Note

A high atom economic approach to prepare chiral #-sulfenylated ketones

Jèssica Margalef, Rahul A. Watile, Thanya Rukkijakan, and Joseph S. M. Samec

J. Org. Chem., **Just Accepted Manuscript** • DOI: 10.1021/acs.joc.9b01424 • Publication Date (Web): 06 Aug 2019

A high atom economic approach to prepare chiral α-sulfenylated ketones

Jèssica Margalef[‡], Rahul A. Watile[†], Thanya Rukkijakan[†], Joseph S. M. Samec*[,†]

[†]Department of Organic Chemistry, Stockholm University, 106 91 Stockholm, Sweden

[‡]Department of Physical and Inorganic Chemistry, Universitat Rovira i Virgili, 43007 Tarragona, Spain

*joseph.samec@su.se

ABSTRACT: Chiral α-sulfenylated ketones are versatile building blocks, although there are still several limitations with their preparation. Here we report a new two-step procedure, consisting in a Pd-catalyzed hydrothiolation of propargylic alcohols followed by an enantioselective Rh-isomerization of allylic alcohols. The isomerization reaction is the key step for obtaining the ketones in their enantioenriched form. The new methodology has high atom economy, no waste is produced and induces good to high levels of enantioselectivity. A mechanism involving a Rh-hydride-enone intermediate is proposed for the isomerization reaction.

INTRODUCTION

Finding efficient catalytic systems able to promote new carbon-sulfur (C-S) bonds is a challenge, since sulfur reagents are known to poison metallic catalysts. Sulfur is present in several synthetic drugs and biologically active natural products.[1] Indeed, approximately 20% of the approved FDA drugs contain sulfur atoms and 31 of them contain a thioether moiety.[2] In addition, molecules bearing a thioether on a stereogenic carbon are also important from the point of view of organic synthesis, since they can be transformed to other relevant molecules in an enantioespecific fashion.[3] The sp^3-hybridized C-S bond in thioethers can be activated towards other functional groups if desired. For example, it could participate in cross-coupling reactions,[4] and be transformed into olefins[5], organometallics[6] and halides[3,7].

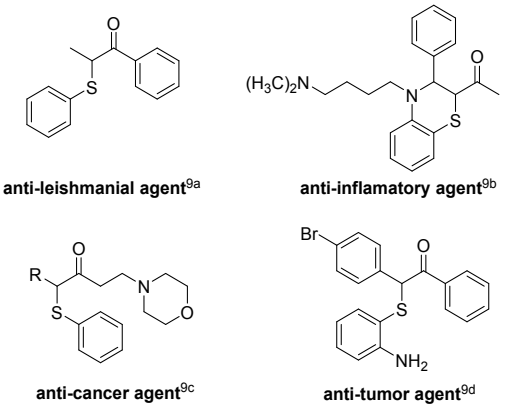
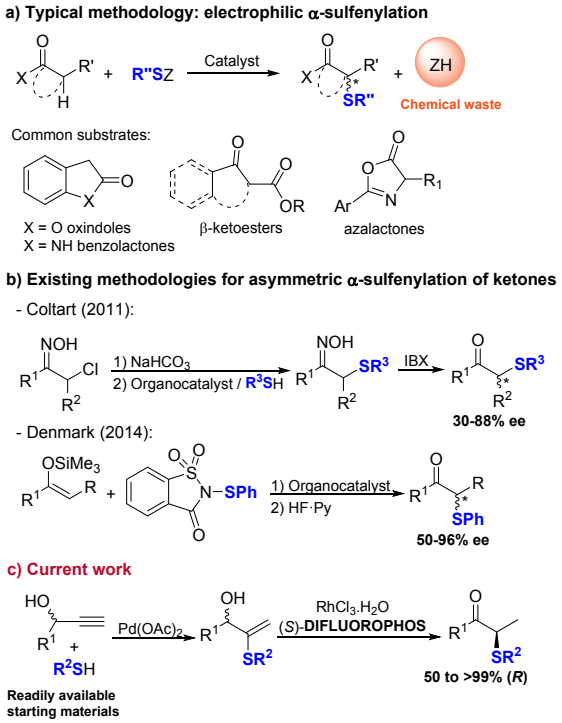


Figure 1. Chiral α-sulfenylated compounds with biological activity.

The enantioselective α-sulfenylation of carbonyl compounds is currently the most straightforward methodology for preparing highly versatile building blocks bearing a sulphide moiety.[1b,d,8] Furthermore, chiral α-sulfenylated carbonyl compounds have shown biological activity (Figure 1).[9] However, the typical sulfenylating agents used in this transformation, generate stoichiometric amounts of chemical waste. In addition, the substrate scope is quite narrow since cyclic and/or activated carbonyl compounds such as oxindoles[10], β-ketoesters,[11] azalactones,[12] and benzolactones[11e,g] are often employed (Scheme 1a). As far as we know, only two efficient catalytic methodologies have been reported for the preparation of chiral α-sulfenylated ketones (Scheme 1b).[13] However, these methodologies have low atom economy.

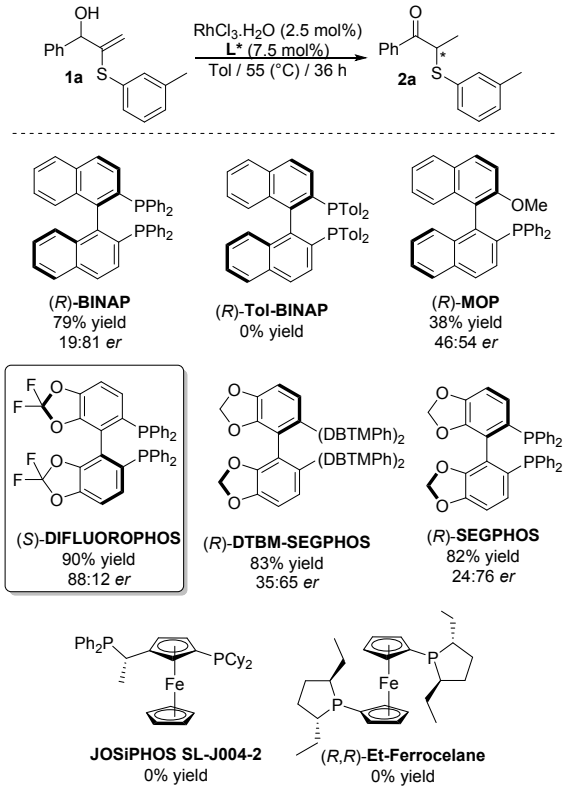
Scheme 1. Catalytic routes to prepare chiral α-sulfenylated ketones



In 2011, Coltart and co-workers reported the first catalytic asymmetric process to prepare such type of compounds, *via* in situ formed nitrosoalkenes.[13a] The main advantage of this transformation is that simple thiols instead of electrophilic sulphur reagents can be employed. Later, Denmark *et al.* published an enantioselective Lewis based-catalyzed *α*-sulfenylation of silyl enol ethers.[13b] Despite these achievements, the scope of sulfenylated ketones and the accomplished enantioselectivities should be further improved. In addition, in order to reach more sustainable processes, new methodologies with a high atom economy are desired.

Our group reported a greener strategy to prepare racemic *α*-sulfenylated ketones, consisting in the tandem hydrothiolation/isomerization of propargylic alcohols, *via* sulfenylated allylic alcohols as intermediates.[14] In one of these studies, $Pd(OAc)_2$ was found to be an efficient catalyst for the hydrothiolation of primary propargylic alcohols.[14d] By using the same conditions, we have been able to synthesize a range of racemic sulfenylated secondary allylic alcohols. We hypothesized that in the presence of a chiral catalyst, these could isomerize to provide chiral *α*-sulfenylated ketones (Scheme 1c). Only very recently, Zhao has reported the Rh-catalyzed isomerization of racemic allylic, homoallylic and bishomoallylic secondary alcohols to produce ketones with *α*-, *β*-, and *γ*-tertiary stereocenters, respectively.[15,16] Inspired by this pioneering work, we were able to find a catalytic system, composed by $RhCl_3.H_2O$ and the commercially available ligand (*S*)-**DIFLUORPHOS**, which can enantioselectively promote the redox-isomerization of allylic alcohols containing a sulphide group. Thus, we report here a two-step procedure to prepare enantiopure *α*-sulfenylated ketones, which overcomes the problem of low-atom economy of the existing methodologies (Scheme 1c).

Table 1. Ligand screening for the asymmetric Rh-catalyzed isomerization of 1a.[a]

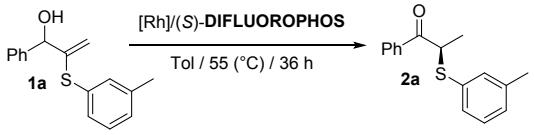


[a]$RhCl_3$ (2.5 mol%), ligand (7.5 mol%), **1a** (0.2 M); NMR yields were determined using 1,3,5-trimethoxybenzene as internal-standard and *er* through HPLC analysis.

RESULTS AND DISCUSSION

Initially, several bisphosphines were screened in the isomerization of allylic alcohol **1a**. In general, only biaryl-type phosphines were able to catalyse the isomerization reaction (Table 1). Among them, the most electrondeficient (*S*)-**DIFLUOROPHOS** provided the highest enantioselectivity (88:12 *er*). With the ligand of choice, we optimized reaction conditions (Table 2). It was found that the simple inorganic salt $RhCl_3.H_2O$ performed better than $[Rh(COD)]BF_4$ or $[Cp^*RhCl_2]_2$ (entries 1-3). Interestingly, anhydrous $RhCl_3$ provided very low conversion (entry 4). This observation suggests that water could have an important role in mediating a proton-transfer process. Therefore, we studied the water effect on the reaction performance. It was observed that our system can operate in the presence of small amounts of water, although the catalytic performance didn't improve by increasing water concentration (see Supporting Information).

Table 2. Optimization of the asymmetric isomerization of secondary alcohol 1a[a]



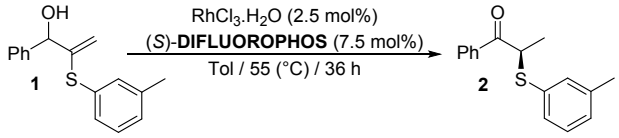
Entry	[Rh]	solvent	% yield[b]	er [c]
1	$[Rh(COD)]BF_4$	Tol	43%	71:29
2	$[Cp^*RhCl_2]_2$	Tol	75%	50:50
3	**$RhCl_3.H_2O$**	**Tol**	**96%**	**88:12**
4	$RhCl_3$	Tol	28%	-
5	$RhCl_3.H_2O$	THF	93%	73:27
6	**$RhCl_3.H_2O$**	**hexane**	**98%**	**88:12**
7	**$RhCl_3.H_2O$**	**cylohexane**	**89%**	**88:12**
8[d]	$RhCl_3.H_2O$	Tol	53%	86:14
9[e]	$RhCl_3.H_2O$	Tol	28%	-
10[f]	$RhCl_3.H_2O$	Tol	82%	88:12
11[g]	$RhCl_3.H_2O$	Tol	97%	50:50
12[h]	$RhCl_3.H_2O$	Tol	95%	87:13
13[i]	$RhCl_3.H_2O$	Tol	90%	85:15

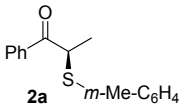
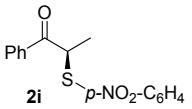
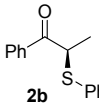
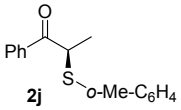
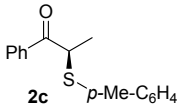
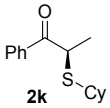
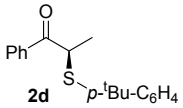
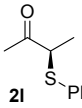
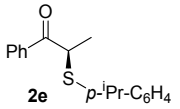
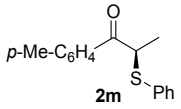
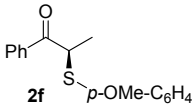
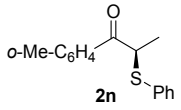
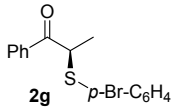
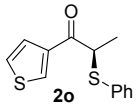
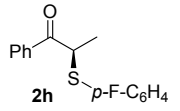
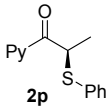
[a][Rh]-precursor (2.5 mol%), (*S*)-**DIFLUORPHOS** (7.5 mol%), **1a** (0.2 M). [b]NMR yields using 1,3,5-trimethoxybenzene as internal-standard. [c]Determined by HPLC. [d] $AgBF_4$ was added. [e]Reaction performed at 0.1 M of **1a**. [f]Reaction performed at 0.4 M of **1a**. [g]Reaction performed at RT. [h]Reaction performed at 80 °C. [i]Reaction performed at 90 °C.

Enantioselectivities were higher in apolar solvents, hence, toluene, hexane and cyclohexane provided similar values (entries 3, 6-7). Nevertheless, we chose toluene since is considered a more benign solvent.[17] The addition of both organic and inorganic bases inhibited the reaction completely, which was unexpected since many methodologies for the metal-catalyzed isomerization of allylic alcohols require the use of catalytic amounts of base (see

Supporting Information).[15f,16,18] Exchange of chlorine atoms by non-coordinating BF_4^- didn't improve the catalytic performance (entry 8). Variations on the concentration didn't show any increase on the enantioselectivity either (entries 9-10). Finally, we observed that by lowering the temperature, the enantioselectivity was completely lost (entry 11), while it remained the same at high temperatures (entry 12). A slight loss in the enantioselectivity was observed at 90 C° (entry 13). This suggests that two competing pathways might operate, where only one is enantioselective. The desired enantioselective pathway requires thermal activation, while the competing non-enantioselective pathway operates at room temperature. We have shown in our previous reports that Lewis acidic Au(I) and Cu(I) species are able to promote a 1,2-H-shift on sulfenylated allylic alcohols.[14] Therefore, traces of free Rh(III) species could be the responsible of the competing non-enantioselective isomerization.

Table 3. Scope of the Rh-catalyzed isomerization of secondary allylic alcohols.[a]



Entry	Ketone	% yield[b]	er[c]	Entry	Ketone	% yield[b]	er[c]
1	 **2a**	90	88:12	9	 **2i**	15[d]	-
2	 **2b**	71	>99:1	10	 **2j**	75	75:25
3	 **2c**	79	88:12	11	 **2k**	88	84:16
4	 **2d**	82	88:12	12	 **2l**	92	60:40
5	 **2e**	71	87.5:12.5	13	 **2m**	80	83.5:16.5
6	 **2f**	85	87:13	14	 **2n**	74	85:15
7	 **2g**	70	82:18	15	 **2o**	57	85:15
8	 **2h**	86	82:18	16	 **2p**	No reaction	-

[a][Rh]-precursor (2.5 mol%), (*S*)-**DIFLUOROPHOS** (7.5 mol%), **1a** (0.2 M). [b]Isolated yields. [c]Determined by HPLC. [d] NMR yield using 1,3,5-trimethoxybenzene as internal-standard.

To study the scope of the reaction, different secondary allylic alcohols were subjected to isomerization under the optimized reaction conditions (Table 3). All compounds were easily obtained through the regioselective hydrothiolation of propargylic alcohols catalyzed by $Pd(OAc)_2$, which allows the introduction of a thioether moiety exclusively at the *β*-position of the alcohol (see Supporting information).[14d,19] A range of substrates bearing different substituents on the aryl of the thioether moiety were isomerized in high yields and good to high enantioselectivities (substrates **2a**-**2h**). We were pleased to see that ketone **2b**, bearing a thiophenyl moiety, was obtained with perfect enantiopurity (>99:1 *er*). As far as we know, this is the highest enantioselectivity obtained for the isomerization of racemic allylic secondary alcohols.[16] The reaction tolerated the presence of alkyl groups in *para*-position and also the more electron donating methoxy group (substrates **2c**-**2f**), maintaining good enantioselectivities (~88:12

er). The presence of halogen groups slightly lowered the enantioselectivity (substrates **2g**-**2h**). The introduction of an electron withdrawing nitro group on the arylthioether moiety resulted in almost no conversion to ketone **2i**. Allylic alcohol with a non-aromatic cyclohexyl thioether group, generated the corresponding ketone with similar enantioselectivity (**2k**).

Similarly, when the aromatic ring next to the carbonyl was changed by a methyl group, the reaction showed poor enantioselectivity (**2l**). On the other hand, we could obtain ketones **2m** and **2n**, having an *o*-, or *p*-methyl group on the phenyl group, with good enantiomeric ratios. The phenyl ring could be also changed for a thiophene, keeping a good level of enantioselectivity (**2o**). Finally, the presence of a pyridine ring completely inhibited the reaction, probably due to coordination of the nitrogen atom to the metal centre (**2p**). It should be noted that the current methodology only allows the formation of ketones with a methyl next to the C-thioether moiety. This is because the Pd-catalyzed hydrothiolation reaction used for the preparation of allylic alcohols, is limited to terminal alkynes due to reactivity and regioselectivity issues. We have therefore only studied the scope of terminal secondary allylic alcohols.

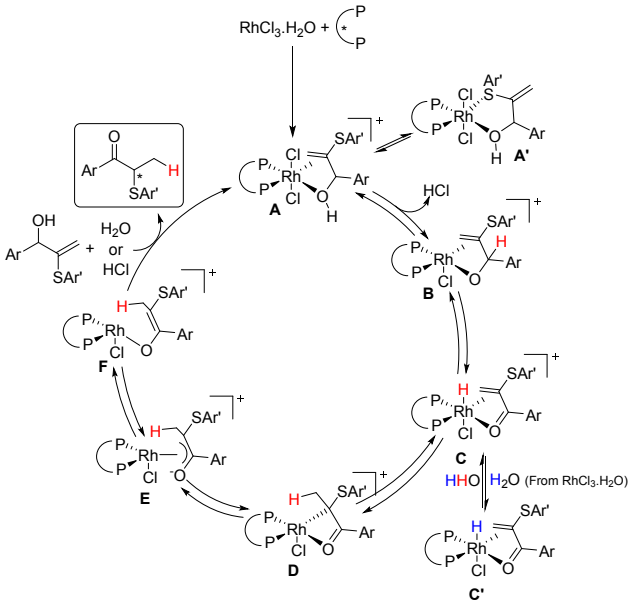
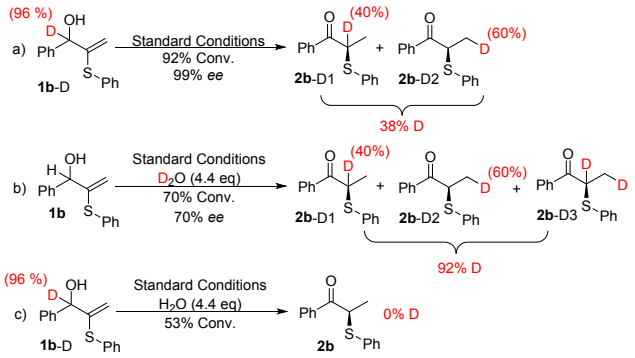


Figure 2. Proposed catalytic cycle for the Rh-catalyzed isomerization of secondary allylic alcohols.

Three different mechanisms have been proposed for the metal-catalyzed isomerization of allylic alcohols, all of them involving metal-hydride species.[20] The first one, involving alkylmetal intermediates, requires the use of a metal-hydride complex as a catalyst, either isolated or generated *in situ*.[21] The second mechanism proceeds through π-allyl intermediates and it has been usually proposed for low valent metals that can undergo an oxidative addition/reductive elimination sequence.[20] The last one, proposed by Trost, involves a coordinated enone as a key intermediate.[22] This mechanism was also supported by Gimeno, Sordo and co-workers with theoretical calculations.[18] Among all mechanistic proposals, this is the only one that assigns a role on the oxygen atom of the allylic alcohol. As suggested by Zhao and co-workers, our catalyst would follow a similar mechanism as the one proposed by Trost (Figure 2).[16a] First, coordination of the substrate followed by HCl formation would generate alkoxide intermediate **B**. It should be noted that the substrates used in this study contain a thioether group, which is known to be a good ligand for transition metals. Consequently, off-cycle species resembling to **A'** might be formed. Subsequent *β*-hydride elimination leads to the enone-Rh-hydride intermediate **C**, where the chirality of the starting material would be lost, enabling a steroconvergent process. Next, this intermediate undergoes 1,2-insertion, leading to **D**, which will form the enolate **F** through tautomerization on specie **E**. Finally, enantioselective protonation of the enolate provides the chiral ketone and catalyst regeneration.

To support the proposed reaction mechanism, we performed deuterium labelling experiments shown in Scheme 2. Isomerization of deuterated substrate **1b**-D under the optimized conditions (Scheme 2a), showed 38% of deuterium incorporation in both, *α*-, and *β*-positions of the ketone (2:3). When non-deuterated allylic alcohol **1b** was isomerized in presence of deuterium oxide, the ketone with the same deuterium distribution (2:3) was obtained, albeit with 92% of deuterium content (Scheme 2b). Both experiments show a proton-deuterium scrambling between *α*-, and *β*-positions. Since hydrated $RhCl_3$ is used, an exchange between the hydride and water present on the system could originate the H/D scrambling (Figure 2, species **C** and **C'**). To corroborate this hypothesis, water was added in the isomerization of deuterated alcohol **1b**-D (Scheme 2c). No deuterium was incorporated in the final product. In addition, we observed a loss of enantioselectivity when deuterium oxide was added in the reaction mixture (Scheme 2b).[23] This suggests that water could participate in the protonation of the enolate, which should be the enantio-determining step. Therefore, water has an important role, as suggested during the optimization of reaction conditions (see Table 2, entry 4 *vs* 3). In summary, deuterium experiments support a mechanism involving a Rh-hydride-enone intermediate. However, all attempts for trapping any reaction intermediate failed.

Scheme 2. Deuterium experiments



In conclusion, we have shown that the asymmetric isomerization of allylic alcohols can be used to obtain chiral *α*-sulfenylated ketones, which are highly versatile building blocks. The starting allylic alcohols can easily be prepared from readily available propargylic alcohols and thiols in presence of $Pd(OAc)_2$. Although good enantioselectivties could be obtained in some cases (typically 87:13 *er* and >99:1 for substrate **1b**), the system is limited to allylic alcohols containing arylthioether groups and aryl ketones. We hope that this report will inspire researchers to further develop benign methodologies to prepare enantioenriched *α*-sulfenylated carbonyl compounds.

EXPERIMENTAL SECTION

General information. All commercially available reagents were purchase from Sigma-Aldrich Company and

used as received without any purification. Solvents were obtained from VAC purification system and nitromethane was purchased in anhydrous grade from Sigma Adrich. Chiral phosphine ligands were purchased from Aldrich or Strem. Rhodium(III) chloride hydrate was purchased in Apollo Scientific. All reactions were carried out using standard Schlenk techniques under an atmosphere of argon with oven-dried glassware. Analytical thin-layer chromatography (TLC) was conducted using Merck analyticl TLC plates (silica gel 60 F-254). Compounds were visualized by ultraviolet light. Flash column chromatography was performed on silica gel (35-70 micron). Proton and carbon nuclear magnetic resonance (NMR) spectra were obtained using a Bruker 400 MHz spectrometer. Chemical shifts were recorded as δ values in ppm. Coupling constants (*J*) are given in Hz. High resolution mass spectrometry was recorded on Bruker Daltonics MicrOTOF. Chiral separation was performed with HPLC (YL-Clarity HPLC instrument) using Daicel Chiralcel columns AD and OJ-H. Optical rotations were recorded in a Perkin-Elmer 241 Polarimeter. The absolute configuration of the obtained chiral ketones was assigned by comparison of the chiral HPLC trace and optical rotation of compound **2b** with the reported in the literature.[13b] Non-commercially available propargylic alcohols were prepared as reported in the literature.[24] Yields for allylic alcohols **1a-1p** were from low to moderate since they decomposed during the purification in silica.

Experimental procedures for the synthesis of allylic alcohols 1a-1p and their spectroscopic data. Pd(OAc)2 (4.5 mg, 2 mol%) was weighed and transferred to a 5 mL microwave vial containing a small magnet. The vial was capped tightly and 2.0 mL of dry toluene (compounds **1a-1j**, **1o-1p**) or nitromethane (compounds **1j-1n**) followed by the corresponding propargylic alcohol (1 mmol) were added and stirred at room temperature for 5 minutes. The desired thiol (1.1 mmol) was added and the reaction mixture was heated at 80 °C (oil bath) for 16 h (compounds **1a**,**1c-1i**, **1l-1n**), at 80 °C (oil bath) for 48 h (compounds **1k**, **1p**) or at 55 °C (oil bath) for 16 h (compounds **1b**, **1j**, **1o**). After completion of the reaction toluene was evaporated under reduced pressure and the residue was purified by silica-gel column chromatography to afford the desired product.

*1-Phenyl-2-(m-tolylthio)prop-2-en-1-ol (**1a**):* yellow oil, (167 mg, 65% yield), (SiO2-chromathography, 10% (v/v) ethyl acetate / petroleum ether); ^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.46 – 7.33 (m, 5H), 7.26 – 7.24 (m, 3H), 7.15 – 7.12 (m, 1H), 5.63 (d, *J* = 1.2 Hz, 1H), 5.30 (d, *J* = 4.0 Hz, 1H), 2.45 (d, *J* = 4.4 Hz, 1H), 2.36 (s, 3H) ppm; ^{13}C{^{1}H} NMR (101 MHz, $CDCl_3$): δ = 148.2, 141.1, 139.1, 133.6, 132.4, 130.0, 129.1, 128.8, 128.4, 128.1, 126.7, 115.1, 76.2, 21.2 ppm; HRMS (ESI-TOF) m/z: [M + Na]$^+$ Calcd for $C_{16}H_{16}OSNa$ 279.0814; Found 279.0809.

*1-Phenyl-2-(m-phenylthio)prop-2-en-1-ol (**1b**)*[25]*:* yellowish oil, (146 mg, 60% yield), (SiO2-chromathography, 10% (v/v) ethyl acetate / petroleum ether); ^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.45 – 7.32 (m, 9H), 5.65 (d, *J* = 1.2 Hz, 1H), 5.30 (d, *J* = 4.0 Hz, 1H), 5.17 (d, *J* = 0.6 Hz, 1H), 2.39 (d, *J* = 4.3 Hz, 1H) ppm; ^{13}C{^{1}H} NMR (101 MHz, $CDCl_3$): δ = 148.0, 140.9, 133.0, 132.5, 129.3, 128.5, 128.2, 128.0, 126.7, 115.2, 76.1 ppm; HRMS (ESI-TOF) m/z: [M + Na]$^+$ Calcd for $C_{15}H_{14}OSNa$ 265.0658; Found 265.0666.

*1-Phenyl-2-(p-tolylthio)prop-2-en-1-ol (**1c**):* yellowish oil, (139 mg, 52% yield), (SiO_2-chromathography, 10% (v/v) ethyl acetate / petroleum ether); ^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.45 – 7.33 (m, 7H), 7.18 – 7.15 (m, 2H), 5.55 (d, *J* = 1.2 Hz, 1H), 5.30 (bs, 1H), 5.07 (d, *J* = 0.6 Hz, 1H), 2.37 (s, 3H); ^{13}C{^{1}H} NMR (101 MHz, Toluene-d_8): δ = 149.7, 141.9, 137.6, 133.5, 129.9, 129.6, 128.0, 126.8, 112.5, 76.0, 20.6 ppm; HRMS (ESI-TOF) m/z: [M + Na]$^+$ Calcd for $C_{16}H_{16}OSNa$ 279.0814; Found 279.0802.

*2-((4-(tert-Butyl)phenyl)thio)-1-phenylprop-2-en-1-ol (**1d**):* yellowish oil (89 mg, 30% yield), (SiO_2-chromathography, 10% (v/v) ethyl acetate / petroleum ether); ^{1}H NMR (400 MHz, Toluene-d_8): δ = 7.40 – 7.37 (m, 2H), 7.35 – 7.31 (m, 2H), 7.20 – 7.16 (m, 2H), 7.12 – 7.09 (m, 3H), 5.56 (d, *J* = 1.2 Hz, 1H), 5.19 – 5.06 (m, 2H), 1.76 (d, *J* = 4.1 Hz, 1H), 1.17 (s, 9H) ppm; ^{13}C{^{1}H} NMR (101 MHz, Toluene-d_8): δ = 150.7, 149.3, 141.9, 133.1, 129.7, 128.1, 126.8, 126.2, 113.1, 76.0, 34.2, 30.8 ppm; HRMS (ESI-TOF) m/z: [M + Na]$^+$ Calcd for $C_{19}H_{22}OSNa$ 321.1284; Found 321.1287.

*2-((4-Isopropylphenyl)thio)-1-phenylprop-2-en-1-ol (**1e**):* yellowish oil (153 mg, 54% yield), (SiO_2-chromathography, 10% (v/v) ethyl acetate / petroleum ether); ^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.43 (m, 2H), 7.41 – 7.33 (m, 5H), 7.20 (d, *J* = 8.1 Hz, 2H), 5.57 (d, *J* = 1.2 Hz, 1H), 5.30 (s, 1H), 5.11 (d, *J* = 0.6 Hz, 1H), 2.91 (m, 1H), 1.27 (d, *J* = 6.9 Hz, 6H) ppm; ^{13}C{^{1}H} NMR (101 MHz, $CDCl_3$): δ = 149.2, 148.8, 141.1, 133.5, 129.1, 128.4, 128.0, 127.4, 126.7, 114.1, 76.2, 33.8, 23.8 ppm; HRMS (ESI-TOF) m/z: [M + Na]$^+$ Calcd for $C_{18}H_{20}OSNa$ 307.1127; Found 307.1124.

*2-((4-Methoxyphenyl)thio)-1-phenylprop-2-en-1-ol (**1f**):* colorless solid (208 mg, 76%, yield), (SiO_2-chromathography, 15% (v/v) ethyl acetate / petroleum ether); ^{1}H NMR (400 MHz, Toluene-d_8): δ = 7.46 – 7.44 (m, 2H), 7.41 – 7.32 (m, 5H), 6.91 – 6.88 (m, 2H), 5.46 (d, *J* = 1.1 Hz, 1H), 5.31 (d, *J* = 4.1 Hz, 1H), 4.92 (d, *J* = 0.5 Hz, 1H), 3.84 (s, 3H), 2.33 (d, *J* = 4.3 Hz, 1H) ppm; ^{13}C{^{1}H} NMR (101 MHz, Toluene-d_8): δ = 160.1, 150.0, 141.1, 136.0, 128.4, 128.1, 126.7, 122.3, 114.9, 111.8, 76.2 ppm; HRMS (ESI-TOF) m/z: [M + Na]$^+$ Calcd for $C_{16}H_{16}O_2SNa$ 295.0763; Found 295.0766.

*2-((4-Bromophenyl)thio)-1-phenylprop-2-en-1-ol (**1g**):* colorless solid (139 mg, 43% yield), (SiO_2-chromathography, 10% (v/v) ethyl acetate / petroleum ether); ^{1}H NMR (400 MHz, Toluene-d_8): δ = 7.47 – 7.44 (m, 2H), 7.42 – 7.34 (m, 5H), 7.29 – 7.26 (m, 2H), 5.70 (d, *J* = 1.2 Hz, 1H), 5.28 (bs, 1H), 5.22 (d, *J* = 0.6 Hz, 1H), 2.30 (bs, 1H) ppm; ^{13}C{^{1}H} NMR (101 MHz, Toluene-d_8): δ = 147.4, 140.8, 134.2, 132.4, 132.1, 128.5, 128.2, 126.7, 122.1, 116.2, 76.2 ppm; HRMS (ESI-TOF) m/z: [M + Na]$^+$ Calcd for $C_{15}H_{13}BrOSNa$ 342.9763; Found 342.9733.

*2-((4-Fluorophenyl)thio)-1-phenylprop-2-en-1-ol (**1h**):* colorless solid (121 mg, 46% yield), (SiO2-chromathography, 10% (v/v) ethyl acetate / petroleum ether); ^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.44 – 7.32 (m, 7H), 7.07 – 7.03 (m, 2H), 5.59 (d, *J* = 1.2 Hz, 1H), 5.30 (b, 1H), 5.04 (s, 1H), 2.33 (d, J = 3.7 Hz, 1H) ppm; ^{13}C{^{1}H} NMR (101 MHz, $CDCl_3$): δ = 162.8 (d, $^1J_{C-F}$ = 248.7 Hz), 148.8, 140.9, 135.7 (d, $^3J_{C-F}$ = 8.3 Hz), 128.5, 128.2, 127.4 (d, $^4J_{C-F}$ = 3.3 Hz), 126.7, 116.5 (d, $^2J_{C-F}$ = 22.0 Hz), 113.8, 76.3 ppm; HRMS (ESI-TOF) m/z: [M + Na]$^+$ Calcd for $C_{15}H_{13}FOSNa$ 283.0563; Found 283.0559.

*2-((4-Nitrophenyl)thio)-1-phenylprop-2-en-1-ol (**1i**):* yellow oil (155 mg, 54% yield), (SiO_2-chromathography, 20% (v/v) ethyl acetate / petroleum ether); ^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.08 (d, *J* = 9.0 Hz, 2H), 7.39 – 7.29 (m, 7H), 6.13 (d, *J* = 1.3 Hz, 1H), 5.69 (d, *J* = 0.8 Hz, 1H), 5.25 (s, 1H) ppm; ^{13}C{^{1}H} NMR (101 MHz, $CDCl_3$): δ = 144.9, 143.5, 140.5, 137.0, 128.9, 128.6, 128.5, 126.7, 124.0, 123.9, 76.6, 30.9 ppm; HRMS (ESI-TOF) m/z: [M + Na]$^+$ Calcd for $C_{15}H_{13}NO_3SNa$ 287.0616; Found 287,0627.

*1-Phenyl-2-(o-tolylthio)prop-2-en-1-ol (**1j**):* yellow oil (111 mg, 43% yield); ^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.47 – 7.44 (m,

3H), 7.43 – 7.33 (m, 3H), 7.30 – 7.25 (m, 2H), 7.24 – 7.18 (m, 1H), 5.51 (d, *J* = 1.2 Hz, 1H), 5.32 (s, 1H), 4.78 (d, *J* = 0.5 Hz, 1H), 2.31 (s, 3H) ppm; $^{13}C\{^1H\}$ NMR (101 MHz, $CDCl_3$): δ = 147.7, 141.7, 141.1, 135.0, 130.8, 128.9, 128.4, 128.2, 127.4, 126.8, 126.6, 111.7, 76.3, 20.4 ppm; HRMS (ESI-TOF) m/z: $[M + Na]^+$ Calcd for $C_{16}H_{16}OSNa$ 279.0814; Found 279.0810.

*2-(Cyclohexylthio)-1-phenylprop-2-en-1-ol (**1k**):* yellow oil (116 mg, 47% yield), (SiO_2-chromathography, 10% (v/v) ethyl acetate / petroleum ether); ^1H NMR (400 MHz, $CDCl_3$): δ = 7.46 – 7.29 (m, 5H), 5.60 (d, *J* = 1.1 Hz, 1H), 5.27 (d, *J* = 5.1 Hz, 1H), 5.19 (s, 1H), 2.97 – 2.91 (m, 1H), 2.46 – 2.44 (m, 1H), 2.03 – 1.97 (m, 2H), 1.80 – 1.73 (m, 2H), 1.64 – 1.59 (m, 1H), 1.39 – 1.23 (m, 5H) ppm; $^{13}C\{^1H\}$ NMR (101 MHz, $CDCl_3$): δ = 146.8, 141.3, 128.3, 127.9, 126.5, 112.2, 77.1, 44.3, 32.9 (x2), 26.0 (x2), 25.8 ppm; HRMS (ESI-TOF) m/z: $[M + Na]^+$ Calcd for $C_{15}H_{20}OSNa$ 271.1127; Found 271.1111.

*3-(Phenylthio)but-3-en-2-ol (**1l**):* yellow oil (92 mg, 51% yield), (SiO_2-chromathography, 10% (v/v) ethyl acetate / petroleum ether); ^1H NMR (400 MHz, C_6D_6): δ = 7.33 (dd, *J* = 8.1, 1.4 Hz, 1H), 7.11 (m, 2H), 6.95 – 6.88 (m, 2H), 5.34 (d, *J* = 1.2 Hz, 1H), 4.94 (d, *J* = 0.6 Hz, 1H), 4.08 (d, *J* = 6.6 Hz, 1H), 1.24 (d, *J* = 6.4 Hz, 3H) ppm; $^{13}C\{^1H\}$ NMR (101 MHz, C_6D_6): δ = 150.4, 133.3, 132.7, 129.1, 112.5, 69.9, 22.8 ppm; HRMS (ESI-TOF) m/z: $[M]^+$ Calcd for $C_{10}H_{12}O^+$ 180,0609; Found 180,0672.

*2-(Phenylthio)-1-(p-tolyl)prop-2-en-1-ol (**1m**):* yellow oil (98 mg, 38% yield), (SiO_2-chromathography, 10% (v/v) ethyl acetate / petroleum ether); ^1H NMR (400 MHz, $CDCl_3$): δ = 7.45 – 7.42 (m, 2H), 7.37 – 7.31 (m, 5H), 7.21 – 7.19 (m, 2H), 5.64 (d, *J* = 1.2 Hz, 1H), 5.26 (d, *J* = 4.2 Hz, 1H), 5.16 (d, *J* = 0.7 Hz, 1H), 2.38 (s, 3H), 2.28 (d, *J* = 4.4 Hz, 1H) ppm; $^{13}C\{^1H\}$ NMR (101 MHz, C_6D_6): δ = 148.3, 138.2, 138.0, 133.1, 132.9, 129.4, 129.3, 128.0, 126.8, 115.0, 76.1, 21.3 ppm; HRMS (ESI-TOF) m/z: $[M + Na]^+$ Calcd for $C_{16}H_{16}OSNa$ 279.0814; Found 279.0806.

*2-(Phenylthio)-1-(o-tolyl)prop-2-en-1-ol (**1n**):* yellow oil (80 mg, 32% yield), (SiO_2-chromathography, 10% (v/v) ethyl acetate / petroleum ether); ^1H NMR (400 MHz, $CDCl_3$): δ = 7.53 (dd, *J* = 2.4 Hz, 6.8 Hz 1H), 7.46 (m, 2H), 7.38 – 7.32 (m, 3H), 7.27 – 7.22 (m, 2H), 7.16 (m, 1H), 5.48 (d, *J* = 1.3 Hz, 1H), 5.45 (d, *J* = 3.9 Hz, 1H), 5.20 (d, *J* = 0.8 Hz, 1H), 2.30 (bs, 1H), 2.28 (s, 3H) ppm; $^{13}C\{^1H\}$ NMR (101 MHz, $CDCl_3$): δ = 147.4, 138.7, 136.0, 133.2, 132.5, 130.4, 129.2, 128.1, 128.0, 126.4, 126.2, 115.5, 72.6, 19.1 ppm; HRMS (ESI-TOF) m/z: $[M + Na]^+$ Calcd for $C_{16}H_{16}OSNa$ 279.0814; Found 279.0827.

*2-(Phenylthio)-1-(thiophen-3-yl)prop-2-en-1-ol (**1o**):* yellow oil (90 mg, 36% yield), (SiO_2-chromathography, 10% (v/v) ethyl acetate / petroleum ether); ^1H NMR (400 MHz, Toluene-d_8): δ = 7.32 – 7.29 (m, 2H), 7.01 – 7.69 (m, 5H), 6.85 (dd, *J* = 5.0, 3.0 Hz, 1H), 5.52 (d, *J* = 1.2 Hz, 1H), 5.08 (s, 1H), 5.07 (d, *J* = 0.6 Hz, 1H) ppm; $^{13}C\{^1H\}$ NMR (101 MHz, Toluene-d_8): δ = 148.4, 143.2, 133.3, 132.8, 129.0, 127.5, 126.2, 125.3, 122.0, 114.0, 72.4 ppm; HRMS (ESI-TOF) m/z: $[M + Na]^+$ Calcd for $C_{13}H_{12}OS_2Na$ 271.0222; Found 271.0216.

*2-(Phenylthio)-1-(pyridin-3-yl)prop-2-en-1-ol (**1p**):* yellow oil (142 mg, 58% yield), (Al_2O_3-chromathography, 99% (v/v) ethyl acetate / triethylamine); ^1H NMR (400 MHz, $CDCl_3$): δ = 8.60 (m, 1H), 8.52 (dd, *J* = 4.9, 1.6 Hz, 1H), 7.81 (dt, *J* = 7.9, 1.8 Hz, 1H), 7.38 – 7.36 (m, 2H), 7.34 – 7.28 (m, 4H), 5.65 (d, *J* = 1.1 Hz, 1H), 5.31 (s, 1H), 5.18 (s, 1H), 2.49 (bs, 1H) ppm; $^{13}C\{^1H\}$ NMR (101 MHz, $CDCl_3$): δ = 148.4, 147.8, 147.4, 134.9, 133.0, 129.4, 128.3, 123.6, 115.7, 73.9 ppm; HRMS (ESI-TOF) m/z: $[M + Na]^+$ Calcd for $C_{14}H_{13}NOSNa$ 243.0718; Found 243.0727.

General procedure for the isomerization of allylic alcohols 1a-p and characterization data for ketones 2a-p. $RhCl_3.H_2O$ (0.52 mg, 2.5 mol%) and (*S*)-**DIFLUORPHOS** (5.12 mg, 7.4 mol%) were weighed and transferred to a 5 mL microwave vial containing a small magnet. The vial was capped tightly and 0.25 mL of dry toluene solvent was added and stirred at room temperature for 15 minutes. Next, a solution of the allylic alcohol (0.1 mmol) in toluene (0.25 mL) was added and the reaction mixture was heated at 55 °C (oil bath) for 36 h. After completion of the reaction, the reaction mixture was filtered through a plug of silica washed with EtOAc. The crude was evaporated under reduced pressure and the residue was purified by silica-gel column chromatography to afford the desired ketone.

*1-Phenyl-2-(m-tolylthio)propan-1-one (**2a**):* yellowish oil (23 mg, 90% yield), (SiO_2-chromathography, 5% (v/v) ethyl acetate / petroleum ether); ^1H NMR (400 MHz, $CDCl_3$): δ = 7.97 (dd, *J* = 8.4, 1.6 Hz, 2H), 7.60 – 7.56 (m, 1H), 7.49 – 7.45 (m, 2H), 7.20 – 7.17 (m, 3H), 7.15 – 7.11 (m, 1H), 4.65 (q, *J* = 6.8 Hz, 1H), 2.32 (s, 3H), 1.57 (d, *J* = 6.8 Hz, 3H) ppm; $^{13}C\{^1H\}$ NMR (101 MHz, $CDCl_3$): δ = 196.4, 138.7, 135.9, 135.0, 133.0, 131.7, 131.3, 129.4, 128.7, 128.6, 128.5, 46.5, 21.2, 17.1 ppm; HRMS (ESI-TOF) m/z: $[M + Na]^+$ Calcd for $C_{16}H_{16}OSNa$ 279.0814; Found 279.0810; HPLC analysis: Daicel Chiralcel OJ-H column, n-Hexane: isopropanol = 90:10, flow rate 1 mL/min, λ = 254 nm (channel 1), 232 nm (channel 2): t_1 (major) = 10.2 min, t_2 (minor) = 19.6 min; 76% *ee*.

*(R)-1-Phenyl-2-(penyllthio)propan-1-one (**2b**)*[13b]*:* yellowish oil (17 mg, 71% yield), (SiO_2-chromathography, 5% (v/v) ethyl acetate / petroleum ether); ^1H NMR (400 MHz, $CDCl_3$): δ = 8.02 – 7.89 (m, 2H), 7.65 – 7.56 (m, 1H), 7.48 (dd, *J* = 8.3, 6.9 Hz, 2H), 7.41 – 7.29 (m, 5H), 4.66 (q, *J* = 6.9 Hz, 1H), 1.55 (d, *J* = 6.9 Hz, 3H) ppm; $^{13}C\{^1H\}$ NMR (101 MHz, $CDCl_3$): δ = 196.3, 135.6, 134.8, 133.2, 131.5, 129.0, 128.7, 128.6, 46.1, 17.0 ppm; HRMS (ESI-TOF) m/z: $[M + Na]^+$ Calcd for $C_{15}H_{14}OSNa$ 265.0658; Found 265.0654; $[\alpha]^{24}_D$ = +48.3 (c = 1.000, $CHCl_3$); HPLC analysis: Daicel Chiralcel OJ-H column, n-Hexane: isopropanol = 98:2, flow rate 1 mL/min, λ = 254 nm (channel 1), 232 nm (channel 2): t_1 (major) = 29.1 min, t_2 (minor) = 59.2 min; >99% *ee* (*R*).

*1-Phenyl-2-(p-tolylthio)propan-1-one (**2c**):* yellowish oil (20 mg, 79% yield), (SiO_2-chromathography, 5% (v/v) ethyl acetate / petroleum ether); ^1H NMR (400 MHz, $CDCl_3$): 8.00 – 7.97 (m, 2H), 7.61 – 7.56 (m, 1H), 7.50 – 7.46 (m, 2H), 7.26 (d, *J* = 8.1 Hz, 2H), 7.11 (d, *J* = 8.6 Hz, 2H) 4.58 (q, *J* = 6.8 Hz, 1H), 2.35 (s, 3H), 1.53 (d, *J* = 6.8 Hz, 3H); $^{13}C\{^1H\}$ NMR (101 MHz, $CDCl_3$): 196.1, 139.0, 135.8, 135.2, 133.0, 129.7, 128.7, 128.5, 127.7, 46.2, 21.2, 16.8; HRMS (ESI-TOF) m/z: $[M + Na]^+$ Calcd for $C_{16}H_{16}OSNa$ 279.0814; Found 279.0804; HPLC analysis: Daicel Chiralcel AD column: n-Hexane: isopropanol = 98:2, flow rate 1 mL/min, λ = 254 nm (channel 1), 232 nm (channel 2): t_1 (major) = 8.4 min, t_2 (minor) = 9.1 min; 76% *ee*.

*2-((4-(tert-Butyl)phenyl)thio)-1-phenylpropan-1-one (**2d**):* yellowish oil (24 mg, 82% yield), (SiO_2-chromathography, 5% (v/v) ethyl acetate / petroleum ether); ^1H NMR (400 MHz, $CDCl_3$): δ = 7.96 (dd, *J* = 8.0, 1.2 Hz, 2H), 7.60 – 7.55 (m, 1H), 7.48 – 7.44 (m, 2H), 7.30 (s, 4H), 4.61 (q, *J* = 6.8 Hz, 1H), 1.55 (d, *J* = 6.8 Hz, 3H), 1.32 (s, 9H) ppm; $^{13}C\{^1H\}$ NMR (101 MHz, $CDCl_3$): δ = 196.5, 152.0, 135.8, 134.7, 133.0, 128.7, 128.5, 128.0, 126.00, 46.2, 34.7, 31.2, 16.9 ppm; HRMS (ESI-TOF) m/z: $[M + Na]^+$ Calcd for $C_{19}H_{22}OSNa$ 321.1284; Found 321.1286; HPLC analysis using: Daicel Chiralcel OJ-H column, n-Hexane: isopropanol = 99.5:0.5, flow rate 1 mL/min, λ = 254 nm

(channel 1), 232 nm (channel 2): t_1 (major) = 13.2 min, t_2 (minor) = 15.1 min; 76% *ee*.

2-((4-Isopropylphenyl)thio)-1-phenylpropan-1-one (**2e**): yellowish oil (20 mg, 71% yield), (SiO_2-chromatography, 5% (v/v) ethyl acetate / petroleum ether); ^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.97 (dd, *J* = 8.4, 1.3 Hz, 2H), 7.57 (m, 1H), 7.46 (t, *J* = 8.3 Hz, 2H), 7.33 – 7.25 (m, 2H), 7.15 (d, *J* = 8.0 Hz, 2H), 4.60 (q, *J* = 6.9 Hz, 1H), 3.03 – 2.80 (m, 1H), 1.54 (d, *J* = 6.8 Hz, 3H), 1.25 (d, *J* = 7.0 Hz, 6H) ppm; ^{13}C{^{1}H} NMR (101 MHz, $CDCl_3$): δ = 196.4, 149.8, 135.8, 135.1, 133.0, 128.7, 128.5, 128.2, 127.1, 46.3, 33.8, 23.9, 23.8, 16.9 ppm; HRMS (ESI-TOF) m/z: $[M + Na]^+$ Calcd for $C_{18}H_{20}OSNa$ 307.1127; Found 307.1126; HPLC analysis: Daicel Chiralcel OJ-H column, n-Hexane: isopropanol = 90:10, flow rate 1 mL/min, λ = 254 nm (channel 1), 232 nm (channel 2): t_1 (major) = 8.6 min, t_2 (minor) = 11.9 min; 75% *ee*.

2-((4-Methoxyphenyl)thio)-1-phenylpropan-1-one (**2f**): white solid (23 mg, 85 % yield), (SiO_2-chromatography, 10% (v/v) ethyl acetate / petroleum ether); ^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.00 – 7.97 (m, 2H), 7.61 – 7.56 (m, 1H), 7.50 – 7.46 (m, 2H), 7.30 – 7.27 (m, 2H), 6.84 – 6.82 (m, 2H), 4.52 (q, *J* = 6.8 Hz, 1H), 3.82 (s, 3H), 1.50 (d, *J* = 6.8 Hz, 3H) ppm; ^{13}C{^{1}H} NMR (101 MHz, $CDCl_3$): δ = 196.0, 160.6, 137.6, 135.9, 132.9, 128.6, 128.6, 121.4, 114.5, 55.3, 46.3, 16.5 ppm; HRMS (ESI-TOF) m/z: $[M + Na]^+$ Calcd for $C_{16}H_{16}O_2SNa$ 295.0763; Found 295.0760; HPLC analysis: Daicel Chiralcel OJ-H column, n-Hexane: isopropanol = 90:10, flow rate 1 mL/min, λ = 254 nm (channel 1), 232 nm (channel 2): t_1 (major) = 50.9 min, t_2 (minor) = 58.3 min; 74% *ee*.

2-((4-Bromophenyl)thio)-1-phenylpropan-1-one (**2g**): white solid (23 mg, 70% yield), (SiO_2-chromatography, 5% (v/v) ethyl acetate / petroleum ether); ^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.98 – 7.96 (m, 2H), 7.62 – 7.58 (m, 1H), 7.51 – 7,47 (m, 2H), 7.42 (d, *J* = 8.4 Hz, 2H), 7.22 (d, *J* = 8.4 Hz, 2H), 4.64 (q, *J* = 6.9 Hz, 1H), 1.54 (d, *J* = 6.9 Hz, 3H) ppm; ^{13}C{^{1}H} NMR (101 MHz, $CDCl_3$): δ = 195.9, 136.2, 135.5, 133.2, 132.1, 130.6, 128.6, 128.7, 123.3, 46.0, 16.9. ppm; HRMS (ESI-TOF) m/z: $[M + Na]^+$ Calcd for $C_{15}H_{13}BrOSNa$ 342.9763; Found 342.9756; HPLC analysis: Daicel Chiralcel AD column, n-Hexane: isopropanol = 95:5, flow rate 1 mL/min, λ = 254 nm (channel 1), 232 nm (channel 2): t_1 (major) = 7.9 min, t_2 (minor) = 8.8 min; 64% *ee*.

2-((4-Fluorophenyl)thio)-1-phenylpropan-1-oneone (**2h**)[26]: yellowish oil (22 mg, 86% yield), (SiO_2-chromatography, 5% (v/v) ethyl acetate / petroleum ether); ^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.97 (dd, *J* = 8.4, 1.4 Hz, 2H), 7.62 – 7.57 (m, 1H), 7.50 – 7.46 (m, 2H), 7.35 – 7.32 (m, 2H), 7.01 – 6.97 (m, 2H), 4.58 (q, *J* = 6.8 Hz, 1H), 1.52 (d, *J* = 6.8 Hz, 3H) ppm; ^{13}C{^{1}H} NMR (101 MHz, $CDCl_3$): δ = 195.9, 163.4 (d, $^1J_{C-F}$ = 249.7 Hz), 137.5 (d, $^3J_{C-F}$ = 8.4 Hz), 135.7, 128.6, 126.34 (d, $^4J_{C-F}$ = 3.5 Hz), 116.0 (d, $^2J_{C-F}$ = 21.9 Hz), 46.1, 16.7 ppm; HRMS (ESI-TOF) m/z: $[M + Na]^+$ Calcd for $C_{15}H_{13}OFSNa$ 283.0563; Found 283.0567; HPLC analysis using Daicel Chiralcel OJ-H column, n-Hexane: isopropanol = 90:10, flow rate 1 mL/min, λ = 254 nm (channel 1), 232 nm (channel 2): t_1 (major) = 13.1 min, t_2 (minor) = 22.2 min; 64% *ee*.

1-Phenyl-2-(o-tolylthio)propan-1-one (**2j**): yellowish oil (19 mg, 75% yield), (SiO_2-chromatography, 5% (v/v) ethyl acetate / petroleum ether); ^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.91 (dd, *J* = 8.4, 1.3 Hz, 2H), 7.59 – 7.5 (m, 1H), 7.46 – 7.41 (m, 2H), 7.36 (d, *J* = 7.4 Hz, 1H), 7.24 – 7.19 (m, 2H), 7.15 – 7.11 (m, 1H), 4.68 (q, *J* = 6.9 Hz, 1H), 2.34 (s, 3H), 1.58 (d, *J* = 6.9 Hz, 3H) ppm; ^{13}C{^{1}H} NMR (101 MHz, $CDCl_3$): δ = 196.8, 141.5, 135.6, 134.5, 133.2, 131.9, 130.5, 128.6, 128.6, 128.5, 126.5, 46.1, 21.0, 17.1 ppm; HRMS (ESI-TOF) m/z: $[M + Na]^+$ Calcd for $C_{16}H_{16}OSNa$ 279.0814; Found 279.0810; HPLC analysis: Daicel Chiralcel AD column, n-Hexane: isopropanol = 95:5, flow rate 1 mL/min, λ = 254 nm (channel 1), 232 nm (channel 2): t_1 (major) = 6.2 min, t_2 (minor) = 6.9 min; 50% *ee*.

2-(Cyclohexylthio)-1-phenylpropan-1-one (**2k**)[14d]: yellowish oil (22 mg, 88% yield), (SiO_2-chromatography, 5% (v/v) ethyl acetate / petroleum ether); ^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.03 (dd, *J* = 8.4, 1.4 Hz, 2H), 7.60 – 7.56 (m, 1H), 7.50 – 7.46 (m, 2H), 4.39 (q, *J* = 6.9 Hz, 1H), 2.80 – 2.73 (m, 1H), 1.98 – 1.93 (m, 1H), 1.86 – 1.84 (m, 1H), 1.76 – 1.68 (m, 2H), 1.60 (d, *J* = 6.9 Hz, 3H), 1.60 – 1.54 (m, 1H), 1.42 – 1.18 (m, 5H) ppm; ^{13}C{^{1}H} NMR (101 MHz, $CDCl_3$): δ = 197.5, 135.9, 132.9, 128.6, 128.5, 42.6, 42.0, 34.7, 34.3, 26.0 (x2), 25.6, 17.7 ppm; HRMS (ESI-TOF) m/z: $[M + Na]^+$ Calcd for $C_{15}H_{20}OSNa$ 271.1127; Found 271.1119; HPLC analysis using Daicel Chiralcel OJ-H column, n-Hexane: isopropanol = 93:7, flow rate 0.5 mL/min, λ = 254 nm (channel 1), 232 nm (channel 2): t_1 (major) = 11.6 min, t_2 (minor) = 15.2 min; 68% *ee*.

3-(Phenylthio)butan-2-one (**2l**)[14d]: yellowish oil (17 mg, 92% yield), (SiO_2-chromatography, 5% (v/v) ethyl acetate / petroleum ether); ^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.42 – 7.39 (m, 2H), 7.35 – 7.30 (m, 3H), 3.79 (q, *J* = 7.0 Hz, 1H), 2.30 (s, 3H), 1.44 (d, *J* = 7.1 Hz, 3H) ppm; ^{13}C{^{1}H} NMR (101 MHz, $CDCl_3$): δ = 205.6, 132.8, 132.6, 129.1, 128.0, 52.1, 26.3, 16.1 ppm; HRMS (ESI-TOF) m/z: $[M + Na]^+$ Calcd for $C_{10}H_{12}OSNa$ 180.0609; Found 180,0602; HPLC analysis using Daicel Chiralcel OJ-H column, n-Hexane: isopropanol = 90:10, flow rate 0.3 mL/min, λ = 254 nm (channel 1), 232 nm (channel 2): t_1 (major) = 47.0 min, t_2 (minor) = 49 min; 20% *ee*.

2-(Phenylthio)-1-(p-tolyl)propan-1-one (**2m**): yellowish oil (20 mg, 80% yield), (SiO_2-chromatography, 5% (v/v) ethyl acetate / petroleum ether); ^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.88 (d, *J* = 8.4 Hz, 2H), 7.39 – 7.37 (m, 2H), 7.33 – 7.26 (m, 5H), 4.64 (q, *J* = 6.8 Hz, 1H), 2.44 (s, 3H), 1.55 (d, *J* = 6.8 Hz, 3H) ppm; ^{13}C{^{1}H} NMR (101 MHz, $CDCl_3$): δ = 196.0, 143.9, 134.4, 133.1, 132.0, 129.3, 128.9, 128.8, 128.5, 46.2, 21.7, 17.1 ppm.]; HRMS (ESI-TOF) m/z: $[M + Na]^+$ Calcd for $C_{16}H_{16}OSNa$ 279.0814; Found 279.0808; HPLC analysis using Daicel Chiralcel OJ-H column, n-Hexane: isopropanol = 90:10, flow rate 1 mL/min, λ = 254 nm (channel 1), 232 nm (channel 2): t_1 (major) = 11.1 min, t_2 (minor) = 26.0 min; 67% *ee*.

2-(Phenylthio)-1-(o-tolyl)propan-1-one (**2n**): yellowish oil (19 mg, 74% yield), (SiO_2-chromatography, 5% (v/v) ethyl acetate / petroleum ether); ^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.53 (dd, *J* = 7.8, 1.3 Hz, 1H), 7.38 – 7.33 (m, 3H), 7.30 – 7.23 (m, 4H), 7.22 – 7.17 (m, 1H), 4.55 (q, *J* = 6.9 Hz, 1H), 2.46 (s, 3H), 1.57 (d, J = 7.0 Hz, 3H) ppm; ^{13}C{^{1}H} NMR (101 MHz, $CDCl_3$): δ = 200.4, 138.6, 137.4, 133.8, 132.8, 131.8, 131.2, 128.9, 128.2, 127.9, 125.4, 49.7, 20.9, 17.1 ppm; HRMS (ESI-TOF) m/z: $[M + Na]^+$ Calcd for $C_{16}H_{16}OSNa$ 279.0814; Found 279.0810; HPLC analysis: Daicel Chiralcel OJ-H column, n-Hexane: isopropanol = 90:10, flow rate 1 mL/min, λ = 254 nm (channel 1), 232 nm (channel 2): t_1 (major) = 11.3 min, t_2 (minor) = 21.1 min. 70% *ee*.

2-(phenylthio)-1-(thiophen-3-yl)propan-1-one (**2o**): yellowish oil (14 mg, 57% yield), (SiO_2-chromatography, 5% (v/v) ethyl acetate / petroleum ether); ^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.06 (dd, *J* = 2.9, 1.3 Hz, 1H), 7.58 (dd, *J* = 5.1, 1.3 Hz, 1H), 7.40 – 7.38 (m, 2H), 7.35 – 7,29 (m, 4H), 4.42 (q, *J* = 6.9 Hz, 1H), 1.54 (d, *J* = 6.9 Hz, 3H) ppm; ^{13}C{^{1}H} NMR (101 MHz, $CDCl_3$): δ = 191.0, 140.4, 134.6, 132.7, 131.8, 129.0, 128.7, 127.5, 126.3, 48.2, 16.9 ppm; HRMS (ESI-TOF) m/z: $[M + Na]^+$ Calcd for $C_{13}H_{12}OS_2Na$ 271.0222; Found 271.0216; HPLC analysis:

Daicel Chiralcel AD column, n-Hexane: isopropanol = 95:5, flow rate 0.5 mL/min, λ = 254 nm (channel 1), 232 nm (channel 2): t_1 (major) = 17.9 min, t_2 (minor) = 19.3 min; 70% *ee*.

Preparation of 1-phenyl-2-(*m*-tolylthio)propan-1-one (2a) at 1 mmol scale. $RhCl_3.H_2O$ (5.2 mg, 2.5 mol%) and (*S*)-**DIFLUORPHOS** (51.2 mg, 7.4 mol%) were weighed and transferred to a Schlenk-tube. Then, 2.5 mL of dry toluene solvent was added and stirred at room temperature for 15 minutes. Next, a solution of allylic alcohol **1a** (1 mmol) in toluene (2.5 mL) was added and the reaction mixture was heated at 55 °C (oil bath) for 36 h. After completion of the reaction, the reaction mixture was filtered through a plug of silica washed with EtOAc. The crude was evaporated under reduced pressure and the residue was purified by silica-gel column chromatography (5% (v/v) ethyl acetate / petroleum ether), to afford the desired ketone (205 mg, 81% yield); HPLC analysis: Daicel Chiralcel OJ-H column, n-Hexane: isopropanol = 99:1, flow rate 1 mL/min, λ = 254 nm (channel 1), 232 nm (channel 2): t_1 (major) = 8.5 min, t_2 (minor) = 9.0 min; 74% *ee*.

ASSOCIATED CONTENT

Experimental details and characterization data, NMR spectra and HPLC chromatograms, are available free of charge via the Internet at http://pubs.acs.org.

AUTHOR INFORMATION

Corresponding Author

*E-mail: joseph.samec@su.se.

ORCID

Joseph S. M. Samec: 0000-0001-8735-5397

Notes

The authors declare no competing financial interest.

ACKNOWLEDGMENT

Financial support from the Swedish Research Council (Formas) and Stiftelsen Olle Engkvist Byggmästare is gratefully acknowledged.

REFERENCES

[1] For reviews on C-S formation, see: (a) Kondo, T.; Mitsudo, T.-A. Metal-Catalyzed Carbon–Sulfur Bond Formation. *Chem. Rev.* **2000**, *100*, 3205. (b) Chauhan, P.; Mahajan, S.; Enders, D. Organocatalytic Carbon–Sulfur Bond-Forming Reactions. *Chem. Rev.* **2014**, *114*, 8807. (c) Shen, C.; Zhang, P.; Sun, Q.; Bai, S.; Hor, T. S. A.; Liu, X. Recent Advances in C–S Bond Formation via C–H Bond Functionalization and Decarboxylation. *Chem. Soc. Rev.* **2015**, *44*, 291. (d) Yu, J.-S.; Huang, H.-M.; Ding, P.-G.; Hu, X.-S.; Zhou, F.; Zhou, J. Catalytic Enantioselective Construction of Sulfur-Containing Tetrasubstituted Carbon Stereocenters. *ACS Catal.* **2016**, *6*, 5319. (e) Qiao, A.; Jiang, X. Recent Developments in Sulfur–Carbon Bond Formation Reaction Involving Thiosulfates. *Org. Biomol. Chem.* **2017**, *15*, 1942. (f) Dunbar, K. L.; Scharf, D. H.; Litomska, A.; Hertweck, C. Enzymatic Carbon–Sulfur Bond Formation in Natural Product Biosynthesis. *Chem. Rev.* **2017**, *117*, 5521.

[2] (a) McGrath, N. A.; Brichacek, M.; Njardarson, J. T. A Graphical Journey of Innovative Organic Architectures That Have Improved Our Lives. *J. Chem. Educ.* **2010**, *87*, 1348. (b) Scott, K. A.; Njardarson, J. T. Analysis of US FDA-Approved Drugs Containing Sulfur Atoms. *Top. Curr. Chem.* **2018**, *376*, 5.

[3] a) Back, T. G.; Baron, D. L.; Yang, K. Desulfurization with Nickel and Cobalt Boride: Scope, Selectivity, Stereochemistry, and Deuterium-Labeling Studies. *J. Org, Chem.* **1993**, *58*, 2407. b) Canestrari, D.; Lancianesi, S.; Badiola, E.; Strinna, C.; Ibrahim, H.; Adamo, M. F. A. Desulfurative Chlorination of Alkyl Phenyl Sulfides. *Org.Lett.* **2017**, *19*, 918.

[4] a) Liebeskind, L. S.; Srogl, J. Heteroaromatic Thioether–Boronic Acid Cross-Coupling under Neutral Reaction Conditions. *Org. Lett*. **2002**, *4*, 979; b) Arambasic, M.; Majhail, M. K.; Straker, R. N.; Neuhaus, J. D.; Willis, M. C. A Rhodium-Catalysed Sonogashira-Type Coupling Exploiting C–S Functionalisation: Orthogonality with Palladium-Catalysed Variants. *Chem. Commun.* **2009**, 55, 2757.

[5] Abramovitch, A.; Varghese, J. P.; Marek, I. α-Sulfinyl Carbanions as A New Source of Olefins. *Org. Lett.* **2004**, *6*, 621-623.

[6] a) Screttas, C. G.; Micha-Screttas, M. Hydrolithiation of Alpha-Olefins by a Regiospecific Two-Step process. Transformation of Alkyl Phenyl Sulfides to Alkyllithium Reagents. *J. Org. Chem*. **1978**, *43*, 1064-1071. b) Foubelo, F.; Yus, M. *Chem. Soc. Rev.*, **2008**, *8*, 5682.

[7] Hugenberga, V.; Fröhlich, R. Haufe, G. Oxidative Desulfurization–Fluorination of Thioethers. Application for the Synthesis of Fluorinated Nitrogen Containing Building Blocks. *Org. Biomol. Chem.* **2010**, 106.

[8] For reviews in asymmetric sulfenylation, see: (a) Wang, W.; Zhang, X. C–X Bond Formation: Organocatalytic α-Sulfenylation and α-Selenenylation *Comprehensive Chirality*. **2012**, *6*, 518. (b) Wladislaw, B.; Marzorati, L.; Di Vitta, C. Sulfanylation Reactions of Carbonyl Compounds and Carboxylic Acid Derivatives Employing Sulfur Electropfflles. A Review. *Org. Prep. Proced. Int.* **2007**, *39*, 447. (c) Zhao, X.; Shen, J.; Jiang, Z. Catalytic Asymmetric α-Sulfenylation: A New and Efficient Pathway to Access Chiral C-S Bonds. *Mini-Rev. Org. Chem.* **2014**, *11*, 424

[9] (a) Aveniente, M.; Pinto, E: F.; Santos, L. S.; Rossi-Bergmann, B.; Barata, L. S. Structure–Activity Relationship of Antileishmanials Neolignan Analogues. *Bioorg. Med. Chem* **2007**, *15*, 7337. (b) Krapcho, J.; Turk, C. F. 4-[3-(Dimethylamino)Propyl]-3,4-Dihydro-2-(1-Hydroxyethyl)-3-Phenyl-2h-1,4-Benzothiazine and Related Compounds. New Class of Antiinflammatory Agents. *J. Med. Chem.* **1973**,*16*, 776. (c) Siatra-Papastaikoudi, T.; Tsotinis, A.; Chinou, I.; Roussakis, C. Synthesis and Anticancer Activity of New Phenyl-Ring Substituted 4-Morpholino-1-Phenylthio-2-Butanones [Mannich Bases]. *Farmaco*, **1994**, *49*, 2217. (d) Hartman, I.; Gillies, A. R.; Arora, S.; Andaya, C.; Royapet, N.; Welsh, W. J.; Wood, D. W.; Zauhar, R. J. Application of Screening Methods, Shape Signatures and Engineered Biosensors in Early Drug Discovery Process. *Pharm. Res.* **2009**, *26*, 2247.

[10] (a) Wang, C.; Yang, X.; Loh, C. C. J.; Raabe, G; Enders, D. Organocatalytic, Asymmetric Synthesis of 3-Sulfenylated N-Boc-Protected Oxindoles. *Chem. Eur. J.* **2012**, *18*, 11531. (b) Li, X.; Liu, C.; Xue, X.-S; Cheng, J.-P. Enantioselective Organocatalyzed Sulfenylation of 3-Substituted Oxindoles. *Org. Lett.* **2012**, *14*, 4374. (c) Han, Z.; Chen, W.; Dong, S.; Yang, C.; Liu, H.; Pan, Y.; Yan, L. Jiang, Z. Highly Enantioselective Organocatalytic Sulfenylation of 3-Aryloxindoles. *Org. Lett.* **2012**, *14*, 4670. (d) Cai, Y.; Li, J.; Chen, W.; Xie, M.; Liu, X.; Lin, L.; Feng, X. Catalytic Asymmetric Sulfenylation of Unprotected 3-Substituted Oxindoles. *Org. Lett.* **2012**, *11*, 2726. (e) Liao, K.; Feng, Z.; Yu, J.-S.; Gaoa, W.-M; Zhou, J. Catalytic Asymmetric Sulfenylation to Structurally Diverse Dithioketals. *Chem. Commun.*, **2015**, *51*, 16255. (f) You, Y.; Wu, Z.-J.; Wang, Z.-H.; Xu, X.-Y.; Zhang, X.-M.; Yuan, W.-C.

Enantioselective Synthesis of 3,3-Disubstituted Oxindoles Bearing Two Different Heteroatoms at the C3 Position by Organocatalyzed Sulfenylation and Selenenylation of 3-Pyrrolyl-oxindoles. *J. Org. Chem.* **2015**, *80*, 8470. (g) Huang, L.; Li, J.; Zhao, Y.; Ye, X.; Liu, Y.; Yan, L.; Tan, C.-H.; Liu, H.; Jiang, Z. Chiral Bicyclic Guanidine-Catalyzed Enantioselective Sulfenylation of Oxindoles and Benzofuran-2(3H)-ones. *J. Org. Chem.* **2015**, *80*, 8933. (h) Gaoa, X.; Han, J.; Wang, L. Chiral Iminophosphorane Organocatalyzed Asymmetric Sulfenylation of 3-Substituted Oxindoles: Substrate-Interrelated Enantioselectivities. *Synthesis*, **2016**, *48*, 2603. (i) Yidan E.; Yuan, T.; Yin, L.; Xu, Y. Asymmetric Sulfenylation of 3-CF_3-Oxindoles Through Organocatalysis with a Quinidine Derivative. *Tetrahedron Lett.* **2017**, *58*, 2521.

[11] (a) Bootwicha, T.; Liu, X.; Pluta, R.; Atodiresei, J.; Rueping M. N-Trifluoromethylthiophthalimide: A Stable Electrophilic SCF_3-Reagent and its Application in the Catalytic Asymmetric Trifluoromethylsulfenylation. *Angew. Chem. Int. Ed.* **2013**, *52*, 12856. (b) Shirakawa, S.; Tokuda, T.; Kasai, A.; Maruoka, K. Design of Chiral Bifunctional Quaternary Phosphonium Bromide Catalysts Possessing an Amide Moiet. *Org. Lett.* **2013**, *15*, 3350. (c) Deng, Q.-H.; Rettenmeier, C.; Wadepohl, H.; Gade, L. H. Copper–Boxmi Complexes as Highly Enantioselective Catalysts for Electrophilic Trifluoromethylthiolations. *Chem. Eur. J.* **2014**, *20*, 93. (d) Cui, L.;You, Y.'en; Mi, X.; Luo, S. Catalytic Enantioselective α-Sulfenylation of β-Ketocarbonyls by Chiral Primary Amines. *Org. Chem. Front.*, **2018**, *5*, 2313.

[12] (a) Xu, M.; Qiao, B.;„Duan, S.; Liu, H.; Jiang, Z. Highly Enantioselective α-Sulfenylation of 5H-Oxazol-4-Ones to N-(Sulfanyl)Succinimides. *Tetrahedron*, **2014**, *70*, 8696; (b) Qiao, B.; Liu, X.; Duan, S.; Yan, L.; Jiang, Z. *Org. Lett.* **2014**, *16*, 672. (c) Jiao, L.; Bu, L.; Ye, X.; Zhao, X.; Jiang, Z. Catalytic Asymmetric Conjugate Addition and Sulfenylation of Diarylthiazolidin-2,4-diones. *J. Org. Chem.* **2016**, *81*, 9620.

[13] (a) Hatcher, J. M.; Kohler, M. C.; Coltart, D. M. Catalytic Asymmetric Addition of Thiols to Nitrosoalkenes Leading to Chiral Non-Racemic α-Sulfenyl Ketones. *Org. Lett.* **2011**, *13*, 3810.; (b) Denmark, S. E.; Rossi, S.; Webster, M. P.; Wang, H. Catalytic, Enantioselective Sulfenylation of Ketone-Derived Enoxysilanes. *J. Am. Chem. Soc.* **2014**, *136*, 13016.

[14] (a) Biswas, S.; Samec, J. S. M. A Gold(I)-Catalyzed Route to α-Sulfenylated Carbonyl Compounds from Propargylic Alcohols and Aryl Thiols. *Chem. Commun.* **2012**, *48*, 6586. (b) Biswas, S.; Dahlstrand, C.; Watile, R. A. Kalek, M.; Himo, F.; Samec, J. S. M. Atom-Efficient Gold(I)-Chloride-Catalyzed Synthesis of α-Sulfenylated Carbonyl Compounds from Propargylic Alcohols and Aryl Thiols: Substrate Scope and Experimental and Theoretical Mechanistic Investigation. *Chem. Eur. J.* **2013**, *19*, 17939. (c) Watile, R. A.; Biswas, S. Samec, J. S. M. An Aqueous and Recyclable Copper(I)-Catalyzed Route to α-Sulfenylated Carbonyl Compounds from Propargylic Alcohols and Aryl Thiols. *Green Chem.* **2013**, *15*, 3176. (d) Biswas, S.; Watile, R. A. Samec, J. S. M. Tandem Pd/Au-Catalyzed Route to α-Sulfenylated Carbonyl Compounds from Terminal Propargylic Alcohols and Thiols. *Chem. Eur. J.* **2014**, *20*, 2159. (e) Cadu, A. Watile, R. A.; Biswas, S.; Orthaber, A. Sjöberg, P. J. R.; Samec, J. S. M. One-Pot Synthesis of Keto Thioethers by Palladium/Gold-Catalyzed Click and Pinacol Reactions. *Org. Lett.* **2014**, *16*, 5556.

[15] Enantioselective isomerization of allylic alcohols has always relayed on the obtention of aldehydes with a *β*-stereocenter: (a) Tanaka, K.; Fu, G. C. A Versatile New Catalyst for the Enantioselective Isomerization of Allylic Alcohols to Aldehydes: Scope and Mechanistic Studies. *J. Org. Chem.* **2001**, *66*, 8177. (b) Mantilli, L.; Gérard, D.; Torche, S.; Besnard, C.; Mazet, C. Iridium-Catalyzed Asymmetric Isomerization of Primary Allylic Alcohols. *Angew. Chem. Int. Ed.* **2009**, *48*, 5143. (c) Mantilli, L.; Mazet, C. Expanded Scope for the Iridium-Catalyzed Asymmetric Isomerization of Primary Allylic Alcohols Using Readily Accessible Second-Generation Catalysts. *Chem. Commun.* **2010**, *46*, 445. (d) Quintard, A.; Alexakis, A.; Mazet, C. Access to High Levels of Molecular Complexity by One-Pot Iridium/Enamine Asymmetric Catalysis. *Angew. Chem., Int. Ed.* **2011**, 50, 2354. (e) Li, J.-Q.; Peters, B.; Andersson, P. G. Highly Enantioselective Asymmetric Isomerization of Primary Allylic Alcohols with an Iridium–N,P Complex. *Chem. Eur. J.* **2011**, *17*, 11143. (f) Arai, N.; Sato, K.; Azuma, K.; Ohkuma, T. Enantioselective Isomerization of Primary Allylic Alcohols into Chiral Aldehydes with the Tol-Binap/dbapen/Ruthenium(II) Catalyst. *Angew. Chem., Int. Ed.* **2013**, 52, 7500. (g) Cahard, D.; Gaillard, S.; Renaud, J.-L. Asymmetric Isomerization of Allylic Alcohols. *Tetrahedron Lett.* **2015**, *56*, 6159.

[16] (a) Liu, T.-L.; Ng T. W.; Zhao, Y. Rhodium-Catalyzed Enantioselective Isomerization of Secondary Allylic Alcohols. *J. Am. Chem. Soc.* **2017**, *139*, 3643. (b) Huang, R.-Z.; Lau, K. K.; Li, Z.; Liu, T.-L.; Zhao, Y. Rhodium-Catalyzed Enantioconvergent Isomerization of Homoallylic and Bishomoallylic Secondary Alcohols. *J. Am. Chem. Soc.* **2018**, *140*, 14647.

[17] Prat, D.; Wells, A.; Hayler, J.; Sneddon, H.; McElroy, R.; Abou-Shehadad, S.; Dunne, P. J. CHEM21 Selection Guide of Classical- and Less Classical-Solvents. *Green Chem.*, **2016**, *18*, 288.

[18] Cadierno, V.; García-Garrido, S. E.; Gimeno, J.; Varela-Álvarez, A.; Sordo, J. A. Bis(allyl)–Ruthenium(IV) Complexes as Highly Efficient Catalysts for the Redox Isomerization of Allylic Alcohols into Carbonyl Compounds in Organic and Aqueous Media: Scope, Limitations, and Theoretical Analysis of the Mechanism. *J. Am. Chem. Soc.* **2006**, *128*, 1360,

[19] Ogawa, A.; Ikeda, T.; Kimura, K.; Hirao, T. Highly Regio- and Stereocontrolled Synthesis of Vinyl Sulfides via Transition-Metal-Catalyzed Hydrothiolation of Alkynes with Thiols. *J. Am. Chem. Soc.* **1999,** *121,* 5108.

[20] (a) Uma, R.; Crévisy, C.; Grée, R. Transposition of Allylic Alcohols into Carbonyl Compounds Mediated by Transition Metal Complexes. *Chem. Rev.* **2003**, *103*, 27. (b) Ahlsten, N.; Bartoszewicza, A.; Martín-Matute, B. Allylic Alcohols as Synthetic Enolate Equivalents: Isomerisation and Tandem Reactions Catalysed by Transition Metal Complexes. *Dalton Trans.* **2012**, *41*, 1660.

[21] McGrath, D. V.; Grubbs, R. H. The Mechanism of Aqueous Ruthenium(II)-Catalyzed Olefin Isomerization. *Organometallics* **1994**, *13*, 224.

[22] Trost, B. M.; Kulawiec, R. J. Chemoselectivity in the Ruthenium-Catalyzed Redox Isomerization of Allyl Alcohols. *J. Am. Chem. Soc.* **1993**, *115*, 2027.

[23] A slightly loss of enantioselectivity was observed when using deuterated substrates: see ref 16b.

[24] Guđmundsson, A.; Gustafson, K. P. J.; Mai, B. K.; Yang, B.; Himo, F.; Bäckvall, J.-E. Efficient Formation of 2,3-Dihydrofurans via Iron-Catalyzed Cycloisomerization of α-Allenols. *ACS Catal.* **2018**, *8*, 12-16.

[25] Yus, M.; Gutiérrez, A.; Foubelo, F. Polylithiation of Thioethers: A Versatile Route for Polyanionic Synthons. *Tetrahedron* **2001**, 57, 4411.

[26] Matsumoto, K.; Kozuki, Y.; Ashikari, Y.; Suga, S.; Kashimura, S.; Yoshida, J. Electrophilic Substitution Reactions Using an Electrogenerated ArS(ArSSAr)$^+$ Cation Pool As an ArS$^+$ Equivalent. *Tetrahedron Lett.* **2012**, *53*, 1916.

Insert Table of Contents artwork here