Supporting Information

Stereoselective Formation of Trisubstituted (*Z*)-Chloroalkenes Adjacent to Tertiary Carbon Stereogenic Centers by Organocuprate-Mediated Reduction/Alkylation

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I. General Information

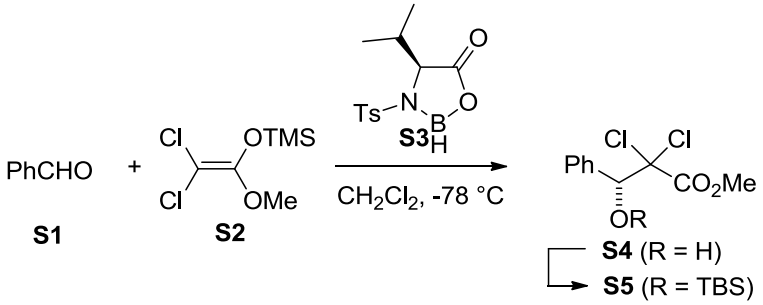
General Methods. All reactions utilizing air- or moisture-sensitive reagents were performed in dried glassware under an atmosphere of nitrogen, using commercially supplied solvents and reagents unless otherwise noted. CH_2Cl_2 was distilled from CaH_2 and stored over molecular sieves. Thin-layer chromatography (TLC) was performed on Merck $60F_{254}$ precoated silica gel plates and were visualized by fluorescence quenching under UV light and by staining with phosphomolybdic acid, *p*-anisaldehyde, or ninhydrin, respectively. Flash column chromatography was carried out using Wakogel C-200 (Wako Pure Chemical Industries, Ltd.) and silica gel 60 N (Kanto Chemical Co., Inc.).

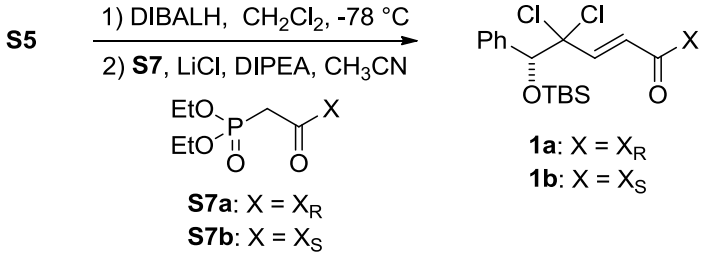
Characterization data. ^{1}H-NMR (400 or 500 MHz) and ^{13}C-NMR (125 MHz) spectra were recorded using a Bruker Avance II spectrometer with a CryoProbe. Chemical shifts are reported in δ (ppm) relative to Me_4Si (in $CDCl_3$) as internal standard. Infrared (IR) spectra were recorded on a SHIMADZU IR Prestige-21 FTIR-8400S and JASCO FT/IR 4100, and are reported as wavenumber (cm^{-1}). Low- and high-resolution mass spectra were recorded on a Brucker Daltonics microTOF (ESI-MS) spectrometers in the positive and negative detection mode. Optical rotations were measured on a JASCO DIP-370 polarimeter operating at the sodium D line with a 100 mm path length cell, and were reported as follows: $[\alpha]_D^T$ (concentration (g/100 mL), solvent).

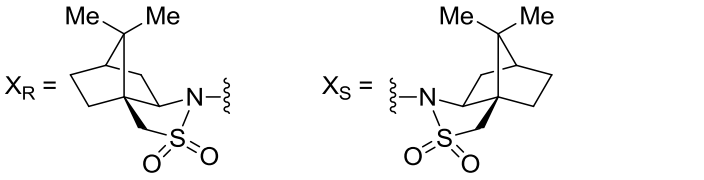
HPLC condition. For chiral HPLC, a Daicel CHIRALPAK ID columns (4.6 x 250 mm) was employed with 10% isocratic of isopropanol in Hexane at a flow rate of 0.4 cm^3 min^{-1} on JASCO PU-2086 plus (JASCO corporation, Ltd., Tokyo, Japan), and eluting products were detected by UV at 230 nm. For analytical HPLC, a Cosmosil Cholester Packed column (4.6 x 250 mm, Nacalai Tesque, Inc., Kyoto, Japan) was employed with a linear gradient of MeCN at a flow rate of 1 cm^3 min^{-1} on a LaChrom Elite HTA system (Hitachi High-Technologies corporation, Ltd., Tokyo, Japan) and JASCO PU-2086 plus (JASCO corporation, Ltd., Tokyo, Japan), and eluting products were detected by UV at 220 or 230 nm.

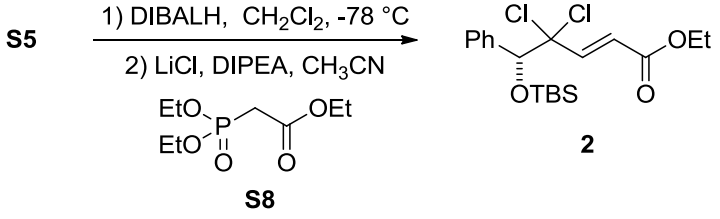
II. Preparation of γ,γ-dichloro-α,β-enoyl sultam 1 and enoate 2

According to the reported procedure,[S1] asymmetric Mukaiyama aldol reaction of benzaldehyde **S1** with α,α-dichloroketene silyl acetal **S2** in the presence of chiral oxazaborolidinone **S3**[S2] followed by acidic removal of TMS group provided the α,α-dichloro-β-hidroxyester **S4** with excellent enatioselectivity (97% ee), which was recrystallized from dichloromethane/hexane to give the optically pure **S4**. TBS protection of hydroxyl group, DIBALH reduction of the ester moiety, and Honer-Wadsworth-Emmons-type coupling with the corresponding phosphates **S7** and **S8** provided sultams **1** and enoate **2**, respectively.

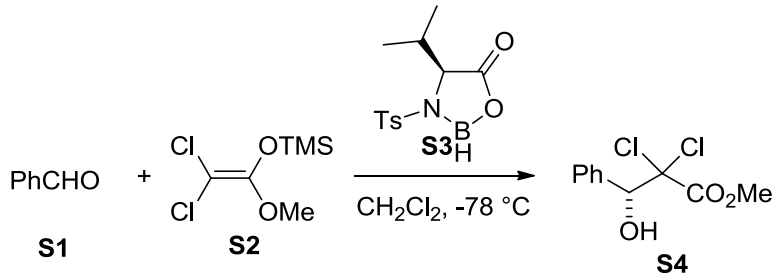








[S1] Imashiro, R.; Kuroda, T. *J. Org. Chem.* **2003**, *68*, 974.
[S2] Kiyooka, S.; Kaneko, Y.; Komura, M.; Matsuo, H., Nakano, M. *J. Org. Chem.* **1991**, *56*, 2276.



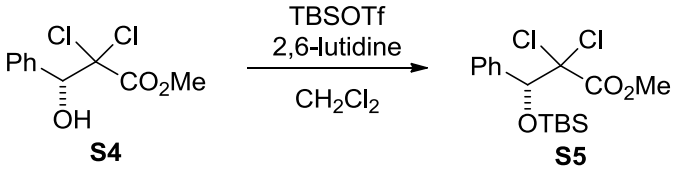
(3*R*)-Methyl 2,2-dichloro-3-hydroxy-3-phenylpropanoate (S4): This compound was prepared according to the reported procedure.[S1] $[\alpha]_D^{25}$ = -16.4 (c 0.73, $CHCl_3$); IR (KBr) ν 3505 (OH), 1746 (CO); ^{1}H NMR (500 MHz, $CDCl_3$) δ 3.25 (d, J = 5.0 Hz, 1H), 3.92 (s, 3H), 5.43 (d, J = 5.0 Hz, 1H), 7.38-7.40 (m, 3H), 7.52-7.53 (m, 2H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 54.6, 78.8, 85.8, 127.8 (2C), 128.8 (2C), 129.2, 135.3, 166.5; Anal. calcd for $C_{10}H_{10}Cl_2O_3$: C, 48.22; H, 4.05; N, 0.00. Found: C, 48.34; H, 3.90; N, 0.01; HRMS (FAB), *m*/*z* calcd for $C_{10}H_{11}Cl_2O_3$ $[M+H]^+$ 249.0085, found 249.0094.

HPLC conditions: Daicel chiral ID colum (4.6 x 250 mm) with 10% ^{i}PrOH in Hexane at a flow rate 0.40 mL/min, detection at 230 nm.

rac-**S4**

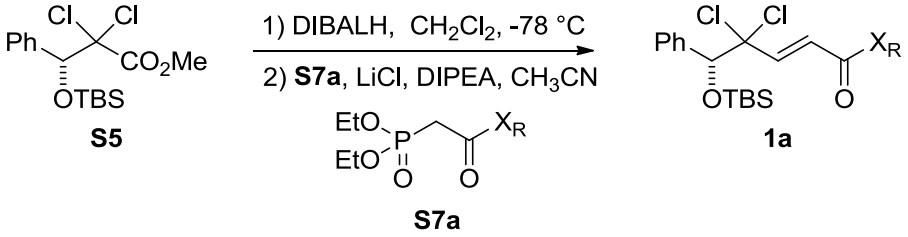
S4 (after asymmetric aldol reaction)

S4 (after recrystallization)



S4 **S5**

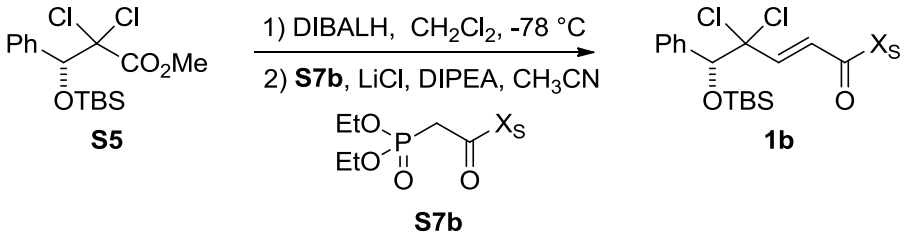
(3*R*)-Methyl 3-[(*tert*-butyldimethylsilyl)oxy]-2,2-dichloro-3-phenylpropanoate (S5): To a solution of alcohol **S4** (456.0 mg, 1.82 mmol) in CH_2Cl_2 (3.64 mL), 2,6-lutidine (0.85 ml, 7.28 mmol) and *tert*-butyldimethylsilyl trifluromethanesulfonate (0.81 mL, 3.64 mmol) were added at 0 ºC under nitrogen. After stirred at room temperature for 12 h, the mixture was diluted with EtOAc and washed with saturated aqueous $NaHCO_3$ and brine, dried over $MgSO_4$. Concentration under reduced pressure followed by flash chromatography over silica gel with *n*-hexane-EtOAc (18:1) gave the title compound **S5** as colorless oil (564.4 mg, 86%): $[\alpha]_D^{25}$ = -36.9 (c 1.07, $CHCl_3$); IR (KBr) ν 1746 (CO); ^{1}H NMR (500 MHz, $CDCl_3$) δ -0.262 (s, 3H), 0.049 (s, 3H), 0.870 (s, 9H), 3.88 (s, 3H), 5.37 (s, 1H), 7.34-7.36 (m, 3H), 7.51-7.54 (m, 2H); ^{13}C NMR(125 MHz, $CDCl_3$) δ -5.54, -4.48, 18.0, 25.5 (3C), 54.4, 79.7, 87.0, 127.5 (2C), 129.0, 129.5 (2C), 136.5, 166.3; HRMS (ESI), *m*/*z* calcd for $C_{16}H_{24}Cl_2NaO_3Si$ $[M+Na]^+$ 385.0769, found 385.0764.



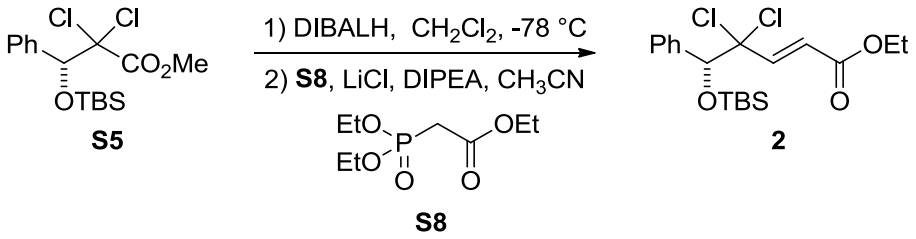
S5 **S7a** **1a**

(5*R*,2*E*)-5-[(*tert*-Butyldimethylsilyl)oxy]-4,4-dichloro-5-phenylpent-3-enoyl-(*R*)-sultam (1a): To a solution of ester **S5** (795.4 mg, 2.19 mmol) in CH_2Cl_2 (21.9 mL) was added dropwise a solution of DIBALH in toluene (1.01 M, 4.34 mL) at -78 ºC under nitrogen, and the mixture was stirred at -78 ºC for 2 h. The reaction was quenched with saturated Rochelle salt and extracted with Et_2O. The extract was washed with brine and dried over $MgSO_4$. Concentration under reduced pressure gave an oily aldehyde, which was used immediately in the next step without purification. To a stirred solution of (*R*)-D-*N*-diethoxyphosphonoacetylcamphorsultam (1092 mg, 2.78 mmol) in MeCN (14.9 mL) were added LiCl (466.4 mg, 11.0 mmol) and DIPEA (1.92 mL, 11.0 mmol) at 0 ºC under nitrogen. After stirred for 30 min, a solution of the above aldehyde in MeCN (7.0 mL) was added to the mixture, and the mixture

was stirred for 12 h at room temperature. The reaction mixture was quenched with saturated NH_4Cl aq and extracted with EtOAc. The extract was washed with brine and dried over $MgSO_4$. Concentration under reduced pressure followed by flash chromatography over silica gel with *n*-hexane-EtOAc (9:1) gave the title compound as a semisolid (959 mg, 77 %): $[\alpha]_D^{25}$ = -103.9 (c 1.23, $CHCl_3$); IR (KBr) ν 1686 (CO), 1334 ($NHSO_2$), 1165 ($NHSO_2$); ^{1}H NMR (500 MHz, $CDCl_3$) δ -0.212 (s, 3H), 0.107 (s, 3H), 0.871 (s, 9H), 0.974 (s, 3H), 1.16 (s, 3H), 1.25 (s, 2H), 1.89-1.91 (m, 3H), 2.09-2.11 (m, 2H), 3.42-3.25 (m, 2H), 3.93-3.96 (m, 1H), 4.99 (s, 1H), 6.95 (d, *J* = 15.0 Hz, 1H), 7.22 (d, *J* = 15.0 Hz, 1H), 7.29-7.31 (m, 3H), 7.37-7.39 (m, 2H); ^{13}C NMR (125 MHz, $CDCl_3$) δ -5.17, -4.81, 18.1, 19.9, 20.8, 25.6 (3C), 26.5, 32.8, 38.4, 44.6, 47.8, 48.7, 53.0, 65.0, 83.3, 90.0, 123.4, 127.6 (2C), 128.7, 129.0 (2C), 137.6, 145.1, 162.7; HRMS (ESI), *m*/*z* calcd for $C_{27}H_{39}Cl_2NNaO_4SSi$ $[M+Na]^+$ 594.1644, found 594.1638.

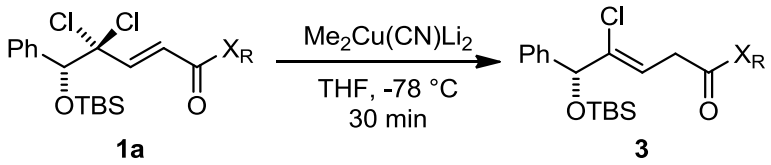


(5*R*,2*E*)-5-(*tert*-Butyldimethylsilyl)oxy-4,4-dichloro-5-phenylpent-3-enoyl-(*S*)-sultam (1b): By use of a procedure similar to that described for the preparation of (*R*)-sultam derivative **1a**, ester **S5** (1.730 g, 4.77 mmol) was converted into the title compound **1b** (2.006 g, 74% yield) as a semisolid: $[\alpha]_D^{25}$ = +3.94 (c 1.03, $CHCl_3$); IR (KBr) ν 1683 (CO), 1334 ($NHSO_2$), 1136 ($NHSO_2$); ^{1}H NMR (500 MHz, $CDCl_3$) δ -0.208 (s, 3H), 0.092 (s, 3H), 0.865 (s, 9H), 0.977 (s, 3H), 1.16 (s, 3H), 1.33-1.47 (m, 2H), 1.84-1.98 (m, 3H), 2.05-2.17 (m, 2H), 3.43-3.53 (m, 2H), 3.93-3.96 (m, 1H), 4.98 (s, 1H), 7.00 (d, *J* = 14.5 Hz, 1H), 7.24 (d, *J* = 14.5 Hz, 1H), 7.30-7.32 (m, 3H), 7.41-7.42 (m, 2H); ^{13}C NMR (125 MHz, $CDCl_3$) δ -5.21, -4.83, 18.1, 19.9, 20.8, 25.6 (3C), 26.5, 32.8, 38.4, 44.7, 47.8, 48.7, 53.0, 65.0, 82.9, 89.8, 123.4, 127.5 (2C), 128.7, 129.1 (2C), 137.5, 145.2, 162.8; HRMS (ESI), *m*/*z* calcd for $C_{27}H_{39}Cl_2NNaO_4SSi$ $[M+Na]^+$ 594.1644, found 594.1638.



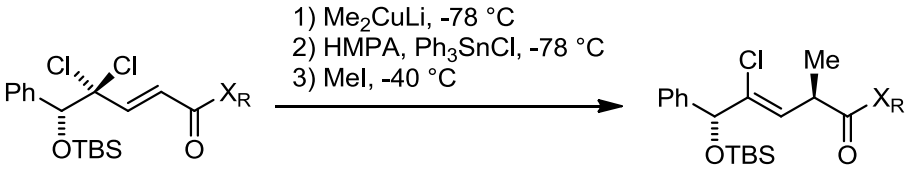
(5*R*,2*Z*)-Ethyl 5-[(*tert*-butyldimethylsilyl)oxy]-4,4-dichloro-5-phenylpent-2-enoate (2): By use of a procedure similar to that described for the preparation of (*R*)-sultam derivative **1a**, ester **S5** was converted into the title compound **2** (1.32 g, 93% yield) as a colorless oil: $[\alpha]_D^{25} = -73.5$ (c 1.05, $CHCl_3$); IR (KBr) ν 1718 (CO); ^{1}H NMR (500 MHz, $CDCl_3$) δ -0.207 (s, 3H), 0.105 (s, 3H), 0.884 (s, 9H), 1.30 (t, J = 7.0 Hz, 3H), 4.23 (q, J = 7.0 Hz, 2H), 4.98 (s, 1H), 6.24 (d, J = 15.0 Hz, 1H), 7.18 (d, J = 15.0, 1H), 7.31-7.32 (m, 3H), 7.32-7.39 (m, 2H); ^{13}C NMR (125 MHz, $CDCl_3$) δ -5.23, -4.78, 14.2, 18.1, 25.6 (3C), 60.9, 83.0, 89.9, 124.2, 127.5 (2C), 128.8, 129.0 (2C), 137.6, 144.2, 165.3; HRMS (ESI), *m*/*z* calcd for $C_{19}H_{28}Cl_2NaO_3Si$ $[M+Na]^+$425.1078, found 425.1077.

III. Experimental procedures of compounds 3, 4a-e, 5a-e, and 6a-d



1a **3**

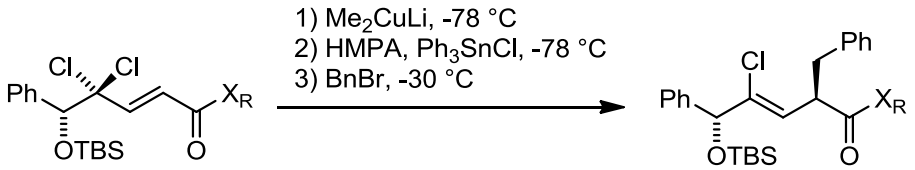
(5*R*,3*Z*)-5-[(*tert*-Butyldimethylsilyl)oxy]-4-chloro-5-phenylpent-3-enoyl-(*R*)-sultam (3): To a suspension of CuCN (35.9 mg, 0.401 mmol) in THF (2.0 mL) was added dropwise a solution of MeLi·LiBr complex in Et_2O (1.5 M, 0.64 mL, 0.960 mmol) at -78 ºC under argon, and the mixture was stirred at 0 ºC for 10 min. To the solution of the above organocuprate was added dropwise a solution of the *N*-enoyl sultam **1a** (57.2 mg, 0.100 mmol) in THF (1.0 mL) at -78 ºC. After stirred at -78 ºC for 30 min, the reaction was quenched by addition of a 3:2 saturated NH_4Cl-28% NH_3 aqueous solution with additional stirring at room temperature for 30 min. The mixture was extracted with Et_2O and the extract was washed with brine and dried over $MgSO_4$. Concentration under reduced pressure followed by flash chromatography over silica gel with *n*-hexane-EtOAc (19:1) gave the title compound (53.3 mg, 99% yield) as a white solid: $[\alpha]_D^{25}$ = -69.5 (*c* 0.630, $CHCl_3$); IR (KBr) ν 1700 (CO), 1333 ($NHSO_2$), 1135 ($NHSO_2$); ^{1}H NMR (500 MHz, $CDCl_3$) δ -0.019 (s, 3H), -0.097 (s, 3H), 0.902 (s, 9H), 0.971 (s, 3H), 1.16 (s, 3H), 1.31-1.45 (m , 2H), 1.84-1.96 (m, 3H), 2.11-2.18 (m, 2H), 3.43-3.52 (m, 2H), 3.66-3.75 (m, 2H), 3.87-3.89 (m, 1H), 5.25 (s, 1H), 6.26 (dd, *J* = 7.0, 1.0 Hz, 1H), 7.30-7.34 (m, 3H), 7.36-7.40 (m, 2H); ^{13}C NMR (125 MHz, $CDCl_3$) δ −5.07, −4.89, 18.3, 19.9, 20.8, 25.7 (3C), 26.4, 32.8, 35.0, 38.4, 44.6, 47.8, 48.6, 52.9, 65.3, 77.6, 117.3, 126.7 (2C), 127.7, 128.1 (2C), 139.9, 141.1, 168.6; HRMS (ESI), *m*/*z* calcd for $C_{27}H_{40}ClNNaO_4SSi$ $[M+Na]^+$ 560.2028, found 560.2026.



1a **4a**

(2*R*,5*R*,3*Z*)-5-[(*tert*-Butyldimethylsilyl)oxy]-4-chloro-2-methyl-5-phenylpent-3-enoyl-(*R*)-sultam (4a): To a suspension of CuI (114.7 mg, 0.60 mmol) in THF (4.0 mL) was added dropwise a solution of MeLi·LiBr complex in Et_2O (1.5 M, 0.960 mL, 1.44 mmol) at -78 ºC under argon, and the mixture was

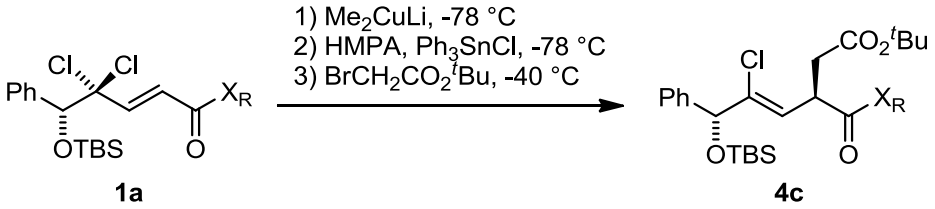
stirred at 0 ºC for 10 min. To the solution of the above organocuprate was added dropwise a solution of the *N*-enoyl sultam **1a** (85.9 mg, 0. 150 mmol) in THF (2.0 mL) at -78 ºC. The mixture was stirred at -78 ºC for 30 min and HMPA (417.6 μL, 2.40 mmol) was added dropwise to the mixture. After stirring at -78 ºC for 30 min, a solution of triphenyltin chloride (115.5 mg, 0.30 mmol) in THF (2.0 mL) was added dropwise, and the mixture was then stirred at -40 ºC for 30 min and methyl iodide (75.0 μL, 1.20 mmol) was added dropwise. The mixture was stirred at -40 ºC for 20 h. The reaction was quenched by addition of a 3:2 saturated NH_4Cl-28% NH_3 aqueous solution with additional stirring at room temperature for 30 min. The mixture was extracted with Et_2O and the extract was washed with brine and dried over $MgSO_4$. Concentration under reduced pressure followed by flash chromatography over silica gel with *n*-hexane-EtOAc (19:1) gave the title compound (47.8 mg, 58% yield) as a white solid; $[\alpha]_D^{25}$ = -78.6 (*c* 1.02, $CHCl_3$); IR (KBr) ν 1695 (CO), 1335 ($NHSO_2$), 1134.1 ($NHSO_2$); ^{1}H NMR (400 MHz, $CDCl_3$) δ -0.018 (s, 3H), -0.090 (s, 3H), 0.899 (s, 9H), 0.972 (s, 3H), 1.16 (s, 3H), 1.25-1.47 (m , 2H), 1.36 (d, *J* = 4.0 Hz, 3H), 1.88-1.92 (m, 3H), 2.06-2.07 (m, 2H), 3.42-3.51 (m, 2H), 3.89-3.91 (m, 1H), 4.19-4.31 (m, 1H), 5.20 (s, 1H), 6.29 (dd, *J* = 8.5, 1.0 Hz, 1H), 7.30-7.33 (m, 3H), 7.36-7.37 (m, 2H); ^{13}C NMR (125 MHz, $CDCl_3$) δ −5.08, −4.89, 18.3, 19.1, 19.9, 20.8, 25.7 (3C), 26.4, 32.8, 38.3, 40.1, 44.6, 47.8, 48.4, 53.0, 65.0, 77.6, 124.2, 126.7 (2C), 127.6, 128.0 (2C), 137.7, 141.1, 173.6; HRMS (ESI), *m*/*z* calcd for $C_{28}H_{42}ClNNaO_4SSi$ $[M+Na]^+$574.2185, found 574.2185.



1a **4b**

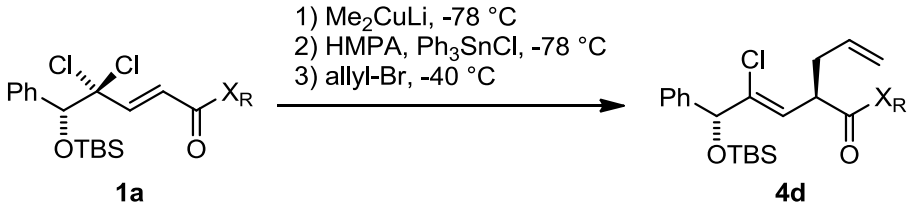
(2*R*,5*R*,3*Z*)-2-Benzyl-5-[(*tert*-butyldimethylsilyl)oxy]-4-chloro-5-phenylpent-3-enoyl-(*R*)-sultam (4b): By use of a procedure similar to that described for the preparation of (*R*)-methyl derivative **4a**, the

(*R*)-sultam derivative **1a** (86.3 mg, 0.151 mmol) was converted into the title compound **4b** (79.1 mg, 83% yield) as a semisolid: $[\alpha]_D^{25}$ = -58.9 (c 2.61, $CHCl_3$); IR (KBr) ν 1692 (CO), 1335 ($NHSO_2$), 1134 ($NHSO_2$); ^{1}H NMR (400 MHz, $CDCl_3$) δ −0.043 (s, 3H), 0.072 (s, 3H), 0.772 (s, 3H), 0.881 (s, 3H), 0.891 (s, 9H), 1.25-1.30 (m, 2H), 1.76-1.84 (m, 3H), 1.97-2.01 (m, 2H), 2.85-2.89 (m, 1H), 3.17-3.21 (m, 1H), 3.35-3.42 (m, 2H), 3.77 (br, 1H), 4.57 (br, 1H), 5.16 (s, 1H), 6.16 (d, J = 9.0 Hz, 1H), 7.21-7.31 (m, 10H); ^{13}C NMR (125 MHz, $CDCl_3$) δ−5.11, −4.88, 18.2, 19.8, 20.5, 25.8 (3C), 26.4, 32.7, 38.3, 39.8, 44.6, 47.2, 47.6, 48.2, 53.0, 64.9, 77.5, 122.8, 126.7, 126.7 (2C), 127.5, 128.0 (2C), 128.3 (2C), 129.5 (2C), 137.3, 139.0, 141.0, 172.4; HRMS (ESI), *m*/*z* calcd for $C_{34}H_{46}ClNNaO_4SSi$ $[M+Na]^+$ 650.2498, found 650.2498.

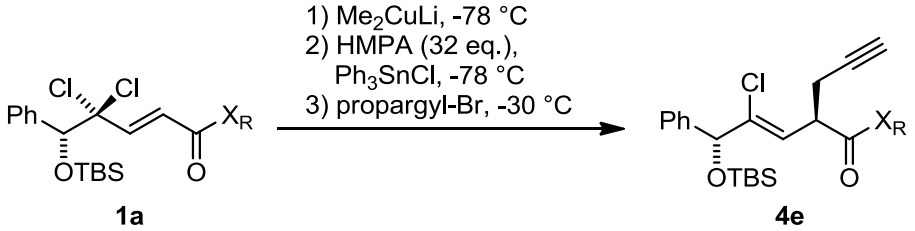


(2*R*,5*R*,3*Z*)-2-(2-*tert*-Butoxy-2-oxoethyl)-5-[(*tert*-butyldimethylsilyl)oxy]-4-chloro-5-phenylpent-3-enoyl-(*R*)-sultam (4c): By use of a procedure similar to that described for the preparation of (*R*)-methyl derivative **4a**, the (*R*)-sultam derivative **1a** (86.0 mg, 0.150 mmol) was converted into the title compound **4c** (88.3 mg, 90% yield) as pale yellow crystals: $[\alpha]_D^{25}$ = −64.8 (c 1.00, $CHCl_3$); IR (KBr) ν 1728 (CO), 1692 (CO), 1337 ($NHSO_2$) 1136 ($NHSO_2$); ^{1}H NMR (400 MHz, $CDCl_3$) δ 0.031 (s, 3H), 0.110 (s, 3H), 0.922 (s, 9H), 0.994 (s, 3H), 1.24 (s, 3H), 1.29-1.38 (m, 2H), 1.44 (s, 9H), 1.87-1.92 (m, 3H), 2.04-2.20 (m, 2H), 2.61-2.66 (dd, J = 5.6, 16 Hz, 1H), 2.83-2.89 (dd, J = 16, 8.0 Hz, 1H), 3.42-3.52 (m, 2H), 3.98-4.01 (m, 1H), 4.38 (m, 1H), 5.22 (s, 1H), 6.15-6.19 (dd, J = 8.8, 0.4 Hz, 1H), 7.29-7.40 (m, 5H); ^{13}C NMR (125 MHz, $CDCl_3$) δ−5.08, −4.90, 18.2, 19.9, 20.6, 25.7 (3C), 26.5, 28.0 (3C), 32.7, 38.0, 38.3, 41.9, 44.7, 47.8, 48.5 52.9, 64.9, 77.5, 81.2, 121.8, 126.8 (2C), 127.7, 128.1 (2C),

139.5, 140.9, 169.8, 171.8; HRMS (ESI), *m*/*z* calcd for $C_{33}H_{50}ClNNaO_6SSi$ $[M+Na]^+$ 674.2709, found 674.2694.

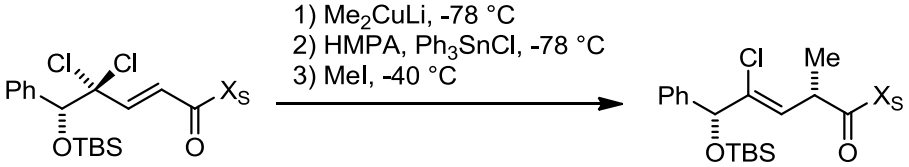


(2*R*,5*R*,3*Z*)-2-Allyl-5-[(*tert*-butyldimethylsilyl)oxy]-4-chloro-5-phenylpent-3-enoyl-(*R*)-sultam (4d): By use of a procedure similar to that described for the preparation of (*R*)-methyl derivative **4a**, the (*R*)-sultam derivative **1a** (86.3 mg, 0.151 mmol) was converted into the title compound **4d** (70.6 mg, 81% yield) as a semisolid: $[\alpha]^{25}_D$ = −57.7 (c 2.59, $CHCl_3$); IR (ATR) ν 1695 (CO), 1337 ($NHSO_2$) 1134 ($NHSO_2$); ^{1}H NMR (500 MHz, $CDCl_3$) δ −0.026 (s, 3H), 0.088 (s, 3H), 0.896 (s, 9H), 0.966 (s, 3H), 1.17 (s, 3H), 1.30-1.44 (m, 2H), 1.83-1.95 (m, 3H), 1.99-2.10 (m, 2H), 2.43-2.51 (m, 1H), 2.55-2.63 (m, 1H), 3.40-3.51 (m, 2H), 3.87-3.93 (m, 1H), 4.28-4.36 (m, 1H), 5.00-5.05 (m, 1H), 5.06-5.11 (m, 1H), 5.21 (s, 1H), 5.73-5.81 (m, 1H), 6.33 (dd, *J* = 8.5, 0.5 Hz, 1H); ^{13}C NMR (125 MHz, $CDCl_3$) δ −5.09, −4.89, 18.3, 19.9, 20.8, 25.7 (3C), 26.4, 32.8, 38.2, 38.4, 44.6, 44.8, 47.7, 48.3, 53.1, 65.1, 77.6, 118.0, 122.5, 126.8 (2C), 127.6, 128.0 (2C), 133.9, 138.6, 141.1, 172.3; HRMS (ESI), *m*/*z* calcd for $C_{30}H_{44}ClNNaO_4SSi$ $[M+Na]^+$ 600.2341, found 600.2348.



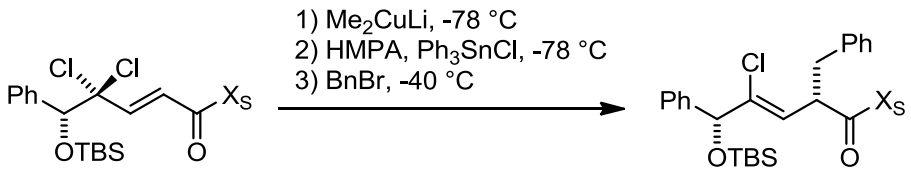
(2*R*,5*R*,3*Z*)-5-[(*tert*-Butyldimethylsilyl)oxy]-4-chloro-5-phenyl-2-(prop-2-yn-1-yl)pent-3-enoyl-(*R*)-sultam (4e): By use of a procedure similar to that described for the preparation of (*R*)-methyl derivative

4a, the (*R*)-sultam derivative **1a** (100.0 mg, 0.175 mmol) was converted into the title compound **4e** (82.8 mg, 82% yield) as a brown oil: $[\alpha]_D^{25}$ = −57.3 (c 1.00, $CHCl_3$); IR (ATR) ν 3310 (HC≡C), 1697 (CO), 1336 ($NHSO_2$), 1135 ($NHSO_2$) ; ^{1}H NMR (400 MHz, $CDCl_3$) δ 0.018 (s, 3H), 0.112 (s, 3H), 0.913 (s, 9H), 0.974 (s, 3H), 1.20 (s, 3H), 1.23-1.47 (m, 2H), 1.83-1.97 (m, 3H), 1.98-2.02 (m, 1H), 2.05-2.18 (m, 2H), 2.67 (ddd, *J* = 16.8, 6.4, 2.8 Hz, 1H), 2.79 (ddd, *J* = 16.8, 5.2, 2.8 Hz, 1H), 3.42-3.52 (m, 2H), 3.91-3.95 (m, 1H), 4.34-4.39 (m, 1H), 5.26 (s, 1H), 6.36 (dd, *J* = 0.8, 8.8 Hz, 1H), 7.23-7.41 (m, 5H); ^{13}C NMR (125 MHz, $CDCl_3$) δ −5.10, −4.91, 18.3, 19.9, 20.7, 23.0, 25.7 (3C), 26.5, 32.7, 38.3, 43.8, 44.6, 47.8, 48.5, 53.0, 65.1, 71.2, 77.5, 79.5, 121.4, 126.8 (2C), 127.7, 128.1 (2C), 139.3, 140.9, 170.9; HRMS (ESI), *m*/*z* calcd for $C_{30}H_{42}ClNNaO_4SSi$ $[M+Na]^+$ 598.2185, found 598.2180.



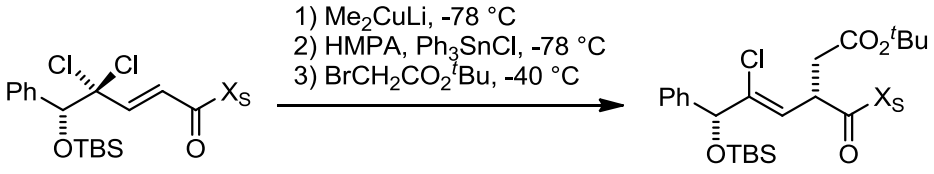
1b **5a**

(2*S*,5*R*,3*Z*)-5-(*tert*-Butyldimethylsilyl)oxy-4-chloro-2-methyl-5-phenylpent-3-enoyl-(*S*)-sultam (5a): By use of a procedure similar to that described for the preparation of (*R*)-methyl derivative **4a**, the (*R*)-sultam derivative **1b** (85.8 mg, 0.150 mmol) was converted into the title compound **5a** (49.6 mg, 60% yield) as a white solid: $[\alpha]^{25}_D$ = +72.8 (c 0.87, $CHCl_3$); IR (KBr) ν 1694 (CO), 1335 ($NHSO_2$), 1134 ($NHSO_2$); ^{1}H NMR (500 MHz, $CDCl_3$) δ 0.026 (s, 3H), 0.028 (s, 3H), 0.940 (s, 9H), 1.00 (s, 3H), 1.19 (s, 3H), 1.40 (d, *J* = 7.0 Hz, 3H), 1.28-1.58 (m, 2H), 1.90-1.93 (m, 3H), 2.09-2.11 (m, 2H), 3.50 (m, 2H), 3.92-3.94 (m, 1H), 4.24-4.27 (m, 1H), 5.26 (s, 1H), 6.33-6.35 (d, *J* = 6.4 Hz, 1H), 7.29-7.35 (m, 3H), 7.38-7.40 (m, 2H); ^{13}C NMR (125 MHz, $CDCl_3$) δ −5.07, −4.76, 18.3, 19.0, 19.9, 20.8, 25.7 (3C), 26.4, 32.8, 38.3, 40.1, 44.6, 47.8, 48.4, 53.0, 65.0, 77.6, 124.2, 126.6 (2C), 127.6, 128.0 (2C), 137.7, 141.1, 173.6; HRMS (ESI), *m*/*z* calcd for $C_{28}H_{42}ClNNaO_4SSi$ $[M+Na]^+$ 574.2185, found 574.2179.



1b **5b**

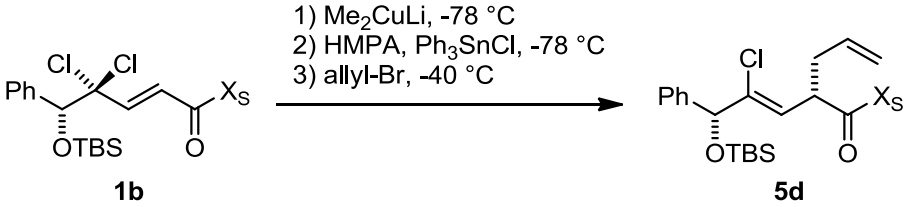
(2*S*,5*R*,3*Z*)-2-Benzyl-5-[(*tert*-butyldimethylsilyl)oxy]-4-chloro-5-phenylpent-3-enoyl-(*S*)-sultam (5b): By use of a procedure similar to that described for the preparation of (*R*)-methyl derivative **4a**, the (*S*)-sultam derivative **1b** (88.9 mg, 0.156 mmol) was converted into the title compound **5b** (83.6 mg, 86% yield) as a pale yellow oil: $[\alpha]_D^{25}$ = +48.6 (*c* 2.79, $CHCl_3$); IR (KBr) ν 1694 (CO), 1337 ($NHSO_2$), 1134 ($NHSO_2$); ^{1}H NMR (500 MHz, $CDCl_3$) δ -0.028 (s, 3H), 0.054 (s, 3H), 0.714 (s, 3H), 0.880 (s, 3H), 0.892 (s, 9H), 1.25-1.33 (m, 2H), 1.75-1.88 (m, 4H), 1.96-2.00 (m, 1H), 2.86-2.90 (m, 1H), 3.14-3.18 (m, 1H), 3.34-3.41 (m, 2H), 3.77 (s, 1H), 4.57-4.58 (m, 1H), 5.17 (s, 1H), 6.19 (d, *J* = 8.5 Hz, 1H), 7.15-7.28 (m, 10H); ^{13}C NMR (125 MHz, $CHCl_3$) δ −5.13, −4.78, 18.2, 19.8, 20.5, 25.8 (3C), 26.4, 32.8, 38.3, 39.7, 44.6, 47.2, 47.6, 48.2, 53.0, 64.9, 77.5, 122.7, 126.7 (2C), 126.7, 127.5, 128.0 (2C), 128.3 (2C), 129.5 (2C), 137.2, 138.8, 141.0, 172.4; HRMS (ESI), *m*/*z* calcd for $C_{34}H_{46}ClNNaO_4SSi$ $[M+Na]^+$ 650.2498, found 650.2506.



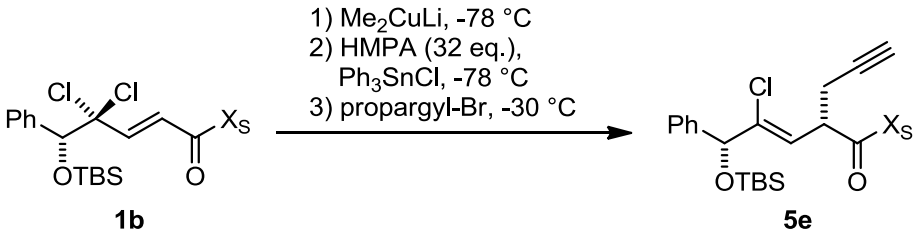
1b **5c**

(2*S*,5*R*,3*Z*)-5-(*tert*-Butyldimethylsilyl)oxy-4-chloro-2-(2-*tert*-buthoxy-2-oxoethyl)-5-phenylpent-3-enoyl-(*S*)-sultam (5c): By use of a procedure similar to that described for the preparation of (*R*)-methyl derivative **4a**, the (*R*)-sultam derivative **1b** (57.2 mg, 0.100 mmol) was converted into the title compound **5c** (37.2 mg, 57% yield) as a white solid: $[\alpha]_D$ = +38.1 (c 1.20, $CHCl_3$); IR (KBr) ν 1728

(CO), 1692 (CO), 1335 ($NHSO_2$) 1134 ($NHSO_2$); ^{1}H NMR (500 MHz, $CDCl_3$) δ −0.007 (s, 3H), 0.088 (s, 3H), 0.894 (s, 9H), 0.964 (s, 3H), 1.22 (s, 3H), 1.29-1.46 (m, 2H), 1.40 (s, 9H), 1.80-1.95 (m, 3H), 2.00-2.08 (m, 1H), 2.09-2.18 (m, 1H), 2.60-2.68 (m, 1H), 2.77-2.87 (m, 1H), 3.38-3.51 (m, 2H), 3.90-3.99 (m, 1H), 4.35 (br, 1H), 5.21 (s, 1H), 6.18 (d, J = 8.5 Hz, 1H), 7.23-7.38 (m, 5H); ^{13}C NMR (125 MHz, $CDCl_3$) δ −5.12, −4.74, 18.2, 19.9, 20.6, 25.7 (3C), 26.5, 28.0 (3C), 32.8, 37.9, 38.1, 41.9, 44.7, 47.8, 48.6, 52.9, 65.0, 77.5, 81.2, 121.8, 126.6 (2C), 127.6, 128.0 (2C), 139.4, 140.9, 169.9, 171.7; HRMS (ESI), m/z calcd for $C_{33}H_{50}ClNNaO_6SSi$ $[M+Na]^+$ 674.2709, found 674.2680.

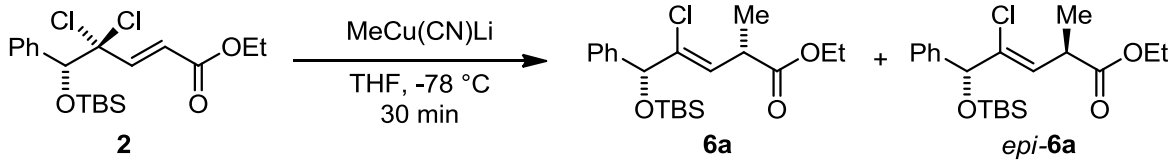


(2*S*,5*R*,3*Z*)-2-Allyl-5-[(*tert*-butyldimethylsilyl)oxy]-4-chloro-5-phenylpent-3-enoyl-(*S*)-sultam (5d): By use of a procedure similar to that described for the preparation of (*R*)-methyl derivative **4a**, the (*R*)-sultam derivative **1a** (85.8 mg, 0.150 mmol) was converted into the title compound **5d** (61.0 mg, 70% yield) as a pale yellow oil: $[\alpha]_D^{25}$ = +35.8 (c 1.05, $CHCl_3$); IR (ATR) ν 1695 (CO), 1337 ($NHSO_2$) 1135 ($NHSO_2$); ^{1}H NMR (500 MHz, $CDCl_3$) δ -0.029 (s, 3H), 0.071 (s, 3H), 0.881 (s, 9H), 0.994 (s, 3H), 1.15 (s, 3H), 1.22-1.42 (m, 2H), 1.79-1.92 (m, 3H), 1.96-2.16 (m, 2H), 2.42-2.50 (m, 1H), 2.54-2.62 (m, 1H), 3.40-3.49 (m, 2H), 3.87-3.89 (m, 1H), 4.28-4.34 (m, 1H), 4.99-5.08 (m, 2H), 5.19 (s, 1H), 5.69-5.79 (m, 1H), 6.22 (dd, J = 9.0, 1.0 Hz, 1H), 7.21-7.38 (m, 5H); ^{13}C NMR (125 MHz, $CDCl_3$) δ −5.07, −4.76, 18.3, 19.9, 20.8, 25.7 (3C), 26.4, 32.8, 38.1, 38.4, 44.6, 44.8, 47.7, 48.3, 53.1, 65.2, 77.6, 118.0, 122.6, 126.7 (2C), 127.6, 128.0 (2C), 133.6, 138.6, 141.1, 172.3; HRMS (ESI), m/z calcd for $C_{30}H_{44}ClNNaO_4SSi$ $[M+Na]^+$ 600.2341, found 600.2333.



1b **5e**

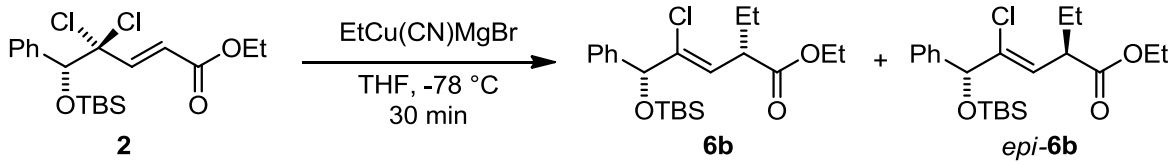
(2*S*,5*R*,3*Z*)-5-[(*tert*-Buthyldimethylsilyl)oxy]-4-chloro-5-phenyl-2-(prop-2-yn-1-yl)pent-3-enoyl-(*S*)-sultam (5e): By use of a procedure similar to that described for the preparation of (*R*)-methyl derivative **4a**, the (*R*)-sultam derivative **1b** (71.4 mg, 0.125 mmol) was converted into the title compound **5e** (33.0 mg, 46% yield) as a brawn oil: $[\alpha]_D$ = +40.3 (c 1.10, $CHCl_3$); IR (KBr) ν 3300 (CCH), 1701 (CO), 1327 ($NHSO_2$); ^{1}H NMR (500 MHz, $CDCl_3$) δ 0.041 (s, 3H), 0.134 (s, 3H), 0.929 (s, 9H), 0.935 (s, 3H), 0.999 (s, 3H), 1.22-1.39 (m,3H), 1.40-1.47 (m, 1H), 1.91-1.93 (m, 3H), 2.02-2.03 (m, 1H), 2.12-2.14 (m, 2H), 2.67-2.84 (m, 2H), 3.45-3.55 (m, 2H), 3.94-3.97 (m, 1H), 4.37-4.41 (m, 1H), 5.28 (s, 1H), 6.38 (dd, *J* = 9.0, 0.5, Hz, 1H), 7.23-7.47 (m, 5H); ^{13}C NMR (125 MHz, $CDCl_3$) δ −5.10, −4.78, 18.3, 19.9, 20.7, 22.9, 25.7 (3C), 26.5, 32.7, 38.3, 43.8, 44.6, 47.8, 48.5, 53.0, 65.1, 71.3, 77.5, 79.5, 121.7, 126.6 (2C), 127.6, 128.0 (2C), 139.6, 140.9, 170.9; HRMS (ESI), *m*/*z* calcd for $C_{30}H_{42}ClNNaO_4SSi$ $[M+Na]^+$ 598.2185, found 598.2181.



2 **6a** *epi*-**6a**

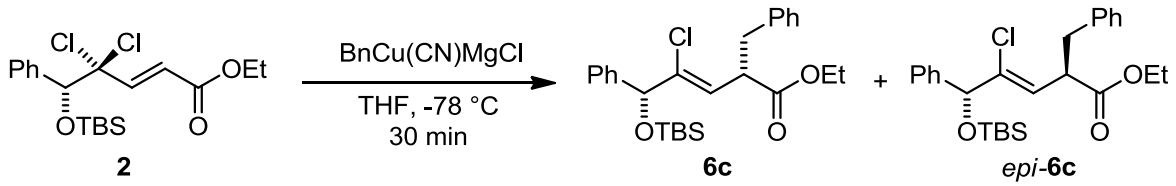
(5*R*,3*Z*)-Ethyl 5-[(*tert*-butyldimethylsilyl)oxy]-4-chloro-2-methyl-5-phenylpent-3-enoate (6a): To a suspension of CuCN (71.6 mg, 0.80 mmol) and LiCl (67.8 mg, 1.60 mmol) in THF (1.00 mL) was added a solution of MeLi·LiBr in Et_2O (1.14 M, 0.702 mL, 0.800 mmol) at -78 ºC under argon, and the mixture was stirred at 0 ºC for 10 min. To the solution of organocuprate was added dropwise a solution of ester **2** (82.0 mg, 0.20 mmol) in THF (1.0 mL) at -78 ºC. The mixture was stirred at -78 ºC for 30 min

and quenched by addition of NH_4Cl-28% NH_3 aqueous solution with additional stirring at room temperature for 30 min. The mixture was extracted with EtOAc and the extract was washed with brine and dried over $MgSO_4$. Concentration under reduced pressure followed by flash chromatography over silica gel with *n*-hexane-EtOAc (19:1) gave the title compound **6a** (74.9 mg, 98% yield) as a colorless oil: IR (KBr) ν 1736 (CO); ^{1}H NMR (400 MHz, $CDCl_3$, mixture of diastereomers) δ 0.009 (s, 3H), 0.102 (s, 3H), 0.893-0.934 (m, 9H), 1.26 (t, J = 7.0 Hz, 3H), 1.29 (d, J = 7.0 Hz, 3H), 3.56-3.65 (m, 1H), 4.11-4.19 (m, 2H), 5.22 (s, 1H), 6.10-6.20 (m, 2H), 7.24-7.39 (m, 5H); ^{13}C NMR (125 MHz, $CDCl_3$, mixture of diastereomers, [minor isomer]) δ −5.05 [−5.07], −4.89 [−4.92], 14.2, 17.1 [17.1], 18.3, 25.7 (3C), 39.2, 60.8 [60.8], 77.5, 124.8 [125.1], 126.6 [126.6] (2C) , 127.7, 128.1 (2C), 137.8 [137.9], 141.1 [141.1], 174.0 [173.9]; HRMS (ESI), *m*/*z* calcd for $C_{20}H_{31}ClNaO_3Si$ $[M+Na]^+$ 405.1623, found 405.1623.



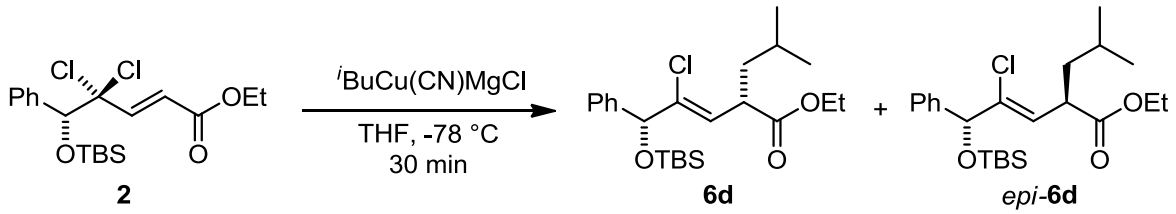
(*Z*)-Ethyl 5-[(*tert*-butyldimethylsilyl)oxy]-4-chloro-2-ethyl-5-phenylpent-3-enoate (6b): By use of a procedure similar to that described for the preparation of compound **6a**, ester **2** (82.0 mg, 0.20 mmol) was converted into the title compound **6b** (76.1 mg, 96% yield) as a colorless oil: IR (KBr) ν 1737 (CO) cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$, mixture of diastereomers) δ −0.004-0.020 (m, 3H), 0.091-0.119 (m, 3H), 0.867-0.955 (m, 3H), 0.922 (s, 9H), 1.24-1.30 (m, 3H), 1.62-1.71 (m, 1H), 1.79-1.90 (m, 1H), 3.44-3.52 (m, 1H), 4.12-4.21 (m, 2H), 5.21-5.26 (m, 1H), 6.08-6.18 (m, 1H), 7.27-7.40 (m, 5H); ^{13}C NMR (125 MHz, $CDCl_3$, mixture of diastereomers, [minor isomer]) δ −5.05, −4.94, 11.4, 14.2 [14.2], 18.3, 25.7 [25.7] (3C), 46.2 [46.3], 60.7, 77.6, 123.5 [123.8], 126.6 [126.6] (2C), 127.7, 128.1 (2C), 138.5,

[138.7], 141.2 [141.2], 173.3, [173.4]; HRMS (ESI), *m/z* calcd for $C_{21}H_{33}ClNaO_3Si$ $[M+Na]^+$ 419.1780, found 419.1774.



2 **6c** *epi*-**6c**

(5*R*,3*Z*)-Ethyl 2-benzyl-5-[(*tert*-butyldimethylsilyl)oxy]-4-chloro-5-phenylpent-3-enoate (6c): By use of a procedure similar to that described for the preparation of compound **6a**, ester **2** (82.0 mg, 0.20 mmol) was converted into the title compound **6c** (64.1 mg, 70% yield) as a colorless oil: IR (KBr) ν 1732 (CO); ^{1}H NMR (500 MHz, $CDCl_3$, mixture of diastereomers) δ −0.071-−0.022 (m, 3H), 0.023-0.065 (m, 2H), 0.863-0.923 (m, 9H), 1.14-1.21 (m, 3H), 2.88-2.97 (m, 1H), 3.07-3.18 (m, 1H), 3.81-3.92 (m, 1H), 4.05-4.15 (m, 2H), 5.10-5.19 (m, 1H), 6.02-6.17 (m, 1H), 7.13-7.32 (m, 10H); ^{13}C NMR (125 MHz, $CDCl_3$, mixture of diastereomers, [minor isomer]) δ −5.09, −4.97, 14.1, 18.2, 25.7 (3C), 38.2 [38.1], 46.6, [46.5], 60.8, [60.9], 77.5, 122.8 [123.4], 126.5 [126.5], 126.7 (2C), 127.7, 128.0 [128.0], 128.3 [128.4], 129.1, 138.0, 138.9 [139.3], 141.0 [140.9], 172.7 [172.6]; HRMS (ESI), *m/z* calcd for $C_{26}H_{35}ClNaO_3Si$ $[M+H]^+$481.1937, found 481.1936.



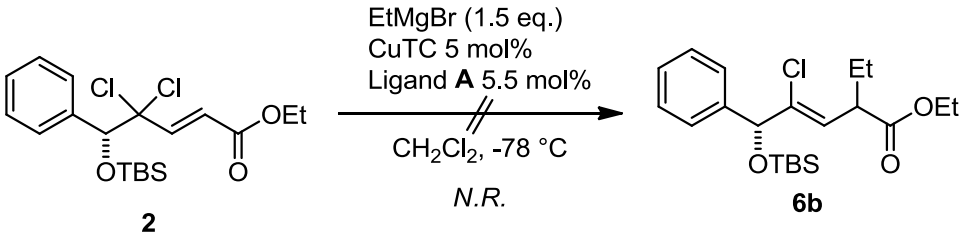
2 **6d** *epi*-**6d**

(5*R*,3*Z*)-Ethyl 5-[(*tert*-butyldimethylsilyl)oxy]-4-chloro-2-isobutyl-5-phenylpent-3-enoate (6d): By use of a procedure similar to that described for the preparation of compound **6a**, ester **2** (82.0 mg, 0.20 mmol) was converted into the title compound **6d** (80.3 mg, 95% yield) as a colorless oil: IR (ATR) ν 1737 (CO) cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$, mixture of diastereomers) δ 0.000-0.002 (m, 3H), 0.089-0.095 (m, 3H), 0.878-0.950 (m, 6 H), 0.912 (s, 9H), 1.23-1.27 (m, 3H), 1.49-1.53 (m, 1H), 1.58-1.61 (m, 1H), 1.68-1.72 (m, 1H), 3.58-3.65 (m, 1H), 4.10-4.18 (m, 2H), 5.19-5.23 (m, 1H), 6.03-6.10 (m, 1H), 6.06-6.11 (m, 0.6 H), 7.24-7.38 (m, 5H);^{13}C NMR (125 MHz, $CDCl_3$, mixture of diastereomers, [minor

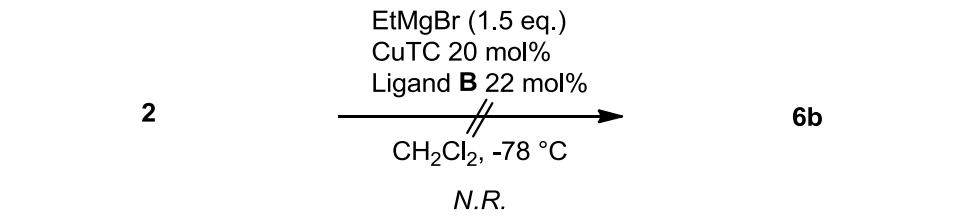
isomer]) δ −5.04, −4.96, 14.2, 18.3, 22.3 [22.3], 22.6 [22.6], 25.7 (3C), 25.9 [25.9], 41.3 [41.4], 43.3, 60.7, 77.6 [77.6], 124.1 [124.4], 126.5 [126.6] (2C), 127.7, 128.1 (2C), 138.2 [138.4], 141.1 [141.2], 173.6 [173.6]; HRMS (ESI), *m*/*z* calcd for $C_{23}H_{37}ClKNO_3Si$ $[M+K]^+$ 463.1832, found 463.1827.

IV. Copper-catalyzed S_N2'-type allylic alkylation

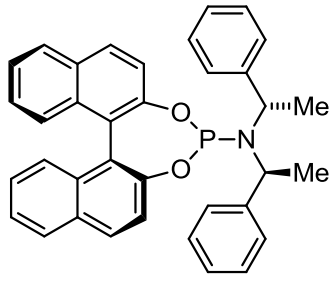
According to Feringa's report[S3], we attempted Cu-catalyzed S_N2'-type allylic alkylation with the enoate **2**. However, the reaction with EtMgBr in the presence of a catalytic amount of CuTC and phosphoroamidite ligands [**A** (SSS) and **B** (SRR)] provided none of α-alkylated products with recovering the starting material. Unfortunately, a similar result was obtained even with increasing the catalyst loading from 5 to 20 mol%, possibly due to the lower reactivity of internal allylic system and/or the steric hindrance to prevent the interaction of copper complex with a Cl group.



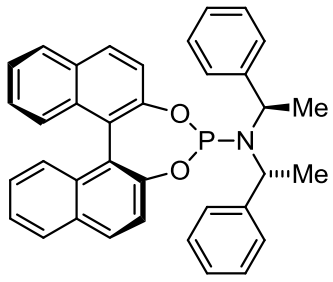
2 **6b**



2 **6b**



Ligand **A** (*S,S,S*)



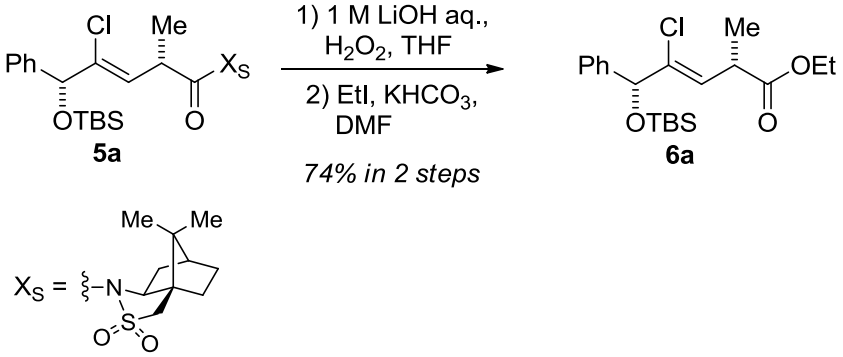
Ligand **B** (*S,R,R*)

[S3] Giannerini, M.; Fañanás-Mastral, M.; Feringa, B. L. *J. Am. Chem. Soc.* **2012**, *134*, 4108.

V. Structural determination of the major isomer of allylic alkylation of enoate 2

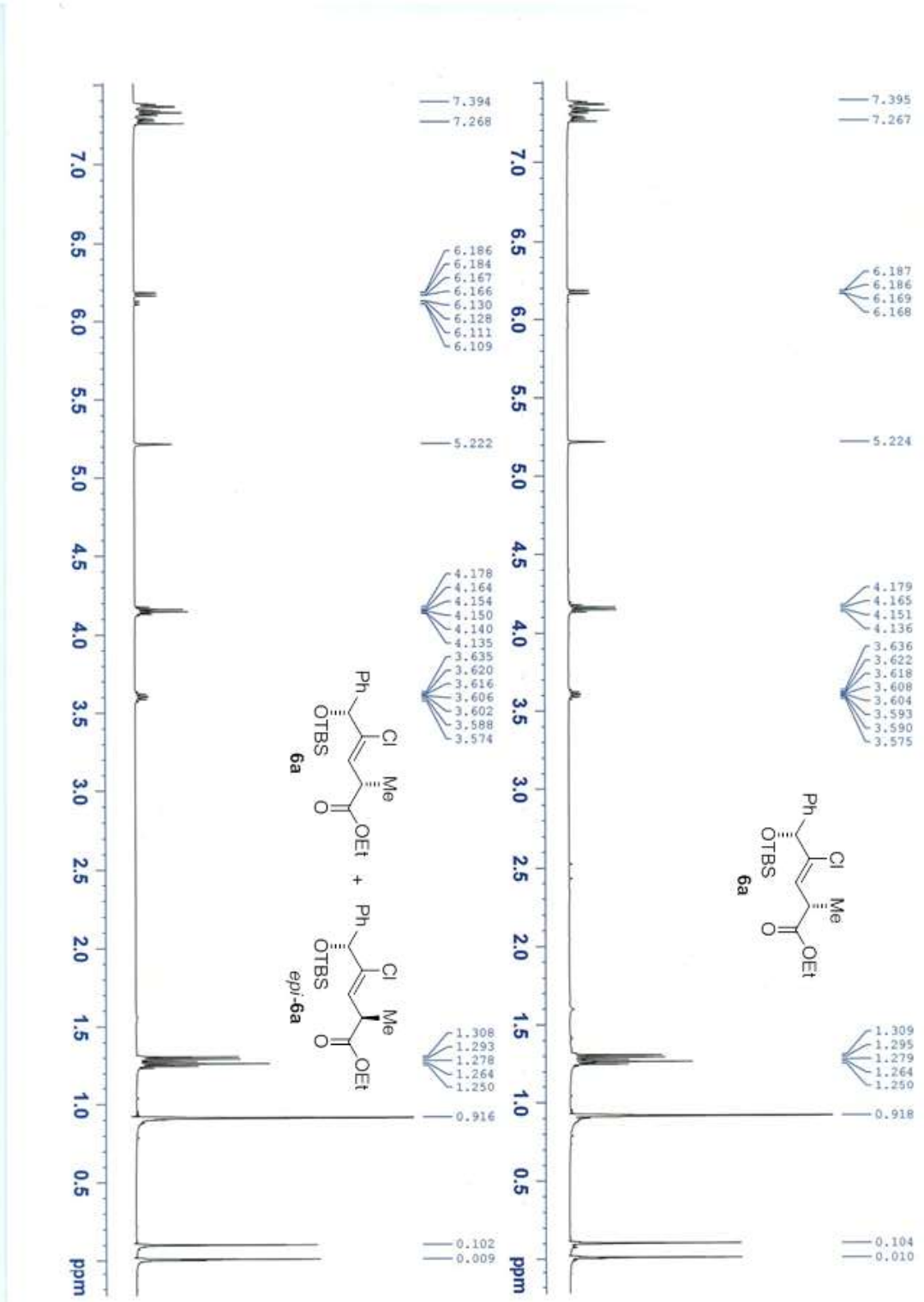
V-I. Preparation of an authentic sample 6a

The preference of the stereochemical outcome of allylic alkylaiton in Table 3 was assigned by the chemical correlation with an authentic sample **6a**, prepared from (*S*)-sultam-derived **5a**. Hydrolysis of **5a** under basic conditions followed by *O*-alkylation with EtI and $KHCO_3$ provided the corresponding (2*S*)-ester **6a**. Others were determined by the retention time of HPLC.

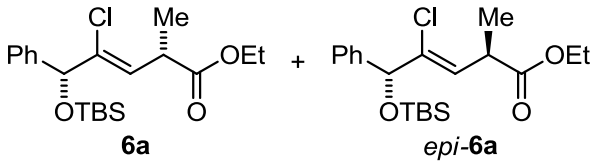


(2*S*,5*R*,3*Z*)-Ethyl 5-[(*tert*-butyldimethylsilyl)oxy]-4-chloro-2-methyl-5-phenylpent-3-enoate (6a): To a solution of the sultam **5a** (55.0 mg, 0.100 mmol) in THF–H_2O (5:1, 3 mL) was added dropwise 30% H_2O_2 aq. (34.0 μL, 0.300 mmol) and 1 M LiOH aq. (0.300 mL, 0.300 mmol) at 0 °C. After being stirred at 0 °C for 1.5 hour and at room temperature for 30 min, the reaction mixture was diluted with Et_2O and washed with saturated NH_4Cl aq. After dried over $MgSO_4$, concentration under reduced pressure gave an oily carboxylic acid, which was used in the next step without further purification. To a solution of the above carboxylic acid in DMF (3.0 mL) was added $KHCO_3$ (50.1 mg, 0.500 mmol) at 0 °C. After being stirred for 10 min, ethyl iodide (39.5 μL, 0.500 mmol) was added dropwise. The mixture was stirred at room temperature for 1 h. After being diluted with Et_2O, the reaction mixture was washed with saturated NH_4Cl aq. and brine, and dried over $MgSO_4$. Concentration under reduced pressure followed by flash chromatography over silica gel with *n*-hexane-AcOEt (20:1) gave the title compound **6a** (28.5 mg, 74% yield): $[\alpha]_D^{25}$ = +15.8 (*c* 1.43, $CHCl_3$); IR (ATR): 1735.6 (CO); ^{1}H NMR (500 MHz, $CDCl_3$) δ 0.010 (s, 3H), 0.104 (s, 3H), 0.918 (s, 9H), 1.26 (t, *J* = 7.0 Hz, 3H), 1.30 (d, *J* = 7.0 Hz, 3H), 3.61 (dq, *J* = 9.0, 7.0 Hz, 1H), 4.16 (d, *J* = 7.0 Hz, 2H), 5.22 (s, 1H), 6.18 (dd, *J* = 9.0, 0.5 Hz, 1H), 7.26-7.40 (m, 5H); ^{13}C NMR (125 MHz, $CDCl_3$) δ -5.05, -4.88, 14.2, 17.1, 18.3, 25.7 (3C), 39.2, 60.8, 77.5, 124.8, 126.6 (2C), 127.7, 128.1 (2C), 137.8, 141.1, 174.0; HRMS (FAB), *m/z* calcd for $C_{20}H_{31}ClNaO_3Si$ ($M+Na^+$) 405.1623, found 405.1622.

V-II. Comparison of NMR charts of compound <u>6a</u>



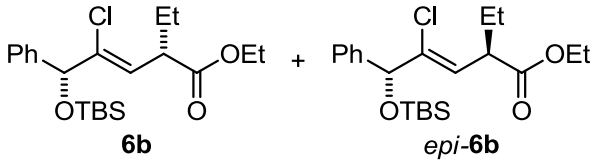
V-III. HPLC charts of compounds 6a-6d



6a *epi*-**6a**

HPLC conditions: Cosmosil Cholester Packed column (4.6 x 250 mm) with 75%MeCN in H_2O at a flow rate 1.0 mL/min, detection at 220 nm.

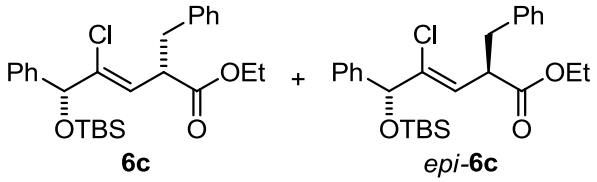
Retention time: t_r **6a** (2*S*,5*R*) = 33.8 min, t_r *epi*-**6a** (2*R*,5*R*) = 35.4 min



6b *epi*-**6b**

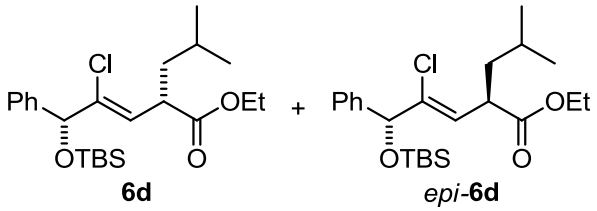
HPLC conditions: Cosmosil Cholester Packed column (4.6 x 250 mm) with 75%MeCN in H_2O at a flow rate 1.0 mL/min, detection at 220 nm.

Retention time: t_r **6b** (2*S*,5*R*) = 43.3 min, t_r *epi*-**6b** (2*R*,5*R*) = 45.4 min



HPLC conditions: Cosmosil Cholester Packed column (4.6 x 250 mm) with 78%MeCN in H_2O at a flow rate 1.0 mL/min, detection at 230 nm.

Retention time: t_r **6c** (2*S*,5*R*) = 42.1 min, t_r *epi*-**6c** (2*R*,5*R*) = 44.0 min



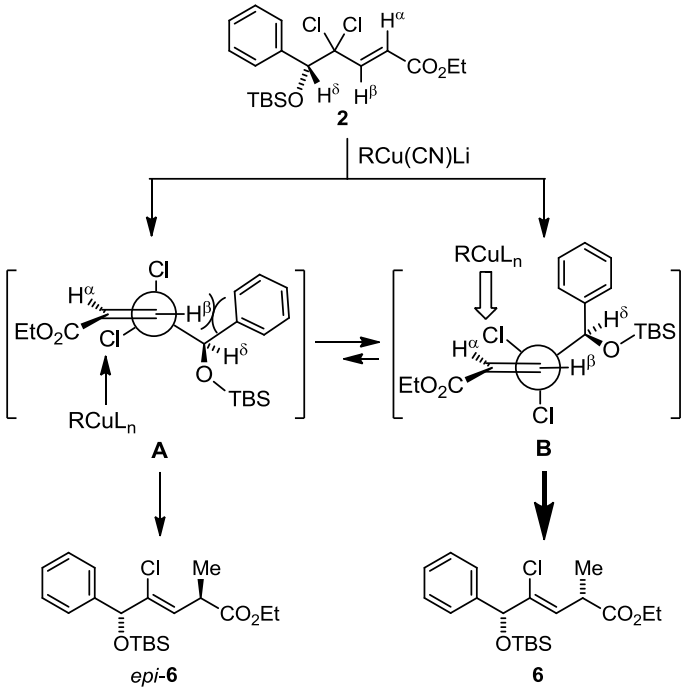
HPLC conditions: Cosmosil Cholester Packed column (4.6 x 250 mm) with 78%MeCN in H_2O at a flow rate 1.0 mL/min, detection at 230 nm.

Retention time: t_r **6d** (2*S*,5*R*) = 53.6 min, t_r *epi*-**6d** (2*R*,5*R*) = 55.4 min

V-IV. DFT calculation of reactive conformers of allylic alkylation of 2

Although the observed diastereoselectivity was not rationalized at the present stage, a possible pathway to the preferable formation of (2*S*)-isomer over (2*R*)-isomer is depicted in Figure S1. It has been well documented that the stereochemical outcome of organocopper-mediated allylic alkylation depends on the nature of the leaving group.[S4] The reaction with allylic halides usually takes place with *anti*-stereochemistry with respect to the leaving group.[S5] Taking account of these reports, two reactive conformers **A** and **B** can be considered to afford the allylic alkylation products. Conformer **A**, which would lead to the (2*R*)-isomer, may be destabilized in comparison with conformer **B** possibly due to the steric interactions between the olefinic proton (H^{β}) and the Ph group at δ-position. In fact, DFT calculations of methyl enoate suggested that the conformer **B** is favored by 4.42 kJ/mol over the conformer **A**. Accordingly, conformer **B** is more likely reacted with organocuprates to lead to the preferential formation of (2*S*)-isomer **6**.

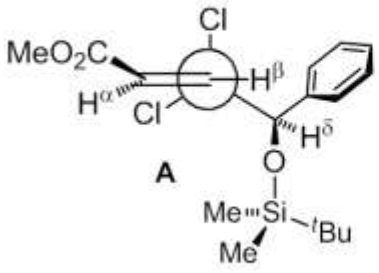
Figure S1. Possible Pathway to the Preferable Formation of **6**.



[S4] (a) Magid, R. M. *Tetrahedron* **1980**, *36*, 1901. (b) Marshall, J. A. *Chem. Rev.* **1989**, *89*, 1503. (c) Lipshutz, B. H. *Synlett*, **1990**, 119. (d) Lipshutz, B. H.; Sengupta, S. *Org. React.* **1992**, *41*, 135.

[S5] (a) Nakamura, E.; Sekiya, K.; Arai, M.; Aoki, S. *J. Am. Chem. Soc.* **1989**, *111*, 3091. (b) Arai, M.; Nakamura, E.; Lipshuz, B. H. *J. Org. Chem.* **1991**, *56*, 5489.

The optimized geometries calculated by AM1 Semi-Empirical method with the Spartan'10 program (version 1.1.0: Wavefunction Inc., Irvine, California) were used as starting geometries for DFT calculations. DFT calculations were carried out with the same program. The geometries were fully optimized in vacuo by using the B3LYP/6-31(d) level of theory.



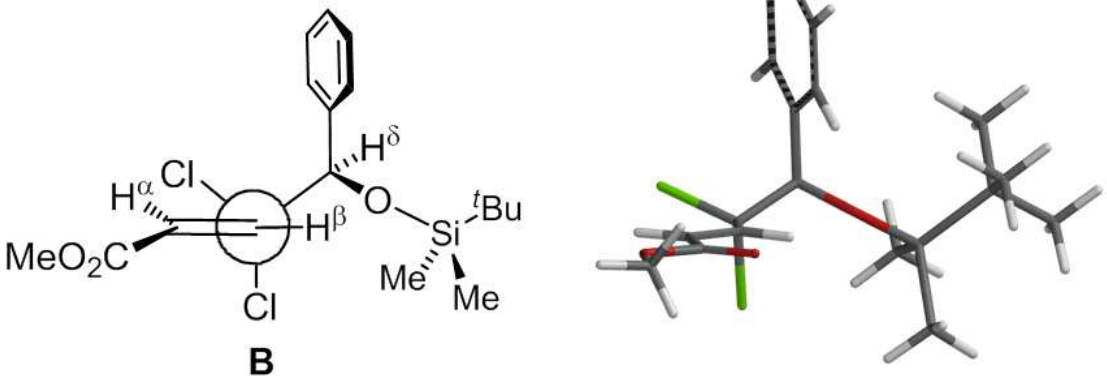
Conformer A

Cartesian Coordinates (Angstroms)

Atom	X	Y	Z
1 C C4	0.4215699	-0.5573128	0.8472474
2 O O3	0.8739950	0.4965078	0.0328823
3 C C5	-1.0299522	-0.1749332	1.3167977
4 Cl Cl1	-1.6563651	-1.5176576	2.4036757
5 Cl Cl2	-0.9212128	1.3245804	2.3413603
6 C C6	-2.0075611	-0.0158386	0.1930154
7 H H12	-1.8572138	-0.6988196	-0.6378069
8 C C7	-3.0724778	0.7887551	0.1625835
9 H H13	-3.3083519	1.4851509	0.9588807
10 C C10	-3.9767545	0.7518908	-1.0126750
11 O O1	-3.8354873	0.0530191	-1.9969973
12 O O2	-5.0045666	1.6148264	-0.8465316
13 C C8	-5.9490760	1.6535193	-1.9278889
14 H H14	-6.6971777	2.3912175	-1.6391531
15 H H15	-6.4098411	0.6727794	-2.0702053
16 Si Si2	2.2200762	1.5120833	0.2364894
17 C C11	3.5117748	1.0782316	-1.1078830
18 C C12	4.7228726	2.0297254	-0.9830896
19 H H11	5.2211182	1.9395858	-0.0110034
20 H H20	4.4404659	3.0798730	-1.1185993
21 H H21	5.4691325	1.7925902	-1.7531280
22 C C13	3.9996204	-0.3771182	-0.9457242
23 H H19	3.1798293	-1.0948166	-1.0488153
24 H H22	4.4769122	-0.5463757	0.0264154

25	H	H23	4.7450931	-0.6149892	-1.7169493
26	C	C14	2.8876992	1.2433826	-2.5097669
27	H	H18	2.0275172	0.5812152	-2.6510654
28	H	H24	3.6250404	0.9983079	-3.2864382
29	H	H25	2.5543168	2.2710776	-2.6909799
30	H	H26	-5.4561394	1.9477883	-2.8577842
31	C	C9	2.9407262	1.2895269	1.9677067
32	H	H9	2.2042732	1.5431008	2.7363683
33	H	H16	3.7976896	1.9586063	2.1015454
34	H	H17	3.2910954	0.2703538	2.1602739
35	C	C15	1.5835495	3.2700491	0.0128540
36	H	H27	2.3980034	4.0013711	0.0456648
37	H	H28	0.8748845	3.5202294	0.8078765
38	H	H29	1.0633419	3.3900914	-0.9425304
39	H	H32	1.0090386	-0.6398400	1.7687804
40	C	C1	0.5059490	-1.8821930	0.0960130
41	C	C2	0.7191378	-4.3179630	-1.2859471
42	C	C3	0.3111210	-1.9335593	-1.2910775
43	C	C16	0.8313852	-3.0613998	0.7764997
44	C	C17	0.9348262	-4.2722622	0.0918557
45	C	C18	0.4106251	-3.1446847	-1.9757778
46	H	H2	0.1030825	-1.0182965	-1.8344754
47	H	H6	1.0027395	-3.0325335	1.8484985
48	H	H5	1.1887284	-5.1776804	0.6350803
49	H	H3	0.2522673	-3.1685997	-3.0498665
50	H	H4	0.8001707	-5.2599641	-1.8203341

Total electronic energy: -5611290.76 kJ/mol
Zero-point energy: +1066.27
Sum of electronic and thermal Enhtalpies: -2136.79545
Sum of electronic and thermal Free energies: -2136.86964



B

Conformer B

Cartesian Coordinates (Angstroms)

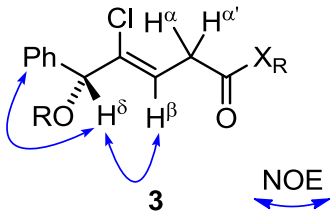
Atom	X	Y	Z
1 C C4	0.3994957	-0.4761683	0.9082898
2 O O3	0.9850176	0.4951677	0.0763837
3 C C5	-0.9900914	0.0875269	1.3607730
4 Cl Cl1	-1.7973068	-1.1415205	2.4296716
5 Cl Cl2	-0.7104445	1.5777531	2.4059313
6 C C6	-1.8641551	0.5043606	0.2171840
7 H H12	-1.3160462	0.9374813	-0.6149186
8 C C7	-3.1982988	0.4893559	0.1737079
9 H H13	-3.8102068	0.0996976	0.9789612
10 C C10	-3.8897616	1.0006058	-1.0352600
11 O O1	-3.3485456	1.4341249	-2.0336130
12 O O2	-5.2310414	0.9171018	-0.8857774
13 C C8	-5.9994362	1.3821043	-2.0068124
14 H H14	-7.0430388	1.2376110	-1.7289439
15 H H15	-5.7563118	0.8069621	-2.9036621
16 Si Si2	2.4810182	1.2875488	0.2070775
17 C C11	3.5681212	0.7208320	-1.2630126
18 C C12	4.8588527	1.5673278	-1.2995199
19 H H11	5.4509750	1.4578542	-0.3832701
20 H H20	4.6479856	2.6336393	-1.4361560
21 H H21	5.4986338	1.2532866	-2.1355415
22 C C13	3.9434093	-0.7685297	-1.1113582
23 H H19	3.0563289	-1.4099106	-1.0873961
24 H H22	4.5203973	-0.9544029	-0.1983607
25 H H23	4.5609062	-1.0949682	-1.9591655
26 C C14	2.7955947	0.9118220	-2.5851315
27 H H18	1.8714041	0.3264989	-2.5943479
28 H H24	3.4074626	0.5843104	-3.4366120

29	H	H25	2.5308120	1.9606174	-2.7595255
30	H	H26	-5.7953067	2.4379934	-2.2009531
31	C	C9	3.2737231	0.8760617	1.8694187
32	H	H9	2.6335944	1.2042921	2.6950353
33	H	H16	4.2303855	1.4004019	1.9690185
34	H	H17	3.4733538	-0.1925718	1.9985323
35	C	C15	2.1112240	3.1307906	0.1049025
36	H	H27	3.0285391	3.7274274	0.1567868
37	H	H28	1.4642431	3.4341399	0.9334576
38	H	H29	1.5977338	3.3889734	-0.8267593
39	H	H32	0.9714712	-0.6216528	1.8319896
40	C	C1	0.2939666	-1.8139348	0.1866331
41	C	C2	0.1614717	-4.2884760	-1.1305590
42	C	C3	-0.0921825	-1.8817795	-1.1588744
43	C	C16	0.6238819	-2.9966325	0.8577981
44	C	C17	0.5568980	-4.2279370	0.2057777
45	C	C18	-0.1603395	-3.1125020	-1.8108814
46	H	H2	-0.3231683	-0.9713155	-1.7005417
47	H	H6	0.9320496	-2.9545109	1.8988711
48	H	H5	0.8176100	-5.1364035	0.7406280
49	H	H3	-0.4605188	-3.1519839	-2.8538786
50	H	H4	0.1105404	-5.2452249	-1.6419815

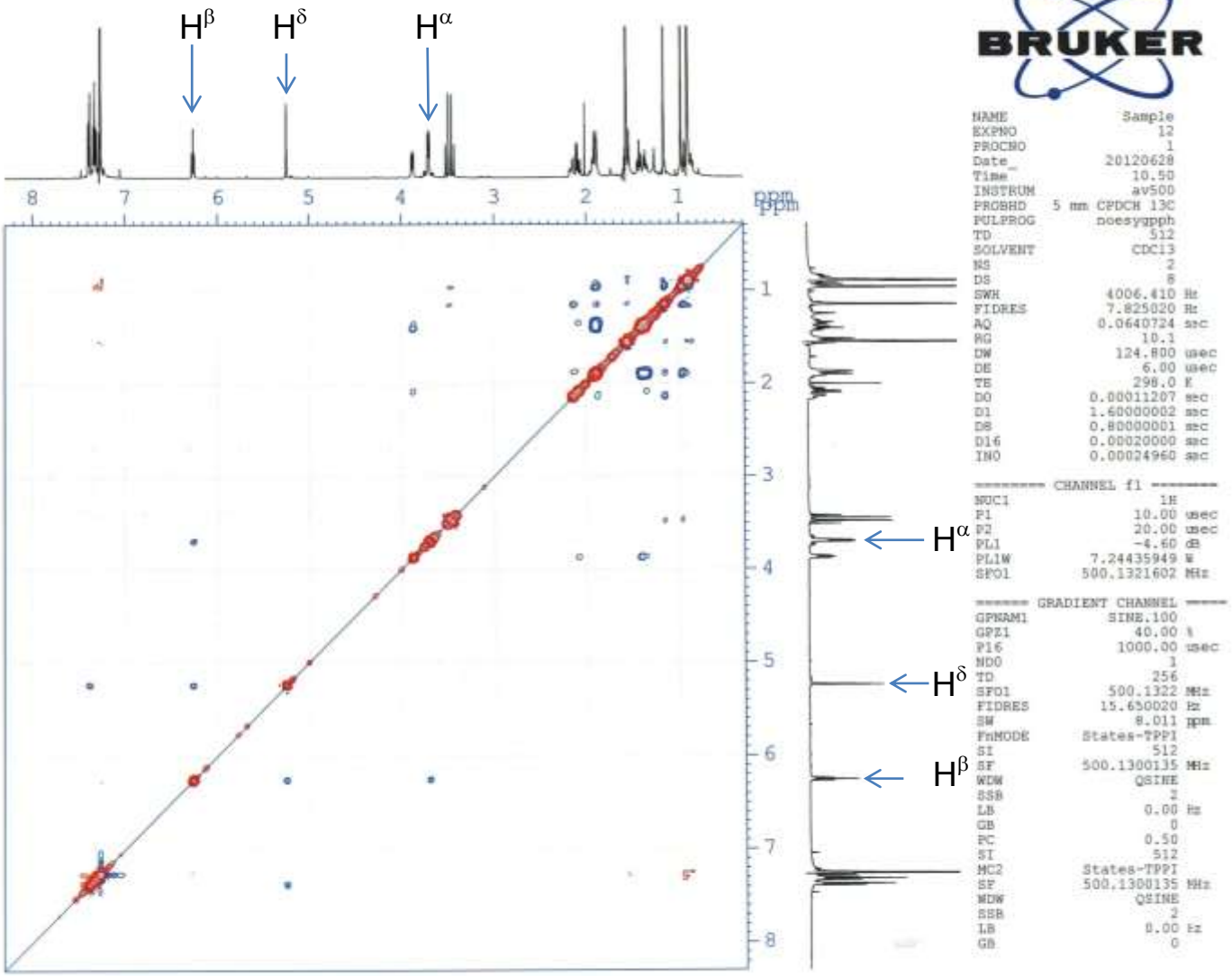
Total electronic energy: -5611295.18 kJ/mol
Zero-point energy: +1066.55
Sum of electronic and thermal Enhtalpies: -2136.79705
Sum of electronic and thermal Free energies: -2136.87111

VI. NMR Spectra

VI-I. NOESY Data of compound 3



3



BRUKER

```
NAME                 Sample
EXPNO                    12
PROCNO                    1
Date_              20120628
Time_                 10.50
INSTRUM                av500
PROBHD   5 mm CPDCH 13C
PULPROG           noesygpph
TD                      512
SOLVENT               CDCl3
NS                        2
DS                        8
SWH                4006.410 Hz
FIDRES             7.825020 Hz
AQ                 0.0640724 sec
RG                      10.1
DW                   124.800 usec
DE                     6.00 usec
TE                   298.0 K
D0                 0.00011207 sec
D1                 1.60000002 sec
D8                 0.80000001 sec
D16                0.00020000 sec
IN0                0.00024960 sec

======== CHANNEL f1 ========
NUC1                      1H
P1                     10.00 usec
P2                     20.00 usec
PL1                    -4.60 dB
PL1W               7.24435949 W
SFO1             500.1321602 MHz

====== GRADIENT CHANNEL =====
GPNAM1               SINE.100
GPZ1                    40.00 %
P16                   1000.00 usec
NDO                       1
TD                      256
SFO1               500.1322 MHz
FIDRES            15.650020 Hz
SW                     8.011 ppm
FnMODE           States-TPPI
SI                      512
SF               500.1300135 MHz
WDW                    QSINE
SSB                       2
LB                     0.00 Hz
GB                        0
PC                     0.50
SI                      512
MC2              States-TPPI
SF               500.1300135 MHz
WDW                    QSINE
SSB                       2
LB                     0.00 Hz
GB                        0
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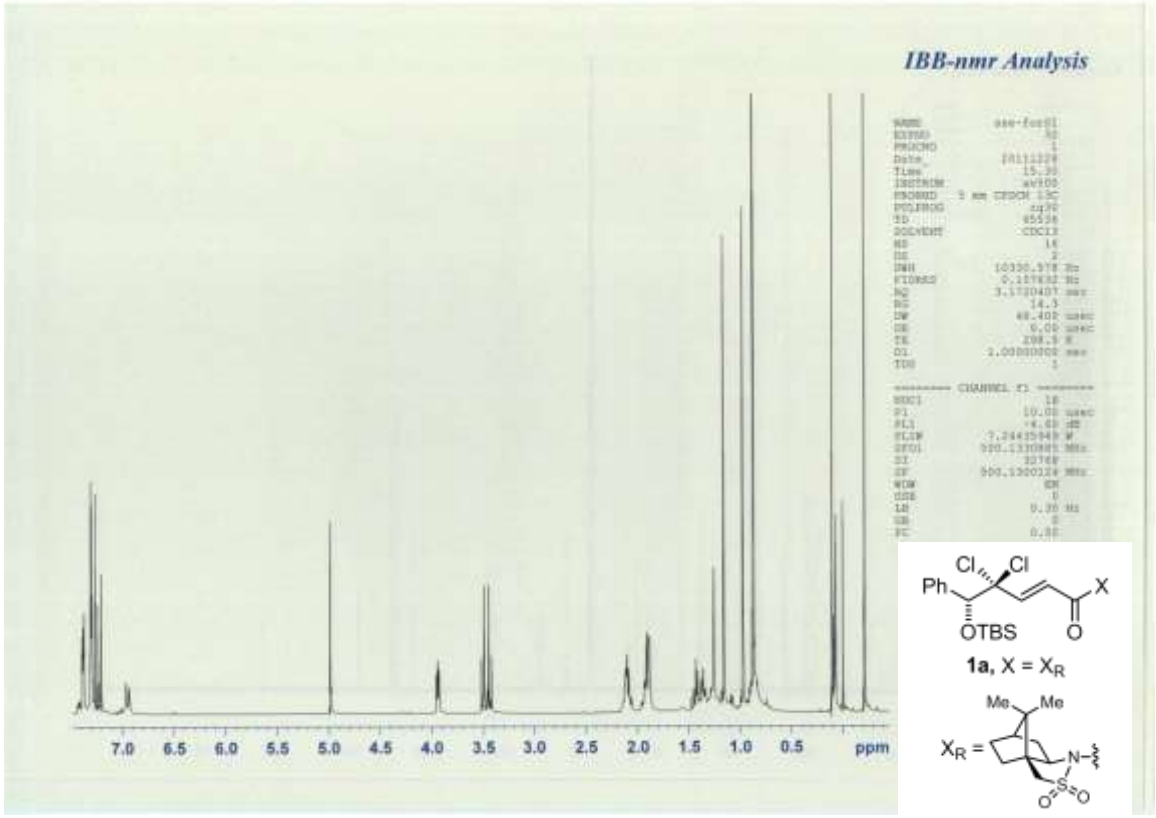
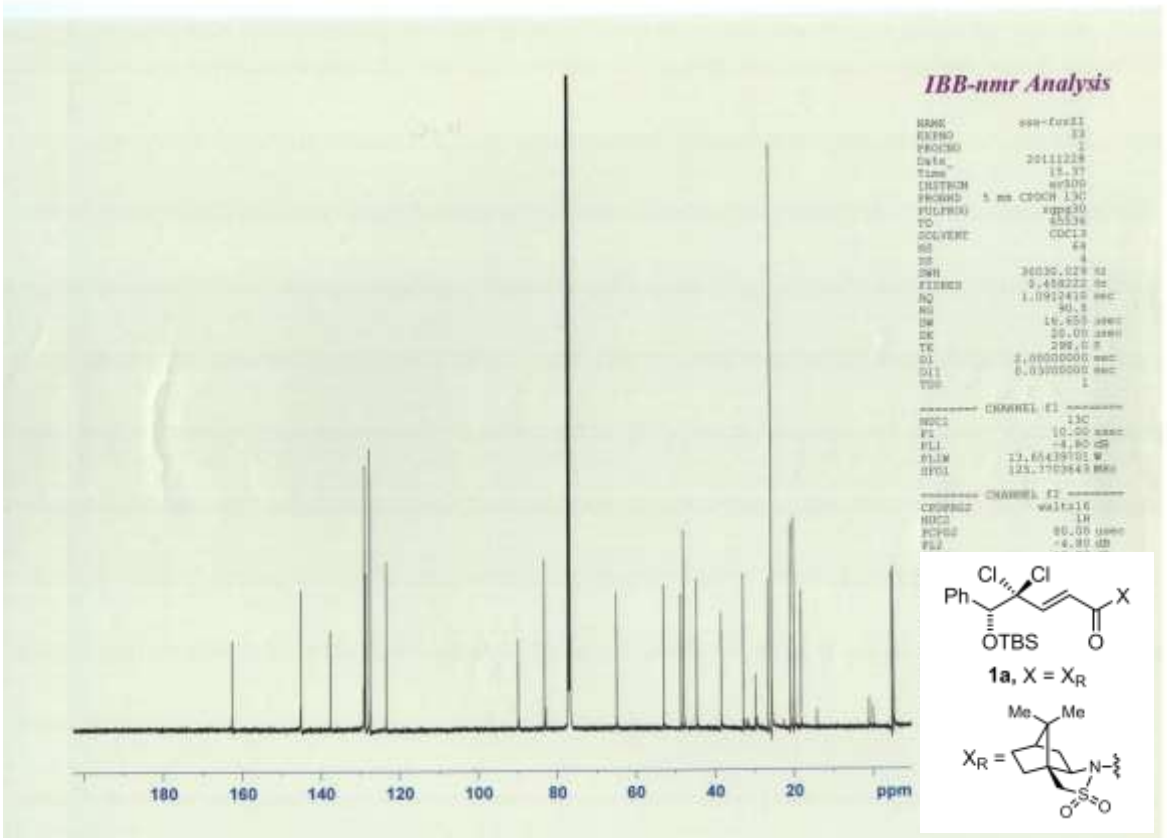
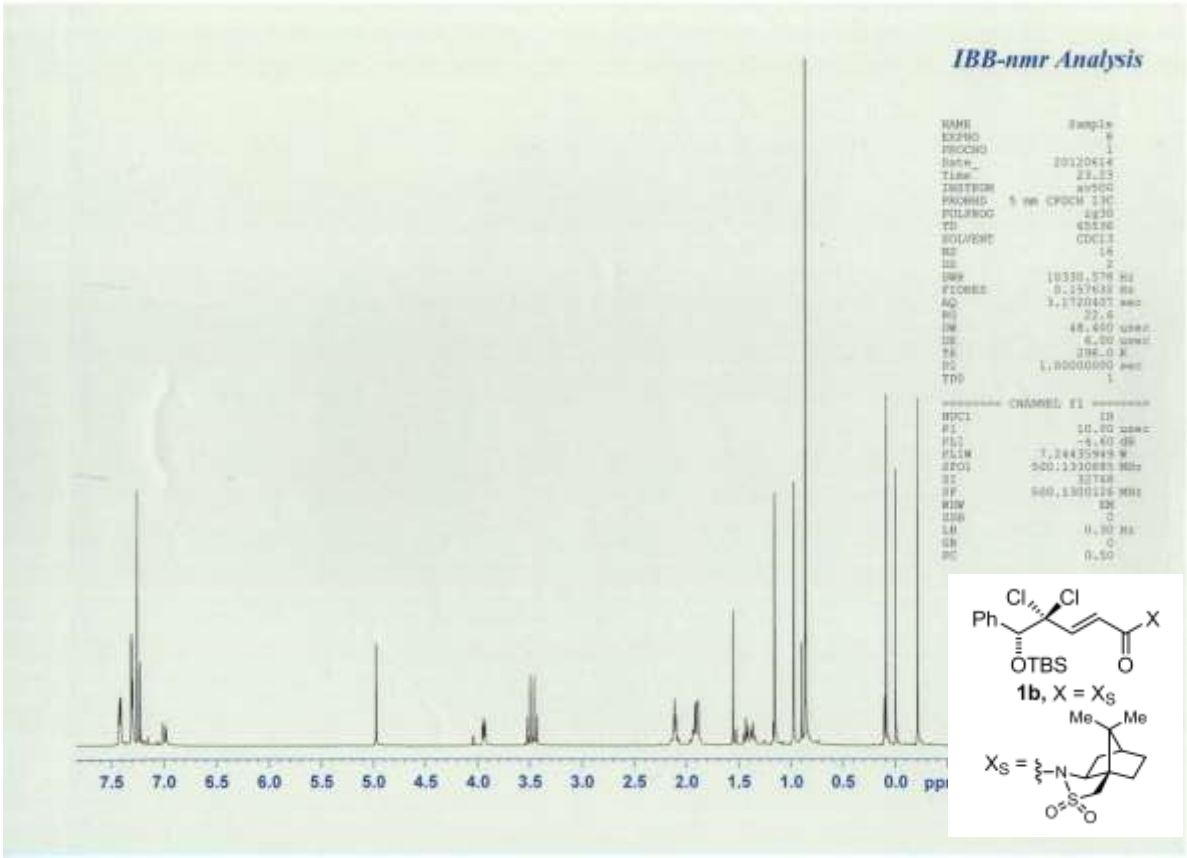
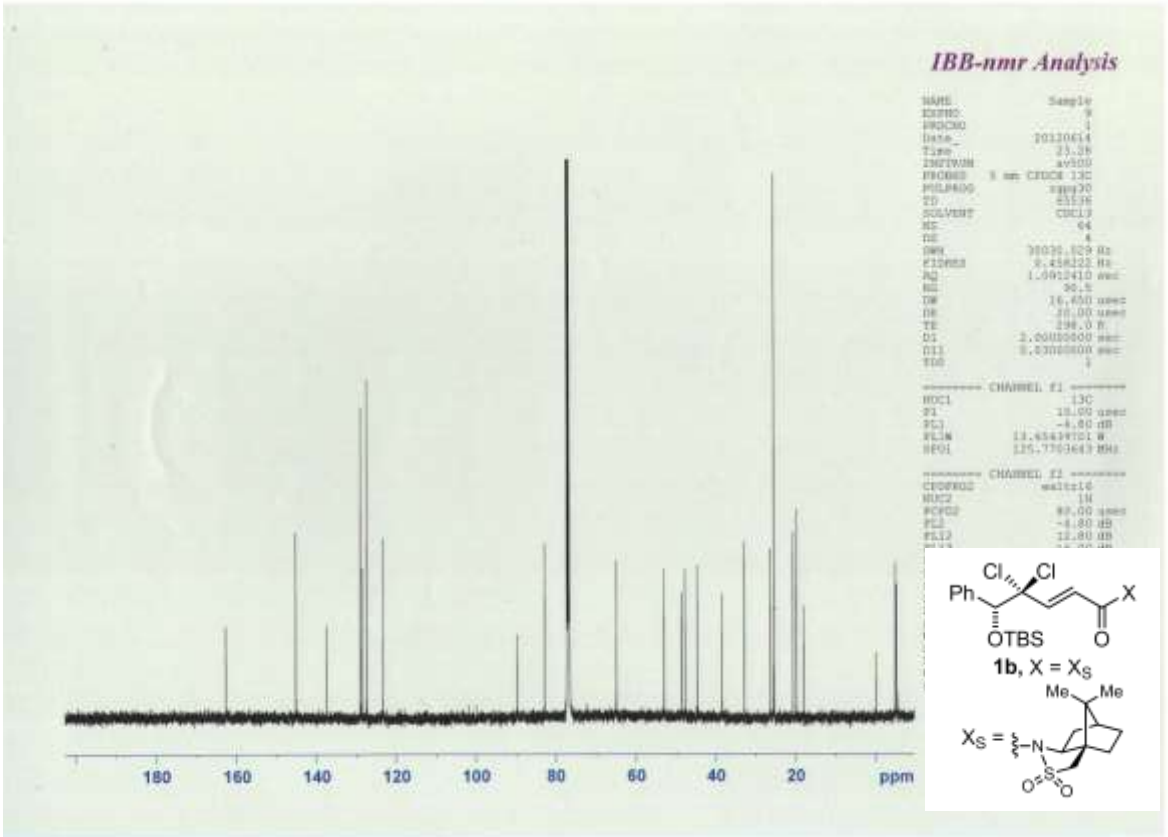
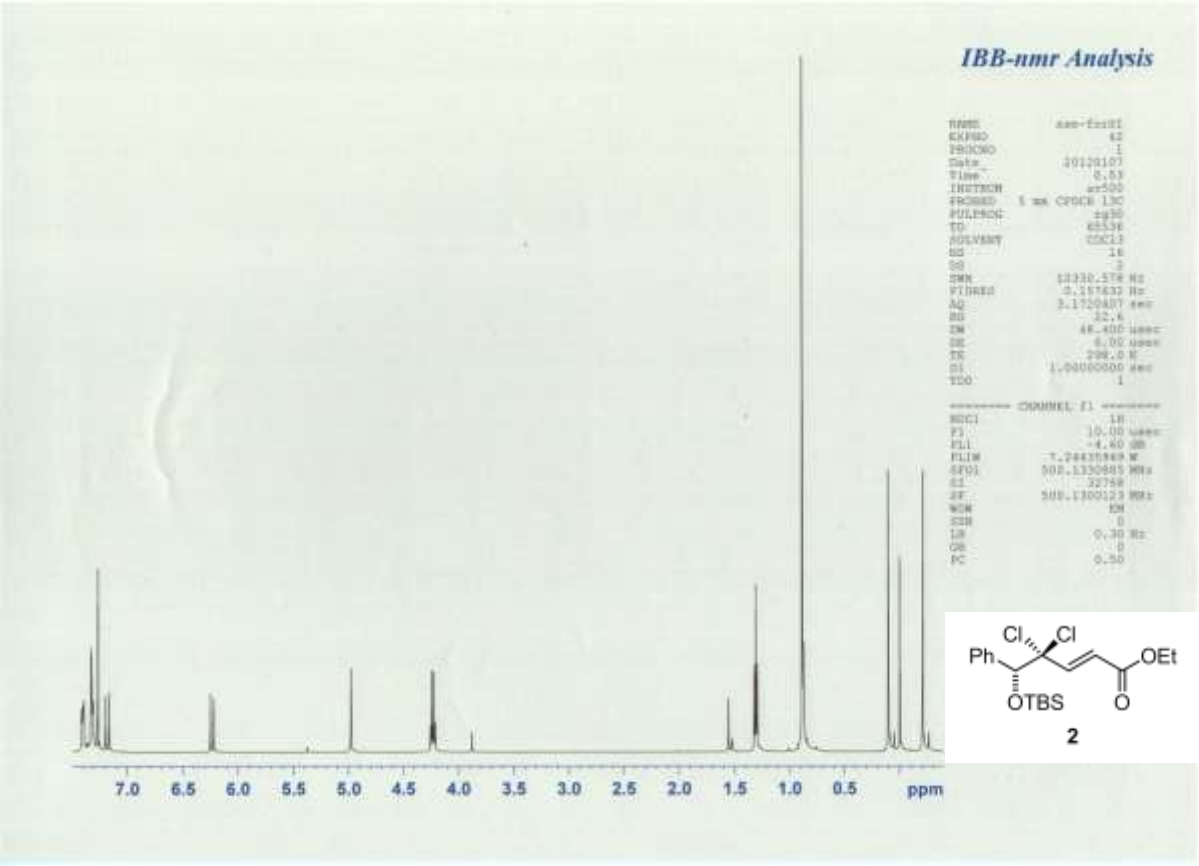
VII-II. ^{1}H NMR and ^{13}C NMR charts of compounds 1-6, S4, and S5

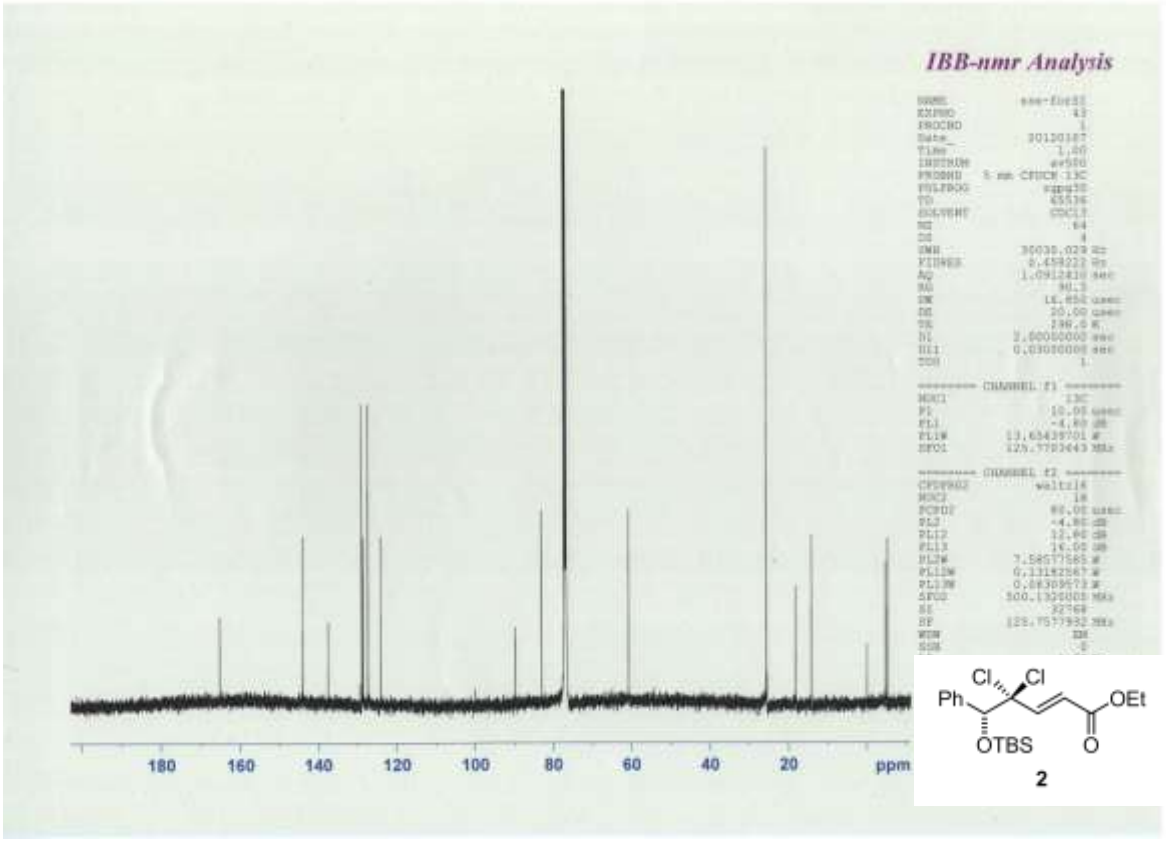





IBB-nmr Analysis
7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 ppm
Cl
Cl
Ph
X
OTBS
O
1b, X = XS
Me
Me
XS =
N
O=S=O


IBB-nmr Analysis
180 160 140 120 100 80 60 40 20 ppm
Cl
Cl
Ph
X
OTBS
O
1b, X = XS
Me
Me
XS =
N
O=S=O


IBB-nmr Analysis
7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 ppm
Cl Cl
Ph
OEt
OTBS
O
2


IBB-nmr Analysis
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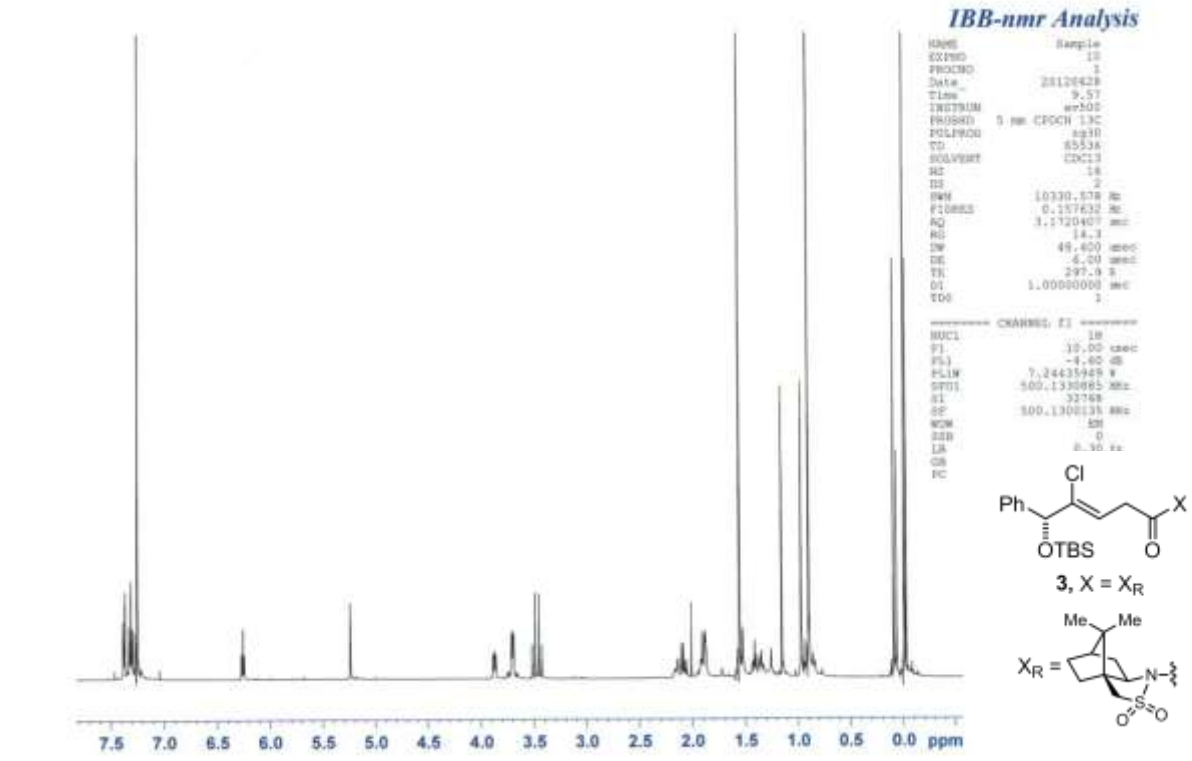
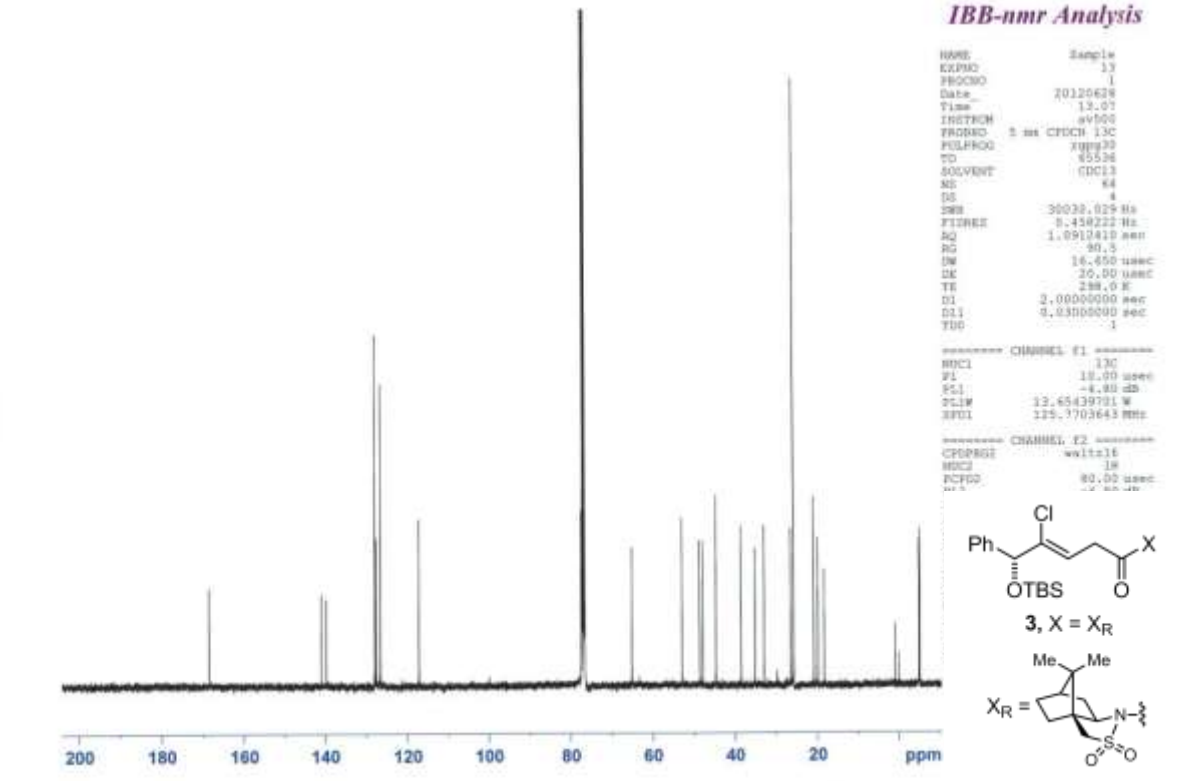
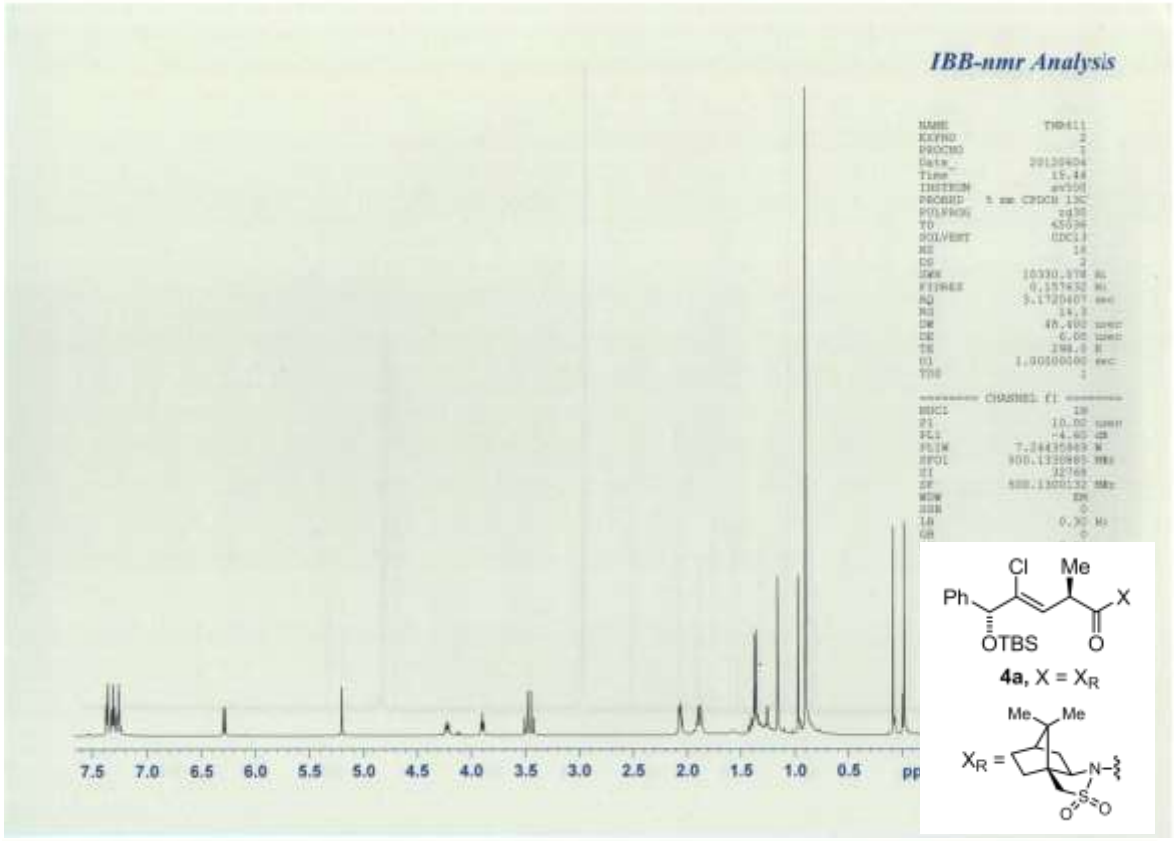
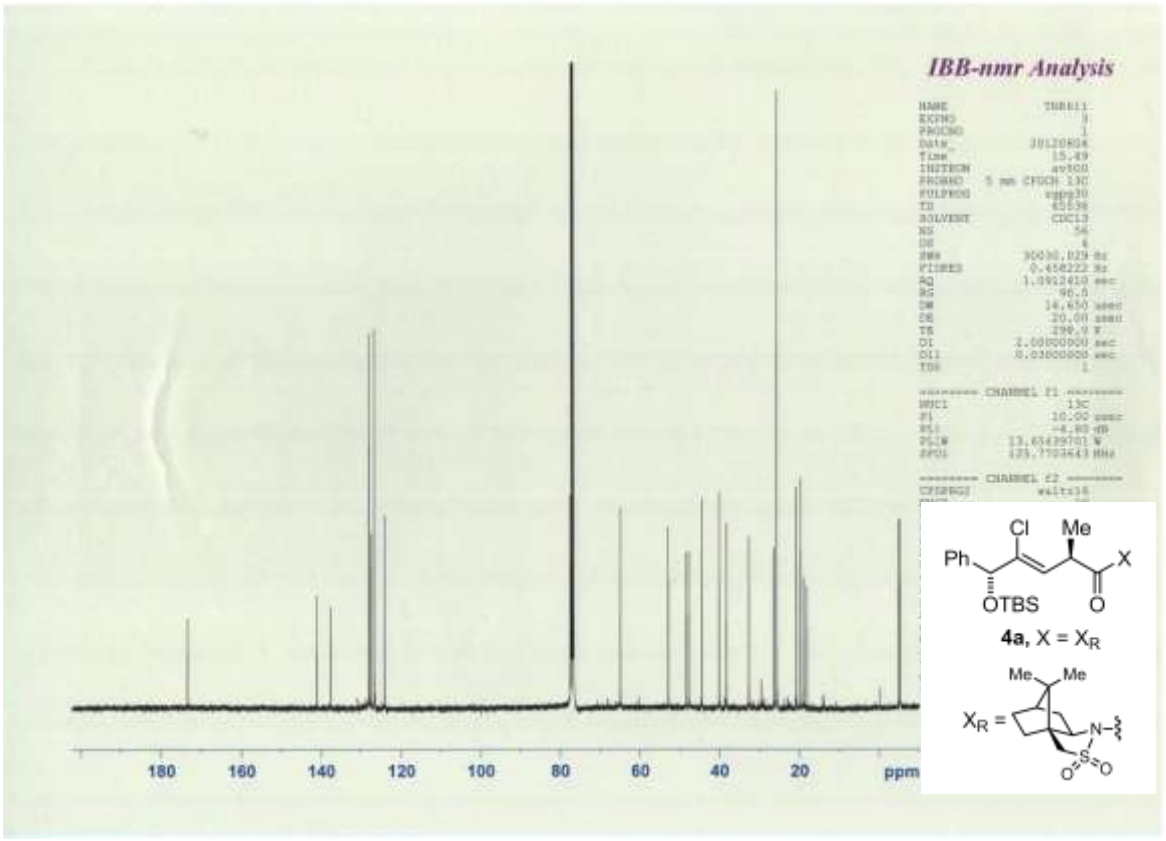
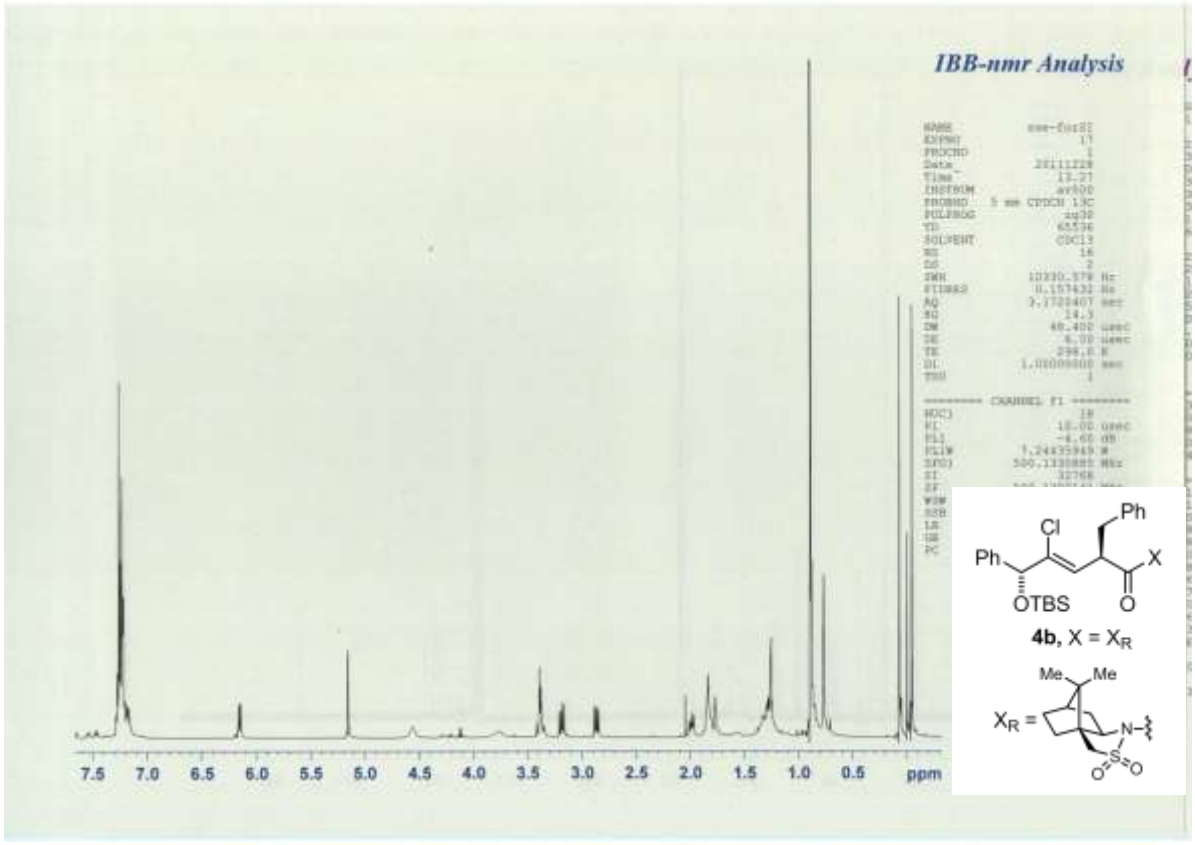
Cl Cl
Ph
OEt
OTBS
O
2

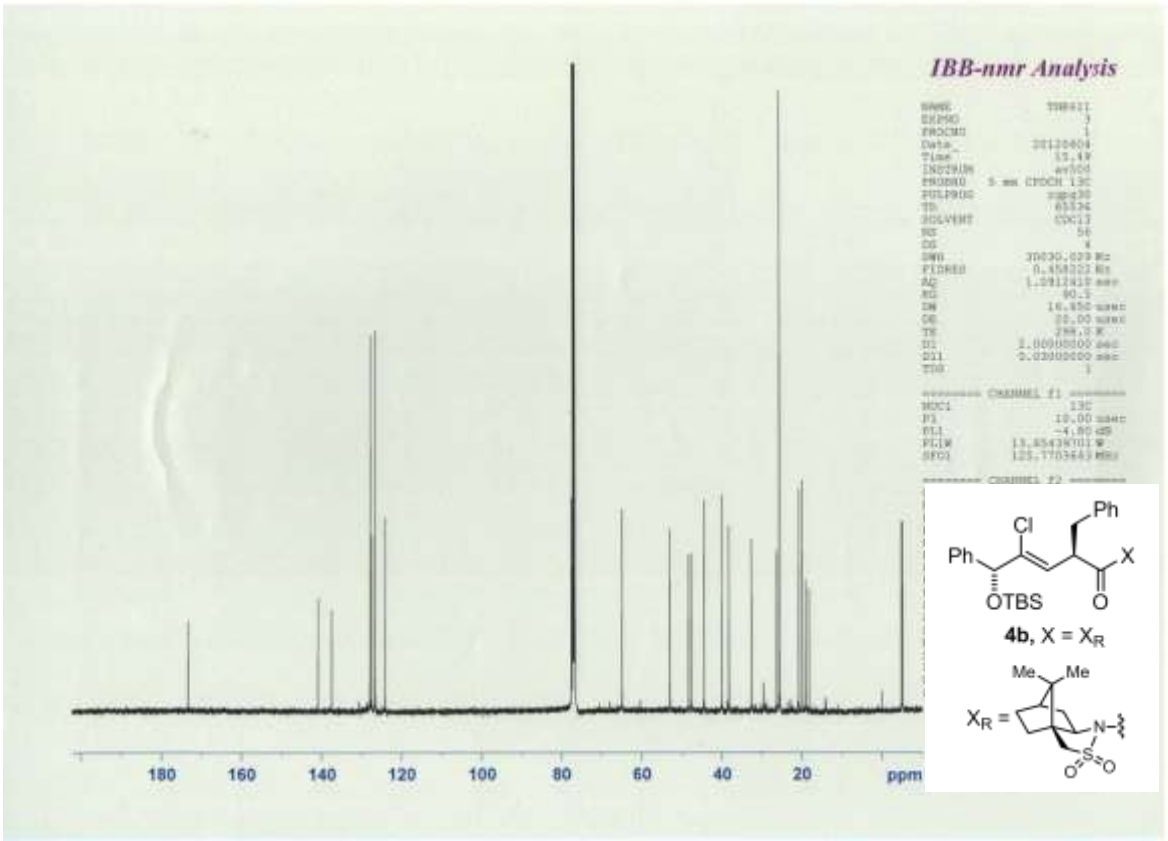

IBB-nmr Analysis
7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 ppm
Cl
Ph
X
OTBS
O
3, X = XR
Me
Me
XR =
N
S
O
O

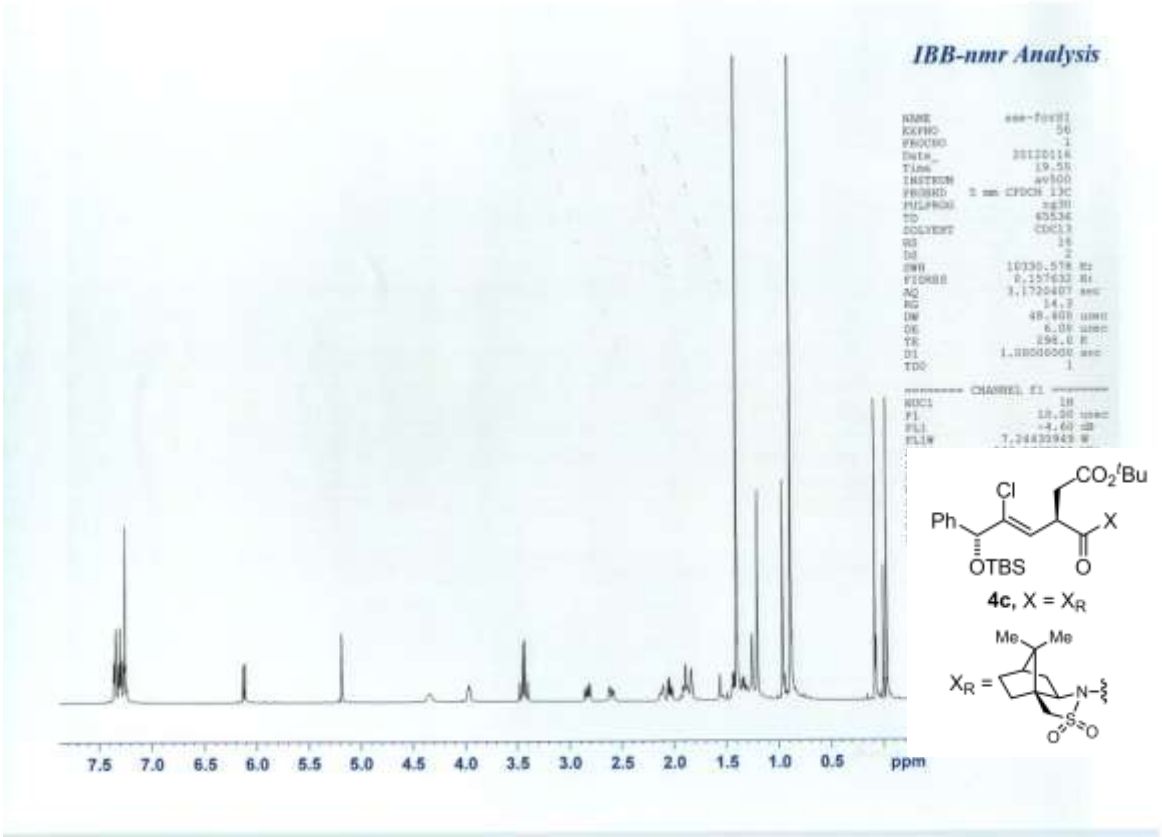

IBB-nmr Analysis
200 180 160 140 120 100 80 60 40 20 ppm
Cl
Ph
X
OTBS
O
3, X = XR
Me
Me
XR =
N
S
O
O

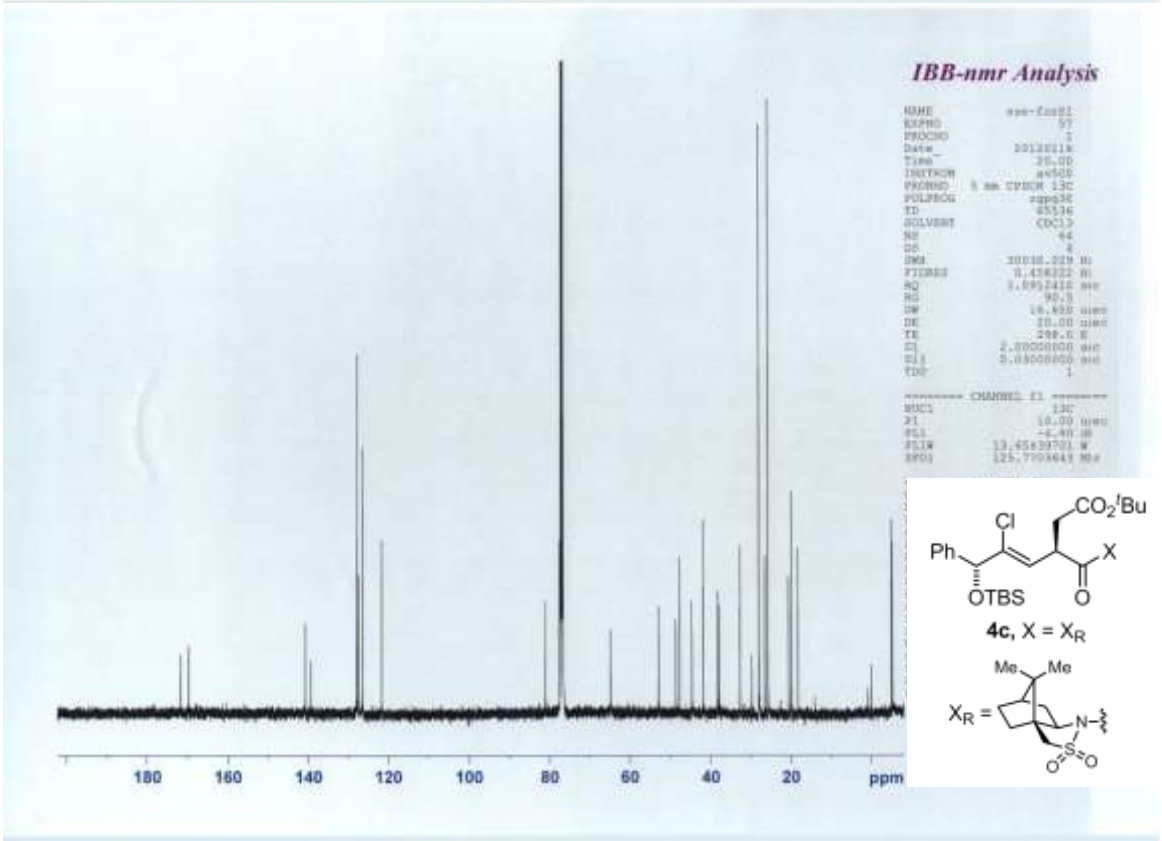

IBB-nmr Analysis
7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5
Cl
Me
Ph
X
OTBS
O
4a, X = XR
Me
Me
XR =
N
S
O
O

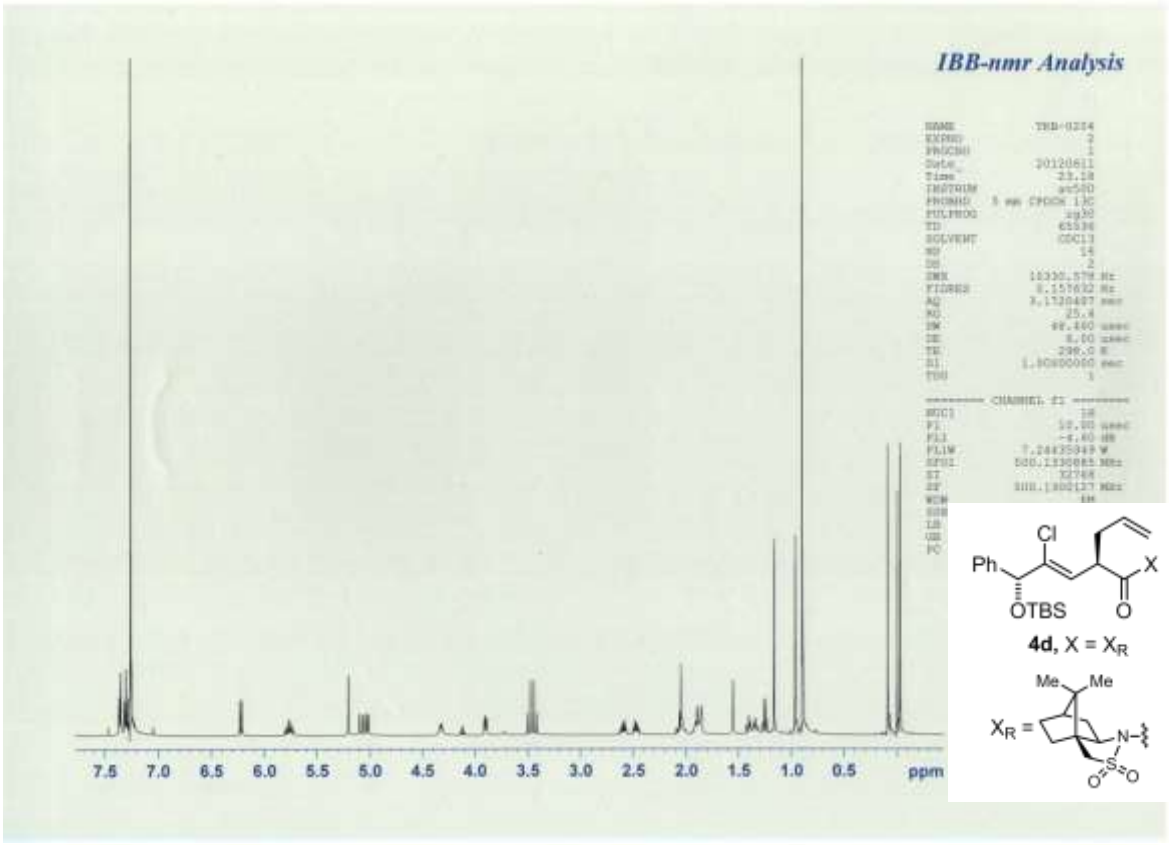

IBB-nmr Analysis
180 160 140 120 100 80 60 40 20 ppm
Cl
Me
Ph
X
OTBS
O
4a, X = XR
Me
Me
XR =
N
S
O
O

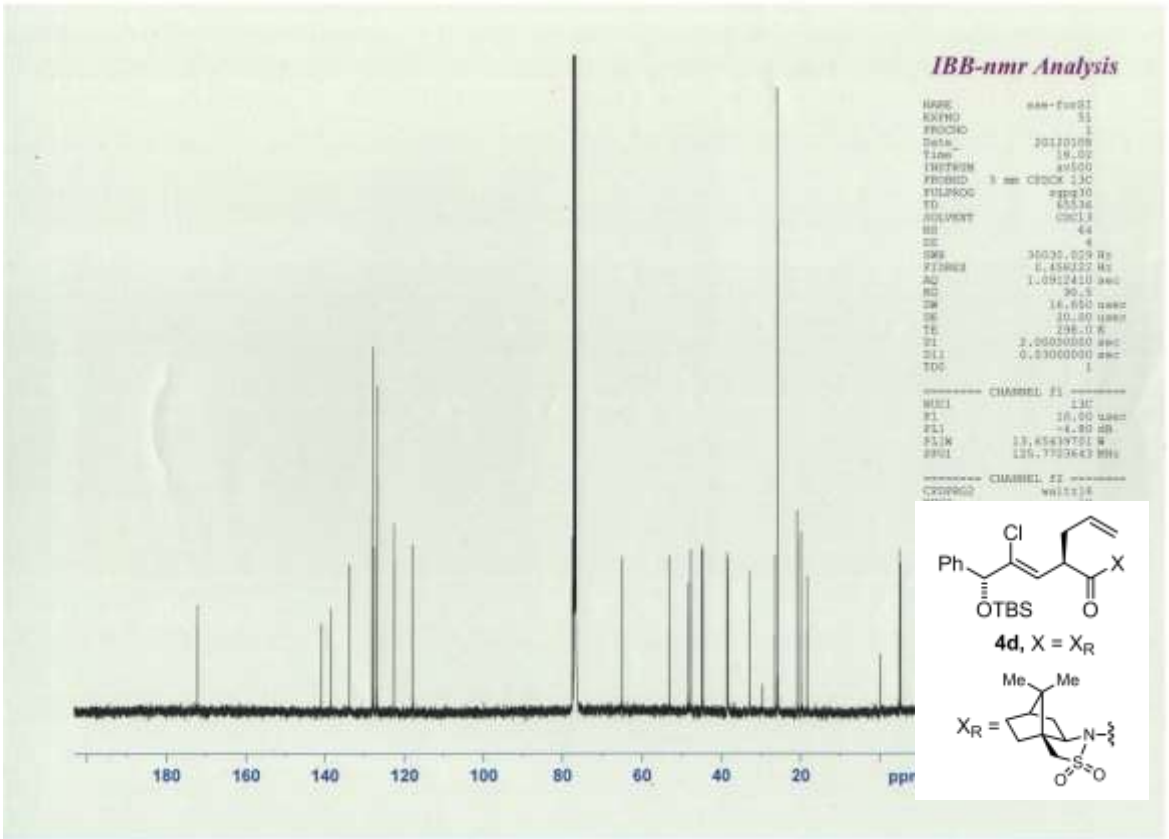

IBB-nmr Analysis
7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 ppm
Cl
Ph
Ph
X
OTBS
O
4b, X = XR
Me
Me
XR =
N
S
O
O

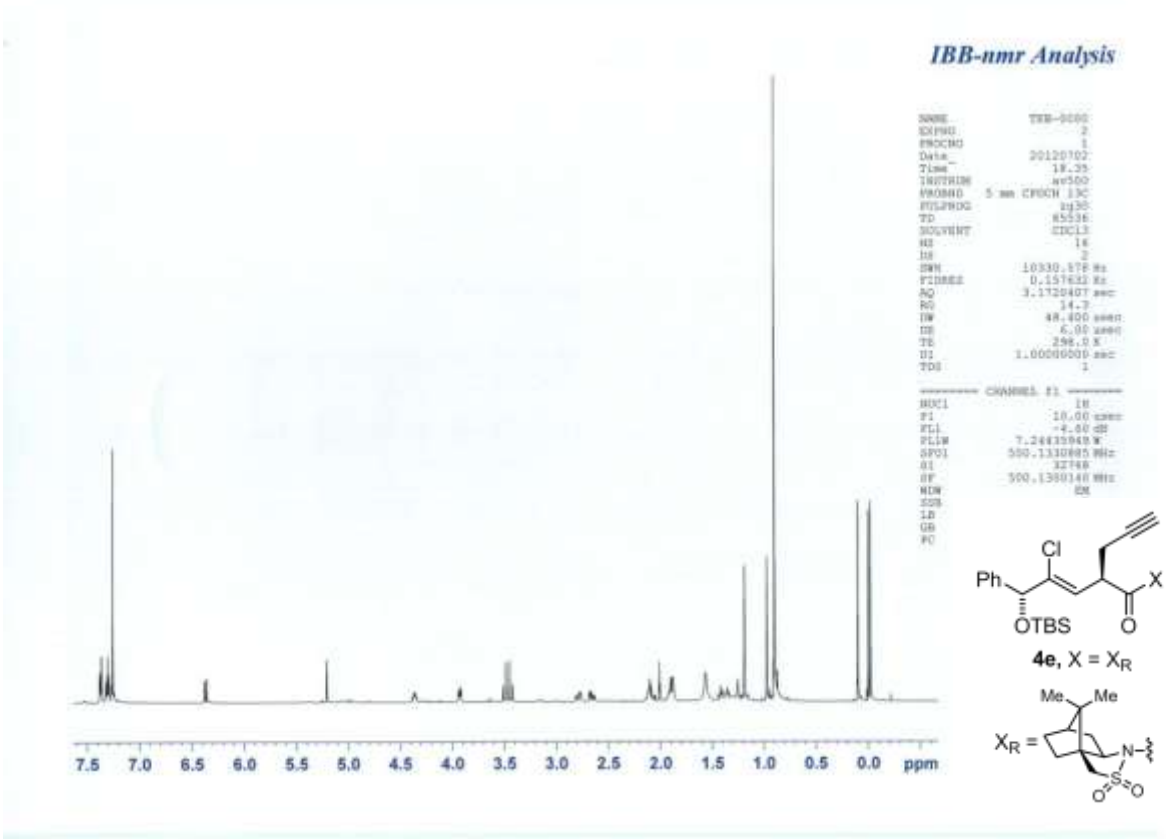

IBB-nmr Analysis
180 160 140 120 100 80 60 40 20 ppm
Cl
Ph
Ph
X
OTBS
O
4b, X = XR
Me
Me
XR =
N
S
O
O

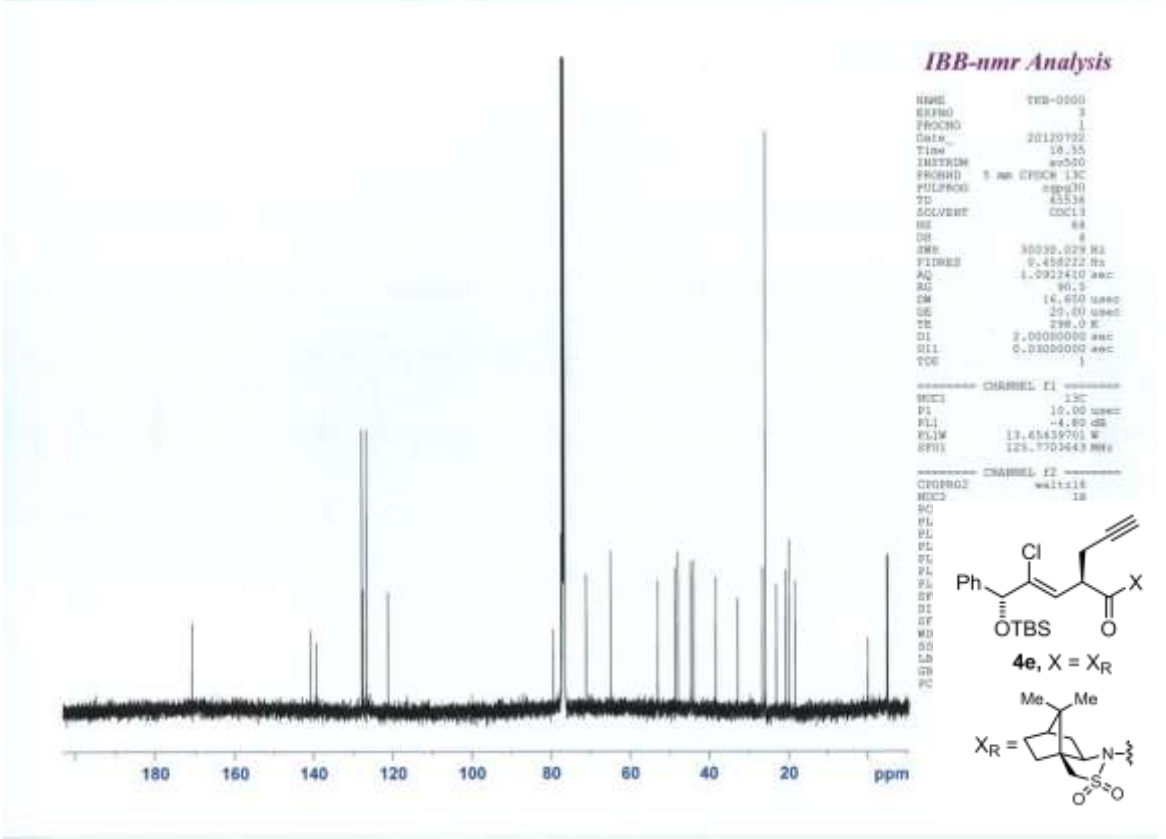

IBB-nmr Analysis
7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 ppm
Cl
CO2tBu
Ph
X
OTBS
O
4c, X = XR
Me
Me
XR =
N
S
O
O


IBB-nmr Analysis
180 160 140 120 100 80 60 40 20 ppm
Cl
CO2tBu
Ph
X
OTBS
O
4c, X = XR
Me
Me
XR =
N
S
O
O


IBB-nmr Analysis
7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 ppm
Cl
Ph
X
OTBS
O
4d, X = XR
Me
Me
XR =
N
S
O
O


IBB-nmr Analysis
180 160 140 120 100 80 60 40 20 ppm
Cl
Ph
X
OTBS
O
4d, X = XR
Me
Me
XR =
N
S
O
O


IBB-nmr Analysis
7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 ppm
Cl
Ph
X
OTBS
O
4e, X = XR
Me
Me
XR =
N
S
O
O


IBB-nmr Analysis
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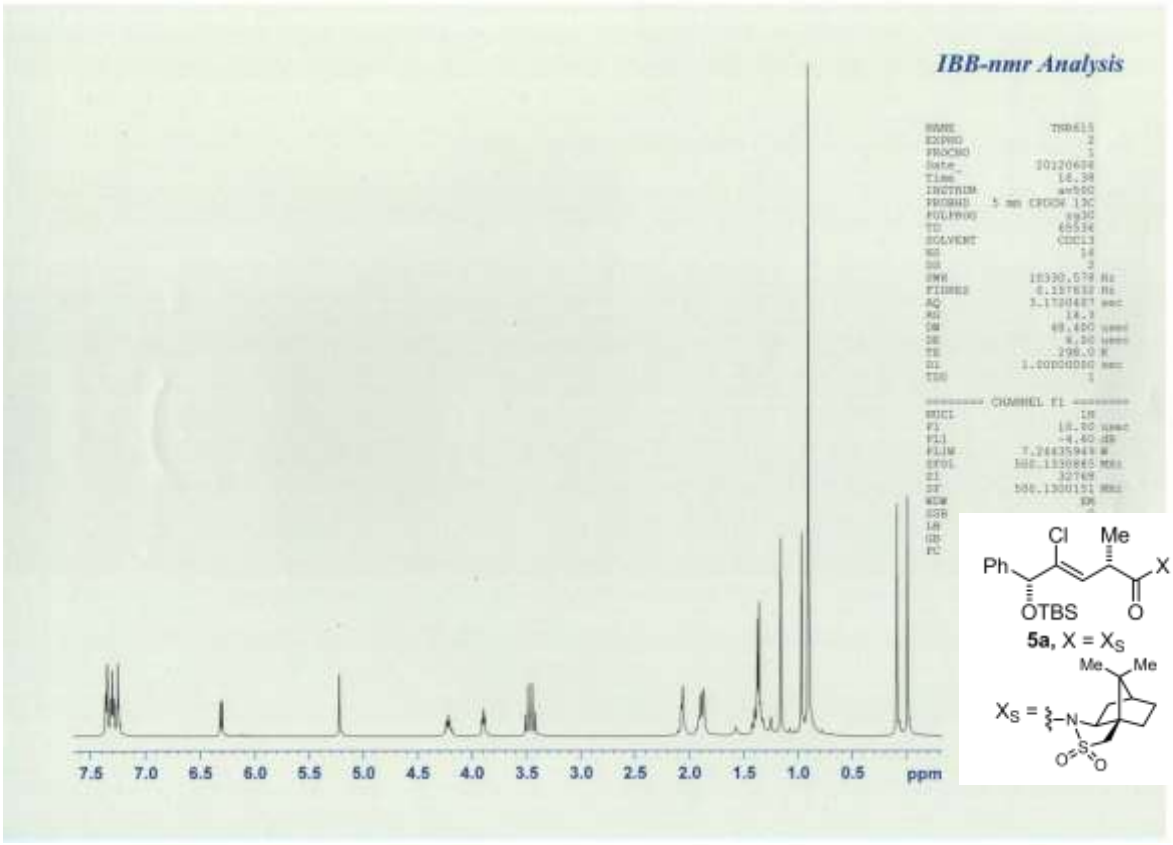
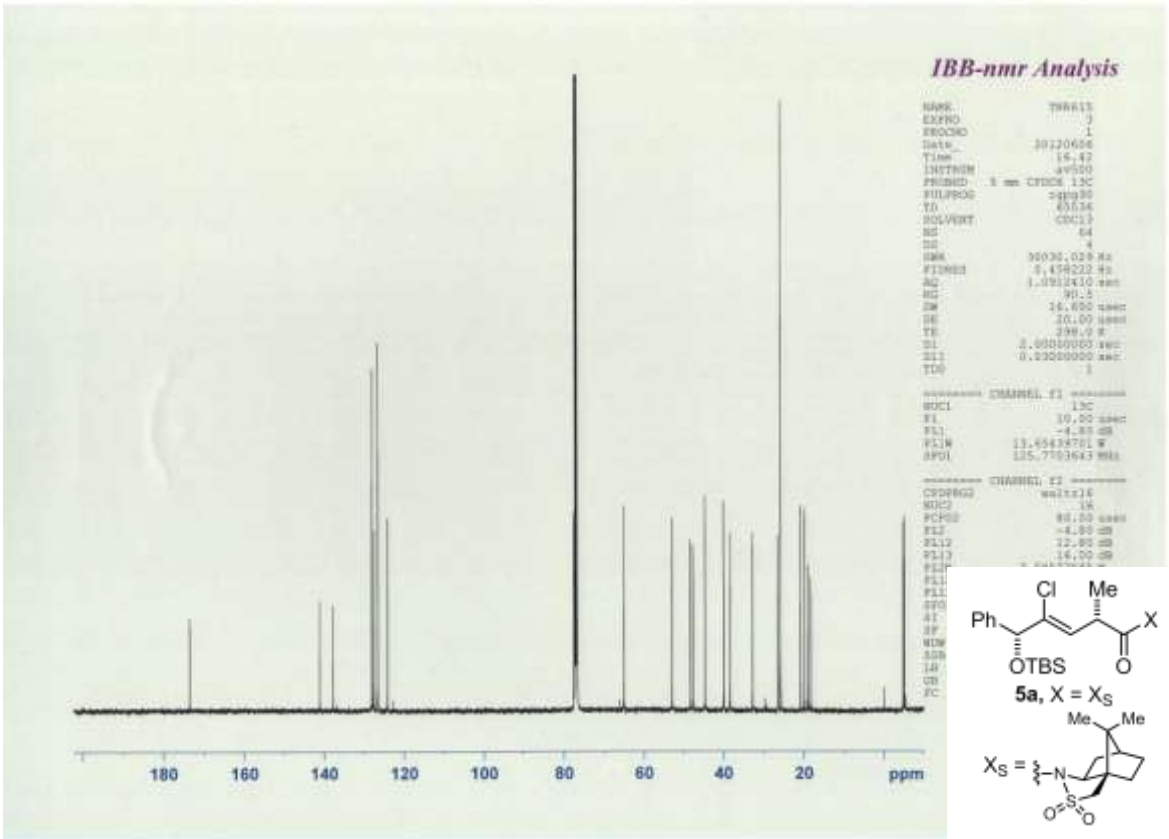
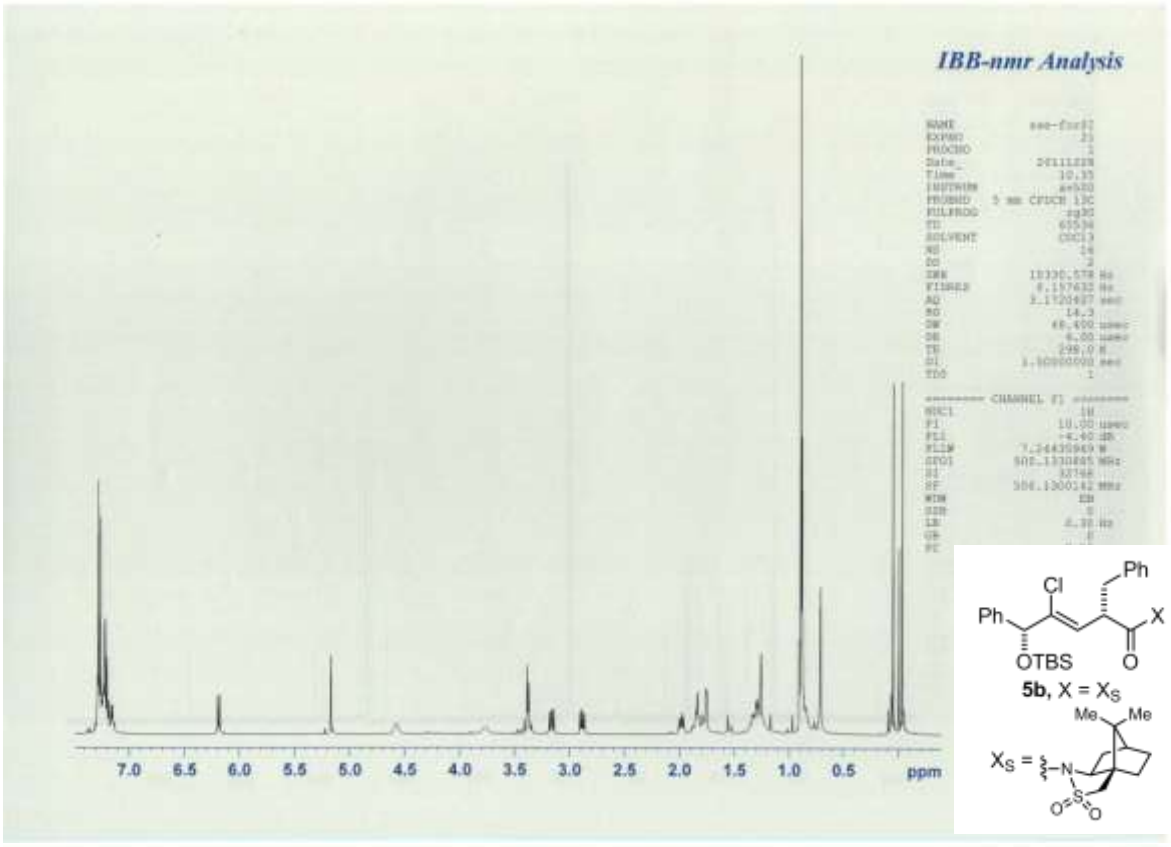
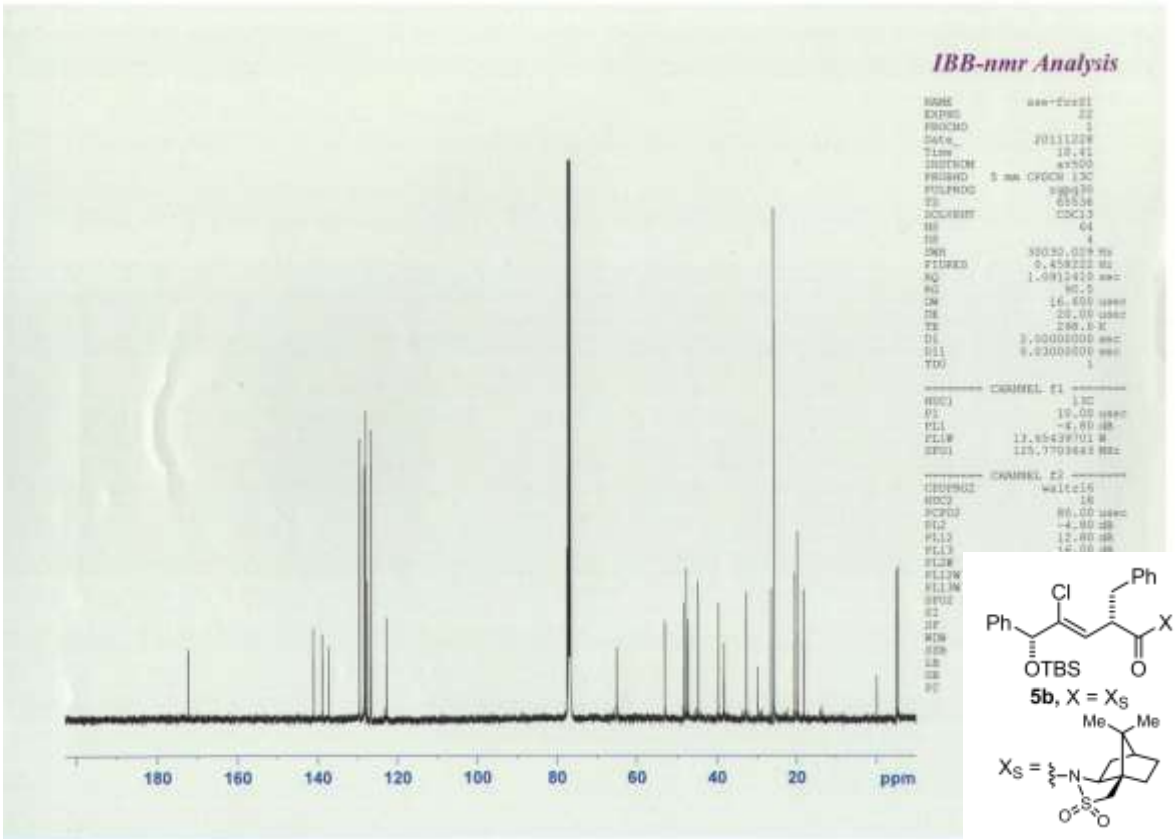
Cl
Ph
X
OTBS
O
4e, X = XR
Me
Me
XR =
N
S
O
O


IBB-nmr Analysis
7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 ppm
Cl Me
Ph X
OTBS O
5a, X = XS
Me Me
XS = N
O S O


IBB-nmr Analysis
180 160 140 120 100 80 60 40 20 ppm
Cl Me
Ph X
OTBS O
5a, X = XS
Me Me
XS = N
O S O


IBB-nmr Analysis
7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 ppm
Cl
Ph
Ph
X
OTBS
O
5b, X = XS
Me
Me
XS =
N
O=S=O


IBB-nmr Analysis
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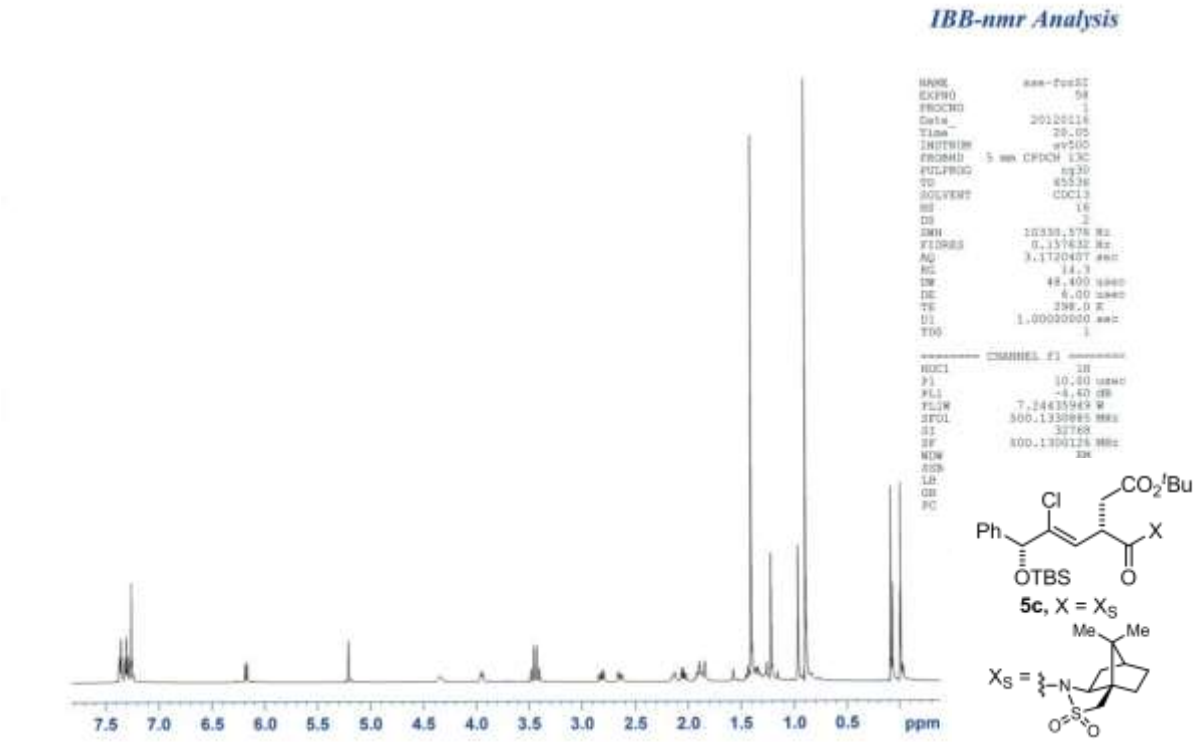
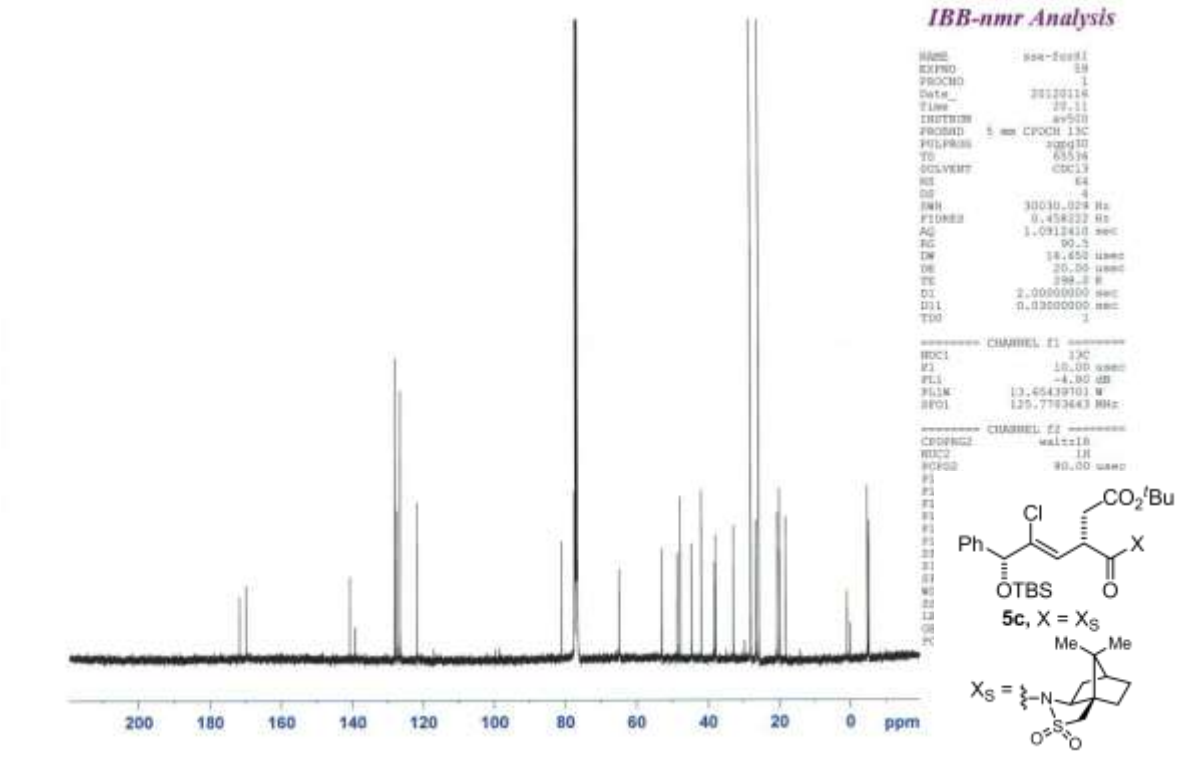
Cl
Ph
Ph
X
OTBS
O
5b, X = XS
Me
Me
XS =
N
O=S=O


IBB-nmr Analysis
7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 ppm
Cl
CO2tBu
Ph
X
OTBS
O
5c, X = XS
Me
Me
XS =
N
S
O
O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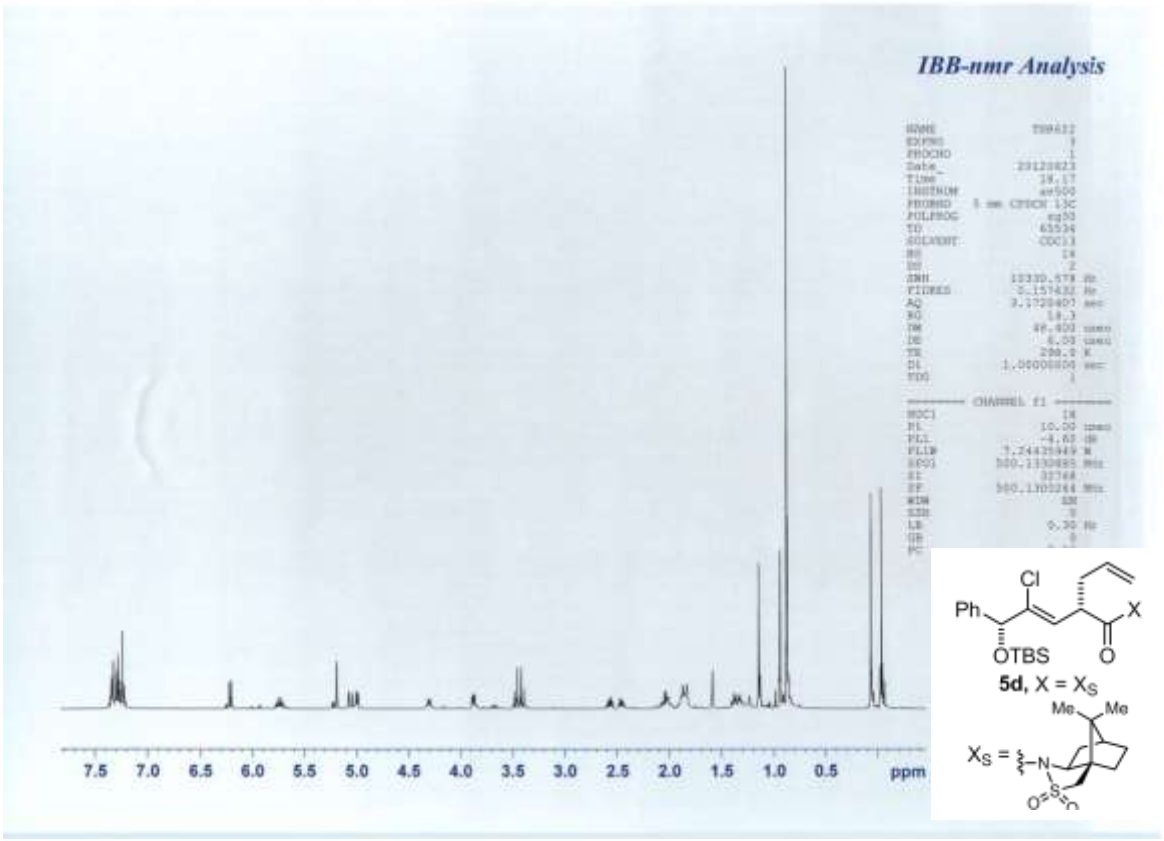
200 180 160 140 120 100 80 60 40 20 0 ppm
Cl
CO2tBu
Ph
X
OTBS
O
5c, X = XS
Me
Me
XS =
N
S
O
O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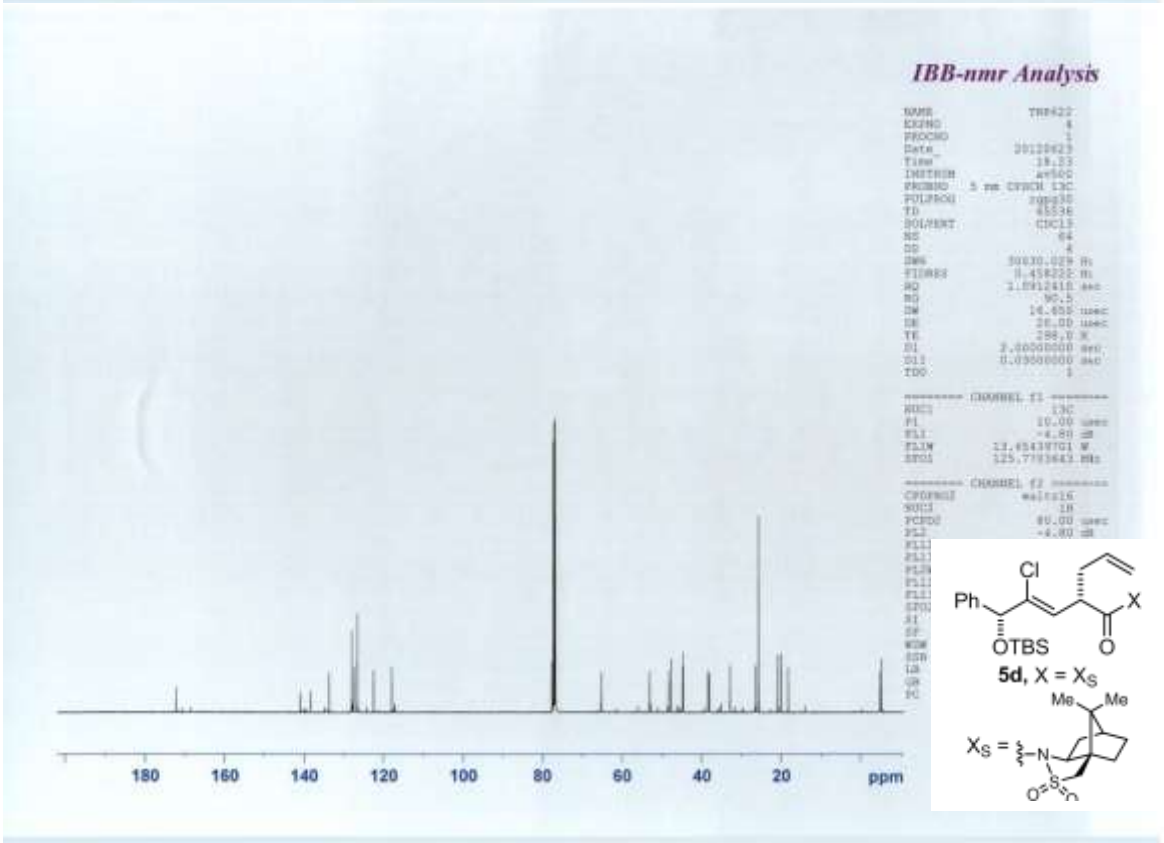
7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 ppm
Cl
Ph
X
OTBS
O
5d, X = XS
Me
Me
XS =
N
S
O


IBB-nmr Analysis
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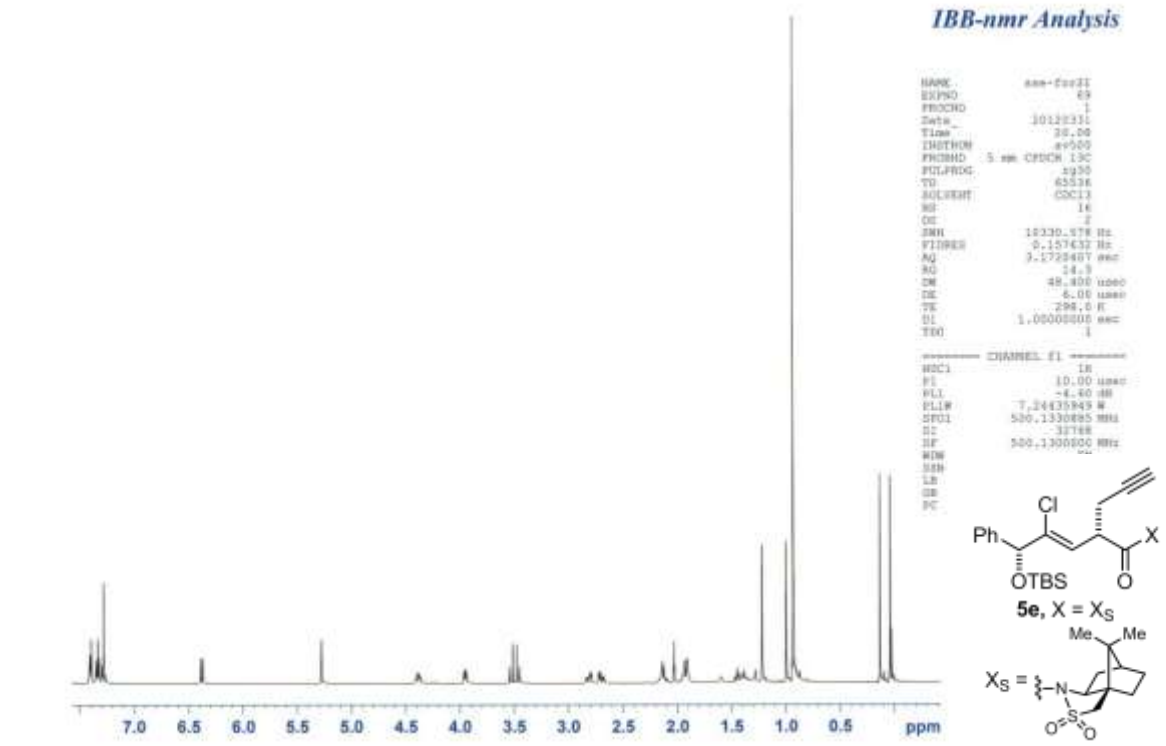
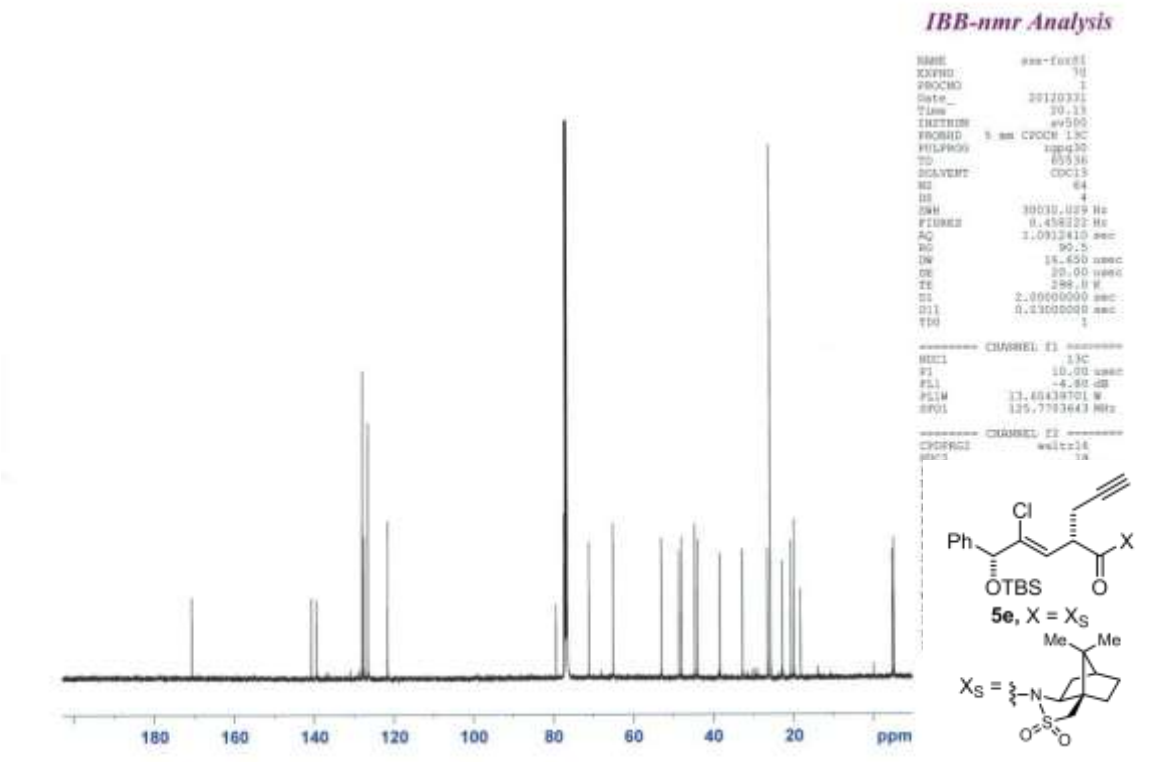
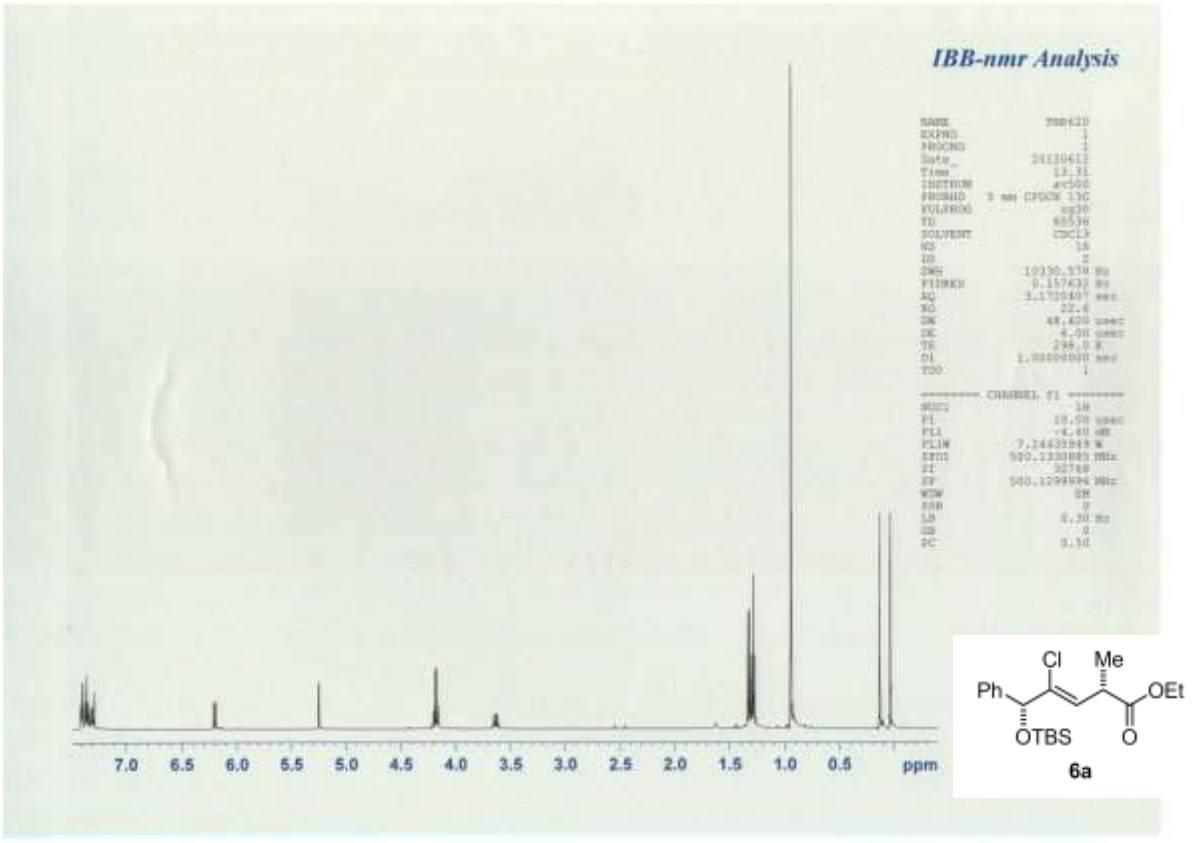
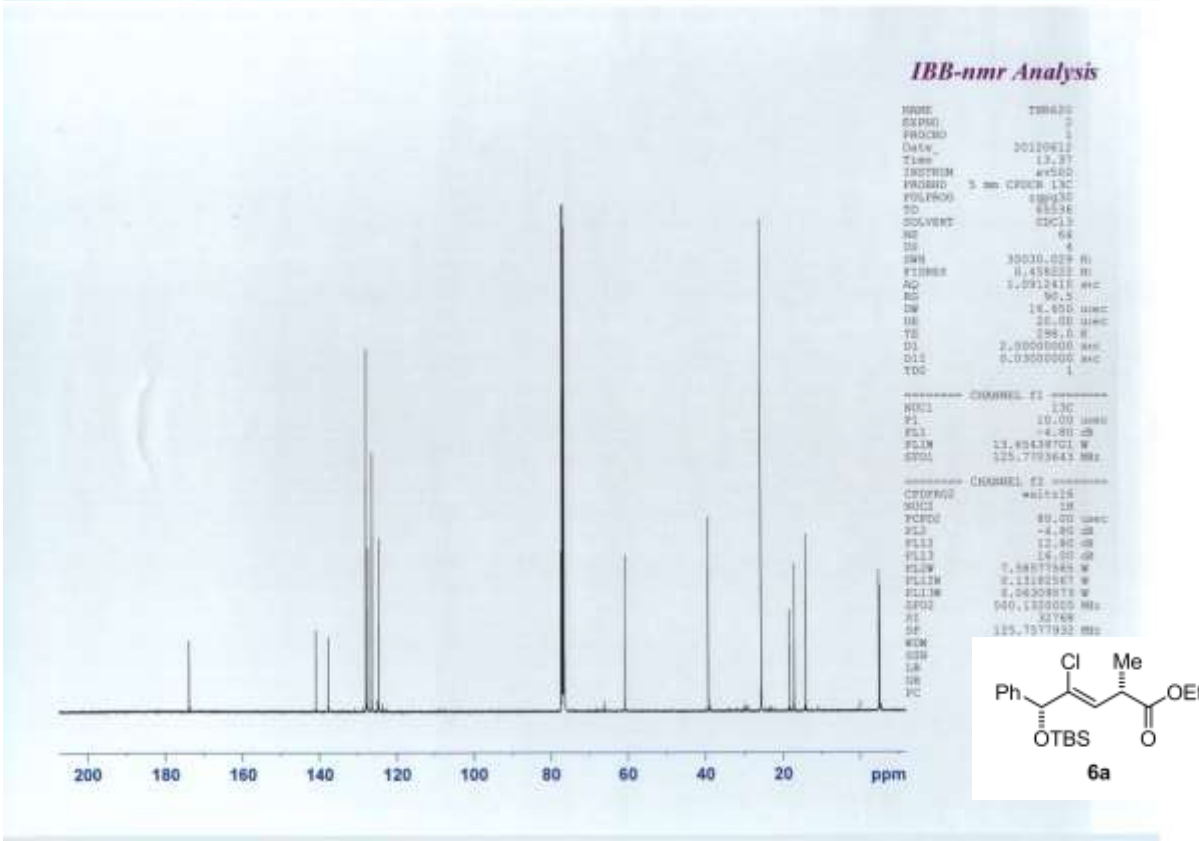
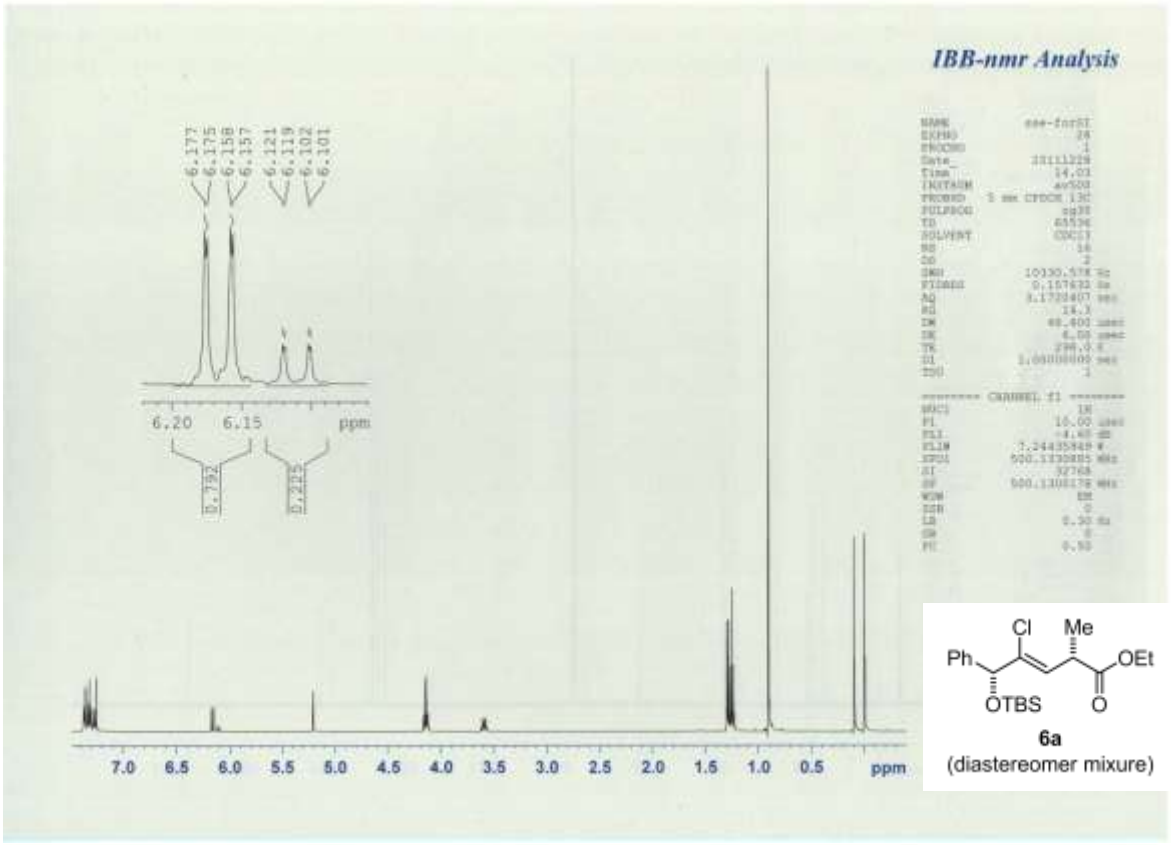
Cl
Ph
X
OTBS
O
5d, X = XS
Me
Me
XS =
N
S
O

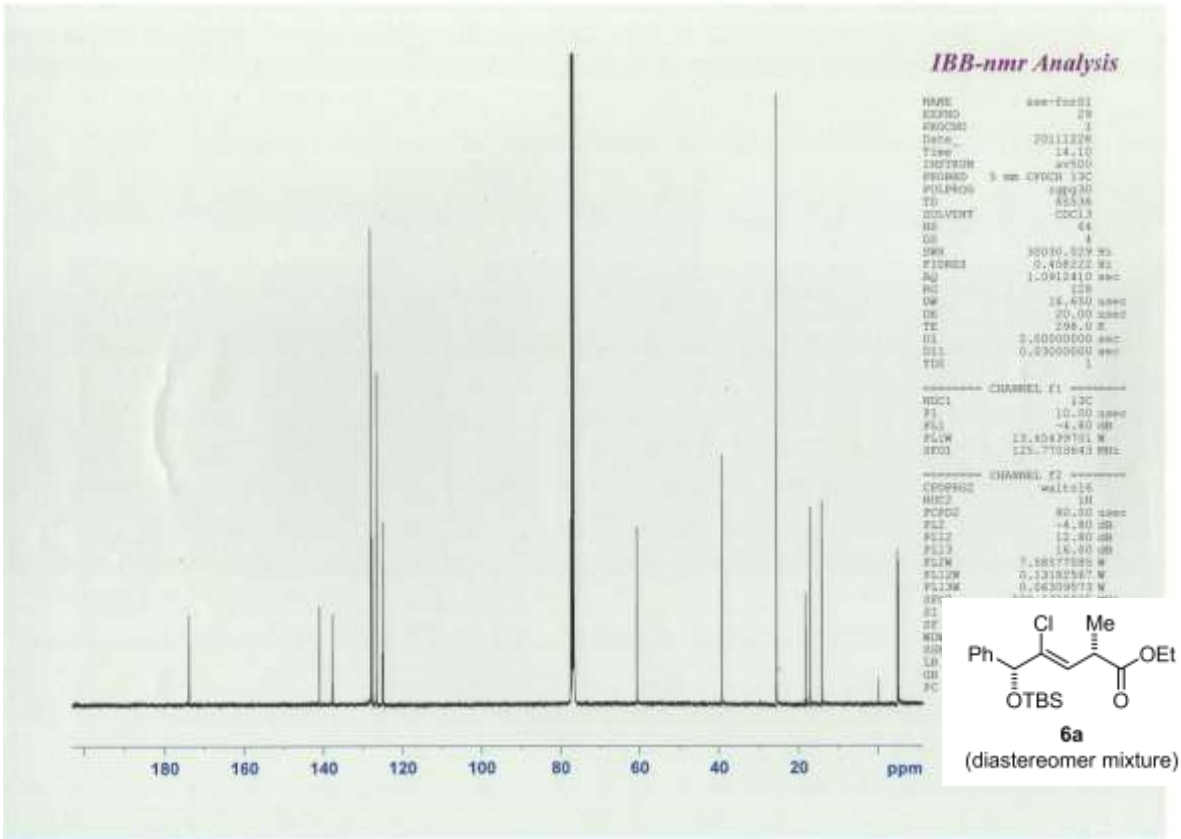

IBB-nmr Analysis
7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 ppm
Cl
Ph
X
OTBS
O
5e, X = XS
Me
Me
XS =
N
S
O
O

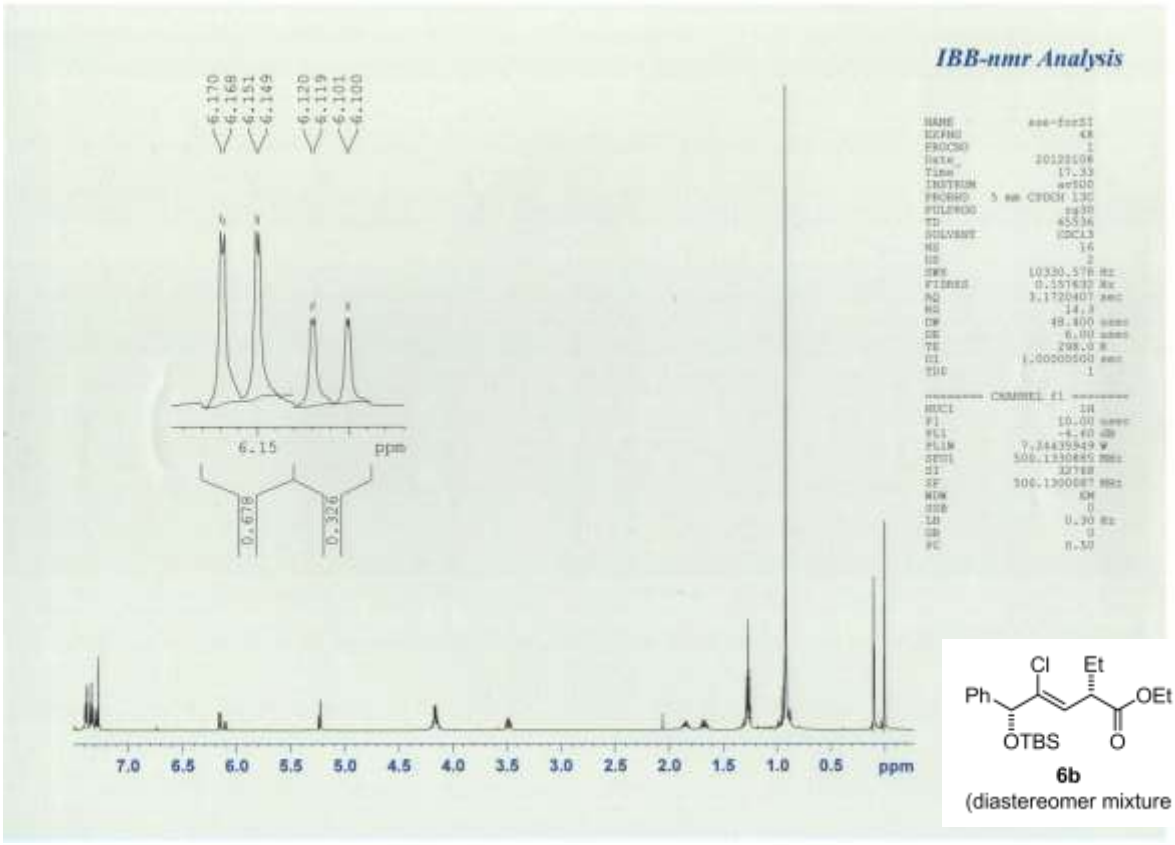

IBB-nmr Analysis
180 160 140 120 100 80 60 40 20 ppm
Cl
Ph
X
OTBS
O
5e, X = XS
Me
Me
XS =
N
S
O
O

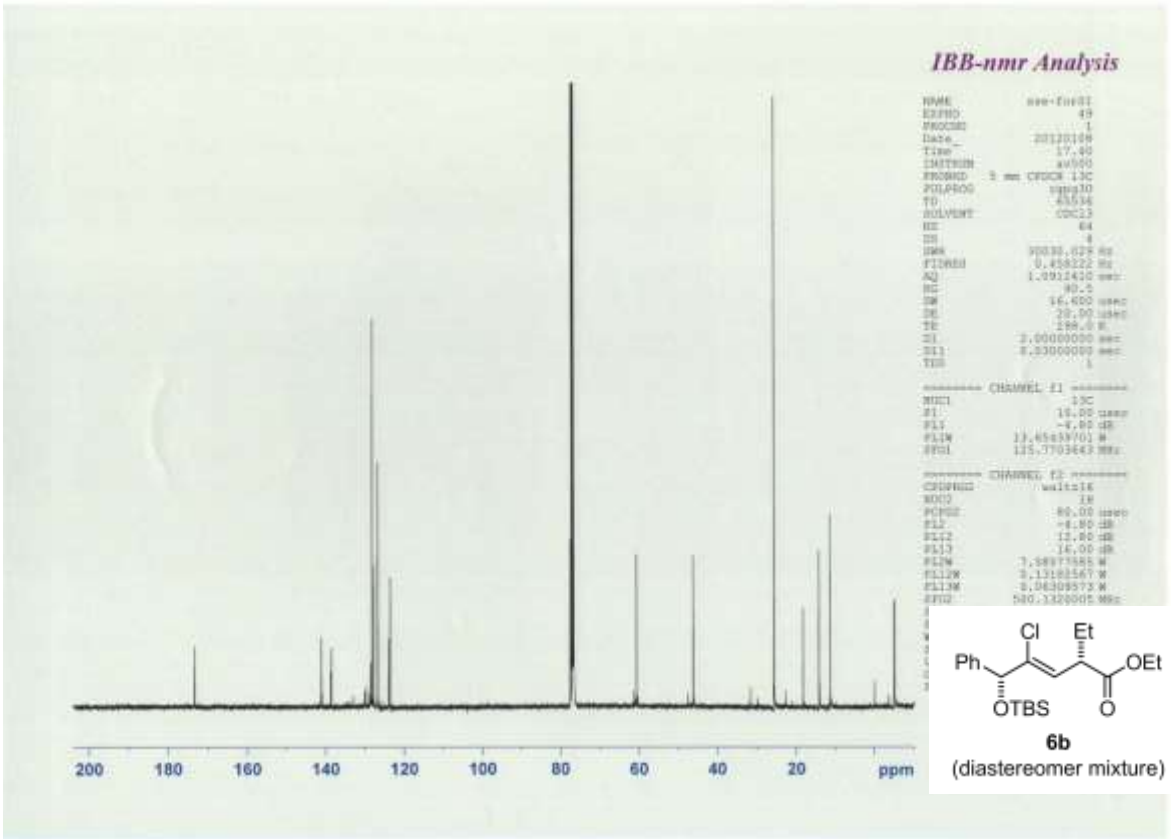

IBB-nmr Analysis
7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5
ppm
Cl
Me
Ph
OEt
OTBS
O
6a

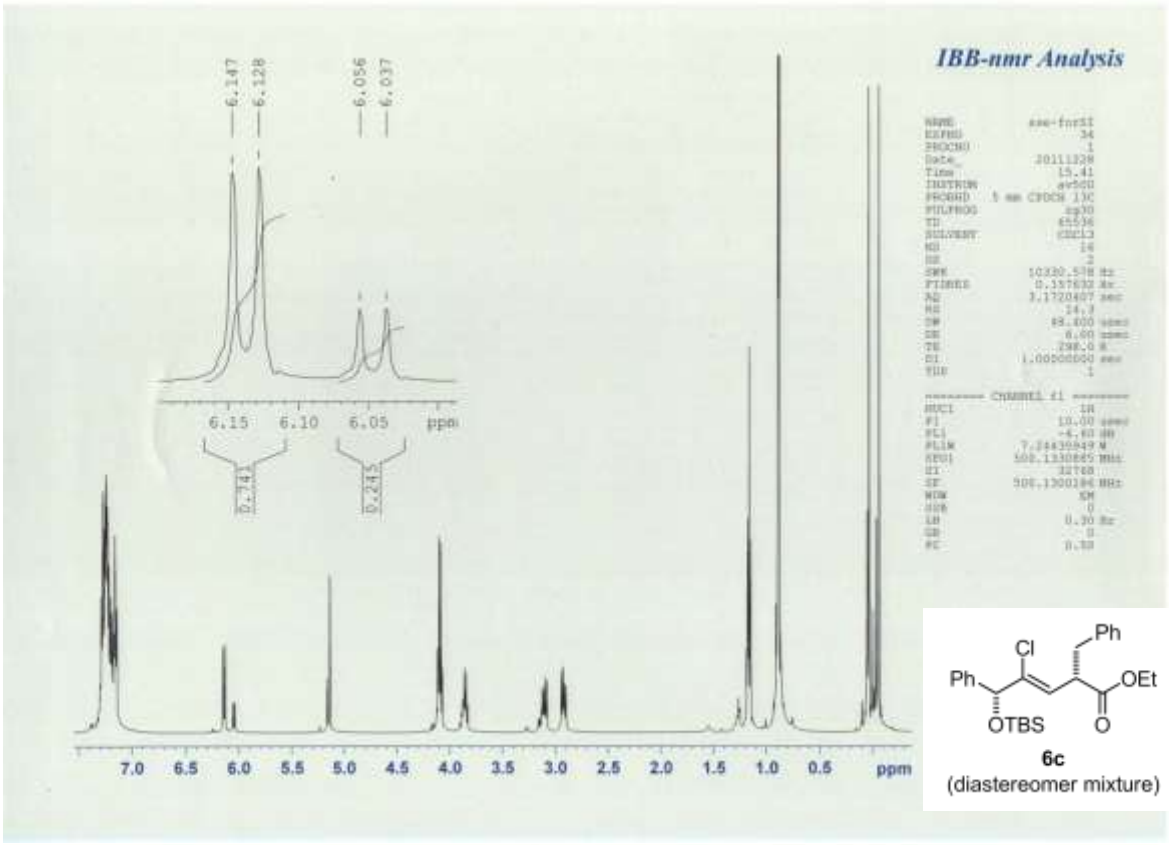

IBB-nmr Analysis
200 180 160 140 120 100 80 60 40 20
ppm
Cl
Me
Ph
OEt
OTBS
O
6a

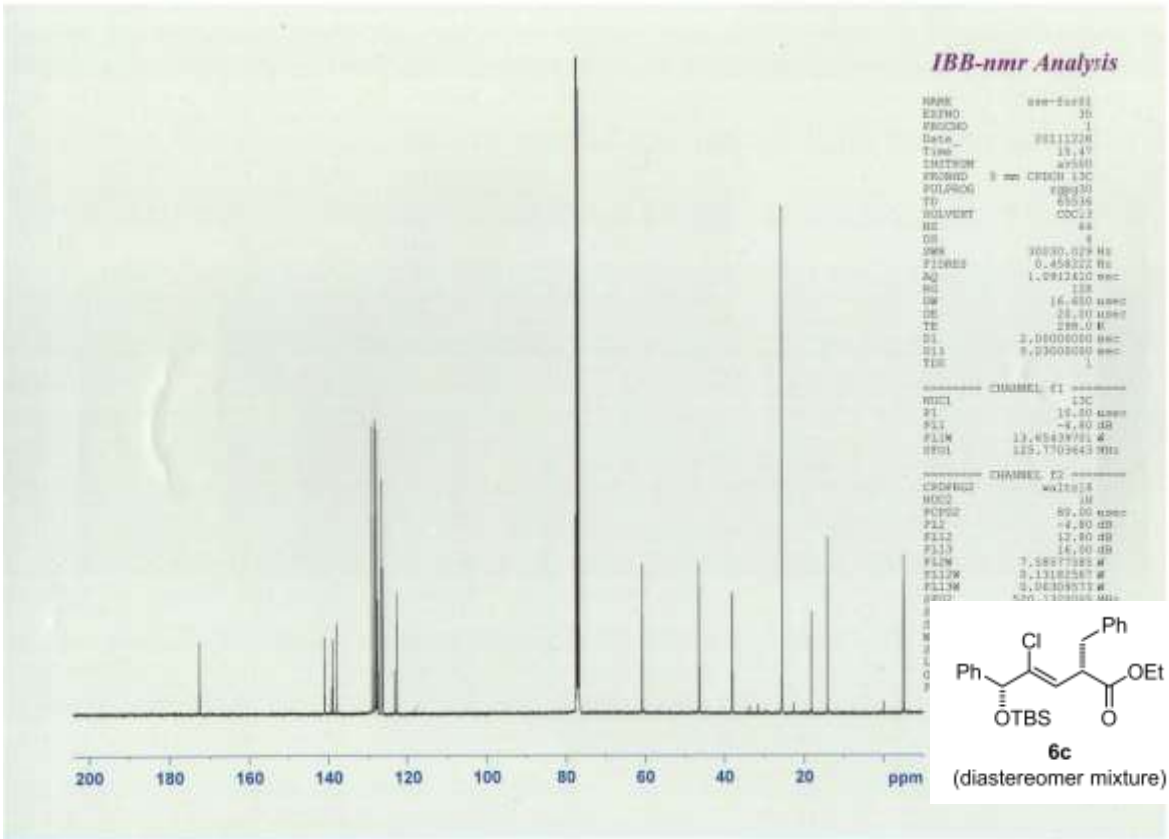

IBB-nmr Analysis
6.177
6.175
6.166
6.157
6.121
6.119
6.102
6.101
6.20
6.15
ppm
0.792
0.225
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
ppm
Cl
Me
Ph
OEt
OTBS
O
6a
(diastereomer mixure)

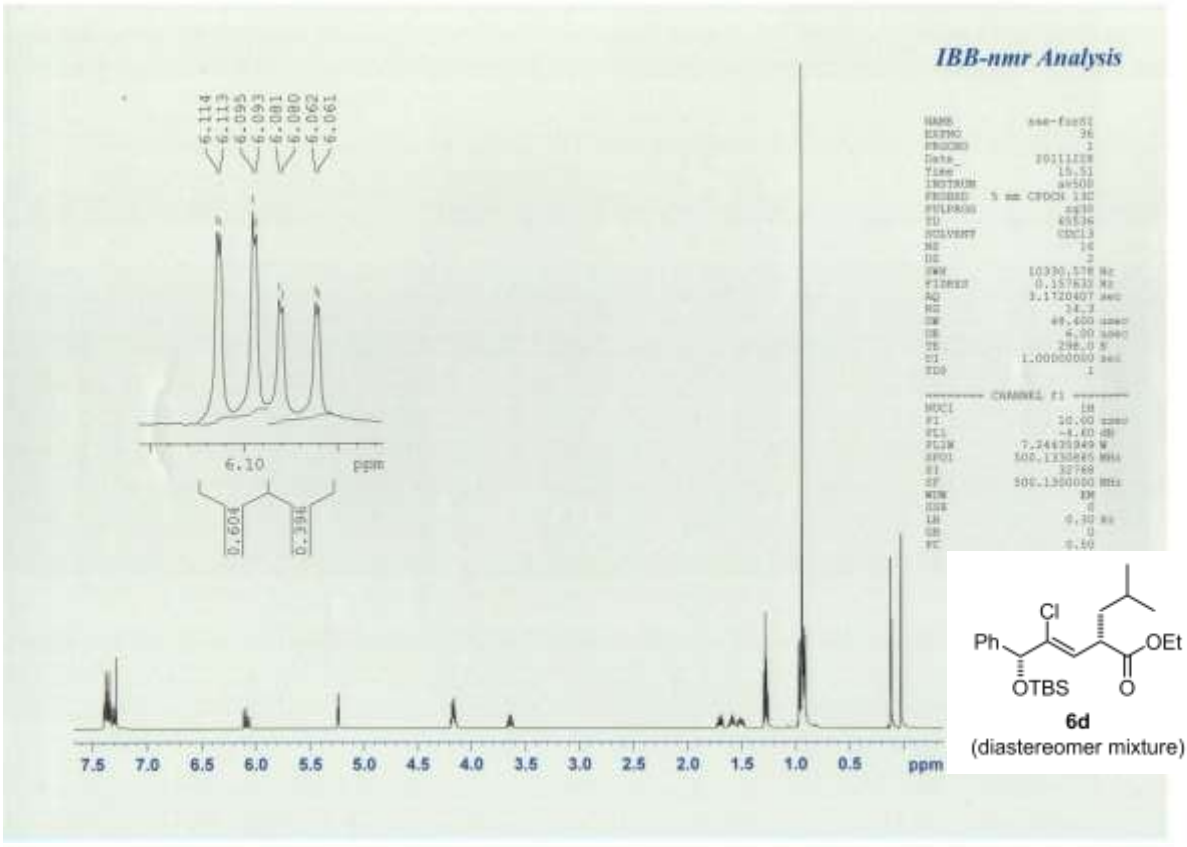

IBB-nmr Analysis
180
160
140
120
100
80
60
40
20
ppm
Cl
Me
Ph
OEt
OTBS
O
6a
(diastereomer mixture)

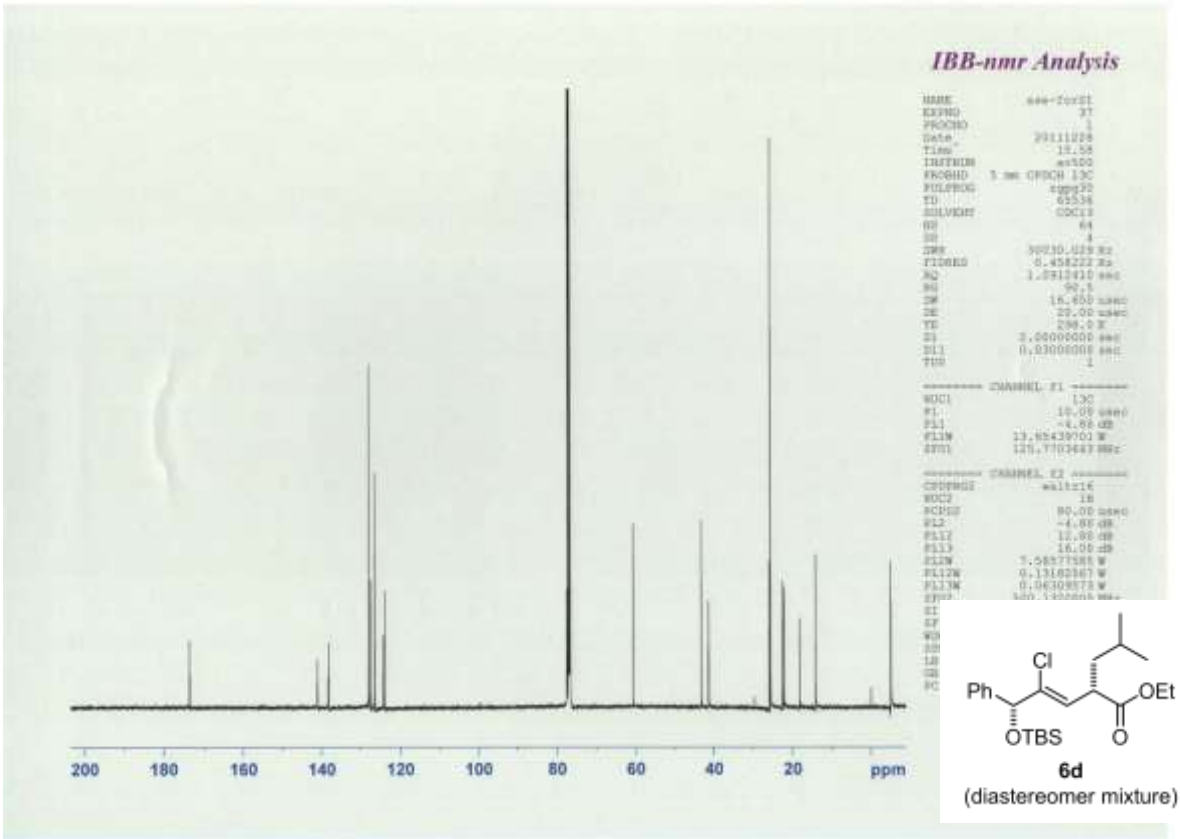

IBB-nmr Analysis
6.170
6.168
6.151
6.149
6.120
6.119
6.101
6.100
6.15
ppm
0.678
0.326
7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 ppm
Cl
Et
Ph
OEt
OTBS
O
6b
(diastereomer mixture

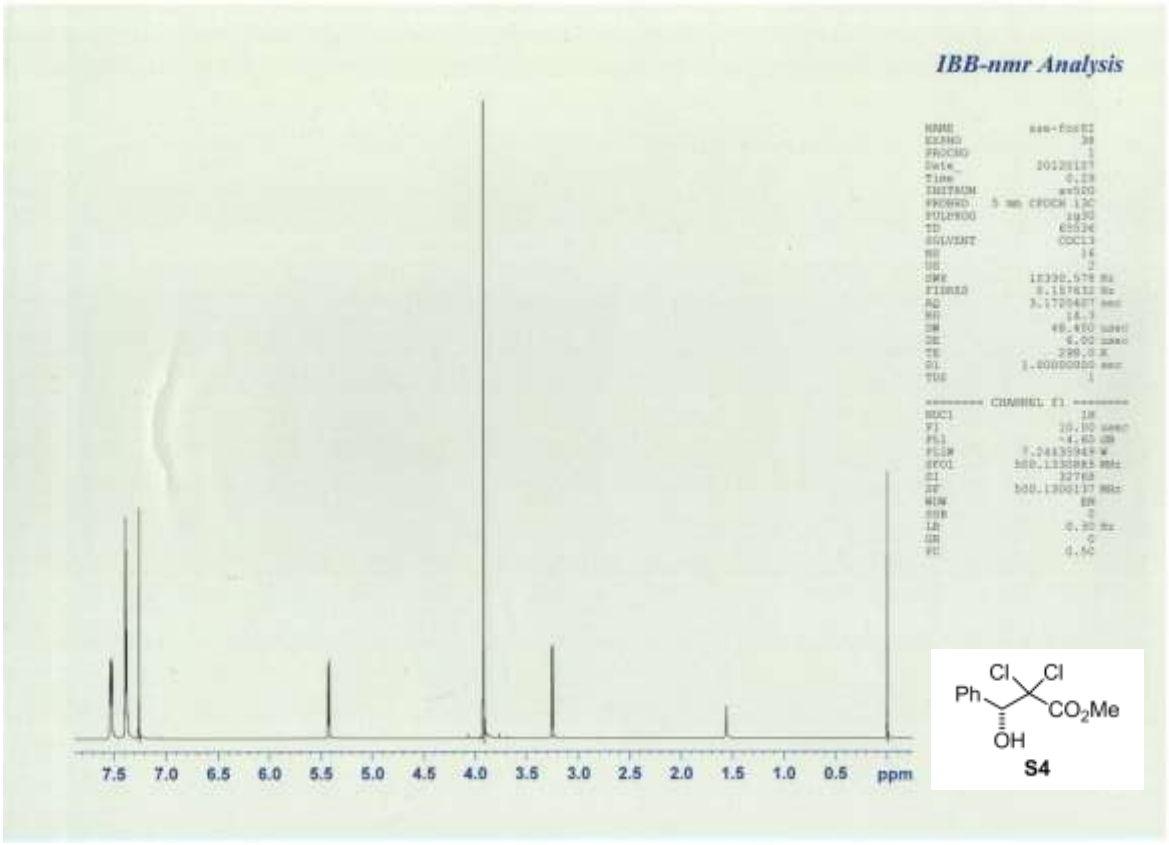

IBB-nmr Analysis
200 180 160 140 120 100 80 60 40 20 ppm
Cl
Et
Ph
OEt
OTBS
O
6b
(diastereomer mixture)

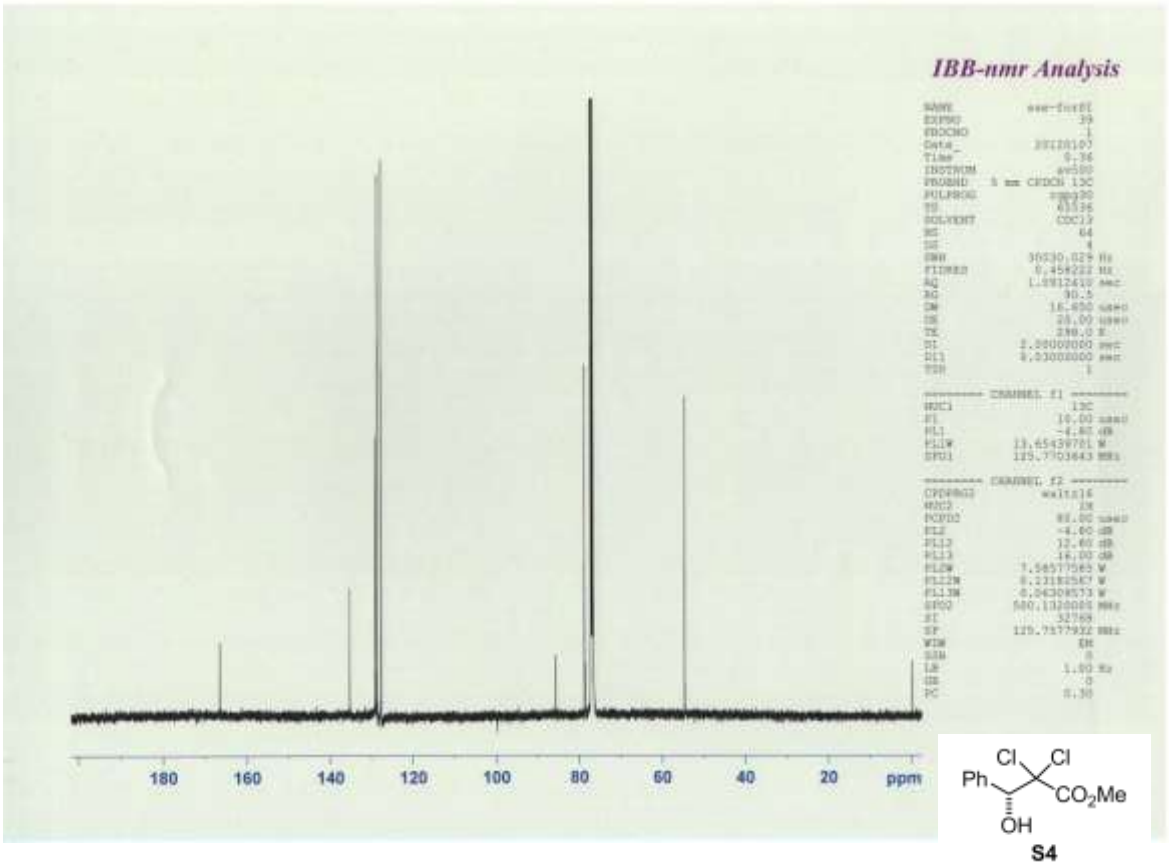

IBB-nmr Analysis
6.147
6.128
6.056
6.037
6.15
6.10
6.05
ppm
0.741
0.245
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
ppm
Ph
Cl
Ph
OEt
OTBS
O
6c
(diastereomer mixture)

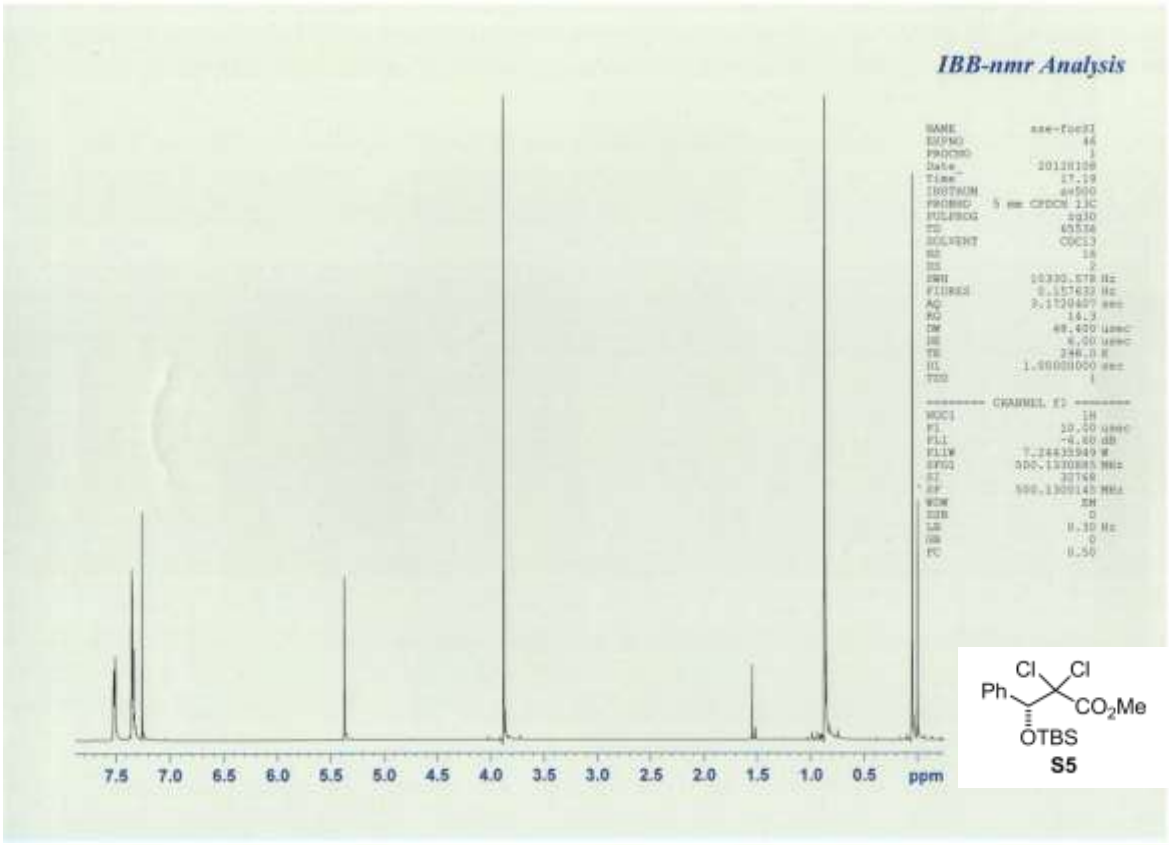

IBB-nmr Analysis
200
180
160
140
120
100
80
60
40
20
ppm
Ph
Cl
Ph
OEt
OTBS
O
6c
(diastereomer mixture)

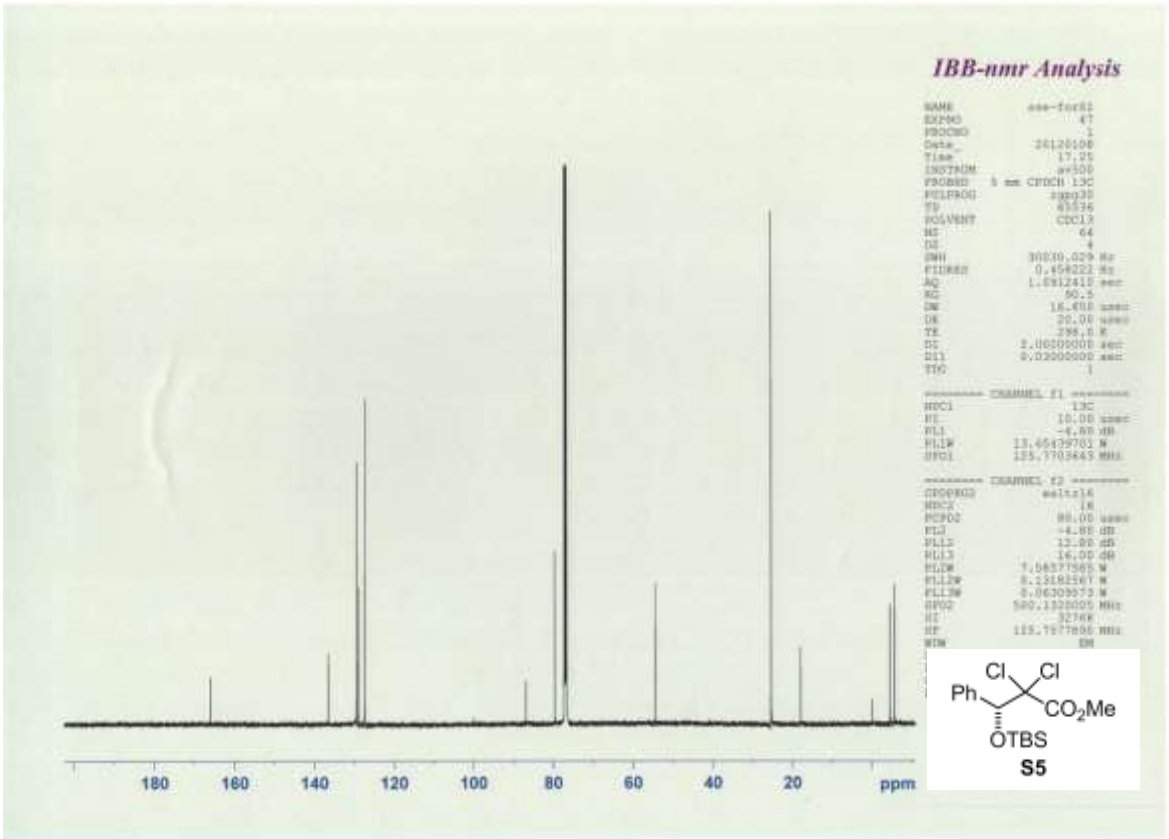

IBB-nmr Analysis
6.114
6.113
6.095
6.093
6.081
6.080
6.092
6.091
6.10
ppm
0.604
0.396
7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 ppm
Cl
Ph
OEt
OTBS
O
6d
(diastereomer mixture)


IBB-nmr Analysis
200 180 160 140 120 100 80 60 40 20 ppm
Cl
Ph
OEt
OTBS
O
6d
(diastereomer mixture)

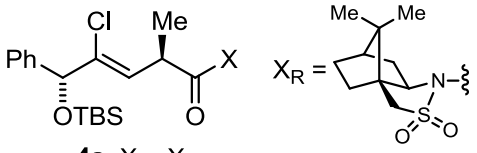

IBB-nmr Analysis
7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 ppm
Cl Cl
Ph
CO2Me
OH
S4


IBB-nmr Analysis
180 160 140 120 100 80 60 40 20 ppm
Cl Cl
Ph
CO2Me
OH
S4


IBB-nmr Analysis
7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 ppm
Cl Cl
Ph
CO2Me
OTBS
S5


IBB-nmr Analysis
180 160 140 120 100 80 60 40 20 ppm
Cl Cl
Ph
CO2Me
OTBS
S5

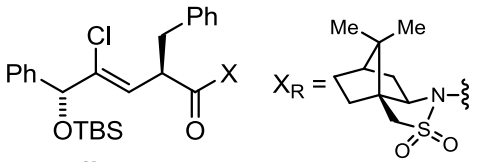
VII-III. HPLC charts of compounds 4a-d, and 5a-d



4a, X = X_R

HPLC conditions: Cosmosil Cholester Packed column (4.6 x 250 mm) with 80%MeCN in H_2O at a flow rate 1.0 mL/min, detection at 220 nm.

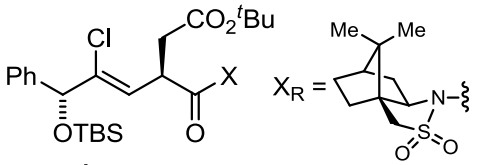
Retention time: t_r **4a** (2*R*,5*R*) = 31.1 min, t_r *epi*-**4a** (2*S*,5*R*) = 33.9 min



4b, X = X_R

HPLC conditions: Cosmosil Cholester Packed column (4.6 x 250 mm) with 80%MeCN in H_2O at a flow rate 1.0 mL/min, detection at 220 nm.

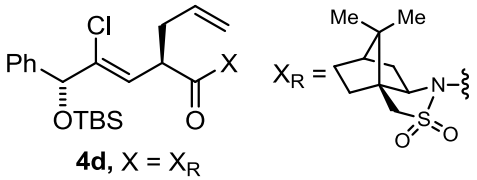
Retention time: t_r **4b** (2*R*,5*R*) = 45.4 min, t_r *epi*-**4b** (2*S*,5*R*) = 48.5 min



4c, X = X_R

HPLC conditions: Cosmosil Cholester Packed column (4.6 x 250 mm) with a liner gradient of MeCN (80-85% over 60 min) in H_2O at a flow rate 0.6 mL/min, detection at 220 nm.

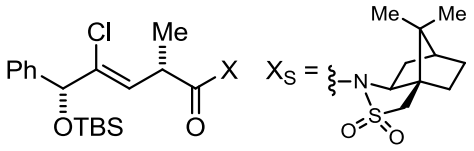
Retention time: t_r **4c** (2*R*,5*R*) = 53.5 min, t_r *epi*-**4c** (2*S*,5*R*) = 55.7 min



4d, X = X_R

HPLC conditions: Cosmosil Cholester Packed column (4.6 x 250 mm) with a liner gradient of MeCN (80-85% over 60 min) in H_2O at a flow rate 0.6 mL/min, detection at 220 nm.

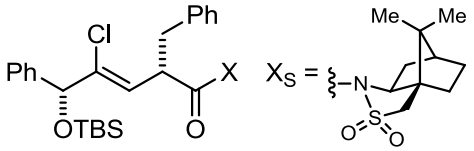
Retention time: t_r **4d** (2*R*,5*R*) = 48.7 min, t_r *epi*-**4d** (2*S*,5*R*) = 51.0 min



5a, X = X_S

HPLC conditions: Cosmosil Cholester Packed column (4.6 x 250 mm) with 80%MeCN in H_2O at a flow rate 1.0 mL/min, detection at 220 nm.

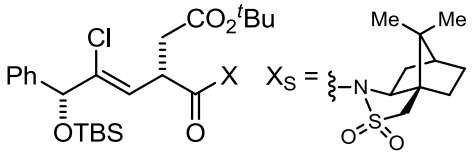
Retention time: t_r **5a** (2*S*,5*R*) = 33.0 min, t_r *epi*-**5a** (2*R*,5*R*) = 30.0 min



5b, X = X_S

HPLC conditions: Cosmosil Cholester Packed column (4.6 x 250 mm) with 85%MeCN in H_2O at a flow rate 1.0 mL/min, detection at 220 nm.

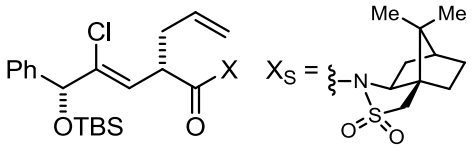
Retention time: t_r **5b** (2*S*,5*R*) = 31.0 min, t_r *epi*-**5b** (2*R*,5*R*) = 29.6 min



5c, X = X_S

HPLC conditions: Cosmosil Cholester Packed column (4.6 x 250 mm) with 80%MeCN in H_2O at a flow rate 1.0 mL/min, detection at 220 nm.

Retention time: t_r **5c** (2*S*,5*R*) = 44.9 min, t_r *epi*-**5c** (2*R*,5*R*) = 43.4 min



5d, X = X_S

HPLC conditions: Cosmosil Cholester Packed column (4.6 x 250 mm) with 80%MeCN in H_2O at a flow rate 0.6 mL/min, detection at 220 nm.

Retention time: t_r **5d** (2*S*,5*R*) = 63.5 min, t_r *epi*-**5d** (2*R*,5*R*) = 58.9 min