Ruthenium(II)/Chiral Carboxylic Acid Catalyzed Enantioselective C–H Functionalization of Sulfoximines

Long-Tao Huang[a]
Yuki Hirata[a]
Yoshimi Kato[a]
Luqing Lin[b,c]
Masahiro Kojima[a]
Tatsuhiko Yoshino[a,*]
Shigeki Matsunaga[a,b,*]

[a] Faculty of Pharmaceutical Sciences, Hokkaido University, Kita-12 Nishi-6, Sapporo, Hokkaido 060-0812, Japan.

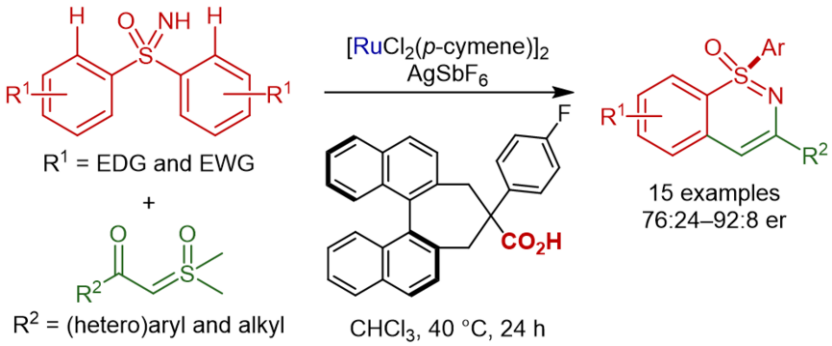
[b] Global Station for Biosurfaces and Drug Discovery, Global Institution for Collaborative Research and Education (GI-CoRE), Hokkaido University, Kita-12 Nishi-6, Sapporo, Hokkaido 060-0812, Japan

[c] Zhang Dayu School of Chemistry, Dalian University of Technology, Dalian 116024, China

* indicates the main/corresponding author.

tyoshino@pharm.hokudai.ac.jp
smatsuna@pharm.hokudai.ac.jp

Click here to insert a dedication



Received:
Accepted:
Published online:
DOI:

Abstract Ru(II)-catalyzed enantioselective C–H functionalization reactions of sulfoximines with sulfoxonium ylides are described. The combination of $[RuCl_2(p\text{-cymene})]_2$ and a pseudo-C_2-symmetric binaphthyl monocarboxylic acid furnished the *S*-chiral products in 76:24–92:8 er.

Key words ruthenium catalysis, C–H activation, asymmetric catalysis, chiral carboxylic acid, sulfoximine

The catalytic C–H functionalization of organic molecules using transition metal catalysts is a powerful strategy that streamlines the synthesis of valuable molecules, such as organic materials, natural products, and biologically active compounds.[1] In this context, Ru(II) catalysts appended with arene ligands have widely been employed in directing group-assisted C–H activation/functionalization processes.[2,3] After a seminal study by Oi, Inoue, and co-workers in 2001,[2] various transformations have been reported by many researchers including Ackermann as well as Bruneau and Dixneuf.[3] Compared to other 4d and 5d transition metals often used for C–H functionalization reactions, for examples, Pd, Rh, and Ir, Ru is relatively inexpensive and is therefore an attractive metal for use in synthetic applications. However, catalytic control of the enantioselectivity of Ru(II)-catalyzed C–H functionalization reactions is still a highly challenging problem and only a few successful examples have been reported to date (Figure 1).[4-8] Cui[5] and Wang[6] independently reported an enantioselective intramolecular hydroarylation based on methodology that utilizes a chiral transient directing group[9] (Figure 1a). Ackermann and co-workers demonstrated that a chiral carboxylic acid can assist an enantioselective intramolecular hydroarylation via a reversible insertion/selective protonation mechanism (Scheme 1b).[7] The [Ru(II)-arene] fragment has similar features to those of group 9 [Cp*M(III)] fragments (Cp* = 1,2,3,4,5-pentamethylcyclopentadienyl; M = Co, Rh, Ir). Both fragments possess a dicationic d^6 metal center and a half-sandwich structure with three available *cis* coordination sites. Thus, asymmetric catalytic systems efficiently employed with the group 9 catalysts[10] can also be used with Ru(II) catalysts, except for the introduction of chiral Cp^x ligands.[10a-c] It is worth noting that both the strategies mentioned above (Figure 1a and 1b) have been successfully employed in Rh(III)-[11] and Co(III)-[12] catalyzed reactions to control the enantio-determining step that exists after the cleavage of a C–H bond.

When C–H bonds are cleaved by an electrophilic high-valent metal catalyst, carboxylates and other basic anionic ligands participate via either an ambiphilic metal–ligand activation (AMLA), a concerted metalation-deprotonation (CMD), or a base-assisted internal electrophilic substitution (BIES) mechanism. Therefore enantio-induction can be achieved by using a chiral carboxylic acid (CCA) or a related ligand.[13] This strategy was first introduced to the field of Pd(II) catalysis by the Yu group[14] and was recently expanded to be used with group 9 metal catalysts.[15] Our group has been engaged in the development of the enantioselective C–H functionalization of prochiral substrates using Co(III)/CCA[15c,f] and Rh(III)/CCA[15b,d,i,j] systems. The similarity between Ru(II) catalysis and Cp*M(III) catalysis as well as our own research background prompted us to investigate the possibility of enantioselective C–H bond cleavage using a Ru(II) catalyst and a CCA. During the preparation of this manuscript, Shi and co-workers reported enantioselective C–H alkylation/cyclization reactions between sulfoximines and sulfoxonium ylides using $[RuCl_2(p\text{-cymene})]_2$ and a C_1-symmetric binaphthyl CCA (Figure 1c).[16] Here we report on our own study demonstrating that a pseudo-C_2-symmetric binaphthyl CCA that we recently developed for Rh(III) catalysis[15j] is a suitable CCA for enantioselective C–H bond cleavage of prochiral sulfoximines (Figure 1d).

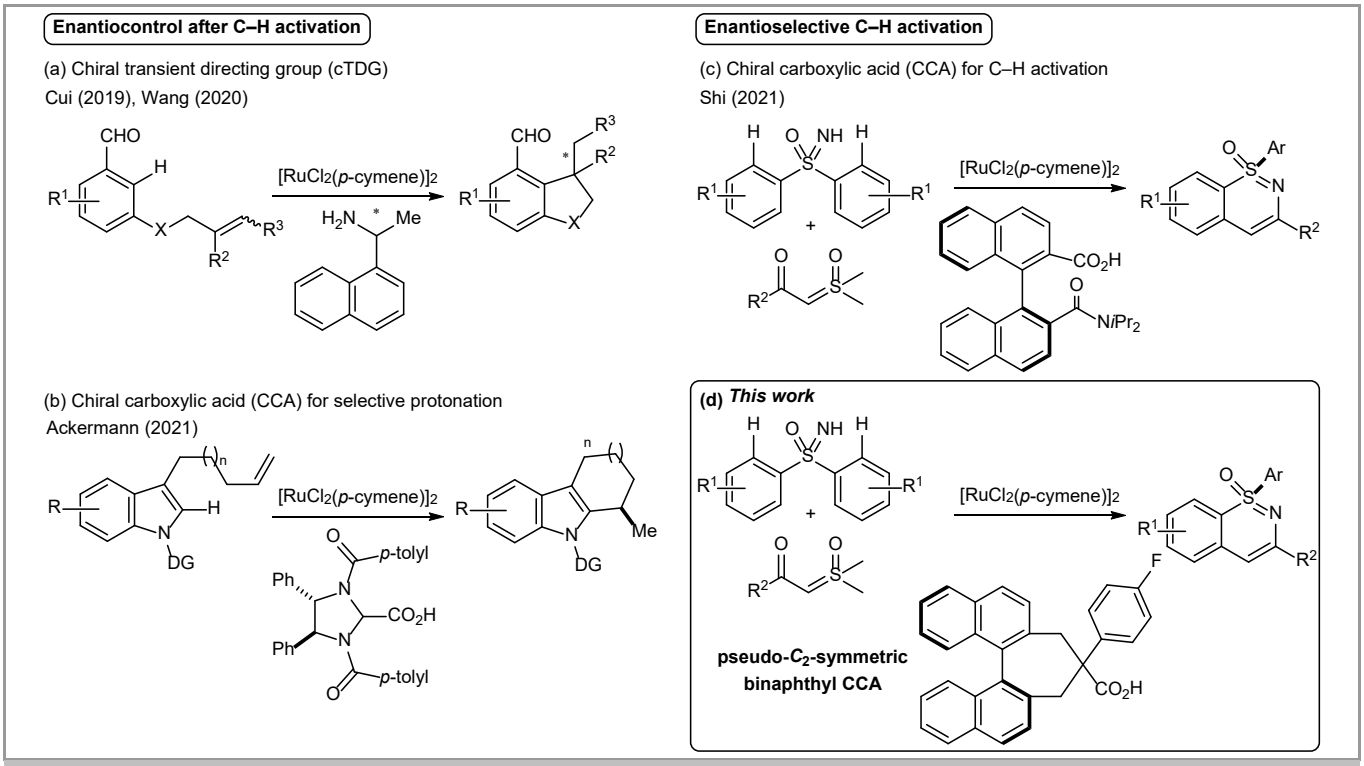
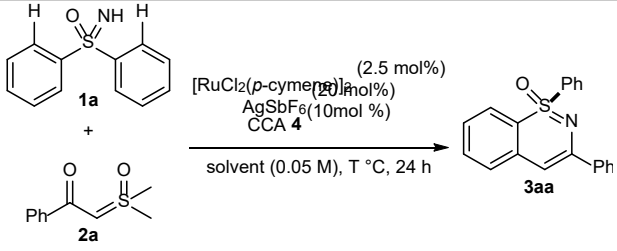
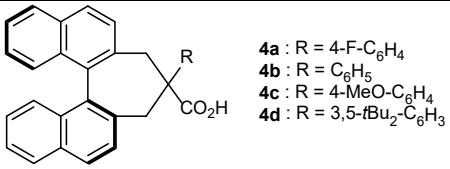


Figure 1 Enantioselective C–H functionalization reactions with Ru(II)-arene catalysts that utilize (a) a chiral transient directing group, (b) a chiral carboxylic acid for enantioselective protonation, (c) (d) chiral carboxylic acids for enantioselective C–H activation.

Table 1 Optimization of the reaction conditions[a]



Entry	T (°C)	Solvent	CCA **4**	% Yield[b]	er[c]
1	20	DCE	**4a**	38	86:14
2	40	DCE	**4a**	>95	86:14
3	80	DCE	**4a**	>95	83:17
4	40	MeOH	**4a**	88	87:13
5	40	HFIP	**4a**	74	76:24
6	40	1,4-dioxane	**4a**	36	83:17
7	40	DMF	**4a**	30	64:36
8	40	toluene	**4a**	50	87:13
9	40	PhCl	**4a**	56	89:11
10	40	CH_2Cl_2	**4a**	90	88:12
11	40	$CHCl_3$	**4a**	>95	90:10
12	40	$CHCl_3$	**4b**	93	90:10
13	40	$CHCl_3$	**4c**	80	89:11
14	40	$CHCl_3$	**4d**	67	85:15

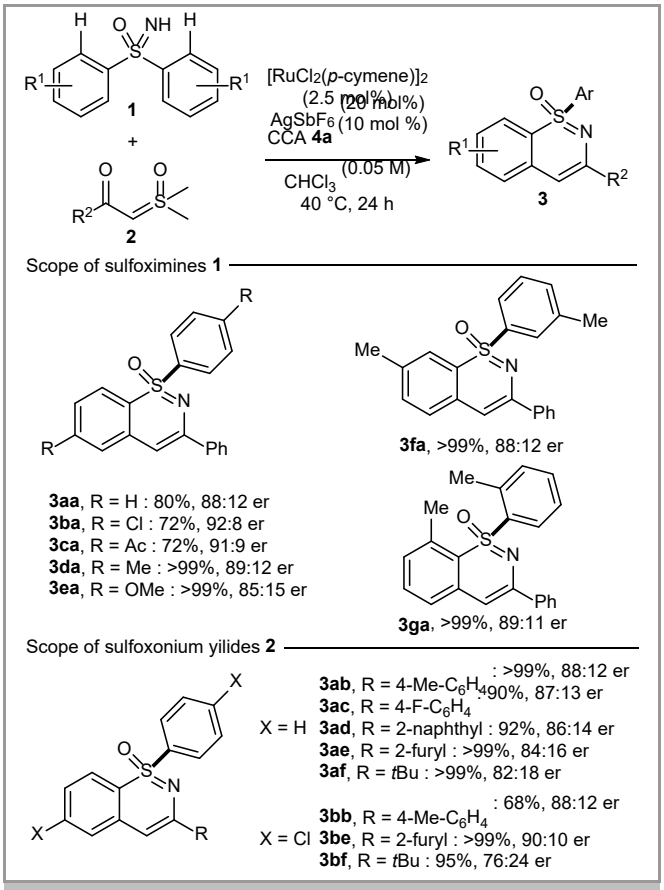


[a] Reaction conditions: **1a** (0.05 mmol), **2a** (0.075 mmol), $[RuCl_2(p\text{-cymene})]_2$ (0.00125 mmol, 2.5 mol%), $AgSbF_6$ (0.01 mmol, 20 mol%), and CCA **4** (0.005 mmol, 10 mol%) in the indicated solvent (1 mL) unless otherwise noted. [b] Determined by ^1H NMR analysis of the crude mixture using 1,1,2,2-tetrachloroethane as the internal standard. [c] Determined by chiral HPLC analysis.

We commenced our investigation using sulfoximine **1a** and sulfoxonium ylide **2a** as the model substrates (Table 1). Sulfoximines and their derivatives bearing an S chiral center are important molecules in medicinal chemistry.[17] As such, directed C–H functionalization reactions of sulfoximines, including enantioselective variants, have recently been reported.[18-20] We selected the standard commercially available $[RuCl_2(p\text{-cymene})]_2/AgSbF_6$ as the metal catalyst. We chose a pseudo C_2-symmetric binaphthyl monocarboxylic acid **4a**, the best performing CCA in our previous report on Rh(III) catalysis,[15j] as the initial CCA. To our delight, the reaction proceeded at 20 °C in DCE in good enantioselectivity (86:14 er), albeit with low reactivity (entry 1). A high yield was achieved without decreasing the selectivity by raising the reaction temperature to 40 °C (entry 2), while lower selectivity was observed at 80 °C (entry 3). We next screened various solvents (entries 4–11), finding that halogenated solvents are suitable in terms of both reactivity and selectivity (entries 2, 10, 11). Slightly higher enantioselectivity was observed with $CHCl_3$ (90:10 er, entry 11) than with DCE. Finally, other related chiral carboxylic acids (**4b**–**4d**) were examined (entries 12–14), but neither of them exhibited higher enantioselectivity. Thus, we concluded that the conditions in entry 11 were optimal.

With the best conditions in hand, we next explored other various sulfoximines **1** and sulfoxonium ylides **2** (Scheme 1). Suloximines with *p*-, *m*-, and *o*-substituents generally provided the corresponding products in good yield and similar enantioselectivity (**3aa**–**3ga**, 85:15–91:9 er). Particularly, sulfoximines bearing electron withdrawing groups afforded higher enantioselectivity (**3ba** and **3ca**) than others albeit with slightly decreased reactivity. A sterically demanding substrate with *o*-Me groups (**1g**) was also compatible with the optimal

catalytic system (**3ga**). We then investigated several sulfoxonium ylides **2** using **1a** and **1b** as substrates (**3ab**-**3af**, **3bb**, **3be**, **3bf**). Aromatic-, heteroaromatic-, and aliphatic-substituted sulfoxonium ylides were all tolerated under the reaction conditions, providing the products in high yield and 76:24–90:10 er. The absolute configuration of **3** was determined to be (*S*) by comparing the optical rotation of **3aa** ($[\alpha]_D^{24}$ = +10.2 in $CHCl_3$) with the previously reported value for the (*R*)-enantiomer ($[\alpha]_D^{20}$ = –11.3 in $CHCl_3$).[20b]



Scheme 1 Substrate scope for enantioselective C–H alkylation/cyclization of sulfoximines **1** with sulfoxonium ylides **2**. Reaction conditions: **1a** (0.2 mmol), **2a** (0.3 mmol), $[RuCl_2(p\text{-cymene})]_2$ (0.005 mmol, 2.5 mol%), $AgSbF_6$ (0.04 mmol, 20 mol%), and CCA **4a** (0.02 mmol, 10 mol%) in $CHCl_3$ (4 mL).

A plausible catalytic cycle is shown in Figure 2. An active Ru-carboxylate catalyst (**A**) is generated from $[RuCl_2(p\text{-cymene})]_2$, $AgSbF_6$, and CCA **4a**, which would be coordinated with **1** (**B**). A key C–H activation step proceeds via a carboxylate-assisted mechanism, in which the chiral carboxylate base derived from CCA **4a** selectively deprotonates one of the enantiotopic protons of **1**. Thus-generated chiral metallacycle **C** reacts with sulfoxonium ylide **2** to afford intermediate **D** with the release of DMSO. The subsequent protonation furnishes **E** and regenerates the active catalyst. Finally, intramolecular condensation between the sulfoximine moiety and introduced ketone provides **3**. While unprotected NH sulfoximines are proposed to undergo deprotonation before the C–H activation in the previous study,[18i] a metallacycle intermediate isolated by Bolm and co-workers clearly has a remaining NH proton.[18a] In addition, our catalytic system does not involve any efficient bases, such as metal carbonates, which facilitates the deprotonation. Therefore, we speculate that the unprotected sulfoximine moiety may work as the directing group without deprotonation, although the catalytic cycle involving the deprotonation of the NH moiety cannot be excluded at this point.

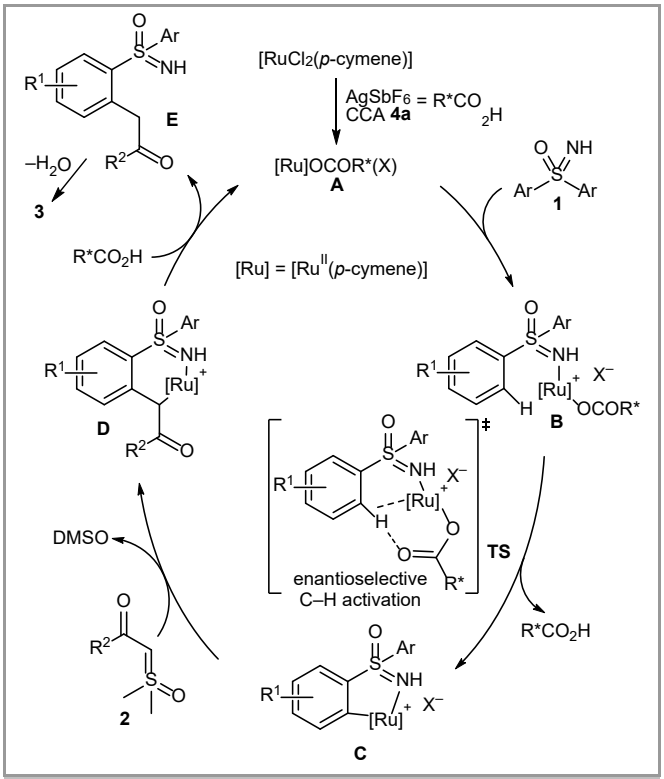


Figure 2 Plausible catalytic cycle.

In summary, we have found that the combination of a Ru(II) catalyst and a pseudo-C_2-symmetric binaphthyl CCA (**4a**) is an effective catalytic system for enantioselective C–H functionalization of sulfoximines **1** with sulfoxonium ylides **2**. Although the observed enantioselectivities were lower than those reported in the recent work by Shi and co-workers (Figure 1c),[16] we demonstrated that our CCA **4a** is also a suitable chiral source for Ru(II)-catalyzed C–H functionalization, in which chiral catalytic systems remain under-developed. Further investigation on the combination of CCAs that we developed and Ru(II) catalysts are ongoing in our group.

The experimental section has no title; please leave this line here.

Reactions were carried out under argon atmosphere unless otherwise noted. Enantioselectivities were determined by high performance liquid chromatography (HPLC) using 4.6 mm × 25 cm Daicel Chiralpak columns. NMR spectra were recorded on JEOL JNM-ECS400 spectrometers operating at 391.78 MHz for ^{1}H NMR and 98.52 MHz for ^{13}C NMR, JOEL JNM-ECX400 spectrometers operating at 395.88 MHz for ^{1}H NMR and 99.55 MHz for ^{13}C NMR, and JNM-ECA500 spectrometers operating at 500.16 MHz for ^{1}H NMR and 125.77 MHz for ^{13}CNMR. ^{1}H and ^{13}C NMR chemical shifts are given in ppm relative to $SiMe_4$, with the solvent resonance used as an internal reference: $CHCl_3$ (7.26 ppm for ^{1}H NMR), $CDCl_3$ (77.16 ppm for ^{13}C NMR). ESI mass spectra were measured on Thermo Scientific Exactive spectrometer. Optical rotations were measured on a JASCO P-1010 polarimeter. Column chromatography was performed with silica gel Kanto Silica gel 60 N (40-50 mesh) or Yamazen YFLC AI-580 using Universal Column SiOH. Dichloromethane (CH_2Cl_2), tetrahydrofuran (THF), diethyl ether (Et_2O), and toluene were purified by Glass Contour solvent purification system before use. 1,2-Dichloroethane (DCE), *N*-methylprolidone (NMP), ethanol, Dimethylformamide (DMF), chloroform and acetonitrile (CH_3CN) were purchased from Kanto Chemicals (dehydrated grade) and used as received. Chlorobenzene and

methanol were purchased from Aldrich (dehydrated grade) and used as received. Sulfoximines **1a-1g**,[21a] sulfoxonium ylides **2a-2f**,[21b] and chiral carboxylic acids **4a-4d**[15j] were prepared according to the literatures. All other reagents were commercially available and used as received unless otherwise noted.

General Procedure (GP): Ru(II)/chiral carboxylic acid-catalyzed enantioselective C–H functionalization of sulfoximines

In an argon-filled glovebox, a screw-capped test tube was charged with sulfoximine **1** (0.20 mmol, 1.0 equiv), sulfoxonium ylide **2** (0.3 mmol, 1.5 equiv), chiral carboxylic acid **4a** (0.02 mmol, 8.4 mg), $AgSbF_6$ (13.6 mg, 20 mol%), $[RuCl_2(p\text{-cymene})]_2$ (3.0 mg, 2.5 mol%), and $CHCl_3$ (4.0 mL). Then the reaction mixture was stirred at 40 °C for 24 h. The resulting mixture was directly purified by silica gel column chromatography (hexane/AcOEt) to afford **3**.

(*S*)-1,3-diphenylbenzo[*e*][1,2]thiazine 1-oxide (3aa)

According to **GP**, sulfoximine **1a** (0.20 mmol, 43.4 mg) and sulfoxonium ylide **2a** (0.30 mmol, 59.1 mg) afforded **3aa** as a yellow foam (51.0 mg, 80%) after chromatographic purification by Yamazen YFLC AI-580 with Universal Column SiOH (hexane/AcOEt gradient to 6:1).

TLC (silica gel): R_f = 0.4 (hexane/AcOEt = 6:1, UV).

^{1}H NMR (400 MHz, $CDCl_3$) δ: 8.03–7.97 (m, 4H), 7.66-7.53 (m, 3H), 7.51-7.30 (m, 6H), 7.25-7.19 (m, 1H), 6.81 (s, 1H).

^{13}C NMR (100 MHz, $CDCl_3$) δ: 147.2, 140.5, 138.7, 136.5, 133.3, 132.1, 129.3, 129.0, 128.8, 128.3, 126.9, 126.6, 126.2, 124.9, 119.6, 98.1.

HPLC: Chiralpak AD-H column, hexane–*i*PrOH (4:1), 1.2 mL/min; t_R (minor) = 10.4 min, t_R (major) = 11.9 min. 12:88 er.

$[\alpha]_D^{24}$ = +10.2 (*c* = 1.0, $CHCl_3$).

The NMR spectra of the obtained product were consistent with the reported data.[16]

(*S*)-6-chloro-1-(4-chlorophenyl)-3-phenylbenzo[*e*][1,2]thiazine-1-oxide (3ba)

According to **GP**, sulfoximine **1b** (0.20 mmol, 56.8 mg) and sulfoxonium ylide **2a** (0.30 mmol, 59.1 mg) afforded **3ba** as a yellow foam (55.0 mg, 72%) after chromatographic purification by Yamazen YFLC AI-580 using Universal Column SiOH (hexane/AcOEt = 8:1).

TLC (silica gel): $\mathbf{R_f}$ = 0.4 (hexane/AcOEt = 3:1, UV).

^{1}H NMR (500 MHz, $CDCl_3$) δ: 7.99-7.95 (m, 2H), 7.92-7.87 (m, 2H), 7.58-7.53 (m, 2H), 7.46-7.36 (m, 4H), 7.26 (t, *J* = 4.3 Hz, 1H), 7.18 (dd, *J* = 8.6, 1.7 Hz, 1H), 6.74 (*s*, 1H).

^{13}C NMR (100 MHz, $CDCl_3$) δ: 148.6, 140.6, 138.8, 138.6, 138.1, 138.1, 130.6, 129.4, 129.3, 128.4, 126.7, 126.7, 126.5, 126.1, 117.3, 97.4

HPLC: Chiralpak AD-H column, hexane–*i*PrOH (4:1), 0.7 mL/min; t_R (major) = 21.8 min, t_R (minor) = 26.9 min. 92:8 er.

The NMR spectra of the obtained product were consistent with the reported data.[16]

(*S*)-1-(4-(6-acetyl-1-oxido-3-phenyl-1l4-benzo[*e*][1,2]thiazin-1-yl)phenyl)ethan-1-one (3ca)

According to **GP**, sulfoximine **1c** (0.20 mmol, 60.2 mg) and sulfoxonium ylide **2a** (0.30 mmol, 59.1 mg) afforded **3ca** as a yellow foam (58.0 mg, 72%) after chromatographic purification by Yamazen YFLC AI-580 using Universal Column SiOH (hexane/AcOEt = 2:1).

TLC (silica gel): $\mathbf{R_f}$ = 0.3 (hexane/AcOEt = 1:1, UV).

^{1}H NMR (400 MHz, $CDCl_3$) δ: 8.14 (d, *J* = 9.0 Hz, 2H), 8.09 (d, *J* = 8.5 Hz, 3H), 8.04-7.97 (m, 3H), 7.75 (dd, *J* = 8.5, 1.8 Hz, 1H), 7.47-7.37 (m, 4H), 6.95 (s, 1H), 2.67 (s, 3H), 2.66 (s, 3H).

^{13}C NMR (100 MHz, $CDCl_3$) δ: 197.0, 196.6, 148.2, 143.6, 140.8, 139.7, 138.0, 136.8, 129.7, 129.3, 128.8, 128.5, 127.9, 126.7, 125.4, 124.9, 121.1, 98.6, 27.0, 26.8

HPLC: Chiralpak AD-H column, hexane–*i*PrOH (2:1), 1.0 mL/min; t_R (major) = 21.4 min, t_R (minor) = 35.2 min. 91:9 er.

The NMR spectra of the obtained product were consistent with the reported data.[16]

(*S*)-6-methyl-3-phenyl-1-(p-tolyl)benzo[*e*][1,2]thiazine-1-oxide (3da)

According to **GP**, sulfoximine **1d** (0.20 mmol, 49.0 mg) and sulfoxonium ylide **2a** (0.30 mmol, 59.1 mg) afforded **3da** as a yellow foam (70.0 mg, >99%) after chromatographic purification by Yamazen YFLC AI-580 using Universal Column SiOH (hexane/AcOEt gradient to 4:1).

TLC (silica gel): $\mathbf{R_f}$ = 0.5 (hexane/AcOEt = 4:1, UV).

^{1}H NMR (400 MHz, $CDCl_3$) δ: 7.99 (d, *J* = 7.2 Hz, 2H), 7.84 (d, *J* = 8.6 Hz, 2H), 7.40 (t, *J* = 7.2 Hz, 2H), 7.37-7.31 (m, 3H), 7.26-7.18 (m, 1H), 7.03 (d, *J* = 8.2 Hz, 1H), 6.73 (s, 1H), 2.43 (s, 3H), 2.38 (s, 3H).

^{13}C NMR (100 MHz, $CDCl_3$) δ: 147.1, 144.2, 142.5, 138.9, 137.9, 136.6, 129.6, 129.2, 128.6, 128.3, 127.6, 126.6, 126.5, 124.8, 117.5, 97.9, 21.7, 21.5

HPLC: Chiralpak AD-H column, hexane–*i*PrOH (4:1), 1.0 mL/min; t_R (major) = 20.5 min, t_R (minor) = 25.7 min. 89:11 er.

The NMR spectra of the obtained product were consistent with the reported data.[16]

(*S*)-6-methoxy-1-(4-methoxyphenyl)-3-phenylbenzo[*e*][1,2]thiazine 1-oxide (3ea)

According to **GP**, sulfoximine **1e** (0.20 mmol, 55.4 mg) and sulfoxonium ylide **2a** (0.30 mmol, 59.1 mg) afforded **3ea** as a yellow solid (75.0 mg, >99%) after chromatographic purification by Yamazen YFLC AI-580 using Universal Column SiOH (hexane/AcOEt gradient to 4:1).

TLC (silica gel): $\mathbf{R_f}$ = 0.5 (hexane/AcOEt = 4:1, UV).

^{1}H NMR (500 MHz, $CDCl_3$) δ: 8.03- 7.96(m, 2H), 7.91-7.84 (m, 2H), 7.44-7.32 (m, 3H), 7.29-7.23 (m, 1H), 7.04-6.97 (m, 2H), 6.82-6.77 (m, 2H), 6.71 (s, 1H), 3.87 (s, 6H).

^{13}C NMR (100 MHz, $CDCl_3$) δ: 163.4, 162.0, 147.8, 138.9, 138.7, 132.6, 131.1, 128.7, 128.3, 126.9, 126.6, 115.8, 114.1, 113.3, 107.4, 98.0, 55.7, 55.5.

HPLC: Chiralpak AD-H column, hexane–*i*PrOH (4:1), 1.2 mL/min; t_R (major) = 26.7 min, t_R (minor) = 30.1 min. 85:15 er.

The NMR spectra of the obtained product were consistent with the reported data.[16]

(*S*)-7-methyl-3-phenyl-1-(*m*-tolyl)benzo[*e*][1,2]thiazine-1-oxide (3fa)

According to **GP**, sulfoximine **1f** (0.20 mmol, 49.0 mg) and sulfoxonium ylide **2a** (0.30 mmol, 59.1 mg) afforded **3fa** as a yellow solid (69.0 mg, >99%) after chromatographic purification by Yamazen YFLC AI-580 using Universal Column SiOH (hexane/AcOEt gradient to 4:1).

TLC (silica gel): $\mathbf{R_f}$ = 0.4 (hexane/AcOEt = 4:1, UV).

^{1}H NMR (400 MHz, $CDCl_3$) δ: 7.99 (dd, *J* = 7.2, 1.6 Hz, 2H), 7.81 (d, *J* = 7.2 Hz, 1H), 7.77 (s, 1H), 7.49-7.28 (m, 7H), 7.11 (s, 1H), 6.78 (s, 1H), 2.43 (s, 3H), 2.30 (s, 3H).

^{13}C NMR (100 MHz, $CDCl_3$) δ: 146.1, 140.4, 139.2, 138.9, 136.5, 134.1, 134.1, 133.6, 129.6, 128.8, 128.5, 128.3, 126.8, 126.5, 124.2, 119.6, 98.0, 21.3, 21.3. One aromatic signal was missing probably due to overlapping.

HPLC: Chiralpak AD-H column, hexane–*i*PrOH (19:1), 1.0 mL/min; t_R (major) = 26.1 min, t_R (minor) = 28.1 min. 88:12 er.

The NMR spectra of the obtained product were consistent with the reported data.[16]

(*S*)-8-methyl-3-phenyl-1-(*o*-tolyl)benzo[*e*][1,2]thiazine-1-oxide (3ga)

According to **GP**, sulfoximine **1g** (0.20 mmol, 49.0 mg) and sulfoxonium ylide **2a** (0.30 mmol, 59.1 mg) afforded **3ga** as a yellow foam (70.0 mg, >99%) after chromatographic purification by Yamazen YFLC AI-580 using Universal Column SiOH (hexane/AcOEt gradient to 4:1).

TLC (silica gel): $\mathbf{R_f}$ = 0.5 (hexane/AcOEt = 4:1, UV).

^{1}H NMR (400 MHz, $CDCl_3$) δ: 8.44-8.38 (m, 1H), 7.97-7.91 (m, 2H), 7.52-7.47 (m, 2H), 7.45-7.28 (m, 5H), 7.24-7.18 (m, 1H), 7.02 (d, *J* = 7.6 Hz, 1H), 6.76 (s, 1H), 2.08 (s, 3H), 1.73 (s, 3H).

^{13}C NMR (100 MHz, $CDCl_3$) δ: 146.2, 140.5, 140.0, 138.5, 135.4, 133.4, 132.8, 132.3, 129.2, 128.7, 128.6, 128.3, 126.4, 126.2, 125.5, 117.0, 97.8, 20.1, 19.1. One aromatic signal was missing probably due to overlapping.

HPLC: Chiralpak AD-H column, hexane–*i*PrOH (4:1), 1.0 mL/min; t_R (minor) = 7.3 min, t_R (major) = 9.0 min. 11:89 er.

The NMR spectra of the obtained product were consistent with the reported data.[16]

(*S*)-1-phenyl-3-(*p*-tolyl)benzo[*e*][1,2]thiazine-1-oxide (3ab)

According to **GP**, sulfoximine **1a** (0.20 mmol, 43.4 mg) and sulfoxonium ylide **2b** (0.30 mmol, 63.3 mg) afforded **3ab** as a yellow foam (66.0 mg, >99%) after chromatographic purification by Yamazen YFLC AI-580 using Universal Column SiOH (hexane/AcOEt = 8:1).

TLC (silica gel): $\mathbf{R}_f$ = 0.5 (hexane/AcOEt = 5:1, UV).

^{1}H NMR (400 MHz, $CDCl_3$) δ: 7.99 (d, *J* = 7.2 Hz, 2H), 7.90 (d, *J* = 8.5 Hz, 2H), 7.63 (t, *J* = 7.2 Hz, 1H), 7.56 (t, *J* = 7.2 Hz, 2H), 7.47 (t, *J* = 7.4 Hz, 1H), 7.42 (d, *J* = 7.2 Hz, 1H), 7.32 (d, *J* = 7.6 Hz, 1H), 7.26-7.17 (m, 3H), 6.78 (s, 1H), 2.38 (s, 3H).

^{13}C NMR (100 MHz, $CDCl_3$) δ: 147.2, 140.4, 138.8, 136.6, 135.9, 133.3, 132.0, 129.3, 129.0, 128.9, 126.7, 126.5, 126.0, 124.9, 119.4, 97.5, 21.3.

HPLC: Chiralpak AD-H column, hexane–*i*PrOH (4:1), 1.2 mL/min; t_R (minor) = 12.1 min, t_R (major) = 13.0 min. 12:88 er.

The NMR spectra of the obtained product were consistent with the reported data.[16]

(*S*)-3-(4-fluorophenyl)-1-phenylbenzo[*e*][1,2]thiazine 1-oxide (3ac)

According to **GP**, sulfoximine **1a** (0.20 mmol, 43.4 mg) and sulfoxonium ylide **2c** (0.30 mmol, 64.2 mg) afforded **3ac** as a yellow foam (60.0 mg, 90%) after chromatographic purification by Yamazen YFLC AI-580 using Universal Column SiOH (hexane/AcOEt = 8:1).

TLC (silica gel): $\mathbf{R}_f$ = 0.3 (hexane/AcOEt = 5:1, UV).

^{1}H NMR (500 MHz, $CDCl_3$) δ: 8.02-7.95 (m, 4H), 7.67-7.62 (m, 1H), 7.61-7.55 (m, 2H), 7.51-7.47 (m, 1H), 7.43 (d, *J* = 7.4 Hz, 1H), 7.32 (d, *J* = 8.6 Hz, 1H), 7.25-7.20 (m, 1H), 7.12-7.06 (m, 2H), 6.75 (s, 1H).

^{13}C NMR (100 MHz, $CDCl_3$) δ: 163.3(d, $^1J_{C\text{-}F}$ = 248.0 Hz), 146.1, 140.1, 136.3, 134.9(d, $^4J_{C\text{-}F}$ = 2.8 Hz), 133.4, 132.1, 129.3, 129.0, 128.4 (d, $^3J_{C\text{-}F}$ = 8.5 Hz), 126.8, 126.3, 124.9, 119.4, 115.2 (d, $^2J_{C\text{-}F}$= 21.6 Hz), 97.9.

HPLC: Chiralpak AD-H column, hexane–*i*PrOH (4:1), 1.2 mL/min; t_R (minor) = 10.6 min, t_R (major) = 12.2 min. 13:87 er.

The NMR spectra of the obtained product were consistent with the reported data.[16]

(*S*)-3-(naphthalen-2-yl)-1-phenylbenzo[*e*][1,2]thiazine-1-oxide (3ad)

According to **GP**, sulfoximine **1a** (0.20 mmol, 43.4 mg) and sulfoxonium ylide **2d** (0.30 mmol, 73.8 mg) afforded **3ad** as a yellow foam (68.0 mg, 92%) after chromatographic purification by Yamazen YFLC AI-580 using Universal Column SiOH (hexane/AcOEt = 8:1).

TLC (silica gel): $\mathbf{R}_f$ = 0.6 (hexane/AcOEt = 3:1, UV).

^{1}H NMR (400 MHz, $CDCl_3$) δ: 8.55 (s, 1H), 8.10-8.01 (m, 3H), 7.91-7.80 (m, 3H), 7.67-7.55 (m, 3H), 7.51-7.44 (m, 4H), 7.34 (d, *J* = 7.6 Hz, 1H), 7.26-7.19 (m, 1H), 6.96 (s, 1H).

^{13}C NMR (100 MHz, $CDCl_3$) δ: 146.9, 140.4, 136.4, 135.9, 133.6, 133.4, 133.4, 132.1, 129.4, 129.0, 128.8, 127.8, 127.5, 127.0, 126.4, 126.4, 126.3, 126.1, 125.0, 124.0, 119.8, 98.7.

HPLC: Chiralpak AD-H column, hexane–*i*PrOH (4:1), 1.2 mL/min; t_R (minor) = 14.1 min, t_R (major) = 17.1 min. 14:86 er.

The NMR spectra of the obtained product were consistent with the reported data.[16]

(*S*)-3-(furan-2-yl)-1-phenylbenzo[*e*][1,2]thiazine-1-oxide (3ae)

According to **GP**, sulfoximine **1a** (0.20 mmol, 43.4 mg) and sulfoxonium ylide **2e** (0.30 mmol, 54.9 mg) afforded **3ae** a brown foam (62.0 mg, >99%) after chromatographic purification by Yamazen YFLC AI-580 using Universal Column SiOH (hexane/AcOEt = 4:1).

TLC (silica gel): $\mathbf{R}_f$ = 0.5 (hexane/AcOEt = 1:1, UV).

^{1}H NMR (400 MHz, $CDCl_3$) δ: 7.94-7.88 (m, 2H), 7.59-7.54 (m, 1H), 7.53-7.47 (m, 2H), 7.42-7.32 (m, 3H), 7.21 (d, *J* = 7.6, 1H), 7.14-7.10 (m, 1H), 6.83 (d, *J* = 3.6 Hz, 1H), 6.73 (s, 1H), 6.40 (dd, *J* = 3.6, 1.8, 1H).

^{13}C NMR (100 MHz, $CDCl_3$) δ: 153.3, 143.0, 140.0, 138.5, 136.1, 133.4, 132.1, 129.4, 129.0, 126.8, 126.1, 125.0, 120.1, 111.8, 109.4, 96.4.

HPLC: Chiralpak IB column, hexane–*i*PrOH (4:1), 1.0 mL/min; t_R (major) = 8.5 min, t_R (minor) = 19.1 min. 84:16 er.

The NMR spectra of the obtained product were consistent with the reported data.[16]

(*S*)-3-(*tert*-butyl)-1-phenylbenzo[*e*][1,2]thiazine-1-oxide (3af)

According to **GP**, sulfoximine **1a** (0.20 mmol, 43.4 mg) and sulfoxonium ylide **2f** (0.30 mmol, 52.8 mg) afforded **3af** as a white solid (60.0 mg, >99%) after chromatographic purification by Yamazen YFLC AI-580 using Universal Column SiOH (hexane/AcOEt = 10:1).

TLC (silica gel): $\mathbf{R}_f$ = 0.5 (hexane/AcOEt = 6:1, UV).

^{1}H NMR (400 MHz, $CDCl_3$) δ: 7.89-7.81 (m, 2H), 7.56-7.45 (m, 3H), 7.36-7.31 (m, 1H), 7.25-7.17 (m, 2H), 7.11-7.06 (m, 1H), 6.12 (s, 1H), 1.27 (s, 9H).

^{13}C NMR (100 MHz, $CDCl_3$) δ: 159.7, 141.0, 136.6, 133.0, 131.7, 129.1, 128.8, 126.5, 125.6, 124.7, 118.6, 95.0, 37.5, 28.9.

HPLC: Chiralpak IF column, hexane–*i*PrOH (19:1), 1.0 mL/min; t_R (minor) = 7.8 min, t_R (major) = 8.5 min. 18:82 er.

The NMR spectra of the obtained product were consistent with the reported data.[16]

(*S*)-6-chloro-1-(4-chlorophenyl)-3-(*p*-tolyl)benzo[e][1,2]thiazine-1-oxide (3bb)

According to **GP**, sulfoximine **1b** (0.20 mmol, 56.8 mg) and sulfoxonium ylide **2b** (0.30 mmol, 63.3 mg) afforded **3bb** as a yellow solid (54.0 mg, 68%) after chromatographic purification by Yamazen YFLC AI-580 using Universal Column SiOH (hexane/AcOEt = 8:1).

TLC (silica gel): $\mathbf{R}_f$ = 0.5 (hexane/AcOEt = 6:1, UV).

Mp. 146-147 °C

^{1}H NMR (400 MHz, $CDCl_3$) δ: 7.83-7.78 (m, 4H), 7.50-7.46 (m, 2H), 7.34 (d, *J* = 1.8 Hz, 1H), 7.17 (t, *J* = 8.0 Hz, 3H), 7.09 (dd, *J* = 8.0, 1.8 Hz, 1H), 6.63 (s, 1H), 2.32 (s, 3H).

^{13}C NMR (100 MHz, $CDCl_3$) δ: 148.6, 140.5, 139.4, 138.9, 138.5, 138.2, 135.3, 130.5, 129.4, 129.2, 126.6, 126.5, 126.4, 125.9, 117.1, 96.8, 21.3.

HPLC: Chiralpak IA column, hexane–*i*PrOH (2:1), 1.0 mL/min; t_R (major) = 10.8 min, t_R (minor) = 14.4 min. 89:11 er.

HRMS (ESI): *m/z* $[M + Na]^+$ calcd for $C_{21}H_{15}Cl_2NOSNa^+$: 422.0144; found: 422.0137.

$[\alpha]_D^{24}$ = +160.4 (*c* = 0.5, $CHCl_3$).

(*S*)-6-chloro-1-(4-chlorophenyl)-3-(furan-2-yl)benzo[*e*][1,2]thiazine-1-oxide (3be)

According to **GP**, sulfoximine **1b** (0.20 mmol, 56.8 mg) and sulfoxonium ylide **2e** (0.30 mmol, 54.9 mg) afforded **3be** as a yellow solid (74.0 mg, >99%) after chromatographic purification by Yamazen YFLC AI-580 using Universal Column SiOH (hexane/AcOEt = 8:1).

TLC (silica gel): $\mathbf{R}_f$ = 0.4 (hexane/AcOEt = 3:1, UV).

Mp. 141-142 °C

^{1}H NMR (400 MHz, $CDCl_3$) δ: 7.81 (d, *J* = 8.5 Hz, 2H), 7.48 (d, *J* = 8.5 Hz, 2H), 7.43 (s, 1H), 7.32 (s, 1H), 7.14 (d, *J* = 8.5 Hz, 1H), 7.08 (d, *J* = 9.0 Hz, 1H), 6.83 (d, *J* = 3.1 Hz, 1H), 6.65 (s, 1H), 6.42 (dd, *J* = 2.9, 1.6 Hz, 1H).

^{13}C NMR (100 MHz, $CDCl_3$) δ: 152.7, 143.5, 140.7, 139.7, 138.7, 138.6, 137.8, 130.6, 129.4, 126.6, 126.5, 125.9, 117.8, 112.0, 110.3, 95.6.

HPLC: Chiralpak IC column, hexane–*i*PrOH (4:1), 1.0 mL/min; t_R (minor) = 8.5 min, t_R (major) = 9.7 min. 10:90 er.

HRMS (ESI): *m/z* [M + Na]$^+$ calcd for $C_{18}H_{11}Cl_2NO_2SNa^+$: 397.9780; found: 397.9775.

$[\alpha]_D^{24}$ = +203.2 (*c* = 0.5, $CHCl_3$).

(*S*)-3-(*tert*-butyl)-6-chloro-1-(4-chlorophenyl)benzo[*e*][1,2]thiazine 1-oxide (3bf)

According to **GP**, sulfoximine **1b** (0.20 mmol, 56.8 mg) and sulfoxonium ylide **2f** (0.30 mmol, 52.8 mg) afforded **3bf** as a yellow oil (70.0 mg, 95%) after chromatographic purification by Yamazen YFLC AI-580 using Universal Column SiOH (hexane/AcOEt = 8:1).

TLC (silica gel): $\mathbf{R_f}$ = 0.6 (hexane/AcOEt = 6:1, UV).

^{1}H NMR (400 MHz, $CDCl_3$) δ: 7.74 (d, *J* = 9.0 Hz, 2H), 7.47 (d, *J* = 8.5 Hz, 2H), 7.24 (d, *J* = 2.2 Hz, 1H), 7.13 (d, *J* = 8.5 Hz, 1H), 7.05 (dd, *J* = 8.5, 2.2 Hz, 1H), 6.05 (s, 1H), 1.24 (s, 9H).

^{13}C NMR (100 MHz, $CDCl_3$) δ: 161.4, 140.2, 139.4, 138.2, 138.2, 130.3, 129.3, 126.3, 126.2, 125.8, 116.3, 94.6, 37.7, 28.8.

HPLC: Chiralpak IC column, hexane–*i*PrOH (19:1), 1.0 mL/min; t_R (major) = 6.3 min, t_R (minor) = 7.2 min. 76:24 er.

HRMS (ESI): *m/z* [M + Na]$^+$ calcd for $C_{18}H_{17}Cl_2NOSNa^+$: 388.0301; found: 388.0294.

$[\alpha]_D^{24}$ = +54.6 (*c* = 0.5, $CHCl_3$).

Funding Information

This work was supported in part by JSPS KAKENHI grant number JP20H02730 and JP20H04794 in Hybrid Catalysis.

Supporting Information

YES (this text will be updated with links prior to publication)

Primary Data

NO (this text will be deleted prior to publication)

References

(1) For selected recent reviews on C–H functionalization, see: (a) Gensch, T.; Hopkinson, M. N.; Glorius, F.; Wencel-Delord, J. *Chem. Soc. Rev.* **2016**, *45*, 2900. (b) Yang, Y.-F.; Hong, X.; Yu, J.-Q.; Houk, K. N. *Acc. Chem. Res.* **2017**, *50*, 2853. (c) Shang, R.; Ilies, L.; Nakamura, E. *Chem. Rev.* **2017**, *117*, 9086. (d) Hummel, J. R.; Boerth, J. A.; Ellman, J. A. *Chem. Rev.* **2017**, *117*, 9163. (e) Dong, Z.; Ren, Z.; Thompson, S. J.; Xu, Y.; Dong, G. *Chem. Rev.* **2017**, *117*, 9333. (f) Xu, Y.; Dong, G. *Chem. Sci.* **2018**, *9*, 1424. (g) Karimov, R. R.; Hartwig, J. F. *Angew. Chem., Int. Ed.* **2018**, *57*, 4234. (h) Sambiagio, C.; Sch önbauer, D.; Blieck, R.; Dao-Huy, T.; Pototschnig, G.; Schaaf, P.; Wiesinger, T.; Zia, M. F.; Wencel-Delord, J.; Besset, T.; Maes, B. U. W.; Schnürch, M. *Chem. Soc. Rev.* **2018**, *47*, 6603. (i) Meyer, T. H.; Finger, L. H.; Gandeepan, P.; Ackermann, L. *Trends Chem* **2019**, *1*, 63. (j) Dutta, U.; Maiti, S.; Bhattacharya, T.; Maiti, D. *Science* **2021**, *372*, eabd5992.

(2) Oi, S.; Fukita, S.; Hirata, N.; Watanuki, N.; Miyano, S.; Inoue, Y., *Org. Lett.* **2001**, *3*, 2579.

(3) For selected reviews on Ru-catalyzed C–H functionalization, see: (a) Arockiam, P. B.; Bruneau, C.; Dixneuf, P. H. *Chem. Rev.* **2012**, *112*, 5879. (b) Ackermann, L. *Acc. Chem. Res.* **2014**, *47*, 281. (c) De Sarkar, S.; Liu, W.; Kozhushkov, S. I.; Ackermann, L. *Adv. Synth. Catal.* **2014**, *356*, 1461. (d) Leitch, J. A.; Frost, C. G. *Chem. Soc. Rev.* **2017**, *46*, 7145. (e) Shan, C.; Zhu, L.; Qu, L.-B.; Bai, R.; Lan, Y. *Chem. Soc. Rev.* **2018**, *47*, 7552.

(4) For selected recent general reviews on enantioselective C–H functionalization, see: (a) Newton, C. G.; Wang, S.-G.; Oliveira, C. C.; Cramer, N. *Chem. Rev.* **2017**, *117*, 8908. (b) Saint-Denis, T. G.; Zhu, R.-Y.; Chen, G.; Wu, Q.-F.; Yu, J.-Q. *Science* **2018**, *359*, eaao4798. (c) Liao, G.; Zhou, T.; Yao, Q.-J.; Shi, B.-F. *Chem. Commun.* **2019**, *55*, 8514. (d) Diesel, J.; Cramer, N. *ACS Catal.* **2019**, *9*, 9164. (e) Loup, J.; Dhawa, U.; Pesciaioli, F.; Wencel-Delord, J.; Ackermann, L. *Angew. Chem., Int. Ed.* **2019**, *58*, 12803. (f) Shao, Q.; Wu, K.; Zhuang, Z.; Qian, S.; Yu, J.-Q. *Acc. Chem. Res.* **2020**, *53*, 833. (g) Achar, T. K.; Maiti, S.; Jana, S.; Maiti, D. *ACS Catal.* **2020**, *10*, 13748. (h) Gu, Q.; Wu, Z.-J.; You, S.-L. *Bull. Chem. Soc. Jpn.* **2021**, *94*, 641.

(5) Li, Z.-Y.; Lakmal, H. H. C.; Qian, X.; Zhu, Z.; Donnadieu, B.; McClain, S. J.; Xu, X.; Cui, X. *J. Am. Chem. Soc.* **2019**, *141*, 15730.

(6) Li, G.; Liu, Q.; Vasamsetty, L.; Guo, W.; Wang, J. *Angew. Chem., Int. Ed.* **2020**, *59*, 3475.

(7) Dhawa, U.; Connon, R.; Oliveira, J. C. A.; Steinbock, R.; Ackermann, L. *Org. Lett.* **2021**, *23*, 2760.

(8) For recent studies on enantioselective C–H amidation via an outer-sphere mechanism using Ru catalysts, see (a) Xing, Q.; Chan, C.-M.; Yeung, Y.-W.; Yu, W.-Y. *J. Am. Chem. Soc.* **2019**, *141*, 3849. (b) Miyazawa, T.; Suzuki, T.; Kumagai, Y.; Takizawa, K.; Kikuchi, T.; Kato, S.; Onoda, A.; Hayashi, T.; Kamei, Y.; Kamiyama, F.; Anada, M.; Kojima, M.; Yoshino, T.; Matsunaga S. *Nat. Catal.* **2020**, *3*, 851. For other examples, see a review: (c) Hayashi, H.; Uchida, T. *Eur. J. Org. Chem.* **2020**, *909*.

(9) For a seminal work on chiral transient directing group-assisted enantioselective C–H functionalization, see: (a) Zhang, F.-L.; Hong, K.; Li, T.-J.; Park, H.; Yu, J.-Q. *Science* **2016**, *351*, 252. For other examples, see reviews: (b) Gandeepan, P.; Ackermann, L. *Chem* **2018**, *4*, 199. (c) Liao, G.; Zhang, T.; Lin, Z.-K.; Shi, B.-F. *Angew. Chem., Int. Ed.* **2020**, *59*, 19773. (d) Bag, D.; Verma, P. K.; Sawant, S. D. *Chem. Asian J.* **2020**, *15*, 3225.

(10) (a) Ye, B.; Cramer, N. *Acc. Chem. Res.* **2015**, *48*, 1308. (b) Yoshino, T.; Satake, S.; Matsunaga, S. *Chem. Eur. J.* **2020**, *26*, 7346. (c) Mas-Roselló, J.; Herraiz, A. G.; Audic, B.; Laverny, A.; Cramer, N. *Angew. Chem., Int. Ed.* **2020**, 60, 13198. (d) Shaaban, S.; Davies, C.; Waldmann, H. *Eur. J. Org. Chem.* **2020**, 6512. (e) Yoshino, T.; Matsunaga, S. *ACS Catal.* **2021**, *11*, 6455.

(11) (a) Satake, S.; Kurihara, T.; Nishikawa, K.; Mochizuki, T.; Hatano, M.; Ishihara, K.; Yoshino, T.; Matsunaga, S. *Nat. Catal.* **2018**, *1*, 585. (b)Li, G.; Jiang, J.; Xie, H.; Wang, J. *Chem. Eur. J.* **2019**, *25*, 4688.

(12) (a) Zell, D.; Bursch, M.; Müller, V.; Grimme, S.; Ackermann, L. *Angew. Chem., Int. Ed.* **2017**, *56*, 10378. (b) Pesciaioli, F.; Dhawa, U.; Oliveira, J. C. A.; Yin, R.; John, M.; Ackermann, L. *Angew. Chem., Int. Ed.* **2018**, *57*, 15425. (c) Kurihara, T.; Kojima, M.; Yoshino, T.; Matsunaga, S. *Asian J. Org. Chem.* **2019**, *9*, 368.

(13) (a) Lapointe, D.; Fagnou, K. *Chem. Lett.* **2010**, *39*, 1118. (b) Ackermann, L. *Chem. Rev.* **2011**, *111*, 1315. (c) Davies, D. L.; Macgregor, S. A.; McMullin, C. L. *Chem. Rev.* **2017**, *117*, 8649. (e) Alharis, R. A.; McMullin, C. L.; Davies, D. L.; Singh, K.; Macgregor, S. A. *J. Am. Chem. Soc.* **2019**, *141*, 8896. (f) Wang, L.; Carrow, B. P. *ACS Catal.* **2019**, *9*, 6821. (g) Rogge, T.; Oliveira, J. C. A.; Kuniyil, R.; Hu, L.; Ackermann, L. *ACS Catal.* **2020**, *10*, 10551.

(14) For a seminal work and selected examples, see: (a) Shi, B.-F.; Maugel, N.; Zhang, Y.-H.; Yu, J.-Q. *Angew. Chem., Int. Ed.* **2008**, *47*, 4882. (b) Shi, B.-F.; Zhang, Y.-H.; Lam, J. K.; Wang, D.-H.; Yu, J.-Q. *J. Am. Chem. Soc.* **2010**, *132*, 460. (c) Wasa, M.; Engle, K. M.; Lin, D. W.; Yoo, E. J.; Yu, J.-Q. *J. Am. Chem. Soc.* **2011**, *133*, 19598. (d) Cheng, X.-F.; Li, Y.; Su, Y.-M.; Yin, F.; Wang, J.-Y.; Sheng, J.; Vora, H. U.; Wang, X.-S.; Yu, J.-Q. *J. Am. Chem. Soc.* **2013**, *135*, 1236. (e) Chu, L.; Xiao, K.-J.; Yu, J.-Q. *Science* **2014**, *346*, 451. (f) Xiao, K.-J.; Lin, D. W.; Miura, M.; Zhu, R.-Y.; Gong, W.; Wasa, M.; Yu, J.-Q. *J. Am. Chem. Soc.* **2014**, *136*, 8138. (g) Chen, G.; Gong, W.; Zhuang, Z.; Andra, M. S.; Chen, Y.-Q.; Hong, X.; Yang, Y.-F.; Liu, T.; Houk, K. N.; Yu, J.-Q. *Science* **2016**, *353*, 1023. (h) Shao, Q.; Wu, Q.-F.; He, J.; Yu, J.-Q. *J. Am. Chem. Soc.* **2018**, *140*, 5322. (i) Hu, L.; Shen, P.-X.; Shao, Q.; Hong, K.; Qiao, J. X.; Yu, J.-Q. *Angew. Chem., Int. Ed.* **2019**, *58*, 2134. (j) Romero, E. A.; Chen, G.; Gembicky, M.; Jazzar, R.; Yu, J.-Q.; Bertrand, G. *J. Am. Chem. Soc.* **2019**, *141*, 16726.

(15) (a) Gwon, D.; Park, S.; Chang, S. *Tetrahedron* **2015**, *71*, 4504. (b) Lin, L.; Fukagawa, S.; Sekine, D.; Tomita, E.; Yoshino, T.; Matsunaga, S.

Angew. Chem., Int. Ed. **2018**, *57*, 12048. (c) Fukagawa, S.; Kato, Y.; Tanaka, R.; Kojima, M.; Yoshino, T.; Matsunaga, S. *Angew. Chem., Int. Ed.* **2019**, *58*, 1153. (d) Fukagawa, S.; Kojima, M.; Yoshino, T.; Matsunaga, S. *Angew. Chem., Int. Ed.* **2019**, *58*, 18154. (e) Liu, Y.-H.; Li, P.-X.; Yao, Q.-J.; Zhang, Z.-Z.; Huang, D.-Y.; Le, M. D.; Song, H.; Liu, L.; Shi, B.-F. *Org. Lett.* **2019**, *21*, 1895. (f) Sekine, D.; Ikeda, K.; Fukagawa, S.; Kojima, M.; Yoshino, T.; Matsunaga, S. *Organometallics* **2019**, *38*, 3921. (g) Liu, L.; Song, H.; Liu, Y.-H.; Wu, L.-S.; Shi, B.-F. *ACS Catal.* **2020**, *10*, 7117. (h) Liu, W.; Yang, W.; Zhu, J.; Guo, Y.; Wang, N.; Ke, J.; Yu, P.; He, C. *ACS Catal.* **2020**, *10*, 7207. (i) Huang, L.-T.; Fukagawa, S.; Kojima, M.; Yoshino, T.; Matsunaga, S. *Org. Lett.* **2020**, *22*, 8256. (j) Kato, Y.; Lin, L.; Kojima, M.; Yoshino, T.; Matsunaga, S. *ACS Catal.* **2021**, *11*, 4271.

(16) Zhou, T.; Qian, P.-F.; Li, J.-Y.; Zhou, Y.-B.; Li, H.-C.; Chen, H.-Y.; Shi, B.-F. *J. Am. Chem. Soc.* **2021**, *143*, 6810.

(17) (a) Lücking, U. *Angew. Chem., Int. Ed.* **2013**, *52*, 9399. (b) Wiezorek, S.; Lamers, P.; Bolm, C. *Chem. Soc. Rev.* **2019**, *48*, 5408. (c) Mäder, P.; Kattner, L. *J. Med. Chem.* **2020**, *63*, 14243. (d) Han, Y.; Xing, K.; Zhang, J.; Tong, T.; Shi, Y.; Cao, H.; Yu, H.; Zhang, Y.; Liu, D.; Zhao, L. *Eur. J. Med. Chem.* **2021**, *209*, 112885. For a review on C–H and N–H functionalization of sulfoximines, see: (e) Ghosh, P.; Ganguly, B.; Das, S. *Asian J. Org. Chem.* **2020**, *9*, 2035.

(18) For selected examples, see: (a) Dong, W.; Wang, L.; Parthasarathy, K.; Pan, F.; Bolm, C. *Angew. Chem., Int. Ed.* **2013**, *52*, 11573. (b) Yu, D.-G.; de Azambuja, F.; Glorius, F. *Angew. Chem.* **2014**, *126*, 2792. (c) Parthasarathy, K.; Bolm, C. *Chem. Eur. J.* **2014**, *20*, 4896. (d) Dong, W.; Parthasarathy, K.; Cheng, Y.; Pan, F.; Bolm, C. *Chem. Eur. J.* **2014**, *20*, 15732. (e) Cheng, Y.; Bolm, C. *Angew. Chem., Int. Ed.* **2015**, *54*, 12349. (f) Chinnagolla, R. K.; Vijeta, A.; Jeganmohan, M. *Chem. Commun.* **2015**, *51*, 12992. (g) Cheng, Y.; Dong, W.; Parthasarathy, K.; Bolm, C. *Org. Lett.* **2017**, *19*, 726. (h) Aher, Y. N.; Lade, D. M.; Pawar, A. B. *Chem. Commun.* **2018**, *54*, 6288. (i) Xie, H. S.; Lan, J.; Gui, J.; Chen, F.; Jiang, H.; Zeng, W. *Adv. Synth. Catal.* **2018**, *360*, 3534. For other examples, see ref. 17e.

(19) Sulfoximines are used as removable and reusable directing groups for C–H functionalization. For selected examples, see: (a) Yadav, M. R.; Rit, R. K.; Sahoo, A. K. *Chem. Eur. J.* **2012**, *18*, 5541. (b) Rit, R. K.; Yadav, M. R.; Sahoo, A. K. *Org. Lett.* **2014**, *16*, 968. (c) Ghosh, K.; Rit, R. K.; Ramesh, E.; Sahoo, A. K. *Angew. Chem., Int. Ed.* **2016**, *55*, 7821. (d) Raghuvanshi, K.; Zell, D.; Ackermann, L. *Org. Lett.* **2017**, *19*, 1278. (e) Shankar, M.; Rit, R. K.; Sau, S.; Mukherjee, K.; Gandon, V.; Sahoo, A. K. *Chem. Sci.* **2020**, *11*, 10770. For other exapmples, see also ref. 17e.

(20) For enantioselective variants, see: (a) Shen, B.; Wan, B.; Li, X. *Angew. Chem., Int. Ed.* **2018**, *57*, 15534. (b) Sun, Y.; Cramer, N. *Angew. Chem., Int. Ed.* **2018**, *57*, 15539. (c) Brauns, M.; Cramer, N. *Angew. Chem., Int. Ed.* **2019**, *58*, 8902.

(21) (a) Tota, A.; Zenzola, M.; Chawner, S. J.; St John-Campbell, S.; Carlucci, C.; Romanazzi, G.; Degennaro, L.; Bull, J. A.; Luisi, R. *Chem. Commun*. **2017**, *53*, 348. (b) Vaitla, J.; Bayer, A.; Hopmann, K. H. *Angew. Chem. Int. Ed.* **2017**, *56*, 4277.