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Highly Enantioselective Ring-Opening of *meso*-Epoxides with O- and *N*-Nucleophiles Catalyzed by a Chiral Sc(III)/bipyridine Complex

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The ring-opening of epoxides is a synthetically significant process widely applied in all kinds of chemistry. Herein, we report the catalytic and highly enantioselective variant of this reaction exploiting our recent endeavors to design and synthesize chiral bipyridine type ligands. A Sc-complex with a newly developed bipyridine ligand exhibited high reactivity and stereocontrol in the desymmetrization of *meso*-epoxides with various alcohols. The respective enantiomerically enriched 1,2-alkoxyalcohols were obtained with e.r. values of up to 99.5:0.5 for various alcohols regardless of their nature (benzyl, alkyl, cycloalkyl, allyl, propargyl, etc.). We attempted ring-opening of *meso*-epoxides with anilines as well; however, it proceeded with lower enantioselectivity and was strongly depended on the electronic effect of substituents attached to the aromatic ring.

Introduction

Desymmetrization is the modification of a molecule that results in the loss of one or more symmetry elements and usually is accompanied by the introduction of chirality. It is generally carried out on achiral or *meso*-compounds[1] and represents a powerful synthesis of chiral compounds because several stereogenic centers can be established concurrently.[2–6] However, catalytic enantioselective desymmetrization of prochiral systems is not an easy task, because it involves a symmetry breaking operation, where two enantiotopic moieties must be differentiated.[7–9]

In this respect, *meso*-epoxides are ideal substrates for testing new chiral catalytic systems or new chiral ligands. The *meso*-epoxides are inexpensive and readily available compounds that after catalytic enantioselective ring-opening give rise to enantiomerically enriched 1,2-difunctionalized building blocks. An array of C, N, O, S, Se, and halogen nucleophiles can be applied and synthesis of substances such as 1,2-cyanoalcohols, 1,2-azidoalcohols, 1,2-aminoalcohols, 1,2-diol monoesters and monoethers, mercaptoalcohols, and 1,2-halohydrins[10–21] have been achieved so far with good enantioselectivities. Chiral Lewis acids or bases usually catalyze such processes, and during the process, two enantiotopic carbon atoms of the epoxide moiety are differentiated by S_N2 nucleophilic attack at one of the epoxide carbon atoms.

Interestingly, alcohols and other oxygen nucleophiles have been rarely used in catalytic enantioselective ring-opening of *meso*-epoxides. There have been just a handful of examples such as the addition of carboxylic acids providing 1,2-diol monoesters and monoether in high yields and reasonable enantioselectivities. Jacobsen et al.[22] utilized a cobalt(III) salen complex as a chiral Lewis acid in the addition of carboxylic acids to epoxides furnishing 1,2-diol monoesters in excellent yields and moderate to high enantioselectivity (up to 93% ee). As for organocatalytic procedures, List et al.[23] showed that a chiral TRIP could catalyze enantioselective ring-opening of *meso*-epoxides with benzoic acid (up to 92% ee). Shibasaki et al.[24] reported a procedure relying on catalysis by a gallium-lithium-BINOL complex, which allowed the addition of *para*-methoxyphenol in good to excellent enantioselectivities (up to 96% ee).[25]

Early examples showed that different rare earth metal triflates are highly active catalysts for the alcoholysis of epoxides ($Sc(OTf)_3$[26–28] and $Yb(OTf)_3$[29]). These works provided a good impetus for Schneider et al., who assessed the scope of alcoholysis of *meso*-epoxides catalyzed by using a chiral catalytic system composed of $Sc(OTf)_3$ (10 mol%) and Bolm's ligand).[30,31] **1** (10 mol%) (Figure 1). Asymmetric induction reached up to 99:1 e.r.[32,33] Interestingly, the only attempt in this direction was a *para*-bromobenzyl alcohol reaction study by Kobayashi et al.[34] Since then, this area has remained dormant, and no significant progress has been reported. On the

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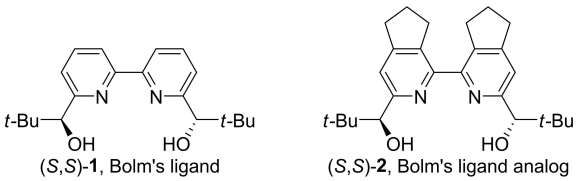


Figure 1. Bolm's ligands.

other hand, it should be also noted that the scope of the use of rare earth metal salts as Lewis acids has been applied to many reactions.[35–37]

Various metal salts in combinations of Bolm's ligand **1** were used to catalyze ring opening of *meso*-epoxides with various amines in a similar manner. Among them are worth mentioning system using $Sc(OTf)_3$ or $Sc(DS)_3$ (10 mol%) that provided product with e.rs up to 97.5:2.5,[32,38,39] $Zn(OTf)_2$ and $Cu(OTf)_2$ (e.rs up to 95:5 and 90:10, respectively),[40] $Fe(ClO_4)_2$ (e.rs up to 97.5:2.5),[41] and In salts (e.rs up to 99:1).[42] Sc salts were also used to catalyze opening of *meso*-epoxides with imines[43] and benzotriazole[32] with e.rs up to 94:6 and 87:13, respectively.[44]

We have recently reported a synthesis of a Bolm's ligand analog (*S,S*)-**2** possessing bicyclic ring systems (Figure 1).[45] Screening of its potential applications as an chiral ligand in various transition metal complex catalyzed reaction revealed that the *in situ* formed scandium complex ($Sc(OTf)_3$ (10 mol%)/(*S,S*)-**2** (10 mol%)) is a good catalyst for ring-opening of *meso*-stilbene oxide **3** with *para*-methoxybenzyl alcohol **4a**. A preliminary screening turned out to give the respective enantioenriched alkoxyalcohol **5a** with e.r. of 98.5:1.5 under mild reaction conditions. (**5a** was obtained with 97.5:2.5 e.r when Bolm's ligand (10 mol%) was used). Although the increase in enantioselectivity could be considered rather marginal, this result sparked our interest to evaluate its potential application in the opening of *meso*-epoxides. We would like to demonstrate in this work that the system composed of $Sc(OTf)_3$/(*S,S*)-**2** is a suitable catalytic system for enantioselective ring-opening of various *meso*-epoxides with a plethora of alcohols (*O*-nucleophiles) providing the corresponding 1,2-alkoxyalcohols in high yields and excellent asymmetric induction.

Results and Discussion

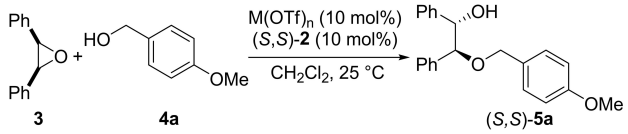
Ring-opening with alcohols. Since other transition metal triflates are known to be potent Lewis acids, enantioselective ring opening of *meso*-stilbene oxide **3** with *para*-methoxybenzyl alcohol **4a** was tested with a combination of several metal triflates (10 mol%) and (*S,S*)-**2** (10 mol%) at 25 °C to assess yields and asymmetric induction. The most important results are summarized in Table 1. The best results in terms of yield and enantioselectivity, 90% and 99:1 e.r., respectively, were obtained with $Sc(OTf)_3$ (Entry 1). High asymmetric induction of 96.5:3.5 e.r. was also observed with $Yb(OTf)_3$, albeit the yield was somewhat mediocre (50%) (Entry 7). The use of $Y(OTf)_3$, $Ho(OTf)_3$, and $In(OTf)_3$ gave the respective product with somewhat lower enantiomeric ratios of 94:6, 91.5:8.5, and 92:8, respectively (Entries 2, 6, and 8). The application of La, Sm, Tb, Bi, and Fe, triflates gave rather average asymmetric induction (73.5:26.5, 71:29, 77.5:22.5, 67:33, and 85.5:14.5 e.r., Entries 3–5, 9, and 10).

Regarding the triflates, the observed trend in asymmetric induction follows the Lewis acidity (oxophility) scale based on the work of Imamoto et al.[46] The obtained results clearly demonstrated that $Sc(OTf)_3$ is the compound with the highest Lewis acidity followed by Yb, Y, and other triflates (see Figure S23). The previous works showed that the optimal catalyst and ligand load for $Sc(OTf)_3$ and Bolm's ligand **1** is 10 mol%.[33] Asymmetric induction started to drop below that value and reaction times became too long (e.g., for 1 mol% load, 86.5:13.5 e.r., five days (120 h)). To assess the optimal reaction conditions in terms of yields, asymmetric induction, and reaction time, we screened the course of the reaction of *meso*-stilbene oxide **3** with *para*-methoxybenzyl alcohol **4a** at 25 °C in CH_2Cl_2 with several different $Sc(OTf)_3$/(*S,S*)-**2** loads (Scheme 1). Initially, carrying out the reaction with the catalyst load of 10 mol% provided **5a** in 90% yield and 99:1 e.r. within 24 h. A decrease of the catalyst loading to 5 mol% gave almost the same result regarding the yield and enantioselectivity, but the reaction time was prolonged to 48 h. Its further lowering to 2 mol% led to a longer reaction time of 72 h, but the yield (90%) and the enantioselectivity (98.5:1.5 e.r.) remained the same.

Lowering the catalyst amount to 1 mol% resulted in a negligible decrease in enantioselectivity (within the limits of experimental error) to only 98:2 e.r. However, the reaction time was 120 h. We decided to carry out the subsequent reactions with the 2 mol% load from a practical point of view.

At the outset, we focused on assessment of the reaction of *meso*-stilbene oxide **3** with respect to various alcohols (Scheme 2). Reactions with *para*- and *meta*-methoxybenzyl alcohols **4a** and **4b** proceeded with high enantiomer ratios of 99:1 (published value for **5a** was 98.5:1.5 e.r.[32]). In the case of *ortho*-methoxybenzyl alcohol **4c** a small drop to 94:6 e.r. was observed, probably due to steric hindrance. As for other *para*-substituted benzyl alcohols, those bearing electron-donating (Me) or -accepting groups (Br, COOMe, NO_2, CF_3) **4d**, **4f**–**4i** as

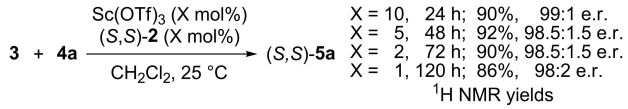
Table 1. Influence of metal triflates on asymmetric induction.



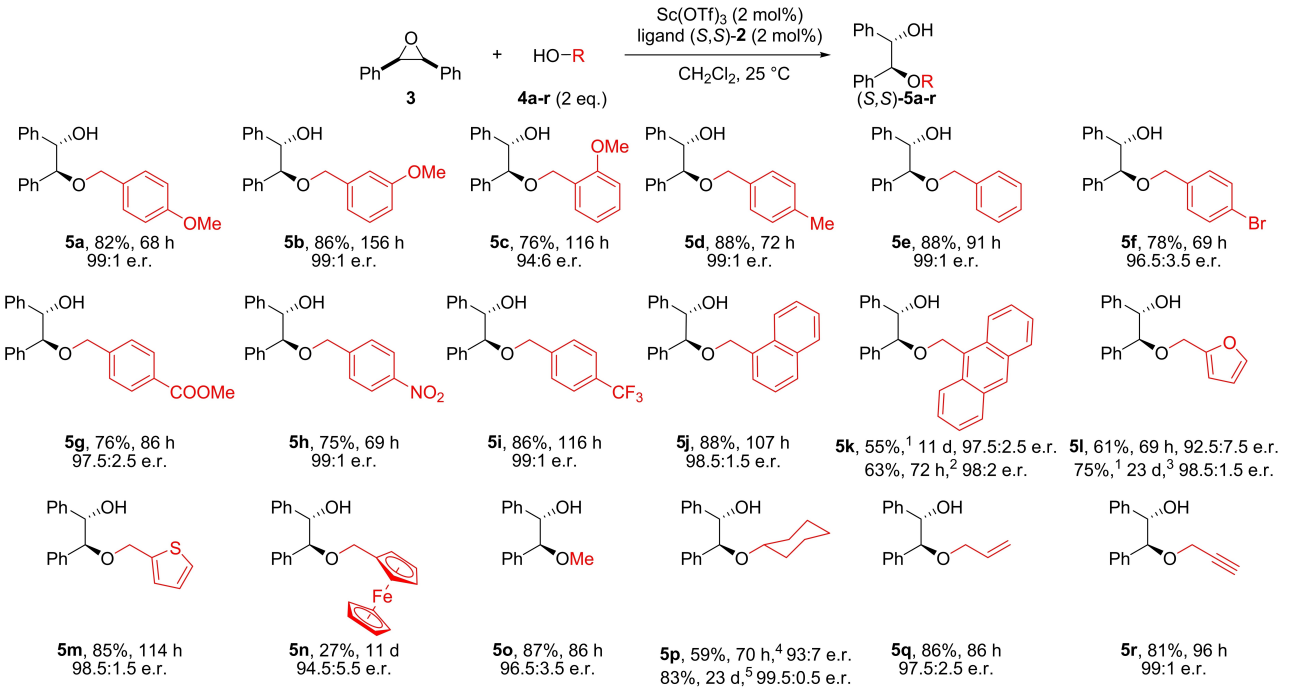
3 **4a** (*S,S*)-**5a**

Entry	$M(OTf)_n$	Yield [%][a]	e.r
1	$Sc(OTf)_3$	90	99:1
2	$Y(OTf)_3$	15[b]	94:6
3	$La(OTf)_3$	2[b]	73.5:26.5
4	$Sm(OTf)_3$	23	71:29
5	$Tb(OTf)_3$	15	77.5:22.5
6	$Ho(OTf)_3$	6[b]	91.5:8.5
7	$Yb(OTf)_3$	50[b]	96.5:3.5
8	$In(OTf)_3$	15[b]	92:8
9	$Bi(OTf)_3$	25[b]	67:33
10	$Fe(OTf)_2$	5[b]	85.5:14.5

[a] Isolated yield unless otherwise mentioned. [b] ^{1}H NMR yield.



Scheme 1. Effect of catalyst loading on enantioselectivity.



[1] ^{1}H NMR yield. [2] 40 °C. [3] With powdered 3Å MS (25% of **3**). [4] *c*-HexOH was distilled. [5] *c*-HexOH was dried over K_2CO_3, distilled, and dried over 3Å MS overnight.

Scheme 2. Scope of the Sc(OTf)$_3$/(*S,S*)-**2**-catalyzed alcoholysis of **3**.

well as for unsubstituted benzyl alcohol **4e**, the ring opening of **3** proceeded with excellent asymmetric induction giving highly enantioenriched **5d**–**5i** in the range of 96.5–99:3.5–1 e.rs (published value for **5f** was 93:7 e.r.[34]). Excellent enantioselectivities of 98.5:1.5 and 98:2 e.rs were obtained for **5j** (86%) and **5k** (63%) that were formed in the reactions of 1-naphthalenemethanol **4j** and 9-anthracenemethanol **4k**. In the latter case, heating of the reaction mixture to 40 °C reduced the reaction time to 3 days. It took 11 days to obtain **5k** in 55% yield (97.5:2.5), when the reaction was carried out at 25 °C. Presumably, the observed lower reactivity of **4k** could be attributed to steric hindrance exercised by the anthracene moiety and its overall low solubility.

Interestingly, the reaction with 2-furfuryl alcohol **4l** was rather sluggish and gave **5l** in only 92.5:7.5 e.r. Gratifyingly, running the reaction in the presence of molecular sieves resulted in the increased asymmetric induction of 98.5:1.5 e.r., but at the expense of a long reaction time (23 d). The ring-opening with (thiophen-2-yl)methanol **4m** proceeded under standard reaction conditions with 98.5:1.5 e.r. The ring opening with ferrocenemethanol **4n** giving rise to **5n** proceeded well with 94.5:5.5 e.r. High enantioselectivities were also obtained with representatives of aliphatic alcohols such as methanol, cyclohexyl, allyl, and propargyl alcohols which gave the respective products **5o**–**5r** with e.rs of 96.5:3.5, 99.5:0.5, 97.5:2.5, and 99:1, respectively (published e.r. values for **5o**, **5q**, and **5r** were 96:4, 97.5:2.5, and 95.5:4.5[32]). The case of cyclohexanol deserves a detailed comment. Under the standard reaction conditions the product was formed in low yield of 35% (^{1}H NMR) (e.r. was not determined). However, meticulous drying and purification of cyclohexanol resulted in a very good isolated yield of **5p** as well as enantioselectivity (99.5:0.5 e.r.), albeit a long reaction time of 23 days was required. Once again, it is assumed that the low reaction rate could be result of steric hindrance of the alcohol. The structure and (*S,S*) configuration of **5p** was confirmed by a single crystal X-ray diffraction analysis (Figure 2). It should be also noted that a fresh batch of Sc(OTf)$_3$ has been always dried prior to the use, a repetitive use of once dried Sc(OTf)$_3$ resulted in lower enantioselectivity along with formation of aldehydes and ketones by acid catalyzed rearrangement of the starting epoxide **3** (see, Table S1).

Besides, the epoxide ring-opening of *meso*-(4-chlorophenyl) oxirane **6** with *para*-methoxybenzyl alcohol **4a** (Scheme 3)

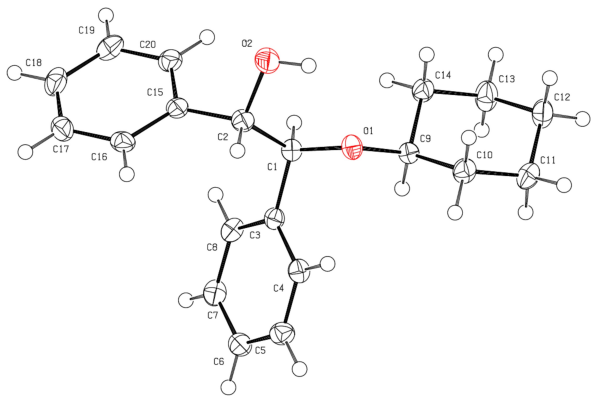
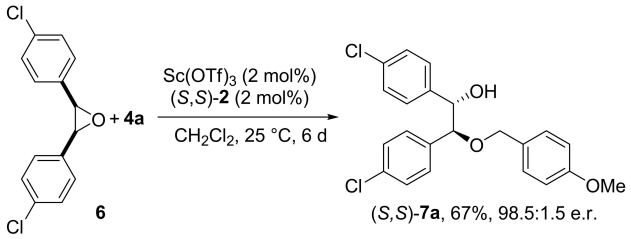


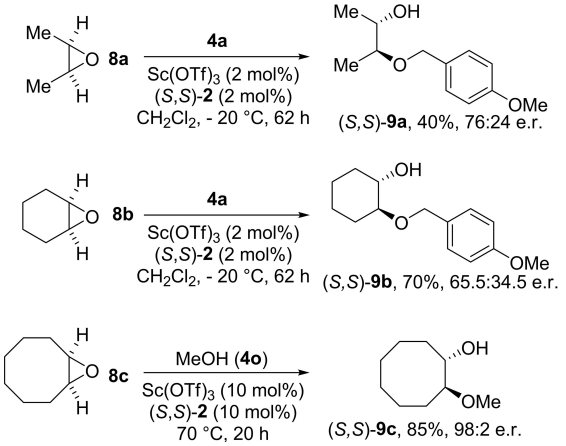
Figure 2. The ORTEP plot of (*S,S*)-**5p**. Elipsoids are shown with 30% probability.



Scheme 3. Reaction of *meso*-(4-chlorophenyl)oxirane **6** with *para*-methoxybenzyl alcohol **4a** catalyzed by the $Sc(OTf)_3$/(*S*,*S*)-**2** complex.

provided the respective product **7** in 67% yield and 98.5:1.5 e.r. (The published value for **7** was 96:4.[33])

Then ring-opening of aliphatic and cyclic epoxides such as *cis*-2-butene oxide (**8a**), cyclohexene oxide (**8b**) and *cis*-cyclooctene oxide (**8c**) was tested with $Sc(OTf)_3$ (2 mol%) and (*S*,*S*)-**2** (2 mol%) at −20 °C. As far as the epoxide ring-opening of **8a** and **8b** with *para*-methoxybenzyl alcohol **4a** are concerned, the reaction provided **9a** and **9b** in moderate enantioselectivities 76:24 and 65.5:34.5 e.r.) and ^{1}H NMR yields of 40 and 70% (Scheme 4). Enantioselectivity of the former is similar to the published one (49% ee using $Sc(OTf)_3$ (10 mol%), Bolm's ligand (*R*,*R*)-**1** (10 mol%)[32]). However, for the latter, it was reduced by almost 20%, the reported value is 52% ee using $Sc(OTf)_3$ (10 mol%) and Bolm's ligand (*R*,*R*)-**1** (10 mol%).[32] (It should be mentioned that we tried to carry out the reaction with Bolm's ligand as well but could not reach the reported value, the product **9b** was obtained in 34% ee). Surprisingly, the epoxide ring opening of *cis*-cyclooctene oxide **8c** did not proceed with *para*-methoxybenzyl alcohol **4a** at all. After many experiments it was found that the reaction could be brought about in pure MeOH (**4o**) at 70 °C. Gratifyingly, enantioselectivity increased substantially to give alcohol **9c** with 98:2 e.r. and in 85% isolated yield. (For the details see Tables S2–S5 in the SI section). An attempted reaction with cyclopentene oxide led to a complex reaction mixture, in which the expected product was not detected.



Scheme 4. Reaction of aliphatic *meso*-epoxides with **4a** and **4o**.

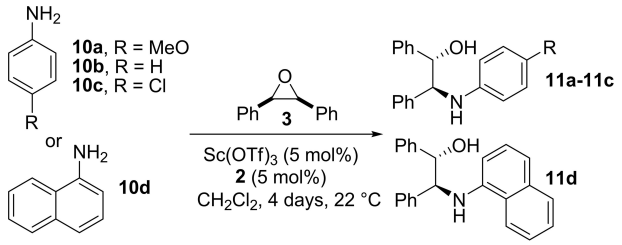
Mechanistic considerations. Kobayashi et al.[47] and Schneider et al.[33] have reported crystal structures of the monomeric scandium (composed of $ScBr_3$ and **1**) and the yttrium catalyst (composed of $Y(OTf)_3$ and **1**). The former had a pentagonal-bipyramidal coordination geometry of the metal, and it can be clearly seen that the bipyridine ligand is twisted along the bipyridine axis (∠ 20.8° for N1a-C1a-C1-N1). The latter corresponded to the eight-coordinate yttrium-bipyridine complex again, having the bipyridine rings slightly twisted along the bipyridine axis (∠ 19.1° N1-C1-C6-N2) and coordinated to the metal center in a tetradentate fashion.

The cyclopentane rings in ligand **2** impose considerable steric hindrance that does not allow the pyridine rings to adopt coplanar conformation. Instead, they are twisted with respect to each other. Hence, the formation of monomeric complexes such as those mentioned above would probably be difficult because of the reactants' expected inefficient orbital alignment. Instead, it could promote the formation of complexes possessing multiple metal centers. This effect was observed previously by us in the case of cationic and neutral Cu/ bipyridine **2** complexes.[45] The twist in the ligand was ~20° in a dimeric cationic Cu-complex. On the other hand, the twist of 90° was in the latter. Therefore we assume that higher aggregates of catalytically active species with a more rigid structure lead, eventually, to higher asymmetric induction. Unfortunately, all attempts to crystalize any Sc-complex were not met with success. Also MS experiments in MeCN and MeOH did not provide any evidence for the formation of polynuclear species, only fragments assignable to a monomeric species were detected.

An attempt to record the ^{1}H NMR spectrum of the Sc/**2** catalytic system and compare it with the spectrum of the Sc/**1** one was carried out (Figure S24). The ^{1}H NMR spectrum of the Sc/**1** catalytic system (turquoise line) indicates the formation of a single structure from $Sc(OTf)_3$ and **1** (red line). On the other hand, mixing $Sc(OTf)_3$ with **2** (yellow line) obviously did not form a single structure as it is indicated by the presence of more than one signal in the aromatic area (blue line). The competitive complexation of ligands **1** and **2** with $Sc(OTf)_3$ in the ratio 1:1:1 revealed that probably both complexes are formed, considering corresponding signals at 5.47 (for **1**) and 5.29 (for **2**). Hence, it is possible to conclude that there is not a significant difference in their coordination capabilities.

Ring-opening with amines. With the above-obtained results in hand, we decided to briefly screen reactions of *cis*-stilbene oxide **3** with various anilines **10** bearing electron-donating and -withdrawing groups catalyzed by the Sc/**2** catalytic system. First, the reaction with aniline (**10b**) was studied under different catalyst loadings (see Table S7). It turned out that the highest yield of the corresponding aminoalcohol **11b** (90%) and asymmetric induction (e.r. 99.5:05) was obtained by using 10 mol% catalyst's load within 2 days. Its reduction to 5 mol% gave **11b** in 72% yield and e.r. of 97.5:2.5 in 4 days (see also Table 2, entry 3). Further lowering of the catalytic system to 2 and 1 mol% resulted in a decrease of yields, e.rs, and longer reaction times were required. It was decided to use 5 mol% load of the Sc/**2** catalytic system for further experiments.

Table 2. Aminolysis of **3** with various anilines **10**.



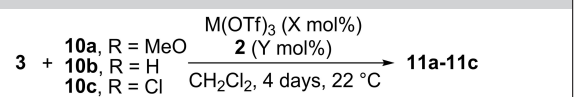
Entry	Amine	T [°C]	Yield [%][a]	e.r.
1	10a	22	45	93:7
2	10a	0	80	84:16
3	10b	22	72	99:1
4	10c	22	53	98.5:1.5
5	10d	22	78	98:2

[a] ^{1}H NMR yield.

The reaction with 4-methoxyaniline **10a** provided product **11a** in 45% yield and 93:7 e.r. (Entry 1). Since it has been shown that higher enantioselectivity could be obtained at a lower reaction temperature, we run a reaction at 0 °C (Entry 2). Albeit the reaction yield increased to 80%, enantioselectivity dropped to 84:16. The reaction with **10b** gave rise to aminoalcohol **11b** in a nice 72% yield and excellent e.r. of 99:1 (Entry 3). Analogically, the reactions with 4-chloroaniline **10c** and 1-aminonaphthalene **10d** provided aminoalcohols **11c** and **11d** in 53 and 78% yields and superb e.rs of 98.5:1.5 and 98:2, respectively (Entries 4 and 5). These values are higher than those obtained with other catalytic systems.[30,34,40]

Also, reactions of **3** with anilines **10** under using indium- (Schneider et al.[42]) and iron-based (Ollevier et al.[41]) catalytic systems were carried out (Table 3). As far as the enantioselectivity is concerned, the In-based catalytic system followed the trend observed for the Sc-catalyzed reactions. The lowest asymmetric induction was observed with **10a** (85.5:14:5, Entry 1)), and the highest one was achieved for the reaction with **10c** (95.5:4.5, Entry 3). Catalysis of the reaction of **10a** with **3** with the Fe-system did not proceed efficiently, forming **11a** in only 10% yield (Entry 1). Surprisingly, a reaction with **10c** gave **11c** with low enantiopurity (82.5:17.5) as well (Entry 6).

Table 3. Aminolysis of **3** with amines **10** catalyzed by In and Fe systems.



Entry	Ma)	Amine	R	Yield (%)b)	e.r.
1	In	10a	OMe	85	85.5:14:5
2	In	10b	H	80	88:12
3	In	10c	Cl	80	95.5:4.5
4c)	Fe	10a	OMe	10	ND
5	Fe	10a	H	55	91.5:8.5
6	Fe	10c	Cl	16	82.5:17.5

[a] For In: X = 10 and Y = 10, for Fe: X = 5 and Y = 6. [b] ^{1}H NMR yield. [c] 80% of **10a** was still present in the reaction mixture. ND = Not Determined.

It is reasonable to presume that a somewhat larger difference in asymmetric induction in the Sc-catalyzed ring-opening of **3** with anilines **10a**–**10c** is caused by the difference in their nucleophilicity.[48] Thus a high asymmetric induction is observed with less nucleophilic 4-chloroaniline (**10c**), because efficient catalysis is required to bring about the reaction. On the other hand, the reaction with more nucleophilic 4-methoxyaniline (**10a**) also proceeded through uncatalyzed ring-opening of **3**, diminishing enantioselectivity. The same trend is also observed in the In-catalyzed process (Table 3).

Conclusion

In conclusion, we have reported substantially enhanced enantioselective ring-opening of *meso*-epoxides with alcohols catalyzed by $Sc(OTf)_3$/Bolm's ligand analog **2**. The reactions proceeded with a high level of stereocontrol giving rise to highly enantioenriched products for a wide range of substrates (alkyl, benzyl, allyl, and propargyl alcohols). The obtained e.rs were up to 99:1 (the major stereoisomer was *S,S*). Moreover, the reaction proceeded with a low catalyst load of just 2 mol% within reasonable reaction times at ambient temperature (usually 25 °C). The obtained e.rs are in most of the cases considerably higher than those achieved under other catalytic conditions (for comparison of various methods, see Table S6). Thus, the results provide evidence that the stereoselectivity of catalytic reactions could be enhanced by the judicious elaboration of structural features of already known ligands. The asymmetric induction is not influenced by the presence of electron-donating or accepting groups in benzyl alcohols. Screening of the reaction conditions with various metal salts revealed that asymmetric induction could be correlated with reasonable probability to Lewis acidity of the metal, at least in the case of lanthanides and neighboring metals. Similar results were also obtained for the ring-opening with amines, where excellent e.rs were obtained in majority of the cases.

Experimental Section

For experimental details, HPLC charts, copies of ^{1}H and ^{13}C NMR spectra and other supplementary material, see the SI section.

General procedure for ring opening of epoxides: synthesis of 2-hydroxyethers (a typical example). The respective oxide (0.3 mmol) and alcohol (0.6 mmol) were added to a prestirred (10 min) solution of $Sc(OTf)_3$ (3 mg, 6 μmoL) and ligand (*S,S*)-**2** (2.5 mg, 6 μmoL) in dry CH_2Cl_2 (1.5 mL) in a 4 mL vial. Then the reaction mixture was stirred at 25 °C for the appropriate period of time, usually until **3** was fully consumed (disappearance of the respective spot on TLC). Finally, the volatiles were removed under reduced pressure. Column chromatography of the residue on silica gel furnished the desired product. Racemic mixtures of products were prepared by the same procedure using racemic Bolm's ligand **1** and isolated by preparative TLC.

(1*S*,2*S*)-2-((4-Methoxybenzyl)oxy)-1,2-diphenylethan-1-ol (5a). According to the general procedure with *p*-methoxybenzyl alcohol **4a** (75 μl, 0.6 mmol) for 68 h. Column chromatography of the residue on silica gel (5/1 hexanes/Et_2O) furnished 82 mg (82%, 98% ee) of

the title compound as colorless crystals. ^{1}H-NMR (400 MHz, $CDCl_3$) δ 7.26–7.20 (m, 5H, Ar–H), 7.19–7.13 (m, 3H, Ar–H), 7.10–6.99 (m, 4H, Ar–H), 6.92–6.86 (m, 2H, Ar–H), 4,70 (d, J = 8.3 Hz, 1H, CH), 4.47 (d, J = 11.0 Hz, 1H, CH_2), 4.33 (d, J = 8.3 Hz, 1H, CH), 4.27 (d, J = 11.0 Hz, 1H, CH_2), 3.83 (s, 3H, CH_3), 3.53 (br s, 1H, OH). ^{13}C NMR (100 MHz, $CDCl_3$) δ 159.51, 139.31, 137.81, 129.93, 129.78, 128.28, 128.20, 128.02, 127.94, 127.79, 127.41, 114.04, 86.77, 78.72, 70.63, 55.44. The recorded values were in agreement with the published data.[33] Daicel Chiralpak IB, *n*-heptane/IPA 95/5, 1 mL/min, 204 nm, $t_{S,S}$ = 10.4 min $t_{R,R}$ = 12.1 min.

(1*S*,2*S*)-2-((3-Methoxybenzyl)oxy)-1,2-diphenylethan-1-ol (5 b). According to the general procedure with 3-methoxybenzyl alcohol **4 b** (75 µl, 0.6 mmol) for 156 h. Column chromatography of the residue on silica gel (5/1 hexanes/Et_2O) furnished 86 mg (86 %, 98 % ee) of the title compound as a colorless oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.31–7.13 (m, 7H, Ar–H), 7.21–7.14 (m, 4H, Ar–H), 6.92–6.83 (m, 3H, Ar–H), 4.74 (d, J = 8.2 Hz, 1H, CH), 4.51 (d, J = 11.6 Hz, 1H, CH_2), 4.37 (d, J = 8.2 Hz, 1H, CH), 4.32 (d, J = 11.6 Hz, 1H, CH_2), 3.82 (s, 3H, CH_3), 3.52 (br s, 1H, OH). ^{13}C NMR (101 MHz, $CDCl_3$) δ 159.88, 139.46, 139.29, 137.66, 129.67, 128.31, 128.27, 128.02, 127.97, 127.83, 127.41, 120.28, 113.54, 113.47, 87.06, 78.73, 70.84, 55.38. IR ν_{max} 3542, 3506, 3434, 3414, 3064, 3028, 2938, 2872, 2833, 1601, 1494, 1458, 1437, 1269, 1198, 1159, 1078, 1057, 1021, 961, 923, 851, 788, 767, 746, 695, 573 cm^{-1}. HRMS (ESI) *m/z* calculated for $C_{22}H_{23}O_3$ (M + H) 335.1647; found 335.1646. $[\alpha]^{20}_D = +16.1°$ ($CHCl_3$, 0.44 g/100 mL). R_f (5/1 hexanes/Et_2O) = 0.25. Daicel Chiralpak IB, *n*-heptane/IPA 80/20, 1 mL/min, 205 nm, $t_{R,R}$ = 7.8 min, $t_{S,S}$ = 10.9 min.

(1*S*,2*S*)-2-((2-Methoxybenzyl)oxy)-1,2-diphenylethan-1-ol (5 c). According to the general procedure with 2-methoxybenzyl alcohol **4 c** (80 µl, 0.6 mmol) for 116 h. Column chromatography of the residue on silica gel (5/1 hexanes/Et_2O) furnished 76 mg (76 %, 88 % ee) of the title compound as colorless crystals. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.39–7.12 (m, 8H, Ar–H), 7.09–7.00 (m, 4H, Ar–H), 6.99–6.90 (m, 2H, Ar–H), 4.68 (d, J = 8.5 Hz, 1H, CH), 4.54 (d, J = 11.3 Hz, 1H, CH_2), 4.47 (d, J = 11.2 Hz, 1H, CH_2), 4.34 (d, J = 8.5 Hz, 1H, CH), 4.00 (br s, 1H, OH), 3.87 (s, 3H, CH_3). ^{13}C NMR (101 MHz, $CDCl_3$) δ 127.87, 139.35, 137.89, 129.96, 129.57, 128.11, 128.06, 127.97, 127.91, 127.75, 127.53, 126.08, 120.58, 110.58, 87.58, 78.88, 67.63, 55.43. Mp = 88-89 °C. IR (drift KBr) ν_{max} 3405, 3064, 3028, 3001, 2965, 2941, 2899, 2872, 2839, 1607, 1586, 1497, 1455, 1395, 1287, 1245, 1201, 1177, 1126, 1093, 1060, 1033, 934 851 776, 755, 701, 656, 626, 558 cm^{-1}. HRMS (ESI) *m/z* calculated for $C_{22}H_{22}O_3Na$ (M + Na) 357.14612; found 357.14555. $[\alpha]^{20}_D = +25.6°$ ($CHCl_3$, 0.39 g/100 mL). R_f (5/1 hexanes/Et_2O) = 0.3. Daicel Chiralpak IB, *n*-heptane/IPA 80/20, 1 mL/min, 192 nm, $t_{S,S}$ = 6.8 min $t_{R,R}$ = 8.7 min.

(1*S*,2*S*)-2-((4-Methylbenzyl)oxy)-1,2-diphenylethan-1-ol (5 d). According to the general procedure with 4-methylbenzyl alcohol **4 d** (74 mg, 0.6 mmol) for 72 h. Column chromatography of the residue on silica gel (5/1 hexanes/Et_2O) furnished 84 mg (88 %, 98 % ee) of the title compound as colorless crystals. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.29–7.12 (m, 10H, Ar–H), 7.10–6.99 (m, 4H, Ar–H), 4.77 (d, J = 8.0 Hz, 1H, CH), 4.49 (d, J = 11.2 Hz, 1H, CH_2), 4.35 (d, J = 8.2 Hz, 1H, CH), 4.30 (d, J = 11.2 Hz, 1H, CH_2), 3.54 (br s, 1H, OH), 2.37 (s, 3H, CH_3). ^{13}C NMR (101 MHz, $CDCl_3$) δ 139.30, 137.80, 137.77, 134.80, 129.33, 128.28, 128.25, 128.21, 128.02, 127.95, 127.80, 127.43, 86.96, 78.76, 70.85, 21.36. Mp = 71-72 °C. IR (drift KBr) ν_{max} 3560, 3088, 3031, 2953, 2914, 1866, 1622, 1458, 1395, 1344, 1320, 1260, 1201, 1180, 1081, 1060, 1033, 1021, 1003, 946, 917, 857, 812, 764, 698, 656, 612, 597, 492 cm^{-1}. HRMS (ESI) *m/z* calculated for $C_{22}H_{23}O_3Na$ (M + Na) 341.15120; found 341.15063. $[\alpha]^{20}_D = +23.4°$ ($CHCl_3$, 0.32 g/100 mL). R_f (5/1 hexanes/Et_2O) = 0.53. Daicel Chiralpak IB, *n*-heptane/IPA 98/2, 1 mL/min, 209 nm, $t_{S,S}$ = 10.5 min, $t_{R,R}$ = 11.8 min.

(1*S*,2*S*)-2-(Benzyloxy)-1,2-diphenylethan-1-ol (5 e). According to the general procedure with benzyl alcohol **4 e** (62 µl, 0.6 mmol) for 91 h. Column chromatography of the residue on silica gel (5/1 hexanes/Et_2O) furnished 80 mg of the title compound (88 %, 98 % ee) as a colorless solid.^{1}H NMR (400 MHz, $CDCl_3$) δ 7.41–7.30 (m, 5H, Ar–H), 7.28–7.23 (m, 3H, Ar–H), 7.21–7.15 (m, 3H, Ar–H), 7.12–7.02 (m, 4H, Ar–H), 4.75 (d, J = 8.2 Hz, 1H, CH), 4.45 (d, J = 11.5 Hz, 1H, CH_2), 4.37 (d, J = 7.9 Hz, 1H, CH), 4.35 (d, J = 11.2 Hz, 1H, CH_2), 3.55 (br s, 1H, OH). ^{13}C NMR (101 MHz, $CDCl_3$) δ 139.28, 137.85, 137.68, 128.62, 128.29, 128.25, 128.09, 128.00, 127.96, 127.81, 127.40, 87.08, 78.74, 70.96. The recorded values were in agreement with the published data.[49] Daicel Chiralpak IB, *n*-heptane/IPA 98/2, 1 mL/min, 209 nm, **5 e**: $t_{R,R}$ = 10.6, min $t_{S,S}$ = 11.4 min.

(1*S*,2*S*)-2-((4-Bromobenzyl)oxy)-1,2-diphenylethan-1-ol (5 f). According to the general procedure with 4-bromobenzyl alcohol **4 f** (112 mg, 0.6 mmol) for 69 h. Column chromatography of the residue on silica gel (5/1 hexanes/Et_2O) furnished 90 mg (78 %, 93 % ee) of the title compound as colorless crystals. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.51–7.45 (m, 2H, Ar–H), 7.25–7.20 (m, 3H, Ar–H), 7.19–7.12 (m, 5H, Ar–H), 7.09–7.00 (m, 4H, Ar–H), 4.74 (d, J = 8.0 Hz, 1H, CH), 4.47 (d, J = 11.7 Hz, 1H, CH_2), 4.34 (d, J = 8.0 Hz, 1H), 4.29 (d, J = 11.7 Hz, 1H, CH_2), 3.40 (br s, 1H, OH). ^{13}C NMR (100 MHz, $CDCl_3$) δ 139.22, 137.46, 136.85, 131.71, 129.67, 128.37, 128.35, 128.00, 127.94, 127.87, 127.33, 121.87, 87.06, 78.65, 70.14. The recorded values were in agreement with the published data.[34] Daicel Chiralpak IB, *n*-heptane/IPA 98/2, 1 mL/min, 205 nm, $t_{S,S}$ = 10.7 min, $t_{R,R}$ = 12.0 min.

Methyl 4-(((1*S*,2*S*)-2-hydroxy-1,2-diphenylethoxy)methyl) benzoate (5 g). According to the general procedure with methyl 4-(hydroxymethyl)benzoate **4 g** (100 mg, 0.6 mmol) for 86 h. Column chromatography of the residue on silica gel (2/1 hexanes/Et_2O) furnished 80 mg (76 %, 95 % ee) of the title compound as colorless crystals. ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.05–7.99 (m, 2H, Ar–H), 7.40–7.34 (m, 2H, Ar–H), 7.30–7.14 (m, 6H, Ar–H), 7.12–7.01 (m, 4H, Ar–H), 4.77 (d, J = 8.7 Hz, 1H, CH), 4.57 (d, J = 12.3 Hz, 1H, CH_2), 4.40 (d, J = 12.3 Hz, 1H, CH_2), 4.37 (d, J = 8.0 Hz, 1H, CH), 3.93 (s, 3H, CH_3), 3.44 (br s, 1H, OH).^{13}C NMR (101 MHz, $CDCl_3$) δ 167.01, 143.08, 139.21, 137.38, 129.91, 129.69, 128.40, 128.02, 127.95, 127.90, 127.57, 127.35, 87.31, 78.69, 70.30, 52.28. Mp = 94-95 °C. IR (drift KBr) ν_{max} 3494, 3452, 3067, 3028, 2953, 2872, 1721, 1613, 1434, 1284, 1198, 1174, 1105, 1023, 967, 914, 845, 758, 698, 576 cm^{-1}. HRMS (ESI) *m/z* calculated for $C_{23}H_{22}O_4Na$ (M + Na) 385.14103; found 385.14041. $[\alpha]^{20}_D = +14.1°$ ($CHCl_3$, 0.39 g/100 mL). R_f (5/1 hexanes/Et_2O) = 0.1. Daicel Chiralpak IB, *n*-heptane/IPA 98/2, 1 mL/min, 204 nm, $t_{S,S}$ = 28.8 min, $t_{R,R}$ = 33.5 min.

(1*S*,2*S*)-2-((4-Nitrobenzyl)oxy)-1,2-diphenylethan-1-ol (5 h). According to the general procedure with 4-nitrobenzyl alcohol **4 h** (92 mg, 0.6 mmol) for 69 h. Column chromatography of the residue on silica gel (5/1 hexanes/Et_2O) furnished 81 mg (75 %, 98 % ee) of the title compound as colorless crystals. ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.25–8.16 (m, 2H, Ar–H), 7.50–7.42 (m, 2H, Ar–H), 7.32–7.14 (m, 6H, Ar–H), 7.11–7.01 (m, 4H, Ar–H), 4.81 (d, J = 7.8 Hz, 1H, CH), 4.61 (d, J = 12.8 Hz, 1H, CH_2), 4.47 (d, J = 12.8 Hz, 1H, CH_2), 4.40 (d, J = 7.8 Hz, 1H, CH), 3.34 (br s, 1H, OH). ^{13}C NMR (101 MHz, $CDCl_3$) δ 147.59, 145.43, 139.14, 137.13, 128.58, 128.53, 128.10, 128.09, 128.03, 127.89, 127.27, 123.83, 87.58, 78.62, 69.72. Mp = 76-77 °C. IR (drift KBr) ν_{max} 3542, 3452, 3114, 3064, 3034, 2872, 1607, 1524, 1494, 4152, 1344, 1317, 1296, 1263, 1251, 1087, 1063, 1042, 1013, 920, 860, 770, 737, 701 cm^{-1}. HRMS (ESI) *m/z* calculated for $C_{21}H_{20}NO_4$ (M + H) 350.1392; found 350.1389. $[\alpha]^{20}_D = +5.1°$ (MeOH, 0.39 g/100 ml). R_f (5/1 hexanes/Et_2O) = 0.21. Daicel Chiralpak IB, *n*-heptane/IPA 96/4, 1 mL/min, 206 nm, $t_{S,S}$ = 27.3 min, $t_{R,R}$ = 35.9 min.

(1*S*,2*S*)-1,2-Diphenyl-2-((4-(trifluoromethyl)benzyl)oxy)ethan-1-ol (5 i). According to the general procedure with 4-(trifluoromethyl) benzyl alcohol **4 i** (83 µl, 0.6 mmol) for 116 h. Column chromatography of the residue on silica gel (5/1 hexanes/Et_2O) furnished

96 mg (86%, 98% ee) of the title compound as colorless crystals. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.64–7.56 (m, 2H, Ar–H), 7.45–7.37 (m, 2H, Ar–H), 7.30–7.14 (m, 6H, Ar–H), 7.12–7.00 (m, 4H, Ar–H), 4.78 (d, J= 8.0 Hz, 1H, CH), 4.57 (d, J=12.3 Hz, 1H, CH_2), 4.41 (d, J=12.3 Hz, 1H, CH_2), 4.39 (d, J=8.0 Hz, 1H, CH), 3.39 (br s, 1H, OH). ^{19}F NMR (376 MHz, $CDCl_3$) δ −62.52. ^{13}C NMR (151 MHz, $CDCl_3$) δ 141.94, 139.19, 137.35, 130.12 (q, $^2J_{C\text{-}F}$=32.5 Hz), 128.46, 128.43, 128.05, 127.94, 127.33, 125.55 (q, $^3J_{C\text{-}F}$=3.5 Hz), 124.26 (q, $^1J_{C\text{-}F}$=272.0 Hz), 87.36, 78.68, 70.13. Mp=75-76 °C. IR (drift KBr) ν_{max} 3524, 3402, 3088, 3064, 3034, 2884, 1616, 1458, 1425, 1395, 1326, 1201, 1168, 1123, 1087, 1069, 1021, 911, 857, 821, 776, 755, 701, 665, 576 cm^{-1}. HRMS (ESI) m/z calculated for $C_{22}H_{19}F_3O_2Na$ (M+Na) 395.12294; found 395.12225. $[\alpha]^{20}_D$=+7.6° ($CHCl_3$, 0.395 g/100 ml). R_f (5/1 hexanes/Et_2O)=0.35. Daicel Chiralpak IB, n-heptane/IPA 95/5, 1 mL/min, 208 nm, $t_{S,S}$=9.2 min, $t_{R,R}$=10.8 min.

(1*S*,2*S*)-2-(Naphthalen-1-ylmethoxy)-1,2-diphenylethan-1-ol (5 j). According to the general procedure with naphthalen-1-ylmethanol **4 j** (95 mg, 0.6 mmol) for 107 h. Column chromatography of the residue on silica gel (5/1 hexanes/Et_2O) furnished 94 mg (88%, 97% ee) of the title compound as colorless crystals. ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.09–8.01 (m, 1H, Ar–H), 7.93–7.82 (m, 2H, Ar–H), 7.59–7.49 (m, 2H, Ar–H), 7.48–7.40 (m, 2H, Ar–H), 7.31–7.24 (m, 3H, Ar–H), 7.20–7.10 (m, 5H, Ar–H), 7.05–6.98 (m, 2H, Ar–H), 4.99 (d, J= 11.5 Hz, 1H, CH_2), 4.78 (d, J=11.5 Hz, 1H, CH_2), 4.74 (d, J=8.3 Hz, 1H, CH), 4.45 (d, J=8.2 Hz, 1H, CH), 3.42 (br s, 1H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 139.26, 137.70, 133.95, 133.32, 131.95, 129.09, 128.85, 128.35, 128.34, 128.11, 127.95, 127.80, 127.39, 127.07, 126.62, 126.03, 125.36, 123.87, 87.35, 78.67, 69.42. Mp=73-74 °C. IR (drift KBr) ν_{max} 3554, 3476, 3440, 3064, 3028, 2881, 1598, 1515, 1488, 1452, 1392, 1257, 1231, 1201, 1171, 1090, 1066, 1042, 1021, 917, 857, 800, 767, 701, 564, 555 cm^{-1}. HRMS (ESI) m/z calculated for $C_{25}H_{22}O_2Na$ (M+Na) 377.15120; found 377.15095. $[\alpha]^{20}_D$=+53.1 ($CHCl_3$, 0.32 g/100 mL). R_f (5/1 hexanes/Et_2O)=0.33. Daicel Chiralpak IB, n-heptane/IPA 80/20, 1 mL/min, 224 nm, $t_{R,R}$=11.2 min, $t_{S,S}$= 13.3 min.

(1*S*,2*S*)-2-(Anthracen-9-ylmethoxy)-1,2-diphenylethan-1-ol (5 k). According to the general procedure with 9-antharecenemethanol **4 k** (125 mg, 0.6 mmol) at 40 °C for 69 hours. Column chromatography of the residue on silica gel (5/1 hexanes/Et_2O) furnished 76 mg (63%, 96% ee) of the title compound as yellowish crystals. ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.50 (s, 1H, Ar–H), 8.19–8.13 (m, 2H, Ar–H), 8.07–8.01 (m, 2H, Ar–H), 7.55–7.45 (m, 4H, Ar–H), 7.38–7.30 (m, 3H, Ar–H), 7.23–7.11 (m, 5H, Ar–H), 7.03–6.98 (m, 2H, Ar–H), 5.46 (d, J=11.2 Hz, 1H, CH_2), 5.34 (d, J=11.1 Hz, 1H, CH_2), 4.69 (d, J=8.2 Hz, 1H, CH), 4.52 (d, J=8.2 Hz, 1H, CH), 3.37 (br s, 1H, OH). ^{13}C NMR (101 MHz, $CDCl_3$) δ 139.18, 138.04, 131.59, 131.18, 129.27, 128.87, 128.51, 128.42, 128.26, 128.19, 127.95, 127.78, 127.37, 126.61, 125.19, 124.14, 87.81, 78.66, 63.41. Mp=143-144 °C. IR (drift KBr) ν_{max} 3509, 3458, 3058, 3031, 2887, 2863, 162, 1452, 1335, 1254, 1234, 1201, 1177, 1156, 1081, 1066, 1048, 1018, 1003, 985, 884, 848, 767, 734, 698, 585, 555 cm^{-1}. HRMS (ESI) m/z calculated for $C_{29}H_{24}O_2$ (M+H) 404.1776; found 404.1771. $[\alpha]^{20}_D$=+101.6° ($CHCl_3$, 0.31 g/ 100 mL). R_f (5/1 hexanes/Et_2O)=0.2. Daicel Chiralpak IB, n-heptane/ IPA 50/50, 1 mL/min, 255 nm, **5 k**: $t_{S,S}$=5.3 min, $t_{R,R}$=13.6 min.

(1*S*,2*S*)-1,2-Diphenyl-2-(furan-2-ylmethoxy)ethan-1-ol (5 l). According to the general procedure with furfuryl alcohol **4 l** (52 µl, 0.6 mmol) for 23 days. Reaction carried out with powdered MS 4 Å (30 mg) and furnished desired alcohol 5 l in 75% ^{1}H NMR yield with 97% ee. The product was isolated by preparative TLC for HPLC analysis. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.44 (dd, J=1.8, 0.8 Hz, 1H, Ar–H), 7.25–7.11 (m, 6H, Ar–H), 7.08–6.97 (m, 4H, Ar–H), 6.45 (dd, J=3.3, 0.75 Hz, 1H, Ar–H), 6.26 (d, J=3.3 Hz, 1H, Ar–H), 4.69 (d, J= 8.3 Hz, 1H, CH), 4.50 (d, J=12.7 Hz, 1H, CH_2), 4.31 (d, J=8.4 Hz, 1H, CH), 4.28 (d, J=12.7 Hz, 1H, CH_2), 3.52 (s, 1H, OH). ^{13}C NMR (101 MHz, $CDCl_3$) δ 151.33, 143.19, 139.16, 137.34, 128.27, 128.04, 127.95, 127.83, 127.46, 110.42, 109.76, 86.71, 78.61, 62.84. IR (drift KBr) ν_{max} 3569, 3539, 3512, 3461, 3431, 3372, 3064, 3028, 2923, 2893, 2866, 1601, 1497, 1455, 1260, 1228, 1198, 1153, 1069, 1021, 984, 949, 923, 890, 851, 815, 752, 701, 647, 576 cm^{-1}. HRMS (ESI) m/z calculated for $C_{19}H_{19}O_3$ (M+H) 295.1335; found 295.1334. $[\alpha]^{20}_D$= +45.7° ($CHCl_3$, 0.35 g/100 mL). R_f (5/1 hexanes/EtOAc)=0.2. Daicel Chiralpak IB, n-heptane/IPA 80/20, 1 mL/min, 209 nm, **5 l**: $t_{S,S}$= 5.3 min, $t_{R,R}$=6.4 min.

(1*S*,2*S*)-1,2-Diphenyl-2-(thiophen-2-ylmethoxy)ethan-1-ol (5 m). According to the general procedure with thiophenyl-2-ylmethanol **4 m** (57 µl, 0.6 mmol) for 114 h. Column chromatography of the residue on silica gel (20/1 hexanes/EtOAc) furnished 79 mg (85%, 97% ee) of the title compound as colorless crystals. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.33 (dd, J=5.1, 1.2 Hz, 1H, Ar–H), 7.28–7.21 (m, 3H, Ar–H,), 7.19–7.11 (m, 3H, Ar–H), 7.09–6.98 (m, 5H, Ar–H), 6.95-6.93 (m, 1H, Ar–H), 4.70-4.66 (m, 2H, CH+CH_2), 4.52 (d, J=12.2 Hz, 1H, CH_2), 4.38 (d, J=8.3 Hz, 1H, CH), 3.47 (br s, 1H, OH). ^{13}C NMR (101 MHz, $CDCl_3$) δ 140.49, 139.16, 137.35, 128.34, 128.06, 127.96, 127.84, 127.44, 126.87, 126.79, 126.27, 86.60, 78.60, 65.27. Mp=61-62 °C. IR (drift KBr) ν_{max} 3530, 3106, 3058, 3031, 2938, 2887, 2860, 1957, 1882, 1817, 1491, 1452, 1932, 1335, 1269, 1222, 1198, 1177, 1069, 1045, 1021, 994, 920, 860, 824, 776, 755, 704, 656, 632, 612, 555, 540, 480, 462 cm^{-1}. HRMS (ESI) m/z calculated for $C_{19}H_{19}O_2S$ 311.1106 (M+H); found 311.1113. $[\alpha]^{20}_D$=+46.7° ($CHCl_3$, 0.54 g/ 100 mL). R_f (10/1 hexanes/EtOAc)=0.2. Daicel Chiralpak IB, n-heptane/IPA 80/20, 1 mL/min, 207 nm, $t_{S,S}$=5.7 min, $t_{R,R}$=7.1 min.

(1*S*,2*S*)-1,2-Diphenyl-2-(ferrocenylmethoxy)ethan-1-ol (5n). According to the general procedure with ferrocenyl methanol **4 n** (135 mg, 0.6 mmol) for 11 days. Column chromatography of the residue on silica gel (5/1 hexanes/Et_2O) furnished 35 mg (27%, 89% ee) of the title compound as orange crystals. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.25–7.12 (m, 6H, Ar–H), 7.07–6.95 (m, 4H, Ar–H), 4.62 (d, J=8.3 Hz, 1H, CH), 4.30 (d, J=8.2 Hz, 1H, CH), 4.29 (d, J=11.2 Hz, 1H, $FcCH_2$), 4.25–4.17 (m, 4H, Cp) 4.14 (d, J=11.2 Hz, 1H, $FcCH_2$), 4.10 (s, 5H, Cp), 3.53 (br s, 1H, OH). ^{13}C NMR (101 MHz, $CDCl_3$) δ 139.28, 137.91, 128.22, 128.14, 127.98, 127.93, 127.78, 127.45, 86.79, 83.32, 78.71, 69.53, 69.19, 68.94, 68.66, 67.38. Mp=108-109 °C. IR (drift KBr) ν_{max} 3560, 3545, 3464, 3446, 3091, 3064, 3028, 2926, 2866, 1658, 1604, 1449, 1413, 1237, 1201, 1108, 1072, 1021, 1003, 923, 824, 770, 698, 576, 504 cm^{-1}. HRMS (ESI) m/z calculated for $C_{25}H_{25}FeO_2$ (M+Na) 435.10179; found 435.10152. $[\alpha]^{20}_D$=+52.1° ($CHCl_3$, 0.48 g/100 mL). R_f (5/1 hexanes/EtOAc)=0.2. Daicel Chiralpak IB, n-heptane/IPA 90/10, 1 mL/min, 206 nm, $t_{S,S}$=9.1 min, $t_{R,R}$=25.1 min.

(1*S*,2*S*)-2-Methoxy-1,2-diphenylethan-1-ol (5 o). According to the general procedure with methanol **4 o** (25 µl, 0.6 mmol) for 86 h. Column chromatography of the residue on silica gel (5/1 hexanes/ Et_2O) furnished 59 mg (87%, 93% ee) of the title compound as colorless crystals. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.24–7.12 (m, 6H, Ar–H), 7.07–6.96 (m, 4H, Ar–H), 4.66 (d, J=8.3 Hz, 1H, CH), 4.13 (d, J=8.3 Hz, 1H, CH), 3.52 (br s, 1H, OH), 3.31 (s, 3H, CH_3). ^{13}C NMR (101 MHz, $CDCl_3$) δ 139.32, 137.54, 128.19, 128.15, 127.97, 127.90, 127.83, 127.43, 89.35, 78.81, 57.05. R_f (5/1 hexanes/Et_2O)=0.2. The recorded values were in agreement with the published data.[33] Daicel Chiralpak IB, n-heptane/IPA 90/10, 1 mL/min, 208 nm, $t_{S,S}$= 6.2 min, $t_{R,R}$=6.8 min.

(1S,2S)-2-(Cyclohexyloxy)-1,2-diphenylethan-1-ol (5 p). According to the general procedure with cyclohexanol **4 p** (60 µl, 0.6 mmol) for 23 d in the presence of powdered MS 4 Å. Column chromatography of the residue on silica gel (20/1 hexanes/Et_2O) furnished 74 mg (83%, 99% ee) of the title compound as colorless crystals. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.22–7.13 (m, 6H, Ar–H), 7.07–6.98 (m, 4H, Ar–H), 4.59 (d, J=8.1 Hz, 1H, CH), 4.35 (d, J=8.1 Hz, 1H, CH), 3.60 (br s, 1H, OH), 3.32–3.23 (m, 1H, CH), 1.80–1.60 (m, 3H, CH_2), 1.52–

1.08 (m, 7H, CH_2). ^{13}C NMR (101 MHz, $CDCl_3$) δ 139.57, 139.05, 128.01, 127.91, 127.86, 127.85, 127.74, 127.44, 84.70, 78.80, 75.72, 33.67, 31.50, 25.83, 24.21, 24.03. Mp = 55-56 °C. IR (drift KBr) ν_{max} 3524, 3061, 3031, 3029, 2887, 2860, 1491, 1449, 1389, 1320, 1260, 1225, 1195, 1084, 1069, 1024, 961, 911, 890, 851, 776, 749, 701, 662, 573 cm^{-1}. HRMS (ESI) *m/z* calculated for $C_{20}H_{25}O_2$ (M + H) 297.1855; found 297.1856. $[\alpha]^{20}_D = 11.5°$ ($CHCl_3$, 0.31 g/100 mL). R_f (5/1 hexanes/EtOAc) = 0.3. Daicel Chiralpak IB, *n*-heptane/IPA 90/10, 1 mL/min, 208 nm, $t_{S,S} = 4.5$ min, $t_{R,R} = 5.0$ min.

(1*S*,2*S*)-2-(Allyloxy)-1,2-diphenylethan-1-ol (5q). According to the general procedure with allyl alcohol **4q** (41 µl, 0.6 mmol) for 86 h. Column chromatography of the residue on silica gel (5/1 hexanes/Et_2O) furnished 65 mg (86%, 95% ee) of the title compound as colorless crystals. ^1H NMR (400 MHz, $CDCl_3$) δ 7.24–7.12 (m, 6H, Ar–H), 7.07–6.96 (m, 4H, Ar–H), 5.99–5.84 (m, 1H, CH), 5.32–5.10 (m, 2H, $=CH_2$), 4.69 (d, $J = 8.4$ Hz, 1H, CH), 4.30 (d, $J = 8.3$ Hz, 1H, CH), 4.00 (app ddt, $J = 12.6$, 5.1, 1.3 Hz, 1H, CH_2), 3.85 (app ddt, $J = 12.6$, 6.1, 1.3 Hz 1H, CH_2), 3.54 (br s, 1H, OH). ^{13}C NMR (101 MHz, $CDCl_3$) δ 139.29, 137.72, 134.45, 128.20, 128.16, 127.97, 127.92, 127.84, 127.45, 117.46, 86.91, 78.74, 69.90. R_f (5/1 hexanes/Et_2O) = 0.3. The recorded values were in agreement with the published data.[33] Daicel Chiralpak IB, *n*-heptane/IPA 90/10, 1 mL/min, 207 nm, $t_{S,S} = 5.3$ min, $t_{R,R} = 5.8$ min.

(1*S*,2*S*)-1,2-Diphenyl-2-(prop-2-yn-1-yloxy)ethan-1-ol (5r). According to the general procedure with propargyl alcohol **4r** (35 µl, 0.6 mmol) for 96 h. Column chromatography of the residue on silica gel (5/1 hexanes/Et_2O) furnished 65 mg (81%, 98% ee) of the title compound as a colorless oil. ^1H NMR (400 MHz, $CDCl_3$) δ 7.25–7.12 (m, 6H, Ar–H), 7.10–6.98 (m, 4H, Ar–H), 4.73 (d, $J = 8.4$ Hz, 1H, CH), 4.51 (d, $J = 8.4$ Hz, 1H, CH), 4.22 (dd, $J = 15.7$, 2.3 Hz 1H, CH_2), 3.95 (dd, $J = 15.7$, 2.2 Hz 1H, CH_2), 3.45 (s, 1H, OH), 2.46 (t, $J = 2.2$ Hz, 1H, $\equiv CH$). ^{13}C NMR (101 MHz, $CDCl_3$) δ 139.08, 136.61, 128.46, 128.32, 128.11, 127.99, 127.91, 127.47, 86.30, 79.41, 78.39, 75.04, 56.14. R_f (5/1 hexanes/Et_2O) = 0.2. The recorded values were in agreement with the published data.[33] Daicel Chiralpak IB, *n*-heptane/IPA 90/10, 1 mL/min, 208 nm, $t_{S,S} = 7.3$ min, $t_{R,R} = 8.4$ min.

Supporting Information (see footnote on the first page of this article): For characterization of other compounds, see the SI.

Deposition Number 2015559 (for **5p**) contains the supplementary crystallographic data for this paper. These data are provided free of charge by the joint Cambridge Crystallographic Data Centre and Fachinformationszentrum Karlsruhe Access Structures service www.ccdc.cam.ac.uk/structures.

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Conflict of Interest

The authors declare no conflict of interest.

Keywords: Chiral ligands · Desymmetrization · Enantioselective reaction · Epoxides · Lewis acid

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