Harnessing Oxonium Ions for Catalysis and Arylation



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A dissertation presented in partial fulfilment of requirements for the award of the degree

Doctor of Philosophy

of the

University of Oxford

This thesis is dedicated to Grandad and DearDear. I wish you could have seen it Grandad.

Declaration

This dissertation describes work carried out in the Chemistry Research Laboratory at the University of Oxford between October 2017 and April 2021. The dissertation is a product of my own work and includes no results obtained through collaboration, except where specifically indicated in the text.

Owen Smith

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To my triumvirate of supervisors, thank you for all your help and guidance over the past 5 years, I would really like to say that you have presided over a golden age, like your ancient Roman counterparts, but that would be really overselling it even if we did manage to make the Devil's oxonium ion! Martin, thank you for taking on a young Part II back in 2016 and helping me get to where I am today, it's been such a pleasure being in the group for the last six years and I will really miss it. Jon, I am deeply grateful for all the time you have poured into shaping this thesis and for giving me shrewd advice whenever I have needed it. Rob, I'm sorry for not doing more computational work - Mihai was just so much better at it than I was - but it has been great collaborating with you.

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Abbreviations

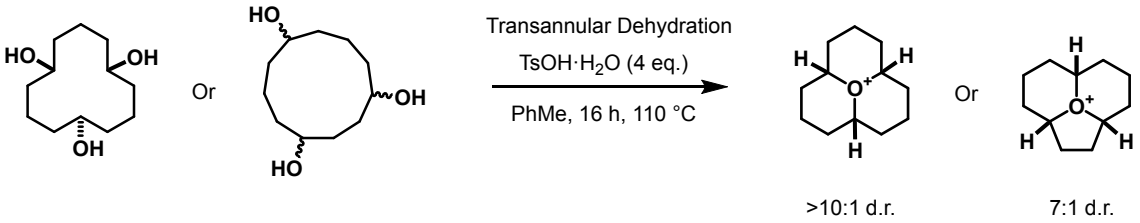
Ac	acetyl
Ar	aryl
aq.	aqueous
APCI	Atmospheric Pressure Chemical Ionisation
atm.	atmospheres
BArF	tetrakis[(3,5-bis(trifluoromethyl)phenyl)]borate
BINOL	1,1'-bi-2-naphthol
Bn	benzyl
n-Bu	*n*-butyl
t-Bu	tert-butyl
cat.	catalytic
CD	circular dichroism
COD	cyclooctadiene
CSA	camphor sulfonic acid
DCE	1,2-dichloroethane
dec.	decomposed
DIPEA	diisopropylethylamine
DMAC	*N*,*N*-dimethylacetamide
DMF	*N*,*N*-dimethylformamide
DMI	*N*,*N*-dimethylimidazolidinone
DMS	dimethylsulfide
DMSO	dimethylsulfoxide
dppf	1,1'-ferrocenediyl-bis(diphenylphosphine)
d.r.	diastereomeric ratio
ee	enantiomeric excess
eq.	equivalents
e.r.	enantiomeric ratio
EWG	Electron-withdrawing Group

ESI	Electrospray Ionisation
Et	ethyl
h	hours
HDDA	Hexadehydro Diels-Alder
HG-II	Hoveyda-Grubbs 2nd generation catalyst
HMDS	hexamethyl disilylazide
HMPT	hexamethylphosphorous triamide
HPLC	High Performance Liquid Chromatography
HRMS	High Resolution Mass Spectrometry
IPA	isopropyl alcohol
i-Pr	isopropyl
kcal	kilocalorie
LDA	lithium diisoproylamide
LG	Leaving Group
LRMS	Low Resolution Mass Spectrometry
m-	*meta*-
m-CPBA	*meta*-chloroperbenzoic acid
Me	methyl
Mes	2,4,6-trimethylphenyl
mins	minutes
MW	Microwave heating
NMR	Nuclear Magnetic Resonance
o-	*ortho*-
Pd/C	palladium on carbon
pftb	perfluorotertbutyl
Ph	phenyl
Pin	pinacolato
Pr	*n*-propyl
qNMR	Quantitative Nuclear Magnetic Resonance
Quant.	quantitative
RCM	Ring Closing Metathesis

r.t.	room temperature
sat.	saturated
t	time
TBA	tetra-*n*-butylammonium
TBAB	tetra-*n*-butylammonium bromide
TBS	tert-butyldimethylsilyl
TEA	tetra-*n*-ethylammonium
Tf	trifluoromethanesulfonate
THF	tetrahydrofuran
TMB	1,3,5-trimethoxybenzene
TMS	trimethylsilyl
Troc	2,2,2-trichloroethoxycarbonyl
Ts	*p*-toluenesulfonyl
VT-NMR	Variable Temperature Nuclear Magnetic Resonance
wt%	percent by weight
w/w	weight by weight
xs	excess

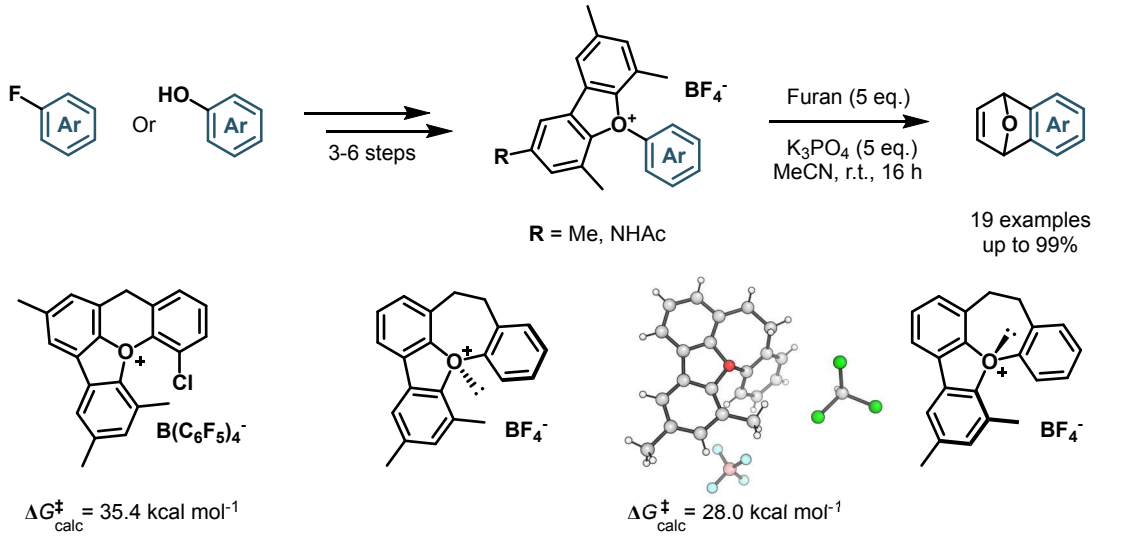
Abstract

This thesis describes work on the synthesis and applications of trialkyl and triaryloxonium ions. Chapter 1 describes the development of a transannular dehydration methodology to construct 'stable' trialkyloxonium ions from cyclic triols along with work towards using them to catalyse simple transformations (**Scheme 1**).



Scheme 1: A transannular dehydration methodology allowed the construction of 'stable' 6,6,6- and 6,6,5-trialkyloxonium ion ring systems from cyclic triols.

In Chapter 2, the development of a mild, functional group tolerant method for the generation of arynes from fluoroarene or phenol derived triaryloxonium ions is described. Further work on triaryloxonium ion chemistry involving the construction of helically chiral triaryloxoniums with defined point chiralty at oxygen and resolution of the enantiomers is described in Chapter 3 (**Scheme 2**).



Scheme 2: Aryne generation from triaryloxonium ions under mild conditions and the design and synthesis of helically chiral triaryloxonium ions with locked point chirality at oxygen.

This thesis consists of three projects split into three chapters with separate introduction, project aim, results and discussion, conclusion and future work sections.

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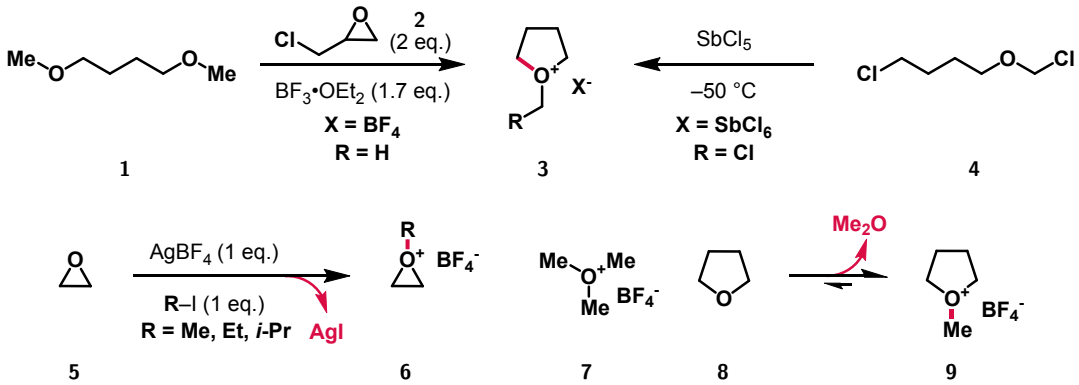
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1 Oxonium Ion Catalysis

1.1 Introduction

1.1.1 Trialkyloxonium Ions

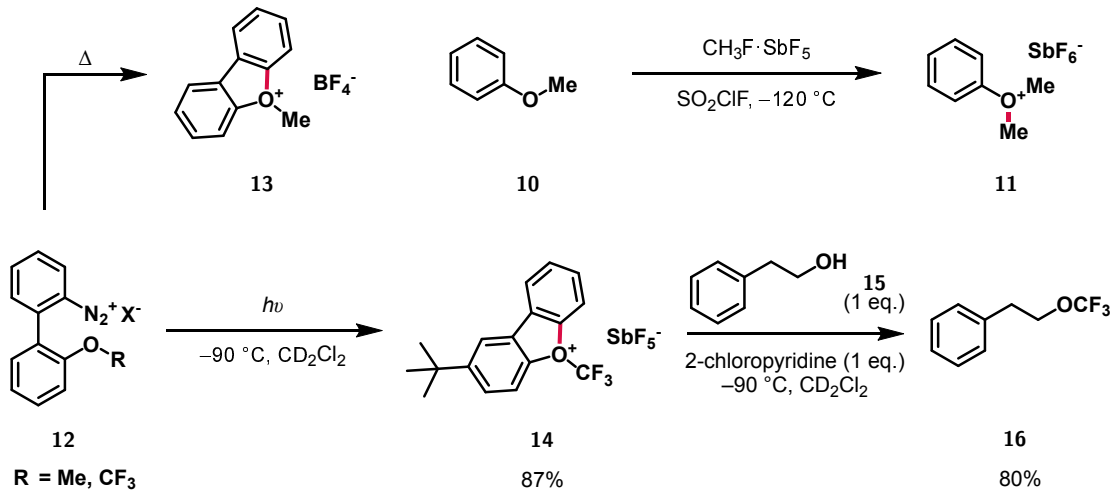
Since their discovery in 1937,[1] trialkyloxonium ions have been used in synthetic chemistry as strong alkylating agents. They can be readily accessed by the activation of ethers using $BF_3{\cdot}Et_2O$ in the presence of epichlorohydrin, **2**.[2] Halide abstraction using $SbCl_5$[3] or $AgBF_4$[4] readily generates trialkyloxonium ions both intra and intermolecularly. Equilibrium alkyl exchange between ethers and other trialkyloxonium ions also occurs rapidly.[5] After the initial alkyl transfer, tetrahydrofuran derived oxonium ion **9** can react at the secondary carbon with a further molecule of THF resulting in the formation of polymerisation products (**Scheme 1.1**).[6]



Scheme 1.1: Synthetic methods for the formation of trialkyloxonium ions.

1.1.2 Mixed Alkyl-Aryl Oxonium Ions

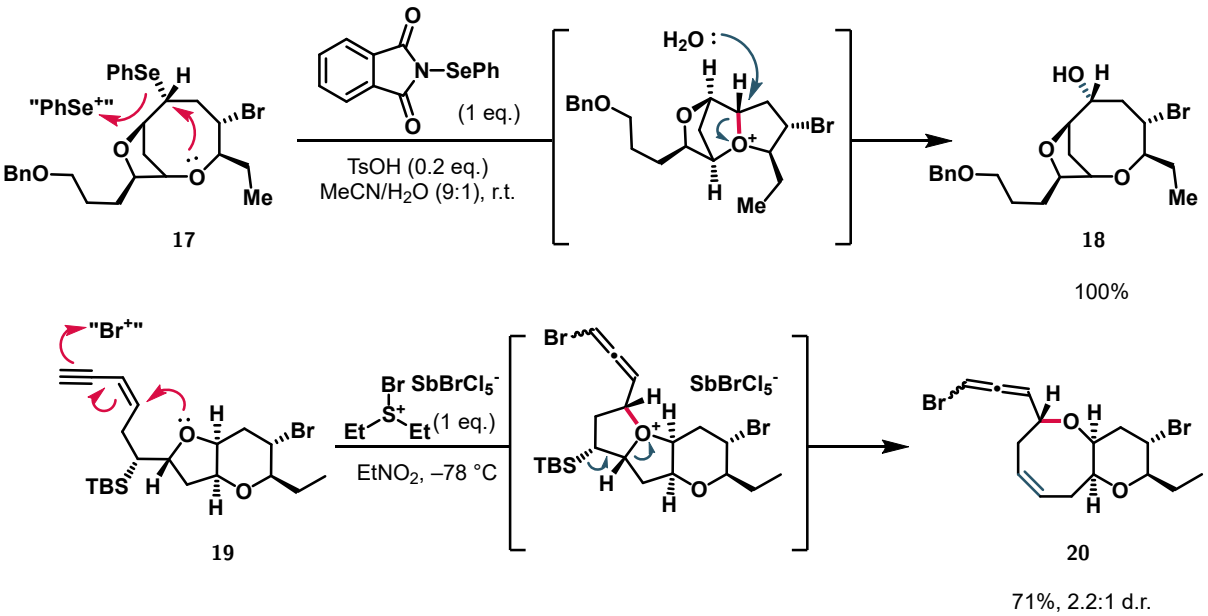
Mixed alkyl-aryl oxonium ions are significantly less stable than their trialkyl counterparts which is proposed to be due to the better leaving group ability of aryl ethers. Olah *et al.* used anisole **10** and a mixture of CH_3F and SbF_5 to prepare dialkylaryl oxonium ion **11** at low temperatures; however, only aryl methylation was observed when the preparation of alkyldiaryl oxonium ions was attempted using this method.[7] Intramolecular ring closure from aryl diazonium salt **12** allowed the preparation of diarylalkyloxonium ions either thermally[8] or by photolysis[9] to give **13** and **14** respectively. Both **13** and **14** are extremely reactive alkylating agents with **14** reacting with fluorinated counterions (BF_4^-, PF_6^-, SbF_6^-) above –70 °C with the loss of CF_4. However, good yields of trifluoromethylated products can be obtained at low temperatures (**Scheme 1.2**).[9]



Scheme 1.2: Methods for the formation of mixed alkyl-aryl oxonium ions.

1.1.3 Biosynthetic Intermediates

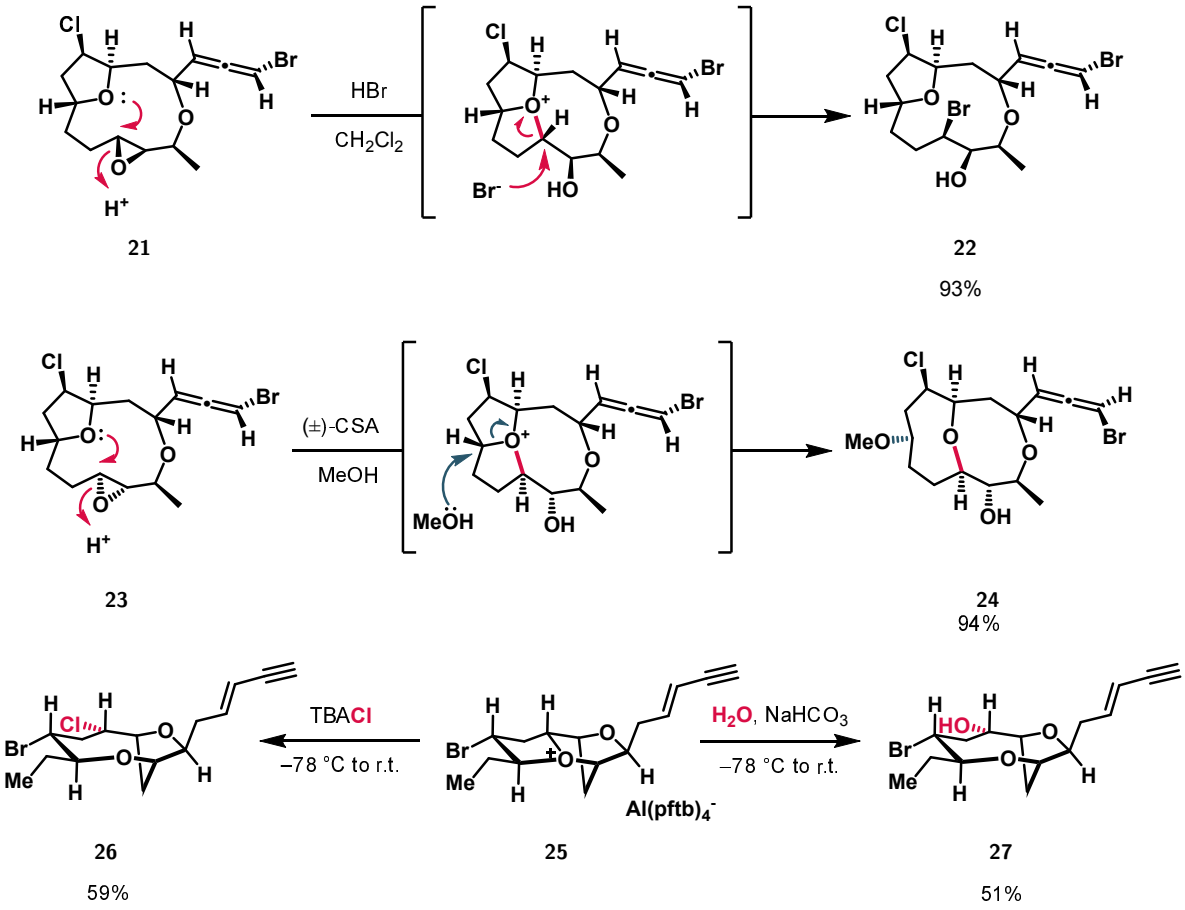
Murai and Fukuzawa first proposed trialkyloxonium ions as an intermediate in the biogenesis of *Laurencia* family natural products.[10] Since the original proposal, there have been a number of biomimetic approaches that invoke trialkyloxonium ion intermediates from Kim,[11] Snyder,[12,13] Braddock,[14,15] and Burton.[16] Activation of the phenylselenide moiety in **17** leads to *in situ* trapping of the oxonium ion intermediate with water to give **18** in excellent yield.[11] Snyder *et al.* demonstrated that bromination of **19** gives an oxonium ion intermediate which gives a mixture of microcladallene A and its epimer upon TBS elimination (**Scheme 1.3**).[12]



Scheme 1.3: Trialkyloxonium ion intermediates formed during the synthesis of (-)-laurefucin and microcladallene A natural products.

Similarly, Braddock proposed that trialkyloxonium ions were intermediates in the synthesis of Obtusallenes[14] and synthetic routes to Obtusallene and Marilzabicycloallene natural products lend significant support to this hypothesis.[15,17] Acidic

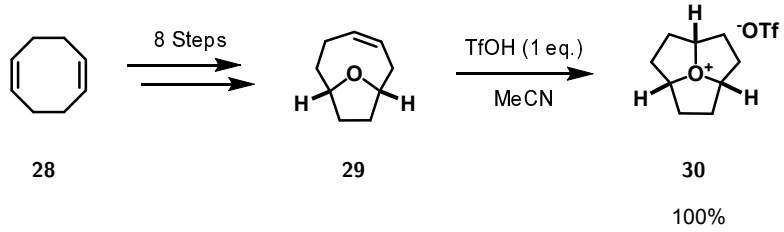
opening of epoxide **21** with HBr proceeds with retention of configuration, indicating that the reaction proceeds *via* an oxonium ion intermediate, to give Obtusallene X, **22**, in excellent yields. Furthermore, treatment of isomeric epoxide **23** under acidic conditions in MeOH results in the formation of Marilzabicycloallene C, **24**, *via* MeOH attack at the 5,5 ring junction.[15] Recently, Burton and Chan characterised **25** and three other oxonium ion isomers using low temperature NMR spectroscopy. The addition of Br^-, Cl^-, AcO^- and H_2O to these oxonium ions directly gave 10 natural products including **26** and **27** providing excellent evidence in support of the hypothesis that **25** is a biosynthetic intermediate (**Scheme 1.4**).[16]



Scheme 1.4: Trialkyloxonium ion intermediates formed in the synthesis of Obtusallene and Marilzabicycloallene natural products.

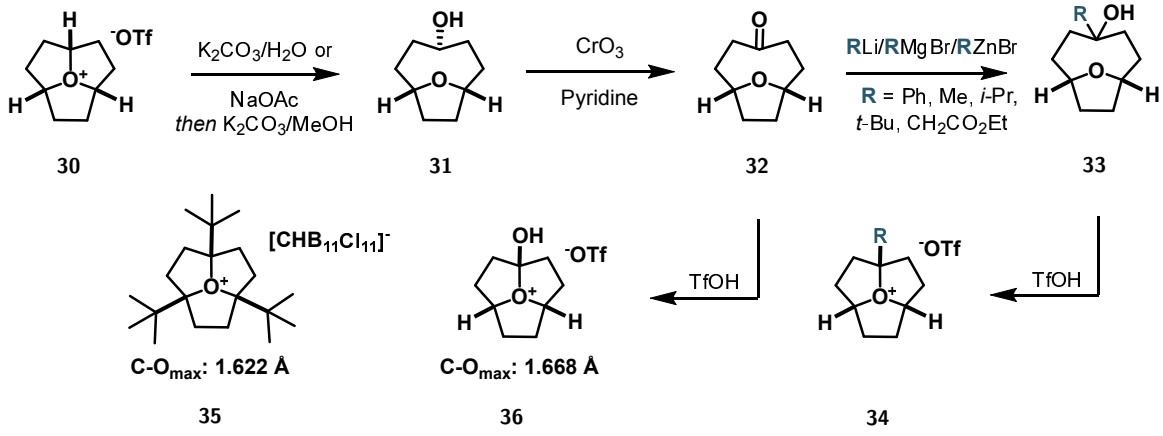
1.1.4 'Stable' Oxonium Ions

Mascal *et al.* reported the first example of an oxonium ion that was stable to some nucleophiles such as H_2O, I^- and sterically hindered base, DIPEA.[18] The desired 5,5,5-oxonium ion, **30**, was accessed in 9 synthetic steps, starting from 1,5-COD,[19] using protonation of cyclic alkene, **29**, to complete the synthesis (**Scheme 1.5**).



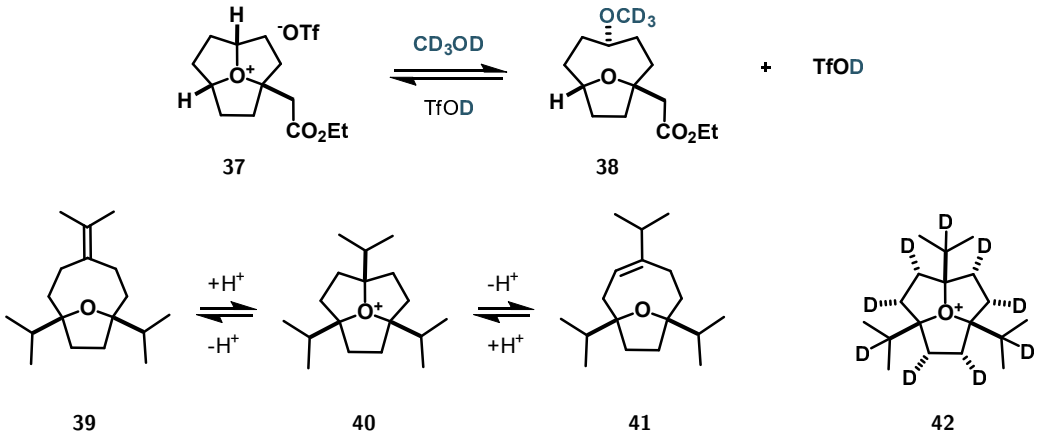
Scheme 1.5: Synthesis of the first 'stable' oxonium ion, **30** .

This scaffold can be modified to give a small library of substituted oxonium ions. Hydrolysis of **30** and oxidation of the resulting alcohol, **31**, gives cyclic ketone **32**. Organometallic addition followed by acid-mediated ring closure from macrocyclic alcohol **33** forms the substituted oxonium ion **34**. This sequence can be repeated to allow substitution of all three positions including tri *t*-Bu oxonium ion **35**.[20,21] Protonation of ketone **32** gives oxonium ion **36** with the longest recorded C-O bond length of 1.668 Å (a typical alkyl C-O bond is 1.43 Å) (**Scheme 1.6**).[22]



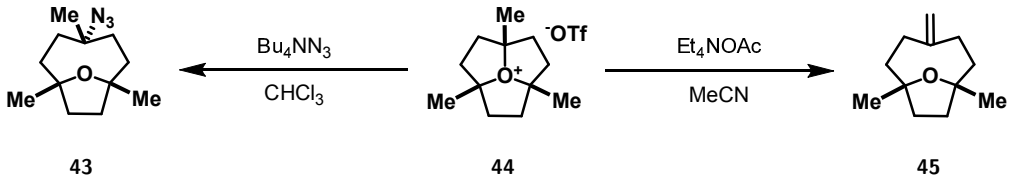
Scheme 1.6: Modification sequence and scope of oxatriquinane oxonium ions.

While the 5,5,5-oxatriquinane oxonium ions are stable in MeCN, they undergo reversible solvolysis in protic solvent (H_2O, MeOH and 'wet' DMSO/acetone). The equilibrium ratio is heavily dependant on proton concentration and at low oxonium ion concentration ring opened product **38** is almost exclusively formed.[21] Oxonium ions with all tertiary carbon centres adjacent to oxygen eliminate and reprotonate reversibly under similar conditions. Trialkyloxonium ion **40** eliminates to give **39** and **41** resulting in deuterated oxonium ion **42** being formed in D_2O (**Scheme 1.7**).



Scheme 1.7: Oxonium Ion ring opening/closing equilibira observed in protic media.

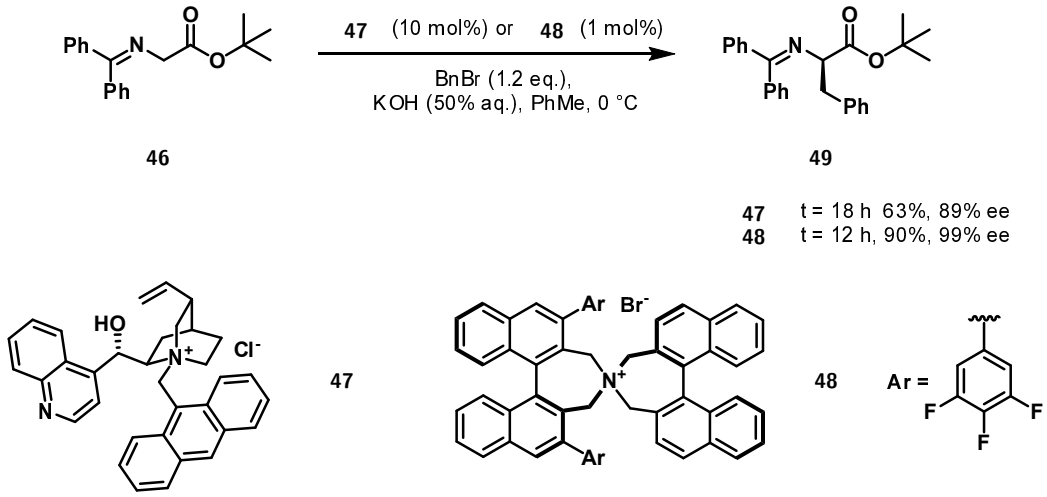
Substitution at trimethyl 5,5,5-oxonium ion, **44**, occurs by an S_N2 mechanism with $TBAN_3$ rather than an S_N1 pathway. This is proposed to be due to the close proximity of the *O*-atom preventing carbocation formation. Basic nucleophiles such as Et_4NOAc cause rapid elimination due to the alignment of the methyl C-H σ bonds with the C-O σ^* (**Scheme 1.8**).[23]



Scheme 1.8: Reactivity of oxatriquinane oxonium ions with nucleophiles.

1.1.5 Onium Ion Catalysis

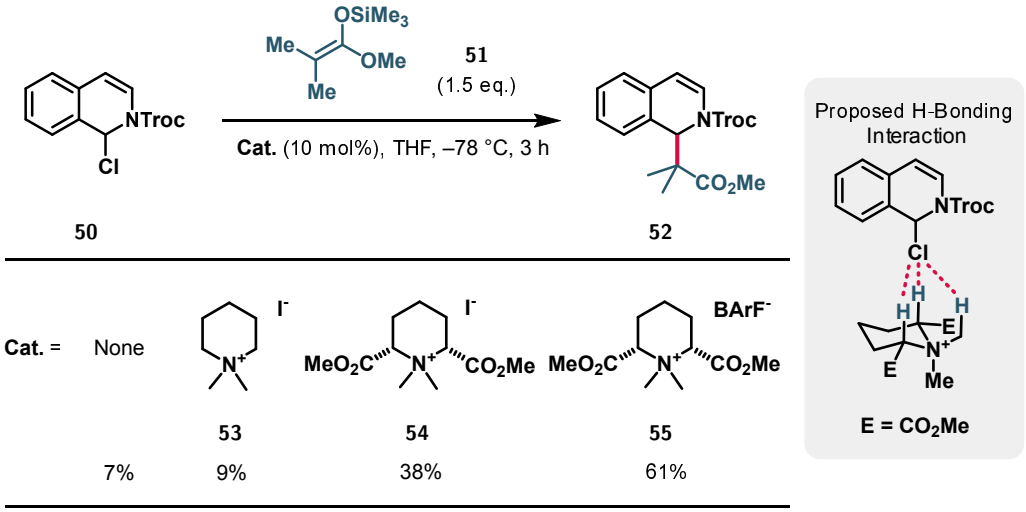
Phosphonium and ammonium salts have found widespread application as phase-transfer catalysts and ammonium salts derived from cinchona alkaloids, such as **47**, or BINOL, such as **48**, are widely used for enantioselective transformations.[24] Lygo demonstrated that 9-anthracenylmethyl cinchoninium chloride, **47**, gave good enantioselectivity for the benzylation of glycine imine **46**;[25] however, significantly higher yields and improved enantioselectivity for the transformation could be obtained using BINOL derived ammonium salt **48** developed by Maruoka *et al.* (**Scheme 1.9**).[26]



Scheme 1.9: Enantiopure phase-transfer catalysts **47**, and **48** and their application to the alkylation of glycine imine.

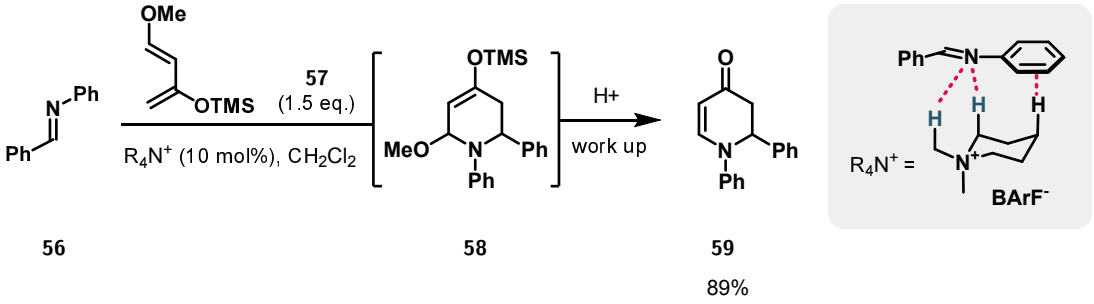
Shirakawa *et al.* demonstrated that ammonium salt hydrogen bonding could be used to catalyse the addition of silyl ketene acetal **51** to *N*-troc isoquinolinium chloride, **50**. The polarised C-H bonds adjacent to the cationic heteroatom are thought to be responsible for the hydrogen bonding interaction that enables catalysis[27] and while the parent ammonium salt **53** gave little/no rate acceleration, installing electron withdrawing ester groups to increase the C-H polarisation resulted in moderate levels

of catalysis. Swapping to the non-coordinating BArF counterion was instrumental in achieving good yields for the transformation. X-ray crystallographic analysis of **54** found that intermolecular H-I distances were significantly shorter (approximately 0.3Å) than those in **53** indicating the formation of a stronger binding interaction. This resulted in the authors proposing that catalysis proceeds *via* the three point binding mode shown below with the chlorine atom occupying the same binding pocket that the iodide anion is found in the crystal structure (**Scheme 1.10**).[28]



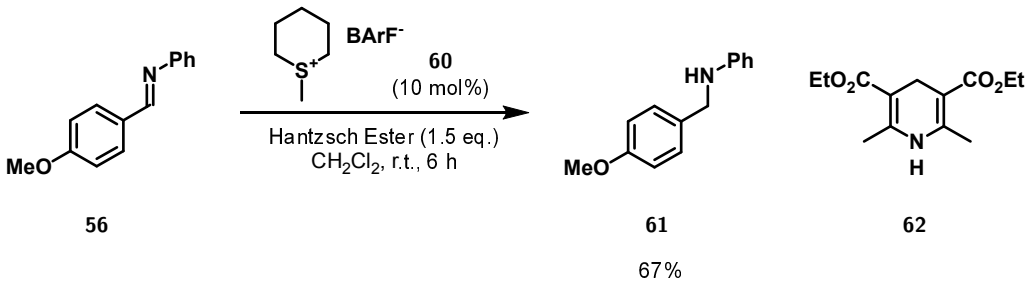
Scheme 1.10: First report of ammonium salt mediated hydrogen bonding catalysis.

This was extended to the aza Diels-Alder reaction between aldimines **56** and Danishefsky's diene giving a good yield of [4+2] cycloadduct **59** in the presence of both piperidine derived,[29] and cinchona alkaloid derived,[30] ammonium salt catalysts. Computational analysis carried out by Houk *et al.* predicts significant lowering of the [4+2] activation energy when the aldimine is bound to the ammonium ion catalyst as shown below (**Scheme 1.11**).[31]



Scheme 1.11: Ammonium Salt catalysed [4+2] aza Diels-Alder reaction.

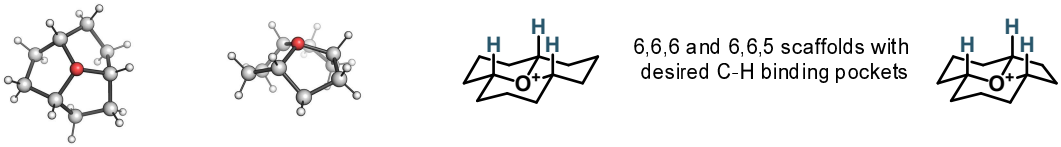
Furthermore, Shirakawa *et al.* reported the use of trialkyl sulfonium salt **60** as an effective catalyst for the addition of silyl ketene acetals to *N*-Troc isoquinolinium chloride, the aza Diels-Alder reaction shown above as well as the reduction of aldimines using Hantzsch ester **62**. Crystallisation of the sulfonium iodide catalyst gave the same binding mode as the catalytically active ammonium salt reported in **Scheme 1.10**, although the intermolecular H-I distances for the sulfonium salt were significantly longer by 0.2 - 0.5 Å (**Scheme 1.12**).[32]



Scheme 1.12: Sulfonium salt catalysed Hantzsch ester aldimine reduction.

1.2 Project Aims

We proposed that it may be possible to catalyse reactions using trialkyloxonium ions as their C-H bonds are polarised similar to their ammonium, and sulfonium, ion counterparts, enabling catalysis. In order to achieve this, it would be necessary to synthesise oxonium ions that were stable under the reaction conditions and had the correct alignment of the α C-H bonds adjacent to the trivalent oxygen in order to create the catalytically active 3-point binding pocket previously reported for ammonium and sulfonium catalysis.[28,32] Using a similar strategy to Mascal *et al.*, we proposed that a tricyclic oxonium ion would be stable under some reaction conditions that would enable us to demonstrate catalysis. The 5,5,5-oxatriquinane oxonium ion has an inverted bowl structure[18] that precludes it from forming the desired binding pocket as the C-H bonds are incorrectly aligned. In order to achieve the desired geometry and alignment of the C-H bond adjacent to the oxygen, the ring systems have to be extended to 6,6,6 or 6,6,5 scaffolds (**Scheme 1.13**).

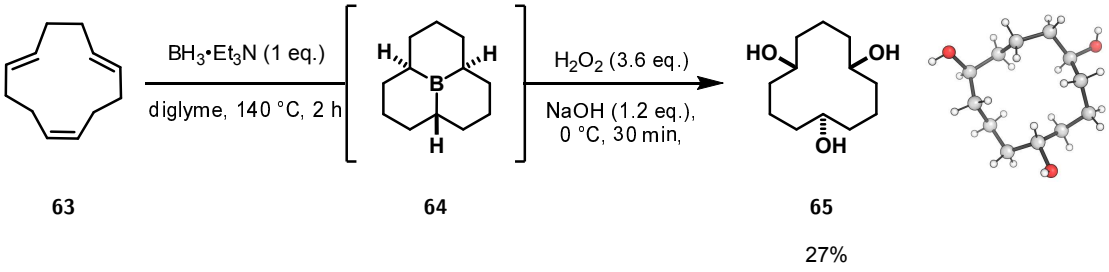


Scheme 1.13: Inverted bowl structure of the 5,5,5-oxonium ion scaffold and the proposed 6,6,6 and 6,6,5 oxoniums ions.

We aimed to syntheise both of these oxonium ion scaffolds and test their ability as catalysts for a range of transformations previously reported as being catalysed by ammonium and sulfonium ions.

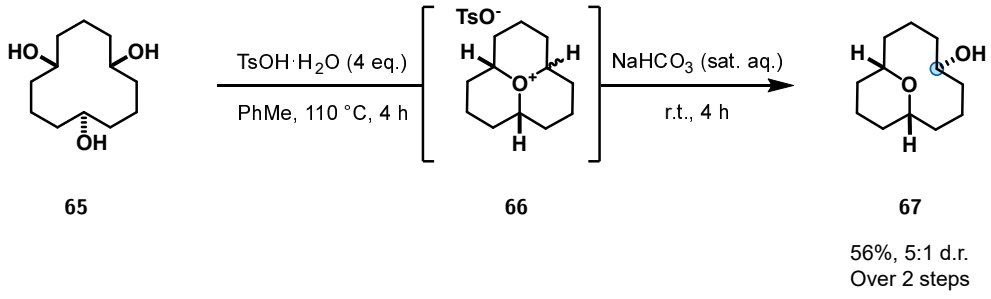
1.3 6,6,6-Oxonium Ion Synthetic Route

1,5,9-*cis*,*cis*,*trans*-Cyclododecatriene, **63**, was regioselectively hydroborated, using a procedure employed by Brown *et al.*,[33] and oxidised to macrocylic triol, **65**. The structure was confirmed by x-ray crystallography and the poor yield of the transformation was attributed to the difficulty extracting the triol from the aqueous reaction conditions (**Scheme 1.14**).



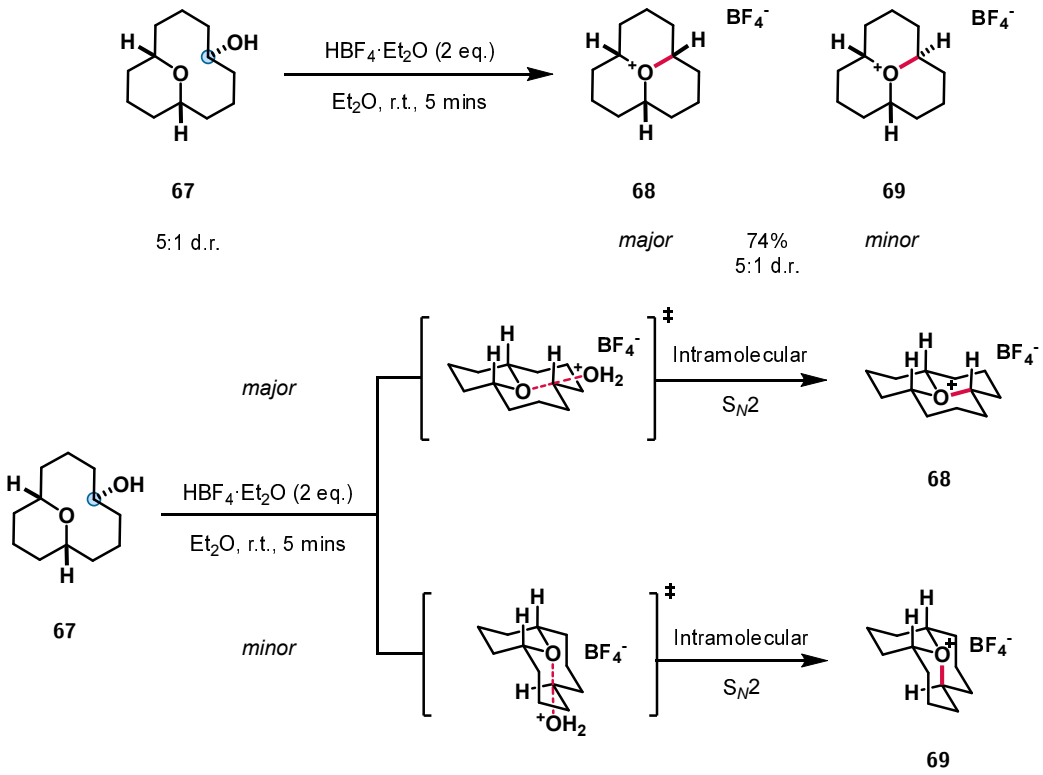
Scheme 1.14: Hydroboration/oxidation sequence to give single triol isomer, **65**.

Refluxing a suspension of macrocylic triol, **65**, in toluene with excess TsOH·H_2O caused a viscous oil to separate from the reaction that was identified as the oxonium tosylate salt, **66**. Unfortunately, this could not be purified from the excess TsOH·H_2O required to form it; however, it could be readily hydrolysed to macrocyclic alcohol, **67**, as a 5:1 mixture of diastereomers (**Scheme 1.15**).



Scheme 1.15: Acid mediated transannular dehydration to form 6,6,6-oxonium ion, **66** and ring opening to isolable alcohol **67**.

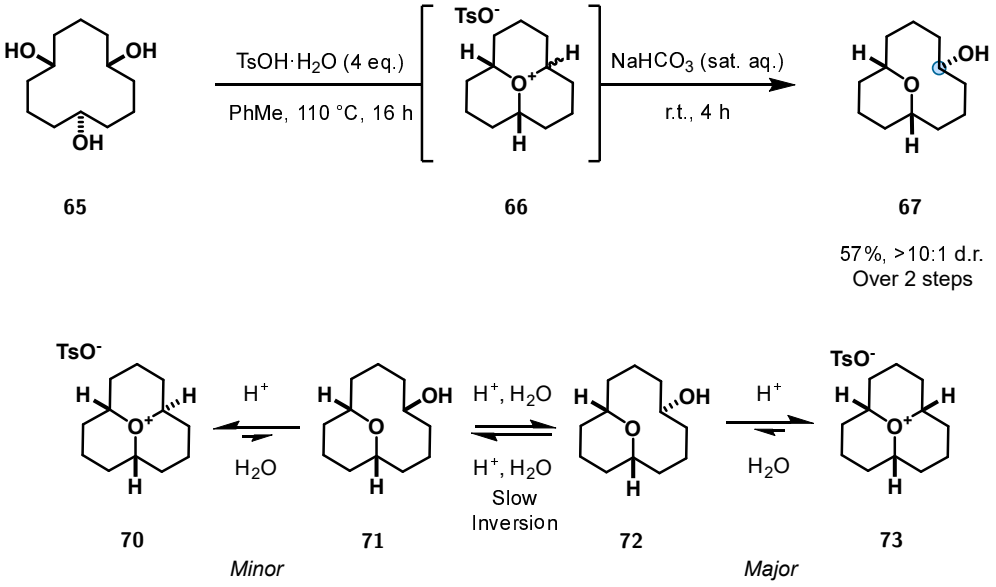
Addition of $HBF_4{\cdot}Et_2O$ to macrocylic alcohol **67** in Et_2O resulted in the precipitation of an inseparable mixture of 6,6,6-oxonium tetrafluoroborate salts, **68** and **69**, in excellent yields. Upon forming the oxonium ion, we observed significant NMR chemical shift changes for both the carbon attached to the trivalent oxygen (approximately 25 ppm) and the proton attached to this carbon (approximately 2 ppm). See **section 4.6.1** for further details. Interestingly, the 5:1 d.r. observed in the macrocylic alcohol, **65**, was retained in the product indicating the oxygen lone pair participates in the loss of water in the transition state making the transformation stereospecific (**Scheme 1.16**).



Scheme 1.16: Acid mediated stereospecific oxonium ion formation.

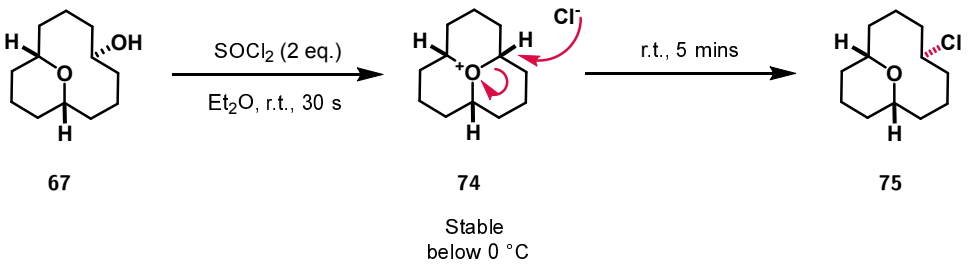
While this proved the synthetic accessibility of the 6,6,6-oxonium ions, we wanted to improve the d.r. so that we could isolate the all-*cis* oxonium ion **68**. Heating the acid-mediated transannular dehydration reaction for 16 h rather than 4 h gave

macrocyclic alcohol **67** in >10:1 d.r.. This indicates that the reaction was under thermodynamic control with slow inversion of macrocyclic alcohols, **71** and **72**, gradually equilibrating the reaction mixture towards the most thermodynamically stable oxonium ion **73** (**Scheme 1.17**).



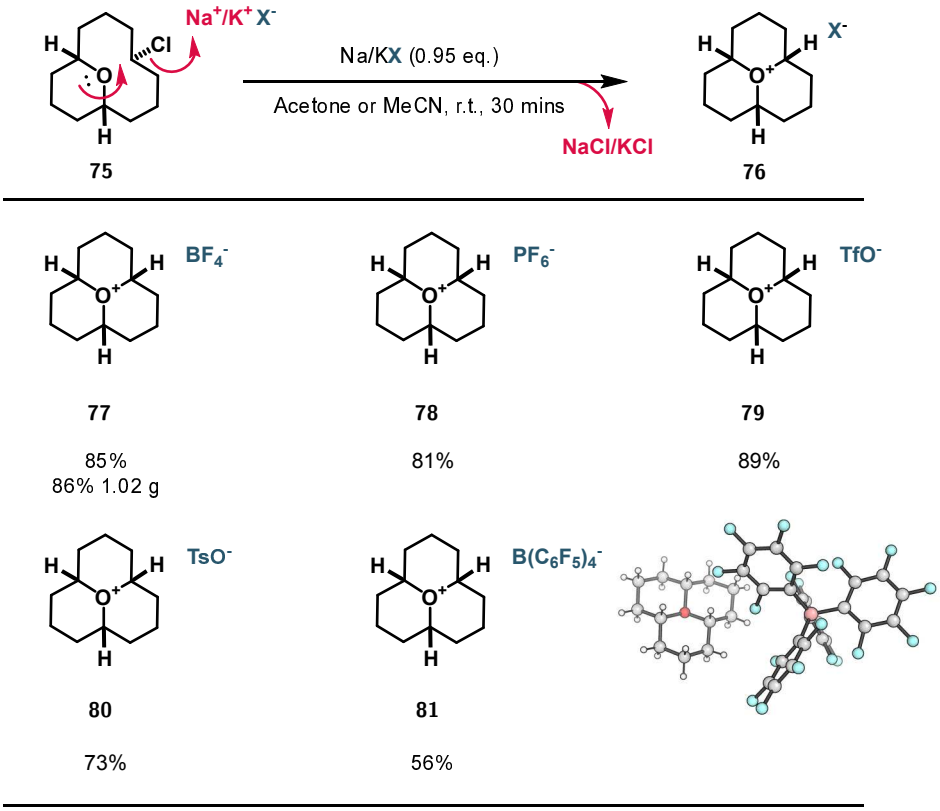
Scheme 1.17: Transannular dehydration and equilibrium inversion/oxonium ion foramtion.

With improved diastereoselectivity for the formation of **67**, we began to investigate the formation of oxonium halide salts as these could be used to generate a range of different counterions by salt metathesis. Addition of $SOCl_2$ to **67** in Et_2O initially resulted in precipitation of oxonium ion **74**; however, this redissolved in less than one minute as the chloride counterion attacked the oxonium ion to give macrocyclic chloride **75**. Oxonium ion chloride salt **74** was formed and characterised at –40 °C by the addition of $SOCl_2$ to **67** in CD_2Cl_2. While stable at low temperatures, warming oxonium ion **74** above 0 °C resulted in the formation of macrocyclic chloride **75** (**Scheme 1.18**).



Scheme 1.18: 6,6,6-oxonium chloride formation and subsequent opening to macrocylic chloride, **75**, under ambient conditions.

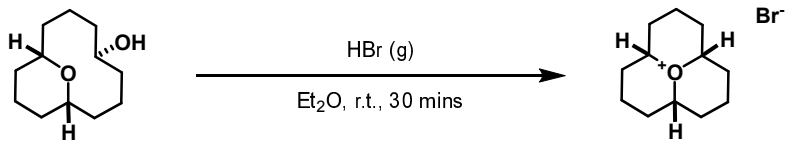
While this was initially a setback, addition of Na/K salts to a solution of macrocyclic chloride, **75**, in acetone or MeCN resulted in the formation of the desired oxonium ions up to gram scale *via* a stereospecific Finkelstein-type reaction and the precipitation of Na/KCl. A small excess of **75** was used to avoid contamination of the oxonium ion with unreacted Na/K counterion salts (**Scheme 1.19**).



Scheme 1.19: Formation of 6,6,6-oxonium ions using Finkelstein-like salt precipitation.

For hygroscopic oxonium ions, **79** and **80**, the oxonium ion obtained from acetone was hydrated and MeCN gave significantly better results. The all-*cis* structure was confirmed by single crystal x-ray crystallography of the $B(C_6F_5)_4^-$ salt **81** and the observation that there is a single ^{13}C NMR resonance for carbon atoms attached to the trivalent oxygen (see **section 4.6.1** for more details).

Oxonium bromide salt, **82**, was synthesised using *in situ* generated HBr. The trialkyloxonium bromide salt **82** was significantly longer lived than the chloride salt **74** but it steadily decomposed in solution at r.t. (**Scheme 1.20**).



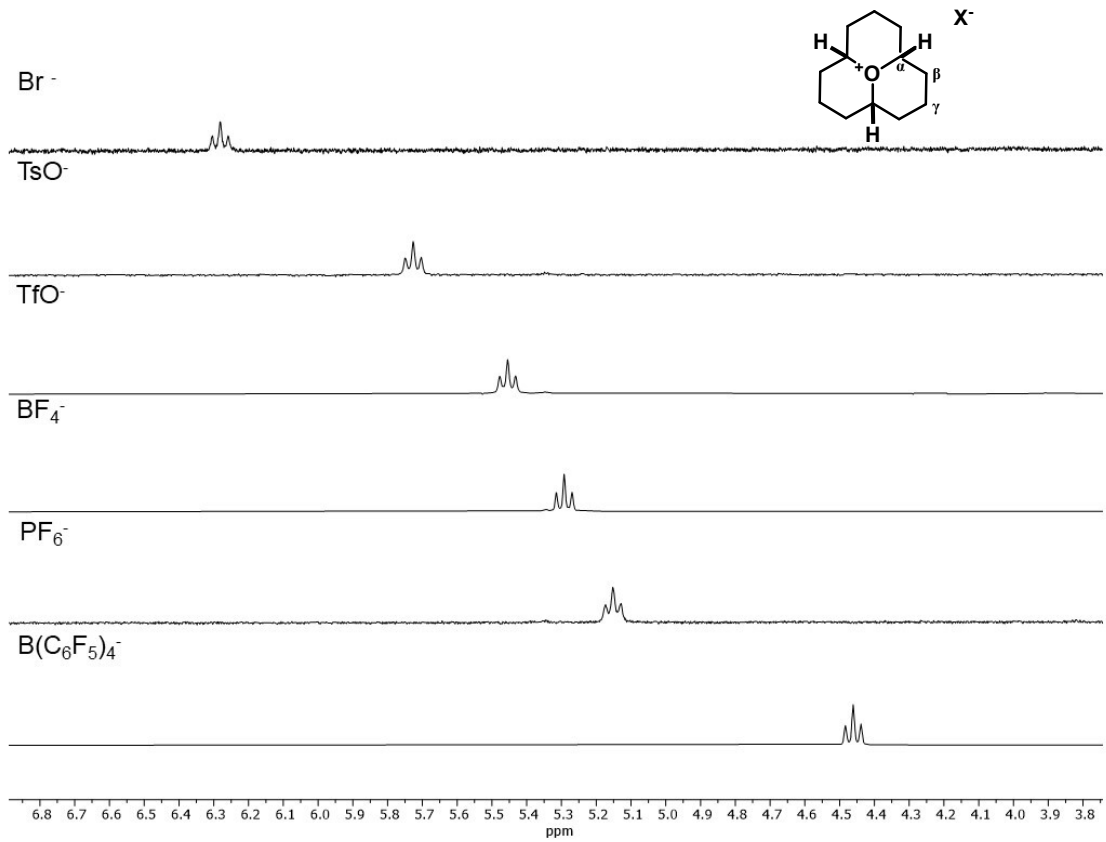
67 **82**

20%

Scheme 1.20: Formation of 6,6,6-oxonium bromide using HBr.

1.3.1 666-Oxonium Ion Chemical Shifts

We observed that the ^1H NMR chemical shift of the oxonium α C-H protons, on the carbon attached to the trivalent oxygen, varied widely for different counterions. To quantify this, we measured ^1H NMR spectra at 0.001 M concentrations to minimise any contributions that may arise from intermolecular interactions. Correlation between the co-ordinating ability of the counterion and the chemical shift was observed, indicating that the α C-H bonds were co-ordinating the counterions with the tightest binding observed for the bromide counterion. We envisaged that this tight binding of halides may lead to catalytic activity (**Scheme 1.21**).



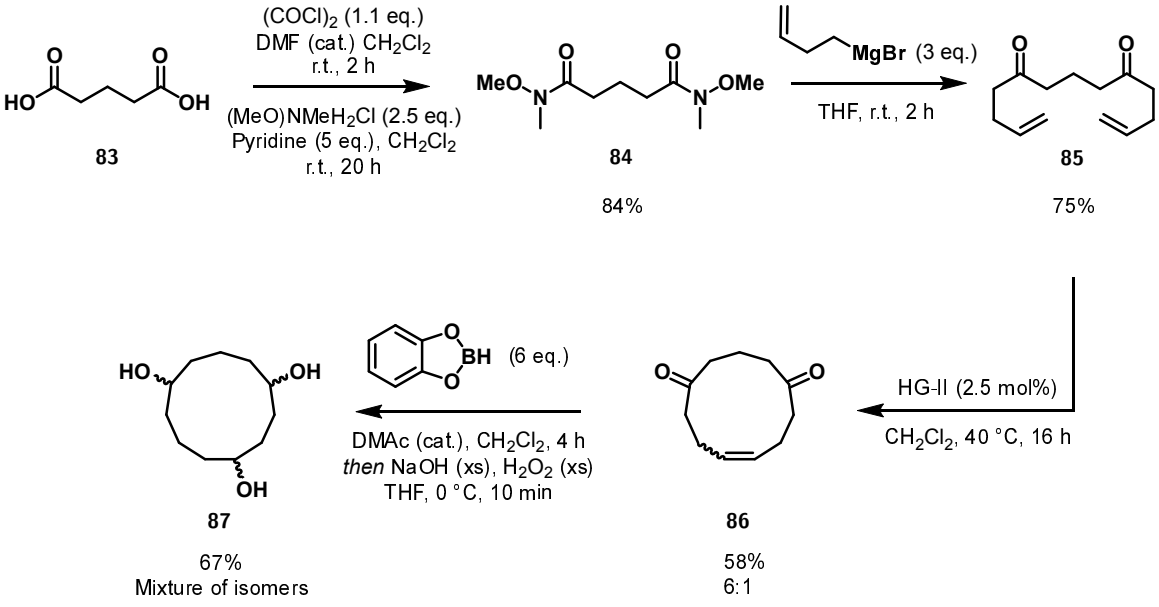
Scheme 1.21: Changing the counterion significantly modulates the α C-H ^{1}H NMR chemical shift indicating significant interaction with the counterion at this site.

To further understand the nature of the anion binding, we titrated a $CDCl_3$ solution of 6,6,6-oxonium ion $B(C_6F_5)_4^-$ salt **81** with TBAB which gave a modest value of 1402 ± 364 M^{-1} for the binding constant, K, based on a 1:1 binding stoichiometry (see **Section 4.5**) for more details. While the result was encouraging and opened the possibility of trialkyloxonium ion catalysis, the binding constant is an order of magnitude smaller than some triazole receptors designed for halide binding.[34]

1.4 6,6,5-Oxonium Ion Synthetic Route

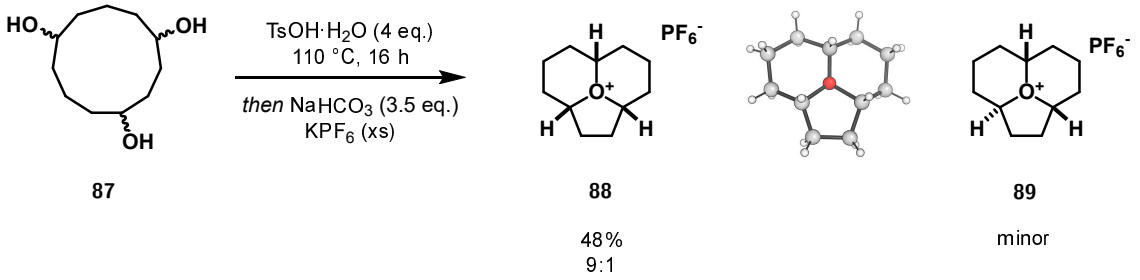
While obtaining the 6,6,6-oxonium ion scaffold was a significant achievement, relying on a commercially available cyclic triene scaffold severely limited the modifications that we could make to potential catalysts. We believed that it would be possible synthesise a medium ring triol and use the acid mediated transannular dehydration reaction to synthesise the desired 6,6,5 oxonium ion scaffold.

Starting from glutaric acid, **83**, Weinreb amide formation proceeded smoothly to give **84**.[35] Grignard reagent addition gave linear dialkene **85** which underwent RCM with HG-II to give 11-membered ring **86** in good yields. Although bis alkene **85** is consumed within 1 h, 16 h was required to form a good yield of cyclic dione **86** which we propose was due to initial polymer formation. Catecholborane effectively reduced the ketone moieties in **86** and concomitant hydroboration/oxidation of the alkene gave a mixture of triols **87** (**Scheme 1.22**).[36]



Scheme 1.22: Formation of transannular dehydration substrate, 11-ring triol **83**.

Treating the mixture of triols **87** under the transannular dehydration conditions followed by aqueous anion exchange gave 6,6,5-oxonium ion, **88**, as a 7:1 mixture of isomers. This indicated that we should be able to form the most thermodynamically stable oxonium ion from cyclic triols without the need to control any stereochemistry prior to the transannular dehydration (**Scheme 1.23**).



87 **88** **89**

48%
9:1

minor

Scheme 1.23: Transannular dehydration to form oxonium ion **88** from triol mixture **87** and characterisation of **88** by single crystal x-ray crystallography.

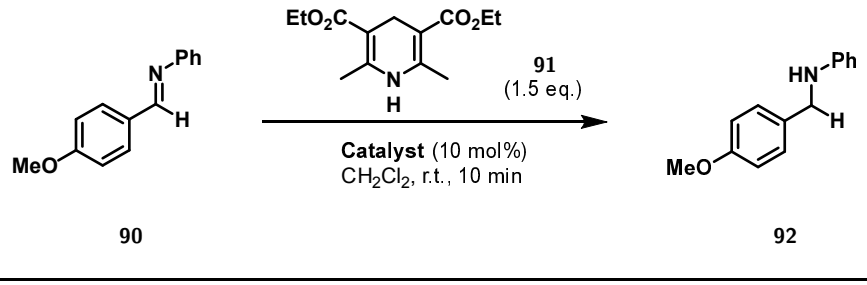
Despite significant counterion disorder and issues arising from having a mixture of diastereomers, preliminary single crystal x-ray diffraction analysis gives the structure as all-*cis* oxonium ion **88** and ^{13}C NMR analysis indicates the minor diasteromer is **89** as three C-O NMR signals are observed compared to the two signals that would be expected for the epimer of **88** at the 6,6 ring junction. See **Section 4.6.2** for further details.

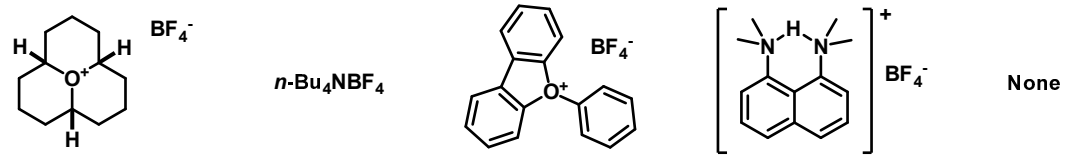
With both the 6,6,6- and 6,6,5-oxonium ions now in hand, we began investigating the ability of the oxonium ion to act as a catalyst for reactions that had previously been successfully catalysed using ammonium and sulfonium salts.

1.5 Trialkyloxonium Ion Catalysis

1.5.1 Hantzsch Ester Reduction

Having secured efficient syntheses of the 6,6,6 and 6,6,5-oxonium ions, we began our investigations into the catalytic potential of oxonium ions by looking at the reduction of aldimines with Hanztsch esters as the reaction could be monitored by ^{1}H NMR. Aldimine **90**[37] and Hantzsch ester **91**[38] were prepared by literature procedures. Aldimine **90** was fully reduced by Hantzsch ester **91** in the presence of both oxonium ion **77** and ammonium salt control tetrabutylammonium tetrafluoroborate, **96**, at 10 mol% catalyst loading. Analysis of the ^{1}H NMR showed the oxonium ion catalyst **77** was unchanged at the end of the reaction indicating that it was stable to the reaction conditions and only 7% of **92** was obtained without **77** (**Scheme 1.24**).



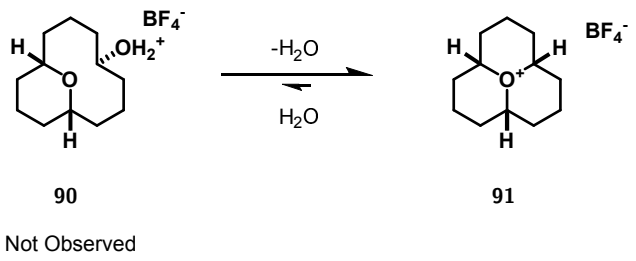


77	93	94	95	
Quant[a]	98%	13%	4%	7%

Scheme 1.24: Oxonium ion catalysed aldimine reduction using Hantzsch esters. [a] Stirred with Proton Sponge® for 2 h before use.

We envisaged that the rate acceleration could come from one of three effects. Firstly, hydrogen bonding catalysis from the α C-H bonds similar to the results previously reported for ammonium and sulfonium salts.[29,30,32] Secondly, from a salt effect whereby increasing the polarity of the solution stabilises the charged transition state. Finally, from HBF_4 that could arise from the synthesis or hydrolysis of the oxonium ion in solution catalysing the reaction.

To probe the salt effect, we added triaryloxonium ion **94**, reported by Nesmeyanov[39] and Hellwinkel,[40] that lacks H-bond donors and found only a small increase in the rate of reaction indicating that a salt effect is unlikely. To ensure that no acid from the synthetic route could be causing the catalysis, **77** was stirred with Proton Sponge® for 2 h to remove any adventitious HBF_4 and was precipitated prior to use. No loss of activity was observed for oxonium ion **77** prepared by this method and Proton Sponge® HBF_4 salt, **95**, did not catalyse the reaction ruling out contamination with **95** resulting in catalysis. Despite these results, we were unable to eliminate the possibility that the oxonium ion could be generating H^+ in solution by hydrolysis, despite not observing the hydrolysis product **67** by ^1H NMR. This indicated that either hydrolysis was not occurring in the organic solution or that the equilibrium position was heavily in favour of the oxonium ion **77** (**Scheme 1.25**).



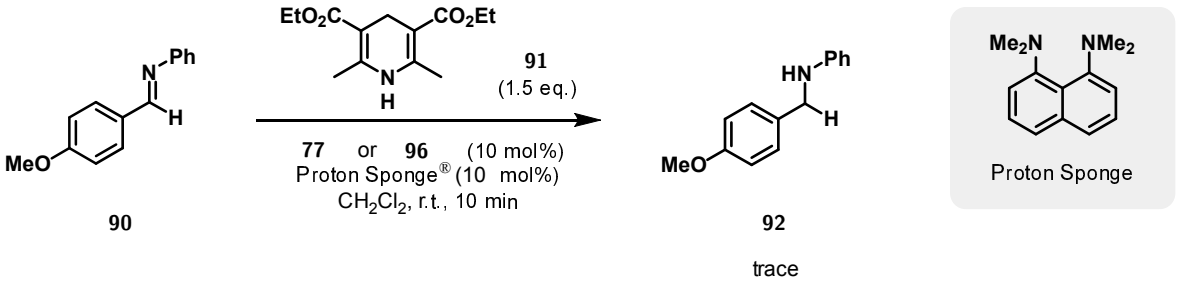
90

Not Observed

91

Scheme 1.25: Possible alternative mode of catalysis by *in situ* generation of HBF_4 *via* hydrolysis of **77**.

To attempt to address this, we conducted the reaction with equimolar amounts of **77** and Proton Sponge® to complex any protons formed by hydrolysis of **77**. No reaction occurred in the presence of Proton Sponge®; however, the results were inconclusive as no product formation was observed when $TBABF_4$, **93**, was substituted for **77** which indicates that Proton Sponge® inhibits the reaction (**Scheme 1.26**).

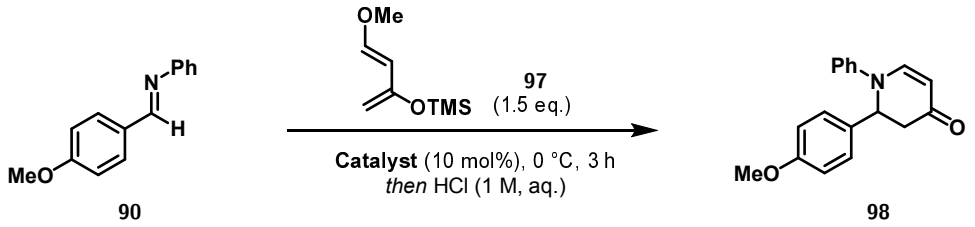


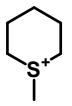
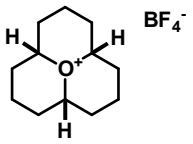
Scheme 1.26: Oxonium Ion catalysed aldimine reduction using Hantzsch esters inhibited by Proton Sponge®.

Having observed a rate acceleration for the reduction of aldimines with Hantzsch esters, we wanted to evaluate the oxonium ion catalyst under reaction conditions where HBF_4 has a weak or negligible catalytic effect to investigate if hydrolysis or equilibrium HBF_4 formation from **77** was responsible for the catalytic effect observed.

1.5.2 Aza Diels-Alder

Shirakawa *et al.* reported that the aza Diels-Alder reaction between aldimine **90** and Danishefsky's diene, **97**, was catalysed by sulfonium ion catalyst **60** and in the presence of Brookhardt's acid, **99**, poor yields of 16% were obtained.[32] In our hands, we observed significant rate acceleration with oxonium ion **77** and only 9% product formation without. However, the addition of $HBF_4{\cdot}Et_2O$ gave the desired [4+2] adduct in excellent yield (**Scheme 1.27**).



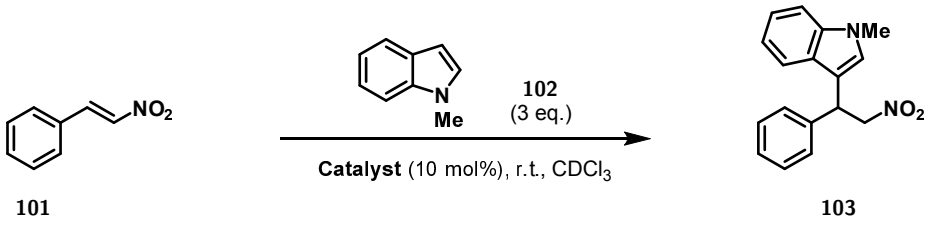
BAr_F^- = $[B(3,5\text{-}(CF_3)_2C_6H_3)_4]^-$				
	$[H(Et_2O)_2]^+BAr_F^-$	$HBF_4{\cdot}Et_2O$		None
60	**99**	**100**	**77**	
82%[a]	16%[a]	Quant%[b]	88%[b]	15%[b]

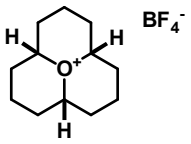
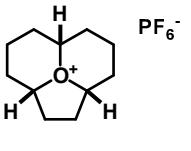
Scheme 1.27: The reaction of aldimine **90** with Danishefsky's diene, **97**, gives excellent yield of [4+2] adduct **98** in the presence of both $HBF_4{\cdot}Et_2O$ and oxonium ion **77**. [a]Reported by Shirakawa and co-workers.[32] [b]Measured using CH_2Br_2 as an internal standard.

As the reaction was catalysed by $HBF_4{\cdot}Et_2O$, we were unable to confirm if the catalysis resulted from hydrogen bonding from the oxonium ion or from *in situ* generated HBF_4 from hydrolysis of **77**.

1.5.3 Friedels-Crafts Alkylation

We selected the Friedels-Crafts alkylation of *trans*-β-nitrostyrene, **101**, with *N*-methylindole, **102**, as it had previously been reported that alkylated indole **103** was formed extremely slowly in the presence of protic acids while being rapidly catalysed by cationic thiourea based catalysts.[41] By comparison of the ^{1}H NMR spectrum to literature spectra for **103**, no conversion was observed over the first 12 h with either oxonium ions **77** or **88** and only traces of **103** were observed with $HBF_4{\cdot}Et_2O$, **100**. After 72 h, $HBF_4{\cdot}Et_2O$, **100**, gave **103** in 12% yield, while **77** had fully decomposed without giving the product and only **88** gave trace alkylation product **103** (**Scheme 1.28**).

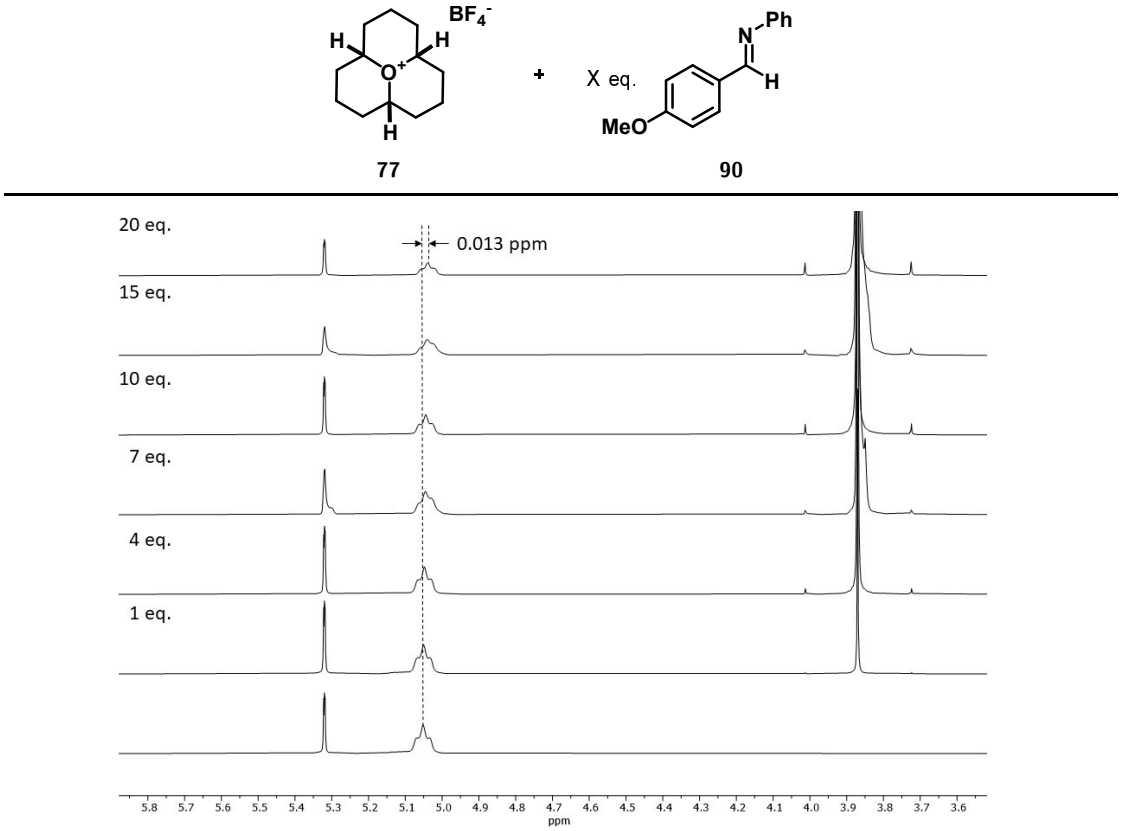


$HBF_4{\cdot}Et_2O$			None
	BF_4^-	PF_6^-	
100	**77**	**88**	
t = 12 h trace	-	-[a]	-
= 72 h 12%	-	trace[a]	3%

Scheme 1.28: Attempted Friedels-Crafts alkylation of *N*-methylindole with *trans*-β-nitrostyrene using trialkyloxonium ion catalysts. [a]reaction carried out in CD_2Cl_2 due to the poor solubility of **88** in $CDCl_3$.

1.5.4 Aldimine Titration Experiment

We then completed a titration study to look for evidence of interaction between the α C-H protons of 6,6,6-oxonium ion **77** and aldimine **90**. Sequential addition of aldimine **90** to **77** gave a small chemical shift change of 0.013 ppm after the addition of 20 eq. of **90** which indicates some interaction between the two species (**Scheme 1.29**).

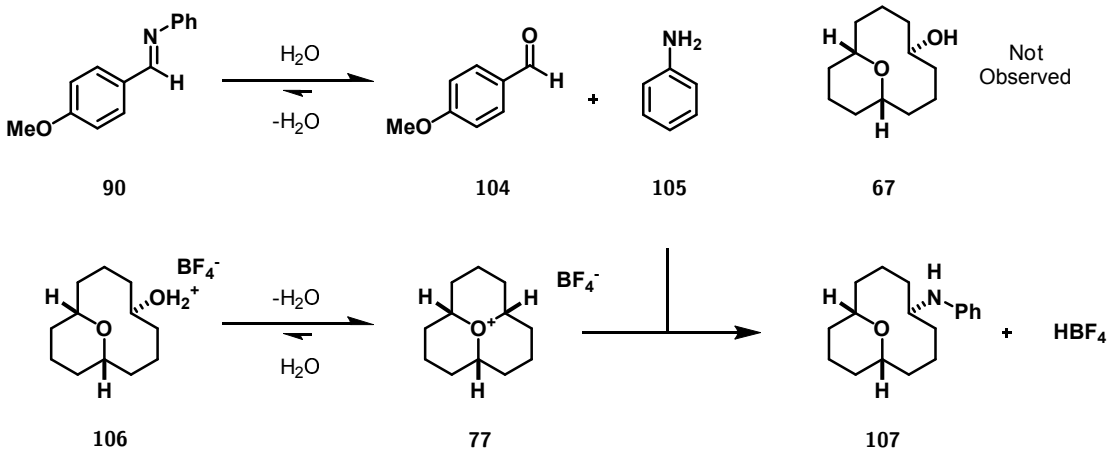


Scheme 1.29: ^{1}H NMR (500 MHz) Titration of aldimine **90** into a solution of oxonium ion **77** in CD_2Cl_2.

6,6,5-Oxonium ion **88** gave a slightly larger chemical shift change of 0.020 ppm under the same conditions indicating slightly improved binding to the substrate; however, this could be attributed to the more weakly co-ordinating PF_6^- counterion

(see **Section 4.5 for more details**).

Despite the indication of an interaction between oxonium ion **77** and aldimine **90**, ^{1}H NMR analysis of the titration mixture after completion of the experiment showed that more than 50% of oxonium ion **77** had been consumed after 8 h. We initially suspected that the water content of the sample had increased over time causing the hydrolysis of **77** to **67**; however, ^{1}H-^{13}C HSQC analysis of the mixture gave a ^{13}C chemical shift of 58 ppm rather than the expected 76 ppm for the carbon bound to the OH group in **67**. This indicates that aniline, **105**, produced by the hydrolysis of aldimine **90** had reacted with the oxonium ion to give **107** rather than macrocyclic alcohol **67**. This provides evidence for another potential pathway for the formation of HBF_4 in the reaction mixture from oxonium ion **77** (**Scheme 1.30**).



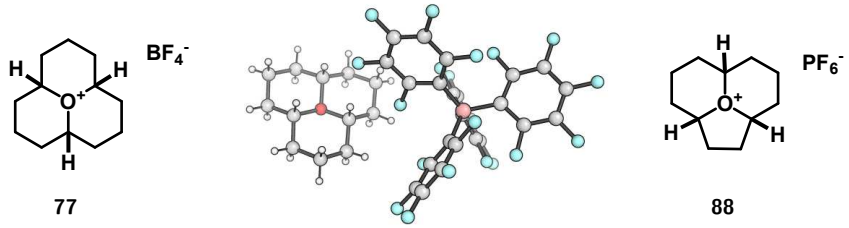
Scheme 1.30: Proposed modes of *in situ* HBF_4 formation from oxonium ion **77** under the reaction conditions from adventitious H_2O.

To establish that the oxonium ions are responsible for catalysis observed for the aldimine reduction using Hantzsch esters in **section 1.5.1** and aldimine [4+2] with Danishefsky's Diene in **section 1.5.2**, the amount of HBF_4 present in solution would have to be quantified and the rate of reaction with the oxonium ion directly

compared to the rate of reaction with HBF_4. As HBF_4 is an excellent catalyst for the reaction, we decided to focus on other applications of oxonium ions.

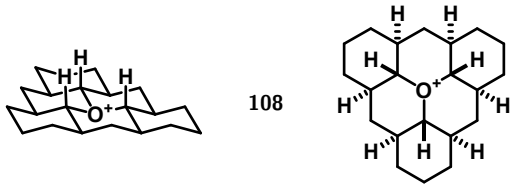
1.6 Conclusion

We have developed the shortest syntheses to 'stable' trialkyloxonium ions **77** and **88** (3 and 5 steps respectively) using a novel transannular dehydration methodology and characterised these oxonium ions by NMR and **77** by x-ray crystallography (**Scheme 1.31**).



Scheme 1.31: Structures of the trialkyloxonium ions scaffolds synthesised using the transannular dehydration methodology

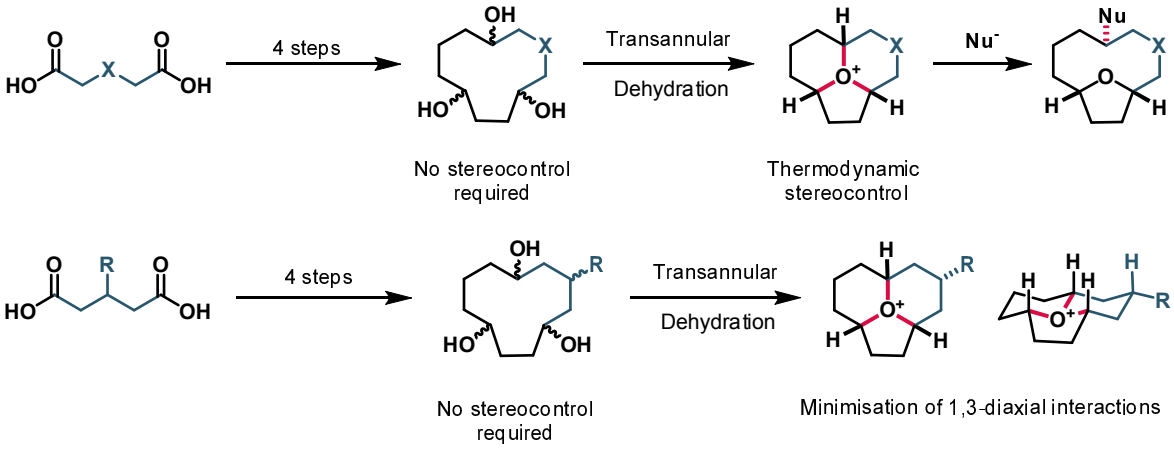
We observed a rate acceleration for the reduction of aldimine **90** with Hantzsch ester **91** and the hetero Diels-Alder reaction of aldimine **90** with Danishefsky's diene **97**; however, it is possible that the rate acceleration could be attributed to the *in situ* formation of HBF_4. Construction of an oxonium ion insensitive to hydrolysis such as **108** or using an enantiopure oxonium ion catalyst and observing enantioenriched product are likely to be the only methods by which oxonium ion catalysis can be confirmed (**Scheme 1.32**).



Scheme 1.32: Confirmation of catalysis requires an oxonium ion insensitive to hydrolysis under the reaction conditions such as **108** or observation of enantioenriched product with an enantiopure oxonium ion.

1.7 Future Work

The transannular dehydration reaction gives oxonium ions in good yields with good d.r., we envisage that this could be utilised to produce a library of stable trialkyloxonium ions. Variation of the glutaric acid moiety would allow the construction of racemic point chiral at oxygen oxonium ions. We predict that when unsymmetrical substitutents are used, 4 stereocentres could be set by the transannular dehydration reaction as the substituent would preferentially sit equatorial to minimise 1,3-diaxial interactions. Reaction of the oxonium ions with nucleophiles would allow access to medium rings ethers with 3 or more stereocentres being set in the key transannular dehydration (**Scheme 1.33**).



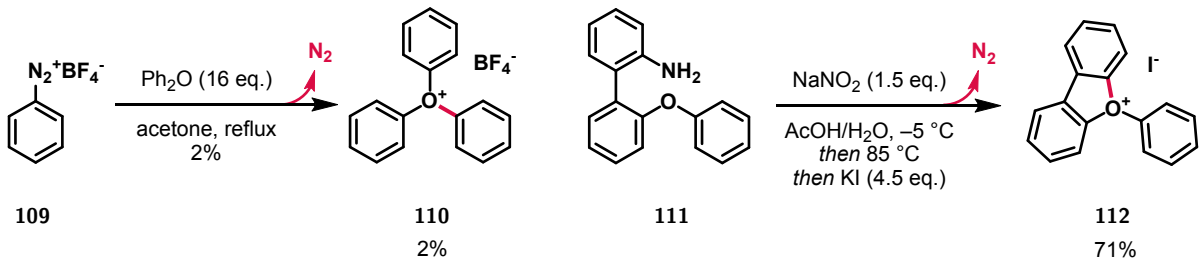
Scheme 1.33: Modular construction of substituted trialkyloxonium ions using a transannular dehydration strategy

2 Triaryloxonium Ions: Aryne Generation

2.1 Introduction

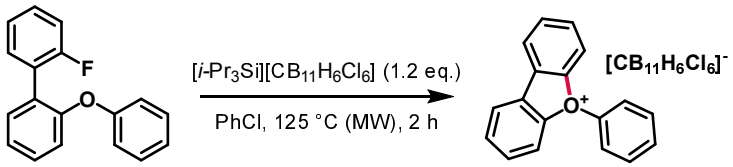
2.1.1 Triaryloxonium Ion Formation

There are very few methods for the synthesis of triaryloxonium ions and it was not until 1957 that the triphenyloxonium ion was synthesised by Nesmeyanov and co-workers. Loss of nitrogen from phenyldiazonium tetrafluoroborate, **109**, in a mixture of acetone and diphenyl ether at reflux gave the desired triphenyl oxonium ion **110** in 2% yield.[39] While the first synthesis of a triaryloxonium ion was a significant achievement, the synthetic utility of intermolecular oxonium ion formation was limited by the low yields. Contrastingly, intramolecular construction of the oxonium ion by diazotization of aniline **111**, and subsequent loss of N_2, gave a good yield of the desired phenyl dibenzofuranium ion **112** (**Scheme 2.1**).[40,42]



Scheme 2.1: Synthetic methods for the formation of triaryloxonium ions using aryl diazonium salts.

Recently, Siegel *et al.* described the use of silylium cations to abstract fluoride from biaryl ether **113** to give oxonium ion **114** in moderate yields (**Scheme 2.2**).[43]



113 **114**

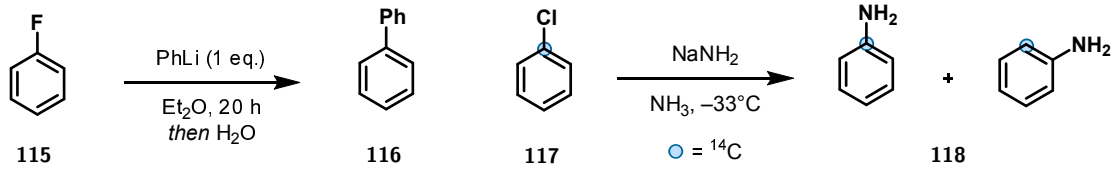
55%

Scheme 2.2: Oxonium ion synthesis *via* F^- abstraction.

Despite the introduction of the silylium method, the sensitivity and expense of the reagents as well as the lack of functional group tolerance mean that intramolecular formation of the oxonium ion from the parent diazonium salt remains the predominate synthetic method.

2.1.2 Aryne Generation: C-H deprotonation

The earliest examples of aryne generation arose from treating aryl halides with strong bases. Wittig showed that *o*-lithiation of fluorobenzene generates benzyne by loss of LiF. This is trapped by PhLi and the lithiated biphenyl can deprotonate fluorobenzene to give biphenyl, **116**, in 70% yield.[44] Roberts *et al.* demonstrated that $NaNH_2$ mediated elimination from ^{14}C labelled chlorobenzene gave a 1:1 mixture of labelled aniline thereby providing evidence for the existence of an aryne intermediate (**Scheme 2.3**).[45]

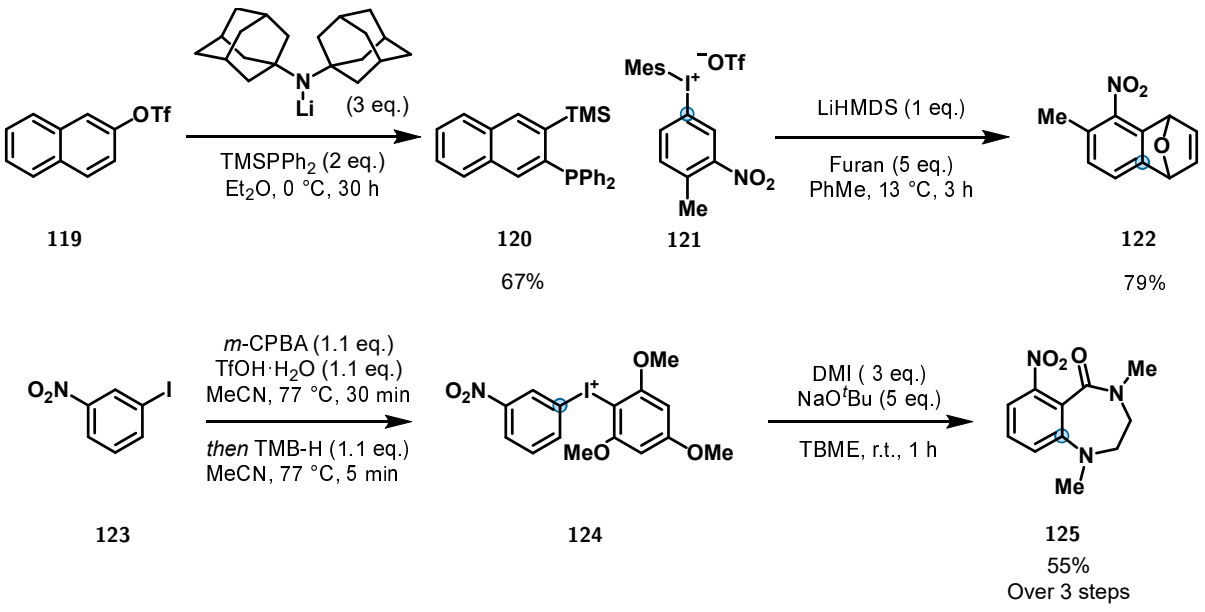


115 **116** **117** **118**

70% 43% 1:1

Scheme 2.3: Early developments in aryne generation *via* C-H deprotonation.

The strong bases required to generate the aryne severely limit the functional group tolerance of both the reagents and the aryne precursor. Furthermore, the base often reacts with the arynes themselves reducing the yield of the desired products. Aryl triflates are deprotonated to give arynes under milder conditions than aryl halides and the use of a sterically hindered base, such as lithium diadamantylamide (LDAM), minimises the reaction of the base with the aryne.[46] Good yields of furan [4+2] adducts were obtained from arynes generated using LiHMDS and aryl iodonium salts. Furthermore, when using unsymmetrical starting materials, good selectivity for a single aryne was observed provided that there was an electronic bias.[47] More recently, the use of *tert*-butoxide as a base was found to also be tolerated for the formation of arynes from aryl iodonium salts.[48] Despite these advances, the bases required to generate arynes *via* C-H deprotonation still severely limit functional group tolerance, and for iodonium ions, the oxidative and strongly acidic conditions required for their synthesis can limit functional group tolerance further (**Scheme 2.4**).

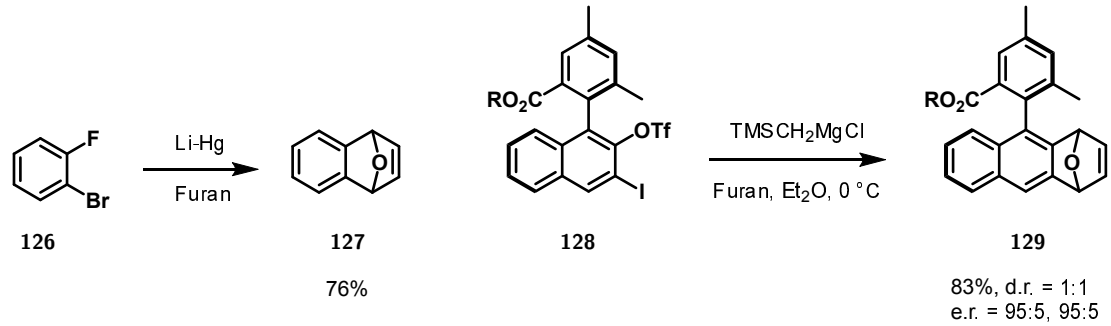


Scheme 2.4: Modern methods for aryne generation *via* C-H deprotonation.

2.1.3 Aryne Generation: 1,2-disubstituted precursors

The most common methods used for aryne generation use 1,2-disubstituted arenes. The substitution pattern allows control of the regioselectivity of aryne formation, however, introducing two substituents often results in more synthetic steps to reach the precursors unless they are readily available and increases the waste generated, in both the reaction and in obtaining the starting materials.

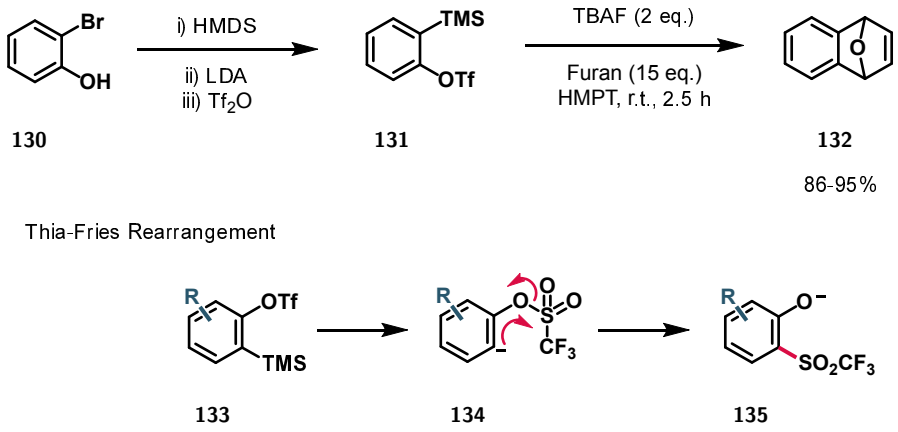
Li-halogen exchange and subsequent elimination from 1,2-dihaloarenes was first demonstrated in 1955 and allows facile aryne generation.[49] The reaction can be improved by replacing one halide with a triflate and this method is commonly employed using $TMSCH_2MgBr$ or *n*-BuLi to generate the aryne, such as in the formation of atropisomeric furan [4+2] adduct **129** (**Scheme 2.5**).[50]



Scheme 2.5: Elimination from Li or Mg metallated arenes to give arynes and their furan [4+2] trapping adduct.

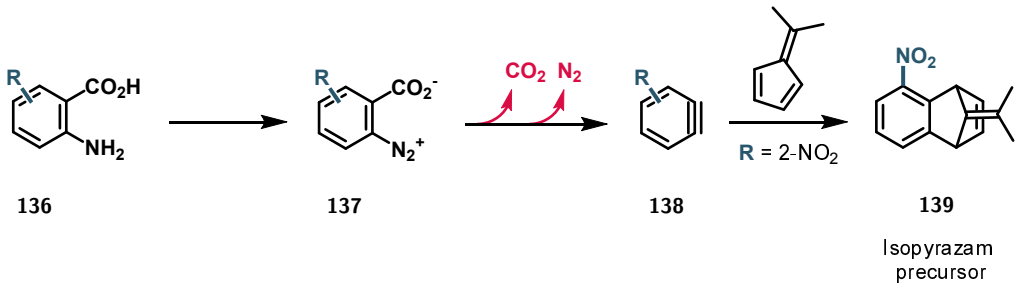
In 1983, Kobayashi *et al.* demonstrated that *o*-trimethylsilyltriflate **131** generates arynes in the presence of F^- that could be trapped in high yields.[51] While the original example uses a soluble fluoride source, it is more common to use sparingly soluble fluoride salts (such as CsF or KF/18-crown-6) to generate a low concentra-

tion of aryne throughout the reaction to minimise aryne-aryne reactions. A wide variety of *o*-trimethylsilyltriflates have been prepared and this is now the most widely used method for aryne generation.[52] Despite their utility, the synthesis of *o*-trimethylsilyltriflates often requires strong bases/organometallic reagents limiting functional group tolerance. Furthermore, sterically demanding substrates,[50] those that form a stable phenolate anion **135** or generate severely strained arynes[53] undergo a thia-fries rearrangement pathway that can reduce aryne reaction yields (**Scheme 2.6**).



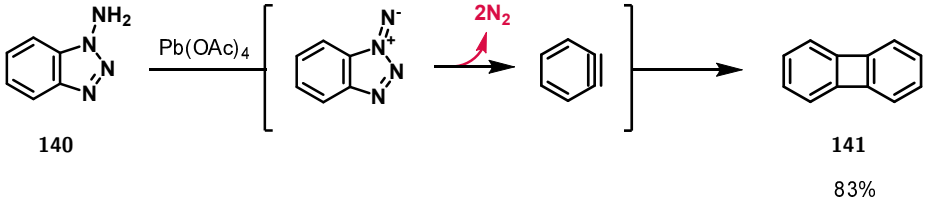
Scheme 2.6: *o*-Trimethylsilyltriflate aryne precursors and alternative thia-fries reaction pathway.

Diazotization of anthranilic acid derivatives followed by loss of N_2 and CO_2 at 40-60 °C effectively generates arynes; however, care needs to be taken as the intermediate diazonium salt can be explosive.[54] Despite this, anthranilic acid derivatives are often cheap and the reaction produces minimal waste making them attractive for industrial production. A key intermediate of anti-fungal agent Isopyrazam is produced using this method (**Scheme 2.7**).[55]



Scheme 2.7: Anthranilic acid derived arynes and their use in the production of Isopyrazam.

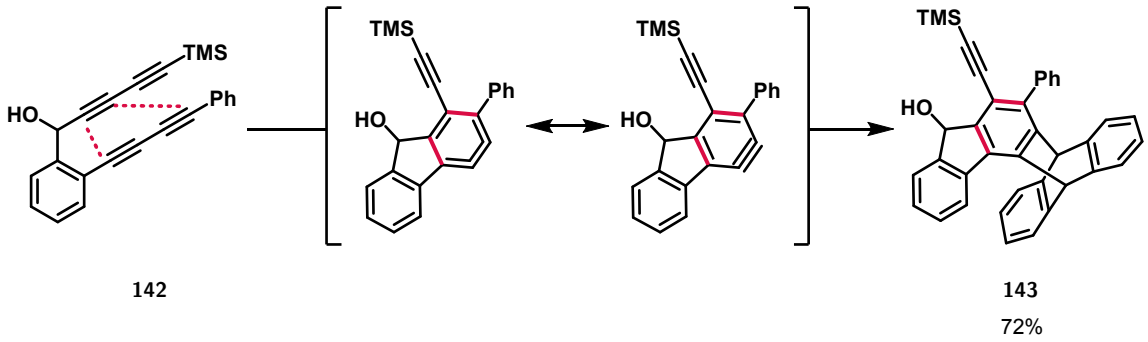
1-Aminobenzotriazoles are rapidly oxidised by $Pb(OAc)_4$ with the resulting intermediate losing two molecules of nitrogen to form an aryne. Campbell and Rees reported that in the absence of arynophiles, biphenylene, **141**, can be prepared in good yield using this methodology.[56] However, the toxicity of the oxidant and the potentially explosive nature of 1-aminobenzotriazoles makes using this method for aryne generation undesirable when alternatives are available (**Scheme 2.8**).



Scheme 2.8: Oxidation of 1-aminobenzotriazole results in the formation of benzyne which dimerises to form biphenylene, **141**, in good yield.

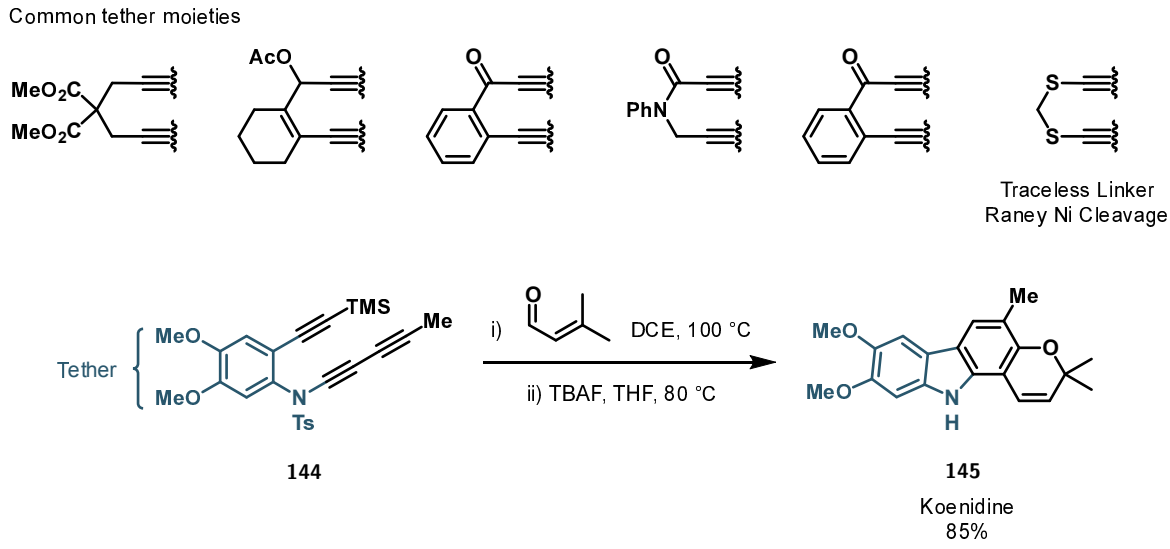
2.1.4 Aryne Generation: Hexa Dehydro Diels-Alder (HDDA)

The Hexa Dehydro Diels-Alder (HDDA) reaction was independently discovered by Ueda[57] and Johnson[58] in 1997 but has been extensively developed, primarily by Hoye and co-workers, since 2012.[59] Intramolecular cyclisation of a 1,3-diyne and a diyneophile gives an aryne intermediate, which can then react with the appropriate trapping reagents such as anthracene (**Scheme 2.9**).[57]



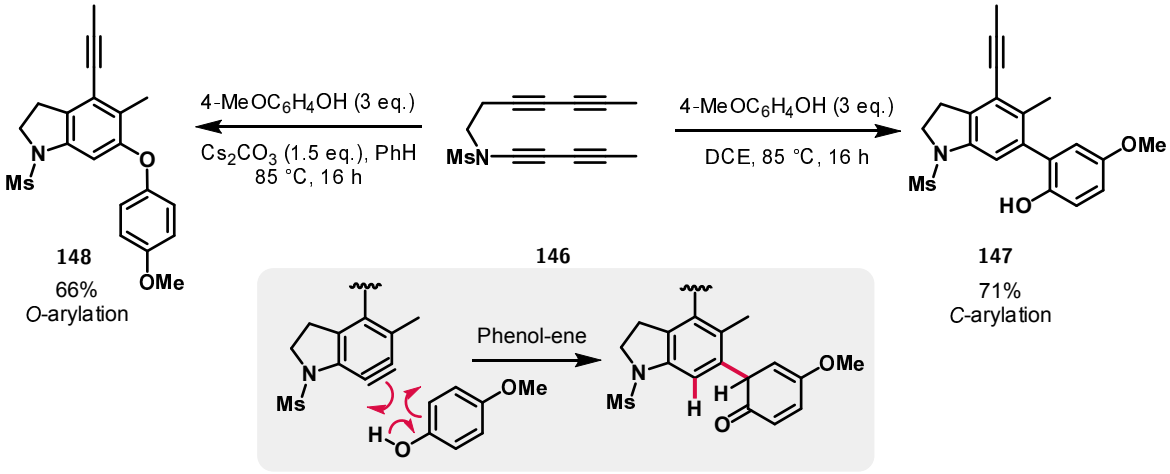
Scheme 2.9: Initial report of the HDDA reaction by Ueda *et al.* using **142** (1 eq.) and anthracene (10 eq.) at 25 °C in THF/Et_2O (1:1) for 72 h.

In the HDDA reaction, the alkyne/diyne moieties are linked by a tether to hold them in close proximity and pre-organise the molecule for the HDDA reaction. The tether is almost exclusively three atoms in length, some common examples are shown below in **Scheme 2.10**, and the HDDA reaction generally proceeds at temperatures ranging between 0 °C and 300 °C, but most commonly 70 - 140 °C.[59] Despite some progress into traceless tethers,[60] and the tether being elegantly incorporated into the synthesis of some natural products, such as koenidine, **145**,[61] their necessity and presence in the final product somewhat limits the utility of the reaction (**Scheme 2.10**).



Scheme 2.10: The use of tethers to facilitate the HDDA Reaction.

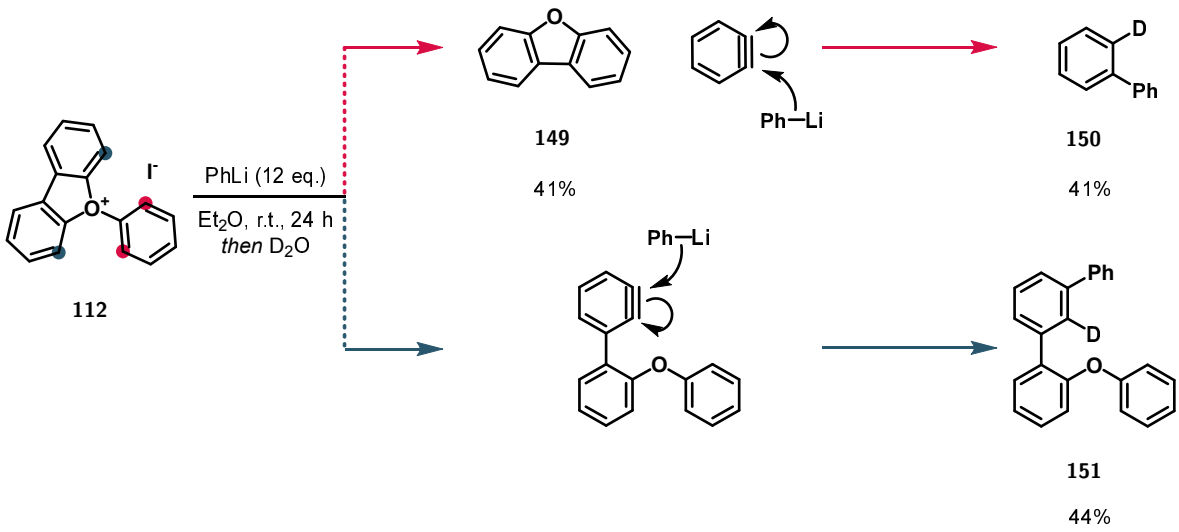
The HDDA aryne is generated without any base or any by-products being present and this facilitates reactivity with substrates and reagents that were previously inaccessible. Phenols traditionally undergo *O*-arylation with arynes;[62] however, under the HDDA reaction conditions the reaction proceeds *via* a phenol-ene pathway to give *C*-arylation product **147** unless additional base is added.[63,64]



Scheme 2.11: Phenol arylation with HDDA genereated arynes.

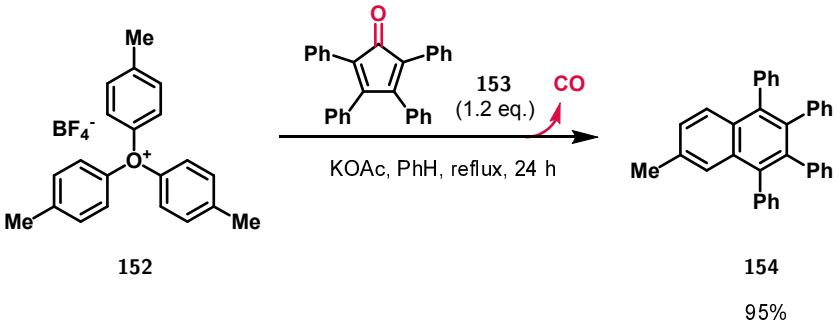
2.1.5 Evidence of Oxonium Ion Generated Arynes

While the decomposition of oxonium ions in the presence of HO^-, AcO^-, NO_2^- etc. is known,[65] the first quantitative investigation into the formation of arynes from oxonium ions in the presence of strong bases was reported in 1972. Addition of PhLi to phenyl dibenzofuranium ion **112** and subsequent quenching with D_2O gave a mixture of deutuerated biphenyl, **150**, and biaryl ether **151**. The product distribution indicated that there is little/no selectivity between deprotonation on the pendant aryl ring and the dibenzofuran (**Scheme 2.12**).[66]



Scheme 2.12: Product distribution from the additon of PhLi to phenyl dibenzofuranium ion **112** and subsequent quenching with D_2O.

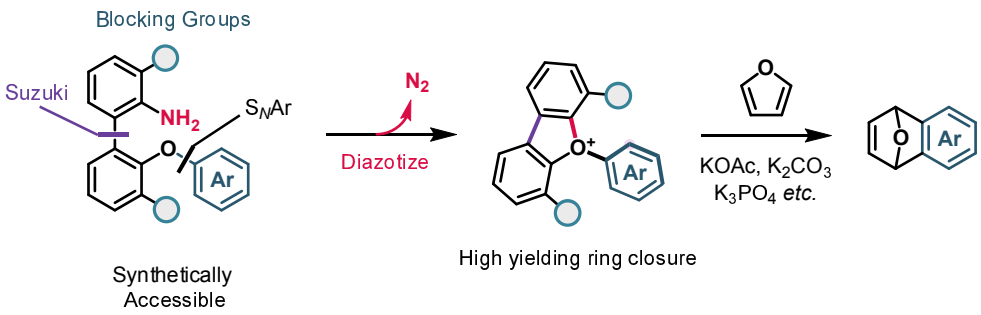
Despite triaryloxonium ions successfully forming arynes with PhLi, aryne generation proceeds under significantly milder conditions. Tolstaya *et al.* demonstrated that treating triaryloxonium ion **152** with KOAc in refluxing benzene generated an aryne that was subsequently trapped with tetraphenylcyclopentadienone, **153**, to give substituted 1,2,3,4-tetraphenylnapthalene **154** in excellent yield (**Scheme 2.13**).[67]



Scheme 2.13: Weak base mediated aryne formation from triaryloxonium ions.

2.2 Project Aims

Following the work of Tolstaya,[67] we proposed that it would be possible to generate arynes from triaryloxonium ions using weak bases such as acetate, carbonate and phosphate. The use of these weak inorganic bases would offer significantly improved functional group tolerance compared to the current gold standard method for generating arynes *via* a C-H deprotonation strategy which involves treating aryliodonium ions with *tert*-butoxide or LiHMDS.[47,48] Furthermore, unlike *tert*-butoxide or LiHMDS, these inorganic bases would not require the reactions to be conducted under inert conditions with careful exclusion of water making the process more operationally accessible. To achieve this, we designed a modular route based on the dibenzofuran scaffold so that we could use intramolecular ring closure to synthesize the triaryloxonium ions in high yields. Furthermore, installing blocking groups adjacent to the dibenzofuran C−O bonds would result in exclusive formation of the aryne from the pendant arene. Furan would be added to the reactions to trap the aryne produced to evaluate the effectiveness of the transformation (**Scheme 2.14**).

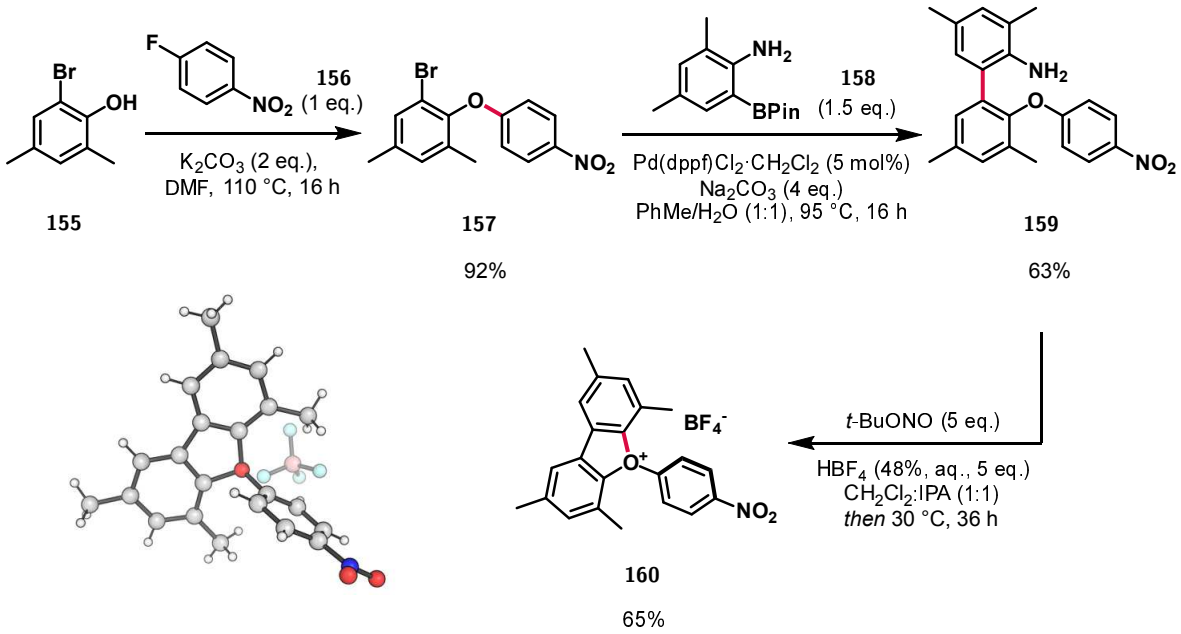


Scheme 2.14: Strategy for the synthesis of triaryloxonium ions and arynes

2.3 Fluoroarene Derived Oxonium Ions

2.3.1 Synthetic Route

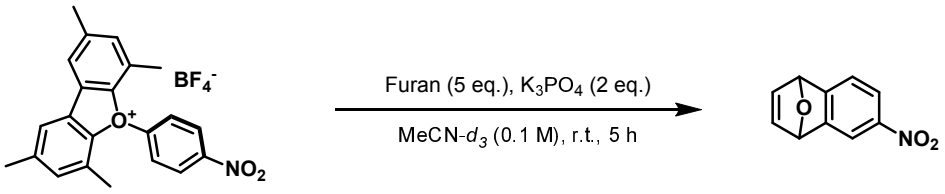
Our initial targets were oxonium ions based upon the 2,4,6,8-tetramethyldibenzofuranium scaffold as both 2,4-dimethylphenol and 2-bromo-4,6-dimethylaniline are commercially available. 2-Bromo-4,6-dimethylphenol, **155**, underwent a facile S_NAr reaction with 1-fluoro-4-nitrobenzene, **156**, to give diaryl ether **157**. Borylated aniline **158** was prepared from 2-bromo-4,6-dimethylaniline under Miyaura borylation conditions[68] and used without further purification in a Suzuki coupling with diaryl ether **157** to give oxonium ion precursor **159**. Diazotization of **159** and loss of N_2 following gentle warming gave a 65% yield of oxonium ion **160** and the structure was verified by single crystal x-ray crystallography (**Scheme 2.15**).



Scheme 2.15: Synthesis of 4-nitrophenyldibenzofuranium ion **160** and structural characterisation by single crystal x-ray crystallography.

2.3.2 Aryne Generation and Reaction Optimisation

To evaluate the ability of the triaryloxonium ions to produce arynes, we subjected a mixture of furan and oxonium ion **160** in MeCN to a range of mild bases and measured the yield of [4+2] cycloadduct **161** by ^{1}H qNMR spectroscopy.[67] Heterogeneous inorganic bases K_3PO_4 and K_2CO_3 gave quantitative yields of cycloadduct **161**, while using KOAc gave a slightly lower product yield after 5 h. $NaHCO_3$ was unable to generate the aryne and oxonium ion **160** was fully recovered. DIPEA gave a complex mixture of products with limited formation of [4+2] cycloadduct **161** whereas 2,6-lutidine was not basic enough to eliminate the dibenzofuran moiety to form the aryne leading to full recovery of **160** (**Scheme 2.16**).



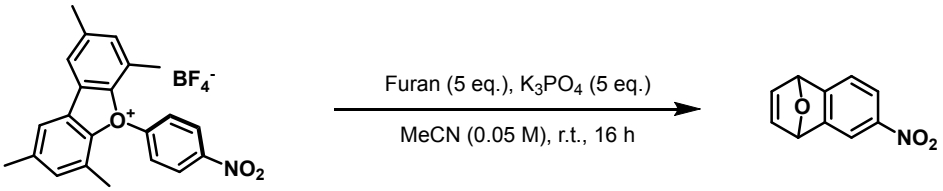
160 **161** Quant.

Entry	Deviation from the standard conditions	Yield (%)[a]
1	K_2CO_3 instead of K_3PO_4	Quant.
2	KOAc instead of K_3PO_4	83%[b]
3	$NaHCO_3$ instead of K_3PO_4	N.R.
4	DIPEA instead of K_3PO_4	25%[c]
5	2,6-lutidine instead of K_3PO_4	N.R.

Scheme 2.16: Optimisation of the aryne generation conditions on a 0.03 mmol scale. [a]By ^{1}H qNMR using CH_2Br_2 (0.015 mmol) as an internal standard. [b]16% remaining **160**. [c]25% remaining **160**.

With effective conditions for the formation of [4+2] cycloadduct **161** obtained from the initial screen, K_3PO_4 was selected for further reaction development rather than K_2CO_3 as we envisaged that the rate of aryne generation could be reduced when the 4-NO_2 group was exchanged for an electron donating group and we wanted to minimise any potential rate reduction by using the stronger base.

In moving from a 0.03 mmol scale to a 0.3 mmol scale, it was found that in order to maintain the high yield a few modifications were required. Firstly, the reaction concentration was reduced to 0.05 M to ensure complete dissolution of **160** at the start of the reaction. Secondly, the number of equivalents of base was increased to five to speed up the reaction. Finally, the reaction time was increased to 16 h to ensure full conversion. These modified conditions were successfully applied to a 1 mmol scale reaction (**Scheme 2.17**).



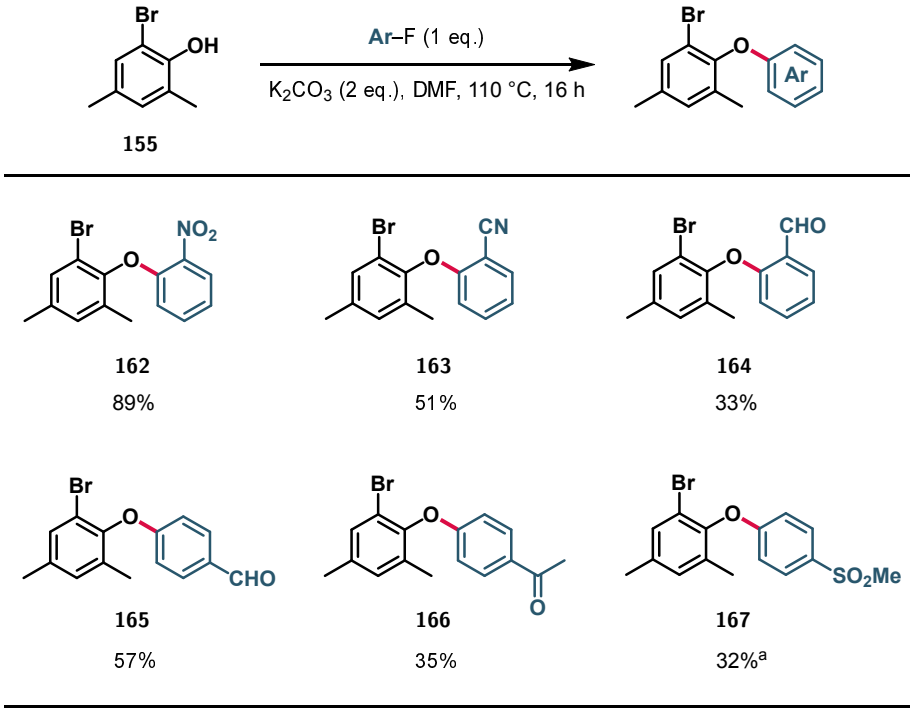
160 **161**
97% (0.30 mmol)
99% (1.00 mmol)

Scheme 2.17: Final conditions selected for substrate scope studies.

2.3.3 Scope Synthesis

To explore the scope of the reaction with respect to arene substitution, a library of oxonium ions were generated using the route detailed in **Section 2.3.1** starting from substituted bromo diaryl ethers.

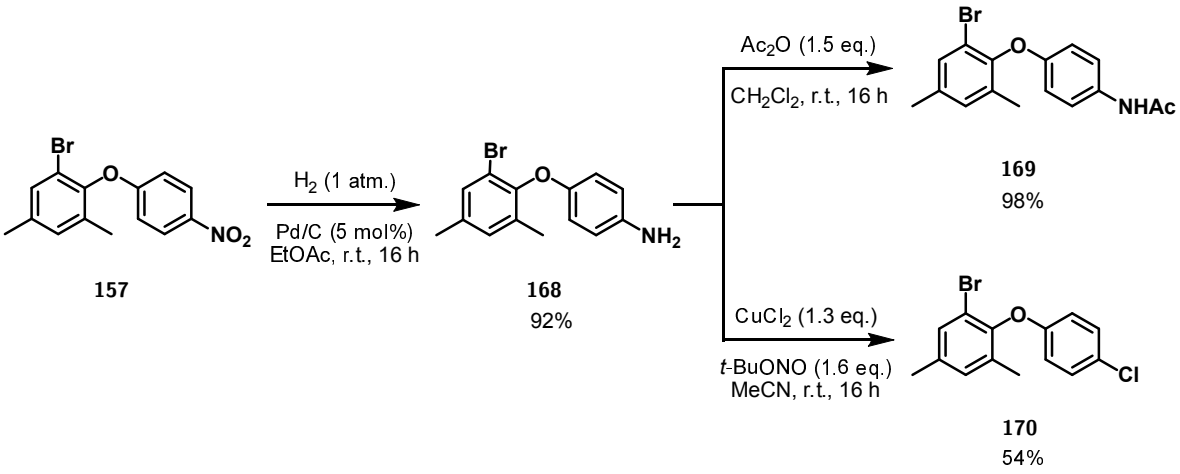
The S_NAr reaction of **155** with a range of aryl fluorides gave 2-nitro diaryl ether **162** in very good yield while more modest results were obtained for diaryl ethers **163**−**167**. 4-SO_2Me diaryl ether **167** was inseparable from the aryl fluoride precursor and could only be obtained as a 2:1 mixture containing 32% of the desired product by mass (**Scheme 2.18**).



Scheme 2.18: Diaryl ether scope from S_NAr of aryl fluoride with **155**. [a]Isolated as a 1:2 mixture of **167**:aryl fluoride

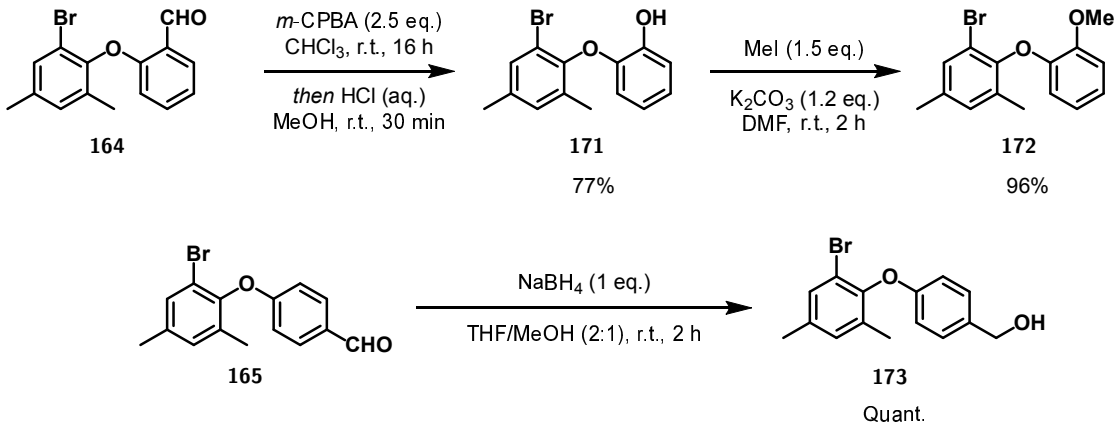
Despite the moderate yields obtained for a number of the transformations, no synthetic bottleneck was encountered as all reactions were easily scaled to greater than 5 mmol which provided ample material to complete the synthetic route to the corresponding oxonium ions.

While the S_NAr reaction requires electron withdrawing groups on the arene, the products can be derivatized to install both electron donating and neutral groups. 4-Nitro substrate **157** was hydrogenated to aniline **168** which could be acetylated or chlorinated[69] to give **169** and **170** respectively (**Scheme 2.19**).



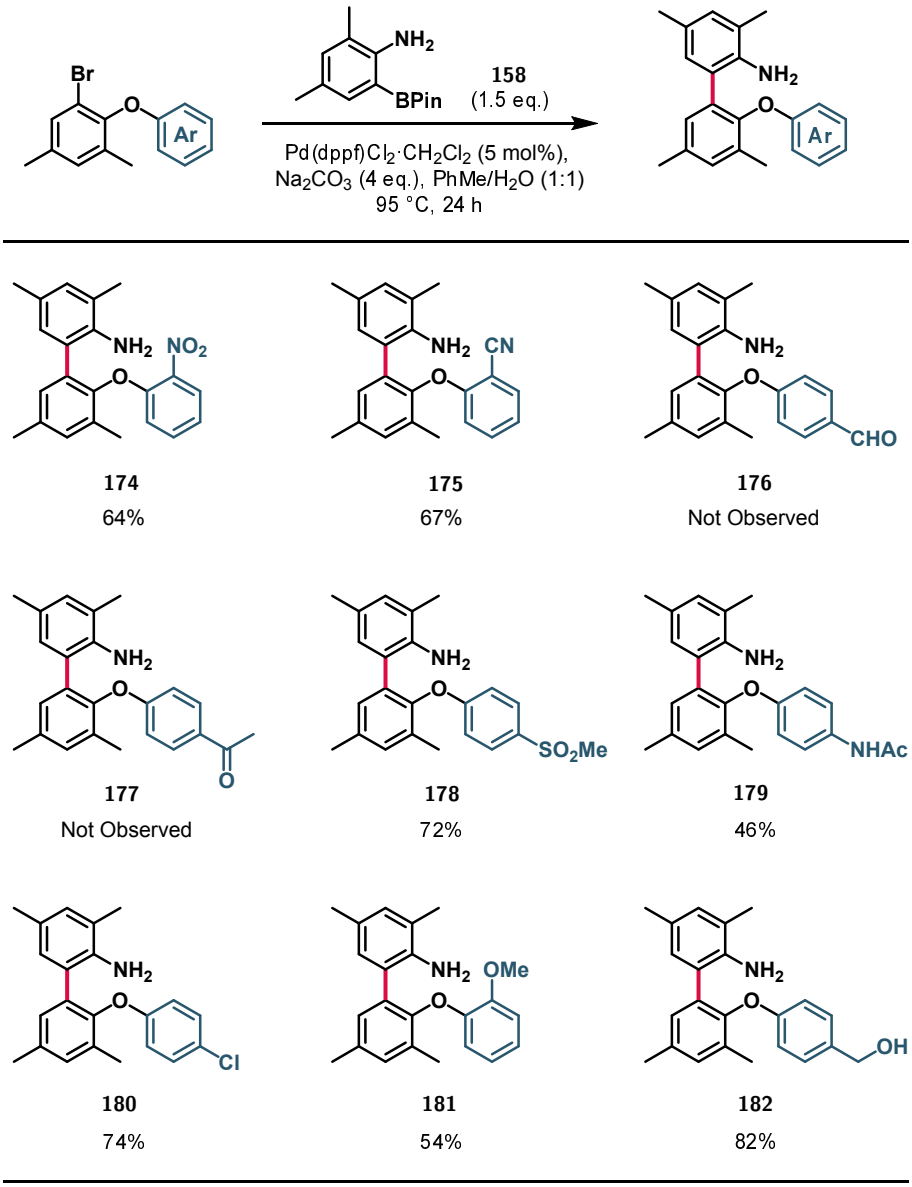
Scheme 2.19: Derivatization of **157** to give amide and chloride substituted intermediates **169** and **170**.

Baeyer-Villiger oxidation of 2-formyl intermediate **164** followed by *in situ* hydrolysis of the intermediate formate ester gave phenol **171**.[70] Methylation of **171** to give **172** proceeded in excellent yield. Furthermore, borohydride reduction of **165** gave free alcohol substrate **173** in quantitative yield (**Scheme 2.20**).



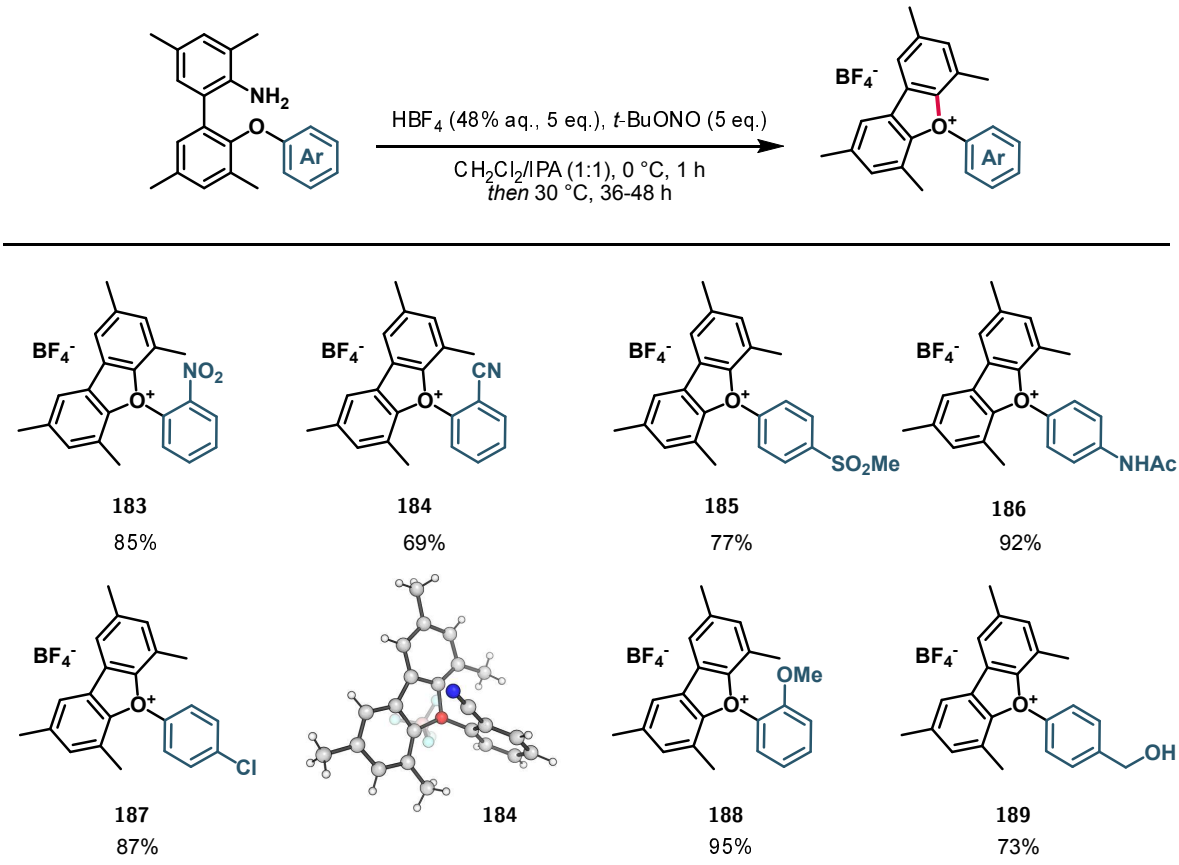
Scheme 2.20: Derivitization of aldehydes to give -OMe substituted **172** and benzylic alcohol substrate **173**.

As before, Suzuki cross coupling of the bromo diaryl ether intermediates with aryl BPin **158** gave the desired biaryl anilines in moderate to good yields for most substitution patterns; however, we were unable to isolate **176** and **177** from the reaction mixture. Anilines are known to condense with aryl aldehydes and ketones to form aldimines[37] and we envisage that the failure of these reactions could be attributed to the formation of polymeric condensation products (**Scheme 2.21**).



Scheme 2.21: Application of cross coupling conditions to a wide range of aryl bromides.

For all biaryl anilines synthesized, diazotization and gentle warming gave the desired oxonium ions in good yields. This process can be monitored by ^{1}H NMR as the four methyl resonances of the biaryl diazonium salt are gradually replaced by two methyl resonances for the symmetrical 2,4,6,8-tetramethyldibenzofuran moiety (see **Section 4.6.4** for more details). The characteristic broad IR band between 1100 and 1000 cm^{-1} is observed for all of the oxonium ions and the structure of 2-cyano substituted oxonium ion **184** was confirmed by x-ray crystallography (**Scheme 2.22**).

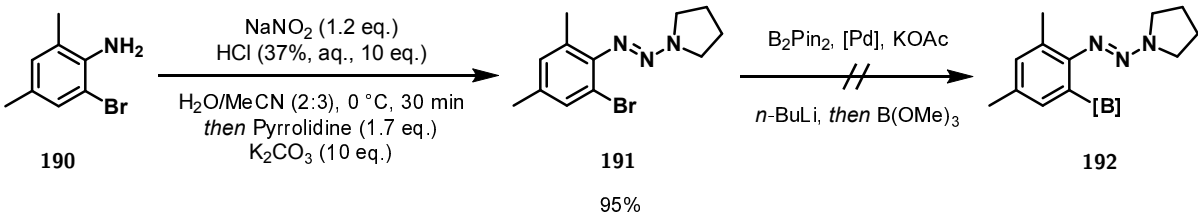


Scheme 2.22: Diazotization and ring closure to give oxonium ions **183**-**189** and single crystal x-ray structure of 2-cyano substituted oxonium ion **184**.

2.3.4 Aniline Intolerant Substrates

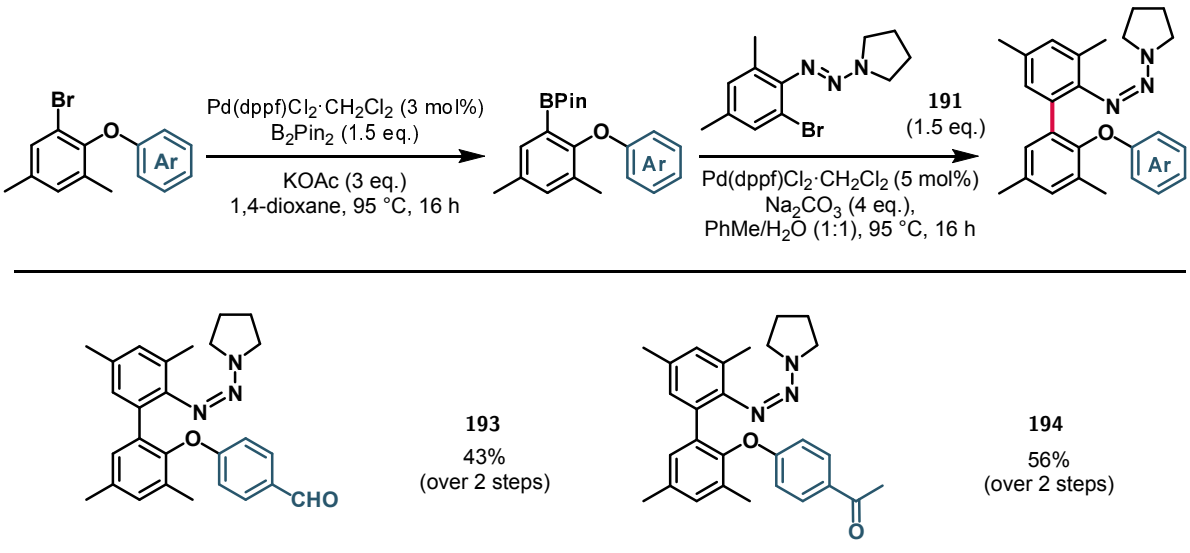
The condensation of aniline **158** with aldehyde and ketone intermediates **165** and **166** was proposed to be responsible for preventing the formation of the desired biaryl aniline oxonium ion precursors **176** and **177** respectively. We envisaged that switching the Suzuki cross coupling partner to a masked diazonium salt, such as a triazene, would allow the cross coupling to proceed as the diazonium salt formed would not react with the aldehyde or ketone moieties.

Diazotization of 2-bromo-4,6-dimethylaniline, **190**, and subsequent formation of triazene **191** upon the addition of pyrrolidine proceeded smoothly.[71] However, attempts to form the BPin/boronic acid **192** from **191** only resulted in decomposition of the material (**Scheme 2.23**).



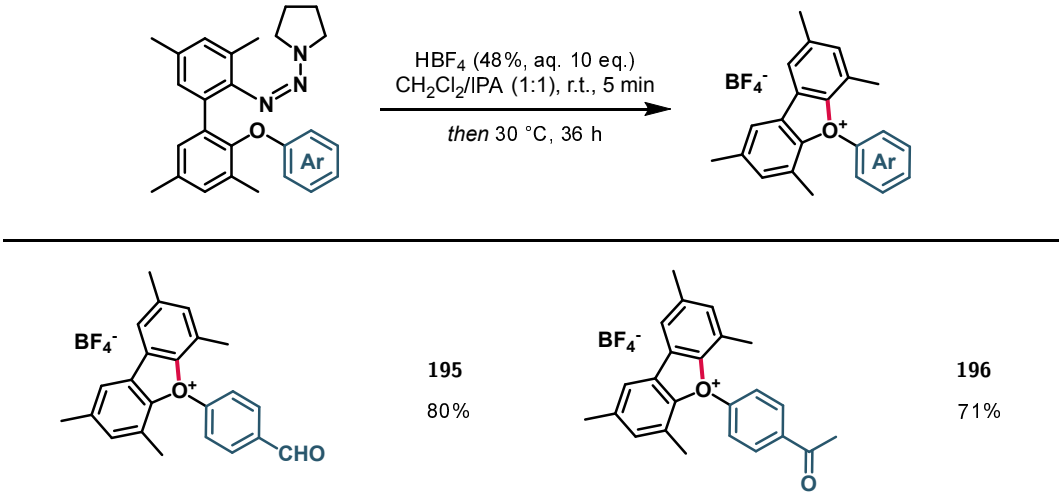
Scheme 2.23: Formation of aryl triazene **191** and unsuccessful borylation conditions.

As we were unable to synthesize the borylated triazene, **192**, we switched the order of synthetic steps. Bromo diaryl ethers **165** and **166** underwent Miyaura borylation[68] followed by a Suzuki cross coupling with **191** to give the desired triazenes **193** and **194** in good yields (**Scheme 2.24**).



Scheme 2.24: Formation of biaryl triazenes **193** and **194**.

The triazenes, **193** and **194**, released the diazonium salt upon washing with aqueous HBF_4; gentle warming gave the desired oxonium ions **195** and **196** in good yields (**Scheme 2.25**).

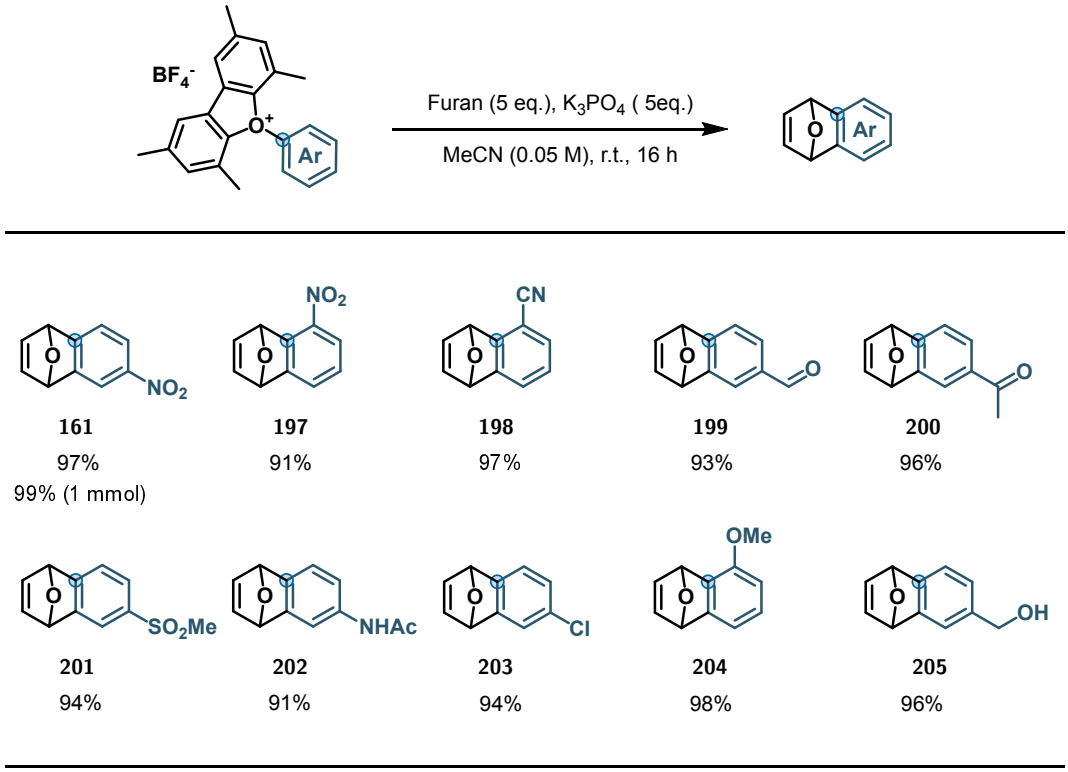


Scheme 2.25: Formation of oxonium ions **195** and **196** from biaryl triazenes.

2.3.5 Scope Overview

Having secured an efficient synthesis of the oxonium ions, we then subjected the oxonium ions to the optimised reaction conditions for aryne generation and they all gave the desired furan [4+2] adduct in excellent yields. We were pleased that nitro substrates **160** and **183**, corresponding to cycloadducts **161** and **197** respectively, were well tolerated as the *o*-trimethylsilyltriflate precursor that would generate 1-nitrobenzyne undergoes a thia-Fries rearrangement.[72] The use of weaker heterogeneous inorganic bases gives significant advantages over previous methods as it avoids deprotonation of OH, NH and enolisable/acidic functional groups allowing the formation of **205**, **202**, **200** and **201** [4+2] cycloadducts respectively in excellent yields. The synthetic route also allows for these groups and carbonyl groups to be

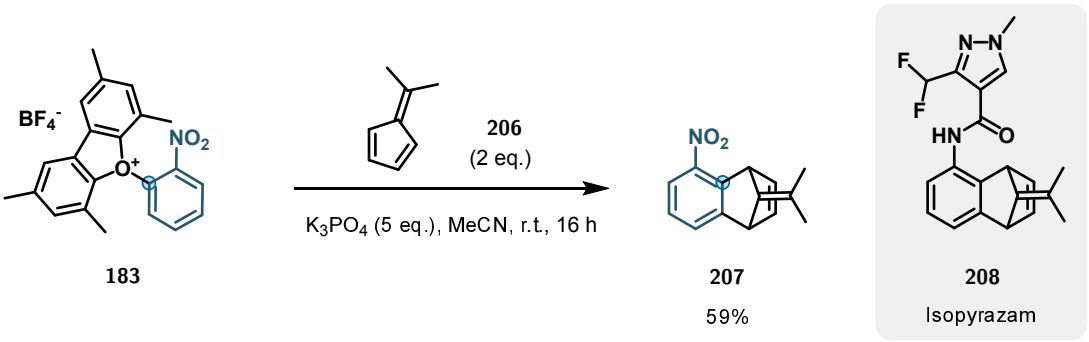
carried through the synthesis without protection (**Scheme 2.26**).



Scheme 2.26: Scope of [4+2] cycloadducts of oxonium-generated arynes and furan on a 0.30 mmol scale.

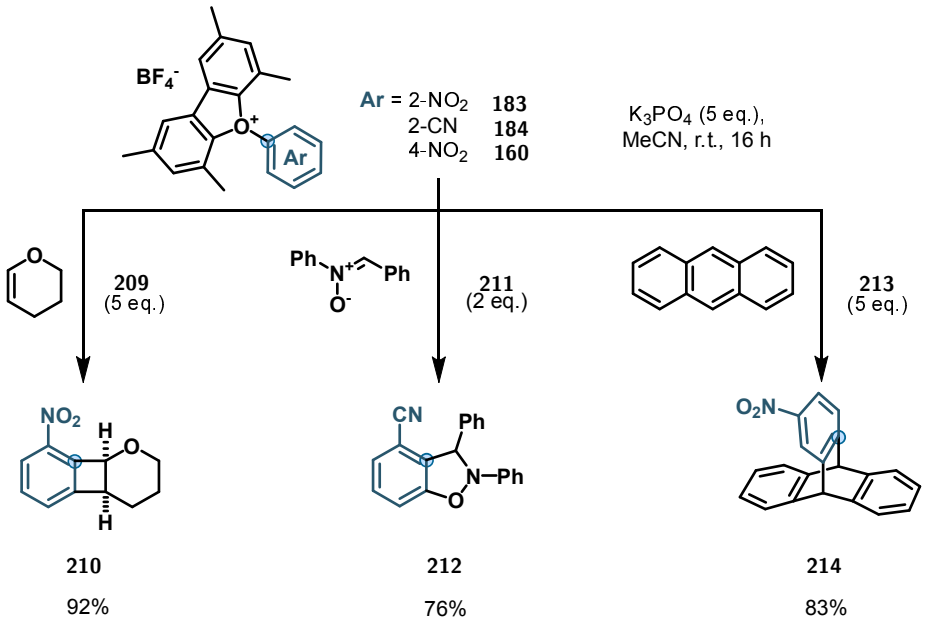
2.4 Aryne Reaction Compatability

Having found suitable conditions for the generation of a wide variety of arynes, we next sought to investigate the compatibility of oxonium ion generated arynes with a range of known arynophiles for arynes formed from anthranilic acids, HDDA precursors or *o*-trimethylsilyltriflates. 1-Nitrobenzyne, generated from the substituted anthranilic acid, reacts with 6,6-dimethylfulvene, **206**, to give **207**; a key precursor in the synthesis of anti-fungal agent Isopyrazam, **208**.[55] Pleasingly, comparable yields could be obtained using **183** making this a safer alternative for small scale synthesis of similar compounds (**Scheme 2.27**).



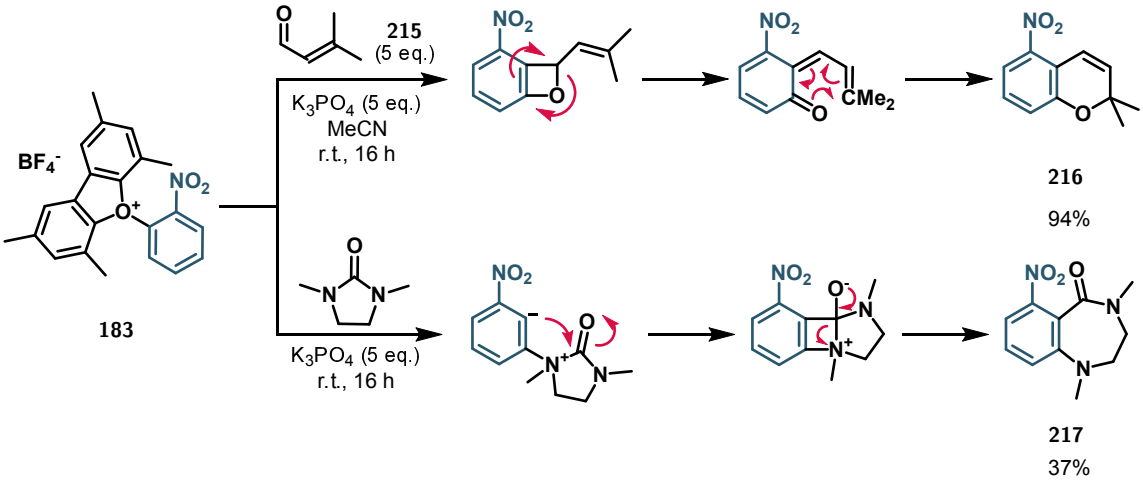
Scheme 2.27: Synthesis of Isopyrazam precursor **207** using triaryloxonium ion generated arynes.

Next, oxonium ions **183** and **184** underwent formal [2+2] and [3+2] cycloadditions respectively with 3,4-dihydro-2*H*-pyran, **209**,[73] and nitrone **211**[74] to give **210** and **212** in good yields. The regioselectivity of previously unknown products **210** and **211** was determined by a ^{3}J ^{1}H-^{13}C HMBC correlation between a C-H resonance on the arynophile moiety and the quaternary carbon bearing the NO_2 or CN groups. [4+2] Cycloaddition of the aryne generated from **160** with anthracene gave triptycene **214** in 83% yield which is significantly higher than the 36% reported previously using the diazotized anthranilic acid method (**Scheme 2.28**).[75]



Scheme 2.28: Examples of cycloadditions that are compatible with triaryloxonium ion generated arynes.

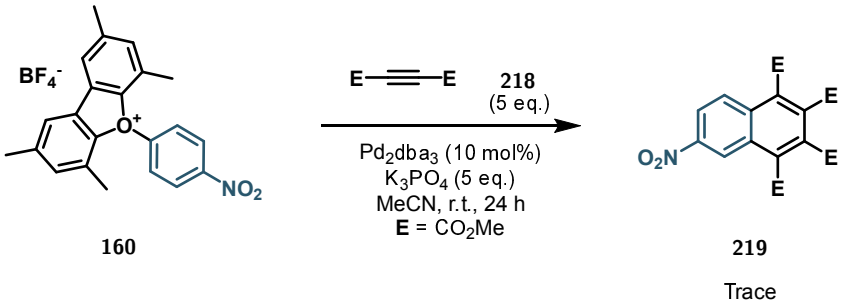
Starting from oxonium ion **183**, 3-methyl-2-butenal, **215**, underwent a formal [2+2] cycloaddition followed by a 4π electrocyclic ring opening and 6π electrocyclic ring closure to give **216**.[61] Carrying out the reaction in DMI[76] rather than MeCN gave ring expansion product **217** in moderate yields. The regiochemistry of **216** was determined by a ^{3}J ^{1}H-^{13}C HMBC correlation between the alkenyl C-H and the quaternary carbon bearing the NO_2 group. For **217**, a ^{3}J ^{1}H-^{13}C HMBC correlation is observed between the NMe group and the quaternary carbon *meta*- to the nitro group (**Scheme 2.29**).



Scheme 2.29: Rearrangement and ring expansion reactions performed by oxonium ion generated arynes.

While the triaryloxonium ions were compatible with a wide range of arynophiles, they were reactive towards strong nucleophiles such as morpholine. ^{1}H NMR analysis of a mixture of excess morpholine and oxonium ion **160** showed consumption of **160** but limited 2,4,6,8-tetramethyldibenzofuran formation indicating that substitution was occurring at the dibenzofuran moiety rather than forming the aryne. We also attempted a phosphine free Pd-catalysed aryne/alkyne trimerisation;[77] however,

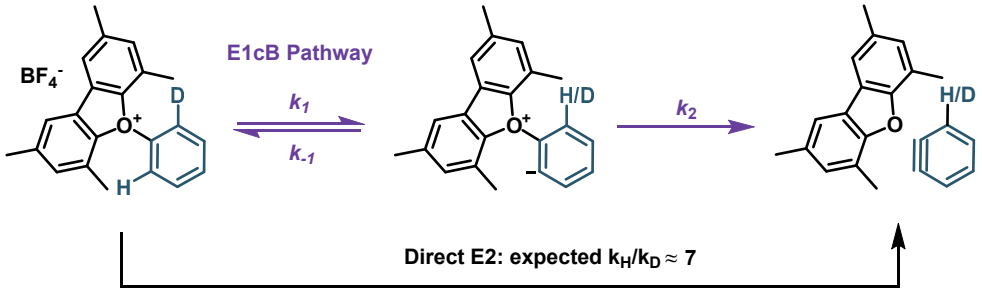
this failed to give more than trace yields of **219**. This may have arisen from the aryne reacting in solution before it could bind to a metal centre (**Scheme 2.30**).



Scheme 2.30: Attempted reaction of oxonium ion generated arynes in metal catalysed aryne/alkyne trimerisation.

2.5 Kinetic Isotope Effect Study

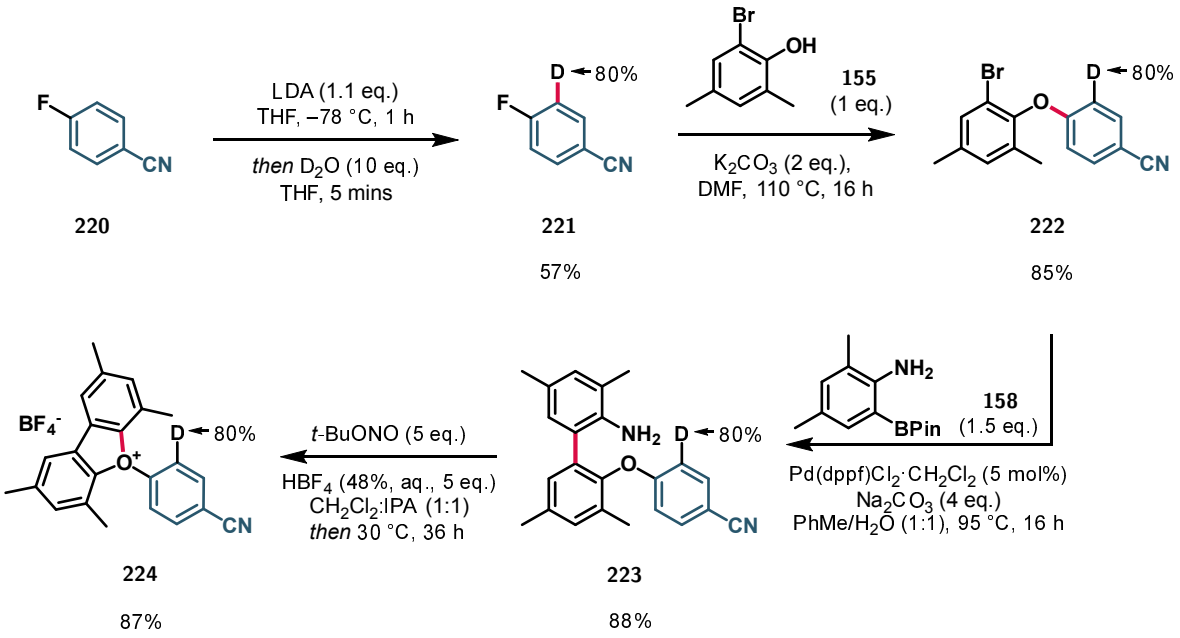
With the knowledge that no reaction occurred in the absence of base, we wanted to elucidate whether the reaction was proceeding *via* an E2 or E1cB pathway using a kinetic isotope effect (KIE) measurement. A large primary kinetic isotope effect of approximately 7 would be expected for an E2 elimination pathway at room temperature; however, an E1cB mechanism would give a lower, hybrid KIE depending on the rate of the reprotonation, k_{-1}. We envisaged that an intramolecular H/D competition experiment would be the best method to assess the kinetic isotope effect as it could be obtained by comparing the H/D ratio in the reaction product. Therefore, we sought to prepare an oxonium ion containing a phenyl ring bearing one *o*-C-H and one *o*-C-D bond (**Scheme 2.31**).



Scheme 2.31: Proposal to use an intramolecular competition KIE experiment to elucidate the mechanism for the elimination of triaryloxonoium ions to form arynes.

2.5.1 Synthetic Route

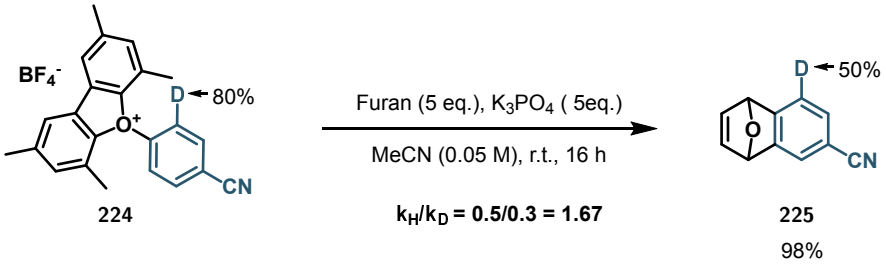
o-Lithiation of 4-fluorobenzonitrile, **220**, using LDA and subsequent trapping with electrophiles such as DMF has previously been reported[78] and substituting the electrophile for D_2O gave monodeuteurated aryl fluoride **221** in moderate yield. The presence of the -CN moiety facilitated the S_NAr reaction with 2-bromo-4,6-dimethylphenol, **155**, to give diaryl ether **222**. Suzuki cross coupling with **158** gave biaryl aniline **223** which gave oxonium ion **224** after diazotization and loss of nitrogen. ^1H qNMR analysis of **221**−**224** showed that the initial deuterium incorporation of 80% was maintained throughout the synthesis (**Scheme 2.32**).



Scheme 2.32: Synthesis of deuterated oxonium ion, **224**, for an intramolecular competition KIE experiment.

2.5.2 Intramolecular Competition Experiment

Subjecting deuterated oxonium ion **224** to the optimised reaction conditions with furan gave the desired [4+2] adduct in 98% yield. Analysis of the ^{1}H qNMR spectrum indicated that **225** retained 50% deuterium incorporation giving a small kinetic isotope effect of 1.67 (**Scheme 2.33**).



Scheme 2.33: Intramolecular competition KIE experiment of **224** gives a small k_H/k_D of 1.67.

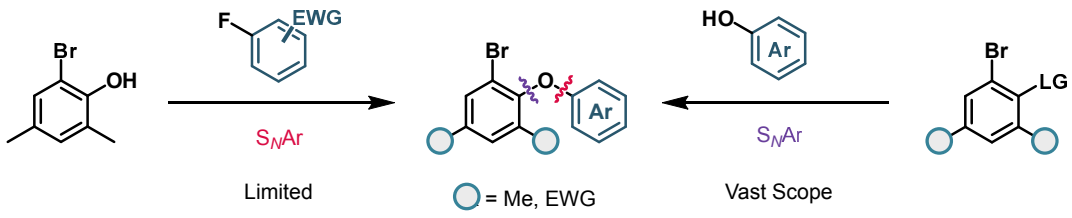
The small observed KIE indicates that the reaction likely proceeds *via* an E1cB mechanism. Preliminary computational studies carried out by our collaborators

support this hypothesis and further deuterium labelling experiments are being designed to confirm this hypothesis by looking for H/D exchange at the C-H/D bonds adjacent to the oxonium ion.

2.6 Phenols as Aryne Precursors

Despite the initial success of the synthesis of oxonium ions generated using S_NAr coupling with 2-bromo-4,6-dimethylphenol, the substrate scope was limited to electron withdrawing groups at the 2- and/or 4-position to facilitate the S_NAr reaction (see **Scheme 2.18**).

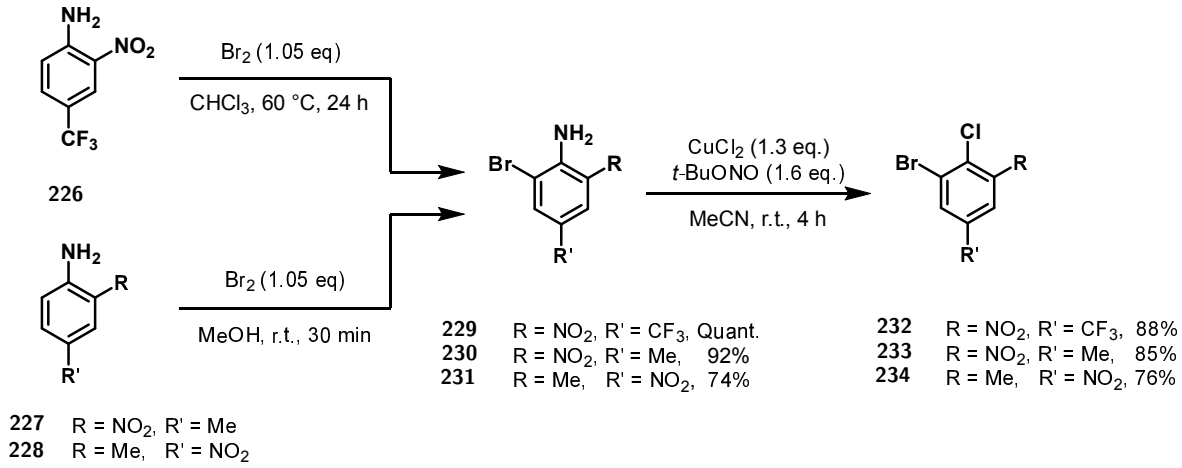
We reasoned that by swapping the functional groups on the coupling partners we could begin to utilise phenols as aryne precursors thereby greatly enhancing the substrate scope of the reaction. To translate this concept into practice, we envisaged retaining the basic scaffold while introducing an electron withdrawing group and a leaving group to facilitate the S_NAr reaction with substituted phenols (**Scheme 2.34**).



Scheme 2.34: Route modification to allow an extended substrate scope

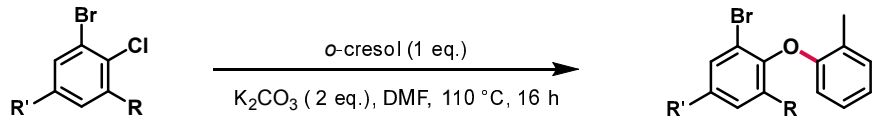
2.6.1 Initial Synthetic Studies

Previously, the S_NAr reaction of 2-bromo-4,6-dimethylphenol, **155**, with 2- and 4-NO_2 fluoroarenes proceeded in excellent yields. Using this knowledge, three potential precursors, **232**−**234**, were synthesized in good yields from cheap and readily available anilines **226**−**228** *via* bromination and subsequent copper-mediated chlorination of the *in situ* generated diazonium ion.[69] Bromination of **226** required more forcing conditions due to the presence of an extra electron withdrawing group (**Scheme 2.35**).



Scheme 2.35: Synthesis of potential triaryloxonium ion precursors.

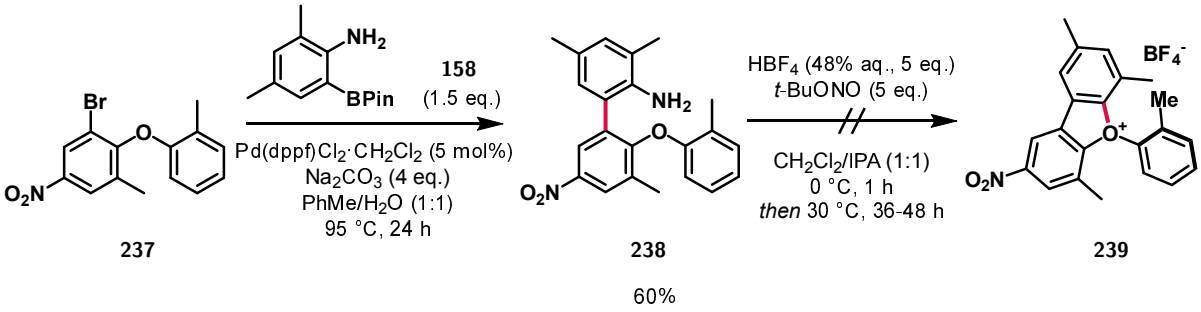
To evaluate the effectiveness of each precursor as an S_NAr electrophile, we reacted them with *o*-cresol, under identical reaction conditions to those used previously for the formation of diaryl ethers in **Scheme 2.18**, and were pleased to observe moderate to very good yields for all precursors. 4-Nitrochlorobenzene derivative **234** gave the highest yields of the desired diaryl ether and was taken forwards in the synthesis (**Scheme 2.36**).



232	R = NO_2, R' = CF_3	**235**	R = NO_2, R' = CF_3, 43%
233	R = NO_2, R' = Me	**236**	R = NO_2, R' = Me, 60%
234	R = Me, R' = NO_2	**237**	R = Me, R' = NO_2, 87%

Scheme 2.36: Evaluation of the S_NAr reaction of *o*-cresol with prospective synthetic starting materials.

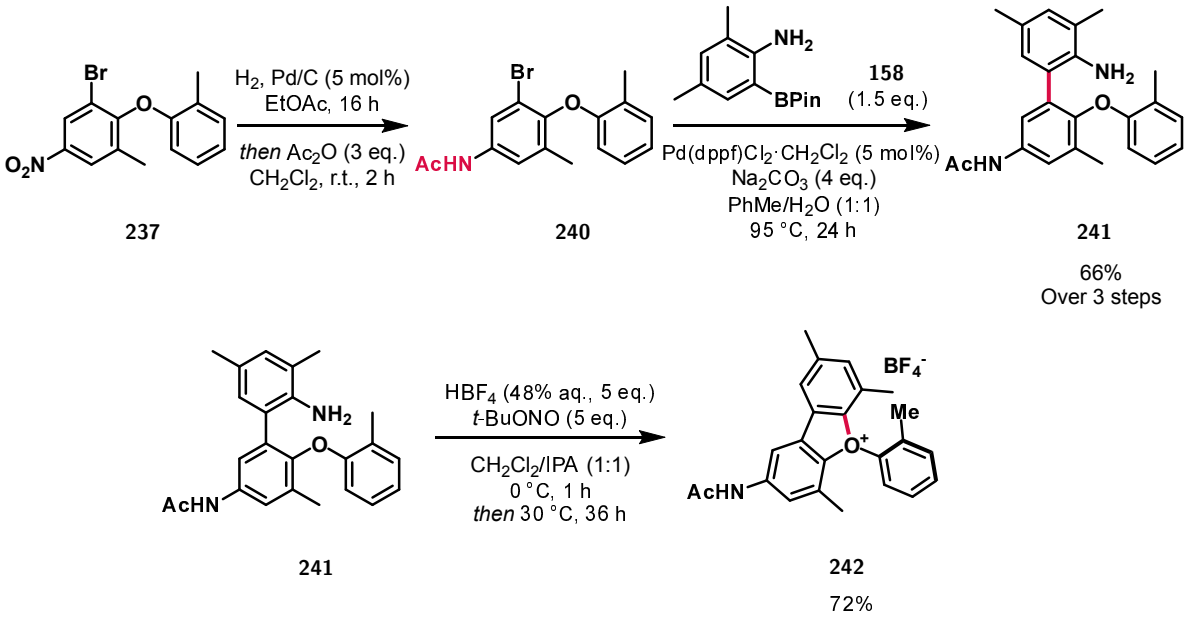
Suzuki cross coupling of bromide **237** with BPin aniline **158** proceeded in good yield to give biaryl ether **238**; however, despite the successful diazotization of **238**, oxonium ion formation was not observed and only decomposition was observed by ^{1}H NMR (**Scheme 2.37**).



Scheme 2.37: Initial attempt to form triaryloxonium ions from phenols.

We believed that the presence of the nitro group could have slowed the rate of ring closure to form the oxonium ion due to conjugation with the oxygen lone pair thereby making it less available to displace N_2 and allowing diazonium salt decomposition pathways to dominate. Therefore, we investigated the effects of derivitizing this group into a moderately electron donating amide moiety. Hydrogenation, acetylation and Suzuki cross coupling of the amide substituted biaryl ether **240** with **158** gave the desired oxonium precursor in good yields over the 3 steps. Diazotization of **241** and loss of nitrogen gave desired oxonium ion **242** in good yield. Significant changes

in the ^{1}H NMR spectrum were observed upon the formation of **242** (see **Section 4.6.5** for more details) and the characteristic broad C-O Ir band at 1000 cm^{-1} was also observed (**Scheme 2.38**).

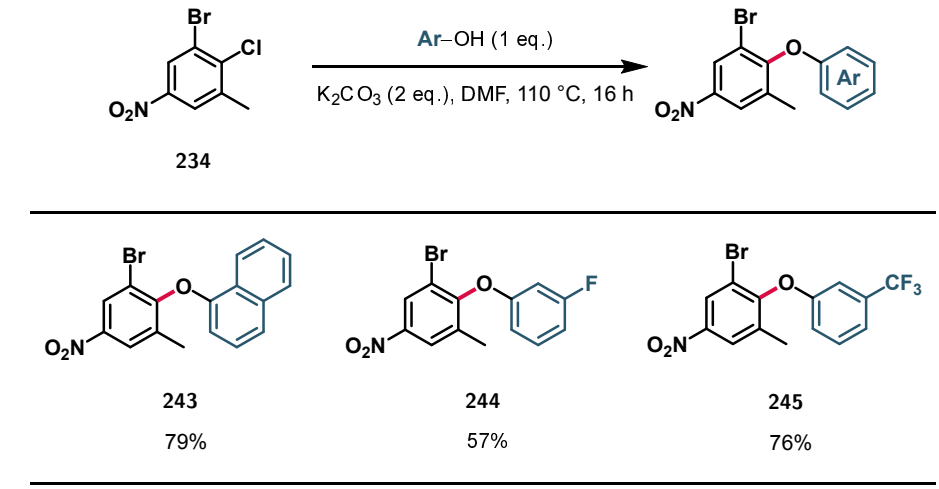


Scheme 2.38: Synthetic route for the formation of phenol derived oxonium ions.

2.6.2 Scope Synthesis

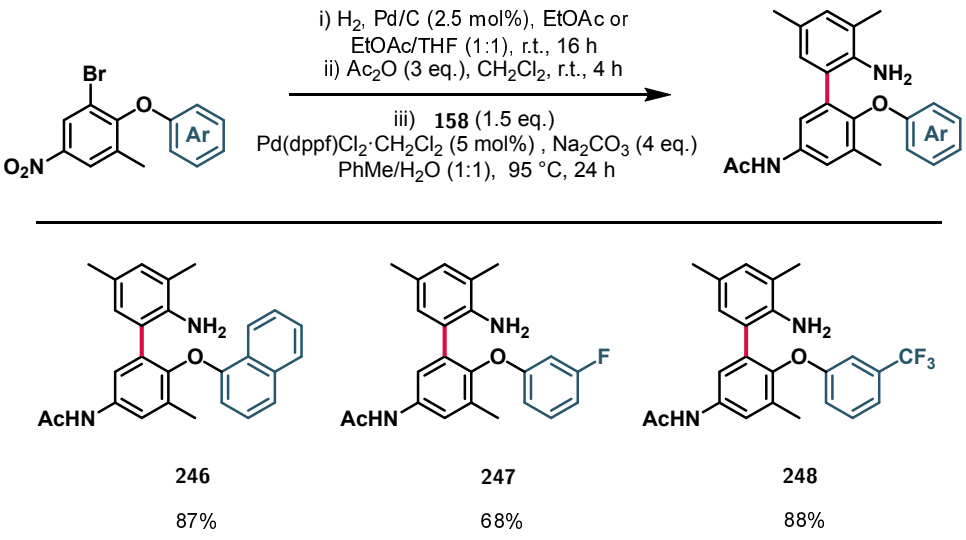
We reasoned that it would be important to demonstrate that this method of converting phenols into oxonium ions could allow access to substrates that would be challenging to synthesize *via* the original S_NAr route described earlier such as *m*-substitution and arenes that do not bear electron withdrawing groups.

1-Napthol, 3-fluorophenol and 3-trifluoromethylphenol all gave good yields of bromo diaryl ethers **243**, **244** and **245** respectively on reaction with **234**. The volatility of 3-fluorophenol was suspected to have caused the reduced yield compared to the other examples (**Scheme 2.39**).



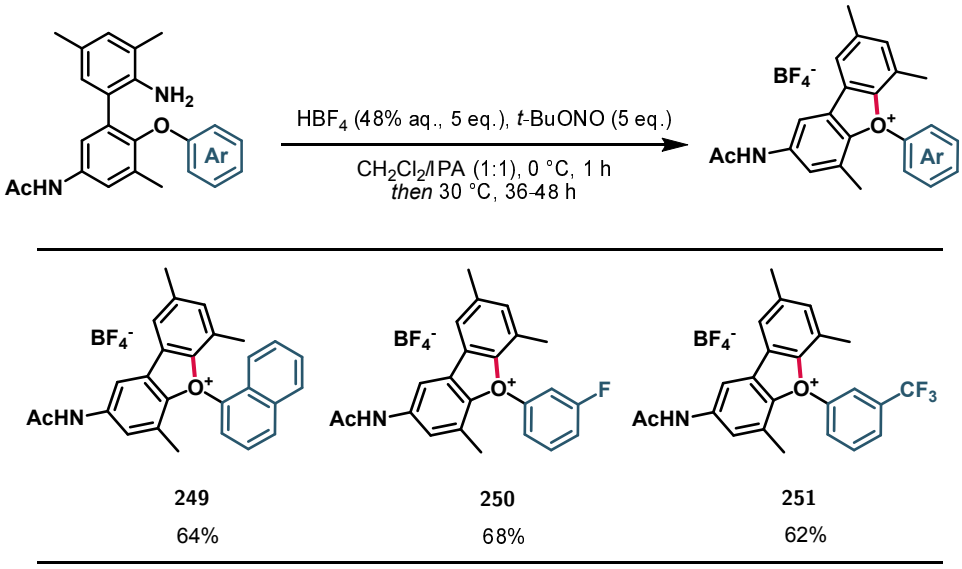
Scheme 2.39: Initial scope of phenol derived bromo diaryl ethers.

Hydrogenation, acetylation and cross coupling with **158** gave the biaryl aniline oxonium ion precursors **246**−**248** in good yields over 3 steps (**Scheme 2.40**).



Scheme 2.40: Initial scope of phenol derived biaryl anilines.

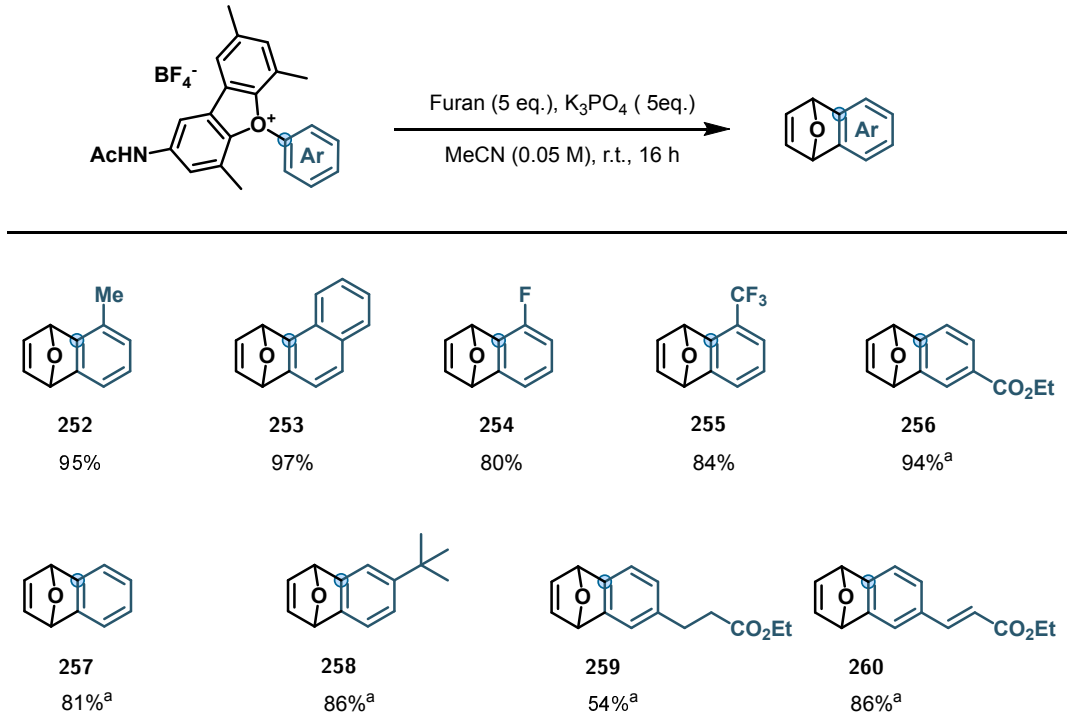
Diazotization of biaryl anilines **246**−**248** and gentle warming of the solutions of the resulting diazonium salts gave the desired oxonium ions **249**−**251** in good yields (**Scheme 2.41**).



Scheme 2.41: Scope of phenol derived triaryloxonium ions.

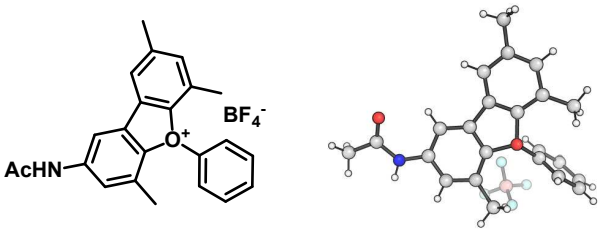
Subjecting the oxonium ions, **242** and **249-251** to the optimised reaction conditions for aryne formation in the presence of furan yielded the desired [4+2] cycloadducts in very good to excellent yields. For oxonium ions **250** and **251**, two possible regioisomeric arynes can be generated; however, for both **250** and **251** only one of the potential regioisomeric cycloadducts was observed (**254** and **255** respectively). We propose that this is due to inductive withdrawal of electron density by the F- and CF_3- groups which acidifies the C-H bonds adjacent to them resulting in more facile deprotonation at this site. Madeleine Hindson (DPhil Student) joined the project and completed the synthetic routes to the oxonium ions and subsequent trapping reactions for **256-260**. She further demonstrated the broad applicability of the method to enolisable/sensitive product functionality (**259** and **260**) and showed

that the *t*-Bu substituted oxonium ion is sterically hindered enough to give selective C-H deprotonation product **258** (**Scheme 2.42**).



Scheme 2.42: Scope of the [4+2] reaction of furan with oxonium derived arynes. [a]Oxonium ion synthesis and [4+2] reaction conducted by Madeleine Hindson.

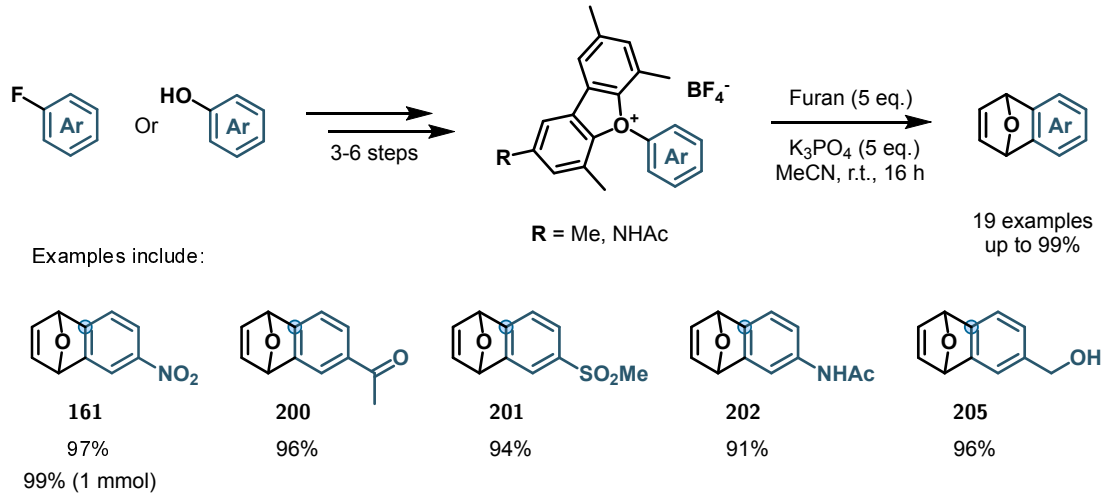
Madeleine Hindson crystallised triaryloxonium ion **261**, precursor to **257**, and the structure was confirmed by x-ray crystallography (**Scheme 2.43**).



Scheme 2.43: Confirmation of the structure of **261** by single crystal x-ray crystallography. Oxonium ion synthesized and sample prepared by Madeleine Hindson.

2.7 Conclusion

We have developed two modular routes to triaryloxonium ions, based on a dibenzofuranium scaffold, starting from fluorinated arenes and phenols respectively. This has allowed us access to triaryloxonium ions where the pendant arene can bear a wide array of functional groups in a variety of substitution patterns. These triaryloxonium ions react with mild heterogenous inorganic bases to produce arynes in excellent yields with excellent functional group tolerance (**Scheme 2.44**).

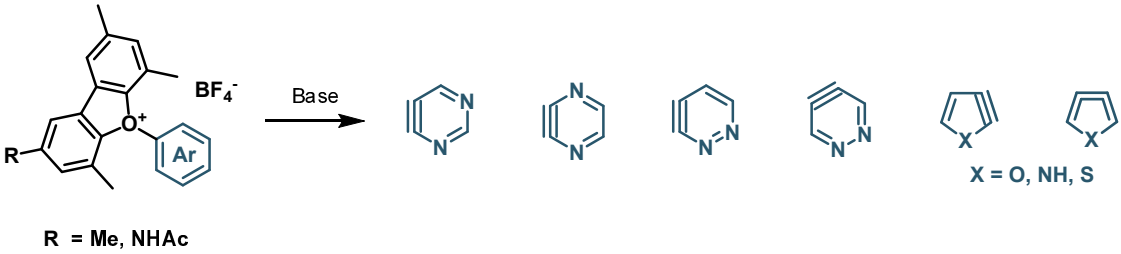


Scheme 2.44: Overview of the method used to generate arynes from triaryloxonium ions and selected examples of successful substrates.

2.8 Future Work

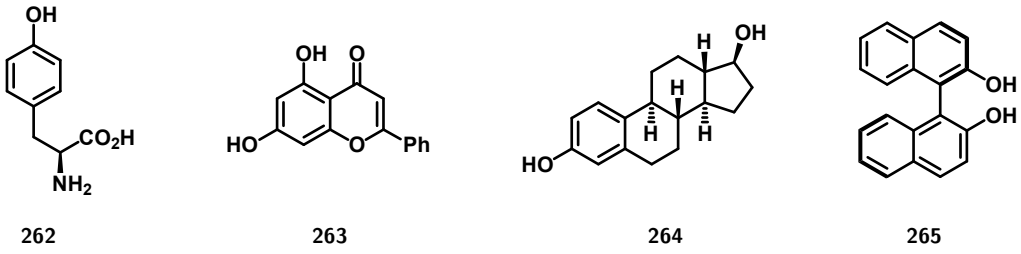
Due to the success of being able to generate arynes under mild conditions and the excellent leaving group ability of oxonium ions, we envisage that it will be possible to form highly strained arynes using triaryloxonium ion chemistry. Currently, there are very few methods to produce heterocyclic arynes derived from pyrimidine,[79]

pyrazine, pyridazine, furan, pyrrole and thiophene.[80] Furthermore, the methods for generating these arynes involve toxic/explosive reagents or are low yielding making them excellent targets to explore the extent that triaryloxonium ions can be used to generate arynes (**Scheme 2.45**).



Scheme 2.45: Examples of hetarynes that we propose can be generated using triaryloxonium ions.

Furthermore, we envisage that it would be possible to form triaryloxonium ions from phenolic natural products, such as tyrosine, chrysin and estradiol, as well as widely used scaffolds such as BINOL to allow diverse structural modification using aryne chemistry (**Scheme 2.46**).



262 **263** **264** **265**

Scheme 2.46: Examples of phenolic natural products and other scaffolds that could be transformed into triaryloxonium ions to allow structural modification using aryne chemistry.

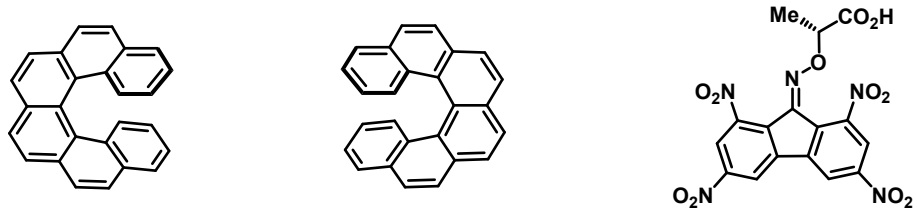
3 Chiral Triaryloxonium Ions

3.1 Introduction

Axial chirality arises when molecules possess a chiral axis. Examples include certain allenes, helicenes and atropisomers. This chapter details our work on the synthesis of helically chiral oxonium ions.

3.1.1 Helicenes

The first enantiopure helicene was obtained in 1955. Resolution of the charge transfer complex between racemic [6]helicene and (*R*)-TAPA, **268**, gave (*M*)-[6]helicene, **266**. In helicenes, steric hinderance of the terminal rings causes them to distort from planarity and this creates a significant energy barrier to interconversion between the two enantiomers (**Scheme 3.1**).[81]

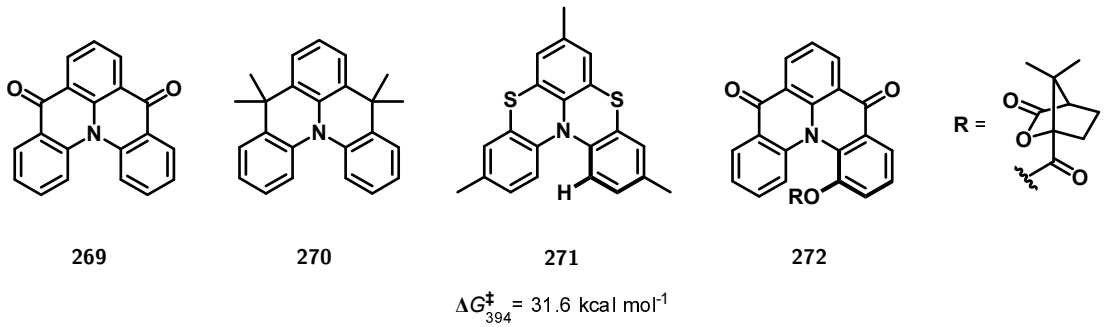


266 (*M*)-[6]Helicene | **267** (*P*)-[6]Helicene | **268** (*R*)-TAPA

Scheme 3.1: First example of the resolution of a helicene.

This allowed the measurement of the optical rotation properties of helicenes ((*M*)-[6]helicene, **266**: $[\alpha]_D^{24}$ = -3640 (c = 0.099, $CHCl_3$))[81] and galvanised further research in this field.[82]

Heterohelicenes containing an *N*-bridging atom were first synthesized by Hellwinkel in 1971 and similar methods have been used in modern synthetic routes.[83–85] These bridging helicenes have significant barriers to enantiomerisation as exemplified by *S*-linked heterohelicene **271**.[86] Furthermore, attachment of camphor derived auxiliaries allowed the chromatographic separation of enantiopure heterohelicene **272** which, upon irradiation, emits light that is 0.1% circularly polarised (**Scheme 3.2**).[87]



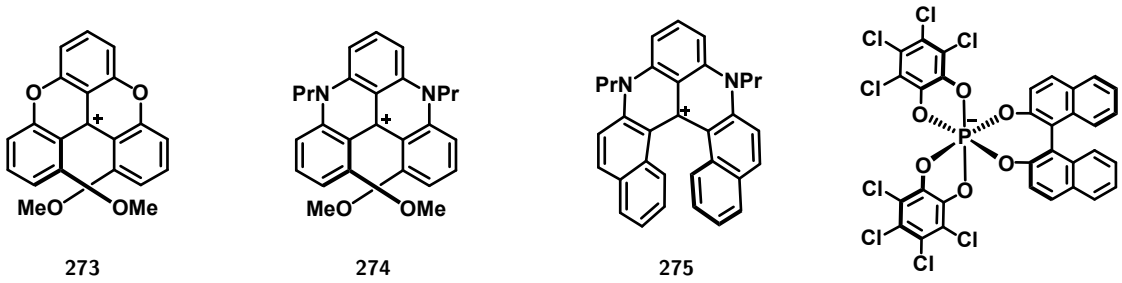
269 **270** **271** **272**

$\Delta G^{\ddagger}_{394}$ = 31.6 kcal mol^{-1}

Scheme 3.2: Range of accessible *N*-heterohelicenes with high enantiomerisation barriers and interesting optical properties.

Carbenium ion based helicenes **273**, **274** and **275** were resolved into their separate enantiomers which enabled the measurement of the high enantiomerisation barriers of this class of helicene. Resolution was achieved by chiral HPLC of the reduced form for **273**,[88] alumina chromatography for **274**[89] and for **275**, crystallisation of the (Λ, *R*)-BINPHAT salts of [4]heterohelicenium cations.[90] It was found that *O*-linkers significantly lowered the enantiomerisation barrier for **273** compared to **274**

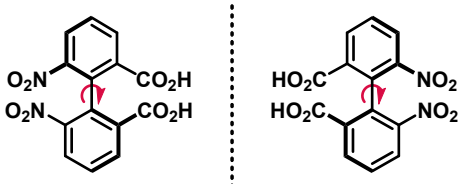
and decomposition prevented the measurement of the barrier of **275**.[88] Varying the functional groups on the naphthyl substituent of **275** allowed tuning of the visible light absorption properties (**Scheme 3.3**).[90]



Scheme 3.3: Axially chiral [4]Heterohelicenium ions and their enantiomerisation barriers.

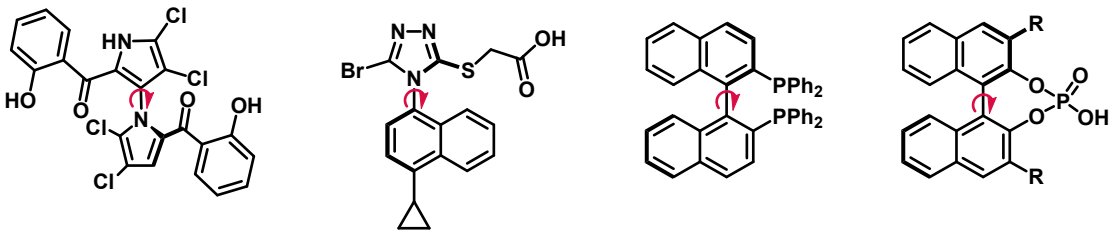
3.1.2 Atropisomerism

Atropisomers arise when restricted rotation about a single bond results in two potentially stereoisomeric conformers. Formally, the half-life of conformer interconversion must exceed 1000 s at a given temperature for a molecule to be considered atropisomeric. This corresponds to a barrier to rotation of approximately 22 kcal mol^{-1} at 298 K.[91] Christie and Kenner reported the first example of atropisomerism in 1922.[92] Restricted rotation about the biaryl axis prevents interconversion between 6,6'-dinitro-2,2'-diphenic acid conformers **276** and **277** (**Scheme 3.4**).[92]



Scheme 3.4: Restricted rotation about the biaryl axis prevents interconversion of the two enantiomers of 6,6'-dinitro-2,2'-diphenic acid.

Atropisomeric axes are present in a variety of important natural products including antibiotic vancomycin, gossypol and antibiotic and anti tumour agent marinopyrrole A, **278**.[93] Single atropisomer drug candidates often exhibit improved selectivity for protein binding; (+)-Lesinurad, **279**, is 3 x more potent in *in vivo* studies than its enantiomer[94] and it was noted that 80% of FDA approved kinase inhibitors contained an atropisomeric axis.[95] Furthermore, atropisomeric ligands such as (*R*)-BINAP, **280**,[96] and BINOL derived phosphoric acids **281** have found widespread use in enantioselective catalysis (**Scheme 3.4**).[97,98]



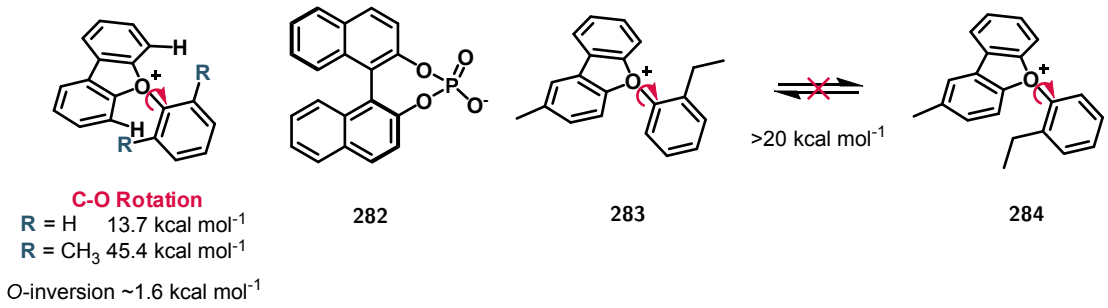
278 **279** **280** **281**

Scheme 3.5: Examples of important atropisomeric natural products, active pharmaceutical agents and catalysts for enantioselective transformations.

3.1.3 Oxonium Ion Atropisomers

Perhaps unsurprisingly, there only appears to be one report of atropisomeric oxonium ions. Siegel *et al.* calculated that, despite facile *O*-inversion, rotation about the C-O bond of dibenzofuran derived oxonium ions was large enough to give stable atropisomers when the pendant arene was substituted.[43] In the presence of BINOL phosphate, **282**, separate ^{1}H NMR resonances were observed for the two enantiomers **283** and **284**. Furthermore, EXSY analysis showed no evidence of exchange between

the enantiomers indicating that the rotational barrier is higher than 20 kcal mol^{-1} (**Scheme 3.6**).[43]



Scheme 3.6: Calculation and experimental determination of the C-O rotational barrier of substituted triaryloxonium ions.

3.1.4 Measurement of Rotation/Inversion Barriers

As detailed above, the free energy barrier to enantiomerization for helicenes and atropisomers determines whether they can be separated into enantiomers that are stable to racemization at ambient temperature. Free energy activation barriers, $\Delta G_T^{\ddagger}$, are obtained by determining the rate constant for enantiomerisation, k_{ent}, and substituting it into to the Eyring equation; for more information see **Section 4.7**.[99]

$$\Delta G_T^{\ddagger} = RTln\left(\frac{k_B T}{h k_{ent}}\right) \tag{3.1}$$

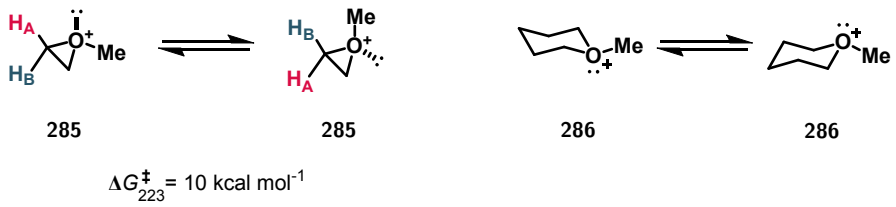
For systems with low barriers to rotation or inversion (<22 kcal mol^{-1}), k_{ent} can be obtained by finding the coalescence temperature using VT-NMR spectroscopy for simple spin systems. This is commonly used to find the rotational barriers for amides.[100–102] For more complex spin systems, NMR lineshape analysis or EXSY experiments can be used to give a value for k_{ent}.[99,103]

When barriers to rotation or inversion result in stable configurations at room temperature, the rate constant for racemisation, k_{rac}, is measured by monitoring the erosion of e.e. of enantioenriched material over time.[99] It is worth noting that $k_{rac} = 2k_{ent}$ as the transformation of one molecule of enantiomer into the other reduces the enantiomeric excess by 2 molecules.[104]

Intermediate barriers can be measured by dynamic chiral chromatography techniques such as HPLC.[99] Interconversion of the two forms results in a raised plateau between the resolved enantiomer peaks, colloquially known as the 'Batman effect'. By modulating the temperature of the stationary phase, and comparing the results to simulated chromatograms, it is possible to estimate the rate of racemisation;[105] however, the racemisation proceeds in a chiral environment and this can exert some degree of influence on k_{rac}.[99]

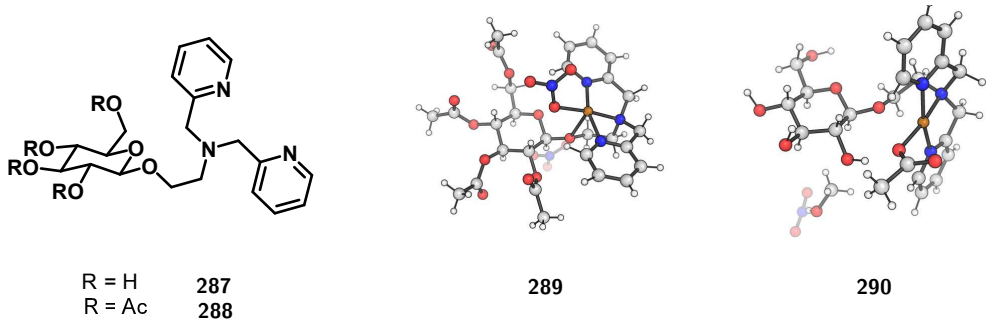
3.1.5 Point Chirality at Oxygen

Pyramidal inversion at oxygen occurs rapidly at room temperature which makes isolation of molecules containing an enantiopure oxygen stereocentre a significant challenge. Low temperature ^{1}H NMR analysis of oxirane derived oxonium ion **285** found coalescence occurred at –50 °C and separate signals were observed for H_A and H_B at –70 °C giving an approximate barrier to enantiomerization of 10 kcal mol^{-1}. No broadening or signal separation of the C-H resonance was observed for tetrahydropyran derived oxonium ion **286** at –70 °C indicating that the barrier to enantiomerization was significantly lower than for **285** (**Scheme 3.7**).[4]



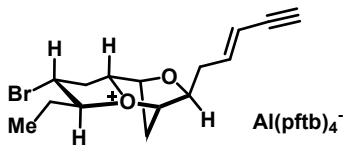
Scheme 3.7: Low temperature ^{1}H NMR analysis of oxirane oxonium ion **285** allowed the calculation of the enantiomerization barrier while no signal separation or broadening was observed for **286**.

The first explicitly discussed examples of compounds bearing characterised stereogenic oxygen atoms were reported by Mikita, Yano and co-workers; however, the authors recognised that several previously reported metal complex crystal structures with ethers, crown ethers and cryptands also possessed stereogenic oxygen atoms. Sugar derived chelating ligands **287** and **288** complexed Cu(II) ions giving metal-ether complexes **289** and **290**, respectively. The solid state structures bearing stereogenic oxygen atoms at the anomeric position were confirmed by x-ray crystallography and CD spectra indicate that the configuration was retained in solution. Addition of pyridine caused the loss of the CD signal for **289** indicating that it had displaced the ether ligand; however, the CD signal persisted for **290** (**Scheme 3.8**).[106,107]



Scheme 3.8: Examples of Cu-ether complexes where the ether oxygen is point chiral.

Burton *et al.* characterised trialkyloxonium ion **25** as an intermediate in the synthesis of *Laurencia* family natural products.[16] The fused ring system prevents *O*-inversion, giving point chirality at the oxygen centre; however, **25** is unstable above –40 °C and requires the extremely weakly coordinating Krossing's anion to stabilise it (**Scheme 3.9**).[108]



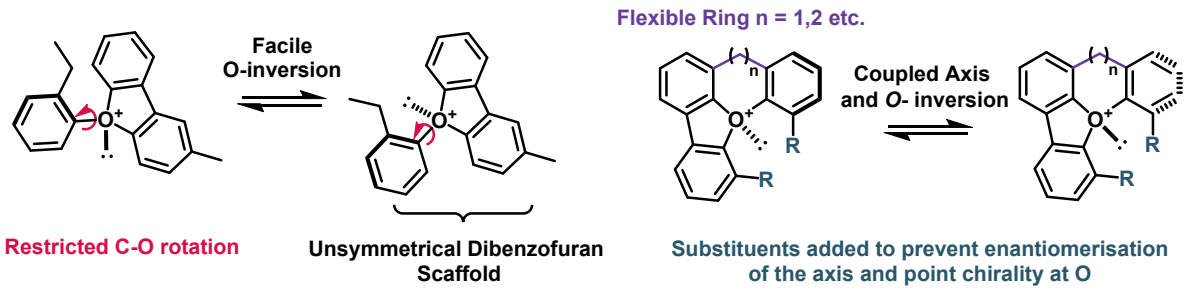
25

Scheme 3.9: Enantiopure oxonium ion **25** containing a point chiral oxygen centre.

A number of chiral at oxygen oxonium ions have been proposed as reactive intermediates including work by Murai,[10] Kim,[11] Braddock[14,15] and Snyder.[12,13] See **Section 1.1.3** for further details.

3.2 Project Aims

Siegel *et al.* had demonstrated that it was possible to synthesize racemic axially chiral oxonium ions due to a high rotational barrier about the C-O bond when the pendant arene was substituted.[43] We proposed that, by linking the dibenzofuran to the pendant arene using a flexible second ring, *O*-inversion would become coupled with inversion of the axially chiral element. If a high enough enantiomerisation barrier (>26 kcal mol^{-1}, $t_{\frac{1}{2}}$ = 7 days at 25 °C) could be achieved, this would lock point chirality at oxygen and should allow us to access molecules containing enantioenriched oxygen stereocentres by resolution (**Scheme 3.10**).



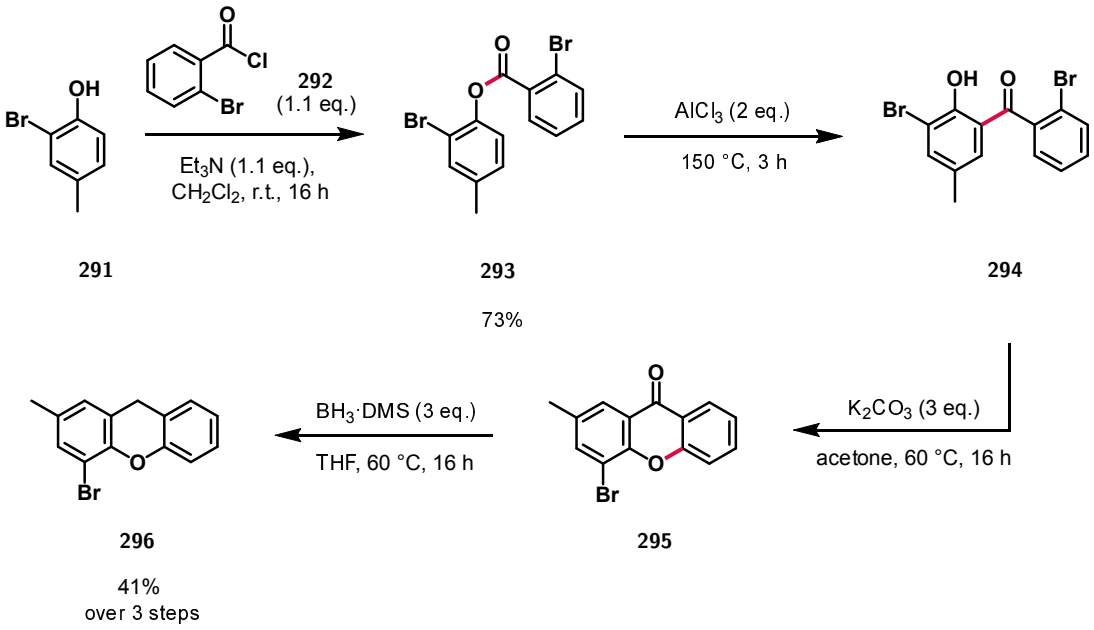
Scheme 3.10: Proposed oxonium ions that would have both an element of axial chirality and point chirality at oxygen.

3.3 Xanthene Scaffold

In order to investigate the synthesis of helically chiral oxonium ions, we initially selected the dibenzofuran-xanthene scaffold (n = 1) for our investigations as the CH_2 protons would be diastereotopic in oxonium ions with restricted enantiomerisation, thereby providing us with a useful handle to measure the inversion barriers by ^{1}H VT-NMR.

3.3.1 Synthetic Route

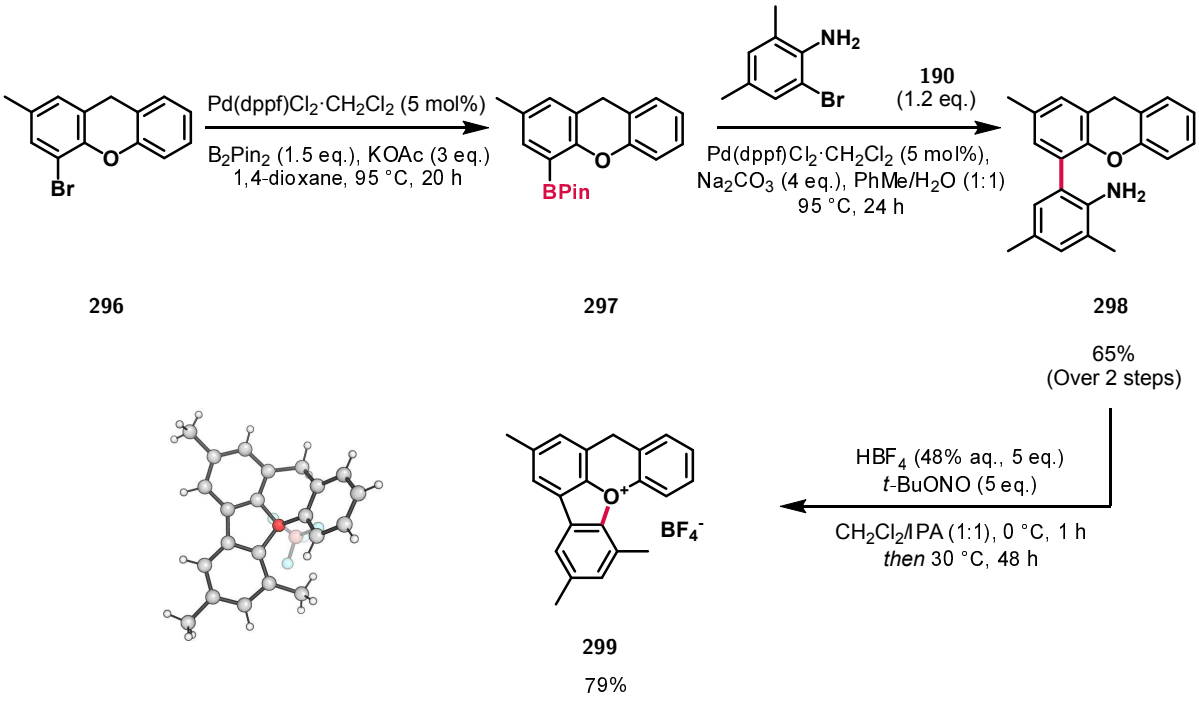
The synthetic route to the desired xanthene was modified from a sequence of literature procedures developed by Vieira *et al.* for accessing substituted xanthenes.[109] 2-Bromo-4-methylphenol, **291**, was acylated with 2-bromobenzoyl chloride, **292**, to give diaryl ester **293** in 73% yield. *O*- to *C*- Fries rearrangement in neat $AlCl_3$ gave **294**. 4-Substitution on the phenol moiety of **293** was used to ensure selective migration of the acyl group to the 2-position in **294**. Acylated phenol **294** underwent a facile intramolecular S_NAr reaction to yield xanthone **295** and this was then reduced with borane-DMS complex to give bromoxanthene **296** in 41% yield over 3 steps without purification of the intermediates. (**Scheme 3.11**).



Scheme 3.11: Synthetic method to construct the xanthene scaffold.

Miyaura borylation[68] of **296** and Suzuki cross coupling with 2-bromo-4,6-dimethyl aniline, **190**, gave biaryl aniline **298** in good yield over two steps. Diazotization of

298 and loss of nitrogen gave the desired 6,5-triaryloxonium ion, **299**, in good yields. A characteristic broad C-O band (1100-1020 cm^{-1}) was observed in the IR spectrum of **299**, significant ^{1}H NMR chemical shift changes were observed for the methyl groups and to a lesser extent the aromatic protons of **299** (see **Section 4.6** for further details). The structure was confirmed by single crystal x-ray crystallography (**Scheme 3.12**).

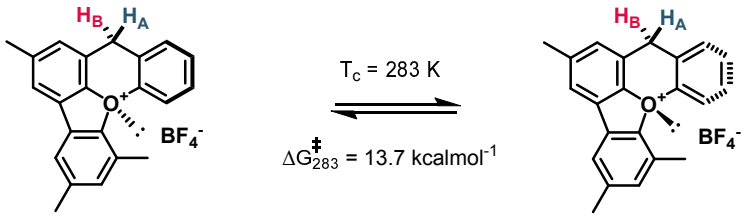


Scheme 3.12: Formation of 6,5-triaryloxonium ion **299** and single crystal x-ray structure of **299**.

3.3.2 Enantiomerisation Barrier Calculation

A low temperature ^{1}H VT-NMR experiment was used to calculate the inversion barrier of **299** using the method from Clayden *et al.*[102] Cooling the sample of **299** in CD_3CN to -35 °C allowed the resolution of the xanthene AB quartet and warming to 10 °C resulted in coalescence which allowed us to estimate the enantiomerisation

barrier as 13.7 kcal mol^{-1} (see **Section 4.7** for further details). This is significantly lower than the 26 kcal mol^{-1} likely to be required to allow us to separate the enantiomers by resolution (**Scheme 3.13**).

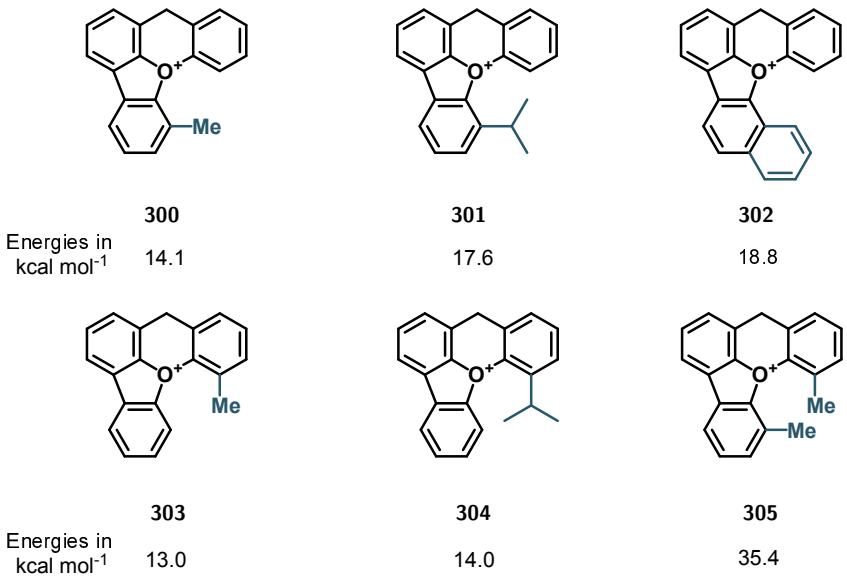


299 **299**

Scheme 3.13: Measurement of the barrier to enantiomerisation of **299**.

3.3.3 Computational Design

With this result in hand, we decided to employ computational analysis to identify potential oxonium ions with enantiomerization barriers exceeding the minimum threshold for stable atropisomers (26 kcal mol^{-1}; racemisation half life = 7 days). We are grateful to Mihai Popescu for performing the enantiomerisation barrier transition state energy calculations. Further details can be found in **Section 4.8**. We were pleased there was good agreement between the calculated value for **300** and the experimentally measured value for **299**. Increasing the size of the substituent at the 2-position of the pendant arene to *i*-Pr and naphthyl resulted in an increased inversion barrier; however, the naphthyl barrier was still at least 7 kcal mol^{-1} smaller than required. Switching the subtitution to the xanthene portion still gave predicted enantiomerization barriers significantly below the desired 26 kcal mol^{-1}. For **305**, the addition of a second Me substituent increased the predicted barrier to enantiomerisation by 22 kcal mol^{-1} to 35.4 kcal mol^{-1}. This, at least theoretically, would enable us to resolve **305** into its constituent enantiomers (**Scheme 3.14**).



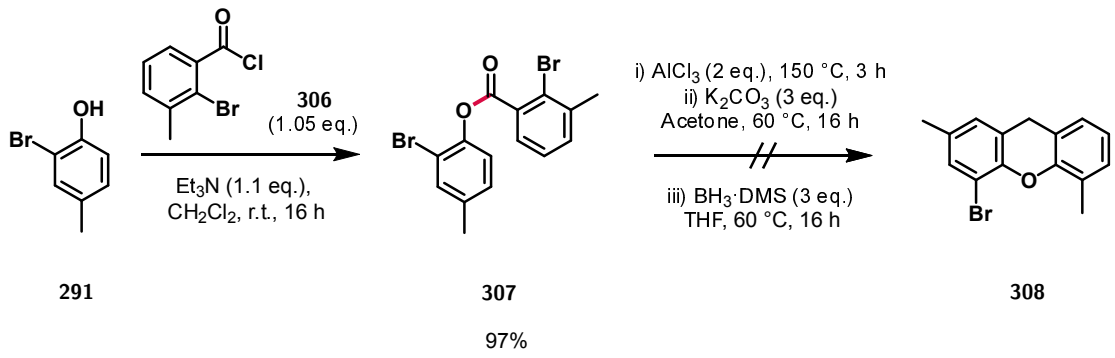
300	301	302
14.1	17.6	18.8

303	304	305
13.0	14.0	35.4

Scheme 3.14: Barrier to enantiomerisation calculations using the B3LYP-D3BJ/6.31+G(d,p) basis set calculated by Mihai Popescu. For further details see **Section 4.8**.

3.3.4 2nd Generation Xanthene Oxonium Ions

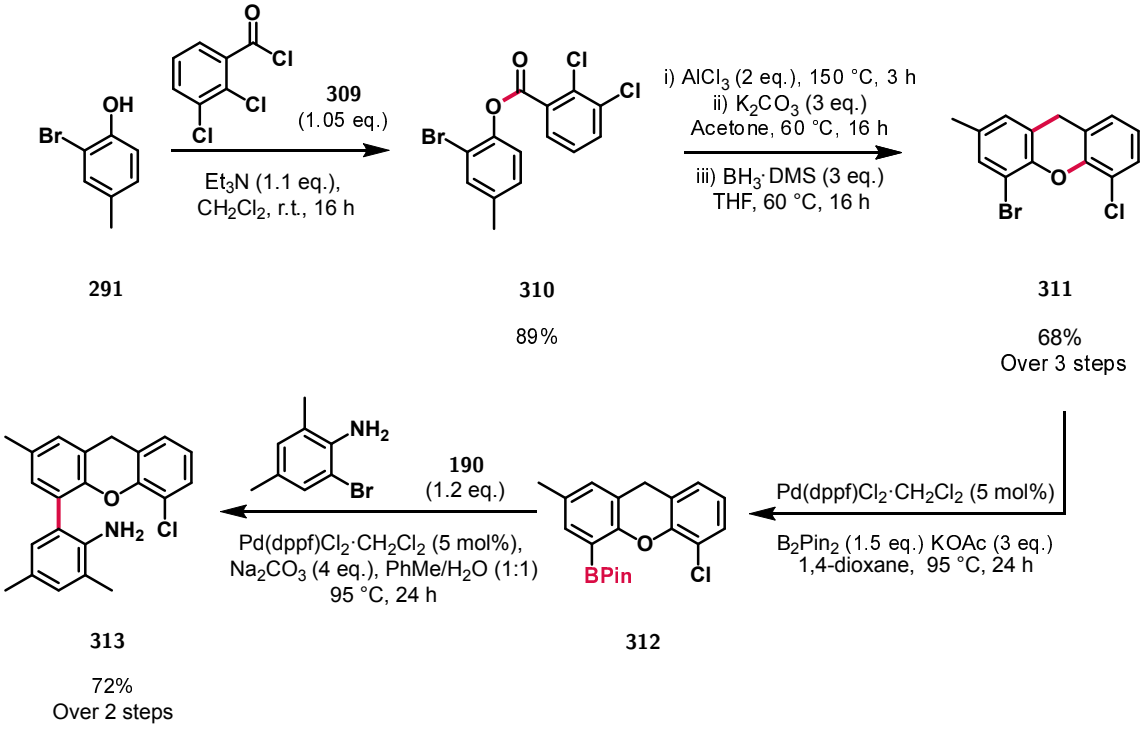
Our approach to oxonium ions related to **305** began with esterfication of **291** with 2-bromo-3-methylbenzoyl chloride, **306**, which gave **307** in good yields. The $AlCl_3$ mediated *O*- to *C*- Fries rearrangement, S_NAr and subsequent reduction sequence from **Scheme 3.11** was repeated; however, this gave a mixture of products and we were unable to isolate the desired substituted xanthene **308** (**Scheme 3.15**).



291	307	308
	97%	

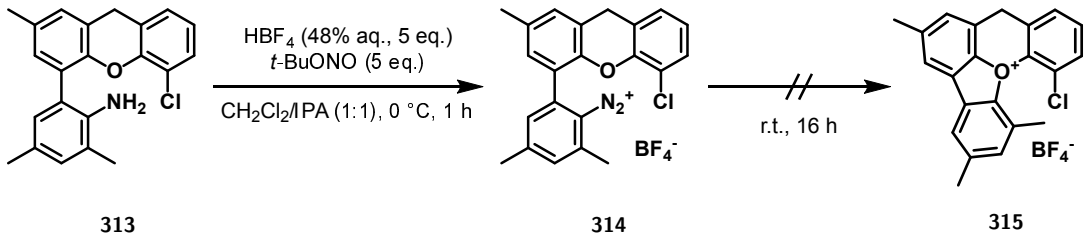
Scheme 3.15: Attempted formation of methylated xanthene scaffold **308**.

As we were unable to obtain **308** by the route outlined in **Scheme 3.15**, we attempted to synthesize chloroxanthene **311** as methyl and chloro substituents occupy similar volumes of space (24 and 20 Å^3, respectively) and interchanging them often results in molecules that are isostructural.[110,111] Esterfication of **291** with 2,3-dichlorobenzoyl chloride, **309**, gave **310** in good yield. The $AlCl_3$ mediated *O*- to *C*- Fries rearrangement, S_NAr and subsequent reduction gave substituted xanthene **311** in moderate yield over 3 steps. Finally, Suzuki cross coupling with **190** gave the desired biaryl aniline oxonium ion precursor **313** (**Scheme 3.16**).



Scheme 3.16: Synthesis of chloro substituted oxonium ion precursor **313**.

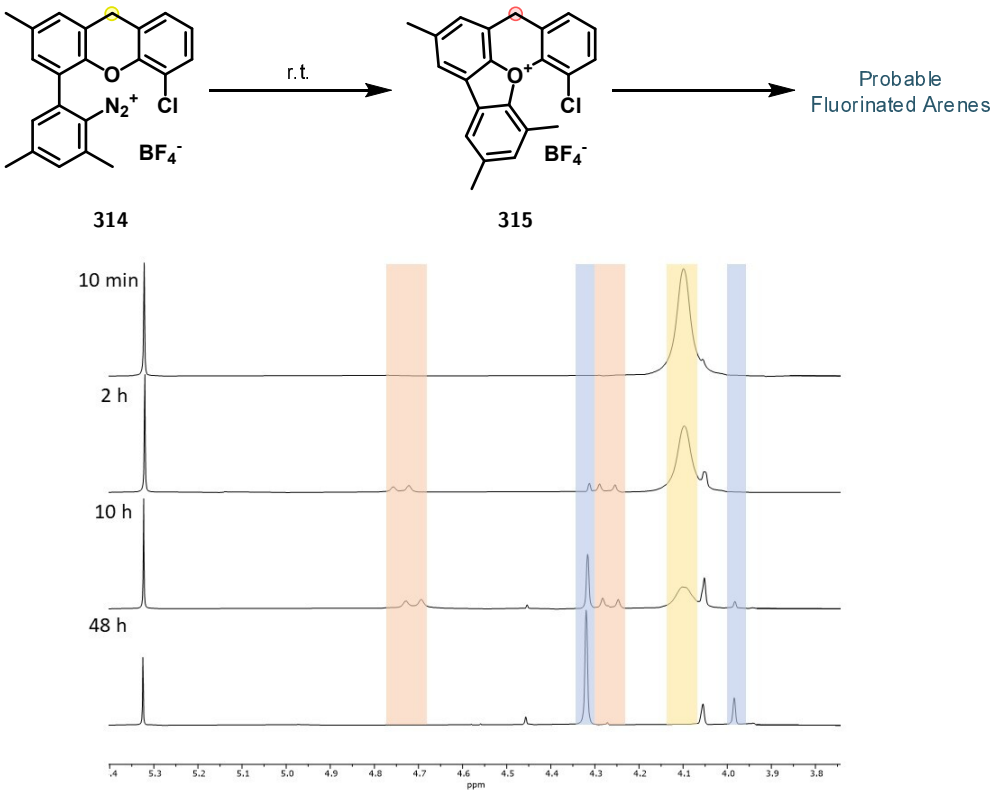
However, although diazotization of **313** gave aryl diazonium salt **314**, warming did not result in the formation of the desired oxonium ion **315** (**Scheme 3.17**).



313 314 315

Scheme 3.17: Attempted formation of atropisomeric oxonium ion **315**.

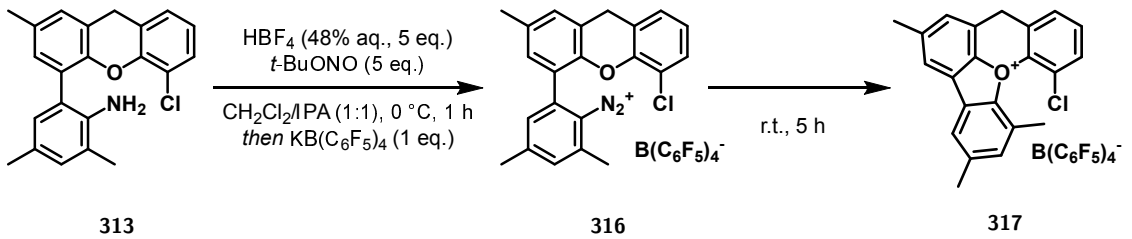
On warming **314** from 0 °C to r.t., we observed the loss of the BF_4^- ^{19}F NMR resonance at –151 ppm which was replaced by a new resonance at -123 ppm. This indicated either: the oxonium ion **315** was a transient intermediate and fluoride from BF_4^- was substituting the C-O bonds shortly after it forms (Balz-Schiemann reaction), or that BF_4^- was directly reacting with diazonium salt **314** and the system was too strained to allow ring closure to form oxonium ion **315**. Aryl diazonium salt **314** was monitored by ^1H NMR and the expected AB quartet of **315** was observed; however, it was present at a steady state concentration indicating that it had a limited lifetime under the reaction conditions and was reacting with the BF_4^- counterion. For more details see **Section 4.6.6** (**Scheme 3.18**).



Scheme 3.18: ^{1}H NMR analysis of a solution of diazonium salt **314** over 48 h showing the formation of oxonium ion **315** and decomposition to fluorinated arenes.

To investigate this reaction further, we performed an anion exchange on **314** to introduce the non-coordinating, non-nucleophilic $B(C_6F_5)_4^-$ anion. After leaving **316** for 5 h at r.t., full formation of oxonium ion **317** was observed by the appearance of an AB quartet in the ^{1}H NMR spectrum and three oxonium C-O signals in the ^{13}C NMR. Despite this success, **317** was not stable for prolonged periods of time and full decomposition had occurred after 72 h at r.t. in solution. Removing the solvent from **317** by a steady stream of N_2 gave a viscous oil that did not crystallise upon the addition of Et_2O or pentane. This unfortunately precluded structural confirmation of **317** by x-ray crystallography. To verify that concentration of **317** did not result

in its decomposition, ^{1}H NMR analysis of the sample previously concentrated to dryness was carried out and no decomposition was observed (**Scheme 3.19**).



313 316 317

Scheme 3.19: Use of weakly coordinating $B(C_6F_5)_4^-$ to facilitate the formation of atropisomeric oxonium ion **317**.

Despite the success of observing **317** in solution, ^{19}F NMR analysis showed that $B(C_6F_5)_4^-$ was unchanged throughout the 72 h decomposition period, indicating that the oxonium ion was reacting with itself, or its decomposition products. Introduction of a second substituent greatly increases the strain energy of **317** and therefore lowers the activation energy barrier to breaking the C-O bonds allowing facile decomposition and the need for highly non-coordinating counterions. In order to obtain a stable atropisomeric oxonium ion that we could attempt to resolve, we needed to redesign the oxonium ion architecture to reduce this strain.

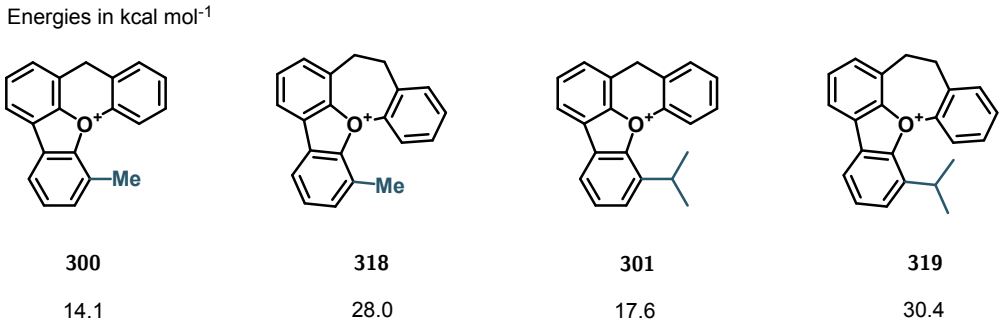
3.4 Dihydrodibenzooxepine Scaffold

The success of the xanthene route to a helically chiral oxonium ion was limited by the lack of stability of the final oxonium ion which was proposed to be due to strain in the molecule. The xanthene scaffold prefers a flattened conformation prior to oxonium ion formation and the twist that it undergoes is inevitably a source of strain. We believed we could eliminate this strain by changing the size

of the ring. Dihydrodibenzooxepines have a puckered structure and we envisaged that a more flexible molecular backbone would be able to better accommodate the conformation required to stabilise helically chiral oxonium ions allowing them to tolerate more sterically crowded environments and ultimately yield configurationally stable molecules.

3.4.1 Computational Design

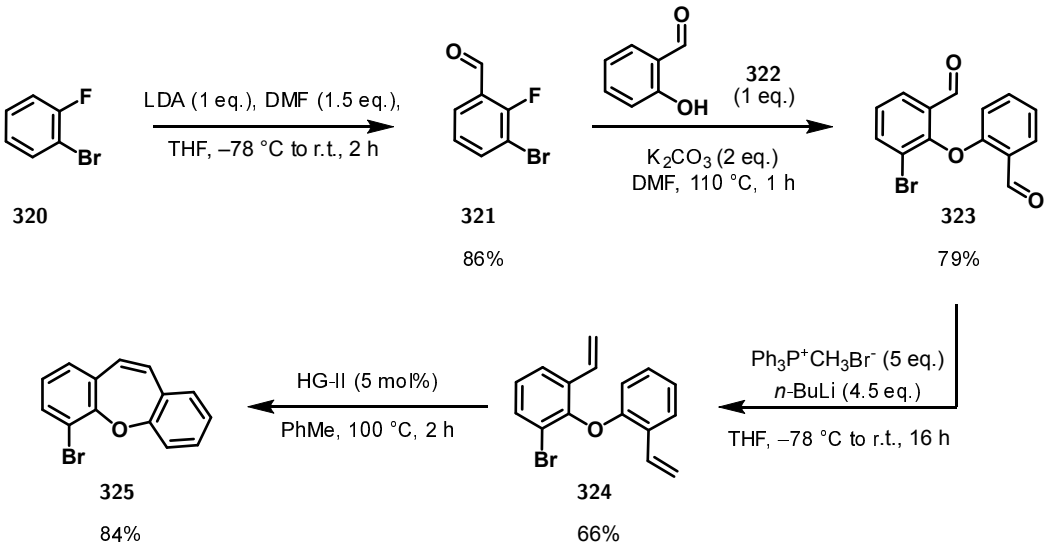
In order to assess the dihydrobenzoxepine scaffold as a structural element of atropisomeric oxonium ions, enantiomerization barriers were calculated for **318** and **319**. We are grateful to Mihai Popescu for performing calculations to assess the barrier to enantiomerization; for further details see **Section 4.8**. We were surprised to see such a large increase in the enantiomerization barrier (12-14 kcal mol^{-1}) simply by changing the scaffold. The predicted enantiomerisation barrier values were large enough for **318** and **319** that these were appropriate targets for synthesis (**Scheme 3.20**).



Scheme 3.20: Enantiomerisation barrier calculations for the dihydrobenzooxepine scaffold and comparison to the xanthene scaffold using the B3LYP-D3BJ/6.31+G(d,p) basis set conducted by Mihai Popescu. For further details see **Section 4.8**.

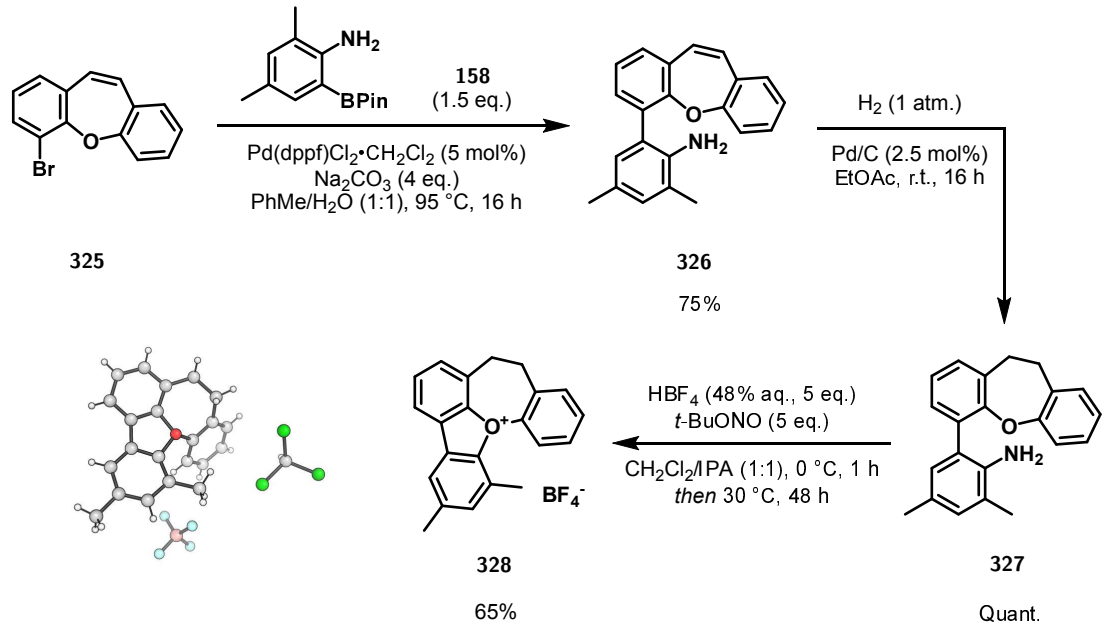
3.4.2 Synthetic Route

Using a procedure from a patent, *o*-lithiation of 1-bromo-2-fluorobenzene, **320**, and trapping the resulting anion with DMF gave aldehyde **321** in good yield.[112,113] Aldehyde **321** then underwent a facile S_NAr reaction with salicylaldehyde, **322**, to give diarylether **323**. Using a sequence that was successfully applied to a closely related system,[114] Wittig olefination of bisaldehyde **323** gave bisstyrene **324** and subsequent RCM with Hoveyda-Grubbs 2nd generation catalyst (HG-II) furnished dibenzooxepine **325** in good yields (**Scheme 3.21**).



Scheme 3.21: Synthetic method for the construction of the dibenzooxepine core.

Using a similar strategy to that used to construct the aryne precursors in **Chapter 2**, **325** was subjected to Suzuki cross coupling conditions with **158** to give biaryl aniline **326**. Hydrogenation gave dibenzooxepane **327** which in turn gave the desired oxonium ion **328** in good yields after diazotization and gentle warming. The structure was confirmed by x-ray crystallography with an additional chloroform of crystallisation (**Scheme 3.22**).

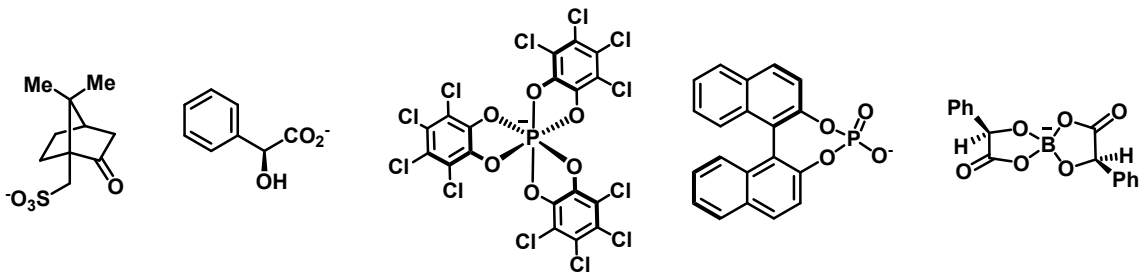


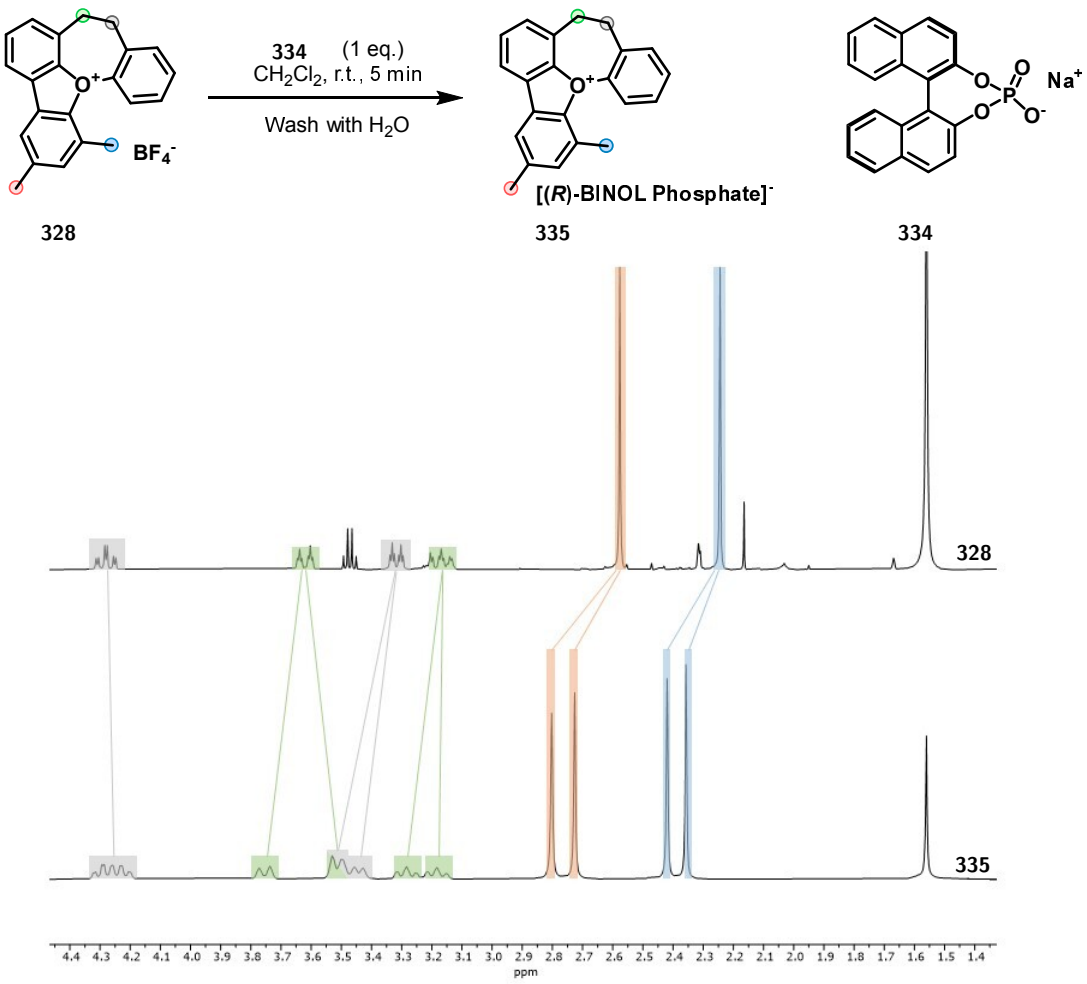
Scheme 3.22: Formation of dihydrodibenzooxepine derived oxonium ion **328** and characterisation by single crystal x-ray crystallography with a chloroform of crystallisation.

3.4.3 Resolution

^{1}H NMR analysis of **328** showed distinct signals for the four diastereotopic protons in the -CH_2CH_2- backbone indicating that the barrier to enantiomerization was large enough that there was little to no enantiomerization on the NMR time scale (see **Section 4.6.7** for more details). With this information in hand, our next step was to attempt the resolution of oxonium ion **328**.

Enantiopure sulfonic and carboxylic acids, hexa- co-ordinate phosphates (such as TRISPHAT, **331**)[115], phosphoric acid salts[116] and borate anions[117] have all have all been employed to resolve racemic cations (**Scheme 3.23**).[118]


Me
Me
O
$^{-}O_3S$
CO_2^-
OH
Cl
O
P
O
O
O

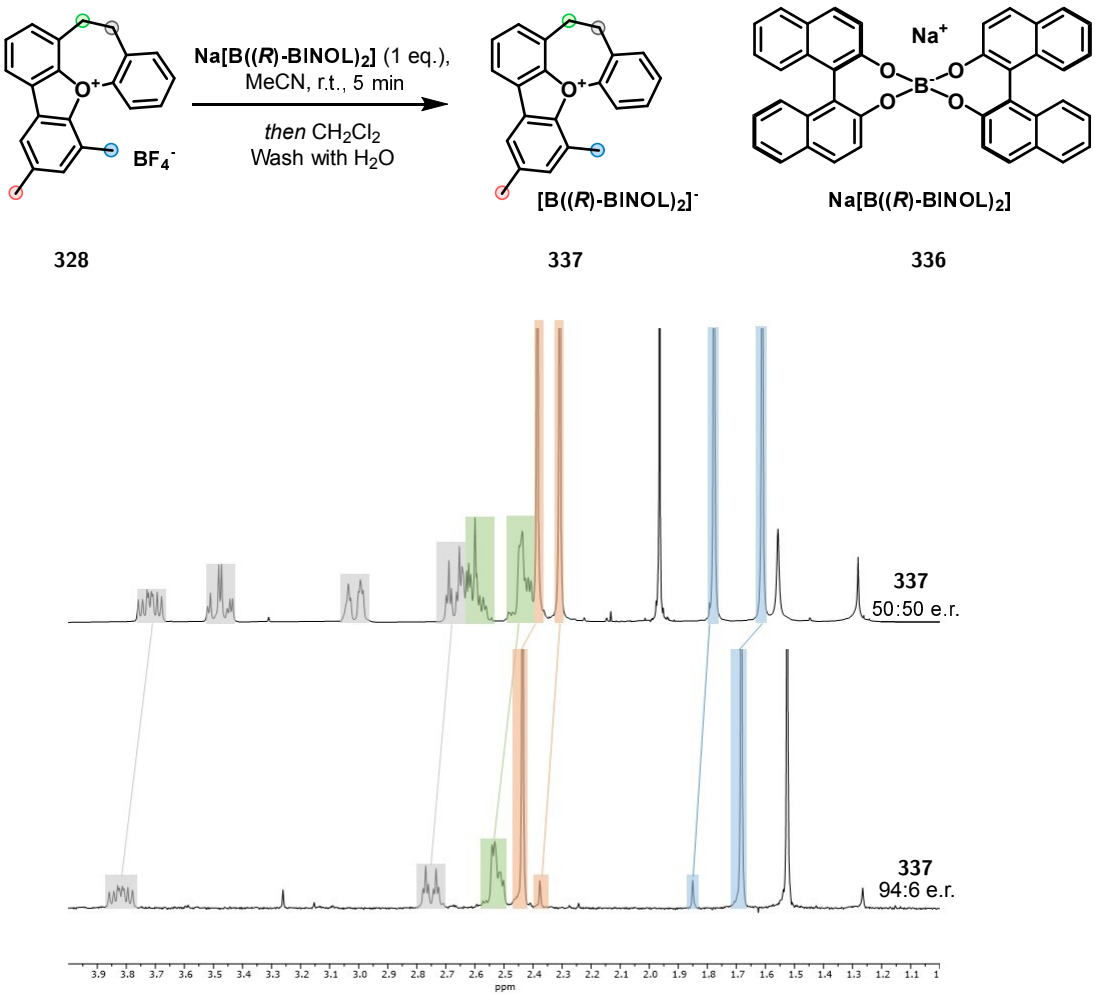


Scheme 3.24: ^{1}H NMR (500 MHz, $CDCl_3$) analysis of the anion exchange product with (*R*)-BINOL phosphate.

Despite this initial success, the oxonium ion slowly degraded in the presence of the phosphate anion at a rate of approximately 10% over a 24 h period. The decomposition was attributed to the phosphate substituting the aryl C-O bonds in the oxonium ion. Furthermore, all crystallisation conditions attempted resulted in no change to the observed ratio of enantiomers in the ^{1}H NMR spectrum.

As the BINOL-phosphate anion appeared to be too nucleophilic, we decided to minimise the possibility of the anion reacting with the oxonium ion by switching to borate anions. Anion exchange with sodium bis-(*R*)-BINOL borate, **336**, and

aqueous removal of $NaBF_4$ proceeded smoothly to give **337**. The ^1H NMR signals of the Me groups and the -CH_2CH_2- backbone of the two enantiomers were significantly split in the chiral environment and no change in the ratio of enantiomers was observed after 7 days in CD_2Cl_2. Dissolution of **337** in $CDCl_3$ resulted in the formation of a precipitate. Comparing the ^1H NMR spectrum of the precipitate in CD_2Cl_2 to the 1:1 mixture of **337** allowed us to demonstrate this material was enantioenriched with an approximate e.r. of 94:6 (**Scheme 3.25**).

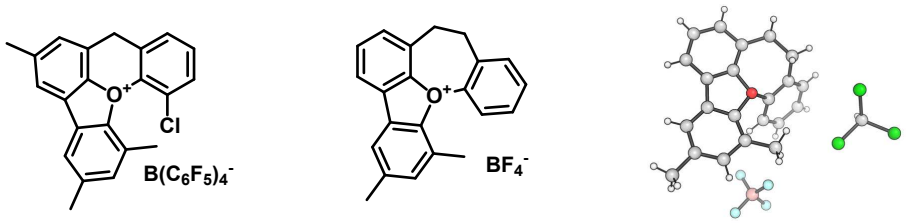


Scheme 3.25: Anion Exchange with Bis (*R*)-BINOL borate and ^1H NMR analysis of racemic **337** against the crystalline precipitate obtained from a $CDCl_3$ solution of **337**.

^{1}H NMR analysis of the material after 24 h showed no erosion of the e.r., indicating a barrier of at least 26 kcal mol^{-1} ($t_{\frac{1}{2}}$ = 7 days). While current attempts to crystallise **337** have been unsuccessful, exchanging the counterion of the enantioenriched oxonium ion salt for BF_4^- will allow us to obtain a single crystal x-ray structure, as this had previously been successful for the racemate. From the crystal structure we will be able to determine the absolute configuration of both the helicity and the oxygen stereocentre of the oxonium ion. Furthermore, isolation of the enantiopure oxonium ion without the chiral counterion will allow us to explore the optical rotation properties of this new class of cationic helicenes and investigate their utility as chiral shift reagents/for racemic anion resolution.

3.5 Conclusion

We have developed two routes to axially chiral triaryloxonium ions with enantiomerisation barriers calculated to be greater than 26 kcal mol^{-1}. Strained xanthene derived oxonium ion **315** could be isolated by using the extremely weakly coordinating anion $B(C_6F_5)_4^-$; however, its reactivity towards counterions prevented its resolution and further investigation into its properties. Expanding the scaffold to 7 ring dihydrodibenzooxepines gave increased stability by reducing the strain gained on forming the oxonium ion. This allowed us to isolate **328** as the BF_4^- salt and characterise it by x-ray crystallography (**Scheme 3.26**).



315 **328**

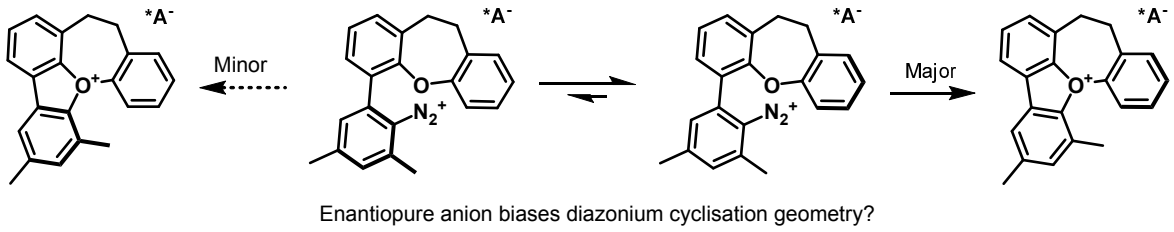
Scheme 3.26: Axially chiral triaryoxonium ions with inversion barriers of greater than 26 kcal mol^{-1}.

Exchanging the counterion of **328** from BF_4^- to enantiopure bis (*R*)-BINOL borate allowed the resolution of the oxonium ion enantiomer to 94:6 e.r. by crystallisation from $CHCl_3$. No racemisation of the material was observed after 24 h and computational analysis, by Mihai Popescu, of the oxonium ion scaffold shows that inversion of point chirality at oxygen is coupled with the inversion of the axial stereochemistry. To the best of our knowledge, this is the first example of a room temperature stable oxonium ion with point chirality at oxygen which is not controlled by point

chiral carbon stereocentres derived from chiral pool starting materials.

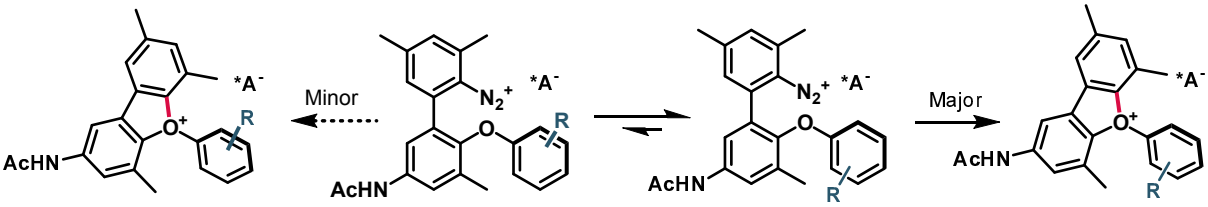
3.6 Future Work

Our initial efforts will be on improving and increasing the scale of the resolution of **337** to allow us to obtain enough material to confirm the absolute stereochemistry by x-ray crystallography and investigate its optical properties. Due to the success of the resolution, we envisage that the presence of the enantiopure bis (*R*)-BINOL borate anion could pre-organise the orientation of the diazonium salt prior to the ring closure to form the oxonium ion. If successful, this would allow the enantioselective synthesis of triaryloxonium ions (**Scheme 3.27**).



Scheme 3.27: Proposed route for the enantioselective synthesis of point chiral at oxygen triaryloxonium ions *via* diazonium ion pre-organisation.

Furthermore, this approach could be applied to the unsymmetrical phenol derived oxonium ions synthesised in **Section 2.6** to obtain enantioenriched oxonium ion atropisomers with restricted rotation about the C-O bond. (**Scheme 3.28**).[43]



Scheme 3.28: Proposed enantioselective synthesis of atropisomeric phenol derived triaryloxonium ions.

4 Supporting Information

4.1 General Information

4.1.1 Naming and Numbering

Compounds have been named according to IUPAC recommendations or commonly used names where appropriate. The atomic numbering within each compound does not correspond to the IUPAC numbering system, it has been arbitrarily chosen for the purpose of consistent assignment of spectra.

4.1.2 Reaction Conditions

Reactions were carried out under ambient conditions unless specified in the procedure. Glassware for reactions carried out under inert conditions using N_2 or Ar atmospheres was flame dried under vacuum prior to use. Room temperature (r.t.) refers to temperatures between 20-25 °C. Temperatures of 0 °C were obtained using a water/ice bath or using a Polar Bear Plus when greater accuracy was required. Temperatures of –78 °C were obtained using a dry ice/acetone bath. Reactions were heated using a DrySyn® heating block and contact thermometer.

4.1.3 Solvents and Reagents

Anhydrous THF, CH_2Cl_2, MeCN, Et_2O, DMF, 1,4-dioxane, triethylamine and pyridine were obtained using an MBraun SPS5 solvent purification system. All other solvents and reagents were used as supplied without further purification.

4.1.4 Chromatography

Thin Layer Chromatography was carried out on Merck Kieselgel 60 F_{254} 0.25 mm precoated aluminium plates. Visualization was achieved by UV light ($\lambda = 254$ nm) followed by staining with basic $KMnO_4$ solution. Flash column chromatography was carried out using silica gel 60 (0.043-0.063 nm, VWR) under pressure (0.2-0.4 bar) from the house N_2 supply.

4.1.5 NMR Spectroscopy

Spectra were recorded on Bruker Avance (700, 600, 500 and 400 MHz (^{1}H)) and Bruker Avance NEO (600 MHz (^{1}H)) spectrometers in the deuterated solvent specified. ^{1}H NMR were referenced to the non-deuterated residual solvent peak, ^{13}C NMR were referenced to the residual solvent peak and ^{19}F NMR were referenced externally to $CFCl_3 = 0$ ppm. Chemical shifts are quoted in ppm with splitting assigned as singlet (s), doublet (d), triplet (t), quartet (q), pentet (p), septet (sept), and multiplet (m) or combinations of the above. The abbreviation br is used to denote broad signals. Coupling constants, J, are measured to the nearest 0.1 Hz and

are presented as observed. Spectra were assigned with the aid of COSY, HSQC, HMBC and NOESY experiments.

Variable Temperature NMR spectroscopy was carried out on a Bruker Avance 500 MHz (^{1}H) spectrometer equipped with a BCU-II temperature regulation unit for analysis to –40 °C.

4.1.6 Infrared Spectroscopy

Infra-red spectra were recorded on a Bruker Tensor 27 FTIR spectrometer equipped with a diamond ATR module. Absorbtion maxima (λ_{max}) are reported in wavenumbers (cm^{-1}).

4.1.7 Mass Spectrometry

Low-resolution mass spectra were recorded on a Micro Mass LCT Premier spectrometer under conditions of electrospray ionization (ESI). High resolution mass spectra were recorded on a Bruker MicroTOF and Micromass GCT spectrometers under conditions of electrospray ionization (ESI), atmospheric pressure chemical ionization (APCI) or electron ionization (EI).

4.1.8 Polarimetry

Optical rotations were recorded on a Schmidt-Haensch Unipol L2000 polarimeter and values are quoted [° mL g^{-1} dm^{-1}]. Concentrations are quoted in g/100 mL.

Temperatures are recorded in °C.

4.1.9 Melting Points

Melting points were determined by using Reichert melting point apparatus and are uncorrected. Unless otherwise stated, the solid material is obtained from *in vacuo* removal of the solvent system used for flash column chromatography.

4.1.10 X-ray Crystallography

X-ray crystallography was carried out by the author using the Rigaku Oxford Diffraction/Agilent Supernovae A diffractometers in the Oxford Chemistry Crystallography Department. For further details see **Section 4.9**.

4.2 General Procedures

General Procedure A for the Synthesis of 6,6,6-Trialkyloxonium ion salts:

$SOCl_2$ (37 μL, 60 mg, 0.50 mmol, 2 eq.) was added to a solution of (1*R*,5*s*,9*S*)-13-oxabicyclo[7.3.1]tridecan-5-ol, **67**, (50 mg, 0.25 mmol, 1 eq.) in Et_2O (5 mL). After 5 minutes, the solvent was removed *in vacuo*. *The appropriate salt* (0.24 mmol, 0.95 eq.) was added to a solution of the crude residue in acetone or MeCN (5 mL). After 2 h, the reaction was filtered (Celite®, 1 mL), eluted (acetone/MeCN, 1 mL) and concentrated *in vacuo*. Acetone/MeCN (0.5 mL) was added to the crude residue and the addition of Et_2O (10 mL) resulted in the precipitation of *the desired oxonium ion*. The solvent was removed, the solid was washed (Et_2O, 2 mL) and dried *in vacuo*.

General Procedure B for the S_NAr reaction of 2-bromo-4,6-dimethylphenol with Aryl Fluorides:

K_2CO_3 (2 eq.) was added to a solution of *the appropriate fluoroarene* (1 eq.) and 2-bromo-4,6-dimethylphenol (1 eq.) in DMF (2.5 mL/mmol) and the reaction mixture was heated to 110 °C for 16 h. The reaction was cooled, H_2O (5 mL/mmol) was added and the mixture was extracted (Et_2O, 3 × 10 mL/mmol). The combined organic layers were washed (H_2O, 10 mL/mmol), dried ($MgSO_4$) and concentrated *in vacuo*.

General Procedure C for cross coupling of aryl bromides with 2,4-dimethyl-6-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)aniline, 158:

The *appropriate aryl bromide* (1 eq.) as a solid or a solution in PhMe or CH_2Cl_2, 2,4-dimethyl-6-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)aniline, **158**, (1.5 eq.) as a solution in PhMe (6 mL/mmol) and water (10 mL/mmol) were sequentially added to $Pd(dppf)Cl_2{\cdot}CH_2Cl_2$ (5 mol%) and Na_2CO_3 (4 eq.) in PhMe (4 mL/mmol) under N_2 at r.t.. Argon was bubbled through the solution for 5 mins and the reaction mixture was heated to 95 °C. After 24 h, the reaction mixture was extracted (CH_2Cl_2, 3 × 10 mL/mmol), dried ($MgSO_4$) and concentrated *in vacuo*.

General Procedure D for cross coupling of aryl bromides with 2,4-dimethyl-6-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)aniline, 158 on a 1.0 mmol scale:

The *appropriate aryl bromide* (1.00 mmol, 1 eq.) as a solid or a solution in PhMe or CH_2Cl_2, 2,4-dimethyl-6-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)aniline, **158**, (1.50 mmol, 1.5 eq.) as a solution in PhMe (6 mL) and water (10 mL) were sequentially added to $Pd(dppf)Cl_2{\cdot}CH_2Cl_2$ (41 mg, 0.05 mmol, 5 mol%) and Na_2CO_3 (423 mg, 4.00 mmol, 4 eq.) in PhMe (4 mL) under N_2 at r.t.. Argon was bubbled through the solution for 5 mins and the reaction mixture was heated to 95 °C. After 24 h, the reaction mixture was extracted (CH_2Cl_2, 3 × 10 mL), dried ($MgSO_4$) and concentrated *in vacuo*.

General Procedure E for cross coupling of aryl bromides with 2,4-dimethyl-6-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)aniline, 158:

The *appropriate aryl bromide* (1 eq.) as a solid or a solution in PhMe or CH_2Cl_2, 2,4-dimethyl-6-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)aniline, **158**, (1.5 eq.) as a solution in PhMe (6 mL/mmol) and water (10 mL/mmol) were sequentially added to $Pd(dppf)Cl_2 \cdot CH_2Cl_2$ (5 mol%) and Na_2CO_3 (4 eq.) in PhMe (4 mL/mmol) under N_2 at r.t.. Argon was bubbled through the solution for 5 mins and the reaction mixture was heated to 95 °C. After 24 h, the reaction mixture was extracted (CH_2Cl_2, 3 × 10 mL/mmol), dried ($MgSO_4$) and concentrated *in vacuo*.

General Procedure F for the formation of Oxonium Ions on a 0.5 mmol scale:

t-BuONO (0.297 mL, 258 mg, 2.50 mmol, 5 eq.) was added to a solution of *the appropriate aniline* (0.5 mmol, 1 eq.) and HBF_4 (48% aq., 0.327 mL, 457 mg, 2.50 mmol, 5 eq.) in CH_2Cl_2:IPA (1:1, 2 mL) at 0 °C. After 1 h, the reaction mixture was diluted (CH_2Cl_2, 3 mL), washed (H_2O, 1 mL) and warmed to 30 °C. After 36-48 h, the solvent was removed by a steady stream of N_2 and Et_2O (5 mL) was added resulting in a solid precipitate. The Et_2O layer was passed through Celite® (1 mL). The solid precipitate was washed and the solvent passed through Celite® (Et_2O, 4 x 1 mL). The solid was dissolved in MeCN (2-6 mL), passed through Celite® and eluted (MeCN, 4 × 2.5 mL). The solvent was removed by a steady stream of N_2 or *in vacuo* at r.t. to give the desired oxonium ion.

General Procedure G for the formation of Oxonium Ions:

t-BuONO (5 eq.) was added to a solution of *the appropriate aniline* (1 eq.) and HBF_4 (48% aq., 5 eq.) in CH_2Cl_2:IPA (1:1, 4 mL/mmol) at 0 °C. After 1 h, the reaction mixture was diluted (CH_2Cl_2, 5 mL/mmol), washed (H_2O, 2 mL/mmol) and warmed to 30 °C. After 36-48 h, the solvent was removed by a steady stream of N_2 and Et_2O (5 mL/mmol) was added resulting in a solid precipitate. The Et_2O layer was passed through Celite® (1 mL/mmol). The solid precipitate was washed and the solvent passed through Celite® (Et_2O, 4 x 1 mL/mmol). The solid was dissolved in MeCN (4-12 mL/mmol), passed through Celite® and eluted (MeCN, 4 × 5 mL/mmol). The solvent was removed by a steady stream of N_2 or *in vacuo* at r.t. to give the desired oxonium ion.

General Procedure H for the formation of oxonium ions from biaryl triazene:

HBF_4 (48% aq., 0.65 mL, 415 mg, 5.00 mmol, 10 eq.) was added to a solution of *the appropriate triazene* (0.50 mmol, 1 eq.) in CH_2Cl_2:IPA (1:1, 2 mL) at 0 °C. After 5 mins, the solution was washed (H_2O, 3 mL) and HBF_4 (48% aq., 0.65 mL, 415 mg, 5.00 mmol, 10 eq.) was added. After a further 5 mins, the solution was washed (H_2O, 3 mL), diluted (CH_2Cl_2, 3 mL) and stirred at 30 °C. After 36 h, the solvent was removed by a steady stream of N_2 and Et_2O (5 mL/mmol) was added resulting in a solid precipitate. The Et_2O layer was passed through Celite® (1 mL/mmol). The solid precipitate was washed and the solvent passed through Celite® (Et_2O, 4 x 1 mL/mmol). The solid was dissolved in MeCN (4-12 mL/mmol), passed through

Celite® and eluted (MeCN, 4 × 5 mL/mmol). The solvent was removed by a steady stream of N_2 or *in vacuo* at r.t. to give the desired oxonium ion.

General Procedure I for the [4+2] Cycloaddition with Furan on a 0.3 mmol scale:

K_3PO_4 (318 mg, 1.50 mmol, 5 eq.) was added to a solution of *the appropriate oxonium ion* (0.30 mmol, 1 eq.) and furan (0.11 mL, 102 mg, 1.50 mmol, 5 eq.) in MeCN (6 mL). After 16 h, the reaction was filtered through Celite®, eluted (CH_2Cl_2, 4 × 5 mL) and concentrated *in vacuo*.

General Procedure J for the S_NAr reaction of 1-bromo-2-chloro-3-methyl-5-nitrobenzene with phenols:

K_2CO_3 (2 eq.) was added to a solution of *the appropriate phenol* (1 eq.) and 1-bromo-2-chloro-3-methyl-5-nitrobenzene (1 eq.) in DMF (2.5 mL/mmol) and the reaction mixture heated to 110 °C. After 16 h, the reaction mixture was cooled, H_2O (5 mL/mmol) was added and the reaction mixture was extracted (Et_2O, 3 × 10 mL/mmol). The combined organic layers were washed (H_2O, 10 mL/mmol), dried ($MgSO_4$) and concentrated *in vacuo*.

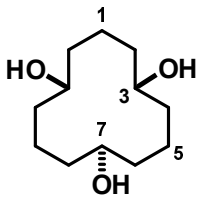
General Procedure K for the hydrogenation, acetylation and cross coupling of aryl bromides with 2,4-dimethyl-6-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)aniline, 158 on a 1.0 mmol scale:

H_2 was sparged through a solution of *the appropriate aryl bromide* (1.00 mmol, 1 eq.) and Pd/C (10 wt%, 27 mg, 2.5 mol%) and EtOAc (5 mL) or EtOAc/THF (1:1, 5 mL)

under N_2 for 5 mins and kept under a H_2 pressure (1 atm). After 16 h, N_2 was sparged through the solution for 10 mins, the reaction was filtered (Celite®, 1 mL) and concentrated *in vacuo*. The crude residue was dissolved in CH_2Cl_2 (5 mL) and Ac_2O (0.29 mL, 309 mg, 3 mmol, 3 eq.) was added. After 4 h, $NaHCO_3$ (sat. aq., 15 mL) was added and the mixture was extracted (CH_2Cl_2, 3 × 5 mL). The organic extracts were washed ($NaHCO_3$, sat. aq., 10 mL), dried ($MgSO_4$) and concentrated *in vacuo*. The crude residue, as a solid or a solution in PhMe or CH_2Cl_2, 2,4-dimethyl-6-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)aniline, **158**, (1.50 mmol, 1.5 eq.) as a solution in PhMe (6 mL) and water (10 mL) were sequentially added to Pd(dppf)Cl_2·CH_2Cl_2 (41 mg, 0.05 mmol, 5 mol%) and Na_2CO_3 (423 mg, 4.00 mmol, 4 eq.) in PhMe (4 mL) under N_2 at r.t.. Argon was bubbled through the solution for 5 mins and the reaction mixture was heated to 95 °C. After 24 h, the reaction mixture was extracted (CH_2Cl_2, 3 × 10 mL), dried ($MgSO_4$) and concentrated *in vacuo*.

4.3 Experimental Data

(*r*)-Cyclododecane-1,5,9-triol, **65**:



Triol **65** was prepared according to a modified literature procedure.[33] A solution of *trans*, *trans*, *cis*-1,5,9-cyclododdecatriene (4.40 mL, 4.00 g, 24.70 mmol, 1 eq.) in diglyme (5 mL) was added *via* syringe pump over 10 minutes to a stirred solution of $BH_3{\cdot}Et_3N$ (3.64 mL, 2.82 g, 24.6 mmol, 1 eq.) in diglyme (15 mL) at 140 °C. After 4 h, the reaction was cooled to 0 °C and NaOH (3 M, aq., 9.84 mL, 1.2 eq.) was added. After 20 mins, H_2O_2 (30% w/w, 9.04 mL, 3.6 eq.) was added dropwise over 30 mins. After a further 30 mins, Na_2SO_3 (0.252 g, 2.00 mmol, 0.1 eq.) was added and the aqueous layer was extracted with EtOAc (10 × 100 mL). The combined organics were dried ($MgSO_4$) and concentrated *in vacuo*. The crude residue was recrystallised (EtOAc:MeOH, 2:1) to afford the title compound as a white solid (1.42 g, 27%).

Melting Point = 179-180 °C (EtOAc:MeOH, 2:1).

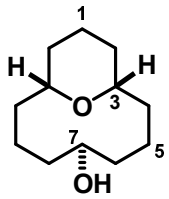
^{1}H NMR (500 MHz, DMSO-d_6): δ_H = 4.29 (d, J = 5.2 Hz, 1H, OH), 4.23 (d, J = 4.5 Hz, 2H, OH), 3.63 – 3.49 (m, 3H, H_7, H_3), 1.59 – 1.33 (m, 11H, H_6, H_5, H_4, H_2, H_1), 1.30 – 1.08 (m, 7H, H_6, H_5, H_4, H_1).

^{13}C NMR (126 MHz, DMSO-d_6): δ_C = 66.8 (C_3), 64.9 (C_7), 33.6 (C_6), 33.0 (C_2), 31.3 (C_4), 20.1 (C_5), 16.2 (C_1).

FTIR (film) $\nu_{max}/\mathbf{cm^{-1}}$ = 3316, 2942, 2863, 1467, 1336, 1197, 1154, 1119, 1079, 1021, 960, 899.

HRMS (ESI^+): m/z calculated for $C_{12}H_{24}O_3Na^+$, $[M+Na]^+ = 239.1618$; m/z found = 239.1620. $\Delta = 0.64$ ppm.

(1*R*,5*s*,9*S*)-13-Oxabicyclo[7.3.1]tridecan-5-ol, **67**:



$TsOH{\cdot}H_2O$ (1.76 g, 9.24 mmol, 4 eq.) was added to a suspension of (*r*)-cyclododecane-1,5,9-triol, **65**, (500 mg, 2.31 mmol, 1 eq.) in PhMe (50 mL) and the resulting mixture was heated to 110 °C. After 16 h, the reaction mixture was concentrated *in vacuo*. The crude residue was dissolved in $CHCl_3$ (50 mL) and the organic layer was washed with $NaHCO_3$ (sat. aq., 150 mL). After 4 h, the aqueous layer was extracted (EtOAc, 3 × 40 mL), the combined organics were dried ($MgSO_4$) and concentrated *in vacuo*. The crude residue was purified by flash column chromatography (EtOAc:Pentane, 20:80, R_f = 0.3) to give the title compound as a colourless oil (260 mg, 57%, >10:1 d.r.).

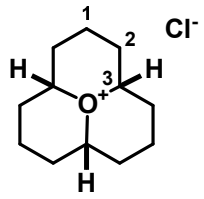
^{1}H NMR (500 MHz, $CDCl_3$): δ_H = 3.48 (p, J = 5.2 Hz, 1H, H_7), 3.26 – 3.15 (m, 2H, H_3), 1.86 – 1.71 (m, 5H, H_6, H_5, H_1), 1.60 – 1.44 (m, 11H, H_6, H_5, H_4, H_2, H_1), 1.32 – 1.12 (m, 2H, H_2).

^{13}C NMR (126 MHz, $CDCl_3$): δ_C = 79.0 (br, C_3), 76.1 (br, C_7), 38.9 (br, C_6), 35.7 (br, C_4), 31.8 (C_2), 24.8 (br, C_5), 24.4 (C_1).

FTIR (film) ν_{max}**/cm^{-1}** = 3362, 2916, 2852, 1442, 1376, 1343, 1186, 1140, 1118, 1089, 1036, 1010, 969, 946, 914, 885, 856, 819.

HRMS (ESI^+): *m/z* calculated for $C_{12}H_{23}O_3^+$, $[M+H]^+$ = 199.1693; *m/z* found = 199.1694. Δ = 0.74 ppm

(3a*s*,6a*s*,9a*s*)-Dodecahydro-3a^1-oxaphenalen-3a^1-ium chloride, **75**:

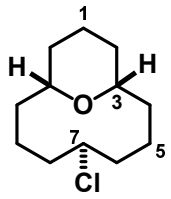


$SOCl_2$ (7.36 $^-$L, 12 mg, 0.10 mmol, 2 eq.) was added to a solution of (1R,5s,9S)-13-oxabicyclo[7.3.1]tridecan-5-ol, **67**, (10 mg, 0.05 mmol, 1 eq.) in CD_2Cl_2 (0.5 mL) at –78 °C in an NMR tube. The sample was immediately transferred to a spectrometer pre-cooled to –40 °C and NMR spectra were recorded.

^{1}H NMR (500 MHz, CD_2Cl_2): δ_H = 5.23 (t, J = 9.3 Hz, 3H, H_3), 2.08 – 1.97 (m, 6H, H_2), 1.99 – 1.83 (m, 9H, H_2, H_1), 1.81 – 1.70 (m, 3H, H_1).

^{13}C NMR (126 MHz, CD_2Cl_2): δ_C = 103.3 (C_3), 33.6 (C_2), 19.7 (C_1).

(1*R*,5*s*,9*S*)-5-Chloro-13-oxabicyclo[7.3.1]tridecane, **74**:



$SOCl_2$ (37 μL, 60 mg, 0.50 mmol, 2 eq.) was added to a solution of (1*R*,5*s*,9*S*)-13-oxabicyclo[7.3.1]tridecan-5-ol, **67**, (50 mg, 0.25 mmol, 1 eq.) in Et_2O. After 5 minutes, the solvent was removed *in vacuo* to give the title compound as a yellow oil (56 mg, Quant.). (<5% (3a*s*,6a*s*,9a*s*)-Dodecahydro-3a^1-oxaphenalen-3a^1-ium chloride, **75**, was observed)

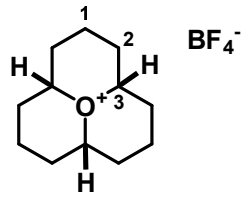
^{1}H NMR (500 MHz, $CDCl_3$): δ_H = 3.81 (p, J = 5.9 Hz, 1H, H_7), 3.21 (t, J = 10.4 Hz, 2H, H_3), 2.09 – 1.98 (m, 2H, H_6), 1.98 – 1.87 (m, 2H, H_6), 1.86 – 1.69 (m, 3H, H_5, H_1), 1.59 – 1.39 (m, 9H, H_5, H_4, H_2, H_1), 1.31 – 1.10 (m, 2H, H_2).

^{13}C NMR (126 MHz, $CDCl_3$): δ_C = 78.8 (br, C_3), 68.1 (br, C_7), 39.6 (br, C_6), 35.2 (br, C_4), 31.6 (C_2), 24.4 (br, C_5), 24.1 (C_1).

FTIR (film) ν_{max}**/cm^{-1}** = 3349, 2928, 2362, 2118, 1639, 1445, 1390, 1082, 879, 810, 734.

HRMS (ESI^+): m/z calculated for $C_{12}H_{21}O^+$, $[M\text{-}Cl]^+$ = 181.1587; m/z found = 181.1588. Δ = 0.42 ppm.

(3a*s*,6a*s*,9a*s*)-Dodecahydro-3a^1-oxaphenalen-3a^1-ium tetrafluoroborate, **77**:



$SOCl_2$ (0.66 mL, 1.08 g, 9.08 mmol, 2 eq.) was added to a solution of (1*R*,5*s*,9*S*)-13-oxabicyclo[7.3.1]tridecan-5-ol, **67**, (900 mg, 4.54 mmol, 1 eq.) in Et_2O(50 mL) . After 5 minutes, the solvent was removed *in vacuo*. $NaBF_4$ (473 mg, 4.31 mmol, 0.95 eq.) was added to a solution of the crude residue in acetone (50 mL). After 2 h, the reaction was filtered (Celite®, 5 mL), eluted (acetone, 3 × 10 mL) and concentrated *in vacuo*. $CHCl_3$ (2 mL) was added to the crude residue and the addition of Et_2O (100 mL) resulted in the precipitation of **77**. The solid was collected by suction filtration, washed (Et_2O, 3 × 5 mL) and dried *in vacuo* to give the title compound as a tan solid (1.02 g, 86%).

Melting Point = 205 ℃ (dec., acetone/Et_2O).

^{1}H NMR (500 MHz, $CDCl_3$): δ_H = 5.27 (t, J = 11.3 Hz, 3H, H_3), 2.07 – 1.94 (m, 9H, H_2, H_1), 1.92 – 1.81 (m, 6H, H_2), 1.79 – 1.68 (m, 3H, H_1).

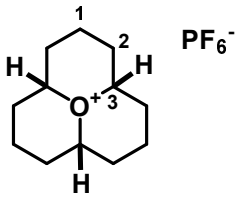
^{13}C NMR (126 MHz, $CDCl_3$): δ_C = 103.5 (C_3), 34.0 (C_2), 19.8 (C_1).

^{19}F NMR (377 MHz, $CDCl_3$): δ_F = -150.5.

FTIR (film) ν_{max}**/cm^{-1}** = 2948, 1453, 1397, 1215, 1053, 967, 882, 837, 743.

HRMS (ESI^+): m/z calculated for $C_{12}H_{18}O^+$, $[M]^+$ = 181.1587; m/z found = 181.1587. Δ = 0.25 ppm.

(3a*s*,6a*s*,9a*s*)-Dodecahydro-3a^1-oxaphenalen-3a^1-ium hexafluorophosphate, **78**:



Hexafluorophosphate salt **78** was prepared according to **General Procedure A** using KPF_6 (44.0 mg, 0.24 mmol, 0.95 eq.) and acetone to give the title compound as a white solid (67 mg, 82%).

Melting Point = 164 ℃ (acetone/Et_2O, dec.).

^{1}H NMR (500 MHz, acetone-d_6): δ_H = 5.05 (tt, J = 11.0, 2.0 Hz, 3H, H_3), 2.19 – 2.13 (m, 6H, H_2), 2.10 – 2.01 (m, 6H, H_2), 1.86 – 1.78 (m, 6H, H_1).

^{13}C NMR (126 MHz, acetone-d_6): δ_C = 105.2 (C_3), 34.4 (C_2), 21.0 (C_1).

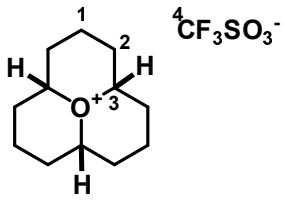
^{19}F NMR (471 MHz, acetone-d_6): δ_F = -72.4 (d, J = 709.4 Hz).

^{31}P NMR (202 MHz, acetone-d_6): δ_P = -137.3 (sept, J = 707.8 Hz).

FTIR (film) ν_{max}**/cm^{-1}** = 2937, 2161, 1591, 1505, 1463, 1450, 1398, 1329, 1268, 1245, 1071, 990, 879, 825, 739.

HRMS (ESI^+): m/z calculated for $C_{12}H_{18}O^+$, $[M]^+$ = 181.1587; m/z found = 181.1587. Δ = 0.00 ppm.

(3a*s*,6a*s*,9a*s*)-Dodecahydro-3a^1-oxaphenalen-3a^1-ium trifluoromethanesulfonate, **79**:



Triflate salt**79** was prepared according to **General Procedure A** using NaOTf (41.3 mg, 0.24 mmol, 0.95 eq.) and MeCN to give the title compound as a hygroscopic white solid (73.6 mg, 89%).

Melting Point = 91 ℃ (MeCN/Et_2O, dec.).

^{1}H NMR (500 MHz, $CDCl_3$): δ_H = 5.30 (t, J = 10.4 Hz, 3H, H_3), 2.07 – 1.83 (m, 15H, H_2, H_1), 1.78 – 1.70 (m, 3H, H_1).

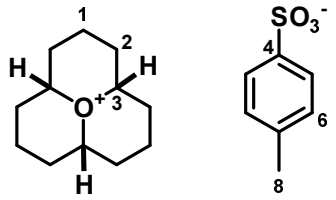
^{13}C NMR (126 MHz, $CDCl_3$): δ_C = 120.8 (q, J = 320.3 Hz, C_4). 103.4 (C_3), 34.1 (C_2), 19.8 (C_1).

^{19}F NMR (471 MHz, $CDCl_3$): δ_F = -78.4.

FTIR (film) ν_{max}**/cm^{-1}** = 3524, 2949, 2361, 1636, 1449, 1397, 1256, 1225, 1156, 1076, 1030, 966, 881, 738, 638.

HRMS (ESI^+): m/z calculated for $C_{12}H_{18}O^+$, $[M]^+$ = 181.1587; m/z found = 181.1589. Δ = 0.92 ppm.

(3a*s*,6a*s*,9a*s*)-Dodecahydro-3a^1-oxaphenalen-3a^1-ium 4-methylbenzenesulfonate, **80**:



Tosylate salt **80** was prepared according to **General Procedure A** using TsONa (46.5 mg, 0.24 mmol, 0.95 eq.) and MeCN to give the title compound as a hygroscopic white solid (64 mg, 73%).

Melting Point: **80** formed an oily hydrate before a melting point could be obtained.

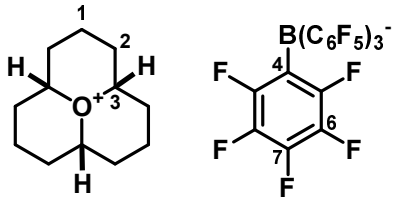
^{1}H NMR (500 MHz, $CDCl_3$): δ_H = 7.81 – 7.76 (m, 2H, H_5), 7.15 (d, J = 7.9 Hz, 2H, H_6), 5.65 (t, J = 11.4 Hz, 3H, H_3), 2.35 (s, 3H, H_8), 2.18 – 2.02 (m, 9H, H_2, H_1), 1.88 – 1.75 (m, 6H, H_2), 1.74 – 1.65 (m, 3H, H_1).

^{13}C NMR (126 MHz, $CDCl_3$): δ_C = 141.4 (C_4), 140.6 (C_5), 128.9 (C_6), 126.3 (C_5), 103.3 (C_3), 34.2 (C_2), 21.5 (C_8), 19.7 (C_1).

FTIR (film) ν_{max}**/cm^{-1}** = 3431, 2924, 1646, 1496, 1446, 1395, 1178, 1120, 1033, 1010, 880, 818, 735, 681

HRMS (ESI^+): m/z calculated for $C_{12}H_{18}O^+$, $[M]^+$ = 181.1587; m/z found = 181.1588. Δ = 0.67 ppm.

(3a*s*,6a*s*,9a*s*)-Dodecahydro-3a^1-oxaphenalen-3a^1-ium, tetrakis(pentafluorophenyl) borate, **81**:



Oxonium ion **81** was prepared according to **General Procedure A** using K[B(C_6F_5)$_4$] (172 mg, 0.24 mmol, 0.95 eq.) and MeCN to give the title compound as a white solid (120 mg, 56%).

Melting Point = 208 ℃ (MeCN/Et_2O, dec.).

^{1}H NMR (500 MHz, $CDCl_3$): δ_H = 4.45 (tt, J = 11.2, 2.0 Hz, 3H, H_3), 2.08 – 1.91 (m, 12H, H_2), 1.86 (dp, J = 14.0, 3.5 Hz, 3H, H_1), 1.63 (dtt, J = 14.1, 12.9, 4.1 Hz, 3H, H_1).

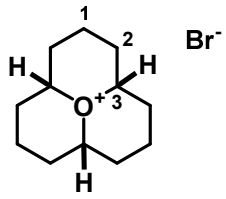
^{13}C NMR (126 MHz, $CDCl_3$): δ_C = 105.2 (C_3), 33.8 (C_2), 20.0 (C_1). ^{13}C NMR Resonances for B(C_6F_5)$_4^-$ were not observed.

^{19}F NMR (471 MHz, $CDCl_3$): δ_F = -132.13 – -132.86 (m, F_5), -162.43 (t, J = 21.5 Hz, F_7), -166.25 – -166.78 (m, F_6).

FTIR (film) ν_{max}**/cm^{-1}** = 2361, 1644, 1514, 1463, 1275, 1087, 979, 880, 756, 736.

HRMS (ESI$^+$): *m/z* calculated for $C_{12}H_{18}O^+$, $[M]^+$ = 181.1587; *m/z* found = 181.1589. Δ = 1.18 ppm.

(3a*s*,6a*s*,9a*s*)-Dodecahydro-3a^1-oxaphenalen-3a^1-ium bromide, **82**:



H_3PO_4 (85% aq., 2.32 mL, 3.96 g, 20.00 mmol, 80 eq.) was added to a stirred mixture of NaBr (2.06 g, 20.00 mmol, 80 eq.) and P_2O_5 (4.00 g, 28.26 mmol, 110 eq.). The HBr generated was continuously bubbled through a solution of (1*R*,5*s*,9*S*)-13-oxabicyclo[7.3.1]tridecan-5-ol, **67**, (50 mg, 0.25 mmol, 1 eq.) in Et_2O (20 mL). Once the addition of H_3PO_4 was complete, the precipitate was collected, washed (Et_2O, 2 mL) and dried *in vacuo* to give the title compound as a white solid (13 mg, 20%).

Melting Point = 89 ℃ (dec., Et_2O)

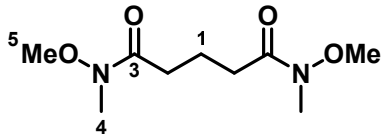
^{1}H NMR (500 MHz, $CDCl_3$): δ_H = 5.43 (t, J = 11.3 Hz, 3H, H_3), 2.19 – 2.06 (m, 9H, H_2, H_1), 2.05 – 1.90 (m, 6H, H_2), 1.86 – 1.75 (m, 3H, H_1).

^{13}C NMR (126 MHz, $CDCl_3$): δ_C = 102.6 (C_3), 34.2 (C_2), 19.7 (C_1).

FTIR (film) ν_{max}**/cm^{-1}** = 3727, 3402, 2951, 2923, 2360, 2342, 1736, 1458, 1443, 1389, 1320, 1291, 1264, 1211, 1117, 1072, 965, 878, 834, 738, 669, 617.

HRMS (ESI^+): *m/z* calculated for $C_{12}H_{18}O^+$, $[M]^+$ = 181.1587; *m/z* found = 181.1587. Δ = 0.25 ppm

N^1,N^5-Dimethoxy-N^1,N^5-dimethylglutaramide, **84**:



Bis amide **84** was prepared according to a modified literature procedure.[35] DMF (3 drops) was added to a suspension of glutaric acid (2.00 g, 15.00 mmol, 1 eq.) and oxalyl chloride (4.23 g, 2.82 mL, 33.00 mmol, 2.2 eq.) in CH_2Cl_2 (25 mL) under N_2. After the evolution of gas had ceased (2 h), the solvent and excess oxalyl chloride were removed *in vacuo*. The crude residue was dissolved in CH_2Cl_2 (15 mL) and *N,O*-dimethylhydroxylamine hydrochloride (3.66 g, 37.50 mmol, 2.5 eq.) was added. Pyridine (7.59 g, 6.60 mL, 75.00 mmol, 5 eq.) was then added dropwise at 0 °C under N_2. Once the addition was complete, the reaction was warmed to r.t. After 20 h, H_2O (15 mL) was added. The organic layer was separated, washed sequentially with HCl (1 M aq., 15 mL) and $NaHCO_3$ (sat. aq., 15 mL) and then dried ($MgSO_4$). The solvent was removed *in vacuo* to give the title compound as an orange oil (2.06 g, 84%).

^{1}H NMR (400 MHz, $CDCl_3$): δ_H = 3.51 (s, 3H, H_5), 2.99 (s, 3H, H_4), 2.33 (t, J = 7.2 Hz, 4H, H_2), 1.77 (p, J = 7.2 Hz, 2H, H_1).

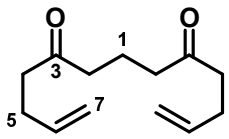
^{13}C NMR (126 MHz, $CDCl_3$): δ_C = 173.8 (C_3), 60.9 (C_5), 31.8 (br, C_4), 30.7 (br, C_2), 19.2 (C_1).

FTIR (film) ν_{max}**/cm^{-1}** = 3505, 2940, 1651, 1417, 1386, 1179, 1115, 991, 874.

LRMS (ESI^+): *m/z* calculated for $C_9H_{18}N_2O_4^+$, $[M+Na]^+$ = 241; *m/z* found = 241.

*Spectra are consistent with literature values.[35]

Trideca-1,12-diene-5,9-dione, **85**:



Magnesium turnings (1.02 g, 42.40 mmol, 4.6 eq.) were heated under vacuum at 150 °C. After 30 mins, they were cooled to r.t. and suspended in THF (20 mL). 4-Bromobut-1-ene (2.90 mL, 3.86 g, 28.40 mmol, 3.1 eq.) was slowly added as a solution in THF (5 mL) to the stirred turnings under N_2. After the reaction flask had returned to r.t. from the addition, the mixture was cooled to 0 °C and a solution of N^1,N^5-dimethoxy-N^1,N^5-dimethylglutaramide, **84**, (2.00 g, 9.20 mmol, 1 eq.) in THF (12 mL) was added. Once the addition was complete the solution was stirred at r.t.. After 2 h, NH_4Cl (sat. aq., 15 mL) was added and the aqueous layer extracted (EtOAc, 3 × 15 mL). The organic layers were dried ($MgSO_4$) and concentrated *in vacuo*. The crude residue was purified by flash column chromatography (EtOAc:Pentane, 10:90, R_f = 0.25) to give the title compound as a white solid (1.42 g, 75%).

Melting Point = 57-58 °C.

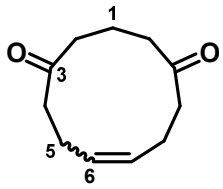
^{1}H NMR (500 MHz, $CDCl_3$): δ_H = 5.78 (ddt, J = 16.8, 10.2, 6.5 Hz, 1H, H_6), 5.05 – 4.93 (m, 2H, H_7), 2.48 (t, J = 7.4 Hz, 2H, H_4), 2.44 (t, J = 7.1 Hz, 2H, H_2), 2.35 – 2.28 (m, 2H, H_5), 1.84 (p, J = 7.1 Hz, 1H, H_1).

^{13}C NMR (126 MHz, $CDCl_3$): δ_C = 209.8 (C_3), 137.2 (C_6), 115.4 (C_7), 41.9 ($C_{4/2}$), 41.7 ($C_{4/2}$), 27.9 (C_5), 17.8 (C_1).

FTIR (film) ν_{max}**/cm^{-1}** = 2942, 1709, 1643, 1413, 1380, 1085, 994, 915, 731, 648.

HRMS (ESI^+): m/z calculated for $C_{13}H_{20}O_2^+$, $[M+Na]^+ = 231.1356$; m/z found = 231.1356. $\Delta = 0.17$ ppm.

Cycloundec-8-ene-1,5-dione, **86**:



HG-II (40 mg, 0.06 mmol, 2.5 mol%) was added as a solution in degassed CH_2Cl_2 (1 mL, Ar sparged) to a solution of trideca-1,12-diene-5,9-dione, **85**, (500 mg, 2.40 mmol, 1 eq.) in degassed CH_2Cl_2 (500 mL, Ar sparged) at 40 °C under N_2. After 16 h, the solvent was removed *in vacuo* and the crude residue purified by flash column chromatography (EtOAc:Pentane, 10:90, R_f = 0.2) to give the title compound as a pale yellow solid as a 6.6:1 mixture of double bond isomers (250 mg, 58%).

Melting Point = 68-69 °C.

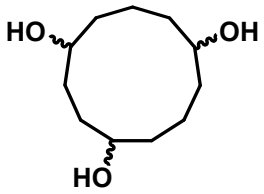
^{1}H NMR (500 MHz, $CDCl_3$): δ_H = Major Isomer: 5.35 – 5.31 (m, 2H, H_6), 2.49 – 2.42 (m, 4H, H_2), 2.32 – 2.27 (m, 6H, H_5, H_4), 1.87 – 1.77 (m, 2H, H_1). Minor Isomer: 5.41 – 5.37 (m, 1H, H_6), 2.41 – 2.37 (m, 2H, H_2). The remaining resonances are obscured by the major isomer; however, they can be obtained from HSQC correlation: 2.32 (H_5, H_4), 1.84 (H_1).

^{13}C NMR (126 MHz, $CDCl_3$): δ_C = Major Isomer: 213.7 (C_3), 129.8 (C_6), 43.0 (C_2), 41.0 (C_4), 31.3 (C_5), 17.0 (C_1). Minor Isomer: 212.7 (C_3), 129.1 (C_6), 43.0 (C_4), 39.6 (C_2), 24.4 (C_5), 17.0 (C_1).

FTIR (film) ν_{max}**/cm^{-1}** = 2930, 2361, 1705, 1436, 1408, 1371, 1265, 1216, 1170, 1128, 1108, 1051, 982, 886, 705.

HRMS (ESI$^+$): *m/z* calculated for $C_{11}H_{17}O_2^+$, $[M+H]^+$ = 181.1223; *m/z* found = 181.1224. Δ = 0.30 ppm

Cycloundecane-1,4,8-triol, mixture of isomers, **87**:

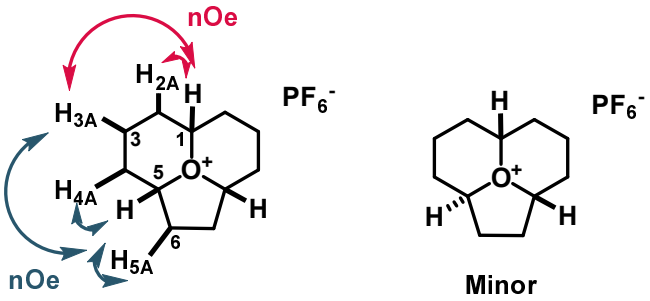


Prepared according to a modified literature procedure for olefin hydroboration using catecholborane.[36] DMAc (0.18 mL) was added to a solution of cycloundec-8-ene-1,5-dione, **86**, (200 mg, 1.11 mmol, 1 eq.) and catecholborane (0.71 mL, 800 mg, 6.67 mmol, 6 eq.) in CH_2Cl_2 (2 mL) at 0 °C under N_2. Once the addition was complete the reaction was warmed to r.t.. After 4 h, the reaction was cooled to 0 °C, diluted (THF, 10 mL) and NaOH (3M aq., 2 mL) was added. H_2O_2 (30% (w/w), 0.2 mL) was added. After 10 mins, brine (15 mL) was added and the mixture was extracted (EtOAc, 6 × 50 mL). The organic extracts were dried ($MgSO_4$), concentrated *in vacuo* and purified by flash column chromatography (CH_2Cl_2:MeOH, 90:10, R_f = 0.1) to give the title compound as a viscous oil (150 mg, 67%)

^{1}H NMR (500 MHz, MeOD): δ_H = 3.85 – 3.70 (br, m, 3H), 1.78 – 1.40 (br, m, 16H).

^{13}C NMR (126 MHz, MeOD): δ_C = 72.9, 72.6, 72.2, 72.2, 71.9, 71.8, 71.5, 36.9, 36.6, 36.4, 36.0, 35.7, 35.4, 35.3, 35.1, 32.6, 32.0, 31.8, 31.7, 21.5, 21.3, 21.0, 20.0.

(2a*R*,5a*r*,8a*S*)-Decahydro-1*H*-2a^1-oxaacenaphthylen-2a^1-ium hexafluorophosphate, **88**:



A suspension of cycloundecane-1,4,8-triol, mixture of isomers, **87**, (150 mg, 0.74 mmol, 1 eq.) and TsOH·H_2O (564, 2.97 mmol, 4 eq.) in PhMe (15 mL) was heated to 110 °C. After 16 h, the solvent was removed *in vacuo* and the crude residue was dissolved in CH_2Cl_2 (3.5 mL). $NaHCO_3$ (217 mg, 2.59 mmol, 3.5 eq.) and KPF_6 (sat. aq., 5 mL) were added and the mixture was stirred at 1000 rpm. After 20 h, the aqueous layer was extracted (CH_2Cl_2, 5 × 5 mL). The organic layers were dried ($MgSO_4$) and concentrated *in vacuo*. The crude residue was dissolved in $CHCl_3$ (1.5 mL) and Et_2O (5 mL) was added. The precipitate was collected by suction filtration, washed (Et_2O, 3 × 5 mL) to give the title compound as a white solid (110 mg, 48%, 7:1 d.r.).

Melting Point = 177 °C ($CHCl_3$/Et_2O, dec.).

^{1}H NMR (600 MHz, CD_3CN): δ_H = Major Isomer: 4.66 (ddt, J = 12.1, 10.5, 2.3 Hz, 1H, H_1), 4.55 – 4.47 (m, 2H, H_{5A}), 2.51 – 2.38 (m, 2H, H_{6A}), 2.27 – 2.18 (m, 2H, H_{4A}), 2.11 – 2.01 (m, 2H, H_2), 2.01 – 1.85 (m, 4H, H_6, H_3), 1.83 – 1.66 (m, 6H, H_4, H_{3A}, H_2).

Minor Isomer: 5.07 – 4.97 (m, 2H), 4.86 (tt, J = 9.5, 4.4 Hz, 1H) The remaining

^{1}H resonances are obscured by the major isomer and could not be determined by HSQC or other 2D methods.

^{13}C NMR (151 MHz, CD_3CN): δ_C = Major Isomer: 100.4 (C_5), 99.8 (C_1), 32.1 (C_2), 30.8 (C_4), 27.5 (C_6), 21.7 (C_3).

Minor Isomer: 97.7, 95.5, 94.1, 29.7, 29.6, 29.2, 29.0, 28.1, 28.1, 22.2, 17.2.

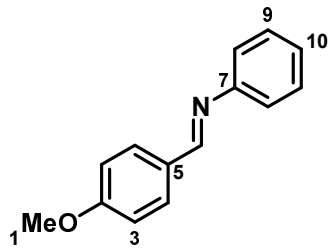
^{19}F NMR (377 MHz, CD_3CN): δ_F = -72.8 (d, J = 706.7 Hz).

^{31}P NMR (162 MHz, CD_3CN): δ_P = -144.6 (sept, J = 706.7 Hz).

FTIR (film) ν_{max}**/cm^{-1}** = 2971, 2260, 1576, 1540, 1465, 1445, 1387, 1212, 1121, 1058, 1006, 945, 922, 873, 822, 741, 707.

HRMS (ESI^+): m/z calculated for $C_{11}H_{19}O^+$, $[M]^+$ = 167.1430; m/z found = 167.1433. Δ = 1.33 ppm.

(*E*)-1-(4-methoxyphenyl)-*N*-phenylmethanimine, **90**:



Prepared according to a modified literature procedure.[37] Aniline (1.82 mL, 1.86 g, 20.00 mmol, 1 eq.) and 4-methoxybenzaldehyde (2.43 mL, 2.72 g, 20.00 mmol, 1 eq.) were dissolved in EtOH (10 mL). After 72 h, the solvent was reduced to 5 mL by a steady stream of N_2. The solid precipitate was collected by suction filtration, washed with EtOH (0 °C, 2 × 1 mL) and dried *in vacuo* to give the title compound as a pale yellow solid (4.20 g, 99%).

Melting Point = 55-56 ℃ (EtOH).

^{1}H NMR (400 MHz, $CDCl_3$): δ_H = 8.39 (s, 1H, H_6), 7.92 – 7.81 (m, 2H, H_{Ar}), 7.44 – 7.34 (m, 2H, H_{Ar}), 7.26 – 7.16 (m, 3H, H_{Ar}), 7.04 – 6.95 (m, 2H, H_{Ar}), 3.88 (s, 3H, H_1).

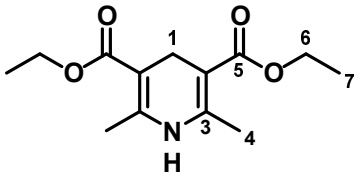
^{13}C NMR (101 MHz, $CDCl_3$): δ_C = 162.5 (C_{Ar}), 159.8 (C_6), 154.4 (C_{Ar}), 132.1 (C_{Ar}), 130.8 (C_{Ar}), 129.3 (C_{Ar}), 125.8 (C_{Ar}), 121.0 (C_{Ar}), 114.4 (C_{Ar}), 55.6 (C_1).

FTIR (film) ν_{max}**/cm^{-1}** = 1623, 1604, 1587, 1573, 1510, 1485, 1421, 1305, 1248, 1162, 1108, 1028, 910, 879, 833, 772, 755, 721, 693, 618.

LRMS (ESI^+): *m/z* calculated for $C_{14}H_{14}NO^+$, $[M+H]^+$ = 212; *m/z* found = 212.

* Spectra are consistent with literature values.[37]

Diethyl 2,6-dimethyl-1,4-dihydropyridine-3,5-dicarboxylate, **91**:



Prepared according to a literature procedure.[38] Formaldehyde (0.37 mL, 37% (w/w) aq., 405 mg, 5.00 mmol, 1 eq.) was added to a solution of ethyl acetoacetate (2.53 mL, 2.60 g, 20.00 mmol, 4 eq.) and NH_4OAc (770 mg, 10.00 mmol, 2 eq.) and the mixture was heated to 85 °C. After 3 h, the yellow precipitate was collected by suction filtration, washed (acetone, 0 °C, 4 × 1.5 mL) and dried under vacuum to give the title compound as a bright yellow solid (732 mg, 58%).

Melting Point = 154-155 °C (H_2O).

^{1}H NMR (400 MHz, $CDCl_3$): δ_H = 5.20 (s, 1H, NH), 4.16 (q, J = 7.1 Hz, 4H, H_6), 3.26 (s, 2H, H_1), 2.18 (s, 6H, H_4), 1.28 (t, J = 7.1 Hz, 6H, H_7).

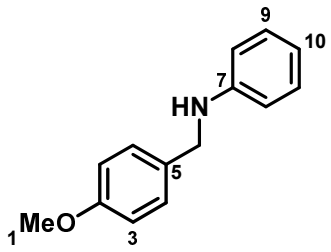
^{13}C NMR (101 MHz, $CDCl_3$): δ_C = 168.2 (C_5), 144.9 (C_3), 99.7 (C_2), 59.8 (C_6), 24.9 (C_1), 19.3 (C_4), 14.6 (C_7).

FTIR (film) ν_{max}**/cm^{-1}** = 3349, 2981, 2360, 1693, 1655, 1509, 1472, 1368, 1321, 1301, 1267, 1218, 1151, 1117, 1091, 1061, 1020, 826, 753, 653.

LRMS (ESI^+): m/z calculated for $C_{13}H_{19}NNaO_4^+$, $[M+H]^+$ = 276; m/z found = 276.

* Spectra are consistent with literature values.[38]

N-(4-Methoxybenzyl)aniline, **92**:



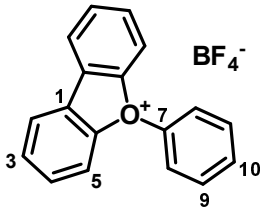
(*E*)-1-(4-Methoxyphenyl)-*N*-phenylmethanimine, **90**, (21.2 mg, 0.10 mmol, 1 eq.), diethyl 2,6-dimethyl-1,4-dihydropyridine-3,5-dicarboxylate, **92**, (30.4 mg, 0.12 mmol, 1.2 eq.) and (3a*s*,6a*s*,9a*s*)-dodecahydro-3a^1-oxaphenalen-3a^1-ium tetrafluoroborate, **77**, (2.68 mg, 0.01 mmol, 10mol%) were dissolved in CH_2Cl_2 (2 mL). After 2 h, the solvent was removed *in vacuo* and the crude residue was purified by flash column chromatography (pentane to EtOAc:pentane, 10:90, R_f = 0.2) to give the title compound as a white solid (15.7 mg, 74%).

^{1}H NMR (400 MHz, $CDCl_3$): δ_H = 7.33 – 7.27 (m, 2H, H_4), 7.23 – 7.16 (m, 2H, H_9), 6.92 – 6.87 (m, 2H, H_3), 6.73 (tt, J = 7.3, 1.1 Hz, 1H, H_{10}), 6.68 – 6.63 (m, 2H, H_8), 4.27 (s, 2H, H_6), 3.82 (s, 3H, H_1).

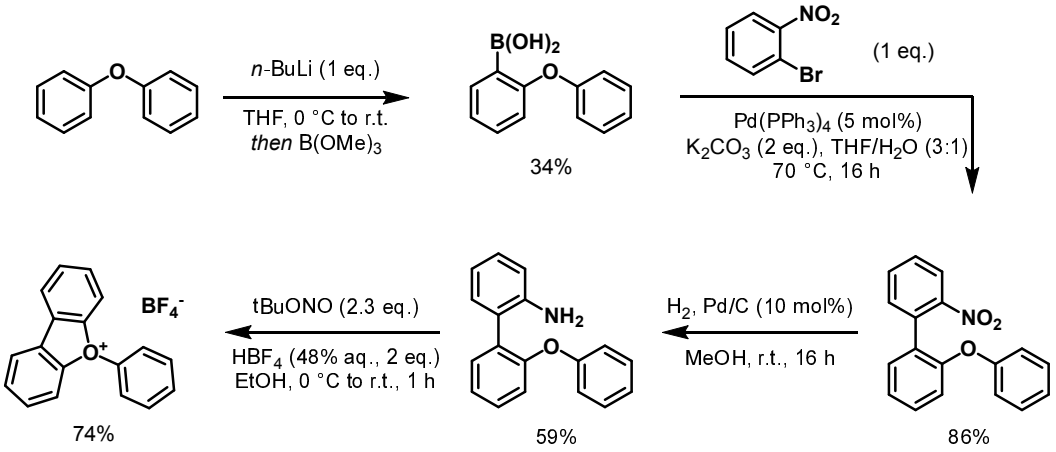
^{13}C NMR (101 MHz, $CDCl_3$): δ_C = 158.9 (C_2), 148.2 (C_7), 131.4 (C_5), 129.3 (C_9), 128.9 (C_4), 117.5 (C_{10}), 114.1 (C_3), 112.9 (C_8), 55.3 (C_1), 47.8 (C_6).

* Spectra are consistent with literature values.[119]

5-Phenyl-5*H*-dibenzo[*b*,*d*]furan-5-ium, tetrafluoroborate, **94**:



Prepared according to the following sequence:



(2-Phenoxyphenyl)boronic acid was prepared according to a modified literature procedure.[120] *n*-BuLi (2.5 M hexanes, 2.00 mL, 5.00 mmol, 1 eq.) was added to a solution of diphenylether (0.79 mL, 850 mg, 5.00 mmol, 1 eq.) in THF (20 mL) at 0 °C. After 30 mins, the reaction was warmed to r.t.. After a further 30 mins, the reaction was cooled to 0 °C and $B(OMe)_3$ (0.613 mL, 511 mg, 5.50 mmol, 1.1 eq.). Once the addition was complete the reaction was warmed to r.t.. After 2 h, HCl (1 M aq., 40 mL) was added, the mixture was extracted (EtOAc, 40 mL) and the organic extracts were dried (Na_2SO_4). The crude residue was purified by flash column chromatography (EtOAc:pentane, 15:85, $R_f = 0.3$) to give (2-phenoxyphenyl)boronic acid as a white solid (362 mg, 34%)

Water (2 mL) and THF (6 mL) were sequentially added to a mixture of (2-phenoxyphenyl)boronic acid (350 mg, 1.64 mmol, 1 eq.), 2-bromonitrobenzene (330 mg, 1.64 mmol, 1 eq.), tetrakis(triphenylphosphine) palladium(0) (95 mg, 0.08 mmol, 5 mol%) and K_2CO_3 (452 mg, 3.27 mmol, 2 eq.) under N_2. Argon was bubbled through the solution for 5 mins and the reaction was heated to 70 °C. After 16 h, H_2O (15 mL) was added, the reaction was extracted with CH_2Cl_2 (3 × 10 mL) and the organic extracts were dried ($MgSO_4$). The crude residue was purified by flash column chromatography (EtOAc:pentane, 10:90 to 15:85, R_f = 0.3) to give 2-nitro-2'-phenoxy-1,1'-biphenyl as a tan solid (410 mg, 86%)

H_2 was bubbled through a solution of 2-nitro-2'-phenoxy-1,1'-biphenyl (400 mg, 1.37 mmol, 1 eq.) and Pd/C (10%, 17 mg, 0.07 mmol, 5 mol%) in MeOH (10 mL) under N_2. After 10 mins the reaction was retained under a positive pressure of H_2. After 16 h, N_2 was bubbled through the solution for 10 mins, the reaction was filtered through Celite® (5 mL), eluted with MeOH (25 mL) and concentrated *in vacuo*. The crude residue was purified by flash column chromatography (EtOAc:pentane, 5:95, R_f = 0.4) to give 2'-phenoxy-[1,1'-biphenyl]-2-amine as a tan solid (210 mg, 59%).

t-BuONO (52 μL, 45 mg, 0.44 mmol, 2.3 eq.) was added to a solution of 2'-phenoxy-[1,1'-biphenyl]-2-amine (50 mg, 0.19 mmol, 1 eq.) and HBF_4 (48% aq., 50 μL 70 mg, 0.38 mmol, 2 eq.) in EtOH (1 mL) at 0 °C. After 1 h, Et_2O (2 mL) was added and the precipitate was collected by suction filtration and washed (Et_2O, 2 × 2 mL). The solid was redissolved in $CHCl_3$ and heated to 50 °C. After 4 h, the mixture was added to Et_2O (4 mL) and the precipitate was collected by suction filtration to give

the title compound as a white solid (47 mg, 74%).

Melting Point = 183 ℃ ($CHCl_3/Et_2O$, dec.).

^{1}H NMR (600 MHz, CD_3CN): δ_H = 8.42 – 8.36 (m, 2H, H_5), 7.94 – 7.83 (m, 7H, H_{10}, H_9, H_8, H_3), 7.76 (ddd, J = 8.8, 7.4, 1.5 Hz, 2H, H_4), 7.58 (ddd, J = 8.8, 0.6, 0.6 Hz, 2H, H_2).

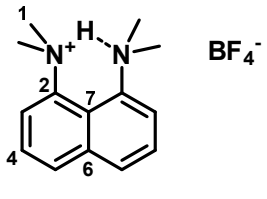
^{13}C NMR (151 MHz, CD_3CN): δ_C = 159.8 (C_6), 155.4 (C_1), 134.4 (C_{Ar}), 133.8 (C_{Ar}), 131.8 (C_4), 131.3 (C_{Ar}), 125.0 (C_5), 122.6 (C_{Ar}, C_1), 112.5 (C_2).

^{19}F NMR (377 MHz, CD_3CN): δ_F = -151.8.

FTIR (film) ν_{max}**/cm^{-1}** = 3074, 1574, 1468, 1458, 1429, 1288, 1162, 1094, 1079, 1049, 993, 892, 831, 766, 749, 684, 625, 612.

HRMS (ESI^+): m/z calculated for $C_{18}H_{13}O^+$, $[M]^+$ = 245.0961; m/z found = 245.0962. Δ = 0.41 ppm.

8-(Dimethylamino)-*N*,*N*-dimethylnaphthalen-1-aminium tetrafluoroborate, **95**:



$HBF_4{\cdot}Et_2O$ (68 μL, 81 mg, 0.50 mmol, 1 eq.) was added to a solution of Proton Sponge® (160 mg, 0.75 mmol, 1.5 eq.) in Et_2O (1 mL). The resulting precipitate was collected by suction filtration, washed with Et_2O (3 × 1.5 mL) and dried *in vacuo* to give the title compound as a tan solid (77 mg, 51%).

Melting Point = 227 ℃ (dec.).

^{1}H NMR (400 MHz, DMSO-d_6): δ_H = 8.14 – 8.06 (m, 4H, H_{Ar}), 7.75 (t, J = 7.9 Hz, 2H, H_{Ar}), 3.18 – 3.10 (m, 12H, H_1), 2.74 (s, 1H, NH).

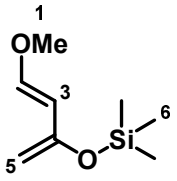
^{13}C NMR (101 MHz, DMSO-d_6): δ_C = 144.6 (C_2), 134.8 (C_{Ar}), 128.9 (C_{Ar}), 126.9 (C_{Ar}), 125.4 (C_{Ar}), 121.8 (C_{Ar}), 119.0 (C_{Ar}), 45.7 (C_6).

^{19}F NMR (377 MHz, DMSO-d_6): δ_F = -148.3.

FTIR (film) ν_{max}**/cm^{-1}** = 1466, 1378, 1302, 1166, 1050, 920, 829, 765, 633.

LRMS (ESI^+): *m/z* calculated for $C_{14}H_{19}N_2^+$, $[M]^+$ = 215; *m/z* found = 215.

(*E*)-((4-Methoxybuta-1,3-dien-2-yl)oxy)trimethylsilane, **97**:



Diene **97** was prepared according to a literature procedure.[121] *trans*-4-Methoxy-3-buten-2-one (2.67 mL, 2.62 g, 26.16 mmol, 1 eq.) and TMSCl (6.68 mL, 5.68 g, 52.28 mmol, 2 eq.) were sequentially added to a solution of Et_3N (8.02 mL, 5.82 g, 57.51 mmol, 2.2 eq.) and $ZnCl_2$ (100 mg, 0.73 mmol, 3 mol%) under N_2 and the resulting solution was heated to 40 °C. After 16 h, Et_2O (50 mL) was added and the reaction was filtered through Celite® (20 mL) and eluted (Et_2O, 40 mL). The reaction was concentrated *in vacuo* and the crude residue was distilled (69-72 °C, 21 mbar) to give the title compound as a colourless oil (3.02 g, 67%).

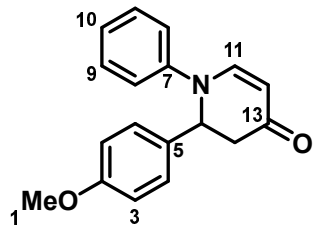
Boiling Point = 69-72 ℃ (21 mbar).

^{1}H NMR (400 MHz, $CDCl_3$): δ_H = 6.83 (d, J = 12.5 Hz, 1H, H_2), 5.35 (d, J = 12.4 Hz, 1H, H_3), 4.09 (d, J = 16.6 Hz, 2H, H_5), 3.58 (s, 3H, H_1), 0.23 (s, 9H, H_6).

^{13}C NMR (101 MHz, $CDCl_3$): δ_C = 154.1 (C_4), 150.5 (C_2), 103.3 (C_3), 91.3 (C_5), 56.6 (C_1), 0.2 (C_6).

* Spectra are consistent with literature values.[121]

2-(4-Methoxyphenyl)-1-phenyl-2,3-dihydropyridin-4(1*H*)-one, **98**:



Danishefsky's diene, **97**, (125 mg, 0.73 mmol, 1.55 eq.) was added to a solution of (*E*)-1-(4-methoxyphenyl)-*N*-phenylmethanimine, **338**, (100 mg, 0.47 mmol, 1 eq.) at r.t. in MeOH (2 mL). After 16 h, the solvent was removed *in vacuo* and the crude residue was purified by flash column chromatography (EtOAc:pentane, 20:80 to 40:60, R_f = 0.15) to give the title compound as a tan solid (111 mg, 85%).

Melting Point = 122-123 ℃.

^{1}H NMR (400 MHz, $CDCl_3$): δ_H = 7.68 – 7.61 (m, 1H, H_{11}), 7.33 – 7.27 (m, 2H, H_9), 7.20 – 7.15 (m, 2H, H_4), 7.11 (tt, J = 7.4, 1.1 Hz, 1H, H_{10}), 7.05 – 7.01 (m, 2H, H_7), 6.87 – 6.80 (m, 2H, H_3), 5.32 – 5.26 (m, 1H, H_{12}), 5.24 (dd, J = 7.1, 3.2 Hz, 1H, H_6), 3.78 (s, 3H, H_1), 3.27 (ddd, J = 16.4, 7.0, 0.9 Hz, 1H, H_{14A}), 2.82 – 2.72 (m, 1H, H_{14B}).

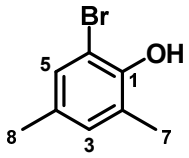
^{13}C NMR (101 MHz, $CDCl_3$): δ_C = 190.6 (C_{13}), 159.3 (C_2), 148.5 (C_{11}), 144.9 (C_7), 129.9 (C_5), 129.7 (C_9), 127.5 (C_4), 124.6 (C_{10}), 118.9 (C_8), 114.5 (C_3), 102.9 (C_{12}), 77.4, 61.5 (C_6), 55.4 (C_1), 43.7 (C_{14}).

FTIR (film) ν_{max}**/cm^{-1}** = 3065, 2926, 1644, 1571, 1509, 1493, 1464, 1439, 1362, 1339, 1322, 1301, 1280, 1248, 1204, 1179, 1100, 1032, 993, 969, 919, 829, 757, 729, 694, 648.

LRMS (ESI$^+$): *m/z* calculated for $C_{18}H_{18}NO_2^+$, $[M+H]^+$ = 280; *m/z* found = 280.

* Spectra are consistent with literature values.[32]

2-Bromo-4,6-dimethylphenol, **155**:



A solution of bromine (4.41 mL, 13.76 g, 8.61 mmol, 1.05 eq.) in CH_2Cl_2 (20 mL) was added *via* a pressure equalising dropping funnel over 5 minutes to a stirred solution of 2,4-dimethylphenol (9.89 mL, 10.00 g, 8.20 mmol, 1 eq.) in CH_2Cl_2 (40 mL) at 0 °C. Once the addition was complete, the reaction was warmed to r.t.. After 1 h, Na_2SO_3 (sat. aq., 30 mL) was added and the aqueous layer was extracted (CH_2Cl_2, 30 mL). The combined organics were dried ($MgSO_4$) and concentrated *in vacuo* to give the title compound as a pale yellow oil (16.25 g, 99 %).

^{1}H NMR (400 MHz, $CDCl_3$): δ_H = 7.16 – 7.10 (m, 1H, H_3), 6.93 – 6.86 (m, 1H, H_5), 5.46 (s, 1H, OH), 2.30 (s, 3H, H_7), 2.26 (s, 3H, H_8).

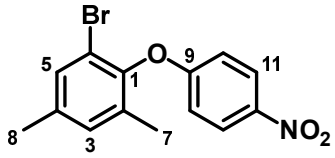
^{13}C NMR (101 MHz, $CDCl_3$): δ_C = 148.2 (C_1), 131.2 (C_5), 130.7 (C_{Ar}), 129.5 (C_3), 125.5 (C_{Ar}), 109.8 (C_6), 20.2 (C_8), 16.7 (C_7).

FTIR (film) ν_{max}**/cm^{-1}** = 3516, 2921, 1482, 1378, 1323, 1288, 1250, 1231, 1209, 1189, 1112, 989, 958, 849, 822, 763, 714.

HRMS (EI^+): *m/z* calculated for $C_8H_9{}^{79}BrO^+$, $[M]^+$ = 199.9831; *m/z* found = 199.9837. Δ = 3.40 ppm.

* Spectra are consistent with literature values.[122]

1-Bromo-3,5-dimethyl-2-(4-nitrophenoxy)benzene, **157**:



Bromide **157** was prepared according to **General Procedure B** on a 20 mmol scale using 2-bromo-4,6-dimethylphenol, **155**, (4.02 g, 20.00 mmol, 1.00 eq.), 1-fluoro-4-nitrobenzene (2.82 g, 20.00 mmol, 1.00 eq.) and K_2CO_3 (5.53 g, 40.00 mmol, 2.00 eq.) in DMF (50 mL). No further purification was required to give the title compound as a bright yellow solid (5.93 g, 92%).

Melting Point = 74-76 ℃ (Et_2O).

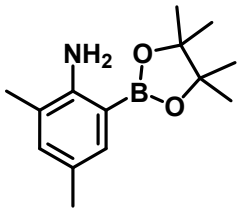
^{1}H NMR (500 MHz, $CDCl_3$): δ_H = 8.24 – 8.18 (m, 2H, H_{11}), 7.36 – 7.32 (m, 1H, H_5), 7.10 – 7.05 (m, 1H, H_3), 6.93 – 6.86 (m, 2H, H_{10}), 2.36 (s, 3H, H_8), 2.16 (s, 3H, H_7).

^{13}C NMR (126 MHz, $CDCl_3$): δ_C = 162.4 (C_9), 146.8 (C_1), 142.7 (C_{12}), 137.6 (C_{Ar}), 133.0 (C_{Ar}), 132.1 (C_5), 131.8 (C_3), 126.3 (C_{11}), 116.7 (C_6), 115.3 (C_{10}), 20.8 (C_8), 16.9 (C_7).

FTIR (film) ν_{max}**/cm^{-1}** = 1610, 1590, 1515, 1489, 1469, 1340, 1278, 1235, 1164, 1110, 1038, 909, 871, 847, 815, 781, 748, 722, 686, 644, 619.

HRMS ($APCI^-$): *m/z* calculated for $C_{14}H_{11}{}^{79}BrNO_3^-$, $[M\text{-}H]^-$ = 319.9928; *m/z* found = 319.9918. Δ = -3.00 ppm.

2,4-Dimethyl-6-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)aniline, **158**:

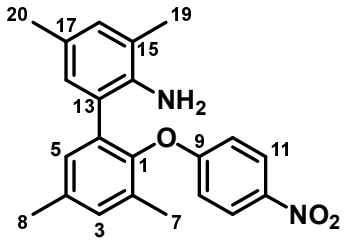


Aniline **158** was prepared according to a modified literature procedure.[68] 1,4-Dioxane (120 mL) was added to a mixture of 2-bromo-4,6-dimethylaniline (3.00 g, 15.00 mmol, 1 eq.), $Pd(dppf)Cl_2 \cdot CH_2Cl_2$ (366 mg, 0.45 mmol, 3 mol%), KOAc (4.41 g, 45.00 mmol, 3 eq.) and B_2Pin_2 (5.71 g, 22.50 mmol, 1.5 eq.) under N_2. Argon was bubbled through the mixture for 5 mins and the reaction was heated to 95 °C. After 24 h, H_2O (100 mL) was added. The resulting mixture was extracted (CH_2Cl_2, 3 × 50 mL), the combined organic extracts were dried ($MgSO_4$) and concentrated *in vacuo*. The crude residue was suspended in pentane (100 mL), filtered through Celite® (20 mL), eluted (pentane, 3 × 30 mL) and concentrated *in vacuo*.

158 was stored in solid form and used without further purification assuming 100% conversion.

The crude solid was dissolved in PhMe (52 mL) to give a total solution volume of 60 mL. The solution was stored at 0 °C and used within 2 weeks of being made.

3,3',5,5'-Tetramethyl-2'-(4-nitrophenoxy)-[1,1'-biphenyl]-2-amine, **159**:



Aniline **159** was prepared according to **General Procedure C** using 1-bromo-3,5-dimethyl-2-(4-nitrophenoxy)benzene, **157** (2.00 g, 6.23 mmol, 1 eq.), 2,4-dimethyl-6-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)aniline, **158**, (9.35 mmo1, 1.5 eq.) in PhMe (38 mL), H_2O (60 mL), Pd(dppf)Cl_2·CH_2Cl_2 (254 mg, 0.31 mmol, 5mol%) and Na_2CO_3 (2.64 g, 24.92 mmol, 4 eq.) in PhMe (22 mL). The crude residue was purified by flash column chromatography (EtOAc :Pentane, 7:93, R_f = 0.2). The crude product was suspended in IPA (20 mL) and H_2O (40 mL) was added. The solid precipitate was collected by suction filtration to give the title compound as a bright yellow solid (1.43 g, 63%).

Melting Point = 149-150 ℃.

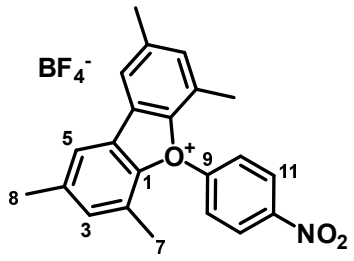
^{1}H NMR (600 MHz, $CDCl_3$): δ_H = 8.04 – 7.96 (m, 2H, H_{11}), 7.14 – 7.10 (m, 1H, H_3), 7.05 (t, J = 1.5 Hz, 1H, H_5), 6.75 – 6.72 (m, 1H, H_{16}), 6.70 (dd, J = 9.3, 1.1 Hz, 2H, H_{10}), 6.57 (d, J = 2.1 Hz, 1H, H_{18}), 2.37 (s, 3H, H_8), 2.17 (s, 3H, H_7), 2.11 (s, 3H, H_{19}), 2.07 (s, 3H, H_{20}). NH_2 not observed.

^{13}C NMR (151 MHz, $CDCl_3$): δ_C = 163.1 (C_9), 147.6 (C_1), 141.9 (C_{12}), 138.7 (br, C_{14}), 136.2 (C_{Ar}), 132.7 (C_6), 131.8 (C_3), 131.4 (C_{16}), 130.7 (C_{Ar}), 130.5 (C_5), 128.7 (C_{18}), 127.3 (br, C_{Ar}), 125.5 (C_{11}), 123.2 (br, C_{13}), 122.8 (br, C_{Ar}), 115.3 (C_{10}), 20.9 (C_8), 20.2 (C_{20}), 17.8 (C_{19}), 16.4 (C_7).

FTIR (film) ν_{max}**/cm^{-1}** = 3385, 2920, 2342, 1588, 1512, 1488, 1340, 1240, 1197, 1163, 1111, 870, 849, 750.

HRMS (ESI$^+$): *m/z* calculated for $C_{22}H_{23}N_2O_3^+$, $[M+H]^+$ = 363.1703; *m/z* found = 363.1700. Δ = -0.93 ppm.

2,4,6,8-Tetramethyl-5-(4-nitrophenyl)-5*H*-dibenzo[*b*,*d*]furan-5-ium tetrafluoroborate, **160**:



Oxonium ion **183** was prepared according to **General Procedure G** using 3,3',5,5'-tetramethyl-2'-(2-nitrophenoxy)-[1,1'-biphenyl]-2-amine, **159**, (1.40 g, 3.87 mmol, 1 eq.), *t*-BuONO (2.23 mL, 1.94 g, 19.35 mmol, 5 eq.), and HBF_4 (48% aq., 2.50 mL, 3.53 g, 19.35 mmol, 5 eq.) to give the title compound as a tan solid (1.10 g, 65%).

Melting Point = 204 ℃ (MeCN, dec.).

^{1}H NMR (500 MHz, CD_3CN): δ_H = 8.49 – 8.42 (m, 2H, H_{10}), 8.04 – 7.98 (m, 2H, H_{11}), 7.93 – 7.89 (m, 2H, H_5), 7.34 – 7.30 (m, 2H, H_3), 2.51 (s, 6H, H_8), 2.13 (s, 6H, H_7).

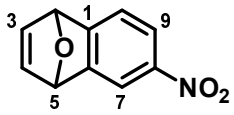
^{13}C NMR (126 MHz, CD_3CN): δ_C = 162.3 (C_9), 161.4 (C_1), 150.4 (C_{12}), 143.4 (C_{Ar}), 135.5 (C_3), 128.5 (C_{10}), 124.7 (C_{Ar}), 124.2 (C_{Ar}), 123.8 (C_{11}), 122.7 (C_5), 21.1 (C_8), 16.7 (C_7).

^{19}F NMR (471 MHz, CD_3CN): δ_F = -151.8.

FTIR (film) ν_{max}**/cm^{-1}** = 3071, 1581, 1538, 1479, 1356, 1309, 1048, 1036, 1001, 859, 781, 738, 675.

HRMS (ESI^+): *m/z* calculated for $C_{22}H_{20}NO_3^+$, $[M]^+$ = 346.1438; *m/z* found = 346.1437. Δ = -0.32 ppm.

6-Nitro-1,4-dihydro-1,4-epoxynaphthalene, **161**:



K_3PO_4 (1.06 g, 5 mmol, 5 eq.) was added to a solution of 2,4,6,8-tetramethyl-5-(4-nitrophenyl)-5*H*-dibenzo[*b*,*d*]furan-5-ium tetrafluoroborate, **160**, (433 mg, 1.00 mmol, 1 eq.) and Furan (0.37 mL, 340 mg, 5 mmol, 5 eq.) in MeCN (6 mL). After 16 h, the reaction was filtered through Celite® (5 mL), eluted (CH_2Cl_2, 4 × 10 mL) and concentrated *in vacuo*. The crude residue was purified by flash column chromatography (Et_2O:Pentane, 15:85, R_f = 0.3) to give the title compound as a white solid (189 mg, 99%).

Melting Point = 108-109 ℃.

^{1}H NMR (400 MHz, $CDCl_3$): δ_H = 8.04 (d, J = 2.0 Hz, 1H, H_7), 7.98 (dd, J = 7.8, 2.0 Hz, 1H, H_9), 7.36 (d, J = 7.8 Hz, 1H, H_{10}), 7.10 (dd, J = 5.5, 1.9 Hz, 1H, $H_{3/4}$), 7.05 (dd, J = 5.5, 1.9 Hz, 1H, $H_{3/4}$), 5.83 – 5.78 (m, 2H, H_2, H_5).

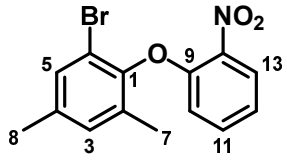
^{13}C NMR (126 MHz, $CDCl_3$): δ_C = 156.6 (C_1), 151.4 (C_6), 145.9 (C_8), 143.6 ($C_{3/4}$), 142.5 ($C_{3/4}$), 122.5 (C_9), 120.2 (C_{10}), 115.4 (C_7), 82.2 ($C_{2/5}$), 82.2 ($C_{2/5}$).

FTIR (film) ν_{max}**/cm^{-1}** = 3097, 1604, 1517, 1447, 1344, 1280, 1140, 1060, 991, 872, 848, 794, 753, 735, 699, 672, 640.

HRMS (APCI$^-$): m/z calculated for $C_{10}H_6NO_3^+$, [M-H]$^-$ = 188.0353; m/z found = 188.0342. Δ = -6.20 ppm.

* Spectra are consistent with literature values.[123]

1-Bromo-3,5-dimethyl-2-(2-nitrophenoxy)benzene, **162**:



Bromide **162** was prepared according to **General Procedure B** on a 10 mmol scale using 2-bromo-4,6-dimethylphenol, **155**, (2.01 g, 10.00 mmol, 1.00 eq.), 1-fluoro-2-nitrobenzene (1.41 g, 10.00 mmol, 1.00 eq.) and K_2CO_3 (2.76 g, 20.00 mmol, 2.00 eq.) in DMF (25 mL). No further purification was required to give the title compound as a bright yellow solid (2.88 g, 89 %).

Melting Point = 74-76 ℃ (Et_2O).

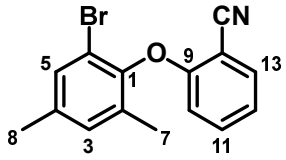
^{1}H NMR (500 MHz, $CDCl_3$): δ_H = 7.97 (dd, J = 8.1, 1.7 Hz, 1H, H_{13}), 7.39 (ddd, J = 8.5, 7.4, 1.7 Hz, 1H, H_{12}), 7.34 – 7.28 (m, 1H, H_5), 7.10 (ddd, J = 8.4, 7.3, 1.2 Hz, 1H, H_{11}), 7.06 – 7.02 (m, 1H, H_3), 6.57 (dd, J = 8.4, 1.2 Hz, 1H, H_{10}), 2.33 (s, 3H, H_8), 2.18 (s, 3H, H_7).

^{13}C NMR (126 MHz, $CDCl_3$): δ_C = 150.6 (C_9), 146.5 (C_1), 139.3 (C_{14}), 137.4 (C_{Ar}), 134.2 (C_{12}), 133.1 (C_{Ar}), 132.0 (C_5), 131.7 (C_3), 126.2 (C_{13}), 121.8 (C_{11}), 116.7 (C_6), 115.5 (C_{10}), 20.8 (C_8), 16.8 (C_7).

FTIR (film) ν_{max}**/cm^{-1}** = 1609, 1525, 1470, 1347, 1280, 1238, 1204, 1162, 1122, 877, 841, 818, 774, 740, 661.

HRMS (APCI$^+$): m/z calculated for $C_{14}H_{13}{}^{79}BrNO_3^+$, $[M+H]^+$ = 322.0073; m/z found = 322.0074. Δ = 0.16 ppm.

2-(2-Bromo-4,6-dimethylphenoxy)benzonitrile, **163**:



Bromide **163** was prepared according to **General Procedure B** on a 5.00 mmol scale using 2-bromo-4,6-dimethylphenol, **155**, (1.00 g, 5.00 mmol, 1.00 eq.), 2-fluorobenzonitrile (605 mg, 5.00 mmol, 1.00 eq.) and K_2CO_3 (1.38 g, 10.00 mmol, 2.00 eq.) in DMF (12.5 mL). The crude residue was purified by flash column chromatography (Et_2O:Pentane, 4:96, $R_f = 0.2$) to give the title compound as a white solid (770 mg, 51%).

Melting Point = 89-90 ℃.

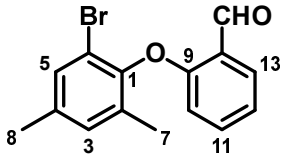
^{1}H NMR (500 MHz, $CDCl_3$): δ_H = 7.67 (dd, J = 7.7, 1.7 Hz, 1H, H_{13}), 7.40 (ddd, J = 8.9, 7.6, 1.7 Hz, 1H, H_{11}), 7.32 – 7.29 (m, 1H, H_5), 7.08 (ddd, J = 7.6, 7.6, 1.0 Hz, 1H, H_{12}), 7.05 – 7.02 (m, 1H, H_3), 6.48 (d, J = 8.5 Hz, 1H, H_{10}), 2.33 (s, 3H, H_5), 2.17 (s, 3H, H_3).

^{13}C NMR (126 MHz, $CDCl_3$): δ_C = 159.1 (C_9), 146.9 (C_1), 137.5 (C_{Ar}), 134.4 (C_{11}), 134.2 (C_{13}), 133.1 (C_{Ar}), 132.1 (C_5), 131.7 (C_3), 122.3 (C_{12}), 116.9 (C_{Ar}), 116.2 (C_{14}), 113.8 (C_{10}), 102.2 (C_{10}), 20.9 (C_8), 16.9 (C_7).

FTIR (film) ν_{max}**/cm^{-1}** = 2922, 2359, 2229, 1601, 1579, 1485, 1470, 1447, 1380, 1281, 1239, 1205, 1161, 1124, 1103, 1037, 991, 871, 853, 821, 783, 756, 724.

HRMS (APCI$^+$): m/z calculated for $C_{15}H_{13}{}^{79}BrNO^+$, $[M+H]^+$ = 302.0175; m/z found = 302.0175. Δ = 0.15 ppm.

2-(2-Bromo-4,6-dimethylphenoxy)benzaldehyde, **164**:



Bromide **164** was prepared according to **General Procedure B** on a 15.00 mmol scale using 2-bromo-4,6-dimethylphenol, **155**, (3.02 g, 15.00 mmol, 1.00 eq.), 2-fluorobenzaldehyde (1.58 mL, 1.86 g, 15.00 mmol, 1.00 eq.) and K_2CO_3 (4.15 g, 30.00 mmol, 2.00 eq.) in DMF (37.5 mL). The crude residue was purified by flash column chromatography (Et_2O:Pentane, 4:96 to 7:93, R_f = 0.2) to give the title compound as a white solid (1.51 g, 33%).

Melting Point = 76-77 ℃.

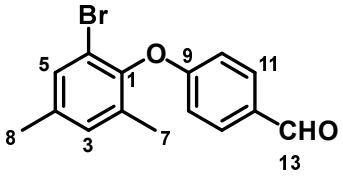
^{1}H NMR (500 MHz, $CDCl_3$): δ_H = 10.78 (s, 1H, H_{15}), 7.96 (dd, J = 7.5, 1.9 Hz, 1H, H_{13}), 7.42 (ddd, J = 8.5, 7.5, 1.9 Hz, 1H, H_{11}), 7.36 – 7.32 (m, 1H, H_5), 7.11 (dd, J = 7.5, 7.5 Hz, 1H, H_{12}), 7.09 – 7.05 (m, 1H, H_3) , 6.48 (d, J = 8.5 Hz, 1H, H_{10}), 2.36 (s, 3H, H_8), 2.21 (s, 3H, H_7).

^{13}C NMR (126 MHz, $CDCl_3$): δ_C = 189.6 (C_{15}), 159.9 (C_9) 147.0 (C_1), 137.3 (C_{Ar}), 136.0 (C_{11}), 133.3 (C_{Ar}), 132.1 (C_5), 131.6 (C_3), 128.8 (C_{13}), 124.8 (C_{14}), 122.3 (C_{12}), 117.1 (C_6), 113.9 (C_{10}), 20.8 (C_8), 17.1 (C_7).

FTIR (film) ν_{max}**/cm^{-1}** = 2922, 2858, 2359, 1689, 1600, 1581, 1471, 1454, 1435, 1395, 1304, 1279, 1231, 1211, 1187, 1155, 1124, 1097, 1036, 990, 958, 869, 852, 827, 812, 783, 755, 715, 647.

HRMS (ESI$^+$): m/z calculated for $C_{15}H_{14}{}^{79}BrO_2^+$, $[M+H]^+$ = 305.0172; m/z found = 305.0173. Δ = 0.44 ppm.

2'-(2-Methoxyphenoxy)-3,3',5,5'-tetramethyl-[1,1'-biphenyl]-2-amine, **165**:



Bromide **165** was prepared according to **General Procedure B** on a 20.00 mmol scale using 2-bromo-4,6-dimethylphenol, **155**, (4.02 g, 20.00 mmol, 1.00 eq.), 4-fluorobenzaldehyde (2.14 mL, 2.48 g, 20.00 mmol, 1.00 eq.) and K_2CO_3 (5.53 g, 40.00 mmol, 2.00 eq.) in DMF (50 mL). The crude residue was purified by flash column chromatography (Et_2O:Pentane, 5:95 to 14:86, $R_f = 0.3$) to give the title compound as a white solid (3.48 g, 57%).

Melting Point = 55-57 ℃.

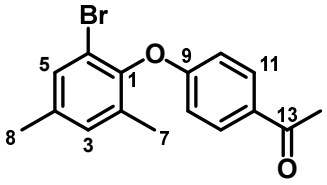
^{1}H NMR (500 MHz, $CDCl_3$): δ_H = 9.90 (s, 1H, H_{13}), 7.86 – 7.79 (m, 2H, H_{11}), 7.33 – 7.29 (m, 1H, H_5), 7.06 – 7.01 (m, 1H, H_3), 6.94 – 6.87 (m, 2H, H_{10}), 2.33 (s, 3H, H_8), 2.13 (s, 3H, H_7).

^{13}C NMR (126 MHz, $CDCl_3$): δ_C = 190.7 (C_{13}), 162.2 (C_9), 146.8 (C_1), 137.1 (C_{Ar}), 132.9 (C_{Ar}), 132.1 (C_{11}), 131.8 (C_5), 131.5 (C_3), 131.0 (C_{12}), 116.7 (C_6), 115.4 (C_{10}), 20.6 (C_8), 16.8 (C_7).

FTIR (film) ν_{max}**/cm^{-1}** = 2922, 2736, 2361, 1695, 1606, 1596, 1584, 1502, 1470, 1391, 1299, 1279, 1232, 1154, 1122, 1105, 868, 831, 805, 711, 648, 618.

HRMS (ESI^+): *m/z* calculated for $C_{15}H_{14}{}^{79}BrO_2^+$, $[M+H]^+$ = 305.0172; *m/z* found = 305.0172. Δ = 0.14 ppm.

1-(4-(2-Bromo-4,6-dimethylphenoxy)phenyl)ethan-1-one, **166**:



Bromide **166** was prepared according to **General Procedure B** on a 5.00 mmol scale using 2-bromo-4,6-dimethylphenol, **155**, (1.01 g, 5.00 mmol, 1.00 eq.), 4-fluoroacetophenone (0.606 mL, 691 mg, 5.00 mmol, 1.00 eq.) and K_2CO_3 (1.38 g, 10.00 mmol, 2.00 eq.) in DMF (12.5 mL). The crude residue was purified by flash column chromatography (Et_2O:Pentane, 7:93, $R_f = 0.25$) to give the title compound as a pale yellow solid (550 mg, 35%).

Melting Point = 63-65 ℃.

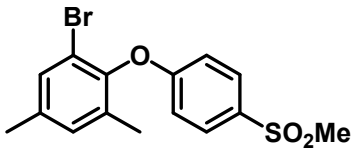
^{1}H NMR (500 MHz, $CDCl_3$): δ_H = 7.96 – 7.88 (m, 2H, H_{11}), 7.33 – 7.29 (m, 1H, H_5), 7.05 – 7.01 (m, 1H, H_3), 6.86 – 6.80 (m, 2H, H_{10}), 2.55 (s, 3H, H_{14}), 2.33 (s, 3H, H_8), 2.13 (s, 3H, H_7).

^{13}C NMR (126 MHz, $CDCl_3$): δ_C = 196.8 (C_{13}), 161.2 (C_9), 147.0 (C_1), 137.0 (C_{Ar}), 133.1 (C_{Ar}), 131.9 (C_5), 131.6 (C_{12}), 131.6 (C_3), 130.9 (C_{11}), 117.0 (C_6), 114.8 (C_{10}), 26.5 (C_{14}), 20.7 (C_8), 16.9 (C_7).

FTIR (film) ν_{max}**/cm^{-1}** = 2922, 1678, 1595, 1502, 1471, 1416, 1357, 1301, 1266, 1230, 1218, 1163, 1123, 1009, 957, 864, 836, 819, 784, 630.

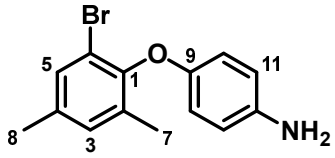
HRMS (ESI^+): m/z calculated for $C_{16}H_{16}{}^{79}BrO_2^+$, $[M+H]^+ = 319.0328$; m/z found = 319.0329. Δ = 0.34 ppm.

1-Bromo-3,5-dimethyl-2-(4-(methylsulfonyl)phenoxy)benzene, **167**:



Bromide **167** was prepared according to **General Procedure B** on a 5.00 mmol scale using 2-bromo-4,6-dimethylphenol, **155**, (1.01 g, 5.00 mmol, 1.00 eq.), 4-Fluorophenyl methyl sulfone (871 mg, 5.00 mmol, 1.00 eq.) and K_2CO_3 (1.38 g, 10.00 mmol, 2.00 eq.) in DMF (12.5 mL). The crude residue was purified by flash column chromatography (EtOAc:Pentane, 10:90 to 20:80, R_f = 0.25). The title compound was obtained as an inseparable mixture (1:2, **167**:4-fluorophenyl methyl sulfone) and was used without further purification (1.12 g comprising 565 mg, **167**, 32%).

4-(2-Bromo-4,6-dimethylphenoxy)aniline, **168**:



EtOAc (40 mL) was added to a mixture of 1-bromo-3,5-dimethyl-2-(4-nitrophenoxy)benzene, **157**, (4.00 g, 12.5 mmol, 1 eq.) and Pd/C (10 wt%, 330 mg, 0.31 mmol, 2.5 mol%) under N_2. The reaction was purged with H_2 and stirred under a positive pressure of H_2. After 24 h, N_2 was bubbled through the solution for 10 mins and then filtered through Celite® (10 mL). The Celite® was eluted (EtOAc, 2 × 10 mL) and the organic fractions were concentrated *in vacuo* to obtain the title compound as an off-white solid (3.37 g, 92%).

Melting Point = 68-69 ℃.

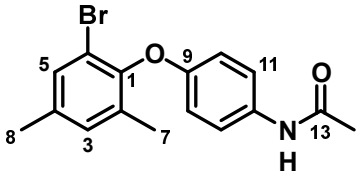
^{1}H NMR (500 MHz, $CDCl_3$): δ_H = 7.30 (d, J = 2.1 Hz, 1H, H_5), 7.01 (d, J = 2.1 Hz, 1H, H_3), 6.63 (s, 4H, H_{11}, H_{10}), 3.54 – 3.22 (br s, 2H, NH), 2.33 (s, 3H, H_8), 2.16 (s, 3H, H_7).

^{13}C NMR (126 MHz, $CDCl_3$): δ_C = 150.6 (C_9), 148.2 (C_1), 140.8 (C_{12}), 136.0 (C_{Ar}), 133.5 (C_{Ar}), 131.6 (C_5), 131.4 (C_3), 117.6 (C_6), 116.5 ($C_{11/10}$), 115.7 ($C_{11/10}$), 20.7 (C_8), 17.1 (C_7).

FTIR (film) ν_{max}**/cm^{-1}** =3363, 2919, 2850, 1624, 1504, 1470, 1321, 1278, 1216, 1197, 1164, 1123, 1009, 907, 863, 824, 800, 729, 647.

HRMS (ESI^+): m/z calculated for $C_{14}H_{15}{}^{79}BrNO^+$, $[M+H]^+$ = 292.0332; m/z found = 292.0335. Δ = 1.32 ppm.

N-(4-(2-Bromo-4,6-dimethylphenoxy)phenyl)acetamide, **169**:



Ac_2O (0.44 mL, 473 mg, 4.64 mmol, 1.5 eq.) was added to a solution of 4-(2-bromo-4,6-dimethylphenoxy)aniline, **168**, (900 mg, 3.09 mmol, 1 eq.) in CH_2Cl_2 (20 mL) at 0 °C. Once the addition was complete the reaction was warmed to r.t.. After 16 h, $NaHCO_3$ (sat. aq., 20 mL) was added, the reaction mixture was extracted (CH_2Cl_2, 3 × 15 mL). The organic extracts were washed with $NaHCO_3$ (sat. aq., 20 mL), dried ($MgSO_4$) and concentrated *in vacuo* to give the title compound as a white solid (1.01 g, 98%).

Melting Point = 142-144 ℃.

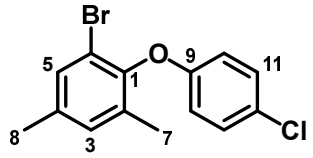
^{1}H NMR (500 MHz, $CDCl_3$): δ_H = 7.40 – 7.35 (m, 3H, NH, H_{11}), 7.29 – 7.27 (m, 1H, H_5), 7.01 – 6.98 (m, 1H, H_3), 6.74 – 6.71 (m, 2H, H_9), 2.31 (s, 3H, H_{14}), 2.15 (s, 3H, H_8), 2.12 (s, 3H, H_7).

^{13}C NMR (126 MHz, $CDCl_3$): δ_C = 168.5 (C_{13}), 154.2 (C_5), 147.6 (C_1), 136.5 (C_{Ar}), 133.4 (C_{Ar}), 132.0 (C_{12}), 131.7 (C_5), 131.5 (C_3), 122.0 (C_{11}), 117.3 (C_6), 115.2 (C_{12}), 24.4 (C_{14}), 20.7 (C_5), 17.0 (C_3).

FTIR (film) ν_{max}**/cm^{-1}** = 3294, 2923, 1660, 1608, 1547, 1504, 1470, 1410, 1371, 1316, 1280, 1214, 1166, 1123, 1014, 909, 868, 830, 810, 732.

HRMS (ESI^+): *m/z* calculated for $C_{16}H_{17}{}^{79}BrNO_2^+$, $[M+H]^+$ = 334.0437; *m/z* found = 334.0438. Δ = 0.13 ppm.

1-Bromo-2-(4-chlorophenoxy)-3,5-dimethylbenzene, **170**:



Prepared according to a modified literature chlorination procedure.[69] 4-(2-Bromo-4,6-dimethylphenoxy)aniline, **168**, (1.40 g, 4.81 mmol, 1 eq.) was slowly added over 5 mins to a solution of *t*-BuONO (0.913 mL, 792 mg, 7.70 mmol, 1.6 eq.) and $CuCl_2$ (840 mg, 6.25 mmol, 1.3 eq.) in MeCN (20 mL) at r.t.. After 16 h, H_2O (20 mL) was added and the reaction mixture was extracted (Et_2O, 3 × 10 mL). The organic extracts were washed (H_2O, 20 mL), dried ($MgSO_4$), concentrated *in vacuo* and purified by flash column chromatography (Pentane, $R_f = 0.5$) to give the title compound as a white solid (818 mg, 54%).

Melting Point = 64-66 ℃.

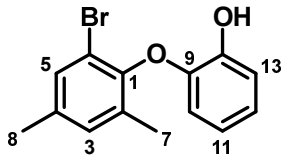
^{1}H NMR (500 MHz, $CDCl_3$): δ_H = 7.30 – 7.28 (m, 1H, H_5), 7.24 – 7.19 (m, 2H, H_{11}), 7.02 – 7.00 (m, 1H, H_3), 6.74 – 6.70 (m, 2H, H_{10}), 2.32 (s, 3H, H_8), 2.12 (s, 3H, H_7).

^{13}C NMR (126 MHz, $CDCl_3$): δ_C = 156.1 (C_9), 147.4 (C_1), 136.7 (C_{Ar}), 133.3 (C_{Ar}), 131.8 (C_5), 131.5 (C_3), 129.7 (C_{11}), 126.9 (C_{12}), 117.2 (C_6), 116.3 (C_{10}), 20.7 (C_8), 16.9 (C_7).

FTIR (film) ν_{max}**/cm^{-1}** = 1542, 1485, 1472, 1318, 1283, 1227, 1163, 1122, 1093, 1009, 854, 825, 729, 650.

HRMS (EI^+): *m/z* calculated for $C_{14}H_{12}{}^{79}Br^{35}ClO^+$, $[M]^+$ = 309.9755; *m/z* found = 309.976. Δ = -2.12 ppm.

2-(2-Bromo-4,6-dimethylphenoxy)phenol, **171**:



Prepared according to a modified literature procedure.[70] *m*-CPBA (77%, 1.84 g, 8.22 mmol, 2.5 eq.) was added to a solution of 2-(2-bromo-4,6-dimethylphenoxy)benzaldehyde, **164**, (1.00 g, 3.29 mmol, 1 eq.) in $CHCl_3$ (20 mL) at r.t.. After 24 h, the reaction mixture was washed (Na_2SO_3, sat. aq., 20 mL), dried ($MgSO_4$) and concentrated *in vacuo*. The crude residue was dissolved in MeOH (20 mL) and concentrated HCl (1 drop) was added. After 30 mins, the reaction was concentrated *in vacuo* and the crude residue was purified by flash column chromatography (Et_2O:Pentane, 4:96, R_f = 0.3) to give the title compound as a white solid (740 g, 77%).

Melting Point = 76-78 ℃.

^{1}H NMR (500 MHz, $CDCl_3$): δ_H = 7.32 – 7.28 (m, 1H, H_5), 7.08 – 6.99 (m, 2H, H_{13}, H_3), 6.94 (ddd, J = 7.8, 7.7, 1.5 Hz, 1H, H_{12}), 6.71 (ddd, J = 7.8, 7.5, 1.6 Hz, 1H, H_{11}), 6.36 (dd, J = 8.1, 1.5 Hz, 1H, H_{10}), 5.86 (s, 1H, OH), 2.33 (s, 3H, H_8), 2.18 (s, 3H, H_7).

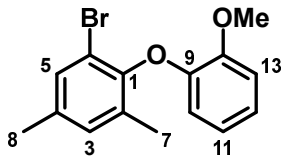
^{13}C NMR (126 MHz, $CDCl_3$): δ_C = 147.3 (C_1), 145.4 (C_{14}), 144.4 (C_9), 136.8 (C_{Ar}), 133.3 (C_{Ar}), 131.8 (C_5), 131.4 (C_3), 123.0 (C_{12}), 120.3 (C_{11}), 117.0 (C_6), 115.8 (C_{13}), 113.0 (C_{10}), 20.7 (C_8), 16.8 (C_7).

FTIR (film) ν_{max}**/cm^{-1}** = 3525, 1605, 1494, 1471, 1354, 1279, 1257, 1204, 1176, 1124, 1096, 1032, 874, 852, 824, 798, 782, 743.

HRMS ($APCI^+$): *m/z* calculated for $C_{14}H_{13}{}^{79}BrO_2^+$, $[M]^+$ = 292.0093; *m/z* found

= 292.0093. Δ = -0.11 ppm.

1-Bromo-2-(2-methoxyphenoxy)-3,5-dimethylbenzene, **172**:



MeI (0.223 mL, 508 mg, 3.59 mmol, 1.5 eq.) was added to a solution of 2-(2-bromo-4,6-dimethylphenoxy)phenol, **171**, (700 mg, 2.39 mmol, 1 eq.) and K_2CO_3 (396 mg, 2.87 mmol, 1.2 eq.) in DMF (5 mL) at r.t.. After 2 h, H_2O (10 mL) was added and the reaction mixture was extracted (Et_2O, 3 × 20 mL). The organic extracts were washed (H_2O, 20 mL), dried ($MgSO_4$), concentrated *in vacuo* to give the title compound as a white solid (701 mg, 96%).

Melting Point = 83-84 ℃.

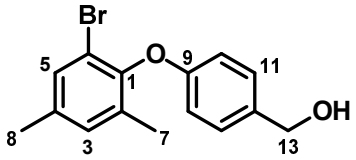
^{1}H NMR (600 MHz, $CDCl_3$): δ_H = 7.30 – 7.26 (m, 1H, H_5), 7.03 – 6.99 (m, 2H, H_{13} H_3), 6.96 (ddd, J = 8.1, 7.3, 1.5 Hz, 1H, H_{12}), 6.76 (ddd, J = 8.0, 7.3, 1.7 Hz, 1H, H_{11}), 6.36 (dd, J = 8.0, 1.5 Hz, 1H, H_{10}), 3.98 (s, 3H, H_{15}), 2.31 (s, 3H, H_8), 2.15 (s, 3H, H_7).

^{13}C NMR (151 MHz, $CDCl_3$): δ_C = 148.8 (C_{14}), 147.9 (C_1), 146.7 (C_9), 136.2 ($C_{4/2}$), 133.3 ($C_{4/2}$), 131.7 (C_5), 131.4 (C_3), 122.2 (C_{12}), 120.9 (C_{11}), 117.3 (C_6), 113.6 (C_{10}), 112.7 (C_{13}), 56.4 (C_{15}), 20.7 (C_8), 16.8 (C_7).

FTIR (film) ν_{max}**/cm^{-1}** = 2922, 1600, 1499, 1454, 1323, 1278, 1251, 1213, 1175, 1126, 1114, 1047, 1029, 853, 819, 781, 742, 612.

HRMS (ESI^+): m/z calculated for $C_{15}H_{15}{}^{79}BrNaO_2^+$, $[M+Na]^+$ = 329.0148; m/z found = 329.0148. Δ = 0.00 ppm.

(4-(2-Bromo-4,6-dimethylphenoxy)phenyl)methanol, **173**:



$NaBH_4$ (75.7 mg, 2.00 mmol, 1 eq.) was added to a solution of 4-(2-bromo-4,6-dimethylphenoxy)benzaldehyde, **165**, (610 mg, 2.00 mmol, 1 eq.) in THF/MeOH (2:1, 6 mL). After 1 h, the reaction was concentrated *in vacuo*. H_2O (10 mL) was added and the reaction mixture was extracted (EtOAc, 3 × 10 mL). The organic extracts were washed (H_2O, 10 mL), dried ($MgSO_4$) and concentrated *in vacuo* to give the title compound as a white solid (615 mg, quant.).

Melting Point = 62-64 ℃.

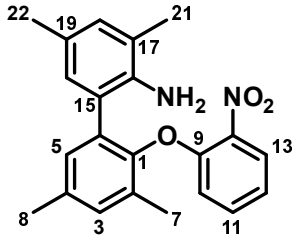
^{1}H NMR (600 MHz, $CDCl_3$): δ_H = 7.34 – 7.31 (m, 1H, H_5), 7.31 – 7.27 (m, 2H, H_{11}), 7.05 – 7.02 (m, 1H, H_3), 6.83 – 6.77 (m, 2H, H_{10}), 4.64 (s, 2H, H_{13}), 2.35 (s, 3H, H_8), 2.16 (s, 3H, H_7). OH was not observed.

^{13}C NMR (151 MHz, $CDCl_3$): δ_C = 156.9 (C_9), 147.5 (C_1), 136.4 ($C_{4/2}$), 134.3 (C_{12}), 133.3 ($C_{4/2}$), 131.6 (C_5), 131.4 (C_3), 128.8 (C_{11}), 117.2 (C_6), 114.9 (C_{10}), 65.0 (C_{13}), 20.6 (C_8), 16.9 (C_7).

FTIR (film) ν_{max}**/cm^{-1}** = 3329, 2922, 1737, 1612, 1569, 1506, 1471, 1379, 1278, 1217, 1165, 1123, 1010, 864, 852, 821, 796, 725.

HRMS (ESI^+): *m/z* calculated for $C_{15}H_{14}{}^{79}BrO^+$, $[M\text{-}OH]^+$ = 289.0223; *m/z* found = 289.0224. Δ = 0.35 ppm.

3,3',5,5'-Tetramethyl-2'-(2-nitrophenoxy)-[1,1'-biphenyl]-2-amine, **159**:



Aniline **159** was prepared according to **General Procedure C** using 1-bromo-3,5-dimethyl-2-(2-nitrophenoxy)benzene, **157** (2.61 g, 8.00 mmol, 1 eq.), 2,4-dimethyl-6-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)aniline, **158**, (12.00 mmo1, 1.5 eq.) in PhMe (48 mL), H_2O (80 mL), $Pd(dppf)Cl_2{\cdot}CH_2Cl_2$ (327 mg, 0.4 mmol, 5mol%) and Na_2CO_3 (3.39 g, 32.00 mmol, 4 eq.) in PhMe (20 mL). The crude residue was purified by flash column chromatography (EtOAc :Pentane, 7:93, $R_f = 0.3$). The crude product was suspended in IPA (20 mL) and H_2O (40 mL) was added. The solid precipitate was collected to give the title compound as a bright yellow solid (1.86 g, 64%).

Melting Point = 128-130 ℃.

^{1}H NMR (600 MHz, $CDCl_3$): δ_H = 7.70 (dd, J = 8.1, 1.7 Hz, 1H, H_{13}), 7.24 (ddd, J = 8.7, 7.4, 1.7 Hz, 1H, H_{11}), 7.14 – 7.10 (m, 1H, H_3), 7.03 (d, J = 2.3 Hz, 1H, H_5), 6.87 (ddd, J = 8.4, 7.4, 1.2 Hz, 1H, H_{12}), 6.72 – 6.69 (m, 1H, H_{18}), 6.56 (dd, J = 8.5, 1.2 Hz, 1H, H_{10}), 6.53 (s, 1H, H_{16}), 3.86 (br s, 2H, NH), 2.37 (s, 3H, H_8), 2.26 (s, 3H, H_7), 2.10 (s, 3H, H_{21}), 2.05 (s, 3H, H_{22}).

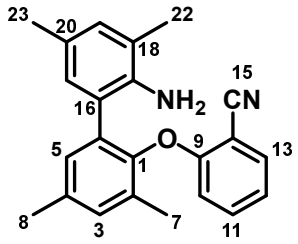
^{13}C NMR (151 MHz, $CDCl_3$): δ_C = 151.6 (C_9), 147.4 (C_1), 139.0 (br, C_{20}), 138.7 (C_{14}), 136.2 (C_{Ar}), 133.6 (C_{11}), 132.7 (C_{Ar}), 131.6 (C_3), 131.4 (C_{15}), 130.6 (C_{18}), (C_5), 128.8 (C_{16}), 127.3 (C_{Ar}), 125.5 (C_{13}), 123.3 (C_{Ar}), 120.9 (C_{12}), 116.4

(C_{10}), 20.9 (C_8), 20.2 (C_{22}), 17.7 (C_{21}), 16.3 (C_7). One quaternary carbon was not observed.

FTIR (film) ν_{max}**/cm^{-1}** = 3447, 2920, 2277, 1607, 1523, 1474, 1347, 1308, 1239, 1196, 1159, 1039, 861, 837, 775, 739.

HRMS (ESI^+): *m/z* calculated for $C_{22}H_{23}N_2O_3^+$, $[M+H]^+$ = 363.1703; *m/z* found = 363.1701. Δ = -0.59 ppm.

2-((2'-Amino-3,3',5,5'-tetramethyl-[1,1'-biphenyl]-2-yl)oxy)benzonitrile, **175**:



Aniline **175** was prepared according to **General Procedure D** using 2-(2-bromo-4,6-dimet-hylphenoxy)benzonitrile, **163**, (301 mg, 1.00 mmol, 1 eq.) and PhMe. The crude residue was purified by flash column chromatography (EtOAc :Pentane, 10:90, R_f = 0.3). The crude product was suspended in IPA (5 mL) and H_2O (5 mL) was added. The precipitate was collected by suction filtration to give the title compound as a white solid (230 g, 67%).

Melting Point = 128-130 ℃.

^{1}H NMR (500 MHz, $CDCl_3$): δ_H = 7.33 (dd, J = 7.7, 1.7 Hz, 1H, H_{13}), 7.24 (ddd, J = 8.5, 7.5, 1.7 Hz, 1H, H_{11}), 7.13 – 7.09 (m, 1H, H_3), 7.03 (d, J = 2.2 Hz, 1H, H_5), 6.84 (ddd, J = 7.6, 7.6, 1.0 Hz, 1H, H_{12}), 6.73 – 6.69 (m, 1H, H_{19}), 6.52 (br s, 1H, H_{21}), 6.47 (d, J = 8.5 Hz, 1H, H_{10}), 3.78 (s, 2H, NH), 2.36 (s, 3H, H_8), 2.25 (s, 3H, H_7), 2.14 (s, 3H, H_{22}), 2.06 (s, 3H, H_{23}).

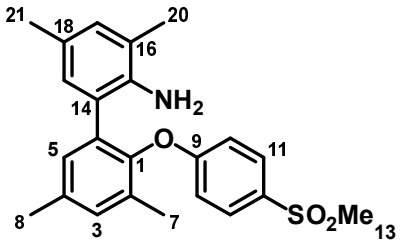
^{13}C NMR (126 MHz, $CDCl_3$): δ_C = 160.0 (C_9), 147.8 (C_1), 139.3 (br, C_{17}), 136.2 (C_{Ar}), 133.6 (C_{11}), 133.3 (C_{13}), 132.8 (C_{Ar}), 131.6 (C_{Ar}), 131.5 (C_3), 130.7 (C_{19}, C_5), 129.1 (C_{21}), 127.3 (br, C_{Ar}), 123.4 (C_{16}), 121.4 (C_{12}), 116.3 (C_{15}), 114.5 (C_{10}), 101.6 (C_{14}), 21.0 (C_8), 20.3 (C_{23}), 17.9 (C_{22}), 16.5 (C_7). One quaternary carbon was not observed.

FTIR (film) ν_{max}**/cm^{-1}** = 3383, 2920, 2360, 2228, 1600, 1484, 1448, 1280, 1241,

1198, 1158, 861, 756.

HRMS (ESI^+): *m/z* calculated for $C_{23}H_{23}N_2O^+$, $[M+H]^+$ = 343.1805; *m/z* found = 343.1804. Δ = -0.38 ppm.

3,3',5,5'-Tetramethyl-2'-(4-(methylsulfonyl)phenoxy)-[1,1'-biphenyl]-2-amine, **178**:



Aniline **178** was prepared accoridng to **General procedure D** using 1-bromo-3,5-dimethyl-2-(4-(methylsulfonyl)phenoxy)benzene, **167**, as a 1:2 mixture with 1-fluoro-4-(methyl sulfonyl)benzene (703 mg, 1.00 mmol, 1 eq.). The crude reside was purified by flash column chromatography (EtOAc:Pentane, 15:85 to 30:70, $R_f = 0.3$) to give the title compound as a viscous oil (283 mg, 72%).

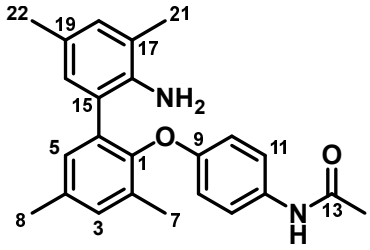
^{1}H NMR (500 MHz, $CDCl_3$): δ_H = δ 7.70 – 7.63 (m, 2H, H_{11}), 7.11 (d, J = 2.2 Hz, 1H, H_3), 7.04 (d, J = 2.2 Hz, 1H, H_5), 6.77 – 6.74 (m, 2H, H_{10}), 6.73 (d, J = 2.0 Hz, 1H, H_{17}), 6.56 (d, J = 2.1 Hz, 1H, H_{19}), 2.96 (s, 3H, H_{13}), 2.37 (s, 3H, H_8), 2.17 (s, 3H, H_7), 2.11 (s, 3H, H_{20}), 2.07 (s, 3H, H_{21}). NH_2 was not observed.

^{13}C NMR (126 MHz, $CDCl_3$): δ_C = 162.4 (C_9), 147.8 (C_1), 138.9 (br, C_{15}), 136.1 (C_{Ar}), 132.9 (C_{12}), 132.9 (C_6), 131.9 (C_3), 131.5 (C_{Ar}), 130.7 (C_{17}), 130.6 (C_5), 129.3 (C_{11}), 128.9 (C_{19}), 127.2 (br, C_{Ar}), 123.5 (C_{14}), 122.9 (br, C_{Ar}), 115.9 (C_{10}), 44.8 (C_{13}), 21.0 (C_8), 20.4 (C_{21}), 17.9 (C_{20}), 16.6 (C_7).

FTIR (film) ν_{max}**/cm^{-1}** = 2981, 2918, 1624, 1588, 1487, 1410, 1380, 1315, 1293, 1237, 1199, 1146, 1091, 1012, 957, 859, 839, 770, 628.

HRMS (ESI^+): m/z calculated for $C_{23}H_{26}NO_3S^+$, $[M+H]^+$ = 396.1628; m/z found = 396.1625. Δ = -0.64 ppm.

N-(4-((2'-Amino-3,3',5,5'-tetramethyl-[1,1'-biphenyl]-2-yl)oxy)phenyl)acetamide, **179**:



Aniline **179** was prepared according to **General Procedure E** using *N*-(4-(2-bromo-4,6-dimethylphenoxy)phenyl)acetamide, **169**, (832 mg, 2.50 mmol, 1 eq.) as a solid, 2,4-dimethyl-6-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)aniline, **158**, (3.75 mmo1, 1.5 eq.) in PhMe (15 mL), $Pd(dppf)Cl_2 \cdot CH_2Cl_2$ (102 mg, 0.12 mmol, 5 mol%), Na_2CO_3 (1.05 g, 10.00 mmol, 4 eq.) in PhMe (10 mL) and H_2O (25 mL). The crude residue was purified by flash column chromatography (EtOAc:Pentane, 50:50 to 60:40, $R_f = 0.2$) to give the title compound as a white solid (430 mg, 46%).

Melting Point = 169-170 ℃.

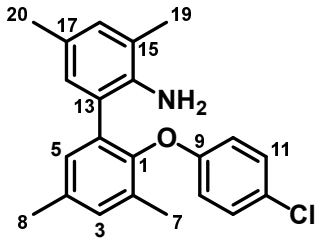
^{1}H NMR (500 MHz, $CDCl_3$): δ_H = 7.32 (s, 1H, NH), 7.17 (d, J = 8.6 Hz, 2H, H_{11}), 7.06 (d, J = 2.2 Hz, 1H, H_3), 6.99 (d, J = 2.2 Hz, 1H, H_5), 6.73 (d, J = 2.1 Hz, 1H, H_{18}), 6.63 (d, J = 2.1 Hz, 1H, H_{20}), 6.54 (d, J = 8.5 Hz, 2H, H_{10}), 3.35 (br s, 2H, NH_2), 2.34 (s, 3H, H_8), 2.15 (s, 3H, H_7), 2.10 (s, 3H, H_{21}), 2.09 (s, 3H, H_{22}), 2.05 (s, 3H, H_{14}).

^{13}C NMR (126 MHz, $CDCl_3$): δ_C = 168.3 (C_{13}), 155.1 (C_9), 148.6 (C_1), 139.1 (C_{16}), 135.2 (C_{Ar}), 133.3 (C_6), 131.9 (C_{12}), 131.7 (C_3), 131.5 (C_{Ar}), 130.5 (C_{18}, C_5), 129.0 (C_{20}), 127.1 (C_{Ar}), 124.4 (C_{15}), 122.8 (C_{Ar}), 121.5 (C_{11}), 115.5 (C_{10}), 24.4 (C_{14}), 20.9 (C_8), 20.4 (C_{22}), 17.9 (C_{21}), 16.7 (C_7).

FTIR (film) ν_{max}**/cm^{-1}** = 3649, 3366, 2920, 1663, 1607, 1541, 1505, 1410, 1372, 1313, 1213, 1166, 1014, 862, 837, 754.

HRMS (ESI$^+$): *m/z* calculated for $C_{24}H_{27}N_2O_2^+$, $[M+H]^+$ = 375.2067; *m/z* found = 375.2065. Δ = -0.51 ppm.

1-Bromo-2-(4-chlorophenoxy)-3,5-dimethylbenzene, **180**:



Aniline **180** was prepared according to **General Procedure E** using 1-bromo-2-(4-chloro-phenoxy)-3,5-dimethylbenzene, **170**, (527 mg, 1.70 mmol, 1 eq.) as a solid, 2,4-dimethyl-6-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)aniline, **158**, (2.55 mmo1, 1.5 eq.) in PhMe (10 mL), $Pd(dppf)Cl_2 \cdot CH_2Cl_2$ (69 mg, 0.085 mmol, 5 mol%), Na_2CO_3 (720 mg, 6.80 mmol, 4 eq.) in PhMe (7 mL) and H_2O (17 mL). The crude residue was purified by flash column chromatography (Et_2O:Pentane, 5:95, R_f = 0.3) to give the title compound as a white solid (440 mg, 74%).

Melting Point = 74-75 ℃.

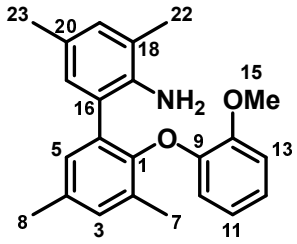
^{1}H NMR (500 MHz, $CDCl_3$): δ_H = 7.10 – 7.06 (m, 1H, H_3), 7.06 – 6.99 (m, 3H, H_{11}, H_5), 6.77 – 6.74 (m, 1H, H_{16}), 6.60 – 6.57 (m, 1H, H_{18}), 6.56 – 6.52 (m, 2H, H_{10}), 3.28 (br, s, 2H, NH_2), 2.36 (s, 3H, H_8), 2.17 (s, 3H, H_7), 2.12 (s, 3H, H_{19}), 2.10 (s, 3H, H_{20}).

^{13}C NMR (126 MHz, $CDCl_3$): δ_C = 157.1 (C_9), 148.6 (C_1), 139.3 (C_{14}), 135.4 (C_{Ar}), 133.2 (C_{Ar}), 131.8 (C_{Ar}), 131.7 (C_3), 130.5 (C_5, C_{16}), 129.1 (C_{11}), 129.0 (C_{18}), 127.0 (C_{Ar}), 126.1 (C_{12}), 123.9 (C_{Ar}), 122.6 (C_{Ar}), 116.7 (C_{10}), 20.9 (C_8), 20.4 (C_{20}), 17.9 (C_{19}), 16.7 (C_7).

FTIR (film) ν_{max}**/cm^{-1}** = 2920, 1622, 1485, 1280, 1225, 1162, 1094, 1009, 858, 827.

HRMS (ESI^+): m/z calculated for $C_{22}H_{23}{}^{35}ClNO_2^+$, $[M+H]^+$ = 352.1463; m/z found = 352.1461. Δ = -0.43 ppm.

2'-(2-Methoxyphenoxy)-3,3',5,5'-tetramethyl-[1,1'-biphenyl]-2-amine, **181**:



Aniline **181** was prepared according to **General Procedure E** using 1-bromo-2-(2-methoxyphenoxy)-3,5-dimethylbenzene, **172**, (512 mg, 1.7 mmol, 1 eq.) as a solid, 2,4-dimethyl-6-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)aniline, **158**, (2.55 mmo1, 1.5 eq.) in PhMe (10 mL), $Pd(dppf)Cl_2 \cdot CH_2Cl_2$ (69 mg, 0.085 mmol, 5 mol%), Na_2CO_3 (720 mg, 6.8 mmol, 4 eq.) in PhMe (7 mL) and H_2O (17 mL). The crude residue was purified by flash column chromatography (Et_2O:Pentane, 20:80, R_f = 0.2) to give the title compound as a white solid (320 mg, 54%).

Melting Point = 156-158 ℃.

^{1}H NMR (500 MHz, $CDCl_3$): δ_H = 7.08 (d, J = 2.2 Hz, 1H, H_3), 6.99 (d, J = 2.2 Hz, 1H, H_5), 6.77 (td, J = 7.7, 1.5 Hz, 1H, H_{11}), 6.71 (d, J = 2.0 Hz, 1H, H_{19}), 6.68 (dd, J = 8.0, 1.5 Hz, 1H, H_{10}), 6.64 (td, J = 7.7, 1.6 Hz, 1H, H_{12}), 6.57 (d, J = 2.0 Hz, 1H, H_{21}), 6.39 (dd, J = 8.0, 1.6 Hz, 1H, H_{13}), 3.69 (s, 3H, H_{15}), 3.56 (br, 2H, NH), 2.34 (s, 3H, H_8), 2.25 (s, 3H, H_7), 2.11 (s, 3H, H_{22}), 2.06 (s, 3H, H_{23}).

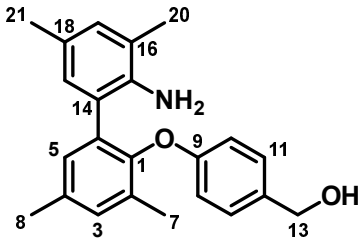
^{13}C NMR (126 MHz, $CDCl_3$): δ_C = 149.5 (C_9), 149.0 (C_{14}), 148.1 (C_1), 138.6 (C_{17}), 134.9 (C_{Ar}), 132.6 (C_6), 132.1 (C_{Ar}), 131.5 (C_3), 130.5 (C_5), 130.2 (C_{19}), 129.1 (C_{21}), 127.5 (C_{Ar}), 124.7 (C_{16}), 123.0 (C_{Ar}), 121.7 (C_{11}), 120.5 (C_{12}), 115.0 (C_{13}), 112.3 (C_{10}), 56.1 (C_{15}), 20.9 (C_8), 20.4 (C_{23}), 18.0 (C_{22}), 16.6 (C_7).

FTIR (film) ν_{max}/cm^{-1} = 3376, 2919, 2361, 2342, 1559, 1500, 1457, 1252, 1212,

1177, 1154, 1116, 1047, 1030, 858, 743.

HRMS (ESI^+): m/z calculated for $C_{22}H_{26}NO_2^+$, $[M+H]^+$ = 348.1958; m/z found = 348.1952. Δ = -1.85 ppm.

(4-((2'-Amino-3,3',5,5'-tetramethyl-[1,1'-biphenyl]-2-yl)oxy)phenyl)methanol, **182**:



Aniline **178** was prepared accoridng to **General procedure D** using (4-(2-bromo-4,6-dimethyl phenoxy)phenyl)methanol, **173**, (306 mg, 1.00 mmol, 1 eq.). The crude reside was purified by flash column chromatography (EtOAc:Pentane, 20:80, R_f = 0.2) to give the title compound as a viscous oil (285 mg, 82%).

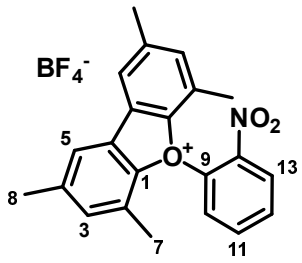
^{1}H NMR (500 MHz, $CDCl_3$): δ_H = 7.09 – 7.03 (m, 3H, H_{11}, H_3), 7.00 (d, J = 2.3 Hz, 1H, H_5), 6.73 (d, J = 2.1 Hz, 1H, H_{17}), 6.63 (s, 1H, H_{19}), 6.61 – 6.55 (m, 2H, H_{10}), 4.48 (s, 2H, H_{13}), 2.35 (s, 3H, H_8), 2.15 (s, 3H, H_7), 2.11 (s, 3H, H_{20}), 2.08 (s, 3H, H_{21}). NH_2 and OH were not observed.

^{13}C NMR (126 MHz, $CDCl_3$): δ_C = 157.9 (C_9), 148.5 (C_1), 138.7 (C_{15}), 135.1 (C_{Ar}), 133.7 (C_{12}), 133.2 (C_6), 131.9 (C_{Ar}), 131.7 (C_3), 130.4 (C_{17}, C_5), 129.1 (C_{19}), 128.3 (C_{11}), 127.4 (C_{Ar}), 124.6 (C_{14}), 123.0 (C_{Ar}), 115.3 (C_{10}), 64.8 (C_{13}), 20.9 (C_8), 20.4 (C_{21}), 17.9 (C_{20}), 16.7 (C_7).

FTIR (film) ν_{max}**/cm^{-1}** = 3380, 2921, 2852, 1611, 1506, 1468, 1368, 1220, 1164, 1108, 1010, 949, 860, 831, 732.

HRMS (ESI^+): m/z calculated for $C_{23}H_{26}NO_2^+$, $[M+H]^+$ = 348.1958; m/z found = 348.1958. Δ = -0.01 ppm.

2,4,6,8-Tetramethyl-5-(2-nitrophenyl)-5*H*-dibenzo[*b*,*d*]furan-5-ium tetrafluoroborate, **183**:



Oxonium ion **183** was prepared according to **General Procedure G** using 3,3',5,5'-tetramethyl-2'-(2-nitrophenoxy)-[1,1'-biphenyl]-2-amine, **159**, (1.81 g, 5.00 mmol, 1 eq.) *t*-BuONO (2.97 mL, 2.58 g, 25.00 mmol, 5 eq.), and HBF_4 (48% aq., 3.27 mL, 2.20 g, 25.00 mmol, 5 eq.) to give the title compound as a tan solid (1.85 g, 85%).

Melting Point = 191 ℃ (MeCN, dec.).

^{1}H NMR (500 MHz, CD_3CN): δ_H = 8.57 – 8.54 (m, 1H, $H_{10/13}$), 8.12 – 8.05 (m, 2H, H_{11}, H_{12}), 7.97 – 7.94 (m, 3H, H_5, $H_{10/13}$), 7.34 – 7.30 (m, 2H, H_3), 2.51 (s, 6H, H_8), 1.96 (s, 6H, H_7).

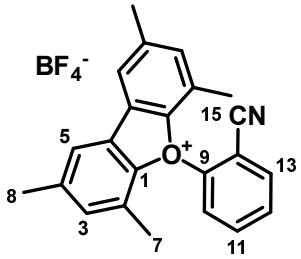
^{13}C NMR (126 MHz, CD_3CN): δ_C = 159.8 (C_1), 148.1 (C_9), 141.8 (C_{Ar}), 140.4 (C_{14}), 138.7 ($C_{11/12}$), 135.2 (C_3), 134.9 ($C_{11/12}$), 128.9 ($C_{10/13}$), 125.0 ($C_{10/13}$), 122.7 (C_{Ar}), 122.4 (C_{Ar}), 121.9 (C_5), 20.0 (C_8), 15.2 (C_7).

^{19}F NMR (377 MHz, CD_3CN): δ_F = -151.8.

FTIR (film) ν_{max}**/cm^{-1}** = 3100, 1584, 1541, 1452, 1390, 1358, 1057, 1031, 873, 842, 808, 734, 692, 620.

HRMS (ESI^+): *m/z* calculated for $C_{22}H_{20}NO_3^+$, $[M]^+$ = 346.1438; *m/z* found = 346.1438. Δ = -0.10 ppm.

5-(2-Cyanophenyl)-2,4,6,8-tetramethyl-5*H*-dibenzo[*b*,*d*]furan-5-ium tetrafluoroborate, **184**:



Oxonium ion **185** was prepared according to **General Procedure F** using 2-((2'-amino-3,3',5,5'-tetramethyl-[1,1'-biphenyl]-2-yl)oxy)benzonitrile, **175**, (171 mg, 0.50 mmol, 1 eq.) to give the title compound as a white solid (142 mg, 69%).

Melting Point = 58-59 ℃.

^{1}H NMR (500 MHz, CD_3CN): δ_H = 8.14 – 8.10 (m, 1H, H_{Ar}), 8.04 – 8.01 (m, 2H, H_{Ar}), 7.98 – 7.92 (m, 3H, H_5, H_{Ar}), 7.37 – 7.33 (m, 2H, H_3), 2.52 (s, 6H, H_8), 2.10 (s, 6H, H_7).

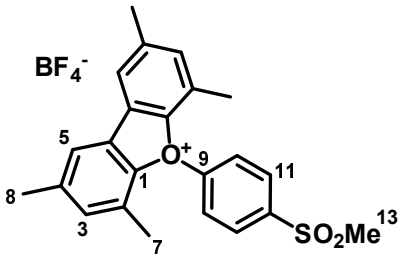
^{13}C NMR (126 MHz, CD_3CN): δ_C = 161.6 (C_1), 157.6 (C_9), 143.4 (C_{Ar}), 138.4 (C_{Ar}), 137.8 (C_{Ar}), 135.8 (C_3), 134.5 (C_{Ar}), 124.7 (C_{Ar}), 124.3 (C_{Ar}), 124.3 (C_{Ar}), 122.6 (C_5), 112.5 ($C_{14/15}$), 107.1 ($C_{14/15}$), 21.0 (C_8), 16.5 (C_7).

^{19}F NMR (471 MHz, CD_3CN): δ_F = -146.4.

FTIR (film) ν_{max}**/cm^{-1}** = 2981, 1612, 1549, 1483, 1444, 1383, 1059, 1037, 868, 802, 733, 699, 619.

HRMS (ESI^+): *m/z* calculated for $C_{23}H_{22}NO^+$, $[M]^+$ = 326.1539; *m/z* found = 326.1539. Δ = 0.06 ppm.

2,4,6,8-Tetramethyl-5-(4-(methylsulfonyl)phenyl)-5*H*-dibenzo[*b*,*d*]furan-5-ium tetrafluoroborate, **185**:



Oxonium ion **185** was prepared according to **General Procedure F** using 3,3',5,5'-tetramethyl-2'-(4-(methylsulfonyl)phenoxy)-[1,1'-biphenyl]-2-amine, **178**, (197 mg, 0.50 mmol, 1 eq.) to give the title compound as a white solid (180 mg, 77%).

Melting Point = 227 ℃ (MeCN, dec.).

^{1}H NMR (500 MHz, CD_3CN): δ_H = 8.22 – 8.16 (m, 2H, H_{11}), 8.02 – 7.96 (m, 2H, H_{10}), 7.93 – 7.89 (m, 2H, H_5), 7.34 – 7.29 (m, 2H, H_3), 3.14 (s, 3H, H_{13}), 2.50 (s, 6H, H_8), 2.14 (s, 6H, H_7).

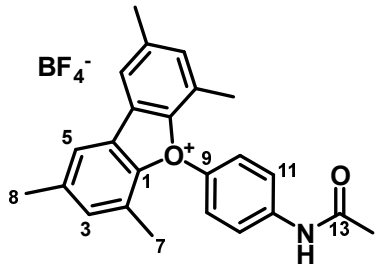
^{13}C NMR (126 MHz, CD_3CN): δ_C = 162.2 (C_9), 161.2 (C_1), 145.2 (C_{12}), 143.1 (C_{Ar}), 135.2 (C_3), 132.4 (C_{11}), 124.6 (C_{Ar}), 124.1 (C_{Ar}), 123.2 (C_{10}), 122.4 (C_5), 44.1 (C_{13}), 20.9 (C_8), 16.6 (C_7).

^{19}F NMR (377 MHz, CD_3CN): δ_F = -151.7.

FTIR (film) ν_{max}**/cm^{-1}** = 2925, 2360, 1559, 1458, 1386, 1319, 1297, 1154, 1061, 1003, 961, 869, 779, 619.

HRMS (ESI^+): *m/z* calculated for $C_{23}H_{23}O_3S^+$, $[M]^+$ = 379.1362; *m/z* found = 379.1360. Δ = -0.51 ppm.

5-(4-Acetamidophenyl)-2,4,6,8-tetramethyl-5*H*-dibenzo[*b*,*d*]furan-5-ium tetrafluoroborate, **186**:



Oxonium ion **186** was prepared according to **General Procedure F** using *N*-(4-((2'-amino-3,3',5,5'-tetramethyl-[1,1'-biphenyl]-2-yl)oxy)phenyl)acetamide, (187 mg, 0.50 mmol, 1 eq.) to give the title compound as a tan solid (202 mg, 92%).

Melting Point = 172 ℃ (MeCN, dec.).

^{1}H NMR (500 MHz, CD_3CN): δ_H = 8.81 (s, 1H, NH), 7.87 – 7.86 (m, 2H, H_5), 7.85 – 7.81 (m, 2H, H_{11}), 7.67 – 7.61 (m, 2H, H_{10}), 7.31 – 7.26 (m, 2H, H_3), 2.49 (s, 6H, H_8), 2.11 (s, 6H, H_7), 2.10 (s, 3H, H_{14}).

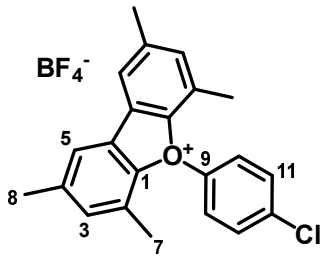
^{13}C NMR (126 MHz, CD_3CN): δ_C = 170.3 (C_{13}), 160.6 (C_1), 155.1 (C_9), 143.3 (C_{12}), 142.7 (C_{Ar}), 135.3 (C_3), 124.7 (C_{Ar}), 124.1 (C_{Ar}), 122.5 (C_{10}), 122.2 (C_5), 121.5 (C_{11}), 24.4 (C_{14}), 21.0 (C_8), 16.8 (C_7).

^{19}F NMR (377 MHz, CD_3CN): δ_F = -151.8.

FTIR (film) ν_{max}**/cm^{-1}** = 3370, 1706, 1588, 1536, 1494, 1461, 1405, 1304, 1257, 1170, 1063, 1008, 853, 622.

HRMS (ESI^+): *m/z* calculated for $C_{24}H_{24}NO_2^+$, $[M]^+$ = 358.1802; *m/z* found = 358.1802. Δ = -0.01 ppm.

5-(4-Chlorophenyl)-2,4,6,8-tetramethyl-5*H*-dibenzo[*b*,*d*]furan-5-ium tetrafluoroborate, **187**:



Oxonium ion **187** was prepared according to **General Procedure F** using 2'-(4-chlorophenoxy)-3,3',5,5'-tetramethyl-[1,1'-biphenyl]-2-amine, **180**, (174 mg, 0.50 mmol, 1 eq.) to give the title compound as a white solid (184 mg, 87%).

Melting Point = 205 ℃ (MeCN, dec.).

^{1}H NMR (500 MHz, CD_3CN): δ_H = 7.91 – 7.86 (m, 2H, H_5), 7.79 – 7.72 (m, 2H, $H_{10/11}$), 7.72 – 7.64 (m, 2H, $H_{10/11}$), 7.32 – 7.27 (m, 2H, H_3), 2.50 (s, 6H, H_8), 2.13 (s, 6H, H_7).

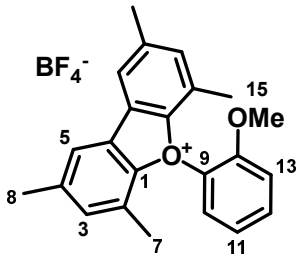
^{13}C NMR (126 MHz, CD_3CN): δ_C = 161.0 (C_1), 158.6 (C_9), 143.0 (C_{Ar}), 138.7 (C_{12}), 135.4 (C_3), 132.8 ($C_{10/11}$), 124.7 (C_{Ar}), 124.1 (C_{Ar}), 123.6 ($C_{10/11}$), 122.4 (C_5), 21.0 (C_8), 16.8 (C_7).

^{19}F NMR (377 MHz, CD_3CN): δ_F = -151.8.

FTIR (film) ν_{max}**/cm^{-1}** = 3104, 1606, 1477, 1460, 1406, 1384, 1046, 999, 879, 846, 732, 705, 620.

HRMS (ESI^+): *m/z* calculated for $C_{22}H_{20}{}^{35}ClO^+$, $[M]^+$ = 335.1197; *m/z* found = 335.1200. Δ = 0.81 ppm.

5-(2-Methoxyphenyl)-2,4,6,8-tetramethyl-5*H*-dibenzo[*b*,*d*]furan-5-ium tetrafluoroborate, **188**:



Oxonium ion **188** was prepared according to **General Procedure F** using 2'-(2-methoxyphenoxy)-3,3',5,5'-tetramethyl-[1,1'-biphenyl]-2-amine, **181** (176 mg, 0.50 mmol, 1 eq.) to give the title compound as a tan solid (198 mg, 95%).

Melting Point = 191 ℃ (MeCN, dec.).

^{1}H NMR (500 MHz, CD_3CN): δ_H = 7.88 – 7.84 (m, 2H, H_5), 7.72 (ddd, J = 8.8, 7.5, 1.5 Hz, 1H, H_{12}), 7.67 (dd, J = 8.5, 1.5 Hz, 1H, H_{10}), 7.39 (dd, J = 8.5, 1.5 Hz, 1H, H_{13}), 7.31 – 7.25 (m, 2H, H_3), 7.19 (ddd, J = 8.8, 7.5, 1.5 Hz, 1H, H_{11}), 3.83 (s, 3H, H_{15}), 2.49 (s, 6H, H_8), 2.06 (s, 6H, H_7).

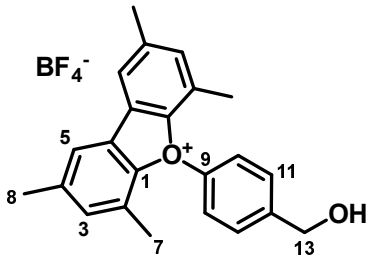
^{13}C NMR (126 MHz, CD_3CN): δ_C = 160.1 (C_1), 151.3 (C_{14}), 147.4 (C_9), 142.2 (C_{Ar}), 135.2 (C_3), 134.9 (C_{12}), 123.9 (C_{Ar}), 123.9 (C_{Ar}), 123.5 (C_{10}), 123.1 (C_{11}), 122.1 (C_5), 116.5 (C_{10}), 57.7 (C_{15}), 21.0 (C_8), 15.8 (C_7).

^{19}F NMR (471 MHz, CD_3CN): δ_F = –151.8.

FTIR (film) ν_{max}**/cm^{-1}** = 1620, 1496, 1454, 1387, 1290, 1261, 1034, 1006, 861, 794, 782, 757, 703, 673, 621.

HRMS (ESI^+): m/z calculated for $C_{23}H_{23}O_2^+$, $[M]^+$ = 331.1693; m/z found = 331.1691. Δ = -0.49 ppm.

5-(4-(Hydroxymethyl)phenyl)-2,4,6,8-tetramethyl-5*H*-dibenzo[*b*,*d*]furan-5-ium tetrafluoroborate, **189**:



Oxonium ion **189** was prepared according to **General Procedure F** using (4-((2'-amino-3,3',5,5'-tetramethyl-[1,1'-biphenyl]-2-yl)oxy)phenyl)methanol, **182**, (173 mg, 0.50 mmol, 1 eq.) to give the title compound as a tan solid (153 mg, 73%).

Melting Point = 279 ℃ (MeCN, dec.).

^{1}H NMR (700 MHz, CD_3CN): δ_H =7.89 – 7.87 (m, 2H, H_5), 7.71 – 7.66 (m, 2H, H_{10}), 7.63 – 7.58 (m, 2H, H_{11}), 7.30 – 7.28 (m, 2H, H_3), 4.68 (s, 2H, H_{13}), 3.54 (s, 1H, OH), 2.50 (s, 6H, H_8), 2.10 (s, 6H, H_7).

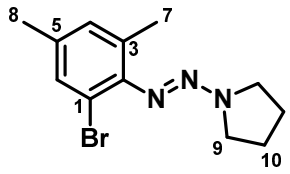
^{13}C NMR (176 MHz, CD_3CN): δ_C = 159.8 (C_1), 158.5 (C_9), 147.3 (C_{12}), 141.8 (C_{Ar}), 134.4 (C_3), 129.1 (C_{11}), 123.8 (C_{Ar}), 123.3 (C_{Ar}), 121.4 (C_5), 120.6 (C_{10}), 62.2 (C_{13}), 20.1 (C_8), 15.9 (C_7).

^{19}F NMR (471 MHz, CD_3CN): δ_F = -151.8.

FTIR (film) ν_{max}**/cm^{-1}** = 3067, 2359, 1602, 1490, 1458, 1387, 1282, 1060, 1001, 861, 843, 765, 734, 621.

HRMS (ESI^+): *m/z* calculated for $C_{23}H_{23}O_2^+$, $[M]^+$ = 331.1693; *m/z* found = 331.1690. Δ = -0.83 ppm.

1-((2-Bromo-4,6-dimethylphenyl)diazenyl)pyrrolidine, **191**:



Prepared according to a modified literature procedure.[71] $NaNO_2$ (414 mg, 6.00 mmol, 1.2 eq.) was added to a solution of 2-bromo-4,6-dimethylaniline (1.00 g, 5.00 mmol, 1 eq.) and HCl (37%, aq., 4.11 mL, 50.00 mmol, 10 eq.) in H_2O:MeCN (2:3, 25 mL) at 0 °C. After 30 mins, the reaction mixture was added to a solution of pyrrolidine (0.515 mL, 605 mg, 8.50 mmol, 1.7 eq.) and K_2CO_3 (6.90 g, 50.00 mmol, 10 eq.) in H_2O:MeCN (1:2, 60 mL) at 0 °C. Once the addition was complete the reaction was warmed to r.t. and extracted (Et_2O, 2 × 40 mL). The organic extracts were washed (brine, 2 × 30 mL), dried ($MgSO_4$) and concentrated *in vacuo* to give the title compound as a bright yellow oil (1.34 g, 95%)

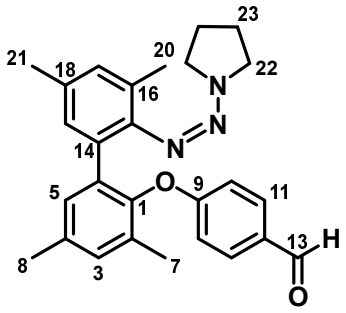
^{1}H NMR (500 MHz, $CDCl_3$): δ_H = 7.25 – 7.23 (m, 1H, H_6), 6.93 – 6.90 (m, 1H, H_4), 3.87 – 3.68 (br, m, 4H, H_9), 2.26 (s, 3H, H_8), 2.18 (s, 3H, H_7), 2.09 – 2.01 (br, m, 4H, H_{10}).

^{13}C NMR (126 MHz, $CDCl_3$): δ_C = 146.0 (C_2), 135.4 (C_3), 131.8 (C_5), 130.9 (C_6), 130.8 (C_4), 117.1 (C_1), 50.8 (br, C_9), 46.5 (br, $C_{9'}$), 23.9 (C_{10}), 20.5 (C_8), 18.9 (C_7).

FTIR (film) ν_{max}**/cm^{-1}** = 2870, 2361, 1558, 1421, 1319, 1264, 1210, 1161, 1108, 1029, 850, 815, 733, 668.

HRMS (ESI^+): *m/z* calculated for $C_{12}H_{17}{}^{79}BrN_3^+$, $[M+H]^+$ = 282.0611; *m/z* found = 282.0601. Δ = -3.71 ppm.

4-((3,3',5,5'-Tetramethyl-2'-(pyrrolidin-1-yldiazenyl)-[1,1'-biphenyl]-2-yl)oxy) benzaldehyde, **193**:



1,4-Dioxane (10 mL) was added to a mixture of 4-(2-bromo-4,6-dimethylphenoxy) benzaldehyde, **165** (456 mg, 1.50 mmol, 1 eq.), Pd(dppf)Cl_2·CH_2Cl_2 (37 mg, 0.045 mmol, 3 mol%), KOAc (442 mg, 4.50 mmol, 3 eq.) and B_2Pin_2 (571 mg, 2.25 mmol, 1,5 eq.) under N_2. Argon was bubbled through the mixture for 5 mins and it was heated to 95 °C. After 24 h, H_2O (20 mL) was added. The resulting mixture was extracted (CH_2Cl_2, 3 × 10 mL), the combined organic extracts were dried ($MgSO_4$) and concentrated *in vacuo*. The crude residue was suspended in pentane (20 mL), filtered through Celite® (5 mL), eluted (pentane, 3 × 10 mL) and concentrated *in vacuo*. The crude residue was used without further purification.

The crude reaction mixture in PhMe (5 mL), 1-((2-bromo-4,6-dimethylphenyl)diazenyl) pyrrolidine, **191**, (633 mg, 2.25 mmol, 1.5 eq.) in PhMe (5 mL) and H_2O (17 mL) were sequentially added to a mixture of Pd(dppf)Cl_2·CH_2Cl_2 (69 mg, 0.085 mmol, 5 mol%) and Na_2CO_3 (720 mg, 6.80 mmol, 4 eq.) in PhMe (7 mL) under N_2. Argon was bubbled through the mixture for 5 mins and it was heated to 95 °C. After 16 h, the reaction mixture was extracted (CH_2Cl_2, 3 × 10 mL), dried ($MgSO_4$) and concentrated *in vacuo*. The crude residue was purified by flash column

chromatography (EtOAc:Pentane, 6:94, R_f = 0.2) to give the title compound as a viscous colourless oil (275 mg, 43%).

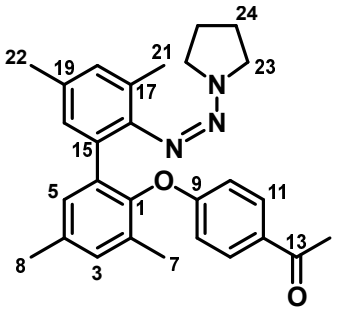
^{1}H NMR (400 MHz, $CDCl_3$): δ_H = 9.78 (s, 1H, H_{13}), 7.65 – 7.57 (m, 2H, H_{11}), 6.98 – 6.95 (m, 1H, H_3), 6.93 – 6.90 (m, 1H, H_5), 6.83 – 6.80 (m, 1H, H_{17}), 6.79 – 6.75 (m, 3H, H_{19}, H_{10}), 3.54 – 3.46 (m, 4H, H_{22}), 2.30 (s, 3H, $H_{21/8}$), 2.18 (s, 3H, H_{20}), 2.13 (s, 3H, $H_{21/8}$), 2.07 (s, 3H, H_7), 1.95 – 1.84 (m, 4H, H_{23}).

^{13}C NMR (126 MHz, $CDCl_3$): δ_C = 190.9 (C_{13}), 163.4 (C_9), 147.1 (C_1), 145.8 (C_{15}), 135.0 (C_6), 134.1 (C_{Ar}), 133.3 (C_{Ar}), 131.5 (C_{10}), 131.3 (C_5), 130.8 (C_{17}), 130.6 (C_{Ar}), 130.2 (C_{Ar}), 130.1 (C_{12}), 130.0 (C_3), 129.6 (C_{Ar}), 129.0 (C_{19}), 115.9 (C_{11}), 48.5 (br, C_{22}), 23.9 (C_{23}), 20.8 ($C_{21/8}$), 20.7 ($C_{21/8}$), 18.5 (C_{20}), 16.5 (C_7).

FTIR (film) ν_{max}**/cm^{-1}** = 2919, 2865, 2359, 1698, 1606, 1594, 1580, 1503, 1471, 1427, 1324, 1299, 1266, 1234, 1212, 1198, 1155, 1124, 1106, 866, 860, 833, 757.

HRMS (ESI$^+$): *m/z* calculated for $C_{23}H_{21}O_2^+$, $[M\text{-}C_4H_8N_3]^+$ = 329.1536; *m/z* found = 329.1534. Δ = -0.78 ppm.

1-(4-((3,3',5,5'-Tetramethyl-2'-(pyrrolidin-1-yldiazenyl)-[1,1'-biphenyl]-2-yl)oxy)phenyl)ethan-1-one, **194**:



1,4-Dioxane (10 mL) was added to a mixture of 1-(4-(2-bromo-4,6-dimethylphenoxy) phenyl)ethan-1-one, **166** (479 mg, 1.50 mmol, 1 eq.), $Pd(dppf)Cl_2 \cdot CH_2Cl_2$ (37 mg, 0.045 mmol, 3 mol%), KOAc (442 mg, 4.50 mmol, 3 eq.) and B_2Pin_2 (571 mg, 2.25 mmol, 1,5 eq.) under N_2. Argon was bubbled through the mixture for 5 mins and it was heated to 95 °C. After 24 h, H_2O (20 mL) was added. The resulting mixture was extracted (CH_2Cl_2, 3 × 10 mL), the combined organic extracts were dried ($MgSO_4$) and concentrated *in vacuo*. The crude residue was suspended in pentane (20 mL), filtered through Celite® (5 mL), eluted (pentane, 3 × 10 mL) and concentrated *in vacuo*. The crude residue was used without further purification.

The crude reaction mixture in PhMe (5 mL), 1-((2-bromo-4,6-dimethylphenyl)diazenyl) pyrrolidine, **191**, (633 mg, 2.25 mmol, 1.5 eq.) in PhMe (5 mL) and H_2O (17 mL) were sequentially added to a mixture of $Pd(dppf)Cl_2 \cdot CH_2Cl_2$ (69 mg, 0.085 mmol, 5 mol%) and Na_2CO_3 (720 mg, 6.80 mmol, 4 eq.) in PhMe (7 mL) under N_2. Argon was bubbled through the mixture for 5 mins and it was heated to 95 °C. After 16 h, the reaction mixture was extracted (CH_2Cl_2, 3 × 10 mL), dried ($MgSO_4$) and concentrated *in vacuo*. The crude residue was purified by flash column

chromatography (EtOAc:Pentane, 6:94, $R_f = 0.2$) to give the title compound as a viscous colourless oil (373 mg, 56%).

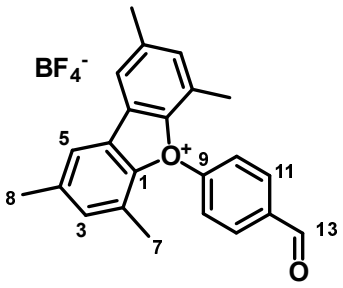
^{1}H NMR (500 MHz, $CDCl_3$): δ_H = 7.75 – 7.68 (m, 2H, H_{11}), 6.95 (d, J = 2.3 Hz, 1H, H_3), 6.90 (d, J = 2.2 Hz, 1H, H_5), 6.83 (d, J = 2.1 Hz, 1H, H_{18}), 6.78 (d, J = 2.0 Hz, 1H, H_{20}), 6.73 – 6.67 (m, 2H, H_{10}), 3.54 – 3.46 (m, 4H, H_{23}), 2.48 (s, 3H, H_{14}), 2.30 (s, 3H, $H_{22/8}$), 2.18 (s, 3H, H_{21}), 2.14 (s, 3H, $H_{22/8}$), 2.06 (s, 3H, H_7), 1.91 – 1.87 (m, 4H, H_{24}).

^{13}C NMR (126 MHz, $CDCl_3$): δ_C = 197.0 (C_{13}), 162.4 (C_9), 147.4 (C_1), 146.0 (C_{16}), 135.2 (C_6), 134.0 (C_{Ar}), 133.3 (C_{Ar}), 131.4 (C_5), 130.9 (C_{18}), 130.7 (C_{Ar}), 130.5 (C_{Ar}), 130.4 (C_{12}), 130.2 (C_{11}), 130.1 (C_3), 129.9 (C_{Ar}), 129.1 (C_{20}), 115.4 (C_{10}), 48.4 (br, C_{23}), 26.4 (C_{14}), 24.1 (C_{24}), 20.9 ($C_{22/8}$), 20.9 ($C_{22/8}$), 18.6 (C_{21}), 16.6 (C_7).

FTIR (film) ν_{max}**/cm^{-1}** = 2921, 2361, 1734, 1677, 1653, 1594, 1559, 1541, 1505, 1430, 1357, 1323, 1267, 1235, 1164, 1124, 957, 858, 837, 729.

HRMS (ESI$^+$): m/z calculated for $C_{24}H_{23}O_2^+$, $[M\text{-}C_4H_8N_3]^+$ = 343.1693; m/z found = 343.1694. Δ = 0.52 ppm.

5-(4-Formylphenyl)-2,4,6,8-tetramethyl-5*H*-dibenzo[*b*,*d*]furan-5-ium tetrafluoroborate, **195**:



Oxonium ion **195** was prepared according to **General Procedure H** using 4-((3,3',5,5'-tetramethyl-2'-(pyrrolidin-1-yldiazenyl)-[1,1'-biphenyl]-2-yl)oxy) benzaldehyde, **193**, (214 mg, 0.50 mmol, 1 eq.) to give the title compound as a white solid (166 mg, 80%).

Melting Point = 182 ℃ (MeCN, dec.).

^{1}H NMR (500 MHz, CD_3CN): δ_H = 10.09 (s, 1H, H_{13}), 8.20 – 8.13 (m, 2H, H_{11}), 7.97 – 7.92 (m, 2H, H_{10}), 7.91 – 7.89 (m, 2H, H_5), 7.33 – 7.29 (m, 2H, H_3), 2.50 (s, 6H, H_8), 2.11 (s, 6H, H_7).

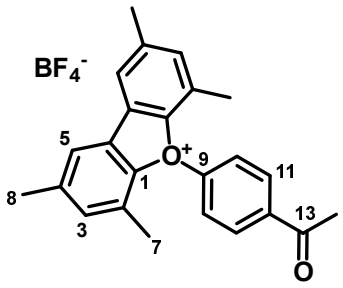
^{13}C NMR (126 MHz, CD_3CN): δ_C = 191.6 (C_{13}), 162.9 (C_9), 161.1 (C_1), 143.1 (C_{Ar}), 139.8 (C_{12}), 135.4 (C_3), 133.7 (C_{11}), 124.7 (C_{Ar}), 124.3 (C_{Ar}), 123.0 (C_{10}), 122.5 (C_5), 21.1 (C_8), 16.8 (C_7).

^{19}F NMR (471 MHz, CD_3CN): δ_F = -151.8.

FTIR (film) ν_{max}**/cm^{-1}** = 2926, 2854, 2359, 1707, 1607, 1586, 1488, 1460, 1386, 1198, 1061, 1033, 1001, 854, 818, 734, 697, 648, 621.

HRMS (ESI$^+$): *m/z* calculated for $C_{23}H_{21}O_2^+$, $[M]^+$ = 329.1536; *m/z* found = 329.1533. Δ = -0.87 ppm.

5-(4-Acetylphenyl)-2,4,6,8-tetramethyl-5*H*-dibenzo[*b*,*d*]furan-5-ium tetrafluoroborate, **196**:



Oxonium ion **196** was prepared according to **General Procedure H** using 1-(4-((3,3',5,5'-tetramethyl-2'-(pyrrolidin-1-yldiazenyl)-[1,1'-biphenyl]-2-yl)oxy)phenyl)ethan-1-one, **194**, (220 mg, 0.50 mmol, 1 eq.) to give the title compound as a tan solid (152 mg, 71%).

Melting Point = 185 ℃ (MeCN, dec.).

^{1}H NMR (500 MHz, CD_3CN): δ_H = 8.22 – 8.15 (m, 2H, H_{11}), 7.92 – 7.89 (m, 2H, H_5), 7.87 – 7.83 (m, 2H, H_{10}), 7.32 – 7.28 (m, 2H, H_3), 2.62 (s, 3H, H_{14}), 2.50 (s, 6H, H_8), 2.11 (s, 6H, H_7).

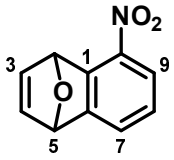
^{13}C NMR (126 MHz, CD_3CN): δ_C = 197.1 (C_{13}), 162.4 (C_9), 161.0 (C_1), 143.1 (C_{Ar}), 140.9 (C_{12}), 135.4 (C_3), 132.8 (C_{11}), 124.7 (C_{Ar}), 124.3 (C_{Ar}), 122.5 (C_{10}), 122.3 (C_5), 27.3 (C_{14}), 21.1 (C_8), 16.8 (C_7).

^{19}F NMR (377 MHz, CD_3CN): δ_F = -151.8.

FTIR (film) ν_{max}**/cm^{-1}** = 3066, 1696, 1585, 1460, 1409, 1359, 1259, 1054, 1000, 957, 856, 706, 620.

HRMS (ESI^+): *m/z* calculated for $C_{24}H_{23}O_2^+$, $[M]^+$ = 343.1693; *m/z* found = 343.1693. Δ = -0.07 ppm.

6-Nitro-1,4-dihydro-1,4-epoxynaphthalene, **197**:



Arene **197** was prepared according to **General Procedure I** using 2,4,6,8-tetramethyl-5-(2-nitrophenyl)-5*H*-dibenzo[*b*,*d*]furan-5-ium tetrafluoroborate, **183**, (129 mg, 0.30 mmol, 1 eq.). The crude residue was purified by flash column chromatography (Et_2O:pentane, 20:80, R_f = 0.3) to give the title compound as a tan solid (52 mg, 91%).

Melting Point = 99-100 ℃.

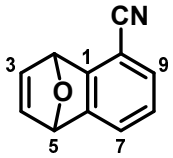
^{1}H NMR (500 MHz, $CDCl_3$): δ_H = 7.72 (d, J = 8.4 Hz, 1H, H_9), 7.49 (d, J = 6.9 Hz, 1H, H_7), 7.19 – 7.10 (m, 3H, H_8, H_3, H_4), 6.51 – 6.47 (m, 1H, H_2), 5.85 – 5.81 (m, 1H, H_5).

^{13}C NMR (126 MHz, $CDCl_3$): δ_C = 152.7 (C_6), 146.9 (C_1), 144.5 (C_4), 142.6 (C_{10}), 142.2 (C_3), 126.9 (C_8), 125.0 (C_7), 119.5 (C_9), 82.8 (C_2), 82.1 (C_5).

FTIR (film) ν_{max}**/cm^{-1}** = 2360, 1523, 1454, 1349, 1279, 1131, 1049, 1013, 877, 861, 842, 810, 789, 767, 743, 711, 650.

HRMS (ESI^-): *m/z* calculated for $C_{10}H_6NO_3^-$, $[M\text{-}H]^-$ = 188.0353; *m/z* found = 188.0344. Δ = -4.80 ppm.

1,4-Dihydro-1,4-epoxynaphthalene-5-carbonitrile, **198**:



Nitrile **161** was prepared according to **General Procedure I** using 2,4,6,8-tetramethyl-5-(2-cyanophenyl)-5*H*-dibenzo[*b*,*d*]furan-5-ium tetrafluoroborate, **184**, (124 mg, 0.30 mmol, 1 eq.). The crude residue was purified by flash column chromatography (Et_2O:pentane, 15:85, $R_f = 0.2$) to give the title compound as a tan solid (49 mg, 97%).

Melting Point = 58-59 ℃.

^{1}H NMR (500 MHz, $CDCl_3$): δ_H = 7.42 (d, J = 7.1 Hz, 1H, H_7), 7.19 (dd, J = 7.9, 0.9 Hz, 1H, H_9), 7.12 – 7.05 (m, 3H, H_8, H_4, H_3), 5.95 (dd, J = 1.0, 1.0 Hz, 1H, H_2), 5.79 (dd, J = 1.1, 1.1 Hz, 1H, H_5).

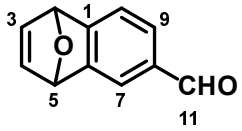
^{13}C NMR (126 MHz, $CDCl_3$): δ_C = 154.7 (C_1), 150.9 (C_6), 143.9 (C_4), 142.4 (C_3), 127.3 (C_9), 126.3 (C_8), 124.0 (C_7), 116.9 (C_{11}), 105.2 (C_{10}), 82.6 (C_5), 81.6 (C_2).

FTIR (film) ν_{max}**/cm^{-1}** = 2918, 2359, 2228, 1604, 1463, 1416, 1351, 1281, 1195, 1136, 1082, 1045, 1016, 961, 931, 873, 857, 821, 797, 779, 746, 721, 658.

HRMS (APCI$^-$): m/z calculated for $C_{11}H_6NO_2^+$, [M-H]$^-$ = 168.0455; m/z found = 168.0444. Δ = -6.41 ppm.

* Spectra are consistent with literature values.[47]

1,4-Dihydro-1,4-epoxynaphthalene-6-carbaldehyde, **199**:



Aldehyde **199** was prepared according to **General Procedure I** using 5-(4-formylphenyl)-2,4,6,8-tetramethyl-5*H*-dibenzo[*b*,*d*]furan-5-ium tetrafluoroborate, **195**, (125 mg, 0.30 mmol, 1 eq.). The crude residue was purified by flash column chromatography (Et_2O:pentane, 20:80, R_f = 0.2) to give the title compound as a colourless oil (48 mg, 93%).

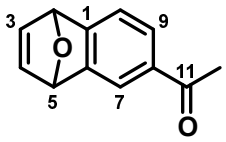
^{1}H NMR (500 MHz, CD_3CN): δ_H = 9.94 (s, 1H, H_{11}), 7.73 (d, J = 1.3 Hz, 1H, H_7), 7.54 (dd, J = 7.2, 1.3 Hz, 1H, H_9), 7.39 (d, J = 7.2 Hz, 1H, H_{10}), 7.07 (dd, J = 5.5, 1.9 Hz, 1H, $H_{3/4}$), 7.02 (dd, J = 5.5, 1.9 Hz, 1H, $H_{3/4}$), 5.80 – 5.74 (m, 2H, H_2, H_5).

^{13}C NMR (126 MHz, CD_3CN): δ_C = 191.9 (C_{11}), 156.3 (C_1), 150.4 (C_6), 143.5 ($C_{3/4}$), 142.3 ($C_{3/4}$), 134.4 (C_8), 131.2 (C_9), 120.5 (C_{10}), 118.8 (C_7), 82.2 ($C_{2/5}$), 82.1 ($C_{2/5}$).

FTIR (film) ν_{max}**/cm^{-1}** = 3016, 2833, 2770, 2728, 1686, 1616, 1589, 1457, 1422, 1349, 1280, 1209, 1194, 1157, 1120, 1086, 1072, 992, 931, 872, 851, 839, 827, 770, 748, 699, 667, 642, 631.

HRMS (APCI$^-$): *m/z* calculated for $C_{11}H_7O_2^-$, [M-H]$^-$ = 171.0452; *m/z* found = 171.0441. Δ = -6.43 ppm.

1-(1,4-Dihydro-1,4-epoxynaphthalen-6-yl)ethan-1-one, **200**:



Ketone **200** was prepared according to **General Procedure I** using 5-(4-acetylphenyl)-2,4,6,8-tetramethyl-5H-dibenzo[*b*,*d*]furan-5-ium, **196** (129 mg, 0.5 mmol, 1 eq.). The crude residue was purified by flash column chromatography (EtOAc:pentane, 20:80, $R_f = 0.2$) to give the title compound as a white solid (53 mg, 96%).

Melting Point = 108-109 ℃.

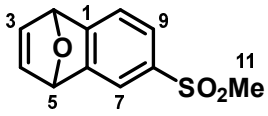
^{1}H NMR (500 MHz, CD_3CN): δ_H = 7.84 – 7.80 (m, 1H, H_7), 7.65 (dd, J = 7.4, 1.5 Hz, 1H, H_9), 7.35 – 7.28 (m, 1H, H_{10}), 7.06 (dd, J = 5.5, 1.9 Hz, 1H, H_3), 7.01 (dd, J = 5.5, 1.9 Hz, 1H, H_4), 5.80 – 5.73 (m, 2H, H_2, H_5), 2.56 (s, 3H, H_{12}).

^{13}C NMR (126 MHz, CD_3CN): δ_C = 197.7 (C_{11}), 154.6 (C_1), 149.9 (C_6), 143.5 (C_3), 142.4 (C_4), 134.8 (C_8), 127.5 (C_9), 120.1 (C_{10}), 119.3 (C_7), 82.3 ($C_{2/5}$), 82.2 ($C_{2/5}$), 26.9 (C_{12}).

FTIR (film) ν_{max}**/cm^{-1}** = 3012, 1732, 1676, 1617, 1583, 1547, 1456, 1418, 1359, 1282, 1251, 1200, 1164, 1106, 993, 966, 872, 849, 749, 706, 650, 631.

HRMS (ESI^+): m/z calculated for $C_{12}H_{11}O_2^+$, $[M+H]^+$ = 187.0754; m/z found = 187.0757. Δ = 1.59 ppm.

6-(Methylsulfonyl)-1,4-dihydro-1,4-epoxynaphthalene, **201**:



201 was prepared according to **General Procedure I** using 2,4,6,8-tetramethyl-5-(4-(methylsulfonyl)phenyl)-5*H*-dibenzo[*b*,*d*]furan-5-ium tetrafluoroborate, (140 mg, 0.30 mmol, 1 eq.). The crude residue was purified by flash column chromatography (EtOAc:Pentane, 40:60, R_f = 0.2) to give the title compound as a tan solid (63 mg, 94%).

Melting Point = 136-138 ℃.

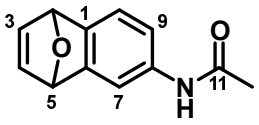
^{1}H NMR (500 MHz, $CDCl_3$): δ_H = 7.75 (d, J = 1.6 Hz, 1H, H_7), 7.65 (dd, J = 7.5, 1.6 Hz, 1H, H_9), 7.40 (d, J = 7.5 Hz, 1H, H_{10}), 7.08 (dd, J = 5.5, 1.8 Hz, 1H, H_3), 7.04 (dd, J = 5.5, 1.8 Hz, 1H, H_4), 5.81 – 5.76 (m, 2H, H_2, H_5), 3.02 (s, 3H, H_{11}).

^{13}C NMR (126 MHz, $CDCl_3$): δ_C = 155.8 (C_1), 151.3 (C_6), 143.4 (C_3), 142.6 (C_4), 137.7 (C_8), 126.3 (C_9), 120.6 (C_{10}), 118.6 (C_7), 82.2 ($C_{2/5}$), 82.2 ($C_{2/5}$), 44.8 (C_{11}).

FTIR (film) ν_{max}**/cm^{-1}** = 3019, 2926, 1409, 1301, 1278, 1155, 1128, 1104, 1057, 993, 961, 871, 850, 814, 764, 748, 700, 642, 607.

HRMS (ESI^+): m/z calculated for $C_{11}H_{10}NaO_3S^+$, $[M+Na]^+$ = 245.0243; m/z found = 245.0245. Δ = 0.80 ppm.

N-(1,4-Dihydro-1,4-epoxynaphthalen-6-yl)acetamide, **202**:



Amide **202** was prepared according to **General Procedure I** using 5-(4-acetamidophenyl)-2,4,6,8-tetramethyl-5*H*-dibenzo[*b*,*d*]furan-5-ium tetrafluoroborate, **186**, (134 mg, 0.30 mmol, 1 eq.). The crude residue was purified by flash column chromatography (EtOAc:Pentane, 50:50, R_f = 0.2) to give the title compound as a tan solid (55 mg, 91%).

Melting Point = 128-129 ℃.

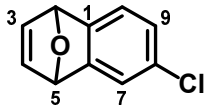
^{1}H NMR (500 MHz, $CDCl_3$): δ_H = 7.57 (s, 2H, H_7, NH), 7.13 (d, J = 7.6 Hz, 1H, H_{10}), 7.01 – 6.96 (m, 2H, H_4, H_3), 6.96 – 6.91 (m, 1H, H_9), 5.67 (s, 1H, H_2), 5.65 (s, 1H, H_5), 2.11 (s, 3H, H_{12}).

^{13}C NMR (126 MHz, $CDCl_3$): δ_C = 168.7 (C_{11}), 150.4 (C_6), 144.8 (C_1), 143.2 (C_3), 142.7 (C_4), 135.2 (C_8), 120.3 (C_{10}), 115.8 (C_9), 114.0 (C_7), 82.5 (C_5), 82.2 (C_2), 24.6 (C_{12}).

FTIR (film) ν_{max}**/cm^{-1}** = 3299, 2361, 1663, 1609, 1546, 1468, 1417, 1373, 1350, 1280, 1196, 1089, 1039, 988, 910, 867, 850, 837, 730, 698, 646.

HRMS (ESI^+): *m/z* calculated for $C_{12}H_{12}NO_2^+$, $[M+H]^+$ = 202.0863; *m/z* found = 202.0865. Δ = 1.32 ppm.

6-Chloro-1,4-dihydro-1,4-epoxynaphthalene, **203**:



Chloride **203** was prepared according to **General Procedure I** using 5-(4-chlorophenyl)-2,4,6,8-tetramethyl-5*H*-dibenzo[*b*,*d*]furan-5-ium tetrafluoroborate, **187**, (127 mg, 0.30 mmol, 1 eq.). The crude residue was purified by flash column chromatography (Et_2O:pentane, 0:100 to 10:90, R_f = 0.4) to give the title compound as a colourless oil (50 mg, 94%).

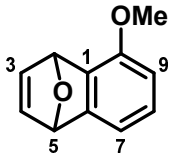
^{1}H NMR (500 MHz, $CDCl_3$): δ_H = 7.23 (d, J = 1.9 Hz, 1H, H_7), 7.15 (d, J = 7.6 Hz, 1H, H_{10}), 7.03 (dd, J = 5.5, 1.8 Hz, 1H, ($H_{4/3}$), 7.01 (dd, J = 5.6, 1.8 Hz, 1H, ($H_{4/3}$), 6.95 (dd, J = 7.5, 1.8 Hz, 1H, H_9), 5.73 – 5.67 (m, 2H).

^{13}C NMR (126 MHz, $CDCl_3$): δ_C = 151.5 (C_6), 147.7 (C_1), 143.3 ($C_{4/3}$), 142.7 ($C_{4/3}$), 130.8 (C_8), 124.7 (C_9), 121.4 (C_7), 121.1 (C_{10}), 82.3 ($C_{5/2}$), 82.2 ($C_{5/2}$).

FTIR (film) ν_{max}**/cm^{-1}** = 3014, 2360, 1590, 1441, 1407, 1328, 1280, 1193, 1165, 1140, 1100, 1059, 992, 951, 866, 849, 823, 807, 749, 697, 682, 641.

HRMS Not found by ESI, APCI or EI.

5-Methoxy-1,4-dihydro-1,4-epoxynaphthalene, **204**:



Arene **204** was prepared according to **General Procedure I** using 5-(2-methoxyphenyl)-2,4,6,8-tetramethyl-5*H*-dibenzo[*b*,*d*]furan-5-ium tetrafluoroborate, **188**, (125 mg, 0.30 mmol, 1 eq.). The crude residue was purified by flash column chromatography (Et_2O:Pentane, 5:95 to 8:92, R_f = 0.2) to give the title compound as a pale yellow oil (51 mg, 98%).

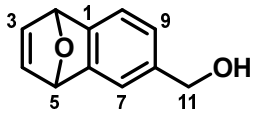
^{1}H NMR (500 MHz, $CDCl_3$): δ_H = 7.08 (dd, J = 5.6, 1.8 Hz, 1H, H_3), 7.03 (dd, J = 5.5, 1.9 Hz, 1H, H_4), 6.99 – 6.92 (m, 2H, H_8, H_7), 6.60 (dd, J = 8.1, 0.9 Hz, 1H, H_9), 5.98 – 5.94 (m, 1H, H_2), 5.73 – 5.69 (m, 1H, H_5), 3.83 (s, 3H, H_{11}).

^{13}C NMR (126 MHz, $CDCl_3$): δ_C = 153.1 (C_{10}), 151.7 (C_6), 143.2 (C_3), 143.0 (C_4), 135.2 (C_1), 127.1 (C_8), 113.8 (C_7), 110.4 (C_9), 82.7 (C_5), 80.2 (C_2), 55.8 (C_{11}).

FTIR (film) ν_{max}**/cm^{-1}** = 3014, 2837, 2361, 1616, 1597, 1478, 1440, 1263, 1176, 1133, 1091, 1065, 999, 922, 855, 822, 791, 771, 738, 721, 667, 625.

HRMS (APCI$^+$): m/z calculated for $C_{11}H_{11}O_2^+$, $[M+H]^+$ = 175.0754; m/z found = 175.0756. Δ = 1.61 ppm.

(1,4-Dihydro-1,4-epoxynaphthalen-6-yl)methanol, **205**:



Arene **205** was prepared according to **General Procedure I** using 5-(4-(hydroxymethyl) phenyl)-2,4,6,8-tetramethyl-5*H*-dibenzo[*b*,*d*]furan-5-ium tetrafluoroborate, **189** (126 mg, 0.30 mmol, 1 eq.). The crude residue was purified by flash column chromatography (EtOAc:Pentane, 40:60, R_f = 0.2) to give the title compound as a colourless oil (50 mg, 96%).

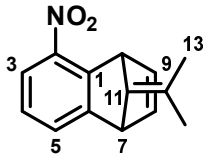
^{1}H NMR (400 MHz, CD_3CN): δ_H = 7.19 – 7.16 (m, 1H, H_7), 7.12 (d, J = 7.2 Hz, 1H, H_{10}), 6.97 – 6.89 (m, 2H, H_3, H_4), 6.86 (dd, J = 7.2, 1.4 Hz, 1H, H_9), 5.65 – 5.58 (m, 2H, H_2, H_5), 4.50 (s, 2H, H_{11}), 2.07 (s, 1H, OH).

^{13}C NMR (176 MHz, CD_3CN): δ_C = 149.8 (C_5), 148.6 (C_1), 143.1 ($C_{3/4}$), 143.0 ($C_{3/4}$), 138.1 (C_8), 123.9 (C_9), 120.2 (C_{10}), 119.6 (C_7), 82.4 ($C_{2/5}$), 82.3 ($C_{2/5}$), 65.4 (C_{11}).

FTIR (film) ν_{max}**/cm^{-1}** = 3384, 3011, 2872, 2361, 1422, 1280, 1210, 1164, 1122, 1086, 988, 869, 849, 750, 697, 639.

HRMS Not found by ESI, APCI or EI.

5-Nitro-9-(propan-2-ylidene)-1,4-dihydro-1,4-methanonaphthalene, **207**:



K_3PO_4 (318 mg, 1.50 mmol, 5 eq.) was added to a solution of 6,6-dimethylfulvene (72 μL, 63.7 mg, 0.60 mmol, 2 eq.) and 2,4,6,8-tetramethyl-5-(2-nitrophenyl)-5*H*-dibenzo[*b*,*d*]furan-5-ium tetrafluoroborate, **183**, (129 mg, 0.30 mmol, 1 eq.) in MeCN (6 mL) under N_2. After 16 h, the reaction was filtered through Celite® (3 mL), eluted (CH_2Cl_2, 3 × 10 mL) and concentrated *in vacuo*. The crude residue was purified by flash column chromatography (Et_2O:Pentane, 2:98, R_f = 0.4) to give the title compound as a tan solid (40 mg, 59%).

Melting Point = 85-86 ℃.

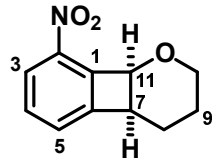
^{1}H NMR (500 MHz, $CDCl_3$): δ_H = 7.70 (dd, J = 8.5, 0.9 Hz, 1H, H_3), 7.44 (d, J = 7.1 Hz, 1H, H_5), 7.07 (dd, J = 8.4, 7.1 Hz, 1H, H_4), 7.03 – 6.95 (m, 2H, H_9, H_8), 5.37 – 5.32 (m, 1H, $H_{10/7}$), 4.50 – 4.45 (m, 1H, $H_{10/7}$), 1.57 (s, 3H, $H_{14/13}$), 1.57 (s, 3H, $H_{14/13}$).

^{13}C NMR (126 MHz, $CDCl_3$): δ_C = 160.0 (C_{12}), 154.5 (C_6), 147.5 (C_1), 144.3 ($C_{9/8}$), 143.1 (C_2), 142.1 ($C_{9/8}$), 125.5 (C_4), 125.4 (C_5), 119.5 (C_3), 105.9 (C_{11}), 50.7 ($C_{10/7}$), 50.6 ($C_{10/7}$), 19.3 ($C_{14/13}$), 19.1 ($C_{14/13}$).

FTIR (film) ν_{max}**/cm^{-1}** = 2915, 1721, 1521, 1448, 1343, 1225, 1164, 1047, 935, 866, 848, 810, 796, 739, 696.

HRMS Mass not found by ESI, APCI or EI.

(4a*S*,8b*S*)-8-Nitro-3,4,4a,8b-tetrahydro-2*H*-benzo[3,4]cyclobuta[1,2-*b*]pyran, **210**:



K_3PO_4 (318 mg, 1.50 mmol, 5 eq.) was added to a solution of 2,4,6,8-tetramethyl-5-(2-nitrophenyl)-5*H*-dibenzo[*b*,*d*]furan-5-ium tetrafluoroborate, **183**, (129 mg, 0.3 mmol, 1 eq.) and 3,4-Dihydro-2*H*-pyran (137 μL, 126 mg, 1.50 mmol, 5 eq.) in MeCN (6 mL). After 16 h, the reaction was filtered through Celite® (1.5 mL), eluted (CH_2Cl_2, 4 × 5 mL) and concentrated *in vacuo*. The crude residue was purified by flash column chromatography (Et_2O:Pentane, 6:94, R_f = 0.2) to give the title compound as a pale yellow oil (61 mg, 92%).

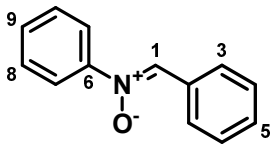
^{1}H NMR (700 MHz, $CDCl_3$): δ_H = 7.99 (d, J = 8.3 Hz, 1H, H_3), 7.51 (dd, J = 7.8, 7.8 Hz, 1H, H_4), 7.47 (d, J = 7.3 Hz, 1H, H_5), 5.40 (d, J = 4.9 Hz, 1H, H_{11}), 3.87 – 3.73 (m, 3H, H_{10}, H_7), 2.27 – 2.19 (m, 1H, H_8), 1.95 (ddt, J = 12.5, 7.3, 5.2 Hz, 1H, H_8), 1.65 – 1.57 (m, 1H, H_9), 1.46 – 1.38 (m, 1H, H_9).

^{13}C NMR (176 MHz, $CDCl_3$): δ_C = 150.2 (C_6), 143.4 (C_2), 141.6 (C_1), 130.9 (C_4), 129.4 (C_5), 122.0 (C_3), 73.4 (C_{11}), 62.6 (C_{10}), 44.1 (C_7), 23.1 (C_8), 19.7 (C_9).

FTIR (film) ν_{max}**/cm^{-1}** = 2943, 2870, 1523, 1455, 1348, 1248, 1221, 1188, 1156, 1098, 1076, 1042, 949, 908, 885, 803, 737, 681, 639.

HRMS (ESI$^+$): m/z calculated for $C_{11}H_{11}NNaO_3^+$, $[M+Na]^+$ = 228.0631; m/z found = 228.0633. Δ = 0.99 ppm.

(*Z*)-*N*,1-Diphenylmethanimine oxide, **211**:



Nitrone **211** was prepared according to a modified literature procedure.[124] Zn dust (980 mg, 15.00 mmol, 3 eq.) and AcOH (1.71 mL, 1.80 g, 30.00 mmol, 6 eq.) were sequentially added to a mixture of nitrobenzene (1.03 mL, 1.23 g, 10.00 mmol, 2 eq.) and benzaldehyde (0.51 mL, 531 mg, 5.00 mmol, 1 eq.) in EtOH (35 mL) at 0 °C and the reaction was allowed to warm to r.t.. After 16 h, the reaction was filtered (Celite®, 5 mL) and eluted (EtOAc, 2 × 10 mL) and concentrated *in vacuo*. The crude solid was suspended in Et_2O (20 mL) and pentane (30 mL) was added. The solid was collected by suction filtration, washed (Et_2O:pentane, 1:1, 10 mL) and dried *in vacuo* to give the title compound as a tan solid (374 mg, 38%).

Melting Point = 103-104 °C (dec.).

^{1}H NMR (400 MHz, DMSO-d_6): δ_H = 8.53 – 8.44 (m, 3H, H_{Ar}, H_1), 7.97 – 7.86 (m, 2H, H_{Ar}), 7.60 – 7.44 (m, 6H, H_{Ar}).

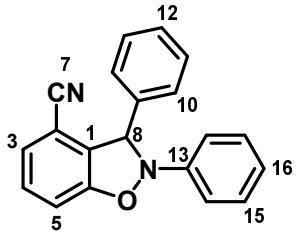
^{13}C NMR (101 MHz, DMSO-d_6): δ_C = 148.5 (C_6), 133.5 (C_1), 131.1 (C_{Ar}), 130.6 (C_{Ar}), 129.8 (C_{Ar}), 129.1 (C_{Ar}), 128.8 (C_{Ar}), 128.4 (C_{Ar}), 121.5 (C_{Ar}).

FTIR (film) ν_{max}**/cm^{-1}** = 3065, 2359, 2225, 1700, 1671, 1626, 1602, 1579, 1496, 1475, 1455, 1394, 1370, 1334, 1277, 1223, 1194, 1158, 1093, 1069, 1047, 1027, 967, 923, 908, 848, 817, 764, 726, 695, 619.

LRMS (ESI^+): *m/z* calculated for $C_{13}H_{12}NO^+$, $[M+H]^+$ = 198; *m/z* found = 198.

*Spectra are consistent with literature values.[125]

2,3-Diphenyl-2,3-dihydrobenzo[*d*]isoxazole-4-carbonitrile, **212**:



K_3PO_4 (318 mg, 1.50 mmol, 5 eq.) was added to a solution of (*Z*)-*N*,1-Diphenylmethanimine oxide, **211**, (118 mg, 0.60 mmol, 2 eq.) and 5-(2-cyanophenyl)-2,4,6,8-tetramethyl-5*H*-dibenzo[*b*,*d*]furan-5-ium tetrafluoroborate, **184**, (124 mg, 0.30 mmol, 1 eq.) in MeCN (6 mL) under N_2. After 16 h, the reaction was filtered through Celite® (3 mL), eluted (CH_2Cl_2, 3 × 10 mL) and concentrated *in vacuo*. The crude residue was purified by flash column chromatography (EtOAc:pentane, 5:95, R_f = 0.2) to give the title compound as a colourless oil (64 mg, 71%).

^{1}H NMR (500 MHz, CD_3CN): δ_H = 7.56 – 7.52 (m, 2H, H_{10}), 7.46 – 7.41 (m, 3H, H_{12}, H_{11}), 7.37 – 7.33 (m, 2H, H_{15}), 7.27 – 7.23 (m, 1H, H_{16}), 7.19 – 7.15 (m, 2H, H_{14}), 7.02 (dd, J = 8.2, 1.1 Hz, 1H, C_3), 6.97 (dd, J = 7.8, 1.1 Hz, 1H, H_5), 6.87 – 6.79 (m, 2H, H_8, H_4).

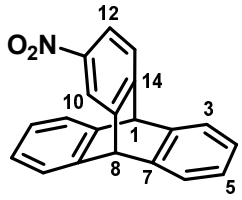
^{13}C NMR (126 MHz, CD_3CN): δ_C = 152.5 (C_6), 141.0 ($C_{13/1}$), 140.9 ($C_{13/1}$), 138.3 (C_9), 131.3 (C_{12}), 130.3 (C_{15}), 129.9 (C_{11}), 128.5 (C_{10}), 128.0 (C_{16}), 126.5 (C_{14}), 125.6 (C_3), 121.8 (C_4), 117.0 (C_7), 112.2 (C_5), 103.1 (C_8), 92.5 (C_2).

FTIR (film) ν_{max}**/cm^{-1}** = 2359, 2224, 1672, 1601, 1581, 1495, 1474, 1453, 1393, 1370, 1336, 1276, 1221, 1196, 1176, 1158, 1093, 1069, 1046, 1027, 966, 846, 817, 759, 725, 695, 666, 619.

HRMS (ESI$^+$): *m/z* calculated for $C_{20}H_{15}N_2O^+$, $[M+H]^+$ = 299.1179; *m/z* found

$= 299.1182$. $\Delta = 1.12$ ppm.

(9*r*,10*r*)-2-Nitro-9,10-dihydro-9,10-[1,2]benzenoanthracene, **214**:



K_3PO_4 (318 mg, 1.50 mmol, 5 eq.) was added to a solution of 2,4,6,8-tetramethyl-5-(4-nitrophenyl)-5*H*-dibenzo[*b*,*d*]furan-5-ium tetrafluoroborate, **160**, (129 mg, 0.30 mmol, 1 eq.) and anthracene (267 mg, 1.50 mmol, 5 eq.) in MeCN (6 mL). After 16 h, the reaction was filtered through Celite® (1.5 mL), eluted (CH_2Cl_2, 4 × 5 mL) and concentrated *in vacuo*. The crude residue was purified by flash column chromatography (CH_2Cl_2:pentane, 10:90 to 30:70, R_f = 0.25) to give the title compound as a pale yellow solid (75 mg, 83%).

Melting Point = >250 ℃.

^{1}H NMR (400 MHz, $CDCl_3$): δ_H = 8.22 (d, J = 2.2 Hz, 1H, H_{10}), 7.93 (dd, J = 8.1, 2.2 Hz, 1H, H_{12}), 7.50 (d, J = 8.1 Hz, 1H, H_{13}), 7.47 – 7.39 (m, 4H, H_{Ar}), 7.12 – 7.00 (m, 4H, H_{Ar}), 5.58 – 5.53 (m, 2H, H_8, H_1).

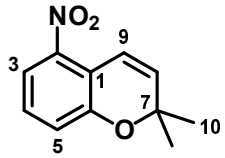
^{13}C NMR (101 MHz, $CDCl_3$): δ_C = 152.6 (C_{Ar}), 147.2 (C_{Ar}), 145.6 (C_{Ar}), 144.1 (C_{Ar}), 143.7 (C_{Ar}), 126.0 (C_{Ar}), 125.9 (C_{Ar}), 124.2 (C_{Ar}), 124.1 (C_{Ar}), 124.1 (C_{13}), 121.6 (C_{12}), 118.8 (C_{10}), 54.1 ($C_{8/1}$), 53.9 ($C_{8/1}$).

FTIR (film) ν_{max}**/cm^{-1}** = 3068, 2361, 1593, 1517, 1459, 1340, 1275, 1194, 1166, 1070, 1021, 908, 891, 836, 801, 749, 738, 709, 653, 637, 628, 611.

HRMS (APCI$^-$): m/z calculated for $C_{20}H_{13}NO_2^-$, $[M+e^-]^-$ = 299.0952; m/z found = 299.0946. Δ = -1.94 ppm.

*Spectra are consistent with literature values.

2,2-Dimethyl-5-nitro-2*H*-chromene, **216**:



K_3PO_4 (318 mg, 1.50 mmol, 5 eq.) was added to a solution of 2,4,6,8-tetramethyl-5-(2-nitrophenyl)-5*H*-dibenzo[*b*,*d*]furan-5-ium tetrafluoroborate, **183**, (129 mg, 0.30 mmol, 1 eq.) and 3-methyl-2-butenal (145 μL, 126 mg, 1.50 mmol, 5 eq.) in MeCN (6 mL). After 16 h, the reaction was filtered through Celite® (1.5 mL), eluted (CH_2Cl_2, 4 × 5 mL) and concentrated *in vacuo*. The crude residue was purified by flash column chromatography (Et_2O:pentane, 2:98, R_f = 0.4) to give the title compound as a pale yellow oil (58 mg, 94%).

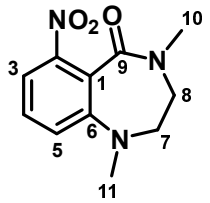
^{1}H NMR (700 MHz, $CDCl_3$): δ_H =7.44 (dd, J = 8.2, 1.2 Hz, 1H, H_3), 7.12 (dd, J = 8.2, 8.2 Hz, 1H, H_4), 6.97 (ddd, J = 8.1, 1.0, 1.0 Hz, 1H, H_5), 6.87 (dd, J = 10.2, 0.8 Hz, 1H, H_9), 5.80 (d, J = 10.2 Hz, 1H, H_8), 1.39 (s, 6H, H_{10}).

^{13}C NMR (176 MHz, $CDCl_3$): δ_C = 154.2 (C_6), 146.1 (C_2), 134.5 (C_8), 128.3 (C_4), 121.9 (C_5), 117.5 (C_9), 117.0 (C_3), 116.0 (C_1), 76.2 (C_7), 27.6 (C_{10}).

FTIR (film) ν_{max}**/cm^{-1}** = 2979, 2360, 1609, 1521, 1453, 1363, 1343, 1310, 1275, 1206, 1165, 1119, 1074, 997, 892, 856, 824, 808, 779, 760, 735, 707, 688.

HRMS (ESI^+): *m/z* calculated for $C_{22}H_{23}N_2O_6^+$, $[2M+H]^+$ = 411.1151; *m/z* found = 411.1150. Δ = -0.16 ppm.

1,4-Dimethyl-6-nitro-1,2,3,4-tetrahydro-5*H*-benzo[*e*][1,4]diazepin-5-one, **217**:



K_3PO_4 (318 mg, 1.50 mmol, 5 eq.) was added to a solution of 2,4,6,8-tetramethyl-5-(2-nitrophenyl)-5*H*-dibenzo[*b*,*d*]furan-5-ium tetrafluoroborate, **183**, (129 mg, 0.30 mmol, 1 eq.) in DMI (6 mL). After 16 h, the reaction was filtered through Celite® (1.5 mL), eluted (CH_2Cl_2, 4 × 5 mL) and concentrated *in vacuo*. The DMI was removed by distillation (110 ℃ at 7 mbar) and the crude residue was purified by flash column chromatography (EtOAc:CH_2Cl_2, 5:95 to 15:85, R_f = 0.3) to give the title compound as a bright yellow solid (26 mg, 37%).

Melting Point = 177-179 ℃ ($CHCl_3$).

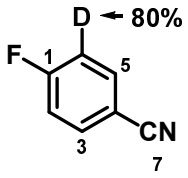
^{1}H NMR (700 MHz, $CDCl_3$): δ_H = 7.44 – 7.37 (m, 2H, H_4, H_3), 7.09 – 7.05 (m, 1H, H_5), 3.59 (t, J = 5.7 Hz, 2H, H_8), 3.32 (t, J = 5.7 Hz, 2H, H_7), 3.21 (s, 3H, H_{10}), 2.86 (s, 3H, H_{11}).

^{13}C NMR (176 MHz, $CDCl_3$): δ_C = 166.4 (C_9), 150.3 (C_2), 147.2 (C_6), 131.1 (C_4), 124.8 (C_1), 122.1 (C_5), 116.9 (C_3), 57.0 (C_8), 48.1 (C_7), 40.4 (C_{11}), 33.8 (C_{10}).

FTIR (film) ν_{max}**/cm^{-1}** = 2946, 2361, 1650, 1607, 1528, 1489, 1456, 1431, 1399, 1359, 1304, 1263, 1189, 1120, 1095, 1059, 931, 852, 815, 769, 724, 664.

HRMS (ESI^+): *m/z* calculated for $C_{11}H_{14}N_3O_3^+$, $[M+H]^+$ = 236.1030; *m/z* found = 236.1030. Δ = 0.12 ppm.

4-Fluorobenzonitrile-3-*d*, **221**:



n-BuLi (1.6 M in hexanes, 6.87 mL, 11.00 mmol, 1.1 eq.) was added to a solution of *i*-Pr_2NH (1.68 mL, 1.21 g, 12.00 mmol, 1.2 eq.) in THF (50 mL) at –78 ℃ under N_2. Once the addition was complete, the reaction was warmed to r.t. for 5 mins and cooled back to –78 °C. 4-Fluorobenzonitrile (1.21 g, 10.00 mmol, 1 eq.) in THF (10 mL) was added dropwise to the stirred reaction mixture.[78] After 1 h at –78 °C, D_2O (2 mL) in THF (10 mL) was slowly added. After 10 minutes, the reaction was warmed to r.t., HCl (3 M, aq., 40 mL) was added and the mixture was extracted with Et_2O (5 × 30 mL). The combined organic extracts were washed with HCl (3M, aq., 30 mL), dried ($MgSO_4$) and concentrated *in vacuo*. The crude residue was purified by flash column chromatography (5:95, Et_2O:pentane, R_f = 0.5) to give the title compound with 80% D incorporation as a white solid (696 mg, 57%).

Melting Point = 34-35 ℃.

^{1}H NMR (500 MHz, $CDCl_3$): δ_H = 7.71 – 7.65 (m, 2H, H_5, H_3), 7.22 – 7.13 (m, 1.2H, H_6, H_2).

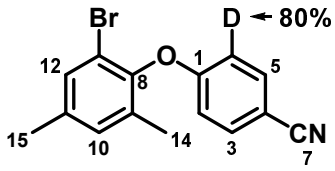
^{13}C NMR (126 MHz, $CDCl_3$): δ_C = Major: 165.2 (d, J = 256.6 Hz, C_1), 134.9 (d, J = 9.3 Hz, $C_{5/3}$), 134.8 (d, J = 9.2 Hz, $C_{5/3}$), 118.2 (C_7), 117.08 (d, J = 22.5 Hz, C_2), 116.9 (d, 1:1:1 t (I = 1), J = 25.4, 22.4 Hz, C_6), 108.82 – 108.73 (m, C_4). Minor: 165.3 (d, J = 256.8 Hz, C_1). All other resonances are obscured by the major isomer.

^{19}F NMR (471 MHz, $CDCl_3$): δ_F = Major: -102.7. Minor: -102.4.

FTIR (film) $\nu_{max}/\mathbf{cm^{-1}}$ = 3107, 2232, 1597, 1507, 1488, 1394, 1275, 1230, 1185, 1163, 1136, 1031, 913, 828, 737, 684, 673.

HRMS Mass not found by ESI, APCI or EI.

4-(2-Bromo-4,6-dimethylphenoxy)benzonitrile-3-*d*, **222**:



Bromide **222** was prepared according to **General Procedure B** on a 5 mmol scale using 2-bromo-4,6-dimethylphenol (1.05 g, 5.00 mmol, 1 eq.), 4-fluorobenzonitrile-3-*d*, **221**, (610 mg, 5.00 mmol, 1 eq.) and K_2CO_3 (1.38 g, 10.00 mmol, 2 eq.) in DMF (12.5 mL). The crude residue was purified by flash column chromatography (Et_2O:pentane, 5:95, $R_f = 0.4$) to give the title compound with 80% D incorporation as a white solid (1.28 g, 85%).

Melting Point = 64-65 ℃.

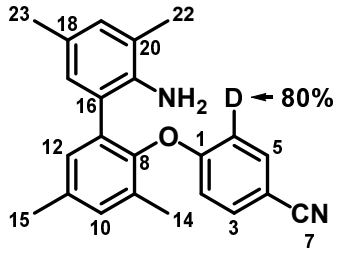
^{1}H NMR (400 MHz, $CDCl_3$): δ_H = 7.61 – 7.55 (m, 2H, H_3, H_5), 7.33 – 7.28 (m, 1H, H_{12}), 7.05 – 7.02 (m, 1H, H_{10}), 6.88 – 6.83 (m, 1.2H, H_2, H_6), 2.33 (s, 3H, H_{15}), 2.12 (s, 3H, H_{14}).

^{13}C NMR (101 MHz, $CDCl_3$): δ_C = Major: 160.5 (C_1), 146.5 (C_8), 137.3 ($C_{10/11}$), 134.3 ($C_{3/5}$), 134.2 ($C_{3/5}$), 132.8 ($C_{10/11}$), 131.9 (C_{12}), 131.5 (C_{10}), 118.9 (C_7), 116.7 (C_{13}), 115.8 (C_2), 115.5 (1:1:1 t (I = 1), J = 25.1 Hz C_6), 105.5 (C_4), 20.6 (C_{15}), 16.7 (C_{14}). Minor: 160.6 (C_1). All other resonances are obscured by the major isomer.

FTIR (film) ν_{max}**/cm^{-1}** = 2360, 2227, 1596, 1559, 1469, 1398, 1279, 1234, 1166, 1122, 1030, 855, 826, 784, 738.

HRMS (APCI$^+$): m/z calculated for calculated for $C_{16}H_{11}{}^2H^{79}BrON^+$, $[M+H]^+$ = 303.0328 ; m/z found = 303.0328. Δ = 0.30 ppm.

4-((2'-Amino-3,3',5,5'-tetramethyl-[1,1'-biphenyl]-2-yl)oxy)benzonitrile-3-*d*, **223**:



Aniline **223** was prepared according to **General Procedure D** using 4-(2-bromo-4,6-dimethyl- phenoxy)benzonitrile-3-d, **222**, (303 mg, 1.00 mmol, 1 eq.) added as a solid. The crude residue was purified by flash column chromatography (EtOAc:Pentane, 8:92 to 10:90, $R_f = 0.25$) to give the title compound as a white solid (303 mg, 88%).

Melting Point = 120-121 ℃.

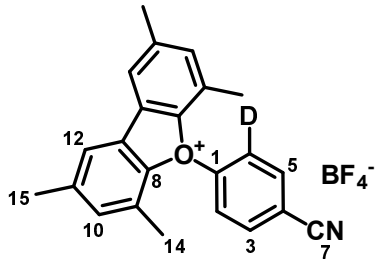
^{1}H NMR (500 MHz, $CDCl_3$): δ_H = 7.41 – 7.35 (m, 2H, H_3, H_5), 7.13 – 7.09 (m, 1H, H_{10}), 7.05 – 7.01 (m, 1H, H_{12}), 6.76 – 6.72 (m, 1H, H_{19}), 6.71 – 6.65 (m, 1.2H, H_2, H_6), 6.56 – 6.52 (m, 1H, H_{17}), 2.36 (s, 3H, H_{15}), 2.16 (s, 3H, H_{14}), 2.11 (s, 3H, H_{22}), 2.07 (s, 3H, H_{23}). NH_2 was not observed.

^{13}C NMR (126 MHz, $CDCl_3$): δ_C = Major: 161.7 (C_1), 147.8 (C_8), 139.0 (C_{21}), 136.2 (C_{Ar}), 133.9 ($C_{3/5}$), 133.8 ($C_{3/5}$), 133.0 (C_{20}), 131.9 (C_{10}), 131.7 (C_{Ar}), 130.8 (C_{19}), 130.7 (C_{12}), 128.9 (C_{17}), 127.3 (C_{Ar}), 123.5 (C_9), 122.9 (C_{Ar}), 119.3 (C_7), 116.2 (C_2), 116.0 (1:1:1 t (I = 1), J = 24.7 Hz, C_6), 104.7 (C_4), 21.1 (C_{15}), 20.5 (C_{23}), 18.0 (C_{22}), 16.7 (C_{14}). Minor: 161.7 (C_1). All other resonances were obscured by the major isomer.

FTIR (film) ν_{max}**/cm^{-1}** = 2921, 2361, 2225, 1653, 1596, 1559, 1541, 1481, 1277, 1237, 1199, 1150, 1013, 912, 860, 834, 733.

HRMS (ESI^+): *m/z* calculated for $C_{23}H_{22}{}^2HON_2^+$, $[M+H]^+ = 344.1868$; *m/z* found = 344.1866. Δ = -0.53 ppm

5-(4-Cyanophenyl-2-*d*)-2,4,6,8-tetramethyl-5*H*-dibenzo[*b*,*d*]furan-5-ium tetrafluoroborate, **224**:



Oxonium ion **224** was prepared according to **General Procedure F** using 4-((2'-amino-3,3',5,5'-tetramethyl-[1,1'-biphenyl]-2-yl)oxy)benzonitrile-3-*d*, **223**, (172 mg, 0.50 mmol, 1 eq.) to give the title compound as a pale yellow solid (181 mg, 87%).

Melting Point = 226 ℃ (dec.).

^{1}H NMR (500 MHz, CD_3CN): δ_H = 8.06 – 8.02 (m, 2H, H_3, H_5), 7.94 – 7.91 (m, 1H, H_2, H_6), 7.91 – 7.88 (m, 2H, H_{12}), 7.32 – 7.30 (m, 2H, H_{10}), 2.50 (s, 3H, H_{15}), 2.11 (s, 3H, H_{14}).

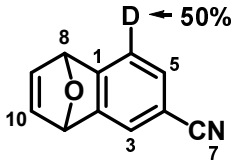
^{13}C NMR (126 MHz, CD_3CN): δ_C = Major: 161.7 (C_1), 161.3 (C_8), 143.3 (C_{Ar}), 137.3 ($C_{3/5}$), 137.2 ($C_{3/5}$), 135.4 (C_{10}), 124.7 (C_{Ar}), 124.2 (C_{Ar}), 123.3 (C_2), 123.2 (1:1:1 t (I = 1), J = 26.5 Hz, C_6) 122.6 (C_{12}), 117.4 ($C_{7/Ar}$), 117.4 ($C_{7/Ar}$, 21.1 (C_{15}), 16.7 (C_{14}). Minor: 161.8 (C_1). All other resonances are obscured by the major isomer.

^{19}F NMR (377 MHz, CD_3CN): δ_F = -151.8.

FTIR (film) ν_{max}**/cm^{-1}** = 3102, 2240, 1606, 1487, 1462, 1386, 1289, 1057 (br), 1008, 909, 870, 840, 734, 704, 619.

HRMS (ESI^+): m/z calculated for calculated for $C_{23}H_{19}{}^2HON^+$, $[M]^+$ = 327.1602; m/z found = 327.1598. Δ = -1.21 ppm.

1,4-Dihydro-1,4-epoxynaphthalene-6-carbonitrile-8-*d*, **225**:



Nitrile **225** was prepared according to **General Procedure I** using 5-(4-cyanophenyl-2-*d*)-2,4,6,8-tetramethyl-5*H*-dibenzo[*b*,*d*]furan-5-ium tetrafluoroborate, **224**, (124 mg, 0.30 mmol, 1 eq.). The crude residue was purified by flash column chromatography (Et_2O:pentane, 20:80, R_f = 0.25) to give the title compound as a white solid (50.2 mg, 98%).

Melting Point = 82-84 ℃.

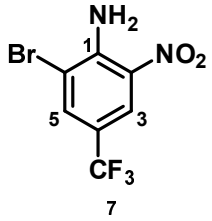
^{1}H NMR (500 MHz, $CDCl_3$): δ_H = 7.48 – 7.44 (m, 1H, H_3), 7.37 – 7.31 (m, 1.5H, H_6, H_5), 7.06 (dd, J = 5.5, 2.0 Hz, 1H, $H_{10/9}$), 7.03 (dd, J = 5.5, 2.0 Hz, 1H, $H_{10/9}$), 5.78 – 5.75 (m, 2H, H_{11}, H_8).

^{13}C NMR (126 MHz, $CDCl_3$): δ_C = 154.6 (C_1), 154.5 ($C_{1'}$), 150.5 (C_2), 143.1 ($C_{10/9}$), 142.6 ($C_{10/9}$), 130.9 (C_5), 130.8 ($C_{5'}$), 122.8 (C_3), 120.7 ($C_{6'}$), 120.4 (1:1:1 t (I = 1), J = 25.2 Hz, C_6), 119.1 (C_7), 108.8 (C_4), 82.1 (C_8), 82.1 ($C_{8'}$), 81.9 (C_{11}).

FTIR (film) ν_{max}**/cm^{-1}** = 3018, 2226, 1614, 1456, 1417, 1398, 1280, 1178, 1079, 997, 871, 852, 839, 821, 749, 701, 645, 615.

HRMS (APCI$^-$): *m/z* calculated for calculated for $C_{11}H_5{}^2HON^-$, [M-H]$^-$ = 169.0502; *m/z* found = 169.0500. Δ = -1.09 ppm.

2-Bromo-6-nitro-4-(trifluoromethyl)aniline, **229**:



Bromine (0.54 mL, 1.68 g, 10.50 mmol, 1.05 eq.) was added as a solution in $CHCl_3$ (5 mL) *via* a pressure-equalising dropping funnel to a solution of 2-nitro-4-(trifluoro -methyl)aniline (2.06 g, 10.00 mmol, 1 eq.) in $CHCl_3$ (15 mL) at r.t.. Once the addition was complete, the reaction was heated to 60 °C. After 24 h, Na_2SO_3 (sat. aq., 20 mL) was added and the reaction mixture was extracted (CH_2Cl_2, 2 × 20 mL). The organic extracts were dried ($MgSO_4$) and concentrated *in vacuo* to give the title compound as a bright yellow solid (2.85 g, Quant.).

Melting Point = 63-64 ℃.

^{1}H NMR (400 MHz, $CDCl_3$): δ_H = 8.47 – 8.41 (m, 1H, H_3), 7.92 (d, J = 2.2 Hz, 1H, H_5), 7.13 (br s, 2H, NH).

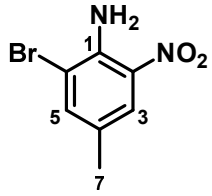
^{13}C NMR (101 MHz, $CDCl_3$): δ_C = 144.1 (C_1), 134.8 (q, J = 3.3 Hz, C_5), 131.6 (C_2), 123.8 (q, J = 4.2 Hz, C_3), 122.73 (q, J = 271.7 Hz, C_7), 118.78 (q, J = 35.2 Hz, C_4), 112.5 (C_6).

^{19}F NMR (377 MHz, $CDCl_3$): δ_F = -62.1.

FTIR (film) ν_{max}**/cm^{-1}** = 3486, 3374, 2922, 2361, 1630, 1558, 1524, 1459, 1343, 1288, 1164, 1120, 904, 765, 731, 665.

4 **HRMS** (ESI^-): m/z calculated for $C_7H_3{}^{79}BrF_3N_2O_2^-$, $[M\text{-}H]^-$ = 282.9335; m/z found = 282.9337. Δ = 0.66 ppm.

2-Bromo-4-methyl-6-nitroaniline, **230**:



Bromine (1.79 mL, 5.58 g, 34.90 mmol, 1.05 eq.) was added as a solution in MeOH (20 mL) *via* a pressure-equalising dropping funnel to a solution of 2-methyl-4-nitroaniline (5.06 g, 33.30 mmol, 1 eq.) in MeOH (120 mL) at 0 °C. After 1 h, H_2O (100 mL) and Na_2SO_3 (sat. aq., 30 mL) were sequentially added. The precipitate was collected by suction filtration, washed (H_2O, 3 × 20 mL), dissolved in acetone (50 mL), dried ($MgSO_4$) and concentrated *in vacuo* to give the title compound as a bright orange solid (7.06 g, 92%).

Melting Point = 65-67 °C (acetone).

^{1}H NMR (400 MHz, $CDCl_3$): δ_H = 7.95 – 7.90 (m, 1H, H_3), 7.54 (d, J = 2.1 Hz, 1H, H_5), 6.45 (br, s, 2H, NH_2), 2.27 (s, 3H, H_7).

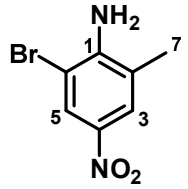
^{13}C NMR (101 MHz, $CDCl_3$): δ_C = 140.4 (C_1), 140.2 (C_5), 132.8 (C_2), 126.6 (C_{14}), 125.7 (C_3), 112.1 (C_6), 20.1 (C_7).

FTIR (film) ν_{max}**/cm^{-1}** = 3477, 3363, 2922, 1633, 1577, 1553, 1514, 1449, 1397, 1347, 1323, 1254, 1206, 1088, 939, 870, 762, 730.

HRMS Not found by ESI, APCI or EI.

*Spectra are consistent with literature values.[126]

2-Bromo-6-methyl-4-nitroaniline, **231**:



Bromine (3.58 mL, 11.16 g, 69.8 mmol, 1.05 eq.) was added as a solution in MeOH (20 mL) *via* a pressure-equalising dropping funnel to a solution of 2-methyl-4-nitroaniline (10.12 g, 66.5 mmol, 1 eq.) in MeOH (500 mL) at 0 °C. After 1 h, the precipitate was collected by suction filtration, washed (MeOH 2 × 5 mL) and dried to give the title compound as a mustard solid (11.4 g, 74%).

Melting Point = 176-177 °C (MeOH).

^{1}H NMR (400 MHz, DMSO-d_6): δ_H = 8.12 (d, J = 2.6 Hz, 1H, H_5), 7.92 – 7.86 (m, 1H, H_3), 6.47 (s, 2H, NH), 2.22 (s, 3H, H_7).

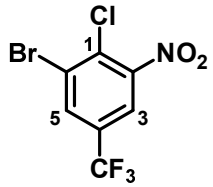
^{13}C NMR (101 MHz, DMSO-d_6): δ_C = 150.4 (C_4), 135.9 (C_1), 126.6 (C_5), 125.0 (C_3), 122.1 (C_2), 105.1 (C_6), 18.4 (C_7).

FTIR (film) ν_{max}**/cm^{-1}** = 3487, 3385, 2922, 2359, 1617, 1480, 1298, 1279, 1203, 1103, 1037, 900, 821, 745, 701.

HRMS Not found by ESI, APCI or EI.

* Spectra are consistent with literature values.[127]

1-Bromo-2-chloro-3-nitro-5-(trifluoromethyl)benzene, **232**:



7

Prepared according to a modified literature chlorination procedure.[69] 2-bromo-6-nitro-4-(trifluoromethyl)aniline, **229**, (800 mg, 2.80 mmol, 1 eq.) was added over 5 mins to a solution of $CuCl_2$ (489 mg, 3.64 mmol, 1.3 eq.) and *t*-BuONO (0.53 mL, 461 mg, 4.48 mmol, 1.6 eq.) in MeCN (20 mL). After 4 h, H_2O (25 mL) was added and the reaction mixture was extracted (Et_2O, 2 × 20 mL). The organic extracts were washed (H_2O, 20 mL), dried ($MgSO_4$) and concentrated *in vacuo*. The crude residue was purified by flash column chromatography (Et_2O:pentane, 5:95, $R_f = 0.7$) to give the title compound as a yellow oil (750 mg, 88%).

^{1}H NMR (400 MHz, $CDCl_3$): δ_H = 8.13 – 8.10 (m, 1H, H_5), 8.01 – 7.98 (m, 1H, H_3).

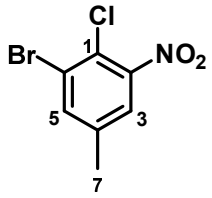
^{13}C NMR (101 MHz, $CDCl_3$): δ_C = 149.6 (C_1), 136.9 (C_2), 133.4 (q, J = 3.6 Hz, C_5), 130.8 (q, J = 35.3 Hz, C_4), 126.6 (C_6), 121.7 (q, J = 273.4 Hz, C_7), 121.1 (q, J = 3.8 Hz, C_3).

^{19}F NMR (377 MHz, $CDCl_3$): δ_F = -63.0.

FTIR (film) ν_{max}**/cm^{-1}** = 3087, 1612, 1543, 1353, 1308, 1273, 1212, 1137, 1108, 1054, 893, 729.

HRMS Not found by ESI, APCI or EI.

1-Bromo-2-chloro-5-methyl-3-nitrobenzene, **233**:



Prepared according to a modified literature chlorination procedure.[69] 2-Bromo-4-methyl-6-nitroaniline, **230**, (2.31 g, 10.00 mmol, 1 eq.) was added over 30 mins to a solution of $CuCl_2$ (1.75 g, 13.00 mmol, 1.3 eq.) and *t*-BuONO (1.90 mL, 1.65 g, 16.00 mmol, 1.6 eq.) in MeCN (100 mL). After 4 h, H_2O (100 mL) was added and the reaction mixture was extracted (CH_2Cl_2, 3 × 50 mL). The organic extracts were washed (H_2O, 100 mL), dried ($MgSO_4$) and concentrated *in vacuo*. The crude residue was purified by flash column chromatography (CH_2Cl_2:pentane, 10:90, R_f = 0.4) to give the title compound as a pale yellow solid (2.13 g, 85%).

Melting Point = 91-92 ℃.

^{1}H NMR (400 MHz, $CDCl_3$): δ_H = 7.68 – 7.65 (m, 1H, H_5), 7.53 – 7.51 (m, 1H, H_3), 2.40 (s, 3H, H_7).

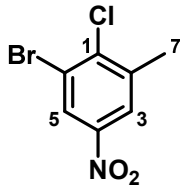
^{13}C NMR (126 MHz, $CDCl_3$): δ_C = 149.3 (C_2), 139.1 (C_4), 137.4 (C_5), 125.0 (C_1), 124.5 (C_3), 123.9 (C_6), 20.6 (C_7).

FTIR (film) ν_{max}**/cm^{-1}** = 2360, 1530, 1446, 1348, 1270, 1155, 1050, 940, 864, 841, 729.

HRMS Not found by ESI, APCI or EI.

*Spectra are consistent with literature values.[69]

1-Bromo-2-chloro-3-methyl-5-nitrobenzene, **234**:



Prepared according to a modified literature chlorination procedure.[69] 2-Bromo-6-methyl-4-nitroaniline, **231**, (10.00 g, 43.20 mmol, 1 eq.) was added over 30 mins to a solution of $CuCl_2$ (7.56 g, 56.27 mmol, 1.3 eq.) and *t*-BuONO (8.22 mL, 7.13 g, 69.12 mmol, 1.6 eq.) in MeCN (500 mL). After 4 h, H_2O (500 mL) was added and the reaction mixture was extracted (Et_2O, 4 × 400 mL). The organic extracts were washed (H_2O, 500 mL), dried ($MgSO_4$) and concentrated *in vacuo*. The crude residue was purified by flash column chromatography (CH_2Cl_2:pentane, 10:90, R_f = 0.4) to give the title compound as a pale yellow solid (8.40 g, 76%).

Melting Point = 91-92 ℃.

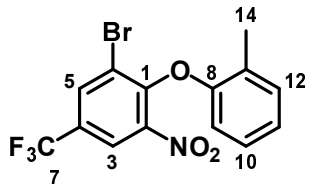
^{1}H NMR (500 MHz, $CDCl_3$): δ_H = 8.34 (d, J = 2.6 Hz, 1H, H_5), 8.07 (dd, J = 2.6, 0.9 Hz, 1H, H_3), 2.55 (s, 3H, H_7).

^{13}C NMR (126 MHz, $CDCl_3$): δ_C = 145.9 (C_4), 141.7 (C_1), 139.8 (C_2), 126.2 (C_5), 124.1 (C_3), 123.6 (C_6), 22.0 (C_7).

FTIR (film) ν_{max}**/cm^{-1}** = 3107, 2361, 1514, 1457, 1415, 1390, 1338, 1288, 1234, 1059, 941, 900, 871, 840, 760, 740, 695, 659.

HRMS Not found by ESI, APCI or EI.

1-Bromo-3-methyl-5-nitro-2-(*o*-tolyloxy)benzene, **235**:



K_2CO_3 (906 mg, 6.56 mmol, 2 eq.) was added to a solution of 1-bromo-2-chloro-3-nitro-5-(trifluoromethyl)benzene, **232**, (1.00 g, 3.28 mmol, 1 eq.) and *o*-cresol (354 mg, 3.28 mmol, 1 eq.) in DMF (10 mL) and the reaction was heated to 110 °C. After 16 h, the reaction mixture was cooled, H_2O (20 mL) was added and the reaction was extracted (Et_2O, 3 × 20 mL). The organic layers were dried ($MgSO_4$), concentrated *in vacuo* and the crude residue was purified by flash column chromatography (pentane, R_f = 0.2) to give the title compound as a pale yellow solid (530 mg, 43%).

Melting Point = 79-80 ℃.

^{1}H NMR (500 MHz, $CDCl_3$): δ_H = 8.19 (d, J = 2.2 Hz, 1H, H_3), 8.16 (d, J = 2.2 Hz, 1H, H_5), 7.31 – 7.23 (m, 1H, H_{12}), 7.09 – 6.97 (m, 2H, H_{11}, H_{10}), 6.32 (dd, J = 7.5, 1.8 Hz, 1H, H_9), 2.43 (s, 3H, H_{14}).

^{13}C NMR (126 MHz, $CDCl_3$): δ_C = 154.7 (C_8), 149.0 (C_1), 135.1 (q, J = 3.5 Hz, C_5), 132.0 (q, J = 3.4 Hz, C_2), 131.8 (C_{12}), 128.5 (q, J = 35.3 Hz, C_4), 127.4 (C_{13}), 126.9 ($C_{11/10}$), 123.7 ($C_{11/10}$), 122.3 (q, J = 3.8 Hz, C_3), 122.0 (q, J = 273.0 Hz, C_7), 121.5 (q, J = 3.8 Hz, C_6), 112.6 (C_9), 16.3 (C_{14}).

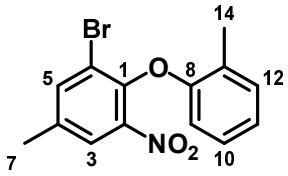
^{19}F NMR (377 MHz, $CDCl_3$): δ_F = -62.5.

FTIR (film) ν_{max}**/cm^{-1}** = 1620, 1588, 1543, 1491, 1463, 1357, 1344, 1316, 1279,

1257, 1220, 1170, 1136, 1114, 1088, 1045, 896, 871, 828, 797, 748, 728, 711, 672.

HRMS Not found by ESI, APCI or EI.

1-Bromo-5-methyl-3-nitro-2-(*o*-tolyloxy)benzene, **236**:



K_2CO_3 (906 mg, 6.56 mmol, 2 eq.) was added to a solution of 1-bromo-2-chloro-5-methyl-3-nitrobenzene, **233**, (817 mg, 3.28 mmol, 1 eq.) and *o*-cresol (354 mg, 3.28 mmol, 1 eq.) in DMF (10 mL) and the reaction was heated to 110 ℃. After 16 h, the reaction mixture was cooled, H_2O (20 mL) was added and the reaction was extracted (Et_2O, 3 × 20 mL). The organic layers were dried ($MgSO_4$), concentrated *in vacuo* and the crude residue was purified by flash column chromatography (Et_2O:pentane, 3:97, $R_f = 0.3$) to give the title compound as a pale yellow solid (630 mg, 60%).

Melting Point = 98-99 ℃.

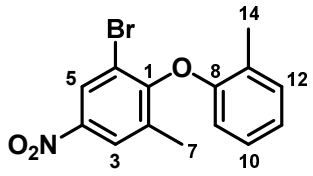
^{1}H NMR (500 MHz, $CDCl_3$): δ_H =7.79 – 7.71 (m, 2H, H_5, H_3), 7.26 (dd, J = 7.3, 1.8 Hz, 1H, H_{12}), 7.04 (ddd, J = 8.0, 7.8, 2.0 Hz, 1H, H_{10}), 6.99 (ddd, J = 7.5, 7.4, 1.3 Hz, 1H, H_{11}), 6.35 (dd, J = 8.1, 1.3 Hz, 1H, H_9), 2.47 (s, 3H, H_7), 2.45 (s, 3H, H_{14}).

^{13}C NMR (126 MHz, $CDCl_3$): δ_C = 155.2 (C_8), 144.4 (C_2), 143.6 (C_1), 138.7 ($C_{5/3}$), 136.8 (C_4), 131.4 (C_{12}), 127.0(C_{13}), 126.6 (C_{10}), 125.1 ($C_{5/3}$), 122.8 (C_{11}), 119.8 (C_6), 112.4 (C_9), 20.6 (C_7), 16.3 (C_{14}).

FTIR (film) ν_{max}**/cm^{-1}** = 2360, 1530, 1446, 1348, 1270, 1155, 1050, 940, 864, 841, 729.

HRMS Not found by ESI, APCI or EI.

1-Bromo-3-methyl-5-nitro-2-(*o*-tolyloxy)benzene, **237**:



Bromide **237** was prepared according to **General Procedure J** using 1-bromo-2-chloro-3-methyl-5-nitrobenzene (1.00 g, 4.00 mmol, 1 eq.), *o*-cresol (432 mg, 4.00 mmol, 1 eq.) and K_2CO_3 (1.11 g, 8.00 mmol, 2 eq.) in DMF (10 mL). The crude residue was purified by flash column chromatography (2:98, Et_2O, pentane, R_f = 0.3) to give the title compound as a white solid (966 mg, 75%).

Melting Point = 101-103 ℃.

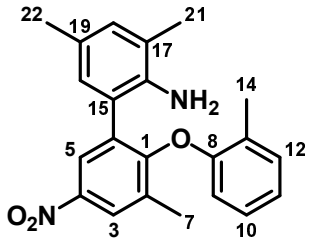
^{1}H NMR (500 MHz, $CDCl_3$): δ_H = 8.42 (d, J = 2.8 Hz, 1H, H_5), 8.20 – 8.13 (m, 1H, H_3), 7.33 – 7.26 (m, 1H, H_{12}), 7.09 – 6.96 (m, 2H, H_{10}, H_{11}), 6.24 (dd, J = 7.9, 1.4 Hz, 1H, H_9), 2.48 (s, 3H, H_{14}), 2.31 (s, 3H, H_7).

^{13}C NMR (126 MHz, $CDCl_3$): δ_C = 156.1 (C_1), 154.4 (C_8), 144.8 (C_4), 135.2 (C_2), 131.7 (C_{12}), 127.1 (C_5), 127.0 ($C_{10/11}$), 126.8 (C_{13}), 125.7 (C_3), 122.8 ($C_{10/11}$), 118.4 (C_6), 112.2 (C_9), 17.3 (C_7), 16.4 (C_{14}).

FTIR (film) ν_{max}**/cm^{-1}** = 3087, 2359, 1575, 1525, 1489, 1460, 1433, 1379, 1343, 1301, 1259, 1224, 1176, 1113, 1090, 1044, 945, 898, 868, 842, 790, 746, 686.

HRMS Not found by ESI, APCI or EI.

3,3',5-Trimethyl-5'-nitro-2'-(*o*-tolyloxy)-[1,1'-biphenyl]-2-amine, **238**:



Aniline **238** was prepared according to **General Procedure C** using 1-bromo-3-methyl-5-nitro-2-(*o*-tolyloxy)benzene, **237**, (266 mg, 0.83 mmol, 1 eq.) as a solid, 2,4-dimethyl-6-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)aniline, **158**, (1.25 mmo1, 1.5 eq.) in PhMe (5 mL), H_2O (5 mL), $Pd(dppf)Cl_2{\cdot}CH_2Cl_2$ (34 mg, 0.04 mmol, 5 mol%) and Na_2CO_3 (348 mg, 3.32 mmol, 4 eq.). The crude residue was purified by flash column chromatography (EtOAc:pentane, 6:94, $R_f = 0.2$) to give the title compound as a yellow solid (180 mg, 60%).

Melting Point = 109-110 ℃.

^{1}H NMR (500 MHz, $CDCl_3$): δ_H = 8.20 (d, J = 2.8 Hz, 1H, H_3), 8.15 (d, J = 2.9 Hz, 1H, H_5), 7.00 (dd, J = 7.5, 1.7 Hz, 1H, H_{12}), 6.91 (ddd, J = 7.9, 7.8, 1.8 Hz, 1H, H_{10}), 6.85 – 6.76 (m, 2H, H_{11}), 6.56 (br s, 1H, H_{20}), 6.25 (d, J = 8.1 Hz, 1H, H_9), 3.50 (s, 2H, NH), 2.35 (s, 3H, H_7), 2.13 (s, 3H, H_{14}), 2.11 (br s, 3H, H_{22}, H_{21}), 2.08 (br s, 3H, H_{22}, H_{21}).

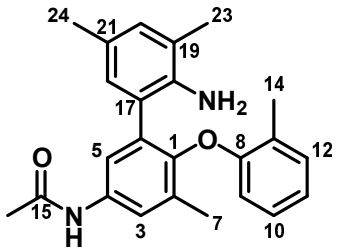
^{13}C NMR (126 MHz, $CDCl_3$): δ_C = 157.1 (C_1), 155.5 (C_8), 144.6 (C_4), 139.0 (br, C_{16}), 134.8 (br, C_{Ar}), 134.2 (C_{Ar}), 131.2 (C_{18}), 131.0 (C_{12}), 128.8 (C_{20}), 127.1 (br, C_{Ar}), 126.6 (C_{13}), 126.4 (C_{10}), 125.7 (C_5, C_3), 122.8 (br, C_{Ar}), 122.1 (C_{11}), 121.8 (br, C_{Ar}), 113.0 (C_9), 20.2 ($C_{22/21}$), 17.8 ($C_{22/21}$), 17.0 (C_7), 15.8 (H_{14}).

FTIR (film) ν_{max}/cm^{-1} = 3389, 2918, 2850, 1624, 1579, 1523, 1487, 1462, 1346,

1302, 1245, 1225, 1203, 1177, 1113, 1092, 1043, 950, 907, 861, 800, 777, 748, 732, 681.

HRMS (ESI^+): *m/z* calculated for $C_{22}H_{23}N_2O_2^+$, $[M+H]^+$ = 363.1703; *m/z* found = 363.1697. Δ = -1.69 ppm.

N-(2'-Amino-3',5,5'-trimethyl-6-(*o*-tolyloxy)-[1,1'-biphenyl]-3-yl)acetamide, **241**:



Aniline **241** was prepared according to **General Procedure K** using 1-bromo-3-methyl-5-nitro-2-(*o*-tolyloxy)benzene, **237**, (357 mg, 1.00 mmol, 1 eq.). The crude residue was purified by flash column chromatography (EtOAc:Pentane, 40:60 to 60:40, R_f = 0.2) to give the title compound as a white solid (247 mg, 66%).

Melting Point = 154-155 ℃.

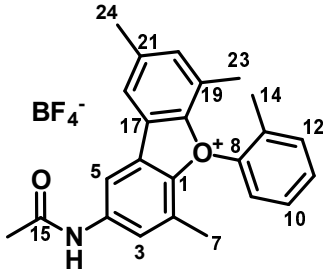
^{1}H NMR (500 MHz, $CDCl_3$): δ_H = 7.66 (d, J = 2.6 Hz, 1H, H_3), 7.22 (s, 1H, NH), 7.11 (d, J = 2.6 Hz, 1H, H_5), 7.00 – 6.93 (m, 1H, H_{12}), 6.88 (ddd, J = 8.2, 7.8, 1.8 Hz, 1H, H_{10}), 6.76 – 6.69 (m, 2H, H_{20}, H_{11}), 6.57 (br s, 1H, H_{22}), 6.28 (dd, J = 8.1, 1.2 Hz, 1H, H_9), 2.21 (s, 3H, H_7), 2.17 (s, 3H, H_{16}), 2.09 – 2.06 (m, 6H, H_{24}, H_{23}), 2.05 (s, 3H, H_{14}). NH_2 was not observed.

^{13}C NMR (151 MHz, $CDCl_3$): δ_C = 168.4 (C_{15}), 156.5 (C_8), 147.8 (C_1), 139.6 (C_{18}), 134.9 (C_{Ar}), 134.1 (br, C_{Ar}), 133.4 (C_{Ar}), 130.7 (C_{12}), 130.5 (C_{20}), 129.1 (C_{22}), 126.7, 126.4 (C_{10}), 123.4 (br, C_{Ar}), 122.4 (C_3), 121.1 (C_5), 121.1 (C_{11}), 112.8 (C_9), 25.0 (C_{16}), 20.3 ($C_{24/23}$), 17.9 ($C_{24/23}$), 16.9 (C_7), 16.0 (C_{14}). Two quaternary carbons were not observed.

FTIR (film) ν_{max}**/cm^{-1}** = 3268, 2921, 2277, 1665, 1602, 1552, 1487, 1469, 1431, 1371, 1300, 1226, 1203, 1183, 1114, 1036, 909, 861, 731, 647.

HRMS (ESI^+): m/z calculated for $C_{24}H_{27}N_2O_2^+$, $[M+H]^+ = 375.2067$; m/z found = 375.2068. $\Delta = 0.38$ ppm.

2-Acetamido-4,6,8-trimethyl-5-(o-tolyl)-5*H*-dibenzo[*b*,*d*]furan-5-ium tetrafluoroborate, **242**:



Oxonium ion **242** was prepared according to **General Procedure F** using *N*-(2'-amino-3',5,5'-trimethyl-6-(*o*-tolyloxy)-[1,1'-biphenyl]-3-yl)acetamide, **241**, (187 mg, 0.50 mmol, 1 eq.) to give the title compound as a tan solid (169 mg, 72%).

Melting Point = 168 ℃ (MeCN, dec.).

^{1}H NMR (500 MHz, CD_3CN): δ_H = 8.77 (br, s, 1H, NH), 8.46 (d, J = 2.4 Hz, 1H, H_5), 7.97 – 7.93 (m, 1H, H_{22}), 7.68 (ddd, J = 8.2, 6.6, 1.8 Hz, 1H, H_{11}), 7.63 – 7.58 (m, 1H, H_{12}), 7.52 – 7.44 (m, 3H, H_{10}, H_9, H_3), 7.34 – 7.29 (m, 1H, H_{20}), 2.50 (s, 3H, H_{24}), 2.43 (s, 3H, H_{14}), 2.14 (s, 3H, H_{16}), 2.01 – 1.98 (m, 6H, H_{23}, H_7).

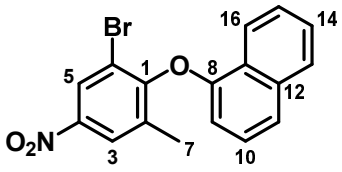
^{13}C NMR (126 MHz, CD_3CN): δ_C = 170.3 (C_{15}), 159.7 (C_{18}), 158.8 (C_8), 156.3 (C_1), 142.5 (C_{Ar}), 142.0 (C_{Ar}), 135.9 (C_{20}), 134.9 (C_{12}), 133.5 (C_{11}), 132.0 (C_{Ar}), 131.0 (C_{10}), 125.2 (C_{Ar}), 124.7 ($C_{3/Ar}$), 124.6 ($C_{3/Ar}$), 124.0 (C_{Ar}), 124.0 (C_{Ar}), 122.5 (C_{22}), 122.0 (C_9), 111.5 (C_5), 24.4 (C_{16}), 20.9 (C_{24}), 16.5 (C_7), 16.2 (C_{23}), 16.1 (C_{14}).

^{19}F NMR (377 MHz, CD_3CN): δ_F = -151.7.

FTIR (film) ν_{max}**/cm^{-1}** = 3360, 1697, 1639, 1559, 1488, 1460, 1385, 1284, 1258, 1060, 1015, 869, 806, 764, 696, 660, 619.

HRMS (ESI^+): m/z calculated for $C_{24}H_{24}NO_2^+$, $[M]^+$ = 358.1802; m/z found = 358.1800. Δ = -0.54 ppm.

1-(2-Bromo-6-methyl-4-nitrophenoxy)naphthalene, **243**:



Bromide **237** was prepared according to **General Procedure J** using 1-bromo-2-chloro-3-methyl-5-nitrobenzene (500 mg, 2.00 mmol, 1 eq.), 1-naphthol (288 mg, 2.00 mmol, 1 eq.) and K_2CO_3 (553 mg, 4.00 mmol, 2 eq.) in DMF (5 mL). The crude residue was purified by flash column chromatography (2:98, Et_2O:pentane, R_f = 0.4) to give the title compound as a bright yellow solid (566 mg, 79%).

Melting Point = 126-128 ℃.

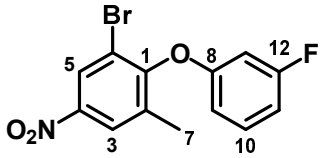
^{1}H NMR (500 MHz, $CDCl_3$): δ_H = 8.53 – 8.45 (m, 2H, H_{16}, H_5), 8.21 (d, J = 2.7 Hz, 1H, H_3), 7.96 – 7.89 (m, 1H, H_{14}), 7.68 – 7.58 (m, 3H, H_{15}, H_{11}, H_{13})), 7.32 – 7.25 (m, 1H, H_{10}), 6.33 (dd, J = 7.6, 1.0 Hz, 1H, H_9), 2.33 (s, 3H, H_7).

^{13}C NMR (126 MHz, $CDCl_3$): δ_C = 155.9 (C_1), 152.0 (C_8), 145.1 (C_4), 135.4 (C_{Ar}), 135.1 (C_{Ar}), 127.9 (C_{14}), 127.2 (C_5), 127.1 ($C_{11/13/15}$), 126.3 ($C_{11/13/15}$), 125.8 (C_3), 125.5 (C_{10}), 124.9 (C_{Ar}), 122.9 ($C_{11/13/15}$), 121.9 (C_{16}), 118.6 (C_6), 106.8 (C_9), 17.3 (C_7).

FTIR (film) ν_{max}**/cm^{-1}** = 2359, 1598, 1573, 1526, 1460, 1434, 1391, 1343, 1297, 1257, 1228, 1210, 1177, 1155, 1092, 1078, 1043, 1015, 945, 898, 844, 792, 770, 742, 719, 685.

HRMS (APCI$^-$): m/z calculated for $C_{17}H_{11}{}^{79}BrNO_3^-$, $[M\text{-}H]^+$ = 355.9928; m/z found = 355.9918. Δ = -2.87 ppm.

1-Bromo-2-(3-fluorophenoxy)-3-methyl-5-nitrobenzene, **244**:



Bromide **244** was prepared according to **General Procedure J** using 1-bromo-2-chloro-3-methyl-5-nitrobenzene (500 mg, 2.00 mmol, 1 eq.), 3-fluorophenol (0.181 mL, 224 mg, 2.00 mmol, 1 eq.) and K_2CO_3 (552 mg, 8.00 mmol, 2 eq.) in DMF (5 mL). The crude residue was purified by flash column chromatography (2:98, Et_2O, pentane, $R_f = 0.3$) to give the title compound as a white solid (370 mg, 57%).

Melting Point = 84-86 ℃.

^{1}H NMR (500 MHz, $CDCl_3$): δ_H = 8.42 (d, J = 2.7 Hz, 1H, H_5), 8.19 – 8.15 (m, 1H, H_3), 7.33 – 7.24 (m, 1H, H_{10}), 6.82 (dddd, J = 8.3, 8.3, 2.4, 0.9 Hz, 1H, H_{11}), 6.60 – 6.52 (m, 2H, H_{13}, H_9), 2.32 (s, 3H, H_7).

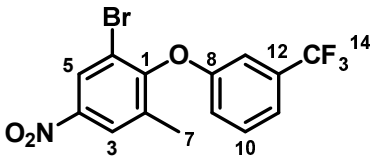
^{13}C NMR (126 MHz, $CDCl_3$): δ_C = 163.7 (d, J = 247.5 Hz, C_{12}), 157.21 (d, J = 10.8 Hz, C_8), 154.8 (C_1), 145.2 (C_4), 135.2 (C_2), 130.9 (d, J = 9.8 Hz, C_{10}), 127.1 (C_5), 125.8 (C_3), 118.3 (C_6), 110.6 (d, J = 3.1 Hz, C_9), 110.0 (d, J = 21.3 Hz, C_{11}), 103.2 (d, J = 25.8 Hz, C_{13}), 17.3 (C_7).

^{19}F NMR (471 MHz, $CDCl_3$): δ_F = -110.2.

FTIR (film) ν_{max}**/cm^{-1}** = 3089, 1601, 1523, 1486, 1460, 1343, 1309, 1262, 1209, 1177, 1118, 1090, 1004, 959, 899, 846, 815, 767, 741, 677.

HRMS Not found by ESI, APCI or EI.

1-Bromo-3-methyl-5-nitro-2-(3-(trifluoromethyl)phenoxy)benzene, **245**:



Bromide **245** was prepared according to **General Procedure J** using 1-bromo-2-chloro-3-methyl-5-nitrobenzene (500 mg, 2.00 mmol, 1 eq.), 3-(trifluoromethyl)phenol (0.36 mL, 486 mg, 2.00 mmol, 1 eq.) and K_2CO_3 (552 mg, 4.00 mmol, 2 eq.) in DMF (5 mL). The crude residue was purified by flash column chromatography (10:90, CH_2Cl_2, pentane, $R_f = 0.2$) to give the title compound as a white solid (568 mg, 76%).

Melting Point = 100-102 ℃.

^{1}H NMR (500 MHz, $CDCl_3$): δ_H = 8.41 (d, J = 2.7 Hz, 1H, H_5), 8.16 (d, J = 2.7 Hz, 1H, H_3), 7.43 (dd, J = 8.0, 8.0 Hz, 1H, H_{10}), 7.35 (d, J = 8.0 Hz, 1H, H_{11}), 7.07 (d, J = 2.5 Hz, 1H, H_{13}), 6.91 (dd, J = 8.0, 2.5 Hz, 1H, H_9), 2.30 (s, 3H).

^{13}C NMR (126 MHz, $CDCl_3$): δ_C = 156.2 (C_8), 154.5 (C_1), 145.3 (C_4), 135.1 (C_2), 132.6 (q, J = 32.8 Hz, C_{12}), 130.6 (C_{10}), 127.2 (C_5), 125.9 (C_3), 123.5 (q, J = 272.5 Hz, C_{14}), 119.8 (q, J = 3.9 Hz, C_{11}), 118.2 (C_6), 118.0 (C_9), 112.2 (q, J = 4.0 Hz, C_{13}), 17.3 (C_7).

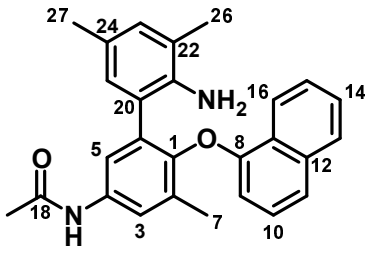
^{19}F NMR (471 MHz, $CDCl_3$): δ_F = -62.7.

FTIR (film) ν_{max}**/cm^{-1}** = 2926, 1603, 1519, 1489, 1448, 1430, 1378, 1347, 1330, 1316, 1280, 1259, 1216, 1193, 1160, 1118, 1090, 1062, 1001, 945, 907, 867, 843, 821, 794, 762, 741, 694, 648.

HRMS (APCI$^-$): m/z calculated for $C_{14}H_8{}^{79}BrF_3NO_3^+$, [M-H]$^-$ = 373.9645; m/z

found = 373.9637. Δ = -2.26 ppm.

N-(2'-Amino-3',5,5'-trimethyl-6-(naphthalen-1-yloxy)-[1,1'-biphenyl]-3-yl)acetamide, **246**:



Aniline **246** was prepared according to **General Procedure K** using 1-(2-bromo-6-methyl-4-nitrophenoxy)naphthalene, **243**, (357 mg, 1.00 mmol, 1 eq.). The crude residue was purified by flash column chromatography (EtOAc:Pentane, 50:50 to 60:40, R_f = 0.25) to give the title compound as a viscous oil (357 mg, 87%).

Melting Point = 127 ℃(dec.).

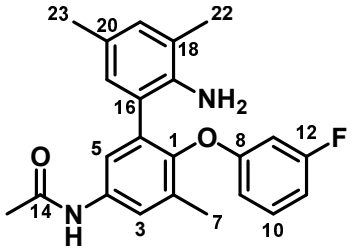
^{1}H NMR (500 MHz, $CDCl_3$): δ_H = 8.26 (d, J = 7.8 Hz, 1H, H_{16}), 7.76 – 7.68 (m, 2H, H_{13}, H_3), 7.48 – 7.40 (m, 2H, H_{15}, H_{14}), 7.40 – 7.26 (m, 2H, C_{11}), 7.20 (s, 1H, H_5), 7.15 (t, J = 7.9 Hz, 1H, H_{10}), 6.66 (br s, 1H, H_{25}), 6.54 (s, 1H, H_{23}), 6.38 (d, J = 7.7 Hz, 1H, H_9), 3.16 (br s, 2H, NH_2), 2.24 (s, 3H, H_7), 2.19 (s, 3H, H_{19}), 2.02 – 1.94 (m, 6H, H_{27}, H_{26}).

^{13}C NMR (126 MHz, $CDCl_3$): δ_C = 168.4 (C_{18}), 154.0 (C_8), 147.6 (C_1), 139.3 (C_{21}), 135.0 (C_{Ar}), 134.4 (C_{12}), 133.2 (C_{Ar}), 130.4 (C_{23}), 128.9 (C_{25}), 127.2 (C_{13}), 126.6 (C_{Ar}), 126.2 ($C_{15/14}$), 125.3 (C_{10}), 125.1 (C_{Ar}), 124.9 ($C_{15/14}$), 122.5 (C_3), 122.4 (C_{Ar}), 121.9 (C_{16}), 121.1 (C_5), 121.0 (C_{11}), 107.3 (C_9), 24.5 (C_{19}), 20.1 ($C_{27/26}$), 17.7 ($C_{27/26}$), 16.8 (C_7). Two quaternary carbons were not observed.

FTIR (film) ν_{max}**/cm^{-1}** = 3299, 3054, 2922, 2856, 2275, 1665, 1599, 1552, 1461, 1392, 1261, 1229, 1204, 1160, 1109, 1080, 1044, 1016, 909, 862, 791, 770, 732, 646.

HRMS (ESI^+): m/z calculated for $C_{27}H_{27}N_2O_2^+$, $[M+H]^+ = 411.2067$; m/z found = 411.2068. $\Delta = 0.29$ ppm

N-(2'-Amino-6-(3-fluorophenoxy)-3',5,5'-trimethyl-[1,1'-biphenyl]-3-yl)acetamide, **247**:



Aniline **247** was prepared according to **General Procedure K** using 1-bromo-2-(3-fluoro phenoxy)-3-methyl-5-nitrobenzene, **244**, (326 mg, 1.00 mmol, 1 eq.). The crude residue was purified by flash column chromatography (EtOAc:Pentane, 50:50 to 60:40, R_f = 0.25) to give the title compound as a viscous oil (257 mg, 68%).

Melting Point = 152-153 ℃.

^{1}H NMR (500 MHz, $CDCl_3$): δ_H = 7.63 (d, J = 2.7 Hz, 1H, H_3), 7.27 (br s, 1H, NH), 7.14 (d, J = 2.7 Hz, 1H, H_5), 7.02 (td, J = 8.3, 6.7 Hz, 1H, H_{10}), 6.77 – 6.72 (m, 1H, H_{19}), 6.59 (d, J = 2.1 Hz, 1H, H_{21}), 6.54 (td, J = 8.3, 2.5 Hz, 1H, H_{11}), 6.42 – 6.35 (m, 1H, H_9), 6.31 (dt, J = 10.7, 2.4 Hz, 1H, H_{13}), 2.20 (s, 3H, H_7), 2.17 (s, 3H, H_{15}), 2.10 (s, 3H, H_{22}), 2.07 (s, 3H, H_{23}). NH_2 was not observed.

^{13}C NMR (126 MHz, $CDCl_3$): δ_C = 168.3 (C_{14}), 163.3 (d, J = 245.2 Hz, C_{12}), 159.4 (d, J = 10.5 Hz, C_8), 146.9 (C_1), 139.4 (C_{17}), 135.2 (C_{Ar}), 134.0 (C_6), 133.0 (C_{Ar}), 130.6 (C_{19}), 129.8 (d, J = 9.9 Hz, H_{10}), 128.8 (C_{21}), 126.7 (C_{Ar}), 122.9 (C_{Ar}), 122.4 (C_3), 122.4 (C_{16}), 121.0 (C_5), 111.0 (d, J = 3.0 Hz, H_9), 108.2 (d, J = 21.4 Hz, H_{11}), 103.1 (d, J = 25.4 Hz, H_{12}), 24.6 (C_{15}), 20.2 (C_{23}), 17.8 (C_{22}), 16.9 (C_7).

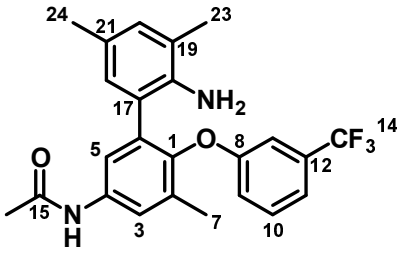
^{19}F NMR (377 MHz, $CDCl_3$): δ_F = -112.1.

FTIR (film) ν_{max}**/cm^{-1}** = 3295, 2922, 2856, 2275, 1665, 1609, 1552, 1484, 1446,

1370, 1302, 1262, 1202, 1165, 1119, 1035, 960, 909, 862, 767, 732, 679.

HRMS (ESI^+): *m/z* calculated for $C_{23}H_{24}FN_2O^+$, $[M+H]^+ = 379.1816$; *m/z* found = 379.1817. $\Delta = 0.10$ ppm.

N-(2'-Amino-3',5,5'-trimethyl-6-(3-(trifluoromethyl)phenoxy)-[1,1'-biphenyl]-3-yl) acetamide, **248**:



Aniline **248** was prepared according to **General Procedure K** using 1-bromo-3-methyl-5-nitro-2-(3-(trifluoromethyl)phenoxy)benzene, **245**, (387 mg, 1.00 mmol, 1 eq.). The crude residue was purified by flash column chromatography (EtOAc:Pentane, 40:60 to 60:40, R_f = 0.3) to give the title compound as a viscous oil (338 mg, 88%).

Melting Point = 115-116 ℃.

^{1}H NMR (600 MHz, $CDCl_3$): δ_H = 7.63 (d, J = 2.9 Hz, 1H, H_3), 7.56 – 7.51 (m, 1H, NH), 7.19 – 7.13 (m, 2H, H_{10}, H_5), 7.06 (d, J = 7.4 Hz, 1H, H_{11}), 6.80 – 6.78 (m, 1H, H_{13}), 6.78 – 6.75 (m, 1H, H_9), 6.69 (d, J = 2.1 Hz, 1H, H_{20}), 6.53 (d, J = 2.1 Hz, 1H, H_{22}), 3.41 (s, 2H, NH_2), 2.21 (s, 2H, H_7), 2.13 (s, 3H, H_{16}), 2.05 (s, 3H, H_{23}), 2.04 (s, 3H, H_{24}).

^{13}C NMR (151 MHz, $CDCl_3$): δ_C = 168.5 (C_{15}), 158.1 (C_8), 146.9 (C_1), 139.3 (C_{18}), 135.4 (C_{Ar}), 133.6 (C_6), 132.8 (C_{Ar}), 131.3 (q, J = 32.5 Hz, C_{12}), 130.6 (C_{20}), 129.5 (C_{10}), 128.8 (C_{22}), 126.8 (C_{Ar}), 123.8 (q, J = 272.3 Hz, C_{14}), 122.7 (C_{Ar}), 122.5 (C_3), 122.4 (C_{Ar}), 121.1 (C_5), 118.8 (C_9), 118.1 (q, J = 3.9 Hz, C_{11}), 112.3 (q, J = 3.9 Hz, C_{13}), 24.5 (C_{16}), 20.1 (C_{24}), 17.6 (C_{23}), 16.8 (C_7).

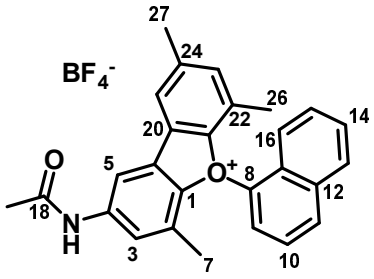
^{19}F NMR (377 MHz, $CDCl_3$): δ_F = -62.7.

FTIR (film) ν_{max}**/cm^{-1}** = 2924, 1666, 1602, 1554, 1472, 1448, 1326, 1283, 1216,

1192, 1167, 1125, 1093, 1063, 1034, 909, 864, 790, 732, 697, 656.

HRMS (ESI^+): *m/z* calculated for $C_{24}H_{24}F_3N_2O_2^+$, $[M+H]^+ = 429.1784$; *m/z* found = 429.1783. Δ = -0.29 ppm.

2-Acetamido-4,6,8-trimethyl-5-(naphthalen-1-yl))-5*H*-dibenzo[*b*,*d*]furan-5-ium tetrafluoroborate, **249**:



Oxonium ion **249** was prepared according to **General Procedure F** using *N*-(2'-amino-3',5,5'-trimethyl-6-(naphthalen-1-yloxy)-[1,1'-biphenyl]-3-yl)acetamide, **246**, (205 mg, 0.50 mmol, 1 eq.) and 1:1 CH_2Cl_2:MeCN elution (5 × 1.5 mL) to give the title compound as a tan solid (154 mg, 64%).

Melting Point = 188 ℃ (MeCN, dec.).

^{1}H NMR (500 MHz, CD_3CN): δ_H = 8.77 (s, 1H, NH), 8.53 (d, J = 2.4 Hz, 1H, H_5), 8.36 – 8.28 (m, 2H, H_{16}, H_{11}), 8.25 (dd, J = 8.2, 1.4 Hz, 1H, H_{13}), 8.03 – 7.99 (m, 1H, H_{25}), 7.89 (ddd, J = 8.4, 7.0, 1.4 Hz, 1H, H_{15}), 7.85 (ddd, J = 8.2, 7.0, 1.2 Hz, 1H, H_{14}), 7.69 (dd, J = 8.1, 1.1 Hz, 1H, H_9), 7.63 (dd, J = 8.0, 8.0 Hz, 1H, H_{10}), 7.38 (dd, J = 2.4, 1.0 Hz, 1H, H_3), 7.29 – 7.25 (m, 1H, H_{23}), 2.51 (s, 3H, H_{27}), 2.16 – 2.11 (m, 3H, H_{19}), 1.73 – 1.68 (m, 6H, H_{26}, H_7).

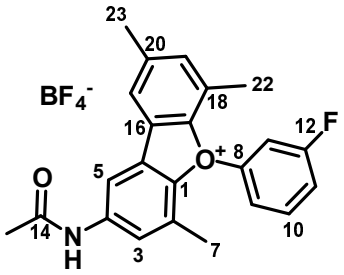
^{13}C NMR (126 MHz, CD_3CN): δ_C = 170.1 (C_{18}), 161.4 (C_{21}), 157.9 (C_1), 156.0 (C_8), 142.4 (C_{Ar}), 141.8 (C_{Ar}), 135.7 (C_{12}), 135.6 (C_{23}), 133.8 (C_{11}), 131.0 (C_{15}), 130.0 (C_{13}), 129.7 (C_{14}), 126.7 (C_{10}), 125.4 (C_{Ar}), 125.2 (C_{Ar}), 124.6 (C_{17}), 124.3 (C_3), 124.0 (C_{Ar}), 123.9 (C_{Ar}), 122.5 (C_{25}), 120.2 (C_{16}), 119.5 (C_9), 111.4 (C_5), 24.2 (C_{19}), 20.7 (C_{27}), 16.8 (C_7), 16.5 (C_{26}).

^{19}F NMR (377 MHz, CD_3CN): δ_C = -151.8.

FTIR (film) ν_{max}**/cm^{-1}** = 3339, 1696, 1638, 1559, 1488, 1448, 1383, 1284, 1258, 1056, 956, 868, 815, 765, 727, 626.

HRMS (ESI$^+$): m/z calculated for $C_{27}H_{24}NO_2^+$, $[M]^+$ = 394.1802; m/z found = 394.1804. Δ = 0.67 ppm.

2-Acetamido-5-(3-fluorophenyl)-4,6,8-trimethyl–5*H*-dibenzo[*b*,*d*]furan-5-ium tetrafluoroborate, **250**:



Oxonium ion **250** was prepared according to **General Procedure F** using *N*-(2'-amino-6-(3-fluorophenoxy)-3',5,5'-trimethyl-[1,1'-biphenyl]-3-yl)acetamide, **247**, (189 mg, 0.50 mmol, 1 eq.) to give the title compound as a tan solid (153 mg, 68%).

Melting Point = 182 ℃ (MeCN, dec.).

^{1}H NMR (700 MHz, CD_3CN): δ_H = 8.77 (s, 1H, NH), 8.45 – 8.42 (m, 1H, H_5), 7.94 – 7.92 (m, 1H, H_{21}), 7.77 – 7.71 (m, 2H, H_{10}, H_9), 7.61 – 7.56 (m, 1H, H_{13}), 7.55 – 7.50 (m, 1H, H_{11}), 7.46 – 7.43 (m, 1H, H_3), 7.33 – 7.30 (m, 1H, H_{19}), 2.50 (s, 3H, H_{23}), 2.17 – 2.12 (m, 9H, H_{22}, H_{15}, H_7).

^{13}C NMR (176 MHz, CD_3CN): δ_C = 169.4 (C_{14}), 162.7 (d, J = 254.3 Hz, C_{12}), 160.5 (C_{17}), 158.8 (d, J = 10.9 Hz, C_8), 157.1 (C_1), 142.2 (C_{Ar}), 141.5 (C_{Ar}), 134.7 (C_{Ar}), 133.0 (d, J = 9.5 Hz, C_{10}), 125.0 (C_{Ar}), 124.1 (C_{21}), 123.9 (C_{Ar}), 123.3 (C_3), 123.3 (C_{Ar}), 121.7 (C_{21}), 120.1 (d, J = 21.0 Hz, C_{11}), 117.6 (d, J = 4.4 Hz, C_9) 110.7 (C_5), 109.6 (d, J = 28.0 Hz, C_{13}), 23.5 (C_{Me}), 20.1 (C_{23}), 16.1 (C_{Me}), 15.8 (C_{Me}).

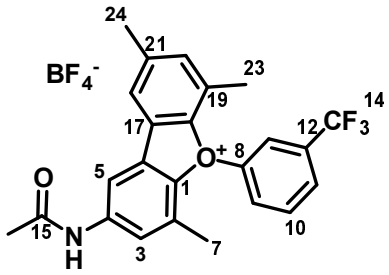
^{19}F NMR (471 MHz, CD_3CN): δ_C = -106.0, -151.7 (BF_4^-).

FTIR (film) ν_{max}**/cm^{-1}** = 3102, 2359, 1698, 1642, 1621, 1559, 1529, 1488, 1448, 1386, 1349, 1327, 1285, 1260, 1229, 1175, 1128, 1093, 1064, 1052, 997, 910, 871, 799,

765, 742, 699, 673, 621.

HRMS (ESI^+): m/z calculated for $C_{24}H_{24}NO_2^+$, $[M]^+ = 362.1551$; m/z found = 362.1551. $\Delta = 0.02$ ppm.

2-Acetamido-4,6,8-trimethyl-5-(3-(trifluoromethyl)phenyl)-5*H*-dibenzo[*b*,*d*]furan-5-ium tetrafluoroborate, **251**:



Oxonium ion **251** was prepared according to **General Procedure F** using *N*-(2'-amino-3',5,5'-trimethyl-6-(3-(trifluoromethyl)phenoxy)-[1,1'-biphenyl]-3-yl)acetamide, **248**, (214 mg, 0.50 mmol, 1 eq.) to give the title compound as a tan solid (155 mg, 62%).

Melting Point = 197 ℃ (MeCN, dec.).

^{1}H NMR (500 MHz, CD_3CN): δ_H = 8.79 (br, s, 1H, NH), 8.45 (d, J = 2.4 Hz, 1H, H_5), 8.13 (dd, J = 8.6, 2.9 Hz, 1H, H_9), 8.11 – 8.08 (m, 1H, C_{13}), 8.08 – 8.05 (m, 1H, H_{11}), 7.94 – 7.93 (m, 1H, H_{22}), 7.93 – 7.88 (m, 1H, H_{10}), 7.45 (dd, J = 2.4, 1.0 Hz, 1H, H_3), 7.33 – 7.29 (m, 1H, H_{20}), 2.50 (s, 3H, H_{24}), 2.14 (s, 3H, H_{16}), 2.11 – 2.07 (m, 6H, H_{23}, H_7).

^{13}C NMR (126 MHz, CD_3CN): δ_C = 170.1 (C_{15}), 161.4 (C_{18}), 159.6 (C_8), 158.0 (C_1), 143.1 (C_{Ar}), 142.4 (C_{Ar}), 135.4 (C_{10}), 134.1 (C_{20}), 134.1 (q, J = 34.6 Hz, C_{12}), 130.4 (q, J = 3.7 Hz, C_{11}), 126.2 (C_9), 125.6 (C_{Ar}), 124.9 (C_{Ar}), 124.4 (C_{Ar}), 124.1 (C_{Ar}), 124.1 (C_3), 123.2 (q, J = 272.5 Hz, C_{14}), 122.6 (C_{22}), 119.2 (q, J = 3.8 Hz, C_{13}), 111.5 (C_5), 24.2 (C_{16}), 20.8 (C_{24}), 16.8 (C_{23}), 16.5 (C_{23}).

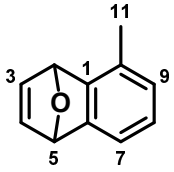
^{19}F NMR (377 MHz, CD_3CN): δ_C = -63.3, -151.6 (BF_4^-).

FTIR (film) ν_{max}**/cm^{-1}** = 3361, 3080, 1696, 1642, 1559, 1489, 1443, 1387, 1322,

1282, 1260, 1179, 1137, 1053, 931, 874, 816, 729, 697, 655, 639.

HRMS (ESI^+): *m/z* calculated for $C_{24}H_{21}F_3NO_2^+$, $[M]^+ = 412.1519$; *m/z* found = 412.1520. $\Delta = 0.29$ ppm.

5-Methyl-1,4-dihydro-1,4-epoxynaphthalene, **252**:



Arene **252** was prepared according to **General Procedure I** using 2-acetamido-4,6,8-trimethyl-5-(o-tolyl)-5*H*-dibenzo[*b*,*d*]furan-5-ium tetrafluoroborate, **242**, (133.5 mg, 0.30 mmol, 1 eq.). The crude residue was purified by flash column chromatography (CH_2Cl_2, R_f = 0.7) to give the title compound as a viscous oil (45 mg, 95 %).

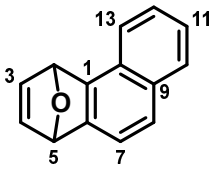
^{1}H NMR (500 MHz, $CDCl_3$): δ_H = 7.09 (d, J = 7.0 Hz, 1H, H_7), 7.06 – 7.01 (m, 2H, H_3, H_4)), 6.91 – 6.85 (m, 1H, H_8), 6.80 – 6.75 (m, 1H, H_9), 5.83 – 5.79 (m, 1H, H_2), 5.73 – 5.68 (m, 1H, H_5), 2.32 (s, 3H, H_{11}).

^{13}C NMR (126 MHz, $CDCl_3$): δ_C = 148.7 (C_6), 147.4 (C_1), 143.2 ($C_{3/4}$), 142.8 ($C_{3/4}$), 130.1 (C_{10}), 126.8 (C_9), 125.1 (C_8), 117.9 (C_7), 82.7 (C_5), 81.0 (C_5), 18.2 (C_{11}).

FTIR (film) ν_{max}**/cm^{-1}** = 3010, 2921, 1615, 1471, 1379, 1280, 1231, 1176, 1135, 1083, 1030, 979, 926, 871, 855, 823, 791, 771, 746, 718, 658, 621.

HRMS (ESI$^+$): *m/z* calculated for $C_{11}H_{11}O^+$, $[M+H]^+$ = 159.0804; *m/z* found = 159.0806. Δ = 1.17 ppm.

1,4-Dihydro-1,4-epoxyphenanthrene, **253**:



[4+2] Cycloadduct **253** was prepared according to **General Procedure I** using 2-acetamido-4,6,8-trimethyl-5-(naphthalen-1-yl))-5*H*-dibenzo[*b*,*d*]furan-5-ium tetrafluoroborate, **249**, (144 mg, 0.30 mmol, 1 eq.). The crude residue was purified by flash column chromatography (Et_2O:pentane, 10:90, R_f = 0.2) to give the title compound as a pale yellow solid (56.8 mg, 97%).

Melting Point = 84-85 ℃.

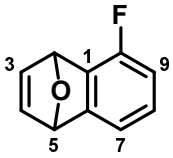
^{1}H NMR (500 MHz, $CDCl_3$): δ_H = 7.84 (d, J = 8.0 Hz, 1H, H_{10}), 7.81 (d, J = 8.0 Hz, 1H, H_{13}), 7.58 (d, J = 7.9 Hz, 1H, H_8), 7.54 (d, J = 7.9 Hz, 1H, H_7), 7.46 (ddd, J = 8.0, 6.7, 1.3 Hz, 1H, H_{12}), 7.38 (ddd, J = 8.0, 6.7, 1.3 Hz, 1H, H_{11}), 7.23 – 7.18 (m, 2H, H_3, H_4), 6.28 – 6.25 (m, 1H, H_2), 5.95 – 5.90 (m, 1H, H_5).

^{13}C NMR (126 MHz, $CDCl_3$): δ_C = 148.4 (C_6), 148.0 (C_1), 145.0 (C_4), 143.5 (C_3), 131.9 (C_9), 128.9 (C_{10}), 127.8 (C_{14}), 126.3 (C_{12}), 125.5 (C_8), 125.3 (C_{11}), 122.8 (C_{13}), 119.4 (C_7), 83.5 (C_5), 81.4 (C_2).

FTIR (film) ν_{max}**/cm^{-1}** = 3051, 3008, 2921, 1519, 1365, 1278, 1185, 1149, 1041, 1004, 960, 923, 858, 824, 809, 778, 747, 718, 685, 665, 638.

HRMS (APCI$^+$): m/z calculated for $C_{14}H_{11}O^+$, $[M+H]^+$ = 195.0804; m/z found = 195.0808. Δ = 1.73 ppm.

5-Fluoro-1,4-dihydro-1,4-epoxynaphthalene, **254**:



Arene **254** was prepared according to **General Procedure I** using 2-acetamido-5-(3-fluorophenyl)-4,6,8-trimethyl–5*H*-dibenzo[*b*,*d*]furan-5-ium tetrafluoroborate, **250**, (134 mg, 0.30 mmol, 1 eq.). The crude residue was purified by flash column chromatography (Et_2O:pentane, 10:90, R_f = 0.2) to give the title compound as a viscous oil (48 mg, 80%).

^{1}H NMR (400 MHz, $CDCl_3$): δ_H = 7.09 – 7.02 (m, 3H, H_3, H_4, H_7), 6.97 (ddd, J = 8.4, 7.0, 4.6 Hz, 1H, H_8), 6.69 (ddd, J = 8.4, 8.4, 0.8 Hz, 1H, H_9), 6.00 – 5.95 (m, 1H, H_2), 5.78 – 5.71 (m, 1H, H_5).

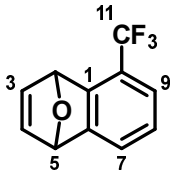
^{13}C NMR (126 MHz, $CDCl_3$): δ_C = 156.0 (d, J = 246.5 Hz, C_{10}), 152.9 (d, J = 4.5 Hz, C_6), 143.2 (C_4), 142.7 (C_3), 133.7 (d, J = 20.9 Hz, C_1), 127.7 (d, J = 5.9 Hz, C_8), 116.5 (d, J = 2.7 Hz, C_7), 114.0 (d, J = 22.2 Hz, C_9), 82.6 C_5), 79.6 (C_2).

^{19}F NMR (471 MHz, $CDCl_3$): δ_F = -120.8.

FTIR (film) ν_{max}**/cm^{-1}** = 3022, 2361, 1633, 1599, 1468, 1280, 1234, 1192, 1177, 1136, 1083, 964, 939, 871, 857, 828, 793, 773, 735, 721, 663, 618.

HRMS Mass not found by ESI, APCI or EI.

5-(Trifluoromethyl)-1,4-dihydro-1,4-epoxynaphthalene, **255**:



Arene **255** was prepared according to **General Procedure I** using 2-acetamido-4,6,8-trimethyl-5-(3-(trifluoromethyl)phenyl)-5*H*-dibenzo[*b*,*d*]furan-5-ium tetrafluoroborate, **251**, (149 mg, 0.30 mmol, 1 eq.). The crude residue was purified by flash column chromatography (Et_2O:pentane, 10:90, R_f = 0.2) to give the title compound as a viscous oil (57.2 mg, 84%).

^{1}H NMR (500 MHz, $CDCl_3$): δ_H = 7.39 (d, J = 7.1 Hz, 1H, H_7), 7.18 (d, J = 8.0 Hz, 1H, H_9), 7.12 – 7.08 (m, 1H, H_8), 7.07 (dd, J = 5.6, 1.8 Hz, 1H, H_4), 7.04 (dd, J = 5.6, 1.8 Hz, 1H, H_3), 6.03 – 5.99 (m, 1H, H_2), 5.80 – 5.75 (m, 1H, H_5).

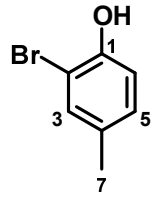
^{13}C NMR (126 MHz, $CDCl_3$): δ_C = 150.6 (C_6), 148.0 (q, J = 2.7 Hz, C_1), 143.8 (C_4), 142.6 (C_3), 125.8 (C_8), 124.1 (q, J = 272.7 Hz, C_{11}), 123.7 (q, J = 33.4 Hz, C_{10}), 123.0 (C_7), 121.2 (q, J = 4.0 Hz, C_9), 82.1 (C_5), 81.6 (q, J = 1.9 Hz, C_2).

^{13}C NMR (377 MHz, $CDCl_3$): δ_F = -60.8.

FTIR (film) ν_{max}**/cm^{-1}** = 1615, 1423, 1355, 1320, 1281, 1259, 1164, 1120, 1101, 1047, 1006, 957, 901, 877, 858, 818, 799, 782, 750, 730, 700, 658, 633.

HRMS (EI^+): m/z calculated for $C_{11}H_7F_3O^+$, $[M]^+$ = 212.04435; m/z found = 212.0449. Δ = -5.42 ppm.

2-Bromo-4-methylphenol, **291**:



Bromine (2.37 mL, 7.39 g, 46.00 mmol, 1 eq.) in $CHCl_3$ (20 mL) was added *via* pressure equalising dropping funnel to a solution of *p*-cresol (5.00 g, 46.00 mmol, 1 eq.) in $CHCl_3$ (40 mL) at 0 °C. After 1 h, the organic layer was washed (Na_2SO_3, sat. aq., 30 mL), dried ($MgSO_4$) and concentrated *in vacuo* to give the title compound as a pale yellow oil (7.53 g, 87%).

^{1}H NMR (400 MHz, $CDCl_3$): δ_H = 7.29 – 7.28 (m, 1H, H_3), 7.04 – 7.00 (m, 1H, H_5), 6.94 (d, J = 8.2 Hz, 1H, H_6), 5.58 (s, 1H, OH), 2.28 (dd, J = 0.8 Hz, 0.8 Hz, 3H, H_7).

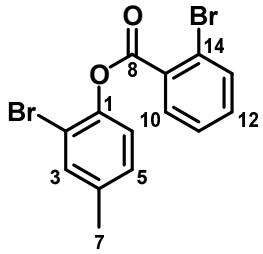
^{13}C NMR (101 MHz, $CDCl_3$): δ_C = 150.1 (C_1), 132.3 (C_3), 131.5 (C_6), 129.9 (C_5), 116.0 (C_6), 110.0 (C_2), 20.3.

FTIR (film) ν_{max}**/cm^{-1}** = 3503, 2922, 2360, 1609, 1494, 1407, 1330, 1283, 1252, 1210, 1180, 1041, 867, 814, 761, 671.

HRMS (EI^+): m/z calculated for $C_7H_7{}^{79}BrO^+$, $[M]^+$ = 185.968; m/z found = 185.9675. Δ = -6.34 ppm

*Spectra are consistent with literature values.[128]

2-Bromo-4-methylphenyl 2-bromobenzoate, **293**:



Triethylamine (1.53 mL, 1.11 g, 11.00 mmol, 1.1 eq.) was added to a solution of 2-bromo-4-methylphenol, **291**, (1.86 g, 10.00 mmol, 1 eq.) in CH_2Cl_2 (20 mL) at 0 °C. After 5 mins, 2-bromobenzoylchloride (1.40 mL, 2.41 g, 11.00 mmol, 1.1 eq.) was added and the reaction was warmed to r.t.. After 16 h, the reaction mixture was sequentially washed with HCl (3 M aq., 10 mL) and $NaHCO_3$ (sat. aq., 30 mL). The organics were dried ($MgSO_4$), concentrated *in vacuo* and the crude residue was purified by flash column chromatography (Et_2O:Pentane, 5:95, R_f = 0.25) to give the title compound as a white solid (3.15 g, 73%).

Melting Point = 52-54 °C.

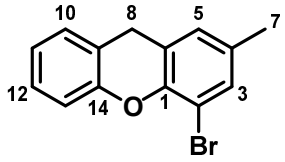
^{1}H NMR (500 MHz, CD_3CN): δ_H = 8.17 (dd, J = 7.6, 1.9 Hz, 1H, H_{10}), 7.75 (dd, J = 7.8, 1.4 Hz, 1H, H_{13}), 7.48 (d, J = 1.3 Hz, 1H, H_3), 7.47 – 7.40 (m, 2H, H_{12}, H_{11}), 7.19 – 7.17 (m, 2H, H_6, H_5), 2.37 (s, 3H, H_7).

^{13}C NMR (126 MHz, $CDCl_3$): δ_C = 163.6 (C_8), 145.9 (C_1), 137.9 (C_4), 134.8 (C_{13}), 133.9 (C_3), 133.5 (C_{12}), 132.3 (C_{10}), 130.8 (C_9), 129.4 (C_5), 127.5 (C_{11}), 123.5 (C_6), 122.8 (C_{14}), 115.8 (C_2), 20.8 (C_7).

FTIR (film) ν_{max}**/cm^{-1}** = 2981, 2360, 1754, 1589, 1487, 1432, 1382, 1224, 1199, 1132, 1079, 1021, 954, 867, 806, 741, 683, 643.

HRMS (ESI^+): *m/z* calculated for $C_{14}H_{10}{}^{79}Br_2NaO_2^+$, $[M+Na]^+$ = 390.8940; *m/z* found = 390.8939. Δ = -0.14 ppm.

4-Bromo-2-methyl-9*H*-xanthene, **296**:



Bromide **296** was prepared according to a modified literature procedure.[109] 2-Bromo-4-methylphenyl 2-bromobenzoate (2.00 g, 5.40 mmol, 1.00 eq.) and $AlCl_3$ (1.44 g, 10.80 mmol, 2.00 eq.) were heated to 150 °C under N_2. After 3 h, the reaction was cooled to r.t. and then 0 °C. HCl (6 M, aq., 40 mL) was added and decanted. The remaining residue was sonicated with H_2O/Et_2O (5 × 10 mL/10 mL) until fully dissolved. All fractions were combined, extracted (Et_2O, 2 × 50 mL), dried ($MgSO_4$) and concentrated *in vacuo*. The crude solid was dissolved in acetone (20 mL), K_2CO_3 (2.24 g, 16.21 mmol, 3 eq.) was added and the reaction was heated to 60 °C. After 16 h, the acetone was removed *in vacuo*. H_2O (50 mL) was added and the mixture was extracted (Et_2O, 3 × 50 mL), dried ($MgSO_4$) and concentrated *in vacuo*. BH_3·DMS (1.54 mL, 1.23 g, 16.20 mmol, 3 eq.) was added to a solution of the crude residue in THF (20 mL) under N_2 and the reaction was heated to 60 °C. After 16 h, MeOH (5 mL) was slowly added to the reaction. The solvent was removed by a steady stream of N_2 and the crude residue was purified by flash column chromatography (Pentane, R_f = 0.3) to give the title compound as a pale yellow solid (605 mg, 41%).

Melting Point = 125-128 ℃.

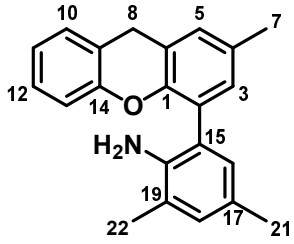
^{1}H NMR (500 MHz, $CDCl_3$): δ_H = 7.25 (s, 1H, H_3), 7.23 – 7.18 (m, 1H, H_{12}), 7.18 – 7.12 (m, 2H, H_{13}, H_{10}), 7.04 (td, J = 7.4, 1.4 Hz, 1H, H_{11}), 6.91 (s, 1H, H_5), 4.01 (s, 2H, H_8), 2.28 (s, 3H, H_7).

^{13}C NMR (126 MHz, $CDCl_3$): δ_C = 152.0 (C_{14}), 146.8 (C_1), 133.5 (C_4), 131.9 (C_3), 128.8 ($C_{13/10}$), 128.6 (C_5), 127.9 (C_{12}), 123.5 (C_{11}), 122.2 (C_6), 120.5 (C_9), 117.0 ($C_{13/10}$), 110.4 (C_2), 28.4 (C_8), 20.5 (C_7).

FTIR (film) ν_{max}**/cm^{-1}** = 2898, 1663, 1613, 1596, 1469, 1411, 1314, 1271, 1238, 1196, 1110, 1039, 929, 891, 843, 755, 713, 647.

HRMS (ESI^+): m/z calculated for $C_{14}H_{10}{}^{79}BrO^+$, $[M\text{-}H]^+$ = 292.9910; m/z found = 292.9911. Δ = 0.61 ppm.

2,4-Dimethyl-6-(2-methyl-9*H*-xanthen-4-yl)aniline, **298**:



1,4-Dioxane (10 mL) was added to a mixture of 4-bromo-2-methyl-9*H*-xanthene (280 mg, 1.02 mmol, 1 eq.), B_2Pin_2 (387 mg, 1.53 mmol, 1.5 eq.), $Pd(dppf)Cl_2{\cdot}CH_2Cl_2$ (24.9 mg, 0.03 mmol, 3 mol%) and KOAc (300 mg, 3.05 mmol, 3 eq.) under N_2. Argon was bubbled through the solution for 10 minutes and the reaction was heated to 95 °C. After 20 h, H_2O (10 mL) was added and the mixture was extracted (CH_2Cl_2, 3 × 10 mL). The organic extracts were dried ($MgSO_4$) and concentrated *in vacuo*. The crude residue was suspended in pentane (15 mL), filtered through Celite®(2 mL), eluted (pentane, 3 × 5 mL) and concentrated *in vacuo*. The crude solid was added as a solution in PhMe (5 mL) to a suspension of 2-bromo-4,6-dimethylaniline (245 mg, 1.22 mmol, 1.2 eq.), $Pd(dppf)Cl_2{\cdot}CH_2Cl_2$ (41.6 mg, 0.05 mmol, 5 mol%) and Na_2CO_3 (428 mg, 4.08 mmol, 4 eq.) in H_2O (5 mL) under N_2. Argon was bubbled through the solution for 10 mins and the reaction was heated to 95 °C. After 16 h, the reaction was extracted (CH_2Cl_2, 3 × 10 mL). The organic extracts were dried ($MgSO_4$), concentrated *in vacuo* and the crude residue was purified by flash column chromatography (Et_2O:pentane, 5:95, R_f = 0.2) to give the title compound as a tan solid (210 mg, 65%).

Melting Point = 118-119 ℃

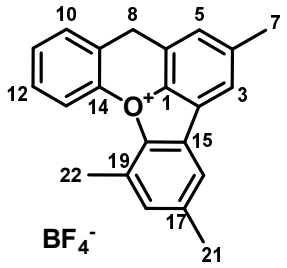
^{1}H NMR (400 MHz, $CDCl_3$): δ_H = 7.23 – 7.13 (m, 2H, H_{12}, H_{10}), 7.07 – 7.02 (m, 3H, H_{11}, H_5, H_3), 7.01 – 6.94 (m, 2H, H_{18}, H_{13}), 6.91 (d, J = 2.1 Hz, 1H, H_{16}), 4.09 (s, 2H, H_8), 3.74 (br s, 2H, NH), 2.37 (s, 3H, H_7), 2.33 (s, 3H, H_{21}), 2.29 (s, 3H, H_{22}).

^{13}C NMR (126 MHz, $CDCl_3$): δ_C = 152.3 (C_{14}), 147.3 (C_1), 139.8 (C_{20}), 132.6 (C_4), 130.7 ($C_{5/3}$), 130.7 (C_{18}), 129.5 (C_{16}), 128.8 ($C_{5/3}$), 128.7 (C_{10}), 127.5 (C_{12}), 127.5 (C_2), 127.3 (C_{Ar}), 124.2 (C_{Ar}), 123.1 (C_{11}), 122.8 (C_{Ar}), 121.4 (C_{Ar}), 121.2 (C_{Ar}), 117.0 (C_{13}), 28.5 (C_8), 20.7 (C_7), 20.6 (C_{21}), 18.1 (C_{22}).

FTIR (film) ν_{max}**/cm^{-1}** = 3384, 2917, 1620, 1584, 1484, 1456, 1292, 1265, 1239, 1209, 1189, 1154, 1098, 1033, 1012, 908, 879, 860, 827, 755, 730, 646.

HRMS (ESI^+): m/z calculated for $C_{22}H_{22}NO^+$, $[M+H]^+$ = 316.1696; m/z found = 316.1697. Δ = 0.37 ppm

1,3,6-Trimethyl-8*H*-benzofuro[3,2,1-*de*]xanthen-13-ium tetrafluoroborate, **299**:



Oxonium ion **299** was prepared according to **General Procedure G** using 2,4-dimethyl-6-(2-methyl-9*H*-xanthen-4-yl)aniline (50 mg, 0.16 mmol, 1 eq.), *t*-BuONO (94 μL, 81 mg, 0.79 mmol, 5 eq.) and HBF_4 (48% aq., 103 μL, 145 mg, 0.79 mmol, 5 eq.) to give the title compound as a white solid (48 mg, 79%).

Melting Point = 157 ℃ (MeCN, dec.).

^{1}H NMR (400 MHz, CD_3CN): δ_H = 7.96 – 7.91 (m, 1H, H_{16}), 7.83 (dd, J = 1.7, 0.9 Hz, 1H, H_3), 7.82 – 7.78 (m, 1H, H_{10}), 7.64 – 7.58 (m, 2H, H_{13}, H_{11}), 7.58 – 7.52 (m, 3H, H_{18}, H_{12}, H_5), 4.40 (br s, 2H, H_8), 2.62 (s, 3H, H_{22}), 2.58 (s, 3H, H_{21}), 2.54 (s, 3H, H_7).

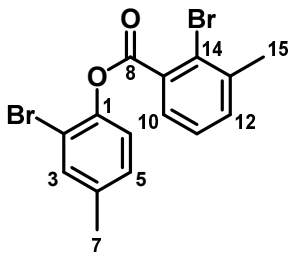
^{13}C NMR (126 MHz, CD_3CN): δ_C = 159.6 (C_{14}), 156.4 (C_1), 155.2 (C_{20}), 143.4 (C_{Ar}), 142.9 (C_{Ar}), 134.6 (C_{18}), 132.7 (C_{10}), 131.1 ($C_{13/11}$), 129.9 ($C_{12/5}$), 129.9 ($C_{12/5}$), 127.7 (C_{Ar}), 125.7 (C_{Ar}), 124.4 (C_{Ar}), 123.5 (C_{16}), 122.0 (C_3), 121.7 (C_{Ar}), 115.1 ($C_{13/11}$), 29.9 (C_8), 21.6 (C_7), 21.3 (C_{21}), 18.4 (C_{22}). One quaternary carbon was not observed.

^{19}F NMR (377 MHz, CD_3CN): δ_F = -151.8.

FTIR (film) ν_{max}**/cm^{-1}** = 1475, 1452, 1386, 1285, 1171, 1051, 1036, 854, 825, 786, 766, 734, 700, 670, 644.

HRMS (ESI^+): *m/z* calculated for $C_{22}H_{19}O^+$, $[M+H]^+ = 299.1430$; *m/z* found = 299.1432. $\Delta = 0.39$ ppm.

2-Bromo-4-methylphenyl 2-bromo-3-methylbenzoate, **307**:



DMF (5 drops) was added to a solution of 2-bromo-3-methylbenzoic acid (2.26 g, 10.50 mmol, 1.05 eq.) and oxalyl chloride (0.930 mL, 1.40 g, 11.00 mmol, 1.1 eq.) in CH_2Cl_2 (40 mL) at r.t.. After 2 h, the solvent was removed *in vacuo*. Triethylamine (1.54 mL, 1.12 g, 11.00 mmol, 1.1 eq.) was added to a solution of 2-bromo-4-methylphenol, **291**, (1.86 g, 10.00 mmol, 1 eq.) and the crude residue in CH_2Cl_2 (40 mL) at 0 °C and the reaction was allowed to warm to r.t.. After 16 h, the reaction mixture was sequentially washed with HCl (3 M aq., 10 mL) and $NaHCO_3$ (sat. aq., 30 mL). The organics were dried ($MgSO_4$), concentrated *in vacuo* to give the title compound as a white solid (3.73 g, 97%).

Melting Point = 86-88 °C.

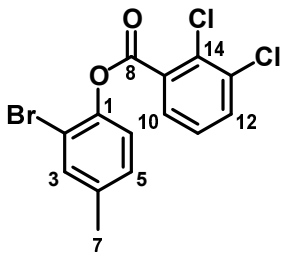
^{1}H NMR (500 MHz, $CDCl_3$): δ_H = 7.90 (dd, J = 7.7, 1.8 Hz, 1H, H_{10}), 7.53 – 7.48 (m, 1H, H_3), 7.46 (dd, J = 7.7, 1.7 Hz, 1H, H_{12}), 7.36 (t, J = 7.5 Hz, 1H, H_{11}), 7.25 – 7.17 (m, 2H, H_6, H_5), 2.53 (s, 3H, H_{15}), 2.39 (s, 3H, H_7).

^{13}C NMR (126 MHz, $CDCl_3$): δ_C = 164.6 (C_8), 145.9 (C_1), 140.2 (C_{13}), 137.9 (C_4), 134.1 (C_{12}), 133.8 (C_3), 132.4 (C_9), 129.4 (C_5), 129.0 (C_{10}), 127.1 (C_{11}), 124.1 (C_{14}), 123.5 (C_6, 115.8 (C_2), 24.0 (C_{15}), 20.8 (C_7).

FTIR (film) ν_{max}**/cm^{-1}** = 2923, 2361, 1755, 1487, 1450, 1407, 1284, 1223, 1200, 1174, 1101, 1030, 904, 841, 801, 746.

HRMS (ESI^+): *m/z* calculated for $C_{15}H_{12}{}^{79}Br_2NaO_2^+$, $[M+Na]^+$ = 404.9096; *m/z* found = 404.9095. Δ = -0.30 ppm.

2-Bromo-4-methylphenyl 2,3-dichlorobenzoate, **310**:



DMF (5 drops) was added to a solution of 2,3-dichlorobenzoic acid (1.50 g, 7.85 mmol, 1 eq.) and oxalyl chloride (0.797 mL, 1.20 g, 9.42 mmol, 1.2 eq.) in CH_2Cl_2 (40 mL) at r.t.. After 2 h, the solvent was removed *in vacuo*. Triethylamine (1.23 mL, 880 mg, 8.64 mmol, 1.1 eq.) was added to a solution of 2-bromo-4-methylphenol, **291**, (1.46 g, 7.85 mmol, 1 eq.) and the crude residue in CH_2Cl_2 (40 mL) at 0 °C and the reaction was allowed to warm to r.t.. After 16 h, the reaction mixture was sequentially washed with HCl (3 M aq., 10 mL) and $NaHCO_3$ (sat. aq., 30 mL). The organics were dried ($MgSO_4$), concentrated *in vacuo* to give the title compound as a white solid (2.52 g, 89%).

Melting Point = 103-105 ℃.

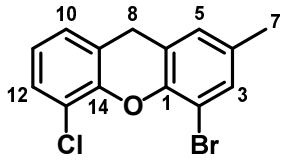
^{1}H NMR (400 MHz, $CDCl_3$): δ_H = 7.95 (dd, J = 7.8, 1.6 Hz, 1H, H_{10}), 7.59 (dd, J = 8.0, 1.6 Hz, 1H, H_{12}), 7.39 (dt, J = 1.4, 0.8 Hz, 1H, $H_{5/3}$), 7.27 (t, J = 7.9 Hz, 1H), 7.12 – 7.06 (m, 2H, H_6, $H_{5/3}$), 2.28 (s, 3H, H_7).

^{13}C NMR (101 MHz, $CDCl_3$): δ_C = 162.8 (C_8), 145.8 (C_1), 138.1 (C_4), 135.1 (C_{13}), 134.1 (C_{12}), 133.9 ($C_{5/3}$), 132.6 (C_{14}), 131.5 (C_9), 130.0 (C_{10}), 129.4 ($C_{5/3}$), 127.4 (C_{11}), 123.4 (C_6), 115.7 (C_2), 20.8 (C_7).

FTIR (film) ν_{max}**/cm^{-1}** = 2922, 1747, 1693, 1579, 1492, 1414, 1311, 1279, 1244, 1197, 1155, 1124, 1097, 1046, 889, 867, 808, 743, 711, 687, 671.

HRMS (APCI$^+$): m/z calculated for $C_{14}H_{10}{}^{79}Br^{35}Cl_2O_2^+$, $[M+H]^+$ = 358.9236; m/z found = 358.9235. Δ = -0.28 ppm.

4-Bromo-5-chloro-2-methyl-9*H*-xanthene, **311**:



Bromide **311** was prepared according to a modified literature procedure.[109] 2-Bromo-4-methylphenyl 2,3-dichlorobenzoate, **310**, (1.80 g, 5.00 mmol, 1.00 eq.) and $AlCl_3$ (1.33 g, 10.00 mmol, 2.00 eq.) were heated to 150 °C under N_2. After 3 h, the reaction was cooled to r.t. and then 0 °C. HCl (6 M, aq., 40 mL) was added and decanted. The remaining residue was sonicated with H_2O/Et_2O (5 × 10 mL/10 mL) until fully dissolved. All fractions were combined, extracted (Et_2O, 2 × 50 mL), dried ($MgSO_4$) and concentrated *in vacuo*. The crude solid was dissolved in acetone (20 mL), K_2CO_3 (2.07 g, 15.00 mmol, 3 eq.) was added and the reaction was heated to 60 °C. After 16 h, the acetone was removed *in vacuo*. H_2O (50 mL) was added and the mixture was extracted (Et_2O, 3 × 50 mL), dried ($MgSO_4$) and concentrated *in vacuo*. BH_3·DMS (1.42 mL, 1.14 g, 15.00 mmol, 3 eq.) was added to a solution of the crude residue in THF (20 mL) under N_2 and the reaction was heated to 60 °C. After 16 h, MeOH (5 mL) was slowly added to the reaction. The solvent was removed by a steady stream of N_2 and the crude residue was purified by flash column chromatography (Pentane, R_f = 0.3) to give the title compound as a pale yellow solid (1.05 g, 68%).

Melting Point = 111-113 ℃.

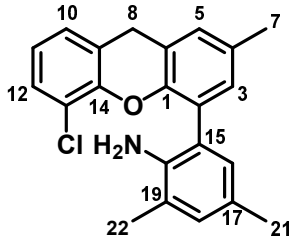
^{1}H NMR (400 MHz, $CDCl_3$): δ_H = 7.32 – 7.26 (m, 2H, H_{12}, H_3), 7.07 (ddt, J = 7.6, 1.8, 1.0 Hz, 1H, H_{10}), 6.98 (t, J = 7.7 Hz, 1H, H_{11}), 6.94 – 6.89 (m, 1H, H_5), 4.03 (s, 2H, H_8), 2.31 (s, 3H, H_7).

^{13}C NMR (126 MHz, $CDCl_3$): δ_C = 148.0 (C_{14}), 146.5 (C_1), 134.2 (C_4), 132.1 (C_3), 128.7 (C_{12}), 128.3 (C_5), 127.0 (C_{10}), 123.6 (C_{11}), 122.4 ($C_{13/9}$), 122.3 ($C_{13/9}$), 121.8 (C_6), 110.8 (C_2), 28.6 (C_8), 20.5 (C_7).

FTIR (film) ν_{max}**/cm^{-1}** = 2918, 1589, 1567, 1457, 1377, 1322, 1302, 1265, 1251, 1235, 1216, 1181, 1146, 1128, 1064, 919, 875, 847, 831, 761, 715, 697, 624.

HRMS (ESI^-): m/z calculated for $C_{14}H_9{}^{79}Br^{35}Cl_2O^-$, $[M\text{-}H]^-$ = 306.9520; m/z found = 306.9521. Δ = 0.26 ppm.

2-(5-Chloro-2-methyl-9*H*-xanthen-4-yl)-4,6-dimethylaniline, **313**:



1,4-Dioxane (10 mL) was added to a mixture of 4-bromo-5-chloro-2-methyl-9*H*-xanthene, **311**, (248 mg, 0.80 mmol, 1 eq.), B_2Pin_2 (305 mg, 1.20 mmol, 1.5 eq.), $Pd(dppf)Cl_2{\cdot}CH_2Cl_2$ (20.0 mg, 0.02 mmol, 3 mol%) and KOAc (235 mg, 2.40 mmol, 3 eq.) under N_2. Argon was bubbled through the solution for 10 minutes and the reaction was heated to 95 °C. After 20 h, H_2O (10 mL) was added and the mixture was extracted (CH_2Cl_2, 3 × 10 mL). The organic extracts were dried ($MgSO_4$) and concentrated *in vacuo*. The crude residue was suspended in pentane (15 mL), filtered through Celite®(2 mL), eluted (pentane, 3 × 5 mL) and concentrated *in vacuo*. The crude solid was added as a solution in PhMe (5 mL) to a suspension of 2-bromo-4,6-dimethylaniline (194 mg, 0.96 mmol, 1.2 eq.), $Pd(dppf)Cl_2{\cdot}CH_2Cl_2$ (32.6 mg, 0.04 mmol, 5 mol%) and Na_2CO_3 (336 mg, 3.20 mmol, 4 eq.) in H_2O (5 mL) under N_2. Argon was bubbled through the solution for 10 mins and the reaction was heated to 95 °C. After 16 h, the reaction was extracted (CH_2Cl_2, 3 × 10 mL). The organic extracts were dried ($MgSO_4$), concentrated *in vacuo* and the crude residue was purified by flash column chromatography (Et_2O:pentane, 10:90, R_f = 0.2) to give the title compound as a viscous yellow oil (202 mg, 72%).

^{1}H NMR (500 MHz, $CDCl_3$): δ_H = 7.20 (dd, J = 7.9, 1.5 Hz, 1H, H_{12}), 7.10 – 7.05 (m, 2H, H_{10}, H_3), 6.99 (d, J = 2.0 Hz, 1H, H_5), 6.95 – 6.91 (m, 2H, H_{18}, H_{11}), 6.90 (d, J = 2.1 Hz, 1H, H_{16}), 4.05 (s, 2H, H_8), 3.53 (s, 2H, NH), 2.34 (s, 3H, H_7), 2.28 (s, 3H, H_{21}), 2.23 (s, 3H, H_{22}).

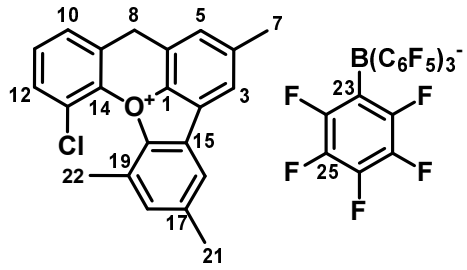
^{13}C NMR (126 MHz, $CDCl_3$): δ_C = 148.3 (C_{14}), 146.8 (C_1), 140.2 (C_{20}), 133.5 (C_4), 130.8 (C_3), 130.7 (C_{18}), 129.6 (C_{16}), 128.5 (C_{12}), 128.4 (C_5), 128.0 (C_2), 127.1 (C_{17}), 127.0 (C_{10}), 123.5 (C_{Ar}), 123.2 (C_{11}), 123.1 (C_{Ar}), 122.9 (C_{19}), 122.2 (C_{13}), 121.0 (C_{Ar}), 28.7 (C_8), 20.8 (C_7), 20.6 (C_{21}), 18.1 (C_{22}).

FTIR (film) ν_{max}**/cm^{-1}** = 2917, 1621, 1454, 1250, 1207, 1184, 1146, 909, 859, 767, 737, 714, 635.

HRMS (ESI^+): m/z calculated for $C_{22}H_{21}{}^{35}ClNO^+$, $[M+H]^+$ = 350.1306; m/z found = 350.1307. Δ = 0.15 ppm.

12-Chloro-1,3,6-trimethyl-8*H*-benzofuro[3,2,1-*de*]xanthen-13-ium tetrakis(perfluorophenyl)borate

315:



t-BuONO (59 μL, 52 mg, 0.5 mmol, 5 eq.) was added to a solution of 2-(5-chloro-2-methyl-9*H*-xanthen-4-yl)-4,6-dimethylaniline, **313** (35 mg, 0.1 mmol, 1 eq.) and HBF_4 (48% aq., 65 μL, 91 mg, 0.5 mmol, 5 eq.) in CH_2Cl_2:IPA (1:1, 2 mL) at 0 °C. After 1 h, the reaction mixture was diluted (CH_2Cl_2, 3 mL) and washed (H_2O, 1 mL). The organics were removed by a steady stream of N_2, Et_2O (5 mL) was added and the precipitate was collected by suction filtration. $KB(C_6F_5)_4$ (44 mg, 0.06 mmol, 1 eq.) was added to a solution of the precipitated diazonium salt (26 mg, 0.06 mmol, 1 eq.) in $CDCl_3$ (0.5 mL) at r.t.. After 30 mins, the reaction was filtered through Celite® (0.2 mL) and eluted ($CDCl_3$, 3 × 0.5 mL). After 5 h, the reaction mixture was subjected to NMR analysis.

^{1}H NMR (500 MHz, $CDCl_3$): δ_H = 7.70 (d, J = 1.9 Hz, 1H, H_{16}), 7.62 (s, 1H, H_3), 7.52 (d, J = 7.3 Hz, 1H, H_{10}), 7.43 (t, J = 7.5 Hz, 1H, H_{11}), 7.36 (s, 1H, H_5), 7.33 (s, 1H, H_{18}), 7.31 – 7.27 (m, 1H, H_{12}), 4.41 (d, J = 17.7 Hz, 1H, H_{8B}), 4.15 (d, J = 17.7 Hz, 1H, H_{8A}), 2.55 (s, 3H, H_{21}), 2.54 (s, 3H, H_{22}), 2.52 (s, 3H, H_7).

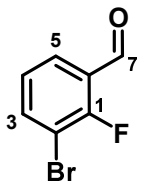
^{13}C NMR (126 MHz, $CDCl_3$): δ_C = 160.4 (C_{14}), 158.0 (C_{20}), 156.5 (C_1), 143.0 (C_{17}), 142.5 (C_4), 134.7 (C_{12}), 132.8 (C_{18}), 130.5 (C_{10}), 130.1 (C_{11}), 128.3 (C_9), 128.3 (C_5), 126.2 (C_{19}), 124.4 (C_{13}), 124.0 (C_{15}), 123.0 (C_6), 122.3 (C_{16}), 121.0 (C_3), 120.3

(C_2), 30.5 (C_8), 21.7 (C_7), 21.4 (C_{21}), 16.0 (C_{22}).

^{19}F NMR (377 MHz, $CDCl_3$): δ_F = -131.94 – -133.08 (m), -162.84 (t, J = 21.3 Hz, F_{26}), -166.50 – -166.95 (m).

FTIR (film) ν_{max}**/cm^{-1}** = 1643, 1513, 1461, 1275, 1086, 978, 909, 853, 775, 756, 734, 684, 661.

3-Bromo-2-fluorobenzaldehyde, **321**:



Aldehyde **321** was prepared according to a literature procedure.[112,113] *n*-BuLi(1.6 M, 7.5 mL, 12 mmol, 1.2 eq.) was added to a stirred solution of diisopropylamine(1.82 mL, 1.32 g, 13 mmol, 1.3 eq.) in THF (10 mL) at –78 ℃. After 30 mins, 1-fluoro-2-bromobenzene (1.09 mL, 1.75 g, 10 mmol, 1 eq.) was added dropwise and the resulting solution was stirred at –78 ℃ for 1 h. DMF (1.16 mL, 1.10 g, 15 mmol, 1.5 eq.) was added and, after 10 mins at –78 ℃, the reaction mixture was warmed to r.t.. After 1 h, water (50 mL) was added and the reaction mixture was extracted (EtOAc, 3 × 15 mL). The organic extracts were dried ($MgSO_4$), concentrated *in vacuo*and purified by flash column chromatography(Et_2O:Pentane, 5:95, $R_f = 0.3$) to give the title compound as a white solid (1.75 g, 86%).

Melting Point = 40-41 ℃.

^{1}H NMR (400 MHz, $CDCl_3$): δ_H = 10.30 (d, J = 0.8 Hz, 1H, H_7), 7.78 (d, J = 7.9 Hz, 1H, H_5), 7.77 (d, J = 7.8 Hz, 1H, H_3), 7.15 (tt, J = 7.9, 0.9 Hz, 1H, H_4).

^{13}C NMR (101 MHz, $CDCl_3$): δ_C = 186.2 (d, J = 6.1 Hz, C_7), 161.0 (d, J = 259.1 Hz, C_1), 139.5 (d, J = 1.5 Hz, C_3), 127.8 (d, J = 1.6 Hz, C_5), 125.7 (d, J = 4.6 Hz, C_4), 125.3 (d, J = 9.0 Hz, C_6), 110.3 (d, J = 20.3 Hz, C_2).

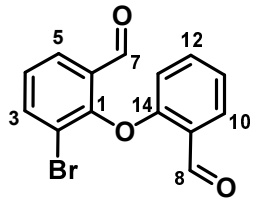
^{19}F NMR (377 MHz, $CDCl_3$): δ_F = -116.1.

FTIR (film) ν_{max}**/cm^{-1}** = 2360, 1715, 1694, 1601, 1575, 1451, 1398, 1249, 1172,

1127, 855, 782, 709, 661.

HRMS: Mass not found by ESI, APCI or EI.

3-Bromo-2-(2-formylphenoxy)benzaldehyde, **323**:



3-bromo-2-fluorobenzaldehyde, **321**, (3.00 g, 11.4 mmol, 1 eq.), Salicylaldehyde (1.21 mL, 1.39 g, 11.4 mmol, 1 eq.) and potassium carbonate (3.15 g, 22.8 mmol, 2 eq.) were added to DMF (15 mL) and heated to 110 ℃ under N_2. After 24 h, H_2O (100 mL) was added and the reaction mixture was extracted (Et_2O, 3 × 60 mL). The combined organic layers were washed (H_2O, 100 mL), dried ($MgSO_4$) and concentrated *in vacuo*. The crude residue was purified by flash column chromatography(Et_2O:Pentane, 15:85. $R_f = 0.3$) to give the title compound as a white solid (2.72 g, 79%).

Melting Point = 100-102 ℃.

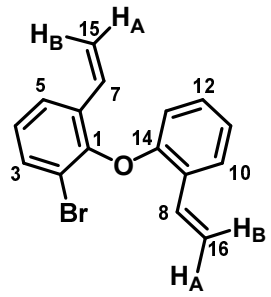
^{1}H NMR (400 MHz, $CDCl_3$): δ_H = 10.76 (s, 1H, H_7), 10.20 (s, 1H, H_8), 8.01 – 7.92 (m, 3H, H_3, H_5, H_{10}) 7.44 (ddd, J = 8.5, 7.5, 2.0 Hz, 1H, H_{12}), 7.36 (t, J = 8.0 Hz, 1H, H_4), 7.19 (t, J = 7.5 Hz, 1H, H_{11}), 6.45 (d, J = 8.5 Hz, 1H, H_{13}).

^{13}C NMR (101 MHz, $CDCl_3$): δ_C = 189.0 (C_8), 188.0 (C_7), 160.2 (C_{14}), 153.3 (C_1), 140.3 (C_3), 136.1 (C_{12}), 131.6 (C_6), 129.5 (C_{10}), 128.8 (C_5), 127.9 (C_4), 125.1 (C_9), 123.5 (C_{11}), 118.7(C_2), 114.5 (C_{13}).

FTIR (film) ν_{max}**/cm^{-1}** = 2862, 1687, 1601, 1585, 1477, 1439, 1391, 1280, 1231, 1205, 1186, 1157, 1122, 1098, 879, 825, 786, 759, 707.

HRMS (ESI^+): *m/z* calculated for $C_{14}H_{10}{}^{79}BrO_3^+$, $[M+H]^+$ = 304.9808; *m/z* found = 304.9810. Δ = 0.82 ppm.

1-Bromo-3-vinyl-2-(2-vinylphenoxy)benzene, **324**:



n-BuLi (1.6 M, 14.3 mL, 23.0 mmol, 4 eq.) was added to a suspension of methyl triphenylphosphonium bromide (9.37 g, 26.2 mmol, 4.5 eq.) in THF (200 mL) at –78 °C. Once the addition was complete, the reaction mixture was warmed to 0 °C for 10 mins before being cooled back to –78 °C. 3-bromo-2-(2-formylphenoxy)benzaldehyde, **323**, (1.75 g, 5.74 mmol, 1 eq.) in THF (20 mL) was added and the reaction was allowed to warm to r.t.. After 16 h, H_2O (150 mL) was added, the mixture was extracted (Et_2O, 3 × 50 mL). The organic extracts were dried ($MgSO_4$), concentrated *in vacuo*and purified by flash column chromatography(Et_2O:Pentane, 5:95, $R_f = 0.6$) to give the title compound as a viscous colourless oil (1.14 g, 66%).

^{1}H NMR (500 MHz, $CDCl_3$): δ_H = 7.59 (dd, J = 7.8, 1.6 Hz, 2H, H_{10}, H_5), 7.56 (dd, J = 7.9, 1.5 Hz, 1H, H_3), 7.30 (dd, J = 17.8, 11.2 Hz, 1H, H_8), 7.12 (t, J = 7.9 Hz, 1H, H_4), 7.09 – 7.04 (m, 1H, H_{12}), 7.00 (td, J = 7.5, 1.2 Hz, 1H, H_{11}), 6.76 (dd, J = 17.6, 11.1 Hz, 1H, H_7), 6.29 (dd, J = 8.2, 1.2 Hz, 1H, H_{13}), 5.88 (dd, J = 17.7, 1.4 Hz, 1H, H_{16B}), 5.76 (dd, J = 17.7, 1.0 Hz, 1H, H_{15B}), 5.39 (dd, J = 11.2, 1.4 Hz, 1H, H_{16A}), 5.25 (dd, J = 11.0, 1.0 Hz, 1H, H_{15A}).

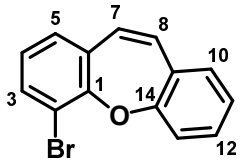
^{13}C NMR (126 MHz, $CDCl_3$): δ_C = 154.8 (C_{14}), 149.1 (C_1), 134.0 (C_6), 133.3 (C_3), 131.4 (C_8), 130.8 (C_7), 128.9 (C_{12}), 127.0 (C_{10}), 126.7 (C_4), 126.7 (C_9), 125.8

(C_5), 122.4 (C_{11}), 118.4 (C_2), 117.3 (C_{15}), 115.4 (C_{16}), 113.6 (C_{13}).

FTIR (film) ν_{max}**/cm^{-1}** = 2981, 1626, 1601, 1577, 1557, 1481, 1451, 1436, 1409, 1310, 1259, 1227, 1183, 1123, 1100, 1022, 991, 914, 880, 829, 790, 773, 760, 746, 641.

HRMS (ESI$^+$): *m/z* calculated for $C_{16}H_{14}{}^{79}BrO^+$, $[M+H]^+ = 301.0223$; *m/z* found = 301.0224. $\Delta = 0.64$ ppm.

4-Bromodibenzo[*b*,*f*]oxepine, **325**:



HG-II (52 mg, 0.083 mmol, 2.5mol%) in degassed PhMe (5 mL) was added to a solution of 1-bromo-3-vinyl-2-(2-vinylphenoxy)benzene, **324**, (1.00 g, 3.33 mmol, 1 eq.) in degassed PhMe (20 mL) at 100 °C over 5 mins. After 2 h, the reaction was cooled to r.t. and diluted (60 mL, 2:98, EtOAc:Pentane). The reaction mixture was filtered though Celite® (10 mL), eluted (EtOAc:Pentane, 2:98, 3 × 20 mL) and concentrated *in vacuo*. The crude residue was purified by flash column chromatography(Et_2O:Pentane, 2:98, R_f = 0.3) to give the title compound as a viscous colourless oil (768 mg, 84%).

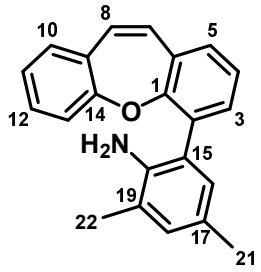
^{1}H NMR (400 MHz, $CDCl_3$): δ_H = 7.56 – 7.49 (m, 2H, 2H_{Ar}), 7.33 (ddd, J = 8.0, 7.0, 2.0 Hz, 1H, H_{Ar}), 7.19 (dd, J = 8.0, 2.0 Hz, 1H, H_{Ar}), 7.14 (td, J = 7.5, 1.0 Hz, 1H, H_{Ar}), 7.11 (dd, J = 8.0, 1.5 Hz, 1H, H_{Ar}), 6.97 (t, J = 8.0 Hz, 1H, H_4), 6.76 (d, J = 11.5 Hz, 1H, H_8), 6.69 (d, J = 11.5 Hz, 1H, H_7).

^{13}C NMR (101 MHz, $CDCl_3$): δ_C = 157.2 (C_{14}), 153.3 (C_1), 133.3 (C_{Ar}), 132.6 (C_6), 131.1 (C_8), 130.4 (C_9), 130.3 (C_{Ar}), 129.6 (C_7), 129.4 (C_{Ar}), 128.7 (C_{Ar}), 125.9 (C_{Ar}), 125.5 (C_{Ar}), 122.6 (C_{Ar}), 116.5 (C_2).

FTIR (film) ν_{max}**/cm^{-1}** = 3649, 2981, 2888, 2361, 1482, 1436, 1383, 1229, 1155, 1073, 956, 747.

HRMS (ESI$^+$): *m/z* calculated for $C_{14}H_{10}{}^{79}BrO^+$, $[M+H]^+$ = 272.9910; *m/z* found = 272.9910. Δ = 0.05 ppm.

2-(Dibenzo[*b*,*f*]oxepin-4-yl)-4,6-dimethylaniline, **326**:



4-Bromodibenzo[*b*,*f*]oxepine, **325**, (135 mg, 0.50 mmol, 1 eq.) as a solution in PhMe (2 mL), 2,4-dimethyl-6-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)aniline, **158**, (1.50 mmol, 1.5 eq.) as a solution in PhMe (3 mL) and water (5 mL) were sequentially added to $Pd(dppf)Cl_2{\cdot}CH_2Cl_2$ (20 mg, 0.03 mmol, 5 mol%) and Na_2CO_3 (212 mg, 4.00 mmol, 4 eq.) under N_2 at r.t.. Argon was bubbled through the solution for 5 mins and the reaction mixture was heated to 95 °C. After 24 h, the reaction mixture was extracted (CH_2Cl_2, 3 × 10 mL), dried ($MgSO_4$) and concentrated *in vacuo*. The crude residue was purified by flash column chromatography (Et_2O:Pentane, 10:90, R_f = 0.3) to give the title compound as a viscous oil (118 mg, 75%).

^{1}H NMR (500 MHz, $CDCl_3$): δ_H = 7.29 (dd, J = 7.1, 2.2 Hz, 1H, H_3), 7.22 – 7.15 (m, 2H, H_5, H_4), 7.15 – 7.08 (m, 2H, H_{12}, H_{10}), 7.04 (td, J = 7.4, 1.3 Hz, 1H, H_{11}), 7.00 (d, J = 2.1 Hz, 1H, H_{18}), 6.82 (d, J = 2.1 Hz, 1H, H_{16}), 6.79 (d, J = 11.4 Hz, 1H, H_7), 6.73 (d, J = 11.4 Hz, 1H, H_8), 6.36 (dd, J = 8.1, 1.3 Hz, 1H, H_{13}), 2.29 (s, 3H, H_{21}), 2.27 (s, 3H, H_{22}).

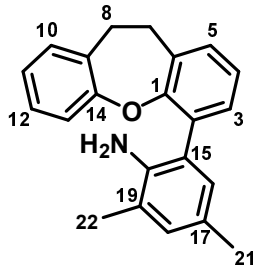
^{13}C NMR (126 MHz, $CDCl_3$): δ_C = 157.0 (C_{14}), 154.3 (C_1), 140.2 (C_{20}), 133.1 (C_2), 132.0 (C_3), 131.4 (C_6), 130.8 (C_{18}, ($C_{19/17}$)), 130.3 (C_7), 130.2 (C_8), 129.7 (C_{12}), 129.4 (C_{16}), 129.0 (C_{10}), 128.9 (C_5), 126.9, 125.1 (C_4), 124.9 (C_{11}), 124.3

(C_{15}), 122.6 ($C_{19/17}$), 122.0 (C_{13}), 20.6 (C_{21}), 18.1 (C_{22}).

FTIR (film) ν_{max}**/cm^{-1}** = 3379, 3022, 2918, 2359, 1621, 1602, 1485, 1443, 1267, 1227, 1196, 1108, 1033, 893, 863, 820, 804, 775, 732.

HRMS (ESI^+): *m/z* calculated for $C_{22}H_{20}NO^+$, $[M+H]^+$ = 314.1539; *m/z* found = 314.1536. Δ = -1.15 ppm.

2-(10,11-Dihydrodibenzo[*b*,*f*]oxepin-4-yl)-4,6-dimethylaniline, **327**:



H_2 was passed through a solution of Pd/C (10%, 12 mg, 2.5 mol%) and 2-(dibenzo[*b*,*f*]oxepin-4-yl)-4,6-dimethylaniline, **326**, (118 mg, 0.43 mmol, 1 eq.) in EtOAc (5 mL) under N_2 and kept under a positive pressure of H_2. After 16 h, N_2 was bubbled through the solution for 10 mins, the reaction was filtered (Celite®, 1 mL) and concentrated *in vacuo* to give the title compound as a viscous oil (119 mg, Quant.).

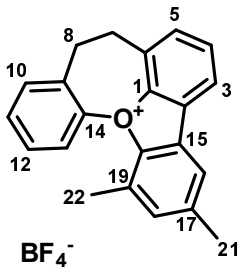
^{1}H NMR (500 MHz, $CDCl_3$): δ_H = 7.20 (dd, J = 7.3, 1.9 Hz, 1H, H_5), 7.14 (dd, J = 7.5, 2.0 Hz, 1H, H_3), 7.10 (t, J = 7.5 Hz, 1H, H_4), 7.05 – 6.99 (m, 2H, H_{18}, H_{10}), 6.96 – 6.90 (m, 2H, H_{12}, H_{11}), 6.80 (d, J = 2.1 Hz, 1H, H_{16}), 6.44 (dd, J = 7.5, 1.9 Hz, 1H, H_{13}), 3.39 (ddd, J = 13.9, 10.5, 3.7 Hz, 1H, H_{7A}), 3.19 – 3.10 (m, 1H, H_{8A}), 3.03 – 2.91 (m, 2H, H_{8B}, H_{7B}), 2.42 (s, 3H, H_{22}), 2.28 (s, 3H, H_{21}).

^{13}C NMR (126 MHz, $CDCl_3$): δ_C = 156.1 (C_{14}), 154.7 (C_1), 134.8 (C_9), 133.4 (br, C_{20}), 131.6 (br, C_{Ar}), 131.0 (C_{18}), 130.8 (C_{10}), 130.6, 129.8 (C_3), 129.6 (C_{16}), 129.4 (C_{Ar}), 128.1 (br, C_{Ar}), 127.0 (C_{12}), 126.8 (br, C_{Ar}), 124.8 (C_4), 124.5 (br, C_{Ar}), 123.7 (C_{11}), 121.6 (C_{13}), 31.2 (C_8), 30.4 (C_7), 20.6 (C_{21}), 18.6 (C_{22}).

FTIR (film) ν_{max}**/cm^{-1}** = 2920, 2360, 1757, 1621, 1575, 1487, 1446, 1225, 1204, 1103, 1030, 901, 862, 802, 771, 670.

HRMS (ESI^+): m/z calculated for $C_{22}H_{22}NO^+$, $[M+H]^+$ = 316.1696; m/z found = 316.1698. Δ = 0.57 ppm.

1,3-Dimethyl-8,9-dihydrobenzo[*b*]benzo[6,7]oxepino[3,2,1-*hi*]benzofuran-14-ium, tetrafluoroborate **328**:



Oxonium ion **328** was prepare according to **General Procedure G** using 2-(10,11-dihydrodibenzo[*b*,*f*]oxepin-4-yl)-4,6-dimethylaniline, **327** (53 mg, 0.17 mmol, 1 eq.), *t*-BuONO (102 μL, 88 mg, 0.85 mmol, 5 eq.) and HBF_4 (48% aq., 111 μL, 155 mg, 0.85 mmol, 5 eq.) to give the title compound as a white solid (42 mg, 65%).

Melting Point = 145-147 ℃ ($CHCl_3$/Et_2O, dec.)

^{1}H NMR (500 MHz, CD_3CN): δ_H = 8.01 – 7.94 (m, 2H, H_{16}, H_3), 7.76 (dd, J = 7.6, 1.8 Hz, 1H, H_{10}), 7.70 – 7.60 (m, 2H, H_{11}, H_4), 7.48 (dq, J = 7.8, 1.1 Hz, 1H, H_5), 7.46 – 7.44 (m, 1H, H_{18}), 7.39 (ddd, J = 9.0, 7.4, 1.8 Hz, 1H, H_{12}), 7.17 (dd, J = 8.8, 1.0 Hz, 1H, H_{13}), 4.10 (td, J = 14.1, 3.9 Hz, 1H, H_8), 3.56 – 3.47 (m, 1H, H_7), 3.27 (dt, J = 14.2, 3.7 Hz, 1H, H_8), 3.21 – 3.09 (m, 1H, H_7), 2.56 (s, 3H, H_{21}), 2.17 (s, 3H, H_{22}).

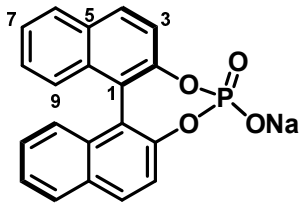
^{13}C NMR (126 MHz, CD_3CN): δ_C = 162.2 (C_{14}), 161.0 (C_1), 153.7 (C_{20}), 143.3 ($C_{19/17}$), 134.7 (C_{18}), 133.6 (C_{10}), 133.5 (C_5), 132.9 (C_{11}), 132.6 (C_9), 131.7 (C_4), 130.5 (C_{12}), 127.3 (C_6), 126.1 ($C_{19/17}$), 125.2 (C_{15}), 123.9 (C_2), 122.9 (C_{16}), 122.3 (C_3), 115.6 (C_{13}), 30.1 (C_7), 27.9 (C_8), 21.3 (C_{21}), 16.8 (C_{22}).

^{19}F NMR (471 MHz, CD_3CN): δ_F = -151.8.

FTIR (film) ν_{max}**/cm^{-1}** = 1481, 1455, 1407, 1051, 900, 828, 799, 773, 734, 613.

HRMS (ESI^+): m/z calculated for $C_{22}H_{19}O^+$, $[M]^+ = 299.1430$; m/z found = 299.1432. $\Delta = 0.49$ ppm.

(*R*)-[1,1'-Binaphthalene]-2,2'-diyl sodium phosphate, **334**:



Prepared according to a modified literature procedure.[129,130] $POCl_3$ (0.65 mL, 1.07 g, 7.00 mmol, 2 eq.) was slowly added to a solution of (*R*)-BINOL (1.00 g, 3.50 mmol, 1 eq.) in pyridine (15 mL) at 0 °C. Once the addition was complete, the reaction was warmed to 95 °C. After 1 h, the reaction was cooled to 0 °C and H_2O (2 mL) was added. Once the addition was complete, the reaction was heated to 90 °C. After 16 h, the reaction was cooled to r.t., diluted (CH_2Cl_2, 50 mL) and washed with 3 M HCl (aq., 3 × 75 mL). The organic layer was dried (Na_2SO_4) and concentrated *in vacuo*. Na_2CO_3 (sat., 20 mL) was added to a solution of the crude residue in H_2O (50 mL) and the resulting precipitate was collected by suction filtration. The precipitate was washed (H_2O, 2 × 25 mL), dissolved in acetone (20 mL) and filtered. The organics were dried (Na_2SO_4) and concentrated *in vacuo* to 2 mL. Et_2O (15 mL) was added and the resulting precipitate was collected by suction filtration, washed (Et_2O, 2 × 5 mL) and dried at 80 °C for 1 h to give the title compound as a white solid (790 mg, 61%).

Melting Point = >250 °C (acetoneether)

^{1}H NMR (500 MHz, DMSO-d_6): δ_H = 8.05 (d, J = 8.8 Hz, 1H, H_4), 8.02 (d, J = 8.5 Hz, 1H, H_6), 7.47 – 7.40 (m, 2H, H_7, H_3), 7.30 (ddd, J = 8.3, 6.7, 1.3 Hz, 1H, H_8), 7.23 (d, J = 8.5 Hz, 1H, H_9).

^{13}C NMR (126 MHz, DMSO-d_6): δ_C = 150.2 (d, J = 9.3 Hz, C_2), 132.0 (C_{10}),

130.4 (C_5), 129.8 (C_4), 128.4 (C_6), 126.1 (C_9, C_8) 124.5 (C_7), 122.7 (d, J = 2.3 Hz, C_3), 121.8 (d, J = 2.1 Hz, C_1).

^{31}P NMR (162 MHz, DMSO-d_6): δ_P = 5.2.

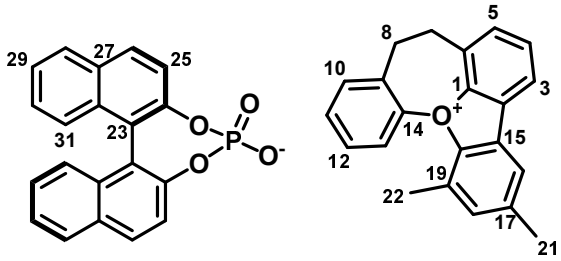
FTIR (film) ν_{max}**/cm^{-1}** = 3053, 1617, 1591, 1505, 1464, 1428, 1366, 1331, 1266, 1246, 1070, 986, 948, 911, 829, 813, 745, 720, 665, 633.

LRMS (ESI$^-$): *m/z* calculated for $C_{20}H_{12}O_4P^-$, $[M]^-$ = 347; *m/z* found = 347.

$[\alpha]_D^{25}$ = -385 (c = 0.2, THF)

*Spectra are consistent with literature values.[130]

(*R*)-[1,1'-Binaphthalene]-2,2'-diyl 1,3-dimethyl-8,9-dihydrobenzo[*b*]benzo[6,7]oxepino[3,2,1-*hi*]benzofuran-14-ium phosphate, **335**:



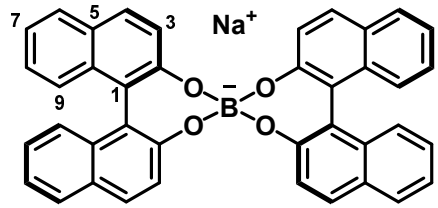
A mixture of 1,3-dimethyl-8,9-dihydrobenzo[*b*]benzo[6,7]oxepino[3,2,1-*hi*]benzofuran-14-ium, tetrafluoroborate **328** (15 mg, 0.039 mmol, 1 eq.) and (*R*)-[1,1'-Binaphthalene]-2,2'-diyl sodium phosphate, **320** (31 mg, 0.05 mmol, 1 eq.) in CH_2Cl_2 (2 mL) was washed with H_2O (2 × 1 mL) and dried ($MgSO_4$). The solvent was removed by a steady stream of N_2 and the solid was dissolved in $CDCl_3$ for analysis.

^{1}H NMR (500 MHz, $CDCl_3$): δ_H = 8.08 - 7.98 (m, 1H, H_{Ar}), 7.90 – 7.71 (m, 9H, H_{Ar}), 7.68 – 7.60 (m, 3H, H_{Ar}), 7.50 – 7.41 (m, 5H, H_{Ar}), 7.38 – 7.32 (m, 2H, H_{Ar}), 7.34 – 7.21 (m, 8H, H_{Ar}), 7.19 – 7.11 (m, 5H, H_{Ar}), 7.07 – 7.00 (m, 3H, H_{Ar}), 6.90 (dd, J = 8.8, 2.1 Hz, 2H, H_{Ar}), 4.06 – 3.89 (m, 2H, H_{8A}), 3.52 – 3.43 (m, 1H, H_{7A}), 3.26 – 3.17 (m, 2H, H_{8B}, H_{7A}), 3.16 (d, J = 14.6 Hz, 1H, H_{8B}), 3.01 (td, J = 14.2, 7.1 Hz, 1H, H_{7B}), 2.95 – 2.84 (m, 1H, H_{7B}), 2.52 (s, 3H, H_{21}), 2.45 (s, 3H, H_{21}), 2.14 (s, 3H, H_{22}), 2.08 (s, 3H, H_{22}).

^{13}C NMR (126 MHz, $CDCl_3$): δ_C = 161.2 (C_{Ar}), 161.2 (C_{Ar}), 160.0 (C_{Ar}), 160.0 (C_{Ar}), 152.4 (C_{20}), 152.3 ($C_{20'}$), 142.6 (C_{Ar}), 142.5 (C_{Ar}), 133.9 (C_{Ar}), 133.8 (C_{Ar}), 133.0 (C_{Ar}), 133.0 (C_{Ar}), 132.5 (C_{Ar}), 132.5 (C_{Ar}), 132.4 (C_{Ar}), 132.0 (C_{Ar}), 132.0 (C_{Ar}), 131.5 (C_{Ar}), 131.4 (C_{Ar}), 131.0 (C_{Ar}), 130.8 (C_{Ar}), 130.7 (C_{Ar}), 129.8 (C_{Ar}), 129.5 (C_{Ar}), 129.4 (C_{Ar}), 128.7 (C_{Ar}), 128.6 (C_{Ar}), 128.1 (C_{Ar}), 127.0 (C_{Ar}),

126.4(C_{Ar}), 126.3 (C_{Ar}), 125.8 (C_{Ar}), 125.7 (C_{Ar}), 125.4 (C_{Ar}), 124.8 (C_{Ar}), 124.7 (C_{Ar}), 124.1 (C_{Ar}), 124.0 (C_{Ar}), 122.8 (C_{Ar}), 122.5 (C_{Ar}), 122.3 (C_{Ar}), 122.2 (C_{Ar}), 121.7 (C_{Ar}), 121.5 (C_{Ar}), 113.6 (C_{Ar}), 113.6 (C_{Ar}), 29.3 (C_7), 29.2 (C_7), 27.4 (C_8), 27.3 (C_8), 21.4 (C_{21}), 21.3 (C_{21}), 16.7 (C_{22}), 16.6 (C_{22}).

Sodium bis-(*R*)-BINOL borate, **336**:



$NaBH_4$ (500 mg, 13.21 mmol, 1 eq.) was slowly added to MeOH (25 mL) at r.t. over 10 mins. After 30 mins the reaction was refluxed. After 1 h, the solvent was removed *in vacuo* and the white solid was dried at 80 °C for 16 h to give $Na(OMe)_4$ as a white solid (2.09 g, Quant.) that was used without further purification.

Prepared according to a modified literature procedure for racemic sodium bis-BINOL borate.[131] (*R*)-BINOL (1.00 g, 3.50 mmol, 2.94 eq.) and $NaB(OMe)_4$ (2.84 g, 1.80 mmol, 1 eq.) were dissolved in THF (30 mL) and heated to reflux. After 20 h, the reaction was cooled to 40 °C and $B(OMe)_3$ (0.25 mL, 235 mg, 2.27 mmol, 1.26 eq.) was added. After 1 h, the reaction was heated to reflux. After 3 h, the reaction was cooled to r.t. and left for 16 h to crystallise. The precipitate was collected by suction filtration and sequentially washed with THF (2 × 20 mL), Et_2O (2 × 20 mL) and pentane (2 × 20 mL). The crude product consisted of the THF adduct sodium bis-(*R*)-BINOL borate·xTHF where x = 2.5. The crude product was dried at 80 °C for 7 d to give the title compound as a white solid (501 mg, 46%).

Melting Point = >250 °C.

^{1}H NMR (400 MHz, DMSO-d_6): δ_H = 7.98 (d, J = 8.8 Hz, 4H, H_4), 7.94 (d, J = 8.2 Hz, 4H, H_6), 7.36 (d, J = 8.7 Hz, 4H, H_3), 7.30 (ddd, J = 8.0, 5.7, 2.2 Hz, 4H, H_7), 7.22 – 7.12 (m, 8H, H_9, H_8).

^{13}C NMR (101 MHz, DMSO-d_6): δ_C = 156.1 (C_2), 132.8 (C_{10}), 128.9 (C_5), 128.2 (C_4), 128.0 (C_6), 125.8 (C_9), 124.8 (C_8), 124.6 (C_3), 122.4 (C_7), 121.8 (C_1).

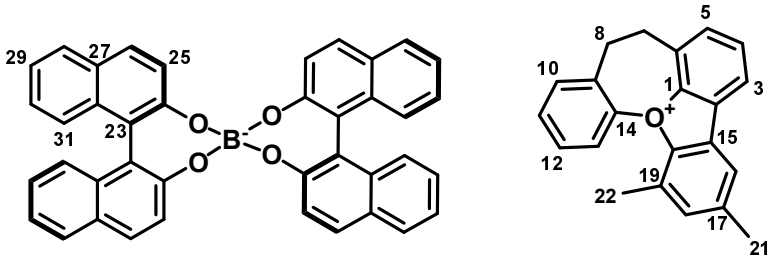
FTIR (film) ν_{max}**/cm^{-1}** = 3053, 2162, 1618, 1590, 1505, 1464, 1428, 1366, 1331, 1266, 1246, 1155, 1071, 986, 948, 910, 828, 812, 744, 720, 665, 633.

LRMS (ESI$^-$): *m/z* calculated for $C_{20}H_{13}O_2^-$, [M-$C_{20}H_{11}BO_2$]$^-$ = 285; *m/z* found = 285.

$[\alpha]_D^{25}$ = -264 (c = 0.5, DMSO)

*Spectra are consistent with literature values.[131]

1,3-Dimethyl-8,9-dihydrobenzo[*b*]benzo[6,7]oxepino[3,2,1-*hi*]benzofuran-14-ium bis-(*R*)-BINOL borate, **337**:



A mixture of 1,3-dimethyl-8,9-dihydrobenzo[*b*]benzo[6,7]oxepino[3,2,1-*hi*]benzofuran-14-ium, tetrafluoroborate **328** (20 mg, 0.05 mmol, 1 eq.) and sodium bis-(*R*)-BINOL borate, **336** (31 mg, 0.05 mmol, 1 eq.) in CH_2Cl_2 (2 mL) was washed with H_2O (2 × 1 mL) and dried ($MgSO_4$). The solvent was removed by a steady stream of N_2 and the solid was dissolved in CD_2Cl_2 for analysis. ' is used to distinquish between resonances belonging to the two enantiomer where the identity is known.

^{1}H NMR (600 MHz, CD_2Cl_2): δ_H = 7.78 – 7.63 (m, 16H, H_{28}, H_{26}), 7.57 (d, J = 8.9 Hz, 1H, H_{Ar}), 7.42 (s, 1H, H_{16}), 7.35 (d, J = 7.6 Hz, 2H, H_{Ar}), 7.27 (d, J = 8.6 Hz, 8H, H_{30}), 7.22 (d, J = 7.8 Hz, 1H, H_{Ar}), 7.17 – 6.96 (m, 21H, H_{31}, H_{29}, H_{Ar}), 6.95 – 6.81 (m, 10H, H_{25}, H_{Ar}), 6.79 (d, J = 7.8 Hz, 1H, H_{Ar}), 6.62 (d, J = 7.7 Hz, 1H, H_{Ar}), 6.49 – 6.43 (m, 3H, H_{Ar}, H_{18}, H_{13}), 3.57 (td, J = 13.8, 4.7 Hz, 1H, H_{8A}), 3.38 – 3.28 (m, 1H, $H_{8A'}$), 2.87 (d, J = 17.0 Hz, 1H, $H_{8B'}$), 2.57 – 2.41 (m, 3H, H_{8B}, $H_{7B'}$, $H_{7A'}$), 2.37 – 2.26 (m, 2H, H_{7B}, H_{7A}), 2.26 (s, 3H, H_{22}), 2.18 (s, 3H, $H_{22'}$), 1.65 (s, 3H, $H_{21'}$), 1.48 (s, 3H, H_{21}).

^{13}C NMR (151 MHz, CD_2Cl_2): δ_C = 161.0 (C_{Ar}), 160.7 (C_{Ar}), 160.2 (C_{Ar}), 160.1 (C_{Ar}), 156.8 (C_{24}), 152.6 (C_{20}), 152.4 (C_{20}), 142.3 (C_{Ar}), 142.0 (C_{Ar}), 134.0 (C_{Ar}), 133.6 (C_{Ar}), 133.6 (C_{32}), 132.7 (C_{Ar}), 132.6 (C_{Ar}), 132.4 (C_{Ar}), 132.3 (C_{Ar}),

132.1 (C_{Ar}), 131.9 (C_{Ar}), 131.8 (C_{Ar}), 131.7 (C_{Ar}), 130.6 (C_{Ar}), 130.1 (C_{Ar}), 129.8 (C_{27}), 129.2 (C_{Ar}), 129.1 (C_{Ar}), 128.5 ($C_{28/26}$), 128.2 ($C_{28/26}$), 127.2 (C_{Ar}), 127.0 (C_{31}), 125.6 (C_{Ar}), 125.6 (C_{Ar}), 125.3 (C_{30}), 124.8 (C_{25}), 124.6 (C_{Ar}), 124.6 (C_{Ar}), 124.3 (C_{Ar}), 124.3 (C_{Ar}), 123.8 (C_{Ar}), 122.8 (C_{29}), 122.6 (C_{23}), 122.1 (C_{Ar}), 121.6 (C_{Ar}), 121.4 (C_{Ar}), 121.1 (C_{Ar}), 113.9 (C_{13}), 113.8 (C_{13}), 29.3 (C_7), 29.1 (C_7), 27.2 (C_8), 27.2 (C_8), 21.3 (C_{21}), 21.3 (C_{21}), 16.5 (C_{22}).

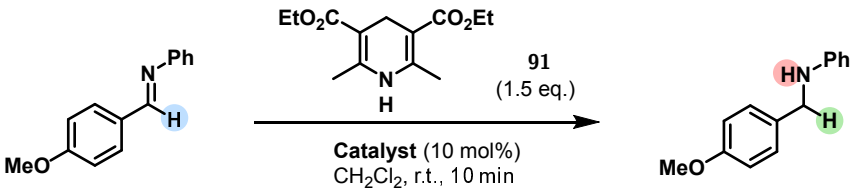
^{19}F NMR (377 MHz, CD_2Cl_2): δ_F = No peaks were observed indicating the loss of the BF_4 counterion.

The solvent was removed by a steady stream of N_2 and the solid sample was dissolved in $CDCl_3$ (1 mL). After 16 h, the mother liquor was removed, the precipitate was washed ($CDCl_3$, 2 × 0.1 mL) and dried *in vacuo* to give enantioenriched **337** as a white solid (1 mg). ^{1}H NMR analysis in CD_2Cl_2 gave the e.r. as 94:6.

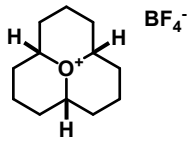
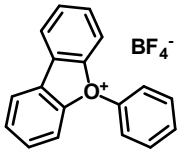
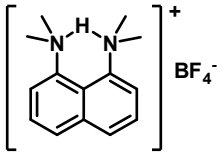
^{1}H NMR (400 MHz, CD_2Cl_2): δ_H = 7.79 – 7.73 (m, 8H, H_{28}, H_{26}), 7.52 (s, 1H, H_{16}), 7.45 (d, J = 7.5 Hz, 1H, H_{Ar}), 7.35 (dd, J = 7.5, 1.8 Hz, 1H, H_{Ar}), 7.32 – 7.21 (m, 5H, H_{30}, H_{Ar}), 7.18 – 7.08 (m, 9H, H_{31}, H_{29}, H_{Ar}), 7.05 – 6.95 (m, 5H, H_{25}, H_{Ar}), 6.76 (d, J = 7.7 Hz, 1H, H_{Ar}), 6.63 – 6.54 (m, 2H, H_{18}, H_{13}), 3.79 – 3.67 (m, 1H, H_{8A}), 2.67 (dt, J = 14.3, 3.7 Hz, 1H, H_{8B}), 2.48 – 2.39 (m, 2H, H_7), 2.35 (s, 3H, H_{22}), 1.60 (s, 3H, H_{21}).

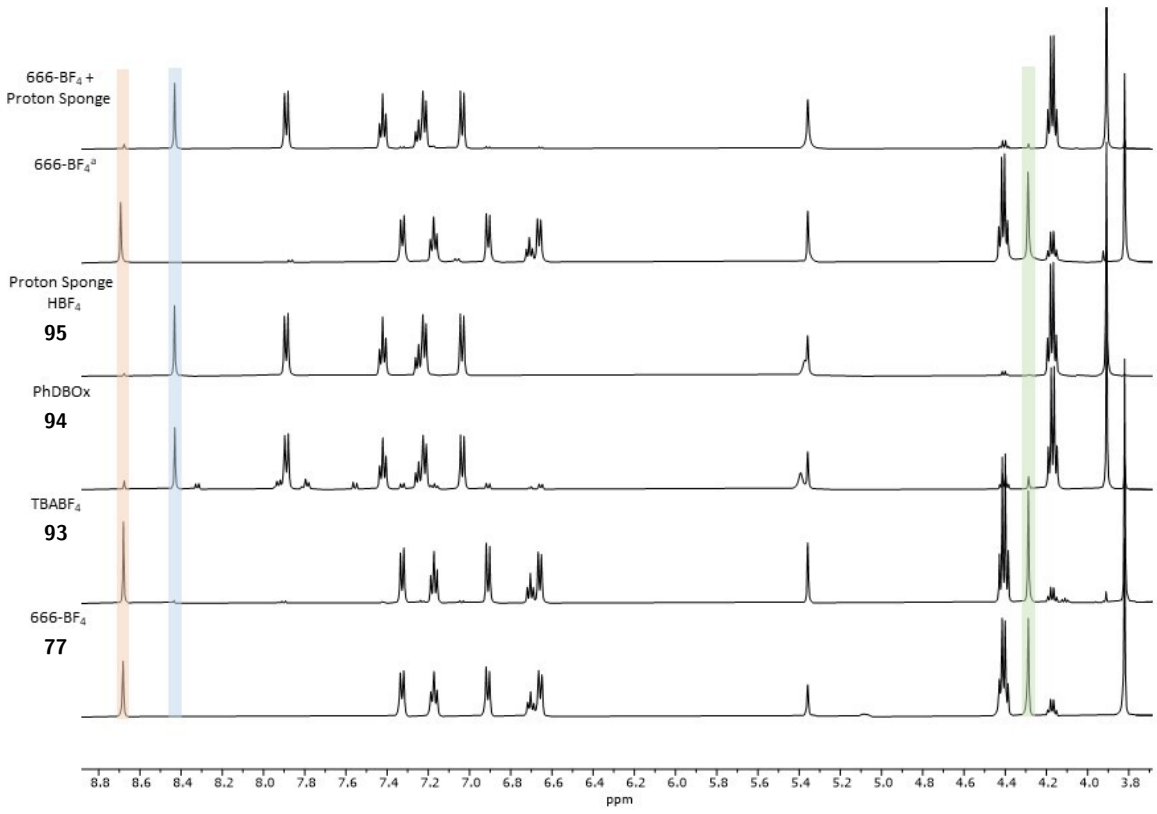
4.4 Catalysis

Aldimine Hantzsch Ester Reduction



90 92

				
77	**93**	**94**	**95**	
Quant[a]	98%	13%	4%	7%



The catalysis reactions were carried out on a 0.025 mmol scale and the following stock solutions were made:

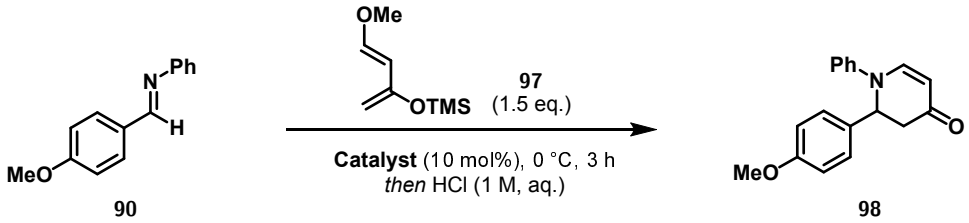
A: Hantzsch Ester **91**, (19.0 mg, 0.075 mmol) in CD_2Cl_2 (0.8 mL).

B: Aldimine **90**(10.6 mg, 0.05 mmol, 1 eq.) + *the appropriate catalyst* (0.005 mmol, 10 mol%) in CD_2Cl_2 (0.2 mL).

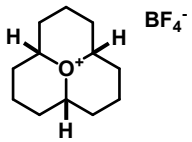
77: (1.34 mg, 0.005 mmol), **93**: (1.65 mg, 0.005 mmol), **94**: (1.66 mg, 0.005 mmol), **95**: (1.51 mg, 0.005 mmol).

Stock solution A (0.4 mL) was added to an NMR tube and the reaction was initiated by the addition of stock solution B (0.1 mL). The first ^1H NMR spectrum was taken after 10 mins and the results are shown above.

Aldimine [4+2] with Danishefsky's Diene



90 **98**

$HBF_4 \cdot Et_2O$		None
100	**77**	
Quant%	88%	15%

The following stock solutions were made:

A: Danishefsky's Diene **339** (129 mg, 0.50 mmol) in CH_2Cl_2 (2.5 mL).

B: Aldimine **90** (106 mg, 0.50 mmol) in CH_2Cl_2 (5 mL).

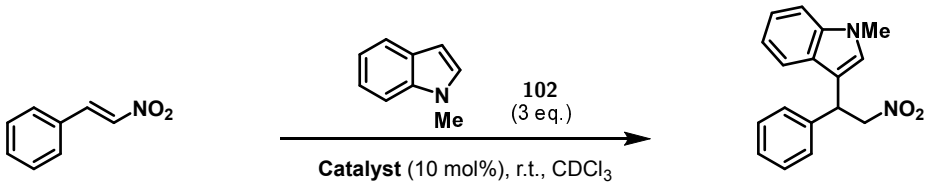
C: *The appropriate catalyst* (0.04 mmol) in CH_2Cl_2 (2 mL).

(3a*s*,6a*s*,9a*s*)-Dodecahydro-3a^{1}oxaphenalen-3a^1-ium tetrafluoroborate, **77**, (10.72 mg, 0.04 mmol), $HBF_4{\cdot}Et_2O$, **100**, (5.5 μL, 6.5 mg, 0.04 mmol).

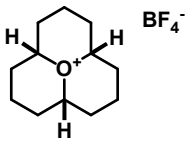
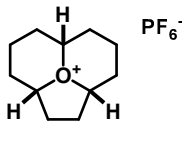
D: CH_2Br_2 (35 μL, 0.50 mmol) in $CHCl_3$ (1 mL)

The reactions were carried out on a 0.1 mmol scale. Stock solution B (1 mL) and Stock solution C (0.5 mL) were added to a vial under N_2 and the reaction mixture was cooled to 0 °C in a Polar Bear Plus cooling system. The reaction was initiated by the addition of Stock Solution A (0.5 mL) to the stirred solution. After 3 h, HCl (1 M aq., 50 μL) was added. After 5 mins, H_2O (2 mL) was added and the reaction was extracted with CH_2Cl_2 (2 × 2 mL). The organic extracts were dried ($MgSO_4$), concentrated *in vacuo*, stock solution D (0.1 mL) was added and the samples were subjected to ^{1}H NMR analysis.

Friedels-Crafts Alkylation of *trans*-β-nitrostyrene



101 **103**

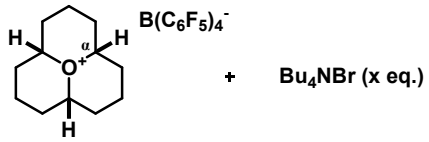
	$HBF_4 \cdot Et_2O$			None
	100	**77**	**88**	
t = 12 h	trace	-	-[a]	-
= 72 h	12%	-	trace[a]	3%

N-methylindole (19 μL, 19.7 mg, 0.15 mmol, 1 eq.) was added to an oven dried NMR tube containing a solution of *trans*-β-nitrostyrene (7.5 mg, 0.05 mmol, 1 eq.) and *the appropriate catalyst* (0.005 mmol, 10 mol%) in $CDCl_3$ (0.5 mL). The reaction was maintained at r.t. and ^{1}H NMR spectra were measured at 0, 12 and 72 h.

$HBF_4 \cdot Et_2O$, **100**, (3.4 μL, 4 mg, 0.025 mmol) was added to $CDCl_3$ (0.5 mL). 0.1 mL of this solution was added to the NMR tube equivalent to 0.005 mmol. (3a*s*,6a*s*,9a*s*)-dodecahydro-3a^1-oxaphenalen-3a^1-ium tetrafluoroborate, **77**, (1.43 mg, 0.005 mmol, 10 mol%) was added as a solid. (2a*R*,5a*r*,8a*S*)-Decahydro-1*H*-2a^1-oxaacenaphthylen-2a^1-ium hexafluorophosphate, **88**, (1.56 mg, 0.005 mmol, 10 mol%) was added as a solid.

4.5 NMR Titration Experiments

Procedure: A 0.075 M solution of TBAB in $CDCl_3$ was titrated into an NMR tube containing 0.5 mL of a 0.0015 M solution of (3a*s*,6a*s*,9a*s*)-Dodecahydro-3a^1-oxaphenalen-3a^1-ium tetrakis(pentafluorophenyl) borate, **81**, in $CDCl_3$. The titration curve consisted of 16 data points at 0.0, 0.2, 0.4, 0.6, 0.8, 1.0, 1.2, 1.4, 1.6, 2.0, 2.5, 3.0, 4.0, 5.0, 7.0 and 10.0 equivalents. The titration curves were derived from the ^{1}H NMR chemical shift of the oxonium ion α C-H protons taken on a 500 MHz spectrometer at 298 K. The data points listed below were input into the bindfit program[132] to give a binding constant of 1402 ± 364 M^{-1} that was consistent with a 1:1 binding stoichiometry.

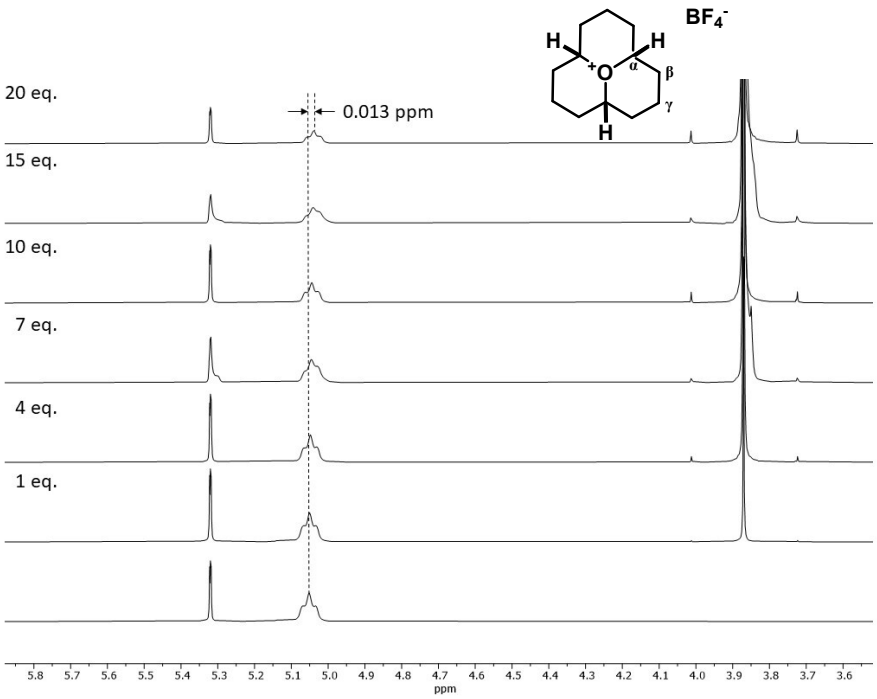


Equivalents	Host Concetration/ M	Guest Concentration/ M	Chemical Shift/ ppm
0.0	0.0015	0	4.3553
0.2	0.001494024	0.000298805	4.5268
0.4	0.001488095	0.000595238	4.7617
0.6	0.001482213	0.000889328	5.0058
0.8	0.001476378	0.001181102	5.1224
1.0	0.001470588	0.001470588	5.3387
1.2	0.001464844	0.001757813	5.5007
1.4	0.001459144	0.002042802	5.6102
1.6	0.001453488	0.002325581	5.7606
2.0	0.001442308	0.002884615	6.1839
2.5	0.001428571	0.003571429	6.2309
3.0	0.001415094	0.004245283	6.2236
4.0	0.001388889	0.005555556	6.2323
5.0	0.001363636	0.006818182	6.2276
7.0	0.001315789	0.009210526	6.2338
10.0	0.00125	0.0125	6.2310

Procedure: *The appropriate oxonium ion* (0.005 mmol) was dissolved in CD_2Cl_2 (0.5 mL) and a ^{1}H NMR spectrum was recorded. CD_2Cl_2 (0.2 mL) was added to aldimine **90** (42 mg, 0.20 mmol) to give a 1 M stock solution. The addition of 5 μL of this stock solution was equivalent to adding one equivalent of aldimine **90** (0.005 mmol). ^{1}H NMR spectra were recorded after the addition of 1, 4, 7, 10, 15 and 20 equivalents of aldimine **90** and the change in the chemical shift of the oxonium ion α C-H resonances was measured.

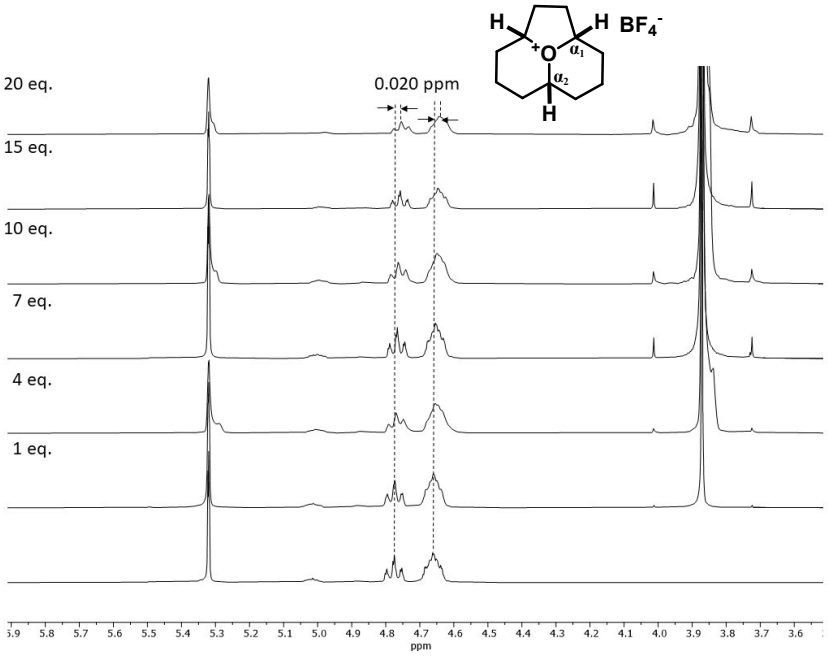
(3a*s*,6a*s*,9a*s*)-Dodecahydro-3a^1-oxaphenalen-3a^1-ium tetrafluoroborate, **77**:

77 (1.34 mg, 0.005 mmol) was dissolved in CD_2Cl_2 (0.5 mL) and aldimine **90** was added as described above and gave a change in chemical shift of 0.013 ppm after the addition of 20 eq. of **90**.



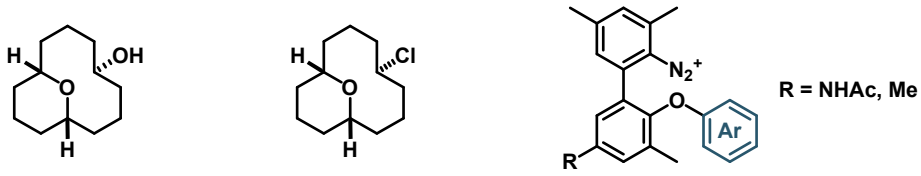
(2a*R*,5a*r*,8a*S*)-decahydro-1*H*-2a^1-oxaacenaphthylen-2a^1-ium hexafluorophosphate, **88**:

88 (1.56 mg, 0.005 mmol) was dissolved in CD_2Cl_2 (0.5 mL) and aldimine **90** was added as described above and gave a change in chemical shift of 0.020 ppm for α_1 and 0.020 for α_2 after the addition of 20 eq. of **90**.



4.6 Evidence for the formation of Oxonium Ions

Mass spectrometry: Mass spectrometry would be the first suggestion to determine if an oxonium ion has formed; however, a variety of oxonium ion precursors can form cations that have the same molecular ion peak as the oxonium ion under ESI^+ conditions. Macrocyclic alcohol **67** and macrocyclic chloride **75** lose HO^- and Cl^- respectively and aryldiazonium salts lose N_2 to form the aryl cation/oxonium ion, therefore, mass spectrometry cannot be used to unambiguously confirm the existence of the desired oxonium ion species (**Scheme 4.1**).



Scheme 4.1: Examples of oxonium ion precursors that form the same molecular ion peak as the oxonium ions under ESI^+ conditions.

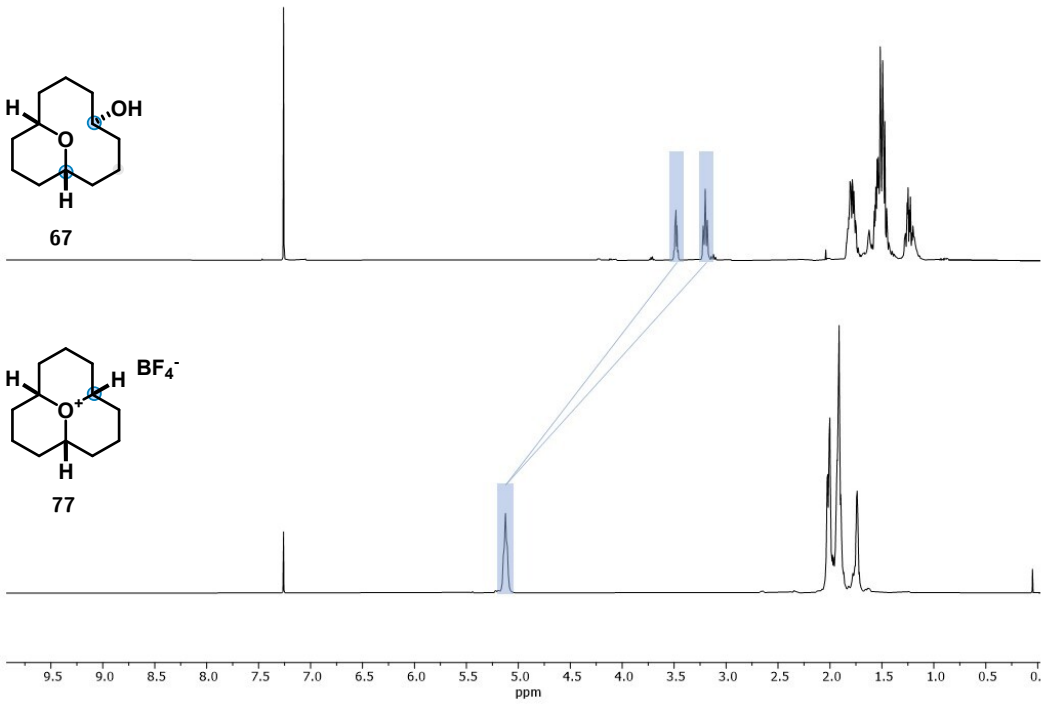
Solubility: Trialklyl and triaryloxonium ions are poorly soluble in Et_2O and can be precipitated from CH_2Cl_2, acetone, MeCN or $CHCl_3$ solution by the addition of Et_2O. Due to their instability to column chromatography or HPLC, precipitation or crystallisation is the primary method of purification.

IR: A broad C-O band is observed in most oxonium ions between 1000-1100 cm^{-1}. For oxonium ions with the $B(C_6F_5)_4^-$ counterion, this is sometimes not observed as the signal is overwhelmed by the counterion.

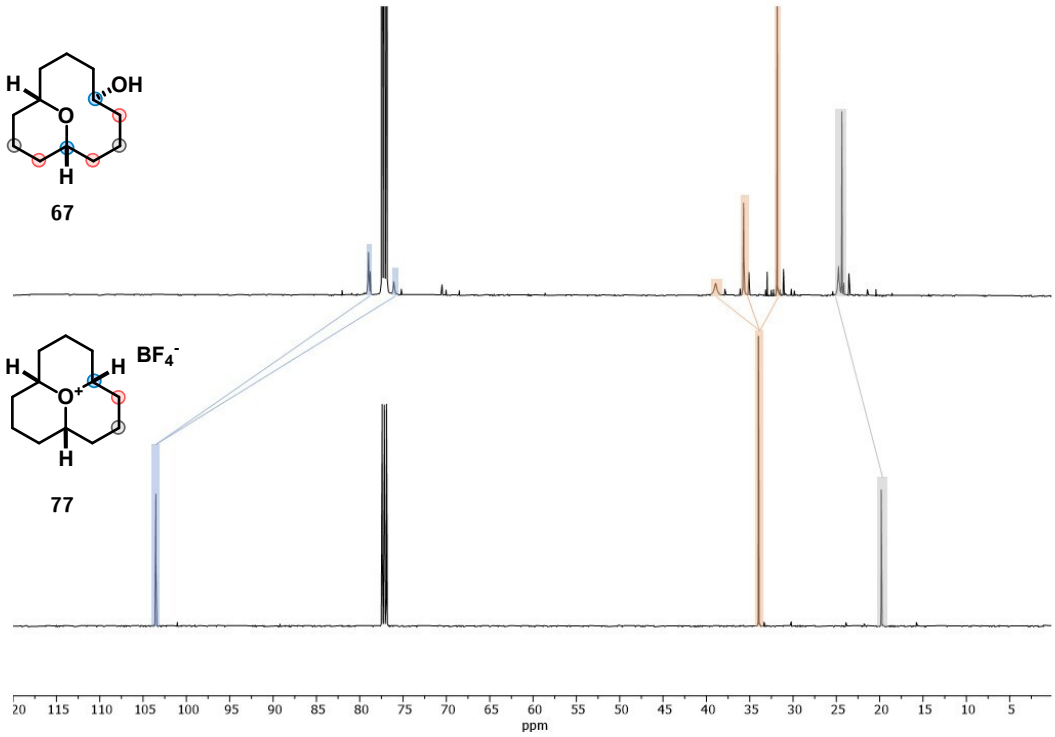
NMR Spectroscopy: See the following sections for the characteristic NMR chemical shifts of the oxonium ions and comparison to the NMR spectra of their precursors.

4.6.1 6,6,6-Trialkyloxonium Ions

The formation of 6,6,6-trialkyloxonium tetrafluoroborate salt, **77**, can be readily observed by ^{1}H and ^{13}C NMR spectroscopy. Upon formation of oxonium ion **77**, the ^{1}H NMR resonance of the C-H environments adjacent to the trivalent oxygen increases by 1.5-2 ppm to become a single resonance at 5.12 ppm.

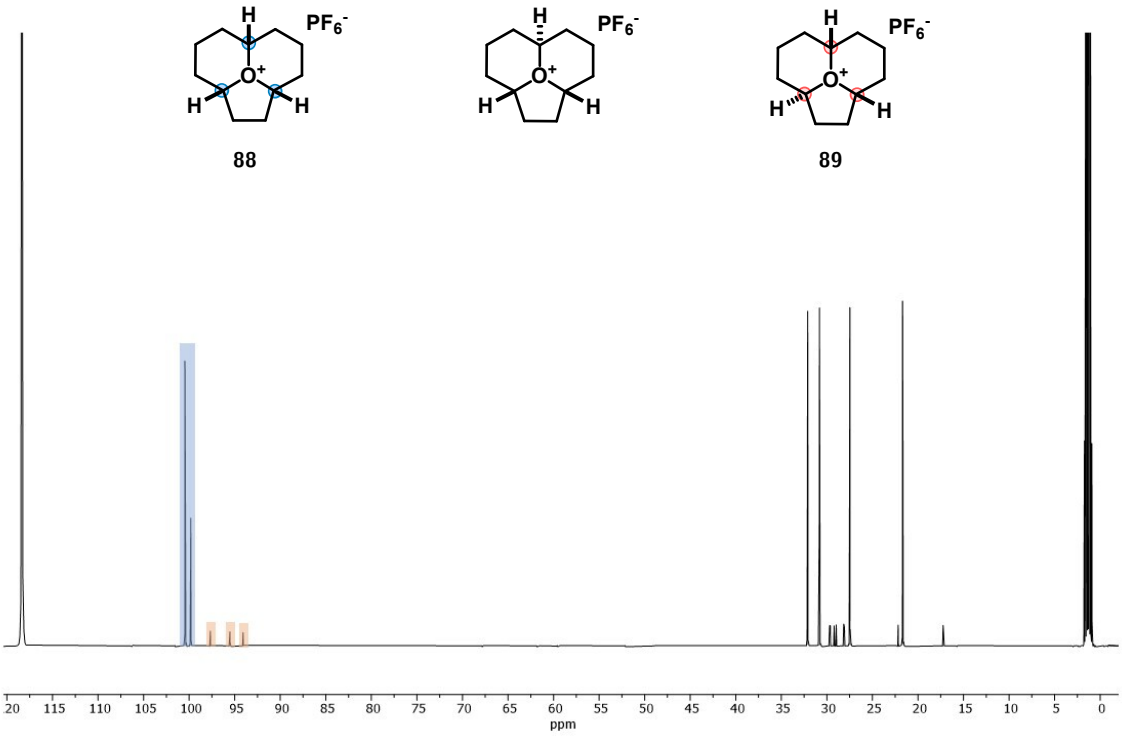


Significant simplification of the ^{13}C NMR occurs upon formation of oxonium ion **77** from macrocyclic alcohol **67** (7 resonances become 3) and the ^{13}C resonances of the carbon atoms attached to the trivalent oxygen increase by 25-30 ppm to 103.5 ppm.



4.6.2 6,6,5-Trialkyloxonium Ions

^{13}C NMR analysis of the 7:1 d.r. mixture shows that the compound has the expected chemical shifts of an oxonium ion at approximately 100 ppm. Single crystal x-ray analysis confirmed that the major diastereomer is all-*cis* **88**. The minor diastereomer has 3 resonances of similar intensity indicating that its identity it **89** rather than the epimer of **88** at the 6,6 ring junction shown below.

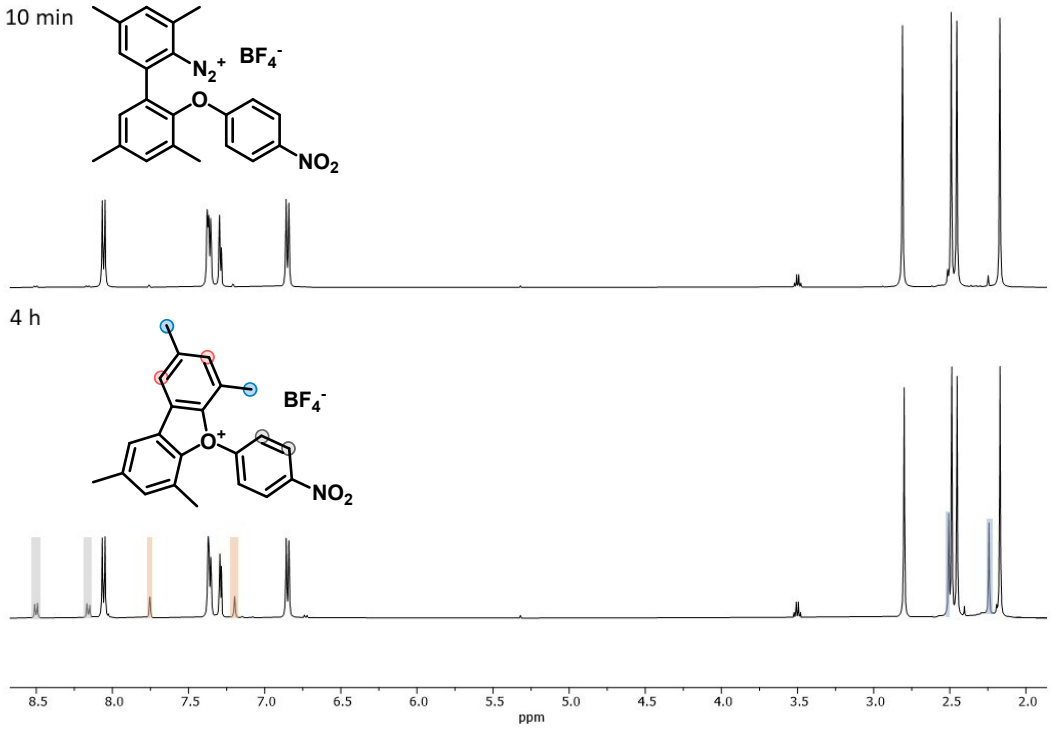


4.6.3 Monitoring Aryl Diazonium Salts by ^{1}H NMR

The aryl diazonium salts were prepared using the conditions described for the formation of the oxonium ion: (*t*-BuONO (5 eq.), HBF_4 (48% aq., 5 eq.) in CH_2Cl_2:IPA (1:1), 0 °C on a 0.025 mmol scale. After 1 h, the mixture was washed with H_2O (2 × 2 mL), the solvent was reduced to 0.1 mL by a steady stream of N_2 and Et_2O (3 mL) was added. The precipitate was collected by suction filtration, washed (Et_2O, 2 × 2 mL) and dried. The solid was dissolved in $CDCl_3$, the solvent was removed by a steady stream of N_2. The residue was dissolved in $CDCl_3$ and analysed at 2 h intervals by ^{1}H NMR for 10 h and a ^{1}H NMR spectrum was measured after 48 h.

4.6.4 Triaryloxonium Ions: Tetramethyldibenzofurans

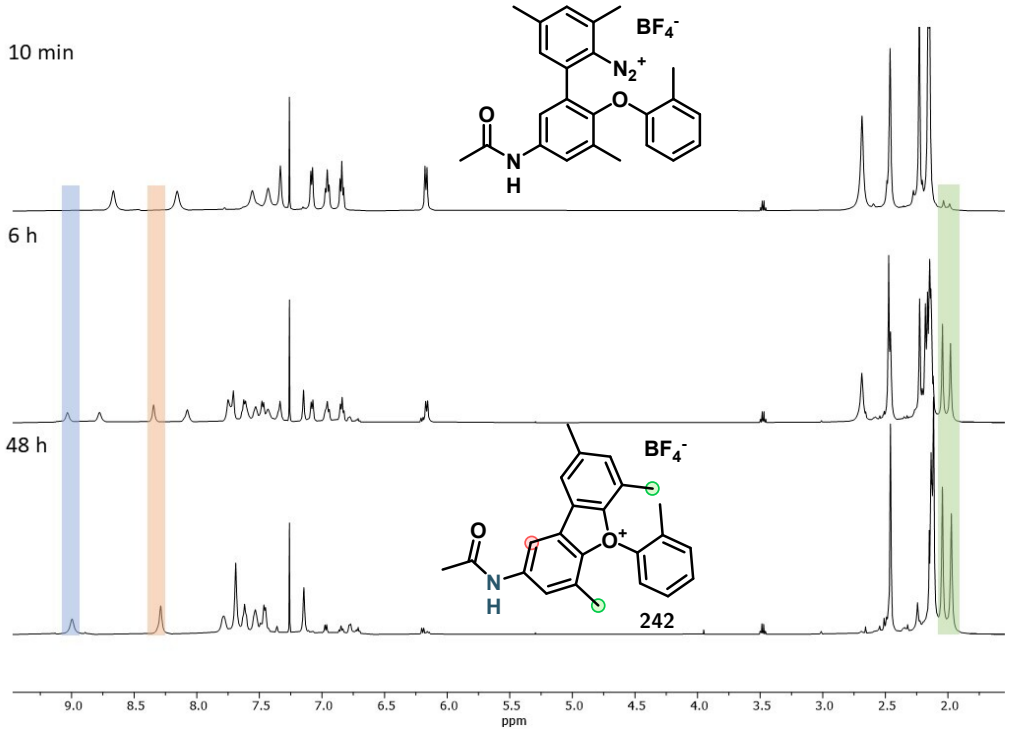
Over time, we observe the appearance of two new methyl resonances and two new C-H resonances as the symmetrical 2,4,6,8-tetramethyldibenzofuran moiety is formed to give oxonium ion **160**. The resonances of the pendant aryl C-H bonds are also significantly shifted with the C-H adjacent to the carbon bearing the trivalent oxygen at 8.50 ppm.



Oxonium ion **160** is poorly soluble in $CDCl_3$ and you do not observe any increase in the amount of **160** by ^1H NMR after 4 h due to the precipitation of **160** from solution.

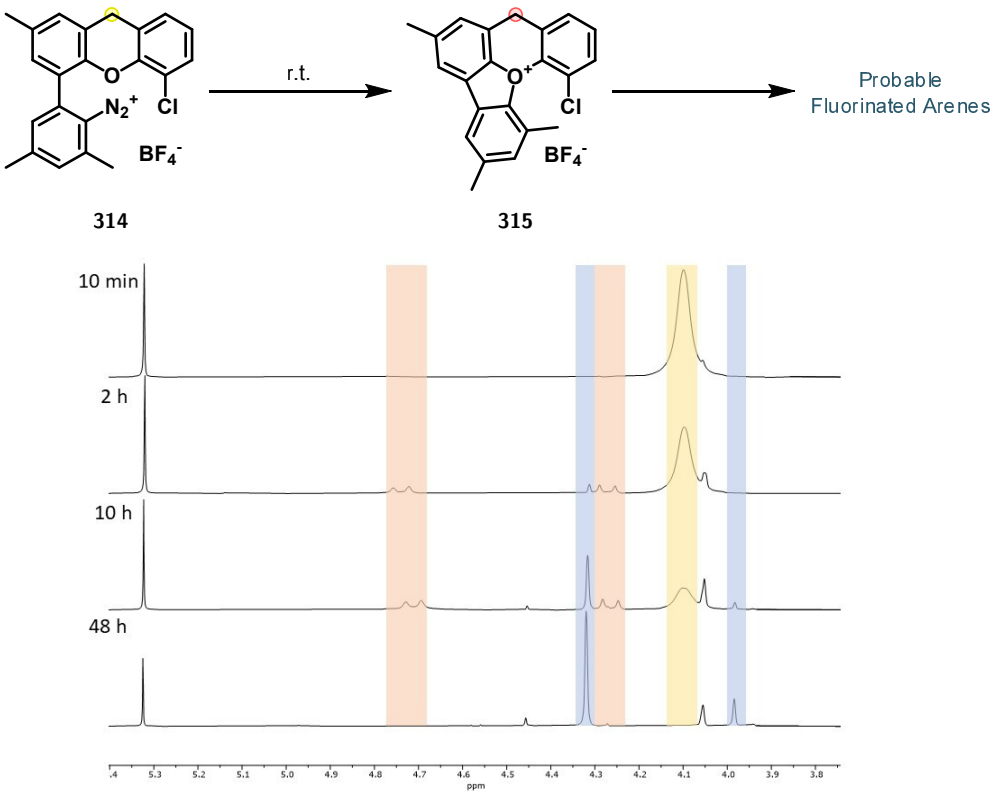
4.6.5 Triaryloxonium Ions - *N*-Ac-trimethyldibenzofuran

While a number of resonances of the oxonium ion **242** overlap with those of the diazonium salt, we are able to observe the formation of **242** by monitoring the NH, aryl C-H and methyl ^{1}H NMR resonances shown below and after 48 h at r.t. oxonium formation is essentially complete.



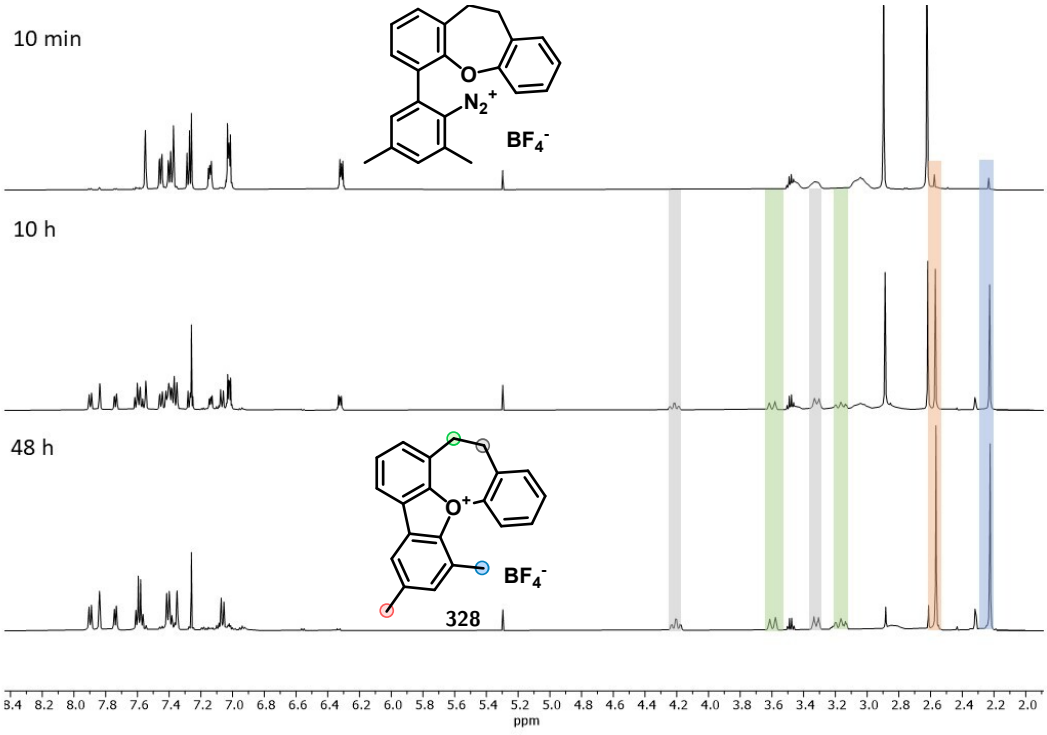
4.6.6 Triaryloxonium Ions - Xanthene Derived

Analysis of aryl diazonium salt **314** over 10 h indicated the formation of triaryloxonium ion **315** by the appearance of the expected AB quartet. A steady state concentration of **315** is observed as the rate of its formation from **314** is balanced by its rate of consumption which was attributed to a Balz-Schiemann type reaction with BF_4^- to form fluorinated arenes.



4.6.7 Triaryloxonium Ions - Dihydrodibenzooxepane derived

The resonances for the -CH_2CH_2- backbone of the aryldiazonium salt are broad and unresolved indicating limited interconversion on the NMR timescale. Upon forming oxonium ion **328**, the peaks become resolved indicating that there is little/no interconversion of the two helical forms on the NMR timescale. Formation of **328** is effectively complete after 48 h.



4.7 Inversion Barrier Measurement

$$\Delta G^{\ddagger}_{T_c} = RT_c ln\left(\frac{k_B T_c}{h k_{ent}}\right)$$

R = Gas Constant, 8.3145 J mol^{-1} K^{-1}

T_c = Coalescence Temperature

k_B = Boltzmann Constant, 1.3806 $\times$ $10^{-}23$ m^2 kg s^{-2} K^{-1}

h = Planck's Constant, 6.62607 $\times$ 10^{-34} m^2 kg s^{-1}

For an AB system:

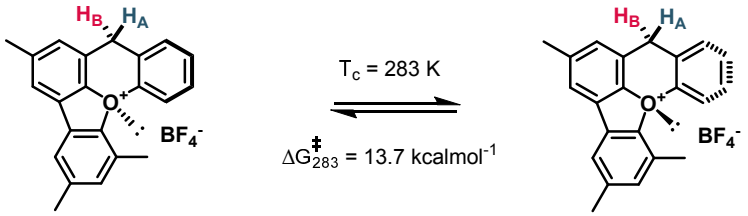
The approximate rate of enantiomerisation, k (s^{-1})= $\pi\sqrt{\frac{(\Delta\nu)^2 + 6(J_{AB})^2}{2}}$

J_{AB} = Coupling constant, $(\nu_1) - (\nu_2) = (\nu_3) - (\nu_4)$

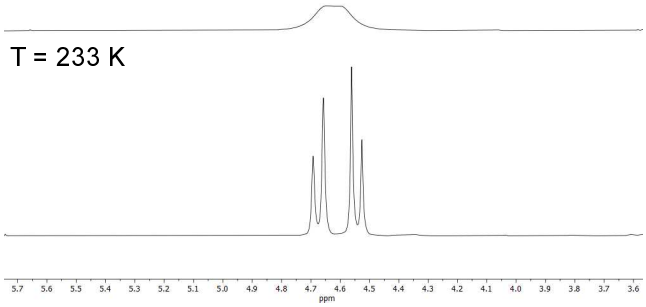
$\Delta\nu = \sqrt{(\nu_1 - \nu_4)((\nu_2 - \nu_3))}$

Where ν_X are the resonances of the AB quartet

Barrier to enantiomerisation measurement for **299**:



T = T_c = 283 K



$T_c = 283$ K

$J_{AB} = 15$ Hz

$\Delta\nu = 0.1265$ ppm $= 63.25$ Hz (500 MHz Spectrometer)

$$k = \pi\sqrt{\frac{(63.25)^2 + 6(15)^2}{2}} = 162.49\ (s^{-1})$$

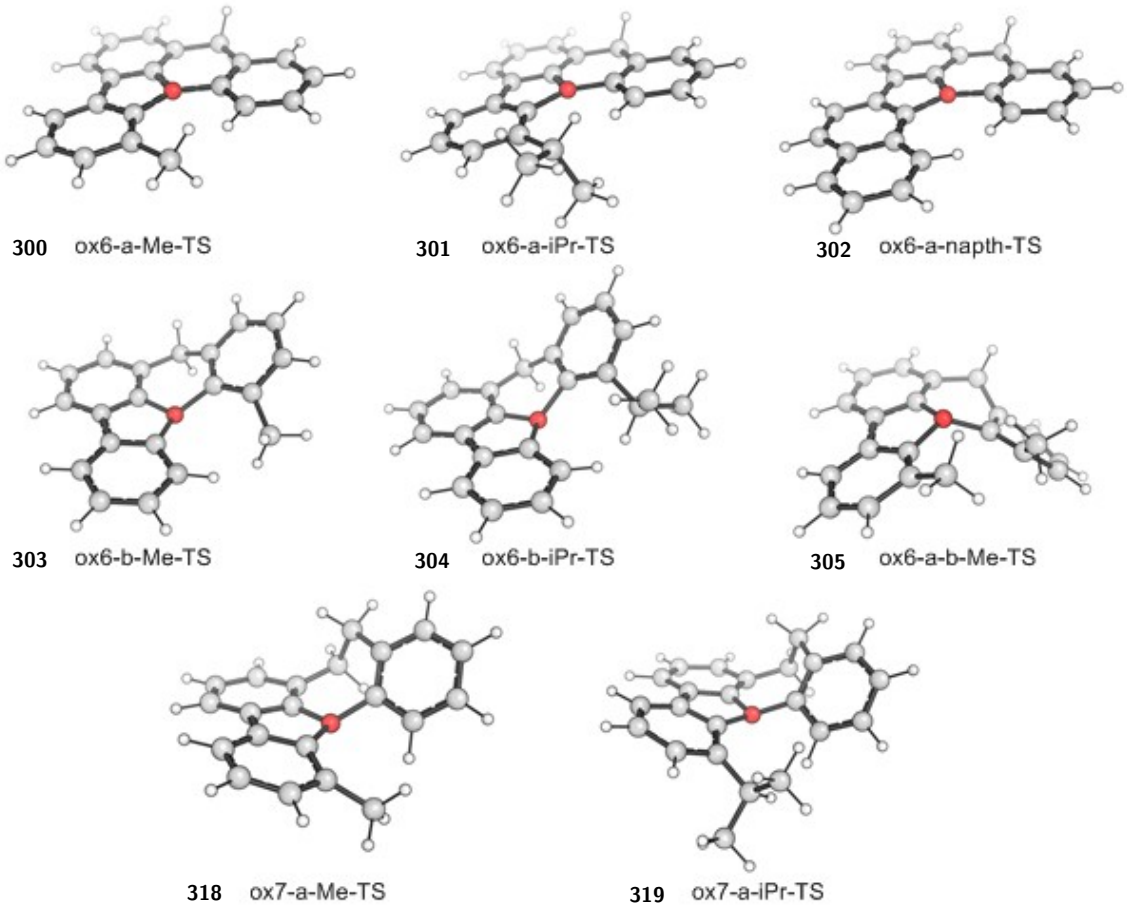
$$\Delta G^{\ddagger}_{283} = 8.3145 \times 283 \times ln(\frac{k_B \times 283}{h \times 162.49}) = 57209\ \text{J mol}^{-1}$$

$\Delta G^{\ddagger}_{283} = 57.2$ kJ mol^{-1} or 13.7 kcalmol^{-1}

4.8 Computational Procedures

We are grateful to Mihai V. Popescu for performing the barrier to enantiomerisation calculations. The B3LYP[133] density functional and the 6.31+G(d,p)[134–138] basis set were used with Grimme's D3 correction with Becke-Johnson damping (GD3BJ)[139,140] to optimize the geometries of all stationary points. The results obtained were found to be in very good agreement with X-ray structures. Gaussian 16[141] was employed for all density functional theory (DFT) calculations, using an "ultrafine" pruned (99,590) grid for numerical integration of the exchange-correlation functional and its derivatives. We performed vibrational frequency calculations to verify that stationary points were either minima or first-order saddle points on the potential energy surface, and to calculate thermal corrections to Gibbs free energies (G). The computed thermochemistry data were corrected following Grimme's quasiharmonic (QHA)[142] model for entropy with a frequency cut-off value of 100.0 cm^{-1} using the GoodVibes[143] program at 298.15 K (25 °C). Molecular graphics were generated using PyMol.[144]

4.8.1 Transition State Structures



Scheme 4.2: Transition state structures for the enantiomerisation of substituted triaryloxonium ions.

GoodVibes information and input line:

GoodVibes v3.0.1 2021/05/17 01:14:51

Luchini, G.; Alegre-Requena J. V.; Guan, Y.; Funes-Ardoiz, I.; Paton, R. S. (2019).

GoodVibes: GoodVibes 3.0.1 http://doi.org/10.5281/zenodo.595246

Requested: –imag

Temperature = 298.15 Kelvin Pressure = 1 atm

All energetic values below shown in Hartree unless otherwise specified. Using vibrational scale factor 1.0 for B3LYP/6-31+G(d,p) level of theory Entropic quasi-harmonic treatment: frequency cut-off value of 100.0 wavenumbers will be applied. QS = Grimme: Using a mixture of RRHO and Free-rotor vibrational entropies.[142]

Structure	E	ZPE	H	T.S	T.qh-S	G(T)	qh-G(T)	im freq
o ox6-a-b-Me-TS	-885.507343	0.318349	-885.171898	0.059228	0.058242	-885.231126	-885.230140	-93.64
o ox6-a-b-Me	-885.563552	0.319020	-885.226689	0.061003	0.059833	-885.287692	-885.286522	
o ox6-a-iPr-TS	-924.862654	0.347859	-924.496413	0.062576	0.061016	-924.558989	-924.557429	-65.44
o ox6-a-iPr	-924.890632	0.348172	-924.523553	0.063589	0.061993	-924.587141	-924.585546	
o ox6-a-Me-TS	-846.221794	0.291309	-845.914881	0.056771	0.055553	-845.971652	-845.970434	-93.77
o ox6-a-Me	-846.243659	0.291333	-845.936126	0.057662	0.056759	-845.993788	-845.992885	
o ox6-b-iPr-TS	-924.857648	0.347822	-924.491656	0.061349	0.060401	-924.553005	-924.552057	-45.66
o ox6-b-iPr	-924.879102	0.347919	-924.512157	0.064020	0.062258	-924.576176	-924.574414	
o ox6-b-Me-TS	-846.214393	0.291320	-845.907679	0.055787	0.055022	-845.963466	-845.962701	-86.31
o ox6-a-napth	-960.586552	0.310568	-960.258793	0.060079	0.058796	-960.318873	-960.317589	
o ox6-a-napth-TS	-960.553110	0.308639	-960.226970	0.063992	0.060723	-960.290962	-960.287693	-250.06
o ox7-a-iPr-1	-964.222406	0.377222	-963.825127	0.066218	0.064209	-963.891345	-963.889336	
o ox7-a-iPr-2	-964.210020	0.376933	-963.812859	0.066930	0.064637	-963.879789	-963.877496	
o ox7-a-iPr-TS	-964.174714	0.377021	-963.778512	0.063464	0.062345	-963.841976	-963.840857	-50.55
o ox7-a-Me-1	-885.575527	0.320362	-885.237813	0.060247	0.059031	-885.298060	-885.296844	
o ox7-a-Me-2	-885.562895	0.320097	-885.225276	0.060881	0.059437	-885.286157	-885.284713	
o ox7-a-Me-TS	-885.532520	0.320647	-885.195555	0.057568	0.056739	-885.253123	-885.252294	-73.17

****

The generation of xyz files was automated with GoodVibes using the --xyz option:

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39
ox6-a-b-Me-TS
Eopt  -885.507343
C    3.744425   -1.470034    0.939263
C    2.896631   -2.440322    0.420120
C    1.645912   -2.183500   -0.198103
C    1.259981   -0.843171   -0.105964
C    2.152136    0.170532    0.266811
C    3.397821   -0.132527    0.811022
O   -0.057124   -0.084353   -0.589963
C    0.310730    1.334750   -0.448545
C    1.616176    1.475161   -0.020192
C   -0.570627    2.391348   -0.550529
C   -0.014284    3.671275   -0.419594
C    1.341436    3.852737   -0.130359
C    2.162931    2.753586    0.115132
C   -2.030825    2.107932   -0.559622
C   -2.282466    0.803065    0.156937
C   -1.512019   -0.344768   -0.092492
C   -2.076526   -1.618488   -0.046863
C   -3.231729   -1.732340    0.754890
C   -3.874404   -0.629361    1.296067
C   -3.450114    0.639288    0.904247
H    4.691480   -1.759869    1.380513
H    3.220574   -3.475479    0.430920
H    4.067701    0.665466    1.109438
H   -0.671765    4.530852   -0.503109
H    1.740340    4.856911   -0.038810
H    3.193947    2.883292    0.423323
H   -2.578850    2.920095   -0.077338
H   -2.427659    2.015291   -1.580322
H   -3.667873   -2.721706    0.858381
H   -4.759389   -0.751938    1.910359
H   -4.042963    1.518488    1.134590
C    1.072051   -3.370297   -0.925874
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H    1.878218   -4.086834   -1.086269
H    0.296947   -3.880287   -0.357750
C   -1.839478   -2.744289   -1.019197
H   -1.612875   -3.695805   -0.538905
H   -2.780286   -2.877951   -1.562492
H   -1.083738   -2.506525   -1.757926
39
ox6-a-b-Me
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C   -1.030752    2.191466    0.471442
C   -0.831190    3.533108    0.114611
C    0.385104    3.940570   -0.462344
C    1.446781    3.055275   -0.696195
C    1.269776    1.708571   -0.354602
C    2.092988    0.497299   -0.300416
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C    1.806576   -1.738991    0.757754
C    3.164137   -1.962277    0.449905
C    3.949690   -1.012964   -0.211589
C    3.436995    0.238505   -0.568929
C   -2.212406    1.517583    1.129672
C   -2.415590    0.144203    0.507443
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C   -2.720394   -2.191188   -1.003526
C   -3.838123   -1.541163   -0.490718
C   -3.688512   -0.354052    0.226162
H   -1.615046    4.261858    0.293099
H    2.379424    3.411313   -1.118732
H    3.612230   -2.899324    0.765521
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H   -3.123524    2.108325    1.017368
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H   -4.558263    0.208012    0.550466
H    0.510065    4.985595   -0.724513
H    4.990738   -1.239624   -0.414616
C    1.009604   -2.702209    1.597705
H   -0.067923   -2.584964    1.474551
H    1.275426   -3.735475    1.361553
H    1.239635   -2.538410    2.656309
C   -0.268585   -2.400486   -1.508912
H    0.456790   -1.680645   -1.891138
H    0.268815   -3.120977   -0.888702
H   -0.677455   -2.944864   -2.361976
42
ox6-a-iPr-TS
Eopt  -924.862654
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C    3.295238   -1.349594    0.081302
C    2.373688   -0.276215    0.104518
C    1.044616   -0.721212    0.069148
C    0.662510   -2.068485    0.037286
C    1.627778   -3.074736    0.025667
O   -0.350387    0.040688    0.051109
C   -1.366188   -0.990733    0.011109
C   -0.769999   -2.237640    0.009825
C   -2.726278   -0.768921   -0.028386
C   -3.519731   -1.925941   -0.061265
C   -2.958773   -3.206072   -0.058250
C   -1.574946   -3.377838   -0.024794
C   -3.294461    0.610467   -0.042679
C   -2.228199    1.669669    0.031655
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H    0.341192    4.602463    0.221646
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H   -3.713734    3.201844    0.026132
C    2.974493    1.127401    0.105303
H    2.408762    1.723716    0.821817
C    4.418789    1.208254    0.629218
H    5.144523    0.778323   -0.066834
H    4.681264    2.262985    0.748839
H    4.530408    0.722865    1.602654
C    2.904154    1.730551   -1.314105
H    3.230737    2.774908   -1.303571
H    3.574231    1.174507   -1.976659
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42
ox6-a-iPr
Eopt  -924.890632
O    0.237275    0.021074    0.393110
C    1.375342   -0.881219    0.303263
C    2.624224   -0.456444    0.677633
C    3.621558   -1.427980    0.507230
C    3.303643   -2.694503   -0.012131
C    2.002841   -3.045124   -0.396470
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C   -0.451365   -2.025047   -0.481757
C   -0.926243   -0.773582   -0.064345
C   -2.245432   -0.389918    0.083166
C   -3.150467   -1.358466   -0.402681
C   -2.736193   -2.593376   -0.908060
C   -1.386143   -2.957405   -0.928154
C    2.750997    0.971972    1.151181
C    1.825665    1.842989    0.318679
C    0.593352    1.369121   -0.126509
C   -0.246027    2.016520   -1.009166
C    0.145204    3.289466   -1.436094
C    1.345236    3.842140   -0.986952
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H    4.647611   -1.195143    0.772680
H    1.792509   -4.026537   -0.805934
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H   -1.074853   -3.941648   -1.259064
H    3.779505    1.327414    1.062454
H    2.478480    1.035039    2.213794
H   -1.158888    1.560856   -1.365982
H   -0.489765    3.834991   -2.125165
H    1.644685    4.829457   -1.320888
H    3.134503    3.535239    0.175896
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H   -3.483596   -3.298096   -1.256237
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H   -1.856574    1.508829    0.978460
C   -3.286537    0.471952    2.183599
H   -3.578119    1.371373    2.733752
H   -4.171449   -0.163487    2.080182
H   -2.547417   -0.071108    2.780031
C   -3.751016    1.658011   -0.013768
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36
ox6-a-Me-TS
Eopt -846.221794
C -3.973829 -1.366455 -0.000085
C -3.035077 -2.393576 -0.000037
C -1.630782 -2.212259 0.000025
C -1.259530 -0.862535 0.000027
C -2.175060 0.200801 -0.000022
C -3.546733 -0.047355 -0.000078
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C 1.861084 -1.917110 0.000123
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C 4.208242 -1.356868 -0.000049
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H -1.383243 4.861049 -0.000146
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H 2.762319 2.359705 0.877183
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H 3.430399 -3.373788 0.000106
H 5.251242 -1.652988 -0.000103
H 4.640901 0.747308 -0.000135
C -0.833555 -3.496272 0.000065
H -1.528376 -4.336131 0.000025
H -0.215331 -3.603238 -0.894755
H -0.215433 -3.603243 0.894956
36
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Eopt -846.243659
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C -1.087195 3.355362 0.190983
C 0.118685 3.868056 -0.316841
C 1.241786 3.062438 -0.546027
C 1.147152 1.698607 -0.245245
C 2.031314 0.534615 -0.300727
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C 1.884443 -1.812187 0.518285
C 3.237921 -1.934245 0.137858
C 3.954892 -0.883936 -0.440986
C 3.372586 0.371542 -0.642968
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C -2.439759 -0.130928 0.330377
C -1.264688 -0.815147 0.025142
C -1.177994 -1.972130 -0.721426
C -2.382730 -2.543156 -1.144267
C -3.597517 -1.934471 -0.826898
C -3.621711 -0.734022 -0.113667
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H 2.154225 3.486897 -0.948959
H 3.739050 -2.876518 0.336660
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H -3.334821 1.770288 0.797535
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H -2.359410 -3.455910 -1.728973
H -4.528898 -2.380786 -1.157474
H -4.567268 -0.241593 0.090298
H 0.177300 4.926081 -0.548102
H 4.996602 -1.036874 -0.701339
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H 0.257846 -2.571099 1.737959
H 0.905535 -3.742136 0.581771
H 1.830505 -3.326080 2.022587
42
ox6-b-iPr-TS
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C 0.049100 2.576250 0.320459
C -0.669246 1.407152 0.176396
C -2.028099 1.397021 -0.152729
C -2.678686 2.597658 -0.444414
O -0.256214 -0.014859 0.499479
C -1.499091 -0.781043 0.309553
C -2.542203 0.050841 -0.058401
C -1.581909 -2.147227 0.433630
C -2.855381 -2.696559 0.229474
C -3.952131 -1.888584 -0.091757
C -3.807365 -0.509551 -0.252172
C -0.325674 -2.911832 0.665045
C 0.826516 -2.198203 -0.000838
C 1.028678 -0.811245 0.069574
C 2.267773 -0.205070 -0.145031
C 3.204137 -1.018781 -0.817147
C 2.979744 -2.355694 -1.102815
C 1.820206 -2.956166 -0.623575
H -2.446260 4.730732 -0.599980
H -0.067054 4.699060 0.105052
H -3.731806 2.591548 -0.702576
H -2.977646 -3.771976 0.309339
H -4.924232 -2.346075 -0.239046
H -4.651240 0.112517 -0.527840
H -0.113627 -2.997260 1.740253
H -0.411629 -3.928302 0.276367
H 4.163019 -0.577417 -1.062371
H 3.730473 -2.939801 -1.623301
H 1.672256 -4.027326 -0.712090
H 1.064997 2.632480 0.650447
C 2.812270 1.094433 0.436337
H 2.081197 1.460406 1.153425
C 3.113899 2.147635 -0.642609
H 3.427679 3.089807 -0.182010
H 3.934299 1.808150 -1.281796
H 2.254187 2.343144 -1.288120
C 4.067186 0.812665 1.291268
H 4.920642 0.499806 0.684827
H 4.354384 1.728875 1.816110
H 3.874654 0.036992 2.037594
42
ox6-b-iPr
Eopt -924.879102
O 0.255023 -0.153544 -0.601348
C 1.284429 -1.008013 -0.057522
C 1.178694 -2.368269 -0.176646
C 2.265929 -3.064139 0.372632
C 3.347479 -2.365489 0.937243
C 3.414937 -0.965646 0.954001
C 2.337092 -0.247985 0.421337
C 2.044464 1.146129 0.082585
C 0.814202 1.195943 -0.581707
C 0.293375 2.283267 -1.243883
C 1.047828 3.459421 -1.140662
C 2.258444 3.485404 -0.433098
C 2.775697 2.335314 0.167889
C -0.011210 -2.891577 -0.943208
C -1.235892 -2.029318 -0.683117
C -1.143624 -0.663723 -0.383711
C -2.163773 0.131526 0.129762
C -3.427605 -0.493444 0.129266
C -3.610135 -1.813663 -0.261038
C -2.509774 -2.592895 -0.619465
H 2.282006 -4.148691 0.340825
H 4.287517 -0.459206 1.350530
H 0.687228 4.358606 -1.627587
H 3.737391 2.354582 0.668412
H -0.234727 -3.925712 -0.672411
H 0.237108 -2.890551 -2.014148
H -4.276852 0.075894 0.489575
H -4.601237 -2.253247 -0.235022
H -2.629330 -3.649088 -0.838192
H 4.174446 -2.933573 1.349272
H 2.817865 4.412648 -0.375524
H -0.638208 2.241676 -1.792719
C -2.033812 1.493226 0.803781
H -0.999187 1.823427 0.753636
C -2.369434 1.359531 2.303500
H -2.205127 2.318985 2.803014
H -3.413810 1.074661 2.459959
H -1.737768 0.608554 2.787266
C -2.910143 2.563492 0.132218
H -3.974137 2.336809 0.247478
H -2.728613 3.537785 0.594729
H -2.707761 2.650248 -0.939261
36
ox6-b-Me-TS
Eopt -846.214393
C -3.579280 -2.295678 0.360117
C -2.462579 -3.063130 0.022852
C -1.218726 -2.479257 -0.259325
C -1.142504 -1.107226 -0.154741
C -2.249727 -0.306729 0.138368
C -3.481484 -0.907802 0.406940
O 0.021707 -0.190502 -0.461527
C -0.533533 1.156842 -0.257326
C -1.877983 1.086837 0.066771
C 0.204216 2.312577 -0.335909
C -0.512049 3.499858 -0.125913
C -1.882979 3.483002 0.153264
C -2.579570 2.278409 0.265129
C 1.672887 2.213418 -0.552836
C 2.203871 0.901509 -0.026001
C 1.531307 -0.326464 -0.132964
C 2.184776 -1.561101 -0.047030
C 3.493742 -1.505298 0.474720
C 4.138678 -0.318109 0.783103
C 3.509439 0.880105 0.471627
H -4.526250 -2.781054 0.568195
H -2.542952 -4.142835 -0.038647
H -4.343689 -0.291667 0.636541
H 0.021437 4.443989 -0.170185
H -2.405831 4.420662 0.306044
H -3.635547 2.263981 0.509579
H 1.909000 2.275851 -1.624884
H 2.189837 3.044896 -0.069025
H 4.020118 -2.447289 0.588888
H 5.143641 -0.327683 1.189863
H 4.031323 1.824602 0.584549
H -0.406517 -3.111708 -0.545326
C 1.784199 -2.914632 -0.588899
H 1.288611 -3.542120 0.155539
H 1.170869 -2.831924 -1.486563
H 2.696083 -3.436477 -0.884029
39
ox6-a-napth
Eopt -960.586552
C 2.942945 -2.080967 0.699198
C 0.820314 -0.548399 -0.050615
C 0.579174 -1.844726 0.366468
C 1.682526 -2.631562 0.771549
O -0.461128 0.053007 -0.459284
C -1.442068 -1.010458 -0.316426
C -0.841221 -2.144222 0.199630
C -2.758651 -0.789432 -0.626078
C -3.578767 -1.907469 -0.411564
C -3.038074 -3.106788 0.082884
C -1.680311 -3.247082 0.398662
C -3.132649 0.595857 -1.095252
C -2.306684 1.613551 -0.327190
C -0.993314 1.346543 0.054966
C -0.215648 2.138034 0.875716
C -0.777764 3.345875 1.302552
C -2.072059 3.694883 0.915988
C -2.830632 2.829898 0.124459
H 3.802543 -2.665162 1.011683
H 1.532030 -3.647381 1.118092
H -4.640586 -1.841828 -0.625296
H -3.700742 -3.951978 0.234131
H -1.296593 -4.182588 0.789289
H -2.938261 0.685095 -2.173082
H -4.196661 0.789233 -0.944818
H 0.779081 1.845481 1.181225
H -0.197804 4.000398 1.943471
H -2.502828 4.632061 1.250858
H -3.852279 3.086755 -0.137151
C 3.175575 -0.773473 0.180962
C 2.073082 0.045753 -0.261093
C 4.489919 -0.256997 0.040924
H 5.323945 -0.860937 0.384307
C 2.326814 1.299231 -0.876555
H 1.505039 1.893340 -1.258237
C 3.623022 1.747097 -1.009578
H 3.813164 2.700638 -1.490903
C 4.710618 0.975022 -0.534355
H 5.722089 1.351802 -0.640805
39
ox6-a-napth-TS
Eopt -960.553110
C 3.228273 -1.964495 -0.002474
C 0.960097 -0.372352 0.002252
C 0.854092 -1.749877 0.003129

C 2.005315 -2.567000 0.001395
O -0.581617 0.089790 0.000665
C -1.354569 -1.130524 0.000930
C -0.506482 -2.220892 0.003411
C -2.731584 -1.211372 -0.002206
C -3.255393 -2.513135 -0.000919
C -2.431757 -3.642372 0.002537
C -1.043775 -3.509899 0.004381
C -3.587729 0.009605 -0.008007
C -2.772652 1.273396 -0.003600
C -1.376580 1.351835 0.000508
C -0.713646 2.560031 0.004665
C -1.430569 3.754306 0.004538
C -2.822407 3.724172 0.000370
C -3.466610 2.493523 -0.003509
H 4.135213 -2.559272 -0.005104
H 1.895153 -3.644618 0.002097
H -4.334479 -2.632862 -0.002999
H -2.879488 -4.629907 0.003410
H -0.399568 -4.381344 0.006403
H -4.240254 0.003059 -0.889508
H -4.251370 0.004095 0.865074
H 0.350204 2.591359 0.007785
H -0.889429 4.693781 0.007781
H -3.397697 4.643135 0.000254
H -4.551828 2.450863 -0.006601
C 3.353676 -0.551134 -0.002774
C 2.197834 0.345674 0.001286
C 4.669212 -0.018025 -0.006200
H 5.492940 -0.724542 -0.009690
C 2.515022 1.730845 0.004644
H 1.762291 2.489600 0.011407
C 3.809670 2.205267 0.001575
H 3.967365 3.278628 0.004621
C 4.912019 1.332627 -0.004729
H 5.925131 1.718483 -0.007459
45
ox7-a-iPr-1
Eopt -964.222406
O -0.226212 -0.013571 0.348325
C -0.219497 1.307813 -0.318282
C -0.959943 2.278495 0.340538
C 0.460289 1.471786 -1.509632
C -0.962822 3.544007 -0.261214
C 0.432614 2.747905 -2.078899
H 0.995282 0.653914 -1.975676
C -0.267576 3.779729 -1.449448
H -1.522143 4.345836 0.210658
H 0.957256 2.926440 -3.010907
H -0.281299 4.770037 -1.891573
C 0.847866 -0.970873 0.036863
C 0.259134 -2.153675 -0.410267
C 2.191087 -0.724227 0.240171
C 1.102833 -3.207460 -0.760688
C 3.006111 -1.811228 -0.139886
C 2.481444 -3.009523 -0.634170
H 0.701409 -4.153292 -1.106246
H 4.080193 -1.715289 -0.024060
C -1.490685 -0.756710 0.188378
C -2.730652 -0.260072 0.535187
C -1.192713 -2.021177 -0.316425
C -3.774442 -1.172793 0.273404
C -2.254366 -2.893806 -0.552016
C -3.546533 -2.444028 -0.260658
H -4.789221 -0.870202 0.513428
H -2.082050 -3.892462 -0.936906
H -4.391547 -3.101384 -0.434255
C -1.788239 1.930510 1.549930
H -2.129976 2.849322 2.031619
H -1.185974 1.387579 2.286847
C -3.020289 1.090909 1.156735
H -3.636704 1.668373 0.457456
H -3.636140 0.924789 2.047152
H 3.161209 -3.810916 -0.902941
C 2.759089 0.538568 0.864609
H 1.933756 1.237352 1.031979
C 3.377580 0.215897 2.238378
H 4.233448 -0.458642 2.137993
H 3.729821 1.136041 2.713665
H 2.649823 -0.258285 2.903614
C 3.775124 1.227707 -0.060947
H 3.333080 1.480221 -1.028643
H 4.131187 2.152737 0.401208
H 4.645807 0.589871 -0.240969
45
ox7-a-iPr-2
Eopt -964.210020
O 0.215383 -0.010145 0.398372
C 0.361316 1.317340 -0.306436
C 1.380964 2.175682 0.097258
C -0.527661 1.571438 -1.341436
C 1.407773 3.405464 -0.591457
C -0.453843 2.798969 -1.994203
H -1.263192 0.838795 -1.640341
C 0.511191 3.727704 -1.603285
H 2.180195 4.117549 -0.315935
H -1.143963 3.015750 -2.801858
H 0.578240 4.690674 -2.097511
C -0.926806 -0.864594 -0.001852
C -0.426267 -2.008669 -0.630230
C -2.243930 -0.568099 0.279256
C -1.347263 -2.946459 -1.094166
C -3.139931 -1.541778 -0.212113
C -2.707189 -2.685329 -0.889644
H -1.018711 -3.859490 -1.577541
H -4.201598 -1.399517 -0.042696
C 1.390864 -0.866285 0.195484
C 2.594921 -0.573340 0.788364
C 1.033386 -2.004731 -0.509963
C 3.602878 -1.506387 0.488186
C 2.054552 -2.919639 -0.783976
C 3.337896 -2.636088 -0.300739
H 4.593756 -1.362988 0.907134
H 1.855267 -3.836466 -1.327096
H 4.143189 -3.334117 -0.502579
C 2.498247 1.959923 1.107858
H 2.382226 2.699610 1.907956
H 3.424385 2.224043 0.585907
C 2.688402 0.578669 1.750901
H 1.932691 0.425646 2.530952
H 3.659372 0.562980 2.251661
H -3.444083 -3.399477 -1.241229
C -2.698586 0.637839 1.081947
H -1.829781 1.284886 1.240616
C -3.765246 1.458857 0.339401
H -3.410150 1.794106 -0.639075
H -4.682054 0.880932 0.189141
H -4.025732 2.344228 0.926009
C -3.201631 0.184462 2.466260
H -3.476864 1.055924 3.067420
H -4.086063 -0.453503 2.373026
H -2.434429 -0.378103 3.006585
45
ox7-a-iPr-TS
Eopt -964.174714
O 0.283229 0.067235 0.421113
C 0.303918 1.524601 0.048360
C 1.376604 2.137467 -0.616428
C -0.791463 2.236916 0.497094
C 1.158079 3.476937 -0.987232
C -0.957576 3.571607 0.133448
H -1.507190 1.770414 1.143820
C 0.004683 4.183939 -0.662457
H 1.961649 3.982965 -1.512633
H -1.828826 4.113842 0.483083
H -0.107571 5.215638 -0.976971
C -0.837293 -0.888554 -0.080265
C -0.176925 -2.061329 -0.457636
C -2.227859 -0.765133 -0.032045
C -0.876244 -3.093483 -1.077422
C -2.877644 -1.801263 -0.747384
C -2.240409 -2.915929 -1.282542
H -0.364396 -3.999041 -1.381966
H -3.956656 -1.741582 -0.821503
C 1.517031 -0.745247 0.410416
C 2.799460 -0.325154 0.738441
C 1.210244 -2.014742 -0.054580
C 3.757229 -1.353784 0.759640
C 2.191164 -3.009785 -0.051757
C 3.461927 -2.673538 0.404590
H 4.777148 -1.085186 1.015442
H 1.960273 -4.012922 -0.391061
H 4.243413 -3.424569 0.439556
C 2.796837 1.630501 -0.705336
H 3.427116 2.466823 -1.014554
H 2.929151 0.839839 -1.450403
C 3.236248 1.109289 0.687626
H 2.804082 1.731886 1.476965
H 4.322270 1.154143 0.792056
H -2.823160 -3.670934 -1.798517
C -3.147492 0.159493 0.765689
H -2.551785 0.651456 1.533091
C -3.842007 1.202264 -0.125900
H -4.444064 1.882030 0.484581
H -3.130184 1.791659 -0.707248
H -4.515299 0.705434 -0.831245
C -4.187740 -0.649991 1.569322
H -4.704114 0.025627 2.257636
H -4.948968 -1.105687 0.931398
H -3.713345 -1.440204 2.157721
39
ox7-a-Me-1
Eopt -885.575527
O -0.006096 -0.107978 -0.470299
C -1.166928 -0.788134 0.144121
C -2.387042 -0.463379 -0.430315
C -0.972724 -1.637381 1.216647
C -3.502621 -1.103975 0.125735
C -2.109873 -2.256237 1.743398
H 0.013067 -1.818421 1.627292
C -3.366474 -1.996470 1.191223
H -4.485051 -0.891350 -0.284153
H -2.005962 -2.935256 2.582335
H -4.245778 -2.483161 1.599052
C 1.332111 -0.684690 -0.293936
C 2.169004 0.299753 0.227348
C 1.680221 -1.967125 -0.675204
C 3.504031 -0.036119 0.457624
C 3.033365 -2.265307 -0.418482
C 3.915554 -1.333624 0.140908
H 4.202351 0.692318 0.853667
H 3.398357 -3.251903 -0.685791
C 0.119888 1.323257 -0.130777
C -0.882125 2.255330 -0.308949
C 1.415406 1.546807 0.332633
C -0.497915 3.550470 0.098656
C 1.754320 2.843936 0.715638
C 0.773959 3.835271 0.603020
H -1.222384 4.352866 -0.002496
H 2.749197 3.077868 1.077055
H 1.009193 4.853250 0.893960
C -2.485730 0.600698 -1.492453
H -3.480236 0.570350 -1.943013
H -1.764774 0.413658 -2.296153
C -2.255554 2.003798 -0.896557
H -3.005810 2.188469 -0.118407
H -2.427529 2.753706 -1.676011
H 4.947906 -1.621040 0.308379
C 0.740674 -2.957109 -1.309146
H 0.179759 -3.515444 -0.552319
H 0.013313 -2.465039 -1.960044
H 1.303866 -3.675682 -1.907762
39
ox7-a-Me-2
Eopt -885.562895
O -0.000867 -0.087248 0.567573
C -1.047051 -0.949965 -0.096982
C -2.389932 -0.682383 0.156514
C -0.581294 -1.940109 -0.951195
C -3.284905 -1.569034 -0.476281
C -1.508328 -2.783747 -1.557687
H 0.474195 -2.056233 -1.152419
C -2.868530 -2.605624 -1.302912
H -4.346793 -1.411289 -0.311638
H -1.161823 -3.564794 -2.225054
H -3.602967 -3.258018 -1.762288
C 1.413263 -0.447199 0.339944
C 2.024216 0.574059 -0.391472
C 2.008167 -1.582671 0.852245
C 3.373127 0.422842 -0.711837
C 3.370097 -1.695513 0.503822
C 4.027513 -0.731345 -0.267421
H 3.903726 1.188601 -1.266164
H 3.921386 -2.557553 0.865812
C -0.087008 1.316099 0.140985
C -1.134797 2.115326 0.528733
C 1.074188 1.681173 -0.522721
C -1.042668 3.428397 0.034482
C 1.141720 2.996413 -0.992173
C 0.059021 3.844338 -0.728427
H -1.824613 4.139117 0.282167
H 2.017531 3.360104 -1.517461
H 0.092749 4.868464 -1.084057
C -3.031004 0.452324 0.942412
H -3.595752 0.014829 1.773256
H -3.776182 0.892897 0.271123
C -2.157067 1.585997 1.496909
H -1.623985 1.240507 2.391103

H	-2.812369	2.398052	1.820825
H	5.077736	-0.870225	-0.500310
C	1.295504	-2.605874	1.693543
H	0.501881	-2.152431	2.292605
H	0.836444	-3.380543	1.069842
H	2.000374	-3.094539	2.369192

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ox7-a-Me-TS

Eopt -885.532520

O	-0.067975	-0.123534	0.507839
C	-1.457420	-0.550194	0.094977
C	-2.369506	0.288005	-0.561243
C	-1.782230	-1.830539	0.500794
C	-3.558478	-0.345846	-0.972190
C	-2.980474	-2.411789	0.094307
H	-1.129269	-2.366302	1.156706
C	-3.857368	-1.675385	-0.696561
H	-4.287684	0.264702	-1.495122
H	-3.219076	-3.420711	0.412021
H	-4.790155	-2.106036	-1.043327
C	1.166861	-0.967501	0.119302
C	2.116926	-0.054403	-0.346315
C	1.443222	-2.320050	0.341314
C	3.336519	-0.499028	-0.851464
C	2.674089	-2.725934	-0.228817
C	3.584598	-1.866624	-0.837443
H	4.067880	0.209979	-1.221902
H	2.932170	-3.775162	-0.130553
C	0.368386	1.280864	0.366367
C	-0.384353	2.412715	0.640068
C	1.668580	1.300366	-0.113587
C	0.324789	3.621202	0.528401
C	2.340114	2.519029	-0.238358
C	1.661065	3.679752	0.121098
H	-0.213334	4.541532	0.731399
H	3.363452	2.551973	-0.593900
H	2.157345	4.641591	0.053294
C	-2.343920	1.797401	-0.650792
H	-3.359035	2.125476	-0.884510
H	-1.699913	2.162804	-1.457436
C	-1.881653	2.408609	0.692845
H	-2.287660	1.833525	1.531024
H	-2.241555	3.434599	0.793157
H	4.511098	-2.263029	-1.237692
C	0.752214	-3.372325	1.181027
H	0.329229	-2.956377	2.098533
H	-0.022289	-3.916105	0.634475
H	1.500827	-4.104133	1.488744

4.9 X-ray Crystallography

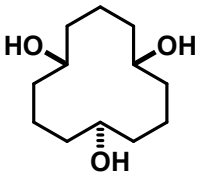
Single crystal X-ray diffraction was carried out by the author using a (Rigaku) Oxford Diffraction/Agilent Supernovae A diffractometer (Cu-Kα radiation, $\lambda = 1.54184$ Å) equipped with a graphite monochromator within the Department of Chemistry, University of Oxford. Samples were mounted in perfluoropoly-ethyl ether oil and cooled to 150 K during the data collection by a N_2 Crysostream open-flow cooling device.[145] The diffraction patterns were integrated and reduced using CrysalisPro. CRYSTALS[146,147] was used to obtain an *ab initio* solution using SuperFlip[148] embedded within CRYSTALS and for structure refinement.

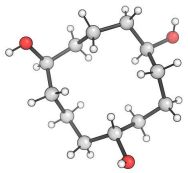
Molecular graphics of the structure solutions were created using Pymol[144] and represent thermal displacement ellipsoid plots of the best fit model drawn at 50% probability.

For enantiopure crystals, the Flack x parameter[149,150] was refined and Bayesian analysis of the Bijvoet pairs was use to give the Hooft y parameter.[151] Analysis of the flack x and hooft y parameters was used to determine the absolute structure of the crystal. If the e.s.d value of the flack x parameter exceeded 0.05, HPLC analysis of the crystal, or comparison to known stereochemistry, was used to confirm the assigned absolute structure.

Raw frame data, unprocessed cif files and completed cif files for all structures are available on request.

(*r*)-Cyclododecane-1,5,9-triol, **65**:

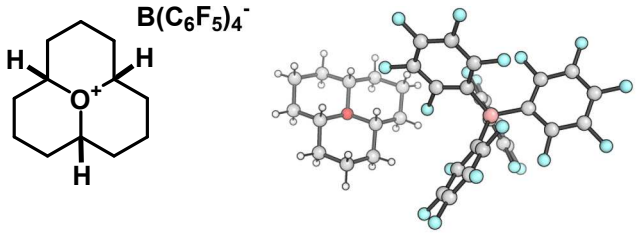




002OS20, $C_{12}H_{24}O_3$: Crystals of x-ray quality were grown by vapour diffusion of EtOAc into a solution of **65** (5 mg) in MeOH (0.3 mL).

Crystal System	Monoclinic
Space Group	P 21/c
Unit Cell Dimensions	a = 9.2050(3) Å α = 90°
	b = 14.6139(3) Å β = 101.570(3)°
	c = 18.8779(6) Å γ = 90°
Volume	2487.87(13) (Å^3)
Z	8
Density (Calculated)	1.155 Mg m^{-3}
Absorption Coefficient	0.645 mm^{-1}
Crystal Size	0.06 × 0.07 × 0.20 mm^3
Theta range for data collection	3.855 to 76.042°
Index Ranges	-11<=h<=11 , -17<=k<=18 , -23<=l<=23
Reflections Collected	20071
Independent Reflections	5167 [R(int)] = 0.044]
Completeness to theta = 74.521°	99.6%
Absorption Correction	multi-scan
Refinement method	Full-matrix least-squares on F^2
Goodness-of-fit on F^2	0.9782
Final R indices [I>2sigma(I)]	R1 = 0.0553, wR2 = 0.1476
R indices (all data)	R1 = 0.0525, wR2 = 0.1433

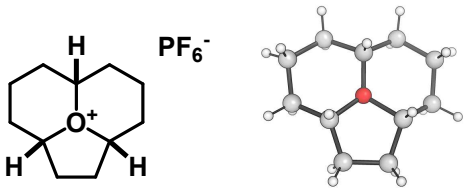
(3a*s*,6a*s*,9a*s*)-Dodecahydro-3a^1-oxaphenalen-3a^1-ium, tetrakis(pentafluorophenyl) borate, **81**:



004OS20, $C_{36}H_{21}BF_{20}O$: Colourless plates were grown by slow evaporation of a mixture of **81** (5 mg) in $CHCl_3/Et_2O$ (1:2, 1.75 mL) over 48 h.

Crystal System	Monoclinic
Space Group	P 21/c
Unit Cell Dimensions	a = 14.17750(10) Å $\alpha = 90°$
	b = 13.6824(2) Å $\beta = 93.0496(9)°$
	c = 17.6258(2) Å $\gamma = 90°$
Volume	3414.25(7) (Å^3)
Z Density (Calculated)	1.674 Mg m^{-3}
Absorption Coefficient	1.588 mm^{-1}
Crystal Size	0.10 × 0.10 × 0.10 mm^3
Theta range for data collection	4.29 to 75.95°
Index Ranges	-12<=h<=17, -16<=k<=17, -22<=l<=19
Reflections Collected	22592
Independent Reflections	7153 [R(int)] = 0.025]
Completeness to theta = 75.559°	99.6 %
Absorption Correction	multi-scan
Refinement method	Full-matrix least-squares on F^2
Goodness-of-fit on F^2	0.9983
Final R indices [I>2sigma(I)]	R1 = 0.0333 , wR2 = 0.0831
R indices (all data)	R1 = 0.0404, wR2 = 0.0888

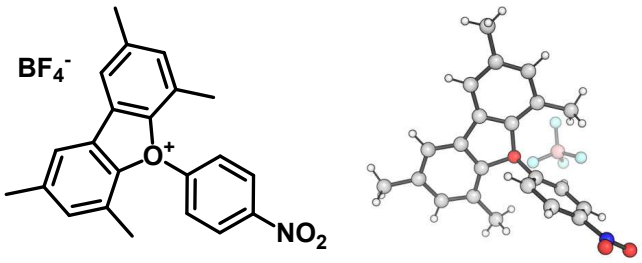
(2a*R*,5a*r*,8a*S*)-Decahydro-1*H*-2a^1-oxaacenaphthylen-2a^1-ium hexafluorophosphate, **88**:



002OS20, $C_{11}H_{19}F_6OP$: Crystals of x-ray quality were grown by vapour diffusion of Et_2O into a solution of **88** (2 mg) in THF (0.6 mL).

Crystal System	Monoclinic
Space Group	P 21/n
Unit Cell Dimensions	a = 7.3208(4) Å α = 90°
	b = 15.4499(8) Å β = 100.932(6)°
	c = 12.2086(8) Å γ = 90°
Volume	1355.80(14) (Å^3)
Z	4
Density (Calculated)	1.530 Mg m^{-3}
Absorption Coefficient	2.411 mm^{-1}
Crystal Size	0.01 × 0.02 × 0.10 mm^3
Theta range for data collection	4.669 to 77.709°
Index Ranges	-9<=h<=8 , -15<=k<=19 , -15<=l<=15
Reflections Collected	5237
Independent Reflections	2823 [R(int)] = 0.025]
Completeness to theta = 56.728°	99.5%
Absorption Correction	multi-scan
Refinement method	Full-matrix least-squares on F^2
Goodness-of-fit on F^2	0.9515
Final R indices [I>2sigma(I)]	R1 = 0.0894, wR2 = 0.2501
R indices (all data)	R1 = 0.1103, wR2 = 0.2791

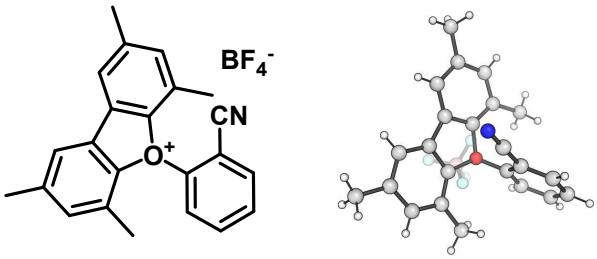
2,4,6,8-Tetramethyl-5-(4-nitrophenyl)-5*H*-dibenzo[*b*,*d*]furan-5-ium tetrafluoroborate, **160**:



015OS20, $C_{22}H_{20}BF_4NO_3$: Yellow blocks were grown by vapour diffusion of Et_2O into a solution of **160** (5 mg) in acetone (0.6 mL) over 48 h.

Crystal System	Monoclinic
Space Group	P 21/c
Unit Cell Dimensions	a = 12.5037(3) Å α = 90°
	b = 10.5734(2) Å β = 101.975(2)°
	c = 15.9053(4) Å γ = 90°
Volume	2057.03(8) (Å^3)
Z Density (Calculated)	1.399 Mg m^{-3}
Absorption Coefficient	0.994 mm^{-1}
Crystal Size	0.07 × 0.13 × 0.15 mm^3
Theta range for data collection	3.613 to 76.208°
Index Ranges	-15<=h<=15, -13<=k<=13 , -17<=l<=19
Reflections Collected	21741
Independent Reflections	4268 [R(int)] = 0.041]
Completeness to theta = 74.684°	99.7 %
Absorption Correction	multi-scan
Refinement method	Full-matrix least-squares on F^2
Goodness-of-fit on F^2	0.9849
Final R indices [I>2sigma(I)]	R1 = 0.0442, wR2 = 0.1148
R indices (all data)	R1 = 0.0540, wR2 = 0.1265

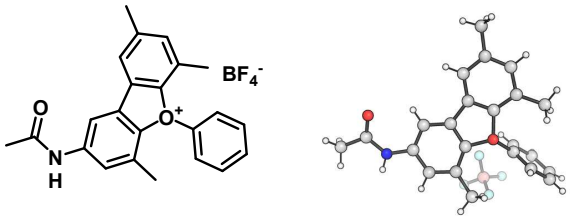
5-(2-Cyanophenyl)-2,4,6,8-tetramethyl-5*H*-dibenzo[*b*,*d*]furan-5-ium tetrafluoroborate, **184**:



011OS20, $C_{23}H_{20}BF_4NO$: Crystals of x-ray quality were grown by vapour diffusion of Et_2O into a solution of **184** (5 mg) in MeCN (0.6 mL).

Crystal System	Monoclinic
Space Group	P 21
Unit Cell Dimensions	a = 7.91700(10) Å α = 90°
	b = 14.4039(2) Å β = 98.7111(12)°
	c = 9.14190(10) Å γ = 90°
Volume	1030.48(2) (Å^3)
Z	2
Density (Calculated)	1.332 Mg m^{-3}
Absorption Coefficient	0.891 mm^{-1}
Crystal Size	0.04 × 0.10 × 0.11 mm^3
Theta range for data collection	4.894 to 76.324°
Index Ranges	-9<=h<=9 , -18<=k<=18 , -11<=l<=11
Reflections Collected	22487
Independent Reflections	4268 [R(int)] = 0.026]
Completeness to theta = 76.324°	99.5%
Absorption Correction	multi-scan
Refinement method	Full-matrix least-squares on F^2
Goodness-of-fit on F^2	0.9759
Final R indices [I>2sigma(I)]	R1 = 0.0422, wR2 = 0.1219
R indices (all data)	R1 = 0.0433, wR2 = 0.1248

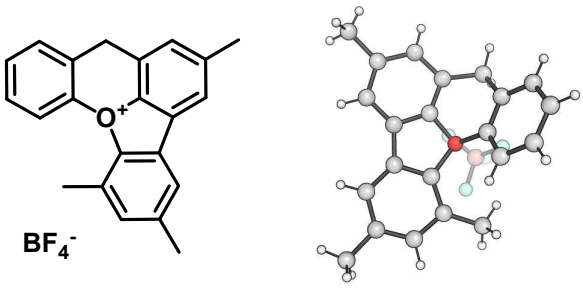
2-Acetamido-4,6,8-trimethyl-5-phenyl-5*H*-dibenzo[*b*,*d*]furan-5-ium tetrafluoroborate, **261**:



004OS21, $C_{23}H_{22}BF_4NO_2$: Crystals of x-ray quality were grown by vapour diffusion of Et_2O into a solution of **261** (5 mg) in CH_2Cl_2 (0.6 mL) by Madeleine Hindson.

Crystal System	Monoclinic
Space Group	P 21/c
Unit Cell Dimensions	a = 7.9272(2)Å $\alpha = 90°$
	b = 13.0127(3) Å $\beta = 97.1934(19°$
	c = 19.8955(4) Å $\gamma = 90°$
Volume	2036.15(8) ($Å^3$)
Z	4
Density (Calculated)	1.407 Mg m^{-3}
Absorption Coefficient	0.962 mm^{-1}
Crystal Size	0.03 × 0.08 × 0.21 mm^3
Theta range for data collection	4.069 to 76.334°
Index Ranges	-9<=h<=9 ,-16<=k<=16 , -21<=l<=24
Reflections Collected	22777
Independent Reflections	4231 [R(int)] = 0.042]
Completeness to theta = 74.808°	99.8%
Absorption Correction	multi-scan
Refinement method	Full-matrix least-squares on F^2
Goodness-of-fit on F^2	0.9865
Final R indices [I>2sigma(I)]	R1 = 0.0414, wR2 = 0.1097
R indices (all data)	R1 = 0.0515, wR2 = 0.1233

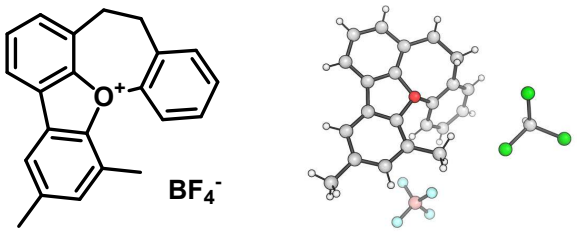
1,3,6-Trimethyl-8*H*-benzofuro[3,2,1-*de*]xanthen-13-ium tetrafluoroborate, **299**:



001OS20, $C_{22}H_{19}BF_4O$: Colourless needles were grown by vapour diffusion of Et_2O into a solution of **299** (5 mg) in acetone (0.6 mL) over 48 h.

Crystal System	Monoclinic
Space Group	P 21/c
Unit Cell Dimensions	a = 8.0432(3) Å α = 90°
	b = 12.6195(5) Å β = 96.911(3)°
	c = 18.0018(7) Å γ = 90°
Volume	1813.93(12) (Å^3)
Z Density (Calculated)	1.414 Mg m^{-3}
Absorption Coefficient	0.954 mm^{-1}
Crystal Size	0.05 × 0.06 × 0.35 mm^3
Theta range for data collection	4.289 to 75.949 °
Index Ranges	-10<=h<=9, -14<=k<=15 , -15<=l<=22
Reflections Collected	11627
Independent Reflections	3735 [R(int)] = 0.046]
Completeness to theta = 75.949°	99.6 %
Absorption Correction	multi-scan
Refinement method	Full-matrix least-squares on F^2
Goodness-of-fit on F^2	1.0100
Final R indices [I>2sigma(I)]	R1 = 0.0505, wR2 = 0.1212
R indices (all data)	R1 = 0.0692, wR2 = 0.1373

1,3-Dimethyl-8,9-dihydrobenzo[*b*]benzo[6,7]oxepino[3,2,1-*hi*]benzofuran-14-ium, tetrafluoroborate **328**:



002OS20, $C_23H_20BCl_3F_4O$: Crystals of x-ray quality were grown by vapour diffusion of Et_2O into a solution of **328** (5 mg) in $CHCl_3$ (0.6 mL).

Crystal System	Triclinic
Space Group	P -1
Unit Cell Dimensions	a = 8.7472(4) Å α = 99.124(4)°
	b = 10.7210(6) Å β = 94.324(4)°
	c = 12.4352(6) Å γ = 98.995(4)°
Volume	1131.22(10) (Å^3)
Z	2
Density (Calculated)	1.484 Mg m^{-3}
Absorption Coefficient	4.091 mm^{-1}
Crystal Size	0.04 × 0.05 × 0.06 mm^3
Theta range for data collection	3.619 to 76.155 °
Index Ranges	-10<=h<=9 , -13<=k<=13 , -13<=l<=15
Reflections Collected	12599
Independent Reflections	4666 [R(int)] = 0.056]
Completeness to theta = 73.871°	99.8%
Absorption Correction	multi-scan
Refinement method	Full-matrix least-squares on F^2
Goodness-of-fit on F^2	0.9842
Final R indices [I>2sigma(I)]	R1 = 0.0703, wR2 = 0.1784
R indices (all data)	R1 = 0.0869, wR2 = 0.2036

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