane/EtOAc = 9/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 3060, 2924, 2850, 2187, 1694, 1641, 1595, 1223, 757, 688. **$^1$H NMR (400 MHz, $(CD_3)_2SO$):** δ 9.78 (s, 1H), 8.24 (d, *J* = 7.6 Hz, 1H), 7.92 (d, *J* = 7.6 Hz, 1H), 7.75-7.68 (m, 3H), 7.57 (t, *J* = 7.5 Hz, 1H), 7.40 (d, *J* = 7.2 Hz, 1H), 7.34-7.32 (m, 5H), 2.31 (s, 3H). **$^{13}$C NMR (100 MHz, $(CD_3)_2SO$):** δ 191.9, 178.4, 143.8, 138.96, 138.93, 137.0, 134.2, 134.0, 133.6, 133.3, 132.59, 132.51, 131.50, 131.4, 130.4, 129.3, 129.1, 128.8, 128.7, 119.0, 93.7, 88.0, 21.0. **HRMS (ESI):** *m/z* calcd for $C_{23}H_{16}O_2Na$ $(M+Na)^+$: 347.1048. Found: 347.1032.

### 2'-(3-(3,4-Dimethoxyphenyl)propioloyl)-[1,1'-biphenyl]-2-carbaldehyde (70e).



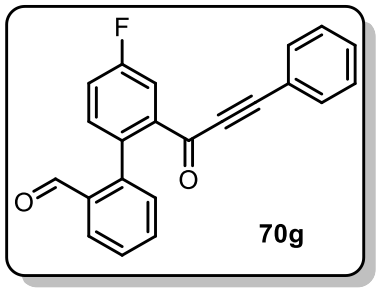

This compound **70e** was prepared by following the general procedure-13 and was isolated as pale-yellow viscous oil. $R_f$ = 0.4 (Hexane/EtOAc = 8/2). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 2925, 2852, 2180, 1693, 1634, 1594, 1513, 1253, 1019. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 9.97 (s, 1H), 8.23-8.20 (m, 1H), 8.03 (d, *J* = 7.7 Hz, 1H), 7.67-7.59 (m, 3H), 7.50 (t, *J* = 7.6 Hz, 1H), 7.35-7.30 (m, 2H), 7.07 (dd, *J* = 8.3 and 1.4 Hz, 1H), 6.86 (d, *J* = 1.4 Hz, 1H), 6.82 (d, *J* = 8.3 Hz, 1H), 3.92 (s, 3H), 3.90 (s, 3H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 191.7, 178.7, 151.6, 148.7, 144.4, 138.5, 137.6, 133.9, 133.4, 132.1, 132.0, 131.1, 131.0, 128.4, 128.1, 127.8, 127.5, 115.2, 111.5, 110.9, 95.4, 88.1, 56.0, 55.9. **HRMS (ESI):** *m/z* calcd for $C_{24}H_{19}O_4$ $(M+H)^+$: 371.1283. Found: 371.1266.

### 2'-(3-Cyclopropylpropioloyl)-[1,1'-biphenyl]-2-carbaldehyde (70f).




This compound **70f** was prepared by following the general procedure-13 and was isolated as colorless oil. $R_f$ = 0.5 (Hexane/EtOAc = 9/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 2956, 2925, 2205, 1694, 1641, 1594, 1567, 1277, 915. **$^1$H NMR (400 MHz, $(CD_3)_2SO$):** δ 9.72 (s, 1H), 8.05 (dd, *J* = 7.6 and 1.2 Hz, 1H), 7.93 (dd, *J* = 7.6 and 1.2 Hz, 1H), 7.70 (dt, *J* = 7.4 and 1.4 Hz, 2H), 7.66-7.59 (m, 2H), 7.36 (dd, *J* = 7.5 and 0.4 Hz, 1H), 7.27 (dd, *J* = 7.5 and 0.8 Hz, 1H), 1.48-1.42 (m, 1H), 0.96-0.92 (m, 2H), 0.69-0.65 (m, 2H). **$^{13}$C NMR (100 MHz, $(CD_3)_2SO$):** δ 191.8, 178.3, 144.0, 138.6, 137.3, 134.1, 134.0, 132.9, 132.3, 131.4, 131.0, 128.9, 128.6, 128.5, 102.8, 77.0, 10.38, 10.30, –0.29. **HRMS (ESI):** *m/z* calcd for $C_{19}H_{15}O_2$ $(M+H)^+$: 275.1072. Found: 275.1086.

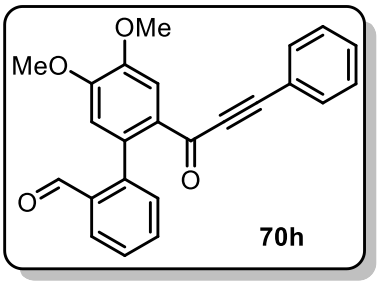
### 4'-Fluoro-2'-(3-phenylpropioloyl)-[1,1'-biphenyl]-2-carbaldehyde (70g).




This compound **70g** was prepared by following the general procedure-13 and was isolated as pale-yellow viscous oil. $R_f$ = 0.5 (Hexane/EtOAc = 9/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 3065, 2922, 2849, 2197, 1694, 1648, 1597, 1160, 761. **$^1$H NMR (400 MHz, $(CD_3)_2SO$):** δ 9.82 (s, 1H), 7.95-7.92 (m, 2H), 7.71 (t, *J* = 7.5 Hz, 1H), 7.64-7.53 (m, 3H), 7.51-7.43 (m, 5H), 7.36 (d, *J* = 7.5 Hz, 1H). **$^{13}$C NMR (100 MHz, $(CD_3)_2SO$):** δ 192.1, 177.2 (d, *J* = 1.9 Hz,

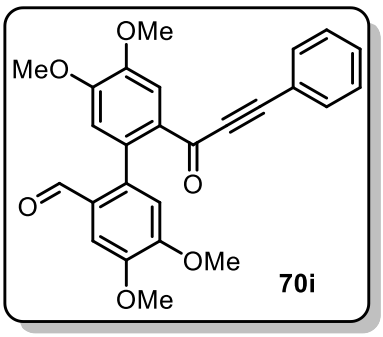
1C), 161.9 (d, *J* = 245.7 Hz, 1C), 142.3, 138.8 (d, *J* = 6.4 Hz, 1C), 135.4 (d, *J* = 3.2 Hz, 1C), 134.6 (d, *J* = 7.7 Hz, 1C), 134.3, 134.2, 133.4(2C), 131.9, 131.7, 129.5, 129.4(2C), 129.0, 120.2 (d, *J* = 21.1 Hz, 1C), 119.0, 117.4 (d, *J* = 23.2 Hz, 1C), 94.3, 87.9. **$^{19}$F NMR (376.5 MHz, $(CD_3)_2SO$):** δ -112.7. **HRMS (ESI):** *m/z* calcd for $C_{22}H_{14}FO_2$ $(M+H)^+$: 329.0978. Found: 329.0964.

### 4',5'-Dimethoxy-2'-(3-phenylpropioloyl)-[1,1'-biphenyl]-2-carbaldehyde (70h).



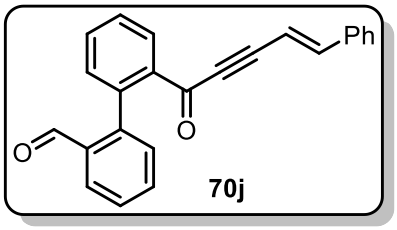

This compound **70h** was prepared by following the general procedure-13 and isolated as pale-yellow viscous oil. $R_f$ = 0.5 (Hexane/EtOAc = 8/2). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 3062, 2934, 2849, 2191, 1694, 1634, 1595, 1516, 1154, 760. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 9.95 (s, 1H), 8.00 (d, *J* = 7.7 Hz, 1H), 7.79 (s, 1H), 7.60 (dt, *J* = 7.4 and 1.0 Hz, 1H), 7.46 (t, *J* = 7.5, 1H), 7.42-7.39 (m, 1H), 7.35-7.31 (m, 5H), 6.75 (s, 1H), 4.06 (s, 3H), 3.94 (s, 3H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 191.7, 176.9, 152.2, 148.5, 144.3, 134.3, 133.6, 133.4, 132.7(2C), 131.3, 130.5, 129.7, 128.4(2C), 128.2, 127.7, 119.9, 114.4, 113.2, 94.1, 88.3, 56.3, 56.2. **HRMS (ESI):** *m/z* calcd for $C_{24}H_{18}O_4Na$ $(M+Na)^+$: 393.1103. Found: 393.1121.

### 4,4',5,5'-Tetramethoxy-2'-(3-phenylpropioloyl)-[1,1'-biphenyl]-2-carbaldehyde (70i).



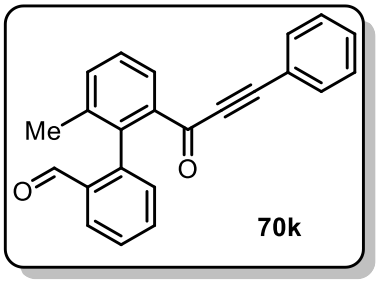

This compound **70i** was prepared by following the general procedure-13 and was isolated as yellow viscous oil. $R_f$ = 0.3 (Hexane/EtOAc = 8/2). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 3003, 2957, 2926, 2192, 1678, 1634, 1594, 1505, 1264, 1024. **$^1$H NMR (400 MHz, $(CD_3)_2SO$):** δ 9.58 (s, 1H), 7.64 (s, 1H), 7.51 (t, *J* = 7.5 Hz, 1H), 7.42 (t, *J* = 7.6 Hz, 2H), 7.35 (d, *J* = 9.8 Hz, 3H), 7.02 (s, 1H), 6.97 (s, 1H), 3.93 (s, 3H), 3.89 (s, 3H), 3.84 (s, 3H), 3.74 (s, 3H). **$^{13}$C NMR (100 MHz, $(CD_3)_2SO$):** δ 190.0, 176.6, 153.5, 152.6, 149.1, 148.7, 139.3, 133.3, 132.8(2C), 131.3, 130.1, 129.2(2C), 128.0, 119.6, 115.5, 114.2, 112.8, 108.9, 93.2, 88.4, 56.6, 56.5, 56.1, 55.9. **HRMS (ESI):** *m/z* calcd for $C_{26}H_{22}O_6Na$ $(M+Na)^+$: 453.1314. Found: 453.1293.

### (*E*)-2'-(5-phenylpent-4-en-2-ynoyl)-[1,1'-biphenyl]-2-carbaldehyde (70j).



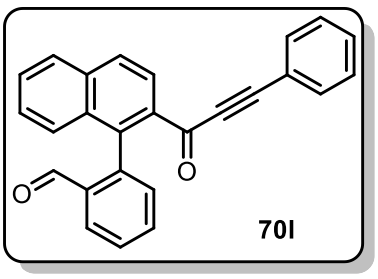

This compound **70j** was prepared by following the general procedure-13 and was isolated as yellow viscous oil. $R_f$ = 0.5 (Hexane/EtOAc = 9/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 2956, 2853, 2173, 1693, 1637, 1595, 1280. **$^1$H NMR (400 MHz, $(CD_3)_2SO$):** δ 9.76 (s, 1H), 8.18 (dd, *J* = 7.4 and 0.7 Hz, 1H), 7.94 (d, *J* = 7.2 Hz, 1H), 7.76-7.67 (m, 3H), 7.62-7.59 (m, 3H), 7.42-7.39 (m, 4H), 7.33 (d, *J* = 7.4 Hz, 1H), 7.27 (d, *J* = 16.3 Hz, 1H), 7.55 (d, *J* = 16.3 Hz, 1H). **$^{13}$C NMR (100 MHz, $(CD_3)_2SO$):** δ 191.9, 178.2, 148.6, 143.9, 138.9, 137.1, 135.3, 134.2, 134.0, 133.3, 132.4, 131.3(2C), 130.7, 129.4(2C), 129.0, 128.8, 128.7, 127.7(2C), 105.5, 94.3, 90.3. **HRMS (ESI):** *m/z* calcd for $C_{24}H_{16}O_2Na$ $(M+Na)^+$: 359.1048. Found: 359.1029.

### 2'-Methyl-6'-(3-phenylpropioloyl)-[1,1'-biphenyl]-2-carbaldehyde (70k).




This compound **70k** was prepared by following the general procedure-13 and was isolated as pale-yellow viscous oil. $R_f$ = 0.5 (Hexane/EtOAc = 9/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 3036, 2925, 2854, 2195, 1688, 1644, 1592, 759, 689. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 9.73 (s, 1H), 8.35 (d, *J* = 7.6 Hz, 1H), 7.86 (d, *J* = 7.6 Hz, 1H), 7.71-7.62 (m, 2H), 7.50-7.44 (m, 4H), 7.42-7.36 (m, 3H), 7.24 (d, *J* = 7.3 Hz, 1H), 2.04 (s, 3H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 192.0, 178.1, 143.9, 137.9, 137.0, 136.7, 135.3, 134.1, 132.9(3C), 131.7, 131.6, 130.7, 128.5(2C), 128.4, 127.8, 125.5, 119.8, 93.6, 87.8, 19.8. **HRMS (ESI):** *m/z* calcd for $C_{23}H_{16}O_2Na$ $(M+Na)^+$: 347.1048. Found: 347.1031.

### 2-(2-(3-Phenylpropioloyl)naphthalen-1-yl)benzaldehyde (70l).



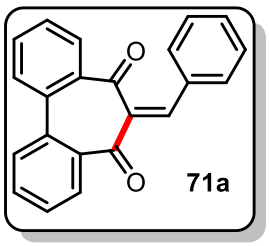

This compound was prepared by following the general procedure-13 and was isolated as yellow viscous oil. $R_f$ = 0.5 (Hexane/EtOAc = 9/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 3061, 2849, 2195, 1691, 1643, 1594, 758. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 9.89 (s, 1H), 8.43-8.40 (m, 1H), 8.07 (d, *J* = 8.6 Hz, 1H), 7.90 (d, *J* = 8.5 Hz, 2H), 7.76-7.74 (m, 2H), 7.63-7.59 (m, 1H), 7.46-7.39 (m, 4H), 7.33-7.29 (m, 2H), 7.26-7.24 (m, 2H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 191.8, 177.8, 145.2, 138.1, 136.2, 136.0, 132.87, 132.84(2C), 132.6, 132.5, 131.5, 131.3,

130.6, 129.0, 128.7, 128.6, 128.4(2C), 128.3, 127.1, 127.0, 122.3, 119.6, 93.9, 87.9. **HRMS (ESI):** *m/z* calcd for $C_{26}H_{17}O_2$ $(M+H)^+$: 361.1229. Found: 361.1245.

### General procedure-14: Synthesis of 1,3-cycloheptadione *via* intramolecular hydroacylation reaction

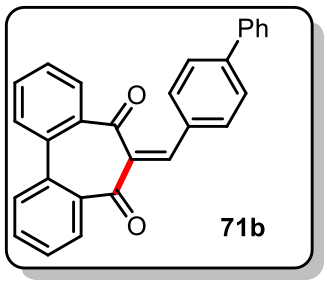
An oven dried 5 mL glass vial was charged with **70** (0.1 mmol), toluene (1.0 mL) and tricyclohexylphosphine (0.01 mmol) at room temperature and stirring continued at 40 °C until **70** disappeared as monitored by TLC. Then the reaction was quenched with water and extracted using ethyl acetate. The organic extracts were combined and dried over anhydrous sodium sulfate and concentrated. The crude product was purified by silica gel flash chromatography using hexane/ethyl acetate as eluent, to afford **71**.

### 6-Benzylidene-5*H*-dibenzo[*a*,*c*][7]annulene-5,7(6*H*)-dione (71a).




This compound was isolated as pale-yellow solid. Following the general procedure-14, 40 mg of **70a** afforded 34.4 mg of **71a** (86% yield). M.P = 138-140 °C. $R_f$ = 0.7 (Hexane/EtOAc = 19/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 3063, 2922, 2852, 1689, 1651, 1582, 1565, 752. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 7.99 (s, 1H), 7.87 (d, *J* = 7.7 Hz, 1H), 7.71 (d, *J* = 7.5 Hz, 2H), 7.67-7.60 (m, 3H), 7.52-7.44 (m, 7H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 198.8, 189.1, 145.1, 142.0, 140.6, 137.5, 137.1, 135.0, 133.3, 133.0, 131.6, 131.2, 130.9(2C), 130.66, 130.60, 129.3, 128.8, 128.7(2C), 128.5, 125.2. **HRMS (ESI):** *m/z* calcd for $C_{22}H_{15}O_2$ $(M+H)^+$: 311.1072. Found: 311.1057.

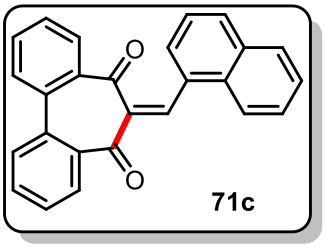
### 6-([1,1'-Biphenyl]-4-ylmethylene)-5*H*-dibenzo[*a*,*c*][7]annulene-5,7(6*H*)-dione (71b).




This compound was isolated as yellow oil. Following the general procedure-14, 35 mg of **70b** afforded 26.2 mg of **71b** (75% yield). $R_f$ = 0.6 (Hexane/EtOAc = 9/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 3061, 2925, 1691, 1651, 1567, 1258, 1000, 761. **$^1$H NMR (400 MHz, $(CD_3)_2SO$):** δ 7.92 (s, 1H), 7.84 (s, 4H), 7.80-7.73 (m, 6H), 7.63-7.59 (m, 4H), 7.52 (t, *J* = 7.2 Hz, 2H), 7.45-7.42 (m, 1H). **$^{13}$C NMR (100 MHz, $(CD_3)_2SO$):** δ 199.5, 188.5, 144.1, 143.5, 141.6, 140.4, 139.2, 137.3, 136.6, 134.4, 134.0, 132.6, 132.2(2C), 132.1, 131.2, 130.7, 130.0, 129.8, 129.6(2C), 129.3, 128.8,

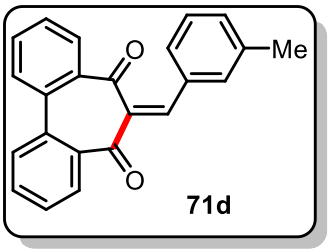
127.5(2C), 127.3(2C), 125.4. **HRMS (ESI):** *m/z* calcd for $C_{28}H_{19}O_2$ $(M+H)^+$: 387.1385. Found: 387.1399.

### 6-(Naphthalen-1-ylmethylene)-5*H*-dibenzo[*a*,*c*][7]annulene-5,7(6*H*)-dione (71c).



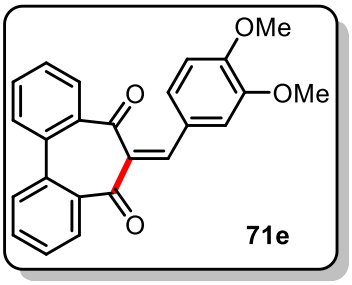

This compound was isolated as yellow oil. Following the general procedure-14, 30 mg of **70c** afforded 22.2 mg of **71c** (74% yield). $R_f$ = 0.6 (Hexane/EtOAc = 9/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 2924, 2852, 1696, 1597, 1263, 751. **$^1$H NMR (400 MHz, $(CD_3)_2SO$):** δ 8.52 (s, 1H), 8.07- 8.02 (m, 2H), 7.96-7.93 (m, 1H), 7.83-7.73 (m, 4H), 7.62-7.61 (m, 7H), 7.36 (d, *J* = 7.5 Hz, 1H). **$^{13}$C NMR (100 MHz, $(CD_3)_2SO$):** δ 197.4, 189.0, 145.1, 144.6, 140.2, 137.6, 136.6, 134.7, 134.0, 133.4, 132.7, 131.7, 131.3, 131.2, 131.0, 130.5, 130.2, 129.8, 129.3, 129.2, 127.7, 127.2, 127.1, 126.3, 125.9, 124.6. **HRMS (ESI):** *m/z* calcd for $C_{26}H_{17}O_2$ $(M+H)^+$: 361.1229. Found: 361.1216.

### 6-(3-Methylbenzylidene)-5*H*-dibenzo[*a*,*c*][7]annulene-5,7(6*H*)-dione (71d).




This compound was isolated as yellow solid. Following the general procedure-14, 40 mg of **70d** afforded 34.4 mg of **71d** (86% yield). M.P = 148-150 $^oC$. $R_f$ = 0.7 (Hexane/EtOAc = 19/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 3061, 2921, 1690, 1652, 1593, 1566, 1227, 743. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 7.97 (s, 1H), 7.87 (d, *J* = 7.6 Hz, 1H), 7.67-7.60 (m, 3H), 7.54-7.46 (m, 6H), 7.35 (t, *J* = 7.5 Hz, 1H), 7.29 (d, *J* = 7.4 Hz, 1H), 2.43 (s, 3H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 198.8, 189.0, 145.4, 141.9, 140.7, 138.4, 137.6, 137.1, 135.1, 133.3, 133.0, 132.1, 131.7, 131.6, 130.66, 130.60, 129.3, 128.7, 128.6, 128.5, 127.8, 125.2, 21.4. **HRMS (ESI):** *m/z* calcd for $C_{23}H_{17}O_2$ $(M+H)^+$: 325.1229. Found: 325.1214.

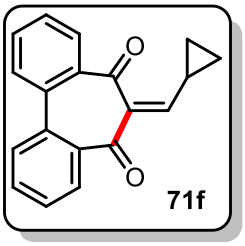
### 6-(3,4-Dimethoxybenzylidene)-5*H*-dibenzo[*a*,*c*][7]annulene-5,7(6*H*)-dione (71e).




This compound was isolated as yellow oil. Following the general procedure-14, 40 mg of **70e** afforded 31.2 mg of **71e** (78% yield). $R_f$ = 0.4 (Hexane/EtOAc = 9/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 2956, 2925, 2853, 1682, 1646, 1594, 1512, 1267, 1022, 737. **$^1$H NMR (400 MHz, $(CD_3)_2SO$):** δ 7.82 (s, 1H), 7.77-7.71 (m, 4H), 7.62-7.57 (m, 3H), 7.47 (d, *J* = 7.6 Hz, 2H), 7.43 (s,

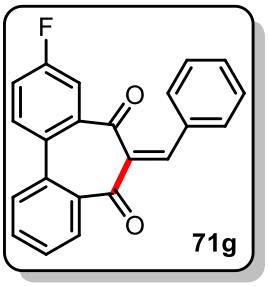
1H), 7.12 (d, *J* = 8.4 Hz, 1H), 3.86 (s, 3H), 3.84 (s, 3H). **$^{13}$C NMR (100 MHz, $(CD_3)_2SO$):** δ 199.9, 188.6, 153.0, 148.9, 144.7, 140.8, 139.1, 137.6, 136.5, 134.1, 133.7, 132.4, 130.9, 130.6, 129.8, 129.7, 129.2, 127.4, 125.5, 125.2, 114.2, 112.2, 56.2, 56.0. **HRMS (ESI):** *m/z* calcd for $C_{24}H_{17}O_4$ $(M-H)^+$: 369.1127. Found: 369.1119.

### 6-(Cyclopropylmethylene)-5*H*-dibenzo[*a*,*c*][7]annulene-5,7(6*H*)-dione (71f).




This compound was isolated as colorless oil. Following the general procedure-14, 30 mg of **70f** afforded 24.6 mg of **71f** (82% yield). $R_f$ = 0.6 (Hexane/EtOAc = 9/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 2923, 2851, 1743, 1693, 1679, 1648, 1594, 1570, 1290, 898, 740. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 7.69 (dd, *J* = 7.6 and 1.4 Hz, 1H), 7.63-7.58 (m, 3H), 7.54-7.52 (m, 1H), 7.50-7.44 (m, 3H), 7.65 (d, *J* = 11.6 Hz, 1H), 2.63-2.54 (m, 1H), 1.32-1.27 (m, 2H), 0.99-0.95 (m, 2H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 195.9, 190.6, 161.5, 142.2, 140.5, 138.8, 136.6, 135.5, 132.4, 131.8, 130.0, 129.5, 129.4, 128.5, 128.3, 127.4, 14.6, 12.1(2C). **HRMS (ESI):** *m/z* calcd for $C_{19}H_{14}O_2Na$ $(M+Na)^+$: 297.0891. Found: 297.0876.

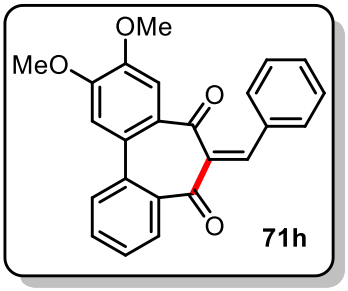
### 6-Benzylidene-3-fluoro-5*H*-dibenzo[*a*,*c*][7]annulene-5,7(6*H*)-dione (major isomer) (71g).




This compound was isolated as pale-yellow viscous oil. Following the general procedure-14, 40 mg of **70g** afforded 33.2 mg of **71g** (83% yield). $R_f$ = 0.6 (Hexane/EtOAc = 9/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 3065, 2957, 2925, 2855, 1689, 1652, 1596, 1566, 1280, 761. **$^1$H NMR (400 MHz, $(CD_3)_2SO$):** δ 7.90 (d, *J* = 4.8 Hz, 1H), 7.83-7.64 (m, 5H), 7.62-7.51 (m, 6H), 7.46 (dd, *J* = 8.2 and 2.2 Hz, 1H). **$^{13}$C NMR (100 MHz, $(CD_3)_2SO$):** δ 198.9, 188.6, 162.6 (d, *J* = 248.0 Hz, 1C), 145.7, 141.4, 140.2, 137.6, 134.0, 133.0, 132.9 (d, *J* = 3.4 Hz, 1C), 132.2, 131.4(2C), 131.2, 130.2, 129.5(2C), 129.4, 121.2 (d, *J* = 21.5 Hz, 1C), 119.7, 117.1, 112.5 (d, *J* = 23.5 Hz, 1C). **$^{19}$F NMR (376.5 MHz, $(CD_3)_2SO$):** δ -112.9. **HRMS (ESI):** *m/z* calcd for $C_{22}H_{14}FO_2$ $(M+H)^+$: 329.0978. Found: 329.0962.

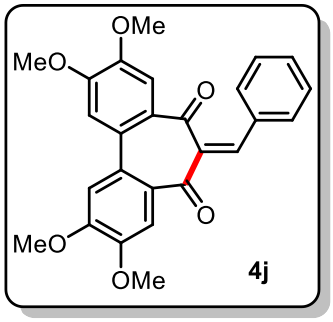
### 6-Benzylidene-2,3-dimethoxy-5*H*-dibenzo[*a*,*c*][7]annulene-5,7(6*H*)-dione (major isomer) (71h).

This compound was isolated as yellow viscous oil. Following the general procedure-14, 35 mg of **70h** afforded 30.1 mg of **71h** (86% yield). $R_f$ = 0.4 (Hexane/EtOAc = 8/2). **IR (thin film,**



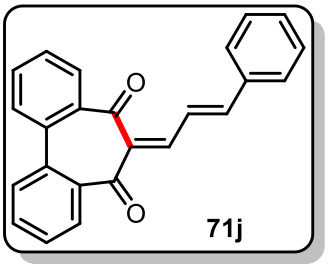

**neat):** $\nu_{max}$/cm$^{-1}$ 3060, 2931, 2850, 1688, 1650, 1596, 1518, 1274, 1163, 759. **$^{1}$H NMR (400 MHz, CDCl$_3$):** δ 7.96 (s, 1H), 7.67-7.57 (m, 4H), 7.45-7.41 (m, 6H), 6.90 (s, 1H), 4.00 (s, 6H). **$^{13}$C NMR (100 MHz, CDCl$_3$):** δ 199.3, 186.8, 153.0, 149.0, 144.6, 142.4, 140.3, 135.1, 133.5, 131.7, 131.5, 131.0, 130.7(2C), 129.1, 128.7(2C), 128.6, 128.4, 125.0, 113.0, 112.8, 56.2, 56.1. **HRMS (ESI):** *m/z* calcd for $C_{24}H_{19}O_4$ $(M+H)^+$: 371. 1283. Found: 371.1267.

### 6-Benzylidene-2,3,9,10-tetramethoxy-5*H*-dibenzo[*a*,*c*][7]annulene-5,7(6*H*)-dione (71i).



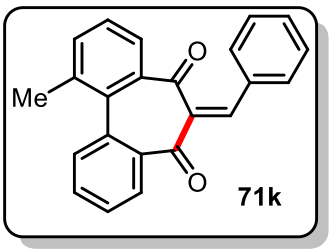

This compound was isolated as pale-yellow viscous oil. Following the general procedure-14, 50 mg of **70i** afforded 36 mg of **71i** (72% yield). $R_f$ = 0.4 (Hexane/EtOAc = 7/3). **IR (thin film, neat):** $\nu_{max}$/cm$^{-1}$ 2926, 1644, 1596, 1509, 1463, 1397, 1261, 1143, 1041, 763. **$^{1}$H NMR (400 MHz, CDCl$_3$):** δ 7.77 (s, 1H), 7.65-7.64 (m, 2H), 7.50-7.49 (m, 3H), 7.33 (s, 1H), 7.29 (s, 1H), 7.08 (s, 1H), 6.95 (s, 1H), 3.94 (d, *J* = 6.1 Hz, 6H), 3.86 (s, 3H), 3.82 (s, 3H). **$^{13}$C NMR (100 MHz, CDCl$_3$):** δ 198.6, 186.5, 153.4, 152.1, 149.3, 148.7, 143.8, 143.0, 133.5, 132.2, 131.7, 131.5, 130.9(2C), 129.3(2C), 128.67, 128.60, 114.0, 113.5, 113.0, 108.5, 56.5, 56.49, 56.43, 56.1. **HRMS (ESI):** *m/z* calcd for $C_{26}H_{22}O_6Na$ $(M+Na)^+$: 453.1314. Found: 453.1298.

### 6-(3-Phenylallylidene)-5*H*-dibenzo[*a*,*c*][7]annulene-5,7(6*H*)-dione (major isomer) (71j).



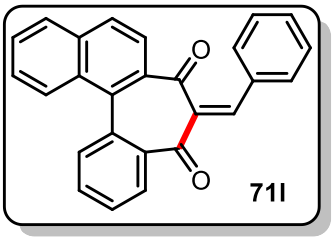

This compound was isolated as pale-yellow viscous oil. Following the general procedure-14, 20 mg of **70j** afforded 14.8 mg of **71j** (74% yield). $R_f$ = 0.6 (Hexane/EtOAc = 9/1). **IR (thin film, neat):** $\nu_{max}$/cm$^{-1}$ 3059, 2922, 2855, 1733, 1651, 1530, 1493, 746. **$^{1}$H NMR (400 MHz, (CD$_3$)$_2$SO):** δ 7.95-7.93 (m, 2H), 7.80-7.76 (m, 2H), 7.70-7.68 (m, 1H), 7.61-7.57 (m, 4H), 7.50-7.46 (m, 2H), 7.45-7.42 (m, 1H), 7.14 (d, *J* = 6.8 Hz, 1H), 7.04 (d, *J* = 6.8 Hz, 1H), 6.40 (d, *J* = 6.8 Hz, 1H), 6.38 (s, 1H). **$^{13}$C NMR (100 MHz, (CD$_3$)$_2$SO):** δ 187.9, 180.0, 156.7, 139.1, 137.6, 133.1, 132.9, 132.3, 131.2, 131.1, 130.8, 129.7, 129.5(2C), 129.0, 128.9, 128.8, 128.1, 127.9, 126.0(2C), 121.7, 92.2, 74.9. **HRMS (ESI):** *m/z* calcd for $C_{24}H_{17}O_2$ $(M+H)^+$: 337.1229. Found: 337.1216.

**6-Benzylidene-1-methyl-5*H*-dibenzo[*a*,*c*][7]annulene-5,7(6*H*)-dione (71k).**




This compound was isolated as yellow viscous oil. Following the general procedure-14, 30 mg of **70k** afforded 20.4 mg of **71k** (68% yield). $R_f$ = 0.7 (Hexane/EtOAc = 19/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 3062, 2924, 2854, 1690, 1651, 1594, 1565, 1286, 993, 741. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 7.88 (s, 1H), 7.77 (dd, *J* = 7.7 and 1.1 Hz, 1H), 7.60 (dd, *J* = 7.0 and 1.3 Hz, 2H), 7.57 (dt, *J* = 7.5 and 1.3 Hz, 1H), 7.47-7.44 (m, 5H), 7.34 (d, *J* = 7.7 Hz, 2H), 7.22 (d, *J* = 7.4 Hz, 1H), 2.39 (s, 3H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 198.9, 190.0, 143.2, 142.5, 141.8, 138.3, 136.9, 135.4, 135.1, 133.9, 131.9, 131.5, 131.2, 131.1(2C), 130.9, 129.8, 128.7(2C), 128.5, 128.2, 122.0, 21.1. **HRMS (ESI):** *m/z* calcd for $C_{23}H_{17}O_2$ $(M+H)^+$: 325.1229. Found: 325.1212.

**8-Benzylidene-7*H*-benzo[6,7]cyclohepta[1,2-*a*]naphthalene-7,9(8*H*)-dione (71l).**




This compound was isolated as pale-yellow viscous oil. Following the general procedure-14, 40 mg of **70l** afforded 29.2 mg of **71l** (73% yield). $R_f$ = 0.6 (Hexane/EtOAc = 19/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 3059, 2926, 1693, 1659, 1591, 1250, 761. **$^1$H NMR (400 MHz, $(CD_3)_2SO$):** δ 8.15 (d, *J* = 8.7 Hz, 1H), 8.09 (d, *J* = 8.0 Hz, 1H), 7.97 (d, *J* = 8.4 Hz, 1H), 7.82 (s, 1H), 7.79-7.70 (m, 4H), 7.69-7.61 (m, 4H), 7.59-7.52 (m, 4H). **$^{13}$C NMR (100 MHz, $(CD_3)_2SO$):** δ 199.3, 189.4, 143.5, 142.9, 138.4, 137.9, 135.2, 133.8, 133.4, 133.0, 132.5, 132.14, 132.13, 131.4, 131.3(2C), 130.5, 130.3, 129.53, 129.51(2C), 128.5, 128.3, 126.1, 125.1, 121.3. **HRMS (ESI):** *m/z* calcd for $C_{26}H_{17}O_2$ $(M+H)^+$: 361.1229. Found: 361.1212.

**General procedure-15: Synthesis of 3-(3-Phenylpropioloyl)benzo[*b*]thiophene-2-carbaldehyde-*d* (53oD).**

**Step-I:** In an oven dried RB flask, benzothiophene-2-carbaldehyde **75** (1.0 g, 6.17 mmol), propane-1,3-dithiol (8.0 mmol, 0.86 mL) and *p*-TSA (0.16 mmol, 27 mg) were dissolved in toluene (6.0 mL). The reaction mixture was refluxed in a Dean-Stark set-up for 2 h until the completion consumption of starting material (by TLC). Upon completion, the reaction mixture was quenched by adding saturated aq. $NaHCO_3$ solution and extracted with EtOAc. The combined organic layers were dried over $Na_2SO_4$, and concentrated under reduced

pressure. The crude product was purified by silica gel column chromatography using 10% ethyl acetate/hexane as an eluent to afford the **76** in near quantitative yield.

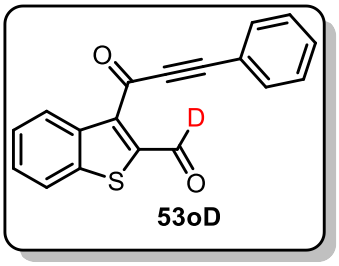
**Step-II:** To a solution of **76** (1.0 g, 4 mmol) in anhydrous THF (7 mL) at −78°C, was added *n*-BuLi (1.6 M in hexane, 3.2 mL, 5.2 mmol) and stirring was continued at −78°C for 40 minutes. Following this, the reaction mixture was warmed to 0 °C and $D_2O$ (0.25 mL) was added and stirring continued for 1 h. The reaction mixture was quenched with saturated aq. $NH_4Cl$ solution and extracted with ethyl acetate. The organic layer was dried and the residue was chromatographed on silica to give **77**.

**Step-III:** IBX (2.2g, 7.9 mmol) was dissolved in DMSO (4.0 mL) with vigorous stirring for approximately 30 min at ambient temperature. This solution was then added to a solution of **77** (1.0 g, 3.9 mmol) in DMSO/$H_2O$ (4:1, 3.0 mL) and stirred at room temperature. The reaction was monitored by TLC until complete consumption of starting material was observed. The mixture was quenched by addition of saturated aqueous $Na_2S_2O_3$ (5 mL). Following extraction with ether (2x5 mL), the organic phase was washed with water, dried over anhydrous sodium sulfate, and concentrated. Final purification was done by column chromatography (silica gel) to furnish the desired aldehyde **78**.

**Step-IV:** To a stirred solution of **78** (500 mg, 3.0 mmol) in DCM (7.0 mL) at 0 °C, was added molecular bromine (0.23 mL, 4.6 mmol). After 15 min of addition, the reaction was warmed to room temperature and continued overnight. Upon completion, the mixture was quenched by addition of saturated aqueous $Na_2S_2O_3$ (5.0 mL) and extracted with DCM. The organic layer was dried and the residue chromatographed on silica to give 3-bromobenzo[*b*]thiophene-2-carbaldehyde-*d* **79**.

**Step-V to Step-IX:** The same procedure was followed as described in general procedure 11.

### 3-(3-Phenylpropioloyl)benzo[*b*]thiophene-2-carbaldehyde-*d* (53oD).

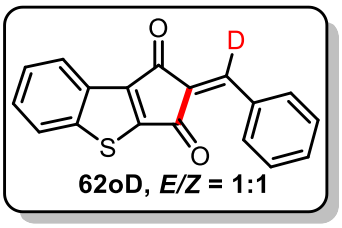


**53oD**

This compound was prepared following the general procedure-15 and isolated as pale-yellow solid (~95%D). M.P = 112-114 °C. $R_f$ = 0.5 (hexane/EtOAc = 9/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 2889, 2191, 1772, 1649, 1490, 1276, 750. **$^1$H NMR (400 MHz, $CDCl_3$):** 10.81 (s, 0.05H), 8.69-8.67 (m, 1H), 7.96-7.94 (m, 1H), 7.67 (d, *J* = 7.8 Hz, 2H), 7.61-754 (m, 3H), 7.48- 7.44 (m, 2H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 185.0 (t, *J* = 30.2 Hz, CD), 172.0, 148.3, 141.2, 139.6, 137.1, 133.4(2C), 131.7, 129(2C), 128.4,

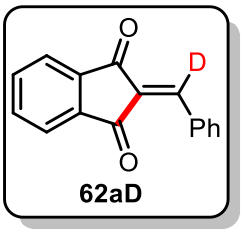
126.5, 126.1, 123.1, 119.2, 95.7, 90.3. **HRMS** (ESI): *m/z* calcd for $C_{18}H_8DO_2S(M-H)^+$: 290.0386, Found: 290.0374.

### 2-Benzylidene-1*H*-benzo[*b*]cyclopenta[*d*]thiophene-1,3(2*H*)-dione-*d* (62oD).



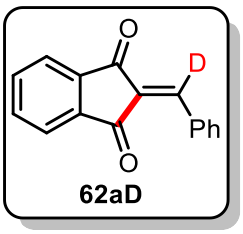

Following the general procedure-14, 25 mg of **53oD** afforded 22.5 mg (90% yield) of **62oD** as pale-yellow solid. M.P = 180-182 °C. $R_f$ = 0.5 (hexane/EtOAc = 9/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 2919, 1710, 1677, 1612, 1504, 1463, 1449, 737. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 8.51- 8.47 (m, 1H), 8.39- 8.35 (m, 2H), 8.02- 7.99 (m, 1H), 7.75 (s, 0.70H), 7.65-7.60 (m, 2H), 7.54-7.52 (m, 3H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 184.1, 183.4, 159.0, 155.5, 151.3, 148.8, 147.5, 142.9 (t, *J* = 5.8 Hz, CD), 133.7, 132.7, 132.4, 129.2, 128.7(2C), 128.5, 127.1, 126.1, 124.0. **HRMS** (ESI): *m/z* calcd for $C_{18}H_{10}DO_2S$ $(M+H)^+$: 292.0542. Found: 292.0536.

### 2-Benzylidene-1*H*-indene-1,3(2*H*)-dione (62aD) in THF/$D_2O$.



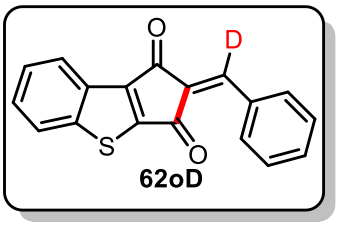

Following the general procedure-14, 20 mg of **53a** afforded 16.2 mg (81% yield) of **62aD** as light yellow solid (~70%D). M.P = 142-144 °C. $R_f$ = 0.4 (hexane/EtOAc = 9/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 2924, 1723, 1689, 1586, 1261, 801, 737, 685. **$^1$H NMR** (400 MHz, $CDCl_3$): δ 8.50 (d, *J* = 7.0 Hz, 2H), 8.04 (d, *J* = 4.5 Hz, 2H), 7.93 (s, 0.03H), 7.85-7.83 (m, 2H), 7.59-7.53 (m, 3H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 190.3, 189.1, 147.0, 142.5, 140.1, 135.4, 135.2, 134.2(2C), 131.1 (t, *J* = 5.5 Hz, CD), 129.2, 129.1, 128.8(2C), 123.4(2C). **HRMS (ESI):** *m/z* calcd for $C_{16}H_{10}DO_2$ $(M+H)^+$: 236.0822. Found: 236.0809.

### 2-Benzylidene-1*H*-indene-1,3(2*H*)-dione (62aD) in THF/MeOH-$d_4$.



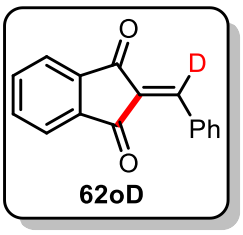

Following the general procedure-14, 20 mg of **53a** afforded 16 mg (80% yield) of **62aD** as light yellow solid (~76%D). M.P = 152-153 °C. $R_f$ = 0.4 (hexane/EtOAc = 9/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 2924, 1724, 1690, 1607, 1586, 1351, 1209, 738, 684. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 8.50-8.47 (m, 2H), 8.06-8.01 (m, 2H), 7.93 (s, 0.24H), 7.86-7.82 (m, 2H), 7.60-7.52 (m, 3H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 190.3, 189.1, 147.0, 142.5, 140.1, 135.4, 135.2, 134.2(2C), 133.1 (t, *J* = 5.5 Hz, CD), 129.2 129.1, 128.8(2C), 123.4(2C).

**2-Benzylidene-1*H*-benzo[*b*]cyclopenta[*d*]thiophene-1,3(2*H*)-dione (62oD) in D-scrambling experiment.**




Following the general procedure-14, 25 mg of **53oD** afforded 10.5 mg (42% yield) of **62oD** as pale-yellow solid (~25%D). M.P = 180-182 °C. $R_f$ = 0.5 (hexane/EtOAc = 9/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 2919, 1710, 1677, 1612, 1504, 1463, 1449, 737. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 8.52-8.47 (m, 1H), 8.39- 8.35 (m, 2H), 8.02- 7.99 (m, 1H), 7.75 (s, 0.75H), 7.65-7.60 (m, 2H), 7.54-7.51 (m, 3H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 184.1, 183.4, 159.0, 155.5, 151.3, 148.8, 147.5, 142.9 (t, *J* = 5.8 Hz, CD), 133.7, 132.7, 132.4, 129.2, 128.7(2C), 128.5, 127.1, 126.1, 124.0.

**2-Benzylidene-1*H*-indene-1,3(2*H*)-dione (62oD) in D-scrambling experiment.**




Following the general procedure-14, 25 mg of **53a** afforded 11 mg (44% yield) of **62oD** as light yellow solid (~10%D). M.P = 149- 151 °C. $R_f$ = 0.4 (hexane/EtOAc = 9/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 2924, 1723, 1689, 1586, 1261, 801, 737, 685. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 8.50 (d, *J* = 7.0 Hz, 2H), 8.04 (d, *J* = 4.5 Hz, 2H), 7.93 (s, 0.90H), 7.85- 7.83 (m, 2H), 7.59-7.53 (m, 3H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 190.3, 189.1, 147.0, 142.5, 140.1, 135.4, 135.2, 134.2(2C), 133.2, 133.1, 129.2, 128.8(2C), 123.4(2C).

**General procedure-16: Synthesis of keto-ynones 92a-j.**

**Step-I:** To a 50 mL RB flask equipped with magnetic stir bar was added the 2-bromo aldehyde **9** (500 mg, 2.7 mmol), anhydrous THF (5.0 ml) under $N_2$ atmosphere and stirred at 0 °C for 2-3 minutes. alkyl magnesium chloride (3.24 mmol) was added dropwise to above solution and stirring was continued for 1 h. The reaction mixture was quenched with dil. HCl and extracted twice with EtOAc. The combined organic layers were dried over anhydrous $Na_2SO_4$, concentrated and purified by silica gel column chromatography to obtain **89** in 82-85% yields.

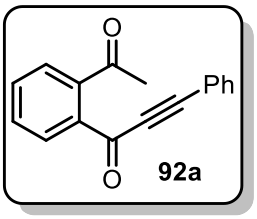
**Step-II:** To a 25 mL long neck RB flask equipped with magnetic stir bar was added 2-bromo alcohol **89** (500 mg, 2.48 mmol), anhydrous THF (5.0 mL) under $N_2$ atmosphere and stirred at –78 °C for 5 mins. *n*-BuLi (1.6 M in hexane, 3.41 mL, 5.46 mmol) was added drop wise to the above solution and stirring was continued for 1 h. Dry DMF (0.4 ml, 5 mmol) was introduced into the reaction mixture at the same temperature and stirred for 1 h. The reaction

mixture was quenched with sat. aq. $NH_4Cl$ solution and extracted with EtOAc. The combined organic layers were dried over anhydrous $Na_2SO_4$, concentrated and purified using silica gel column chromatography to give **90** in 80-86% yields.

**Step-III:** To a 25 mL long neck RB flask equipped with magnetic stir bar was added alkyne (4.4 mmol), anhydrous THF (5.0 mL) under $N_2$ atmosphere and stirred at -78 $^oC$ for 5 minutes. *n*-BuLi (1.6 M in hexane, 2.75 mL, 4.4 mmol) was added drop wise to the above solution and stirring was continued for 1 h. The hydroxy-aldehyde **90** (300 mg, 2.0 mmol) was then introduced to the reaction mixture at the same temperature and stirred for 1 h. The reaction mixture was quenched with sat. aq. $NH_4Cl$ solution and extracted with EtOAc. The combined organic layers were dried over anhydrous $Na_2SO_4$, concentrated and purified using silica gel column chromatography to give **91** in 82-85% yields.

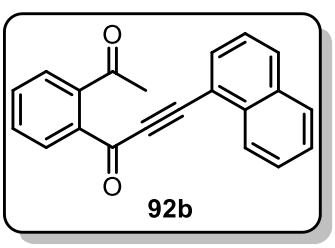
**Step-IV: T**he yndiol **91** (425 mg, 1.68 mmol) was dissolved in EtOAc (10 ml) and IBX (1.0 g, 3.7 mmol) was introduced and refluxed at 78 $^oC$ for 4-5 h. After completion of the reaction, the reaction mixture was filtered through celite pad. The filtrate was concentrated and purified using column chromatography to obtain **92a-j** in 75-78% yields over two-steps.

### 1-(2-Acetylphenyl)-3-phenylprop-2-yn-1-one (92a).




This compound **92a** was prepared following the general procedure-16 and isolated as pale-yellow solid. M.P = 52-54 $^oC$. $R_f$ = 0.4 (hexane/EtOAc = 4/1**). IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 3062, 2198, 1701, 1636, 1594, 1569, 1489, 1286, 1245, 1210, 1012, 758, 689. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 8.23 (d, *J* = 7.5 Hz, 1H), 7.69-7.59 (m, 4H), 7.54-7.50 (m, 1H), 7.46-7.42 (m, 2H), 7.40 (d, *J* = 7.5 Hz, 1H), 2.55 (s, 3H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 204.1, 178.1, 143.2, 135.2, 133.5, 133.1(2C), 131.5, 131.1, 129.8, 128.7(2C), 126.5, 119.7, 94.2, 87.0, 30.4. **HRMS (ESI):** *m/z* calcd for $C_{17}H_{13}O_2$ $(M+H)^+$: 249.0916, Found: 249.0907.

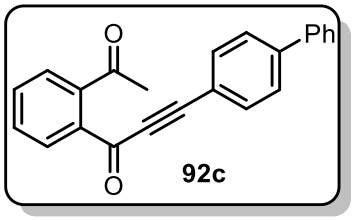
### 1-(2-Acetylphenyl)-3-(naphthalen-1-yl)prop-2-yn-1-one (92b).




This compound **92b** was prepared by following the general procedure-16 and isolated as pale-yellow semi-solid. $R_f$ = 0.5 (Hexane/EtOAc = 9/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 2926, 2187, 1771, 1697, 1633, 1285, 759. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 8.38 (d, *J* = 8.2 Hz, 1H), 8.33 (dd, *J* = 7.1 and 0.9 Hz, 1H), 8.01

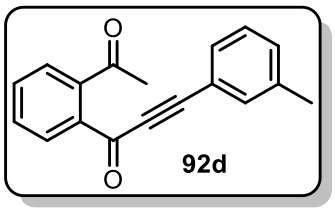
(d, *J* = 9.3 Hz, 1H), 7.96-7.91 (m, 2H), 7.71-7.63 (m, 3H), 7.62-7.58 (m, 1H), 7.55-7.51 (m, 1H), 7.43 (dd, *J* = 7.4 and 1.3 Hz, 1H), 2.59 (s, 3H). **$^{13}$C NMR (100 MHz, CDCl$_3$):** δ 204.0, 178.1, 143.2, 135.4, 133.6, 133.5, 133.4, 133.0, 131.8, 131.5, 129.9, 128.6, 127.8, 127.0, 126.6, 125.7, 125.2, 117.3, 92.6, 91.7, 30.4. **HRMS (ESI):** *m/z* calcd for $C_{21}H_{14}O_2Na$ $(M+Na)^+$: 321.0891. Found: 321.0887.

### 3-([1,1'-Biphenyl]-4-yl)-1-(2-acetylphenyl)prop-2-yn-1-one (92c).



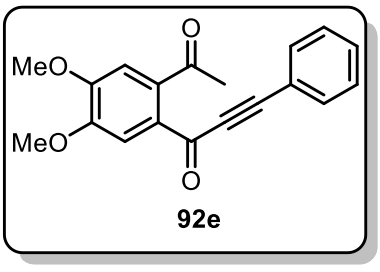

This compound **92c** was prepared by following the general procedure-16 and isolated as pale-yellow semi-solid. $R_f$ = 0.5 (Hexane/EtOAc = 10/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 2924, 2852, 2195, 1701, 1634, 1485, 1006. **$^1$H NMR (400 MHz, CDCl$_3$):** δ 8.25 (dd, *J* = 7.4 and 0.9 Hz, 1H), 7.77-7.75 (m, 2H), 7.70-7.63 (m, 6H), 7.50 (t, *J* = 7.1 Hz, 2H), 7.44-7.39 (m, 2H), 2.56 (s, 3H). **$^{13}$C NMR (100 MHz, CDCl$_3$):** δ 204.1, 178.0, 143.9, 143.3, 139.7, 135.2, 133.7(2C), 133.5, 131.5, 129.8, 129.0(2C), 128.3, 127.4(2C), 127.1(2C), 126.5, 118.4, 94.3, 87.7, 30.4. **HRMS (ESI):** *m/z* calcd for $C_{23}H_{16}O_2Na$ $(M+Na)^+$: 347.1048. Found: 347.1034.

### 1-(2-Acetylphenyl)-3-(*m*-tolyl)prop-2-yn-1-one (92d).




This compound **92d** was prepared by following the general procedure-16 and isolated as pale-yellow viscous liquid. $R_f$ = 0.5 (Hexane/EtOAc = 9/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 2955. 2924, 2190, 1742, 1730, 1465. **$^1$H NMR (400 MHz, CDCl$_3$):** δ 8.23 (dd, *J* = 7.4 and 0.8 Hz, 1H), 7.68-7.59 (m, 2H), 7.49-7.47 (m, 2H), 7.38 (dd, *J* = 7.4 and 1.0 Hz, 1H), 7.33-7.31 (m, 2H), 2.54 (s, 3H), 2.39 (s, 3H). **$^{13}$C NMR (100 MHz, CDCl$_3$):** δ 204.1, 178.0, 143.2, 138.6, 135.2, 133.6, 133.4, 132.0, 131.5, 130.3, 129.8, 128.6, 126.5, 119.5, 94.6, 86.7, 30.4, 21.2. **HRMS (ESI):** *m/z* calcd for $C_{18}H_{15}O_2$ $(M+H)^+$: 263.1072. Found: 263.1077.

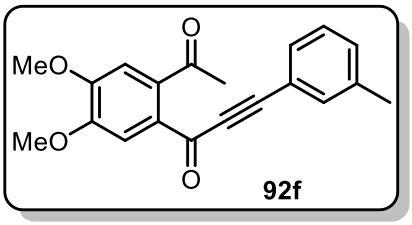
### 1-(2-Acetyl-4,5-dimethoxyphenyl)-3-phenylprop-2-yn-1-one (92e).




This compound **92e** was prepared following the general procedure-16 and isolated as white solid. M.P = 138-140 $^o$C. $R_f$ = 0.4 (hexane/EtOAc = 7/3**). IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 2936, 2195, 1696, 1630, 1592, 1563, 1515, 1463, 1350, 1285, 1196, 1159, 1076. **$^1$H NMR (400 MHz, CDCl$_3$):** δ 7.68 (s,

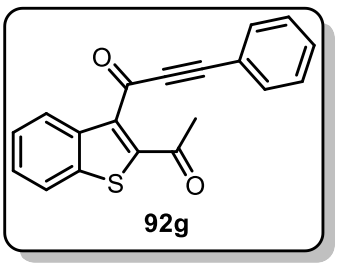
1H), 7.65-7.63 (m, 2H), 7.52-7.48 (m, 1H), 7.44-7.41 (m, 2H), 6.84 (s, 1H), 4.02 (s, 3H), 3.98 (s, 3H), 2.50 (s, 3H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 203.9, 176.6, 153.2, 149.3, 137.9, 133.0(2C), 131.0, 128.8(2C), 128.1, 119.8, 113.5, 109.5, 93.8, 87.2, 56.4, 56.2, 30.7. **HRMS (ESI):** *m/z* calcd for $C_{19}H_{16}O_4Na$ $(M+Na)^+$: 331.0947. Found: 331.0937.

### 1-(2-Acetyl-4,5-dimethoxyphenyl)-3-(*m*-tolyl)prop-2-yn-1-one (92f).



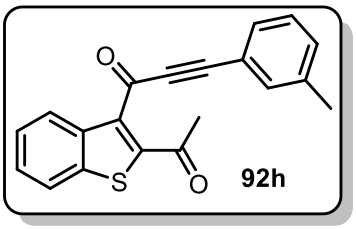

This compound **92f** was prepared following the general procedure-16 and isolated as white solid. M.P = 131-133 °C. $R_f$ = 0.5 (hexane/EtOAc = 7/3**). IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 2936, 2195, 1696, 1630, 1592, 1563, 1515, 1463, 1350, 1285, 1196, 1159, 1076. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 7.67 (s, 1H), 7.44 (s, 2H), 7.32-7.29 (m, 2H), 6.83 (s, 1H), 4.01 (s, 3H), 3.96 (s, 3H), 2.49 (s, 3H), 2.37 (s, 3H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 203.9, 176.6, 153.1, 149.2, 138.6, 137.9, 133.4, 132.0, 130.1, 128.7, 128.2, 119.6, 113.5, 109.5, 94.2, 86.9, 56.4, 56.2, 30.7, 21.2. **HRMS (ESI):** *m/z* calcd for $C_{20}H_{18}O_4Na$ $(M+Na)^+$: 345.1103. Found: 345.1119.

### 1-(2-Acetylbenzo[*b*]thiophen-3-yl)-3-phenylprop-2-yn-1-one (92g).




This compound **92g** was prepared following the general procedure-16 and isolated as pale-yellow solid. M.P = 124-126 °C. $R_f$ = 0.4 (hexane/EtOAc = 9/1**). IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 3060, 2194, 1684, 1646, 1504, 1459, 1428, 1356, 1279, 1228, 1146, 1121, 758. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 8.26-8.23 (m, 1H), 7.93-7.90 (m, 1H), 7.61 (d, *J* = 7.3 Hz, 2H), 7.57-7.53 (m, 2H), 7.50 (d, *J* = 7.5 Hz, 1H), 7.42 (t, *J* = 7.7 Hz, 2H), 2.72 (s, 3H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 193.1, 175.4, 144.9, 139.8, 137.6, 136.8, 133.3(2C), 131.3, 128.7(2C), 127.6, 126.2, 125.0, 122.7, 119.6, 94.5, 89.1, 30.4. **HRMS (ESI):** *m/z* calcd for $C_{19}H_{12}O_2SNa(M+Na)^+$: 327.0456, Found: 327.0450.

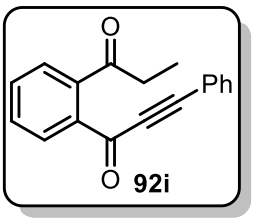
### 1-(2-Acetylbenzo[*b*]thiophen-3-yl)-3-(*m*-tolyl)prop-2-yn-1-one (92h).




This compound **92h** was prepared following the general procedure-16 and isolated as pale-brown solid. M.P = 82-84 °C. $R_f$ = 0.4 (hexane/EtOAc = 9/1**). IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 3058, 2919, 2185, 1680, 1627, 1501, 1117, 735. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 8.24-8.22 (m, 1H), 7.90-7.88 (m, 1H), 7.55-

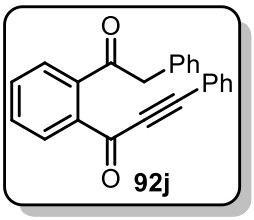
7.50 (m, 2H), 7.42-7.40 (m, 2H), 7.30-7.28 (m, 2H), 2.71 (s, 3H), 2.36 (s, 3H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 193.1, 175.5, 144.8, 139.8, 138.6, 137.7, 136.8, 133.7, 132.3, 130.5, 128.6, 127.6, 126.2, 125.0, 122.7, 119.3, 95.0, 89.0, 30.4, 21.2. **HRMS (ESI):** *m/z* calcd for $C_{20}H_{14}O_2SNa$ $(M+Na)^+$: 341.0613. Found: 341.0620.

### 3-Phenyl-1-(2-propionylphenyl)prop-2-yn-1-one (92i).




This compound **92i** was prepared by following the general procedure-16 and isolated as pale-brown liquid. $R_f$ = 0.6 (Hexane/EtOAc = 4/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 2978, 2199, 1702, 1636, 1490, 1302, 1209, 1012, 995, 759, 688. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 8.26-8.24 (m, 1H), 7.68-7.57 (m, 4H), 7.52-7.48 (m, 1H), 7.44-7.41 (m,2H), 7.33-7.31 (m, 1H), 2.75 (q, *J* = 7.2 Hz, 2H), 1.26 (t, *J* = 7.2 Hz, 3H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 207.5, 178.0, 143.6, 135.0,133.6, 133.2(2C), 131.8, 131.1, 129.6, 128.8(2C), 126.5, 119.8, 94.3, 86.9, 36.6, 8.5. **HRMS (ESI):** *m/z* calcd for $C_{18}H_{15}O_2$ $(M+H)^+$: 263.1072. Found: 263.1065.

### 3-Phenyl-1-(2-(2-phenylacetyl)phenyl)prop-2-yn-1-one (92j).

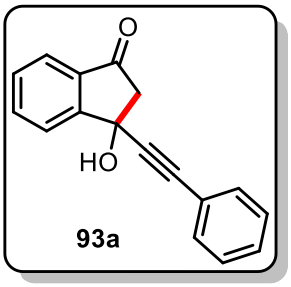



This compound **92j** was prepared following the general procedure-16 and isolated as white solid. M.P = 100-102 °C. $R_f$ = 0.5 (hexane/EtOAc = 4/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 3064, 2198, 1703, 1634, 1596, 1568, 1489, 1443, 1307, 1291, 1210, 1013, 995, 756, 688. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 8.33-8.31 (m, 1H), 7.72- 7.70 (m, 2H), 7.62-7.60 (m, 2H), 7.56-7.52 (m, 1H), 7.48-7.44 (m, 2H), 7.34-7.27 (m, 5H), 7.20-7.18 (m, 1H), 4.10 (s, 2H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 204.2, 177.8, 143.0, 134.6, 133.9, 133.7, 133.2(2C), 132.0, 131.2, 130.0(2C), 129.6, 128.8(2C), 128.5(2C), 127.0(2C), 119.7, 94.6, 86.7, 50.0. **HRMS (ESI):** *m/z* calcd for $C_{23}H_{16}O_2Na$ $(M+Na)^+$: 347.1048. Found: 347.1038.

### General procedure-17: Synthesis of 93a-j.

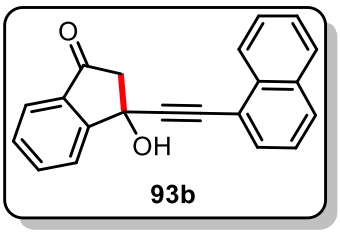
An oven dried 5 mL glass vial was charged with **92** (0.1 mmol). $^t$BuOH (1.0 mL) and $PBu_3$ (0.02 mmol) were introduced at room temperature (rt) and stirred until **92** disappeared as monitored by TLC. Then the reaction was quenched with water and extracted using ethyl acetate. The organic extracts were combined and dried over anhydrous sodium sulfate and concentrated. The crude product was purified by silica gel flash chromatography using hexane/ethyl acetate as eluent, to afford **93**.

### 3-Hydroxy-3-(phenylethynyl)-2,3-dihydro-1*H*-inden-1-one (93a).



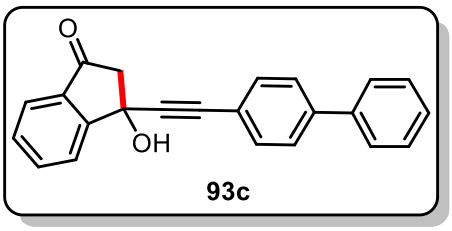

Following the general procedure-17, 20 mg of **92a** afforded 17.4 mg (87% yield) of **93a** as a pale brown oil. $R_f$ = 0.25 (hexane/EtOAc = 4/1). IR **(thin film, neat):** $\nu_{max}/cm^{-1}$ 3398, 2924, 2293, 1721, 1604, 1490, 1463, 1288, 1236, 1039, 757, 691. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 7.91 (d, *J* = 7.7 Hz, 1H), 7.80-7.75 (m, 2H), 7.56 (t, *J* = 7.4 Hz, 1H), 7.45-7.43 (m, 2H), 7.36-7.31 (m, 3H), 3.30 (ABq, $J_{AB}$ = 18.7 Hz, 2H), 3.06 (s, 1H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 201.9, 155.5, 135.9, 134.8, 131.7(2C), 130.1, 128.9, 128.4(2C), 124.8, 123.4, 121.8, 89.7, 85.8, 69.9, 54.3. **HRMS (ESI):** *m/z* calcd for $C_{17}H_{13}O_2$ $(M+H)^+$: 249.0916, Found: 249.0927.

### 3-Hydroxy-3-(naphthalen-1-ylethynyl)-2,3-dihydro-1*H*-inden-1-one (93b).




Following the general procedure-17, 35 mg of **92b** afforded 23.8 mg of **93b** (68% yield) as pale brown oil. $R_f$ = 0.3 (Hexane/EtOAc = 4/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 3394, 2925, 2216, 1710, 1592, 1032, 761. **$^1$H NMR (400 MHz, $(CD_3)_2SO$):** δ 8.26-8.22 (m, 1H), 8.03 (d, *J* = 7.6 Hz, 1H), 7.98 (d, *J* = 8.1 Hz, 2H), 7.88 (t, *J* = 7.4 Hz, 1H), 7.82-7.80 (m, 1H), 7.71 (dd, *J* = 7.5 and 3.6 Hz, 1H), 7.67-7.64 (m, 1H), 7.63-7.57 (m, 2H), 7.51 (t, *J* = 7.8 Hz, 1H), 6.90 (s, 1H), 3.27 (ABq, $J_{AB}$ = 18.5 Hz, 2H). **$^{13}$C NMR (100 MHz, $(CD_3)_2SO$):** δ 202.3, 157.0, 136.4, 134.6, 133.2, 132.9, 130.9, 130.3, 129.7, 128.9, 127.7, 127.2, 126.0, 125.86, 125.83, 123.0, 119.6, 97.4, 82.2, 69.2, 54.6. **HRMS (ESI):** *m/z* calcd for $C_{21}H_{15}O_2$ $(M+H)^+$: 299.1072. Found: 299.1058.

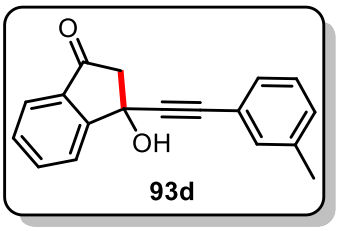
### 3-([1,1'-Biphenyl]-4-ylethynyl)-3-hydroxy-2,3-dihydro-1*H*-inden-1-one (93c).




This compound was isolated as yellow oil. Following the general procedure-17, 30 mg of **92c** afforded 21.6 mg of **93c** (72% yield). $R_f$ = 0.3 (Hexane/EtOAc = 4/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 3398, 2946, 2930, 2221, 1728, 1610, 1641, 1240, 758. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 7.94 (d, *J* = 7.5 Hz, 1H), 7.85 (t, *J* = 7.2 Hz, 1H), 7.69 (dd, *J* = 8.3 and 3.8 Hz, 5H), 7.60 (t, *J* = 7.2 Hz, 1H), 7.53 (d, *J* = 8.1 Hz, 1H), 7.49-7.45 (m, 2H), 7.40-7.36 (m, 2H), 6.77 (s, 1H), 3.16 (ABq, $J_{AB}$ = 18.5 Hz, 2H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 201.8, 155.5, 141.7,

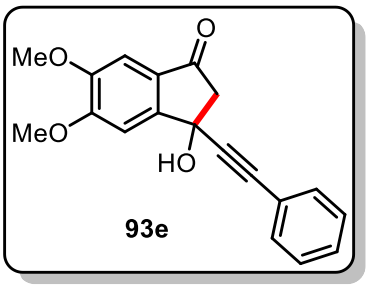
140.1, 135.9, 134.8, 132.1(3C), 130.1, 128.9(2C), 127.8, 127.0(3C), 124.8, 123.4, 120.6, 90.3, 85.7, 69.9, 54.3. **HRMS (ESI):** *m/z* calcd for $C_{23}H_{17}O_2$ $(M+H)^+$: 325.1229. Found: 325.1265.

### 3-Hydroxy-3-(*m*-tolylethynyl)-2,3-dihydro-1*H*-inden-1-one (93d).



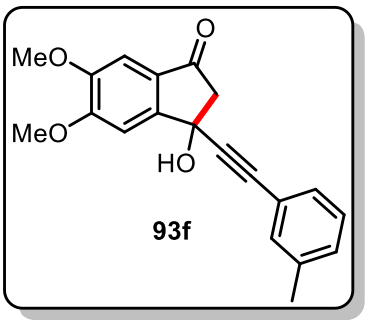

This compound was isolated as pale-yellow oil. Following the general procedure-17, 30 mg of **92d** afforded 23.4 mg of **93d** (78% yield). $R_f$ = 0.3 (Hexane/EtOAc = 4/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 3396, 2956, 2924, 2226, 1722, 1603, 1640. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 7.91 (td, *J* = 7.6 and 0.8 Hz, 1H), 7.80-7.75 (m, 2H), 7.56 (dt, *J* = 7.4 and 0.7 Hz, 1H), 7.27-7.16 (m, 4H), 3.29 (ABq, $J_{AB}$ = 18.6 Hz, 2H), 3.00 (bs, 1H), 2.33 (s, 3H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 201.9, 155.5, 138.1, 135.9, 134.8, 132.3, 130.1, 129.8, 128.8, 128.2, 124.8, 123.3, 121.5, 89.3, 86.0, 69.9, 54.3, 21.2. **HRMS (ESI):** *m/z* calcd for $C_{18}H_{15}O_2$ $(M+H)^+$: 263.1072. Found: 263.1080.

### 3-Hydroxy-5,6-dimethoxy-3-(phenylethynyl)-2,3-dihydro-1*H*-inden-1-one (93e).




Following the general procedure-17, 20 mg of **92e** afforded 17.6 mg (88% yield) of **93e** as pale brown oil. $R_f$ = 0.5 (hexane/EtOAc = 6/4). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 3443, 2923, 2851, 2227, 1703, 1594, 1499, 1461, 1298, 1214. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 7.44-7.42 (m, 2H), 7.37-7.28 (m, 4H), 7.16 (s, 1H), 4.04 (s, 3H), 3.94 (s, 3H), 3.40, 3.15 (ABq, $J_{AB}$ =18.5 Hz, 2H) 3.29 (s, 1H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 200.6, 156.2, 151.3, 150.6, 131.7(2C), 128.9, 128.4(2C), 128.1, 121.9, 105.5, 103.5, 89.9, 85.4, 69.7, 56.5, 56.3, 54.7. **HRMS (ESI):** *m/z* calcd for $C_{19}H_{17}O_4$ $(M+H)^+$: 309.1127. Found: 309.1112.

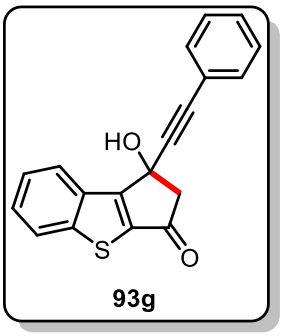
### 3-Hydroxy-5,6-dimethoxy-3-(*m*-tolylethynyl)-2,3-dihydro-1*H*-inden-1-one (93f).




Following the general procedure-17, 20 mg of **92f** afforded 17.2 mg (86% yield) of **93f** as pale-yellow solid. M.P = 121-122 °C. $R_f$ = 0.5 (hexane/EtOAc = 6/4**). IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 3360, 2926, 2853, 2232, 1709, 1596, 1501, 1460, 1300, 1217. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 7.28-7.15 (m, 6H), 4.05 (s, 3H), 3.95 (s, 3H), 3.15 (ABq, $J_{AB}$ =18.5 Hz, 3H), 2.33 (s, 3H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 200.5, 156.2, 151.3, 150.6, 138.1, 132.2, 129.8, 128.8, 128.3,

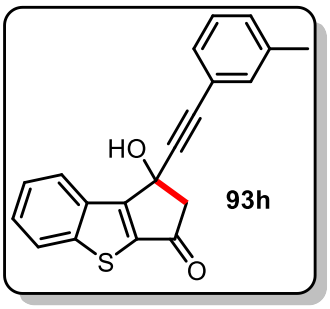
128.1, 121.6, 105.5, 103.4, 89.5, 85.6, 69.7, 56.5, 56.3, 54.7, 21.2. **HRMS (ESI):** *m/z* calcd for $C_{20}H_{18}O_4Na$ $(M+Na)^+$: 345.1103. Found: 345.1107.

### 1-Hydroxy-1-(phenylethynyl)-1*H*-benzo[*b*]cyclopenta[*d*]thiophen-3(2*H*)-one (93g).



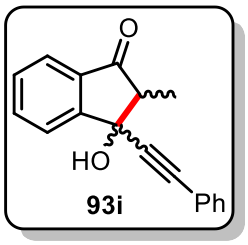

Following the general procedure-17, 20 mg of **92g** afforded 15.8 mg (79% yield) of **93g** as pale brown solid. M.P = 127-129 °C. $R_f$ = 0.15 (hexane/EtOAc = 9/1). IR **(thin film, neat):** $\nu_{max}/cm^{-1}$ 3392, 2922, 2231, 1708, 1596, 1520, 1489, 1268, 1245, 1038, 755, 732. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 8.31-8.29 (m, 1H), 7.97-7.95 (m, 1H), 7.59-7.54 (m, 2H), 7.44 (d, *J* = 7.9 Hz, 2H), 7.38-7.31 (m, 3H), 3.61 (ABq, $J_{AB}$ = 18.2 Hz, 2H), 3.14 (s, 1H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 193.5, 162.2, 148.7, 141.3, 131.9(2C), 131.8(2C), 129.1, 128.5, 128.4, 125.7, 124.6(2C), 121.5, 88.0, 86.3, 67.5, 58.5. **HRMS (ESI):** *m/z* calcd for $C_{19}H_{11}O_2S$ $(M-H)^+$: 303.0480. Found: 303.0467.

### 1-Hydroxy-1-(*m*-tolylethynyl)-1*H*-benzo[*b*]cyclopenta[*d*]thiophen-3(2*H*)-one (93h).




Following the general procedure-17, 20 mg of **92h** afforded 14.4 mg (72% yield) of **93h** as pale brown solid. M.P = 111-113 °C. $R_f$ = 0.5 (hexane/EtOAc = 4/1**). IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 3433, 2925, 2854, 2232, 1711, 1595, 1520, 1426, 1271, 1246, 1094, 1041. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 8.31-8.29 (m, 1H), 7.97-7.94 (m, 1H), 7.59-7.54 (m, 2H), 7.26-7.16 (m, 4H), 3.73, 3.48 (ABq, $J_{AB}$ =18.2 Hz, 2H), 3.27 (s, 1H), 2.32 (s, 3H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 193.7, 162.4, 148.7, 141.2, 138.2, 132.3, 131.9, 130, 128.9, 128.5, 128.3, 125.7, 124.6, 124.5, 121.4, 87.7, 86.5, 67.5, 58.6, 21.2. **HRMS (ESI):** *m/z* calcd for $C_{20}H_{13}O_2S$ $(M-H)^+$: 317.0637. Found: 317.0625.

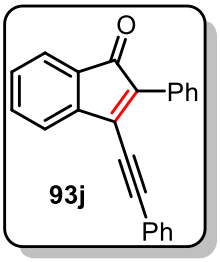
### 3-Hydroxy-2-methyl-3-(phenylethynyl)-2,3-dihydro-1*H*-inden-1-one (93i).




This compound was isolated as pale brown oil. Following the general procedure-17, 100 mg of **92i** afforded 71.7 mg of **93i** (72% yield). $R_f$ = 0.5 (Hexane/EtOAc = 7/3). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 3193, 3067, 2960, 2934, 1721, 1605, 1466, 1289, 1227, 1146, 1095, 757, 693. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 7.89 (d, *J* = 7.7 Hz, 1H), 7.78-7.68 (m,

2H), 7.54-7.50 (m,1H), 7.40-7.38 (m, 2H), 7.35-7.26 (m, 3H), 3.16 (s, 1H), 3.00 (q, *J* = 7.4 Hz, 1H), 1.51 (d, *J* = 7.4 Hz, 3H). **$^{13}$C NMR (100 MHz, CDCl$_3$):** δ 203.8, 154.5, 135.7, 134.2, 131.8(2C), 130.0, 129.0, 128.4(2C), 124.6, 123.5, 122.0, 89.4, 87.7, 75.3, 56.8, 12.2. **HRMS (ESI):** *m/z* calcd for $C_{18}H_{14}O_2$ $(M+H)^+$: 311.1072. Found: 311.1056.

### 2-Phenyl-3-(phenylethynyl)-1*H*-inden-1-one (93j).

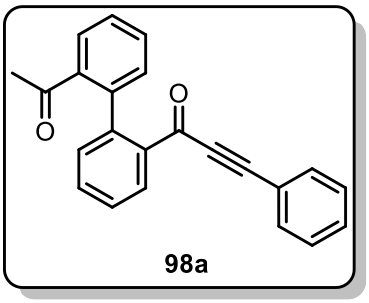



Following the general procedure-17, 20 mg of **92j** afforded 16 mg (80% yield) of **93j** as pale-yellow solid. M.P = 98-100 °C. $R_f$ = 0.7 (hexane/EtOAc = 9/1). **IR (thin film, neat):** $\nu_{max}$/cm$^{-1}$ 3059, 2918, 2188, 1712, 1698, 1599, 1493, 1456, 1368, 1069, 753, 688. **$^1$H NMR (400 MHz, CDCl$_3$):** δ 8.10 (d, *J* = 7.3 Hz, 2H), 7.64- 7.61 (m, 2H), 7.56-7.48 (m, 4H), 7.46-7.39 (m, 5H), 7.36-7.32 (m, 1H). **$^{13}$C NMR (100 MHz, CDCl$_3$):** δ 196.2, 143.5, 136.2, 135.9, 134.2, 132.2(2C), 131.1, 130.0, 129.9, 129.3, 129.0(2C), 128.8, 128.7(2C), 128.3(2C), 122.6, 122.2, 120.7, 108.4, 83.9. **HRMS (ESI):** *m/z* calcd for $C_{23}H_{15}O$ $(M+H)^+$: 307.1123. Found: 307.1122.

### General procedure-18: Synthesis of biaryl keto-ynones 98.

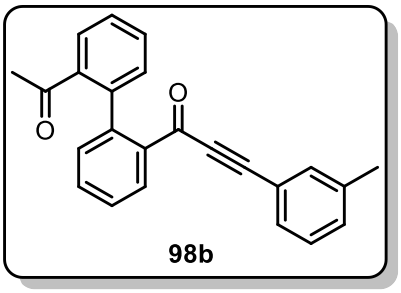
These biaryl keto-ynones **98** were synthesized from biaryl ynone-aldyhydes **70** by following a simple two-step procedure as described in general procedure 16.

### 1-(2'-Acetyl-[1,1'-biphenyl]-2-yl)-3-phenylprop-2-yn-1-one (98a).



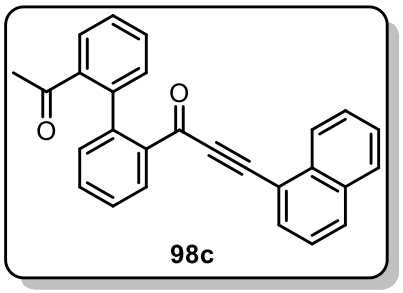

This compound **98a** was prepared by following the general procedure-18 and isolated as pale-yellow oil. $R_f$ = 0.5 (Hexane/EtOAc = 9/1). **IR (thin film, neat):** $\nu_{max}$/cm$^{-1}$ 2955, 2925, 2197, 1739, 1711, 1463, 1015. **$^1$H NMR (400 MHz, CDCl$_3$):** δ 8.26-8.24 (m, 1H), 7.76 (d, *J* = 7.6 Hz, 1H), 7.61 (dt, *J* = 7.3 and 1.2 Hz, 1H), 7.55 (dt, *J* = 7.6 and 1.2 Hz, 1H), 7.50 (dd, *J* = 7.4 and 1.0 Hz, 1H), 7.47-7.43 (m, 4H), 7.38-7.34 (m, 2H), 7.24 (d, *J* = 7.4 Hz, 2H), 2.29 (s, 3H). **$^{13}$C NMR (100 MHz, CDCl$_3$):** δ 201.6, 178.9, 142.3, 140.2, 138.8, 135.9, 132.9(2C), 132.5, 131.5, 131.3, 131.0, 130.9, 130.6, 128.5(3C), 127.7, 127.6, 120.0, 93.1, 88.1, 29.1. **HRMS (ESI):** *m/z* calcd for $C_{23}H_{16}O_2Na$ $(M+Na)^+$: 347.1048. Found: 347.1042.

**1-(2'-Acetyl-[1,1'-biphenyl]-2-yl)-3-(*m*-tolyl)prop-2-yn-1-one (98b).**



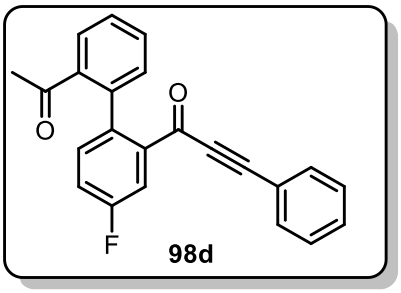

This compound **98b** was prepared by following the general procedure-18 and isolated as pale-yellow oil. $R_f$ = 0.5 (Hexane/EtOAc = 10/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 2956, 2924, 2854, 2186, 1687, 1637, 1222, 756. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 8.26 (dd, *J* = 7.5 and 1.2 Hz, 1H), 7.77 (dd, *J* = 7.6 and 1.0 Hz, 1H), 7.62-7.43 (m, 4H), 7.28-7.23 (m, 6H), 2.36 (s, 3H), 2.29 (s, 3H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 201.6, 178.9, 142.3, 140.3, 138.9, 138.3, 135.9, 133.4, 132.5, 131.5(2C), 131.3, 131.0, 130.9, 130.0, 128.5, 128.4, 127.7, 127.6, 119.8, 93.5, 29.1, 21.2. **HRMS (ESI):** *m/z* calcd for $C_{24}H_{18}O_2Na$ $(M+Na)^+$: 361.1204. Found: 361.1217.

**1-(2'-Acetyl-[1,1'-biphenyl]-2-yl)-3-(naphthalen-1-yl)prop-2-yn-1-one (98c).**




This compound **98c** was prepared by following the general procedure-18 and isolated as colorless oil. $R_f$ = 0.5 (Hexane/EtOAc = 9/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 2955, 2924, 2854, 2188, 1685, 1636, 1298, 982. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 8.38 (dd, *J* = 7.3 and 1.3 Hz, 1H), 8.25 (d, *J* = 8.1 Hz, 1H), 7.96 (d, *J* = 8.2 Hz, 1H), 7.89 (dd, *J* = 7.4 and 1.1 Hz, 1H), 7.77 (dd, *J* = 7.6 and 0.96 Hz, 1H), 7.73 (dd, *J* = 7.1 and 0.92 Hz, 1H), 7.64-7.57 (m, 4H), 7.52-7.43 (m, 3H), 7.29-7.26 (m, 2H), 2.32 (s, 3H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 201.5, 178.8, 142.5, 140.3, 138.7, 135.9, 133.5, 133.0, 132.8, 132.6, 131.7, 131.3(2C), 131.1, 130.8, 128.5, 128.4, 127.7, 127.63, 127.61, 126.9, 125.9, 125.1, 117.7, 92.9, 91.3, 29.1. **HRMS (ESI):** *m/z* calcd for $C_{27}H_{18}O_2Na$ $(M+Na)^+$: 397.1204. Found: 397.1217.

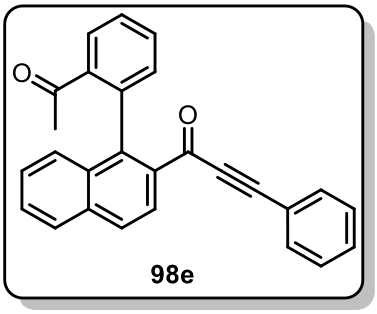
**1-(2'-Acetyl-4-fluoro-[1,1'-biphenyl]-2-yl)-3-phenylprop-2-yn-1-one (98d).**




This compound **98d** was prepared by following the general procedure-18 and isolated as pale-yellow oil. $R_f$ = 0.5 (Hexane/EtOAc = 10/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 2957, 2923, 2853, 2195, 1688, 1645, 1267, 1158, 757. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 7.92 (dd, *J* = 9.1 and 2.7 Hz, 1H), 7.77 (dd, *J* = 8.7 and 1.0 Hz, 1H), 7.52 (dt, *J* = 7.4 and 1.2 Hz, 1H), 7.48-7.44 (m, 4H), 7.39-7.35 (m, 2H), 7.33-7.29 (m, 1H), 7.23-7.20 (m, 2H), 2.35

(s, 3H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 201.1, 177.5, 161.6 (d, *J* = 247.2 Hz, 1C), 139.3, 138.6, 138.3 (d, *J* = 3.6 Hz, 1C), 137.3 (d, *J* = 6.2 Hz, 1C), 132.9(2C), 132.8 (d, *J* = 7.2 Hz, 1C), 131.2, 131.1, 130.8, 128.7, 128.5(2C), 127.8, 119.7 (d, *J* = 12.8 Hz, 1C), 119.4, 117.9 (d, *J* = 22.9 Hz, 1C), 93.8, 87.7, 29.0. **$^{19}$F NMR (376.5 MHz, $CDCl_3$):** δ -113.5. **HRMS (ESI):** *m/z* calcd for $C_{23}H_{15}FO_2Na$ $(M+Na)^+$: 365.0954. Found: 365.0970.

### 1-(1-(2-Acetylphenyl)naphthalen-2-yl)-3-phenylprop-2-yn-1-one (98e).



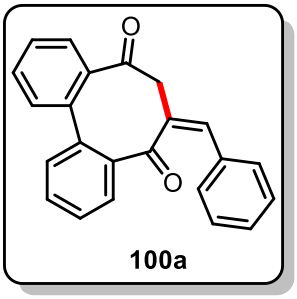

This compound **98e** was prepared by following the general procedure-18 and isolated as colorless oil. $R_f$ = 0.5 (Hexane/EtOAc = 10/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 2956, 2924, 2201, 1737, 1688, 1643, 1594, 759. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 8.28 (dd, *J* = 8.8 and 1.2 Hz, 1H), 8.01 (d, *J* = 8.4 Hz, 1H), 7.95-7.93 (m, 2H), 7.61-7.55 (m, 4H), 7.48-7.42 (m, 3H), 7.40-7.35 (m, 3H), 7.28-7.26 (m, 1H), 2.20 (s, 3H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 200.1, 179.3, 142.0, 139.5, 137.8, 135.2, 132.8(2C), 132.61, 132.6, 131.7, 131.6, 130.5, 129.1, 128.5(2C), 128.3, 128.1, 128.11, 128.0, 127.5, 127.1, 126.3, 120.2, 93.7, 88.7, 28.6. **HRMS (ESI):** *m/z* calcd for $C_{27}H_{18}O_2Na$ $(M+Na)^+$: 397.1204. Found: 397.1195.

### General procedure-19: Synthesis of cyclooctanedione 100a-e.

An oven dried 5 mL glass vial was charged with **98** (0.1 mmol). *t*-BuOH (1.0 mL) and tricyclohexyl phosphine (0.02 mmol) were introduced at rt and stirring continued until **98** disappeared as monitored by TLC. When the reaction was complete, the reaction was quenched with water and extracted using ethyl acetate. The organic extracts were combined dried over anhydrous sodium sulfate and concentrated. The crude product was purified by silica gel flash chromatography using hexane/ethyl acetate as eluent, to afford **100**.

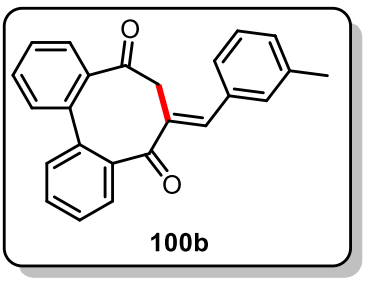
### 6-Benzylidene-6,7-dihydrodibenzo[*a*,*c*][8]annulene-5,8-dione (100a).

This compound was isolated as colorless viscous oil. Following the general procedure-19, 30 mg of **98a** afforded 20.1 mg of **100a** (67% yield). $R_f$ = 0.6 (Hexane/EtOAc = 19/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 3026, 2966, 1680, 1594, 1446, 1292, 755, 700. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 7.83 (s, 1H), 7.64 (dd, *J* = 7.7 and 1.2 Hz, 1H), 7.59-7.57 (m, 3H), 7.53 (dt, *J* = 7.5 and 1.3 Hz, 1H), 7.46-7.40 (m, 6H), 7.26-7.24 (m, 1H), 7.18-7.16 (m, 1H), 3.80 (ABq, $J_{AB}$ =



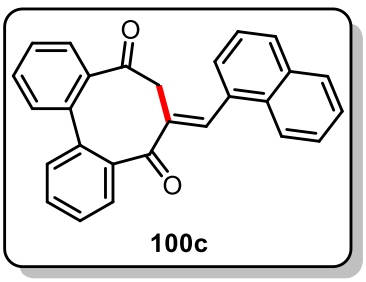

17.4 Hz, 2H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 202.8, 197.7, 141.5, 139.1, 137.7, 137.5, 134.2, 132.1, 132.0, 131.3, 131.0, 130.7, 130.5(2C), 130.0, 129.0, 128.9(3C), 128.5, 127.8, 126.7, 45.8. **HRMS (ESI):** *m/z* calcd for $C_{23}H_{16}O_2Na$ $(M+Na)^+$: 347.1048. Found: 347.1039.

### 6-(3-Methylbenzylidene)-6,7-dihydrodibenzo[*a,c*][8]annulene-5,8-dione (100b).



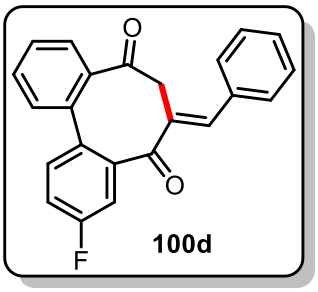

This compound was isolated as colorless viscous oil. Following the general procedure-19, 35 mg of **98b** afforded 22.7 mg of **100b** (65% yield). $R_f$ = 0.6 (Hexane/EtOAc = 19/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 2925, 2921, 2851, 1672, 1591, 1277, 767. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 7.81 (s, 1H), 7.64 (dd, *J* = 7.6 and 1.1 Hz, 1H), 7.58-7.56 (m, 3H), 7.52 (dt, *J* = 7.5 and 1.2 Hz, 1H), 7.42 (dt, *J* = 7.6 and 1.0 Hz, 1H), 7.35 (t, *J* = 7.9 Hz, 1H), 7.26-7.23 (m, 4H), 7.17 (d, *J* = 7.1 Hz, 1H), 3.78 (ABq, $J_{AB}$ = 17.5 Hz, 2H), 2.42 (s, 3H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 202.9, 197.7, 141.8, 139.1, 138.6, 137.78, 137.71, 137.5, 134.2, 132.1, 132.0, 131.4, 131.3, 130.9, 130.8, 130.7, 129.0, 128.8, 128.5, 127.8, 127.4, 126.7, 45.9, 21.4. **HRMS (ESI):** *m/z* calcd for $C_{24}H_{19}O_2$ $(M+H)^+$: 339.1385. Found: 339.1381.

### 6-(Naphthalen-1-ylmethylene)-6,7-dihydrodibenzo[*a,c*][8]annulene-5,8-dione (100c).



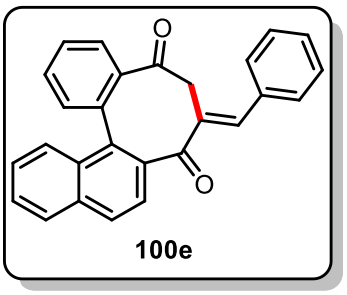

This compound was isolated as pale-yellow solid. Following the general procedure-19, 35 mg of **98c** afforded 27.3 mg of **100c** (78% yield). $R_f$ = 0.6 (Hexane/EtOAc = 19/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 2955, 2869, 1738, 1679, 1594, 1461, 1293. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 8.47 (s, 1H), 7.91-7.89 (m, 2H), 7.90 (d, *J* = 8.0 Hz, 1H), 7.61-7.47 (m, 9H), 7.26-7.21 (m, 3H), 3.66 (ABq, $J_{AB}$ = 17.4 Hz, 2H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 202.9, 197.4, 140.2, 139.0, 138.0, 137.5, 137.4, 133.8, 133.4, 132.0, 131.9, 131.7, 131.5, 131.3, 130.8, 129.9, 129.0, 128.7, 128.6, 127.9, 126.7, 126.6, 126.4(2C), 125.2, 124.4, 45.6. **HRMS (ESI):** *m/z* calcd for $C_{27}H_{19}O_2$ $(M+H)^+$: 375.1385. Found: 375.1383.

### 6-(3-Methylbenzylidene)-6,7-dihydrodibenzo[*a*,*c*][8]annulene-5,8-dione (100d).




This compound was isolated as pale-yellow oil. Following the general procedure-19, 20 mg of **98d** afforded 13.2 mg of **100d** (66% yield). $R_f$ = 0.7 (Hexane/EtOAc = 19/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 3063, 2923, 2852, 1679, 1598, 1472, 1409, 1285, 866. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 7.84 (s, 1H), 7.64 (dd, *J* = 7.6 and 1.1 Hz, 1H), 7.53 (dt, *J* = 7.5 and 1.4 Hz, 1H), 7.47-7.41 (m, 6H), 7.29 (m, 1H), 7.27 (m, 1H), 7.26-7.24 (m, 1H), 7.15 (dd, *J* = 7.6 and 0.8 Hz, 1H), 3.80 (ABq, $J_{AB}$ = 17.4 Hz, 2H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 202.9, 196.1, 162.8 (d, *J* = 249.5 Hz, 1C), 142.2, 140.8 (d, *J* = 6.6 Hz, 1C), 137.8, 136.5, 134.0, 133.6 (d, *J* = 3.7 Hz, 1C), 133.5 (d, *J* = 7.6 Hz, 1C), 132.2, 132.1, 130.6(2C), 130.4, 130.2, 128.9(2C), 128.7, 128.0, 117.7 (d, *J* = 21.1 Hz, 1C), 113.8 (d, *J* = 23.0 Hz, 1C), 45.7. **$^{19}$F NMR (376.5 MHz, $CDCl_3$):** δ -111.9. **HRMS (ESI):** *m/z* calcd for $C_{23}H_{16}FO_2$ $(M+H)^+$: 343.1134. Found: 343.1124.

### 7-Benzylidene-6,7-dihydrobenzo[7,8]cycloocta[1,2-*a*]naphthalene-5,8-dione (100e).




This compound was isolated as colorless viscous oil. Following the general procedure-19, 30 mg of **98e** afforded 20.7 mg of **100e** (69% yield). $R_f$ = 0.7 (Hexane/EtOAc = 10/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 2924, 1688, 1593, 1284, 763, 691. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 8.06 (d, *J* = 8.3 Hz, 1H), 7.95 (d, *J* = 8.2 Hz, 1H), 7.87 (s, 1H), 7.71 (dd, *J* = 7.5 and 1.3 Hz, 1H), 7.63 (d, *J* = 8.4 Hz, 1H), 7.57 (dq, *J* = 6.9 and 0.9 Hz, 2H), 7.51 (dd, *J* = 7.5 and 1.3 Hz, 1H), 7.49-7.40 (m, 6H), 7.27 (d, *J* = 7.9 Hz, 1H), 7.23 (dd, *J* = 7.5 and 1.1 Hz, 1H), 3.72 (ABq, $J_{AB}$ = 17.7 Hz, 2H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 203.3, 198.1, 141.3, 138.9, 135.8, 134.6, 134.4, 134.2, 133.1, 132.6, 131.6, 131.3, 130.4(3C), 129.9, 129.8, 128.9(2C), 128.8, 128.2, 127.8, 127.4, 127.3, 126.6, 123.0, 46.0. **HRMS (ESI):** *m/z* calcd for $C_{27}H_{19}O_2$ $(M+H)^+$: 375.1385. Found: 375.1380.

### General procedure-20: Synthesis of racemic biaryl ynone-aldehydes 116.

All the biaryl enone-aldehydes **116** were synthesized using a Suzuki coupling reaction between **115** and **72** by following the procedure as described in general procedure 5 and 13.

**General procedure-21: Synthesis of axially chiral biaryl enone-aldehydes (–)-116.**

**Step-I:** To an oven-dried 25 mL Schlenk tube, biaryl aldehyde **122** (1.0 eq), *n*-butyl acrylate (3.0 eq), $Pd(OAc)_2$ (0.1 eq), *L*-tert-Leucine (0.2 eq), *p*-benzoquinone (0.1 eq), HFIP (0.8 mL) and AcOH (0.2 mL) were taken and the tube was purged with $O_2$ gas then the reaction mixture was stirred for 48 h at 60 °C until the aldehyde **122** disappeared as monitored by TLC. The resulting reaction mixture was quenched with aq. $NaHCO_3$ (~2-3 mL), filtered through a celite pad and concentrated in *vacuo*. Then it was extracted using ethyl acetate (2x5 mL). The organic extracts were combined, dried over anhydrous sodium sulphate and concentrated. The product was purified by neutral alumina column chromatography using hexane/ethyl acetate (50:1) as eluent to afford chiral-**123** (yield 70-80%).

**Step-II:** A 25 mL oven-dried RB flask was charged with chiral biaryl ester aldehyde chiral-**123**, ethylene glycol (1.2 eq), 10 mL toluene and *p*-TSA (0.03 eq). The reaction flask was connected to the Dean-Stark apparatus and heated at 150 °C until aldehyde chiral-**123** disappeared as monitored by TLC. The reaction mixture was cooled to room temperature and carefully quenched with triethylamine. The reaction mixture was concentrated under reduced pressure and then subsequently extracted with EtOAc (2x5 mL). The organic extracts were combined, dried over anhydrous sodium sulphate and concentrated. The product was purified by silica gel column chromatography using hexane/ethyl acetate (10:1) as eluent to afford chiral-**124** (yield 90-92%).

**Step-III:** To an oven-dried 25 mL long neck RB flask, chiral-**124** was dissolved in DCM. Then the reaction flask was kept at -78 $^oC$ and charged with $O_3$ for 2-5 minutes (6.0-8.0 g/min flow rate) until the reaction mixture turned pale blue. The excess amount of $O_3$ was removed from reaction mixture by purging $N_2$ through the reaction mixture. Then, $PPh_3$ (1.5 eq) was added at the room temperature (rt) and stirred at rt for 12-15 h until the color of the reaction mixture became pale-yellow. The resulting reaction mixture was quenched by water (~5-6 mL), filtered through a celite pad and extracted using DCM (2x6 mL). The organic extracts were combined, dried over anhydrous sodium sulphate and concentrated. The product was purified by silica gel column chromatography using hexane/ethyl acetate (10:1) as eluent to afford chiral biaryl aldehyde chiral-**125** (yield 85-90%).

**Step-IV:** An oven-dried 25 mL RB flask was charged with chiral biaryl aldehyde chiral-**125** in 10 mL dry THF and placed at 0 $^oC$ under $N_2$ atmosphere. The methyl magnesium chloride (3.0 M in THF, 1.2 eq) was added dropwise at the same temperature and stirred for 1 h. Upon completion, the reaction mixture was quenched with water (~2-3 mL) and extracted

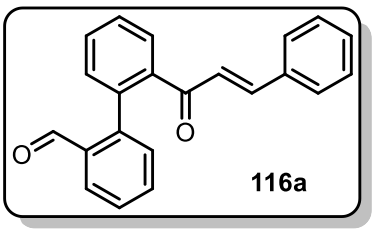
with ethyl acetate (2x5 mL). The organic extracts were combined and dried over anhydrous $Na_2SO_4$, and concentrated under reduced pressure. The crude product was taken to the next step without further purification.

The crude product was dissolved in ethyl acetate, and IBX (1.2 eq) was added. The suspension was stirred at reflux condition until the alcohol disappeared as monitored by TLC. The mixture was filtered through celite pad. The residue was washed with ethyl acetate (2x6 mL). The combined organic layers were washed with brine, dried over anhydrous $Na_2SO_4$, and concentrated under reduced pressure. The residue was purified by silica gel column chromatography using hexane/ethyl acetate (5:1) as eluent to afford chiral biaryl ketone chiral-**126** (yield 70-80%).

**Step-V:** The chiral biaryl ketone chiral-**126** and the corresponding aldehyde (1.0 eq) was dissolved in MeOH and KOH (1.0 eq) was introduced at -10 °C. The reaction mixture was stirred at the same temperature until the reactant chiral-**126** disappeared as monitored by TLC. The reaction mixture was quenched with saturated aqueous $NH_4Cl$ (~2-3 mL) solution and extracted with ethyl acetate (2x5 mL). The organic extracts were combined, dried over anhydrous sodium sulphate and concentrated. The crude product was taken to the next step without further purification.

The crude product was dissolved in acetone (5 mL), and a catalytic amount of *p*-TSA was added at room temperature. After completion of the reaction (monitored by TLC), the reaction was quenched with aqueous $NaHCO_3$ (~2-3 mL), and acetone was removed under reduced pressure. The aqueous layer was extracted with ethyl acetate (2x5 mL). The combined organic extracts were dried over anhydrous sodium sulphate and concentrated. The residue was purified by silica gel column chromatography using hexane/ethyl acetate (5:1) as eluent to afford **(–)-116** (yield 88-90%).

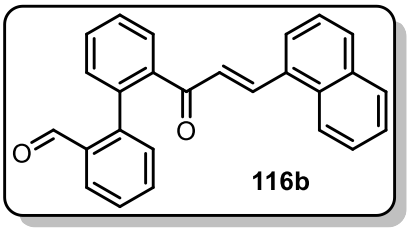
### 2'-Cinnamoyl-[1,1'-biphenyl]-2-carbaldehyde (116a).




This compound **116a** was prepared by following the general procedure-20 (condition A) and isolated as yellow oil. $R_f$ = 0.5 (hexane/EtOAc = 5/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 3060, 3027, 1694, 1667, 1597, 1208, 757. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 9.96 (s, 1H), 8.00 (d, *J* = 7.7 Hz, 1H), 7.78-7.76 (m, 1H), 7.60-7.55 (m, 3H), 7.49-7.42 (m, 2H), 7.38-7.31 (m, 7H), 6.78 (d, *J* = 15.9 Hz, 1H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 194.69, 191.62, 145.4, 143.9, 140.0, 137.1, 134.2, 134.0, 133.4,

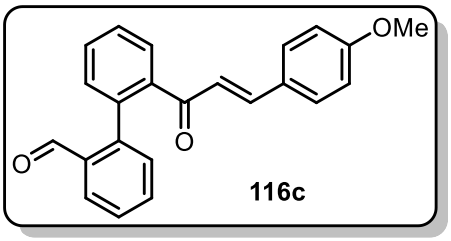
131.7, 131.1, 130.7, 130.5, 128.9 (2C), 128.6, 128.37 (2C), 128.32, 128.2, 128.1, 125.8. **HRMS (ESI):** *m/z* calcd for $C_{22}H_{16}O_2Na$ $(M+Na)^+$: 335.1048. Found: 335.1055.

### 2'-(3-(Naphthalen-1-yl)acryloyl)-[1,1'-biphenyl]-2-carbaldehyde (116b).



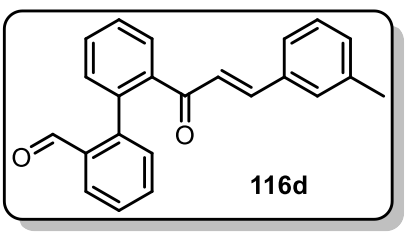

This compound **116b** was prepared by following the general procedure-20 (condition A) and isolated as pale-yellow oil. $R_f$ = 0.6 (hexane/EtOAc = 5/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 3079, 3059, 3042, 1694, 1662, 1597, 1252, 756. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 9.99 (s, 1H), 8.30 (d, *J* = 15.6 Hz, 1H), 8.06-8.01 (m, 2H), 7.87 (t, *J* = 7.4 Hz, 3H), 7.66-7.50 (m, 6H), 7.47-7.38 (m, 4H), 6.89 (d, *J* = 15.6 Hz, 1H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 194.1, 191.5, 144.0, 141.8, 140.1, 137.2, 134.1, 133.6, 133.4, 131.8, 131.7, 131.5, 131.2, 130.9, 130.6, 128.7 (2C), 128.3 (2C), 128.1 (2C), 127.0, 126.3, 125.3, 125.2, 123.2. **HRMS (ESI):** *m/z* calculated for $C_{26}H_{18}O_2Na$ $(M+Na)^+$: 385.1204. Found: 385.1226.

### 2'-(3-(4-Methoxyphenyl)acryloyl)-[1,1'-biphenyl]-2-carbaldehyde (116c).




This compound **116c** was prepared by following the general procedure-20 (condition A) and isolated as yellow oil. $R_f$ = 0.3 (hexane/EtOAc = 4/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 3064, 3016, 2933, 1692, 1636, 1595, 1255, 757. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 9.95 (s, 1H), 7.99 (dd, *J* = 7.7 and 1.0 Hz, 1H), 7.75-7.73 (m, 1H), 7.59-7.54 (m, 3H), 7.46 (t, *J* = 7.5 Hz, 1H), 7.38-7.29 (m, 5H), 6.85 (d, *J* = 8.7 Hz, 2H), 6.65 (d, *J* = 15.8 Hz, 1H), 3.82 (s, 3H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 194.7, 191.6, 161.8, 145.3, 144.0, 140.3, 137.0, 134.0, 133.3, 131.7, 131.0, 130.2, 130.1 (2C), 128.5, 128.2 (2C), 127.9, 126.9, 123.8, 114.3 (2C), 55.4. **HRMS (ESI):** *m/z* calculated for $C_{23}H_{19}O_3$ $(M+H)^+$: 343.1334. Found: 343.1341.

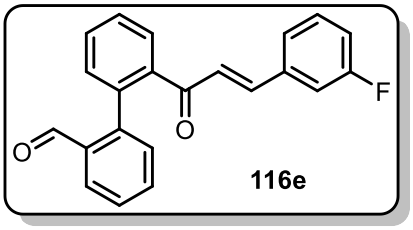
### 2'-(3-(*m*-Tolyl)acryloyl)-[1,1'-biphenyl]-2-carbaldehyde (116d).




This compound **116d** was prepared by following the general procedure-20 (condition A) and isolated as yellow oil. $R_f$ = 0.5 (hexane/EtOAc = 5/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 3059, 3023, 2982, 2922, 1694, 1644, 1598, 1239, 770. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 9.96 (s, 1H), 8.00 (d, *J* = 7.7 Hz,

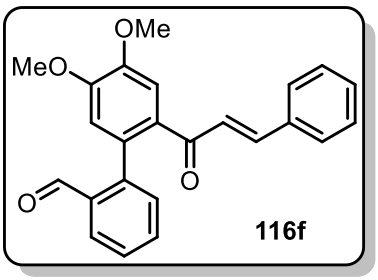
1H), 7.77 (d, *J* = 7.1 Hz, 1H), 7.62-7.56 (m, 3H), 7.48 (t, *J* = 7.5 Hz, 1H), 7.39-7.32 (m, 3H), 7.25-7.17 (m, 4H), 6.78 (d, *J* = 15.9 Hz, 1H), 2.34 (s, 3H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 194.6, 191.5, 145.6, 143.9, 140.1, 138.5, 137.1, 134.2, 134.1, 133.3, 131.7, 131.5, 131.0, 130.4, 129.0, 128.7, 128.5, 128.28, 128.23, 128.0, 125.8, 125.5, 21.2. **HRMS (ESI):** *m/z* calculated for $C_{23}H_{18}O_2Na$ $(M+Na)^+$: 349.1204. Found: 349.1212.

### 2'-(3-(3-Fluorophenyl)acryloyl)-[1,1'-biphenyl]-2-carbaldehyde (116e).



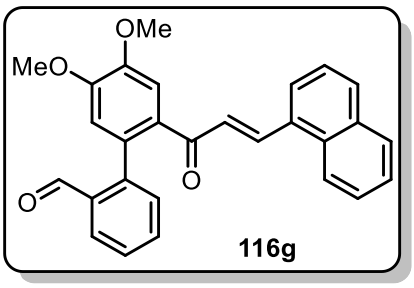

This compound **116e** was prepared by following the general procedure-20 (condition A) and isolated as yellow oil. $R_f$ = 0.4 (hexane/EtOAc = 5/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 2925, 2855, 1697, 1657, 1596, 1079, 756. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 9.91 (s, 1H), 7.98 (d, *J* = 7.7 Hz, 1H), 7.76 (d, *J* = 7.2 Hz, 1H), 7.62-7.54 (m, 3H), 7.47 (t, *J* = 7.5 Hz, 1H), 7.38-7.28 (m, 4H), 7.10-6.98 (m, 3H), 6.72 (d, *J* = 15.9 Hz, 1H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 194.1, 191.5, 162.9 (d, *J* = 245.6 Hz, 1C), 143.7, 143.5 (d, *J* = 2.4 Hz, 1C), 139.7, 137.3, 136.6 (d, *J* = 7.7 Hz, 1C), 134.1, 133.4, 131.7, 131.0, 130.7, 130.4, 130.3 (d, *J* = 8.1 Hz, 1C), 128.6, 128.4, 128.3 (d, *J* = 2.6 Hz, 1C), 126.8, 124.3 (d, *J* = 2.7 Hz, 1C), 117.4 (d, *J* = 21.2 Hz, 1C), 114.3 (d, *J* = 21.7 Hz, 1C). **$^{19}$F NMR (376.4 MHz, $CDCl_3$):** δ –112.3. **HRMS (ESI):** *m/z* calculated for $C_{22}H_{16}O_2F$ $(M+H)^+$: 331.1134 Found: 331.1148.

### 2'-Cinnamoyl-4',5'-dimethoxy-[1,1'-biphenyl]-2-carbaldehyde (116f).



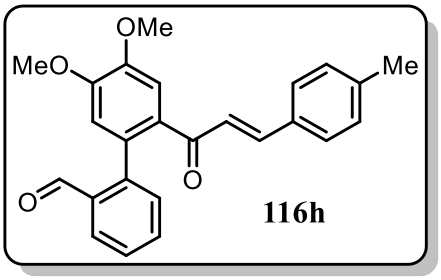

This compound **116f** was prepared by following the general procedure-20 (condition A) and isolated as dark yellow oil. $R_f$ = 0.3 (hexane/EtOAc = 3/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 3061, 3001, 2970, 2933, 1693, 1658, 1596, 1232, 773. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 9.98 (s, 1H), 8.00 (d, *J* = 7.7 Hz, 1H), 7.60 (t, *J* = 7.4 Hz, 1H), 7.50-7.44 (m, 2H), 7.40-7.34 (m, 3H), 7.32-7.30 (m, 2H), 7.23-7.22 (m, 2H), 6.82 (s, 1H), 6.61 (d, *J* = 15.7 Hz, 1H), 4.02 (s, 3H), 3.96 (s, 3H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 192.6, 191.5, 150.8, 148.7, 144.2, 143.7, 134.5, 134.3, 133.5, 132.8, 131.4, 130.9, 130.4, 128.7 (2C), 128.3, 128.2 (2C), 128.0, 125.6, 114.1, 111.9, 56.2 (2C). **HRMS (ESI):** *m/z* calculated for $C_{24}H_{20}O_4Na$ $(M+Na)^+$: 395.1259. Found: 395.1274.

### 4',5'-Dimethoxy-2'-(3-(naphthalen-1-yl)acryloyl)-[1,1'-biphenyl]-2-carbaldehyde (116g).




This compound **116g** was prepared by following the general procedure-20 (condition A) and isolated as yellow oil. $R_f$ = 0.3 (hexane/EtOAc = 3/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 3004, 2962, 2940, 2849, 1694, 1652, 1597, 1572, 1351, 1235, 1022, 732. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 10.01 (s, 1H), 8.31 (d, *J* = 15.5 Hz, 1H), 8.06-8.02 (m, 2H), 7.86-7.84 (m, 2H), 7.63 (td, *J* = 7.4 and 1.2 Hz, 1H), 7.56-7.50 (m, 3H), 7.46 (s, 1H), 7.42 (d, *J* = 7.5 Hz, 1H), 7.37 (t, *J* = 7.6 Hz, 1H), 7.22 (d, *J* = 7.2 Hz, 1H), 6.84 (s, 1H), 6.72 (d, *J* = 15.4 Hz, 1H), 4.04 (s, 3H), 3.97 (s, 3H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 192.3, 191.5, 150.9, 148.7, 144.3, 140.4, 134.4, 133.6 (2C), 132.9, 131.8, 131.5 (2C), 131.1, 130.7, 128.7, 128.3, 128.0 (2C), 126.9, 126.2, 125.2, 125.0, 123.3, 114.2, 111.9, 56.28, 56.27. **HRMS (ESI):** *m/z* calcd for $C_{28}H_{22}O_4Na$ $(M+Na)^+$: 445.1416. Found: 445.1398.

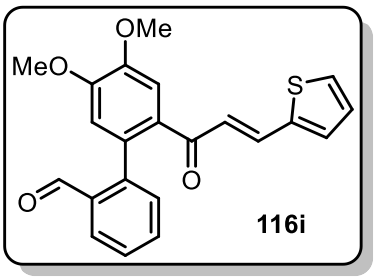
### 4',5'-Dimethoxy-2'-(3-(*p*-tolyl)acryloyl)-[1,1'-biphenyl]-2-carbaldehyde (116h).




This compound **116h** was prepared by following the general procedure-20 (condition A) and isolated as yellow oil. $R_f$ = 0.3 (hexane/EtOAc = 3/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 3004, 2970, 2940, 2852, 1693, 1658, 1597, 1567, 1390, 1235, 1022, 814, 733. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 9.98 (s, 1H), 7.99 (d, *J* = 7.7 Hz, 1H), 7.59 (t, *J* = 7.4 Hz, 1H), 7.47 (t, *J* = 7.5 Hz, 1H), 7.41-7.35 (m, 3H), 7.14-7.09 (m, 4H), 6.82 (s, 1H), 6.56 (d, *J* = 15.7 Hz, 1H), 4.02 (s, 3H), 3.95 (s, 3H), 2.34 (s, 3H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 192.7, 191.5, 150.7, 148.7, 144.3, 143.9, 141.0, 134.3, 133.4, 132.9, 131.7, 131.3, 130.8, 129.5 (2C), 128.3, 128.2 (2C), 127.9, 124.7, 114.1, 111.8, 56.2 (2C), 21.4. **HRMS (ESI):** *m/z* calcd for $C_{25}H_{22}O_4Na$ $(M+Na)^+$: 409.1416. Found: 409.1444.

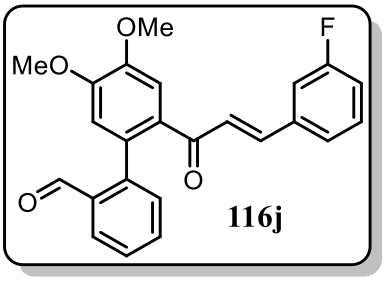
### 4',5'-Dimethoxy-2'-(3-(thiophen-2-yl)acryloyl)-[1,1'-biphenyl]-2-carbaldehyde (116i).

This compound **116i** was prepared by following the general procedure-20 (condition A) and isolated as yellow oil. $R_f$ = 0.4 (hexane/EtOAc = 3/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 3012, 2962, 2936, 2845, 1693, 1651, 1596, 1515, 1391, 1235, 1021, 776. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 8.01 (d, *J* = 7.8 Hz, 1H), 7.61 (td, *J* = 7.5 and 1.1 Hz, 2H), 7.54 (d, *J* = 15.4 Hz, 1H), 7.49 (t, *J* = 7.6 Hz, 1H), 7.38-7.35 (m, 2H), 7.31-7.28 (m, 1H), 7.11(d, *J* = 3.4 Hz, 1H),



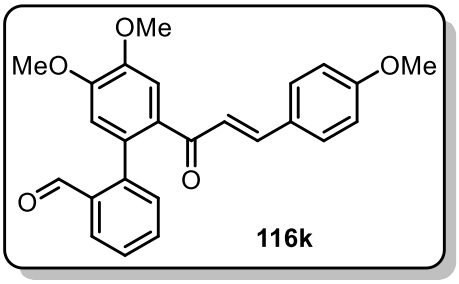

7.00-6.97 (m, 1H), 6.81 (s, 1H), 6.37 (d, *J* = 15.4 Hz, 1H), 4.02 (s, 3H), 3.95 (s, 3H). **$^{13}$C NMR (100 MHz, CDCl$_3$):** δ 191.8, 191.5, 150.8, 148.7, 144.1, 140.0, 135.8, 134.3, 133.5, 132.8, 131.7, 131.3, 131.0, 128.8, 128.4, 128.2, 128.0, 124.5, 114.1, 111.8, 56.2 (2C). **HRMS (ESI):** *m/z* calcd for $C_{22}H_{18}O_4SNa$ $(M+Na)^+$: 401.0823. Found: 401.0817.

### 2'-(3-(3-Fluorophenyl)acryloyl)-4',5'-dimethoxy-[1,1'-biphenyl]-2-carbaldehyde (116j).




This compound **116j** was prepared by following the general procedure-20 (condition A) and isolated as yellow oil. $R_f$ = 0.4 (hexane/EtOAc = 3/1). **IR (thin film, neat):** $\nu_{max}$/cm$^{-1}$ 3061, 3004, 2970, 2940, 1693, 1661, 1596, 1516, 1267, 1021, 733. **$^1$H NMR (400 MHz, CDCl$_3$):** δ 9.93 (s, 1H), 7.99 (d, *J* = 7.7 Hz, 1H), 7.62 (t, *J* = 7.4 Hz, 1H), 7.49 (t, *J* = 7.5 Hz, 1H), 7.39 (s, 2H), 7.35 (d, *J* = 15.2 Hz, 1H), 7.27-7.22 (m, 1H), 7.03-6.97 (m, 2H), 6.84-6.82 (m, 2H), 6.54 (d, *J* = 15.7 Hz, 1H), 4.01 (s, 3H), 3.95 (s, 3H). **$^{13}$C NMR (100 MHz, CDCl$_3$):** δ 192.0, 191.4, 162.8 (d, *J* = 245.4 Hz, 1C), 151.0, 148.8, 144.1, 141.9 (d, *J* = 2.4 Hz, 1C), 136.8 (d, *J* = 7.5 Hz, 1C), 134.4, 133.6, 132.5, 131.3, 131.1, 130.3 (d, *J* = 8.2 Hz, 1C), 128.5, 128.1, 126.6, 124.3 (d, *J* = 2.7 Hz, 1C), 117.2 (d, *J* = 21.2 Hz, 1C), 114.2, 114.0, 111.8, 56.2 (2C). **$^{19}$F NMR (376.4 MHz, CDCl$_3$):** δ –112.5. **HRMS (ESI):** *m/z* calcd for $C_{24}H_{19}FO_4Na$ $(M+Na)^+$: 413.1165. Found: 413.1146.

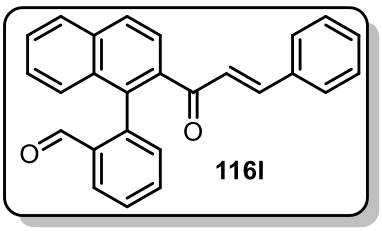
### 4',5'-Dimethoxy-2'-(3-(4-methoxyphenyl)acryloyl)-1,1'-biphenyl-2-carbaldehyde (116k).




This compound **116k** was prepared by following the general procedure-20 (condition A) and isolated as yellow oil. $R_f$ = 0.3 (hexane/EtOAc = 3/1). **IR (thin film, neat):** $\nu_{max}$/cm$^{-1}$ 2936, 2846, 1692, 1595, 1570, 1350, 1152, 1023, 770. **$^1$H NMR (500 MHz, CDCl$_3$):** δ 9.93 (s, 1H), 7.94 (d, *J* = 7.7 Hz, 1H), 7.54 (td, *J* = 7.5 and 1.2 Hz, 1H), 7.42 (t, *J* = 7.5 Hz, 1H), 7.35-7.32 (m, 3H), 7.15-7.13 (m, 2H), 6.78-6.76 (m, 3H), 6.44 (d, *J* = 15.7 Hz, 1H), 3.97 (s, 3H), 3.90 (s, 3H), 3.78 (s, 3H). **$^{13}$C NMR (125 MHz, CDCl$_3$):** δ 192.7, 191.6, 161.5, 150.6, 148.7, 144.3, 143.7, 134.3, 133.4, 133.1, 131.3, 130.7,

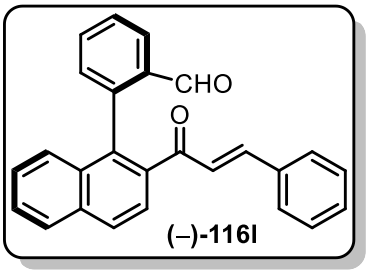
129.9 (2C), 128.2, 127.8, 127.1, 123.5, 114.2 (2C), 114.1, 111.8, 56.2 (2C), 55.3. **HRMS (ESI):** *m/z* calcd for $C_{25}H_{23}O_5$ $(M+H)^+$: 403.1545. Found: 403.1564.

### 2-(2-Cinnamoylnaphthalen-1-yl)benzaldehyde (116l).



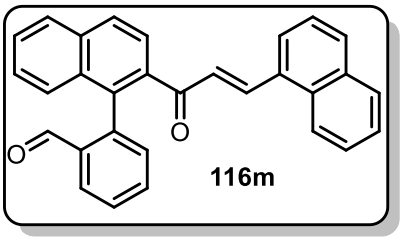

This compound **116l** was prepared by following the general procedure-20 (condition A) and isolated as pale-yellow oil. $R_f$ = 0.5 (hexane/EtOAc = 5/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 3061, 3023, 1701, 1642, 1596, 1217, 766. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 9.67 (s, 1H), 8.07 (d, *J* = 7.7 Hz, 1H), 8.03 (d, *J* = 8.4 Hz, 1H), 7.97 (d, *J* = 8.2 Hz, 1H), 7.74 (d, *J* = 8.4 Hz, 1H), 7.64-7.51 (m, 3H), 7.47-7.38 (m, 2H), 7.36-7.33 (m, 7H), 6.78 (d, *J* = 16.0 Hz, 1H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 195.7, 191.4, 145.7, 141.1, 137.6, 135.4, 134.6, 134.2, 133.9, 133.6, 132.9, 131.8, 130.7, 128.9 (2C), 128.78, 128.73, 128.4 (2C), 128.3, 127.7, 127.56, 127.54, 126.8, 126.4, 124.3. **HRMS (ESI):** *m/z* calculated for $C_{26}H_{19}O_2$ $(M+H)^+$: 363.1385. Found: 363.1398.

### (*Ra*)-2-(2-Cinnamoylnaphthalen-1-yl)benzaldehyde (–)-116l.




This compound **(–)-116l** was prepared by following the general procedure-21 and isolated as pale-yellow oil. **Optical rotation:** $[\alpha]_D^{25}$ –31.0 (*c* 0.13, $CHCl_3$) for a sample with *ee* 97%. The enantiomeric excess was determined by HPLC analysis using Daicel Chiralpak OD-H Column (90:10 *n*-Hexane/2-Propanol, 0.8 mL/min, 254 nm, $\tau_{major}$ = 23.6 min, $\tau_{minor}$ = 21.5 min).

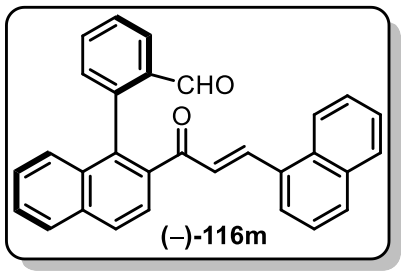
### 2-(2-(3-(Naphthalen-1-yl)acryloyl)naphthalen-1-yl)benzaldehyde (116m).




This compound **116m** was prepared by following the general procedure-20 (condition A) and isolated as yellow oil. $R_f$ = 0.5 (hexane/EtOAc = 5/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 3066, 2852, 1659, 1649, 1596, 1348, 1198, 797, 764. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 9.69 (s, 1H), 8.24 (d, *J* = 15.7 Hz, 1H), 8.00 (dd, *J* = 7.6 and 0.9 Hz, 1H), 8.06 (d, *J* = 8.5 Hz, 1H), 7.99-7.96 (m, 2H), 7.87-7.82 (m, 3H), 7.66-7.60 (m, 1H), 7.59-7.52 (m, 2H), 7.51-7.47 (m, 3H), 7.46-7.37 (m, 4H), 6.90 (d, *J* = 15.7 Hz, 1H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 195.2, 191.4, 142.2, 141.2, 137.7, 135.5, 134.8, 134.0, 133.69, 133.67, 132.9, 131.9, 131.59, 131.53, 131.0, 128.8 (3C), 128.6,

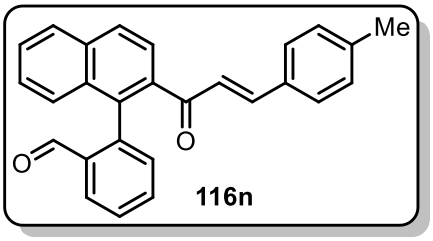
128.3, 127.8, 127.6, 127.5, 127.0, 126.9, 126.3, 125.3, 125.2, 124.4, 123.2. **HRMS (ESI):** *m/z* calculated for $C_{30}H_{20}O_2Na$ $(M+Na)^+$: 435.1361. Found: 435.1371.

### (*Ra*)-2-(2-(3-(Naphthalen-1-yl)acryloyl)naphthalen-1-yl)benzaldehyde ((–)-116m).



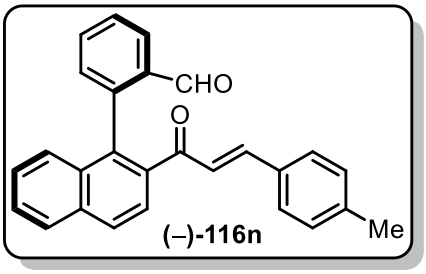

This compound **(–)-116m** was prepared by following the general procedure-21 and isolated as yellow oil. **Optical rotation:** $[\alpha]_D^{25}$ –52.0 (*c* 0.27, $CHCl_3$) for a sample with *ee* 99%. The enantiomeric excess was determined by HPLC analysis using Daicel Chiralpak OD-H Column (90:10 *n*-Hexane/2-Propanol, 0.8 mL/min, 348 nm, $\tau_{major}$ = 32.9 min, $\tau_{minor}$ = 28.6 min).

### 2-(2-(3-(*p*-Tolyl)acryloyl)naphthalen-1-yl)benzaldehyde (116n).



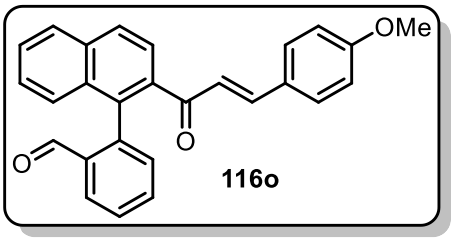

This compound **116n** was prepared by following the general procedure-20 (condition A) and isolated as yellow oil. $R_f$ = 0.5 (hexane/EtOAc = 5/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 3027, 2923, 2848, 1694, 1644, 1596, 1568, 1337, 1051, 753. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 9.67 (s, 1H), 8.08-8.01 (m, 2H), 7.97 (d, *J* = 8.2 Hz, 1H), 7.73 (d, *J* = 8.4 Hz, 1H), 7.62-7.53 (m, 3H), 7.46-7.38 (m, 2H), 7.34-7.29 (m, 2H), 7.26-7.24 (m, 2H), 7.14-7.12 (m, 2H), 6.74 (d, *J* = 16.0 Hz, 1H), 2.34 (s, 3H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 195.7, 191.4, 145.9, 141.3, 141.2, 137.8, 135.4, 134.4, 133.9, 133.6, 132.9, 131.8, 131.5, 129.6 (2C), 128.7, 128.6, 128.4 (2C), 128.3, 127.7, 127.5, 127.4, 126.8, 125.5, 124.4, 21.5. **HRMS (ESI):** *m/z* calcd for $C_{27}H_{20}O_2Na$ $(M+Na)^+$: 399.1361. Found: 399.1351.

### (*Ra*)-2-(2-(3-(*p*-Tolyl)acryloyl)naphthalen-1-yl)benzaldehyde ((–)-116n).



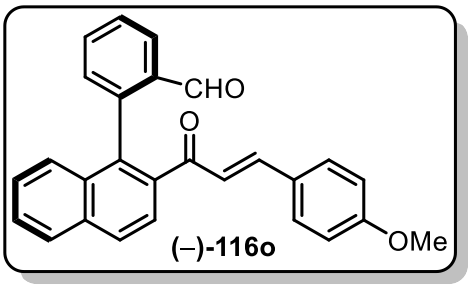

This compound **(–)-116n** was prepared by following the general procedure-21 and isolated as yellow oil. **Optical rotation:** $[\alpha]_D^{25}$ –41.8 (*c* 0.27, $CHCl_3$) for a sample with *ee* 96%. The enantiomeric excess was determined by HPLC analysis using Daicel Chiralpak OD-H Column (94:6 *n*-Hexane/2-Propanol, 0.5 mL/min, 219 nm, $\tau_{major}$ = 43.1 min, $\tau_{minor}$ = 37.9 min).

### 2-(2-(3-(4-Methoxyphenyl)acryloyl)naphthalen-1-yl)benzaldehyde (116o).



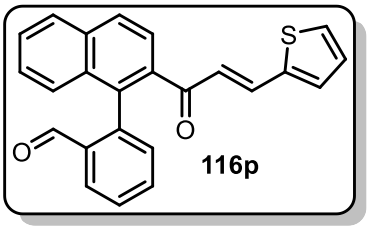

This compound**116o** was prepared by following the general procedure-20 (condition A) and isolated as yellow viscous oil. $R_f$ = 0.3 (hexane/EtOAc = 4/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 3008, 2966, 2936, 2841, 1694, 1634, 1597, 1572, 1337, 1251, 1028, 735. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 9.69 (s, 1H), 8.09 (d, *J* = 7.8 Hz, 1H), 8.05 (d, *J* = 8.4 Hz, 1H), 8.00 (d, *J* = 8.2 Hz, 1H), 7.76 (d, *J* = 8.4 Hz, 1H), 7.67-7.54 (m, 3H), 7.47 (t, *J* = 8.1 Hz, 1H), 7.42-7.28 (m, 5H), 6.87 (d, *J* = 8.3 Hz, 2H), 6.69 (d, *J* = 15.9 Hz, 1H), 3.84 (s, 3H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 195.7, 191.5, 161.8, 145.7, 141.2, 137.9, 135.3, 134.3, 133.8, 133.6, 132.9, 131.8, 130.2 (2C), 128.68, 128.65, 128.3, 127.6, 127.4, 127.3, 136.9, 126.8, 124.4, 124.3, 114.4 (2C), 55.4. **HRMS (ESI):** *m/z* calcd for $C_{27}H_{20}O_3Na$ $(M+Na)^+$: 415.1310. Found: 415.1295.

### (*Ra*)-2-(2-(3-(4-Methoxyphenyl)acryloyl)naphthalen-1-yl)benzaldehyde ((–)-116o).




This compound **(–)-116o** was prepared by following the general procedure-21 and isolated as yellow oil. **Optical rotation:** $[\alpha]_D^{25}$ –49.1 (*c* 0.37, $CHCl_3$) for a sample with *ee* 95%. The enantiomeric excess was determined by HPLC analysis using Daicel Chiralpak OD-H Column (90:10 *n*-Hexane/2-Propanol, 0.8 mL/min, 219 nm, $\tau_{major}$ = 32.8 min, $\tau_{minor}$ = 28.2 min).

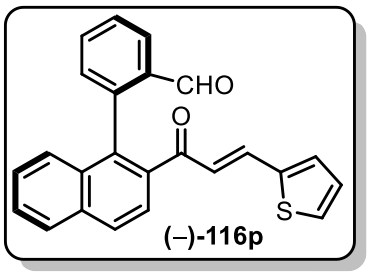
### 2-(2-(3-(Thiophen-2-yl)acryloyl)naphthalen-1-yl)benzaldehyde (116p).




This compound **116p** was prepared by following the general procedure-20 (condition A) and isolated as pale-yellow solid. $R_f$ = 0.5 (hexane/EtOAc = 5/1). M.P. = 197-199 °C. **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 3060, 2925, 2850, 2749, 1697, 1651, 1594, 1583, 1270, 1073, 732. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 9.69 (s, 1H), 8.11 (d, *J* = 7.7 Hz, 1H), 8.05 (d, *J* = 8.4 Hz, 1H), 7.99 (d, *J* = 8.2 Hz, 1H), 7.77 (d, *J* = 8.4 Hz, 1H), 7.67 (t, *J* = 7.4 Hz, 1H), 7.62-7.56 (m, 2H), 7.52-7.46 (m, 2H), 7.42-7.35 (m, 3H), 7.17 (d, *J* = 3.0 Hz, 1H), 7.03 (t, *J* = 4.8 Hz, 1H), 6.60 (d, *J* = 15.6 Hz, 1H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 194.8, 191.4, 141.1, 139.7, 137.68, 137.62, 135.4, 134.6, 134.0, 133.7,

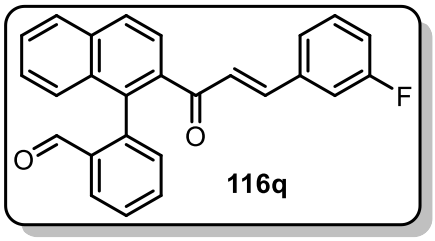
132.9, 132.1, 131.8, 129.3, 128.8, 128.7, 128.34, 128.30, 127.8, 127.5 (2C), 126.8, 125.1, 124.4. **HRMS (ESI):** *m/z* calcd for $C_{24}H_{16}O_2SNa$ $(M+Na)^+$: 391.0768. Found: 391.0770.

### (*Ra*)-2-(2-(3-(Thiophen-2-yl)acryloyl)naphthalen-1-yl)benzaldehyde ((–)-116p).



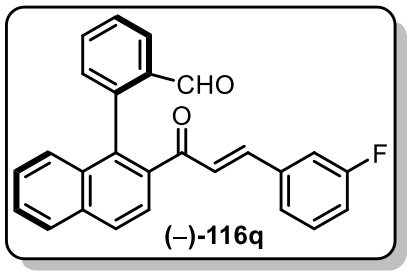

This compound **(–)-116p** was prepared by following the general procedure-21 and isolated as pale-yellow semi-solid. **Optical rotation:** $[\alpha]_D^{25}$ –60.4 (*c* 0.27, $CHCl_3$) for a sample with *ee* 96%. The enantiomeric excess was determined by HPLC analysis using Daicel Chiralpak OD-H Column (90:10 *n*-Hexane/2-Propanol, 0.8 mL/min, 254 nm, $\tau_{major}$ = 24.1 min, $\tau_{minor}$ = 22.0 min).

### 2-(2-(3-(3-Fluorophenyl)acryloyl)naphthalen-1-yl)benzaldehyde (116q).



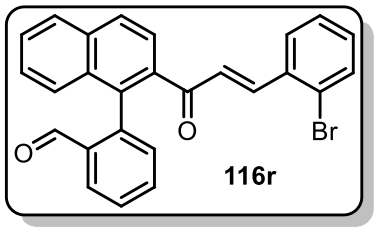

This compound **116q** was prepared by following the general procedure-20 (condition A) and isolated as yellow semi-solid. $R_f$ = 0.5 (hexane/EtOAc = 5/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 3065, 2955, 2928, 2852, 1697, 1650, 1598, 1582, 1242, 971, 765. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 9.69 (s, 1H), 8.10 (dd, *J* = 7.7 and 0.9 Hz, 1H), 8.06 (d, *J* = 8.5 Hz, 1H), 7.78 (d, *J* = 8.5 Hz, 1H), 7.67 (td, *J* = 7.5 and 1.2 Hz, 1H), 7.64-7.56 (m, 2H), 7.48 (td, *J* = 7.0 and 1.0 Hz, 1H), 7.42 (d, *J* = 8.5 Hz, 1H), 6.78 (d, *J* = 16.6 Hz, 1H), 7.37 (d, *J* = 7.4 Hz, 1H), 7.34-7.29 (m, 2H), 7.14 (d, *J* = 7.6 Hz, 1H), 7.09-7.04 (m, 2H), 6.78 (d, *J* = 15.9 Hz, 1H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 195.1, 191.3, 162.9 (d, *J* = 245.5 Hz, 1C), 143.8, 141.0, 137.3, 136 (d, *J* = 7.6 Hz, 1C), 135.4, 134.8, 134.0, 133.6, 132.8, 131.9, 130.4 (d, *J* = 8.1 Hz, 1C), 128.8 (d, *J* = 4.9 Hz, 2C), 128.3, 127.9, 127.5 (d, *J* = 6.4 Hz, 1C), 127.3, 126.9, 124.4 (d, *J* = 2.6 Hz, 1C), 124.3 (2C), 117.5 (d, *J* = 21.2 Hz, 1C), 114.4 (d, *J* = 21.8 Hz, 1C). **$^{19}$F NMR (376.4 MHz, $CDCl_3$):** δ –112.3. **HRMS (ESI):** *m/z* calcd for $C_{26}H_{17}FO_2Na$ $(M+Na)^+$: 403.1110. Found: 403.1127.

### (*Ra*)-2-(2-(3-(3-Fluorophenyl)acryloyl)naphthalen-1-yl)benzaldehyde ((–)-116q).



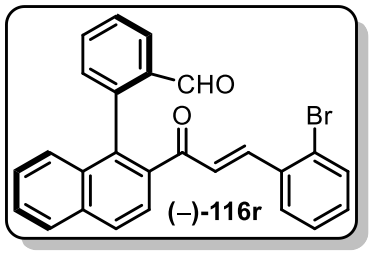

This compound **(–)-116q** was prepared by following the general procedure-21 and isolated as yellow oil. **Optical rotation:** $[\alpha]_D^{25}$ –85.4 (*c* 0.05, $CH_2Cl_2$) for a sample with *ee* 96%. The enantiomeric excess was determined by HPLC analysis using Daicel Chiralpak OD-H Column (90:10 *n*-Hexane/2-Propanol, 1.0 mL/min, 220 nm, $\tau_{major}$ = 18.5 min, $\tau_{minor}$ = 16.8 min).

### 2-(2-(3-(2-Bromophenyl)acryloyl)naphthalen-1-yl)benzaldehyde (116r).



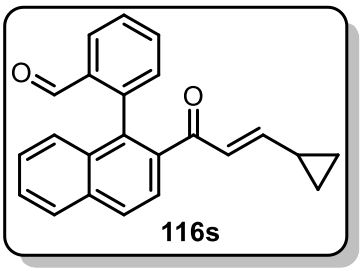

This compound **116r** was prepared by following the general procedure-21 (by using DL-*tert*-leucine as catalyst) and isolated as yellow oil. $R_f$ = 0.6 (hexane/EtOAc = 5/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 3056, 2934, 1697, 1657, 1602, 1467, 1267, 738. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 9.65 (s, 1H), 8.09 (d, *J* = 7.7 Hz, 1H), 8.04 (d, *J* = 8.4 Hz, 1H), 7.97 (d, *J* = 8.2 Hz, 1H), 7.77-7.70 (m, 2H), 7.64-7.54 (m, 4H), 7.45 (t, *J* = 8.1 Hz, 1H), 7.40-7.35 (m, 3H), 7.28-7.24 (m, 1H), 7.19 (t, *J* = 8.1 Hz, 1H), 6.71 (d, *J* = 16.0 Hz, 1H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 195.4, 191.4, 144.0, 141.1, 137.3, 135.4, 134.7, 134.3, 134.0, 133.6, 133.4, 132.9, 131.9, 131.5, 129.0, 128.78, 128.71, 128.3, 127.7, 127.70, 127.6, 127.5 (2C), 126.9, 125.8, 124.4. **HRMS (ESI):** *m/z* calculated for $C_{26}H_{17}BrO_2Na$ $(M+Na)^+$: 463.0310. Found: 463.0317.

### (*Ra*)-2-(2-(3-(2-Bromophenyl)acryloyl)naphthalen-1-yl)benzaldehyde ((–)-116r).



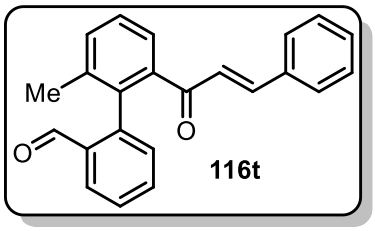

This compound **(–)-116r** was prepared by following the general procedure-21 and isolated as yellow oil. **Optical rotation:** $[\alpha]_D^{25}$ –31.0 (*c* 0.09, $CHCl_3$) for a sample with *ee* 98%. The enantiomeric excess was determined by HPLC analysis using Daicel Chiralpak IA Column (90:10 *n*-Hexane/2-Propanol, 1.0 mL/min, 254 nm, $\tau_{major}$ = 15.1 min, $\tau_{minor}$ = 12.9 min).

### 2-(2-(3-Cyclopropylacryloyl)naphthalen-1-yl)benzaldehyde (116s).



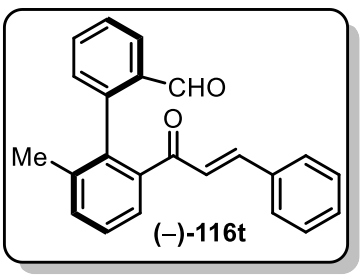

This compound **116s** was prepared by following the general procedure-20 (condition A) and isolated as yellow oil. $R_f$ = 0.4 (hexane/EtOAc = 10/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 2956, 2924, 1695, 1642, 1596, 1377, 1195, 762. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 9.58 (s, 1H), 8.08 (dd, *J* = 7.6 and 1.3 Hz, 1H), 7.98 (d, *J* = 8.4 Hz, 1H), 7.94 (d, *J* = 8.2 Hz, 1H), 7.67-7.61 (m, 2H), 7.59-7.53 (m, 2H), 7.45-7.40 (m, 1H), 7.36-7.34 (m, 1H), 7.29 (dd, *J* = 7.5 and 1.0 Hz, 1H), 6.27 (d, *J* = 15.4 Hz, 1H), 6.11-6.04 (m, 1H), 1.48-1.42 (m, 1H), 0.94-0.90 (m, 2H), 0.54-0.50 (m, 2H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 195.3, 191.5, 157.1, 141.3, 137.7, 135.2, 134.0, 133.7, 133.5, 132.9, 131.9, 128.59, 128.52, 128.2, 127.7, 127.47, 127.43, 127.2, 126.7, 124.2, 15.1, 9.57, 9.53. **HRMS (ESI):** *m/z* calculated for $C_{23}H_{19}O_2$ $(M+H)^+$: 327.1385. Found: 327.1383.

### 2'-Cinnamoyl-6'-methyl-[1,1'-biphenyl]-2-carbaldehyde (116t).




This compound **116t** was prepared by following the general procedure-20 (condition A) and isolated as yellow semi-solid. $R_f$ = 0.6 (hexane/EtOAc = 5/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 3064, 3034, 2971, 1694, 1644, 1596, 1229, 763. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 9.84 (s, 1H), 8.00 (d, *J* = 7.7 Hz, 1H), 7.59-7.52 (m, 2H), 7.48-7.44 (m, 3H), 7.42-7.40 (m, 2H), 7.37-7.33 (m, 4H), 7.21 (d, *J* = 7.6 Hz, 1H), 6.81 (d, *J* = 16.0 Hz, 1H), 2.08 (s, 3H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 195.5, 191.8, 145.7, 142.5, 140.1, 137.6, 136.3, 134.36, 134.31, 133.7, 132.2, 130.74, 130.72, 128.9 (2C), 128.4 (2C), 128.2, 127.99, 127.92, 126.3, 125.6, 20.6. **HRMS (ESI):** *m/z* calculated for $C_{23}H_{18}O_2Na$ $(M+Na)^+$: 349.1204. Found: 349.1213.

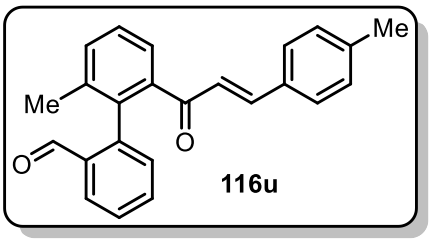
### (*Ra*)-2'-Cinnamoyl-6'-methyl-[1,1'-biphenyl]-2-carbaldehyde ((–)-116t).




This compound **(–)-116t** was prepared by following the general procedure-21 and isolated as yellow semi-solid. **Optical rotation:** $[\alpha]_D^{25}$ –69.0 (*c* 0.09, $CH_2Cl_2$) for a sample with *ee* 88%. The enantiomeric excess was determined by HPLC analysis using Daicel Chiralpak IA Column (95:5 *n*-Hexane/2-

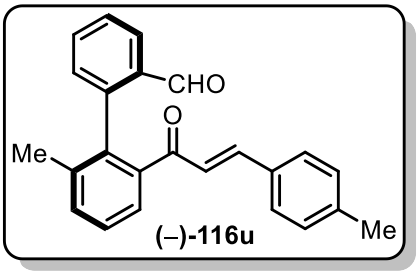
Propanol, 1.0 mL/min, 295 nm, $\tau_{major}$ = 20.9 min, $\tau_{minor}$ = 18.3 min).

### 2'-Methyl-6'-(3-(p-tolyl)acryloyl)-[1,1'-biphenyl]-2-carbaldehyde (116u).



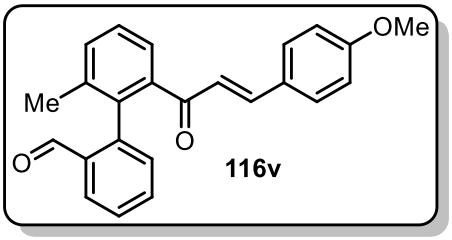

This compound **116u** was prepared by following the general procedure-20 (condition A) and isolated as yellow oil. $R_f$ = 0.5 (hexane/EtOAc = 5/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 2956, 2855, 1694, 1648, 1596, 1452, 987, 758. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 9.80 (s, 1H), 7.96 (d, *J* = 7.7 Hz, 1H), 7.54 (td, *J* = 7.4 and 0.8 Hz, 1H), 7.49-7.47 (m, 1H), 7.45-7.41 (m, 3H), 7.30-7.27 (m, 3H), 7.17 (d, *J* = 7.5 Hz, 1H), 7.14 (d, *J* = 8.0 Hz, 2H), 6.72 (d, *J* = 16.0 Hz, 1H), 2.34 (s, 3H), 2.05 (s, 3H). **$^{13}$C NMR (125 MHz, $CDCl_3$):** δ 195.6, 191.8, 145.9, 142.6, 141.3, 140.3, 137.6, 136.2, 134.3, 133.7, 132.0, 131.5, 130.7, 129.6 (2C), 128.4 (2C), 128.2, 127.9, 127.8, 125.54, 125.53, 21.5, 20.6. **HRMS (ESI):** *m/z* calculated for $C_{24}H_{21}O_2$ $(M+H)^+$: 341.1542. Found: 341.1557.

### (*Ra*)-2'-Methyl-6'-(3-(*p*-tolyl)acryloyl)-[1,1'-biphenyl]-2-carbaldehyde ((–)-116u).




This compound **(–)-116u** was prepared by following the general procedure-21 and isolated as yellow oil. **Optical rotation:** $[\alpha]_D^{25}$ –115.2 (*c* 0.11, $CH_2Cl_2$) for a sample with *ee* 92%. The enantiomeric excess was determined by HPLC analysis using Daicel Chiralpak IA Column (95:5 *n*-Hexane/2-Propanol, 1.0 mL/min, 302 nm, $\tau_{major}$ = 21.9 min, $\tau_{minor}$ = 17.9 min).

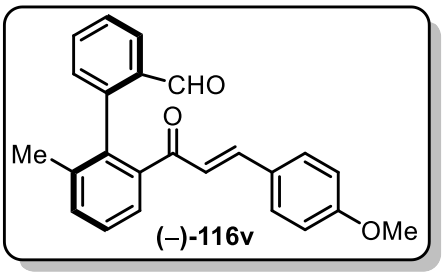
### 2'-(3-(4-Methoxyphenyl)acryloyl)-6'-methyl-[1,1'-biphenyl]-2-carbaldehyde (116v).




This compound **116v** was prepared by following the general procedure-20 (condition A) and isolated as yellow oil. $R_f$ = 0.5 (hexane/EtOAc = 5/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 2956, 2843, 1694, 1596, 1570, 1254, 829, 759. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 9.80 (s, 1H), 7.96 (dd, *J* = 7.7 and 0.9 Hz, 1H), 7.55 (td, *J* = 7.4 and 1.2 Hz, 1H), 7.49-7.46 (m, 1H), 7.43-7.42 (m, 3H), 7.34 (d, *J* = 8.7 Hz, 2H), 7.27 (d, *J* = 16.0 Hz, 1H), 7.18 (d, *J* = 7.4 Hz, 1H), 6.85 (d, *J* = 8.7 Hz, 2H), 6.64 (d, *J* = 15.9 Hz, 1H), 3.82 (s, 3H), 2.05 (s, 3H). **$^{13}$C NMR (125 MHz,**

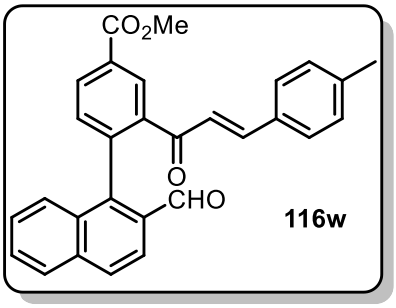
**$CDCl_3$):** δ 195.6, 191.8, 161.7, 145.7, 142.6, 140.4, 137.5, 136.1, 134.3, 133.7, 131.9, 130.7, 130.1 (2C), 128.1, 127.9, 127.8, 127.0, 125.4, 124.3, 114.3 (2C), 55.4, 20.6. **HRMS (ESI):** *m/z* calculated for $C_{24}H_{20}O_3Na$ $(M+Na)^+$: 379.1310. Found: 379.1295.

### (*Ra*)-2'-(3-(4-Methoxyphenyl)acryloyl)-6'-methyl-[1,1'-biphenyl]-2-carbaldehyde ((–)-116v).




This compound **(–)-116v** was prepared by following the general procedure-21 and isolated as yellow oil. **Optical rotation:** $[\alpha]_D^{25}$ –113.8 (*c* 0.07, $CH_2Cl_2$) for a sample with *ee* 92%. The enantiomeric excess was determined by HPLC analysis using Daicel Chiralpak IA Column (95:5 *n*-Hexane/2-Propanol, 1.0 mL/min, 328 nm, $\tau_{major}$ = 36.9 min, $\tau_{minor}$ = 29.9 min).

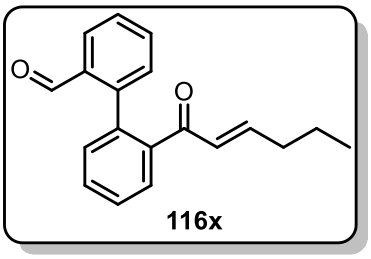
### Methyl-4-(2-formylnaphthalen-1-yl)-3-(3-(*p*-tolyl)acryloyl)benzoate (116w).




This compound **116w** was prepared by following the general procedure-21 (by using DL-*tert*-leucine as catalyst) and isolated as yellow oil. $R_f$ = 0.5 (hexane/EtOAc = 5/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 2956, 2923, 1726, 1693, 1596, 1437, 1298, 976, 766. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 9.86 (s, 1H), 8.53 (d, *J* = 1.32 Hz, 1H), 8.32 (dd, *J* = 7.9 and 1.5 Hz, 1H), 8.03 (d, *J* = 8.6 Hz, 1H), 7.92-7.88 (m, 2H), 7.59-7.53 (m, 2H), 7.48-7.45 (m, 2H), 7.30 (d, *J* = 15.8 Hz, 1H), 7.08 (s, 4H), 6.72 (d, *J* = 15.8 Hz, 1H), 4.02 (s, 3H), 2.32 (s, 3H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 192.3, 191.4, 166.0, 145.9, 143.2, 141.5, 141.4, 139.5, 135.9, 132.6, 131.9, 131.34, 131.30 (2C), 130.6, 129.5 (2C), 129.54, 129.1, 128.8, 128.5, 128.4 (2C), 127.3, 126.9, 123.3, 122.4, 52.6, 21.5. **HRMS (ESI):** *m/z* calculated for $C_{29}H_{23}O_4$ $(M+H)^+$: 435.1596. Found: 435.1589.

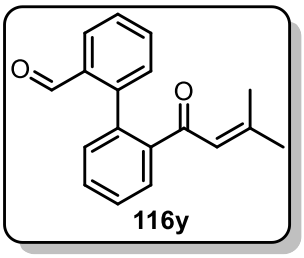
### 2'-(Hex-2-enoyl)-[1,1'-biphenyl]-2-carbaldehyde (116x).

This compound **116x** was prepared by following the general procedure-20 (condition B) and isolated as yellow oil. $R_f$ = 0.7 (hexane/EtOAc = 10/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 2872, 1694, 1652, 1619, 1293, 981, 757. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 9.87 (s, 1H), 7.98 (dd, *J* = 7.6 and 0.7 Hz, 1H), 7.61 (dd, *J* = 7.0 and 1.3 Hz, 1H), 7.58-7.45 (m, 4H), 7.31 (dd, *J* = 7.6



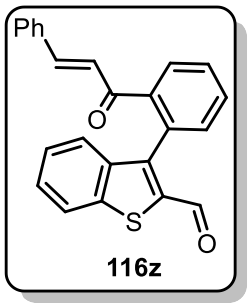

and 1.6 Hz, 1H), 7.25 (d, *J* = 7.5 Hz, 1H), 6.64-6.57 (m, 1H), 6.11 (d, *J* = 15.7 Hz, 1H), 2.06-2.00 (m, 2H), 1.35-1.25 (m, 2H), 0.80 (t, *J* = 7.3 Hz, 3H). **$^{13}$C NMR (100 MHz, CDCl$_3$):** δ 195.4, 191.5, 151.2, 144.0, 140.0, 136.7, 133.9, 133.3, 131.6, 131.0, 130.2, 130.1, 128.4, 128.19, 128.12, 127.8, 34.5, 21.1, 13.6. **HRMS (ESI):** *m/z* calculated for $C_{19}H_{18}O_2Na$ $(M+Na)^+$: 301.1204. Found: 301.1232.

### 2'-(3-Methylbut-2-enoyl)-[1,1'-biphenyl]-2-carbaldehyde (116y).




This compound **116y** was prepared by following the general procedure-20 (condition B) and isolated as yellow oil. $R_f$ = 0.6 (hexane/EtOAc = 10/1). **IR (thin film, neat):** $\nu_{max}$/cm$^{-1}$ 2923, 1694, 1661, 1614, 1447, 1251, 757. **$^1$H NMR (400 MHz, CDCl$_3$):** δ 9.86 (s, 1H), 7.99 (d, *J* = 7.1 Hz, 1H), 7.71-7.69 (m, 1H), 7.58 (t, *J* = 7.2 Hz, 1H), 7.52-7.46 (m, 3H), 7.30-7.27 (m, 2H), 6.06 (s, 1H), 1.97 (s, 3H), 1.70 (s, 3H). **$^{13}$C NMR (100 MHz, CDCl$_3$):** δ 194.3, 191.6, 156.6, 144.6, 141.7, 136.7, 134.0, 133.3, 131.5, 131.0, 130.2, 128.3, 128.2, 128.0, 127.5, 124.5, 27.6, 20.8. **HRMS (ESI):** *m/z* calculated for $C_{18}H_{16}O_2Na$ $(M+Na)^+$: 287.1048. Found: 287.1080.

### 3-(2-Cinnamoylphenyl)benzo[*b*]thiophene-2-carbaldehyde (116z).




This compound **116z** was prepared by following the general procedure-20 (condition A) and isolated as yellow oil. $R_f$ = 0.5 (hexane/EtOAc = 5/1). **IR (thin film, neat):** $\nu_{max}$/cm$^{-1}$ 2924, 2853, 1715, 1667, 1604, 1209, 758. **$^1$H NMR (400 MHz, CDCl$_3$):** δ 9.82 (s, 1H), 7.89-7.84 (m, 2H), 7.70-7.67 (m, 2H), 7.62 (d, *J* = 8.0 Hz, 1H), 7.54 (d, *J* = 6.9 Hz, 1H), 7.49 (t, *J* = 7.5 Hz, 1H), 7.39 (t, *J* = 7.7 Hz, 1H), 7.31-7.27 (m, 2H), 7.24-7.21 (m, 2H), 7.10-7.08 (m, 2H), 6.65 (d, *J* = 15.8 Hz, 1H). **$^{13}$C NMR (100 MHz, CDCl$_3$):** δ 193.6, 185.0, 145.5, 144.8, 141.6, 141.3, 139.7, 139.5, 134.1, 131.7, 131.2, 131.1, 130.6, 129.4, 129.2, 128.7 (2C), 128.4, 128.2 (2C), 125.5, 125.1, 124.7, 123.3. **HRMS (ESI):** *m/z* calculated for $C_{24}H_{16}O_2SNa$ $(M+Na)^+$: 391.0769. Found: 391.0762.

### General procedure-22: PBu$_3$-Catalyzed synthesis of racemic and chiral 117.

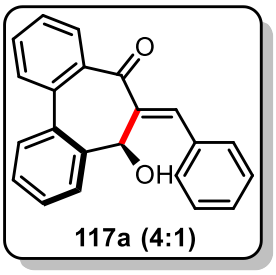
An oven-dried 5 mL glass vial was charged with the racemic or chiral **116** (0.1 mmol), DMF (1.0 mL), and tributylphosphine (0.02 mmol) at room temperature and stirred until **116**

disappeared as monitored by TLC. Then the reaction mixture was quenched with water (~1-2 mL) and extracted using ethyl acetate (2x3 mL). The organic extracts were combined and dried over anhydrous sodium sulfate and concentrated. The crude product was purified by silica gel column chromatography using hexane/ethyl acetate as an eluent to afford **117** or **(+/–)-117**.

### General procedure-23: Synthesis of chiral dibenzocycloheptenones (+/–)-117 catalyzed by C1.

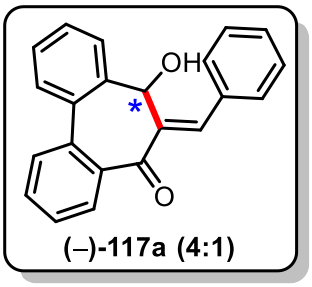
An oven-dried 5 mL glass vial was charged with **(±)-116** (0.1 mmol), and 1,1,1,3,3,3-hexafluoroisopropanol (HFIP, 0.5 mL), water (0.5 mmol), and the catalyst **C1** (0.02 mmol) were introduced. The reaction mixture was then stirred at 50 °C for 5 days. Volatiles were removed under reduced pressure. The crude product was purified by silica gel column chromatography using hexane/ethyl acetate as eluent to afford **(+/–)-117**.

### 6-Benzylidene-7-hydroxy-6,7-dihydro-5*H*-dibenzo[*a*,*c*][7]annulen-5-one (major isomer) (117a).



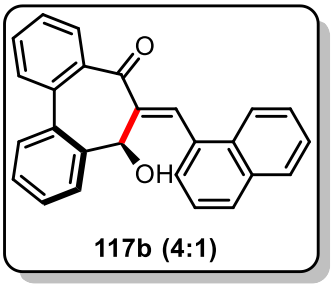

This compound was isolated as pale-yellow oil. Following the general procedure-22, 40 mg of **116a** afforded 34 mg of **117a** (85% yield). $R_f$ = 0.4 (hexane/EtOAc = 5/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 3434, 3061, 3023, 2960, 1660, 1597, 743. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 7.92 (s, 1H), 7.82 (d, *J* = 7.7 Hz, 1H), 7.65-7.61 (m, 1H), 7.56-7.42 (m, 9H), 7.31 (t, *J* = 7.4 Hz, 1H), 7.19 (d, *J* = 7.5 Hz, 1H), 5.92 (d, *J* = 3.4 Hz, 1H), 2.13 (d, *J* = 4.6 Hz, 1H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 192.8, 141.7, 139.9, 139.1, 138.9, 138.1, 137.2, 134.9, 132.4, 131.2, 129.9, 129.49, 129.43 (3C), 129.0, 128.6 (3C), 128.4, 128.1, 71.5. **HRMS (ESI):** *m/z* calculated for $C_{22}H_{16}O_2Na$ $(M+Na)^+$: 335.1048. Found: 335.1058.

### 6-Benzylidene-7-hydroxy-6,7-dihydro-5*H*-dibenzo[*a*,*c*][7]annulen-5-one (major isomer) ((–)-117a).



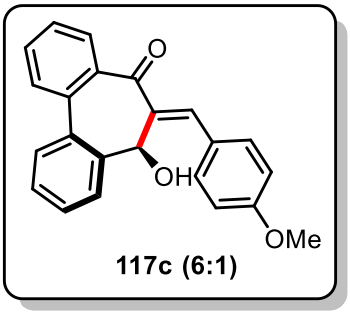

Following the general procedure-23, 25 mg of **(±)-116a** afforded 5.0 mg of **(–)-117a** (20% yield). **Optical rotation:** $[\alpha]_D^{25}$ –36.7 (*c* 0.05, $CHCl_3$) for a sample with *ee* 76%. The enantiomeric excess was determined by HPLC analysis using Daicel Chiralpak IB Column (96:04 *n*-Hexane/2-Propanol, 1.0 mL/min, 244 nm, $\tau_{major}$ = 79.0 min, $\tau_{minor}$ = 32.2 min).

**7-Hydroxy-6-(naphthalen-1-ylmethylene)-6,7-dihydro-5*H*-dibenzo[*a*,*c*][7]annulen-5-one (major isomer) (117b).**



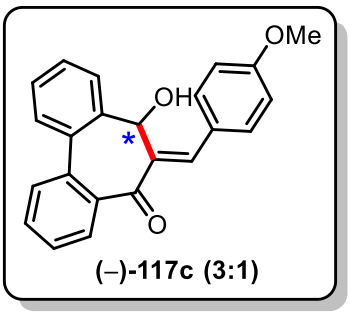

This compound was isolated as pale-yellow solid. Following the general procedure-22, 40 mg of **116b** afforded 32.4 mg of **117b** (81% yield). M.P. = 92-95 $^{o}$C. $R_f$ = 0.4 (hexane/EtOAc = 5/1). **IR (thin film, neat):** $\nu_{max}$/cm$^{-1}$ 3441, 3060, 2925, 1660, 1596, 742. **$^{1}$H NMR (400 MHz, CDCl$_3$):** δ 8.39 (s, 1H), 7.93-7.91 (m, 3H), 7.64 (t, *J* = 7.0 Hz, 1H), 7.58-7.48 (m, 7H), 7.45-7.35 (m, 2H), 7.25 (s, 1H), 7.01 (d, *J* = 7.3 Hz, 1H), 5.75 (s, 1H), 2.04 (brs, 1H). **$^{13}$C NMR (100 MHz, CDCl$_3$):** δ 192.3, 143.4, 139.0, 138.97, 138.93, 138.4, 137.2, 133.5, 132.5 (2C), 131.6, 131.2, 130.1, 129.66, 129.63, 129.35, 129.31, 128.5, 128.4, 128.1, 126.7, 126.58, 126.53, 125.2, 125.1, 72.0. **HRMS (ESI):** *m/z* calculated for $C_{26}H_{18}O_2Na$ $(M+Na)^+$: 385.1204. Found: 385.1221.

**7-Hydroxy-6-(4-methoxybenzylidene)-6,7-dihydro-5*H*-dibenzo[*a*,*c*][*7*]annulen-5-one (major isomer) (117c).**



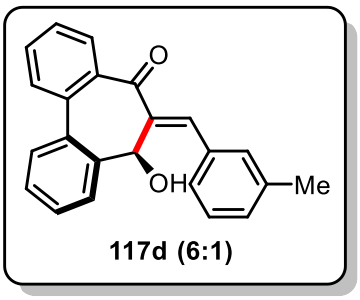

This compound was isolated as yellow viscous oil. Following the general procedure-22, 35 mg of **116c** afforded 26.6 mg of **117c** (76% yield). $R_f$ = 0.3 (hexane/EtOAc = 4/1). **IR (thin film, neat):** $\nu_{max}$/cm$^{-1}$ 3440, 3061, 2960, 2930, 1654, 1597, 742. **$^{1}$H NMR (400 MHz, CDCl$_3$):** δ 7.86 (s, 1H), 7.80 (d, *J* = 7.5 Hz, 1H), 7.62 (t, *J* = 7.8 Hz, 1H), 7.54-7.41 (m, 6H), 7.32-7.22 (m, 2H), 6.99 (d, *J* = 8.5 Hz, 2H), 5.98 (d, *J* = 4.6 Hz, 1H), 3.87 (s, 3H), 2.14 (d, *J* = 4.9 Hz, 1H). **$^{13}$C NMR (100 MHz, CDCl$_3$):** δ 193.0, 160.5, 140.2, 139.9, 139.4, 139.1, 137.9, 137.19, 137.15, 132.2, 131.5 (2C), 131.1, 129.8, 129.37, 129.33, 128.4, 128.1, 127.1, 114.2 (2C), 71.7, 55.3. **HRMS (ESI):** *m/z* calculated for $C_{23}H_{18}O_3Na$ $(M+Na)^+$: 365.1154. Found: 365.1163.

### 7-Hydroxy-6-(4-methoxybenzylidene)-6,7-dihydro-5*H*-dibenzo[*a*,*c*][7]annulen-5-one (major isomer) ((–)-117c).



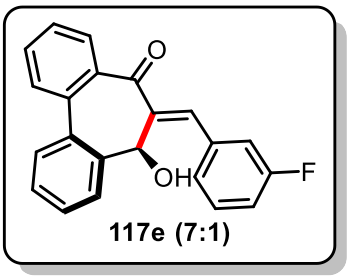

Following the general procedure-23, 20 mg of **(±)-116c** afforded 3.6 mg of **(–)-117c** (18% yield). **Optical rotation:** $[\alpha]_D^{25}$ –34.9 (*c* 0.02, $CH_2Cl_2$) for a sample with *ee* 78%. The enantiomeric excess was determined by HPLC analysis using Daicel Chiralpak IB Column (90:10 *n*-Hexane/2-Propanol, 1.0 mL/min, 330 nm, $\tau_{major}$ = 56.6 min, $\tau_{minor}$ = 22.6 min).

### 7-Hydroxy-6-(3-methylbenzylidene)-6,7-dihydro-5*H*-dibenzo[*a*,*c*][7]annulen-5-one (major isomer) (117d).




This compound was isolated as yellow oil. Following the general procedure-22, 40 mg of **116d** afforded 35.6 mg of **117d** (89% yield). $R_f$ = 0.4 (hexane/EtOAc = 5/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 3443, 3064, 3027, 2982, 2960, 1658, 1597, 741. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 7.89 (s, 1H), 7.82 (dd, *J* = 7.7 and 1.0 Hz, 1H), 7.62 (td, *J* = 7.7 and 1.4 Hz, 1H), 7.54-7.41 (m, 4H), 7.37-7.20 (m, 6H), 5.93 (d, *J* = 5.3 Hz, 1H), 2.42 (s, 3H), 2.12 (d, *J* = 5.4 Hz, 1H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 192.8, 141.6, 140.1, 139.2, 139.0, 138.3, 138.1, 137.2, 134.9, 132.4, 131.1, 130.0, 129.9, 129.8, 129.5, 129.3, 128.5, 128.4, 128.1, 127.9, 126.4, 71.5, 21.4. **HRMS (ESI):** *m/z* calculated for $C_{23}H_{18}O_2Na$ $(M+Na)^+$: 349.1204. Found: 349.1227.

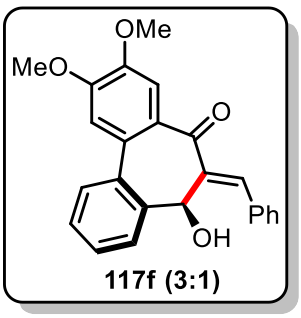
### 6-(3-Fluorobenzylidene)-7-hydroxy-6,7-dihydro-5*H*-dibenzo[*a*,*c*][7]annulen-5-one (major isomer) (117e).




This compound was isolated as yellow viscous oil. Following the general procedure-22, 30 mg of **116e** afforded 21.6 mg of **117e** (72% yield). $R_f$ = 0.4 (hexane/EtOAc = 5/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 3428, 3069, 2930, 1692, 1657, 1446, 1077, 757, 738. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 7.82-7.80 (m, 2H), 7.63 (td, *J* = 7.7 and 1.4 Hz, 1H), 7.54-7.49 (m, 2H), 7.47-7.40 (m, 3H), 7.32 (td, *J* = 7.5 and 1.2 Hz, 1H), 7.25-7.23 (m, 1H), 7.19-7.17 (m, 2H), 7.12 (td, *J* = 8.4 and 2.3 Hz, 1H), 5.85 (d, *J* = 5.0 Hz, 1H), 2.14 (d, *J* = 5.3 Hz, 1H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 192.6, 162.7 (d, *J* = 245.7 Hz, 1C), 142.5, 138.9, 138.5, 138.1, 137.2 (d, *J* = 4.8 Hz, 1C),

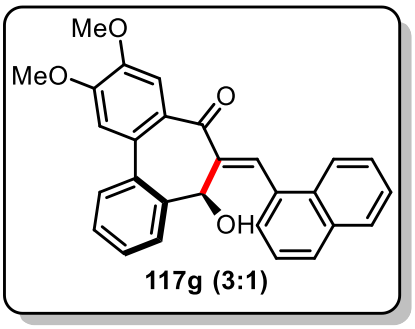
137.0, 132.5, 131.2, 130.3 (d, *J* = 8.3 Hz, 1C), 130.0, 129.5 (2C), 128.5, 128.2, 127.9 (d, *J* = 2.5 Hz, 1C), 125.1 (d, *J* = 2.9 Hz, 1C), 116.2, 116.0, 115.8, 71.5. **$^{19}$F NMR (376.4 MHz, $CDCl_3$):** δ –112.1. **HRMS (ESI):** *m/z* calcd for $C_{22}H_{15}FO_2Na$ $(M+Na)^+$: 353.0954. Found: 353.0965.

### 6-Benzylidene-7-hydroxy-2,3-dimethoxy-6,7-dihydro-5*H*-dibenzo[*a*,*c*][*7*]annulen-5-one (major isomer) (117f).



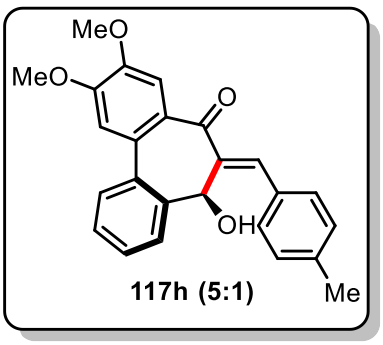

This compound was isolated as yellow viscous oil. Following the general procedure-22, 30 mg of **116f** afforded 26.1 mg of **117f** (87% yield). $R_f$ = 0.2 (hexane/EtOAc = 4/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 3479, 3076, 3064, 2956, 2932, 1651, 1586, 1268, 760. **$^1$H NMR (400 MHz, $(CD_3)_2SO$):** δ 7.65-7.63 (m, 2H), 7.54-7.52 (m, 3H), 7.46-7.40 (m, 3H), 7.34-7.25 (m, 3H), 7.19 (brs, 1H), 7.04 (s, 1H), 5.81 (s, 1H), 3.94 (s, 3H), 3.87 (s, 3H). **$^{13}$C NMR (100 MHz, $(CD_3)_2SO$):** δ 191.2, 152.3, 148.2, 143.1, 140.0, 137.7, 135.4, 131.5, 131.4, 131.3, 130.1, 129.9, 129.8, 129.3, 129.1 (2C), 128.8, 128.3 (2C), 112.77, 112.73, 70.2, 56.1, 56.0. **HRMS (ESI):** *m/z* calculated for $C_{24}H_{20}O_4Na$ $(M+Na)^+$: 395.1259. Found: 395.1273.

### 7-Hydroxy-2,3-dimethoxy-6-(naphthalen-1-ylmethylene)-6,7-dihydro-5*H*-dibenzo[*a*,*c*][*7*]annulen-5-one (major isomer) (117g).



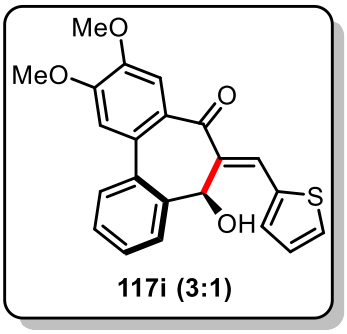

This compound was isolated as yellow oil. Following the general procedure-22, 50 mg of **116g** afforded 40.5 mg of **117g** (81% yield). $R_f$ = 0.2 (hexane/EtOAc = 4/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 3493, 3058, 2962, 2929, 1651, 1588, 1517, 1395, 1269, 1021, 784. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 8.35 (s, 1H), 7.91 (d, *J* = 8.0 Hz, 2H), 7.87 (d, *J* = 8.2 Hz, 1H), 7.55-7.48 (m, 5H), 7.46-7.39 (m, 3H), 7.22 (t, *J* = 7.2 Hz, 1H), 6.99 (s, 1H), 5.73 (s, 1H), 4.01 (s, 3H), 3.99 (s, 3H), 2.31 (brs, 1H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 190.4, 152.5, 148.7, 143.4, 138.7, 133.4, 132.7, 132.6, 131.6, 131.1, 130.8, 129.2, 129.1, 128.7, 128.5, 128.1, 126.7, 126.5 (3C), 125.1 (3C), 112.8, 112.2, 72.1, 56.16, 56.10. **HRMS (ESI):** *m/z* calcd for $C_{28}H_{23}O_4$ $(M+H)^+$: 423.1596. Found: 423.1578.

### 7-Hydroxy-2,3-dimethoxy-6-(4-methylbenzylidene)-6,7-dihydro-5*H*-dibenzo[*a*,*c*][7]annulen-5-one (major isomer) (117h).




This compound was isolated as yellow oil. Following the general procedure-22, 40 mg of **116h** afforded 33.2 mg of **117h** (83% yield). $R_f$ = 0.2 (hexane/EtOAc = 4/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 3495, 3005, 2956, 2926, 1651, 1601, 1585, 1356, 1268, 1022, 782. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 7.86 (s, 1H), 7.49 (d, *J* = 7.5 Hz, 1H), 7.42-7.35 (m, 5H), 7.29-7.27 (m, 1H), 7.24-7.19 (m, 2H), 6.97 (s, 1H), 5.94 (s, 1H), 3.98 (s, 3H), 3.96 (s, 3H), 2.41 (s, 3H), 2.05 (s, 1H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 191.1, 152.3, 148.7, 141.2, 139.2, 138.8, 137.1, 132.4, 132.1, 131.4, 130.8, 129.9, 129.5 (2C), 129.3 (2C), 129.1, 128.6, 128.1, 112.7, 112.1, 71.6, 56.1, 56.0, 21.4. **HRMS (ESI):** *m/z* calcd for $C_{25}H_{23}O_4$ $(M+H)^+$: 387.1596. Found: 387.1579.

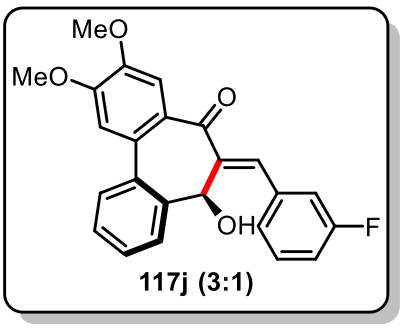
### 7-Hydroxy-2,3-dimethoxy-6-(thiophen-2-ylmethylene)-6,7-dihydro-5*H*-dibenzo[*a*,*c*][7]annulen-5-one (major isomer) (117i).




This compound was isolated as yellow oil. Following the general procedure-22, 35 mg of **116i** afforded 29.7 mg of **117i** (85% yield). $R_f$ = 0.2 (hexane/EtOAc = 4/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 3429, 3012, 2966, 2849, 1640, 1601, 1557, 1354, 1269, 1021, 731. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 7.69 (d, *J* = 7.0 Hz, 1H), 7.57 (s, 1H), 7.51 (s, 1H), 7.48-7.44 (m, 3H), 7.41-7.35 (m, 2H). 7.09-7.07 (m, 1H), 6.95 (s, 1H), 5.69 (s, 1H), 3.99 (s, 3H), 3.98 (s, 3H), 2.64 (s, 1H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 190.4, 152.3, 148.7, 140.6, 138.4, 138.0, 134.7, 132.4, 131.9, 130.8, 129.14, 129.13, 128.4 (2C), 127.6, 126.8 (2C), 112.2, 111.7, 77.2, 56.16, 56.14. **HRMS (ESI):** *m/z* calcd for $C_{22}H_{19}O_4S$ $(M+H)^+$: 379.1004. Found: 379.1016.

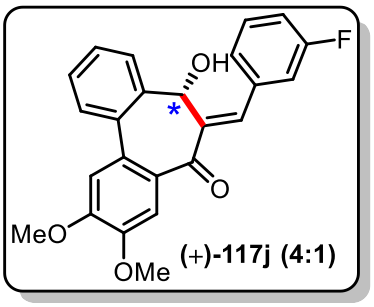
### 6-(3-Fluorobenzylidene)-7-hydroxy-2,3-dimethoxy-6,7-dihydro-5*H*-dibenzo[*a*,*c*][7]annulen-5-one (major isomer) (117j).

This compound was isolated as yellow oil. Following the general procedure-22, 40 mg of **116j** afforded 34.4 mg of **117j** (86% yield). $R_f$ = 0.2 (hexane/EtOAc = 4/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 3436, 3065, 2966, 2936, 1583, 1651, 1518, 1357, 1267, 1022, 754. **$^1$H NMR (400**



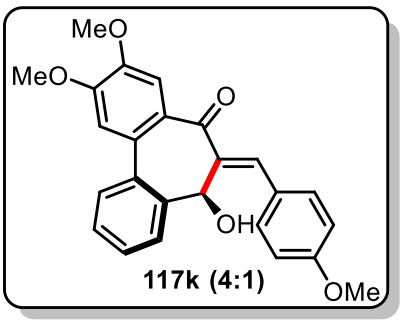

**MHz, $CDCl_3$):** δ 7.81 (s, 1H), 7.51 (d, *J* = 7.8 Hz, 1H), 7.45-7.42 (m, 3H), 7.31 (t, *J* = 7.4 Hz, 1H), 7.22-7.18 (m, 2H), 7.15-7.09 (m, 2H), 6.98 (s, 1H), 5.84 (s, 1H), 4.00 (s, 3H), 3.98 (s, 3H), 2.34 (brs, 1H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 190.7, 162.7 (d, *J* = 245.3 Hz, 1C), 152.5, 148.7, 142.5, 138.3, 138.2, 137.3 (d, *J* = 7.8 Hz, 1C), 132.4, 131.0, 130.9, 130.3, 130.2, 129.3, 128.3, 125.0 (d, *J* = 2.8 Hz, 1C), 116.0 (d, *J* = 21.7 Hz, 1C), 115.8 (d, *J* = 21.0 Hz, 1C), 112.6 (2C), 112.1, 71.6, 56.17, 56.10. **$^{19}$F NMR (376.4 MHz, $CDCl_3$):** δ –112.2. **HRMS (ESI):** *m/z* calcd for $C_{24}H_{20}FO_4$ $(M+H)^+$: 391.1345. Found: 391.1328.

### 6-(3-Fluorobenzylidene)-7-hydroxy-2,3-dimethoxy-6,7-dihydro-5*H*-dibenzo[*a*,*c*][7]annulen-5-one (major isomer) ((+)-117j).



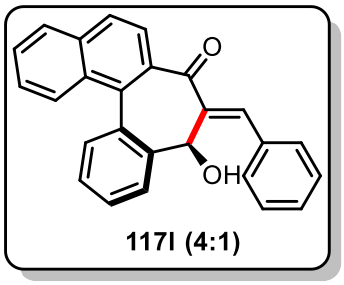

Following the general procedure-23, 50 mg of **(±)-116j** afforded 6.0 mg of **(+)-117j** (12% yield). **Optical rotation:** $[\alpha]_D^{25}$ +9.9 (*c* 0.05, $CH_2Cl_2$) for a sample with *ee* 67%. The enantiomeric excess was determined by HPLC analysis using Daicel Chiralpak IA Column (90:10 *n*-Hexane/2-Propanol, 1.0 mL/min, 260 nm, $\tau_{major}$ = 19.3 min, $\tau_{minor}$ = 16.3 min).

### 7-Hydroxy-2,3-dimethoxy-6-(4-methoxybenzylidene)-6,7-dihydro-5*H*-dibenzo[*a*,*c*][7]annulen-5-one (major isomer) (117k).



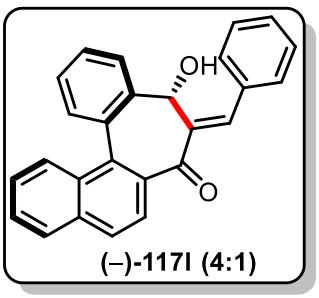

This compound was isolated as yellow oil. Following the general procedure-22, 48 mg of **116k** afforded 41 mg of **117k** (85% yield). $R_f$ = 0.2 (hexane/EtOAc = 3/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 3423, 2927, 2849, 1651, 1602, 1566, 1355, 1165, 1024. **$^1$H NMR (500 MHz, $CDCl_3$):** δ 7.86 (s, 1H), 7.50-7.46 (m, 3H), 7.44-7.41 (m, 2H), 7.29 (t, *J* = 7.5 Hz, 1H), 7.23 (brs, 1H), 7.00-6.97 (m, 3H), 5.97 (s, 1H), 4.00 (s, 3H), 3.98 (s, 3H), 3.87 (s, 3H), 2.34 (brs, 1H). **$^{13}$C NMR (125 MHz, $CDCl_3$):** δ 191.1, 160.4, 152.3, 148.7, 140.3, 140.0, 138.9, 132.3, 132.1, 131.4 (2C), 130.8, 129.1, 128.1, 127.3, 114.1 (3C), 113.2, 112.6, 112.0, 71.7, 56.1, 56.0, 55.4. **HRMS (ESI):** *m/z* calcd for $C_{25}H_{23}O_5$ $(M+H)^+$: 403.1545. Found: 403.1560.

**8-Benzylidene-9-hydroxy-8,9-dihydro-7*H*-benzo[6,7]cyclohepta[1,2-*a*]naphthalen-7-one (major isomer) (117l).**



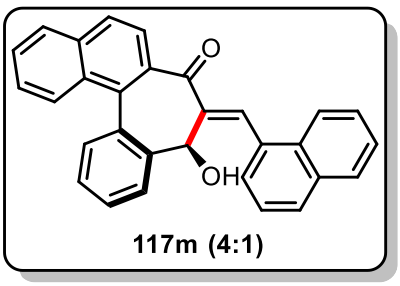

This compound was isolated as yellow oil. Following the general procedure-22, 30 mg of **116l** afforded 23.4 mg of **117l** (78% yield). $R_f$ = 0.3 (hexane/EtOAc = 5/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 3443, 3057, 3031, 2967, 2925, 1660, 1592, 763. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 8.12 (d, *J* = 8.5 Hz, 1H), 7.93 (d, *J* = 8.2 Hz, 2H), 7.84 (s, 1H), 7.75 (d, *J* = 8.5 Hz, 1H), 7.61-7.45 (m, 3H), 7.51-7.47 (m, 4H), 7.45-7.40 (m, 2H), 7.31 (t, *J* = 7.3 Hz, 1H), 7.20 (d, *J* = 7.4 Hz, 1H), 5.89 (d, *J* = 6.3 Hz, 1H), 2.25 (d, *J* = 6.5 Hz, 1H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 194.2, 142.7, 139.8, 139.5, 136.8, 136.4, 135.8, 134.7, 134.1, 134.0, 130.9, 129.6 (2C), 129.2, 128.7 (2C), 128.65, 128.62, 128.5, 128.4, 128.1, 127.7, 127.1, 126.9, 125.1, 71.6. **HRMS (ESI):** *m/z* calculated for $C_{26}H_{18}O_2Na$ $(M+Na)^+$: 385.1204. Found: 385.1219.

**(9*S*)-8-Benzylidene-9-hydroxy-8,9-dihydro-7*H*-benzo[6,7]cyclohepta[1,2-*a*]naphthalen-7-one (major isomer) ((–)-117l).**




This compound was isolated as yellow oil. Following the general procedure-22, 30 mg of **(–)-116l** afforded 25.5 mg of **(–)-117l** (85% yield). **Optical rotation:** $[\alpha]_D^{25}$ –48.9 (*c* 0.31, $CHCl_3$) for a sample with *ee* 96%. The enantiomeric excess was determined by HPLC analysis using Daicel Chiralpak IC Column (96:4 *n*-Hexane/2-Propanol, 0.5 mL/min, 254 nm, $\tau_{major}$ = 47.5 min, $\tau_{minor}$ = 43.5 min).

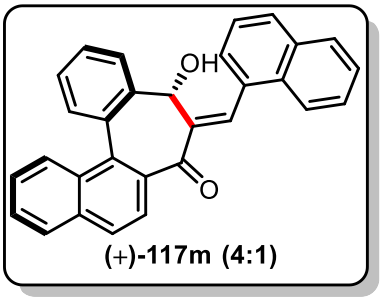
**9-Hydroxy-8-(naphthalen-1-ylmethylene)-8,9-dihydro-7*H*-benzo[6,7]cyclohepta[1,2-*a*]naphthalen-7-one (major isomer) (117m).**




This compound was isolated as yellow viscous oil. Following the general procedure-22, 30 mg of **116m** afforded 24.6 mg of **117m** (82% yield). $R_f$ = 0.2 (hexane/EtOAc = 4/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 3427, 2930, 2853, 1694, 1659, 1595, 1032, 762. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 8.38 (s, 1H), 8.10 (d, *J* = 8.4 Hz, 1H), 7.96-7.94 (m, 2H), 7.92-7.91 (m, 2H), 7.86 (d, *J* = 8.5 Hz, 1H), 7.62-7.59 (m, 2H), 7.58-7.56 (m, 2H), 7.54-7.52 (m, 2H), 7.51-7.48 (m, 1H), 7.44-7.43 (m, 1H), 7.41-7.31 (m, 1H), 7.28-7.24

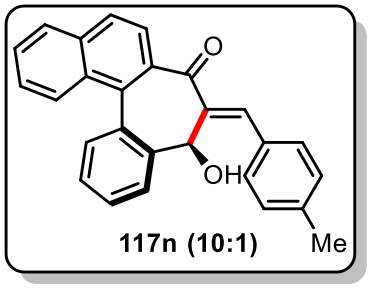
(m, 1H), 7.04 (d, *J* = 7.6 Hz, 1H), 5.76 (s, 1H), 2.29 (brs, 1H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 193.5, 144.2, 139.8, 138.1, 136.9, 136.7, 135.9, 134.2, 134.0, 133.5, 132.2, 131.8, 131.0, 129.5, 128.6 (2C), 128.5, 128.4, 128.3, 128.0, 127.7, 127.3, 126.86, 126.82, 126.7, 126.5, 125.4, 125.3, 125.0, 72.0. **HRMS (ESI):** *m/z* calculated for $C_{30}H_{20}O_2Na$ $(M+Na)^+$: 435.1361. Found: 435.1373.

### (9*S*)-9-Hydroxy-8-(naphthalen-1-ylmethylene)-8,9-dihydro-7*H*-benzo[6,7]cyclohepta[1,2-*a*]naphthalen-7-one (major isomer) ((+)-117m).



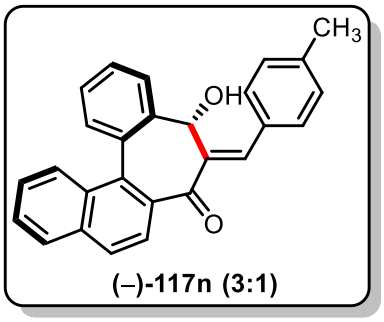

This compound was isolated as yellow viscous oil. Following the general procedure-22, 30 mg of **(–)-116m** afforded 27.0 mg of **(+)-117m** (90% yield). **Optical rotation:** $[\alpha]_D^{25}$ +18.5 (*c* 0.21, $CHCl_3$) for a sample with *ee* 93%. The enantiomeric excess was determined by HPLC analysis using Daicel Chiralpak IC Column (95:5 *n*-Hexane/2-Propanol, 1.0 mL/min, 254 nm, $\tau_{major}$ = 23.6 min, $\tau_{minor}$ = 13.4 min).

### 9-Hydroxy-8-(4-methylbenzylidene)-8,9-dihydro-7*H*-benzo[6,7]cyclohepta[1,2-*a*]naphthalen-7-one (major isomer) (117n).



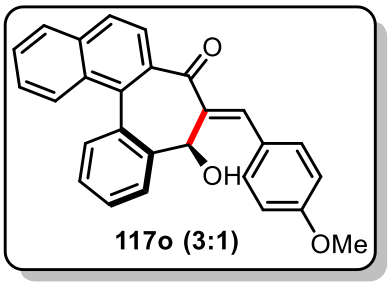

This compound was isolated as yellow oil. Following the general procedure-22, 35 mg of **116n** afforded 31.1 mg of **117n** (89% yield). $R_f$ = 0.2 (hexane/EtOAc = 4/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 3449, 3054, 2979, 2921, 1655, 1590, 1508, 1338, 1234, 1032, 757. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 8.12 (d, *J* = 8.4 Hz, 1H), 7.93-7.90 (m, 2H), 7.82 (s, 1H), 7.74 (d, *J* = 8.6 Hz, 1H), 7.59 (t, *J* = 7.1 Hz, 1H), 7.54-7.50 (m, 2H), 7.48-7.45 (m, 3H), 7.30-7.27 (m, 3H), 7.21 (d, *J* = 7.5 Hz, 1H), 5.92 (d, *J* = 6.6 Hz, 1H), 2.42 (s, 3H), 2.28 (d, *J* = 6.8 Hz, 1H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 194.3, 142.1, 139.9, 139.7, 139.6, 137.0, 136.4, 135.7, 134.04, 134.0, 132.1, 131.7, 130.9, 130.2, 129.8 (2C), 129.5 (2C), 128.6, 128.4, 128.1, 127.6, 127.1, 126.8, 125.1, 71.7, 21.5. **HRMS (ESI):** *m/z* calcd for $C_{27}H_{21}O_2$ $(M+H)^+$: 377.1541. Found: 377.1528.

**(9*S*,13*b*)-9-Hydroxy-8-(4-methylbenzylidene)-8,9-dihydro-7*H*-benzo[6,7]cyclohepta[1,2-*a*]naphthalen-7-one (major isomer) ((–)-117n).**



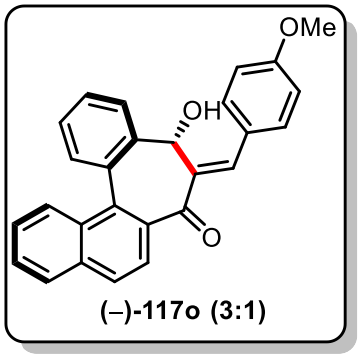

This compound was isolated as yellow oil. Following the general procedure-22, 35 mg of **(–)-116n** afforded 30.1 mg of **(–)-117n** (86% yield). **Optical rotation:** $[\alpha]_D^{25}$ –37.4 (*c* 0.04, $CHCl_3$) for a sample with *ee* 95%. The enantiomeric excess was determined by HPLC analysis using Daicel Chiralpak IC Column (95:5 *n*-Hexane/2-Propanol, 1.0 mL/min, 270 nm, $\tau_{major}$ = 22.1 min, $\tau_{minor}$ = 26.3 min).

**9-Hydroxy-8-(4-methoxybenzylidene)-8,9-dihydro-7*H*-benzo[6,7]cyclohepta[1,2-*a*]naphthalen-7-one (major isomer) (117o).**



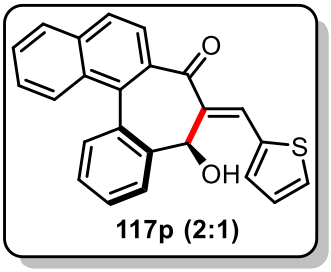

This compound was isolated as yellow oil. Following the general procedure-22, 30 mg of **116o** afforded 22.5 mg of **117o** (75% yield). $R_f$ = 0.2 (hexane/EtOAc = 3/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 3438, 2924, 2854, 1651, 1604, 1509, 1338, 1247, 1033, 822. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 8.12 (d, *J* = 8.4 Hz, 1H), 7.93-7.90 (m, 2H), 7.78 (s, 1H), 7.72 (d, *J* = 8.5 Hz, 1H), 7.61-7.54 (m, 3H), 7.52-7.48 (m, 2H), 7.41 (t, *J* = 7.2 Hz, 1H), 7.30 (t, *J* = 7.2 Hz, 1H), 7.23 (d, *J* = 7.4 Hz, 1H), 6.99 (d, *J* = 8.4 Hz, 2H), 5.93 (d, *J* = 5.3 Hz, 1H), 3.87 (s, 3H), 2.30 (d, *J* = 6.3 Hz, 1H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 194.4, 160.7, 141.2, 140.0, 139.5, 137.1, 136.2, 135.7, 133.9, 132.9, 131.7 (2C), 130.8, 128.68, 128.62, 128.4 (2C), 128.1, 127.6, 127.1, 126.9, 126.8, 125.1, 114.3 (2C), 71.8, 55.4. **HRMS (ESI):** *m/z* calcd for $C_{27}H_{21}O_3$ $(M+H)^+$: 393.1490. Found: 393.1476.

### (9*S*)-9-Hydroxy-8-(4-methoxybenzylidene)-8,9-dihydro-7*H*-benzo[6,7]cyclohepta[1,2-*a*]naphthalen-7-one (major isomer) ((–)-117o).



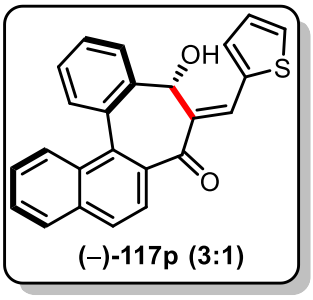

This compound was isolated as yellow oil. Following the general procedure-22, 30 mg of **(–)-116o** afforded 24.6 mg of **(–)-117o** (82% yield). **Optical rotation:** $[\alpha]_D^{25}$ –70.7 (*c* 0.12, $CHCl_3$) for a sample with *ee* 96%. The enantiomeric excess was determined by HPLC analysis using Daicel Chiralpak IC Column (95:5 *n*-Hexane/2-Propanol, 1.0 mL/min, 268 nm, $\tau_{major}$ = 52.2 min, $\tau_{minor}$ = 43.5 min).

### 9-Hydroxy-8-(thiophen-2-ylmethylene)-8,9-dihydro-7*H*-benzo[6,7]cyclohepta[1,2-*a*]naphthalen-7-one (major isomer) (117p).



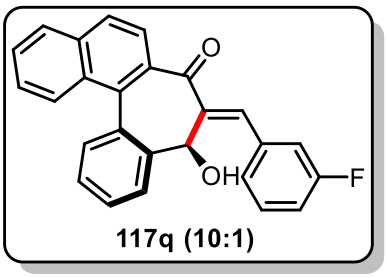

This compound was isolated as yellow oil. Following the general procedure-22, 30 mg of **116p** afforded 21.0 mg of **117p** (70% yield). $R_f$ = 0.3 (hexane/EtOAc = 4/1). M.P. = 136-137 °C. **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 3436, 2960, 2935, 1650, 1601, 1584, 1356, 783. **$^1$H NMR (400 MHz, $(CD_3)_2SO$):** δ 8.10-8.05 (m, 2H), 8.02 (d, *J* = 7.9 Hz, 1H), 7.99-7.95 (m, 1H), 7.81-7.78 (m, 3H), 7.69-7.67 (m, 1H), 7.65-7.60 (m, 1H), 7.57-7.54 (m, 1H), 7.52-7.46 (m, 2H), 7.44-7.39 (m, 1H), 7.22-7.20 (m, 1H), 6.49 (d, *J* = 4.0 Hz, 1H), 5.62 (d, *J* = 3.1 Hz, 1H). **$^{13}$C NMR (100 MHz, $(CD_3)_2SO$):** δ 193.5, 143.3, 139.7, 138.2, 137.1, 136.8, 135.6, 134.5, 133.9, 132.6, 130.8, 130.2, 129.7, 129.0, 128.8, 128.7, 128.2, 127.9, 127.5, 127.1, 126.7, 125.6, 122.7, 70.0. **HRMS (ESI):** *m/z* calcd for $C_{24}H_{17}O_2S$ $(M+H)^+$: 369.0949. Found: 369.0934.

### (9*S*)-9-Hydroxy-8-(thiophen-2-ylmethylene)-8,9-dihydro-7*H*-benzo[6,7]cyclohepta[1,2-*a*]naphthalen-7-one (major isomer) ((–)-117p).



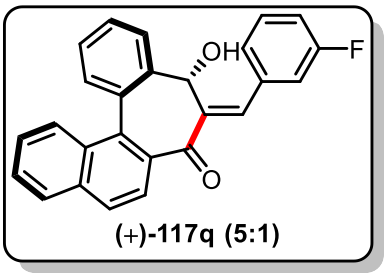

This compound was isolated as yellow oil. Following the general procedure-22, 30 mg of **(–)-116p** afforded 25.2 mg of **(–)-117p** (84% yield). **Optical rotation:** $[\alpha]_D^{25}$ –34.3 (*c* 0.18, $CHCl_3$). *ee* of the sample cannot be determined as the isomers were not resolving in HPLC.

**8-(3-Fluorobenzylidene)-9-hydroxy-8,9-dihydro-7*H*-benzo[6,7]cyclohepta[1,2-*a*]naphthalen-7-one (major isomer) (117q).**



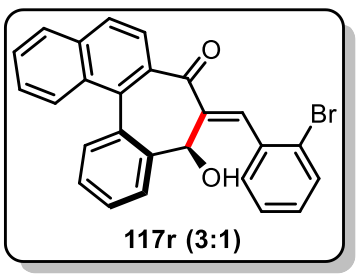

This compound was isolated as yellow oil. Following the general procedure-22, 35 mg of **116q** afforded 30.1 mg of **117q** (86% yield). $R_f$ = 0.3 (hexane/EtOAc = 4/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 3444, 2956, 1660, 1593, 1579, 1233, 1033, 760, 737. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 8.08 (d, *J* = 8.5 Hz, 1H), 7.89 (t, *J* = 8.0 Hz, 2H), 7.73-7.69 (m, 1H), 7.57 (t, *J* = 7.4 Hz, 1H), 7.48-7.44 (m, 2H), 7.42-7.38 (m, 2H), 7.34-7.27 (m, 2H), 7.24-7.21 (m, 2H), 7.17 (d, *J* = 7.4 Hz, 1H), 7.11 (t, *J* = 8.3 Hz, 1H), 5.81 (s, 1H), 2.42 (brs, 1H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 194.1, 162.8 (d, *J* = 245.5 Hz, 1C), 143.5, 139.4, 137.8 (d, *J* = 1.9 Hz, 1C), 136.9, 136.8, 136.6 (d, *J* = 2.8 Hz, 1C), 135.8, 134.1, 133.5, 131.7, 130.8, 130.4 (d, *J* = 8.2 Hz, 1C), 128.66, 128.62, 128.4, 128.3, 127.7, 127.1, 126.9, 125.3 (d, *J* = 2.8 Hz, 1C), 125.1, 116.3 (d, *J* = 15.6 Hz, 1C), 116.1 (d, *J* = 14.8 Hz, 1C), 71.5. **$^{19}$F NMR (376.4 MHz, $CDCl_3$):** δ –112.0. **HRMS (ESI):** *m/z* calcd for $C_{26}H_{16}FO_2$ $(M–H)^+$: 379.1134. Found: 379.1121.

**(9*S*,13*bR*)-8-(3-Fluorobenzylidene)-9-hydroxy-8,9-dihydro-7*H*-benzo[6,7]cyclohepta[1,2-*a*]naphthalen-7-one (major isomer) ((+)-117q).**




This compound was isolated as yellow oil. Following the general procedure-22, 35 mg of **(–)-116q** afforded 31.5 mg of **(+)-117q** (90% yield). **Optical rotation:** $[\alpha]_D^{25}$ +03.5 (*c* 0.14, $CHCl_3$) for a sample with *ee* 95%. The enantiomeric excess was determined by HPLC analysis using Daicel Chiralpak IB Column (96:4 *n*-Hexane/2-Propanol, 0.5 mL/min, 275 nm, $\tau_{major}$ = 57.2 min, $\tau_{minor}$ = 38.7 min).

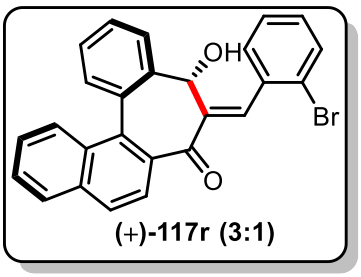
**8-(2-Bromobenzylidene)-9-hydroxy-8,9-dihydro-7*H*-benzo[6,7]cyclohepta[1,2-*a*]naphthalen-7-one (major isomer) (117r).**




This compound was isolated as pale-yellow solid. Following the general procedure-22, 40 mg of **116r** afforded 36 mg of **117r** (90% yield). $R_f$ = 0.5 (hexane/EtOAc = 5/1). M.P. = 78-80 °C. **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 3254, 2360, 2255, 1653, 1538, 1418, 1048, 827, 765. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 8.08 (d, *J* = 8.5 Hz, 1H), 7.91 (m, 2H), 7.82 (s, 1H), 7.79 (d, *J* = 8.4 Hz, 1H), 7.68-7.64 (m, 1H), 7.50-7.45 (m,

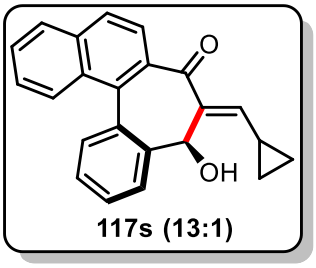
4H), 7.41-7.39 (m, 2H), 7.30-7.27 (m, 2H), 7.15 (d, *J* = 7.6 Hz, 1H), 5.64 (s, 1H), 2.27 (brs, 1H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 193.3, 143.4. 139.3, 138.4, 136.9, 136.5, 135.9, 135.5, 134.2, 133.0, 130.9, 130.4, 130.3, 128.6, 128.5, 128.4, 128.3, 128.2, 127.7. 127.4, 127.2, 126.8, 125.3, 124.4, 121.9, 71.7. **HRMS (ESI):** *m/z* calculated for $C_{26}H_{18}BrO_2$ $(M+H)^+$: 441.0490. Found: 441. 0503.

### (9*S*,13*bR*)-8-(2-Bromobenzylidene)-9-hydroxy-8,9-dihydro-7*H*-benzo[6,7]cyclohepta[1,2-*a*]naphthalen-7-one (major isomer) ((+)-117r).



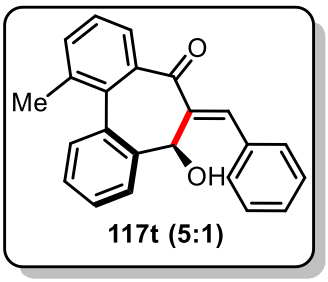

This compound was isolated as yellow solid. Following the general procedure-22, 35 mg of **(–)-116r** afforded 29.7 mg of **(+)-117r** (85% yield). **Optical rotation:** $[\alpha]_D^{25}$ +34.6 (*c* 0.06, $CHCl_3$) for a sample with *ee* >99%. The enantiomeric excess was determined by HPLC analysis using Daicel Chiralpak IB Column (96:4 *n*-Hexane/2-Propanol, 0.5 mL/min, 273 nm, $\tau_{major}$ = 52.6 min).

### 8-(Cyclopropylmethylene)-7-hydroxy-7,8-dihydro-9*H*-benzo[6,7]cyclohepta[1,2-*a*]naphthalen-9-one (major isomer) (117s).



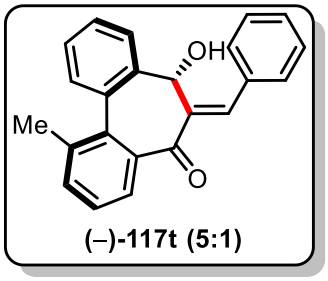

This compound was isolated as pale-yellow oil. Following the general procedure-22, 30 mg of **116s** afforded 10 mg of **117s** (33% yield). $R_f$ = 0.4 (hexane/EtOAc = 10/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 3422, 2956, 2854, 1693, 1656, 1591, 1377, 762. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 8.06 (d, *J* = 8.5 Hz, 1H), 7.91-7.86 (m, 2H), 7.73 (d, *J* = 8.5 Hz, 1H), 7.68 (d, *J* = 7.7 Hz, 1H), 7.56 (t, *J* = 7.4 Hz, 1H), 7.48-7.40 (m, 3H), 7.35-7.33 (m, 1H), 5.78 (dd, *J* = 11.0 and 1.2 Hz, 1H), 5.65 (s, 1H), 3.23-3.14 (m, 1H), 2.35 (s, 1H), 1.05-1.00 (m, 2H), 0.63-0.61 (m, 2H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 194.5, 146.7, 141.9, 139.6, 137.3, 135.4, 134.5, 132.1, 131.2, 130.6, 128.7, 128.5, 128.3, 127.4, 127.3, 126.6, 126.2, 125.0, 121.3, 69.5, 12.7, 10.2, 10.0. **HRMS (ESI):** *m/z* calculated for $C_{23}H_{19}O_2$ $(M+H)^+$: 327.1385. Found: 327.1409.

### 6-Benzylidene-7-hydroxy-1-methyl-6,7-dihydro-5*H*-dibenzo[*a*,*c*][7]annulen-5-one (major isomer) (117t).



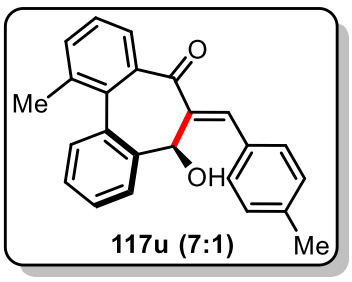

This compound was isolated as brown viscous oil. Following the general procedure-22, 30 mg of **116t** afforded 21.6 mg of **117t** (72% yield). $R_f$ = 0.2 (hexane/EtOAc = 4/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 3445, 3064, 3027, 2971, 2926, 1661, 1593, 748. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 7.76 (s, 1H), 7.53-7.41 (m, 7H), 7.37-7.34 (m, 3H), 7.25-7.20 (m, 1H), 7.10 (d, *J* = 7.5 Hz, 1H), 5.78 (s, 1H), 2.40 (s, 3H), 2.23 (brs, 1H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 194.6, 142.5, 140.7, 139.1, 138.8, 136.8, 135.8, 134.9, 134.7, 132.6, 129.6 (3C), 129.1, 128.7 (2C), 128.27, 128.25, 128.1, 128.0, 126.7, 71.6, 21.3. **HRMS (ESI):** *m/z* calculated for $C_{23}H_{18}O_2Na$ $(M+Na)^+$: 349.1204. Found: 349.1214.

### (7*S*)-6-Benzylidene-7-hydroxy-1-methyl-6,7-dihydro-5*H*-dibenzo[*a*,*c*][7]annulen-5-one (major isomer) ((–)-117t).




This compound was isolated as brown viscous oil. Following the general procedure-22, 30 mg of **(–)-116t** afforded 22.5 mg of **(–)-117t** (75% yield). **Optical rotation:** $[\alpha]_D^{25}$ –84.8 (*c* 0.10, $CH_2Cl_2$) for a sample with *ee* 83%. The enantiomeric excess was determined by HPLC analysis using Daicel Chiralpak OD-H Column (96:4 *n*-Hexane/2-Propanol, 1.0 mL/min, 298 nm, $\tau_{major}$ = 18.5 min, $\tau_{minor}$ = 25.2 min).

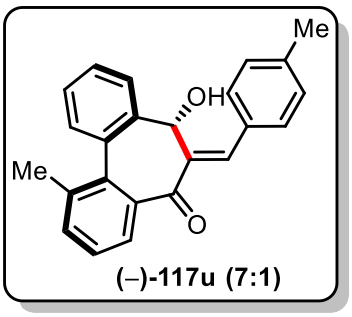
### 7-Hydroxy-1-methyl-6-(4-methylbenzylidene)-6,7-dihydro-5*H*-dibenzo[*a*,*c*][7]annulen-5-one (major isomer) (117u).




This compound was isolated as yellow oil. Following the general procedure-22, 30 mg of **116u** afforded 25.2 mg of **117u** (84% yield). $R_f$ = 0.2 (hexane/EtOAc = 4/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 3450, 2956, 2858, 1695, 1662, 1595, 1263, 1029, 751. **$^1$H NMR (500 MHz, $CDCl_3$):** δ 7.73 (s, 1H), 7.50-7.47 (m, 2H), 7.44 (d, *J* = 8.0 Hz, 2H), 7.36-7.32 (m, 3H), 7.27-7.25 (m, 2H), 7.23-7.20 (m, 1H), 7.11 (d, *J* = 7.5 Hz, 1H), 5.18 (s, 1H), 2.41 (s, 3H), 2.40 (s, 3H), 2.23 (brs, 1H). **$^{13}$C NMR (125 MHz, $CDCl_3$):** δ 194.6, 141.9, 140.8, 139.5, 139.3, 138.9, 136.8, 135.8,

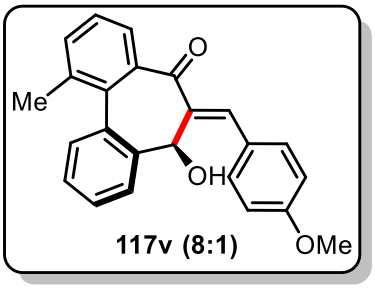
134.9, 134.5, 132.5, 131.7, 129.7 (2C), 129.5 (2C), 128.2, 128.19, 128.10, 128.0, 126.7, 71.6, 21.4, 21.2. **HRMS (ESI):** *m/z* calculated for $C_{24}H_{20}O_2Na$ $(M+Na)^+$: 363.1361. Found: 363.1375.

### (7*S*)-7-Hydroxy-1-methyl-6-(4-methylbenzylidene)-6,7-dihydro-5*H*-dibenzo[*a*,*c*][7]annulen-5-one (major isomer) ((–)-117u).



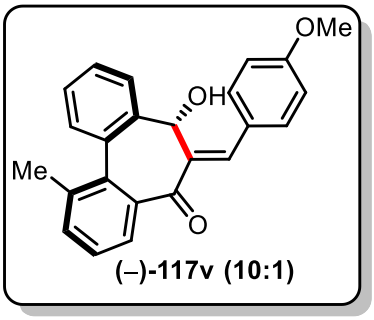

This compound was isolated as yellow oil. Following the general procedure-22, 30 mg of **(–)-116u** afforded 23.4 mg of **(–)-117u** (78% yield). **Optical rotation:** $[\alpha]_D^{25}$ –82.0 (*c* 0.09, $CH_2Cl_2$) for a sample with *ee* 86%. The enantiomeric excess was determined by HPLC analysis using Daicel Chiralpak IC Column (90:10 *n*-Hexane/2-Propanol, 1.0 mL/min, 237 nm, $\tau_{major}$ = 10.4 min, $\tau_{minor}$ = 12.1 min).

### 7-Hydroxy-6-(4-methoxybenzylidene)-1-methyl-6,7-dihydro-5*H*-dibenzo[*a*,*c*][7]annulen-5-one (major isomer) (117v).



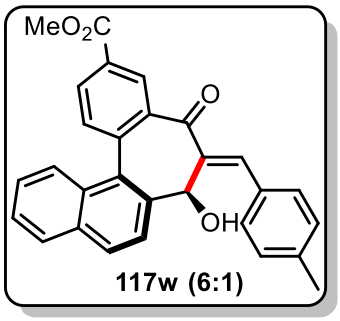

This compound was isolated as yellow oil. Following the general procedure-22, 30 mg of **116v** afforded 22.8 mg of **117v** (76% yield). $R_f$ = 0.2 (hexane/EtOAc = 3/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 3450, 2927, 2855, 1663, 1592, 1510, 1032, 751. **$^1$H NMR (500 MHz, $CDCl_3$):** δ 7.70 (s, 1H), 7.54-7.52 (m, 2H), 7.49 (d, *J* = 7.6 Hz, 1H), 7.47 (dd, *J* = 7.6 and 0.75 Hz, 1H), 7.36-7.33 (m, 3H), 7.23-7.20 (m, 1H), 7.13 (d, *J* = 7.2 Hz, 1H), 6.99 (d, *J* = 8.7 Hz, 2H), 5.82 (s, 1H), 3.87 (s, 3H), 2.41 (s, 3H), 2.25 (brs, 1H). **$^{13}$C NMR (125 MHz, $CDCl_3$):** δ 194.7, 160.6, 140.99, 140.91, 139.4, 138.7, 136.6, 135.7, 134.9, 134.5, 132.7, 132.5, 131.6 (2C), 128.3, 128.1, 128.0, 126.9, 126.6, 114.3 (2C), 71.8, 55.4, 21.2. **HRMS (ESI):** *m/z* calculated for $C_{24}H_{21}O_3$ $(M+H)^+$: 357.1491. Found: 357.1481.

**(7*S*)-7-Hydroxy-6-(4-methoxybenzylidene)-1-methyl-6,7-dihydro-5*H*-dibenzo[*a*,*c*][7]annulen-5-one (major isomer) ((–)-117v).**



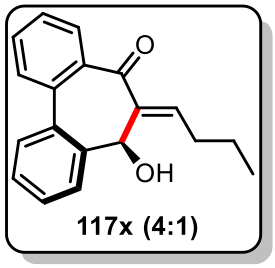

This compound was isolated as yellow oil. Following the general procedure-22, 30 mg of **(–)-116v** afforded 22.2 mg of **(–)-117v** (74% yield). **Optical rotation:** $[\alpha]_D^{25}$ –37.9 (*c* 0.05, $CH_2Cl_2$) for a sample with *ee* 88%. The enantiomeric excess was determined by HPLC analysis using Daicel Chiralpak IA Column (90:10 *n*-Hexane/2-Propanol, 1.0 mL/min, 297 nm, $\tau_{major}$ = 26.7 min, $\tau_{minor}$ = 45.3 min).

**Methyl-7-hydroxy-8-(4-methylbenzylidene)-9-oxo-8,9-dihydro-7*H*-benzo[6,7]cyclohepta[1,2-*a*]naphthalene-11-carboxylate (major isomer) (117w).**




This compound was isolated as pale-yellow oil. Following the general procedure-22, 20 mg of **116w** afforded 15 mg of **117w** (75% yield). $R_f$ = 0.4 (hexane/EtOAc = 5/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 3455, 2956, 2920, 1721, 1605, 1656, 1377, 1251, 1120. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 8.48 (d, *J* = 1.6 Hz, 1H), 8.27 (dd, *J* = 8.0 and 1.7 Hz, 1H), 7.92 (d, *J* = 8.2 Hz, 1H), 7.86-7.81 (m, 3H), 7.68 (d, *J* = 8.0 Hz, 1H), 7.54-7.43 (m, 2H), 7.40-7.38 (m, 2H), 7.29-7.25 (m, 3H), 6.08 (s, 1H), 3.97 (s, 3H), 2.43 (s, 3H), 2.05 (brs, 1H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 192.8, 166.2, 141.4, 140.8, 140.0, 139.9, 139.7, 136.7, 134.3, 133.0, 132.4, 132.1, 131.6, 131.2, 130.8, 129.8, 129.7, 129.6 (2C), 129.5 (2C), 128.4, 127.0, 126.4, 125.8, 125.6, 71.7, 52.4, 21.5. **HRMS (ESI):** *m/z* calculated for $C_{29}H_{22}O_4Na$ $(M+Na)^+$: 457.1416. Found: 457.1418.

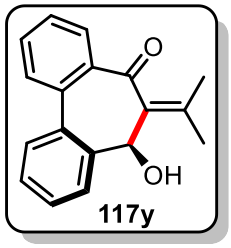
**6-Butylidene-7-hydroxy-6,7-dihydro-5*H*-dibenzo[*a*,*c*][7]annulen-5-one (major isomer) (117x).**




This compound was isolated as pale-yellow oil. Following the general procedure-22, 40 mg of **116x** afforded 26.8 mg of **117x** (67% yield). $R_f$ = 0.5 (hexane/EtOAc = 10/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 3441, 2961, 2872, 1661, 1605, 1447, 1228, 742. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 7.85 (dd, *J* = 7.7 and 0.84 Hz, 1H), 7.60 (td, *J* = 7.8 and 1.2 Hz, 1H), 7.52-7.49 (m, 2H), 7.46-7.40 (m, 2H), 7.35-7.34 (m, 2H), 6.91 (t, *J* = 7.7 Hz, 1H), 5.77 (d, *J* = 1.1 Hz, 1H), 2.50-2.37 (m, 2H), 2.08 (brs, 1H), 1.57-1.51 (m, 2H), 0.97 (t, *J* = 7.3

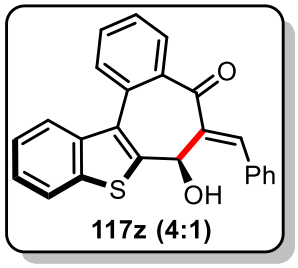
Hz, 3H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 191.8, 143.3, 141.9, 139.5, 138.7, 138.3, 132.3, 131.07, 131.04, 130.1, 129.6, 129.0, 128.8, 128.4, 128.0, 71.3, 30.2, 22.0, 14.1. **HRMS (ESI):** *m/z* calculated for $C_{19}H_{17}O_2$ $(M-H)^+$: 277.1229. Found: 277.1252.

### 7-Hydroxy-6-(propan-2-ylidene)-6,7-dihydro-5*H*-dibenzo[*a*,*c*][7]annulen-5-one (major isomer) (117y).




This compound was isolated as pale-yellow oil. Following the general procedure-22, 35 mg of **116y** afforded 10.5 mg of **117y** (30% yield). $R_f$ = 0.3 (hexane/EtOAc = 10/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 3482, 2961, 2854, 1694, 1611, 1463, 1194, 756. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 7.94 (dd, *J* = 7.8 and 0.5 Hz, 1H), 7.59-7.52 (m, 3H), 7.46-7.40 (m, 2H), 7.36-7.31 (m, 2H), 5.77 (s, 1H), 2.31 (s, 4H), 2.06 (s, 3H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 193.2, 148.9, 140.0, 139.0, 138.8, 137.7, 136.9, 131.9, 130.8, 129.79, 129.72, 128.7, 128.2, 127.9, 126.8, 72.8, 24.8, 23.3. **HRMS (ESI):** *m/z* calculated for $C_{18}H_{16}O_2Na$ $(M+Na)^+$: 287.1048. Found: 287.1082.

### 6-Benzylidene-7-hydroxy-6,7-dihydro-5*H*-benzo[*b*]benzo[6,7]cyclohepta[1,2-*d*]thiophen-5-one (major isomer) (117z).



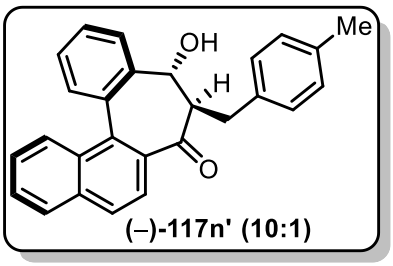

This compound was isolated as yellow oil. Following the general procedure-22, 45 mg of **116z** afforded 36 mg of **117z** (80% yield). $R_f$ = 0.4 (hexane/EtOAc = 5/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 3420, 2924, 2853, 1652, 1598, 1436, 1205, 772, 731. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 7.96 (d, *J* = 7.1 Hz, 1H), 7.92-7.91 (m, 2H), 7.85 (d, *J* = 7.6 Hz, 1H), 7.78 (d, *J* = 7.4 Hz, 1H), 7.65 (t, *J* = 7.4 Hz, 1H), 7.52-7.45 (m, 5H), 7.42-7.39 (m, 3H), 6.02 (s, 1H), 2.39 (brs, 1H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 192.8, 141.2, 140.1, 139.5, 139.0, 138.7, 134.5, 132.4, 131.8, 131.2, 129.8, 129.5 (2C), 129.2, 128.7 (2C), 128.6, 128.0, 127.9, 125.1, 125.0, 122.9 (2C), 64.7. **HRMS (ESI):** *m/z* calculated for $C_{24}H_{16}O_2SNa$ $(M+Na)^+$: 391.0769. Found: 391.0782.

### General procedure 24: Synthesis of (–)-117n"

**Step-I:** A 25 mL oven-dried RB flask was charged with chiral MBH product **(–)-117n** (1.0 eq), Crabtree's catalyst (0.02 eq), 5 mL dry DCM and placed under $H_2$ atmosphere for 48 h. Upon completion, the resulting reaction mixture was quenched by water (~1-2 mL) and extracted using DCM (2x10 mL). The organic extracts were combined, dried over anhydrous sodium sulphate and concentrated. The product was purified by silica gel column chromatography using hexane/ethyl acetate (10:1) as eluent, to afford **(–)-117n'** (yield 86%).

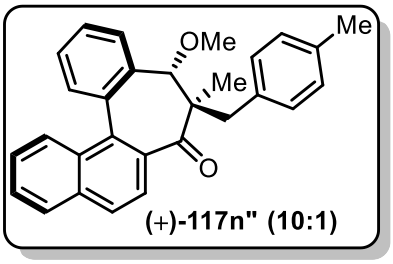
**Step-II:** An oven-dried 25 mL RB flask was charged with **(–)-117n'** (1.0 eq), sodium hydride (2.2 eq), 10 mL dry THF and placed at 0 °C under $N_2$ atmosphere. Methyl iodide (2.5 eq) was added dropwise at the same temperature and stirred for 1 h. Upon completion, the reaction mixture was quenched by water (~2-3 mL) and extracted with ethyl acetate (2x10 mL). The organic extracts were combined and dried over anhydrous $Na_2SO_4$, and concentrated under reduced pressure. The product was purified by silica gel column chromatography using hexane/ethyl acetate (20:1) as eluent, to afford **(+)-117n"** (yield 85%).

### (8*R*,9*R*)-9-Hydroxy-8-(4-methylbenzyl)-8,9-dihydro-7*H*-benzo[6,7]cyclohepta[1,2-*a*]naphthalen-7-one (major isomer) ((–)-117n').



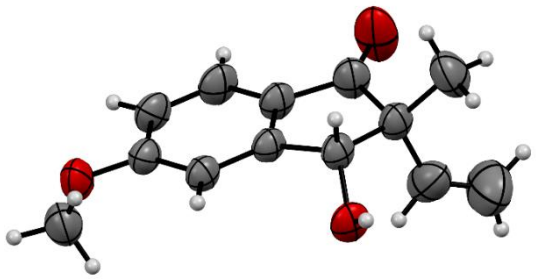

This compound was isolated as yellow oil. Following the procedure-24, 50 mg of **(–)-117n** afforded 43.2 mg of **(–)-117n'** (86% yield). $R_f$ = 0.5 (hexane/EtOAc = 10/1). **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 3466, 3056, 2856, 1680, 1513, 1256, 1070, 815, 760. **$^1$H NMR (500 MHz, $CDCl_3$):** δ 8.03 (d, *J* = 10.6 Hz, 1H), 7.86 (d, *J* = 10.2 Hz, 1H), 7.81-7.77 (m, 2H), 7.55-7.52 (m, 1H), 7.47-7.41 (m, 2H), 7.35-7.23 (m, 3H), 7.17-7.10 (m, 2H), 7.03 (d, *J* = 9.6 Hz, 2H), 5.09 (d, *J* = 12.7 Hz, 1H), 3.30-3.24 (m, 1H), 3.13-3.04 (m, 2H), 2.25 (s, 3H), 2.20 (brs, 1H). **$^{13}$C NMR (125 MHz, $CDCl_3$):** δ 207.0, 141.3, 137.4, 136.3, 135.2, 134.6, 135.2, 134.6, 134.5, 132.3, 132.0, 130.3, 129.4 (2C), 129.3 (2C), 128.9, 128.6, 128.4, 127.3, 127.1, 126.9, 126.7, 123.69, 123.6, 69.7, 67.7, 36.8, 21.1. **Optical rotation:** $[\alpha]_D^{25}$ –33.1 (*c* 0.10, $CHCl_3$). **HRMS (ESI):** *m/z* calculated for $C_{27}H_{22}O_2Na$ $(M+Na)^+$: 401.1517. Found: 401.1505.

**(8*R*,9*S*)-9-Methoxy-8-methyl-8-(4-methylbenzyl)-8,9-dihydro-7*H*-benzo[6,7]cyclohepta[1,2-*a*]naphthalen-7-one (major isomer) ((+)-117n").**



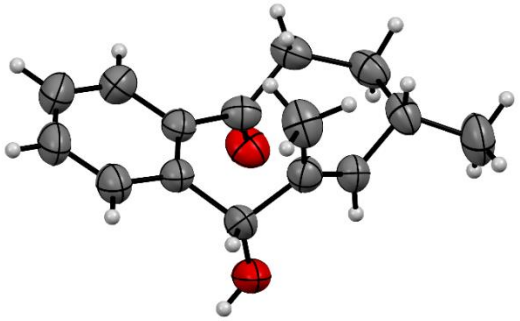

This compound was isolated as white solid. Following the procedure-24, 40 mg of **(–)-117n'** afforded 36.5 mg of **(+)-117n"** (85% yield). $R_f$ = 0.7 (hexane/EtOAc = 20/1). M.P. = 172-174 $^oC$. **IR (thin film, neat):** $\nu_{max}/cm^{-1}$ 2960, 2923, 2853, 1740, 1676, 1463, 1260, 1086, 800, 760. **$^1$H NMR (400 MHz, $CDCl_3$):** δ 8.10 (d, *J* = 8.56 Hz, 1H), 7.87 (d, *J* = 8.0 Hz, 1H), 7.77 (d, *J* = 8.4 Hz, 1H), 7.61-7.52 (m, 2H), 7.49-7.43 (m, 3H), 7.41-7.36 (m, 2H), 7.05-6.99 (m, 4H), 4.70 (s, 1H), 3.40 (s, 3H), 3.07 (s, 2H), 2.24 (s, 3H), 0.97 (s, 3H). **$^{13}$C NMR (100 MHz, $CDCl_3$):** δ 209.0, 137.5, 136.9, 136.0, 135.1, 134.4, 133.7, 133.4, 132.3, 130.3 (2C), 130.2, 128.7 (2C), 128.3, 128.0, 127.8, 127.2, 127.1, 126.8, 126.6, 125.9, 124.7, 80.3, 63.8, 57.5, 43.5, 21.1, 16.3. **Optical rotation:** $[\alpha]_D^{25}$ +3.2 (*c* 0.39, $CHCl_3$). **HRMS (ESI):** *m/z* calculated for $C_{29}H_{27}O_2$ $(M+H)^+$: 407.2011. Found: 407.2015.

**Table 19: Crystal data and structure refinement for 3-hydroxy indanone 6d.**



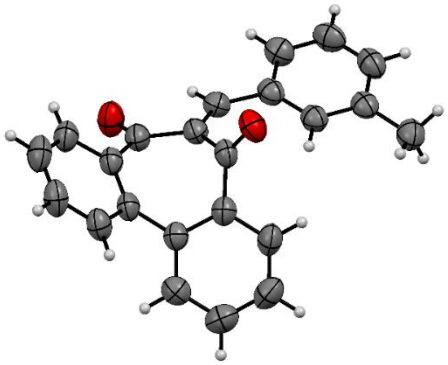
| | | |
|---|---|---|
| Empirical formula | $C_{13}H_{14}O_3$ | |
| Formula weight | 218.24 | |
| Temperature | 298 K | |
| Crystal system | triclinic | |
| Space group | P-1 | |
| Unit cell dimensions | a = 9.4694(4) Å | α = 108.725° |
| | b = 10.7377(6) Å | β = 91.302° |
| | c = 12.3519(5) Å | γ = 101.478° |
| Volume | 1160.59(10) $Å^3$ | |
| Z | 4 | |
| $\rho_{calc}$ | 1.249 $g/cm^3$ | |
| μ | 0.088 $mm^{-1}$ | |
| F(000) | 464.0 | |
| Crystal size | 0.4 × 0.2 × 0.2 $mm^3$ | |
| Radiation | Mo Kα (λ = 0.71073) | |
| 2Θ range for data collection | 5.33 to 65.384° | |
| Index ranges | -13 ≤ h ≤ 12, -16 ≤ k ≤ 14, -17 ≤ l ≤ 18 | |
| Reflections collected | 9637 | |
| Independent reflections | 7377 [$R_{int}$ = 0.0134, $R_{sigma}$ = 0.0321] | |
| Data/restraints/parameters | 7377/0/307 | |
| Goodness-of-fit on $F^2$ | 1.061 | |
| Final R indexes [I>=2σ (I)] | $R_1$ = 0.0627, $wR_2$ = 0.1745 | |
| Final R indexes [all data] | $R_1$ = 0.0852, $wR_2$ = 0.2020 | |
| Largest diff. peak/hole | 0.27/-0.28 e $Å^{-3}$ | |
| CCDC | 2117421 | |

**Table 20:** **Crystal data and structure refinement for nine-membered carbocycle 40b.**



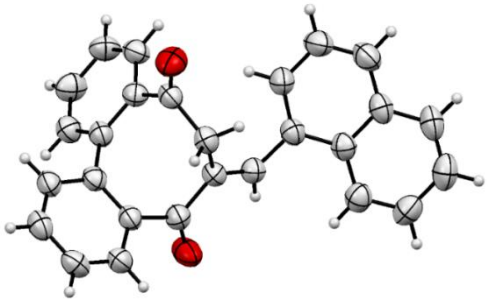
| | | |
|---|---|---|
| Empirical formula | $C_{15}H_{18}O_2$ | |
| Formula weight | 230.29 | |
| Temperature | 298 K | |
| Crystal system | monoclinic | |
| Space group | $P2_1/c$ | |
| Unit cell dimensions | a = 8.1464(12) Å | α = 90° |
| | b = 23.783(3) Å | β = 115.306° |
| | c = 7.3403(12) Å | γ = 90° |
| Volume | 1285.7(4) $Å^3$ | |
| Z | 4 | |
| $\rho_{calc}$ | 1.190 $g/cm^3$ | |
| μ | 0.077 $mm^{-1}$ | |
| F(000) | 496.0 | |
| Crystal size | 0.3 × 0.3 × 0.25 $mm^3$ | |
| Radiation | Mo Kα (λ = 0.71073) | |
| 2Θ range for data collection | 5.532 to 65.568 | |
| Index ranges | $-11 \leq h \leq 11$, $-33 \leq k \leq 15$, $-8 \leq l \leq 10$ | |
| Reflections collected | 6778 | |
| Independent reflections | 4213 [$R_{int}$ = 0.0476, $R_{sigma}$ = 0.0821] | |
| Data/restraints/parameters | 4213/0/158 | |
| Goodness-of-fit on $F^2$ | 1.073 | |
| Final R indexes [I>=2σ (I)] | $R_1$ = 0.0822, $wR_2$ = 0.2265 | |
| Final R indexes [all data] | $R_1$ = 0.1466, $wR_2$ = 0.3262 | |
| Largest diff. peak/hole | 0.48/-0.32 e $Å^{-3}$ | |
| CCDC | 2117423 | |

**Table 21: Crystal data and structure refinement for 1,3-cycloheptanedione 71d.**



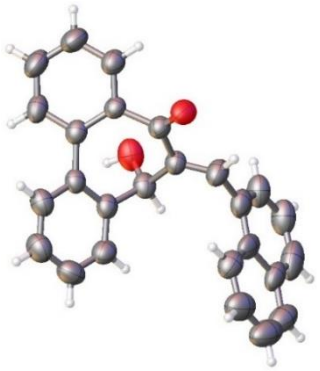
| | | |
|---|---|---|
| Empirical formula | $C_{23}H_{16}O_2$ | |
| Formula weight | 324.36 | |
| Temperature | 273 K | |
| Crystal system | monoclinic | |
| Space group | C2/c | |
| Unit cell dimensions | a = 15.5108(12) Å | α = 90° |
| | b = 22.574(2) Å | β = 99.083° |
| | c = 28.558(3) Å | γ = 90° |
| Volume | 9873.9(16) $Å^3$ | |
| Z | 24 | |
| $\rho_{calc}$ | 1.309 $g/cm^3$ | |
| μ | 0.083 $mm^{-1}$ | |
| F(000) | 4080.0 | |
| Crystal size | 0.4 × 0.3 × 0.12 $mm^3$ | |
| Radiation | MoKα (λ = 0.71073) | |
| 2Θ range for data collection | 5.046 to 65.656 | |
| Index ranges | $-21 \leq h \leq 23$, $-25 \leq k \leq 34$, $-39 \leq l \leq 43$ | |
| Reflections collected | 28871 | |
| Independent reflections | 18364 [$R_{int}$ = 0.0524, $R_{sigma}$ = 0.1010] | |
| Data/restraints/parameters | 18364/0/679 | |
| Goodness-of-fit on $F^2$ | 0.850 | |
| Final R indexes [I>=2σ (I)] | $R_1$ = 0.0644, $wR_2$ = 0.1647 | |
| Final R indexes [all data] | $R_1$ = 0.2751, $wR_2$ = 0.3229 | |
| Largest diff. peak/hole | 0.25/-0.19 e $Å^{-3}$ | |
| CCDC | 1584071 | |

**Table 22: Crystal data and structure refinement for dibenzo-fused cyclooctadione 100c.**



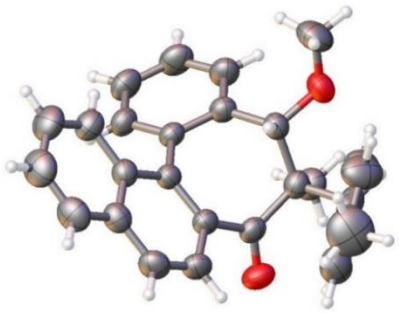
| | | |
|---|---|---|
| Empirical formula | $C_{27}H_{18}O_2$ | |
| Formula weight | 374.41 | |
| Temperature | 293 K | |
| Crystal system | monoclinic | |
| Space group | $P2_1/c$ | |
| Unit cell dimensions | a = 17.4516(9) Å | α = 90° |
| | b = 7.5513(4) Å | β = 107.604° |
| | c = 15.1340(8) Å | γ = 90° |
| Volume | 1901.00(18) $Å^3$ | |
| Z | 4 | |
| $\rho_{calc}$ | 1.3082 $g/cm^3$ | |
| μ | 0.081 $mm^{-1}$ | |
| F(000) | 784.0 | |
| Crystal size | 0.2 × 0.2 × 0.15 $mm^3$ | |
| Radiation | Mo Kα (λ = 0.71073) | |
| 2Θ range for data collection | 5.44 to 65.62 | |
| Index ranges | -26 ≤ h ≤ 26, -11 ≤ k ≤ 11, -23 ≤ l ≤ 23 | |
| Reflections collected | 26485 | |
| Independent reflections | 7063 [$R_{int}$ = 0.0828, $R_{sigma}$ = 0.0963] | |
| Data/restraints/parameters | 7063/0/262 | |
| Goodness-of-fit on $F^2$ | 1.095 | |
| Final R indexes [I>=2σ (I)] | $R_1$ = 0.0834, $wR_2$ = 0.1897 | |
| Final R indexes [all data] | $R_1$ = 0.2215, $wR_2$ = 0.2728 | |
| Largest diff. peak/hole | 0.55/-0.53 e $Å^{-3}$ | |
| CCDC | 1814310 | |

**Table 23: Crystal data and structure refinement for dibenzocycloheptanone 117b.**



| | | |
|---|---|---|
| Empirical formula | $C_{26}H_{18}O_2$ | |
| Formula weight | 362.40 | |
| Temperature | 298.00 K | |
| Crystal system | monoclinic | |
| Space group | $P2_1/c$ | |
| Unit cell dimensions | a = 8.3826(15) Å | α = 90° |
| | b = 12.595(2) Å | β = 95.527(16)° |
| | c = 17.554(3) Å | γ = 90° |
| Volume | 1844.8(6) $Å^3$ | |
| Z | 4 | |
| $\rho_{calc}$ | 1.305 $g/cm^3$ | |
| μ | 0.081 $mm^{-1}$ | |
| F(000) | 760.0 | |
| Crystal size | 0.3 × 0.25 × 0.25 $mm^3$ | |
| Radiation | MoKα (λ = 0.71073) | |
| 2Θ range for data collection | 5.676 to 49.986 | |
| Index ranges | $-9 \leq h \leq 6$, $-9 \leq k \leq 14$, $-20 \leq l \leq 20$ | |
| Reflections collected | 5990 | |
| Independent reflections | 3233 [$R_{int}$ = 0.0492, $R_{sigma}$ = 0.0876] | |
| Data/restraints/parameters | 3233/0/254 | |
| Goodness-of-fit on $F^2$ | 0.986 | |
| Final R indexes [I>=2σ (I)] | $R_1$ = 0.0822, $wR_2$ = 0.2132 | |
| Final R indexes [all data] | $R_1$ = 0.1497, $wR_2$ = 0.2842 | |
| Largest diff. peak/hole | 0.43/-0.28 e $Å^{-3}$ | |
| CCDC | 1916664 | |

**Table 24: Crystal data and structure refinement for dibenzocycloheptanone (+)-117n".**



| | | |
|---|---|---|
| Empirical formula | $C_{29}H_{26}O_2$ | |
| Formula weight | 406.50 | |
| Temperature | 298.0(2) K | |
| Crystal system | triclinic | |
| Space group | P-1 | |
| Unit cell dimensions | a = 9.1696(5) Å | α = 87.619(5)° |
| | b = 10.6774(7) Å | β = 87.821(4)° |
| | c = 12.2477(7) Å | γ = 72.126(5)° |
| Volume | 1139.88(12) $Å^3$ | |
| Z | 2 | |
| $\rho_{calc}$ | 1.184 $g/cm^3$ | |
| μ | 0.073 $mm^{-1}$ | |
| F(000) | 432.0 | |
| Crystal size | 0.4 × 0.35 × 0.3 $mm^3$ | |
| Radiation | MoKα (λ = 0.71073) | |
| 2Θ range for data collection | 5.132 to 65.53 | |
| Index ranges | $-13 \leq h \leq 12$, $-15 \leq k \leq 16$, $-18 \leq l \leq 18$ | |
| Reflections collected | 25197 | |
| Independent reflections | 7910 [$R_{int}$ = 0.0512, $R_{sigma}$ = 0.0449] | |
| Data/restraints/parameters | 7910/0/283 | |
| Goodness-of-fit on $F^2$ | 1.040 | |
| Final R indexes [I>=2σ (I)] | $R_1$ = 0.0799, $wR_2$ = 0.2234 | |
| Final R indexes [all data] | $R_1$ = 0.1208, $wR_2$ = 0.2854 | |
| Largest diff. peak/hole | 0.59/-0.23 e $Å^{-3}$ | |
| CCDC | 2080392 | |

## References


(1) Review on organocatalysis, see (a) List, B. *Chem. Rev.* **2007**, *107*, 5413. (b) MacMillan, D.W.C. *Nature* **2008**, *455*, 304. (c) Xiang, SH.; Tan, B. *Nat Commun.* **2020**, *11*, 3786. (d) Dalko, I. P.; Moisan, L. *Angew. Chem. Int. Ed.* **2001**, *40*, 3726. (e) Oliveira, V.d.G.; Cardoso M.F.d.C.; Forezi, L.d.S.M. *Catalysts* **2018**, *12*, 605.

(2) (a) Guo, H.; Fan, Y. C; Sun, Z.; Wu, Y.; Kwon, O. *Chem. Rev.* **2018**, *118,* 10049. (b) Marinetti, A.; Voituriez, A. *Synlett* **2010**, *2*, 174.

(3) Rauhut, M. M.; Currier, H. U. S. *Patent 3074999*, **1963**; *Chem. Abstr*. **1963**, *58*, 66109.

(4) (a) Morita, K.; Suzuki, Z.; Hirose, H. *Bull. Chem. Soc. Jpn*. **1968**, *41*, 2815; (b) Baylis, A. B.; Hillman, M. E. D. *German Patent 2155113*, **1972** [*Chem. Abstr*. **1972**, *77*, 34174q].

(5) For recent reviews, see: (a) Liu, T.-Y.; Xie, M.; Chen, Y.-C. *Chem. Soc. Rev*. **2012**, *41*, 4101; (b) Xie, P.; Huang, Y. *Org. Biomol. Chem*. **2015**, *13*, 8578.

(6) (a) Heasley, B. *Curr. Org. Chem.* **2014**, *18*, 641. (b) Bonito, M. C.; Cicala, C.; Marcotullio, M. C.; Maione, F.; Mascolo, N. *Nat. Prod. Comm*. **2011**, *6*, 1205. For hybridalactone, see (c) Corey, E. J.; De, B. *J. Am. Chem. Soc.* **1984**, *106*, 2735. (d) Ota, K.; Sugata, N.; Ohshiro, Y.; Kawashima, E.; Miyaoka, H. *Chem. Eur. J.* **2012**, *18*, 13531. For Coriolin, see (e) Takeuchi, T.; limuma, H.; Iwanaga, J.; Takahasmi, S.; Takita, T.; Umezawa, H.; *J. Antibiotics*, **1969**, *22*, 215. For Taiwaniaquinol A, see (f) Thommen, C.; Jana, C. K.; Neuburger, M.; Gademann, K. *Org. Lett.* **2013**, *15*, 1390. For Brazilin, see (g) Perkin, W. H.; Robinson, R. *J. Chem. Soc. Trans.* **1908**, *93*, 489. (h) Nirmal, N. P.; Rajput, M. S.; Prasad, R. G. S. V.; Ahmad M. *Asian Pac. J. Trop. Med.* **2015**, *8*, 421. For Helenalin, see (i) François, G.; Passreiter, C. M. *Phytother. Res*. **2004**, *18*, 184. For Faveline, see (j) Ghosh, A. K.; Ray, C.; Ghatak, U. R. *Tetrahedron Lett.* **1992**, *33*, 655. For Frondosin B, see (k) Li, X.; T. V. *Org. Lett.* **2007**, *9*, 3837. For Rosmaridiphenol see (l) Le, Q. T.; Guo, L.; Lee, S. L.; Lee, J.; Oh, C. H. *Org. Lett.* **2020**, *22*, 9225. Recent reviews, see: (m) Stempel, E.; Gaich, T. *Acc. Chem. Res*. **2016**, *49*, 2390. (n) Satpathi, B.; Mondal, A.; Ramasastry, S. S. V. *Chem. Asian. J.* **2018**, *13*, 1642. (o) Vivekanand, T.; Satpathi, B.; Bankar, S. K.; Ramasastry, S. S. V. *RSC Adv.* **2018**, *8*, 18576.

(7) Few selected reports: (a) Dhiman, S.; Ramasastry, S. S. V. *Ind. J. Chem.* **2013**, *52A*, 1103. (b) Shirke, R. P.; Ramasastry, S. S. V. *J. Org. Chem.* **2015**, *80*, 4893. (c) Mishra, U. K.; Yadav, S.; Ramasastry, S. S. V. *J. Org. Chem.* **2017**, *82*, 6729. (d) Bankar, S. K.; Singh, B.; Tung, P.; Ramasastry, S. S. V. *Angew. Chem. Int. Ed.* **2018**, *57*, 1678. (e) Satpathi, B.; Dutta, L.; Ramasastry, S. S. V. *Org. Lett*. **2019**, *21*, 170. (f) Satpathi, B.; Dutta, L.; Ramasastry, S. S. V. *Org. Biomol. Chem*. **2019**, *17*, 1547. (g) Maurya, J. P.; Ramasastry, S. S. V. *J. Org. Chem.* **2021**, *86*, 525.

(8) Satpathi, B.; Ramasastry, S. S. V. *Angew. Chem. Int. Ed.* **2016**, *55*, 1777.

(9) Satpathi, B.; Wagulde, S. V.; Ramasastry, S. S. V. *Chem. Commun.* **2017**, *53*, 8042.

(10) Zhu, Y.-F.; Geng, X.-L.; Guan, Y.-H.; Teng, W.; Fan, X. *Synlett* **2017**, *28*, 1821.

(11) Mondal, A.; Satpathi, B.; Ramasastry, S. S. V. *Org. Lett.* **2022**, *24*, 256.

(12) For representative reviews on aldol reactions, see: (a) Palomo, C.; Oiarbide, M.; García, J. M. *Chem. Eur. J.* **2002**, *8*, 36. (b) Mestres, R. *Green Chem.* **2004**, *6*, 583. (c) Geary, L. M.; Hultin, P. G. *Tetrahedron:Asymmetry* 2009, *20*, 131. (d) Dutta, L.; Mondal, A.; Ramasastry, S. S. V. *Asian J. Org. Chem*. **2021**, *10*, 680.

(13) For leading reviews on this topic, see: (a) Casiraghi, G.; Zanardi, F.; Appendino, G.; Rassu, G. *Chem. Rev*. **2000**, *100*, 1929. (b) Denmark, S. E.; Heemstra, J. R.; Jr.; Beutner, G. L. *Angew. Chem. Int. Ed*. **2005**, *44*, 4682. (c) Casiraghi, G.; Battistini, L.; Curti, C.; Rassu, G.; Zanardi, F. *Chem. Rev*. **2011**, *111*, 3076. (d) Pansare, S. V.; Paul, E. K. *Chem.-Eur. J.* **2011**, *17*, 8770. (e) Bisai, V. *Synthesis* **2012**, *44*, 1453.

(14) (a) Fuson, R. C. *Chem. Rev*. **1935**, *16*, 1. (b) Christ, R. E.; Fuson, R. C. *J. Am. Chem. Soc*. **1937**, *59*, 893.

(15) Stork, G.; Kraus, G. A. *J. Am. Chem. Soc*. **1976**, *97*, 2351.

(16) Mukaiyama, T.; Ishida, A. *Chem. Lett.* **1975**, 319.

(17) Selected reviews on the vinylogous Mukaiyama reaction: (a) Rassu, G.; Zanardi, F.; Battistini, L.; Casiraghi, G. *Synlett* **1999**, *9*, 1333. (b) Kalesse, M.; Cordes, M.; Symkenberg, G.; Lu, H.-H. *Nat. Prod. Rep*. **2014**, *31*, 563. (c) Frias, M.; Cieslik, W.; Fraile, A.; Rosado-Abon, A.; Garrido-Castro, A. F.; Yuste, F.; Aleman, J. *Chem.-Eur. J*. **2018**, *24*, 10906. (d) Hosokawa, S. *Tetrahedron Lett*. **2018**, *59*, 77. (e) Cordes, M.; Kalesse, M. *Molecules* **2019**, *24*, 3040.

(18) For the complex synthesis of silyl dienolates, see: (a) Denmark, S. E.; Beutner, G. L. *J. Am. Chem. Soc*. **2003**, *125*, 7800. (b) Moreau, X.; Bazán-Tejeda, B.; Campagne, J.-M. *J. Am. Chem. Soc*. **2005**, *127*, 7288. (c) Ratjen, L.; Garcia-Garcia, P.; Lay, F.; Beck, M. E.; List, B. *Angew. Chem. Int. Ed.* **2011**, *50*, 754. (d) Gupta, V.; Sudhir, V. S.; Mandal, T.; Schneider, C. *Angew. Chem. Int. Ed.* **2012**, *51*, 12609. (e) Curti, C.; Sartori, A.; Battistini, L.; Brindani, N.; Rassu, G.; Pelosi, G.; Lodola, A.; Mor, M.; Casiraghi, G.; Zanardi, F. *Chem.-Eur. J*. **2015**, *21*, 6433.

(19) Saito, S.; Shiozawa, M.; Ito, M.; Yamamoto, H. *J. Am. Chem. Soc*. **1998**, *120*, 813.

(20) Khong, S. N.; Tran, S. Y.; Kwon, O. *Tetrahedron* **2010**, *66*, 4760.

(21) Qin, Z.; Ma, R.; Xu, S.; He, Z. *Tetrahedron* **2013**, *69*, 10424.

(22) Dong, X.; Sun, J. *Org. Lett*. **2014**, *16*, 2450.

(23) Zhang, L.; Zhang, Z.; Liu, Q.; Liu, T.; Zhang, G. *J. Org. Chem*. **2014**, *79*, 2281.

(24) Zhang, H.-J.; Yin, L. *J. Am. Chem. Soc*. **2018**, *140*, 12270.

(25) Wang, W.; Bao, X.; Wei, S.; Nawaz, S.; Qu, J.; Wang, B. *Chem. Commun*. **2021**, *57*, 363.

(26) A few representative studies on the success of the MBH or MBH-type reactions in polar media: (a) Aggarwal, V. K.; Dean, D. K.; Mereu, A.; Williams, R. *J. Org. Chem*. **2002**, *67*, 510. (b) Price, K. E.; Broadwater, S. J.; Jung, H. M.; McQuade, D. T. *Org. Lett*. **2005**, *7*, 147. (c) Davies, H. J.; Ruda, A. M.; Tomkinson, N. C. O. *Tetrahedron Lett*. **2007**, *48*, 1461.

(27) These scaffolds serve as allocolchicine analogues. For an example, see: Bhowmik, S.; Khanna, S.; Srivastava, K.; Hasanain, M.; Sarkar, J.; Verma, S.; Batra, S. *ChemMedChem* **2013**, *8*, 1767.

(28) Xia, Y.; Qu, P.; Liu, Z.; Ge, R.; Xiao, Q.; Zhang, Y.; Wang, J. *Angew. Chem. Int. Ed*. **2013**, *52*, 2543.

(29) For insights into the mechanism, see: (a) Stewart, I. C.; Bergman, R. G.; Toste, F. D. *J. Am. Chem. Soc*. **2003**, *125*, 8696. (b) White, D. A.; Baizer, M. M. *Tetrahedron Lett*. **1973**, *14*, 3597.

(30) For oxy-Cope reactions forming nine-membered rings, see: (a) Sudha, A. V. R. L.; Nagarajan, M. *Chem. Commun*. **1996**, 1359. (b) Thornton, P. D.; Burnell, D. J. *Org. Lett*. **2006**, *8*, 3195.

(31) Huber, T.; Wildermuth, R. E.; Magauer, T. *Chem.-Eur. J*. **2018**, *24*, 12107.

(32) For rubratoxin A, see (a) Emeh, C. O.; Marth, E. H. *Mycopathologia* **1976**, *59*, 137. For protoxenicin A, see (b) Urda, C.; Fernández, R.; Pérez, M.; Rodríguez, J.; Jiménez, C.; Cuevas, C. *J. Nat. Prod*. **2017**, *80*, 713. For *a*-viniferin, see (c) Chung, E. Y.; Roh, E.; Kwak, J.-A.; Lee, H.-S.; Lee, S. H.; Lee, C.-K.; Han, S.-B.; Kim, Y. *J. Pharmacol. Sci*. **2010**, *112*, 405. (d) Sung, S. H.; Kang, S. Y.; Lee, K. Y.; Park, M. J.; Kim, J. H.; Park, J. H.; Kim, Y. C.; Kim, J.; Kim, Y. C. *Biol. Pharm. Bull*. **2002**, *25*, 125.

(33) Suzuki, S.; Murayama, T.; Shiono, Y. *J. Chem. Sci*. **2006**, *61*, 1295.

(34) Yoshikawa, K.; Kaneko, A.; Matsumoto, Y.; Hama, H.; Arihara, S. *J. Nat. Prod*. **2006**, *69*, 1267.

(35) For recent reviews on MBH reactions, see (a) Masson, G.; Housseman, C.; Zhu, J. *Angew. Chem. Int. Ed*. **2007**, *46*, 4614. (b) Singh, V.; Batra, S. *Tetrahedron* **2008**, *64*, 4511. (c) Declerck, V.; Martinez, J.; Lamaty, F. *Chem. Rev*. **2009**, *109*, 1. (d) Basavaiah, D.; Reddy, B. S.; Badsara, S. S. *Chem. Rev*. **2010**, *110*, 5447. (e) Wei, Y.; Shi, M. *Acc. Chem. Res*. **2010**, *43*, 1005. (f) Mansilla, J.; Saá, J. M. *Molecules* **2010**, *15*, 709. (g) Basavaiah,

D.; Veeraraghavaiah, G. *Chem. Soc. Rev*. **2012**, *41*, 68. (h) Wei, Y.; Shi, M. *Chem. Rev*. **2013**, *113*, 6659. (i) Fan, Y. C.; Kwon, O. *Chem. Commun*. **2013**, *49*, 11588. (j) Bharadwaj, K. C. *RSC Adv*. **2015**, *5*, 75923. (k) Pellissier, H. *Tetrahedron* **2017**, *73*, 2831. (l) Basavaiah, D.; Naganaboina, R. T. ***New J. Chem.*** **2018**, ***42***, 14036.

(36) For a seminal contribution, see: (a) Kataoka, T.; Kinoshita, H.; Kinoshita, S.; Iwamura, T.; Watanabe, S.-I. *Angew. Chem. Int. Ed*. **2000**, *39*, 2358. Recent reviews on this topic, see: (b) McGarrigle, E. M.; Myers, E. L.; Illa, O.; Shaw, M. A.; Riches, S. L.; Aggarwal, V. K. *Chem. Rev*. **2007**, *107*, 5841. (c) Cież, D.; Pałasz, A.; Trzewik, B. *Eur. J. Org. Chem.* **2016**, *2016*, 1476.

(37) Few selected articles on this topic, see: (a) Li, G.; Xu, X.; Chen, D.; Timmons, C.; Carducci, M. D.; Headley, A. D. *Org. Lett*. **2003**, *5*, 329. (b) Chen, D.; Timmons, C.; Liu, J.; Headley, A.; Li, G. *Eur. J. Org. Chem.* **2004**, *2004*, 3330. (c) Senapati, B. K.; Hwang, G.-S.; Lee, S.; Ryu, D. H. *Angew. Chem. Int. Ed*. **2009**, *48*, 4398. (d) Hachiya, I.; Ito, S.; Kayaki, S.; Shimizu, M. *Asian J. Org. Chem*. **2013**, *2*, 931.

(38) Zhang, Y.; Ye, S.; Ji, M.; Li, L.; Guo, D.; Zhu, G. *J. Org. Chem*, **2017**, *82*, 6811.

(39) Mondal, A.; Hazra, R.; Grover, J.; Raghu, M.; Ramasastry, S. S. V. *ACS Catal*. **2018**, *8*, 2748.

(40) Li, Z.; Li, H.; Guo, X.; Cao, L.; Yu, R.; Li, H.; Pan, S. *Org. Lett.* **2008**, *10*, 803.

(41) (a) Willis, M. C.; Randell-Sly, H. E.; Woodward, R. L.; McNally, S. J.; Currie, G. S. *J. Org. Chem*. **2006**, *71*, 5291. (b) Khong, S.; Kwon, O. *Asian J. Org. Chem*. **2014**, *3*, 453.

(42) (a) Gabriele, B.; Mancuso, R.; Veltri, L. *Chem.-Eur. J*. **2016**, *22*, 5056. (b) Manisha; Dhiman, S.; Mathew, J.; Ramasastry, S. S. V. *Org. Biomol. Chem*. **2016**, *14*, 5563 and references cited therein.

(43) Review on C-H activation and functionalization, see (a) Rogge, T.; Kaplaneri, N.; Chatani, N.; Kim, J.; Chang, S.; Punji, B.; Schafer, L. L.; Musaev, D. G.; Wencel-Delord, J.; Roberts, C. A.; Sarpong, R.; Wilson, Z. E.; Brimble, M. A.; Johansson, M. J.; Ackermann L. *Nat Rev Methods Primers*, **2021**, *43*, 1. (b) Lam, N. Y. S.; Wu, K.; Yu, J.-Q. *Angew. Chem. Int. Ed*. **2021**, *60*, 15767. (c) Davies, H. M. L.; Morton, D. *J. Org. Chem.* **2016**, *81*, 2, 343. (d) Watsona I. D. G.; Toste, F. D. *Chem. Sci.* **2012**, *3*, 2899.

(44) Recent reviews on hydroacylation reactions, see (a) Ghosh, A.; Johnson, K. F.; Vickerman, K. L.; Walker, J. A.; Stanley L. M. *Org. Chem. Front*. **2016**, *3*, 639. (b) Murphy, S. K.; Bruch A.; Dong, V. M. *Angew. Chem. Int. Ed.* **2014**, *53*, 2455. (c) Leung, J. C.; Krische, M. J. *Chem. Sci*. **2012**, *3*, 2202. (d) Willis, M. C. *Chem. Rev*. **2010**, *110*, 2, 725.

(45) Sakai, K.; Ide, J.; Oda, O.; Nakamura, N. *Tetrahedron Lett*. **1972**, *13*, 1287.

(46) For reviews, see: (a) Park, J.-W.; Kou, K. G. M.; Kim, D. K.; Dong, V. M. *Chem. Sci.* **2015**, *6*, 4479. (b) Yang, L.; Huang, H. *Chem. Rev*. **2015**, *115*, 3468. (c) Chudasama, V.; Fitzmaurice, R.; Caddick, S. *Nature Chem.* **2010**, *2*, 592. (d) Park, Y. J.; Park, J.-W.; Jun, C.-H. *Acc. Chem. Res*. **2008**, *41*, 222. (e) Jun, C.-H.; Jo, E.-A.; Park, J.-W. *Eur. J. Org. Chem*. **2007**, 1869.

(47) Yetra, S. R.; Patra, A.; Biju, A. T. *Synthesis* **2015**, *47*, 1357.

(48) Tsuda, T.; Kiyoi, T.; Saegusa, T. *J. Org. Chem*. **1990**, *55*, 2555.

(49) For different metal catalyzed hydroacylation of alkynes, see (a) Leung, C. J.; Krische, M. J. *Chem. Sci*. **2012**, *3*, 2202. For Rh-catalyst, see (b) Kokubo, K.; Matsumasa, K.; Nishinaka, Y.; Miura, M.; Nomura, M. *Bull. Chem. Soc. Jpn*. **1999**, *72*, 303. (c) lez-Rodriguez, C. G; Pawley, R. J.; Chaplin, A. B.; Thompson, A. L.; Weller, A. S.; Willis, M. C. *Angew. Chem. Int. Ed*. **2011**, *50*, 5134. (d) Castaing, M.; Wason, S. L.; Estepa, B.; Hooper, J. F.; Willis, M. C. *Angew. Chem. Int. Ed*. **2013**, *52*, 13280. (e) Du, X.-W.; Stanley L. M. *Org. Lett*. **2015**, *17*, 3276. For Ru-catalyst, see (f) Miura, H.; Wada, K.; Hosokawa, S.; Inoue, M. *Chem. Eur. J.* **2013**, *19*, 861. (g) Chen, Q.-A.; Cruz, F. A.; Dong, V. M. *J. Am. Chem. Soc*. **2015**, *137*, 3157. For Ir-catalyst, see (h) Hatanaka, S.; Obora, Y.; Ishii, Y. *Chem. Eur. J.* **2010**, *16*, 1883.

(50) Oonishi, Y. *Chem. Pharm. Bull*. 2015, *63*, 397.

(51) (a) Tanaka, K.; Fu, G. C. *J. Am. Chem. Soc.* **2001**, *123*, 11492. Similar reports, see (b) Takeishi, K.; Sugishima, K.; Sasaki, K.; Tanaka, K. *Chem. Eur. J.* **2004**, *10*, 5681. (c) Tanaka, K.; Sasaki, K.; Takeishi, K.; Hirano, M. *Eur. J. Org. Chem.* **2007**, 5675.

(52) Yang, F.; Jin, T.; Yamamoto, Y. *Tetrahedron* **2012**, *68*, 5223.

(53) Shi, S.; Wang, T.; Weingand, V.; Rudolph, M.; Hashmi, A. S. K. *Angew. Chem. Int. Ed*. **2014**, *53*, 1148.

(54) Chen, S.; Li, X.; Zhao, H.; Li, B. *J. Org. Chem*. **2014**, *79*, 4137.

(55) Santhoshkumar, R.; Mannathan, S.; Cheng, C.-H. *J. Am. Chem. Soc.* **2015**, *137*, 16116.

(56) Biju, A. T.; Wurz, N. E.; Glorius, F. *J. Am. Chem. Soc*. **2010**, *132*, 5970.

(57) Vedachalam, S.; Wong, Q.-L.; Maji, B.; Zeng, J.; Ma, J.; Liu, X.-W. *Adv. Synth. Catal*. **2011**, *353*, 219.

(58) Wang, Z.; Yu, Z.; Wang, Y.; Shi, D. *Synthesis* **2012**, *44*, 1559.

(59) Kodolins, O.; Lusis, V.; Muceniece, D. *Chem. Heterocycl. Compd*. **2014**, *50*, 1270.

(60) (a) Bhowmik, S.; Khanna, S.; Srivastava, K.; Hasanain, M.; Sarkar, J.; Verma, S.; Batra, S. *ChemMedChem* **2013**, *8*, 1767. (b) Pflasterer, D.; Rudolph, M.; Yates, B. F.; Ariafard,

A.; Hashmi, A. S. K. *Adv. Synth. Catal*. **2016**, *358*, 1. (c) Takubo, K.; Furutsu, K.; Ide, T.; Nemoto, H.; Ueda, Y.; Tsujikawa, K.; Ikawa, T.; Yoshimitsu, T.; Akai, S. *Eur. J. Org. Chem*. **2016**, 1562. (d) Broady, S. D.; Golden, M. D.; Leonard, J.; Muir, J. C.; Maudet, M. *Tetrahedron Lett*. **2007**, *48*, 4627.

(61) For a phosphine-catalyzed Mukaiyama aldol reaction, see: (a) Matsukawa, S.; Fukazawa, K.; Kimura, J. *RSC Adv*. **2014**, *4*, 27780. For a phosphine-catalyzed nitroaldol reaction, see: (b) Weeden, J. A.; Chisholm, J. D. *Tetrahedron Lett*. **2006**, *47*, 9313. For an aldol reaction triggered by a Rauhut−Currier reaction, see: (c) Thalji, R. K.; Roush, W. R. *J. Am. Chem. Soc*. **2005**, *127*, 16778.

(62) Review on eight-membered carbocycles, see (a) Baloglu, E.; Kingston, D. G. I. *J. Nat. Prod.* **1999**, *62*, 1448. (b) Hu, Y.-J.; Li, L.-X.; Han, J.-C.; Min, L.; Li, C.-C. *Chem. Rev*. **2020**, *120*, 5910.

(63) (a) Tan, R.; Li, L.; Fang, Q. *Planta Med*. **1986**, *52*, 49. (b) Liu, J.-S.; Li, L. *Phytochemistry* **1995**, *38*, 1009. (c) Monovich, L. G.; Le Huerou, Y.; Roenn, M.; Molander, G. A. *J. Am. Chem. Soc.* **2000**, *122*, 52. (d) Beryozkina, T.; Appukkuttan, P.; Mont, N.; Van der Eycken, E. *Org. Lett*. **2006**, *8*, 487. (e) Gong, W.; Babu, T. V. R. *Chem. Sci*. **2013**, *4*, 3979. (f) Iwai, T.; Okochi, H.; Ito, H.; Sawamura, M. *Angew. Chem. Int. Ed*. **2013**, *52*, 4239.

(64) For allocolchicine, see (a) Banwell, M. G.; Cameron, J. M.; Corbett, M.; Dupuche, J. R.; Hamel, E.; Lambert, J. N.; Lin C. M.; Mackay, M. F. *Aust. J. Chem.* **1992**, *45*, 1967. (b) Micheletti, G.; Poli, M.; Borsotti, P.; Martinelli, M.; Imberti, B.; Taraboletti G.; Giavazzi, R. *Cancer Res.* **2003**, *63*, 1534. (c) Graening, T.; Schmalz, H.-G. *Angew. Chem. Int. Ed*. **2004**, *43*, 3230; (d) Larsson, S.; Ronsted, N. *Curr. Top. Med. Chem*. **2014**, *14*, 274. For tenuifolin, see (e) Lin, R.-J.; Cheng, M.-J.; Huang, J.-C.; Lo, W.-L.; Yeh, Y.-T.; Yen, C.-M.; Lu, C.-M.; Chen, C.-Y. J. *Nat. Prod.* **2009**, *72*, 1816. (f) Tang, C.; Li, Z.; Wang, Y.; Xu, J.; Kong, L.; Yao, H.; Wu, X. *Tetrahedron Lett.* **2011**, *52*, 3275. For multifloramine, see (g) Kametani, T.; Koizumi, M. ***J. Chem. Soc. C***. **1971**, 3976. For metasequirin B, see (h) Hackeloer, K.; Schnakenburg, G.; Waldvogel, S. R. *Org. Lett.* **2011**, *13*, 916. (I) Wang, P.-S.; Zhou, X.-L.; Gong, L. Z. *Org. Lett*. **2014**, *16*, 976. For pharmaceutically important dibenzocycloheptanes, see (j) Amr, A.-G. E.; Mohamed, A. M.; Mohamed, S. F.; Abdel-Hafez, N. A.; Hammam, A. E.-F. G. *Bioorg. Med. Chem*. **2006**, *14*, 5481. (k) Lin, H.-C.; Lee, S.-S. *J. Nat. Prod*. **2012**, *75*, 1735.

(65) Takada, T.; Arisawa, M.; Gyoten, M.; Hamada, R.; Tohma, H.; Kita. Y. *J. Org. Chem.* **1998**, *63*, 7698.

(66) Leblanc, M.; Fagnou, K. *Org. Lett*. **2005**, *7*, 2849.

(67) Hackeloer, K.; Schnakenburg, G.; Waldvogel, S. R. *Org. Lett*. **2011**, *13*, 916.

(68) Seganish, W. M.; DeShong, P. *Org. Lett*. **2006**, *8*, 3951.

(69) Vorogushin, A. V.; Wulff, W. D.; Hansen, H.-J. *J. Am. Chem. Soc*. **2002**, *124*, 6512.

(70) Paymode, D. J.; Ramana, C. V. *ACS Omega* **2017**, *2*, 5591.

(71) Djurdjevic, S.; Green, J. R. *Org. Lett*. **2007**, *9*, 5505.

(72) Pflästerer, D.; Rettenmeier, E.; Schneider, S.; de Las Heras Ruiz, E.; Rudolph, M.; Hashmi, A. S. K. *Chem. Eur. J*. **2014**, *20*, 6752.

(73) Kong, W.; Fuentes, N.; García-Domínguez, A.; Merino, E.; Nevado, C. *Angew. Chem. Int. Ed.* **2015**, *54*, 2487.

(74) Lu, D.; Wan, Y.; Kong, L.; Zhu, G. *Chem. Commun.* **2016**, *52*, 13971.

(75) Yeo, J. E.; Yang, X.; Kim, H. J.; Koo, S. *Chem. Commun*. **2004**, 236.

(76) More phosphine catalyzed annulation strategies, see (a) Satpathi, B.; Ramasastry, S. S. V. *Synlett* **2016**, *27*, 2178. (b) Raghu, M.; Grover, J.; Ramasastry, S. S. V. *Chem. Eur. J.* **2016**, *22*, 18316. (c) Singh, N. K.; Satpathi, B.; Balanarayan, P.; Ramasastry, S. S. V. *Org. Biomol. Chem.* **2017**, *15*, 10212. (d) Grover, J.; Raghu, M.; Hazra, R.; Mondal, A.; Ramasastry, S. S. V. *Synthesis* **2018**, 5*0*, 1462. (e) Kumar, P.; Shirke, R. P.; Yadav, S.; Ramasastry, S. S. V. *Org. Lett*. **2021**, *23*, 4909.

(77) Reports on Suzuki-coupling for biaryls, see (a) Sawyer, J. S.; Macdonald, T. L. *Tetrahedron Lett*. **1988**, *29*, 4839. (b) Banwell, M. G.; Lambert, J. N.; Mackay, M. F.; Greenwood, R. J. *J. Chem. Soc. Chem. Commun*. **1992**, 974. (c) Kramer, B.; Waldvogel, S. R. *Angew. Chem. Int. Ed*. **2004**, *43*, 2446.

(78) Mondal, A.; Shivangi.; Tung, P.; Wagulde, S. V.; Ramasastry, S. S. V. *Chem. Comm.* **2021**, *57*, 9260.

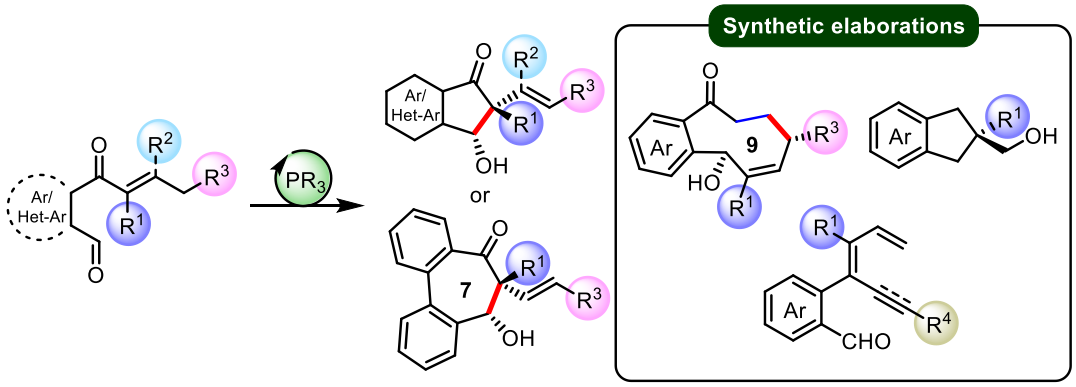
(79) For Atroposelective Synthesis of Axially Chiral Biaryl Compounds, see (a) Bringmann, G.; Price Mortimer, A. J.; Keller, P. A.; Gresser, M. J.; Garner, J.; Breuning, M. *Angew. Chem. Int. Ed.* **2005**, *44*, 5384. (b) Bringmann, G.; Gulder, T.; Gulder, T. A. M.; Breuning, M. *Chem. Rev.* **2011**, *111*, 563. (c) Cozzi, P. G.; Emer, E.; Gualandi, A. *Angew. Chem. Int. Ed.* **2011**, *50*, 3847. (d) Loxq, P.; Manoury, E.; Poli, R.; Deydier, E.; Labande, A. *Coord. Chem. Rev*. **2016**, *308*, 131. (e) Nguyen, T. T. *Org. Biomol. Chem.* **2019**, *17*, 6952. (f) Nguyen, T. T. *Eur. J. Org. Chem.* **2020**, *2020*, 147. (g) Carmona, J. A.; Rodríguez-Franco, C.; Fernández, R.; Hornillos, V.; Lassaletta, J. M. *Chem. Soc. Rev.* **2021**, *50*, 2968. (h) Cheng, J. K.; Xiang, S.-H.; Li, S.; Ye, L.; Tan, B. *Chem. Rev.* **2021**, *121*, 4805.

(80) (a) Yao, Q.-J.; Zhang, S.; Zhan, B.-B.; Shi, B.-F. *Angew. Chem. Int. Ed*. **2017**, *56*, 6617.
(b) Liao, G.; Zhang, T.; Lin, Z.-K.; Shi, B.-F. *Angew. Chem. Int. Ed*. **2020**, *59*, 19773.

# List of Publications

(1) *"Phosphine-Catalyzed Intramolecular Vinylogous Aldol Reaction of α-Substituted Enones"*

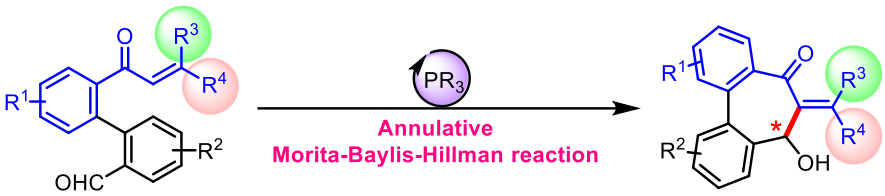
**Mondal, A.**; Satpathi, B.; Ramasastry, S. S. V. *Org. Lett.* **2022**, *24*, 256-261.




*- First phosphine-catalyzed intramolecular vinylogous aldol reaction of α-substituted enones.*
*- General and efficient protocol with excellent substrate scpe; up to 94% yield and moderate diastereoselectivity.*
*- Two-step elaboration to nine-membered carbocycles, natural product analogues and ring-opened products.*

(2) *"Annulative Morita-Baylis-Hillman reaction to synthesize chiral dibenzocycloheptanes"*

**Mondal, A.**; Shivangi.;† Tung, P.;† Wagulde, S. V.; Ramasastry, S. S. V. *Chem. Comm.* **2021**, *57*, 9260-9263. *[†These authors contributed equally to this work]*

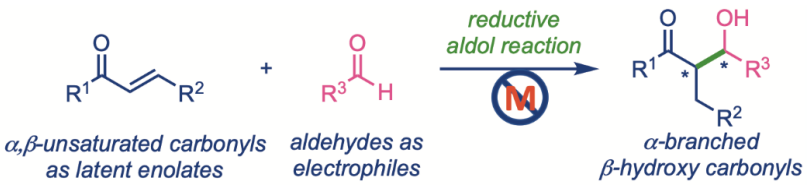



*-First catalytic and metal-free strategy for the synthesis of chiral dibenzocycloheptanes.*
*- Annulative Morita-Baylis-Hillman reaction of the biaryl β,β-disubstituted and α,β-unsaturated enones.*
*- Efficient access to dibenzocycloheptanes; yields up to 87% and ee up to >99%.*

(3) *"Metal-Free Reductive Aldol Reactions"*

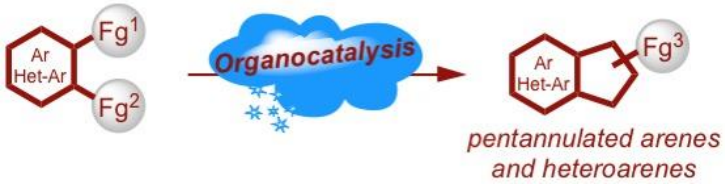
Dutta, L.; **Mondal, A.**; Ramasastry, S. S. V. *Asian J. Org. Chem.* **2021**, *10*, 680-691.

[Invited for a special issue on 'Organocatalysis']



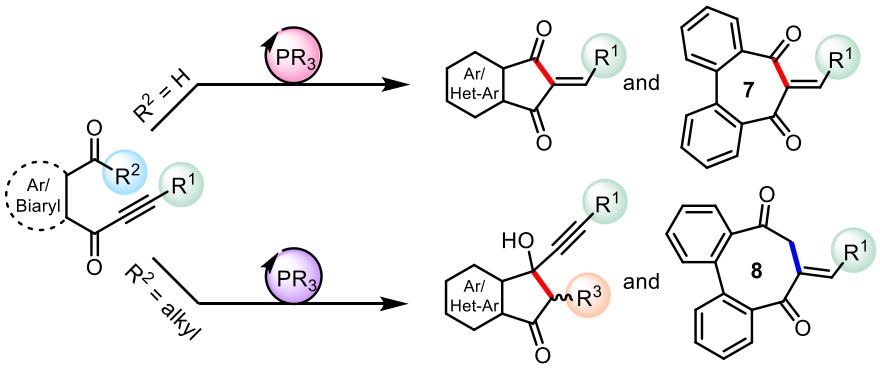
(4) *"Organocatalytic Strategies for the Synthesis of Cyclopenta-Fused Arenes and Heteroarenes"*

Satpathi, B.; **Mondal, A.**; Ramasastry, S. S. V. *Chem. Asian. J.* **2018**, *13*, 1642. ['Focus Review' invited by the Editor]




(5) *"Organophosphine-Catalyzed Intramolecular Hydroacylation of Activated Alkynes"*

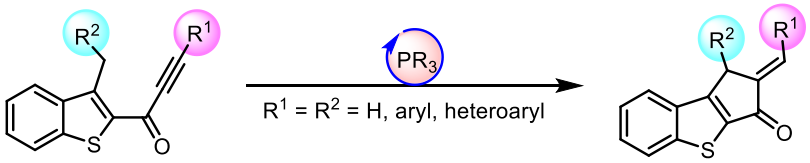
**Mondal, A.**; Hazra, R.; Grover, J.; Raghu, M.; Ramasastry, S. S. V. *ACS Catal*. **2018**, *8*, 2748. [one of the most read articles during Feb-Mar, 2018]




*- First metal-free (and organocatalytic) alternative for the intramolecular hydroacylation of ynones.*
*- Efficient method to synthesize 1,3-cyclopenta-,cyclohepta-, and cyclooctadione-fused arenes and heteroarenes.*
*- New strategy comprising of a δ'[C(sp$^3$)-H]- and ω'[C(sp$^3$)-H]-functionalization of α,β-ynones.*

(6) *"Organocatalytic γ'[C(sp$^3$)-H] functionalization of ynones: An unusual approach for the cyclopentannulation of benzothiophenes"*

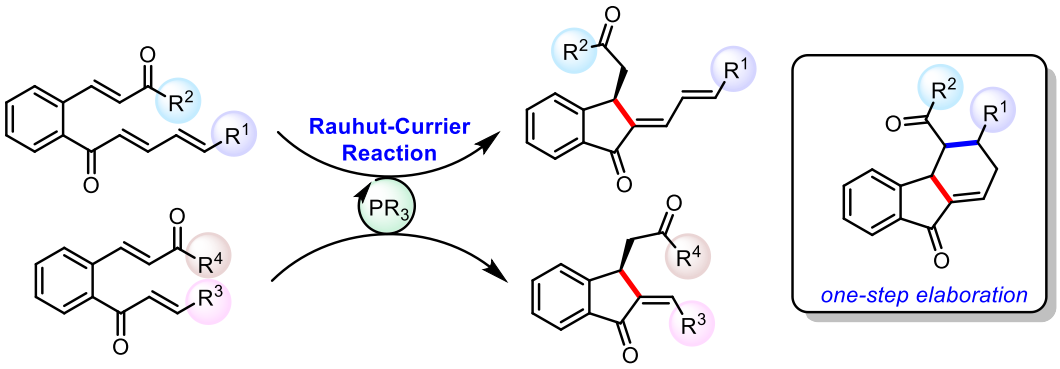
Grover, J.;† Raghu, M.;† Hazra, R.; **Mondal, A.**; Ramasastry, S. S. V. *Synthesis* **2018**, *50*, 1462. *[†These authors contributed equally to this work]*




*-Organocatalytic intramolecular hydroalkylation of ynones via γ'[C(sp$^3$)-H]-functionalization.*
*-Unique access to cyclopenta[b]annulated benzothiophenes; upto 92% yields.*

(7) *"Phosphine-Catalyzed Intramolecular Rauhut-Currier (RC) Reaction of Unsymmetrical Enones and Dienones, and Unusual Elaboration of RC Adducts"*

**Mondal, A.**; Satpathi, B.; Sharma, K.; Ramasastry, S. S. V. *Manuscript under preparation.*




- *Phosphine catalysed Rauhut-Currier reaction of unsymmetrial enones and dienones.*
- *Efficient strategy for the synthesis of new class of cyclopentannulated arenes; upto 87% yields.*

(8) *"Recent Trends in Organocatalytic Intramolecular Morita-Baylis-Hillman, Hydroacylation/ Hydroalkylation, Vinylogous Aldol and Redox Reactions"*

**Mondal, A.**; Dutta, L.; Gandhi, P.; Chattopadhyay, A.; Ramasastry, S. S. V. *Manuscript under preparation*.

# ATANU MONDAL

Date of Birth: 30th May 1993

Place of Birth: Basirhat, North 24 Parganas, West Bengal, India

Gender: Male

E-mail: atanu716@gmail.com; ph16029@iisermohali.ac.in

Contact No: (+91)-7696820209

## Academic Summary:

| | |
|---|---|
| Aug 2016 – till date | **Ph.D. Scholar** at Indian Institute of Science Education and Research (IISER) Mohali, India. Thesis title: "**Phosphine-Catalyzed Annulation of Designed Enones and Ynones**." Supervisor: Dr. S.S.V. Ramasastry. CPI: 8.3/10 in Course work. |
| Aug 2014 – May 2016 | **M.Sc. in Organic Chemistry** from Ramakrishna Mission Residential College (RKMRC) Narendrapur, University of Calcutta, West Bengal, India. Marks obtained: 78.3%, First Class. |
| July 2011 – June 2014 | **B.Sc. in Chemistry (Honours)** from Scottish Church College, University of Calcutta, India. Marks obtained: 72.0%, First Class. |
| May 2009 – June 2011 | **Higher Secondary (W.B.C.H.S.E) in Science** from Basirhat High School, West Bengal, India. Marks obtained: 86%, First Class. |
| April 2009 | **Secondary (W.B.B.S.E)** from Basirhat High School, West Bengal, India. Marks obtained: 89.5%, First Class. |

## Academic Achievements:

- Qualified **Graduate Aptitude Test in Engineering (GATE 2016)** (All India Rank 457).
- Recipient of **IASc-INSA-NASI Summer Research Fellowship 2015**.
- Recipient of **Merit Award** from Scottish Church College (2014) and RKMRC Narendrapur (2015).
- Qualified **Joint Admission for M.Sc. (JAM 2014)** (All India Rank 903).
- Recipient of **INSPIRE Scholarship (2011-2016)** by the Department of Science and Technology (DST) of India. (For being among the top 1% in the state board and pursuing science at undergraduate and post graduate level with first-class)
- Recipient of **Merit Award by the Govt. of West Bengal** for securing above 80% score in Higher Secondary Examination 2011

## Research Interests:

- Organic synthesis and its direct application in biological systems and bio-catalysis.
- Photoredox catalysis, Metal catalysis and organo-catalysis.
- Asymmetric methodology development.
- Total synthesis of natural products.

## Experiences:

- **Research Experiences:**

| | |
|---|---|
| Aug 2016 – till date | **Senior Research Fellow** at IISER Mohali, India.<br>Thesis title: Phosphine-Catalyzed Annulation of Designed Enones and Ynones.<br>Supervisor: Dr. S.S.V. Ramasastry. |
| March 2016 – May 2016 | **M. Sc. project work** at IISER Mohali.<br>Project title: Enantioselective Synthesis of Indolyl Alcohols.<br>Supervisor: Dr. S.S.V. Ramasastry. |
| May 2015 – July 2015 | **IASc sponsored Summer Internship** at IISER Mohali.<br>Project title: Synthesis of Some Useful Heterocyclic Scaffolds.<br>Supervisor: Dr. S.S.V. Ramasastry. |

- **Teaching Experiences:**

| | |
|---|---|
| Aug 2017 – Nov 2017 | Teaching Assistant in CHM211 Laboratory Course for BS-MS. |
| Jan 2018 – Apr 2018 | Teaching Assistant in CHM212 Laboratory Course for BS-MS. |
| Aug 2016 – till date | Trained Three Masters Students and Three Summer Interns. |

## Expertise and Skill:

- First-hand experience in multi-step organic synthesis by handling air/moisture sensitive reagents/reactions and gram/milligram scale reactions.
- Synthesis of highly sensitive chiral phosphines, and complex chiral amines for catalysis.
- Well versed with various computer packages viz. Microsoft Office, Paint, ChemDraw, SciFinder and X-Ray crystallographic packages viz. Olex2 and Mercury.
- Trained and expertise in handling instruments like IR (Perkin–Elmer FT-IR), NMR (Bruker Biospin Avance III FT-NMR, 400 MHz), HPLC (Waters 502), S-XRD (Rigaku XtaLAB mini X-ray diffractometer), GC-MS (Agilent), Polarimeter (Anton-Par).

- Good communication skills, self-motivated, creative, well organized and a good team worker with leadership qualities.

## Publications:

(1) **Mondal, A.**; Satpathi, B.; Ramasastry, S. S. V. Phosphine-Catalyzed Intramolecular Vinylogous Aldol Reaction of $\alpha$-Substituted Enones. *Org. Lett.* **2022**, *24*, 256.

(2) **Mondal, A.**; Shivangi;† Tung, P.;† Wagulde, S. V.; Ramasastry, S. S. V. Annulative Morita-Baylis-Hillman reaction to synthesize chiral dibenzocycloheptanes. *Chem. Comm.* **2021**, *57*, 9260.

(3) Dutta, L.; **Mondal, A.**; Ramasastry, S. S. V. Metal-Free Reductive Aldol Reactions. *Asian J. Org. Chem.* **2021**, *10*, 680. [*Invited for a special issue on 'Organocatalysis'*]

(4) Satpathi, B.; **Mondal, A.**; Ramasastry, S. S. V. Organocatalytic Strategies for the Synthesis of Cyclopenta-Fused Arenes and Heteroarenes. *Chem. Asian. J.* **2018**, *13*, 1642. [*'Focus Review' invited by the Editor*]

(5) **Mondal, A.**; Hazra, R.; Grover, J.; Raghu, M.; Ramasastry, S. S. V. Organophosphine-Catalyzed Intramolecular Hydroacylation of Activated Alkynes. *ACS Catal.* **2018**, *8*, 2748. [*one of the most read articles during Feb-Mar, 2018*]

(6) Grover, J.;† Raghu, M.;† Hazra, R.; **Mondal, A.**; Ramasastry, S. S. V. Organocatalytic $\gamma$'[C($sp^3$)-H] functionalization of ynones: An unusual approach for the cyclopentannulation of benzothiophenes. *Synthesis* **2018**, *50*, 1462.

(7) **Mondal, A.**; Satpathi, B.; Sharma, K.; Ramasastry, S. S. V. Phosphine-Catalyzed Intramolecular Rauhut-Currier (RC) Reaction of Unsymmetrical Enones and Dienones, and Unusual Elaboration of RC Adducts. *Manuscript under preparation*.

(8) **Mondal, A.**; Dutta, L.; Gandhi, P.; Chattopadhyay, A.; Ramasastry, S. S. V. Recent Trends in Organocatalytic Intramolecular Morita-Baylis-Hillman, Hydroacylation/ Hydroalkylation, Vinylogous Aldol and Redox Reactions. *Manuscript under preparation*.

## Conferences Attended:

- Presented a poster at the ***RSC Twitter Conference 2022*** (1st March 2022).
- Presented a poster in the ***CRSI National Symposium in Chemistry (NSC-27)*** at the IISER Kolkata, West Bengal, India (16th-19th July 2021).

- Participated in the ***1st CRIKC Chemistry Symposium (CCS-2019)*** at the Indian Institute of Science Education and Research (IISER) Mohali, India (2nd-3rd November 2019).
- Presented a poster in a ***Symposium on Recent Advances in Bioorganic and Medicinal Chemistry (RABMC)*** at the National Institute of Pharmaceutical Education and Research (NIPER), Mohali, India (30th August 2019).
- Presented a poster in the ***Recent Advances in Organic and Bio-organic Chemistry (RAOBC)*** at the Indian Institute of Science Education and Research (IISER) Mohali, India (22nd-24th March 2019).
- Delivered an oral presentation in the ***14th Junior National Organic Symposium (J-NOST)*** at CSIR-Indian Institute of Chemical Technology (IICT), Hyderabad, India. (28th November-1st December 2018).