Regioselective Syntheses and Functionalizations of Polycyclic Aromatic Hydrocarbons

Directed Metalation and C–H Activation

by

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the requirements for the degree of
PHILOSOPHIAE DOCTOR
(PhD)

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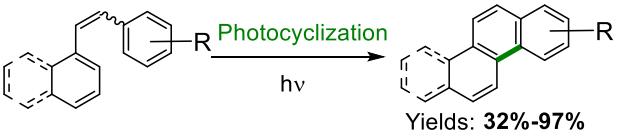
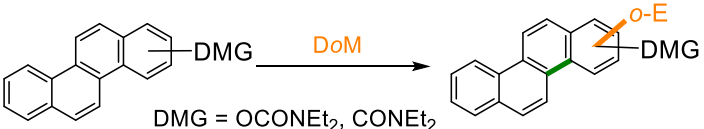
Graphical abstract

Chapter 3: Preparation of substrates by photocyclization



Yields: **32%-97%**

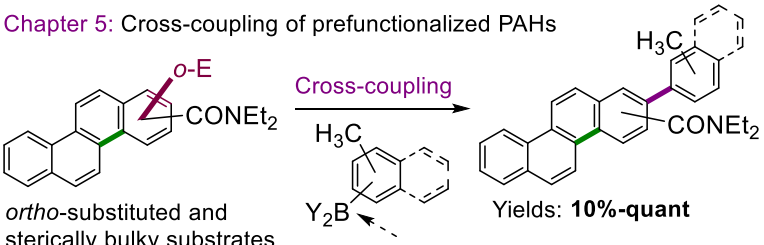
Chapter 4: Functionalization of PAHs by directed *ortho* metalation (DoM)



DMG = $OCONEt_2$, $CONEt_2$
E^+ = TMSCl, C_2Cl_6, Br_2, I_2, CH_3I, $ClCONEt_2$, DMF

Yields: **27%-quant**

Chapter 5: Cross-coupling of prefunctionalized PAHs

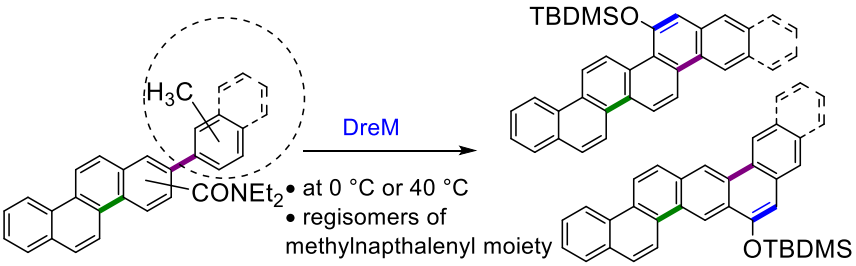


ortho-substituted and sterically bulky substrates

Miyaura borylation
Yields: **23%-78%**

Yields: **10%-quant**

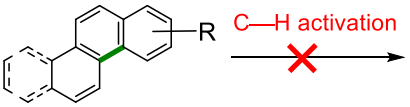
Chapter 6: Synthesis of larger PAHs by directed remote metalation (DreM)



• at 0 °C or 40 °C
• regisomers of methylnapthalenyl moiety

Yields: **44%-quant**

Chapter 7: Functionalization of PAHs by C—H activation



Attempts towards Pd-catalyzed acetoxylation and olefination resulted in recovery of substrates

include anthracene, phenanthrene, perylene and chrysene derivatives.

Abstract

Polycyclic aromatic hydrocarbons (PAHs) are well-known as pollutants and carcinogenic compounds. Lately, considering their opto-electronic and photophysical properties, PAHs are being developed as materials to be used in electronics, non-linear optics (NLOs) and light-emitting diodes (LEDs). Surprisingly, their binding affinity towards DNA has evolved into a study of their potential usage as anti-cancer and anti-malarial agents. Within the realm of these possibilities, the syntheses and functionalizations of PAHs has become an important area of research.

The classical method of oxidative photocyclization is used to prepare gram-scale phenanthrene and chrysene derivatives required as starting materials for all the experiments. The study investigates directed *ortho* metalation (D*o*M) and non-directed C─H activation as methods to functionalize chrysene derivatives. D*o*M proved to be an efficient strategy in the presence of directing metalation group (DMG) affording di-substituted chrysene derivatives in 27% to quant yields. However, C─H activation needs further experiments to develop the catalyst system suitable for activating C(sp^2)─H bonds in PAH derivatives.

This thesis is also focussed on approaches to synthesize smaller to larger PAHs. In this context, cross-coupling, and directed remote metalation (DreM) are studied. The Suzuki-Miyaura cross-coupling protocol is optimized using a simple commercial catalyst to cross-couple *ortho*-substituted bulky substrates such as chrysenyl carboxamides and methylnaphthalenyl boronic esters. The importance of electronic and steric factors is discussed when sterically demanding cross-coupling partners are involved. Finally, the cross-coupled products are cyclized following a DreM strategy to achieve the planned larger 6− and 7− ring fluorescent PAHs. The UV-visible and fluorescence spectra of all the synthesized PAHs are presented. The experiments are also aimed to understand the mechanism involved in attaining the products regioselectively.

Keywords: *polycyclic aromatic hydrocarbons, directed ortho metalation, directed remote metalation, cross-coupling, C─H bond functionalization, regioselective synthesis*

Table of contents

Abbreviations

AcOH	Acetic acid
Ac_2O	Acetic anhydride
ACN	Acetonitrile
AIBN	Azobisisobutyronitrile
Anhyd	Anhydrous
AT	Adenine, thymine
BPinH	4,4,5,5-Tetramethyl-1,3,2-dioxaborolane
Bu	Butyl
Calcd	Calculated
CIPE	Complex induced proximity effect
Dba	Dibenzylideneacetone
DCE	Dichloroethane
DCM	Dichloromethane
DDQ	2,3-Dichloro-5,6-dicyano-1,4-benzoquinone
Dehal compd	Dehalogenated compound
Desilyl compd	Desilylated compound
DIB	Diffuse interstellar bands
DIIPA	Diisopropyl amine
DME	Dimethoxyethane
DMF	*N*,*N*-dimethylformamide
DMG	Directing metalation group
DMPU	*N*,*N*′-dimethylpropylene urea
DMSO	Dimethyl sulfoxide
DNA	Deoxyribonucleic acid
D*o*M	Directed *ortho* metalation
Dppe	[1,1′-bis(Diphenylphosphino)ethane]
Dppf	[1,1′-bis(Diphenylphosphino)ferrocene]
Dppm	[1,1′-bis(Diphenylphosphino)methane]
Dppp	[1,1′-bis(Diphenylphosphino)propane]
DPQ	3,3',5,5'-tetra-*tert*-butyldiphenoquinone
DreM	Directed remote metalation
Em	Emission
Et	Ethyl
EtOAc	Ethyl acetate
Et_2O	Diethyl ether
Ex	Excitation
FTIR	Fourier transform infrared spectroscopy
FVP	Flash vacuum pyrolysis

GC	Guanine, cytosine
h	hours
HBC	Hexabenzocoronene
HFIP	Hexafluoroisoproponol
HMBC	Heteronuclear Multiple Bond Correlation
HOMO	Highest occupied molecular orbital
HRMS	High resolution mass spectrometry
Hz	Hertz
i-Pr	*iso*-Propyl
ISQ	*In situ* quench
KEM	Kinetically enhanced mechanism
LDA	Lithium diisopropyl amine
LUMO	Lowest unoccupied molecular orbital
Max	Maximum
Me	Methyl
MeOH	Methanol
Mes	Mesityl
Min	Minutes
MIS	Matrix isolation spectroscopy
MP	Melting point
MS	Molecular sieves
m/z	mass-to-charge ratio
n-Bu_2O	Di-*n*-butyl ether
NLO	Non-linear optics
NMP	N-Methyl-2-pyrrolidone
NMR	Nuclear magnetic resonance
OLED	Organic light emitting diodes
o-TBA	*ortho*-Tolyl boronic acid
OTFET	Organic thin field effect transistors
PAH	Polycyclic aromatic hydrocarbons
PBD	Pyrrolobenzodiazepine
PE	Petroleum ether
Pd-PEPPSI-iPr	[1,3-bis(2,6-Diisopropylphenyl)imidazol-2-ylidene](3-chloropyridyl)palladium(II) dichloride
RCM	Ring closing metthesis
rt	Room temperature
SPhos	2-Dicyclohexylphosphino-2′,6′-dimethoxybiphenyl
Start mat	Starting material
TBDMSCl	*tert*-Butyl dimethyl silyl chloride
t-Bu	*tert*-Butyl

t-BuBrettPhos	2-(Di-*tert*-butylphosphino)-2′,4′,6′-triisopropyl-3,6-dimethoxy-1,1′-biphenyl
TCNE	Tetracyanoethylene
TEMPO	(2,2,6,6-Tetramethylpiperidin-1-yl)oxyl
TFA	Trifluoroacetic acid
TFE	2,2,2-Trifluorethanol
THF	Tetrahydrofuran
TLC	Thin layer chromatography
TM	Transition metal
TMEDA	*N,N,N',N'*-tetramethylethylenediamine
TMP	Tetramethylpiperidide
UV-Vis	UV-visible spectroscopy

List of articles

1. Directed *ortho*-Metalation and Anionic *ortho*-Fries Rearrangement of Polycyclic Aromatic O-Carbamates: Regioselective Synthesis of Substituted Chrysenes; Sindhu Kancherla, Marianne Lorentzen, Victor Snieckus, and Kåre B. Jørgensen; *The Journal of Organic Chemistry* **2018,** *83*(7), 3590-3598; DOI: 10.1021/acs.joc.7b03210.

2. Recent developments in palladium-catalysed non-directed C─H bond activation in arenes; Sindhu Kancherla, Kåre B. Jørgensen, M. Ángeles Fernández-Ibáñez; *Synthesis* **2019**, 51(03), 643-663; DOI: 10.1055/s-0037-1610852.

3. Directed Remote Metalation of Suzuki-Miyaura Cross-Coupled (Methylnaphthalenyl)Chrysenyl Carboxamide derivatives: Synthesis of larger PAHs with Photophysical Properties; Sindhu Kancherla, Kåre B. Jørgensen, **2019** (manuscript submitted).

Poster presentations

1. Directed *ortho* metalation on larger aromatic systems. 17th Tetrahedron symposium, Spain, June 2016.

2. Directed metalation on larger aromatic systems. 21st International conference on organic synthesis, India, Dec 2016.

3. Directed Metalations for the Synthesis and Functionalization of Polycyclic Aromatic Hydrocarbons. 10th Balticum Organicum Syntheticum, Estonia, July 2018.

Oral presentations

1. Regioselectivity in lithiation of chrysene derivatives; 33rd Organisk Kjemisk Vintermøte, Norway, Jan 2018.

2. Directed metalation and cross-coupling in the synthesis of larger PAHs; 34th Organisk Kjemisk Vintermøte, Norway, Jan 2019.

Chapter 1. Introduction

Polycyclic aromatic hydrocarbons (PAHs) are present on the earth surface stemming from natural and anthropogenic sources.[1] Since the early years they have been in focus as pollutants and carcinogenic compounds.[2] Consequently, synthetic methods have been directed towards their analytical evaluation. However, a large class of these extended π-conjugated systems are of diverse importance in many branches of chemistry, material science and astrophysics. These two-dimensional graphite segments have caught the attention of researchers due to their opto-electronic properties and their potential use in electronic devices,[3] NLOs and LEDs. They are also being studied by medicinal chemists as anti-cancer agents.

In this context, a brief overview of the applications and syntheses of PAHs is presented below. Thereafter, research gaps are identified and discussed. Subsequently, the objectives defined for this work are presented, followed by an outline of thesis.

1.1 Applications of PAHs

The importance and applications of PAHs are broadly categorized into four categories: material science, organic syntheses, medicinal chemistry and astrophysics.

1.1.1 Material science: Electronics, optics and nanomaterials

For the past half-century, silicon dioxide insulators, gallium semiconductors and metallic conductors such as Al and Cu have been in-use. However, the organic semiconductors have beneficial properties such as flexiblity, light-weight, and can be easily shaped compared to silicon or other inorganic materials.[4] Larger PAHs in their solid state are promising candidates in such material science applications. Experimental[3] and theoretical studies[5] are being reported to evaluate their properties which can promote their applicability as active materials in opto-electronic devices such as organic thin film field effect transistors (OTFET), light emitting diodes (LED), photovoltaic cells, and liquid crystals. The extended π-backbone in these molecules results in a reduced HOMO-LUMO gap and increased self-assembling due to π-π interactions,

which in turn has shown significant increase in the charge carrier mobility.[6] Functionalized acenes have been actively explored by researchers in this regard.[7]

Not only the pure hydrocarbons but heteroatomic PAHs are also reported to be better substrates.[8] The presence of heteroatom enables diversification of structure, reactivity and properties. Thienyl ring-containing PAH derivatives, for example the hexabenzocoronene (HBC) derivatives shown in Figure 1, are reported to display particular photophysical properties (**A**)[9] and hole transport properties (**B**)[10], making them promising candidates for organic solar cells.

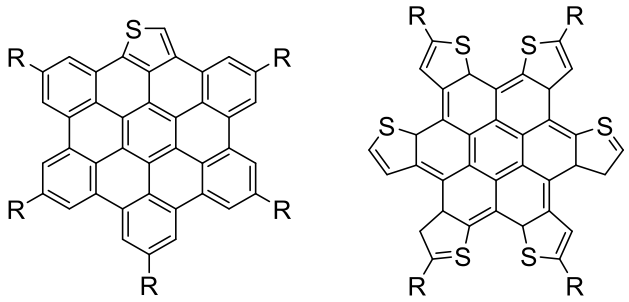


Figure 1: Thienyl containing HBCs useful in organic solar cells.[9,10]

A combination of discotic liquid crystal hexa-peri-HBC and perylene dye was used to produce thin films with large interfacial surface area. The thin films have vertically segregated perylene and HBC π-systems.[11] This combination has the benefits of efficient photoinduced charge transfer between the hexabenzocoronene and perylene, while the vertical segregation of perylene and HBC π systems resulted in effective charge transport. Such studies are enabling development of novel high performance thin films for photovoltaic technology.

Similar to the presence of heteroatoms, the π-conjugated substitutions also promote structural diversification. Pyrene based π-conjugated derivatives have been reported to possess potential for their usage as emitters in OLEDs.[12] Their cruciform shape facilitates lower π-stacking in solid state, thereby increasing the quantum efficiency (Figure 2).

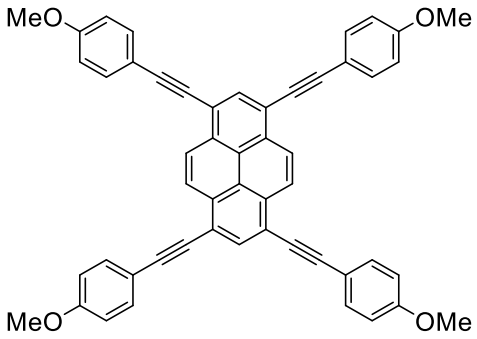


Figure 2: Cruciform shaped PAH in OLEDS.[12]

Helical PAHs are also known for optical properties since many years now. Some of the examples shown in Figure 3 are reported as novel OLED materials.[13,14]

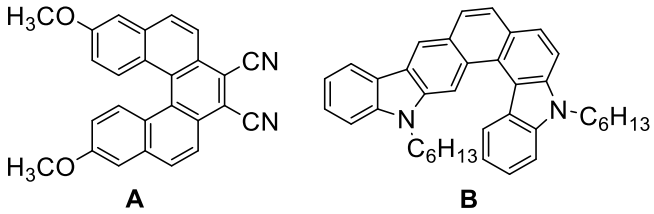
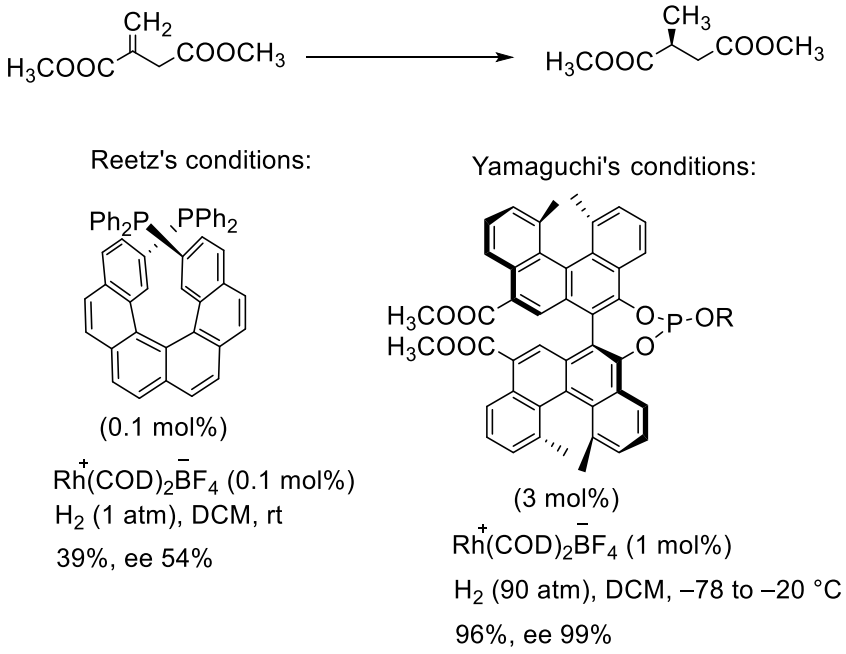


Figure 3: **A**) 3,12-Dimethoxy-7,8-dicyano-[5]helicene as a novel emissive material for organic light-emitting diode. **B**) Carbazole-based diaza[7]helicene in a deep-blue-emitting OLED.[13,14]

1.1.2 Organic syntheses

As precursors for the syntheses of fullerenes and graphenes, PAHs are gaining importance in organic syntheses. By using a suitable complex of PAH coated on catalytically active surfaces such as platinum (111), the corresponding fullerenes can be prepared by a highly efficient surface catalysed cyclodehydrogenation process at 750 K.[15] Bottom-up synthetic approaches use strategically substituted PAH derivatives to build graphenes.[16] Using PAHs as the carbon source allows the growth of graphenes on dielectric surfaces such as SiO_2. The thermal annealing on the SiO_2 surface proceeds at lower temperature in the presence of Cu-layer as catalyst on top of the PAH layer.[17]

PAHs also play an important role in asymmetric catalysis as chiral ligands and also as substrates to synthesize these ligands. The first example of helicene-derived optically pure diphosphane ligand, named as Phelix, was successfully demonstrated in rhodium-catalyzed hydrogenation of itaconic acid ester.[18] The enantiomers of bis[5]helicenediol ([5]HELOL) were described to promote the addition of diethylzinc to aldehydes.[19] Inspired by it, Yamaguchi and co-workers synthesized a helicene-derived phosphite ligand and showed its application in Rh-catalyzed hydrogenation of dimethyl itaconate (Scheme 1).[20]



Scheme 1: Hydrogenation of dimethyl itaconate using chiral helicene-derived ligands.[18,20]

Helicene tetradentate ligands attach to metal centers in any of the different conformations resulting in three diastereomeric complexes: *cis*-α, *cis*-β or *trans*. These complexes have a highly enantioselective pocket for the reactions to take place selectively. Several excellent reviews have been published bringing together the remarkable PAH-derived chiral ligands and their applications in organic syntheses.[21]

1.1.3 Medicinal chemistry

The class of chemical compounds known as DNA intercalators, are an important category of anti-tumor DNA binders. These compounds are characterized by the tendency to insert planar (hetero)aromatic rings in between DNA base pairs,[22,23] which then inhibit the functioning of topoisomerase I and II.[24-26] One of the important criteria for the functioning of the drug molecule is its interaction with DNA, which depends on the hydrogen bonding or π-stacking capability of the drug molecule and is not the only factor for its cytotoxic effect. The intrinsic π-stacking ability of PAHs and hydrogen bonding from peripheral substituents on the core structure render them as potential anti-tumor agents.[27,28]

Medicinal chemists have conducted studies to understand the effect of structural changes of PAHs on DNA binding and cytotoxic activity.[29,30] The size and shape of the aromatic ring system was found to determine the magnitude of DNA interaction, which increases along with the number of rings and surface area. While the anti-tumor activity was affected by the shape of the PAH. Reports have been published describing the affect of side chains such as basic amine groups[31] and substituent-positions[32] on biological acitivity. Compounds like (methoxy)dibenzofluorene derivatives with basic substituents such as piperidine and amide were evaluated for their anti-tumor activity.[33,34] Similarly, disubstituted chrysene with basic piperidine susbtituents also showed efficient anti-tumor activity.[35-38] The 1,4-disubstituted anthracene was significantly cytotoxic but bisantrene was more potent than the former. Some of the anthracene based DNA intercalators such as 6-ethoxy substituted azonafide, were under preclinical studies as anti-cancer agents especially for human breast and lung cancer.[39] Not only pure PAHs can be anti-cancer agents as exemplified above, but also the PAH-pyrrolobenzodiazepine (PBD) hybrids with chrysene[40] and pyrene[41] were found to improve DNA binding capability of the naturally occurring anti-tumour PBD antibiotics isolated from *Streptomyces* species. Similarly isoxazolidinyl-, isoxazolinyl- and isoxazolyl-PAHs hybrids with pyrene and phenanthrene were also evaluated using biological and docking studies.[42-45] These compounds approached the DNA from its minor groove, with a pure selectivity for the AT or GC nucleobases. However, as mentioned earlier and as observed from transition melt tempertures (ΔT_m), DNA interaction is not the only criterion for anti-tumor

activity.[46] The synthetic and biological studies conducted on isoxazolidine-PAHs have showed the requirement of formation of a stable DNA−intercalator−enzyme complex with significant half-life in order to completely block the enzymatic process.[44]

PAH based nanomaterials such as graphene quantum dots are being studied for their application in anti-cancer therapy.[47] Additionally, halogenated phenanthrene-1-amino alcohols were reported to show anti-malarial activity in mice.[48] Phenanthrenes also form the core of many biologically active natural products such as phenanthroindolizidine and alkaloids (Figure 4).[49-51]

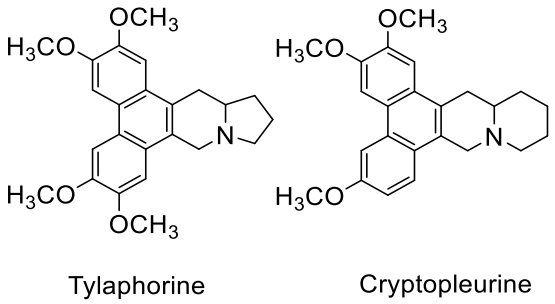


Figure 4: Phenanthrene based natural products.[49]

1.1.4 Astrophysics

PAHs are considered as important constituents in the evolution of interstellar medium, which is responsible for interstellar IR bands. They are being constantly studied to understand their origin in the space. In the early 1990s, Raman and IR spectra of small PAHs were compared to the unidentified interstellar bands inferring that the physical processes such as vibrational excitation, charge state, physical phase and electronic state can affect the spectral profiles of PAHs.[52] Using UV-near-IR spectroscopic data and experimental results from matrix isolation spectroscopy (MIS), the absorption spectra of neutral and ionized molecules of small and larger PAHs were measured and compared with astronomical observation of diffuse interstellar bands (DIB).[53,54] Small ionized PAHs absorb in visible and near-IR, thereby may be contributing to the DIB. Some larger PAHs were shortlisted for further gas-phase experiments. Time dependent-DFT calculations were done to predict the absorptions of protonated forms of PAHs in the visible spectral region,

which represent a strong class of candidate carriers of DIB.[55] The plausible origin of stable PAHs such as chrysene and phenanthrene, were shown experimentally from simple benzene through shock waves generated by projectile impact similar to the interstellar environment.[56] Experimental and theoretical observations were made using phenyl radical reactions to challenge the conventional belief that PAH formation requires high temperatures. The study suggested the low temperature (10 K) synthesis of PAH in the interstellar medium similar to cold molecular clouds.[57] However, in case of the molecules as large as fullerenes, such chemical routes are highly inefficient. Laboratory experiments indicated the photochemical mode of formation of larger PAHs, through the initial formation of fully dehydrogenated PAHs and loss of C2 units converting graphenes into cages by a top-down chemistry.[58] Recently, mass spectrometric experiments were conducted on positive and negative ionic species in a naphthalene plasma to understand the growth of PAHs.[59] The results provided evidence for the occurrence of hydrogen abstraction-acetylene addition mechanism under plasma conditions. Conclusions drawn predicted the role of negatively charged larger PAH anions involved in the growth of PAHs.

1.2 Functionalizations and syntheses of PAHs

With these recently known commercially important applications and scientifically relevant properties, syntheses and functionalizations of PAHs has become another important area of research.[60] The properties of these PAHs can be tailored through chemical syntheses that are categorized into following: (1) Introduction of peripheral functional groups, (2) Incorporation of heteroatoms B, N and P into the core structure or introduction of dopants, and (3) Extension of π-conjugation by the addition of aromatic rings. These structural changes can influence the optical band gap, electronic coupling, and molecular packing in solid states.[61,62] However, larger PAHs with greater conjugation suffer from chemical instability[63,64] upon exposure to light and air. They also have poor solubility due to strong π-π interactions in case of non-polar, planar molecules. Presence of peripheral substitutions can sometimes disrupt the π-stacking thereby affecting the charge carrier transport.[65] In order to overcome these limitations it is necessary to design and synthesize the PAHs strategically.[66,67]

1.2.1 Functionalizations of PAHs

According to Clar's sextet rule, PAHs with linear structure such as acenes are more reactive (distributes the sextet among the rings thereby have reduced benzenoid character) compared to their angular counterparts (generates an extra sextet with each angular aromatic ring).[68-70] The structural, magnetic and electron delocalization studies conducted by the group of Poater and Solà on three different classes of benzenoid compounds (Figure 5a) inferred the order of reactivity as: acenes > helicenes ≥ phenacenes.[71,72] The local aromaticity in a given series also follows a general trend such as in acenes the inner rings are more aromatic and apparently most reactive. The contradiction can be explained by the large gain in aromaticity when moving from reactants to products in an addition type reaction.[73] While the local aromaticity in phenacences follows the trend with the outer rings being comparatively more aromatic than the central rings. [71,72] Further, it varies in a damped fashion from external to central ring. Due to non-planarity in helicenes they are slightly less aromatic than phenacenes, but both seem to follow the same trend in local aromaticity. Moreover in a fully benzenoid PAHs, the outer two π-electrons which are not involved in the sextet are less stabilized and possess partial olefinic character.[74] The outer π-electrons, referred to as the K-region (Figure 5b), are observed with increased reactivity and are regarded important in metabolic oxidations[75] and selective hydrogenations.[76]

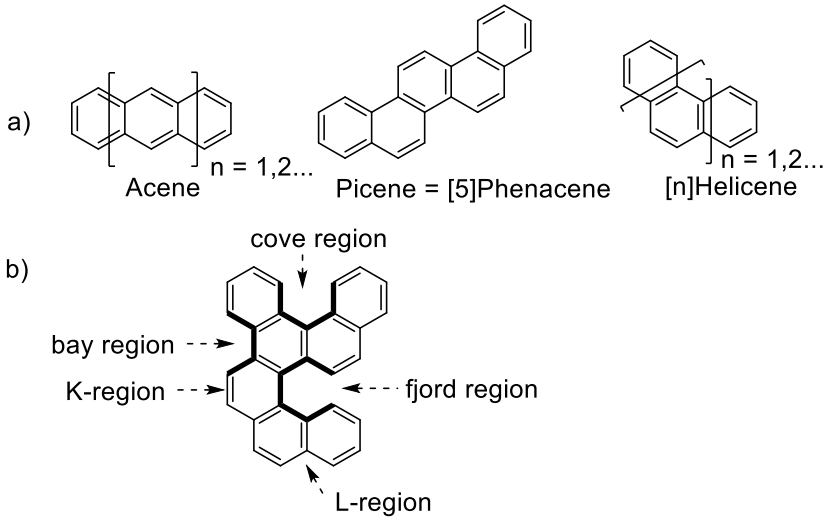
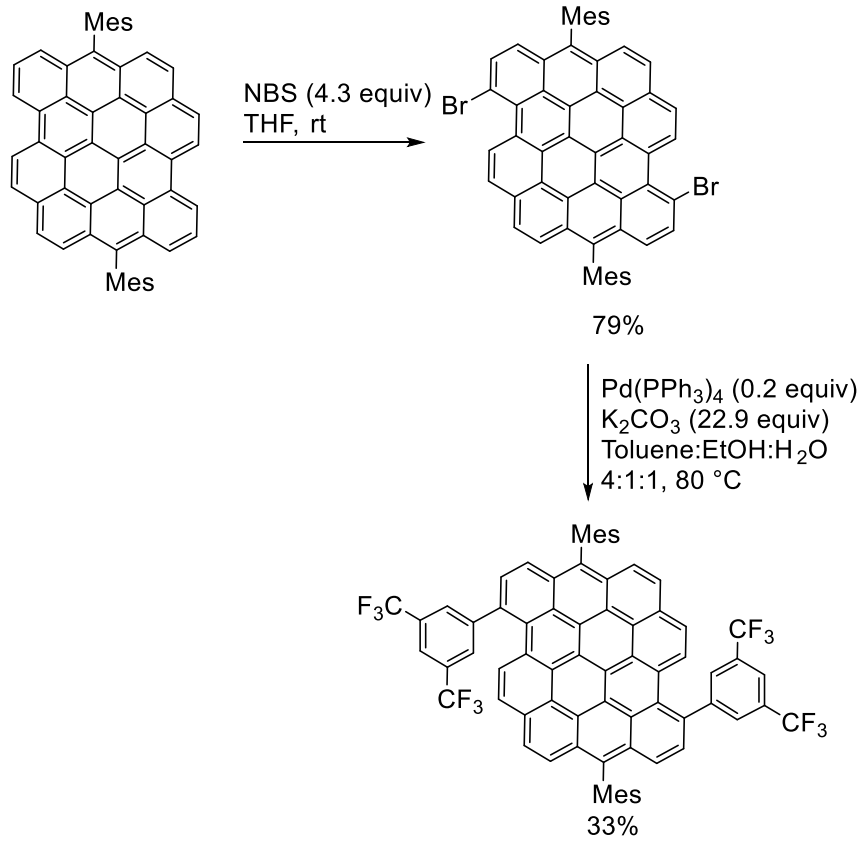


Figure 5: a) Categories of PAHs; b) The peripheral regions of PAHs.[74]

Generally, C─H bonds in PAHs are known for their inert nature and poor regioselectivity. Therefore, the conventional method of obtaining a functionalized PAH has been installing the functional groups on the precursor during synthesis of the PAH.[77] However, certain approaches to functionalize PAHs have been reported such as electrophilic aromatic substitution,[78,79] alkylation,[80] lithiation,[81] oxidation substitution[82] and reduction (Scheme 2). Recently, transition metal catalysed C─H bond functionalization is also being developed as an effective tool for the regioselective functionalization of extended π-systems.[83,84]



Scheme 2: Electrophilic bromination and subsequent cross-coupling of dibenzo[*hi*,*st*]ovalene.[78]

To overcome the problem of poor reactivity and regioselectivity in these molecules, directing groups, templates and transient directing groups are being used to selectively functionalize C─H bonds in PAHs.[85] Additionally, metal-PAH complexes such as chromium tricarbonyl-PAH complexes are being studied as substrates to achieve enhanced reactivity towards substitution reactions by increasing the acidity of protons.[86]

1.2.2 Syntheses of PAHs

Numerous synthetic methodologies have been developed to build the core PAHs.[87,88] Some of the classic methods are catalyst free approaches such as thermolysis and flash-vacuum pyrolysis (FVP) using high temperature (Figure 6), intramolecular photocyclization reactions, intermolecular Diels–Alder reactions, Pschorr synthesis,[89,90] alkylation of activated carbonyl compounds and intramolecular oxidative cyclodehydrogenation reactions.[87] While the other approaches include metal catalysed annulations,[60] inter and intramolecular cross-couplings, homolytic aromatic substitution[91,92] and so forth. The general trend in most of the strategies is the synthesis of suitable precursor by a multi-step approach, which is subsequently cyclised by various reactions to afford PAHs. The above mentioned strategies have been reviewed in several articles[87,88,93,94] and books.[95] Some of the general and recent cyclization approaches are outlined below as examples.

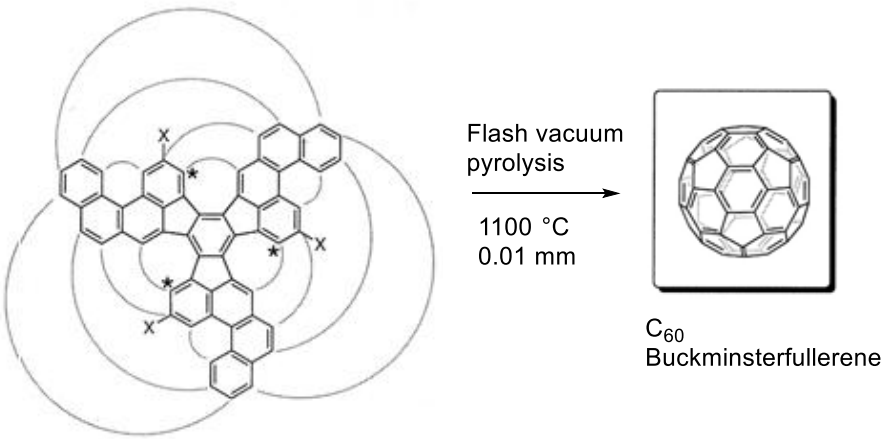
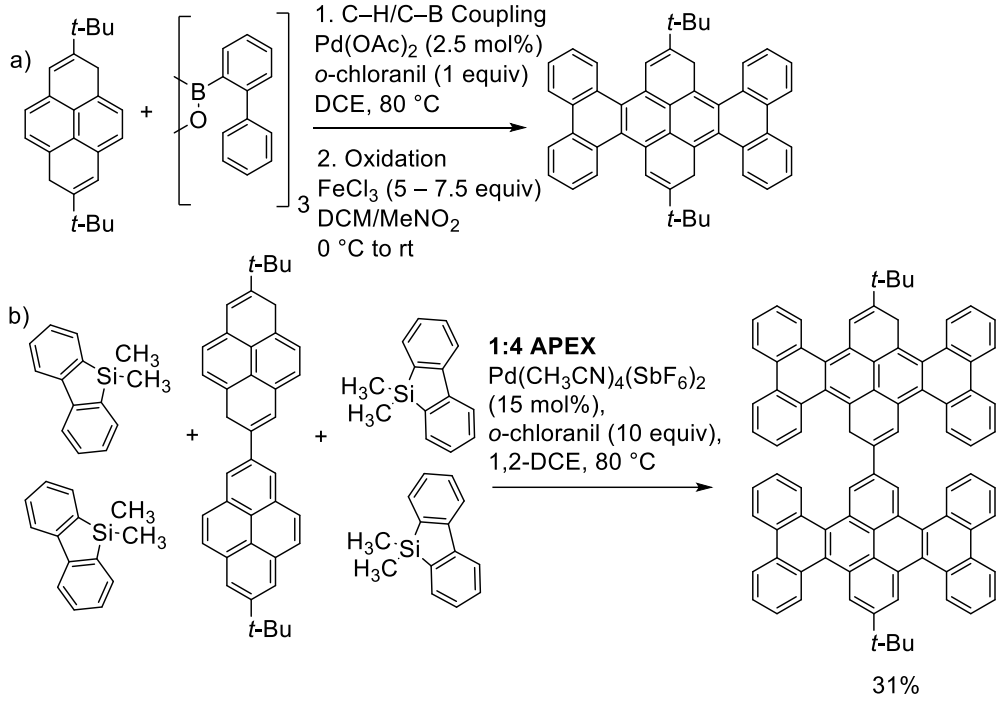


Figure 6: FVP in the synthesis of buckminsterfullerene.[96]

1) C─H activation and cyclodehydrogenation or Scholl reaction

The polyphenylene precursors for Lewis acid ($FeCl_3$ or $AlCl_3$-$Cu(OTf)_2$ catalysed Scholl reaction or oxidative cyclodehydrogenation[97] can be obtained by $Co_2(CO)_8$ catalyzed cyclotrimerization of diphenylacetylenes,[98] intermolecular Diels-Alder reaction or cross-coupling.[88,99]

Extended π-molecules and their precursors for cyclodehydrogenation reactions have been synthesized from (hetero)aromatic substrates through a step-efficient C─H activation approach since the 1990s.[100,101] However, only few examples have been reported using PAHs due to their poor reactivity and selectivity.[102] In 2011, Itami and co-workers discovered direct arylation of C–H bond of PAHs with arylboroxins selectively at the K-region catalysed by $Pd(OAc)_2$ /*o*-chloranil. Subsequent $FeCl_3$-mediated cyclodehydrogenation resulted in the extension of a parent PAH π-system with high directionality (Scheme 3a).[103]

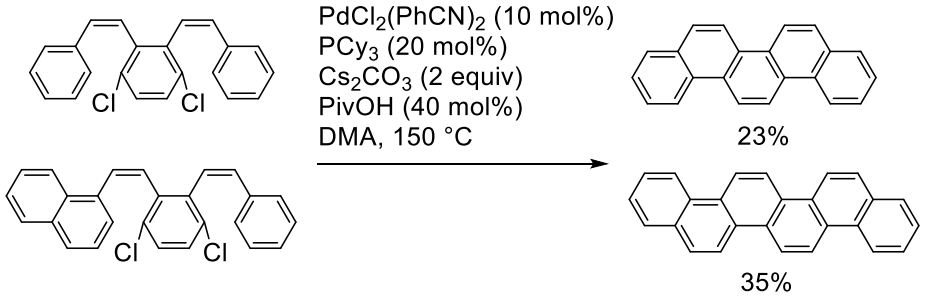


Scheme 3: Synthesis of PAHs by C─H activation and Scholl reaction.[103,104]

The C─H activation strategy was developed to a robust protocol, K-selective APEX reactions by the same group. The reactions are catalysed by $Pd(CH_3CN)_4(SbF_6)_2$ /*o*-chloranil (Scheme 3b) to synthesize nanographenes[105] and twisted structures such as hexabenzo[*a,c,fg,j,l,op*]tetracene (58%) and 21,21'-di-*tert*-butyl-10,10'-bihexabenzo[*a,c,fg,j,l,op*]tetracene (31%).[104]

2) Intra-annulation by C(sp²)─H bond functionalization

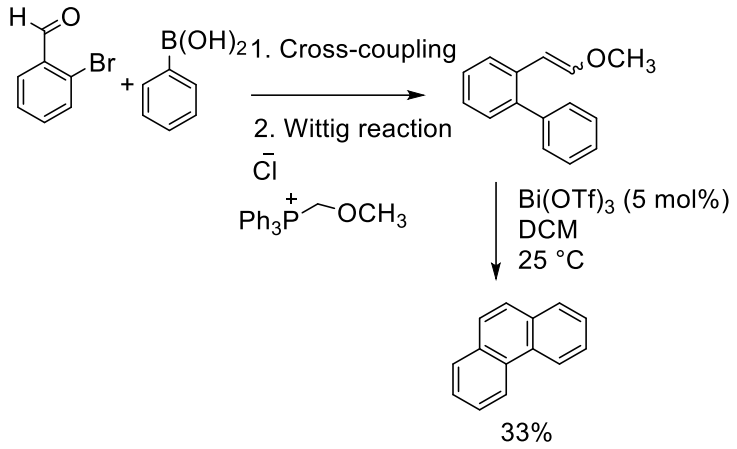
PAH derivatives such as helicenes and picenes can also be prepared by an efficent transition metal catalysed intramolecular double C─H arylation.[106] 2,3-bis[(1*Z*)-2-phenylethenyl]-1,4-dichlorobenzenes, which are readily prepared by Suzuki–Miyaura cross-coupling reactions, undergo double intramolecular cyclization in the presence of a Pd-catalyst resulting in the formation of picene derivatives (Scheme 4).[107]



Scheme 4: Synthesis of zig-zag PAHs (phenacenes) from intramolecular arylations.[107]

3) Oxidative cyclization

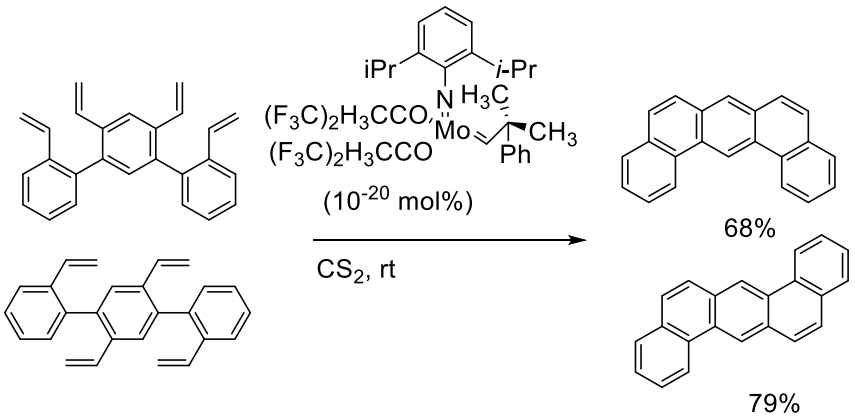
2-(2-Arylphenyl)vinyl ethers gave cyclized PAHs in excellent yields under mild reaction conditions in the presence of catalytic amount of $Bi(OTf)_3$ (Scheme 5).[108] The cyclization precursors were obtained from simple cross-coupling and Wittig reactions. When electron-withdrawing groups were present on the substrate, the reaction proceeded efficently in the presence of $FeCl_3$ /MeOH. Similar to this cyclization reaction is $FeCl_3$ catalyzed carbonyl–olefin metathesis, in which the olefinic bond reacts with carbonyl group on the other aromatic ring of the biaryl structure resulting in the formation of cyclised PAH.[109]



Scheme 5: Synthesis of PAHs by oxidative cyclization.[108]

4) Olefin ring-closing-metathesis (RCM)

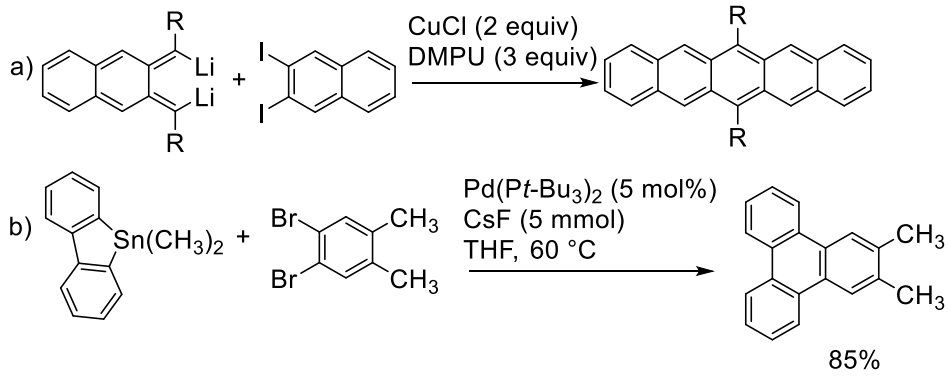
Overcoming the limitation of regioselectivity in intramolecular annulation methods such as Friedal-crafts acylation, RCM has become the general method to form multiple aromatic rings in single step.[110] King and co-workers reported an efficient RCM synthesis of larger PAHs at rt using CS_2 as solvent and commercially available Schrock catalyst (Scheme 6).[111] The required tetravinylterphenyls substrates for the reaction were prepared by a multi-step procedure in good yields.



Scheme 6: Synthesis of PAHs by RCM.[111]

5) Double cross-coupling reactions

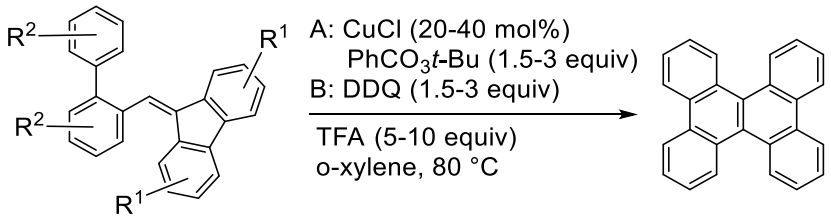
Transition metal catalysed cross-coupling of organometals with organic halides is one of the efficient methods to form $C(sp^2)$─$C(sp^2)$ bond regio- and stereo-selectively. Consequently, double cross-coupling reaction using organodimetallics and dihalides can be a promising approach to construct PAHs. The reaction can be categorized as the coupling of 1,2-dimetal reagents with 1,4-dihalogenated compounds or vice-versa.[112] The aromatic derivatives of dilithiobutadiene can be cross-coupled with bihaloarenes in the presence of CuCl and DMPU to get access to larger acenes (Scheme 7a).[112] Other example is the reaction between 9-stannafluorenes with 1,2-dihaloarenes catalysed by $Pd(Pt\text{-}Bu_3)_2$ affording several substituted PAHs in good yields (Scheme 7b).[113] Recently, the double cross-couple reaction of (*Z*)-1,2-diaryl-1,2-bis(pinacolatoboryl)ethenes with 1-bromo-2-[(*Z*)-2-bromoethenyl]arenes was reported by Hiyama and co-workers. The reaction proceeded in the presence of $[Pd(PPh_3)_4]$ as catalyst and 3 M aqueous Cs_2CO_3 as base in THF at 80 °C to afford substituted PAHs.[114-116]



Scheme 7: Synthesis of PAHs by cross-coupling reactions.[112,113]

6) Oxidative spirocyclization /1,2-aryl migration

In 2017, Jin *et al* reported the selective single-electron oxidation of more electron-rich alkene moiety of *o*-biphenylyl-substituted methylenefluorenes by CuCl-catalyst /$PhCO_3t$-Bu or DDQ oxidation system in the presence of TFA, followed by a tandem 1,2-aryl migration resulting in the formation of extended PAHs (Scheme 8).[117]



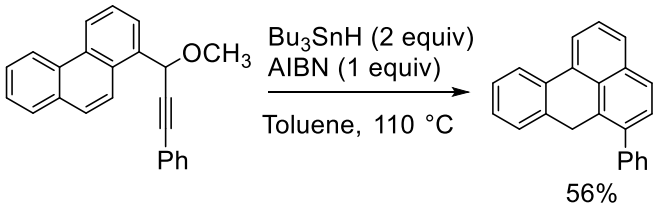
Scheme 8: Synthesis of PAHs by oxidative spirocyclization and 1,2-aryl migration.[117]

7) C≡C mediated benzannulation strategies

Arynes and alkyne substituents have been in use to construct PAHs owing to their high reactivity towards Diels Alder reaction, metal-catalyzed annulation,[118,119] annulation with 2-halo biaryls,[120] co-cyclization with alkynes and trimerization.[121-123]

7a) Radical alkyne peri-annulation

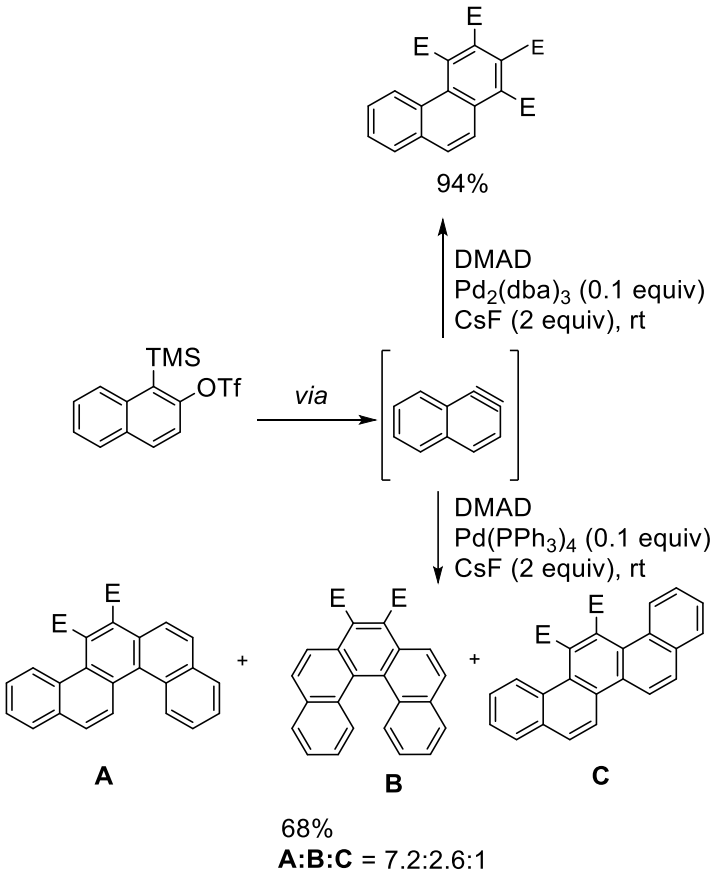
Most of the benzannulation reactions occur at K-region of the aromatic substrate and are often termed as "annulative π-extension" (APEX) reactions.[124,125] There are examples reported using Diels-Alder protocol,[126] acid- and electrophile-promoted alkyne cyclizations,[127,128] Brønsted acid-promoted alkyne cyclizations,[129] transition metal catalysed[130] and oxidative radical pathways.[131] Alabugin and co-workers reported a remarkable procedure for the addition of 6-membered aromatic ring at the L-region of propargylic ethers using Bu_3Sn-mediated radical pathway (Scheme 9).[132]



Scheme 9: Radical alkyne peri-annulation in the synthesis of PAHs.[132]

7b) Cyclotrimerization or [2+2+2] cycloaddition

As an example of co-cyclization with alkynes, Pérez and co-workers demonstrated the generation of 1,2-naphthyne from the corresponding triflate in the presence of CsF, dimethyl acetylenedicarboxylate (DMAD) and 5 mol% of $Pd(PPh_3)_4$ (Scheme 10).[133] The polycyclic aryne thereafter afforded a mixture of three possible regioisomers resulting from the cycloaddition of two molecules of naphthyne and one molecule of alkyne. The reaction can be selectively directed by changing the catalyst to $Pd_2(dba)_3$ towards the synthesis of smaller PAHs resulting from cocyclization of one molecule of aryne and two molecules of alkyne.



Scheme 10: Cyclotrimerization reaction in the synthesis of PAHs.[133]

1.3 Research gaps

As discussed in the previous Section 1.2, several approaches were discovered and are being developed for the functionalizations and syntheses of PAHs. Using these methods various PAHs with determinate substitutions, shape and dimensionality have been synthesized since several years. However, there are certain knowledge gaps in some of these strategies to be discussed in-detail in Chapter 2. The present work has been speculated on the basis of the following research gaps.

1. Directed *ortho* metalation (D*o*M) was studied extensively on smaller aromatic structures such as benzenes and very few reports are published on napthalenes and PAHs. These reactions together with cross-couplings were demonstrated in the synthesis of smaller biaryl derivatives.
2. Directed remote metalation (DreM) was engaged to synthesize various heterocyclic and carbocyclic compounds as large as phenanthrenes, benzo[*a*]anthracene.
3. Further, the newly developing research area C─H activation, is also being studied mostly on simple smaller molecules.

1.4 Objectives

Based on the above identified research gaps, following objectives towards the synthesis of functionalized larger PAHs are defined for this thesis work.

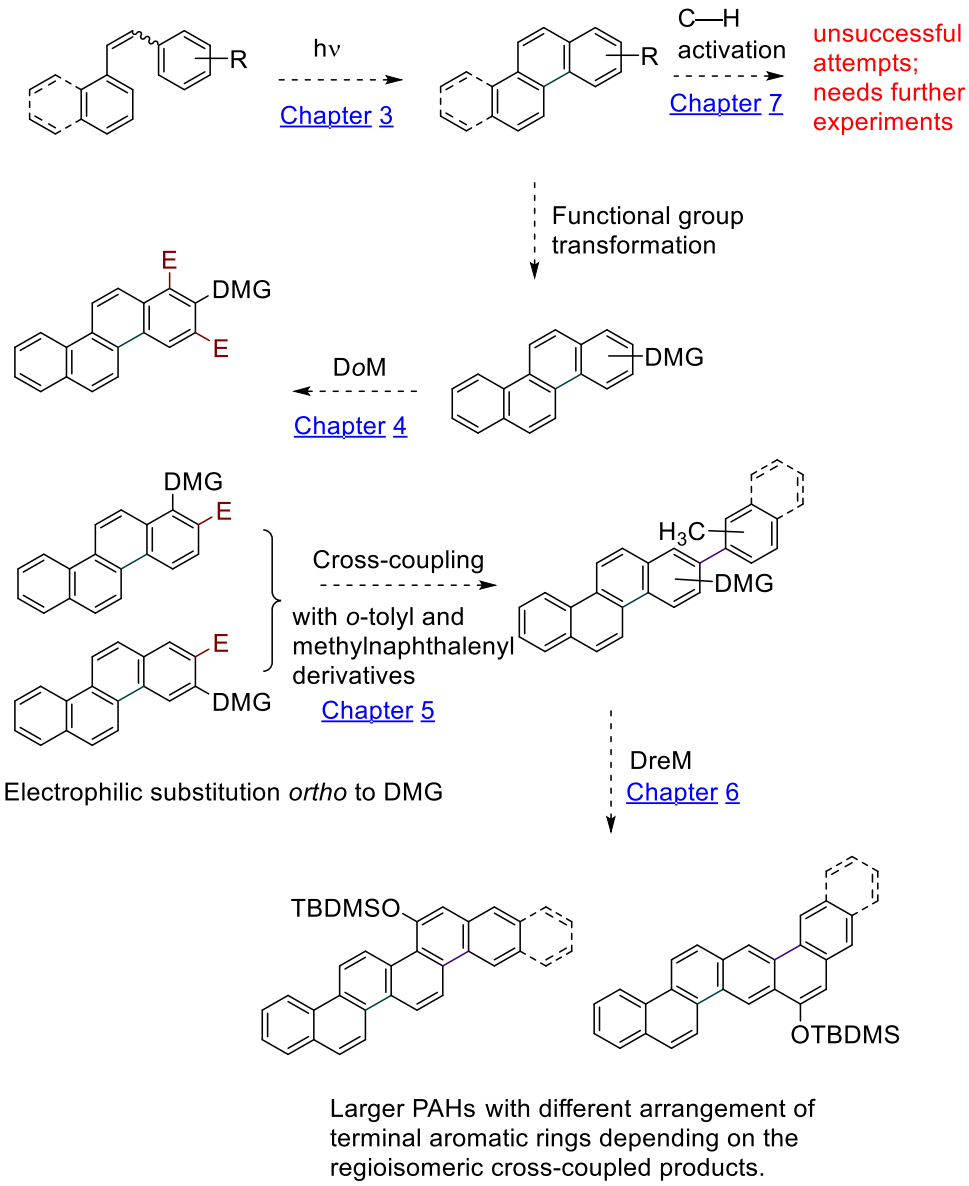
1. To study the application of D*o*M with various electrophiles on more complex and bulkier aromatic structures. The effect of directing metalation group (DMG), Li-base, and strategic blocking of preferable *ortho* site, on the regioselectivity when multiple sites are available for the reaction.
2. To explore and optimize economic cross-coupling conditions for *ortho*-substituted sterically demanding PAHs, pre-functionalized by D*o*M.
3. To study the application and regioselectivity of DreM on the cross-coupled products towards the synthesis of PAHs as large as picene and other PAH derivatives.

4. Preliminary attempts of acetoxylation and olefination of phenanthrene and chrysene derivatives through C─H activation.

1.5 Overview of the thesis

As a part of the devlopments in the functionalizations and syntheses of larger PAHs in a step-economic and atom-economic way, this thesis presents directed metalation and cross-coupling strategies as an approach to attain fluorescent larger PAHs. The thesis starts with a critical literature review along with a brief understanding of mechanistic aspects of the employed strategies in Chapter 2. Subsequently the experiments conducted to achieve the objectives are described in Chapter 3−7. The starting materials needed in gram scale for these experiments were prepared by means of classical oxidative photocyclization method (Chapter 3). In Chapter 4, D*o*M studies conducted on chrysenyl derivatives using two different DMGs to achieve objective 1 are discussed. The *ortho* functionalised chrysenyl carboxamides were further subjected to cross-coupling with *o*-tolyl and methylnapthalenyl boronates following objective 2 and are discussed in Chapter 5. According to objective 3, intramolecular cyclizations of these cross-coupled products were directed through DreM to achieve the syntheses of larger PAHs, which are reported in Chapter 6. Preliminary attempts of C─H activation to functionalize phenanthrene and chrysene derivatives (objective 4) are discussed in Chapter 7. Finally, the work is concluded with a summary and its future scope in Chapter 8.

The schematic representation of the work discussed in Chapter 3 to7 is shown in Scheme 11.



Scheme 11: Schematic representation of work presented in this thesis.

Chapter 2. Theory

The rapidly evolving applications of PAHs as discussed in Chapter 1, demand the development of economic and compatible chemical strategies to make these compounds accessible. In this context, some research gaps in directed metalation and C─H activation were identified in Section 1.3. To overcome them, following approaches were investigated and are discussed in this thesis.

2.1 Photocyclization to prepare starting materials

The photochemical cyclization of stilbene derivatives under UV light has been a classical method for the synthesis of PAHs in gram-scale. The first examples by Mallory[134,135] followed by Schloz[136] and Martin[137] has led to the development and eventually proved the effectiveness of this approach. For instance, Stuparu and co-workers reported the application of photocyclization strategy for the preparation of non-planar corannulene and planar pyrene hydrid (78%) in the presence of propylene oxide.[138,139] The photocyclizations are still in use even though limited by low concentration and long reaction times. The scalability of the reaction is typically determined by the size of the batch reactor. However, the continuous flow method might be used to increase the scalability of the reaction.[140] The photochemical cyclization has been reviewed in book chapters[141,142] and review articles[143-147] consolidating the applications and reactivity aspects explored so far.

The scope of photocyclization was elaborated with the introduction of I_2 as oxidant in the presence of air /O_2 by Mallory[135] and later on with the introduction of Katz's conditions where methyloxirane under inert atmosphere was used to quench the HI formed as the by-product during the reaction. The Katz's conditions allow the use of stoichiometric amounts of I_2 and avoid air/O_2 which causes side-products.[148] Till date, both the protocols are equally used for the gram-scale syntheses of phenanthrenes, chrysenes and even larger PAHs, depending on the chemical compatibility of the substrates and functional groups with the reagents. Modern-age oxidants[149-151] such as TEMPO, KI, DPQ, TCNE, and chloranil and HI-scavangers[139,152,153] such as K_2CO_3, THF, and propylene oxide were reported to improve the scope and reactivity of subtrates undergoing photocyclization.

2.1.1 Mechanistic aspects

Mixture of *cis* and *trans* isomers of stilbene derivatives can be used in the photocyclization reactions to give the same product.[154] Upon irradiation, the *trans* form isomerizes rapidly to *cis* form, which is capable to form cyclization products by either oxidation or elimination.[155] Experimental and theoretical studies were reported to support the involvement of an excited singlet state[154] of *cis*-stilbene which then forms a cyclised interemediate[134] in the pathway before giving out photocyclised product (Figure 7).

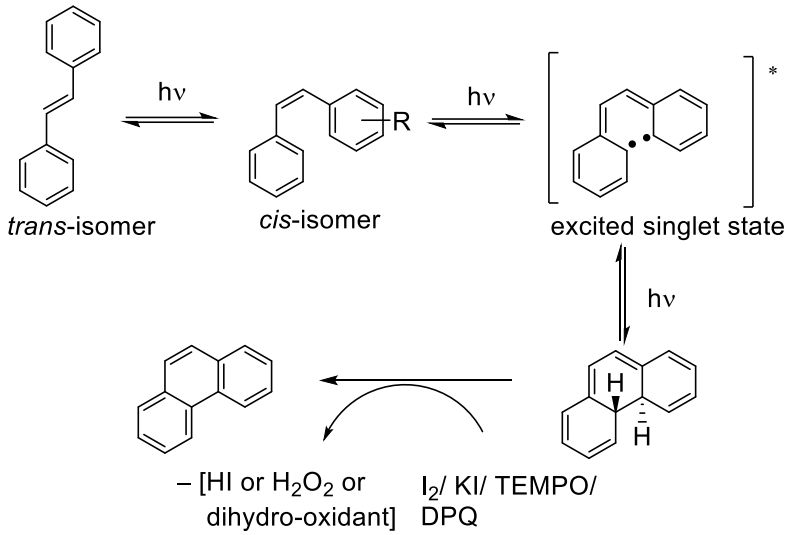


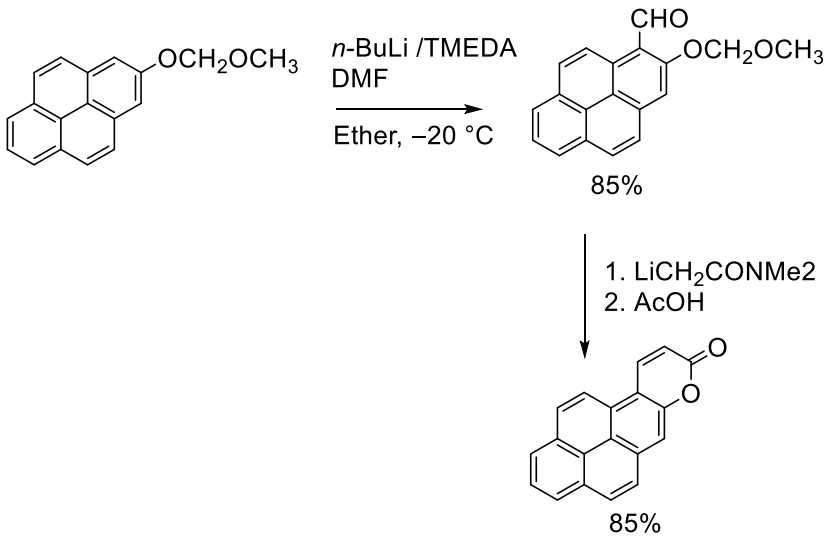
Figure 7: Mechanistic pathway of photocyclization of stilbene.

The oxidative photocyclization was used in this thesis work to prepare gram-scale quanitities of starting materials such as phenanthrene and chrysene derivatives following literature procedures (Chapter 3).

2.2 Directed *ortho* metalation

Installation of substituents and functional groups on PAHs has been one of the key targets for researchers working with π-extended aromatic molecules. Functionalization of PAHs has been a bit tedious task due to the poor reactivity

and selectivity of C─H bonds in these molecules. D*o*M has been one of the most regioselective and efficient methods to attach electrophiles exclusively to the *ortho*-position of a DMG. Since the independent discovery of *ortho* lithiation by Gilman-Bebb[156] and Wittig-Fuhrman,[157] further remarkable developments have been made by Snieckus[81] and other researchers.[158] Most of the D*o*M studies were conducted on simplest aromatic benzene derivatives.[81,159,160] The directing effect of different functional groups were also demonstrated on them. The benzene substrates are suitable to construct molecules as large as phenathrenes. Nevertheless, starting from a polyaromatic structure can be step-efficient in case of total synthesis of larger moieties of PAHs and natural products. Henceforth, the much needed functionalization of polyaromatic structures using D*o*M has been demonstrated on few PAHs such as pyrene-1-carboxaldehyde (Scheme 12),[161] 2-naphthyl-*O*-carbamates,[162] and pyrene-1-carboxamide.[163] As discussed in Section 1.2, reactivity varies between acenes, phenacene and helicenes. Therefore, in the present work C─H bond functionalizations of chrysene derivatives by D*o*M strategy are discussed in Chapter 4.



Scheme 12: D*o*M on pyrene-1-carboxaldehyde and subsequent cyclization.[161]

2.2.1 Mechanistic aspects

The D*o*M reaction requires a substrate with a heteroatom containing DMG that can coordinate with Li-base. The *ortho* proton on the aromatic ring is activated towards metalation by coordination and /or electronic effect. The metalated substrate undergoes electrophilic quench with a suitable electrophile. Over the past few decades, researchers have reported various DMGs as strong, moderate and weak based on their relative coordination and electronic effects (Figure 8).

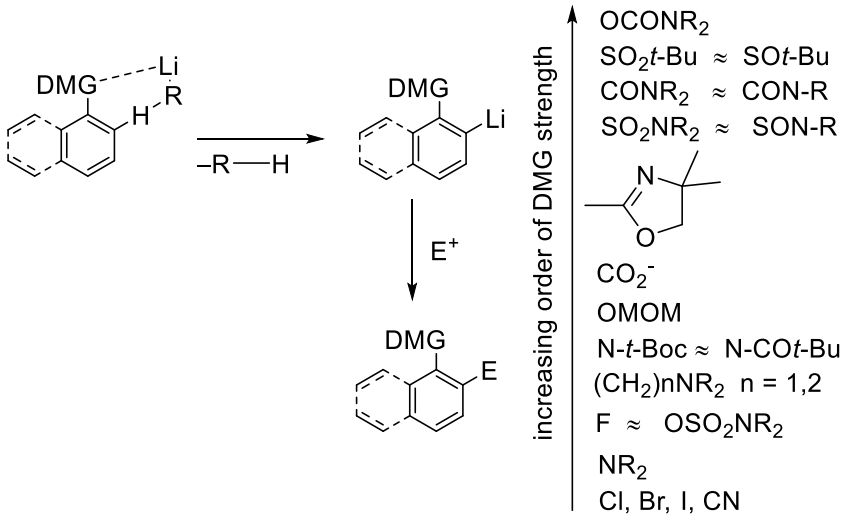


Figure 8: Mechanistic pathway of D*o*M and the strength of DMGs in increasing order.[81]

Three possible mechanisms for the D*o*M reaction has been postulated to explain the regioselectivity of product formation.[164] Firstly, the complex induced proximity effect (CIPE) was introduced to explain the formation of kinetic products. In this model, a pre-lithiation complex is formed when a Li-base coordinates to the heteroatom containing DMG, before the rate determining metalation step. Secondly, Schleyer and co-workers proposed kinetically enhanced metalation (KEM), in which the existence of a rate determining transition structure was suggested. The transition state supposedly has a stabilizing metal-substituent interaction and favourable charge distribution.[165] Researchers believe that the mechanism of directed metalation can be rationalized in a better way if both CIPE and KEM are combined properly.[158]

The chelation of the metal with the substrate increases the rate of reaction by lowering the activation energy (E_a) as shown in Figure 9. According to KEM, two transition states might be involved with their own activation energy (E_{a1} and E_{a2}). The third mechanism postulated was an overriding base mechanism, predicated in case of strong or fully complexed bases. According to this mechanism, the reaction takes place preferentially at acidic protons or positions where the negative charge can be stabilized, disregard to pre-coordination to a substituent.[160,166] The mechanism followed by D*o*M is still not definitive and needs a careful investigation of specific reaction conditions including the nature of base and DMG on the substrate.

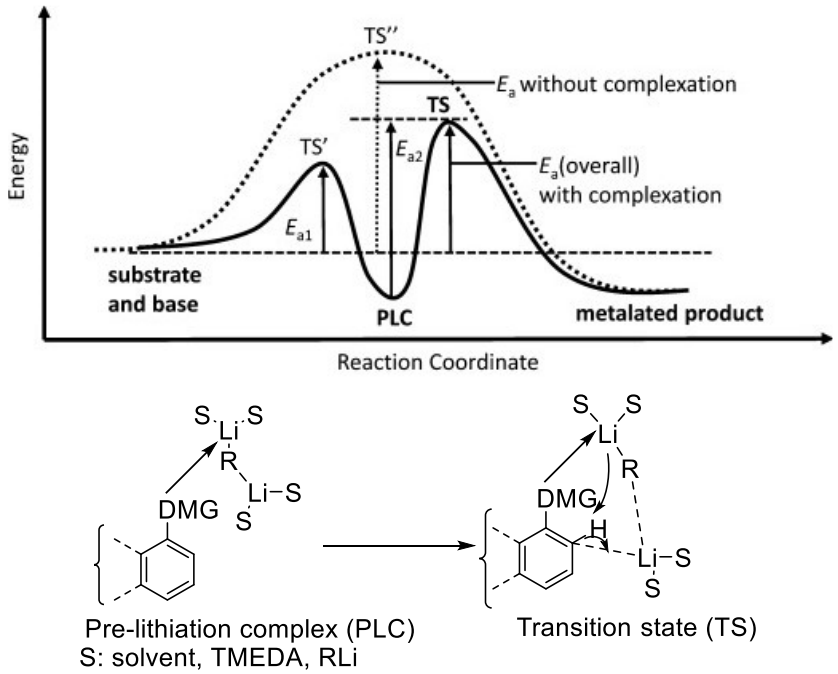


Figure 9: Qualitative energy diagram and transiently formed species for directed metalations.[158,164]

As a part of functionalization of PAHs, D*o*M experiments were conducted using chrysenyl derivatives. The observed reactivity and regioselectivity in the presence of different Li-base and various electrophiles are explained in Chapter 4. Among the di-substituted chrysenes obtained from the D*o*M experiments, the

halogenated chrysenyl carboxamides were used to expand the aromatic core structure by means of cross-coupling and DreM connections.

2.3 Cross-coupling

To expand the aromatic core through aryl-aryl bond formation, cross-coupling reactions such as Suzuki–Miyaura,[167] Stille,[168] Corriu-Kumada,[169] Negishi,[170] Hiyama,[171] and recently with organolithium substrates,[172] have been the versatile approach. Though many transition metals have been explored so far, first row metals such as Pd-based catalysts are most commonly used considering their affordability and earth abundance.[173] With direct C─H arylation approach being in early stages,[174,175] Pd-catalyzed cross-couplings have been the irreplaceable step for the synthesis of core structures of natural products,[176] pharmaceuticals,[177] agro-chemicals[178] and other compounds of commercial importance.

2.3.1 Mechanistic aspects

Despite the wide-spread use of cross-coupling reactions, their application has often been on trial-error approach. This can be attributed to the lack of mechanistic information purely derived from experimental techniques and also lack of supporting computational evidence on the full catalytic cycle due to the possibility of manifold similar energy pathways. The cross-coupling cycle is generally categorized into three main steps: oxidative addition, transmetalation, and reductive elimination (Figure 10) based on experimental and computational observations made so far.[179]. These three main steps in turn are influenced by the electronic and steric factors of the individual reaction and reactants.

Oxidative addition involves the formation of a transition state involving a organic halide (or triflate) with the metal catalyst by either a concerted pathway (retaining the stereo-center configuration) or a S_N2 analogous mechanism (causing the inversion of configuration). Subsequent transmetalation is exclusive for each type of cross-coupling and is defined by the organometallic species (nucleophile) involved (B, Sn, Zn, Li). In case of Suzuki-Miyaura cross-coupling, the external base reacts either with the boronic acid to generate nucleophilic organoboronate species or with the metal center to replace the leaving group (halide or triflate) in the coordination sphere of the catalyst. In general, transmetalation involves the transfer of an aryl group from

organometallic species to the catalyst metal center. If the cross-coupling substrates are present in *trans* position in the catalyst coordinating sphere, an additional *trans* to *cis* isomerization takes place before the reductive elimination of the expected product. Ultimately, the cross-coupled product is formed by the reductive elimination of two organo-coupling partners in *cis* position on the metal center. The generally accepted mechanism of the final step is a concerted pathway involving a three-coordinated transition state.

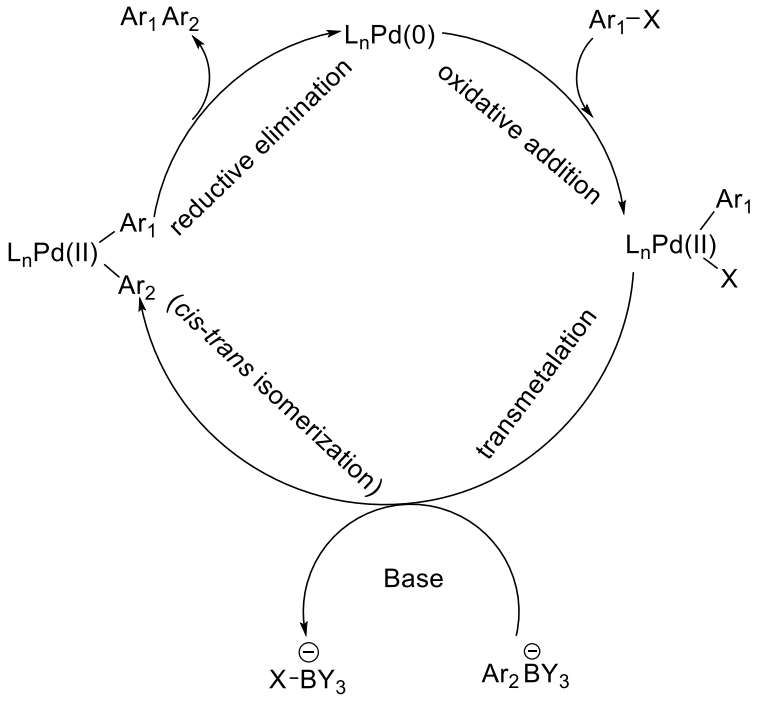


Figure 10: Catalytic cycle of Suzuki-Miyaura cross-coupling reaction.

Variuos polyfunctional biaryls have been synthesized through the D*o*M and cross-coupling sequence.[180] Similarly, the regioisomers of *N*,*N*-diethyl-2-(methylnaphthalenyl)chrysene carboxamides were prepared as discussed in Chapter 5, to use as substrates for the sequential DreM experiments.

2.4 Directed remote metalation

The work of Gschwend, Rodriguez,[181] Snieckus,[81,182] Beak,[183,184] Schlosser,[185,186] and Clayden[187] along with many other researchers have shown the immense scope of directed metalations giving access to an elaborate range

of polycyclic (hetero)aromatic structures. The reaction sequence of D*o*M to pre-functionalize the substrate, followed by cross-coupling and intramolecular cyclization through DreM has previously been applied to synthesize phenanthrenes,[188] benzo[*a*]anthracene,[189] chrysene[190] and other heteroaromatic natural products.[191-193] In this sequence the biaryl derivatives obtained from cross-coupling, can undergo *ortho*-metalation next to DMG in the presence of strong base such as *s*-BuLi and /or low temperatures at −78 °C (Figure 11).[164] For instance, an *in situ* quench experiment of *N*,*N*-diethyl-2-biphenylcarboxamide with premixed LDA and TMSCl at –78 °C afforded *ortho*-silylated product exclusively. However, instead of TMSCl, addition of 0.1 equiv of diisopropylamine (DIIPA) shifted the equilibrium of *ortho*-metalated species towards remote metalation resulting in the formation of fluorenone.[194] The reaction and regioselectivity outcome of directed metalation depends on various factors such as rigidity of the core structure, stability of metalated species, nature and strength of the base, DMG and electrophiles, and reaction pathway (thermodynamic or kinetic) among other parameters.

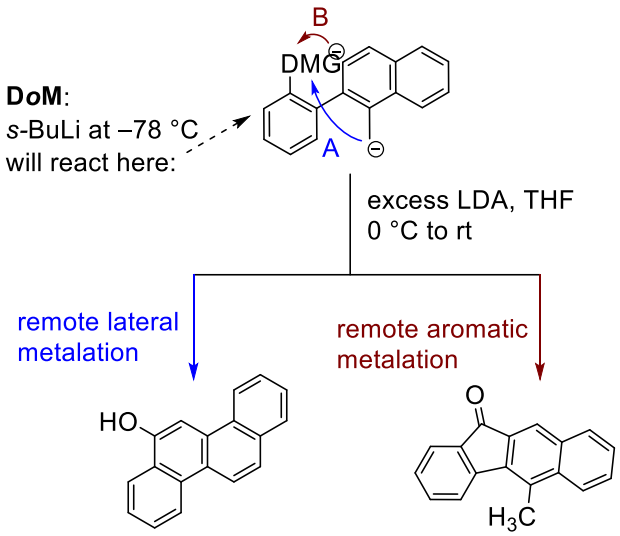
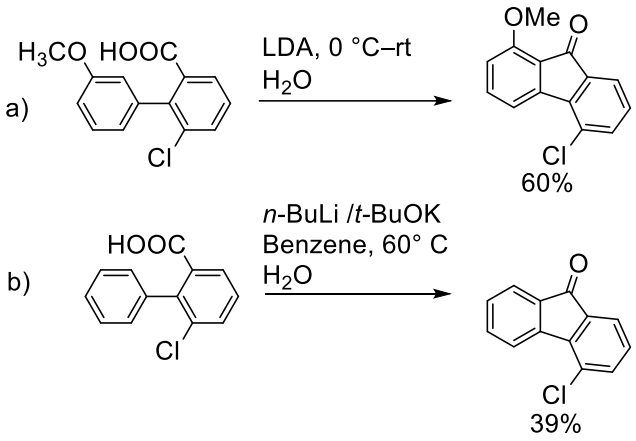


Figure 11: Categories of directed metalation and general reaction conditions.

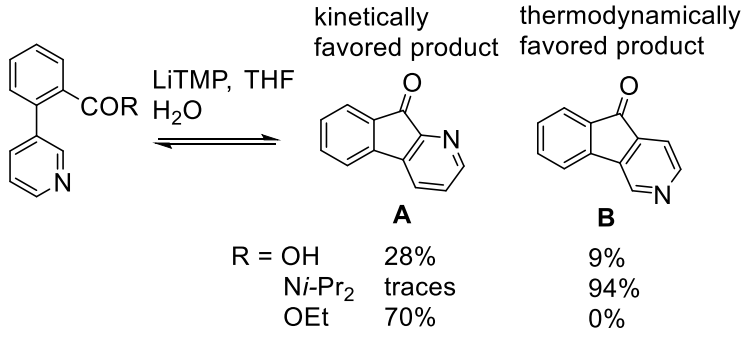
2.4.1 Mechanistic aspects

The possible mechanisms for D*o*M reactions were discussed in Section 2.2.1 explaining the regioselectivity of product formation.[164] However, their direct application to rationalize the regioselective product formation by DreM has been undue with regard to the differences in experimental conditions. When compared to D*o*M, higher temperatures are required for DreM to undergo intramolecular irreversible nucleophilic quenching, where most of the examples were demonstrated at temperatures above −50 °C.[194] Some substrates require even reflux temperatures, for example 6-chloro-2-biphenylcarboxylic acid.[195] Those involving anionic remote Fries rearrangements, with systematically protected *ortho*-sites, occur at 0 °C to rt.[196] In case of DreM, flexibility of the substrate, and irreversible or reversible metalation sites dictates the alterations of mechanisms and thereby optimization of reaction conditions.

While the efficiency of DMG depends on the combination of factors such as electrophilic strength, Lewis basicity, long range acidification and conformational constraints due to steric hindrance at the DMG. The remote protons can also be acidified through inductive effects due to the presence of heteroatom-based proximal substitutents and by coordination of metal bases with these substituents together with DMG (Scheme 13).[195] When the formation of different regioisomers of products is a possibility, the choice of DMG is crucial for regioselectivity.[197] In the given example, COOEt is a strong electrophile compared to CON*i*-Pr_2, while the latter is stronger Lewis base (Scheme 14). Several examples of DreM in the presence of external electrophiles and isomerization of preformed anions have been reported and reviewed.[164]



Scheme 13: Effect of a proximal methoxy substituent on DreM reaction conditions.[195]

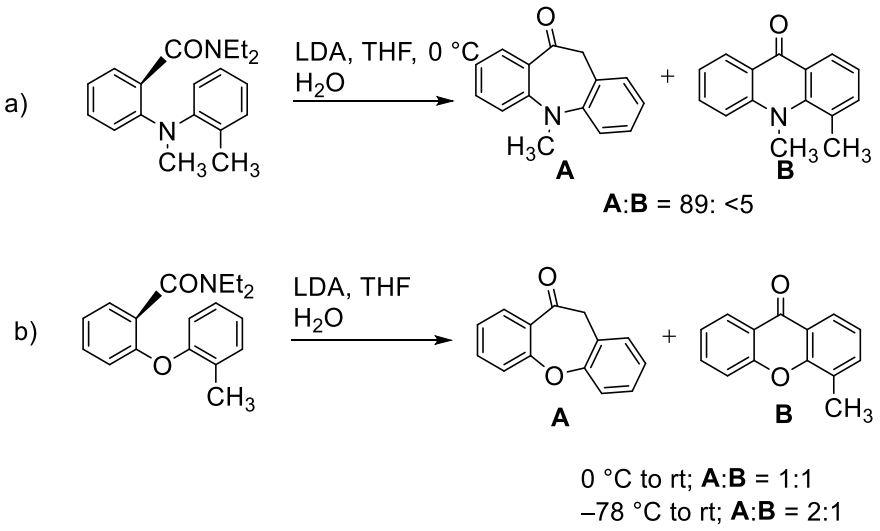


Scheme 14: Effect of DMG on regioselectivity of DreM.[197]

2.4.2 Directed aromatic and lateral metalations

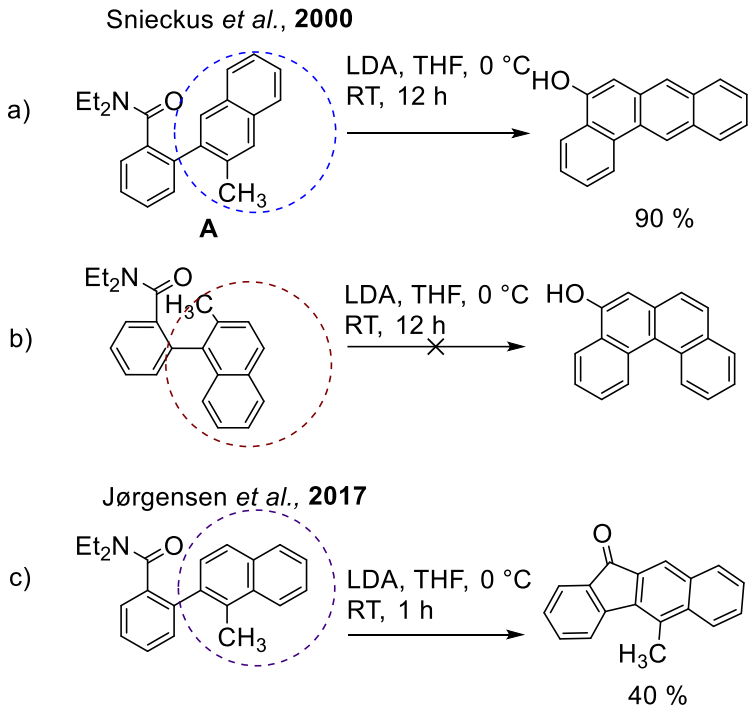
In biarylic substrates having *o*-tolyl moiety DreM is further categorized to aromatic and lateral metalation. Initially, directed aromatic and lateral remote metalations were observed in heteroatom-bridged biaryl substrates (Scheme 15).[198,199] DFT studies have shown that the lateral metalation products are thermodynamically unfavourable and the transition states leading to them are more stable from their enthalpy difference. Henceforth, reduced temperatures are required to achieve lateral metalation. However, the aromatic metalations can be promoted through the presence of second proximal activating group. The

remote metalation on lateral position was explained through CIPE and under kinetic control.[189]



Scheme 15: DreM on N–[199] and O–[198] bridged biaryl *N,N*-diethyl amides.

Similar to DreM in heteroatom-bridged biaryls, the strategy was successfully applied to the synthesis of carbocyclic PAHs as large as phenanthrenes.[200-202] Although, intriguing regioselectivity patterns were obtained by the DreM when the substrates have different regioisomers of methylnapthalenyl moiety, in place of *o*-tolyl moiety. *N,N*-diethyl-2-(3-methylnaphthalen-2-yl)benzamide (Scheme 16a) was found to cyclize to tetraphen-5-ol.[189] However, *N,N*-diethyl-2-(2-methylnaphthalen-1-yl)benzamide (Scheme 16b) failed to undergo intramolecular cyclization under regular DreM (LDA, 0 °C) conditions. In contrast, *N,N*-diethyl-2-(1-methylnaphthalen-2-yl)benzamide (Scheme 16c) resulted in the formation of fluorenone in low yield.[190,203] Previous studies by Jørgensen's research group using variable temperature ^{1}H NMR, EXSY NMR and some computational studies dismissed rotational energy barriers among atropisomers as important for the selectivity in *N,N*-diethyl-2-(methylnaphthalenyl)benzamides.



Scheme 16: Reactivity pattern of DreM in methylnaphthalenyl-benzamides.[189,190,203]

Henceforth, the work was envisaged to extend the DreM strategy towards the syntheses of larger PAHs while studying the reactivity trend and mechanism in the presence of different regioisomers of methylnaphthalenyl moieties in the substrates.

2.5 C─H activation

As a minor off-shoot part of the thesis, functionalization of PAHs through non-directed C─H activation was envisaged. C─H activation is developing as a direct and step-efficient method to make C─C or C─heteroatom bond-connections, compared to the traditional methods of pre-functionalization of the target molecule. Several transition metals are applied as catalysts in these reactions, like Rh, Ir, Cu, Ni, Pd, Pt and Co.[204] Among the many available catalysts, Pd is much favoured because of its ease in handling, tolerance towards slight moisture and air. In the presence of a suitable transition-metal

(TM) catalyst, the C─H bonds in an organic molecule can be activated by two strategies as shown in Figure 12.

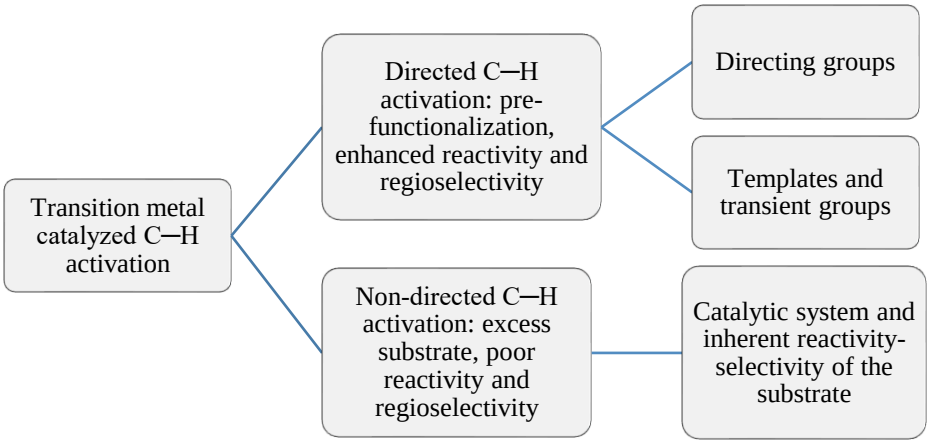


Figure 12: Schematic representation of C─H activation approaches.

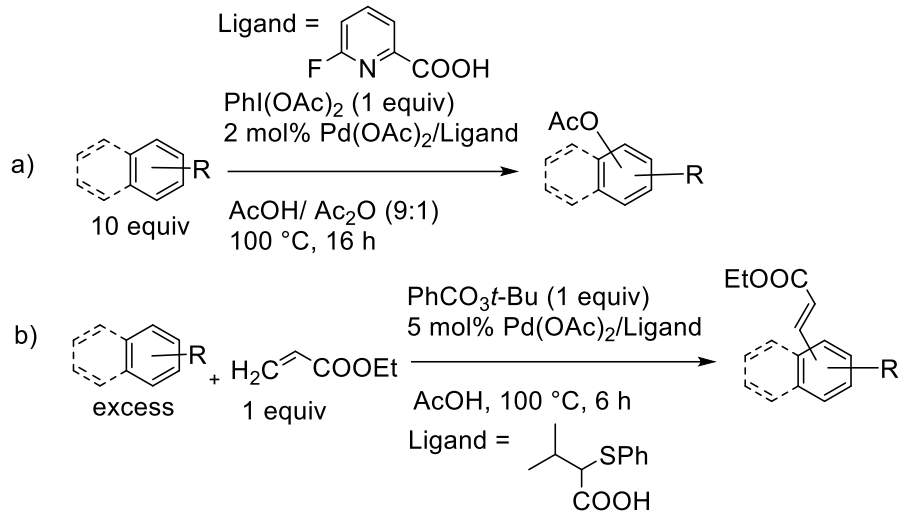
1) *Directed C─H bond activation*: The directing groups, templates or transient groups chelate to the TM and enhance the reactivity-selectivity of the substrate through CIPE.[205] Henceforth, it has been the most studied category of C─H functionalisation. However, sometimes the application of directed C─H functionalisation is limited due to required pre-functionalization, catalyst poisoning and formation of unexpected products.[206]
2) *Non-directed C─H bond activation*: In this category, there is no directing group employed. The reactivity and selectivity of the reaction are governed by the catalytic system and /or by the activating /deactivating groups present on the substrate.[207,208] The present work is focussed on non-directed C─H activation of PAHs since most of developments in this category are limited to benzene and naphthalene derivatives.[102]

2.5.1 Mechanistic aspects

The mechanism of C─H activation is also being studied at large considering the many factors which affect the pathways such as, kind of bond transformation, presence of heteroatoms, catalyst, ligand, solvent and

temperature. Generally depending on the factors, the C─H bond can be activated by any of the four mechanistic pathways: a) oxidative addition, b) σ-bond metathesis, c) electrophilic metalation, and d) concerted metalation–deprotonation (CMD). Taking into account the second reacting partner which can be an organohalide, organometallic species or a simple aromatic hydrocarbon; the reaction can be non-oxidative, oxidative or cross-dehydrogenative transformation.

Among the non-directed C−H activations, acetoxylation is an attractive process for the oxidation of C−H bonds to prepare compounds with many industrial purposes. There are few catalyst systems available to promote the reaction, but they also come with the limitation of poor selectivity. M. Á. Fernández Ibáñez's research group at the University of Amsterdam (UvA) developed the $Pd(OAc)_2$-pyridinecarboxylic acid catalyst system based on a bidentate ligand using $PhI(OAc)_2$ as the oxidant for C─H acetoxylation of simple arenes with high turnover number (TON = 7800) and increased site selectivity (Scheme 17a).[209] Following this research, they have also developed a new class of S, O-ligands, $Pd(OAc)_2$-thioethercarboxylic acid catalyst system, for C─H olefination and allylation of aromatic compounds. It was also efficient in preparative scale and late-stage functionalization of complex molecules (Scheme 17b).[210,211] Henceforth, in collaboration with Fernández Ibáñez's research group, both reactions were attempted on smaller PAHs such as phenanthrene, chrysene, and perylene (Figure 13) to study the reactivity and selectivity when multiple sites are available for the reaction.



Scheme 17: a) Pd-catalysed C─H acetoxylation; [209] b) Pd-catalysed C─H olefination.[210,211]

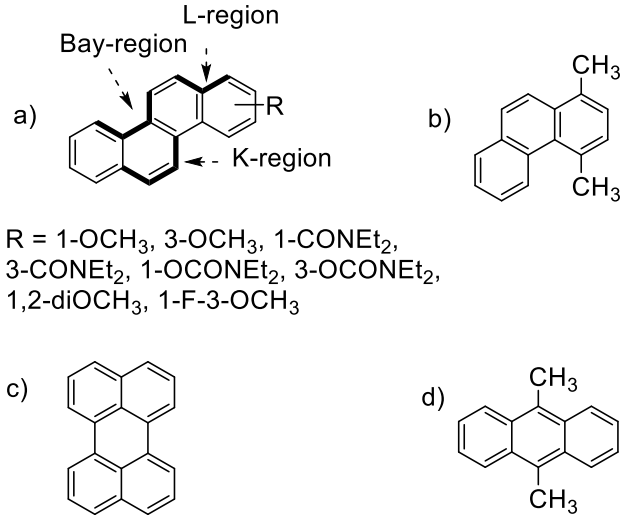


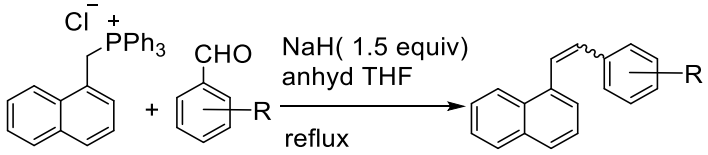
Figure 13: Smaller PAH substrates planned for the C─H activation experiments.

Chapter 3. Preparation of starting materials

Photochemical cyclization of stilbenoid derivatives have been used since several years for the synthesis of phenanthrene and chrysene derivatives.[87,147] The two step strategy, involving Wittig reaction and photocyclization, has proven to be an efficient way for the synthesis of starting materials in gram-scale. There are two literature procedures employed for this work: Mallory approach[135] which involves the use of catalytic amount of iodine in the presence of air and Katz approach[212] which involves the use of stoichiometric amount of iodine along with HI-scavenger under inert atmosphere. In the present chapter, the photochemical synthesis of various phenathrenes and chrysenes derivatives are discussed. The influence of substitutions on the regioselectivity, reaction rate and conditions can be observed.

3.1 Synthesis of chrysene derivatives

The required stilbenoid substrates (mixture of *E* and *Z* isomers) were prepared in the presence of NaH (1.5 equiv) from the corresponding benzaldehyde derivative (1 equiv) and naphthalen-1-yltriphenylphosphonium chloride (1.2 equiv) by the general Wittig reaction in THF (Scheme 18). The stilbenoid substrates were then subjected to Katz conditions using 30 equiv of 1,2-epoxybutane and 1.5 equiv of I_2 in degassed toluene to obtain the photocyclized products (Table 1).[212] For the synthesis of chrysene derivatives, Katz conditions were found to be better in terms of yield and reaction time.



Scheme 18: Wittig reaction to prepare stilbenoid precursors.

The methoxychrysenes (Table 1, entries 1−3) were prepared following the reported procedures.[212] The photocyclization of stilbenoid precursor **3** resulted in a mixture 2-methoxy- and 3-methoxy-chrysenes, which were separated by recrystallization of 2-methoxychrysene (**4**) in acetone. The 3-methoxychrysene

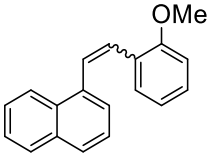
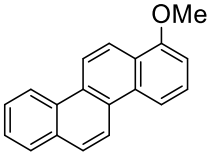
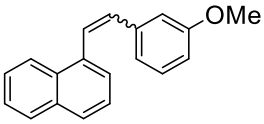
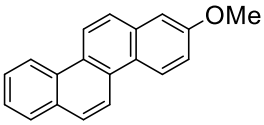
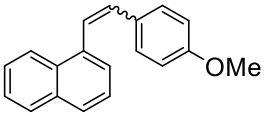
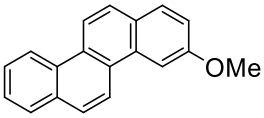
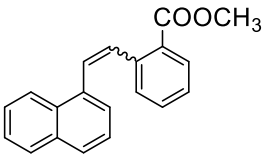
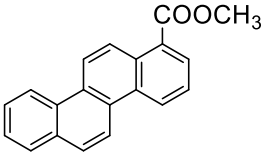
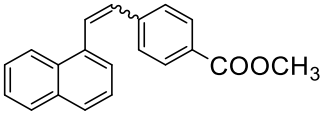
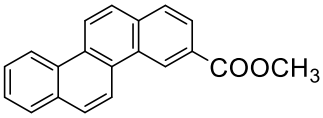
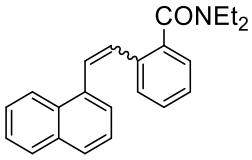
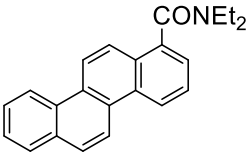
(**6**, entry 3) was obtained in 79% (purified by flash column chromatography) compared to previously reported[212] yield of 42% (recrystallized product).

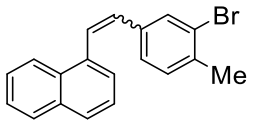
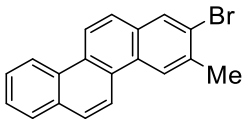
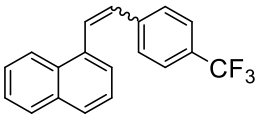
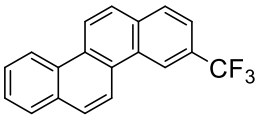
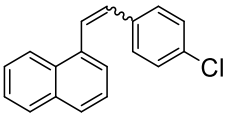
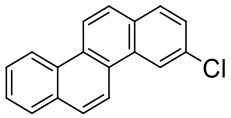
The photocyclization of stilbenoid ester derivatives **7** and **9** (Table 1, entry 4 and 5) showed a major variation in reactivity with regard to the position of ester group on the precursor. The photocyclized product methyl chrysene-1-carboxylate (**8**) was obtained in low yield (48%) compared to methyl chrysene-3-carboxylate (**10**, 11.5 h reaction time, 85% yield). The yield of compound **8** did not improve even after increasing the reaction time from 20 h to 27 h. The position of substituent on the substrate was observed to affect the reactivity. The chrysene-1-yl derivatives such as 1-methoxychrysene (**2**) and **8** (Table 1, entry 1 and 4) were obtained in lower yields when compared to chrysene-3-yl derivatives, **6** and **10** (entry 3 and 5) respectively.

The photocyclization of *N*,*N*-diethylamide substituted stilbenoid derivative (**11**) is also a suitable approach to obtain chrysen-1-yl-*N*,*N*-diethyl amide (**12**, Table 1, entry 6) considering the overnight reaction time and good yield. However, the stilbenoid substrate for the synthesis of chrysene-3-yl-*N*,*N*-diethyl amide was not prepared from the corresponding *N*,*N*-diethyl-4-formylbenzamide. The required *N*,*N*-diethyl-4-formylbenzamide (commercially expensive) was obtained in low yield (27%) from 4-formylbenzoic acid.

The photocyclization of 1-(3-bromo-4-methylstyryl)naphthalene (**13**) did not proceed to completion despite increasing the amount of I_2 from 1.5 equiv to 3 equiv. The reaction mixture turned from dark pink to yellow in both the experiments indicating the complete consumption of I_2 in 24 h. The corresponding stilbenoid precursor **13** was recovered from both the experiments. Formation of traces of debrominated substrate was also observed from the NMR. 3-(trifluormethyl)chrysene (**16**, Table 1, entry 8) and 3-chlorochrysene (**18**, entry 9) were obtained in comparable yields using Katz conditions, while the photochemical synthesis of the compound **18** was reported previously by Mallory in 70% yield.[141]

Table 1: Synthesis of substituted chrysene derivatives by photocyclization.

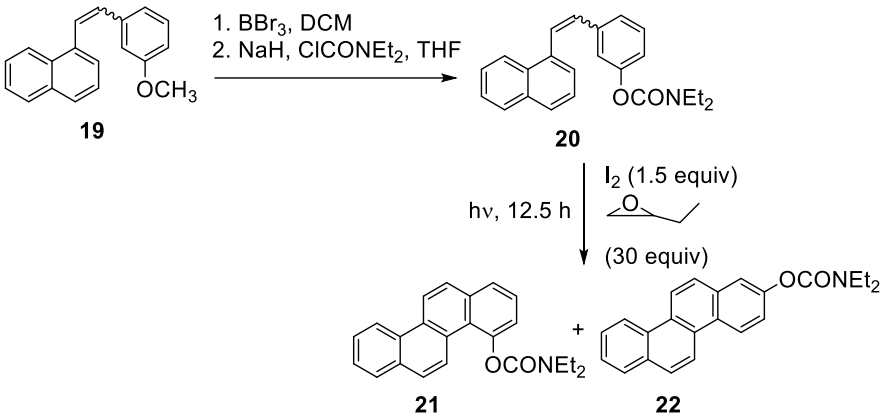
Entry	Stilbenoid precursors[a]	Photocyclized products[b]
1[212]	 **1.** quant	 **2.** 40%
2[212]	 **3.** 98%	 **4.** 32%
3[212]	 **5.** quant	 **6.** 79%
4	 **7.** 79%	 **8.** 48%
5	 **9.** 88%	 **10.** 85%
6	 **11**	 **12.** 55%

Entry	Stilbenoid precursors[a]	Photocyclized products[b]
7	 **13.** quant	 **14.** 57%
8	 **15.** 98%	 **16.** 71%
9	 **17.** quant	 **18.** 63%

[a] Aromatic aldehyde (1 equiv), Wittig salt (1.2 equiv), NaH (1.5 equiv), THF, reflux; [b] Katz conditions: stilbenoid precursor (1 equiv), 1,2-epoxybutane (30 equiv), I_2 (1.5−3 equiv).

3.1.1 Attempts to synthesize chrysen-4-yl *N*,*N*-diethyl O-carbamate

The 1-(3-methoxystyryl)naphthalene (**19**) obtained by following the general Wittig reaction (Scheme 18), was deprotected by adding BBr_3 in DCM at 0 °C and the reaction mixture was stirred at rt for 21 h. The crude phenolic derivative was treated with a suspension of NaH in THF at 0 °C and then with *N*,*N*-diethyl carbamoyl chloride at rt for 21 h to obtain compound **20** in 59% yield. The stilbenoid substrate **20** was photocyclised by Katz conditions to furnish a mixture of chrysen-4-yl-*N*,*N*-diethyl-*O*-carbamate (**21**) and chrysen-2-yl-*N*,*N*-diethyl-*O*-carbamate (**22**) in the ratio 3:7 and 68% total yield (Scheme 19). The steric factors were reported to influence regioselectivity and reactivity of photocyclization.[147] Similarly, the presence of a bulky carbamate group influenced the regioselelctivity by forming **22** as the major product.



Scheme 19: Attempt to synthesize chrysene-4-yl-*N*,*N*-diethyl-*O*-carbamate.

For an ongoing collaboration with Prof. Daniel Gryko's group at the Institute of Organic Chemistry (Polish Academy of Sciences, Poland), Dr. Olena Vakuliuk attempted D*o*M and photocylization in Jørgensen's laboratory towards the total syntheses of diketopyrrolopyrrole dyes (CHAOS Cost Action 15106 STSM project, Figure 14) and PhD candidate Krzysztof Gutkowski attempted photocyclizations to synthesize dihydropyrrolo[3,2-*b*]pyrrole dyes (CHAOS Cost Action 15106 STSM project, Scheme 23a) respectively.

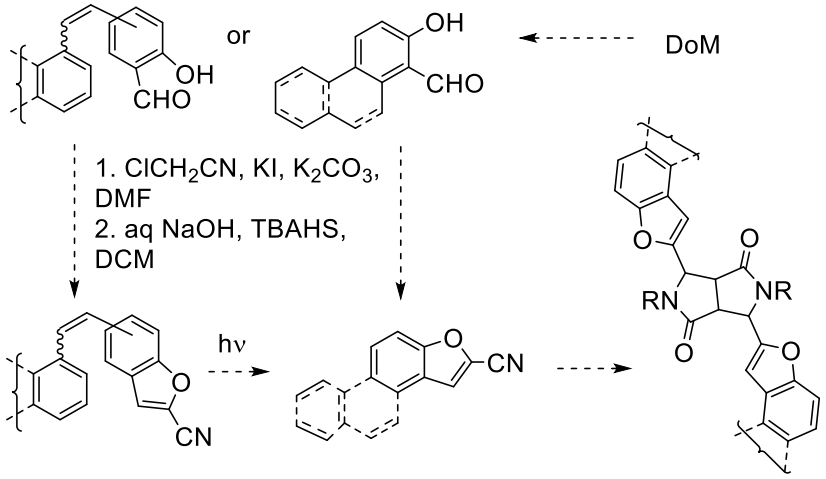
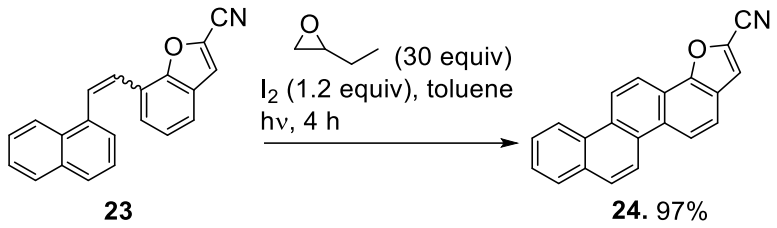


Figure 14: Schematic outline of the planned synthesis diketopyrrolopyrrole dyes.

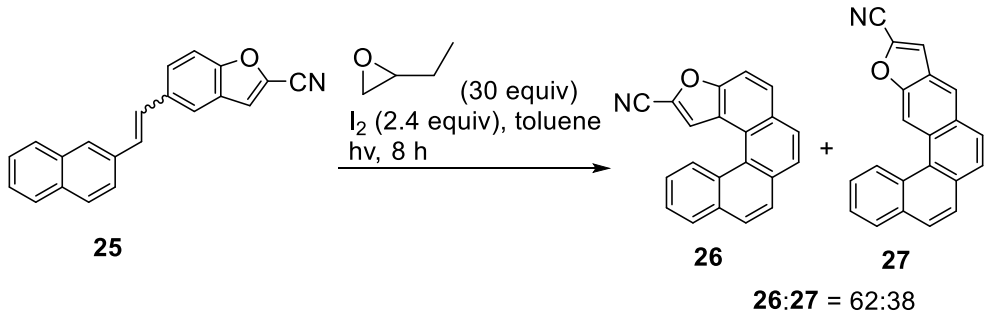
To continue this collaborative study towards the synthesis of diketopyrrolopyrrole dyes, a set of three stilbenoid derivatives bearing furan-2-carbonitrile group were subjected to Katz conditions of photocyclization. The compound chryseno[1,2-*b*]furan-2-carbonitrile (**24**) was obtained without any side-products from its corresponding precursor 7-(2-(naphthalen-1-yl)vinyl)benzofuran-2-carbonitrile (**23**, Scheme 20). Notably, the new C─C bond formed during photocyclization did not involve the *peri* position but cyclized at the *ortho* position on the 1-naphthalene moiety. The end product was highly insoluble for purification and characterization. The soluble impurities were removed by washing the crude product with EtOAc to obtain a white solid product in 97% yield.



23 **24**. 97%

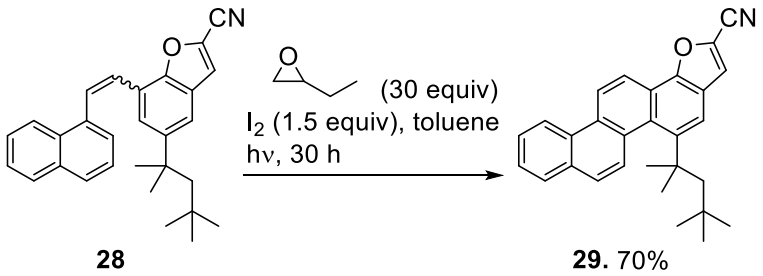
Scheme 20: Synthesis of stilbenoid derivative **23**.

The stilbenoid substrate 5-(2-(naphthalen-2-yl)vinyl)benzofuran-2-carbonitrile (**25**) has two competing *ortho* sites for photocyclization on benzofuran-2-carbonitrile moiety and as expected led to the formation of a mixture of two products in the ratio 62:38, which were separated using column chromatography (Scheme 21). Simultaneously, there were also two *ortho* positions available for photocyclization on the 2-naphthalenyl moiety in **25**. However, the reaction is strictly biased towards the 1-position rather than 3-position on the naphthalene ring, which is in agreement with the previous observations on 3-methoxy-2-styrylnapthalene by Mallory and co-workers.[213] The oxidative photocyclization prefers the formation of thermodynamically stable products.[214] Introduction of strategically placed blocking groups such as chloro might change the regioselectivity of such reaction.[215] The reaction was comparatively slower than the previous experiment (**23** → **24**).



Scheme 21: Photocyclization of stilbenoid precursor **25**.

The third stilbenoid substrate 7-(2-(naphthalen-1-yl)vinyl)-5-(2,4,4-trimethylpentan-2-yl)benzofuran-2-carbonitrile (**28**), which has an additional aliphatic chain on it when compared to the substrate **23**, formed the expected product 5-(2,4,4-trimethylpentan-2-yl)chryseno[1,2-*b*]furan-2-carbonitrile (**29**) in 70% yield (Scheme 22). The photocyclised product **29** with the aliphatic chain has better solubility in organic solvents than the compound **24**. However, the aliphatic group seemed to affect the reactivity considerably demanding longer reaction time for completion and affording comparatively lower yield.

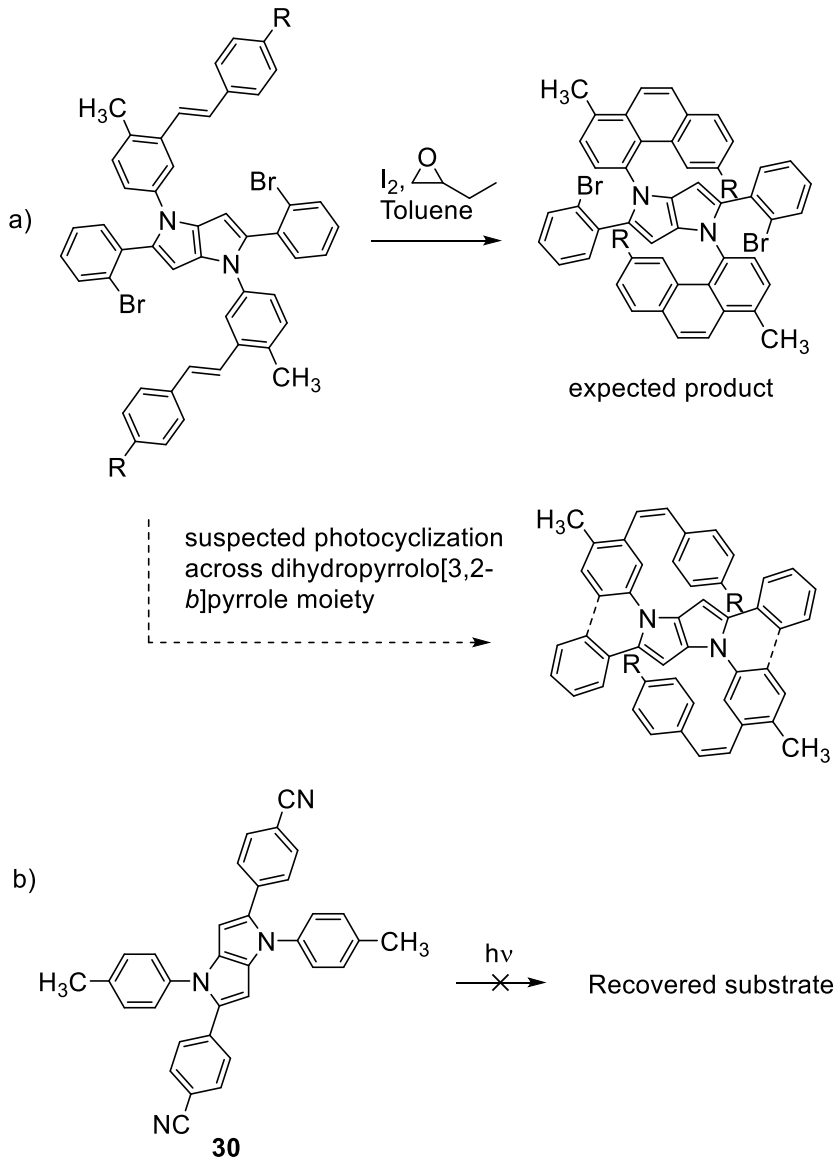


Scheme 22: Photocyclization of stilbenoid derivative **28**.

During the syntheses of pyrrolo[3,2-*b*]pyrrole dyes through photocyclization as one of the steps, PhD candidate Krzysztof Gutkowski did not obtain the expected product nor recovered the substrate, as shown in Scheme 23a. The unexpected formation of photocyclization bond across dihydropyrrolo[3,2-*b*]pyrrole moiety was suspected. Further, the presence of Br is yet to be confirmed from complex NMR spectra and HRMS, inorder to conclude the preferable site of unexpected bond formation on the aromatic ring.

Nevertheless, the pathway followed during a usual photocyclization reaction shows the involvement of a styryl double bond to afford the photocyclized product. The mechanism involves the formation of bi-radicals in the excited singlet state of the *Z*-isomer by breaking the styryl double bond before photocyclization (Section 2.1.1, Figure 7).

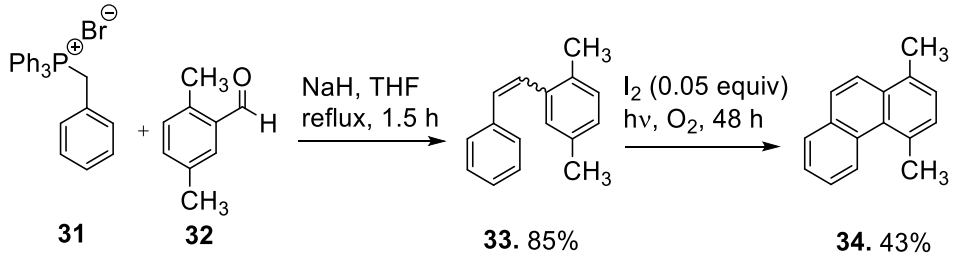
To support the collaboration study by checking the possibility of photocyclization across pyrrolo[3,2-*b*]pyrrole moiety in non-stilbene based substrates, 4,4'-(1,4-di-*p*-tolyl-1,4-dihydropyrrolo[3,2-*b*]pyrrole-2,5-diyl)dibenzonitrile (**30**) was subjected to oxidative photocyclization (Scheme 23b). The substrate did not react using Mallory nor Katz conditions. It might be possible that the double bond or the lone pair in the electron-rich dihydropyrrolo[3,2-*b*]pyrrole moiety are not sufficiently similar to the classical styryl double bond for the occurrence of oxidative photocyclization across dihydropyrrolopyrrole. Further, the role of molecular orbitals involved in the reaction can not be ruled out. Previous studies have reported several unsuccessful photocyclizations in which the stilbene substrates at first excited state have a sum of free valence indices less than unity.[216] Therefore, it is also important to understand the role of molecular orbitals to rationalize the unsuccessful attempt to photocyclize compound **30**.



Scheme 23: a) Experimental work done by PhD candidate Krzysztof Gutkowski (CHAOS Cost Action 15106 STSM project) to synthesize dpp dyes; b) Photocyclization of 4,4'-(1,4-di-*p*-tolyl-1,4-dihydropyrrolo[3,2-*b*]pyrrole-2,5-diyl)dibenzonitrile.

3.2 Synthesis of phenanthrene derivatives

1,4-Dimethyl phenanthrene (**34**) was required to conduct the crude oil toxicity studies on different stages of marine life by Lisbet Sørensen and Sonnich Meier at the Institute of Marine Research (IMR, Bergen, Norway) and John Incardona at NOAA Fisheries (Seattle, the U.S.A.). The compound was also requested for an RCN project 267829: EGGTOX project and Assoc. Prof. Odd André Carlsen at the University of Bergen. For these collaborations, 1,4-dimethyl-2-styrylbenzene (**33**) was prepared from a simple Wittig reaction in 85% yield as shown in Scheme 24. The stilbene **33** was then subjected to Mallory conditions to obtain **34** (^{1}H-NMR, Figure 15) and showed good conversion on TLC. However, there were some photo-oxidative side reactions taking place in the reaction mixture resulting in the formation of impurities.[148] The highly non-polar end-product was inseparable from these impurities using flash column chromatography and hence was purified by distillation under reduced pressure to afford 43% yield. The photocyclization conditions were later on improved by students in our group using TEMPO.



Scheme 24: Photochemical synthesis of **34**.

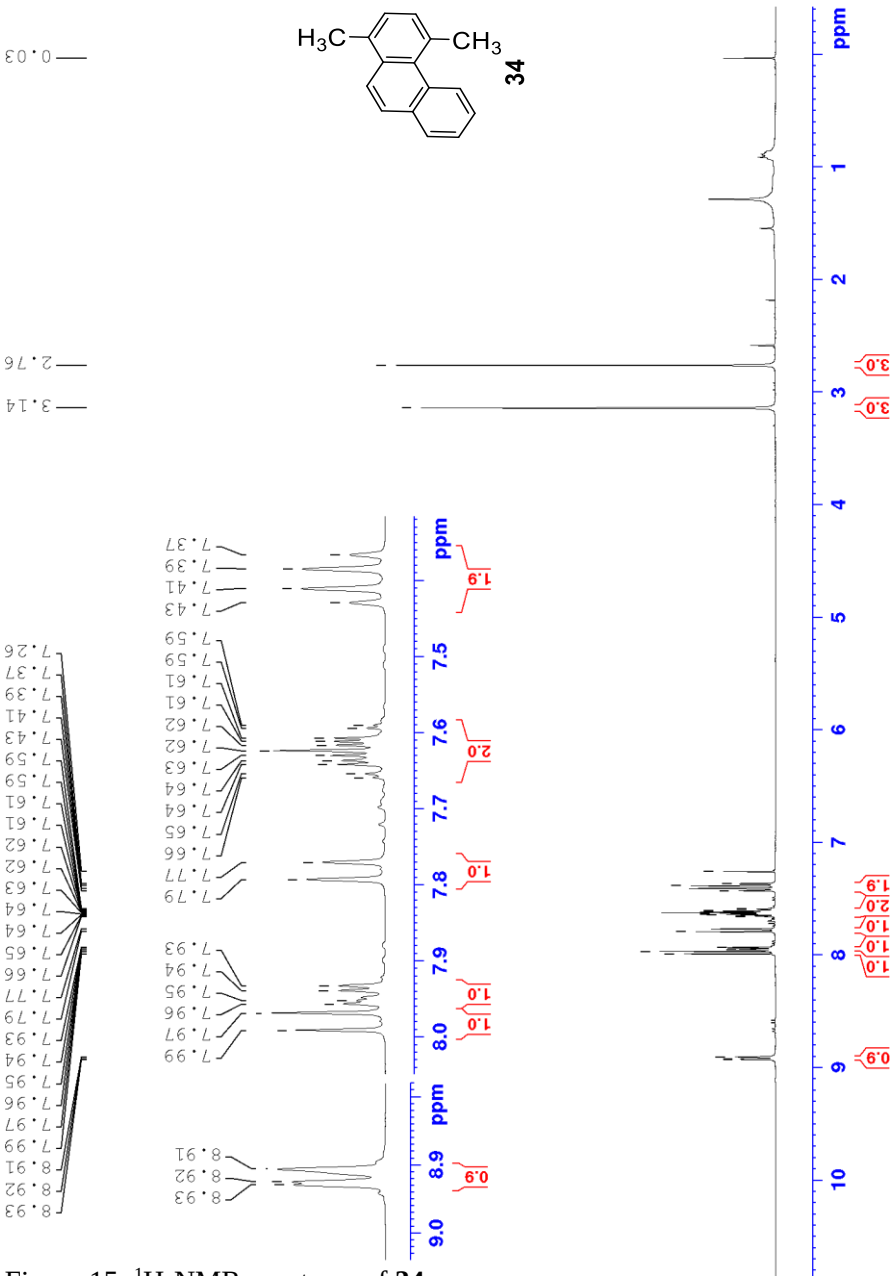
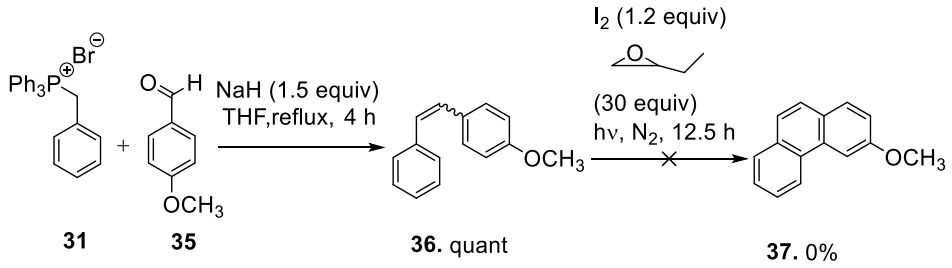


Figure 15: ^{1}H-NMR spectrum of **34**.

Similary, 1-methoxy-4-styrylbenzene (**36**) was prepared in quantitative yield as a mixure of *Z* and *E* configurations by Wittig reaction. However, the photocyclization of the stilbene **36** was unsuccessful using Katz conditions in toluene and resulted in the recovery of starting material as *E* isomer (Scheme 25). In a different experiment, the reaction mixture was irraditiated for 16 h with TEMPO (5 equiv) under N_2 atmosphere in cyclohexane:toluene (3:1; 1-methoxystilbene was insoluble in cyclohexane at rt). It was highly difficult to separate TEMPO from the crude reaction mixture either by washing with 0.5 M HCl, 0.1 M NaOH separately or by column chromatography eluting with pure heptane. The photocyclization of compound **36** was also attempted with KI (2.90 equiv) under an atmosphere of air in toluene, irradiated for 16 h but led to the recovery of starting material. In this case, using toluene as solvent could have impeded the photocyclization. The substrate **36** was reportedly photocyclised using Mallory conditions in cyclohexane to obtain 42% of recrystallized product.[135] It was also obtained in good yields, 50% using KI (1 equiv) or 80% using K_2CO_3 (10 equiv) in cyclohexane under an atmosphere of air.[149]



Scheme 25: Attempt to synthesize **37**.

3.3 Conclusions

The oxidative photocylization was used as an efficient approach to prepare PAH derivatives in gram-scale, which are used in further experiments discussed in Chapters 4−7. Additionally, some of the factors affecting the oxidative photocyclization of stilbenes and stilbenoid derivatives were discussed. The relative difference in the yields of formation of chrysene-1-yl (**2**, **8**) and chrysene-3-yl derivatives (**6**, **10**) was observed due to the variation in the positions of substitutions on the stilbenoid substrates. The presence of bulky

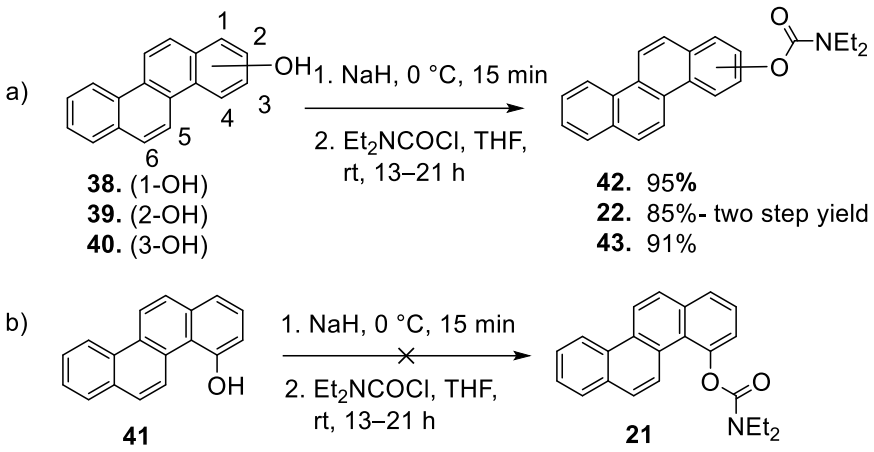
group such as *N*,*N*-diethyl-*O*-carbamate affected the regioselectivity in the product formation, as observed in Scheme 19 affording **22** as the major product. The oxidative photocyclization gave preference to the formation of thermodynamic product as observed in case of compounds **26** and **27**, which is in agreement with the literature. The presence of an aliphatic chain in the stilbenoid compound **28** considerably slowed down the photocyclization, even though it improved the solubility of the end-product **29** in organic solvents when compared with **24**. The photocyclized product **34** was sent for toxicology studies in fish. The pivotal role of the solvent in product formation was seen in an unsuccessful attempt to synthesize **37**.

Chapter 4. D*o*M of chrysenyl derivatives

As discussed in Section 2.2, D*o*M has been an efficient method to attain regioselective functionalization of aromatic compounds such as benzenes and naphthalenes.[81,162] The scope of this approach has been extended to few PAHs namely, pyrene-1-carboxaldehyde (Section 2.2, Scheme 12)[161] and pyrene-1-carboxamide.[163] The D*o*M experiments on chrysenyl carbamates were started by a previous PhD in the group, Dr. Marianne Lorentzen.[203] The work with chrysenyl carbamates was continued using more electrophiles. The effect on regioselectivity of D*o*M in the presence multiple sites of reaction and different Li-bases was studied. The approach was also employed to install substitutions on chrysenyl carboxamides. The effect of changing DMG, from carbamate to carboxamide, on the regioselectivity of D*o*M experiments in chrysenes was observed. The required carbamates and carboxamides were obtained from the methoxychrysenes (Chapter 3, Table 1, entries 1−3) and chrysene carboxylates (Chapter 3, Table 1, entries 4−6).

4.1 D*o*M on chrysenyl carbamates

The 1-, 2- and 3-methoxy chrysenes (**2**, **4** and **6**) prepared from photochemical cyclization of the corresponding stilbenoid derivatives (Section 3.1, Table 1) were subjected to deprotection and functional group conversion to *N*,*N*-diethyl-*O*-carbamate in excellent yields.[203] The 4-methoxychrysene, obtained in the same photocyclization reaction as a mixture of isomers and separated from **4** (Section 3.1, Table 1, entry 2), was deprotected using BBr_3 in DCM at 0 °C and stirred at rt. The general procedure followed to prepare the isomers of chrysenyl-*N*,*N*-diethyl-*O*-carbamates from the corresponding chrysenols (Scheme 26) did not yield the compound **21**, possibly due to the steric crowding in the bay region and bulkiness of the DMG.

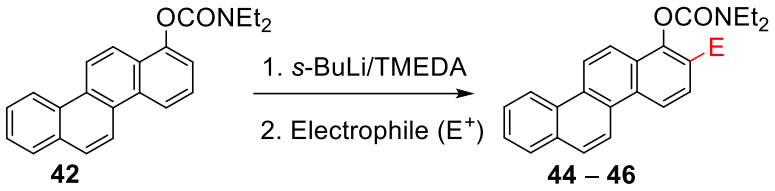


Scheme 26: Syntheses of chrysenyl carbamates from chrysenols.

D*o*M experiments under standard metalation conditions (*s*-BuLi /TMEDA, 30 min) using various electrophiles were subsequently conducted on the available three regioisomers of chrysenyl *N*,*N*-diethyl-*O*-carbamates. The results of these experiments are presented below in Tables 2−4.

As presented in Table 2, chrysene-1-yl *N*,*N*-diethyl-*O*-carbamate (**42**) upon metalation with *s*-BuLi turns dark yellow in color and afforded substituted products (**44**−**46**) in excellent to modest yields upon quenching with corresponding electrophiles. All the reactions were considerably fast needing only 3 to 4 h of reaction time after the addition of electrophiles. Addition of MeI to metalated substrate, changes the color to pale yellow. The addition of MeI was done a bit faster considering the reported formation of ethyl derivative due to competitive quenching of methyl anion of product.[188] Otherwise the rate of electrophile addition is adjusted so as to keep the temperature below -73 °C. During the addition of electrophile, the temperature of reaction mixture was monitored constantly using a thermometer. The optimization experiments using 1.1 equiv of *s*-BuLi /TMEDA (as reported in previous PhD thesis[203] and suitable for TMSCl, I_2, Br_2, C_2Cl_6) afforded the product **44** in 41% yield, **45** in 81%, **46** in 35% yield. Increasing the amount of base to 2 equiv also improved the yield significantly (Table 2). When the metalated substrate was quenched with DMF, decarbamoylation occurred to give 2-(hydroxy)chrysene-1-carbaldehyde (**46**, entry 3) probably by an *in situ* generated amine base.

Table 2: D*o*M reactions of Chrysene-1-yl *N*,*N*-diethyl-*O*-carbamates (**42**).



Entry	E^+	Product	E	Yield %
1[a]	MeI	**44**	Me	quant.
2[a]	Et_2NCOCl	**45**	$CONEt_2$	88
3[a]	DMF	**46**	CHO[b]	65

[a] 1) *s*-BuLi /TMEDA (2 equiv), −95 °C, 15 min; 2) E^+ (3 equiv), −85 °C to rt, 3 to 4 h; [b] Decarbamoylation occurred during the reaction with DMF to give the chrysenol derivative.

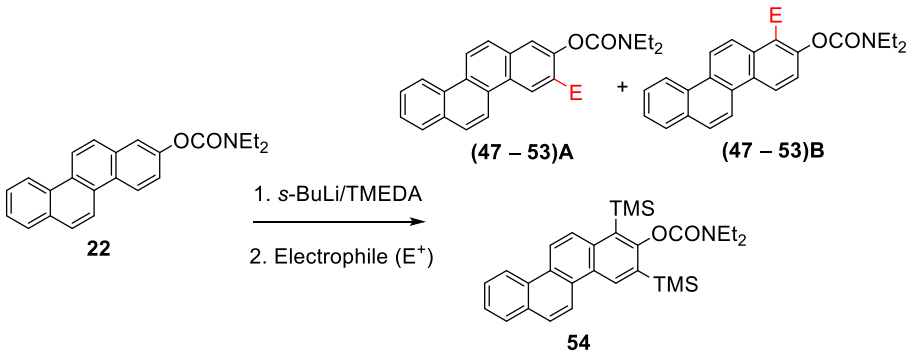
Previous reports have shown the possibility of *peri*-lithiation on 1-napthylamine along with *ortho*-substituted product.[217] However, there were no *peri*-substituted (C-12) products observed in the present work. A plausible reason for the absence of *peri*-lithiation could be the rotational orientation of DMG (steric factor) and the difference in the acidity of C-2 (electronic effect of DMG) and C-12 (*peri*) protons. Infact, ^{7}Li-^{1}H HOESY NMR studies of complexes of lithiated 1-naphthol have shown that the peri (C-8) hydrogen is in closer proximity to the prelithiated complex than C-2 hydrogen and exhibits a stronger agostic interaction with the alkyl lithium base.[218] However, attempts to *peri*-lithiate 1-napthamide [219] and 1-methoxynapthalenes[220] were either futile or gave low yields affording kinetic product or mostly *ortho*-substitution, in the presence of stronger DMG.

Similar to the D*o*M experiments conducted on compound **42**, chrysen-2-yl *N*,*N*-diethyl-*O*-carbamate (**22**) was subjected to the same reaction conditions as shown in Table 3. The experiments in Table 3, entry 1 and 3−5, were reproduced to reassign the ratio of regioisomeric products A:B.[203] Using 1.1 equiv base and 1.5 equiv DMF afforded **53** in 37% yield. In case of $ClCONEt_2$ and MeI, using 1.1 equiv base with 3 equiv of electrophile resulted **52** in 70% yield and **51** in 52% yield respectively. Henceforth, in view of the improved

yield and shorter reaction time, the reaction conditions were optimized as shown in Table 3. With the availability of two competing *ortho*-sites for metalation, a mixture of two regioisomeric products was obtained in all cases except with TMSCl. Rationalization of minor regioselectivity observed in the electrophilic substitution at C-1 and C-3 positions in entries 3-6 based on steric effects is complicated taking into account the high complexity of organolithium reactions involving lithium aggregates[221] and undefined mechanism.[182,222,223] Rate of substitution of lithiated species might be competitive due to exchange with alternate deprotonation sites as a function of electrophile. At the same time, the wide difference in the ratio of **52** (**A**:**B**) and **53** (**A**:**B**) with Et_2NCOCl (entry 7) and DMF (entry 8) respectively can be elucidated based on steric effects.

By virtue of the base-electrophiles *in situ* compatibility, D*o*M experiments with TMSCl were conducted under Martin condition.[224] Using 1.1 equiv of base and 1.5 equiv of TMSCl afforded a single isomer of mono-silylated product **47A** in 27% NMR yield (Table 3, entry 1). Upon increasing the amount of base to 2.5 equiv and TMSCl to 3 equiv, the experiment resulted in the formationof a di-silylated product **54** (entry 2). In contrast, excess of base followed by quench with excess electrophile in entries 6−8 led to monosubstituted products. The formation of **54** can be interpreted by a sequential deprotonation-silylation pathway in which decomposition of electrophile is sufficiently slow to facilitate double silylation at C-1 and C-3 positions.[81] This result is similar to that accomplished in benzamide[81,225,226] and naphthyl-2-*N*,*N*-diethyl-*O*-carbamate[162] and might have synthetic value.

Table 3: DoM reactions on chrysene-2-yl *N*,*N*-diethyl-*O*-carbamate (**22**).



Entry	E^+	Product	E	Yield % (Ratio A:B)[a]
1[b,c]	TMSCl	**47 (A:B)**	TMS	27 (100 : 0)[d]
2[c,e]	TMSCl	**54**	1,3-di-TMS	98%
3[b]	I_2	**48 (A:B)**	I	68 (57 : 43)
4[b]	Br_2	**49 (A:B)**	Br	67 (56 : 44)
5[b]	C_2Cl_6	**50 (A:B)**	Cl	96 (59 : 41)
6[f]	MeI	**51 (A:B)**	Me	79 (54 : 46)
7[f]	Et_2NCOCl	**52 (A:B)**	$CONEt_2$	70 (75 : 25)
8[f]	DMF	**53 (A:B)**	CHO[g]	64 (68 : 32)
9[h]	I_2	**48 (A:B)**	I	89 (100 : 0)

[a] The products were isolated as mixture of two isomers and their ratio was determined by NMR analysis; [b] 1) *s*-BuLi /TMEDA (1.1 equiv), −78 °C, 30 min; 2) E^+ (1.5 equiv), −78 °C to rt, 1.5-18 h; [c] TMSCl was added to the reaction mixture before *s*-BuLi; [d] yield by NMR analysis; [e] *s*-BuLi /TMEDA (2.5 equiv), TMSCl (3 equiv); [f] 1) *s*-BuLi /TMEDA (2 equiv), −95 °C, 15 min; 2) E^+ (3 equiv), −85 °C to rt, 3-4 h; [g] Decarbamoylation occurred during reaction with DMF to give the chrysenol derivative; [h] 1) LiTMP (3 equiv), −78 °C, 1.5 h, 2) I_2 (3 equiv), −78 °C to rt, 5.5 h.

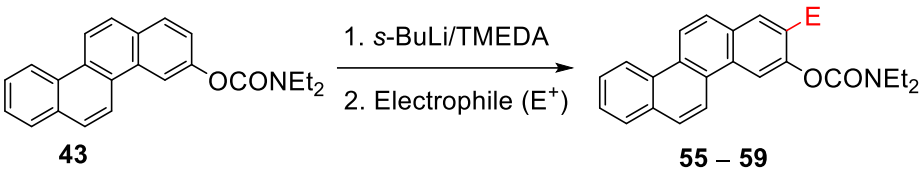
The C-1 and C-3 regioselectivity in substrates like **22** can be achieved by using a more sterically demanding base such as LiTMP for metalation. To

demonstrate it, metalation of **22** was conducted with LiTMP followed by electrophilic quench with I_2 that afforded 3-iodochrysen-2-yl *N*,*N*-diethyl-*O*-carbamate (**48A**) as a single regioisomer in 89% yield (Table 3, entry 9). The observed result was analogous with the selectivity observed in experiments conducted on naphthyl 2-carbamate.[162]

The D*o*M reaction on **42** and **22** was also attempted with electrophiles such as dibromoethane, benzaldehyde, *p*-nitrobenzaldehyde, 2-methoxyethoxymethyl chloride and 2-methylbenzyl chloride. These experiments did not yield the expected products but led to the recovery of unreacted starting materials. While benzaldehyde was previously used as an electrophile on benzyl[81] and napthyl carbamates,[81,162] however, it seemed to be unreactive with chrysenyl carbamates.

With chrysene-3-yl *N*,*N*-diethyl-*O*-carbamate (**43**) the reaction conditions were optimized after some trials. In case of Br_2 and C_2Cl_6, using 1.1 equiv of base and 1.5 equiv of electrophile was suitable. At the same time, 1.5 equiv base and 3 equiv MeI afforded the product **57** in 88% yield. Henceforth, in the Table 4, entries 3−5, 2 equiv of base and 3 equiv of electrophile were used to afford good yields and shorter reaction time. The substrate **43** also has two competing sites and was subjected to similar *ortho*-metalation experiments as discussed for the other substrates. Unlike **22**, complete regioselective products were formed in these experiments with **43** (Table 4). The regioselectivity was in accordance with the expected steric crowding in the bay-region of the substrate.[95,227] D*o*M experiments with Br_2 (entry 1) needed carefully controlled addition of electrophile to avoid formation of dibrominated product (confirmed by HRMS analysis) along with a complex mixture of side products.

Table 4: DoM reactions on chrysene-3-yl *N*,*N*-diethyl-*O*-carbamate (**43**).



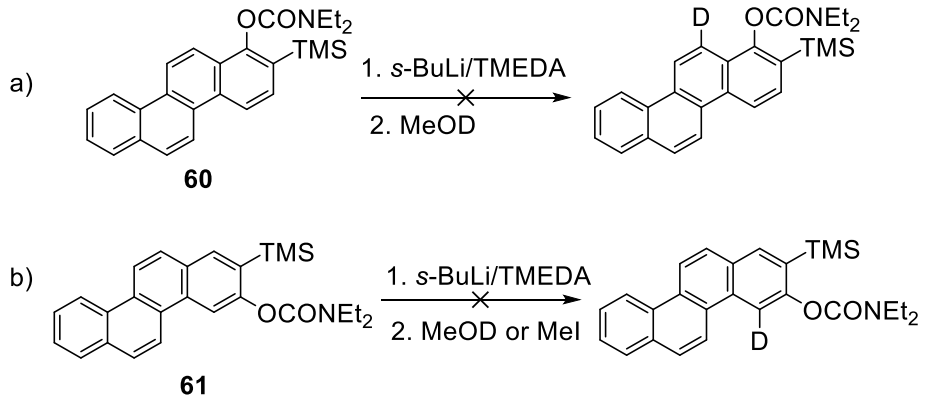
43 **55 – 59**

Entry	E^+	Product	E	Yield %
1[a]	Br_2	**55**	Br	57[b]
2[a]	C_2Cl_6	**56**	Cl	70[b]
3[c]	MeI	**57**	Me	96
4[c]	Et_2NCOCl	**58**	$CONEt_2$	88
5[c]	DMF	**59**	CHO[d]	72

[a] 1) *s*-BuLi /TMEDA (1.1 equiv), −78 °C, 30 min; 2) E^+ (1.5 equiv), −78 °C to rt, 1.5 h to 18 h; [b] Yield by NMR analysis; [c] 1) *s*-BuLi /TMEDA (2 equiv), −95 °C, 15 min; 2) E^+ (3 equiv), −85 °C to rt, 3 to 4 h; [d] Decarbamoylation occurred during reaction with DMF to give the chrysenol derivative.

In situ quench (ISQ) experiments

In an attempt to allow *peri*-lithiation, the *ortho*-position in substrate **60** was blocked with TMS group,[225,228] and then subjected to a second metalation-deuterium sequence (Scheme 27a). Interpretation of data from ^{1}H-NMR[203] and HRMS concluded the recovery of starting material. The interpretation was in agreement with previous reports of naphthalene derivatives.[219,220] The unsuccessful *peri*-lithiation attempt is possibly indicating the inability to attain a high population of the suitable rotamer, where carbonyl is oriented towards the *peri*-proton, resulting in deprotonation. Similarly, attempts to facilitate C-4 metalation of **61** when the C-2 position was blocked with TMS, also turned futile with recovery of starting material when MeOD or MeI were used as electrophiles (Scheme 27b, confirmed from NMR and HRMS analysis).



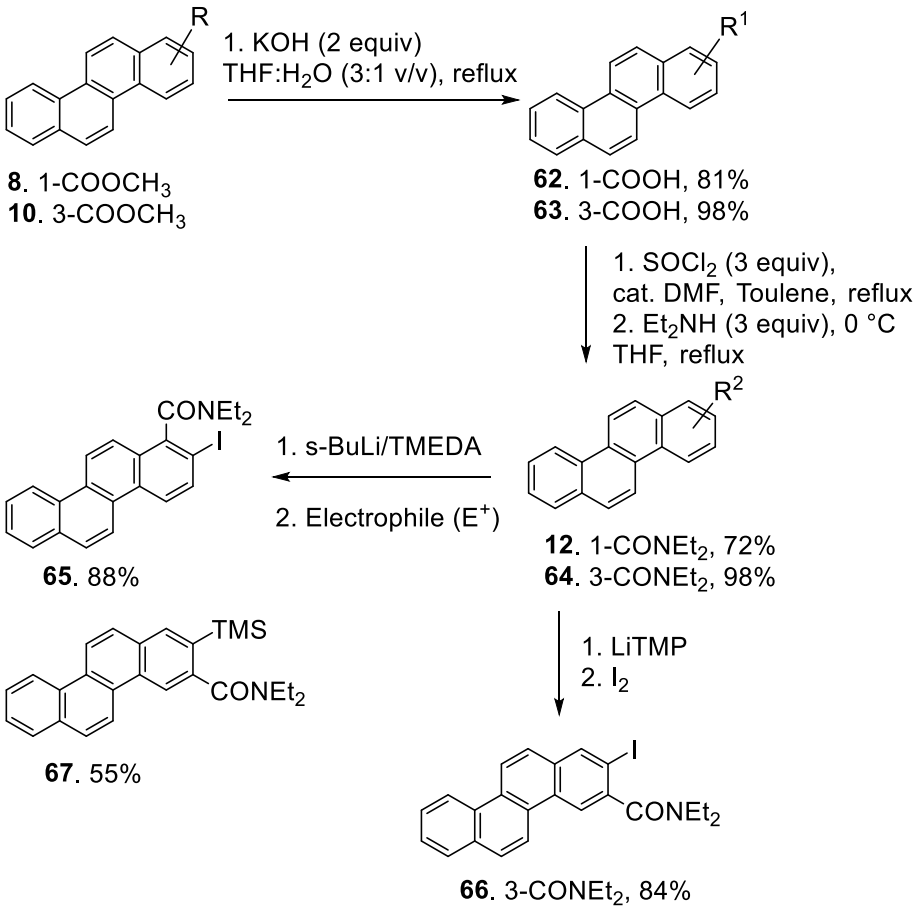
Scheme 27: Attempts to metalate *peri*-position and C-4 position separately.

4.2 D*o*M on chrysenyl amides

The required 1- and 3- chrysenyl *N*,*N*-diethyl amides (**12** and **64** respectively) for D*o*M experiments were prepared from the corresponding esters **8** and **10** using literature procedures in good yields (Scheme 28). Since **12** and **64** are required to be pre-functionalized as cross-coupling partners (Chapter 5), electrophilic quench was attempted with only suitable electrophiles. Attempts to quench lithiated substrates **12** and **64** with electrophiles Br_2 and $B(OCH_3)_3$ were unsuccessful. Notably, similar bromination on chrysenes with *N*,*N*-diethyl carbamate as DMG (**42**, **22** and **43**), by electrophilic quench with Br_2 afforded the expected brominated products in good to modest yields (discussed in previous Section 4.1).[229]

Taking into account the order of reactivity in the oxidative addition step of the Suzuki-Miyaura cross-coupling as: I ~ OTf > Br >> Cl, D*o*M experiments with I_2 as electrophile were performed. *N*,*N*-diethyl-2-iodochrysene-1- carboxamide (**65**) was obtained in excellent yield using 1.5 equiv each of *s*-BuLi /TMEDA and 1 M I_2 in THF (Scheme 28). Conversely, applying the same reaction conditions on **64** gave poor yield (30%) of the expected product *N*,*N*-diethyl-2-iodochrysene-3-carboxamide (**66**) due to formation of a complex mixture of unexpected side products. An *in-situ* quench (ISQ) study with same reaction conditions and TMSCl resulted in a similar poor yield of the silylated product (**67**) due to competitive side reactions in the metalation of **64** (Scheme 28). The mixture of side products from the ISQ reaction were analysed by ^{1}H-NMR and

the complex spectrum indicated the formation of C-4 TMS substituted product. Nevertheless, by choosing a weaker and sterically more bulky base, LiTMP, the expected iodinated product **66** was obtained in good yield (84%, Scheme 28). The result with LiTMP was comparable to that observed in the iodination of chrysenyl *N*,*N*-diethyl-*O*-carbamates.[229] Unlike **64**, in the presence of *s*-BuLi /TMEDA chrysenyl carbamate **43** resulted in the C-2 iodinated product regioselectively. It is well-known that *N*,*N*-diethyl-*O*-carbamate is an extremely strong DMG but in the present D*o*M study it has also assisted in blocking the bay-region of chrysene.



Scheme 28: Preparation and D*o*M of chrysenyl-*N*,*N*-diethyl carboxamides.

4.3 Conclusions

The present work has shown the efficient application of D*o*M to functionalize chrysene derivatives. Using the strongest DMG, *N*,*N*-diethyl-*O*-carbamate, all three regioisomers of chrysenes were functionalized to form disubstituted products in excellent to modest yields (Table 2−4). The reaction conditions were changed depending on the reactivity of the specific electrophile. Compound **22** showed no preferential regioselectivity for the two *ortho*-sites under standard s-BuLi /TMEDA conditions. In such case, LiTMP seemed to be a promising base for attaining regioselectivity. *Peri*-metalation in compound **42**, and C-4 metalation in compound **43** seemed to be impossible even after blocking the preferred *ortho*-site strategically.

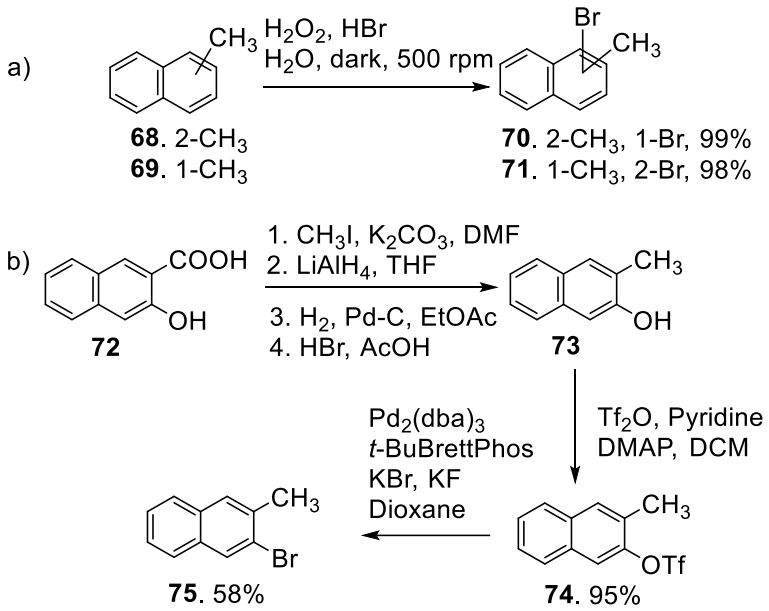
Notably, the change of DMG from carbamate to *N*,*N*-diethyl carboxamide affected the bromination of chrysenes. Unlike in **43**, bromination attempts on **12** and **64** were unsuccessful. However, neither of the two DMGs in chrysene-1-yl allowed *peri*-metalation but afforded only the *ortho*-iodinated product in good yield (Scheme 28). The regioselecitivity was compromised for compound **64** under standard *s*-BuLi /TMEDA conditions but the usage of LiTMP afforded the *ortho*-iodinated product **66** in good yield. The D*o*M approach can thus be used to pre-functionalize substrates for cross-coupling, such as **65** and **66**. In conclusion, the utility of the D*o*M strategy described herein may be anticipated for the functionalization of other PAH-type molecules.

Chapter 5. Cross-coupling of larger PAHs

Some protocols have been reported for syntheses of *ortho* substituted (unsymmetrical) biaryls containing naphthalenyl, anthracenyl moieties.[230-234] As discussed in Section 2.3, the reaction conditions in cross-coupling experiments are highly specific for the set of substrates depending on electronic and steric factors. In this chapter, the cross-couplings of iodochrysenyl-*N*,*N*-diethyl carboxamides (**65** and **66** obtained from D*o*M experiments in Chapter 4) with commercially available *o*-tolyl boronic acid (*o*-TBA), and laboratory-synthesized methylnapthalenyl, methylchrysenyl boronates are discussed. The role of electronic and steric factors involved in the cross-coupling of PAHs are observed. The end-products of this work will be used for the subsequent DreM experiements to synthesize larger PAHs.

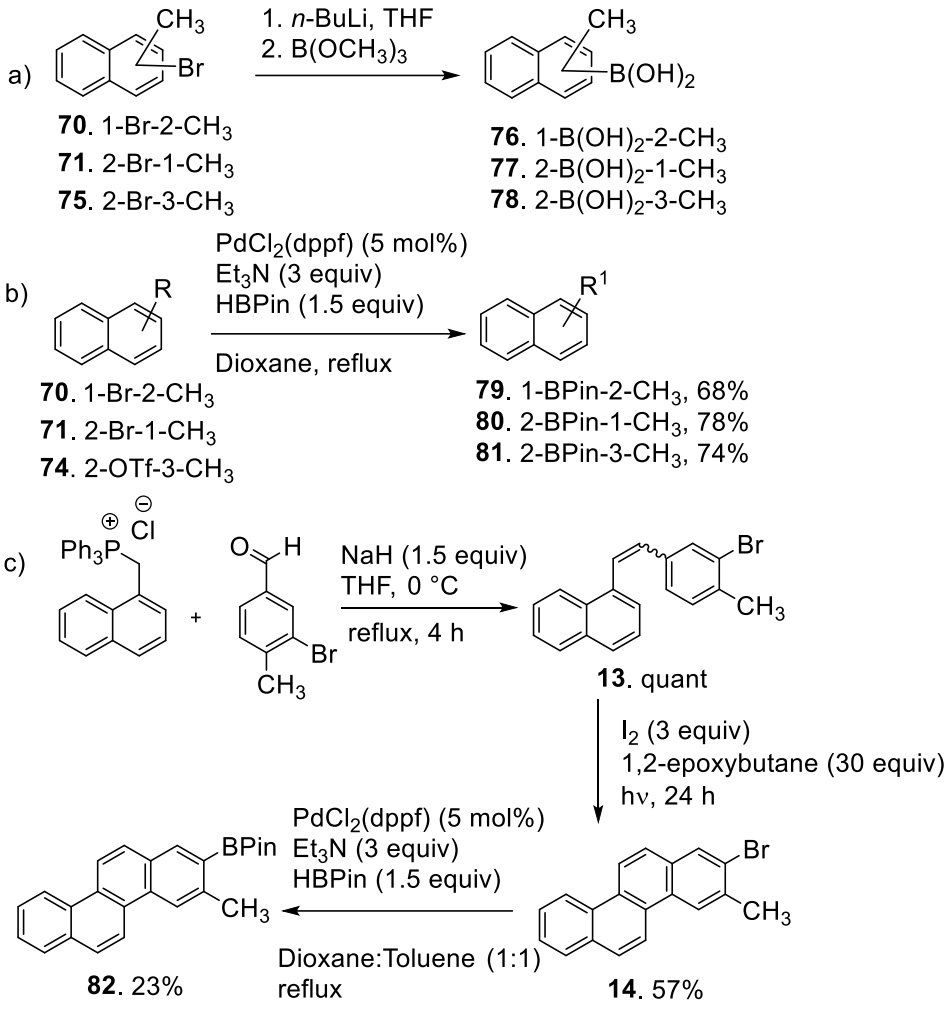
5.1 Synthesis of methylnaphthalenyl boronates

For the cross-coupling reactions, the boronate partners were prepared from bromo-methylnaphthalene regioisomers. Following the literature procedures, 1-bromo-2-methylnaphthalene (**70**), 2-bromo-1-methylnaphthalene (**71**) were prepared from the corresponding methylnapthalenes **68** and **69** respectively, using HBr-H_2O_2 reaction (Scheme 29a).[235] A multi-step approach was followed to prepare 3-bromo-2-methyl naphthalene (**75**) concurrently. The commercially available 3-hydroxy-2-naphthoic acid (**72**) was converted to 2-methylnaphthalen-3-ol (**73**) in good yield following a reported procedure (Scheme 29b),[236] which was subsequently transformed to 2-methylnaphthalen-3-yl trifluoromethanesulfonate (**74**) and further converted to **75** in 58% yield.[119]



Scheme 29: a) Syntheses of bromo-methylnaphthalenes; b) Synthesis of 2-methylnaphthalen-3-yl trifluoromethanesulfonate.

The bromo-methylnaphthalenes **70**, **71** and **75** were converted to boronic acids (**76**–**78**) by metal-halogen exchange reactions using *n*-BuLi, followed by quenching with excess of trimethyl borate; and used further without purification (Scheme 30a).[237] However, considering the ease of handling, purification, solubility of boronic esters in apolar solvents and also to avoid bromination of **74**, the naphthalene derivatives **70**, **71** and **74** were all subjected to Miyaura borylation (Scheme 30b) to synthesize the pinacol esters **79**–**81** in good yields. To further extend the scope of work, an attempt to synthesize 4,4,5,5-tetramethyl-2-(3-methylchrysen-2-yl)-1,3,2-dioxaborolane (**82**) was implemented by following a photchemical cyclization and Miyaura borylation route (Scheme 30c). 2-Bromo-3-methylchrysene (**14**) was prepared by Wittig reaction and photochemical cyclization in moderate yield (57%, Chapter 3) which was then subjected to borylation to afford the expected product in 23% yield. A mixture of dioxane: toluene was used due to poor solubility of **14** in pure dioxane.



Scheme 30: a) Synthesis of methylnaphthalene boronic esters; b) Synthesis of methylchrysene boronic ester.

5.2 Cross-coupling of chrysene derivatives with boronate partners

The compound **65** and **66** in DME were cross-coupled with commercially available *o*-TBA, using a literature procedure, in the presence of 5 mol% $PdCl_2$(dppf) and 2 M Na_2CO_3 in DME.[203] The experimental conditions were

highly efficient for these substrates resulting in the formation of products in 90% and 77% yield respectively. With these initial results, the same catalytic system was employed to cross-couple iodo-chrysenyl *N,N*-diethyl carboxamides with methylnapthalenyl boronic esters as shown in Figure 16 and Table 5. An attempt to cross-couple **65** and **66** with **81** and **80** respectively, was conducted by using the same previous reaction conditions (Table 5, entries 1 and 2). However, the experiments led to recovery of dehalogenated chrysenyl amides.

Several attempts were done to cross couple the substrates shown in Figure 16 and Table 5 before tracing out the suitable catalyst and optimization of reaction conditions. Boronic acids are stronger Lewis acids compared to boronic esters and hence are more reactive.[238] On the negative side, sterically hindered *ortho*-substituted arylboronic acids are generally known to give low yields due to hydrolytic deboronation.[239] In some cases, both electron-donating and electron-withdrawing groups were found to accelerate protonolysis.[239] Hence most of the trials in Table 5 were done with boronic esters except entries 4, 5, 6, 10 and 12. Similarly, using DME as solvent was observed to suppress deboronation.[240] Anhydrous conditions to avoid the scope of protonolysis were attempted in entries 3, 11 and 12.

The catalyst $PdCl_2$(dppf) was tested in aqueous and anhydrous conditions with different combination of reactants and three bases aq Na_2CO_3, anhyd CsF and aq $Ba(OH)_2$ (Table 5, entries 1−6). Among all the trials, $PdCl_2$(dppf) with a strong base aq $Ba(OH)_2$ in DME at 90 °C facilitated the cross-coupling of **65** and **77** affording the product in 60% yield. However, using the same conditions to cross-couple **66** and **76** was not successful (entry 5). Repetition of the experiment with the addition of SPhos ligand afforded product in 40% yield (Table 5, entry 6). Replacing SPhos with *t*-BuBrettPhos ligand in these reaction conditions did not afford cross-coupling product with **66** and **81** (entry 7).

The effect of different bases (boronate or oxo-palladium pathway) on Suzuki-Miyaura cross-coupling of bulky boronic acids, in terms of strength and cation size has been studied.[241-243] Stronger bases and /or larger cations have shown to be effective in such cases. Using the strong base aq $Ba(OH)_2$, different catalysts were tested such as $Pd(OAc)_2$ /SPhos (Table 5, entry 8), $PdCl_2$ /PPh_3 (entry 9), $PdCl_2$(dppf) (entry 4−7). To avoid base mediated protodeboronation and

oxidation of boronic acids by strong base and ethereal solvents,[244,245] a weaker base with larger cation size such as CsF was used maintaining anhydrous DMF as solvent (Table 5, entry 3), which however could not accelerate the transmetalation and resulted in recovery of starting material. Previous literature reported that catalysts based on SPhos have shown extraordinary reaction rate and stability even in the cross-coupling of *ortho*-substituted aromatic substrates.[246,247] DFT and NMR studies infer that the most favoured structures show Pd-arene interaction with the *ipso* carbon or Pd-O interaction with ─OMe group of the ligand that might contribute to the stability and efficiency of SPhos based catalysts. In entries 8 and 11, SPhos ligand was used with different Pd-catalysts $Pd(OAc)_2$, $Pd_2(dba)_3$ and strong bases but both led to recovery of mixture of starting material and dehalogenated compound.

The electron rich *N*-heterocyclic carbene-based Pd catalysts were reported to be effective in the cross-coupling of sterically demanding substrates.[248-250] However, Pd-PEPPSI-*i*Pr catalyst even in the presence of Cs_2CO_3 weak base with large cation resulted in the recovery of the dehalogenated compound (Table 5, entry 12). Recovery of dehalogenated compound in most of the trials indicated the possibility of the transmetalation step being the rate determining step. Changing the reaction conditions like ligands, base, anhydrous solvent and temperature did not afford the expected Suzuki-Miyaura cross-coupled products. Henceforth, various other cross-coupling methods such as Negishi and Hiyama were also attempted with less success than the Suzuki-Miyaura cross-coupling (Table 6).

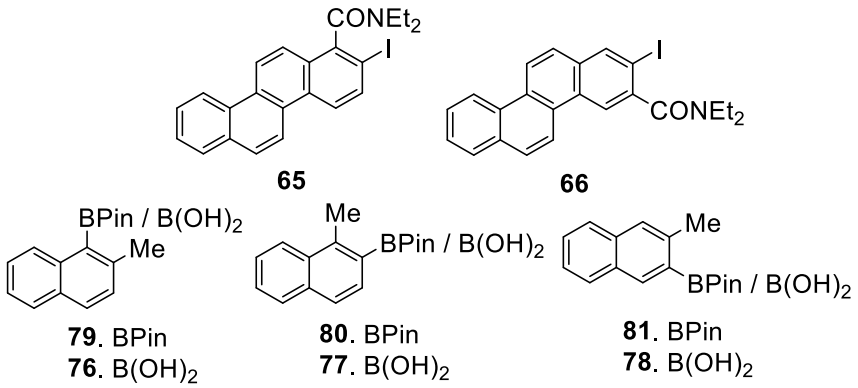


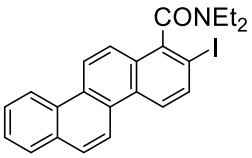
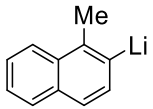
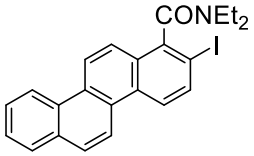
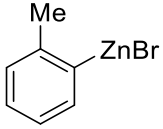
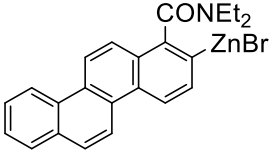
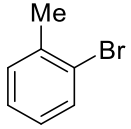
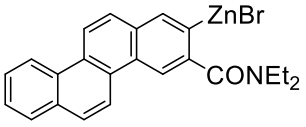
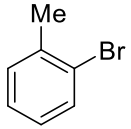
Figure 16: PAH molecules used as cross-coupling partners in Table 5.

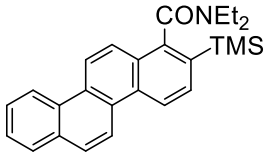
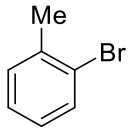
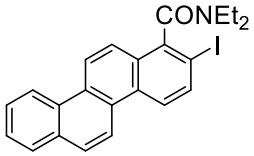
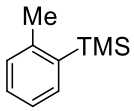
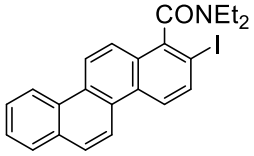
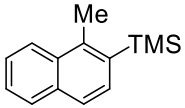
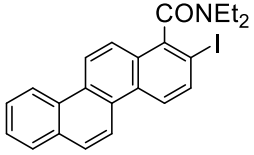
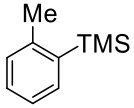
Table 5: Complete overview of the Suzuki-Myaura cross-coupling trials in search of suitable reaction conditions.

Entry	Reactants	Catalyst[a]	Base	Result
1[b]	**65 + 81**	$PdCl_2$(dppf)	2 M Na_2CO_3	Dehal. compd.
2[b]	**66 +80**	$PdCl_2$(dppf)	2 M Na_2CO_3	Dehal. compd.
3[c,e]	**65 + 80**	$PdCl_2$(dppf)	CsF	Start. mat.
4[b]	**65 + 77**	$PdCl_2$(dppf)	aq $Ba(OH)_2$	**60% expected product**
5[b]	**66 + 76**	$PdCl_2$(dppf)	aq $Ba(OH)_2$	Mixture of dehal. compd. and start. mat.
6[b]	**66 + 76**	(1:2) $PdCl_2$(dppf) and SPhos	aq $Ba(OH)_2$	**40% expected product**
7[d]	**66 + 81**	(1:2) $PdCl_2$(dppf), and *t*-BuBrettPhos	aq $Ba(OH)_2$	Dehal. compd.
8[b]	**65 + 81**	(1:2) $Pd(OAc)_2$ and SPhos	aq $Ba(OH)_2$	Mixture of dehal. compd. and start. mat.
9[b,e]	**66 + 80**	(1:2) $PdCl_2$ and PPh_3	aq $Ba(OH)_2$	Start. mat.
10[b]	**65 + 76**	$Pd(PPh_3)_4$	2 M Na_2CO_3	Dehal. compd.
11[f]	**66 + 80**	(1:2) $Pd_2(dba)_3$ and SPhos	KO^tBu	Mixture of dehal. compd. and start. mat.
12[b,g]	**66 + 77**	Pd-PEPPSI-*i*Pr	Cs_2CO_3,	Dehal. compd.

[a] 5 mol% Pd-catalyst; [b] DME at 90 °C; [c] DMF at 100 °C, 4 Å MS; [d] DME at 100 °C; [e] 3 days; [f] Toluene at 100 °C; [g] NMP (0.1 mL) as additive, 4 Å MS.

Table 6: Other cross couplings attempted in search of suitable conditions for the synthesis of biaryls.

Entry	Coupling partner- 1	Coupling partner- 2	Reaction conditions	Result
Organolithium coupling[172,251,252]			5 mol% $Pd_2(dba)_3$, 20 mol% XPhos, Toluene-THF, 40 °C, 16 h	Dehal. compd
Negishi coupling[253,254]			5 mol% Pd-PEPPSI-IPr, THF, 40 °C to reflux, 16 h	Start. mat. and dehal. compd
Negishi coupling[253,254]			5 mol% $PdCl_2$(dppf), THF, 40 °C, 16 h Later reflux, 16 h	Start. mat.
Negishi coupling[255,256]			5 mol% $Ni(acac)_2$, 10 mol% PPh_3, THF, 70 °C, 16 h	Start. mat.

Entry	Coupling partner- 1	Coupling partner- 2	Reaction conditions	Result
Hiyama coupling[257]			1 mol% $Pd_2(dba)_3$, 4 mol% XPhos, 10 mol% CuF_2, 1.3 equiv CsF, DMI, 120 °C	Desilyl. compd
Hiyama coupling[257]			2 mol% $Pd_2(dba)_3$, 8 mol% XPhos, 1.3 equiv CuF_2, 1.3 equiv CsF, DMI, 120 °C, 3 days	Dehal. compd
Hiyama coupling[257]			5 mol% $Pd_2(dba)_3$, 20 mol% XPhos, 1.3 equiv CuF_2, 1.3 equiv CsF, DMI, 120 °C, 3 days	Dehal. compd
Hiyama coupling[257]			5 mol% $Pd_2(dba)_3$, 20 mol%$Ph_2P(2\text{-}NMe_2C_6H_4)$, 1.3 equiv CuF_2, 1.3 equiv CsF, DMF, 110 °C, 2 days	Dehal. compd

The concept of catalyst ligand bite-angle

The above experiments led us to question the influence of steric factors on the reactivity of bulky substrates over electronic factors. In many such examples involving bulky substrates, the ligand bite-angle at the Pd-center has been calculated computationally.[258] It is well-known that bite-angle plays an influential role on reaction barriers during oxidative addition of C─X to the metal center[259] and also during reductive elimination of product.[260] Previously the origin of bite angle effect on these reaction barriers was accepted to be electronic in nature.[261,262] Many pioneering studies have shown the bite angle, ligand-metal-ligand angle, to have steric effects predominantly.[263] The strain in the catalyst complex is increased with an increase in the bite-angle due to unfavourable non-bonded interaction of the catalyst with the substrate resulting in a deformed catalyst.[264] The catalyst with a smaller bite-angle, by bending away the ligands, makes more space for coordinating substrates. Albeit, the existence of steric factors do not rule out the effect of electronic factors. Electronic factors are involved in stabilization of the catalyst complex through π back-donation from metal d-orbitals to the substrate σ^*_{C-X} acceptor orbitals.[265]

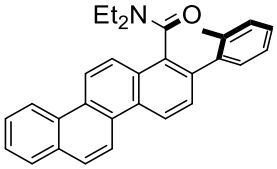
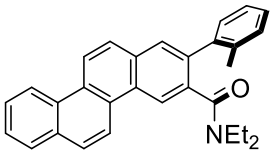
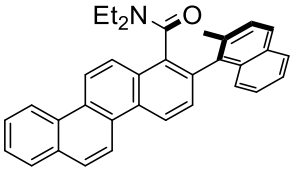
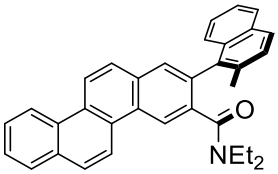
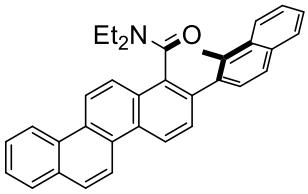
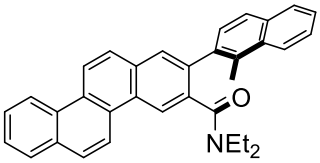
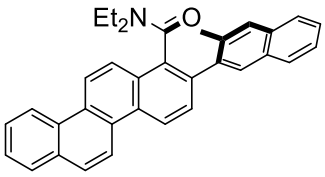
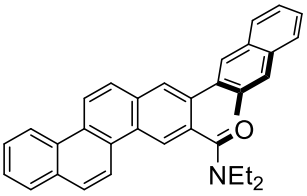
Generally sterically demanding substrates require a wide bite-angled *trans*-spanning ligand to allow the oxidative addition and transmetalation in *trans* position. However, for a successful reductive elimination, the Pd-center has to undergo a *trans* to *cis* isomerization. To avoid the isomerization, deformed catalyst and additional non-bonded steric interactions, we anticipated that a small ligand bite-angled Pd-catalyst together with a large base cation could be equally effective leading to a *cis* conformation at the metal center. The cross-coupling condition in Table 5, entry 4 using $PdCl_2$(dppf) gave 60% expected product but was incompatible with other substrates. Nevertheles, the catalyst afforded good yields in cross-coupling reactions of **65** /**66** with *o*-TBA. The $PdCl_2$(dppp) based catalysts have been reported to catalyse the cross-coupling towards the synthesis of oligo(naphthalene-2,3-diyl)s.[236] Henceforth, in the series of Pd-dpp bidentate catalysts (Table 7), the $PdCl_2$(dppe) catalyst with a ligand bite-angle of 85.8° was chosen (Table 7). Extremely small bite-angles as in $PdCl_2$(dppm) might be unsuitable for an efficient reductive elimination due to reduced electron density at the metal center.[266]

Table 7: Bite angles of Pd-diphosphine series of bidentate catalysts.

Catalyst	Pd─P (Å)	P1─Pd─P2 (°)	Reference
$PdCl_2$(dppf)	2.283(1); 2.301(1)	99.07(5)	[267]
$PdCl_2$(dppp)	2.244(1); 2.249(1)	90.58(5)	[259,267]
$PdCl_2$(dppe)	2.233(2); 2.226(2)	85.82(7)	[259,268]
$PdCl_2$(dppm)	2.234(1); 2.250(1)	72.68(3)	[268]

The chosen catalyst $PdCl_2$(dppe) was suitable for the cross-coupling of bulky **65** and **66** chrysenyl substrates with methylnaphthalenyl boronic esters **79**–**81** (Table 8). To avoid deboronation, usually observed in such cross-couplings, the use of boronic esters and anhydrous reaction conditions (anhyd solvent and MS) were continued. Both Cs_2CO_3 and KO*t*-Bu (in *t*-BuOH as solvent) was found equally efficient for the reaction. Cs_2CO_3 in DMF as solvent was preferable compared to toluene considering the improvement in the yield of all the cross-coupling reactions, for example, the yield of compound **88** increased from 10% to 46%. Henceforth, using 5 mol% $PdCl_2$(dppe) and Cs_2CO_3 in DMF with 4 Å MS, the methylnapthalene boronic esters were successfully cross-coupled with **65** and **66** in modest to excellent yields (Table 8). The comparatively lower yields of cross-coupling reactions with **66** is attributed to the increased steric crowding due to the amide group at C-3 position.

Table 8: List of products from Suzuki-Miyaura cross-coupling reactions.

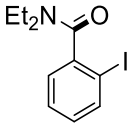
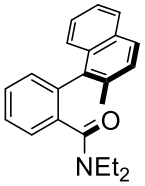
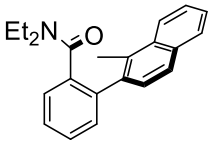
Boronic esters	Cross-coupled product from 65	Cross-coupled product from 66
***o*-TBA**	 **83**. 90%[a]	 **87**. 77%[a]
79	 **84**. 66%[b] 62%[c]	 **88**. 46%[b] 10%[c]
80	 **85**. quant[b] 76%[c]	 **89**. 93%[b] 78%[c]
81	 **86**. 81%[b] 82%[c]	 **90**. 81%[b] 71%[c]

[a] **65** /**66** (1 equiv), boronic ester (1.5 equiv), $PdCl_2$(dppf) (5 mol%), Na_2CO_3 (3 equiv), DME: H_2O, 90 °C. [b] **65** /**66** (1 equiv), boronic ester (1.5 equiv), $PdCl_2$(dppe) (5

mol%), Cs_2CO_3 (3 equiv), DMF, 4 Å MS, 120 °C. [c] **65** /**66** (1 equiv), boronic ester (1.5 equiv), $PdCl_2$(dppe) (5 mol%), Cs_2CO_3 (3 equiv), toluene, 4 Å MS, 114 °C.

With these successful results, we attempted cross-coupling of *N*,*N*-diethyl-2-iodobenzamide (**91**, prepared by D*o*M, 68% yield) with **79** that was previously reported to give 25% yield.[189] Using 5 mol% $PdCl_2$(dppf) with 2 M Na_2CO_3, the biaryl product **92** was formed in 17% yield while the reaction conditions $PdCl_2$(dppe) with Cs_2CO_3 afforded 24% product. Remarkably, changing the catalyst to Pd_2dba_3 /SPhos (1:4) afforded 78% product (Table 9). Additionally, using the same catalyst resulted the formation of compound **93** in quantative yield (Table 9).

Table 9: Suzuki-Miyaura cross-coupling products of *N*,*N*-diethyl-2-iodobenzamide.

Boronic esters	**2-Iodobenzamide (91)**	**Cross-coupled product from 91**
79	 **91**	 **92**. 78%[a]
80		 **93**. quant[a]

[a] **91** (1 equiv), boronic ester (1.5 equiv), $Pd_2(dba)_3$ (5 mol%), SPhos (20 mol%), Cs_2CO_3 (3 equiv), DMF, 4 Å MS, 120 °C.

Due to low yield (23%) of methylchrysenyl boronic ester **82**, it was only possible to do one further cross-coupling reaction with **65**. The expected cross-coupled product using 5 mol% $PdCl_2$(dppe), 3 equiv Cs_2CO_3 in DMF at 120 °C for 24 h, was obtained in very low yield insufficient and insoluble for characterization and therefore further attempts were not considered.

Nonetheless, the catalyst might not be efficient for cross-coupling of two chrysenyl derivatives considering the increased steric crowding at the metal center.

5.3 Conclusions

An efficient Pd-catalysed Suzuki-Miyaura cross-coupling protocols of *ortho*-substituted and sterically demanding PAHs were discussed (Table 8 and 9). The reaction conditions were suitable to cross-couple chrysenyl carboxamides **65** and **66** with *o*-TBA and different regiosiomers of methylnaphthalenyl boronic esters. The importance of steric factors overriding the electronic effects was observed during the cross-coupling trials. At the end, a series of isomers of *N*,*N*-diethyl-2-(methylnaphthalenyl)chrysene carboxamides **84**−**86** and **88**−**90** were synthesized in modest to excellent yields using commercially available economic $PdCl_2$(dppe). The yields of cross-coupling of **91** with methylnaphthalenyl boronic esters affording **92** and **93**, were also improved significantly by changing the reaction conditions especially Pd-catalyst. The trials and optimization of cross-coupling conditions discussed in this chapter are anticipated to be useful for future cross-couplings of large PAHs.

Chapter 6. DreM on larger PAHs

As discussed in Section 2.4, DreM has been used to synthesize smaller (hetero)aromatic cores.[164] Consolidating the results reported by Snieckus *et al* and Jørgensen *et al*, an intriguing cyclization pattern was observed when *N,N*-diethyl-2-(methylnaphthalenyl)benzamides were subjected to DreM resulting in tetraphen-5-ol and fluorenone (Section 2.4.2, Scheme 16).[189,190] The work to be presented in this chapter was aimed to study the reactivity trend and mechanism in the presence of different regioisomers of methylnaphthalenyl moieties in the biarylic derivatives while extending the DreM strategy towards the syntheses of larger PAHs. The unsymmetrical biaryls **83** to **90**, **92** and **93** synthesized in the previous Chapter 5 are used as starting materials for the DreM experiments discussed below.

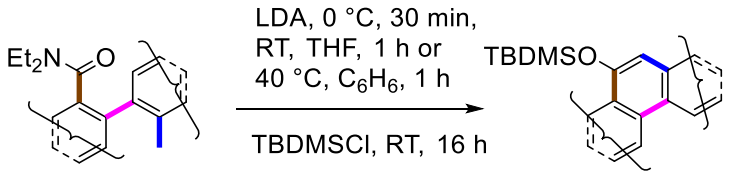
6.1 DreM on unsymmetrical biaryl-derivatives of chrysenes

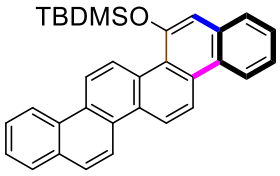
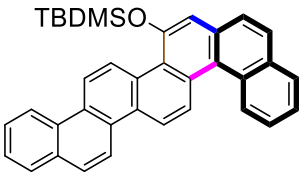
Subjecting the biaryl derivatives to DreM conditions resulted in the formation of larger PAHs, presented in Table 10. The end-products of DreM reactions were protected in a one-pot strategy by the addition of 1 M TBDMSCl at rt to avoid the oxidation of phenolic derivatives. Using the standard DreM conditions of excess LDA in THF at 0 °C, the biaryl derivatives **83**, **86**, **87**, and **90** were cyclized smoothly to the corresponding PAHs (Table 10, DreM at rt). However, the biarylic derivatives **84** and **88** did not cyclize under standard DreM conditions. For these biarylic derivatives, a slight increase in temperature to 40 °C after the addition of LDA at 0 °C promoted the formation of corresponding PAHs. The slightly higher temperature possibly facilitated in attaining the required conformation to form the cyclized products. In these two experiments (Table 10, DreM at 40 °C), benzene was used as solvent instead of THF to avoid unexpected side reactions of solvent with LDA at elevated temperatures. Additionally, using benzene facilitated the addition of LDA at 40 °C, which afforded slightly higher yields. Compound **92** reportedly did not cyclize when subjected to normal DreM conditions.[189] With these successful DreM cyclizations of **84** and **88**, an attempt to cyclize compound **92** was performed at 40 °C, in which LDA addition was done at 0 °C. Although DreM was successful affording 88% yield of corresponding benzo[*c*]anthracene

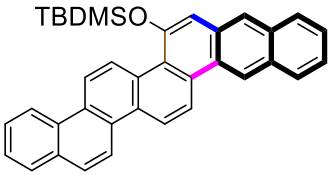
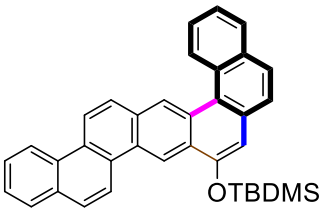
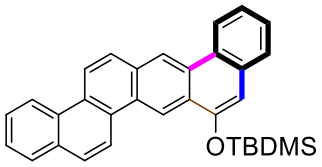
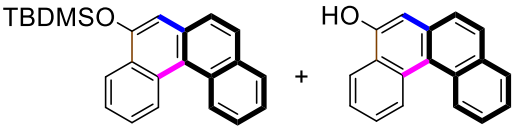
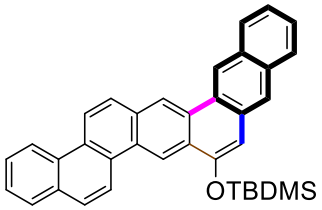
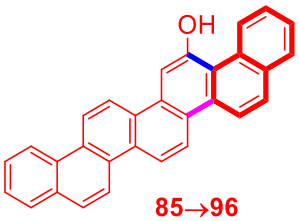
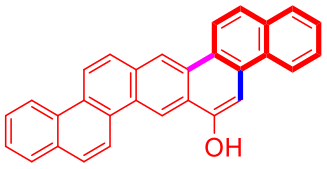
derivative, protection with TBDMSCl was less efficient resulting in the isolation of unprotected phenolic derivative as the major product.

Unfortunately, compounds **85** and **89** did not cyclize to form the corresponding PAHs, not even in the presence of excess LDA in refluxing benzene, which led to partial decomposition of starting materials. These biarylic derivatives were subjected to DreM using strong base such as *n*-BuLi, which were also futile and led to the decomposition of substrates. The observed reactivity trend in biarylic derivatives containing the methylnaphthalene moiety (Scheme 16 and Table 10) might be due to the position of methyl group and the biarylic bond. For instance, the biarylic derivatives **84**, **88** and **92** which contain (1-methylnaphthalen-2-yl) moiety undergo DreM only after increasing the temperature to 40 °C. While, their regiosomers **86** and **90**, containing (3-methylnaphthalen-2-yl) moiety, react efficiently under standard DreM conditions at 0 °C. The biarylic derivatives **85** and **89** did not react under standard DreM conditions nor in the presence of strong base or refluxing temperature. The definite mechanism and conformational barriers that might influence the reactivity trend have not been explored still. Previous studies by Jørgensen *et al* has dismissed the role of rotational barriers and atropisomers in the regioselecitvity of DreM in biarylic substrates **92** and **93**.[190]

Table 10: PAHs synthesized from DreM on cross-coupled products.



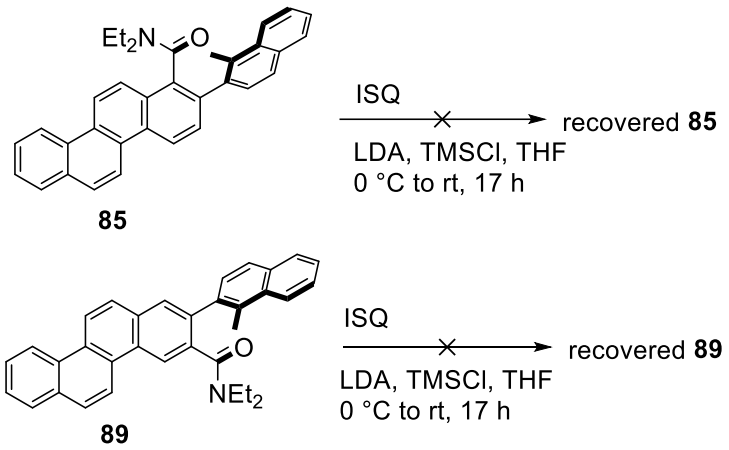
DreM at rt[a]	**DreM at 40 °C**[b]
 **83**→**94**. 63%	 **84**→**95**. 62% 85% (addition of base at 40 °C)

DreM at rt[a]	**DreM at 40 °C[b]**
 **86→97**. quant	 **88→99**. 44% 50% (addition of base at 40 °C)
 **87→98**. 68%	 **102A**. 22% **102B**. 66% **92→102**
	DreM of **85** and **89** failed to form:
 **90→101**. 54%	 **85→96**  **89→100**

[a] LDA (3 equiv), THF, 0 °C, 30 min then rt, 1 h, TBDMSCl (3.1 equiv), rt, 17 h; [b] LDA (3.5 equiv), 0 °C, 30 min, benzene, then 40 °C, 1 h, TBDMSCl (3.5 equiv), rt, 17 h.

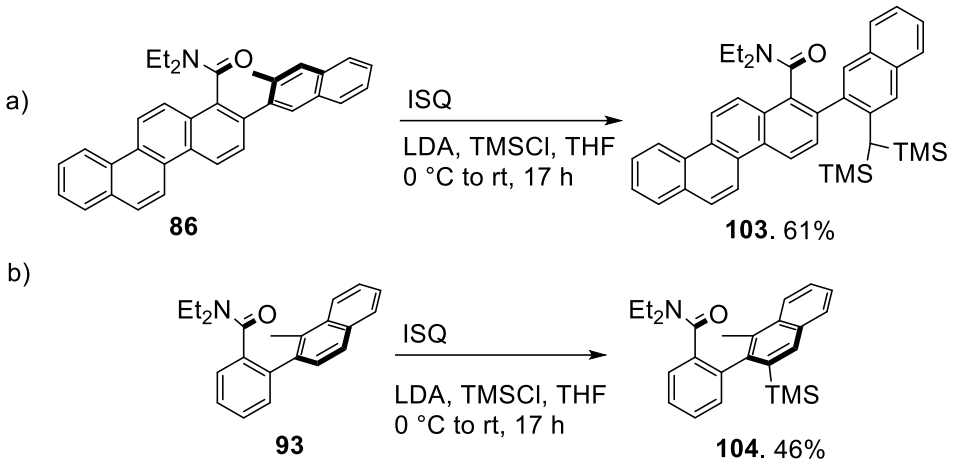
Deuterium quench experiments and *in situ* quench with TMSCl on compounds **85** and **89** were futile as well (Scheme 31). At low temperature such as 0 °C, *in situ* quench experiments with LDA base were expected to trap remote metalated species (refer Section 2.4).[164] However, if the remote position is unavailable,

stronger bases can deprotonate indiscriminately incase of negligible difference in pK_a among the C─H bonds resulting in the decomposition of substrate. The reason behind the unsuccessful DreM experiments conducted on biarylic derivatives **85** and **89** is still unclear. Probably the suitable orientation for the subtrates **85** and **89** to undergo DreM reaction at remote position might not be attained. Nevertheless, the variable temperature NMR and computational studies conducted on compound **93** ruled out the involvment of bond-rotation barriers in regioselecivity of DreM.[190]



Scheme 31: Attempt to trap metalated species of biarylic substrates **85** and **89**.

To cross-check the possibility of *in situ* quench with TMSCl on these sterically bulky biarylic derivatives, a similar experiment was conducted with the other regioisomer **86**. The biarylic derivative **86** was successfully bis-silylated on the methyl substituent of naphthalene moiety (confirmed from ^{1}H-NMR, Scheme 32a). Notably, the compound **86** was also subjected to DreM reaction forming the corresponding PAH **97** efficiently as shown in Table 10.



Scheme 32*: In situ* quench experiments on selected substrates.

A fluorenone was reportedly formed instead of the expected chrysene-6-ol when the biarylic derivative **93** was subjected to standard DreM conditions.[190] An *in situ* quench experiment was henceforth conducted to trap the remote metalated species of **93,** which might rationalize the formation of fluorenone instead of chrysene-6-ol (Scheme 32b). HMBC spectrum of the product **104** obtained from the *in situ* quench experiment showed correlation between amide C=O and *ortho*-proton (Figure 17) of benzamide's aromatic ring eliminating the possibility of D*o*M. Lack of correlation between TMS-proton and methylnapthalenyl's methyl cabons excluded silylation on the methyl group of methylnaphthalenyl moiety. The ^{1}H-NMR spectrum of substrate **93** (Figure 18) showed broad peaks, while the silylated product **104** showed sharper peaks (Figure 19) of the two atropisomers, indicating increased rotational barriers. Therefore, silylation at C-3' position seems to be reasonable and in agreement with the fluorenone formation (Scheme 32b).

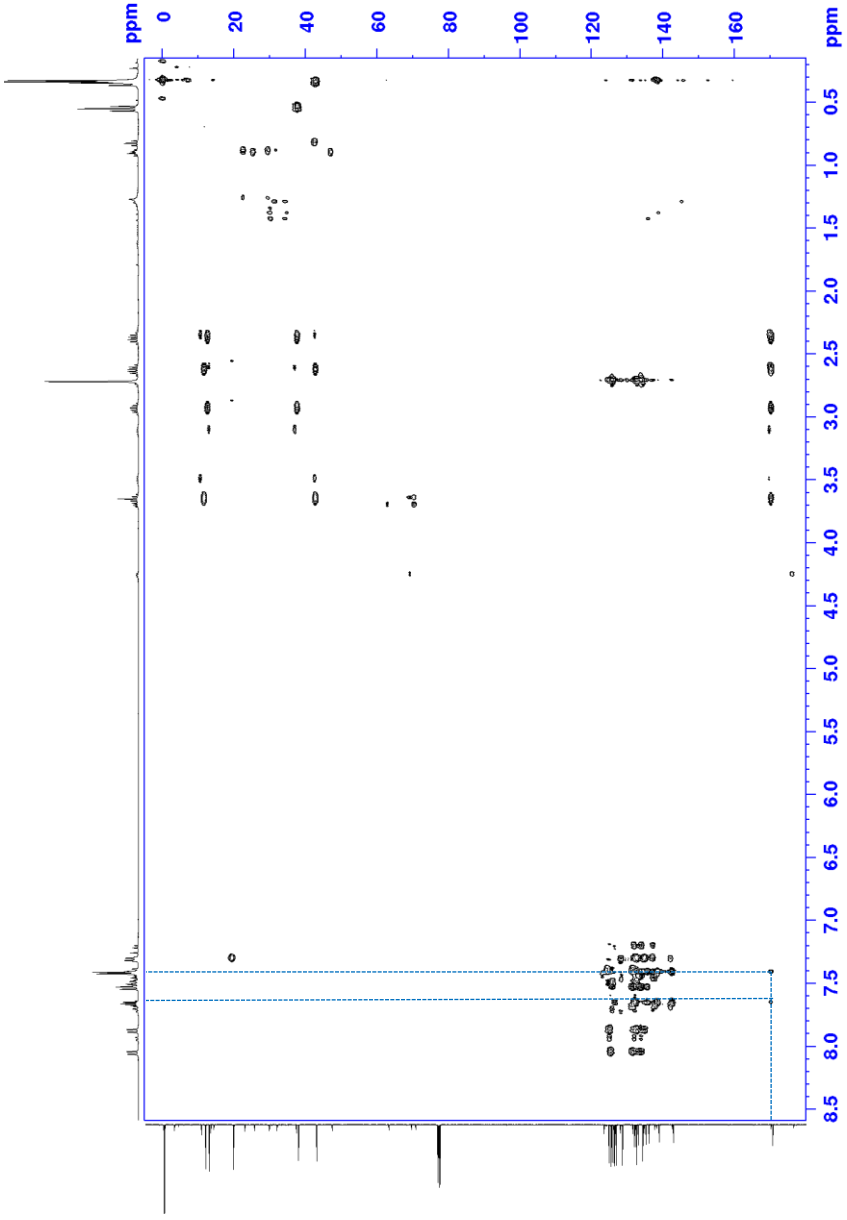


Figure 17: HMBC spectrum of the compound **104** with ^{1}H-NMR on horizontal axis and ^{13}C-NMR on vertical axis.

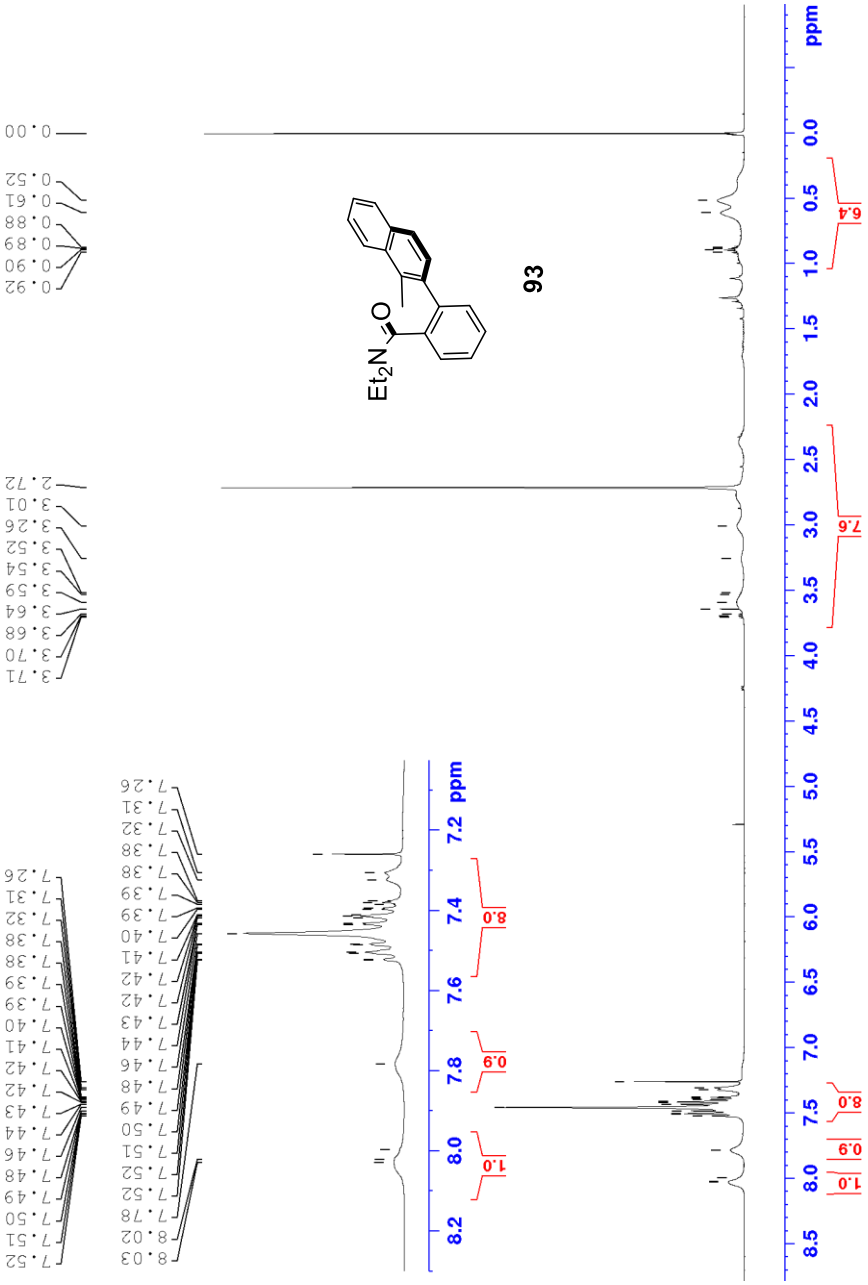


Figure 18: ^{1}H-NMR spectrum of biarylic derivative **93**, showing broad peaks.

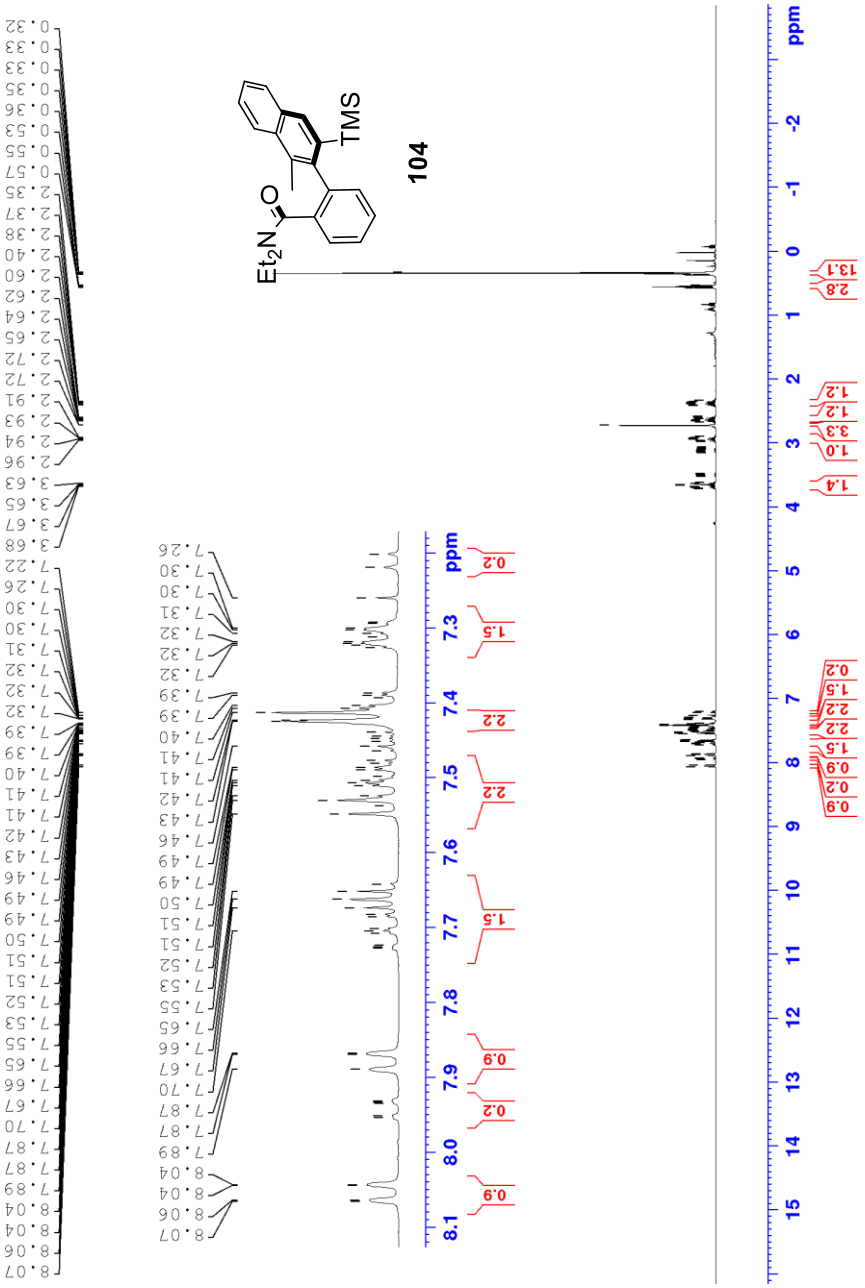


Figure 19: ^{1}H-NMR spectrum of biarylic derivative **104**, showing sharper peaks.

6.2 Fluorescence

The end-products of the DreM studies showed a bluish fluorescence in UV-light (Figure 20), which led to measure the UV-visible and fluorescence spectra of these PAHs. All the measurements were done using samples of concentration $1*10^{-6}$ M solution in $CHCl_3$ and slit widh of 2.5 nm was used to record fluorescence spectra. Taking into account the solubility of larger PAHs, $CHCl_3$ was chosen as the solubilizing media although it has significant absorption below 250 nm, which did not interfere with the area of interest in the spectra. The normalized spectra are given in Figure 21, while λ_{max} and Stokes shifts are given in Table 11.

Figure 20: Bluish fluorescence shown by the compound **97** under UV light.

It is well-known that the photophysical properties depend on the structure of the molecules. It can be seen in fluorescence spectra affected by the changes in molecular shape, rigidity and planarity of the compounds.[269] The synthesized PAHs have almost similar size except slight variation in the geometrical arrangement of terminal aromatic rings such as **95** and **99** might be twisted on the helical end.[270] However, the non-planarity of these compounds had no considerable affect on the spectra.

Linearly extended acenes are known to have strong bathochromic shifts compared to angular phenacenes.[269,271,272] The PAHs **94**, **95**, **97** to **99**, **101** and **102A** showed a small red-shift, but the Stokes shift was slightly larger when there was an anthracene moiety in the core structure *i.e.* for compounds **97** and **101**. On the whole, the UV-visible and fluorescence spectra of all the end-products showed almost similar perturbations.

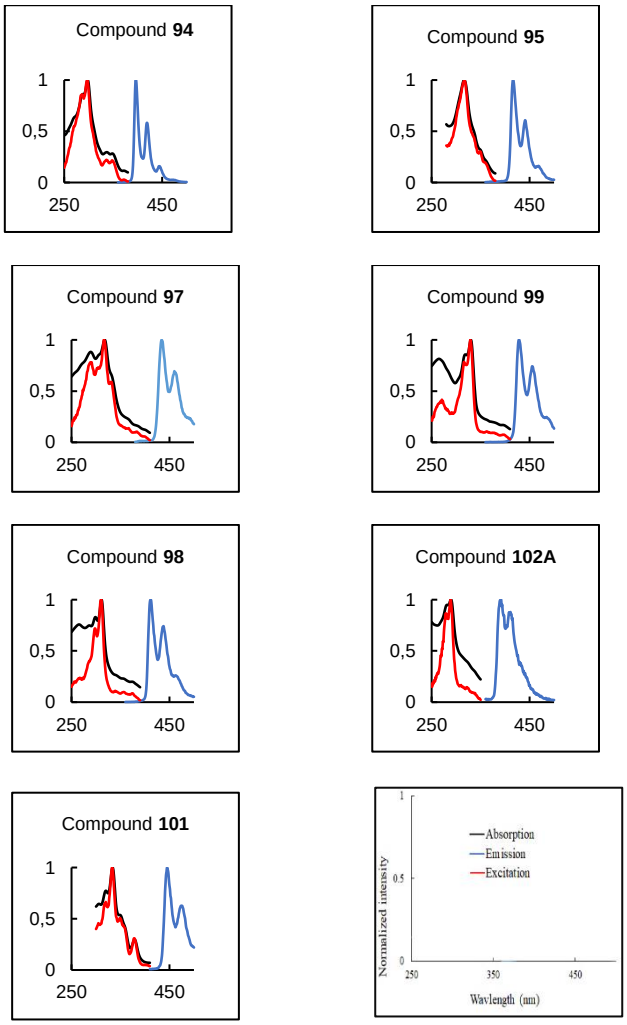


Figure 21: Plots showing UV-Vis absorption and fluorescence spectra of PAHs dissolved in $CHCl_3$ and recorded on VWR UV-1600PC spectrophotometer; F-7000 FL Spectrophotometer.

Chang and co-workers reported the Stokes shift of [6]phenacene to 90 nm while some derivatives with substituents on the terminal ring had 90−95 nm Stokes shift.[271] The Stokes shift of [6]phenacene derivative, **94** was 98 nm which was found to be in good agreement with the reported analogues.

The smaller PAHs **102A** and **102B** showed a lower signal strength than their larger counterparts, particularly **102B** had too weak fluorescence. Benzo[*c*]phenanthrene is reported to have a quantum yield of 0.12, and a fluorescence spectrum similar to **102A**.[271] The peak intensities of larger PAHs **94**, **95**, **97**−**99**, and **101** in fluorescence spectra were stronger compared to **102A**, henceforth much higher quantum yields are expected for these larger PAHs.

Table 11: Stokes shift of the synthesized PAHs.

Entry	Compound	λ_{abs} (nm)	λ_{exc} (nm)	λ_{emis} (nm)	Stokes shift (nm)
1	**94**	298	297	396	98
2	**95**	317	317	416	99
3	**97**	318	316	434	116
4	**98**	311	311	412	101
5	**99**	330	329	428	98
6	**101**	334	333	445	111
7	**102A**	290	289	392	102

6.3 Cryogenic crystallization of DreM reaction intermediates

Based on purely experimental observations it was difficult to understand the mechanism and reactivity trend in DreM reactions for substrates **84**−**86**, **88**−**90**, **92** and **93**. Henceforth, it was envisioned that X-ray diffraction studies of reaction intermediate and subsequent computational calculations might give more insight.

In collaboration with Assoc. Prof. Marta E. G. Mosquera (University of Alcalá, Spain), attempts were made to crystallize DreM reaction intermediates of biaryl derivatives **86**, **92**, **93** and *N*,*N*-diethyl-2-(*o*-tolyl)-1-naphthamide (**105**). The substrates were subjected to DreM reactions at −78 °C in toluene:THF mixture as solvent using excess LDA. The stirring was stopped immediately after the

addition of LDA when the color change from metalation was observed. The excess toluene and complete THF was removed under high vacuum, keeping the reaction mixture at −78 °C. A second set of attempts to crystallize the intermediates from concentrated reaction mixtures in THF at −78 °C were also conducted. All the trials are stored in freezer at −78 °C for slow crystallization of metalated compounds.

6.4 Conclusions

The present study provides an efficient application of DreM for the synthesis of larger PAHs (Table 10). The substrates **86** and **90** containing (3-methylnaphthalen-2-yl) moiety undergo DreM reaction smoothly under standard condiions. Increasing the temperature slightly facilitated the progress of DreM reaction in substrates **84**, **88** and **92** containing the 2-methylnaphthalen-1-yl moiety that did not cyclize under standard conditions, to afford PAHs **95**, **99** and **102**. However, the biarylic derivatives **85** and **89** containing the 1-methylnaphthalen-2-yl moiety, did not form the corresponding PAHs or the expected fluorenones even at higher temperatures nor using strong base such *n*-BuLi, instead they decomposed partially during these experiments. These substrates also did not undergo metalation during *in situ* quench experiments. The DreM experiments discussed in this chapter using the substrates **83** to **90** reveal similar reactivity pattern reported with the (methylnaphthalenyl)benzamides **92** and **93** (Scheme 16). The factors affecting the reactivity and selectivity in substrates **84**−**86**, **88**−**90**, **92** and **93** in relation with methylnaphthalenyl moiety is not yet clear. Further studies through cryogenic crystallization and computational calculations are in progress to understand the mechanism of DreM. The UV-visible absorptions and fluorescence spectra were measured for the synthesized PAHs. Although quantum yields for these compounds were not measured, the strong intensities of UV-visible and fluorescence spectral peaks when compared to smaller PAH **102A**, infer them as the promising candidates for further advanced photophysical studies.

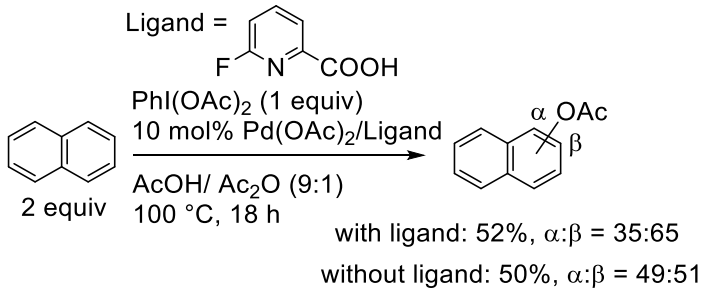
Chapter 7. C─H activation on PAHs

C─H activation is one of the actively developing fields of functionalizations of organic compounds. Various transition metals such as Pd, Ni, Pt, Ir, Rh and Ru have been used to activate the C─H bond in simple aromatic compounds.[204] Due to its abundance in earth and ease of handling Pd-catalysts are used mostly in C─H activation.[102] As discussed in Section 2.5, only few examples were reported involving the activation of C─H bonds in PAHs.[102,103] Henceforth, in collaboration with Assoc. Prof. M. Á. Fernández Ibáñez (University of Amsterdam, the Netherlands), preliminary experiments were conducted to extend the scope of C─H activation to PAHs. The challenges faced and observations made while attempting the Pd-catalyzed C─H acetoxylation and C─H olefination on different PAH substrates are presented. The substrates for the study were synthesized by oxidative photocyclization discussed in Chapter 3.

7.1 Acetoxylation

According to the reported original reaction conditions, C─H acetoxylation requires 10 equiv arene, 1 equiv $PhI(OAc)_2$ oxidant and 2 mol% $Pd(OAc)_2$-pyridinecarboxylic acid catalytic system in AcOH: Ac_2O (9:1) as solvent.[209] However, due to the limited quantity of laboratory-synthesized PAHs stock, the original experimental conditions were changed to 2 equiv arene, 1 equiv $PhI(OAc)_2$ oxidant and 10 mol% $Pd(OAc)_2$-pyridinecarboxylic acid catalytic system. In both the experimental conditions the ratio of arene and catalytic system was kept similar. The revised experimental conditions were first tested on naphthalene (Scheme 33) to compare it with original reported conditions (Section 2.5.1, Scheme 17a). The reported original reaction conditions for C─H acetoxylation of naphthalene, in the presence of ligand afforded 69% product (α:β =29:71) and in the absence of ligand gave 81% yield (α:β =57:43). Similalrly, two C─H acetoxylation experiments, one with ligand and the other without ligand, were performed on 2 equiv of naphthalene using revised conditions in AcOH:Ac_2O (9:1) at 100 °C for 18 h. The yields of the experiments were deduced by GC-FID analysis. The experiment done in the presence of ligand gave a mixture of α and β isomers in 52% yield (α:β =35:65), while the experiment done without ligand gave a mixture of α and β isomers in

50% yield (α:β =49:51). Compared to the original conditions, the yield was reduced slightly in both the experiments, however, the revised conditions afforded the acetoxylation on naphthalene.

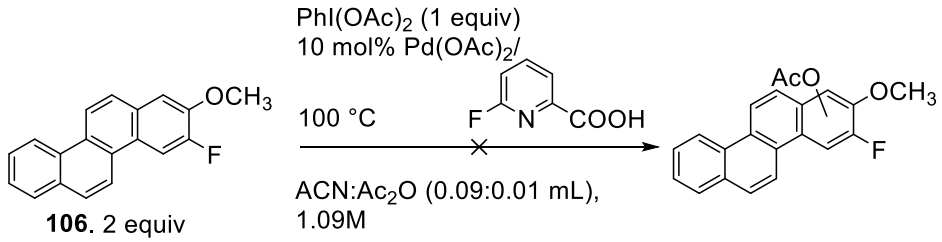


Scheme 33: Revised C─H acetoxylation conditions tested on naphthalene.

The preliminary observations with PAHs were that chrysene and phenanthrene derivatives are insoluble in AcOH, which resulted in screening of various suitable organic solvents.

1. Screening of solvents

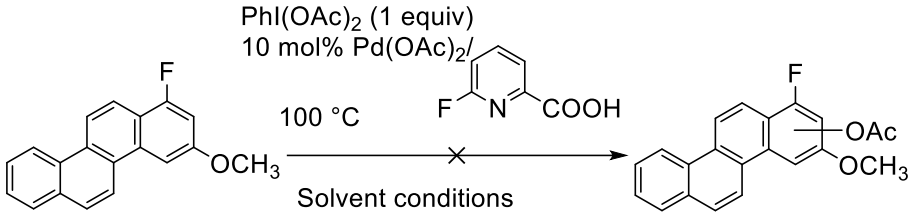
According to general procedure, 3-fluoro-2-methoxychrysene (**106**) was subjected to C−H acetoxylation in ACN: Ac_2O (9:1 v /v) but even after stirring at 100 ℃ during the reaction, compound **106** was left undissolved (Scheme 34). Thus, acetonitrile was concluded as not suitable for the substrate.



Scheme 34: C─H acetoxylation of **106**.

Since there was limited amount of compound **106** available for experiments, further screening of solvents was continued with 1-fluoro-3-methoxychrysene (**107**). The PAH **107** was subjected to C−H acetoxylation at 100 ℃ in different polar solvents as solvent mixtures with AcOH in varying ratios (Table 12).

Table 12: Solvents screened for C─H acetoxylation of **107**.



107. 2 equiv

Entry	Solvent composition	Solvent volume (mL)	Molarity (M)
1[a]	EtOAc + AcOH	0.45 + 0.05	0.22
2[a]	EtOAc + AcOH + Ac_2O	0.24 + 0.09 + 0.01	0.32
3[a]	Acetone + AcOH + Ac_2O	0.24 + 0.18 + 0.05	0.23
4[a]	1,4-dioxane + AcOH + Ac_2O	0.24 + 0.18 + 0.05	0.23
5[a]	DMSO + AcOH + Ac_2O	0.24 + 0.18 + 0.05	0.23
6[a]	DCE + AcOH + Ac_2O	0.24 + 0.18 + 0.05	0.23
7[a]	DCE + AcOH + Ac_2O	0.24 + 0.09 + 0.01	0.32
8[a]	DCE + AcOH + Ac_2O	0.05 + 0.3 + 0.01	0.30
9[a]	THF + AcOH + Ac_2O	0.20 + 0.09 + 0.01	0.36
10[a]	Propionic acid + Ac_2O	0.22 + 0.02	0.46
11[a]	Propionic acid+AcOH+Ac_2O	0.10 + 0.20 + 0.01	0.35
12[b]	Propionic acid+AcOH+Ac_2O	0.10 + 0.40 + 0.01	0.21
13[b]	Propionic acid+AcOH+Ac_2O	0.05 + 0.60 + 0.01	0.17

[a] PAH was recovered in entries 1 to 11; [b] PAH was insoluble in entries 12 and 13.

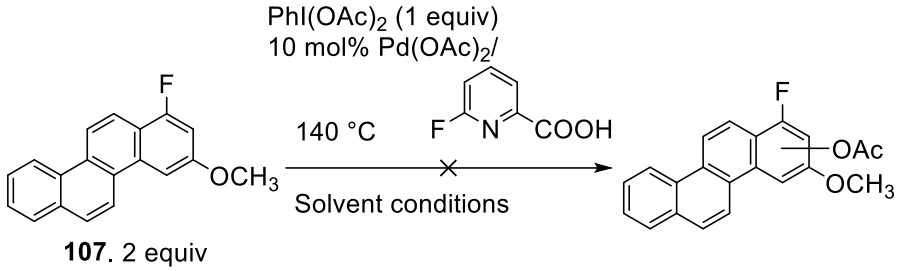
To maintain polar and protic environment during the reaction AcOH was added in all the reactions. A minimum volume of Ac_2O was added to remove any excess of moisture in the reaction. In Table 12, from entries 1−9, no product was observed in the experiments done in different organic solvents along with AcOH. Assuming that the organic solvents might be unsuitable for the reaction, experiments were done in propionic acid but unfortunately no product was observed (Table 12, entry 10). Considering AcOH to be necessary for the C─H acetoxylation, three experiments (Table 12, entries 11−13) were done in different ratios of propionic acid:AcOH. Although there was no product formation in any of the experiments, it was observed that PAHs were soluble in propionic acid, but increasing the percentage of AcOH in the solvent mixture caused precipitation of the substrate (Table 12, entries 12 and 13).

Among the several solvents screened for solubility and reactivity, propionic acid, being polar and protic solvent, was envisioned to be the more suitable replacement of AcOH for the acetoxylation reactions. Henceforth, the C─H acetoxylation experiments were conducted in propionic acid solvent changing other parameters of the reaction like temperature and amount of substrate.

2. Effect of temperature

Compound **107** was subjected to C−H acetoxylation at 140 ℃, close to the boiling point of propionic acid, using the same revised reaction conditions with and without AcOH (Table 13). However, no product was observed in either case.

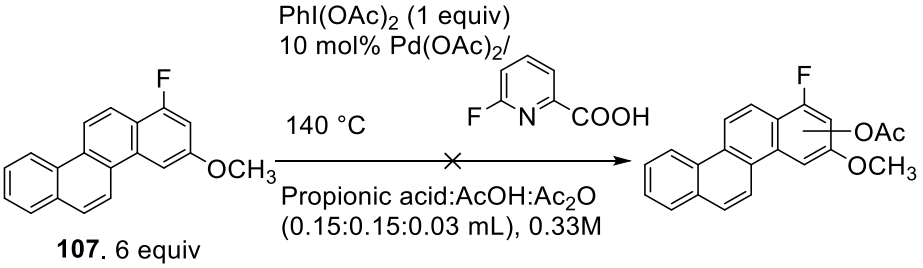
Table 13: C−H acetoxylation of **107** at 140 ℃.



Entry	Solvent composition	Solvent volume (mL)	Molarity (M)	Result
1	Propionic acid + Ac_2O	0.12 + 0.01	0.84	Recovered PAH
2	Propionic acid + AcOH + Ac_2O	0.05 + 0.05 + 0.01	0.99	Recovered PAH

3. Effect of the amount of arene

Most of the non-directed C─H activations reported so far require excess of arene, including the reported original conditions required 10 equiv for C─H acetoxylation. Therefore, compound **107** in large excess of 6 equiv was subjected to C─H acetoxylation as shown in Scheme 35. Unfortunately, no product was observed even with large excess of PAH.



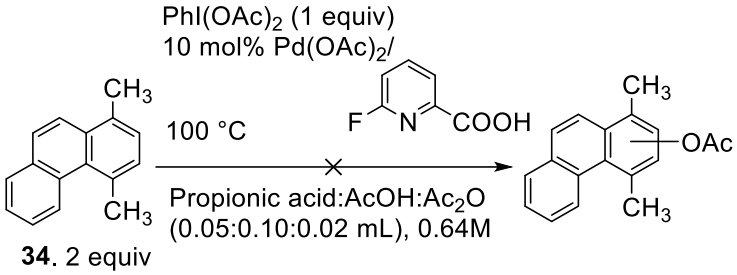
Scheme 35: C−H acetoxylation of **107** using 6 equiv of PAH.

4. Effect of electron donating groups

The presence of electron donating groups on the substrate is known to activate the neighbouring C─H bonds. On that account, 1,2-dimethoxychrysene with two ring activating groups was chosen as substrate. Unfortunately, it was insoluble in propionic acid and addition of co-solvents like DCE or THF did not improve the solubility.

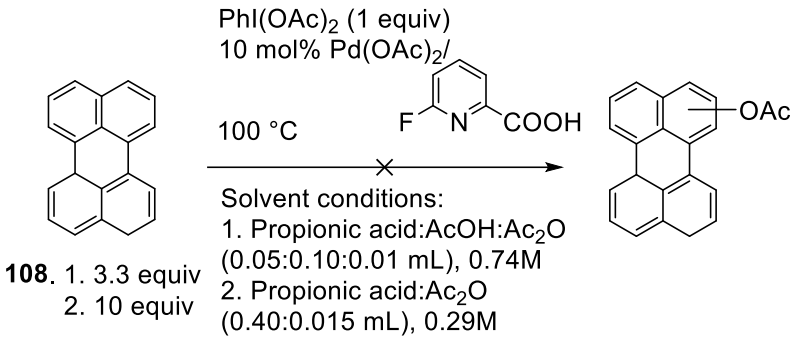
5. Reactivity of phenanthrene, perylene and anthracene

After facing solubility issues with chrysene derivatives, further acetoxylation attempts were conducted on 1,4-dimethylphenanthrene (**34**), a smaller PAH than chrysene. Compound **34** was subjected to C─H acetoxylation in a solvent mixture of propionic acid and AcOH at 100 °C for 18 h (Scheme 36). However, no product was formed under these conditions.



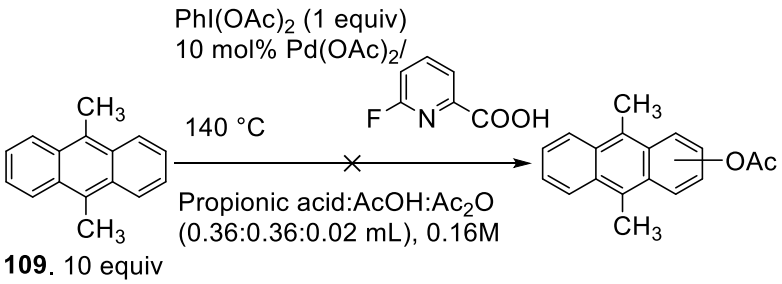
Scheme 36: C−H acetoxylation of **34**.

Following Clar's rule of aromatic sextets (Section 1.2),[68] **34** and chrysene derivatives are highly stable and chemically less reactive than perylene. Therefore, perylene (**108)** was subjected to C─H acetoxylation at 100 °C (Scheme 37). Compound **108** was insoluble in solvent mixture of propionic acid and AcOH. The experiment was also repeated in propionic acid but compound **108** was still insoluble. Due to the absence of any substitutents on the aromatic structure, it is highly non-polar and thus has poor solubility in polar solvents even at high temperature.



Scheme 37: C─H acetoxylation of **108**.

According to Clar's concept of benzenoid character, anthracene which belongs to same acene series as benzene and naphthalene, has relatively reduced benzenoid character with one sextet distributed among 3 fused rings. Henceforth, 9,10-dimethylanthracene (**109**) was subjected to C─H acetoxylation at 140 ℃ (Scheme 38). Compound **109** was partially soluble in AcOH. Therefore, a 1:1 solvent mixture of propionic acid and AcOH was considered as a suitable solvent for the experiment. Unfortunately, no product was formed in this experiment. The reason behind the differential reactivity of **109** compared to benzene and naphthalene is unclear.



Scheme 38: C─H acetoxylation of **109**.

7.2 Olefination

C─H olefination which follows a different palladium cycle, was attempted with a thought that different experimental conditions might activate the less reactive C─H bonds in PAHs. The experimental conditions reported were excess of arene with 1 equiv of ethyl acrylate, 1 equiv of $PhCO_3$*t*-Bu oxidant and 5 mol%

$Pd(OAc)_2$-thioethercarboxylic acid catalytic system in AcOH (Scheme 17b).[210] The reaction conditions used for this work due to the limited amount and reactivity of subtrates were 1 equiv arene, 1.5 equiv of ethyl acrylate, 1.5 equiv of $PhCO_3t$-Bu and 10 mol% $Pd(OAc)_2$-thioethercarboxylic acid catalytic system in suitable solvent. Also considering the poor reactivity of PAHs, the reaction time was increased to 18 h from the original 6 h.

1. Screening of solvents, temperature and amount of catalyst

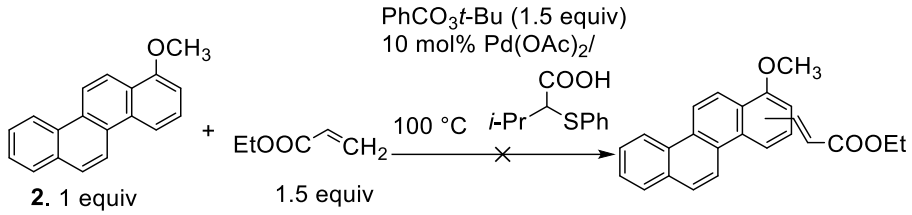
During their research on C−H olefination, M. Á. Fernández Ibáñez's group has screened several solvents like HFIP, *t*-amyl alcohol, THF, TFE etc but obtained high yields when experiments were done in AcOH.[210] Since AcOH was not suitable for chrysene and phenanthrene derivatives, other solvents such as propionic acid, *t*-amyl alcohol, TFE and THF were screened eventhough they were known to give poor yields for this reaction.

*1-methoxychrysene (**2**)*

According to the general procedure and using revised conditions, compound **2** was subjected to C─H olefination at 100 °C for 18 h (Table 14). Compound **2** was soluble in propionic acid and THF during the reaction, but in the remaining solvents it was insoluble (Table 14, entries 1−4). Unfortunately no product was observed in experiments using propionic acid or THF.

Considering propionic acid to be a better replacement for the original solvent AcOH in C─H olefination, an experiment was conducted at 140 °C to observe the effect of temperature and amount of catalyst together by increasing the Pd-ligand catalytic system to 1 equiv. However, no product was observed in this experiment (Table 14, entry 5).

Table 14: C─H olefination of compound **2**.



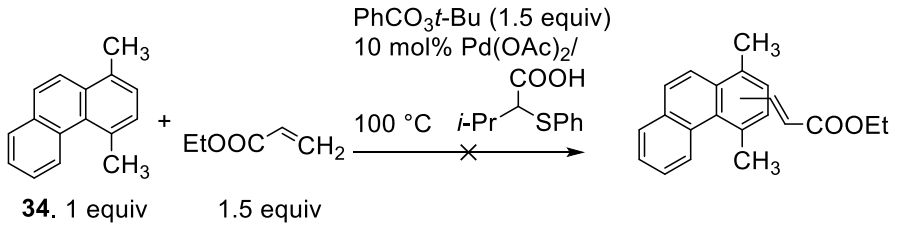
Entry	Catalytic system (equiv)	Solvent composition (volume mL)	Molarity (M)
1[a]	0.10	Propionic acid (0.97)	0.20
2[b]	0.10	*t*-Amyl alcohol (0.97)	0.20
3[a]	0.10	THF (0.97)	0.20
4[b]	0.10	TFE (0.97)	0.20
5[a,c]	1	Propionic acid (0.36)	0.20

[a] Recovered PAH; [b] PAH insoluble; [c] Reaction temperature 140 °C.

*1,4-dimethylphenanthrene (**34**)*

Compound **34** was subjected to C─H olefination at 100 °C (Table 15). It was soluble in propionic acid, *t*-amyl alcohol and THF but partially soluble in TFE (Table 15, entries 1−4). Unfortunately, no product was observed in any of the four experiments. Another set of experiments using 1 equiv Pd-ligand catalytic system were performed in propionic acid at 140 °C (Table 15, entry 5) and *t*-amyl alcohol at 100 °C (Table 15, entry 6) to check the effect of temperature and amount of catalyst on the reactivity of **34**. However, there was no product observed in either case.

Table 15: C─H olefination of **34**.



Entry	Catalytic system (equiv)	Solvent (volume mL)	Molarity (M)
1[a]	0.10	Propionic acid (0.97)	0.20
2[a]	0.10	*t*-Amyl alcohol (0.97)	0.20
3[a]	0.10	THF (0.97)	0.20
4[a]	0.10	TFE (0.97)	0.20
5[a,b]	1	Propionic acid (0.36)	0.20
6[a]	1	*t*-Amyl alcohol (0.36)	0.20
7[a,c]	0.10	Propionic acid (0.97)	0.20

[a] Recovered PAH; [b] Reaction temperature 140 °C; [c] Microwave irradiation.

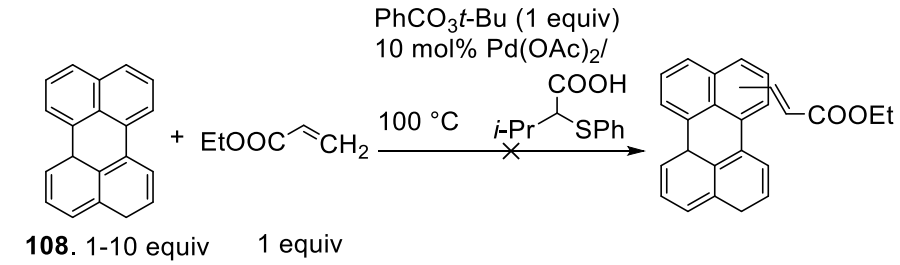
After the several attempts to activate chrysene and phenanthrene derivatives, it was assumed that microwave radiation might activate the chemically less reactive PAHs. Hence compound **34**, as shown in Table 15, entry 7, was irradiated for 6 h at 100 ℃ in a microwave reactor. Unfortunately, no product was formed in this experiment either.

2. Reactivity of perylene (108) and anthracene (109)

Since both the compounds **108** and **109** are commercially available, experiments were performed with excess of arenes.

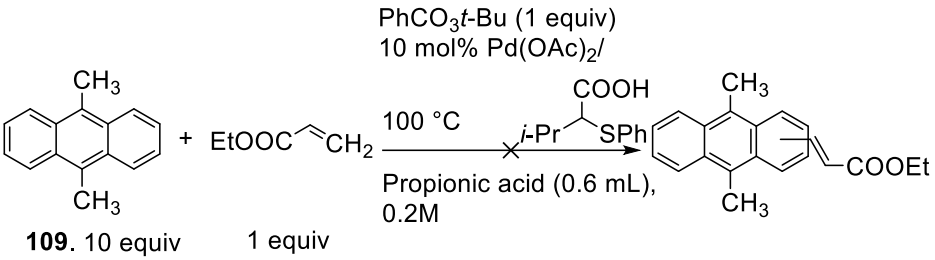
The PAH **108** was subjected to C─H olefination at 100 ℃ with 1.5 equiv of oxidant and 10 mol% Pd-ligand in different solvents and different amounts of PAH, as shown in Table 16. However, perylene was found to be insoluble in AcOH, propionic acid, DCE and THF (Table 16, entries 1−4).

Table 16: C─H olefination of **108**.



Entry	Arene (equiv)	Solvent composition	Solvent volume (mL)	Molarity (M)
1	3.3	Propionic acid + AcOH	0.10 + 0.15	0.48
2	1	Propionic acid	0.15	2.64
3	10	DCE	3.50	0.034
4	10	THF	3.20	0.037

To check the reactivity of C─H olefination in a higher member of acene series, an experiment using 10 equiv of PAH **109** was performed in propionic acid at 140 ℃, as shown in Scheme 39. However, no product was formed under these conditions.

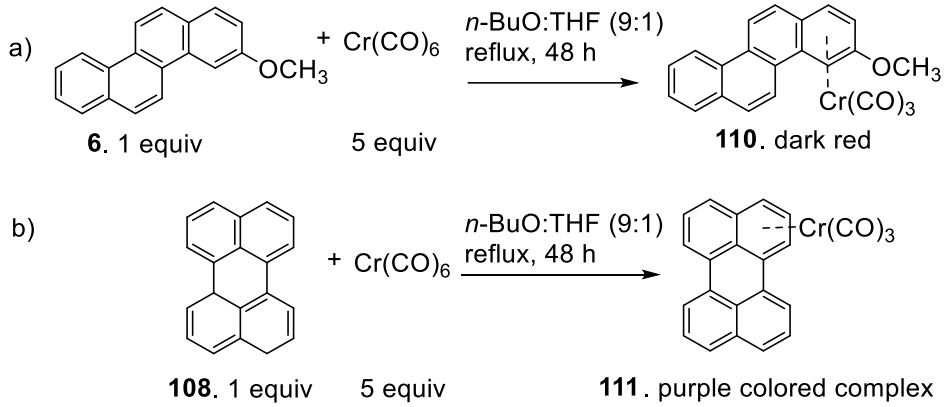


Scheme 39: C−H olefination of **109**.

7.3 *η*6 arene-chromium tricarbonyl complex

In order to increase the reactivity of C─H bonds, an attempt to synthesize metal complexes of PAHs were made in which the C─H bonds can be more acidic. Larrosa *et al* have employed arene-metal π-complexes in C─H arylations. The

formation of η^6 arene-chromium tricarbonyl complex reduces the electron density on the ring thereby increasing the acidity of corresponding C─H bonds.[273,274] Therefore, employing these arene-metal complexes were anticipated to assist in increasing the reactivity towards C─H bond activation.



Scheme 40: Preparation of η^6 arene-chromium tricarbonyl complexes a) η^6 3-methoxychrysene-chromium tricarbonyl complex (**110**); b) η^6 perylene-chromium tricarbonyl complex (**111**).

Experiments were done to prepare η^6 arene-chromium tricarbonyl complex with **6** (Scheme 40a) and **108** (Scheme 40b).[275] The progress of the reaction was checked intermittently for the formation of green precipitate (associated with decomposition) during the reaction time. As reported in literature, the reaction mixture turned dark red (chrysene complex) and purple (perylene complex) respectively.[276] TLC analysis of both the reactions showed a new spot below the starting material. The reaction mixture for compound **110** was purified by column chromatography and a dark red solid was obtained. Intriguingly, the ^{1}H-NMR spectrum of this solid was not found in agreement with literature.[276] There was no upfield shift observed in its proton peaks as expected. Although the HRMS of the compound correlated with η^6 3-methoxychrysene-chromium tricarbonyl complex (**110**). In case of compound **111**, it was observed that purple colour changed to green while evaporating the solvent after completion of the reaction. The complex **110** was found to be soluble in AcOH and thereby was further subjected to both acetoxylation and olefination at 100 °C in AcOH. In the experiment with C−H acetoxylation of the complex, the mixture in the pressure vial turned green, with some gas formation immediately after the

addition of AcOH and reagents. It might be possible that the complex is incompatible with reagents involved in the reaction. In the C−H olefination experiment, the reaction mixture after heating for 20 minutes turned dark green indicating decomposition of chrysene-chromium complex probably due to high temperature condition 100 °C. At the end of reaction time, the reaction mixtures from both the reactions were extracted and analyzed separately by ^{1}H-NMR, which showed the recovery of starting material **6**.

7.4 Conclusions

After testing the revised reaction conditions for C─H acetoxylation in naphthalene, attempts were focussed on chrysene and phenanthrene derivatives. The C─H acetoxylation and olefination experiments using PAHs were initially challenged with poor solubility of substrates in polar, protic solvents such as AcOH, which was overcome by using propionic acid. However, several attempts to functionalise the C─H bonds in PAHs performed by changing the possible parameters afforded no product formation. It was difficult to extend the scope of the catalytic systems of C─H acetoxylation and olefination to even anthracenes belonging to same acene series similar to benzene and naphthalene. As discussed in Section 1.2, phenacenes are known to be less reactive than acenes. However, the reason behind the futile attempts in activating C─H bonds in **109** is still unclear.

C─H bond activation is growing to an enormous field with several catalysts being developed and optimised answering the needs of the synthetic chemist. However, there are only few methods demonstrated in the functionalization of PAHs using this apporach.[102,277] Therefore, the method needs development of stronger catalytic conditions with suitable solvents for the activation of chemically less reactive PAHs.

Chapter 8. Summary and future outlook

Oxidative photocyclization has always proved to be a robust approach to prepare PAHs as starting materials. The procedure was employed efficiently using literature procedures to prepare starting materials in Chapter 3 for most of the experiments during the study. Methoxychrysenes **2**, **4**, and **6**, Methylchrysene carboxylates **8** and **10**, other chrysene derivatives **12**, **14**, **16** and **18** were all synthesized in 32% to 85% yields. The compatibility of the reagents with the substitutions on the core structure was neccessary. During the synthesis of 2-bromo-3-methylchrysene (**14**), traces of debrominated side-product was observed.

The presence of sterically bulky substituents such as *N*,*N*-diethyl-*O*-carbamates assisted in achieving regioselectivity preferring the formation of sterically less crowded isomer chrysene-2-yl *N*,*N*-diethyl-O-carbamate (**22**) over chrysene-4-yl *N*,*N*-diethyl-*O*-carbamate (**21**) in 7:3 ratio. Additionally, the presence of aliphatic substituents such as 2,4,4-trimethylpentan-2-yl as observed in Scheme 22 (**28** → **29**), improved the solubility of the reactant and product at the cost of longer reaction time and reduced yield. The regioselectivity was also attained with the formation of thermodynamically stable products in the presence of multiple sites of photocyclization as observed in the photocyclization of 5-(2-(naphthalene-2-yl)benzofuran-2-crabonitrile (**25** → **26** + **27**, Scheme 21).

The presence of styryl double bond was deemed important for the progress of oxidative photocyclization after a futile attempt to photocylize non-stilbene based dihydropyrrolo[3,2-*b*]pyrrole substrate **30**. In some cases, optimization of reaction conditions was required for the specific substrates such as using TEMPO in-place of I_2 for 1,4-dimethylphenanthrene (**34)** and solvent conditions for 3-methoxyphenanthrene (**37)**. It is therefore necessary to continue the development of new alternative oxidants and reaction conditions from time-to-time depending on different substrates and their reactivity.

Using the methoxychrysenes **2**, **4** and **6** and methylchrysene carboxylates **8** and **10**, from Section 3.1, chrysenyl carbamates (**42**, **22** and **43**) and chrysenyl carboxamides (**12** and **64**) were prepared respectively, to conduct D*o*M experiments on chrysenes (Chapter 4). The approach was highly efficient to

attach electrophiles on the PAHs. Chrysenyl carbamate **42** gave *ortho*-substituted products selectively as single isomers in good yields. Notably, the choice of base and DMG is important to attain complete regioselectivity. For instance, **22** resulted in the formation of mixture of di-substituted regioisomers under the standard conditions of *s*-BuLi /TMEDA and electrophilic quench. However, changing the base to sterically demanding LiTMP afforded complete regioselectivity in these experiments. Similarly, on changing the DMG from *N*,*N*-diethyl-O-carbamate (**43**) to *N*,*N*-diethylcarboxamide (**64**) in chrysen-3-yl, the regioselectivity was compromised under standard conditions. In such circumstances also, using a sterically demanding LiTMP was more efficient in achieving complete regioselective product. The choice of LiTMP base was depedent on the reactivity and steric crowding on the substrate. When the preferable *ortho*-position was strategically blocked in **60** and **61**, *peri*-lithiations and lithiation at other available sites were not successful in chrysen-1-yl and chrysen-3-yl carbamates. Nevertheless, few reports are available discussing the successful *peri*-lithiation of naphthalene derivatives.[219] Henceforth, further experimental and computational studies are needed to confirm the absence of metalation at *peri*-position and other available sites in chrysene derivatives. However, the strategy was efficient in providing pre-functionalized substrated **65** and **66** for subsequent cross-coupling experiments in Chapter 5.

The application of sequential cross-coupling and DreM have been used to synthesize various (hetero)aromatic structures that form basis of many natural products and pharmaceutical products.[193] The approach has been successfully applied to 2-iodochrysene carboxamides **65** and **66** obtained from D*o*M study, for the synthesis of larger PAHs as discussed in this thesis, Chapter 5 and 6. During the process, cross-coupling of bulky substrates **65** and **66** with methylnaphthalenyl boronic esters **79**–**81** became the crucial point. The cross-coupling reaction conditions have been specific to the substrates and demands optimization most of the time. In this study, the rection conditions used for the cross-coupling of **65** /**66** with *o*-TBA were not suitable in experiments with **79**–**81**. Similarly, the catalyst which was efficient in cross-coupling of **65** /**66** with **79**–**81** turned out to be sluggish for **65** with **82**. In the event of cross-coupling bulky and sterically demanding substrates, the steric factors were dominant over electronic parameters. The choice of catalyst considering the ligand bite-

angle was crucial for the success of this step. Further experimentation can be done to optimize the catalyst suitable to cross-couple **65** /**66** with **82**.

In Chapter 6, DreM experiments afforded the formation of larger PAHs **94** and **98** under standard conditions. Similarly, the unsymmetrical biarylic substrates **86** and **90**, containing 3-methylnaphthalen-2-yl moiety, also resulted in efficient formation of the PAHs **97** and **101** respectively under standard DreM conditions at rt. While the substrates **84**, **88** and **92**, containing 2-methylnaphthalen-1-yl moiety, required slightly higher temperature 40 °C to form the PAHs **95**, **99** and **102** respectively. However, the DreM experiments conducted during this study were not sufficient to understand the mechanism of fluorenone formation from **93**. For the reason that in larger substrates bearing 1-methylnaphthalen-2-yl moiety, the DreM experiements were unsuccessful and did not afford fluorenone, for e.g. **85** and **89**. To understand the intriguing reactivity pattern of DreM in the presence of different methylnaphthalenyl moieties, cryogenic crystallizations of reaction intermediates were attempted and the work is in progress. Computational calculations are also planned to rationalize the regioselective DreM cyclization to form a 6-membered aromatic ring as in PAHs or 5-membered aromatic ring as in fluorenone. Nonetheless, the study resulted in the synthesis of larger PAHs on which the preliminary measurements of fluorescence and UV-visible spectra were conducted. The synthesized larger PAHs seemed to be potential candidates for advanced studies to estimate their photophysical properties and scope of usage in material science. The directed metalation and sequential cross-coupling was also presented as a step- and atom-efficient method to synthesize larger organic structures.

An alternative way to functionalize chrysene derivatives by conducting acetoxylation and olefination on PAHs through C─H activation did not yield any preliminary results although several reactions parameters were altered (Chapter 7). Most of the developments in this area are being done on simpler aromatic systems such as benzenes and naphthalenes. New catalytic systems that are compatible and show high regioselecitivity with complex and bulky molecules are required and which can be applied in a step-efficient organic syntheses.

Chapter 9. Experimental information

9.1 General information

Materials

The reactions were conducted in an oven-dried glassware under inert N_2 or air atmosphere as mentioned in the experimental procedures. The anhyd solvents tetrahydrofuran (THF), *N*,*N*-dimethylformamide (DMF), toluene and benzene were purchased commercially and used as supplied. All other solvents were dried over molecular sieves (MS) before use. Butyllithium (BuLi in cyclohexane) was titrated before use to know the accurate concentration for stoichiometric calculations.[278] *N*,*N*,*N'*,*N'*-tetramethylethylenediamine (TMEDA) and diisopropyl amine (DIIPA) were distilled from KOH before use. 4,4,5,5-tetramethyl-1,3,2-dioxaborolane (pinBH), all other reagents, and catalysts was purchased commercially and used as procured.

Methods and instrumentation

Photocyclizations were conducted using a 400 W, medium pressure, and Mercury vapour lamp. The synthesized compounds were purified using silica gel 40-63 µm. Routine TLC analysis was carried out on aluminium sheets coated with silica gel purchased from Merck KGaA. TLC plates were viewed with a 254 nm UV lamp. ^{1}H-NMR spectra were obtained on a 400 MHz Bruker spectrometer. ^{13}C-NMR spectra were obtained at 100 MHz. High-resolution mass spectra (HRMS) were obtained by using either (positive or negative) electrospray ionisation (ESI) or electron impact (EI) technique . Infrared spectra (IR) were recorded on Perkin Elmer FTIR spectrometer using KBr pellets. Melting points (MP) were recorded on a Stuart Scientific melting point apparatus SMP3 and are uncorrected. UV-visible absorption spectra was measured on VWR UV-1600PC spectrophotometer. Fluorescence emission and excitation spectra were measured on F-7000 FL spectrophotometer.

NMR data

All NMR spectra were processed using Topspin© NMR software. All chemical shift values are reported in parts per million (ppm) relative to the solvent signal.

The NMR spectra were determined for the samples dissolved in either $CDCl_3$ + TMS ($CDCl_3$ at ^{1}H-NMR: 7.26 ppm, singlet and ^{13}C-NMR: 77.0 ± 0.2 ppm, triplet; TMS at 0 ppm, singlet in both ^{1}H and ^{13}C- NMR) or $C_2D_2Cl_4$ (^{1}H-NMR: 5.91 ppm, singlet and ^{13}C-NMR: 73.78 ppm, triplet) or DMSO-d_6 (^{1}H-NMR: 2.50 ppm, quintet and ^{13}C-NMR: 39.52 ppm, septet). The coupling constant (*J*) values are reported in Hz. The notation of signals is: ^{1}H-NMR (solvent): δ = chemical shift in ppm (multiplicity, *J* value(s), number of protons); ^{13}C- NMR (solvent): δ = chemical shift in ppm (number of carbons). If assignment is ambiguous, for example in the case of overlapping signals, a range of shifts is reported as multiplet. The NMR peak splitting is described as singlet (s), doublet (d), triplet (t), doublet of doublet (dd), triplet of doublet (td) and multiplet (m). The peaks due to solvent impurities in the region of 0-5 ppm (^{1}H-NMR) and 0-40 ppm (^{13}C-NMR) were left unassigned.

9.2 Preparation of starting materials

General procedure (A) for the preparation of Wittig salt

Triphenylphosphine (1 equiv) was dissolved in anhyd toluene (1 mL/mmol). Subsequently, 1-(chloromethyl)naphthalene (1 equiv) or (bromomethyl)benzene (1 equiv) was added to this solution. The reaction mixture was refluxed for 2 days or until the complete consumption of starting materials under N_2 atmosphere for the product to precipitate out. The solvent is removed under reduced pressure and the crude Wittig salt is washed with Et_2O for 5 times to remove left over reactants. The pure salt is dried under reduced pressure and used further for Wittig reactions.[212]

General procedure (B) for Wittig reaction

The Wittig salt (1.2 equiv) was suspended in a solution of the corresponding benzaldehyde derivative (1 equiv) in anhyd THF. The contents were cooled down to 0 °C before the slow addition of NaH (1.5 equiv, 60% dispersion). The reaction mixture was refluxed at 65 °C under N_2 atmosphere and monitored by TLC at frequent time intervals. After the completion of reaction, the reaction mixture was cooled down to rt and subsequently quenched with ice-cold water. The product was extracted with Et_2O, washed with brine and dried over anhyd $MgSO_4$. The crude product was purified by flash column chromatography

(eluted using EtOAc in Heptane). The pure stilbenoid derivatives were used as substrates for photocyclization reactions.

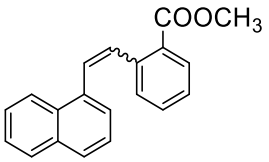
General procedure (C) for photocyclization

The stilbenoid derivative (1 equiv) was dissolved in degassed toluene or cyclohexane (250 − 900 mL) and fed into the photoreactor. The required reagents were added to the solution in the photoreactor depending on the suitable reaction conditions followed: in Mallory conditions, catalytic amount of I_2 (5 mol%) was added to conduct the reaction in the presence of air. In Katz conditions, 1,2-epoxybutane (30 equiv) and stoichiometric amount of I_2 (1.2 − 3 equiv) was added to the reaction mixture under N_2 atmosphere. The reaction mixture was irradiated until the completion of reaction, monitored at frequent intervals of time using TLC or ^{1}H-NMR. After the completion of reaction, the excess solvent was evaporated *in vacuo*. The reaction mixture was washed with 10% aq $Na_2S_2O_3$, followed with brine and dried over anhyd $MgSO_4$. The solvent was removed under reduced pressure to obtain crude product which was purified using flash column chromatography (eluted with EtOAc in Heptane or pure cyclohexane).

9.2.1 Synthesis of chrysene derivatives

The stilbenoid precursors and photocyclized products (**1** – **6**) were prepared by following literature procedures (general procedure B followed by C using Katz conditions). The characterization data was in accordance with those reported in literature for all the compounds.[212]

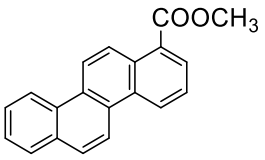
Methyl 2-(2-(naphthalen-1-yl)vinyl)benzoate (7)



(Naphthalen-1-ylmethyl)triphenylphosphonium chloride (6.417 g, 14.62 mmol) was suspended in a solution of methyl 2-formylbenzoate (1.999 g, 12.18 mmol) dissolved in THF (90 mL). NaH (0.731 g, 18.30 mmol, 60% dispersion) was added to the suspension at 0 °C. The reaction mixture was refluxed for 7

h. It was cooled down to rt before quenching with ice-cold water (75 mL). The crude product was extracted with Et_2O (3 * 75 mL) and purified with flash chromatography (0 to 10% EtOAc in heptane) to obtain a pale yellow liquid (2.78 g, 79%) as a mixture of *Z* and *E* isomer in 1:2 ratio (from NMR). ^{1}H-NMR (400 MHz, $CDCl_3$): δ = 8.26 (d, *J* = 8.2 Hz, 1H – E isomer), 8.16 – 8.14 (m, 1H – *Z* isomer), 8.02 (d, *J* = 15.9 Hz, 1H – *E* isomer), 7.99 (dd, *J* = 1.1, 7.9 Hz, 1H – *E* isomer), 7.94 (dd, *J* = 1.2,7.8 Hz, 2H – *Z* isomer), 7.90 – 7.82 (m, 5H), 7.79 (d, *J* = 16 Hz, 1H – *E* isomer), 7.69 (d, *J* = 8.2 Hz, 1H – *Z* isomer), 7.60 – 7.50 (m, 6H), 7.40 – 7.36 (m, 1H – *E* isomer, 1H – *Z* isomer), 7.25 – 7.16 (m, 1H – *E* isomer, 2H – *Z*), 7.13 – 7.11 (m, 1H – *Z* isomer), 7.08 – 7.04 (m, 1H – *Z* isomer), 6.95 (d, *J* = 7.8 Hz, 1H – *Z* isomer), 3.95 (s, 3H – *E* isomer), 3.91 (s, 3H – *Z* isomer) ; ^{13}C-NMR (100 MHz, $CDCl_3$): δ = 168.1 (*E* isomer), 167.8 (*Z* isomer), 139.7 (*E* isomer), 139.4 (*Z* isomer), 135.1, 134.5, 133.9, 133.7, 132.4, 132.3, 132.1, 131.7, 131.6, 131.3, 130.9, 130.7, 130.5, 129.5, 128.9, 128.8, 128.6, 128.59, 128.5, 128.4, 127.7, 127.54, 127.52, 127.5, 127, 126.3, 126.2, 125.9 (2C), 125.5, 124.8, 124.4, 123.9, 52.3 (*E* isomer), 52.2 (*Z* isomer) ; FTIR (KBr, cm^{-1}): 3059, 2949, 1718, 1596, 1480, 1433, 1293, 1278, 1259, 1244, 1130, 1076, 963; HRMS (ESI) m/z sample sent for analysis.

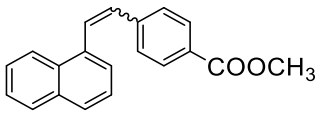
Methyl chrysene-1-carboxylate (8)



The stilbenoid derivative **7** (2.99 g, 10.40 mmol), 1,2-epoxybutane (27 mL, 0.31 mol) and I_2 (3.17 g, 12.50 mmol) was dissolved in degassed toluene (900 mL) and charged into a photoreactor and irradiated for 19 h. The reaction mixture was then washed with with 10% aq $Na_2S_2O_3$ solution followed with brine. The organic layer was dried on anhyd $MgSO_4$ and the solvent was evaporated completely under reduced pressure. The crude product was purified by flash column chromatography (10% EtOAc in heptane) to obtain white solid as product (1.43 g, 48% yield). MP (°C): 164.0 – 166.0 (Heptane + EtOAc); ^{1}H-NMR (400 MHz, $CDCl_3$): δ = 9.06 (dd, *J* = 0.6, 9.6 Hz, 1H), 9.01 (d, *J* = 8.7 Hz, 1H), 8.85 (d, *J* = 9.5 Hz, 1H), 8.81 (d, *J* = 8.1 Hz, 1H), 8.71 (d, *J* = 9.1 Hz, 1H), 8.28 (dd, *J* = 1.2, 7.3 Hz, 1H), 8.03 (d, *J* = 9.2 Hz, 1H), 8.01 (dd, *J* =

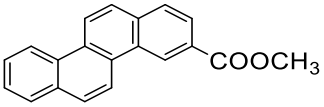
1.3, 8.1 Hz, 1H), 7.76 – 7.71 (m, 2H), 7.69 – 7.75 (m, 1H), 4.07 (s, 3H); ^{13}C-NMR (100 MHz, $CDCl_3$): δ = 168.5, 132.3, 131.2, 130.7, 130.4, 130.0, 128.6, 128.2 (2C), 128.1, 127.92, 127.9, 127.0, 126.9, 125.4, 124.5, 123.4, 123.2, 121.2, 52.5; FTIR (KBr, cm^{-1}) 2953, 1720, 1438, 1296, 1270, 1255, 1144, 1112, 803, 760; HRMS (ESI) *m/z* $[M + Na]^+$ for formula $C_{20}H_{14}NaO_2$: calcd 309.0886; found 309.0889.

Methyl 4-(2-(naphthalen-1-yl)vinyl)benzoate (9)



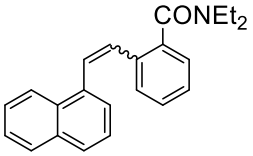
(Naphthalen-1-ylmethyl)triphenylphosphonium chloride (12.83 g, 29.23 mmol) was suspended in a solution of methyl 4-formylbenzoate (4.395 g, 26.77 mmol) dissolved in THF (180 mL). NaH (1.46 g, 36.50 mmol, 60% dispersion) was added to the suspension at 0 °C. The reaction mixture was refluxed for 7 h before cooling down to rt. It was then quenched with ice-cold water (150 mL). The crude product was extracted with Et_2O (3 * 150 mL) and purified with flash chromatography (10% EtOAc in heptane) to a pale yellow solid (6.8 g, 88%) as a mixture of *Z* and *E* isomers in the ratio 36:64 (from NMR). MP (°C) 77.1 – 82.6 (EtOAc); ^{1}H-NMR (400 MHz, $CDCl_3$): δ = 8.23 (d, *J* = 8.3 Hz, 1H), 8.09 – 8.04 (m, 1H), 8.08 (d, *J* = 8.42 Hz, 2H), 8.01 (d, *J* = 16.1 Hz, 1H – *E* isomer) 7.90 – 7.88 (m, 3H – *Z* isomer), 7.84 (d, *J* = 8.2 Hz, 1H), 7.80 – 7.75 (m, 3H – *Z* isomer), 7.66 (d, *J* = 8.2 Hz, 2H), 7.59 – 7.47 (m, 5H), 7.35 – 7.30 (m, 3H – *Z* isomer), 7.20 (d, J = 11.8 Hz, 1H – *Z* isomer), 7.19 (d, *J* = 16.2 Hz, 1H – *E* isomer), 7.14 (d, *J* = 8.3 Hz, 1H), 6.87 (d, *J* = 12.2 Hz, 1H – *Z* isomer), 3.95 (s, 3H – *E* isomer), 3.85 (s, 3H – *Z* isomer); ^{13}C-NMR (100 MHz, $CDCl_3$): δ = 167.1 (*E* isomer), 167.0 (*Z* isomer), 142.2 (*E* isomer), 141.7 (*Z* isomer), 134.8 (*Z* isomer), 134.6 (*E* isomer), 133.9 (*E* isomer), 133.87 (*Z* isomer), 131.6 (*Z* isomer), 131.55 (*E* isomer), 131.3, 131.1, 130.8, 130.3 (3C), 129.5, 129.3, 129.1, 128.9, 128.8, 128.7, 128.65, 128.5, 128.4, 128.1, 126.7 (3C), 126.5, 126.4, 126.3, 126.2, 125.8, 125.7, 124.9, 124.1, 123.8, 52.3 (*E* isomer), 52.1 (*Z* isomer); FTIR (KBr, cm^{-1}): 3060, 2951, 1715, 1602, 1507, 1437, 1412, 1285, 1194, 1109, 1016, 973, 792; HRMS (ESI) *m/z* $[M + H]^+$ for formula $C_{20}H_{17}O_2$: calcd 289.1224; found 289.1226.

Methyl chrysene-3-carboxylate (10)



Methyl 4-(2-(naphthalen-1-yl)vinyl)benzoate (**9**) (2.36 g, 8.17 mmol), 1,2-epoxybutane (21 mL, 0.25 mol) and I_2 (2.50 g, 9.80 mmol) was dissolved in degassed toluene (900 mL) and charged into a photoreactor and irradiated for 11.5 h. After the completion of reaction, the reaction mixture was washed with with 10% aq $Na_2S_2O_3$ solution followed with brine. The organic layer was dried on anhyd $MgSO_4$ and the solvent was evaporated completely under reduced pressure. The crude product was purified by flash column chromatography (10% EtOAc in heptane) to obtain white solid as product **10** (1.99 g, 85% yield). MP (°C) 139.0 – 141.3 (cyclohexane + DCM); ^{1}H-NMR (400 MHz, $CDCl_3$): δ = 9.50 (s, 1H), 8.77 (dd, *J* = 1.8, 9.1 Hz, 2H), 8.74 (d, *J* = 8.4 Hz, 1H), 8.21 (dd, *J* = 1.6, 8.4 Hz, 1H), 8.04 (d, *J* = 9.1 Hz, 1H), 8.01 – 7.97 (m, 3H), 7.74 – 7.70 (m, 1H), 7.68 – 7.64 (m, 1H), 4.05 (s, 3H); ^{13}C-NMR (100 MHz, $CDCl_3$): δ = 167.5, 134.8, 132.4, 130.5, 130.0, 128.9, 128.8 (2C), 128.6, 128.2, 128.0, 127.0, 126.9, 126.8, 126.2, 126.1, 123.8, 123.2, 121.2, 52.5; FTIR (KBr, cm^{-1}) 2953, 1719, 1619, 1433, 1298, 1274, 1242, 1118, 857, 812, 758; HRMS (ESI) *m/z* [M + Na]$^+$ for formula $C_{20}H_{14}NaO_2$: calcd 309.0886; found 309.0892.

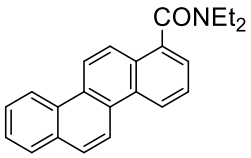
***N,N*-diethyl-2-(2-(naphthalen-1-yl)vinyl)benzamide (11)**



Following the general procedure B, *N,N*-diethyl-2-(2-(naphthalen-1-yl)vinyl)benzamide (**11**) was prepared from (naphthalen-1-ylmethyl)triphenylphosphonium chloride Wittig salt (10.30 g, 23.40 mmol) and *N,N*-diethyl-2-formylbenzamide (4.002 g, 19.49 mmol) in the presence of NaH (1.17 g, 29.30 mmol, 60% dispersion). The reaction mixture in THF was refluxed for 3 h. After completion of the reaction, it was quenched with ice-cold water (100 mL). Normal workup with Et_2O (3 * 150 mL) and purification

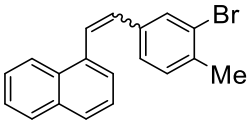
of crude compound by flash column chromatography (25% EtOAc in PE) afforded the stilbenoid derivative in more than 90% yield.

***N,N*-diethylchrysene-1-carboxamide (12)**



The stilbenoid derivative **11** (3.68 g, 11.20 mmol), 1,2-epoxybutane (29 mL, 0.34 mol) and I_2 (3.97 g, 15.60 mmol) was dissolved in degassed toluene (900 mL) and charged into a photoreactor and irradiated for 2.5 days. The reaction mixture was then washed with with 10% aq $Na_2S_2O_3$ solution followed with brine. The organic layer was dried on anhyd $MgSO_4$ and the solvent was evaporated completely under reduced pressure. The crude product was purified by flash column chromatography (20% EtOAc in heptane) to obtain off-white solid as product (2.02 g, 55% yield). The characterization data are presented in subsequent Section 9.3.

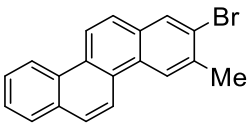
1-(3-bromo-4-methylstyryl)naphthalene (13)



(Naphthalen-1-ylmethyl)triphenylphosphonium chloride (5.30 g, 12 mmol) was suspended in a solution of 3-bromo-4-methylbenzaldehyde (2 g, 10 mmol) dissolved in THF (100 mL). NaH (0.80 g, 20 mmol) was added to the suspension at 0 °C. The reaction mixture was refluxed for 3 h before cooling down to rt. It was then quenched with ice-cold water (75 mL). The crude product was extracted with Et_2O (3 * 75 mL) and purified with flash chromatography (heptane) to obtain a pale yellow solid of **13** (3.65 g, quant) as mixture of *Z* and *E* isomers in the ratio 75:25 (from NMR). MP (°C): 84.8 – 90.3 (cyclohexane + DCM); ^{1}H-NMR (400 MHz, CDCl3): δ = 8.23 (dd, *J* = 1.1, 8.2 Hz, 1H – *E* isomer), 8.08 – 8.06 (m, 1H – *Z*), 8.03 – 8.01 (m, 1H – *Z*), 7.91 – 7.86 (m, 2H – *E* and Z), 7.83 – 7.79 (m, 3H – *E* and Z), 7.75 – 7.72 (m,

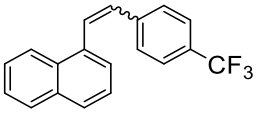
1H – *E*, 1H, *Z*), 7.75 – 7.49 (m, 4H – *E* and *Z*), 7.44 (dd, *J* = 1.8, 7.8 Hz – 1H, *E*), 7.41 – 7.40 (m, 1H – *Z*), 7.38 – 7.33 (m, 1H – *E*), 7.26 (d, *J* = 7.9 Hz, 1H – *E*), 7.08 (d, *J* = 12.0 Hz, 1H – *Z*), 7.06 (d, *J* = 16.0 Hz, 1H – *E*), 6.90 – 6.84 (m, 2H – *Z*), 6.75 (d, *J* = 12.0 Hz, 1H – *Z*), 2.72 (s, 3H – *Z*), 2.45 (s, 3H – *E*), 2.29 (s, 3H – *Z*); ^{13}C-NMR (100 MHz, $CDCl_3$): δ = 137.3, 136.7, 136.3, 134.9, 134.8, 134.4, 133.9, 133.8, 133.7, 133.0, 132.7, 131.6, 131.5, 131.1, 130.5, 130.4, 130.35, 130.2, 129.3, 128.8, 128.7, 128.6, 128.4, 127.9, 127.8, 126.7, 126.6, 126.5, 126.4, 126.3, 126.26, 126.1, 126.0, 125.83, 125.8, 125.7, 125.66, 125.5, 124.9, 124.6, 124.2, 123.8, 123.79, 22.9, 22.7, 19.5; FTIR (KBr, cm^{-1}): 3046, 1489, 1033, 978, 957, 886, 818, 793, 770, 739; HRMS (ESI) m/z $[M]^+$ for formula $C_{19}H_{15}Br$: calcd 322.0352; found 322.0353.

2-bromo-3-methylchrysene (14)



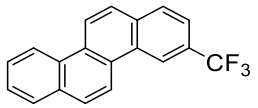
The stilbenoid derivative **13** (1.53 g, 4.75 mmol) was dissolved in degassed toluene (900 mL) followed by the addition of 1,2-epoxybutane (13 mL, 0.14 mol) and I_2 (3.62 g, 14.30 mmol) and charged into a photoreactor vessel. The reaction mixture was irradiated for 24 h. After the completion of reaction, the organic layer was washed with 10% aq $Na_2S_2O_3$ (300 mL), brine (300 mL) and dried over anhyd Na_2SO_4. The crude compound was purified with flash chromatography (heptane) to obtain white solid as product **14** (0.86 g, 57%). MP (°C): 248.0 – 250.1 (DCM); ^{1}H-NMR (400 MHz, CDCl3): δ = 8.75 (d, *J* = 8.3 Hz, 1H), 8.65 (app t, *J* = 9.2 Hz, 2H), 8.60 (s, 1H), 8.17 (s, 1H), 8.00 (d, *J* = 9.6 Hz, 1H), 7.99 (dd, *J* = 1.3, 7.8 Hz, 1H), 7.86 (d, *J* = 9.1 Hz, 1H), 7.73 – 7.69 (m, 1H), 7.66 – 7.62 (m, 1H), 2.70 (s, 3H); ^{13}C-NMR (100 MHz, CDCl3): δ = 136.1, 132.3, 131.9, 131.5, 130.7, 129.8, 128.7, 128.5, 127.73, 127.7, 127.0, 126.7, 126.0, 124.8, 124.0, 123.3, 121.7, 121.1, 23.9; FTIR (KBr, cm^{-1}): 3049, 1434, 1256, 953, 887, 828, 814, 749; HRMS (ESI) m/z $[M]^+$ for formula $C_{19}H_{13}Br$: calcd 320.0196; found 320.0195.

1-(4-(Trifluoromethyl)styryl)naphthalene (15)



(Naphthalen-1-ylmethyl)triphenylphosphonium chloride (6.05 g, 13.8 mmol) was suspended in a solution of *p*-trifluoromethylbenzaldehyde (1.57 mL, 2 g, 11.50 mmol) dissolved in THF (90 mL). NaH (0.689 g, 17.2 mmol, 60% dispersion) was added to the suspension at 0 °C. The reaction mixture was refluxed for 8 h. After the completion of the reaction, it was cooled down to rt before quenching with ice-cold water. The crude product was extracted with Et_2O and purified with flash chromatography (5% EtOAc in heptane) to obtain a pale yellow solid of **15** (3.35 g, 98%) as a mixture of *Z* and *E* isomers in 17:83 ratio (from NMR). MP (°C): 113.2 – 116 (EtOAc); ^{1}H-NMR (400 MHz, $CDCl_3$): δ = 8.22 (d, *J* = 8.2 Hz, 1H), 7.99 (d, *J* = 16.1 Hz, 1H – *E* isomer), 7.91 – 7.89 (m, 1H – *E* isomer, 1H – *Z* isomer), 7.86 (d, *J* = 8.2 Hz, 1H – *E* isomer, 1H – *Z* isomer), 7.77 (d, *J* = 7.2 Hz, 1H), 7.71 – 7.65 (m, 4H), 7.60 – 7.50 (m, 4H), 7.38 – 7.31 (m, 3H – *Z* isomer), 7.22 – 7.17 (m, 2H – *Z* isomer), 7.18 (d, *J* = 16.1 Hz, 1H – *E* isomer), 6.87 (d, *J* = 12.2 Hz, 1H – *Z* isomer); ^{13}C-NMR (100 MHz, $CDCl_3$): δ = 141.22, 141.21, 134.5, 133.9, 131.6, 131.55, 131.1, 130.8, 130.4, 129.8, 129.5, 129.4, 128.9, 128.86, 128.8, 128.5, 128.2, 126.9 (2C), 126.6, 126.5, 126.47, 126.3, 126.2, 125.93, 125.9, 125.86, 125.84, 125.8, 124.8, 124.1, 123.8, 123.1; FTIR (KBr, cm^{-1}): 3050, 1612, 1415, 1329, 1162, 1128, 1109, 1067, 1014, 969, 827, 796, 777; HRMS (ESI) m/z mass sample sent for analysis.

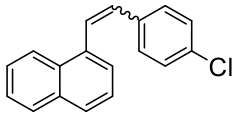
3-(Trifluoromethyl)chrysene (16)



1-(4-(trifluoromethyl)styryl)naphthalene (**15**) (3.43 g, 11.51 mmol), 1,2-epoxybutane (30 mL, 0.35 mmol) and I_2 (3.51 g, 13.81 mmol) in 900 mL of degassed toluene was charged into a photoreactor under inert atmosphere. The reaction was irradiated for 21 h before washing with 10% aq $Na_2S_2O_3$, brine and dried over anhyd $MgSO_4$. The crude compound was purified by flash

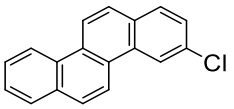
column chromatography (5% EtOAc in heptane) and then recrystallized in EtOAc to obtain **16** as white solid (2.42 g, 71% yield). MP (°C) 153.2 – 155.2 (EtOAc); ^{1}H NMR (400 MHz, $CDCl_3$) δ 9.06 (s, 1H), 8.84 (d, *J* = 9.1 Hz, 1H), 8.79 (d, *J* = 8.3 Hz, 1H), 8.71 (d, *J* = 9.1 Hz, 1H), 8.11-8.02 (m, 4H), 7.82 (dd, *J* = 1.4, 8.4 Hz, 1H), 7.77-7.73 (m, 1H), 7.70-7.66 (m, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 133.9, 132.6, 130.5, 130.0, 129.6, 129.0, 128.9, 128.7, 128.5, 128.4, 127.2, 127.1, 126.9, 126.2, 123.7, 123.5, 123.3, 122.34, 122.31, 121.1, 121.0, 120.96; FTIR (KBr, cm^{-1}): 1379, 1319, 1288, 1196, 1181, 1168, 1157, 1106, 1086, 1069, 912, 893, 847, 830, 756; HRMS (ESI) m/z mass sample sent for analysis.

1-(4-chlorostyryl)naphthalene (17)



(Naphthalen-1-ylmethyl)triphenylphosphonium chloride (8.27 g, 18.85 mmol) was suspended in a solution of *p*-chlorobenzaldehyde (2.208 g, 15.71 mmol) dissolved in THF (90 mL). NaH (0.854 g, 21.34 mmol, 60% dispersion) was added to the suspension at 0 °C. The reaction mixture was refluxed for 7.5 h. After the completion of the reaction, it was cooled down to rt before quenching with ice cold H_2O. The crude product was extracted with diethyl ether and purified with flash chromatography (5 − 10% EtOAc in heptane) to obtain a pale yellow product of **17** (4.15 g, quant) as a mixture of *Z* and *E* isomers.

3-Chlorochrysene (18)

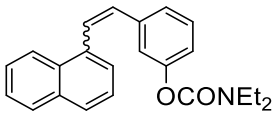


In a photoreactor under N_2 atmosphere, was taken the stilbenoid derivative **17** (4.87 g, 18.4 mmol), 1,2-epoxybutane (48 mL, 0.55 mmol) and I_2 (5.6 g, 22 mmol) in degassed toluene (900 mL). The reaction mixture was irradiated for 21 h. After the completion of reaction, the reaction mixture was washed with 10% aq $Na_2S_2O_3$ and brine. The organic layer was dried over anhyd $MgSO_4$ and the solvent was evaporated completely under reduced pressure. The crude

compound was purified by flash column chromatography (5% EtOAc in heptane) to obtain **18** as an off-white solid (3.05 g, 63% yield). MP (°C) 156.9 – 158.9 (EtOAc); ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.76 (dd, *J* = 0.3, 8.3 Hz, 1H), 8.72 (app s, 1H), 8.69 (d, *J* = 9.1 Hz, 1H), 8.58 (d, *J* = 9.1 Hz, 1H), 8.01-7.99 (m, 2H), 7.95 (d, *J* = 9.0 Hz, 1H), 7.91 (d, *J* = 8.6 Hz, 1H), 7.74-7.70 (m, 1H), 7.68-7.64 (m, 1H), 7.58 (dd, *J* = 2.0, 8.6 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 132.9, 132.5, 131.7, 130.54, 130.52, 130.1, 128.9, 128.8, 127.9, 127.5, 127.1, 127.0, 126.9 (2C), 123.4, 122.9, 121.7, 121.1; FTIR (KBr, cm^{-1}): 3050, 1592, 1483, 1430, 1090, 1024, 904, 840, 821, 797, 778, 752; HRMS (ESI) m/z mass sample sent for analysis.

Attempts to synthesize chrysen-4-yl N,N-diethyl O-carbamate (21)

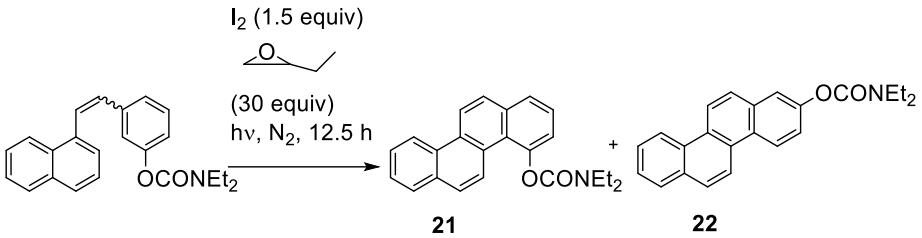
3-(2-(Naphthalen-1-yl)vinyl)phenyl diethylcarbamate (20)



The 1-(3-methoxystyryl)naphthalene (**19**) was prepared in gram-scale by following the general procedure B as reported in litertature.[212] The stilbenoid derivative **19** (5.735 g, 22.03 mmol) in DCM (150 mL) was treated with BBr_3 (3.18 mL, 33.10 mmol) at 0 °C. The reaction mixture was stirred at rt for 21 h. Normal work-up (extraction with EtOAc) and evaporation to dryness yielded the crude 3-(2-(naphthalen-1-yl)vinyl)phenol, which was disolved in THF (100 mL) and the resulting solution added to a suspension of NaH (1.32 g, 33.10 mmol, 60% dispersion) in THF (100 mL) at 0 °C, followed by the drop-wise addition of *N,N*-diethyl carbamoyl choride (3.1 mL, 24.23 mmol) at rt. The reaction mixture is stirred at rt for 21 h. Normal workup (extraction with EtOAc, 3 * 150 mL) and purification by flash column chromatography (25% EtOAc in PE) afforded a brown liquid **20** (4.51 g, 59%);^{1}H NMR (400 MHz, $CDCl_3$) δ = 8.23 (d, *J* = 8.1 Hz, 1H), 7.90 – 7.87 (m, 2H), 7.82 (d, *J* = 8.2 Hz, 1H), 7.73 (d, *J* = 7.2 Hz, 1 H), 7.57 – 7.48 (m, 3H), 7.44 – 7.37 (m, 3H), 7.14 (d, *J* = 15.9 Hz, 1H), 7.08 (dt, *J* = 2.1, 7.7 Hz, 1H), 3.50 – 3.40 (br. m, 4H), 1.32 – 1.23 (br. m, 6H); ^{13}C NMR (100 MHz, $CDCl_3$) δ = 154.2, 152.0, 139.0, 134.8, 133.7, 131.3, 131.1, 129.4, 128.6, 128.1, 126.5, 126.1, 125.8, 125.6, 123.8, 123.7, 123.67, 121.1, 119.6,42.2, 41.9, 14.3, 13.4; FTIR (NaCl, cm^{-1}) 2954, 2924, 2854, 1721, 1462, 1416, 1377, 1254, 1220, 1158, 1045, 970, 792,

770; HRMS (ESI) *m/z* $[M + H]^+$ for formula $C_{23}H_{24}NO_2$: calcd 346.1802; found 346.1804.

Chrysen-4-yl *N,N*-diethyl *O*-carbamate (21) and Chrysen-2-yl *N,N*-diethyl *O*-carbamate (22)

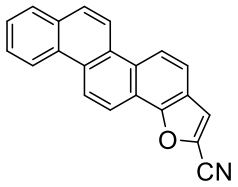


21 **22**

Following the general procedure C, the stilbenoid derivative **20** (4.511 g, 13.06 mmol) dissolved in degassed toluene (900 mL), was irradiated for 4 h in the presence of 1,2-epoxybutane (3 mL, 0.39 mol) and I_2 (3.98 g, 15.67 mmol). The excess solvent was evaporated under reduced pressure. The crude compound was extracted with EtOAc (3 * 150 mL), washed with 10% aq $Na_2S_2O_3$ and followed with brine. The organic layer dired on anhyd $MgSO_4$ was concentrated and purified by flash column chromatography (25% EtOAc in PE) to obtain a mixture of products **21** and **22** in the 3:7 ratio as a pale brown solid (3.06 g, 68%). MP (°C) 167.9 – 169.0 (EtOAc); ^{1}H NMR (400 MHz, $CDCl_3$): δ = 9,11 (d, *J* = 9.5 Hz, 1H, – **21**), 8.76 (d, *J* = 8.8 Hz, 2H – **22**), 8.72 (d, *J* = 9.0 Hz, 1H – **22**), 8.67 (d, *J* = 9.1 Hz, 1H – **22**), 8.01 – 7.95 (m, 3H – **22**, 1H – **21**), 7.93 (d, *J* = 9.4 Hz, 1H – **21**), 7.88 (dd, *J* = 1.2, 8.0 Hz, 1H – **21**), 7.76 (app d, *J* = 2.4 Hz, 1H – **22**), 7.73 – 7.68 (m, 1H – **22**, 1H – **21**), 7.66 – 7.61 (m, 1H – **22**, 1H – **21**), 7,60 (d, *J* = 7.8 Hz, 1H – **21**), 7.51 (dd, *J* = 2.4, 9.1 Hz, 1H – **22**), 7.39 (dd, *J* = 1.3, 7.6 Hz – **21**), 3.79 (q, *J* = 7.1 Hz, 2H – **21**), 3.56 – 3.27 (m, 4H – **22**, 2H – **21**), 1.49 (t, *J* = 7.1 Hz, 3H – **21**), 1.34 (t, *J* = 6.8 Hz, 3H – **22**), 1.30 – 1.25 (m, 3H – **22**, 3H – **21**); ^{13}C NMR (100 MHz, $CDCl_3$): δ = 154.3, 154.1, 149.8, 149.4, 134.6,132.9, 132.0, 131.8, 130.5, 130.3, 129.3, 128.5, 128.1, 127.99, 127.8, 127.6, 127.5, 127.4, 126.9, 126.7, 126.66, 126.5, 126.44, 126.42, 126.3, 126.1, 124.5, 124.46, 123.3, 123.0, 122.0, 121.9, 121.7, 121.68, 121.2, 119.4, 42.3, 422, 42.0, 41.9, 14.5, 14.3, 13.4 (2C); FTIR (KBr, cm^{-1}) 2979, 2965, 2932, 1703, 1473, 1456, 1420, 1379, 1272, 1242, 1219, 1185, 1164,

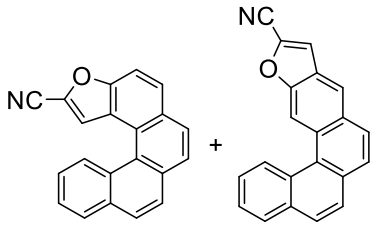
1097, 972, 880, 812, 798, 775, 758; HRMS (ESI) m/z $[M + Na]^+$ for formula $C_{23}H_{21}NNaO_2$: calcd 366.1465; found 366.1477.

Chryseno[1,2-*b*]furan-2-carbonitrile (24)



According to the general procedure C, the stilbenoid derivative **23** sent by the collaborators, (245 mg, 0.83 mmol) was dissolved in degassed toluene (approx. 200 ml) and fed into the photochemical reactor under N_2. It was followed by the addition of I_2 (0.25 g, 0.99 mmol) and 1,2- epoxybutane (2.17 mL, 24.91 mmol). The reaction mixture was irradiated for 4 h, by monitoring the progress on TLC. At the end of the reaction, the reaction mixture was washed with 10% aq $Na_2S_2O_3$ solution (100 mL) and followed with brine (100 mL). The organic layer was dried on anhyd $MgSO_4$ and the solvent was evaporated completely under reduced pressure. The crude product was washed with EtOAc to remove impurities and obtain white solid as product (236 mg, 97%). ^{1}H NMR (400 MHz, $C_2D_2Cl_4$): δ = 8.86 (d, *J* = 9.2 Hz, 1H), 8.75 (d, *J* = 8.3 Hz, 1H), 8.65 (d, *J* = 8.9 Hz, 1H), 8.64 (d, *J* = 9.2 Hz, 1H), 8.46 (d, *J* = 9.1 Hz, 1H), 8.00 (d, *J* = 9.2 Hz, 1H), 7.96 (dd, *J* = 1.1, 7.9 Hz, 1H), 7.82 (d, *J* = 8.9 Hz, 1H), 7.72 – 7.68 (m, 1H), 7.65 – 7.61 (m, 1H), 7.61 (s, 1H). The compound was highly insoluble in most of the solvents hence it was difficult to get a good ^{13}C-NMR spectrum. FTIR (KBr, cm^{-1}) 2227, 1592, 1290, 1260, 952, 800, 755. HRMS (ESI) m/z $[M]^+$ for formula $C_{21}H_{11}NO$: calcd 293.0836; found 293.0837.

Benzo[5,6]phenanthro[3,4-*b*]furan-2-carbonitrile (26) and benzo[5,6]phenanthro[3,2-*b*]furan-11-carbonitrile (27)



26 **27**

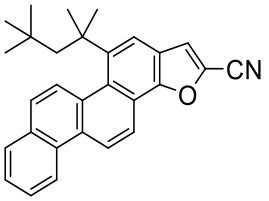
According to the general procedure C, the stilbenoid derivative **25** (52 mg, 0.18 mmol) sent by the collaborators, was dissolved in degassed toluene (200 mL) and fed into the photochemical reactor under N_2. It was followed by the addition of I_2 (0.11 g, 0.41 mmol) and 1,2- epoxybutane (0.50 mL, 5.30 mmol). The reaction mixture was irradiated for 8 h, by monitoring the progress on TLC. After completion of the reaction, the reaction mixture was washed with 10% aq $Na_2S_2O_3$ solution (100 mL) followed with brine (100 mL). The organic layer was dried on anhyd $MgSO_4$ and the solvent was removed completely under reduced pressure. The crude product was purified by flash column chromatography (3% EtOAc in Heptane) to afford two separate pale yellow solids in the ratio 62:38 (**26**:**27**, from NMR) respectively. The compound **26** has some inseparable impurities, and was obtained in 60% yield (31 mg from NMR). The compound **27** was obtained in 38% yield (19 mg).

Compound **26**: ^{1}H-NMR (400 MHz, CDCl3): δ = 8.72 (d, *J* = 8.4 Hz, 1H), 8.10 (d, *J* = 8.9 Hz, 1H), 8.03 (dd, *J* = 1,1, 8.0 Hz, 1H), 7.99 (d, *J* = 2.6 Hz, 1H), 7.98 (s, 1H), 7.97 (d, *J* = 2.6 Hz, 1H), 7.87 (d, *J* = 3.3 Hz, 1H), 7.85 (d, *J* = 3.5 Hz, 1H), 7.81 (dd, *J* = 0.9, 8.9 Hz, 1H), 7.68 – 7.64 (m, 1H), 7.59 – 7.55 (m, 1H); ^{13}C-NMR (100 MHz, CDCl3): δ = 155.3, 133.4, 132.4, 131.3, 130.5, 129.6, 128.6, 128.4, 128.1, 127.9, 127.0, 126.8, 126.6, 126.57, 125.4, 125.0, 124.7, 122.6, 121.5, 112.4; FTIR (KBr, cm^{-1}) 2225, 1602, 1258, 1156, 840, 787. HRMS (ESI) m/z $[M]^+$ for formula $C_{21}H_{11}NO$: calcd 293.0836; found 293.0834.

Compound **27**: ^{1}H-NMR (400 MHz, CDCl3): δ = 9.21 (s, 1H), 9.07 (d, *J* = 8.5 Hz, 1H), 8.24 (s, 1H), 8.05 (dd, *J* = 1.2, 7.9 Hz), 7.95 (d, J = 8.5 Hz, 1H), 7.92 (d, J = 8.7 Hz, 1H), 7.82 (d, J = 8.5 Hz, 1H), 7.76 (d, J = 8.8 Hz, 1H), 7.74 –

7.70 (m, 1H), 7.68 – 7.64 (m, 1H), 7.60 (s, 1H); ^{13}C-NMR (100 MHz, CDCl3): δ = 154.6, 133.7, 131.4, 131.2, 130.7, 130.4, 129.3, 129.0, 128.6, 127.8, 127.1, 127.0, 126.8, 126.6, 126.3, 124.8, 121.7, 118.3, 112.0, 109.5; FTIR (KBr, cm^{-1}) 2227, 1633, 1599, 1250, 1163, 1086, 891, 831, 752. HRMS (ESI) m/z $[M]^+$ for formula $C_{21}H_{11}NO$: calcd 293.0836; found 293.0836.

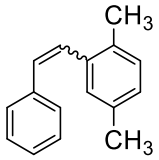
5-(2,4,4-Trimethylpentan-2-yl)chryseno[1,2-*b*]furan-2-carbonitrile (29)



Following general procedure C, the stilbenoid derivative **28** (200 mg, 0.49 mmol) sent by collaborators, was fed into the photoreactor along with 1,2-epoxybutane (1.3 mL, 14.70 mmol) and I_2 (0.19 g, 0.74 mmol) in degassed toluene (200 mL) under N_2 atmosphere. The reaction mixture was irradiated for 30 h before washing with 10% aq $Na_2S_2O_3$ solution (100 mL) followed with brine (100 mL). The organic layer was dried on anhyd $MgSO_4$ and the solvent was evaporated completely under reduced pressure. The crude product was purified by flash column chromatography (cyclohexane) to obtain photocyclized product **29** as pale yellow solid (140 mg, 70% yield). MP (°C) 180.4 – 184.5 (MeOH); ^{1}H-NMR (400 MHz, CDCl3): δ = 8.71 (d, *J* = 8.2 Hz, 1H), 8.67 (d, *J* = 8.9 Hz, 1H), 8.48 (d, *J* = 9.1 Hz, 1H), 8.31 (d, *J* = 8.9 Hz, 1H), 8.04 (s, 1H), 7.96 (dd, *J* = 1.3, 7.6 Hz, 1H), 7.74 (d, *J* = 9.1 Hz, 1H), 7.72 – 7.68 (m, 1H), 7.68 – 7.64 (m, 1H), 7.55 (s, 1H), 2.32 (s, 2H), 1.57 (s, 6H), 0.87 (s, 9H); ^{13}C-NMR (100 MHz, CDCl3): δ = 151.4, 146.6, 131.9, 131.7, 130.0, 129.7, 128.1, 127.1, 126.9, 126.8, 123.7, 123.1, 122.6, 122.5, 121.1, 120.0, 119.3, 119.2, 112.4, 58.9, 43.2, 34.3, 32.7, 31.9 (3C); FTIR (KBr, cm^{-1}) 2953, 2229, 1552, 1473, 760. HRMS (ESI) m/z sample sent for analysis.

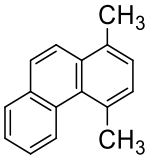
9.2.2 Synthesis of phenanthrene derivatives

1,4-Dimethyl-2-styrylbenzene (33)



According to the general procedure B, the commercially available 2,5-dimethylbenzaldehyde (**32**, 1.88 g, 14.01 mmol) and benzyltriphenylphosphonium bromide (Wittig salt **31**, 7.29 g, 16.80 mmol) were dissolved in anhyd THF (140 mL). The solution was cooled down to 0 °C before adding NaH (0.84 g, 21 mmol, 60% dispersion). The reaction mixture was refluxed for 4 h. After the completion of reaction, it was cooled down to rt before quenching with ice-cold water (75 mL). The crude compound was extracted with Et_2O (2 * 75 mL) and purified by flash column chromatography (1% EtOAc in heptane) to afford white solid **33** (2.47 g, 85% yield) as a mixture of *Z* and *E* isomers in 1:2 ratio (from NMR) respectively. The characterization data are in accordance with that reported in literature.[247]

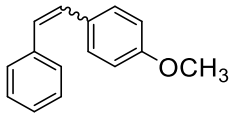
1,4-(Dimethyl)phenanthrene (34)



Following the general procedure C, the photoreactor was loaded with 1,4-dimethyl-2-styrylbenzene (**33**) (3.33 g, 16 mmol) and I_2 (0.41 g, 1.6 mmol) in toluene (900 mL) under air atmosphere. The reaction mixture was irradiated for 48 h while monitoring the progress using ^{1}H-NMR. After the completion of reaction, the excess solvent was evaporated under reduced pressure. The concentrated reaction mixture was washed with 10% aq $Na_2S_2O_3$ (100 mL), brine (100 mL) and dried over anhyd $MgSO_4$. The organic solvent was evaporated completely under reduced pressure and the crude product was purified by distillation to obtain **34** as white solid (1.41 g, 43%). MP (°C) 42.1

– 46.9 (MeOH); ^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.92 (dd, *J* = 1.8, 7.4 Hz, 1H), 7.98 (d, *J* = 9.1 Hz, 1H), 7.96-7.93 (m, 1H), 7.78 (d, *J* = 9.0 Hz, 1H), 7.66 – 7.59 (m, 2H), 7.43 – 7.37 (m, 2H), 3.14 (s, 3H), 2.76 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ = 133.3, 133.1, 132.8, 132.2, 131.9, 130.7, 130.3, 128.5, 127.7, 127.3, 126.8, 125.7, 125.3, 123.4, 27.4, 20.3; FTIR (KBr, cm^{-1}): 1448, 1432, 1032, 864, 820, 747, 711. HRMS (ESI) *m/z* $[M + H]^+$ for formula $C_{16}H_{15}$: calcd 207.1169; found 207.1168. The characterization data are in accordance with that reported in literature.[279]

1-Methoxy-4-styrylbenzene (36)



According to general procedure B, the commercially purchased 4-methoxybenzaldehyde (**35**, 2.998 g, 22.04 mmol) and benzyltriphenylphosphonium bromide (Wittig salt **31**, 11.46 g, 26.45 mmol) were dissolved in anhyd THF (100 mL). The solution was cooled down to 0 °C before adding NaH (1.32 g, 33.06 mmol, 60% dispersion). The reaction mixture was refluxed for 4 h until the completion of reaction. The reaction mixture was cooled down to rt and quenched with ice-cold water (75 mL). The crude compound was extracted with Et_2O (2 * 100 mL) and purified by flash column chromatography (25% EtOAc in heptane) to afford white solid **36** (4.77 g, quant yield) as a mixture of *Z* and *E* isomers in 3:7 ratio (from NMR) respectively. MP (°C) 110.4 – 112.8 (DCM); ^{1}H NMR (400 MHz, $CDCl_3$, both isomers): δ = 7.50 – 7.47 (m, 2H – *E* isomer), 7.45 (d, *J* = 8.6 Hz, 2H – *E* isomer), 7.36 – 7.32 (m, 2H – *E* isomer), 7.28 – 7.17 (m, 8H – *Z* isomer, 1H – *E* isomer), 7.02 (AB q, *J* = 16.3 Hz, 2H – *E* isomer), 6.90 (d, *J* = 8.8 Hz, 2H – *E* isomer), 6.75 (d, *J* = 8.8 Hz, 2H – *Z* isomer), 6.52 (app d, *J* = 1.8 Hz, 2H – *Z* isomer), 3.83 (s, 3H – *E* isomer), 3.78 (s, 3H – *Z* isomer) ; ^{13}C NMR (100 MHz, $CDCl_3$): δ = 159.5 (*E* isomer), 158.9 (*Z* isomer), 137.84 (*E* isomer), 137.8 (*Z* isomer), 130.34 (*Z* isomer), 130.32 (*E* isomer), 129.9 (*E* isomer), 129.8 (*Z* isomer), 129.0 (*E* isomer), 128.9 (*Z* isomer), 128.8, 128.4, 127.9, 127.4, 127.1, 126.8, 126.4, 114.3 (*E* isomer), 113.8 (*Z* isomer), 55.5 (*E* isomer), 55.4 (*Z* isomer). FTIR (KBr, cm^{-1}): 2926, 1603, 1510, 1464, 1446, 1296, 1250, 1179, 1030, 967, 860, 828, 812, 749, 689. HRMS (ESI) *m/z* $[M + H]^+$ for formula $C_{15}H_{15}O$: calcd

211.1118; found 211.1116. The characterization data is in accordance with that reported in literature.[280]

9.3 Directed *ortho* metalation

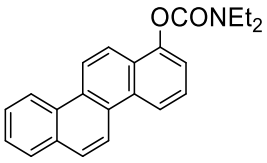
Synthesis of Chrysenols and chrysenyl N,N-diethyl-O-carbamates

Chrysenols **38**-**40** were synthesized by oxidative photocyclization of stilbenes followed by demethylation with BBr_3, as previously described.[212]

General Procedure (D) for the Synthesis of Chrysenyl *N,N*-diethyl-*O*-carbamate from Chrysenols

The chrysenol (1 equiv) in anhyd THF was added to a suspension of NaH (1.2 equiv) in anhyd THF at 0 °C under N_2 atmosphere. The reaction mixture was allowed to stir for 15 min and then warmed to rt before drop-wise addition of *N,N*-diethylcarbamoyl chloride (1.1 equiv). The mixture was stirred until completion of the reaction and quenched with satd aq NH_4Cl solution. The solution was extracted with either Et_2O or EtOAc and the combined organic phase was washed with brine, dried over anhyd $MgSO_4$ and evaporated to dryness under reduced pressure. The crude residue was purified by gradient flash column chromatography (EtOAc and PE).[203]

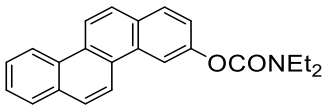
Chrysen-1-yl *N,N*-diethyl-*O*-carbamate (42)



Following the general procedure D, chrysen-1-ol (**38,** 668 mg, 2.73 mmol) dissolved in anhyd THF (8 mL) was added to a suspension of NaH (0.17 g, 4.18 mmol) in anhyd THF (8 mL) at 0 °C. The reaction mixture was allowed to stir for 15 min and then warmed to rt before drop-wise addition of *N,N*-diethylcarbamoyl chloride (0.37 mL, 2.92 mmol). It was then stirred for 13 h at rt before quenching with satd aq NH_4Cl solution (20 mL). The crude compound was extracted with Et_2O (3 * 25 mL), washed with brine (70 mL). The combined organic layer was dried over anhyd $MgSO_4$ and concentrated under

reduced pressure.The crude product was purified by flash column chromatography (EtOAc:PE 1:5) afforded product **42** (886 mg , 95%) as a white shiny powder.[203] MP (°C) 172.0 − 173.0 (EtOAc); ^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.78 (d, *J* = 8.2 Hz, 1H), 8.76 (d, *J* = 9.2 Hz, 1H), 8.70 (d, *J* = 9.1 Hz, 1H), 8.65 (d, *J* = 8.6 Hz, 1H), 8.13 (d, *J* = 9.2 Hz, 1H), 8.01 (d, *J* = 9.0 Hz, 1H), 8.00 (dd, *J* = 1.3, 7.8 Hz, 1H), 7.74 − 7.63 (m, 3H), 7.46 (d, *J* = 7.7 Hz, 1H), 3.68 (q, *J* = 6.9 Hz, 2H), 3.50 (q, *J* = 6.9 Hz, 2H), 1.45 (t, *J* = 6.9 Hz, 3H), 1.30 (t, *J* = 7.0 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ = 154.3, 147.9, 132.2, 132.0, 130.4, 128.5, 128.2, 128.1, 127.6, 126.7, 126.5, 126.3, 126.0, 123.1, 121.7, 121.4, 120.4, 120.2, 118.9, 42.4, 42.1, 14.5, 13.5; FTIR (KBr, cm^{-1}) 2976, 2936, 1716, 1596, 1409, 1273, 1259; HRMS (ESI) m/z $[M + Na]^+$ for formula $C_{23}H_{21}NNaO_2$: calcd 366.1465; found 366.1477.

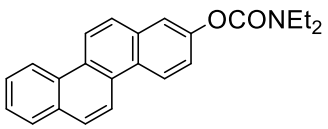
Chrysen-3-yl *N*,*N*-diethyl-*O*-carbamate (43)



Following the general procedure D, chrysen-3-ol (**40,** 6.04 g, 24.70 mmol) dissolved in anhyd THF (120 mL) was added to a suspension of NaH (1.48 g, 37.06 mmol) in anhyd THF (110 mL) at 0 °C. The reaction mixture was allowed to stir for 15 min and then warmed to rt before drop-wise addition of *N*,*N*-diethylcarbamoyl chloride (3.44 mL, 27.20 mmol). It was then stirred for 14 h at rt before quenching with satd aq NH_4Cl solution (120 mL). The crude compound was extracted with Et_2O (3 * 100 mL), washed with brine (200 mL). The combined organic layer was dried over anhyd $MgSO_4$ and concentrated under reduced pressure. The crude product was purified by flash column chromatography (EtOAc:hexane 1:5, with 10% DCM) afforded product **43** (7.76 g , 91%) as a white shiny powder.[203] MP (°C) 121.5 − 122.5 (EtOAc); ^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.77 (d, *J* = 8.2 Hz, 1H), 8.67 (d, *J* = 9.0 Hz, 1H), 8.61 (d, *J* = 9.2 Hz, 1H), 8.48 (app d, *J* = 2.0 Hz 1H), 7.98 (d, *J* = 8.7 Hz, 2H), 7.97 (d, *J* = 8.9 Hz, 2H) 7.72−7.68 (m, 1H), 7.65−7.61 (m, 1H), 7.44 (dd, *J* = 2.2, 8.7 Hz, 1H), 3.55 (br. q, *J* = 6.8 Hz, 2H), 3.46 (br. q, *J* = 6.8 Hz, 2H) 1.35 (br. t, *J* = 6.9 Hz, 3H), 1.26 (br. t, *J* = 7.0 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ = 154.4, 150.2, 132.2, 131.4, 130.5, 129.7, 129.6, 128.5, 128.4, 127.9, 127.2, 126.9, 126.6, 126.4, 123.2, 121.6, 121.4, 120.6, 115.0, 42.3, 42.0, 14.3, 13.4;

FTIR (KBr, cm^{-1}) 2975, 1715, 1618, 1596, 1470, 1456, 1418, 1376, 1313, 1272, 1248; HRMS (ESI) m/z $[M + Na]^+$ for formula $C_{23}H_{21}NNaO_2$: calcd 366.1465; found 366.1477.

Chrysen-2-yl *N,N*-diethyl-*O*-carbamate (22)

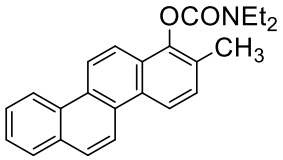


To a solution of 2-methoxychrysene (**4**) (833 mg, 3.23 mmol) in DCM (30 mL) was added BBr_3 (4.84 mL, 4.84 mmol) at 0 °C. After stirring for 21 h, the reaction mixture was quenched with water (14 mL). The aqueous layer was extracted with EtOAc (3 x 30 mL), before the combined organic phase was dried over $MgSO_4$ and concentrated *in vacuo*. The crude chrysen-2-ol (**39**) (3.23 mmol) in THF (15 mL) was added to a suspension of NaH (193 mg, 4.83 mmol) in THF (10 mL) at 0 °C. After 15 min. of stirring the mixture was warmed to rt before *N*,*N*- diethylcarbamoyl chloride (0.42 mL, 3.31 mmol) was added, and the reaction mixture was stirred overnight (21 h). The crude compound was extracted with Et_2O (3 * 30 mL), washed with brine (70 mL). The combined organic layer was dried over anhyd $MgSO_4$ and concentrated under reduced pressure. The crude product was purified by flash column chromatography (EtOAc:PE 1:2, with 10% DCM), product **22** (936 mg , 85% - two steps) was obtained as a white shiny powder. MP (°C) 189.0 − 190.0 (EtOAc); ^{1}H NMR (100 MHz, $CDCl_3$): δ = 8.76 (d, *J* = 8.9 Hz, 1H), 8.72 (d, *J* = 9.3 Hz, 1H), 8.67 (d, *J* = 9.2 Hz, 1H), 8.61−7.94 (m, 3H), 7.76 (app d, *J* = 2.3 Hz, 1 H), 7.73−7.61 (m, 2 H), 7.51 (dd, *J* = 2.4, 9.0 Hz, 1 H), 3.55−3.45 (m, 4H), 1.36−1.27 (m, 6H); ^{13}C NMR (100 MHz, $CDCl_3$): δ = 154.3, 149.8, 132.9, 132.0, 130.5, 128.5, 128.2, 128.0, 127.8, 127.5, 126.9, 126.7, 126.3, 124.5, 123.0, 121.9, 121.7, 121.2, 119.4, 42.3, 42.0, 14.3, 13.4; FTIR (KBr, cm^{-1}) 2978, 1703, 1522, 1474, 1422, 1364, 1272; HRMS (ESI) m/z $[M + Na]^+$ for formula $C_{23}H_{21}NNaO_2$: calcd 366.1465; found 366.1477.

General procedure (E) for the DoM Reaction on Chrysenyl *N,N*-diethyl-*O*-carbamates

To a solution of chrysenyl *N,N*-diethyl carbamate (1 equiv) dissolved in THF was added anhyd TMEDA (1.1 – 3.0 equiv) under N_2 atmosphere. The solution was cooled to −78 °C before adding *s*-BuLi (1.1 – 3.0 equiv) slowly in drop-wise manner. After stirring for 30 min, the electrophile (1.5 equiv) was added to the reaction mixture. It was then stirred and allowed to reach rt over 1.5 h to 18 h. The reaction mixture was quenched with satd aq NH_4Cl solution. The solution was extracted with EtOAc and the organic layer was washed with brine and dried over anhyd $MgSO_4$. The organic layer was evaporated to dryness under reduced pressure. The residue was purified by gradient flash column chromatography (EtOAc and PE) to obtain pure product.

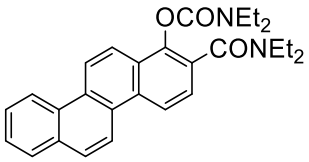
2-Methylchrysen-1-yl *N,N*-diethyl-*O*-carbamate (44)



According to the general procedure E, chrysenyl carbamate **42** (111 mg, 0.32 mmol) dissolved in anhyd THF (2.2 mL) was treated with *s*-BuLi (0.57 mL, 0.65 mmol), TMEDA (0.10 mL, 0.65 mmol) and MeI (0.06 mL, 0.97 mmol) at −95 °C. The reaction mixture was allowed to reach rt over 4 h. The reaction mixture was quenched with satd aq NH_4Cl solution (10 mL). The solution was extracted with EtOAc (3 * 10 mL) and the organic layer was washed with brine (10 mL) and dried over anhyd $MgSO_4$. The combined organic layer was evaporated to dryness under reduced pressure. The crude product was purified by flash column chromatography (EtOAc:PE 1:8) to isolate compound **44** as a brown solid (116 mg, 100%). MP (°C) 179.5 − 180.6 (EtOAc); ^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.78-8.74 (m, 2H), 8.64 (d, *J* = 9.0 Hz, 1H), 8.53 (d, *J* = 8.7 Hz, 1H), 8.06 (d, *J* = 9.3 Hz, 1H), 8.00−7.95 (m, 2H), 7.73−7.69 (m, 1H), 7.66−7.62 (m, 1H), 7.55 (d, *J* = 8.6 Hz, 1H), 3.70 (q, *J* = 6.9 Hz, 2H), 3.53 (q, *J* = 6.9 Hz, 2H), 2.48 (s, 3H), 1.47 (t, *J* = 7.05 Hz, 3H), 1.33 (t, *J* = 7.04 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ = 153.7, 145.6, 131.9, 130.4, 130.2, 129.1, 128.4, 128.1, 127.7, 127.5, 127.3, 126.5, 126.4, 126.1 122.9, 121.7, 121.2,

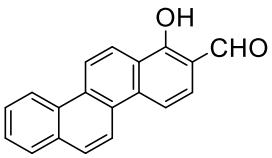
120.4, 120.0, 42.3, 42.0, 16.4, 14.5, 13.4; FTIR (KBr, cm^{-1}) 2980, 1714, 1475, 1418, 1397, 1271, 1256, 1184; HRMS (ESI) *m/z* $[M + Na]^+$ for formula $C_{24}H_{23}NNaO_2$: calcd 380.1626; found 380.1621.

2-(*N*,*N*-Diethyl carbamoyl)chrysen-1-yl *N*,*N*-diethyl-*O*-carbamate (45)



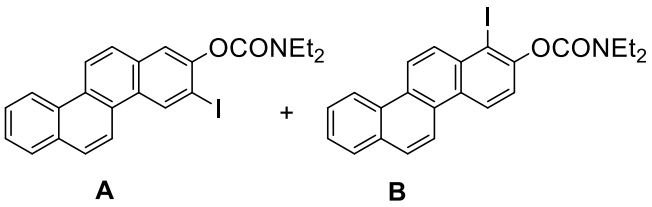
According to the general procedure E, the chrysenyl carbamate **42** (100 mg, 0.29 mmol) dissolved in anhyd THF (2.2 mL) was treated with *s*-BuLi (0.52 mL, 0.58 mmol), TMEDA (0.09 mL, 0.58 mmol) and Et_2NCOCl (0.11 mL, 0.87 mmol) at −95 °C. The reaction mixture was allowed to reach rt over 4 h. The reaction mixture was quenched with satd aq NH_4Cl solution (10 mL). The solution was extracted with EtOAc (3 * 10 mL) and the organic layer was washed with brine (10 mL) and dried over anhyd $MgSO_4$. The combined organic layer was evaporated to dryness under reduced pressure. The crude product was purified by flash column chromatography (EtOAc:PE 1:2) to isolate compound **45** as an off-white solid (113 mg, 88%). MP (°C) 183.0 − 184.5 (EtOAc); ^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.77−8.72 (m, 2H), 8.65−8.63 (m, 2H), 8.06 (d, *J* = 9.3 Hz, 1H), 7.97 (br. d, *J* = 8.6 Hz, 1H), 7.71−7.67 (m, 1H), 7.65−7.61 (m, 1H), 7.57 (d, *J* = 8.6 Hz, 1H), 3.64−3.43 (m, 8H), 1.42 (t, *J* = 7.1 Hz, 3H), 1.29−1.23 (m, 6H), 1.12 (t, *J* = 7.1 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ = 167.7, 153.5, 144.1, 132.2, 131.8, 130.2, 128.4, 128.37, 127.9, 127.75, 127.7, 126.8, 126.7, 126.6, 123.7, 123.0, 122.3, 121.7, 120.7, 120.4, 42.8, 42.4, 42.3, 38.5, 14.4, 13.8, 13.4, 12.6; FTIR (KBr, cm^{-1}) 2975, 2934, 1716, 1633, 1472, 1420, 1383, 1366, 1270; HRMS (ESI) *m/z* $[M + Na]^+$ for formula $C_{28}H_{30}N_2NaO_3$: calcd 465.2154 ; found 465.2140.

2-(Hydroxy)chrysene-1-carbaldehyde (46)



According to the general procedure E, chrysenyl carbamate **42** (103 mg, 0.30 mmol) dissolved in anhyd THF (2.2 mL) was treated with *s*-BuLi (0.53 mL, 0.60 mmol), TMEDA (0.09 mL, 0.60 mmol) and DMF (0.07 mL, 0.90 mmol) at −95 °C. The reaction mixture was allowed to reach rt over 3.5 h. The reaction mixture was quenched with satd aq NH_4Cl solution (10 mL). The solution was extracted with EtOAc (3 * 10 mL) and the organic layer was washed with brine (10 mL) and dried over anhyd $MgSO_4$. The combined organic layer was evaporated to dryness under reduced pressure. The crude product was purified by flash column chromatography (EtOAc:PE 1:8) to obtain compound **46** as a yellow solid (52 mg, 65%, NMR yield). MP (°C) 179.0 − 180.6 (Acetone); ^{1}H NMR (400 MHz, $CDCl_3$): δ = 12.48 (s, 1H), 10.06 (s, 1H), 8.82−8.77 (m, 2H), 8.63 (d, *J* = 9.1 Hz, 1H), 8.59 (d, *J* = 9.3 Hz, 1H), 8.30 (d, *J* = 8.8 Hz, 1H), 8.02 (d, *J* = 9.1 Hz, 1H), 8.00 (dd, *J* = 1.4, 7.9 Hz, 2H), 7.72, (d, *J* = 8.8 Hz, 1H), 7.77−7.67 (m, 2H); ^{13}C NMR (100 MHz, $CDCl_3$): δ = 196.3, 161.2, 135.8, 132.7, 131.2, 130.2, 128.6, 127.9, 127.86, 127.4, 127.39, 127.0, 123.6, 122.7, 121.7, 121.6, 121.4, 115.1, 114.7; FTIR (KBr, cm^{-1}) 1646, 1627, 1588, 1460, 1384, 1320; HRMS (ESI) *m/z* $[M - H]^-$ for formula $C_{19}H_{11}O_2$: calcd 271.0759; found 271.0764.

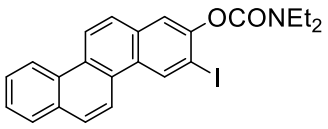
3-Iodochrysen-2-yl *N,N*-diethyl-*O*-carbamate (48A) and 1-Iodochrysen-2-yl *N,N*-diethyl-*O*-carbamate (48B)



According to the general procedure E, the chrysenyl carbamate **22** (139 mg, 0.41 mmol) dissolved in anhyd THF (10 mL) was treated with *s*-BuLi (0.43

mL, 0.43 mmol), TMEDA (0.07 mL, 0.46 mmol) and I_2 (0.6 mL, 0.6 mmol, 1 M in THF) at −78 °C. The reaction mixture was allowed to reach rt over 5.5 h. The reaction mixture was quenched with satd aq NH_4Cl solution (10 mL). The solution was extracted with EtOAc (3 * 10 mL) and the organic layer was washed with brine (10 mL) and dried over anhyd $MgSO_4$. The organic layer was evaporated to dryness under reduced pressure. The crude product was purified by flash column chromatography (EtOAc:hexane 1:6) to isolate a beige solid as a mixture of **48A** and **48B** (130 mg, 68%, 57:43). MP (°C) 171.5 − 173.0 (EtOAc); ^{1}H NMR (400 MHz, $CDCl_3$): δ = 9.16 (s, 1H – **48A**), 8.71 (d, J = 9.0 Hz, 1H – **48A**, 1H – **48B**), 8.70 (d, J = 9.2 Hz, 1H - **48B**), 8.69−8.67 (m, 1H – **48B**), 8.64 (d, J = 9.1 Hz, 1H – **48A**), 8.58 (d, J = 9.1 Hz, 1H – **48B**), 8.50 (d, J = 9.1 Hz, 1H – **48A**), 8.32 (d, J = 9.3 Hz, 1H – **48B**), 7.96−7.93 (m, 1H – **48A**, 1H – **48B**), 7.77 (s, 1H – **48A**), 7.71−7.59 (m, 1H – **48A**, 1H – **48B**), 7.50 (d, J = 9.0 Hz, 1H – **48B**), 3.66−3.58 (m, 2H – **48A**, 2H – **48B**), 3.46 (q, J = 7.0 Hz, 2H – **48A**, 2H – **48B**), 1.42−1.37 (m, 3H – **48A** , 3H – **48B**), 1.27 (t, J = 7.0 Hz, 3H – **48A**, 3H – **48B**); ^{13}C NMR (100 MHz, $CDCl_3$): δ = 153.22, 153.2, 150.9, 149.0, 134.7, 134.1, 132.7, 132.1, 132.08, 130.9 (2C), 130.3, 130.2, 129.6, 128.9, 128.5, 128.46, 128.1, 128.0 (2C), 127.8, 126.9, 126.8, 126.76, 126.6, 126.5, 126.47, 124.7, 123.5, 123.05, 123.0, 122.4, 121.1, 120.8, 120.7, 96.0, 90.7, 42.4, 42.3, 42.1 (2C), 14.5, 14.4, 13.4 (2C); FTIR (KBr, cm^{-1}) 2978, 2933, 1713, 1591, 1473, 1416, 1380, 1313, 1272; HRMS (ESI) m/z $[M + Na]^+$ for formula $C_{23}H_{20}INNaO_2$: calcd 492.0436; found 492.0434.

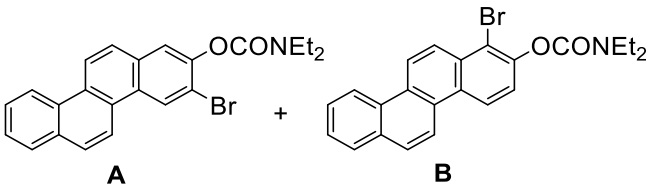
3-Iodochrysen-2-yl *N*,*N*-diethyl-*O*-carbamate (48A)



According to general procedure E, the chrysenyl carbamate **22** (100 mg, 0.29 mmol) dissolved in anhyd THF (3 mL) was treated with LiTMP (0.87 mmol, prepared *in situ* by adding 0.87 mmol of *n*-BuLi to 0.96 mmol of 2,2,6,6-tetramethylpiperdine in 1 mL THF at 0 °C) for 1.5 h followed by the addition of I_2 (0.87 mL , 0.87 mmol, 1 M in THF) at −78 °C. The reaction mixture was allowed to reach rt over 5.5 h. The reaction mixture was quenched with satd aq NH_4Cl solution (10 mL). The solution was extracted with EtOAc (3 * 10 mL) and the organic layer was washed with brine (10 mL) and dried over anhyd

$MgSO_4$. The combined organic layer was evaporated to dryness under reduced pressure. The crude product was purified by flash column chromatography (EtOAc:hexane 1:6) afforded **48A** (116 mg, 89%) as a white solid. MP (°C) 171.8 − 172.8 (EtOAc); ^{1}H NMR (400 MHz, $CDCl_3$): δ = 9.09 (s, 1H), 8.61 (d, *J* = 9.0 Hz, 1H), 8.54 (d, *J* = 9.1 Hz, 1H), 8.39 (d, *J* = 9.1 Hz, 1H), 7.92 (app dd, J = 1.2, 7.7 Hz, 1H), 7.87 (d, *J* = 9.1 Hz, 1H), 7.78−7.75 (m, 1H), 7.75 (s, 1H), 7.66−7.58 (m, 2H), 3.61 (q, *J* = 7.2 Hz, 2H), 3.50 (q, *J* = 7.2 Hz, 2H), 1.41 (t, *J* = 7.1 Hz, 3H), 1.31 (t, *J* = 7.1 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ = 153.1, 148.9, 134.5, 132.5, 131.9, 130.1, 129.4, 128.4, 127.8, 126.7, 126.5, 126.4, 126.3, 122.9, 122.3, 120.6, 120.57, 90.6, 42.3, 42.1, 14.4, 13.3; FTIR (KBr, cm^{-1}) 2974, 1714, 1473, 1416, 1380, 1244; HRMS (ESI) m/z $[M + Na]^+$ for formula $C_{23}H_{20}INNaO_2$: calcd 492.0436; found 492.0434.

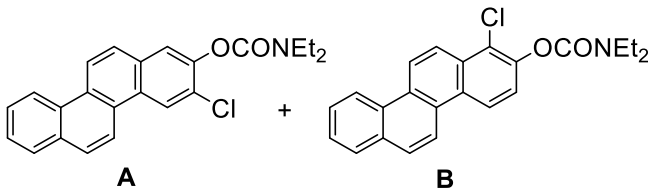
3-Bromochrysen-2-yl *N,N*-diethyl-*O*-carbamate (49A) and 1-Bromochrysen-2-yl *N,N*-diethyl-*O*-carbamate (49B)



According to the general procedure E, the chrysenyl carbamate **22** (89 mg, 0.26 mmol) dissolved in anhyd THF (6 mL) was treated with *s*-BuLi (0.38 mL, 0.27 mmol), TMEDA (0.04 mL, 0.27 mmol) and Br_2 (0.04 mL, 0.77 mmol) at −78 °C. The reaction mixture was allowed to reach rt over 5 h. The reaction mixture was quenched with satd aq NH_4Cl solution (10 mL). The solution was extracted with EtOAc (3 * 10 mL) and the organic layer was washed with brine (10 mL) and dried over anhyd $MgSO_4$. The combined organic layer was evaporated to dryness under reduced pressure. The crude product was purified by flash column chromatography (EtOAc:hexane 1:4) to obtain a mixture of **49A** and **49B** (73 mg, 67%, 56:44) as a beige solid. MP (°C) 198.5 − 200.0 (EtOAc); ^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.91 (s, 1H – **49A**), 8.70 − 8.65 (m, 1H – **49A**, 3H – **49B**), 8.61 (d, *J* = 9.2 Hz, 1H – **49A**), 8.53 (d, *J* = 9.0 Hz, 1H – **49B**), 8.45 (d, *J* = 9.0 Hz, 1H – **49A**), 8.38 (d, *J* = 9.4 Hz, 1H – **49B**), 7.95 − 7.91 (m, 2H – **49A**, 2H – **49B**), 7.82 (d, *J* = 9.3 Hz, 1H – **49A**), 7.81 (s, 1H – **49A**), 7.71 − 7.60 (m, 2H – **49A**, 2H – **49B**), 7.54 (d, *J* = 9.1 Hz, 1H – **49B**), 3.63 − 3.58 (m,

2H – **49A**, 2H – **49B**), 3.51 − 3.46 (q, *J* = 6.9 Hz, 2H – **49A**, 2H – **49B**), 1.43 − 1.39 (m, 3H – **49A**, 3H – **49B**), 1.31 − 1.28 (m, 3H – **49A**, 3H – **49B**); ^{13}C NMR (100 MHz, $CDCl_3$): δ = 153.2, 153.19, 147.4, 146.5, 132.0, 131.8, 131.5, 130.2, 130.1, 129.2, 129.1, 128.5, 128.4, 128.1, 127.94, 127.9, 127.8, 127.77, 127.7, 126.9, 126.8, 126.7, 126.6, 126.5, 126.3, 125.5, 123.4, 123.0, 122.99, 122.95, 122.6, 122.2, 121.7, 121.0, 120.7, 116.24, 116.21, 42.4 (2C), 42.1 (2C), 14.3, 14.2, 13.4 (2C); FTIR (KBr, cm^{-1}) 2978, 2933, 1726, 1472, 1417, 1381, 1273, 1249; HRMS (ESI) m/z $[M + Na]^+$ for formula $C_{23}H_{20}BrNNaO_2$: calcd 444.0575; found 444.0589.

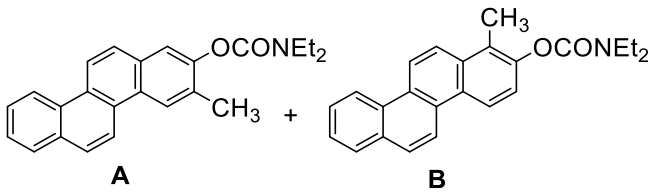
3-Chlorochrysen-2-yl *N,N*-diethyl-*O*-carbamate (50A) and 1-Chlorochrysen-2-yl *N,N*-diethyl-*O*-carbamate (50B)



According to the general procedure E, the chrysenyl carbamate **22** (130 mg, 0.38 mmol) in THF (6 mL) was treated with *s*-BuLi (0.44 mL, 0.44 mmol), TMEDA (0.07 mL, 0.46 mmol) and Cl_3CCCl_3 (1 M, 0.57 mL, 0.57 mmol) at −78 °C. The reaction mixture was allowed to reach rt over 16 h. The reaction mixture was quenched with satd aq NH_4Cl solution (10 mL). The solution was extracted with EtOAc (3 * 10 mL) and the organic layer was washed with brine (10 mL) and dried over anhyd $MgSO_4$. The combined organic layer was evaporated to dryness under reduced pressure. The crude product was purified by flash column chromatography (EtOAc:PE 1:2) afforded a mixture of **50A** and **50B** as an off-white solid (138 mg, 96%, 59:41). MP (°C) 184.5 − 185.5 (EtOAc); ^{1}H NMR (300 MHz, $CDCl_3$): δ = 8.77 − 8.62 (m, 2H – **50A**, 3H – **50B**), 8.58 (d, *J* = 9.3 Hz, 1H – **50B**), 8.49 (d, *J* = 9.3 Hz, 1H – **50A**), 8.40 (d, *J* = 9.6 Hz, 1H – **50B**), 7.96 − 7.94 (m, 2H – **50A**, 2H – **50B**), 7.86 (d, *J* = 9.0 Hz, 1H – **50A**), 7.81 (s, 1H – **50A**), 7.72 − 7.59 (m, 2H – **50A**, 2H – **50B**), 7.55 (d, *J* = 9.1 Hz, 1H – **50B**), 3.60 − 3.53 (m, 2H – **50A**, 2H – **50B**), 3.45 (q, *J* = 6.9 Hz, 2H – **50A**, 2H – **50B**), 1.38 − 1.34 (m, 3H – **50A**, 3H – **50B**), 1.28 − 1.26 (m, 3H – **50A**, 3H – **50B**); ^{13}C NMR (75 MHz, $CDCl_3$): δ = 153.4 (2C), 145.9, 145.6, 132.1, 132.07, 131.4, 130.3, 130.27, 130.2, 129.2, 128.8, 128.5,

128.49, 128.2, 127.9, 127.89, 127.8, 127.6, 127.1, 126.9, 126.8, 126.6, 126.55, 126.3, 124.7, 123.1, 123.0, 122.9, 122.8, 122.6, 122.5, 122.1, 122.0, 121.0, 120.8, 120.2, 42.5 (2C), 42.1 (2C), 14.2 (2C), 13.3 (2C); FTIR (KBr, cm^{-1}) 2978, 2934, 1731, 1472, 1419, 1381, 1274, 751; HRMS (ESI) m/z $[M + Na]^+$ for formula $C_{23}H_{20}ClNNaO_2$: calcd 400.1080; found 400.1090.

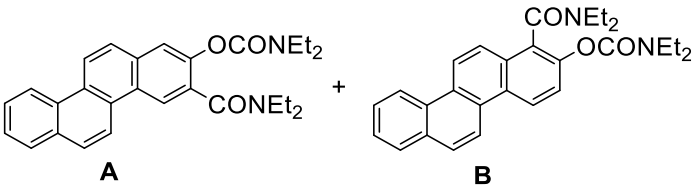
3-Methylchrysen-2-yl *N,N*-diethyl-*O*-carbamate (51A) and 1-Methylchrysen-2-yl *N,N*-diethyl-*O*-carbamate (51B)



According to the general procedure E, the chrysenyl carbamate **22** (104 mg, 0.30 mmol) dissolved in anhyd THF (2.2 mL) was treated with *s*-BuLi (0.54 mL, 0.61 mmol), TMEDA (0.09 mL, 0.61 mmol) and MeI (0.06 mL, 0.91 mmol) at −95 °C. The reaction mixture was allowed to reach rt over 4 h. The reaction mixture was quenched with satd aq NH_4Cl solution (10 mL). The solution was extracted with EtOAc (3 * 10 mL) and the organic layer was washed with brine (10 mL) and dried over anhyd $MgSO_4$. The combined organic layer was evaporated to dryness under reduced pressure. The crude product was purified by flash column chromatography (EtOAc:PE 1:8) to isolate a mixture of **51A** and **51B** (85 mg, 79%, 54:46) as an off-white solid. MP (°C) 193.0 − 194.5 (EtOAc); ^{1}H NMR: (400 MHz, $CDCl_3$): δ = 8.77 − 8.71 (m, 1H – **51A**, 2H – **51B**), 8.68 − 8.63 (m, 2H – **51A**, 2H – **51B**), 8.59 (s, 1H−**51A**), 7.99 − 7.96 (m, 2H – **51A**, 2H – **51B**), 7.92 (d, *J* = 9.1 Hz, 1H – **51A**), 7.73 (s, 1H – **51A**), 7.72 − 7.68 (m, 1H – **51A**, 1H – **51B**), 7.66 − 7.61 (m, 1H – **51A**, 1H – **51B**), 3.59 − 3.56 (m, 2H – **51A**, 2H – **51B**), 3.49 − 3.47 (m, 2H – **51A**, 2H – **51B**), 2.54 (s, 3H – **51A**), 2.65 (s, 3H – **51B**), 1.38 − 1.35 (m, 3H – **51A**, 3H – **51B**), 1.30 − 1.27 (m, 3H – **51A**, 3H – **51B**); ^{13}C NMR (100 MHz, $CDCl_3$): δ = 154.2, 154.0, 149.1, 147.6, 132.1, 131.9, 131.87, 131.5, 130.5, 130.4, 130.3, 128.5, 128.4, 128.3, 128.27, 127.8, 127.6, 127.4, 127.3, 127.1, 126.7, 126.6, 126.5, 126.2, 126.1, 125.5, 125.1, 123.1, 123.0, 122.9,122.0, 121.9, 121.5, 121.4, 121.2, 120.9, 119.9, 42.3 (2C), 41.9 (2C), 17.4, 14.4, 14.3, 13.4 (2C), 12.0; FTIR (KBr, cm^{-1}) 2976, 1720, 1420, 1273,

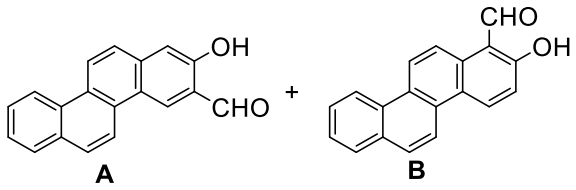
1246; HRMS (ESI) *m/z* $[M + H]^+$ for formula $C_{24}H_{24}O_2N$: calcd 358.1807; found 358.1805.

3-(*N*,*N*-Diethylcarbamoyl)chrysen-2-yl N,N-diethyl-*O*-carbamate (52A) and 1-(*N*,*N*-Diethylcarbamoyl)chrysen-2-yl N,N-diethyl-*O*-carbamate (52B)



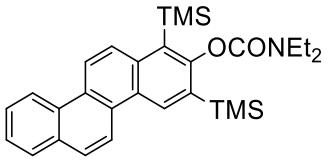
According to the general procedure E, the chrysenyl carbamate **22** (107 mg, 0.31 mmol) dissolved in anhyd THF (2.2 mL) was treated with *s*-BuLi (0.55 mL, 0.62 mmol), TMEDA (0.09 mL, 0.62 mmol) and Et_2NCOCl (0.12 mL, 0.93 mmol) at −95 °C. The reaction mixture was allowed to reach rt over 4 h. The reaction mixture was quenched with satd aq NH_4Cl solution (10 mL). The solution was extracted with EtOAc (3 * 10 mL) and the organic layer was washed with brine (10 mL) and dried over anhyd $MgSO_4$. The combined organic layer was evaporated to dryness under reduced pressure. The crude product was purified by flash column chromatography (EtOAc:PE 1:2), a mixture of compounds **52A** and **52B** were isolated as a beige solid (96 mg, 70%, 75:25). MP (°C) 181.5 − 182.5 (EtOAc); ^{1}H NMR: (400 MHz, $CDCl_3$): δ = 8.78 − 8.73 (m, 2H – **52B**), 8.71 (d, *J* = 8.2 Hz, 1H – **52A**), 8.70 (d, *J* = 9.1 Hz, 1H – **52A**), 8.67 (s, 1H – **52A**), 8.63 (d, *J* = 9.2 Hz, 1H – **52B**), 8.59 (d, *J* = 9.1 Hz, 1H – **52A**), 7.99 − 7.91 (m, 3H – **52A**, 2H – **52B**), 7.89 (s, 1H − **52A**), 7.69 − 7.59 (m, 2H – **52A**, 2H – **52B**), 3.83 − 3.07 (m, 8H – **52A**, 8H – **52B**), 1.39 (t, *J* = 7.1 Hz, 3H – **52B**), 1.33 − 1.25 (m, 6H – **52A**, 3H – **52B**), 1.22 (t, *J* = 7.1 Hz, 3H – **52A**, 3H – **52B**), 1.11 (t, *J* = 7.1 Hz, 3H- **52A**), 0.94 (t, *J* = 7.1 Hz, 3H – **52B**); ^{13}C NMR (100 MHz, $CDCl_3$): δ = 167.9, 166.6, 153.5, 153.4, 145.7, 145.3, 132.8, 131.9, 130.3, 130.2, 130.1, 129.2, 128.4, 128.0, 127.9, 127.8, 127.75, 127.7, 127.5, 126.7, 126.6, 126.4, 126.37, 124.4, 123.4, 122.9, 122.86, 122.6, 122.4, 122.3, 121.8, 120.94, 120.91, 120.7, 42.9, 42.87, 42.2, 42.0, 38.9, 38.7, 14.1, 13.9, 13.8, 13.3, 12.9, 12.7; FTIR (KBr, cm^{-1}) 2971, 2932, 1714, 1637, 1474, 1420, 1271, 1246; HRMS (ESI) *m/z* $[M + H]^+$ for formula $C_{28}H_{30}O_3N_2Na$: calcd 465.2154; found 465.2141.

3-(Hydroxy)chrysene-2-carbaldehyde (53A) and 1-(Hydroxy)chrysene-2-carbaldehyde (53B)



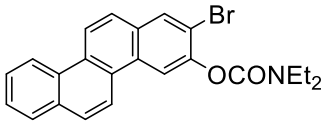
According to the general procedure E, the chrysenyl carbamate **22** (103 mg, 0.30 mmol) dissolved in anhyd THF (2.2 mL) was treated with *s*-BuLi (0.53 mL, 0.60 mmol), TMEDA (0.09 mL, 0.60 mmol) and DMF (0.07 mL, 0.90 mmol) at −95 °C. The reaction mixture was allowed to reach rt over 3.5 hours. The reaction mixture was quenched with satd aq NH_4Cl solution (10 mL). The solution was extracted with EtOAc (3 * 10 mL) and the organic layer was washed with brine (10 mL) and dried over anhyd $MgSO_4$. The combined organic layer was evaporated to dryness under reduced pressure. The crude product was purified by flash column chromatography (EtOAc:PE 1:8) afforded a mixture of compound **53A** and **53B** as a yellow solid (53 mg, 64%, 68:32). MP (°C) 221.1 − 222.1 (Acetone); ^{1}H NMR: (400 MHz, $CDCl_3$): δ = 13.02 (s, 1H – **53B**), 10.99 (s, 1H – **53B**), 10.62 (s, 1H – **53A**), 10.22 (s, 1H – **53A**), 8.97 (s, 1H – **53A**), 8.96 (d, *J* = 9.6 Hz, 1H – **53B**), 8.88 (d, *J* = 9.6 Hz, 1H – **53B**), 8.78 (d, *J* = 9.3 Hz, 1H – **53A**), 8.75 (d, *J* = 8.4 Hz, 1H – **53B**), 8.72 (d, *J* = 8.4 Hz, 1H – **53A**), 8.62 (d, *J* = 9.0 Hz, 1H – **53A**), 8.57 (d, *J* = 9.0 Hz, 2H – **53B**), 8.06 (d, *J* = 8.9 Hz, 1H – **53A**), 8.04 − 7.99 (m, 2H – **53B**), 8.00 (app d, *J* = 9.4 Hz, 1H – **53A**), 7.86 (d, *J* = 9.1 Hz, 1H – **53A**), 7.76 − 7.72 (m, 1H – **53B**), 7.75 − 7.71 (m, 1H – **53A**), 7.68 − 7.64 (m, 1H – **53B**), 7.67 − 7.63 (m, 1H – **53A**), 7.44 (s, 1H – **53A**), 7.34 (d, *J* = 9.3 Hz, H – **53B**); ^{13}C NMR: (100 MHz, $CDCl_3$): δ = 196.8, 193.9, 157.2, 138.0, 133.8, 132.2, 131.9, 130.4, 128.8, 128.7 (2C), 128.6,128.5, 127.2, 126.9, 126.5, 126.0, 125.9, 124.7, 124.2, 122.8, 121.5, 120.5, 120.3, 118.8, 117.8, 113.5; FTIR (KBr, cm^{-1}) 2924, 1723, 1660, 1630, 1530, 1509, 1452, 1434, 1293, 1174, 818; HRMS (ESI) *m/z* [M - H]$^-$ for formula $C_{19}H_{11}O_2$: calcd 271.0759; found 271.0764.

1,3-bis(Trimethylsilyl)chrysen-2-yl *N,N*-diethylcarbamate (54)



According to the general procedure E, the chrysenyl carbamate **22** (71 mg, 0.21 mmol) dissolved in anhyd THF (2.0 mL) was treated with *s*-BuLi (0.46 mL, 0.53 mmol), TMEDA (0.03 mL, 0.41 mmol) and TMSCl (0.05 mL, 0.41 mmol) at −78 °C. The reaction mixture was allowed to reach rt over 12 h. The reaction mixture was quenched with satd aq NH_4Cl solution (10 mL). The solution was extracted with EtOAc (3 * 10 mL) and the organic layer was washed with brine (10 mL) and dried over anhyd $MgSO_4$. The combined organic layer was evaporated to dryness under reduced pressure. The crude product was purified by flash column chromatography (EtOAc:PE 1:4) afforded product **54** (99 mg, 98%) as a colorless solid. MP (°C) 166.4 − 167.1 (EtOAc); ^{1}H NMR (400 MHz, $CDCl_3$): δ = 9.05 (s, 1H), 8.80 − 8.74 (m, 3H), 8.42 (d, *J* = 9.5 Hz, 1H), 8.03 − 8.00 (m, 2H), 7.74 − 7.70 (m, 1H), 7.67 − 7.63 (m, 1H), 3.79 − 3.62 (m, 2H), 3.49 − 3.43 (m, 2H), 1.36 (t, *J* = 7.1 Hz, 3H), 1.27 (t, *J* = 7.1 Hz, 3H), 0.60 (s, 9H), 0.50 (s, 9H); ^{13}C NMR (100 MHz, $CDCl_3$): δ = 159.1, 154.9, 138.0, 133.2, 132.0, 131.9, 130.4, 129.1, 128.9, 128.4, 127.9, 127.4, 127.3, 127.1, 126.6, 126.2, 123.0, 121.2, 121.18, 40.9, 40.7, 13.5, 12.8, 2.4, -0.4; FTIR (KBr, cm^{-1}) 2976, 2955, 2898, 1707, 1472, 1422, 1379, 1343, 1279, 1236; HRMS (ESI) m/z $[M + Na]^+$ for formula $C_{29}H_{37}NNaO_2Si_2$: calcd 510.2261; found 510.2255.

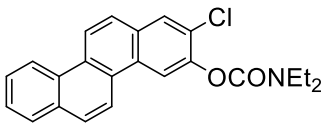
2-Bromochrysen-3-yl *N,N*-diethyl-*O*-carbamate (55)



According to the general procedure E, the chrysenyl carbamate **43** (100 mg, 0.29 mmol) in THF (2.2 mL) was treated with *s*-BuLi (0.28 mL, 0.32 mmol), TMEDA (0.05 mL, 0.32 mmol) and Br_2 (0.02 mL, 0.44 mmol) at −78 °C. The reaction mixture was allowed to reach rt over 16 h. The reaction mixture was quenched with satd aq NH_4Cl solution (10 mL). The solution was extracted

with EtOAc (3 * 10 mL) and the organic layer was washed with brine (10 mL) and dried over anhyd $MgSO_4$. The combined organic layer was evaporated to dryness under reduced pressure. The crude product was purified by flash column chromatography (EtOAc:PE 1:4) afforded product **55** (69.7 mg, 57%) as a beige solid. MP (°C) 117.0−118.0 (EtOAc); ^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.71 (d, *J* = 8.5 Hz, 1H), 8.63 (d, *J* = 9.3 Hz, 1H), 8.56 (s, 1H), 8.53 (d, *J* = 9.2 Hz, 1H), 8.19 (s, 1H), 7.97 (dd, *J* = 1.2 Hz, 7.8 Hz, 1H), 7.96 (d, *J* = 9.0 Hz, 1H), 7.83 (d, *J* = 9.1 Hz, 1H), 7.71 − 7.67 (m, 1H), 7.66 − 7.62 (m, 1H), 3.63 (q, *J* = 7.1 Hz, 2H), 3.49 (q, *J* = 7.1 Hz, 2H), 1.41 (t, *J* = 7.1 Hz, 3H), 1.30 (t, *J* = 7.1 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ = 153.4, 146.9, 132.4, 132.3, 130.8, 130.4, 128.5, 128.3, 127.6, 127.5, 126.8, 126.6, 125.6, 123.1, 121.8, 121.1,117.1, 115.9, 42.4, 42.1, 14.3, 13.3; FTIR (KBr, cm^{-1}) 2972, 1722, 1470, 1417, 1380, 1318, 1274, 747; HRMS (ESI) m/z $[M + H]^+$ for formula $C_{23}H_{22}{}^{81}BrNNaO_2$: calcd 446.0732; found 446.0548.

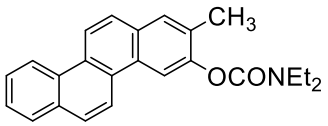
2-Chlorochrysen-3-yl *N*,*N*-diethyl-*O*-carbamate (56)



According to the general procedure E, the chrysenyl carbamate **43** (102 mg, 0.30 mmol) dissolved in anhyd THF (2.2 mL) was treated with *s*-BuLi (0.30 mL, 0.33 mmol), TMEDA (0.05 mL, 0.33 mmol) and Cl_3CCCl_3 (106 mg, 0.45 mmol) in anhyd THF (1 mL) at −78 °C. The reaction mixture was allowed to reach rt over 9 h. The reaction mixture was quenched with satd aq NH_4Cl solution (10 mL). The solution was extracted with EtOAc (3 * 10 mL) and the organic layer was washed with brine (10 mL) and dried over anhyd $MgSO_4$. The combined organic layer was evaporated to dryness under reduced pressure. The crude product was purified by flash column chromatography (EtOAc:hexane 1:9) afforded product **56** as an orange solid (78 mg, 70%). MP (°C) 184.5 − 185.5 (EtOAc); ^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.66 (d, *J* = 8.4 Hz, 1H), 8.58 (d, *J* = 9.1 Hz, 1H), 8.54 (s, 1H), 8.48 (d, *J* = 9.1 Hz, 1H), 7.98 (s, 1H), 7.96 − 7.91 (m, 2H), 7.78 (d, *J* = 9.1 Hz, 1H), 7.69 − 7.61 (m, 2H), 3.61 (q, *J* = 7.0 Hz, 2H), 3.50 (q, *J* = 6.9 Hz, 2H), 1.41 (t, *J* = 7.1 Hz, 3H), 1.31 (t, *J* = 7.1 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ = 153.5, 146.0, 132.2, 130.4, 130.3, 129.8, 129.0, 128.5, 128.3, 127.53, 127.52, 126.8, 126.6, 126.5, 125.7,

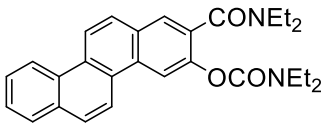
123.1, 121.8, 121.1, 117.8, 42.5, 42.1, 14.2, 13.3; FTIR (KBr, cm^{-1}) 2975, 2936, 1724, 1471, 1419, 1381, 1318, 1276, 747; HRMS (ESI) m/z $[M + Na]^+$ for formula $C_{23}H_{20}ClNNaO_2$: calcd 400.1080; found 400.1078.

2-Methylchrysen-3-yl *N*,*N*-diethyl-*O*-carbamate (57)



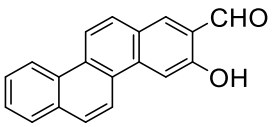
According to the general procedure E, the chrysenyl carbamate **43** (100 mg, 0.29 mmol) dissolved in anhyd THF (2.2 mL) was treated with *s*-BuLi (0.52 mL, 0.58 mmol), TMEDA (0.09 mL, 0.58 mmol) and MeI (0.05 mL, 0.87 mmol) at −95 °C. The reaction mixture was allowed to reach rt over 4 h. The reaction mixture was quenched with satd aq NH_4Cl solution (10 mL). The solution was extracted with EtOAc (3 * 10 mL) and the organic layer was washed with brine (10 mL) and dried over anhyd $MgSO_4$. The combined organic layer was evaporated to dryness under reduced pressure. The crude product was purified by flash column chromatography (EtOAc:PE 1:8), afforded compound **57** as pale yellow solid (100 mg, 96%). MP (°C) 166.2 − 167.0 (EtOAc); ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.75 (d, *J* = 8.3 Hz, 1H), 8.62 (d, *J* = 9.5 Hz, 2H), 8.47 (s, 1H), 8.00 − 7.96 (m, 2H), 7.90 (d, *J* = 9.0 Hz, 1H), 7.80 (s, 1H), 7.72−7.68 (m, 1H), 7.65 − 7.61 (m, 1H), 3.59 (q, *J* = 6.8 Hz, 2H), 3.50 (q, *J* = 7.0 Hz, 2H), 2.48 (s, 3H), 1.39 (t, *J* = 7.7 Hz, 3H), 1.30 (t, *J* = 6.9 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ = 154.1, 149.4, 132.0, 130.5, 130.3, 130.1, 130.0, 129.8, 128.4, 127.8, 127.0, 126.5, 126.4, 126.1, 123.0, 121.4, 120.6, 115.6, 42.3, 41.9, 16.7, 14.3, 13.4; FTIR (KBr, cm^{-1}) 2972, 1718, 1473, 1420, 1275, 1260; HRMS (ESI) *m/z* $[M + H]^+$ for formula $C_{24}H_{24}O_2N$: calcd 358.1807; found 358.1803.

2-(*N*,*N*-Diethyl carbamoyl)chrysen-3-yl *N*,*N*-diethyl-*O*-carbamate (58)



According to the general procedure E, the chrysenyl carbamate **43** (102 mg, 0.30 mmol) dissolved in anhyd THF (2.2 mL) was treated with *s*-BuLi (0.53 mL, 0.59 mmol), TMEDA (0.09 mL, 0.59 mmol) and Et_2NCOCl (0.11 mL, 0.89 mmol) at −95 °C. The reaction mixture was allowed to reach rt over 4 h. The reaction mixture was quenched with satd aq NH_4Cl solution (10 mL). The solution was extracted with EtOAc (3 * 10 mL) and the organic layer was washed with brine (10 mL) and dried over anhyd $MgSO_4$. The combined organic layer was evaporated to dryness under reduced pressure. The crude product was purified by flash column chromatography (EtOAc:PE 1:2), afforded compound **58** as colorless solid (116 mg, 88%). MP (°C) 180.2 − 181.2 (EtOAc); ^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.72 (d, *J* = 8.3 Hz, 1H), 8.65 (d, *J* = 9.1 Hz, 1H), 8.61 (s, 1H), 8.58 (d, *J* = 9.1 Hz, 1H), 7.97 − 7.92 (m, 2H), 7.89 (s, 1H), 7.70 − 7.65 (m, 1H), 7.64 − 7.60 (m, 1H), 3.92 − 3.13 (br m, 8H), 1.33 − 1.26 (m, 6H), 1.23 (t, *J* = 7.0 Hz, 3H), 1.10 (t, *J* = 7.2 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ = 167.5, 153.7, 146.1, 132.2, 131.3, 130.2, 130.1, 129.1, 128.5, 128.4, 127.5, 127.3, 126.6, 126.54, 126.51, 123.1, 121.3, 116.7, 42.9, 42.2, 42.0, 38.8, 14.1, 13.8, 13.3, 12.6; FTIR (KBr, cm^{-1}) 2978, 2933, 1719, 1630, 1472, 1420, 1382, 1347, 1317, 1295, 1272; HRMS (ESI) *m/z* $[M + H]^+$ for formula $C_{28}H_{30}O_3N_2Na$: calcd 465.2154; found 465.2149.

2-(Hydroxy)chrysene-3-carbaldehyde (59)



According to the general procedure E, the chrysenyl carbamate **43** (1.08 g, 3.15 mmol) dissolved in anhyd THF (20 mL) was treated with *s*-BuLi (7.05 mL, 6.30 mmol), TMEDA (0.94 mL, 6.30 mmol) and DMF (0.73 mL, 9.44 mmol) at −95 °C. The reaction mixture was allowed to reach rt over 3.5 h. The reaction mixture was quenched with satd aq NH_4Cl solution (10 mL). The solution was

extracted with EtOAc (3 * 10 mL) and the organic layer was washed with brine (10 mL) and dried over anhyd $MgSO_4$. The combined organic layer was evaporated to dryness under reduced pressure. The crude product was purified by flash column chromatography (EtOAc:PE 1:8), afforded compound **59** as yellow solid (1.23 g, 72%). MP (°C) 230.5 − 231 5 (Acetone); ^{1}H NMR (400 MHz, $CDCl_3$) δ 10.61 (s, 1H), 10.13 (s, 1H), 8.74 (d, *J* = 8.1 Hz, 1H), 8.56 (t, *J* = 8.0 Hz, 2H), 8.20 (s, 2H), 8.00 (d, *J* = 8.6 Hz, 1H), 7.95 (d, *J* = 9.1 Hz, 1H), 7.72−7.68 (m, 2H); ^{13}C NMR (100 MHz, $CDCl_3$): δ = 196.4, 157.5, 136.8, 133.0, 130.8, 130.2, 128.7, 127.7, 127.4, 127.3, 127.0, 126.8, 125.8, 123.5, 121.6, 121.4, 119.9,109.2; FTIR (KBr, cm^{-1}) 3460, 1666, 1634, 1435, 1384, 1343; HRMS (ESI) *m/z* $[M - H]^-$ for formula $C_{19}H_{11}O_2$: calcd 271.0759; found 271.0764.

The *o*-TMS substituted chrysenyl carbamates **60** and **61** were synthesized following the procedures reported by Dr. Marianne Lorentzen in her PhD thesis.[203] The characterization data for both the compounds was similar to that reported.

Preparation of Chrysenyl N,N-diethyl amides

General Procedure (F) for Chrysene carboxylic acid: Ester hydrolysis

In an oven-dried round bottom flask methyl chrysene carboxylate (1 equiv) was dissolved in THF. To this solution, KOH (2 equiv) and water were added and refluxed for 10 h under N_2 atmosphere. After completion of the reaction, the reaction mixture was extracted with Et_2O and water. The aqueous layer was acidified with conc HCl to isolate the product as precipitate. The pure product was filtered through a sintered glass funnel and washed with cold water. The final product was evaporated *in vacuo* and used for subsequent reaction.

General Procedure (G) for *N,N*-diethylchrysene carboxamide: Amidation

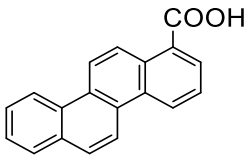
To chrysene carboxylic acid (1 equiv) in anhyd toluene was added $SOCl_2$ (3 equiv) and a drop of DMF as catalyst in a suitable oven-dried round bottom flask under N_2 atmosphere. The reaction mixture was refluxed for 10 h. After cooling down to rt, the solvent was evaporated *in vacuo* and the crude product was subsequently used.

To chrysene carbonyl chloride (1 equiv) in anhyd THF at 0 °C diethyl amine (3 equiv) was added slowly. The reaction mixture was refluxed for 16 h. After cooling down to rt, it was quenched with 1 M HCl. The crude compound was extracted with EtOAc. The organic layer was washed with sat aq $NaHCO_3$ and brine. It was dried over anhyd Na_2SO_4 and evaporated *in vacuo*. The crude product was purified using column chromatography (Heptane: EtOAc).

General Procedure (H) for *N,N*-diethyl-2-iodochrysene carboxamide: Directed *ortho* metalation

In a round bottom flask under inert N_2 atmosphere, *s*-BuLi (1.5 equiv) or freshly prepared LiTMP (3 equiv, prepapred by adding 3 equiv n-BuLi to 3.1 equiv 2,2,6,6-tetramethylpiperidine in anhyd THF at 0 °C and stirred for 15 min) was added to *N,N*-diethyl chrysene carboxamide (1 equiv) in anhyd THF at −78 °C. The reaction mixture was stirred at the same temperature for 30 min to 1.5 h while temperature was being monitored. I_2 (1.5 to 3 equiv) in THF was added to the reaction at −78 °C and was allowed to reach rt in 15 h. After the completion of the reaction, it was quenched with sat aq NH_4Cl. The product was extracted with EtOAc, washed with brine, dried over anhyd Na_2SO_4 and evaporated *in vacuo*. The crude product was purified using column chromatography (EtOAc in heptane).

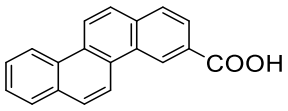
Chrysene-1-carboxylic acid (62)



According to general procedure F, KOH (0.80 g, 8.07 mmol) and H_2O (10 mL) was added to a solution of 1-methyl chrysene carboxylate (**8**) (1.11 g, 4.04 mmol) dissolved in THF (35 mL). The reaction mixture was stirred at 80 °C for 16 h. Normal extraction was done with Et_2O (60 mL) and water (3 * 60 mL). The aqueous layer was acidified with conc HCl until the product precipitates out. The pure product was filtered through a sintered glass funnel and washed with cold water. The final product (0.86 g, 81%) was dried *in vacuo*. MP (°C): More than 250 °C; ^{1}H NMR (400 MHz, DMSO-d_6): δ = 9.23 (d, *J* = 8.0 Hz,

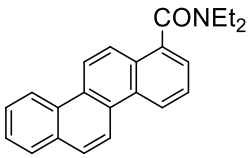
1H), 9.02 (app s, 2H), 8.95 (app t, *J* = 9.4 Hz, 2H), 8.26 (dd, *J* = 1.0, 7.3 Hz, 1H), 8.16 (d, *J* = 9.1 Hz, 1H), 8.13 (dd, *J* = 1.3, 7.9 Hz, 1H), 7.83 (dd, *J* = 7.3, 8.5 Hz, 1H), 7.80−7.76 (m, 1H), 7.74−7.70 ppm (m, 1H); ^{13}C NMR (100 MHz, DMSO-d_6): δ = 169.0, 131.8, 130.6, 129.74, 129.7, 129.6, 128.8, 128.5, 127.9, 127.8, 127.7, 127.4, 127.2, 127.0, 126.0, 124.3, 123.5, 123.0, 121.6 ppm; FTIR (KBr, cm^{-1}): 3050, 1676, 1486, 1418, 1301, 1283, 1258, 795, 758; HRMS (ESI) m/z $[M - H]^-$ for formula $C_{19}H_{11}O_2$: calcd 271.0764; found 271.0761.

Chrysene-3-carboxylic acid (63)



According to general procedure F, KOH (0.73 g, 14.1 mmol) and H_2O (10 mL) was added to a solution of 3-methyl chrysene carboxylate (**10**) (2.03 g, 7.06 mmol) dissolved in THF (35 mL). The reaction mixture was stirred at 80 °C for 16 h. Normal extraction was done with Et_2O (60 mL) and water (3 * 60 mL). The aqueous layer was acidified with conc HCl until the product precipitates out. The pure product was filtered through a sintered glass funnel and washed with cold water. The final product (1.88 g, 98%) was dried *in vacuo*. MP (°C): More than 250 °C; ^{1}H-NMR (400 MHz, DMSO-d_6): δ = 13.25 (br, 1H), 9.49 (s, 1H), 9.04 (d, *J* = 9.2 Hz, 1H), 8.98 (d, *J* = 8.3 Hz, 1H), 8.90 (d, *J* = 9.1 Hz, 1H), 8.23−8.17 (m, 4H), 8.14 (dd, *J* = 1.3, 8.0 Hz, 1H), 7.81−7.77 (m, 1H), 7.75−7.71 (m, 1H); ^{13}C-NMR (100 MHz, DMSO-d_6): δ = 167.6, 134.2, 131.9, 129.9, 129.2, 128.9 (2C), 128.6, 128.3, 128.1, 128.08, 127.3, 127.0, 126.99, 126.2, 125.3, 123.9, 123.5, 121.1; FTIR (KBr, cm^{-1}): 3046, 1687, 1450, 1418, 1309, 1278, 849, 801, 755; HRMS (ESI) m/z $[M - H]^-$ for formula $C_{19}H_{11}O_2$: calcd 271.0764; found 271.0763.

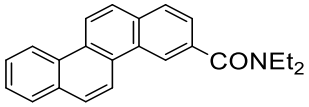
***N,N*-diethylchrysene-1-carboxamide (12)**



According to general procedure G, the chrysene carboxylic acid **62** (0.73 g, 2.69 mmol) dissolved in anhyd toluene (15 mL) was refluxed with $SOCl_2$ (0.59 mL, 8.06 mmol) and a drop of DMF as catalyst for 16 h. After cooling down to rt, the solvent was evaporated under reduced pressure and the yellow solid crude product was used in next reaction.

Diethyl amine (0.84 mL, 8.06 mmol) was added slowly to the crude chrysene-1-carbonyl chloride (2.69 mmol) dissolved in THF (60 mL) at 0 °C. The reaction mixture was refluxed for 16 h. After cooling down to rt, the reaction mixture was quenched with 1 M HCl (60 mL) and extracted with Et_2O (3 * 60 mL). The organic layer was washed with sat aq $NaHCO_3$ (60 mL) and brine (60 mL). It was dried over anhyd Na_2SO_4 and the solvent was evaporated *in vacuo*. The crude product was purified using column chromatography (20% EtOAc in heptane) to obtain off-white solid **12** (0.84 g, 99%). MP (°C): 156.5−158.3 (cyclohexane + DCM); ^{1}H−NMR (400 MHz, $CDCl_3$): δ = 8.82 (d, *J* = 8.8 Hz, 1H), 8.78 (d, *J* = 8.2 Hz, 1H), 8.77 (d, *J* = 9.2 Hz, 1H), 8.72 (d, *J* = 9.1 Hz, 1H), 8.04 (d, *J* = 9.1 Hz, 1H), 8.02−7.98 (m, 2H), 7.75−7.70 (m, 2H), 7.68−7.64 (m, 1H), 7.55 (dd, *J* = 1.0, 7.0 Hz, 1H), 3.96−3.88 (br m, 1H), 3.64−3.56 (br m, 1H), 3.19−3.11 (br m, 2H), 1.43 (t, *J* = 7.1 Hz, 3H), 1.02 (t, *J* = 7.1 Hz, 3H); ^{13}C-NMR (100 MHz, $CDCl_3$): δ = 170.5, 135.9, 132.3, 130.9, 130.5, 128.7, 128.4 (2C), 128.3, 127.9, 127.0, 126.7, 126.2, 123.9, 123.8, 123.77, 123.3, 122.4, 121.2, 43.3, 39.2, 14.4, 13.3; FTIR (KBr, cm^{-1}): 2965, 1619, 1594, 1465, 1287, 1101, 774; HRMS (ESI) m/z $[M + H]^+$ for formula $C_{23}H_{22}ON$: calcd 328.1696; found 328.1698.

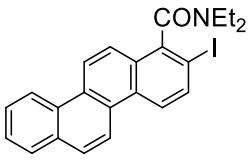
***N,N*-diethylchrysene-3-carboxamide (64)**



According to general procedure G, the chrysene carboxylic acid **63** (1.68 g, 6.12 mmol) dissolved in anhyd toluene (20 mL) was refluxed with $SOCl_2$ (3.3 mL, 18.6 mmol) and a drop of DMF as catalyst for 16 h. After cooling down to rt, the solvent was evaporated under reduced pressure and the yellow solid crude product was subsequently used.

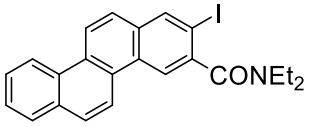
Diethyl amine (1.93 mL, 18.6 mmol) was added slowly to the crude chrysene-1-carbonyl chloride (6.18 mmol) dissolved in THF (100 mL) at 0 °C. The reaction mixture was refluxed for 16 h. After cooling down to rt, the reaction mixture was quenched with 1 M HCl (100 mL)and extracted with Et_2O (3 * 100 mL). The organic layer was washed with sat aq $NaHCO_3$ (100 mL) and brine (100 mL). It was dried over anhyd Na_2SO_4 and evaporated *in vacuo*. The crude product was purified using flash column chromatography (20% EtOAc in heptane) to obtain off-white solid **64** (2.03 g, quant). MP (°C) 156.5−157.7 (cyclohexane + DCM); ^{1}H−NMR (400 MHz, $CDCl_3$): δ = 8.82 (s, 1H), 8.71 (d, *J* = 9.0 Hz, 1H), 8.69 (d, *J* = 9.2 Hz, 1H), 8.67 (d, *J* = 8.9 Hz, 1H), 7.99 (d, *J* = 8.5 Hz, 1H), 7.97 (d, *J* = 6.9 Hz, 1H), 7.97 (s, 1H), 7.95 (d, *J* = 7.0 Hz, 1H), 7.70−7.60 (m, 2H), 7.63 (dd, *J* = 1.2, 8.1 Hz, 1H), 3.66 (br s, 2H), 3.33 (br s, 2H), 1.35 (br s, 3H), 1.16 (br s, 3H); ^{13}C-NMR (100 MHz, $CDCl_3$): δ = 171.6, 135.3, 132.3, 132.2, 130.4, 130.2, 128.7, 128.6 (2C), 128.2, 127.7, 126.9, 126.8, 126.6, 124.2, 123.1, 122.2, 121.4, 121.0, 43.5, 39.5, 14.3, 13.1; FTIR (KBr, cm^{-1}): 2975, 1623, 1425, 1283, 1094, 828, 762; HRMS (ESI) m/z $[M + H]^+$ for formula $C_{23}H_{22}ON$: calcd 328.1696; found 328.1702.

***N,N*-diethyl-2-iodochrysene-1-carboxamide (65)**



According to the general procedure H, the chrysenyl amide **12** (873 g, 2.67 mmol) in THF (35 mL) was treated with *s*-BuLi (3.55 mL, 4.01 mmol, 1.13 M in cyclohexane) and TMEDA (0.6 mL, 4.01 mmol) for 30 min before adding I_2 (4 mL, 4.01 mmol, 1 M in THF) at −78 °C. The reaction mixture was allowed to reach rt over 8 h. The reaction mixture was quenched with satd aq NH_4Cl solution (50 mL). The solution was extracted with EtOAc (3 * 50 mL) and the combined organic layer was washed with brine (50 mL) and dried over anhyd $MgSO_4$. The organic layer was evaporated to dryness under reduced pressure. The crude product was purified by flash column chromatography (20% EtOAc in heptane) to isolate the product **65** as an off-white solid (1.16 g, 96%). MP (°C): 237.6 − 241.0 (cyclohexane + DCM); ^{1}H-NMR (400 MHz, $CDCl_3$): δ = 8.73 (d, *J* = 8.2 Hz, 1H), 8.72 (d, *J* = 9.3 Hz, 1H), 8.61 (d, *J* = 9.1 Hz, 1H), 8.45 (d, *J* = 8.9 Hz, 1H), 8.03 (d, *J* = 8.9 Hz, 1H), 8.01 (d, *J* = 9.1Hz, 1H), 7.99 (dd, *J* = 1.1, 9.1 Hz, 1H), 7.91 (d, *J* = 9.3 Hz, 1H), 7.74 − 7.69 (m, 1H), 7.67 − 7.63 (m, 1H), 4.03 − 3.95 (m, 1H), 3.66 − 3.95 (m, 1H), 3.19 − 3.14 (m, 2H) 1.46 (t, *J* = 7.1 Hz, 3H), 1.01 (t, *J* = 7.2 Hz, 3H); ^{13}C-NMR (100 MHz, $CDCl_3$): δ = 169.7, 140.9, 136.2, 132.5, 130.4, 130.3, 129.9, 128.7, 128.4, 128.3, 128.1, 127.2, 127.0, 125.0, 124.1, 123.3, 123.25, 120.8, 91.8, 43.2, 39.2, 14.1, 12.7; FTIR (KBr, cm^{-1}): 2963, 1616, 1436, 1274, 1099, 811, 752; HRMS (ESI) m/z $[M + H]^+$ for formula $C_{23}H_{21}ONI$: calcd 454.0662; found 454.0662.

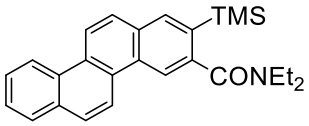
***N,N*-diethyl-2-iodochrysene-3-carboxamide (66)**



According to the general procedure H, the chrysenyl amide **64** (500 mg, 1.53 mmol) in THF (15 mL) was treated with freshly prepared LiTMP (4.58 mmol in 3 mL THF) for 1.5 h before adding I_2 (5.35 mL, 5.35 mmol, 1 M in THF) at

−78 °C. The reaction mixture was allowed to reach rt over 16 h. The reaction mixture was quenched with satd aq NH_4Cl solution (20 mL). The solution was extracted with EtOAc (3 * 20 mL) and the organic layer was washed with brine (20 mL) and dried over anhyd $MgSO_4$. The combined organic layer was evaporated to dryness under reduced pressure. The crude product was purified by flash column chromatography (20% EtOAc in heptane), afforded the product **66** as an off-white solid (0.58 g, 84%). MP (°C): 224.7 − 226.5 (cyclohexane + DCM); ^{1}H-NMR (400 MHz, $CDCl_3$): δ = 8.71 − 8.67 (m, 2H), 8.58 (s, 1H), 8.56 (d, *J* = 9.2 Hz, 1H), 8.43 (s, 1H), 7.99 − 7.95 (m, 2H), 7.82 (d, *J* = 9.1 Hz, 1H), 7.71 − 7.67 (m, 1H), 7.66 − 7.62 (m, 1H), 4.00 − 3.97 (br m, 1H), 3.42 − 3.39 (br m, 1H), 3.25 − 3.17 (br m, 2H) 1.40 (t, *J* = 7.1 Hz, 3H), 1.10 (t, *J* = 7.1 Hz, 3H); ^{13}C-NMR (100 MHz, $CDCl_3$): δ = 170.4, 140.2, 139.0, 133.3, 132.4, 130.4, 129.9, 128.8, 128.7, 128.2, 127.9, 127.1, 126.9, 125.6, 123.2, 123.0, 121.5, 120.6, 90.2, 43.1, 39.3, 14.1, 12.7; FTIR (KBr, cm^{-1}): 2965, 1635, 1423, 1279, 1106, 823, 812, 756; HRMS (ESI) m/z $[M + H]^+$ for formula $C_{23}H_{21}ONI$: calcd 454.0662; found 454.0666.

_N,N_-diethyl-2-(trimethylsilyl)chrysene-3-carboxamide (67)



According to the general procedure H, the chrysenyl amide **64** (0.108 g, 0.33 mmol) and TMSCl (0.06 mL, 0.50 mmol) dissolved in THF (4 mL) was treated with *s*-BuLi (0.44 mL, 0.50 mmol, 1.13 M in cyclohexane) and TMEDA (0.07 mL, 0.50 mmol) for 30 min at −78 °C. The reaction mixture was allowed to reach rt over 7 h. The reaction mixture was quenched with satd aq NH_4Cl solution (10 mL). The solution was extracted with EtOAc (3 * 10 mL) and the organic layer was washed with brine (10 mL) and dried over anhyd $MgSO_4$. The combined organic layer was evaporated to dryness under reduced pressure. The crude product was purified by flash column chromatography (15-20% EtOAc in heptane), afforded the product **67** as an off-white solid (73 mg, 55%). MP (°C): 166.9 − 169.0 (cyclohexane + DCM); ^{1}H-NMR (400 MHz, $CDCl_3$): δ = 8.78 (d, *J* = 8.3 Hz, 1H), 8.75 (d, *J* = 9.1 Hz, 1H), 8.65 (d, *J* = 9.1 Hz, 1H), 8.58 (s, 1H), 8.23 (s, 1H), 8.02 (d, *J* = 8.9 Hz, 2H), 8.00 (dd, *J* = 1.0, 7.0 Hz, 1H), 7.74 − 7.70 (m, 1H), 7.67 − 7.63 (m, 1H), 3.70 (q, *J* = 7.0 Hz, 2H), 3.27

(q, *J* = 7.0 Hz, 2H), 1.40 (t, *J* = 7.0 Hz, 3H), 1.16 (t, *J* = 7.0 Hz, 3H), 0.43 (s, 1H); ^{13}C-NMR (100 MHz, $CDCl_3$): δ = 172.9, 140.4, 136.6, 135.8, 132.4, 131.4, 130.6, 130.1, 129.0, 128.7, 128.0, 127.8, 127.3, 127.0, 126.7, 123.3, 122.0, 121.0, 120.1, 43.8, 39.4, 14.2, 13.1, 0.1; FTIR (KBr, cm^{-1}): 2966, 1633, 1457, 1283, 1243, 1112, 861, 839, 749; HRMS (ESI) m/z $[M + H]^+$ for formula $C_{26}H_{30}ONSi$: calcd 400.2091; found 400.2093.

9.4 Cross-coupling of larger PAHs

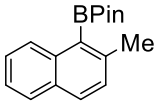
General Procedure (I) for borylation of methylnapthalenes

An over-dried round bottom flask fitted with a reflux condenser was purged with N_2 to maintain inert atmosphere. Bromo-methylnapthalene (1 equiv) and $PdCl_2$(dppf) (5 mol%) were transferred to the reaction flask and stirred in anhyd dioxane at rt for 10 min. Subsequently, triethyl amine (3 equiv) and BPinH (1.5 equiv) was added to the reaction mixture. It was refluxed for 18 h. After completion of reaction, it was cooled to reach rt and filtered through a pad of celite to remove Pd-black. The reaction mixture was extracted with EtOAc and water. The organic layer was dried over anhyd Na_2SO_4 and evaporated *in vacuo*. The crude product was purified using flash column chromatography with silica gel deactivated with 5% Et_3N in heptane (starting material eluted with pure heptane).

General Procedure (J) for cross-coupling

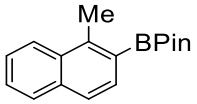
An over-dried round bottom flask fitted with a condenser was purged with N_2 to maintain inert atmosphere. A mixture of *N*,*N*-diethyl-2-iodochrysene carboxamide (1 equiv) and $PdCl_2$(dppf) or $PdCl_2$(dppe) (5 mol%) was stirred in DME or anhyd DMF at rt for 10 min. *o*-Tolyl boronic acid or methynaphthalenyl boronic ester (1.5 equiv) was added followed by the addition of 2 M Na_2CO_3 (3 mL) or Cs_2CO_3 (3 equiv). The reaction mixture was refluxed for 18 h or 24 h. After completion of the reaction, it was cooled down to rt and filtered through a pad of celite. The reaction mixture was extracted with EtOAc and water. The organic layer was dried over anhyd Na_2SO_4 and evaporated *in vacuo*. The crude product was purified using flash column chromatography (EtOAc in heptane).

4,4,5,5-Tetramethyl-2-(2-methylnaphthalen-1-yl)-1,3,2-dioxaborolane (79)



Following general procedure I, 1-bromo-2-methyl naphthalene (**70**) (2.08 g, 9.05 mmol) was stirred with $PdCl_2$(dppf) (0.37 g, 5 mol%) for 10 min in anhyd dioxane (36 mL) before adding BPinH (1.97 mL, 13.6 mmol) and Et_3N (3.78 mL, 27.2 mmol) at rt. The reaction mixture was refluxed for 17 h. After completion of reaction, it was cooled to reach rt and filtered through a pad of celite to remove Pd-black. The reaction mixture was extracted with EtOAc (3 * 50 mL) and water (50 mL). The combined organic layer was dried over anhyd Na_2SO_4 and evaporated *in vacuo*. The crude product was purified by flash chromatography (initially with pure heptane and then silica was deactivated with 5% Et_3N in heptane) afforded product **79** (1.67 g, 68%) as an off-white solid. Scaling-up the reagents relatively with 3.12 g of **70** afforded **79** in 65% yield. MP (°C): 91.4 − 94.5 (cyclohexane + DCM); ^{1}H-NMR (400 MHz, $CDCl_3$): δ = 8.11 (d, *J* = 8.5 Hz, 1H), 7.76 (dd, *J* = 1.3, 7.4 Hz, 1H), 7.75 (d, *J* = 8.4 Hz, 1H), 7.46 −7 .42 (m, 1H), 7.40 − 7.36 (m, 1H), 7.28 (d, *J* = 8.5 Hz, 1H), 2.62 (s, 3H), 1.49 (s, 12H); ^{13}C-NMR (100 MHz, $CDCl_3$): δ = 141.5, 136.8, 131.5, 129.7, 128.6, 128.3 (2C), 127.6, 126.1, 124.7, 84.1 (2C), 25.2 (3C), 25.1, 22.8; FTIR (KBr, cm^{-1}): 2975, 1507, 1467, 1303, 1258, 1144, 1132, 857, 843, 816, 742; HRMS (ESI) m/z $[M + H]^+$ for formula $C_{17}H_{22}O_2B$: calcd 269.1713; found 269.1707.

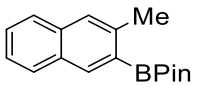
4,4,5,5-Tetramethyl-2-(1-methylnaphthalen-2-yl)-1,3,2-dioxaborolane (80)



Following general procedure I, 2-bromo-1-methyl naphthalene (**71**) (2.97 g, 13.42 mmol) was stirred with $PdCl_2$(dppf) (0.49 g, 5 mol%) for 10 min in anhyd dioxane (40 mL) before adding BPinH (2.93 mL, 20.14 mmol) and Et_3N (5.62 mL, 40.3 mmol) at rt. The reaction mixture was refluxed for 17 h. After completion of reaction, it was cooled down to rt and filtered through a pad of celite to remove Pd-black. The reaction mixture was extracted with EtOAc (3

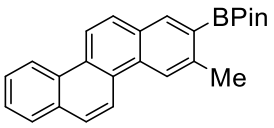
* 50 mL) and water (50 mL). The combined organic layer was dried over anhyd Na_2SO_4 and evaporated *in vacuo*. The crude product was purified by flash chromatography (initially with pure heptane and then silica was deactivated with 5% Et_3N in heptane) afforded product **80** (2.82 g, 78%) as an off-white solid. Repeating the experiment with 2 g of **71** resulted product **80** in 77% yield. MP (°C): 83.2 − 84.1 (cyclohexane + DCM); ^{1}H-NMR (400 MHz, $CDCl_3$): δ = 8.83 − 8.80 (m, 1H), 8.04 − 8.01 (m, 1H), 8.00 (d, *J* = 7.0 Hz, 1H), 7.57 − 7.50 (m, 2H), 7.34 (dd, *J* = 0.8, 7.0 Hz, 1H), 2.72 (s, 3H), 1.43 (s, 12H); ^{13}C-NMR (100 MHz, $CDCl_3$): δ = 138.1, 137.0, 135.6, 132.4, 129.0, 126.0 (3C), 125.3, 124.2, 83.6 (2C), 24.9 (4C), 19.9; FTIR (KBr, cm^{-1}): 2979, 1344, 1291, 1145, 1114, 858, 849, 760; HRMS (ESI) m/z $[M + H]^+$ for formula $C_{17}H_{22}O_2B$: calcd 269.1713; found 269.1707.

4,4,5,5-Tetramethyl-2-(3-methylnaphthalen-2-yl)-1,3,2-dioxaborolane (81)



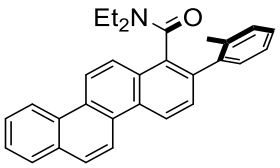
Following general procedure I, 2-methylnaphthalen-3-yl trifluoromethanesulfonate (**74**) (1 g, 3.45 mmol) was stirred with $PdCl_2$(dppf) (141 mg, 5 mol%) for 10 min in anhyd dioxane (15 mL) before adding BPinH (0.6 mL, 4.13 mmol) and Et_3N (1.5 mL, 10.4 mmol) at rt. The reaction mixture was refluxed for 17 h. After completion of reaction, it was cooled down to rt and filtered through a pad of celite to remove Pd-black. The reaction mixture was extracted with EtOAc (3 * 50 mL) and water (50 mL). The combined organic layer was dried over anhyd Na_2SO_4 and evaporated *in vacuo*. The crude product was purified byflash chromatography (initially with pure heptane and then silica was deactivated with 5% Et_3N in heptane) afforded product (0.68 g, 74%) as an off-white solid. Scaling-up the reagents by using 2.02 g of **74** afforded product **81** in 66% yield. MP (°C): 61.3 − 62.8 (cyclohexane + DCM); ^{1}H-NMR (400 MHz, $CDCl_3$): δ = 8.35 (s, 1H), 7.85 (d, *J* = 8.1 Hz, 1H), 7.74 (d, *J* = 8.2 Hz, 1H), 7.60 (s, 1H), 7.50 − 7.45 (m, 1H), 7.42 − 7.38 (m, 1H), 2.70 (s, 3H), 1.41 (s, 12H); ^{13}C-NMR (100 MHz, $CDCl_3$): δ = 140.5, 137.5 (2C), 135.1, 131.2, 128.4, 127.3, 127.1, 127.0, 125.0, 83.7 (2C), 25.1 (4C), 22.8; FTIR (KBr, cm^{-1}): 2976, 1350, 1329, 1147, 1135, 1031, 960, 856, 754, 750; HRMS (ESI) m/z $[M + H]^+$ for formula $C_{17}H_{22}O_2B$: calcd 269.1713; found 269.1706.

4,4,5,5-Tetramethyl-2-(3-methylchrysen-2-yl)-1,3,2-dioxaborolane (82)



Following general procedure I, 2-bromo-3-methylchrysene **14** (1.12 g, 3.47 mmol) was stirred with $PdCl_2$(dppf) (150 mg, 5 mol%) for 10 min in a anhyd solvent mixture of dioxane and toluene (1:1 ratio, 30 mL) before adding BPinH (0.76 mL, 5.21 mmol) and Et_3N (1.45 mL, 10.4 mmol) at rt. The reaction mixture was refluxed for 17 h. After completion of reaction, it was cooled to reach rt and filtered through a pad of celite to remove Pd-black. The reaction mixture was extracted with EtOAc (3 * 50 mL) and water (50 mL). The combined organic layer was dried over anhyd Na_2SO_4 and evaporated *in vacuo*. The crude product was purified by flash chromatography (initially with pure heptane and then silica was deactivated with 5% Et_3N in heptane) to isolate product **82** (0.29 g, 23%) as an off-white solid. MP (°C): 195.8 − 198.9 (Acetone); ^{1}H-NMR (400 MHz, $CDCl_3$): δ = 8.76 (d, *J* = 8.6 Hz, 1H), 8.74 (d, *J* = 9.2 Hz, 1H), 8.64 (d, *J* = 9.1 Hz, 1H), 8.59 (s, 1H), 8.58 (s, 1H), 8.07 (d, *J* = 9.0 Hz, 1H), 8.00 (dd, *J* = 1.4, 7.3 Hz, 1H), 7.98 (d, *J* = 8.9 Hz, 1H), 7.73 − 7.69 (m, 1H), 7.68 − 7.64 (m, 1H), 2.95 (s, 3H), 1.51 (s, 12H); ^{13}C-NMR (100 MHz, $CDCl_3$): δ = 141.9, 137.7, 132.4, 132.2, 130.6, 129.6, 129.1, 128.5, 127.6 (2C), 127.0, 126.6, 126.4, 123.3, 123.2, 121.4, 120.2, 83.7 (2C), 25.0 (4C), 23.4; FTIR (KBr, cm^{-1}): 2922, 1435, 1258, 953, 887, 827, 814, 748; HRMS (ESI) m/z $[M + H]^+$ for formula $C_{25}H_{25}O_2B$: calcd 368.1948 found 368.1941.

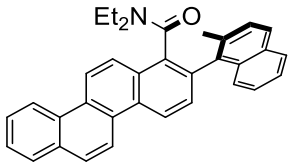
***N,N*-diethyl-2-(o-tolyl)chrysene-1-carboxamide (83)**



According to general procedure J, iodochrysenyl amide **65** (110 mg, 0.24 mmol), $PdCl_2$(dppf) (9 mg, 5 mol%), *o*-TBA (40 mg, 0.29 mmol) and Na_2CO_3 (77 mg, 0.73 mmol) were all added in sequence to DME (5 mL) and then water (2 mL) was added to the reaction mixture. The reaction mixture was stirred at

85 °C for 17 h. After completion of reaction, it was cooled down to rt and filtered through a pad of celite to remove Pd-black. The reaction mixture was extracted with EtOAc (3 * 10 mL) and water (10 mL). The combined organic layer was dried over anhyd Na_2SO_4 and evaporated *in vacuo*. The crude product was purified by flash chromatography (20% EtOAc in heptane) to isolate cross-coupled product **83** (91 mg, 90%) as brown solid (major: minor rotamers = 56:44). MP (°C): 205.2 − 210.3 (cyclohexane + DCM); ^{1}H-NMR (400 MHz, $CDCl_3$): δ = 8.85 − 8.73 (br m, 8H), 8.05 − 8.00 (br m, 6H), 7.75−7.71 (m, 2H), 7.68 − 7.56 (br m, 5H), 7.30 − 7.18 (br m, 7H), 3.93 (br, 2H), 3.25 − 2.78 (br, 6H), 2.31 (s, 3H), 2.26 (s, 3H, minor), 0.93 − 0.77 (m, 12H); ^{13}C-NMR (100 MHz, $CDCl_3$): δ = 169.2, 169.1, 139.9, 138.6, 138.1, 136.7, 135.4, 135.2, 134.9, 134.6, 132.3, 131.5, 130.5 (2C), 130.2, 129.9, 129.2, 129.1, 128.7 (2C), 128.3, 128.2, 128.0 (2C), 127.9, 127.0 (2C), 126.7 (2C), 125.8, 124.7, 123.5 (2C), 123.3, 122.8, 122.4 (2C), 121.2 (2C), 42.9, 42.4, 38.0, 37.8, 20.6, 20.5, 14.0 (2C), 12.1, 11.8; FTIR (KBr, cm^{-1}): 2976, 2929, 1622, 1438, 1271, 1220, 1099, 796, 761; HRMS (ESI) m/z $[M + H]^+$ for formula $C_{30}H_{28}ON$: calcd 418.2165 found 418.2167.

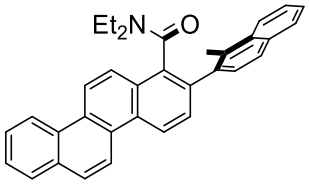
_N,N_-diethyl-2-(2-methylnaphthalen-1-yl)chrysene-1-carboxamide (84)



According to general procedure J, iodochrysenyl amide **65** (104 mg, 0.23 mmol), $PdCl_2$(dppe) (7 mg, 5 mol%), methylnaphthalenyl boronic ester **79** (123 mg, 0.46 mmol) and Cs_2CO_3 (224 mg, 0.69 mmol) were all added in sequence to anhyd DMF (3 mL) containing 4 Å MS. The reaction mixture was stirred at 120 °C for 24 h. After completion of reaction, it was cooled down to rt and filtered through a pad of celite to remove Pd-black. The reaction mixture was extracted with EtOAc (3 * 10 mL) and water (10 mL). The combined organic layer was dried over anhyd Na_2SO_4 and evaporated *in vacuo*. The crude product was purified by flash chromatography (15% EtOAc in heptane) afforded cross-coupled product **84** (71 mg, 66%) as brown solid (major: minor rotamers = 83:17). MP (°C) 91.3 − 94.8 (cyclohexane + DCM); ^{1}H-NMR (400 MHz, $CDCl_3$): δ = 8.94 (d, *J* = 8.5 Hz, 1H), 8.81 (d, *J* = 9.0 Hz, 2H), 8.80 (d, *J* = 9.1

Hz, 1H), 8.07 (d, *J* = 9.1 Hz, 1H), 8.06 (d, *J* = 9.2 Hz, 1H), 8.04 − 8.02 (m, 1H), 7.89 − 7.87 (m, 1H), 7.83 (d, *J* = 8.4 Hz, 1H), 7.76 − 7.72 (m, 1H), 7.70 (d, *J* = 8.6 Hz, 1H), 7.69 − 7.68 (m, 1H), 7.66 − 7.63 (m, 1H − minor), 7.48 (d, *J* = 8.4 Hz, 1H), 7.42 − 7.39 (m, 2H), 7.31 − 7.27 (m, 1H), 3.79 − 3.74 (m, 1H), 3.21 − 3.16 (m, 1H), 2.84 − 2.79 (m, 2H), 2.43 (s, 3H), 2.34 (s, 3H − minor), 0.92 (app t, *J* = 7.0 Hz, 3H − minor), 0.71 (t, *J* = 7.1 Hz, 3H), 0.39 (t, *J* = 7.1 Hz, 3H); ^{13}C-NMR (100 MHz, $CDCl_3$, major rotamer): δ = 168.7, 136.4, 135.9, 135.0, 134.7, 132.6, 132.4, 131.8, 130.5, 130.1, 129.3, 129.1, 128.7, 128.4, 128.3, 128.2, 127.9, 127.89, 127.8, 127.0, 126.7, 126.0, 125.4, 124.6, 124.5, 123.4, 123.3, 122.4, 121.2, 42.9, 37.3, 21.5, 13.9, 11.4; FTIR (KBr, cm^{-1}): 2925, 1630, 1439, 1273, 1097, 812, 752; HRMS (ESI) m/z $[M + H]^+$ for formula $C_{34}H_{30}ON$ calcd 468.2322; found 468.2322.

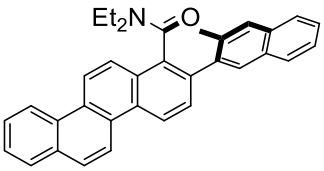
***N,N*-diethyl-2-(1-methylnaphthalen-2-yl)chrysene-1-carboxamide (85)**



According to general procedure J, iodochrysenyl amide **65** (94 mg, 0.21 mmol), $PdCl_2$(dppe) (6 mg, 5 mol%), methylnaphthalenyl boronic ester **80** (111 mg, 0.42 mmol) and Cs_2CO_3 (203 mg, 0.66 mmol) were all added in sequence to anhyd DMF (3 mL) containing 4 Å MS. The reaction mixture was stirred at 120 °C for 24 h. After completion of reaction, it was cooled to reach rt and filtered through a pad of celite to remove Pd-black. The reaction mixture was extracted with EtOAc (3 * 10 mL) and water (10 mL). The combined organic layer was dried over anhyd Na_2SO_4 and evaporated *in vacuo*. The crude product was purified by flash chromatography (15% EtOAc in heptane) to afford cross-coupled product **85** (97 mg, quant) as red solid (major: minor rotamers = 77:13). MP (°C) 194.5 − 198.1 (cyclohexane + DCM); ^{1}H-NMR (400 MHz, $CDCl_3$): δ = 8.88 (d, *J* = 7.9 Hz, 1H − minor), 8.86 (d, *J* = 8.6 Hz, 1H), 8.81 (app dd, *J* = 3.2, 9.6 Hz, 2H), 8.77 (d, *J* = 9.2 Hz, 1H), 8.13 − 8.10 (m, 2H), 8.05 (d, *J* = 9.1 Hz, 1H), 8.02 (br d, *J* = 8.0 Hz, 1H), 7.86 (d, *J* = 8.3 Hz, 1H), 7.80 (d, *J* = 8.6 Hz, 1H), 7.78 (d, *J* = 7.00 Hz, 1H), 7.76 − 7.72 (m, 1H − major, 1H − minor), 7.69 (d, *J* = 8.6 Hz, 1H − minor), 7.69 − 7.65 (m, 1H − major, 1H − minor),

7.58 − 7.52 (m, 1H − major, 1H, minor), 7.47 − 7.42 (m, 2H, major, 2H, minor), 7.36 (dd, *J* = 0.6, 7.2 Hz, 1H − minor), 7.29 (d, *J* = 7.1 Hz, 1H − minor), 3.81 − 3.74 (m, 1H − major, 1H − minor), 3.36−3.27 (m, 1H − minor), 3.13 − 3.00 (m, 2H), 2.96 − 2.88 (m, 2H − minor), 2.78 (s, 3H − major), 2.77 (s, 3H − minor), 2.50 − 2.41 (m, 1H), 0.93 (t, *J* = 7.1 Hz, 3H − minor), 0.71 (t, 3H, *J* = 7.1 Hz, 3H), 0.54 (t, *J* = 7.1 Hz, 3H), 0.52 (t, *J* = 7.1 Hz, 1H − minor); ^{13}C-NMR (100 MHz, $CDCl_3$): δ = 169.2 (major), 168.8 (minor), 136.6, 135.7, 135.6, 135.4, 134.8, 134.6, 134.5, 132.9, 132.6, 132.5, 132.4, 131.9, 130.5, 130.2, 130.1, 130.06, 129.6, 129.3, 128.7, 128.67 (2C), 128.5, 128.4, 128.3, 128.27, 127.9, 126.9 (2C), 126.7, 126.3, 126.2, 126.1, 125.7, 125.6, 125.5, 125.2, 124.8, 124.76, 124.7, 123.7, 123.4, 123.3, 122.7, 122.5, 121.2 (2C), 43.0 (minor), 42.7 (major), 38.0 (major), 37.7 (minor), 19.7 (2C), 14.1 (minor), 13.8 (major), 12.0 (major), 11.7 (minor); FTIR (KBr, cm^{-1}): 2973, 2930, 1626, 1481, 1274, 1097, 806, 760; HRMS (ESI) m/z $[M + H]^+$ for formula $C_{34}H_{30}ON$: calcd 468.2322; found 468.2324.

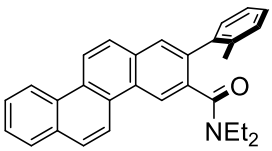
***N,N*-diethyl-2-(3-methylnaphthalen-2-yl)chrysene-1-carboxamide (86)**



According to general procedure J, iodochrysenyl amide **65** (104 mg, 0.23 mmol), $PdCl_2$(dppe) (7 mg, 5 mol%), methylnaphthalenyl boronic ester **81** (123 mg, 0.46 mmol) and Cs_2CO_3 (224 mg, 0.69 mmol) were all added in sequence to anhyd DMF (3 mL) containing 4 Å MS. The reaction mixture was stirred at 120 °C for 24 h. After completion of reaction, it was cooled to reach rt and filtered through a pad of celite to remove Pd-black. The reaction mixture was extracted with EtOAc (3 * 10 mL) and water (10 mL). The combined organic layer was dried over anhyd Na_2SO_4 and evaporated *in vacuo*. The crude product was purified by flash chromatography (15% EtOAc in heptane) afforded cross-coupled product **86** (87 mg, 81%) as off-white solid (major: minor rotamers = 51:49). Scaling-up the reagents by using 1.16 g of **65** resulted **86** in 58% yield. MP (°C) 208.7 − 212.4 (cyclohexane + DCM); ^{1}H-NMR (400 MHz, $CDCl_3$): δ = 8.87 − 8.72 (m, 8H), 8.19 (s, 1H), 8.13 − 8.01 (m, 6H), 7.94 − 7.92 (br d, *J* =

7.5 Hz, 1H), 7.85 − 7.62 (m, 12H), 7.52 − 7.45 (m, 4H), 3.81 (br s, 2H), 3.42 − 3.33 (br m, 1H), 3.17 − 3.01 (br m, 4H), 2.79 − 2.72 (br m, 1H), 2.47 (s, 3H − major), 2.44 (s, 3H − minor), 0.98 (br m, 3H), 0.76 (br t, *J* = 6.6 Hz, 3H), 0.65 − 0.57 (br m, 6H); ^{13}C-NMR (100 MHz, $CDCl_3$): δ = 169.1 (major), 169.0 (minor), 139.2, 136.9, 136.5, 135.0, 134.8, 133.5, 133.3, 133.1, 132.3 (2C), 131.8, 131.3, 130.6, 130.5, 130.0, 129.3, 129.0, 128.7 (2C), 128.5, 128.4, 128.2, 127.9, 127.85, 127.3, 127.0, 126.9, 126.7, 126.3, 126.0, 125.6, 125.4, 124.8, 124.5, 123.4, 123.3 (2C), 122.8, 122.5, 121.2 , 42.9, 42.6, 38.2, 37.7, 21.1, 14.0 (2C), 11.9, 11.7; FTIR (KBr, cm^{-1}): 2969, 2927, 1628, 1469, 1422, 1276, 1097, 798, 744; HRMS (ESI) m/z $[M + H]^+$ for formula $C_{34}H_{30}ON$: calcd 468.2322; found 468.2325.

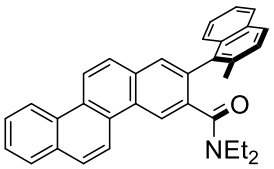
_N,N_-diethyl-2-(_o_-tolyl)chrysene-3-carboxamide (87)



According to general procedure J, iodochrysenyl amide **66** (65 mg, 0.14 mmol), $PdCl_2$(dppf) (6 mg, 5 mol%), *o-TBA* (24 mg, 0.17 mmol) and Na_2CO_3 (46 mg, 0.43 mmol) were all added in sequence to DME (2 mL) and then H_2O (1 mL) was added to the reaction mixture. The reaction mixture was stirred at 85 °C for 17 h. After completion of reaction, it was cooled to reach rt and filtered through a pad of celite to remove Pd-black. The reaction mixture was extracted with EtOAc (3 * 10 mL) and water (10 mL). The combined organic layer was dried over anhyd Na_2SO_4 and evaporated *in vacuo*. The crude product was purified by flash chromatography (20% EtOAc in heptane) to afford cross-coupled product **87** (46 mg, 77%, mixture of rotamers) as an off-white solid. MP (°C) 195.4 − 199.0 (cyclohexane + DCM); ^{1}H-NMR (400 MHz, $CDCl_3$): δ = 8.80 (s, 1H), 8.79 (d, *J* = 8.3 Hz, 1H), 8.78 (d, *J* = 9.1 Hz, 1H), 8.72 (d, *J* = 9.1 Hz, 1H), 8.04 (d, *J* = 9.1 Hz, 1H), 8.02 (app d, *J* = 1.3, 8.0 Hz, 1H), 8.00 (d, *J* = 8.9 Hz, 1H), 7.89 (s, 1H), 7.75 − 7.71 (m, 1H), 7.68 − 7.64 (m, 1H), 7.31 − 7.24 (br peak, 4H), 3.89 (br s, 1H), 3.19 − 2.90 (br peak, 3H), 2.33 (br s, 3H), 0.95 (br s, 3H), 0.77 (br s, 3H); ^{13}C-NMR (100 MHz, $CDCl_3$): δ = 170.4, 132.4, 130.6, 130.3, 129.6, 128.8 (2C), 128.6, 128.2, 127.94, 127.9 (2C), 127.0 (2C), 126.9 (2C), 126.7, 123.3 (2C), 122.4, 121.2, 42.6 (2C), 38.2 (2C), 20.5, 13.9

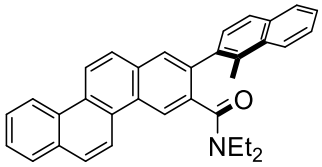
(2C), 11.9 (2C); FTIR (KBr, cm^{-1}): 2969, 2930, 1637, 1470, 1433, 1281, 1096, 1081, 822, 813, 753; HRMS (ESI) m/z $[M + H]^+$ for formula $C_{30}H_{28}ON$: calcd 418.2165; found 418.2167.

_N,N_-diethyl-2-(2-methylnaphthalen-1-yl)chrysene-3-carboxamide (88)



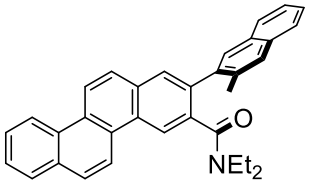
According to general procedure J, iodochrysenyl amide **66** (106 mg, 0.22 mmol), $PdCl_2$(dppe) (7 mg, 5 mol%), methylnaphthalenyl boronic ester **79** (118 mg, 0.44 mmol) and Cs_2CO_3 (216 mg, 0.66 mmol) were all added in sequence to anhyd DMF (3 mL) containing 4 Å MS. The reaction mixture was stirred at 120 °C for 24 h. After completion of reaction, it was cooled to reach rt and filtered through a pad of celite to remove Pd-black. The reaction mixture was extracted with EtOAc (3 * 10 mL) and water (10 mL). The combined organic layer was dried over anhyd Na_2SO_4 and evaporated *in vacuo*. The crude product was purified by flash chromatography (20% EtOAc in heptane) to afford cross-coupled product **88** (48 mg, 46%, mixture of rotamers) as pale brown solid. MP (°C): 237.4 − 240.8 (cyclohexane + DCM); ^{1}H-NMR (400 MHz, $CDCl_3$): δ = 8.87 (s, 1H), 8.82 (d, *J* = 8.9 Hz, 2H), 8.75 (d, *J* = 9.1 Hz, 1H), 8.07 (d, *J* = 9.1 Hz, 1H), 8.04 (d, *J* = 8.5 Hz, 2H), 7.99 (s, 1H), 7.86 (d, *J* = 8.2 Hz, 1H), 7.83 (d, *J* = 8.5 Hz, 1H), 7.77 − 7.73 (m, 1H), 7.70 − 7.66 (m, 1H), 7.47 (br d, *J* = 8.4 Hz, 2H), 7.42 − 7.38 (m, 1H), 7.33 − 7.29 (br m, 1H), 3.65 − 2.49 (br m, 4H), 2.41 (s, 3H), 0.94 (s, 3H), 0.36 (br t, *J* = 6.9 Hz, 3H); ^{13}C-NMR (100 MHz, $CDCl_3$): δ = 169.8, 137.0, 135.3, 135.0, 132.8, 132.4, 132.1, 131.9, 130.9, 130.6, 129.6, 128.8, 128.7, 128.2, 128.0, 127.8, 127.1, 127.0, 126.7, 125.5, 124.6, 123.3, 122.4, 121.1, 43.1, 37.9, 21.4, 14.0, 11.4; FTIR (KBr, cm^{-1}): 2969, 2929, 1629, 1467, 1425, 1282, 1067, 818, 749; HRMS (ESI) m/z $[M + H]^+$ for formula $C_{34}H_{30}ON$: calcd 468.2322; found 468.2322.

_N,N_-diethyl-2-(1-methylnaphthalen-2-yl)chrysene-3-carboxamide (89)



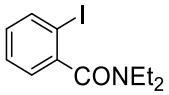
According to general procedure J, iodochrysenyl amide **66** (107 mg, 0.24 mmol), $PdCl_2$(dppe) (7 mg, 5 mol%), methylnaphthalenyl boronic ester **80** (127 mg, 0.47 mmol) and Cs_2CO_3 (231 mg, 0.71 mmol) were all added in sequence to anhyd DMF (3 mL) containing 4 Å MS. The reaction mixture was stirred at 120 °C for 24 h. After completion of reaction, it was cooled to reach rt and filtered through a pad of celite to remove Pd-black. The reaction mixture was extracted with EtOAc (3 * 10 mL) and water (10 mL). The combined organic layer was dried over anhyd Na_2SO_4 and evaporated *in vacuo*. The crude product was purified by flash chromatography (20% EtOAc in heptane) to isolate cross-coupled product **89** (103 mg, 93%, mixture of rotamers) as brown solid. MP (°C) 228.0 − 230.0 (cyclohexane + DCM); ^{1}H-NMR (400 MHz, $CDCl_3$): δ 8.92 (s, 1H), 8.77 (app dd, *J* = 2.6, 9.1 Hz, 3H), 8.16 − 7.82 (br m, 3H), 8.05 (br d, *J* = 9.1 Hz, 1H), 8.02 (br d, *J* = 7.9 Hz, 1H), 8.00 (br d, *J* = 9.1 Hz, 1H), 7.74 − 7.64 (br m, 3H), 7.59 − 7.55 (br m, 1H), 7.49 − 7.27 (br m, 3H), 3.76 (br s, 1H), 3.31 − 3.16 (br, 1H), 2.89 − 2.46 (br, 2H), 2.79 (s, 3H), 1.01 − 0.37 (br m, 6H); ^{13}C-NMR (100 MHz, $CDCl_3$): δ 170.3, 137.1, 136.3, 135.7, 134.9, 134.4, 132.9, 132.5, 132.4, 131.8, 131.5, 131.3, 130.5, 130.2, 129.6, 129.1, 128.7, 128.6, 128.1, 127.9, 127.0, 126.9, 126.6, 126.2, 126.0, 125.7, 125.5, 124.8, 124.2, 123.8, 123.2, 122.4, 121.9, 121.5, 121.2, 42.8, 38.1, 19.7, 13.6, 11.8; FTIR (KBr, cm^{-1}): 2975, 1618, 1426, 1275, 767, 748; HRMS (ESI) m/z $[M + H]^+$ for formula $C_{34}H_{30}ON$: calcd 468.2322; found 468.2324.

_N,N_-diethyl-2-(3-methylnaphthalen-2-yl)chrysene-3-carboxamide (90)



According to general procedure J, iodochrysenyl amide **66** (83 mg, 0.18 mmol), $PdCl_2$(dppe) (5 mg, 5 mol%), methylnaphthalenyl boronic ester **81** (98 mg, 0.37 mmol) and Cs_2CO_3 (179 mg, 0.55 mmol) were all added in sequence to anhyd DMF (3 mL) containing 4 Å MS. The reaction mixture was stirred at 120 °C for 24 h. After completion of reaction, it was cooled to reach rt and filtered through a pad of celite to remove Pd-black. The reaction mixture was extracted with EtOAc (3 * 10 mL) and water (10 mL). The combined organic layer was dried over anhyd Na_2SO_4 and evaporated *in vacuo*. The crude product was purified by flash chromatography (20% EtOAc in heptane) afforded cross-coupled product (69 mg, 81%, mixture of rotamers) as pale brown solid **90**. MP (°C) 225.4 − 230.8 (cyclohexane + DCM); ^{1}H-NMR (400 MHz, $CDCl_3$): δ 8.86 (br s, 1H), 8.78 (d, J = 8.3 Hz, 1H), 8.77 (d, *J* = 9.2 Hz, 1H), 8.75 (d, *J* = 9.1 Hz, 1H), 8.05 (d, *J* = 9.0 Hz, 1H), 8.03 − 7.99 (m, 2H), 7.97 (s, 1H), 7.83 (br d, *J* = 7.8 Hz, 2H), 7.79 (br s, 1H), 7.75 − 7.71 (m, 1H), 7.68 − 7.65 (m, 1H), 7.52 − 7.44 (m, 2H), 3.77 − 2.92 (br m, 4H), 2.50 (s, 3H), 0.96 (br s, 3H), 0.57 (t, *J* = 7.1 Hz, 3H); ^{13}C-NMR (100 MHz, $CDCl_3$): δ 170.3, 136.3, 133.3, 132.4, 131.8, 131.5, 130.5, 130.0, 129.6, 128.7 (2C), 128.6, 128.1, 127.9 (2C), 127.0 (2C), 126.9 (2C), 126.7, 126.2, 125.5, 123.2, 122.4, 121.1, 42.7, 38.2, 21.1, 13.9, 11.8; FTIR (KBr, cm^{-1}): 2974, 1634, 1624, 1424, 1285, 1094, 1068, 889, 811, 748; HRMS (ESI) m/z $[M + H]^+$ for formula $C_{34}H_{30}ON$: calcd 468.2322; found 468.2324.

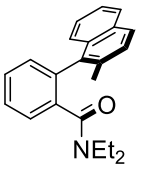
_N,N_-diethyl-2-iodobenzamide (91)



According to the general procedure H, *N,N*-diethylbenzamide (386 mg, 2.18 mmol) dissolved in anhyd THF (3 mL) was added slowly to a solution of *s*-

BuLi (2.9 mL, 3.27 mmol, 1.13 M in cyclohexane) and TMEDA (0.49 mL,3.27 mmol) in anhyd THF (2 mL). The reaction mixture was stirred for 30 min before adding I_2 (3.3 mL, 1 M in THF) at −78 °C. It was allowed to reach rt over 6 h. The reaction mixture was quenched with satd aq NH_4Cl solution (10 mL). The solution was extracted with EtOAc (3 * 10 mL) and the combined organic layer was washed with brine (10 mL) and dried over anhyd $MgSO_4$. It was evaporated to dryness under reduced pressure. The crude product was purified by flash column chromatography (20% EtOAc in heptane) to isolate the product **91** as yellow oil (0.46 g, 68%). The characterization data was found to be in accordance with literature.[281]

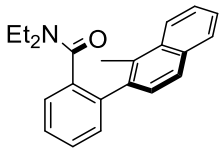
***N*,*N*-diethyl-2-(2-methylnaphthalen-1-yl)benzamide (92)**



According to general procedure J, *o*-iodobenzamide **91** (145 mg, 0.48 mmol), $Pd_2(dba)_3$ (22 mg, 5 mol%), SPhos (39 mg, 20 mol%), methylnaphthalenyl boronic ester **79** (154 mg, 0.57 mmol) and Cs_2CO_3 (468 mg, 1.5 mmol) were all added in sequence to anhyd DMF (4 mL) containing 4 Å MS. The reaction mixture was stirred at 120 °C for 17 h. After completion of reaction, it was cooled to reach rt and filtered through a pad of celite to remove Pd-black. The reaction mixture was extracted with EtOAc (3 * 10 mL) and water (10 mL). The combined organic layer was dried over anhyd Na_2SO_4 and evaporated *in vacuo*. The crude product was purified by flash chromatography (20% EtOAc in heptane) to isolate cross-coupled product **92** (118 mg, 78%, mixture of rotamers) as red solid. Scaling-up the reagents by using 1.32 g of **91** resulted **92** in 60% yield. Characterization data was found to be in accordance with literature.[189] MP (°C) 137.8 − 138.8 (DCM); ^{1}H-NMR (400 MHz, $CDCl_3$): δ = 7.80 (d, *J* = 7.5 Hz, 1H), 7.75 (d, *J* = 8.4 Hz, 1H), 7.54 − 7.43 (m, 3H), 7.39 − 7.28 (m, 5H), 3.47 − 2.60 (br, 4H), 2.31 (s, 3H), 0.86 (br s, 3H), 0.27 (t, *J* = 6.9 Hz, 3H); ^{13}C-NMR (100 MHz, $CDCl_3$): δ = 169.6, 138.1, 137.1, 135.3, 132.6, 131.8, 131.3, 128.7 (2C), 127.9, 127.5 (2C), 126.4, 125.4, 124.6, 42.9, 37.7, 21.3, 13.9, 11.4; FTIR (KBr, cm^{-1}): 2972, 1627, 1459, 1432, 1290, 1081, 826,

783, 767; HRMS (ESI) m/z [M + Na]$^+$ for formula $C_{22}H_{23}ONNa$: calcd 340.1672; found 340.1675.

***N,N*-diethyl-2-(1-methylnaphthalen-2-yl)benzamide (93)**



According to general procedure J, *o*-iodobenzamide **91** (1.33 g, 4.39 mmol), $Pd_2(dba)_3$ (200 mg, 5 mol%), SPhos (360 mg, 20 mol%), methylnaphthalenyl boronic ester **80** (1.42 g, 5.28 mmol) and Cs_2CO_3 (4.30 g, 13.2 mmol) were all added in sequence to anhyd DMF (40 mL) containing 4 Å MS. The reaction mixture was stirred at 120 °C for 17 h. After the completion of reaction, it was cooled to reach rt and filtered through a pad of celite to remove Pd-black. The reaction mixture was extracted with EtOAc (3 * 50 mL) and water (50 mL). The combined organic layer was dried over anhyd Na_2SO_4 and evaporated *in vacuo*. The crude product was purified by flash chromatography (20% EtOAc in heptane) to afford cross-coupled product **93** (1.389 g, quant, mixture of rotamers) as pale red solid. Spectral data was found to be in accordance with literature.[190] MP (°C): solidifies slowly to red solid 89.3 − 91.7 (DCM); HRMS (ESI) m/z [M + Na]$^+$ for formula $C_{22}H_{23}ONNa$: calcd 340.1672; found 340.1675.

9.5 Directed remote metalation

General procedure (K) for DreM

An oven-dried round bottom flask was purged with N_2 before dissolving unsymmetrical biarylic derivative (1 equiv) in anhyd THF. A freshly prepared LDA (3-3.5 equiv, prepared *in situ* by adding 1 equiv of *n*-BuLi to 1.1 equiv of DIIPA in anhyd THF at 0 °C and stirred for 15 min) was added drop-wise to it at 0 °C under N_2 atmosphere. The reaction mixture was stirred at 0 °C for 30 min before allowing it to reach rt or 40 °C. At this temperature, it was stirred for 1 h. Subsequently, the reaction mixture was cooled down to rt, if it was at 40 °C, to add TBDMSCl (3-3.5 equiv, 1 M in THF) slowly. The reaction was allowed to progress at rt for 14 h. After completion of the reaction, it was

quenched with sat aq NH_4Cl. The product was extracted with EtOAc and washed with brine. The combined organic layer was dried over anhyd Na_2SO_4 and evaporated *in vacuo*. The crude product was purified using column chromatography (EtOAc or DCM in heptane).

General procedure (L) for UV-visible spectroscopic and fluorescence measurements

Using end-products **94, 95, 97**−**99, 101** and **103A** stock solutions of 10^{-3} M in $CHCl_3$ were prepared, which were diluted in the same solvent to 10^{-6} M. These solutions were used to record the maximum absorption wavelength by scanning the sample from 200 to 900 nm.

Using the same samples from 10^{-6} M solutions, the emission spectra of all the synthesised PAHs were recorded at maximum absorption wavelength. The excitation spectra were subsequently measured using maximum emission wavelength. All the data from UV-visible absorption spectroscopy and fluorescence were plotted in normalized graphs to calculate the Stoke's shift.

General procedure (M) for cryogenic crystallization of DreM reaction intermediates

Under inert N_2 atmosphere, 1 equiv of unsymmetrical biarylic derivative (200 mg to 370 mg, 1 equiv) was taken in a schlenk tube and dissolved in a minimum volume of either anhyd toluene (2−10 mL) or anhyd THF (2−10 mL) or suitable anhyd mixture of toluene-THF. The solution was cooled down to −78 °C before adding 3 equiv of freshly prepared LDA (3 equiv of *n*-BuLi was added to 3.1 equiv of DIIPA in anhyd THF stirred at 0 °C for 15 min) was added drop-wise to it. The reaction mixture was stirred at −78 °C for 10 min before leaving them undisturbed to form crystals in a freezer at −78 °C. In some experiments, the excess solvent was removed under reduced pressure maintaining −78 °C. The reaction mixtures of substrate **86** in THF and toluene separately and substrate **92** in toluene, showed the formation of microcrystals which were not suitable for X-ray diffraction studies.

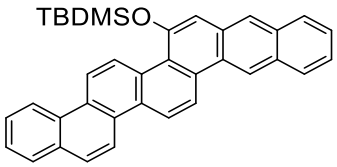
(Benzo[*c*]picen-7-yloxy)(*tert*-butyl)dimethylsilane (94)

According to general procedure K, the biarylic derivative **83** (94 mg, 0.23 mmol) dissolved in anhyd THF (3 mL) was treated with the freshly prepared LDA (0.56 mmol in 1 mL THF) at 0 °C and stirred for 30 min. The reaction mixture was then stirred at rt for 1 h before adding TBDMSCl (0.56 mL, 0.56 mmol, 1 M in THF) to it and allowed to react for 17 h at rt. The reaction mixture was subsequently quenched with satd aq NH_4Cl solution (10 mL). The product has poor solubility and hence extracted with toluene (3 * 10 mL). The combined organic layer was washed with brine (10 mL) and dried over anhyd $MgSO_4$. It was evaporated to dryness under reduced pressure. The crude product was washed with acetone to obtain pure TBDMS-protected product **94** (70 mg, 63%) as an off-white solid. MP (°C) 261.0 − 263.0 (Acetone); ^{1}H-NMR (400 MHz, $C_2D_2Cl_4$): δ = 9.99 (d, *J* = 9.6 Hz. 1H), 8.97 (d, *J* = 9.4, 1H), 8.89 (d, *J* = 9.5 Hz, 1H), 8.84 (d, *J* = 8.3 Hz, 1H), 8.79 (d, *J* = 9.5 Hz, 1H), 8.77 (d, *J* = 10.0 Hz, 1H), 8.71 − 8.69 (m, 1H), 8.00 − 7.96 (m, 2H), 7.81 − 7.79 (m, 1H), 7.72 − 7.68 (m, 1H), 7.64 − 7.60 (m, 1H), 7.57 − 7.53 (m, 2H), 7.35 (s, 1H), 1.08 (s, 9H), 0.28 (s, 6H); ^{13}C-NMR (100 MHz, $C_2D_2Cl_4$): δ = 152.1, 132.5, 131.8, 130.8, 130.0, 129.4, 129.1, 128.5, 127.9, 127.7, 127.65, 127.1, 126.9, 126.7, 126.67 (2C), 126.4, 124.7, 124.0, 123.3, 123.1, 122.6, 121.8, 121.7, 120.1, 114.7, 26.1 (3C), 18.6, −3.8 (2C); FTIR (KBr, cm^{-1}): 2957, 2927, 1615, 1441, 1284, 1252, 1104, 837, 762; UV-Vis ($CHCl_3$): λ_{max} (ε) = 298 nm; Fluorescence ($CHCl_3$): λ_{ex} = 297 nm; λ_{em} = 396 nm; HRMS (ESI) m/z $[M]^+$ for formula $C_{32}H_{30}OSi$: calcd 458.2060; found 458.2059.

***tert*-Butyl(dibenzo[*a,m*]picen-17-yloxy)dimethylsilane (95)**

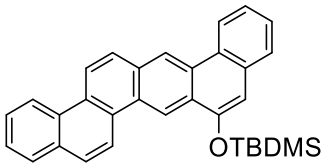
Following general procedure K, freshly prepared LDA (0.39 mmol in 1 mL anhyd C_6H_6) was added to the solution of biarylic derivative **84** (52 mg, 0.11 mmol) in anhyd C_6H_6 (2 mL) at 0 °C amd stirred for 30 min. The reaction mixture was then stirred at 40 °C for 1 h before adding TBDMSCl (0.39 mL, 0.39 mmol, 1 M in THF) at rt and allowed to react for 17 h at rt. The reaction mixture was quenched with satd aq NH_4Cl solution (10 mL). The solution was extracted with EtOAc (3 * 10 mL) and the organic layer was washed with brine (10 mL) and dried over anhyd $MgSO_4$. It was evaporated to dryness under reduced pressure. The crude product was purified by flash column chromatography (5% EtOAc in heptane), afforded TBDMS-protected product **95** (35 mg, 62%) as red solid. MP (°C) 230.6 − 238.2 (DCM); ^{1}H-NMR (400 MHz, $CDCl_3$): δ = 10.01 (d, *J* = 9.5 Hz, 1H), 9.20 (d, *J* = 9.4 Hz, 1H), 9.03 (d, *J* = 8.4 Hz, 1H), 8.92 (d, *J* = 8.3 Hz, 1H), 8.88 (d, *J* = 9.5 Hz, 1H), 8.87 (d, *J* = 9.6 Hz, 1H), 8.83 (d, *J* = 9.2 Hz, 1H), 8.02 (app d, *J* = 9.0 Hz, 3H), 7.90 (app d, *J* = 8.6 Hz, 1H), 7.78 − 7.60 (m, 5H), 7.48 (s, 1H), 1.20 (s, 9H), 0.40 (s, 6H); ^{13}C-NMR (100 MHz, $CDCl_3$): δ = 152.6, 132.9, 132.1, 131.6, 131.5, 130.5, 130.3, 129.1, 129.0, 128.7, 128.6, 128.4, 128.1, 128.1, 127.9, 127.8, 127.4, 127.2, 126.7, 126.6, 126.3, 125.8, 125.4, 124.9, 123.4, 123.0, 122.0, 121.3, 120.0, 115.4, 26.4 (3C), 18.9, -3.5 (2C); FTIR (KBr, cm^{-1}): 2926, 2856, 1596, 1532, 1424, 1361, 1259, 1199, 1105, 1061, 838, 781; UV-Vis ($CHCl_3$): λ_{max} (ε)= 317 nm; Fluorescence ($CHCl_3$): λ_{ex} = 317 nm; λ_{em} = 416 nm; HRMS (ESI) m/z $[M + H]^+$ for formula $C_{36}H_{33}OSi$: calcd 509.2295; found 509.2281.

***tert*-Butyl(dibenzo[*b,m*]picen-7-yloxy)dimethylsilane (97)**



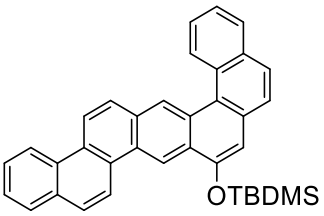
Following general procedure K, freshly prepared LDA (0.46 mmol in 1 mL THF) was added to the solution of biarylic derivative **86** (71 mg, 0.15 mmol) in THF (2 mL) at 0 °C amd stirred for 30 min. The reaction mixture was then stirred at rt °C for 1 h before adding TBDMSCl (0.47 mmol, 1 M in THF) and allowed to react for 17 h at rt. The reaction mixture was quenched with satd aq NH_4Cl solution (10 mL). The solution was extracted with EtOAc (3 * 10 mL) and the organic layer was washed with brine (10 mL) and dried over anhyd $MgSO_4$. It was evaporated to dryness under reduced pressure. The crude product was purified by flash column chromatography (30% DCM in heptane), afforded TBDMS-protected product **97** (77 mg, quant) as brown solid. MP (°C) 310.4 − 312.7 (DCM); ^{1}H-NMR (400 MHz, $C_2D_2Cl_4$): δ 9.95 (d, *J* = 9.7 Hz, 1H), 9.21 (s, 1H), 9.08 (d, *J* = 9.5, 1H), 9.02 (d, *J* = 9.3 Hz, 1H), 8.84 (d, *J* = 8.4 Hz, 1H), 8.80 (d, *J* = 9.3 Hz, 1H), 8.76 (d, *J* = 9.8 Hz, 1H), 8.27 (s, 1H), 8.11 (d, *J* = 7.5 Hz, 1H), 8.01 − 7.97 (m, 3H), 7.72 − 7.68 (m, 1H), 7.64 − 7.61 (m, 1H), 7.52 − 7.45 (m, 2H), 7.40 (s, 1H), 1.08 (s, 9H), 0.31 (s, 6H); ^{13}C-NMR (100 MHz, $C_2D_2Cl_4$): δ 151.9, 132.1, 131.8, 131.0, 130.9, 130.6, 129.94, 129.9, 129.1, 128.6, 128.5, 127.9, 127.8, 127.7, 127.1, 127.08, 126.8, 126.7, 126.1, 124.9, 124.8, 123.8, 123.3, 122.9, 122.2, 122.0, 121.7, 120.2, 113.8, 99.4, 26.1 (3C), 18.6, -3.8 (2C); FTIR (KBr, cm^{-1}): 2928, 2857, 1617, 1440, 1261, 1220, 1167, 1107, 878, 849, 814, 780; UV-Vis ($CHCl_3$): λ_{max} (ε)= 318 nm; Fluorescence ($CHCl_3$): λ_{ex} = 316 nm; λ_{em} = 434 nm; HRMS (ESI) m/z $[M+H]^+$ for formula $C_{36}H_{33}OSi$: calcd 509.2295; found 509.2286.

***tert*-Butyl(dibenzo[*c*,*k*]tetraphen-13-yloxy)dimethylsilane (98)**



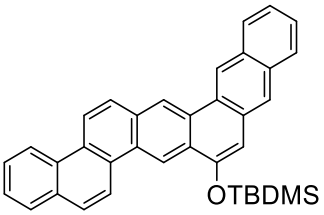
According to general procedure K, biarylic derivative **87** (46 mg, 0.11 mmol) in THF (2 mL) was added to the freshly prepared LDA (0.28 mmol in 1 mL THF) at 0 °C and stirred for 30 min. The reaction mixture was then stirred at rt for 1 h before adding TBDMSCl (0.28 mL, 0.28 mmol, 1 M in THF) and allowed to react for 17 h at rt. The reaction mixture was quenched with satd aq NH_4Cl solution (10 mL). The solution was extracted with EtOAc (3 * 10 mL) and the organic layer was washed with brine (10 mL) and dried over anhyd $MgSO_4$. It was evaporated to dryness under reduced pressure. The crude product was purified by flash column chromatography (10% EtOAc in heptane), afforded TBDMS-protected product **98** (34 mg, 68%) as brown solid. MP (°C) 227.4 − 229.1 (EtOAc); ^{1}H-NMR (400 MHz, $CDCl_3$): δ 9.73 (s, 1H), 9.19 (s, 1H), 8.89 (d, *J* = 9.0 Hz, 1H), 8.79 (d, J = 9.3 Hz, 1H), 8.78 (d, J = 8.12 Hz, 1H), 8.72 (d, *J* = 9.2 Hz, 1H), 8.20 (d, *J* = 9.2 Hz, 1H), 8.10 (d, *J* = 9.0 Hz, 1H), 8.03 (dd, *J* = 0.7, 8.0 Hz, 1H), 7.78 − 7.76 (m, 1H), 7.75 − 7.70 (m, 1H), 7.67 − 7.63 (m, 1H), 7.62 − 7.56 (m, 2H), 7.09 (s, 1H), 1.30 (s, 9H), 0.45 (s, 6H); ^{13}C-NMR (100 MHz, $CDCl_3$): δ 150.1, 133.2, 132.5, 131.0, 130.8, 130.4, 129.1, 128.7, 128.68, 128.2, 128.0, 127.9, 127.8, 127.4, 127.36, 127.2, 126.9, 126.5, 124.9, 123.3, 122.9, 122.3, 121.8, 121.4, 117.9, 110.8, 26.3 (3C), 18.8, -3.9 (2C); FTIR (KBr, cm^{-1}): 2956, 2926, 1613, 1553, 1455, 1311, 1252, 1190, 1104, 890, 835, 812, 780, 750; UV-Vis ($CHCl_3$): λ_{max} (ε) = 311 nm; Fluorescence ($CHCl_3$): λ_{ex} = 412 nm; λ_{em} = 311 nm; HRMS (ESI) m/z $[M + H]^+$ for formula $C_{32}H_{31}OSi$: calcd 459.2139; found 459.2133.

(Benzo[*a*]naphtho[2,1-*k*]tetraphen-15-yloxy)(*tert*-butyl)dimethylsilane (99)



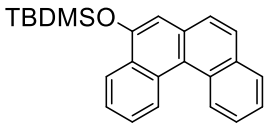
According to general procedure K, the biarylic derivative **88** (48 mg, 0.10 mmol) in anhyd C_6H_6 (2 mL) at 0 °C was treated with the freshly prepared LDA (0.36 mmol in 1 mL anhyd C_6H_6) for 30 min. The reaction mixture was then stirred at 40 °C for 1 h before adding TBDMSCl (0.36 mL, 0.36 mmol, 1 M in THF) at rt and allowed to react for 17 h at rt. The reaction mixture was quenched with satd aq NH_4Cl solution (10 mL). The solution was extracted with EtOAc (3 * 10 mL) and the organic layer was washed with brine (10 mL) and dried over anhyd $MgSO_4$. It was evaporated to dryness under reduced pressure. The crude product was purified by flash column chromatography (5% EtOAc in heptane), afforded TBDMS-protected product **99** (23 mg, 44%) as red solid along with traces of unprotected product. MP (°C) 217.1 − 223.5 (cyclohexane + DCM); ^{1}H-NMR (400 MHz, $CDCl_3$): δ 9.85 (s, 1H), 9.71 (s, 1H), 9.28 (d, *J* = 8.5 Hz, 1H), 8.94 (d, *J* = 9.1 Hz, 1H), 8.82 (d, *J* = 8.3 Hz, 1H), 8.77 (d, *J* = 9.2 Hz, 1H), 8.26 (d, *J* = 9.2 Hz, 1H), 8.14 (d, *J* = 8.9 Hz, 1H), 8.05 (d, *J* = 8.0 Hz, 2H), 7.94 (d, *J* = 8.4 Hz, 1H), 7.79 − 7.73 (m, 3H), 7.69 − 7.60 (m, 2H), 7.20 (s, 1H), 1.31 (s, 9H), 0.48 (s, 6H); ^{13}C-NMR (100 MHz, $CDCl_3$): δ 150.5, 132.8, 132.6, 132.0, 130.8, 130.78, 130.7, 130.3, 128.9, 128.8 (2C), 128.5, 128.4, 128.3, 128.2, 128.1, 127.9, 127.8, 127.2, 126.9, 126.8, 126.5 (2C), 125.1, 123.4, 122.8, 121.8, 121.5, 117.6, 111.5, 26.3 (3C), 18.8, −3.9 (2C); FTIR (KBr, cm^{-1}): 2953, 2925, 1596, 1422, 1257, 1104, 849, 750; UV-Vis ($CHCl_3$): λ_{max} (ε) = 330 nm; Fluorescence ($CHCl_3$): λ_{ex} = 329 nm; λ_{em} = 428 nm; HRMS (ESI) m/z $[M + H]^+$ for formula $C_{36}H_{33}OSi$: calcd 509.2295; found 509.2289.

***tert*-Butyldimethyl(naphtho[1,2-*c*]pentaphen-8-yloxy)silane (101)**



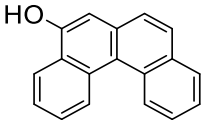
Following general procedure K, freshly prepared LDA (0.51 mmol in 1 mL THF) was added to the solution of biarylic derivative **90** (80 mg, 0.17 mmol) in anhyd THF (3 mL) at 0 °C amd stirred for 30 min. The reaction mixture was then stirred at rt °C for 1 h before adding TBDMSCl (0.56 mL, 0.56 mmol, 1 M in THF) and allowed to react for 17 h at rt. The reaction mixture was quenched with satd aq NH_4Cl solution (10 mL). The solution was extracted with EtOAc (3 * 10 mL) and the organic layer was washed with brine (10 mL) and dried over anhyd $MgSO_4$. It was evaporated to dryness under reduced pressure. The crude product was purified by flash column chromatography (30% DCM in heptane), afforded TBDMS-protected product **101** (48 mg, 54%) as brown solid. MP (°C) 246.3 − 248.1 (EtOAc); ^{1}H-NMR (400 MHz, $CDCl_3$): δ = 9.63 (s, 1H), 9.27 (s, 1H), 9.20 (s, 1H), 8.85 (d, *J* = 9.0 Hz, 1H), 8.79 (d, *J* = 8.40 Hz, 1H), 8.76 (d, *J* = 9.2 Hz, 1H), 8.24 (d, *J* = 9.1 Hz, 1H), 8.14 (s, 1H), 8.14 − 8.12 (m, 1H), 8.08 (d, *J* = 9.0 Hz, 1H), 8.01 (dd, *J* = 0.9, 8.0 Hz, 1H), 7.99 − 7.97 (m, 1H), 7.75 − 7.70 (m, 1H), 7.67 − 7.63 (m, 1H), 7.57 − 7.50 (m, 2H), 7.09 (s, 1H), 1.30 (s, 9H), 0.47 (s, 6H); ^{13}C-NMR (100 MHz, $CDCl_3$): δ = 149.9, 132.8, 132.5, 131.8, 131.2, 131.1, 130.8, 130.5, 129.4, 128.7, 128.63, 128.6, 128.5, 128.4, 127.8, 127.8, 127.3, 126.9, 126.7, 126.5, 126.1, 125.1, 124.7, 123.3, 122.6, 121.9, 121.89, 121.3, 117.9, 110.4, 26.3 (3C), 18.8, -3.9 (2C); FTIR (KBr, cm^{-1}): 2955, 2927, 1620, 1447, 1341, 1252, 1208, 1098, 888, 744; UV-Vis ($CHCl_3$): λ_{max} (ε) = 334 nm; Fluorescence ($CHCl_3$): λ_{ex} = 333 nm; λ_{em} = 445 nm; HRMS (ESI) m/z $[M + H]^+$ for formula $C_{36}H_{33}OSi$: calcd 509.2295; found 509.2288.

(Benzo[*c*]phenanthren-5-yloxy)(tert-butyl)dimethylsilane (102A)



Following general procedure K, freshly prepared LDA (0.72 mmol in 1 mL anhyd C_6H_6) was added to the solution of biarylic derivative **92** (65 mg, 0.21 mmol) in anhyd C_6H_6 (2 mL) at 0 °C amd stirred for 30 min. The reaction mixture was then stirred at 40 °C for 1 h before adding TBDMSCl (0.72 mL, 0.72 mmol, 1 M in THF) at rt and allowed to react for 17 h at rt. The reaction mixture was quenched with satd aq NH_4Cl solution (10 mL). The solution was extracted with EtOAc (3 * 10 mL) and the organic layer was washed with brine (10 mL) and dried over anhyd $MgSO_4$. It was evaporated to dryness under reduced pressure. The crude product was purified by flash column chromatography (gradient elution 5−15% EtOAc in heptane), afforded TBDMS-protected product **102A** (33 mg, 66%) as red oil and unprotected product **102B** (16 mg, 22%) as red solid. ^{1}H-NMR (400 MHz, $CDCl_3$, **102A**): δ = 9.12 (d, *J* = 8.4 Hz, 1H), 9.05 (d, *J* = 8.5 Hz, 1H), 8.45 (dd, *J* = 1.3, 8.0 Hz, 1H), 7.99 (dd, *J* = 1.3, 8.0 Hz, 1H), 7.86 (d, *J* = 8.5 Hz, 1H), 7.73 − 7.70 (m, 1H), 7.71 (d, *J* = 8.5 Hz, 1H), 7.69 − 7.63 (m, 3H), 7.59 − 7.55 (m, 1H), 7.18 (s, 1H), 1.16 (s, 9H), 0.38 (s, 6H); ^{13}C-NMR (100 MHz, $CDCl_3$): δ = 150.3, 132.7, 131.9, 130.5, 129.3, 128.7, 128.0, 127.7, 127.5, 126.5, 126.47, 126.3, 125.6, 125.1, 123.1, 122.9, 111.7, 26.1, 18.7, -4.0; FTIR (KBr, cm^{-1}): 2956, 2928, 1599, 1254, 1093, 855, 833; UV-Vis ($CHCl_3$): λ_{max} (ε) = 290 nm; Fluorescence ($CHCl_3$): λ_{ex} = 289 nm; λ_{em} = 392 nm; HRMS (ESI) m/z calcd for $C_{24}H_{27}OSi$: calcd 359.1826 $[M + H]^+$ found 359.1825.

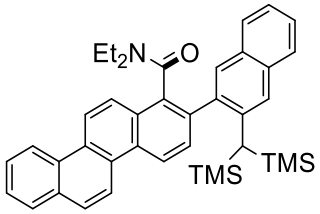
Benzo[*c*]phenanthren-5-ol (102B)



Spectral details match with the previous report[282]. MP (°C) 98.6 − 103.5 (EtOAc); ^{1}H-NMR (400 MHz, $CDCl_3$): δ = 9.14 (d, *J* = 8.5 Hz, 1H), 9.05 (d, *J* = 8.5 Hz, 1H), 8.45 (d, *J* = 7.8 Hz, 1H), 7.99 (dd, *J* = 1.2, 7.9 Hz, 1H), 7.84 (d,

J = 8.4 Hz, 1H), 7.73 − 7.63 (m, 4H), 7.59 − 7.55 (m, 1H), 7.09 (br s, 1H), 5.71 (br s , 1H); ^{13}C-NMR (100 MHz, $CDCl_3$): δ = 150.1, 132.6, 131.8, 130.5, 128.7, 128.0, 127.9, 127.4, 126.8, 126.4, 126.1, 126.0, 125.7, 125.0, 122.7, 122.3, 107.4; FTIR (KBr, cm^{-1}): 3388, 1697, 1674, 1586, 1426, 1276, 1224, 753; HRMS (ESI) m/z calcd for $C_{18}H_{11}O_2$: calcd 259.0765, $[M - H + O]^-$ found 259.0764.

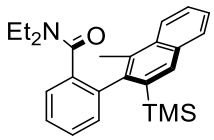
2-(3-(bis(Trimethylsilyl)methyl)naphthalen-2-yl)-*N*,*N*-diethylchrysene-1-carboxamide (103)



According to general procedure K, the biarylic derivative **86** (96 mg, 0.21 mmol) and TMSCl (0.08 mL, 0.64 mmol) dissolved in anhyd THF (5 mL) were treated with the freshly prepared LDA (0.62 mmol in 1 mL THF) for 1.5 h at 0 °C. The reaction mixture was allowed to reach rt over 17 h. The reaction mixture was quenched with satd aq NH_4Cl solution (10 mL). The solution was extracted with EtOAc (3 * 10 mL) and the organic layer was washed with brine (10 mL) and dried over anhyd $MgSO_4$. It was evaporated to dryness under reduced pressure. The crude product was purified by flash column chromatography (gradient elution 5−15% EtOAc in heptane), afforded **103** (77 mg, 61%) as an off-white solid. MP (°C) 221.0 − 226.5 (EtOAc); ^{1}H-NMR (400 MHz, $CDCl_3$): δ = 8.84 (d, *J* = 8.7 Hz, 1H), 8.81 (d, *J* = 6.7 Hz, 1H), 8.79 (d, *J* = 8.6 Hz, 2H), 8.08 (d, *J* = 9.1 Hz, 1H), 8.07 (d, *J* = 9.3 Hz, 1H), 8.03 (dd, *J* = 1.0, 7.9 Hz, 1H), 7.81 (d, *J* = 8.1 Hz, 1H), 7.77 − 7.66 (m, 4H), 7.64 (s, 1H), 7.55 (s, 1H), 7.50 − 7.45 (m, 1H), 7.41 − 7.37 (m, 1H), 3.78 − 3.69 (m, 1H), 3.47 − 3.38 (m, 1H), 3.31 − 3.14 (m, 1H), 2.11 (s, 1H), 1.00 − 0.94 (m, 6H), 0.13 (s, 6H), 0.10 (s, 6H); ^{13}C-NMR (100 MHz, $CDCl_3$): δ = 168.6, 141.5, 138.9, 136.0, 135.4, 133.2, 132.4, 130.8, 130.5, 129.9, 129.7, 128.7, 128.65, 128.6, 128.4, 128.2, 127.9, 127.4, 127.1, 127.0, 126.98, 126.8, 126.0, 125.0, 124.6, 123.3, 122.3, 122.25, 121.3, 42.6, 37.1, 24.0, 13.8, 12.5, 1.4 (3C), 1.2

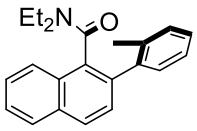
(3C); FTIR (KBr, cm^{-1}): 2951, 2896, 1638, 1438, 1247, 1095, 839, 746; HRMS (ESI) m/z calcd for $C_{40}H_{46}ONSi_2$: calcd 612.3112 $[M + H]^+$ found 612.3119

_N,N_-diethyl-2-(1-methyl-3-(trimethylsilyl)naphthalen-2-yl)benzamide (104)



According to the general procedure K, the biarylic derivative **93** (123 mg, 0.39 mmol) and TMSCl (0.15 mL, 1.2 mmol) in anhyd THF (3 mL) were treated with the freshly prepared LDA (1.16 mmol in 1 mL THF), at 0 °C for 1.5 h and then stirred at rt for 16 h. The reaction mixture was quenched with satd aq NH_4Cl solution (10 mL). The solution was extracted with EtOAc (3 * 10 mL) and the organic layer was washed with brine (10 mL) and dried over anhyd $MgSO_4$. The organic layer was evaporated to dryness under reduced pressure. The crude product was purified by flash column chromatography (30% EtOAc:heptane), afforded **104** (70 mg, 46%) as a brown amorphous solid; ^{1}H-NMR (400 MHz, $CDCl_3$): δ 8.05 (d, *J* = 8.4 Hz, 1H), 7.88 (d, *J* = 8.5 Hz, 1H), 7.73 − 7.68 (m, 1H), 7.67 − 7.65 (m, 1H), 7.55 − 7.53 (m, 1H), 7.53 − 7.49 (m, 1H), 7.43 − 7.41 (m, 1H), 7.42 (s, 1H), 7.33 − 7.30 (m, 1H), 3.71 − 3.61 (m, 1H), 2.98 − 2.89 (m, 1H), 2.72 (s, 3H), 2.67 − 2.58 (m, 1H), 2.42 − 2.33 (m, 1H), 0.55 (t, *J* = 7.1 Hz, 3H), 0.36 − 0.32 (m, 3H), 0.33 (s, 9H); ^{13}C-NMR (100 MHz, $CDCl_3$): δ 170.6, 142.9, 138.8, 136.0, 135.2, 134.2, 134.1, 133.0, 132.5, 131.8, 128.6, 126.8, 126.3, 126.2, 125.7, 125.4, 124.8, 43.0, 37.9, 19.7, 12.9, 11.9, 0.3 (3C); FTIR (KBr, cm^{-1}): 2957, 2935, 1633, 1479, 1460, 1440, 1288, 1243, 1138, 1112, 1094, 990, 854; HRMS (ESI) m/z $[M + H]^+$ for formula $C_{25}H_{32}ONSi$: calcd 390.2253; found 390.2251.

***N*,*N*-diethyl-2-(*o*-tolyl)-1-naphthamide (105)**



According to the general procedure H, 1-naphthamide (1.85 g, 8.16 mmol) was dissolved in THF (8 mL) and was added to a solution of *s*-BuLi (10.9 mL, 12.3 mmol, 1.13 M) and TMEDA (1.84 mL, 12.3 mmol) in anhyd THF (12 mL) at −78 °C. The reaction mixture was stirred for 1 h before adding $B(OCH_3)_3$ (2.3 mL, 20.4 mmol) and subsequently allowed to react at −78 °C for additional 1.5 h. It was then allowed to reach rt and stirred for 12 h. After the completion of reaction, the mixture was quenched with sat. NH_4Cl and extracted with Et_2O. The organic layer was evaporated under reduced pressure. The crude compound (1-(diethylcarbamoyl)naphthalen-2-yl)boronic acid was used further without purification.

Following general procedure J, 1-bromotoluene (1.18 g, 6.96 mmol), $PdCl_2$(dppf) (249 mg, 5 mol%), crude (1-(diethylcarbamoyl)naphthalen-2-yl)boronic acid and Na_2CO_3 (2.16 g, 20.4 mmol) were all added in sequence to DME (12 mL), followed by the addition of water (6 mL). The reaction mixture was stirred at 90 °C for 18 h. After completion of reaction, it was cooled down to rt and filtered through a pad of celite to remove Pd-black. The reaction mixture was extracted with EtOAc (3 * 50 mL) and water (50 mL). The organic layer was dried over anhyd Na_2SO_4 and evaporated *in vacuo*. The crude product was purified by flash chromatography (10% EtOAc in heptane) afforded cross-coupled product **105** (2.22 mg, 86%) as brown oil. The characterization data was in accordance to those reported in literature.[203]

9.6 C─H activation on PAHs

General procedure (N) for C─H acetoxylation

The calculated amount of $PhI(OAc)_2$ (1 equiv, 0.11 mmol.), $Pd(OAc)_2$ (0.10 equiv, 0.01 mmol) and 6-fluoro-2-pyridinecarboxylic acid ligand (0.10 equiv, 0.01 mmol) were added to a pressure vial. The minimum volume of solvent was added to the vial and the reaction mixture was stirred for 15 seconds followed

by the addition of PAH (2 equiv, 0.22 mmol). The vial was sealed with a Teflon-lined cap and reaction mixture was stirred at 100 ℃ or 140 ℃ in a preheated oil bath for 18 h. After completion of the reaction, the vial was cooled down to rt. The reaction mixture was diluted with EtOAc (2 mL) and filtered through a plug of celite. The filtrate was washed with a sat aq K_2CO_3 solution (3 M in deionised H_2O, 2 * 2 mL). The organic layer was evaporated to dryness under reduced pressure and analysed by ^{1}H-NMR techniques.[3]

General procedure (O) for C─H olefination

A stock solution of 3-methyl-2-(phenylthio)butanoic acid ligand (0.10 equiv, 0.02 mmol, 0.0846 M in DCM) was added to a pressure vial and dried under a stream of N_2 flow. Subsequently, $Pd(OAc)_2$ (0.10 equiv, 0.02 mmol), *tert*-butyl peroxybenzoate (1.5 equiv, 0.33 mmol), ethyl acrylate (1.5 equiv, 0.33 mmol), the corresponding PAH (1 equiv, 0.22 mmol) and solvent (0.2 mL) were added in sequence. The pressure vial was sealed with a teflon-lined screw cap and placed in 100 °C pre-heated oil bath for 18 h. After the completion of reaction time, it was allowed to cool down to rt. The resulting mixture was diluted with EtOAc and quenched with 10% aq Na_2SO_3 solution. The organic layer was washed with sat aq $NaHCO_3$ solution, dried over anhyd $MgSO_4$. It was filtered through a plug of celite and concentrated under reduced pressure. The crude mixture was then analysed by ^{1}H-NMR techniques.[4]

General procedure (P) for the preparation of η^6 arene-chromium tricarbonyl complex

To an oven-dried two-neck round bottom flask wrapped in Al-foil and fitted with a condenser, was added $Cr(CO)_6$ (5.00 equiv, 7.74 mmol). The flask was evacuated and filled with N_2 to maintain inert atmosphere. The corresponding arene (1.00 equiv, 1.55 mmol) followed by *n*-Bu_2O: THF (20 mL, 9:1 v/v, anhyd solvents) were added to the flask. The resulting suspension was subjected to three freeze-pump-thaw cycles to maintain complete anaerobic atmosphere. The reaction mixture was then refluxed for 48 h in a sand bath under N_2. The CO formed during the reaction was removed intermittently. The reaction was monitored by TLC and at the end of the reaction when a green coloured precipitate started to appear, the reaction mixture was cooled down to rt and the solvent was evaporated completely under reduced pressure. The remaining

solid was dissolved in minimum amount of toluene and purified by flash column chromatography using toluene as eluent. The product was analysed by TLC and ^{1}H-NMR techniques.[276] HRMS (ESI) *m/z* $[M + K]^+$ of methoxychrysene-chromium tricarbonyl complex **110** for formula $C_{22}H_{14}CrKO_4$: calcd 432.9934; found 432.9939.

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Paper I

Directed *ortho*-Metalation and Anionic *ortho*-Fries Rearrangement of Polycyclic Aromatic *O*-Carbamates: Regioselective Synthesis of Substituted Chrysenes

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Paper II

Recent developments in palladium-catalysed non-directed C─H bond activation in arenes

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Paper III

Directed Remote Metalation of Suzuki-Miyaura Cross-Coupled (Methylnaphthalenyl)Chrysenyl Carboxamide derivatives: Synthesis of larger PAHs with Photophysical Properties

Sindhu Kancherla, Kåre B. Jørgensen

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