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Scandium-Bipyridine-Catalyzed, Enantioselective Alcoholysis of *meso*-Epoxides

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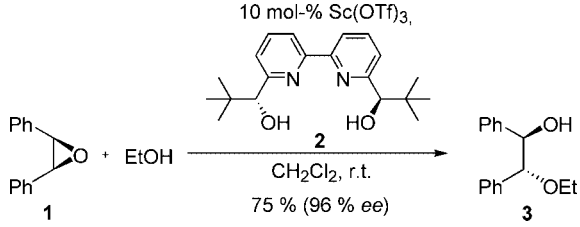
The scandium-bipyridine-catalyzed ring-opening of *meso*-epoxides with aliphatic alcohols has been studied. Aromatic epoxides were ring-opened with >90% *ee* furnishing valuable 1,2-diol monoethers in typically good yields whereas aliphatic epoxides gave rise to moderate enantioselectivities. The catalyst loading may be lowered to 2–5 mol-% with only marginal effects on yield and enantioselectivity. A strong positive non-linear effect was observed pointing to aggregation phenomena of the chiral catalyst.

Introduction

The catalytic enantioselective ring-opening of *meso*-epoxides has been frequently employed in recent years for the synthesis of valuable, highly enantiomerically enriched 1,2-difunctionalized fine chemicals starting from achiral commodity compounds.[1] Azides,[2] amines,[3] acids,[4] phenols,[5] thiols,[6] selenols,[7] halides,[8] cyanides,[9] and various organometal compounds[10] have been employed as nucleophiles which typically ring-open the epoxides in a unified S_N2-pathway with support of a chiral Lewis acid furnishing the corresponding β-functionalized alcohols in good to excellent enantioselectivities.

The catalytic enantioselective addition of oxygen nucleophiles to *meso*-epoxides has been the subject of only a few reports. Actually, prior to this study there had been no report on the catalytic, enantioselective addition of aliphatic alcohols to *meso*-epoxides. Jacobsen et al.[4] utilized a cobalt(III) salen complex as chiral Lewis acid in the addition of carboxylic acids to epoxides furnishing 1,2-diol monoesters in excellent yield and moderate to very good enantioselectivities. Shibasaki et al.[5] developed a gallium-lithium-BINOL complex which was capable of catalyzing the addition of phenols to *meso*-epoxides in good to excellent enantioselectivities.

We have recently shown that a scandium bipyridine complex composed of $Sc(OTf)_3$ and the chiral ligand **2** effectively catalyzes the nucleophilic ring-opening of *meso*-epoxides with aliphatic alcohols.[11a] For example, *cis*-stilbene oxide (**1**) was ring-opened with ethanol in 75% yield and 96% *ee* in a reaction catalyzed with 10 mol-% of the $Sc(OTf)_3$-bipyridine[12] complex (Scheme 1).



Scheme 1. Scandium-bipyridine-catalyzed ring opening of *cis*-stilbene oxide (**1**) with ethanol.

We have now investigated this process in more detail and give a full account of this work.

Results and Discussion

In order to further optimize this process and investigate scope and limitations we decided to select the reactions of *cis*-stilbene oxide (**1**) as an aromatic epoxide and cyclohexene oxide (**6**) as an aliphatic epoxide with either *p*-methoxybenzyl alcohol (PMBOH) or allyl alcohol as model reactions which we carefully studied with respect to metal triflate, solvent, temperature, ligand architecture, and catalyst loading (Scheme 2).

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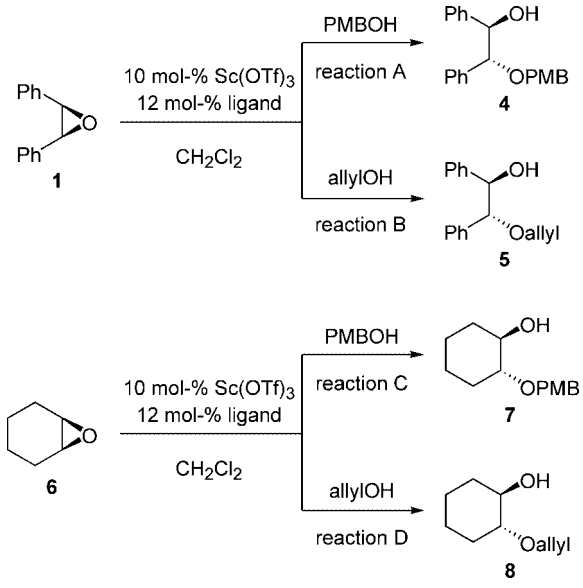


Scheme 2. Model reactions A–D selected for further optimization.

Influence of Metal Triflate

Since the scandium-bipyridine complex performed so well in the alcoholysis of *meso*-epoxides, we screened other lanthanide and metal triflates in combination with bipyridine **2** in model reactions A and C and investigated their catalytic activity and enantioselectivity. All reactions were conducted with 10 mol-% of metal triflate and 12 mol-% of bipyridine ligand **2** in CH_2Cl_2 as solvent at temperatures between –20 °C and r.t. (Table 1 and Table 2).

Table 1. Screening of different metal triflates in model reaction A (Scheme 2).

Entry	$M(OTf)_3$	*T* [°C]	*t*	Yield (%)[a]	*ee* (%)[b]
1	$Sc(OTf)_3$	r.t.	16 h	82	97
2	$Y(OTf)_3$	r.t.	3 d	61	93
3	$La(OTf)_3$	r.t.	7 d	3	32
4	$Ce(OTf)_3$	r.t.	22 h	33	12
5	$Nd(OTf)_3$	r.t.	8 d	14	26
6	$Sm(OTf)_3$	r.t.	7 d	6	44
7	$Tb(OTf)_3$	0	16 d	9	26
8	$Tm(OTf)_3$	r.t.	8 d	17	33
9	$Yb(OTf)_3$	r.t.	8.5 d	23	64
10	$Cu(OTf)_2$	r.t.	3 d	26	–38[c]
11	$Zn(OTf)_2$	r.t.	8 d	15	–51[c]

[a] Isolated yield after flash column chromatography. [b] Determined by chiral HPLC analysis. [c] Negative sign indicates that the opposite enantiomer is formed as the major product.

Inspection of Table 1 clearly reveals that the $Sc(OTf)_3$-bipyridine combination was the chiral catalyst of choice for this reaction displaying the best catalytic activity and highest enantioselectivity (entry 1, 82% yield, 97% *ee*). The corresponding yttrium-bipyridine complex was less active and required an extended period of reaction time, but furnished the product in almost the same level of optical purity (entry 2, 61% yield, 93% *ee*). All other lanthanide triflate bipyridine complexes which we investigated were significantly less enantioselective and furnished the product in low yields. Quite interestingly, the copper and zinc bipyridine complexes predominantly furnished the opposite enantiomer in low yields and 38% *ee* and 51% *ee*, respectively, which may be attributed to their different coordination geometry compared to the lanthanide metals (entries 10, 11).

Table 2. Screening of different metal triflates in model reaction C (Scheme 2).

Entry	$M(OTf)_n$	*T* [°C]	*t*	Yield (%)[a]	*ee* (%)[b]
1	$Sc(OTf)_3$	–20	2.5 h	90	54
2	$Y(OTf)_3$	r.t.	2.5 d	56	40
3	$La(OTf)_3$	r.t.	7 d	43	0
4	$Ce(OTf)_3$	r.t.	18 h	47	0
5	$Nd(OTf)_3$	r.t.	7 d	47	11
6	$Sm(OTf)_3$	r.t.	7 d	44	9
7	$Tb(OTf)_3$	0	15 d	21	4
8	$Tm(OTf)_3$	r.t.	8 d	43	3
9	$Yb(OTf)_3$	r.t.	8 d	48	12
10	$Cu(OTf)_2$	r.t.	2 d	48	–30[c]
12	$Zn(OTf)_2$	r.t.	8 d	45	–45[c]

[a] Isolated yield after flash column chromatography. [b] Determined by chiral GC analysis. [c] Negative sign indicates that the opposite enantiomer is formed as the major product.

A similar picture emerged in the alcoholysis of cyclohexene oxide (**6**) (Table 2). Again, the scandium and yttrium bipyridine complexes exhibited the highest enantioselectivity with up to 54% *ee*. The $Sc(OTf)_3$-bipyridine complex was also the most active one reaching full conversion within 2–3 h at –20 °C. This observation nicely relates to the well-known Lewis acidity of Sc(III) among the rare earth metals, which, in contrast to conventional metal triflates, is not affected by protic solvents or reagents.[13]

Optimization of Solvent

In earlier experiments we had found that coordinating and highly dipolar solvents such as DMF, CH_3CN, and THF shut down the catalytic activity of the scandium-bipyridine complex presumably because of coordination to the Lewis acidic metal center. Weakly coordinating or non coordinating solvents such as toluene and diethyl ether gave rise to high product yields but furnished the product 1,2-diol monoethers with no enantioselectivity. Since CH_2Cl_2 was initially found to be optimal, we investigated other halogenated solvents in model reactions A and D (Table 3).

Table 3. Solvent optimization for model reactions A and D (Scheme 2).

Entry	Solvent	*T* [°C]	*t* [d]	Yield (%)[a]		*ee* (%)	
				A	D	A[b]	D[c]
1	CH_2Cl_2	–20	3	73	54	97	50
2	$CHCl_3$	–20	2	54	34	97	57
3	CCl_4	–20	2	84	61	94	31
4	$C_2H_4Cl_2$	–20	2	80	86	97	46
5	$CHBr_3$	–20	2	33	32	94	30

[a] Isolated yield after flash column chromatography. [b] Determined by chiral HPLC analysis. [c] Determined by chiral GC analysis.

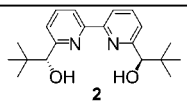
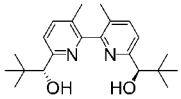
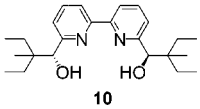
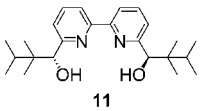
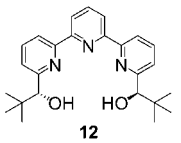
1,2-Dichloroethane proved to be a good alternative to dichloromethane both in terms of yield and enantioselectivity (Table 3, entry 4). In $CHCl_3$, the ring-opening of cyclohexene oxide proceeded in slightly higher enantioselectivity than in CH_2Cl_2 but in lower yield. A similar trend of equal enantioselectivity and lower yield was observed for the alcoholysis of *cis*-stilbene oxide (entry 2). CCl_4 and $CHBr_3$ turned out to be less suitable solvents especially in the ring-opening of cyclohexene oxide.

Variation of Ligand Architecture

In our preliminary experiments we had investigated a number of so-called priviliged chiral ligands (e.g. bisoxazolines, pyridine bisoxazolines and salen ligands) for the scandium-catalyzed alcoholysis of *meso*-epoxides none of which gave rise to an enantioselective alcoholysis. We then discovered the bipyridine ligand **2** which apparently offered some important structural advantages for a highly enantioselective scandium complex. Thus, it was interesting to modify the bipyridine structure at specific sites.

The first effort was to investigate the influence of the torsion angle between the two pyridine rings in the scandium-bipyridine complex. Ligand **9** was prepared in analogy to a synthetic protocol of Denmark et al.[14] and was expected to have a significantly enhanced torsion angle in the scandium complex because of the presence of the *ortho* methyl groups. However, yields and enantioselectivities in model reactions B and D were almost identical with both scandium-bipyridine complexes (Table 4, entries 1, 2).

Table 4. Results for model reactions B and D performed with modified ligands **9**–**12** (Scheme 2).

Entry	Ligand	Ph, OH, Ph, Oallyl: *t* [h]	Yield (%)[a]	*ee* (%)[b]	OH, Oallyl: *t* [h]	Yield (%)[a]	*ee* (%)[c]
1	 **2**	24	81	96	24	44	48
2	 **9**	19	82	96	23	55	43
3	 **10**	24	68	93	22	43	49
4	 **11**	23	73	95	19	71	47
5	 **12**	48	44	30	25	50	0

[a] Isolated yield after flash column chromatography. [b] Determined by chiral HPLC analysis. [c] Determined by chiral GC analysis.

Next we increased the size of the alkyl group at the carbinol center and prepared ligands **10** and **11** in analogy to the parent bipyridine ligand. In the scandium-catalyzed reaction of *cis*-stilbene oxide (**1**) with allyl alcohol (reaction B) both ligands led to almost identical enantioselectivity but in slightly lower yields. Cyclohexene oxide (**6**) was ring-opened with allyl alcohol (reaction D) and either of the two chiral scandium catalysts in almost the same enantioselectivity as with the $Sc(OTf)_3$-bipyridine **2** complex (entries 3 and 4).

Yet another modification concerned the ligand backbone in that an additional pyridine ring was placed inbetween the bipyridine yielding a tripyridine. The $Sc(OTf)_3$-tripyridine **12** catalyst, however, did not give rise to an enantioselective catalyst furnishing 1,2-diol monoether **5** in low *ee* and the 1,2-diol monoether **8** in racemic form (entry 5).

Catalyst Loading

The amount of catalyst required for a highly enantioselective reaction in good yield was investigated in the reaction of *cis*-stilbene oxide (**1**) and *p*-methoxybenzyl alcohol (Table 5) at room temp. in CH_2Cl_2.

Table 5. Variation of catalyst loading in model reaction A (Scheme 2).

Entry	Loading [mol-%]	*t* [d]	Yield (%)[a]	*ee* (%)[b]
1	15	0.5	84	98
2	10	0.5	82	97
3	5	5	84	94
4	2	8	75	90
5	1	9	70	73

[a] Isolated yield after flash column chromatography. [b] Determined by chiral HPLC analysis.

A catalyst loading of 10 mol-% provided 1,2-diol monoether **4** in 82% yield and 97% *ee* within several hours. Increasing the catalyst loading to 15 mol-% resulted in a slightly higher selectivity and higher yields. Lowering the catalyst amount to 5 mol-% led to a significant increase in reaction time. The product **4** was, however, obtained in good yield and still excellent selectivity of 94% *ee*. With a catalyst loading of only 2 mol-% the reaction time further increased. The yield was good and the enantioselectivity was still on a high level of 90% *ee*. A sharp decrease in selectivity to only 73% *ee* was observed when the amount of catalyst was further lowered to 1 mol-%. Hence, the threshold of catalytic efficiency can be considered about 2 mol-%.

Non Linear Effect

In order to get a deeper insight into the catalyst structure we investigated the relation between product-*ee* and ligand-*ee*. Model reaction A in Scheme 2 was performed with ligands of different *ee*'s and the enantiomeric excess of the product 1,2-diol monoether **4** was measured (Figure 1).

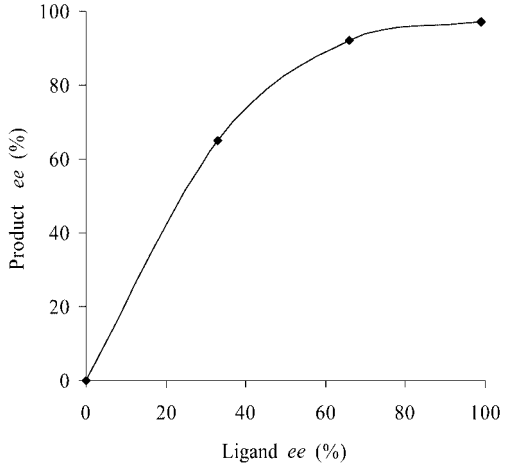


Figure 1. Non linear effect exhibited by the scandium-bipyridine **2** complex.

With a ligand-*ee* of 33% we already obtained the product with 65% *ee* and with 66% ligand-*ee* a product with 92% *ee* was formed. This strong positive non-linear effect suggests that two or more monomeric catalyst species form catalytically inactive oligomeric aggregates thereby enhancing the proportion of one catalytically active scandium bipyridine enantiomer.[15]

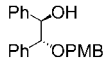
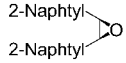
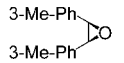
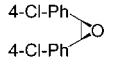
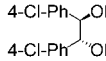
Scope and Limitations

According to the optimized protocol developed above several *meso*-epoxides were then tested in this scandium-bipyridine-catalyzed alcoholysis (Table 6 and Table 7). *cis*-Stilbene oxide (**1**) was ring-opened with various alcohols in good yields and excellent enantioselectivities. *p*-Methoxybenzyl alcohol performed best and gave rise to 1,2-diol monoether **4** in 82% yield and 97% *ee* (Table 6, entry 1). But also more conventional alcohols such as methanol, ethanol, 1-butanol, 2-propanol, allyl, and propargyl alcohol ring-opened *cis*-stilbene oxide in good yields and excellent enantioselectivities (Table 6, entries 2–7). Other aromatic epoxides **13**–**15** were tested in this reaction giving rise to good yields and high enantioselectivities, too (entries 8–10).

Aliphatic cyclic *meso*-epoxides **6**, **23**, and **24** were ring-opened with only moderate enantioselectivity (Table 7, entries 1–5). Significantly, the α-branched allylic epoxide **23** gave rise to the highest enantioselectivity in this series (entry 4). Acyclic *meso*-epoxides **25**–**27** underwent the alcoholysis with varying yields and again moderate enantioselectivity. Apparently, α- and β-branched side chains retarded the reaction rate so that no full conversion was achieved within 2 d and side reactions set in (entries 7 and 8).

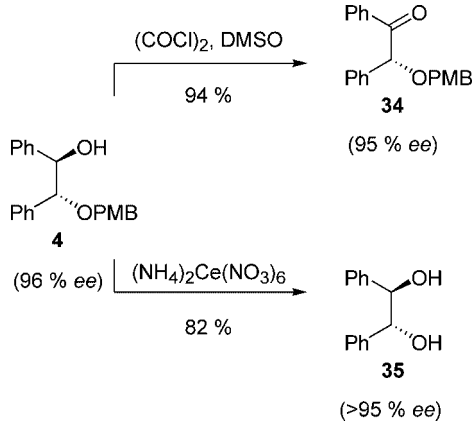
The ring-opened products are interesting synthetic building blocks. Thus, 1,2-diol monoether **4** was converted into the PMB-protected acyloin **34** by Swern oxidation[16] in 94% yield and almost complete retention of configuration.

Table 6. Scandium-bipyridine **2** catalyzed ring-opening of aromatic *meso*-epoxides with alcohols.[a]

Entry	Epoxide	Alcohol	Product	Yield (%)[b]	*ee* (%)[c,d]
1	 **1**	PMBOH	 **4**	82	97
2	**1**	allylOH	 **5**	78	95
3	**1**	MeOH	 **16**	81	92
4	**1**	EtOH	 **3**	75	96
5	**1**	*n*BuOH	 **17**	80	94
6	**1**	*i*PrOH	 **18**	72	89
7	**1**		 **19**	73	91
8	 **13**	MeOH	 **20**	83	98
9	 **14**	MeOH	 **21**	75	96
10	 **15**	PMBOH	 **22**	75	92

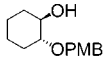
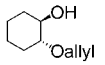
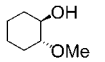
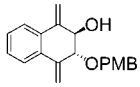
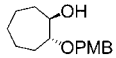
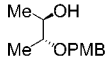
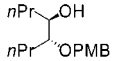
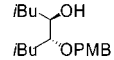
[a] Reaction conditions: 1 equiv. epoxide, 2 equiv. alcohol, 10 mol-% $Sc(OTf)_3$, 12 mol-% bipyridine **2**, CH_2Cl_2, r.t., 24 h. [b] Isolated yield after flash column chromatography. [c] Determined by chiral HPLC analysis. [d] Assignment of absolute configuration was made by comparison to literature values or by analogy.

Alternatively, oxidation with ceric ammonium nitrate[17] furnished the unprotected 1,2-diol **35** in 82% yield and >95% *ee* (Scheme 3).



Scheme 3. Synthetic manipulation of 1,2-diol monoether **4**.

Table 7. Scandium-bipyridine **2** catalyzed ring-opening of aliphatic *meso*-epoxides with alcohols.[a]

Entry	Epoxide	Alcohol	Product	Yield (%)[b]	*ee* (%)[c,d]
1	 **6**	PMBOH	 **7**	90	54
2	**6**	allylOH	 **8**	54	50
3	**6**	MeOH	 **28**	92	45
4[e]	 **23**	PMBOH	 **29**	73	62
5[e]	 **24**	PMBOH	 **30**	46	53
6	 **25**	PMBOH	 **31**	93	49
7[f]	 **26**	PMBOH	 **32**	25	44
8[e]	 **27**	PMBOH	 **33**	33	45

[a] Reaction conditions: 1 equiv. epoxide, 2 equiv. alcohol, 10 mol-% $Sc(OTf)_3$, 12 mol-% bipyridine **2**, CH_2Cl_2, –20 °C, 24 h. [b] Isolated yield after flash column chromatography. [c] Determined by chiral HPLC or chiral GC analysis. [d] Assignment of absolute configuration was made by comparison to literature values or by analogy. [e] Reaction was performed at r.t. [f] Reaction was performed at 0 °C.

Mechanistic Considerations

After optimizing this process we intended to gain structural information about the chiral catalyst and make some mechanistic proposal about the reaction path. In an unrelated investigation, Kobayashi et al. have reported a crystal structure of the scandium catalyst composed of $ScBr_3$ and bipyridine **2** which revealed a pentagonal-bipyramidal coordination geometry of the metal.[18] We successfully obtained a crystal structure of the corresponding eight-coordinate yttrium-bipyridine complex which exhibited the same sense of asymmetric induction and comparable level of enantioselectivity as the scandium catalyst (Figure 2). It clearly shows that the bipyridine ligand **2** was slightly twisted along the bipyridine axis (19.1°) and coordinated in a tetradentate fashion to the metal center. Besides the tetracoordinate ligand, two triflate groups and two water molecules were bound to the metal center.

What neither of the two structures could tell was the existence or nonexistence of the two hydroxy protons in the complexes. That this issue was of critical importance was clear from the totally unselective performance of the bis-*O*-methylated bipyridine ligand **36** in the scandium-catalyzed alcoholysis of *cis*-stilbene oxide (**1**) which furnished 1,2-diol monoether **4** in 69% yield and 0% *ee* (Scheme 4). Additional evidence for the supporting effect of the hydroxy protons was obtained from the reaction of *cis*-stilbene oxide (**1**) and *p*-methoxybenzyl alcohol with the scandium-bipyridine catalyst which had been prepared in the presence of 2 equiv. of NaH (relative to bipyridine **2**). The reaction rate decreased dramatically and the product **4** was obtained in only 5% yield and 83% *ee* after 24 h at r.t. (Scheme 4).

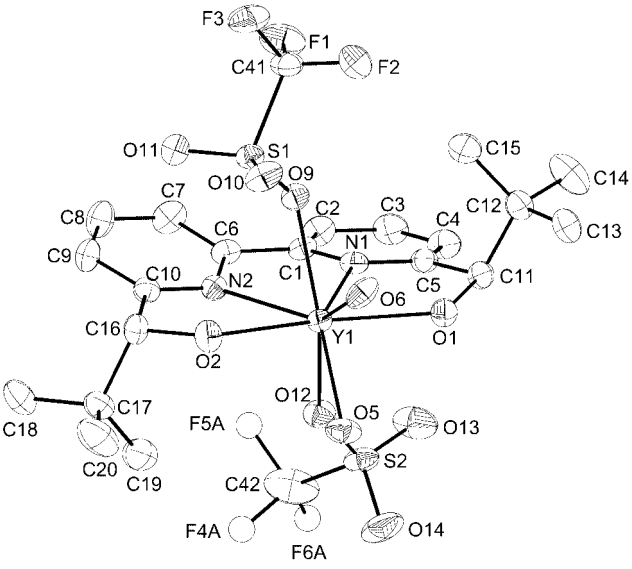
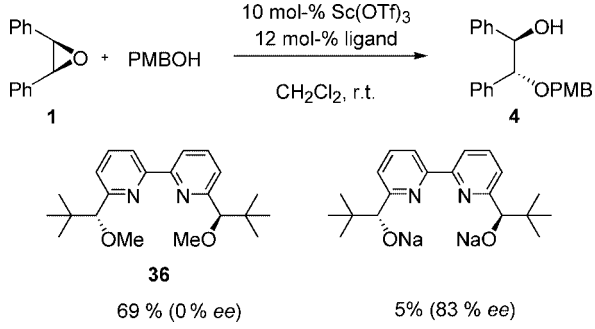


Figure 2. Crystal structure of the $Y(OTf)_3$-bipyridine **2** complex.



Scheme 4.

To further shed light on this issue ESI-MS spectra of the $Sc(OTf)_3$-bipyridine **2** complex (MW 820) in CH_2Cl_2/CH_3CN solution were recorded which showed the characteristic isotope pattern for a $[M - H]^-$ fragment proving that the hydroxy protons were still bound in the complex (Figure 3).

These results clearly indicate that the hydroxy protons play an important role in the alcoholysis of the epoxides, possibly by hydrogen bonding to the incoming alcohol, thereby guiding it to the activated Sc-bound epoxide.

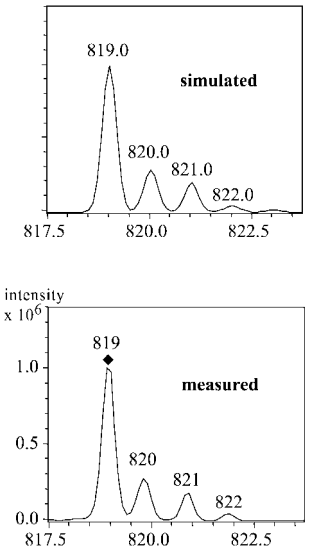


Figure 3. Simulated and measured ESI-MS spectra of the $Sc(OTf)_3$-bipyridine **2** complex (negative mode).

Conclusions

The catalytic, enantioselective ring-opening of *meso*-epoxides with alcohols is an excellent method to furnish valuable, enantiomerically enriched 1,2-diol monoethers. In this study we have developed the scandium-bipyridine-catalyzed alcoholysis of *meso*-epoxides and have optimized this process with respect to metal, ligand, solvent, catalyst loading, epoxide and alcohol components. Aromatic *meso*-epoxides turned out to be excellent substrates which were ring-opened with typically >90% *ee* whereas aliphatic *meso*-epoxides gave rise to only moderate enantioselectivity. While most reactions were conducted with 10 mol-% catalyst it was shown that the amount of catalyst can be reduced to just 5 mol-% or even less without without significant effects on yield and enantioselectivity. A significant nonlinear effect was observed pointing to aggregation phenomena of the catalyst.

Experimental Section

General: All reactions were performed in flame-dried glassware under an atmosphere of dry nitrogen. The solvents were distilled from the indicated drying agents: dichloromethane (CaH_2), tetrahydrofuran ($LiAlH_4$, triphenylmethane), diethyl ether (Na, benzophenone), toluene (Na, benzophenone), *N*,*N*-dimethylformamide (Acros ACS grade), acetonitrile (Acros ACS grade), chloroform (Acros ACS grade). Diethyl ether and petroleum ether for chromatography were technical grade and distilled from KOH. All reactions were monitored by thin-layer chromatography (TLC) on precoated silica gel SIL G/UV254 plates (Machery–Nagel & Co.); spots were visualized by treatment with a solution of vanillin (0.5 g), conc. acetic acid (10 mL), and conc. H_2SO_4 (5 mL) in methanol (90 mL). Flash column chromatography was performed by using Merck silica gel 60 230–400 mesh (0.040–0.063 mm). (*Z*)-1,2-Bis(naphthalen-2-yl)ethene,[19] (*Z*)-1,2-di-*m*-tolylethene,[19] *cis*-1,2-bis(*p*-chlorophenyl)ethane oxide[20] and 1,4-dimethylidene-2,3-epoxy-2,3-dihydronaphthalene[10e] were prepared according to literature procedures. Epoxides **13**–**14**, **24** and **26**–**27** were prepared by *m*-CPBA oxidation of the corresponding *cis*-alkenes. Bipyridine **2** was best prepared using a new procedure developed by Kobayashi.[27] All other chemicals were used as received from commercial suppliers. ^1H and ^{13}C NMR spectra were recorded with Varian Gemini 200 and 2000 (200 MHz), Varian Gemini 300 BB (300 MHz) or a Bruker Avance DRX 400 (400 MHz) spectrometer in $CDCl_3$ at 25 °C with TMS as internal standard. Melting points were determined on a Boetius heating Table and were uncorrected. IR spectra were obtained with a FTIR spectrometer (Genesis ATI, Mattson/Unicam). All ESI mass spectra were recorded on a Bruker APEX II FT-ICR. Optical rotations were measured using a Polarotronic polarometer (Schmidt & Haensch). HPLC analyses were performed on a JASCO MD-2010 plus instrument with a chiral stationary phase column (Chiralcel OD purchased from Daicel Co., Ltd.). GC analyses were performed on a HP 5890 Series II Plus with MSD 5972 or a HP 6890 Series Plus with FID from Agilent Technologies.

General Procedure for the Scandium-Bipyridine-Catalyzed Alcoholysis of Epoxides: A solution of $Sc(OTf)_3$ (0.10 mmol) and chiral bipyridine **2** (0.12 mmol) in dichloromethane (4 mL) was stirred under nitrogen for 10 min, after which the epoxide (1.00 mmol) was added. The reaction mixture was cooled to the reaction temperature mentioned in the tables and stirred for 10 min followed by the addition of the alcohol (2.00 mmol). After stirring at that temperature for the time mentioned in the tables the solvent was evaporated in vacuo and the product was purified by flash column chromatography over silica gel using mixtures of diethyl ether/petroleum ether or ethyl acetate/petroleum ether as eluent. All known compounds were compared with the reported data and all new compounds were fully characterized. For authentication purposes the racemic ring-opened products were also prepared using an achiral scandium-bipyridine complex and the HPLC or GC retention times compared to the enantioselective runs. The absolute configuration of the products was assigned by comparison of the optical rotation values with reported data or by analogy.

(1*R*,2*R*)-2-Ethoxy-1,2-diphenylethanol (3): Yield 182 mg, 75%, colorless liquid. $[a]_D^{25}$ = +58.8 (*c* = 1.7, CH_2Cl_2); *ee* = 96%. The enantiomeric assay: Chiralcel OD, isocratic (*n*-hexane/*i*PrOH, 95:5, flow 1 mL/min) λ_{max} = 203 nm, (1*S*,2*S*): 7.1 min; (1*R*,2*R*): 8.1 min. ^1H NMR (200 MHz, $CDCl_3$): δ = 1.23 (t, *J* = 7.0 Hz, 3 H, CH_2CH_3), 3.36–3.56 (m, 3 H, CH_2CH_3, OH), 4.21 (d, *J* = 8.5 Hz, 1 H, $CHOCH_2$), 4.63 (d, *J* = 8.5 Hz, 1 H, CHOH), 6.97–7.26 (m, 10 H, ArH) ppm. ^{13}C NMR (50 MHz, $CDCl_3$): δ = 15.2, 64.5, 78.5, 87.3, 127.2, 127.6, 127.7, 127.8, 127.9, 138.0, 139.1 ppm. IR (film): $\tilde{\nu}$ = 3471, 3062, 2876, 1603, 1453, 1388, 1197, 1091 cm^{-1}. HRMS-ESI: *m*/*z* $[M + Na]^+$ calcd. for $C_{16}H_{18}O_2$: 265.11990; found: 265.11985.

(1*R*,2*R*)-2-(4-Methoxybenzyloxy)-1,2-diphenylethanol (4):[23] Yield 234 mg, 70%, white solid, m.p. 85–86 °C. $[a]_D^{25}$ = –41.6 (*c* = 0.72, CH_2Cl_2); *ee* = 97%. The enantiomeric assay: Chiralcel OD, isocratic (*n*-hexane/*i*PrOH, 90:10, flow 1 mL/min) λ_{max} = 199 nm, (1*S*,2*S*): 10.3 min, (1*R*,2*R*): 11.7 min. ^1H NMR (300 MHz, $CDCl_3$): δ = 3.54 (d, *J* = 1.0 Hz, 1 H, OH), 3.82 (s, 3 H, OCH_3), 4.27 (d, *J* = 11.0 Hz, 1 H, OCH_AH_B), 4.33 (d, *J* = 8.5 Hz, 1 H, $CHOCH_2$), 4.47 (d, *J* = 11.0 Hz, 1 H, OCH_AH_B), 4.70 (dd, *J* = 8.5, 1.0 Hz, 1 H, CHOH), 6.88–6.91 (m, 2 H, ArH), 7.00–7.25 (m, 12 H, ArH) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 55.4, 70.6, 78.7, 86.7, 114.0, 127.4, 127.8, 127.9, 128.0, 128.2, 129.7, 137.8, 139.3, 159.5 ppm. IR (KBr): $\tilde{\nu}$ = 3521, 3432, 2865, 1610, 1509, 1241, 1195, 1022 cm^{-1}. HRMS-ESI: *m*/*z* $[M + Na]^+$ calcd. for $C_{22}H_{22}O_3$: 357.14587; found: 357.14612.

(1*R*,2*R*)-2-(Allyloxy)-1,2-diphenylethanol (5):[22] Yield 198 mg, 78%, colorless liquid. $[\alpha]_D^{25}$ = –27.2 (*c* = 1.1, CH_2Cl_2); *ee* = 95%. The enantiomeric assay: Chiralcel OD, isocratic (*n*-hexane/*i*PrOH, 97:3, flow 1 mL/min) λ_{max} = 203 nm, (1*S*,2*S*): 8.9 min, (1*R*,2*R*): 10.6 min. ^{1}H NMR (200 MHz, $CDCl_3$): δ = 3.61 (d, *J* = 1.0 Hz, 1 H, OH), 3.87 (ddt, *J* = 12.5, 5.5, 1.5 Hz, 1 H, OCH_AH$_B$), 4.04 (ddt, *J* = 12.5, 5.5, 1.5 Hz, 1 H, OCH$_A$$H_B$), 4.33 (d, *J* = 8.5 Hz, 1 H, C*H*OCH$_2$), 4.73 (dd, *J* = 8.5, 1.0 Hz, 1 H, C*H*OH), 5.19–5.34 (m, 2 H, CH=CH_2), 5.86–5.98 (m, 1 H, C*H*=CH$_2$), 7.01–7.28 (m, 10 H, ArH) ppm. ^{13}C NMR (50 MHz, $CDCl_3$): δ = 69.7, 78.6, 86.8, 105.4, 117.3, 127.3, 127.7, 127.8, 128.0, 128.1, 134.3, 137.6, 139.2 ppm. IR (film): $\tilde{\nu}$ = 3455, 3031, 2867, 1647, 1453, 1339, 1196, 1074 cm^{-1}. HRMS-ESI: *m*/*z* [M + Na]$^+$ calcd. for $C_{17}H_{18}O_2$: 277.11990; found: 277.11978.

(1*R*,2*R*)-2-(4-Methoxybenzyloxy)cyclohexanol (7):[23] Yield 213 mg, 90%, colorless liquid. $[\alpha]_D^{25}$ = –25.0 (*c* = 1.6, CH_2Cl_2); *ee* = 54%. The enantiomeric assay: Chiral GC analysis 15 m (2,6-Me-3-pentyl-γ-CD), 135° (50% in OV 1701). (1*R*,2*R*): 38.2 min, (1*S*,2*S*): 39.1 min. ^{1}H NMR (300 MHz, $CDCl_3$): δ = 1.20–1.26 (m, 4 H, CH_2), 1.69–1.77 (m, 2 H, CH_2), 1.95–2.21 (m, 2 H, CH_2), 2.68 (s, 1 H, OH), 3.10–3.22 (m, 1 H, C*H*OCH$_2$), 3.40–3.52 (m, 1 H, C*H*OH), 3.80 (s, 3 H, OCH_3), 4.39 (d, *J* = 11.0 Hz, 1 H, OCH_AH$_B$), 4.63 (d, *J* = 11.0 Hz, 1 H, OCH$_A$$H_B$), 6.89 (d, *J* = 8.5 Hz, 2 H, ArH), 7.27 (d, *J* = 8.5 Hz, 2 H, ArH) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 23.9, 24.2, 29.2, 32.0, 55.2, 70.4, 73.7, 83.1, 113.8, 129.3, 130.7, 159.2 ppm. IR (film): $\tilde{\nu}$ = 3438, 2998, 2861, 1610, 1511, 1299, 1079, 1033 cm^{-1}. HRMS-ESI: *m*/*z* [M + Na]$^+$ calcd. for $C_{14}H_{20}O_3$: 259.13047; found: 259.13064.

(1*R*,2*R*)-2-(Allyloxy)cyclohexanol (8):[26] Yield 84 mg, 54%, colorless liquid. $[\alpha]_D^{25}$ = –20.5 (*c* = 1.2, CH_2Cl_2); *ee* = 50%. The enantiomeric assay: Chiral GC analysis 25 m (FS-Hydrodex β-3-P). (1*S*,2*S*): 20.81 min, (1*R*,2*R*): 21.13 min. ^{1}H NMR (300 MHz, $CDCl_3$): δ = 1.05–1.40 (m, 4 H, CH_2), 1.60–1.80 (m, 2 H, CH_2), 1.95–2.15 (m, 2 H, CH_2), 2.75 (s, 1 H, OH), 3.04–3.14 (m, 1 H, C*H*OCH$_2$), 3.40–3.52 (m, 1 H, C*H*OH), 3.97 (ddt, *J* = 12.5, 5.5, 1.5 Hz, 1 H, OCH_AH$_B$), 4.17 (ddt, *J* = 12.5, 5.5, 1.5 Hz, 1 H, OCH$_A$$H_B$), 5.18 (dq, *J* = 10.5, 1.5 Hz, 1 H, CH=CH_AH$_B$), 5.29 (dd, *J* = 17.0, 1.5 Hz, 1 H, CH=CH$_A$$H_B$), 5.95 (ddt, *J* = 17.0, 10.5, 5.5 Hz, 1 H, C*H* = CH$_2$) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 23.9, 24.2, 29.2, 32.0, 69.7, 73.7, 83.2, 116.9, 135.1 ppm. IR (film): $\tilde{\nu}$ = 3439, 2933, 2861, 1647, 1451, 1302, 1233, 1882 cm^{-1}. MS (ESI): *m*/*z* = 179.1 [M + Na]$^+$, 335.2 [2M + Na]$^+$.

(1*R*,2*R*)-2-Methoxy-1,2-diphenylethanol (16):[21] Yield 185 mg, 81%, white solid, m.p. 69–70 °C. $[\alpha]_D^{25}$ = +53.3 (*c* = 1.5, $CHCl_3$); *ee* = 92%. The enantiomeric assay: Chiralcel OD, isocratic (*n*-hexane/*i*PrOH, 90:10, flow 0.8 mL/min) λ_{max} = 203 nm, (1*S*,2*S*): 7.8 min; (1*R*,2*R*): 8.7 min. ^{1}H NMR (200 MHz, $CDCl_3$): δ = 3.31 (s, 3 H, OCH_3), 3.51 (s, 1 H, OH), 4.12 (d, *J* = 8.5 Hz, 1 H, C*H*OCH_3), 4.65 (d, *J* = 8.5 Hz, 1 H, C*H*OH), 6.97–7.23 (m, 10 H, ArH) ppm. ^{13}C NMR (50 MHz, $CDCl_3$): δ = 56.8, 78.6, 89.1, 127.2, 127.6, 127.7, 127.8, 128.0, 137.3, 139.1 ppm. IR (KBr): $\tilde{\nu}$ = 3405, 3061, 1492, 1453, 1337, 1201, 1102, 1059 cm^{-1}. HRMS-ESI: *m*/*z* [M + Na]$^+$ calcd. for $C_{15}H_{16}O_2$: 251.10425; found: 251.10446.

(1*R*,2*R*)-2-Butoxy-1,2-diphenylethanol (17): Yield 216 mg, 80%, white solid, m.p. 55–56 °C. $[\alpha]_D^{25}$ = +31.2 (*c* = 1.6, CH_2Cl_2); *ee* = 94%. The enantiomeric assay: Chiralcel OD, isocratic (*n*-hexane/*i*PrOH, 95:5, flow 1 mL/min) λ_{max} = 203 nm, (1*S*,2*S*): 6.3 min, (1*R*,2*R*): 7.1 min. ^{1}H NMR (200 MHz, $CDCl_3$): δ = 0.94 (t, *J* = 7.0 Hz, 3 H, CH_3), 1.41–1.51 (m, 2 H, CH_2), 1.58–1.71 (m, 2 H, CH_2), 3.35–3.47 (m, 2 H, OCH_2), 3.67 (d, *J* = 1.0 Hz, 1 H, OH), 4.23 (d, *J* = 8.5 Hz, 1 H, C*H*OCH$_2$), 4.68 (dd, *J* = 8.5, 1.0 Hz, 1 H, C*H*OH), 7.00–7.25 (m, 10 H, ArH) ppm. ^{13}C NMR (50 MHz, $CDCl_3$): δ = 14.0, 19.5, 32.0, 69.0, 78.8, 87.7, 127.4, 127.7, 127.8, 127.9, 128.0, 128.1, 138.1, 139.3 ppm. IR (KBr): $\tilde{\nu}$ = 3525, 3029, 1490, 1386, 1257, 1025 cm^{-1}. HRMS-ESI: *m*/*z* [M + Na]$^+$ calcd. for $C_{18}H_{22}O_2$: 293.15120; found: 293.15114.

(1*R*,2*R*)-2-Isopropyloxy-1,2-diphenylethanol (18): Yield 185 mg, 72%, colorless liquid. $[\alpha]_D^{25}$ = +11.7 (*c* = 0.85, CH_2Cl_2); *ee* = 89%. The enantiomeric assay: Chiralcel OD, isocratic (*n*-hexane/*i*PrOH, 97:3, flow 1 mL/min) λ_{max} = 203 nm, (1*S*,2*S*): 6.5 min; (1*R*,2*R*): 7.7 min. ^{1}H NMR (200 MHz, $CDCl_3$): δ = 1.12 (d, *J* = 6.0 Hz, 3 H, CH_3), 1.20 (d, *J* = 6.0 Hz, 3 H, CH_3), 1.57 (br. s, 1 H, OH), 3.57 (hept, *J* = 6.0 Hz, 1 H, C*H*(CH_3)$_2$), 4.30 (d, *J* = 8.5 Hz, 1 H, C*H*OCH), 4.59 (d, *J* = 8.5 Hz, 1 H, C*H*OH), 6.98–7.25 (m, 10 H, ArH) ppm. ^{13}C NMR (50 MHz, $CDCl_3$): δ = 21.2, 23.5, 69.7, 78.5, 84.8, 127.2, 127.5, 127.6, 127.7, 127.8, 138.6, 139.3 ppm. IR (film): $\tilde{\nu}$ = 3550, 2971, 2887, 1603, 1453, 1383, 1196, 1122 cm^{-1}. HRMS-ESI: *m*/*z* [M + Na]$^+$ calcd. for $C_{17}H_{20}O_2$: 279.13555; found: 279.13552.

(1*R*,2*R*)-1,2-Diphenyl-2-(prop-2-ynyloxy)ethanol (19): Yield 184 mg, 73%, colorless liquid. $[\alpha]_D^{25}$ = –69.2 (*c* = 1.3, CH_2Cl_2); *ee* = 91%. The enantiomeric assay: Chiralcel OD, isocratic (*n*-hexane/*i*PrOH, 90:10, flow 0.8 mL/min) λ_{max} = 207 nm, (1*S*,2*S*): 11.4 min, (1*R*,2*R*): 13.4 min. ^{1}H NMR (300 MHz, $CDCl_3$): δ = 2.46 (t, *J* = 2.5 Hz, 1 H, alkyne-CH), 3.46 (d, *J* = 1.5 Hz, 1 H, OH), 3.93 (dd, *J* = 15.5, 2.5 Hz, 1 H, OCH_AH$_B$), 4.21 (dd, *J* = 15.5, 2.5 Hz, 1 H, OCH$_A$$H_B$), 4.50 (d, *J* = 8.5 Hz, 1 H, C*H*OCH$_2$), 4.72 (dd, *J* = 8.5, 1.5 Hz, 1 H, C*H*OH), 7.00–7.25 (m, 10 H, ArH) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 56.2, 75.2, 78.5, 79.5, 86.4, 127.6, 128.0, 128.1, 128.2, 128.4, 128.6, 136.7, 139.1 ppm. IR (film): $\tilde{\nu}$ = 3453, 3031, 1603, 1454, 1196, 1082 cm^{-1}. HRMS-ESI: *m*/*z* [M + Na]$^+$ calcd. for $C_{17}H_{16}O_2$: 275.10425; found: 275.10349.

(1*R*,2*R*)-2-Methoxy-2-(naphthalen-3-yl)-1-(naphthalen-6-yl)ethanol (20): Yield 273 mg, 83%, white solid, m.p. 98–99 °C. $[\alpha]_D^{25}$ = +184.6 (*c* = 0.65, CH_2Cl_2); *ee* = 98%. The enantiomeric assay: Chiralcel OD, isocratic (*n*-hexane/*i*PrOH, 95:5, flow 0.8 mL/min) λ_{max} = 210 nm, (1*R*,2*R*): 29.5 min, (1*S*,2*S*): 31.1 min. ^{1}H NMR (200 MHz, $CDCl_3$): δ = 3.38 (s, 3 H, OCH_3), 3.75 (d, *J* = 1.0 Hz, 1 H, OH), 4.42 (d, *J* = 8.5 Hz, 1 H, C*H*OCH_3), 4.99 (dd, *J* = 8.5, 1.0 Hz, 1 H, C*H*OH), 7.09–7.20 (m, 2 H, ArH), 7.39–7.82 (m, 12 H, ArH) ppm. ^{13}C NMR (50 MHz, $CDCl_3$): δ = 57.1, 78.6, 89.2, 125.3, 125.4, 125.8, 126.1, 126.4, 127.3, 127.5, 127.6, 127.7, 128.0, 133.0, 135.0, 136.8 ppm. IR (KBr): $\tilde{\nu}$ = 3444, 3019, 2890, 1600, 1506, 1361, 1268, 1162, 1062 cm^{-1}. HRMS-ESI: *m*/*z* [M + Na]$^+$ calcd. for $C_{23}H_{20}O_2$: 351.13555; found: 351.13527.

(1*R*,2*R*)-2-Methoxy-1,2-di-*m*-tolylethanol (21): Yield 197 mg, 77%, colorless liquid. $[\alpha]_D^{25}$ = +70.0 (*c* = 1.0, CH_2Cl_2); *ee* = 96%. The enantiomeric assay: Chiralcel OD, isocratic (*n*-hexane/*i*PrOH, 95:5, flow 0.8 mL/min) λ_{max} = 203 nm, (1*S*,2*S*): 9.8 min, (1*R*,2*R*): 10.9 min. ^{1}H NMR (300 MHz, $CDCl_3$): δ = 2.24 (s, 3 H, CH_3), 2.26 (s, 3 H, CH_3), 3.31 (s, 3 H, OCH_3), 3.47 (s, 1 H, OH), 4.08 (d, *J* = 8.5 Hz, 1 H, C*H*OCH_3), 4.61 (d, *J* = 8.5 Hz, 1 H, C*H*OH), 6.77–7.20 (m, 8 H, ArH) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 21.6, 57.2, 78.7, 89.3, 124.7, 125.2, 127.8, 128.1, 128.6, 128.9, 137.5, 137.7, 137.8, 139.5 ppm. IR (film): $\tilde{\nu}$ = 3463, 2979, 2823, 1606, 1508, 1382, 1182, 973 cm^{-1}. HRMS-ESI: *m*/*z* [M + Na]$^+$ calcd. for $C_{17}H_{20}O_2$: 279.13555; found: 279.13561.

(1*R*,2*R*)-1,2-Bis(4-chlorophenyl)-2-(4-methoxybenzyloxy)ethanol (22): Yield 303 mg, 75%, white solid, m.p. 72–74 °C. $[\alpha]_D^{25}$ = +28.8 (*c* = 1.2, $CHCl_3$); *ee* = 92%. The enantiomeric assay: Chiralcel OD, isocratic (*n*-hexane/*i*PrOH, 95:5, flow 1.0 mL/min) λ_{max} = 203 nm, (1*S*,2*S*): 19.8 min, (1*R*,2*R*): 22.3 min. ^{1}H NMR (300 MHz, $CDCl_3$): δ = 3.47 (s, 1 H, OH), 3.82 (s, 3 H, OCH_3), 4.24 (d, *J* = 8.5 Hz, 1 H, C*H*OCH$_2$), 4.24 (d, *J* = 11.0 Hz, 1 H, OCH_AH$_B$), 4.44 (d, *J* =

11.0 Hz, 1 H, OCH_AH_B), 4.63 (d, J = 8.5 Hz, 1 H, C*H*OH), 6.88–7.00 (m, 6 H, ArH), 7.14–7.25 (m, 6 H, ArH) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 55.3, 70.6, 77.8, 85.7, 114.0, 128.1, 128.5, 128.6, 129.2, 129.3, 129.7, 133.5, 134.0, 135.9, 137.4, 159.5 ppm. IR (KBr): $\tilde{\nu}$ = 3536, 2959, 2875, 2857, 1614, 1515, 1488, 1255, 1190, 1010 cm^{-1}. MS (ESI): m/z = 425.0 $[M + Na]^+$. $C_{22}H_{20}Cl_2O_3$: calcd. C 65.52, H 5.00; found C 65.48, H 5.08.

(1*R*,2*R*)-2-Methoxycyclohexanol (28):[25] Yield 120 mg, 92%, colorless liquid. $[\alpha]_D^{25}$ = –23.5 (c = 1.7, CH_2Cl_2); *ee* = 45%. The enantiomeric assay: Chiral GC analysis 25 m (FS-Hydrodex β-3-P). (1*S*,2*S*): 18.0 min, (1*R*,2*R*): 18.6 min. ^1H NMR (300 MHz, $CDCl_3$): δ = 0.98–1.24 (m, 4 H, CH_2), 1.60–1.65 (m, 2 H, CH_2), 1.88–2.06 (m, 2 H, CH_2), 2.80–2.92 (m, 1 H, C*H*OCH_3), 3.06 (br. s, 1 H, OH), 3.30–3.45 (m, 1 H, C*H*OH), 3.35 (s, 3 H, OCH_3) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 24.0, 24.1, 28.4, 32.1, 56.3, 73.7, 85.0 ppm. IR (film): $\tilde{\nu}$ = 3432, 2861, 1452, 1301, 1232, 1095 cm^{-1}. MS (ESI): m/z = 283.2 $[2M + Na]^+$.

(2*R*,3*R*)-3-(4-Methoxybenzyloxy)-1,4-dimethylene-1,2,3,4-tetrahydronaphthalen-2-ol (29): Yield 225 mg, 73%, colorless liquid. $[\alpha]_D^{23}$ = –73.9 (c = 1.4, $CHCl_3$); *ee* = 62%. The enantiomeric assay: Chiralcel OD, isocratic (*n*-hexane/*i*PrOH, 90:10, flow 1.0 mL/min) λ_{max} = 262 nm, (1*R*,2*R*): 13.5 min, (1*S*,2*S*): 15.2 min. ^1H NMR (400 MHz, $CDCl_3$): δ = 2.52 (d, J = 3 Hz, 1 H, OH), 3.81 (s, 3 H, OCH_3), 4.12 (d, J = 8.0 Hz, 1 H, C*H*OCH_2), 4.40 (d, J = 8.0 Hz, 1 H, C*H*OH), 4.53 (d, J = 11.5 Hz, 1 H, OCH_AH_B), 4.74 (d, J = 11.5 Hz, 1 H, OCH_AH_B), 5.43 (s, 1 H, C=CH_2), 5.52 (s, 1 H, C=CH_2), 5.72 (s, 1 H, C=CH_2), 5.79 (s, 1 H, C=CH_2), 6.89 (d, J = 8.5 Hz, 2 H, ArH), 7.29 (d, J = 8.5 Hz, 2 H, ArH), 7.27–7.32 (m, 2 H, ArH), 7.60–7.62 (m, 1 H, ArH), 7.68–7.71 (m, 1 H, ArH) ppm. ^{13}C NMR (50 MHz, $CDCl_3$): δ = 55.3, 71.9, 73.8, 81.9, 111.0, 111.8, 113.9, 124.6, 125.2, 128.5, 128.6, 129.5, 129.9, 131.8, 132.5, 141.6, 142.8, 159.4 ppm. IR (film): $\tilde{\nu}$ = 3435, 3063, 3032, 2998, 2933, 2870, 2835, 1612, 1585, 1513, 1455, 1248, 1173, 1090, 787, 763 cm^{-1}. HRMS-ESI: m/z $[M + Na]^+$ calcd. for $C_{13}H_{18}O_3$: 331.13047; found: 331.13022.

(1*R*,2*R*)-2-(4-Methoxybenzyloxy)cycloheptanol (30): Yield 115 mg, 46%, colorless oil. $[\alpha]_D^{25}$ = –8.3 (c = 1.0, $CHCl_3$); *ee* = 53%. The enantiomeric assay: NMR of the corresponding Mosher ester. ^1H NMR (300 MHz, $CDCl_3$): δ = 1.39–1.58 (m, 6 H, CH_2), 1.62–1.75 (m, 2 H, CH_2), 1.86–2.03 (m, 2 H, CH_2), 2.73 (br. s, 1 H, OH), 3.23 (td, J = 8.5, 3.5 Hz, 1 H, C*H*OCH_2), 3.56 (td, J = 8.5, 3.5 Hz, 1 H, C*H*OH), 3.80 (s, 3 H, OCH_3), 4.37 (d, J = 11.0 Hz, 1 H, CH_AH_B), 4.62 (d, J = 11.0 Hz, 1 H, CH_AH_B), 6.89 (d, J = 8.5 Hz, 2 H, ArH), 7.27 (d, J = 8.5 Hz, 2 H, ArH) ppm. ^{13}C NMR (50 MHz, $CDCl_3$): δ = 22.2, 22.5, 27.0, 28.4, 31.5, 55.3, 70.7, 75.9, 85.7, 113.9, 129.4, 130.4, 159.3 ppm. IR (film): $\tilde{\nu}$ = 3444, 2932, 2864, 1612, 1572, 1513, 1440, 1070, 787 cm^{-1}. HRMS-ESI: m/z $[M + Na]^+$ calcd. for $C_{15}H_{22}O_3$: 273.14612; found: 273.14617.

(2*R*,3*R*)-3-(4-Methoxybenzyloxy)butan-2-ol (31):[23] Yield 196 mg, 93%, colorless liquid. $[\alpha]_D^{25}$ = –33.3 (c = 2.4, CH_2Cl_2); *ee* = 49%. The enantiomeric assay: Chiral GC analysis 25 m (6T-2,3-Me-β-CD), 120° (50% in OV 1701). (1*R*,2*R*): 37.9 min, (1*S*,2*S*): 38.8 min. ^1H NMR (300 MHz, $CDCl_3$): δ = 1.17 (d, J = 6.5 Hz, 3 H, CH_3), 1.18 (d, J = 6.5 Hz, 3 H, CH_3), 2.30 (d, J = 4.5 Hz, 1 H, OH), 3.28 (qd, J = 6.5, 3.5 Hz, 1 H, C*H*OCH_2), 3.84 (s, 3 H, OCH_3), 3.84–3.98 (m, 1 H, C*H*OH), 4.47 (d, J = 11.0 Hz, 1 H, OCH_AH_B), 4.59 (d, J = 11.0 Hz, 1 H, OCH_AH_B), 6.92 (d, J = 8.5 Hz, 2 H, ArH), 7.31 (d, J = 8.5 Hz, 2 H, ArH) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 13.5, 17.7, 55.3, 69.2, 70.4, 77.9, 113.8, 129.3, 130.7, 159.2 ppm. IR (film): $\tilde{\nu}$ = 3415, 2931, 2873, 1612, 1511, 1245, 1085, 819 cm^{-1}. HRMS-ESI: m/z $[M + Na]^+$ calcd. for $C_{12}H_{18}O_3$: 233.11482; found: 233.11504.

(1*R*,2*R*)-5-(4-Methoxybenzyloxy)octan-4-ol (32): Yield 67 mg, 25%, colorless oil. $[\alpha]_D^{25}$ = –5.0 (c = 0.94, $CHCl_3$); *ee* = 44%. The enantiomeric assay: Chiralcel OD, isocratic (*n*-hexane/*i*PrOH, 99.5:0.5, flow 1.0 mL/min) λ_{max} = 203 nm, (1*S*,2*S*): 23.6 min, (1*R*,2*R*): 25.0 min. ^1H NMR (200 MHz, $CDCl_3$): δ = 0.92 (t, J = 7.0 Hz, 3 H, CH_3), 0.94 (t, J = 7.0 Hz, 3 H, CH_3), 1.32–1.64 (m, 8 H, CH_2), 2.27 (br. s, 1 H, OH), 3.25 (q, J = 5.5 Hz, 1 H, C*H*OCH_2), 3.46–3.58 (m, 1 H, C*H*OH), 3.81 (s, 3 H, OCH_3), 4.42 (d, J = 11.0 Hz, 1 H, OCH_AH_B), 4.59 (d, J = 11.0 Hz, 1 H, OCH_AH_B), 6.88 (d, J = 8.5 Hz, 2 H, ArH), 7.27 (d, J = 8.5 Hz, 2 H, ArH) ppm. ^{13}C NMR (50 MHz, $CDCl_3$): δ = 14.1, 14.4, 18.5, 19.0, 32.7, 35.6, 55.3, 72.1, 72.5, 82.0, 113.9, 129.4, 130.6, 159.3 ppm. IR (film): $\tilde{\nu}$ = 3444, 2957, 2933, 2871, 1613, 1586, 1514, 1464, 1380, 1110, 822 cm^{-1}. HRMS-ESI: m/z $[M + Na]^+$ calcd. for $C_{16}H_{26}O_3$: 289.17742; found: 289.17745.

(1*R*,2*R*)-5-(4-Methoxybenzyloxy)-2,7-dimethyloctan-4-ol (33): Yield 97 mg, 33%, colorless oil. $[\alpha]_D^{25}$ = +1.1 (c = 1.5, $CHCl_3$); *ee* = 45%. The enantiomeric assay: Mosher ester of the product. ^1H NMR (400 MHz, $CDCl_3$): δ = 0.90–0.95 (m, 12 H, CH_3), 1.18–1.26 (m, 1 H, C*H*$(CH_3)_2$), 1.36–1.52 (m, 3 H, C*H*$(CH_3)_2$, CH_2), 1.71–1.86 (m, 2 H, CH_2), 2.16 (br. s, 1 H, OH), 3.29 (dt, J = 7.0, 5.0 Hz, 1 H, C*H*OCH_2), 3.55–3.60 (m, 1 H, C*H*OH), 3.80 (s, 3 H, OCH_3), 4.46 (d, J = 11.0 Hz, 1 H, OCH_AH_B), 4.58 (d, J = 11.0 Hz, 1 H, OCH_AH_B), 6.88 (d, J = 8.5 Hz, 2 H, ArH), 7.26 (d, J = 8.5 Hz, 2 H, ArH) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ = 21.8, 22.7, 23.4, 23.7, 24.6, 24.7, 40.1, 42.8, 55.3, 71.3, 72.3, 80.7, 113.9, 129.4, 130.6, 159.3 ppm. IR (film): $\tilde{\nu}$ = 3422, 2955, 2868, 1612, 1584, 1513, 1467, 1383, 1075, 817 cm^{-1}. HRMS-ESI: m/z $[M + Na]^+$ calcd. for $C_{18}H_{30}O_3$: 317.20872; found: 317.20881.

(*R*)-2-(4-Methoxybenzyloxy)-1,2-diphenylethanone (34): To a stirred solution of oxalyl chloride (0.022 mL, 0.25 mmol) in CH_2Cl_2 (0.5 mL) under nitrogen at –78 °C was added a solution of DMSO (30 μL, 0.42 mmol) in CH_2Cl_2 (0.2 mL). After 10 min, a solution of alcohol **4** (56 mg, 0.17 mmol) in CH_2Cl_2 (1 mL) was added dropwise over a period of 5 min at the same temperature. After stirring for 15 min at –78 °C, Et_3N (0.11 mL, 0.84 mmol) was added and further stirred for 10 min at –78 °C and warmed to room temp. and stirred for 30 min. Water was added to quench the reaction, the layers were separated, and the aqueous phase was extracted with CH_2Cl_2. The organic phases were washed with brine, 1% H_2SO_4, water and 5% $NaHCO_3$ solution, dried with $MgSO_4$, filtered, and the solvents evaporated in vacuo. Flash chromatography over silica gel with diethyl ether/petroleum ether, 1:3 afforded 52 mg (94%) of the title compound as a colorless oil. $[\alpha]_D^{25}$ = –36.8 (c = 1.9, CH_2Cl_2); *ee* = 95%. The enantiomeric assay: Chiralcel OD, isocratic (*n*-hexane/*i*PrOH, 95:5, flow 0.8 mL/min) λ_{max} = 203 nm, (*S*): 13.1 min, (*R*): 14.4 min. ^1H NMR (300 MHz, $CDCl_3$): δ = 3.81 (s, 3 H, OCH_3), 4.55 (d, J = 8.5 Hz, 1 H, CH_AH_B), 4.58 (d, J = 8.5 Hz, 1 H, CH_AH_B), 5.63 (s, 1 H, C*H*OCH_2), 6.87 (d, J = 8.5 Hz, 2 H, ArH), 7.24–7.49 (m, 10 H, ArH), 7.94 (d, J = 8.5 Hz, 2 H, ArH) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 55.3, 71.0, 83.4, 113.9, 127.7, 128.5, 128.9, 129.2, 129.4, 129.9, 133.3, 135.1, 136.3, 159.5, 197.5 ppm. IR (film): $\tilde{\nu}$ = 2929, 1641, 1450, 1301, 1178, 1070, 962 cm^{-1}. HRMS-ESI: m/z $[M + Na]^+$ calcd. for $C_{22}H_{20}O_3$: 355.13047; found: 355.12996.

(1*R*,2*R*)-1,2-Diphenylethane-1,2-diol (35):[24] To a stirred solution of alcohol **4** (56 mg, 0.17 mmol) in CH_3CN/H_2O (2 mL/0.5 mL) at room temp. was added CAN (0.37 g, 0.67 mmol) and the reaction mixture was stirred for 30 min. The reaction was quenched by the addition of 3 mL of 6 N HCl, the layers were separated, and the aqueous phase was extracted with CH_2Cl_2 (3 × 10 mL). The organic phases were washed with water and brine, dried with $MgSO_4$,

filtered, and the solvents evaporated in vacuo. Flash chromatography over silica gel with diethyl ether/petroleum ether, 1:1 afforded 29 mg (82%) of the title compound as a colorless solid. M.p. 148–150 °C. $[\alpha]_D^{25}$ = +91.9 (*c* = 0.87, EtOH); *ee* = 96% (lit. $[\alpha]_D^{25}$ = +95 (*c* = 0.87, EtOH)).[22] ^{1}H NMR (300 MHz, $CDCl_3$): δ = 2.85 (s, 2 H, OH), 4.71 (s, 2 H, C*H*OH), 7.11–7.25 (m, 10 H, ArH) ppm. ^{13}C NMR (50 MHz, $CDCl_3$): δ = 79.2, 127.0, 128.0, 128.2, 139.9 ppm. IR (KBr): $\tilde{\nu}$ = 3498, 2921, 1650, 1384, 1078 cm^{-1}. HRMS-ESI: *m*/*z* $[M + Na]^+$ calcd. for $C_{14}H_{14}O_2$: 237.08860; found: 237.08868.

Crystal Data for the Y(OTf)$_3$/bipyridine 2 Complex: Empirical formula $C_{23}H_{32}F_9N_2O_{13}S_3Y{\cdot}0.5CH_2Cl_2$. M = 973.06, T = 180(2) K, λ = 0.71073 Å, crystal system: monoclinic, space group: P2(1). Unit cell dimensions: a = 11.7963(3), b = 13.5670(3), c = 24.6087(7) Å, $\alpha = \gamma$ = 90°, β = 103.618(2), V = 3827.67(17) Å^3, Z = 4. ρ(calculated) = 1.636 g/cm^3, absorption coefficient 1.859 mm^{-1}. F(000) = 1908. Crystal size: 0.50 × 0.08 × 0.06 mm. Θ = 3.13 to 26.00°. Index ranges: $-14 \le h \le 14$, $-16 \le k \le 16$, $-30 \le l \le 30$. Reflections collected: 51515. Independent reflections: 14973 [R_{int} = 0.0526]. Completeness to 2Θ = 26.00°: 99.7%. Refinement method: Full-matrix least-squares on F^2. Data/restraints/parameters: 14973/1/986. Goodness-of-fit on F^2: 1.094. Final R indices [$I > 2\sigma(I)$]: R_1 = 0.0429, wR_2 = 0.0923. R indices (all data): R_1 = 0.0492, wR_2 = 0.0950. Absolute structure parameter: –0.008(3).

CCDC-617014 contains the supplementary crystallographic data for this paper. These data can be obtained free of charge from The Cambridge Crystallographic Data Centre via www.ccdc.cam.ac.uk/data_request/cif.

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