Copper-catalysed silicon and boron functionalisation of heterocycles and allenes

A thesis submitted to The University of Manchester for the degree of Doctor of Philosophy in the faculty of Engineering and Physical Sciences

2015

James P. Rae

School of Chemistry
Experimental procedures for Chapter 1.3 101
Experimental procedures for Chapter 1.4 132
Experimental procedures for Chapter 2 152
Experimental procedures for Chapter 3 178
Appendix: X-ray crystal structures 194
Chapter six – References 202
Abstract

Silicon holds a privileged position in organic chemistry as the carbon-silicon bond can be utilised in many important transformations. As such, developing practical and efficient methods for the enantioselective and regioselective insertion of silicon into organic molecules is a worthy challenge in chemical synthesis. To this end, we have developed an affordable copper-catalysed protocol for the asymmetric silylation of lactones, lactams and amides, providing silylated products with up to >99:1 er and in good yields. Furthermore, we have demonstrated the synthetic utility of this protocol in the target synthesis of natural or biologically active molecules.

We also present the first copper-catalysed silylation of allenes using a silylborane reagent. This affords useful allyl- or vinylsilane building blocks with high regioselectivity, efficiency and a large functional group tolerance. The allylcopper intermediates can be intercepted by aldehydes in a diastereoselective three-component coupling to furnish homoallylic alcohols. We extend this concept to the copper-catalysed three-component coupling of boron, allenes and imines, providing access to homoallylic amines with a vinylborane motif.
Declaration
No portion of the work referred to in the thesis has been submitted in support of an application for another degree or qualification of this or any other university or other institute of learning.

Part of this work has been published in peer reviewed journals:

• “NHC–Cu(I) catalysed asymmetric conjugate silyl transfer to unsaturated lactones: application in kinetic resolution”
  Vittorio Pace, James P. Rae, Hassan Y. Harb and David J. Procter, Chem. Commun., 2013, 49, 5150

• “Cu(I)–NHC Catalyzed Asymmetric Silyl Transfer to Unsaturated Lactams and Amides”
  Vittorio Pace, James P. Rae, and David J. Procter, Org. Lett., 2014, 16, 476

• “Cu(I)–NHC-Catalyzed Silylation of Allenes: Diastereoselective Three-Component Coupling with Aldehydes”
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Acknowledgements

Firstly, I would like to thank David for giving me the opportunity to work as part of his group. I have benefited greatly from your attention to detail, encouragement, enthusiasm, patience and the obvious pleasure and enjoyment you derive from organic chemistry. I sincerely appreciate the freedom you have given me during this time as well as your invaluable guidance and support.

To Vittorio, Iris and Kay, who I have had the pleasure of working closely with, and sharing the many ups and downs of research, thank you for your time, patience and hard work.

A huge thank you to Amandine, Andrew, David, Nico and Xavi who have proof-read parts or all (possibly many times..) of this thesis. Thank you to Andrew, Matt H. and Michal in particular for your time, invaluable insight and encouragement throughout my studies – I wish you nothing but the best for the future!

A most sincere thank you to the people I have had the opportunity to work next to and annoy on a daily basis: Brice, Sarah (alright petal?) and Miles, thank you for your friendship and patience through these testing times! A thank you to Donnie and Andrew for those amusing lunchtime therapy sessions and your tremendous friendship, I could not ask for more!

I am fortunate to have worked with many talented and inspiring colleagues, many who have become friends, we’ve had a lot of laughs and a lot of good times, it’s been a great pleasure to share this journey with you: Amandine, An Jie, Andrew (I am just a dreamer, but you are just a dream), Boris, Brice (I still remember that headlock!), Chris S. (I’ve gone big, I’m going home..), Chris T. (who’s awesome? You’re awesome!), Donnie, Gabri, Iris, José F-S, José G-L, Karl, Kay, Laura, Malcolm, Mateusz (thanks for the last minute X-rays!), Matt H., Matt L., Michal, Miles (in’t it?), Neal, Paula, Pierre, Sarah, Sachin, Seidjolo, Sinead, Sohel, Susannah, Tom S., Trung, Vagner and Xavi (El Chabsterito). Thank you – I have learnt so much from all of you! I would like to thank the University of Manchester for providing a challenging arena to work in, and not allowing my entrance into dogmatic slumber.. A big thank you to the technical staff Garath, Rehana, Carol and Jim.

Finally, I would like to thank my brother Andrew and mother Barbara, for your endless love, patience and support.

Muchas gracias!
### List of abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>2-MeTHF</td>
<td>2-methyltetrahydrofuran</td>
</tr>
<tr>
<td>Ac</td>
<td>acetyl</td>
</tr>
<tr>
<td>Acac</td>
<td>acetylacetone</td>
</tr>
<tr>
<td>Ar</td>
<td>aryl</td>
</tr>
<tr>
<td>BINAP</td>
<td>2,2’-bis(diphenylphosphino)-1,1’-binaphthyl</td>
</tr>
<tr>
<td>Bn</td>
<td>benzyl</td>
</tr>
<tr>
<td>Boc</td>
<td>t-butoxycarbonyl</td>
</tr>
<tr>
<td>br.</td>
<td>broad (NMR)</td>
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<tr>
<td>Bu</td>
<td>butyl</td>
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<tr>
<td>Bz</td>
<td>benzoyl</td>
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<td>c-</td>
<td>cyclo</td>
</tr>
<tr>
<td>Cbz</td>
<td>benzylxycarbonyl</td>
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<tr>
<td>COD</td>
<td>cis,cis-1,5-cyclooctadiene</td>
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<tr>
<td>Conv.</td>
<td>conversion</td>
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<tr>
<td>Cy</td>
<td>cyclohexyl</td>
</tr>
<tr>
<td>d</td>
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</tr>
<tr>
<td>dba</td>
<td>dibenzylideneacetone</td>
</tr>
<tr>
<td>DBU</td>
<td>1,8-diazabicyclo[5.4.0]undec-7-ene</td>
</tr>
<tr>
<td>(DHQD)$_2$PYR</td>
<td>hydroquinidine-2,5-diphenyl-4,6-pyrimidinediyl diether</td>
</tr>
<tr>
<td>DMDO</td>
<td>dimethyl dioxirane</td>
</tr>
<tr>
<td>DME</td>
<td>1,2-dimethoxyethane</td>
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<tr>
<td>DMF</td>
<td>N,N-dimethylformamide</td>
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<tr>
<td>DMP</td>
<td>Dess – Martin periodinane</td>
</tr>
<tr>
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<td>dimethylsulfoxide</td>
</tr>
<tr>
<td>DPPE</td>
<td>ethylenebis(diphenylphosphine)</td>
</tr>
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<td>dppf</td>
<td>1,1’-bis(diphenylphosphino)ferrocene</td>
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<tr>
<td>dr</td>
<td>diastereoisomeric ratio</td>
</tr>
<tr>
<td>equiv</td>
<td>equivalent</td>
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<tr>
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<td>Et</td>
<td>ethyl</td>
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<td>h</td>
<td>hour</td>
</tr>
<tr>
<td>HRMS</td>
<td>high resolution mass spectrum</td>
</tr>
<tr>
<td>ICy</td>
<td>1,3-dicyclohexylimidazolium</td>
</tr>
<tr>
<td>Abbreviation</td>
<td>Full Form</td>
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<td>IMes</td>
<td>1,3-\textit{bis}(2,4,6-\textit{trimethylphenyl})imidazolium</td>
</tr>
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<td>IPr</td>
<td>1,3-\textit{bis}(2,6-\textit{diisopropylphenyl})imidazolium</td>
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<td>\textit{i}-Pr</td>
<td>isopropyl</td>
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<tr>
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<td>infrared</td>
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<td>m-</td>
<td>meta</td>
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<td>m</td>
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<td>\textit{m}-\textit{chloroperbenzoic acid}</td>
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<tr>
<td>Me</td>
<td>methyl</td>
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<tr>
<td>MeCN</td>
<td>acetonitrile</td>
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<tr>
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<tr>
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</tr>
<tr>
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</tr>
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<td>MS</td>
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<td>4 Å MS</td>
<td>molecular sieves</td>
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<td>NHC</td>
<td>\textit{N-heterocyclic carbene}</td>
</tr>
<tr>
<td>NMR</td>
<td>nuclear magnetic resonance</td>
</tr>
<tr>
<td>o-</td>
<td>\textit{ortho}</td>
</tr>
<tr>
<td>OMe</td>
<td>methoxy</td>
</tr>
<tr>
<td>p-</td>
<td>para</td>
</tr>
<tr>
<td>PG</td>
<td>protecting group</td>
</tr>
<tr>
<td>Ph</td>
<td>phenyl</td>
</tr>
<tr>
<td>pin</td>
<td>pinacol</td>
</tr>
<tr>
<td>PMB</td>
<td>\textit{p}-\textit{methoxybenzyl}</td>
</tr>
<tr>
<td>PMP</td>
<td>\textit{p}-\textit{methoxyphenyl}</td>
</tr>
<tr>
<td>ppm</td>
<td>parts per million</td>
</tr>
<tr>
<td>PPTS</td>
<td>pyridinium \textit{p}-\textit{toluenesulfonate}</td>
</tr>
<tr>
<td>Pr</td>
<td>propyl</td>
</tr>
<tr>
<td>q</td>
<td>quartet (NMR)</td>
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<td>quin</td>
<td>quintet (NMR)</td>
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<tr>
<td>rt</td>
<td>room temperature</td>
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<td>singlet (NMR)</td>
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<td>SIMes</td>
<td>1,3-\textit{bis}(2,4,6-\textit{trimethylphenyl})imidazolinium</td>
</tr>
<tr>
<td>Abbreviation</td>
<td>Description</td>
</tr>
<tr>
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<td>--------------------------------------</td>
</tr>
<tr>
<td>sxt</td>
<td>sextet (NMR)</td>
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<tr>
<td>t</td>
<td>triplet (NMR)</td>
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<tr>
<td>TBAF</td>
<td>tetrabutylammonium fluoride</td>
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<tr>
<td>TBS</td>
<td>tert-butyldimethylsilyl</td>
</tr>
<tr>
<td>t-Bu</td>
<td>tert-butyl</td>
</tr>
<tr>
<td>TFA</td>
<td>trifluoroacetic acid</td>
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<td>TFE</td>
<td>2,2,2-trifluoroethanol</td>
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<tr>
<td>TfOH</td>
<td>trifluoromethanesulfonic acid</td>
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<td>THF</td>
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<td>TMS</td>
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<td>Ts</td>
<td>Tosyl</td>
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<td>δ</td>
<td>chemical shift relative to tetramethylsilane (NMR)</td>
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Chapter one – The copper-catalysed asymmetric silylation of unsaturated lactones, lactams and amides

1.1 β-Silyl carbonyl motifs in organic synthesis

The development of practical and efficient catalytic methods for the generation of enantiomerically enriched organosilicon compounds is an important goal in organic synthesis due to their broad utility.\(^1\,\text{-}\,^2\) For example, carbon-silicon bonds are robust synthetic equivalents of carbon-oxygen bonds, courtesy of the stereospecific Fleming-Tamao oxidation.\(^2\,\text{-}\,^6\) The carbon-silicon bond is also tolerant to a range of functionalisation processes without suffering decomposition or side reactions. When placed in the β-position to a carbonyl, oxidation affords β-hydroxy carbonyl compounds, which are an invaluable motif synonymous with the aldol reaction and present in countless synthetic strategies and natural products.\(^7\) Incorporating the β-silyl carbonyl motif into a synthetic strategy allows for a late-stage oxidation to reveal the β-hydroxy carbonyl (a motif that is prone to retro-aldol processes), thus negating the use of alcohol protecting groups.\(^2\) This strategy is used to great effect in Barret’s total synthesis of (+)-pramanicin (Scheme 1.1).\(^8\,\text{-}\,^9\) A diastereoselective conjugate addition of silicon into lactam 1, followed by trapping of the enolate generated furnished adduct 3. Dess-Martin periodinane and Ni(acac)\(_2\) catalysed DMDO oxidations proceeded to yield 4, in anticipation for unmasking the β-hydroxy motif found in 5 via Fleming-Tamao oxidation. Nitrogen and alcohol deprotection yielded (+)-pramanicin 6.
Scheme 1.1 A silicon conjugate addition and late-stage Fleming-Tamao oxidation in Barrett’s total synthesis of (+)-pramanicin.

To obtain these useful enantiomerically enriched \(\beta\)-silyl carbonyl compounds, multi-step procedures are often required. For example, Panek has showcased a strategy that allows for the synthesis of many diverse natural products (See scheme 1.2 for a small selection) commencing from enantiomerically pure 9.\(^{10-12}\) Crotylsilane 9 is synthesised in three steps from commercially available starting materials. The route involves the use of a platinum catalyst to synthesise vinylsilane 7, and an enzyme mediated kinetic resolution to afford allylic alcohol 8.\(^{13}\)
1.2 The synthesis of enantiomerically enriched β-silyl carbonyl motifs

1.2.1 Catalytic methods of generating enantiomerically enriched β-silyl carbonyl motifs

Many groups have reported catalytic protocols for generating the β-silyl carbonyl motif. A common strategy has been the asymmetric conjugate addition of nucleophiles to acyclic β-silyl-α,β-unsaturated carbonyl systems. For example, Lipshutz has disclosed a copper-catalysed enantioselective conjugate reduction approach, using poly(methylhydrosiloxane) as a stoichiometric hydride source and ferrocenyl ligand 13, generating enantioenriched β-silyl esters with up to >97.5:2.5 er in excellent yields (Scheme 1.3).14 It was found that (R) and (S) enantiomers could be generated selectively from either the (E) or (Z) geometric isomers respectively (entries a and b).
Lipshutz’s asymmetric copper hydride additions to β-silyl-α,β-unsaturated carbonyl systems.

Continuing with this theme, Hayashi reported a rhodium-catalysed enantioselective conjugate addition of arylboronic acids to β-silyl-α,β-unsaturated enones and esters, affording enantiomerically enriched β-silyl substituted enones with up to >99.5:0.5 er in excellent yields (Scheme 1.4).<sup>15</sup> The conjugate additions proceeded efficiently with a range of arylboronic acids, however, a slight diminishment in enantioselectivity was observed with the bulkier naphthyl (entry b) and o-tolyl substituted boronic acids. Hayashi also found that a range of silyl groups (t-BuMe<sub>2</sub>Si, Ph<sub>3</sub>Si) (entry c) also provided high enantiomeric ratios. However, this methodology was not extended to include the use of alkylboronic acids.

Jacobsen has also contributed to this field, utilising an aluminium-salen catalyst for the conjugate addition of various nucleophiles (malononitrile and substituted cyanoacetate derivatives) to α,β-unsaturated β-silyl imide substrates, affording products with up to >99.5:0.5 er in good yields after 2-5 day reaction times (Scheme 1.5).<sup>16</sup> When α-aminonitriles were used, an
intramolecular cyclisation occurred to give β-silyl γ-lactams (entry d) with excellent enantio- and
diastereoselectivity in excellent yield.

\[
\text{R-CN} + \text{Me}_2\text{Si}-\text{alkene} \rightarrow \text{Me}_2\text{Si}-(\text{salen})\text{Al}
\]

cyclohexane, 23 °C

**Selected examples:**

<table>
<thead>
<tr>
<th>Entry</th>
<th>Yields</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>98.5:1.5 er, 81% yield 2 days(^a)</td>
</tr>
<tr>
<td>b</td>
<td>96.4 er, 75:25 dr, 73% yield 5 days(^b)</td>
</tr>
<tr>
<td>c</td>
<td>&gt;99.5:0.5 er, 88% yield 5 days(^b)</td>
</tr>
<tr>
<td>d</td>
<td>99.5:0.5 er, 94:6 dr, 81% yield 5 days(^a)</td>
</tr>
</tbody>
</table>

**Scheme 1.5** Jacobsen’s aluminium salen complex catalysed asymmetric additions to β-silyl-α,β-
unsaturated carbonyl systems. \(^a\)(R,R)-(salen)Al \(^b\)(S,S)-(salen)Al.

The Hoveyda group has reported the copper-catalysed asymmetric conjugate addition of
organozinc reagents to β-silyl-α,β-unsaturated enones in the presence of an amino acid derived
phosphine ligand 15, affording products with up to 98:2 er in good to excellent yields (Scheme
1.6).\(^1\) The protocol tolerated the addition of Me\(_2\)Zn (entries a and b) and Et\(_2\)Zn reagents, but less
than 5% conversion was observed for (n-Bu)\(_2\)Zn, (i-Pr)\(_2\)Zn or other selected functionalised
dialkylzinc reagents. Interestingly, this study represented the first example of efficient catalytic
asymmetric conjugate addition of diarylzinc reagents to acyclic enones (entries c and d).

\[
\text{PhMe}_2\text{Si-O-R} + (\text{CuOTf})_2\cdot\text{C}_6\text{H}_6 \text{ (1 mol%)} \rightarrow \text{PhMe}_2\text{Si-O-R, R}^1\text{zZn}
\]

**Selected examples:**

<table>
<thead>
<tr>
<th>Entry</th>
<th>Yields</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>98:2 er, 96% yield(^a)</td>
</tr>
<tr>
<td>b</td>
<td>96.5:3.5 er, 77% yield(^a)</td>
</tr>
<tr>
<td>c</td>
<td>97:3 er, 79% yield(^b)</td>
</tr>
<tr>
<td>d</td>
<td>93.5:6.5 er, 82% yield(^b)</td>
</tr>
</tbody>
</table>

**Scheme 1.6** Hoveyda’s asymmetric conjugate addition to β-silyl-α,β-unsaturated carbonyl
systems. \(^a\)(alkyl)\(_2\)Zn (3 equiv), toluene, 22 °C, 6 h \(^b\)(aryl)\(_2\)Zn (1.5-2 equiv), DME, 0 °C, 6-16 h.

More recently, the Loh group disclosed the copper-catalysed asymmetric conjugate
addition of alkyl Grignard reagents to a β-silyl-α,β-unsaturated ester in the presence of a BINAP
derived ligand. Products with up to 99.5:0.5 er were isolated in good to excellent yields (Scheme 1.7). However, the protocol suffered from a limited β-silyl-α,β-unsaturated ester substrate scope. Additionally, only sterically unhindered alkyl Grignard reagents were used for the asymmetric addition. Loh extended the protocol to include the trapping of the reactive magnesium enolate (generated in situ) in a subsequent aldol reaction (entries c and d). This generated β-silyl carbonyl compounds containing three contiguous stereocenters with moderate diastereoselectivity and in moderate yields.

![Scheme 1.7 Loh’s asymmetric conjugate addition to β-silyl-α,β-unsaturated carbonyl systems](image)

Despite the significant advances detailed above, there are many shortcomings in the asymmetric conjugate addition of nucleophiles to β-silyl-α,β-unsaturated carbonyl systems. Although the range of nucleophiles for the conjugate addition seems plentiful, generating a silicon containing quaternary β-stereocenter from a β,β-disubstituted olefin has yet to be addressed. Moreover, no reports have investigated the use of carbo- or heterocyclic systems in these reactions, although Jacobsen’s protocol can furnish β-silyl γ-lactams after subsequent ring closure (Scheme 1.5).

### 1.2.2 Catalytic methods for the asymmetric conjugate addition of silicon

Although there have been numerous reports of the generation of enantiomerically enriched β-silyl carbonyl motifs from the enantioselective conjugate addition or reduction to β-silyl-α,β-unsaturated enones, there were only four reports of the catalytic, enantioselective conjugate addition of silyl groups to α,β-unsaturated systems when we commenced our studies. In the time that has followed, this area has matured to include strategies ranging from transition
metal-catalysed processes to organocatalysis.

Hayashi and Ito pioneered the early development of asymmetric conjugate silylation using palladium-catalysis (Scheme 1.8). They found that as little as 0.5 mol% of a BINAP-ligated palladium species could catalyse the conjugate addition of a Cl$_2$PhSi-moiety, which after treatment with MeLi afforded β-silyl carbonyl compounds with up to 96:4 er, in moderate to good yields. Utilising the lithium enolate generated in situ, it was found that α-alkylation could be effected by the addition of an alkyl halide (entry d), yielding compounds with two contiguous stereocenters with excellent diastereoselectivity. However, this protocol necessitated the use of 6 equivalents of methyl lithium to methylate the β-dihalosilyl carbonyl prior to product isolation.

\[
\text{Scheme 1.8 Hayashi's asymmetric conjugate addition of silicon}^{a} \text{ MeL (5 equiv) added at -78 °C.}
\]

In 2006, Oestreich disclosed an asymmetric conjugate silylation protocol using a silicon-boron reagent$^{20-22}$ (PhMe$_2$SiBpin) in the presence of an enantiomerically pure rhodium catalyst (Scheme 1.9).$^{23}$ Although this methodology gave compounds in excellent er, the silylated products underwent adventitious formal conjugate reduction under the reaction conditions, affording mixtures of compounds, of which the desired silylated adducts were isolated in low to moderate yields. However, this protocol represented a significant advance, showing asymmetric silylation could be applied for the first time to cyclic (entries a to f) and heterocyclic (entries d to f) substrates. This essentially provided a catalytic route to enantioenriched cyclic β-hydroxyl carbonyl systems, which, in contrast to acyclic β-hydroxyl carbonyl systems, are not readily accessible from either aldol or oxy-Michael related processes.
When acyclic \((E)\)-\(\alpha,\beta\)-unsaturated ester substrates were submitted to these reaction conditions, the \(\beta\)-silylated esters were isolated with low enantioselectivity (61:39 er) and yield. It was found that in order to effectively access acyclic systems, \((Z)\)-\(\alpha,\beta\)-unsaturated ester substrates were required (Scheme 1.10).\(^{24}\) Therefore, acyclic \(\beta\)-silyl carbonyl compounds could be afforded with excellent enantioselectivity and in moderate yield. Conjugate reduction was still an issue, and accounted for 10-20% of material under these conditions. It was also found that a number of \(\alpha,\beta\)-unsaturated acceptors were unreactive (\(\alpha,\beta\)-unsaturated thioesters, amides and nitrile compounds, figure 1.2, \textit{vida infra}). Furthermore, as the reaction proceeded in \(\text{H}_2\text{O}\) as a co-solvent, further elaboration of an enolate generated \textit{in situ} could not be exploited. Nonetheless, Oestreich’s contributions are significant as they allow for the synthesis of cyclic \(\beta\)-silyl carbonyl systems (a feature not available from previous technologies), and the use of the less common \((Z)\)-\(\alpha,\beta\)-unsaturated ester substrates.
In 2010, a complementary protocol from Hoveyda employed homochiral $N$-heterocyclic carbene (NHC) ligands in a copper-catalysed asymmetric conjugate addition of PhMe$_2$SiBpin to $\alpha,\beta$-unsaturated carbonyl systems (Scheme 1.11). This mild, general and high yielding method was applicable to $\alpha,\beta$-unsaturated carbocyclic (entries a - c), heterocyclic (entry d), acyclic systems (entries e - g), as well as $\alpha,\beta$-unsaturated esters (entries e - f) and nitrile substrates (entry g), affording $\beta$-silyl adducts with excellent enantioselectivity. Hoveyda also demonstrated that the boron enolate generated in situ could be trapped with an aldehyde in a subsequent aldol reaction (see scheme 1.23 for a further discussion on this topic).

Scheme 1.11 Hoveyda’s copper-catalysed asymmetric silylation. $^a$ Ligand 16a ($R^1 = $ Me) $^b$ CuCl (2 mol%), NaOt-Bu (4.4 mol%), Ligand 16b ($R^1 = i$-Pr, 2.2 mol%), 12 h.
Showcasing the versatility of this approach, Hoveyda extended this protocol to the asymmetric 1,6-silylation of cyclic and acyclic dienones and dienoates (Scheme 1.12). It was found that by substituting the β-position (to give a tri-substituted olefin), silicon insertion occurred exclusively at the less hindered 6-position, offering a convenient and direct route to a range of enantioenriched allylsilanes, often with complete enantioselectivity and in good to excellent yields.

Despite the success with transition metal-catalysed asymmetric silyl conjugate addition, no reports had emerged of additions to α,β-unsaturated aldehyde substrates. In fact, α,β-unsaturated enals are known to be challenging substrates in asymmetric conjugate addition, as often fast 1,2-addition can out-compete the 1,4-addition. In 2011, Córdova reported that copper catalysis combined with chiral amine catalysis (organocatalyst 18) could target these elusive substrates (Scheme 1.13). The reaction was shown to go via iminium activation, and tolerated a range of α,β-unsaturated enals, affording products with up to 97:3 er. This procedure also yielded the only example to date for the generation of a quaternary silicon containing β-stereocenter from a β,β-disubstituted olefin (entry d).
Following this report, Hoveyda provided the first example of a metal-free, organocatalytic protocol for the formation of C-Si bonds using a silicon-boron reagent in an aqueous medium (Scheme 1.14). Here, NHC pre-cursor 19 acts as a chiral Lewis base via coordination and subsequent activation of the boron atom. Additions to a range of cyclic (entries a to c), acyclic (entries d and e) and α,β-unsaturated enal (entry e) systems proceeded efficiently under these mild conditions. However, in general, additions to acyclic substrates were slightly less enantioselective when compared to the corresponding protocol using copper-catalysis (Scheme 1.11). Nevertheless, this process provided metal-free access to enantioenriched β-silyl carbonyl compounds with greater procedural simplicity than the analogous transition metal-catalysed protocols, and with excellent efficiency.
1.2.3 Conjugate addition to α,β-unsaturated heterocycles

Although the catalytic asymmetric silylation protocols described above allow for the asymmetric silylation of a range of cyclic and acyclic substrates (e.g. enones, enoates, enals etc.), limited studies of silyl transfer to heterocyclic systems (for example α,β-unsaturated lactone and lactam substrates) had been described. Moreover, it can be noted from the representative examples presented in sections 1.2.1 to 1.2.2, that just a small number of simple α,β-unsaturated substrates are commonly used in generating enantioenriched β-silyl carbonyl motifs. This is again true when considering copper-catalysed asymmetric conjugate addition in general (where for example, there have been over four thousand relevant asymmetric conjugate additions to cyclohexanone reported to date), whilst the range of conditions and ligands used to effect conjugate addition seems ever expanding, the scope of the Michael acceptor is not augmented at the same rate. Thus it can be seen that despite the outstanding progress of the last decade, the region of chemical space explored in copper-catalysed asymmetric conjugate addition remains relatively small.

In general, heterocyclic systems are a distinct and under-represented substrate class in asymmetric conjugate addition reactions when compared to enones. More specifically, it is often noted that conjugate additions to α,β-unsaturated lactones are generally challenging. Early methods involved high catalyst loading and often only reported conversion. Although lactones superficially resemble cyclic ketones, key properties such as conformation and strain energies are very different. For example, the 6-membered δ-valerolactone has a strain energy that is significantly higher than other 6-membered cyclic compounds (Figure 1.1, cf. entries a, b and f), and interestingly, also higher than the analogous 5-membered lactone (cf. entries e and f) (the reverse order of strain energies measured for carbocyclic compounds).

Due to this heightened reactivity, enolates generated after conjugate addition can often attack lactone starting material, with oligomerisation being noted in some reports. Methods to suppress this tendency include the slow addition of the α,β-unsaturated lactone to a dilute solution of catalyst and nucleophile, or carrying out the reaction in the presence of an aldehyde, to trap the reactive enolate in an aldol reaction. A pertinent example of this strategy is Hoveyda’s
work on the enantioselective conjugate addition of dialkylzinc reagents to unsaturated lactones, where the reaction is carried out in the presence of an aldehyde to trap the reactive enolate furnishing aldol adduct 21, which can then be converted to the enantioenriched β-alkyl carbonyl 22 by a subsequent retro-aldol reaction (Scheme 1.15).37

Scheme 1.15 Hoveyda’s enantioselective conjugate addition of dialkylzinc reagents to unsaturated lactones.

When considering α,β-unsaturated lactones in the asymmetric conjugate silylation, Hoveyda et al. again had difficulty finding a highly selective ligand for additions to lactones, and considered 5-membered α,β-unsaturated lactone 20a and lactam 27 substrates amongst the “Limitations of the current protocol” (Figure 1.2).38 In contrast to the reactivity of α,β-unsaturated lactones, Oestreich and co-workers found an analogous α,β-unsaturated amide 26 to be unreactive under their reaction conditions. Asymmetric conjugate additions to 5-membered cyclic substrates are known to be challenging in general as they are flat and reactive compounds, and this is reflected in the enantioselectivity values reported (vide supra).39–41

Figure 1.2 Limitations of the current asymmetric catalytic conjugate silylation technologies.
In this regard, it can be seen that heterocyclic substrates are challenging and underrepresented in asymmetric conjugate addition, and as such, represent a key challenge for the continued growth of enantioselective catalysis. Indeed, this is a worthy challenge as heterocycles exist in countless natural products and biologically active compounds. For example, the γ-butyrolactone skeleton is present in more than 13000 natural products (Figure 1.3 for selected examples). Developing the efficient asymmetric conjugate addition of silicon to these challenging lactone substrates would allow access to enantioenriched β-silyl lactone skeletons.

![Figure 1.3 Representative γ-butyrolactone containing natural products.](image)

In fact, the main impetus behind our efforts is revealed by previous work in the group using 36a as a building block towards natural products such as Taedolidol 38 (Scheme 1.16). Previous access to this silylated lactone had exploited a Sharpless asymmetric dihydroxylation of vinylsilane 33, followed by a further four steps to furnish lactone 36a.

![Scheme 1.16 A proposed approach to Taedolidol exploiting silicon as a stereocontrol element and an oxygen place-holder.](image)
1.3 The copper-catalysed asymmetric silylation of lactones

Impressed with the apparent generality of Hoveyda’s copper-catalysed system, we adopted this protocol and commenced our investigation by constructing a library of chiral NHC pre-ligands to investigate the effects of various substitution patterns on the enantioselectivity of the reaction. A hallmark of chiral monodentate NHC ligands is the ease with which their structure can be modified, allowing for a thorough and facile ligand screen. Scheme 1.17 highlights a series of modular disconnections for $C_1$-symmetric pre-ligands, and shows that both $C_1$-and $C_2$-symmetric pre-ligands can be synthesised in either three or four steps from a common chiral diamine 43, utilising known Suzuki and Buchwald-Hartwig procedures.

Thus, a representative synthesis of a $C_2$-symmetric pre-ligand is described in Scheme 1.18. Aryl bromide 45 was accessed via a palladium-catalysed Suzuki reaction of 44 and the corresponding aryl boronic acid. Buchwald-Hartwig coupling with chiral diamine 43 furnished 46, which could be efficiently cyclised to give $C_2$-symmetric pre-ligand 47 as an off-white solid.
In order to build upon Oestreich’s studies, we selected furanone 20a as our challenging model substrate. Working with Dr. Vittorio Pace, we found that when we employed Hoveyda’s optimal ligand 16a (Table 1.1), poor enantiocontrol was observed in the silylation of 20a (entry 1). Equipped now with a practical understanding of the reaction, we continued to investigate other pre-ligands which had displayed good enantioinduction in Hoveyda’s related silylation procedures (16b, 17a, 19). However, subtle modifications of the C$_2$-symmetric imidazolinium core did little to improve the enantioselectivity of the reaction (entries 2 - 5). For furanone 20a, enantioselectivities were improved by a switch to C$_2$-symmetric ligands (entries 6 - 10). In particular, the best results were obtained using C$_2$-symmetric ligands 41 and 47 bearing extended aromatic systems (naphthyl and anthracenyl, entries 8 and 10) on the N-phenyl substituent. However, the presence of additional steric bulk (51) had a detrimental effect on enantioinduction (entry 9). Thus, the use of C$_2$-symmetric ligand 41 gave the best result in silyl transfer to 20a.
Table 1.1 Ligand screen for the copper-catalysed asymmetric silylation of $\alpha,\beta$-unsaturated lactones.

<table>
<thead>
<tr>
<th>Entry</th>
<th>Ligand</th>
<th>Type</th>
<th>R</th>
<th>$R^1$</th>
<th>$R^2$</th>
<th>er</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>16a</td>
<td>$C_1$</td>
<td>Me</td>
<td>Et</td>
<td>H</td>
<td>62:38</td>
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<tr>
<td>2</td>
<td>48</td>
<td>$C_1$</td>
<td>H</td>
<td>Et</td>
<td>H</td>
<td>56:44</td>
</tr>
<tr>
<td>3</td>
<td>16b</td>
<td>$C_1$</td>
<td>i-Pr</td>
<td>Et</td>
<td>H</td>
<td>60:40</td>
</tr>
<tr>
<td>4</td>
<td>49</td>
<td>$C_1$</td>
<td>H</td>
<td>Me</td>
<td>Me</td>
<td>75:25</td>
</tr>
<tr>
<td>5</td>
<td>50</td>
<td>$C_1$</td>
<td>Me</td>
<td>Me</td>
<td>Me</td>
<td>66.5:33.5</td>
</tr>
<tr>
<td>6</td>
<td>17a</td>
<td>$C_2$</td>
<td>Ph</td>
<td>H</td>
<td>-</td>
<td>80.5:20.5</td>
</tr>
<tr>
<td>7</td>
<td>19</td>
<td>$C_2$</td>
<td>Ph</td>
<td>Me</td>
<td>-</td>
<td>72:28</td>
</tr>
<tr>
<td>8</td>
<td>41</td>
<td>$C_2$</td>
<td>2-naphthyl</td>
<td>H</td>
<td>-</td>
<td>93:7</td>
</tr>
<tr>
<td>9</td>
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<td>$C_2$</td>
<td>2-naphthyl</td>
<td>i-Pr</td>
<td>-</td>
<td>54:46</td>
</tr>
<tr>
<td>10</td>
<td>47</td>
<td>$C_2$</td>
<td>2-anthracenyl</td>
<td>H</td>
<td>-</td>
<td>92:8</td>
</tr>
</tbody>
</table>

With optimised conditions in hand, we applied the protocol to the asymmetric conjugate silylation of 5- (20a-b), 6- (20c) and 7-membered (20d-e) $\alpha,\beta$-unsaturated lactones (Scheme 1.19). The desired $\beta$-silyl adducts were obtained in up to 96.5:3.5 er and in good yield. Although the 5- and 7-membered lactones 20a and 20d proceeded with 97:3 and 96.5:3.5 er respectively, the 6-membered lactone 20c gave a noticeably lower er of 84:16. However, the reaction still proceeded in a good yield of 86%. Interestingly, no reaction was observed with the 8-membered lactone 20f, presumably due to conformational or transannular effects, and only starting material was recovered. When a 7-membered lactone was fused with an aromatic ring (20e), there was a deleterious effect upon enantiocontrol although the yield remained high. Moderate selectivity was also observed in the silylation of a 2-substituted lactone 20b yielding 36b with 66:34 dr.
Asymmetric conjugate additions are known to often be sensitive to α-substitution, and this result is in line with these observations. Of note, there was no loss of yield attributed to adventitious intermolecular reactions between intermediate enolates and lactone starting material which is known to plague conjugate additions to lactones (vide supra). Presumably, this is due to the strong oxygen-boron bond present in the enolate generated in situ, leading to a relatively less reactive species when compared to magnesium or zinc enolates.

![Scheme 1.19](image1.png)

Scheme 1.19 Copper-catalysed asymmetric silyl transfer to unsaturated lactones.

The protocol was also found to be amenable to large scale preparative synthesis, allowing 1.82 g of silylated butenolide 36a to be prepared in 70% yield from 11.8 mmol of 20a and with no loss of enantioselectivity when compared to the smaller scale reaction (Scheme 1.20).

![Scheme 1.20](image2.png)

Scheme 1.20 Preparative scale copper-catalysed asymmetric silylation.
1.3.2 The copper-catalysed kinetic resolution of 5-substituted butenolides

To further explore the scope of the protocol, the kinetic resolution of a series of racemic 5-substituted butenolides was carried out using copper-catalysed asymmetric silyl transfer.\textsuperscript{48,49} Excitingly, this approach gave access to enantioenriched compounds containing two contiguous stereocenters with an anti-relationship, from a racemic starting material. Pleasingly, we found that treatment of 5-substituted butenolides with 60-70 mol% of PhMe\textsubscript{2}SiBpin in conjunction with the C\textsubscript{2}-symmetric catalyst derived from 41 and CuI, afforded silylated products after kinetic resolution in good yields, good enantiomeric ratios and as single anti-diastereoisomers (Table 1.2).\textsuperscript{50} The rate of addition to 5-substituted butenolides was slower than silyl transfer to unsubstituted lactones, presumably due to increased steric hindrance around the α,β-unsaturated system, and therefore longer reaction times and higher catalyst loading were often required.

Primary alkyl (52a-d), allyl (52e), benzyl (52g) and phenyl (52h) substituents at the 5-position of butenolides were found to be compatible with the process affording silylated adducts with up to 91:9 er and in 50% isolated yield, with a selectivity factor of up to 25.0.\textsuperscript{51,52} When 5-substituted butenolides bearing branched alkyl substituents were used, these conditions resulted in very low or no conversion (iso-propyl and tert-butyl 5-substituted butenolides not shown). To our knowledge, these examples represent the first kinetic resolutions achieved by copper-catalysed silyl transfer from a silylborane reagent.

![Chemical structure](image)

<table>
<thead>
<tr>
<th>Entry</th>
<th>Product</th>
<th>R</th>
<th>Conversion (%)\textsuperscript{a}</th>
<th>Yield (%)\textsuperscript{b}</th>
<th>er</th>
<th>(s^c)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>53a</td>
<td>Me</td>
<td>50</td>
<td>46</td>
<td>86:14</td>
<td>13.04</td>
</tr>
<tr>
<td>2</td>
<td>53b</td>
<td>Et</td>
<td>52</td>
<td>50</td>
<td>90:10</td>
<td>25.03</td>
</tr>
<tr>
<td>3\textsuperscript{d}</td>
<td>53c</td>
<td>n-Bu</td>
<td>43</td>
<td>43</td>
<td>91:9</td>
<td>18.94</td>
</tr>
<tr>
<td>4\textsuperscript{d}</td>
<td>53d</td>
<td>n-Pentyl</td>
<td>48</td>
<td>43</td>
<td>86:14</td>
<td>12.10</td>
</tr>
<tr>
<td>5</td>
<td>53e</td>
<td>Allyl</td>
<td>47</td>
<td>46</td>
<td>84:16</td>
<td>9.56</td>
</tr>
<tr>
<td>6\textsuperscript{d}</td>
<td>53f</td>
<td>2-chloroprop-1-ene</td>
<td>49</td>
<td>48</td>
<td>89:11</td>
<td>18.04</td>
</tr>
<tr>
<td>7\textsuperscript{d}</td>
<td>53g</td>
<td>Benzyl</td>
<td>43</td>
<td>42</td>
<td>86:14</td>
<td>10.49</td>
</tr>
<tr>
<td>8</td>
<td>53h</td>
<td>Phenyl</td>
<td>45</td>
<td>41</td>
<td>88.5:11.5</td>
<td>14.57</td>
</tr>
</tbody>
</table>

Table 1.2 Substrate scope of the copper-catalysed kinetic resolution. \textsuperscript{a} Determined by \textsuperscript{1}H NMR. \textsuperscript{b} Yield of isolated product. \textsuperscript{c} Selectivity factor determined according to ref 52. \textsuperscript{d} 10 mol% catalyst loading, 0.7 equiv (PhMe\textsubscript{2}SiBpin).
To demonstrate the value of this kinetic resolution protocol, we completed a concise synthesis of (+)-blastmycinone 29, a natural product arising from the hydrolysis of the antibiotic (+)-antimycin A₃ (Scheme 1.21). The synthesis of 3,4,5-trisubstituted γ-lactones presents a challenge due to the control of the relative and absolute stereochemistry required for generating the three contiguous stereocenters when building the five-membered ring. Previous strategies for exerting this control have included enzymatic resolution, Sharpless dihydroxylation and intramolecular lactonisation amongst others. Our strategy commenced with the alkylation of silylated lactone 53a (see Table 1.2 entry 1), providing 54 with three contiguous stereocenters as a single diastereoisomer. Late-stage Fleming-Tamao oxidation unmasked the β-hydroxyl motif in lactone 55, which after esterification afforded (+)-blastmycinone 29, in just five steps from commercially available starting material.

Scheme 1.21 Catalytic asymmetric synthesis of (+)-blastmycinone.

1.3.3 Copper-catalysed asymmetric silylation of lactones with a domino aldol reaction

Mechanistically, it is proposed that after species I is formed from the transmetalation of the silylboration, it can undergo addition into the α,β-unsaturated lactone 20a in the 3,4-position, affording a carbon centred copper enolate II (Scheme 1.22). Copper can then migrate to give the oxygen centred enolate III, which can then transmetalate with the silylboration reagent, yielding the boron enolate IV and species I to complete the catalytic cycle. Enolate IV is protonated upon aqueous workup to afford the silylated lactone 36a.
In Hoveyda’s original communication, he describes quenching the pinacolboron enolate with benzaldehyde, yielding five and seven membered carbocycles (57a-b) with three-contiguous stereocenters with moderate to good diastereoselectivity and in excellent yield (Scheme 1.23). \(^{25,61}\)

Scheme 1.23 Hoveyda’s domino silylative aldol reaction.

However, when these conditions were applied to \(\alpha,\beta\)-unsaturated lactone 20a, no aldol adduct was obtained (Table 1.3, entry 1). After some experimentation, it was found that by adding an equivalent of NaOt-Bu, a one pot asymmetric silylative aldol reaction could be carried out, providing a 12:88 mixture of 36a and aldol adduct 58a (entry 2). Seeking to enhance the efficiency of this transformation, we investigated the use of a range of other additives, but found little improvement (entries 3 - 6). Upon further refinement, we found that the use of 0.5 equiv. of NaOt-Bu allowed for complete transformation of the boron enolate to the aldol adduct.
A control experiment, where benzaldehyde and NaOt-Bu were added 4 hours after the initial α,β-unsaturated substrate, displayed complete conversion to the aldol adduct, and suggested that the active enolate was not II or III (see Scheme 1.22), but probably the boron enolate activated by the base, the use of KF (entry 6) to promote the reaction is also congruent with this proposal. Interestingly, the major diastereomer isolated from the reaction, was consistent with an open transition state in the aldol reaction. This presumably arises as the boron is coordinatively saturated by the added base, which acts as a Lewis base, and so cannot direct the aldehyde.

Interestingly, two by-products 59 and 60 were isolated when 1.5 equiv of NaOt-Bu was used. Both of these adducts can be derived from an aldol reaction resulting from an extended enolate 61 formed in situ (Scheme 1.24), followed by conjugate silylation to give 63.52,63 Subsequent protonation of the pinacolboron enolate 63 in the work up furnishes 60, whilst a further aldol reaction with another molecule of benzaldehyde yields 59. However, as intermediate 62 is racemic, it was not investigated whether 59 and 60 were enantioenriched to a degree that was synthetically useful.

Table 1.3 Optimisation of the domino aldol reaction. *As determined from 1H NMR spectra of crude samples.
Scheme 1.24 Characterised by-products in the domino aldol reaction, and a proposed mechanism for the formation of 59 and 60. a \(^1\)H NMR ratio of silylated products b relative stereochemistry only.

The optimised conditions presented in Table 1.3 were applied to a range of aromatic and aliphatic aldehydes (Scheme 1.25), affording heterocyclic aldol adducts with moderate to good diastereoselectivity and in good yield. Notably, excellent chemoselectivity was observed in all reactions, with no undesired 1,2-addition of silicon to the aldehyde being observed, a potentially competing reaction as both the \(\alpha,\beta\)-acceptor and aldehyde are present in the reaction vessel. The enantiomeric ratio of 58a was found to be high (90:10 er) and comparable to that obtained by the parent process in the absence of added aldehyde. For aromatic aldehydes, the diastereoselectivity was a moderate 76:24 at best (58a-f), but this could be improved up to 88:12 (58h and 58j) upon moving to bulky aliphatic aldehydes.
Scheme 1.25 Substrate scope in the conjugate silylation with a domino aldol reaction. a 4 equivalents of aldehyde used b Only minor diastereomer isolated.

Unfortunately 6-membered lactones displayed poor diastereoselectivity in the three-component coupling and gave products in low yield under these conditions (58l-m). t-Bu-ester ring-opened species were observed due to nucleophilic attack of the base on the lactone starting material and products. However full characterisation was impeded due to their transient nature. Although two diastereoisomers were observed in the crude $^1$H NMR spectra of 58m, only the minor diastereomer could be isolated after column chromatography, perhaps indicating decomposition via a retro-aldol reaction during purification. Gratifyingly, 58m yielded a crystalline compound of the minor diastereomer, which confirmed the absolute and relative stereochemistry of the products (Figure 1.4).
1.4 Copper-catalysed asymmetric silylation of unsaturated lactams and amides

Motivated by our success with the copper-catalysed asymmetric silylation of \( \alpha,\beta \)-unsaturated lactones and the importance of aza-heterocyclic motifs in natural products and biologically active compounds, we considered whether an analogous protocol could be applied for the first time to \( \alpha,\beta \)-unsaturated lactams to give access to valuable optically active nitrogen-containing heterocyclic building blocks. In particular, the \( \gamma \)-lactam skeleton is present in numerous biologically active compounds (see Figure 1.5 for three examples with a \( \beta \)-hydroxy carbonyl motif),\(^9\) \(^{64,65} \) and has shown itself to be a valuable intermediate for the synthesis of \( \gamma \)-amino acids when asymmetrically functionalised.\(^66\)

\[\begin{align*}
\text{64} \quad & \text{Pramanicin antibiotic} \\
\text{65} \quad & \text{Lactacyclin proteasome inhibitor} \\
\text{66} \quad & \text{Omuralide proteasome inhibitor}
\end{align*}\]

As highlighted recently by Alexakis,\(^67\) such substrates are problematic Michael acceptors and present a significant challenge for the development of new methods.\(^67-76\) For example, unactivated \( \alpha,\beta \)-unsaturated lactams are known to possess inherent low reactivity (especially when compared to the heightened reactivity of \( \alpha,\beta \)-unsaturated lactones, vide supra), and in fact, the non-asymmetric silylcuprate addition to lactams remains essentially unexplored.\(^9,78,79\) Analogous additions of silicon nucleophiles to acyclic amides are known, asymmetric variants rely
on chiral auxiliary control.\textsuperscript{80–84} As previously noted, Oestreich found rhodium-catalysed asymmetric conjugate silylation of amides ineffectual, presumably due to this inherent low reactivity. With this in mind, the development of a catalytic asymmetric variant represented an exciting challenge.

Working with Dr. Vittorio Pace, in order to study the asymmetric silylation of \(\alpha,\beta\)-unsaturated lactams, we selected pyrrolidinone 67a bearing an electron-withdrawing protecting group on nitrogen as our model substrate. We commenced our investigation by studying the effects of various NHC ligand precursors on the enantioselectivity of the reaction. The use of \(C_1\)-symmetric imidazolinium 16a, a salt that has previously been employed successfully in conjugate silyl transfer to carbocyclic substrates (Table 1.4, entry 1) gave low enantiocontrol. Modification of the aryl substituents on nitrogen in a series of \(C_2\)-symmetric imidazolinium salts did little to increase the enantioinduction (entries 2 - 5). In a result that parallels our previous findings with the asymmetric silylation of lactones, a significant improvement was achieved upon switching from \(C_1\)-symmetric to \(C_2\)-symmetric ligands (entries 6 - 11). Pleasingly, the use of imidazolinium salt 41, which provided the best results for (5-membered) lactone substrates (\textit{vide supra}), proved to be optimal for asymmetric silyl transfer to pyrrolidinone 67a, and 68a was formed with high enantioselectivity (96.5:3.5 er). In the study, 2-MeTHF was used as an attractive green alternative to THF.\textsuperscript{85} Although the use of THF gave very similar yields, a noted diminishment in enantioselectivity was observed (entries 8 vs 11).
With optimised conditions in hand, we next studied the scope of the reaction (Scheme 1.26). 5-Membered lactam substrates bearing an arylsulfonyl substituent on nitrogen underwent efficient asymmetric silyltransfer to give β-silyl adducts in high yield and with er up to >99:1 (67a, b, c and i). In one case, a subtle change from an N-tosyl to an N-4-methoxybenzenesulfonyl protecting group resulted in an increase in enantioselectivity from 96.5:3.5 er (68a) to >99:1 er (68c). Substrates bearing p-methoxybenzoyl (67e) and tert-butoxycarbonyl (67d) groups on nitrogen underwent high yielding silyl transfer although enantioselectivities were lower, possibly due to an unselective conjugate addition promoted by the extra coordinating group on the substrate. In line with our observations on copper-catalysed silyl transfer to racemic lactone
substrates (*vida supra*), the kinetic resolution of a racemic lactam was also possible: 68i was obtained in 47% yield and 82:18 er. This slight diminishment in enantioselectivity suggests that the added steric congestion caused by the methyl substituent in the 5-position of the pyrrolidinone unit causes a drop in selectivity. Importantly, imidazolium salt 41 gave the best yields and selectivities for all the 5-membered lactam substrates studied.

In contrast, for 6-membered lactam substrates, Hoveyda’s C₃-symmetric imidazolium salt 16a gave the best results: asymmetric silyl transfer gave N-tosylpiperidin-2-one 68f and N-Cbz-piperid-2-one 68g in good yields and with selectivities up to 89:11 er. A similar observation was made in the preparation of N-Boc-caprolactam 68h (65% yield, 90:10 er) using imidazolium salt 16a. In comparison, pre-ligand 41 gave 67:33 er and 71:29 er for 68f and 68g respectively. These results clearly show that the ring size and the identity of the activating nitrogen substituent in lactam substrates are crucial when selecting the ligand for the asymmetric silyl transfer.

Scheme 1.26 Copper-catalysed asymmetric silyl transfer to unsaturated lactams. a 16a was used in place of 41. b 0.70 equiv. of PhMe₂SiBpin used.
Pleasingly, we found this protocol amenable to preparative scale synthesis, allowing 1.74 g of 68a to be synthesised in 93% yield with no loss of enantioselectivity when compared to the corresponding small scale transformation (Scheme 1.27).

Scheme 1.27 Preparative scale copper-catalysed asymmetric silylation.

Next, Vittorio extended the protocol to linear N-tosyl α,β-unsaturated amides. Pleasingly, imidazolinium salt 41 provided efficient silyl transfer and good levels of enantioinduction were observed (up to 92:8 er) (Scheme 1.28) across a range of α,β-unsaturated amides. This process was found to be compatible with substrates bearing β-aryl (69a-c and e), heteroaryl (69d) and alkyl (69f) substituents on the electron-deficient alkene. However, in general, enantioselectivities were lower for α,β-unsaturated amides than the corresponding α,β-unsaturated lactams. We also found that the use of primary and secondary amides resulted in no conversion. These results represent the first copper-catalysed asymmetric silylations of lactam and amide substrates, providing access to valuable chiral building blocks with high enantiopurity.
Interestingly, when we sought to apply our silyl transfer in a domino aldol process (vide supra), we isolated only small amounts of the aldol adducts 71a-b (18-22% yield), with the major product being silylated lactam 67a (Scheme 1.29). Presumably, this is due to the electron withdrawing N-Tosyl group presenting a less reactive enolate.

The synthetic value of the protocol was showcased by Dr. Vittorio Pace in an expedient asymmetric synthesis of the (R)-enantiomer of oxiracetam 75, a nootropic drug employed in the treatment of diseases related to Alzheimers (Scheme 1.30). Thus, β-silyl lactam 67a, underwent efficient removal of the N-tosyl group upon treatment with SmI₂. The resulting unprotected...
lactam 72 underwent \(N\)-alkylation with 73 to give 74 in 74\% yield. Subsequent late-stage oxidation under Fleming-Tamao conditions gave (\(R\))-oxiracetam 75 in 78\% yield.

\[
\begin{align*}
\text{PhMe}_2\text{Si}^+ & \quad \text{Sml}_2 (8.0 \text{ equiv}, 0.1 \text{ M}) & \quad \text{THF, 0 \degree \text{C to rt}, 0.5 \text{ h}} & \quad \text{PhMe}_2\text{Si}^+ \\
\text{67a} & \quad (96:4 \text{ er}) & \quad & \quad \text{72} \quad 94\%
\end{align*}
\]

\[
\begin{align*}
\text{PhMe}_2\text{Si}^+ \quad \text{KBr (2.5 equiv)} \quad \text{AcONa (3.2 equiv)} & \quad \text{AcOH-AcOOH} & \quad \text{0 \degree \text{C to rt}, 3 \text{ h}} & \quad \text{74} \quad 74\% \quad \text{75} \quad 78\% \\
\text{74} & \quad & \quad & \quad \text{(R)-oxiracetam} \\
\text{75} & \quad (\text{R)-oxiracetam} & \quad \text{nootropic drug}
\end{align*}
\]

Scheme 1.30 Asymmetric synthesis of (\(R\))-oxiracetam 75.

1.5 Summary

In conclusion, we have optimised a convenient procedure for the copper-catalysed asymmetric silylation of unsaturated lactones, lactams and amides using bulky pre-ligand 41. These results provide the first asymmetric silylations of their kind for the lactam and amide substrate classes. The copper-catalysed process delivers \(\beta\)-silylated heterocycles in good yields and enantioselectivities up to >99:1 er. Kinetic resolution using copper-catalysed silyl transfer was applied to racemic 5-butenolides and afforded products with good enantiocontrol and excellent diastereocntrol. This process was then utilised in expedient asymmetric synthesis of (\(+\))-blastmycinone and (\(R\))-oxiracetam. Furthermore, it was found that the boron enolate generated \textit{in situ} could be trapped with aldehydes, affording \(\beta\)-silyl-\(\beta'\)-hydroxy carbonyl motifs from an asymmetric catalytic three-component process.
Chapter two – The copper-catalysed silylation of allenes

2.1 Vinysilanes

Vinysilanes are invaluable organic building blocks and take part in a wide range of transformations. They are not only robust, synthetic equivalents of carbonyl compounds (courtesy of the Fleming-Tamao oxidation), but they also serve as versatile, low-cost, non-toxic coupling partners in the palladium-catalysed Hiyama cross-coupling (Scheme 2.1). However, regioselectively generating geometrically defined vinysilanes remains non-trivial.

Scheme 2.1 A silicon-mediated cross-coupling strategy used in Denmark’s total synthesis of (+)-brasilenyne.

2.1.2 Metal-catalysed approaches to vinysilanes

Conceptually, the most straightforward strategy for the construction of vinysilanes is the hydrosilylation of unsaturated functional groups such as alkynes or allenes. Traditionally, alkynes have been the substrate of choice for this process. This area of research has grown to be mature and well-established with catalytic protocols featuring palladium, platinum, rhodium, ruthenium, nickel and copper complexes. A pertinent example of this approach is present in López’s synthesis of vitamin A, a strategy comprising a platinum-catalysed hydrosilylation of terminal alkyne to afford vinysilane, followed by a Hiyama cross-coupling and THP deprotection to furnish vitamin A (Scheme 2.2).
Scheme 2.2 López’s synthesis of vitamin A utilising a platinum-catalysed hydrosilylation.

In comparison to the hydrosilylation of alkynes, a richer selection of regioisomeric compounds, including vinyl- and allylsilanes, can potentially be obtained via the hydrosilylation of allenes (Scheme 2.3). This synthetic versatility, combined with the ease of access to allenic compounds, makes them attractive substrates for hydrosilylation. However, in comparison to the hydrosilylation of alkynes, this field is currently underdeveloped. Allenes have enjoyed a surge in popularity over the past two decades as they are extremely versatile building blocks and are utilised in a range of synthetic applications. The key challenge in any addition process across an allene is one of regiocontrol. For example, the addition of the Si–M species into an unsymmetrical allene 83 can occur with four possible outcomes, which can lead to six products (85a-f), and typically yields mixtures of inseparable regioisomers.

Scheme 2.3 The challenge of regioselectivity in the silylation of allenes.
2.3 Metal-catalysed silylation of allenes

The silylation of allenes has been largely dependent on the use of stoichiometric organometallic reagents (e.g. Co$_2$(CO)$_8$, Zn, Cu$^{117-119}$). However, more economic metal-catalysed processes have been reported. When combined with the metal-catalysed bis-metallation of allenes, this field has evolved from first gaining regiocontrol over the reaction, to include control of the diastereo- and enantioselective outcome of the process. The seminal report of a metal-catalysed silylation of allene 86 appeared from Tsuji in 1974 (Scheme 2.4)$^{120}$. Presenting just one example, this work was part of a larger effort to establish palladium catalysis in the hydrosilylation of olefins, which had previously relied on the use of platinum catalysts. Tsuji demonstrated that a low catalytic loading of palladium could promote the hydrosilylation of allene, affording allylsilane in good yield.

![Scheme 2.4](image)

Several years later, Oshima capitalised on this advance, showing that the regioselectivity of silyl-metal insertion could be controlled by a judicious choice of metal catalyst (Scheme 2.5)$^{121}$. By selection of either a copper or palladium catalyst, a vinylsilane or allylsilane could be accessed with up to >95:5 regioselectivity from 1,2-cyclononadiene and a stoichiometric amount of a silicon-magnesium or silicon-aluminium organometallic reagent.

![Scheme 2.5](image)

Oshima went on to demonstrate that the allylmagnesium species generated in situ could subsequently react with a number of electrophiles (Scheme 2.6) (entries b - d), generating substituted vinylsilanes in moderate yields, and as single regioisomers.
Changing tack from metal-silicon insertions, Yamamoto and co-workers chose to exploit Lewis acid catalysis in the silylation of allenes (scheme 2.7).\textsuperscript{122} Using 25 mol% of AlCl\textsubscript{3}, they demonstrated that silylation of a range of aryl substituted allenes occurred under mild conditions in up to 96% yield. Only one regioisomer of the product vinylsilane was observed, and it was found that both 1,1- and 1,3-disubstituted aryl allenes (entries c and d) reacted smoothly in addition to terminal aryl allenes.

Interestingly, the group found that aliphatic allenes displayed no reactivity when exposed to the reaction conditions. A lack of suitable stabilisation of the carbocation intermediate was cited for this absence of reactivity. A lack of reactivity was also observed for a \(p\)-CF\textsubscript{3} aryl substituted allene. In accordance with these results, the mechanism presented in Scheme 2.8 was proposed. Coordination of aluminium to the allene and subsequent addition leads to zwitterionic intermediate III with the cation stabilised by the aromatic ring. Intermediate III can then undergo
hydride insertion from the silane to give IV, which can undergo facile transmetalation to afford the vinylsilane and AlCl₃ I.

![Diagram of a proposed mechanism for Yamamoto’s AlCl₃ catalysed silylation of aryl allenes.](image_url)

Scheme 2.8 A proposed mechanism for Yamamoto’s AlCl₃ catalysed silylation of aryl allenes.

When considering metal-silicon insertion across an allene, the generated carbon-metal bond has the potential to be intercepted in further carbon-carbon bond forming events. Cheng et al. embraced this strategy in a report describing the palladium-catalysed carbosilylation of allenes to afford substituted allylsilanes in good yields (Scheme 2.9). Cheng showed that a vinyl or aryl iodide could be inserted across an allene using palladium-catalysis. Following transmetalation and reductive elimination of the silylstannane reagent, this provided access to substituted allylicsilanes. The process was shown to be compatible with both aliphatic (entries a - c) and aromatic allenes (entry d) and a range of iodide coupling partners (entries e and f). Importantly, this communication showed that the stoichiometric silicon source need not be a freshly prepared silyl magnesium or aluminium reagent, and that loading silicon onto the reactive metal catalyst could be achieved using a milder transmetalating reagent (albeit a toxic organostannane).
Terao followed up on this advance, removing the necessity for the use of toxic organostannanes, but reverting back to using stoichiometric Grignard reagents (Scheme 2.10).\textsuperscript{124}

Cheng built upon his previous work in the area by extending the range of coupling partners to acylchlorides or chloroformates, thus providing 2-acylallylsilanes in moderate to good yields (Scheme 2.11).\textsuperscript{125} High regioselectivity was attained, and complete chemoselectivity was observed in all reactions – no direct coupling between the disilane and the acylchloride or decarbonylative coupling events were observed. The generality of Cheng’s earlier work was again reflected in the range of allenic substrates tolerated, with 1,1-disubstituted (entries a and d) and aryl (entry c) allenes all undergoing smooth reaction. Interestingly, aryl allene substrates demonstrated a lower \( E:Z \) selectivity. Further to this study, Cheng also found similar processes
could be carried out with boron and tin reagents providing access to 2-acylallylboron or tin reagents.

![Scheme 2.11 Cheng's acylsilylation of allenes.](image)

Rhodium-catalysed silylcarbocyclisations of various combinations of \( \pi \)-systems have been comprehensively investigated as part of a programme by Ojima.\(^{126} \) However, silylcarbocyclisations of allene derivatives had not been described until Yu provided the first report (Scheme 2.12).\(^{127} \) It was found that carbocyclisations could be affected by the treatment of an allenal or allenone with a silane and catalytic rhodium under a carbon monoxide atmosphere. Diastereomerically pure 5- and 6- membered carbocycles (entries a and c) and heterocycles (entries b - d) bearing either secondary (entries a and d) or tertiary alcohols (entries b and c) could be attained in moderate yields after 8 hours.

![Scheme 2.12 Yu’s silylative carbocyclisation of allenyl-carbonyl compounds.](image)

Shibata extended this concept to allenynes to allow for an intramolecular carbocyclisation initiated by a silicon-metalation (Scheme 2.13).\(^{128} \) It was found that by treating an allenyne with a
catalytic rhodium species and a silane, under an atmosphere of carbon monoxide, silicon-rhodium addition across the allene could trigger carbocyclisation, affording 1,4-diene hetero- (entries a – c) or carbo-cyclic (entry d) products in moderate to good yields.

![Scheme 2.13 Shibata’s carbosilylation of allenynes.](image)

Significant advances have also been made in the regioselective bis-metalation of allenes using silicon-silicon, silicon-boron and silicon-tin reagents. These silicon sources have negated the requirement of freshly prepared silicon-magnesium or silicon-aluminium reagents, and allow for the introduction of two functionalisable groups to the allene. The first report of this kind of bis-functionalisation incorporating silicon was from Watanabe and co-workers (Scheme 2.14). Extending Tsuji’s related conditions (Scheme 2.4) to the palladium-catalysed bis-silylation of allene and buta-1,2-diene, reactions proceeded efficiently with a range of simple substituted disilanes, affording olefins with both vinyl and allylsilane functionality in moderate to good yields.
Expanding on this theme, Mitchell et al. reported the palladium-catalysed addition of silicon and tin to allenes using the analogous silicon-tin reagent (Scheme 2.15).\textsuperscript{131,132} A range of allene substrates with either alkyl (entries a and b) or aryl (entry c) substitution were shown to undergo silylstannylation, affording products containing both vinylsilane and allylstannane functionality, in moderate yields. Mitchell found the regioselectivity of the reaction to be dependent on both the substituents of the allene and the tin reagent, although in all cases silicon was bonded to the central allene carbon, the position of tin varied. It was shown that the kinetic product resulted from metal-silicon addition of the internal double bond, and then at higher temperatures tin migrated to the terminal position to give the more substituted double bond and thermodynamic product. Unfortunately, the synthetic applicability of this protocol was marred by inseperable mixtures of products which isomerised upon purification by distillation.
Rajanbabu extended Mitchell’s efforts, and found that after refining his conditions, intramolecular cyclisations of allenye substrates could be achieved (Scheme 2.16). This yielded vinylsilane and vinylstannane containing compounds in moderate to good yields. A range of allenye substrates was studied, including oxygen (entries c and d) and nitrogen (entries b and d) containing compounds, yielding the corresponding carbo- (entry a) or heterocyclic (entries b - d) 1,4-dienes, with both vinylsilane and stannane functionality.

![Scheme 2.16 Rajanbabu’s silylstannylation of allenynes.](image)

Shortly after this, Rajanbabu reported the corresponding allenal cyclisation in a synthetic effort towards indolizidine 223A, suggesting that a range of internal electrophiles could potentially be used to trap the allylmetal intermediate (Scheme 2.17).

![Scheme 2.17 Rajanbabu’s silylation of an allene followed by concomitant allylation of a tethered aldehyde.](image)

Independently, Tanaka and Ito used palladium-catalysis to add a bench-stable silylborane reagent across an allene, affording bis-functionalised products with excellent
regioselectivity in good to excellent yields (Scheme 2.18). Here, without exception, boron was bonded to the central carbon of the allene unit. Tanaka reported the regioselectivity of the insertion of the palladium species across the allene to be dependent on the nature of the allene substituents. For example, when 1,1-diphenyl allene was used as a substrate, silicon was inserted exclusively at the terminal position (entry b), when these conditions were applied to 1,1-dimethyl allene, a 52:48 regioisomeric mixture was obtained (entry c). Further investigation revealed that the use of PPh₃ gave a clean regioselective reaction (entry d). Changing the catalyst from palladium to platinum resulted in a complete switch in regioselectivity, affording e with 100% regioselectivity. Analogous conditions from Ito looked at a slightly broader selection of allenes, but reported similar results. Interestingly, it was found that using an electron deficient allene gave a reversal in the regioselectivity, affording i, suggesting a significant electronic component to the regioselectivity of insertion.

Scheme 2.18 Tanaka’s and Ito’s work on the silylboration of allenes. a Allene (3 equiv), Pd₂(dba)₃ (2.5 mol%), 91 (10 mol%), PhMe₂SiBpin (1 equiv), THF, 80 °C, 9 h. b Pd₂(dba)₃ (2.5 mol%), PPh₃ (10 mol%). c (CH₂=CH₂)Pt(PPh₃)₂ (5 mol%), 3 h. d Allene (1.5 equiv), PhMe₂SiBpin (1 equiv), Pd(acac)₂ (2 mol%), 2,6-xylyl isocyanide (8 mol%), octane, 120 °C, 2 h.

These results, matched with a theoretical investigation, were merged into a detailed mechanistic picture (Scheme 2.19). Oxidative addition of the silylborane to the palladium (0) complex gives II, which can then add across the more electron-deficient and sterically unhindered...
terminal double bond, in a rate-determining step. The regio-determining step is the isomerisation from a \( \sigma \)-allylic palladium intermediate \( \text{IV} \), to a \( \pi \)-allylic palladium intermediate \( \text{V} \), as the subsequent reductive elimination is instantaneous, bringing together the \( \text{cis} \) silyl and allyl ligands, to afford the silaboration product and regenerate the catalytic species. The reductive elimination was found to be faster than any \( \text{cis} \) to \( \text{trans} \) isomerisation in \( \text{V} \) (which would potentially form the complementing regioisomer), and explains the formation of the thermodynamically less stable internal addition product.

![Scheme 2.19 Proposed mechanism for the palladium-catalysed silaboration of allenes.](image)

Cheng and co-workers reported that the presence of a catalytic amount of an organic iodide \( \text{90} \) in the reaction affected a complete change in regioselectivity (Scheme 2.20).\(^{139}\) These modified conditions afforded products with the silicon bonded to the central carbon of the allene and boron at the terminal position, to give aliphatic (entries \( \text{b} \) and \( \text{c} \)) or aromatic (entry \( \text{a} \)) products with vinylsilane and allylborane functionality. This high yielding process could also be applied to a stereoselective one-pot allylation reaction of aldehydes, where the allylborane species attacks an aldehyde \( \text{in situ} \) to afford homoallylic alcohols with excellent diastereoselectivity and yield (entry \( \text{d} \)).
As the start of a program aimed at the asymmetric silaboration of allenes, Murakami and Suginome found that a matched combination of the pinanediol-derived enantiopure silylborane 93 and ligand 94 afforded aliphatic (entries a and b) and aromatic (entries c and d) allylsilanes with high diastereoselectivities and in excellent yields (Scheme 2.21). This strategy of double asymmetric induction was necessary as the achiral PhMe₂SiBpin reagent gave only a moderate 84:16 er.

Selected examples:

<table>
<thead>
<tr>
<th>Entry</th>
<th>Product</th>
<th>Diastereoselectivity</th>
<th>Yield</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>&gt;99% E:Z</td>
<td>82% yield</td>
<td></td>
</tr>
<tr>
<td>b</td>
<td>95.5% E:Z</td>
<td>84% yield</td>
<td></td>
</tr>
<tr>
<td>c</td>
<td>93.7% E:Z</td>
<td>82% yield</td>
<td></td>
</tr>
<tr>
<td>d</td>
<td>&gt;99:1 dr</td>
<td>96% yield</td>
<td></td>
</tr>
</tbody>
</table>

Scheme 2.21 Suginome’s asymmetric silylboration of allenes.
After further investigation, Suginome and co-workers found they could avoid the use of a chiral auxiliary on boron by fine-tuning the enantiocontrol exerted by the ligand (Scheme 2.22).

Thus, it was found that the use of ligand 95 gave good to excellent enantioinduction to alkyl (entries a and b) and aromatic (entries c and d) substituted allenes, providing access to allylsilanes with up to 95.5:4.5 er and in excellent yields.

Scheme 2.22: Suginome’s asymmetric silylboration of allenes.

However, despite the significant advances achieved with the bis-metalation of allenes, a general, metal-catalysed protocol for the conceptually simpler hydrosilylation of allenes remained lacking when we commenced our studies. During the course of our work, Montgomery reported a regiodivergent hydrosilylation of allenes catalysed by either a nickel or palladium complex, affording vinyl- or allylsilanes respectively (Scheme 2.23). Silylation proceeded with excellent regioselectivity and in moderate to excellent yields. Although both phenyl and alkyl allenes were shown to undergo smooth reaction, functional group tolerance was limited with only alcohol (entry c) and protected amine (entry d) groups showing compatibility with the process.
Despite the excellent work of Montgomery, an affordable and general copper-catalysed protocol has remained elusive. Loh’s related work on the copper-catalysed regioselective silylation of terminal alkynes using a silylborane reagent provided the main impetus for our strategy, and demonstrated the potential for ligand based regiocontrol (Scheme 2.24).\textsuperscript{106} We sought to apply this approach to the copper-catalysed regioselective silylation of allenes.

**Scheme 2.24** Loh’s copper-catalysed regioselective silylation of terminal alkynes.

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**2.4 The copper-catalysed silylation of allenes**

We commenced our studies by examining the effects of various phosphine ligands upon the regioselectivity of silylation of phenylallene 97a. Table 2.1 highlights selected results from the...
initial phosphine ligand screen for this process. Initially, we found that silylation of phenylallene 97a proceeded efficiently under mild conditions, but with little regiocontrol when using conditions analogous to those employed in Loh’s copper-catalysed silylation of terminal alkynes (entries 2 and 3).106 Whilst both mono and bis coordinating phosphines displayed an obvious ligand effect upon the regioselectivity, they provided mixed results. For example, bis coordinating phosphines displayed a notable preference for delivering vinylsilane 98a (entries 3, 7 and 9). The best regioselectivity was achieved by the use of P(2,4-(OMe)2C6H3)3, affording vinylsilane 98a with 85% regioselectivity (entry 10). A control reaction using unligated copper revealed an interesting preference for allylsilane product 100 (entry 1). Importantly, this reaction highlighted the need for an efficient metal-ligand coordination, as an unligated copper salt could lead to a competing background reaction.

![Diagram of silylation reaction]

<table>
<thead>
<tr>
<th>Entry</th>
<th>Phosphine Ligand</th>
<th>Conversion</th>
<th>98a : 99a : 100a</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>None</td>
<td>97%</td>
<td>17 : 13 : 70</td>
</tr>
<tr>
<td>2</td>
<td>Johnphos</td>
<td>60%</td>
<td>32 : 14 : 54</td>
</tr>
<tr>
<td>3</td>
<td>Xantphos</td>
<td>92%</td>
<td>76 : 14 : 28</td>
</tr>
<tr>
<td>4</td>
<td>P(4-OMeC6H4)3</td>
<td>95%</td>
<td>19 : 22 : 59</td>
</tr>
<tr>
<td>5b</td>
<td>P(Cy3)•HBF4</td>
<td>&gt;95%</td>
<td>34 : 48 : 18</td>
</tr>
<tr>
<td>6b</td>
<td>P(t-Bu)3•HBF4</td>
<td>68%</td>
<td>22 : 73 : 5</td>
</tr>
<tr>
<td>7</td>
<td>DPPE</td>
<td>60%</td>
<td>73 : 24 : 3</td>
</tr>
<tr>
<td>8</td>
<td>P(n-Bu)3</td>
<td>80%</td>
<td>29 : 71 : 0</td>
</tr>
<tr>
<td>9</td>
<td>BINAP</td>
<td>30%</td>
<td>65 : 27 : 8</td>
</tr>
<tr>
<td>10</td>
<td>P(2,4-(OMe)2C6H3)3</td>
<td>91%</td>
<td>85 : 10 : 5</td>
</tr>
</tbody>
</table>

Table 2.1 A selection of results for the screen of phosphine ligands for aryl allene silylation.a

Determined by 1H NMR analysis of crude samples using an internal standard. b 11 mol% KOr-Bu.

Having screened for a suitable phosphine ligand, we turned our attention to the use of NHC ligands (Table 2.2). We found that silylation of phenylallene proceeded efficiently, and in a reduced reaction time of just 1 hour. However, NHC precursor 101 afforded only moderate regiocontrol with a preference for vinylsilane 98a (entry 1). We then examined the use of other commonly used 5-membered NHC precursors (entries 2 - 6) and found that the bulky 102 gave
97.5% regioselectivity. Encouraged by this, we pursued bulkier NHC precursors, and found that a 6-membered pre-ligand 107 achieved a comparable 97.5% regioselectivity combined with a small increase in the yield (entry 7). Pleasingly, we discovered that upon switching to the less usual 7-membered NHC precursor 109, optimal regioselectivity was achieved and vinylsilane 98a was obtained with >98:2 regiocontrol in excellent yield, at room temperature after 1 hour (entry 9). When considering the use of extremely bulky pre-ligands 108 and 110 (entries 8 and 10), we observed a slight preference for allylsilane 100. We ascribe these results to the possible combination of two factors: 1) incomplete ligation of the copper salt in the formation of the catalyst, caused by the bulky nature of the ligand, leading to a subsequent background reaction of unligated copper (which has been shown to favour 100 (Table 2.1, entry 1). 2) The bulky ligand leads to a looser, less organised transition state in the reaction, resulting in poor regioselectivity.
Table 2.2 Screening of Cu-NHC catalysts for aryl allene silylation. † Combined yield of regioisomers determined by 1H NMR analysis of crude samples using a standard. ‡ Determined by 1H NMR analysis of crude samples using a standard.

To date, copper complexes derived from NHC precursors with an expanded heterocyclic ring, have not been well explored in catalysis.145–152 Due to their expanded ring they exhibit steric and electronic properties distinct from their 5-membered counterparts. For example, due to the increased ring size, the N-C-N bond angle increases from 100-110 ° in the five-membered series, to 115-125 ° in the seven-membered series (Table 2.3 for representative complexes).153 This results in the N-substituents being projected further into the coordination sphere of the metal, increasing the percentage buried volume (%Vbur)154 (entries 1–4).155 The increase in N-C-N bond angle also correlates with an increase in the pKa value of six- and seven-membered NHC precursors, suggesting that the larger ring systems are more basic and can provide an enhanced...
donor ability when acting as a ligand.\textsuperscript{156,157} This is reflected in the decreased carbonyl stretching frequencies of the rhodium NHC complexes (Entries 5 – 8).\textsuperscript{155}

\begin{table}[h]
\begin{tabular}{|c|c|c|c|}
\hline
Entry & Complex & N-C-N angle & \%$\nu_{\text{bur}}$ \\hline
1 & (SiMes)AgCl & 104.4 & 36.1 \\hline
2 & (6-Mes)AgCl & 118.3 & 44.0 \\hline
3 & (7-Mes)AgCl & 118.8 & 44.7 \\hline
4 & (8-Mes)AgCl & 123.2 & 48.7 \\hline
5 & (SiMes)Rh(CO)$_2$Cl & & 2038 \\hline
6 & (6-Mes)Rh(CO)$_2$Cl & & 2029 \\hline
7 & (7-Mes)Rh(CO)$_2$Cl & & 2028 \\hline
8 & (8-o-tolyl)Rh(CO)$_2$Cl & & 2025 \\hline
\end{tabular}
\caption{An overview of steric and electronic properties of selected Metal-NHC complexes.}
\end{table}

The facile synthesis of allenic compounds is well documented.\textsuperscript{108} Using known methods we were able to quickly build a library of aryl allene derivatives. For example, a range of commercially available styrene derivatives 111a-i were easily converted to the corresponding 1- and 1,1-substituted aryl allenes in two steps (Scheme 2.25). This involved the synthesis of (2,2-dibromocyclopropyl)benzene derivatives 112a-i, and subsequent Grignard reagent-promoted rearrangement.

\begin{scheme}
\begin{center}
\includegraphics[width=\textwidth]{scheme225.png}
\end{center}
\caption{Representative synthesis of terminal aryl allene substrates from substituted styrenes.}
\end{scheme}

Many of the functional groups we wanted to evaluate for compatibility with our process were not tolerant of the use of a super stoichiometric Grignard reagent, and so an alternative synthetic route to functionalised substrates was put to use (Scheme 2.26). Commercially available benzoic acid 113 was converted to amide 114a and functionalised esters 114b-d via the acyl
chloride. A Crabbe homologation furnished allenes containing ester (97r), amide (97s), nitrile (97q) and alcohol (97m) functional groups, which could then be further manipulated using conventional chemistry to give bromide 97n, iodide 97o and azide 97p in moderate to excellent yields. In this way, aryl substituted allenes containing a wide range of functional groups could be easily accessed using simple chemistry. Furthermore, all the allenes synthesised were found to be stable for prolonged periods of time when stored in a freezer.

Scheme 2.26 Functionalised substrate synthesis. a from 97m: CBr4 (1.1 equiv), PPh3 (1.1 equiv), CH2Cl2, 0 °C, 2 h. b from 97m: PPh3 (1.3 equiv), imidazole (1.3 equiv), I2 (1.3 equiv), CH2Cl2, rt, 3 h. c from 97o: NaN3 (2.5 equiv), DMF, 50 °C, 3 h.

Thus, now equipped with a library of aryl allene derivatives and with mild and operationally simple, optimised conditions in hand, we explored the scope of the copper-catalysed process (Scheme 2.27). We found that a range of aryl allene derivatives afforded the corresponding vinylsilanes with excellent regioselectivity and good yields, in just one hour at room temperature. This included hindered substrates bearing an o-tolyl group (97c), a hindered mesityl substrate (97d), albeit with slightly diminished regioselectivity and yield, and a naphthyl group (97b). The presence of an electron withdrawing CF3 group (97f) had a slight deleterious effect upon the regiocontrol (92:8), which was further accentuated (75:25) by the presence of two CF3 groups (97l), although yields remained high. An electron donating OMe group (98e) and a variety of halogen substituents were tolerated (98f-l). Of particular note, it was found these mild conditions tolerated primary iodo (98o) and bromo (98n) groups that are sensitive to elimination or substitution. Crucially, examples of the hydrosilylation of alkynes or allenes in the presence of these sensitive functional groups are not well described. Furthermore, ester (98r), amide (98s), nitrile (98q), azide (98p) and unprotected alcohol (98m) functional groups were all well tolerated, with silylations exhibiting excellent regioselectivity and affording the corresponding products in
good yields. The process was also found to tolerate 1,1-disubstitution on the allene: vinylsilane 98t was obtained with excellent regioselectivity, albeit in reduced yield. A 1,3-disubstituted allene also underwent copper-catalysed silylation with excellent regiocontrol giving 98u as a mixture of geometric isomers.

\[ 
\text{Scheme 2.27} \quad \text{Substrate scope in the copper-catalysed silylation of aryl allenes.} \]  
\footnotesize{\textsuperscript{a} 10 mol\% Catalyst loading, MeOH (6 equiv), 18 h reaction time. \textsuperscript{b} 18 h reaction time.}

Silylation of 97a in the presence of CD\textsubscript{3}OD yielded 98a-D with 86% deuterium incorporation in the benzylic position (Scheme 2.28). This seemingly low deuterium incorporation, likely arises from the 10 mol\% of t-BuOH present in the reaction mixture from the deprotonation of the pre-ligand and subsequent catalyst formation.

\[ 
\text{Scheme 2.28} \quad \text{Deuterium incorporation experiment.} 
\]
In agreement with the position of deuterium incorporation, we proposed the mechanism shown in Scheme 2.29. After initial formation of the ligated copper-alkoxide I, transmetalation with the silylborane yields II; the driving force for this process originates from the formation of a strong oxygen-boron bond in the ROBpin by-product. Regioselective insertion of the allene then gives σ-allylcopper III. We hypothesise that the bulky nature of the NHC ligand on copper provides a kinetically controlled addition across the terminal double bond of the allene, placing copper in the less hindered terminal position. The resulting allylcopper may be resistant to π-allyl or intermolecular isomerisation due to the sterically congested profile of the species.\(^{158}\) Allylcopper III then undergoes selective protonation to afford the vinylsilane and copper alkoxide I.

![Scheme 2.29 A proposed catalytic cycle for the copper-catalysed silylation of allenes.](image)

Despite working well for a range of aryl substituted allenes, the above conditions did not extend well to alkyl substituted allenes, and in most cases, complex mixtures of inseparable regioisomers were obtained after extended reaction times (Scheme 2.30). For example, pre-ligand 109 afforded a vinylsilane 116a with a TBS protected alcohol in 90% regioselectivity; however, the use of an allene bearing an unprotected alcohol 115b gave a complex mixture, presumably due to a mixture of substrate coordinated direction and ligand influence. Other non-functionalised allenes 115c-d gave 69-76% regioselectivity in favour of the vinylsilane 116c-d.
In response, we screened several ligands on a selection of alkyl-substituted allene substrates in an effort to affect regiocontrol. The highlights of this endeavour are summarised in Table 2.4. In general, it was found that alkyl-substituted allenes displayed a preference for delivering the allylsilane product (entries 2, 3, 4 and 6), and it was only when the bulky 7-membered 109 was used that a notable preference for a vinylsilane was observed (entries 7 and 8). In many cases high preference for the allylsilane could be achieved with selectivities of 80-92% (entries 2, 3 and 4), with pre-ligand 106 giving the highest selectivity. However, these examples proved to be substrate-ligand specific and not generally applicable to other allenes (for example entries 1 vs 2).
NHC precursors:

Table 2.4 Screening of Cu-NHC catalysts for alkyl allene silylation. \(^a\) Determined by \(^1\)H NMR analysis of crude samples.

<table>
<thead>
<tr>
<th>Entry</th>
<th>NHC precursor</th>
<th>R</th>
<th>116 : 117 : 118(^a)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>101</td>
<td>Cy</td>
<td>28.5 : 28.7 : 42.8</td>
</tr>
<tr>
<td>2</td>
<td>101</td>
<td>C(_8)H(_17)</td>
<td>14 : 6 : 80</td>
</tr>
<tr>
<td>3</td>
<td>105</td>
<td>Cy</td>
<td>7 : 4 : 89</td>
</tr>
<tr>
<td>4</td>
<td>106</td>
<td>Cy</td>
<td>3 : 5 : 92</td>
</tr>
<tr>
<td>5</td>
<td>107</td>
<td>Cy</td>
<td>48 : 5.5 : 46.5</td>
</tr>
<tr>
<td>6</td>
<td>107</td>
<td>C(_8)H(_17)</td>
<td>37 : 6 : 57</td>
</tr>
<tr>
<td>7</td>
<td>109</td>
<td>Cy</td>
<td>69 : 17 : 14</td>
</tr>
<tr>
<td>8</td>
<td>109</td>
<td>C(_8)H(_17)</td>
<td>76 : 11.5 : 12.5</td>
</tr>
</tbody>
</table>

Nonetheless, encouraged by the general switch in regioselectivity when comparing aryl and alkyl substituted allenes, we investigated the use of bulkier silylborane reagents in an effort to promote the addition of silicon at the terminal position to furnish the allylsilane product. Satisfyingly, we found that the combination of a bulkier silylborane reagent Ph\(_2\)MeSiBpin and the smaller pre-ligand 106 furnished \((Z)\)-allylsilanes 121a-e with >98% regioselectivity and in moderate to good yield (Scheme 2.31). The conditions proved sufficiently mild to tolerate an unprotected primary alcohol group (121d) as well as a phthalimido moiety (121c), with protosilylations proceeding smoothly to afford \((Z)\)-allylsilanes with excellent regioselectivity. It is worth noting the complete regioselectivity of both these substrates which bear a potential for a substrate directed reaction, which could override the ligand control. We found the choice of ligand to be crucial for high regioselectivity, and the use of the smaller 106 (\(\%V_{bur} = 27.7\)) compared to 109 (\(\%V_{bur} = 44.7\)) delivered outstanding selectivity in every case. This regiodivergence to afford either allyl- or vinylsilanes depending on the allene used demonstrates
the versatility of allenic functionality. Indeed, a match between substrate and ligand based regiocontrol allows access to allylsilane compounds that cannot easily be obtained by the hydrosilylation of alkynes using copper.

![Scheme 2.31 Copper-catalysed silylations of alkyl allenes. Regioselectivity determined by $^3$H NMR analysis of crude samples.](image)

To rationalise the origin of the (Z)-selectivity, we proposed the following catalytic cycle (Scheme 2.32). After initial formation of the ligated copper alkoxide I, transmetalation with the silylborane yields II. The copper complex can then coordinate with the least hindered face of the allene, where the bulky SiMePh$_2$ group is positioned for addition in to the terminal position, and copper with the small ICy NHC ligand can add in the internal position. Insertion of the allene gives intermediate vinylcopper IV, which after protonation affords (Z)-allylsilane.
Whilst investigating the use of increased bulk on the silylborane reagent, we discovered that Ph₃SiBpin and Ph₂t-BuSiBpin led to little or no conversion. Pleasingly however, Ph₂t-BuSiBpin afforded single crystals that allowed for analysis by X-ray crystallography (Figure 2.1). Interestingly, structural studies on silylpinacolborane reagents are relatively sparse in the literature and only four comparable crystal structures have been reported, of which 122 is the least hindered example. Structural analysis of Ph₂t-BuSiBpin revealed an alignment of the t-Bu-Si σ-bond and the unoccupied p-orbital on the boron atom, suggesting a hyperconjugative interaction. The Si-B bond length of 2.032 Å is comparable with previously reported silylboranes.

Towards the end of our studies, Loh built upon his previous copper-catalysed silylation of terminal alkynes (Scheme 2.24), and reported the conjugate addition of silicon into allenoate-type substrates (Scheme 2.33), furnishing multi-substituted vinylsilanes in moderate to good yields.
Because of the electronic predisposition of the allenoate substrates, β-silyl products were observed with a range of ligands, with no other regioisomers being reported.

\[
\begin{align*}
\text{R} & \quad \text{CuBr (10 mol%), dppe (11 mol%)} \quad \text{Et}_{3}N (11 \text{ mol%}) \\
\text{EWG} & \quad \text{PhMe}_{2}Si\text{Bpin (1.1 equiv)} \quad t\text{-BuOH, } 40^\circ \text{C, 24 h}
\end{align*}
\]

Selected examples:

\[
\begin{align*}
a & \quad 83\% \text{ yield} \\
b & \quad 68\% \text{ yield} \\
c & \quad 83:19 \ E:Z \quad 68\% \text{ yield} \\
d & \quad 74\% \text{ yield}
\end{align*}
\]

Scheme 2.33 Loh’s conjugate silylation of allenoate-type substrates.

Wanting to explore the generality of our copper-catalysed hydrosilylation conditions in other related processes, we found that the 7-membered pre-ligand 109 afforded excellent regiocontrol in the silylation of an aryl substituted terminal alkyne 123 (Scheme 2.34). Surprisingly, the regioselectivity for the addition of silicon across the terminal alkyne put the bulky NHC-ligated copper in the internal position, and gave access to the linear vinylsilane 124. This study provided a complementary regioselectivity to that observed by Loh, and on a substrate class (aryl alkynes) Loh found to be particularly challenging in terms of regiocontrol (cf Scheme 2.24; Loh’s conditions led to 62:38 selectivity in favour of the branched vinylsilane for aryl alkynes). The use of the 7-membered pre-ligand 107 also resulted in complete regiocontrol in the borylation of phenyllallene 97a, affording a single regioisomer of vinylborane 125. These examples highlight the versatility of the expanded ring NHC copper complexes in catalysis.

\[
\begin{align*}
\text{123} & \quad 109 \ (10 \text{ mol%}) \quad \text{Cul (5 mol%)} \quad \text{KO}t\text{-Bu (16.5 mol%)}; \\
& \quad \text{PhMe}_{2}Si\text{Bpin (1.1 equiv)} \quad \text{MeOH (3 equiv)} \quad \text{THF, rt, 1 h} \\
& \quad 60\% \text{ yield, single regioisomer}
\end{align*}
\]

\[
\begin{align*}
\text{97a} & \quad 109 \ (10 \text{ mol%}) \quad \text{Cul (5 mol%)} \quad \text{KO}t\text{-Bu (16.5 mol%)}; \\
& \quad \text{B}_{2}\text{pin}_{2} \ (1.1 \text{ equiv}) \quad \text{MeOH (3 equiv)} \quad \text{THF, rt, 1 h} \\
& \quad 76\% \text{ yield, single regioisomer}
\end{align*}
\]

Scheme 2.34 Exploring the use of our conditions in related copper-catalysed processes.

Regioselectivity determined by \(^1\text{H NMR analysis of crude samples.}\)
We next conducted a series of competition reactions to ascertain orders of reactivity and selectivity. A competition reaction involving phenyl allene 97a and phenylacetylene 123 revealed that our catalytic system displayed a reactive predisposition towards aryl alkynes over aryl allenes after 40% conversion, providing >98% of 124 (Scheme 2.35). Accordingly, we suggest this preference is kinetic in origin and a result of an unfavourable steric interaction between the α-hydrogen of the allene and the bulky silicon group (coordination model I), leading to a slower insertion of the allene when compared to the flat, reactive profile of phenylacetylene (coordination model II).

Scheme 2.35 Phenyl allene and phenylacetylene competition reaction. Regioselectivity determined by 1H NMR analysis of crude samples.

Next, we compared the reactivity of the silylborane reagent and the analogous B₂pin₂ reagent. Limiting conversion to 40%, we found a 66:34 preference for the addition of boron into the allene (Scheme 2.36). We deduced that this preference could originate from the kinetics of the transmetalation event. Here, the driving force for transmetalation is the formation of a strong oxygen-boron bond (ΔH° B-O 125 kcal mol⁻¹) in the ROBpin by-product (Scheme 2.29); accordingly, we can assume a non-reversible transmetalation of either silicon or boron onto the copper catalyst.¹⁶² As the bond dissociation energies of the silicon-boron and boron-boron bonds are comparable (289 kJmol⁻¹ and 297 kJmol⁻¹ respectively), we suggest that the preference for transmetalation with B₂pin₂ originates from the steric accessibility of the reagent when compared to the bulkier silylborane.
We also observed a significant electronic influence on the reaction when we conducted a competition experiment between 97e and 97f (Scheme 2.37). After 30% conversion we observed exclusive formation of 98f. This suggests that an electronically more rewarding coordination occurs between the copper species and an electron-deficient allene when compared to an electron rich allene.

To investigate the nature of the coordination and insertion events, we conducted stoichiometric cross-over reactions to determine if the insertion of the allene into the copper-silicon bond is reversible (Scheme 2.38). This provided an insight into the thermodynamic and kinetic attributes of the regioselectivity and chemoselectivity observed in the reaction and elucidated the product-determining step. The results of this investigation found that when intermediate 126 was treated with an excess of phenylacetylene (a substrate that had been shown to have a higher affinity for the copper-silicon species – Scheme 2.35), 98a and 124 were observed in a 95:5 ratio when using copper pre-catalyst 127, and an 89:11 ratio when using 128. This suggested that the copper-silicon addition into the allene was likely irreversible, and that the regiochemical distribution of the product was not controlled by a thermodynamic difference between intermediates resulting from addition. Furthermore, as the regioselectivity observed in
the addition to the allene was comparable in both cases to that reported in Table 2.2, we propose that intermediate 126 is resistant to π-allyl or intermolecular isomerisation, likely due to the large steric attributes of the ligand. Consistent with these results, is the assumption that either catalyst-substrate coordination or the subsequent allene insertion determines the vinylsilane (98a and 99a) or allylsilane (100) product identity. Fitting with this model, it is credible that the regioisomeric distribution of vinylsilanes 98a and 99a could be due to the rapid protonation of the Cu-C bond of allylcopper intermediate 126.

Scheme 2.38 A stoichiometric crossover experiment. Product distribution determined by $^1$H NMR analysis of crude samples.

2.5 The copper-catalysed silylative allylation of aldehydes

With a broad substrate scope evaluated in our copper-catalysed silylation of aryl substituted allenes, we turned our attention to utilising the σ-allylcopper intermediate III (Scheme 2.29), that is generated catalytically, in a three-component coupling. Working with a talented Masters student, Ya Chu Hu, it was quickly found that homoallylic alcohols could be furnished upon replacing MeOH with an aldehyde (Scheme 2.39). The homoallylic alcohol motif is a valuable building block commonly used in the construction of a wide variety of complex natural products. With this in mind, we were excited by the possibility of forming this moiety with regio-, diastereo- and chemoselectivity, in a single reaction vessel. We found this process to be amenable to both aromatic (129a-d) and aliphatic (129e-j) aldehydes, providing homoallylic
alcohols from the corresponding aldehydes and allene in 3 hours, with good to excellent diastereoselectivity and in moderate to good yields (up to 86%). Both sterically accessible (129e-f) and hindered (129g, h and j) aliphatic aldehydes proceeded to deliver adducts with high diastereoselectivity. A bulky mesitaldehyde also gave excellent diastereoselectivity in the coupling (129d), and the relative stereochemistry of the product was confirmed by X-ray crystallographic analysis. The high diastereoselectivity observed in this process suggests that the addition to the aldehyde proceeds via a closed, six-membered transition state, with oxygen coordinating to copper (cf Scheme 2.29). It is worth mentioning at this point that the allylcopper intermediate is inaccessible from the analogous silylations of alkynes, and represents an avenue of reactivity only currently available to allenes.

Scheme 2.39 Copper-catalysed silylative allylation of aldehydes.

No desired product was observed when we tested ketones in this three component coupling. However, Tsuji later managed to utilise these less reactive substrates in a similar, high
yielding copper-catalysed process furnishing adducts with a complementary regioselectivity (Scheme 2.40). Interestingly, Tsuji utilised an electron-rich phosphine ligand and a triethylsilylborane to affect silylation of an alkyl allene.

Continuing with this theme, Tsuji recently reported the regiodivergent silacarboxylation of allenes (Scheme 2.41). Again, utilising the allylicopper intermediate formed in situ, a large ligand effect upon the regioselectivity of the reaction was found, and products containing either allyl- or vinylsilanes could be accessed in high yields and regioselectivity, again highlighting the synthetic versatility of allenic substrates.

2.6 The copper-catalysed silylative allylation of imines

In an effort to build upon our success with the regioselective silylation of aryl substituted allenes and the subsequent three-component coupling, we decided to extend the protocol to include imines and the formation of homoallylic amines (Table 2.5). Initially, we found that by simply adding an N-phenyl aromatic imine 135a, we could obtain the desired adduct 136 with excellent regioselectivity and with 89:11 dr, but in only 20% yield after 18 hours (entry 1). In an
effort to increase the yield, we investigated the effects of various stoichiometric additives upon the reaction (entries 2 - 9). This revealed that the use of a base or KF could help promote the reaction to varying degrees. Presumably, the base is involved in the transmetalation step by coordination to boron in the silylborane reagent. This screen identified Cs$_2$CO$_3$ to be an effective additive (entry 9). However, although the yield was significantly increased to 77%, the regioselectivity of the reaction had diminished somewhat to 87:13. To address this issue, a number of NHC pre-ligands that had previously shown high regioselectivity were tested (entries 10 - 12), and pre-ligand 103 was identified to be optimal in this transformation, affording the homoallylic amine in a moderate 69% yield, with 98% regioselectivity and 93% dr (entry 12). The relative stereochemistry proposed is based upon analogous work discussed in chapter 3.
Table 2.5 Selected optimisation results for the copper-catalysed silylative allylation of imines. \(^a\)

Determined by \(^1\)H NMR analysis of crude samples using a standard, relative stereochemistry assigned based upon comparison to Scheme 3.17 (\textit{vide infra}). \(^b\) Combined yield of regioisomers determined by \(^1\)H NMR analysis of crude samples using a standard.

### 2.7 Summary

We have developed a mild, low-cost, general and efficient copper-catalysed silylation of aryl allenes using a bench-stable and commercially available silylborane reagent that provides vinylsilanes with excellent regiocontrol. Further investigation found that by fine-tuning the steric parameters of the ligand and silylborane reagent, we could affect a switch in regioselectivity and furnish allylsilanes from the corresponding alkyl substituted allenes. By replacing the proton
source with an aldehyde we found we could provide access to a highly diastereoselective, one-pot, three-component coupling that delivers silylated homoallylic alcohols by exploiting the catalytic generation of allylcopper intermediates, a process not accessible using other technologies. Preliminary studies, aimed at extending the scope of this process to imines, were also carried out.
Chapter three - The copper-catalysed borylative allylation of imines

3.1 Introduction

Due to the moderate yield and sluggish reactivity encountered in the copper-catalysed silylative allylation of imines, we decided to conduct a variant of the reaction with the analogous B$_2$pin$_2$ reagent as a comparison. Conceptually, this would provide access to homoallylic amine and vinylboron containing compounds with control of regiochemistry and relative stereochemistry (Scheme 3.1).

![Scheme 3.1A proposed borylative allylation of imines.](image)

Homoallylic amines constitute a class of valuable N-substituted building block, as the motif is present in a number of important biologically active alkaloids such as the analgesic angustifoline$^{167}$ 138, as well as the in the antibiotics indolizomycin$^{168}$ 139 and eponemycin$^{169}$ 140 (Figure 3.1).

![Figure 3.1 A selection of homoallylic amine-containing biologically relevant compounds.](image)

The synthesis of homoallylic amines is typically achieved by the addition of an allylmetal nucleophile to an imine (Scheme 3.2). Although conceptually similar to the allylation of aldehydes to form homoallylic alcohols (vide supra), imines possess distinct characteristics that result in various challenges associated with nucleophilic addition. Owing to the difference in
electronegativities between oxygen and nitrogen, the C=N double bond is less polarised than the corresponding C=O bond; this results in a diminution of bond dipole, electrophilic character and reactivity in imines. Imines bearing an α-proton are often prone to rapid tautomerisation between imine and enamine forms. Due to this low imine-enamine tautomerisation energy barrier, an equilibrium favouring the enamine form can be readily established, not only resulting in a reduced effective concentration of the electrophilic imine, but also in potential side reactions due to the presence of the nucleophilic enamine. Due to a third substituent on nitrogen (commonly a nitrogen protecting or activating group), controlling the imine geometry around the C=N bond is often non-trivial, as E/Z isomerisation can also occur via the imine-enamine tautomerisation. This third substituent on nitrogen also sterically encumbers nucleophilic approach to the imine, an issue that is accentuated in nucleophilic additions to ketoimines.

\[ \begin{align*}
\text{Electronegativities: } & O = 3.44, N = 3.04, C = 2.55 \text{ (Pauling's scale)} \\
\end{align*} \]

Scheme 3.2 The synthesis of homoallylic amines and associated challenges.

### 3.2 The copper-catalysed borylation of allenes

In the last four years there has been increased interest centred on the copper-catalysed regioselective borylation of allenes. Undoubtedly, this pays tribute to the valuable synthetic utility of the afforded vinylboron compounds. This journey commenced with gaining regiocontrol in the reaction and has proceeded with the development of enantioselective variants and three-component coupling procedures that generate useful building blocks for organic synthesis.

Santos provided the first example of a copper-catalysed regioselective borylation of allenic compounds using an internally activated \( \text{sp}^2-\text{sp}^3 \) hybridised diboron reagent 141 (Scheme 3.3).\(^{170} \) This protocol took racemic mixtures of allenolate compounds, and provided access to a
limited range of geometrically defined β,γ-unsaturated esters with excellent E:Z ratios, albeit in low to moderate yields. The use of the diboron 141 reagent, circumvented the need for a strong base (typically an alkoxide) for the activation and transmetalation of the diboron reagent, and exclusive transfer of the Bpin moiety was observed.

Ma later presented a ligand controlled regioselective borylation of allenes. Here, the use of a mono-coordinating ligand furnishes the terminal vinylborane (entries a and b), whereas a bis-coordinating ligand completely switches the regioselectivity to provide access to the internal (Z)-vinylborane (entries c and d) (Scheme 3.4). Both processes proceed with excellent efficiency, regioselectivity and (Z) selectivity (for the internal vinylboranes). The substrate scope focuses firmly on the regioselective borylation of aryl substituted allenes (entries a, c and d), and presents two general ligands for this process. Ma found that the borylation of alkyl substituted allenes required the use of an alternative bis-coordinating ligand for effective regiocontrol (entry b).
Changing the strategy for attaining regiocontrol, Ma subsequently investigated the use of an amide directing group on the allene, and found the issues of regio- and stereoselectivity could now be addressed (Scheme 3.5).\textsuperscript{172} Under mild conditions, allenamide compounds could be transformed to the corresponding (Z)-vinylboranes in moderate to good yields. The reaction was found to tolerate various substitution patterns on the allenamide substrates, whereas in contrast, related allenoates and 1,3-disubstituted allenes afforded regioisomeric mixtures under the same conditions, indicating the importance of the amide directing group.

**Scheme 3.5 Ma’s amide-directed copper-catalysed borylation of allenes.**

Tsuji reported an excellent account of copper-catalysed allene borylation, using a combination of reagent and ligand control to effect excellent regiocontrol across a range of aryl
and alkyl substituted allenes possessing a variety of substitution patterns (Scheme 3.6).\textsuperscript{158} For the first time, this provided access to both allyl- (entry a) and vinylboranes (entries b - d). The key to this selectivity was the use of either HBpin, or B\textsubscript{2}pin\textsubscript{2} to affect either hydrocupration or borylcupration, respectively. It was found that under these conditions, a range of allenes could be borylated, with excellent regio- and stereoselectivity, in moderate to excellent yields. This thorough study also presented crystal structures of isolated reaction intermediates, such as the intermediate allylcopper species.

\begin{center}
\textbf{Scheme 3.6} Tsuji’s copper-catalysed borylation of allenes. \textsuperscript{a} CuCl (2 mol%), 143 (2 mol%), NaOt-Bu (12 mol%), HBpin (1.2 equiv), dioxane, 28 °C, 2 h \textsuperscript{b} CuCl (2 mol%), 144 (2 mol%), NaOt-Bu (12 mol%), B\textsubscript{2}pin\textsubscript{2} (1.1 equiv), MeOH (8 equiv), -20 °C, 2 h \textsuperscript{c} CuCl (2 mol%), 145 (2 mol%), NaOt-Bu (12 mol%), B\textsubscript{2}pin\textsubscript{2} (1.2 equiv), MeOH (2 equiv), 28 °C, 2 h.
\end{center}

At the same time as Tsuji’s study, Hoveyda disclosed a similar report detailing the use of two NHC pre-ligands for the regioselective borylations of terminal allenes, affording either the terminal (entries a and b) or trisubstituted (entries c and d) vinylboranes with excellent selectivity and in good yields (Scheme 3.7).\textsuperscript{173} The scope of the method encompassed selections of both aryl (entry a) and alkyl (entries b - d) allenes, and demonstrated the synthetic utility of the protocol in natural product synthesis.
Hoveyda also proposed a general mechanistic picture that was supported by DFT calculations and explained the observed regioselectivity trends present in Ma’s and Tsuji’s work (Scheme 3.8). It was proposed that independent of ligand choice, initial insertion of the allene places copper in the less hindered terminal position I. If there is a large ligand present on copper, this can then undergo subsequent γ-protonation via II to afford the terminal vinylborane. Conversely, if there is a small ligand present on copper, interconversion of I to III via the copper π-allyl can occur. The DFT study revealed that intermediate III is higher in energy than I and therefore will undergo γ-protonation via IV faster than the analogous process via II. With large ligands the product determining γ-protonation via II is faster than any interconversion between I and III, whereas with smaller ligands, it is the faster protonation from the higher energy III that controls the product distribution.

Continuing with this work, Hoveyda investigated the enantioselective protonation of intermediates analogous to II, by the use of a homochiral ligand on copper (Scheme 3.9).\textsuperscript{174} It was
found that the use of pre-ligand 148 could effect high enantioselectivity in the process to provide access to enantioenriched vinylboranes with up to >98% regioselectivity in excellent yield. This process was largely limited to the use of aryl substituted allenes as it was noted that di-alkyl substituted allenes furnished products with low site selectivity and enantioselectivity, and in moderate yields, again highlighting the reactive differences between alkyl and aryl substituted allenes.

Scheme 3.9 Hoveyda’s enantioselective protoboration of 1,1-disubstituted allenes.

Hoveyda further developed this theme with a three component coupling involving boron, allenes and aldehydes or ketones (Scheme 3.10). This process exploited the in situ generation of allylcopper intermediate I (See Scheme 3.8) by trapping it with an aldehyde or ketone. It was found the vinylborane adducts were unstable to silica gel chromatography, and so necessitated the use of an oxidative workup to afford the isolable β-hydroxyketones in good yields with excellent diastereoselectivities. For aldehyde substrates, the best results were obtained by the use of a bulky adamantyl NHC pre-ligand (entry a). Although this also displayed high selectivities for ketones, the use of rac-BINAP afforded adducts with slightly higher diastereoselectivity (entry b). The use of homochiral phosphine ligands enabled the development of an asymmetric variant of the reaction, and allowed enantioenriched β-hydroxyketones to be accessed in good to high enantioselectivities and in good yields (entries c and d).
Investigating a similar concept, Brown reported a copper-catalysed cross-coupling, and its application in the carboboration of alkynes and allenes (Scheme 3.11).\textsuperscript{176} This utilises the allylcopper intermediate generated \textit{in situ}, and couples this reaction sequence with an $sp^3$-$sp^2$ copper-catalysed cross-coupling, providing access to stereodefined (Z)-vinylborane compounds, with the coupling occurring at the least hindered terminal site. The couplings proceeded with excellent regio- and stereocontrol, and in moderate to high yields.
Shortly afterwards, Tsuji reported the first copper-catalysed borylative allyl-allyl coupling using allenes (Scheme 3.12).\textsuperscript{177} Here, the \textit{in situ} generated allylcopper intermediate is intercepted by an allylic phosphate in an $S_N2'$ reaction to furnish 1,5-diene motifs in moderate to good yield with excellent regioselectivity. It was observed that in accordance with Brown's study, the coupling proceeded to occur at the least hindered site of the allene. The process was ineffectual with phenylallene, 1,1- and 1,3-disubstituted allenes, all of which failed to provide satisfactory selectivity.

Almost immediately after this disclosure, the enantioselective variant of the reaction emerged from Hoveyda's laboratory (Scheme 3.13).\textsuperscript{178} It was found that \textit{bis}-phosphines were ineffectual in this transformation, and led to the undesired borylation of the allylic phosphate instead of the allene. It was proposed that the lower Lewis basicity and lower steric bulk of the...
bis-phosphine ligands allowed association of the allylic phosphate more readily to the copper centre, followed by subsequent reaction yielding undesired by-products. A distinct improvement of chemo- and site-selectivity was observed upon moving to the use of homochiral NHC pre-ligands in the reaction. Three-component couplings proceeded smoothly to afford the corresponding 1,5-dienes with excellent regioselectivity, stereoselectivity and enantioselectivity in moderate to good yields. This strategy was then used in the gram-scale synthesis of complex natural products. In contrast to Brown’s (Scheme 3.11) and Tsuji’s (Scheme 3.12) reports, Hoveyda and co-workers showcased a broad substrate scope with protected alcohol (entry a), amine (entry b), Weinreb amide (entry c) and alkyne (entry d) substrates undergoing efficient transformations.

![Scheme 3.13 Hoveyda’s copper-catalysed enantioselective allyl-allyl coupling.](image)

When considering a three-component coupling using the diboron reagent, allenes and imines, to our knowledge there exists just one example of a comparable protocol. Morken reported the asymmetric palladium-catalysed diborylation of allenes, with in situ trapping of the intermediate allyl-borane species with imines (Scheme 3.14). Typically, products were not isolated as the vinylboronate, but oxidised to the ketone (entries a - c): there were only three examples of isolated vinylboronate adducts (for example entry d). Nonetheless, the reaction provided Mannich-type adducts after oxidation with excellent enantioselectivities and in moderate yields.
Scheme 3.14 Morken’s palladium-catalysed aminoaalkylation. a No oxidation by H₂O₂.

3.3 The copper-catalysed borylative allylation of imines

After carefully considering Hoveyda’s conditions (Scheme 3.7), we decided to switch from the use of moisture and light sensitive CuCl, to a well-defined, easy to handle, bench-stable and commercially available pre-catalyst IPrCuCl₁₂₇, which we hoped would control the regioselectivity of the reaction. Commencing our optimisation of the reaction using phenylallene ₉₇ₐ, we first investigated the addition of base to the reaction as we had found this to be key in the analogous copper-catalysed silylative allylation of imines (vide supra). Initially, we found that the use of 6 mol% of KOT-Bu with N-phenyl aromatic imine ₁₃₅ₐ delivered the corresponding homoallylic amine with 27% conversion and 57:43 dr (Table 3.1, entry 1). We observed that by increasing the amount of base present in the reaction to 1 equivalent (entries 2 - 5), we could effect near complete conversion (94%) with 62:38 dr. We found that the use of Cs₂CO₃ in the reaction led to 41% conversion (cf Table 2.5). Suspecting a strong dependence of the diastereoselectivity of the reaction on the substrate, we surveyed cyclohexylallene ₁₁₅ᵈ in the reaction (entry 6), and found a notable increase in the dr to 77:23 along with complete conversion in just 1.5 hours. We then probed the effect of lowering the temperature on both the diastereoselectivity and efficiency (entries 7 - 10), and found that at lower temperatures the diastereoselectivity increased but at the expense of the conversion. This led us to observe that at -42 °C, although the reaction proceeded with 92:8 dr, there was only 12% conversion after 3 hours (entry 8), and at -78 °C, the reaction did not proceed at all (entry 9). As a compromise, we settled with starting the reaction at -78 °C and leaving it to warm to ambient temperature over 18 hours (entry 10). This resulted in 100% conversion and 85:15 dr.
With optimised conditions in hand, working with a well organised and talented MChem student Kay Chor Yeung, we set about evaluating the substrate scope of the reaction (Scheme 3.15). In general, it was found that the reaction was high yielding and delivered compounds with moderate to excellent diastereoselectivity and with complete regioselectivity. A range of allenes were tolerated, yielding adducts with linear alkyl (155d and t), phenyl (155a), and 1,1-disubstitution (155p-s, u and v). 1,1-Disubstitution in the starting allene allowed for the construction of quaternary centres in the three-component coupling (155p-s, u and v). The use of the synthetically useful para-methoxyphenyl protecting group on nitrogen was adopted, and a range of aryl substituted imines were assessed. It was found that the reaction tolerated p-OMe (155k and r), p-CF₃ (155l) and p-Br (155m and s) substituents on the aryl group of the imine, affording adducts with up to 85:15 dr and in up to 97% yield. Oxygen (155n and p) and sulfur (155o and q) heterocyclic imines were also well tolerated in high yielding reactions. When the steric bulk of the imine was increased, an increase in the diastereoselectivity of the reaction was noted, with i-Pr (155h), t-Bu (155i), 1-naphthyl (155e) and o-tolyl (155g) substituted products.
being afforded with excellent diastereoselectivity (between 94:6 and >98:2 diastereoselectivity).

An illustration of the steric influence of the imine can be found in the comparison between products 155d and 155t, where the use of an o-tolyl substituted imine significantly increases the diastereoselectivity of the reaction from 79:21 to 92:8 dr. Interestingly, the t-Bu imine (155i) gave only 6% isolated yield, while the i-Pr imine (155h) afforded a low 37% yield, and the mesityl imine (155f) displayed no reactivity. Although the i-Pr imine may be subject to imine-enamine tautomerisation under these conditions (due to the comparatively low imine-enamine tautomerisation energy barrier), these results suggest that the reaction was slowed significantly by the use of bulky groups on the imine. In particular, the t-Bu substituted imine allowed for just one catalyst turn-over, suggesting a very slow transmetalation event involving the Cu-N bond and B$_2$pin$_2$ reagent when using this bulky imine.

Pleasingly, all the imines with an N-Ar group afforded products that were stable to silica gel column chromatography, and showed no signs of proto-deborylation - a problem plaguing related vinylboron containing compounds. However, the use of N-benzyl-protected imines afforded products that decomposed on silica, and so an oxidative workup was used to facilitate...
product isolation (Figure 3.2). Thus, benzyl-protected Mannich adducts could be accessed after the three component coupling and subsequent oxidation, in good to excellent yields and diastereoselectivity (156a and b).

![Mannich-type products isolated after oxidative workup. Conditions: the copper-catalysed process was completed as described in Scheme 3.15, then the crude product was treated with H$_2$O$_2$ (5 equiv) and NaOH (5 equiv) in THF/H$_2$O at 0 °C for 20 min.]

A reaction starting with 0.5 g (2.2 mmol) of imine 135d yielded 1.0 g of the corresponding adduct 153g, in 97% yield, and with comparable diastereocontrol to that achieved in the smaller scale reaction (Scheme 3.16), demonstrating the applicability of the protocol to preparative scale synthesis.

![A preparative scale copper-catalysed borylative allylation of an imine.]

Interestingly, upon examination of the $^{11}$B NMR spectra of our products, we found the chemical shift of the boron atom to be in the range of -2.9 ppm to 11 ppm, instead of the more usual 35 ppm for a Bpin group. This suggested the existence of a dative coordination from the non-bonding lone pair on nitrogen to the unoccupied p-orbital on boron, to give an sp$^3$ hybridised boron, consistent with the $^{11}$B NMR data.$^{180}$ Intriguingly, upon X-ray crystallographic analysis of a single crystal of 155v, we found there to be no nitrogen to boron interaction in the solid state, despite a $^{11}$B NMR shift of 11 ppm for this compound (Figure 3.3). Instead a hydrogen bond between the N-H and oxygen of the pinacol unit was observed.
It was found that upon treatment with an equivalent amount of triflic acid, 155g afforded single crystals suitable for X-ray crystallographic analysis, and the relative stereochemistry of the adducts was confirmed (Scheme 3.17). Interestingly, this highlights the trans relationship found in the products, a different relative stereochemistry when compared to the silylative allylation of aldehydes (vide supra). This likely relates to a change in transition state when using imines in the reaction, and highlights the steric and electronic differences between aldehydes and imines (see section 3.1 for a discussion).

During this work, it was found that imines containing sulfinyl, phosphoryl and Boc N-protecting groups displayed no reactivity. This was an unexpected observation considering the electron-deficient nature of these imines. It was speculated that this was due to an unproductive substrate coordination to the copper catalyst. A competition experiment was designed in which, to a solution containing the copper pre-catalyst, B$_2$pin$_2$, KOT-Bu, N-tosyl imine 158 and allene 115d were added with stirring, followed by the addition of N-phenyl imine 135a 30 seconds later (Scheme 3.18). The 30 second delay between additions was intended to allow for N-tosyl coordination to copper. The N-phenyl imine is known to undergo reaction (Scheme 3.15), and so it was hypothesised that if no reaction was observed under these conditions, it would be due to the
presence of the \( N \)-tosyl group in the reaction. As expected, no reaction was observed, and both imines were observed quantitatively in the crude \(^1\)H NMR.

\[ 
\text{Competition experiment:} 
\]

\[
\begin{aligned}
\text{N-Tosyl imine (158)} & \quad + \quad \text{N-phenyl imine (135a)} \\
\text{Added after 30 seconds} & \quad \xrightarrow{\text{THF, rt, 18 h}} \quad \text{Product (155b or 159)} 
\end{aligned}
\]

Scheme 3.18 An \( N \)-tosyl and \( N \)-phenyl imine competition reaction.

This led us to propose coordination adduct 161 (Scheme 3.19), in which the \( N \)-tosyl imine chelates to the copper catalyst \textit{via} both the nitrogen and oxygen atoms. This leads to a tetrahedral, 18 electron copper complex that would be coordinatively saturated and thus unable to coordinate or add into an allene.

Interestingly, the lack of reactivity for this imine class was not accompanied by any 1,2-addition of boron into the imine - a potentially competing reaction that was not observed in any of the three-component couplings. A survey of the related literature surrounding copper-catalysed addition of Bpin or allyl groups to imines suggested the use of a proton source is key for catalyst turnover (owing to the slow transmetalation of the subsequent Cu-N bond with B\(_2\)pin\(_2\)). However, our studies investigating the use of an alcohol additive bore no fruit. A reaction in which addition of a stoichiometric amount of the copper reagent to 132, to generate \textit{in situ} the allylcopper intermediate 162, followed by addition of the \( N \)-tosyl imine 158 generated the \( N \)-tosyl adduct 163 in 56% yield (Scheme 3.20). This iterative reaction sequence avoided the possibility of forming an unproductive substrate-catalyst complex, and allowed for the allylcopper species to be effectively trapped by the \( N \)-tosyl imine.
3.4 Summary

In conclusion, we have successfully expanded on the theme of the copper-catalysed three-component couplings established in chapter 2, and developed a protocol for the copper-catalysed borylative allylation of imines. This work features the use of a bench-stable copper pre-catalyst, and allows for the allylation of imines in a convenient, regioselective, diastereoselective and high yielding reaction.
Chapter four – Overall summary and future work

4.1 Summary

An affordable copper-catalysed protocol for the enantioselective silylation of lactone, lactam and amide substrates has been developed, providing silylated adducts with up to >99:1 er in good yields (Scheme 4.1). Further investigation showed that kinetic resolution and enolate trapping events could be used to rapidly build molecular complexity, furnishing valuable enantio enriched chiral building blocks with two or three contiguous stereocenters.

![Scheme 4.1 Copper-catalysed asymmetric silylation of lactones, lactams and amides.](image)

We have illustrated the synthetic utility of this catalytic processes by carrying out the expedient asymmetric target syntheses of the natural product (+)-blastmycinone and the drug oxiracetam (Scheme 4.2).

![Scheme 4.2 Asymmetric synthesis of (+)-blastmycinone and (R)-oxiracetam.](image)

We have also developed the first copper-catalysed silylation of allenes using a commercial silylborane reagent (Scheme 4.3). When using aryl substituted allenes, the use of an unusual 7-
membered NHC ligand affords useful vinylsilane building blocks with high regioselectivity, efficiency and with a large functional group tolerance. By increasing the size of the silyl group transferred, and with judicious ligand selection, we could effect a switch in regioselectivity for alkyl substituted allenes to provide access to allylsilanes. The allylcopper intermediates can be intercepted by aldehydes in a highly diastereoselective three-component coupling to furnish homoallylic alcohols in moderate to good yield.

Scheme 4.3 Copper-catalysed regioselective silylation of allenes and trapping with aldehydes.

We expanded upon this theme, with the copper-catalysed three-component coupling of boron, allenes and imines (Scheme 4.4). This process affords homoallylic amines with a vinylborane motif in excellent yield, regioselectivity and diastereoselectivity.
4.2 Future work

After the unexpected isolation of 59 and 60 encountered when conducting the copper-catalysed silyl transfer to lactones with a domino aldol reaction when using an excess of base, it was rationalised that the reaction was proceeding via homoenolate 61. With this in mind, we propose the investigation of a dynamic kinetic resolution as shown in Scheme 4.5. Here, we note Buchwald’s first copper-catalysed dynamic kinetic resolution of unsaturated butenolides, demonstrating that such a concept has precedent.\(^4\)\(^8\) We propose that treatment of racemic 5-substituted butenolide 52h or 166 may lead to a rapidly racemising system under equilibrium, which when exposed to our enantioselective copper-catalysed conditions would result in a dynamic kinetic resolution, affording 5-substituted β-silyl lactones such as 167.
Perhaps the most obvious avenue for future investigation into the three-component coupling methodology is the pursuit of an enantioselective variant, providing access to enantioenriched homoallylic amines 158 (Scheme 4.6). Both Ma\textsuperscript{171} and Hoveyda\textsuperscript{175} have shown bidentate phosphine ligands to be an effective controller for the copper-catalysed regioselective borylation of allenes (such as 150 and 151). There are a large number of homochiral bidentate phosphine ligands commercially available, many of which have proven to be invaluable with regards to asymmetric copper catalysis. With this in mind, future efforts will centre on investigating the effects of a variety of homochiral bidentate phosphine ligands on the enantioselectivity of the reaction.
Having successfully established access to allylsilanes via the silylation of alkyl substituted allenes, we proposed the intermediacy of a vinylcopper species in the reaction (Scheme 2.30). Brown’s work on the carboboration of alkenes has prompted us to ask if this intermediate copper species can be used in a palladium-catalysed cross-coupling (Scheme 4.7).\textsuperscript{181,182} A plausible mechanistic proposal would first allow generation of copper-silicon complex II from reaction of I, the silylborane reagent and base. After regioselective insertion of the allene into the copper-silicon bond, affording III, the vinylcopper intermediate can then transmetalate with palladium species IV to give vinylpalladium species V which can undergo reductive elimination to afford VI and palladium species VII. This copper-palladium synergistic catalysis would allow for carbosilylation reactions of allenes, furnishing trisubstituted allylsilanes 171, a process which has previously relied on the use of tin precursors (Scheme 2.9), stoichiometric Grignard reagents (Scheme 2.10), reactive acid chloride reagents (Scheme 2.11) or tethered electrophiles in carbocyclisation reactions (Scheme 2.12 and Scheme 2.13).
One of the attractions of the three-component couplings we have developed is the ease of divergent reactivity. Future efforts will develop the use of new combinations of heteroatom reagents, electrophiles and \( \pi \)-systems (Scheme 4.8). To date, the reactivity of sulfurborane\(^{183}\) reagent 172 is completely unexplored in metal catalysis, whilst there is just one very recent preliminary result of the use of phosphinoborane\(^{184}\) 173 in metal catalysis. We envisage the use of these reagents, in conjunction with the copper-catalysed systems we have developed, would allow for the facile introduction of sulfur and phosphorous into unsaturated organic molecules (180 and 181 for example).

The use of nitrogen containing compound 174 has attracted a lot of recent attention in copper-catalysis as an electrophilic amination reagent, the use of 174 in a three-component allylation reaction seems a natural progression, providing access to allylic amines such as 179.\(^{185-187}\) Beller’s work on cyanation reactions has provided a convenient electrophilic cyanating reagent 175.\(^{188}\) We propose this could be utilised to provide access to useful allylnitrile motifs such as 180. The 3-hydroxy-2-oxindole heterocyclic motif 178 has the potential for rich structural diversity, and is present in many biologically relevant molecules.\(^{190}\) Isatin 176 possesses a strained cyclic dicarboxyl system as well as a potentially coordinating cyclic amide group. With this in mind, we expect this class of \( \alpha \)-keto amide to be a particularly receptive electrophile to quench the allylcopper species generated in our reactions. With the use of various combinations of
heteroatom borane reagents and electrophiles, it can be seen a wide variety of transformations can be potentially accessed. The conceptual scope of the process increases even further when considering enantioselective variants of these processes.

**General copper-catalysed three-component coupling:**

```
\begin{center}
\begin{tikzpicture}
\node (A) at (0,0) {\text{R} = \text{Cu} \rightarrow \text{X}};
\node (B) at (1,0) {\text{R}};
\node (C) at (2,0) {\text{X}};
\node (D) at (3,0) {\text{E}};
\node (E) at (4,0) {\text{\text{Cu}}};
\draw[->] (B) -- (C);
\draw[->] (C) -- (D);
\draw[->] (D) -- (E);
\end{tikzpicture}
\end{center}
```

- Generality of heteroatom nucleophile?
- Generality of electrophile?
- Regioselectivity of insertion?
- Regioselectivity of trapping?
- Enantioselective variant?
- Efficiency?
- Substrate scope?

**Heteroatom reagents to investigate:**

- PhS–B
- Ph₂P–B
- R₂N–OBz
- Ph

**Electrophiles to investigate:**

- sulfur
- phosphorus
- nitrogen
- nitrile
- isatin

**Selected examples of proposed adducts:**

- 172
- 173
- 174
- 175
- 176

Scheme 4.8 A selection of future reagents to investigate.

In addition to the three-component couplings of allenes proposed above, we also put forward the synthetic utility of 1,3-enyne substrates (Scheme 4.9). Few reports have addressed the reactivity of silylborane reagents with enyne substrates, and there are no disclosures relating to copper-catalysis.\(^{191}\) Here, we propose that a ligand controlled regioselective insertion of the alkene into the copper-silicon bond would lead to a propargyl copper species I. It is plausible that I would be in equilibrium with isomer II, and subsequent regioselective trapping with an electrophile (we propose either an aldehyde or imine) would furnish allene 183 or alkyne 184.\(^{192}\) The nature of this reaction would allow for an enantioselective variant to be developed, and could provide access to enantioenriched allenic compounds. Moreover, the exciting possibility of merging the proposed heteroatom reagents and electrophiles found in Scheme 4.8 with enyne substrates using copper-catalysis leads to further structural diversity.
Scheme 4.9 Copper-catalysed silylation of enyne substrates.
Chapter five - Experimental

All experiments were performed under an atmosphere of nitrogen, using anhydrous solvents, unless stated otherwise. THF was distilled from sodium / benzophenone. Dichloromethane was distilled from CaH₂.

¹H NMR and ¹³C NMR were recorded using 300, 400 and 500 MHz spectrometers, with chemical shift values being reported in ppm relative to residual chloroform (δ_H = 7.27 or δ_C = 77.2) as internal standards. All coupling constants (J) are reported in Hertz (Hz). Mass spectra were obtained using positive and negative electrospray (ES±) or gas chromatography (GC) methodology. Infra-red spectra were recorded as evaporated films or neat using a FT/IR spectrometer. Column chromatography was carried out using 35 – 70 m, 60A silica gel. Routine TLC analysis was carried out on aluminium sheets coated with silica gel 60 F254, 0.2 mm thickness. Plates were viewed using a 254 mm ultraviolet lamp and dipped in aqueous potassium permanganate or p-anisaldehyde.

Chiral HPLC was carried out with Chiralcel OD-H, Chiralcel OJ, Chiralpak AD-H, Chiralpak IA or Chiralpak IB columns as indicated.

Reagents were either purchased directly from commercial suppliers or prepared according to literature procedures.

Experimental procedures for Chapter 1.3

PhMe₂SiBpin was prepared using a literature procedure.¹⁹³ 2-Chloro-3-iodoprop-1-ene was prepared using a literature method.¹⁹⁴ (Furan-2-ylxy)trimethylsilane was distilled before use.

Lactone substrates:

Furan-2(5H)-one (20a) and 5,6-dihydro-2H-pyran-2-one (20c) were purchased from commercial suppliers, and used as received. 6,7-Dihydrooxepin-2(5H)-one (20d), (Z)-5,6,7,8-tetrahydro-2H-oxocin-2-one (20f), benzo[b]oxepin-2(5H)-one (20e), 5-methylfuran-2(5H)-one (52a), 5-ethylfuran-2(5H)-one (52b), 5-butylfuran-2(5H)-one (52c), 5-pentylfuran-2(5H)-one (52d), 5-allylfuran-2(5H)-one (52e), 5-phenylfuran-2(5H)-one (52h) and 5-benzylfuran-2(5H)-one (52g) were prepared using literature procedures.
Ligands: 16a, 16b, 17a, 19, 41, 48, 49, 50 were prepared using literature routes.\textsuperscript{46,47}

Representative procedure for the synthesis of imidazolinium salts:

General procedure 1:

2-(2-Bromophenyl)anthracene (45)

![Structure of 2-(2-Bromophenyl)anthracene (45)]

Bromo-2-iodobenzene (1.27 g, 4.50 mmol, 1 equiv), anthracen-2-ylboronic acid (1.0 g, 4.50 mmol, 1 equiv), K$_2$CO$_3$ (1.24 g, 9.01 mmol, 2 equiv) and Pd(PPh$_3$)$_4$ (156 mg, 0.135 mmol, 3 mol%) were placed in a microwave vial and capped. Toluene (5 mL) and H$_2$O (5 mL) were added and the reaction mixture was irradiated in a microwave reactor at 150 °C for 3 hours. The solution was allowed to cool, the organic layer was then dried (Na$_2$CO$_3$) and concentrated \textit{in vacuo}. The crude mixture was then purified by column chromatography (silica gel, hexanes) to yield 2-(2-bromophenyl)anthracene as a cream solid (1.29 g, 3.87 mmol, 86%).

MS (ES$^+$) $m/z$: 333 (M+H$^+$); HRMS calcd for C$_{20}$H$_{13}$Br: 332.0195. Found: 332.0183; $\nu_{max}$ (thin film/cm$^{-1}$): 3052, 3018, 2963, 2926, 1673, 1624, 1591, 1560, 1528, 1469, 1452, 1437, 1422, 1360, 1327, 1312, 1285, 1274, 1248, 1216, 1157, 1117, 1023, 1011; $^1$H NMR (300 MHz, CDCl$_3$) $\delta$ ppm 7.24 - 7.31 (2 H, m, ArH), 7.43 (1 H, td, $J = 7.3$, 1.1 Hz, ArH), 7.47 - 7.49 (1 H, m, ArH) 7.50 (1 H, d, $J = 3.2$ Hz, ArH), 7.57 (1 H, dd, $J = 8.8$, 1.6 Hz, ArH), 7.74 (1 H, dd, $J = 8.1$, 0.9 Hz, ArH), 7.97 - 8.10 (4 H, m, ArH), 8.46 (2 H, s, ArH); $^{13}$C NMR (126 MHz, CDCl$_3$) $\delta$ 125.5 (ArCH), 126.1 (ArCH), 126.6 (ArCH), 127.4 (ArCH), 127.5 (ArCH), 127.6 (ArCH), 128.2 (ArCH), 128.3 (ArCH), 128.9 (ArCH), 130.8 (ArC), 131.3 (ArC), 131.5 (ArCH), 132.0 (ArC), 133.2 (ArCH); mp 139 °C (hexane/CH$_2$Cl$_2$).

General procedure 2:

$(1S,2S)$-$N_1,N_2$-bis(2-(Anthracen-2-yl)phenyl)-1,2-diphenylethane-1,2-diamine (46)

![Structure of $(1S,2S)$-$N_1,N_2$-bis(2-(Anthracen-2-yl)phenyl)-1,2-diphenylethane-1,2-diamine (46)]

2-(2-Bromophenyl)anthracene (1.29 g, 3.87 mmol, 2.2 equiv), $(1S,2S)$-1,2-diphenylethane-1,2-diamine (374 mg, 1.76 mmol, 1 equiv), NaOt-Bu (372 mg, 3.87 mmol, 2.2 equiv), rac-BINAP (219
mg, 0.352 mmol 20% mol) and Pd(dba)$_2$ (101 mg, 0.176 mmol, 10% mol) were added to a microwave vial and the vial was capped. The vial was then evacuated and backfilled with argon three times. $\alpha$, $\alpha$, $\alpha$-Trifluorotoluene (10 mL) was then added and the reaction mixture irradiated in a microwave reactor at 110 °C for 6 hours. The reaction mixture was allowed to cool, filtered through a plug of celite and then concentrated in vacuo. The crude mixture was then purified by column chromatography (silica gel, 5% EtOAc in Hexanes) to afford (1S,2S)-N$_1$,N$_2$-bis(2-(anthracen-2-yl)phenyl)-1,2-diphenylethane-1,2-diamine as a thick yellow oil (757 mg, 1.056 mmol, 60%).

MS (ES$^+$) m/z: 717 (M+H$^+$); HRMS calcd for C$_{54}$H$_{41}$N$_2$: 717.3265. Found: 717.3271; $\alpha$$_{D}^{25}$ = -117.3 (c = 1 in CHCl$_3$); $\nu$$_{max}$ (thin film/cm$^{-1}$): 3408, 3050, 3021, 2955, 2924, 2854, 1626, 1600, 1578, 1502, 1452, 1306, 1275, 1215, 1160, 1132, 1068, 1025; $^1$H NMR (300 MHz, CDCl$_3$) $\delta$ ppm: 4.6 (2 H, s, CH$_2$), 6.2 (2 H, d, $J$ = 7.2 Hz, ArH), 6.7 (2 H, t, $J$ = 7.3 Hz, ArH), 6.8 - 6.9 (4 H, m, ArH), 6.9 - 7.0 (6 H, m, ArH), 7.0 - 7.1 (2 H, m, ArH), 7.1 (2 H, dd, $J$ = 7.3, 1.5 Hz, ArH), 7.3 (2 H, d, $J$ = 8.9 Hz, ArH), 7.5 - 7.6 (4 H, m, ArH), 7.8 (2 H, s, ArH), 8.0 (2 H, d, $J$ = 8.7 Hz, ArH), 8.0 - 8.1 (4 H, m, ArH), 8.4 (2 H, s, ArH), 8.5 (2 H, s, ArH); $^{13}$C NMR (75 MHz, CDCl$_3$) $\delta$ ppm: 63.9 (CH), 125.6 (ArC), 125.7 (ArC), 126.2 (ArC), 126.4 (ArC), 126.7 (ArC), 127.3 (ArC), 127.5 (ArC), 128.2 (ArC), 128.3 (ArC), 128.5 (ArC), 128.6 (ArC), 128.8 (ArC), 130.7 (ArC), 131.8 (ArC), 131.9 (ArC), 132.0 (ArC).

**General procedure 3:**

(4S,5S)-1,3-bis(2-(Anthracen-2-yl)phenyl)-4,5-diphenyl-4,5-dihydro-1H-imidazol-3-ium tetrafluoroborate (47)

(15,2S)-N$_1$N$_2$-bis(2-(Anthracen-2-yl)phenyl)-1,2-diphenylethane-1,2-diamine (757 mg, 1.06 mmol, 1 equiv), ammonium tetrafluoroborate (166 mg, 1.58 mmol, 1.5 equiv) and triethyl orthoformate (2.34 mL) were heated to 130 °C for 4 hours with stirring. The reaction mixture was concentrated in vacuo and purified by column chromatography (silica gel, 80% EtOAc in hexanes) to afford (4S,5S)-1,3-bis(2-(anthracen-2-yl)phenyl)-4,5-diphenyl-4,5-dihydro-1H-imidazol-3-ium tetrafluoroborate as a yellow solid, which was then triturated with CH$_2$Cl$_2$/Hexane to give a cream-white solid (766 mg, 0.940 mmol, 89%).

MS (ES$^+$) m/z: 728 (M-BF$_4$+H$^+$); HRMS calcd for C$_{55}$H$_{39}$N$_2$: 727.3108. Found: 727.3109; $\alpha$$_{D}^{28}$ = 50.5 (c = 1 in CHCl$_3$); $\nu$$_{max}$ (thin film/cm$^{-1}$): 3058, 2961, 2924, 2853, 1731, 1672, 1597, 1573, 1530, 1495,
1456, 1304, 1265, 1217, 1185, 1158, 1057; $^1$H NMR (500 MHz, CDCl$_3$) $\delta$ ppm 4.63 (2 H, s, CHCH), 6.44 (4 H, d, $J$ = 7.6 Hz, ArH), 6.66 (4 H, t, $J$ = 7.3 Hz, ArH), 6.91 (2 H, t, $J$ = 7.6 Hz, ArH), 7.25 - 7.35 (6 H, m, ArH), 7.40 - 7.47 (4 H, m, ArH), 7.54 - 7.59 (4 H, m, ArH), 8.05 - 8.10 (4 H, m, ArH), 8.11 - 8.18 (4 H, m, ArH), 8.48 (2 H, s, ArH), 8.68 (2 H, br. s, ArH), 9.39 (1 H, s, N=CH); $^{13}$C NMR (126 MHz, CDCl$_3$) $\delta$ 75.1 (CH), 126.1 (ArCH), 126.3 (ArC), 126.4 (ArCH), 127.1 (ArCH), 127.7 (ArCH), 128.2 (ArCH), 128.3 (ArCH), 128.5 (ArCH), 128.8 (ArCH), 129.3 (ArCH), 129.5 (ArCH), 129.6 (ArCH), 130.0 (ArCH), 130.6 (ArC), 131.2 (ArCH), 131.2 (ArC), 131.7 (ArC), 132.2 (ArC), 132.4 (ArC), 133.6 (ArC), 134.5 (ArC), 137.8 (ArC), 157.4 (N=CH); mp 190 °C (hexane/CH$_2$Cl$_2$).

2-(2-Bromo-4-isopropylphenyl)naphthalene

Prepared according to General Procedure 1, on a 2.29 mmol scale, column chromatography (Hexanes) afforded the title compound as a pale yellow solid (375 mg, 1.15 mmol, 50%).

MS (ES$^+$) m/z: 324 (M); HRMS calcd for C$_{19}$H$_{17}$Br: 324.0508. Found: 324.0504; $\nu_{\text{max}}$ (thin film/cm$^{-1}$): 3053, 2958, 2924, 2866, 1909, 1602, 1490, 1459, 1397, 1362, 1345, 1325, 1268, 1208, 1191, 1129, 1055, 1020, 1012; $^1$H NMR (300 MHz, CDCl$_3$) $\delta$ ppm 1.41 (6 H, d, $J$ = 7.0 Hz, (CH$_3$)$_2$), 3.03 (1 H, spt, $J$ = 6.9 Hz, Ar-CH(CH$_3$)$_2$), 7.34 (1 H ,dd, $J$ = 7.8, 1.6 Hz, ArH), 7.45 (1 H, d, $J$ = 7.9 Hz, ArH), 7.60 (2 H, dd, $J$ = 6.2, 3.4 Hz, ArH), 7.69 (2 H, dd, $J$ = 8.7, 1.5 Hz, ArH) 7.93 - 8.02 (4 H, m, ArH); $^{13}$C NMR (126 MHz, CDCl$_3$) $\delta$ 23.8 (CH$_3$), 33.6 (Ar-CH(CH$_3$)$_2$), 122.6 (ArC), 125.6 (ArCH), 126.1 (ArCH), 127.2 (ArCH), 127.6 (ArCH), 127.7 (ArCH), 128.1 (ArCH), 128.2 (ArCH), 131.1 (ArCH), 131.4 (ArCH), 132.5 (ArC), 133.0 (ArC), 138.6 (ArC), 139.8 (ArC), 149.9 (ArC); mp 79 °C (hexane).

(15,25)-N$_1$N$_2$-bis(5-Isopropyl-2-(naphthalen-2-yl)phenyl)-1,2-diphenylethane-1,2-diamine

Prepared according to General Procedure 2, on a 0.520 mmol scale, column chromatography (5% EtOAc in Hexanes) afforded the title compound as a thick yellow oil (111 mg, 0.158 mmol, 30%).
Chapter five

MS (ES') m/z: 701 (M+H+); HRMS calcd for C_{52}H_{49}N_{2}: 701.3891. Found: 701.3885; [α]_D^{28} = -190.1 (c = 1 in CHCl₃; v_max (thin film/cm⁻¹): 3056, 3028, 2957, 2929, 2865, 2241, 2165, 1733, 1717, 1699, 1684, 1653, 1636, 1609, 1566, 1541, 1520, 1507, 1499, 1456, 1424, 1362, 1344, 1298, 1271, 1197, 1271, 1197, 1142, 1129; ^1H NMR (300 MHz, CDCl₃) δ ppm 0.96 (6 H, d, J = 6.8 Hz, Ar-CH(CH₃)₂), 1.01 (6 H, d, J = 6.8 Hz, Ar-CH(CH₃)₂), 2.60 (2 H, spt, J = 6.8 Hz, Ar-CH(CH₃)₂), 4.54 (2 H, s, CHCH), 6.10 (2 H, br. s., NH), 6.58 (2 H, d, J=7.7 Hz, ArH), 6.86 - 7.11 (4 H, m, ArH), 7.32 (2 H, d, J = 8.3 Hz, ArH), 7.50 - 7.59 (4 H, m, ArH), 7.63 (2 H, s, ArH), 7.73 - 7.83 (4 H, m, ArH), 7.86 - 7.95 (2 H, m, ArH); ^13C NMR (75 MHz, CDCl₃) δ ppm 23.4 (Ar-CH(CH₃)₂), 23.9 (Ar-CH(CH₃)₂), 33.8 (Ar-CH(CH₃)₂), 63.7 (CH), 110.5 (ArC), 115.4 (ArC), 126.0 (ArCH), 126.2 (ArCH), 126.6 (ArCH), 127.3 (ArCH), 127.7 (ArCH), 127.8 (ArCH), 128.0 (ArCH), 128.4 (ArCH), 128.4 (ArCH), 129.7 (ArCH), 132.4 (ArC), 133.8 (ArC), 136.6 (ArC), 139.6 (ArC), 143.6 (ArC), 149.1 (ArC).

(45,5S)-1,3-bis(2-(Anthracen-2-yl)phenyl)-4,5-diphenyl-4,5-dihydro-1H-imidazol-3-ium tetrafluoroborate (51)

Prepared according to General Procedure 3, on a 0.158 mmol scale, column chromatography (80% EtOAc in Hexanes) afforded the title compound as a yellow solid (107 mg, 0.134 mmol, 85%).

MS (ES') m/z: 711 (M-BF₄). HRMS calcd for C_{53}H_{47}N_{2}: 711.3734. Found: 711.3739; [α]_D^{28} = -117.3 (c = 1 in CHCl₃; v_max (thin film/cm⁻¹): 3036, 2961, 2928, 2871, 1623, 1605, 1660, 1497, 1457, 1415, 1375, 1338, 1280, 1215, 1054; ^1H NMR (500 MHz, CDCl₃) δ ppm 1.11 (6 H, d, J = 6.6 Hz, Ar-CH(CH₃)₂), 1.15 (6 H, d, J = 6.9 Hz, Ar-CH(CH₃)₂), 2.83 (2 H, spt, J = 6.6 Hz, Ar-CH(CH₃)₂), 4.57 (2 H, s, CHCH), 6.32 (4 H, d, J = 7.9 Hz, ArH), 6.76 (4 H, t, J = 7.6 Hz, ArH), 6.86 (2 H, br. s, ArH), 7.07 (2 H, t, J = 7.3 Hz, ArH), 7.21 (4 H, apparent q, J = 7.6 Hz, ArH), 7.48 (2 H, d, J = 7.9 Hz, ArH), 7.64 - 7.71 (4 H, m, ArH), 7.96 - 8.04 (6 H, m, ArH), 8.12 (2 H, d, J = 8.8 Hz, ArH), 9.24 (1 H, br. s, N=CH); ^13C NMR (126 MHz, CDCl₃) δ ppm 23.0 (Ar-CH(CH₃)₂), 23.8 (Ar-CH(CH₃)₂), 33.4 (Ar-CH(CH₃)₂), 75.2 (CH), 127.0 (ArCH), 127.0 (ArCH), 127.2 (ArCH), 127.8 (ArCH), 127.9 (ArCH), 128.1 (ArCH), 128.5 (ArCH), 128.6 (ArCH), 128.8 (ArCH), 129.0 (ArCH), 129.7 (ArC), 131.0 (ArCH), 131.3 (ArC), 132.8 (ArC), 133.5 (ArC), 133.8 (ArC), 135.3 (ArC), 135.8 (ArC), 150.2 (ArC), 156.9 (N=CH); mp 229 °C (hexane/CH₂Cl₂).
General procedure 4 for Cu-catalysed 1,4-conjugate silyl additions:

\((R)-4-(\text{Dimethyl(phenyl)silyl})\text{dihydrofuran-2(3H)-one})^{202} (36a)\)

In an oven-dried vial equipped with a stirrer bar, \((4S,5S)-1,3\text{-bis}(2-(naphthalen-2-yl)phenyl)-4,5\)-diphenyl-4,5-dihydro-1H-imidazol-3-ium tetrafluoroborate salt 41 (7.9 mg, 0.011 mmol, 3.3 mol%), NaOt-Bu (2.1 mg, 0.022 mmol, 6.6 mol%) and CuCl (1 mg, 0.010 mmol, 3 mol%) were placed and 1.5 mL of THF was added. The solution was allowed to stir for 3 hours at 50 °C under nitrogen and then filtered through a short plug of oven-dried Celite under nitrogen. PhMe\(_2\)SiBpin (0.1 mL, 0.367 mmol, 1.1 equiv) was added to the filtrate and the reaction stirred for 15 min. The solution was then cooled to \(-78 \degree C\), and a solution of furan-2(5H)-one (28 mg, 0.334 mmol, 1 equiv) in dry THF (0.5 mL) was added and the mixture was allowed to stir for 3.5 hours at \(-78 \degree C\), after which the reaction was quenched by the addition of H\(_2\)O (0.5 mL) and allowed to warm to room temperature overnight. The aqueous layer was then washed with Et\(_2\)O (3 x 2 mL) and dried over MgSO\(_4\). Concentration \textit{in vacuo} and purification by column chromatography (silica gel, 20% EtOAc in hexanes) yielded \((R)-4-(\text{dimethyl(phenyl)silyl})\text{dihydrofuran-2(3H)-one})\) as a pale yellow oil (62.5 mg, 0.283 mmol, 85%).

\([\alpha]_D^{28} = -6.93 \ (c = 1 \ \text{in CHCl}_3)\) for a sample of 93:7 er. Lit: \([\alpha]_D^{20} = -5.64 \ (c 0.99, \text{CHCl}_3)\) for a sample of \(>99.5:0.5\) er.\(^{202}\)

\(\text{H NMR (400 MHz, CDCl}_3) \delta \text{ ppm 0.37 (3 H, s, SiCH}_3\text{), 0.38 (3 H, s, SiCH}_3\text{), 2.07 (1 H, ddt, J = 12.8, 11.3, 8.6 Hz, SiCH), 2.30 (1 H, dd, J = 17.4, 12.6 Hz, CH}_2\text{C}=\text{O), 2.52 (1 H, dd, J = 17.4, 8.8 Hz, CH}_2\text{C}=\text{O), 4.12 (1 H, dd, J = 11.3, 8.8 Hz, CH}_2\text{O), 4.43 (1 H, t, J = 8.7 Hz, CH}_2\text{O ), 7.38 - 7.50 (5 H, m, ArH); 13C NMR (101 MHz, CDCl}_3) \delta \text{ ppm -5.2 (SiCH}_3\text{), -4.9 (SiCH}_3\text{), 23.8 (SiCH), 30.3 (CH}_2\text{C}=\text{O), 70.8 (CH}_2\text{O), 128.2 (ArCH), 129.9 (ArCH), 133.6 (ArCH), 135.1 (ArC), 178.0 (C}=\text{O).} \)
Chiralcel OD-H column, 28 °C, λ = 220 nm. Eluent: hexane : iso-propanol 90 : 10 v / v. Flow: 1 mL / min

**Racemate**

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**Enantiomerically enriched**

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(3R,4R)-4-(Dimethyl(phenyl)silyl)-3-methyldihydrofuran-2(3H)-one (36b)

Prepared according to General Procedure 4, on a 0.334 mmol scale, column chromatography (20% EtOAc in Hexanes) afforded the title compound as an oil (51 mg, 0.217 mmol, 65%).

Data for major diastereoisomer: MS (ES+) m/z: 257 (M+Na+). HRMS calcd for C\textsubscript{13}H\textsubscript{18}O\textsubscript{2}SiNa: 257.0968. Found: 257.0968; [α]\textsubscript{D}\textsuperscript{28} = -31.2 for a sample of 77:23 er; \nu\textsubscript{max} (thin film/cm\textsuperscript{-1}): 3070, 3051, 2957, 2933, 2898, 1767, 1455, 1428, 1379, 1296, 1252, 1193, 1169, 1115, 1077, 1051, 1012; \textsuperscript{1}H NMR (400 MHz, CDCl\textsubscript{3}) \textgreek{δ} ppm 0.40 (3 H, s, SiCH\textsubscript{3}), 0.40 (3 H, s, SiCH\textsubscript{3}), 1.19 (3 H, d, \text{J} = 7.1 Hz, CH\textsubscript{3}), 1.70 (1 H, td, \text{J} = 12.4, 8.6 Hz, SiCH), 2.35 (1 H, dq, \text{J} = 12.9, 7.1 Hz, CHC=O), 3.99 (1 H, dd, \text{J} = 12.4, 9.1 Hz, CH\textsubscript{2}), 4.31 (1 H, t, \text{J} = 8.8 Hz, CH\textsubscript{2}O), 7.42 (2 H, m, ArH), 7.47 - 7.51 (1 H, m, ArH), 7.59 - 7.64 (2 H, m, ArH); \textsuperscript{13}C NMR (126 MHz, CDCl\textsubscript{3}) \textgreek{δ} ppm -4.7 (SiCH\textsubscript{3}), -4.6 (SiCH\textsubscript{3}), 15.7 (CH\textsubscript{3}), 32.0 (SiCH), 36.8 (CHC=O), 68.7 (CH\textsubscript{2}O), 128.2 (ArCH), 129.9 (ArCH), 133.6 (ArCH), 135.1 (ArC), 180.8 (C=O).
Chiralcel OD-H column, 28 °C, λ = 220 nm. Eluent: hexane : iso-propanol 99.5 : 0.5 v / v. Flow: 1 mL / min

**Racemic**

**Enantiomerically enriched**

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**(S)-4-(Dimethyl(phenyl)silyl)tetrahydro-2H-pyran-2-one**  

Prepared according to General Procedure 4, on a 0.334 mmol scale, column chromatography (20% EtOAc in Hexanes) afforded the title compound as an oil (67 mg, 0.287 mmol, 86%).  

[$\alpha$]$_D^28$ = -23 (c = 1 in CHCl$_3$) for a sample of 84:16 er. Lit: [$\alpha$]$_D^{20}$ = -36.3 (c 1.0, CHCl$_3$) for a sample of 99:1 er.  

$^1$H NMR (400 MHz, CDCl$_3$) δ ppm 0.21 (6 H, s, Si(CH$_3$)$_2$), 1.22 - 1.34 (1 H, m, CH$_2$), 1.47 - 1.59 (1 H, m, CH$_2$), 1.68 - 1.77 (1 H, m, SiCH), 2.16 (1 H, dd, $J = 17.3$, 12.6 Hz, CH$_2$C=O), 2.44 (1 H, ddd, $J = 17.3$, 6.1, 1.5 Hz, CH$_2$C=O), 4.13 (1 H, ddd, $J = 11.1$, 9.6, 4.0 Hz, CH$_2$O), 4.22 (1 H, dt, $J = 11.6$, 4.5 Hz, CH$_2$O), 7.23 - 7.29 (3 H, m, ArH), 7.32 - 7.40 (2 H, m, ArH); $^{13}$C NMR (101 MHz, CDCl$_3$) δ ppm -5.8 (SiCH$_3$), -5.7 (SiCH$_3$), 18.4 (CH$_3$), 23.6 (SiCH), 30.9 (CH$_2$C=O), 70.3 (CH$_2$O), 128.1 (ArCH), 129.6 (ArCH), 133.8 (ArCH), 135.5 (ArC), 171.6 (C=O).
Chiralcel OD-H column, 28 °C, λ = 220 nm. Eluent: hexane : iso-propanol 90 : 10 v / v. Flow: 1 mL / min

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**Racemate**

**Enantiomerically enriched**

(S)-4-(Dimethyl(phenyl)silyloxepan-2-one (36d)

Prepared according to General Procedure 4, on a 0.334 mmol scale, column chromatography (20% EtOAc in Hexanes) afforded the title compound as an oil (71 mg, 0.288 mmol, 86%).

MS (ES⁺) m/z: 271 (M+Na⁺). HRMS calcd for C₁₄H₂₀O₂SiNa: 271.1125 Found: 271.1120; [α]D₂⁸ = 3.1 for a sample of 96.5:3.5 er; νmax (thin film/cm⁻¹): 3069, 3047, 2954, 2927, 2852, 1725, 1475, 1427, 1390, 1361, 1297, 1272, 1251, 1203, 1165, 1111, 1072, 1051; ¹H NMR (400 MHz, CDCl₃) δ ppm 0.34 (3 H, s, SiCH₃), 0.35 (3 H, s, SiCH₃), 1.14 (1 H, tdd, J = 13.1, 2.5, 1.0 Hz, SiCH), 1.31 - 1.44 (1 H, m, SiCH₂CH₂), 1.67 - 1.80 (1 H, m, OCH₂CH₂), 1.91 - 2.04 (2 H, m, OCH₂CH₂ and SiCH₂CH₂), 2.40 (1 H, dd, J = 13.9, 12.1 Hz, CH₂C=O), 2.67 (1 H, apparent dt, J = 13.9, 1.3 Hz, CH₂C=O), 4.10 (1 H, dd, J = 12.6, 10.8 Hz, CH₂O), 4.27 (1 H, dtt, J=12.6, 5.0, 1.3, 1.3 Hz, CH₂O), 7.35 - 7.42 (3 H, m, ArH), 7.47 - 7.51 (2 H, m, ArH); ¹³C NMR (101 MHz, CDCl₃) δ ppm -5.3 (SiCH₃), -5.0 (SiCH₃), 22.1 (SiCH), 29.9 (CH₂), 30.6 (CH₂), 35.1 (CH₂C=O), 69.1 (CH₂O), 128.0 (ArCH), 129.5 (ArCH), 133.9 (ArCH), 136.1 (ArC), 176.6 (C=O).
Chiralpak AD-H column, 28 °C, λ = 220 nm. Eluent: hexane : iso-propanol 97 : 3 v/v. Flow: 1 mL / min

*Racemic*  

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*(S)-4-(Dimethyl(phenyl)silyl)-4,5-dihydrobenzo[b]oxepin-2(3H)-one (36e)*

Prepared according to General Procedure 4, on a 0.334 mmol scale, column chromatography (20% EtOAc in Hexanes) afforded the title compound as an oil (83 mg, 0.280 mmol, 84%).

MS (ES') m/z: 319 (M+Na'). HRMS calcd for C_{18}H_{20}O_{2}SiNa: 319.1125 Found: 319.1121; [α]_D^{28} = 4.4 (c = 1.49 in CHCl_3) for a sample of 83:17 er; \( \nu_{\text{max}} \) (thin film/cm\(^{-1}\)): 3069, 3047, 3024, 2954, 2925, 2856, 1754, 1608, 1583, 1485, 1457, 1427, 1334, 1312, 1250, 1220, 1185, 1166, 1151, 1112, 1090, 1035; \(^1\)H NMR (300 MHz, CDCl_3) δ ppm 0.32 (3 H, s, SiCH_3), 0.35 (3 H, s, SiCH_3), 1.9 (1 H, quin, \( J = 7.9 \) Hz, SiCH), 2.36 - 2.53 (1 H, m, SiCHCH_3), 2.45 (1 H, t, \( J = 7.7 \) Hz, SiCHCH_3), 2.76 (1 H, dd, \( J = 14.1, 6.8 \) Hz, CH_3C=O), 2.95 (1 H, dd, \( J = 14.1, 8.3 \) Hz, CH_3C=O), 7.02 - 7.15 (3 H, m, ArH), 7.21 - 7.30 (1 H, m, ArH), 7.34 - 7.43 (3 H, m, ArH), 7.47 - 7.59 (2 H, m, ArH); \(^13\)C NMR (101 MHz, CDCl_3) δ ppm -4.8 (SiCH_3), -4.7 (SiCH_3), 26.4 (SiCH), 29.4 (CH_3C=O), 32.0 (SiCHCH_3), 119.2 (ArCH), 125.7 (ArCH), 127.9 (ArCH), 128.0 (ArCH), 128.2 (ArCH), 129.5 (ArCH), 129.9 (ArCH), 133.8 (ArC), 136.5 (ArC), 151.8 (ArC), 172.0 (C=O).
Chiralcel OD-H column, 28 °C, λ = 220 nm. Eluent: hexane : iso-propanol 95 : 5 v / v. Flow: 1 mL / min

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5-(2-Chloroallyl)furan-2(SH)-one (52f)

To a stirred solution of silver triflate (2.14 g, 8.32 mmol, 1.3 equiv) in CH₂Cl₂ (15 mL), (furan-2-yloxy)trimethylsilane (1.08 mL, 6.40 mmol, 1 equiv) and 2-chloro-3-iodoprop-1-ene (1.67 g, 8.32 mmol, 1.3 equiv) were added at –78 °C and left to warm to room temperature with stirring overnight. The crude mixture was then filtered through celite. Concentration in vacuo followed by purification by column chromatography (silica gel, 15% EtOAc in hexanes) gave the title compound as a dark brown oil (512 mg, 3.24 mmol, 51%).

MS (ES⁺) m/z: 158 (M); HRMS calcd for C₇H₈O₂Cl: 159.0208. Found: 159.0208; \( \nu_{\text{max}} \) (thin film/cm⁻¹): 2959, 2932, 1739, 1717, 1427, 1246, 1148, 1119, 1065; \(^1\)H NMR (500 MHz, CDCl₃) \( \delta \) ppm 2.71 (1 H, dd, \( J = 14.8, 6.3 \) Hz, CH₂), 2.81 (1 H, dd, \( J = 14.2, 6.9 \) Hz, CH₂), 5.29 - 5.36 (2 H, m, CCl=CH₂), 5.37 (1 H, m, CHO), 6.18 (1 H, dd, \( J = 5.7, 1.9 \) Hz, CH=CHC=O), 7.55 (1 H, dd, \( J = 5.7, 1.6 \) Hz, CH=CHC=O); \(^{13}\)C NMR (126 MHz, CDCl₃) \( \delta \) 43.0 (CH₂), 80.1 (CHO), 116.8 (CCl=CH₂), 122.2 (CH=CHC=O), 135.6 (CCl=CH₂), 155.0 (CH=CHC=O), 172.4 (C=O).
General procedure 5 for Cu-catalysed 1,4-conjugate silyl addition with a kinetic resolution: (4R,5S)-4-(dimethyl(phenyl)silyl)-5-methyldihydrofuran-2(3H)-one \(^{203}\) (53a)

In an oven-dried vial equipped with a stirrer bar, \((4S,5S)-1,3\text{-bis}(2\text{-}(naphthalen-2-yl)phenyl)-4,5\text{-diphenyl-4,5-dihydro-1H-imidazol-3-ium tetrafluoroborate salt 41 (7.9 mg, 0.011 mmol, 3.3 mol%), NaOt-Bu (2.1 mg, 0.022 mmol, 6.6 mol%) and CuCl (1 mg, 0.010 mmol, 3 mol%) were placed and 1.5 mL of THF was added. The solution was allowed to stir for 3 hours at 50 °C under nitrogen, it was then filtered through a short plug of oven-dried Celite under nitrogen. PhMe\(_2\)SiBpin (0.055 mL, 0.200 mmol, 0.6 equiv) was added to the filtrate and the mixture stirred for 15 min. The solution was then cooled to –78 °C, and a solution of 5-methylfuran-2(5H)-one (32.7 mg, 0.334 mmol, 1 equiv) in dry THF (0.5 mL) was added and the mixture was allowed to stir for 7 hours at –78 °C, after which time the reaction was quenched by the addition of H\(_2\)O (0.5 mL) and allowed to warm to room temperature overnight. The aqueous layer was then washed with Et\(_2\)O (3 x 2 mL) and dried over MgSO\(_4\). Concentration in vacuo and separation by column chromatography (silica gel, 20% EtOAc in hexanes) yielded (4R,5S)-4-(dimethyl(phenyl)silyl)-5-methyldihydrofuran-2(3H)-one as a pale yellow oil (36.0 mg, 0.153 mmol, 46%).

\([\alpha]_D^{28} = -18.5 \text{ (c = 3.2 in CHCl}_3\text{) for a sample of 86:14 er. Lit: } [\alpha]_D^{20} = -22 \text{ (c = 0.44 in CHCl}_3\text{) for a sample of 89:11 er.}^{203} \)

\(^1\)H NMR (500 MHz, CDCl\(_3\)) \(\delta\) ppm 0.39 (3 H, s, SiC\(_3\)), 0.40 (3 H, s, SiC\(_3\)), 1.30 (3 H, d, \(J = 6.0\) Hz, CH\(_3\)), 1.62 (1 H, ddd, \(J = 12.9, 10.4, 8.8\) Hz, SiCH), 2.40 (1 H, dd, \(J = 17.7, 12.9\) Hz, CH\(_3\)C=O), 2.56 (1 H, dd, \(J = 17.7, 8.8\) Hz, CH\(_3\)C=O), 4.46 (1 H, dq, \(J = 10.4, 6.0\) Hz, CH\(_2\)O), 7.36 - 7.45 (3 H, m, ArH), 7.46 - 7.52 (2 H, m, ArH); \(^{13}\)C NMR (126 MHz, CDCl\(_3\)) \(\delta\) -4.8 (SiCH\(_3\)), -4.3 (SiCH\(_3\)), 21.7 (CH\(_3\)), 31.8 (SiCH), 32.5 (CH\(_3\)C=O), 79.9 (CHO), 128.2 (ArCH), 129.9 (ArCH), 133.6 (ArCH), 135.3 (ArC), 177.1 (C=O).
Chiralcel OD-H column, 28 °C, λ = 220 nm. Eluent: hexane : iso-propanol 90 : 10 v/v. Flow: 1 mL/min

\[ \text{Racemate} \quad \text{Enantiomerically enriched} \]

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\((4R,5S)-4\text{-}(\text{Dimethyl(phenyl)silyl})-5\text{-ethylidihydrofuran-2}(3\text{H})\text{-one}^{204}\ (53\text{b})\)

Prepared according to General Procedure 5, on a 0.334 mmol scale, column chromatography (20% EtOAc in Hexanes) afforded the title compound as an oil (41 mg, 0.167 mmol, 50%). 

\([\alpha]_{D}^{28} = -25.0 \ (c = 1.67 \ \text{in CHCl}_3)\) for a sample of 90:10 er. Lit: \([\alpha]_{D}^{25} = 31.8 \ (c = 0.66 \ \text{in CHCl}_3)\) for a sample of the opposite enantiomer in 99:1 er.\(^{204}\) 1H NMR (500 MHz, CDCl\(_3\)) δ ppm 0.38 (3 H, s, SiCH\(_3\)), 0.39 (3 H, s, SiCH\(_3\)), 0.97 (3 H, t, J = 7.4 Hz, CH\(_3\)), 1.50 (1 H, m, CH\(_2\)), 1.56 - 1.64 (1 H, m, CH\(_2\)), 1.69 (1 H, dt, J = 12.1, 9.6 Hz, SiCH), 2.39 (1 H, dd, J = 17.8, 12.1 Hz, CH\(_2\)=O), 2.57 (1 H, dd, J = 17.7, 9.5 Hz, CH\(_2\)=O), 4.31 (1 H, ddd, J = 9.8, 7.9, 3.2 Hz, CHO), 7.37 - 7.44 (3 H, m, ArH), 7.46 - 7.50 (2 H, m, ArH); \(^{13}\)C NMR (126 MHz, CDCl\(_3\)) δ ppm -4.8 (SiCH\(_3\)), -4.4 (SiCH\(_3\)), 10.0 (CH\(_3\)), 28.5 (SiCH), 29.0 (CH\(_3\)), 31.9 (CH\(_2\)=O), 84.9 (CHO), 128.2 (ArCH), 129.9 (ArCH), 133.7 (ArCH), 135.4 (ArC), 177.3 (C=O).
Chiralcel OD-H column, 28 °C, λ = 220 nm. Eluent: hexane : iso-propanol 95 : 5 v/v. Flow: 1 mL / min

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(4R,5S)-5-Butyl-4-(dimethyl(phenyl)silyl)dihydrofuran-2(3H)-one\(^{204}\) (**53c**)

Prepared according to General Procedure 5, on a 0.334 mmol scale, column chromatography (20% EtOAc in Hexanes) afforded the title compound as an oil (40 mg, 0.144 mmol, 43%). 

\([\alpha]_D^{28} = -4.13 \) (c = 1 in CHCl\(_3\)) for a sample of 91:9 er. Lit: \([\alpha]_D^{25} = 49.0 \) (c = 1.51 in CHCl\(_3\)) for a sample of the opposite enantiomer in 99.5:0.5 er.

\(^{1}H\) NMR (500 MHz, CDCl\(_3\)) \(\delta\) ppm 0.39 (3 H, s, SiC\(_\text{H}_3\)), 0.42 (3 H, s, SiC\(_\text{H}_3\)), 0.85 (3 H, t, \(J = 7.3\) Hz, CH\(_3\)), 1.20 - 1.36 (4 H, m, CH\(_2\)), 1.41 - 1.52 (2 H, m, CH\(_2\)), 1.67 (1 H, dt, \(J = 12.3,9.6\) Hz, SiCH), 2.38 (1 H, dd, \(J = 17.7, 12.3\) Hz, CH\(_2\)C=O), 2.56 (1 H, dd, \(J = 17.7,9.1\) Hz, CH\(_2\)C=O), 4.31 - 4.38 (1 H, m, CHO), 7.38 - 7.44 (3 H, m, ArH), 7.46 - 7.50 (1 H, m, ArH), 7.59 - 7.63 (1 H, m, ArH); \(^{13}C\) NMR (75 MHz, CDCl\(_3\)) \(\delta\) ppm -48, -4.4, 13.8 (CH\(_3\)), 22.3 (CH\(_3\)), 27.8 (SiCH), 29.1 (CH\(_2\)), 31.9 (CH\(_2\)C=O), 35.8 (CH\(_3\)), 83.7 (CHO), 127.7 (ArCH), 128.2 (ArCH), 133.7 (ArCH), 133.8 (ArC), 177.3 (C=O).
Chiralcel OD-H column, 28 °C, λ = 220 nm. Eluent: hexane : iso-propanol 95 : 5 v/v. Flow: 1 mL/min

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**\((4R,5S)-4-\text{(Dimethyl(phenyl)silyl)}-5\text{-pentyldihydrofuran-2(3H)}-\text{one}\)**

\text{Prepared according to General Procedure 5, on a 0.334 mmol scale, column chromatography (20% EtOAc in Hexanes) afforded the title compound as an oil (42 mg, 0.144 mmol, 43%).}

\([\alpha]_D^{28} = -22.5 \text{ (c = 0.38 in CHCl}_3\text{) for a sample of 86:14 er. Lit: [\alpha]_D^{25} = 45.1 \text{ (c = 0.82 in CHCl}_3\text{) for a sample of the opposite enantiomer in 99:1 er.}^{204} \text{H NMR (300 MHz, CDCl}_3\text{) \text{δ ppm 0.38 (3 H, s, SiCH}_3\text{), 0.39 (3 H, s, SiCH}_3\text{), 0.87 (3 H, t, } J = 6.6 \text{ Hz, CH}_3\text{), 1.11 - 1.36 (6 H, m, 3 x CH}_2\text{), 1.39 - 1.57 (2 H, m, CH}_3\text{), 1.67 (1 H, dt, } J = 12.1, 9.6 \text{ Hz, SiCH}_3\text{), 2.38 (1 H, dd, } J = 17.5, 12.1 \text{ Hz, CH}_2\text{C=O), 2.56 (1 H, dd, } J = 17.5, 9.2 \text{ Hz, CH}_2\text{C=O), 4.28 - 4.41 (1 H, m, CHO), 7.34 - 7.45 (3 H, m, ArH), 7.45 - 7.52 (2 H, m, ArH);}^{13}\text{C NMR (126 MHz, CDCl}_3\text{) \text{δ ppm -4.8 (SiCH}_3\text{), -4.4 (SiCH}_3\text{), 13.9 (CH}_3\text{), 22.4 (CH}_2\text{), 25.4 (CH}_3\text{), 29.1 (SiCH}, 31.4 (CH}_2\text{), 31.9 (CH}_2\text{C=O), 36.1 (CH}_2\text{), 83.7 (CHO), 128.2 (ArCH), 129.9 (ArCH), 133.7 (ArCH), 135.4 (ArC), 177.3 (C=O).}
Chiralcel OD-H column, 28 °C, λ = 220 nm. Eluent hexane : iso-propanol 95 : 5 v / v. Flow: 1 mL / min

**Racemate**

Enantiomerically enriched

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**(4R,5S)-5-Allyl-4-(dimethyl(phenyl)silyl)dihydrofuran-2(3H)-one (53e)**

Prepared according to General Procedure 5, on a 0.334 mmol scale, column chromatography (20% EtOAc in Hexanes) afforded the title compound as an oil (40 mg, 0.154 mmol, 46%).

MS (ES<sup>+</sup>) m/z: 283 (M+Na<sup>+</sup>). HRMS calcd for C<sub>15</sub>H<sub>20</sub>O<sub>2</sub>SiNa: 283.1125. Found: 283.1122; [α]<sub>D</sub><sup>28</sup> = -15.3 (c = 1.58 in CHCl<sub>3</sub>) for a sample of 84:16 er; ν<sub>max</sub> (thin film/cm<sup>-1</sup>): 3072, 3050, 3011, 2956, 1773, 1428, 1367, 1351, 1253, 1206, 1171, 1149, 1114, 1080, 1044, 1024; <sup>1</sup>H NMR (500 MHz, CDCl<sub>3</sub>) δ ppm 0.39 (3 H, s, SiC<sub>H</sub><sub>3</sub>), 0.40 (3 H, s, SiC<sub>H</sub><sub>3</sub>), 1.75 (1 H, dt, J = 12.0, 9.8 Hz, SiC<sub>H</sub><sub>3</sub>), 2.15 (1 H, dt, J = 14.8, 7.3 Hz, CH<sub>2</sub>), 2.33 - 2.39 (1 H, m, CH<sub>2</sub>), 2.39 (1 H, dd, J = 17.7, 12.0 Hz, CH<sub>2</sub>C=O), 2.57 (1 H, dd, J = 17.7, 9.5 Hz, CH<sub>2</sub>C=O), 4.43 (1 H, ddd, J = 10.1, 6.6, 3.5 Hz, CHO), 5.00 (1 H, dq, J = 17.0, 1.6 Hz, CH=CH<sub>2</sub> trans), 5.10 (1 H, dt, J = 10.4, 0.9 Hz, CH=CH<sub>2</sub> cis), 5.76 (1 H, ddt, J = 17.3, 10.1, 6.9 Hz, CH=CH<sub>2</sub>), 7.38 - 7.44 (3 H, m, ArH), 7.47 - 7.51 (2 H, m, ArH); <sup>13</sup>C NMR (126 MHz, CDCl<sub>3</sub>) δ -50.0 (SiCH<sub>3</sub>), -4.4 (SiCH<sub>3</sub>), 27.7 (SiCH), 31.7 (CH<sub>2</sub>C=O), 39.4 (CH<sub>2</sub>), 82.6 (CHO), 118.7 (HC=CH<sub>2</sub>), 128.2 (ArCH), 129.9 (ArCH), 132.5 (HC=CH<sub>2</sub>), 133.7 (ArCH), 135.2 (ArC), 177.1 (C=O).
Chiralcel OD-H column, 28 °C, λ = 220 nm. Eluent: hexane : iso-propanol 95 : 5 v/v. Flow: 1 mL/min

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(4R,5S)-5-(2-Chloroallyl)-4-(dimethyl(phenyl)silyl)dihydrofuran-2(3H)-one (53f)

Prepared according to General Procedure 5, on a 0.334 mmol scale, column chromatography (20% EtOAc in Hexanes) afforded the title compound as an oil (47 mg, 0.160 mmol, 48%).

MS (ES⁺) m/z: 317 (M+Na⁺) HRMS calcd for C₁₅H₁₉O₂SiNa: 317.0736. Found: 317.0724; [α]D²⁸ = -19.3 (c = 1.17 in CHCl₃) for a sample of 89:11 er; νmax (thin film/cm⁻¹): 2956, 1772, 1639, 1352, 1253, 1206, 1176, 1115, 1022; ¹H NMR (400 MHz, CDCl₃) δ ppm 0.41 (3 H, s, SiC₃H₃), 0.43 (3 H, s, SiC₃H₃), 1.70 (1 H, dt, J = 12.0, 9.6 Hz, SiCH), 2.35 - 2.48 (1 H, m, CH₂), 2.41 (1 H, dd, J = 17.7, 11.9 Hz, CH₂C=O), 2.54 (1 H, dd, J = 14.9, 8.6 Hz, CH₂), 2.60 (1 H, dd, J = 17.7, 9.6 Hz, CH₂C=O), 4.67 (1 H, ddd, J = 9.9, 8.6, 2.8 Hz, CHO), 5.24 (2 H, apparent dd, J = 15.4, 1.3 Hz, C=CH₂), 7.38 - 7.45 (3 H, m, ArH), 7.48 - 7.53 (2 H, m, ArH); ¹³C NMR (126 MHz, CDCl₃) δ ppm -5.0 (SiCH₃), -4.4 (SiCH₃), 28.4 (SiCH), 31.6 (CH₂C=O), 45.5 (CH₂), 79.8 (CHO), 115.6 (CCl=CH₂), 128.3 (ArCH), 130.1 (ArCH), 133.8 (ArCH), 134.8 (ArC), 137.1 (CCl=CH₂), 176.5 (C=O).
Chiralcel OD-H column, 28 °C, λ = 220 nm. Eluent: hexane : iso-propanol 90 : 10 v/v

Flow: 1 mL / min

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(4R,5S)-5-Benzyl-4-(dimethyl(phenyl)silyl)dihydrofuran-2(3H)-one (53g)

Prepared according to General Procedure 5, on a 0.334 mmol scale, column chromatography (20% EtOAc in Hexanes) afforded the title compound as an oil (44 mg, 0.140 mmol, 42%).

MS (ES') m/z: 333 (M+Na+). HRMS calcd for C_{19}H_{22}O_{2}SiNa: 333.1281. Found: 333.1285; [α]_{D}^{28} = -20.1 (c = 1.33 in CHCl₃) for a sample of 86:14 er; v_{max} (thin film/cm⁻¹): 3068, 3029, 2955, 2919, 2866, 1770, 1604, 1495, 1455, 1427, 1352, 1252, 1204, 1148, 1114, 1073, 1047, 1018; ¹H NMR (300 MHz, CDCl₃) δ ppm 0.39 (6 H, s, Si(CH₃)₂), 1.73 (1 H, dt, J = 11.3, 9.6 Hz, SiCH), 2.36 (1 H, dd, J = 17.9, 11.5 Hz, CH₂C=O), 2.51 (1 H, dd, J = 17.9, 10.0 Hz, CH₂C=O), 2.71 (1 H, dd, J = 14.3, 7.3 Hz, CH₂Ph), 2.85 (1 H, dd, J = 14.3, 3.2 Hz, CH₂Ph), 4.59 (1 H, ddd, J = 9.5, 7.1, 3.4 Hz, CHO), 7.04 - 7.11 (2 H, m, ArH), 7.21 - 7.31 (3 H, m, ArH), 7.38 - 7.46 (3 H, m, ArH), 7.47 - 7.55 (2 H, m, ArH); ¹³C NMR (75 MHz, CDCl₃) δ -5.1 (SiCH₃), -4.3 (SiCH₃), 27.7 (SiCH₃), 31.6 (CH₂C=O), 41.7 (CH₂Ph), 83.5 (CHO), 126.8 (ArCH), 127.9 (ArCH), 128.3 (ArCH), 128.4 (ArCH), 129.6 (ArCH), 130.0 (ArCH), 133.0 (ArCH), 133.8 (ArCH), 135.3 (ArC), 136.5 (ArC), 176.9 (C=O).
Chiralcel OD-H column, 28 °C, λ = 220 nm. Eluent: hexane : ethanol 95 : 5 v / v. Flow: 1 mL / min

**Racemate**

**Enantiomerically enriched**

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(4R,5S)-4-(Dimethyl(phenyl)silyl)-5-phenyldihydrofuran-2(3H)-one (53h)

Prepared according to General Procedure 5, on a 0.334 mmol scale, column chromatography (20% EtOAc in Hexanes) afforded the title compound as an oil (41 mg, 0.137 mmol, 41%).

MS (ES') m/z: 319 (M+Na'). HRMS calcd for C_{18}H_{20}O_2SiNa: 319.1125. Found: 319.1120; [α]_D^{28} = -20.9 (c = 1.55 in CHCl_3) for a sample of 88.5:11.5 er; ν_{max} (thin film/cm\(^{-1}\)): 3068, 3017, 2955, 2923, 2854, 1773, 1648, 1619, 1497, 1457, 1427, 1373, 1251, 1219, 1205, 1164, 1113, 1048, 1023; \(^1\)H NMR (500 MHz, CDCl_3) δ ppm 0.23 (3 H, s, SiCH_3), 0.26 (3 H, s, SiCH_3), 2.09 (1 H, ddd, J = 12.3, 10.1, 8.8 Hz, SiCH), 2.51 (1 H, dd, J = 17.3, 12.3 Hz, CH_2C=O), 2.69 (1 H, dd, J = 17.3, 8.8 Hz, CH_2C=O), 5.21 (1 H, d, J = 10.4 Hz, CHO), 7.27 (2 H, m, ArH), 7.32 - 7.44 (6 H, m, ArH), 7.58 - 7.63 (2 H, m, ArH); \(^13\)C NMR (101 MHz, CDCl_3) δ ppm -4.7 (SiCH_3), -4.3 (SiCH_3), 32.4 (CH_2C=O), 32.7 (SiCH), 85.0 (CHO), 126.8 (ArCH), 127.9 (ArC), 128.2 (ArCH), 128.6 (ArCH), 129.0 (ArCH), 133.0 (ArCH), 133.8 (ArCH), 135.0 (ArC), 176.9 (C=O).
Chiralpak IA column, 28 °C, λ = 220 nm. Eluent hexane: ethanol 97 : 3 v/v. Flow: 0.85 mL / min

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\((3S,4R,5S)-3\text{-Butyl-4-}(\text{dimethyl(phenyl)silyl})\text{-5-methyldihydrofuran-2(3H)-one})^{55} \ (54)\)

To a stirred solution of diisopropylamine (0.036 mL, 0.256 mmol, 1.5 equiv) in dry THF (0.12 mL) at –78 °C, was added \(n\)-BuLi (0.18 mL, 1.44 M, 1.5 equiv) dropwise, and the mixture stirred for 1 h. To the resulting LDA solution, \((4R,5S)-4\text{-}(\text{dimethyl(phenyl)silyl})\text{-5-methyldihydrofuran-2(3H)-one})\) (40 mg, 0.171 mmol, 1 equiv) in dry THF (0.12 mL) was added dropwise and stirred for 1.5 hours at –78 °C. A solution of \(n\)-Bul (0.058 mL, 0.512 mmol, 3 equiv) in DMPU (0.03 mL) was then added dropwise at –78 °C. The reaction was then allowed to warm to room temperature overnight and quenched with saturated NH\(_4\)Cl solution (1 mL) at 0 °C. The aqueous layer was then extracted with Et\(_2\)O (3 x 2 mL) and dried over NaSO\(_4\). Concentration \textit{in vacuo} and purification by column chromatography (silica gel, 10% EtOAc in hexanes) yielded the title compound as a pale yellow oil (36.2 mg, 0.125 mmol, 73%).

The spectroscopic data was in agreement with the literature other than: \([\alpha]_0^{25} = -11.53 \ (c = 2 \ in \ CHCl_3)\) for a sample of 89:11 er, Lit: \([\alpha]_0^{25} = -9.48 \ (c = 3.13 \ in \ CHCl_3)\) for a sample of 85:15 er.\(^{55}\) \(^1\)H NMR (300 MHz, CDCl\(_3\)) δ ppm 0.4 (6 H, s, Si(CH\(_3\)_2)), 0.8 (3 H, t, \(J = 7.0\) Hz, CH\(_2\)CH\(_3\)), 1.1 - 1.2 (3 H, m, CH\(_2\)), 1.3 (3 H, d, \(J = 6.0\) Hz, CH\(_3\)), 1.3 - 1.4 (2 H, m, CH\(_2\)), 1.4 (1 H, dd, \(J = 12.1, 10.2\) Hz, SiCH), 1.5 - 1.7 (1 H, m, CH\(_2\)), 2.5 (1 H, ddd, \(J = 12.0, 6.4, 4.1\) Hz, CHC=O), 4.4 (1 H, dq, \(J = 10.0, 6.0\) Hz, CHO),
7.3 - 7.4 (3 H, m, ArH), 7.5 - 7.6 (2 H, m, ArH); 13C NMR (101 MHz, CDCl₃) δ ppm: 4.3 (Si(CH₃)₃), -4.2 (Si(CH₃)₂), 13.8 (CH₂CH₃), 22.2 (CH₃), 22.6 (CH₂), 27.9 (SiCH), 29.9 (CH₂), 35.5 (CH₂), 43.3 (CHC=O), 77.4 (CHO), 128.2 (ArCH), 129.8 (ArCH), 133.7 (ArCH), 135.6 (ArC), 179.4 (C=O).

(3R,4R,5S)-3-Butyl-4-hydroxy-5-methylidihydrofuran-2(3H)-one²⁰⁵ (55)

![Structure of (3R,4R,5S)-3-Butyl-4-hydroxy-5-methylidihydrofuran-2(3H)-one]

To a solution of lactone 54 (35 mg, 0.120 mmol, 1 equiv), KBr (34 mg, 0.289 mmol, 2.4 equiv) and NaOAc (30 mg, 0.371 mmol, 3.1 equiv) in acetic acid (0.5 mL) at 0 °C, was added peracetic acid (0.5 mL) dropwise, and the reaction was left to warm to room temperature over 2 h. The crude product was loaded directly on to silica, and chromatography (silica gel, 25% EtOAc in hexanes) afforded the title compound (16 mg, 0.091 mmol, 76%).

The spectroscopic data was in agreement with the literature other than: [α]₀²⁰⁵ = -12.8 (c = 2 in CHCl₃) for a sample of 89:11 er, Lit: [α]₀²² = -16.0 (c = 1.0 in CHCl₃) for a sample of >98.5:1.5 er.²⁰⁵

¹H NMR (300 MHz, CDCl₃) δ ppm: 0.92 (3 H, t, J = 7.2 Hz, CH₂C₃H₇), 1.21 - 1.69 (5 H, m, CH₂), 1.46 (3 H, d, J = 6.2 Hz, CHOC₃H₇), 1.79 - 1.95 (1 H, m, CH₂), 2.29 (1 H, br. s, OH), 2.57 (1 H, ddd, J = 8.7, 7.3, 5.7 Hz, CHC=O), 3.85 (1 H, dd, J = 8.7, 7.2 Hz, CHO), 4.16 - 4.27 (1 H, m, CHO).³¹C NMR (75 MHz, CDCl₃) 13.8 (CH₂CH₃), 18.2 (OCH₃CH₂), 22.6 (CH₂), 28.1 (CH₂), 28.8 (CH₂), 48.6 (CHC=O), 79.0 (CHOH), 80.0 (OCH₃CH₂), 176.3 (C=O).

(25,3R,4R)-4-Butyl-2-methyl-5-oxotetrahydrofuran-3-yl 3-methylbutanoate²⁵ (29)

![Structure of (25,3R,4R)-4-Butyl-2-methyl-5-oxotetrahydrofuran-3-yl 3-methylbutanoate]

To a solution of lactone 55 (7.4 mg, 0.043 mmol, 1 equiv) in pyridine (0.92 mL) at 0 °C, was added isovaleryl chloride (0.027 mL, 2.15 mmol, 5 equiv), and the reaction mixture stirred at room temperature for 6 hours. The crude mixture was then diluted with EtOAc, washed with aqueous CuSO₄ solution and then brine and dried. Chromatography (silica gel, 10% EtOAc in hexanes) afforded the title compound (9.1 mg, 0.036 mmol, 83%).

The spectroscopic data was in agreement with the literature other than: [α]₀²⁸ = 5.65 (c = 1.25 in CHCl₃) for a sample of 89:11 er, Lit: [α]₀²⁵ = 11.8 (c = 1.2 in CHCl₃) for a sample of >98.5:1.5 er.²⁵ ¹H NMR (400 MHz, CDCl₃) δ ppm: 0.92 (3 H, t, J = 7.1 Hz, CH₂CH₃), 0.99 (6 H, d, J = 6.6 Hz, CH(CH₃)₂), 1.28 - 1.46 (4 H, m, CH₂), 1.48 (3 H, d, J = 6.6 Hz, CHOCH₃), 1.61 - 1.70 (1 H, m, CH₂), 1.81 - 1.92 (1 H, m, CH₂), 2.05 - 2.18 (1 H, m, CH(CH₃)₂), 2.24 (2 H, d, J = 7.1 Hz, CH₂C=O), 2.69 (1 H, dt, J = 8.3,
5.8 Hz, CHC=O), 4.37 (1 H, qd, J = 6.6, 4.5 Hz, CHOCH₃), 4.95 (1 H, dd, J = 5.8, 4.8 Hz, CHOC=O).¹³C NMR (101 MHz, CDCl₃) δ ppm 13.8 (CH₂CH₃), 19.4 (OCHCH₃), 22.30 (CH₂), 22.32 (CH(CH₃)₂), 22.4 (CH(CH₃)₂), 25.7 (CH(CH₃)₂), 28.9 (CH₂), 29.0 (CH₂), 43.1 (CH₂=O), 46.4 (CH=O), 78.4 (OCH), 79.4 (OCHCH₃), 172.4 (C=O), 176.0 (C=O).

General procedure 6 for copper-catalysed 1,4-conjugate silyl addition with domino aldol: 

\((3\text{S,}4\text{R})\)-4-(Dimethyl(phenyl)silyl)-3-\{(\text{S})\}-hydroxy(phenyl)methyl)dihydrofuran-2(3H)-one (58a)

In an oven-dried vial equipped with a stirrer bar, was added (45,55)-1,3-bis(2-(naphthalen-2-yl)phenyl)-4,5-diphenyl-4,5-dihydro-1H-imidazol-3-ium tetrafluoroborate salt 41 (12.3 mg, 0.017 mmol, 4.4 mol%), NaOt-Bu (3.3 mg, 0.034 mmol, 8.8 mol%) and Cul (3 mg, 0.010 mmol, 4 mol%), and of THF (1 mL) was added. The solution was allowed to stir for 3 hours at 50 °C under nitrogen and then filtered through a short plug of oven-dried Celite under nitrogen. The catalyst solution was then added to NaOt-Bu (20 mg, 0.208 mmol, 0.5 equiv.). PhMe₂SiBpin (0.136 mL, 0.450 mmol, 1.2 equiv) was added, followed by the reaction mixture was then stirred for 15 min. The solution was cooled to –78 °C, and a solution of furan-2(5H)-one (35 mg, 0.416 mmol, 1 equiv) and benzaldehyde (0.085 mL, 0.833 mmol, 2 equiv) in dry THF (0.5 mL) was added at –78 °C and the mixture was allowed to stir overnight warming to room temperature. The reaction was then quenched by the addition of H₂O (0.1 mL) and the resultant solution filtered through a plug of silica. Concentration in vacuo and separation by column chromatography (silica gel, 20% EtOAc in hexanes) yielded (3S,4R)-4-(dimethyl(phenyl)silyl)-3-(\{(S\})-hydroxy(phenyl)methyl)dihydrofuran-2(3H)-one as a pale yellow oil (111.5 mg, 0.342 mmol, 82%). MS (ES⁺) m/z: 349 (M+Na⁺). HRMS calcld for C$_{36}$H$_{32}$O$_2$Si$_3$Na$_1$: 349.1236. Found: 349.1234; [α]$_{D}^{28}$ = -23.6 (c = 5.3 in CHCl₃) for a sample of 70:30 dr; ν$_{max}$ (thin film/cm⁻¹): 3446, 2955, 2908, 1748, 1495, 1451, 1427, 1381, 1253, 1180, 1113, 1088, 1050, 1024; major diastereomer: H NMR (500 MHz, CDCl₃) δ ppm 0.82 (s, 3 H, SiCH₃), 0.15 (s, 3 H, SiCH₃), 1.87 - 1.95 (m, 1 H, SiCH), 2.86 - 2.91 (m, 1 H, CHC=O), 4.10 (dd, J = 8.7, 7.4 Hz, 1 H, CH₂O), 4.32 - 4.38 (m, 1 H, CH₂O), 5.16 (d, J = 3.2 Hz, 1 H, CHO), 7.17 - 7.47 (m, 10 H, ArH); minor diastereomer: H NMR (500 MHz, CDCl₃) δ ppm 0.16 (s, 3 H, SiCH₃), 0.25 (s, 3 H, SiCH₃), 1.83 (q, J = 8.8 Hz, 1 H, SiCH), 2.86 - 2.92 (m, 1 H, CHC=O), 4.02 (t, J = 9.1 Hz, 1 H, CH₂O), 4.13 (t, J = 9.1 Hz, 1 H, CH₂O), 4.99 (d, J = 6.0 Hz, 1 H, CHO), 7.20 - 7.45 (m, 10 H, ArH); major diastereomer: C NMR (101 MHz, CDCl₃) δ ppm -5.6 (SiCH₃), -5.3 (SiCH₃), 17.7 (SiCH), 49.3 (CHC=O), 70.0 (CH₂O), 73.5 (CHOH), 125.9 (ArCH), 128.2 (ArCH), 128.6 (ArCH), 129.8 (ArCH), 133.6 (ArCH), 135.1 (ArC), 140.8 (ArC), 179.5 (C=O); minor diastereomer: C NMR (101
In an oven-dried vial equipped with a stirrer bar, was added (4S,5S)-1,3-bis(2-(naphthalen-2-yl)phenyl)-4,5-diphenyl-4,5-dihydro-1H-imidazol-3-ium tetrafluoroborate salt 41 (9.3 mg, 0.013 mmol, 4.4 mol%), NaOt-Bu (2.5 mg, 0.026 mmol, 8.8 mol%) and Cul (2.3 mg, 0.012 mmol, 4 mol%), and of THF (1 mL) was added. The solution was allowed to stir for 3 hours at 50 °C under nitrogen and then filtered through a short plug of oven-dried Celite under nitrogen. The catalyst solution was then added to NaOt-Bu (43 mg, 0.446 mmol, 1.5 equiv). PhMe2SiBpin (0.10 mL, 0.357 mmol, 1.2 equiv) was added, turning the solution black, and the reaction mixture was then stirred for 15 min. The solution was cooled to −78 °C, and a solution of furan-2(5H)-one (25 mg, 0.297 mmol, 1 equiv) and benzaldehyde (0.03 mL, 0.297 mmol, 1 equiv) in dry THF (0.5 mL) was added at −78 °C and the mixture was allowed to stir overnight warming to room temperature. The reaction was then quenched by the addition of H2O (0.1 mL) and the resultant solution filtered through a plug of silica. Concentration in vacuo and separation by column chromatography (silica gel, 20% EtOAc in hexanes) yielded 36a (13.3 mg, 60.36 µmol, 20%), 58a (16.1 mg, 49.39 µmol, 17%), 59 (9.3 mg, 21.50 µmol, 7%) and 60 (5.4 mg, 16.55 µmol, 6%).

MS (ES') m/z: 455 (M+Na'). HRMS calcd for C26H28O4SiNa: 455.1649. Found: 455.1639; νmax (thin film/cm⁻¹): 3424, 3067, 3031, 2956, 2923, 1737, 1603, 1588, 1493, 1452, 1427, 1412, 1356, 1337, 1302, 1254, 1202, 1186, 1113, 1064, 1025; ¹H NMR (300 MHz, CDCl₃) δ ppm -0.40 (s, 3 H, SiCH₃), -0.37 (s, 4 H, SiCH₃), 1.69 (t, J = 4.7 Hz, 1 H, SiCH), 2.63 (dd, J = 7.6, 5.2 Hz, 1 H, CHC=O), 4.54 (dd, J = 4.0, 3.0 Hz, 1 H, CHO), 4.83 (d, J = 7.5 Hz, 1 H, CH(OH)CHC=O), 4.92 (d, J = 2.4 Hz, 1 H, CHO), 7.08 - 7.16 (m, 2 H, ArH), 7.20 - 7.38 (m, 13 H, ArH); ¹³C NMR (75 MHz, CDCl₃) δ ppm -6.4 (SiCH₃), -6.2 (SiCH₃), 21.5 (SiCH), 49.6 (CHC=O), 74.4 (CHOH), 75.0 (CH(OH)CHC=O), 84.4 (CHO), 126.2 (ArCH), 126.8 (ArCH), 128.1 (ArCH), 128.2 (ArCH), 128.3 (ArCH), 128.7 (ArCH), 129.6 (ArCH), 133.6 (ArCH), 134.7 (ArC), 138.3 (ArC), 140.6 (ArC), 178.9 (C=O).
(4R,5S)-4-(Dimethyl(phenyl)silyl)-5-((S)-hydroxy(phenyl)methyl)dihydrofuran-2(3H)-one (60)

MS (ES') m/z: 349 (M+Na'). HRMS calcd for C_{19}H_{22}O_3SiNa: 349.1230. Found: 349.1222; \( \nu_{\text{max}} \) (thin film/cm\(^{-1}\)): 3477, 3068, 3027, 2954, 2927, 1771, 1603, 1589, 1495, 1427, 1354, 1253, 1197, 1175, 1114, 1050, 1018; \(^1\)H NMR (400 MHz, CDCl\(_3\)) \( \delta \) ppm 0.08 (s, 3 H, SiCH\(_3\)), 0.13 (s, 3 H, SiCH\(_3\)), 1.89 (ddd, \( J = 11.4, 6.1, 4.9 \) Hz, 1 H, SiCH), 2.29 (dd, \( J = 18.2, 6.1 \) Hz, 1 H, CH\(_2\)C=O), 2.72 (dd, \( J = 18.2, 11.6 \) Hz, 1 H, CH\(_2\)C=O), 4.62 (dd, \( J = 4.9, 2.9 \) Hz, 1 H, CHO), 4.94 (d, \( J = 2.8 \) Hz, 1 H, CHOH), 7.26 - 7.41 (m, 10 H, ArH); \(^{13}\)C NMR (101 MHz, CDCl\(_3\)) \( \delta \) ppm -5.6 (SiCH\(_3\)), -5.5 (SiCH\(_3\)), 20.1 (SiCH), 30.7 (CH\(_2\)C=O), 75.4 (CHOH), 84.9 (CHO), 126.4 (ArCH), 128.1 (ArCH), 128.6 (ArCH), 129.7 (ArCH), 133.6 (ArCH), 135.2 (ArC), 138.3 (ArC), 177.7 (C=O).

(3S,4R)-4-(Dimethyl(phenyl)silyl)-3-((S)-hydroxy(4-methoxyphenyl)methyl)dihydrofuran-2(3H)-one (58b)

Prepared according to General Procedure 6, on a 0.416 mmol scale, column chromatography (92% EtOAc in Hexanes) afforded the title compound as an oil (127 mg, 0.354 mmol, 85%).

MS (ES') m/z: 379 (M+Na'). HRMS calcd for C\(_{20}\)H\(_{24}\)O\(_3\)SiNa: 379.1336. Found: 379.1329; \([\alpha]_D^{28} = -28.7 (c = 4.76 in CHCl\(_3\)) for a sample of 71:29 dr; \( \nu_{\text{max}} \) (thin film/cm\(^{-1}\)): 3478, 3089, 3069, 3046, 3033, 2998, 2956, 2908, 2836, 1758, 1612, 1586, 1512, 1488, 1463, 1442, 1427, 1381, 1303, 1248, 1175, 1113, 1027; major diastereomer: \(^1\)H NMR (400 MHz, CDCl\(_3\)) \( \delta \) ppm 0.14 (3 H, s, SiCH\(_3\)), 0.19 (3 H, s, SiCH\(_3\)), 1.85 (1 H, dt, \( J = 9.3, 8.1 \) Hz, SiCH), 2.86 (1 H, dd, \( J = 8.2, 3.9 \) Hz, CHC=O), 3.36 (1 H, br, s, OH), 3.81 (3H, s, OCH\(_3\)), 4.06 - 4.17 (1 H, m, CH\(_2\)O), 4.33 (1 H, t, \( J = 9.1 \) Hz, CH\(_2\)O), 5.05 (1 H, d, \( J = 3.3 \) Hz, CHOH), 6.81 - 6.88 (2 H, m, ArH), 7.08 - 7.13 (1 H, m, ArH), 7.32 - 7.45 (6 H, m, ArH); minor diastereomer: \(^1\)H NMR (400 MHz, CDCl\(_3\)) \( \delta \) ppm 0.18 (3 H, s, SiCH\(_3\)), 0.26 (3 H, s, SiCH\(_3\)), 1.81 (1 H, q, \( J = 8.6 \) Hz, SiCH), 2.87 (1 H, dd, \( J = 8.8, 6.1 \) Hz, CHC=O), 3.21 (1 H, br, s, OH), 4.01 (1 H, t, \( J = 8.8 \) Hz, CH\(_2\)O), 4.06 - 4.14 (1 H, m, CH\(_2\)O), 4.12 (3 H, s, OCH\(_3\)), 4.95 (1 H, d, \( J = 6.1 \) Hz, CHOH), 6.80 - 6.88 (2 H, m, ArH), 7.07 - 7.15 (1 H, m, ArH), 7.18 - 7.45 (6 H, m, ArH); major diastereomer: \(^{13}\)C NMR (101 MHz, CDCl\(_3\)) \( \delta \) ppm -5.3 (SiCH\(_3\)), -5.3 (SiCH\(_3\)), 22.3 (SiCH), 49.1 (CHC=O), 55.2 (OCH\(_3\)), 69.9 (CH\(_2\)O), 73.3 (CHOH), 113.90 (ArCH), 127.2 (ArCH), 128.2 (ArCH), 129.8 (ArCH), 132.8 (ArC), 133.6 (ArCH), 135.1 (ArC), 159.2 (ArC), 179.6 (C=O); minor diastereomer: \(^{13}\)C NMR (101 MHz,
CDCl$_3$ δ ppm -5.2 (SiCH$_3$), -4.8 (SiCH$_3$), 21.0 (SiCH), 49.2 (CHC=O), 60.4 (OCH$_3$), 69.3 (CH$_3$O), 73.7 (CHOH), 113.86 (ArCH), 128.0 (ArCH), 128.1 (ArCH), 129.7 (ArCH), 132.3 (ArC), 133.8 (ArCH), 135.2 (ArC), 159.5 (ArC), 178.9 (C=O).

(3S,4R)-4-(Dimethyl(phenyl)silyl)-3-((S)-(4-fluorophenyl)(hydroxy)methyl)dihydrofuran-2(3H)-one (58c)

Prepared according to General Procedure 6, on a 0.416 mmol scale, column chromatography (80% EtOAc in Hexanes) afforded the title compound as an oil (106 mg, 0.308 mmol, 74%).

MS (ES$^+$) m/z: 367 (M+Na$^+$). HRMS calcd for C$_{19}$H$_{21}$O$_3$SiNaF: 367.1142. Found: 367.1145; $\alpha$D$_{28}$ = -19.71 (c = 4.49 in CHCl$_3$) for a sample of 69:31 dr; $\nu_{max}$ (thin film/cm$^{-1}$): 3459, 3072, 2957, 2911, 1751, 1605, 1509, 1488, 1428, 1411, 1381, 1337, 1318, 1254, 1221, 1183, 1156, 1114, 1058, 1024, 1000; major diastereomer: $^1$H NMR (500 MHz, CDCl$_3$) δ ppm 0.15 (3 H, s, SiCH$_3$), 0.19 (3 H, s, SiCH$_3$), 1.84 (1 H, dt, $J = 9.1$, 7.9 Hz, SiCH), 2.85 (1 H, dd, $J = 8.2$, 3.8 Hz, CHC=O), 3.19 (1 H, br. s, OH), 4.12 (1 H, dd, $J = 8.7$, 7.7 Hz, CH$_2$O), 4.37 (1 H, t, $J = 9.1$ Hz, CH$_2$O), 5.10 (1 H, br. s, CHOH), 6.95 - 7.03 (2 H, m, ArH), 7.11 - 7.17 (1 H, m, ArH), 7.31 - 7.44 (6 H, m, ArH); minor diastereomer: $^1$H NMR (500 MHz, CDCl$_3$) δ ppm 0.20 (3 H, s, SiCH$_3$), 0.26 (3 H, s, SiCH$_3$), 1.80 (1 H, q, $J = 9.0$ Hz, SiCH), 2.83 - 2.88 (1 H, m, CHC=O), 3.15 (1 H, br. s, OH), 4.05 (1 H, t, $J = 9.0$ Hz, CH$_2$O), 4.18 (1 H, t, $J = 9.1$ Hz, CH$_2$O), 4.97 (1 H, d, $J = 6.0$ Hz, CHOH), 6.94 - 7.05 (1 H, m, ArH), 7.10 - 7.19 (2 H, m, ArH), 7.23 - 7.45 (6 H, m, ArH); major diastereomer: $^{13}$C NMR (126 MHz, CDCl$_3$) δ ppm -5.4 (SiCH$_3$), -5.3 (SiCH$_3$), 22.2 (SiCH), 49.2 (CHC=O), 72.9 (CHOH), 115.4 (d, $J = 22.1$ Hz, ArCH), 127.6 (d, $J = 8.1$ Hz, ArCH), 128.2 (ArCH), 129.8 (ArCH), 133.6 (ArCH), 135.0 (ArC), 136.6 (d, $J = 3.0$ Hz, ArC), 162.2 (d, $J = 246.9$ Hz, CF), 179.2 (C=O); minor diastereomer: $^{13}$C NMR (126 MHz, CDCl$_3$) δ ppm -5.1 (SiCH$_3$), -4.9 (SiCH$_3$), 23.9 (SiCH), 49.1 (CHC=O), 69.3 (CH$_3$O), 69.9 (CH$_2$O), 73.5 (CHOH), 115.4 (d, $J = 21.4$ Hz, ArCH), 128.2 (ArCH), 128.5 (d, $J = 8.1$ Hz, ArCH), 129.8 (ArCH), 133.8 (ArCH), 135.1 (ArC), 136.0 (d, $J = 3.0$ Hz, ArC), 162.5 (d, $J = 248.4$ Hz, CF), 179.0 (C=O).
Prepared according to General Procedure 6, on a 0.416 mmol scale, column chromatography (20% EtOAc in Hexanes) afforded the title compound as an amorphous solid (138 mg, 0.366 mmol, 88%).

MS (ES+ m/z: 399 (M+Na)+. HRMS calcd for C_{23}H_{24}O_{3}SiNa: 399.1387. Found: 399.1385; [α]_D^{28} = -39.06 (c = 3.94 in CHCl_{3}) for a sample of 75:25 dr; v_max (thin film/cm^{-1}): 3436, 3068, 3049, 2957, 2904, 1761, 1427, 1378, 1254, 1172, 1153, 1027; major diastereomer: \(^1\)H NMR (500 MHz, CDCl_{3}) δ ppm -0.13 (3 H, s, SiC_{3}H_{3}), -0.02 (3 H, s, SiC_{3}H_{3}), 1.97 (1 H, q, J = 7.6 Hz, SiC_{3}H), 3.10 (1 H, t, J = 7.3 Hz, CHC=O), 3.72 (1 H, br. s, C_{6}H_{2}O), 4.12 (1 H, dd, J = 8.8, 7.9 Hz, CH_{2}O), 4.40 (1 H, t, J = 9.1 Hz, CH_{2}O), 5.46 (1 H, d, J = 6.9 Hz, CHOH), 7.23 - 7.28 (2 H, m, ArH), 7.31 (2 H, t, J = 7.6 Hz, ArH), 7.38 (1 H, tt, J = 7.3, 2.2 Hz, ArH), 7.43 - 7.53 (3 H, m, ArH), 7.62 (1 H, d, J = 6.9 Hz, ArH), 7.81 - 7.91 (2 H, m, ArH); minor diastereomer: \(^1\)H NMR (500 MHz, CDCl_{3}) δ ppm -0.38 (3 H, s, SiC_{3}H_{3}), -0.27 (3 H, s, SiC_{3}H_{3}), 2.11 (1 H, dt, J = 9.8, 5.7 Hz, SiCH), 3.02 (1 H, dd, J = 5.8, 2.4 Hz, CHC=O), 4.17 (1 H, dd, J = 8.5, 5.7 Hz, CH_{2}O), 4.55 (1 H, dd, J = 9.5, 8.5 Hz, CH_{2}O), 6.16 (1 H, d, J = 1.6 Hz, CHOH), 6.97 (2 H, dd, J = 7.9, 1.3 Hz, ArH), 7.09 (2 H, t, J = 7.7 Hz, ArH), 7.17 - 7.43 (2 H, m, ArH), 7.48 - 7.58 (2 H, m, ArH), 7.76 - 7.84 (2 H, m, ArH), 7.85 - 7.95 (2 H, m, ArH); major diastereomer: \(^1\)C NMR (126 MHz, CDCl_{3}) δ ppm -5.5 (SiC_{3}H_{3}), -5.4 (SiC_{3}H_{3}), 25.5 (SiCH), 47.8 (CHC=O), 69.4 (CH_{2}O), 72.6 (CHOH), 123.1 (ArCH), 125.3 (ArCH), 125.6 (ArCH), 125.6 (ArCH), 126.3 (ArCH), 128.2 (ArCH), 129.1 (ArCH), 129.2 (ArCH), 129.8 (ArCH), 130.9 (ArC), 133.6 (ArCH), 134.0 (ArC), 135.0 (ArC), 135.7 (ArC), 179.2 (C=O); minor diastereomer: \(^1\)C NMR (126 MHz, CDCl_{3}) δ ppm -6.1 (SiC_{3}H_{3}), -5.8 (SiC_{3}H_{3}), 20.0 (SiCH), 48.4 (CHC=O), 70.2 (CH_{2}O), 70.3 (CHOH), 122.0 (ArCH), 122.9 (ArCH), 125.2 (ArCH), 125.8 (ArCH), 126.6 (ArCH), 127.8 (ArCH), 128.1 (ArCH), 128.5 (ArCH), 129.1 (ArCH), 129.36 (ArCH), 129.40 (ArCH), 133.2 (ArCH), 133.6 (ArC), 133.7 (ArC), 133.8 (ArC), 134.4 (ArC), 136.6 (ArC), 179.6 (C=O).
(3S,4R)-4-(Dimethyl(phenyl)silyl)-3-((S)-hydroxy(naphthalen-2-yl)methyl)dihydrofuran-2(3H)-one (58e)

Prepared according to General Procedure 6, on a 0.416 mmol scale, column chromatography (20% EtOAc in Hexanes) afforded the title compound as a solid (111 mg, 2.95 mmol, 71%).

Mp: 80-82 °C; MS (ES') m/z: 399 (M+Na'). HRMS calcd for C_{28}H_{24}O_{2}SiNa: 399.1392. Found: 399.1393; [α]_D^{28} = -31.3 (c = 5.26 in CHCl_3) for a sample of 58:42 dr; ν_max (thin film/cm^{-1}): 3467, 3053, 2955, 2905, 1750, 1601, 1509, 1427, 1406, 1253, 1171, 1114, 1160, 1024, 1000; major diastereomer: ^1H NMR (500 MHz, CDCl_3) δ ppm 0.06 (3 H, s, SiCH_3), 0.10 (3 H, s, SiCH_3), 1.95 (1 H, dt, J = 9.3, 7.6 Hz, SiCH), 2.96 (1 H, dd, J = 7.9, 3.8 Hz, CHC=O), 4.12 (1 H, t, J = 9.1 Hz, CH_2O), 4.40 (1 H, t, J = 9.0 Hz, CH_2O), 5.30 (1 H, d, J = 3.5 Hz, CHO), 7.26 (6 H, m, ArH), 7.47 - 7.55 (2 H, m, ArH), 7.63 (1 H, s, ArH), 7.73 - 7.88 (3 H, m, ArH); minor diastereomer: ^1H NMR (500 MHz, CDCl_3) δ ppm 0.17 (3 H, s, SiCH_3), 0.24 (3 H, s, SiCH_3), 1.86 (1 H, q, J = 8.9 Hz, SiCH), 3.00 (1 H, dd, J = 8.8, 6.0 Hz, CHC=O), 4.02 (1 H, t, J = 9.1 Hz, CH_2O), 4.12 (1 H, t, J = 8.5 Hz, CH_2O), 5.18 (1 H, d, J = 6.0 Hz, CHO), 7.26 (6 H, m, ArH), 7.48 - 7.54 (2 H, m, ArH), 7.63 (1 H, s, ArH), 7.74 - 7.87 (3 H, m, ArH);

^{13}C NMR (101 MHz, CDCl_3) δ ppm -5.5 (min SiCH_3), -5.3 (maj SiCH_3), -5.0 (maj SiCH_3), -4.9 (min SiCH_3), 23.9 (maj SiCH), 24.8 (min SiCH), 49.0 (maj CHC=O), 49.2 (min CHC=O), 69.4 (min CH_2O), 70.0 (maj CH_2O), 73.7 (maj CHO), 74.1 (min CHO), 123.7 (ArCH), 124.4 (ArCH), 125.1 (ArCH), 126.0 (ArCH), 126.1 (ArCH), 126.2 (ArCH), 126.3 (ArCH), 126.3 (ArCH), 127.7 (ArCH), 128.0 (ArCH), 128.1 (ArCH), 128.5 (ArCH), 128.9 (ArCH), 129.7 (ArCH), 132.9 (ArC), 133.0 (ArC), 133.1 (ArC), 133.2 (ArC), 133.6 (ArCH), 133.8 (ArCH), 135.0 (ArC), 135.1 (ArC), 137.6 (ArC), 138.2 (ArC), 178.8 (C=O), 179.6 (C=O).

(3S,4R)-4-(Dimethyl(phenyl)silyl)-3-((S)-hydroxy(o-tolyl)methyl)dihydrofuran-2(3H)-one (58f)

Prepared according to General Procedure 6, on a 0.416 mmol scale, column chromatography (20% EtOAc in Hexanes) afforded the title compound as a waxy solid (118 mg, 0.345 mmol, 83%).

MS (ES') m/z: 363 (M+Na'). HRMS calcd for C_{28}H_{24}O_2SiNa: 358.1833. Found: 358.1833 (M+NH_4'); [α]_D^{28} = -11.0 (c = 2.64 in CHCl_3) for a sample of 52:48 dr; ν_max (thin film/cm^{-1}): 3439, 2957, 2908, 1764, 1487, 1461, 1428, 1379, 1254, 1183, 1162, 1114, 1026; major diastereomer: ^1H NMR (500 MHz, CDCl_3) δ ppm -0.07 (3 H, s, SiCH_3), 0.01 (3 H, s, SiCH_3), 2.12 (1 H, dt, J = 9.5, 5.5 Hz, SiCH), 127
2.18 (3 H, s, ArCH₃), 2.71 (1 H, dd, J = 5.7, 2.8 Hz, CHC=O), 4.19 (1 H, dd, J = 8.5, 5.4 Hz, CH₂O), 4.54 (1 H, dd, J = 9.5, 8.8 Hz, CH₂O), 5.53 (1 H, d, J = 2.8 Hz, CHOH), 7.10 (1 H, d, J = 7.3 Hz, ArH), 7.15 - 7.43 (7 H, m, ArH), 7.58 (1 H, d, J = 7.6 Hz, ArH); minor diastereomer: ¹H NMR (500 MHz, CDCl₃) δ ppm 0.04 (3 H, s, SiCH₃), 0.15 (3 H, s, SiCH₃), 1.83 (1 H, dt, J = 9.0, 7.6 Hz, SiCH), 2.28 (3 H, s, ArCH₃), 2.85 (1 H, t, J = 7.6 Hz, CHC=O), 3.55 (1 H, br. s, OH), 4.12 (1 H, dd, J = 9.1, 7.6 Hz, CH₂O), 4.35 (1 H, t, J = 9.0 Hz, CH₂O), 5.03 (1 H, d, J = 7.3 Hz, CHOH), 7.08 - 7.24 (4 H, m, ArH), 7.31 - 7.44 (5 H, m, ArH); major diastereomer: ¹³C NMR (126 MHz, CDCl₃) δ ppm -5.7 (SiCH₃), -5.7 (SiCH₃), 18.7 (Ar-CH₃), 19.9 (SiCH), 47.2 (CHC=O), 70.0 (CH₂O), 70.6 (CHOH), 125.3 (ArCH), 126.2 (ArCH), 127.8 (ArCH), 128.1 (ArCH), 129.5 (ArCH), 130.8 (ArCH), 133.5 (ArCH), 134.0 (ArC), 135.2 (ArC), 139.2 (ArC), 179.2 (C=O); minor diastereomer: ¹³C NMR (126 MHz, CDCl₃) δ ppm -5.5 (SiCH₃), -5.1 (SiCH₃), 19.5 (Ar-CH₃), 25.2 (SiCH), 47.8 (CHC=O), 69.4 (CH₂O), 71.1 (CHOH), 126.5 (ArCH), 127.3 (ArCH), 128.18 (ArCH), 128.22 (ArCH), 129.9 (ArCH), 130.8 (ArCH), 133.7 (ArCH), 135.1 (ArC), 135.5 (ArC), 138.3 (ArC), 179.4 (C=O).

(3S,4R)-4-{(Dimethyl(phenyl)silyl)-3-((R)-1-hydroxypropyl)dihydrofuran-2(3H)-one (58g)

Prepared according to General Procedure 6, on a 0.416 mmol scale, column chromatography (20% EtOAc in Hexanes) afforded the title compound as an oil (79 mg, 0.287 mmol, 69%).

MS (ES⁺) m/z: 301 (M+Na⁺). HRMS calcd for C₃₅H₃₂O₅Si: 279.1411. Found: 279.1405; [α]₂⁰ = -30.6 (c = 4.88 in CHCl₃) for a sample of 78:22 dr; νmax (thin film/cm⁻¹): 3484, 2962, 2906, 2877, 1761, 1427, 1378, 1253, 1169, 1113, 1025; major diastereomer: ¹H NMR (500 MHz, CDCl₃) δ ppm 0.40 (6 H, s, Si(CH₃)₂), 0.91 (3 H, t, J = 7.4 Hz, CH₃), 1.59 - 1.75 (2 H, m, CH₂), 2.13 (1 H, td, J = 10.7, 9.1 Hz, SiCH), 2.51 (1 H, dd, J = 11.0, 3.2 Hz, CHC=O), 3.50 (1 H, ddd, J = 8.3, 5.1, 3.3 Hz, CHOH), 4.06 (1 H, dd, J = 10.4, 9.1 Hz, CH₂O), 4.37 (1 H, t, J = 9.0 Hz, CH₂O), 7.37 - 7.45 (3 H, m, ArH), 7.47 - 7.53 (2 H, m, ArH); minor diastereomer: ¹H NMR (500 MHz, CDCl₃) δ ppm 0.38 (3 H, s, SiCH₃), 0.39 (3 H, s, SiCH₃), 0.88 (3 H, t, J = 7.6 Hz, CH₃), 1.29 - 1.46 (2 H, m, CH₂), 1.98 (1 H, q, J = 9.1 Hz, SiCH), 2.63 (1 H, dd, J = 9.8, 3.8 Hz, CHC=O), 3.71 (1 H, dt, J = 9.5, 3.8 Hz, CHOH), 4.11 (1 H, t, J = 9.0 Hz, CH₂O), 4.41 (1 H, t, J = 9.1 Hz, CH₂O), 7.36 - 7.46 (3 H, m, ArH), 7.47 - 7.53 (2 H, m, ArH); major diastereomer: ¹³C NMR (126 MHz, CDCl₃) δ ppm -4.7 (SiCH₃), -4.7(SiCH₃), 10.5 (CH₃), 25.6 (SiCH), 27.8 (CH₂), 46.9 (CHC=O), 69.1 (CH₂O), 73.2 (CHOH), 128.2 (ArCH), 129.9 (ArCH), 133.7 (ArCH), 135.2 (ArC), 178.3 (C=O).
(35,4R)-4-(Dimethyl(phenyl)silyl)-3-((R)-1-hydroxy-2-methylpropyl)dihydrofuran-2(3H)-one (58h)

Prepared according to General Procedure 6, on a 0.416 mmol scale, column chromatography (20% EtOAc in Hexanes) afforded the title compound as a solid (87 mg, 0.230 mmol, 72%).

Mp: 53-55 °C; MS (ES⁺) m/z: 315 (M+Na⁺). HRMS calcd for C₁₆H₂₅O₂Si: 293.1567. Found: 293.1565; [α]_D2⁸ = -27.2 (c = 3.03 in CHCl₃) for a sample of 88:12 dr; ν_max (thin film/cm⁻¹): 3520, 2960, 2906, 2873, 1752, 1472, 1428, 1378, 1253, 1163, 1114, 1025, 1008; major diastereomer: ¹H NMR (500 MHz, CDCl₃) δ ppm 0.41 (6 H, s, Si(CH₃)₂), 086 (3 H, d, J = 6.6 Hz, CH₃), 0.92 (3 H, d, J = 6.6 Hz, CH₃), 2.13 - 2.26 (2 H, m, SiCH + CH(CH₃)₂), 2.67 (1 H, dd, J = 11.2, 2.7 Hz, CHC=O), 3.10 (1 H, dd, J = 8.5, 2.5 Hz, CHOH), 4.06 (1 H, dd, J = 10.7, 9.1 Hz, CH₂O), 4.39 (1 H, t, J = 9.1 Hz, CH₂O), 7.36 - 7.46 (3 H, m, ArH), 7.47 - 7.55 (2 H, m, ArH); major diastereomer: ¹³C NMR (126 MHz, CDCl₃) δ ppm -4.7 (SiCH₃), -4.6 (SiCH₃), 18.9 (CH₃), 19.6 (CH₃), 26.3 (SiCH), 31.3 (CH(CH₃)₂), 44.7 (CHC=O), 69.1 (CH₂O), 77.3 (CHOH), 128.2 (ArCH), 129.9 (ArCH), 133.7 (ArCH), 135.1 (ArC), 178.1 (C=O).

(35,4R)-3-((R)-Cyclopropyl(hydroxy)methyl)-4-(dimethyl(phenyl)silyl)dihydrofuran-2(3H)-one (58i)

Prepared according to General Procedure 6, on a 0.416 mmol scale, column chromatography (20% EtOAc in Hexanes) afforded the title compound as a solid (77 mg, 0.266 mmol, 64%).

Mp: 49-51 °C; MS (ES⁺) m/z: 313 (M+Na⁺). HRMS calcd for C₁₆H₂₅O₂Si: 308.1676. Found: 308.1674 (M+NH⁺); [α]_D2⁸ = -22.2 (c = 3.06 in CHCl₃) for a sample of 74:24 dr; ν_max (thin film/cm⁻¹): 3463, 3003, 2956, 2906, 2873, 1752, 1472, 1427, 1253, 1169, 1114, 1046; major diastereomer: ¹H NMR (500 MHz, CDCl₃) δ ppm 0.05 - 0.11 (m, 1 H, CH₂), 0.20 - 0.27 (m, 1 H, CH₂), 0.39 (s, 3 H, SiCH₃), 0.39 (s, 3 H, SiCH₃), 0.52 (m, 2 H, CH₂), 1.43 (dtt, J = 9.3, 8.1, 4.9 Hz, 1 H, CH), 2.18 - 2.26 (m, 1 H, SiCH), 2.69 (dd, J = 10.6, 2.8 Hz, 1 H, CHC=O), 2.79 (dd, J = 9.2, 2.6 Hz, 1 H, CHOH), 4.07 (dd, J = 10.2, 9.0 Hz, 1 H, CH₂O), 4.40 (t, J = 9.1 Hz, 1 H, CH₂O), 7.35 - 7.44 (m, 3 H, ArH), 7.47 - 7.55 (m, 2 H, ArH); minor diastereomer: ¹H NMR (400 MHz, CDCl₃) δ ppm 0.05 - 0.11 (m, 1 H, CH₂), 0.20 - 0.27 (m, 1 H, CH₂), 0.39 (s, 6 H, Si(CH₃)₂), 0.46 - 0.59 (m, 2 H, CH₂), 0.73 - 0.83 (m, 1 H, CH), 2.16 - 2.29 (m, 1 H, SiCH), 2.74 (dd, J = 9.3, 3.3 Hz, 1 H, CHC=O), 3.14 (dd, J = 9.1, 3.3 Hz, 1 H, CHOH), 4.14 (t, J = 8.7 Hz, 1 H, CH₂O), 4.46 (t, J = 9.0 Hz, 1 H, CH₂O), 7.35 - 7.44 (m, 3 H, ArH), 7.47 - 7.55.
(m, 2 H, ArH); major diastereomer: $^{13}$C NMR (101 MHz, CDCl$_3$) δ ppm -4.9 (SiCH$_3$), -4.6 (SiCH$_3$), 3.0 (CH$_3$), 3.8 (CH$_3$), 15.0 (CH), 25.3 (SiCH), 47.5 (CHC=O), 69.1 (CH$_2$O), 76.6 (CHOH), 128.2 (ArCH), 129.9 (ArCH), 133.8 (ArCH), 135.3 (ArC), 178.1 (C=O).

(35,4R)-3-(R)-Cyclohexyl(hydroxy)methyl)-4-{dimethyl(phenyl)silyl}dihydrofuran-2(3H)-one (58j)

Prepared according to General Procedure 6, on a 0.416 mmol scale, column chromatography (20% EtOAc in Hexanes) afforded the title compound as a solid (91 mg, 0.316 mmol, 76%).

Mp: 61-63 °C; MS (ES$^+$) m/z: 355 (M+Na$^+$). HRMS calcld for C$_{19}$H$_{25}$O$_2$Si: 333.1880. Found: 333.1879; [α]$_D^{28}$ = -1.9 (c = 5.4 in CHCl$_3$) for a sample of 88:12 dr.

$\nu$$_{max}$ (thin film/cm$^{-1}$): 3454, 2923, 2851, 1760, 1449, 1428, 1378, 1253, 1170, 1088, 1062, 1225, 1008; major diastereomer: $^1$H NMR (400 MHz, CDCl$_3$) δ ppm 0.73 - 1.9 (6H, s, Si(CH$_3$)$_3$), 0.76 - 0.93 (2 H, m, CH$_2$), 1.04 - 1.34 (3 H, m, CH$_3$), 1.58 - 1.78 (5 H, m, CH$_2$), 1.82 - 1.95 (1 H, m, CH), 2.22 (1 H, td, J = 11.0, 9.1 Hz, SiCH$_3$), 2.70 (1 H, dd, J = 11.2, 2.4 Hz, CHC=O), 3.16 (1 H, dd, J = 8.3, 2.3 Hz, CHOH), 4.05 (1 H, dd, J = 10.8, 9.1 Hz, CH$_2$O), 4.39 (1 H, t, J = 9.0 Hz, CH$_2$O), 7.36 - 7.45 (3 H, m, ArH), 7.47 - 7.55 (2 H, m, ArH); major diastereomer: $^{13}$C NMR (126 MHz, CDCl$_3$) δ ppm -4.7 (SiCH$_3$), -4.6 (SiCH$_3$), 25.5 (CH$_2$), 25.8 (CH$_3$), 26.1 (CH$_2$), 26.2 (SiCH), 29.3 (CH$_2$), 29.8 (CH$_2$), 40.5 (CH), 44.2 (CHC=O), 69.0 (CH$_2$O), 76.2 (CHOH), 128.2 (ArCH), 129.9 (ArCH), 133.7 (ArCH), 135.2 (ArC), 178.0 (C=O).

(35,4R)-4-{Dimethyl(phenyl)silyl}-3-{(S)-1-hydroxy-2,2-dimethylpropyl}dihydrofuran-2(3H)-one (58k)

Prepared according to General Procedure 6, on a 0.416 mmol scale, column chromatography (20% EtOAc in Hexanes) afforded the title compound as a solid (43 mg, 0.141 mmol, 34%).

Mp: 58-60 °C; MS (ES$^+$) m/z: 329 (M+Na$^+$). HRMS calcld for C$_{17}$H$_{30}$O$_3$SiN: 324.1989. Found: 324.1988 (M+NH$_4^+$); [α]$_D^{28}$ = -13.5 (c = 2.22 in CHCl$_3$); $\nu$$_{max}$ (thin film/cm$^{-1}$): 3492, 2956, 2904, 1761, 1253, 1168, 1014; major diastereomer: $^1$H NMR (400 MHz, CDCl$_3$) δ ppm 0.40 (3 H, s, SiCH$_3$), 0.42 (3 H, s, SiCH$_3$), 0.90 (9 H, s, t-Bu), 2.19 - 2.27 (1 H, m, SiCH), 2.73 (1 H, dd, J = 11.7, 0.6 Hz, CHC=O), 3.20 (1 H, s, CHOH), 4.08 (1 H, dd, J = 11.1, 9.1 Hz, CH$_2$O), 4.29 - 4.38 (1 H, m, CH$_2$O), 7.34 - 7.45 (3 H, m, ArH), 7.48 - 7.56 (2 H, m, ArH); major diastereomer: $^{13}$C NMR (101 MHz, CDCl$_3$) δ ppm -4.6...
(SiCH$_3$)$_3$, 4.6 (SiCH$_3$), 26.6 (CH$_3$), 30.1 (SiCH), 36.0 (C(CH$_3$)$_3$), 43.7 (CHC=O), 69.1 (CH$_2$O), 79.7 (CHOH), 128.2 (ArCH), 129.9 (ArCH), 133.8 (ArCH), 135.1 (ArC), 177.6 (C=O).

(3S,4S)-4-(Dimethyl(phenyl)silyl)-3-((S)-hydroxy(phenyl)methyl)tetrahydro-2H-pyran-2-one

Prepared according to General Procedure 6, on a 0.408 mmol scale, column chromatography (20% EtOAc in Hexanes) afforded the title compound as a solid (58 mg, 0.167 mmol, 41%).

Mp: 70-72 °C; MS (ES$^+$) m/z: 363 (M+Na$^+$). HRMS calcd for C$_{20}$H$_{24}$O$_3$SiNa: 363.1387. Found: 363.1386; [α]$_D$ = -0.9 (c = 2.51 in CHCl$_3$) for a sample of 54:46 dr; $\nu_{\text{max}}$ (thin film/cm$^{-1}$): 3413, 2955, 2909, 1704, 1453, 1427, 1397, 1261, 1200, 1182, 1113, 1073, 1054, 1028; major diastereomer: $^1$H NMR (500 MHz, CDCl$_3$) $\delta$ ppm 0.27 (3 H, s, SiC$_2$H$_3$), 0.32 (3 H, s, SiC$_2$H$_3$), 1.55 (1 H, ddd, J = 8.5, 7.3, 5.0 Hz, SiCH), 1.66 - 1.76 (1 H, m, CH$_2$), 1.86 (1 H, m, CH$_2$), 2.97 (1 H, dd, J = 6.0, 5.0 Hz, CHC=O), 4.16 - 4.20 (2 H, m, CH$_2$O), 4.84 (1 H, d, J = 5.7 Hz, CHOH), 7.17 (2 H, dd, J = 7.4, 1.7 Hz, ArH), 7.25 - 7.33 (3 H, m, ArH), 7.34 - 7.45 (5 H, m, ArH); major diastereomer: $^{13}$C NMR (126 MHz, CDCl$_3$) $\delta$ ppm -4.8 (SiC$_2$H$_3$), -4.6 (SiC$_2$H$_3$), 20.0 (SiCH), 23.5 (CH$_2$), 48.7 (CHC=O), 68.8 (CH$_2$O), 75.4 (CHOH), 126.4 (ArCH), 128.0 (ArCH), 128.1 (ArCH), 128.4 (ArCH), 129.6 (ArCH), 133.8 (ArCH), 136.0 (ArC), 141.0 (ArC), 172.5 (C=O).

(35,4S)-4-(Dimethyl(phenyl)silyl)-3-((5)-1-hydroxy-2-methylpropyl)tetrahydro-2H-pyran-2-one

Prepared according to General Procedure 6, on a 0.408 mmol scale, column chromatography (20% EtOAc in Hexanes) afforded the title compound as a white solid (45 mg, 0.167 mmol, 41%).

Mp: 118-120 °C; MS (ES$^+$) m/z: 307 (M+H$^+$). HRMS calcd for C$_{17}$H$_{26}$O$_3$SiNa: 329.1549. Found: 329.1552; [α]$_D$ = -1.6 (c = 6.62 in CHCl$_3$) for a sample of 63:37 dr; $\nu_{\text{max}}$ (thin film/cm$^{-1}$): 3435, 2957, 2870, 1701, 1474, 1427, 1398, 1321, 1265, 1191, 1114, 1077, 1050; minor diastereomer: $^1$H NMR (300 MHz, CDCl$_3$) $\delta$ ppm 0.38 (6 H, s, Si(CH$_3$)$_2$), 0.79 (3 H, d, J = 6.6 Hz, CH(CH$_3$)$_3$), 0.85 (3 H, d, J = 6.6 Hz, CH(CH$_3$)$_3$), 1.59 - 1.83 (2 H, m, SiCH, CH(CH$_3$)$_3$), 1.85 - 2.08 (2 H, m, CH$_2$), 2.82 (1 H, dd, J = 8.1, 2.4 Hz, CHC=O), 3.04 (1 H, dd, J = 8.7, 2.6 Hz, CHOH), 4.19 (1 H, ddd, J = 10.7, 5.8, 3.5 Hz, CH$_2$O), 4.31 - 4.43 (1 H, m, CH$_2$O), 7.33 - 7.44 (3 H, m, ArH), 7.46 - 7.59 (2 H, m, ArH); minor
Experimental procedures for Chapter 1.4

The following substrates have been prepared adapting known protocols: 1-tosyl-1,5-dihydro-2H-pyrrol-2-one\(^6\) (67a), 1-(phenylsulfonyl)-1,5-dihydro-2H-pyrrol-2-one\(^206\) (67b), 1-((4-methoxyphenyl)sulfonyl)-1,5-dihydro-2H-pyrrol-2-one\(^206\) (67c), tert-butyl 2-oxo-2,5-dihydro-1H-pyrrole-1-carboxylate\(^6\) (67d), 1-(4-methoxybenzoyl)-1,5-dihydro-2H-pyrrol-2-one\(^206\) (55e), 1-tosyl-5,6-dihydropyridin-2(1H)-one\(^207\) (67f), benzyl 6-oxo-3,6-dihydropyridine-1(2H)-carboxylate\(^67\) (67g), 7-oxo-2,3,4,7-tetrahydro-1H-azepine-1-carboxylate\(^7\) (67h), 5-methyl-1-tosyl-1,5-dihydro-2H-pyrrol-2-one\(^208\) (67), N-methyl-N-tosylcinnamamide\(^208\) (70a).

General procedure 7 for Cu-catalyzed 1,4-conjugate silyl additions:

(R)-4-(Dimethyl(phenyl)silyl)-1-tosylpyrrolidin-2-one (68a)

In an oven-dried vial equipped with a stirrer bar, (4S,5S)-1,3-bis(2-(naphthalen-2-yl)phenyl)-4,5-diphenyl-4,5-dihydro-1H-imidazol-3-ium tetrafluoroborate salt \(41\) (7.9 mg, 0.010 mmol, 5.0 mol%), NaOt-Bu (2.1 mg, 0.023 mmol, 11.0 mol%) and Cul (1.9 mg, 0.010 mmol, 5 mol%) were placed and 2.0 mL of 2-MeTHF was added. The solution was allowed to stir for 3 hours at 50 °C under nitrogen and then filtered through a short plug of oven-dried Celite under nitrogen. PhMe\(_2\)SiBpin (66.4 mg, 0.069 mL, 0.253 mmol, 1.2 equiv) was added to the filtrate and the reaction stirred for 15 min. The solution was then cooled to −78 °C, and a solution of 1-tosyl-1,5-dihydro-2H-pyrrol-2-one (50 mg, 0.211 mmol, 1.0 equiv) in dry 2-MeTHF (0.5 mL) was added and the mixture was allowed to stir overnight (−78 °C to rt), after which time the reaction was quenched by the addition of H\(_2\)O (0.5 mL). The aqueous layer was then washed with Et\(_2\)O (3 x 2 mL) and dried over Na\(_2\)SO\(_4\). Concentration in vacuo and separation by column chromatography (silica gel, 20% EtOAc in hexanes) yielded (R)-4-(dimethyl(phenyl)silyl)-1-tosylpyrrolidin-2-one as a pale yellow oil (71 mg, 90%).

diastereomer: \(^{13}\)C NMR (126 MHz, CDCl\(_3\)) \(\delta\) ppm -4.6 (SiCH\(_3\)), -4.3 (SiCH\(_3\)), 18.9 (CH\(_3\)), 22.5 (SiCH), 24.7 (CH\(_3\)), 31.9 (CH), 43.4 (CH=O), 69.0 (CH\(_2\)), 80.2 (CHOH), 128.1 (ArCH), 129.7 (ArCH), 133.9 (ArCH), 136.3 (ArC), 172.7 (C=O).
\[ \alpha \]_D^{28} = +18.2 (c = 1 in CHCl₃) for a sample of 96.5:3.5 er. MS (ES⁺) m/z: 396 (M+Na⁺). HRMS calcd for C₁₉H₂₄NO₃SSi: 374.1241, Found: 374.1252; ν_max (thin film/cm⁻¹): 3083, 1726, 1593, 1353, 1299, 1258, 1118, 1022, 899; \(^1\)H NMR (500 MHz, CDCl₃) δ ppm 0.32 (3 H, s, SiC₃H₃), 0.33 (3 H, s, SiC₃H₃), 1.81 (1 H, ddt, J = 12.9, 11.1, 8.8 Hz, SiC₃H₃), 2.26 (1 H, dd, J = 17.2, 8.8 Hz, CH₂C=O), 2.42 (1 H, dd, J = 17.2, 8.8 Hz, CH₂C=O), 2.44 (3 H, s, ArCH₃), 3.65 (1 H, dd, J = 11.1, 8.8 Hz, C₆H₂N), 4.02 (1 H, dd, J = 11.1, 8.8 Hz, C₆H₂N), 7.28 – 7.45 (7 H, m, ArH), 7.78 – 8.00 (m, 2H, ArH); \(^13\)C NMR (125 MHz, CDCl₃) δ ppm -5.1 (SiC₃H₃), -4.9 (SiC₃H₃), 19.6 (SiC₃H₃), 21.1 (Ar-CH₃), 34.6 (CH₂C=O), 49.6 (CH₃N), 128.2 (ArCH), 128.4 (ArCH), 129.7 (ArCH), 130.1 (ArCH), 133.8 (ArCH), 135.2 (ArC), 135.4 (ArC), 145.2 (ArC), 174.0 (C=O).


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\((R)-4-(Dimethyl(phenyl)silyl)-1-(phenylsulfonyl)pyrrolidin-2-one (68b)\)

Prepared according to General Procedure 7, on a 0.211 mmol scale, column chromatography (20% EtOAc in Hexanes) afforded the title compound as an oil (68 mg, 0.190 mmol, 90%).

\[ \alpha \]_D^{28} = +14.0 (c = 0.95 in CHCl₃) for a sample of 96:4 er. MS (ES⁺) m/z: MS (ES⁺) m/z: 382 (M+Na⁺). HRMS calcd for C₁₈H₂₂N₃O₃Si: 360.1084. Found: 360.1090; ν_max (thin film/cm⁻¹): 3079, 1726, 1595, 1347, 1301, 1255, 1169, 1120, 1027; \(^1\)H NMR (300 MHz, CDCl₃) δ ppm 0.31 (3 H, s, SiCH₃), 0.32 (3 H, s, SiCH₃), 1.82 (1 H, ddt, J = 12.4, 11.0, 8.7 Hz, SiCH₃), 2.26 (1 H, dd, J = 17.3, 12.4 Hz,
CH$_2$C=O), 2.43 (1 H, dd, $J = 17.3, 8.7$ Hz, CH$_2$C=O), 3.65 (1 H, t, $J = 10.4$ Hz, CH$_2$N), 4.03 (1 H, dd, $J = 10.5, 8.5$ Hz, CH$_2$N), 7.28 - 7.76 (8 H, m, ArH), 8.15 - 7.88 (m, 2H, ArH); $^{13}$C NMR (125 MHz, CDCl$_3$) δ ppm -5.2 (SiCH$_3$), -5.1 (SiCH$_3$), 19.5 (SiCH), 34.6 (CH$_2$C=O), 49.5 (CH$_2$N), 127.9 (ArCH), 128.3 (ArCH), 129.0 (ArCH), 130.0 (ArCH), 133.6 (ArCH), 134.0 (ArCH), 134.9 (ArC), 138.3 (ArC), 173.8 (C=O).

Chiralcel OD-H column, 28 °C, $\lambda = 220$ nm. Eluent: hexane : iso-propanol 80 : 20 v / v. Flow: 1 mL / min

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(R)-4-(Dimethyl(phenyl)silyl)-1-((4-methoxyphenyl)sulfonyl)pyrrolidin-2-one (68c)

![Chemical structure of R-4-(Dimethyl(phenyl)silyl)-1-((4-methoxyphenyl)sulfonyl)pyrrolidin-2-one (68c)](image)

Prepared according to General Procedure 7, on a 0.211 mmol scale, column chromatography (20% EtOAc in Hexanes) afforded the title compound as an oil (69 mg, 0.177 mmol, 84%).

$[\alpha]_D^{28} = +12.5$ (c = 0.75 in CHCl$_3$) for a sample of > 99:1 er. MS (ES$^+$) m/z: 412 (M+Na$^+$). HRMS calcd for C$_{19}$H$_{23}$N$_1$O$_4$S$_1$Si$_1$: 389.1117. Found: 389.1115; $\nu_{max}$ (thin film/cm$^{-1}$): 3080, 1730, 1597, 1360, 1299, 1277, 1263, 1121, 1018; $^1$H NMR (500 MHz, CDCl$_3$) δ ppm 0.31 (3 H, s, SiCH$_3$), 0.32 (3 H, s, SiCH$_3$), 1.81 (1 H, ddt, $J = 12.3, 10.7, 8.6$ Hz, SiCH), 2.25 (1 H, dd, $J = 17.4, 12.3$ Hz, CH$_2$C=O), 2.42 (1 H, dd, $J = 17.4, 8.8$ Hz, CH$_2$C=O), 3.64 (1 H, dd, $J = 10.8, 10.0$ Hz, CH$_2$N), 3.87 (3 H, s, OCH$_3$), 4.01 (1 H, dd, $J = 10.0, 8.5$ Hz, CH$_2$N), 7.01-6.93 (2 H, m, ArH), 7.47 - 7.33 (5 H, m, ArH), 7.98-7.90 (2H, m, ArH); $^{13}$C NMR (125 MHz, CDCl$_3$) δ ppm -5.1 (SiCH$_3$), -4.9 (SiCH$_3$), 19.6 (SiCH), 34.6 (CH$_2$C=O), 49.4
(CH$_3$N), 55.7 (OCH$_3$), 114.3 (ArCH), 128.4 (ArCH), 129.8 (ArC), 129.9 (ArCH), 130.3 (ArCH), 133.7 (ArCH), 135.1 (ArCH), 135.7 (ArC), 163.9 (ArC), 174.0 (C=O).


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**tert-Butyl (R)-4-(dimethyl(phenyl)silyl)-2-oxopyrrolidine-1-carboxylate (68d)**

Prepared according to General Procedure 7, on a 0.211 mmol scale, column chromatography (15% EtOAc in Hexanes) afforded the title compound as an oil (63 mg, 0.196 mmol, 93%).

[α]$_D^{28}$ = +17.7 (c = 1.00 in CHCl$_3$) for a sample of 87:13 er. MS (ES') m/z: 242 (M+Na$^+$). HRMS calcd for C$_{17}$H$_{26}$NO$_3$Si: 320.1676 Found: 320.1681; $\nu_{max}$ (thin film/cm$^{-1}$): 3077, 1785, 1753, 1712, 1311, 1255, 1121, 1021, 1001; $^1$H NMR (500 MHz, CDCl$_3$) $\delta$ ppm 0.31 (3 H, s, SiCH$_3$), 0.32 (3 H, s, SiCH$_3$), 1.51 (9 H, s, t-Bu), 1.72 (1 H, ddt, $J = 12.7$, 11.2, 8.7 Hz, SiCH), 2.35 (1 H, dd, $J = 17.3$, 12.7 Hz, CH$_2$C=O), 2.49 (1 H, dd, $J = 17.3$, 8.8 Hz, CH$_2$C=O), 3.50 (1 H, t, $J = 11.0$ Hz, CH$_3$N), 3.83 (1 H, dd, $J = 10.9$, 8.6 Hz, CH$_2$N), 7.31 - 7.43 (3 H, m, ArH), 7.43 - 7.59 (2 H, m, ArH); $^{13}$C NMR (125 MHz, CDCl$_3$) $\delta$ ppm -5.1 (SiCH$_3$), -5.0 (SiCH$_3$), 18.5 (SiCH), 28.2 ((CH$_3$)$_2$C), 35.3 (CH$_2$C=O), 48.6 (CH$_2$N), 83.0 ((CH$_3$)$_2$C), 128.2 (ArCH), 129.9 (ArCH), 133.8 (ArCH), 135.7 (ArC), 150.5 (Boc C=O), 175.2 (C=O).
Chiralpak OD-H column, 28 °C, λ = 220 nm. Eluent: hexane : iso-propanol 95 : 5 v / v. Flow: 1 mL / min

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(R)-4-(Dimethyl(phenyl)silyl)-1-(4-methoxybenzoyl)pyrrolidin-2-one (68e)

Prepared according to General Procedure 7, on a 0.211 mmol scale, column chromatography (15% EtOAc in Hexanes) afforded the title compound as an oil (54 mg, 0.154 mmol, 73%).

\[ \alpha \] \textsubscript{D} \textsubscript{28} = +8.9 (c = 0.98 in CHCl\textsubscript{3}) for a sample of 80:20 er. MS (ES +) m/z: 377 (M+Na +). HRMS calcd for C\textsubscript{20}H\textsubscript{23}N\textsubscript{1}O\textsubscript{3}Si: 353.1447. Found: 353.1444; \( \nu \)\textsubscript{max} (thin film/cm\textsuperscript{-1}): 3083, 1743, 1662, 1353, 1262, 1121, 1016, 997; \textsuperscript{1}H NMR (400 MHz, CDCl\textsubscript{3}) \( \delta \) ppm 0.31 (3 H, s, SiCH\textsubscript{3}), 0.33 (3 H, s, SiCH\textsubscript{3}), 1.81 (1 H, m, SiCH), 2.43 (1 H, dd, \( J = 17.7, 11.8 \) Hz, CH\textsubscript{2}C=O), 2.62 (1 H, dd, \( J = 17.7, 8.9 \) Hz, CH\textsubscript{2}C=O), 3.79 (1 H, dd, \( J = 11.3, 9.0 \) Hz, CH\textsubscript{2}N), 3.85 (3 H, s, OCH\textsubscript{3}) 3.99 (1 H, dd, \( J = 11.3, 8.9 \) Hz, CH\textsubscript{2}N), 7.02-6.59 (2 H, m, ArH), 7.89 – 7.24 (7 H, m, ArH); \textsuperscript{13}C NMR (125 MHz, CDCl\textsubscript{3}) \( \delta \) ppm -4.9 (SiCH\textsubscript{3}), -4.8 (SiCH\textsubscript{3}), 18.6 (SiCH), 35.7 (CH\textsubscript{2}C=O), 49.5 (CH\textsubscript{2}N), 55.5 (OCH\textsubscript{3}), 113.7 (ArCH), 126.2 (ArC), 128.3 (ArCH), 129.8 (ArCH), 131.8 (ArCH), 133.9 (ArCH), 135.6 (ArC), 162.9 (ArC), 170.2 (Ar-C=O), 175.2 (C=O).
Chiralpak IA column, 28 °C, λ = 220 nm. Eluent: hexane : ethanol 80 : 20 v/v. Flow: 1 mL / min

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(S)-4-(Dimethyl(phenyl)silyl)-1-tosylpiperidin-2-one (68f)

Prepared according to General Procedure 7 using ligand 16a, on a 0.211 mmol scale, column chromatography (20% EtOAc in Hexanes) afforded the title compound as an oil (68 mg, 0.175 mmol, 83%).

[α]D28 = +17.3 (c = 0.95 in CHCl3) for a sample of 88:12 er. MS (ES+) m/z: MS (ES+) m/z: 410 (M+Na+). HRMS calcld for C20H26N1O3Si1: 388.1397 Found: 388.1394; νmax (thin film/cm⁻¹): 3077, 1687, 1590, 1381, 1353, 1257, 1123, 1024, 902; 1H NMR (500 MHz, CDCl3) δ ppm 0.29 (6 H, s, SiCH3), 1.22 - 1.34 (1 H, m, CH2), 1.47 - 1.59 (1 H, m, CH2), 1.68 - 1.77 (1 H, m, SiCH), 2.15 (1 H, dd, J = 17.5, 13.4 Hz, CH2C=O), 2.38 (1 H, m, CH2C=O), 2.41 (3 H, s, Ar-CH3), 3.60 (1 H, ddt, J = 11.7, 9.5, 4.4 Hz, CH2N), 4.13 (1 H, dt, J = 11.7, 4.4 Hz, CH2N), 7.28 (2 H, d, J = 8.0 Hz, ArH), 7.32 - 7.41 (3 H, ArH), 7.43 - 7.45 (2 H, m ArH), 7.91 - 7.84 (2 H, m, ArH); 13C NMR (125 MHz, CDCl3) δ -5.6 (SiCH3), -5.4 (SiCH3), 19.9 (CH2), 21.8 (ArCH3), 24.7 (SiCH), 35.5 (CH2C=O), 48.2 (NCH3), 128.2 (ArCH), 128.8 (ArCH), 129.4 (ArCH), 129.8 (ArCH) 133.9 (ArCH), 135.6 (ArC), 136.1 (ArC), 144.8 (ArC), 170.6 (C=O).

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*Benzyl (S)-4-((dimethyl(phenyl)silyl)-2-oxopiperidine-1-carboxylate (68g)*

Prepared according to General Procedure 7 using ligand _16a_, on a 0.211 mmol scale, column chromatography (15% EtOAc in Hexanes) afforded the title compound as an oil (55 mg, 1.50 mmol, 71%).

[α]_D_28 = +13.3 (c = 0.70 in CHCl₃) for a sample of 89.5:10.5 er. MS (ES⁺) m/z: 390 (M+Na⁺). HRMS calcd for C₂₁H₂₅N₁O₃Si₁: 367.1604 Found: 367.1602; ν_max (thin film/cm⁻¹): 3081, 1692, 1421, 1261, 1250, 1148, 1114, 1022, 989; ¹H NMR (500 MHz, CDCl₃) δ ppm 0.32 (6 H, s, Si(CH₃)₂), 1.26 - 1.38 (1 H, m, CH₂), 1.53 - 1.59 (1 H, m, CH₂), 1.91 (1 H, dtt, J = 13.6, 4.4, 2.3 Hz, SiCH), 2.27 (1 H, dd, J = 17.0, 13.2 Hz, CH₂C=O), 2.55 (1 H, ddd, J = 17.0, 4.9, 2.0 Hz, CH₂C=O), 3.60 (1 H, ddd, J = 12.7, 10.4, 4.7 Hz, CH₂N), 3.80 (1 H, dt, J = 12.7, 4.7 Hz, CH₂N), 5.26 (2 H, s, OCH₂Ph), 7.60 - 7.26 (10 H, ArH); ¹³C NMR (125 MHz, CDCl₃) δ -5.5 (SiCH₃), -5.4 (SiCH₃), 19.9 (CH₂), 24.0 (SiCH), 36.1 (CH₂C=O), 47.7 (NCH₂), 68.5 (OCH₂Ph), 128.1 (ArCH), 128.2 (ArCH), 128.4 (ArCH), 128.7 (ArCH), 129.7 (ArCH), 134.0 (ArCH), 135.6 (ArC), 135.9 (ArC), 154.2 (Cbz C=O), 171.8 (C=O).
Chiralcel OJ column, 28 °C, $\lambda = 220$ nm. Eluent: heptane : iso-propanol 99 : 1 v/v. Flow: 0.7 mL / min

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**tert-Butyl (S)-4-(dimethyl(phenyl)silyl)-2-oxazepane-1-carboxylate (68h)**

Prepared according to General Procedure 7 using ligand 16a, on a 0.211 mmol scale, column chromatography (20% EtOAc in Hexanes) afforded the title compound as an oil (48 mg, 1.37 mmol, 65%).

$[\alpha]_D^{28} = +11.6$ (c = 0.95 in CHCl$_3$) for a sample of 90:10 er. MS (ES$^+$) m/z: 370 (M+Na$^+$). HRMS calcd for C$_{19}$H$_{29}$NO$_3$SiNa: 370.1809, Found: 370.1807; $\nu_{\text{max}}$ (thin film/cm$^{-1}$): 3081, 1769, 1717, 1454, 1367, 1301, 1254, 1111, 1021; $^1$H NMR (400 MHz, CDCl$_3$) $\delta$ ppm 0.30 (3 H, s, SiCH$_3$), 0.31 (3 H, s, SiCH$_3$), 1.14 (1 H, tdd, J = 13.0, 2.3, 1.0 Hz, SiCH), 1.51 (9 H, s, t-Bu), 1.67 - 1.80 (1 H, m, NCH$_2$CH$_2$), 1.84 - 1.99 (2 H, m, NCH$_2$CH$_2$ and SiCHCH$_2$), 2.49 (1 H, dd, J = 14.1, 11.3 Hz, CH$_2$C=O), 2.61 (1 H, dt, J = 14.1, 1.4 Hz, CH$_3$C=O), 3.25 (1 H, dd, J = 15.2, 10.5 Hz, CH$_2$N), 4.08 - 4.27 (1 H, m, CH$_2$N), 7.33 - 7.37 (3 H, m, ArH), 7.42 - 7.53 (2 H, m, ArH); $^{13}$C NMR (100 MHz, CDCl$_3$) $\delta$ ppm -5.1 (SiCH$_3$), -4.7 (SiCH$_3$), 22.8 (SiCH), 28.2 ((CH$_3$)$_3$C), 30.2 (CH$_2$), 30.4 (CH$_2$), 40.3 (CH$_2$C=O), 46.2 (CH$_2$N), 82.9 (CH$_3$C), 128.1 (ArCH), 129.5 (ArCH), 131.4 (ArCH), 136.7 (ArC), 153.2 (Boc C=O), 176.2 (C=O).
Chiralpak IB column, 28 °C, λ = 220 nm. Eluent: hexane : iso-propanol 98.2 : 0.8 v/v. Flow: 1 mL /min.

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**(4R,5S)-4-(Dimethyl(phenyl)silyl)-5-methyl-1-tosylpyrrolidin-2-one (68i)**

Prepared according to General Procedure 7 using 0.7 equivalents of PhMe$_2$SiBpin, on a 0.208 mmol scale, column chromatography (20% EtOAc in Hexanes) afforded the title compound as an oil (38 mg, 0.098 mmol, 47%).

$[\alpha]_D^{28} = +11.9$ (c = 1.0 in CHCl$_3$) for a sample of 82:18 er. MS (ES$^+$) m/z: 410 (M+Na$^+$). HRMS calcd for C$_{20}$H$_{25}$NO$_3$SiNa: 410.1222, Found: 410.1212; $\nu_{\text{max}}$ (thin film/cm$^{-1}$): 3080, 1728, 1597, 1351, 1303, 1261, 1120, 904; $^1$H NMR (500 MHz, CDCl$_3$) δ ppm 0.27 (3 H, s, SiC$_3$H$_3$), 0.29 (3 H, s, SiC$_3$H$_3$), 1.35 (1 H, ddd, $J = 10.8, 6.3$, 4.5 Hz, SiCH), 1.45 (3 H, d, $J = 6.0$ Hz, CHCH$_3$), 2.24 (1 H, dd, $J = 18.0, 6.4$ Hz, CH$_2$C=O), 2.42 (3 H, s, Ar-CH$_3$), 2.65 (1 H, dd, $J = 18.0, 10.7$ Hz, CH$_2$C=O), 4.34 (1 H, dq, $J = 10.7, 6.0$ Hz, CH$_3$N), 7.29 (2 H, d, $J = 8.1$ Hz, ArH), 7.35 - 7.45 (5 H, m, ArH), 7.81 - 7.89 (2 H, m, ArH); $^{13}$C NMR (125 MHz, CDCl$_3$) δ -5.2 (SiCH$_3$), -5.0 (SiCH$_3$), 21.8 (ArCH$_3$), 24.0 (SiCH), 26.3 (CHCH$_3$), 32.8 (CH$_2$C=O), 58.3 (NCH), 128.3 (ArCH), 128.4 (ArCH), 129.6 (ArCH), 130.0 (ArCH), 133.9 (ArCH), 135.5 (ArC), 136.2 (ArC), 145.0 (ArC), 173.8 (C=O).

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**General procedure 8 for the synthesis of linear amides (69b-f).**

**N-Ethyl-N-tosylcinnamamide (69b)**

To a solution of *N*-ethyl-4-methylbenzenesulfonamide (6.00 mmol, 1.195 g, 1.0 equiv) in anhydrous THF (12 mL) cooled at 0 °C was added under nitrogen a solution of *n*-BuLi (1.55 M in hexanes, 6.60 mmol, 4.25 mL, 1.1 equiv) and the resulting mixture was stirred for 15 min. Subsequently, cinnamoyl chloride (6.60 mmol, 1.1 g, 1.1 equiv) dissolved in anhydrous THF (5 mL) was added and the mixture was left to warm to rt over 2 h. Saturated (aq) NH₄Cl (10 mL) was added and the mixture was extracted with EtOAc (3 x 15 mL). The organic layer was then dried (Na₂SO₄), filtered and concentrated under reduced pressure. The crude mixture was then purified by column chromatography on silica gel (60% EtOAc in hexane) to yield *N*-ethyl-*N*-tosylcinnamamide as a cream solid (1.66 g, 5.04 mmol, 84%).

MS (ES⁺) m/z: 330 (M+H⁺); HRMS calcd for C₁₈H₁₉O₃N₂S₁: 329.1086. Found: 329.1083; νₘₐₓ (thin film/cm⁻¹): 1684, 1422, 1373, 1166; ¹H NMR (400 MHz, CDCl₃) δ ppm 1.37 (3 H, t, J = 7.0 Hz, CH₂CH₃), 2.41 (3 H, s, Ar-CH₃), 3.96 (2 H, q, J = 7.0 Hz, CH₂CH₃), 7.30 (2 H, m, ArH), 7.31 (1 H, d, J = 15.4 Hz, Ar-CH), 7.39 (3 H, m, ArH), 7.50 (2 H, m, ArH), 7.67 (1 H, d, J = 15.4 Hz, Ph-CH), 7.81 (m,
2H, ArH); $^{13}$C NMR (100 MHz, CDCl$_3$) δ ppm 15.4 (CH$_2$CH$_3$), 21.6 (Ar-CH$_3$), 42.0 (CH$_2$CH$_3$), 118.2 (CH=O), 127.3 (ArCH), 128.3 (ArCH), 128.9 (ArCH), 129.8 (ArCH), 130.5 (ArCH), 134.5 (ArC), 137.1 (ArC), 144.7 (ArC), 145.7 (Ph-CH), 165.7 (C=O).

(E)-N-Methyl-N-tosyl-3-(3-(trifluoromethyl)phenyl)acrylamide (69c)

Prepared according to General Procedure 8 in 80% yield.

MS (ES$^+$) m/z: 384 (M+H$^+$); HRMS calcd for C$_{18}$H$_{17}$O$_3$N$_1$F$_3$: 384.0876. Found: 384.0874; $\nu$$_{max}$ (thin film/cm$^{-1}$): 1689, 1431, 1374, 1352, 1165, 991; $^1$H NMR (400 MHz, CDCl$_3$) δ ppm 2.42 (3 H, s, Ar-CH$_3$), 3.33 (3 H, s, NCH$_3$), 7.33 (2 H, m, ArH), 7.51 (1 H, d, J = 15.5 Hz, CHC=O), 7.52 (1 H, m, ArH), 7.63 (1 H, m, ArH), 7.65 (1 H, d, J = 15.5 Hz, Ph-CH), 7.71 (2 H, m, ArH), 7.76 (2 H, m, ArH); $^{13}$C NMR (101 MHz, CDCl$_3$) δ ppm 21.5 (Ar-CH$_3$), 33.1 (NCH$_3$), 120.5 (CHC=O), 123.7 (q, J = 272.5 Hz, CF$_3$), 124.8 (q, J = 3.8 Hz, ArCH), 126.8 (q, J = 3.7 Hz, ArCH), 127.2 (ArCH), 129.5 (ArCH), 130.0 (ArCH), 131.1 (ArCH), 131.4 (q, J = 32.6 Hz, ArCCF$_3$), 135.3 (ArC), 136.0 (ArC), 143.4 (ArC), 145.1 (Ph-CH), 165.9 (C=O); $^{19}$F NMR (470 MHz, CDCl$_3$) δ -62.9 (bs, CF$_3$).

(E)-3-(Furan-2-yl)-N-methyl-N-tosylacrylamide (69d)

Prepared according to General Procedure 8 in 88% yield.

MS (ES$^+$) m/z: 306 (M+H$^+$); HRMS calcd for C$_{15}$H$_{16}$O$_4$N$_1$: 306.0795. Found: 306.0797; $\nu$$_{max}$ (thin film/cm$^{-1}$): 3074, 1682, 1363, 1148, 960, 896; $^1$H NMR (400 MHz, CDCl$_3$) δ ppm 2.41 (3 H, s, Ar-CH$_3$), 3.34 (3 H, s, NCH$_3$), 6.47 (1 H, dd, J = 3.4, 1.8 Hz, furH), 6.63 (1 H, d, J = 3.4 Hz, furH), 7.30 (1 H, d, J = 15.2 Hz, CHC=O), 7.31 (2 H, m, ArH), 7.43 (1 H, d, J = 15.2 Hz, fur-CH), 7.50 (1 H, d, J = 1.8 Hz, furH), 7.79 (2 H, m, ArH); $^{13}$C NMR (101 MHz, CDCl$_3$) δ ppm 21.6 (Ar-CH$_3$), 33.1 (CH$_3$), 112.5 (fur CH), 115.5 (CHC=O), 115.8 (fur CH), 127.3 (Ar CH), 129.8 (Ar CH), 131.9 (fur CH), 136.2 (Ar C), 144.8 (Ar C), 145.1 (fur-CH), 151.1 (fur C), 166.2 (C=O).
N-Benzyl-N-tosylcinnamamide (69e)

Prepared according to General Procedure 8 in 77% yield.

MS (ES⁺) m/z: 392 (M+H⁺); HRMS calcd for C₂₃H₂₂O₃N₁S₁: 392.1315. Found: 392.1313; νmax (thin film/cm⁻¹): 1688, 1426, 1377, 1171, 988, 797; ¹H NMR (400 MHz, CDCl₃) δ ppm 2.39 (3 H, s, Ar-C₂H₃), 5.16 (2 H, s, C₂H₂Ph), 7.24 (2 H, m, ArH), 7.27 (1 H, d, J = 15.4 Hz, CHC=O), 7.29 (1 H, m, ArH), 7.35 (2 H, m, ArH), 7.37 (3 H, m, ArH), 7.43 (4 H, m, ArH), 7.66 (1 H, d, J = 15.4 Hz, Ph-CH), 7.67 (m, 2H, ArH); ¹³C NMR (100 MHz, CDCl₃) δ ppm 21.6 (Ar-C₂H₃), 49.4 (C₂H₂Ph), 118.1 (C=O), 127.6 (ArCH), 127.7 (ArCH), 128.0 (ArCH), 128.3 (ArCH), 128.9 (ArCH), 129.7 (ArCH), 130.6 (ArCH), 134.4 (ArC), 136.8 (ArC), 136.9 (ArC), 144.8 (ArC), 146.1 (Ph-CH), 166.1 (C=O).

(E)-N-Methyl-N-tosyl-but-2-enamide (69f)

Prepared according to General Procedure 8 in 71% yield.

MS (ES⁺) m/z: 277 (M+H⁺); HRMS calcd for C₁₂H₁₆O₃N₁S₁: 254.0845. Found: 254.0848; νmax (thin film/cm⁻¹): 1694, 1371, 1333, 1154; ¹H NMR (400 MHz, CDCl₃) δ ppm 1.85 (3 H, dd, J = 6.9, 1.6 Hz, CH₂C₂H₃), 2.38 (3 H, s, Ar-C₂H₃), 3.24 (3 H, s, NCH₃), 6.75 (1 H, dd, J = 15.0, 1.6 Hz, CHC=O), 6.92 (1 H, dd, J = 15.0, 6.9 Hz, C₂H₂C₂H₃), 7.29 (2 H, m, ArH), 7.71 (2 H, m, ArH); ¹³C NMR (100 MHz, CDCl₃) δ ppm 18.3 (CH₂C₂H₃), 21.4 (Ar-C₂H₃), 32.8 (NCH₃), 62.9 (CHC=O), 127.1 (ArCH), 129.7 (ArCH), 136.1 (ArC), 144.6 (ArC), 145.8 (CH=CH₂C₂H₃), 166.0 (C=O).

(R)-3-(Dimethyl(phenyl)silyl)-N-methyl-3-phenyl-N-tosylpropanamide (70a)

Prepared according to General Procedure 7, on a 0.211 mmol scale, column chromatography (20% EtOAc in Hexanes) afforded the title compound as an oil (83 mg, 0.184 mmol, 87%).

[α]D₂⁸ = +21.6 (c = 1.0 in CHCl₃) for a sample of 92:8 er. MS (ES⁺) m/z: 474 (M+Na⁺). HRMS calcd for C₂₅H₂₉N₁O₃S₁SiNa₂: 474.1535 Found: 474.1526; νmax (thin film/cm⁻¹): 3078, 2967, 1705, 1461, 1354, 1254, 1118, 1021; ¹H NMR (500 MHz, CDCl₃) δ ppm 0.09 (3 H, s, SiC₂H₃), 0.13 (3 H, s, SiC₂H₃), 2.34 (3 H, s, Ar-CH₃), 2.67 – 2.89 (2 H, m, CH₂C₂H₃), 3.03 (3 H, s, NCH₃), 3.18 (1 H, dd, J = 16.8, 10.6 Hz, SiCH), 6.53 – 6.61 (2 H, m, ArH), 6.88 – 6.95 (3 H, m, ArH), 7.03 – 7.09 (2 H, m, ArH), 7.12 – 7.22 (5 H, m, ArH), 7.29 – 7.35 (2 H, m, ArH); ¹³C NMR (125 MHz, CDCl₃) δ -5.2 (SiCH₃), -3.9 (SiCH₃),
21.8 (ArCH$_3$), 31.9 (SiCH), 33.2 (NCH$_3$), 37.2 (CH$_2$=O), 124.9 (ArCH), 127.5 (ArCH), 127.9 (ArCH),
128.0 (ArCH), 129.4 (ArCH), 129.7 (ArCH), 130.0 (ArCH), 133.1 (ArCH), 134.5 (ArCH), 136.6 (ArC),
142.0 (ArC), 144.8 (ArC), 172.6 (C=O).


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**($R$)-3-(Dimethyl(phenyl)silyl)-N-ethyl-3-phenyl-N-tosylpropanamide (70b)**

Prepared according to General Procedure 7, on a 0.211 mmol scale, column chromatography (20%
EtOAc in Hexanes) afforded the title compound as an oil (81 mg, 0.173 mmol, 82%).

[α]$^{D}_{28} = +15.2$ (c = 1.1 in CHCl$_3$) for a sample of 90:10 er. MS (ES$^+$) m/z: 466 (M+H$^+$). HRMS calcd for
C$_{26}$H$_{35}$N$_2$O$_3$Si: 483.2132 Found: 483.2122; $\nu_{max}$ (thin film/cm$^{-1}$): 3081, 1702, 1463, 1351, 1257,
1120, 1015; $^1$H NMR (500 MHz, CDCl$_3$) δ ppm 0.12 (3 H, s, SiCH$_3$), 0.17 (3 H, s, SiCH$_3$), 1.10 (3 H, t, J
= 6.9 Hz, CH$_3$), 2.45 (3 H, s, Ar-CH$_3$), 2.70 – 2.95 (2 H, m, CH$_2$=O), 3.15 (1 H, dd, J = 17.3, 11.3 Hz,
SiCH), 3.73 (2 H, m, CH$_2$CH$_3$), 6.51 – 6.65 (2 H, m, ArH), 6.96 – 7.08 (3 H, m, ArH), 7.24 (2 H, d, J =
8.2 Hz, ArH), 7.29 – 7.38 (5 H, m, ArH), 7.57 (2 H, d, J = 8.2 Hz, ArH); $^{13}$C NMR (125 MHz, CDCl$_3$) δ -
5.1 (SiCH$_3$), -3.9 (SiCH$_3$), 15.3 (CH$_3$), 21.8 (Ar-CH$_3$), 31.8 (SiCH), 37.3 (CH$_2$=O), 42.5 (CH$_2$CH$_3$), 124.8
(ArCH), 127.3 (ArCH), 127.5 (ArCH), 127.9 (ArCH), 128.1 (ArCH), 129.4 (ArCH), 130.0 (ArCH), 134.4
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(R)-3-(Dimethyl(phenyl)silyl)-N-methyl-N-tosyl-3-(3-(trifluoromethyl)phenyl)propanamide (70c)

Prepared according to General Procedure 7, on a 0.211 mmol scale, column chromatography (20% EtOAc in Hexanes) afforded the title compound as an oil (103 mg, 0.198 mmol, 94%). 

$[\alpha]_{D}^{28} = +12.8$ (c = 0.8 in CHCl$_3$) for a sample of 85:15 er. MS (ES$^+$) m/z: 520 (M+H$^+$). HRMS calcd for C$_{26}$H$_{28}$N$_1$O$_3$S$_1$Na: 542.1403 Found: 542.1396; $\nu_{\text{max}}$ (thin film/cm$^{-1}$): 3084, 2965, 1701, 1462, 1351, 1262, 1124, 1113, 1022, 697; $^1$H NMR (500 MHz, CDCl$_3$, major rotamer) δ ppm 0.17 (3 H, s, SiC$_3$H$_3$), 0.24 (3 H, s, SiC$_3$H$_3$), 2.43 (3 H, s, Ar-CH$_3$), 2.90 - 3.05 (2 H, m, CH$_2$C=O), 3.15 (3 H, s, NCH$_3$), 3.20 (1 H, dd, J = 17.8, 11.5 Hz, SiCH), 6.78 (1 H, t, J = 1.8 Hz, ArH), 6.91 (1 H, d, J = 7.7 Hz, ArH), 7.18 (1 H, t, J = 7.7 Hz, ArH), 7.23 (2 H, d, J = 7.8 Hz, ArH), 7.28 (1 H, d, J = 7.8 Hz, ArH), 7.29 - 7.34 (2 H, m, ArH), 7.37 (2 H, t, J = 7.7 Hz, ArH), 7.41 - 7.46 (1 H, m, ArH), 7.53 – 7.56 (2 H, m, ArH); $^{13}$C NMR (125 MHz, CDCl$_3$, 2 rotamers) δ -5.2 (SiCH$_3$), -4.3 (SiCH$_3$), 21.7 (Ar-CH$_3$), 31.7 (SiCH), 33.2 (NCH$_3$), 37.1 (COCH$_3$), 121.8 (q, $J = 3.8$ Hz, ArCH), 123.5 (q, $J = 3.7$ Hz, ArCH), 124.2 (q, $J = 272.5$ Hz, CF$_3$), 127.1 (ArCH), 128.0 (ArCH), 128.5 (ArCH), 130.0 (ArCH), 131.1 (ArCH), 131.3 (q, $J = 32.6$ Hz, ArCCF$_3$), 133.2 (ArCH), 134.3 (ArCH), 135.6 (ArC), 136.4 (ArC), 143.4 (ArC), 145.2 (ArC), 172.1 (C=O); $^{19}$F NMR (470 MHz, CDCl$_3$) δ -62.9 (bs, CF$_3$).
Chiralpak IA column, 28 °C, λ = 220 nm. Eluent: hexane : iso-propanol 98 : 2 v/v. Flow: 1 mL / min

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**(R)-3-(Dimethyl(phenyl)silyl)-3-(furan-2-yl)-N-methyl-N-tosylpropanamide (70d)**

Prepared according to General Procedure 7, on a 0.211 mmol scale, column chromatography (20% EtOAc in Hexanes) afforded the title compound as an oil (67 mg, 1.52 mmol, 72%).

[α]_D28 = +10.8 (c = 1.0 in CHCl₃) for a sample of 83:17 er. MS (ES⁺) m/z: 442 (M+H⁺). HRMS calcd for C₂₃H₂₇N₁O₄S₁Si: 464.1328. Found: 464.1327; νmax (thin film/cm⁻¹): 3076, 1707, 1460, 1351, 1260, 1122, 1017, 961, 887; ¹H NMR (400 MHz, CDCl₃) δ ppm 0.19 (3 H, s, SiC₃H₃), 0.26 (3 H, s, SiC₃H₃), 2.44 (3 H, s, Ar-CH₃), 2.72 (1 H, dd, J = 17.2, 3.5 Hz, CH₂C=O), 3.02 (1 H, dd, J = 11.3, 3.5 Hz, CH₂C=O) 3.15 (3 H, s, NCH₃), 3.16 - 3.24 (1 H, m, SiCH), 5.57 (1 H, d, J = 3.3 Hz, furH), 6.16 (1 H, dd, J = 3.3, 1.7 Hz, furH), 7.12 (1 H, d, J = 1.7 Hz, furH), 7.24 – 7.43 (7 H, m, ArH), 7.50 – 7.63 (2 H, m, ArH); ¹³C NMR (125 MHz, CDCl₃) δ -4.8 (SiCH₃), -3.8 (SiCH₃), 21.8 (Ar-CH₃), 25.2 (SiCH), 33.2 (NCH₃), 35.9 (CH₂C=O), 104.0 (fur CH), 110.4 (fur CH), 127.4 (ArCH), 127.9 (ArCH), 128.0 (ArCH), 129.5 (ArCH), 130.0 (ArCH), 134.4 (ArCH), 136.5 (ArC), 140.3 (fur C), 144.8 (ArC), 156.1 (fur C), 172.5 (C=O).
Chiralpak IB column, 28 °C, λ = 220 nm. Eluent: hexane : iso-propanol 99 : 1 v/v. Flow: 0.8 mL / min

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(R)-N-Benzyl-3-(dimethyl(phenyl)silyl)-3-phenyl-N-tosylpropanamide (70e)

Prepared according to General Procedure 7, on a 0.211 mmol scale, column chromatography (20% EtOAc in Hexanes) afforded the title compound as an oil (87 mg, 0.165 mmol, 78%).

\[\alpha\]_D^{28} = +9.1 (c = 0.5 in CHCl_3) for a sample of 87:13 er. MS (ES^+) m/z: 545 (M+NH_4^+). HRMS calcd for C_{31}H_{37}N_{1}O_{3}S_{1}SiN_{2}: 545.2289 Found: 545.2278; \nu_{max} (thin film/cm\(^{-1}\)): 3083, 1704, 1462, 1351, 1252, 1121, 1014, 998, 698; \^\text{1}H NMR (400 MHz, CDCl_3) \(\delta\) ppm 0.11 (3 H, s, SiC\(_3\)H), 0.15 (3 H, s, SiC\(_3\)H), 2.42 (3 H, s, Ar-CH\(_3\)), 2.74 (1 H, dd, J = 17.3, 3.7 Hz, CH\(_2\)C=O), 2.88 (1 H, dd, J = 11.7, 3.7 Hz, CH\(_2\)C=O), 3.13 (1 H, dd, J = 17.3, 11.7 Hz, SiCH), 4.87 (1 H, d, J = 15.6 Hz, PhCH\(_2\)N), 5.09 (1 H, d, J = 15.6 Hz, PhCH\(_2\)N), 6.29 – 6.57 (2 H, m, ArH), 6.80 – 7.53 (17 H, m, ArH); \^\text{13}C NMR (125 MHz, CDCl_3) \(\delta\) -5.0 (SiCH\(_3\)), -3.9 (SiCH\(_3\)), 21.7 (Ar-CH\(_3\)), 31.9 (SiCH), 37.3 (CH\(_2\)C=O), 49.1 (PhCH\(_2\)N), 124.8 (ArCH), 127.5 (ArCH), 127.6 (ArCH), 127.7 (ArCH), 127.8 (ArCH), 127.9 (ArCH), 128.1 (ArCH), 128.2 (ArCH), 128.6 (ArCH), 129.4 (ArCH), 129.8 (ArCH), 134.4 (ArC), 136.5 (ArC), 136.7 (ArC), 141.8 (ArC), 144.6 (ArC), 172.4 (C=O).
Chiralpak IB column, 28 °C, λ = 220 nm. Eluent: hexane : iso-propanol 98 : 2 v/v. Flow: 0.9 mL / min

\textbf{Racemic} \hspace{1cm} \textbf{Enantiomerically enriched}

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\textit{(S)-3-(Dimethyl(phenyl)silyl)-N-methyl-N-tosylbutanamide (70f)}

Prepared according to General Procedure 7, on a 0.211 mmol scale, column chromatography (20% EtOAc in Hexanes) afforded the title compound as an oil (56 mg, 0.143 mmol, 68%).

$[\alpha]_D^{28} = +9.9 \ (c = 0.8 \text{ in CHCl}_3)$ for a sample of 82:18 er. MS (ES$^+$) m/z: 412 (M+Na$^+$). HRMS calcd for C$_{20}$H$_{27}$NO$_3$SSiNa: 412.1379, Found: 412.1394; $\nu_{\text{max}}$ (thin film/cm$^{-1}$): 3081, 1702, 1357, 1260, 1156, 1124, 989; $^1$H NMR (500 MHz, CDCl$_3$) δ ppm 0.18 (3 H, s, SiC$_3$H$_3$), 0.24 (3 H, s, SiC$_3$H$_3$), 0.82 (3 H, d, J = 7.3 Hz, CHCH$_3$), 1.50 (1 H, m, SiCH), 2.42 (3 H, s, Ar-CH$_3$), 2.47 (1 H, dd, J = 16.6, 10.9 Hz, CH$_2$C=O), 2.59 (1 H, dd, J = 16.6, 3.6 Hz, CH$_2$C=O), 3.24 (3 H, s, NCH$_3$), 7.25 – 7.29 (2 H, m, ArH), 7.33 – 7.42 (3 H, m, ArH), 7.44 – 7.47 (2 H, m, ArH), 7.62 – 7.65 (2 H, m, ArH); $^{13}$C NMR (125 MHz, CDCl$_3$) δ -5.2 (SiCH$_3$), -4.7 (SiCH$_3$), 14.4 (CHCH$_3$), 16.1 (SiCH), 21.8 (Ar-CH$_3$), 33.2 (NCH$_3$), 38.9 (CH$_2$C=O), 127.5 (ArCH), 127.9 (ArCH), 129.2 (ArCH), 129.7 (ArCH), 129.9 (ArCH), 136.7 (ArC), 137.4 (ArC), 144.8 (ArC), 173.5 (C=O).
Chiralpak IB column, 28 °C, \( \lambda = 220 \) nm. Eluent: heptane : iso-propanol 80 : 20 \( \nu / \nu \). Flow: 1 mL / min

**Racemic**

**Enantiomerically enriched**

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\((3S,4R)-4-(\text{Dimethyl} (\text{phenyl}) \text{silyl})-3-((R)-1-\text{hydroxy}-2-\text{methyl} \text{propyl})-\text{1-tosylpyrrolidin-2-one} \ (71a)\)

Prepared according to General Procedure 6, on a 0.148 mmol scale, column chromatography (30% EtOAc in Hexanes) afforded the title compound as an oil (12 mg, 0.027 mmol, 18%).

\( [\alpha]_D^{28} = -2.9 \) (c = 1.78 in CHCl\(_3\)) for a sample of 90:10 dr. MS (ES') \( m/z \): 446 (M+H\(^+\)). HRMS calcd for C\(_{23}\)H\(_{31}\)NSO\(_4\)SiNa: 468.1641. Found: 468.1642; \( \nu_{\text{max}} \) (thin film/cm\(^{-1}\)): 2959, 1729, 1360, 1186, 1114, 1091, 1046; \(^1\)H NMR (500 MHz, CDCl\(_3\)) \( \delta \) ppm 0.35 (3 H, s, SiC\(_3\)H\(_3\)), 0.35 (3 H, s, SiC\(_3\)H\(_3\)), 0.76 (3 H, d, J = 6.9 Hz, CH(C\(_6\)H\(_3\))\(_2\)), 0.81 (3 H, d, J = 6.6 Hz, CH(C\(_6\)H\(_3\))\(_2\)), 1.93 (1 H, q, J = 9.2 Hz, SiCH), 2.01 - 2.10 (1 H, m, CH(C\(_6\)H\(_3\))\(_2\)), 2.44 (3 H, s, Ar-CH\(_3\)), 2.61 (1 H, dd, J = 9.9, 2.7 Hz, CH=O), 2.97 (1 H, dd, J = 8.5, 2.8 Hz, CHO\(_2\)), 3.63 (1 H, t, J = 9.6 Hz, CH\(_2\)N), 3.99 (1 H, t, J = 9.6 Hz, CH\(_2\)N), 7.28 - 7.53 (9 H, m, ArH); \(^{13}\)C NMR (126 MHz, CDCl\(_3\)) \( \delta \) ppm -5.0 (-SiCH\(_3\)), -4.6 (-SiCH\(_3\)), 18.8 (CH\(_3\)), 19.6 (CH\(_3\)), 21.7 (SiCH), 22.1 (ArCH\(_3\)), 31.3 (CH), 47.6 (CH\(_3\)N), 47.7 (CH=O), 78.2 (CHO\(_2\)), 128.0 (ArCH), 128.3 (ArCH), 129.6 (ArCH), 132.8 (ArCH), 135.1 (ArC), 135.3 (ArC), 145.1 (ArC), 174.4 (C=O).
(3S,4R)-4-(Dimethyl(phenyl)silyl)-3-((S)-hydroxy(naphthalen-1-yl)methyl)-1-tosylpyrrolidin-2-one (71b)

Prepared according to General Procedure 6 using 3 equivalents of aldehyde, on a 0.211 mmol scale, column chromatography (30% EtOAc in Hexanes) afforded the title compound as an oil (25 mg, 0.046 mmol, 22%). 

\[ \alpha_D^{28} = -0.95 \text{ (c = 2.4 in CHCl}_3 \text{) for a sample of 89:11 dr. MS (ES') m/z: 552 (M+Na'). HRMS calcd for C_{30}H_{31}NSO_4SiNa: 552.1641. Found: 552.1641; v_{max} \text{ (thin film/cm}^{-1}: 3516, 3068, 3051, 1723, 1596, 1427, 1359, 1252, 1187, 1168, 1120, 1089; ^1H NMR (500 MHz, CDCl}_3 \delta ppm -0.12 \text{ (3 H, s, SiCH}_3\text{)}, -0.06 \text{ (3 H, s, SiCH}_3\text{)}, 1.67 \text{ (1 H, dt, } J = 9.5, 5.3 \text{ Hz, SiCH}_2\text{)}, 2.46 \text{ (3 H, s, Ar-CH}_3\text{)}, 2.97 \text{ (1 H, dd, } J = 6.6, 5.7 \text{ Hz, CHC=O)}, 3.70 \text{ (1 H, dd, } J = 9.9, 5.2 \text{ Hz, CH}_2\text{N)}, 4.02 \text{ (1 H, t, } J = 9.8 \text{ Hz, CH}_2\text{N)}, 5.34 \text{ (1 H, d, } J = 6.6 \text{ Hz, CHO}), 7.17 - 7.51 \text{ (10 H, m, ArH)}, 7.74 - 7.95 \text{ (6 H, m, ArH)}; ^13C NMR (126 MHz, CDCl}_3 \delta ppm -5.8 \text{ (SiCH}_3\text{)}, -5.6 \text{ (SiCH}_3\text{)}, 20.8 \text{ (SiCH)}, 21.7 \text{ (ArCH}_3\text{)}, 47.4 \text{ (CH}_2\text{N)}, 51.0 \text{ (CHC=O)}, 73.1 \text{ (CHOH)}, 123.0 \text{ (ArCH)}, 125.2 \text{ (ArCH)}, 125.5 \text{ (ArCH)}, 125.6 \text{ (ArCH)}, 126.3 \text{ (ArCH)}, 128.1 \text{ (ArCH)}, 128.2 \text{ (ArCH)}, 128.99 \text{ (ArCH)}, 129.05 \text{ (ArCH)}, 129.7 \text{ (ArCH)}, 129.8 \text{ (ArCH)}, 130.8 \text{ (ArC)}, 133.6 \text{ (ArCH)}, 133.9 \text{ (ArC)}, 134.9 \text{ (ArC)}, 134.9 \text{ (ArC)}, 135.4 \text{ (ArC)}, 145.3 \text{ (ArC)}, 174.6 \text{ (C=O)}.

\( (R)-4-(Dimethyl(phenyl)silyl)pyrrolidin-2-one \) (72)

To a THF (10 mL) solution of tosylactam 56a (200 mg, 0.54 mmol, 1 equiv) cooled at 0 °C was added dropwise a solution of SmI\(_2\)\(^{209}\) (0.1 M in THF, 2.70 mmol, 27.0 mL, 5 equiv) and the resulting mixture was stirred for 10 min at 0 °C and then, left to warm to rt during 20 min. 1 M HCl (5 mL) was added and the stirring was continued for 5 min. After extracting with CH\(_2\)Cl\(_2\) (3 x 15 mL) and washing with brine (10 mL), the organic phase was dried (Na\(_2\)SO\(_4\)) filtered and the solvent was removed under reduced pressure. Pure compound 7 (118 mg, 94%) was obtained as a colorless oil after eluting the crude on a small plug of silica (EtOAc).

\[ \alpha_D^{28} = +17.9 \text{ (c = 1.0 in CHCl}_3 \text{) for a sample of 89:11 dr. MS (EI) m/z: 218 (M-H'). HRMS calcd for C\(_{12}\)H\(_{17}\)NOSi: 219.1074. Found: 219.1070; v_{max} \text{ (thin film/cm}^{-1}: 3203, 3076, 1608, 1503, 1261, 1181, 1118, 1022, 984; ^1H NMR (300 MHz, CDCl}_3 \delta ppm 0.15 \text{ (3 H, s, SiCH}_3\text{)}, 0.32 \text{ (3 H, s, SiCH}_3\text{)}, 1.94 \text{ (1 H, dq, } J = 11.0, 9.4 \text{ Hz, SiCH)}, 2.19 \text{ (1 H, dd, } J = 16.9, 11.0 \text{ Hz, CH}_2\text{C}=O), 2.36 \text{ (1 H, dd, } J = 16.9, 9.6 \text{ Hz, CH}_2\text{C}=O), 3.27 \text{ (1
H, t, J = 9.5 Hz, CH$_2$NH), 3.42 (1 H, t, J = 9.5 Hz, CH$_2$NH), 7.33 – 7.42 (3 H, m, ArH), 7.44 – 7.50 (2 H, m, ArH); $^{13}$C NMR (125 MHz, CDCl$_3$) δ -5.1 (SiCH$_3$), -4.7 (SiCH$_3$), 21.5 (SiCH), 32.1 (CH$_2$NH), 44.2 (COCH$_2$), 128.2 (ArCH), 129.7 (ArCH), 133.8 (ArCH), 136.3 (ArC), 179.6 (C=O).

(R)-2-(4-(Dimethyl(phenyl)silyl)-2-oxopyrrolidin-1-yl)acetamide (74)

To a solution of compound 60 (115 mg, 0.52 mmol, 1 equiv) in anhydrous THF (3 mL) cooled at -30 °C was added dropwise n-BuLi (1.55 M in hexanes, 0.58 mmol, 0.37 mL, 1.1 equiv) and the mixture was stirred for 30 min. A solution of 2-bromoacetamide (93 mg, 0.68 mmol, 1.3 equiv) in dry THF (2 mL) was then added and the mixture was further stirred at rt for 2 h. NH$_4$Cl (sat, aq) (4 mL) was added and the mixture was extracted with EtOAc (3 x 5 mL). The organic phase was washed with brine (5 mL), filtered, dried (Na$_2$SO$_4$) and the solvent was removed in vacuo. The title compound (106 mg, 74%) was obtained after purification (column chromatography on silica, eluent: 50% acetone in hexanes) as a viscous oil.

[α]$_D^{28}$ = +11.4 (c = 0.8 in MeOH). MS (ES$^+$) m/z: 277 (M+H$^+$). HRMS calcd for C$_{18}$H$_{17}$N$_2$O$_1$: 277.1335, Found: 277.1335; $\nu$$_{max}$ (thin film/cm$^{-1}$): 3341, 3074, 2997, 1697, 1658, 1496, 1432, 1255, 1125, 1023, 978; $^1$H NMR (500 MHz, CD$_2$Cl$_2$) δ ppm 0.23 (3 H, s, SiCH$_3$), 0.36 (3 H, s, SiCH$_3$), 1.86 (1 H, m, SiCH), 2.26 (1 H, dd, J = 17.1, 10.8 Hz, CH$_2$C=O), 2.46 (1 H, dd, J = 17.1, 9.8 Hz, CH$_2$C=O), 3.32 (1 H, t, J = 9.5 Hz, CH$_2$N), 3.35 (1 H, t, J = 9.5 Hz, CH$_2$N), 3.71 (1 H, d, J = 16.0 Hz, CH$_2$CONH$_2$), 3.89 (1 H, d, J = 16.0 Hz, CH$_2$CONH$_2$), 5.82 (2 H, bs, NH$_2$), 7.29 – 7.44 (3 H, m, ArH), 7.45 – 7.59 (2 H, m, ArH). $^{33}$C NMR (125 MHz, CD$_2$Cl$_2$) δ -4.9 (SiCH$_3$), -4.6 (SiCH$_3$), 18.9 (SiCH), 33.0 (SiCH$_2$CONH$_2$), 47.3 (CH$_2$C=O), 50.7 (NCH$_2$CONH$_2$), 128.6 (ArCH), 130.1 (ArCH), 134.4 (ArCH), 136.8 (ArC), 170.6 (C=ONH$_2$), 176.5 (C=O).

(R)-2-(4-Hydroxy-2-oxopyrrolidin-1-yl)acetamide [(R)-Oxiracetam]$^{210}$ (75)

To a cooled solution (0 °C) of lactam 61 (100 mg, 0.36 mmol, 1 equiv) in AcOH (1 mL) were added potassium bromide (108 mg, 0.91 mmol, 2.5 equiv) and sodium acetate (95 mg, 1.15 mmol, 3.2 equiv). To this mixture was dropwise added peracetic acid (32% wt in dilute acetic acid, 1 mL) and the stirring was continued for 3 h at rt. Sodium thiosulfate powder was added (500 mg) and the
resulting solution was filtered through a small plug of silica (EtOAc) thus, affording the title compound (44 mg, 78%) as a white solid.

mp 165 °C, lit.\(^{210}\) 163-167 °C; \([\alpha]_D^{28} = + 34.2\) (c = 1.0 in H\(_2\)O), lit. + 36.4 (c = 1.0 in H\(_2\)O)\(^{20}\). MS (ES\(^+\)) m/z: 159 (M+H\(^+\)). HRMS calcd for C\(_6\)H\(_{11}\)N\(_2\)O\(_3\): 159.0764, Found: 159.0762; \(\nu_{\text{max}}\) (thin film/cm\(^{-1}\)): 3418, 3335, 3079, 1701, 1659, 1501, 1338, 1250, 1124, 1028, 998; \(^1\)H NMR (500 MHz, CD\(_3\)OD) \(\delta\) ppm 2.30 (1 H, dd, \(J = 17.3, 2.2\) Hz, CH\(_2\)C=O), 2.75 (1 H, dd, \(J = 17.3, 6.4\) Hz, CH\(_2\)C=O), 3.33 (1 H, dd, \(J = 10.0, 2.0\) Hz, CHOHC\(_2\)N), 3.78 (1 H, dd, \(J = 10.0, 6.5\) Hz, CHOHC\(_2\)N), 3.90 (1 H, d, \(J = 16.8\) Hz, CH\(_2\)CONH\(_2\)), 4.06 (1 H, d, \(J = 16.8\) Hz, CH\(_2\)CONH\(_2\)), 4.46 (m, CH\(_2\)OH); \(^{13}\)C NMR (125 MHz, CD\(_3\)OD) \(\delta\) ppm 41.5 (C\(_2\)H\(_2\)C=O), 46.0 (CHOH), 58.5 (NCH\(_2\)CONH\(_2\)), 172.8 (C=ONH\(_2\)), 176.4 (C=O).

Experimental procedures for Chapter 2

Reagents were either purchased directly from commercial suppliers or prepared according to literature procedures.

Ligands:

107, 108, 109, 110 were prepared using a literature procedure.\(^{145,211}\)

Synthesis of allenic substrates:

Ethyl-3-(ethynyl)benzoate\(^{212}\) (114b), (propa-1,2-dien-1-yl)benzene\(^{158}\) (97a), 2-(propa-1,2-dien-1-yl)naphthalene\(^{116}\) (97b), 1-methyl-2-(propa-1,2-dien-1-yl)benzene\(^{213}\) (97c), 1-methoxy-4-(propa-1,2-dien-1-yl)benzene\(^{158}\) (97e), 1-(propa-1,2-dien-1-yl)-4-(trifluoromethyl)benzene\(^{214}\) (97f), 1-fluoro-4-(propa-1,2-dien-1-yl)benzene\(^{116}\) (97g), 1-chloro-4-(propa-1,2-dien-1-yl)benzene\(^{158}\) (97h), 1-bromo-4-(propa-1,2-dien-1-yl)benzene\(^{116}\) (97i), propa-1,2-diene-1,1-diyl dibenzene\(^{215}\) (97t), (hepta-1,2-dien-1-yl)benzene\(^{216}\) (97u), tert-butyl(hepta-5,6-dien-1-yl)oxy)dimethylsilane\(^{217}\) (115a), hepta-5,6-dien-1-0\(^{218}\) (115b), undeca-1,2-diene\(^{219}\) (115c), buta-2,3-dien-1-ylcyclohexane\(^{220}\) (115e), 2-(hexa-4,5-dien-1-yl)isoindoline-1,3-dione\(^{221}\) (115f) were prepared using literature procedures.
Substrate synthesis:

General Procedure 9
2-Cyanoethyl 3-ethynylbenzoate (114c)

To 3-ethynylbenzoic acid (0.667 g, 4.56 mmol, 1 equiv) in CH$_2$Cl$_2$ (25 mL), was added 3 drops of DMF. Oxalyl chloride (0.39 mL, 6.84 mmol, 1.5 equiv) was then added dropwise and the reaction was stirred at room temperature for 3 hours and then concentrated $\text{in vacuo}$ to afford 3-ethynylbenzoyl chloride. To 3-hydroxypropanenitrile (0.47 mL, 6.84 mmol, 1.5 equiv) and triethylamine (0.64 mL, 4.56 mmol, 1 equiv) in THF (6 mL), 3-ethynylbenzoyl chloride in THF (6 mL) was added dropwise at 0 °C, allowed to warm to room temperature and stirred overnight. Saturated aqueous NaHCO$_3$ (10 mL) was added and the aqueous layer separated with Et$_2$O (2 x 15 mL), dried over MgSO$_4$, and concentrated $\text{in vacuo}$. Column chromatography (20% EtOAc in Hexanes) afforded the title compound as an oil (0.78 g, 3.92 mmol, 86%).

MS (ES$^+$) $m/z$: 222 (M+Na$^+$); HRMS calcd for C$_{12}$H$_9$O$_2$N$_1$: 199.0628. Found: 199.0626; $\nu_{\max}$ (thin film/cm$^{-1}$): 3282, 2968, 2255, 1723, 1602, 1580, 1472, 1428, 1382, 1333, 1270, 1185, 1107, 1082; $^1$H NMR (400 MHz, CDCl$_3$) $\delta$ ppm: 2.86 (t, $J = 6.3$ Hz, 2 H, CH$_2$CN), 3.15 (s, 1 H, CH), 4.55 (t, $J = 6.3$ Hz, 2 H, CH$_2$O), 7.44 (t, $J = 7.8$ Hz, 1 H, ArH), 7.71 (dt, $J = 7.7$, 1.3 Hz, 1 H, ArH), 8.04 (dt, $J = 7.9$, 1.4 Hz, 1 H, ArH), 8.18 (t, $J = 1.4$ Hz, 1 H, ArH); $^{13}$C NMR (101 MHz, CDCl$_3$) $\delta$: 18.1 (CH$_2$CN), 59.4 (CH$_2$O), 78.5 (CH), 82.3 (C), 116.6 (CN), 122.8 (ArC), 128.7 (ArCH), 129.4 (ArC), 129.9 (ArCH), 133.4 (ArCH), 136.8 (ArCH), 165.1 (C=O).

$\text{N,N-Diethyl-3-ethynylbenzamide (114a)}$

Prepared according to General Procedure 9, on a 4.56 mmol scale, column chromatography (15% EtOAc in Hexanes) afforded the title compound as an oil (0.82 g, 4.06 mmol, 89%).

MS (ES$^+$) $m/z$: 224 (M+Na$^+$); HRMS calcd for C$_{13}$H$_{15}$O$_1$N$_1$: 201.1148. Found: 201.1149; $\nu_{\max}$ (thin film/cm$^{-1}$): 3221, 2971, 1723, 1434, 1382, 1291, 1214, 1162, 1100; $^1$H NMR (400 MHz, CDCl$_3$) $\delta$ ppm: 1.07 - 1.17 (m, 3 H, CH$_3$), 1.20 - 1.32 (m, 3 H, CH$_3$), 3.11 (s, 1 H, CH), 3.25 (br. s., 2 H, CH$_2$), 3.55 (br. s., 2 H, CH$_2$), 7.32 - 7.40 (m, 2 H, ArH), 7.48 - 7.55 (m, 2 H, ArH); $^{13}$C NMR (101 MHz, CDCl$_3$) $\delta$: 12.8 (CH$_3$), 14.2 (CH$_3$), 39.5 (CH$_3$), 43.3 (CH$_2$), 77.9 (CH), 82.8 (C), 122.5 (ArC), 126.6 (ArCH), 128.5 (ArCH), 129.9 (ArCH), 132.7 (ArCH), 137.5 (ArC), 170.2 (C=O).
3-Hydroxypropyl 3-ethylbenzoate (114d)

Prepared according to General Procedure 9, on a 9.03 mmol scale, column chromatography (30% EtOAc in Hexanes) afforded the title compound as an oil (1.55 g, 7.59 mmol, 84%).

MS (ES') m/z: 227 (M+Na); \( \nu_{\text{max}} \) (thin film/cm\(^{-1}\)) : 3290, 2959, 1718, 1601, 1580, 1474, 1428, 1390, 1358, 1272, 1189, 1109, 1081, 1051; \(^1\)H NMR (400 MHz, CDCl\(_3\)) \( \delta \) ppm 1.90 (br. s, 1 H, OH), 2.02 (quin, \( J = 6.1 \) Hz, 2 H, CH\(_2\)), 3.14 (s, 1 H, CH), 3.79 (t, \( J = 6.1 \) Hz, 2 H, CH\(_2\)OH), 4.50 (t, \( J = 6.2 \) Hz, 2 H, CH\(_2\)O), 7.42 (t, \( J = 7.8 \) Hz, 1 H, ArH), 7.68 (dt, \( J = 7.7, 1.3 \) Hz, 1 H, ArH), 8.02 (dt, \( J = 7.9, 1.3 \) Hz, 1 H, ArH), 8.16 (s, 1 H, ArH); \(^13\)C NMR (101 MHz, CDCl\(_3\)) \( \delta \) ppm 31.8 (CH\(_2\)), 59.1 (CH\(_2\)OH), 62.0 (CH\(_2\)O), 78.2 (CH), 82.5 (C), 122.6 (ArC), 128.5 (ArCH), 129.8 (ArCH), 130.4 (ArC), 133.2 (ArCH), 136.3 (ArCH), 166.1 (C=O).

General Procedure 10

1,3,5-Trimethyl-2-(propa-1,2-dien-1-yl)benzene (97d)

To a solution of formaldehyde (0.521 g, 17.3 mmol, 2.5 equiv), CuI (0.660 g, 3.47 mmol, 0.5 equiv) and diisopropylamine (1.94 mL, 13.9 mmol, 2 equiv) in dioxane (13.9 mL), was added 2-ethylbenzene (1.00 g, 6.93 mmol, 1 equiv) and the mixture was refluxed overnight. After allowing to cool to room temperature, the reaction mixture was separated with water (25 mL) and Et\(_2\)O (3 x 30 mL), dried over MgSO\(_4\) and concentrated in vacuo. Column chromatography (Hexanes) afforded the title compound as an oil (0.384 g, 35%).

MS (GCMS) m/z: 158 (M); HRMS calcd for C\(_{12}\)H\(_{14}\): 158.1090. Found: 158.1086; \( \nu_{\text{max}} \) (thin film/cm\(^{-1}\)) : 2919, 1945, 1727, 1688, 1610, 1481, 1441, 1378, 1257, 1166, 1076, 1033; \(^1\)H NMR (400 MHz, CDCl\(_3\)) \( \delta \) ppm 2.27 (s, 3 H, CH\(_3\)), 2.35 (s, 6 H, (CH\(_3\))\(_2\)), 4.92 (d, \( J = 7.0 \) Hz, 2 H, C=CH\(_2\)), 6.24 (t, \( J = 7.0 \) Hz, 1 H, C=CH), 6.87 (s, 2 H, ArH); \(^13\)C NMR (101 MHz, CDCl\(_3\)) \( \delta \) ppm 20.9 (CH\(_3\)), 21.1 (CH\(_3\)), 75.8 (C=CH\(_2\)), 89.3 (C=CH), 128.1 (ArC), 128.9 (ArCH), 136.2 (ArC), 136.4 (ArC), 210.3 (C=C=C).
1-Fluoro-3-(propa-1,2-dien-1-yl)benzene (97j)

Prepared according to General Procedure 10, on a 20.81 mmol scale, column chromatography (Hexanes) afforded the title compound as an oil (1.16 g, 4.06 mmol, 41%).

MS (GCMS) m/z: 134 (M); \( \nu_{\text{max}} \) (thin film/cm\(^{-1}\)): 2956, 1720, 1590, 1486, 1447, 1273, 1191, 1110; \(^1\)H NMR (400 MHz, CDCl\(_3\)) \( \delta \) ppm 5.19 (d, \( J = 6.7 \) Hz, 2 H, C=CH\(_2\)), 6.15 (t, \( J = 6.8 \) Hz, 1 H, C=CH), 6.90 (td, \( J = 8.4, 2.3 \) Hz, 1 H, ArH), 7.02 (d, \( J = 10.1 \) Hz, 1 H, ArH), 7.06 (d, \( J = 7.7 \) Hz, 1 H, ArH), 7.21 - 7.31 (m, 1 H, ArH); \(^13\)C NMR (126 MHz, CDCl\(_3\)) \( \delta \) 79.3 (C=CH\(_2\)), 93.3 (d, \( J = 2.7 \) Hz, C=CH), 113.2 (d, \( J = 22.7 \) Hz, ArCH), 113.7 (d, \( J = 22.7 \) Hz, ArCH), 122.4 (d, \( J = 2.7 \) Hz, ArCH), 130.0 (d, \( J = 8.2 \) Hz, ArCH), 136.4 (d, \( J = 8.2 \) Hz, ArC), 163.1 (d, \( J = 246.1 \) Hz, ArCF), 209.9 (C=C=C).

1-Chloro-3-(propa-1,2-dien-1-yl)benzene (97k)

Prepared according to General Procedure 10, on a 7.32 mmol scale, column chromatography (Hexane) afforded the title compound as an oil (0.37 g, 2.46 mmol, 34%).

MS (GCMS) m/z: 150 (M); HRMS calcd for C\(_9\)H\(_7\)Cl: 150.0231. Found: 150.0235; \( \nu_{\text{max}} \) (thin film/cm\(^{-1}\)): 3061, 2981, 2924, 1941, 1715, 1593, 1569, 1476, 1446, 1436, 1417, 1337, 1321, 1252, 1196, 1163, 1094, 1078; \(^1\)H NMR (400 MHz, CDCl\(_3\)) \( \delta \) ppm 5.20 (d, \( J = 6.8 \) Hz, 2 H, C=CH\(_2\)), 6.12 (t, \( J = 6.7 \) Hz, 1 H, C=CH), 7.13 - 7.20 (m, 2 H, ArH), 7.21 - 7.26 (m, 1 H, ArH), 7.30 (s, 1 H, ArH); \(^13\)C NMR (101 MHz, CDCl\(_3\)) \( \delta \) 79.4 (C=CH\(_2\)), 93.3 (C=CH), 124.8 (ArCH), 126.5 (ArCH), 126.9 (ArCH), 129.8 (ArCH), 134.5 (ArC), 136.0 (ArC), 209.9 (C=C=C).

1-(Propa-1,2-dien-1-yl)-3,5-bis(trifluoromethyl)benzene (97l)

Prepared according to General Procedure 10, on a 4.19 mmol scale, column chromatography (Hexanes) afforded the title compound as a volatile oil (0.16 g, 0.63 mmol, 15%).

\( \nu_{\text{max}} \) (thin film/cm\(^{-1}\)): 1381, 1174, 1133; \(^1\)H NMR (400 MHz, CDCl\(_3\)) \( \delta \) ppm 5.32 (d, \( J = 6.8 \) Hz, 2 H, C=CH\(_2\)), 6.24 (t, \( J = 6.8 \) Hz, 1 H), 7.68 - 7.73 (m, 3 H, ArH); \(^13\)C NMR (126 MHz, CDCl\(_3\)) \( \delta \) 80.5 (C=CH\(_2\)), 92.5 (C=CH), 123.3 (q, \( J = 271.3 \) Hz, CF\(_3\)), 120.4 (q, \( J = 3.7 \) Hz, ArCH), 126.4 (q, \( J = 3.7 \) Hz, ArCH), 132.0 (q, \( J = 33.2 \) Hz, ArCCF\(_3\)), 136.7 (ArC), 210.4 (C=C=C); \(^19\)F NMR (400 MHz) -63.1.
3-Hydroxypropyl 3-(propa-1,2-dien-1-yl)benzoate (97m)

Prepared according to General Procedure 10, on a 7.59 mmol scale, column chromatography (30% EtOAc in Hexanes) afforded the title compound as an oil (0.89 g, 4.10 mmol, 54%).

MS (ES$^+$) m/z: 241 (M+Na$^+$); HRMS calcd for C$_{13}$H$_{14}$O$_3$: 241.0841. Found: 241.0849; $\nu_{\text{max}}$ (thin film/cm$^{-1}$): 3434, 2960, 1942, 1718, 1604, 1584, 1445, 1414, 1389, 1250, 1191, 1112, 1081, 1051; $^1$H NMR (400 MHz, CDCl$_3$) $\delta$ ppm: 2.03 (2 H, quin, $J = 6.3$ Hz, CH$_2$), 3.78 (2 H, t, $J = 6.1$ Hz, C$_2$H$_2$OH), 4.50 (2 H, t, $J = 6.1$ Hz, CH$_2$O), 5.21 (2 H, d, $J = 6.6$ Hz, C=CH$_2$), 6.21 (1 H, t, $J = 6.8$ Hz, C=CH), 7.39 (1 H, t, $J = 7.8$ Hz, ArH), 7.51 (1 H, d, $J = 7.6$ Hz, ArH), 7.87 (1 H, d, $J = 7.8$ Hz, ArH), 7.95 (1 H, s, ArH);

$^{13}$C NMR (101 MHz, CDCl$_3$) $\delta$ 29.4 (CH$_2$), 31.8 (CH$_2$Br), 62.7 (CH$_2$O), 79.4 (C=CH$_2$), 93.3 (C=CH), 127.8 (ArCH), 128.0 (ArCH), 128.7 (ArCH), 130.5 (ArC), 131.1 (ArCH), 134.5 (ArC), 166.9 (C=O), 209.9 (C=C=C).

3-Bromopropyl 3-(propa-1,2-dien-1-yl)benzoate (97n)

To a solution of 3-hydroxypropyl 3-(propa-1,2-dien-1-yl)benzoate (200 mg, 0.917 mmol, 1 equiv) and CBr$_4$ (332 mg, 1.00 mmol, 1.1 equiv) in CH$_2$Cl$_2$ (0.39 mL), was added PPh$_3$ (265 mg, 1.01 mmol, 1.1 equiv) at 0 °C, and the resulting mixture was stirred for 2 hours. The reaction was then concentrated in vacuo and chromatographed (5% EtOAc in hexanes) to afford the title compound (200 mg, 0.712 mmol, 78%) as an oil.

MS (ES$^+$) m/z: 303 (M+Na$^+$); $\nu_{\text{max}}$ (thin film/cm$^{-1}$): 1942, 1718, 1272, 1247, 1189, 1109; $^1$H NMR (400 MHz, CDCl$_3$) $\delta$ ppm: 2.34 (quin, $J = 6.3$ Hz, 2 H, CH$_2$), 3.56 (t, $J = 6.5$ Hz, 2 H, CH$_2$Br), 4.48 (t, $J = 6.1$ Hz, 2 H, CH$_2$O), 5.22 (d, $J = 6.7$ Hz, 2 H, C=CH$_2$), 6.21 (t, $J = 6.8$ Hz, 1 H, C=CH), 7.39 (t, $J = 8.7$ Hz, 1 H, ArH), 7.51 (d, $J = 7.8$ Hz, 1 H, ArH), 7.87 (d, $J = 7.7$ Hz, 1 H, ArH), 7.95 (s, 1 H, ArH); $^{13}$C NMR (101 MHz, CDCl$_3$) $\delta$ 29.4 (CH$_2$), 31.8 (CH$_2$Br), 62.7 (CH$_2$O), 79.4 (C=CH$_2$), 93.3 (C=CH), 127.7 (ArCH), 127.9 (ArCH), 128.7 (ArCH), 130.4 (ArC), 131.1 (ArCH), 134.6 (ArC), 166.3 (C=O), 210.0 (C=C=C).
3-Iodopropyl 3-(propa-1,2-dien-1-yl)benzoate (97o)

To a solution of PPh$_3$ (156 mg, 0.593 mmol, 1.3 equiv) in CH$_2$Cl$_2$ (1 mL), was added imidazole (41 mg, 0.593 mmol, 1.3 equiv) and I$_2$ (151 mg, 0.593 mmol, 1.3 equiv), and the resulting mixture stirred for 10 minutes. 3-Hydroxypropyl 3-(propa-1,2-dien-1-yl)benzoate (100 mg, 0.458 mmol, 1 equiv) in CH$_2$Cl$_2$ (0.4 mL) was then added and stirred for 3 hours. The mixture was extracted with an aqueous solution of Na$_2$S$_2$O$_3$ (2 mL) and hexane (3 x 5 mL), dried over MgSO$_4$ and concentrated in vacuo. Column chromatography (5% EtOAc in hexanes) yielded the title compound (108 mg, 0.322 mmol, 54%) as an oil.

MS (ES$^+$) m/z: 351 (M+Na$^+$); $\nu_{\text{max}}$ (thin film/cm$^{-1}$): 2957, 1941, 1716, 1583, 1444, 1382, 1271, 1247, 1186, 1107, 1081; $^1$H NMR (400 MHz, CDCl$_3$) $\delta$ ppm 2.31 (quin, $J = 6.3$ Hz, 2 H, CH$_2$I), 3.32 (t, $J = 6.8$ Hz, 2 H, CH$_2$I), 4.41 (t, $J = 5.9$ Hz, 2 H, CH$_2$O), 5.22 (d, $J = 6.8$ Hz, 2 H, C=CH$_2$), 6.21 (t, $J = 6.8$ Hz, 1 H, C=CH), 7.36 - 7.42 (m, 1 H, ArH), 7.51 (d, $J = 7.6$ Hz, 1 H, ArH), 7.86 (d, $J = 7.8$ Hz, 1 H, ArH), 7.94 (s, 1 H, ArH); $^{13}$C NMR (101 MHz, CDCl$_3$) $\delta$ ppm 1.4 (CH$_2$I), 32.5 (CH$_2$I), 64.6 (CH$_2$O), 79.4 (C=CH$_2$), 93.3 (C=CH), 127.7 (ArCH), 127.9 (ArCH), 128.7 (ArCH), 130.4 (ArC), 131.1 (ArC), 134.5 (ArC), 166.3 (C=O), 209.9 (C=C=C).

3-Azidopropyl 3-(propa-1,2-dien-1-yl)benzoate (97p)

A solution of 3-bromopropyl 3-(propa-1,2-dien-1-yl)benzoate (100 mg, 0.356 mmol, 1 equiv) and sodium azide (57.8 mg, 0.8897 mmol, 2.5 equiv) in DMF (0.46 mL) was heated at 50 °C for 3 hours. After cooling to room temperature, the reaction mixture was extracted with water (1mL) and Et$_2$O (3 x 5 mL), dried over MgSO$_4$ and concentrated in vacuo. Column chromatography (5% EtOAc in hexanes) yielded the title compound (87.5 mg, 0.356 mmol, 100%) as an oil.

MS (ES$^+$) m/z: 266 (M+Na$^+$); $\nu_{\text{max}}$ (thin film/cm$^{-1}$): 2962, 2097, 1942, 1718, 1604, 1584, 1456, 1387, 1270, 1247, 1189, 1110, 1081, 1034; $^1$H NMR (400 MHz, CDCl$_3$) $\delta$ ppm 2.07 (quin, $J = 6.4$ Hz, 2 H, CH$_2$), 3.50 (t, $J = 6.7$ Hz, 2 H, CH$_2$N$_3$), 4.43 (t, $J = 6.2$ Hz, 2 H, CH$_2$O), 5.21 (d, $J = 6.7$ Hz, 2 H, C=CH$_2$), 6.21 (t, $J = 6.8$ Hz, 1 H, C=CH), 6.37 (t, $J = 8.1$ Hz, 1 H, ArH), 7.39 (t, $J = 7.7$ Hz, 1 H, ArH), 7.51 (d, $J = 7.7$ Hz, 1 H, ArH), 7.87 (d, $J = 7.7$ Hz, 1 H, ArH), 7.95 (s, 1 H, ArH); $^{13}$C NMR (101 MHz, CDCl$_3$) $\delta$ ppm 28.3 (CH$_2$), 48.3 (CH$_2$N$_3$), 61.9 (CH$_2$O), 79.4 (C=CH$_2$), 93.3 (C=CH), 127.7 (ArCH), 127.9 (ArCH), 128.7 (ArCH), 130.4 (ArC), 131.1 (ArCH), 134.6 (ArC), 166.3 (C=O), 209.9 (C=C=C).
2-Cyanoethyl 3-(propa-1,2-dien-1-yl)benzoate (97q)

Prepared according to General Procedure 10, on a 1.82 mmol scale, column chromatography (20% EthOAc in Hexanes) afforded the title compound as an oil (0.12 g, 0.56 mmol, 31%).

MS (ES+): m/z: 236 (M+Na+); \(\nu_{\text{max}}\) (thin film/cm\(^{-1}\)): 2967, 1942, 1723, 1604, 1583, 1457, 1415, 1383, 1333, 1270, 1248, 1189, 1110, 1085; \(^1\)H NMR (500 MHz, CDCl\(_3\)) \(\delta\) ppm 2.78 (t, \(J = 6.3\) Hz, 2 H, CH\(_2\)CN), 4.47 (t, \(J = 6.3\) Hz, 2 H, CH\(_2\)O), 5.14 (d, \(J = 6.6\) Hz, 2 H, C=CH\(_2\)), 6.14 (t, \(J = 6.8\) Hz, 1 H, C=CH), 7.33 (t, \(J = 8.5\) Hz, 1 H, ArH), 7.46 (d, \(J = 7.9\) Hz, 1 H, ArH), 7.82 (d, \(J = 7.9\) Hz, 1 H, ArH), 7.89 (s, 1 H, ArH); \(^{13}\)C NMR (101 MHz, CDCl\(_3\)) 18.2 (CH\(_3\)CN), 59.2 (CH\(_2\)O), 79.5 (C=CH\(_2\)), 93.2 (C=CH), 116.6 (CN), 127.9 (ArCH), 128.1 (ArCH), 128.8 (ArCH), 129.5 (ArC), 131.6 (ArCH), 134.7 (ArC), 165.7 (C=O), 210.0 (C=C=C).

Ethyl-3-(propa-1,2-dien-1-yl)benzoate (97r)

Prepared according to General Procedure 10, on a 3.22 mmol scale, column chromatography (2% EthOAc in Hexanes) afforded the title compound as an oil (0.40 g, 2.13 mmol, 66%).

MS (GCMS): m/z: 188 (M); \(\nu_{\text{max}}\) (thin film/cm\(^{-1}\)): 1943, 1715, 1367, 1272, 1248, 1190, 1105, 1080, 1022; \(^1\)H NMR (500 MHz, CDCl\(_3\)) \(\delta\) ppm 1.41 (t, \(J = 7.6\) Hz, 3 H, CH\(_3\)), 4.39 (q, \(J = 7.3\) Hz, 2 H, CH\(_2\)O), 5.21 (d, \(J = 6.9\) Hz, 2 H, C=CH\(_2\)), 6.21 (t, \(J = 6.8\) Hz, 1 H, C=CH), 7.36 - 7.40 (m, 1 H, ArH), 7.50 (d, \(J = 7.9\) Hz, 1 H, ArH), 7.88 (d, \(J = 7.9\) Hz, 1 H, ArH), 7.95 (s, 1 H, ArH); \(^{13}\)C NMR (101 MHz, CDCl\(_3\)) 14.3 (CH\(_3\)), 61.0 (CH\(_2\)O), 79.3 (C=CH\(_2\)), 93.4 (C=CH), 127.7 (ArCH), 127.9 (ArCH), 128.6 (ArCH), 130.8 (ArCH), 130.9 (ArC), 134.4 (ArC), 166.5 (C=O), 209.9 (C=C=C).

\(\text{N,N-Diethyl-3-(propa-1,2-dien-1-yl)benzamide (97s)}\)

Prepared according to General Procedure 10, on a 7.52 mmol scale, column chromatography (2% EthOAc in Hexanes) afforded the title compound as an oil (0.76 g, 3.53 mmol, 47%).

MS (ES+): m/z: 238 (M+Na+); HRMS calcld for C\(_{14}\)H\(_{18}\)O\(_3\)N\(_2\): 216.1388. Found: 216.1392; \(\nu_{\text{max}}\) (thin film/cm\(^{-1}\)): 2973, 2934, 1941, 1628, 1579, 1472, 1489, 1458, 1430, 1381, 1364, 1314, 1289, 1260, 1221, 1167, 1102; \(^1\)H NMR (500 MHz, CDCl\(_3\)) \(\delta\) ppm 1.12 (br. s., 3 H, CH\(_3\)), 1.21 - 1.29 (m, 3 H, CH\(_2\)).
3.26 (br. s., 2 H, CH$_2$), 3.55 (br. s., 2 H, CH$_2$), 5.17 (d, $J = 6.9$ Hz, 2 H, C=CH$_2$), 6.17 (t, $J = 6.8$ Hz, 1 H, C=CH), 7.19 (dt, $J = 6.1$, 2.0 Hz, 1 H, ArH), 7.30 - 7.35 (m, 3 H, ArH); $^{13}$C NMR (101 MHz, CDCl$_3$) δ 12.8 (CH$_3$), 14.2 (CH$_3$), 39.1 (CH$_2$), 43.2 (CH$_2$), 79.2 (C=CH$_2$), 93.5 (C=CH), 124.5 (ArCH), 124.6 (ArCH), 127.3 (ArCH), 128.6 (ArCH), 134.3 (ArC), 137.6 (ArC), 171.1 (C=O), 209.9 (C=C=C).

**General Procedure 11 for the copper-catalyzed silylation of allenes**

**Dimethyl(phenyl)(3-phenylprop-1-en-2-yl)silane**

To a solution of 109 (10.9 mg, 0.026 mmol, 10 mol%) and CuI (2.5 mg, 0.013 mmol, 5 mol%) in THF (0.8 mL), was added KO$_2$-Bu (0.043 mL of a 1 M THF solution, 0.043 mmol, 16.5 mol%), and the reaction stirred for 1 hour at room temperature. PhMe$_2$SiBpin (0.079 mL, 0.289 mmol, 1.1 equiv) was then added and the mixture stirred for 15 min. A solution of (propa-1,2-dien-1-yl)benzene (30.5 mg, 0.263 mmol, 1 equiv) and MeOH (0.032 mL, 0.788 mmol, 3 equiv) in THF (0.5 mL) was then added dropwise, and the reaction stirred at room temperature for 1 hour. The reaction mixture was then filtered through a silica plug, concentrated in vacuo and purified by chromatography (pentane) to afford the title compound (61.1 mg, 0.242 mmol, 92%).

$^1$H NMR (400 MHz, CDCl$_3$) δ ppm 0.28 (s, 6 H, Si(CH$_3$)$_2$), 3.44 (s, 2 H, Ar-CH$_2$), 5.48 - 5.53 (m, 1 H, C=CH$_2$), 5.57 (dt, $J = 2.9$, 1.6 Hz, 1 H, C=CH$_2$), 7.02 - 7.11 (m, 2 H, ArH), 7.14 - 7.29 (m, 3 H, ArH), 7.31 - 7.41 (m, 3 H, ArH), 7.46 - 7.52 (m, 2 H, ArH); $^{13}$C NMR (101 MHz, CDCl$_3$) δ -3.0 (Si(CH$_3$)$_2$), 42.5 (Ar-CH$_2$), 125.9 (ArCH), 127.7 (C=CH$_2$), 127.8 (ArCH), 128.1 (ArCH), 128.9 (ArCH), 129.1 (ArCH), 134.0 (ArCH), 137.9 (ArC), 139.8 (ArC), 149.6 (C=CH$_2$).

**Dimethyl(3-(naphthalen-2-yl)prop-1-en-2-yl)(phenyl)silane**

Prepared according to General Procedure 11, on a 0.263 mmol scale, column chromatography (Hexanes) afforded the title compound as an oil (70.8 mg, 0.242 mmol, 92%).

MS (GCMS) m/z: 302 (M); HRMS calcd for C$_{21}$H$_{22}$Si: 302.1485. Found: 302.1482; $\nu$$_{max}$ (thin film/cm$^{-1}$): 3050, 2956, 1600, 1508, 1428, 1248, 1111; $^1$H NMR (400 MHz, CDCl$_3$) δ ppm 0.20 (s, 6 H, Si(CH$_3$)$_2$), 3.51 (s, 2 H, Ar-CH$_2$), 5.44 - 5.49 (m, 1 H, C=CH$_2$), 5.52 (dt, $J = 2.8$, 1.5 Hz, 1 H, C=CH$_2$), 7.13 (dd, $J = 8.4$, 1.6 Hz, 1 H, ArH), 7.22 - 7.29 (m, 2 H, ArH), 7.30 - 7.43 (m, 5 H, ArH), 7.63 (s, 2 H, ArH), 7.68 - 7.74 (m, 2 H, ArH); $^{13}$C NMR (101 MHz, CDCl$_3$) δ -3.0 (Si(CH$_3$)$_2$), 42.6 (Ar-CH$_2$), 125.1
(ArCH), 125.7 (ArCH), 127.5 (ArCH), 127.55 (ArCH), 127.7 (ArCH), 127.98 (ArCH), 128.02 (ArCH), 129.0 (ArCH), 132.0 (ArC), 133.5 (ArC), 134.0 (ArCH), 137.4 (ArC), 137.9 (ArC), 149.6 (C=CH₂).

**Dimethyl(phenyl)(3-(o-tolyl)prop-1-en-2-yl)silane (98c)**

Prepared according to General Procedure 11, on a 0.263 mmol scale, column chromatography (Hexanes) afforded the title compound as an oil (52.6 mg, 0.197 mmol, 75%).

MS (GCMS) m/z: 266 (M); HRMS calcd for C₁₈H₂₂Si: 266.1485. Found: 266.1487; \( \nu_{\text{max}} \) (thin film/cm⁻¹): 3049, 2956, 1608, 1487, 1428, 1247, 1111; \(^1\)H NMR (400 MHz, CDCl₃) \( \delta \) ppm 0.28 (s, 6 H, Si(CH₃)₂), 2.29 (s, 3 H, CH₃), 3.40 (s, 2 H, Ar-CH₂), 5.47 - 5.51 (m, 1 H, C=CH₂), 5.57 (dt, J = 3.0, 1.5 Hz, 1 H, C=CH₂), 6.84 - 6.91 (m, 2 H, ArH), 6.99 (d, J = 7.6 Hz, 1 H, ArH), 7.10 - 7.17 (m, 1 H, ArH), 7.30 - 7.40 (m, 3 H, ArH), 7.45 - 7.51 (m, 2 H, ArH); \(^{13}\)C NMR (101 MHz, CDCl₃) \( \delta \) ppm 3.0 (Si(CH₃)₂), 21.3 (CH₃), 42.5 (ArCH₂), 126.4 (ArCH), 126.6 (ArCH), 127.6 (C=CH₂), 127.7 (ArCH), 128.0 (ArCH), 128.9 (ArCH), 130.2 (ArCH), 134.0 (ArCH), 137.6 (ArC), 138.0 (ArC), 139.7 (ArC), 149.7 (C=CH₂).

**(3-Mesitylprop-1-en-2-yl)dimethyl(phenyl)silane (98d)**

Prepared according to General Procedure 11, on a 0.263 mmol scale, column chromatography (Hexanes) afforded the title compound as an oil (52.7 mg, 0.179 mmol, 68%).

MS (GCMS) m/z: 294 (M); HRMS calcd for C₂₀H₂₆Si: 294.1798. Found: 294.1789; \( \nu_{\text{max}} \) (thin film/cm⁻¹): 2955, 2918, 1613, 1484, 1428, 1375, 1248, 1103, 1030; \(^1\)H NMR (400 MHz, CDCl₃) \( \delta \) ppm 0.48 (s, 6 H, Si(CH₃)₂), 2.09 (s, 6 H, CH₃), 2.28 (s, 3 H, CH₃), 3.22 (s, 2 H, Ar-CH₂), 5.04 (d, J = 2.2 Hz, 1 H, C=CH₂), 5.34 (d, J = 2.1 Hz, 1 H, C=CH₂), 6.82 - 6.86 (m, 2 H, ArH), 7.36 - 7.46 (m, 3 H, ArH), 7.61 (dd, J = 6.1, 2.9 Hz, 2 H, ArH); \(^{13}\)C NMR (101 MHz, CDCl₃) \( \delta \) ppm 3.4 (Si(CH₃)₂), 19.5 (CH₃), 20.9 (CH₃), 34.0 (Ar-CH₂), 124.4 (C=CH₂), 127.8 (ArCH), 128.4 (ArCH), 129.1 (ArCH), 133.9 (ArC), 135.3 (ArCH), 136.9 (ArC), 137.9 (ArC), 138.7 (ArC), 147.0 (C=CH₂).
(3-(4-Methoxyphenyl)prop-1-en-2-yl)dimethyl(phenyl)silane (98e)

Prepared according to General Procedure 11, on a 0.263 mmol scale, column chromatography (Hexanes) afforded the title compound as an oil (55.0 mg, 0.195 mmol, 74%).

$\nu_{\text{max}}$ (thin film/cm$^{-1}$): 2954, 2833, 1611, 1509, 1464, 1428, 1245, 1175, 1110, 1038; $^1$H NMR (400 MHz, CDCl$_3$) $\delta$ ppm 0.28 (s, 6 H, Si(CH$_3$)$_2$), 3.38 (s, 2 H, Ar-CH$_2$), 3.80 (s, 3 H, OCH$_3$), 5.45 - 5.51 (m, 1 H, C=CH$_2$), 5.57 (dt, $J = 2.9$, 1.5 Hz, 1 H, C=CH$_2$), 6.76 - 6.83 (m, 2 H, ArH), 6.98 (d, $J = 8.6$ Hz, 2 H, ArH), 7.31 - 7.41 (m, 3 H, ArH); $^{13}$C NMR (101 MHz, CDCl$_3$) $\delta$ -2.9 (Si(CH$_3$)$_2$), 41.7 (Ar-CH$_2$), 55.2 (OCH$_3$), 113.5 (ArCH), 127.4 (C=C=H), 127.7 (ArCH), 128.9 (ArCH), 130.2 (ArCH), 131.8 (ArC), 134.0 (ArCH), 138.0 (ArC), 150.0 (C=CH$_2$), 157.9 (ArCOCH$_3$).

Dimethyl(phenyl)(3-(4-(trifluoromethyl)phenyl)prop-1-en-2-yl)silane (98f)

Prepared according to General Procedure 11, on a 0.263 mmol scale, column chromatography (Hexanes) afforded the title compound as an oil (80.0 mg, 0.250 mmol, 95%).

MS (GCMS) $m/z$: 320 (M); HRMS calcd for C$_{18}$H$_{19}$F$_3$Si: 320.1203. Found: 320.1201; $\nu_{\text{max}}$ (thin film/cm$^{-1}$): 2958, 1617, 1428, 1417, 1323, 1249, 1163, 1122, 1109, 1066, 1019; $^1$H NMR (500 MHz, CDCl$_3$) $\delta$ ppm 0.30 (s, 6 H, Si(CH$_3$)$_2$), 3.47 (s, 2 H, Ar-CH$_2$), 5.53 - 5.63 (m, 2 H, C=CH$_2$), 7.15 (d, $J = 7.9$ Hz, 2 H, ArH), 7.31 - 7.50 (m, 7 H, ArH); $^{13}$C NMR (126 MHz, CDCl$_3$) $\delta$ -3.1 (Si(CH$_3$)$_2$), 42.3 (Ar-CH$_2$), 124.3 (q, $J = 271.6$ Hz, CF$_3$), 125.0 (q, $J = 3.6$ Hz, ArCH), 127.8 (ArCH), 128.4 (C=CH$_2$), 129.1 (ArCH), 129.5 (ArC), 133.8 (ArCH), 134.0 (ArCH), 137.5 (ArCH), 144.0 (ArC), 148.9 (C=CH$_2$) (ArCCF$_3$ not observed).

(3-(4-Fluorophenyl)prop-1-en-2-yl)dimethyl(phenyl)silane (98g)

Prepared according to General Procedure 11, on a 0.263 mmol scale, column chromatography (Hexanes) afforded the title compound as an oil (61.9 mg, 0.229 mmol, 87%).

MS (GCMS) $m/z$: 270 (M); HRMS calcd for C$_{17}$H$_{19}$F$_3$Si: 270.1235. Found: 270.1223; $\nu_{\text{max}}$ (thin film/cm$^{-1}$): 3049, 2957, 1602, 1507, 1428, 1414, 1248, 1221, 1156, 111, 1092, 1016; $^1$H NMR (400 MHz, CDCl$_3$) $\delta$ ppm 0.18 (s, 6 H, Si(CH$_3$)$_2$), 3.31 (s, 2 H, Ar-CH$_2$), 5.40 - 5.43 (m, 1 H, C=CH$_2$), 5.47 (dt, $J = 2.8$, 1.5 Hz, 1 H, C=CH$_2$), 6.78 - 6.86 (m, 2 H, ArH), 6.88 - 6.94 (m, 2 H, ArH), 7.22 - 7.32 (m, 3 H,
ArH), 7.34 – 7.39 (m, 2 H, ArH); $^{13}$C NMR (101 MHz, CDCl$_3$) δ -3.0 (Si(CH$_3$)$_2$), 41.8 (Ar-CH$_2$), 114.8 (d, $J = 20.5$ Hz, ArCH) 127.7 (C=CH$_2$), 127.8 (ArCH), 129.0 (ArCH), 130.6 (d, $J = 7.3$ Hz, ArCH), 133.9 (ArCH), 135.4 (d, $J = 3.7$ Hz, ArC), 137.8 (ArC), 149.6 (C=CH$_2$), 161.3 (d, $J = 245.0$ Hz, ArCF).

(3-(4-Chlorophenyl)prop-1-en-2-yl)dimethyl(phenyl)silane$^{222}$ (98h)

Prepared according to General Procedure 11, on a 0.263 mmol scale, column chromatography (Hexanes) afforded the title compound as an oil (58.1 mg, 0.203 mmol, 77%).

MS (GCMS) $m/z$: 286 (M); HRMS calcd for C$_{17}$H$_{19}$ClSi: 286.0939. Found: 286.0927; $\nu_{\text{max}}$ (thin film/cm$^{-1}$): 3049, 2956, 1490, 1428, 1406, 1248, 1110, 1090, 1010; $^1$H NMR (400 MHz, CDCl$_3$) δ ppm 0.37 (s, 6 H, Si(CH$_3$)$_2$), 3.47 (s, 2 H, Ar-CH$_2$), 5.59 - 5.62 (m, 1 H, C=CH$_2$), 5.65 (dt, $J = 2.8$, 1.5 Hz, 1 H, C=CH$_2$), 7.07 (d, $J = 8.6$ Hz, 2 H, ArH), 7.25 - 7.31 (m, 2 H, ArH), 7.40 - 7.48 (m, 3 H, ArH), 7.52 - 7.56 (m, 2 H, ArH); $^{13}$C NMR (101 MHz, CDCl$_3$) δ -3.0 (Si(CH$_3$)$_2$), 41.9 (Ar-CH$_2$), 127.7 (C=CH$_2$), 128.0 (ArCH), 128.2 (ArCH), 129.0 (ArCH), 130.6 (ArC), 131.6 (ArC), 133.9 (ArCH), 137.7 (ArC), 138.3 (ArC), 149.3 (C=CH$_2$).

(3-(4-Bromophenyl)prop-1-en-2-yl)dimethyl(phenyl)silane$^{222}$ (98i)

Prepared according to General Procedure 11, on a 0.263 mmol scale, column chromatography (Hexanes) afforded the title compound as an oil (68.0 mg, 0.205 mmol, 78%).

MS (GCMS) $m/z$: 330 (M); HRMS calcd for C$_{17}$H$_{19}$BrSi: 330.0434. Found: 330.0425; $\nu_{\text{max}}$ (thin film/cm$^{-1}$): 3049, 2956, 1589, 1486, 1428, 1404, 1248, 1110, 1071, 1012; $^1$H NMR (400 MHz, CDCl$_3$) δ ppm 0.28 (s, 6 H, Si(CH$_3$)$_2$), 3.37 (s, 2 H, Ar-CH$_2$), 5.52 (dt, $J = 2.6$, 1.1 Hz, 1 H, C=CH$_2$), 5.56 (dt, $J = 2.8$, 1.5 Hz, 1 H, C=CH$_2$), 6.92 (d, $J = 8.3$ Hz, 2 H, ArH), 7.31 - 7.41 (m, 5 H, ArH), 7.42 - 7.48 (m, 2 H, ArH); $^{13}$C NMR (101 MHz, CDCl$_3$) δ -3.0 (Si(CH$_3$)$_2$), 42.0 (Ar-CH$_2$), 119.7 (ArC), 127.8 (C=CH$_2$), 128.0 (ArCH), 129.0 (ArCH), 131.0 (ArCH), 131.1 (ArCH), 133.9 (ArCH), 137.6 (ArC), 138.8 (ArC), 149.2 (C=CH$_2$).

(3-(3-Fluorophenyl)prop-1-en-2-yl)dimethyl(phenyl)silane (98j)

Prepared according to General Procedure 11, on a 0.263 mmol scale, column chromatography (Hexanes) afforded the title compound as an oil (59.0 mg, 0.218 mmol, 83%).
MS (GCMS) m/z: 270 (M); HRMS calcd for C_{17}H_{19}F_{1}Si: 270.1235. Found: 270.1223; \nu_{\text{max}}\ (\text{thin film/cm}^{-1}): 3056, 2959, 1501, 1428, 1412, 1248, 1156, 1111, 1089, 1015; \textsuperscript{1}H NMR (400 MHz, CDCl\textsubscript{3}) \delta ppm 0.19 (s, 6 H, Si(CH\textsubscript{3})\textsubscript{2}), 3.32 (s, 2 H, Ar-CH\textsubscript{2}), 5.42 - 5.45 (m, 1 H, C=CH\textsubscript{2}), 5.49 (dt, J = 2.7, 1.5 Hz, 1 H, C=CH\textsubscript{2}), 6.67 (dd, J = 10.1, 1.8 Hz, 1 H, ArH), 6.72 - 6.81 (m, 2 H, ArH), 7.08 (td, J = 7.8, 6.1 Hz, 1 H, ArH), 7.22 - 7.31 (m, 3 H, ArH), 7.34 - 7.40 (m, 2 H, ArH); \textsuperscript{13}C NMR (101 MHz, CDCl\textsubscript{3}) \delta -3.0 (Si(CH\textsubscript{3})\textsubscript{2}), 42.3 (Ar-CH\textsubscript{2}), 112.8 (d, J = 21.2 Hz, ArCH), 116.0 (d, J = 23.1 Hz, ArCH), 124.9 (d, J = 2.8 Hz, ArCH), 127.7 (ArCH), 128.2 (C=CH\textsubscript{2}), 129.0 (ArCH), 129.4 (d, J = 8.3 Hz, ArCH), 133.9 (ArCH), 137.7 (ArC), 142.5 (d, J = 7.4 Hz, ArC), 149.0 (C=CH\textsubscript{2}) (ArCF not observed).

(3-(3-Chlorophenyl)prop-1-en-2-yl)dimethyl(phenyl)silane (98k)

Prepared according to General Procedure 11, on a 0.263 mmol scale, column chromatography (Hexanes) afforded the title compound as an oil (61.9 mg, 0.216 mmol, 82%).

MS (GCMS) m/z: 286 (M); HRMS calcd for C_{17}H_{19}Cl_{1}Si: 286.0939. Found: 286.0929; \nu_{\text{max}}\ (\text{thin film/cm}^{-1}): 3056, 2959, 1596, 1573, 1474, 1427, 1248, 1111, 1078; \textsuperscript{1}H NMR (400 MHz, CDCl\textsubscript{3}) \delta ppm 0.19 (s, 6 H, Si(CH\textsubscript{3})\textsubscript{2}), 3.30 (s, 2 H, Ar-CH\textsubscript{2}), 5.44 (d, J = 2.6 Hz, 1 H, C=CH\textsubscript{2}), 5.46 - 5.51 (m, 1 H, C=CH\textsubscript{2}), 6.81 - 6.87 (m, 1 H, ArH), 6.94 (s, 1 H, ArH), 7.02 - 7.08 (m, 2 H, ArH), 7.22 - 7.32 (m, 3 H, ArH), 7.34 - 7.40 (m, 2 H, ArH); \textsuperscript{13}C NMR (101 MHz, CDCl\textsubscript{3}) \delta -3.0 (Si(CH\textsubscript{3})\textsubscript{2}), 42.2 (Ar-CH\textsubscript{2}), 126.1 (ArCH), 127.5 (ArCH), 128.2 (C=CH\textsubscript{2}), 129.0 (ArCH), 129.1 (ArCH), 129.3 (ArC), 129.4 (ArCH), 133.9 (ArCH), 137.6 (ArC), 141.9 (ArC), 149.0 (C=CH\textsubscript{2}).

(3-(3,5-bis(Trifluoromethyl)phenyl)prop-1-en-2-yl)dimethyl(phenyl)silane (98l)

Prepared according to General Procedure 11, on a 0.157 mmol scale, column chromatography (Hexanes) afforded the title compound as an oil (39 mg, 0.100 mmol, 64%).

MS (GCMS) m/z: 388 (M); HRMS calcd for C_{19}H_{18}F_{6}Si: 388.1076. Found: 388.1076; \nu_{\text{max}}\ (\text{thin film/cm}^{-1}): 2961, 1375, 1278, 1172, 1133; major regioisomer: \textsuperscript{1}H NMR (500 MHz, CDCl\textsubscript{3}) \delta ppm 0.31 (s, 6 H, Si(CH\textsubscript{3})\textsubscript{2}), 3.52 (s, 2 H, Ar-CH\textsubscript{2}), 7.28 - 7.46 (m, 6 H, ArH) 7.65 (s, 1 H, ArH); major and minor regioisomer: \textsuperscript{13}C NMR (126 MHz, CDCl\textsubscript{3}) \delta -3.7 (min Si(CH\textsubscript{3})\textsubscript{2}), -3.2 (maj Si(CH\textsubscript{3})\textsubscript{2}), 16.6 (min CH\textsubscript{3}), 42.4 (maj Ar-CH\textsubscript{2}), 120.0 (ArCH), 122.3, 124.4, 127.8 (ArCH), 128.0 (ArCH), 129.1 (maj C=CH\textsubscript{2}), 129.2, 129.3, 129.4, 131.2 (q, J = 34.5 Hz, ArCH), 133.7, 134.0, 135.6 (min C=CH), 136.9, 140.0, 142.4, 143.4, 148.3.
3-Hydroxypropyl 3-(2-(dimethyl(phenyl)silyl)allyl)benzoate (98m)

Prepared according to General Procedure 11, on a 0.263 mmol scale, column chromatography (Hexanes) afforded the title compound as an oil (70.0 mg, 0.197 mmol, 75%).

MS (ES⁺) m/z: 377 (M+Na⁺); HRMS calcd for C₂₁H₂₆O₃SiNa: 377.1549. Found: 377.1537; νmax (thin film/cm⁻¹): 3429 (Broad), 3049, 2957, 1717, 1588, 1428, 1276, 1190, 1110, 1081, 1052; ¹H NMR (400 MHz, CDCl₃) δ ppm 0.29 (s, 6 H, Si(CH₃)₂), 2.02 (quin, J = 6.1 Hz, 2 H, CH₂), 3.47 (s, 2 H, Ar-CH₂), 3.78 (m, 2 H, HOC₂H₂), 4.49 (t, J = 6.1 Hz, 2 H, OCH₂), 5.51 - 5.57 (m, 2 H, C=CH₂), 7.23 - 7.37 (m, 5 H, ArH), 7.43 - 7.48 (m, 2 H, ArH), 7.71 - 7.75 (m, 1 H, ArH), 7.84 (dt, J = 7.6, 1.5 Hz, 1 H, ArH); ¹³C NMR (101 MHz, CDCl₃) δ -3.0 (Si(CH₃)₂), 31.9 (CH₂), 42.3 (Ar-CH₂), 59.2 (HOCH₂), 61.6 (OCH₂), 127.3 (ArCH), 127.7 (C=CH₂), 128.2 (ArCH), 128.2 (ArCH), 129.0 (ArCH), 129.9 (ArCH), 130.5 (ArC), 133.9 (ArCH), 134.1 (ArCH), 137.6 (ArC), 140.3 (ArC), 149.1 (C=CH₂), 167.1 (C=O).

3-Bromopropyl 3-(2-(dimethyl(phenyl)silyl)allyl)benzoate (98n)

Prepared according to General Procedure 11, on a 0.263 mmol scale, column chromatography (Hexanes) afforded the title compound as an oil (85.6 mg, 0.205 mmol, 78%).

MS (ES⁺) m/z: 439 (M+Na⁺); HRMS calcd for C₂₁H₂₅BrO₂SiNa: 439.0705. Found: 439.0707; νmax (thin film/cm⁻¹): 3049, 2957, 2028, 1719, 1587, 1486, 1428, 1275, 1216, 1188, 1109, 1080; ¹H NMR (400 MHz, CDCl₃) δ ppm 0.29 (s, 6 H, Si(CH₃)₂), 2.33 (quin, J = 6.3 Hz, 2 H, CH₂), 3.47 (s, 2 H, Ar-CH₂), 3.56 (t, J = 6.6 Hz, 2 H, CH₂Br), 4.46 (t, J = 6.1 Hz, 2 H, OCH₂), 5.52 - 5.58 (m, 2 H, C=CH₂), 7.24 - 7.38 (m, 5 H, ArH), 7.43 - 7.48 (m, 2 H, ArH), 7.72 (s, 1 H, ArH), 7.84 (dt, J = 7.6, 1.5 Hz, 1 H, ArH); ¹³C NMR (101 MHz, CDCl₃) δ -3.0(Si(CH₃)₂), 29.5 (CH₂), 31.9 (BrCH₂), 42.3 (Ar-CH₂), 62.6 (OCH₂), 127.3 (ArCH), 127.7 (ArCH), 128.18 (ArCH), 128.22 (C=CH₂), 129.0 (ArCH), 129.8 (ArC), 130.4 (ArCH), 133.9 (ArCH), 134.1 (ArCH), 137.6 (ArC), 140.3 (ArC), 149.2 (C=CH₂), 166.5 (C=O).
3-Iodopropyl 3-(2-(dimethyl(phenyl)silyl)allyl)benzoate (98o)

Prepared according to General Procedure 11, on a 0.263 mmol scale, column chromatography (Hexanes) afforded the title compound as an oil (75.7 mg, 0.163 mmol, 62%).

MS (ES+) m/z: 487 (M+Na+); HRMS calcd for C21H25O2I1Na1Si1: 487.0561. Found: 487.0569; \( \nu_{\text{max}} \) (thin film/cm\(^{-1}\)): 3048, 2955, 1718, 1587, 1427, 1273, 1184, 1108, 1108, 1080; \(^1\)H NMR (500 MHz, CDCl\(_3\)) \( \delta \) ppm 0.29 (s, 6 H, Si(CH\(_3\))\(_2\)), 2.30 (quin, \( J = 6.4 \) Hz, 2 H, CH\(_2\)), 3.31 (t, \( J = 6.8 \) Hz, 2 H, ICH\(_2\)), 3.47 (s, 2 H, Ar-CH\(_2\)), 4.39 (t, \( J = 6.0 \) Hz, 2 H, OCH\(_2\)), 5.54 (s, 1 H, C=CH\(_2\)), 5.55 (s, 1 H, C=CH\(_2\)), 7.24 - 7.38 (m, 5 H, ArH), 7.45 (d, \( J = 7.6 \) Hz, 2 H, ArH), 7.72 (s, 1 H, ArH), 7.84 (d, \( J = 7.6 \) Hz, 1 H, ArH); \(^{13}\)C NMR (126 MHz, CDCl\(_3\)) \( \delta \) -3.0 (Si(CH\(_3\))\(_2\)), 32.5 (CH\(_2\)), 42.2 (Ar-CH\(_2\)), 64.4 (OCH\(_2\)), 127.3 (ArCH), 127.7 (ArCH), 128.17 (ArCH), 128.21 (C=CH\(_2\)), 129.0 (ArCH), 129.8 (ArC), 130.4 (ArCH), 133.9 (ArCH), 134.1 (ArCH), 137.6 (ArC), 140.3 (ArC), 149.1 (C=CH\(_2\)), 166.5 (C=O).

3-Azidopropyl 3-(2-(dimethyl(phenyl)silyl)allyl)benzoate (98p)

Prepared according to General Procedure 11, on a 0.263 mmol scale, column chromatography (Hexanes) afforded the title compound as an oil (83.8 mg, 0.221 mmol, 84%).

MS (ES+) m/z: 402 (M+Na+); HRMS calcd for C\(_{21}\)H\(_{26}\)O\(_2\)N\(_3\)Si1Na1: 402.1614. Found: 402.1600; \( \nu_{\text{max}} \) (thin film/cm\(^{-1}\)): 3049, 2958, 2097, 1720, 1588, 1428, 1275, 1189, 1111, 1081, 1033; \(^1\)H NMR (400 MHz, CDCl\(_3\)) \( \delta \) ppm 0.29 (s, 6 H, Si(CH\(_3\))\(_2\)), 2.06 (quin, \( J = 6.4 \) Hz, 2 H, CH\(_2\)), 3.47 (s, 2 H, Ar-CH\(_2\)), 4.41 (t, \( J = 6.2 \) Hz, 2 H, OCH\(_2\)), 5.52 - 5.58 (m, 2 H, C=CH\(_2\)), 7.22 - 7.38 (m, 5 H, ArH), 7.43 - 7.48 (m, 2 H, ArH), 7.71 - 7.76 (m, 1 H, ArH), 7.84 (dt, \( J = 7.6 \), 1.5 Hz, 1 H, ArH); \(^{13}\)C NMR (101 MHz, CDCl\(_3\)) \( \delta \) -3.0 (Si(CH\(_3\))\(_2\)), 28.3 (CH\(_2\)), 42.3 (Ar-CH\(_2\)), 48.3 (N\(_3\)CH\(_3\)), 61.7 (OCH\(_2\)), 127.3 (ArCH), 127.7 (ArCH), 128.19 (ArCH), 128.23 (C=CH\(_2\)), 129.0 (ArCH), 129.8 (ArC), 130.4 (ArCH), 133.9 (ArCH), 134.1 (ArCH), 137.6 (ArC), 140.3 (ArC), 149.1 (C=CH\(_2\)), 166.5 (C=O).

2-Cyanoethyl 3-(2-(dimethyl(phenyl)silyl)allyl)benzoate (98q)

Prepared according to General Procedure 11, on a 0.263 mmol scale, column chromatography (20% EtOAc in Hexanes) afforded the title compound as an oil (65.3 mg, 0.187 mmol, 71%).
MS (ES\textsuperscript{+}) m/z: 372 (M); HRMS calcd for C\textsubscript{21}H\textsubscript{23}O\textsubscript{2}N\textsubscript{1}Na\textsubscript{1}: 372.1390. Found: 372.1385; \(\nu\)\textsubscript{max} (thin film/cm\textsuperscript{-1}): 2957, 1723, 1640, 1588, 1486, 1460, 1428, 1380, 1331, 1272, 1186, 1108, 1082, 1027; \(^1\)H NMR (400 MHz, CDCl\textsubscript{3}) \(\delta\) ppm 0.29 (s, 6 H, Si(CH\textsubscript{3})\textsubscript{2}), 2.85 (t, \(J = 6.3\) Hz, 2 H, CH\textsubscript{2}), 3.48 (s, 2 H, Ar-CH\textsubscript{2}), 4.52 (t, \(J = 6.4\) Hz, 2 H, OCH\textsubscript{2}), 5.51 - 5.59 (m, 1 H, C=CH\textsubscript{2}), 7.28 - 7.42 (m, 6 H, ArH + C=CH\textsubscript{2}), 7.43 - 7.47 (m, 2 H ArH), 7.74 (s, 1 H ArH), 7.86 (dt, \(J = 7.4, 1.7\) Hz, 1 H ArH); \(^13\)C NMR (101 MHz, CDCl\textsubscript{3}) \(\delta\) ppm 3.0 (Si(CH\textsubscript{3})\textsubscript{2}), 18.1 (CH\textsubscript{2}), 42.2 (Ar-CH\textsubscript{2}), 59.0 (CH\textsubscript{2}O), 116.7 (CN), 127.6 (ArC), 128.3 (C=CH\textsubscript{2}), 128.9 (ArCH), 129.0 (ArCH), 129.6 (ArC), 130.6 (ArCH), 133.0 (ArCH), 133.9 (ArCH), 134.6 (ArCH), 137.6 (ArCH), 140.4 (ArC), 149.1 (C=CH\textsubscript{2}), 166.1 (C=O).

**Ethyl 3-(2-(dimethyl(phenyl)silyl)allyl)benzoate (98r)**

![Ethyl 3-(2-(dimethyl(phenyl)silyl)allyl)benzoate](image)

Prepared according to General Procedure 11, on a 0.263 mmol scale, column chromatography (2% EtOAc in Hexanes) afforded the title compound as an oil (77.7 mg, 0.239 mmol, 91%).

MS (ES\textsuperscript{+}) m/z: 347 (M+Na\textsuperscript{+}); HRMS calcd for C\textsubscript{20}H\textsubscript{24}O\textsubscript{2}Si\textsubscript{1}Na\textsubscript{1}: 347.1443. Found: 347.1450; \(\nu\)\textsubscript{max} (thin film/cm\textsuperscript{-1}): 2957, 1718, 1428, 1367, 1276, 1190, 1105, 1081, 1025; \(^1\)H NMR (400 MHz, CDCl\textsubscript{3}) \(\delta\) ppm 0.29 (s, 6 H, Si(CH\textsubscript{3})\textsubscript{2}), 1.41 (t, \(J = 7.2\) Hz, 3 H, CH\textsubscript{3}), 3.47 (s, 2 H, Ar-CH\textsubscript{2}), 4.37 (q, \(J = 7.1\) Hz, 2 H, OCH\textsubscript{2}), 5.52 - 5.56 (m, 2 H, C=CH\textsubscript{2}), 7.21 - 7.40 (m, 5 H, ArH), 7.44 - 7.49 (m, 2 H, ArH), 7.74 (s, 1 H, ArH), 7.85 (dt, \(J = 7.6, 1.5\) Hz, 1 H, ArH); \(^13\)C NMR (101 MHz, CDCl\textsubscript{3}) \(\delta\) ppm 3.0 (Si(CH\textsubscript{3})\textsubscript{2}), 14.3 (CH\textsubscript{3}), 42.3 (Ar-CH\textsubscript{2}), 60.8 (OCH\textsubscript{2}), 127.2 (ArCH), 127.7 (C=CH\textsubscript{2}), 128.1 (ArCH), 128.2 (ArCH), 129.0 (ArCH), 130.3 (ArC), 130.4 (ArCH), 133.8 (ArCH), 133.9 (ArCH), 137.7 (ArC), 140.1 (ArC), 149.2 (C=CH\textsubscript{2}), 166.7 (C=O).

**3-(2-(Dimethyl(phenyl)silyl)allyl)-N,N-diethylbenzamide (98s)**

![3-(2-(Dimethyl(phenyl)silyl)allyl)-N,N-diethylbenzamide](image)

Prepared according to General Procedure 11, on a 0.263 mmol scale, column chromatography (2% EtOAc in Hexanes) afforded the title compound as an oil (71.1 mg, 0.203 mmol, 77%).

MS (ES\textsuperscript{+}) m/z: 351 (M+H\textsuperscript{+}); HRMS calcd for C\textsubscript{22}H\textsubscript{29}O\textsubscript{1}N\textsubscript{1}Si\textsubscript{1}: 351.2018. Found: 351.2020; \(\nu\)\textsubscript{max} (thin film/cm\textsuperscript{-1}): 3049, 2967, 1632, 1583, 1487, 1457, 1427, 1380, 1364, 1315, 1287, 1248, 1216, 1163, 111, 1099; \(^1\)H NMR (400 MHz, CDCl\textsubscript{3}) \(\delta\) ppm 0.28 (s, 5 H, Si(C\textsubscript{H}\textsubscript{3})\textsubscript{2}), 1.10 (br. s., 3 H, CH\textsubscript{3}), 1.26 (br. s, 3 H, CH\textsubscript{3}), 3.22 (br. s., 2 H, NCH\textsubscript{2}), 3.44 (s, 2 H, Ar-CH\textsubscript{2}), 3.54 (br. s., 2 H, NCH\textsubscript{2}), 5.49 - 5.60 (m, 2 H, C=CH\textsubscript{2}), 7.05 - 7.14 (m, 2 H, ArH), 7.22 - 7.31 (m, 2 H, ArH), 7.31 - 7.42 (m, 3 H, ArH), 7.43 - 7.52 (m, 2 H, ArH); \(^13\)C NMR (400 MHz, CDCl\textsubscript{3}) \(\delta\) ppm -3.0 (Si(CH\textsubscript{3})\textsubscript{2}), 42.3 (Ar-CH\textsubscript{2}), 123.9 (ArCH), 127.1
(ArCH), 127.7 (C=CH2), 128.1 (ArCH), 128.2 (ArCH), 129.0 (ArCH), 130.1 (ArCH), 133.9 (ArCH), 137.1 (ArC), 137.7 (ArC), 140.2 (ArC), 149.2 (C=CH2), 171.4 (C=O) (NCH2CH3 not observed).

**3,3-Diphenylprop-1-en-2-yl)dimethyl(phenyl)silane (98t)**

Prepared according to General Procedure 11, on a 0.263 mmol scale, column chromatography (Hexanes) afforded the title compound as an oil (49.2 mg, 0.150 mmol, 57%).

MS (GCMS) m/z: 328 (M); HRMS calcd for C23H24Si: 328.1642. Found: 328.1633; \(\nu_{\text{max}}\) (thin film/cm\(^{-1}\)): 3061, 3024, 2956, 1597, 1492, 1449, 1427, 1248, 1109, 1078, 1031; \(^1\)H NMR (400 MHz, CDCl\(_3\)) \(\delta\) ppm: 0.22 (s, 6 H, Si(CH\(_3\))\(_2\)), 4.96 (s, 1 H, Ar-CH), 5.39 (t, \(J = 1.8\) Hz, 1 H, C=CH\(_2\)), 5.78 (d, \(J = 1.3\) Hz, 1 H, C=CH\(_2\)), 7.04 – 7.11 (m, 4 H, ArH), 7.16 – 7.23 (m, 2 H, ArH), 7.24 – 7.31 (m, 4 H, ArH), 7.34 – 7.42 (m, 3 H, ArH), 7.46 – 7.53 (m, 2 H, ArH); \(^{13}\)C NMR (101 MHz, CDCl\(_3\)) \(\delta\) ppm: 2.7 (Si(CH\(_3\))\(_2\)), 56.0 (ArCH), 126.1 (ArCH), 127.7 (ArCH), 128.0 (ArCH), 129.0 (C=CH\(_2\)), 129.4 (ArC), 129.6 (ArCH), 134.0 (ArCH), 138.0 (ArC), 142.3 (ArC), 153.0 (C=CH\(_2\)).

**Dimethyl(phenyl)(1-phenylhept-2-en-2-yl)silane (98u)**

Prepared according to General Procedure 11, on a 0.263 mmol scale, column chromatography (Hexanes) afforded the title compound as an oil (77.1 mg, 0.250 mmol, 95%).

MS (GCMS) m/z: 293 (M-CH\(_3\)); HRMS calcd for C\(_{20}\)H\(_{25}\)Si: 292.9819. Found: 292.9819; \(\nu_{\text{max}}\) (thin film/cm\(^{-1}\)): 3067, 3025, 2955, 2924, 1610, 1493, 1452, 1427, 1247, 1110, 1075, 1029; \(^1\)H NMR (400 MHz, CDCl\(_3\)) \(\delta\) ppm: 0.18 (s, 6 H, Si(CH\(_3\))\(_2\)), 0.27 (s, 6 H, Ar-CH), 0.80 (t, \(J = 7.2\) Hz, 3 H, CH\(_3\)), 0.90 (t, \(J = 7.2\) Hz, 3 H, (E), CH\(_3\)), 1.12 - 1.46 (m, 8 H, (E) + (Z), CH\(_2\)), 2.03 (q, \(J = 7.4\) Hz, 2 H, (Z), CH\(_2\)), 2.20 (q, \(J = 7.1\) Hz, 2 H, (E), CH\(_2\)), 3.48 (s, 2 H (Z), ArCH\(_2\)), 3.52 (s, 2 H (E), ArCH\(_2\)), 6.04 (t, \(J = 6.8\) Hz, 1 H, C=CH), 6.11 (t, \(J = 7.5\) Hz (Z), 1 H, C=CH), 7.04 - 7.46 (m, 20 H (E) + (Z), ArH); \(^{13}\)C NMR (101 MHz, CDCl\(_3\)) \(\delta\) ppm: -2.6 (Si(CH\(_3\))\(_2\)), -1.0 (Si(CH\(_3\))\(_2\)), 14.0 (Si(CH\(_3\))\(_2\)), 14.0 (CH\(_3\)), 22.4 (CH\(_3\)), 22.5 (CH\(_3\)), 28.8 (C=CHCH\(_3\)), 31.6 (CH\(_3\)), 31.9 (CH\(_3\)), 32.2 (C=CHCH\(_3\)), 35.3 (Ar-CH\(_3\)), 44.8 (Ar-CH\(_3\)), 125.6 (ArCH), 125.7 (ArCH), 127.6 (ArCH), 128.6 (ArCH), 128.7 (ArCH), 129.0 (ArCH), 133.8 (ArCH), 134.0 (ArCH).
(ArC), 135.5 (C=CH), 136.9 (C=CH), 138.9 (ArC), 139.6 (ArC), 140.7 (ArC), 141.2 (ArC), 144.3 (C=CH), 147.3 (C=CH).

tert-Butyl[(6-{dimethyl(phenyl)silyl}hept-6-yl)oxy]dimethylsilane (116a)

Prepared according to General Procedure 11, with 6 equiv of MeOH, for 18 h, on a 0.263 mmol scale, column chromatography (x% EtOAc in Hexanes) afforded the title compound as an oil (62 mg, 0.171 mmol, 65%).

$\nu_{\text{max}}$ (thin film/cm$^{-1}$): 2929, 2856, 1417, 1428, 1388, 1361, 1249, 1106, 1006; $^1$H NMR (400 MHz, CDCl$_3$) $\delta$ ppm 0.04 (s, 6 H, Si(CH$_3$)$_2$), 0.37 (s, 6 H, Si(CH$_3$)$_2$), 0.89 (s, 9 H, (CH$_3$)$_3$), 1.20 - 1.74 (m, 6 H, CH$_2$), 2.12 (t, $J$ = 8.1 Hz, 2 H, CH$_2$C=CH$_2$), 3.55 (t, $J$ = 6.7 Hz, 2 H, OCH$_2$), 5.39 - 5.41 (m, 1 H, C=CH$_2$), 5.68 (dt, $J$ = 2.8, 1.5 Hz, 1 H, C=CH$_2$), 7.30 - 7.39 (m, 3 H, ArH), 7.48 - 7.55 (m, 2 H, ArH); $^{13}$C NMR (101 MHz, CDCl$_3$) $\delta$ ppm -5.3 (Si(CH$_3$)$_2$), -2.9 (Si(CH$_3$)$_2$), 25.6 (CH$_3$)$_3$, 26.0 ((CH$_3$)$_3$), 28.6 (CH$_3$), 31.6 (SiC(CH$_3$)$_3$), 32.7 (CH$_3$), 36.0 (CH$_2$C=CH$_2$), 63.2 (OCH$_2$), 125.7 (C=CH$_2$), 127.7 (ArCH), 128.9 (ArCH), 133.6 (ArC), 133.9 (ArCH), 138.4 (ArC), 150.4 (C=CH$_2$).

(Z)-Methyldiphenyl(undec-2-yl)silane (121a)

Prepared according to General Procedure 11, using 106, with 6 equiv of MeOH and 1.1 equiv of Ph$_2$MeSiBpin, for 18 h, on a 0.263 mmol scale, column chromatography (Hexanes) afforded the title compound as an oil (57 mg, 0.163 mmol, 62%).

$\nu_{\text{max}}$ (thin film/cm$^{-1}$): 3068, 3049, 2955, 2924, 2853, 1465, 1428, 1250, 1150, 1113; $^1$H NMR (500 MHz, CDCl$_3$) $\delta$ ppm 0.46 (s, 3 H, SiCH$_3$), 0.79 (t, $J$ = 6.9 Hz, 3 H, CH$_3$), 1.07 - 1.24 (m, 12 H, 6 x CH$_2$), 1.75 - 1.84 (m, 2 H, CH$_2$CH=CH), 1.94 (d, $J$ = 8.5 Hz, 2 H, CH$_2$SiMePh$_2$), 5.20 (dt, $J$ = 10.4, 7.3 Hz, 1 H), 5.31 (q, $J$ = 10.1 Hz, 1 H), 7.22 - 7.32 (m, 6 H, ArH), 7.40 - 7.49 (m, 4 H, ArH); $^{13}$C NMR (126 MHz, CDCl$_3$) $\delta$ ppm -4.7 (SiCH$_3$), 14.1 (CH$_3$), 15.9 (CH=CHCH$_2$Si), 22.7 (CH$_3$), 27.2 (CH$_3$), 29.3 (CH$_3$), 29.4 (CH$_3$), 29.5 (CH$_2$), 29.6 (CH$_3$), 31.9 (CH$_3$), 123.9 (CH=CHCH$_2$Si), 127.8 (ArCH), 129.2 (ArCH), 129.3 (CH=CHCH$_2$Si), 134.5 (ArCH), 136.9 (ArC).
(Z)-(3-Cyclohexylallyl)(methyl)diphenylsilane (121b)

Prepared according to General Procedure 11, using 106, with 6 equiv of MeOH and 1.1 equiv of Ph₃MeSiBpin, for 18 h, on a 0.263 mmol scale, column chromatography (Hexanes) afforded the title compound as an oil (62 mg, 0.195 mmol, 74%).

$\nu_{\text{max}}$ (thin film/cm$^{-1}$): 3068, 3009, 2920, 2849, 1448, 1427, 1250, 1149, 1112; $^1$H NMR (500 MHz, CDCl$_3$) $\delta$ ppm 0.47 (s, 3 H, SiCH$_3$), 0.79 - 0.90 (m, 2 H, CH$_2$), 0.98 - 1.13 (m, 3 H, CH$_3$), 1.30 (dd, $J = 13.2$, 1.9 Hz, 2 H, CH$_2$), 1.46 - 1.57 (m, 3 H, CH$_3$), 1.94 (dd, $J = 8.5$, 1.0 Hz, 2 H, CH$_2$SiMePh$_2$), 1.97 - 2.06 (m, 1 H, CH), 5.03 (t, $J = 10.3$ Hz, 1 H, CyCH=CH), 5.21 (dt, $J = 10.6$, 8.4 Hz, 1 H, C=CHCH$_2$), 7.23 - 7.29 (m, 6 H, ArH), 7.41 - 7.47 (m, 4 H, ArH); $^{13}$C NMR (126 MHz, CDCl$_3$) $\delta$ ppm -4.8 (SiCH$_3$), 16.0 (CH=CHCH$_2$), 26.0 (CH$_2$), 26.1 (CH$_2$), 33.0 (CH$_2$), 36.1 (CH), 121.8 (CH=CHCH$_2$), 127.8 (ArCH), 129.2 (ArCH), 134.5 (ArCH), 135.3 (CyCH=CH), 136.8 (ArC).

(Z)-(4-Cyclohexylbut-2-en-1-yl)(methyl)diphenylsilane (121c)

Prepared according to General Procedure 11, using 106, with 6 equiv of MeOH and 1.1 equiv of Ph₃MeSiBpin, for 18 h, on a 0.263 mmol scale, column chromatography (Hexanes) afforded the title compound as an oil (76 mg, 0.226 mmol, 86%).

$\nu_{\text{max}}$ (thin film/cm$^{-1}$): 3068, 3009, 2920, 2849, 1448, 1427, 1250, 1149, 1112, 1030; $^1$H NMR (400 MHz, CDCl$_3$) $\delta$ ppm 0.57 (s, 3 H, SiCH$_3$), 0.78 - 0.90 (m, 2 H, CH$_2$), 1.09 - 1.26 (m, 4 H, CH$_2$), 1.59 - 1.73 (m, 5 H, CH$_2$ + CH), 1.82 (t, $J = 6.8$ Hz, 2 H, CH$_2$), 2.05 (d, $J = 8.1$ Hz, 2 H, CH$_2$SiMePh$_2$), 5.31 - 5.39 (m, 1 H, CH=CH), 5.47 (dt, $J = 10.3$, 8.8 Hz, 1 H, CH=CH), 7.33 - 7.43 (m, 6 H, ArH), 7.50 - 7.61 (m, 4 H, ArH); $^{13}$C NMR (101 MHz, CDCl$_3$) $\delta$ ppm -4.6 (SiCH$_3$), 15.9 (CH=CHCH$_2$Si), 26.4 (CH$_2$), 26.6 (CH$_2$), 33.2 (CH$_2$), 34.9 (CH$_2$), 38.2 (CH), 124.5 (CH=CH), 127.8 (CH=CH + ArCH), 129.2 (ArCH), 134.5 (ArCH), 136.9 (ArC).
(Z)-7-(Methyldiphenylsilyl)hept-5-en-1-ol (121d)

Prepared according to General Procedure 11, using 106, with 11 equiv of MeOH and 1.1 equiv of Ph$_3$MeSiBpin, for 18 h, on a 0.263 mmol scale, column chromatography (15% EtOAc in Hexanes) afforded the title compound as an oil (57 mg, 0.184 mmol, 70%).

MS (ES$^+$) $m/z$: 333 (M+Na$^+$). HRMS calcd for C$_{20}$H$_{26}$O$_1$Si$_1$Na: 333.1651. Found: 333.1664; $\nu$$_{max}$ (thin film/cm$^{-1}$): 3340, 3068, 3007, 2933, 1427, 1250, 1150, 1112, 1066; $^1$H NMR (400 MHz, CDCl$_3$) $\delta$ ppm 0.56 (s, 3 H, SiCH$_3$), 1.22 - 1.31 (m, 2 H, CH$_2$), 1.45 - 1.54 (m, 2 H, CH$_2$), 1.92 (q, J = 7.1 Hz, 2 H, CH$_2$), 2.04 (d, J = 8.4 Hz, 2 H, CH$_2$SiMePh$_2$), 3.59 (t, J = 6.7 Hz, 2 H, CH$_2$OH), 5.29 (dt, J = 11.1, 7.0 Hz, 1 H, CH=CHCH$_2$Si), 5.45 (dtt, J = 10.7, 6.9, 1.3 Hz, 1 H, CH=C=HCH$_2$Si), 7.32 - 7.43 (m, 6 H, ArH), 7.49 - 7.59 (m, 4 H, ArH); $^{13}$C NMR (101 MHz, CDCl$_3$) $\delta$ ppm -4.7 (SiCH$_3$), 16.0 (CH=CHC=H), 25.6 (CH$_2$), 26.8 (CH$_2$), 62.9 (CH$_2$OH), 124.4 (CH=CHCH$_2$Si), 127.8 (ArCH), 128.6 (CH=CH), 129.2 (ArCH), 134.5 (ArCH), 136.7 (ArC).

(Z)-2-(6-(Methyldiphenylsilyl)hex-4-en-1-yl)isoindoline-1,3-dione (121e)

Prepared according to General Procedure 11, using 106, with 6 equiv of MeOH and 1.1 equiv of Ph$_3$MeSiBpin, for 18 h, on a 0.263 mmol scale, column chromatography (10% EtOAc in Hexanes) afforded the title compound as an oil (93 mg, 0.218 mmol, 83%).

MS (ES$^+$) $m/z$: 448 (M+Na$^+$). HRMS calcd for C$_{27}$H$_{27}$O$_2$N$_1$Si$_1$K$_1$: 464.1448. Found: 464.1467; $\nu$$_{max}$ (thin film/cm$^{-1}$): 3008, 2940, 1708, 1428, 1394, 1368, 1250, 1111, 1017; $^1$H NMR (400 MHz, CDCl$_3$) $\delta$ ppm 0.55 (s, 3 H, SiCH$_3$), 1.60 (dt, J = 14.9, 7.5 Hz, 2 H, CH$_2$), 1.94 (q, J = 7.0 Hz, 2 H, CH$_2$), 2.02 (d, J = 8.5 Hz, 2 H, CH$_2$SiMePh$_2$), 3.59 (t, J = 7.6 Hz, 2 H, CH$_2$N), 5.30 (dtt, J = 10.7, 6.9, 1.3 Hz, 1 H, CH=CHCH$_2$Si), 5.46 (dtt, J = 10.7, 8.5, 1.6 Hz, 1 H, CH=CHCH$_2$Si), 7.32 - 7.37 (m, 6 H, ArH), 7.50 - 7.54 (m, 4 H, ArH), 7.70 - 7.74 (m, 2 H, ArH), 7.82 - 7.87 (m, 2 H, ArH); $^{13}$C NMR (126 MHz, CDCl$_3$) $\delta$ ppm -4.7 (SiCH$_3$), 16.2 (CH=CHCH$_2$Si), 24.5 (CH$_2$), 28.3 (CH$_2$), 37.7 (CH$_2$N), 123.1 (ArCH), 125.2 (CH=CHCH$_2$Si), 127.4 (CH=CH), 127.8 (ArCH), 129.2 (ArCH), 132.2 (ArC), 133.8 (ArCH), 134.4 (ArCH), 136.6 (ArC), 168.3 (C=O).
**tert-Butyldiphenyl(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)silane (122)**

![Structural formula of tert-Butyldiphenyl(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)silane](image)

To a stirred solution of tert-butyldiphenylsilylchloride (12.7 mL, 48.8 mmol, 1 equiv) in THF (25 mL), lithium metal (1.01 g, 147 mmol, 3 equiv) was added in portions at 0 °C, and the resultant mixture stirred for 3 hours to give a dark green solution. The solution was then added dropwise to a stirred solution of 4,4,5,5-tetramethyl-1,3,2-dioxaborolane (14.2 mL, 97.7 mmol, 2 equiv) in hexane (25 mL) via cannula over 30 min at 0 °C. The reaction mixture was stirred at room temperature overnight. The solvent was removed by evaporation under nitrogen to give a white solid. Hexane (45 mL) was added and the suspension filtered through a needle with a filter attachment under a nitrogen atmosphere. The filtrate was then evaporated in vacuo to give the title compound as a white solid (5.14 g, 22.94 mmol, 47%).

Mp: 73-75 °C (Hexane); MS (ES+) m/z: 389 (M+Na+). HRMS calcd for C22H31O2Si1B1Na1: 389.2103. Found: 389.2096; νmax (thin film/cm⁻¹): 3070, 2977, 2928, 2855, 1471, 1427, 1390, 1371, 1272, 1239, 1211, 1166, 1135, 1102, 1009; ¹H NMR (400 MHz, CDCl₃) δ ppm: 1.02 (s, 9 H, C(CH₃)₃), 1.24 (s, 12 H, 4 x CH₃), 7.24 - 7.30 (m, 6 H, ArH), 7.62 - 7.68 (m, 4 H, ArH); ¹³C NMR (101 MHz, CDCl₃) δ ppm: 18.4 (C(CH₃)₃), 25.0 (CH₃), 28.0 (C(CH₃)₃), 83.5 (OC), 127.5 (ArCH), 128.6 (ArCH), 135.5 (ArCH), 136.3 (ArC); ¹¹B NMR (128 MHz, CDCl₃) δ ppm: 35.19.

**(E)-Dimethyl(phenyl)(styryl)silane** (123)

Prepared according to General Procedure 11, on a 0.263 mmol scale, column chromatography (Hexanes) afforded the title compound as an oil (38 mg, 0.158 mmol, 60%).

¹H NMR (500 MHz, CDCl₃) δ ppm: 0.33 (s, 6 H, Si(CH₃)₂), 6.48 (d, J = 19.1 Hz, 1 H, C=CH), 6.84 (d, J = 19.1 Hz, 1 H, C=CH), 7.13 - 7.17 (m, 1 H, ArH), 7.19 - 7.24 (m, 2 H, ArH), 7.25 - 7.28 (m, 3 H, ArH), 7.32 - 7.36 (m, 2 H, ArH), 7.45 - 7.49 (m, 2 H, ArH); ¹³C NMR (101 MHz, CDCl₃) δ ppm: 2.5 (Si(CH₃)₂), 126.5 (ArCH), 127.1 (C=CH), 127.8 (ArCH), 128.1 (ArCH), 128.5 (ArCH), 129.0 (ArCH), 133.9 (ArCH), 138.1 (ArC), 138.6 (ArC), 145.3 (C=CH).

**4,4,5,5-Tetramethyl-2-[3-phenylprop-1-en-2-yl]-1,3,2-dioxaborolane** (125)

Prepared according to General Procedure 11, with B₂pin₂ (1.1 equiv), on a 0.263 mmol scale, column chromatography (Hexanes) afforded the title compound (49 mg, 0.200 mmol, 76%).
Chapter five

1H NMR (400 MHz, CDCl₃) δ ppm 1.22 (s, 12 H, (CH₃)₄), 3.49 (s, 2 H, Ar-CH₂), 5.54 (br. s., 1 H, C=CH₂), 5.84 (d, J = 3.3 Hz, 1 H, C=CH₂), 7.14 - 7.23 (m, 3 H, Ar-CH), 7.24 - 7.30 (m, 2 H, ArCH); 13C NMR (101 MHz, CDCl₃) δ ppm 24.7 (CH₃), 41.3 (CH₂), 83.5 (OC), 125.7 (ArCH), 128.1 (ArCH), 129.1 (ArCH), 129.8 (C=CH₂), 140.7 (ArC), BC=CH₂ not observed.

Procedure for competition experiment in Scheme 2.37
To a solution of 127 (50 mg, 0.103 mmol, 1 equiv) in THF (1.5 mL), was added KOt-Bu (0.11 mL of a 1 M THF solution, 0.108 mL, 0.108 mmol, 1.05 equiv) and left to stir for 5 min. PhMe₂SiBpin (0.03 mL, 0.0113 mmol, 1.1 equiv) was added and the reaction stirred for 15 min. A solution of (propa-1,2-dien-1-yl)benzene (12.5 mg, 0.108 mmol, 1.05 equiv) in THF (0.6 mL) was added and the reaction stirred for 1 h. Phenylacetylene (0.056 mL, 0.513 mmol, 5 equiv) was added and the reaction was stirred for 18 h. The reaction mixture was then filtered through a silica plug, concentrated in vacuo and the product distribution measured by crude ¹H NMR.

General Procedure 12 for the copper catalysed silylation of allenes trapping with an aldehyde rac-(1S,2S)-3-(Dimethyl(phenyl)silyl)-1,2-diphenylbut-3-en-1-ol139 (129a)

To a solution of 109 (10.9 mg, 0.026 mmol, 10 mol%) and CuI (2.5 mg, 0.013 mmol, 5 mol%) in THF (0.8 mL), was added KOT-Bu (0.043 mL of a 1 M THF solution, 0.043 mmol, 16.5 mol%), and the reaction was stirred for 1 hour at room temperature. PhMe₂SiBpin (0.079 mL, 0.284 mmol, 1.1 equiv) was then added and the resulting mixture stirred for 15 min. A solution of (propa-1,2-dien-1-yl)benzene (30.5 mg, 0.263 mmol, 1 equiv) and benzaldehyde (0.029 mL, 0.284 mmol, 1.1 equiv) in THF (0.5 mL) was then added dropwise, and the reaction stirred at room temperature for 3 hours. The reaction mixture was then filtered through a silica plug, concentrated in vacuo and purified by chromatography (2% EtOAc in hexanes) to afford the title compound (73.6 mg, 0.205 mmol, 78%).

¹H NMR (400 MHz, CDCl₃) δ ppm 0.03 (s, 3 H, Si(CH₃)₂), 0.11 (s, 3 H, Si(CH₃)₂), 3.79 (d, J = 7.9 Hz, 1 H, Ar-CH), 5.15 (dd, J = 7.9, 3.3 Hz, 1 H, Ar-CHOH), 5.67 (d, J = 1.8 Hz, 1 H, C=CH₂), 6.13 (t, J = 1.4 Hz, 1 H, C=CH₂), 7.16 - 7.21 (m, 4 H, ArH), 7.23 - 7.32 (m, 11 H, ArH); ¹³C NMR (101 MHz, CDCl₃) δ -3.2 (Si(CH₃)₂), -3.1 (Si(CH₃)₂), 56.8 (Ar-CH), 76.2 (Ar-CHOH), 127.0 (ArCH), 127.2 (ArCH), 127.4
(ArCH), 127.7 (ArCH), 128.0 (ArCH), 128.2 (ArCH), 128.3 (C=CH\textsubscript{2}), 129.0 (ArCH), 129.6 (ArCH), 134.1 (ArCH), 137.4 (ArC), 139.5 (ArC), 142.6 (ArC), 150.4 (C=CH\textsubscript{2}).

rac-(\textbf{1S,2S})-3-(Dimethyl(phenyl)silyl)-1-(4-methoxyphenyl)-2-phenylbut-3-en-1-ol (129b)

Prepared according to General Procedure 12, on a 0.263 mmol scale, column chromatography (4% EtOAc in hexanes) afforded the title compound as an oil (67.4 mg, 0.174 mmol, 66%).

\(^1\)H NMR (400 MHz, CDCl\textsubscript{3}) \(\delta\) ppm 0.03 (s, 3 H, Si(CH\textsubscript{3})\textsubscript{2}), 0.10 - 0.15 (m, 3 H, Si(CH\textsubscript{3})\textsubscript{2}), 3.76 (d, \(J = 8.4\) Hz, 1 H, Ar-CH), 3.82 (s, 3 H, OCH\textsubscript{3}), 5.09 (d, \(J = 8.3\) Hz, 1 H, Ar-CHOH), 5.65 (d, \(J = 1.8\) Hz, 1 H, C=CH\textsubscript{2}), 6.08 (s, 1 H, C=CH\textsubscript{2}), 6.77 - 6.84 (m, 2 H, ArH), 7.08 - 7.14 (m, 2 H, ArH), 7.17 - 7.39 (m, 10 H, ArH); \(^{13}\)C NMR (101 MHz, CDCl\textsubscript{3}) \(\delta\) -3.3 (Si(CH\textsubscript{3})\textsubscript{2}), -3.0 (Si(CH\textsubscript{3})\textsubscript{2}), 55.3 (OCH\textsubscript{3}), 56.7 (Ar-CH), 75.8 (Ar-CHOH), 113.4 (ArCH), 127.0 (ArCH), 127.6 (C=CH\textsubscript{2}), 128.0 (ArCH), 128.3 (ArCH), 128.4 (ArCH), 129.0 (ArCH), 129.5 (ArCH), 134.1(ArCH), 135.0 (ArC), 137.4 (ArC), 139.6 (ArC), 150.1 (C=CH\textsubscript{2}), 158.4 (ArCOCH\textsubscript{3}).

(\textbf{15,25})-3-(Dimethyl(phenyl)silyl)-1-(4-fluorophenyl)-2-phenylbut-3-en-1-ol (129c)

Prepared according to General Procedure 12, on a 0.263 mmol scale, column chromatography (2% EtOAc in hexanes) afforded the title compound as an oil (62.4 mg, 0.166 mmol, 63%).

MS (ES\textsuperscript{+}) m/z: 399 (M+Na\textsuperscript{+}); HRMS calcd for C\textsubscript{24}H\textsubscript{25}O\textsubscript{1}Si\textsubscript{1}F\textsubscript{1}Na\textsubscript{1}: 399.1556. Found: 399.1560; \(\nu\)\textsubscript{max} (thin film/cm\textsuperscript{-1}): 3433, 3067, 2957, 1603, 1510, 1493, 1452, 1306, 1248, 1228, 1222, 1184, 1157, 1110, 1041, 1013; \(^1\)H NMR (500 MHz, CDCl\textsubscript{3}) \(\delta\) ppm 0.02 (s, 3 H, SiCH\textsubscript{3}), 0.11 (s, 3 H, SiCH\textsubscript{3}), 3.70 (d, \(J = 8.2\) Hz, 1 H, Ar-CH), 5.10 (d, \(J = 8.2\) Hz, 1 H, Ar-CHOH), 5.67 (d, \(J = 1.9\) Hz, 1 H, C=CH\textsubscript{2}), 6.07 - 6.09 (m, 1 H, C=CH\textsubscript{2}), 6.89 - 6.96 (m, 2 H, ArH), 7.10 - 7.15 (m, 2 H, ArH), 7.16 - 7.21 (m, 2 H, ArH), 7.22 - 7.31 (m, 7 H, ArH), 7.32 - 7.42 (m, 1 H, ArH); \(^{13}\)C NMR (101 MHz, CDCl\textsubscript{3}) \(\delta\) -3.3 (Si(CH\textsubscript{3})\textsubscript{2}), -3.1 (Si(CH\textsubscript{3})\textsubscript{2}), 57.0 (CH), 75.5 (Ar-CHOH), 114.8 (d, \(J = 21.3\) Hz, ArCH), 127.1 (ArCH), 127.7 (ArCH), 128.1 (C=CH\textsubscript{2}), 128.4 (ArCH), 128.8 (d, \(J = 8.1\) Hz, ArCH), 129.0 (ArCH), 129.5 (ArCH), 134.0 (ArCH), 137.1 (ArC), 138.3 (d, \(J = 2.9\) Hz, ArC), 139.3 (ArC), 150.3 (C=CH\textsubscript{2}), 162.1 (d, \(J = 246.5\) Hz, ArCF).
rac-(1S,2S)-3-(Dimethyl(phenyl)silyl)-1-(2,4,6-trimethylphenyl)-2-phenylbut-3-en-1-ol (129d)

Prepared according to General Procedure 12, on a 0.263 mmol scale, column chromatography (2% EtOAc in hexanes) afforded the title compound as a solid (71.7 mg, 0.179 mmol, 68%).

Mp: 85 °C (CH$_2$Cl$_2$ : Hexane); MS (ES$^+$) m/z: 423 (M+Na$^+$); HRMS calcd for C$_{27}$H$_{32}$O$_1$Si$_1$Na: 423.2120. Found: 423.2109; $\nu_{\text{max}}$ (thin film/cm$^{-1}$): 3557, 3024, 2955, 1611, 1492, 1452, 1428, 1248, 1110, 1077, 1032; $^1$H NMR (400 MHz, CDCl$_3$) $\delta$ ppm -0.01 (s, 3 H, Si(CH$_3$)$_2$), 0.05 (s, 3 H, Si(CH$_3$)$_2$), 1.64 (d, $J = 4.0$ Hz, 1 H, OH), 2.16 (s, 6 H, (CH$_3$)$_2$), 2.25 (s, 3 H, CH$_3$), 4.07 (d, $J = 7.8$ Hz, 1 H, Ar-CH), 5.54 (dd, $J = 7.7$, 3.9 Hz, 1 H, Ar-COH), 5.64 (d, $J = 1.8$ Hz, 1 H, C=CH$_2$), 6.24 (s, 1 H, C=CH$_2$), 6.74 (s, 2 H, ArCH), 7.12 - 7.17 (m, 2 H, ArCH), 7.23 - 7.36 (m, 8 H, ArCH); $^{13}$C NMR (101 MHz, CDCl$_3$) $\delta$ ppm 3.1 (Si(CH$_3$)$_2$), -3.0 (Si(CH$_3$)$_2$), 20.7 (CH$_3$), 53.8 (Ar-CH), 73.7 (Ar-COH), 126.9 (ArCH), 127.6 (C=CH$_2$), 127.8 (ArC), 128.4 (ArCH), 128.9 (ArCH), 129.5 (ArCH), 130.3 (ArCH), 130.4 (ArCH), 134.0 (ArCH), 135.3 (ArC), 136.4 (ArC), 137.6 (ArC), 140.5 (ArC), 150.7 (C=CH$_2$).

rac-(3R,4S)-5-(dimethyl(phenyl)silyl)-1,4-diphenylhex-5-en-3-ol (129e)

Prepared according to General Procedure 12, on a 0.263 mmol scale, column chromatography (4% EtOAc in hexanes) afforded the title compound as an oil (68.1 mg, 0.176 mmol, 67%).

MS (ES$^+$) m/z: 409 (M+Na$^+$); HRMS calcd for C$_{26}$H$_{30}$O$_1$Si$_1$: 409.1964. Found: 409.1973; $\nu_{\text{max}}$ (thin film/cm$^{-1}$): 3574, 3064, 3025, 2957, 1601, 1493, 1453, 1428, 1248, 1110, 1066, 1031; $^1$H NMR (500 MHz, CDCl$_3$) $\delta$ ppm 0.15 (s, 3 H, Si(CH$_3$)$_2$), 0.23 (s, 3 H, Si(CH$_3$)$_2$), 1.53 - 1.63 (m, 1 H, CH$_2$), 1.86 - 1.97 (m, 1 H, CH$_2$), 2.61 (ddd, $J = 13.9$, 9.5, 7.3 Hz, 1 H, CH$_2$), 2.76 (ddd, $J = 14.1$, 9.5, 5.0 Hz, 1 H, CH$_2$), 3.40 (d, $J = 7.3$ Hz, 1 H, Ar-CH), 3.96 - 4.03 (m, 1 H, CHOH), 5.65 (d, $J = 1.9$ Hz, 1 H, C=CH$_2$), 5.85 - 5.87 (m, 1 H, C=CH$_2$), 7.11 - 7.41 (m, 15 H, ArH); $^{13}$C NMR (126 MHz, CDCl$_3$) $\delta$ ppm -3.1 (Si(CH$_3$)$_2$), -2.8 (Si(CH$_3$)$_2$), 32.2 (CH$_2$), 36.6 (CH$_2$), 56.1 (Ar-CH), 72.2 (CHOH), 125.7 (ArCH), 126.9 (ArCH), 127.2 (C=CH$_2$), 127.7 (ArCH), 128.3 (ArCH), 128.4 (ArCH), 128.5 (ArCH), 129.1 (ArCH), 129.6 (ArCH), 134.0 (ArCH), 137.4 (ArC), 139.8 (ArC), 142.2 (ArC), 151.3 (C=CH$_2$).
rac-(3R,4S)-5-(Dimethyl(phenyl)silyl)-4-phenylhex-5-en-3-ol (129f)

Prepared according to General Procedure 12, on a 0.263 mmol scale, column chromatography (2% EtOAc in hexanes) afforded the title compound as an oil (70.2 mg, 0.226 mmol, 86%).

MS (ES\(^+\)) m/z: 333 (M+Na\(^+\)); HRMS calcd for C\(_{20}\)H\(_{26}\)O\(_{1}\)Si\(_{1}\)Na: 333.1651. Found: 333.1649; \(\nu_{\text{max}}\) (thin film/cm\(^{-1}\)): 3457, 3067, 3025, 2959, 1597, 1492, 1452, 1428, 1248, 1110, 1030; \(^1\)H NMR (400 MHz, CDCl\(_3\)) \(\delta\) ppm 0.18 (s, 3 H, Si(CH\(_3\))\(_2\)), 0.26 (s, 3 H, Si(CH\(_3\))\(_2\)), 0.89 (t, \(J = 7.4\) Hz, 3 H, CH\(_3\)), 1.24 - 1.37 (m, 1 H, CH\(_2\)), 1.58 - 1.70 (m, 1 H, CH\(_2\)), 3.40 (d, \(J = 7.5\) Hz, 1 H, Ar-CH), 3.93 (dt, \(J = 7.5, 3.7\) Hz, 1 H, CHOH), 5.67 (d, \(J = 1.8\) Hz, 1 H, C=CH\(_2\)), 5.99 (s, 1 H, C=CH\(_2\)), 7.14 - 7.36 (m, 8 H, ArH), 7.38 - 7.44 (m, 2 H, ArH); \(^{13}\)C NMR (101 MHz, CDCl\(_3\)) \(\delta\) ppm 3.0 (Si(CH\(_3\))\(_2\)), -2.8 (Si(CH\(_3\))\(_2\)), 10.3 (CH\(_3\)), 27.8 (CH\(_2\)), 55.4 (Ar-CH), 74.5 (CHOH), 126.8 (ArCH), 127.2 (C=CH\(_2\)), 127.7 (ArCH), 128.3 (ArCH), 129.0 (ArCH), 129.6 (ArCH), 134.0 (ArCH), 137.5 (ArC), 139.8 (ArC), 151.5 (C=CH\(_2\)).

rac-(3R,4S)-5-(Dimethyl(phenyl)silyl)-2-methyl-4-phenylhex-5-en-3-ol (129g)

Prepared according to General Procedure 12, on a 0.263 mmol scale, column chromatography (2% EtOAc in hexanes) afforded the title compound as an oil (54.6 mg, 0.168 mmol, 64%).

MS (ES\(^+\)) m/z: 347 (M+Na\(^+\)); HRMS calcd for C\(_{21}\)H\(_{28}\)O\(_{1}\)Si\(_{1}\)Na: 347.1807. Found: 347.1820; \(\nu_{\text{max}}\) (thin film/cm\(^{-1}\)): 3580, 3067, 2959, 1596, 1492, 1451, 1428, 1390, 1248, 1172, 1110, 1076, 1051; \(^1\)H NMR (400 MHz, CDCl\(_3\)) \(\delta\) ppm 0.21 (s, 3 H, Si(CH\(_3\))\(_2\)), 0.28 (s, 3 H, Si(CH\(_3\))\(_2\)), 0.78 (d, \(J = 6.8\) Hz, 3 H, CH\(_3\)), 0.85 (d, \(J = 7.0\) Hz, 3 H, CH\(_3\)), 1.21 (d, \(J = 4.0\) Hz, 1 H, OH), 1.71 - 1.87 (m, 1 H, CH), 3.58 (d, \(J = 7.0\) Hz, 1 H, Ar-CH), 3.67 - 3.73 (m, 1 H, CHOH), 5.70 (d, \(J = 2.0\) Hz, 1 H, C=CH\(_2\)), 5.91 - 5.95 (m, 1 H, C=CH\(_2\)), 7.19 - 7.29 (m, 5 H, ArH), 7.32 - 7.37 (m, 3 H, ArH), 7.41 - 7.46 (m, 2 H, ArH); \(^{13}\)C NMR (101 MHz, CDCl\(_3\)) \(\delta\) ppm -2.9 (Si(CH\(_3\))\(_2\)), -2.6 (Si(CH\(_3\))\(_2\)), 16.4 (CH\(_3\)), 20.2 (CH\(_3\)), 30.0 (CH), 53.1 (Ar-CH), 77.2 (CHOH), 126.6 (ArCH), 127.7 (C=CH\(_2\)), 127.8 (ArCH), 128.2 (ArCH), 129.1 (ArCH), 129.8 (ArCH), 134.0 (ArCH), 137.6 (ArC), 140.0 (ArC), 151.5 (C=CH\(_2\)).
(3S,4S)-5-(Dimethyl(phenyl)silyl)-2,2-dimethyl-4-phenylhex-5-en-3-ol (129h)

Prepared according to General Procedure 12, on a 0.263 mmol scale, column chromatography (2% EtOAc in hexanes) afforded the title compound as an oil (66.8 mg, 0.197 mmol, 75%).

MS (ES') m/z: 362 (M+Na'); $\nu_{\text{max}}$ (thin film/cm$^{-1}$): 3585, 3065, 2955, 1596, 1478, 1453, 1428, 1397, 1249, 1191, 1106, 1067, 1011; $^1$H NMR (500 MHz, CDCl$_3$) $\delta$ ppm 0.22 (s, 3 H, Si(CH$_3$)$_2$), 0.32 (s, 3 H, Si(CH$_3$)$_2$), 0.71 (s, 9 H, (CH$_3$)$_3$), 1.37 (d, J = 5.7 Hz, 1 H, OH), 3.68 (dd, $J$ = 3.5, 5.7 Hz, 1 H, CH$_2$OH), 3.75 (d, J = 3.5 Hz, 1 H, Ar-CH), 5.69 (d, J = 1.6 Hz, 1 H, C=CH$_2$), 6.06 (t, J = 1.6 Hz, 1 H, C=CH$_2$), 7.15 - 7.25 (m, 5 H, ArH), 7.31 - 7.38 (m, 3 H, ArH), 7.43 - 7.47 (m, 2 H, ArH); $^{13}$C NMR (126 MHz, CDCl$_3$) $\delta$ -2.8 (Si(CH$_3$)$_2$), -2.4 (Si(CH$_3$)$_2$), 26.9 (CH$_3$), 36.0 (C), 50.6 (Ar-CH), 79.2 (CHOH), 126.5 (ArCH), 127.5 (C=CH$_2$), 127.8 (ArCH), 128.0 (ArCH), 129.1 (ArCH), 130.9 (ArCH), 134.0 (ArCH), 137.8 (ArC), 139.8 (ArC), 152.8 (C=CH$_2$).

rac-(1R,2S)-1-Cyclopropyl-3-(dimethyl(phenyl)silyl)-2-phenylbut-3-en-1-ol (129i)

Prepared according to General Procedure 12, on a 0.263 mmol scale, column chromatography (2% EtOAc in hexanes) afforded the title compound as an oil (47.5 mg, 0.147 mmol, 56%).

MS (ES') m/z: 345 (M+Na'); HRMS calcd for C$_{21}$H$_{26}$O$_2$Si$_3$Na: 345.1651. Found: 345.1661; $\nu_{\text{max}}$ (thin film/cm$^{-1}$): 3570, 3067, 3003, 2957, 2893, 1597, 1493, 1452, 1428, 1248, 1110, 1078, 1032; $^1$H NMR (400 MHz, CDCl$_3$) $\delta$ ppm 0.12 - 0.18 (m, 1 H, CH$_2$), 0.20 (s, 3 H, Si(CH$_3$)$_2$), 0.25 - 0.34 (m, 1 H, CH$_2$), 0.29 (s, 3 H, Si(CH$_3$)$_2$), 0.34 - 0.46 (m, 2 H, CH$_2$), 0.78 (qt, J = 8.1, 5.0 Hz, 1 H, CH), 3.36 (dt, J = 8.1, 4.4 Hz, 1 H, CH$_2$OH), 3.62 (d, J = 4.9 Hz, 1 H, Ar-CH), 5.70 (d, J = 2.1 Hz, 1 H, C=CH$_2$), 6.05 - 6.10 (m, 1 H, C=CH$_2$), 7.18 - 7.28 (m, 5 H, ArH), 7.29 - 7.39 (m, 3 H, ArH), 7.39 - 7.47 (m, 2 H, ArH); $^{13}$C NMR (101 MHz, CDCl$_3$) $\delta$ ppm -2.9 (Si(CH$_3$)$_2$), -2.7 (Si(CH$_3$)$_2$), 2.9 (CH$_3$), 3.4 (CH$_2$), 16.3 (CH), 55.5 (Ar-CH), 76.9 (CHOH), 126.6 (ArCH), 127.7 (ArCH), 127.8 (C=CH$_2$), 128.1 (ArCH), 129.0 (ArCH), 129.9 (ArCH), 134.0 (ArCH), 137.5 (ArC), 139.5 (ArC), 151.2 (C=CH$_2$).
**rac-(1R,2S)-1-cyclohexyl-3-(dimethyl(phenyl)silyl)-2-phenylbut-3-en-1-ol (129)**

Prepared according to General Procedure 12, on a 0.263 mmol scale, column chromatography (2% EtOAc in hexanes) afforded the title compound as an oil (57.5 mg, 0.158 mmol, 60%).

MS (ES⁺) m/z: 387 (M+Na⁺); HRMS calcd for C₂₄H₃₂O₁Si₁Na₁: 387.2120. Found: 387.2114; \( \nu_{max} \) (thin film/cm⁻¹): 3574, 3066, 2924, 2851, 1596, 1492, 1450, 1428, 1249, 1110, 1032; \(^1\)H NMR (400 MHz, CDCl₃) δ ppm: 0.20 (s, 3 H, Si(CH₃)₂), 0.28 (s, 3 H, Si(CH₃)₂), 0.82 - 1.73 (m, 11 H, CH₂ + CH), 3.61 (d, \( J = 6.8 \) Hz, 1 H, Ar-CH), 3.68 - 3.74 (m, 1 H, CHOH), 5.71 (d, \( J = 1.8 \) Hz, 1 H, C=CH₂), 5.92 (s, 1 H, C=CH₂), 7.16 - 7.29 (m, 5 H, ArH), 7.30 - 7.38 (m, 3 H, ArH), 7.42 - 7.46 (m, 2 H, ArH); \(^{13}\)C NMR (101 MHz, CDCl₃) δ ppm: 3.0 (Si(CH₃)₂), 2.6 (Si(CH₃)₂), 26.0 (CH₂), 26.4 (CH₂), 26.8 (CH₂), 30.4 (CH₂), 39.7 (CH), 52.2 (Ar-CH), 76.8 (CHOH), 126.6 (ArCH), 127.75 (C=CH₂), 127.84 (ArCH), 128.2 (ArCH), 129.1 (ArCH), 134.0 (ArCH), 137.5 (ArC), 140.1 (ArC), 151.4 (C=CH₂).

**rac-N-((1R,2S)-3-(Dimethyl(phenyl)silyl)-1,2-diphenylbut-3-en-1-yl)aniline (139)**

To a solution of **103** (10.9 mg, 0.026 mmol, 10 mol%) and CuI (2.5 mg, 0.013 mmol, 5 mol%) in THF (0.8 mL), was added KOT-Bu (0.043 mL of a 1 M THF solution, 0.043 mmol, 16.5 mol%), and the reaction was stirred for 1 hour at room temperature. The resulting solution was transferred to a vessel containing anhydrous Cs₂CO₃ (84.1 mg, 0.263 mmol, 1 equiv) in THF (1 ml). PhMe₂SiBpin (0.079 mL, 0.284 mmol, 1.1 equiv) was then added and the resulting mixture stirred for 15 min. A solution of (propa-1,2-dien-1-yl)benzene (45 mg, 0.387 mmol, 1.5 equiv) and (E)-N,1-diphenylmethanimine (46.8 mg, 0.263 mmol, 1 equiv) in THF (0.5 mL) was then added dropwise, and the reaction stirred at room temperature for 18 hours. The reaction mixture was filtered through a silica plug, concentrated in vacuo and purified by chromatography (2% EtOAc in hexanes) to afford the title compound (77mg, 0.178 mmol, 69%).

MS (ES⁺) m/z: 434 (M+H⁺). HRMS calcd for C₃₀H₃₂NSiNa: 456.2123. Found: 456.2111; \( \nu_{max} \) (thin film/cm⁻¹): 3409, 3026, 2956, 1600, 1502, 1453, 1427, 1316, 1249, 1179, 1155, 1110, 1076, 1028; \(^1\)H NMR (400 MHz, CDCl₃) δ ppm: -0.02 (s, 3 H, SiCH₃), 0.13 (s, 3 H, SiCH₃), 3.46 (d, \( J = 10.3 \) Hz, 1 H, CHC=CH₂), 3.90 (br. s, 1 H, NH), 4.39 (d, \( J = 10.3 \) Hz, 1 H, CHN), 5.71 (d, \( J = 1.5 \) Hz, 1 H, C=CH₂), 5.97
(s, 1 H, C=CH₂), 6.23 (dd, J = 8.6, 1.0 Hz, 2 H, ArCH), 6.47 (t, J = 7.3 Hz, 1 H, ArCH), 6.63 (dd, J = 7.7, 1.6 Hz, 2 H, ArCH), 6.74 - 6.80 (m, 2 H, ArCH), 6.83 - 6.98 (m, 8 H, ArCH), 7.22 - 7.30 (m, 3 H, ArCH), 7.32 - 7.38 (m, 2 H, ArCH); ¹³C NMR (101 MHz, CDCl₃) δ ppm: -3.5 (SiCH₃), -3.0 (SiCH₃), 58.1 (CHN), 62.0 (CH₂=CH₂), 113.4 (ArCH), 117.3 (ArCH), 126.4 (ArCH), 126.5 (ArCH), 126.9 (C=CH₂), 127.3 (ArCH), 127.6 (ArCH), 127.7 (ArCH), 128.0 (ArCH), 128.9 (ArCH), 129.3 (ArCH), 129.5 (ArCH), 133.9 (ArCH), 137.5 (ArC), 139.4 (ArC), 142.4 (ArC), 147.6 (ArC), 149.9 (C=CH₂).

**Experimental procedures for Chapter 3**

Reagents were either purchased directly from commercial suppliers or prepared according to literature procedures.

**Imines:** The following imines are known compounds:

- (E)-N-(4-methoxyphenyl)-1-(naphthalen-1-yl)methanimine (135b)
- (E)-1-mesityl-N-(4-methoxyphenyl)methanimine (135c)
- (E)-N-(4-methoxyphenyl)-1-(o-toly)l)methanimine (135d)
- (E)-N-(4-methoxyphenyl)-2-methylpropan-1-imine (135e)
- (E)-N-(4-methoxyphenyl)-2,2-dimethylpropan-1-imine (135f)
- (E)-N-(4-methoxyphenyl)-1-phenylmethanimine (135g)
- (E)-N,1-bis(4-methoxyphenyl)methanimine (135h)
- (E)-N-(4-methoxyphenyl)-1-(4-(trifluoromethyl)phenyl)methanimine (135i)
- (E)-1-(4-bromophenyl)-N-(4-methoxyphenyl)methanimine (135j)
- (E)-1-(furan-2-yl)-N-(4-methoxyphenyl)methanimine (135k)
- (E)-N-(4-methoxyphenyl)-1-(thiophen-3-yl)methanimine (135l)
- (E)-N-benzyl-1-(o-toly)l)methanimine (135m)
- (E)-N-benzyl-1-phenylmethanimine (135n)
- (E)-N-benzylidene-4-methylbenzenesulfonamide (135o)

**General Procedure 13 for the copper-catalysed borylation of allenes trapping with an imine**

rac-N-((1R,2S)-1,2-Diphenyl-3-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)but-3-en-1-yl)aniline (135a)

![Diagram](image)

To a solution of IPrCuCl (6.3 mg, 0.013 mmol, 5 mol%) in THF (0.8 mL), was added t-BuOK (0.26 mL of a 1 M THF solution, 0.258 mmol, 1 equiv), and the reaction was stirred for 5 minutes at room temperature. B₂Pin₂ (72.1 mg, 0.284 mmol, 1.1 equiv) in THF (0.75 mL) was then added and the resulting mixture stirred for 30 min. A solution of (propa-1,2-dien-1-yl)benzene (45mg, 0.387 mmol, 1.5 equiv) and (E)-N,1-diphenylmethanimine (46.8 mg, 0.258 mmol, 1 equiv) in THF (1 mL) was then added dropwise at -78 °C, and the reaction allowed to warm to room temperature with stirring overnight. The mixture was then filtered through a silica plug, concentrated *in vacuo* and...
the crude product mixture was purified by chromatography (2% EtOAc in hexanes) to afford the title compound as an orange gum (96.6 mg, 0.227 mmol, 88%).

MS (ES\(^+\)) \(m/z\): 426 (M+H\(^+\)). HRMS calcd for C\(_{28}\)H\(_{33}\)NBO\(_2\)Na: 426.2604. Found: 426.2614; \(\nu_{\text{max}}\) (thin film/cm\(^{-1}\)): 2977, 1601, 1503, 1453, 1429, 1359, 1312, 1263, 1139; Major diastereoisomer: \(^1\)H NMR (400 MHz, CDCl\(_3\)) \(\delta\) ppm 1.09 (s, 6 H, 2 x CH\(_3\)), 1.14 (s, 6 H, 2 x CH\(_3\)), 3.73 (d, \(J = 9.2\) Hz, 1 H, CH=CH\(_2\)), 4.98 (d, \(J = 9.2\) Hz, 1 H, CHN), 5.65 (d, \(J = 2.2\) Hz, 1 H, C=CH\(_2\)), 5.98 (d, \(J = 2.8\) Hz, 1 H, C=CH\(_2\)), 6.51 (d, \(J = 7.7\) Hz, 1 H, ArCH), 6.60 (t, \(J = 7.3\) Hz, 1 H, ArCH), 6.98 - 7.59 (m, 13 H, ArCH);

Minor diastereoisomer: \(^{13}\)C NMR (101 MHz, CDCl\(_3\)) \(\delta\) ppm 24.5 (CH\(_3\)), 24.6 (CH\(_3\)), 59.4 (C=CH=CH\(_2\)), 60.6 (CHN), 83.7 (OC), 113.5 (ArCH), 116.9 (ArCH), 126.1 (ArCH), 126.7 (ArCH), 126.8 (ArCH), 128.0 (ArCH), 128.3 (ArCH), 132.2 (C=CH\(_2\)), 142.0 (ArC), 143.2 (ArC), 147.4 (ArC), (BC=CH\(_2\) not observed); \(^{11}\)B NMR (128 MHz, CDCl\(_3\)) \(\delta\) ppm 8.3.

**rac-N-((1R,2R)-2-Cyclohexyl-1-phenyl-3-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)but-3-en-1-yl)aniline (155b)**

Prepared according to General Procedure 13, on a 0.258 mmol scale, column chromatography (2% EtOAc in Hexanes) afforded the title compound as an orange gum (97.9 mg, 0.227 mmol, 88%).

MS (ES\(^+\)) \(m/z\): 432 (M+H\(^+\)). HRMS calcd for C\(_{28}\)H\(_{38}\)NBO\(_2\)Na: 453.2930. Found: 453.2924; \(\nu_{\text{max}}\) (thin film/cm\(^{-1}\)): 3405, 3025, 2976, 2924, 2850, 1600, 1521, 1499, 1450, 1423, 1371, 1300, 1217, 1165, 1144, 1112, 1077, 1029; \(^1\)H NMR (400 MHz, CDCl\(_3\)) \(\delta\) ppm 0.82 - 1.16 (m, 2 H, CH\(_2\)), 1.19 - 1.35 (m, 3 H, CH\(_3\)), 1.39 (s, 6 H, 2 x CH\(_3\)), 1.41 (s, 6 H, 2 x CH\(_3\)), 1.67 - 1.85 (m, 4 H, CH\(_2\) + CH), 2.34 (dd, \(J = 9.5, 4.9\) Hz, 1 H, CH=CH\(_2\)), 4.84 (d, \(J = 5.0\) Hz, 1 H, CHN), 5.08 (d, \(J = 3.5\) Hz, 1 H, C=CH\(_2\)), 5.80 (d, \(J = 3.5\) Hz, 1 H, C=CH\(_2\)), 5.84 (br. s, 1 H, NH), 6.52 (dd, \(J = 8.6, 1.0\) Hz, 2 H, ArCH), 6.61 - 6.67 (m, 1 H, ArCH), 7.10 - 7.17 (m, 2 H, ArCH), 7.19 - 7.29 (m, 3 H, ArCH), 7.29 - 7.37 (m, 2 H, ArCH); \(^{13}\)C NMR (101 MHz, CDCl\(_3\)) \(\delta\) ppm 24.4 (CH\(_3\)), 24.9 (CH\(_3\)), 26.3 (CH\(_3\)), 26.4 (CH\(_3\)), 26.5 (CH\(_3\)), 31.3 (CH\(_3\)), 32.4 (CH\(_3\)), 36.8 (CH), 57.4 (CHN), 61.4 (CH=CH\(_2\)), 83.7 (OC), 112.5 (ArCH), 115.8 (ArCH), 126.1 (ArCH), 127.1 (ArCH), 127.9 (ArCH), 128.9 (ArCH), 135.0 (C=CH\(_2\)), 143.6 (ArC), 148.1 (ArC), (BC=CH\(_2\) not observed); \(^{11}\)B NMR (128 MHz, CDCl\(_3\)) \(\delta\) ppm 7.8.
**rac-N-((1R,2R)-2-(Cyclohexylmethyl)-1-phenyl-3-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)but-3-en-1-yl)aniline (155c)**

Prepared according to General Procedure 13, on a 0.258 mmol scale, column chromatography (3% EtOAc in Hexanes) afforded the title compound as a yellow solid (115 mg, 0.258 mmol, 99%).

Mp: 102-104 °C; MS (ES⁺) m/z: 445 (M). HRMS calcd for C$_{29}$H$_{41}$NBO$_2$Na: 446.3230. Found: 446.3231; \( \nu_{\text{max}} \) (thin film/cm$^{-1}$): 3404, 2976, 2921, 2850, 1601, 1501, 1449, 1420, 1370, 1310, 1262, 1212, 1167, 1141, 1077, 1029; $^1$H NMR (400 MHz, CDCl$_3$) \( \delta \) ppm: 0.49 - 0.68 (m, 1 H, CH$_2$), 0.88 (d, \( J = 3.0 \) Hz, 1 H, CH$_3$), 1.01 - 1.21 (m, 4 H, CH$_2$), 1.24 (s, 6 H, 2 x CH$_3$), 1.25 (s, 6 H, 2 x CH$_3$), 1.50 - 1.79 (m, 7 H, CH$_2$ + CH), 2.56 - 2.67 (m, 1 H, CHC=CH$_2$), 4.35 (d, \( J = 7.1 \) Hz, 1 H, CHN), 5.07 (br. s, 1 H, NH), 5.42 (br. s, 1 H, C=CH$_2$), 5.88 (d, \( J = 3.5 \) Hz, 1 H, C=CH$_2$), 6.46 (d, \( J = 8.3 \) Hz, 2 H, ArCH), 6.57 (q, \( J = 7.1 \) Hz, 1 H, ArCH), 6.98 - 7.08 (m, 2 H, ArCH), 7.14 - 7.21 (m, 1 H, ArCH), 7.24 - 7.34 (m, 4 H, ArCH); $^{13}$C NMR (101 MHz, CDCl$_3$) \( \delta \) ppm: 24.5 (CH$_3$), 24.8 (CH$_3$), 26.0 (CH$_2$), 26.4 (CH$_2$), 26.6 (CH$_3$), 31.7 (CH$_3$), 34.5 (CH$_2$), 35.0 (CH$_2$), 39.0 (CH), 51.6 (CHC=CH$_2$), 63.6 (CHN), 83.6 (OC), 113.1 (ArCH), 126.5 (ArCH), 127.3 (ArCH), 127.4 (ArCH), 128.0 (ArCH), 128.8 (ArCH), 133.2 (C=CH$_2$), 143.5 (ArC), 148.1 (ArC), (BC=CH$_2$ not observed); $^{11}$B NMR (128 MHz, CDCl$_3$) \( \delta \) ppm 4.7.

**rac-N-((1R,2R)-1-Phenyl-2-(1-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)vinyl)decyl)aniline (155d)**

Prepared according to General Procedure 13, on a 0.258 mmol scale, column chromatography (3% EtOAc in Hexanes) afforded the title compound as a yellow gum (119 mg, 0.258 mmol, 99%).

MS (ES⁺) m/z: 462 (M+H$^+$). HRMS calcd for C$_{30}$H$_{45}$NBO$_2$Na: 462.3543. Found: 462.3536; \( \nu_{\text{max}} \) (thin film/cm$^{-1}$): 3405, 2924, 2854, 1601, 1502, 1452, 1419, 1370, 1309, 1262, 1213, 1141, 1111, 1077, 1029; $^1$H NMR (500 MHz, CDCl$_3$) \( \delta \) ppm: 0.87 (t, \( J = 7.1 \) Hz, 3 H, CH$_3$), 0.96 - 1.77 (m, 14 H, CH$_2$), 1.23 (s, 12 H, 4 x CH$_3$), 2.38 - 2.50 (m, 1 H, CHC=CH$_2$), 4.41 (d, \( J = 7.6 \) Hz, 1 H, CHN), 4.97 (br. s, 1 H, NH), 5.41 - 5.49 (m, 1 H, C=CH$_2$), 5.90 (d, \( J = 3.5 \) Hz, 1 H, C=CH$_2$), 6.41 - 6.50 (m, 2 H, ArCH), 6.53 - 6.60 (m, 1 H, ArCH), 6.99 - 7.07 (m, 2 H, ArCH), 7.15 - 7.22 (m, 1 H, ArCH), 7.24 - 7.35 (m, 4 H, ArCH); $^{13}$C NMR (126 MHz, CDCl$_3$) \( \delta \) ppm: 14.1 (CH$_3$), 22.6 (CH$_2$), 24.6 (CH$_3$), 24.7 (CH$_3$), 27.8 (CH$_2$), 29.2 (CH$_3$), 29.4 (2 x CH$_2$), 31.2 (CH$_3$), 31.8 (CH$_3$), 54.8 (CHC=CH$_2$), 61.7 (CN), 83.5 (OC), 112.9
Chapter five


(ArCH), 116.3 (ArCH), 126.5 (ArCH), 127.4 (ArCH), 128.1 (ArCH), 128.8 (ArCH), 133.0 (C=CH₂), 143.8 (ArC), 148.0 (ArC), (BC=CH₂ not observed); "B NMR (128 MHz, CDCl₃) δ ppm 5.1.

rac-N-((1R,2R)-2-Cyclohexyl-1-(naphthalen-1-yl)-3-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)but-3-en-1-yl)-4-methoxyaniline (155e)

Prepared according to General Procedure 13, on a 0.258 mmol scale, column chromatography (3% EtOAc in Hexanes) afforded the title compound as a yellow gum (98.8 mg, 0.191 mmol, 74%).

MS (ES⁺) m/z: 512 (M+H⁺). HRMS calcd for C₃₃H₄₃NBO₃: 512.3336. Found: 512.3332; νmax (thin film/cm⁻¹): 3408, 2976, 2926, 2850, 1598, 1511, 1422, 1371, 1302, 1234, 1173, 1142, 1040; ¹H NMR (400 MHz, CDCl₃) δ ppm 0.71 - 0.98 (m, 2 H, CH₂), 1.03 - 1.29 (m, 3 H, CH₂), 1.32 (s, 6 H, 2 x CH₃), 1.37 (s, 6 H, 2 x CH₃), 1.53 - 1.87 (m, 4 H, CH₂), 1.99 - 2.13 (m, 1 H, CH₃), 2.18 - 2.28 (m, 1 H, CH), 2.49 - 2.59 (m, 1 H, CH=CH₂), 3.65 (s, 3 H, OCH₃), 4.54 (br. s., 1 H, C=CH₂), 5.52 (d, J = 3.0 Hz, 1 H, C=CH₂), 5.55 (br. s., 1 H, CHN), 5.77 (br. s., 1 H, NH), 6.34 (d, J = 7.8 Hz, 2 H, ArCH), 6.58 - 6.66 (m, 2 H, ArCH), 7.21 - 7.38 (m, 2 H, ArCH), 7.45 - 7.61 (m, 2 H, ArCH), 7.62 - 7.70 (m, 1 H, ArCH), 7.88 (d, J = 7.1 Hz, 1 H, ArCH), 8.20 (d, J = 8.3 Hz, 1 H, ArCH); ¹³C NMR (101 MHz, CDCl₃) δ ppm 24.4 (CH₃), 25.0 (CH₃), 26.5 (CH₃), 26.6 (CH₃), 31.1 (CH₃), 33.2 (CH₃), 37.1 (CH), 53.9 (CHN), 55.8 (OCH₃), 58.7 (CH=CH₂), 83.8 (OC), 113.1 (ArCH), 114.8 (ArCH), 122.4 (ArCH), 124.9 (ArCH), 125.2 (ArCH), 125.4 (ArCH), 125.6 (ArCH), 126.7 (ArCH), 129.2 (ArC), 130.9 (ArC), 134.0 (ArC), 134.7 (C=CH₂), 138.0 (ArC), 142.3 (ArC), (BC=CH₂ not observed); "B NMR (128 MHz, CDCl₃) δ ppm 5.1.

rac-N-((1R,2R)-2-Cyclohexyl-3-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)-1-(o-tolyl)but-3-en-1-yl)-4-methoxyaniline (155g)

Prepared according to General Procedure 13, on a 0.258 mmol scale, column chromatography (3% EtOAc in Hexanes) afforded the title compound as a yellow gum (97.6 mg, 0.206 mmol, 80%).

MS (ES⁺) m/z: 476 (M+H⁺). HRMS calcd for C₃₀H₄₂NBO₃: 476.3341. Found: 476.3357; νmax (thin film/cm⁻¹): 3408, 2976, 2927, 2850, 1525, 1462, 1447, 1421, 1371, 1300, 1277, 1233, 1180, 1165, 1142, 1041; ¹H NMR (400 MHz, CDCl₃) δ ppm 0.71 - 1.23 (m, 5 H, CH₂), 1.31 (s, 6 H, 2 x CH₃), 1.36 (s, 6 H, 2 x CH₃), 1.55 - 1.79 (m, 4 H, CH₂), 1.88 - 2.08 (m, 2 H, CH₂ + CH), 2.20 (d, J = 7.6 Hz, 1 H,
\[ \text{CHC=CH}, \ 2.46 \text{ (br. s., 3 H, Ar-CH)}, \ 3.68 \text{ (s, 3 H, OCH)}, \ 4.88 \text{ (br. s., 2 H, CHN + C=CH)}, \ 5.56 \text{ (br. s., 1 H, NH)}, \ 5.70 \text{ (br. s., 1 H, C=CH)}, \ 6.30 \text{ (d, } J = 8.1 \text{ Hz, 2 H, ArCH)}, \ 6.63 - 6.69 \text{ (m, 2 H, ArCH)}, \ 6.94 - 7.15 \text{ (m, 4 H, ArCH)}; \ 13^C \text{ NMR (101 MHz, CDCl}_3\delta ppm 19.1 \text{ (Ar-C)}, 24.4 \text{ (CH)}, 25.0 \text{ (CH)}, 26.4 \text{ (CH)}, 26.5 \text{ (CH)}, 31.0 \text{ (CH)}, 33.0 \text{ (CH), 36.9 (CH), 54.4 (CHN), 55.8 (OCH), 58.2 (CHC=CH), 83.7 (OC), 112.9 (ArCH), 114.8 (ArCH), 125.4 (ArCH), 125.8 (ArCH), 127.8 (ArCH), 130.1 (ArCH), 134.2 (ArC), 134.8 (C=CH), 140.9 (ArC), 142.5 (ArC), 150.7 \text{ (ArCOCH)}, (\text{BC=CH not observed); 11B NMR (128 MHz, CDCl}_3\delta ppm 8.0.}

**rac-N-((3S,4R)-4-Cyclohexyl-2-methyl-5-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)hex-5-en-3-yl)-4-methoxyaniline (155h)**

Prepared according to General Procedure 13, on a 0.258 mmol scale, column chromatography (3% EtOAc in Hexanes) afforded the title compound as a brown gum (40.4 mg, 0.096 mmol, 37%).

MS (ES^+ m/z: 428 (M+H^+). HRMS calcd for C_{26}H_{43}NBO: 428.3336. Found: 428.3329; \nu_{\text{max}} (thin film/cm^{-1}): 3402, 2923, 2850, 1617, 1510, 1448, 1371, 1301, 1232, 1166, 1142, 1041; \text{^1H NMR (400 MHz, CDCl}_3\delta ppm 0.92 \text{ (t, } J = 6.1 \text{ Hz, 6 H, 2 x CH}_3), 1.02 - 1.15 \text{ (m, 3 H, CH}_2), 1.26 \text{ (s, 6 H, 2 x CH}_3), 1.27 - 1.29 \text{ (m, 6 H, 2 x CH}_3), 1.49 - 1.76 \text{ (m, 9 H, (CH}_3)_2CH + CH}_2 + CH), 2.26 \text{ (dd, } J = 5.0 \text{ Hz, 1 H, CHC=CH}_2), 3.27 \text{ (dd, } J = 5.4, 3.7 \text{ Hz, 1 H, CHN), 3.74 \text{ (s, 3 H, OCH}_3), 4.43 \text{ (br. s, 1 H, NH), 5.62 \text{ (d, } J = 2.8 \text{ Hz, 1 H, C=CH}_2), 5.96 \text{ (d, } J = 2.8 \text{ Hz, 1 H, C=CH}_2), 6.53 \text{ (d, } J = 8.3 \text{ Hz, 2 H, ArCH), 6.72 \text{ (d, } J = 8.3 \text{ Hz, 2 H, ArCH); 13C NMR (101 MHz, CDCl}_3\delta ppm 19.8 \text{ (CH(CH}_3)_2), 20.5 \text{ (CH(CH}_3)_2), 24.4 \text{ (CH(CH}_3)_2), 24.9 \text{ (CH}_3), 26.2 \text{ (CH}_2), 26.5 \text{ (CH}_2), 26.6 \text{ (CH}_2), 31.9 \text{ (CH}_3), 32.1 \text{ (CH}_2), 37.2 \text{ (CH), 55.9 \text{ (CHN + OCH}_3), 59.2 \text{ (CH=CH}_2), 83.3 \text{ (OC), 113.1 \text{ (ArCH), 114.7 \text{ (ArCH), 132.8 \text{ (C=CH}_2), 144.9 \text{ (ArC), 150.3 \text{ (ArC), (BC=CH not observed); 11B NMR (128 MHz, CDCl}_3\delta ppm 9.1.}}}

**rac-N-((3R,4R)-4-Cyclohexyl-2,2-dimethyl-5-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)hex-5-en-3-yl)-4-methoxyaniline (155i)**

Prepared according to General Procedure 13, on a 0.258 mmol scale, column chromatography (2% EtOAc in Hexanes) afforded the title compound as a brown gum (6.3 mg, 0.016 mmol, 6%).

MS (ES^+ m/z: 443 (M+H^+). HRMS calcd for C_{27}H_{45}NBO: 442.3493. Found: 442.3481; \nu_{\text{max}} (thin film/cm^{-1}): 3394, 2924, 2852, 1509, 1465, 1370, 1302, 1233, 1142, 1043; \text{^1H NMR (400 MHz, CDCl}_3)
δ ppm 0.92 (s, 9 H, 3 x CH₃), 1.03 - 1.12 (m, 3 H, CH₂), 1.24 (s, 6 H, 2 x CH₃), 1.25 (s, 6 H, 2 x CH₃), 1.48 - 1.65 (m, 7 H, CH₂), 1.83 - 1.92 (m, 1 H, CH), 2.36 (d, J = 9.4 Hz, 1 H, CH=CH₂), 3.30 - 3.39 (m, 1 H, CHN), 3.75 (s, 3 H, OCH₃), 4.64 (br. s, 1 H, NH), 5.56 (d, J = 3.3 Hz, 1 H, C=CH₂), 5.93 (d, J = 3.5 Hz, 1 H, C=CH₂), 6.53 - 6.64 (m, 2 H, ArCH), 6.73 (d, J = 8.6 Hz, 2 H, ArCH); ¹³C NMR (101 MHz, CDCl₃) δ ppm 24.6 (CH₃), 25.0 (CH₃), 26.2 (CH₂), 26.4 (CH₂), 26.6 (CH₂), 27.9 (C(CH₃)₃), 29.7 (C(CH₃)₃), 32.4 (CH₃), 32.5 (CH₂), 38.0 (CH), 55.3 (CH=CH₂), 56.0 (OCH₃), 62.8 (CHN), 83.3 (OC), 113.8 (ArCH), 114.6 (ArCH), 131.9 (C=CH₂), 145.3 (ArC), 150.6 (ArC), (BC=CH₂ not observed).

**rac-N-((1R,2R)-2-Cyclohexyl-1-phenyl-3-{4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl}but-3-en-1-yl)-4-methoxyaniline (155j)**

Prepared according to General Procedure 13, on a 0.258 mmol scale, column chromatography (3% EtOAc in Hexanes) afforded the title compound as an orange gum (105 mg, 0.227 mmol, 88%).

MS (ES⁺) m/z: 462 (M+H⁺). HRMS calcd for C₂₉H₄₁NBO₃: 462.3179. Found: 462.3162; νₘₐₓ (thin film/cm⁻¹): 3407, 2976, 2925, 2850, 1510, 1450, 1421, 1389, 1371, 1300, 1233, 1218, 1140, 1115, 1069, 1040; ¹H NMR (500 MHz, CDCl₃) δ ppm 0.75 - 0.86 (m, 1 H, CH₂), 1.04 (qd, J = 11.7, 2.5 Hz, 1 H, CH₂), 1.09 - 1.27 (m, 3 H, CH₂), 1.29 (s, 6 H, 2 x CH₃), 1.32 (s, 6 H, 2 x CH₃), 1.60 - 1.76 (m, 4 H, CH₂), 1.77 - 1.91 (m, 2 H, CH₂ + CH), 2.26 (dd, J = 9.0, 5.2 Hz, 1 H, CH=CH₂), 3.69 (s, 3 H, OCH₃), 4.69 (d, J = 5.0 Hz, 1 H, CHN), 5.04 (d, J = 3.5 Hz, 1 H, C=CH₂), 5.33 (br. s., 1 H, NH), 5.74 (d, J = 3.8 Hz, 1 H, C=CH₂), 6.39 (d, J = 8.8 Hz, 2 H, ArCH), 6.67 (d, J = 8.8 Hz, 2 H, ArCH), 7.14 (tt, J = 6.9, 1.3 Hz, 1 H, ArCH), 7.18 - 7.22 (m, 2 H, ArCH), 7.22 - 7.28 (m, 2 H, ArCH); ¹³C NMR (126 MHz, CDCl₃) δ ppm 24.4 (CH₃), 24.9 (CH₃), 26.3 (CH₂), 26.4 (CH₃), 26.6 (CH₂), 31.4 (CH₂), 32.2 (CH₂), 36.9 (CH), 55.8 (CHN), 58.1 (OCH₃), 61.3 (CH=CH₂), 83.6 (OC), 113.3 (ArCH), 114.7 (ArCH), 126.1 (ArCH), 127.2 (ArCH), 127.9 (ArCH), 134.6 (C=CH₂), 142.6 (ArC), 144.0 (ArC), 150.9 (ArC), (BC=CH₂ not observed); ¹¹B NMR (128 MHz, CDCl₃) δ ppm 1.5.
**rac-N-((1R,2R)-2-Cyclohexyl-1-(4-methoxyphenyl)-3-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)but-3-en-1-yl)-4-methoxyaniline (155k)**

Prepared according to General Procedure 13, on a 0.258 mmol scale, column chromatography (4% EtOAc in Hexanes) afforded the title compound as an orange gum (123 mg, 0.250 mmol, 97%).

MS (ES') m/z: 492 (M+H'). HRMS calcd for C$_{30}$H$_{43}$NBO$_4$: 492.3285. Found: 492.3305; $\nu$ max (thin film/cm$^{-1}$): 3409, 2927, 2850, 1610, 1511, 1421, 1371, 1301, 1243, 1170, 1142; $^1$H NMR (400 MHz, CDCl$_3$) $\delta$ ppm: 0.68 - 0.92 (m, 1 H, CH$_2$), 1.09 - 1.24 (m, 4 H, CH$_2$), 1.27 (s, 6 H, 2 x CH$_3$), 1.32 - 1.39 (s, 6 H, 2 x CH$_3$), 1.39 - 1.43 (s, 6 H, 2 x CH$_3$), 1.53 - 1.92 (m, 5 H, CH$_2$ + CH), 2.19 (dd, $J = 8.7$, 5.4 Hz, 1 H, CHC=CH$_2$), 3.68 (s, 3 H, OCH$_3$), 3.77 (s, 3 H, OCH$_3$), 4.62 (d, $J = 5.3$ Hz, 1 H, CHN), 5.06 (d, $J = 3.5$ Hz, 1 H, C=CH$_2$), 5.75 (d, $J = 3.8$ Hz, 1 H, C=CH$_2$), 6.37 (d, $J = 8.8$ Hz, 2 H, ArCH), 6.63 - 6.67 (m, 2 H, ArCH), 6.78 (d, $J = 8.5$ Hz, 2 H, ArCH), 7.09 (d, $J = 8.5$ Hz, 2 H, ArCH); $^{13}$C NMR (101 MHz, CDCl$_3$) $\delta$ ppm: 24.4 (CH$_3$), 24.9 (CH$_3$), 26.3 (CH$_2$), 26.4 (CH$_2$), 26.6 (CH$_2$), 31.4 (CH$_2$), 32.1 (CH$_2$), 36.8 (CH), 55.1 (OCH$_3$), 55.8 (OCH$_3$), 57.5 (CHN), 61.4 (CHC=CH$_2$), 83.6 (OC), 113.3 (ArCH), 113.4 (ArCH), 114.7 (ArCH), 128.1 (ArCH), 134.6 (C=CH$_2$), 135.9 (ArC), 142.7 (ArC), 150.8 (ArC), 157.8 (ArC), (BC=CH not observed); $^{11}$B NMR (128 MHz, CDCl$_3$) $\delta$ ppm: 4.4.

**rac-N-((1R,2R)-2-Cyclohexyl-3-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)-1-(4-(trifluoromethyl)phenyl)but-3-en-1-yl)-4-methoxyaniline (155I)**

Prepared according to General Procedure 13, on a 0.258 mmol scale, column chromatography (3% EtOAc in Hexanes) afforded the title compound as a brown gum (103 mg, 0.194 mmol, 75%).

MS (ES') m/z: 530 (M+H'). HRMS calcd for C$_{30}$H$_{40}$NBO$_2$F$_3$: 530.3062. Found: 530.3059; $\nu$ max (thin film/cm$^{-1}$): 3405, 2977, 2927, 2851, 1617, 1511, 1420, 1371, 1334, 1234, 1066, 1040, 1016; $^1$H NMR (400 MHz, CDCl$_3$) $\delta$ ppm: 0.73 - 1.09 (m, 2 H, CH$_2$), 1.12 - 1.26 (m, 3 H, CH$_3$), 1.30 (s, 6 H, 2 x CH$_3$), 1.33 - 1.61 (s, 6 H, 2 x CH$_3$), 1.61 - 1.77 (m, 4 H, CH$_2$ + CH), 1.87 (t, $J = 11.9$ Hz, 2 H, CH$_2$), 2.25 (dd, $J = 9.3$, 4.6 Hz, 1 H, CHC=CH$_2$), 3.69 (s, 3 H, OCH$_3$), 4.73 (d, $J = 4.5$ Hz, 1 H, CHN), 5.00 (d, $J = 3.2$ Hz, 1 H, C=CH$_2$), 5.73 (d, $J = 3.4$ Hz, 1 H, C=CH$_2$), 6.36 (d, $J = 8.8$ Hz, 2 H, ArCH), 6.69 (d, $J = 8.8$ Hz, 2 H, ArCH), 7.25 - 7.34 (m, 2 H, ArCH), 7.51 (d, $J = 8.1$ Hz, 2 H, ArCH); $^{13}$C NMR (101 MHz, CDCl$_3$) $\delta$ ppm: 24.4 (CH$_3$), 24.9 (CH$_3$), 26.3 (CH$_2$), 26.4 (CH$_2$), 26.5 (CH$_2$), 31.2 (CH$_2$), 32.4 (CH$_2$), 36.8 (CH), 55.8
(CHN), 57.9 (OCH₃), 61.1 (CHC=CH₂), 83.8 (OC), 114.8 (ArCH), 124.4 (q, J = 272.0 Hz, CF₃), 124.9 (ArCH), 124.9 (q, J = 3.7 Hz, ArCH), 127.5 (ArCH), 128.4 (q, J = 31.7 Hz, CCF₃), 135.1 (ArCH), 142.0 (ArC), 148.5 (ArC), 151.2 (ArC), (BC=CH₂ not observed).

rac-N-((1R,2R)-1-{4-Bromophenyl}-2-cyclohexyl-3-{4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl}but-3-en-1-yl)-4-methoxyaniline (155m)

Prepared according to General Procedure 13, on a 0.258 mmol scale, column chromatography (3% EtOAc in Hexanes) afforded the title compound as an orange gum (111 mg, 0.206 mmol, 80%).

MS (ES⁺) m/z: 542 (M+H⁺). HRMS calcd for C₂₉H₄₀NBO₃Br: 540.2285. Found: 540.2273; νmax (thin film/cm⁻¹): 3405, 2976, 2926, 2850, 1515, 1484, 1421, 1371, 1302, 1234, 1167, 1141, 1071, 1040, 1009; ¹H NMR (500 MHz, CDCl₃) δ ppm 1.07 - 1.23 (m, 5 H, CH₂), 1.28 (s, 6 H, 2 x CH₃), 1.31 (s, 6 H, 2 x CH₃), 1.59 - 1.73 (m, 4 H, CH₂), 1.76 - 1.89 (m, 2 H, CH + CH₂), 2.19 (dd, J = 9.1, 5.0 Hz, 1 H, CHC=CH₂), 3.69 (s, 3 H, OCH₃), 4.62 (d, J = 5.0 Hz, 1 H, CHN), 5.03 (d, J = 3.2 Hz, 1 H, C=CH₂), 5.33 (br. s, 1 H, NH), 5.74 (d, J = 3.5 Hz, 1 H, C=CH₂), 6.34 (d, J = 8.8 Hz, 2 H, ArCH), 6.66 (d, J = 8.8 Hz, 2 H, ArCH), 7.06 (d, J = 8.2 Hz, 2 H, ArCH), 7.35 (d, J = 8.5 Hz, 2 H, ArCH); ¹³C NMR (126 MHz, CDCl₃) δ ppm 24.4 (CH₃), 24.9 (CH₃), 26.3 (CH₂), 26.4 (CH₂), 26.5 (CH₂), 31.3 (CH₃), 32.3 (CH₂), 36.8 (CH), 55.8 (OCH₃), 57.7 (CHN), 61.2 (CHC=CH₂), 83.7 (OC), 113.4 (ArCH), 114.8 (ArCH), 119.7 (ArC), 129.0 (ArCH), 131.0 (ArCH), 135.0 (C=CH₂), 142.2 (ArC), 143.2 (ArC), 151.1 (ArC), (BC=CH₂ not observed); ¹¹B NMR (128 MHz, CDCl₃) δ ppm 9.7.

rac-N-((1R,2R)-2-Cyclohexyl-1-{furan-2-yl}-3-{4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl}but-3-en-1-yl)-4-methoxyaniline (155n)

Prepared according to General Procedure 13, on a 0.258 mmol scale, column chromatography (3% EtOAc in Hexanes) afforded the title compound as a brown gum (81.3 mg, 0.181 mmol, 70%).

MS (ES⁺) m/z: 452 (M+H⁺). HRMS calcd for C₂₇H₃₉NBO₄: 452.2972. Found: 452.2976; νmax (thin film/cm⁻¹): 3404, 2976, 2926, 2850, 1516, 1448, 1422, 1371, 1301, 1233, 1142, 1339; ¹H NMR (400 MHz, CDCl₃) δ ppm 0.73 - 1.22 (m, 5 H, CH₂), 1.25 (s, 6 H, 2 x CH₃), 1.26 (s, 6 H, 2 x CH₃), 1.54 - 1.85 (m, 6 H, CH₂ + CH), 2.23 (dd, J = 7.8, 6.3 Hz, 1 H, CHC=CH₂), 3.71 (s, 3 H, OCH₃), 4.65 (d, J = 6.1 Hz, 1
H, CHN), 5.37 (d, J = 3.5 Hz, 1 H, C=CH₂), 5.88 (d, J = 3.5 Hz, 1 H, C=CH₂), 6.23 (dd, J = 1.8, 0.8 Hz, 1 H, ArCH), 6.43 - 6.53 (m, 2 H, ArCH), 6.66 - 6.73 (m, 2 H, ArCH), 7.14 - 7.19 (m, 1 H, ArCH), 7.28 - 7.34 (m, 1 H, ArCH); ¹³C NMR (101 MHz, CDCl₃) δ ppm 24.4 (CH₃), 24.9 (CH₃), 26.4 (CH₂), 26.4 (CH₂), 26.5 (CH₂), 31.5 (CH₂), 31.7 (CH₂), 36.9 (CH), 50.6 (OCH₃), 55.8 (CH=CH₂), 83.5 (OC), 109.6 (ArCH), 113.6 (ArCH), 114.65 (ArCH), 114.7 (ArCH), 128.3 (ArCH), 134.2 (C=CH₂), 140.1 (ArC), 142.6 (ArC), 151.2 (ArC), (BC=CH₂ not observed); ¹¹B NMR (128 MHz, CDCl₃) δ ppm 30.6.

\textit{rac-}N-((1R,2R)-2-Cyclohexyl-3-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)-1-(thiophen-2-yl)but-3-en-1-yl)-4-methoxyaniline (155o)

\begin{center}
\includegraphics[width=0.2\textwidth]{rac-N-(1R,2R)-2-Cyclohexyl-3-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)-1-(thiophen-2-yl)but-3-en-1-yl)-4-methoxyaniline (155o)}
\end{center}

Prepared according to General Procedure 13, on a 0.258 mmol scale, column chromatography (3% EtOAc in Hexanes) afforded the title compound as an orange gum (95.1 mg, 0.204 mmol, 79%).

MS (ES⁺) m/z: 468 (M+H⁺). HRMS calcld for C₂₇H₃₀NBO₃S: 468.2744. Found: 468.2728; νₘₐₓ (thin film/cm⁻¹): 3401, 2976, 2926, 2850, 1511, 1422, 1371, 1302, 1234, 1169, 1141, 1040; ¹H NMR (400 MHz, CDCl₃) δ ppm 0.73 - 1.17 (m, 5 H, CH₂), 1.26 (s, 6 H, 2 x CH₃), 1.27 (s, 6 H, 2 x CH₃), 1.58 - 1.82 (m, 6 H, CH₂ + CH), 2.30 (t, J = 7.1 Hz, 1 H, CH=CH₂), 3.70 (s, 3 H, OCH₃), 4.96 (d, J = 6.2 Hz, 1 H, CHN), 5.14 (br. s., 1 H, NH), 5.33 (d, J = 3.4 Hz, 1 H, C=CH₂), 5.83 (d, J = 3.7 Hz, 1 H, C=CH₂), 6.45 - 6.54 (m, 2 H, ArCH), 6.66 - 6.73 (m, 2 H, ArCH), 6.81 - 6.86 (m, 1 H, ArCH), 6.89 (dd, J = 4.9, 3.5 Hz, 1 H, ArCH), 7.03 - 7.11 (m, 1 H, ArCH); ¹³C NMR (101 MHz, CDCl₃) δ ppm 24.4 (CH₃), 24.9 (CH₃), 26.4 (CH₂), 26.5 (CH₂), 26.5 (CH₂), 31.5 (CH₂), 31.6 (CH₂), 37.1 (CH), 54.8 (CHN), 55.8 (OCH₃), 61.8 (CH=CH₂), 83.6 (OC), 113.6 (ArCH), 114.7 (ArCH), 123.0 (ArCH), 123.3 (ArCH), 126.5 (ArCH), 134.6 (C=CH₂), 142.3 (ArC), 150.4 (ArC), 151.3 (ArC), (BC=CH₂ not observed); ¹¹B NMR (128 MHz, CDCl₃) δ ppm 8.7.

\textit{N-}((Furan-2-yl)(1-(1-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)vinyl)cyclohexyl)methyl)-4-methoxyaniline (155p)

\begin{center}
\includegraphics[width=0.2\textwidth]{N-((Furan-2-yl)(1-(1-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)vinyl)cyclohexyl)methyl)-4-methoxyaniline (155p)}
\end{center}

Prepared according to General Procedure 13, on a 0.258 mmol scale, column chromatography (4% EtOAc in Hexanes) afforded the title compound as a brown gum (94 mg, 0.222 mmol, 86%).

νₘₐₓ (thin film/cm⁻¹): 3410, 2975, 2931, 2855, 1631, 1511, 1453, 1371, 1244, 1142, 1119, 1036; ¹H NMR (400 MHz, CDCl₃) δ ppm 1.10 - 1.22 (m, 1 H, CH₂), 1.30 (s, 12 H, CH₃), 1.32 - 1.62 (m, 7 H, 186
CH₂), 2.06 - 2.13 (m, 1 H, CH₂), 2.20 - 2.31 (m, 1 H, CH₂), 3.69 (s, 3 H, OCH₃), 4.06 (s, 1 H, CHN), 4.87 (br. s., 1 H, NH), 5.50 (d, J = 2.5 Hz, 1 H, C=CH₂), 6.08 (d, J = 2.3 Hz, 1 H, C=CH₂), 6.28 - 6.31 (m, 1 H, ArCH), 6.40 - 6.46 (m, 2 H, ArCH), 6.65 - 6.70 (m, 2 H, ArCH), 7.22 - 7.24 (m, 1 H, ArCH), 7.29 (t, J = 1.6 Hz, 1 H, ArCH); ¹³C NMR (101 MHz, CDCl₃) δ ppm 22.0 (CH₂), 22.5 (CH₂), 24.65 (CH₃), 24.69 (CH₃), 26.6 (CH₃), 32.0 (CH₃), 34.2 (CH₃), 46.4 (CC=CH₂), 55.8 (OCH₃), 61.2 (CHN), 83.7 (OC), 111.6 (ArCH), 113.7 (ArCH), 114.7 (ArCH), 122.0 (ArCH), 125.6 (C=CH₂), 132.2 (ArCH), 141.0 (ArC), 141.7 (ArC), 151.2 (ArC), (BC=CH₂ not observed); ¹¹B NMR (128 MHz, CDCl₃) δ -2.94.

4-Methoxy-N-(1-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)vinyl)cyclohexyl)(thiophen-2-yl)methyl)aniline (155q)

Prepared according to General Procedure 13, on a 0.258 mmol scale, column chromatography (4% EtOAc in Hexanes) afforded the title compound as a brown gum (100 mg, 0.227 mmol, 88%).

ν_max (thin film/cm⁻¹): 3405, 2975, 2930, 2955, 1616, 1510, 1451, 1371, 1296, 1275, 1246, 1194, 1141, 1118, 1036; ¹H NMR (400 MHz, CDCl₃) δ ppm 1.08 - 1.22 (m, 1 H, CH₂), 1.31 (s, 6 H, 2 x CH₃), 1.31 (s, 6 H, 2 x CH₃), 1.35 - 1.68 (m, 7 H, CH₂), 2.13 - 2.22 (m, 1 H, CH₂), 2.24 - 2.33 (m, 1 H, CH₂), 3.68 (s, 3 H, OCH₃), 4.35 (d, J = 4.3 Hz, 1 H, CHN), 5.22 (d, J = 4.0 Hz, 1 H, NH), 5.52 (d, J = 2.3 Hz, 1 H, C=CH₂), 6.11 (d, J = 2.3 Hz, 1 H, C=CH₂), 6.40 - 6.47 (m, 2 H, ArCH), 6.63 - 6.70 (m, 2 H, ArCH), 6.91 - 6.96 (m, 2 H, ArCH), 7.13 (dd, J = 4.8, 1.5 Hz, 1 H, ArCH); ¹³C NMR (101 MHz, CDCl₃) δ ppm 22.1 (CH₂), 22.5 (CH₂), 24.69 (CH₃), 24.65 (CH₃), 26.5 (CH₂), 31.7 (CH₂), 34.4 (CH₂), 46.7 (CC=CH₂), 55.7 (OCH₃), 65.4 (CHN), 83.8 (OC), 113.7 (ArCH), 114.6 (ArCH), 123.7 (ArCH), 125.3 (ArCH), 126.0 (C=CH₂), 132.8 (ArCH), 142.7 (ArC), 147.3 (ArC), 151.4 (ArC), (BC=CH₂ not observed); ¹¹B NMR (128 MHz, CDCl₃) δ 6.4.

4-Methoxy-N-(1-(4-methoxyphenyl)-2,2-dimethyl-3-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)but-3-en-1-yl)aniline (155r)

Prepared according to General Procedure 13, on a 0.258 mmol scale, column chromatography (6% EtOAc in Hexanes) afforded the title compound as a brown solid (97 mg, 0.222 mmol, 86%).
Mp: 71-73 °C; MS (ES') m/z: 438 (M+H'). HRMS calcd for C_{26}H_{36}NBO_4Na: 460.2635. Found: 460.2652; ν_{max} (thin film/cm\textsuperscript{-1}): 3409, 2975, 2933, 2833, 1609, 1583, 1509, 1464, 1442, 1411, 1353, 1301, 1236, 1168, 1144, 1120, 1036; \textsuperscript{1}H NMR (400 MHz, CDCl\textsubscript{3}) δ ppm 1.00 (s, 3 H, CH\textsubscript{3}), 1.10 (s, 3 H, CH\textsubscript{3}), 1.15 (s, 6 H, 2 x CH\textsubscript{3}), 1.17 (s, 6 H, 2 x CH\textsubscript{3}), 3.66 (s, 3 H, OCH\textsubscript{3}), 3.79 (s, 3 H, OCH\textsubscript{3}), 4.11 (br. s., 1 H, NH), 4.45 (s, 1 H, CHN), 5.92 (d, J = 2.5 Hz, 1 H, C=CH\textsubscript{2}), 6.33 - 6.39 (m, 2 H, ArCH), 6.57 - 6.63 (m, 2 H, ArCH), 7.25 - 7.30 (m, 2 H, ArCH); \textsuperscript{13}C NMR (101 MHz, CDCl\textsubscript{3}) δ ppm 21.1 (CH\textsubscript{3}), 24.6 (CH\textsubscript{3}), 24.7 (CH\textsubscript{3}), 26.8 (CH\textsubscript{3}), 83.4 (OC), 112.9 (ArCH), 114.4 (ArCH), 127.7 (C=CH\textsubscript{2}), 129.9 (ArCH), 133.1 (ArC), 142.6 (ArC), 151.5 (ArC), 158.3 (ArC), (BC=CH\textsubscript{2} not observed); \textsuperscript{11}B NMR (128 MHz, CDCl\textsubscript{3}) δ 4.5.

\textit{N)-(1-(4-Bromophenyl)-2,2-dimethyl-3-(4,4,5,5-tetramethyl-1,3,2-dioxaborolanyl-2-yl)but-3-en-1-yl)-4-methoxyaniline (155s)}

Prepared according to General Procedure 13, on a 0.258 mmol scale, column chromatography (4% EtOAc in Hexanes) afforded the title compound as a brown solid (103 mg, 0.211 mmol, 82%).

Mp: 53-55 °C; MS (ES') m/z: 486 (M+H'). HRMS calcd for C_{25}H_{34}NBO_3Br: 486.1815. Found: 486.1811; ν_{max} (thin film/cm\textsuperscript{-1}): 3404, 2975, 2932, 2831, 1601, 1510, 1485, 1442, 1372, 1353, 1236, 1216, 1144, 1119, 1109; \textsuperscript{1}H NMR (400 MHz, CDCl\textsubscript{3}) δ ppm 0.99 (s, 3 H, CH\textsubscript{3}), 1.11 (s, 3 H, CH\textsubscript{3}), 1.15 (s, 6 H, CH\textsubscript{3}), 1.17 (s, 6 H, CH\textsubscript{3}), 3.66 (s, 3 H, OCH\textsubscript{3}), 4.12 (br. s., 1 H, NH), 4.48 (s, 1 H, CHN), 5.68 (d, J = 2.3 Hz, 1 H, C=CH\textsubscript{2}), 5.95 (d, J = 2.3 Hz, 1 H, C=CH\textsubscript{2}), 6.29 - 6.35 (m, 2 H, ArCH), 6.58 - 6.63 (m, 2 H, ArCH), 7.23 - 7.29 (m, 2 H, ArCH), 7.38 - 7.44 (m, 2 H, ArCH); \textsuperscript{13}C NMR (101 MHz, CDCl\textsubscript{3}) δ ppm 21.1 (CH\textsubscript{3}), 24.6 (CH\textsubscript{3}), 24.7 (CH\textsubscript{3}), 26.8 (CH\textsubscript{3}), 43.0 (CC=CH\textsubscript{2}), 55.7 (OCH\textsubscript{3}), 83.5 (OC), 114.3 (ArCH), 114.5 (ArCH), 120.4 (ArC), 128.4 (C=CH\textsubscript{2}), 130.6 (ArCH), 130.7 (ArCH), 140.4 (ArC), 142.1 (ArC), 151.6 (ArC), (C=CH\textsubscript{2} not observed); \textsuperscript{11}B NMR (128 MHz, CDCl\textsubscript{3}) δ 2.88.
**rac-4-Methoxy-N-{[(1R,2R)-2-{1-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)vinyl}-1-(o-toly)decyl]aniline (155t)**

Prepared according to General Procedure 13, on a 0.258 mmol scale, column chromatography (4% EtOAc in Hexanes) afforded the title compound as an orange gum (119 mg, 0.235 mmol, 91%). MS (ES\(^{+}\)) m/z: 505 (M+H\(^{+}\)). HRMS calcd for C\(_{32}\)H\(_{49}\)N\(_{2}\)O\(_{3}\)Na: 506.3806. Found: 506.3802; \(\nu\)\(_{max}\) (thin film/cm\(^{-1}\)): 3406, 2924, 2854, 1606, 1510, 1463, 1365, 1307, 1237, 1167, 1141, 1110, 1041; \(\text{H NMR (400 MHz, CDCl}\_3) \delta ppm\):

- 0.83 - 0.90 (m, 3 H, CH\(_3\)), 1.01 - 1.37 (m, 13 H, CH\(_2\)), 1.23 (s, 6 H, 2 x CH\(_3\)), 1.24 (s, 6 H, 2 x CH\(_3\)), 1.71 (m, 1 H, CH\(_2\)), 2.35 - 2.45 (m, 1 H, CHC=CH\(_2\)), 2.50 (s, 3 H, Ar-CH\(_3\)), 3.67 (s, 3 H, OCH\(_3\)), 4.58 (br. s., 1 H, NH), 4.64 (d, \(J = 6.3\) Hz, 1 H, CHN), 5.45 (br. s., 1 H, C=CH\(_2\)), 5.91 (d, \(J = 3.0\) Hz, 1 H, C=CH\(_2\)), 6.33 (d, \(J = 6.8\) Hz, 2 H, ArCH), 6.63 (d, \(J = 8.3\) Hz, 2 H, ArCH), 7.04 - 7.15 (m, 3 H, ArCH), 7.22 - 7.33 (m, 1 H, ArCH); \(\text{C NMR (101 MHz, CDCl}\_3) \delta ppm\):

- 14.1 (CH\(_3\)), 19.4 (Ar-CH\(_3\)), 22.6 (CH\(_2\)), 24.7 (CH\(_3\)), 24.8 (CH\(_3\)), 27.9 (CH\(_3\)), 29.2 (CH\(_2\)), 29.4 (CH\(_3\)), 29.4 (CH\(_3\)), 30.4 (CH\(_2\)), 31.8 (CH\(_2\)), 54.1 (CHN), 55.7 (OCH\(_3\)), 58.1 (CHC=CH\(_2\)), 83.4 (OC), 113.8 (ArCH), 114.6 (ArCH), 126.0 (ArCH), 126.1 (ArCH), 126.9 (ArCH), 130.1 (ArCH), 132.4 (C=CH\(_2\)), 132.8 (ArC), 135.4 (ArC), 141.7 (ArC), 142.6 (ArCOCH\(_3\)), (BC=CH\(_2\) not observed); \(\text{B NMR (128 MHz, CDCl}\_3) \delta ppm\) 10.2.

**N-{(2,2-Dimethyl-1-phenyl-3-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)but-3-en-1-yl)aniline (155u)**

Prepared according to General Procedure 13, on a 0.258 mmol scale, preparative thin layer chromatography (CH\(_2\)Cl\(_2\)) afforded the title compound as a yellow solid (68.2 mg, 0.181 mmol, 70%). Mp: 103-104 °C; MS (ES\(^{+}\)) m/z: 378 (M+H\(^{+}\)). HRMS calcd for C\(_{24}\)H\(_{33}\)N\(_{2}\)O\(_{2}\): 378.2604. Found: 378.2616; \(\nu\)\(_{max}\) (thin film/cm\(^{-1}\)): 3407, 2976, 2930, 1601, 1503, 1453, 1411, 1389, 1372, 1353, 1301, 1275, 1215, 1144, 1119, 1078, 1029; \(\text{H NMR (500 MHz, CDCl}\_3) \delta ppm\):

- 1.02 (s, 3 H, CH\(_3\)), 1.15 (s, 3 H, CH\(_3\)), 1.17 (s, 6 H, 2 x CH\(_3\)), 1.18 (s, 6 H, 2 x CH\(_3\)), 4.44 (br. s., 1 H, NH), 4.59 (d, \(J = 2.2\) Hz, 1 H, CHN), 5.66 (d, \(J = 2.5\) Hz, 1 H, C=CH\(_2\)), 5.94 (d, \(J = 2.5\) Hz, 1 H, C=CH\(_2\)), 6.40 (dd, \(J = 8.7, 1.1\) Hz, 2 H, ArCH), 6.54 (tt, \(J = 7.3, 0.9\) Hz, 1 H, ArCH), 6.98 (dd, \(J = 8.5, 7.3\) Hz, 2 H, ArCH), 7.19 - 7.24 (m, 1 H, ArCH), 7.28 (m, 2 H, ArCH), 7.34 - 7.39 (m, 2 H, ArCH); \(\text{C NMR (126 MHz, CDCl}\_3) \delta ppm\)
21.4 (CH₃), 24.6 (CH₃), 24.7 (CH₃), 26.9 (CH₃), 43.1 (CC=CH₂), 65.0 (CHN), 83.5 (OC), 113.2 (ArCH), 116.6 (ArCH), 126.6 (ArCH), 127.5 (ArCH), 128.2 (C=CH₂), 128.7 (ArCH), 129.0 (ArCH), 141.1 (ArC), 148.1 (ArC), (BC=CH₂ not observed); ¹¹B NMR (128 MHz, CDCl₃) δ ppm 6.8.

\[ N-(\text{Pheny}1-\{1-(4,4,5,5\text{-}\text{tetramethyl-1,3,2-dioxaborolan-2-yl}vinyl)cyclohexyl\}methyl)aniline \]

(155v)

Prepared according to General Procedure 13, on a 0.258 mmol scale, preparative thin layer chromatography (CH₂Cl₂) afforded the title compound as a yellow gum (88.7 mg, 0.212 mmol, 82%).

\[ \text{MP: } 95\text{-}97^\circ \text{C; MS (ES') } m/z: 418 (M+H'). \text{ HRMS calcd for } C_{27}H_{37}NBO_2: 418.2917. \text{ Found: 418.2914; } \]

\[ \nu_{\text{max}} \text{ (thin film/cm}^{-1} \text{): } 3412, 2929, 2855, 1600, 1499, 1451, 1371, 1299, 1213, 1141, 1119; \]

\[ ^1H \text{ NMR (400 MHz, CDCl}_3 \text{ }) \delta \text{ ppm } 1.22 \text{-} 1.32 \text{ (m, 5 H, CH}_2 \text{)}, 1.35 \text{ (s, 12 H, 4 x CH}_3 \text{)}, 1.45 \text{-} 1.54 \text{ (m, 3 H, CH}_2 \text{)}, 1.94 \text{-} 2.02 \text{ (m, 1 H, CH}_2 \text{)}, 2.34 \text{-} 2.43 \text{ (m, 1 H, CH}_2 \text{)}, 4.14 \text{ (s, 1 H, CHN)}, 5.29 \text{ (d, } J = 2.0 \text{ Hz, 1 H, C=CH}_2 \text{)}, 5.69 \text{ (br. s, 1 H, NH)}, 6.07 \text{ (d, } J = 2.3 \text{ Hz, 1 H, C=CH}_2 \text{)}, 6.40 \text{ (d, } J = 7.6 \text{ Hz, 2 H, ArCH)}, 6.52 \text{ (t, } J = 7.3 \text{ Hz, 1 H, ArCH)}, 6.97 \text{-} 7.04 \text{ (m, 2 H, ArCH)}, 7.16 \text{-} 7.27 \text{ (m, 5 H, ArCH); } \]

\[ ^13C \text{ NMR (101 MHz, CDCl}_3 \text{ }) \delta \text{ ppm } 21.8 \text{ (Cy)}, 22.6 \text{ (Cy)}, 24.7 \text{ (CH}_3 \text{)}, 26.5 \text{ (Cy)}, 32.2 \text{ (Cy)}, 35.1 \text{ (Cy)}, 46.6 \text{ (CC=CH}_2 \text{)}, 68.7 \text{ (CHN)}, 83.9 \text{ (OC)}, 112.4 \text{ (ArCH)}, 115.8 \text{ (ArCH)}, 126.6 \text{ (ArCH)}, 127.1 \text{ (ArCH)}, 128.8 \text{ (ArCH)}, 129.4 \text{ (ArCH)}, 132.9 \text{ (C=CH}_2 \text{)}, 140.8 \text{ (ArC)}, 148.4 \text{ (ArC), (BC=CH}_2 \text{ not observed); } \]

\[ ^11B \text{ NMR (128 MHz, CDCl}_3 \text{ }) \delta \text{ ppm 11.0. } \]

**General Procedure 14 for the copper-catalysed borylation of allenes and trapping with an imine followed by an oxidative workup**

\[ \text{rac-(3S,4R)-4-(Benzylamino)-3-cyclohexyl-4-(o-tolyl)butan-2-one (156a)} \]

To a solution of IPrCuCl (6.3 mg, 0.013 mmol, 5 mol%) in THF (0.8 mL), was added t-BuOK (0.26 mL of a 1 M THF solution, 0.258 mmol, 1 equiv), and the reaction was stirred for 5 minutes at room temperature. B₂Pin₂ (72.1 mg, 0.284 mmol, 1.1 equiv) in THF (0.75 mL) was then added and the resulting mixture stirred for 30 min. A solution of (1,2-propadienyl)cyclohexane (47.3 mg, 0.387 mmol, 1.5 equiv) and (E)-N-benzyl-1-(o-tolyl)methanimine (54 mg, 0.258 mmol, 1 equiv) in THF (1
mL) were then added dropwise at -78 °C, and the reaction allowed to warm to room temperature with stirring overnight. The reaction mixture was then filtered through a silica plug and concentrated **in vacuo**. To this crude mixture in THF (1.29 mL) at 0 °C was added H2O2 (0.14 mL of a 30% w:v aqueous solution, 1.29 mmol, 5 equiv) and NaOH (0.65 mL of a 2 M aqueous solution, 1.29 mmol, 5 equiv) and stirred for 20 min. The aqueous layer was then washed with Et2O (3 x 2 mL) and dried over MgSO4. Concentration **in vacuo** and purification by chromatography (3% EtOAc in hexanes) afforded the title compound as an oil (70 mg, 0.201 mmol, 78%).

MS (ES⁺) m/z: 350 (M+H⁺). HRMS calcd for C24H32NO: 350.2484. Found: 350.2471; νmax (thin film/cm⁻¹): 3026, 2922, 2850, 1703, 1494, 1450, 1356, 1277, 1225, 1166, 1125, 1028; ¹H NMR (400 MHz, CDCl3) δ ppm 0.78 - 0.99 (m, 2 H, CH₂), 1.04 - 1.32 (m, 3 H, CH₃), 1.50 - 1.71 (m, 4 H, CH₂), 1.75 (s, 3 H, CH₃), 1.79 - 1.93 (m, 1 H, CH₂), 2.11 (d, J = 14.5 Hz, 1 H, CH), 2.26 (s, 3 H, Ar-CH₃), 2.64 (dd, J = 7.9, 6.5 Hz, 1 H, CHC=O), 3.36 (d, J = 13.2 Hz, 1 H, Ph-CH₂), 3.71 (d, J = 13.2 Hz, 1 H, Ph-CH₂), 4.18 (d, J = 6.0 Hz, 1 H, CHN), 7.15 - 7.19 (m, 2 H, ArCH), 7.20 - 7.26 (m, 4 H, ArCH), 7.26 - 7.32 (m, 3 H, ArCH); ¹³C NMR (101 MHz, CDCl3) δ ppm 19.1 (Ar-C=H), 26.2 (CH₂), 26.3 (CH₃), 26.4 (CH₂), 30.7 (CH₂), 31.3 (CH₂), 34.7 (CH₃), 37.5 (CH), 50.6 (PhCH₂), 55.2 (CHN), 62.7 (CHC=O), 126.3 (ArCH), 126.7 (ArCH), 126.8 (ArCH), 128.1 (ArCH), 128.3 (ArCH), 130.8 (ArCH), 135.7 (ArC), 139.6 (ArC), 140.6 (ArC), 213.9 (C=O);

**1-(1-((Benzylamino)(phenyl)methyl)cyclohexyl)ethan-1-one (156b)**

![Chemical Structure](image_url)

Prepared according to General Procedure 14, on a 0.258 mmol scale, column chromatography (3% EtOAc in Hexanes) afforded the title compound as a white solid (79.1 mg, 0.246 mmol, 95%).

Mp: 71-72 °C; MS (ES⁺) m/z: 322 (M+H⁺). HRMS calcd for C22H28NO: 322.2171. Found: 322.2179; νmax (thin film/cm⁻¹): 3061, 3026, 2931, 2854, 1696, 1601, 1493, 1453, 1352, 1201, 1123, 1072, 1028, 1002; ¹H NMR (500 MHz, CDCl3) δ ppm 0.87 - 0.98 (m, 1 H, CH₂), 0.98 - 1.08 (m, 1 H, CH₂), 1.09 - 1.18 (m, 2 H, CH₂), 1.22 - 1.42 (m, 2 H, CH₂), 1.47 - 1.59 (m, 3 H, CH₃), 2.03 (s, 3 H, CH₃), 2.11 (dd, J = 13.1, 2.7 Hz, 1 H, CH₃), 3.30 (d, J = 13.6 Hz, 1 H, Ph-CH₂), 3.61 - 3.68 (m, 2 H, Ph-CH₂ + CHN), 7.17 (d, J = 6.9 Hz, 2 H, ArCH), 7.24 (d, J = 6.9 Hz, 3 H, ArCH), 7.28 - 7.31 (m, 2 H, ArCH), 7.31 - 7.35 (m, 1 H, ArCH), 7.36 - 7.40 (m, 2 H, ArCH), (NH not observed); ¹³C NMR (126 MHz, CD₂OH) δ ppm 22.8 (Cy), 23.6 (Cy), 25.8 (Cy), 26.3 (CH₃), 27.5 (Cy), 32.8 (Cy), 51.2 (PhCH₂), 56.8 (CC=O), 67.8
(CHN), 126.9 (ArCH), 127.4 (ArCH), 127.9 (ArCH), 128.2 (ArCH), 128.4 (ArCH), 129.3 (ArCH), 138.8 (ArC), 140.1 (ArC), 212.8 (C=O).

**rac-(3R,4S)-3-Cyclohexyl-4-((4-methoxyphenyl)amino)-4-(o-toly)butan-2-one (156c)**

![Structure](image)

Prepared according to General Procedure 14, on a 0.070 mmol scale, column chromatography (3% EtOAc in Hexanes) afforded the title compound as a yellow gum (25.6 mg, 0.070 mmol, 99%).

MS (ES^+^) m/z: 366 (M+H^+^). HRMS calcd for C_{24}H_{32}NO_2: 366.2433. Found: 366.2415; \( \nu_{\text{max}} \) (thin film/cm\(^{-1}\)): 3407, 2924, 2851, 1702, 1511, 1484, 1359, 1241, 1225, 1168, 1110, 1039; \(^1^H\) NMR (400 MHz, CDCl_3) \( \delta \) ppm 0.79 - 1.42 (m, 6 H, CH_2), 1.54 (s, 3 H, CH_3), 1.57 - 1.80 (m, 3 H, CH_2), 1.93 - 2.13 (m, 2 H, CH_2 + CH), 2.50 (s, 3 H, Ar-CH_3), 2.78 (dd, \( J = 10.3, 3.3 \) Hz, 1 H, CHC=O), 3.68 (s, 3 H, OCH_3), 4.86 (d, \( J = 3.5 \) Hz, 1 H, CHN), 5.25 (br. s., 1 H, NH), 6.36 (d, \( J = 8.8 \) Hz, 2 H, ArCH), 6.62 - 6.71 (m, 2 H, ArCH), 7.02 - 7.15 (m, 3 H, ArCH), 7.16 - 7.21 (m, 1 H, ArCH); \(^1^C\) NMR (101 MHz, CDCl_3) \( \delta \) ppm 18.9 (Ar-CH_3), 26.0 (2 x Cy), 26.3 (CH_2), 29.8 (CH_2), 32.2 (CH_3C=O), 35.5 (CH_2), 37.6 (CH_3), 51.8 (CHN), 55.7 (OCH_3), 60.6 (CHC=O), 113.3 (ArCH), 114.8 (ArCH), 125.9 (ArCH), 126.5 (ArCH), 126.9 (ArCH), 130.8 (ArCH), 134.1 (ArC), 139.3 (ArC), 141.0 (ArC), 151.2 (ArC), 215.4 (C=O).

**rac-N-((1R,2R)-2-Cyclohexyl-3-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)-1-(o-toly)but-3-en-1-yl)-4-methoxybenzenaminium trifluoromethanesulfonate (157)**

To a solution of 155g (50 mg, 0.105 mmol, 1 equiv) in CH_2Cl_2 (0.62 mL) at -30 °C, was added triflic acid (15.8 mg, 0.105 mmol, 1 equiv) in CH_2Cl_2 (0.093 mL), dropwise. The reaction mixture was allowed to warm to room temperature over 2 h before being concentrated in vacuo and recrystallized from pentane to give the title compound as brown crystals (58.5 mg, 0.094 mmol, 89%).

Mp: 123-125 °C (Pentane); MS (ES^+^) m/z: 476 (M – OTf); \( \nu_{\text{max}} \) (thin film/cm\(^{-1}\)): 2976, 2927, 2853, 1606, 1513, 1449, 1424, 1392, 1373, 1362, 1247, 1167, 1138, 1029; \(^1^H\) NMR (400 MHz, CDCl_3) \( \delta \) ppm 0.76 - 1.19 (m, 7 H, CH_2), 1.22 – 1.37 (m, 1 H, CH_2), 1.43 (s, 6 H, CH_3), 1.44 (s, 6 H, CH_3), 1.49 - 1.74 (m, 3 H, CH_2 + CH), 1.88 (s, 3 H, Ar-CH_3), 3.14 (d, \( J = 11.9 \) Hz, 1 H, CHC=CH_2), 3.74 (s, 3 H, OCH_3), 5.33 (t, \( J = 8.8 \) Hz, 1 H, CHN), 6.24 (br. s., 1 H, C=CH_2), 6.31 (s, 1 H, C=CH_2), 6.71 (d, \( J = 9.1 \) Hz, 1 H, C=CH_2), 7.02 - 7.15 (m, 3 H, ArCH), 7.16 - 7.21 (m, 1 H, ArCH).
Hz, 2 H, ArCH), 6.99 (d, J = 7.6 Hz, 1 H, ArCH), 7.04 (d, J = 8.8 Hz, 2 H, ArCH), 7.23 (s, 1 H, ArCH), 7.41 (s, 1 H, ArCH), 7.87 (d, J = 7.6 Hz, 1 H, ArCH), 10.33 (br. s, 1 H, NH); \(^{13}\)C NMR (126 MHz, CDCl\(_3\)) \(\delta\) ppm 19.1 (Ar-CH\(_3\)), 24.4 (CH\(_3\)), 25.4 (CH\(_3\)), 25.9 (CH\(_2\)), 26.0 (CH\(_2\)), 26.2 (CH\(_2\)), 29.0 (CH\(_2\)), 31.8 (CH\(_2\)), 39.0 (CH), 55.5 (OCH\(_3\)), 57.6 (CH=CH\(_2\)), 65.6 (CHN), 84.7 (OC), 114.5 (ArCH), 124.7 (ArCH), 125.9 (ArC), 127.2 (ArCH), 127.9 (ArCH), 129.5 (ArCH), 130.6 (ArCH), 131.1 (ArC), 137.8 (ArC), 140.1 (C=CH\(_2\)), 160.1 (ArCOCH\(_3\)), (BC=CH\(_2\) not observed); \(^{11}\)B NMR (128 MHz, CDCl\(_3\)) \(\delta\) 4.8.

\(N\)-(2,2-Dimethyl-1-phenyl-3-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)but-3-en-1-yl)-4-methylbenzenesulfonamide (163)

\[
\text{To a solution of IPrCuCl (50 mg, 0.103 mmol, 1 equiv) in THF (1.5 mL), was added KOt-Bu (0.11 mL of a 1 M solution in THF, 0.108 mmol, 1 equiv) and stirred for 5 minutes. Bpin\(_2\) (28.6 mg, 0.128 mmol, 1.1 equiv) in THF (0.5 mL) was added and stirred for 10 minutes. 3-Methyl-1,2-butadiene (8.4 mg, 0.012 mL, 0.123 mmol, 1.2 equiv) was added neat and stirred for 5 minutes. (E)-N-benzylidene-4-methylbenzenesulfonamide (40 mg, 0.154 mmol, 1.5 equiv) in THF (0.5 mL) was then added and the reaction stirred at room temperature for 18 hours. The reaction mixture was then filtered through a silica plug, concentrated in vacuo and purified by chromatography (10% EtOAc in hexanes) to afford the title compound (28 mg, 61.92 µmol, 56%).}

Mp: 128-130 °C (Pentane); MS (ES\(^{+}\)) \(m/z\): 456 (M+H\(^{+}\)). HRMS calcd for C\(_{25}\)H\(_{35}\)NO\(_4\)BS: 456.2385. Found: 456.2365; \(\nu_{\max}\) (thin film/cm\(^{-1}\)): 3288, 2976, 2927, 1600, 1495, 1457, 1412, 1355, 1325, 1302, 1214, 1160, 1144, 1114, 1095, 1056, 1030; \(^{1}H\) NMR (400 MHz, CDCl\(_3\)) \(\delta\) ppm 0.98 (s, 3 H, CH\(_3\)), 1.10 (s, 3 H, CH\(_3\)), 1.36 (s, 12 H, CH\(_3\)), 2.30 (s, 3 H, Ar-CH\(_3\)), 4.40 (d, J = 6.7 Hz, 1 H, CHN), 5.31 (s, 1 H, C=CH\(_2\)), 5.82 (d, J = 1.8 Hz, 1 H, C=CH\(_2\)), 6.33 (d, J = 6.2 Hz, 1 H, NH), 6.90 (d, J = 7.0 Hz, 2 H, ArH), 6.96 - 7.10 (m, 5 H, ArH), 7.37 (d, J = 8.1 Hz, 2 H, ArH); \(^{13}\)C NMR (101 MHz, CDCl\(_3\)) \(\delta\) ppm 21.4 (Ar-CH\(_3\)), 24.3 (CH\(_3\)), 24.6 (CH\(_3\)), 24.8 (CH\(_3\)), 26.2 (CH\(_3\)), 42.8 (CC=CH\(_2\)), 65.7 (CHN), 84.2 (OC), 126.6 (ArCH), 126.90 (ArCH), 126.92 (ArCH), 128.8 (ArCH), 130.7 (C=CH\(_2\)), 137.8 (ArC), 138.3 (ArC), 142.2 (ArC), (BC=CH\(_2\) not observed).
Appendix: X-ray crystal structures

(35,4S)-4-(Dimethyl(phenyl)silyl)-3-((S)-1-hydroxy-2-methylpropyl)tetrahydro-2H-pyran-2-one (58m)

Empirical formula \( \text{C}_{17}\text{H}_{26}\text{O}_3\text{Si} \)
Formula weight \( 306.47 \)
Temperature \( 100(2) \) K
Wavelength \( 1.54178 \) Å
Crystal system, space group Monoclinic, \( \text{P}2(1)/\text{n} \)
Unit cell dimensions \( a = 9.8456(2) \) Å \( \alpha = 90 \) deg.
\( b = 10.0887(2) \) Å \( \beta = 100.9640(10) \) deg.
\( c = 17.4419(3) \) Å \( \gamma = 90 \) deg.
Volume \( 1700.87(6) \) Å\(^3\)
Z, Calculated density \( 4, \) 1.197 Mg/m\(^3\)
Absorption coefficient \( 1.276 \) mm\(^{-1}\)
\( F(000) \) \( 664 \)
Crystal size \( 0.22 \times 0.21 \times 0.19 \) mm
Theta range for data collection 5.09 to 72.27 deg.
Limiting indices \(-12 \leq h \leq 11, -12 \leq k \leq 12, -21 \leq l \leq 20\)
Reflections collected / unique \( 8913 / 3256 \) [\( R(\text{int}) = 0.0245 \)]
Completeness to theta = \( 66.60 \) 97.9 %
Absorption correction Semi-empirical from equivalents
Max. and min. transmission \( 0.7935 \) and \( 0.716635 \)
Refinement method: Full-matrix least-squares on $F^2$

Data / restraints / parameters: 3256 / 0 / 195

Goodness-of-fit on $F^2$: 1.052

Final R indices [I>2sigma(I)]: $R_1 = 0.0334$, $wR_2 = 0.0826$

R indices (all data): $R_1 = 0.0387$, $wR_2 = 0.0860$

Largest diff. peak and hole: 0.447 and -0.210 e.A^-3

**tert-Butyldiphenyl(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)silane (122)**

Empirical formula: $C_{22}H_{31}BO_2Si$

Formula weight: 366.37

Temperature: 100(2) K

Wavelength: 1.54178 Å

Crystal system, space group: Triclinic, P-1

Unit cell dimensions:
- $a = 10.5887(3)$ Å, $\alpha = 87.064(2)$ deg.
- $b = 14.2668(4)$ Å, $\beta = 82.3220(10)$ deg.
- $c = 14.4225(4)$ Å, $\gamma = 88.1270(10)$ deg.

Volume: 2155.66(10) Å$^3$

Z, Calculated density: 4, 1.129 Mg/m$^3$

Absorption coefficient: 1.042 mm$^{-1}$

$F(000)$: 792

Crystal size: 0.29 x 0.25 x 0.21 mm

Theta range for data collection: 3.10 to 72.38 deg.

Limiting indices: $-13 \leq h \leq 13$, $-17 \leq k \leq 17$, $-11 \leq l \leq 16$

Reflections collected / unique: 14845 / 7923 [$R(int) = 0.0244]$
Completeness to theta = 67.00 95.2 %
Absorption correction  Semi-empirical from equivalents
Max. and min. transmission  0.8108 and 0.651136
Refinement method  Full-matrix least-squares on F^2
Data / restraints / parameters  7923 / 16 / 536
Goodness-of-fit on F^2  1.026
Final R indices [I>2sigma(I)]  R1 = 0.0461, wR2 = 0.1203
R indices (all data)  R1 = 0.0539, wR2 = 0.1269
Largest diff. peak and hole  0.651 and -0.474 e.A^-3

*rac-(1S,2S)-3-(Dimethyl(phenyl)silyl)-1-(2,4,6-trimethylphenyl)-2-phenylbut-3-en-1-ol (129)*

Empirical formula  C_{27}H_{32}OSi
Formula weight  400.62
Temperature  100(2) K
Wavelength  1.54178 Å
Crystal system, space group  Triclinic, P-1
Unit cell dimensions  a = 10.0983(3) Å  alpha = 78.594(2) deg.
b = 10.9825(4) Å  beta = 72.391(2) deg.
c = 12.1700(3) Å  gamma = 65.268(2) deg.
Volume  1164.51(6) Å^3
Z, Calculated density  2, 1.143 Mg/m^3
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<th>Property</th>
<th>Value</th>
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<td>Absorption coefficient</td>
<td>0.983 mm^-1</td>
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<td>F(000)</td>
<td>432</td>
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<td>Crystal size</td>
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<tr>
<td>Theta range for data collection</td>
<td>3.82 to 72.33 deg.</td>
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<tr>
<td>Limiting indices</td>
<td>-12&lt;=h&lt;=12, -11&lt;=k&lt;=13, -14&lt;=l&lt;=15</td>
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<td>Reflections collected / unique</td>
<td>9911 / 4382 [R(int) = 0.0398]</td>
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<tr>
<td>Completeness to theta =</td>
<td>67.00  96.7 %</td>
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<td>Absorption correction</td>
<td>Semi-empirical from equivalents</td>
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<td>Max. and min. transmission</td>
<td>0.9617 and 0.698688</td>
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<td>Refinement method</td>
<td>Full-matrix least-squares on F^2</td>
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<td>Data / restraints / parameters</td>
<td>4382 / 0 / 270</td>
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<td>Goodness-of-fit on F^2</td>
<td>1.071</td>
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<td>Final R indices [I&gt;2sigma(I)]</td>
<td>R1 = 0.0424, wR2 = 0.1149</td>
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<td>R indices (all data)</td>
<td>R1 = 0.0526, wR2 = 0.1278</td>
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<td>Largest diff. peak and hole</td>
<td>0.364 and -0.284 e.A^-3</td>
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1-(1-((Benzylamino)(phenyl)methyl)cyclohexyl)ethan-1-one (156b)

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<td>Empirical formula</td>
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<td>100(2) K</td>
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<td>Wavelength</td>
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<td></td>
<td>b = 26.3168(8) Å</td>
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<td></td>
<td>c = 15.7312(4) Å</td>
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<tr>
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<td>1392</td>
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<td>Crystal size</td>
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<td>Theta range for data collection</td>
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<td>Reflections collected / unique</td>
<td>28338 / 3645 [R(int) = 0.0928]</td>
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<td>67.00 99.6 %</td>
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<td>Max. and min. transmission</td>
<td>1.00000 and 0.76173</td>
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Appendix

Refinement method
Full-matrix least-squares on $F^2$

Data / restraints / parameters
3645 / 0 / 222

Goodness-of-fit on $F^2$
1.069

Final R indices [l>2sigma(I)]
R1 = 0.0666, wR2 = 0.1749

R indices (all data)
R1 = 0.0862, wR2 = 0.1896

Largest diff. peak and hole
0.451 and -0.241 e.A^-3

rac-N-((1R,2R)-2-Cyclohexyl-3-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)-1-(o-tolyl)but-3-en-1-yl)-4-methoxybenzenaminium trifluoromethanesulfonate (157)

Empirical formula
C_{31}H_{43}BF_{3}NO_{6}S

Formula weight
625.53

Temperature
180(2) K

Wavelength
1.54178 A

Crystal system, space group
Monoclinic, C2/c

Unit cell dimensions
a = 45.0013(9) A  alpha = 90 deg.
b = 16.7167(4) A  beta = 112.9670(10) deg.
c = 20.6259(4) A  gamma = 90 deg.

Volume
14286.3(5) A^3

Z, Calculated density
16, 1.163 Mg/m^3

Absorption coefficient
1.268 mm^-1

F(000)
5312
Crystal size 0.28 x 0.22 x 0.10 mm
Theta range for data collection 2.13 to 72.18 deg.
Limiting indices -55<=h<=54, -20<=k<=19, -25<=l<=25
Reflections collected / unique 51205 / 13943 [R(int) = 0.0417]
Completeness to theta = 67.00 99.3 %
Absorption correction Semi-empirical from equivalents
Max. and min. transmission 0.8837 and 0.794345
Refinement method Full-matrix least-squares on F^2
Data / restraints / parameters 13943 / 1 / 825
Goodness-of-fit on F^2 1.012
Final R indices | I > 2sigma(I) | R1 = 0.0750, wR2 = 0.2267
R indices (all data) R1 = 0.0892, wR2 = 0.2462
Largest diff. peak and hole 1.871 and -0.495 e.A^-3

N-(Phenyl(1-{1-(4,4,5-tetramethyl-1,3,2-dioxaborolan-2-yl)vinyl)cyclohexyl)methyl)aniline (155v)

Empirical formula C_{27}H_{36}BNO_2
Formula weight 417.38
Temperature 293(2) K
Crystal system, space group Orthorhombic, Pbca
Unit cell dimensions a = 15.7307(12)  A alpha = 90 deg
Appendix

b = 11.4540(12)Å  beta = 90 deg

c = 27.311(2) Å  gamma = 90 deg

Volume 4921.0(7) Å³

Z calculated density 8

ρ_{calc}/g/cm³ 1.127

μ/mm⁻¹ 0.069

F(000) 1808.0

Radiation MoKα (λ = 0.71073)

2Θ range for data collection/° 7.27 to 50.69

Index ranges -15 ≤ h ≤ 18, -8 ≤ k ≤ 13, -32 ≤ l ≤ 31

Reflections collected 11702

Independent reflections 4483 [R_{int} = 0.0432, R_{sigma} = 0.0636]

Data/restraints/parameters 4483/0/332

Goodness-of-fit on F² 1.017

Final R indexes [I>=2σ (I)] R₁ = 0.0522, wR₂ = 0.1081

Final R indexes [all data] R₁ = 0.0925, wR₂ = 0.1277

Largest diff. peak/hole / e Å⁻³ 0.22/-0.22
Chapter six – References

38 K. S. Lee, Boston College, 2010.


208


