Rh-Catalyzed Highly Enantioselective Synthesis of Aliphatic Sulfonyl Fluorides

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**HIGHLIGHTS**

- Enantioselective synthesis of di(hetero)arylalkyl sulfonyl fluorides were achieved
- These novel SuFEx Clickable molecules will play significant roles for drug discovery
- The asymmetric C-C bond construction is a new portal to chiral sulfonyl fluorides
- This protocol features with mild condition, wide scope, and excellent compatibility
Rh-Catalyzed Highly Enantioselective Synthesis of Aliphatic Sulfonyl Fluorides

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SUMMARY
Rh-catalyzed, highly enantioselective (up to 99.8% ee) synthesis of aliphatic sulfonyl fluorides was accomplished. This protocol provides a portal to a class of novel 2-aryl substituted chiral sulfonyl fluorides, which are otherwise extremely difficult to access. This asymmetric synthesis has the feature of mild conditions, excellent functional group compatibility, and wide substrate scope (51 examples) generating a wide array of structurally unique chiral β-arylated sulfonyl fluorides for sulfur(VI) fluoride exchange (SuFEx) click reaction and drug discovery.

INTRODUCTION
Since the seminal work reported by K. B. Sharpless group in 2014 (Dong et al., 2014a, 2014b), sulfur(VI) fluoride exchange (SuFEx) click reaction has grown into a powerful synthetic tool, attracting increasing interest with wide applications in various disciplines such as polymer chemistry (Dong et al., 2014a, 2014b; Yatvin et al., 2015; Oakdale et al., 2016; Brendel et al., 2017; Gao et al., 2017; Wang et al., 2017; Zhang et al., 2019), surface chemistry (Brooks et al., 2016), bioconjugation (Zelli et al., 2016; Li et al., 2016), protein target identification (Jones, 2018a, 2018b; Mortenson et al., 2018; Wang et al., 2018a, 2018b, 2018c, 2018d; Zhao et al., 2017), and covalent protein inhibition (Alvarez et al., 2017; Chen et al., 2016a, 2016b; Fadeyi et al., 2017; Gehringer and Lauffer, 2019; Hett et al., 2015; Liu et al., 2018; Narayanan and Jones, 2015; Shishido et al., 2017). Sulfonyl fluoride moiety as the sulfur(VI)-containing functional group at the heart of SuFEx methodology is imbued with a stability and chemoselectivity profile that is highly desirable for click chemistry applications (Chinthakindi and Arvidsson, 2018; Mukherjee et al., 2018; Chinthakindi et al., 2016; Kwon and Kim, 2019; Smedley et al., 2018; Leng and Qin, 2018, Thomas and Fokin, 2018). For instance, sulfonyl fluoride headed molecules have gained a renewed interest for both organic and medicinal chemists as privileged warheads in chemical biology and drug discovery (Figure 1)(Akc¸ay et al., 2016; Brouwer et al., 2012; Dalton et al., 2018; Dubiella et al., 2014; Jones, 2018a, 2018b, Tschan et al., 2013). Moreover, the synthesis of 2-substituted ethenesulfonyl fluorides has recently attracted significant attention because of their unique properties as both “perfect” Michael acceptors and electrophiles for SuFEx manipulation (Allga¨uer et al., 2017; Chen et al., 2016a, 2016b, 2017, 2018, 2019; Chinthakindi et al., 2017; Li et al., 2018; Ncube and Huestis, 2019; Qin et al., 2016; Ungureanu et al., 2015; Wang et al., 2018a, 2018b, Zha et al., 2017a, 2017b), because the pioneering work by Truce and Hoerger in 1954 (Truce and Hoerger, 1954). However, β-arylethenesulfonyl fluorides have rarely been explored as latent precursors for the constructions of chiral sulfonyl fluoride molecules (Barrow et al., 2019).

Di(hetero)aryalkanes are ubiquitous and important structures as building blocks in drug discovery (Figure 2)(Zhou et al., 2013; He et al., 2018; Graffner-Nordberg et al., 2001; Boyd et al., 2001; Hsin et al., 1998; Silva et al., 1999; Malhotra et al., 2009; Hu et al., 2010; Pathak et al., 2010; Ameen and Snape, 2013). To accelerate the discovery of new covalent drug candidates, we plan to build diversified compound libraries bearing both di(hetero)aryalkane and sulfonyl fluoride functionalities (Schreiber, 2000; O’Connor et al., 2012; Nadin et al., 2012).

Carbon-carbon (C-C) bond formation represents one of the most straightforward and atom-efficient strategy for the construction of new organic molecules because the framework of most organic molecules is a carbon chain (Gruttadauria and Giacalone, 2011; Jacobsen et al., 1999; Jumde et al., 2016; Mu et al., 2017; Schmidt et al., 2016; Schwarzwalder et al., 2019; Wang et al., 2018a, 2018b, 2018c, 2018d; Li and Fu, 2015). Particularly, in recent years, organoboron reagents participated in rhodium-catalyzed asymmetric 1,4-conjugate additions to activated alkenes for the synthesis of C-C bonds have emerged as robust, reliable, and versatile methods to construct chiral gem-diaryl alkanes, whereas diverse aryl and alkynyl groups are incorporated with high enantioselectivity (Sidera and Fletcher, 2015; Tian et al., 2012; Edwards et al., 2015; Weckhuysen et al., 2016).
et al., 2010; Hayashi and Yamasaki, 2003; Fagnou and Lautens, 2003; Müller and Alexakis, 2012). The Rh/ 
binap catalyzed asymmetric addition of arylboronic acids to conjugated enones was firstly reported by 
Hayashi and Miyaura in 1998 (Takaya et al., 1998). This pioneering method has been rapidly developed 
in addition to various functional groups attached alkenes such as \( \alpha, \beta \)-unsaturated esters (Duchemin 
and Cramer, 2019; Paquin et al., 2005a, 2005b; Sakuma et al., 2000), amides (Yuan and Sigman, 2018; 
Wang et al., 2014; Hargrave et al., 2006; Sakuma and Miyaura, 2001; Senda et al., 2001), carbonyl 
(Bocknack et al., 2004; Kadam et al., 2017; Khiar et al., 2013; Moragues et al., 2015; Paquin et al., 2005a, 2005b; 
Shintani et al., 2006; Yasukawa et al., 2015), phosphonates (Hayashi et al., 1999), imines (Cui et al., 2011; 
Jagt et al., 2006; Lee and Kim, 2015; Nishimura et al., 2012a, 2012b; Shintani et al., 2010; Trincado and 
Ellman, 2008; Wu et al., 2018), sulfonyl (Lim and Hayashi, 2015; Liu et al., 2019; Mauleon and Carretero, 
2005; Nishimura et al., 2012a, 2012b; Takechi and Nishimura, 2015; Yan et al., 2019), nitro compounds 
(Wang et al., 2010; Hayashi et al., 2000; He et al., 2015; Miyamura et al., 2017), borylalkenes (Sasaki and 
Hayashi, 2010), and other electron-deficient alkenylarenes (Pattison et al., 2010; Saxena and Lam, 2011). 
We envision that through using Rh(I) catalyst and appropriate chiral ligand, the reaction of 2-arylethene-
sofluorides with arylboronic acids would furnish a class of novel chiral molecules bearing both chiral 
gem-diarylmethane moiety and sulfonyl fluoride functionality (Scheme 1). However, to the best of our 
knowledge, the asymmetric addition of organometallic reagents to \( \alpha, \beta \)-unsaturated sulfonyl fluorides 
for producing chiral \( \beta, \beta \)-diarylethanesulfonyl fluorides has not been divulged because there are two major 
challenges: first, the sulfonyl fluoride moiety (R-SO\(_2\)F) is fragile in the presence of bases such as Et\(_3\)N, 
NaHCO\(_3\), and DBU to undergo nucleophilic reactions (Chen et al., 2017, 2018; Dong et al., 2014a, 
2014b; Ungureanu et al., 2015), whereas for the Rh(I)-catalyzed 1,4-addition system, strong bases such as 
NaOH, KOH, CsOH, and K\(_2\)CO\(_3\) are typically required to drive the desired transformation to occur 
(Sidera and Fletcher, 2015; Tian et al., 2012; Edwards et al., 2010; Hayashi and Yamasaki, 2003; Fagnou 
and Lautens, 2003; Müller and Alexakis, 2012), which could partially or even completely destroy the 
S(VI)-F functionality; second, the -SO\(_2\)F motif is much more electron withdrawing comparing with other 
sulfonyl groups, carbonyl groups, phosphonates, and nitro counterparts, which makes the olefins con-
jugated with -SO\(_2\)F a lot more (more than 100 times) reactive than alkenes conjugated with other elec-
tron-withdrawing groups; therefore, ethenesulfonyl fluoride performs as “perfect” Michael acceptor to 
proceed the addition in very short time (Allgäuer et al., 2017; Chen et al., 2016a, 2016b), which further 
makes the control of enantioselectivity a lot more challenging.

![Figure 1. Representative Molecules Bearing Sulfonyl Fluoride Moiety with Biological Significance](image)
In the course of our research program on SuFEx chemistry, we have developed an efficient entry into diverse α,β-ethenesulfonyl fluorides (Qin et al., 2016; Zha et al., 2017a, 2017b); herein, we report the first example (to the best of our knowledge) of Rh-catalyzed highly enantioselective conjugate addition of aryl boronic acids to this category of vinyl sulfonyl fluorides to generate a class of novel chiral sulfonyl fluoride compounds with potential pharmaceutical significance for drug discovery (Scheme 1) (Herrán et al., 2005; Hayashi et al., 2005; Nishimura et al., 2006).

RESULTS AND DISCUSSION

We commenced our investigation by testing the feasibility of asymmetric 1,4-conjugate addition of (4-(methylthio)phenyl)boronic acid (2a) to (E)-2-phenylethenesulfonyl fluoride (1a). To attain the desired 1,4-addition product with high ee, different chiral phosphene ((R)- or (S)-binap) and diene ligands (L1-L6) (Table 1) were evaluated subsequently. In reaction with the use of only rhodium catalyst (no ligand), no conversion was observed (entry 1). The use of the most widely applied rhodium-bisphosphine complex, [RhCl((R)-binap)]2 or RhCl((S)-binap)]2 complex, afforded desired addition product in only a trace amount (entries 2 and 3). To our delight, chiral diene ligands L1–L3 with ester functional groups, from a readily available natural product ((R)-phellandrene, exhibited excellent catalytic activity for achieving enantioselectivity (entries 4–6). Surprisingly, the use of ligand L3 bearing a less bulky group ((2,6-dimethyl)phenyl ester) afforded the addition product in even higher yield of 85% and better enantiopurity, 92% ee, than the using of ligand L2 bearing a more bulky group ((2,6-diisopropyl)phenyl ester) (81% yield with 80% ee) (entry 5 vs entry 6). The chiral diene ligands with amide moieties (L4 and L5) displayed less catalytic activities than those chiral diene ligands with ester moieties (entries 7 and 8). And,
the chiral diene ligand bearing ketone moiety (L6) also showed less catalytic activity and poor enantioselectivity providing the product 3a in 65% yield with 49% ee (entry 9). Therefore, the condition of entry 6 with L3 was utilized for further substrate scope exploration and functional group compatibility examination.

**Substrate Scope Study**

The obtained promising results persuaded us to explore the scope of [RhCl(L3)]2 catalyzed asymmetric 1,4-addition of various arylboronic acids 2 to phenylethenesulfonyl fluoride 1a, as summarized in Scheme 2. The aryl boronic acids 2 containing either electron donating or electron withdrawing groups at the para-positions of aromatic rings reacted with phenylethenesulfonyl fluoride 1a smoothly to afford desired chiral β-phenyl β-arylethenesulfonfluoride products in good to excellent yields (75–99%) with excellent enantioselectivities (61%–99% ee) (3a–3k). However, boronic acid bearing 2,4-difluoro electron withdrawing group 2l reacted with the vinyl sulfonyl fluoride 1a sluggishly to furnish desired product 3l in 77% yield with slightly lower enantioselectivity (89% ee). Notably, no conversion was observed when the reaction was performed with ortho-substituted phenylboronic acids such as 2-Cl, 2-Br, 2-I, 2-Me, and 2-iPr. Arylboronic acids 2m–2p possessing electron withdrawing groups at meta-positions afforded the desired products in high yields (84%–99%) and high enantioselectivities (94%–97% ee) (3m–3p). Interestingly, the boronic acid 2q containing strong electron-donating group at the meta-position provided the corresponding product 3q in 87% yield; however, the enantioselectivity was significantly low (74% ee). Sterically hindered arylboronic acids 2r–2t also proceeded the addition to the vinyl sulfonyl fluoride 1a successfully furnishing their corresponding products (3r–3t) in good to high yields.

| Entry | Ligand | Yield (%) | ee (%) |
|-------|--------|-----------|--------|
| 1     | –      | 0         | ND     |
| 2     | R-BINAP| trace     | ND     |
| 3     | S-BINAP| trace     | ND     |
| 4     | L1     | 84        | 70     |
| 5     | L2     | 81        | 80     |
| 6     | L3     | 85        | 92     |
| 7     | L4     | 80        | 41     |
| 8     | L5     | 84        | 51     |
| 9     | L6     | 65        | 49     |
Scheme 2. Rhodium-Catalyzed Asymmetric Addition of Arylboronic Acids (2) to (E)-2-Pheny ethanesulfonyl Fluoride (1a)

Reactions conditions: a mixture of 1a (0.5 mmol), 2 (1.0 mmol), [RhCl(L3)]2 (10 mol%), and CsF (1.0 mmol) was dissolved in EA + H2O (5.0 + 0.5 mL) and reacted at 50 °C for 12 h under argon atmosphere.

\[ \text{Ar}^+ \text{B(OH)}_2 + \text{1a} \xrightarrow{\text{Rh-L3 Complex (10 mol%)}} \text{Ar}^+ \text{SO}_2 \text{F} + \text{2} \]

Determined by chiral HPLC analysis.

Based on recovery of 1a.
Next, the scope of the addition of phenylboronic acid 2z to a variety of α,β-unsaturated arylboronic acids 21-3w containing N-, O-, S- hetero atoms also underwent the addition smoothly providing their corresponding 1,4-addition products (3u-3w) in high yields (82–99%) with excellent enantioselectivities (>99% ee). The reactions of benzofuran-3-yl boronic acid (2x) and benzo[b]thiophen-3-yl boronic acid (2y) with vinyl sulfonyl fluoride 1a were much slower than using other aryloboronic acids, providing the corresponding 1,4-addition products (3x, 3y) in moderate yield 63% (3x, 89% based on recovery of starting material 1a) and 50% (3y, 92% based on recovery of starting material 1a) respectively due to the incomplete conversion of 1a, whereas their enantioselectivities were excellent (3x, >99% ee and 3y, 97% ee).

Afterward, diversifications of the 1,4-addition products were examined to demonstrate the further utility of these chiral sulfonyl fluorides (Scheme 4). Reaction of compound 3w with amine 5 in the presence of triethyl amine produced the corresponding sulfonamide 6w in 98% yield and greater than 99% ee. The SuFEx click reaction of compound 3w with phenol 7 afforded the corresponding sulfonate 8w in 99% yield and higher than 99.9% ee. Compound 9 obtained from corresponding boronic acid and α,β-unsaturated sulfonyl fluoride was also successfully transformed into the corresponding sulfonyl amide 11 in 88% yield and 98% ee through a SuFEx click process with benzylamine 10. And the sulfonyl amide 11 proceeded an intramolecular C-H amination (Martínez et al., 2016) to generate a cyclic amine 12 in 80% yield and 92% ee.

Conclusion
In summary, Rh-catalyzed, highly enantioselective, conjugate additions of aryloboronic acids to α,β-ethene-sulfonyl fluorides was achieved providing a portal to a class of novel 2-aryl substituted chiral sulfonyl fluorides, which are extremely difficult to access otherwise. This method has feature of mild conditions, excellent functional group compatibility, and wide scope generating a wide array of structurally diverse β-arylated sulfonyl fluorides. Further developments and synthetic applications of these molecules in chemical biology and drug discovery are in progress.

Limitations of the Study
The results of examination of substrate scope showed that the present method was not suitable for the conjugate addition of ortho-substituted aryloboronic acids to 2-ethenesulfonyl fluorides.

METHODS
All methods can be found in the accompanying Transparent Methods supplemental file.
DATA AND CODE AVAILABILITY

The structure of 4d reported in this article has been deposited in the Cambridge Crystallographic Data Center under accession numbers CCDC: 1906557.

Scheme 3. Rhodium-Catalyzed Asymmetric Addition of Phenylboronic Acid (2z) to α,β-Unsaturated Sulfonyl Fluorides (1)

a Reaction conditions: a mixture of 1 (0.5 mmol), 2z (1.0 mmol), [RhCl(L3)] (10 mol%), and CsF (1.0 mmol) was dissolved in EA + H2O (5.0 + 0.5 mL) and reacted at 50°C for 12 h under argon atmosphere.

b Determined by chiral HPLC analysis.
SUPPLEMENTAL INFORMATION

Supplemental Information can be found online at https://doi.org/10.1016/j.isci.2019.10.051.

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AUTHOR CONTRIBUTIONS

B. Moku and W.-Y. Fang contribute equally to this work. H.-L. Qin conceived the project and designed the experiments; B. Moku conducted the experiments; B. Moku, W.-Y. Fang, J. Leng and K. P. Rakesh wrote the Supplemental Information and analyzed the data. H.-L. Qin wrote the article; L. Li and G.-F. Zha commented on the manuscript.

DECLARATION OF INTERESTS

The authors declare no competing interests.

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REFERENCES

Alçay, G., Belmonte, M.A., Aquila, B., Chuqua, C., Hird, A.W., Lamb, M.L., Rawlins, P.B., Su, N., Tentarelli, S., Grimster, N.P., and Su, Q. (2016). Inhibition of Mcl-1 through covalent modification of a noncatalytic lysine side chain. Nat. Chem. Biol. 12, 931-936.

Allgäuer, D.S., Jangra, H., Asahara, H., Li, Z., Chen, Q., Zipse, H., Öfäl, A.R., and Mayr, H. (2017). Quantification and theoretical analysis of the electrophilicities of Michael acceptors. J. Am. Chem. Soc. 139, 13318-13329.

Alvarez, H.N., van de Langemheen, H., Brouwer, A.J., and Liskamp, R.M.J. (2017). Potential peptidic proteasome inhibitors by incorporation of an electrophilic trap based on amino acid derived a-substituted sulfonyl fluorides. Bioorg. Med. Chem. 25, 5055-5063.

Ameen, D., and Snape, T.J. (2013). Chiral 1, 1-diaryl compounds as important pharmacophores. Med. Chem. Commun. 4, 893-907.

Barrow, A.S., Smedley, C.J., Zheng, Q., Li, S., Dong, J., and Moses, J.E. (2019). The growing applications of SuFEx click chemistry. Chem. Soc. Rev. 48, 4731-4758.

Bocknack, B.M., Wang, L.-C., and Krische, M.J. (2004). Desymmetrization of enone-diones via rhodium-catalyzed diastereo- and enantioselectivetandem conjugate addition-aldol cyclization. Proc. Natl. Acad. Sci. U S A 101, 5421-5424.
Jones, L. H. (2018a). Emerging utility of fluorosulfate chemical probes. ACS Med. Chem. Lett. 9, 584–586.
Jones, L. H. (2018b). Reactive chemical probes beyond the kinase cysteinome. Angew. Chem. Int. Ed. 57, 9220–9223.
Jumada, R. P., Lanza, F., Veenstra, M. J., and Harutyunyan, S. R. (2016). Catalytic asymmetric addition of ingridiant reagents to alkyl-substituted aromatic N-heterocycles. Science 22, 433–437.
Kadam, A. A., Ellern, A., and Stanley, L. M. (2017). Enantioselective, palladium-catalyzed conjugate additions of arylboronic acids to electron-deficient amines. J. Org. Chem. 78, 6510–6521.
Kwon, J., and Kim, B. M. (2019). Synthesis of arenesulfonyl fluorides via sulfonyl chloride incorporation from amines. Org. Lett. 21, 428–433.
Lee, A., and Kim, H. (2015). Rhodium-catalyzed asymmetric 1,4-addition of a β-unsaturated imino electrophile with chiral bicyclic bridgehead phosphoramidite ligands. J. Am. Chem. Soc. 137, 11250–11253.
Leng, J., and Qin, H. L. (2018). 1-Bromothene-1-sulfonyl fluoride (1-Br-ESF), a new SuFEx clickable reagent, and its application for regioselective construction of 5-sulfonylfluoro isoxazoles. Chem. Commun. (Camb.) 54, 4477–4480.
Li, C., Wang, S.-M., and Qin, H.-L. (2018). Rh-catalyzed and moisture tolerant aldehyde (Ketone)-Directed fluorosulfonyle-vinylation of aryl Csp2=CH bonds. Org. Lett. 20, 4699–4703.
Li, S., Cohen-Karni, D., Beringer, L. T., Wu, C., Kallick, E., Edington, H., Passieau, M. J., and Ashworth, S. (2016). Direct introduction of RS(O)F moieties into proteins and protein-polymer conjugation using SuFEx chemistry. Polymer 99, 7.
Liang, Y., and Fu, G.C. (2015). Stereoreconvergent Negishi ariyations of racemic secondary alkyl electrophiles: differentiating between a CF3 and an alkyl group. J. Am. Chem. Soc. 137, 9523–9526.
Lim, K.M.-H., and Hayashi, T. (2015). Rhodium-catalyzed asymmetric arylation of α,ω-unsaturated amines under mild conditions of isomerization into α,ω-unsaturatedaines. J. Am. Chem. Soc. 137, 3201–3204.
Liu, G., Zhang, H., Huang, Y., Han, Z., Liu, G., Liu, Y., Dong, X.-Q., and Zhang, X. (2019). Efficient synthesis of chiral 2,3-Dihydro-benz[b]thiophene 1,1-dioxides via Rh-catalyzed hydrogenation. Chem. Sci. 10, 2507–2512.
Liu, Z., Li, J., Li, S., Li, G., Sharpless, K.B., and Wu, P. (2018). SuFEx Click chemistry enabled late-stage drug functionalization. J. Am. Chem. Soc. 140, 2919–2925.
Malhotra, B., Gandelman, K., Sachse, R., Wood, N., and Michel, M. C. (2009). The design and development of fesoterodine as a produg of 5-hydroxymethyl tolterodine (5-HMT), the active metabolite of tolterodine. Curr. Med. Chem. 16, 4481–4489.
Martínez, C., Bosniadou, A.E., Allmendinger, S., and Munz, K. (2016). Towards uniform iodine catalysis: intramolecular C-H amination of amines under visible light. Chem. Eur. J. 22, 9929–9932.
Mauleon, P., and Carretero, J. C. (2005). Enantioselective construction of stereogenic quaternary centers via Rh-catalyzed asymmetric addition of alkylboron compounds to α,β-unsaturated vinyl sulfoxides. Chem. Commun. (Camb.), 4961–4963.
Miyamura, H., Nishino, K., Yasukawa, T., and Kobayashi, S. (2017). Rhodium-catalyzed asymmetric 1,4-additions of aryl boronic acids with nitroalkenes: reaction mechanism and development of homogeneous and heterogeneous catalysts. Chem. Soc. 8, 8362–8372.
Moragues, A., Neatu, F., Pávulescu, V.I., Marcos, M.D., Amorós, P., and Michelet, V. (2015). Heterogeneous gold catalyst: synthesis, characterization, and application in 1,4-addition of boronic acids to enones. ACS Catal. 5, 5060–5067.
Mortensen, D.E., Brighty, G.J., Plate, L., Bare, G., Chen, W., Li, S., Wang, H., Cravatt, B.F., Flori, S., Powers, E.T., et al. (2018). “Inverse drug discovery”: strategy to identify proteins that are targeted by latent electrophiles as exemplified by aryl fluorosulfonates. J. Am. Chem. Soc. 140, 200–210.
Mu, X., Shibata, Y., Makida, Y., and Fu, G.C. (2017). Control of vicinal stereocenters through nickel-catalyzed αi-αiylalkyl cross-coupling. Angew. Chem. Int. Ed. 56, 5821–5824.
Mukherjee, P., Woroch, C.P., Cleary, L., Rusznak, M., Franzese, R.W., Reese, M.R., Tucker, J.W., Humphrey, J.M., Etuk, S.M., Kwan, S.C., et al. (2018). Sulfonamide synthesis via calcium triflimide activation of sulfonyl fluorides. Org. Lett. 20, 3943–3947.
Müller, D., and Alexakis, A. (2012). Rhodium-catalyzed asymmetric conjugate addition of alkyl nucleophiles. Chem. Commun. (Camb.) 48, 12037–12049.
Nadin, A., Hattotuwagama, C., and Churcher, I. (2012). Lead-Oriented synthesis: a new opportunity for synthetic chemistry. Angew. Chem. Int. Ed. 51, 1114–1122.
Narayanan, A., and Jones, L.H. (2015). Sulfonyl fluorides as privileged warheads in chemical biology. Chem. Soc. 6, 2650–2659.
Ncuble, G., and Huestis, M.P. (2019). Directed hydroxymethyl tolterodine (5-HMT), the active metabolite of tolterodine. Curr. Med. Chem. 134, 9086–9089.
Nishimura, T., Yasuhara, Y., and Hayashi, T. (2006). Highly selective 1,4-addition of arylboronic acids to α,β-unsaturated carbonyl compounds catalyzed by an iridium complex. Angew. Chem. Int. Ed. 45, 5164–5166.
Oakdale, J.S., Kwisne, L., and Fokin, V.V. (2016). Selective and orthogonal post-polymerization modification using sulfur(V) fluoride exchange (SuFEx) and copper-catalyzed Azide–alkyne cycloaddition (CuAAC) reactions. Macromolecules 49, 4473–4479.
O’Connor, C.J., Beckmann, H.S.G., and Spring, D.R. (2012). Diversity-oriented synthesis: producing chemical tools for dissecting biology. Chem. Soc. Rev. 41, 4444–4456.
Paquin, J.-F., Stephenson, C.R.J., Defieber, C., and Carrera, E.M. (2005a). Catalytic asymmetric synthesis of 3,3-dialkyranalpropanals with chiral diene-rhodium catalysts. J. Am. Chem. Soc. 127, 10850–10851.
Pathak, T.P., Gligorich, K.M., Welm, B.E., and Sigman, M.S. (2010). Synthesis and preliminary biological studies of 3-substituted indoles accessed by a palladium-catalyzed enantioselective alken di functionalization reaction. J. Am. Chem. Soc. 132, 7870–7871.
Pattison, G., Piraux, G., and Lam, H.W. (2010). Enantioselective rhodium-catalyzed addition of arylboronic acids to α,β-unsaturated enones. J. Am. Chem. Soc. 132, 14373–14375.
Qin, H.-L., Zheng, Q., Bare, G.A.L., Wu, P., and Sharpless, K.B. (2016). A Heck–Matsuda process for the synthesis of β-arylthenesulfonyl fluorides: selectively addressable bis-electrophiles for SuFEx click chemistry. Angew. Chem. Int. Ed. 55, 14155–14158.
Sakuma, S., Sakai, M., Itooka, R., and Miyaura, N. (2000). Asymmetric conjugate 1,4-addition of arylboronic acids to α,β-unsaturated esters catalyzed by rhodium(II)/(I)-binap. J. Org. Chem. 65, 5951–5955.
Sakuma, S., and Miyaura, N. (2001). Rhodium(II)-Catalyzed asymmetric 1,4-addition of arylboronic acids to α,β-unsaturated amides. J. Org. Chem. 66, 8944–8946.
Sasaki, K., and Hayashi, T. (2010). Rhodium-catalyzed asymmetric conjugate addition of arylboroxines to borylalkenes: asymmetric synthesis of β-arylalkylboranes. Angew. Chem. Int. Ed. 49, 8145–8147.
Saxena, A., and Lam, H.W. (2011). Enantioselective rhodium-catalyzed arylation of electron-deficient alkenylarenes. Chem. Sci. 2, 2326–2331.
Schmidt, J., Choi, J., Liu, A.T., Slusarczyk, M., and Fu, G.C. (2016). A general, modular method for the catalytic asymmetric synthesis of allylboronate esters. Science 354, 1265–1269.
Trincado, M., and Ellman, J.A. (2008). Enantioselective synthesis of α-aryl alkylamines by Rh-catalyzed addition reactions of aryllithiums to aliphatic imines. Angew. Chem. Int. Ed. 47, 5623–5626.

Truce, W.E., and Hoeger, F.D. (1954). Diels–Alder reactions with arylenesulfonfonyl fluorides. J. Am. Chem. Soc. 76, 3230–3232.

Tschan, S., Brouwer, A.J., Werkhoven, P.R., Jonker, A.M., Wagner, L., Knittel, S., Aminaka, M.N., Pradel, G., Joanny, F., Liskamp, R.M.J., and Mordmuller, B. (2013). Broad-spectrum antimalarial activity of peptide sulfonfonyl fluorides, a new class of proteasome inhibitors. Antimicrob. Agents Chemother. 57, 3576–3584.

Ungureanu, A., Levens, A., Candish, L., and Lupton, D.W. (2015). N-heterocyclic carbene catalysed synthesis of α-sultones via α,β-unsaturated sulfonfonyl azolium intermediates. Angew. Chem. Int. Ed. 54, 11780–11784.

Wang, H., Zhou, F., Ren, G., Zheng, Q., Chen, H., Gao, B., Klvansky, L., Liu, Y., Wu, B., Xu, Q., et al. (2017). SuFEx-based polysulfonate formation from ethanesulfonfonyl fluoride–amine adducts. Angew. Chem. Int. Ed. 56, 11203–11208.

Wang, J., Wang, M., Cao, P., Jiang, L., Chen, G., and Liao, J. (2014). Rhodium-catalyzed asymmetric arylation of β,γ-unsaturated α-ketoamides for the synthesis of nonracemic γ,γ-dialkylcarbonyl compounds. Angew. Chem. Int. Ed. 53, 6673–6677.

Wang, S.-M., Li, C., Leng, J., Bukhari, S.N.A., and Qin, H.-L. (2018a). Gram-scale synthesis of β-[(4H)-arylenesulfonfonyl] fluorides via a Pd(OAc)2 catalyzed oxidative Heck process with DDQ or AgNO3 as an oxidant. Adv. Synth. Catal. 359, 5287.

Wang, G.-F., Bare, G.A.L., Leng, J., Shang, Z.-P., Luo, Z., and Qin, H.-L. (2017a). A click ligation based on SuFEx for the metal-free synthesis of sugar and iminosugar clusters. Eur. J. Org. Chem. 2016, 5102.

Wang, S.-M., Moku, B., Leng, J., and Qin, H.-L. (2018b). Rh-catalyzed carboxylates directed C-H activation for synthesis of ortho-carboxyl-2-arylenesulfonfonyl fluorides: access to unique electrophilic for SuFEx click chemistry. Eur. J. Org. Chem. 2018, 4407.

Wang, N., Yang, B., Fu, C., Zhu, H., Zheng, F., Kobayashi, T., Liu, J., Li, S., Ma, C., Wang, P.G., et al. (2016c). Genetically encoding fluorosulfolate-L-tyrosine to react with lysine, histidine, and tyrosine via SuFEx in proteins in vivo. J. Am. Chem. Soc. 140, 4995–4999.

Wang, Z., Yin, H., and Fu, G.C. (2018d). Catalytic enantioconvergent coupling of secondary and tertiary electrophiles with olefins. Nature 563, 379–383.

Wang, Z.-Q., Feng, C.-G., Zhang, S.-S., Xu, M.-H., and Lin, G.-Q. (2010). Rhodium-catalyzed asymmetric conjugate addition of organoboronates to nitroalkanes using chiral bicyclo[3.3.0] diene ligands. Angew. Chem. Int. Ed. 49, 5780–5783.

Wu, C.-Y., Zhang, Y.-F., and Xu, M.-H. (2018). Ligand-controlled rhodium-catalyzed site-selective asymmetric addition of aryllithiums to α,β-unsaturated cyclic N-sulfonfonyl ketimines. Org. Lett. 20, 1789–1793.

Yan, Q., Xiao, G., Wang, Y., Zi, G., Zhang, Z., and Hou, G. (2019). Highly efficient enantioselective synthesis of chiral sulfones by Rh-catalyzed asymmetric hydrogenation. J. Am. Chem. Soc. 141, 1749–1756.

Yasukawa, T., Suzuki, A., Miyamura, H., Nishino, K., and Kobayashi, S. (2015). Chiral metal nanoparticle systems as heterogeneous catalysts beyond homogeneous metal complex catalysts for asymmetric addition of aryllithiums to α,β-unsaturated carbonyl compounds. J. Am. Chem. Soc. 137, 6616–6623.

Yatvin, J., Brooks, K., and Locklin, J. (2015). SuFEx on the surface: a flexible platform for postpolymerization modification of polymer brushes. Angew. Chem. Int. Ed. 54, 13370–13373.

Yuan, Q., and Sigman, M.S. (2018). Palladium-catalyzed enantioselective relay Heck arylation of ene lactams: accessing α,β-unsaturated α-lactams. J. Am. Chem. Soc. 140, 6527–6530.

Zelli, R., Tommasone, S., Dumy, P., Marra, A., and Diondoni, A. (2016). A click ligation based on SuFEx for the metal-free synthesis of sugar and iminosugar clusters. Eur. J. Org. Chem. 2016, 5102.

Zha, G.-F., Bare, G.A.L., Leng, J., Shang, Z.-P., Luo, Z., and Qin, H.-L. (2017a). Gram-scale synthesis of β-[(4H)-arylenesulfonfonyl] fluorides via a Pd(OAc)2 catalyzed oxidative Heck process with DDQ or AgNO3 as an oxidant. Adv. Synth. Catal. 359, 5237.

Zha, G.-F., Zheng, Q., Leng, J., Wu, P., Qin, H.-L., and Sharpless, K.B. (2017b). Palladium-catalyzed fluorosulfonfonylation of organic iodides. Angew. Chem. Int. Ed. 56, 4849–4852.

Zhang, X., Moku, B., Leng, J., Rakesh, K.P., and Qin, H.-L. (2019). 2-Azidoethane-1-sulfonfonyl fluoride (ASF), a versatile bis-clickable reagent for SuFEx and CuAAC click reactions. Eur. J. Org. Chem. 2019, 1763.
Supplemental Information

Rh-Catalyzed Highly Enantioselective Synthesis
of Aliphatic Sulfonyl Fluorides

Balakrishna Moku, Wan-Yin Fang, Jing Leng, Linxian Li, Gao-Feng Zha, K.P. Rakesh, and Hua-Li Qin
Supplemental Figures for NMR spectra

**Figure S1.** $^1$H NMR spectrum of Ligand (R)-L1, related to Table 1

![Ligand (R)-L1](image)

**Figure S2.** $^1$H NMR spectrum of Ligand (R)-L2, related to Table 1

![Ligand (R)-L2](image)
Figure S3. $^1$H NMR spectrum of Ligand (R)-L3, related to Table 1

Figure S4. $^1$H NMR spectrum of Ligand (R)-L4, related to Table 1
Figure S5. $^1$H NMR spectrum of Ligand (R)-L5, related to Table 1

Figure S6. $^1$H NMR spectrum of Ligand (R)-L6, related to Table 1
Figure S7. $^{13}$C NMR spectrum of Ligand $(R)$-L6, related to Table 1

Figure S8. $^1$H NMR spectrum of Ligand $[\text{RhCl}(R)$-$\text{L3}]_2$, related to Table 1
Figure S9. $^{13}$C NMR spectrum of Ligand [RhCl($R$)-L3]$_2$, related to Table 1

Figure S10. $^1$H NMR spectrum of 3a, related to Scheme 2
Figure S11. $^{13}$C NMR spectrum of 3a, related to Scheme 2

![Figure S11. $^{13}$C NMR spectrum of 3a, related to Scheme 2](image)

Figure S12. $^{19}$F NMR spectrum of 3a, related to Scheme 2

![Figure S12. $^{19}$F NMR spectrum of 3a, related to Scheme 2](image)
Figure S13. $^1$H NMR spectrum of $3b$, related to Scheme 2

Figure S14. $^{13}$C NMR spectrum of $3b$, related to Scheme 2
Figure S15. $^{19}$F NMR spectrum of 3b, related to Scheme 2

Figure S16. $^1$H NMR spectrum of 3c, related to Scheme 2
Figure S17. $^{13}$C NMR spectrum of 3c, related to Scheme 2

Figure S18. $^{19}$F NMR spectrum of 3c, related to Scheme 2
Figure S19. $^1$H NMR spectrum of 3d, related to Scheme 2

Figure S20. $^{13}$C NMR spectrum of 3d, related to Scheme 2
Figure S21. $^{19}$F NMR spectrum of 3d, related to Scheme 2

Figure S22. $^1$H NMR spectrum of 3e, related to Scheme 2
Figure S23. $^{13}$C NMR spectrum of 3e, related to Scheme 2

Figure S24. $^{19}$F NMR spectrum of 3e, related to Scheme 2
Figure S25. $^1$H NMR spectrum of 3f, related to Scheme 2

Figure S26. $^{13}$C NMR spectrum of 3f, related to Scheme 2
Figure S27. $^{19}$F NMR spectrum of 3f, related to Scheme 2

Figure S28. $^1$H NMR spectrum of 3g, related to Scheme 2
Figure S29. $^{13}$C NMR spectrum of 3g, related to Scheme 2

Figure S30. $^{19}$F NMR spectrum of 3g, related to Scheme 2
Figure S31. $^1$H NMR spectrum of 3h, related to Scheme 2

Figure S32. $^{13}$C NMR spectrum of 3h, related to Scheme 2
Figure S33. $^{19}$F NMR spectrum of 3h, related to Scheme 2

Figure S34. $^1$H NMR spectrum of 3i, related to Scheme 2
Figure S35. $^{13}$C NMR spectrum of 3i, related to Scheme 2

Figure S36. $^{19}$F NMR spectrum of 3i, related to Scheme 2
Figure S37. $^1$H NMR spectrum of 3j, related to Scheme 2

Figure S38. $^{13}$C NMR spectrum of 3j, related to Scheme 2
Figure S39. $^{19}$F NMR spectrum of 3j, related to Scheme 2

Figure S40. $^1$H NMR spectrum of 3k, related to Scheme 2
Figure S41. $^{13}$C NMR spectrum of 3k, related to Scheme 2

Figure S42. $^{19}$F NMR spectrum of 3k, related to Scheme 2
Figure S43. $^1$H NMR spectrum of 3I, related to Scheme 2

Figure S44. $^{13}$C NMR spectrum of 3I, related to Scheme 2
Figure S45. $^{19}$F NMR spectrum of 3l, related to Scheme 2

Figure S46. $^1$H NMR spectrum of 3m, related to Scheme 2
Figure S47. $^{13}$C NMR spectrum of 3m, related to Scheme 2

Figure S48. $^{19}$F NMR spectrum of 3m, related to Scheme 2
Figure S49. $^1$H NMR spectrum of 3n, related to Scheme 2

Figure S50. $^{13}$C NMR spectrum of 3n, related to Scheme 2
Figure S51. $^{19}$F NMR spectrum of 3n, related to Scheme 2

Figure S52. $^1$H NMR spectrum of 3o, related to Scheme 2
Figure S53. $^{13}$C NMR spectrum of 3o, related to Scheme 2

Figure S54. $^{19}$F NMR spectrum of 3o, related to Scheme 2
Figure S55. $^1$H NMR spectrum of 3p, related to Scheme 2

Figure S56. $^{13}$C NMR spectrum of 3p, related to Scheme 2
Figure S57. $^{19}$F NMR spectrum of 3p, related to Scheme 2

Figure S58. $^1$H NMR spectrum of 3q, related to Scheme 2
Figure S59. $^{13}$C NMR spectrum of 3q, related to Scheme 2

Figure S60. $^{19}$F NMR spectrum of 3q, related to Scheme 2
Figure S61. $^1$H NMR spectrum of 3r, related to Scheme 2

Figure S62. $^{13}$C NMR spectrum of 3r, related to Scheme 2
Figure S63. $^{19}$F NMR spectrum of 3r, related to Scheme 2

Figure S64. $^1$H NMR spectrum of 3s, related to Scheme 2
Figure S65. $^{13}$C NMR spectrum of 3s, related to Scheme 2

Figure S66. $^{19}$F NMR spectrum of 3s, related to Scheme 2
Figure S67. $^1$H NMR spectrum of 3t, related to Scheme 2

Figure S68. $^{13}$C NMR spectrum of 3t, related to Scheme 2
Figure S69. $^{19}$F NMR spectrum of 3t, related to Scheme 2

![Figure S69](image)

Figure S70. $^1$H NMR spectrum of 3u, related to Scheme 2

![Figure S70](image)
Figure S71. $^{13}$C NMR spectrum of 3u, related to Scheme 2

Figure S72. $^{19}$F NMR spectrum of 3u, related to Scheme 2
Figure S73. $^1$H NMR spectrum of 3v, related to Scheme 2

Figure S74. $^{13}$C NMR spectrum of 3v, related to Scheme 2
Figure S75. $^{19}$F NMR spectrum of 3v, related to Scheme 2

![19F NMR spectrum of 3v](image)

Figure S76. $^1$H NMR spectrum of 3w, related to Scheme 2

![1H NMR spectrum of 3w](image)
**Figure S77.** $^{13}$C NMR spectrum of 3w, related to Scheme 2

![13C NMR spectrum of 3w](image)

**Figure S78.** $^{19}$F NMR spectrum of 3w, related to Scheme 2

![19F NMR spectrum of 3w](image)
Figure S79. $^1$H NMR spectrum of 3x, related to Scheme 2

Figure S80. $^{13}$C NMR spectrum of 3x, related to Scheme 2
Figure S81. $^{19}$F NMR spectrum of 3x, related to Scheme 2

Figure S82. $^1$H NMR spectrum of 3y, related to Scheme 2
Figure S83. $^{13}$C NMR spectrum of 3y, related to Scheme 2

Figure S84. $^{19}$F NMR spectrum of 3y, related to Scheme 2
Figure S85. $^1$H NMR spectrum of 4a, related to Scheme 3

Figure S86. $^{13}$C NMR spectrum of 4a, related to Scheme 3
Figure S87. $^{19}$F NMR spectrum of 4a, related to Scheme 3

Figure S88. $^1$H NMR spectrum of 4b, related to Scheme 3
Figure S89. $^{13}$C NMR spectrum of 4b, related to Scheme 3

Figure S90. $^{19}$F NMR spectrum of 4b, related to Scheme 3
Figure S91. $^1$H NMR spectrum of 4c, related to Scheme 3

Figure S92. $^{13}$C NMR spectrum of 4c, related to Scheme 3
Figure S93. $^{19}$F NMR spectrum of 4c, related to Scheme 3

Figure S94. $^1$H NMR spectrum of 4d, related to Scheme 3
Figure S95. $^{13}$C NMR spectrum of 4d, related to Scheme 3

Figure S96. $^{19}$F NMR spectrum of 4d, related to Scheme 3
Figure S97. $^1$H NMR spectrum of 4e, related to Scheme 3

Figure S98. $^{13}$C NMR spectrum of 4e, related to Scheme 3
Figure S99. $^{19}$F NMR spectrum of 4e, related to Scheme 3

Figure S100. $^1$H NMR spectrum of 4f, related to Scheme 3
Figure S101. $^{13}$C NMR spectrum of 4f, related to Scheme 3

Figure S102. $^{19}$F NMR spectrum of 4f, related to Scheme 3
Figure S103. $^1$H NMR spectrum of 4g, related to Scheme 3

Figure S104. $^{13}$C NMR spectrum of 4g, related to Scheme 3
Figure S105. $^{19}$F NMR spectrum of 4g, related to Scheme 3

Figure S106. $^1$H NMR spectrum of 4h, related to Scheme 3
Figure S107. $^{13}$C NMR spectrum of 4h, related to Scheme 3

Figure S108. $^{19}$F NMR spectrum of 4h, related to Scheme 3
Figure S109. $^1$H NMR spectrum of 4i, related to Scheme 3

Figure S110. $^{13}$C NMR spectrum of 4i, related to Scheme 3
Figure S111. $^{19}$F NMR spectrum of 4i, related to Scheme 3

Figure S112. $^1$H NMR spectrum of 4j, related to Scheme 3
Figure S113. $^{13}$C NMR spectrum of 4j, related to Scheme 3

Figure S114. $^{19}$F NMR spectrum of 4j, related to Scheme 3
Figure S115. $^1$H NMR spectrum of 4k, related to Scheme 3

Figure S116. $^{13}$C NMR spectrum of 4k, related to Scheme 3
Figure S117. $^{19}$F NMR spectrum of 4k, related to Scheme 3

Figure S118. $^1$H NMR spectrum of 4l, related to Scheme 3
Figure S119. $^{13}$C NMR spectrum of 4l, related to Scheme 3

Figure S120. $^{19}$F NMR spectrum of 4l, related to Scheme 3
Figure S121. $^1$H NMR spectrum of 4m, related to Scheme 3

Figure S122. $^{13}$C NMR spectrum of 4m, related to Scheme 3
Figure S123. $^{19}$F NMR spectrum of 4m, related to Scheme 3

Figure S124. $^1$H NMR spectrum of 4n, related to Scheme 3
Figure S125. $^{13}$C NMR spectrum of 4n, related to Scheme 3

Figure S126. $^{19}$F NMR spectrum of 4n, related to Scheme 3
Figure S127. $^1$H NMR spectrum of 4o, related to Scheme 3

Figure S128. $^{13}$C NMR spectrum of 4o, related to Scheme 3
Figure S129. $^{19}$F NMR spectrum of 4o, related to Scheme 3

Figure S130. $^1$H NMR spectrum of 4p, related to Scheme 3
Figure S131. $^{13}$C NMR spectrum of 4p, related to Scheme 3

Figure S132. $^{19}$F NMR spectrum of 4p, related to Scheme 3
Figure S133. $^1$H NMR spectrum of 4q, related to Scheme 3

Figure S134. $^{13}$C NMR spectrum of 4q, related to Scheme 3
Figure S135. $^{19}$F NMR spectrum of $4q$, related to Scheme 3

Figure S136. $^1$H NMR spectrum of $4r$, related to Scheme 3
Figure S137. $^{13}$C NMR spectrum of 4r, related to Scheme 3

Figure S138. $^{19}$F NMR spectrum of 4r, related to Scheme 3
Figure S139. $^1$H NMR spectrum of 4s, related to Scheme 3

Figure S140. $^{13}$C NMR spectrum of 4s, related to Scheme 3
Figure S141. $^{19}$F NMR spectrum of 4s, related to Scheme 3

Figure S142. $^1$H NMR spectrum of 4t, related to Scheme 3
Figure S143. $^{13}$C NMR spectrum of 4t, related to Scheme 3

Figure S144. $^{19}$F NMR spectrum of 4t, related to Scheme 3
Figure S145. $^1$H NMR spectrum of 4u, related to Scheme 3

Figure S146. $^{13}$C NMR spectrum of 4u, related to Scheme 3
Figure S147. $^{19}$F NMR spectrum of 4u, related to Scheme 3

Figure S148. $^1$HNMR spectrum of 4v, related to Scheme 3
Figure S149 $^{13}$CNMR spectrum of 4v, related to Scheme 3

Figure S150 $^{19}$F NMR spectrum of 4v, related to Scheme 3
Figure S151. $^1$H NMR spectrum of 4w, related to Scheme 3

Figure S152. $^{13}$C NMR spectrum of 4w, related to Scheme 3
Figure S153. $^{19}$F NMR spectrum of 4w, related to Scheme 3

Figure S154. $^1$H NMR spectrum of 4x, related to Scheme 3
Figure S155. $^{13}$C NMR spectrum of 4x, related to Scheme 3

Figure S156. $^{19}$F NMR spectrum of 4x, related to Scheme 3
Figure S157. $^1$H NMR spectrum of 4y, related to Scheme 3

Figure S158. $^{13}$C NMR spectrum of 4y, related to Scheme 3
**Figure S159.** $^{19}$F NMR spectrum of 4y, related to Scheme 3

![Figure S159: $^{19}$F NMR spectrum of 4y](image)

**Figure S160.** $^1$H NMR spectrum of 6w, related to Scheme 4

![Figure S160: $^1$H NMR spectrum of 6w](image)
Figure S161. $^{13}$C NMR spectrum of 6w, related to Scheme 4

Figure S162. $^1$H NMR spectrum of 8w, related to Scheme 4
Figure S163. $^{13}$C NMR spectrum of $8w$, related to Scheme 4

Figure S164. $^1$H NMR spectrum of $9$, related to Scheme 4
Figure S165. $^{13}$C NMR spectrum of 9, related to Scheme 4

![C NMR spectrum of 9](image1)

Figure S166. $^{19}$F NMR spectrum of 9, related to Scheme 4

![F NMR spectrum of 9](image2)
**Figure S167.** $^1$H NMR spectrum of 11, related to Scheme 4

![H NMR spectrum of 11](image)

**Figure S168.** $^{13}$C NMR spectrum of 11, related to Scheme 4

![C NMR spectrum of 11](image)
Figure S169. $^1$H NMR spectrum of 12, related to Scheme 4
Supplemental Figures for HPLC spectra

**Figure S170.** HPLC spectrum of racemic-3a, related to **Scheme 2**

|   | $t_R$ [min] | Area [mAU.s] | Height [mAU] | Area Ratio [%] |
|---|-------------|--------------|--------------|----------------|
| 1 | 20.980      | 39559.493    | 1592.348     | 50.1           |
| 2 | 23.036      | 39445.923    | 1496.76      | 49.9           |
| Total | | 79005.416 | 3089.108 | 100.0 |

**Figure S171.** HPLC spectrum of 3a, related to **Scheme 2**

|   | $t_R$ [min] | Area [mAU.s] | Height [mAU] | Area Ratio [%] |
|---|-------------|--------------|--------------|----------------|
| 1 | 20.806      | 76139.193    | 2774.233     | 95.9           |
| 2 | 22.961      | 3243.584     | 125.834      | 4.1            |
| Total | | 79382.777 | 2900.067 | 100.0 |
Figure S172. HPLC spectrum of racemic-3b, related to Scheme 2

|       | $t_R$ [min] | Area [mAU.s] | Height [mAU] | Area Ratio [%] |
|-------|-------------|--------------|--------------|----------------|
| 1     | 13.913      | 3113.344     | 137.750      | 50.4           |
| 2     | 15.845      | 3063.054     | 116.518      | 49.6           |
| Total |             | 6176.398     | 254.268      | 100.0          |

Figure S173. HPLC spectrum of 3b, related to Scheme 2

|       | $t_R$ [min] | Area [mAU.s] | Height [mAU] | Area Ratio [%] |
|-------|-------------|--------------|--------------|----------------|
| 1     | 13.913      | 14184.591    | 561.196      | 96.2           |
| 2     | 15.845      | 553.422      | 21.114       | 3.8            |
| Total |             | 14738.013    | 582.310      | 100.0          |
Figure S174. HPLC spectrum of racemic-3c, related to Scheme 2

| t_R [min] | Area [mAU.s] | Height [mAU] | Area Ratio [%] |
|-----------|--------------|--------------|----------------|
| 1         | 17.407       | 3867.887     | 144.544        | 50.1           |
| 2         | 19.701       | 3849.132     | 137.771        | 49.9           |
| Total     | 7717.019     | 282.315      | 100.0          |

Figure S175. HPLC spectrum of 3c, related to Scheme 2

| t_R [min] | Area [mAU.s] | Height [mAU] | Area Ratio [%] |
|-----------|--------------|--------------|----------------|
| 1         | 17.247       | 5050.257     | 183.369        | 97.4           |
| 2         | 19.772       | 134.725      | 5.052          | 2.6            |
| Total     | 5184.983     | 188.421      | 100.0          |
### Figure S176. HPLC spectrum of racemic-3d, related to Scheme 2

| t_R [min] | Area [mAU.s] | Height [mAU] | Area Ratio [%] |
|-----------|--------------|--------------|----------------|
| 1         | 21.854       | 2136.321     | 90.577         | 49.6           |
| 2         | 24.925       | 2173.316     | 72.918         | 50.4           |
| Total     | 4309.636     | 163.495      | 100.0          |

### Figure S177. HPLC spectrum of 3d, related to Scheme 2

| t_R [min] | Area [mAU.s] | Height [mAU] | Area Ratio [%] |
|-----------|--------------|--------------|----------------|
| 1         | 21.782       | 2300.652     | 93.965         | 93.6           |
| 2         | 25.028       | 156.267      | 5.718          | 6.4            |
| Total     | 2456.919     | 99.683       | 100.0          |
Figure S178. HPLC spectrum of racemic-3e, related to Scheme 2

|   | $t_R$ [min] | Area [mAU.s] | Height [mAU] | Area Ratio [%] |
|---|-------------|--------------|--------------|----------------|
| 1 | 32.574      | 15435.539    | 169.265      | 50.8           |
| 2 | 45.774      | 14930.820    | 123.426      | 49.2           |
| Total |          | 30366.359    | 292.692      | 100.0          |

Figure S179. HPLC spectrum of 3e, related to Scheme 2

|   | $t_R$ [min] | Area [mAU.s] | Height [mAU] | Area Ratio [%] |
|---|-------------|--------------|--------------|----------------|
| 1 | 33.597      | 282.998      | 3.881        | 1.0            |
| 2 | 46.672      | 27241.473    | 223.120      | 99.0           |
| Total |          | 27524.471    | 227.001      | 100.0          |
**Figure S180.** HPLC spectrum of racemic-3f, related to Scheme 2

| t_R [min] | Area [mAU.s] | Height [mAU] | Area Ratio [%] |
|-----------|--------------|--------------|----------------|
| 1         | 41.432       | 3991.483     | 81.979         | 49.9           |
| 2         | 43.621       | 4012.473     | 76.097         | 50.1           |
| Total     | 8003.955     | 158.076      | 100.0          |

**Figure S181.** HPLC spectrum of 3f, related to Scheme 2

| t_R [min] | Area [mAU.s] | Height [mAU] | Area Ratio [%] |
|-----------|--------------|--------------|----------------|
| 1         | 41.510       | 7230.715     | 146.002        | 80.5           |
| 2         | 43.898       | 1752.361     | 33.131         | 19.5           |
| Total     | 8983.075     | 179.133      | 100.0          |
**Figure S182.** HPLC spectrum of racemic-3g, related to Scheme 2

|          | \( t_R \) [min] | Area [mAU.s] | Height [mAU] | Area Ratio [%] |
|----------|-----------------|--------------|--------------|----------------|
| 1        | 25.203          | 11269.729    | 243.551      | 49.5           |
| 2        | 27.726          | 11503.894    | 241.684      | 50.5           |
| **Total**|                 | **22773.613**| **485.235**  | **100.0**      |

**Figure S183.** HPLC spectrum of 3g, related to Scheme 2

|          | \( t_R \) [min] | Area [mAU.s] | Height [mAU] | Area Ratio [%] |
|----------|-----------------|--------------|--------------|----------------|
| 1        | 24.265          | 49994.266    | 1121.610     | 95.1           |
| 2        | 27.019          | 2569.479     | 61.581       | 4.9            |
| **Total**|                 | **52563.745**| **1183.191** | **100.0**      |
Figure S184. HPLC spectrum of racemic-3h, related to Scheme 2

|   | t_R [min] | Area [mAU.s] | Height [mAU] | Area Ratio [%] |
|---|-----------|--------------|--------------|----------------|
| 1 | 41.249    | 2492.363     | 14.852       | 50.9           |
| 2 | 63.516    | 2400.321     | 9.117        | 49.1           |
| Total |           | 4892.685     | 23.970       | 100.0          |

Figure S185. HPLC spectrum of 3h, related to Scheme 2

|   | t_R [min] | Area [mAU.s] | Height [mAU] | Area Ratio [%] |
|---|-----------|--------------|--------------|----------------|
| 1 | 40.261    | 5834.402     | 32.626       | 99.0           |
| 2 | 64.874    | 56.892       | 0.287        | 1.0            |
| Total |           | 5891.294     | 32.913       | 100.0          |
**Figure S186.** HPLC spectrum of racemic-3i, related to Scheme 2

|     | $t_R$ [min] | Area [mAU.s] | Height [mAU] | Area Ratio [%] |
|-----|-------------|--------------|--------------|----------------|
| 1   | 38.943      | 93706.126    | 808.192      | 49.5           |
| 2   | 51.448      | 95461.435    | 613.165      | 50.5           |
| Total |             | 189167.562   | 1421.357     | 100.0          |

**Figure S187.** HPLC spectrum of 3i, related to Scheme 2

|     | $t_R$ [min] | Area [mAU.s] | Height [mAU] | Area Ratio [%] |
|-----|-------------|--------------|--------------|----------------|
| 1   | 40.057      | 3199.603     | 32.187       | 3.4            |
| 2   | 51.131      | 91805.344    | 597.785      | 96.6           |
| Total |             | 95004.947    | 629.972      | 100.0          |
**Figure S188.** HPLC spectrum of racemic-3j, related to Scheme 2

|      | $t_R$ [min] | Area [mAU.s] | Height [mAU] | Area Ratio [%] |
|------|-------------|--------------|--------------|----------------|
| 1    | 34.734      | 12983.696    | 250.200      | 46.3           |
| 2    | 38.247      | 15088.550    | 252.935      | 53.7           |
| Total|              | 28072.246    | 503.135      | 100.0          |

**Figure S189.** HPLC spectrum of racemic-3j, related to Scheme 2

|      | $t_R$ [min] | Area [mAU.s] | Height [mAU] | Area Ratio [%] |
|------|-------------|--------------|--------------|----------------|
| 1    | 34.902      | 13.178       | 0.534        | 0.1            |
| 2    | 37.822      | 10768.697    | 182.262      | 99.9           |
| Total|              | 10781.875    | 182.796      | 100.0          |
Figure S190. HPLC spectrum of racemic-3k, related to Scheme 2

| t_R [min] | Area [mAU.s] | Height [mAU] | Area Ratio [%] |
|-----------|--------------|--------------|---------------|
| 1         | 22.269       | 69770.448    | 341.846       | 49.1          |
| 2         | 37.342       | 72458.074    | 281.038       | 50.9          |
| Total     | 142228.523   | 622.885      | 100.0         |

Figure S191. HPLC spectrum of 3k, related to Scheme 2

| t_R [min] | Area [mAU.s] | Height [mAU] | Area Ratio [%] |
|-----------|--------------|--------------|---------------|
| 1         | 17.214       | 64090.113    | 378.489       | 83.4          |
| 2         | 37.118       | 12762.872    | 59.277        | 16.6          |
| Total     | 76852.985    | 437.765      | 100           |
Figure S192. HPLC spectrum of racemic-3l, related to Scheme 2

|   | $t_R$ [min] | Area [mAU.s] | Height [mAU] | Area Ratio [%] |
|---|------------|--------------|--------------|---------------|
| 1 | 16.657     | 4677.409     | 214.023      | 50.0          |
| 2 | 18.055     | 4682.156     | 184.684      | 50.0          |
| Total | | 9359.565 | 398.707 | 100.0 |

Figure S193. HPLC spectrum of 3l, related to Scheme 2

|   | $t_R$ [min] | Area [mAU.s] | Height [mAU] | Area Ratio [%] |
|---|------------|--------------|--------------|---------------|
| 1 | 15.620     | 23714.030    | 891.931      | 94.7          |
| 2 | 18.283     | 1325.459     | 51.610       | 5.3           |
| Total | | 25039.488 | 943.541 | 100.0 |
Figure S194. HPLC spectrum of racemic-3m, related to Scheme 2

|   | t_R [min] | Area [mAU.s] | Height [mAU] | Area Ratio [%] |
|---|-----------|--------------|--------------|----------------|
| 1 | 44.574    | 1407.970     | 10.346       | 49.9           |
| 2 | 57.804    | 1414.127     | 7.631        | 50.1           |
| Total |     | 2822.096     | 17.977       | 100.0          |

Figure S195. HPLC spectrum of 3m, related to Scheme 2

|   | t_R [min] | Area [mAU.s] | Height [mAU] | Area Ratio [%] |
|---|-----------|--------------|--------------|----------------|
| 1 | 45.883    | 112.576      | 1.028        | 1.8            |
| 2 | 54.795    | 6001.826     | 25.643       | 98.2           |
| Total |     | 6114.402     | 26.671       | 100.0          |
Figure S196. HPLC spectrum of racemic-3n, related to Scheme 2

|   | t_R [min] | Area [mAU.s] | Height [mAU] | Area Ratio [%] |
|---|-----------|--------------|--------------|----------------|
| 1 | 16.434    | 3282.593     | 157.626      | 48.8           |
| 2 | 17.502    | 3445.284     | 137.522      | 51.2           |
| Total |          | 6727.877     | 295.148      | 100.0          |

Figure S197. HPLC spectrum of 3n, related to Scheme 2

|   | t_R [min] | Area [mAU.s] | Height [mAU] | Area Ratio [%] |
|---|-----------|--------------|--------------|----------------|
| 1 | 16.523    | 5072.937     | 235.832      | 98.0           |
| 2 | 17.674    | 103.101      | 5.241        | 2.0            |
| Total |        | 5176.038     | 241.073      | 100.0          |
Figure S198. HPLC spectrum of racemic-3o, related to Scheme 2

|      | \( t_R \) [min] | Area [mAU.s] | Height [mAU] | Area Ratio [%] |
|------|------------------|--------------|--------------|----------------|
| 1    | 24.481           | 32218.133    | 498.862      | 49.8           |
| 2    | 39.148           | 32432.909    | 291.208      | 50.2           |
| Total|                  | 64651.042    | 790.070      | 100.0          |

Figure S199. HPLC spectrum of 3o, related to Scheme 2

|      | \( t_R \) [min] | Area [mAU.s] | Height [mAU] | Area Ratio [%] |
|------|------------------|--------------|--------------|----------------|
| 1    | 25.078           | 662.585      | 10.725       | 3.0            |
| 2    | 39.542           | 21702.437    | 196.862      | 97.0           |
| Total|                  | 22365.022    | 207.587      | 100.0          |
**Figure S200.** HPLC spectrum of racemic-3p, related to Scheme 2

|       | t_R [min] | Area [mAU.s] | Height [mAU] | Area Ratio [%] |
|-------|-----------|--------------|--------------|----------------|
| 1     | 30.232    | 16471.835    | 226.391      | 50.1           |
| 2     | 62.680    | 16415.168    | 104.790      | 49.9           |
| Total | 32887.003 | 331.18       |              | 100.0          |

**Figure S201.** HPLC spectrum of 3p, related to Scheme 2

|       | t_R [min] | Area [mAU.s] | Height [mAU] | Area Ratio [%] |
|-------|-----------|--------------|--------------|----------------|
| 1     | 30.856    | 592.436      | 8.781        | 1.5            |
| 2     | 62.650    | 40248.591    | 235.207      | 98.5           |
| Total | 40841.026 | 243.988      |              | 100.0          |
Figure S202. HPLC spectrum of racemic-3q, related to Scheme 2

| t_R [min] | Area [mAU.s] | Height [mAU] | Area Ratio [%] |
|-----------|--------------|--------------|----------------|
| 1         | 17.634       | 1064.246     | 20.489         | 49.7           |
| 2         | 19.658       | 1078.728     | 17.107         | 50.3           |
| Total     | 2142.974     | 37.596       | 100.0          |

Figure S203. HPLC spectrum of 3q, related to Scheme 2

| t_R [min] | Area [mAU.s] | Height [mAU] | Area Ratio [%] |
|-----------|--------------|--------------|----------------|
| 1         | 17.915       | 456.030      | 9.720          | 12.8           |
| 2         | 19.640       | 3105.344     | 48.268         | 87.2           |
| Total     | 3561.374     | 57.988       | 100.0          |
**Figure S204.** HPLC spectrum of racemic-3r, related to Scheme 2

| t<sub>R</sub> [min] | Area [mAU.s] | Height [mAU] | Area Ratio [%] |
|---------------------|--------------|--------------|----------------|
| 1                   | 11.746       | 2185.593     | 148.989        | 49.8           |
| 2                   | 12.717       | 2205.589     | 136.153        | 50.2           |
| **Total**           | **4391.182** | **285.142**  | **100.0**      |

**Figure S205.** HPLC spectrum of 3r, related to Scheme 2

| t<sub>R</sub> [min] | Area [mAU.s] | Height [mAU] | Area Ratio [%] |
|---------------------|--------------|--------------|----------------|
| 1                   | 11.752       | 11349.794    | 749.573        | 99.1           |
| 2                   | 12.700       | 97.826       | 7.672          | 0.9            |
| **Total**           | **11447.620**| **757.245**  | **100.0**      |
Figure S206. HPLC spectrum of racemic-3s, related to Scheme 2

|      | tᵣ [min] | Area [mAU.s] | Height [mAU] | Area Ratio [%] |
|------|----------|--------------|--------------|----------------|
| 1    | 6.909    | 72441.694    | 2065.787     | 45.7           |
| 2    | 16.567   | 86135.194    | 1068.904     | 54.3           |
| Total|          | 158576.888   | 3134.691     | 100.0          |

Figure S207. HPLC spectrum of 3s, related to Scheme 2

|      | tᵣ [min] | Area [mAU.s] | Height [mAU] | Area Ratio [%] |
|------|----------|--------------|--------------|----------------|
| 1    | 6.840    | 80148.196    | 2234.598     | 98.4           |
| 2    | 15.819   | 1318.462     | 34.305       | 1.6            |
| Total|          | 81466.658    | 2268.903     | 100.0          |
**Figure S208.** HPLC spectrum of racemic-3t, related to Scheme 2

|      | $t_R$ [min] | Area [mAU.s] | Height [mAU] | Area Ratio [%] |
|------|-------------|--------------|--------------|----------------|
| 1    | 22.628      | 19665.882    | 731.188      | 50.0           |
| 2    | 28.209      | 19680.730    | 528.043      | 50.0           |
| Total|             | 39346.613    | 1259.231     | 100.0          |

**Figure S209.** HPLC spectrum of 3t, related to Scheme 2

|      | $t_R$ [min] | Area [mAU.s] | Height [mAU] | Area Ratio [%] |
|------|-------------|--------------|--------------|----------------|
| 1    | 22.609      | 73810.923    | 2635.329     | 98.6           |
| 2    | 29.230      | 1053.464     | 30.195       | 1.4            |
| Total|             | 74864.387    | 2665.524     | 100.0          |
**Figure S210.** HPLC spectrum of racemic-3u, related to Scheme 2

| tR [min] | Area [mAU.s] | Height [mAU] | Area Ratio [%] |
|----------|--------------|--------------|----------------|
| 1        | 14.376       | 3541.772     | 154.270        | 49.8           |
| 2        | 15.418       | 3564.606     | 136.608        | 50.2           |
| Total    | 7106.378     | 290.879      | 100.0          |

**Figure S211.** HPLC spectrum of 3u, related to Scheme 2

| tR [min] | Area [mAU.s] | Height [mAU] | Area Ratio [%] |
|----------|--------------|--------------|----------------|
| 1        | 14.098       | 18215.279    | 700.271        | 99.3           |
| 2        | 15.495       | 132.741      | 5.755          | 0.7            |
| Total    | 18348.020    | 706.026      | 100.0          |
Figure S212. HPLC spectrum of racemic-3v, related to Scheme 2

|   | t_R [min] | Area [mAU.s] | Height [mAU] | Area Ratio [%] |
|---|-----------|--------------|--------------|----------------|
| 1 | 25.305    | 9163.331     | 151.121      | 49.9           |
| 2 | 28.758    | 9217.131     | 131.812      | 50.1           |
| Total |     | 18380.463   | 282.933      | 100.0          |

Figure S213. HPLC spectrum of 3v, related to Scheme 2

|   | t_R [min] | Area [mAU.s] | Height [mAU] | Area Ratio [%] |
|---|-----------|--------------|--------------|----------------|
| 1 | 25.331    | 86.269       | 2.081        | 0.3            |
| 2 | 28.378    | 32772.716    | 439.179      | 99.7           |
| Total |     | 32858.985   | 441.260      | 100.0          |
**Figure S214.** HPLC spectrum of racemic-3w, related to Scheme 2

|   | $t_R$ [min] | Area [mAU.s] | Height [mAU] | Area Ratio [%] |
|---|------------|--------------|--------------|----------------|
| 1 | 31.847     | 51344.475    | 341.022      | 50.4           |
| 2 | 67.379     | 50574.468    | 137.265      | 49.6           |
| Total |           | 101918.944   | 478.287      | 100.0          |

**Figure S215.** HPLC spectrum of 3w, related to Scheme 2

|   | $t_R$ [min] | Area [mAU.s] | Height [mAU] | Area Ratio [%] |
|---|------------|--------------|--------------|----------------|
| 1 | 31.043     | 84797.089    | 836.496      | 99.9           |
| 2 | 70.700     | 121.592      | 0.865        | 0.1            |
| Total |         | 84918.681    | 837.361      | 100.0          |
Figure S216. HPLC spectrum of racemic-3x, related to Scheme 2

|   | t<sub>R</sub> [min] | Area [mAU.s] | Height [mAU] | Area Ratio [%] |
|---|-------------------|-------------|-------------|--------------|
| 1 | 19.273            | 27461.135   | 1030.715    | 51.0         |
| 2 | 21.262            | 26373.485   | 983.924     | 49.0         |
| Total |                | 53834.621   | 2014.639    | 100.0        |

Figure S217. HPLC spectrum of 3x, related to Scheme 2

|   | t<sub>R</sub> [min] | Area [mAU.s] | Height [mAU] | Area Ratio [%] |
|---|-------------------|-------------|-------------|--------------|
| 1 | 19.105            | 39416.984   | 1587.680    | 99.8         |
| 2 | 21.166            | 93.025      | 5.168       | 0.2          |
| Total |                | 39510.009   | 1592.848    | 100.0        |
Figure S218. HPLC spectrum of racemic-3y, related to Scheme 2

|   | t_R [min] | Area [mAU.s] | Height [mAU] | Area Ratio [%] |
|---|-----------|--------------|--------------|----------------|
| 1 | 18.983    | 4960.888     | 186.450      | 49.2           |
| 2 | 22.822    | 5125.910     | 197.424      | 50.8           |
| Total |        | 10086.798   | 383.873      | 100.0          |

Figure S219. HPLC spectrum of 3y, related to Scheme 2

|   | t_R [min] | Area [mAU.s] | Height [mAU] | Area Ratio [%] |
|---|-----------|--------------|--------------|----------------|
| 1 | 18.804    | 47414.357    | 1811.334     | 99.2           |
| 2 | 22.730    | 366.554      | 15.691       | 0.8            |
| Total |        | 47780.911   | 1827.025     | 100.0          |
**Figure S220.** HPLC spectrum of racemic-4a, related to Scheme 3

|       | $t_R$ [min] | Area [mAU.s] | Height [mAU] | Area Ratio [%] |
|-------|-------------|--------------|--------------|----------------|
| 1     | 19.728      | 5863.557     | 103.585      | 50.3           |
| 2     | 24.057      | 5782.322     | 82.491       | 49.7           |
| Total |             | 11645.880    | 186.076      | 100.0          |

**Figure S221.** HPLC spectrum of 4a, related to Scheme 3

|       | $t_R$ [min] | Area [mAU.s] | Height [mAU] | Area Ratio [%] |
|-------|-------------|--------------|--------------|----------------|
| 1     | 19.859      | 16429.741    | 277.680      | 91.6           |
| 2     | 24.258      | 1512.586     | 20.850       | 8.4            |
| Total |             | 17942.327    | 298.530      | 100.0          |
Figure S222. HPLC spectrum of racemic-4b, related to Scheme 3

|   | t<sub>R</sub> [min] | Area [mAU.s] | Height [mAU] | Area Ratio [%] |
|---|-------------------|--------------|--------------|----------------|
| 1 | 21.854            | 2136.321     | 90.577       | 49.6           |
| 2 | 24.925            | 2173.316     | 72.918       | 50.4           |
| Total | 4309.636     | 163.495   | 100.0       |

Figure S223. HPLC spectrum of 4b, related to Scheme 3

|   | t<sub>R</sub> [min] | Area [mAU.s] | Height [mAU] | Area Ratio [%] |
|---|-------------------|--------------|--------------|----------------|
| 1 | 22.040            | 1127.177     | 48.192       | 14.1           |
| 2 | 24.966            | 6875.321     | 211.336      | 85.9           |
| Total | 8002.498     | 259.528   | 100.0       |
Figure S224. HPLC spectrum of racemic-4c, related to Scheme 3

|      | $t_R$ [min] | Area [mAU.s] | Height [mAU] | Area Ratio [%] |
|------|-------------|--------------|--------------|----------------|
| 1    | 14.275      | 2303.068     | 84.904       | 24.5           |
| 2    | 15.753      | 7109.101     | 257.471      | 75.5           |
| Total|              | 9412.169     | 342.375      | 100.0          |

Figure S225. HPLC spectrum of 4c, related to Scheme 3

|      | $t_R$ [min] | Area [mAU.s] | Height [mAU] | Area Ratio [%] |
|------|-------------|--------------|--------------|----------------|
| 1    | 14.181      | 3113.344     | 137.750      | 50.4           |
| 2    | 15.840      | 3063.054     | 116.518      | 49.6           |
| Total|              | 6176.398     | 254.268      | 100.0          |
**Figure S226.** HPLC spectrum of racemic-4d, related to Scheme 3

| t<sub>R</sub> [min] | Area [mAU.s] | Height [mAU] | Area Ratio [%] |
|------------------|--------------|--------------|----------------|
| 1                | 32.574       | 15435.539    | 169.265        | 50.8           |
| 2                | 45.774       | 14930.820    | 123.426        | 49.2           |
| Total            |              | 30366.359    | 292.692        | 100.0          |

**Figure S227.** HPLC spectrum of 4d, related to Scheme 3

| t<sub>R</sub> [min] | Area [mAU] | Height [mAU] | Area Ratio [%] |
|------------------|------------|--------------|----------------|
| 1                | 32.656     | 17466.813    | 203.720        | 91.8           |
| 2                | 46.890     | 1568.332     | 14.562         | 8.2            |
| Total            |            | 19035.145    | 218.282        | 100.0          |
Figure S228. HPLC spectrum of racemic-4e, related to Scheme 3

|   | $t_R$ [min] | Area [mAU.s] | Height [mAU] | Area Ratio [%] |
|---|------------|--------------|--------------|---------------|
| 1 | 34.734     | 12983.696    | 250.200      | 46.3          |
| 2 | 38.247     | 15088.550    | 252.935      | 53.7          |
| Total |          | 28072.246 | 503.135      | 100.0         |

Figure S229. HPLC spectrum of 4e, related to Scheme 3

|   | $t_R$ [min] | Area [mAU.s] | Height [mAU] | Area Ratio [%] |
|---|------------|--------------|--------------|---------------|
| 1 | 34.400     | 13058.419    | 217.925      | 99.2          |
| 2 | 37.671     | 109.592      | 1.785        | 0.8           |
| Total |          | 13168.011 | 219.710      | 100.0         |
**Figure S230.** HPLC spectrum of racemic-4f, related to Scheme 3

|    | $t_R$ [min] | Area [mAU.s] | Height [mAU] | Area Ratio [%] |
|----|-------------|--------------|--------------|----------------|
| 1  | 48.418      | 3012.572     | 26.585       | 49.4           |
| 2  | 54.450      | 3081.979     | 20.533       | 50.6           |
| Total |            | 6094.550     | 47.118       | 100.0          |

**Figure S231.** HPLC spectrum of 4f, related to Scheme 3

|    | $t_R$ [min] | Area [mAU.s] | Height [mAU] | Area Ratio [%] |
|----|-------------|--------------|--------------|----------------|
| 1  | 47.298      | 8894.087     | 54.758       | 85.6           |
| 2  | 55.943      | 1495.609     | 10.524       | 14.4           |
| Total |            | 10389.697    | 65.282       | 100.0          |
Figure S232. HPLC spectrum of racemic-4g, related to Scheme 3

|    | t_R [min] | Area [mAU.s] | Height [mAU] | Area Ratio [%] |
|----|-----------|--------------|--------------|----------------|
| 1  | 25.203    | 11269.729    | 243.551      | 49.5           |
| 2  | 27.726    | 11503.894    | 241.684      | 50.5           |
| Total |          | 22773.613    | 485.235      | 100.0          |

Figure S233. HPLC spectrum of 4g, related to Scheme 3

|    | t_R [min] | Area [mAU.s] | Height [mAU] | Area Ratio [%] |
|----|-----------|--------------|--------------|----------------|
| 1  | 24.839    | 5919.005     | 157.086      | 14.1           |
| 2  | 26.793    | 36135.038    | 774.381      | 85.9           |
| Total |          | 42054.043    | 931.467      | 100.0          |
Figure S234. HPLC spectrum of racemic-4h, related to Scheme 3

|       | t_R [min] | Area [mAU.s] | Height [mAU] | Area Ratio [%] |
|-------|-----------|--------------|--------------|----------------|
| 1     | 22.269    | 69770.448    | 341.846      | 49.1           |
| 2     | 37.342    | 72458.074    | 281.038      | 50.9           |
| Total |           | 142228.523   | 622.885      | 100.0          |

Figure S235. HPLC spectrum of 4h, related to Scheme 3

|       | t_R [min] | Area [mAU.s] | Height [mAU] | Area Ratio [%] |
|-------|-----------|--------------|--------------|----------------|
| 1     | 24.858    | 2277.573     | 15.907       | 4.5            |
| 2     | 41.602    | 48724.816    | 240.416      | 95.5           |
| Total |           | 51002.389    | 256.323      | 100.0          |
**Figure S236.** HPLC spectrum of racemic-4i, related to Scheme 3

|   | $t_R$ [min] | Area [mAU.s]     | Height [mAU] | Area Ratio [%] |
|---|-------------|------------------|--------------|----------------|
| 1 | 38.943      | 93706.126        | 808.192      | 49.5           |
| 2 | 51.448      | 95461.435        | 613.165      | 50.5           |
| Total |          | 189167.562     | 1421.357     | 100.0          |

**Figure S237.** HPLC spectrum of 4i, related to Scheme 3

|   | $t_R$ [min] | Area [mAU.s]     | Height [mAU] | Area Ratio [%] |
|---|-------------|------------------|--------------|----------------|
| 1 | 38.986      | 96156.076        | 814.774      | 89.5           |
| 2 | 52.796      | 11321.742        | 81.267       | 10.5           |
| Total |          | 107477.818      | 896.041      | 100.0          |
**Figure S238.** HPLC spectrum of racemic-4j, related to Scheme 3

|   | $t_R$ [min] | Area [mAU.s] | Height [mAU] | Area Ratio [%] |
|---|-------------|--------------|--------------|----------------|
| 1 | 11.526      | 17923.160    | 1083.325     | 49.7           |
| 2 | 12.303      | 18135.885    | 964.150      | 50.3           |
| Total |          | 36059.045    | 2047.475     | 100.0          |

**Figure S239.** HPLC spectrum of 4j, related to Scheme 3

|   | $t_R$ [min] | Area [mAU.s] | Height [mAU] | Area Ratio [%] |
|---|-------------|--------------|--------------|----------------|
| 1 | 11.646      | 1148.894     | 76.078       | 10.1           |
| 2 | 12.390      | 10229.152    | 565.576      | 89.9           |
| Total |          | 11378.045    | 641.654      | 100.0          |
Figure S240. HPLC spectrum of racemic-4k, related to Scheme 3

|       | $t_R$ [min] | Area [mAU.s] | Height [mAU] | Area Ratio [%] |
|-------|-------------|--------------|--------------|----------------|
| 1     | 28.628      | 7083.653     | 81.194       | 50.2           |
| 2     | 57.422      | 7029.075     | 32.709       | 49.8           |
| Total |             | 14112.727    | 113.903      | 100.0          |

Figure S241. HPLC spectrum of 4k, related to Scheme 3

|       | $t_R$ [min] | Area [mAU.s] | Height [mAU] | Area Ratio [%] |
|-------|-------------|--------------|--------------|----------------|
| 1     | 28.547      | 1062.911     | 11.910       | 15.4           |
| 2     | 57.065      | 5848.525     | 29.212       | 84.6           |
| Total |             | 6911.436     | 41.122       | 100.0          |
**Figure S242.** HPLC spectrum of racemic-4l, related to Scheme 3

|   | tᵣ [min] | Area [mAU.s] | Height [mAU] | Area Ratio [%] |
|---|----------|--------------|--------------|----------------|
| 1 | 63.193   | 2176.917     | 13.302       | 50.3           |
| 2 | 71.401   | 2149.105     | 10.803       | 49.7           |
| Total | | 4326.022 | 24.105 | 100.0 |

**Figure S243.** HPLC spectrum of 4l, related to Scheme 3

|   | tᵣ [min] | Area [mAU.s] | Height [mAU] | Area Ratio [%] |
|---|----------|--------------|--------------|----------------|
| 1 | 60.276   | 10296.082    | 43.282       | 84.1           |
| 2 | 71.740   | 1946.271     | 9.164        | 15.9           |
| Total | | 12242.354 | 52.446 | 100.0 |
Figure S244. HPLC spectrum of racemic-4m, related to Scheme 3

| t_R [min] | Area [mAU.s]   | Height [mAU] | Area Ratio [%] |
|-----------|----------------|--------------|---------------|
| 1         | 22.653         | 25001.135    | 457.395       | 50.1          |
| 2         | 36.553         | 24940.843    | 266.751       | 49.9          |
| Total     | 49941.979      | 724.145      | 100.0         |

Figure S245. HPLC spectrum of 4m, related to Scheme 3

| t_R [min] | Area [mAU.s]   | Height [mAU] | Area Ratio [%] |
|-----------|----------------|--------------|---------------|
| 1         | 22.492         | 75342.195    | 1307.414      | 82.6          |
| 2         | 36.801         | 15921.431    | 172.753       | 17.4          |
| Total     | 91263.626      | 1480.167     | 100.0         |
Figure S246. HPLC spectrum of racemic-4n, related to Scheme 3

|      | t_R [min] | Area [mAU.s] | Height [mAU] | Area Ratio [%] |
|------|-----------|--------------|--------------|----------------|
| 1    | 14.400    | 4841.926     | 247.814      | 49.8           |
| 2    | 16.186    | 4873.459     | 220.183      | 50.2           |
| Total|           | 9715.386     | 467.997      | 100.0          |

Figure S247. HPLC spectrum of 4n, related to Scheme 3

|      | t_R [min] | Area [mAU.s] | Height [mAU] | Area Ratio [%] |
|------|-----------|--------------|--------------|----------------|
| 1    | 14.459    | 438.642      | 22.626       | 15.2           |
| 2    | 16.213    | 2439.861     | 115.337      | 84.8           |
| Total|           | 2878.502     | 137.963      | 100.0          |
Figure S248. HPLC spectrum of racemic-4o, related to Scheme 3

|     | tR [min] | Area [mAU.s] | Height [mAU] | Area Ratio [%] |
|-----|----------|--------------|--------------|----------------|
| 1   | 25.756   | 713.694      | 7.393        | 51.1           |
| 2   | 39.312   | 682.811      | 2.261        | 48.9           |
| Total |          | 1396.505     | 9.654        | 100.0          |

Figure S249. HPLC spectrum of 4o, related to Scheme 3

|     | tR [min] | Area [mAU.s] | Height [mAU] | Area Ratio [%] |
|-----|----------|--------------|--------------|----------------|
| 1   | 25.425   | 656.788      | 7.287        | 12.7           |
| 2   | 36.387   | 4531.426     | 14.402       | 87.3           |
| Total |          | 5188.215     | 21.689       | 100.0          |
**Figure S250.** HPLC spectrum of racemic-4p, related to Scheme 3

| t_R [min] | Area [mAU.s] | Height [mAU] | Area Ratio [%] |
|-----------|--------------|--------------|----------------|
| 1         | 30.232       | 16471.835    | 226.391        | 50.1           |
| 2         | 62.680       | 16415.168    | 104.790        | 49.9           |
| Total     |              | 32887.003    | 331.18         | 100.0          |

**Figure S251.** HPLC spectrum of 4p, related to Scheme 3

| t_R [min] | Area [mAU.s] | Height [mAU] | Area Ratio [%] |
|-----------|--------------|--------------|----------------|
| 1         | 30.308       | 29573.407    | 390.257        | 90.1           |
| 2         | 63.255       | 3255.458     | 22.591         | 9.9            |
| Total     |              | 32828.865    | 412.848        | 100.0          |
Figure S252. HPLC spectrum of racemic-4q, related to Scheme 3

|        | t_R [min] | Area [mAU.s] | Height [mAU] | Area Ratio [%] |
|--------|-----------|--------------|--------------|----------------|
| 1      | 46.789    | 1327.297     | 8.291        | 50.4           |
| 2      | 76.859    | 1308.786     | 4.687        | 49.6           |
| Total  |           | 2636.084     | 12.978       | 100.0          |

Figure S253. HPLC spectrum of 4q, related to Scheme 3

|        | t_R [min] | Area [mAU.s] | Height [mAU] | Area Ratio [%] |
|--------|-----------|--------------|--------------|----------------|
| 1      | 45.661    | 936.736      | 6.405        | 12.2           |
| 2      | 69.031    | 6761.242     | 18.263       | 87.3           |
| Total  |           | 7697.978     | 24.668       | 100.0          |
**Figure S254.** HPLC spectrum of racemic-4r, related to Scheme 3

|       | \( t_H \) [min] | Area [mAU.s] | Height [mAU] | Area Ratio [%] |
|-------|------------------|--------------|--------------|----------------|
| 1     | 11.746           | 2185.593     | 148.989      | 49.8           |
| 2     | 12.717           | 2205.589     | 136.153      | 50.2           |
| Total |                  | 4391.182     | 285.142      | 100.0          |

**Figure S255.** HPLC spectrum of 4r, related to Scheme 3

|       | \( t_H \) [min] | Area [mAU.s] | Height [mAU] | Area Ratio [%] |
|-------|------------------|--------------|--------------|----------------|
| 1     | 11.745           | 1505.169     | 85.357       | 6.8            |
| 2     | 12.687           | 20540.455    | 1268.228     | 93.2           |
| Total |                  | 22045.625    | 1353.585     | 100.0          |
Figure S256. HPLC spectrum of racemic-4s, related to Scheme 3

|   | t_R [min] | Area [mAU.s] | Height [mAU] | Area Ratio [%] |
|---|-----------|--------------|--------------|----------------|
| 1 | 10.462    | 2324.791     | 140.646      | 50.0           |
| 2 | 11.227    | 2325.521     | 133.532      | 50.0           |
| Total | | 4650.312   | 274.177      | 100.0          |

Figure S257. HPLC spectrum of 4s, related to Scheme 3

|   | t_R [min] | Area [mAU.s] | Height [mAU] | Area Ratio [%] |
|---|-----------|--------------|--------------|----------------|
| 1 | 10.488    | 232.548      | 15.339       | 2.6            |
| 2 | 11.195    | 8873.752     | 492.755      | 97.4           |
| Total | | 9106.299   | 508.094      | 100.0          |
**Figure S258.** HPLC spectrum of racemic-4t, related to Scheme 3

|    | $t_R$ [min] | Area [mAU.s] | Height [mAU] | Area Ratio [%] |
|----|-------------|--------------|--------------|----------------|
| 1  | 23.034      | 11152.213    | 291.335      | 50.1           |
| 2  | 25.968      | 11119.138    | 275.003      | 49.9           |
| Total |            | 22271.351    | 566.339      | 100.0          |

**Figure S259.** HPLC spectrum of 4t, related to Scheme 3

|    | $t_R$ [min] | Area [mAU.s] | Height [mAU] | Area Ratio [%] |
|----|-------------|--------------|--------------|----------------|
| 1  | 23.161      | 899.862      | 24.631       | 4.6            |
| 2  | 25.946      | 18868.180    | 463.874      | 95.4           |
| Total |            | 19768.042    | 488.505      | 100.0          |
Figure S260. HPLC spectrum of racemic-4u, related to Scheme 3

|    | t_R [min] | Area [mAU.s] | Height [mAU] | Area Ratio [%] |
|----|-----------|--------------|--------------|----------------|
| 1  | 14.376    | 3541.772     | 154.270      | 49.8           |
| 2  | 15.418    | 3564.606     | 136.608      | 50.2           |
| Total |          | 7106.378     | 290.879      | 100.0          |

Figure S261. HPLC spectrum of 4u, related to Scheme 3

|    | t_R [min] | Area [mAU.s] | Height [mAU] | Area Ratio [%] |
|----|-----------|--------------|--------------|----------------|
| 1  | 14.357    | 533.981      | 27.363       | 4.1            |
| 2  | 15.075    | 12384.218    | 425.113      | 95.9           |
| Total |          | 12918.200    | 452.477      | 100.0          |
Figure S262. HPLC spectrum of racemic-4v, related to Scheme 3

|   | $t_R$ [min] | Area [mAU.s] | Height [mAU] | Area Ratio [%] |
|---|------------|--------------|--------------|----------------|
| 1 | 31.847     | 51344.475    | 341.022      | 50.4           |
| 2 | 67.379     | 50574.468    | 137.265      | 49.6           |
| Total |           | 101918.944  | 478.287      | 100.0          |

Figure S263. HPLC spectrum of 4v, related to Scheme 3

|   | $t_R$ [min] | Area [mAU.s] | Height [mAU] | Area Ratio [%] |
|---|------------|--------------|--------------|----------------|
| 1 | 29.722     | 3997.335     | 47.538       | 2.9            |
| 2 | 60.782     | 132790.003   | 501.130      | 97.1           |
| Total |         | 136787.338  | 548.668      | 100.0          |
Figure S264. HPLC spectrum of racemic-4w, related to Scheme 3

|   | t_R [min] | Area [mAU.s] | Height [mAU] | Area Ratio [%] |
|---|-----------|--------------|--------------|----------------|
| 1 | 41.425    | 804.147      | 15.450       | 49.9           |
| 2 | 44.245    | 808.617      | 14.710       | 50.1           |
| Total |         | 1612.764     | 30.161       | 100.0          |

Figure S265. HPLC spectrum of 4w, related to Scheme 3

|   | t_R [min] | Area [mAU.s] | Height [mAU] | Area Ratio [%] |
|---|-----------|--------------|--------------|----------------|
| 1 | 40.000    | 341.624      | 7.507        | 2.3            |
| 2 | 42.679    | 14339.833    | 270.721      | 97.7           |
| Total |         | 14681.457    | 278.228      | 100.0          |
**Figure S26.** HPLC spectrum of racemic-4x, related to Scheme 3

|   | t_R [min] | Area [mAU.s] | Height [mAU] | Area Ratio [%] |
|---|-----------|--------------|--------------|----------------|
| 1 | 35.282    | 7788.952     | 113.143      | 50.0           |
| 2 | 60.697    | 7802.249     | 62.863       | 50.0           |
| Total |  | 15591.202    | 176.005      | 100.0          |

**Figure S267.** HPLC spectrum of 4x, related to Scheme 3

|   | t_R [min] | Area [mAU.s] | Height [mAU] | Area Ratio [%] |
|---|-----------|--------------|--------------|----------------|
| 1 | 34.043    | 31348.585    | 359.227      | 94.0           |
| 2 | 61.178    | 2010.734     | 18.377       | 6.0            |
| Total |   | 33359.319   | 377.603      | 100.0          |
**Figure S268.** HPLC spectrum of racemic 4y, related to Scheme 3

|     | t_R [min] | Area [mAU.s] | Height [mAU] | Area Ratio [%] |
|-----|-----------|--------------|--------------|----------------|
| 1   | 40.192    | 3299.359     | 42.745       | 49.8           |
| 2   | 55.927    | 3324.834     | 29.478       | 50.2           |
| Total|           | 6624.193     | 72.223       | 100.0          |

**Figure S269.** HPLC spectrum of 4y, related to Scheme 3

|     | t_R [min] | Area [mAU.s] | Height [mAU] | Area Ratio [%] |
|-----|-----------|--------------|--------------|----------------|
| 1   | 39.138    | 21145.627    | 190.057      | 97.8           |
| 2   | 57.220    | 484.565      | 5.089        | 2.2            |
| Total|           | 21630.192    | 195.145      | 100.0          |
Figure S270. HPLC spectrum of racemic 6w, related to Scheme 4

|   | t_R [min] | Area [mAU.s] | Height [mAU] | Area Ratio [%] |
|---|-----------|--------------|--------------|----------------|
| 1 | 22.922    | 8101.628     | 76.22        | 51.3           |
| 2 | 47.503    | 7705.483     | 35.860       | 48.7           |
| Total     | 15807.110 | 112.082      |              | 100.0          |

Figure S270. HPLC spectrum of 6w, related to Scheme 4

|   | t_R [min] | Area [mAU.s] | Height [mAU] | Area Ratio [%] |
|---|-----------|--------------|--------------|----------------|
| 1 | 22.613    | 50008.996    | 511.793      | 99.9           |
| 2 | 47.531    | 73.294       | 0.661        | 0.1            |
| Total     | 50082.290 | 512.454      |              | 100.0          |
Figure S272. HPLC spectrum of racemic 8w, related to Scheme 4

|   | tR [min] | Area [mAU.s] | Height [mAU] | Area Ratio [%] |
|---|----------|--------------|--------------|----------------|
| 1 | 34.410   | 7063.212     | 61.578       | 50.7           |
| 2 | 71.894   | 6869.136     | 27.998       | 49.3           |
| Total |          | 13932.348    | 89.576       | 100.0          |

Figure S273. HPLC spectrum of 8w, related to Scheme 4

|   | tR [min] | Area [mAU.s] | Height [mAU] | Area Ratio [%] |
|---|----------|--------------|--------------|----------------|
| 1 | 34.068   | 29871.505    | 268.970      | 100.0          |
| Total |          | 29871.505    | 268.970      | 100.0          |
**Figure S274.** HPLC spectrum of racemic 9, related to Scheme 4

|   | $t_R$ [min] | Area [mAU.s] | Height [mAU] | Area Ratio [%] |
|---|-------------|--------------|--------------|----------------|
| 1 | 14.123      | 9397.647     | 311.423      | 50.0           |
| 2 | 16.196      | 9414.725     | 271.088      | 50.0           |
| Total |          | 18812.372 | 582.511      | 100.0          |

**Figure S275.** HPLC spectrum of 9, related to Scheme 4

|   | $t_R$ [min] | Area [mAU.s] | Height [mAU] | Area Ratio [%] |
|---|-------------|--------------|--------------|----------------|
| 1 | 14.006      | 1382.329     | 44.682       | 4.1            |
| 2 | 16.663      | 32479.831    | 673.419      | 95.9           |
| Total |          | 33862.160 | 718.101      | 100.0          |
Figure S276. HPLC spectrum of racemic-11, related to Scheme 4

|     | $t_R$ [min] | Area [mAU.s] | Height [mAU] | Area Ratio [%] |
|-----|-------------|--------------|--------------|----------------|
| 1   | 92.054      | 5255.478     | 20.777       | 50.3           |
| 2   | 99.078      | 5200.607     | 12.144       | 49.7           |
| Total |           | 10456.086    | 32.921       | 100.0          |

Figure S277. HPLC spectrum of 11, related to Scheme 4

|     | $t_R$ [min] | Area [mAU.s] | Height [mAU] | Area Ratio [%] |
|-----|-------------|--------------|--------------|----------------|
| 1   | 89.275      | 7504.115     | 24.680       | 99.0           |
| 2   | 106.923     | 76.303       | 0.437        | 1.0            |
| Total |           | 7580.418     | 25.116       | 100.0          |
Figure S27. HPLC spectrum of racemic-12, related to Scheme 4

|    | $t_R$ [min] | Area [mAU.s] | Height [mAU] | Area Ratio [%] |
|----|------------|--------------|--------------|----------------|
| 1  | 51.606     | 7869.949     | 47.270       | 78.7           |
| 2  | 56.314     | 2130.837     | 12.443       | 21.3           |
| Total |          | 10000.786    | 59.713       | 100.0          |

Figure S279. HPLC spectrum of 12, related to Scheme 4

|    | $t_R$ [min] | Area [mAU.s] | Height [mAU] | Area Ratio [%] |
|----|------------|--------------|--------------|----------------|
| 1  | 52.164     | 100191.428   | 572.001      | 95.5           |
| 2  | 56.159     | 4718.964     | 31.281       | 4.5            |
| Total |          | 104910.392   | 603.283      | 100.0          |
Supplemental Tables

Optimization of the reaction conditions with high enantioselectivity

Table S1. Screening of different catalysts and ligands, related to Table 1

Table S2 Screening of the bases, related to Table 1
Table S3. Screening the amount of [RhCl((R)-L1)]2, related to Table 1a

| Entry | Catalyst (mol%) | Conversion (1a, %)\(^b\) | Yield (3a, %)\(^c\) | ee (3a, %)\(^d\) |
|-------|-----------------|--------------------------|---------------------|------------------|
| 1     | 5.0             | 49                       | 41                  | 70               |
| 2     | 7.5             | 71                       | 55                  | 70               |
| 3     | 10.0            | 100                      | 71                  | 69               |

\(^{a}\)Reaction conditions: A sealed tube (25 mL) was charged with 1a (46.5 mg, 0.25 mmol, 1 equiv), 2a (84.0 mg, 0.5 mmol, 2.0 equiv), [RhCl(C2H4)2]2 (4.85 mg, 5.0 mol%), CsF (75.5 mg, 0.5 mmol, 2 equiv.) and 1,4-Dioxane+H2O (2.5 mL+0.25 mL). Then the mixture was stirred at 70 °C under Argon atmosphere for 12 hours. \(^{b}\)Determined by \(^1\)H NMR of crude reaction mixture. \(^{c}\)Isolated yield. \(^{d}\)Determined by chiral HPLC analysis.
Table S4 Screening of solvents, related to Table 1

| Entry | Solvent          | Conversion (1a, %) | Yield (2a, %) | ee (3a, %) |
|-------|------------------|--------------------|---------------|------------|
| 1     | MeOH             | 0                  | -             | -          |
| 2     | CH₂Cl₂           | 0                  | -             | -          |
| 3     | Ethyl Acetate (EA) | 100              | 75            | 70         |
| 4     | THF              | 100                | 63            | 69         |
| 5     | CH₃CN            | 27                 | -             | -          |
| 6     | 1,4-Dioxane      | 100                | 71            | 70         |

*aReaction conditions: A sealed tube (25 mL) was charged with 1a (46.5 mg, 0.25 mmol, 1 equiv), 2a (84.0 mg, 0.5 mmol, 2.0 equiv), [RhCl((R)-L1)]₂ (23.5 mg, 10 mol%), CsF (75.5 mg, 0.5 mmol, 2 equiv), and Solvent+H₂O (2.5 mL+0.25 mL). Then the mixture was stirred at 70 °C under Argon atmosphere for 12 hours. bDetermined by ¹H NMR of crude reaction mixture. cIsolated yield. dDetermined by chiral HPLC analysis.

Table S5. Screening of the reaction temperatures, related to Table 1

| Entry | Temperature | Conversion (1a, %) | Yield (3a, %) | ee (3a, %) |
|-------|-------------|--------------------|---------------|------------|
| 1     | 30 °C       | 68                 | 58            | -          |
| 2     | 40 °C       | 77                 | 64            | -          |
| 3     | 50 °C       | 100                | 84            | 70         |
| 4     | 60 °C       | 100                | 80            | 69         |
| 5     | 70 °C       | 100                | 75            | 70         |
| 6     | 100 °C      | 100                | 70            | 70         |

*aReaction conditions: A sealed tube (25 mL) was charged with 1a (46.5 mg, 0.25 mmol, 1 equiv), 2a (84.0 mg, 0.5 mmol, 2.0 equiv), [RhCl((R)-L1)]₂ (23.5 mg, 10 mol%), CsF (75.5 mg, 0.5 mmol, 2 equiv), and EA+H₂O (2.5 mL+0.25 mL). Then the mixture was stirred at different temperatures under Argon atmosphere for 12 hours. bDetermined by ¹H NMR of crude reaction mixture. cIsolated yield. dDetermined by chiral HPLC analysis.
**Table S6** Screening of the different ligands, related to Table 1a

![Reaction scheme](image)

| Entry | Ligand | Base | Solvent | Yield (3a, %) | ee (3a, %) |
|-------|--------|------|---------|---------------|-------------|
| 1     | -      | CsF  | EA      | 0             | n.d.        |
| 2     | R-BINAP| CsF  | EA      | trace         | n.d.        |
| 3     | S-BINAP| CsF  | EA      | trace         | n.d.        |
| 4     | L1     | CsF  | EA      | 84            | 70          |
| 5     | L2     | CsF  | EA      | 81            | 80          |
| 6     | L3     | CsF  | EA      | **85**        | **92**      |
| 7     | L4     | CsF  | EA      | 80            | 41          |
| 8     | L5     | CsF  | EA      | 84            | 51          |
| 9     | L6     | CsF  | EA      | 65            | 49          |
| 10    | L3     | KF   | EA      | 61            | 91          |
| 11    | L3     | K₃PO₄| EA      | 81            | 91          |
| 12    | L3     | CsF  | THF     | 84            | 87          |
| 13    | L3     | CsF  | 1,4-Dioxane | 56            | 91          |

aReaction conditions: A sealed tube (25 mL) was charged with 1a (46.5 mg, 0.25 mmol, 1 equiv), 2a (84.0 mg, 0.5 mmol, 2.0 equiv), [RhCl((R)-L)]₂ (10 mol%), Base (0.5 mmol, 2.0 equiv.) and Solvent+H₂O (2.5 mL+0.25 mL). Then the mixture was stirred at 50 °C under Argon atmosphere for 12 hours. bIsolated yield. cDetermined by chiral HPLC analysis.
Data of Crystal Structure of 4d

Table S7. Crystal data and structure refinement for 190102h, related to Scheme 3

| Identification code        | 190102h                  |
|---------------------------|--------------------------|
| Empirical formula         | C14 H12 F N O4 S         |
| Formula weight            | 309.31                   |
| Temperature               | 298(2) K                 |
| Wavelength                | 0.71073 Å                |
| Crystal system, space group | Orthorhombic, P2(1)2(1)2(1) |
| Unit cell dimensions      | a = 7.7968(6) Å, alpha = 90 deg.  |
|                           | b = 10.4464(9) Å, beta = 90 deg.  |
|                           | c = 17.2117(15) Å, gamma = 90 deg.  |
| Volume                    | 1401.9(2) Å^3            |
| Z, Calculated density     | 4, 1.466 Mg/m^3          |
| Absorption coefficient    | 0.257 mm^-1              |
| F(000)                    | 640                      |
| Crystal size              | 0.45 x 0.43 x 0.40 mm    |
| Theta range for data collection | 2.28 to 25.02 deg.     |
| Limiting indices          | -9<=h<=7, -12<=k<=12, -18<=l<=20 |
| Reflections collected / unique | 7034 / 2485 [R(int) = 0.0375] |
| Completeness to theta = 25.02 | 99.9 %                  |
| Absorption correction     | Semi-empirical from equivalents |
| Max. and min. transmission | 0.9041 and 0.8930        |
| Property                                      | Value                  |
|----------------------------------------------|------------------------|
| Refinement method                            | Full-matrix least-squares on F^2 |
| Data / restraints / parameters                | 2485 / 42 / 200        |
| Goodness-of-fit on F^2                       | 1.034                  |
| Final R indices [I>2sigma(I)]                | R1 = 0.0460, wR2 = 0.0983 |
| R indices (all data)                         | R1 = 0.0783, wR2 = 0.1127 |
| Absolute structure parameter                 | 0.15(17)               |
| Largest diff. peak and hole                  | 0.265 and -0.212 e.A^-3 |
**Table S8.** Atomic coordinates ($x \times 10^4$) and equivalent isotropic, displacement parameters (A$^2 \times 10^3$) for 190102h, related to Scheme 3

$U(\text{eq})$ is defined as one third of the trace of the orthogonalized $U_{ij}$ tensor.

|   | x (\times 10^4) | y (\times 10^4) | z (\times 10^4) | U(\text{eq}) (\times 10^3) |
|---|----------------|----------------|----------------|---------------------------|
| F(1) | 1497(5) | 5681(5) | 8551(3) | 106(2) |
| O(2') | 2040(30) | 4131(16) | 8500(13) | 109(2) |
| N(1) | 10406(3) | 5081(4) | 11092(2) | 52(1) |
| O(1) | 3319(6) | 5747(5) | 9646(2) | 91(1) |
| O(2) | 2867(7) | 3781(4) | 8950(4) | 109(2) |
| F(1') | 2070(20) | 6130(20) | 8768(12) | 106(2) |
| O(1') | 3450(20) | 4620(20) | 9608(9) | 91(1) |
| O(3) | 10709(4) | 6119(3) | 11366(2) | 76(1) |
| O(4) | 10949(4) | 4082(3) | 11374(2) | 74(1) |
| S(1) | 3085(1) | 5093(1) | 8928(1) | 60(1) |
| C(1) | 4701(4) | 5520(4) | 8270(2) | 57(1) |
| C(2) | 6285(4) | 4667(4) | 8339(2) | 50(1) |
| C(3) | 7280(4) | 4818(4) | 9095(2) | 45(1) |
| C(4) | 7711(5) | 6002(4) | 9411(2) | 55(1) |
| C(5) | 8724(5) | 6107(4) | 10068(2) | 55(1) |
| C(6) | 9318(4) | 4996(4) | 10395(2) | 45(1) |
| C(7) | 8913(5) | 3816(4) | 10105(2) | 53(1) |
| C(8) | 7896(6) | 3742(4) | 9456(2) | 54(1) |
| C(9) | 7492(4) | 4871(4) | 7650(2) | 51(1) |
| C(10) | 8214(7) | 3817(4) | 7315(3) | 70(1) |
| C(11) | 9346(7) | 3932(6) | 6704(3) | 89(2) |
| C(12) | 9783(5) | 5124(7) | 6432(2) | 85(2) |
| C(13) | 9076(6) | 6190(5) | 6752(3) | 80(2) |
| C(14) | 7917(6) | 6063(4) | 7363(2) | 65(1) |
**Table S9.** Bond lengths [Å] and angles [deg] for 190102h, related to Scheme 3

| Bond/Angle | Length/Angle |
|------------|--------------|
| F(1)-S(1)  | 1.527(4)     |
| O(2')-S(1) | 1.49(2)      |
| N(1)-O(3)  | 1.206(4)     |
| N(1)-O(4)  | 1.226(4)     |
| N(1)-C(6)  | 1.473(4)     |
| O(1)-S(1)  | 1.423(4)     |
| O(2)-S(1)  | 1.381(4)     |
| F(1')-S(1) | 1.37(2)      |
| O(1')-S(1) | 1.299(18)    |
| S(1)-C(1)  | 1.752(3)     |
| C(1)-C(2)  | 1.528(5)     |
| C(1)-H(1A) | 0.9700       |
| C(1)-H(1B) | 0.9700       |
| C(2)-C(3)  | 1.524(4)     |
| C(2)-C(9)  | 1.529(4)     |
| C(2)-H(2)  | 0.9800       |
| C(3)-C(8)  | 1.371(5)     |
| C(3)-C(4)  | 1.392(5)     |
| C(4)-C(5)  | 1.384(5)     |
| C(4)-H(4)  | 0.9300       |
| C(5)-C(6)  | 1.370(5)     |
| C(5)-H(5)  | 0.9300       |
| C(6)-C(7)  | 1.367(5)     |
| C(7)-C(8)  | 1.372(5)     |
| C(7)-H(7)  | 0.9300       |
| C(8)-H(8)  | 0.9300       |
| C(9)-C(10) | 1.364(5)     |
| C(9)-C(14) | 1.379(5)     |
| C(10)-C(11)| 1.379(7)     |
| C(10)-H(10)| 0.9300       |
| C(11)-C(12)| 1.373(7)     |
| C(11)-H(11)| 0.9300       |
| C(12)-C(13)| 1.359(7)     |
| C(12)-H(12)| 0.9300       |
| C(13)-C(14)| 1.393(6)     |
| C(13)-H(13)| 0.9300       |
| C(14)-H(14)| 0.9300       |
O(3)-N(1)-O(4) 123.0(3)
O(3)-N(1)-C(6) 119.0(4)
O(4)-N(1)-C(6) 118.0(4)
O(1')-S(1)-F(1') 127.2(12)
O(1')-S(1)-O(2) 68.2(8)
F(1')-S(1)-O(2) 136.0(9)
O(1')-S(1)-O(1) 51.1(8)
F(1')-S(1)-O(1) 82.5(9)
O(2)-S(1)-O(1) 117.9(3)
O(1')-S(1)-O(2') 108.0(10)
F(1')-S(1)-O(2') 96.8(10)
O(2)-S(1)-O(2') 43.7(7)
O(1)-S(1)-O(2') 145.4(8)
O(1')-S(1)-F(1) 135.3(8)
F(1')-S(1)-F(1) 29.4(8)
O(2)-S(1)-F(1) 108.1(3)
O(1)-S(1)-F(1) 106.3(3)
O(2')-S(1)-F(1) 67.5(7)
O(1')-S(1)-C(1) 121.5(8)
F(1')-S(1)-C(1) 94.8(9)
O(2)-S(1)-C(1) 111.0(2)
O(1)-S(1)-C(1) 110.3(2)
O(2')-S(1)-C(1) 104.2(8)
F(1)-S(1)-C(1) 101.9(2)
C(2)-C(1)-S(1) 112.5(3)
C(2)-C(1)-H(1A) 109.1
S(1)-C(1)-H(1A) 109.1
C(2)-C(1)-H(1B) 109.1
S(1)-C(1)-H(1B) 109.1
H(1A)-C(1)-H(1B) 107.8
C(3)-C(2)-C(1) 114.7(3)
C(3)-C(2)-C(9) 109.5(2)
C(1)-C(2)-C(9) 110.9(3)
C(3)-C(2)-H(2) 107.1
C(1)-C(2)-H(2) 107.1
C(9)-C(2)-H(2) 107.1
C(8)-C(3)-C(4) 117.8(3)
C(8)-C(3)-C(2) 118.7(3)
C(4)-C(3)-C(2) 123.3(3)
C(5)-C(4)-C(3) 121.8(4)
C(5)-C(4)-H(4) 119.1
C(3)-C(4)-H(4)  119.1
C(6)-C(5)-C(4)  117.5(4)
C(6)-C(5)-H(5)  121.3
C(4)-C(5)-H(5)  121.3
C(7)-C(6)-C(5)  122.4(3)
C(7)-C(6)-N(1)  119.0(4)
C(5)-C(6)-N(1)  118.6(4)
C(6)-C(7)-C(8)  118.8(4)
C(6)-C(7)-H(7)  120.6
C(8)-C(7)-H(7)  120.6
C(3)-C(8)-C(7)  121.7(4)
C(3)-C(8)-H(8)  119.2
C(7)-C(8)-H(8)  119.2
C(10)-C(9)-C(14)  118.6(3)
C(10)-C(9)-C(2)  118.0(4)
C(14)-C(9)-C(2)  123.4(4)
C(9)-C(10)-C(11)  121.1(5)
C(9)-C(10)-H(10)  119.4
C(11)-C(10)-H(10)  119.4
C(12)-C(11)-C(10)  119.8(5)
C(12)-C(11)-H(11)  120.1
C(10)-C(11)-H(11)  120.1
C(13)-C(12)-C(11)  120.3(4)
C(13)-C(12)-H(12)  119.8
C(11)-C(12)-H(12)  119.8
C(12)-C(13)-C(14)  119.4(5)
C(12)-C(13)-H(13)  120.3
C(14)-C(13)-H(13)  120.3
C(9)-C(14)-C(13)  120.8(4)
C(9)-C(14)-H(14)  119.6
C(13)-C(14)-H(14)  119.6

Symmetry transformations used to generate equivalent atoms:
Table S10. Anisotropic displacement parameters (A^2 x 10^3) for 190102h, related to Scheme 3

The anisotropic displacement factor exponent takes the form:
\[-2 \pi^2 \left[ h^2 a^*^2 U_{11} + \ldots + 2 h k a^* b^* U_{12} \right]\]

|       | U11  | U22  | U33  | U23  | U13  | U12  |
|-------|------|------|------|------|------|------|
| F(1)  | 44(3)| 169(5)| 105(3)| 31(3)| -13(2)| 10(2)|
| O(2') | 91(3)| 53(2)| 183(5)| 19(3)| 28(4)| -8(2)|
| N(1)  | 43(2)| 70(2)| 42(2)| -1(2)| 3(1)| -3(2)|
| O(1)  | 80(2)| 133(4)| 60(2)| -24(3)| 12(2)| -22(3)|
| O(2)  | 91(3)| 53(2)| 183(5)| 19(3)| 28(4)| -8(2)|
| F(1') | 44(3)| 169(5)| 105(3)| 31(3)| -13(2)| 10(2)|
| O(1') | 80(2)| 133(4)| 60(2)| -24(3)| 12(2)| -22(3)|
| O(3)  | 75(2)| 87(2)| 67(2)| -13(2)| -11(2)| -15(2)|
| O(4)  | 75(2)| 92(2)| 54(2)| 8(2)| -13(2)| 14(2)|
| S(1)  | 43(1)| 69(1)| 68(1)| 8(1)| 6(1)| 0(1)|
| C(1)  | 46(2)| 75(3)| 52(2)| 3(2)| 3(2)| 3(2)|
| C(2)  | 44(2)| 55(2)| 50(2)| -1(2)| -2(2)| 2(2)|
| C(3)  | 37(2)| 55(2)| 43(2)| -5(2)| 4(1)| 1(2)|
| C(4)  | 53(3)| 55(2)| 58(3)| 4(2)| -4(2)| 10(2)|
| C(5)  | 58(3)| 48(2)| 58(3)| -9(2)| 0(2)| 1(2)|
| C(6)  | 36(2)| 61(2)| 38(2)| -2(2)| 3(1)| -1(2)|
| C(7)  | 55(3)| 50(2)| 54(3)| 6(2)| -5(2)| 4(2)|
| C(8)  | 59(3)| 46(2)| 56(3)| 1(2)| -5(2)| 0(2)|
| C(9)  | 39(2)| 70(3)| 43(2)| -6(2)| -5(1)| 3(2)|
| C(10) | 61(3)| 79(3)| 70(3)| -16(2)| 0(3)| 11(3)|
| C(11) | 70(4)| 117(5)| 79(4)| -31(3)| 7(3)| 28(3)|
| C(12) | 46(2)| 152(5)| 58(2)| -12(4)| 7(2)| 5(4)|
| C(13) | 61(3)| 106(4)| 73(4)| 13(3)| -1(3)| -11(3)|
| C(14) | 55(3)| 78(3)| 63(3)| -6(2)| 8(2)| 2(3)|
Table S11. Hydrogen coordinates ($x \times 10^4$) and isotropic displacement parameters ($A^2 \times 10^3$) for 190102h, related to Scheme 3

|    | x    | y    | z    | U(eq) |
|----|------|------|------|-------|
| H(1A)| 4252 | 5462 | 7745 | 69    |
| H(1B)| 5031 | 6402 | 8362 | 69    |
| H(2) | 5888 | 3777 | 8315 | 59    |
| H(4) | 7306 | 6743 | 9174 | 66    |
| H(5) | 8991 | 6901 | 10280| 65    |
| H(7) | 9319 | 3077 | 10343| 64    |
| H(8) | 7617 | 2942 | 9256 | 64    |
| H(10)| 7939 | 3008 | 7503 | 84    |
| H(11)| 9811 | 3203 | 6475 | 106   |
| H(12)| 10568| 5203 | 6028 | 102   |
| H(13)| 9363 | 6997 | 6565 | 96    |
| H(14)| 7423 | 6790 | 7581 | 78    |
Table S12. Torsion angles [deg] for 190102h, related to Scheme 3

| Bond                  | Torsion Angle [deg] |
|-----------------------|---------------------|
| O(1')-S(1)-C(1)-C(2) | 32.4(11)            |
| F(1')-S(1)-C(1)-C(2) | 172.1(9)            |
| O(2)-S(1)-C(1)-C(2)  | -44.2(4)            |
| O(1)-S(1)-C(1)-C(2)  | 88.4(4)             |
| O(2')-S(1)-C(1)-C(2) | -89.6(8)            |
| F(1)-S(1)-C(1)-C(2)  | -159.1(3)           |
| S(1)-C(1)-C(2)-C(3)  | -67.6(4)            |
| S(1)-C(1)-C(2)-C(9)  | 167.7(3)            |
| C(1)-C(2)-C(3)-C(8)  | 138.4(4)            |
| C(9)-C(2)-C(3)-C(8)  | -96.2(4)            |
| C(1)-C(2)-C(3)-C(4)  | -46.5(4)            |
| C(9)-C(2)-C(3)-C(4)  | 78.8(4)             |
| C(8)-C(3)-C(4)-C(5)  | 0.0(5)              |
| C(2)-C(3)-C(4)-C(5)  | -175.1(3)           |
| C(3)-C(4)-C(5)-C(6)  | 0.9(6)              |
| C(4)-C(5)-C(6)-C(7)  | -1.4(5)             |
| C(4)-C(5)-C(6)-N(1)  | 179.7(3)            |
| O(3)-N(1)-C(6)-C(7)  | -177.2(3)           |
| O(4)-N(1)-C(6)-C(7)  | 2.0(4)              |
| O(3)-N(1)-C(6)-C(5)  | 1.8(4)              |
| O(4)-N(1)-C(6)-C(5)  | -179.1(3)           |
| C(5)-C(6)-C(7)-C(8)  | 1.0(5)              |
| N(1)-C(6)-C(7)-C(8)  | 179.9(3)            |
| C(4)-C(3)-C(8)-C(7)  | -0.4(5)             |
| C(2)-C(3)-C(8)-C(7)  | 174.9(3)            |
| C(6)-C(7)-C(8)-C(3)  | -0.1(6)             |
| C(3)-C(2)-C(9)-C(10) | 95.3(4)             |
| C(1)-C(2)-C(9)-C(10) | -137.1(4)           |
| C(3)-C(2)-C(9)-C(14) | -83.1(4)            |
| C(1)-C(2)-C(9)-C(14) | 44.5(5)             |
| C(14)-C(9)-C(10)-C(11)| 0.0(6)              |
| C(2)-C(9)-C(10)-C(11)| -178.5(4)           |
| C(9)-C(10)-C(11)-C(12)| 1.2(7)             |
| C(10)-C(11)-C(12)-C(13)| -1.5(7)          |
| C(11)-C(12)-C(13)-C(14)| 0.7(6)           |
| C(10)-C(9)-C(14)-C(13)| -0.9(5)            |
| C(2)-C(9)-C(14)-C(13)| 177.6(3)            |
| C(12)-C(13)-C(14)-C(9)| 0.5(6)            |
Symmetry transformations used to generate equivalent atoms:
Table S13. Hydrogen bonds for 190102h [Å and deg.], related to Scheme 3

|          | d(D-H) | d(H...A) | d(D...A) | <(DHA) |
|----------|--------|----------|----------|--------|
| D-H...A  |        |          |          |        |
Transparent Methods

General information

All reactions were carried under argon atmosphere. Unless otherwise noted, reagents and solvents used in this work were purchased from commercial sources and used as received. The extent of reaction was monitored by thin-layer chromatography (TLC), performed on 250 μm silica gel G plates with F254 indicator. The TLC plates were visualized by ultraviolet light (254 nm) and treatment with potassium permanganate stain followed by gentle heating. Flash chromatography was performed using 40–63 μm (230–400 mesh) silica gel.

Unless otherwise stated, NMR spectra were recorded in CDCl$_3$ on a 500 MHz (for $^1$H), 471 MHz (for $^{19}$F) and 126 MHz (for $^{13}$C) spectrometer. Data for $^1$H NMR spectra is reported as follows: chemical shift (ppm, referenced to residual solvent peak), coupling constant (Hz), integration, and proton identification is highlighted in bold. Data for $^{13}$C NMR is reported in terms of chemical shift, δ (ppm) relative to residual solvent peak (CDCl$_3$ singlet at 77.16 ppm). Data for $^{19}$F NMR is reported in terms of chemical shift (ppm). The following abbreviations were used to explain the multiplicities: s = singlet, d = doublet, t = triplet, q = quartet, m = multiplet, br = broad. Melting points were measured and uncorrected.

Experimental Procedures and Characterization Data

Materials

1,4-Dioxane was purified by passing through a neutral alumina column under N$_2$. Chiral ligands (R)-L$_1$ (>99.5% ee) (Okamoto et al., 2009), (R)-L$_2$ (Nishimura et al., 2012), (R)-L$_3$ (Okamoto et al., 2009), (R)-L$_4$ (Saxena et al., 2011), and (R)-L$_5$ (Saxena et al., 2011) were prepared according to the reported procedures. Rhodium complexes, [RhCl(C$_2$H$_4$)$_2$]$_2$ (Uson et al., 1985), [Rh(OH)(cod)]$_2$ (Uson et al., 1985) and [RhCl((R)-L$_3$)$_2$] (Nishimura et al., 2012) were prepared according to the reported procedures.

Characterization of Ligand 1-6.

Ligand (R)-L$_1$.

![Ligand (R)-L$_1$](image)
Ligand (R)-L2.

![Ligand (R)-L2](image)

$^1$H NMR (500 MHz, CDCl$_3$) $\delta$ 0.85 (d, $J = 6.5$ Hz, 3H), 0.99 (d, $J = 6.5$ Hz, 3H), 1.03 (ddd, $J = 2.5$, 5.0, 11.5 Hz, 1H), 1.10-1.25 (m, 2H), 1.18 (d, $J = 6.5$ Hz, 12H), 1.62-1.67 (m, 1H), 1.87 (d, $J = 1.5$ Hz, 3H), 2.88 (m, 2H), 3.46-3.48 (m, 1H), 4.20-4.21 (m, 1H), 5.87 (dd, $J = 1.5$, 4.5 Hz, 1H), 7.13-7.15 (m, 2H), 7.19 (dd, $J = 6.5$, 9.0 Hz, 1H), 7.55 (dd, $J = 2.0$, 6.5 Hz, 1H).

Ligand (R)-L3.

![Ligand (R)-L3](image)

$^1$H NMR (500 MHz, CDCl$_3$) $\delta$ 0.85 (d, $J = 6.5$ Hz, 3H), 0.99 (d, $J = 6.5$ Hz, 3H), 1.03 (ddd, $J = 2.5$, 5.0, 7.5, 11.5 Hz, 1H), 1.12-1.15 (m, 1H), 1.24 (t, $J = 7.0$ Hz, 1H), 1.61-1.66 (m, 1H), 1.86 (d, $J = 1.5$ Hz, 3H), 2.12 (s, 6H), 3.45-3.47 (m, 1H), 4.19 (td, $J = 2.0$, 6.0 Hz, 1H), 5.86 (br d, $J = 1.5$, 6.0 Hz, 1H), 7.02-7.06 (m, 3H), 7.56 (dd, $J = 2.0$, 6.5 Hz, 1H).

Ligand (R)-L4.

![Ligand (R)-L4](image)

$^1$H NMR (500 MHz, CDCl$_3$) $\delta$ 0.80 (d, $J = 7.0$ Hz, 3H), 0.91 (ddd, $J = 2.5$, 5.0, 11.5 Hz, 1H), 0.94 (d, $J = 6.5$ Hz, 3H), 1.02-1.09 (m, 1H), 1.38-1.43 (m, 1H), 1.59-1.65 (m, 1H), 1.77 (d, $J = 1.5$ Hz, 3H), 3.25-3.27 (m, 1H), 3.81 (td, $J = 1.5$, 6.0 Hz, 1H), 4.42-4.68 (m, 4H), 5.75 (d, $J = 6.0$ Hz, 1H), 6.48 (dd, $J = 1.5$, 6.0 Hz, 1H), 7.17 (br s, 4H), 7.25-7.33 (m, 6H).

Ligand (R)-L5.

![Ligand (R)-L5](image)

$^1$H NMR (500 MHz, CDCl$_3$) $\delta$ 0.79 (d, $J = 7.0$ Hz, 3H), 0.89 (ddd, $J = 2.5$, 4.5, 11.5 Hz, 1H), 0.95 (d, $J =
6.5 Hz, 3H), 1.00-1.10 (m, 2H), 1.11-1.37 (m, 10H), 1.37-1.42 (m, 2H), 1.60-1.65 (m, 1H), 1.81 (d, \( J = 1.5 \) Hz, 3H), 3.25-3.27 (m, 1H), 3.58 (dt, \( J = 1.5, 5.5 \) Hz, 1H), 3.36-4.05 (br s, 2H), 5.78 (dd, \( J = 1.5, 4.5 \) Hz, 1H), 6.21 (dd, \( J = 1.5, 6.0 \) Hz, 1H).

**Preparation of Ligand \((R)-L6\):**

To a stirred solution of \((R)-L0\) (100 mg, 0.485 mmol) and DMF (5 µL) in CH₂Cl₂ (4.0 mL) was added thionyl chloride (105 µL, 1.45 mmol) at 0 °C, and the mixture was allowed to stir at room temperature for 2 h, then the solvent was removed under reduced pressure, the residue was dissolved in 2.0 mL dried THF for the following step reaction. To a solution of \(n\)-BuLi (242 µL, 2.0 M, 0.485 mmol) in THF (4 mL) was added a solution of the acid chloride in THF (2 mL) dropwise at 0 °C, and the mixture was stirred at room temperature for 24 h. Aqueous NH₄Cl was added, the organic layer was separated, aqueous phase was extracted with EtOAc (3 x 10 mL), the combined organic phase was washed with brine, dried over Na₂SO₄, filtered, and concentrated on a rotary evaporator. The residue was purified by preparative TLC to give \((R)-L6\) as Yellow oil (95 mg, 85% yield); \(^1\)H NMR (500 MHz, CDCl₃) δ 0.80 (d, \( J = 6.5 \) Hz, 3H), 0.91-0.98 (m, 7H), 1.04-1.10 (m, 1H), 1.11-1.17 (m, 1H), 1.35-1.43 (m, 2H), 1.52-1.56 (m, 1H), 1.60-1.65 (m, 2H), 1.80 (d, \( J = 1.5 \) Hz, 3H), 3.34-3.37 (m, 1H), 4.06 (td, \( J = 2.0, 6.0 \) Hz, 1H), 4.08-4.14 (m, 2H), 5.79 (dd, \( J = 1.5, 4.5 \) Hz, 1H), 7.25 (dd, \( J = 2.0, 6.5 \) Hz, 1H). \(^{13}\)C NMR (126 MHz, CDCl₃) δ 13.85, 19.05, 19.35, 21.42, 21.93, 30.87, 31.65, 33.86, 39.66, 44.04, 47.81, 64.11, 124.28, 141.38, 145.33, 145.69, 165.36. ESI-MS HRMS calculated for C₂₇H₂₇O [M+H]⁺ 247.2056, found. 247.2050.

**Preparation of \([\text{RhCl(}(R)-L3)]_2\):**

\([\text{RhCl(}(R)-L3)]_2\) was prepared according to the reported literature. A mixture of \((R)-L3\) (0.5 g, 1.61 mmol) and [RhCl(C₂H₄)₂]₂ (344 mg, 1.77 mmol of Rh) in CH₂Cl₂ (25 mL) was stirred at room temperature for 21 h. The mixture was subjected to column chromatography on silica gel under air (hexane/EtOAc = 10/1–2/1) to give [RhCl(\((R)-L3\)]₂ (694 mg, 1.48 mmol of Rh, 92% yield). \(^1\)H NMR (500 MHz, CDCl₃) δ 0.77-0.79 (m, 2H), 0.84 (d, \( J = 6.5 \) Hz, 6H), 0.88-0.91 (m, 2H), 0.94 (d, \( J = 6.0 \) Hz, 6H), 1.25-1.30 (m, 2H), 1.34-1.38 (m, 2H), 1.55 (s, 6H), 2.24 (br s, 12H), 3.40 (d, \( J = 4.5 \) Hz, 2H), 4.16 (br s, 2H), 4.23 (d, \( J = 5.0 \) Hz, 2H), 4.75 (d, \( J = 4.5 \) Hz, 2H), 6.85 (m, 6H); \(^{13}\)C NMR (126 MHz, CDCl₃) δ 20.87, 21.05, 23.10, 24.26 (d, \( J = 17.3 \) Hz), 27.46 (d, \( J = 25.5 \) Hz), 30.69, 30.94, 43.85, 46.89, 48.07, 49.74 (d, \( J = 11.8 \) Hz), 51.05 (d, \( J = 11.0 \) Hz), 52.62 (d, \( J = 10.0 \) Hz), 73.01, 123.90 (d, \( J = 18.3 \) Hz), 126.43 , 140.72, 146.14, 168.83.
General procedure for rhodium-catalyzed enantioselective addition of boronic acid to 2-arylethenesulfonyl fluorides (3 and 4).

The sealed tube equipped with a stirrer bar was charged with α,β-sulfonyl fluoride 1 (0.5 mmol), boronic acid 2 (1.0 mmol), CsF (1.0 mmol) and [RhCl((R)-L3)]2 (10 mol%). The tube was closed with septum, air in the tube was evacuated with vacuum pump, Ethylacetate+H2O (5.0 mL+0.5 mL) was added and tube was backfilled with argon. Subsequently, the septum was removed, the reaction tube was closed with Teflon screw cap immediately and the mixture was stirred at 50 °C for 12 hours. Then the resulting mixture was cooled to room temperature and purified by flash column chromatography using petroleum ether and ethyl acetate as eluent to give the desired product 3 and 4.

(R)-2-(4-(methylthio)phenyl)-2-phenylethenesulfonfonyl fluoride (3a):

Compound 3a was synthesized according to general procedure. Off-white solid (132 mg, 85% Yield, 92% ee); the ee was measured by HPLC (Chiralpak AD-H column, hexane/isopropanol = 90/10, flow 0.6 mL/min, 254 nm, t1 = 20.8 min (Major), t2 = 22.9 min (Minor); [α]D28 = +13.6 (c = 0.366, CH2Cl2); 1H NMR (500 MHz, CDCl3) δ 2.45 (s, 3H), 4.09 (dd, J = 3.5, 7.5 Hz, 2H), 4.64 (t, J = 7.5 Hz, 1H), 7.17-7.22 (m, 4H), 7.23-7.27 (m, 3H), 7.32-7.35 (m, 2H); 13C NMR (126 MHz, CDCl3) δ 15.78, 45.96, 56.48 (d, J = 13.7 Hz), 127.14, 127.51, 127.87, 128.07, 129.27, 136.94, 138.33, 140.26; 19F NMR (471 MHz, CDCl3) δ 59.32. ESI-MS HRMS calculated for C15H16FO2S2 [M+H]+ 311.0570, found. 311.0568. M.P.: 77-80 °C.

(R)-2-phenyl-2-(4-(trifluoromethoxy)phenyl)ethanesulfonfonyl fluoride (3b):

Compound 3b was synthesized according to general procedure. Colorless viscous liquid (141 mg, 81% Yield, 93% ee); the ee was measured by HPLC (Chiralpak AD-H column, hexane/isopropanol = 95/5, flow 0.6 mL/min, 254 nm, t1 = 13.9 min (Major), t2 = 15.8 min (Minor); [α]D25 = +2.7 (c = 1.23, CHCl3); 1H NMR (500 MHz, CDCl3) δ 4.09-4.12 (m, 2H), 4.71 (t, J = 7.5 Hz, 1H), 7.2 (d, J = 8.0 Hz, 2H), 7.26 (dd, J = 1.5, 6.5 Hz, 2H), 7.28-7.32 (m, 3H), 7.35-7.38 (m, 2H); 13C NMR (126 MHz, CDCl3) δ 45.84, 56.40 (d, J = 13.6 Hz), 120.57 (q, J = 258.6 Hz), 121.62, 127.49, 128.11, 129.11,
129.41, 138.91, 139.76, 148.72 (q, J = 1.8 Hz); $^{19}$F NMR (471 MHz, CDCl$_3$) δ -57.88, 59.38. ESI-MS HRMS calculated for C$_{15}$H$_{12}$F$_4$NaO$_3$S [M+Na]$^+$ 371.0335, found. 371.0338.

($R$)-2-phenyl-2-(4-(trifluoromethyl)phenyl)ethanesulfonyl fluoride (3c):

![Chemical Structure](image)

Compound 3c was synthesized according to general procedure. Colorless viscous liquid (125 mg, 75% Yield, 95% ee); the ee was measured by HPLC (Chiralpak AD-H column, hexane/isopropanol = 95/5, flow 0.6 mL/min, 254 nm, $t_1 = 17.2$ min (Major), $t_2 = 19.7$ min (Minor); $[\alpha]_D^{24} = -5.4$ (c = 1.0, CH$_2$Cl$_2$); $^1$H NMR (500 MHz, CDCl$_3$) δ 4.14 (dd, J = 3.0, 7.0 Hz, 2H), 4.76 (t, J = 7.0 Hz, 1H), 7.25-7.27 (m, 2H), 7.29-7.32 (m, 1H), 7.36-7.39 (m, 2H), 7.42 (d, J = 8.0 Hz, 2H), 7.62 (d, J = 8.5 Hz, 2H); $^{13}$C NMR (126 MHz, CDCl$_3$) δ 46.24, 56.04 (d, J = 14.5 Hz), 124.01 (q, J = 272.0 Hz), 126.19 (q, J = 3.5 Hz), 127.49, 128.09, 128.19, 129.44, 130.11 (q, J = 32.8 Hz), 139.46, 144.16; $^{19}$F NMR (471 MHz, CDCl$_3$) δ -62.64, 59.43. ESI-MS HRMS calculated for C$_{15}$H$_{12}$F$_4$NaO$_3$S [M+Na]$^+$ 355.0386, found. 355.0387.

($R$)-2-(4-bromophenyl)-2-phenylethanesulfonyl fluoride (3d):

![Chemical Structure](image)

Compound 3d was synthesized according to general procedure. Colorless viscous liquid (147 mg, 86% Yield, 87% ee); the ee was measured by HPLC (Chiralpak AD-H column, hexane/isopropanol = 95/5, flow 0.6 mL/min, 254 nm, $t_1 = 21.7$ min (Major), $t_2 = 25.0$ min (Minor); $[\alpha]_D^{24} = -4.8$ (c = 1.0, CH$_2$Cl$_2$); $^1$H NMR (500 MHz, CDCl$_3$) δ 4.09 (dd, J = 3.5, 7.5 Hz, 2H), 4.65 (t, J = 7.5 Hz, 1H), 7.16 (d, J = 8.5 Hz, 2H), 7.24 (d, J = 7.0 Hz, 2H), 7.27-7.30 (m, 1H), 7.34-7.37 (m, 2H), 7.47 (d, J = 8.5 Hz, 2H); $^{13}$C NMR (126 MHz, CDCl$_3$) δ 45.88, 56.20 (d, J = 13.6 Hz), 121.83, 127.43, 128.02, 129.33, 129.35, 132.33, 139.22, 139.78; $^{19}$F NMR (471 MHz, CDCl$_3$) δ 59.44. ESI-MS HRMS calculated for C$_{15}$H$_{13}$BrFO$_2$S [M+H]$^+$ 342.9798, found. 342.9802.
(R)-2-(4-nitrophenyl)-2-phenylethanesulfonfonyl fluoride (3e):

![Chemical Structure](image)

Compound 3e was synthesized according to general procedure. Off-white solid (131 mg, 85% Yield, 98% ee); the ee was measured by HPLC (Chiralpak OD-H column, hexane/isopropanol = 60/40, flow 1.0 mL/min, 254 nm, t<sub>f</sub> = 33.6 min (Minor), t<sub>m</sub> = 46.6 min (Major); [α]<sub>D</sub><sup>25</sup> = +6.2 (c = 1.02, CH<sub>2</sub>Cl<sub>2</sub>); <sup>1</sup>H NMR (500 MHz, CDCl<sub>3</sub>) δ 4.11-4.21 (m, 2H), 4.80 (t, <i>J</i> = 7.5 Hz, 1H), 7.24 (d, <i>J</i> = 7.5 Hz, 2H), 7.30-7.33 (m, 1H), 7.36-7.39 (m, 2H), 7.48 (d, <i>J</i> = 9.0 Hz, 2H), 8.21 (d, <i>J</i> = 9.0 Hz, 2H); <sup>13</sup>C NMR (126 MHz, CDCl<sub>3</sub>) δ 46.24, 55.91 (d, <i>J</i> = 14.6 Hz), 124.44, 127.44, 128.46, 128.72, 129.63, 138.93, 147.25, 147.54; <sup>19</sup>F NMR (471 MHz, CDCl<sub>3</sub>) δ 59.61. ESI-MS HRMS calculated for C<sub>14</sub>H<sub>13</sub>FNO<sub>4</sub>S [M+H]<sup>+</sup> 310.0544, found. 310.0550; M.P: 141-144 °C.

(R)-2-(4-(benzylloxy)phenyl)-2-phenylethanesulfonfonyl fluoride (3f):

![Chemical Structure](image)

Compound 3f was synthesized according to general procedure. Off-white solid (148 mg, 80% Yield, 61% ee); the ee was measured by HPLC (Chiralpak AD-H column, hexane/isopropanol = 95/5, flow 0.6 mL/min, 254 nm, t<sub>f</sub> = 41.5 min (Major), t<sub>m</sub> = 43.9 min (Minor); [α]<sub>D</sub><sup>25</sup> = +3.4 (c = 1.0, CH<sub>2</sub>Cl<sub>2</sub>); <sup>1</sup>H NMR (500 MHz, CDCl<sub>3</sub>) δ 4.08 (dd, <i>J</i> = 3.5, 7.5 Hz, 2H), 4.65 (t, <i>J</i> = 7.5 Hz, 1H), 5.03 (s, 2H), 6.95 (d, <i>J</i> = 8.5 Hz, 2H), 7.19 (d, <i>J</i> = 8.5 Hz, 2H), 7.25-7.28 (m, 3H), 7.35-7.42 (m, 7H); <sup>13</sup>C NMR (126 MHz, CDCl<sub>3</sub>) δ 45.67, 56.67 (d, <i>J</i> = 12.7 Hz), 70.15, 115.43, 127.48, 127.44, 128.60, 127.69, 128.17, 128.70, 128.73, 129.17, 132.58, 136.88, 140.60, 158.30; <sup>19</sup>F NMR (471 MHz, CDCl<sub>3</sub>) δ 59.29. ESI-MS HRMS calculated for C<sub>21</sub>H<sub>20</sub>FO<sub>3</sub>S [M+H]<sup>+</sup> 371.1112, found. 371.1111; M.P: 66-69 °C.

(R)-ethyl 4-(2-(fluorosulfonyl)-1-phenylethyl)benzoate (3g):
Compound 3g was synthesized according to general procedure. Off-white solid (164 mg, 98% yield, 90% ee); the ee was measured by HPLC (Chiralpak AD-H column, hexane/isopropanol = 90/10, flow 0.6 mL/min, 254 nm, $t_1 = 24.2$ min (Major), $t_2 = 27.0$ min (Minor); $[\alpha]_D^{24} = -10.8$ (c = 1.23, CHCl$_3$); $^1$H NMR (500 MHz, CDCl$_3$) $\delta$ 1.37 (t, $J = 7.5$ Hz, 3H), 4.13-4.15 (m, 2H), 4.36 (q, $J = 7.0$ Hz, 2H), 4.74 (t, $J = 7.0$ Hz, 2H), 4.74 (t, $J = 7.0$ Hz, 1H), 7.24-7.29 (m, 3H), 7.33-7.37 (m, 4H), 8.02 (d, $J = 8.5$ Hz, 2H); $^{13}$C NMR (126 MHz, CDCl$_3$) $\delta$ 14.39, 46.35, 56.10 (d, $J = 13.7$ Hz), 61.19, 127.51, 127.65, 128.06, 129.36, 130.09, 130.45, 139.64, 145.01, 166.13; $^{19}$F NMR (471 MHz, CDCl$_3$) $\delta$ 59.37; ESI-MS HRMS calculated for C$_{17}$H$_{18}$FO$_4$S $[M+H]^+$ 337.0904, found. 337.0909; M.P: 68-71°C.

(R)-2-(4-(methylsulfonyl)phenyl)-2-phenylethanesulfonyl fluoride (3h):

\[
\begin{align*}
\text{SO}_2\text{Me} & \\
\text{Ph} & \\
\text{SO}_2F & 
\end{align*}
\]

Compound 3h was synthesized according to general procedure. Off-white solid (145 mg, 85% yield, 98% ee); the ee was measured by HPLC (Chiralpak AS-H column, hexane/isopropanol = 60/40, flow 1.0 mL/min, 254 nm, $t_1 = 40.2$ min (Major), $t_2 = 64.8$ min (Minor); $[\alpha]_D^{22} = -8.6$ (c = 1.2, CHCl$_3$); $^1$H NMR (500 MHz, CDCl$_3$) $\delta$ 3.03 (s, 3H), 4.15-4.18 (m, 2H), 4.77 (t, $J = 7.0$ Hz, 1H), 7.25 (d, $J = 7.5$ Hz, 2H), 7.29-7.31 (m, 1H), 7.35-7.38 (m, 2H), 7.51 (d, $J = 8.5$ Hz, 2H), 7.52 (d, $J = 8.0$ Hz, 2H), 9.98 (s, 1H); $^{13}$C NMR (126 MHz, CDCl$_3$) $\delta$ 44.54, 46.31, 55.84 (d, $J = 15.5$ Hz), 127.47, 128.33, 128.35, 128.75, 129.55, 139.07, 140.05, 146.32; $^{19}$F NMR (471 MHz, CDCl$_3$) $\delta$ 59.56; ESI-MS HRMS calculated for C$_{15}$H$_{16}$FO$_3$S $[M+H]^+$ 343.0469, found. 343.0470; M.P: 132-135°C.

(R)-2-(4-formylphenyl)-2-phenylethanesulfonyl fluoride (3i):

\[
\begin{align*}
\text{O} & \\
\text{Ph} & \\
\text{SO}_2F & 
\end{align*}
\]

Compound 3i was synthesized according to general procedure. Brown viscous liquid (144 mg, 99% yield, 93% ee); the ee was measured by HPLC (Chiralpak OD-H column, hexane/isopropanol = 50/50, flow 1.0 mL/min, 254 nm, $t_1 = 40.0$ min (Minor), $t_2 = 51.1$ min (Major); $[\alpha]_D^{25} = +5.0$ (c = 1.0, CHCl$_3$); $^1$H NMR (500 MHz, CDCl$_3$) $\delta$ 4.12-4.21 (m, 2H), 4.77 (t, $J = 7.5$ Hz, 1H), 7.26-7.31 (m, 3H), 7.35-7.38 (m, 2H), 7.47 (d, $J = 8.0$ Hz, 2H), 7.87 (d, $J = 8.0$ Hz, 2H), 9.98 (s, 1H); $^{13}$C NMR (126 MHz, CDCl$_3$) $\delta$ 46.55, 56.07 (d, $J = 14.5$ Hz), 127.52, 128.25, 128.42, 129.50, 130.56, 135.94, 139.40, 146.77, 191.52; $^{19}$F NMR (471 MHz, CDCl$_3$) $\delta$ 59.45. ESI-MS HRMS calculated for C$_{13}$H$_{18}$FO$_3$S $[M+H]^+$ 293.0642, found. 293.0645.
(R)-2-(4-cyanophenyl)-2-phenylethanesulfonyl fluoride (3j):

![Chemical structure](attachment:image.png)

Compound 3j was synthesized according to general procedure. White solid (132 mg, 91% Yield, 99.8% ee); the ee was measured by HPLC (Chiralpak AD-H column, hexane/isopropanol = 90/10, flow 0.6 mL/min, 254 nm, \( t_1 = 34.9 \) min (Minor), \( t_2 = 37.8 \) min (Major); \([\alpha]_{D}^{26} = +5.3 \) (c = 0.93, CH\(_2\)Cl\(_2\)); \(^1\)H NMR (500 MHz, CDCl\(_3\)) \( \delta \) 4.12-4.14 (m, 2H), 4.73 (t, \( J = 7.0 \) Hz, 1H), 7.23 (d, \( J = 7.5 \) Hz, 2H), 7.29-7.32 (m, 1H), 7.35-7.38 (m, 2H), 7.41 (d, \( J = 8.0 \) Hz, 2H), 7.64 (d, \( J = 8.0 \) Hz, 2H); \(^13\)C NMR (126 MHz, CDCl\(_3\)) \( \delta \) 46.45, 55.90 (d, \( J = 14.6 \) Hz, 1H), 112.00, 118.37, 127.45, 128.40, 128.57, 129.57, 133.01, 139.03, 145.36; \(^19\)F NMR (471 MHz, CDCl\(_3\)) \( \delta \) 59.56; ESI-MS HRMS calculated for C\(_{15}\)H\(_{13}\)FNO\(_2\)S [M+H]\(^+\) 290.0646, found. 290.0653; M.P: 87-91 °C.

(R)-2-(4-acetylphenyl)-2-phenylethanesulfonyl fluoride (3k):

![Chemical structure](attachment:image.png)

Compound 3k was synthesized according to general procedure. Yellow solid (141 mg, 92% Yield 67% ee); the ee was measured by HPLC (Chiralpak OD-H column, hexane/isopropanol = 80/20, flow 1.0 mL/min, 254 nm, \( t_1 = 17.2 \) min (Major), \( t_2 = 37.1 \) min (Minor); \([\alpha]_{D}^{29} = -9.0 \) (c = 1.0, CH\(_2\)Cl\(_2\)); \(^1\)H NMR (500 MHz, CDCl\(_3\)) \( \delta \) 2.57 (s, 3H), 4.13-4.16 (m, 2H), 4.74 (t, \( J = 7.5 \) Hz, 1H), 7.25-7.30 (m, 3H), 7.34-7.40 (m, 4H), 7.94 (d, \( J = 8.5 \) Hz, 2H); \(^13\)C NMR (126 MHz, CDCl\(_3\)) \( \delta \) 26.66, 46.40, 56.14 (d, \( J = 14.5 \) Hz, 1H), 127.52, 127.94, 128.15, 129.26, 129.44, 136.66, 139.61, 145.29, 197.40; \(^19\)F NMR (471 MHz, CDCl\(_3\)) \( \delta \) 59.40; ESI-MS HRMS calculated for C\(_{16}\)H\(_{16}\)FO\(_3\)S [M+H]\(^+\) 307.0799, found. 307.0807; MP: 94-97 °C.

(R)-2-(2,4-difluorophenyl)-2-phenylethanesulfonyl fluoride (3l):

![Chemical structure](attachment:image.png)

Compound 3l was synthesized according to general procedure. Brown oil (116 mg, 77% Yield, 89%
ee); the ee was measured by HPLC (Chiralpak AD-H column, hexane/isopropanol = 95/5, flow 0.6 mL/min, 254 nm, \( t_1 = 15.6 \) min (Major), \( t_2 = 18.2 \) min (Minor); [\( \alpha \]) \(_{D}^{26} = +2.9 \) (c = 1.16, CH\(_{2}\)Cl\(_{2}\)); \(^1\)H NMR (500 MHz, CDCl\(_3\)) \( \delta 4.06-4.11 \) (m, 1H), 4.17-4.23 (m, 1H), 4.86 (t, \( J = 7.5 \) Hz, 1H), 6.81-6.89 (m, 2H), 7.21-7.30 (m, 4H), 7.33-7.36 (m, 2H); \(^{13}\)C NMR (126 MHz, CDCl\(_3\)) \( \delta 40.81, 55.07 \) (q, \( J = 11.8 \) Hz), 104.88 (t, \( J = 26.5 \) Hz), 112.03 (dd, \( J = 3.6 \) Hz, \( J = 19.6 \) Hz), 123.24 (dd, \( J = 3.6 \) Hz, \( J = 13.6 \) Hz), 127.48, 128.12, 129.33, 130.21 (dd, \( J = 5.4 \) Hz, \( J = 9.9 \) Hz), 138.87, 160.65 (dd, \( J = 11.8 \) Hz, \( J = 250.2 \) Hz), 162.66 (dd, \( J = 12.7 \) Hz, \( J = 250.2 \) Hz); \(^{19}\)F NMR (471 MHz, CDCl\(_3\)) \( \delta -111.59 \) (m), \( -110.04 \) (m), 58.62. ESI-MS HRMS calculated for C\(_{14}\)H\(_{12}\)F\(_3\)O\(_2\)S [M+H]\(^+\) 301.0505, found 301.0509.

\((R)-2\text{-phenyl-2-(3-(trifluoromethyl)phenyl)}\text{ethanesulfonyl fluoride (3m):}\)

\[
\begin{align*}
\textbf{CF}_3 \\
\textbf{SO}_2\text{F}
\end{align*}
\]

Compound 3m was synthesized according to general procedure. Colorless viscous liquid (141 mg, 85% Yield, 96% ee); the ee was measured by HPLC (Chiralpak OJ-H column, hexane/isopropanol = 90/10, flow 1.0 mL/min, 254 nm, \( t_1 = 45.8 \) min (Minor), \( t_2 = 54.7 \) min (Major); [\( \alpha \]) \(_{D}^{24} = -9.26 \) (c = 0.93, CHCl\(_3\)); \(^1\)H NMR (500 MHz, CDCl\(_3\)) \( \delta 4.14 \) (dd, \( J = 3.5, 7.5 \) Hz, 2H), 4.76 (t, \( J = 7.5 \) Hz, 1H), 7.26-7.28 (m, 2H), 7.29-7.32 (m, 1H), 7.36-7.39 (m, 2H), 7.48-7.50 (m, 2H), 7.54-7.56 (m, 2H); \(^{13}\)C NMR (126 MHz, CDCl\(_3\)) \( \delta 46.29, 56.21 \) (d, \( J = 14.5 \) Hz), 123.94 (q, \( J = 273.0 \) Hz), 124.39 (q, \( J = 3.7 \) Hz), 124.82 (d, \( J = 3.7 \) Hz), 127.50, 128.23, 129.50, 129.79, 131.11, 131.61 (q, \( J = 32.8 \) Hz), 139.44, 141.24; \(^{19}\)F NMR (471 MHz, CDCl\(_3\)) \( \delta -62.65 \), 59.42. ESI-MS HRMS calculated for C\(_{15}\)H\(_{13}\)F\(_4\)O\(_2\)S [M+H]\(^+\) 333.0567, found 333.0566.

\((R)-2-(3\text{-bromophenyl)}-2\text{-phenylethanesulfonyl fluoride (3n):}\)

\[
\begin{align*}
\textbf{Br} \\
\textbf{SO}_2\text{F}
\end{align*}
\]

Compound 3n was synthesized according to general procedure. Colorless viscous liquid (143 mg, 84% Yield, 96%); the ee was measured by HPLC (Chiralpak AD-H column, hexane/isopropanol = 95/5, flow 0.6 mL/min, 254 nm, \( t_1 = 16.5 \) min (Major), \( t_2 = 17.6 \) min (Minor); [\( \alpha \]) \(_{D}^{25} = -10.5 \) (c = 0.8, CHCl\(_3\)); \(^1\)H NMR (500 MHz, CDCl\(_3\)) \( \delta 4.10 \) (dd, \( J = 3.5, 7.5 \) Hz, 2H), 4.65 (t, \( J = 7.5 \) Hz, 1H), 7.22-7.26 (m, 4H), 7.28-7.31 (m, 1H), 7.35-7.42 (m, 4H); \(^{13}\)C NMR (126 MHz, CDCl\(_3\)) \( \delta 46.09, 56.22 \) (d, \( J = 14.6 \) Hz), 123.25, 126.27, 127.51, 128.12, 129.40, 130.72, 130.75, 131.03, 139.55, 142.50; \(^{19}\)F NMR (471 MHz, CDCl\(_3\)) \( \delta 59.37 \). ESI-MS HRMS calculated for C\(_{15}\)H\(_{13}\)BrFO\(_2\)S [M+H]\(^+\) 333.0567, found 333.0566.
(R)-2-(3-formylphenyl)-2-phenylethanesulfonfyl fluoride (3o):

Compound 3o was synthesized according to general procedure. Brown viscous liquid (143 mg, 98% yield, 94% ee); the ee was measured by HPLC (Chiralpak OD-H column, hexane/isopropanol = 50/50, flow 1.0 mL/min, 254 nm, t1 = 25.0 min (Minor), t2 = 39.5 min (Major); [α]D25 = -17.2 (c = 1.1, CHCl3); 1H NMR (500 MHz, CDCl3) δ 4.12-4.21 (m, 2H), 4.77 (t, J = 7.0 Hz, 1H), 7.26-7.30 (m, 3H), 7.35-7.38 (m, 2H), 7.52-7.58 (m, 2H), 7.79 (dt, J = 1.0, 7.0 Hz, 1H), 7.82 (s, 1H), 9.99 (s, 1H); 13C NMR (126 MHz, CDCl3) δ 46.26, 56.24 (d, J = 14.5 Hz), 127.51, 127.91, 128.19, 129.49, 129.78, 130.00, 133.83, 137.22, 139.66, 141.51, 191.79; 19F NMR (471 MHz, CDCl3) δ 59.43. ESI-MS HRMS calculated for C15H14FO3S [M+H]+ 293.0642, found. 293.0645.

(R)-2-(3-nitrophenyl)-2-phenylethanesulfonfyl fluoride (3p):

Compound 3p was synthesized according to general procedure. Off-white solid (153 mg, 99% yield, 97% ee); the ee was measured by HPLC (Chiralpak OD-H column, hexane/isopropanol = 60/40, flow 1.0 mL/min, 254 nm, t1 = 30.8 min (Minor), t2 = 62.6 min (Major); [α]D26 = -6.0 (c = 1.0, CH2Cl2); 1H NMR (500 MHz, CDCl3) δ 4.16-4.22 (m, 2H), 4.83 (t, J = 7.5 Hz, 1H), 7.29 (d, J = 7.7 Hz, 2H), 7.32-7.35 (m, 1H), 7.39-7.42 (m, 2H), 7.57 (t, J = 8.0 Hz, 1H), 7.68 (d, J = 7.5 Hz, 1H), 8.17-8.20 (m, 2H); 13C NMR (126 MHz, CDCl3) δ 46.18, 56.06 (d, J = 14.6 Hz), 122.55, 123.00, 127.44, 128.48, 129.68, 130.29, 133.97, 139.09, 142.29, 148.86; 19F NMR (471 MHz, CDCl3) δ 59.61. ESI-MS HRMS calculated for C14H13FNO4S [M+H]+ 310.0544, found. 310.0549; M.P: 97-100 °C.
(R)-2-(3,5-dimethoxyphenyl)-2-phenylethanesulfonyl fluoride (3q):

\[
\text{OMe} \quad \text{OMe} \quad \text{MeO} \quad \text{SO}_2 \text{F}
\]

Compound 3q was synthesized according to general procedure. Off-white solid (141 mg, 87% Yield, 74% ee); the ee was measured by HPLC (Chiralpak OD-H column, hexane/isopropanol = 20/80, flow 1.0 mL/min, 254 nm, \(t_1 = 17.9\) min (Minor), \(t_2 = 19.6\) min (Major); \([\alpha]_D^{22} = -8.9\) (c = 2.4, CHCl\(_3\)); \(^1\)H NMR (500 MHz, CDCl\(_3\)) \(\delta 3.76\) (s, 6H), 4.09 (dd, \(J = 3.5, 7.5\) Hz, 2H), 4.60 (t, \(J = 7.5\) Hz, 1H), 6.36 (t, \(J = 2.0\) Hz, 1H), 6.42 (d, \(J = 2.0\) Hz, 2H), 7.26-7.29 (m, 3H), 7.33-7.36 (m, 2H); \(^13\)C NMR (126 MHz, CDCl\(_3\)) \(\delta 46.50, 55.40, 56.32\) (d, \(J = 13.6\) Hz), 98.96, 105.99, 127.51, 127.81, 129.14, 139.98, 142.62, 161.29; \(^19\)F NMR (471 MHz, CDCl\(_3\)) \(\delta 59.14\). ESI-MS HRMS calculated for C\(_{16}\)H\(_{18}\)FO\(_4\)S [M+H]\(^+\) 325.0904, found. 325.0902; M.P.: 96-99 °C.

(R)-2-(naphthalen-1-yl)-2-phenylethanesulfonyl fluoride (3r):

\[
\text{SO}_2 \text{F}
\]

Compound 3r was synthesized according to general procedure. Light brown viscous liquid (140 mg, 89% Yield, 98% ee); the ee was measured by HPLC (Chiralpak AD-H column, hexane/isopropanol = 95/5, flow 0.6 mL/min, 254 nm, \(t_1 = 11.7\) min (Major), \(t_2 = 12.7\) min (Minor); \([\alpha]_D^{27} = +32.9\) (c = 0.7, CH\(_2\)Cl\(_2\)); \(^1\)H NMR (500 MHz, CDCl\(_3\)) \(\delta 4.23-4.26\) (m, 2H), 5.56 (t, \(J = 7.0\) Hz, 1H), 7.26-7.29 (m, 1H), 7.33-7.39 (m, 5H), 7.46-7.53 (m, 2H), 7.55-7.58 (m, 1H), 7.82 (d, \(J = 8.0\) Hz, 1H), 7.89 (d, \(J = 8.0\) Hz, 1H), 8.14 (d, \(J = 8.5\) Hz, 1H); \(^13\)C NMR (126 MHz, CDCl\(_3\)) \(\delta 41.86, 56.45\) (d, \(J = 13.6\) Hz), 122.88, 124.74, 125.30, 126.17, 126.30, 127.10, 128.05, 128.16, 129.16, 129.35, 130.83, 134.36, 135.91, 139.56; \(^19\)F NMR (471 MHz, CDCl\(_3\)) \(\delta 59.46\). ESI-MS HRMS calculated for C\(_{18}\)H\(_{16}\)FO\(_2\)S [M+H]\(^+\) 315.0850, found. 315.0851.

(R)-2-(anthracen-9-yl)-2-phenylethanesulfonyl fluoride (3s):

\[
\text{SO}_2 \text{F}
\]

Compound 3s was synthesized according to general procedure. Off-white solid (151 mg, 83% Yield, 97% ee); The ee was measured by HPLC (Chiralpak OD-H column, hexane/isopropanol = 50/50, flow 1.0 mL/min, 254 nm, \(t_1 = 6.8\) min (Major), \(t_2 = 15.8\) min (Minor); \([\alpha]_D^{22} = +12.6\) (c = 0.96,
CHCl$_3$; $^1$H NMR (500 MHz, CDCl$_3$) δ 4.45 (dd, $J = 7.0$, 15.5 Hz, 1H), 4.83 (ddd, $J = 5.0$, 7.5, 15.5 Hz, 1H), 6.40 (t, $J = 5.5$ Hz, 1H), 7.23-7.62 (m, 10H), 8.01-8.09 (m, 2H), 8.44-8.54 (m, 2H); $^{13}$C NMR (126 MHz, CDCl$_3$) δ 37.77, 56.49 (d, $J = 14.6$ Hz), 125.14, 125.47, 126.35, 126.71, 127.11, 128.28, 129.07, 129.13, 129.94, 131.97, 140.69; $^{19}$F NMR (471 MHz, CDCl$_3$) δ 56.56 (d, 1F); M.P.: 187-192 °C; ESI-MS HRMS calculated for C$_{22}$H$_{17}$FNaO$_2$S [M+Na]$^+$ 387.0825, found 387.0830.

(R)-2-(phenanthren-9-yl)-2-phenylethanesulfonyl fluoride (3t):

![Chemical Structure](image)

Compound 3t was synthesized according to general procedure. Off-white solid (136 mg, 75% Yield, 97% ee); the ee was measured by HPLC (Chiralpak AD-H column, hexane/isopropanol = 95/5, flow 0.6 mL/min, 254 nm, $t_1 = 22.6$ min (Major), $t_2 = 28.2$ min (Minor); $[^{23}]$D = -55.8 (c = 0.76, CHCl$_3$); $^1$H NMR (500 MHz, CDCl$_3$) δ 4.26-4.36 (m, 2H), 5.53 (dd, $J = 6.0$, 8.5 Hz, 1H), 7.27-7.30 (m, 1H), 7.35 (t, $J = 7.0$ Hz, 2H), 7.43 (d, $J = 7.5$ Hz, 2H), 7.61-7.69 (m, 5H), 7.87 (d, $J = 8.0$ Hz, 1H), 8.14 (d, $J = 8.0$ Hz, 1H), 8.66 (d, $J = 8.5$ Hz, 1H), 8.75 (d, $J = 8.0$ Hz, 1H); $^{13}$C NMR (126 MHz, CDCl$_3$) δ 42.33, 56.52 (d, $J = 13.7$ Hz), 122.67, 123.74, 123.86, 126.06, 126.95, 127.21, 127.42, 128.04, 128.21, 128.90, 129.25, 129.80, 130.31, 131.07, 131.39, 134.15, 139.36; $^{19}$F NMR (471 MHz, CDCl$_3$) δ 59.82; ESI-MS HRMS calculated for C$_{22}$H$_{18}$FO$_2$S [M+H]$^+$ 365.1006, found 365.1005; M.P.: 137-141 °C.

(R)-2-phenyl-2-(6-(trifluoromethyl)pyridin-3-yl)ethanesulfonyl fluoride (3u):

![Chemical Structure](image)

Compound 3u was synthesized according to general procedure. Colorless viscous liquid (136 mg, 82% Yield, 99% ee); the ee was measured by HPLC (Chiralpak AD-H column, hexane/isopropanol = 90/10, flow 1.0 mL/min, 254 nm, $t_1 = 14.09$ min (Major), $t_2 = 15.4$ min (Minor); $[^{24}]$D = +13.5 (c = 1.1, CH$_2$Cl$_2$); $^1$H NMR (500 MHz, CDCl$_3$) δ 4.16 (dd, $J = 3.0$, 7.5 Hz, 2H), 4.79 (t, $J = 7.5$ Hz, 1H), 7.25 (d, $J = 8.5$ Hz, 2H), 7.31-7.34 (m, 1H), 7.38-7.41 (m, 2H), 7.67 (d, $J = 8.5$ Hz, 1H), 7.80 (dd, $J = 2.0$, 8.0 Hz, 1H), 8.71 (d, $J = 2.0$ Hz, 1H); $^{13}$C NMR (126 MHz, CDCl$_3$) δ 44.16, 55.70 (d, $J = 15.5$ Hz), 120.78 (q, $J = 2.8$ Hz), 121.44 (q, $J = 274.8$ Hz), 127.42, 128.68, 128.90, 130.31, 131.07, 131.39, 134.15, 139.36; $^{19}$F NMR (471 MHz, CDCl$_3$) δ -67.93, 59.68. ESI-MS HRMS calculated for C$_{14}$H$_{12}$F$_{4}$NO$_2$S [M+H]$^+$ 334.0519, found 334.0527.
(R)-2-(dibenzo[b,d]furan-4-yl)-2-phenylethanesulfonyl fluoride (3v):

![Compound 3v](image)

Compound 3v was synthesized according to general procedure. Off-white solid (163 mg, 92% Yield, 99.4% ee); the ee was measured by HPLC (Chiralpak OD-H column, hexane/isopropanol = 80/20, flow 1.0 mL/min, 254 nm, $t_1 = 25.3$ min (Minor), $t_2 = 28.3$ min (Major); $[\alpha]_D^{27} = -24.9$ (c = 1.0, CH$_2$Cl$_2$); $^1$H NMR (500 MHz, CDCl$_3$) $\delta$ 4.32-4.37 (m, 1H), 4.59-4.65 (m, 1H), 5.16 (t, $J = 7.0$ Hz, 1H), 7.25-7.28 (m, 1H), 7.30-7.38 (m, 5H), 7.46-7.51 (m, 3H), 7.64 (d, $J = 8.5$ Hz, 1H), 7.88 (dd, $J = 2.5$, 6.5 Hz, 1H), 7.95 (dd, $J = 0.5$, 8.0 Hz, 1H); $^{13}$C NMR (126 MHz, CDCl$_3$) $\delta$ 43.08, 55.30 (d, $J = 14.5$ Hz), 121.05, 120.45, 120.99, 123.30, 123.50, 124.17, 124.28, 125.26, 126.48, 127.69, 127.83, 127.99, 129.22, 139.41, 153.57, 156.17; $^{19}$F NMR (471 MHz, CDCl$_3$) $\delta$ 58.40; ESI-MS HRMS calculated for C$_{20}$H$_{16}$FO$_3$S [M+H]$^+$ 355.0799, found. 355.0801; M.P: 50-54 °C.

(3w)

(3x)

(3x)
Compound 3x was synthesized according to general procedure. Pale yellow solid (91 mg, 63% Yield, 99.6% ee); the ee was measured by HPLC (Chiralpak AD-H column, hexane/isopropanol = 95/5, flow 0.6 mL/min, 254 nm, $t_1 = 19.1$ min (Major), $t_2 = 21.1$ min (Minor); $[\alpha]_{D}^{20} = +13.7$ (c = 1.0, CH$_2$Cl$_2$); $^1$H NMR (500 MHz, CDCl$_3$) $\delta$ 4.05-4.10 (m, 1H), 4.17-4.22 (m, 1H), 4.87 (t, $J = 7.0$ Hz, 1H), 7.20 (t, $J = 7.5$ Hz, 1H), 7.30-7.40 (m, 7H), 7.48-7.51 (m, 2H); $^{13}$C NMR (126 MHz, CDCl$_3$) $\delta$ 37.75, 55.95 (d, $J = 13.6$ Hz), 112.03, 119.80, 120.33, 123.14, 125.18, 126.19, 127.75, 128.31, 129.34, 138.56, 142.00, 155.85; $^{19}$F NMR (471 MHz, CDCl$_3$) $\delta$ 59.39. ESI-MS HRMS calculated for C$_{16}$H$_{13}$FNaO$_3$S [M+Na]$^+$ 327.0462, found. 327.0460; M.P.: 84-88 °C.

(R)-2-(benzo[b]thiophen-3-yl)-2-phenylethanesulfonyl fluoride (3y):

Compound 3y was synthesized according to general procedure. Red solid (80 mg, 50% Yield, 98% ee); the ee was measured by HPLC (Chiralpak AD-H column, hexane/isopropanol = 95/5, flow 0.6 mL/min, 254 nm, $t_1 = 18.8$ min (Major), $t_2 = 22.7$ min (Minor); $[\alpha]_{D}^{26} = +8.1$ (c = 0.6, CH$_2$Cl$_2$); $^1$H NMR (500 MHz, CDCl$_3$) $\delta$ 4.13 (ddd, $J = 1.5$, 8.5, 15.0 Hz, 1H), 4.22 (td, $J = 5.0$, 14.5 Hz, 1H), 5.07 (dd, $J = 5.5$, 8.5 Hz, 1H), 7.24 (s, 1H), 7.28-7.32 (m, 1H), 7.34-7.37 (m, 6H), 7.68-7.71 (m, 1H), 7.84-7.87 (m, 1H); $^{13}$C NMR (126 MHz, CDCl$_3$) $\delta$ 40.89, 56.27 (d, $J = 13.6$ Hz), 121.77, 123.26, 123.37, 124.72, 125.09, 127.91, 128.23, 129.34, 134.70, 137.35, 138.69, 140.86; $^{19}$F NMR (471 MHz, CDCl$_3$) $\delta$ 59.46. ESI-MS HRMS calculated for C$_{16}$H$_{14}$FO$_2$S [M+H]$^+$ 321.0414, found. 321.0422. M.P.: 72-76 °C.

(S)-2-(4-methoxyphenyl)-2-phenylethanesulfonyl fluoride (4a):

Compound 4a was synthesized according to general procedure. Pale brown oil (135 mg, 92% Yield, 83% ee); the ee was measured by HPLC (Chiralpak OD-H column, hexane/isopropanol = 20/80, flow 1.0 mL/min, 254 nm, $t_1 = 19.8$ min (Major), $t_2 = 24.2$ min (Minor); $[\alpha]_{D}^{26} = -6.8$ (c = 0.83, CHCl$_3$); $^1$H NMR (500 MHz, CDCl$_3$) $\delta$ 3.77 (s, 3H), 4.082 (dd, $J = 3.0$, 7.0 Hz, 2H), 4.64 (t, $J = 7.5$ Hz, 1H), 6.85-6.88 (m, 2H), 7.17-7.20 (m, 2H), 7.24-7.26 (m, 3H), 7.32-7.35 (m, 2H); $^{13}$C NMR (126 MHz, CDCl$_3$) $\delta$ 45.69, 55.40, 56.76 (d, $J = 13.6$ Hz), 114.57, 127.48, 127.71, 128.69, 129.20, 132.29, 140.69, 159.11. $^{19}$F NMR (471 MHz, CDCl$_3$) $\delta$ 59.25. ESI-MS HRMS calculated for C$_{15}$H$_{16}$FO$_2$S [M+H]$^+$ 295.0799, found. 295.0807.
(S)-2-(4-bromophenyl)-2-phenylethanesulfonyl fluoride (4b):

![Chemical Structure](image)

Compound 4b was synthesized according to general procedure. Colorless oil (155 mg, 95% Yield, 72% ee). The ee was measured by HPLC (Chiralpak AD-H column, hexane/isopropanol = 95/5, flow 0.6 mL/min, 254 nm, $t_1 = 22.0$ min (Minor), $t_2 = 24.9$ min (Major); $[\alpha]_D^{26} = +2.0$ (c = 1.0, CH$_2$Cl$_2$). $^1$H NMR (500 MHz, CDCl$_3$) $\delta$ 4.10 (dd, $J = 3.5$, 7.5 Hz, 2H), 4.6 (t, $J = 7.5$ Hz, 1H), 7.17 (d, $J = 8.4$ Hz, 2H), 7.24 (d, $J = 7.2$ Hz, 2H), 7.29 (t, $J = 7.3$ Hz, 1H), 7.36 (m, $J = 7.2$ Hz, 2H), 7.48 (d, $J = 8.6$ Hz, 2H); $^{13}$C NMR (126 MHz, CDCl$_3$) $\delta$ 45.89, 56.21 (d, $J = 13.7$ Hz), 121.83, 127.43, 128.03, 129.33, 132.33, 139.22, 139.78; $^{19}$F NMR (471 MHz, CDCl$_3$) $\delta$ 59.45. ESI-MS HRMS calculated for C$_{14}$H$_{13}$BrFO$_2$S [M+H]$^+$ 342.9798, found. 342.9802.

(S)-2-phenyl-2-(4-(trifluoromethoxy)phenyl)ethanesulfonyl fluoride (4c):

![Chemical Structure](image)

Compound 4c was synthesized according to general procedure. Pale brown oil (148 mg, 85% Yield, 51% ee). The ee was measured by HPLC (Chiralpak AD-H column, hexane/isopropanol = 95/5, flow 0.6 mL/min, 254 nm, $t_1 = 14.2$ min (Minor), $t_2 = 15.7$ min (Major); $[\alpha]_D^{26} = -14.8$ (c = 1.36, CHCl$_3$). $^1$H NMR (500 MHz, CDCl$_3$) $\delta$ 4.12-4.15 (m, 2H), 4.74 (t, $J = 7.5$ Hz, 1H), 7.22 (d, $J = 8.2$ Hz, 2H), 7.28-7.30 (m, 2H), 7.31-7.35 (m, 3H), 7.40 (t, $J = 7.5$ Hz, 2H); $^{13}$C NMR (126 MHz, CDCl$_3$) $\delta$ 45.84, 56.41 (d, $J = 13.6$ Hz), 120.54 (q, $J = 258.0$ Hz), 121.62, 127.50, 128.11, 129.12, 129.41, 138.91, 139.76, 148.73; $^{19}$F NMR (471 MHz, CDCl$_3$) $\delta$ -57.88, 59.39. ESI-MS HRMS calculated for C$_{15}$H$_{13}$F$_4$O$_3$S [M+H]$^+$ 349.0516, found. 349.0523.

(S)-2-(4-nitrophenyl)-2-phenylethanesulfonyl fluoride (4d):

![Chemical Structure](image)

Compound 4d was synthesized according to general procedure. Pale brown oil (134 mg, 87% Yield, 84% ee). The ee was measured by HPLC (Chiralpak OD-H column, hexane/isopropanol =
60/40, flow 1.0 mL/min, 254 nm, \( t_1 = 32.6 \) min (Major), \( t_2 = 46.8 \) min (Minor); \([\alpha]_D^{25} = -4.6 \) (c = 1.36, CHCl₃). \(^1\)H NMR (500 MHz, CDCl₃) \( \delta \) 4.17-4.21 (m, 2H), 4.82 (t, \( J = 7.5 \) Hz, 1H), 7.24-7.28 (m, 2H), 7.34 (t, \( J = 7.4 \) Hz, 1H), 7.40 (t, \( J = 7.2 \) Hz, 2H), 7.51 (d, \( J = 8.8 \) Hz, 2H), 8.24 (d, \( J = 8.8 \) Hz, 2H); \(^13\)C NMR (126 MHz, CDCl₃) \( \delta \) 46.25, 55.91 (d, \( J = 14.5 \) Hz), 124.44, 127.44, 128.47, 128.73, 129.64, 138.94, 147.26, 147.55; \(^{19}\)F NMR (471 MHz, CDCl₃) \( \delta \) -114.38 (m, 1F), 59.39 (s, 1F). ESI-MS HRMS calculated for C₁₄H₁₃FNO₃S [M+H]+ 283.0599, found. 283.0542.

(S)-2-(4-cyanophenyl)-2-phenylethanesulfonyl fluoride (4e):

Compound 4e was synthesized according to general procedure. Brown solid (134 mg, 93% Yield, 98% ee); the ee was measured by HPLC (Chiralpak AD-H column, hexane/isopropanol = 90/10, flow 0.6 mL/min, 254 nm, \( t_1 = 34.4 \) min (Major), \( t_2 = 37.6 \) min (Minor); \([\alpha]_D^{26} = +6.7 \) (c = 1.1, CHCl₃). \(^1\)H NMR (500 MHz, CDCl₃) \( \delta \) 4.11-4.15 (m, 2H), 4.74 (t, \( J = 7.4 \) Hz, 1H), 7.23 (d, \( J = 7.4 \) Hz, 2H), 7.31 (t, \( J = 7.3 \) Hz, 1H), 7.37 (t, \( J = 7.6 \) Hz, 2H), 7.42 (d, \( J = 8.3 \) Hz, 2H), 7.64 (d, \( J = 8.3 \) Hz, 2H); \(^13\)C NMR (126 MHz, CDCl₃) \( \delta \) 46.45, 55.91 (d, \( J = 14.5 \) Hz), 112.00, 118.38, 127.46, 128.40, 128.58, 129.58, 133.02, 139.03, 145.37; \(^{19}\)F NMR (471 MHz, CDCl₃) \( \delta \) -114.38 (m, 1F), 59.39 (s, 1F). ESI-MS HRMS calculated for C₁₅H₁₃FNO₂S [M+H]+ 290.0653, MP: 90-94 °C.

(S)-2-(4-fluorophenyl)-2-phenylethanesulfonyl fluoride (4f):

Compound 4f was synthesized according to general procedure. Colorless oil (87 mg, 62% Yield, 71% ee); the ee was measured by HPLC (Chiralpak OJ-H column, hexane/isopropanol = 90/10, flow 1.0 mL/min, 254 nm, \( t_1 = 47.3 \) min (Major), \( t_2 = 55.9 \) min (Minor); \([\alpha]_D^{25} = -1.2 \) (c = 0.9, CH₂Cl₂). \(^1\)H NMR (500 MHz, CDCl₃) \( \delta \) 4.09 (dd, \( J = 3.5, 8.0 \) Hz, 2H), 4.68 (t, \( J = 7.5 \) Hz, 1H), 7.03 (t, \( J = 8.5 \) Hz, 2H), 7.24-7.30 (m, 5H), 7.35 (t, \( J = 7.0 \) Hz, 2H); \(^13\)C NMR (126 MHz, CDCl₃) \( \delta \) 45.76, 56.63 (d, \( J = 13.6 \) Hz), 116.16 (d, \( J = 21.9 \) Hz), 127.46, 127.96, 129.28, 129.34, 136.06 (d, \( J = 2.8 \) Hz), 140.19, 162.26 (d, \( J = 247.5 \) Hz); \(^{19}\)F NMR (471 MHz, CDCl₃) \( \delta \) -114.38 (m, 1F), 59.39 (s, 1F). ESI-MS HRMS calculated for C₁₄H₁₂F₂O₂S [M+H]+ 283.0599, found. 283.0604.
(S)-ethyl 4-(2-(fluorosulfonyl)-1-phenylethyl)benzoate (4g):

Compound 4g was synthesized according to general procedure. Off-white solid (146 mg, 87% Yield, 72% ee); the ee was measured by HPLC (Chiralpak AD-H column, hexane/isopropanol = 90/10, flow 0.6 mL/min, 254 nm, $t_1 = 24.8$ min (Minor), $t_2 = 26.7$ min (Major); $[\alpha]_D^{27} = +10.1$ (c = 1.16, CH$_2$Cl$_2$). $^1$H NMR (500 MHz, CDCl$_3$) $\delta$ 1.40 (t, $J$ = 7.0 Hz, 3H), 4.15-4.18 (m, 2H), 4.38 (q, $J$ = 7.0 Hz, 2H), 4.77 (t, $J$ = 7.3 Hz, 1H), 7.27-7.32 (m, 3H), 7.36-7.40 (m, 4H), 8.05 (d, $J$ = 8.4 Hz, 2H); $^{13}$C NMR (126 MHz, CDCl$_3$) $\delta$ 14.40, 46.36, 56.10 (d, $J$ = 13.7 Hz), 61.19, 127.51, 127.66, 128.06, 129.36, 130.09, 130.45, 139.61, 145.01, 166.13; $^{19}$F NMR (471 MHz, CDCl$_3$) $\delta$ 59.38; ESI-MS HRMS calculated for C$_{17}$H$_{18}$FO$_4$S [M+H]$^+$ 337.0904, found. 337.091; M.P.: 60-64 °C.

(S)-2-(4-acetylphenyl)-2-phenylethanesulfonyl fluoride (4h):

Compound 4h was synthesized according to general procedure. Off-white solid (147 mg, 96% Yield, 91% ee); the ee was measured by HPLC (Chiralpak OD-H column, hexane/isopropanol = 80/20, flow 1.0 mL/min, 254 nm, $t_1 = 24.8$ min (Minor), $t_2 = 41.6$ min (Major); $[\alpha]_D^{26} = -5.4$ (c = 1.0, CH$_2$Cl$_2$). $^1$H NMR (500 MHz, CDCl$_3$) $\delta$ 2.48 (s, 3H), 4.04-4.07 (m, 2H), 4.65 (t, $J$ = 7.3 Hz, 1H), 7.16-7.21 (m, 3H), 7.26 (t, $J$ = 7.5 Hz, 2H), 7.30 (d, $J$ = 8.3 Hz, 2H), 7.85 (d, $J$ = 8.4 Hz, 2H); $^{13}$C NMR (126 MHz, CDCl$_3$) $\delta$ 26.67, 46.40, 56.14 (d, $J$ = 14.5 Hz), 127.52, 127.95, 128.16, 129.27, 129.44, 136.66, 139.61, 145.30, 197.40; $^{19}$F NMR (471 MHz, CDCl$_3$) $\delta$ 59.41; ESI-MS HRMS calculated for C$_{16}$H$_{16}$FO$_3$S [M+H]$^+$ 307.0799, found. 307.0805; M.P.: 103-107 °C.

(S)-2-(4-formylphenyl)-2-phenylethanesulfonyl fluoride (4i):

Compound 4i was synthesized according to general procedure. Yellow oil (108 mg, 74% Yield, 79% ee); the ee was measured by HPLC (Chiralpak OD-H column, hexane/isopropanol = 50/50, flow
1.0 mL/min, 254 nm, $t_1 = 38.9$ min (Major), $t_2 = 52.8$ min (Minor); $[\alpha]_D^{27} = -6.5$ (c = 0.5, CH$_2$Cl$_2$). $^1$H NMR (500 MHz, CDCl$_3$) $\delta$ 4.11-4.21 (m, 2H), 4.77 (t, J = 7.3 Hz, 1H), 7.25-7.27 (m, 2H), 7.28-7.31 (m, 1H), 7.35-7.38 (m, 2H), 7.47 (d, J = 8.1 Hz, 2H), 7.87 (d, J = 8.3 Hz, 2H), 9.98 (s, 1H); $^{13}$C NMR (126 MHz, CDCl$_3$) $\delta$ 46.56, 56.08 (d, J = 14.5 Hz), 127.53, 128.25, 128.42, 129.50, 130.57, 135.94, 139.40, 146.78, 191.52; $^{19}$F NMR (471 MHz, CDCl$_3$) $\delta$ 59.45. ESI-MS HRMS calculated for C$_{15}$H$_{14}$FO$_3$S [M+H]$^+$ 293.064, found. 293.0643.

**(S)-2-(4-phenoxyphenyl)-2-phenylethanesulfonil fluoride (4j):**

![Chemical Structure](image)

Compound 4j was synthesized according to general procedure. Colorless oil (171 mg, 96% Yield, 80% ee); the ee was measured by HPLC (Chiralpak AD-H column, hexane/isopropanol = 90/10, flow 1.0 mL/min, 254 nm, $t_1 = 11.6$ min (Minor), $t_2 = 12.3$ min (Major); $[\alpha]_D^{28} = -1.86$ (c = 0.5, CH$_2$Cl$_2$); $^1$H NMR (500 MHz, CDCl$_3$) $\delta$ 4.11 (dd, J = 3.5, 7.5 Hz, 2H), 4.69 (t, J = 7.5 Hz, 1H), 6.98 (d, J = 8.5 Hz, 2H), 7.01 (d, J = 8.0 Hz, 2H), 7.13 (t, J = 7.5 Hz, 1H), 7.24 (d, J = 8.5 Hz, 2H), 7.28-7.31 (m, 3H), 7.33-7.39 (m, 4H); $^{13}$C NMR (126 MHz, CDCl$_3$) $\delta$ 45.72, 56.78 (d, J = 13.7 Hz), 119.21, 119.35, 123.78, 127.55, 128.98, 129.29, 129.96, 134.89, 140.42, 156.91, 157.09; $^{19}$F NMR (471 MHz, CDCl$_3$) $\delta$ 59.36. ESI-MS HRMS calculated for C$_{20}$H$_{18}$FO$_3$S [M+H]$^+$ 357.0955, found. 357.0953.

**(S)-2-(3-methoxyphenyl)-2-phenylethanesulfonil fluoride (4k):**

![Chemical Structure](image)

Compound 4k was synthesized according to general procedure. Brown solid (129 mg, 88% Yield, 69% ee); the ee was measured by HPLC (Chiralpak OD-H column, hexane/isopropanol = 20/80, flow 1.0 mL/min, 254 nm, $t_1 = 28.5$ min (Minor), $t_2 = 57.0$ min (Major); $[\alpha]_D^{24} = -11.6$ (c = 1.3, CHCl$_3$); $^1$H NMR (500 MHz, CDCl$_3$) $\delta$ 3.78 (s, 3H), 4.11 (dd, J = 4.0, 7.5 Hz, 2H), 4.65 (t, J = 7.5 Hz, 1H), 6.80-6.81 (m, 2H), 6.87 (d, J = Hz, 1H), 7.25-7.29 (m, 4H), 7.33-7.36 (m, 2H); $^{13}$C NMR (126 MHz, CDCl$_3$) $\delta$ 46.40, 55.35, 56.47 (d, J = 13.6 Hz), 112.61, 113.98, 119.72, 127.56, 127.83, 129.20, 130.25, 140.15, 141.87, 160.12; $^{19}$F NMR (471 MHz, CDCl$_3$) $\delta$ 59.36. ESI-MS HRMS calculated for C$_{15}$H$_{16}$FO$_3$S [M+H]$^+$ 295.0799, found. 295.0805; MP: 47-51 ºC.
(S)-2-(3-fluorophenyl)-2-phenylethanesulfonyl fluoride (4l):

![Chemical Structure](image)

Compound 4l was synthesized according to general procedure. White solid (134 mg, 95% Yield, 68% ee); the ee was measured by HPLC (Chiralpak OJ-H column, hexane/isopropanol = 90/10, flow 1.0 mL/min, 254 nm, t₁ = 60.2 min (Major), t₂ = 71.7 min (Minor); [α]D²⁷ = -8.5 (c = 1.0, CH₂Cl₂);

¹H NMR (500 MHz, CDCl₃) δ 4.10 (dd, J = 3.0, 7.5 Hz, 2H), 4.68 (t, J = 7.0 Hz, 1H), 6.96-6.98 (m, 2H), 7.09 (d, J = 8.0 Hz, 1H), 7.25-7.38 (m, 6H); ¹³C NMR (126 MHz, CDCl₃) δ 46.13 (d, J = 1.8 Hz), 56.29 (d, J = 14.6 Hz), 114.74 (d, J = 11.8 Hz), 114.91 (dd, J = 10.0 Hz), 123.29 (d, J = 2.7 Hz), 127.51, 128.09, 129.37, 130.81 (d, J = 8.2 Hz), 139.66, 142.70 (d, J = 7.3 Hz), 163.14 (d, J = 247.5 Hz); ¹⁹F NMR (471 MHz, CDCl₃) δ 59.31 (s, 1F), -111.54 (m, 1F).

ESI-MS HRMS calculated for C₁₄H₁₃F₂O₂S [M+H]+ 283.0599, found. 283.0605; MP: 43-46 °C.

(S)-2-(3-formylphenyl)-2-phenylethanesulfonyl fluoride (4m):

![Chemical Structure](image)

Compound 4m was synthesized according to general procedure. Brown oil (128 mg, 88% Yield, 65% ee); the ee was measured by HPLC (Chiralpak OD-H column, hexane/isopropanol = 50/50, flow 1.0 mL/min, 254 nm, t₁ = 22.4 min (Major), t₂ = 36.8 min (Minor); [α]D²⁴ = +2.3 (c = 1.0, CH₂Cl₂);

¹H NMR (500 MHz, CDCl₃) δ 4.14-4.24 (m, 2H), 4.80 (t, J = 7.5 Hz, 1H), 7.28-7.33 (m, 3H), 7.39 (t, J = 7.1 Hz, 2H), 7.56 (t, J = 7.4 Hz, 1H), 7.59-7.61 (m, 1H), 7.81 (dt, J = 1.3, 7.3 Hz, 1H), 7.85 (s, 1H), 10.02 (s, 1H); ¹³C NMR (126 MHz, CDCl₃) δ 46.26, 56.24 (d, J = 14.5 Hz), 127.51, 127.91, 128.19, 129.49, 129.78, 130.00, 133.83, 137.23, 139.66, 141.52, 191.80; ¹⁹F NMR (471 MHz, CDCl₃) δ 59.43. ESI-MS HRMS calculated for C₁₅H₁₄FO₃S [M+H]+ 293.0642, found. 293.0643.

(S)-2-(4-bromo-3-methylphenyl)-2-phenylethanesulfonyl fluoride (4n):

![Chemical Structure](image)

Compound 4n was synthesized according to general procedure. Colorless oil (171 mg, 96% Yield,
70% ee); the ee was measured by HPLC (Chiralpak AD-H column, hexane/isopropanol = 95/5, flow 0.6 mL/min, 254 nm, t1 = 14.4 min (Minor), t2 = 16.2 min (Major); [α]D24 = -7.1 (c = 1.0, CH2Cl2); 1H NMR (500 MHz, CDCl3) δ 2.38 (s, 3H), 4.09 (dd, J = 3.0, 7.0 Hz, 2H), 4.62 (t, J = 7.5 Hz, 1H), 6.97 (dd, J = 2.0, 8.0 Hz, 1H), 7.14 (d, J = 1.5 Hz, 1H), 7.24-7.30 (m, 3H), 7.34-7.37 (m, 2H), 7.5 (d, J = 8.0 Hz, 1H); 13C NMR (126 MHz, CDCl3) δ 23.11, 45.86, 56.22 (d, J = 13.7 Hz), 124.25, 126.35, 127.42, 127.94, 129.30, 130.12, 133.04, 138.84, 139.46, 139.93; 19F NMR (471 MHz, CDCl3) δ 59.36. ESI-MS HRMS calculated for C15H15BrFO2S [M+H]+ 356.9955, found. 356.9950.

(S)-2-(3,5-dimethylphenyl)-2-phenylethanesulfonyl fluoride (4o):

![Structure of 4o]

Compound 4o was synthesized according to general procedure. Off-white solid (131 mg, 90% yield, 74% ee); the ee was measured by HPLC (Chiralpak OJ-H column, hexane/isopropanol = 90/10, flow 1.0 mL/min, 254 nm, t1 = 25.4 min (Minor), t2 = 36.3 min (Major); [α]D22 = +3.9 (c = 0.86, CHCl3); 1H NMR (500 MHz, CDCl3) δ 2.29 (s, 6H), 4.09-4.11 (m, 2H), 4.60 (t, J = 7.5 Hz, 1H), 6.84-6.90 (m, 3H), 7.25-7.29 (m, 3H), 7.33-7.36 (m, 2H); 13C NMR (126 MHz, CDCl3) δ 21.47, 46.35, 56.61 (d, J = 12.7 Hz), 125.29, 127.59, 127.70, 129.17, 129.45, 138.78, 140.28, 140.50; 19F NMR (471 MHz, CDCl3) δ 59.02. ESI-MS HRMS calculated for C16H18FO2S [M+H]+ 293.1006, found. 293.1012; M.P.: 67-72 °C.

(S)-2-(3-nitrophenyl)-2-phenylethanesulfonyl fluoride (4p):

![Structure of 4p]

Compound 4p was synthesized according to general procedure. Pale brown solid (145 mg, 94% yield, 80% ee); the ee was measured by HPLC (Chiralpak OD-H column, hexane/isopropanol = 60/40, flow 1.0 mL/min, 254 nm, t1 = 30.3 min (Major), t2 = 63.2 min (Minor); [α]D24 = +3.2 (c = 1.0, CHCl3); 1H NMR (500 MHz, CDCl3) δ 4.15-4.25 (m, 2H), 4.83 (t, J = 7.2 Hz, 1H), 7.29 (d, J = 7.7 Hz, 2H), 7.34 (t, J = 7.2 Hz, 1H), 7.41 (t, J = 7.5 Hz, 2H), 7.57 (t, J = 7.8 Hz, 1H), 7.68 (d, J = 7.7 Hz, 1H), 8.17-8.20 (m, 2H); 13C NMR (126 MHz, CDCl3) δ 46.18, 56.06 (d, J = 14.5 Hz), 122.56, 123.01, 127.44, 128.49, 129.69, 130.29, 133.98, 139.10, 142.30, 148.86; 19F NMR (471 MHz, CDCl3) δ 59.61. ESI-MS HRMS calculated for C14H13FNO2S [M+H]+ 310.0544, found. 310.0551; M.P.: 90-94 °C.
(S)-2-phenyl-2-(o-toly)ethanesulfonyl fluoride (4q):

![Chemical Structure](image)

Compound 4q was synthesized according to general procedure. Brown solid (125 mg, 90% Yield, 75% ee); the ee was measured by HPLC (Chiralpak OJ-H column, hexane/isopropanol = 95/5, flow 1.0 mL/min, 254 nm, \( t_1 = 45.6 \) min (Minor), \( t_2 = 69.0 \) min (Major); \([\alpha]_D^{23} = +10.1\) (c = 0.95, CH\(_2\)Cl\(_2\)); \(^1\)H NMR (500 MHz, CDCl\(_3\)) \( \delta \) 3.06 (s, 3H), 4.10 (dd, \( J = 3.5, 7.5 \) Hz, 2H), 4.92 (t, \( J = 7.5 \) Hz, 1H), 7.17–7.21 (m, 2H), 7.23–7.27 (m, 5H), 7.31–7.34 (m, 2H); \(^{13}\)C NMR (126 MHz, CDCl\(_3\)) \( \delta \) 19.81, 42.10, 56.73 (d, \( J = 13.6 \) Hz), 126.26, 126.66, 127.72, 128.00, 129.14, 131.47, 136.23, 138.30, 139.82; \(^{19}\)F NMR (471 MHz, CDCl\(_3\)) \( \delta \) 59.09; M.P.: ESI-MS HRMS calculated for C\(_{15}\)H\(_{16}\)FO\(_2\)S [M+H]\(^+\) 279.0850, found. 279.0848; M.P.: 72-76 °C.

Note: In the \(^{13}\)C NMR spectrum of 4q, theoretically, there should be thirteen peaks. Due to the compact overlaying, it is difficult to specify the overlaying peaks.

(S)-2-(naphthalen-1-yl)-2-phenylethane-1-sulfonyl fluoride (4r):

![Chemical Structure](image)

Compound 4r was synthesized according to general procedure. Pale yellow oil (132 mg, 84% Yield, 86% ee); the ee was measured by HPLC (Chiralpak AD-H column, hexane/isopropanol = 95/5, flow 0.6 mL/min, 254 nm, \( t_1 = 11.7 \) min (Minor), \( t_2 = 12.6 \) min (Major); \([\alpha]_D^{24} = -37.0\) (c = 0.7, CH\(_2\)Cl\(_2\)); \(^1\)H NMR (500 MHz, CDCl\(_3\)) \( \delta \) 4.21–4.30 (m, 2H), 5.56 (t, \( J = 7.1 \) Hz, 1H), 7.29 (t, \( J = 7.2 \) Hz, 1H), 7.34–7.40 (m, 5H), 7.47–7.54 (m, 2H), 7.56–7.59 (m, 1H), 7.83 (d, \( J = 8.2 \) Hz, 1H), 7.90 (d, \( J = 7.8 \) Hz, 1H), 8.15 (d, \( J = 8.5 \) Hz, 1H); \(^{13}\)C NMR (126 MHz, CDCl\(_3\)) \( \delta \) 41.85, 56.44 (d, \( J = 13.6 \) Hz), 122.88, 124.74, 125.30, 126.17, 127.10, 127.86, 128.05, 128.73, 129.15, 129.35, 130.84, 134.36, 135.91, 139.57; \(^{19}\)F NMR (471 MHz, CDCl\(_3\)) \( \delta \) 59.46. ESI-MS HRMS calculated for C\(_{18}\)H\(_{16}\)FO\(_2\)S [M+H]\(^+\) 315.0850, found. 315.0849.

(S)-2-(2,6-difluoropyridin-4-yl)-2-phenylethanesulfonyl fluoride (4s):

![Chemical Structure](image)

Compound 4s was synthesized according to general procedure. Off-white solid (78 mg, 52% Yield,
95% ee); the ee was measured by HPLC (Chiralpak AD-H column, hexane/isopropanol = 90/10, flow 1.0 mL/min, 254 nm, \( t_1 = 10.4 \) min (Minor), \( t_2 = 11.1 \) min (Major); \([\alpha]_D^{26} = +3.1 \) (c = 0.93, CHCl\(_3\)); \(^1\)H NMR (500 MHz, CDCl\(_3\)) \( \delta \) 4.06-4.16 (m, 2H), 4.70 (t, \( J = 7.5 \) Hz, 1H), 6.76 (s, 2H), 7.23-7.25 (m, 2H), 7.34-7.42 (m, 3H); \(^13\)C NMR (126 MHz, CDCl\(_3\)) \( \delta \) 45.81 (t, \( J = 2.6 \) Hz), 55.29 (d, \( J = 7.3 \) Hz), 105.31 (dd, \( J = 12.7 \) Hz, \( J = 29.1 \) Hz), 127.45, 128.98, 129.86, 137.59, 159.19 (t, \( J = 16.4 \) Hz), 162.34 (dd, \( J = 16.4 \) Hz, \( J = 248.5 \) Hz); \(^19\)F NMR (471 MHz, CDCl\(_3\)) \( \delta \) -66.46, 59.61.

ESI-MS HRMS calculated for C\(_{13}\)H\(_{11}\)F\(_3\)NO\(_2\)S \([\text{M+H}]^+\) 302.0457, found. 302.0464; M.P.: 75-78 °C.

(S)-2-phenyl-2-(1-tosyl-1H-indol-3-yl)ethanesulfonyl fluoride (4t):

Compound 4t was synthesized according to general procedure. Off-white solid (222 mg, 97% Yield, 91% ee); the ee was measured by HPLC (Chiralpak AD-H column, hexane/isopropanol = 90/10, flow 1.0 mL/min, 254 nm, \( t_1 = 23.1 \) min (Minor), \( t_2 = 25.9 \) min (Major); \([\alpha]_D^{26} = +5.1 \) (c = 1.0, CH\(_2\)Cl\(_2\)); \(^1\)H NMR (500 MHz, CDCl\(_3\)) \( \delta \) 2.34 (s, 3H), 4.04 (ddd, \( J = 1.5, 7.0, 14.5 \) Hz, 1H), 4.19 (ddd, \( J = 4.0, 7.5, 15.0 \) Hz, 1H), 4.86 (t, \( J = 7.0 \) Hz, 1H), 7.16 (t, \( J = 8.0 \) Hz, 1H), 7.22 (d, \( J = 8.0 \) Hz, 2H), 7.29-7.35 (m, 7H), 7.56 (s, 1H), 7.75 (d, \( J = 8.5 \) Hz, 2H), 7.96 (d, \( J = 8.5 \) Hz, 1H); \(^13\)C NMR (126 MHz, CDCl\(_3\)) \( \delta \) 21.65, 38.46, 56.08 (d, \( J = 13.6 \) Hz), 114.03, 119.69, 121.66, 123.65, 123.76, 125.44, 126.99, 127.68, 128.25, 129.15, 129.34, 130.06, 135.01, 135.61, 138.65, 145.30; \(^19\)F NMR (471 MHz, CDCl\(_3\)) \( \delta \) 59.68.

ESI-MS HRMS calculated for C\(_{23}\)H\(_{21}\)F\(_3\)NO\(_2\)S \([\text{M+H}]^+\) 458.089, found. 458.0889; M.P.: 66-70 °C.

(S)-2-phenyl-2-(6-(trifluoromethyl)pyridin-3-yl)ethanesulfonyl fluoride (4u):

Compound 4u was synthesized according to general procedure. Brown oil (128 mg, 77% Yield, 92% ee); the ee was measured by HPLC (Chiralpak AD-H column, hexane/isopropanol = 90/10, flow 1.0 mL/min, 254 nm, \( t_1 = 14.3 \) min (Minor), \( t_2 = 15.0 \) min (Major); \([\alpha]_D^{26} = -37.0 \) (c = 1.0, CH\(_2\)Cl\(_2\)); \(^1\)H NMR (500 MHz, CDCl\(_3\)) \( \delta \) 4.17 (dd, \( J = 3.2, 7.5 \) Hz, 2H), 4.79 (t, \( J = 7.5 \) Hz, 1H), 7.25 (d, \( J = 8.1 \) Hz, 2H), 7.31-7.34 (m, 1H), 7.39 (t, \( J = 7.1 \) Hz, 2H), 7.67 (d, \( J = 8.3 \) Hz, 1H), 7.80 (dd, \( J = 2.2, 8.1 \) Hz, 1H), 8.71 (d, \( J = 1.8 \) Hz, 1H); \(^13\)C NMR (126 MHz, CDCl\(_3\)) \( \delta \) 44.16, 55.71 (d, \( J = 15.4 \) Hz), 120.79 (q, \( J = 2.8 \) Hz), 121.45 (q, \( J = 274.3 \) Hz), 127.43, 128.68, 129.80, 136.53, 138.47, 139.02, 147.85 (q, \( J = 35.5 \) Hz), 149.51; \(^19\)F NMR (471 MHz, CDCl\(_3\)) \( \delta \) -67.93, 59.69. ESI-MS HRMS calculated for
Compound 4v was synthesized according to general procedure. Pale yellow solid (144 mg, 78% Yield, 94% ee); the ee was measured by HPLC (Chiralpak OD-H column, hexane/isopropanol = 50/50, flow 1.0 mL/min, 254 nm, $t_1 = 29.7$ min (Minor), $t_2 = 60.7$ min (Major); $[\alpha]_D^{26} = -75.5$ (c = 0.93, CH$_2$Cl$_2$). $^1$H NMR (500 MHz, CDCl$_3$) $\delta$ 4.26-4.31 (m, 1H), 4.35-4.41 (m, 1H), 5.03 (t, $J$ = 7.2 Hz, 1H), 7.30-7.33 (m, 8H), 7.37-7.55 (m, 8H), 7.85-7.87 (m, 1H), 8.11-8.17 (m, 2H); $^{13}$C NMR (126 MHz, CDCl$_3$) $\delta$ 45.56, 55.39 (d, $J$ = 14.5 Hz), 121.22, 121.97, 122.94, 124.47, 124.86, 125.21, 127.30, 128.06, 128.21, 129.18, 134.67, 135.84, 136.87, 138.25, 138.93, 139.08; $^{19}$F NMR (471 MHz, CDCl$_3$) $\delta$ 59.37. ESI-MS HRMS calculated for C$_{20}$H$_{16}$FO$_2$S$_2$ [M+H]$^+$ 371.0570, found. 371.0576; M.P.: 104-107 °C.

Compound 4w was synthesized according to general procedure. Dark solid (105 mg, 75% Yield, 95% ee); the ee was measured by HPLC (Chiralpak AD-H column, hexane/isopropanol = 95/5, flow 0.6 mL/min, 254 nm, $t_1 = 40.0$ min (Minor), $t_2 = 42.6$ min (Major); $[\alpha]_D^{23} = +205$ (c = 0.93, CH$_2$Cl$_2$); $^1$H NMR (500 MHz, CDCl$_3$) $\delta$ 3.95 (ddd, $J$ = 3.5, 6.5, 15.0 Hz, 1H), 4.35 (ddd, $J$ = 4.0, 8.0, 14.5 Hz, 1H), 4.77 (t, $J$ = 7.0 Hz, 1H), 6.39 (d, $J$ = 3.5 Hz, 1H), 7.18 (d, $J$ = 3.5 Hz, 1H), 7.33-7.36 (m, 3H), 7.38-7.41 (m, 2H), 9.59 (s, 1H); $^{13}$C NMR (126 MHz, CDCl$_3$) $\delta$ 41.25, 54.70 (d, $J$ = 15.5 Hz), 110.96, 122.51, 127.80, 128.87, 129.63, 136.62, 153.03, 158.39, 177.36; $^{19}$F NMR (471 MHz, CDCl$_3$) $\delta$ 58.45. ESI-MS HRMS calculated for C$_{13}$H$_{12}$FO$_4$S [M+H]$^+$ 283.0435, found. 283.0442; M.P.: 52-56 °C.

$^{(R)}$-2-phenyl-2-(thiophen-2-yl)ethanesulfonyl fluoride (4x):
Compound 4x was synthesized according to general procedure. Off-white solid (113 mg, 84% Yield, 88% ee); the ee was measured by HPLC (Chiralpak OD-H column, hexane/isopropanol = 90/10, flow 1.0 mL/min, 254 nm, \( t_1 = 34.0 \text{ min (Major)} \), \( t_2 = 61.1 \text{ min (Minor)} \); \([\alpha]_D^{26} = -15.8 \text{ (c = 1.1, CHCl}_3\) ); \(^1\)H NMR (500 MHz, CDCl\(_3\)) \( \delta 4.07-4.18 \text{ (m, 2H)} \), 4.93 (t, \( J = 7.5 \text{ Hz, 1H} \)), 6.96 (d, \( J = 3.5 \text{ Hz, 2H} \)), 7.24 (t, \( J = 3.0 \text{ Hz, 1H} \)), 7.27-7.40 (m, 5H); \(^{13}\)C NMR (126 MHz, CDCl\(_3\)) \( \delta 42.36, 57.67 \text{ (d, } J = 13.6 \text{ Hz)} \), 125.43, 125.52, 127.17, 127.55, 128.30, 129.31, 139.91, 143.85; \(^{19}\)F NMR (471 MHz, CDCl\(_3\)) \( \delta 59.39 \). ESI-MS HRMS calculated for C\(_{12}\)H\(_{12}\)FO\(_2\)S\(_2\) \([M+H]^+\) 271.0257, found 271.0254; M.P.: 56-60 °C.

(S)-2-phenyl-2-(thiophen-3-yl)ethanesulfonyl fluoride (4y):

\[
\text{\includegraphics{compound4y.png}}
\]

Compound 4y was synthesized according to general procedure. Brown oil (108 mg, 80% Yield, 95% ee); the ee was measured by HPLC (Chiralpak OD-H column, hexane/isopropanol = 90/10, flow 1.0 mL/min, 254 nm, \( t_1 = 39.1 \text{ min (Major)} \), \( t_2 = 57.2 \text{ min (Minor)} \); \([\alpha]_D^{26} = +5.5 \text{ (c = 1.2, CHCl}_3\) ); \(^1\)H NMR (500 MHz, CDCl\(_3\)) \( \delta 4.04 \text{ (ddd, } J = 3.0, 8.0, 15.0 \text{ Hz, 1H)} \), 4.11 (ddd, \( J = 4.0, 7.0, 14.5 \text{ Hz, 1H}) \), 4.77 (t, \( J = 7.0 \text{ Hz, 1H} \)), 6.96 (dd, \( J = 1.5, 5.0 \text{ Hz, 1H} \)), 7.10 (dd, \( J = 1.0, 1.5 \text{ Hz, 1H}) \), 7.27-7.33 (m, 4H), 7.35-7.38 (m, 2H); \(^{13}\)C NMR (126 MHz, CDCl\(_3\)) \( \delta 42.30, 56.97 \text{ (d, } J = 13.6 \text{ Hz)} \), 121.96, 126.86, 127.08, 127.68, 127.99, 129.26, 139.99, 140.93; \(^{19}\)F NMR (471 MHz, CDCl\(_3\)) \( \delta 59.23 \). ESI-MS HRMS calculated for C\(_{12}\)H\(_{12}\)FO\(_2\)S\(_2\) \([M+H]^+\) 271.0257, found 271.0254.

**General procedure for synthesis of chiral sulfonates 6w, 8w, 9, 11 and 12.**

(R)-1-(3-chlorophenyl)-4-((2-(dibenzo[b,d]thiophen-4-yl)-2-phenylethyl)sulfonyl) piperazine (6w):

\[
\text{\includegraphics{compound6w.png}}
\]

Sulfonamides 6w were synthesized by modifying previous literature procedure (Bogolubsky et al., 2014). An oven-dried reaction tube (20 mL) was charged with compound 3w (50 mg, 0.135 mmol), alkyl amine 5 (62 mg, 0.27 mmol, 2.0 equiv.), triethylamine (0.54 mmol, 4.0 equiv.) and acetonitrile (1.5 mL). Then the mixture was stirred at room temperature for 12 h. To achieve full conversion, the mixture was then sonicated at 50 °C for 4 h before the addition of another portion of triethylamine (0.54 mmol, 4.0 equiv.) and the stirring lasted for further 6 h at room temperature.
The crude product was purified by flash column chromatography to get the sulfonamide 6w as off-white solid (72 mg, 98% Yield, 99.8% ee); the ee was measured by HPLC (Chiralpak OD-H column, hexane/isopropanol = 30/70, flow 1.0 mL/min, 254 nm, t1 = 22.6 min (Major), t2 = 47.5 min (Minor); [α]D25 = +55.5 (c = 0.4, CH2Cl2). 1H NMR (500 MHz, CDCl3) δ 2.92 (t, J = 4.5 Hz, 4H), 3.12 (t, J = 5.0 Hz, 4H), 3.85 (dd, J = 6.5, 14.5 Hz, 1H), 4.04 (dd, J = 7.0, 14.5 Hz, 1H), 4.93 (t, J = 7.0 Hz, 1H), 6.62 (d, J = 8.0 Hz, 1H), 6.71 (s, 1H), 6.83 (d, J = 7.5 Hz, 1H), 7.11 (t, J = 8.5 Hz, 1H), 7.23 (t, J = 7.5 Hz, 1H), 7.32 (t, J = 7.0 Hz, 2H), 7.41 (d, J = 7.5 Hz, 3H), 7.44-7.49 (m, 3H), 7.84-7.85 (m, 1H), 8.04 (d, J = 8.0 Hz, 1H), 8.10-8.12 (m, 1H). 13C NMR (126 MHz, CDCl3) δ 45.12, 45.88, 49.12, 54.85, 114.83, 116.83, 120.45, 120.72, 121.96, 122.94, 124.74, 125.18, 127.21, 127.65, 128.03, 129.00, 130.23, 135.15, 135.94, 136.51, 136.68, 139.09, 139.12, 140.28, 151.91; ESI-MS HRMS calculated for C30H28ClN2O2S2 [M+H]+ 547.1257, found. 547.1284; M.P. 106-110 °C.

4-(benzyloxy)phenyl (R)-2-(dibenzo[b,d]thiophen-4-yl)-2-phenylethane-1-sulfonate (8w):

K2CO3 (0.27 mmol) was added to a stirred solution of compound 3w (0.135 mmol) and phenol 7 (0.135 mmol) in MeCN (1.5 mL), and the resulting mixture was allowed to stir at room temperature for 4 h. After completion of reaction, the mixture was purified by flash column chromatography using Petroleum ether and Ethyl acetate as eluent to get the desired sulfonates 8w as off-white solid (74 mg, 99% Yield, 100% ee); the ee was measured by HPLC (Chiralpak OD-H column, hexane/isopropanol = 50/50, flow 1.0 mL/min, 254 nm, t = 34.1 min; [α]D25 = +33.0 (c = 0.3, CH2Cl2). 1H NMR (500 MHz, CDCl3) δ 4.16 (dd, J = 7.5, 14.5 Hz, 1H), 4.27 (dd, J = 6.5, 14.5 Hz, 1H), 5.01 (s, 2H), 5.10 (t, J = 7.0 Hz, 1H), 6.86-6.84 (m, 4H), 7.27-7.54 (m, 14H), 7.85 (dd, J = 3.0, 5.5 Hz, 1H), 8.1 (d, J = 8.0 Hz, 1H), 8.15 (dd, J = 3.0, 5.0 Hz, 1H), 13C NMR (126 MHz, CDCl3) δ 45.79, 54.80, 70.56, 115.85, 120.86, 121.89, 122.92, 123.03, 124.71, 124.77, 125.12, 127.55, 127.82, 128.25, 128.31, 128.77, 128.96, 135.81, 135.90, 136.67, 139.11, 139.22, 139.44, 142.58, 157.60; ESI-MS HRMS calculated for C33H27ClN2O2S2 [M+H]+ 551.1345, found. 551.1357; M.P. 48-52 °C.

Note: In the 13C NMR spectrum of 8w, theoretically, there should be twenty seven peaks. Due to the compact overlaying, it is difficult to specify the overlaying peaks.
(R)-2-(4-fluorophenyl)-2-(4-methoxyphenyl)ethane-1-sulfon fluoride (9):

Compound 9 was synthesized according to the general procedure for synthesis of compounds 3 and 4. Yellow oil (135 mg, 87% Yield, 92% ee); the ee was measured by HPLC (Chiralpak OD-H column, hexane/isopropanol = 50/50, flow 1.0 mL/min, 254 nm, t₁ = 14.01 min (Minor), t₂ = 16.66 min (Major); [α]₀^D⁺ = -1.5 (c = 0.6, CH₂Cl₂); ¹H NMR (500 MHz, CDCl₃) δ 3.78 (s, 3H), 4.05 (dd, J = 3.0, 7.5 Hz, 2H), 4.64 (t, J = 7.5 Hz, 1H), 6.87 (d, J = 8.5 Hz, 2H), 7.03 (t, J = 8.5 Hz, 2H), 7.15 (d, J = 9.0 Hz, 2H), 7.23 (dd, J = 5.0, 8.0 Hz, 2H); ¹³C NMR (126 MHz, CDCl₃) δ 45.02, 55.43 (d, J = 1.8 Hz), 56.84 (d, J = 13.6 Hz), 114.70, 116.12 (d, J = 21.8 Hz), 128.57, 129.19 (d, J = 8.1 Hz), 132.16, 136.43 (d, J = 2.6 Hz), 159.26, 162.20 (d, J = 245.5 Hz); ¹⁹F NMR (471 MHz, CDCl₃) δ -114.6 (q, 1F), 59.44 (s, 1F). ESI-MS HRMS calculated for C₁₅H₁₅F₂O₃S [M+H]^+ 313.0704, found. 313.0711.

(R)-N-benzyl-2-(4-fluorophenyl)-2-(4-methoxyphenyl)ethane-1-sulfonamide (11):

Compound 11 was prepared according to the method described for the synthesis of compound 6w. Compound 9 (130 mg, 0.41 mmol) and amine 10 (88 mg, 0.82 mmol) were used to obtain the pure product 11 as off-white solid. (146 mg, 88% Yield, 98% ee); the ee was measured by HPLC (Chiralpak OD-H column, hexane/isopropanol = 95/5, flow 1.0 mL/min, 254 nm, t₁ = 89.27 min, t₂ = 106.9 min; [α]₀^D⁺ = +1.8 (c = 0.3, CH₂Cl₂); ¹H NMR (500 MHz, CDCl₃) δ 3.67-3.73 (m, 2H), 3.77 (s, 3H), 3.89 (dd, J = 5.5, 13.5 Hz, 1H), 3.99 (dd, J = 6.5, 13.5 Hz, 1H), 4.57 (t, J = 7.5 Hz, 1H), 6.85 (d, J = 8.0 Hz, 2H), 7.00 (t, J = 8.5 Hz, 2H), 7.12 (d, J = 7.0 Hz, 2H), 7.17 (d, J = 8.0 Hz, 2H), 7.21 (dd, J = 6.0, 8.0 Hz, 2H), 7.30-7.33 (m, 3H). ¹³C NMR (126 MHz, CDCl₃) δ 45.2, 47.22, 55.27, 57.71, 114.5, 115.78 (d, J = 21.6 Hz), 127.98, 128.06, 128.62, 128.73, 129.04 (d, J = 8.1 Hz), 133.65, 136.32, 138.02 (d, J = 3.6 Hz), 158.84, 161.76 (d, J = 245.6 Hz); ESI-MS HRMS calculated for C₂₂H₂₃FNO₃S [M+H]^+ 400.1377, found. 400.1388; M.P. 95-98 °C.
(S)-1-benzyl-4-(4-fluorophenyl)-7-methoxy-3,4-dihydro-1H-benzo[c][1,2]thiazine 2,2-dioxide (12):

Cyclisation was performed according to the previously reported literature (Martnez et al., 2016). An oven-dried flask (25 mL) equipped with a stirrer bar was charged with sulfonamide substrate 11 (50 mg, 0.125 mmol), I₂ (5 mol%) and PhI(mcba)₂ (70 mg, 0.13 mmol). Then the air in the reaction tube was evacuated and backfilled with argon, before the addition of dry dichloroethane (2 mL). The solution was stirred at room temperature for 12 h under visible light. Then the reaction mixture was diluted with DCM and the mixture was washed with an aqueous solution of Na₂S₂O₃ and NaHCO₃. The aqueous phase was extracted with DCM (2 x 10 mL) and the combined organic phases were dried over Na₂SO₄ before the solvent was removed under reduced pressure. The residue was purified by flash column chromatography (n-hexane/EtOAc) to give the pure product 12 as white solid (40 mg, 80% Yield, 92% ee); the ee was measured by HPLC (Chiralpak AD-H column, hexane/isopropanol = 90/10, flow 0.6 mL/min, 254 nm, t₁ = 52.16 min, t₂ = 56.16 min; [α]D²⁵ = +25.6 (c = 0.63, CH₂Cl₂); ¹H NMR (500 MHz, CDCl₃) δ 2.99 (t, J = Hz, 1H), 3.47-3.52 (m, 1H), 3.72 (s, 3H), 4.60-4.64 (m, 1H), 5.08 (s, 2H), 6.55 (dd, J = 2.5, 8.5 Hz, 1H), 6.65 (d, J = 2.0 Hz, 1H), 6.67 (d, J = 9.0 Hz, 1H), 6.91-6.94 (m, 2H), 6.98-7.02 (m, 2H), 7.34-7.39 (m, 5H); M.P. 118-122 °C.

Supplemental Reference
Bogolubsky, A.V., Moroz, Y.S., Mykhailiuk, P.K., Pipko, S.E., Konovets, A.I., Sadkova, I.V., and Tolmachev, A. (2014). Sulfonyl Fluorides as Alternative to Sulfonyl Chlorides in Parallel Synthesis of Aliphatic Sulfonamides. ACS Comb. Sci. 16, 192-197.

Martnez, C., Bosnidou, A.E., Allmendinger, S., and MuÇiz, K. (2016). Towards Uniform Iodine Catalysis: Intramolecular CH Amination of Arenes under Visible Light, Chem. Eur. J. 22, 9929-9932.

Nishimura, T., Noishiki, A., Tsui, G.C., and Hayashi, T. (2012). Asymmetric Synthesis of (Triaryl)methylamines by RhodiumCatalyzed Addition of Arylboroxines to Cyclic N-Sulfonyl Ketimines, J. Am. Chem. Soc. 134, 5056-5059.
Okamoto, K., Hayashi, T., and Rawal, V.R. (2009). Electronic and steric tuning of chiral diene ligands for rhodium-catalyzed asymmetric arylation of imines. Chem. Commun. 4815-4817.

Saxena, A., and Lam, H.W. (2011). Enantioselective rhodium-catalyzed arylation of electron-deficient alkenylarenes. Chem. Sci., 2, 2326-2331.

Uson, R., Oro, L.A., and Cabeza, J.A. (1985). Dinuclear Methoxy, Cyclooctadiene, and Barrelene Complexes of Rhodium (I) and Iridium (I). Inorg. Synth. 23, 126-130.