Synthesis of *α*-Chiral Silanes by Asymmetric Conjugate Addition of Silicon Nucleophiles to Unsaturated Acceptors

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PUBLICATIONS

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W. Mao, M. Oestreich, *Org*. *Lett*. **2020**, *22*, 8096–8100.

Collaborative work in other projects:

[3] "Enantioselective Construction of α-Chiral Silanes by Nickel-Catalyzed C(sp^3)–C(sp^3) Cross-Coupling"
H. Yi,† W. Mao,† M. Oestreich, *Angew*. *Chem*. *Int*. *Ed*. **2019**, *58*, 3575–3578; *Angew*. *Chem*. **2019**, *131*, 3613–3616.
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[4] "Mechanistic Dichotomy of Magnesium- and Zinc-Based Germanium Nucleophiles in the C(sp^3)–Ge Cross-Coupling with Alkyl Electrophiles"
W. Xue,† W. Mao,† L. Zhang, M. Oestreich, *Angew*. *Chem*. *Int*. *Ed*. **2019**, *58*, 6440–6443; *Angew*. *Chem*. **2019**, *131*, 6506–6509.

A review article:

[5] "Activation of the Si–B Interelement Bond related to Catalysis"
J.-J. Feng,† W. Mao,† L. Zhang,† M. Oestreich, *Chem*. *Soc*. *Rev*. **2021**, *50*, 2010–2073.

POSTER PRESENTATION

[1] W. Mao,† W. Xue,† E. Irran, M. Oestreich,
"Copper-Catalyzed Regio- and Enantioselective Addition of Silicon Grignard Reagents to Alkenes Activated by Azaaryl Groups"
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ABSTRACT

This dissertation focuses on the development of asymmetric conjugate addition of silicon nucleophiles or silicon pronucleophiles to activated alkenes, providing general and efficient methods for stereodefined silanes. Silicon GRIGNARD reagents and Si–B reagents are mainly employed as silicon sources for the enantioselective 1,4-silyl transfer.

The first part is about the application of silicon GRIGNARD reagents in the conjugate addition to azaaryl-substituted alkenes. Racemic and chiral versions were successfully established under the assistance of the LEWIS acid $BF_3 \cdot OEt_2$. Various azaaryl groups could be employed to activate the C–C double bond in the racemic transformation, demonstrating good functional group tolerance. A CuCl/Josiphos precatalyst plays a crucial role in high levels of enantioinduction in the asymmetric conjugate addition of $Me_2PhSiMgHal$ to benzoxazole-activated alkenes. Good to high enantioselectivities, up to 94% *ee*, were achieved with exclusive *β*-selectivity in 20 examples.

The second part demonstrates a general and efficient method for the synthesis of enantioenriched propargylic silanes through asymmetric conjugate addition of silylboronic esters to enyne-type *α*,*β*,*γ*,*δ*-acceptors. Ketones, esters and amides proved to be suitable Michael acceptors under our catalytic system, delivering the corresponding chiral propargylic silanes in good to excellent yields with high enantiomeric excesses of up to 95% *ee*. Good functional group tolerance, operationally simple procedure, exclusive 1,4-selectivity and excellent enantioselectivity are features of our method. The geometry of the C–C double bond in the substrate shows a non-negligible influence in the chemoselectivity. (*Z*)-Configuration results exclusively in propargylic silanes while (*E*)-Configuration mainly leads to allenylsilanes.

In the following, two chapters describe our ongoing efforts about asymmetric conjugate addition reactions. *α*,*β*-Unsaturated sulfones and phosphine oxides are chosen as MICHAEL acceptors. Moderate results with regard to yield and enantioselectivity have been obtained for the project of *α*,*β*-unsaturated sulfones, however, only racemic mixtures were achieved with *α*,*β*-unsaturated phosphine oxides. Further investigations are still ongoing for the optimal reaction conditions.

ZUSAMMENFASSUNG

Die vorliegende Dissertation befasst sich mit der Entwicklung asymmetrischer konjugierter Additionen von Siliciumnukleophilen und Siliciumpronukleophilen an aktivierte Alkene, um allgemein anwendbare und effiziente Methoden für die Darstellung von Silanen mit festgesetzter Stereoinformation zu erschließen. Silicium-GRIGNARD- und Si–B-Reagenzien dienten hauptsächlich als Siliciumquellen für enantioselektive 1,4-Silyl-Übertragungen.

Der erste Teil beschäftigt sich mit der Anwendung von Silicium-GRIGNARD-Reagenzien in konjugierten Additionsreaktionen an azaarylsubstituierte Alkene. Eine racemische und chirale Reaktionsführung wurden erfolgreich unter Zuhilfenahme der LEWIS-Säure $BF_3 \cdot OEt_2$ erarbeitet. Verschiedene Azaarylgruppen fanden in der Aktivierung der C–C-Doppelbindung der racemischen Variante Verwendung, welche eine gute Toleranz gegenüber funktionellen Gruppen unter Beweis stellte. Ein CuCl/Josiphos Präkatalysator spielte eine entscheidende Rolle für die hohe Enantioinduktion in einer asymmetrischen konjugierten Addition von $Me_2PhSiMgHal$ an benzoxazolaktivierte Alkene. Gute bis hohe Enantioselektivitäten, bis zu 94% *ee*, wurden mit ausschließlich *β*-Selektivität für 20 Beispiele erzielt.

Der zweite Teil befasst sich mit einer allgemein anwendbaren und effizienten Methode enantiomerenangereicherte Propargylsilane durch asymmetrische konjugierte Addition von Silylboronsäureestern an *α*,*β*,*γ*,*δ*-Akzeptoren des Enin-Typs darzustellen. Ketone, Ester und Amide stellten sich als geeignete MICHAEL-Akzeptoren in unserem optimierten katalytischen System heraus, welches die entsprechenden chiralen Propargylsilane in guten bis sehr guten Ausbeuten mit hohen Enantiomerenüberschüssen, bis zu 95% *ee*, lieferte. Unsere Methode zeichnet sich durch hohe Toleranz gegenüber funktionellen Gruppen, synthetisch geringem Aufwand, ausschließlicher 1,4-Selektivität und hohe Enantioselektivitäten aus. Zudem hat die Geometrie der C–C-Doppelbindung des Substrats einen nicht vernachlässigbaren Einfluss auf die Chemoselektivität der Reaktion. (*Z*)-Konfiguration führt zu Propargylsilanen, wohingegen (*E*)-Konfiguration hauptsächlich Allenysilane hervorbringt.

In den darauffolgenden zwei Kapiteln sind unsere noch andauernden Untersuchungen zur asymmetrischen konjugierten Addition dargestellt. *α*,*β*-ungesättigte Sulfone und Phophinoxide wurden als Substrate gewählt. Moderate Ausbeuten und Enantioselektivitäten wurden für die *α*,*β*-ungesättigten Sulfone erzielt, allerdings wurden einzig racemische Produkte *α*,*β*-ungesättigter Phophinoxide beobachtet. Die Optimierung der Reaktionsbedingungen dauert an.

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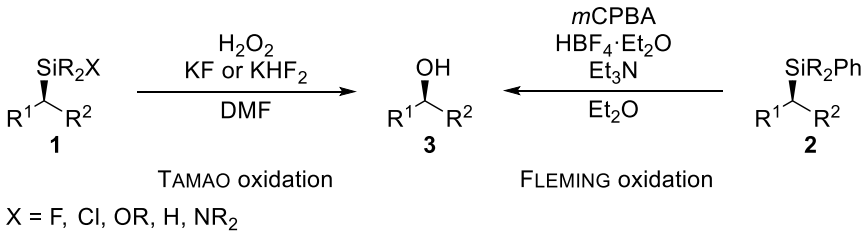
THEORETICAL PART

1 INTRODUCTION

Silicon, known as the second most abundant element in the earth's crust, is the crucial component in organosilicon compounds, which have been extensively investigated in medicinal chemistry,[1] agricultural chemistry[2] and material science.[3] Given this, reactions based on organosilicon compounds have attracted evergrowing attention of organic chemists and great achievements in this area have been made in the past decades.[4] For example, the TAMAO–FLEMING oxidation accomplishes the transformation from *α*-chiral silanes to chiral alcohols in a stereospecific manner, and thus silyl groups are often considered to be "masked hydroxy groups" (**1**→**3** and **2**→**3**, Scheme 1.1).[5] For these reasons, developing new methods to prepare organosilicon compounds is critical to the development of organosilicon chemistry. As an important part, new methods for the preparation of chiral *α*-stereogenic silanes are highly desirable.



Scheme 1.1: Oxidative degradation of *α*-chiral alkylsilanes. DMF = *N*,*N*-dimethylformamide; *m*CPBA = 3-chloroperbenzoic acid.

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[4] For selected reviews, see: a) T. Hiyama, M. Oestreich in *Organosilicon Chemistry—Novel Approaches and Reactions* (Eds.: T. Hiyama, M. Oestreich), Wilely-VCH, Weinheim, **2019**; b) T. Komiyama, Y. Minami, T. Hiyama, *ACS Catal.* **2017**, *7*, 631–651; c) S. E. Denmark, J. H.-C. Liu, *Angew. Chem. Int. Ed.* **2010**, *49*, 2987–2986; *Angew. Chem.* **2010**, *122*, 3040–3049; d) B. Marciniec, *Hydrosilylation* in *Advances in Silicon Science* (Ed.: B. Marciniec), Springer, Berlin, **2009**.

[5] For a representative review, see: a) G. R. Jones, Y. Landais, *Tetrahedron* **1996**, *52*, 7599–7662; for original works, see: b) K. Tamao, N. Ishida, M. Kumada, *J. Org. Chem.* **1983**, *48*, 2120–2122; c) I. Fleming, R. Henning, H. Plaut, *J. Chem. Soc. Chem. Commun.* **1984**, 29–31.

The past decades have witnessed a booming growth in methods for the preparation of chiral *α*-chiral silanes through C–Si bond formation.[4a,4d,6] Here, methods for asymmetric silyl transfer from silicon reagents to C–C multiple bonds are described in four parts. Chapter 1.1 is mainly about asymmetric 1,2-addition of silicon reagents to C–C double bonds, including a brief introduction about asymmetric hydrosilylation at the beginning. Chater 1.2 focuses on asymmetric 1,4-addition reactions by using hydrosilanes or silylboronic esters as silicon source. Methods involving dienes, enynes, and *α*,*β*-unsaturated carbonyl compounds and their derivatives are presented in this part. Chapter 1.3 will give an introduction about asymmetric 1,6-addition of Si–B reagents to diene- or enyne-type acceptors. The last section, Chapter 1.4, reports methods about construction of *α*-chiral silanes by using alkynes as starting materials. Concepts about asymmetric double hydrosilylation are described here.

1.1 Asymmetric 1,2-Addition Reaction

1.1.1 Asymmetric 1,2-Addition of Hydrosilanes to C–C Double Bond

Asymmetric 1,2-addition of hydrosilanes across alkenes represents a straightforward and atom economic approach to access *α*-chiral silanes, and great achievements have been accomplished with terminal alkenes in the last decades (Scheme 1.2, **5** → **6**).[4d,6d,7] To address main challenges in this area, involving regioselectivity and enantioinduction, various transition metal catalysts, based on Pd, Fe, Co, Cu, and Rh, have been successfully applied.[8] However, compared to well-developed hydrosilylation of terminal alkenes, internal alkenes are less exploited and substrates are limited (Scheme 1.2, **7** → **8**).[9]

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[6] For selected reviews about silylboronic esters, see: a) J.-J. Feng, W. Mao, L. Zhang, M. Oestreich, *Chem. Soc. Rev.* **2021**, *50*, 2010–2073; b) W. Xue, M. Oestreich, *ACS Cent. Sci.* **2020**, *6*, 1070–1081; M. Oestreich, E. Hartmann, M. Mewald, *Chem. Rev.* **2013**, *113*, 402–441; for a recent review about asymmetric hydrosilylation, see: d) M. Zaranek, P. Pawluc, *ACS Catal.* **2018**, *8*, 9865–9876.

[7] For selected reviews, see: a) L. D. de Almeida, H. Wang, K. Junge, X. Cui, M. Beller, *Angew. Chem. Int. Ed.* **2021**, *60*, 550–565; *Angew. Chem.* **2021**, *133*, 558–573; b) T. Hayashi, *Catal. Today*, **2000**, *62*, 3–15; for mechanism, see: c) A. J. Chalk, J. F. Harrod, *J. Am. Chem. Soc.* **1965**, *87*, 16–21; d) A. M. LaPointe, F. C. Rix, M. Brookhart, *J. Am. Chem. Soc.* **1997**, *119*, 906–917.

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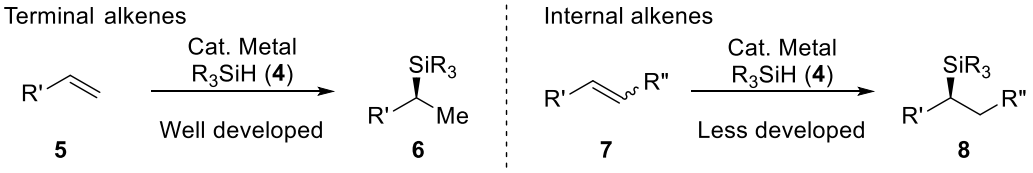


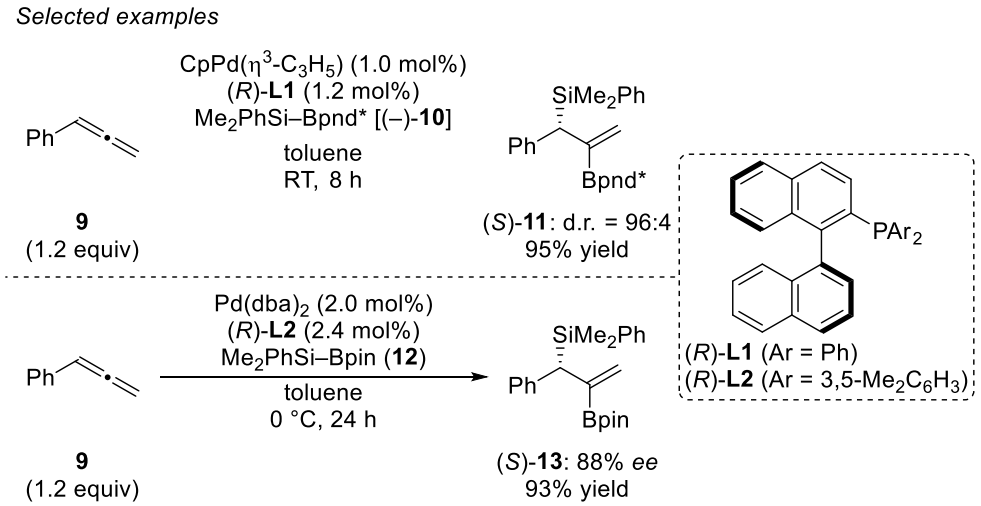
Scheme 1.2: Transition metal-catalyzed hydrosilylation.

1.1.2 Asymmetric 1,2-Addition of Silylboronic Esters to C–C Double Bond

As an alternative, silylboronic esters have been successfully employed as a silicon source in asymmetric 1,2-addition reactions, but are less studied. Activation of silylboronic esters through oxidative addition has been successfully applied in asymmetric 1,2-difunctionalization of allenes.[10] From 2003 to 2006, SUGINOME, MURAKAMI and co-workers reported their continuous efforts on palladium-catalyzed enantioselective addition of silylboronic esters across an internal C–C double bond of terminal allenes (Scheme 1.3).[10] Great advance of their methods was achieved in the following three years, changing from double asymmetric induction conditions, based on an optically pure ligand and a chiral silylboronic ester [Scheme 1.3, **9** → (*S*)-**11**], to catalytic asymmetric conditions, only based on a chiral ligand [Scheme 1.3, **9** → (*S*)-**13**]. This extensively simplified the operation and broadened the generality of their protocol.

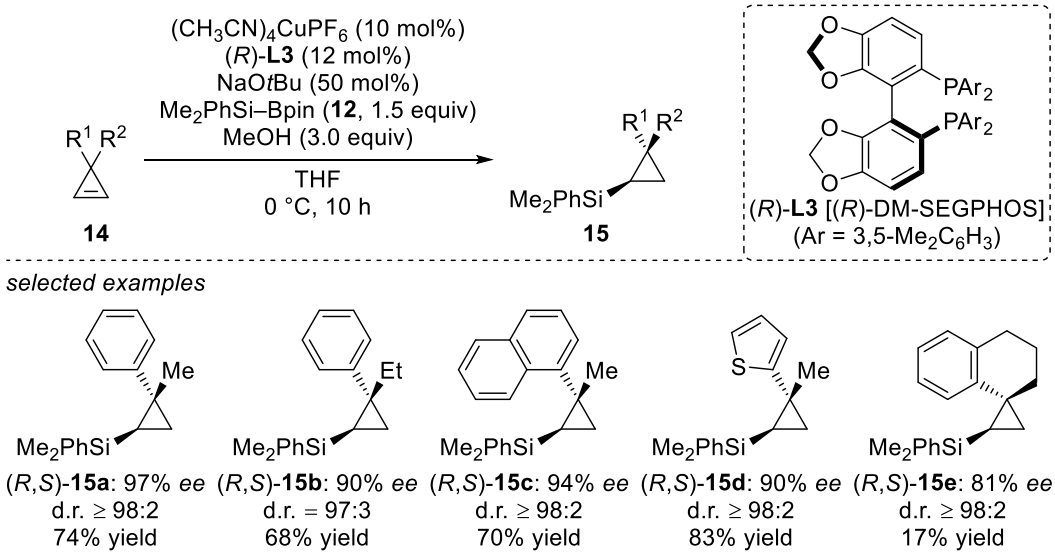
1993, *34*, 2335–2338; d) T. I. Gountchev, T. D. Tilley, *Organometallics* **1999**, *18*, 5661–5667; e) M. Oestreich, S. Rendler, *Angew. Chem. Int. Ed.* **2005**, *44*, 1661–1664; *Angew, Chem.* **2005**, *117*, 1688–1691; f) S. Rendler, M. Oestreich, C. P. Butts, G. C. Lloyd-Jones, *J. Am. Chem. Soc.* **2007**, *129*, 502–503; g) Z.-Y. Zhao, Y.-X. Nie, R.-H. Tang, G.-W. Yin, J. Cao, Z. Xu, Y.-M. Cui, Z.-J. Zheng, L.-W. Xu, *ACS Catal.* **2019**, *9*, 9110–9116; for an example about internal alkene, see: h) J. F. Jensen, B. Y. Svendsen, T. V. Ia Cour, H. L. Pedersen, M. Johannsen, *J. Am. Chem. Soc.* **2002**, *124*, 4558–4559; for examples about alkenylboronic esters, see: i) A. A. Szymaniak, C. Zhang, J. R. Coombs, J. P. Morken, *ACS Catal.* **2018**, *8*, 2897–2901; for examples about alkenylsilanes, see: j) Z. Cheng, S. Xing, J. Guo, B. Cheng, L.-F. Hu, X.-H. Zhang, Z. Lu, *Chin. J. Chem.* **2019**, *37*, 457–461.

[10] a) M. Suginome, T. Ohmura, Y. Miyake, S. Mitani, Y. Ito, M. Murakami, *J. Am. Chem. Soc.* **2003**, *125*, 11174–11175; b) T. Ohmura, M. Suginome, *Org. Lett.* **2006**, *8*, 2503–2506; c) T. Ohmura, H. Taniguchi, M. Suginome, *J. Am. Chem. Soc.* **2006**, *128*, 13682–13683.



Scheme 1.3: Palladium-catalyzed asymmetric addition to an internal C–C double bond of terminal allenes. Cp = cyclopentadienyl; Bpnd* = optically pure pinanediolatoboron; dba = dibenzylideneacetone; Bpin = pinacolatoboron.

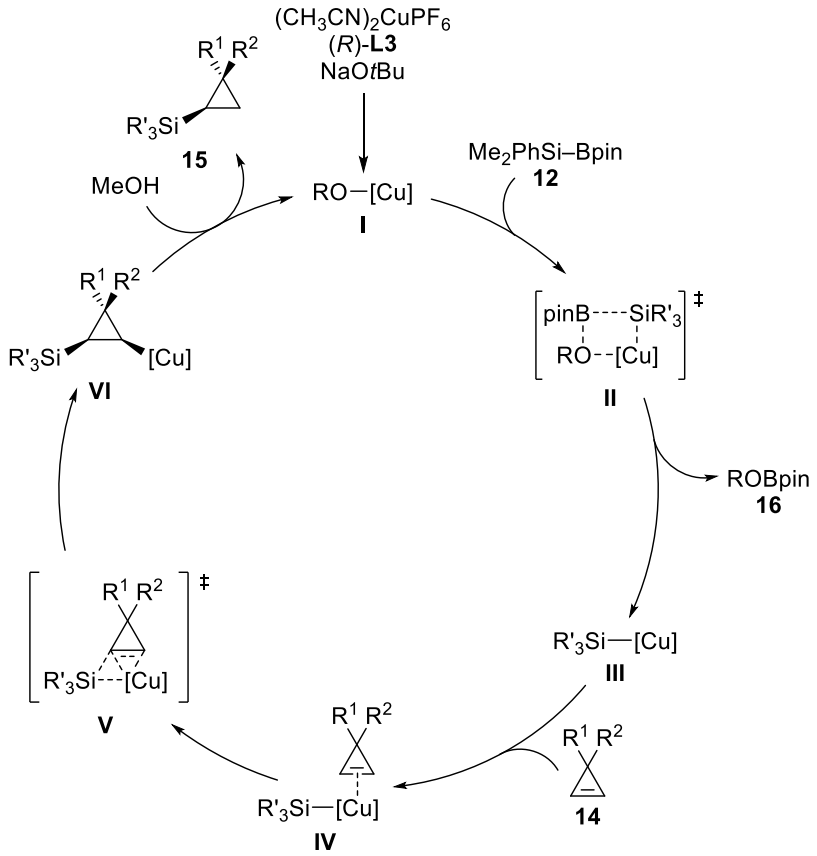
Other applications of silylboronic esters in this area involve Cu–Si species, which results from transmetalation through σ-bond metathesis. OESTREICH group applied this Cu–Si species in the asymmetric reaction of strained-ring compounds. In 2019, ZHANG and OESTREICH accomplished an asymmetric addition of silylboronic esters to cyclopropenes, providing a straightforward access to chiral cyclopropylsilanes (Scheme 1.4, **14a**–**e** → **15a**–**e**).[11] Excellent enantiomeric excesses (up to 99% *ee*) and diastereoselectivity (most d.r. ≥ 98:2) were observed under their optimized conditions. It is noteworthy that no directing group is needed for this transformation.



Scheme 1.4: Asymmetric 1,2-addition of silylboronic esters to 3,3-disubstituted cyclopropenes. THF = tetrahydrofuran.

[11] L. Zhang, M. Oestreich, *Chem. Eur. J.* **2019**, *25*, 14304–14307.

A plausible mechanistic scenario is outlined in Scheme 1.5. The catalytic cycle starts from the formation of copper alkoxide **I**, which first forms from $(CH_3CN)_4CuPF_6$, chiral ligand (*R*)-**L3** and NaO*t*Bu. Transmetalation between copper alkoxide **I** and silylboronic esters liberates [Cu]–Si species **III** and ROBpin **16** through σ-bond metathesis (**II**). Cyclopropene **14** coordinates to [Cu]–Si species **III** to form a π-complex **IV**. Then the [Cu]–Si species **III** adds across the alkene in a *syn*-fashion (**IV** → **V**), forming intermediate **VI**. Protonation generates the desired product **15** and reliberates catalyst **I**.

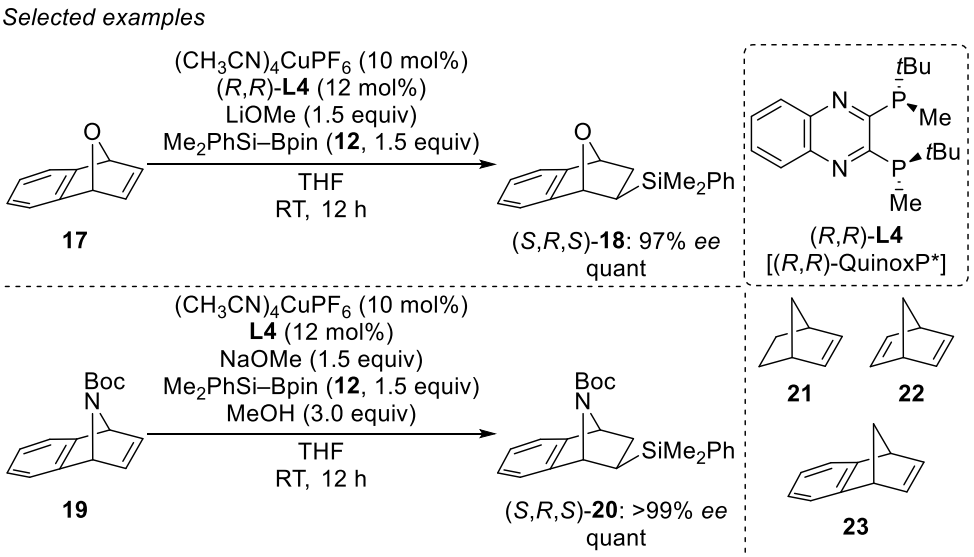


Scheme 1.5: Proposed mechanism for asymmetric 1,2-addition of silylboronic esters to 3,3-disubstituted cyclopropenes.

Complementary to this method, a highly enantioselective addition of silylboronic esters to 7-oxa- and 7-azabenzonorbornadiene derivatives was reported by CUI and OESTREICH in 2020 (Scheme 1.6).[12] Exclusive *exo*-selectivity happened throughout. Surprisingly, an opposite influence of exogenous proton source, such as methanol, was observed. MeOH is detrimental to the reaction of 7-oxabenzonorbornadiene [Scheme 1.6, **17** → (*S*,*R*,*S*)-**18**], while it is indispensable with 7-azabenzonorbornadiene [Scheme 1.6, **19** → (*S*,*R*,*S*)-**20**]. Either

[12] M. Cui, M. Oestreich, *Org*. *Lett*. **2020**, *22*, 3684–3687.

norbornene (**21**), norbornadiene (**22**) or benzonorbornene (**23**) was suitable under their optimal setup. Notably, no ring-opening product was observed under their optimal conditions.



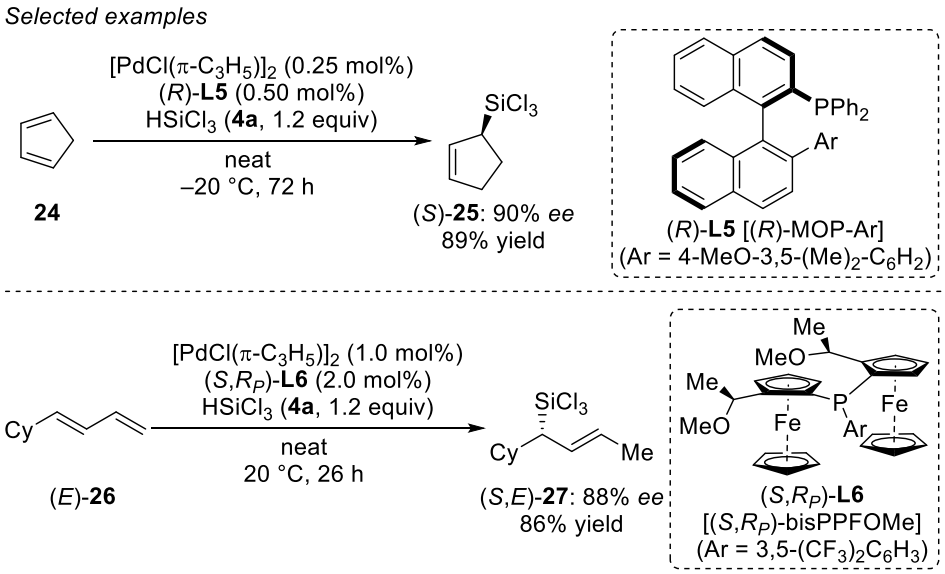
Scheme 1.6: Asymmetric 1,2-addition to 7-oxa- and 7-azabenzonorbornadiene derivatives. Boc = *tert*-butoxycarbonyl.

1.2 Asymmetric 1,4-Addition Reaction

1.2.1 Asymmetric 1,4-Addition Reaction of Dienes or Enynes

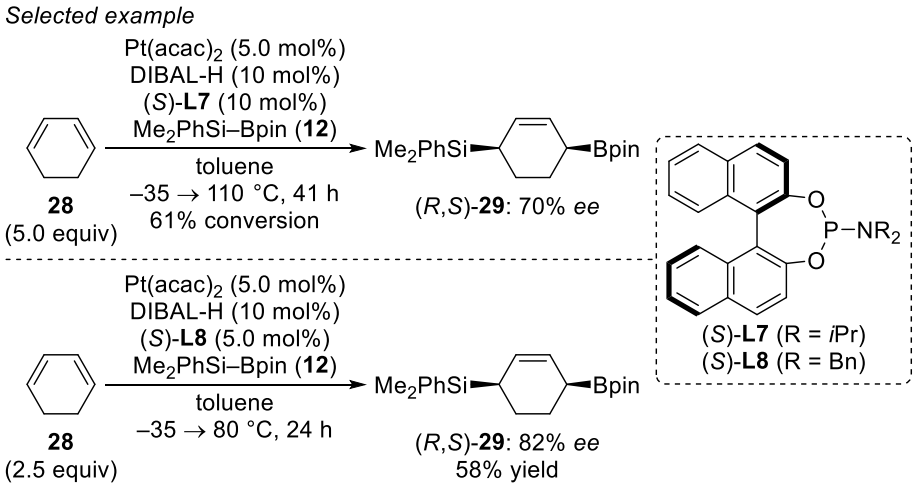
1.2.1.1 Dienes. Enantioselective 1,4-hydrosilylation of dienes, using hydrosilanes as silicon source, has been demonstrated as an efficient approach to access a large library of chiral allylic silanes.[13] Cyclic and acyclic dienes were identified as suitable substrates in this area, and various chiral ligands have been designed and investigated by using palladium complex $[PdCl(\pi\text{-}C_3H_5)]_2$ as catalyst [Scheme 1.7, **24** → (*S*)-**25** and (*E*)-**26** → (*S*,*E*)-**27**].

[13] For reviews, see: a) J. W. Han, T. Hayashi, *Tetrahydron: Asymmetry* **2010**, *21*, 2193–2197; b) T. Hayashi, *Acc*. *Chem*. *Res*. **2000**, *33*, 354–362; c) T. Hayashi, *Acta Chem*. *Scand*. **1996**, *50*, 259–266; for selected examples for cyclic dienes, see: d) T. Hayashi, J. W. Han, A. Takeda, J. Tang, K. Nohmi, K. Mukaide, H. Tsuji, Y. Uozumi, *Adv*. *Synth*. *Catal*. **2001**, *343*, 279–283; e) J. W. Han, T. Hayashi, *Tetrahedron: Asymmetry* **2002**, *13*, 325–331; for a selected example for acyclic dienes, see: f) J. W. Han, N. Tokunaga, T. Hayashi, *Helv*. *Chim*. *Acta* **2002**, *85*, 3848–3854.



Scheme 1.7: Asymmetric 1,4-hydrosilylation of dienes.

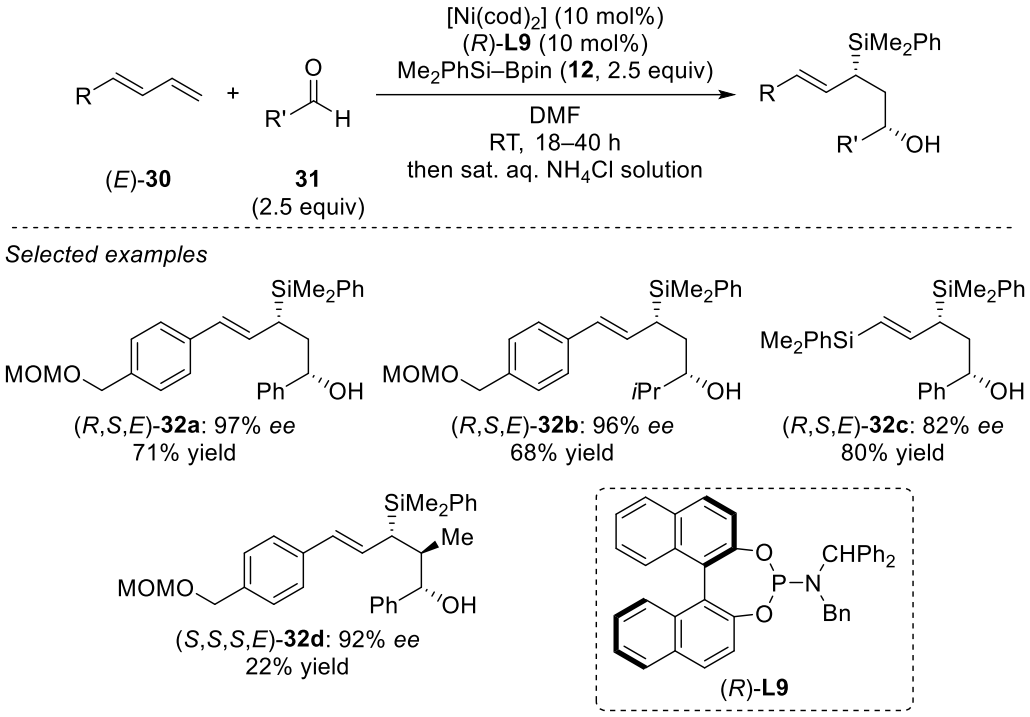
Enantioselective 1,4-silaboration of dienes was investigated carefully by MOBERG, JUTAND and co-workers [Scheme 1.8, **28** → (*R*,*S*)-**29**].[14] In 2005, a Pt/(*S*)-**L7** catalysis was applied in the asymmetric addition of silylboronic esters to cyclohexa-1,3-diene, although only moderate enantioselectivity (70% *ee*) was obtained (Scheme 1.8, top). This started their exploration in the asymmetric addition reaction of cyclic 1,3-dienes, using catalysts based on metals in group 10. A systematic survey of reaction conditions increased the enantioselection to 82% *ee* (Scheme 1.8, bottom). Other catalysts, such as $Ni(acac)_2$, only resulted in low levels of enantiomeric excess.



Scheme 1.8: Enantioselective silaboration of 1,3-cyclohexadiene. DIBAL-H = diisobutylaluminium hydride. acac = acetylacetonate.

[14] a) M. Gerdin, C. Moberg, *Adv. Synth. Catal.* **2005**, *347*, 749–753; b) G. Durieux, M. Gerdin, C. Moberg, A. Jutand, *Eur. J. Inorg. Chem.* **2008**, 4236–4241; c) M. Gerdin, M. Penhoat, R. Zalubovskis, C. Pétermann, C. Moberg, *J. Organomet. Chem.* **2008**, *693*, 3519–3526.

In 2012, SAITO, KOBAYSHI and SATO reported a nickel-catalyzed enantio- and diastereoselective 1,2-difunctionalization of 1,3-dienes, simultaneously constructing multiple stereogenic centers with high efficiency [Scheme 1.9, (*E*)-**30a**–**c** → (*E*)-**32a**–**c**].[15] Diastereoselectivity was excellent throughout, and enantioselection was good (most with more than 90% *ee*). Internal diene (*E*,*E*)-**30d** was also tried and did work under the optimal conditions, delivering the desired product (*S*,*S*,*S*,*E*)-**32d** with high enantio- and diastereoselectivity, although in a low yield (22%).



Scheme 1.9: Asymmetric 1,2-difunctionalization of dienes. DMF = dimethylformamide; cod = cycloocta-1,5-diene; MOM = methoxymethyl.

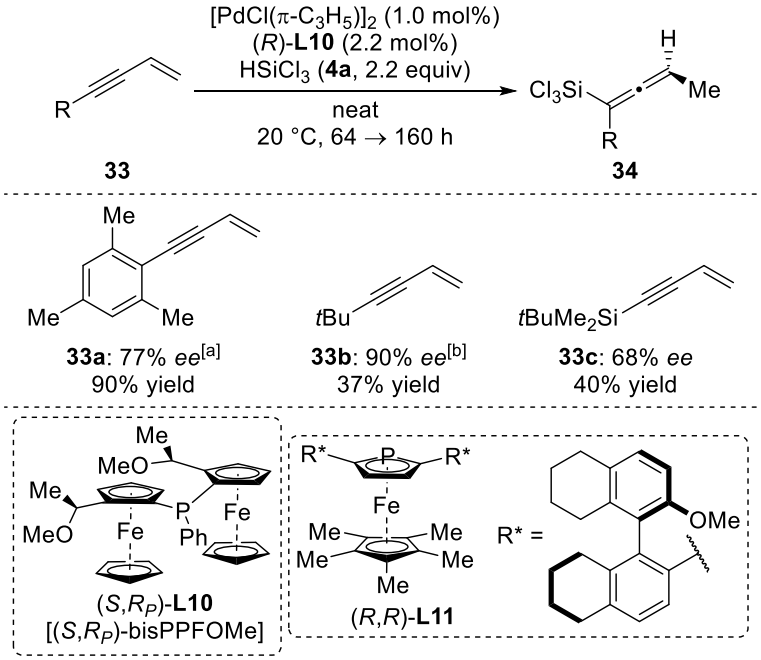
1.2.1.2 Enynes. Asymmetric 1,4-addition to enynes by using $HSiCl_3$ (**23**) as silicon source provides new avenues for the synthesis of axially chiral allenyl silanes.[16] In 2001, HAYASHI and co-workers reported their work about asymmetric 1,4-hydrosilylation of enynes by using $[PdCl(\pi\text{-}C_3H_5)]_2$ as catalyst and bisPPFOMe [(*S*,R_P)-**L10**] as ligand (Scheme 1.10, **33** → **34**).[17] Three substrates were researched in their work, and moderate to high levels of enantioselection were reported under their optimal conditions. Yields were comparatively low for **33b** and **33c**. Their following research about 1,4-hydrosilylation of enynes concentrated on new ligand design. In 2006, they found chiral ligand (*R*,*R*)-**L11** was superior in the

[15] N. Saito, A. Kobayashi, Y. Sato, *Angew. Chem. Int. Ed.* **2012**, *51*, 1228–1231, *Angew. Chem.* **2012**, *124*, 1254–1257.

[16] For a recent review, see: L. Fu, S. Greßies, P. Chen, G. Liu, *Chin. J. Chem.* **2020**, *38*, 91–100.

[17] J. W. Han, N. Tokunaga, T. Hayashi, *J. Am. Chem. Soc.* **2001**, *123*, 12915–12916.

reaction of **33b**, compared with chiral ligand (*S*,*R*$_P$)-**L10**.[18] 80% yield of 1,4-addition product (*S*)-**34b** was obtained with slightly higher enantioselectivity (92% *ee*). Other new ligands prepared in this work proved to be less efficient in both yields and levels of enantioinduction.



Scheme 1.10: Asymmetric 1,4-hydrosilylation of enynes. [a] 1.1 equiv $HSiCl_3$ was used. [b] Reaction was conducted at 0 °C.

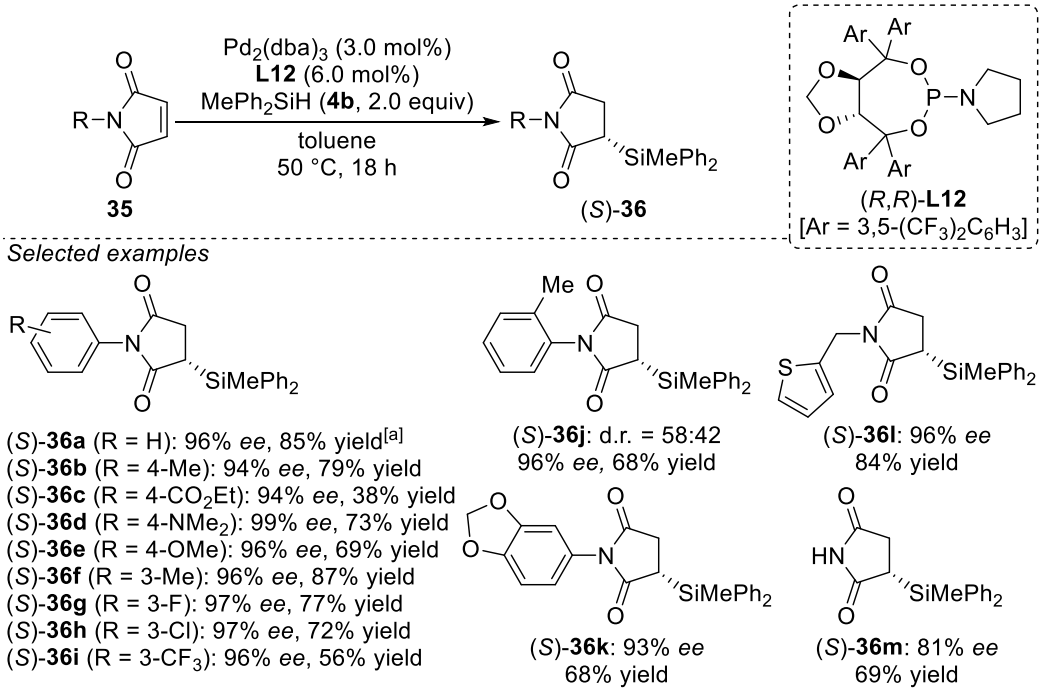
1.2.2 Asymmetric 1,4-Addition Reaction of *α,β*-Unsaturated Carbonyl and Carboxyl Compounds

1.2.2.1 Hydrosilanes. Methods for the construction of chiral silanes through asymmetric conjugate addition of hydrosilanes to *α,β*-unsaturated carbonyl compounds and their derivatives are elusive due to challenges in chemo-, regio- and enantioselectivity. In 2020, XU and co-workers reported their investigation about the palladium-catalyzed asymmetric hydrosilylation of maleimides [Scheme 1.11, **35a**–**m** → (*S*)-**36a**–**m**].[19] Chemoselectivity becomes one of the challenges in this work because the reduction of C–C double bond is less energetically favored. By using $Pd_2(dba)_3{\cdot}CHCl_3$ as catalyst and a chiral TADDOL-derived phosphoramidite (*R*,*R*)-**L12** as ligand, they realized the construction of chiral silyl succinimides in excellect yields (up to 99% yield) with excellent enantioselectivity (up to 99% ee). Functional groups include an ester as in (*S*)-**36c**, an amine as in (*S*)-**36d**, an alkoxy group as in (*S*)-**36e**, halo groups as in (*S*)-**36g** and (*S*)-**36h**, a trifluoromethyl group as in (*S*)-

[18] M. Ogasawara, A. Ito, K. Yoshida, T. Hayashi, *Organometallics* **2006**, *25*, 2715–2718.

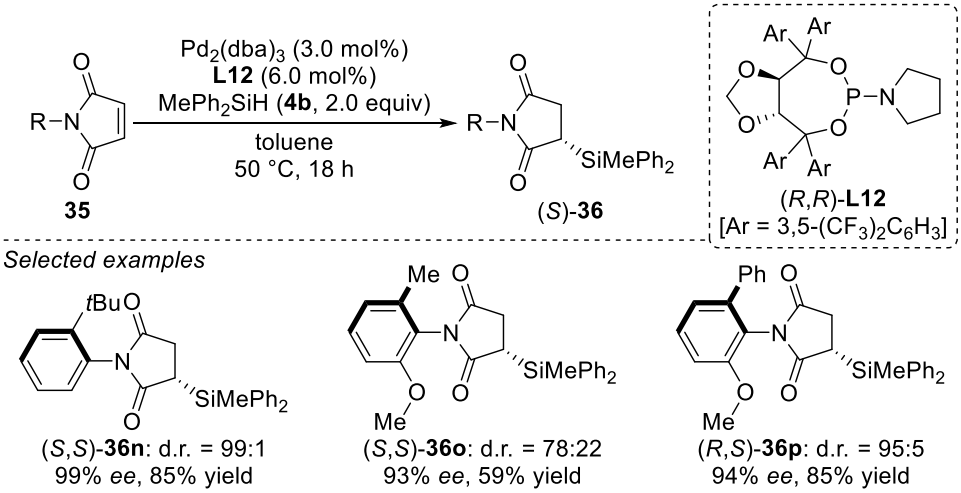
[19] X.-W. Gu, Y.-L. Sun, J.-L. Xie, X.-B. Wang, Z. Xu, G.-W. Yin, L. Li, K.-F. Yang, L.-W. Xu, *Nat. Commun*. **2020**, *11*, 2904.

36i, an acetal as in (*S*)-**36k**, and a thiophene as in (*S*)-**36l**. Unprotected maleimide **35m** worked smoothly, delivering the hydrosilylation product (*S*)-**36m** in 69% yield with 81% *ee*. A gram-scale reaction of **35a** was conducted under the optimal setup, and a slightly lower yield was observed, with hardly any erosion of enantioselection.



Scheme 1.11: Asymmetric addition of hydrosilanes to internal alkenes. [a] Gram-scale reaction of **35a** afforded the silylation product (*S*)-**36a** in 74% yield with 96% *ee*.

As seen in (*S*)-**36j** in Scheme 1.11, only low diastereoselectivity was observed when *ortho*-substituted maleimide **35j** was subjected to their optimal conditions. Diastereoselection became an urgent issue for them. They found high enantio- and diastereoselectivity could be obtained by increasing the steric congestion in the *β*-position of phenyl ring [Scheme 1.12, **35n**–**p** → (*S*)-**36n**–**p**].[19] Several follow-up transformations by using hydrosilylation product (*S*)-**36a** as starting material were conducted to demonstrate the utility of their method (not shown).

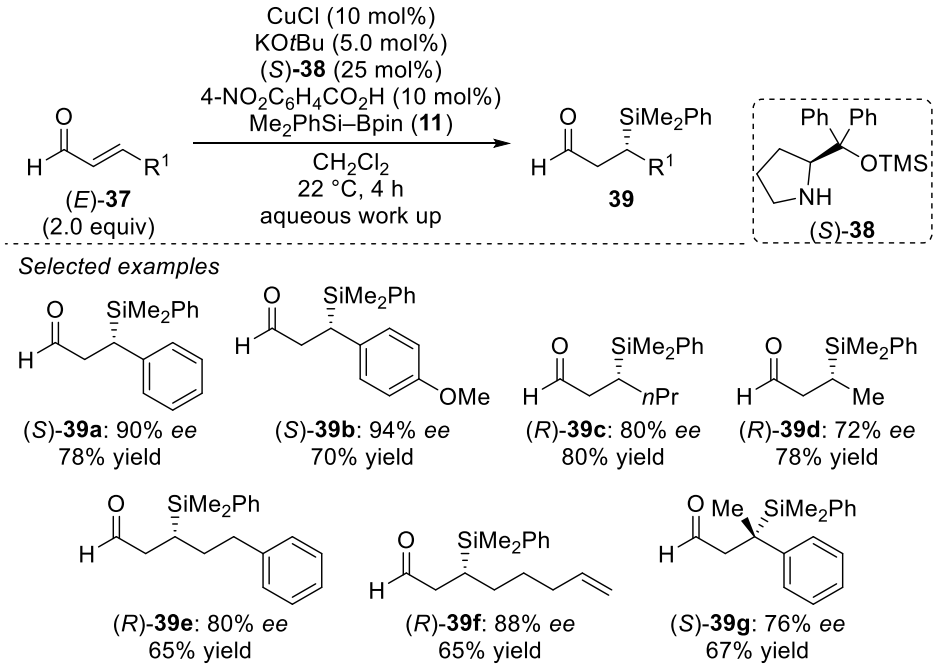


Scheme 1.12: Palladium-catalyzed enantio- and diastereoselective hydrosilylation.

1.2.2.2 Silylboronic esters. Contrary to little progress about hydrosilylation of *α*,*β*-unsaturated carbonyl compounds and their derivatives, asymmetric 1,4-addition reaction by using silylboronic esters as silicon source has been researched deeply and significantly advanced. Various catalytic systems have been reported, respectively. This part is arranged according to the *α*,*β*-unsaturated acceptors used in the research.

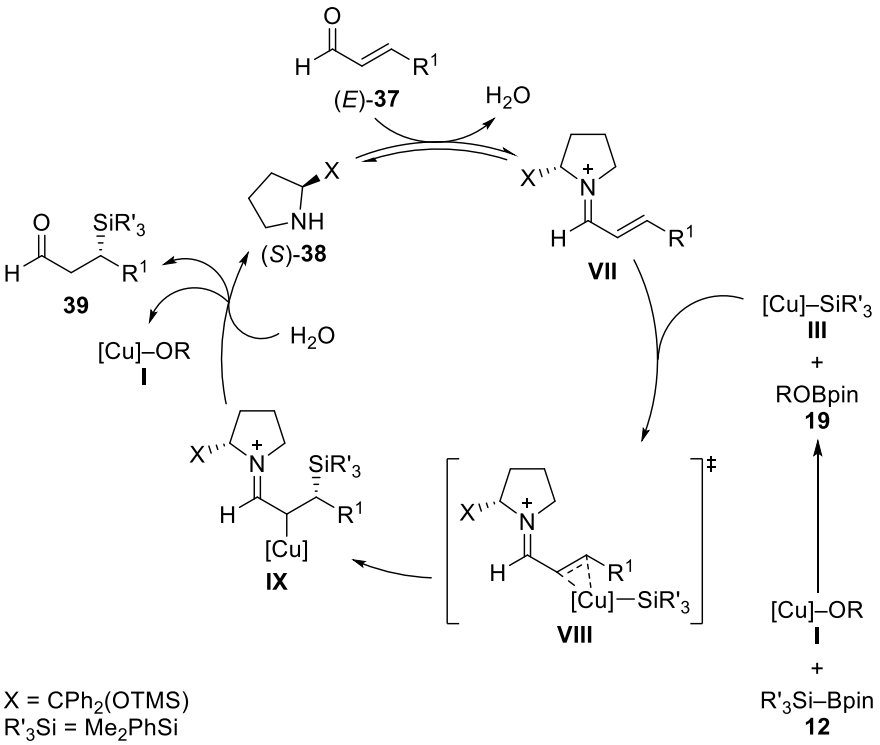
In 2011, IBRAHEM, CÓRDOVA and co-workers disclosed an enantioselective silyl transfer to *α*,*β*-unsaturated aldehydes, providing a mild and efficient method for chiral *β*-silyl aldehydes in good yields with high enantioselectivity (up to 94% *ee*) [Scheme 1.13, (*E*)-**37a**–**g** → **39a**–**g**].[20] This new approach proceeded through combination of amine-mediated iminium activation and copper-aided nucleophilic activation of silylboronic esters. Exclusive 1,4-selectivity took place in the reaction. Control experiments showed that KO*t*Bu and 4-$NO_2C_6H_4CO_2H$ are critical (no KO*t*Bu → 45% yield, 80% *ee*; no 4-$NO_2C_6H_4CO_2H$ → 55% yield, 25% *ee*). Functional group tolerance was good under their setup. Another C–C double bond as in (*R*)-**39f** was intact after the reaction. *β*-Methyl-substituted aldehyde (*E*)-**37g** proved to be reactive, making this method suitable for the preparation of silanes with a quaternary stereocenter. *α*,*β*-Unsaturated esters were tried under their optimal conditions, yet no desired product was detected. Further derivatizations of *β*-silylation products were conducted to illustrate the utility of this method (not shown).

[20] I. Ibrahem, S. Santoro, F. Himo, A. Córdova, *Adv. Synth. Catal.* **2011**, *353*, 245–252.



Scheme 1.13: Asymmetric silyl transfer to *α*,*β*-unsaturated aldehydes.

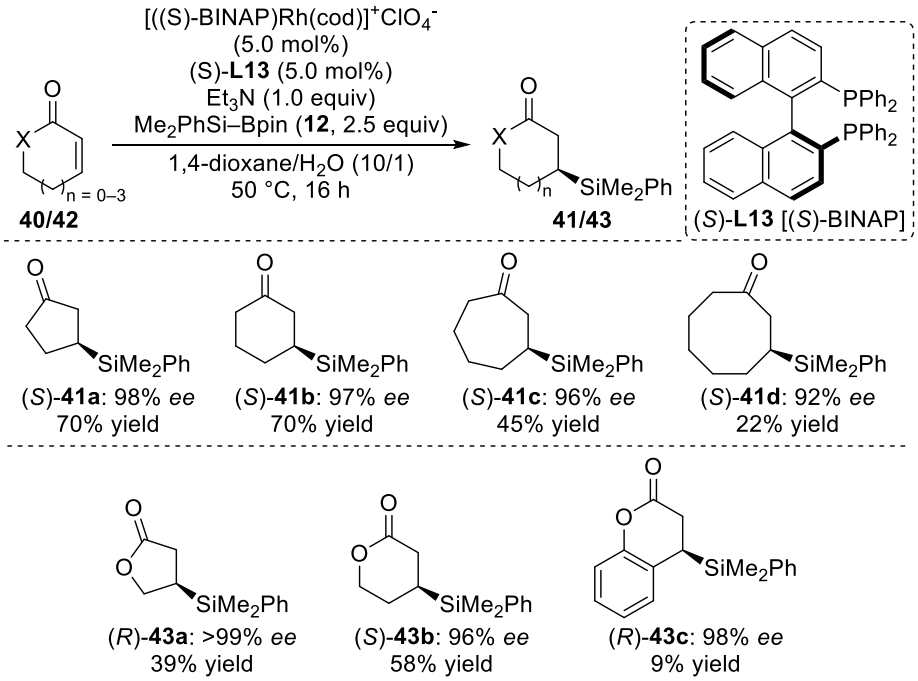
To shed light on the reaction mechanism, density functional theory (DFT) calculations were performed on the silylation step, and a plausible reaction pathway was proposed (Scheme 1.14). Activation of *α*,*β*-unsaturated aldehydes **37** with chiral amine (*S*)-**38** forms the intermediate **VII**, which was confirmed through ^{1}H NMR and HRMS analysis. Intermediate **VII** first coordinates to [Cu]–Si species **III**, which originates from the reaction between copper salt, base and silylboronic esters, and then Cu–Si species **III** adds caross the C–C double bond to generate a [Cu]–C species **IX** through transition state **VIII**. Hydrolysis of intermediate **IX** liberates the silylation product **39**, regenerating chiral amine (*S*)-**38** and [Cu]–O complex **I**.



Scheme 1.14: A possible mechanistic scenario for asymmetric silyl transfer to *α*,*β*-unsaturated aldehydes (counteranion is undefined and omitted for clarity).

α,*β*-Unsaturated ketones and esters have been identified as suitable substrates in the asymmetric conjugate silyl transfer by HOVEYDA and co-workers, KOBAYASHI and co-workers, OESTREICH and co-workers, PROCTER and co-workers, and XU and co-workers, independently. In 2006 and 2009, OESTREICH group demonstrated their application of Rh/BINAP catalysis in the enantioselective conjugate addition of silylboronic esters to cyclic *α*,*β*-unsaturated ketones and esters [Scheme 1.15, **40a**–**d** → (*S*)-**41a**–**d** and **42a**–**c** → **43a**–**c**].[21] Seven substrates were tried under the optimal conditions, delivering the corresponding products in synthetically useful yields with excellent enantioinduction (more than 90% *ee*). Assessment of bases in the reaction of **40b** revealed that K_3PO_4 (98% *ee*, 71% yield) was superior to 2,2,6,6-tetramethylpiperidine (TMP, 96% *ee*, 75% yield), morpholine (trace), KOH (59% *ee*, 68% yield) and Et_3N (97% *ee*, 70% yield).

[21] a) C. Walter, G. Auer, M. Oestreich, *Angew. Chem. Int. Ed.* **2006**, *45*, 5675–5677; *Angew. Chem.* **2006**, *118*, 5803–5805; b) C. Walter, R. Fröhlich, M. Oestreich, *Tetrahedron* **2009**, *65*, 5513–5520.



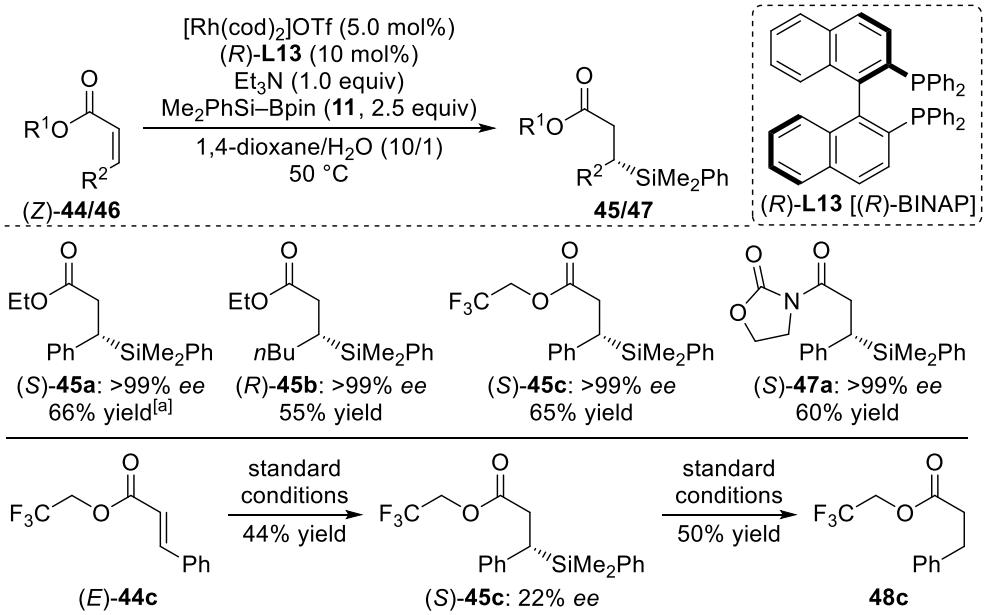
Scheme 1.15: Asymmetric conjugate silyl transfer to cyclic *α*,*β*-unsaturated acceptors.

In their following research, they expanded the substrate scope to acyclic *α*,*β*-unsaturated esters [Scheme 1.16, (*Z*)-**44a**–**c** → **45a**–**c** and (*Z*)-**46a** → **47a**].[22,21b] Changing substituents in the *β*-position from an aryl group as in (*Z*)-**44a**, to an alkyl group as in (*Z*)-**44b** had a negligible influence on enantioinduction. Activated *α*,*β*-unsaturated amide (*Z*)-**46a** reacted well, providing the enantioenriched silane (*S*)-**47a** in 60% yield with more than 99% *ee*. Compared to *E*-configured esters, *Z*-configured ones worked more efficiently with regard to yield and enantioselection (Scheme 1.16, bottom). (*E*)-**44c** was subjected to their optimal setup, and 44% yield of desired product (*S*)-**45c** was obtained with low *ee* value (22% ee), along with the formation of the reduction product **48c** in 42% yield. Further investigation verified that protodesilylation of (*S*)-**45c** occurred under their reaction conditions, arriving at the reduction product **48c**. Surprisingly, **45c** achieved from either (*Z*)- and (*E*)-configured **44c** has the same configuration, which indicated different transition states in the reaction. Utility of this asymmetric conjugate silyl transfer strategy was demonstrated in the synthesis of the C7–C16 fragment of (+)-neopeltolide[23] and the C17–C25 fragment of dermostain A[24] (not shown).

[22] C. Walter, M. Oestreich, *Angew*. *Chem*. *Int*. *Ed*. **2008**, *47*, 3818–3820; *Angew*. *Chem*. **2008**, *120*, 3878–3880.

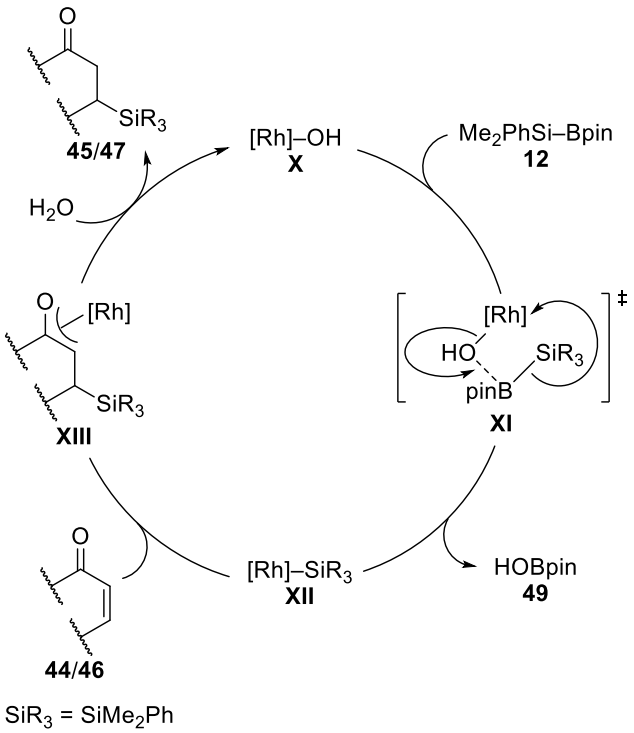
[23] E. Hartmann, M. Oestreich, *Angew*. *Chem*. *Int*. *Ed*. **2010**, *49*, 6195–6198; *Angew*. *Chem*. **2010**, *122*, 6331–6334.

[24] E. Hartmann, M. Oestreich, *Org*. *Lett*. **2012**, *14*, 2406–2409.



Scheme 1.16: Asymmetric conjugate silyl transfer to acyclic *α*,*β*-unsaturated esters. [a] reaction was carried out at 45 °C.

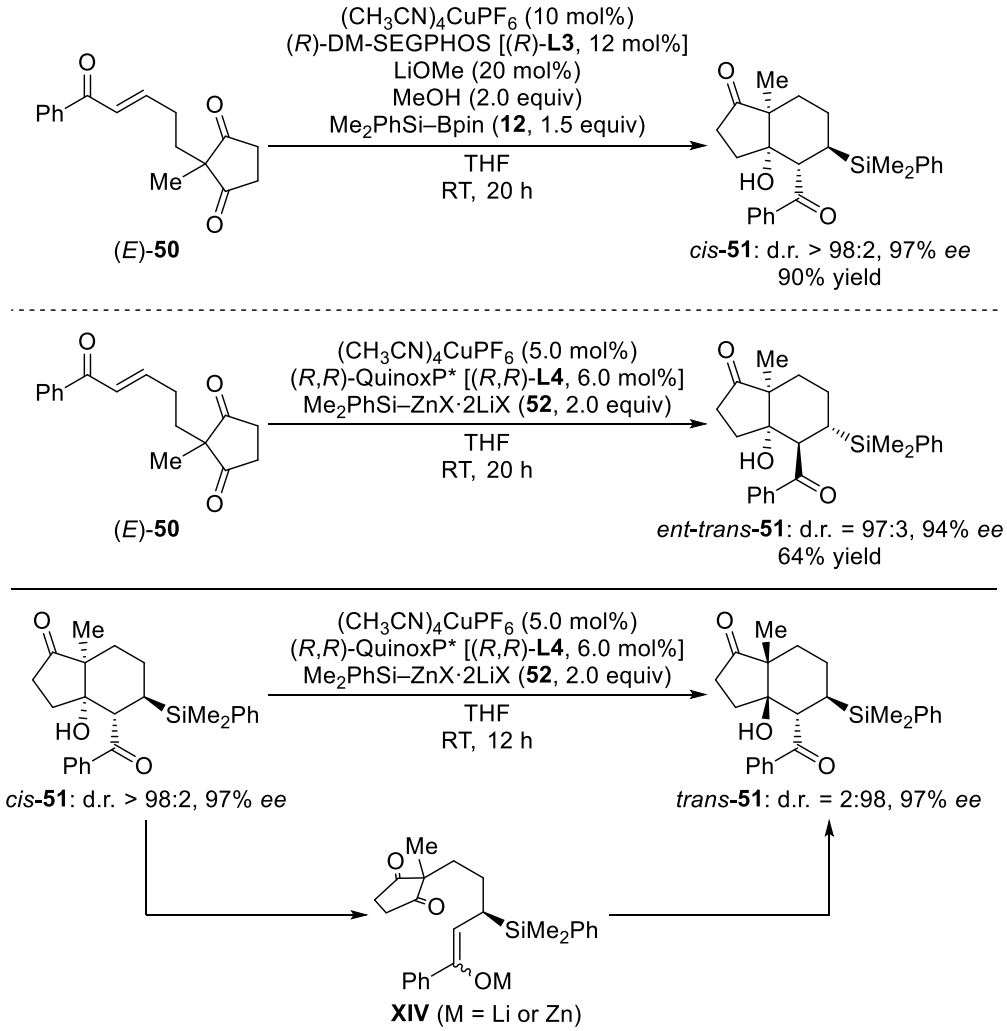
A tentative mechanism was proposed (Scheme 1.17). The catalytic cycle starts with the activation of silylboronic ester. [Rh]–OH complex **X**, which comes from the reaction between $[Rh(cod)_2]OTf$, (*R*)-**L13**, Et_3N and H_2O, reacts with silylboronic ester **12** to form a nucleophilic [Rh]–SiR_3 species **XII** and HOBpin (**49**) in a concerted way (**X** → **XI** → **XII**). 1,4-selective addition of [Rh]–SiR_3 species **XII** to *α*,*β*-unsaturated esters forms Rh enolate **XIII**. Its hydrolysis liberates the silylation product and regenerates catalyst [Rh]–OH complex **X**, which starts a new catalytic cycle.



Scheme 1.17: A tentative mechanistic cycle.

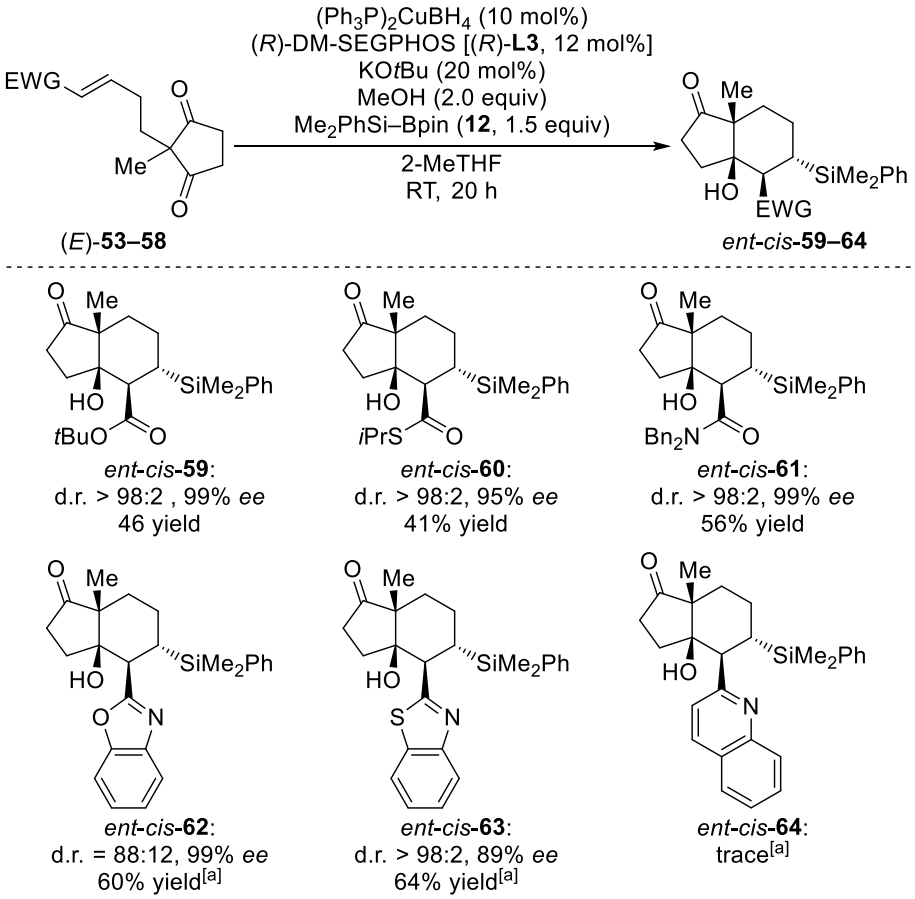
In 2021, ZHANG and OESTREICH reported their research about diastereotopic group-selective intramolecular aldol reactions through a 1,4-addition–cyclization domino process [Scheme 1.18, (*E*)-**50** → *cis*-**51** and (*E*)-**50** → *ent-trans*-**51**].[25] Four continuous stereocenters were formed in this new procedure with excellent diastereo- and enantioselectivity. The use of silicon nucleophile had a significant influence in the diastereoselectivity of the intramolecular aldol reaction. Silylboronic esters preferred *cis*-selectivity while organozinc reagents led to *trans*-selectivity. Distinguished selectivity arised from *cis-trans* isomerization through a retro-aldol–aldol process in the transformation, which was mediated by the more basic organozinc reagents (Scheme 1.18, *cis*-**51** → *trans*-**51**). Reaction of *cis*-**51** under the standard conditions with organozinc reagents **52** afforded *trans*-**51** with hardly any erosion of diastereo- and enantioselection. Large-scale reaction of (*E*)-**50** was conducted with silylboronic ester **12**, providing the desired product *ent-trans*-**51** in 43% yield with a slight decrease in stereocontrol (d.r. = 97:3, 92% *ee*). Subsequent transformations of **51** by TAMAO–FLEMING oxidation and dehydration were conducted to further highlight the synthetic utility of this method (not shown).

[25] L. Zhang, M. Oestreich, *ACS Catal.* **2021**, *11*, 3516–3522.



Scheme 1.18: Diastereotopic group-selective intramolecular aldol reactions.

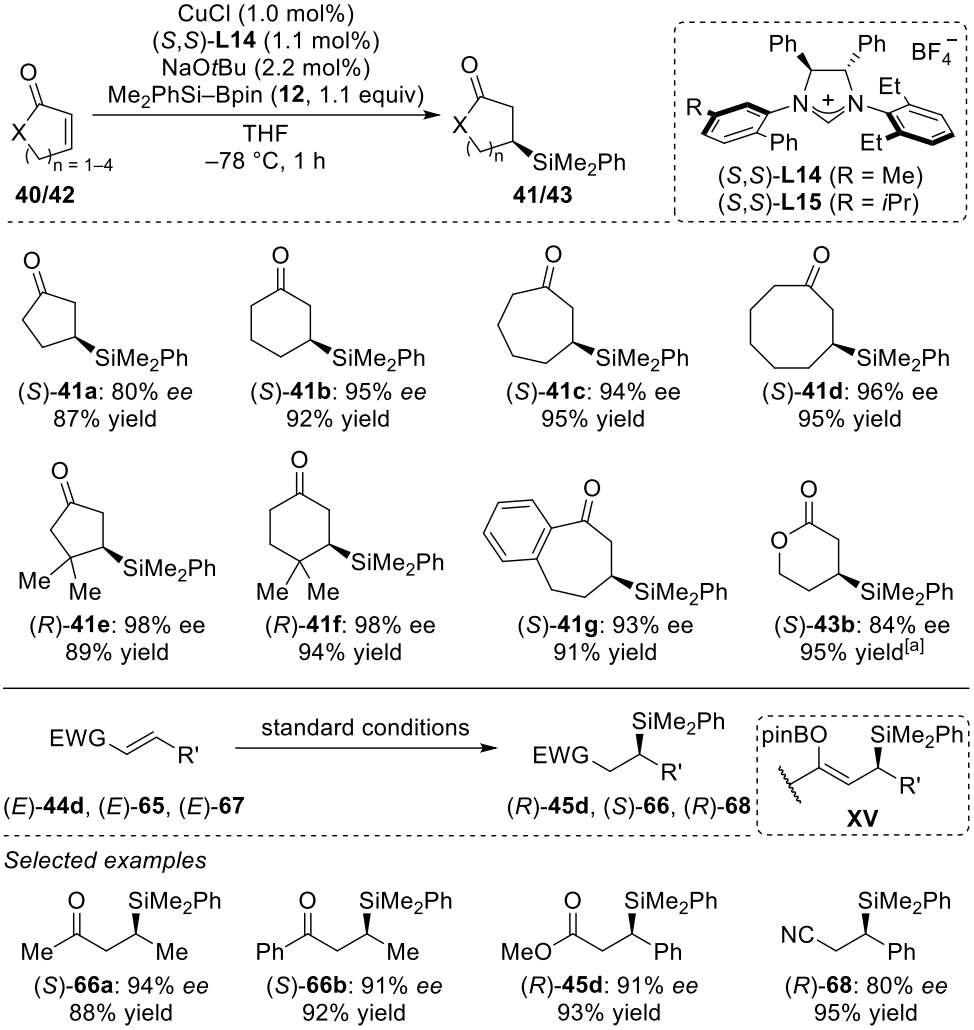
Aside from ketones as electron-withdrawing groups in the substrate, an ester as in (*E*)-**53**, a thioester as in (*E*)-**54**, an amide as in (*E*)-**55** and heterocycles, such as a benzoxazole as in (*E*)-**56** and a benzothiazole as in (*E*)-**57** were compatible in this reaction by using silylboronic ester **12** as the silicon source (Scheme 1.19). Subtle modification of reaction conditions was necessary to achieve good results. Excellent levels of diastereo- and enantioselectivity were achieved throughout, although yields were only moderate. Quinoline-derived acceptor (*E*)-**58** was not efficient under the reaction conditions, only resulting in trace amounts of product *ent-cis*-**64**.



Scheme 1.19: Different electron-withdrawing groups (EWG). 2-MeTHF = 2-methyltetrahydrofuran. [a] CuCl was used instead of $(Ph_3P)_2CuBH_4$ and THF was used instead of 2-MeTHF.

The HOVEYDA group, PROCTER group and XU group independently investigated the use of chiral Cu/NHC (N-heterocyclic carbene) complexs in asymmetric 1,4-addition reactions by using silylboronic esters as the silicon source. In 2010, a general and efficient approach to make chiral silanes through enantioselective addition of silylboronic esters to *α*,*β*-unsaturated acceptors was reported by HOVEYDA and co-workers [Scheme 1.20, **40a**–**g** → **41a**–**g**, **42b** → **43b**, (*E*)-**44d** → (*R*)-**45d**, and (*E*)-**65a**–**b** → **66a**–**b**].[26] High levels of enantioselection were achieved by using CuCl/NHC catalysis. This procedure is applicable to both cyclic and acyclic *α*,*β*-unsaturated ketones and esters, delivering the enantioenriched silanes in excellent yields. Acrylonitrile (*E*)-**67** was compatible under their optimal setup, giving the desired product (*R*)-**68** in 95% yield with 80% *ee*. Exogenous proton sources were not required to close the catalytic cycle in this transformation because of the formation of boron enolate **XV**, which would convert into the target products through work-up with water.

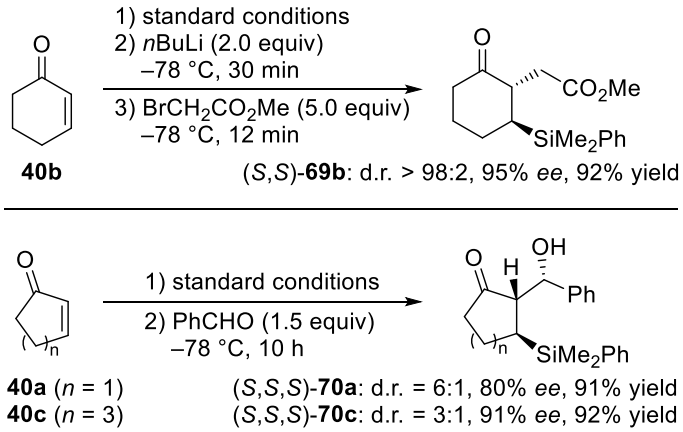
[26] K.-s. Lee, A. H. Hoveyda, *J. Am. Chem. Soc.* **2010**, *132*, 2898–2900.



Scheme 1.20: Asymmetric conjugate addition of silylboronic ester **12** to cyclic and acyclic *α*,*β*-unsaturated acceptors. [a] 2.0 mol% CuCl was used with 2.2 mol% (*S*,*S*)-**L15** and 4.4 mol% NaO*t*Bu.

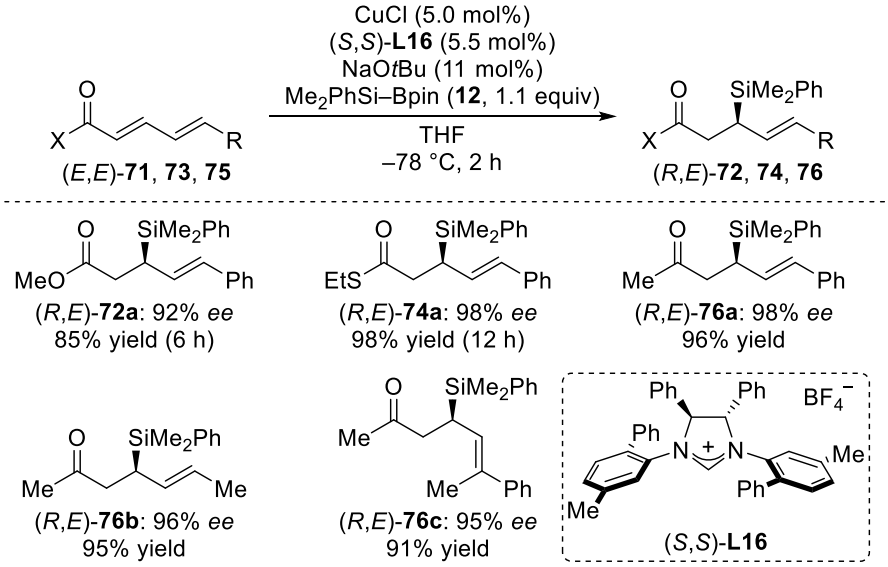
As part of their work, a one-pot two-step procedure was developed to construct chiral polysubstituted cyclic silanes. Boron enolate **XV**, obtained during their reaction (cf. Scheme 1.20), was used as linchpin for further C–C bond formation. Cyclic *α*,*β*-unsaturated ketone **40b** could be easily converted to chiral ketoester (*S*,*S*)-**69b**, which had been used as an intermediate in the preparation of (+)-erysotramidine (Scheme 1.21, top).[27] 92% yield of (*S*,*S*)-**69b** was obtained as a single diastereomer with 95% *ee*. By adding benzaldehyde directly after the asymmetric 1,4-addition reaction of **40a** and **40c**, three consecutive chiral carbon centers were formed with moderate diastereocontrol (Scheme 1.21, bottom).

[27] L. F. Tietze, N. Tölle, D. Kratzert, D. Stalke, *Org. Lett.* **2009**, *11*, 5230–5233.



Scheme 1.21: One-pot two-step procedures for chiral polysubstituted cyclic silanes.

In 2012, their method was successfully expanded to dienones and dienoates as substrates [Scheme 1.22, (*E*,*E*)-**71a** → (*R*,*E*)-**72a**, (*E*,*E*)-**73a** → (*R*,*E*)-**74a**, and (*E*,*E*)-**75a**–**c** → (*R*,*E*)-**76a**–**c**].[28] Excellent regio- and enantioselectivity were observed in this efficient method. Five substrates were subjected to their optimized reaction conditions, delivering the target allylic silanes in high isolated yields and with excellent diastereo- and enantioselection (all *ee* values >90%).

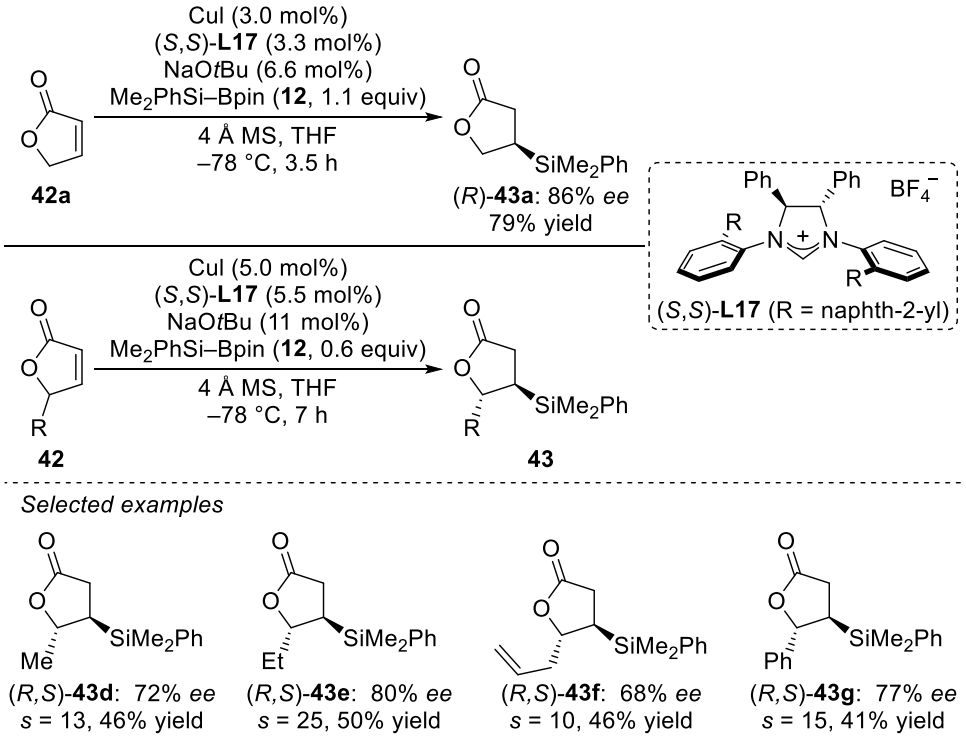


Scheme 1.22: Asymmetric 1,4-addition to dienones and dienoates.

To fill the gaps of this strategy, asymmetric conjugate addition of Me_2PhSi–Bpin (**12**) to 5-membered lactones by using Cu/NHC catalysis has been accomplished by PROCTER and co-

[28] K.-s. Lee, H. Wu, F. Haeffner, A. H. Hoveyda, *Organometallics* **2012**, *31*, 7823–7826.

workers [Scheme 1.23, **42a** → (*R*)-**43a**].[29] 79% yield of the desired product was achieved with a high level of enantioselectivity. To further expand the toolbox for this area, They combined asymmetric conjugate addition with kinetic resolution, providing a new avenue to optically pure polysubstituted lactones (Scheme 1.23, **42d**–**g** → **43d**–**g**).[29b] The utility of this method was elaborated by converting chiral (*R*,*S*)-**43d** into the natural product (+)-blastmycinone (not shown).



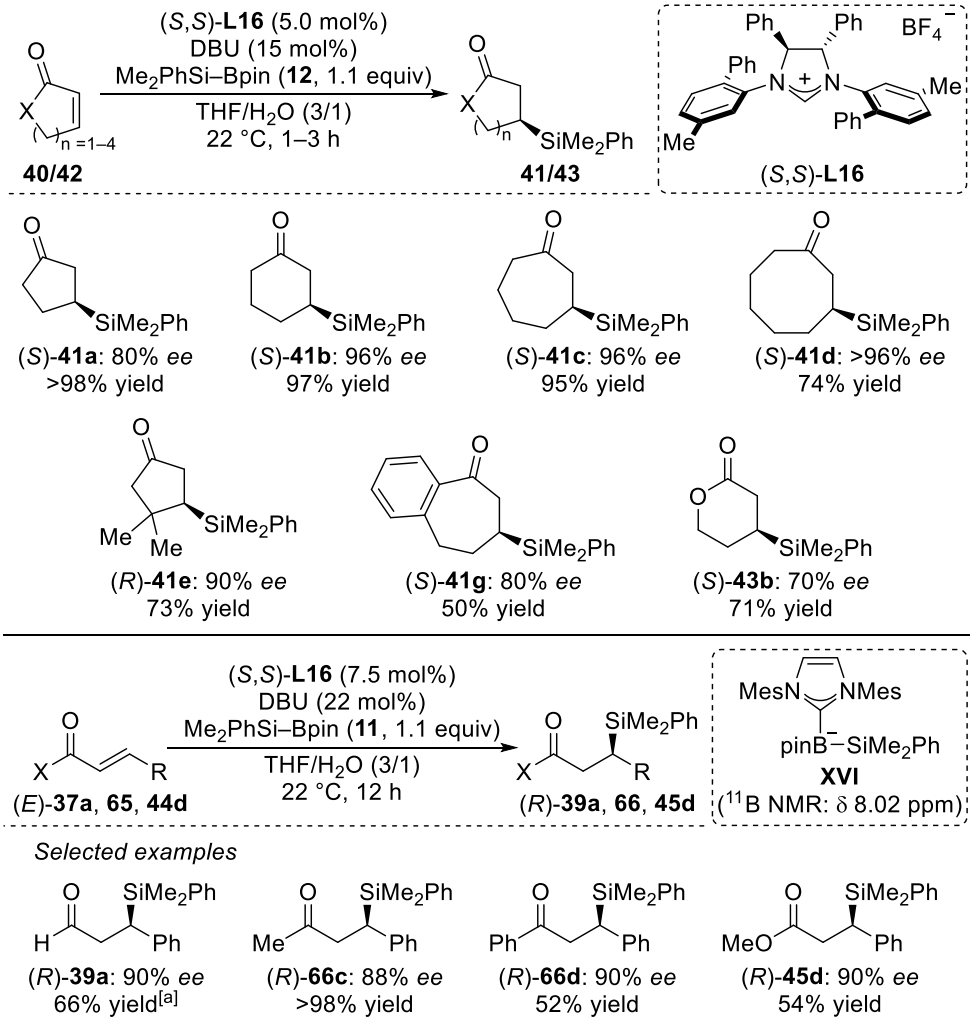
Scheme 1.23: Enantioselective addition of silylboronic esters to 5-membered lactones.

Another significant advance in the NHC-catalyzed asymmetric silyl transfer to cyclic and acyclic *α*,*β*-unsaturated carbonyl compounds has been made by HOVEYDA group in 2011 (Scheme 1.24, **40** → **41**, **42** → **43**, (*E*)-**37a** → (*R*)-**39a**, (*E*)-**65** → (*R*)-**66** and (*E*)-**44d** → (*R*)-**45d**).[30] Direct activation of silylboronic esters was accomplished in the presence of NHC (cf. **XVI**; *note*: it was detected by ^{11}B NMR in the reaction of Me_2PhSi–Bpin and an achiral NHC in the presence of DBU and THF-d_8). *α*,*β*-Unsaturated aldehydes, ketones and esters proved to be efficient substrates under their optimal setup. Mechanistic studies rendered a radical pathway in this reaction unlikely. They also revealed that the solubility of 1,8-diazabicyclo[5.4.0]undec-7-ene (DBU) in H_2O and THF helped transport a sufficient amount

[29] a) H. Y. Harb, K. D. Collins, J. V. G. Altur, S. Bowker, L. Campbell, D. J. Procter, *Org. Lett.* **2010**, *12*, 5446–5449; b) V. Pace, J. P. Rae, H. Y. Harb, D. J. Procter, *Chem. Commun.* **2013**, *49*, 5150–5152.

[30] a) J. M. O'Brien, A. H. Hoveyda, *J. Am. Chem. Soc.* **2011**, *133*, 7712–7715; b) H. Wu, J. M. Garcia, F. Haeffner, S. Radomkit, A. R. Zhugralin, A. H. Hoveyda, *J. Am. Chem. Soc.* **2015**, *137*, 10585–10602.

of hydroxide ions from H_2O to THF in the form of $HDBU^{+\cdot}{}^{-}OH$, which would transform the Bpin group of Me_2PhSi–Bpin (**12**) into the $B(OH)_2$ unit. This newly formed silylboronic acid is more reactive and leads to the formation of NHC-silylboronic acid complex efficiently (cf. **XVI**). Appropriate concentration of hydroxide ions in THF was pivotal, because too high concentration would result in decomposition of catalyst and silylboronic acid.

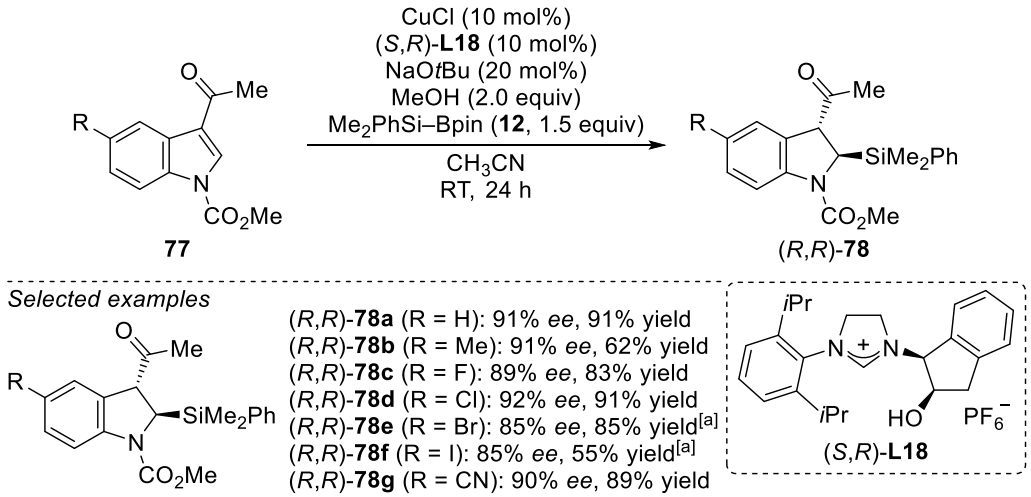


Scheme 1.24: NHC-catalyzed asymmetric silyl transfer to *α*,*β*-unsaturated carbonyl compounds. [a] 12.5 mol% (*S*,*S*)-**L16** and 37.5 mol% DBU were used in the reaction. Mes = mesityl; DBU = 1,8-diazabicyclo[5.4.0]undec-7-ene.

In 2018, XU and co-workers reported their protocol about asymmetric 1,4-addition of Me_2PhSi–Bpin (**12**) to 3-acylindoles by using CuCl as catalyst and NHC (*S*,*R*)-**L18** as ligand [Scheme 1.25, **77a–g** → (*R*,*R*)-**78a–g**].[31] Dearomatization of indoles was accomplished with good enantioselectivities (more than 85% *ee*). All the target products were produced as a single diastereomer in a *trans* manner. Halo groups as in (*R*,*R*)-**78c**–**f** and a cyano group as in (*R*,*R*)-**78g** were compatible under their reaction conditions. Monitoring the reaction process of **77a** by ^1H NMR verified the epimerization from *cis*-**78a** to *trans*-**78a**. Further trans-

[31] Y. Shi, Q. Gao, S. Xu, *J. Org. Chem.* **2018**, *83*, 14758–14767.

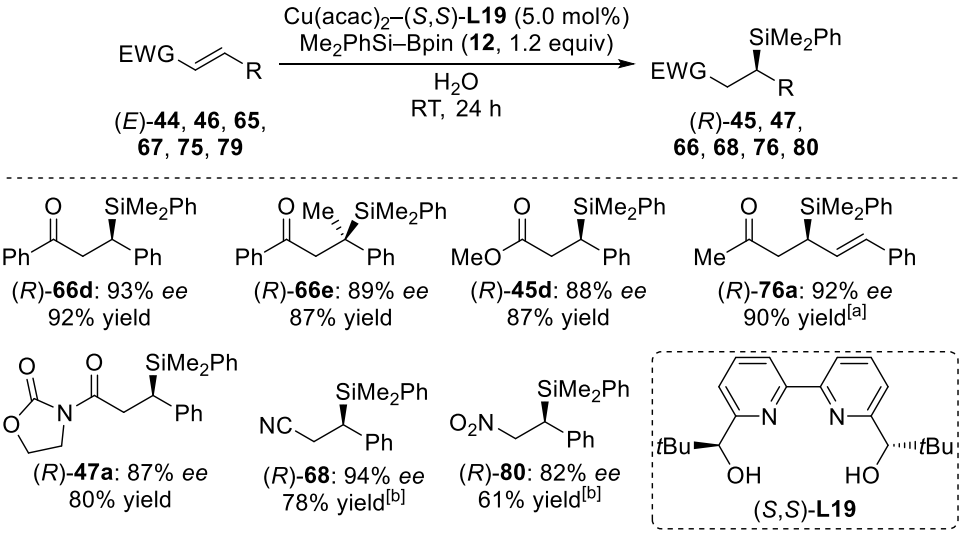
formations of (*R*,*R*)-**78a** have been conducted to illustrate the potential of this efficient method (not shown).



Scheme 1.25: Asymmetric dearomatization of 3-acylindoles. [a] THF was used instead of CH_3CN.

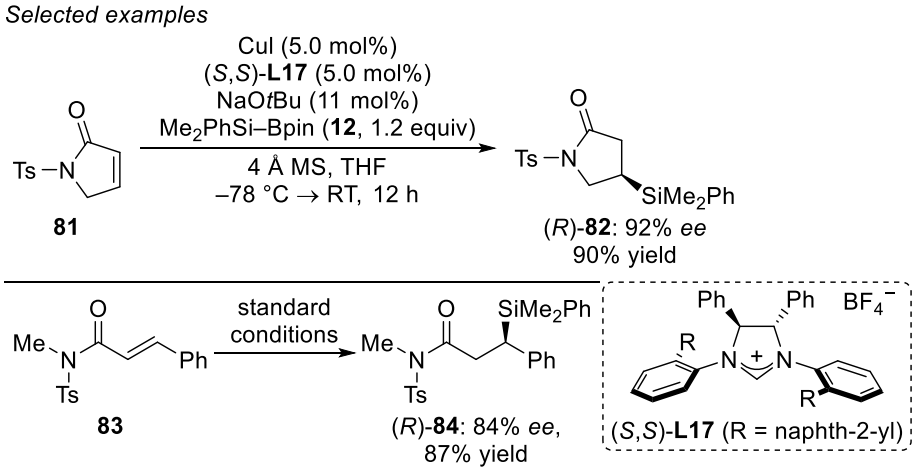
In some cases of asymmetric silyl transfer reactions, a solvent mixture of water and organic solvent was indispensable for high efficacy. However, only water as solvent was still elusive. In 2015. KOBAYASHI and co-workers developed a new catalyst from $Cu(acac)_2$ and chiral bipyridine ligand (*S*,*S*)-**L19** (Scheme 1.26) and successfully applied it in the asymmetric conjugate addition of silylboronic ester **12** to MICHAEL acceptors.[32] This new catalyst was compatible with a wide range of *α*,*β*-unsaturated acceptors such as ketones (*E*)-**65d**, (*E*)-**65e** and (*E*)-**75a**, and an ester (*E*)-**44d**, and an amide (*E*)-**46a**. Alkenes with electron-withdrawing groups such as a cyano group as in (*E*)-**67** and a nitro group as in (*E*)-**79** proved to be reactive, providing the target products in good yields with high to excellent enantiomeric excesses. Gram-scale synthesis of (*R*)-**66d** was done in a little lower yield (90%) with the same level of enantioinduction. Addition of THF into the reaction dramatically lowered the enantio-selectivity, however, with slight erosion of yield. Moreover, the catalyst could be easily recycled after the reaction, however, slightly less efficient than original ones with regard to both yield and *ee* value. Water worked as proton source here and was believed to play an important role in the sterically congested transition states.

[32] T. Kitanosono, L. Zhu, C. Liu, P. Xu, S. Kobayashi, *J. Am. Chem. Soc.* **2015**, *137*, 15422–15425.



Scheme 1.26: Asymmetric silyl transfer. [a] Triton X-100 (25 mg) was added; [b] Me_2PhSi–Bpin (**11**, 1.5 equiv) was used.

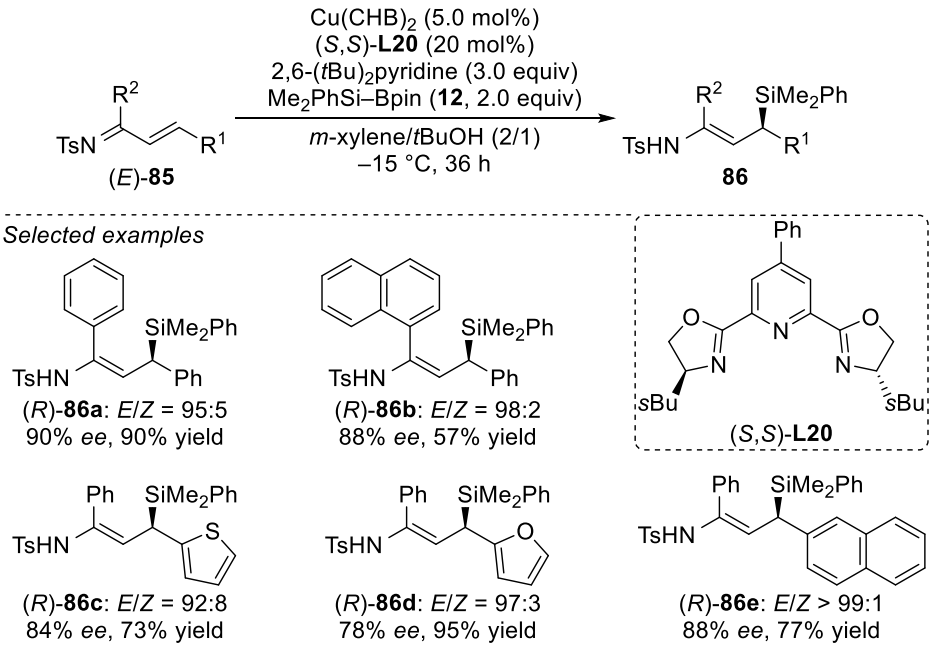
α,*β*-Unsaturated amide **44a** has been illustrated as an efficient substrate for asymmetric 1,4-addition reaction by using silylboronic esters as silicon source (cf. Schemes 1.16, 1.19 and 1.26). A modular method for the synthesis of chiral *β*-silyl amides was disclosed by PROCTER and co-workers in 2013 [Scheme 1.27, **81** → (*R*)-**82** and **83** → (R)-**84**].[33] Lactams and acyclic amides were compatible under their reaction conditions. The optimal setup consisted of 5.0 mol% CuI, 5.0 mol% NHC ligand (*S*,*S*)-**L17**, 11 mol% NaO*t*Bu and 4 Å MS in 2-MeTHF. Good yields and enantioselectivities of up to >98% *ee* were observed throughout. The potential of their methods was elaborated by synthesis of (*R*)-oxiracetam, a drug derived from (*R*)-**82** (not shown).



Scheme 1.27: Asymmetric silyl transfer from Me_2PhSi–Bpin (**12**) to lactams and amides. Ts = tosyl.

[33] V. Pace, J. P. Rae, D. J. Procter, *Org. Lett.* **2014**, *16*, 476–479.

In 2018, XU, LOH and co-workers developed a general and efficient route for the enantioselective addition of Me_2PhSi–Bpin (**12**) to *α*,*β*-unsaturated imines [Scheme 1.28, (*E*)-**85a**–**e** → **86a**–**e**].[34] Good diastereo- and enantiocontrol were obtained by using $Cu(CHB)_2$ as catalyst and PyBOX (*S*,*S*)-**L20** as ligand. (*E*)-Configured chiral allylic silanes were obtained as the main product in this enantioselective transformation. Heterocycles, such as a thienyl group as in (*E*)-**85c** and a furyl group as in (*E*)-**85d**, were tolerated, providing the target 1,4-addition products in good to excellent yields with good diastereo- and enantioselectivities. Transformations of **86a** were performed to demonstrate the synthetic values (not shown).



Scheme 1.28: Enantioselective 1,4-hydrosilylation of *α*,*β*-unsaturated imines. $Cu(CHB)_2$ = copper(II) bis(4-cyclohexylbutyrate)

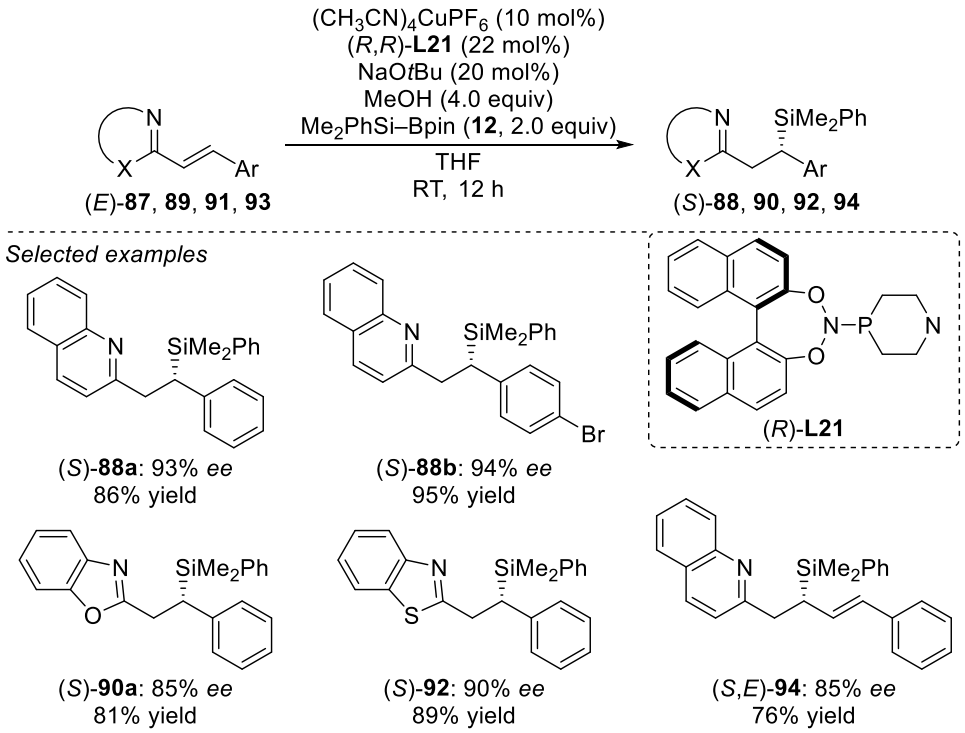
Shortly after our publication about asymmetric silyl transfer from silicon GRIGNARD reagents to heterocycle-substituted alkenes,[35] CHU, LIU and co-workers reported a Cu-catalyzed highly enantioselective conjugate addition of Me_2PhSi–Bpin (**12**) to quinoline-substituted alkenes [Scheme 1.29, (*E*)-**87a** and **b** → (*S*)-**88a** and **b**].[36] Excellent enantioinduction was achieved by using $(CH_3CN)_4CuPF_6$ as precatalyst and chiral phosphoramidite (*R*)-**L21** as ligand. All reactions proceeded at room temperature, and a wide range of functional groups were compatible. High yields with excellent enantiomeric ratios of up to 95% *ee* were

[34] B.-C. Da, Q.-J. Liang, Y.-C. Luo, T. Ahmad, Y.-H. Xu, T.-P. Loh, *ACS Catal*. **2018**, *8*, 6239–6245.

[35] W. Mao, W. Xue, E. Irran, M. Oestreich, *Angew*. *Chem*. *Int*. *Ed*. **2019**, *58*, 10723–10726; *Angew*. *Chem*. **2019**, *131*, 10833–10836.

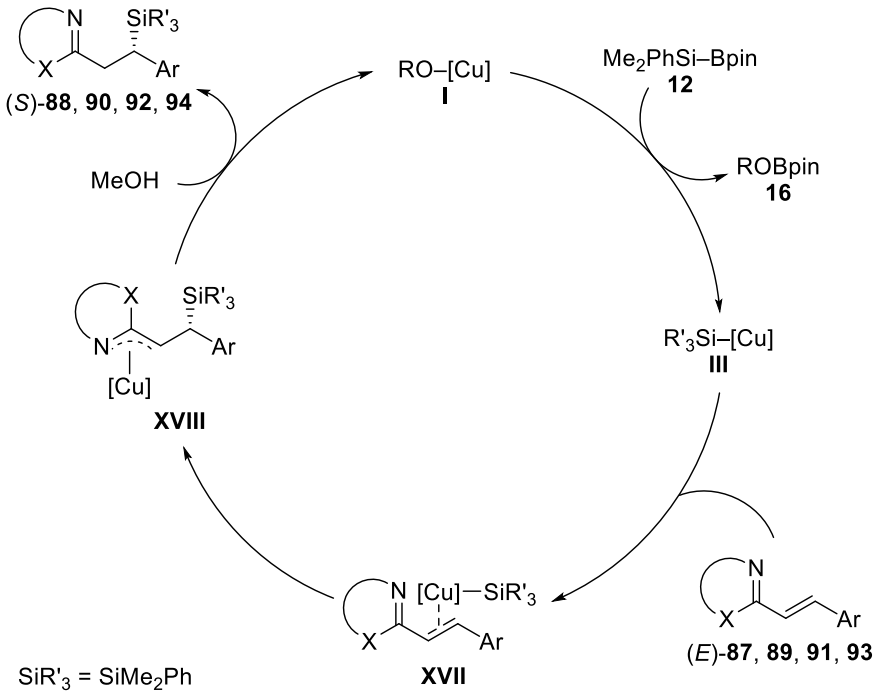
[36] Y.-L. Zeng, B. Chen, Y.-T. Wang, C.-Y. He, Z.-Y. Mu, J.-Y. Du, L. He, W.-D. Chu, Q.-Z. Liu, *Chem*. *Commun*. **2020**, *56*, 1693–1696.

observed with *β*-aryl-substituted quinolines. Diene-attached quinoline (*E*)-**93** exclusively afforded the 1,4-addition product (*S*,*E*)-**94** in 76% yield with 85% *ee*. Benzoxazole (*E*)-**89a** and benzothiazole (*E*)-**91** proved to be reactive, leading to the corresponding products in good yields with excellent enantioselection. Gram-scale reaction of (*E*)-**87b** was performed with almost same efficiency, highlighting the practicality of this method. Oxidative degradation of chiral silane (*S*)-**88b** was done through TAMAO–FLEMING procedure to afford the target chiral alcohol with the same enantioselectivity, further demonstrating the synthetical utility of this methods (not shown).



Scheme 1.29: Enantioselective conjugate addition of Me_2PhSi–Bpin (**12**) to azaaryl-substituted alkenes.

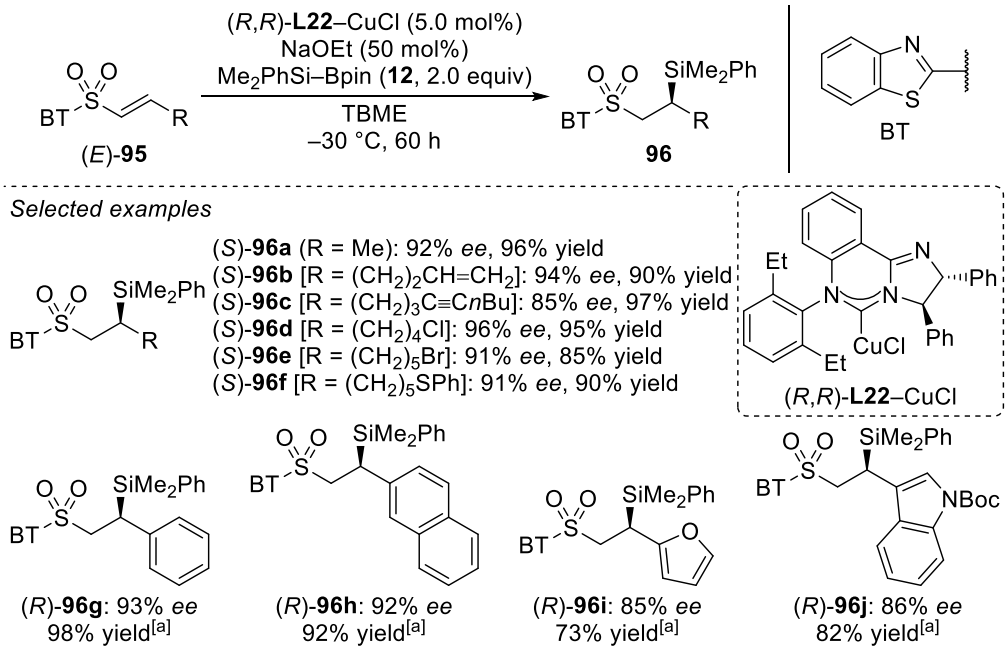
A possible mechanism was proposed (Scheme 1.30). Transmetalation between copper alkoxide **I** and Me_2PhSi–Bpin (**12**) generates a nucleophilic [Cu]–Si species **III** in a concerted manner. Heterocycle-substituted alkene coordinates to Cu–Si species **III** to form a π-complex **XVII** and then the Cu–Si species **III** adds to alkene in 1,4-selectivity, forming the intermediate **XVIII**. Protonation of the intermediate **XVIII** liberates the desired chiral silanes, along with the formation of copper alkoxide **I**.



Scheme 1.30: Catalytic cycle of enantioselective conjugate addition to azaaryl-substituted alkenes.

Asymmetric 1,4-addition of $Me_2PhSi–Bpin$ (**12**) to *α*,*β*-unsaturated sulfones was investigated by YIN group [Scheme 1.31, (*E*)-**95a**–**j** → **96a**–**j**].[37] The newly developed NHC–CuCl complex [(*R*,*R*)-**L22**–CuCl] showed high reactivity in this reaction. *α*,*β*-Unsaturated sulfones bearing an alkyl or an aryl group in the *β*-position were reactive, giving the corresponding silylation products efficiently. Excellent yields with high levels of stereocontrol of up to 96% *ee* were observed throughout. Their methods displayed a high level of tolerance towards another C–C unsaturated bond as in (*E*)-**95b** and (*E*)-**95c**, halo groups as in (*E*)-**95d** and (*E*)-**95e**, a thioether as in (*E*)-**95f** and heterocycles as in (*E*)-**95i** and (*E*)-**95j**. Subsequent derivatization of chiral products through JULIA–KOCIENSKI olefination provided a new and general avenue to access chiral allylic silanes (not shown).

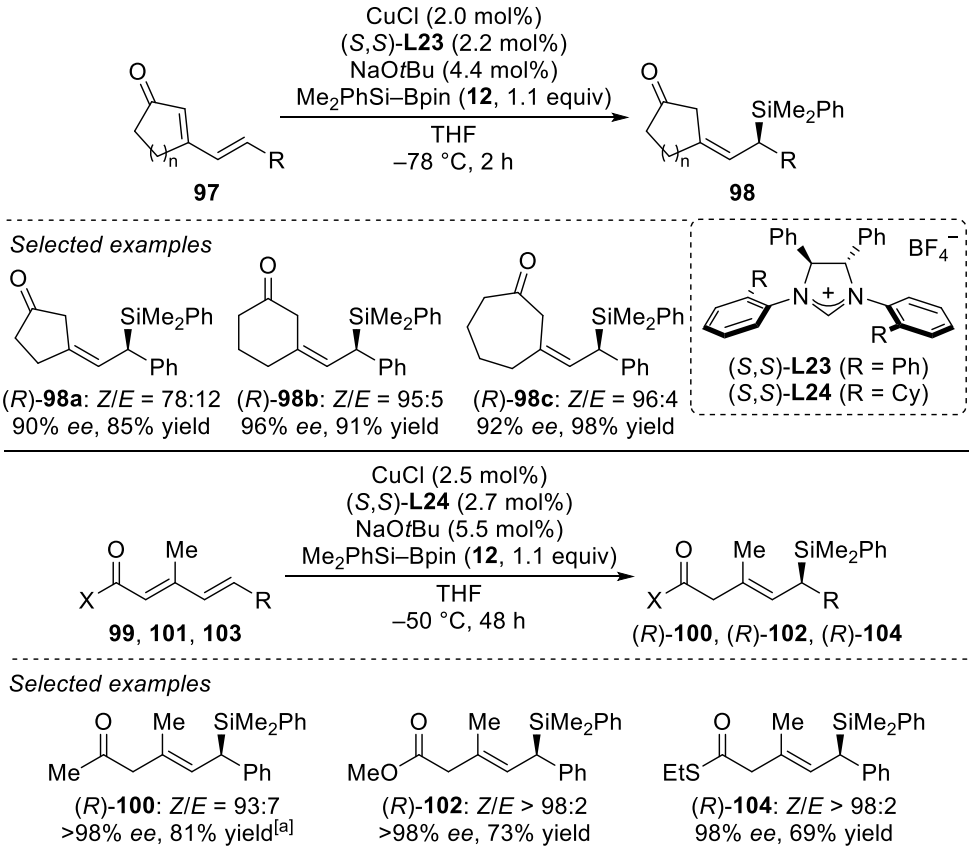
[37] X.-L. Wang, X.-H. Yin, J.-Z. Xiao, X.-S. Jia, L. Yin, *Chin. J. Chem.* **2021**, *39*, 1916–1922.



Scheme 1.31: Enantioselective silyl transfer from $Me_2PhSi–Bpin$ (**12**) to *α*,*β*-unsaturated sulfones. TBME = *tert*-butyl methyl ether. [a] NaOMe (1.0 equiv) was used instead of NaOEt.

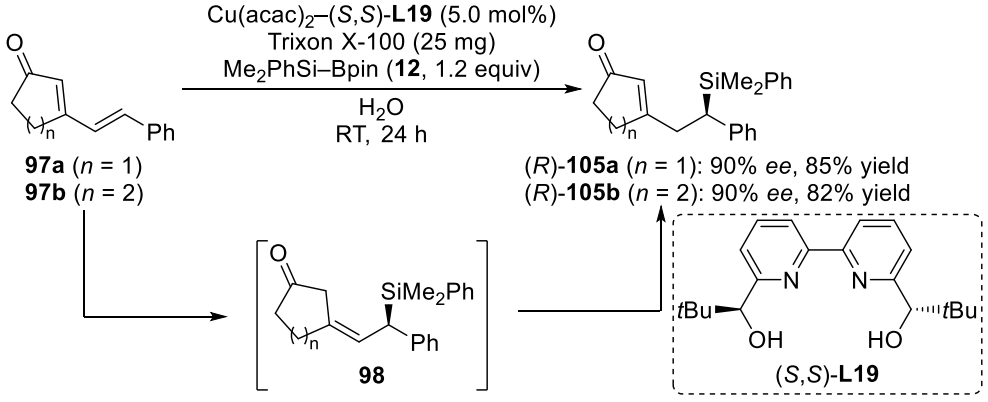
1.3 Asymmetric 1,6-Addition Reaction

Dienones and Dienoates. Asymmetric 1,6-addition of silylboronic esters to dienones and dienoates concentrated on *β*-occupied substrates. As part of the aforementioned work (cf. Schemes 1.22 and 1.26), HOVEYDA group and KOBAYASHI group reported the application of their asymmetric catalysis in this field independently. Successful application of Cu–NHC catalysis has been done to cyclic and acyclic dienones and dienoates by HOVEYDA and co-workers (Scheme 1.32).[26,28] Chiral allylic silanes were obtained with high diastereo- and enantioselectivity. Reactions of cyclic substrates were finished within 2 hours with comparatively lower loadings of catalyst (**97a**–**c** → **98a**–**c**). Prolonging reaction time was necessary for acyclic compounds, especially for dienoates (**99** → **100**, **101** → **102**, **103** → **104**).



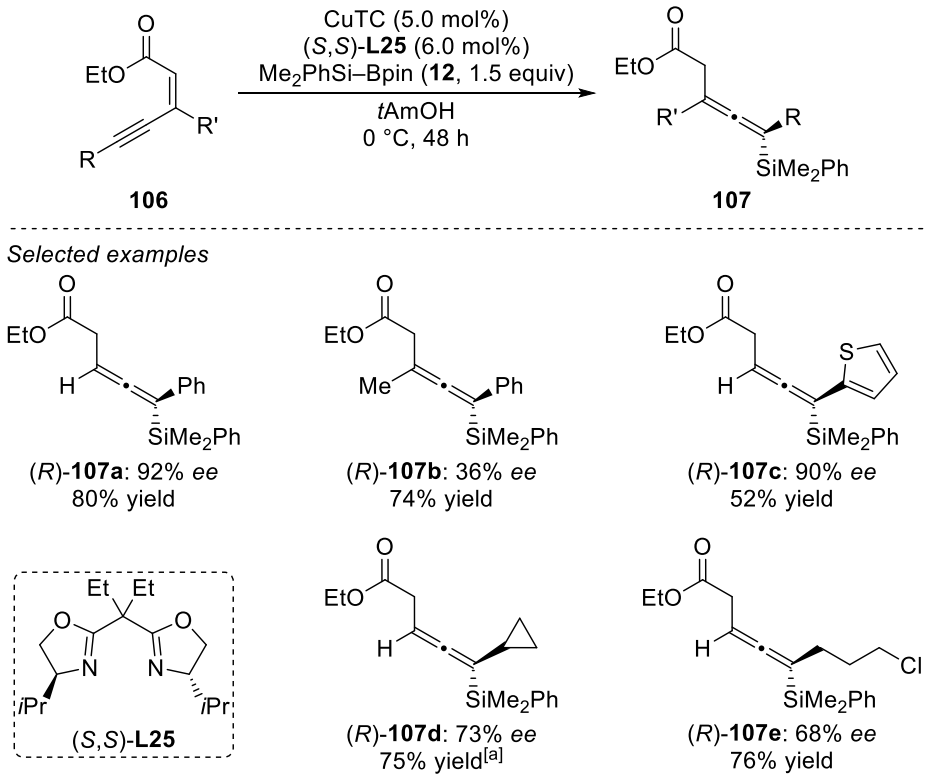
Scheme 1.32: Asymmetric silyl transfer to dienones and dienoates. [a] Reaction was carried out at –78 °C for 6 h.

Distinct products were obtained when Cu(acac)$_2$–(*S*,*S*)-**L19** catalysis from KOBAYASHI group was used to catalyze the reaction of **97a** and **97b** (Scheme 1.33).[32] A single diastereomer was obtained exclusively under the optimal reaction conditions. Monitoring the reaction of **97b** by ^{1}H NMR corroborated that kinetically favored **98b** occurred during the reaction and then entirely converted into **105b**.



Scheme 1.33: Enantioselective 1,6-addition to cyclic dienones.

Enynoates. In 2015, XU, LOH and co-workers disclosed their results concerning the formation of enantioenriched allenylsilanes through asymmetric 1,6-addition of Me_2PhSi–Bpin (**12**) to enynoates [Scheme 1.34, (*Z*)-**106a**–**d** → **107a**–**d**].[38] This 1,6-silyl transfer procedure was general and efficient. CuTC, combined with BOX ligand **L25**, contributed to excellent enantioinduction in the reaction (mostly >90% *ee*). Configuration of C–C double bond in the enynoate was crucial to the high efficiency in the reaction in terms of yields and enantioselectivities. *(E)*-Configured **106a** only afforded the 1,6-addition product (*R*)-**107a** in 17% yield with 63% *ee*. Increased sterically congestion in the *β*-position as in (*Z*)-**106b** was detrimental to enantioselectivity, leading to a polysubstituted allene with low *ee* value.



Scheme 1.34: Synthesis of chiral allenylsilanes by asymmetric 1,6-addition reactions. [a] Reaction was set at –5 °C for 72 h. CuTC = copper(I) thiophene-2-carboxylate; *t*AmOH = *tert*-amyl alcohol.

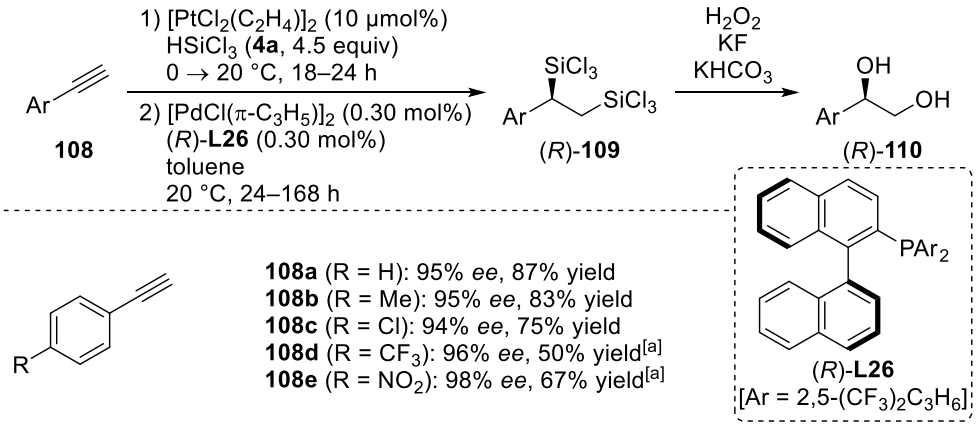
1.4 Miscellaneous Methods

Asymmetric consecutive double hydrofunctionalization of alkynes through one-pot procedure has emerged as a thriving research area and received considerable attention from organic chemists.[39] In 2002, HAYASHI and co-workers developed a one-pot procedure for the asym-

[38] M. Wang, Z.-L. Liu, X. Zhang, P.-P. Tian, Y.-H. Xu, T.-P. Loh, *J. Am. Chem. Soc.* **2015**, *137*, 14830–14833.

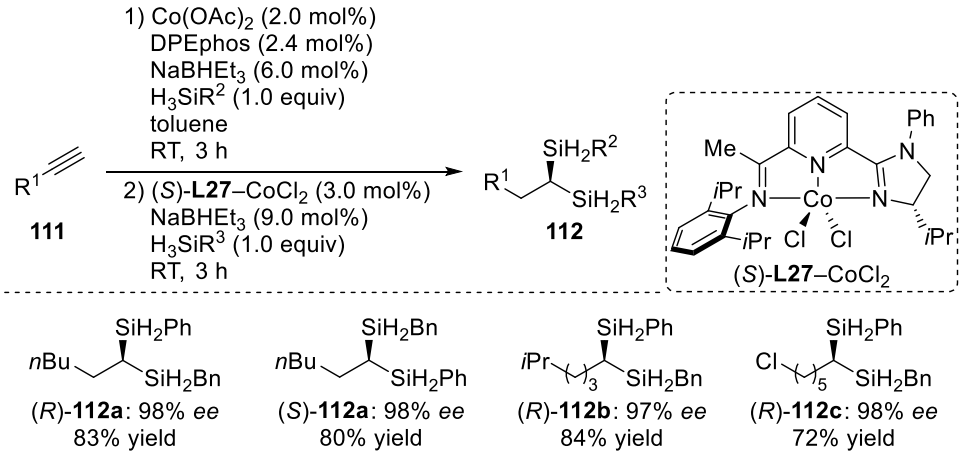
[39] A recent review, see: Z. Cheng, J. Guo, Z. Lu, *Chem. Commun.* **2020**, *56*, 2229–2239.

metric double hydrosilylation of aromatic alkynes [Scheme 1.35, **108a**–**e** → (*R*)-**109a**–**e** and **109a**–**e** → (*R*)-**110a**–**e**].[40] Excellent levels of enantioselection were observed throughout with good to excellent yields. Low loadings of catalysts were used in the reaction. Aliphatic alkynes were not suitable under their reaction conditions because of low transformation in the asymmetric hydrosilylation step.



Scheme 1.35: Asymmetric double hydrosilylation of alkynes in one-pot procedure. [a] $[PdCl(\pi\text{-}C_3H_5)]_2$ (0.60 mol%) and (*R*)-**L26** (1.2 mol%) were used.

Stereogenic sites switched when two same hydrosilanes were used as silicon source in the work of LU group about the asymmetric double hydrosilylation of aliphatic alkynes (Scheme 1.36, **111** → **112**).[9j] This one-pot two-step procedure was developed by using $Co(OAc)_2$ and (*S*)-**L27**–$CoCl_2$ as catalysts. Yields were high for three substrates with excellent regio- and enantioselection. Enantiomers could be easily obtained by switching the addition sequence of hydrosilanes [**111a** → (*R*)-**112a** and (*S*)-**112a**].

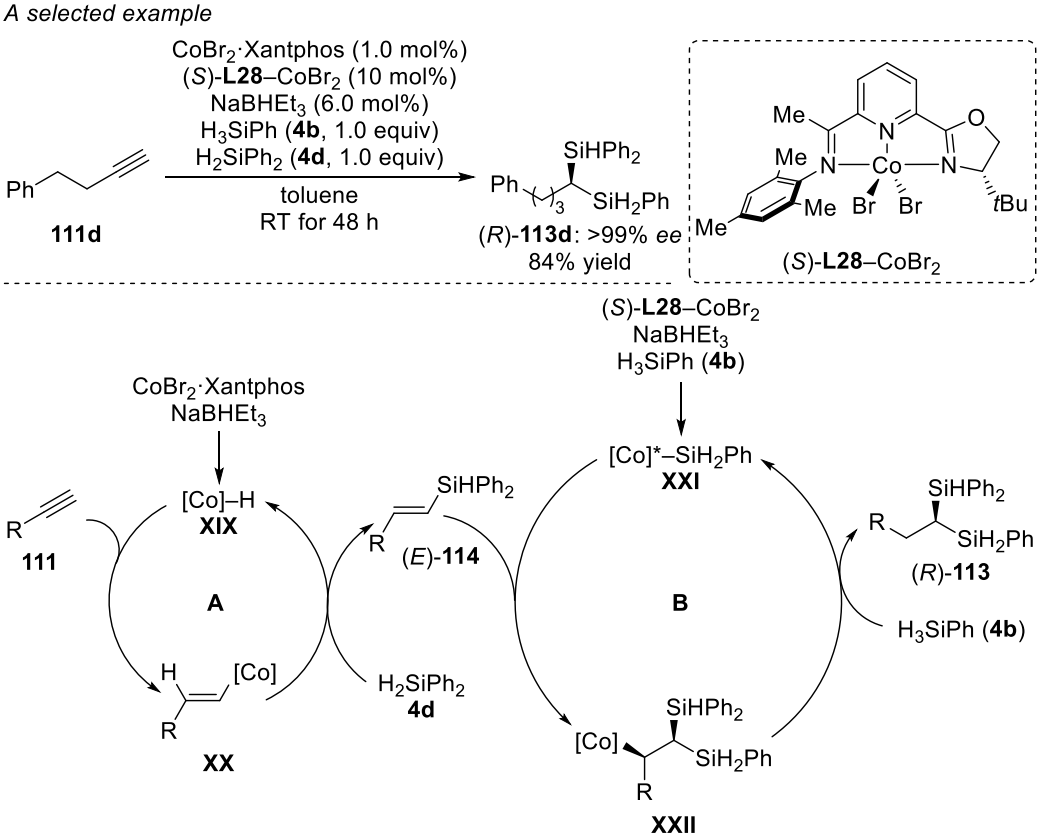


[40] T. Shimada, K. Mukaide, A. Shinohara, J. W. Han, T. Hayashi, *J. Am. Chem. Soc.* **2002**, *124*, 1584–1585

Scheme 1.36: Asymmetric double hydrosilylation of alkynes in one-pot procedure. DPEphos = Bis[(2-diphenylphosphino)phenyl] ether.

Then different hydrosilanes were applied in the asymmetric double hydrosilylation of alkynes through tandem reaction by the same group shortly thereafter [Scheme 1.37, **111d** → (*R*)-**113d**].[41] All the starting materials were added sequentially at the beginning of the reaction. They found the addition sequence of reagents used in the reaction was crucial to the high efficacy of this approach. Chemo-, regio- and enantioselectivity are significant challenges. Generality of this method was demonstrated by 29 examples in yields varying from 25% to 85%, with excellent levels of enantioselection of more than 90% *ee*. Gram-scale synthesis was facilitated through subtle modification of catalyst loadings. A plausible mechanism was provided on the basis of control experiments and DFT calculations. Catalytic cycle (**A**) starts from the formation of [Co]–H species **XIX** from $CoBr_2$·Xantphos and $NaBHEt_3$. Alkyne **106** coordinates to [Co]–H **XIX**, and then [Co]–H **XIX** adds across C≡C triple bond to form a [Co]–C(sp^2) species **XX**. Ligand displacement between [Co]–C(sp^2) species **XX** and hydrosilane **4d** through σ-bond metathesis generates intermediate (*E*)-**114**, along with the formation of [Co]–H species **XIX**. Asymmetric addition of chiral [Co]*–Si species **XXI**, which originates from (*S*)-**L28**–$CoBr_2$, $NaBHEt_3$ and H_3SiPh (**4b**), to alkenylsilane (*E*)-**114** affords a [Co]*–C(sp^3) species **XXII**. Ligand exchange between [Co]*–C(sp^3) species **XXII** and H_3SiPh (**4b**) through σ-bond metathesis liberates the target product (*R*)-**113** and regenerates chiral [Co]*–Si species **XXI**.

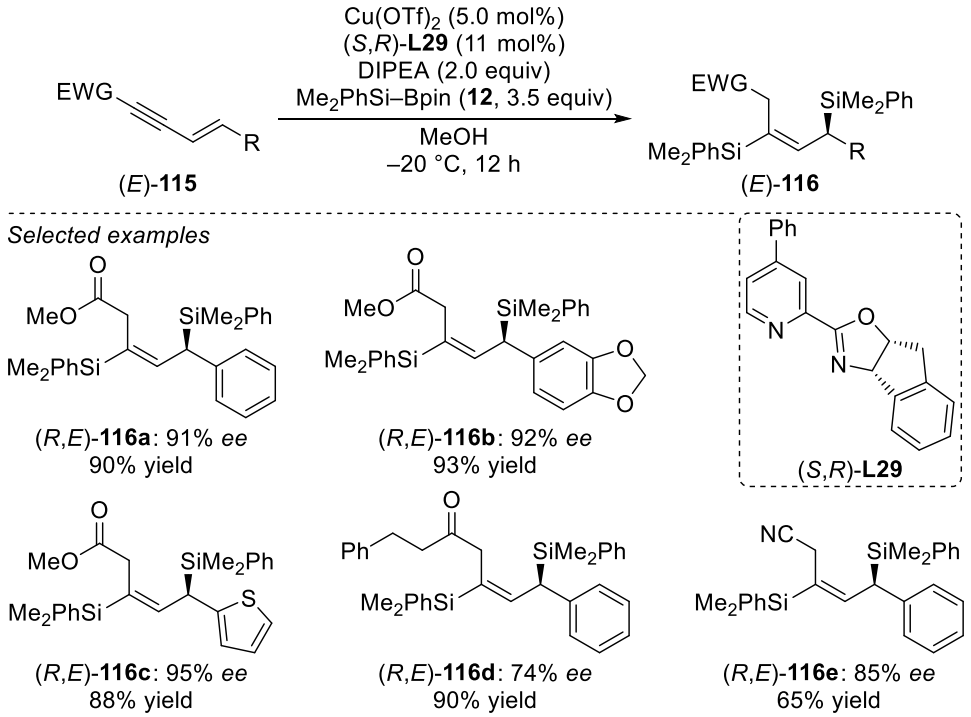
[41] J. Guo, H. Wang, S. Xing, X Hong, Z. Lu, *Chem* **2019**, *5*, 881–895.



Scheme 1.37: Asymmetric double hydrosilylation of alkynes by tandem reaction. Xantphos = (9,9-Dimethyl-9*H*-xanthene-4,5-diyl)bis(diphenylphosphane).

Consecutive asymmetric double hydrosilylation of enynes has been reported by XU, LOH and co-workers in 2018.[42] Optically pure 1,3-bis(silyl)propene compounds were obtained through asymmetric conjugate addition of Me_2PhSi–Bpin (**12**) to enyne-type acceptors by using $Cu(OTf)_2$ as precatalyst and chiral oxazoline (*S*,*R*)-**L29** as ligand [Scheme 1.38, (*E*)-**115** → (*E*)-**116**]. Methanol worked as solvent and proton source. This new procedure featured high yields, high regio- and enantioselectivity and good functional group compatibility. Exclusive *E*-configured C–C double bond formation emerged during the transformation. This procedure was compatible with gram-scale synthesis. 1.12 g of enyne (*E*)-**115a** reacted under the optimal reaction conditions, providing the target stereodefined product (*R*,*E*)-**116a** in 95% yield with 90% *ee*.

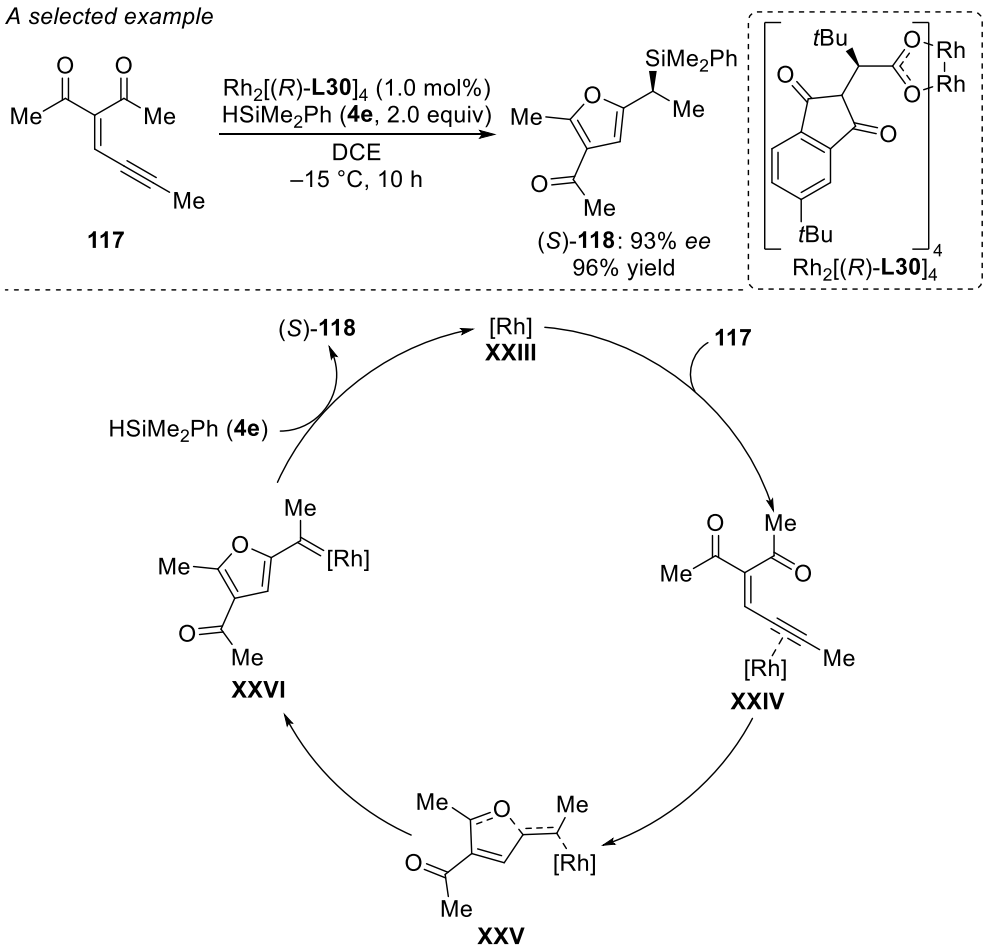
[42] F.-F. Meng, J.-H. Xie, Y.-H. Xu, T.-P. Loh, *ACS Catal.* **2018**, *8*, 5306–5312.



Scheme 1.38: Asymmetric consecutive double hydrosilylation of enynes. $Cu(OTf)_2$ = copper(II) triflate; DIPEA = *N*,*N*-diisopropylethylamine.

In 2019, ZHU and co-workers demonstrated their research about Si–H bond insertion reactions of alkynes [Scheme 1.39, **117** → (*S*)-**118**].[43] High efficiency with regard to both yield and enantioselection was obtained by using chiral Rh catalyst. Functional group compatibility is good. Halo groups such as fluoro and chloro, trifluormethyl group, acetal group, thienyl group and another C–C double bond were tolerated, affording the corresponding products in good to excellent yields with high enantioselectivities, up to 97% *ee* (not shown). A possible mechanistic scenario is depicted in Scheme 1.39 (bottom). Enyne **117** coordinates to Rh catalyst **XXIII**, and then *5-exo-dig* cyclization forms a carbene intermediate (**XXIV** → **XXV** → **XXVI)**. Insertion of the carbene intermediate **XXVI** into $HSiMe_2Ph$ (**4e**) generates the desired product (*S*)-**118** and Rh catalyst **XXIII**. This step proved to be the rate-determining step by kinetic isotopic studies.

[43] M.-Y. Huang, J.-M. Yang, Y.-T. Zhao, S.-F. Zhu, *ACS Catal.* **2019**, *9*, 5353–5357.



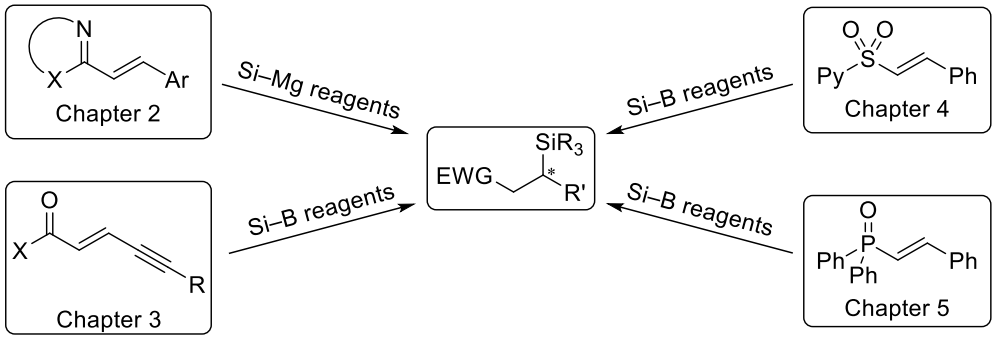
Scheme 1.39: Asymmetric 1,1-hydrosilylation of carbene precursors. DCE = 1,2-dichloroethane.

1.5 Objective

Details involving asymmetric 1,4-addition of silicon nucleophiles to *α*,*β*-unsaturated carbonyl compounds and their derivatives have been demonstrated in Chapter 1.2.2 and significant progress has been made in the past decades.[6] Si–B reagents are prevalent in this field, generating nucleophilic M–Si species (M = metal) through transmetalation in a σ-bond metathesis manner. Although great achievements have been made in this area, limitations still exist. Direct applications of silicon nucleophiles such as Si–Zn reagents and Si–Mg reagents in asymmetric conjugate reactions are elusive because of their higher reactivity.[25] Moreover, methods for special MICHAEL acceptors such as enyne-type acceptors,[38] *α*,*β*-unsaturated sulfonyl compounds[37] and *α*,*β*-unsaturated phosphine oxides are less reported. Thus, further research about 1,4-asymmetric addition reactions is highly desired for the development of organosilicon chemistry.

This dissertation reports our research about asymmetric conjugate 1,4-silyl transfer reactions (Scheme 1.40). Chapter 2 demonstrates an asymmetric addition of Si–Mg reagents to

heterocycle-substituted alkenes. Silicon GRIGNARD reagents were first successfully applied in an asymmetric transformation, complementing the methods for asymmetric conjugate addition reactions. 1,4-Selective addition of Si–B reagents to enyne-type *α*,*β*,*γ*,*δ*-unsaturated acceptors is described in Chapter 3, expanding the toolbox for optically pure propargylic silanes. Methods using *α*,*β*-unsaturated sulfonyl compounds as MICHAEL acceptors are detailed in Chapter 4. Chapter 5 describes our progress about enantioselective 1,4-addition of Si–B reagents to *α*,*β*-unsaturated phosphine oxides.

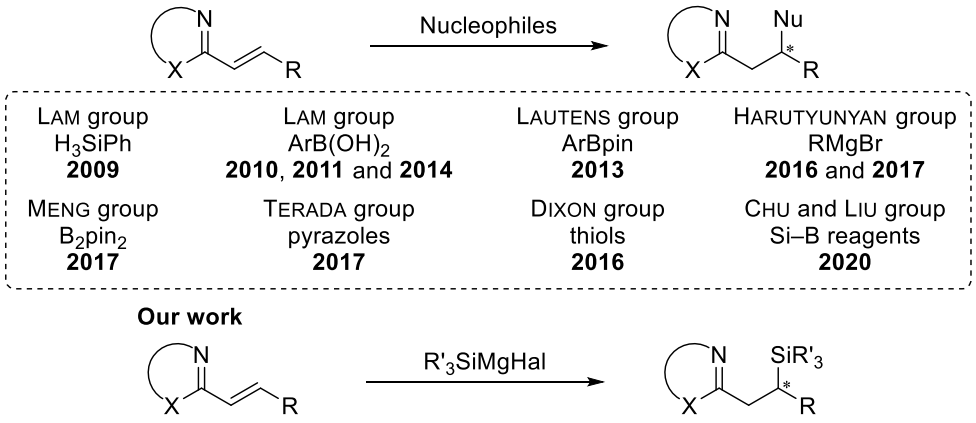


Scheme 1.40: Asymmetric silyl transfer from silicon (pro)nucleophiles to MICHAEL acceptors. Py = pyridyl.

2 ASYMMETRIC CONJUGATE 1,4-SILYL TRANSFER TO AZAARYL-SUBSTITUTED ALKENES

2.1 Introduction

Asymmetric conjugate addition of nucleophiles to azaaryl-substituted alkenes[44] has been researched for years. Starting from LAM's seminal work about asymmetric hydrogenation of in 2009,[45] successful applications of various nucleophiles in this area have been reported (Scheme 2.1). Carbon nucleophiles from arylboronic acids,[46] arylboronic esters,[47] and GRIGNARD reagents,[48] boron nucleophiles from B_2Pin_2,[49] nitrogen nucleophiles from pyrazoles,[50] silicon nucleophiles from Si–B reagents[36] and sulfur nucleophiles from thiols[51] proved to be efficient by using azaaryl-substituted alkenes as acceptors. Inspired by these innovative works, we planned to investigate enantioselective addition of silicon Grignard reagents to azaaryl-substituted alkenes. It is noteworthy that the project using Si–B reagents as silicon source had not been known before our publication.



[44] a) M. Lautens, A. Roy, K. Fukuoka, K. Fagnou, B. Martín-Matute, *J. Am. Chem. Soc.* **2001**, *123*, 5358–5359; b) R. Amengual, V. Michelet, J.-P. Genêt, *Tetrahedron Lett.* **2002**, *43*, 5905–5908.

[45] L. Rupnicki, A. Saxena, H. W. Lam, *J. Am. Chem. Soc.* **2009**, *131*, 10386–10387.

[46] a) G. Pattison, G. Piraux, H. W. Lam, *J. Am. Chem. Soc.* **2010**, *132*, 14373–14375; b) A. Saxena, H. W. Lam, *Chem. Sci.* **2011**, *2*, 2326–2331; c) I. D. Roy, A. R. Burns, G. Pattison, B. Michel, A. J. Parkerc, H. W. Lam, *Chem. Commun.* **2014**, *50*, 2865–2868.

[47] A. A. Friedman, J. Panteleev, J. Tsoung, V. Huynh, M. Lautens, *Angew. Chem. Int. Ed.* **2013**, *52*, 9755–9758; *Angew. Chem.* **2013**, *125*, 9937–9940.

[48] a) R. P. Jumde, F. Lanza, M. J. Veenstra, S. R. Harutyunyan, *Science* **2016**, *352*, 433–437; b) R. P. Jumde, F. Lanza, T. Pellegrini, S. R. Harutyunyan, *Nat. Commun.* **2017**, *8*, 2058.

[49] L. Wen, Z. Yue, H. Zhang, Q. Chong, F. Meng, *Org. Lett.* **2017**, *19*, 6610–6613.

[50] Y.-Y. Wang, K. Kanomata, T. Korenaga, M. Terada, *Angew. Chem. Int. Ed.* **2016**, *55*, 927–931; *Angew. Chem.* **2016**, *128*, 939–943.

[51] M. Formica, G. Sorin, A. J. M. Farley, J. Díaz, R. S. Paton, D. J. Dixon, *Chem. Sci.* **2018**, *9*, 6969–6974.

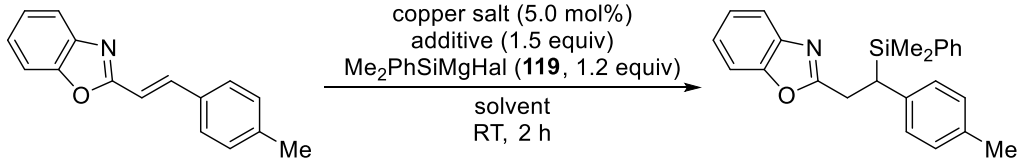
Scheme 2.1: Asymmetric conjugate addition to azaaryl-substituted alkenes. Hal = Cl or Br.

2.2 Racemic Version

2.2.1 Optimization Study

Our research started from racemic transformation by using benzoxazole-substituted alkene (*E*)-**89b** as model substrate and $Me_2PhSiMgHal$ (**119**) as silicon source (Table 2.1). 73% yield of desired silylation product *rac*-**90b** was obtained when (*E*)-**89b** reacted with $Me_2PhSiMgHal$ (**119**) by using CuCl as catalyst and LEWIS acid $BF_3{\cdot}OEt_2$ as additive in THF (entry 1). From various copper salts used, CuSCN stood out, affording the target product *rac*-**90b** in 79% isolated yield (entries 1–8). Other BF_3-based LEWIS acids were examined; however, no better results were observed (entries 9–11). A solvent screening identified THF as the optimal choice (entries 12–14). Low reactivity was found without either copper salt or additive (entries 15–16). Reaction of (*E*)-**89b** with either of $Me_2PhSiZnCl$ (**120**), Me_2PhSi–Bpin (**12**), and $Me_2PhSiLi$ (**121**) resulted in much less transformation (entries 17–19). It is noteworthy that exclusive *β*-selectivity was observed in the transformation.

Table 2.1: A condition screening for racemic transformation.[a]



(*E*)-**89b** *rac*-**90b**

entry	copper salt	additive	solvent	yield (%)[b]
1	CuCl	$BF_3{\cdot}OEt_2$	THF	73
2	CuBr	$BF_3{\cdot}OEt_2$	THF	74
3	CuI	$BF_3{\cdot}OEt_2$	THF	68
4	CuTc	$BF_3{\cdot}OEt_2$	THF	75
5	CuCN	$BF_3{\cdot}OEt_2$	THF	69
6	CuSCN	$BF_3{\cdot}OEt_2$	THF	80 (79)
7	$CuBr{\cdot}Me_2S$	$BF_3{\cdot}OEt_2$	THF	65
8	$CuCl_2$	$BF_3{\cdot}OEt_2$	THF	57
9	CuSCN	$BF_3{\cdot}OMe_2$	THF	73
10	CuSCN	$BF_3{\cdot}OBu_2$	THF	79 (76)
11	CuSCN	$BF_3{\cdot}SMe_2$	THF	75
12	CuSCN	$BF_3{\cdot}OEt_2$	Et_2O/THF	51
13	CuSCN	$BF_3{\cdot}OEt_2$	CH_2Cl_2/THF	51

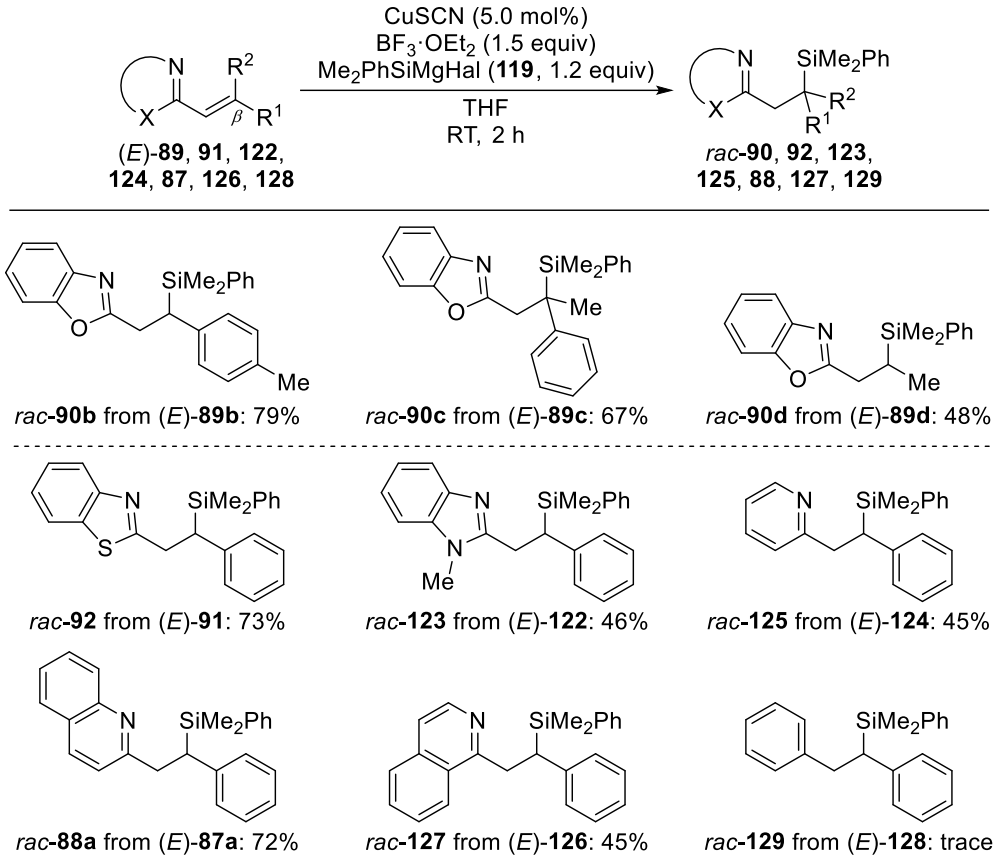
14	CuSCN	$BF_3 \cdot OEt_2$	toluene/THF	47
15	-	$BF_3 \cdot OEt_2$	THF	39
16	CuSCN	-	THF	36
17[c]	CuSCN	$BF_3 \cdot OEt_2$	THF	17
18[d]	CuSCN	$BF_3 \cdot OEt_2$	THF	0
19[e]	CuSCN	$BF_3 \cdot OEt_2$	THF	11

[a] All reactions were performed on a 0.15 mmol scale. [b] Yields were determined by GLC analysis with tetracosane as an internal standard; Isolated yields were in parentheses. [c] $Me_2PhSiMgHal$ (**119**) was replaced by $Me_2PhSiZnCl$ (**120**). [d] $Me_2PhSiMgHal$ was replaced by Me_2PhSi–Bpin (**12**). [e] $Me_2PhSiMgHal$ was replaced by $Me_2PhSiLi$ (**121**). Hal = Br or Cl.

2.2.2 Substrate Scope for Racemic Transformation

Having the optimal reaction conditions in hand, we then assessed the generality of this method (Scheme 2.2). *β*,*β*-Disubstituted (*E*)-**89c** reacted smoothly, arriving at the silylated product *rac*-**90c** in 67% yield. An alkyl group in the *β*-position as in (*E*)-**89d** was compatible, and a moderate yield was obtained. The compatibility of azaaryl groups was further studied (Scheme 2.2, bottom). A benzothiozole as in (*E*)-**91**, a benzimidazole as in (*E*)-**122**, a pyridine as in (*E*)-**124**, and quinolines as in (*E*)-**87a** and (*E*)-**126** were tolerated, affording the corresponding addition products in yields varying from 45% to 73%. However, only trace amount of *rac*-**129** was detected when (*E*)-stilbene [(*E*)-**128**] was used as substrate. This result suggested the necessity of azaaryl groups for the smooth conversion because of electronic activation of C–C double bond by azaaryl groups.[52] Furthermore, it might work as a directing or coordinating group, which explains the exclusive *β*-selectivity.

[52] D. Best, H. W. Lam, *J. Org. Chem.* **2014**, *79*, 831–845.

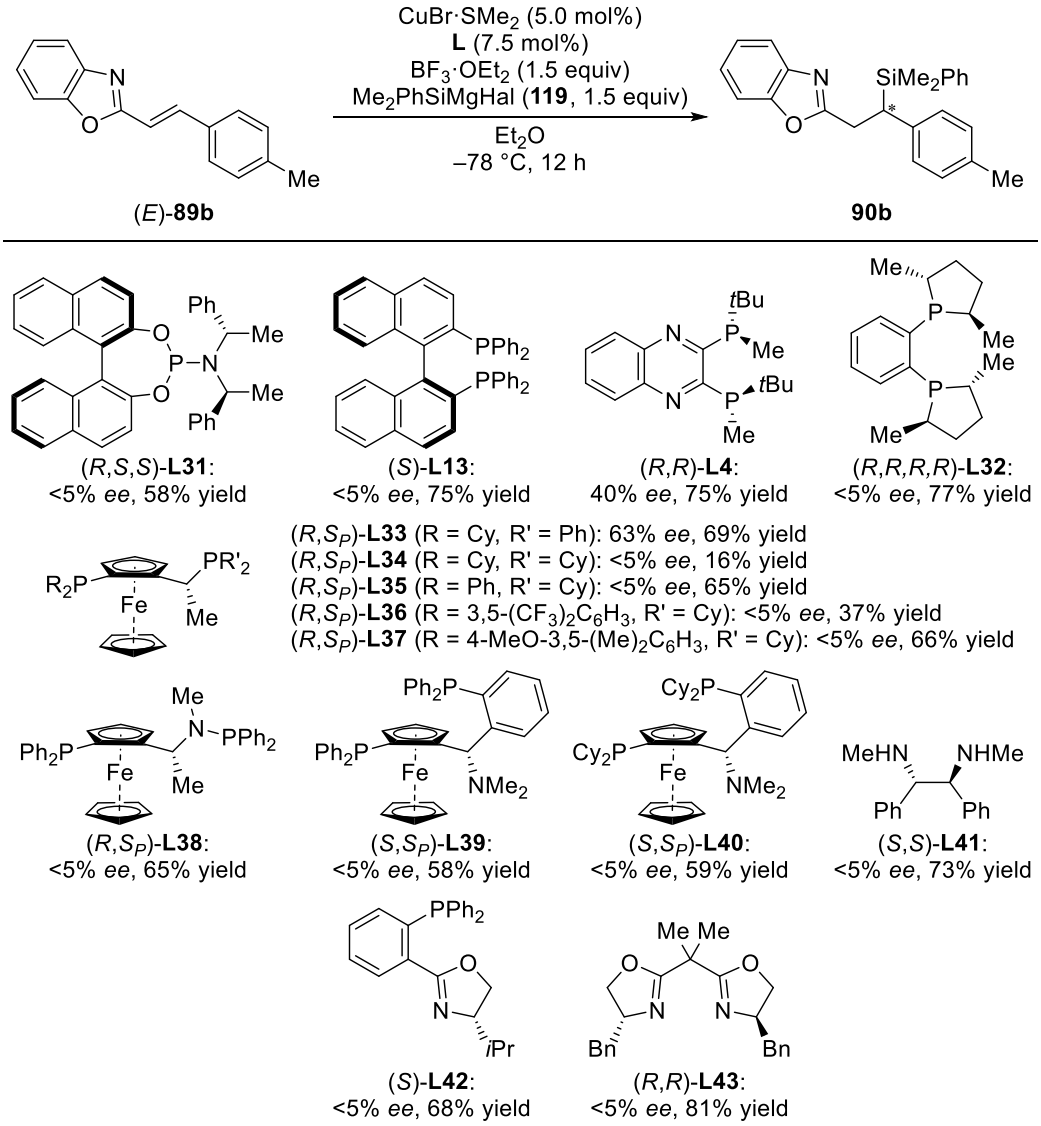


Scheme 2.2: Conjugate addition of silicon GRIGNARD reagents to azaaryl-substituted alkenes. All reactions were performed on a 0.15 mmol scale. Isolated yields were obtained after flash column chromatography on silica gel.

2.3 Chiral Version

2.3.1 Optimization Study

Then, our research moved on to asymmetric transformation, and various chiral ligands were probed (Scheme 2.3). Monodentate phosphoramidite (*R*,*S*,*S*)-**L31** only gave racemic mixtures as product in 58% yield. Chiral phosphine ligands such as (*S*)-BINAP [(*S*)-**L13**], (*R*,*R*)-QuinoxP* [(*R*,*R*)-**L4**], DuPhos (*R*,*R*,*R*,*R*)-**L32** and ferrocene-derived ligands [**L33**–**L40**] were investigated. Only QuinoxP* [(*R*,*R*)-**L4**] and Josiphos (*R*,S_P)-**L33** successfully induced moderate enantioselectivity (40% ee and 63% ee, respectively). Low levels of enantioselection were obtained when either of diamine (*S*,*S*)-**L41**, oxazoline (*S*,*S*)-**L42**, and bisoxazoline (*S*,*S*)-**L43** was used as ligand in the reaction. Given higher *ee* value obtained with Josiphos (*R*,S_P)-**L33**, we determined to survey other parameters with it.

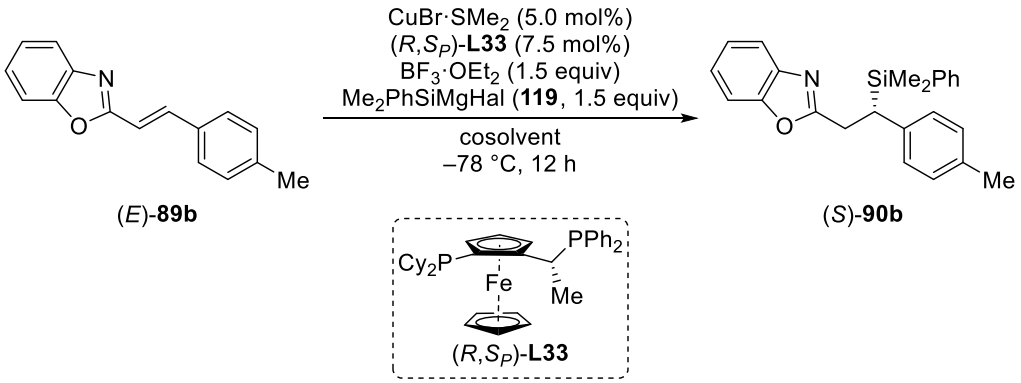


Scheme 2.3: A ligand screening for asymmetric transformation. All reactions were performed on a 0.10 mmol scale. Isolated yields were obtained after flash column chromatography on silica gel. ee values were determined by HPLC analysis on a chiral stationary phase. Hal = Cl and Br.

The influence of solvent was evaluated after the ligand screening (Table 2.2). Enantioinduction collapsed when THF or 2-MeTHF was used in the reaction. This is likely due to the strong ability of THF or 2-MeTHF to coordinate to copper salt (entries 2 and 3).[53] Toluene, CH_2Cl_2 and TBME were inferior compared to Et_2O (entries 4–6). We fortuitously found that *ee* value improved to 80% by increasing loadings of catalysts, and this only happened by using toluene and Et_2O as cosolvents (entry 7).

[53] T. Robert, J. Velder, H. G. Schmalz, *Angew. Chem. Int. Ed.* **2008**, *47*, 7718–7721; *Angew. Chem.* **2008**, *120*, 7832–7835.

Table 2.2: A solvent screening for asymmetric transformation.[a]



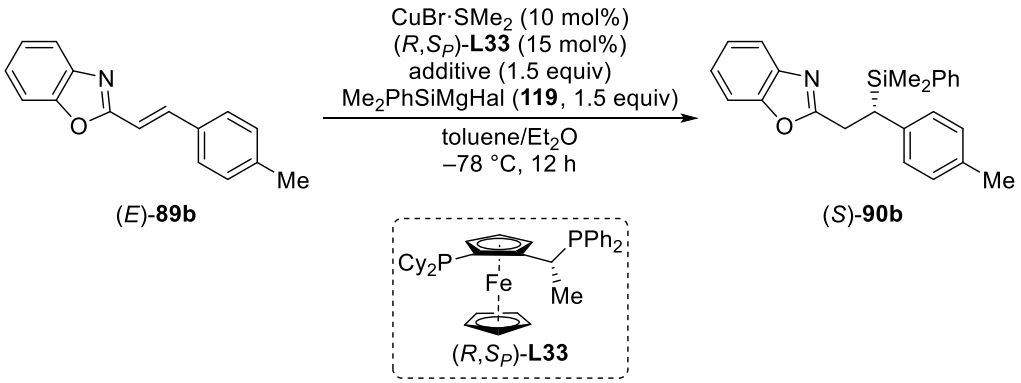
(*E*)-**89b** (*S*)-**90b** (*R*,*S*$_P$)-**L33**

entry	solvent	yield (%)[b]	*ee* (%)[c]
1	Et_2O	69	63
2	THF/Et_2O	73	<5
3	2-MeTHF/Et_2O	84	<5
4	toluene/Et_2O	65	50
5	CH_2Cl_2/Et_2O	70	31
6	TBME/Et_2O	85	40
7[d]	toluene/Et_2O	70	80

[a] All reactions were performed on a 0.10 mmol scale. [b] Isolated yields were obtained after flash column chromatography on silica gel. [c] ee values were determined by HPLC analysis on a chiral stationary phase. [d] CuBr·SMe$_2$ (10 mol%) and (*R*,*S*$_P$)-**L33** (15 mol%) were used. Hal = Cl and Br. TBME = *tert*-butyl methyl ether.

Various LEWIS acids used as additive were explored by using CuBr·SMe$_2$ (10 mol%) as precatalyst and Josiphos (*R*,*S*$_P$)-**L33** (15 mol%) as ligand in the mixture solvent of toluene and Et_2O (Table 2.3). BF_3-derived LEWIS acids proved to be effective (entries 1–3). Good to ex-cellent yields were obtained with moderate to high enantioselectivities, and $BF_3{\cdot}OEt_2$ was superior in enantioselection (entry 1). Others such as BCl_3, BBr_3, BPh_3, $CeCl_3$, $AlCl_3$, $Fe(OTf)_2$, $Sc(OTf)_3$, $Ti(OiPr)_4$ and TMSOTf, were detrimental, resulting in a dramatical decrease in *ee* values (entries 4–12).

Table 2.3: An additive screening for asymmetric transformation.[a]

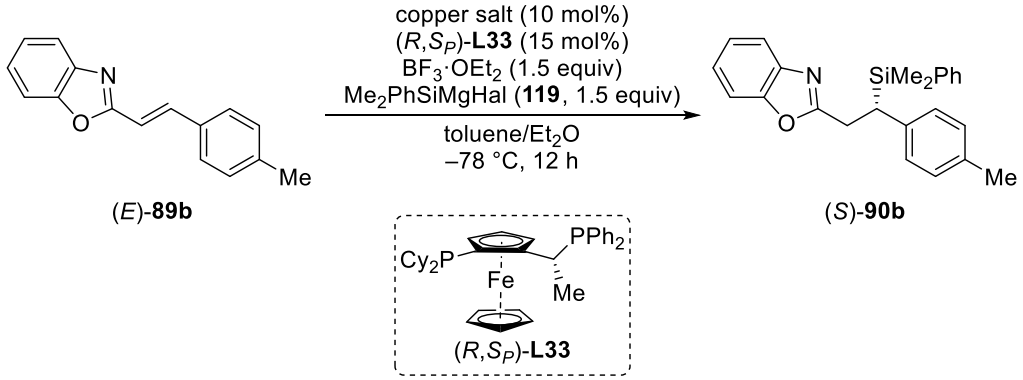


entry	additive	yield (%)[b]	*ee* (%)[c]
1	$BF_3{\cdot}OEt_2$	70	80
2	$BF_3{\cdot}OBu_2$	65	75
3	$BF_3{\cdot}SMe_2$	90	61
4	BCl_3 in heptane	38	<5
5	BBr_3	53	<5
6	BPh_3	49	<5
7	$CeCl_3$	58	<5
8	$AlCl_3$	70	<5
9	$Fe(OTf)_2$	10	<5
10	$Sc(OTf)_3$	45	<5
11	$Ti(O\textit{i}Pr)_4$	28	<5
12	TMSOTf	33	<5

[a] All reactions were performed on a 0.10 mmol scale. [b] Isolated yields were obtained after flash column chromatography on silica gel. [c] ee values were determined by HPLC analysis on a chiral stationary phase. TMSOTf = trimethylsilyl triflate. Hal = Cl and Br.

After assessment of additives, we turned our attention to different copper salts (Table 2.4). Employing CuCl instead of $CuBr{\cdot}SMe_2$ increased the yield from 70% to 82% and enantioselectivity from 80% to 85% (entries 1 and 2). Other typical copper salts were examined, but inferior levels of enantioselection were observed (entries 3–13). Excellent result was achieved by using 2.0 equivalents of $BF_3{\cdot}OEt_2$ (entry 14). Significance of $BF_3{\cdot}OEt_2$ was revealed in entry 15. Reaction of (*E*)-**89b** without $BF_3{\cdot}OEt_2$ was rendered racemic. Thus, the optimal reaction setup was comprised of 10 mol% CuCl as precatalyst, 15 mol% Josiphos (*R,S*$_P$)-**L33** as ligand, and 2.0 equivalents of $BF_3{\cdot}OEt_2$ as additive in the solvent mixture of toluene and Et_2O at –78 °C.

Table 2.4: A copper salt screening for asymmetric transformation.[a]



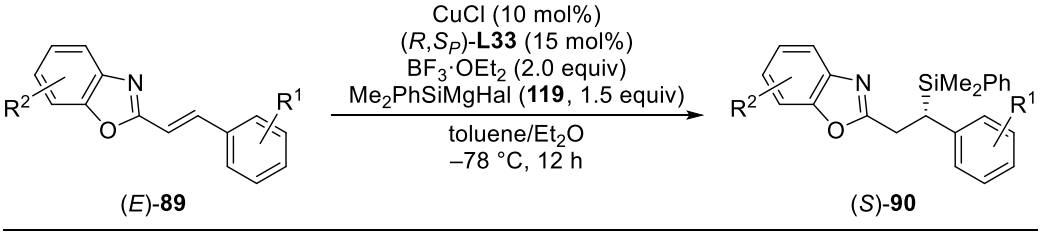
entry	catalyst	yield (%)[b]	ee (%)[c]
1	$CuBr{\cdot}SMe_2$	70	80
2	CuCl	82	85
3	CuBr	87	75
4	CuI	92	77
5	CuTc	72	73
6	CuCN	49	60
7	CuSCN	83	57
8	$(Ph_3PCuH)_6$	29	53
9	$(CF_3SO_3Cu)_2{\cdot}C_6H_6$	87	79
10	$(CH_3CN)_4CuBF_4$	78	77
11	$(Ph_3P)_2CuBH_4$	60	61
12	$(CH_3CN)_4CuPF_6$	69	65
13	$CuCl_2$	81	<5
14[d]	CuCl	80	94
15[e]	CuCl	80	<5

[a] All reactions were performed on a 0.10 mmol scale. [b] Isolated yields were obtained after flash column chromatography on silica gel. [c] ee values were determined by HPLC analysis on a chiral stationary phase. [d] $BF_3{\cdot}OEt_2$ (2.0 equiv) was used. [e] reaction was carried out without (*R,SP*)-**L33**. Hal = Cl and Br.

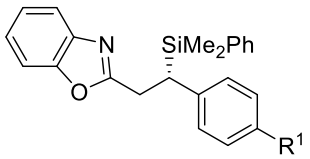
2.3.2 Substrate Scope for Asymmetric Transformation

Our optimal reaction conditions turned out to be general for various *β*-aryl-substituted akenes activated by benzoxazole (Scheme 2.4). Alkyl groups as in (*E*)-**89b** and (*E*)-**89e**, an alkoxy group as in (*E*)-**89f**, and halo groups as in (*E*)-**89g** and (*E*)-**89h** in the *para*-position of phenyl ring were compatible under our optimal reaction setup, delivering the corresponding silylated products in acceptable yields with good to high enantioselectivities of up to 91% *ee*. *meta*-Substituted (*E*)-**89i** and (*E*)-**89j** showed less efficient, compared to corresponding *para*-

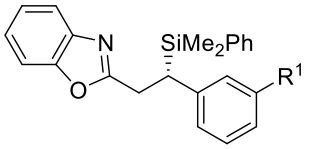
substituted alkenes [cf. (*E*)-**89b** and (*E*)-**89f**]. Substrates bearing heterocycles in the *β*-position reacted smoothly. A benzothiazole as in (*E*)-**89k**, a furyl group as in (*E*)-**89l** and (*E*)-**89n**, and a thienyl group as in (*E*)-**89m** and (*E*)-**89o** were tolerated; good to high yields were obtained with *ee* values ranging from 70% to 90%. The influence of substituents in the benzoxazole was investigated [(*E*)-**89p**–**v**]. A methyl group as in (*E*)-**89p** and (*E*)-**89t**, a phenyl group as in (*E*)-**89q**, and halo groups as in (*E*)-**89r**, (*E*)-**89s** and (*E*)-**89u** were compatible. Dimethyl-substituted (*E*)-**89v** did react in the reaction, giving the target product (*S*)-**90v** with 82% *ee*, although in a low yield. The absolute configuration of **90a** was determined as (*S*) through X-ray diffraction analysis, and others were assigned by analogy.



aryl substitution

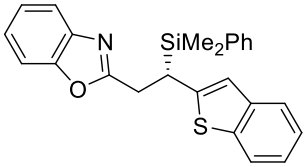


(*S*)-**90a** (R^1 = H): 93% *ee*, 65% yield (X-ray)
(*S*)-**90e** (R^1 = *i*Pr):86% *ee*, 76% yield
(*S*)-**90f** (R^1 = OMe): 91% *ee*, 45% yield
(*S*)-**90g** (R^1 = F): 80% *ee*, 51% yield[a]
(*S*)-**90h** (R^1 = Cl): 61% *ee*, 63% yield

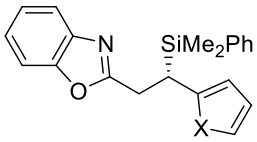


(*S*)-**90i** (R^1 = Me): 76% *ee*, 77% yield
(*S*)-**90j** (R^1 = OMe): 75% *ee*, 70% yield

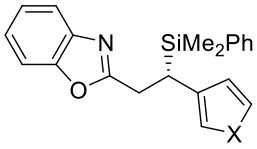
hetaryl substitution



(*S*)-**90k**: 70% *ee*, 80% yield

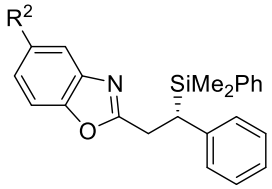


(*S*)-**90l** (X = O): 75% *ee*, 62% yield
(*S*)-**90m** (X = S): 82% *ee*, 75% yield

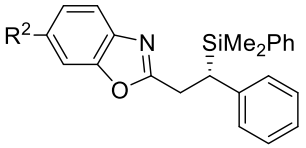


(*S*)-**90n** (X = O): 72% *ee*, 79% yield
(*S*)-**90o** (X = S): 90% *ee*, 88% yield

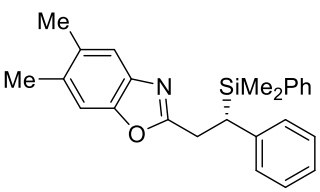
benzoxazole substitution



(*S*)-**90p** (R^2 = Me): 80% *ee*, 82% yield
(*S*)-**90q** (R^2 = Ph): 70% *ee*, 50% yield
(*S*)-**90r** (R^2 = F): 76% *ee*, 70% yield
(*S*)-**90s** (R^2 = Cl): 80% *ee*, 58% yield



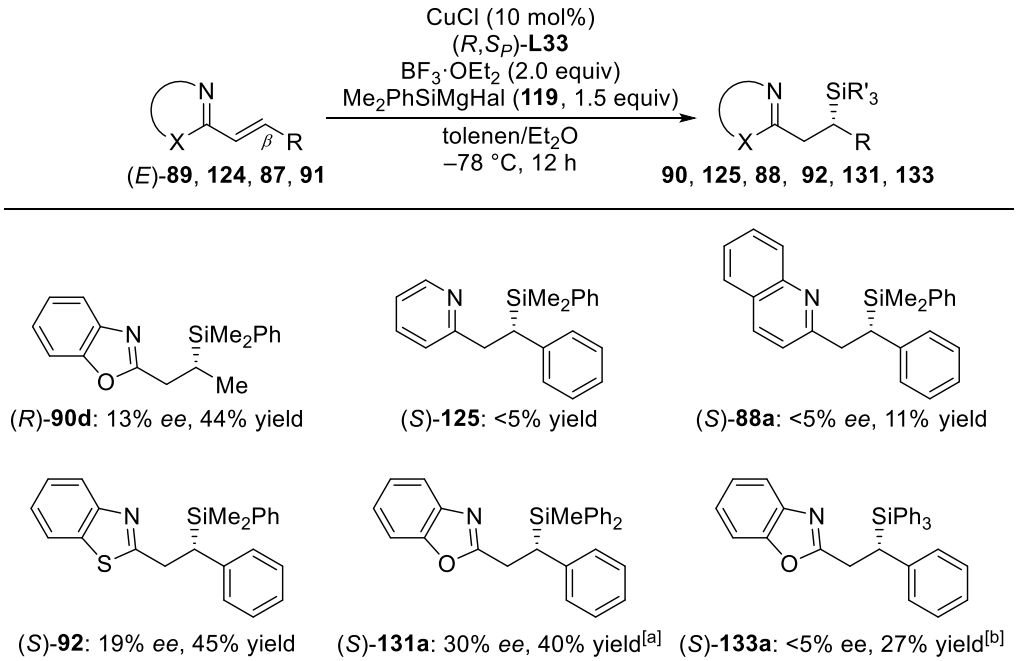
(*S*)-**90t** (R^2 = Me): 90% *ee*, 73% yield
(*S*)-**90u** (R^2 = F): 79% *ee*, 76% yield



(*S*)-**90v**: 82% *ee*, 35% yield[a]

Scheme 2.4: Asymmetric 1,4-addition of silicon nucleophiles to azaary-substituted alkenes. All reactions were performed on a 0.15 mmol scale. Isolated yields were obtained after flash column chromatography on silica gel. *ee* values were determined by HPLC analysis on a chiral stationary phase. [a] 5.0 equiv of $BF_3 \cdot OEt_2$ were used. Hal = Cl or Br.

No method fits all sizes (Scheme 2.5). *β*-Alkyl (*E*)-**89d** failed to afford enantioenriched product (*R*)-**90d**. Heterocycles, which could be used instead of benzoxazole in the racemic transformation, proved to be incompatible in the asymmetric transformation [(*E*)-**124** → (*S*)-**125**, (*E*)-**87a** → (*S*)-**88a**, and (*E*)-**91** → (*S*)-**92**]. Increasing sterical congestion to silicon atom in GRIGNARD reagents resulted in sharply diminution in both yields and *ee* values [(*E*)-**89a** → (*S*)-**131a** and (*S*)-**133a**].

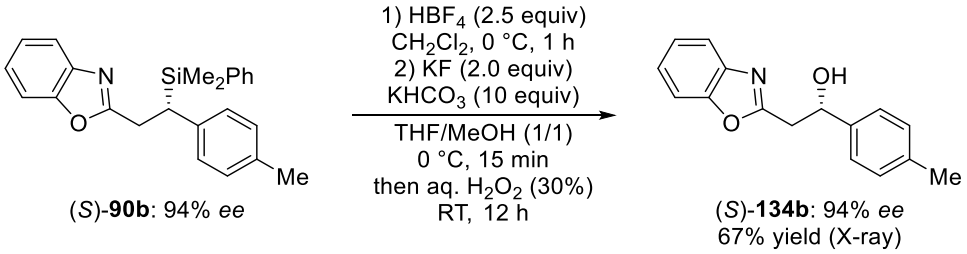


Scheme 2.5: Failed examples for asymmetric transformation. All reactions were performed on a 0.15 mmol scale. Isolated yields were obtained after flash column chromatography on silica gel. *ee* values were determined by HPLC analysis on a chiral stationary phase. [a] $MePh_2SiMgHal$ (**130**) was used instead of $Me_2PhSiMgHal$ (**119**). [b] $Ph_3SiMgHal$ (**132**) was used instead of $Me_2PhSiMgHal$ (**119**).

2.3.3 Follow-Up Chemistry

As aforementioned (cf. Scheme 1.1), stereospecific transformation of silyl groups into hydroxy groups is one of the foremost synthetical applications of chiral silanes, which is known as TAMAO–FLEMING oxidation. Oxidative degradation of (*S*)-**90b** was performed through a two-step procedure, delivering the desired chiral alcohol (*S*)-**134b** in 67% yield,

without any loss of enantioselectivity (Scheme 2.6). Absolute configuration of (*S*)-**134b** was confirmed as (*S*) through single crystal X-ray crystallography. This result is in accordance with retention of configuration in TAMAO–FLEMING oxidation.



Scheme 2.6: TAMAO–FLEMING oxidation of (*S*)-**90b**. Reaction was performed on a 0.20 mmol scale. Isolated yields were obtained after flash column chromatography on silica gel. *ee* values were determined by HPLC analysis on a chiral stationary phase.

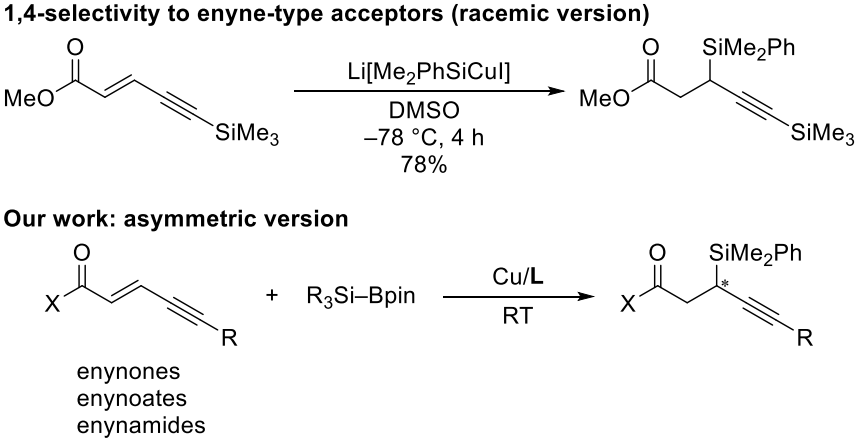
2.4 Conclusion

In summary, we have reported a copper-catalysed silyl transfer from silicon GRIGNARD reagents to azaaryl-substituted alkenes with exclusive *β*-selectivity. Eight substrates in the racemic transformation demonstrated good functional group compatibility. Enantioselective version of benzoxazole-activated alkenes was accomplished by using CuCl as precatalyst and Josiphos (*R*,*S*$_P$)-**L33** as ligand. Good to high enantioselectivities of up to 94% *ee* were observed in this C–Si bond formation. LEWIS acid $BF_3{\cdot}Et_2O$ was indispensable for both yields and high levels of enantioselection.

3 ASYMMETRIC CONJUGATE 1,4-SILYL TRANSFER TO ENYNE-TYPE *α,β,γ,δ*-UNSATURATED ACCEPTORS

3.1 Introduction

Enantioselective conjugate addition of Si–B reagents to diene-type *α,β,γ,δ*-unsaturated carbonyl compounds and their derivatives to construct chiral allylic silanes has been disclosed by HOVEYDA and co-workers (cf. Scheme 1.22),[28] KOBAYASHI group and co-workers (cf. Scheme 1.26),[32] and CHU, LIU and co-workers (cf. Scheme 1.29),[36] respectively. These methods feature High regio- and enantioselectivity. In 2015, XU, LOH and co-workers reported their protocol about copper-catalyzed enantioselective 1,6-addition of Si–B reagents to (*Z*)-configured enynoates, demonstrating general and efficient avenues for a wide range of optically pure allenylsilanes (cf. Scheme 1.34).[38] However, synthesis of propargylic silane through 1,4-addition of Si–B reagents to enynoates is still limited to a racemic transformation (Scheme 3.1, top).[54] These intrigued us to explore new methods for chiral propargylic silanes through asymmetric conjugate addition of Si–B reagents to enyne-type *α,β,γ,δ*-unsaturated acceptors. In the following chapter is reported a copper-catalyzed highly chemo- and enantioselective 1,4-silyl transfer from Si–B reagents to *α,β,γ,δ*-unsaturated acceptors.



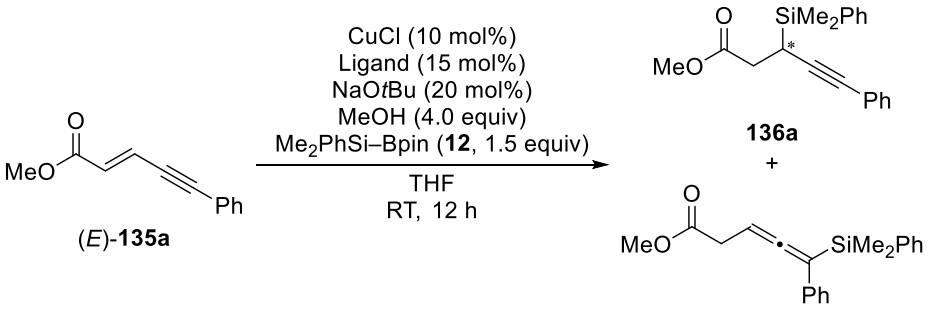
Scheme 3.1: Asymmetric 1,4-silyl transfer to enyne-type acceptors.

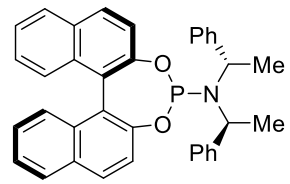
3.2 Optimization Study

We commenced our study with evaluating different chiral ligands in the addition reaction by employing enynoate (*E*)-**135a** as model substrate and Me_2PhSi–Bpin (**12)** as silicon source (Scheme 3.2). The use of phosphoramidite (*R*,*S*,*S*)-**L31** in the presence of CuCl, NaO*t*Bu

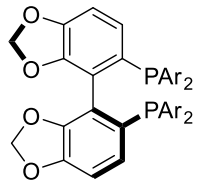
[54] J. Dambacher, M. Bergdahl, *J. Org. Chem.* **2005**, *70*, 580–589.

and MeOH in THF, afforded the 1,4-addition product **136a** in 75% yield, however with low enantioselectivity. Significant improvements of *ee* values were observed by using SEGPHOS ligands, but allenylsilane *rac*-**137a** was the main product [(*R*)-**L3**, (*S*)-**L44** and (*S*)-**L45**]. Good result was achieved in the reaction by using (*R*,*R*)-QuinoxP* [(*R*,*R*)-**L4**] as ligand. 84% yield of 1,4-selective product **136a** was obtained with 70% *ee*. Ligands derived from BINAP showed less efficient in regioselectivity, delivering the target **136a** in far lower yields [(*R*)-**L13**, (*R*)-**L46**, and (*R*)-**L47**]. Josiphos (*R*,S_p)-**L33** only induced 57% *ee*, not as good as (*R*,*R*)-QuinoxP* [(*R*,*R*)-**L4**]. Diamine ligand (*S*,*S*)-**L48** did promote the reaction enantioselectively, affording chiral **136a** in 25% yield with 47% *ee*. (*S*,*S*)-**L49** failed to afford the product. Low levels of enantioinduction were found by using oxazole ligands [(*S*)-**L42**, (*S*)-**L50**, and (*S*)-**L51**]. NHC ligands were tried, but did not give better results [(*S*,*S*)-**L52** and (*S*)-**L53**]. Thus, (*R*,*R*)-QuinoxP* [(*R*,*R*)-**L4**] was identified as the optimal choice of ligand to carry on our further optimization.

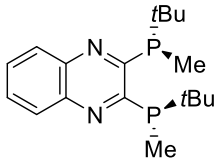




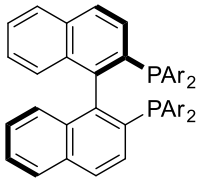
(*R*,*S*,*S*)-**L31**: 13% *ee*[a]
75% yield,[b] 92:8[c]



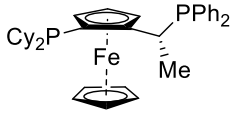
(*S*)-**L44** [(*S*)-SEGPHOS]: 80% *ee*, 20% yield, 25:75
(*R*)-**L3** [(*R*)-DM-SEGPHOS]: 94% *ee*, 33% yield, 33:67
(*S*)-**L45** [(*S*)-DTBM-SEGPHOS]: 3% yield, 60:40



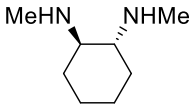
(*R*,*R*)-**L4** [(*R*,*R*)-QuinoxP*]:
70% *ee*, 84% yield, 96:4



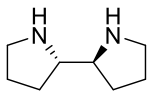
(*R*)-**L13** [(*R*)-BINAP]: 50% *ee*, 25% yield, 40:60
(*R*)-**L46** [(*R*)-Tol-BINAP]: 80% *ee*, 13% yield, 29:71
(*R*)-**L47** [(*R*)-Xyl-BINAP]: 75% *ee*, 19% yield, 29:71



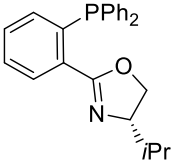
(*R*,S_P)-**L33**: 57% *ee*
74% yield, 86:14



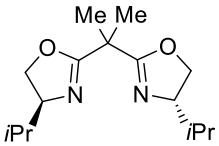
(*S*,*S*)-**L48**: 47% *ee*
25% yield, 50:50



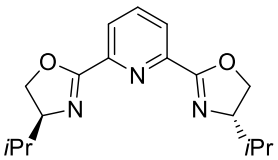
(*R*,*R*)-**L49**: trace



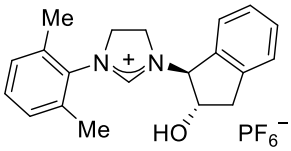
(*S*)-**L42**: 7% *ee*
27% yield, >98:2



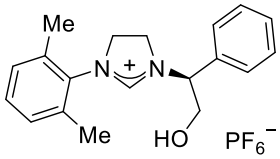
(*S*,*S*)-**L50**: 12% *ee*
54% yield, 72:28



(*S*,*S*)-**L51**: 20% *ee*
62% yield, 76:24



(*S*,*S*)-**L50**: 20% *ee*
84% yield, 90:10

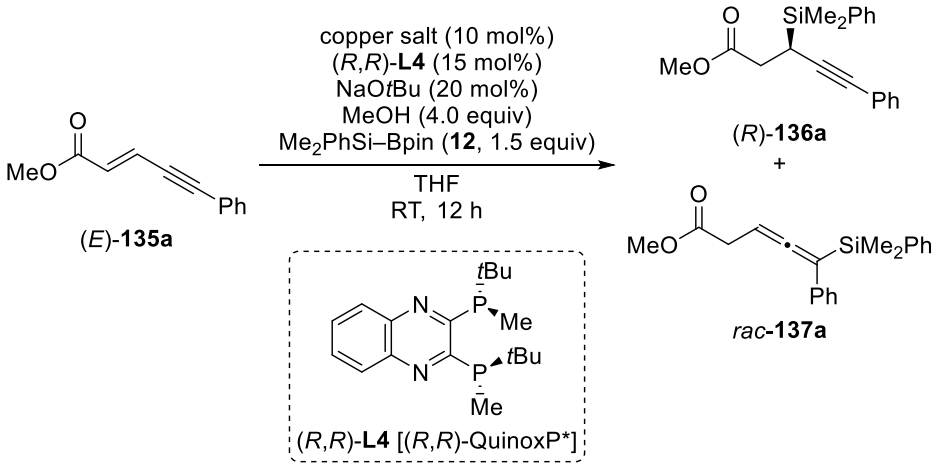


(*S*)-**L51**: <5% *ee*
92% yield, 92:8

Scheme 3.2: A ligand screening for asymmetric transformation. All reactions were performed on a 0.10 mmol scale. [a] *ee* values were determined by HPLC analysis on a chiral stationary phase. [b] Isolated yields were obtained after flash column chromatography on silica gel. [c] Ratios for 1,4- and 1,6-selectivity were determined by ^{1}H NMR spectroscopy.

A copper salt screening was conducted after the ligand screening (Table 3.1). CuBr offered the best results among the copper halides used in the reaction, affording the desired 1,4-addition product (*R*)-**136a** in 79% yield with 80% *ee* (entries 1–3). Slightly improvement of enantioselection from 80% *ee* to 82% *ee* was accomplished by using CuTC instead of CuBr (entry 4). CuCN and CuOAc failed to catalyze the silyl transfer from Me_2PhSi–Bpin (**12**) to enynoate (*E*)-**135a** (entries 5 and 6). Similar or even better levels of enantioselection were obtained, however with far less conversion by using either of CuSCN and $CuBr{\cdot}SMe_2$ as precatalyst (entries 7 and 8). $(Ph_3P)_2CuBH_4$ provided a comparatively superb result, providing the target (*R*)-**136a** in 84% yield with 83% *ee* (entry 9). Excellent ratio for 1,4- versus 1,6 selectivity was also observed. Only trace amounts of product (*R*)-**136a** was detected when $(CH_3CN)_4CuPF_6$ was used (entry 10).

Table 3.1: A copper salt screening for asymmetric transformation.[a]

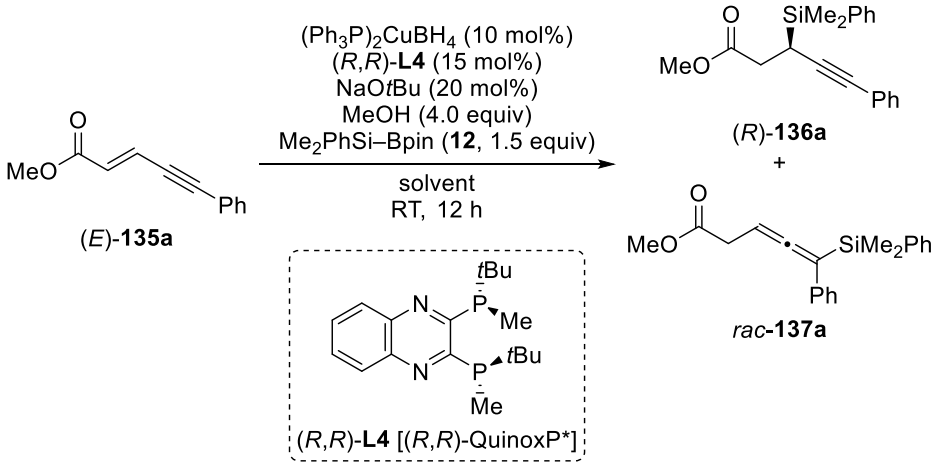


entry	copper salt	1,4:1,6[b]	yield of **136a** (%)[c]	*ee* of **136a** (%)[d]
1	CuCl	96:4	74	70
2	CuI	>98:2	16	33
3	CuBr	97:3	79	80
4	CuTC	>98:2	71	82
5	CuCN	-	trace	-
6	CuOAc	-	trace	-
7	CuSCN	>98:2	29	90
8	$CuBr{\cdot}SMe_2$	>98:2	55	81
9	$(Ph_3P)_2CuBH_4$	>98:2	84	83
10	$(CH_3CN)_4CuPF_6$	-	trace	-

[a] All reactions were performed on a 0.10 mmol scale. [b] Ratios for 1,4- versus 1,6-selectivity were determined by ^1H NMR spectroscopy. [c] Isolated yields were obtained after flash column chromatography on silica gel. [d] *ee* values were determined by HPLC analysis on a chiral stationary phase.

We then investigated the influence of solvent in our method (Table 3.2). Assessment of different ether solvents identified 2-MeTHF as the optimal choice, affording (*R*)-**136a** in high yield with excellent enantioselectivity (entries 1–3). Only trace amounts of desired product were observed in CH_2Cl_2 or EtOH (entries 4 and 5). Use of *t*AmOH or toluene as solvent led to low conversion (entries 6 and 7).

Table 3.2: A solvent screening for asymmetric transformation.[a]

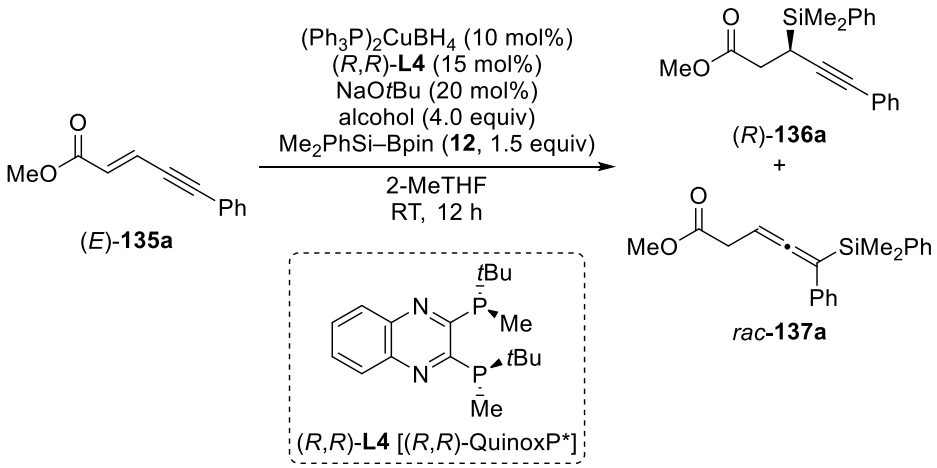


entry	solvent	1,4:1,6[b]	yield of **136a** (%)[c]	*ee* of **136a** (%)[d]
1	THF	>98:2	84	83
2	Et_2O	>98:2	80	75
3	2-MeTHF	>98:2	85	91
4	CH_2Cl_2	-	trace	-
5	EtOH	-	trace	-
6	*t*AmOH	>98:2	33	78
7	toluene	92:8	42	60

[a] All reactions were performed on a 0.10 mmol scale. [b] ratios for 1,4- versus 1,6-selectivity were determined by ^{1}H NMR spectroscopy. [c] Isolated yields were obtained after flash column chromatography on silica gel. [d] *ee* values were determined by HPLC analysis on a chiral stationary phase. 2-MeTHF = 2-methyltetrahydrofuran; *t*AmOH = *tert*-amyl alcohol.

Different kinds of alcohols were then evaluated (Table 3.3). Similar results were obtained for EtOH, *n*PrOH and *i*PrOH, but not as good as MeOH (entries 1–4). H_2O also worked, delivering 75% yield of (*R*)-**136a** with 88% *ee* (entry 5). It was notewothy that same level of site selectivity [(*R*)-**136a**:*rac*-**137a** > 98:2] was observed with different alcohols.

Table 3.3: An alcohol screening for asymmetric transformation.[a]

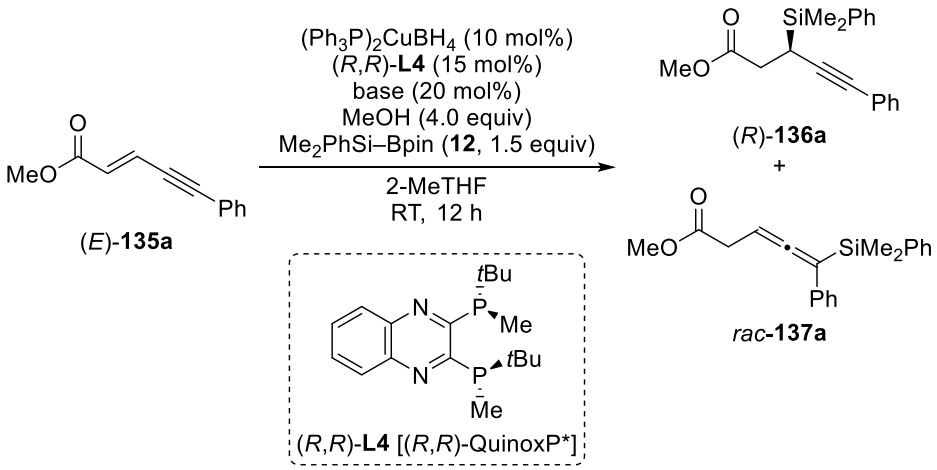


entry	alcohol	1,4:1,6[b]	yield of **136a** (%)[c]	*ee* of **136a** (%)[d]
1	MeOH	>98:2	85	91
2	EtOH	>98:2	82	87
3	*n*PrOH	>98:2	84	82
4	*i*PrOH	>98:2	55	89
5	H_2O	>98:2	75	88

[a] All reactions were performed on a 0.10 mmol scale. [b] Ratios for 1,4- versus 1,6-selectivity were determined by ^{1}H NMR spectroscopy. [c] Isolated yields were obtained after flash column chromatography on silica gel. [d] *ee* values were determined by HPLC analysis on a chiral stationary phase.

Various bases were probed by using $(Ph_3Ph)_2CuBH_4$ as precatalyst, (*R*,*R*)-QuinoxP* [(*R*,*R*)-**L4**] as ligand and MeOH as proton source in 2-MeTHF and results were outlined in Table 3.4. Sodium alkoxides and sodium hydroxide result in similar enantioselectivities (entries 1–4). LiO*t*Bu was slightly less efficient in both yield and *ee* values, and KO*t*Bu appeared to be same, compared to NaO*t*Bu (entries 5 and 6). 80% yield of (*R*)-**136a** was obtained with 83% *ee* in the presence of Et_3N (entry 7). Lowering loadings of catalytic system would increase the yield from 92% to 95% yield, without any loss of enantioenrichment. Thus, the optimal reaction conditions for pilot substrate (*E*)-**135a** comprised $(Ph_3P)_2CuBH_4$ (0.50 mol%), (*R*,*R*)-QuinoxP* [(*R*,*R*)-**L4**, 0.75 mol%], KO*t*Bu (5.0 mol%), and MeOH (2.0 equiv) in 2-MeTHF (1 mL).

Table 3.4: A base screening for asymmetric transformation.[a]

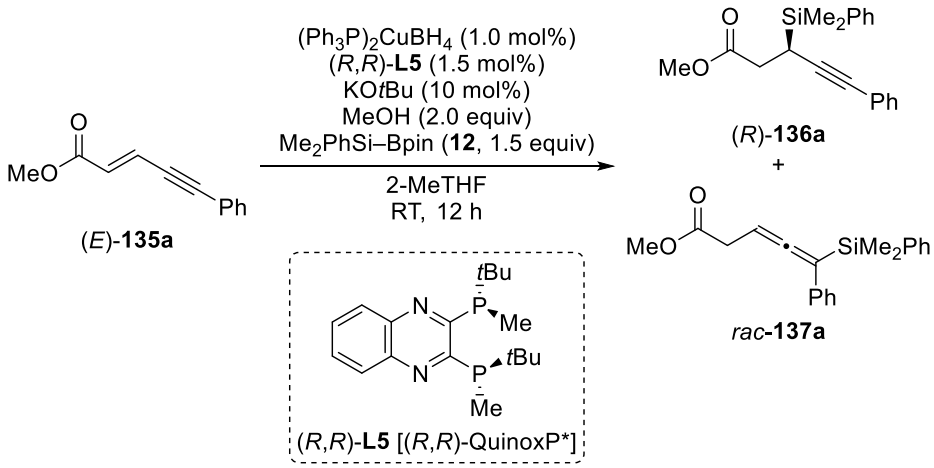


entry	base	1,4:1,6[b]	yield of **136a** (%)[c]	*ee* of **136a** (%)[d]
1	NaO*t*Bu	>98:2	85	91
2	NaOMe	>98:2	81	90
3	NaOEt	>98:2	66	87
4	NaOH	>98:2	73	90
5	LiO*t*Bu	>98:2	75	89
6	KO*t*Bu	>98:2	85	92
7	Et_3N	>98:2	80	83
8[e]	KO*t*Bu	>98:2	95	92

[a] All reactions were performed on a 0.10 mmol scale. [b] Ratios for 1,4- versus 1,6-selectivity were determined by ^{1}H NMR spectroscopy. [c] Isolated yields were obtained after flash column chromatography on silica gel. [d] *ee* values were determined by HPLC analysis on a chiral stationary phase. [e] Reaction was carried out by using 0.40 mol (*E*)-**135a**, 1.5 equiv of Me_2PhSi–Bpin (**12**), 0.50 mol% $(Ph_3P)_2CuBH_4$, 0.75 mol% (*R*,*R*)-QuinoxP* [(*R*,*R*)-**L4**], 5.0 mol% KO*t*Bu, and 2.0 equiv of MeOH in 1 mL of 2-MeTHF.

Control experiments were done to verify the necessity of copper salt, base and alcohol (Table 3.5). Only trace amounts of (*R*)-**136a** were detected without $(Ph_3P)_2CuBH_4$ (entry 1). Reaction removing KO*t*Bu led to noticeable erosion in both yield and enantioselectivity (entry 2). Absence of MeOH resulted in 7% of the desired product (*R*)-**136a** (entry 3).

Table 3.5: Control experiments for asymmetric transformation.[a]



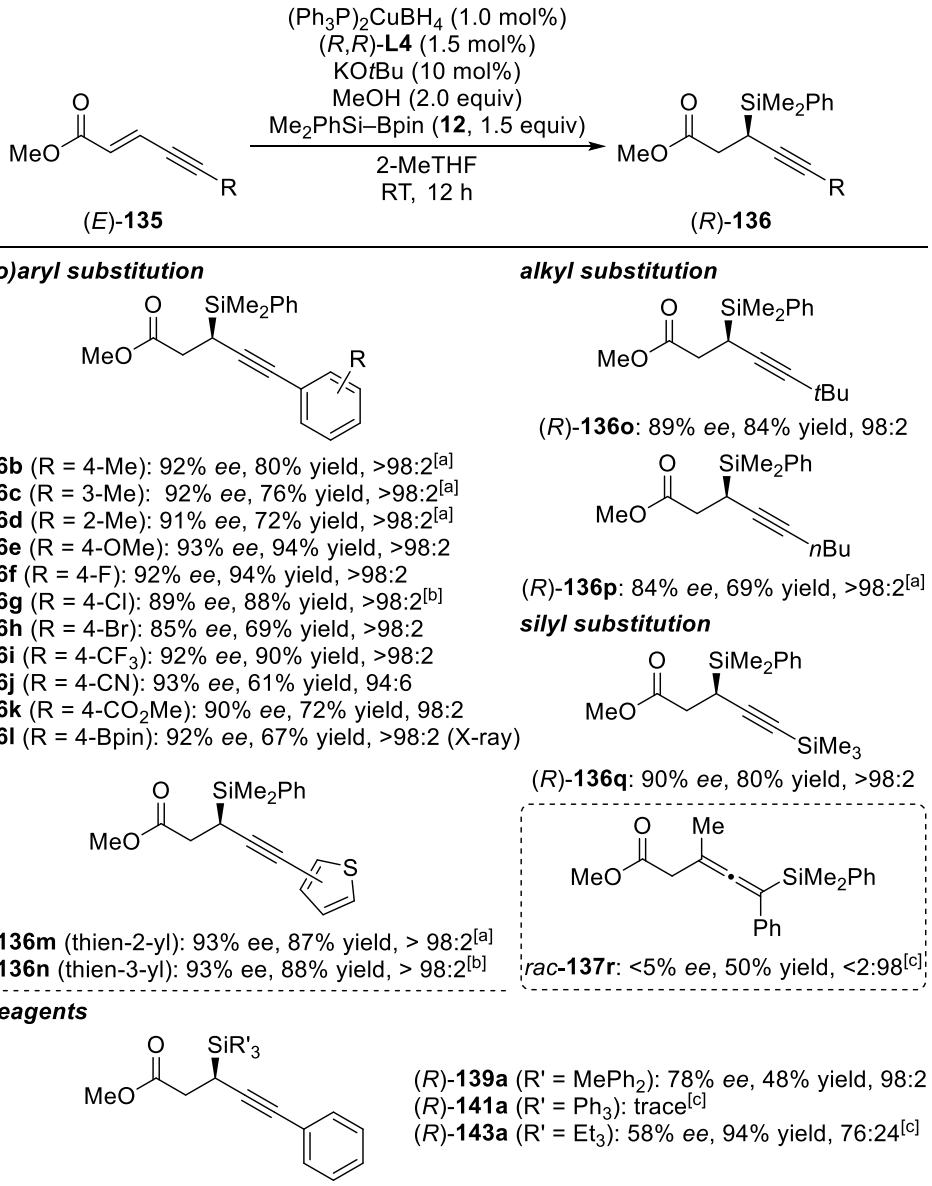
entry	variation	1,4:1,6[b]	yield of **136a** (%)[c]	*ee* of **136a** (%)[d]
1	w/o $(Ph_3P)_2CuBH_4$	-	trace	-
2	w/o KO*t*Bu	>98:2	13	75
3	w/o MeOH	96:4	7	-

[a] All reactions were performed on a 0.20 mmol scale. [b] Ratios for 1,4- versus 1,6-selectivity were determined by ^{1}H NMR spectroscopy. [c] Isolated yields were obtained after flash column chromatography on silica gel. [d] *ee* values were determined by HPLC analysis on a chiral stationary phase.

3.3 Substrate Scope

We then probed the substrate scopes for this new method and various enyne-type *α*,*β*,*γ*,*δ*-unsaturated (*E*)-configured enynoates were prepared and subjected into our optimal setup (Scheme 3.3). Aryl groups in the *δ*-position, with electron-withdrawing groups or electron-donating groups were tolerated under our optimal conditions, providing the corresponding products in good to excellent yields, with excellent enantio- and regioselectivities [(*E*)-**135b**–**l** → (*R*)-**136b**–**l**]. Good functional group compatibility was observed in the tolerance with halo [(*R*)-**136f**, (*R*)-**136g** and (*R*)-**136h**], CF_3 [(*R*)-**136i**], cyano [(*R*)-**136j**], ester [(*R*)-**136k**] and boryl groups [(*R*)-**136l**]. It is noteworthy that these groups are important linchpins for further elaboration. *δ*-Thienyl-substituted (*E*)-**135m** and (*E*)-**135n** were reactive, delivering similar results. Alkyl-substituted (*E*)-**135o**, as well as (*E*)-**135p** appeared to be less efficient in enantioinduction, compared to aryl-substituted enynoates. A silyl group as in (*E*)-**135q** remained intact after the transformation. Substrate (*E*)-**135r** with a methyl group in the *β*-position delivered racemic allene *rac*-**137r** as the main product. Influence of steric congestion around the silicon atom of Si–B reagents was further investigated. It seemed the Me_2PhSi group was optimal choice. Sterically less or more demanding silyl groups led to less *ee* values or no transformation [(*E*)-**135a** → (*R*)-**139a**, (*R*)-**141a**, and (*R*)-**143a**]. Absolute

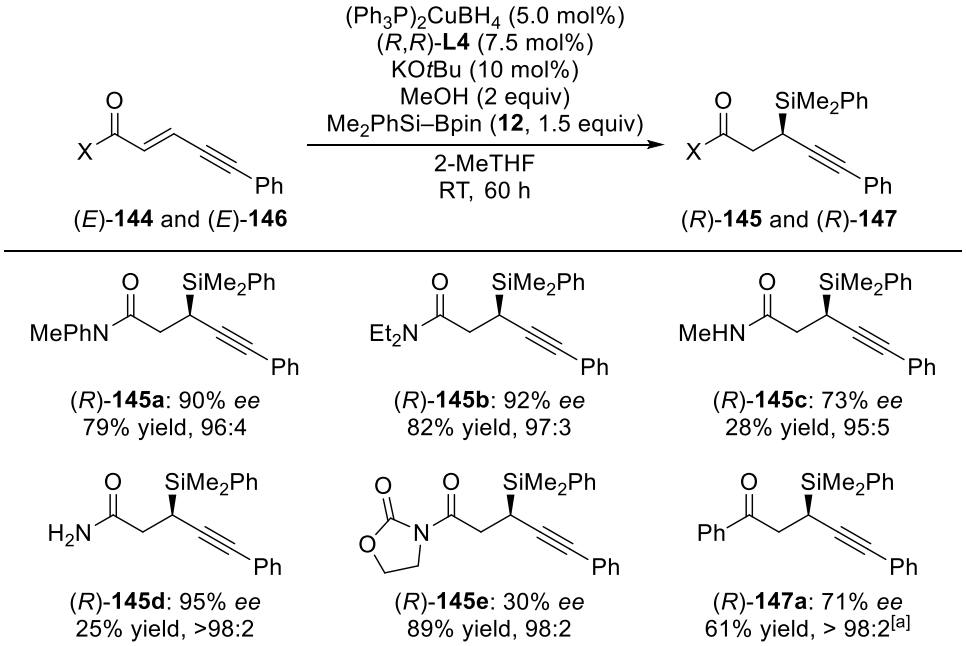
configuration of **136l** was determined as (*R*) through single crystal X-ray crystallography and others were assigned by analogy.



Scheme 3.3: Asymmetric 1,4-addition of Si–B reagents to (*E*)-enynoates. All reactions were performed on a 0.20 mmol scale. Isolated yields were obtained after flash column chromatography on silica gel. *ee* values were determined by HPLC analysis on a chiral stationary phase. [a] 5.0 mol% $(Ph_3P)_2CuBH_4$ and 7.5 mol% (*R*,*R*)-**L4** were used. [b] 2.5 mol% $(Ph_3P)_2CuBH_4$ and 3.8 mol% (*R*,*R*)-**L4** were used. [c] 10 mol% $(Ph_3P)_2CuBH_4$ and 15 mol% (*R*,*R*)-**L4** were used. $MePh_2Si$–Bpin (**138**), Ph_3Si–Bpin (**140**) and Et_3Si–Bpin (**142**) were used for (*R*)-**139a**, (*R*)-**141a** and (*R*)-**143a**, respectively.

We then applied our method to different enynamides (Scheme 3.4). *N*-Aryl or -alkyl protected substrates were compatible under our optimal setup, however, prolonging reaction time was

inevitable for high efficacy [(*E*)-**144a** → (*R*)-**145a** and (*E*)-**144b** → (*R*)-**145b**]. Free H atom attached to nitrogen atom as in (*E*)-**144c** and (*E*)-**144d** was also tolerated, however, far less conversion was observed. Activated enynimide (*E*)-**144e** gave (*R*)-**145e** in 89% yield with only 30% *ee*. Our method proved to be less reactive for enynone (*E*)-**146a**, and only 71% *ee* was induced. It is worth mentioning that excellent ratios for 1,4- versus 1,6-selectivity were obtained for all the aforementioned examples, more than 95:5 in most cases.

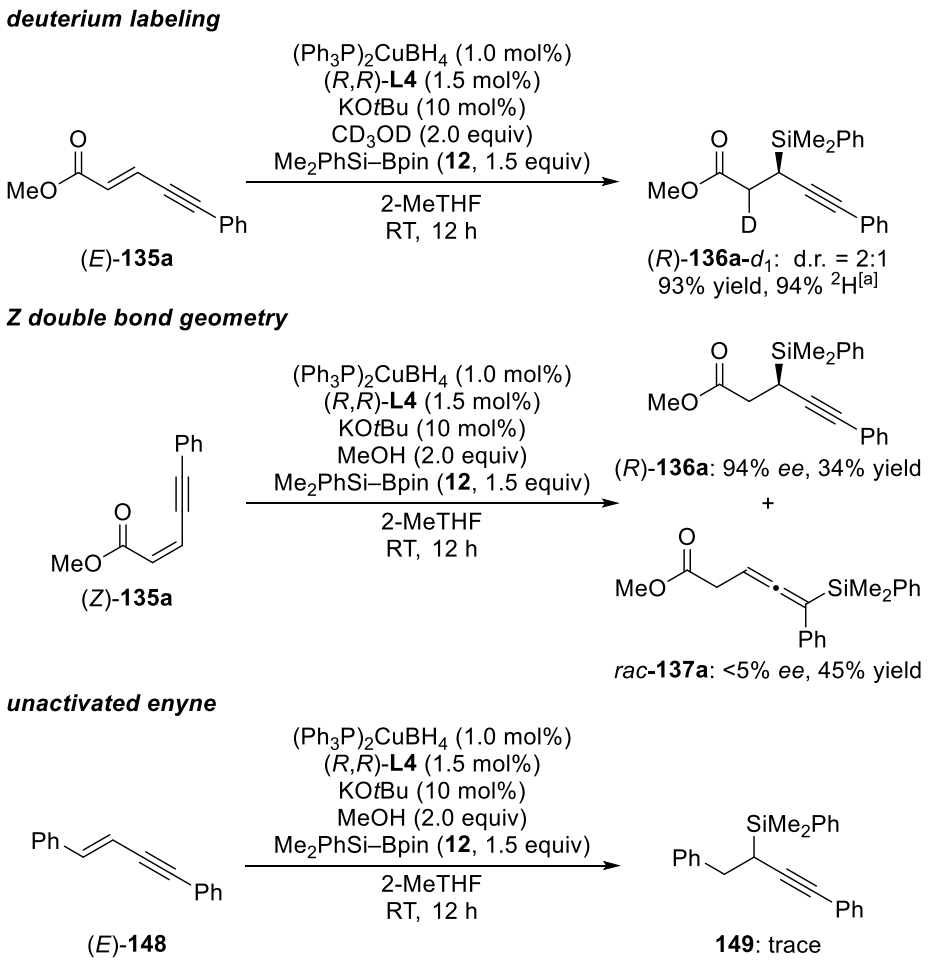


Scheme 3.4: Asymmetric 1,4-addition of Si–B reagents to (*E*)-enynamides and (*E*)-enynones. All reactions were performed on a 0.20 mmol scale. Isolated yields were obtained after flash column chromatography on silica gel. *ee* values were determined by HPLC analysis on a chiral stationary phase. [a] 1.0 mol% $(Ph_3P)_2CuBH_4$ and 1.5 mol% (*R*,*R*)-**L4** were used for 12 h.

3.4 Control Experiments

To shed more light on the mechanism of our method, three control experiments were carried out (Scheme 3.5). Firstly, deuterated methanol was used instead of MeOH in the reaction of (*E*)-**127a**. H/D scrambling exclusively happened in the *α*-position, resulting in the incorporation of 94% deuterium. This result suggested the role of MeOH as proton source in the reaction. Then, (*Z*)-**135a**, which represented optimal choice in XU and LOH's work,[38] was prepared and subjected into our optimal reaction conditions. 34% yield of propargylic silane (*R*)-**136a** was obtained with 94% *ee*, along with the formation of 45% yield of racemic allene *rac*-**137a**. This result corroborated the importance about (*E*)-configuration of C–C double bond in substrate to the domination of 1,4-selectivity. Finally, (*E*)-**148** was tried, and all

starting material recovered after the reaction, partially indicating the participation of C–O double bond in the reaction.



Scheme 3.5: Control experiments for asymmetric transformation. All reactions were performed on a 0.20 mmol scale. Isolated yields were obtained after flash column chromatography on silica gel. *ee* values were determined by HPLC analysis on a chiral stationary phase. [a] Diastereomeric ratio and deuterium incorporation were estimated through ^{1}H NMR spectroscopy.

3.5 Conclusion

In summary, we developed a general and efficient approach for optically pure propargylic silanes through enantioselective conjugate addition of Si–B reagents to enyne-type *α*,*β*,*γ*,*δ*-unsaturated acceptors.[55] Merits of our method included high efficiency with regard to yield, chemo- and enantio-selectivity, excellent functional group tolerance, and simple operation procedure. Enynoates, enynamides and enynones were all suitable substrates, delivering the

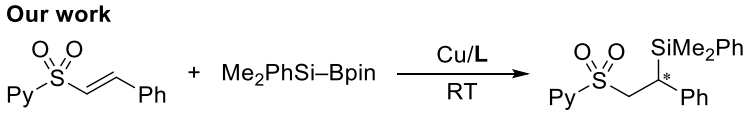
[55] W. Mao, M. Oestreich, *Org. Lett.* **2020**, *22*, 8096–8100.

desired products with hardly any formation of 1,6-selective adducts. (*Z*)-configured C–C double bond is an important factor in the domination of 1,4-selectivity in our method.

4 ASYMMETRIC CONJUGATE 1,4-SILYL TRANSFER TO α,β-UNSATURATED SULFONES

4.1 Introduction

α,β-Unsaturated sulfones as suitable MICHAEL acceptors have been researched for years,[56] and asymmetric applications have been successfully made in the hydrogenation,[57] C–C bond formation,[58] C–N bond formation,[59], C–O bond formation,[60] and C–P bond formation[61]. C–Si bond formation had not been realized between α,β-unsaturated sulfones and silicon nucleophiles until YIN's publication in 2021 (cf. Scheme 1.31).[37] Long reaction time (≥ 60 hours) and low reaction temperature (≤–30 °C), to some extent, limited their development. Thus, operationally simple and efficient modular methods for chiral silanes through asymmetric conjugate addition of Si–B reagents to α,β-unsaturated sulfones are still highly desirable. Notably, our project was ongoing when YIN and co-workers reported their work. This chapter discloses our progress about enantioselective silylation of α,β-unsaturated sulfones employing Me_2PhSi–Bpin (**12**) as silicon source (Scheme 4.1).



Scheme 4.1: Asymmetric 1,4 silyl transfer to α,β-unsaturated sulfones.

[56] For selected reviews, see: a) M. Mauduit, O. Baslé, H. Clavier, C. Crévisy, A. Denicourt-Nowicki, in *Comprehensive Organic Synthesis*, 2nd ed.; (Eds: G. A. Molander, P. Knochel), Elsevier: Oxford, **2014**, Vol. 4, pp. 189–341; b) A. Alexakis, N. Krause, S. Woodward, in *Copper-Catalyzed Asymmetric Synthesis*, (Eds.: A. Alexakis, N. Krause, S. Woodward), Wiley-VCH, Weinheim, **2014**, pp. 33–68.

[57] Selected examples for asymmetric hydrogenation, see: a) J.-N. Desrosiers, A. B. Charette, *Angew. Chem. Int. Ed.* **2007**, *46*, 5955–5957; *Angew. Chem.* **2007**, *119*, 6059–6061; b) Y. Sun, J. Jiang, X. Guo, J. Wen, X. Zhang, *Org. Chem. Front.* **2019**, *6*, 1438–1441.

[58] Selected examples for C–C bond formation, see: a) H. Li, J. Song, L. Deng, *Tetrahedron* **2009**, *65*, 3139–3148; b) J. J. Murphy, A. Quintard, P. McArdle, A. Alexakis, J. C. Stephen, *Angew. Chem. Int. Ed.* **2011**, *50*, 5095 –5098; *Angew. Chem.* **2011**, *123*, 5201–5204; c) T. Nishimura, Y. Takiguchi, T. Hayashi, *J. Am. Chem. Soc.* **2012**, *134*, 9086–9089; d) K. M.-H. Lim, T. Hayashi, *J. Am. Chem. Soc.* **2015**, *137*, 3201–3204; e) R. Takechi, T. Nishimura, *Chem. Commun.* **2015**, *51*, 8528–8531;

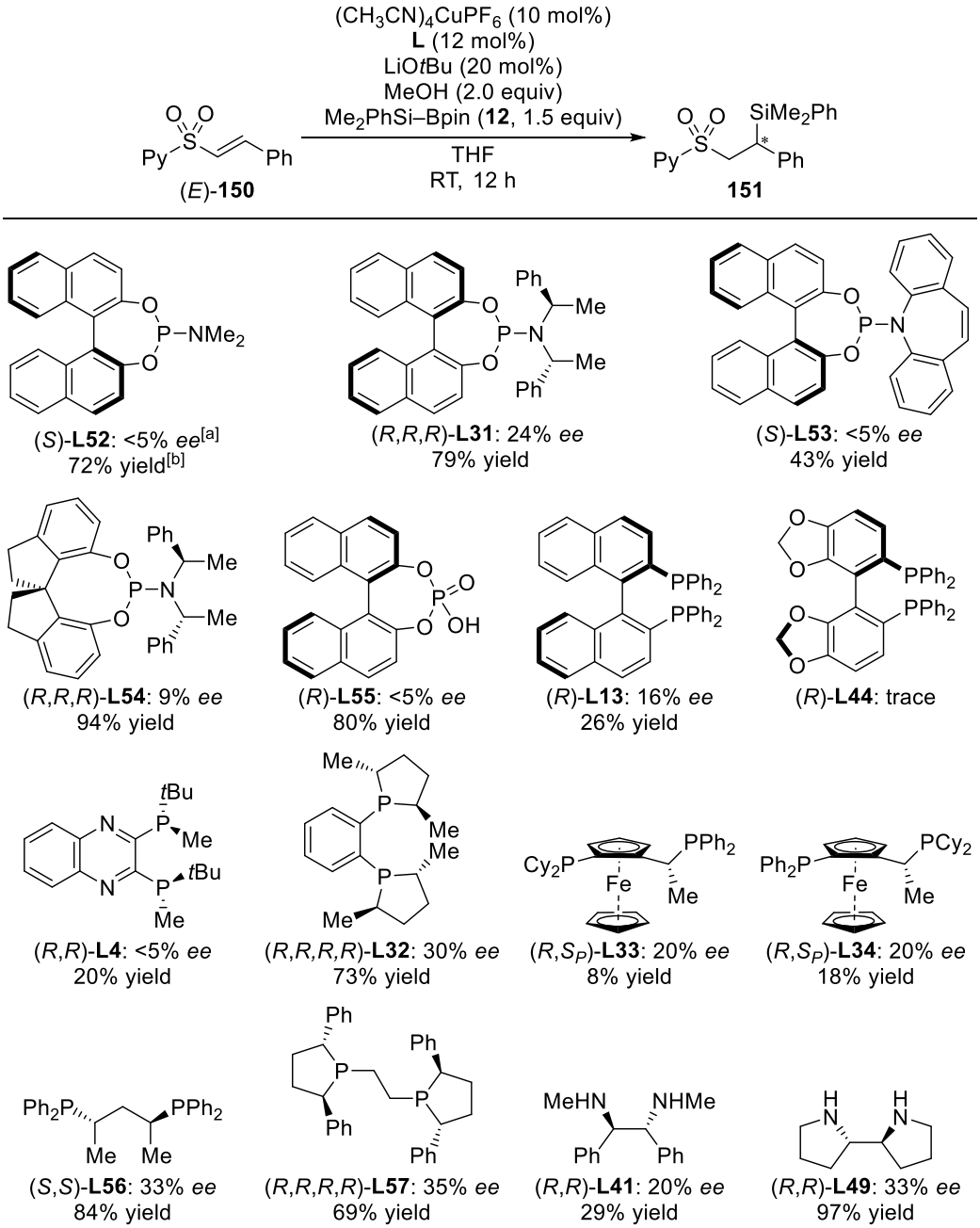
[59] D. Enders, S. F. Müller, G. Raabe, J. Runsink, *Eur. J. Org. Chem.* **2000**, 879–892.

[60] X. Yang, F. Cheng, Y.-D. Kou, S. Pang, Y.-C. Shen, Y.-Y. Huang, N. Shibata, *Angew. Chem. Int. Ed.* **2017**, *56*,1510–1514; *Angew. Chem.* **2017**, *129*, 1–6.

[61] a) J. Lu, J. Ye, W.-L. Duan, *Org. Lett.* **2013**, *15*, 5016–5019; b) J. Lu, J. Yeb, W.-L. Duan, *Chem. Commun.* **2014**, *50*, 698–700.

4.2 Optimization Study

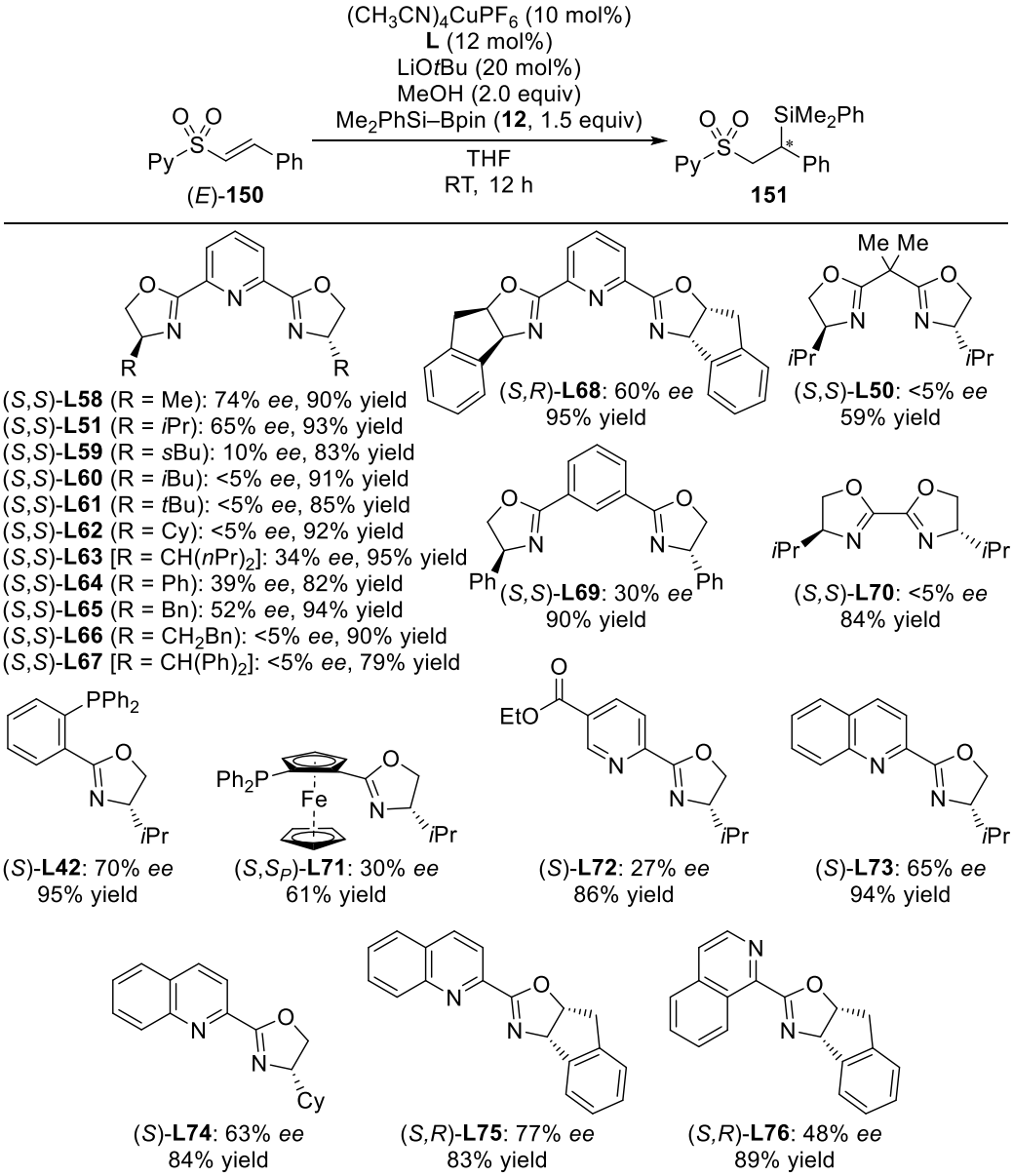
α,*β*-Unsaturated sulfone (*E*)-**150** was chosen as model substrate and Me_2PhSi–Bpin (**12**) as silicon source to evaluate different chiral ligands in the presence of $(CH_3CN)_4CuPF_6$, LiO*t*Bu and MeOH in THF (Scheme 4.2). Phosphoramidites [(*R*)-**L52**, (*R*,*R*,*R*)-**L31**, (*R*)-**L53**, and (*R*,*R*,*R*)-**L54**] as ligand all successfully converted *α*,*β*-unsaturated sulfone (*E*)-**150** into the desired product **151**, however with low levels of enantioselection. Phosphoric acid (*R*)-**L55** as ligand delivered **151** racemically. Bidentate phosphine ligands such as (*R*)-BINAP [(*R*)-**L13**], (*R*)-SEGPHOS [(*R*)-**L44**], (*R*,*R*)-Quinoxp* [(*R*,*R*)-**L5**], DuPhos (*R*,*R*,*R*,*R*)-**L32**, Josiphos ligands (*R*,S_P)-**L33** and (*R*,S_P)-**L34**, (*S*,*S*)-BDPP [(*S*,*S*)-**L56**] and (*R*,*R*)-Ph-BPE [(*R*,*R*,*R*,*R*)-**L57**] all failed to produce enantioenriched **151**. Diamine ligands (*R*,*R*)-**L41** and (*R*,*R*)-**L49** did not provide superior results in enantioselectivity, compared to aforementioned chiral ligands.



Scheme 4.2: A ligand screening for asymmetric transformation. All reactions were performed on a 0.10 mmol scale. [a] *ee* values were determined by HPLC analysis on a chiral stationary phase. [b] Isolated yields were obtained after flash column chromatography on silica gel.

Huge improvement in enantioselectivity was observed in the assessment of oxazoline ligands (Scheme 4.3). Tridentate PyBOX ligands with different substituents were firstly examined (**L51**, and **L58**–**L68**). 74% *ee* was achieved when methyl-substituted (*S*,*S*)-**L58** was employed as ligand. Increasing congestion in the ring of oxazoline did not provide further improvement. Other bidentate bisoxazoline ligands were investigated, but less efficient in enantiocontrol [(*S*,*S*)-**L50**, (*S*,*S*)-**L69**, and (*S*,*S*)-**L70**]. (*S*)-**L42** worked well, delivering **151** in 95% yield with 70% *ee*. Ferrocene-derived (*S*,S_p)-**L71** and Pyridine-derived

(*S*)-**L72** led to dramatic decrease of enantioselectivity. Quinoline-substituted oxazoline ligands (**L73**–**L76**) were suitable, and (*S*,*R*)-**L75** outperformed other ligands checked, increasing the *ee* value to 77%.

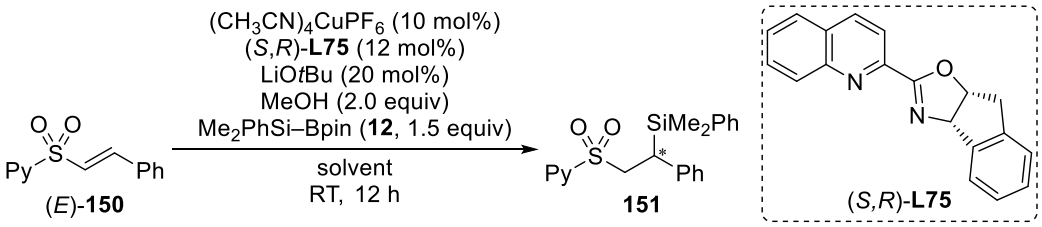


Scheme 4.3: A ligand screening for asymmetric transformation. All reactions were performed on a 0.10 mmol scale. Isolated yields were obtained after flash column chromatography on silica gel. *ee* values were determined by HPLC analysis on a chiral stationary phase.

After identifying (*S*,*R*)-**L75** to be the optimal choice of ligand, we then investigated the influence of solvents (Table 4.1). Use of Et_2O as solvent further improved the *ee* value to 83% (entry 2), and similar result was obtained with 2-MeTHF (entry 3). Dioxane, *t*AmOH and MeOH proved to be less efficient (entries 4–6). EtOAc offered the target **151** in 90% yield with 78% *ee* (entry 7). Water as solvent did promote the reaction, however was not better

than Et_2O (entry 8). Unfortunately, similar work from YIN's group was published at this time. We decided to stop and start next project.

Table 4.1: A solvent screening for asymmetric transformation.[a]



entry	solvent	yield (%)[b]	*ee* (%)[c]
1	THF	83	77
2	Et_2O	91	83
3	2-MeTHF	94	80
4	dioxane	90	68
5	*t*AmOH	85	53
6	MeOH	86	40
7	EtOAc	90	78
8	H_2O	44	72

[a] All reactions were performed on a 0.10 mmol scale. [b] Isolated yields were obtained through flash column chromatography on silica gel. [c] *ee* values were determined by HPLC analysis on a chiral stationary phase.

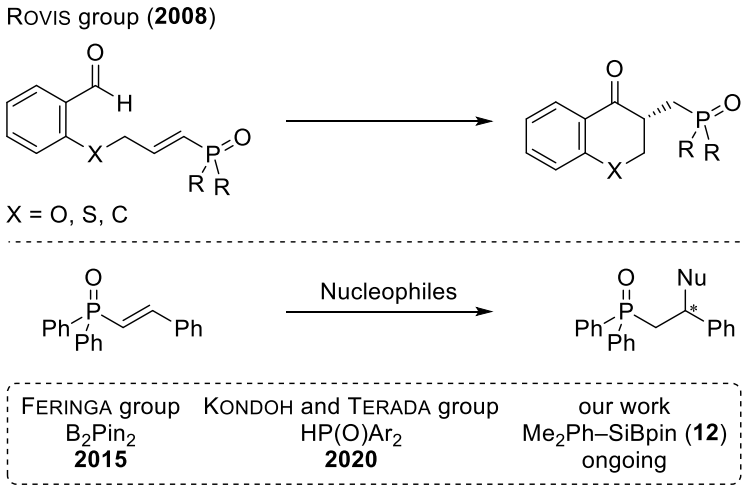
4.3 Conclusion

In summary, we reported our investigation about asymmetric conjugate addition of Me_2PhSi–Bpin (**12**) to *α*,*β*-unsaturated sulfone (*E*)-**150**. Assessment of ligands and solvents has been done and 83% *ee* has been achieved. We believe that further evaluation about silicon source, catalyst, base, proton source, and temperature might provide an excellent enantioselectivity for this asymmetric transformation.

5 ASYMMETRIC CONJUGATE 1,4-SILYL TRANSFER TO α,β-UNSATURATED PHOSPHINE OXIDES

5.1 Introduction

Asymmetric conjugate addition reactions involving α,β-unsaturated phosphine oxides as MICHAEL acceptors are still elusive (Scheme 5.1). In 2008, enantioselective intramolecular STETTER reaction was reported by CULLEN and ROVIS through asymmetric addition of C pronucleophiles to α,β-unsaturated phosphine oxides or α,β-unsaturated phosphonates.[62] B_2Pin_2[63] and phosphine oxides[64] proved to be suitable pronucleophiles later by FERINGA and co-workers, and KONDOH, TERADA and co-worker, respectively. These outcomes intrigued us to explore asymmetric conjugate addition of Si nucleophiles to α,β-unsaturated phosphine oxides. In the following chapter is reported our progress about enantioselective 1,4-addition of Me_2PhSi–Bpin (**12**) to α,β-unsaturated phosphine oxide **152**.



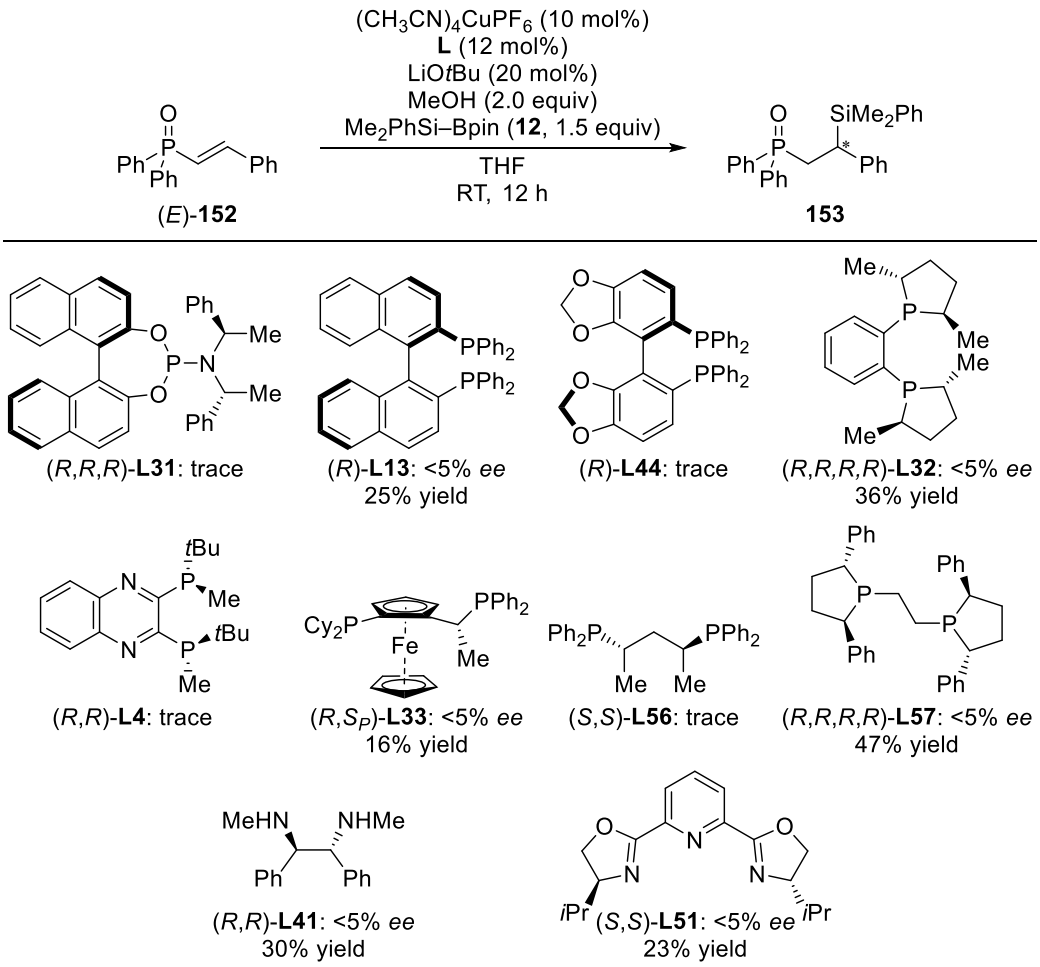
Scheme 5.1: asymmetric conjugate addition reactions of α,β-unsaturated phosphine oxides.

5.2 Optimization Study

Our study was initiated by using α,β-unsaturated phosphine oxide (*E*)-**152** as model substrate and Me_2PhSi–Bpin (**12**) as silicon source for a ligand screening (Scheme 5.2). Monodentate phosphoramidite (*R*,*R*,*R*)-**L31** failed to deliver the target **153**. Low to moderate yields of **153** were obtained when bidentate phosphine ligands such as (*R*)-BINAP [(*R*)-**L13**],

[62] S. C. Cullen, T. Rovis, *Org. Lett.* **2008**, *10*, 3141–3144.
[63] V. Hornillos, C. Vila, E. Otten, B. L. Feringa, *Angew. Chem. Int. Ed.* **2015**, *54*, 7867–7871; *Angew. Chem.* **2015**, *127*, 7978–7982.
[64] A. Kondoh, S. Ishikawa, M. Terada, *Org. Biomol. Chem.* **2020**, *18*, 7814–7817.

DuPhos [(*R*,*R*,*R*,*R*)-**L32**], Josiphos (*R*,*S*$_P$)-**L33** and (*R*,*R*)-Ph-BPE [(*R*,*R*,*R*,*R*)-**L57**] were used as the ligand, however without any enantioselectivity. Other bidentate phosphine ligands such as (*R*)-SEGPHOS [(*R*)-**L44**], (*R*,*R*)-QuinoxP* [(*R*,*R*)-**L4**] and (*S*,*S*)-BDPP [(S,S)-**L56**] only gave trace amounts of **146**. Diamine (*R*,*R*)-**L41** and PyBOX (*S*,*S*)-**L51** worked with similar result to (*R*)-BINAP [(*R*)-**L13**]. Further investigation is still ongoing in our lab.



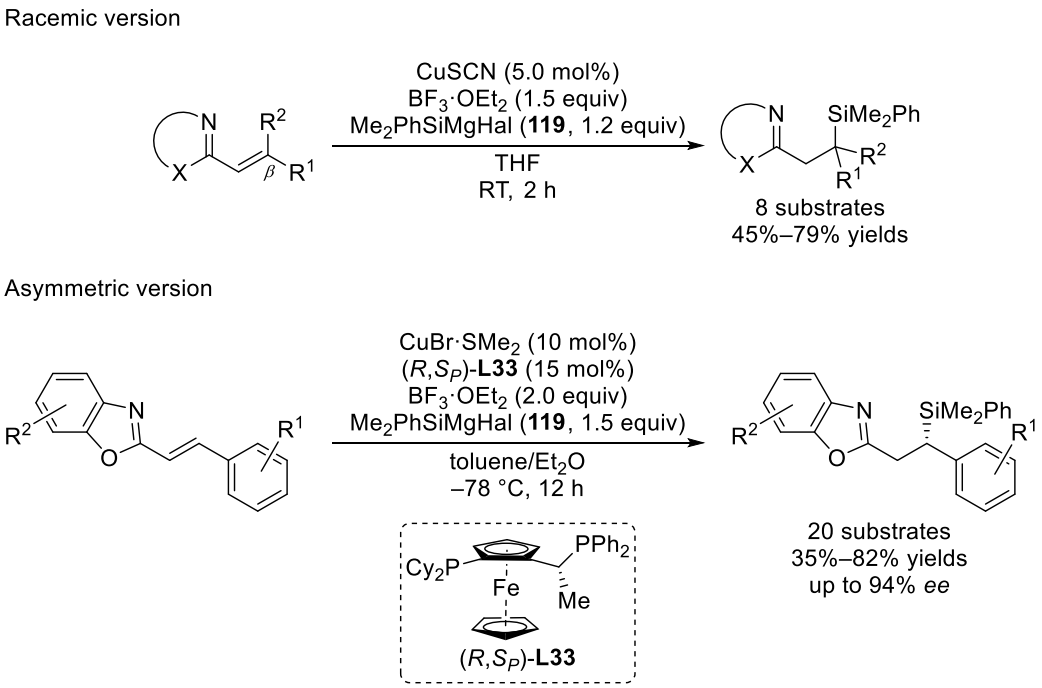
Scheme 5.2: A ligand screening for asymmetric transformation. All reactions were performed on a 0.10 mmol scale. Isolated yields were obtained after flash column chromatography on silica gel. *ee* values were determined by HPLC analysis on a chiral stationary phase.

5.3 Conclusion

In summary, we were exploring a general and efficient method to prepare chiral silanes through enantioselective 1,4-addition of Si–B reagents to *α*,*β*-unsaturated phosphine oxides. Optimal reaction conditions are still under exploration. Several chiral ligands were tried, and only racemic mixtures were obtained. Further investigation will concentrate on assessment of ligand, base, solvent, proton source and temperature.

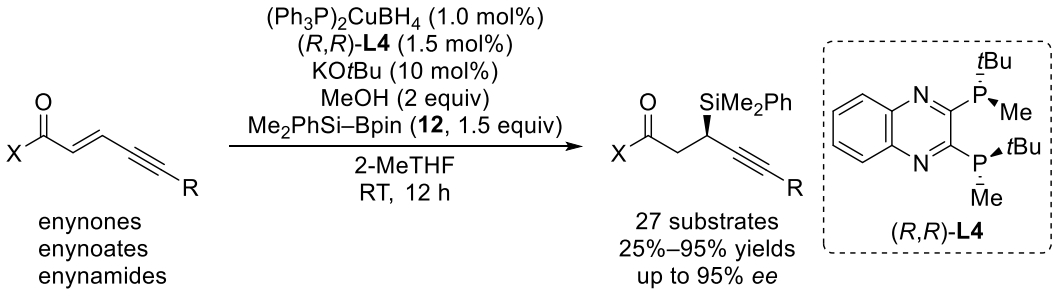
6 SUMMARY

This dissertation describes our research about asymmetric conjugate addition of silicon nucleophiles to *α*,*β*-unsaturated acceptors. Heterocycle-substituted alkenes were used as substrates in the first project (Scheme 6.1). Six different heterocycles including benzoxazole, benzothiazole, benzimidazole, pyridine, 1-quinoline and 2-quinoline, were successfully assembled in substrates, and tolerated under our optimized setup. Furthermore, $Me_2PhSiMgHal$ (**119**) as silicon nucleophile was first applied in asymmetric transformation by using benzoxazole-substituted alkenes as substrates. Good to high enantioselectivities of up to 94% *ee*, were achieved in 20 examples. Providing limited substrate scope in asymmetric version, further investigation is still needed to expand the utility of our method.



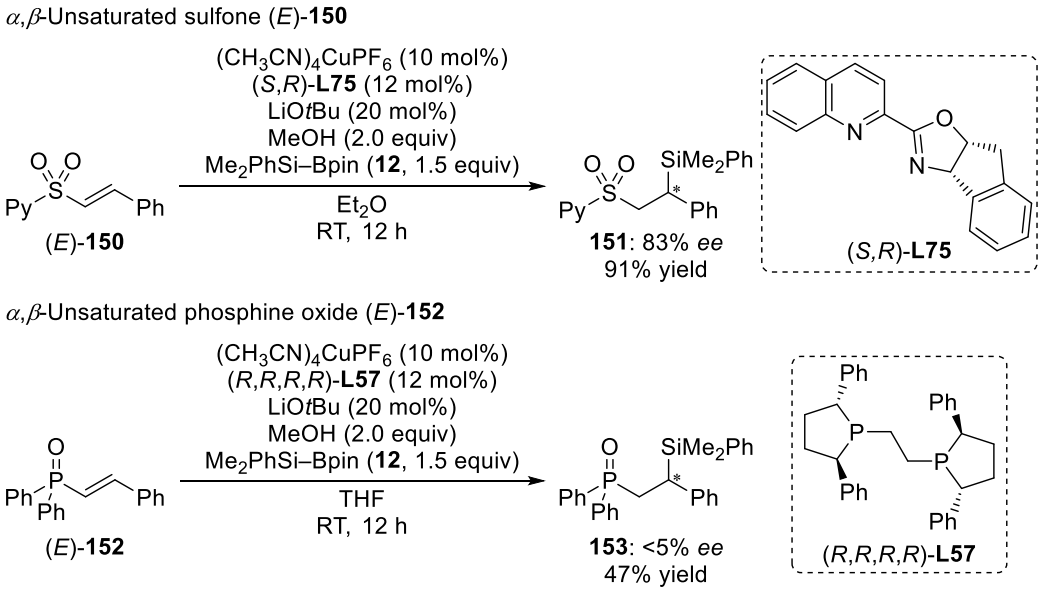
Scheme 6.1: Conjugate addition of silicon GRIGNARD reagents to heterocycle-substituted alkenes.

Our second project provides an efficient and straightforward method to prepare optically pure propargylic silanes through asymmetric conjugate addition of Si–B reagents to enyne-type *α*,*β*,*γ*,*δ*-unsaturated acceptors(Scheme 6.2). Enynones, enynoates and enynamides proved to be reactive under our optimal conditions. A wide range of functional groups were tolerated. Enantio- and chemoselectivity were excellent throughout. (Z)-configuration of C–C double bond in substrates plays an irreplaceable influence in 1,4-selectivity. Moreover, operationally simple procedure makes our method more appealing. An existing challenge in our method is to improve efficiency in the reaction of enynamides, because of their innate low reactivity.



Scheme 6.2: Asymmetric conjugate addition of Si–B reagents to enyne-type acceptors.

Investigations involving the use of *α*,*β*-unsaturated sulfones and *α*,*β*-unsaturated phosphine oxides as MICHAEL acceptor in the asymmetric 1,4-silyl transfer are ongoing and details are reported in chapter 4 and chapter 5 (Scheme 6.3). *α*,*β*-Unsaturated sulfone (*E*)-**150** was reactive by using $(CH_3CN)_4CuPF_6$ as precatalyst and (*S*,*R*)-**L75** as ligand, delivering the target **151** in 91% yield with 83% *ee*. Further investigation is needed to improve the enantioselectivity. 1,4-Silyl transfer from Me_2PhSi–Bpin (**12**) to *α*,*β*-unsaturated phosphine oxide (*E*)-**152** still limited to racemic transformation after assessment of several chiral ligands. Further examination to improve efficiency with regard to yield and enantioselectivity is ongoing in our group.



Scheme 6.3: Asymmetric conjugate addition of Si–B reagents to *α*,*β*-unsaturated sulfones and *α*,*β*-Unsaturated phosphine oxides.

Asymmetric conjugate addition of silicon nucleophiles to MICHAEL acceptors represents a well-established method to construct optically pure silanes. Various catalytic systems have been reported. Challenges are still remaining. For example, construction of quaternary *C*-stereogenic center by asymmetric conjugate addition of silicon nucleophiles to MICHAEL

acceptors is less reported (cf. Schemes 1.13 and 1.26). This is an urgent issue to further develop our method. Another issue is about application of enolate intermediate formed in the reaction (cf. Schemes 1.19 and 1.21). In most cases, protonation is the most common choice. Further application of enolate intermediate could help construct more continuous chiral centers. Solving these two issues will make our methods more attractive.

EXPERIMENTAL PART

1 GENERAL INFORMATION

All reactions take place in heat gun-dried glassware under nitrogen by Schlenk techniques. Procedures for cleaning glassware include soak in an *i*PrOH/KOH bath overnight, rinse with water, neutralization with saturated citric acid bath, rinse with water, soak in a distilled water bath for at least six hours, rinse with distilled water again and then desiccation at 120 °C in an oven overnight. Glassware, used with transition metals, is washed with aqua regia (conc. HCl and conc. HNO_3 in a ratio of 3:1) before soak in an *i*PrOH/KOH bath. Disposable syringes and needles are used to transfer liquid chemicals into the reaction under nitrogen. Glass syringes, stainless-steel needles and cannulas are reused, and all of them are stored at 120 °C in an oven before use. Solid chemicals are added directly against the current of nitrogen, or dissolve in a solvent before addition. Low temperature reactions are carried out by using a cooling bath or cryostat (EK90 from *Haake* and TC100E-F from *Huber*).

Solvents and reagents

*n*Pentane and dichloromethane (CH_2Cl_2) are distilled at reflux over CaH_2 under N_2. By using benzophenone as indicator, diethyl ether (Et_2O), tetrahydrofuran (THF), 1,4-dioxane and toluene are distilled at reflux over sodium under N_2. Copper(I) thiocyanate (CuSCN, anhydrous, 96% from *Alfa Aesar*), copper(I) chloride (CuCl, anhydrous, 99% from *Acros*), Bis(triphenylphosphine)copper(I) borohydride ($(Ph_3P)_2CuBH_4$, from *Fluka*), (*R*,*R*)-(–)-2,3-Bis-(*tert*-butylmethylphosphino)quinoxaline ((*R*,*R*)-QuinoxP*, 98% from *ABCR*), Josiphos ligands (anhydrous, 99% from Solvias' donation). boron trifluoride diethyl etherate ($BF_3{\cdot}Et_2O$ from *Merck*), potassium *tert*-butoxide (KO*t*Bu, ⩾98% from *SigmaAldrich*), 2-methyltetrahydrofuran (2-MeTHF, anhydrous, ⩾99.5% from *SigmaAldrich*), HPLC grade solvents (*n*heptane from *Roth*, *i*PrOH from *Roth*, acetonitrile from *Roth* and water from *SigmaAldrich*) and all other commercially available chemicals are delivered from suppliers and used directly unless otherwise stated. Technical grade solvents (ethyl acetate, cyclohexane, *tert*-butyl methyl ether, *n*pentane, CH_2Cl_2, and methanol) which are used for extraction or flash column chromatography are used after distillation through rotatory evaporator under reduced pressure.

Chromatography

Qualitative **thin-layer chromatography** (TLC) is conducted on glass plates with silica gel 60 F254 which were purchased from *Merck KGaA*.

Methods for visualizing TLC plates are as following:

1) UV light is a common method to visualize stains on TLC plates for compounds with aromatic or conjugated system.

2) The solution of $KMnO_4$ (3.0 g), K_2CO_3 (20 g), and KOH (0.30 g) in distilled H_2O (300 mL) is used to visualize stains of compounds bearing C–C unsaturated bonds, or oxidizable groups.

Flash column chromatography are conducted using silica gel (40-63 µm, 230-400 mesh, ASTM) from *Merck*.

Gas liquid chromatography (GLC) analyses are carried out on an *Agilent* Technologies 7820A gas chromatograph with an *Agilent* Technologies J&W HP-5 capillary column (30 m × 0.32 mm, 0.25 µm film thickness), adopting the following program: N_2 carrier gas, injection temperature 250 °C, detector temperature 300 °C, flow rate: 1.7 mL/min; temperature program: start temperature 40 °C, heating rate 10 °C/min, end temperature 280 °C for 10–30 min.

Nuclear magnetic resonance (NMR) spectroscopy

^{1}H, ^{13}C, ^{19}F and ^{29}Si NMR spectra are measured in $CDCl_3$ or $(CD_3)_2SO$ on *Bruker* AV400 and AV500 instruments. Chemical shifts are recorded in parts per million (ppm) and referenced to the residual solvent resonance as the internal standard ($CHCl_3$: δ = 7.26 ppm for ^{1}H NMR and $CDCl_3$: δ = 77.0 ppm for ^{13}C NMR; $(CD_3)_2SO$: δ = 2.50 ppm for ^{1}H NMR and $(CD_3)_2SO$: δ = 39.5 ppm for ^{13}C NMR). All other nuclei (^{19}F and ^{29}Si) are referenced in compliance with the unified scale for NMR chemical shifts as recommended by the IUPAC stating the chemical shift relative to $BF_3{\cdot}Et_2O$, CCl_3F and Me_4Si.[65] Data are reported as following: chemical shift, multiplicity (s = singlet, d = doublet, t = triplet, q = quartet, m = multiplet, mc = centrosymmetric multiplet, br = broad signal), coupling constants (Hz), and integration. The assignment of signals refers to the numbering of the structures in the figures and accords with careful interpretations made from 2D NMR spectroscopy ($^{1}H/^{1}H$-COSY, $^{1}H/^{13}C$-HMQC, $^{1}H/^{13}C$-HMBC, ^{13}C-DEPT, $^{1}H/^{29}Si$-HMQC NMR). Peaks that are within 0.01 ppm for ^{1}H NMR or 0.1 ppm for ^{13}C NMR and ^{29}Si DEPT NMR but are still distinguishable are reported to 0.001 ppm and 0.01 ppm, respectively. Coupling constants are quoted to the nearest 0.1 Hz for ^{1}H NMR and ^{13}C NMR. The term “Ar” refers to unspecified protons or carbon atoms of an aromatic system. All samples were measured in reusable oven-dried standard NMR tubes.

High performance liquid chromatography (HPLC) analyses are performed on an *Agilent Technologies* 1290 Infinity instrument equipped with a chiral stationary phase, by using *Daicel Chiralcel* IB, OD-H and AD-H columns. Solvent mixture of *n*heptane and *i*propanol is used as eluent.

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[65] R. K. Harris, E. D. Becker, S. M. Cabral de Menezes; R. Goodfellow, P. Granger, *Pure Appl. Chem*. **2001**, *73*, 1795–1818.

Optical rotations

Optical rotations are measured on a *Schmidt* & *Haensch Polartronic* H532 Polarimeter with α_λ^t values reported in 10^{-1} (° cm^2 g^{-1}); with the concentration c in g/100 mL and λ indicated.

Mass spectrometry

High resolution mass spectra (HRMS) analyses are performed on a *Thermo Fisher Scientific* LTQ Orbitrap XL apparatus using APCI/ESI/LIFDI techniques with a linear ion trap analyzer by colleagues from the Analytical Facility of *Institut für Chemie* in *Technische Universität Berlin*. The in-detail fragmentation is omitted and only the molecular ion peak or characteristic molecular fragments are considered.

Infrared spectroscopy

Infrared (IR) **spectra** are measured on an *Agilent* Technologies Cary 630 FTIR spectrophotometer equipped with an ATR unit and were reported as wave numbers (cm^{-1}).

X-ray crystal structural analysis

Data collection for the single crystal structure on an Agilent SuperNova diffractometer equipped with a CCD area Atlas detector and a mirror monochromator by utilizing Cu-Kα radiation (λ = 1.5418 Å) is finished by PAULA NIXDORF from the Analytical Facility of *Institut für Chemie* in *Technische Universität Berlin*, and then analyzed by Dr. ELISABETH IRRAN.

Physical data

Melting points (M.P.) are measured on a *Leica Galen* III melting point apparatus (Wagner & Munz).

Software

GC-data are recorded and analyzed using EZChrom Elite Compact by *Agilent*. NMR data are recorded and analyzed using Topspin 3.2 or 3.5 by *Bruker*. The stacked NMR spectra are generated using GIMP 2.8.4 image manipulation program. GC-MS data are measured and analyzed using Enhanced ChemStation 02.02.1431 by *Agilent Technologies*. The HRMS data are analyzed using Mass++ 2.7.4 by *Shimadzu* and *Eisai Co*., *Ltd*. IR data are recorded and analyzed using Microlab and Agilent Resolutions Pro 5.2.0 by *Agilent Technologies*. X-ray structures are analyzed using Mercury 3.10.3 by *CCDC*. 3D graphics are generated using CYLview 1.0b. All schemes in this thesis are drawn in ChemDraw Professional 17.1 by

PerkinElmer. The references are retrieved using Chemistry Reference Resolver.[66] The thesis is written using Microsoft Office 2016 by *Microsoft*.

Nomenclature and numbering

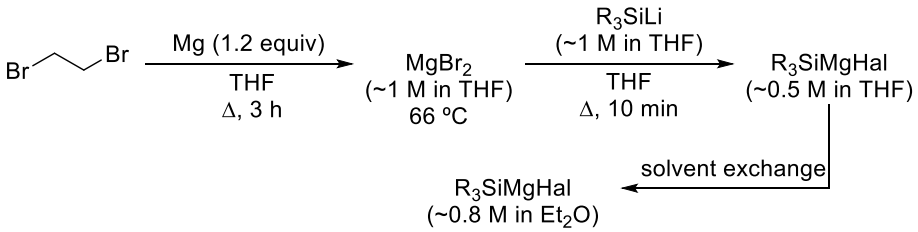
The numbering of compounds is done analogous to their representative structural drawing and does not correspond to the IUPAC recommendations.

[66] http://chemsearch.kovsky.net/

2 GENERAL PROCEDURE

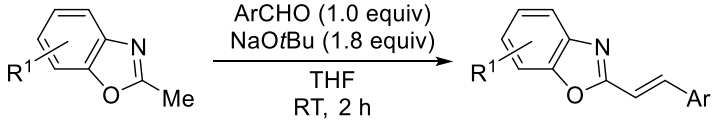
2.1 General Procedures for Asymmetric Conjugate 1.4-Silyl Transfer to Azaaryl-Substituted Alkenes

2.1.1 GP 1.1: General Procedure for Silicon GRIGNARD Reagents in Et_2O



A heat gun-dried two-neck round-bottom flask equipped with a water condenser and a magnetic stir bar is purged with N_2. To the flask are added magnesium turnings (292 mg, 12.0 mmol, 1.20 equiv) and THF (10 mL), and then it is heated at reflux in an oil bath. 1,2-Dibromoethane (1.88 g, 10.0 mmol, 1.00 equiv) is added to the flask quickly, and stirred at reflux for 3 hours to generate $MgBr_2$ solution (~1 M in THF at 66 °C; note: *high water flow rate in the condenser is necessary for safety because large amounts of explosive gas are produced during the reaction!*). Dropwise addition of the freshly prepared R_3SiLi solution (~1 M in THF, 10.0 mmol, 1.00 equiv) through syringe to the $MgBr_2$ solution at reflux lasts at least 10 minutes to secure the concentration, and then the reaction mixture is allowed to cool to room temperature, affording the corresponding silicon GRIGNARD reagent in THF.[67] THF in the reaction is removed under *vacuum*, and 10 mL dried Et_2O is used to dissolve the residue. Concentration of $R_3SiMgHal$ solution (~0.8 M in Et_2O) is titrated, using KNOCHEL's method.[68] These silicon GRIGNARD reagents could be preserved at 2–8 °C in the fridge under N_2.

2.1.2 GP 1.2: General Procedure for Azaaryl-Substituted Alkenes



[67] W. Xue, R. Shishido, M. Oestreich, *Angew. Chem. Int. Ed.* **2018**, *57*, 12141–12145; *Angew. Chem.* **2018**, *130*, 12318–12322.

[68] A. Krasovskiy, P. Knochel, *Synthesis* **2006**, 890−891.

A heat gun-dried two-neck round-bottom flask equipped with a magnetic stir bar is purged with N_2. Sodium *tert*-butoxide (865 mg, 9.00 mmol, 1.80 equiv) and THF (10 mL) are added in sequence at 0 °C in an ice bath, and then methyl-substituted benzoxazole (5.00 mmol, 1.00 equiv) is added slowly. The reaction mixture is stirred at 0 °C for 30 minutes, and then the corresponding aldehyde (5.00 mmol, 1.00 equiv) is added. After stirring at room temperature for 2 hours, the reaction is quenched by water (20 mL), and extracted by CH_2Cl_2 (3 × 25 mL). The combined organic phases are dried over anhydrous $MgSO_4$, filtered, and concentrated under reduced pressure. Purifying the residue by flash column chromatography on silica gel with indicated solvent as eluent or recrystallization in MeOH delivers the corresponding azaaryl-substituted alkene.[69]

2.1.3 GP 1.3: General Procedure for Racemic Products

A heat gun-dried Schlenk tube equipped with a magnetic stir bar and a septum is purged with N_2. CuSCN (0.912mg, 7.50 µmol, 5.00 mol%) and the corresponding azaaryl-substituted alkene (0.150 mmol, 1.00 equiv) are added in sequence, and then the tube is evacuated and backfilled with N_2. After that, THF (1 mL), $BF_3{\cdot}Et_2O$ (31.9 mg, 0.225 mmol, 1.50 equiv) and $Me_2PhSiMgHal$ (0.180 mmol, 1.20 equiv) are added sequentially to the tube and the reaction mixture is stirred at room temperature for 2 hours. The reaction is quenched by Water (10 mL), and extracted by CH_2Cl_2 (3 × 10 mL). The combined organic phases are dried over anhydrous $MgSO_4$, filtered, and concentrated under reduced pressure. Purifying the residue by flash column chromatography on silica gel with indicated solvent as eluent delivers the corresponding racemic product.

2.1.4 GP 1.4: General Procedure for Enantioenriched Products

A heat gun-dried Schlenk tube equipped with a magnetic stir bar and a septum is purged with N_2. CuCl (1.49 mg, 15.0 µmol, 10.0 mol%) and (*R,S*$_P$)-**L33** (13.4 mg, 22.5 µmol, 15.0 mol%) are added in sequence, and then the tube is evacuated and backfilled with N_2. After that, dried toluene (1 mL) is added to the Schlenk tube, and then the reaction mixture is stirred at room temperature for 30 minutes. The corresponding azaaryl-substituted alkene (0.150

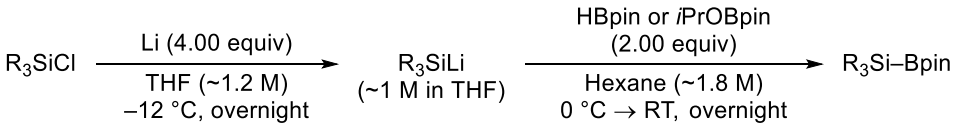
[69] a) G. Evindar, R. A. Batey, *J. Org. Chem.* **2006**, *71*, 1802–1808; b) R. D. Viirre, G. Evindar, R. A. Batey, *J. Org. Chem.* **2008**, *73*, 3452–3459; c) L. Meng, Y. Kamada, K. Muto, J. Yamaguchi, K. Itami, *Angew. Chem. Int. Ed.* **2013**, *52*, 10048–10051; *Angew. Chem.* **2013**, *125*, 10232–10235; d) W.-C. Lee, T.-H. Wang, T.-G. Ong, *Chem. Commun.* **2014**, *50*, 3671–3673; e) A. A. Aleksandrov, E. V. Illenyeer, M. M. El'chaninov, *Russ. J. Org. Chem.* **2015**, *51*, 1111–1113; f) H. B. Hepburn, P. Melchiorre, *Chem. Commun.* **2016**, *52*, 3520–3523; g) R. P. Jumde, F. Lanza, M. J. Veenstra, S. R. Harutyunyan, *Science* **2016**, *352*, 433–437; h) R. Sharma, M. Abdullaha, S. B. Bharate, *J. Org. Chem.* **2017**, *82*, 9786–9793; i) G. Zhang, T. Irrgang, T. Dietel, F. Kallmeier, R. Kempe, *Angew. Chem. Int. Ed.* **2018**, *57*, 9131–9135; *Angew. Chem.* **2018**, *130*, 9269–9273.

mmol, 1.00 equiv) is added. After stirring for 5 minutes at room temperature, the reaction mixture is allowed to cool to –78 °C by using a cryostat. Then, $BF_3{\cdot}Et_2O$ (42.6 mg, 0.300 mmol, 2.00 equiv) and $Me_2PhSiMgHal$ (0.225 mmol, 1.50 equiv) are added sequentially and the reaction mixture is stirred at –78 °C for 12 hours. The reaction is quenched by Water (10 mL), and extracted by CH_2Cl_2 (3 × 10 mL). The combined organic phases are dried over anhydrous $MgSO_4$, filtered, and concentrated under reduced pressure. Purifying the residue by flash column chromatography on silica gel with indicated solvent as eluent delivers the corresponding enantioenriched product.

2.2 General Procedures for Asymmetric Conjugate 1.4-Silyl Transfer to *α,β,γ,δ*-Unsaturated Acceptors

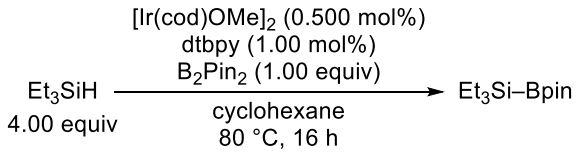
2.2.1 GP 2.1: General Procedure for Si–B Reagents

Method A



A heat gun-dried two-neck round-bottom flask equipped with a magnetic stir bar and activated lithium chunks (999 mg, 144 mmol, 4.00 equiv) is purged with N_2, followed by the addition of THF (30 mL, ~1.2 M). The reaction mixture then cools to −12 °C by using a cryostat, followed by the addition of R_3SiCl (36.0 mmol, 1.00 equiv). The reaction mixture is allowed to warm to room temperature after 12 hours, and then is added to a solution of *iso*propoxy-4,4,5,5-tetramethyl-1,3,2-dioxaborolane (*i*PrOBpin, 13.4 g, 72.0 mmol, 2.00 equiv) or 4,4,5,5-tetramethyl-1,3,2-dioxaborolane (HBpin, 9.21 g, 72.0 mmol, 2.00 equiv) in hexane (40 mL, ~1.8 M) over 30 minutes at 0 °C in an ice bath. After stirring overnight at room temperature, the reaction mixture is filtered through a sintered glass filter, and concentrated under reduced pressure. Purifying the residue by distillation delivers the corresponding Si–B reagent.[70a]

Method B

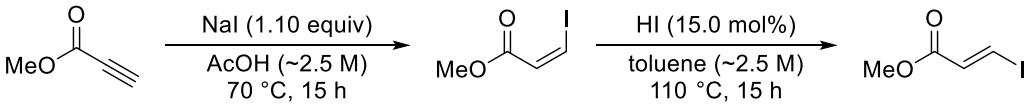


[70] a) M. Suginome, T. Matsuda, Y. Ito, *Organometallics* **2000**, *19*, 4647–4649; b) T. A. Boebel, J. F. Hartwig, *Organometallics* **2008**, *27*, 6013–6019.

A heat gun-dried two-neck round-bottom flask equipped with a magnetic stir bar and a condenser is purged with N_2, followed by the addition of $[Ir(cod)OMe]_2$ (66.3 mg, 0.100 mmol, 0.500 mol%), 4,4′-di-tert-butyl-2,2′-dipyridyl (dtbpy, 53.7 mg, 0.200 mmol, 1.00 mol%) and bis(pinacolato)diboron (5.08 g, 20.0 mmol, 1.00 equiv). Cyclohexane (40 mL, ~0.5 M) and Et_3SiH (4.65 g, 80.0 mmol, 4.00 equiv) are added in sequence, and then the reaction mixture is stirred at 80 °C in an oil bath. After 16 hours, it is allowed to cool to room temperature, and then solvent is removed under reduced pressure. Purifying the residue by flash column chromatography with clcylohexane/EtOAc = 20/1 as eluent delivers the crude product as a gray oil. Further purification by short-path distillation affords pure Et_3Si–Bpin as a colourless oil.[70b]

2.2.2 GP 2.2: General Procedure for *α,β,γ,δ*-Unsaturated Acceptors

Step A:

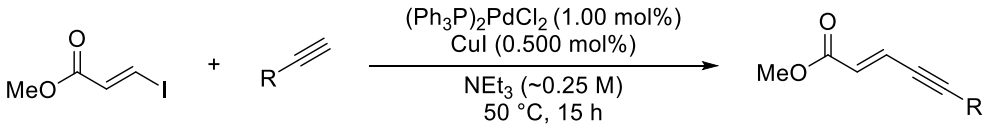


To a solution of methyl propiolate (4.20 g, 50.0 mmol, 1.00 equiv) in glacial acetic acid (20 mL, ~2.5 M) is added NaI (8.24 g, 55.0 mmol, 1.10 equiv), and then the reaction mixture is stirred at 70 °C in an oil bath for 15 hours. After cooling to room temperature, NaOH (7.00 g in 50 mL) is added slowly, and then the reaction mixture is extracted by Diethyl ether (3 × 50 mL). The combined organic phases are washed with sat. aq. K_2CO_3 solution (3 × 50 mL) and sat. aq. $NaSO_3$ solution (3 × 50 mL), dried over anhydrous $MgSO_4$, filtered and concentrated under reduced pressure to deliver the crude methyl (*Z*)-3-iodoacrylate which is used in the next step without further purification.

To a solution of crude methyl (*Z*)-3-iodoacrylate in toluene (20 mL, ~2.5 M) is added HI (7.50 mmol, 15.0 mol%, 57% in water, 1 mL), and then the reaction mixture is stirred at 110 °C in an oil bath for 15 hours. After cooling to room temperature, the reaction mixture is diluted with diethyl ether (50 mL), and then washed with sat. aq. K_2CO_3 solution (3 × 50 mL) and sat. aq. $NaSO_3$ solution (3 × 50 mL). The organic phase is dried over anhydrous $MgSO_4$, filtered and concentrated under reduced pressure. Purifying the residue by flash column chromatography on silica gel with *n*pentane/EtOAc = 100/1 as eluent delivers the desired methyl (*E*)-3-iodoacrylate as a white solid. Its spectroscopic data accord with those reported.[71]

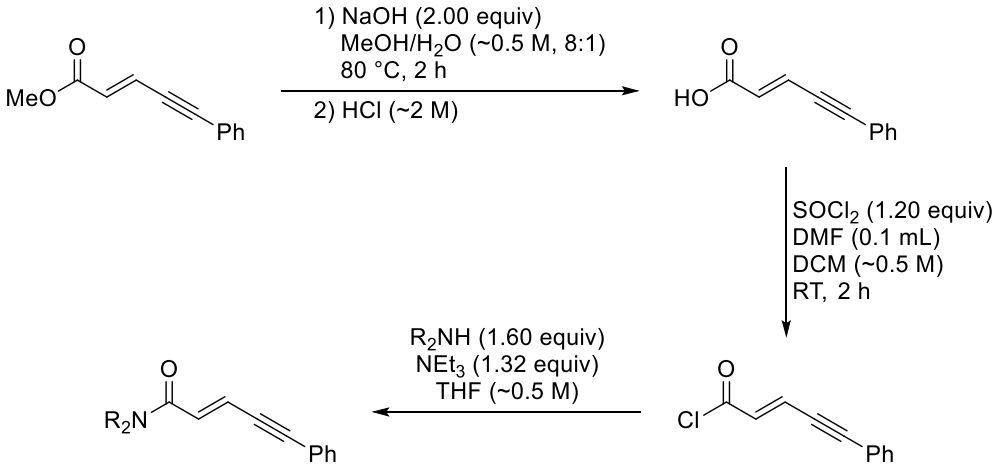
[71] P. Koukal, J. Ulč, D. Nečas, M. Kotora, *Eur. J. Org. Chem.* **2016**, 2110–2114.

Step B:



To a solution of methyl (*E*)-3-iodoacrylate (1.06 g, 5.00 mmol, 1.00 equiv) in triethylamine (20 mL, ~0.25 M) are added $(Ph_3P)_2PdCl_2$ (35.1 mg, 50.0 *μ*mol, 1.00 mol%), CuI (4.75 mg, 25.0 *μ*mol, 0.500 mol%) and the corresponding alkyne (5.50 mmol, 1.10 equiv), and then the reaction mixture is stirred at 50 °C in an oil bath for 15 hours. After cooling to room temperature, the reaction is quenched by water (20 mL), and extracted by EtOAc (3 × 25 mL). The combined organic phases are dried over anhydrous $MgSO_4$, filtered and concentrated under reduced pressure. Purifying the residue by flash column chromatography on silica gel with indicated solvent as eluent delivers the corresponding enyne.[72]

Step C:



To a solution of methyl (*E*)-5-phenylpent-2-en-4-ynoate (0.931 g, 5.00 mmol, 1.00 equiv) in a mixture solvent ($MeOH/H_2O$ = 8/1, 10 mL, ~0.5 M) is added NaOH (0.400 g, 10.0 mmol, 2.00 equiv), and then the reaction mixture is stirred for 2 hours at 80 °C in an oil bath. After cooling to room temperature, methanol is removed under reduced pressure, and then a solution of HCl (5 mL, ~2 M) is used for work-up. The reaction mixture is extracted by EtOAc (3 × 25 mL). The combined organic phases are dried over anhydrous $MgSO_4$, filtered and

[72] a) R. Takeuchi, K. Tanabe, S. Tanaka, *J. Org. Chem.* **2000**, *65*, 1558–1561; b) B. C. Ranu, K. Chattopadhyay, *Org. Lett.* **2007**, *9*, 2409–2412; c) P.-Y. Tseng, S.-C. Chuang, *Adv. Synth. Catal.* **2013**, *355*, 2165–2171; d) B. Schmidt, S. Audörsch, *Org. Lett.* **2016**, *18*, 1162–1165; e) L. Chen, C.-J. Li, *Tetrahedron Lett.* **2004**, *45*, 2771–2774; f) A. A. Golovanov, D. R. Latypova, V. V. Bekin, V. S. Pisareva, A.V. Vologzhanina, V. A. Dokichev, *Russ. J. Org. Chem.* **2013**, *49*, 1264–1269; g) Z. Zhu, T. Li, X. Qu, P. Sun, H. Yang, J. Mao, *Org. Biomol. Chem.* **2011**, *9*, 7309–7312.

concentrated under reduced pressure to deliver the crude acid which is directly used in the next step.

To a solution of the aforementioned crude acid in dry CH_2Cl_2 (10 mL, ~0.5 M), are slowly added $SOCl_2$ (0.713 g, 6.00 mmol, 1.20 equiv) and DMF (1 mL) at room temperature. After stirring for 2 hours, CH_2Cl_2 is evaporated under reduced pressure to provide the crude acyl chloride. The residue is dissolved in THF (10 mL), followed by the addition of R_2NH (8.00 mmol, 1.60 equiv) and triethylamine (6.60 mmol, 1.32 equiv). Then the reaction mixture is stirred at room temperature for 2 hours. The reaction is quenched by water (20 mL) and extracted by EtOAc (3 × 25 mL). The combined organic phases are dried over anhydrous $MgSO_4$, filtered, and concentrated under reduced pressure. Purifying the residue by flash column chromatography on silica gel with indicated solvent as eluent delivers the corresponding product.[73]

2.2.3 GP 2.3: General Procedure for Racemic Products

A heat gun-dried Schlenk tube charged with a magnetic stir bar and a septum is purged with N_2, followed by the addition of $(Ph_3P)_2CuBH_4$ (1.20 mg, 2.00 *μ*mol, 1.00 mol%) and KO*t*Bu (2.30 mg, 20.0 *μ*mol, 10.0 mol%). The tube is evacuated and backfilled with N_2 and then 2-MeTHF (1 mL) and $R_3SiBpin$ (0.300 mmol, 1.50 equiv) are added in sequence. After stirring at room temperature for 20 minutes, the corresponding enyne (0.200 mmol, 1.00 equiv) and methanol (13.0 mg, 0.400 mmol, 2.00 equiv) are added successively. The reaction mixture is stirred at room temperature overnight, and then concentrated under reduced pressure. Purifying the residue by flash column chromatography on silica gel with indicated solvent as eluent delivers the corresponding product.

2.2.4 GP 2.4: General Procedure for Enantioenriched Products

A heat gun-dried Schlenk tube charged with a magnetic stir bar and a septum is purged with N_2, followed by the addition of $(Ph_3P)_2CuBH_4$ (1.20 mg, 2.00 *μ*mol, 1.00 mol%), (*R*,*R*)-QuinoxP* [(*R*,*R*)-**L4**, 1.00 mg, 3.00 *μ*mol, 1.50 mol%] and KO*t*Bu (2.30 mg, 20.0 *μ*mol, 10.0 mol%). The tube is evacuated and backfilled with N_2 and then 2-MeTHF (1 mL) is added. After stirring at room temperature for an hour, $R_3SiBpin$ (0.300 mmol, 1.50 equiv) is added. The corresponding enyne (0.200 mmol, 1.00 equiv) and methanol (13.0 mg, 0.400 mmol, 2.00 equiv) are successively added in 20 minutes. The reaction mixture is stirred at room temperature overnight, and then concentrated under reduced pressure. Purifying the residue

[73] Y. Guo, J. Kootstra, S. R. Harutyunyan, *Angew. Chem., Int. Ed.* **2018**, *57*, 13547–13550; *Angew*. *Chem*. **2018**, *130*, 13735–13738.

through flash column chromatography on silica gel with indicated solvent as eluent renders the corresponding product.

3 DESCRIPTION OF EXPERIMENTS

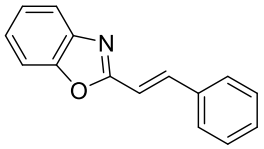
3.1 Asymmetric Conjugate 1.4-Silyl Transfer to Azaaryl-Substituted Alkenes

3.1.1 Preparation of Silicon GRIGNARD Reagents

All silicon GRIGNARD reagents were synthesized according to **GP 1.1**, a procedure reported by OESTREICH group.[67]

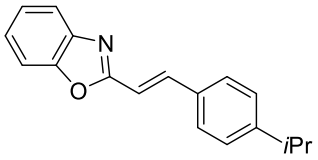
3.1.2 Experimental Details and Characterization Data for Azaarenes

89b,[69f] **89c**,[69d] **89d**,[69a] **89f**,[69f] **89g**,[69f] **89p**,[69d] **89t**,[69d] **122**,[69d] and **124**,[69f] were prepared according to reported procedures and all spectroscopic data accord with those known. **128** is commercially available.



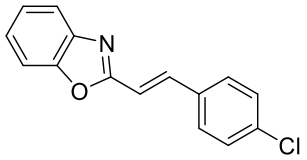
(*E*)-**89a**
$C_{15}H_{11}NO$
M = 221.26 g/mol

(*E*)-2-Styrylbenzoxazole [(*E*)-**89a**]: Synthesized from benzaldehyde (531 mg, 5.00 mmol, 1.00 equiv) and 2-methyl-1,3-benzoxazole (666 mg, 5.00 mmol, 1.00 equiv) according to **GP 1.2**. Purification by flash column chromatography on silica gel with cyclohexane/EtOAc = 30/1 as eluent delivered (*E*)-**89a** as a yellow solid (375 mg, 56% yield). All spectroscopic data accord with those reported.[69d]



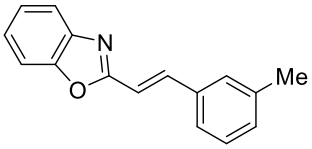
(*E*)-**89e**
$C_{18}H_{17}NO$
M = 263.34 g/mol

(*E*)-2-(4-Isopropylstyryl)benzoxazole [(*E*)-**89e**]: Synthesized from cuminaldehyde (741 mg, 5.00 mmol, 1.00 equiv) and 2-methyl-1,3-benzoxazole (666 mg, 5.00 mmol, 1.00 equiv) according to **GP 1.2**. Purification by recrystallization in MeOH delivered (*E*)-**89e** as a white solid (590 mg, 44% yield). All spectroscopic data accord with those reported.[69g]



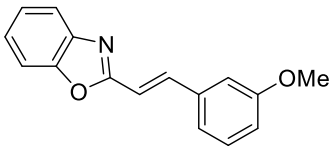
(*E*)-**89h**
$C_{15}H_{10}ClNO$
M = 255.70 g/mol

(*E*)-2-(4-Chlorostyryl)benzoxazole [(*E*)-**89h**]: Synthesized from 4-chlorobenzaldehyde (703 mg, 5.00 mmol, 1.00 equiv) and 2-methyl-1,3-benzoxazole (666 mg, 5.00 mmol, 1.00 equiv) according to **GP 1.2**. Purification by recrystallization in MeOH delivered (*E*)-**89h** as a yellow solid (519 mg, 41% yield). All spectroscopic data accord with those reported.[69g]



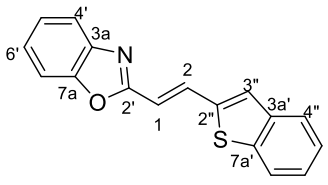
(*E*)-**89i**
$C_{16}H_{13}NO$
M = 235.29 g/mol

(*E*)-2-(3-Methylstyryl)benzoxazole [(*E*)-**89i**]: Synthesized from *m*-tolualdehyde (601 mg, 5.00 mmol, 1.00 equiv) and 2-methyl-1,3-benzoxazole (666 mg, 5.00 mmol, 1.00 equiv) according to **GP 1.2**. Purification by recrystallization in MeOH delivered (*E*)-**89i** as a yellow solid (593 mg, 51% yield). All spectroscopic data accord with those reported.[69d]



(*E*)-**89j**
$C_{16}H_{13}NO_2$
M = 251.29 g/mol

(*E*)-2-(3-Methoxystyryl)benzoxazole [(*E*)-**89j**]: Synthesized from *m*-anisaldehyde (681 mg, 5.00 mmol, 1.00 equiv) and 2-methyl-1,3-benzoxazole (666 mg, 5.00 mmol, 1.00 equiv) according to **GP 1.2**. Purification by flash column chromatography on silica gel with cyclohexane/EtOAc = 10/1 as eluent delivered (*E*)-**89j** as a yellow solid (0.416 g, 33% yield). All spectroscopic data accord with those reported.[69g]



(*E*)-**89k**
$C_{17}H_{11}NOS$
M = 277.34 g/mol

(*E*)-2-(2-(Benzo[b]thiophen-2-yl)vinyl)benzoxazole [(*E*)-**89k**]: Synthesized from benzothiophene-2-carboxaldehyde (810 mg, 5.00 mmol, 1.00 equiv) and 2-methyl-1,3-benzoxazole (670 mg, 5.00 mmol, 1.00 equiv) according to **GP 1.2**. Purification by recrystallization in MeOH delivered (*E*)-**89k** as a yellow solid (0.313 g, 23% yield).

$\mathbf{R_f}$ = 0.50 (cyclohexane/EtOAc = 10/1).

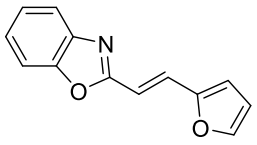
M.**P**. 180–181 °C.

^{1}H NMR (500 MHz, $CDCl_3$, 298 K): δ 6.92 (d, $^3J_{1,2}$ = 16.0 Hz, 1H, H-1), 7.32–7.37 (m, 4H, H-4', H-7', H-6" and H-7"), 7.43 (s, 1H, H-3"), 7.50–7.53 (m, 1H, H-5' or H-6'), 7.70–7.76 (m, 2H, H-5' or H-6' and H-4"), 7.71–7.81 (m, 1H, H-5"), 7.95 (d, $^3J_{2,1}$ = 16.0 Hz, 1H, H-2) ppm.

^{13}C NMR (125 MHz, $CDCl_3$, 298 K): δ 110.3 (C-5' or C-6'), 115.3 (C-1), 119.9 (C-5' or C-6'), 122.4 (C-5"), 124.2 (C-4"), 124.6 (C-4' or C-7'), 124.8 (C-7"), 125.4 (C-4' or C-7'), 126.0 (C-6"), 127.3 (C-3"), 132.5 (C-2), 139.7 (C-3a' or C-7a'), 140.0 (3a' or C-7a'), 140.4 (C-2"), 142.2 (C-3a or C-7a), 150.5 (C-3a or C-7a), 162.1 (C-2') ppm.

HRMS (APCI) m/z: $[M+H]^+$ calcd for $C_{17}H_{12}NOS$ 278.0634, found 278.0624.

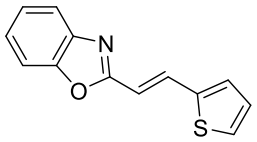
IR (ATR): ṽ 860, 965, 1024, 1145, 1268, 1636, 1673, 3026, 3060 cm^{-1}.



(*E*)-**89l**
$C_{13}H_9NO_2$
M = 211.22 g/mol

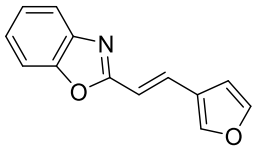
(*E*)-2-(2-(Furan-2-yl)vinyl)benzoxazole [(*E*)-**89l**]: Synthesized from furfural (480 mg, 5.00 mmol, 1.00 equiv) and 2-methyl-1,3-benzoxazole (666 mg, 5.00 mmol, 1.00 equiv) according

to **GP 1.2**. Purification by recrystallization in MeOH delivered (*E*)-**89l** as a yellow solid (528 mg, 50% yield). All the spectroscopic data accord with those reported.[69e]



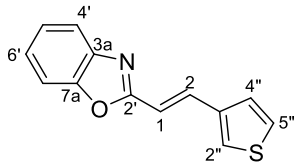
(*E*)-**89m**
$C_{13}H_9NOS$
M = 227.28 g/mol

(*E*)-2-(2-(Thiophen-2-yl)vinyl)benzoxazole [(*E*)-**89m**]: Synthesized from thiophene-2-carbox-aldehyde (561 mg, 5.00 mmol, 1.00 equiv) and 2-methyl-1,3-benzoxazole (666 mg, 5.00 mmol, 1.00 equiv) according to **GP 1.2**. Purification by recrystallization in MeOH afforded (*E*)-**89m** as a yellow solid (676 mg, 60% yield). All spectroscopic data accord with those reported.[69c]



(*E*)-**89n**
$C_{13}H_9NO_2$
M = 211.22 g/mol

(*E*)-2-(2-(Furan-3-yl)vinyl)benzoxazole [(*E*)-**89n**]: Synthesized from 3-furaldehyde (480 mg, 5.00 mmol, 1.00 equiv) and 2-methyl-1,3-benzoxazole (666 mg, 5.00 mmol, 1.00 equiv) according to **GP 1.2**. Purification by flash column chromatography on silica gel with cyclohexane/EtOAc = 30/1 as eluent delivered (*E*)-**89n** as a gray solid (0.386 g, 37% yield). All spectroscopic data accord with those reported.[69c]



(*E*)-**89o**
$C_{13}H_9NOS$
M = 227.28 g/mol

(*E*)-2-(2-(Thiophen-3-yl)vinyl)benzoxazole [(*E*)-**89o**]: Synthesized from 3-thiophenecarbox-aldehyde (560 mg, 5.00 mmol, 1.00 equiv) and 2-methyl-1,3-benzoxazole (670 mg, 5.00 mmol, 1.00 equiv) according to **GP 1.2**. Purification by recrystallization in MeOH delivered (*E*)-**89o** as a grey solid (0.595 g, 52% yield).

R_f = 0.50 (cyclohexane/EtOAc = 10/1).

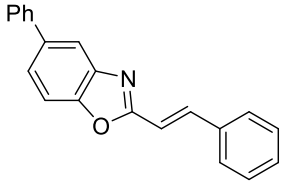
M.P. 130–131 °C.

^{1}H NMR (400 MHz, $CDCl_3$, 298 K): δ 6.89 (d, $^3J_{1,2}$ = 16.2 Hz, 1H, H-1), 7.29–7.34 (m, 2H, H-4' and H-7'), 7.34–7.39 (m, 2H, H-2" and H-5"), 7.47–7.53 (m, 2H, H-5' or H-6' and H-4"), 7.68–7.72 (m, 1H, H-5' or H-6'), 7.77 (d, $^3J_{2,1}$ = 16.2 Hz, 1H, H-2) ppm.

^{13}C NMR (125 MHz, $CDCl_3$, 298 K): δ 110.2 (C-5' or C-6'), 113.7 (C-1), 119.7 (C-5' or C-6'), 124.4 (C-4' or C-7'), 124.8 (C-2"), 125.0 (C-4' or C-7'), 126.6 (C-4"), 126.9 (C-5"), 133.1 (C-2), 138.2 (C-3"), 142.2 (C-3a or C-7a), 150.3 (C-3a or C-7a), 162.8 (C-2') ppm.

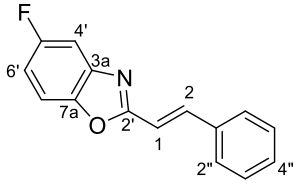
HRMS (APCI) m/z: $[M+H]^+$ calcd for $C_{13}H_{10}NOS$ 228.0478, found 228.0470.

IR (ATR): ṽ 868, 969, 1092, 1147, 1237, 1639, 3020, 3060 cm^{-1}.



(*E*)-**89q**
$C_{21}H_{15}NO$
M = 297.36 g/mol

(*E*)-5-Phenyl-2-styrylbenzoxazole [(*E*)-**89q**]: Synthesized from benzaldehyde (531 mg, 5.00 mmol, 1.00 equiv) and 2-methyl-5-phenylbenzoxazole (1.05 g, 5.00 mmol, 1.00 equiv) according to **GP 1.2**. Purification by recrystallization in MeOH delivered (*E*)-**89q** as a yellow solid (907 mg, 61% yield). All spectroscopic data accord with those reported.[69d]



(*E*)-**89r**
$C_{15}H_{10}FNO$
M = 239.25 g/mol

(*E*)-5-Fluoro-2-styrylbenzoxazole [(*E*)-**89r**]: Synthesized from benzaldehyde (531 mg, 5.00 mmol, 1.00 equiv) and 5-fluoro-2-methylbenzoxazole (755 mg, 5.00 mmol, 1.00 equiv)

according to **GP 1.2**. Purification by recrystallization in MeOH rendered (*E*)-**89r** as a yellow solid (0.450 g, 38% yield).

$\mathbf{R_f}$ = 0.50 (cyclohexane/EtOAc = 10/1).

M.**P**. 108–109 °C.

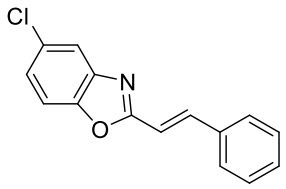
^{1}H NMR (500 MHz, $CDCl_3$, 298 K): δ 7.06 (d, $^3J_{1,2}$ = 16.4 Hz, 1H, H-1), 7.04–7.09 (m, 1H, H-6'), 7.37–7.48 (m, 5H, H-4', H-7', H-3" and H-4"), 7.59–7.62 (m, 2H, H-2"), 7.80 (d, $^3J_{2,1}$ = 16.4 Hz, 1H, H-2) ppm.

^{13}C NMR (100 MHz, $CDCl_3$, 298 K): δ 106.2 (d, $^2J_{C,F}$ = 25.4 Hz, C-4'), 110.5 (d, $^3J_{C,F}$ = 10.0 Hz, C-7'), 112.7 (d, $^2J_{C,F}$ = 26.2 Hz, C-6'), 113.6 (C-1), 127.6 (C-2"), 129.0 (C-3" or C-4"), 130.0 (C-3"or C-4"), 134.9 (C-1"), 140.1 (C-2), 143.0 (d, $^3J_{C,F}$ = 13.3 Hz, C-3a), 146.7 (C-7a), 160.1 (d, $^1J_{C,F}$ = 239.0 Hz, C-5'), 164.5 (C-2') ppm.

^{19}F NMR (471 MHz, $CDCl_3$, 298 K): δ −117.8 (Ar*F*) ppm.

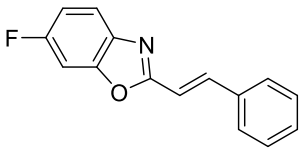
HRMS (APCI) m/z: $[M+H]^+$ calcd for $C_{15}H_{11}FNO$ 240.0819, found 240.0820.

IR (ATR): ṽ 853, 959, 1130, 1248, 1638, 3027, 3060 cm^{-1}.



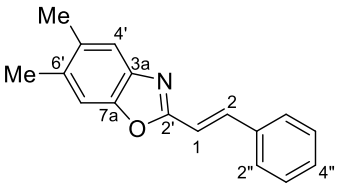
(*E*)-**89s**
$C_{15}H_{10}ClNO$
M = 255.70 g/mol

(*E*)-5-Chloro-2-styrylbenzoxazole [(*E*)-**89s**]: Synthesized from benzaldehyde (531 mg, 5.00 mmol, 1.00 equiv) and 5-chloro-2-methylbenzoxazole (838 mg, 5.00 mmol, 1.00 equiv) according to **GP 1.2**. Purification by recrystallization in MeOH delivered (*E*)-**89s** as a yellow solid (570 mg, 45% yield). All spectroscopic data accord with those reported.[69d]



(*E*)-**89u**
$C_{15}H_{10}FNO$
M = 239.25 g/mol

(*E*)-6-Fluoro-2-styrylbenzoxazole [(*E*)-**89u**]: Synthesized from benzaldehyde (531 mg, 5.00 mmol, 1.00 equiv) and 6-fluoro-2-methylbenzoxazole (756 mg, 5.00 mmol, 1.00 equiv) according to **GP 1.2**. Purification by recrystallization in MeOH delivered (*E*)-**89u** as a yellow solid (289 mg, 24% yield). All spectroscopic data accord with those reported.[69b]



(*E*)-**89v**
$C_{17}H_{15}NO$
M = 249.31 g/mol

(*E*)-5,6-Dimethyl-2-styrylbenzoxazole [(*E*)-**89v**]: Synthesized from benzaldehyde (531 mg, 5.00 mmol, 1.00 equiv) and 2,5,6-trimethylbenzoxazole (805 mg, 5.00 mmol, 1.00 equiv) according to **GP 1.2**. Purification by recrystallization in MeOH delivered (*E*)-**89v** as a yellow solid (710 mg, 57% yield).

R_f = 0.50 (cyclohexane/EtOAc = 10/1).

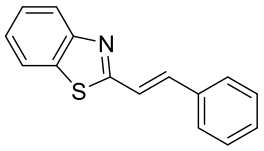
M.**P**. 137–138 °C.

^{1}H NMR (500 MHz, $CDCl_3$, 298 K): δ 2.34 (s, 3H, 5'- or 6'-CH_3), 2.36 (s, 3H, 5'- or 6'-CH_3), 7.04 (d, $^3J_{1,2}$ = 16.4 Hz, 1H), 7.28 (s, 1H, H-4' or H-5'), 7.33–7.37 (m, 1H, H-4"), 7.37–7.42 (m, 2H, H-3"), 7.46 (s, 1H, H-4' or H-5'), 7.55–7.58 (m, 2H, H-2"), 7.71 (d, $^3J_{2,1}$ = 16.4 Hz, 1H, H-2) ppm.

^{13}C NMR (125 MHz, $CDCl_3$, 298 K): δ 20.0 (5'- or 6'-*C*H_3), 20.4 (5'- or 6'-*C*H_3), 110.5 (C-4' or C-7'), 114.1 (C-1), 119.8 (C-4' or C-7'), 127.3 (C-2"), 128.8 (C-3"), 129.4 (C-4"), 133.1 (C-4' or C-5'), 134.4 (C-4' or C-5'), 135.2 (C-1"), 138.3 (C-2), 140.3 (C-3a or C-7a), 149.0 (C-3a or C-7a), 162.0 (C-2') ppm.

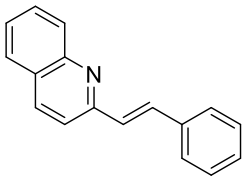
HRMS (APCI) m/z: $[M+H]^+$ calcd for $C_{17}H_{16}NO$ 250.1226, found 250.1217.

IR (ATR): ṽ 824, 949, 1139, 1241, 1447, 1631, 2996, 3042 cm^{-1}.



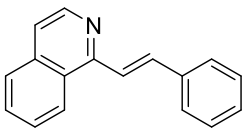
(*E*)-**91**
$C_{15}H_{11}NS$
M = 237.32 g/mol

(*E*)-2-Styrylbenzothiazole [(*E*)-**91**]: Synthesized from benzaldehyde (531 mg, 5.00 mmol, 1.00 equiv) and 2-methylbenzothiazole (746 mg, 5.00 mmol, 1.00 equiv) according to **GP 1.2**. Purification by flash column chromatography on silica gel with cyclohexane/EtOAc = 20/1 as eluent delivered (*E*)-**91** as a yellow solid (431 mg, 36% yield). All spectroscopic data accord with those reported.[69d]



(*E*)-**87a**
$C_{17}H_{13}N$
M =231.30 g/mol

(*E*)-2-Styrylquinoline [(*E*)-**87a**]: Synthesized from benzaldehyde (531 mg, 5.00 mmol, 1.00 equiv) and quinaldine (716 mg, 5.00 mmol, 1.00 equiv) according to **GP 1.2**. Purification by flash column chromatography on silica gel with cyclohexane/EtOAc = 20/1 as eluent delivered (*E*)-**87a** as a yellow solid (433 mg, 38% yield). All spectroscopic data accord with those reported.[69h]

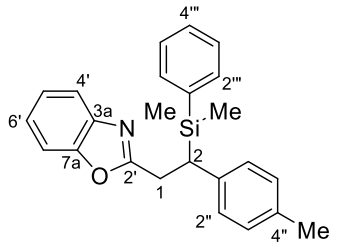


(*E*)-**126**
$C_{17}H_{13}N$
M =231.30 g/mol

(*E*)-1-Styrylisoquinoline [(*E*)-**126**]: Synthesized from benzaldehyde (531 mg, 5.00 mmol, 1.00 equiv) and 1-methylisoquinoline (716 mg, 5.00 mmol, 1.00 equiv) according to **GP 1.2**. Purification by flash column chromatography on silica gel with cyclohexane/EtOAc = 20/1 as

eluent delivered (*E*)-**126** as a yellow solid (445 mg, 39% yield). All spectroscopic data accord with those reported.[69i]

3.1.3 Experimental Details and Characterization Data for Racemic Products



rac-**90b**
$C_{24}H_{25}NOSi$
M = 371.56 g/mol

2-(2-(Dimethyl(phenyl)silyl)-2-(*p*-tolyl)ethyl)benzoxazole (*rac*-**90b**): Synthesized from (*E*)-2-(4-methylstyryl)benzoxazole [(*E*)-**89b**, 35.3 mg, 0.150 mmol, 1.00 equiv) according to **GP 1.3**. Purification by flash column chromatography on silica gel with cyclohexane/EtOAc = 30/1 as eluent delivered *rac*-**90b** as a white solid (44.0 mg, 79% yield).

$\mathbf{R_f}$ = 0.50 (cyclohexane/EtOAc = 10/1).

M.**P**. 54–55 °C.

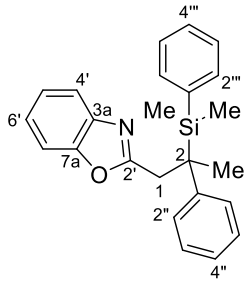
^{1}H NMR (500 MHz, $CDCl_3$, 298 K): δ 0.23 (s, 3H, SiCH_3), 0.30 (s, 3H, SiCH_3), 2.24 (s, 3H, ArCH_3), 3.08 (dd, $^3J_{2,1A}$ = 10.9 Hz, $^3J_{2,1B}$ = 5.7 Hz, 1H, H-2), 3.26–3.39 (m, 2H, H-1), 6.92 (d, $^3J_{2",3"}$ = 8.0 Hz, 2H, H-2"), 6.98 (d, $^3J_{3",2"}$ = 8.0 Hz, 2H, H-3"), 7.17–7.23 (m, 2H, Ar), 7.27–7.35 (m, 4H, H-4', or H-7', H-3''' and H-4'''), 7.42–7.45 (m, 2H, H-2'''), 7.53–7.56 (m, 1H, H-5' or H-6') ppm.

^{13}C NMR (125 MHz, $CDCl_3$, 298 K): δ −5.7 (SiCH$_3$), −3.9 (SiCH$_3$), 20.9 (ArCH$_3$), 29.5 (C-2), 33.5 (C-1), 110.1 (Ar), 119.4 (Ar), 123.8 (Ar), 124.1 (Ar), 127.5 (C-2"), 127.7 (C-3'''), 128.8 (C-3"), 129.2 (C-4'''), 134.1 (C-2'''), 134.4 (C-4"), 136.3 (C-1'''), 137.8 (C-1"), 141.2 (C-3a or C-7a), 150.6 (C-3a or C-7a), 166.7 (C-2') ppm.

^{29}Si DEPT NMR (99 MHz, $CDCl_3$, 298 K): δ −1.1 (*Si*Me$_2$Ph) ppm.

HRMS (APCI) m/z: $[M+H]^+$ calcd for $C_{24}H_{26}NOSi$ 372.1784, found 372.1788.

IR (ATR): ṽ 695, 731, 826, 946, 1003, 1111, 1242, 1427, 1565, 1655, 2957, 3107 cm^{-1}.



rac-**90c**
$C_{24}H_{25}NOSi$
M = 371.56 g/mol

2-(2-(Dimethyl(phenyl)silyl)-2-phenylpropyl)benzoxazole (*rac*-**90c**): Synthesized from (*E*)-2-(2-phenylprop-1-en-1-yl)benzoxazole [(*E*)-**89c**, 35.3 mg, 0.150 mmol, 1.00 equiv] according to **GP 1.3**. Purification by flash column chromatography on silica gel with cyclohexane/EtOAc = 30/1 as eluent delivered *rac*-**90c** as a brown solid (37.2 mg, 67% yield).

R*f* = 0.50 (cyclohexane/EtOAc = 10/1).

M.**P**. 108–109 °C.

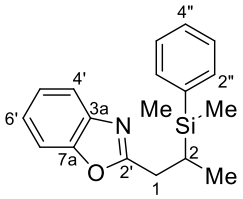
^{1}H NMR (500 MHz, $CDCl_3$, 298 K): δ 0.27 (s, 3H, SiC*H*$_3$), 0.31 (s, 3H, SiC*H*$_3$), 1.62 (s, 3H, C*H*$_3$), 3.20 (d, $^2J_{1A,1B}$ = 15.0 Hz, 1H, H-1A), 3.73 (d, $^2J_{1B,1A}$ = 15.0 Hz, 1H, H-1B), 7.05–7.09 (m, 1H, H-4'), 7.09–7.13 (m, 2H, H-2''), 7.15–7.22 (m, 4H, Ar and H-3''), 7.27–7.29 (m, 1H, Ar), 7.29–7.32 (m, 4H, Ar and H-2'''), 7.35–7.40 (m, 1H, Ar), 7.54–7.57 (m, 1H, Ar) ppm

^{13}C NMR (125 MHz, $CDCl_3$, 298 K): δ −5.9 (Si*C*H$_3$), −5.6 (Si*C*H$_3$), 20.7 (*C*H$_3$), 31.8 (C-2), 35.4 (C-1), 110.2 (Ar), 119.4 (Ar), 123.8 (Ar), 124.1 (Ar), 124.7 (C-4''), 126.8 (C-2''), 127.5 (Ar), 127.6 (Ar), 129.4 (Ar), 134.9 (Ar), 135.5 (C-1'''), 141.0 (C-3a or C-7a), 143.6 (C-1''), 150.6 (C-3a or C-7a), 165.4 (C-2') ppm.

^{29}Si DEPT NMR (99 MHz, $CDCl_3$, 298 K): δ 3.2 (*Si*Me$_2$Ph) ppm.

HRMS (APCI) m/z: $[M+H]^+$ calcd for $C_{24}H_{26}NOSi$ 372.1778, found 372.1777.

IR (ATR): ṽ 692, 740, 814, 936, 1028, 1113, 1245, 1428, 1599, 1603, 2962, 3057 cm^{-1}.



rac-**90d**
$C_{18}H_{21}NOSi$
M = 295.46 g/mol

2-(2-(Dimethyl(phenyl)silyl)propyl)benzoxazole (*rac*-**90d**): Synthesized from (*E*)-2-(prop-1-en-1-yl)benzoxazole [(*E*)-**89d**, 23.9 mg, 0.150 mmol, 1.00 equiv) according to **GP 1.3**. Purification by flash column chromatography on silica gel with cyclohexane/EtOAc = 30/1 as eluent delivered *rac*-**90d** as a yellow oil (21.4 mg, 48% yield).

$\mathbf{R_f}$ = 0.50 (cyclohexane/EtOAc = 10/1).

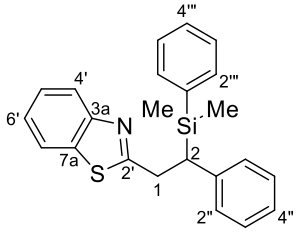
^{1}H NMR (500 MHz, $CDCl_3$, 298 K): δ 0.33 (s, 3H, SiCH_3), 0.34 (s, 3H, SiCH_3), 1.02 (d, $^3J_{3,2}$ = 7.4 Hz, 3H, CH_3), 1.61–1.70 (m, 1H, H-2), 2.70 (dd, $^2J_{1A,1B}$ = 15.2 Hz, $^3J_{1A,2}$ = 11.3 Hz, 1H, H-1A), 3.03 (dd, $^2J_{1B,1A}$ = 15.2 Hz, $^3J_{1B,2}$ = 4.4 Hz, 1H, H-1B), 7.25–7.30 (m, 2H, Ar), 7.33–7.36 (m, 3H, H-3" and H-4"), 7.42–7.45 (m, 1H, Ar), 7.51–7.54 (m, 2H, H-2"), 7.63–7.66 (m, 1H, Ar) ppm.

^{13}C NMR (125 MHz, $CDCl_3$, 298 K): δ −5.5 (Si*C*H_3), −5.0 (Si*C*H_3), 14.4 (*C*H_3), 18.4 (C-2), 31.1 (C-1), 110.2 (Ar), 119.5 (Ar), 124.0 (Ar), 124.3 (Ar), 127.8 (C-3"), 129.1 (C-4"), 133.9 (C-2"), 137.0 (C-1"), 141.4 (C-3a or C-7a), 150.7 (C-3a or C-7a), 167.4 (C-2') ppm.

^{29}Si DEPT NMR (99 MHz, $CDCl_3$, 298 K): δ −0.7 (*Si*Me_2Ph) ppm.

HRMS (APCI) m/z: $[M+H]^+$ calcd for $C_{18}H_{22}NOSi$ 296.1465, found 296.1472.

IR (ATR): ṽ 698, 777, 831, 1001, 1025, 1108, 1242, 1453, 1565, 1611, 2951, 3064 cm^{-1}.



rac-**92**
$C_{23}H_{23}NSSi$
M = 373.59 g/mol

2-(2-(Dimethyl(phenyl)silyl)-2-phenylethyl)benzothiazole (*rac*-**92**): Synthesized from (*E*)-2-styrylbenzothiazole [(*E*)-**91**, 35.6 mg, 0.150 mmol, 1.00 equiv) according to **GP 1.3**. Purification by flash column chromatography on silica gel with cyclohexane/EtOAc = 30/1 as eluent rendered *rac*-**92** as a brown oil (40.7 mg, 73% yield).

$\mathbf{R_f}$ = 0.50 (cyclohexane/EtOAc = 10/1).

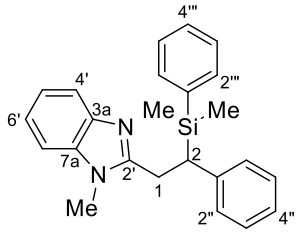
^{1}H NMR (500 MHz, $CDCl_3$, 298 K): δ 0.31 (s, 3H, SiCH_3), 0.32 (s, 3H, SiCH_3), 2.93 (dd, $^3J_{2,1A}$ = 11.4 Hz, $^3J_{2,1B}$ = 5.1 Hz, 1H, H-2), 3.52–3.62 (m, 2H, H-1), 6.99–7.02 (m, 2H, H-2''), 7.06–7.10 (m, 1H, H-4''), 7.16–7.21 (m, 2H, H-3''), 7.23–7.27 (m, 1H, H-5' or H-6'), 7.32–7.39 (m, 4H, H-5' or H-6', H-3''' and H-4'''), 7.42–7.46 (m, 2H, H-2'''), 7.66–7.69 (m, 1H, H-4' or H-7'), 7.86–7.89 (m, 1H, H-4' or H-7') ppm.

^{13}C NMR (125 MHz, $CDCl_3$, 298 K): δ −5.3 (Si*C*H_3), −4.0 (Si*C*H_3), 34.6 (C-1), 36.8 (C-2), 121.3 (C-4' or C-7'), 122.3 (C-4' or C-7'), 124.4 (C-5' or C-6'), 125.2 (C-4''), 125.6 (C-5' or C-6'), 127.8 (C-3'''), 128.0 (C-2''), 128.1 (C-2''), 129.4 (C-4'''), 134.2 (C-2'''), 135.2 (C-3a or C-7a), 136.2 (C-1'''), 140.7 (C-1''), 152.7 (C-3a or C-7a), 172.4 (C-2') ppm.

^{29}Si DEPT NMR (99 MHz, $CDCl_3$, 298 K): δ −0.9 (*Si*Me_2Ph) ppm.

HRMS (APCI) m/z: $[M+H]^+$ calcd for $C_{23}H_{24}NSSi$ 374.1393, found 374.1400.

IR (ATR): ṽ 697, 757, 831, 938, 1062, 1113, 1246, 1428, 1595, 1655, 2951, 3058 cm^{-1}.



rac-**123**
$C_{24}H_{26}N_2Si$
M = 370.57 g/mol

2-(2-(Dimethyl(phenyl)silyl)-2-phenylethyl)-1-methylbenzimidazole (*rac*-**123**): synthesized from (*E*)-1-methyl-2-styrylbenzimidazole [(*E*)-**122**, 35.2 mg, 0.150 mmol, 1.00 equiv) according to **GP 1.3**. Purification by flash column chromatography on silica gel with cyclohexane/EtOAc = 5/1 as eluent delivered *rac*-**123** as a yellow oil (25.7 mg, 46% yield).

$\mathbf{R_f}$ = 0.30 (cyclohexane/EtOAc = 5/1).

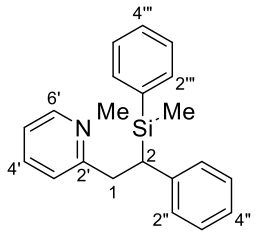
^{1}H NMR (500 MHz, $CDCl_3$, 298 K): δ 0.29 (s, 3H, SiCH_3), 0.30 (s, 3H, SiCH_3), 3.19 (dd, $^{3}J_{2,1A}$ = 9.9 Hz, $^{3}J_{2,1B}$ = 5.7 Hz, 1H, H-2), 3.20–3.35 (m, 2H, H-1), 3.38 (s, 3H, NCH_3), 6.99–7.02 (m, 2H, H-2"), 7.02–7.07 (m, 1H, H-4"), 7.09–7.20 (m, 5H, H-4', H-5', H-7' and H-3"), 7.25–7.30 (m, 2H, H-3'"), 7.30–7.35 (m, 1H, H-4'"), 7.39–7.43 (m, 2H, H-2'"), 7.64–7.68 (m, 1H, H-6') ppm.

^{13}C NMR (100 MHz, $CDCl_3$, 298 K): δ −5.1 (SiCH$_3$), −3.7 (SiCH$_3$), 28.6 (C-1), 29.6 (NCH$_3$), 35.5 (C-2), 108.8 (Ar), 119.0 (C-6'), 121.6 (Ar), 121.7 (Ar), 125.1 (C-4"), 127.6 (C-3'"), 128.0 (C-2"), 128.1 (C-3"), 129.2 (C-4'"), 134.1 (C-2'"), 135.6 (C-7a), 136.6 (C-1'"), 141.9 (C-1"), 154.8 (C-2') ppm. Signal for C-3a overlaps with others.

^{29}Si DEPT NMR (99 MHz, $CDCl_3$, 298 K): δ −1.0 (*Si*Me$_2$Ph) ppm.

HRMS (APCI) m/z: $[M+H]^+$ calcd for $C_{24}H_{27}N_2Si$ 371.1938, found 371.1934.

IR (ATR): ṽ 697, 734, 831, 902, 1074, 1111, 1247, 1426, 1596, 2952, 3050 cm^{-1}.



rac-**125**
$C_{21}H_{23}NSi$
M = 317.51 g/mol

2-(2-(Dimethyl(phenyl)silyl)-2-phenylethyl)pyridine (*rac*-**125**): Synthesized from (*E*)-2-styrylpyridine [(*E*)-**124**, 27.2 mg, 0.150 mmol, 1.00 equiv] according to **GP 1.3**. Purification by flash column chromatography on silica gel with cyclohexane/EtOAc = 10/1 as eluent delivered *rac*-**125** as a yellow oil (21.3 mg, 45% yield).

R$_f$ = 0.20 (cyclohexane/EtOAc = 10/1).

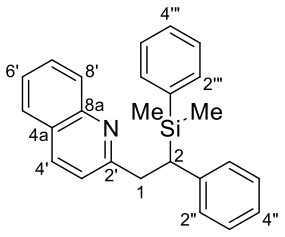
^{1}H NMR (500 MHz, $CDCl_3$, 298 K): δ 0.25 (s, 3H, SiCH_3), 0.28 (s, 3H, SiCH_3), 2.95 (dd, $^{3}J_{2,1A}$ = 10.5 Hz, $^{3}J_{2,1B}$ = 5.8 Hz, 1H, H-2), 3.18–3.28 (m, 2H, H-1), 6.86–6.89 (m, 1H, H-3'), 6.89–6.95 (m, 3H, H-5' and H-2"), 6.97–7.02 (m, 1H, H-4"), 7.08–7.12 (m, 2H, H-3"), 7.29–7.38 (m, 4H, H-4', H-2'" and H-4'"), 7.40–7.43 (m, 2H, H-3'"), 8.40–8.43 (m, 1H, H-6') ppm.

^{13}C NMR (100 MHz, $CDCl_3$, 298 K): δ −5.1 (Si*C*H_3), −4.0 (Si*C*H_3), 36.1 (C-2), 37.9 (C-1), 120.8 (C-5'), 122.9 (C-3'), 124.5 (C-4"), 127.6 (C-2'" or C-4'"), 127.8 (C-3"), 128.1 (C-2"), 129.1 (C-2'" or C-4'"), 134.2 (C-3'"), 135.8 (C-4'), 137.0 (C-1'"), 141.9 (C-1"), 149.0 (C-6'), 161.4 (C-2') ppm.

^{29}Si DEPT NMR (99 MHz, $CDCl_3$, 298 K): δ −1.3 (*Si*Me_2Ph) ppm.

HRMS (APCI) m/z: $[M+H]^+$ calcd for $C_{21}H_{24}NSi$ 318.1673, found 318.1675.

IR (ATR): ṽ 699, 735, 813, 904, 1074, 1112, 1248, 1428, 1590, 2952, 3064 cm^{-1}.



rac-**88a**
$C_{25}H_{25}NSi$
M = 367.57 g/mol

2-(2-(Dimethyl(phenyl)silyl)-2-phenylethyl)quinoline (*rac*-**88a**): Synthesized from (*E*)-2-styrylquinoline [(*E*)-**87a**, 34.7 mg, 0.150 mmol, 1.00 equiv] according to **GP 1.3**. Purification by flash column chromatography on silica gel with cyclohexane/EtOAc = 30/1 as eluent delivered *rac*-**88a** as a yellow oil (39.8 mg, 72% yield).

R_f = 0.50 (cyclohexane/EtOAc = 10/1).

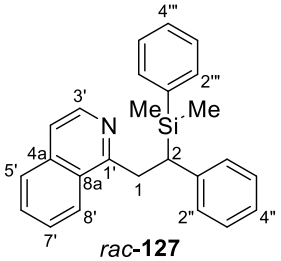
^{1}H NMR (500 MHz, $CDCl_3$, 298 K): δ 0.29 (s, 3H, SiCH_3), 0.32 (s, 3H, SiCH_3), 3.08 (dd, $^3J_{2,1A}$ = 11.0 Hz, $^3J_{2,1B}$ = 5.5 Hz, 1H, H-2), 3.42–3.53 (m, 2H, H-1), 6.98–7.02 (m, 3H, H-2" and H-4"), 7.08 (d, $^3J_{3',4'}$ = 8.5 Hz, 1H, H-3'), 7.09–7.13 (m, 2H, H-3"), 7.29–7.36 (m, 3H, H-3'" and H-4'"), 7.39–7.43 (m, 1H, H-6'), 7.43–7.47 (m, 2H, H-2'"), 7.60–7.67 (m, 2H, H-5' and H-7'), 7.83 (d, $^3J_{4',3'}$ = 8.5 Hz, 1H, H-4'), 7.99 (d, *J* = 8.5 Hz, 1H, H-8') ppm.

^{13}C NMR (125 MHz, $CDCl_3$, 298 K): δ −5.1 (Si*C*H_3), −3.9 (Si*C*H_3), 36.0 (C-2), 38.7 (C-1), 121.0 (C-3'), 124.6 (C-4"), 125.5 (C-6'), 126.6 (C-4a), 127.3 (C-5'), 127.6 (C-3'"), 127.9 (C-3"), 128.1 (C-2"), 128.7 (C-8'), 129.0 (C-7' and C-4'"), 134.2 (C-2'"), 135.6 (C-4'), 137.0 (C-1'"), 141.9 (C-1"), 147.7 (C-8a), 162.1 (C-2') ppm.

^{29}Si DEPT NMR (99 MHz, $CDCl_3$, 298 K): δ −1.1 (*Si*Me_2Ph) ppm.

HRMS (APCI) m/z: $[M+H]^+$ calcd for $C_{25}H_{26}NSi$ 368.1829, found 368.1834.

IR (ATR): ṽ 696, 733, 816, 906, 1074, 1111, 1247, 1424, 1595, 2952, 3051 cm^{-1}.



rac-**127**
$C_{25}H_{25}NSi$
M = 367.57 g/mol

1-(2-(Dimethyl(phenyl)silyl)-2-phenylethyl)isoquinoline (*rac*-**127**): Synthesized from (*E*)-1-styrylisoquinoline [(*E*)-**126**, 34.7 mg, 0.150 mmol, 1.00 equiv) according to **GP 1.3**. Purification by flash column chromatography on silica gel with cyclohexane/EtOAc = 30/1 as eluent delivered *rac*-**127** as a yellow oil (30.1 mg, 55% yield).

$\mathbf{R_f}$ = 0.30 (cyclohexane/EtOAc = 10/1).

^{1}H NMR (500 MHz, $CDCl_3$, 298 K): δ 0.24 (s, 3H, SiCH_3), 0.33 (s, 3H, SiCH_3), 3.19 (dd, $^3J_{2,1A}$ = 9.6 Hz, $^3J_{2,1B}$ = 5.8 Hz, 1H), 3.68–3.79 (m, 2H, H-1), 6.98–7.02 (m, 3H, H-2" and H4"), 7.08–7.13 (m, 2H, H-3"), 7.30–7.38 (m, 4H, H-4' H-3''' and H-4'''), 7.44–7.48 (m, 3H, H-7' and H-2'''), 7.56–7.60 (m, 1H, H-6'), 7.70 (d, $^3J_{5',6'}$ = 8.2 Hz, 1H, H-5'), 7.90 (d, $^3J_{8',7'}$ = 8.5 Hz, 1H, H-8'), 8.28 (d, $^3J_{3',4'}$ = 5.7 Hz, 1H, H-3') ppm.

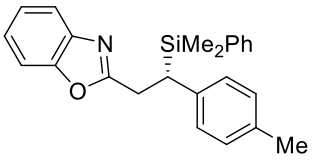
^{13}C NMR (100 MHz, $CDCl_3$, 298 K): δ −5.1 (SiCH$_3$), −3.7 (SiCH$_3$), 35.3 (C-1), 36.3 (C-2), 119.0 (C-4'), 124.5 (C-4"), 125.1 (C-8'), 126.6 (C-7'), 127.0 (C-8a), 127.3 (C-5'), 127.6 (C-3'''), 127.8 (C-3"), 128.2 (C-2"), 129.0 (C-4'''), 129.4 (C-6'), 134.2 (C-2'''), 136.1 (C-4a), 137.4 (C-1'''), 141.6 (C-3'), 142.6 (C-1"), 161.1 (C-1') ppm.

^{29}Si DEPT NMR (99 MHz, $CDCl_3$, 298 K): δ −1.1 (*Si*Me$_2$Ph) ppm.

HRMS (APCI) m/z: $[M+H]^+$ calcd for $C_{25}H_{26}NSi$ 368.1829, found 368.1824.

IR (ATR): ṽ 696, 731, 813, 902, 1073, 1110, 1247, 1425, 1584, 2953, 3049 cm^{-1}.

3.1.4 Experimental Details and Characterization Data for Enantioenriched Products

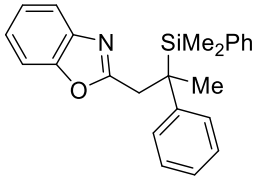


(*S*)-**90b**
$C_{24}H_{25}NOSi$
M = 371.56 g/mol

(*S*)-2-(2-(Dimethyl(phenyl)silyl)-2-(*p*-tolyl)ethyl)benzoxazole [(*S*)-**90b**): Synthesized from (*E*)-2-(4-methylstyryl)benzoxazole [(*E*)-**89b**, 35.3 mg, 0.150 mmol, 1.00 equiv) according to **GP 1.4**. Purification by flash column chromatography on silica gel with cyclohexane/EtOAc = 30/1 as eluent delivered (*S*)-**90b** as a white solid (44.5 mg, 80% yield). All data accord with those of *rac*-**90b**.

Optical rotation: $[\alpha]_D^{20}$ = +44.2 (*c* 0.2, $CHCl_3$, 94% *ee*).

The enantiomeric ratio of **90b** was determined by HPLC analysis on a chiral stationary phase (*Daicel Chiralcel* OD-H column, column temperature 20 °C, solvent: *n*heptane/*i*PrOH = 99.5/0.5, flow rate = 0.3 mL/min): t_R = 47.3 min (minor), t_S = 50.2 min (major).

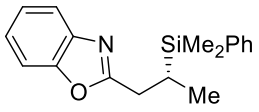


rac-**90c**
$C_{24}H_{25}NOSi$
M = 371.56 g/mol

2-(2-(Dimethyl(phenyl)silyl)-2-phenylpropyl)benzoxazole (*rac*-**90c**): Synthesized from (*E*)-2-(2-phenylprop-1-en-1-yl)benzoxazole [(*E*)-**89c**, 35.3 mg, 0.150 mmol, 1.00 equiv] according to **GP 1.4**. Purification by flash column chromatography on silica gel with cyclohexane/EtOAc = 30/1 as eluent rendered *rac*-**90c** as a brown solid (31.2 mg, 56% yield).

Optical rotation: $[\alpha]_D^{20}$ = 0 (*c* 0.5, $CHCl_3$, <5% *ee*).

The enantiomeric ratio of *rac*-**90c** was determined by HPLC analysis on a chiral stationary phase (*Daicel Chiralcel* OD-H column, column temperature 20 °C, solvent: *n*heptane/*i*PrOH = 99/1, flow rate = 0.6 mL/min): *t* = 13.6 min, *t* = 14.8 min.

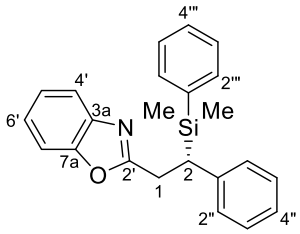


(*R*)-**90d**
$C_{18}H_{21}NOSi$
M = 295.46 g/mol

(*R*)-2-(2-(Dimethyl(phenyl)silyl)propyl)benzoxazole [(R)-**90d**]: Synthesized from (*E*)-2-(prop-1-en-1-yl)benzoxazole [(*E*)-**89d**, 23.9 mg, 0.150 mmol, 1.00 equiv] according to **GP 1.4**. Purification by flash column chromatography on silica gel with cyclohexane/EtOAc = 30/1 delivered (*R*)-**90d** as a yellow oil (19.5 mg, 44% yield). All data accord with those of *rac*-**90d**.

Optical rotation: $[\alpha]_D^{20}$ = -1.20 (*c* 0.1, $CHCl_3$, 13% *ee*).

The enantiomeric ratio of (*R*)-**90d** was determined by HPLC analysis on a chiral stationary phase (*Daicel Chiralcel* OD-H column, column temperature 20 °C, solvent: *n*heptane/*i*PrOH = 99.5/0.5, flow rate = 0.3 mL/min): t_R = 30.6 min (major), t_S = 34.6 min (minor).



(*S*)-**90a**
$C_{23}H_{23}NOSi$
M = 357.53 g/mol

(*S*)-2-(2-(Dimethyl(phenyl)silyl)-2-phenylethyl)benzoxazole [(*S*)-**90a**]: Synthesized from (*E*)-2-styrylbenzoxazole [(*E*)-**89a**, 33.2 mg, 0.150 mmol, 1.00 equiv] according to **GP 1.4**. Purification by flash column chromatography on silica gel with cyclohexane/EtOAc = 30/1 as eluent deliver (*S*)-**90a** as a white solid (35.1 mg, 65% yield).

R_f = 0.50 (cyclohexane/EtOAc = 10/1).

M.P. 96–97 °C.

^{1}H NMR (500 MHz, $CDCl_3$, 298 K): δ 0.24 (s, 3H, SiC*H*$_3$), 0.31 (s, 3H, SiC*H*$_3$), 3.11 (dd, $^3J_{2,1A}$ = 10.8 Hz, $^3J_{2,1B}$ = 5.7 Hz, 1H, H-2), 3.28–3.42 (m, 2H, H-1), 7.00–7.03 (m, 2H, H-2"), 7.03–

7.07 (m, 1H, H-4"), 7.14–7.19 (m, 2H, H-3"), 7.19–7.23 (m, 2H, Ar), 7.27–7.31 (m, 2H, H-3'"), 7.31–7.35 (m, 2H, Ar and H-4'"), 7.40–7.43 (m, 2H, H-2'"), 7.53–7.56 (m, 1H, Ar) ppm.

^{13}C NMR (125 MHz, $CDCl_3$, 298 K): δ −5.6 (Si*C*H$_3$), −4.0 (Si*C*H$_3$), 29.4 (C-1), 34.1 (C-2), 110.1 (Ar), 119.4 (Ar), 123.8 (Ar), 124.2 (Ar), 125.1 (C-4"), 127.6 (C-2" or C-3'"), 127.7 (C-2" or C-3'"), 128.1 (C-3"), 129.2 (C-4'"), 134.1 (C-2'"), 136.1 (C-1'"), 141.1 (C-1"), 141.2 (C-3a or C-7a), 150.6 (C-3a or C-7a), 166.5 (C-2') ppm.

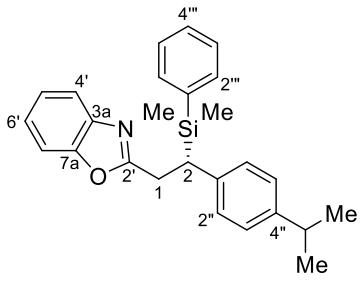
^{29}Si DEPT NMR (99 MHz, $CDCl_3$, 298 K): δ −0.9 (*Si*Me$_2$Ph) ppm.

HRMS (APCI) m/z: $[M+H]^+$ calcd for $C_{23}H_{24}NOSi$ 358.1627, found 358.1632.

IR (ATR): ṽ 700, 730, 812, 934, 1076, 1114, 1242, 1428, 1597, 2951, 3062 cm^{-1}.

Optical rotation: $[\alpha]_D^{20}$ = +24.0 (*c* 0.8, $CHCl_3$, 93% *ee*).

The enantiomeric ratio of (*S*)-**90a** was determined by HPLC analysis on a chiral stationary phase (*Daicel Chiralcel* OD-H column, column temperature 20 °C, solvent: *n*heptane/*i*PrOH = 99.5:0.5, flow rate = 0.3 mL/min): t_R = 48.6 min (minor), t_S = 51.6 min (major).



(*S*)-**90e**
$C_{26}H_{29}NOSi$
M = 399.61 g/mol

(*S*)-2-(2-(Dimethyl(phenyl)silyl)-2-(4-isopropylphenyl)ethyl)benzoxazole [(S)-**90e**): Synthesized from (*E*)-2-(4-isopropylstyryl)benzoxazole [(*E*)-**89e**, 39.5 mg, 0.150 mmol, 1.00 equiv] according to **GP 1.4**. Purification by flash column chromatography on silica gel with cyclohexane/EtOAc = 30/1 as eluent delivered (*S*)-**90e** as a brown solid (45.6 mg, 76% yield).

R$_f$ = 0.50 (cyclohexane/EtOAc = 10/1).

M.P. 59–60 °C.

^{1}H NMR (500 MHz, $CDCl_3$, 298 K): δ 0.21 (s, 3H, SiCH_3), 0.30 (s, 3H, SiCH_3), 1.18 [d, ^{3}J = 7.0 Hz, 6H, CH(CH_3)$_2$], 2.76–2.86 [m, 1H, CH(CH$_3$)$_2$], 3.08 (dd, J = 10.4, 6.1 Hz, 1H, H-2), 3.26–3.39 (m, 2H, H-1), 6.94 (d, $^{3}J_{2'',3''}$ = 8.2 Hz, 2H, C-2''), 7.03 (d, $^{3}J_{3'',2''}$ = 8.2 Hz, 2H, C-3''), 7.17–7.23 (m, 2H, Ar), 7.24–7.30 (m, 3H, H-3''' and H-4'''), 7.32–7.35 (m, 1H, Ar), 7.38–7.41 (m, 2H, H-2'''), 7.53–7.57 (m, 1H, Ar) ppm.

^{13}C NMR (125 MHz, $CDCl_3$, 298 K): δ −5.6 ($SiCH_3$), −3.9 ($SiCH_3$), 23.9 [CH(*C*H$_3$)$_2$], 29.5 (C-2), 33.4 [C-1 or *C*H(CH$_3$)$_2$], 33.5 [C-1 or *C*H(CH$_3$)$_2$], 110.1 (Ar), 119.4 (Ar), 123.8 (Ar), 124.1 (Ar), 126.1 (C-3''), 127.4 (C-2''), 127.6 (C-3'''), 129.1 (C-4'''), 134.0 (C-2'''), 136.4 (C-1'''), 138.2 (C-1''), 141.3 (C-3a or C-7a), 145.5 (C-4''), 150.6 (C-3a or C-7a), 166.7 (C-2') ppm.

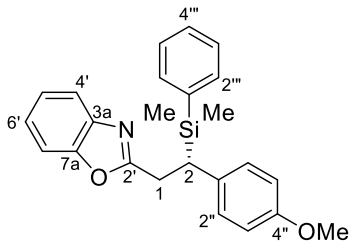
^{29}Si DEPT NMR (99 MHz, $CDCl_3$, 298 K): δ −1.0 (*Si*Me$_2$Ph) ppm.

HRMS (APCI) m/z: $[M+H]^+$ calcd for $C_{26}H_{30}NOSi$ 400.2091, found 400.2099.

IR (ATR): ṽ 699, 732, 812, 922, 1056, 1108, 1242, 1425, 1568, 2955, 3048 cm^{-1}.

Optical rotation: $[\alpha]_D^{20}$ = +34.0 (*c* 1.5, $CHCl_3$, 86% *ee*).

The enantiomeric ratio of (*S*)-**90e** was determined by HPLC analysis on a chiral stationary phase (*Daicel Chiralcel* OD-H column, column temperature 20 °C, solvent: *n*heptane/*i*PrOH = 99.5/0.5, flow rate = 0.3 mL/min): t_R = 38.7 min (minor), t_S = 46.6 min (major).



(*S*)-**90f**
$C_{24}H_{25}NO_2Si$
M = 387.55 g/mol

(*S*)-2-(2-(Dimethyl(phenyl)silyl)-2-(4-methoxyphenyl)ethyl)benzoxazole [(*S*)-**90f**): Synthesized from (*E*)-2-(4-methoxystyryl)benzoxazole [(*E*)-**89f**, 37.7 mg, 0.150 mmol, 1.00 equiv] according to **GP 1.4**. Purification by flash column chromatography on silica gel with cyclohexane/EtOAc = 30/1 as eluent delivered (*S*)-**90f** as a yellow oil (26.0 mg, 45% yield).

R_f = 0.50 (cyclohexane/EtOAc = 10/1).

^{1}H NMR (500 MHz, $CDCl_3$, 298 K): δ 0.23 (s, 3H, SiC*H*$_3$), 0.30 (s, 3H, SiC*H*$_3$), 3.04 (dd, $^3J_{2,1A}$ = 10.6 Hz, $^3J_{2,1B}$ = 6.2 Hz, 1H, H-2), 3.25–3.35 (m, 2H, H-1), 3.73 (s, 3H, OC*H*$_3$), 6.71 (d, $^3J_{3",2"}$ = 8.6 Hz, 2H, H-3"), 6.92 (d, $^3J_{2",3"}$ = 8.6 Hz, 2H, H-2"), 7.17–7.23 (m, 2H, Ar), 7.27–7.36 (m, 4H, Ar, H-3'" and H-4'"), 7.41–7.44 (m, 2H, H-2'"), 7.53–7.56 (m, 1H, Ar) ppm.

^{13}C NMR (125 MHz, $CDCl_3$, 298 K): δ −5.5 (Si*C*H$_3$), −4.0 (Si*C*H$_3$), 29.6 (C-1), 33.0 (C-2), 55.1 (O*C*H$_3$), 110.1 (Ar), 113.6 (C-3"), 119.4 (Ar), 123.8 (Ar), 124.1 (Ar), 127.7 (C-3'"), 128.5 (C-2"), 129.2 (C-4'"), 132.9 (C-1"), 134.1 (C-2'"), 136.3 (C-1'"), 141.2 (C-3a or C-7a), 150.6 (C-3a or C-7a), 157.2 (C-4"), 166.6 (C-2') ppm.

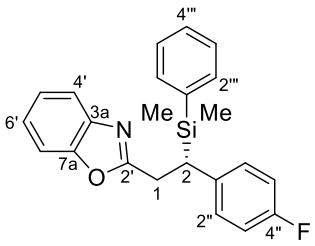
^{29}Si DEPT NMR (99 MHz, $CDCl_3$, 298 K): δ −1.1 (*Si*Me$_2$Ph) ppm.

HRMS (APCI) m/z: $[M+H]^+$ calcd for $C_{24}H_{26}ClNOSi$ 388.1727, found 388.1724.

IR (ATR): ṽ 694, 731, 836, 914, 1027, 1109, 1241, 1424, 1563, 2956, 3049 cm^{-1}.

Optical rotation: $[\alpha]_D^{20}$ = +50.1 (*c* 0.6, $CHCl_3$, 91% *ee*).

The enantiomeric ratio of (*S*)-**90f** was determined by HPLC analysis on a chiral stationary phase (*Daicel Chiralcel* OD-H column, column temperature 20 °C, solvent: *n*heptane/*i*PrOH = 99.5/0.5, flow rate = 0.6 mL/min): t_R = 81.4 min (minor), t_S = 91.0 min (major).



(*S*)-**90g**
$C_{23}H_{22}FNOSi$
M = 375.52 g/mol

(*S*)-2-(2-(Dimethyl(phenyl)silyl)-2-(4-fluorophenyl)ethyl)benzoxazole [(*S*)-**90g**]: Synthesized from (*E*)-2-(4-fluorostyryl)benzoxazole [(*E*)-**89g**, 35.9 mg, 0.150 mmol, 1.00 equiv) according to **GP 1.4**. Purification by flash column chromatography on silica gel with cyclohexane/EtOAc = 30/1 as eluent delivered (*S*)-**90g** as a white solid (28.9 mg, 51% yield).

R_f = 0.50 (cyclohexane/EtOAc = 10/1).

M.P. 87–88 °C.

^{1}H NMR (500 MHz, $CDCl_3$, 298 K): δ 0.26 (s, 3H, SiCH_3), 0.30 (s, 3H, SiCH_3), 3.08 (dd, $^3J_{2,1A}$ = 9.5 Hz, $^3J_{2,1B}$ = 7.2 Hz, 1H, H-2), 3.29–3.33 (m, 2H, H-1), 6.82–6.87 (m, 2H, H-3"), 6.91–6.96 (m, 2H, H-2"), 7.20–7.23 (m, 2H, Ar), 7.30–7.35 (m, 4H, Ar, H-3'" and H-4'"), 7.39–7.42 (m, 2H, H-2'"), 7.53–7.56 (m, 1H, Ar) ppm.

^{13}C NMR (125 MHz, $CDCl_3$, 298 K): δ −5.5 (SiCH$_3$), −4.2 (SiCH$_3$), 29.5 (C-1), 33.4 (C-2), 110.1 (Ar), 114.9 ($^2J_{C,F}$ = 21.0 Hz, C-3"), 119.5 (Ar), 123.9 (Ar), 124.3 (Ar), 127.8 (C-3'"), 128.8 ($^3J_{C,F}$ = 7.5 Hz, C-2"), 129.4 (C-4'"), 134.1 (C-2'"), 135.8 (C-1'"), 136.6 ($^4J_{C,F}$ = 2.8 Hz, C-4"), 141.2 (C-3a or C-7a), 150.6 (C-3a or C-7a), 160.7 ($^1J_{C,F}$ = 241.6 Hz, C-4"), 166.3 (C-2') ppm.

^{29}Si DEPT NMR (99 MHz, $CDCl_3$, 298 K): δ −0.9 (*Si*Me_2Ph) ppm.

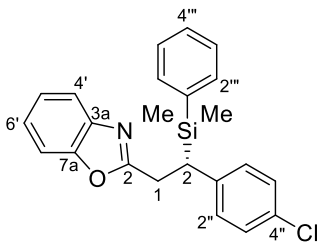
^{19}F NMR (471 MHz, $CDCl_3$, 298 K): δ −118.4 (Ar*F*) ppm.

HRMS (APCI) m/z: $[M+H]^+$ calcd for $C_{23}H_{23}FNOSi$ 376.1527, found 376.1529.

IR (ATR): ṽ 693, 731, 835, 932, 1094, 1116, 1242, 1428, 1564, 2952, 3049 cm^{-1}.

Optical rotation: $[\alpha]_D^{20}$ = +26.9 (*c* 0.4, $CHCl_3$, 80% *ee*).

The enantiomeric ratio of (*S*)-**90g** was determined by HPLC analysis on a chiral stationary phase (*Daicel Chiralcel* AD-H column, column temperature 20 °C, solvent: *n*heptane/*i*PrOH = 99.5/0.5, flow rate = 0.6 mL/min): t_S = 66.8 min (major), t_R = 80.4 min (minor).



(*S*)-**90h**
$C_{23}H_{22}ClNOSi$
M = 391.97 g/mol

(*S*)-2-(2-(4-Chlorophenyl)-2-(dimethyl(phenyl)silyl)ethyl)benzoxazole [(*S*)-**90h**): Synthesized from (*E*)-2-(4-chlorostyryl)benzoxazole [(*E*)-**89h**, 38.3 mg, 0.150 mmol, 1.00 equiv] according to **GP 1.4**. Purification through flash column chromatography on silica gel with cyclohexane/EtOAc = 30/1 as eluent delivered (*S*)-**90h** as a yellow solid (25.9 mg, 61% yield).

R_f = 0.50 (cyclohexane/EtOAc = 10/1).

M.**P**. 62–63 °C.

^{1}H NMR (500 MHz, $CDCl_3$, 298 K): δ 0.26 (s, 3H, SiCH_3), 0.30 (s, 3H, SiCH_3), 3.08 (dd, $^3J_{2,1A}$ = 10.2 Hz, $^3J_{2,1B}$ = 6.5 Hz, 1H, H-2), 3.27–3.34 (m, 2H), 6.92 (d, *J* = 8.5 Hz, 2H, H-2"), 7.12 (d, *J* = 8.5 Hz, 2H, H-3"), 7.20–7.23 (m, 2H, Ar), 7.29–7.38 (m, 4H, Ar, H-3"' and H-4"'), 7.39–7.42 (m, 2H, H-2"'), 7.53–7.56 (m, 1H, Ar) ppm.

^{13}C NMR (125 MHz, $CDCl_3$, 298 K): δ −5.5 (Si*C*H_3), −4.2 (Si*C*H_3), 29.2 (C-1), 33.7 (C-2), 110.1 (Ar), 119.5 (Ar), 123.9 (Ar), 124.3 (Ar), 127.8 (C-3"'), 128.2 (C-3"), 128.9 (C-2"), 129.5 (C-4"'), 130.7 (C-4"), 134.1 (C-2"'), 135.6 (C-1"'), 139.6 (C-1"), 141.1 (C-3a or C-7a), 150.6 (C-3a or C-7a), 166.2 (C-2') ppm.

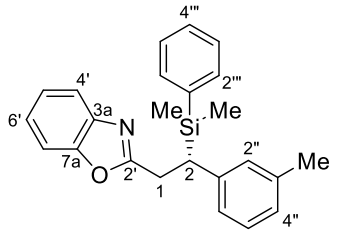
^{29}Si DEPT NMR (99 MHz, $CDCl_3$, 298 K): δ −0.8 (*Si*Me_2Ph) ppm.

HRMS (APCI) m/z: $[M+H]^+$ calcd for $C_{23}H_{23}ClNOSi$ 392.1232, found 392.1238.

IR (ATR): ṽ 697, 732, 812, 927, 1091, 1114, 1242, 1453, 1564, 2955, 3049 cm^{-1}.

Optical rotation: $[\alpha]_D^{20}$ = +38.9 (*c* 1.1, $CHCl_3$, 62% *ee*).

The enantiomeric ratio of (*S*)-**90h** was determined by HPLC analysis on a chiral stationary phase (*Daicel Chiralcel* AD-H column, column temperature 20 °C, solvent: *n*heptane/*i*PrOH = 99.5/0.5, flow rate = 0.3 mL/min): t_R = 72.1 min (minor), t_S = 76.2 min (major).



(*S*)-**90i**
$C_{24}H_{25}NOSi$
M = 371.56 g/mol

(*S*)-2-(2-(Dimethyl(phenyl)silyl)-2-(*m*-tolyl)ethyl)benzoxazole [(*S*)-**90i**): Synthesized from (*E*)-2-(3-methylstyryl)benzoxazole [(*E*)-**89i**, 35.3 mg, 0.150 mmol, 1.00 equiv) according to **GP 1.4**. Purification by flash column chromatography on silica gel with cyclohexane/EtOAc = 30/1 as eluent delivered (*S*)-**90i** as a brown solid (43.0 mg, 77% yield).

R_f = 0.50 (cyclohexane/EtOAc = 10/1).

M.**P**. 58–59 °C.

^{1}H NMR (500 MHz, $CDCl_3$, 298 K): δ 0.23 (s, 3H, SiCH_3), 0.30 (s, 3H, SiCH_3), 2.23 (s, 3H, CH_3), 3.08 (dd, $^3J_{2,1A}$ = 10.6 Hz, $^3J_{2,1A}$ = 5.9 Hz, 1H, H-2), 3.27–3.40 (m, 2H, H-1), 6.79 (s, 1H, H-2"), 6.84 (d, $^3J_{6",5"}$ = 7.7 Hz, 1H, H-6"), 6.87 (d, $^3J_{4",5"}$ = 7.5 Hz, 1H, H-4"), 7.04–7.09 (m, 1H, H-5'), 7.18–7.24 (m, 2H, Ar), 7.27–7.35 (m, 4H, Ar, H-3''' and H-4'''), 7.40–7.43 (m, 2H, H-2'''), 7.54–7.57 (m, 1H, Ar) ppm.

^{13}C NMR (125 MHz, $CDCl_3$, 298 K): δ −5.6 (SiCH$_3$), −4.0 (SiCH$_3$), 21.3 (CH$_3$), 29.4 (C-1), 33.8 (C-2), 110.1 (Ar), 119.4 (Ar), 123.8 (Ar), 124.1 (Ar), 124.6 (C-6"), 125.8 (C-4"), 127.6 (C-3'''), 127.9 (C-5"), 128.6 (C-2"), 129.2 (C-4'''), 134.1 (C-2'''), 136.2 (C-1'''), 137.4 (C-3"), 141.0 (C-1"), 141.3 (C-3a or C-7a), 150.6 (C-3a or C-7a), 166.6 (C-2') ppm.

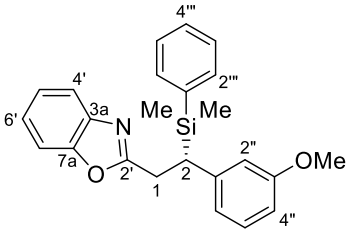
^{29}Si DEPT NMR (99 MHz, $CDCl_3$, 298 K): δ −1.0 ppm.

HRMS (APCI) m/z: $[M+H]^+$ calcd for $C_{24}H_{26}NOSi$ 372.1778, found 372.1782.

IR (ATR): ṽ 696, 732, 835, 926, 1031, 1110, 1241, 1452, 1564, 2952, 3051 cm^{-1}.

Optical rotation: $[\alpha]_D^{20}$ = +18.1 (*c* 2.1, $CHCl_3$, 76% *ee*).

The enantiomeric ratio of (*S*)-**90i** was determined by HPLC analysis on a chiral stationary phase (*Daicel Chiralcel* OD-H column, column temperature 20 °C, solvent: *n*heptane/*i*PrOH = 99.5/0.5, flow rate = 0.3 mL/min): t_R = 43.3 min (minor), t_S = 46.5 min (major).



(*S*)-**90j**
$C_{24}H_{25}NO_2Si$
M = 387.55 g/mol

(*S*)-2-(2-(Dimethyl(phenyl)silyl)-2-(3-methoxyphenyl)ethyl)benzoxazole [(*S*)-**90j**]: Synthesized from (*E*)-2-(3-methoxystyryl)benzoxazole [(*E*)-**89j**, 37.7 mg, 0.150 mmol, 1.00 equiv] according to **GP 1.4**. Purification by flash column chromatography on silica gel with cyclohexane/EtOAc = 30/1 as eluent delivered (*S*)-**90j** as a yellow oil (40.6 mg, 70% yield).

R_f = 0.50 (cyclohexane/EtOAc = 10/1).

^{1}H NMR (500 MHz, $CDCl_3$, 298 K): δ 0.25 (s, 3H, SiC*H*$_3$), 0.32 (s, 3H, SiC*H*$_3$), 3.10 (dd, $^3J_{2,1A}$ = 10.6 Hz, $^3J_{2,1B}$ = 5.9 Hz, 1H, H-2), 3.27–3.40 (m, 2H, H-1), 3.66 (s, 3H, OC*H*$_3$), 6.51 (s, 1H, H-2"), 6.59–6.62 (m, 1H, H-4"), 6.64 (d, $^3J_{6",5"}$ = 5.2 Hz, 1H, H-6"), 7.06–7.11 (m, 1H, H-5"), 7.19–7.23 (m, 2H, Ar), 7.27–7.33 (m, 3H H-3''' and H-4'''), 7.33–37.36 (m, 1H, Ar), 7.40–7.44 (m, 2H, H-2'''), 7.54–7.57 (m, 1H, Ar) ppm.

^{13}C NMR (125 MHz, $CDCl_3$, 298 K): δ −5.5 (Si*C*H$_3$), −4.0 (Si*C*H$_3$), 29.4 (C-1), 34.2 (C-2), 54.9 (O*C*H$_3$), 110.1 (Ar), 110.8 (C-4"), 113.3 (C-2"), 119.4 (Ar), 120.8 (C-6"), 123.8 (Ar), 124.2 (Ar), 127.7 (C-3'''), 129.0 (C-5"), 129.3 (C-4'''), 134.1 (C-2'''), 136.2 (C-1'''), 141.2 (C-3a or C-7a), 142.8 (C-1"), 150.6 (C-3a or C-7a), 159.3 (C-3"), 166.5 (C-2') ppm.

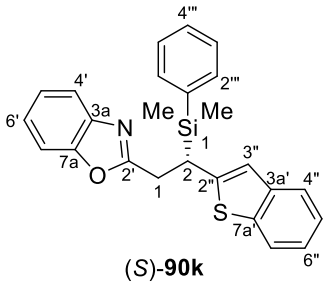
^{29}Si DEPT NMR (99 MHz, $CDCl_3$, 298 K): δ −0.9 (*Si*Me$_2$Ph) ppm.

HRMS (APCI) m/z: $[M+H]^+$ calcd for $C_{24}H_{26}NO_2Si$ 388.1727, found 388.1731.

IR (ATR): ṽ 695, 745, 837, 928, 1025, 1112, 1241, 1452, 1571, 2956, 3064 cm^{-1}.

Optical rotation: $[\alpha]_D^{20}$ = +19.1 (*c* 1.0, $CHCl_3$, 75% *ee*).

The enantiomeric ratio of (*S*)-**90j** was determined by HPLC analysis on a chiral stationary phase (*Daicel Chiralcel* OD-H column, column temperature 20 °C, solvent: *n*heptane/*i*PrOH = 99.5/0.5, flow rate 0.3 mL/min): t_R = 50.4 min (minor), t_S = 52.7 min (major).



(*S*)-**90k**
$C_{25}H_{23}NOSSi$
M = 413.61 g/mol

(*S*)-2-(2-(Benzothiophen-2-yl)-2-(dimethyl(phenyl)silyl)ethyl)benzoxazole [(*S*)-**90k**]: Synthesized from (*E*)-2-(2-(benzothiophen-2-yl)vinyl)benzoxazole [(*E*)-**89k**, 41.6 mg, 0.150 mmol, 1.00 equiv] according to **GP 1.4**. Purification by flash column chromatography on silica gel with cyclohexane/EtOAc = 30/1 as eluent delivered (*S*)-**90k** as a yellow solid (49.4 mg, 80% yield).

R_f = 0.50 (cyclohexane/EtOAc = 10/1).

M.**P**. 123–124 °C.

^{1}H NMR (500 MHz, $CDCl_3$, 298 K): δ 0.37 (s, 3H, SiCH_3), 0.45 (s, 3H, SiCH_3), 3.34–3.43 (m, 2H, H-1), 3.49 (dd, $^3J_{2,1A}$ = 10.3 Hz, $^3J_{2,1B}$ = 5.7 Hz, 1H, H-2), 6.86 (s, 1H, H-3"), 7.17–7.22 (m, 3H, Ar), 7.23–7.27 (m, 1H, Ar), 7.30–7.37 (m, 4H, Ar, H-3''' and H-4'''), 7.50–7.53 (m, 2H, H-2'''), 7.54–7.59 (m, 2H, H-4"), 7.68 (d, *J* = 8.0 Hz, 1H, Ar) ppm.

^{13}C NMR (125 MHz, $CDCl_3$, 298 K): δ −5.5 (SiCH$_3$), −3.8 (SiCH$_3$), 30.4 (C-2), 30.9 (C-1), 110.2 (Ar), 119.5 (Ar), 119.7 (C-3"), 121.8 (Ar), 122.4 (C-4"), 123.0 (Ar), 123.9 (Ar), 124.3 (Ar), 127.9 (C-3'''), 129.5 (C-4'''), 134.0 (C-2'''), 135.6 (C-1'''), 138.5 (C-3a' or C-7a'), 140.2 (C-3a' or C-7a'), 141.2 (C-3a or C-7a), 145.9 (C-2"), 150.6 (C-3a or C-7a), 165.8 (C-2') ppm. A signal for carbon overlaps with others.

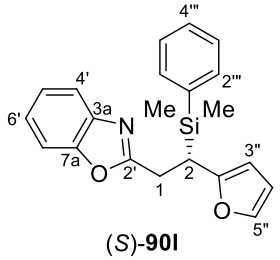
^{29}Si DEPT NMR (99 MHz, $CDCl_3$, 298 K): δ −0.4 (*Si*Me$_2$Ph) ppm.

HRMS (APCI) m/z: $[M+H]^+$ calcd for $C_{25}H_{24}NOSSi$ 414.1342, found 414.1346.

IR (ATR): ṽ 696, 732, 839, 928, 1017, 1114, 1238, 1452, 1566, 2962, 3048 cm^{-1}.

Optical rotation: $[\alpha]_D^{20}$ = +56.5 (*c* 1.0, $CHCl_3$, 70% *ee*).

The enantiomeric ratio of (*S*)-**90k** was determined by HPLC analysis on a chiral stationary phase (*Daicel Chiralcel* OD-H column, column temperature 20 °C, solvent: *n*heptane/*i*PrOH = 95/5, flow rate = 0.6 mL/min): t_R = 10.5 min (minor), t_S = 12.0 min (major).



(*S*)-**90l**
$C_{21}H_{21}NO_2Si$
M = 347.49 g/mol

(*S*)-2-(2-(Dimethyl(phenyl)silyl)-2-(furan-2-yl)ethyl)benzoxazole [(*S*)-**90l**]: Synthesized from (*E*)-2-(4-methoxystyryl)benzoxazole [(*E*)-**89l**, 31.7 mg, 0.150 mmol, 1.00 equiv] according to **GP 1.4**. Purification by flash column chromatography on silica gel with cyclohexane/EtOAc = 30/1 as eluent delivered (*S*)-**90l** as a brown oil (32.2 mg, 62% yield).

$\mathbf{R_f}$ = 0.50 (cyclohexane/EtOAc = 10/1).

^{1}H NMR (500 MHz, $CDCl_3$, 298 K): δ 0.31 (s, 3H, SiCH_3), 0.39 (s, 3H, SiCH_3), 3.14–3.23 (m, 2H, H-1A and H-2), 3.29 (dd, $^3J_{1B,2}$ = 13.5 Hz, $^2J_{1B,1A}$ = 9.6 Hz, 1H, H-1B), 5.84 (d, $^3J_{3",4"}$ = 3.2 Hz, 1H, H-3"), 6.19 (dd, $^3J_{4",3"}$ = 3.2 Hz, $^3J_{4",5"}$ = 1.9 Hz, 1H, H-4"), 7.22–7.24 (m, 1H, Ar), 7.24–7.25 (m, 2H, Ar and H-5"), 7.30–7.33 (m, 3H, H-3''' and H-4'''), 7.35–7.38 (m, 1H, Ar), 7.45–7.48 (m, 2H, H-2'''), 7.57–7.60 (m, 1H, Ar) ppm.

^{13}C NMR (125 MHz, $CDCl_3$, 298 K): δ −5.2 (Si*C*H_3), −3.8 (Si*C*H_3), 27.5 (C-2), 28.3 (C-1), 104.7 (C-3"), 110.2 (Ar), 110.3 (C-4"), 119.5 (Ar), 123.9 (Ar), 124.3 (Ar), 127.8 (C-3'''), 129.3 (C-4'''), 133.9 (C-2'''), 136.1 (C-1'''), 140.6 (C-5"), 141.3 (C-3a or C-7a), 150.7 (C-3a or C-7a), 155.3 (C-1"), 166.3 (C-2') ppm.

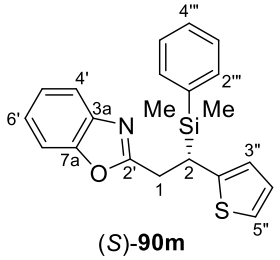
^{29}Si DEPT NMR (99 MHz, $CDCl_3$, 298 K): δ −0.3 (*Si*Me_2Ph) ppm.

HRMS (APCI) m/z: $[M+H]^+$ calcd for $C_{21}H_{22}NO_2Si$ 348.1414, found 348.1411.

IR (ATR): ṽ 697, 728, 833, 927, 1003, 1114, 1242, 1453, 1568, 2954, 3048 cm^{-1}.

Optical rotation: $[\alpha]_D^{20}$ = +25.2 (*c* 1.3, $CHCl_3$, 75% *ee*).

The enantiomeric ratio of (*S*)-**90l** was determined by HPLC analysis on a chiral stationary phase (*Daicel Chiralcel* AD-H column, column temperature 20 °C, solvent: *n*heptane/*i*PrOH = 99.5/0.5, flow rate = 0.3 mL/min): t_S = 56.1 min (major), t_R = 60.6 min (minor).



(*S*)-**90m**
$C_{21}H_{21}NOSSi$
M = 363.55 g/mol

(*S*)-2-(2-(Dimethyl(phenyl)silyl)-2-(thiophen-2-yl)ethyl)benzoxazole [(*S*)-**90m**): Synthesized from (*E*)-2-(2-(thiophen-2-yl)vinyl)benzoxazole [(*E*)-**89m**, 34.1 mg, 0.150 mmol, 1.00 equiv] according to **GP 1.4**. Purification by flash column chromatography on silica gel with cyclohexane/EtOAc = 30/1 as eluent delivered (*S*)-**90m** as a brown solid (40.7 mg, 75% yield).

R_f = 0.50 (cyclohexane/EtOAc = 10/1).

M.**P**. 62–63 °C.

^{1}H NMR (500 MHz, $CDCl_3$, 298 K): δ 0.31 (s, 3H, SiCH_3), 0.41 (s, 3H, SiCH_3), 3.29–3.33 (m, 2H, H-1), 3.43 (dd, $^3J_{2,1A}$ = 9.6 Hz, $^3J_{2,1B}$ = 6.6 Hz, 1H, H-2), 6.62–6.64 (d, $^3J_{3",4"}$ = 3.5 Hz, 1H, H-3"), 6.82 (dd, $^3J_{4",5"}$ = 5.1 Hz, $^3J_{4",3"}$ = 3.5 Hz, 1H, H-4"), 6.95–6.98 (d, $^3J_{5",4"}$ = 5.1 Hz, 1H, H-5"), 7.20–7.25 (m, 2H, Ar), 7.30–7.34 (m, 3H, H-3''' and H-4'''), 7.34–7.38 (m, 1H, Ar), 7.46–7.49 (m, 2H, H-2'''), 7.56–7.59 (m, 1H, Ar) ppm.

^{13}C NMR (125 MHz, $CDCl_3$, 298 K): δ −5.6 (Si*C*H_3), −4.0 (Si*C*H_3), 29.4 (C-2), 31.3 (C-1), 110.1 (Ar), 119.5 (Ar), 121.9 (C-5"), 123.4 (C-3"), 123.9 (Ar), 124.3 (Ar), 126.7 (C-4"), 127.7 (C-3'''), 129.4 (C-4'''), 134.0 (C-2'''), 135.9 (C-1'''), 141.2 (C-3a or C-7a), 144.5 (C-2"), 150.6 (C-3a or C-7a), 166.0 (C-2') ppm.

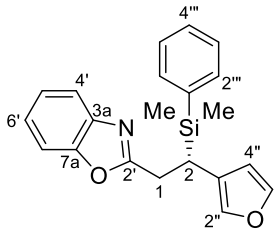
^{29}Si DEPT NMR (99 MHz, $CDCl_3$, 298 K): δ −0.9 (*Si*Me_2Ph) ppm.

HRMS (APCI) m/z: $[M+H]^+$ calcd for $C_{21}H_{22}NOSSi$ 364.1186, found 364.1189.

IR (ATR): ṽ 687, 740, 832, 927, 1000, 1108, 1239, 1452, 1568, 2952, 3066 cm^{-1}.

Optical rotation: $[\alpha]_D^{20}$ = +8.10 (*c* 1.9, $CHCl_3$, 82% *ee*).

The enantiomeric ratio of (*S*)-**90m** was determined by HPLC analysis on a chiral stationary phase (*Daicel Chiralcel* OD-H column, column temperature 20 °C, solvent: *n*heptane/*i*PrOH = 99.5/0.5, flow rate = 0.3 mL/min): t_R = 51.9 min (minor), t_S = 56.0 min (major).



(*S*)-**90n**
$C_{21}H_{21}NO_2Si$
M = 347.49 g/mol

(*S*)-2-(2-(Dimethyl(phenyl)silyl)-2-(furan-3-yl)ethyl)benzoxazole [(*S*)-**90n**]: Synthesized from (*E*)-2-(2-(furan-3-yl)vinyl)benzoxazole [(*E*)-**89n**, 31.7 mg, 0.150 mmol, 1.00 equiv] according to **GP 1.4**. Purification by flash column chromatography on silica gel with cyclohexane/EtOAc = 30/1 as eluent delivered (*S*)-**90n** as a brown oil (40.9 mg, 79% yield).

R_f = 0.50 (cyclohexane/EtOAc = 10/1).

^{1}H NMR (400 MHz, $CDCl_3$, 298 K): δ 0.31 (s, 3H, SiCH_3), 0.36 (s, 3H, SiCH_3), 2.96 (dd, $^3J_{2,1A}$ = 10.9 Hz, $^3J_{2,1B}$ = 5.4 Hz, 1H, H-2), 3.10–3.25 (m, 2H, H-1), 6.10 (d, $^3J_{4",5"}$ = 1.0 Hz, 1H, H-4"), 7.07 (s, 1H, H-2"), 7.21–7.25 (m, 3H, Ar and H-5"), 7.30–7.36 (m, 3H, H-3''' and H-4'''), 7.36–7.40 (m, 1H, Ar), 7.46–7.50 (m, 2H, H-2'''), 7.55–7.60 (m, 1H, Ar) ppm.

^{13}C NMR (125 MHz, $CDCl_3$, 298 K): δ −5.4 (SiCH_3), −4.3 (SiCH_3), 23.7 (C-2), 29.6 (C-1), 110.2 (Ar), 110.6 (C-4"), 119.4 (Ar), 123.9 (Ar), 124.0 (C-3"), 124.3 (Ar), 127.8 (C-3'''), 129.3 (C-4'''), 134.0 (C-2'''), 136.2 (C-1'''), 138.3 (C-2"), 141.2 (C-3a or C-7a), 142.4 (C-5"), 150.6 (C-3a or C-7a), 166.6 (C-2') ppm.

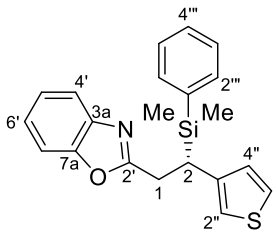
^{29}Si DEPT NMR (99 MHz, $CDCl_3$, 298 K): δ −1.1 (*Si*Me_2Ph) ppm.

HRMS (APCI) m/z: $[M+H]^+$ calcd for $C_{21}H_{22}NO_2Si$ 348.1414, found 348.1422.

IR (ATR): ṽ 697, 739, 830, 931, 1025, 1114, 1242, 1453, 1565, 2955, 3048 cm^{-1}.

Optical rotation: $[\alpha]_D^{20}$ = +28.3 (*c* 1.1, $CHCl_3$, 72% *ee*).

The enantiomeric ratio of (*S*)-**90n** was determined by HPLC analysis on a chiral stationary phase (*Daicel Chiralcel* AD-H column, column temperature 20 °C, solvent: *n*heptane/*i*PrOH = 99.5/0.5, flow rate = 0.3 mL/min): t_S = 42.3 min (major), t_R = 48.2 min (minor).



(*S*)-**90o**
$C_{21}H_{21}NOSSi$
M = 363.55 g/mol

(*S*)-2-(2-(Dimethyl(phenyl)silyl)-2-(thiophen-3-yl)ethyl)benzoxazole [(*S*)-**90o**): Synthesized from (*E*)-2-(2-(thiophen-3-yl)vinyl)benzoxazole [(*E*)-**89o**, 34.1 mg, 0.150 mmol, 1.00 equiv] according to **GP 1.4**. Purification by flash column chromatography on silica gel with cyclohexane/EtOAc = 30/1 delivered (*S*)-**90o** as a yellow solid (48.1 mg, 88% yield).

$\mathbf{R_f}$ = 0.50 (cyclohexane/EtOAc = 10/1).

M.**P**. 74–75 °C.

^{1}H NMR (400 MHz, $CDCl_3$, 298 K): δ 0.27 (s, 3H, SiCH_3), 0.32 (s, 3H, SiCH_3), 3.23–3.31 (m, 3H, H-1 and H-2), 6.71–6.73 (dd, $^4J_{2",5"}$ = 3.0 Hz, $^4J_{2",4"}$ = 1.3 Hz, 1H, H-2"), 6.75–6.78 (dd, $^3J_{4",5"}$ = 5.0 Hz, $^4J_{4",2"}$ = 1.3 Hz, 1H, H-4"), 7.13 (dd, $^3J_{5",4"}$ = 5.0 Hz, $^4J_{5",2"}$ = 3.0 Hz, 1H, H-5"), 7.20–7.24 (m, 2H, Ar), 7.28–7.34 (m, 3H, H-3''' and H-4'''), 7.34–7.37 (m, 1H, Ar), 7.40–7.44 (m, 2H, H-2'''), 7.54–7.58 (m, 1H, Ar) ppm.

^{13}C NMR (125 MHz, $CDCl_3$, 298 K): δ −5.4 (Si*C*H_3), −4.1 (Si*C*H_3), 29.7 (C-2), 29.9 (C-1), 110.1 (Ar), 118.7 (C-2"), 119.5 (Ar), 123.9 (Ar), 124.2 (Ar), 124.8 (C-5"), 127.7 (C-4" and C-3'''), 129.3 (C-4'''), 134.0 (C-2'''), 136.1 (C-1'''), 141.2 (C-3a or C-7a and C-3"), 150.6 (C-3a or C-7a), 166.5 (C-2') ppm.

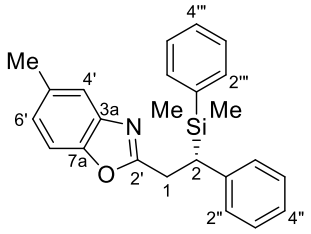
^{29}Si DEPT NMR (99 MHz, $CDCl_3$, 298 K): δ −1.2 (*Si*Me_2Ph) ppm.

HRMS (APCI) m/z: $[M+H]^+$ calcd for $C_{21}H_{22}NOSSi$ 364.1186, found 364.1194.

IR (ATR): ṽ 694, 745, 824, 932, 1021, 1115, 1244, 1453, 1563, 2949, 3078 cm^{-1}.

Optical rotation: $[\alpha]_D^{20}$ = +32.3 (*c* 1.1, $CHCl_3$, 90% *ee*).

The enantiomeric ratio of (*S*)-**90o** was determined by HPLC analysis on a chiral stationary phase (*Daicel Chiralcel* OD-H column, column temperature 20 °C, solvent: *n*heptane/*i*PrOH = 99.5/0.5, flow rate = 0.3 mL/min): t_R = 36.7 min (minor), t_S = 39.0 min (major).



(*S*)-**90p**
$C_{24}H_{25}NOSi$
M = 371.56 g/mol

(*S*)-2-(2-(Dimethyl(phenyl)silyl)-2-phenylethyl)-5-methylbenzoxazole [(*S*)-**90p**]: Synthesized from (*E*)-5-methyl-2-styrylbenzoxazole [(*E*)-**89p**, 35.3 mg, 0.150 mmol, 1.00 equiv] according to **GP 1.4**. Purification by flash column chromatography on silica gel with cyclohexane/EtOAc = 30/1 as eluent delivered (*S*)-**90p** as a yellow solid (45.4 mg, 82% yield).

R_f = 0.50 (cyclohexane/EtOAc = 10/1).

M.**P**. 52–53 °C.

^{1}H NMR (500 MHz, $CDCl_3$, 298 K): δ 0.23 (s, 3H, SiC*H*$_3$), 0.29 (s, 3H, SiC*H*$_3$), 2.39 (s, 3H, ArC*H*$_3$), 3.09 (dd, $^3J_{2,1A}$ = 10.9 Hz, $^3J_{2,1B}$ = 5.7 Hz, 1H, H-2), 3.25–3.40 (m, 2H, H-1), 6.98–7.02 (m, 3H, H-6', and H-2"), 7.02–7.06 (m, 1H, H-4"), 7.13–7.17 (m, 2H, H-3"), 7.20 (d, *J* = 8.3 Hz, 1H, H-7'), 7.27–7.35 (m, 4H, H-4', H-3''' and H-4'''), 7.40–7.43 (m, 2H, H-2''') ppm.

^{13}C NMR (125 MHz, $CDCl_3$, 298 K): δ −5.5 (Si*C*H$_3$), −4.0 (Si*C*H$_3$), 21.3 (Ar*C*H$_3$), 29.4 (C-1), 34.0 (C-2), 109.5 (C-7), 119.4 (C-4'), 125.0 (C-4"), 125.2 (C-6'), 127.6 (C-2" or C-3'"), 127.7

(C-2" or C-3'"), 128.1 (C-3"), 129.3 (C-4'"), 133.6 (C-5'), 134.1 (C-2'"), 136.2 (C-1'"), 141.1 (C-1"), 141.4 (C-3a), 148.8 (C-7a), 166.6 (C-2') ppm.

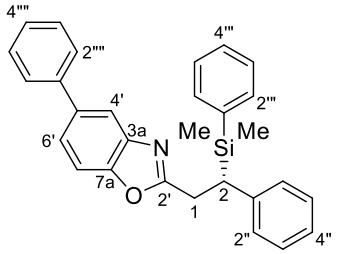
^{29}Si DEPT NMR (99 MHz, $CDCl_3$, 298 K): δ −0.9 (*Si*Me_2Ph) ppm.

HRMS (APCI) m/z: $[M+H]^+$ calcd for $C_{24}H_{26}NOSi$ 372.1778, found 372.1784.

IR (ATR): ṽ 696, 732, 833, 921, 1011, 1112, 1258, 1425, 1569, 2953, 3055 cm^{-1}.

Optical rotation: $[\alpha]_D^{20}$ = +21.7 (*c* 1.8, $CHCl_3$, 80% *ee*).

The enantiomeric ratio of (*S*)-**90p** was determined by HPLC analysis on a chiral stationary phase (*Daicel Chiralcel* OD-H column, column temperature 20 °C, solvent: *n*heptane/*i*PrOH = 95/5, flow rate = 0.6 mL/min): t_S = 9.0 min (major), t_R = 10.2 min (minor).



(*S*)-**90q**
$C_{29}H_{27}NOSi$
M = 433.63 g/mol

(*S*)-2-(2-(Dimethyl(phenyl)silyl)-2-phenylethyl)-5-phenylbenzoxazole [(*S*)-**90q**]: Synthesized from (*E*)-5-phenyl-2-styrylbenzoxazole [(*E*)-**89q**, 44.6 mg, 0.150 mmol, 1.00 equiv] according to **GP 1.4**. Purification by flash column chromatography on silica gel with cyclohexane/EtOAc = 30/1 as eluent delivered (*S*)-**90q** as a white solid (32.3 mg, 50% yield).

R_f = 0.50 (cyclohexane/EtOAc = 10/1).

M.**P**. 94–95 °C.

^{1}H NMR (500 MHz, $CDCl_3$, 298 K): δ 0.25 (s, 3H, SiC*H*$_3$), 0.32 (s, 3H, SiC*H*$_3$), 3.12 (dd, $^3J_{2,1A}$ = 10.8 Hz, $^3J_{2,1B}$ = 5.7 Hz, 1H, H-2), 3.30–3.43 (m, 2H, H-1), 7.02–7.08 (m, 3H, H-2" and H-4"), 7.15–7.20 (m, 2H, H-3"), 7.27–7.33 (m, 4H, Ar, H-3'" and H-4'"), 7.36–7.39 (m, 1H, Ar), 7.41–7.45 (m, 5H, Ar and H-2'"), 7.54–7.57 (m, 2H, C-2"" or C-3""), 7.72–7.74 (m, 1H, Ar) ppm.

^{13}C NMR (125 MHz, $CDCl_3$, 298 K): δ −5.6 (Si*C*H_3), −4.0 (Si*C*H_3), 29.5 (C-1), 34.1 (C-2), 110.1 (Ar), 118.0 (Ar), 123.8 (Ar), 125.1 (C-4''), 127.1 (Ar), 127.4 (Ar), 127.6 (C-2'''' or C-3'''), 127.7 (C-2'' or C-3'''), 128.1 (C-3''), 128.8 (Ar), 129.3 (C-4'''), 134.1 (C-2'''), 136.1 (C-1'''), 137.8 (C-1'''' or C-5'), 141.0 (C-1'' or Ar), 141.2 (C-1'' or Ar), 141.9 (Ar), 150.2 (Ar), 167.2 (C-2') ppm.

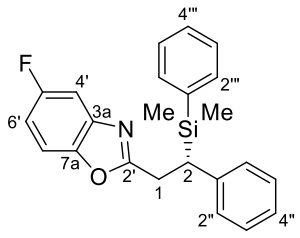
^{29}Si DEPT NMR (99 MHz, $CDCl_3$, 298 K): δ −0.9 (*Si*Me_2Ph) ppm.

HRMS (APCI) m/z: $[M+H]^+$ calcd for $C_{29}H_{28}NOSi$ 434.1935, found 434.1927.

IR (ATR): ṽ 697, 743, 833, 924, 1007, 1114, 1249, 1425, 1565, 2954, 3063 cm^{-1}.

Optical rotation: $[\alpha]_D^{20}$ = +18.9 (*c* 0.6, $CHCl_3$, 70% *ee*).

The enantiomeric ratio of (*S*)-**90q** was determined by HPLC analysis on a chiral stationary phase (*Daicel Chiralcel* OD-H column, column temperature 20 °C, solvent: *n*heptane/*i*PrOH = 90/10, flow rate = 0.6 mL/min): t_R = 37.9 min (minor), t_S = 50.0 min (major).



(*S*)-**90r**
$C_{23}H_{22}FNOSi$
M = 375.52 g/mol

(*S*)-2-(2-(Dimethyl(phenyl)silyl)-2-phenylethyl)-5-fluorobenzoxazole [(*S*)-**90r**]: Synthesized from (*E*)-5-fluoro-2-styrylbenzoxazole [(*E*)-**89r**, 35.9 mg, 0.150 mmol, 1.00 equiv] according to **GP 1.4**. Purification by flash column chromatography on silica gel with cyclohexane/EtOAc = 30/1 as eluent delivered (*S*)-**90r** as a white solid (39.4 mg, 70% yield).

R_f = 0.50 (cyclohexane/EtOAc = 10/1).

M.**P**. 79–80 °C.

^{1}H NMR (500 MHz, $CDCl_3$, 298 K): δ 0.23 (s, 3H, SiCH_3), 0.31 (s, 3H, SiCH_3), 3.08 (dd, $^3J_{2,1A}$ = 10.7 Hz, $^3J_{2,1B}$ = 5.9 Hz, 1H, H-2), 3.26–3.39 (m, 2H, H-1), 6.89–6.95 (m, 1H, H-6'), 7.00–

7.03 (m, 2H, H-2"), 7.04–7.09 (m, 1H, H-4"), 7.15–7.19 (m, 2H, H-3"), 7.19–7.23 (m, 2H, H-4' and H-7'), 7.26–7.33 (m, 3H, H-3'" and H-4'"), 7.39–7.42 (m, 2H, H-2'") ppm.

^{13}C NMR (125 MHz, $CDCl_3$, 298 K): δ −5.7 (Si*C*H$_3$), −4.0 (Si*C*H$_3$), 29.5 (C-1), 34.1 (C-2), 105.9 ($^2J_{C,F}$ = 29.1 Hz, C-4'), 110.3 ($^3J_{C,F}$ = 9.9 Hz, C-7'), 111.7 ($^2J_{C,F}$ = 26.2 Hz, C-6'), 125.2 (C-4"), 127.6 (C-2" or C-3'"), 127.7 (C-2" or C-3'"), 128.1 (C-3"), 129.3 (C-4'"), 134.0 (C-2'"), 136.0 (C-1'"), 141.0 (C-1"), 142.0 ($^3J_{C,F}$ = 13.0 Hz, C-3a), 146.9 (C-7a), 159.7 ($^1J_{C,F}$ = 238.2 Hz, C-5'), 168.4 (C-2') ppm.

^{29}Si DEPT NMR (99 MHz, $CDCl_3$, 298 K): δ −0.9 (*Si*Me$_2$Ph) ppm.

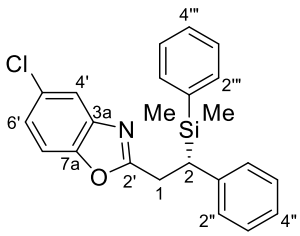
^{19}F NMR (471 MHz, $CDCl_3$, 298 K): δ −118.9 (Ar*F*) ppm.

HRMS (APCI) m/z: $[M+H]^+$ calcd for $C_{23}H_{23}FNOSi$ 376.1527, found 376.1532.

IR (ATR): ṽ 700, 834, 966, 1076, 1129, 1248, 1560, 1624, 2956, 3056 cm^{-1}.

Optical rotation: $[\alpha]_D^{20}$ = +18.9 (*c* 1.5, $CHCl_3$, 76% *ee*).

The enantiomeric ratio of (*S*)-**90r** was determined by HPLC analysis on a chiral stationary phase (*Daicel Chiralcel* OD-H column, column temperature 20 °C, solvent: *n*heptane/*i*PrOH = 99.5/0.5, flow rate = 0.3 mL/min): t_R = 31.9 min (minor), t_S = 34.6 min (major).



(*S*)-**90s**
$C_{23}H_{22}ClNOSi$
M = 391.97 g/mol

(*S*)-5-Chloro-2-(2-(dimethyl(phenyl)silyl)-2-phenylethyl)benzoxazole [(*S*)-**90s**]: Synthesized from (*E*)-5-chloro-2-styrylbenzoxazole [(*E*)-**89s**, 38.4 mg, 0.150 mmol, 1.00 equiv] according to **GP 1.4**. Purification by flash column chromatography on silica gel with cyclohexane/EtOAc = 30/1 as eluent delivered (*S*)-**90s** as a yellow oil (34.2 mg, 58% yield).

R$_f$ = 0.50 (cyclohexane/EtOAc = 10/1).

^{1}H NMR (500 MHz, $CDCl_3$, 298 K): δ 0.23 (s, 3H, SiCH_3), 0.31 (s, 3H, SiCH_3), 3.07 (dd, $^{3}J_{2,1A}$ = 10.8 Hz, $^{3}J_{2,1B}$ = 5.9 Hz, 1H, H-2), 3.26–3.40 (m, 2H, H-1), 7.00 (d, *J* = 7.3 Hz, 2H, H-2"), 7.04–7.08 (m, 1H, H-4"), 7.14–7.19 (m, 3H, Ar and H-3"), 7.23 (d, *J* = 8.7 Hz, 1H, Ar), 7.28–7.33 (m, 3H, H-3'" and H-4'"), 7.39–7.42 (m, 2H, H-2'"), 7.50 (d, *J* = 1.9 Hz, 1H, Ar) ppm.

^{13}C NMR (125 MHz, $CDCl_3$, 298 K): δ −5.7 (Si*C*H_3), −4.0 (Si*C*H_3), 29.5 (C-1), 34.1 (C-2), 110.8 (Ar), 119.5 (Ar), 124.5 (Ar), 125.2 (C-4"), 127.6 (C-2" or C-3'"), 127.7 (C-2" or C-3'"), 128.2, 129.3 (C-4'"), 129.4 (Ar), 134.0 (C-2'"), 136.0 (C-1'"), 140.9 (C-1"), 142.3 (Ar), 149.1 (Ar), 168.0 (C-2') ppm.

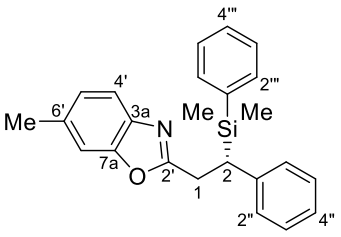
^{29}Si DEPT NMR (99 MHz, $CDCl_3$, 298 K): δ −0.9 (*Si*Me_2Ph) ppm.

HRMS (APCI) m/z: $[M+H]^+$ calcd for $C_{23}H_{23}ClNOSi$ 392.1232, found 392.1237.

IR (ATR): ṽ 697, 731, 838, 950, 1076, 1111, 1249, 1424, 1559, 2054, 3064 cm^{-1}.

Optical rotation: $[\alpha]_D^{20}$ = +16.0 (*c* 0.2, $CHCl_3$, 80% *ee*).

The enantiomeric ratio of (*S*)-**90s** was determined by HPLC analysis on a chiral stationary phase (*Daicel Chiralcel* AD-H column, column temperature 20 °C, solvent: *n*heptane/*i*PrOH = 99.5/0.5, flow rate = 0.3 mL/min): t_S = 52.6 min (major), t_R = 62.3 min (minor).



(*S*)-**90t**
$C_{24}H_{25}NOSi$
M = 371.56 g/mol

(*S*)-2-(2-(Dimethyl(phenyl)silyl)-2-phenylethyl)-6-methylbenzoxazole [(*S*)-**90t**): Synthesized from (*E*)-6-methyl-2-styrylbenzoxazole [(*E*)-**89t**, 35.3 mg, 0.150 mmol, 1.00 equiv] according to **GP 1.4**. Purification by flash column chromatography on silica gel with cyclohexane/EtOAc = 30/1 as eluent delivered (*S*)-**90t** as a white solid (40.5 mg, 73% yield).

R_f = 0.50 (cyclohexane/EtOAc = 10/1).

M.P. 63–64 °C.

^{1}H NMR (500 MHz, $CDCl_3$, 298 K): δ 0.23 (s, 3H, SiCH_3), 0.29 (s, 3H, SiCH_3), 2.41 (s, 3H, ArCH_3), 3.09 (dd, $^{3}J_{2,1A}$ = 10.9 Hz, $^{3}J_{2,1B}$ = 5.7 Hz, 1H, H-2), 3.25–3.39 (m, 2H, H-1), 6.99–7.07 (m, 4H, H-5', H-2" and H-4"), 7.13–7.18 (m, 3H, H-7', and H-3"), 7.27–7.36 (m, 3H, H-3'" and H-4'"), 7.39–7.43 (m, 3H, H-4' and H-2'") ppm.

^{13}C NMR (125 MHz, $CDCl_3$, 298 K): δ −5.5 (SiCH$_3$), −4.0 (SiCH$_3$), 21.6 (ArCH$_3$), 29.3 (C-1), 34.1 (C-2), 110.3 (C-7'), 118.7 (C-4'), 124.9 (C-5' or C-4"), 125.0 (C-5' or C-4"), 127.6 (C-2" or C-3'"), 127.7 (C-2" or C-3'"), 128.1 (C-3"), 129.2 (C-4'"), 134.1 (C-2'"), 134.5 (C-6'), 136.2 (C-1'"), 139.0 (C-3a), 141.1 (C-1"), 150.9 (C-7a), 166.0 (C-2') ppm.

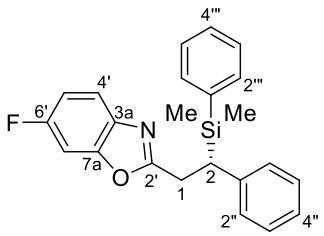
^{29}Si DEPT NMR (99 MHz, $CDCl_3$, 298 K): δ −0.9 (*Si*Me$_2$Ph) ppm.

HRMS (APCI) m/z: $[M+H]^+$ calcd for $C_{24}H_{26}NOSi$ 372.1778, found 372.1781.

IR (ATR): ṽ 696, 731, 834, 939, 1076, 1113, 1242, 1426, 1596, 2051, 3055 cm^{-1}.

Optical rotation: $[\alpha]_D^{20}$ = +26.8 (*c* 1.4, $CHCl_3$, 90% *ee*).

The enantiomeric ratio of (*S*)-**90t** was determined by HPLC analysis on a chiral stationary phase (*Daicel Chiralcel* OD-H column, column temperature 20 °C, solvent: *n*heptane/*i*PrOH = 95/5, flow rate = 0.6 mL/min): t_S = 10.3 min (major), t_R = 12.5 min (minor).



(*S*)-**90u**
$C_{23}H_{22}FNOSi$
M = 375.52 g/mol

(*S*)-2-(2-(Dimethyl(phenyl)silyl)-2-phenylethyl)-6-fluorobenzoxazole [(*S*)-**90u**]: Synthesized from (*E*)-6-fluoro-2-styrylbenzoxazole [(*E*)-**89u**, 35.9 mg, 0.150 mmol, 1.00 equiv] according to **GP 1.4**. Purification by flash column chromatography on silica gel with cyclohexane/EtOAc = 30/1 as eluent delivered (*S*)-**90u** as a white solid (43.0 mg, 76% yield).

R$_f$ = 0.50 (cyclohexane/EtOAc = 10/1).

M.**P**. 82–83 °C.

^{1}H NMR (500 MHz, $CDCl_3$, 298 K): δ 0.22 (s, 3H, SiCH_3), 0.31 (s, 3H, SiCH_3), 3.07 (dd, $^{3}J_{2,1A}$ = 10.6 Hz, $^{3}J_{2,1B}$ = 5.9 Hz, 1H, H-2), 3.25–3.38 (m, 2H, H-1), 6.92–6.97 (m, 1H, H-5'), 6.99–7.03 (m, 2H, H-2"), 7.03–7.08 (m, 2H, H-7' and H-4"), 7.15–7.20 (m, 2H, H-3"), 7.26–7.34 (m, 3H, H-3'" and H-4'"), 7.39–7.42 (m, 2H, H-2'"), 7.44(m, 1H, H-4') ppm.

^{13}C NMR (100 MHz, $CDCl_3$, 298 K): δ −5.7 (SiCH$_3$), −3.9 (SiCH$_3$), 29.4 (C-1), 34.1 (C-2), 98.2 ($^{2}J_{C,F}$ = 28.0 Hz, C-7'), 111.6 ($^{2}J_{C,F}$ = 24.4 Hz, C-5'), 119.6 ($^{3}J_{C,F}$ = 10.1 Hz, C-4'), 125.2 (C-4"), 127.6 (C-2" or C-3'"), 127.7 (C-2" or C-3'"), 128.1 (C-3"), 129.3 (C-4'"), 134.0 (C-2'"), 136.0 (C-1'"), 137.4 (3a), 141.0 (C-1"), 150.4 ($^{3}J_{C,F}$ = 14.6 Hz, C-7a), 160.1 ($^{1}J_{C,F}$ = 241.4 Hz), 167.1 (C-2') ppm.

^{29}Si DEPT NMR (99 MHz, $CDCl_3$, 298 K): δ −0.9 (*Si*Me$_2$Ph) ppm.

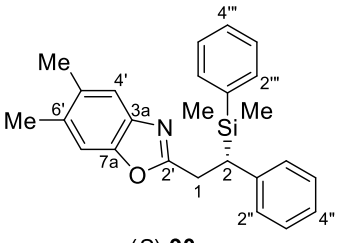
^{19}F NMR (471 MHz, $CDCl_3$, 298 K): δ −116.7 (Ar*F*) ppm.

HRMS (APCI) m/z: $[M+H]^+$ calcd for $C_{23}H_{23}FNOSi$ 376.1527, found 376.1534.

IR (ATR): ṽ 812, 950, 1076, 1117, 1249, 1577, 1619, 3019, 3063 cm^{-1}.

Optical rotation: $[\alpha]_D^{20}$ = +16.7 (*c* 0.8, $CHCl_3$, 79% *ee*).

The enantiomeric ratio of (*S*)-**90u** was determined by HPLC analysis on a chiral stationary phase (*Daicel Chiralcel* OD-H column, column temperature 20 °C, solvent: *n*heptane/*i*PrOH = 99/1, flow rate = 0.6 mL/min): t_R = 13.9 min (minor), t_S = 15.1 min (major).



(*S*)-**90v**
$C_{25}H_{27}NOSi$
M = 385.58 g/mol

(*S*)-2-(2-(Dimethyl(phenyl)silyl)-2-phenylethyl)-5,6-dimethylbenzoxazole [(*S*)-**90v**]: Synthesized from (*E*)-5,6-dimethyl-2-styrylbenzoxazole [(*E*)-**89v**, 37.4 mg, 0.150 mmol, 1.00

equiv] according to **GP 1.4**. Purification by flash column chromatography on silica gel with cyclohexane/EtOAc = 30/1 as eluent delivered (*S*)-**90v** as a white solid (20.1 mg, 35% yield).

R_f = 0.50 (cyclohexane/EtOAc = 10/1).

M.**P**. 116–117 °C.

^{1}H NMR (500 MHz, $CDCl_3$, 298 K): δ 0.23 (s, 3H, SiCH_3), 0.28 (s, 3H, SiCH_3), 2.28 (s, 3H, ArCH_3), 2.29 (s, 3H, ArCH_3), 3.07 (dd, *J* = 10.9, 5.6 Hz, 1H), 3.23–3.37 (m, 2H), 6.98 (d, $3J_{2'',3''}$ = 7.3 Hz, 2H, H-2''), 7.00–7.05 (m, 1H, H-4''), 7.10–7.16 (m, 3H, H-3' or H-7', and H-3''), 7.28–7.36 (m, 4H, H-3' or H-7', H-3''' and H-4'''), 7.39–7.43 (m, 2H, H-2''') ppm.

^{13}C NMR (125 MHz, $CDCl_3$, 298 K): δ −5.4 (SiCH_3), −4.1 (SiCH_3), 20.0 (ArCH_3), 20.3 (ArCH_3), 29.3 (C-1), 34.1 (C-2), 110.5 (C-4' or C-7'), 119.5 (C-4' or C-7'), 125.0 (C-4''), 127.6 (C-2'' or C-3'''), 127.7 (C-2'' or C-3'''), 128.0 (C-3''), 129.3 (C-4'''), 132.4 (C-5' or C-6'), 133.1 (C-5' or C-6'), 134.1 (C-2'''), 136.2 (C-1'''), 139.4 (C-3a or C-7a), 141.1 (C-1''), 149.2 (C-3a or C-7a), 165.7 (C-2') ppm.

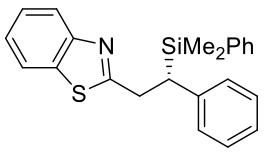
^{29}Si DEPT NMR (99 MHz, $CDCl_3$, 298 K): δ −1.0 (*Si*Me_2Ph) ppm.

HRMS (APCI) m/z: $[M+H]^+$ calcd for $C_{25}H_{28}NOSi$ 386.1935, found 386.1938.

IR (ATR): ṽ 697, 734, 834, 931, 1011, 1112, 1248, 1426, 3070, 3053 cm^{-1}.

Optical rotation: $[\alpha]_D^{20}$ = +23.1 (*c* 0.6, $CHCl_3$, 83% *ee*).

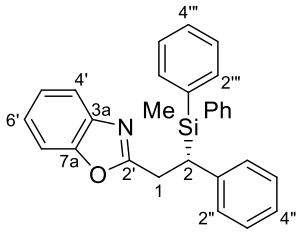
The enantiomeric ratio of (*S*)-**90v** was measured through HPLC analysis on a chiral stationary phase (*Daicel Chiralcel* OD-H column, column temperature 20 °C, solvent: *n*heptane/*i*PrOH = 90/10, flow rate = 0.6 mL/min): t_S = 9.8 min (major), t_R = 15.1 min (minor).



(*S*)-**92**
$C_{23}H_{23}NSSi$
M = 373.59 g/mol

(*S*)-2-(2-(Dimethyl(phenyl)silyl)-2-phenylethyl)benzothiazole [(*S*)-**92**]: Synthesized from (*E*)-2-styrylbenzothiazole [(*E*)-**91**, 35.6 mg, 0.150 mmol, 1.00 equiv] according to **GP 1.4**. Purification by flash column chromatography on silica gel with cyclohexane/EtOAc = 30/1 as eluent delivered (*S*)-**92** as a brown oil (16.3 mg, 29% yield). All data accord with those of *rac*-**92**.

The enantiomeric ratio of (*S*)-**92** was determined by HPLC analysis on a chiral stationary phase (*Daicel Chiralcel* OD-H column, column temperature 20 °C, solvent: *n*heptane/*i*PrOH = 99.5/0.5, flow rate = 0.3 mL/min): t_R = 43.4 min (minor), t_S = 51.0 min (major).



(*S*)-**131a**
$C_{28}H_{25}NOSi$
M = 419.60 g/mol

(*S*)-2-(2-(Methyldiphenylsilyl)-2-phenylethyl)benzoxazole [(*S*)-**131a**]: Synthesized from (*E*)-2-styryl-benzoxazole [(*E*)-**89a**, 33.2 mg, 0.150 mmol, 1.00 equiv] according to **GP 1.4**. Purification by flash column chromatography on silica gel with cyclohexane/EtOAc = 30/1 as eluent delivered it as a yellow oil (25.2 mg, 40% yield).

R_f = 0.50 (cyclohexane/EtOAc = 10/1).

^{1}H NMR (500 MHz, $CDCl_3$, 298 K): δ 0.50 (s, 3H, SiCH_3), 3.40–3.44 (m, 2H, H-1), 3.53 (dd, $^3J_{2,1A}$ = 10.5 Hz, $^3J_{2,1B}$ = 5.8 Hz, 1H, H-2), 6.93–6.96 (m, 2H, H-2''), 7.00–7.04 (m, 1H, H-4'), 7.07–7.11 (m, 2H, H-3''), 7.18–7.21 (m, 2H, Ar), 7.25–7.29 (m, 2H, H-3'''), 7.31–7.35 (m, 2H, Ar and H-4'''), 7.35–7.39 (m, 2H, H-3'''), 7.39–7.43 (m, 3H, H-2''' and H-4'''), 7.51–7.54 (m, 1H, Ar), 7.55–7.59 (m, 2H, H-2''') ppm.

^{13}C NMR (125 MHz, $CDCl_3$, 298 K): δ −5.5 (SiCH_3), 30.0 (C-1), 32.7 (C-2), 110.1 (Ar), 119.5 (Ar), 123.8 (Ar), 124.1 (Ar), 125.3 (C-4''), 127.7 (C-3'''), 127.9 (C-3'''), 128.0 (C-3''), 128.1 (C-2''), 129.4 (C-4'''), 129.6 (C-4'''), 133.8 (C-1'''), 134.8 (C-1'''), 134.9 (C-2'''), 135.2 (C-2'''), 140.4 (C-1''), 141.3 (C-3a or C-7a), 150.6 (C-3a or C-7a), 166.4 (C-2') ppm.

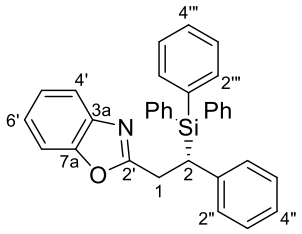
^{29}Si DEPT NMR (99 MHz, $CDCl_3$, 298 K): δ −6.4 (*Si*$MePh_2$) ppm.

HRMS (APCI) m/z: $[M+H]^+$ calcd for $C_{28}H_{26}NOSi$ 420.1778, found 420.1773.

IR (ATR): ṽ 694, 724, 838, 923, 999, 1105, 1240, 1426, 1565, 2956, 3048 cm^{-1}.

Optical rotation: $[\alpha]_D^{20}$ = −7.76 (*c* 0.2, $CHCl_3$, 30% *ee*).

The enantiomeric ratio of (*S*)-**131a** was determined by HPLC analysis on a chiral stationary phase (*Daicel Chiralcel* OD-H column, column temperature 20 °C, solvent: *n*heptane/*i*PrOH = 95/5, flow rate = 0.6 mL/min): t_S = 8.39 min (major), t_R = 8.94 min (minor).



(*S*)-**133a**
$C_{33}H_{27}NOSi$
M = 481.67 g/mol

(*S*)-2-(2-(Methyldiphenylsilyl)-2-phenylethyl)benzoxazole [(*S*)-**133a**]: Synthesized from (*E*)-2-styryl-benzoxazole [(*E*)-**89a**, 33.2 mg, 0.150 mmol, 1.00 equiv] according to **GP 1.4**. Purification by flash column chromatography on silica gel with cyclohexane/EtOAc = 30/1 delivered (*S*)-**133a** as a yellow oil (19.5 mg, 27% yield).

$\mathbf{R_f}$ = 0.50 (cyclohexane/EtOAc = 10/1).

^{1}H NMR (500 MHz, $CDCl_3$, 298 K): δ 3.50 (dd, $^2J_{1A,1B}$ = 15.6 Hz, $^3J_{2,1A}$ = 12.2 Hz, 1H, H-1A), 3.65 (dd, $^2J_{1B,1A}$ = 15.6 Hz, $^2J_{1B,2}$ = 3.8 Hz, 1H, H-1B), 3.79 (dd, $^3J_{2,1A}$ = 12.2 Hz, $^3J_{2,1B}$ = 3.8 Hz, 1H, H-2), 6.87–6.91 (m, 2H, H-2''), 7.03–7.06 (m, 3H, H-3'' and C-4''), 7.18–7.22 (m, 2H, Ar), 7.31–7.36 (m, 7H, Ar and H-3'''), 7.39–7.46 (m, 9H, H-2''' and H-4'''), 7.52–7.55 (m, 1H, Ar) ppm.

^{13}C NMR (125 MHz, $CDCl_3$, 298 K): δ 31.6 (C-1), 32.5 (C-2), 110.1 (Ar), 119.5 (Ar), 123.8 (Ar), 124.1 (Ar), 125.6 (C-4''), 127.9 (C-3'''), 128.1 (C-2''), 129.1 (C-2''), 129.7 (C-4'''), 132.8 (C-1'''), 136.3 (C-2'''), 140.1 (C-1''), 141.3 (C-3a or C-7a), 150.7 (C-3a or C-7a), 166.2 (C-2') ppm.

^{1}H /^{29}Si HMQC NMR (500/99 MHz, $CDCl_3$, 298 K, optimized for *J* = 7.0 Hz): δ 3.50/–11.6 (H-2/Si), 3.65/–11.6 (H-1A/Si), 3.79/–11.6 (H-1B/Si), 7.44/–11.6 (H-2'''/Si) ppm.

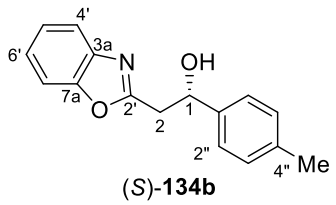
HRMS (APCI) m/z: $[M+H]^+$ calcd for $C_{33}H_{28}NOSi$ 482.1935, found 482.1928.

IR (ATR): $\tilde{\nu}$ 699, 735, 834, 948, 999, 1105, 1240, 1424, 1566, 2956, 3048 cm^{-1}.

Optical rotation: $[\alpha]_D^{20}$ = 0 (*c* 0.3, $CHCl_3$, <5% *ee*).

The enantiomeric ratio of (*S*)-**133a** was determined by HPLC analysis on a chiral stationary phase (*Daicel Chiralcel* OD-H column, column temperature 20 °C, solvent: *n*heptane/*i*PrOH = 99.7/0.3, flow rate = 0.3 mL/min): *t* = 49.9 min, *t* = 53.3 min.

3.1.5 Experimental Detail and Characterization Data for Enantioenriched Alcohol



(*S*)-**134b**
$C_{16}H_{15}NO_2$
M = 253.30 g/mol

(*S*)-2-(Benzoxazol-2-yl)-1-(p-tolyl)ethan-1-ol [(*S*)-**134b**]

To a solution of (*S*)-2-(2-(dimethyl(phenyl)silyl)-2-(*p*-tolyl)ethyl)benzoxazole [(*S*)-**90b**, 74.3 mg, 0.200 mmol, 1.00 equiv) in CH_2Cl_2 (1 mL) at 0 °C, was added dropwise tetrafluoroboric acid diethyl ether complex (81.0 mg, 0.500 mmol, 2.50 equiv). After stirring for 1 hour at 0 °C, the solvent was removed under reduced pressure. To the residue were added MeOH (1 mL), THF (1 mL), KF (23.2 mg, 0.400 mmol, 2.00 equiv) and $KHCO_3$ (201 mg, 2.00 mmol, 10.0 equiv) in sequence at 0 °C. The reaction mixture was stirred at 0 °C for 15 minutes, followed by the addition of H_2O_2 (272 mg, 2.40 mmol, 13 equiv, 30% in water). After stirring for 12 hours at room temperature, the reaction was quenched by the addition of $Na_2S_2O_3$ solution (2 M, 10 mL), and then the reaction mixture was poured into HCl solution (0.5 M, 2 mL). CH_2Cl_2 (20 mL) was used for extraction. The organic layer was washed with brine (20 mL) and water (20 mL), and then the aqueous layer was extracted with CH_2Cl_2 (2 × 20 mL). The combined organic layers were dried over anhydrous $MgSO_4$, filtered and concentrated under reduced pressure. Purifying the residue by flash column chromatography on silica gel with cyclohexane/EtOAc = 10/1 as eluent delivered (*S*)-**134b** as a white solid (33.9 mg, 67% yield).

R_f = 0.20 (cyclohexane/EtOAc = 5/1). **M**.**P**. 129–130 °C.

^{1}H NMR (500 MHz, $CDCl_3$, 298 K): δ 2.36 (s, 3H, ArC*H*$_3$), 3.25–3.37 (m, 2H, H-2), 3.83 (d, *J* = 3.2 Hz, 1H, O*H*), 5.30–5.35 (m, 1H, H-1), 7.19 (d, *J* = 7.9 Hz, 2H, H-3"), 7.31–7.34 (m, 2H, Ar), 7.34–7.37 (m, 2H, H-2"), 7.48–7.52 (m, 1H, Ar), 7.65–7.70 (m, 1H, Ar) ppm.

^{13}C NMR (125 MHz, $CDCl_3$, 298 K): δ 21.1 (Ar*C*H$_3$), 38.1 (C-2), 71.1 (C-1), 110.4 (Ar), 119.6 (Ar), 124.3 (Ar), 124.8 (Ar), 125.6 (C-2"), 129.3 (C-3"), 137.6 (C-4"), 139.6 (C-1"), 140.8 (C-3a or C-7a), 150.5 (C-3a or C-7a), 164.8 (C-2') ppm.

HRMS (APCI) m/z: $[M+H]^+$ calcd for $C_{16}H_{16}NO_2$ 254.1176, found 254.1168.

IR (ATR): ṽ 738, 834, 945, 1062, 1154, 1245, 1453, 1563, 2915, 3052, 3268 cm^{-1}.

Optical rotation: $[\alpha]_D^{20}$ = −41.5 (*c* 0.5, $CHCl_3$, 94% *ee*).

The enantiomeric ratio of (*S*)-**134a** was determined by HPLC analysis on a chiral stationary phase (*Daicel Chiralcel* OD-H column, column temperature 20 °C, solvent: *n*heptane/*i*PrOH = 97/3, flow rate = 1.0 mL/min): t_R = 17.9 min (minor), t_S = 19.8 min (major).

3.2 Asymmetric Conjugate 1.4-Silyl Transfer to Enyne-Type *α,β,γ,δ*-Unsaturated Acceptors

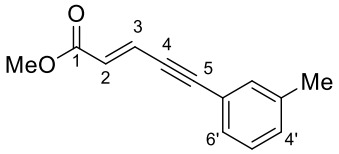
3.2.1 Preparation of Si–B Reagents

Me_2PhSi–Bpin (**12**), $MePh_2Si$–Bpin (**138**), and Ph_3Si–Bpin (**140**) were prepared according to **GP 2.1** (Method A). All spectroscopic data accord with those reported.[70a]

Et_3Si–Bpin (**142**) was prepared according to **GP 2.1** (Method B). All spectroscopic data accord with those reported.[70b]

3.2.2 Experimental Details and Characterization Data for Enyne-Type *α,β,γ,δ*-Unsaturated Acceptors

(*E*)-**135a**,[72a] (*E*)-**135b**,[72b] (*E*)-**135e**,[72c] (*E*)-**135f**,[72c] (*E*)-**135g**,[72b] (*E*)-**135p**,[72a] (*E*)-**135q**,[72d] (*E*)-**135r**,[72e] (*E*)-**146a**,[72f] and (*E*)-**148**,[72g] were synthesized according to known procedures and all spectroscopic data accord with those reported.



(*E*)-**135c**
$C_{13}H_{12}O_2$
M = 200.24

Methyl (*E*)-5-(*m*-tolyl)pent-2-en-4-ynoate [(*E*)-**135c**]: Synthesized from methyl (*E*)-3-iodoacrylate (1.06 g, 5.00 mmol, 1.00 equiv) according to **GP 2.2** (Method B). Purification by flash column chromatography on silica gel with pentane/EtOAc = 100/1 as eluent delivered (*E*)-**135c** as a brown solid (500 mg, 50% yield).

$\mathbf{R_f}$ = 0.40 (cyclohexane/EtOAc = 30/1).

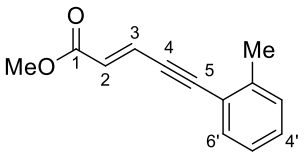
M.P. 51–52 °C.

^{1}H NMR (400 MHz, $CDCl_3$, 298 K): δ 2.34 (s, 3H, CH_3), 3.78 (s, 3H, OCH_3), 6.30 (d, $^3J_{2,3}$ = 15.8 Hz, 1H, H-2), 6.99 (d, $^3J_{3,2}$ = 15.8 Hz, 1H, H-3), 7.15–7.20 (m, 1H, H-4'), 7.21–7.27 (m, 1H, H-6'), 7.27–7.36 (m, 2H, H-5' and H-2') ppm.

^{13}C NMR (100 MHz, $CDCl_3$, 298 K): δ 21.1 (*C*H_3), 51.8 (O*C*H_3), 86.0 (C-4), 98.7 (C-5), 121.9 (C-1'), 125.4 (C-3), 128.3 (C-6'), 129.0 (C-5'), 129.3 (C-2), 130.2 (C-4'), 132.5 (C-2'), 138.2 (C-3'), 166.4 (C-1) ppm.

HRMS (APCI) m/z: $[M+H]^+$ calcd for $C_{13}H_{13}O_2$ 201.0910, found 201.0912.

IR (ATR): ṽ 1259, 1378, 1441, 1479, 1615, 1714, 2191, 2951 cm^{-1}.



(*E*)-**135d**
$C_{13}H_{12}O_2$
M = 200.24

Methyl (*E*)-5-(o-tolyl)pent-2-en-4-ynoate [(*E*)-**135d**]: Synthesized from methyl (*E*)-3-iodoacrylate (1.06 g, 5.00 mmol, 1.00 equiv) according to **GP 2.2** (Method B). Purification by flash column chromatography on silica gel with pentane/EtOAc = 100/1 as eluent delivered (*E*)-**135d** as a brown oil (770 mg, 77% yield).

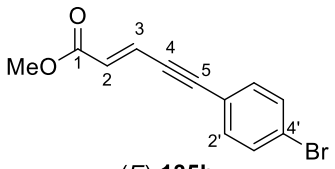
R_f = 0.40 (cyclohexane/EtOAc = 30/1).

^{1}H NMR (400 MHz, $CDCl_3$, 298 K): δ 2.45 (s, 3H, C*H*$_3$), 3.79 (s, 3H, OC*H*$_3$), 6.31 (d, $^3J_{2,3}$ = 15.8 Hz, 1H, H-2), 7.04 (d, $^3J_{3,2}$ = 15.8 Hz, 1H, H-3), 7.14–7.19 (m, 1H, H-5'), 7.21–7.24 (m, 1H, H-3'), 7.25–7.30 (m, 1H, H-4'), 7.43–7.46 (m, 1H, H-6') ppm.

^{13}C NMR (100 MHz, $CDCl_3$, 298 K): δ 20.6 (*C*H_3), 51.9 (O*C*H_3), 90.1 (C-4), 97.5 (C-5), 121.9 (C-1'), 125.5 (C-3), 125.7 (C-5'), 129.2 (C-2), 129.4 (C-4'), 129.6 (C-3'),, 132.3 (C-6'), 140.8 (C-2'), 166.4 (C-1) ppm.

HRMS (APCI) m/z: $[M+H]^+$ calcd for $C_{13}H_{13}O_2$ 201.0910, found 201.0909.

IR (ATR): ṽ 1248, 1378, 1435, 1484, 1617, 1718, 2194, 2949 cm^{-1}.



(*E*)-**135h**
$C_{12}H_9BrO_2$
M = 265.10

Methyl (*E*)-5-(4-bromophenyl)pent-2-en-4-ynoate [(*E*)-**135h**]: Synthesized from methyl (*E*)-3-iodoacrylate (1.06 g, 5.00 mmol, 1.00 equiv) according to **GP 2.2** (Method B). Purification by flash column chromatography on silica gel with *n*pentane/EtOAc = 100/1 as eluent delivered (*E*)-**135h** as a yellow solid (1.00 g, 75% yield).

$\mathbf{R_f}$ = 0.40 (cyclohexane/EtOAc = 30/1).

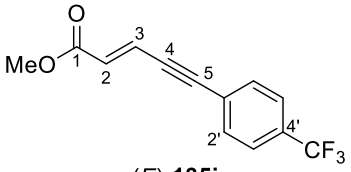
M.**P**. 84–86 °C.

^{1}H NMR (400 MHz, $CDCl_3$, 298 K): δ 3.79 (s, 3H, OCH_3), 6.32 (d, $^3J_{2,3}$ = 15.8 Hz, 1H, H-2), 6.95 (d, $^3J_{3,2}$ = 15.8 Hz, 1H, H-3), 7.34 (d, $^3J_{2',3'}$ = 8.4 Hz, 2H, H-2'), 7.49 (d, $^3J_{3',2'}$ = 8.4 Hz, 2H, H-3') ppm.

^{13}C NMR (100 MHz, $CDCl_3$, 298 K): δ 51.9 (OCH$_3$), 87.3 (C-4), 97.1 (C-5), 121.1 (C-1'), 123.8 (C-4'), 124.9 (C-3), 130.0 (C-2), 131.8 (C-3'), 133.3 (C-2'), 166.2 (C-1) ppm.

HRMS (APCI) m/z: $[M+H]^+$ calcd for $C_{12}H_{10}BrO_2$ 264.9859, found 264.9860.

IR (ATR): ṽ 1250, 1392, 1435, 1483, 1576, 1616, 1710, 2194, 2947 cm^{-1}.



(*E*)-**135i**
$C_{13}H_9F_3O_2$
M = 254.21 g/mol

Methyl (*E*)-5-(4-(trifluoromethyl)phenyl)pent-2-en-4-ynoate [(*E*)-**135i**]: Synthesized from methyl (*E*)-3-iodoacrylate (1.06 g, 5.00 mmol, 1.00 equiv) according to **GP 2.2** (Method B). Purification by flash column chromatography on silica gel with *n*pentane/EtOAc = 100/1 as eluent delivered (*E*)-**135i** as a yellow solid (620 mg, 49% yield).

R_f = 0.40 (cyclohexane/EtOAc = 30/1).

M.**P**. 45–47 °C.

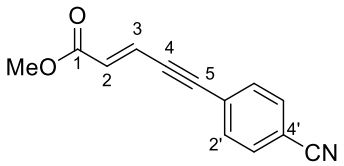
^{1}H NMR (400 MHz, $CDCl_3$, 298 K): δ 3.80 (s, 3H, OCH_3), 6.36 (d, $^3J_{2,3}$ = 15.9 Hz, 1H, H-2), 6.98 (d, $^3J_{3,2}$ = 15.9 Hz, 1H, H-3), 7.56–7.64 (m, 4H, H-2' and H-3') ppm.

^{13}C NMR (100 MHz, $CDCl_3$, 298 K): δ 52.0 (OCH$_3$), 88.1 (C-4), 96.3 (C-5), 123.7 (q, $^1J_{C,F}$ = 270.6 Hz, CF$_3$), 124.6 (C-3), 125.4 (q, $^3J_{C,F}$ = 3.7 Hz, C-3'), 125.9(C-1'), 130.7 (C-2), 130.9 (q, $^2J_{C,F}$ = 32.5 Hz, C-4'), 132.1 (C-2'), 166.1 (C-1) ppm.

^{19}F NMR (471 MHz, $CDCl_3$, 298 K): δ −63.0 (ArF) ppm.

HRMS (APCI) m/z: $[M+H]^+$ calcd for $C_{13}H_{10}F_3O_2$ 255.0627, found 255.0623.

IR (ATR): ṽ 955, 1104, 1163, 1250, 1315, 1616, 1718, 2198, 2952 cm^{-1}.



(*E*)-**135j**
$C_{13}H_9NO_2$
M = 211.22

Methyl (*E*)-5-(4-cyanophenyl)pent-2-en-4-ynoate [(*E*)-**135j**]: Synthesized from methyl (*E*)-3-iodoacrylate (1.06 g, 5.00 mmol, 1.00 equiv) according to **GP 2.2** (Method B). Purification by flash column chromatography on silica gel with *n*pentane/EtOAc = 10/1 as eluent delivered (*E*)-**135j** as a white solid (700 mg, 66% yield).

R_f = 0.25 (cyclohexane/EtOAc = 10/1).

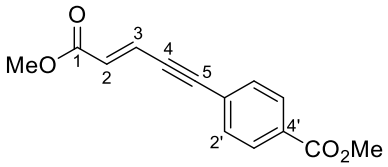
M.**P**. 99–101 °C.

^{1}H NMR (400 MHz, $CDCl_3$, 298 K): δ 3.78 (s, 3H, OCH_3), 6.35 (d, $^3J_{2,3}$ = 15.9 Hz, 1H, H-2), 6.95 (d, $^3J_{3,2}$ = 15.9 Hz, 1H, H-3), 7.53–7.57 (m, 2H, H-2'), 7.61–7.65 (m, 2H, H-3') ppm.

^{13}C NMR (100 MHz, $CDCl_3$, 298 K): δ 52.0 (OCH$_3$), 89.8 (C-4), 95.6 (C-5), 112.5 (C-4'), 118.1 (ArCN), 124.1 (C-3), 126.9 (C-1'), 131.2 (C-2), 132.1 (C-3'), 132.3 (C-2'), 165.8 (C-1) ppm.

HRMS (APCI) m/z: $[M+H]^+$ calcd for $C_{13}H_{10}NO_2$ 212.0706, found 212.0704.

IR (ATR): ṽ 1169, 1274, 1438, 1501, 1544, 1618, 1718, 2199, 2224, 2954 cm^{-1}.



(*E*)-**135k**
$C_{14}H_{12}O_4$
M = 244.25

Methyl (*E*)-4-(5-methoxy-5-oxopent-3-en-1-yn-1-yl)benzoate [(*E*)-**135k**]: Synthesized from methyl (*E*)-3-iodoacrylate (1.06 g, 5.00 mmol, 1.00 equiv) according to **GP 2.2** (Method B). Purification by flash column chromatography on silica gel with *n*pentane/EtOAc = 10/1 as eluent delivered (*E*)-**135k** as a white solid (642 mg, 53% yield).

$\mathbf{R_f}$ = 0.25 (cyclohexane/EtOAc = 10/1).

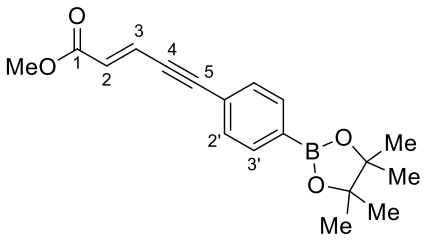
M.**P**. 116–118 °C.

^{1}H NMR (500 MHz, $CDCl_3$, 298 K): δ 3.80 (s, 3H, OCH_3), 3.93 (s, 3H, $ArCO_2CH_3$), 6.35 (d, $^3J_{2,3}$ = 15.8 Hz, 1H, H-2), 6.99 (d, $^3J_{3,2}$ = 15.8 Hz, 1H, H-3), 7.54 (d, $^3J_{2',3'}$ = 8.6 Hz, 2H, H-2'), 8.02 (d, $^3J_{3',2'}$ = 8.6 Hz, 2H, H-3') ppm.

^{13}C NMR (100 MHz, $CDCl_3$, 298 K): δ 52.0 (OCH_3), 52.3 ($ArCO_2CH_3$), 88.7 (C-4), 97.0 (C-5), 124.7 (C-3), 126.7 (C-1'), 129.6 (C-3'), 130.5 (C-4'), 130.6 (C-2), 131.8 (C-2'), 166.1 (C-1), 166.3 (ArCO_2Me) ppm.

HRMS (APCI) m/z: $[M+H]^+$ calcd for $C_{14}H_{13}O_4$ 245.0808, found 245.0806.

IR (ATR): ṽ 1170, 1275, 1433, 1507, 1580, 1618, 1715, 2201, 2959 cm^{-1}.



(*E*)-**135l**
$C_{18}H_{21}BO_4$
M = 312.17

Methyl (*E*)-5-(4-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)phenyl)pent-2-en-4-ynoate [(*E*)-**135l**]: Synthesized from methyl (*E*)-3-iodoacrylate (1.06 g, 5.00 mmol, 1.00 equiv) according to **GP 2.2** (Method B). Purification by flash column chromatography on silica gel with *n*pentane/EtOAc = 10/1 as eluent afforded (*E*)-**135l** as a yellow solid (300 mg, 19% yield).

R_f = 0.30 (cyclohexane/EtOAc = 10/1).

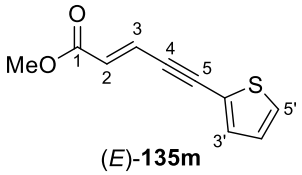
M.**P**. 113–115 °C.

^{1}H NMR (400 MHz, $CDCl_3$, 298 K): δ 1.34 [s, 12H, OC(C*H*$_3$)$_2$], 3.78 (s, 3H, OC*H*$_3$), 6.32 (d, $^3J_{2,3}$ = 15.8 Hz, 1H, H-2), 6.99 (d, $^3J_{3,2}$ = 15.8 Hz, 1H, H-3), 7.47 (d, $^3J_{2',3'}$ = 8.2 Hz, 2H, H-2'), 7.78 (d, $^3J_{3',2'}$ = 8.2 Hz, 2H, H-3') ppm.

^{13}C NMR (100 MHz, $CDCl_3$, 298 K): δ 24.8 (OC(*C*H$_3$)$_2$), 51.9 (O*C*H$_3$), 84.0 [O*C*(CH$_3$)$_2$], 87.4 (C-4), 98.4 (C-5), 124.6 (C-1'), 125.2 (C-3), 129.8 (C-2), 131.0 (C-2' and C-4'), 134.6 (C-3'), 166.3 (C-1) ppm.

HRMS (APCI) m/z: $[M+H]^+$ calcd for $C_{18}H_{22}BO_4$ 313.1606, found 313.1607.

IR (ATR): ṽ 1165, 1249, 1353, 1511, 1614, 1716, 2199, 2981 cm^{-1}.



(*E*)-**135m**
$C_{10}H_8O_2S$
M = 192.23

Methyl (*E*)-5-(thiophen-2-yl)pent-2-en-4-ynoate [(*E*)-**135m**]: Synthesized from methyl (*E*)-3-iodoacrylate (1.06 g, 5.00 mmol, 1.00 equiv) according to **GP 2.2** (Method B). Purification

by flash column chromatography on silica gel with *n*pentane/EtOAc = 10/1 as eluent delivered (*E*)-**135m** as a white solid (160 mg, 17% yield).

R_f = 0.50 (cyclohexane/EtOAc = 30/1).

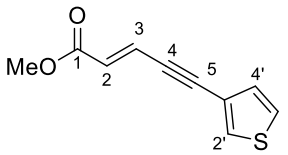
M.**P**. 61–63 °C.

^{1}H NMR (400 MHz, $CDCl_3$, 298 K): δ 3.78 (s, 3H, OCH_3), 6.28 (d, $^3J_{2,3}$ = 15.8 Hz, 1H, H-2), 6.98 (d, $^3J_{3,2}$ = 15.8 Hz, 1H, H-3), 7.02 (dd, $^3J_{4',5'}$ = 5,1 Hz, $^3J_{4',3'}$ = 3.6 Hz, 1H, H-4'), 7.30 (dd, $^3J_{3',4'}$ = 3.6 Hz, $^4J_{3',5'}$ = 0.8 Hz, 1H, H-3'), 7.36 (dd, $^3J_{5',4'}$ = = 5.1 Hz, $^4J_{5',3'}$ = 0.8 Hz, 1H, H-5') ppm.

^{13}C NMR (100 MHz, $CDCl_3$, 298 K): δ 51.9 (OCH$_3$), 90.5 (C-4), 91.8 (C-5), 122.1 (C-2'), 124.9 (C-3), 127.4 (C-4'), 129.0 (C-2), 129.2 (C-5'), 133.6 (C-3'), 166.3 (C-1) ppm.

HRMS (APCI) m/z: $[M+H]^+$ calcd for $C_{10}H_9O_2S$ 193.0318, found 193.0316.

IR (ATR): ṽ 712, 1164, 1275, 1434, 1508, 1616, 1702, 2184, 2946 cm^{-1}.



(*E*)-**135n**
$C_{10}H_8O_2S$
M = 192.23

Methyl (*E*)-5-(thiophen-3-yl)pent-2-en-4-ynoate [(*E*)-**135n**]: Synthesized from methyl (*E*)-3-iodoacrylate (1.06 g, 5.00 mmol, 1.00 equiv) according to **GP 2.2** (Method B). Purification by flash column chromatography on silica gel with *n*pentane/EtOAc = 10/1 as eluent delivered (*E*)-**135n** as a white solid (426 mg, 44% yield).

R_f = 0.50 (cyclohexane/EtOAc = 30/1).

M.**P**. 42–44 °C.

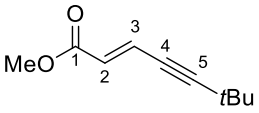
^{1}H NMR (400 MHz, $CDCl_3$, 298 K): δ 3.78 (s, 3H, OCH_3), 6.29 (d, $^3J_{2,3}$ = 15.8 Hz, 1H, H-2), 6.97 (d, $^3J_{3,2}$ = 15.8 Hz, 1H, H-3), 7.15 (dd, $^3J_{4',5'}$ = 5.0 Hz, $^3J_{4',2'}$ = 1.2 Hz, 1H, H-4'), 7.30 (dd,

$^{3}J_{5',4'}$ = 5.0 Hz, $^{3}J_{5',2'}$ = 3.0 Hz, 1H, H-5'), 7.56 (dd, $^{3}J_{2',5'}$ = 3.0 Hz, $^{3}J_{2',4'}$ = 1.2 Hz, 1H, H-2') ppm.

^{13}C NMR (100 MHz, $CDCl_3$, 298 K): δ 51.9 (O*C*H$_3$), 86.2 (C-4), 93.7 (C-5), 121.4 (C-3'), 125.3 (C-3), 125.7 (C-5'), 129.3 (C-2), 129.8 (C-4'), 130.5 (C-2'), 166.4 (C-1) ppm.

HRMS (APCI) m/z: $[M+H]^+$ calcd for $C_{10}H_9O_2S$ 193.0318, found 193.0317.

IR (ATR): ṽ 718, 1167, 1277, 1435, 1510, 1614, 1706, 2193, 2915 cm^{-1}.



(*E*)-**135o**
$C_{10}H_{14}O_2$
M = 166.22

Methyl (*E*)-6,6-dimethylhept-2-en-4-ynoate [(*E*)-**135o**]: Synthesized from methyl (*E*)-3-iodoacrylate (1.06 g, 5.00 mmol, 1.00 equiv) according to **GP 2.2** (Method B). Purification by flash column chromatography on silica gel with *n*pentane/EtOAc = 150/1 as eluent delivered (*E*)-**135o** as a colourless oil (450 mg, 54% yield).

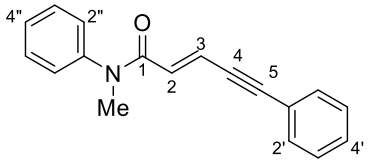
R$_f$ = 0.40 (cyclohexane/EtOAc = 30/1).

^{1}H NMR (500 MHz, $CDCl_3$, 298 K): δ 1.26 [s, 9H, C(C*H*$_3$)$_3$], 3.74 (s, 3H, OC*H*$_3$), 6.13 (d, $^{3}J_{2,3}$ = 15.8 Hz, 1H, H-2), 6.77 (d, $^{3}J_{3,2}$ = 15.8 Hz, 1H, H-3) ppm.

^{13}C NMR (100 MHz, $CDCl_3$, 298 K): δ 28.3 [*C*(CH$_3$)$_3$], 30.6 [C(*C*H$_3$)$_3$], 51.7 (O*C*H$_3$), 76.5 (C-4), 108.7 (C-5), 126.4 (C-3), 128.5 (C-2), 166.6 (C-1) ppm.

HRMS (APCI) m/z: $[M+H]^+$ calcd for $C_{10}H_{15}O_2$ 167.1067, found 167.1065.

IR (ATR): ṽ 1166, 1255, 1455, 1475, 1619, 1719, 2222, 2868, 2969 cm^{-1}.



(*E*)-**144a**
$C_{18}H_{15}NO$
M = 261.32 g/mol

(*E*)-*N*-methyl-*N*,5-diphenylpent-2-en-4-ynamide [(*E*)-**144a**]: Synthesized from methyl (*E*)-5-phenylpent-2-en-4-ynoate (931 mg, 5.00 mmol, 1.00 equiv) according to **GP 2.2** (Method C). Purification by flash column chromatography on silica gel with cyclohexane/EtOAc = 10/1 as eluent delivered (*E*)-**144a** as a brown solid (953 mg, 73% yield).

R_f = 0.30 (cyclohexane/EtOAc = 10/1).

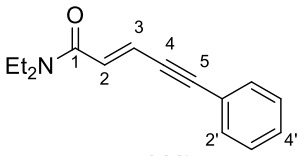
M.**P**. 104–106 °C.

^{1}H NMR (400 MHz, $CDCl_3$, 298 K): δ 3.38 (s, 3H, NCH_3), 6.27 (d, $^3J_{2,3}$ = 15.4 Hz, 1H, H-2), 7.00 (d, $^3J_{3,2}$ = 15.4 Hz, 1H, H-3), 7.18–7.23 (m, 2H, H-2"), 7.26–7.32 (m, 3H, H-3' and H-4'), 7.34–7.42 (m, 3H, H-2' and H-4"), 7.42–7.47 (m, 2H, H-3") ppm.

^{13}C NMR (100 MHz, $CDCl_3$, 298 K): δ 37.6 (NCH_3), 87.2 (C-4), 96.7 (C-5), 122.1 (C-3), 122.4 (C-1'), 127.3 (C-2"), 127.7 (C-4"), 128.3 (C-3'), 128.9 (C-4'), 129.7 (C-3"), 130.1 (C-2), 131.7 (C-2'), 143.1 (C-1"), 164.9 (C-1) ppm.

HRMS (APCI) m/z: $[M+H]^+$ calcd for $C_{18}H_{16}NO$ 262.1226, found 262.1222.

IR (ATR): ṽ 1117, 1261, 1456,1587, 1602, 1643, 2194, 2928 cm^{-1}.



(*E*)-**144b**
$C_{15}H_{17}NO$
M = 227.31 g/mol

***(E)*-*N,N*-Diethyl-5-phenylpent-2-en-4-ynamide** [(*E*)-**144b**]: Synthesized from methyl (*E*)-5-phenylpent-2-en-4-ynoate (931 mg, 5.00 mmol, 1.00 equiv) according to **GP 2.2** (Method C). Purification by flash column chromatography on silica gel with cyclohexane/EtOAc = 5/1 as eluent delivered (*E*)-**144b** as a brown oil (918 mg, 81% yield).

R_f = 0.30 (cyclohexane/EtOAc = 4/1).

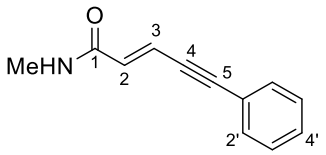
^{1}H NMR (500 MHz, $CDCl_3$, 298 K): δ 1.17 [t, ^3J = 7.1 Hz, 3H, N($CH_2C\mathit{H}_3$)$_2$], 1.24 [t, ^3J = 7.1 Hz, 3H, N($CH_2C\mathit{H}_3$)$_2$], 3.41 [q, ^3J = 7.1 Hz, 2H, N($C\mathit{H}_2CH_3$)$_2$], 3.54 [q, ^3J = 7.1 Hz, 2H,

N(C*H*$_2$CH$_3$)$_2$], 6.76 (d, $^3J_{2,3}$ = 15.3 Hz, 1H, H-2), 7.00 (d, $^3J_{3,2}$ = 15.3 Hz, 1H, H-3), 7.31–7.37 (m, 3H, H-3' and H-4'), 7.46–7.50 (m, 2H, H-2') ppm.

^{13}C NMR (125 MHz, $CDCl_3$, 298 K): δ 13.1 [N(CH$_2$*C*H$_3$)$_2$], 15.1 [N(CH$_2$*C*H$_3$)$_2$], 41.1 [N(*C*H$_2$CH$_3$)$_2$], 42.2 [N(*C*H$_2$CH$_3$)$_2$], 87.4 (C-4), 96.1 (C-5), 122.6 (C-1' and C-3), 128.4 (C-3'), 128.9 (C-4'), 129.6 (C-2), 131.8 (C-2'), 164.5 (C-1) ppm.

HRMS (APCI) m/z: $[M+H]^+$ calcd for $C_{15}H_{18}NO$ 228.1383, found 228.1383.

IR (ATR): ṽ 1137, 1479,1479, 1599, 1632, 2195, 2930, 2971 cm^{-1}.



(*E*)-**144c**
$C_{12}H_{11}NO$
M = 185.23 g/mol

(*E*)-*N*-methyl-5-phenylpent-2-en-4-ynamide [(*E*)-**144c**]: Synthesized from methyl (*E*)-5-phenylpent-2-en-4-ynoate (931 mg, 5.00 mmol, 1.00 equiv) according to **GP 2.2** (Method C). Purification by flash column chromatography on silica gel with cyclohexane/EtOAc = 1/1 as eluent delivered (*E*)-**144c** as a brown solid (500 mg, 54% yield).

R$_f$ = 0.15 (cyclohexane/EtOAc = 1/1).

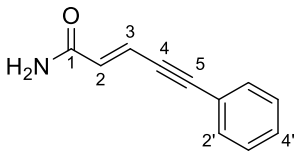
M.P. 118–120 °C.

^{1}H NMR (400 MHz, $CDCl_3$, 298 K): δ 2.91 (d, ^3J = 5.0 Hz, 3H, NHC*H*$_3$), 5.97 (s, 1H, N*H*), 6.33 (d, $^3J_{2,3}$ = 15.4 Hz, 1H, H-2), 6.94 (d, $^3J_{3,2}$ = 15.3 Hz, 1H, H-3), 7.28–7.36 (m, 3H, H-3' and H-4'), 7.43–7.47 (m, 2H, H-2') ppm.

^{13}C NMR (100 MHz, $CDCl_3$, 298 K): δ 26.6 (NH*C*H$_3$), 86.8 (C-4), 96.4 (C-5), 121.4 (C-3), 122.5 (C-1'), 128.5 (C-3'), 129.1 (C-4'), 131.9 (C-2'), 132.3 (C-2), 166.5 (C-1) ppm.

HRMS (APCI) m/z: $[M+H]^+$ calcd for $C_{12}H_{12}NO$ 186.0913, found 186.0907.

IR (ATR): ṽ 1162, 1338, 1443,1613, 1645, 2197, 2956, 3306 cm^{-1}.



(*E*)-**144d**
$C_{11}H_9NO$
M = 171.20 g/mol

(*E*)-5-phenylpent-2-en-4-ynamide [(*E*)-**144d**]: Synthesized from methyl (*E*)-5-phenylpent-2-en-4-ynoate (931 mg, 5.00 mmol, 1.00 equiv) according to **GP 2.2** (Method C). Purification by flash column chromatography on silica gel with cyclohexane/EtOAc = 1/2 as eluent delivered (*E*)-**144d** as a brown solid (633 mg, 74% yield).

R_f = 0.30 (cyclohexane/EtOAc = 1/3).

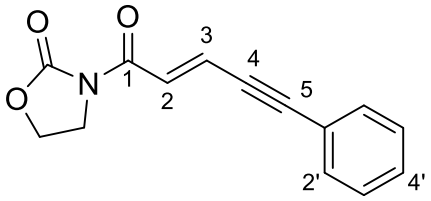
M.**P**. 157–159 °C.

^{1}H NMR (400 MHz, $(CD_3)_2SO$, 298 K): δ 6.49 (d, $^3J_{2,3}$ = 15.8 Hz, 1H, H-2), 6.73 (d, $^3J_{3,2}$ = 15.8 Hz, 1H and H-3), 7.29 (s, 1H, NH_2), 7.40–7.46 (m, 3H, H-3' and H-4'), 7.49–7.54 (m, 2H, H-2'), 7.65 (s, 1H, NH_2) ppm.

^{13}C NMR (125 MHz, $CDCl_3$, 298 K): δ 87.1 (C-4), 95.2 (C-5), 119.2 (C-3), 121.7 (C-1'), 128.9 (C-3'), 129.5 (C-4'), 131.6 (C-2'), 134.8 (C-2), 165.3 (C-1) ppm.

HRMS (APCI) m/z: $[M+H]^+$ calcd for $C_{11}H_{10}NO$ 172.0757, found 172.0751.

IR (ATR): ṽ 1266, 1387, 1439,1587, 1666, 2195, 2932, 3294 cm^{-1}.



(*E*)-**144e**
$C_{14}H_{11}NO_3$
M = 241.25 g/mol

(*E*)-3-(5-phenylpent-2-en-4-ynoyl)oxazolidin-2-one [(*E*)-**144e**]: Synthesized from methyl (*E*)-5-phenylpent-2-en-4-ynoate (931 mg, 5.00 mmol, 1.00 equiv) according to **GP 2.2**. Purification by recrystallization delivered (*E*)-**144e** as a yellow solid (0.300 g, 25% yield).

R_f = 0.30 (cyclohexane/EtOAc = 3/1).

M.**P**. 123–125 °C.

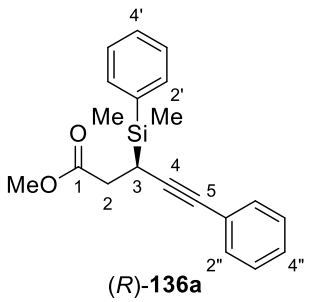
^{1}H NMR (500 MHz, $CDCl_3$, 298 K): δ 4.10 (t, ^3J = 8.0 Hz, 2H, NCH_2), 4.45 (t, ^3J = 8.0 Hz, 2H, OCH_2), 7.16 (d, $^3J_{3,2}$ = 15.6 Hz, 1H, H-3), 7.33–7.40 (m, 3H, H-3' and H-4'), 7.48–7.53 (m, 2H, H-2'), 7.73 (d, $^3J_{2,3}$ = 15.6 Hz, 1H, H-2) ppm.

^{13}C NMR (125 MHz, $CDCl_3$, 298 K): δ 42.7 (NCH$_2$), 62.1 (OCH$_2$), 87.2 (C-4), 99.8 (C-5), 122.1 (C-1'), 126.6 (C-1'), 128.0 (C-2), 128.5 (C-3'), 129.4 (C-4'), 132.1 (C-2'), 153.3 [OC(O)N], 164.4 (C-1) ppm.

HRMS (APCI) m/z: $[M+H]^+$ calcd for $C_{14}H_{12}NO_3$ 242.0812, found 242.0809.

IR (ATR): ṽ 1115, 1214, 1473,1587, 1601, 1669, 1771, 2195, 2989 cm^{-1}.

3.2.3 Experimental Details and Characterization Data for Enantioenriched Products



(*R*)-**136a**
$C_{20}H_{22}O_2Si$
M = 322.48 g/mol

Methyl (*R*)-3-(dimethyl(phenyl)silyl)-5-phenylpent-4-ynoate [(*R*)-**136a**]: Synthesized from methyl (*E*)-5-phenylpent-2-en-4-ynoate [(*E*)-**135a**, 74.6 mg, 0.400 mmol, 1.00 equiv] according to **GP 2.4**. Purification by flash column chromatography on silica gel with cyclohexane/EtOAc = 80/1 as eluent delivered (*R*)-**136a** as a yellow oil (122 mg, 95% yield).

R_f = 0.35 (cyclohexane/EtOAc = 30/1).

^{1}H NMR (500 MHz, $CDCl_3$, 298 K): δ 0.44 (s, 3H, SiC*H*$_3$), 0.45 (s, 3H, SiC*H*$_3$), 2.36–2.49 (m, 2H, H-2), 2.60 (dd, $^3J_{3,2A}$ = 10.3 Hz, $^3J_{3,2B}$ = 4.9 Hz, 1H, H-3), 3.63 (s, 3H, OC*H*$_3$), 7.21–7.27 (m, 3H, H-3" and H-4"), 7.30–7.34 (m, 2H, H-2"), 7.34–7.41 (m, 3H, H-3' and H-4'), 7.56–7.59 (m, 2H, H-2') ppm.

^{13}C NMR (125 MHz, $CDCl_3$, 298 K): δ −5.3 (Si*C*H$_3$), −4.4 (Si*C*H$_3$), 16.9 (C-3), 34.7 (C-2), 51.7 (O*C*H$_3$), 82.1 (C-5), 90.3 (C-4), 124.3 (C-1"), 127.3 (C-4"), 127.9 (C-3'), 128.1 (C-3"), 129.6 (C-4'), 131.5 (C-2"), 134.1 (C-2'), 135.7 (C-1'), 172.9 (C-1) ppm.

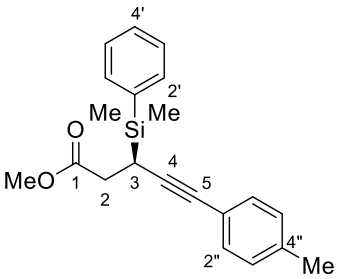
^{29}Si DEPT NMR (99 MHz, $CDCl_3$, 298 K): δ −0.3 (*Si*Me$_2$Ph) ppm.

HRMS (APCI) m/z: $[M+H]^+$ calcd for $C_{20}H_{23}O_2Si$ 323.1462, found 323.1466.

IR (ATR): ṽ 691, 814, 1054, 1113, 1249, 1428, 1595, 1735, 2217, 2952 cm^{-1}.

Optical rotation: $[\alpha]_D^{20}$ = −72.8 (*c* 1.0, $CHCl_3$, 92% *ee*).

The enantiomeric ratio of (*R*)-**136a** was determined by HPLC analysis on a chiral stationary phase (*Daicel Chiralcel* OD-H column, column temperature 20 °C, solvent: *n*heptane/*i*PrOH = 98/2, flow rate = 0.5 mL/min): t_S = 12.8 min (minor), t_R = 16.5 min (major).



(*R*)-**136b**
$C_{21}H_{24}O_2Si$
M = 336.51 g/mol

Methyl (*R*)-3-(dimethyl(phenyl)silyl)-5-(*p*-tolyl)pent-4-ynoate [(*R*)-**136b**]: Synthesized from methyl (*E*)-5-(*p*-tolyl)pent-2-en-4-ynoate [(*E*)-**135b**, 40.1 mg, 0.200 mmol, 1.00 equiv] according to **GP 2.4**. Purification by flash column chromatography on silica gel with cyclohexane/EtOAc = 80/1 as eluent delivered (*R*)-**136b** as a colourless oil (53.8 mg, 80% yield).

R_f = 0.35 (cyclohexane/EtOAc = 30/1).

^{1}H NMR (500 MHz, $CDCl_3$, 298 K): δ 0.46 (s, 3H, SiC*H*$_3$), 0.47 (s, 3H, SiC*H*$_3$), 2.33 (s, 3H, ArC*H*$_3$), 2.37–2.52 (m, 2H, H-2), 2.61 (dd, $^3J_{3,2A}$ = 8.2 Hz, $^3J_{3,2B}$ = 4.9 Hz, 1H, H-3), 3.65 (s, 3H, OC*H*$_3$), 7.08 (d, $^3J_{3",2"}$ = 8.0 Hz, 2H, H-3"), 7.24 (d, $^3J_{2",3"}$ = 8.0 Hz, 2H, H-2"), 7.35–7.43 (m, 3H, H-3' and H-4'), 7.58–7.62 (m, 2H, H-2') ppm.

^{13}C NMR (100 MHz, $CDCl_3$, 298 K): δ −5.3 (Si*C*H$_3$), −4.4 (Si*C*H$_3$), 16.9 (C-3), 21.4 (Ar*C*H$_3$), 34.8 (C-2), 51.7 (O*C*H$_3$), 82.1 (C-5), 89.4 (C-4), 121.2 (C-1"), 127.9 (C-3'), 128.8 (C-3"), 129.6 (C-4'), 131.4 (C-2"), 134.1 (C-2'), 135.7 (C-1'), 137.3 (C-4"), 173.0 (C-1) ppm.

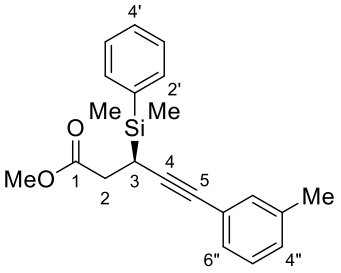
^{29}Si DEPT NMR (99 MHz, $CDCl_3$, 298 K): δ −0.3 (*Si*Me$_2$Ph) ppm.

HRMS (APCI) m/z: $[M+H]^+$ calcd for $C_{21}H_{25}O_2Si$ 337.1618, found 337.1620.

IR (ATR): ṽ 699, 814, 1050, 1113, 1249, 1428, 1605, 1736, 2217, 2952 cm^{-1}.

Optical rotation: $[\alpha]_D^{20}$ = − 66.6 (*c* 1.0, $CHCl_3$, 92% *ee*).

The enantiomeric ratio of (*R*)-**136b** was determined by HPLC analysis on a chiral stationary phase (*Daicel Chiralcel* OD-H column, column temperature 20 °C, solvent: *n*heptane/*i*PrOH = 98/2, flow rate = 0.5 mL/min): t_S = 12.3 min (minor), t_R = 15.1 min (major).



(*R*)-**136c**
$C_{21}H_{24}O_2Si$
M = 336.51 g/mol

Methyl (*R*)-3-(dimethyl(phenyl)silyl)-5-(*m*-tolyl)pent-4-ynoate [(*R*)-**136c**]: Synthesized from methyl (*E*)-5-(*m*-tolyl)pent-2-en-4-ynoate [(*E*)-**135c**, 40.0 mg, 0.200 mmol, 1.00 equiv] according to **GP 2.4**. Purification by flash column chromatography on silica gel with cyclohexane/EtOAc = 60/1 as eluent delivered (*R*)-**136c** as a yellow oil (51.2 mg, 76% yield).

$\mathbf{R_f}$ = 0.20 (cyclohexane/EtOAc = 50/1).

^{1}H NMR (400 MHz, $CDCl_3$, 298 K): δ 0.48 (s, 3H, SiCH_3), 0.49 (s, 3H, SiCH_3), 2.32 (s, 3H, CH_3), 2.39–2.54 (m, 2H, H-2), 2.63 (dd, $^3J_{3,2A}$ = 10.1 Hz, $^3J_{3,2B}$ = 5.0 Hz, 1H, H-3), 3.66 (s, 3H, OCH_3), 7.05–7.11 (m, 1H, H-4"), 7.16–7.20 (m, 3H, H-2", H-5" and H-6"), 7.36–7.45 (m, 3H, H-3' and H-4'), 7.60–7.64 (m, 2H, H-2') ppm.

^{13}C NMR (100 MHz, $CDCl_3$, 298 K): δ −5.3 (Si*C*H_3), −4.4 (Si*C*H_3), 16.9 (C-3), 21.2 (*C*H_3), 34.7 (C-2), 51.7 (O*C*H_3), 82.2 (C-5), 89.9 (C-4), 124.0 (C-1"), 127.9 (C-3') 128.0 (C-6"), 128.2 (C-4"), 128.5 (C-5"), 129.6 (C-4'), 132.1 (C-2"), 134.0 (C-2'), 135.7 (C-1'), 137.7 (C-3"), 172.9 (C-1) ppm.

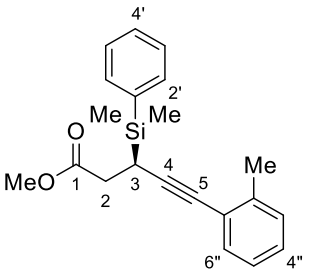
^{29}Si DEPT NMR (99 MHz, $CDCl_3$, 298 K): δ −0.3 (*Si*Me_2Ph) ppm.

HRMS (APCI) m/z: $[M+H]^+$ calcd for $C_{21}H_{25}O_2Si$ 337.1618, found 337.1621.

IR (ATR): ṽ 691, 1112, 1249, 1428, 1483, 1599, 1736, 2212, 2952 cm^{-1}.

Optical rotation: $[\alpha]_D^{20}$ = −78.8 (*c* 1.0, $CHCl_3$, 92% *ee*).

The enantiomeric ratio of (*R*)-**136c** was determined by HPLC analysis on a chiral stationary phase (*Daicel Chiralcel* OD-H column, column temperature 20 °C, solvent: *n*heptane/*i*PrOH = 98/2, flow rate = 0.5 mL/min): t_S = 12.4 min (minor), t_R = 15.3 min (major).



(*R*)-**136d**
$C_{21}H_{24}O_2Si$
M = 336.51 g/mol

Methyl (*R*)-3-(dimethyl(phenyl)silyl)-5-(*o*-tolyl)pent-4-ynoate [(*R*)-**136d**]: Synthesized from methyl (*E*)-5-(*o*-tolyl)pent-2-en-4-ynoate [(*E*)-**135d**, 40.0 mg, 0.200 mmol, 1.00 equiv] according to **GP 2.4**. Purification by flash column chromatography on silica gel with cyclohexane/EtOAc = 60/1 as eluent delivered (*R*)-**136d** as a yellow oil (51.2 mg, 76% yield).

$\mathbf{R_f}$ = 0.20 (cyclohexane/EtOAc = 50/1).

^{1}H NMR (500 MHz, $CDCl_3$, 298 K): δ 0.50 (s, 3H, SiC*H*$_3$), 0.50 (s, 3H, SiC*H*$_3$), 2.37 (s, 3H, C*H*$_3$), 2.43–2.56 (m, 2H, H-2), 2.71 (dd, $^3J_{3,2A}$ = 10.5 Hz, $^3J_{3,2B}$ = 4.9 Hz, 1H, H-3), 3.67 (s, 3H, OC*H*$_3$), 7.04–7.14 (m, 1H, H-5"), 7.14–7.19 (m, 2H, H-3" and H-4"), 7.34 (d, $^3J_{6",5"}$ = 7.4 Hz, 1H, H-6"), 7.37–7.44 (m, 3H, H-3' and H-4'), 7.60–7.64 (m, 2H, H-2') ppm.

^{13}C NMR (100 MHz, $CDCl_3$, 298 K): δ −5.3 (Si*C*H$_3$), −4.4 (Si*C*H$_3$), 17.2 (C-3), 20.7 (*C*H$_3$), 34.9 (C-2), 51.7 (O*C*H$_3$), 80.9 (C-5), 94.2 (C-4), 124.0 (C-1"), 125.3 (C-5") 127.3 (C-4"), 127.9 (C-3'), 129.2 (C-3"), 129.6 (C-4'), 131.8 (C-6"), 134.0 (C-2'), 135.7 (C-1'), 139.8 (C-2"), 172.9 (C-1) ppm.

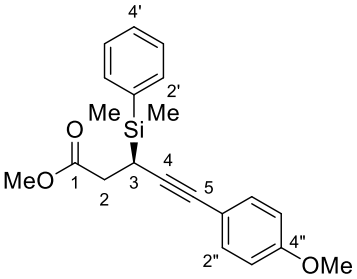
^{29}Si DEPT NMR (99 MHz, $CDCl_3$, 298 K): δ −0.4 (*Si*Me$_2$Ph) ppm.

HRMS (APCI) m/z: $[M+H]^+$ calcd for $C_{21}H_{25}O_2Si$ 337.1618, found 337.1621.

IR (ATR): ṽ 697, 1112, 1249, 1428, 1454, 1597, 1736, 2215, 2951 cm^{-1}.

Optical rotation: $[\alpha]_D^{20}$ = −84.3 (*c* 1.0, $CHCl_3$, 91% *ee*).

The enantiomeric ratio of (*R*)-**136d** was determined by HPLC analysis on a chiral stationary phase (*Daicel Chiralcel* OD-H column, column temperature 20 °C, solvent: *n*heptane/*i*PrOH = 98/2, flow rate = 0.5 mL/min): t_S = 12.2 min (minor), t_R = 15.6 min (major).



(*R*)-**136e**
$C_{21}H_{24}O_3Si$
M = 352.51 g/mol

Methyl (*R*)-3-(dimethyl(phenyl)silyl)-5-(4-methoxyphenyl)pent-4-ynoate [(*R*)-**136e**]: Synthesized from methyl (*E*)-5-(4-methoxyphenyl)pent-2-en-4-ynoate [(*E*)-**135e**, 43.3 mg, 0.200 mmol, 1.00 equiv] according to **GP 2.4**. Purification by flash column chromatography on silica gel with cyclohexane/EtOAc = 30/1 as eluent delivered (*R*)-**136e** as a brown oil (66.1 mg, 94% yield).

R_f = 0.40 (cyclohexane/EtOAc = 10/1).

^{1}H NMR (400 MHz, $CDCl_3$, 298 K): δ 0.48 (s, 3H, SiC*H*$_3$), 0.48 (s, 3H, SiC*H*$_3$), 2.29–2.53 (m, 2H, H-2), 2.62 (dd, $^3J_{3,2A}$ = 10.1 Hz, $^3J_{3,2B}$ = 5.1 Hz, 1H, H-3), 3.66 (s, 3H, OC*H*$_3$), 3.80 (s, 3H, ArOC*H*$_3$), 6.81 (d, $^3J_{3",2"}$ = 8.8 Hz, 2H, H-3"), 7.30 (d, $^3J_{2",3"}$ = 8.8 Hz, 2H, H-2"), 7.36–7.44 (m, 3H, H-3' and H-4'), 7.59–7.63 (m, 2H, H-2') ppm.

^{13}C NMR (100 MHz, $CDCl_3$, 298 K): δ −5.3 (Si*C*H$_3$), −4.4 (Si*C*H$_3$), 16.8 (C-3), 34.8 (C-2), 51.7 (O*C*H$_3$), 55.2 (ArO*C*H$_3$), 81.7 (C-5), 88.5 (C-4), 113.7 (C-3"), 116.4 (C-1"), 127.8 (C-3'), 129.6 (C-4'), 132.8 (C-2"), 134.0 (C-2'), 135.7 (C-1'), 158.9 (C-4"), 172.9 (C-1) ppm.

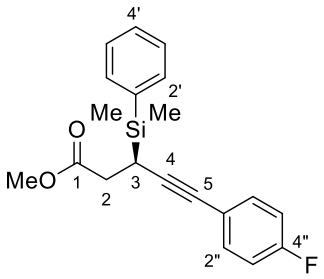
^{29}Si DEPT NMR (99 MHz, $CDCl_3$, 298 K): δ −0.4 (*Si*Me$_2$Ph) ppm.

HRMS (APCI) m/z: $[M+H]^+$ calcd for $C_{21}H_{25}O_3Si$ 353.1567, found 353.1571.

IR (ATR): ṽ 699, 1109, 1243, 1428, 1507, 1603, 1734, 2216, 2952 cm^{-1}.

Optical rotation: $[\alpha]_D^{20}$ = −71.8 (*c* 1.0, $CHCl_3$, 93% *ee*).

The enantiomeric ratio of (*R*)-**136e** was determined by HPLC analysis on a chiral stationary phase (*Daicel Chiralcel* OD-H column, column temperature 20 °C, solvent: *n*heptane/*i*PrOH = 98/2, flow rate = 0.5 mL/min): t_S = 19.6 min (minor), t_R = 24.3 min (major).



(*R*)-**136f**
$C_{20}H_{21}FO_2Si$
M = 340.47 g/mol

Methyl (*R*)-3-(dimethyl(phenyl)silyl)-5-(4-fluorophenyl)pent-4-ynoate [(*R*)-**136f**]: Synthesized from methyl (*E*)-5-(4-fluorophenyl)pent-2-en-4-ynoate [(*E*)-**135f**, 40.9 mg, 0.200 mmol, 1.00 equiv] according to **GP 2.4**. Purification by flash column chromatography on silica gel with cyclohexane/EtOAc = 60/1 as eluent delivered (*R*)-**136f** as a colourless oil (64.1 mg, 94% yield).

R_f = 0.50 (cyclohexane/EtOAc = 20/1).

^{1}H NMR (500 MHz, $CDCl_3$, 298 K): δ 0.47 (s, 3H, SiC*H*$_3$), 0.47 (s, 3H, SiC*H*$_3$), 2.39–2.53 (m, 2H, H-2), 2.61 (dd, $^3J_{3,2A}$ = 10.0 Hz, $^3J_{3,2B}$ = 5.2 Hz, 1H, H-3), 3.66 (s, 3H, OC*H*$_3$), 6.93–6.99 (m, 2H, H-3"), 7.28–7.34 (m, 2H, H-2"), 7.36–7.44 (m, 3H, H-3' and H-4'), 7.58–7.62 (m, 2H, H-2') ppm.

^{13}C NMR (100 MHz, $CDCl_3$, 298 K): δ −5.3 (Si*C*H$_3$), −4.4 (Si*C*H$_3$), 16.8 (C-3), 34.6 (C-2), 51.7 (O*C*H$_3$), 80.9 (C-5), 89.9 (C-4), 115.3 (d, $^2J_{C,F}$ = 21.8 Hz, C-3"), 120.3 (d, $^4J_{C,F}$ = 3.3 Hz, C-1"), 127.9 (C-3'), 129.7 (C-4'), 133.2 (d, $^3J_{C,F}$ = 8.2 Hz, C-2"), 134.0 (C-2'), 135.6 (C-1'), 161.9 (d, $^1J_{C,F}$ = 246.4 Hz, C-4"), 172.9 (C-1) ppm.

^{29}Si DEPT NMR (99 MHz, $CDCl_3$, 298 K): δ −0.2 (*Si*Me$_2$Ph) ppm.

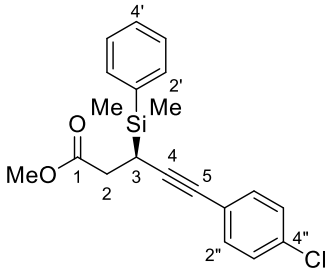
^{19}F NMR (471 MHz, $CDCl_3$, 298 K): δ −112.6 (Ar*F*) ppm.

HRMS (APCI) m/z: $[M+H]^+$ calcd for $C_{20}H_{22}FO_2Si$ 341.1368, found 341.1372.

IR (ATR): ṽ 699, 1092, 1249, 1429, 1504, 1599, 1736, 2220, 2952 cm^{-1}.

Optical rotation: $[\alpha]_D^{20}$ = −78.6 (*c* 1.0, $CHCl_3$, 92% *ee*).

The enantiomeric ratio of (*R*)-**136f** was determined by HPLC analysis on a chiral stationary phase (*Daicel Chiralcel* OD-H column, column temperature 20 °C, solvent: *n*heptane/*i*PrOH = 98/2, flow rate = 0.5 mL/min): t_S = 12.6 min (minor), t_R = 15.6 min (major).



(*R*)-**136g**
$C_{20}H_{21}ClO_2Si$
M = 356.92 g/mol

Methyl (*R*)-5-(4-chlorophenyl)-3-(dimethyl(phenyl)silyl)pent-4-ynoate [(*R*)-**136g**]: Synthesized from methyl (*E*)-5-(4-chlorophenyl)pent-2-en-4-ynoate [(*E*)-**135g**, 44.1 mg, 0.200 mmol, 1.00 equiv] according to **GP 2.4**. Purification by flash column chromatography on silica gel with cyclohexane/EtOAc = 80/1 as eluent delivered (*R*)-**136g** as a colourless oil (63.1 mg, 88% yield).

$\mathbf{R_f}$ = 0.35 (cyclohexane/EtOAc = 30/1).

^{1}H NMR (400 MHz, $CDCl_3$, 298 K): δ 0.46 (s, 3H, SiC*H*$_3$), 0.46 (s, 3H, SiC*H*$_3$), 2.38–2.52 (m, 2H, H-2), 2.61 (dd, $^3J_{3,2A}$ = 9.9 Hz, $^3J_{3,2B}$ = 5.2 Hz, 1H, H-3), 3.65 (s, 3H, OC*H*$_3$), 7.21–7.28 (m, 4H, H-2" and H-3"), 7.35–7.45 (m, 3H, H-3' and H-4'), 7.56–7.60 (m, 2H, H-2') ppm.

^{13}C NMR (100 MHz, $CDCl_3$, 298 K): δ −5.3 (Si*C*H$_3$), −4.4 (Si*C*H$_3$), 16.9 (C-3), 34.6 (C-2), 51.8 (O*C*H$_3$), 81.0 (C-5), 91.5 (C-4), 122.7 (C-1"), 127.9 (C-3'), 128.4 (C-3"), 129.7 (C-4'), 132.7 (C-2"), 133.2 (C-4"), 134.0 (C-2'), 135.5 (C-1'), 172.8 (C-1) ppm.

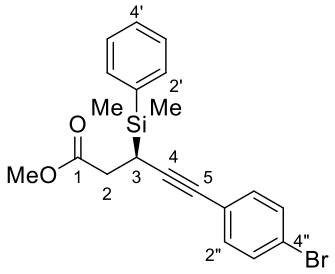
^{29}Si DEPT NMR (99 MHz, $CDCl_3$, 298 K): δ −0.2 (*Si*Me$_2$Ph) ppm.

HRMS (APCI) m/z: $[M+H]^+$ calcd for $C_{20}H_{22}ClO_2Si$ 357.1072, found 357.1075.

IR (ATR): ṽ 699, 814, 1051, 1112, 1249, 1428, 1589, 1735, 2218, 2951 cm^{-1}.

Optical rotation: $[\alpha]_D^{20}$ = −87.2 (*c* 1.0, $CHCl_3$, 89% *ee*).

The enantiomeric ratio of (*R*)-**136g** was determined by HPLC analysis on a chiral stationary phase (*Daicel Chiralcel* OD-H column, column temperature 20 °C, solvent: *n*heptane/*i*PrOH = 98/2, flow rate = 0.5 mL/min): t_S = 12.5 min (minor), t_R = 15.0 min (major).



(*R*)-**136h**
$C_{20}H_{21}BrO_2Si$
M = 401.38 g/mol

Methyl (*R*)-5-(4-bromophenyl)-3-(dimethyl(phenyl)silyl)pent-4-ynoate [(*R*)-**136h**]: Synthesized from methyl (*E*)-5-(4-bromophenyl)pent-2-en-4-ynoate [(*E*)-**135h**, 53.1 mg, 0.200 mmol, 1.00 equiv] according to **GP 2.4**. Purification by flash column chromatography on silica gel with cyclohexane/EtOAc = 80/1 as eluent delivered (*R*)-**136h** as a colourless oil (55.5 mg, 69% yield).

$\mathbf{R_f}$ = 0.35 (cyclohexane/EtOAc = 30/1).

^{1}H NMR (400 MHz, $CDCl_3$, 298 K): δ 0.46 (s, 3H, SiC*H*$_3$), 0.47 (s, 3H, SiC*H*$_3$), 2.38–2.52 (m, 2H, H-2), 2.61 (dd, $^3J_{3,2A}$ = 9.9 Hz, $^3J_{3,2B}$ = 5.2 Hz, 1H, H-3), 3.65 (s, 3H, OC*H*$_3$), 7.17–7.21 (m, 2H, H-2"), 7.36–7.43 (m, 5H, H-3', H-4' and H-3"), 7.56–7.61 (m, 2H, H-2') ppm.

^{13}C NMR (100 MHz, $CDCl_3$, 298 K): δ −5.3 (Si*C*H$_3$), −4.4 (Si*C*H$_3$), 17.0 (C-3), 34.5 (C-2), 51.8 (O*C*H$_3$), 81.0 (C-5), 91.8 (C-4), 121.3 (C-4"), 123.2 (C-1"), 127.9 (C-3'), 129.7 (C-4'), 131.3 (C-3"), 132.9 (C-2"), 134.0 (C-2'), 135.5 (C-1'), 172.8 (C-1) ppm.

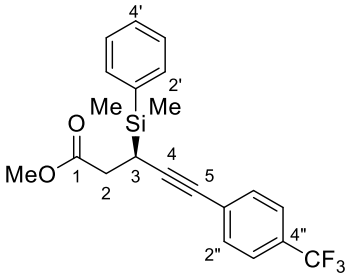
^{29}Si DEPT NMR (99 MHz, $CDCl_3$, 298 K): δ −0.2 (*Si*Me$_2$Ph) ppm.

HRMS (APCI) m/z: $[M+H]^+$ calcd for $C_{20}H_{22}BrO_2Si$ 401.0567, found 401.0569.

IR (ATR): ṽ 672, 698, 815, 1069, 1112, 1249, 1428, 1586, 1735, 2218, 2951 cm^{-1}.

Optical rotation: $[\alpha]_D^{20}$ = −83.0 (*c* 1.0, $CHCl_3$, 89% *ee*).

The enantiomeric ratio of (*R*)-**136h** was determined by HPLC analysis on a chiral stationary phase (*Daicel Chiralcel* OD-H column, column temperature 20 °C, solvent: *n*heptane/*i*PrOH = 98/2, flow rate = 0.5 mL/min): t_S = 13.3 min (minor), t_R = 15.6 min (major).



(*R*)-**136i**
$C_{21}H_{21}F_3O_2Si$
M = 390.48 g/mol

Methyl (*R*)-3-(dimethyl(phenyl)silyl)-5-(4-(trifluoromethyl)phenyl)pent-4-ynoate [(*R*)-**136i**]: Synthesized from methyl (*E*)-5-(4-(trifluoromethyl)phenyl)pent-2-en-4-ynoate [(*E*)-**135i**, 50.9 mg, 0.200 mmol, 1.00 equiv] according to **GP 2.4**. Purification by flash column chromatography on silica gel with cyclohexane/EtOAc = 60/1 as eluent delivered (*R*)-**136i** as a colourless oil (70.7 mg, 92% yield).

$\mathbf{R_f}$ = 0.30 (cyclohexane/EtOAc = 30/1).

^{1}H NMR (400 MHz, $CDCl_3$, 298 K): δ 0.48 (s, 3H, SiC*H*$_3$), 0.48 (s, 3H, SiC*H*$_3$), 2.41–2.54 (m, 2H, H-2), 2.65 (dd, $^3J_{3,2A}$ = 9.9 Hz, $^3J_{3,2B}$ = 5.2 Hz, 1H, H-3), 3.66 (s, 3H, OC*H*$_3$), 7.36–7.45 (m, 5H, H-3', H-4' and H-2"), 7.52 (d, $^3J_{3",2"}$ = 8.1 Hz, 2H, H-3"), 7.57–7.61 (m, 2H, H-2') ppm.

^{13}C NMR (100 MHz, $CDCl_3$, 298 K): δ −5.3 (Si*C*H$_3$), −4.5 (Si*C*H$_3$), 17.1 (C-3), 34.5 (C-2), 51.8 (O*C*H$_3$), 81.0 (C-5), 93.5 (C-4), 124.0 (q, $^1J_{C,F}$ = 270.3 Hz, *C*F$_3$), 125.0 (q, $^3J_{C,F}$ = 3.76 Hz, C-3"), 127.9 (C-3'), 128.1 (C-1"), 129.0 (q, $^2J_{C,F}$ = 32.5 Hz, C-4"), 129.8 (C-4'), 131.6 (C-2"), 134.0 (C-2'), 135.3 (C-1'), 172.7 (C-1) ppm.

^{29}Si DEPT NMR (99 MHz, $CDCl_3$, 298 K): δ −0.0 (*Si*Me$_2$Ph) ppm.

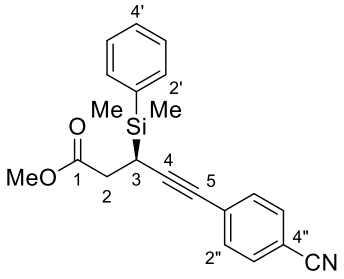
^{19}F NMR (471 MHz, $CDCl_3$, 298 K): δ −62.7 (C*F*$_3$) ppm.

HRMS (APCI) m/z: $[M+H]^+$ calcd for $C_{21}H_{22}F_3O_2Si$ 391.1336, found 391.1339.

IR (ATR): $\tilde{\nu}$ 698, 1104, 1118, 1252, 1428, 1512, 1613, 1736, 2220, 2954 cm^{-1}.

Optical rotation: $[\alpha]_D^{20}$ = −59.3 (*c* 1.0, $CHCl_3$, 92% *ee*).

The enantiomeric ratio of (*R*)-**136i** was determined by HPLC analysis on a chiral stationary phase (*Daicel Chiralcel* OD-H column, column temperature 20 °C, solvent: *n*heptane/*i*PrOH = 95/5, flow rate = 0.3 mL/min): t_S = 16.2 min (minor), t_R = 17.3 min (major).



(*R*)-**136j**
$C_{21}H_{21}NO_2Si$
M = 347.49 g/mol

Methyl (*R*)-5-(4-cyanophenyl)-3-(dimethyl(phenyl)silyl)pent-4-ynoate [(*R*)-**136j**]: Synthesized from methyl (*E*)-5-(4-cyanophenyl)pent-2-en-4-ynoate [(*E*)-**135j**, 42.3 mg, 0.200 mmol, 1.00 equiv] according to **GP 2.4**. Purification by flash column chromatography on silica gel with cyclohexane/EtOAc = 18/1 as eluent delivered (*R*)-**136j** as a colourless oil (42.1 mg, 61% yield).

$\mathbf{R_f}$ = 0.30 (cyclohexane/EtOAc = 10/1).

^{1}H NMR (400 MHz, $CDCl_3$, 298 K): δ 0.47 (s, 3H, SiC*H*$_3$), 0.47 (s, 3H, SiC*H*$_3$), 2.40–2.52 (m, 2H, H-2), 2.64 (dd, $^3J_{3,2A}$ = 9.7 Hz, $^3J_{3,2B}$ = 5.5 Hz, 1H, H-3), 3.66 (s, 3H, OC*H*$_3$), 7.35–7.44 (m, 5H, H-2", H-3' and H-4'), 7.52–7.59 (m, 4H, H-2' and H-3") ppm.

^{13}C NMR (100 MHz, $CDCl_3$, 298 K): δ −5.2 (Si*C*H$_3$), −4.5 (Si*C*H$_3$), 17.2 (C-3), 34.3 (C-2), 51.9 (O*C*H$_3$), 80.9 (C-5), 96.1 (C-4), 110.5 (C-4"), 118.7 (*C*N), 128.0 (C-3'), 129.2 (C-1"), 129.8 (C-4'), 131.8 (C-2"), 131.9 (C-2'), 134.0 (C-3"), 135.2 (C-1'), 172.7 (C-1) ppm.

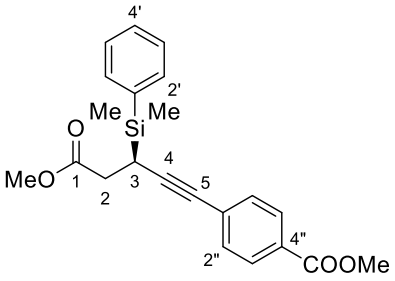
^{29}Si DEPT NMR (99 MHz, $CDCl_3$, 298 K): δ −0.2 (*Si*Me$_2$Ph) ppm.

HRMS (APCI) m/z: $[M+H]^+$ calcd for $C_{21}H_{22}NO_2Si$ 348.1414, found 348.1418.

IR (ATR): ṽ 699, 1112, 1249, 1428, 1499, 1602, 1734, 2219, 2952 cm^{-1}.

Optical rotation: $[\alpha]_D^{20}$ = −36.1 (*c* 1.0, $CHCl_3$, 93% *ee*).

The enantiomeric ratio of (*R*)-**136j** was determined by HPLC analysis on a chiral stationary phase (*Daicel Chiralcel* OD-H column, column temperature 20 °C, solvent: *n*heptane/*i*PrOH = 95/5, flow rate = 0.5 mL/min): t_S = 21.8 min (minor), t_R = 24.9 min (major).



(*R*)-**136k**
$C_{22}H_{24}O_4Si$
M = 380.52 g/mol

Methyl (*R*)-4-(3-(dimethyl(phenyl)silyl)-5-methoxy-5-oxopent-1-yn-1-yl)benzoate [(*R*)-**136k**]: Synthesized from methyl methyl (*E*)-4-(5-methoxy-5-oxopent-3-en-1-yn-1-yl)benzoate [(*E*)-**135k**, 48.8 mg, 0.200 mmol, 1.00 equiv] according to **GP 2.4**. Purification by flash column chromatography on silica gel with cyclohexane/EtOAc = 20/1 as eluent delivered (*R*)-**136k** as a yellow oil (55.0 mg, 72% yield).

$\mathbf{R_f}$ = 0.30 (cyclohexane/EtOAc = 10/1).

^{1}H NMR (500 MHz, $CDCl_3$, 298 K): δ 0.48 (s, 3H, SiCH_3), 0.48 (s, 3H, SiCH_3), 2.41–2.58 (m, 2H, H-2), 2.65 (dd, $^3J_{3,2A}$ = 10.2 Hz, $^3J_{3,2B}$ = 5.0 Hz, 1H, H-3), 3.66 (s, 3H, OCH_3), 3.91 (s, 3H, ArCOOCH_3), 7.35–7.44 (m, 5H, H-2", H-3' and H-4'), 7.57–7.61 (m, 2H, H-2'), 7.94 (d, $^3J_{3",2"}$ = 8.4 Hz, 2H, H-3") ppm.

^{13}C NMR (125 MHz, $CDCl_3$, 298 K): δ −5.3 (SiCH$_3$), −4.4 (SiCH$_3$), 17.2 (C-3), 34.5 (C-2), 51.8 (OCH$_3$), 52.1 (ArCO$_2$$CH_3$), 81.6 (C-5), 94.2 (C-4), 127.9 (C-3'), 128.6 (C-4"), 129.1 (C-1"), 129.3 (C-3"), 129.8 (C-4'), 131.3 (C-2"), 134.0 (C-2'), 135.4 (C-1'), 166.7 (ArCO$_2$Me), 172.8 (C-1) ppm.

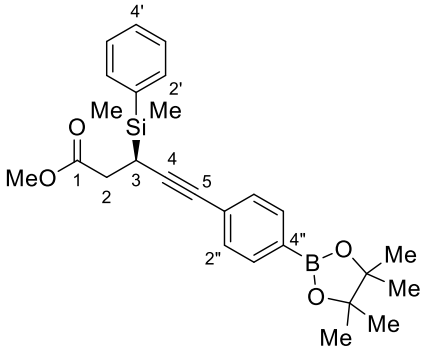
^{29}Si DEPT NMR (99 MHz, $CDCl_3$, 298 K): δ −0.0 (*Si*Me$_2$Ph) ppm.

HRMS (APCI) m/z: $[M+H]^+$ calcd for $C_{22}H_{25}O_4Si$ 381.1517, found 381.1519.

IR (ATR): ṽ 696, 1106, 1271, 1432, 1505, 1603, 1718, 2216, 2951 cm^{-1}.

Optical rotation: $[\alpha]_D^{20}$ = −63.4 (*c* 1.0, $CHCl_3$, 90% *ee*).

The enantiomeric ratio of (*R*)-**136k** was determined by HPLC analysis on a chiral stationary phase (*Daicel Chiralcel* OD-H column, column temperature 20 °C, solvent: *n*heptane/*i*PrOH = 95/5, flow rate = 0.5 mL/min): t_S = 15.9 min (minor), t_R = 18.0 min (major).



(*R*)-**136l**
$C_{26}H_{33}BO_4Si$
M = 448.44 g/mol

Methyl (*R*)-3-(dimethyl(phenyl)silyl)-5-(4-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)-phenyl)pent-4-ynoate [(*R*)-**136l**]: Synthesized from methyl (*E*)-5-(4-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)phenyl)pent-2-en-4-ynoate [(*E*)-**135l**, 62.5 mg, 0.200 mmol, 1.00 equiv] according to **GP 2.4**. Purification by flash column chromatography on silica gel with cyclohexane/EtOAc = 15/1 as eluent delivered (*R*)-**136l** as a white solid (60.1 mg, 67% yield).

R_f = 0.40 (cyclohexane/EtOAc = 10/1).

M.P. 103–105 °C.

^{1}H NMR (400 MHz, $CDCl_3$, 298 K): δ 0.47 (s, 3H, SiCH_3), 0.48 (s, 3H, SiCH_3), 1.34 (s, 12H, OC(CH_3)$_2$), 2.37–2.53 (m, 2H, H-2), 2.63 (dd, $^3J_{3,2A}$ = 10.1 Hz, $^3J_{3,2B}$ = 5.0 Hz, 1H, H-3), 3.65 (s, 3H, OCH_3), 7.33 (d, $^3J_{2",3"}$ = 8.1 Hz, 2H, H-2"), 7.35–7.44 (m, 3H, H-3' and H-4'), 7.57–7.61 (m, 2H, H-2'), 7.71 (d, $^3J_{3",2"}$ = 8.1 Hz, 2H, H-3") ppm.

^{13}C NMR (100 MHz, $CDCl_3$, 298 K): δ −5.3 (SiCH$_3$), −4.4 (SiCH$_3$), 17.0 (C-3), 24.8 [OC(CH$_3$)$_2$], 34.6 (C-2), 51.7 (OCH$_3$), 82.3 (C-5), 83.8 [OC(CH$_3$)$_2$], 92.0 (C-4), 127.0 (C-1"), 127.9 (C-3'), 129.6 (C-4'), 130.6 (C-2" and C-4"), 134.0 (C-2'), 134.4 (C-3"), 135.6 (C-1'), 172.9 (C-1) ppm.

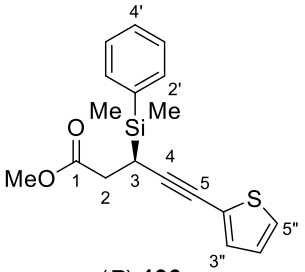
^{29}Si DEPT NMR (99 MHz, $CDCl_3$, 298 K): δ −0.2 (*Si*Me_2Ph) ppm.

HRMS (APCI) m/z: $[M+H]^+$ calcd for $C_{26}H_{34}BO_4Si$ $[M+H]^+$: calculated 449.2314, found 449.2316.

IR (ATR): ṽ 697, 1086, 1111, 1255, 1429, 1605, 1734, 2219, 2952 cm^{-1}.

Optical rotation: $[\alpha]_D^{20}$ = −65.2 (*c* 1.0, $CHCl_3$, 92% *ee*).

The enantiomeric ratio of (*R*)-**136l** was determined by HPLC analysis on a chiral stationary phase (*Daicel Chiralcel* OD-H column, column temperature 20 °C, solvent: *n*heptane/*i*PrOH = 98/2, flow rate = 0.5 mL/min): t_S = 11.4 min (minor), t_R = 14.0 min (major).



(*R*)-**136m**
$C_{18}H_{20}O_2SSi$
M = 328.50 g/mol

Methyl (*R*)-3-(dimethyl(phenyl)silyl)-5-(thiophen-2-yl)pent-4-ynoate [(*R*)-**136m**]: Synthesized from methyl (*E*)-5-(thiophen-2-yl)pent-2-en-4-ynoate [(*E*)-**135m**, 38.4 mg, 0.200 mmol, 1.00 equiv] according to **GP 2.4**. Purification by flash column chromatography on silica gel with cyclohexane/EtOAc = 60/1 as eluent delivered (*R*)-**136m** as a brown oil (57.2 mg, 87% yield).

R_f = 0.50 (cyclohexane/EtOAc = 20/1).

^{1}H NMR (400 MHz, $CDCl_3$, 298 K): δ 0.47 (s, 3H, SiC*H*$_3$), 0.48 (s, 3H, SiC*H*$_3$), 2.39–2.53 (m, 2H, H-2), 2.55 (dd, $^3J_{3,2A}$ = 10.0 Hz, $^3J_{3,2B}$ = 5.1 Hz, 1H, H-3), 3.66 (s, 3H, OC*H*$_3$), 6.93 (dd, $^3J_{4",5"}$ = 5.2 Hz, $^3J_{4",3"}$ = 3.6 Hz, 1H, H-4"), 7.08 (dd, $^3J_{3",4"}$ = 3.6 Hz, $^3J_{3",5"}$ = 1.1 Hz, 1H, H-3"), 7.16 (dd, $^3J_{5",4"}$ = 5.2 Hz, $^3J_{5",3"}$ = 1.1 Hz, 1H, H-5"), 7.36–7.45 (m, 3H, H-3' and H-4'), 7.58–7.62 (m, 2H, H-2') ppm.

^{13}C NMR (100 MHz, $CDCl_3$, 298 K): δ −5.3 (Si*C*H_3), −4.4 (Si*C*H_3), 17.3 (C-3), 34.5 (C-2), 51.8 (O*C*H_3), 75.0 (C-5), 94.5 (C-4), 124.4 (C-2"), 125.8 (C-5"), 126.7 (C-4"), 127.9 (C-3'), 129.7 (C-4'), 130.8 (C-3"), 134.0 (C-2'), 135.4 (C-1'), 172.8 (C-1) ppm.

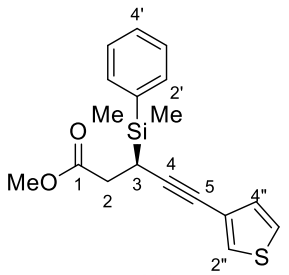
^{29}Si DEPT NMR (99 MHz, $CDCl_3$, 298 K): δ −0.2 (*Si*Me_2Ph) ppm.

HRMS (APCI) m/z: $[M+H]^+$ calcd for $C_{18}H_{21}O_2SSi$ 329.1026, found 329.1030.

IR (ATR): ṽ 695, 780, 1112, 1250, 1427, 1517, 1588, 1735, 2208, 2951 cm^{-1}.

Optical rotation: $[\alpha]_D^{20}$ = −97.0 (*c* 1.0, $CHCl_3$, 93% *ee*).

The enantiomeric ratio of (*R*)-**136m** was determined by HPLC analysis on a chiral stationary phase (*Daicel Chiralcel* OD-H column, column temperature 20 °C, solvent: *n*heptane/*i*PrOH = 98/2, flow rate = 0.5 mL/min): t_S = 15.3 min (minor), t_R = 22.6 min (major).



(*R*)-**136n**
$C_{18}H_{20}O_2SSi$
M = 328.50 g/mol

Methyl (*R*)-3-(dimethyl(phenyl)silyl)-5-(thiophen-3-yl)pent-4-ynoate [(*R*)-**136n**]: Synthesized from methyl methyl (*E*)-5-(thiophen-3-yl)pent-2-en-4-ynoate [(*E*)-**135n**, 38.4 mg, 0.200 mmol, 1.00 equiv] according to **GP 2.4**. Purification by flash column chromatography on silica gel with cyclohexane/EtOAc = 60/1 as eluent delivered (*R*)-**136n** as a brown oil (57.8 mg, 88% yield).

R_f = 0.50 (cyclohexane/EtOAc = 20/1).

^{1}H NMR (500 MHz, $CDCl_3$, 298 K): δ 0.47 (s, 3H, SiC*H*$_3$), 0.48 (s, 3H, SiC*H*$_3$), 2.39–2.52 (m, 2H, H-2), 2.61 (dd, $^3J_{3,2A}$ = 10.2 Hz, $^3J_{3,2B}$ = 4.9 Hz, 1H, H-3), 3.65 (s, 3H, OC*H*$_3$), 7.03 (dd, $^3J_{4",5"}$ = 5.0 Hz, $^3J_{4",2"}$ = 1.1 Hz, 1H, H-4"), 7.22 (dd, $^3J_{5",4"}$ = 5.0 Hz, $^3J_{5",2"}$ = 3.0 Hz, 1H, H-5"), 7.28 (dd, $^3J_{2",5"}$ = 3.0 Hz, $^3J_{2",4"}$ = 1.1 Hz, 1H, H-2"), 7.36–7.44 (m, 3H, H-3' and H-4'), 7.59–7.62 (m, 2H, H-2') ppm.

^{13}C NMR (100 MHz, $CDCl_3$, 298 K): δ −5.3 (Si*C*H_3), −4.4 (Si*C*H_3), 16.8 (C-3), 34.6 (C-2), 51.7 (O*C*H_3), 76.9 (C-5), 89.7 (C-4), 123.2 (C-3"), 124.8 (C-5"), 127.3 (C-2"), 127.8 (C-3'), 129.6 (C-4'), 130.0 (C-4"), 134.0 (C-2'), 135.6 (C-1'), 172.9 (C-1) ppm.

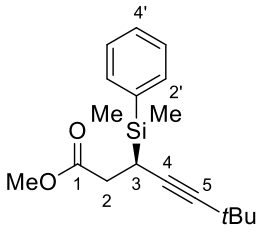
^{29}Si DEPT NMR (99 MHz, $CDCl_3$, 298 K): δ −0.3 (*Si*Me_2Ph) ppm.

HRMS (APCI) m/z: $[M+H]^+$ calcd for $C_{18}H_{21}O_2SSi$ $[M+H]^+$: calculated 329.1026, found 329.1030.

IR (ATR): ṽ 698, 776, 1112, 1249, 1428, 1520, 1588, 1734, 2215, 2951 cm^{-1}.

Optical rotation: $[\alpha]_D^{20}$ = −93.7 (*c* 1.0, $CHCl_3$, 93% *ee*).

The enantiomeric ratio of (*R*)-**136n** was determined by HPLC analysis on a chiral stationary phase (*Daicel Chiralcel* OD-H column, column temperature 20 °C, solvent: *n*heptane/*i*PrOH = 98/2, flow rate = 0.5 mL/min): t_S = 15.2 min (minor), t_R = 21.1 min (major).



(*R*)-**136o**
$C_{18}H_{26}O_2Si$
M = 302.49 g/mol

Methyl (*R*)-3-(dimethyl(phenyl)silyl)-6,6-dimethylhept-4-ynoate [(*R*)-**136o**): Synthesized from methyl (*E*)-5-(trimethylsilyl)pent-2-en-4-ynoate [(*E*)-**135o**, 33.2 mg, 0.200 mmol, 1.00 equiv] according to **GP 2.4**. Purification by flash column chromatography on silica gel with cyclohexane/EtOAc = 150/1 delivered (*R*)-**136o** as a yellow oil (51.1 mg, 84% yield).

R_f = 0.25 (cyclohexane/EtOAc = 100/1).

^{1}H NMR (400 MHz, $CDCl_3$, 298 K): δ 0.39 (s, 3H, SiC*H*$_3$), 0.39 (s, 3H, SiC*H*$_3$), 1.17 (s, 9H, C(C*H*$_3$)$_3$), 2.28–2.36 (m, 3H, H-2 and H-3), 3.62 (s, 3H, OC*H*$_3$), 7.33–7.41 (m, 3H, H-3' and H-4'), 7.55–7.59 (m, 2H, H-2') ppm.

^{13}C NMR (100 MHz, $CDCl_3$, 298 K): δ −5.5 (Si*C*H_3), −4.6 (Si*C*H_3), 16.0 (C-3), 27.4 (*C*$(CH_3)_3$), 31.3 (C(*C*$H_3)_3$), 35.2 (C-2), 51.5 (O*C*H_3), 78.0 (C-4), 90.6 (C-5), 127.7 (C-3'), 129.4 (C-4'), 134.0 (C-2'), 136.1 (C-1'), 173.2 (C-1) ppm.

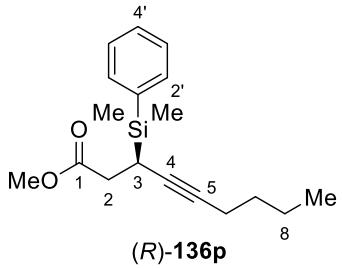
^{29}Si DEPT NMR (99 MHz, $CDCl_3$, 298 K): δ −1.1 (*Si*Me_2Ph) ppm.

HRMS (APCI) m/z: $[M+H]^+$ calcd for $C_{18}H_{27}O_2Si$ 303.1775, found 303.1776.

IR (ATR): ṽ 699, 1030, 1112, 1429, 1455, 1589, 1738, 2209, 2963 cm^{-1}.

Optical rotation: $[\alpha]_D^{20}$ = − 51.9 (*c* 1.0, $CHCl_3$, 89% *ee*).

The enantiomeric ratio of (*R*)-**136o** was determined by HPLC analysis on a chiral stationary phase (*Daicel Chiralcel* OD-H column, column temperature 20 °C, solvent: heptane/*i*PrOH = 98/2, flow rate = 0.5 mL/min): t_S = 8.4 min (minor), t_R = 9.5 min (major).



(*R*)-**136p**
$C_{18}H_{26}O_2Si$
M = 302.49 g/mol

Methyl (*R*)-3-(dimethyl(phenyl)silyl)non-4-ynoate [(*R*)-**136p**]: Synthesized from methyl (*E*)-non-2-en-4-ynoate [(*E*)-**135p**, 33.3 mg, 0.200 mmol, 1.00 equiv] according to **GP 2.4**. Purification by flash column chromatography on silica gel with cyclohexane/EtOAc = 150/1 as eluent delivered (*R*)-**136p** as a colourless oil (41.9 mg, 69% yield).

R_f = 0.50 (cyclohexane/EtOAc = 30/1).

^{1}H NMR (500 MHz, $CDCl_3$, 298 K): δ 0.40 (s, 3H, SiCH_3), 0.40 (s, 3H, SiCH_3), 0.90 (t, $^3J_{9,8}$ = 7.3 Hz, 3H, H-9), 1.35–1.45 (m, 2H, H-8), 1.45–1.48 (m, 2H, H-7) 2.14–2.18 (m, 2H, H-6), 2.29–2.38 (m, 3H, H-3 and H-2), 3.63 (s, 3H, OCH_3), 7.34–7.39 (m, 3H, H-3' and H-4'), 7.54–7.57 (m, 2H, H-2') ppm.

^{13}C NMR (100 MHz, $CDCl_3$, 298 K): δ −5.5 (Si*C*H_3), −4.5 (Si*C*H_3), 13.6 (C-9), 16.1 (C-3), 18.6 (C-6), 21.8 (C-8), 31.3 (C-7), 35.1 (C-2), 51.5 (O*C*H_3), 79.6 (C-4), 81.8 (C-5), 127.8 (C-3'), 129.4 (C-4'), 134.0 (C-2'), 136.1 (C-1'), 173.2 (C-1) ppm.

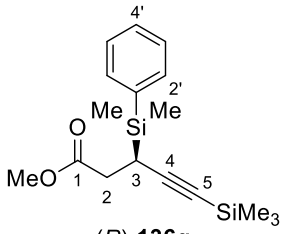
^{29}Si DEPT NMR (99 MHz, $CDCl_3$, 298 K): δ −0.8 (*Si*Me_2Ph) ppm.

HRMS (APCI) m/z: $[M+H]^+$ calcd for $C_{18}H_{27}O_2Si$ 303.1775, found 303.1776.

IR (ATR): ṽ 700, 814, 1036, 1113, 1250, 1429, 1589, 1738, 2216, 2954 cm^{-1}.

Optical rotation: $[\alpha]_D^{20}$ = −34.1 (*c* 1.0, $CHCl_3$, 84% *ee*).

The enantiomeric ratio of (*R*)-**136p** was determined by HPLC analysis on a chiral stationary phase (*Daicel Chiralcel* OD-H column, column temperature 20 °C, solvent: *n*heptane/*i*PrOH = 99/1, flow rate = 0.5 mL/min): t_S = 13.5 min (minor), t_R = 14.2 min (major).



(*R*)-**136q**
$C_{17}H_{26}O_2Si_2$
M = 318.56 g/mol

Methyl (*R*)-3-(dimethyl(phenyl)silyl)-5-(trimethylsilyl)pent-4-ynoate [(*R*)-**136q**]: Synthesized from methyl (*E*)-5-(trimethylsilyl)pent-2-en-4-ynoate [(*E*)-**135q**, 36.5 mg, 0.200 mmol, 1.00 equiv] according to **GP 2.4**. Purification by flash column chromatography on silica gel with cyclohexane/EtOAc = 100/1 delivered (*R*)-**136q** as a colourless oil (50.9 mg, 80% yield).

R_f = 0.25 (cyclohexane/EtOAc = 50/1).

^{1}H NMR (500 MHz, $CDCl_3$, 298 K): δ 0.13 (s, 9H, Si(C*H*$_3$)$_3$), 0.42 (s, 3H, SiC*H*$_3$), 0.43 (s, 3H, SiC*H*$_3$), 2.30–2.46 (m, 3H, H-2 and H-3), 3.62 (s, 3H, OC*H*$_3$), 7.34–7.42 (m, 3H, H-3' and H-4'), 7.55–7.58 (m, 2H, H-2') ppm.

^{13}C NMR (100 MHz, $CDCl_3$, 298 K): δ −5.5 (Si*C*H_3), −4.6 (Si*C*H_3), 0.1 (Si(*C*H_3)$_3$), 17.6 (C-3), 34.6 (C-2), 51.6 (O*C*H_3), 85.9 (C-5), 107.4 (C-4), 127.8 (C-3'), 129.6 (C-4'), 134.1 (C-2'), 135.6 (C-1'), 172.7 (C-1) ppm.

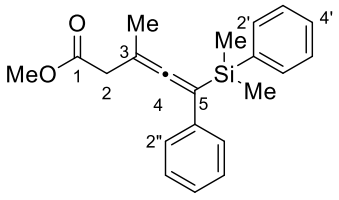
^{29}Si DEPT NMR (99 MHz, $CDCl_3$, 298 K): δ −0.8 (*Si*Me_2Ph), −19.4 (*Si*Me_3) ppm.

HRMS (APCI) m/z: $[M+H]^+$ calcd for $C_{17}H_{27}O_2Si_2$ 319.1544, found 319.1547.

IR (ATR): ṽ 698, 813, 1028, 1114, 1248, 1428, 1589, 1738, 2156, 2955 cm^{-1}.

Optical rotation: $[\alpha]_D^{20}$ = −59.4 (*c* 1.0, $CHCl_3$, 90% *ee*).

The enantiomeric ratio of (*R*)-**136q** was determined by HPLC analysis on a chiral stationary phase (*Daicel Chiralcel* OD-H column, column temperature 20 °C, solvent: *n*heptane/*i*PrOH = 98/2, flow rate = 0.5 mL/min): t_S = 8.6 min (minor), t_R = 9.9 min (major).



137r
$C_{21}H_{24}O_2Si$
M = 336.51 g/mol

Methyl 5-(dimethyl(phenyl)silyl)-3-methyl-5-phenylpenta-3,4-dienoate (**137r**): Synthesized from methyl (*E*)-3-methyl-5-phenylpent-2-en-4-ynoate [(*E*)-**135r**, 40.1 mg, 0.200 mmol, 1.00 equiv] according to **GP 2.4**. Purification by flash column chromatography on silica gel with cyclohexane/EtOAc = 100/1 as eluent delivered **137r** as a yellow oil (33.6 mg, 50% yield).

R_f = 0.40 (cyclohexane/EtOAc = 30/1).

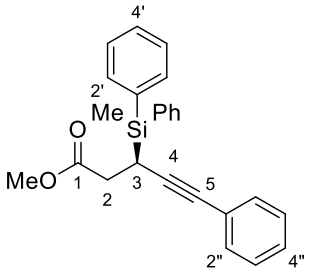
^{1}H NMR (500 MHz, $CDCl_3$, 298 K): δ 0.45 (s, 3H, SiCH_3), 0.45 (s, 3H, SiCH_3), 1.85 (s, 3H, CH_3), 3.02 (AB system d, $^2J_{2A,2B}$ = 15.0 Hz, 1H, H-2A), 3.07 (AB system d, $^2J_{2B,2A}$ = 15.0 Hz, 1H, H-2B), 3.67 (s, 3H, OCH_3), 7.10–7.15 (m, 1H, H-4"), 7.18–7.22 (m, 4H, H-2" and H-3"), 7.32–7.38 (m, 3H, H-3' and H-4'), 7.57–7.60 (m, 2H, H-2') ppm.

^{13}C NMR (100 MHz, $CDCl_3$, 298 K): δ –2.0 (Si*C*H_3), –1.8 (Si*C*H_3), 18.2 (*C*H_3), 39.4 (C-2), 51.7 (O*C*H_3), 90.4 (C-3), 98.9 (C-5), 126.2 (C-4"), 127.8 (C-2"), 128.0 (C-3"), 128.3 (C-2'), 129.1 (C-4'), 133.9 (C-2'), 137.3 (C-1"), 138.5 (C-1'), 171.6 (C-1), 209.0 (C-4) ppm.

^{29}Si DEPT NMR (99 MHz, $CDCl_3$, 298 K): δ −7.9 (*Si*Me_2Ph) ppm.

HRMS (APCI) m/z: $[M+H]^+$ calcd for $C_{21}H_{25}O_2Si$ 337.1618, found 337.1619.

IR (ATR): ṽ 695, 1110, 1249, 1429, 1594, 1737, 1935, 2196, 2950 cm^{-1}.



(*R*)-**139a**
$C_{25}H_{24}O_2Si$
M = 384.55 g/mol

Methyl (*R*)-3-(methyldiphenylsilyl)-5-phenylpent-4-ynoate [(*R*)-**139a**]: Synthesized from methyl (*E*)-5-phenylpent-2-en-4-ynoate [(*E*)-**135a**, 37.8 mg, 0.200 mmol, 1.00 equiv] according to **GP 2.4**. Purification by flash column chromatography on silica gel with cyclohexane/EtOAc = 100/1 as eluent delivered (*R*)-**139a** as a yellow oil (37.2 mg, 48% yield).

R_f = 0.20 (cyclohexane/EtOAc = 20/1).

^{1}H NMR (500 MHz, $CDCl_3$, 298 K): δ 0.72 (s, 3H, SiC*H*Ph_2), 2.45–2.60 (m, 2H, H-2), 3.01 (dd, $^3J_{3,2A}$ = 10.3 Hz, $^3J_{3,2B}$ = 4.8 Hz, 1H, H-3), 3.64 (s, 3H, OC*H*$_3$), 7.20–7.24 (m, 3H, H-3" and H-4"), 7.24–7.28 (m, 2H, H-2"), 7.34–7.44 (m, 6H, H-3' and H-4'), 7.63 (d, $^3J_{2',3'}$ = 6.8 Hz, 2H, H-2'), 7.67 (d, $^3J_{2',3'}$ = 6.8 Hz, 2H, H-2') ppm.

^{13}C NMR (125 MHz, $CDCl_3$, 298 K): δ –5.7 (Si*C*H_3Ph_2), 15.8 (C-3), 35.0 (C-2), 51.8 (O*C*H_3), 82.8 (C-5), 90.2 (C-4), 124.2 (C-1"), 127.3 (C-4"), 127.9 (C-3'), 128.0 (C-3'), 128.0 (C-3"), 129.8 (C-4'), 129.8 (C-4'), 131.4 (C-2"), 133.9 (C-1'), 134.1 (C-1'), 135.0 (C-2', 2C), 172.8 (C-1) ppm.

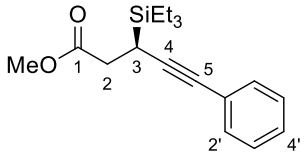
^{29}Si DEPT NMR (99 MHz, $CDCl_3$, 298 K): δ −6.4 (*Si*$MePh_2$) ppm.

HRMS (LIFDI) m/z: $[M]^{\bullet+}$ calcd for $C_{25}H_{24}O_2Si$ 384.1546, found 384.1537.

IR (ATR): ṽ 691, 1109, 1166, 1252, 1427, 1594, 1622, 1735, 2219, 2950 cm^{-1}.

Optical rotation: $[\alpha]_D^{20}$ = −40.3 (*c* 1.6, $CHCl_3$, 78% *ee*).

The enantiomeric ratio of (*R*)-**139a** was determined by HPLC analysis on a chiral stationary phase (*Daicel Chiralcel* OD-H column, column temperature 20 °C, solvent: *n*heptane/*i*PrOH = 98/2, flow rate = 0.5 mL/min): t_S = 17.2 min (minor), t_S = 27.6 min (major).



(*R*)-**143a**
$C_{18}H_{26}O_2Si$
M = 302.49 g/mol

Methyl (*R*)-5-phenyl-3-(triethylsilyl)pent-4-ynoate [(*R*)-**143a**]: Synthesized from methyl (*E*)-5-phenylpent-2-en-4-ynoate [(*E*)-**135a**, 39.8 mg, 0.200 mmol, 1.00 equiv] according to **GP 2.4**. Purification by flash column chromatography on silica gel with cyclohexane/EtOAc = 100/1 as eluent delivered (*R*)-**143a** as a brown oil (43.0 mg, 71% yield).

$\mathbf{R_f}$ = 0.45 (cyclohexane/EtOAc = 30/1).

^{1}H NMR (400 MHz, $CDCl_3$, 298 K): δ 0.60–0.68 (m, 6H, $SiCH_2CH_3$), 0.96 (t, 9H, ^3J = 8.0 Hz, $SiCH_2CH_3$), 2.38–2.55 (m, 3H, H-2 and H-3), 3.67 (s, 3H, OCH_3), 7.15–7.21 (m, 3H, H-3' and H-4'), 7.25–7.29 (m, 2H, H-2') ppm.

^{13}C NMR (100 MHz, $CDCl_3$, 298 K): δ 2.4 ($SiCH_2CH_3$), 7.4 ($SiCH_2CH_3$), 13.9 (C-3), 34.8 (C-2), 51.8 (OCH_3), 81.5 (C-5), 90.8 (C-4), 124.5 (C-1'), 127.2 (C-4'), 128.1 (C-3'), 131.4 (C-2'), 173.2 (C-1) ppm.

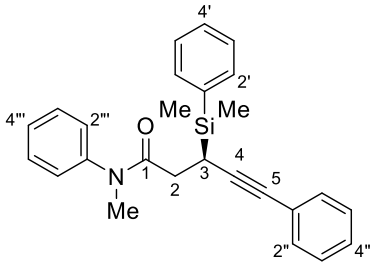
^{29}Si DEPT NMR (99 MHz, $CDCl_3$, 298 K): δ 9.4 ($SiEt_3$) ppm.

HRMS (APCI) m/z: $[M+H]^+$ calcd for $C_{18}H_{27}O_2Si$ 303.1775, found 303.1774.

IR (ATR): ṽ 690, 1116, 1239, 1435, 1596, 1685, 1736, 2218, 2952 cm^{-1}.

Optical rotation: $[\alpha]_D^{20}$ = −28.4 (*c* 0.6, $CHCl_3$, 58% *ee*).

The enantiomeric ratio of (*R*)-**143a** was determined HPLC analysis on a chiral stationary phase (*Daicel Chiralcel* OD-H column, column temperature 20 °C, solvent: *n*heptane/*i*PrOH = 98/2, flow rate = 0.5 mL/min): t_S = 9.9 min (minor), t_R = 11.0 min (major).



(*R*)-**145a**
$C_{26}H_{27}NOSi$
M = 397.59 g/mol

(*R*)-3-(dimethyl(phenyl)silyl)-*N*-methyl-*N*,5-diphenylpent-4-ynamide [(*R*)-**145a**): Synthesized from methyl (*E*)-*N*-methyl-*N*,5-diphenylpent-2-en-4-ynamide [(*E*)-**144a**, 52.2 mg, 0.200 mmol, 1.00 equiv] according to **GP 2.4**. Purification by flash column chromatography on silica gel with cyclohexane/EtOAc = 10/1 as eluent delivered (*R*)-**145a** as a colourless oil (62.9 mg, 79% yield).

R_f = 0.50 (cyclohexane/EtOAc = 5/1).

^{1}H NMR (400 MHz, $CDCl_3$, 298 K): δ 0.32 (s, 3H, SiC*H*$_3$), 0.34 (s, 3H, SiC*H*$_3$), 2.11 (dd, $^2J_{2A,2B}$ = 15.0 Hz, $^2J_{2A,3}$ = 4.7 Hz, 1H, H-2A), 2.35 (dd, $^2J_{2B,2A}$ = 15.0 Hz, $^2J_{2B,2A}$ = 10.1 Hz, 1H, H-2B), 2.76 (dd, $^3J_{3,2B}$ = 10.1 Hz, $^3J_{3,2A}$ = 4.7 Hz, 1H, H-3), 3.25 (s, 3H, NC*H*$_3$), 7.10–7.14 (m, 2H, H-2'''), 7.25–7.28 (m, 3H, H-3'' and H-4''), 7.28–7.36 (m, 8H, H-3', H-4', H-2'', H-3''' and H-4'''), 7.44–7.49 (m, 2H, H-2') ppm.

^{13}C NMR (100 MHz, $CDCl_3$, 298 K): δ −5.1 (Si*C*H$_3$), −4.3 (Si*C*H$_3$), 16.9 (C-3), 33.8 (C-2), 37.5 (N*C*H$_3$), 81.7 (C-5), 91.5 (C-4), 124.6 (C-1''), 127.2 (C-4''), 127.5 (C-2'''), 127.6 (C-4'''), 127.7 (C-3'), 128.1 (C-3''), 129.3 (C-3'''), 129.5 (C-4'), 131.4 (C-2''), 134.0 (C-2'), 136.1 (C-1'), 143.9 (C-1'''), 171.7 (C-1) ppm.

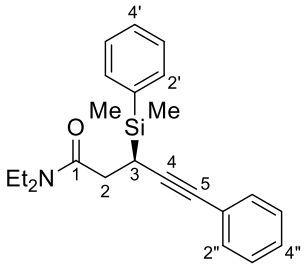
^{29}Si DEPT NMR (99 MHz, $CDCl_3$, 298 K): δ −0.2 (*Si*Me$_2$Ph) ppm.

HRMS (APCI) m/z: $[M+H]^+$ calcd for $C_{26}H_{28}NOSi$ 398.1935, found 398.1930.

IR (ATR): ṽ 692, 1112, 1173, 1249, 1424, 1592, 1653, 2213, 2954 cm^{-1}.

Optical rotation: $[\alpha]_D^{20}$ = +66.9 (*c* 2.0, $CHCl_3$, 90% *ee*).

The enantiomeric ratio of (*R*)-**145a** was determined by HPLC analysis on a chiral stationary phase (*Daicel Chiralcel* OD-H column, column temperature 20 °C, solvent: *n*heptane/*i*PrOH = 98/2, flow rate = 0.5 mL/min): t_S = 27.2 min (minor), t_R = 42.4 min (major).



(*R*)-**145b**
$C_{23}H_{29}NO_2Si$
M = 363.58 g/mol

(*R*)-3-(dimethyl(phenyl)silyl)-*N*,*N*-diethyl-5-phenylpent-4-ynamide [(*R*)-**145b**]: Synthesized from (*E*)-*N*,*N*-diethyl-5-phenylpent-2-en-4-ynamide [(*E*)-**144b**, 45.5 mg, 0.200 mmol, 1.00 equiv] according to **GP 2.4**. Purification by flash column chromatography on silica gel with cyclohexane/EtOAc = 5/1 as eluent delivered (*R*)-**145b** as a brown oil (59.7 mg, 82% yield).

R_f = 0.20 (cyclohexane/EtOAc = 8/1).

^{1}H NMR (500 MHz, $CDCl_3$, 298 K): δ 0.47 (s, 3H, SiC*H*$_3$), 0.48 (s, 3H, SiC*H*$_3$), 1.08 [t, ^3J = 7.2 Hz, 3H, N(CH_2CH_3)$_2$], 1.09 [t, ^3J = 7.2 Hz, 3H, N(CH_2CH_3)$_2$], 2.28 (dd, $^2J_{2A,2B}$ = 14.7 Hz, $^3J_{2A,3}$ = 4.8 Hz, 1H, H-2A), 2.60 (dd, $^2J_{2B,2A}$ = 14.7 Hz, $^3J_{2B,3}$ = 9.8 Hz, 1H, H-2B), 2.84 (dd, $^3J_{3,2B}$ = 9.8 Hz, $^3J_{3,2A}$ = 4.8 Hz, 1H, H-3), 3.10–3.22 [m, 1H, N(C*H*$_2$CH$_3$)$_2$], 3.27–3.37 [m, 2H, N(C*H*$_2$CH$_3$)$_2$], 3.37–3.45 [m, 1H, N(C*H*$_2$CH$_3$)$_2$], 7.20–7.27 (m, 3H, H-3" and H-4"), 7.30–7.33 (m, 2H, H-2"), 7.33–7.41 (m, 3H, H-3' and H-4'), 7.61–7.65 (m, 2H, H-2') ppm.

^{13}C NMR (100 MHz, $CDCl_3$, 298 K): δ −4.7 (Si*C*H$_3$), −4.3 (Si*C*H$_3$), 13.1 [N(CH_2CH$_3$)$_2$], 14.3 [N(CH_2CH$_3$)$_2$], 17.0 (C-3), 32.7 (C-2), 40.5 [N(*C*H$_2$CH$_3$)$_2$], 42.1 [N(*C*H$_2$CH$_3$)$_2$], 81.6 (C-5), 91.4 (C-4), 124.8 (C-1"), 127.1 (C-4"), 127.7 (C-3'), 128.0 (C-3"), 129.4 (C-4'), 131.3 (C-2"), 134.1 (C-2'), 136.2 (C-1'), 170.8 (C-1) ppm.

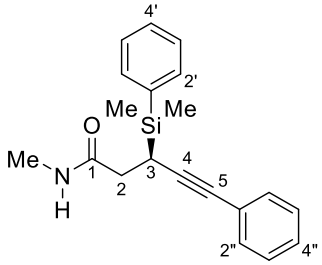
^{29}Si DEPT NMR (99 MHz, $CDCl_3$, 298 K): δ −0.2 (*Si*Me$_2$Ph) ppm.

HRMS (APCI) m/z: $[M+H]^+$ calcd for $C_{23}H_{30}NOSi$ 364.2091, found 364.2097.

IR (ATR): ṽ 691, 812, 1069, 1111, 1249, 1425, 1596, 1636, 2215, 2967 cm^{-1}.

Optical rotation: $[\alpha]_D^{20}$ = −67.6 (*c* 1.0, $CHCl_3$, 92% *ee*).

The enantiomeric ratio of (*R*)-**145b** was determined by HPLC analysis on a chiral stationary phase (*Daicel Chiralcel* OD-H column, column temperature 20 °C, solvent: heptane/*i*PrOH = 98/2, flow rate = 0.5 mL/min): t_S = 24.1 min (minor), t_R = 34.0 min (major).



(*R*)-**145c**
$C_{20}H_{23}NOSi$
M = 321.50 g/mol

(*R*)-3-(dimethyl(phenyl)silyl)-*N*-methyl-5-phenylpent-4-ynamide [(*R*)-**145c**]: Synthesized from methyl (*E*)-*N*-methyl-5-phenylpent-2-en-4-ynamide [(*E*)-**144c**, 37.1 mg, 0.200 mmol, 1.00 equiv] according to **GP 2.4**. Purification by flash column chromatography on silica gel with cyclohexane/EtOAc = 2/1 as eluent delivered (*R*)-**145c** as a colourless oil (18.1 mg, 28% yield).

$\mathbf{R_f}$ = 0.20 (cyclohexane/EtOAc = 2/1).

^{1}H NMR (400 MHz, $CDCl_3$, 298 K): δ 0.39 (s, 3H, SiCH_3), 0.40 (s, 3H, SiCH_3), 2.17 (dd, $^2J_{2A,2B}$ = 14.7 Hz, $^3J_{2A,3}$ = 11.4 Hz, 1H, H-2A), 2.28 (dd, $^2J_{2B,2A}$ = 14.7 Hz, $^3J_{2B,3}$ = 3.6 Hz, 1H, H-2B), 2.47 (dd, $^3J_{3,2A}$ = 11.4 Hz, $^3J_{3,2B}$ = 3.6 Hz, 1H, H-3), 2.72 (d, ^3J = 4.9 Hz, 3H, NCH_3), 5.84 (s, 1H, NH_2), 7.18–7.22 (m, 3H, H-3" and H-4"), 7.24–7.29 (m, 2H, H-2"), 7.29–7.34 (m, 3H, H-3' and H-4'), 7.51–7.54 (m, 2H, H-2') ppm.

^{13}C NMR (100 MHz, $CDCl_3$, 298 K): δ −5.0 (SiCH$_3$), −4.6 (SiCH$_3$), 17.4 (C-3), 26.4 (NCH$_3$), 36.7 (C-2), 82.9 (C-5), 90.6 (C-4), 123.9 (C-1"), 127.6 (C-4"), 127.9 (C-3'), 128.2 (C-3"), 129.7 (C-4'), 131.4 (C-2"), 134.1 (C-2'), 135.5 (C-1'), 172.6 (C-1) ppm.

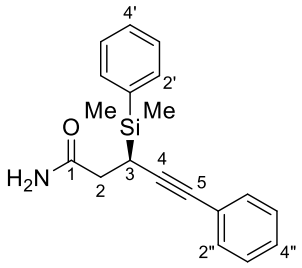
^{29}Si DEPT NMR (99 MHz, $CDCl_3$, 298 K): δ −0.2 (*Si*Me$_2$Ph) ppm.

HRMS (APCI) m/z: $[M+H]^+$ calcd for $C_{20}H_{24}NOSi$ 322.1622, found 322.1615.

IR (ATR): ṽ 691, 1112, 1157, 1249, 1426, 1544, 1642, 2215, 2954 cm^{-1}.

Optical rotation: $[\alpha]_D^{20}$ = −68.9 (*c* 0.5, $CHCl_3$, 73% *ee*).

The enantiomeric ratio of (*R*)-**145c** was determined by HPLC analysis on a chiral stationary phase (*Daicel Chiralcel* AS-H column, column temperature 20 °C, solvent: *n*heptane/*i*PrOH = 90/10, flow rate = 0.5 mL/min): t_S = 54.8 min (minor), t_R = 74.7 min (major).



(*R*)-**145d**
$C_{19}H_{21}NOSi$
M = 307.47 g/mol

(*R*)-3-(dimethyl(phenyl)silyl)-5-phenylpent-4-ynamide [(*R*)-**145d**]: Synthesized from (*E*)-5-phenylpent-2-en-4-ynamide [(*E*)-**144d**, 34.2 mg, 0.200 mmol, 1.00 equiv] according to **GP 2.4**. Purification by flash column chromatography on silica gel with cyclohexane/EtOAc = 1/1 as eluent delivered (*R*)-**145d** as a colourless oil (15.6 mg, 25% yield).

$\mathbf{R_f}$ = 0.20 (cyclohexane/EtOAc = 1/1).

^{1}H NMR (400 MHz, $CDCl_3$, 298 K): δ 0.40 (s, 3H, SiC*H*$_3$), 0.40 (s, 3H, SiC*H*$_3$), 2.17–2.28 (m, 2H, H-2), 2.46 (dd, $^3J_{3,2A}$ = 10.6 H, $^3J_{3,2B}$ = 4.5 Hz, 1H, H-3), 5.53 (s, 1H, N*H*$_2$), 5.89 (s, 1H, N*H*$_2$), 7.18–7.22 (m, 3H, H-3" and H-4"), 7.25–7.30 (m, 2H, H-2"), 7.30–7.35 (m, 3H, H-3' and H-4'), 7.51–7.54 (m, 2H, H-2') ppm.

^{13}C NMR (100 MHz, $CDCl_3$, 298 K): δ −5.1 (Si*C*H$_3$), −4.6 (Si*C*H$_3$), 17.4 (C-3), 36.2 (C-2), 82.9 (C-5), 90.4 (C-4), 123.8 (C-1"), 127.6 (C-4"), 127.9 (C-3'), 128.2 (C-3"), 129.7 (C-4'), 131.4 (C-2"), 134.1 (C-2'), 135.4 (C-1'), 174.6 (C-1) ppm.

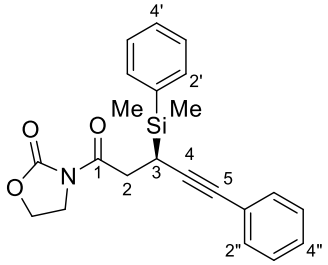
^{29}Si DEPT NMR (99 MHz, $CDCl_3$, 298 K): δ 0.0 (*Si*Me$_2$Ph) ppm.

HRMS (APCI) m/z: $[M+H]^+$ calcd for $C_{19}H_{22}NOSi$ 308.1465, found 308.1462.

IR (ATR): ṽ 691, 1112, 1189, 1249, 1425, 1595, 1655, 2215, 2956 cm^{-1}.

Optical rotation: $[\alpha]_D^{20}$ = −62.0 (*c* 0.8, $CHCl_3$, 95% *ee*).

The enantiomeric ratio of (*R*)-**145d** was determined by HPLC analysis on a chiral stationary phase (*Daicel Chiralcel* AS-H column, column temperature 20 °C, solvent: *n*heptane/*i*PrOH = 70/30, flow rate = 0.5 mL/min): t_R = 57.6 min (major), t_S = 77.9 min (minor).



(*R*)-**145e**
$C_{22}H_{23}NO_3Si$
M = 377.52 g/mol

(*R*)-3-(3-(dimethyl(phenyl)silyl)-5-phenylpent-4-ynoyl)oxazolidin-2-one [(*R*)-**145e**]: Synthesized from (*E*)-3-(5-phenylpent-2-en-4-ynoyl)oxazolidin-2-one [(*E*)-**144e**, 48.2 mg, 0.200 mmol, 1.00 equiv] according to **GP 2.4**. Purification by flash column chromatography on silica gel with cyclohexane/EtOAc = 5/1 as eluent delivered (*R*)-**145e** as a brown oil (67.4 mg, 82% yield).

R_f = 0.30 (cyclohexane/EtOAc = 3/1).

^{1}H NMR (500 MHz, $CDCl_3$, 298 K): δ 0.41 (s, 3H, SiC*H*$_3$), 0.43 (s, 3H, SiC*H*$_3$), 2.65 (dd, $^3J_{3,2B}$ = 10.7 Hz, $^3J_{3,2A}$ = 4.3 Hz, 1H, H-3), 2.92 (dd, $^2J_{2A,2B}$ = 16.3 Hz, $^3J_{2A,3}$ = 4.3 Hz, 1H, H-2A), 2.84 (dd, $^2J_{2B,2A}$ = 16.3 Hz, $^3J_{2B,3}$ = 10.7 Hz, 1H, H-2B), 3.75–3.84 (m, 1H, NC*H*$_2$), 3.84–3.91 (m, 1H, NC*H*$_2$), 4.23 (t, ^3J = 8.3 Hz, 2H, OC*H*$_2$), 7.15–7.20 (m, 3H, H-3" and H-4"), 7.24–7.27 (m, 2H, H-2"), 7.27–7.34 (m, 3H, H-3' and H-4'), 7.51–7.55 (m, 2H, H-2') ppm.

^{13}C NMR (125 MHz, $CDCl_3$, 298 K): δ −5.4 (Si*C*H$_3$), −4.3 (Si*C*H$_3$), 16.2 (C-3), 35.4 (C-2), 42.5 (NC*H*$_2$), 62.0 (OC*H*$_2$), 82.0 (C-5), 90.5 (C-4), 124.2 (C-1"), 127.3 (C-4"), 127.8 (C-3'), 128.1 (C-3"), 129.6 (C-4'), 131.4 (C-2"), 134.1 (C-2'), 135.8 (C-1'), 153.4 (O*C*(O)N), 171.9 (C-1) ppm.

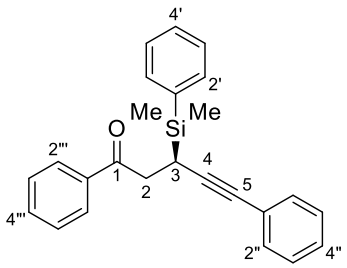
^{29}Si DEPT NMR (99 MHz, $CDCl_3$, 298 K): δ 0.2 (*Si*Me$_2$Ph) ppm.

HRMS (APCI) m/z: $[M+H]^+$ calcd for $C_{22}H_{24}NO_3Si$ 378.1520, found 378.1513.

IR (ATR): ṽ 692, 811, 1094, 1111, 1248, 1426, 1595, 1697, 1773, 2215, 2955 cm^{-1}.

Optical rotation: $[\alpha]_D^{20}$ = −23.6 (*c* 0.5, $CHCl_3$, 30% *ee*).

The enantiomeric ratio of (*R*)-**145e** was determined by HPLC analysis on a chiral stationary phase (*Daicel Chiralcel* OD-H column, column temperature 20 °C, solvent: *n*heptane/*i*PrOH = 96/4, flow rate = 0.3 mL/min): t_R = 212.9 min (major), t_S = 252.9 min (minor).



(*R*)-**147a**
$C_{25}H_{24}OSi$
M = 368.55 g/mol

(*R*)-3-(dimethyl(phenyl)silyl)-1,5-diphenylpent-4-yn-1-one [(*R*)-**147a**]: Synthesized from (*E*)-1,5-diphenylpent-2-en-4-yn-1-one [(*E*)-**146a**, 46.5 mg, 0.200 mmol, 1.00 equiv] according to **GP 2.4**. Purification by flash column chromatography on silica gel with cyclohexane/EtOAc = 60/1 as eluent delivered (*R*)-**147a** as a brown oil (45.2 mg, 61% yield).

R_f = 0.50 (cyclohexane/EtOAc = 10/1).

^{1}H NMR (400 MHz, $CDCl_3$, 298 K): δ 0.51 (s, 3H, SiC*H*$_3$), 0.53 (s, 3H, SiC*H*$_3$), 2.87 (dd, $^3J_{3,2B}$ = 9.8 Hz, $^3J_{3,2A}$ = 4.1 Hz, 1H, H-3), 2.96 (dd, $^2J_{2A,2B}$ = 16.5 Hz, $^3J_{2A,3}$ = 4.1 Hz, 1H, H-2A), 3.26 (dd, $^2J_{2B,2A}$ = 16.5 Hz, $^3J_{2B,3}$ = 9.8 Hz, 1H, H-2B), 7.22–7.26 (m, 3H, H-3" and H-4"), 7.26–7.31 (m, 2H, H-2"), 7.39–7.46 (m, 5H, H-3', H-4' and H-3'''), 7.52–7.57 (m, 1H, H-4'''), 7.63–7.68 (m, 2H, H-2'), 7.88–7.92 (m, 2H, H-2''') ppm.

^{13}C NMR (100 MHz, $CDCl_3$, 298 K): δ −4.9 (Si*C*H$_3$), −4.2 (Si*C*H$_3$), 15.7 (C-3), 38.7 (C-2), 81.8 (C-5), 91.2 (C-4), 124.3 (C-1"), 127.2 (C-4"), 127.9 (C-3'), 128.0 (C-3'''), 128.2 (C-2'''), 128.5 (C-3"), 129.6 (C-4'), 131.4 (C-2"), 132.9 (C-4'''), 134.1 (C-2'), 136.0 (C-1'), 136.9 (C-1'''), 198.5 (C-1) ppm.

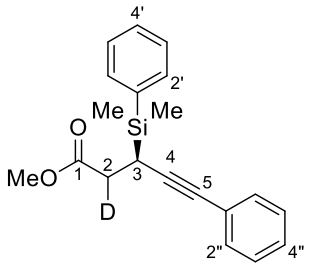
^{29}Si DEPT NMR (99 MHz, $CDCl_3$, 298 K): δ −0.2 (*Si*Me_2Ph) ppm.

HRMS (LIFDI) m/z: $[M]^{\bullet+}$ calcd for $C_{25}H_{24}OSi$ 368.1596, found 368.1561.

IR (ATR): ṽ 687, 1111, 1178, 1249, 1425, 1543, 1684, 1772, 2214, 2956 cm^{-1}.

Optical rotation: $[\alpha]_D^{20}$ = −46.1 (*c* 1.9, $CHCl_3$, 71% *ee*).

The enantiomeric ratio of (*R*)-**147a** was determined by HPLC analysis on a chiral stationary phase (*Daicel Chiralcel* AD-H column, column temperature 20 °C, solvent: *n*heptane/*i*PrOH = 99/1, flow rate = 0.5 mL/min): t_R = 28.5 min (major), t_S = 32.9 min (minor).



(*R*)-**136a**-d_1
$C_{20}H_{21}DO_2Si$
M = 323.48 g/mol

Methyl (3*R*)-3-(dimethyl(phenyl)silyl)-5-phenylpent-4-ynoate [(*R*)-**136a**-d_1): Synthesized from methyl (*E*)-5-phenylpent-2-en-4-ynoate [(*E*)-**135a**, 37.2 mg, 0.200 mmol, 1.00 equiv] according to **GP 2.4** (CD_3OD was used instead of CH_3OH). Purification by flash column chromatography on silica gel with cyclohexane/EtOAc = 80/1 as eluent delivered (*R*)-**136a**-d_1 as a yellow oil (60.0 mg, 93% yield).

R_f = 0.35 (cyclohexane/EtOAc = 30/1).

^{1}H NMR (500 MHz, $CDCl_3$, 298 K): δ 0.44 (s, 3H, SiC*H*$_3$), 0.45 (s, 3H, SiC*H*$_3$), 2.36–2.49 (m, 1.05H, H-2), 2.60 (dd, $^3J_{3,2A}$ = 7.6 Hz, $^3J_{3,2B}$ = 3.2 Hz, 1H, H-3), 3.63 (s, 3H, OC*H*$_3$), 7.21–7.27 (m, 3H, H-3" and H-4"), 7.30–7.34 (m, 2H, H-2"), 7.34–7.41 (m, 3H, H-3' and H-4'), 7.56–7.59 (m, 2H, H-2') ppm.

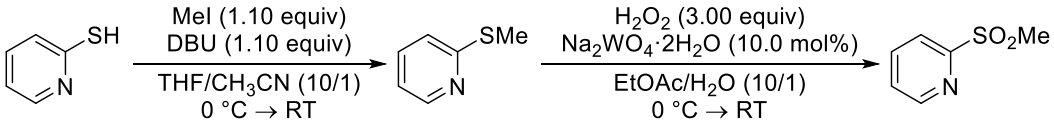
^{13}C NMR (125 MHz, $CDCl_3$, 298 K): δ −5.3 (Si*C*H$_3$), −4.4 (Si*C*H$_3$), 16.8 (C-3), 34.4 (t, $^1J_{C,D}$ = 80.6 Hz, C-2), 51.7 (O*C*H$_3$), 82.0 (C-5), 90.3 (C-4), 124.2 (C-1"), 127.3 (C-4"), 127.9 (C-3'), 128.1 (C-3"), 129.6 (C-4'), 131.4 (C-2"), 134.0 (C-2'), 135.6 (C-1'), 172.9 (C-1) ppm.

^{29}Si DEPT NMR (99 MHz, $CDCl_3$, 298 K): δ −0.3 (*Si*Me_2Ph) ppm.

HRMS (APCI) m/z: [M+H]+ calcd for $C_{20}H_{22}DO_2Si^+$ 324.1525; found 324.1529.

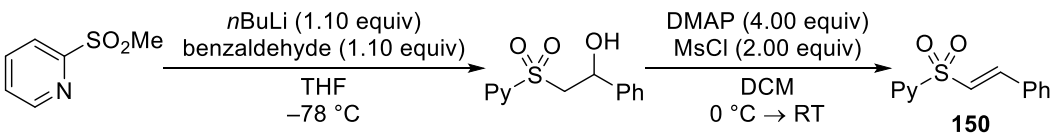
3.3 Asymmetric Conjugate 1.4-Silyl Transfer to *α,β*-Unsaturated Sulfones

3.3.1 Procedure for (*E*)-150



To a solution of 2-mercaptopyridine (2.22 g, 20 mmol) in a mixture solvent of CH_3CN (4 mL) and dry THF (40 mL) at 0 °C, was added 1,8-Diazabicyclo[5.4.0]undec-7-ene (DBU, 3.35 g, 22.0 mmol, 1.1 equiv). After stirring at 0 °C for 5 minutes, MeI (3.12 g, 22.0 mmol, 1.10 equiv) was added slowly. Then the reaction mixture was allowed to warm to room temperature and stirred overnight. The reaction mixture was quenched by water (30 mL) and extracted by EtOAc (3 × 30 mL). The combined organic phases were dried over anhydrous $MgSO_4$, filtered and concentrated under reduced pressure. Purifying the residue by flash column chromatography on silica gel with cyclohexane/EtOAc = 20/1 as eluent delivered the desired methyl 2-pyridyl sulfide as a colorless oil (2.23 g, 90%) and all spectroscopic data accord with those reported.[74].

To a solution of methyl 2-pyridyl sulfide (1.25 g, 10 mmol) in a mixture solvent of EtOAc (20 mL) and H_2O (2 mL), was added $Na_2WO_4{\cdot}2H_2O$ (329 mg, 1.00 mmol, 10.0 mol%). A aq. H_2O_2 solution (30%, 1.143 g, 30.0 mmol, 3.00 equiv) was added to the reaction mixture at 0 °C. After stirring at this temperature for 30 minutes, the reaction mixture was allowed to warm to room temperature, and then stirred at this temperature for an hour. The reaction was quenched by slow addition of sat. aq. $NaHSO_3$ (25 mL) at 0 °C, and then extracted by CH_2Cl_2 (3 x 20 mL). The combined organic phases were dried over anhydrous $MgSO_4$, filtered and concentrated under reduced pressure. Purifying the residue by flash column chromatography on silica gel with cyclohexane/EtOAc = 1/2 as eluent delivered the 2-(methylsulfonyl)pyridine as a colorless oil (1.32 g, 84%) and all spectroscopic data accord with those reported.[74]



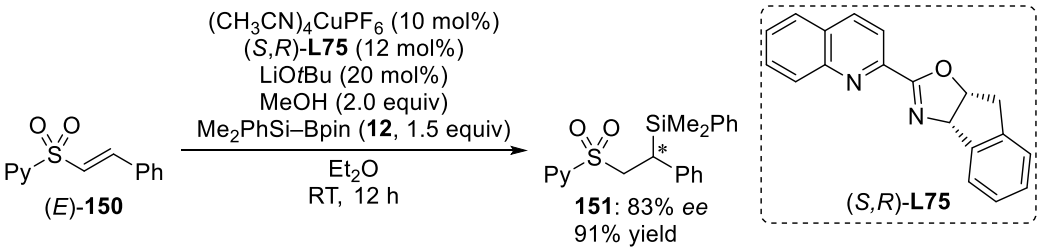
A heat gun-dried three-neck round-bottom flask equipped with a magnetic stir bar and a septum is purged with N_2, followed by the addition of 2-(methylsulfonyl)pyridine (1.57g, 10.0 mmol) and dry THF (20 mL). After cooling to –78 °C in a dry ice/acetone bath, a solution of

[74] P. H. Bos, A. J. Minnaard, B. L. Feringa, *Org*. *Lett*. **2008**, *10*, 4219–4222.

*n*BuLi in hexane (2.5 M, 4.4 mL, 11.0 mmol, 1.10 equiv) was added slowly. After stirring at –78 °C for 30 minutes, benzaldehyde (2.33 g, 11.0 mmol, 1.10 equiv) was added to the reaction mixture and then it was allowed to warm to room temperature. The reaction was quenched by addition of sat. aq. NH_4Cl solution (25 mL) and extracted by CH_2Cl_2 (3 x 20 mL). The combined organic phases were dried over anhydrous $MgSO_4$, filtered and concentrated under reduced pressure. Purifying the residue by flash column chromatography on silica gel with cyclohexane/EtOAc = 2/1 as eluent delivered a crude 2-pyridylsulfonylalcohol, which was used in the next step without any further purification.

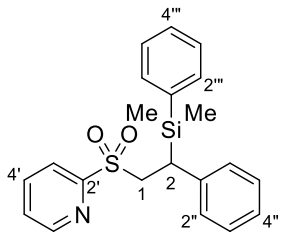
To a solution of crude 2-pyridylsulfonylalcohol and 4-Dimethylaminopyridine (DMAP, 4.89 g, 40.0 mmol, 4.00 equiv) in dry CH_2Cl_2, was added methanesulfonyl chloride (MsCl, 2.29 g, 20.0 mmol, 2.00 equiv) at 0 °C. The reaction mixture was allowed to warm to room temperature slowly and then stirred overnight. The reaction was quenched by addition of sat. aq. NH_4Cl solution (25 mL) and extracted by CH_2Cl_2 (3 x 20 mL). The combined organic phases were dried over anhydrous $MgSO_4$, filtered and concentrated under reduced pressure. Purifying the residue by flash column chromatography on silica gel with cyclohexane/EtOAc = 3/1 as eluent delivered the target **150** as a white solid (1.66 g, 68%) and all spectroscopic data accord with those reported.[74]

3.3.2 Procedure for Enantioenriched Product 151



A heat gun-dried Schlenk tube equipped with a magnetic stir bar and a septum was purged with N_2, followed by the addition of $(Ph_3P)_2CuBH_4$ (3.73 mg, 10.0 *µ*mol, 10.0 mol%), (*S*,*R*)-**L75** (2.86 mg, 12.0 *µ*mol, 12.0 mol%) and LiO*t*Bu (1.60 mg, 20.0 *µ*mol, 20.0 mol%). The tube was evacuated and backfilled with N_2 and then Et_2O (1 mL) was added. After stirring at room temperature for an hour, Me_2PhSi–Bpin (**12**, 39.3 mg, 0.150 mmol, 1.50 equiv) was added. *α*,*β*-Unsaturated sulfone **150** (24.5 mg, 0.100 mmol, 1.00 equiv) and methanol (6.48 mg, 0.200 mmol, 2.00 equiv) were added successively in 20 minutes. The reaction mixture was stirred at room temperature overnight, and then concentrated under reduced pressure. Purifying the residue by flash column chromatography on silica gel with cyclohexane/EtOAc = 3/1 as eluent delivered the corresponding product **151** as a white solid (34.7 mg, 91%).

3.3.3 Characterization Data for 151



151
$C_{21}H_{23}NO_2SSi$
M = 381.57 g/mol

2-{[2-(Dimethylphenylsilyl)-2-phenylethyl]sul-fonyl}pyridine

R_f = 0.50 (cyclohexane/EtOAc = 1/1).

M.**P**. 113–114 °C.

^{1}H NMR (500 MHz, $CDCl_3$, 298 K) δ 0.21 (s, 3H, SiCH_3), 0.24 (s, 3H, SiCH_3), 2.93 (dd, $^3J_{2,1B}$ = 13.1 Hz, $^3J_{2,1A}$ = 2.1 Hz, 1H, H-2), 3.41 (dd, $^2J_{1A,1B}$ = 15.1 Hz, $^3J_{1A,2}$ = 2.1 Hz, 1H, H-1A), 4.16 (dd, $^2J_{1B,1A}$ = 15.1 Hz, $^3J_{1B,2}$ = 13.1 Hz, 1H, H-1B), 6.59–6.63 (m, 2H, H-2"), 6.80–6.87 (m, 3H, H-3" and H-4"), 7.20–7.24 (m, 1H, H-5'), 7.32–7.37 (m, 4H, H-2'", H-3'"), 7.37–7.42 (m, 1H, 4'"), 7.43–7.50 (m, 2H, H-3', and H-4'), 8.47 (d, *J* = 4.7 Hz, 1H, H-6') ppm.

^{13}C NMR (125 MHz, $CDCl_3$, 298 K) δ -5.6 (SiCH_3), -4.2 (SiCH_3), 31.8 (C-2), 53.3 (C-1), 122.7 (C-3'), 125.0 (C-4"), 126.5 (C-5'), 127.7 (C-3"), 127.9 (C-2" or C-3'"), 128.0 (C-2" or C-3'"), 129.8 (C-4'"), 134.1 (C-2'"), 135.0 (C-1'"), 137.3 (C-4'), 137.9 (C-1"), 149.7 (C-6'), 157.6 (C-2') ppm.

^{29}Si dept (99 MHz, $CDCl_3$, 298 K) δ –0.5 (*Si*Me_2Ph) ppm

HRMS (APCI) m/z: $[M+H]^+$ calcd for $C_{21}H_{24}NO_2SSi$ 382.1292, found 382.1296.

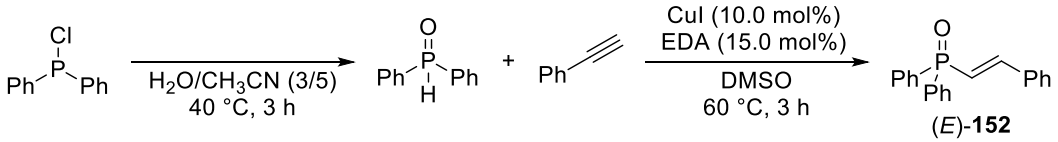
IR (ATR): ṽ 698, 729, 807, 991, 1033, 1107, 1244, 1426, 1596, 2955, 3065 cm^{-1}.

Optical rotation: $[\alpha]_D^{20}$ = +5.86 (*c* 1.0, $CHCl_3$, 83% *ee*).

The enantiomeric ratio of **151** was determined by HPLC analysis on a chiral stationary phase (*Daicel Chiralcel* IB column, column temperature 20 °C, solvent: *n*heptane/*i*PrOH = 90/10, flow rate = 1.0 mL/min): *t* = 15.8 min (minor), *t* = 17.4 min (major).

3.4 Asymmetric Conjugate 1.4-Silyl Transfer to *α,β*-Unsaturated Phosphine Oxides

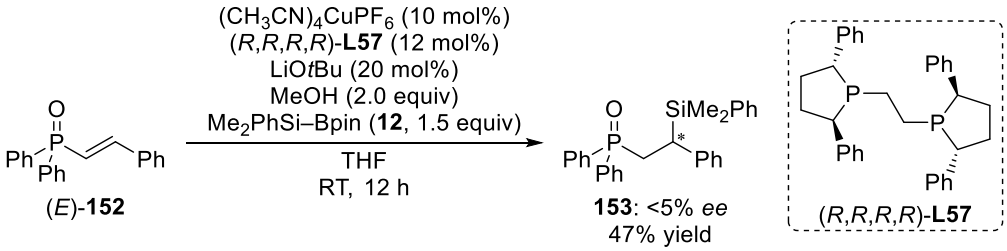
3.4.1 Procedure for (*E*)-152



To a solution of chlorodiphenylphosphine (2.21 g, 10.0 mmol) in CH_3CN (10 mL) at 0 °C, was added dropwise distilled water (6 mL). After stirring at 40 °C in an oil bath for 3 hours, the reaction mixture was allowed to cool to room temperature, and then extracted by CH_2Cl_2 (3 × 10 mL). The combined organic phases were washed by sat. aq. $NaHCO_3$ solution (2 × 10 mL) and sat. aq. NaCl solution (2 × 10 mL), dried over anhydrous $MgSO_4$, filtered, and concentrated under reduced pressure to afford the crude diphenylphosphine oxide,[75] which was used directly in the next step without any further purification.

To a solution of the crude diphenylphosphine oxide in DMSO (25 mL), were added phenylacetylene (1.53 g, 15.0 mmol, 1.50 equiv), CuI (190 mg, 1.00 mmol, 10.0 mol%) and ethylenediamine (EDA, 90.2 mg, 1.50 mmol, 15.0 mol%). After stirring at 60 °C in an oil bath for 3 hours, the reaction mixture was allowed to cool to room temperature. The reaction was quenched by H_2O (30 mL), and extracted by CH_2Cl_2 (30 mL). The organic phase was washed by H_2O (3 × 30 mL), dried over anhydrous Na_2SO_4, filtered, and concentrated under reduced pressure. Purifying the residue by flash column chromatography on silica gel with cyclohexane/EtOAc = 1/3 as eluent delivered the target (*E*)-**152** as a white solid (2.58 g, 85%) and all spectroscopic data accord with those reported.[76]

3.4.2 Procedure for Product 153

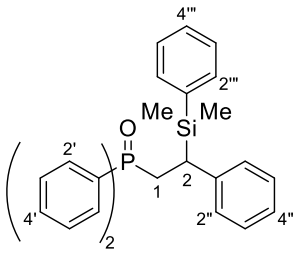


[75] L. Noël-Duchesneau, E. Lagadic, F. Morlet-Savary, J.-F. Lohier, I. Chataigner, M. Breugst, J. Lalevée, A.-C. Gaumont, S. Lakhdar, *Org. Lett.* **2016**, *18*, 5900–5903.

[76] J.-S. Zhang, J.-Q Zhang, T. Chen, L.-B. Han, *Org. Biomol. Chem.* **2017**, *15*, 5462–5467.

A heat gun-dried Schlenk tube equipped with a magnetic stir bar and a septum was purged with N_2, followed by the addition of $(Ph_3P)_2CuBH_4$ (3.73 mg, 10.0 *μ*mol, 10.0 mol%), (*R*,*R*,*R*,*R*)-**L57** (6.08 mg, 12.0 *μ*mol, 12.0 mol%) and Li*O*t*Bu (1.60 mg, 20.0 *μ*mol, 20.0 mol%). The tube was evacuated and backfilled with N_2, followed by the addition of THF (1 mL). After stirring at room temperature for an hour, Me_2PhSi–Bpin (**12**, 39.3 mg, 0.150 mmol, 1.50 equiv) was added. *α*,*β*-Unsaturated phosphine oxide (*E*)-**152** (30.4 mg, 0.100 mmol, 1.00 equiv) and methanol (6.48 mg, 0.200 mmol, 2.00 equiv) were added successively in 20 minutes. The reaction mixture was stirred at room temperature overnight, and then concentrated under reduced pressure. Purifying the residue by flash column chromatography on silica gel with cyclohexane/EtOAc = 1/3 as eluent delivered the corresponding product **153** as a white solid (20.7 mg, 47%).

3.4.3 Characterization Data for 153



153
$C_{28}H_{29}OPSi$
M = 440.60 g/mol

{2-[Dimethyl(phenyl)silyl]-2-phenylethyl}diphenyl-phosphine oxide

R*f* = 0.20 (cyclohexane/EtOAc = 1/1).

M.**P**. 191–192 °C.

^{1}H NMR (500 MHz, $CDCl_3$, 298 K) δ 0.21 (s, 3H, SiC*H*$_3$), 0.25 (s, 3H, SiC*H*$_3$), 2.58–2.75 (m, 2H, H-1), 2.82–2.90 (m, 1H, H-1, H-2), 6.70–6.74 (m, 2H, H-2''), 6.87–6.95 (m, 3H, H-3'' and H-4''), 7.11–7.16 (m, 2H, H-2'), 7.24–7.28 (m, 1H, H-4'), 7.31–7.42 (m, 9H, H-2', H-3' H-2''', H-3''' and H-4'''), 7.42–7.46 (m, 1H, H-4'), 7.52–7.58 (m, 2H, H-3') ppm.

^{13}C NMR (100 MHz, $CDCl_3$, 298 K) δ -5.5 (Si*C*H$_3$), -4.1 (Si*C*H$_3$), 28.6 (d, $^2J_{C,P}$ = 6.0 Hz, C-2), 30.2 (d, $^1J_{C,P}$ = 66.9 Hz, C-1), 124.7 (C-4''), 127.7 (C-2''), 127.8 (C-3'''), 127.9 (d, $^2J_{C,P}$ = 11.5 Hz, C-2'), 128.1 (C-3''), 128.4 (d, $^2J_{C,P}$ = 11.5 Hz, C-2'), 129.3 (C-4'''), 130.6 (d, $^3J_{C,P}$ = 9.1 Hz, C-3'), 130.9 (d, $^3J_{C,P}$ = 9.1 Hz, C-3'), 130.9 (d, $^4J_{C,P}$ = 2.8 Hz, C-4'), 131.4 (d, $^4J_{C,P}$ = 2.8 Hz,

C-4'), 132.6 (d, $^{1}J_{C,P}$ = 96.3 Hz, C-1'), 134.0 (d, $^{1}J_{C,P}$ = 96.3 Hz, C-1'), 134.3 (C-2'''), 136.3 (C-1'''), 141.0 (C-1'') ppm.

^{29}Si dept (99 MHz, $CDCl_3$, 298 K) δ –0.1 (d, $^{3}J_{Si,P}$ = 20.7 Hz, *Si*Me_2Ph) ppm

^{31}P NMR (202 MHz, $CDCl_3$, 298 K) δ 31.5 (*P*=O) ppm

HRMS (APCI) m/z: $[M+H]^+$ calcd for $C_{28}H_{30}OPSi$ 441.1798, found 441.1795.

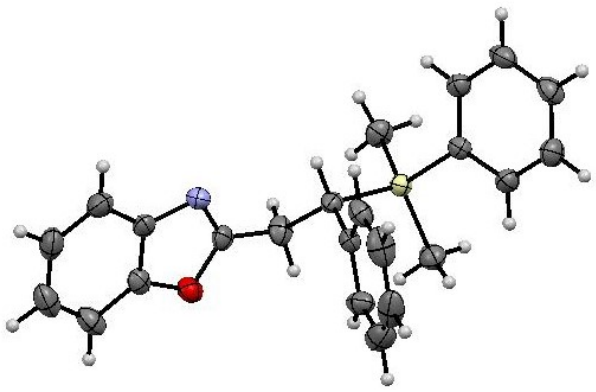
IR (ATR): ṽ 698, 733, 809, 995, 1069, 1174, 1248, 1434, 1594, 2959, 3057 cm^{-1}.

The enantiomeric ratio of **153** was determined by HPLC analysis on a chiral stationary phase (*Daicel Chiralcel* AD-H column, column temperature 20 °C, solvent: *n*heptane:*i*PrOH = 90:10, flow rate = 0.8 mL/min): *t* = 15.8 min, *t* = 24.2 min.

APPENDIX

A1 X-RAY STRUCTURE DATA

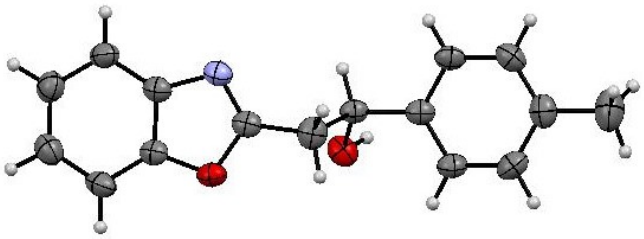
A1.1 Molecular Structure of (*S*)-90a



Cambridge structural data CCDC	1913584	
Empirical formula	$C_{23}H_{23}NOSi$	
Formula weight	357.51	
Temperature	150.00(10) K	
Wavelength	1.54184 Å	
Crystal system	Monoclinic	
Space group	P21	
Unit cell dimensions	a = 6.2273(2) Å	α= 90°.
	b = 18.9912(7) Å	β= 95.272(4)°.
	c = 8.2297(4) Å	ɣ = 90°.
Volume	969.16(7) $Å^3$	
Z	2	
Density (calculated)	1.225 Mg/m^3	
Absorption coefficient	1.141 mm^{-1}	
F(000)	380	
Crystal size	0.16 x 0.10 x 0.04 mm^3	
Theta range for data collection	4.66 to 67.48°.	
Index ranges	-7<=h<=5, -18<=k<=22, -8<=l<=9	
Reflections collected	3351	
Independent reflections	2563 [R(int) = 0.0208]	
Completeness to theta = 67.48°	99.8 %	
Absorption correction	Semi-empirical from equivalents	
Max. and min. transmission	0.9515 and 0.8421	

Refinement method	Full-matrix least-squares on F^2
Data / restraints / parameters	2563 / 1 / 237
Goodness-of-fit on F^2	1.037
Final R indices [I>2sigma(I)]	R1 = 0.0413, wR2 = 0.1059
R indices (all data)	R1 = 0.0444, wR2 = 0.1093
Absolute structure parameter	0.06(3)
Largest diff. peak and hole	0.266 and -0.285 e.Å^{-3}

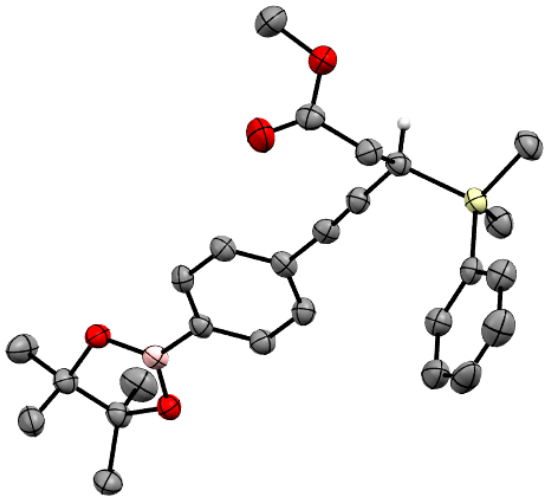
A1.2 Molecular Structure of (*S*)-134b



Cambridge structural data CCDC	1913585	
Empirical formula	$C_{16}H_{15}NO_2$	
Formula weight	253.29	
Temperature	150.00(10) K	
Wavelength	1.54184 Å	
Crystal system	Monoclinic	
Space group	P21	
Unit cell dimensions	a = 5.6833(5) Å	α= 90°.
	b = 7.8915(6) Å	β= 90.324(5)°.
	c = 14.9791(13) Å	ɣ = 90°.
Volume	671.80(9) Å^3	
Z	2	
Density (calculated)	1.252 Mg/m^3	
Absorption coefficient	0.664 mm^{-1}	
F(000) 268		
Crystal size	0.27 x 0.23 x 0.04 mm^3	
Theta range for data collection	2.95 to 67.43°.	
Index ranges	-6<=h<=6, -8<=k<=9, -17<=l<=9	
Reflections collected	2317	

Independent reflections	1795 [R(int) = 0.0224]
Completeness to theta = 67.43°	99.7 %
Absorption correction	Semi-empirical from equivalents
Max. and min. transmission	0.9739 and 0.8401
Refinement method	Full-matrix least-squares on F^2
Data / restraints / parameters	1795 / 1 / 175
Goodness-of-fit on F^2	1.067
Final R indices [I>2sigma(I)]	R1 = 0.0362, wR2 = 0.0945
R indices (all data)	R1 = 0.0385, wR2 = 0.0991
Absolute structure parameter	0.1(3)
Largest diff. peak and hole	0.134 and -0.178 e.Å^{-3}

A1.3 Molecular Structure of (*R*)-136l



Cambridge structural data CCDC	2025553	
Empirical formula	$C_{26}H_{33}BO_4Si$	
Formula weight	448.42	
Temperature	150.01(10) K	
Wavelength	1.54184 Å	
Crystal system	Orthorhombic	
Space group	P212121	
Unit cell dimensions	a = 9.0375(4) Å	α = 90°
	b = 15.2924(9) Å	β = 90°
	c = 18.4289(10) Å	γ = 90°
Volume	2547.0(2) Å3	

Z	4
Density (calculated)	1.169 Mg/m3
Absorption coefficient	1.034 mm-1
F(000) 960	
Crystal size	0.11 x 0.06 x 0.03 mm3
Theta range for data collection	3.76 to 67.45°.
Index ranges	-10<=h<=10, -11<=k<=18, -21<=l<=22
Reflections collected	9922
Independent reflections	4556 [R(int) = 0.0491]
Completeness to theta = 67.45°	100.0 %
Absorption correction	Semi-empirical from equivalents
Max. and min. transmission	0.9696 and 0.8929
Refinement method	Full-matrix least-squares on F2
Data / restraints / parameters	4556 / 0 / 296
Goodness-of-fit on F2	1.009
Final R indices [I>2sigma(I)]	R1 = 0.0433, wR2 = 0.0862
R indices (all data)	R1 = 0.0632, wR2 = 0.0973
Absolute structure parameter	-0.09 (3)
Largest diff. peak and hole	0.154 and -0.199 e. Å-3

A2 ABBREVIATION

Δ	chemical shift
Λ	wavelength
ṽ	wavenumber
δ	chemical shift
Å	angstrom
Ac	acetyl
acac	acetylacetone
*t*AmOH	*tert*-amyl alcohol
APCI	atmospheric pressure chemical ionization
Ar	aryl
ATR	Attenuated Total Reflection
Bn	benzyl
Boc	tert-butoxycarbonyl
br	broad signal
*n*Bu	*n*buty
*i*Bu	*iso*-butyl
*t*Bu	*tert*-butyl
Bz	Benzoate
Bpnd*	pure optical pinanediolatoboron
Bpin	pinacolatoboron.
°C	degree Celsius
Cbz	benzyloxycarbonyl
cm	centimeter
cod	1,5-cyclooctadiene
conc.	Concentrated
Conv.	Conversion
COSY	Correlation Spectroscopy
Cp	cyclopentadienyl
*m*CPBA	3-chloroperbenzoic acid
Cy	Cyclohexyl
$Cu(CHB)_2$	copper bis(4-cyclohexylbutyrate)

d	doublet
dba	dibenzylideneacetone
DBU	1,8-diazabicyclo[5.4.0]undec-7-ene
DCE	1,2-dichloroethane
DFT	density functional theory
DIBAL-H	diisobutylaluminium hydride
DIPEA	*N*,*N*-di*iso*-propylethylamine
DMAP	4-Dimethylaminopyridine
DMF	*N*,*N*-dimethylformamide
DMSO	dimethyl sulfoxide
d.r.	diastereomeric Ratio
dtbpy	4,4′-di-tert-butyl-2,2′-dipyridyl
EDA	ethylenediamine
ee	enantiomeric excess
ent	enantiomer
ESI	electron spray ionization
Et	ethyl
equiv	equivalent
EWG	electron-withdrawing group
g	gram
GC-MS	gas chromatography–mass spectrometry
GLC	gas-liquid chromatography
Glyme	1,2-dimethoxyethane
GP	general procedure
h	hour
Hal	halogen
HCl	hydrogen chloride
hept	heptyl
hex	hexyl
HMBC	heteronuclear multiple bond coherence
HMQC	heteronuclear multiple quantum coherence
HRMS	high resolution mass spectra
H_2O	water

Hz	hertz
IR	infrared spectroscopy
IUPAC	International Union of Pure and Applied Chemistry
J	coupling constant
L	ligand or liter
LIFDI	Liquid Injection Field Desorption Ionization
M	molecular mass or metal
M	molarity
M	multiplet or medium or milli or meter
Me	methyl
MeOH	methanol
Mes	mesityl
2-MeTHF	2-methyltetrahysrofuran
min	minute
mol	molar
mol%	mole percent
M.**p**.	melting point
MS	mass spectrometr
MsCl	methanesulfonyl chloride
n	number of units
NMR	nuclear magnetic resonance
o	ortho
OTf	triflate
p	para
Ph	phenyl
pin	pinacolato
ppm	parts per million
*i*Pr	*iso*propyl

q	quartet
R	organic rest or as defined in the text
Rf	retention factor
rac	racemic
RT	room temperature
s	singlet or strong
Si	triorganosilyl group
t	triplet
*t*AmOH	*tert*-amyl alcohol
TBME	*tert*-butyl methyl ether
TC	thiophene-2-carboxylate
THF	tetrahydrofuran
TLC	thin-layer chromatography
TM	transition metal
TMP	2,2,6,6-tetramethylpiperidine
TMS	trimethylsilyl
Ts	tosyl
UV	ultraviolet
w	weak
X	heteroatom

Ligand	
BDPP	2,4-Bis-(diphenylphosphino)-pentane
BINAP	2,2'-bis(diphenylphosphino)-1,1'-binaphthyl
BOX	bis(oxazoline)
NHC	N-heterocyclic carbene
Ph-BPE	1,2-Bis-(2,5-diphenylphospholano)-ethane
QuinoxP	2,3-Bis(*tert*-butylmethylphosphino)quinoxaline
SEGPHOS	5,5'-Bis(diphenylphosphino)-4,4'-bi-1,3-benzodioxole
Xantphos	(9,9-Dimethyl-9*H*-xanthene-4,5-diyl)bis(diphenylphosphane)
TADDOL	*α*,*α*,*α*',*α*'-tetraaryl-2,2-disubstituted 1,3-dioxolane-4,5-dimethanol

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