Desymmetrisation of Cyclopentadienylsilane by Asymmetric Cyclopropanation

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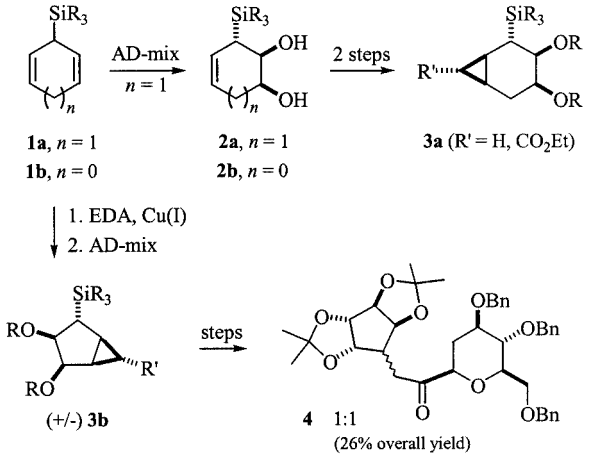
Desymmetrisation of silylcyclopenta-2,4-diene was carried out by an asymmetric copper(I)-mediated cyclopropanation. An in-depth investigation with various ligands led to the discovery that the PyBox ligands **10a–c** were the most efficient ligands for this transformation and led to the cyclopropane **7a** with an *ee* of up to 72%. Further studies aimed at providing insights into the origin of this enantiocontrol are also provided.

Introduction

We recently reported that desymmetrisation of silylcyclohexa-2,5-dienes of type **1a** (n = 1, Scheme 1) through Sharpless dihydroxylation gave access to diols **2a** (n = 1) in high yield, with complete diastereocontrol and reasonable enantiocontrol.[1] Cyclopropanation of the remaining double bond was then shown to provide stereoselectively the corresponding cyclopropylmethylsilanes **3**, which could be opened, with concomitant desilylation, under electrophilic[2a] (R′ = H) or nucleophilic[2b] (R′ = CO_2Et) conditions, leading to trisubstituted cyclohexenes which were converted later into a range of sugar mimics (Scheme 1). When trying to extend this strategy to the silylcyclopenta-2,4-diene analogues **1b** (n = 0), decomposition of the starting material occurred during dihydroxylation and no trace of the desired diol **2b** could be isolated.[2a] At the time, this plagued our efforts to access homologous cyclopentitols and carbo-furanose, thus limiting the scope of our methodology. The preparation of enantiopure carba-*C*-furanosides was, however, carried out using the reverse strategy instead, i.e. cyclopropanation of silylcyclopenta-2,4-diene **1b** then dihydroxylation of the remaining allylsilane moiety to give the fully functionalised cyclopentane **3b**.[2] This approach eventually led to the synthesis of optically pure carba-*C*-furanoside **4** in good overall yield, following the coupling of the carba-furanose moiety with a lithio-glycoside.



Scheme 1

Results and Discussion

The limited scope of the strategy above and the known utility of cyclopropylmethylsilanes[2a] as synthons for organic synthesis prompted us to start an investigation on the desymmetrisation of silylcyclopenta-2,4-diene **6** through copper-catalysed cyclopropanation (Scheme 2, Table 1). Based on earlier observations that Schiff bases catalysed cyclopropanation reactions efficiently,[3] our preliminary studies were carried out with the simple C_2-symmetric Schiff bases **8a–b** (Scheme 3). As shown in Table 1 (Scheme 2), these led to the expected mono-cyclopropanated product **7a** along with a minor isomer **7b** (not shown) but with no enantioselectivity (entries 1–2, Table 1). Similar results were observed with bis-oxazolines **9a–b**,[4] which are known to be highly efficient ligands for cyclopropanations (entries 3–4). Finally, we were pleased to find that Nishiyama's PyBox **10a**[5] provided the desired cyclopropanes **7a–b** with good diastereocontrol in reasonable

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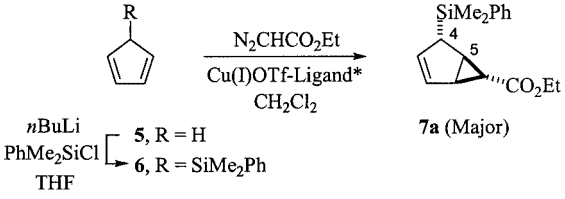
yield[6] (over two steps) with 68% enantiomeric excess for both the major and the minor isomers (entry 5). Cyclopropanation using other PyBox-type ligands (**10b**−**c**) also led to the same behaviour, although with a lower enantioselectivity (entries 6−7, Table 1).[7] It is noteworthy that no trace of bis-cyclopropanation product could be detected during these processes. The involvement of a kinetic amplification which would raise the level of enantioselectivity by consumption of the minor enantiomer may thus be ruled out.[8] To the best of our knowledge, this is the first example of a desymmetrisation using an asymmetric cyclopropanation.[9] Both diastereomers were readily separated by chromatography and, after extensive ^1H and ^{13}C NMR experiments (DEPT, COSY, HMQC, NOESY and HMBC), their relative configurations were determined unambiguously. As observed in the racemic series,[2a] the major isomer **7a** was shown to possess the C4−C5-*trans* configuration, demonstrating that the carbenoid species approaches *anti* relative to the silicon group. More surprisingly, NOE experiments indicated that the minor isomer **7b** had the C4-C5-*cis* stereochemistry (Figure 1) showing that, to a certain extent, the electrophilic carbenoid reagent (vide infra) can also approach *syn* relative to the bulky silicon group. This result is particularly surprising considering the wealth of data indicating *anti* stereospecificity for electrophilic processes occurring with chiral allylsilanes.[10]



Scheme 2

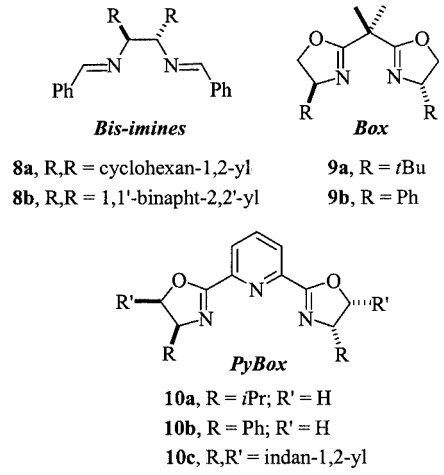
Table 1. Asymmetric cyclopropanation of **6** (Scheme 2); study on the nature of the ligand L*

Entry	L*	*dr*[a]	$ee_{maj.}$ [b]	$ee_{min.}$ [b]	Yield (%)[c]
1	**8a**	95:5	2	−	20
2	**8b**	95:5	2	−	26
3	**9a**	94:6	4	−	28
4	**9b**	95:5	0	−	47
5	**10a**	82:18	68	68	48
6	**10b**	98:2	6	10	45
7	**10c**	96:4	48	36	41

[a] Estimated from the ^1H NMR spectrum of the crude mixture. [b] Measured by HPLC (hexane/*i*PrOH, 95:5), Chiralcel OD-H®. [c] Overall yield starting from **5** (two steps) after purification by chromatography.

With these results in hand we then investigated the mechanism of the reaction and the origin of the enantioselectivity in more detail. We first varied the Cu^I/**10a** ratio and found that when PyBox **10a** was slightly in excess or in an equimolar amount with the copper(I) salt, not only was cyclopropanation not observed but ethyl diazoacetate was not even decomposed.[11] This may indicate that the tridentate ligand sequesters the metal to form a stable copper complex in solution. Tridentate ligands such as pyridine-bis-benzimidazoles and PyBox are known to form stable helicate complexes with copper and silver in solution.[12] The structure of these complexes has also been determined by X-ray crystallography.[12b] Unfortunately, we were unable to crystallise a 1:1 Cu^I:**10a** complex. However, we found that adding a slight excess of Cu^IOTf to the 1:1 Cu^I:**10a** mixture restored the catalytic activity of the system. As Cu^I-PyBox:**10a** ratio as low as 1:0.2 could be used without any noticeable decrease in yield or enantioselectivity (entries 1−3, Table 2), suggesting that copper aggregates are involved in the process. These aggregates then dissociate when Cu^I is in excess, providing the catalytically active species (probably monomeric) involved in the stereochemistry-determining step. In order to get further insights on the nature and relative stability of the copper complexes involved in our cyclopropanation, we examined the possible occurrence of a nonlinear effect.[13] As depicted in Figure 2 (entries 6−9, Table 2), we observed a linear relationship between the *ee* of the product and the *ee* of **10a** (Figure 2). It is noteworthy that the diastereocontrol remained the same when varying the *ee* of the ligand. We also changed the metal involved in the reaction and performed the same experiments with $RhCl_3$.[5c] Surprisingly, the reaction did not afford the desired cyclopropane. Finally, negligible temperature effects were observed on the enantioselectivity (72% vs. 68%) and yield of the process (entries 3−5, Table 2).

We also varied the number of chelating groups (N) on the ligands in order to obtain additional information about the implication of the different chelating sites of PyBox.[14]



Scheme 3

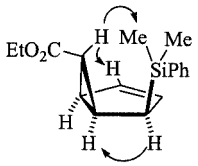


Figure 1. NOE effects in **7b** (minor)

Table 2. Asymmetric cyclopropanation of **6** (Scheme 2)

Entry	Ligand[a]	T (°C)	dr[b]	$ee_{maj.}$ [c]	$ee_{min.}$ [c]	Yield (%)[d]
1	(*S*)-**10a**[e]	20	84:16	68	77	48
2	(*S*)-**10a**[f]	20	83:17	66	74	48
3	(*S*)-**10a**	20	82:18	68	68	48
4	(*S*)-**10a**	26	83:17	68	84	48
5	(*S*)-**10a**	11	85:15	72	82	50
6	(*S*)-**10a**	20	84:16	72	72	47
7	(*S*)-(70%)	20	84:16	52	52	42
8	(*S*)-(50%)	20	85:15	32	32	43
9	(*S*)-(30%)	20	85:15	20	22	45
10	**11a**	20	91:9	6	4	23
11	**11b**	20	89:11	16	2	46

[a] Unless indicated otherwise the Cu^{I}:ligand ratio is 1:0.5. [b] Estimated from the ^1H NMR spectrum of the crude mixture. [c] Measured by HPLC (Hexane/*i*PrOH, 95:5), Chiralcel OD-H®. [d] Overall yield over two steps after purification by chromatography.[e] Cu^{I}:ligand ratio of 1:0.8. [f] Cu^{I}:ligand ratio of 1:0.2.

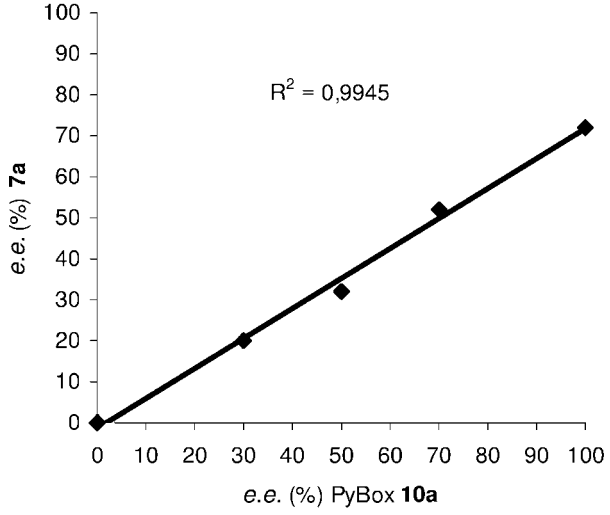
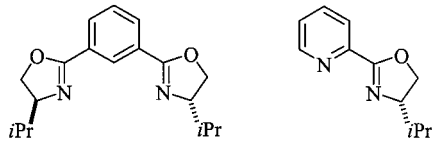


Figure 2. Variation of the *ee* of **7a** as a function of the *ee* of ligand **10a**

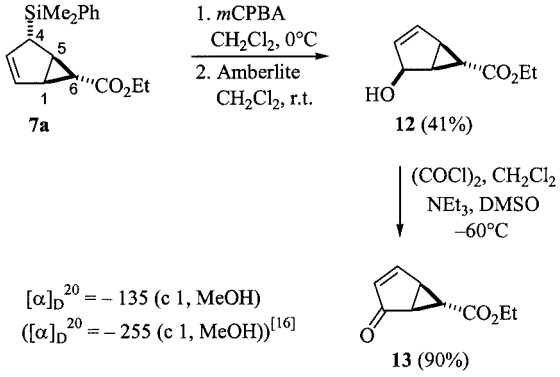
Ligands **11a** and **11b** were thus designed as bidentate analogues (Scheme 4). In the former, the trinuclear skeleton was maintained with a nonchelating phenyl replacing pyridine and in the latter, one oxazoline was removed. As summarised in Table 2 (entries 10−11), PheBox (**11a)** led to low enantioselectivity but also to a poorer conversion than **10a**. PyOx (**11b**) led to cyclopropanes **7a**−**b** with yield and diastereoselectivity similar to those obtained with **10a** but again with poor enantiocontrol. This demonstrates that the three chelating sites of PyBox are required to obtain high levels of enantioselectivity. These observations and the absence of a nonlinear effect suggest that the catalytically active species in the stereochemistry-determining step may involve only one chiral ligand (vide infra). If copper aggregates are present in solution, they probably dissociate with low energy of activation.[13]

The absolute configuration of **7a** was determined using the sequence summarised in Scheme 5. Epoxidation of the



Scheme 4

allylsilane **7a** produced the desired epoxide, which was not isolated but transformed directly into the alcohol **12**[15] through an acid-catalysed Peterson reaction. Swern oxidation of the alcohol finally furnished the known cyclopropane **13**[16] with a specific rotation of −135° (ref.[16] −255°), indicating that **7a** has the absolute configuration (1*R*,4*S*,5*R*,6*R*) shown below.



Scheme 5

With the absolute configuration of **7a** in hand and considering the information collected previously, we next attempted to explain the origin of the enantioselectivity. Recent calculations by Noorby et al.[17] have shown that the stereochemistry-determining step of copper-catalysed cyclopropanation proceeds through a concerted but asynchronous addition of an electrophilic copper-carbenoid species[18] onto the alkene. An open transition state was thus proposed for the cyclopropanation of styrene, where bonding between the less-substituted end of the olefin and the carbenoid centre occurred very early on, leaving a partial positive charge at the benzylic position. The cyclopropane was then formed upon ring closure at a later stage, although still in a concerted manner. In our case, such a scenario could also operate with the development of a partial positive charge β to the silicon group, stabilised through hyperconjugation (silicon β-effect).[19] The diene would thus approach the ligand-copper-carbenoid complex as shown in Figure 3. The enantioselectivity of the process is thought to be governed by steric interactions developing between substituents on the carbene (carboxylate) and those on the chiral ligand (*i*Pr groups), during carbenoid pyramidalisation, as proposed earlier by Pfaltz[4a] and confirmed by Noorby's calculations.[17] The preferential attack of the carbenoid species at the pro-(*S*) double bond (*anti* relative to the SiR_3 group, Figure 3) would thus prevent steric interactions developing

between the *i*Pr group at C-1 and the carboxylate. Calculations also suggested that bonding between Cu and the carbenoid centre was best represented as Cu−C$^+$, corresponding to the lone pair of a singlet carbene coordinated to a Cu^I cation.[17] As already mentioned, Cu^I cations are efficiently coordinated by tridentate ligands. The three nitrogens present in PyBox (**10a**) would thus be required to stabilise the monomeric carbenoid species through coordination to Cu^I. Finally, the formation of the minor isomer **7b**, with relatively high enantioselectivities (Table 1−2), may be rationalised using a similar transition state model. This would result from an approach of the carbenoid species, *syn* relative to the silicon group. Such an approach would not suffer from too much steric crowding because the bonding between the carbenoid centre and the allylsilane is thought to occur first at the γ-position relative to the silicon bond (vide supra). Although this has not been firmly established, using this model the pro-(*R*) enantiotopic double bond of **6** would thus be cyclopropanated to form **7b** (Figure 1).

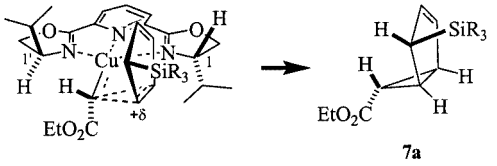


Figure 3. Transition state model for the asymmetric cyclopropanation of **6**

Conclusion

In conclusion, we have developed an enantioselective approach towards cyclopropanes (i.e. **7**), having a useful allylsilane moiety, which are valuable intermediates for organic synthesis. As shown in earlier reports, synthons such as **7** can be elaborated further to cyclopentitols[2a] and carba-*C*-disaccharides.[2b] Our approach also provides a more straightforward access to recently discovered excitatory amino acids.[16] Moreover, some mechanistic insights have been obtained which might be useful for the design of more efficient ligands for the cyclopropanation of cyclic as well as acyclic (*Z*)-olefins.

Experimental Section

General Remarks: NMR spectra were performed in $CDCl_3$ solutions with chloroform as internal reference (^{1}H: δ = 7.26; ^{13}C: δ = 77.0 ppm). Structural assignments were based on DEPT, COSY, HMQC, HMBC and NOESY experiments. 1D ^{1}H and ^{13}C NMR spectra were recorded on a Bruker AC 200 spectrometer at 200 and 50.3 MHz respectively. 2D NMR experiments were recorded on a Bruker ARX 400 spectrometer (400 MHz). HPLC were performed on a Waters 600 equipped with a 996 photodiode array detector and a Chiralcel OD® column. IR spectra of thin layers of samples between KBr plates were obtained on a Bruker instrument. LRMS data were recorded on a HP mass spectrometer. HRMS data were determined at the Centre Régional de Mesures Physiques de l'Ouest (Rennes). Optical rotations were measured on a Perkin−Elmer polarimeter using a 10 cm cell. CH_2Cl_2, Et_3N were distilled from CaH_2. THF was distilled from over sodium/benzophenone. Ligands **10a−c** were purchased from Aldrich (99%) and used in without further purification.

(Cyclopenta-2,4-dien-1-yl)dimethylphenylsilane (6):[2a] A 2.5 M solution of *n*BuLi in hexanes (14.4 mL, 36 mmol) was added, at −78 °C, to a solution of freshly distilled cyclopentadiene (2 g, 30 mmol) in anhydrous THF (90 mL). The solution was stirred at −78 °C for 45 minutes, then a solution of $PhMe_2SiCl$ (5 mL, 30 mmol) in THF (10 mL) was added. The reaction mixture was stirred at −78 °C for 1.5 h, then quenched with a saturated solution of NH_4Cl and allowed to warm to room temperature. The organic layer was decanted and the aqueous layer extracted with diethyl ether. The combined extracts were washed with brine, dried over $MgSO_4$ and concentrated in vacuo to give **6** as a yellow oil (5.4 g, 92%). The crude product was used in the next step without further purification.

Ethyl 4-(Dimethylphenylsilyl)bicyclo[3.1.0]hex-2-ene-6-carboxylate (7a and 7b): Two drops of ethyl diazoacetate were added to a dark red solution of copper(I) trifluoromethanesulfonate-benzene complex (28 mg, 0.1 mmol) and PyBox (**10a**; 15 mg, 0.05 mmol) in dry CH_2Cl_2 (3 mL) to initiate the reaction. Then, a solution of **6** (200 mg, 1 mmol) and ethyl diazoacetate (140 μL, 1.3 mmol) in CH_2Cl_2 (10 mL) was added over a period of 3.5 h and the dark red mixture turned successively orange and then brown. At the end of the addition, the solvent was removed under reduced pressure and the remaining brown oil was purified by chromatography through silica gel (petroleum ether/CH_2Cl_2, 60:40) affording **7a−b** as a colourless oil (138 mg, 48%). The two diastereomers were then separated by chromatography over silica gel (2% ethyl acetate/petroleum ether).

Major Diastereomer (7a): *ee* 68%. (R_f = 0.45; EtOAc/petroleum ether, 95:5). IR (KBr): $\tilde{\nu}_{max}$ = 3069 cm^{-1}, 3050, 2979, 2957, 2903, 2871, 1732, 1722, 1717 (C=O), 1428, 1398, 1380, 1283, 1263, 1250, 1161, 1115, 1047, 943. ^{1}H NMR ($CDCl_3$): δ = 7.51−7.57 (m, 2 H, H_{arom}), 7.34−7.41 (m, 3 H, H_{arom}), 5.83−5.89 (m, 1 H, 2-H), 5.46−5.51 (m, 1 H, 3-H), 4.10 (q, *J* = 7.2 Hz, 2 H, CH_2), 2.40−2.47 (m, 1 H, 1-H), 2.33−2.37 (m, 1 H, 4-H), 2.07−2.12 (m, 1 H, 5-H), 1.24 (t, *J* = 7.2 Hz, 3 H, CH_3), 0.88−0.91 (m, 1 H, 6-H), 0.31 (s, 3 H, $SiCH_3$), 0.29 (s, 3 H, $SiCH_3$) ppm. ^{13}C NMR ($CDCl_3$): δ = 174.4 (C=O), 137.1 (C_{arom}), 133.9 (2 × CH_{arom}), 131.6 (C-3), 129.6 (C-2), 129.2 (CH_{arom}), 127.8 (2 × CH_{arom}), 60.3 (CH_2), 39.7 (C-4), 35.1 (C-1), 29.1 (C-6), 27.5 (C-5), 14.3 (CH_3), −5.2 ($SiCH_3$), −5.5 ($SiCH_3$) ppm. MS (CI$^+$, NH_3): *m*/*z* = 304 [M + NH_4]$^+$, 287 [M + 1]$^+$, 209, 152 [M + 1−$PhMe_2Si$]$^+$. MS (EI): *m*/*z* = 135 (100) [$PhMe_2Si$]$^+$. HRMS (EI) $C_{17}H_{22}O_2Si$: calcd. 286.13891; found: 286.13800. $[\alpha]_D^{20}$ = +147 (*c* = 0.27, MeOH).

Minor Diastereomer (7b): *ee* 68%. (R_f = 0.40; EtOAc/petroleum ether, 95:5). IR (KBr): $\tilde{\nu}_{max}$ = 3068 cm^{-1}, 3050, 2979, 2956, 2901, 2871, 1738−1733 (C=O), 1427, 1404, 1382, 1248, 1186, 1140, 1115, 1029, 951. ^{1}H NMR ($CDCl_3$): δ = 7.52−7.57 (m, 2 H, H_{arom}), 7.33−7.39 (m, 3 H, H_{arom}), 5.63−5.69 (m, 1 H, 3-H), 5.54−5.60 (m, 1 H, 2-H), 4.03 (q, *J* = 7.2 Hz, 2 H, CH_2), 2.68−2.71 (m, 1 H, 4-H), 2.37−2.47 (m, 1 H, 6-H), 1.84−1.91 (m, 1 H, 5-H), 1.61−1.69 (m, 1 H, 1-H), 1.20 (t, *J* = 7.2 Hz, 3 H, CH_3), 0.30 (s, 3 H, $SiCH_3$), 0.29 (s, 3 H, $SiCH_3$) ppm. ^{13}C NMR ($CDCl_3$): δ = 169.5 (C=O), 137.3 (C_{arom}), 133.9 (2 × CH_{arom}), 133.7 (C-3), 129.1 (CH_{arom}), 127.7 (2 × CH_{arom}), 124.2 (C-2), 59.7 (CH_2), 35.1 (C-4), 32.0 (C-6), 23.3 (C-5), 20.7 (C-1), 14.3 (CH_3), −4.9 ($SiCH_3$), −5.6 ($SiCH_3$) ppm. MS (CI$^+$, NH_3): *m*/*z* = 304 [M + NH_4]$^+$, 287 [M + 1]$^+$, 209, 152 [M + 1−$PhMe_2Si$]$^+$. MS (EI): *m*/*z* = 135

([$PhMe_2Si$]$^+$, 100). HRMS (EI) $C_{17}H_{22}O_2Si$: calcd. 286.13891; found: 286.13800.

Ethyl 4-Hydroxybicyclo[3.1.0]hex-2-ene-6-carboxylate (12): A 70% suspension of *m*CPBA (300 mg, 1.2 mmol) was added, at 0 °C, to a suspension of silane **7a** (290 mg, 1.0 mmol) and $NaHCO_3$ (100 mg, 1.2 mmol) in CH_2Cl_2 (10 mL). The reaction was stirred at 0 °C for 1 h then allowed to warm to room temperature. After 6 h at room temperature, the mixture was diluted with diethyl ether, washed with a 20% solution of NaOH, dried over $MgSO_4$ and concentrated in vacuo. The resulting crude mixture was then diluted with CH_2Cl_2 and amberlite IR-120 (200 mg) was added to the solution. After 12 h at room temperature the mixture was filtered, concentrated in vacuo and the resulting white solid was purified by silica gel chromatography (petroleum ether/EtOAc, 90:10 → 80:20) to give **12** as a colourless oil (70 mg, 41%). ^{1}H NMR ($CDCl_3$): δ = 6.20−6.18 (m, 1 H, =CH), 5.70−5.67 (m, 1 H, =CH), 4.60−4.50 (m, 1 H, C*H*OH), 4.12 (q, *J* = 7 Hz, 2 H, OCH_2CH$_3$), 2.53−2.33 (m, 3 H), 1.39−1.13 (m, 3 H) ppm. Other spectroscopic data were in good agreement with those reported in the literature.[16]

Ethyl 4-Oxobicyclo[3.1.0]hex-2-ene-6-carboxylate (13): A solution of DMSO (65 μL, 0.92 mmol) in CH_2Cl_2 (1 mL) was added, at −60 °C, to a solution of oxalyl chloride (39 μL, 0.46 mmol) in anhydrous CH_2Cl_2 (1 mL). After 10 minutes, a solution of the alcohol **12** (70 mg, 0.41 mmol) in dry CH_2Cl_2 (0.5 mL) was added dropwise at −60 °C and the mixture was stirred for 15 minutes. NEt_3 (0.3 mL, 2.1 mmol) was then added to the solution. The reaction mixture was stirred for 5 minutes at −60 °C, then allowed to warm to room temperature and water (2 mL) was added. After 10 minutes, the organic layer was decanted then washed successively with water, a 1% solution of HCl, a 5% solution of Na_2CO_3, water, dried over $MgSO_4$ and the solvents were concentrated in vacuo. The residue was purified by gel chromatography (petroleum ether/EtOAc, 95:5) to give **13** as a white solid (62 mg, 90%). M.p. 97−99 °C. IR (KBr): $\tilde{\nu}_{max}$ = 3070 cm^{-1}, 2950, 1715, 1695, 1469, 1265, 1177, 876, 854, 818. ^{1}H NMR ($CDCl_3$): δ = 7.61 [dd, *J* = 5.7 Hz, 2.6 Hz, 1 H, C(O)CH=C*H*], 5.74 [d, *J* = 5.7 Hz, 1 H, C(O)CH=], 4.15 (q, *J* = 7 Hz, 2 H, OCH_2CH$_3$), 2.96 (dt, *J* = 4.8 Hz, 2.6 Hz, 1 H), 2.65−2.59 (m, 1 H), 2.27 (t, *J* = 2.6 Hz, 1 H), 1.26 (t, *J* = 7 Hz, 3 H, OCH$_2$C*H*$_3$) ppm. ^{13}C NMR ($CDCl_3$): δ = 203.4 (C=O), 168.0 (*C*OOCH$_2$CH$_3$), 159.7 [C(O)CH=*C*H), 129.7 [C(O)*C*H=), 61.4 (O*C*H$_2$CH$_3$), 45.9, 30.1, 29.0, 14.2 ppm. $[\alpha]_D^{20}$ = − 135 (*c* = 1, MeOH) [ref.[16]: $[\alpha]_D^{20}$ = − 255 (*c* = 1, MeOH)]. Other spectroscopic data were in good agreement with those reported in the literature.[16]

Acknowledgments

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[1] [1a] R. Angelaud, Y. Landais, *J. Org. Chem.* **1996**, *61*, 5202−5203. [1b] R. Angelaud, Y. Landais, *Tetrahedron Lett.* **1997**, *38*, 8841−8844. [1c] R. Angelaud, O. Babot, T. Charvat, Y. Landais, *J. Org. Chem.* **1999**, *64*, 9613−9624.

[2] [2a] Y. Landais, L. Parra-Rapado, *Eur. J. Org. Chem.* **2000**, *2*, 401−418. [2b] R. Angelaud, Y. Landais, L. Parra-Rapado, *Tetrahedron Lett.* **1997**, *38*, 8845−8848.

[3] [3a] T. Aratani, *Pure Appl. Chem.* **1985**, *57*, 1839−1844. [3b] K. Ito; T. Katsuki, *Synlett* **1993**, 638−640. [3c] T. Uchida; R. Irie; T. Katsuki, *Synlett* **1999**, 1793−1795. [3d] T. Uchida; R. Irie; T. Katsuki, *Synlett* **1999**, 1163−1165. [3e] T. Katsuki, *Adv. Synth. Catal.* **2002**, *344*, 131−147.

[4] [4a] H. Fritschi; U. Letenegger; A. Pfaltz, *Helv. Chim. Acta* **1988**, *71*, 1553−1565. [4b] D. A. Evans; K. A. Woerpel; M. M. Hinman; M. M. Foul, *J. Am. Chem. Soc.* **1991**, *113*, 726−728. [4c] R. E. Lowenthal; S. Masamune, *Tetrahedron Lett.* **1991**, *32*, 7373−7376.

[5] [5a] H. Nishiyama; Y. Itoh; H. Matsumoto; S.-B. Park; K. Itoh, *J. Am. Chem. Soc.* **1994**, *116*, 2223−2224. [5b] H. Nishiyama; Y. Itoh; Y. Sugawara; H. Matsumoto; K. Aoki; K. Itoh, *Bull. Chem. Soc. Jpn.* **1995**, *68*, 1247−1262. [5c] For the use of related bis(pyrazolyl)pyridines, see: D. L. Christenson; C. J. Tokar; W. B. Tolman, *Organometallics* **1995**, *14*, 2148−2150.

[6] The moderate overall yield over the two steps is due to the formation of several isomers over the silylation step (**5** → **6**) which do not react in the second step.

[7] It is noteworthy that attempts to perform this asymmetric cyclopropanation using Doyle's chiral Rh_2(MEPY)$_4$ led to no enantioselectivity: M. P. Doyle, M. A. McKervey, T. Ye in "*Modern Catalytic Methods for Organic Synthesis with Diazo Compounds*", John Wiley & Sons, New York, **1998**.

[8] S. L. Schreiber, T. S. Schreiber, D. B. Smith, *J. Am. Chem. Soc.* **1987**, *109*, 1525−1529.

[9] [9a] T.-L. Ho, "*Symmetry: A Basis for Synthesis Design*", John Wiley & Sons, New York, **1995**. [9b] M. C. Willis, *J. Chem. Soc., Perkin Trans. 1* **1999**, 1765−1784.

[10] I. Fleming, J. Dunoguès, R. Smithers, *Org. React.* **1989**, *37*, 57−575.

[11] During copper(I)- and rhodium(II)-mediated cyclopropanations, decomposition of ethyl diazoacetate produces various amount of diethyl fumarate and maleate along with the cyclopropane. These were absent in our experiment when using a 1:1 **10a**/Cu^I ratio.

[12] [12a] C. Provent; S. Hewage; G. Brand; G. Bernardinelli; L. J. Charboniere; A. F. Williams, *Angew. Chem. Int. Ed. Engl.* **1997**, *36*, 1287−1289. [12b] S. Rüttimann; C. Piguet; G. Bernardinelli; B. Bocquet; A. F. Williams, *J. Am. Chem. Soc.* **1992**, *114*, 4230−4237. [12c] C. Piguet; G. Bernardinelli; G. Hopfgartner, *Chem. Rev.* **1997**, *97*, 2005−2062.

[13] [13a] H. B. Kagan; C. Girard, *Angew. Chem. Int. Ed.* **1998**, *37*, 2922−2959. [13b] K. Mikami; M. Terada; T. Korenaga; Y. Matsumoto; M. Ueki; R. Angelaud, *Angew. Chem. Int. Ed.* **2000**, *39*, 3532−3556.

[14] C.-X. Zhao; M. O. Duffey; S. J. Taylor; J. P. Morken, *Org. Lett.* **2001**, *3*, 1829−1831.

[15] The relative configuration of the allylic alcohol **12** was assumed to be *cis* as shown, resulting from an epoxidation which occurred *anti* relative to the silicon group.[10]

[16] [16a] E. D. Moher, *Tetrahedron Lett.* **1996**, *37*, 8637−8640. [16b] C. Dominguez; J. Ezquerra; L. Prieto; M. Espada; C. Pedregal, *Tetrahedron: Asymmetry* **1997**, *8*, 511−514.

[17] T. Rasmussen; J. F. Jensen; N. Ostergaard; D. Tanner; T. Ziegler; P.-O. Norrby, *Chem. Eur. J.* **2002**, *8*, 177−184.

[18] Various Hammett studies and calculations on the mechanism of copper-catalysed cyclopropanation have shown that the putative copper carbenoid species is electrophilic in nature.[17] Similar conclusions were reached with copper-catalysed insertion of diazo ester into Si−H bonds, see: [18a] Y. Landais; L. Parra-Rapado; D. Planchenault; V. Weber, *Tetrahedron Lett.* **1997**, *38*, 229−232. [18b] L. A. Dakin; P. C. Ong; J. S. Panek; R. J. Staples; P. Stavropoulos, *Organometallics* **2000**, *19*, 2896−2908.

[19] J. B. Lambert, *Tetrahedron* **1990**, *46*, 2677−2689 and references cited therein.

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