Catalytic Enantioselective Synthesis of Quaternary Stereocenters via Intermolecular C-Acylation of Silyl Ketene Acetals: Dual Activation of the Electrophile and the Nucleophile

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Supporting Information

I. General

THF, CH_2Cl_2, and Et_2O were purified by passage through a neutral alumina column. Ac_2O was distilled from phosphorus pentoxide. Benzoic anhydride was recrystallized from Et_2O. $[Me_4N]OAc$ (Alfa Aesar) was purified by recrystallization from 2:1 CH_3CN/CH_2Cl_2. *n*-BuLi (Alfa Aesar) was titrated with diphenylacetic acid (Aldrich) prior to each use. Methylene chloride-d_2 (Cambridge Isotope Laboratories) was distilled from CaH_2. Phenylacetic acid (Aldrich), 4-methoxyphenylacetic acid (Avocado), 4-trifluoromethylphenylacetic acid (Avocado), *o*-tolylacetic acid (Avocado), naphthalene-1-acetic acid (Avocado), thiophene-2-acetic acid (Avocado), thiophene-3-acetic acid (Avocado), 1-methyl-3-indoleacetic acid (Aldrich), 1,3,2-dioxathiolane 2,2-dioxide (Aldrich), diisopropylamine (Aldrich), 1,4-dioxane (Aldrich), Me_3SiCl (Avocado), isobutylene oxide (TCI), chloroform (Mallinckrodt), pentane (Burdick & Jackson), hydrochloric acid (Fisher), bromine (Fluka), $FeBr_3$ (Strem), $AgSbF_6$ (Strem), oxalyl chloride (Aldrich), 2-methyl-2-propanol (Aldrich), NEt_3 (EM Science), *N*,*N*-dimethylformamide (Aldrich), 2-phenylbutyric acid (Aldrich), tetrabutylammonium

chloride (TCI), acetonitrile (Aldrich), and absolute EtOH (Pharmco) were used as received. Catalysts **1-4** were prepared as previously reported.[1]

All experiments were conducted under an argon or nitrogen atmosphere in oven-dried glassware with magnetic stirring, unless otherwise specified.

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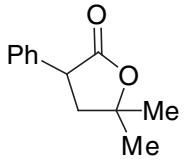
(1) (a) Ruble, J. C.; Fu, G. C. *J. Org. Chem.* **1996**, *61*, 7230-7231. (b) Ruble, J. C.; Latham, H. A.; Fu, G. C. *J. Am. Chem. Soc.* **1997**, *119*, 1492-1493. (c) Ruble, J. C.; Fu, G. C. *J. Am. Chem. Soc.* **1998**, *120*, 11532-11533. (d) Tao, B.; Ruble, J. C.; Hoic, D. A.; Fu, G. C. *J. Am. Chem. Soc.* **1999**, *121*, 5091-5092.

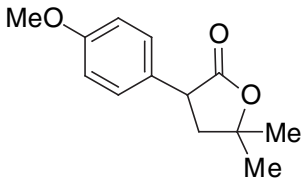
II. Preparation of Esters

These reactions have not been optimized.



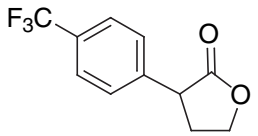
A solution of *n*-BuLi (in hexanes; 75.6 mL, 185 mmol) was added via syringe to a –78 °C solution of diisopropylamine (25.9 mL, 185 mmol) in THF (100 mL). This solution was stirred at –78 °C for 45 minutes, and then a solution of phenylacetic acid (12.0 g, 88.1 mmol) in THF (75 mL) was added via cannula. The reaction mixture was stirred at –78 °C for 20 minutes, then warmed to room temperature and stirred for 2 hours. The solution was then cooled to 0 °C, and neat isobutylene oxide (7.90 mL, 88.1 mmol) was added via syringe, resulting in a clear yellow solution, which was stirred for 12 hours at room temperature. Water (50 mL) was then added, resulting in a clear colorless solution, which was refluxed for 2 hours. Then, the reaction mixture was cooled to room temperature and washed with Et_2O (3 x 150 mL). The aqueous layer was diluted with 95% EtOH (100 mL), acidified with concentrated HCl (25 mL), and refluxed for 3 hours. Then, it was cooled to room temperature and extracted with $CHCl_3$ (3 x 200 mL). The $CHCl_3$ layer was washed with saturated aqueous $NaHCO_3$ (2 x 100 mL), then dried (Na_2SO_4) and concentrated. The resulting white solid was recrystallized from Et_2O/pentane (9:1) to afford white crystals, which were collected, washed with pentane, and dried under vacuum (13.7 g, 82%).

^{1}H NMR (500 MHz, $CDCl_3$) δ 7.36-7.39 (m, 2H), 7.27-7.32 (m, 3H), 4.05 (dd, 1H, J=12.0, J=9.5), 2.59 (dd, 1H, J=12.5, J=9.5), 2.25 (app t, 1H, J=12.5), 1.56 (s, 3H), 1.51 (s, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 176.7, 137.2, 129.1, 128.3, 127.7, 82.3, 47.2, 44.4, 29.1, 27.2. FTIR (CH_2Cl_2) 3031, 2979, 2945, 1772, 1653, 1498, 1457, 1375, 1261, 1141 cm^{-1}. HRMS (EI, *m/z*) calcd. for $C_{12}H_{14}O_2$ (M^+) 190.0994, found 190.0989. mp 63-66 °C.



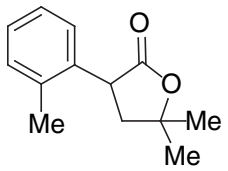
A solution of *n*-BuLi (in hexanes; 48.6 mL, 126 mmol) was added via syringe to a –78 °C solution of diisopropylamine (17.7 mL, 126 mmol) in THF (150 mL). This mixture was stirred at –78 °C for 30 minutes, then warmed to 0 °C. A solution of 4-methoxyphenylacetic acid (7.00 g, 42.1 mmol) in THF (50 mL) was added via cannula, and the resulting mixture was warmed to 40 °C and stirred for 1 hour. Neat isobutylene oxide (7.90 mL, 88.1 mmol) was then added via syringe, and the resulting solution was refluxed for 18 hours. The reaction mixture was cooled to 0 °C, and water (100 mL) was added, resulting in a clear, colorless solution. This mixture was refluxed for 2 hours, then cooled to room temperature, diluted with water (100 mL), and washed with Et_2O (3 x 150 mL). The aqueous layer was diluted with absolute EtOH (100 mL), acidified with 6 N HCl (70 mL), and then refluxed for 4 hours. The mixture was cooled to room temperature and extracted with $CHCl_3$ (3 x 200 mL). The $CHCl_3$ layer was washed with saturated aqueous $NaHCO_3$ (2 x 100 mL), dried ($MgSO_4$), and concentrated. The resulting yellow solid was recrystallized in 3 crops from Et_2O/CH_2Cl_2/pentane (5:4:50) to afford flocculent white needles, which were collected, washed with pentane, and dried under vacuum (7.79 g, 84%).

^{1}H NMR (500 MHz, $CDCl_3$) δ 7.20 (d, 2H, J=8.5), 6.90 (d, 2H, J=9.0), 3.99 (dd, 1H, J=12.0, J=9.5), 3.80 (s, 3H), 2.55 (dd, 1H, J=12.5, J=9.0), 2.20 (dd, 1H, J=12.5, J=12.0), 1.54 (s, 3H), 1.48 (s, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 177.0, 159.1, 129.3, 129.1, 114.5, 82.2, 55.5, 46.4, 44.4, 29.1, 27.1. FTIR (CH_2Cl_2) 2975, 2935, 2838, 1771, 1653, 1615, 1516, 1375, 1250, 1139 cm^{-1}. HRMS (EI, *m/z*) calcd. for $C_{13}H_{16}O_3$ (M^+) 220.1094, found 220.1090. mp 64-68 °C.



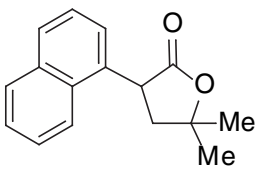
A solution of *n*-BuLi (in hexanes; 6.32 mL, 17.7 mmol) was added via syringe to a –78 °C solution of diisopropylamine (2.48 mL, 17.7 mmol) in THF (50 mL). The reaction mixture was stirred at –78 °C for 45 minutes, after which a solution of 4-trifluoromethylphenylacetic acid (1.72 g, 8.43 mmol) in THF (10 mL) was added via cannula, resulting in a deep-red solution. This mixture was stirred for 45 minutes at –78 °C, after which 1,3,2-dioxathiolane 2,2-dioxide (1.05 g, 8.43 mmol) in THF (10 mL) was added via cannula. The resulting mixture was stirred at –78 °C for 10 minutes, warmed to room temperature, and then refluxed for 12 hours. The reaction mixture was cooled to room temperature, water (20 mL) was added, and the solution was refluxed for 1 hour. The reaction mixture was then cooled to room temperature and extracted with Et_2O (3 x 100 mL). The organic layer was dried over $MgSO_4$ and concentrated to a yellow liquid, which was purified by flash chromatography (Et_2O), furnishing a clear, light-yellow oil (1.27 g, 65%).

^{1}H NMR (500 MHz, C_6D_6) δ 7.32 (d, 2H, J=8.0), 6.87 (d, 2H, J=8.0), 3.58 (ddd, 1H, J=11.5, J=8.5, J=3.0), 3.37 (m, 1H), 2.92 (dd, 1H, J=15.5, J=9.5), 1.37-1.54 (m, 2H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 176.7, 140.7, 130.1 (q, J=32.8), 128.6, 126.0 (q, J=3.4), 124.2 (q, J=272), 66.7, 45.5, 31.5. FTIR (neat) 2996, 2915, 1772, 1620, 1421, 1375, 1327, 1116 cm^{-1}. HRMS (EI, *m/z*) calcd. for $C_{11}H_9F_3O_2$ (M^+) 220.1094, found 220.1090. bp 145-147 °C (0.5 mm Hg).



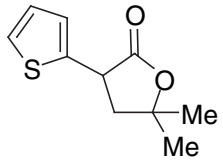
A solution of *n*-BuLi (in hexanes; 27.6 mL, 73.3 mmol) was added via syringe to a –78 °C solution of diisopropylamine (10.3 mL, 73.3 mmol) in THF (80 mL). The mixture was stirred at –78 °C for 30 minutes and then warmed to 0 °C. A solution of *o*-tolylacetic acid (5.00 g, 33.3 mmol) in THF (20 mL) was then added via cannula. The reaction mixture was warmed to 40 °C and stirred for 1 hour, and then neat isobutylene oxide (3.00 mL, 88.1 mmol) was added via syringe. The resulting solution was stirred at 0 °C for 1 hour, then refluxed for 18 hours. The solution was cooled to 0 °C, water (50 mL) was added, and the reaction mixture was refluxed for 2 hours. It was then cooled to room temperature, diluted with water (100 mL), and washed with Et_2O (3 x 50 mL). The aqueous layer was diluted with absolute EtOH (50 mL), acidified with 6 N HCl (200 mL), and refluxed for 2 hours. The reaction mixture was then cooled to room temperature and extracted with $CHCl_3$ (3 x 200 mL). The $CHCl_3$ layer was washed with saturated aqueous $NaHCO_3$ (2 x 100 mL), dried (Na_2SO_4), and concentrated. The resulting yellow solid was recrystallized in 2 crops from Et_2O/pentane (1:10) to afford white crystals, which were collected, washed with pentane, and dried under vacuum (4.14 g, 61%).

^{1}H NMR (500 MHz, $CDCl_3$) δ 7.17-7.27 (m, 4H), 4.21 (dd, 1H, J=11.0, J=9.0), 2.57 (dd, 1H, J=12.5, J=9.5), 2.36 (s, 3H), 2.13 (dd, 1H, J=12.5, J=11.5), 1.55 (s, 3H), 1.51 (s, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 177.0, 136.4, 136.0, 130.9, 128.0, 127.7, 126.9, 82.4, 44.7, 43.8, 29.2, 27.4, 19.9. FTIR (CH_2Cl_2) 3019, 2983, 1750, 1653, 1497, 1457, 1377, 1278, 1144 cm^{-1}. HRMS (EI, *m/z*) calcd. for $C_{13}H_{16}O_2$ (M^+) 204.1145, found 204.1136. mp 64-66 °C.



A solution of *n*-BuLi (in hexanes; 30.4 mL, 80.6 mmol) was added via syringe to a –78 °C solution of diisopropylamine (8.15 mL, 80.6 mmol) in THF (100 mL). The mixture was stirred at –78 °C for 30 minutes and then warmed to 0 °C. A solution of naphthalene-1-acetic acid (5.00 g, 26.9 mmol) in THF (20 mL) was then added via cannula, resulting in a bright-orange solution. The reaction mixture was warmed to 50 °C and stirred for 1 hour. Then, neat isobutylene oxide (2.40 mL, 26.9 mmol) was added via syringe. The resulting deep-red solution was stirred at 60 °C for 12 hours. The solution was cooled to 0 °C, diluted with water (60 mL), and then refluxed for 2 hours. It was then cooled to room temperature, diluted with water (100 mL), and washed with Et_2O (3 x 50 mL). The aqueous layer was diluted with absolute EtOH (75 mL), acidified with 6 N HCl (50 mL), and refluxed for 2 hours. Then, it was cooled to room temperature and extracted with $CHCl_3$ (3 x 200 mL). The $CHCl_3$ layer was successively washed with saturated aqueous $NaHCO_3$ (2 x 100 mL) and NaCl (1 x 100 mL), dried ($MgSO_4$), and concentrated. The resulting yellow solid was recrystallized in 2 crops from CH_2Cl_2/pentane (1:5) to afford white crystals, which were collected, washed with pentane, and dried under vacuum (5.53 g, 86%).

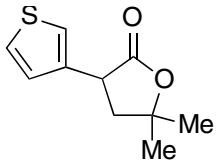
^{1}H NMR (300 MHz, $CDCl_3$) δ 7.78-7.91 (m, 3H), 7.44-7.58 (m, 4H), 4.73 (dd, 1H, J=10.5, J=9.6), 2.74 (dd, 1H, J=12.9, J=9.3), 2.30 (dd, 1H, J=12.9, J=10.5), 1.60 (s, 3H), 1.57 (s, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 176.9, 134.2, 133.8, 131.4, 129.4, 128.5, 126.6, 126.0, 125.8, 123.0, 82.7, 44.7, 44.2, 29.2, 27.7. FTIR (CH_2Cl_2) 3053, 2975, 2932, 1763, 1653, 1512, 1457, 1375, 1268, 1138 cm^{-1}. HRMS (EI, *m/z*) calcd. for $C_{16}H_{16}O_2$ (M^+) 240.1145, found 220.1140. mp 122-125 °C.



A solution of *n*-BuLi (in hexanes; 38.8 mL, 101 mmol) was added via syringe to a –78 °C solution of diisopropylamine (14.2 mL, 101 mmol) in THF (150 mL). The mixture

was stirred at –78 °C for 30 minutes and then warmed to 0 °C. A solution of thiophene-2-acetic acid (7.00 g, 49.2 mmol) in THF (50 mL) was added via cannula, and the mixture was warmed to 40 °C and stirred for 1 hour. Neat isobutylene oxide (4.44 mL, 49.2 mmol) was added via syringe, and the resulting solution was refluxed for 18 hours. Water (100 mL) was then added, and the reaction mixture was refluxed for 2 hours. It was then cooled to room temperature and washed with Et_2O (3 x 150 mL). The aqueous layer was diluted with absolute EtOH (100 mL), acidified with 1N HCl (75 mL), and refluxed for 2 hours. It was then cooled to room temperature and extracted with $CHCl_3$ (3 x 200 mL). The $CHCl_3$ layer was washed successively with saturated aqueous $NaHCO_3$ (2 x 100 mL) and NaCl (2 x 100 mL), dried ($MgSO_4$), and concentrated. The resulting tan solid was recrystallized in 2 crops from CH_2Cl_2/pentane (3:10) to afford light-tan crystals, which were collected, washed with pentane, and dried under vacuum (8.60 g, 89%).

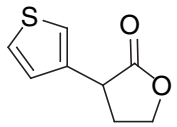
^{1}H NMR (300 MHz, $CDCl_3$) δ 7.25 (dd, 1H, J=5.1, J=1.2), 6.97-7.03 (m, 2H), 4.27 (ddd, 1H, J=12.6, J=11.7, J=1.2), 2.67 (dd, 1H, J=12.6, J=9.0), 2.34 (dd, 1H, J=12.9, J=11.4), 1.54 (s, 3H), 1.49 (s, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 175.0, 138.6, 126.9, 125.6, 124.9, 82.5, 43.7, 42.1, 28.7, 26.9. FTIR (CH_2Cl_2) 3102, 2972, 2931, 2870, 1759, 1653, 1456, 1375, 1300, 1139 cm^{-1}. HRMS (EI, *m/z*) calcd. for $C_{10}H_{12}O_2S$ (M^+) 196.0553, found 196.0561. mp 61-63 °C.



A solution of *n*-BuLi (in hexanes; 16.7 mL, 44.3 mmol) was added via syringe to a –78 °C solution of diisopropylamine (6.21 mL, 44.3 mmol) in THF (70 mL). The mixture was stirred at –78 °C for 30 minutes and then warmed to 0 °C. A solution of thiophene-3-acetic acid (3.00 g, 21.1 mmol) in THF (10 mL) was added via cannula, and the reaction mixture was warmed to 50 °C and stirred for 40 minutes. Neat isobutylene oxide (1.90 mL, 21.1 mmol) was added via syringe, and the resulting solution was stirred at 50 °C

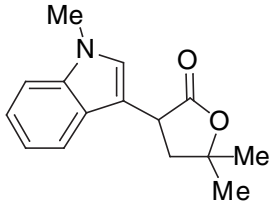
for 12 hours. Water (100 mL) was added, and the reaction mixture was refluxed for 2 hours. It was then cooled to room temperature and washed with Et_2O (3 x 150 mL). The aqueous layer was diluted with absolute EtOH (50 mL), acidified with 2 N HCl (75 mL), and refluxed for 2 hours. Then, it was cooled to room temperature and extracted with $CHCl_3$ (4 x 200 mL). The $CHCl_3$ layer was washed with saturated aqueous $NaHCO_3$ (2 x 100 mL), dried (Na_2SO_4), and concentrated to afford a gold oil, which was purified by flash chromatography (25% Et_2O/75% pentane ‡ 40% Et_2O/60% pentane) to provide a clear, light-yellow oil (2.91 g, 70%).

^{1}H NMR (300 MHz, $CDCl_3$) δ 7.34 (dd, 1H, J=5.1, J=2.7), 7.23-7.26 (m, 1H), 7.09 (dd, 1H, J=5.1, J=1.2), 4.12 (dd, 1H, J=11.4, J=9.0), 2.58 (dd, 1H, J=12.6, J=9.0), 2.25 (app t, 1H, J=12.0), 1.52 (s, 3H), 1.48 (s, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 176.0, 136.7, 127.0, 126.3, 122.1, 82.4, 42.9, 42.1, 28.8, 26.9. FTIR (neat) 3105, 2977, 2934, 1762, 1456, 1375, 1261, 1140 cm^{-1}. HRMS (EI, *m/z*) calcd. for $C_{10}H_{12}O_2S$ (M^+) 196.0553, found 196.0557.



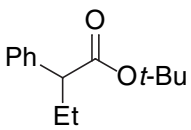
A solution of *n*-BuLi (in hexanes; 16.0 mL, 42.3 mmol) was added via syringe to a –78 °C solution of diisopropylamine (5.93 mL, 42.3 mmol) in THF (20 mL). The mixture was stirred at –78 °C for 45 minutes, and then a solution of thiophene-3-acetic acid (2.86 g, 20.1 mmol) in THF (20 mL) was added via cannula. The mixture was stirred for 20 minutes at –78 °C, warmed to room temperature, and stirred for 45 minutes. A solution of 1,3,2-dioxathiolane 2,2-dioxide (2.50 g, 20.1 mmol) in THF (20 mL) was added via syringe. 1,2-Dimethoxyethane (15 mL) was added, and the resulting solution was refluxed for 16 hours. Water (20 mL) was then added, and the resulting mixture was extracted with CH_2Cl_2 (3 x 100 mL). The organic layer was washed successively with saturated aqueous $NaHCO_3$ (2 x 100 mL) and NaCl (1 x 50 mL), and then it was concentrated, affording a yellow liquid. Purification by flash chromatography (50% Et_2O/50% pentane ‡ 75% Et_2O/25% pentane) provided a clear, light-yellow oil (1.86 g, 55%).

^{1}H NMR (300 MHz, $CDCl_3$) δ 7.35 (dd, 1H, J=4.8, J=3.0), 7.24-7.26 (m, 1H), 7.10 (dd, 1H, J=4.8, J=1.2), 4.47 (ddd, 1H, J=12.3, J=8.7, J=3.6), 4.35 (ddd, 1H, J=15.6, J=9.0, J=6.6), 3.91 (dd, 1H, J=9.6, J=9.0), 2.68-2.79 (m, 1H), 2.40-2.53 (m, 1H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 177.0, 136.3, 126.9, 126.4, 122.1, 66.7, 40.7, 30.6. FTIR (neat) 3103, 2990, 2910, 1772, 1482, 1373, 1156, 1024 cm^{-1}. HRMS (ESI, *m/z*) calcd. for $C_8H_8O_2S$ $(M+Na)^+$ 191.0137, found 191.0141.



A solution of *n*-BuLi (in hexanes; 19.6 mL, 58.1 mmol) was added via syringe to a –78 °C solution of diisopropylamine (8.15 mL, 58.1 mmol) in THF (50 mL). The mixture was stirred at –78 °C for 40 minutes, and then a solution of 1-methyl-indole-3-acetic acid (5.00 g, 26.4 mmol) in THF (20 mL) was added via cannula. The mixture was stirred at –78° C for 75 minutes, and then neat isobutylene oxide (2.38 mL, 26.4 mmol) was added via syringe. The resulting solution was warmed to room temperature and stirred for 12 hours. Water (100 mL) was then added, and the resulting solution was refluxed for 2 hours. It was then cooled to room temperature, washed with Et_2O (3 x 150 mL), diluted with water (160 mL) and absolute EtOH (50 mL), and acidified with 6 N HCl (70 mL). This reaction mixture was refluxed for 4 hours and then cooled to room temperature and extracted with $CHCl_3$ (3 x 200 mL). The $CHCl_3$ layer was successively washed with saturated aqueous $NaHCO_3$ (3 x 100 mL) and water (2 x 100 mL), dried (Na_2SO_4), and concentrated. The resulting brown solid was recrystallized in 2 crops from EtOH/H_2O (1:1) to afford dark-tan crystals, which were collected, washed with pentane, and dried under vacuum (5.09 g, 79%).

^{1}H NMR (300 MHz, C_6D_6) δ 7.54 (d, 1H, J=7.2), 7.16-7.29 (m, 2H), 7.03 (d, 1H, J=7.8), 6.95 (s, 1H), 4.00 (dd, 1H, J=10.2, J=9.9), 2.91 (s, 3H), 2.11 (dd, 1H, J=12.3, J=9.3), 1.87 (dd, 1H, J=12.3, J=11.1), 1.10 (s, 3H), 1.02 (s, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 177.2, 137.4, 127.1, 126.7, 122.0, 119.4, 118.9, 110.0, 109.7, 82.5, 43.5, 38.9, 38.8, 29.1, 27.2. FTIR (CH_2Cl_2) 3055, 2975, 2934, 1770, 1653, 1558, 1474, 1375, 1256, 1140 cm^{-1}. HRMS (EI, *m/z*) calcd. for $C_{15}H_{17}NO_2$ (M^+) 243.1254, found 243.1255. mp 121-122 °C.

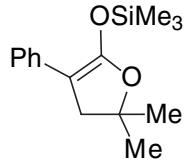


Oxalyl chloride (10.6 mL, 122 mmol) was added over 5 minutes to a –78 °C solution of 2-phenylbutyric acid (8.00 g, 48.7 mmol) and *N,N* dimethylformamide (3 drops) in CH_2Cl_2 (40 mL). The resulting mixture was stirred at –78 °C for 2 hours, and then it was warmed to room temperature and concentrated. CH_2Cl_2 (40 mL) was then added to the unpurified acid chloride, and the resulting solution was cooled to 0 °C. To this solution was added 2-methyl-2-propanol (5.13 mL, 53.6 mmol) and then NEt_3 (3 mL). The reaction mixture was slowly warmed to room temperature and then stirred for 15 hours. Saturated NH_4Cl (50 mL) was added, and then the reaction mixture was extracted with CH_2Cl_2 (3 x 50 mL). The combined organic layers were washed with saturated $NaHCO_3$ (2 x 100 mL) and water (2 x 50 mL), dried over $MgSO_4$, filtered, and concentrated, to yield an orange oil. Purification by vacuum distillation (83–85 °C, 1 mm Hg) furnished the target compound as a clear, colorless liquid (6.06 g, 52%).

^{1}H NMR (500 MHz, C_6D_6) δ 7.32 (dd, 2H, J=6.0, J=0.5), 7.13 (m, 2H), 7.04 (tt, 1H, J=7.5, J=1.5), 3.35 (t, 1H, J= 7.5), 2.12 (d app t, 1H, J=13.5, J=7.5), 1.70 (d app t, 1H, J=13.5, J=7.5), 1.29 (s, 9H), 0.83 (app t, 3H J=7.5). ^{13}C NMR (125 MHz, $CDCl_3$) δ 173.5, 139.9, 128.5, 128.0, 127.0, 80.6, 54.6, 28.1, 27.0, 12.4. FTIR (thin film) 3030, 2969, 2933, 2876, 1729, 1454, 1148, 1078, 749, 698 cm^{-1}.

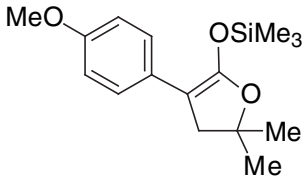
III. Preparation of Silyl Ketene Acetals

These reactions have not been optimized.



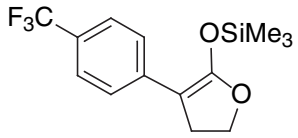
General procedure. A solution of *n*-BuLi (in hexanes; 9.00 mL, 22.1 mmol) was added via syringe to a –78 °C solution of diisopropylamine (3.10 mL, 22.1 mmol) in THF (10 mL). The mixture was stirred at –78 °C for 45 minutes, and then a solution of the lactone (4.0 g, 21.0 mmol) in THF (10 mL) was added via cannula. The mixture was stirred at –78 °C for 60 minutes, and then Me_3SiCl (2.80 mL, 22.1 mmol) was added, resulting in a clear, light-yellow solution which was warmed to room temperature and stirred for 3 hours. The THF was then removed, and the residue was taken up in pentane and filtered. The solvent was removed, and the yellow liquid was purified by fractional distillation (126-128 °C, 0.5 mm Hg) to afford a clear, colorless liquid (2.01 g, 37%).

^{1}H NMR (300 MHz, C_6D_6) δ 7.70-7.75 (m, 2H), 7.43-7.49 (m, 2H), 7.14-7.19 (m, 1H), 2.67 (s, 2H), 1.29 (s, 6H), 0.35 (s, 9H). ^{13}C NMR (125 MHz, C_6D_6) δ 153.8, 137.3, 129.5, 128.8, 124.3, 123.3, 82.0, 43.9, 29.2, 1.0. FTIR (CH_2Cl_2) 2900, 2849, 1662, 1659, 1600, 1502, 1461, 1371, 1170, 1161, 1068, 1004, 983, 857 cm^{-1}. bp 126-128 °C (0.5 mm Hg).



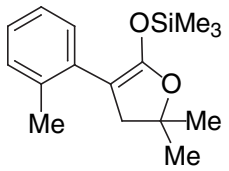
The general procedure was followed, using *n*-BuLi (in hexanes; 3.40 mL, 9.53 mmol), diisopropylamine (0.965 mL, 9.53 mmol), lactone (2.00 g, 9.08 mmol), and Me_3SiCl (1.25 mL, 9.53 mmol) in THF (25 mL). Purification by chromatography on Florisil (pentane) inside a glove box afforded a white crystalline solid (1.98 g, 75%).

^{1}H NMR (300 MHz, C_6D_6) 7.25 (dd, 2H, J=6.9, J=2.1), 6.81 (dd, 2H, J=6.9, J=2.1), 3.77 (s, 3H), 1.43 (s, 6H), 0.33 (s, 9H). ^{13}C NMR (125 MHz, C_6D_6) δ 156.2, 152.2, 129.8, 125.1, 114.1, 81.6, 81.4, 55.7, 43.9, 29.0, 0.7. FTIR (CH_2Cl_2) 3152, 3007, 2899, 1669, 1666, 1514, 1369, 1240, 1168, 1093, 991 cm^{-1}. HRMS (EI, *m/z*) calcd. for $C_{16}H_{24}O_3Si$ (M^+) 292.1489, found 292.1480. mp 54-56 °C.



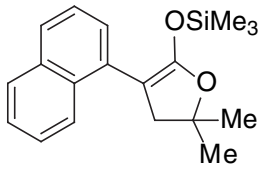
The general procedure was followed, using *n*-BuLi (in hexanes; 2.30 mL, 6.48 mmol), diisopropylamine (0.910 mL, 6.48 mmol), lactone (1.42 g, 6.17 mmol), and Me_3SiCl (0.822 mL, 6.48 mmol) in THF (30 mL). Purification by chromatography on Florisil (pentane) inside a glove box afforded a white crystalline solid (1.21 g, 65%).

^{1}H NMR (300 MHz, C_6D_6) 7.51 (dd, 2H, J=9.0, J=0.9), 7.37 (dd, 2H, J=9.0, J=0.9), 3.80 (t, 2H, J=8.4), 2.40 (t, 2H, J=8.1), 0.20 (s, 9H). ^{13}C NMR (125 MHz, CD_2Cl_2) δ 157.9, 140.7, 129.2, 125.5 (q, J=4.0), 124.4 (q, J=32.4), 123.9, 82.4, 67.6, 30.4, 0.7. FTIR (CH_2Cl_2) 3152, 3008, 1658, 1607, 1529, 1327, 1192, 1121, 1067, 990 cm^{-1}. HRMS (EI, *m/z*) calcd. for $C_{14}H_{17}F_3O_2Si$ (M^+) 302.0944, found 302.0944. mp 43-44 °C.



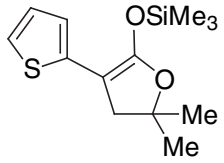
The general procedure was followed, using *n*-BuLi (in hexanes; 1.39 mL, 3.89 mmol), diisopropylamine (0.545 mL, 3.89 mmol), lactone (0.795 g, 3.89 mmol), and Me_3SiCl (0.494 mL, 3.89 mmol) in THF (22 mL). Purification by chromatography on Florisil (pentane) inside a glove box afforded a clear, colorless oil (0.865 g, 81%).

^{1}H NMR (300 MHz, C_6D_6) δ 7.30-7.33 (m, 1H), 6.99-7.15 (m, 3H), 2.62 (s, 2H), 2.56 (s, 3H), 1.22 (s, 6H), 0.10 (s, 9H). ^{13}C NMR (125 MHz, C_6D_6) δ 152.1, 136.9, 136.1, 131.0, 129.5, 126.1, 126.0, 82.7, 81.4, 46.7, 28.6, 21.6, 0.7. FTIR (CH_2Cl_2) 2971, 1688, 1679, 1598, 1461, 1354, 1169, 1084, 994, 857 cm^{-1}. HRMS (ESI, *m/z*) calcd. for $C_{16}H_{24}O_2Si$ $(M+H)^+$ 277.1618, found 277.1624.



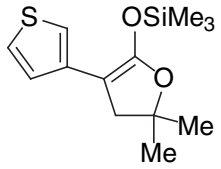
The general procedure was followed, using *n*-BuLi (in hexanes; 1.78 mL, 4.98 mmol), diisopropylamine (0.698 mL, 4.98 mmol), lactone (1.14 g, 4.74 mmol), and Me_3SiCl (0.632 mL, 4.98 mmol) in THF (25 mL). Purification by chromatography on Florisil (pentane) inside a glove box afforded a white solid (0.709 g, 48%).

^{1}H NMR (300 MHz, C_6D_6) δ 8.31 (ddt, 1H, J=8.1, J=0.1), 7.66 (ddt, 1H, J=8.1, J=0.6), 7.53 (d, 1H, J=8.1), 7.24-7.39 (m, 4H), 2.76 (s, 2H), 1.27 (s, 6H), 0.00 (s, 9H). ^{13}C NMR (75 MHz, C_6D_6) δ 152.9, 135.2, 135.0, 132.7, 129.1, 127.9, 126.7, 126.3, 126.11, 126.06, 125.4, 81.8, 81.6, 47.3, 28.7, 0.7. FTIR (CH_2Cl_2) 3054, 2985, 1558, 1540, 1506, 1456, 1420, 1265, 856 cm^{-1}. HRMS (EI, *m/z*) calcd. for $C_{19}H_{24}O_2Si$ (M^+) 312.1540, found 312.1549. mp 86-89 °C.



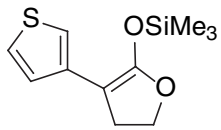
A solution of *n*-BuLi (in hexanes; 2.78 mL, 7.79 mmol) was added via syringe to a –78 °C solution of diisopropylamine (1.10 mL, 7.79 mmol) in THF (15 mL). The mixture was stirred at –78 °C for 45 minutes, and then a solution of lactone (1.53 g, 7.79 mmol) in THF (10 mL) was added via cannula. The mixture was stirred at –78 °C for 60 minutes, after which Me_3SiCl (0.988 mL, 7.79 mmol) was added, resulting in a clear, light-yellow solution, which was warmed to room temperature and stirred for 3 hours. The THF was then removed, and the yellow residue was taken up in pentane and filtered. The pentane was removed, and the yellow residue was taken into a glove box and purified by chromatography on activated Florisil (pentane), which afforded a clear, colorless oil (1.02 g, 49%).

^{1}H NMR (500 MHz, C_6D_6) δ 6.88-6.95 (m, 2H), 6.68 (dd, 1H, J=3.3, J=1.5), 2.53 (s, 2H), 1.14 (s, 6H), 0.27 (s, 9H). ^{13}C NMR (75 MHz, C_6D_6) δ 152.8, 140.3, 127.1, 120.8, 118.8, 82.8, 81.3, 44.2, 28.8, 0.8. FTIR (CH_2Cl_2) 2963, 2901, 2851, 1678, 1665, 1520, 1461, 1369, 1238, 1166, 1091, 1043, 939 cm^{-1}. HRMS (ESI, *m/z*) calcd. for $C_{13}H_{20}O_2SSi$ $(M+H)^+$ 269.1026, found 269.1030.



The general procedure was followed, using *n*-BuLi (in hexanes; 2.17 mL, 5.76 mmol), diisopropylamine (0.807 mL, 5.76 mmol), lactone (1.13 g, 5.76 mmol), and Me_3SiCl (0.731 mL, 5.76 mmol) in THF (25 mL). Purification by chromatography on Florisil (pentane) inside a glove box afforded a clear, colorless oil (0.824 g, 53%).

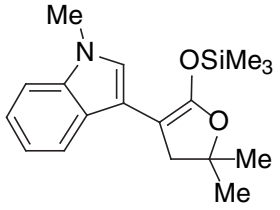
^{1}H NMR (300 MHz, C_6D_6) δ 7.57 (dd, 1H, J=5.1, J=1.2), 7.08 (dd, 1H, J=5.4, J=3.0), 6.68 (dd, 1H, J=2.7, J=1.2), 2.48 (s, 2H), 1.18 (s, 6H), 0.22 (s, 9H). ^{13}C NMR (75 MHz, C_6D_6) δ 152.5, 138.0, 126.1, 125.3, 114.1, 82.0, 80.7, 44.1, 28.9, 0.8. FTIR (CH_2Cl_2) 2962, 2900, 2849, 1689, 1679, 1527, 1461, 1382, 1370, 1342, 1228, 1198, 1163, 1098, 1016, 914 cm^{-1}. HRMS (EI, *m/z*) calcd. for $C_{13}H_{20}O_2SSi$ (M^+) 268.0948, found 268.0941.



A solution of *n*-BuLi (in hexanes; 7.24 mL, 17.8 mmol) was added via syringe to a –78 °C solution of diisopropylamine (2.49 mL, 17.8 mmol) in THF (20 mL). The mixture was stirred at –78 °C for 45 minutes, after which a solution of the lactone (2.85 g, 16.9 mmol) in THF (15 mL) was added via cannula. The mixture was stirred at –78 °C for 60 minutes, and then Me_3SiCl (2.26 mL, 17.8 mmol) was added, resulting in a clear, light-yellow solution, which was warmed to room temperature and stirred for 3 hours. The THF was then removed, and the orange residue was taken up in pentane and filtered. The solvent was removed, and the orange liquid was purified by fractional distillation (127 °C, 1.0 mm Hg), which afforded a clear, colorless oil (1.50 g, 45%).

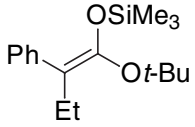
^{1}H NMR (500 MHz, C_6D_6) δ 7.57 (dd, 1H, J=5.0, J=1.0), 7.07 (dd, 1H, J=5.0, J=3.0), 6.66 (dd, 1H, J=3.0, J=1.5), 3.87 (t, 2H, J=9.0), 2.52 (t, 2H, J=8.0), 0.22 (s, 9H). ^{13}C NMR (125 MHz, C_6D_6) δ 137.5, 128.7, 126.0, 125.5, 114.5, 81.2, 67.1, 31.1, 0.7. FTIR (CH_2Cl_2) 3008,

2961, 2902, 2856, 1688, 1679, 1528, 1365, 1327, 1254, 1191 cm^{-1}. HRMS (ESI, *m/z*) calcd. for $C_{11}H_{16}O_2SSi$ $(M+H)^+$ 241.0713, found 241.0713. bp 127-128 °C (1.0 mm Hg).



The general procedure was followed, using *n*-BuLi (in hexanes; 1.03 mL, 2.89 mmol), diisopropylamine (0.405 mL, 2.89 mmol), lactone (0.704 g, 2.89 mmol), and Me_3SiCl (0.367 mL, 2.89 mmol) in THF (20 mL). Purification by chromatography on Florisil (pentane) inside a glove box afforded a viscous yellow oil (0.270 g, 30%).

^1H NMR (300 MHz, C_6D_6) δ 8.37-8.42 (m, 1H), 7.32-7.41 (m, 2H), 7.12-7.18 (m, 1H), 6.92 (s, 1H), 3.09 (s, 3H), 2.97 (s, 2H), 1.37 (s, 6H), 0.36 (s, 9H). ^{13}C NMR (75 MHz, C_6D_6) δ 150.7, 137.9, 127.8, 124.6, 123.0, 122.1, 119.1, 111.9, 109.7, 81.5, 78.4, 45.7, 32.3, 29.1, 1.0. FTIR (CH_2Cl_2) 2970, 2880, 1691, 1680, 1547, 1534, 1479, 1369, 1320, 1173, 1062 cm^{-1}. HRMS (EI, *m/z*) calcd. for $C_{18}H_{25}NO_2Si$ $(M+H)^+$ 316.1727, found 316.1738.



~2:1 mixture of isomers

A solution of *n*-BuLi (4.41 mL, 11.3 mmol in hexanes) was added via syringe to a –78 °C solution of diisopropylamine (1.58 mL, 11.3 mmol) in THF (20 mL). The mixture was stirred at –78 °C for 45 minutes, and then a solution of the ester (2.50 g, 11.3 mmol) in THF (20 mL) was added via cannula. The mixture was stirred at –78 °C for 90 minutes, and then Me_3SiCl (1.43 mL, 11.3 mmol) was added, resulting in a clear, light-yellow solution which was warmed to room temperature and stirred for 3 hours. The THF was then removed, and the residue was taken up in pentane and filtered. The solvent was removed, and the yellow liquid was purified by fractional distillation (88-91 °C, 1.0 mm Hg) to afford a clear, colorless oil (1.80 g, 55%).

^{1}H NMR (500 MHz, C_6D_6) δ 6.99-7.47 (m, 10H, major, minor), 2.56 (q, 2H, J=7.5, major), 2.52 (q, 2H, J=7.5, minor), 1.36 (s, 9H, major), 1.04 (s, 9H, minor), 1.03 (t, 3H, J=7.2, minor), 0.99 (t, 3H, J=7.5, major), 0.24 (s, 9H, minor), –0.92 (s, 9H, major). ^{13}C NMR (125 MHz, $CDCl_3$) δ 149.2, 149.1, 140.9, 140.3, 130.4, 130.3, 126.1, 125.9, 109.7, 108.7, 80.5, 79.0, 55.7, 55.2, 29.8, 29.5, 24.6 (isochronous with other isomer), 14.0 (isochronous with other isomer), 1.0, 0.6. FTIR (CH_2Cl_2) 2967, 2876, 1658, 1642, 1598, 1367, 1218, 1148, 1093, 987 cm^{-1}.

IV. Enantioselectivity as a Function of Catalyst (eq 2)

General. Although several of the silyl ketene acetals were purified by chromatography on Florisil inside a glove box (Section III), this level of purity is not essential for catalytic enantioselective C-acylations–we have used unpurified silyl ketene acetals, and they furnish the same ee. However, we routinely purify the silyl ketene acetals in order to accurately determine the yields of the acylation reactions.

Unless otherwise specified, all reactions are the average of two runs. These acylations were set up in a glove box, due to the moisture sensitivity of the trimethylsilyl ketene acetals, which results in lower yields when reactions are set up without a glove box.

Catalyst (–)-1. A solution of (–)-**1** (2.7 mg, 0.0077 mmol) in 1.4 mL of Et_2O/CH_2Cl_2 (14:1) was added to a 20-mL vial containing the silyl ketene acetal (28 mg, 0.11 mmol). The pink mixture was stirred for 5 minutes at room temperature, after which Ac_2O (0.013 mL, 0.14 mmol) was added, resulting in a bright-gold solution. The vial was capped and removed from the glove box. After stirring for 24 hours at room temperature, the reaction mixture was purified directly by flash chromatography (25% Et_2O/75% pentane). The product was analyzed by chiral GC (Chiraldex G-TA, 20 m x 0.25 mm, 110 °C, 1.0 mL/min, retention times of enantiomers: 40.2 min (minor), 41.9 min (major)), which showed 42% ee.

Run 2: silyl ketene acetal (47 mg, 0.18 mmol), (–)-**1** (3.2 mg, 0.0091 mmol), Ac_2O (0.022 mL, 0.23 mmol), and 2.4 mL of Et_2O/CH_2Cl_2 (14:1); 37% ee.

Catalyst (–)-2. A solution of (–)-**2** (2.6 mg, 0.0069 mmol) in 1.8 mL of Et_2O/CH_2Cl_2 (14:1) was added to a 20-mL vial containing the silyl ketene acetal (36 mg, 0.14 mmol). The pink mixture was stirred for 5 minutes at room temperature, after which Ac_2O (0.017 mL, 0.18 mmol) was added, resulting in a bright-gold solution. The vial was capped and removed from the glove box. After stirring for 24 hours at room temperature, the reaction mixture was purified directly by flash chromatography (25% Et_2O/75% pentane). The product was analyzed by chiral GC, which showed 31% ee.

Run 2: silyl ketene acetal (42 mg, 0.16 mmol), (–)-**2** (3.0 mg, 0.0080 mmol), Ac_2O (0.019 mL, 0.21 mmol), and 2.1 mL of Et_2O/CH_2Cl_2 (14:1); 34% ee.

Catalyst (–)-3. A solution of (–)-**3** (4.2 mg, 0.0064 mmol) in 1.7 mL of Et_2O/CH_2Cl_2 (14:1) was added to a 20-mL vial containing the silyl ketene acetal (33 mg, 0.13 mmol). The pink mixture was stirred for 5 minutes at room temperature, after which Ac_2O (0.016 mL, 0.17 mmol) was added. The vial was capped and removed from the glove box. After stirring for 24 hours at room temperature, the reaction mixture was purified directly by flash chromatography (25% Et_2O/75% pentane). The product was analyzed by chiral GC, which showed 87% ee.

Run 2: silyl ketene acetal (32 mg, 0.12 mmol), (–)-**3** (4.0 mg, 0.0061 mmol), Ac_2O (0.015 mL, 0.16 mmol), and 1.6 mL of Et_2O/CH_2Cl_2 (14:1); 87% ee.

Catalyst (–)-4. The experimental procedure and the characterization data are located in Section V, Table 1, entry 1.

V. Catalytic Enantioselective Intermolecular C-Acylation of Silyl Ketene Acetals (Table 1 and eq 3)

General. Although several of the silyl ketene acetals were purified by chromatography on Florisil inside a glove box (Section III), this level of purity is not essential for catalytic enantioselective C-acylations–we have used unpurified silyl ketene acetals, and they furnish the same ee. However, we routinely purify the silyl ketene acetals in order to accurately determine the yields of the acylation reactions.

Unless otherwise specified, all reactions are the average of two runs (one run with each enantiomer of the catalyst). The acylations were set up in a glove box (exceptions: Table 1, entries 2 and 5), due to the moisture sensitivity of the trimethylsilyl ketene acetals, which results in lower yields when reactions are set up without a glove box.

General Procedure. A solution of catalyst (0.05 equiv) in Et_2O/CH_2Cl_2 (14:1) was added to a 20-mL vial containing the silyl ketene acetal (1.0 equiv). The resulting solution was stirred for 5 minutes at room temperature, after which Ac_2O (1.3 equiv) was added. The vial was capped and removed from the glove box, and the reaction mixture was stirred for 24 hours at room temperature. The product was then purified directly by flash chromatography (25% Et_2O/75% pentane). The catalyst was recovered by eluting with 3 volumes of CH_2Cl_2, followed by 10% Et_3N/90% EtOAc. The ee of the product was determined either by chiral HPLC or by chiral GC.

Table 1, entry 1. The general procedure was followed, using silyl ketene acetal (0.164 g, 0.626 mmol), Ac_2O (0.0768 mL, 0.814 mmol), (**+**)-**4** (0.0215 g, 0.0313 mmol), and 8.2 mL of Et_2O/CH_2Cl_2 (14:1) to produce 78% (0.113 g, 0.487 mmol) of a white crystalline solid, which was shown by chiral GC (Chiraldex G-TA, 20 m x 0.25 mm, 110 °C, 1.0 mL/min, retention times of enantiomers: 42.0 min (major), 41.3 min (minor)) to have 90% ee.

For run 2, the silyl ketene acetal (0.156 g, 0.582 mmol), Ac_2O (0.0714 mL, 0.757 mmol), and (–)-**4** (0.0200 g, 0.0290 mmol) in 7.7 mL of Et_2O/CH_2Cl_2 (14:1) furnished

81% of the product (0.109 g, 0.470 mmol), which was shown by chiral GC to have 90% ee.

^{1}H NMR (300 MHz, C_6D_6) δ 7.30-7.34 (m, 2H), 6.92-7.04 (m, 3H), 3.25 (d, 1H, J=13.5), 2.10 (s, 3H), 1.82 (d, 1H, J=13.5), 1.04 (s, 3H), 0.81 (s, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 201.4, 172.8, 138.9, 129.6, 128.3, 126.7, 82.6, 68.6, 44.7, 29.1, 28.9, 26.5. FTIR (CH_2Cl_2) 2983, 2932, 1750, 1718, 1559, 1455, 1373, 1275, 1182, 1151, 1097 cm^{-1}. HRMS (ESI, *m/z*) calcd. for $C_{14}H_{16}O_3$ $(M+Na)^+$ 255.0992, found 255.0993. $[\alpha]^{20}_D$ = –213° (c=0.89, CH_2Cl_2; for product with 90% ee). mp 64-66 °C.

Table 1, entry 2. The general procedure was followed, without the use of a glove box, with silyl ketene acetal (0.148 g, 0.506 mmol), Ac_2O (0.0621 mL, 0.658 mmol), (+)-**4** (0.0174 g, 0.0253 mmol), and 6.7 mL of Et_2O/CH_2Cl_2 (14:1) to produce 76% (0.101 g, 0.385 mmol) of a colorless crystalline solid, which was shown by chiral GC (Chiraldex G-TA, 20 m x 0.25 mm, 120 °C, 1.0 mL/min, retention times of enantiomers: 105 min (major), 108 min (minor)) to have 95% ee.

For run 2 (inside a glove box), the silyl ketene acetal (0.150 g, 0.513 mmol), Ac_2O (0.0629 mL, 0.667 mmol), and (–)-**4** (0.0176 g, 0.0260 mmol) in 6.8 mL of Et_2O/CH_2Cl_2 (14:1) furnished 80% of the product (0.107 g, 0.408 mmol), which was shown by chiral GC to have 95% ee.

^{1}H NMR (500 MHz, C_6D_6) δ 7.23 (d, 2H, J=9.0), 6.61 (d, 2H, J=9.0), 3.21 (d, 1H, J=13.5), 3.17 (s, 3H), 2.12 (s, 3H), 1.83 (d, 1H, J=13.5), 1.04 (s, 3H), 0.82 (s, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 201.1, 173.0, 160.0, 131.8, 128.5, 115.2, 81.8, 68.2, 55.1, 45.0, 29.0, 28.8, 26.2. FTIR (CH_2Cl_2) 2979, 2937, 2839, 1751, 1716, 1609, 1512, 1457, 1375, 1356, 1254, 1183, 1031 cm^{-1}. HRMS (EI, *m/z*) calcd. for $C_{15}H_{18}O_4$ (M^+) 262.1200, found 262.1196. $[\alpha]^{20}_D$ = –235° (c=1.0, CH_2Cl_2; for product with 95% ee). mp 47-49 °C.

Table 1, entry 3. The general procedure was followed, using silyl ketene acetal (0.141 g, 0.466 mmol), Ac_2O (0.0572 mL, 0.606 mmol), (+)-**4** (0.0160 g, 0.0233 mmol), and 6.1 mL of Et_2O/CH_2Cl_2 (14:1) to produce 85% (0.108 g, 0.394 mmol) of a clear, colorless oil, which was shown by chiral GC (Chiraldex G-TA, 20 m x 0.25 mm, 150 °C, 1.0

mL/min, retention times of enantiomers: 9.48 min (major), 12.9 min (minor)) to have 90% ee.

For run 2, the silyl ketene acetal (0.150 g, 0.496 mmol), Ac_2O (0.0609 mL, 0.645 mmol), and (–)-**4** (0.0170 g, 0.0248 mmol) in 6.5 mL of Et_2O/CH_2Cl_2 (14:1) furnished 83% of the product (0.111 g, 0.408 mmol), which was shown by chiral GC to have 90% ee.

^1H NMR (300 MHz, $CDCl_3$) δ 7.67 (dd, 2H, J=8.7, J=0.6), 7.56 (dd, 2H, J=8.7, J=0.6), 4.22-4.36 (m, 2H), 3.35-3.44 (m, 1H), 2.39 (ddd, 1H, J=13.2, J=7.5, J=7.5), 2.22 (s, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 200.0, 173.0, 140.6, 130.8 (q, J=32.8), 127.4, 126.5 (q, J=4.0) 123.8 (q, J=272.4), 65.9, 65.8, 33.4, 26.5. FTIR (CH_2Cl_2) 3077, 3001, 2921, 1771, 1717, 1617, 1414, 1360, 1328, 1328, 1120, 1069, 1019, 843 cm^{-1}. HRMS (ESI, *m/z*) calcd. for $C_{13}H_{11}F_3O_3$ $(M+Na)^+$ 295.0552, found 295.0555. $[\alpha]^{20}_D = -150°$ (c=0.32, CH_2Cl_2; for product with 90% ee).

Table 1, entry 4. The general procedure was followed, using silyl ketene acetal (0.150 g, 0.543 mmol), Ac_2O (0.0666 mL, 0.706 mmol), (–)-**4** (0.0186 g, 0.0270 mmol), and 7.1 mL of Et_2O/CH_2Cl_2 (14:1), except that the reaction was stirred for 36 hours at room temperature. The reaction produced 87% (0.117 g, 0.475 mmol) of a white crystalline solid, which was shown by chiral HPLC (Daicel CHIRALPAK AD, 4.6 mm x 25 cm, hexane/isopropanol 90:10, 1.0 mL/min, retention times of enantiomers: 4.51 min (minor), 5.10 min (major)) to have 94% ee.

For run 2, the silyl ketene acetal (0.155 g, 0.562 mmol), Ac_2O (0.0689 mL, 0.731 mmol), and (+)-**4** (0.0193 g, 0.0281 mmol) in 7.4 mL of Et_2O/CH_2Cl_2 (14:1) furnished 90% of the product (0.125 g, 0.509 mmol), which was shown by chiral HPLC to have 96% ee.

^1H NMR (300 MHz, $CDCl_3$) δ 7.46-7.49 (m, 1H), 7.16-7.28 (m, 3H), 3.56 (d, 1H, J=13.2), 2.21 (s, 3H), 2.10 (d, 1H, J=13.2), 2.09 (s, 3H), 1.51 (s, 3H), 1.27 (s, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 203.1, 173.0, 138.6, 135.4, 132.7, 128.4, 127.9, 127.0, 83.0, 69.5, 43.5, 29.5, 29.4, 27.2, 20.2. FTIR (CH_2Cl_2) 3065, 2978, 2934, 2875, 1750, 1716, 1456, 1375, 1271, 1182, 1143, 1104, 1036, 961 cm^{-1}. HRMS (ESI, *m/z*) calcd. for $C_{15}H_{18}O_3$ $(M+Na)^+$

269.1148, found 269.1141. $[\alpha]^{20}_D$ = + 256° (c=0.39, CH_2Cl_2; for product with 94% ee). mp 67-68 °C.

Table 1, entry 5. The general procedure was followed, using silyl ketene acetal (0.150 g, 0.480 mmol), Ac_2O (0.0589 mL, 0.624 mmol), (–)-**4** (0.0165 g, 0.0240 mmol), and 6.3 mL of Et_2O/CH_2Cl_2 (14:1) to produce 79% (0.107 g, 0.379 mmol) of a white crystalline solid, which was shown by chiral HPLC (Daicel CHIRALCEL OD, 4.6 mm x 25 cm, hexane/isopropanol 99:1, 1.0 mL/min, retention times of enantiomers: 8.68 min (minor), 9.76 min (major)) to have 99% ee.

For run 2 (outside a glove box), the silyl ketene acetal (0.155 g, 0.495 mmol), Ac_2O (0.0607 mL, 0.644 mmol), and (+)-**4** (0.0170 g, 0.0248 mmol) in 6.5 mL of Et_2O/CH_2Cl_2 (14:1) furnished 84% of the product (0.117 g, 0.415 mmol), which was shown by chiral HPLC to have 99% ee.

^{1}H NMR (300 MHz, $CDCl_3$) δ 7.86-7.93 (m, 2H), 7.75 (dd, 1H, J=6.3, J=0.9), 7.39-7.55 (m, 4H), 3.80 (d, 1H, J=13.2), 2.35 (d, 1H, J=13.2), 2.10 (s, 3H), 1.57 (s, 3H), 1.20 (s, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 204.3, 173.1, 135.9, 134.9, 130.3, 129.9, 129.5, 127.4, 126.32, 126.31, 125.7, 123.5, 83.4, 69.3, 44.2, 29.5, 29.4, 27.4. FTIR (CH_2Cl_2) 3061, 3001, 2981, 1747, 1715, 1559, 1456, 1388, 1351, 1272, 1179, 1149, 1132, 1064, 953 cm^{-1}. HRMS (EI, *m/z*) calcd. for $C_{18}H_{18}O_3$ (M^+) 282.1250, found 282.1259. $[\alpha]^{20}_D$ = +349° (c=0.64, CH_2Cl_2; for product with 99% ee). mp 123-126 °C.

Table 1, entry 6. The general procedure was followed, using silyl ketene acetal (0.140 g, 0.521 mmol), Ac_2O (0.0639 mL, 0.678 mmol), (+)-**4** (0.0179 g, 0.0261 mmol), and 6.9 mL of Et_2O/CH_2Cl_2 (14:1) to produce 86% (0.108 g, 0.453 mmol) of a clear, colorless oil, which was shown by chiral HPLC (Daicel CHIRALCEL OD, 4.6 mm x 25 cm, hexane/isopropanol 99:1, 1.0 mL/min, retention times of enantiomers: 8.79 min (major), 9.99 min (minor)) to have 75% ee.

For run 2, the silyl ketene acetal (0.158 g, 0.588 mmol), Ac_2O (0.0721 mL, 0.764 mmol), and (–)-**4** (0.0202 g, 0.0290 mmol) in 7.7 mL of Et_2O/CH_2Cl_2 (14:1) furnished 81% of the product (0.113 g, 0.474 mmol), which was shown by chiral HPLC to have 77% ee.

^{1}H NMR (300 MHz, $CDCl_3$) δ 7.32 (dd, 1H, J=5.1, J=1.2), 7.17 (dd, 1H, J=3.6, J=1.2), 7.20 (dd, 1H, J=5.1, J=3.6), 3.41 (d, 1H, J=13.2), 2.41 (d, 1H, J=13.2), 2.33 (s, 3H), 1.45 (s, 3H), 1.32 (s, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 200.1, 172.4, 140.6, 127.5, 126.7, 126.4, 83.2, 65.0, 45.1, 29.1, 28.5, 25.6. FTIR (neat) 3109, 2980, 2935, 1757, 1717, 1456, 1376, 1272, 1132, 961 cm^{-1}. HRMS (ESI, *m/z*) calcd. for $C_{12}H_{14}O_3S$ $(M+Na)^+$ 261.0556, found 261.0566. $[\alpha]^{20}_D = -154°$ (c=0.54, CH_2Cl_2; for product with 75% ee).

Table 1, entry 7. The general procedure was followed, using silyl ketene acetal (0.148 g, 0.551 mmol), Ac_2O (0.0675 mL, 0.716 mmol), (+)-**4** (0.0189 g, 0.0275 mmol), and 7.2 mL of Et_2O/CH_2Cl_2 (14:1) to produce 84% (0.110 g, 0.460 mmol) of a clear, colorless oil, which was shown by chiral HPLC (Daicel CHIRALCEL OD, 4.6 mm x 25 cm, hexane/isopropanol 99:1, 1.0 mL/min, retention times of enantiomers: 8.99 min (major), 9.84 min (minor)) to have 86% ee.

For run 2, the silyl ketene acetal (0.133 g, 0.495 mmol), Ac_2O (0.0607 mL, 0.644 mmol), and (–)-**4** (0.0170 g, 0.0248 mmol) in 6.5 mL of Et_2O/CH_2Cl_2 (14:1) furnished 88% of the product (0.104 g, 0.436 mmol), which was shown by chiral HPLC to have 88% ee.

^{1}H NMR (300 MHz, $CDCl_3$) δ 7.46 (dd, 1H, J=3.0, J=1.2), 7.36 (dd, 1H, J=5.1, J=3.0), 6.97 (dd, 1H, J=5.1, J=1.2), 3.34 (d, 1H, J=13.5), 2.31 (d, 1H, J=13.5), 2.25 (s, 3H), 1.42 (s, 3H), 1.32 (s, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 200.8, 173.1, 138.2, 127.6, 126.1, 123.0, 82.8, 65.4, 43.9, 29.1, 28.7, 26.0. FTIR (neat) 3109, 2980, 2935, 1752, 1717, 1456, 1375, 1272, 1180, 1131, 1096, 960 cm^{-1}. HRMS (ESI, *m/z*) calcd. for $C_{12}H_{14}O_3S$ $(M+Na)^+$ 261.0556, found 261.0565. $[\alpha]^{20}_D = -209°$ (c=0.64, CH_2Cl_2; for product with 86% ee).

Table 1, entry 8. The general procedure was followed, using silyl ketene acetal (0.163 g, 0.679 mmol), Ac_2O (0.0832 mL, 0.882 mmol), (–)-**4** (0.0233 g, 0.0340 mmol), and 8.9 mL of Et_2O/CH_2Cl_2 (14:1) to produce 70% (0.100 g, 0.476 mmol) of a clear, colorless oil, which was shown by chiral HPLC (Daicel CHIRALPAK AD, 4.6 mm x 25 cm, hexane/isopropanol 90:10, 1.0 mL/min, retention times of enantiomers: 7.25 min (minor), 7.91 min (major)) to have 80% ee.

For run 2, the silyl ketene acetal (0.162 g, 0.673 mmol), Ac_2O (0.0825 mL, 0.875 mmol), and (+)-**4** (0.0231 g, 0.0336 mmol) in 8.9 mL of Et_2O/CH_2Cl_2 (14:1) furnished 76% of the product (0.108 g, 0.514 mmol), which was shown by chiral HPLC to have 80% ee.

^1H NMR (300 MHz, $CDCl_3$) δ 7.50 (dd, 1H, J=2.7, J=2.4), 7.39 (dd, 1H, J=5.1, J=2.7), 7.04 (dd, 1H, J=5.1, J=2.4), 4.22-4.35 (m, 2H), 3.27-3.35 (m, 1H), 2.42 (d app t, 1H, J=12.9, J=7.5), 2.27 (s, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 201.3, 174.3, 137.0, 128.1, 126.7, 124.0, 66.7, 63.4, 33.3, 26.7. FTIR (neat) 3108, 2978, 2917, 1771, 1716, 1456, 1419, 1373, 1162 cm^{-1}. HRMS (ESI, *m/z*) calcd. for $C_{10}H_{10}O_3S$ $(M+Na)^+$ 233.0243, found 233.0244. $[\alpha]^{20}_D = +174°$ (c=0.23, CH_2Cl_2; for product with 80% ee).

Table 1, entry 9. The general procedure was followed, using silyl ketene acetal (0.163 g, 0.518 mmol), Ac_2O (0.0636 mL, 0.674 mmol), (**–**)-**4** (0.0178 g, 0.0260 mmol), and 6.8 mL of Et_2O/CH_2Cl_2 (14:1) to produce 94% (0.139 g, 0.489 mmol) of a white crystalline solid, which was shown by chiral HPLC (Daicel CHIRALCEL OD, 4.6 mm x 25 cm, hexane/isopropanol 90:10, 1.0 mL/min, retention times of enantiomers: 6.10 min (minor), 7.20 min (major)) to have 95% ee.

For run 2, the silyl ketene acetal (0.139 g, 0.440 mmol), Ac_2O (0.0539 mL, 0.572 mmol), and (+)-**4** (0.0151 g, 0.0220 mmol) in 5.8 mL of Et_2O/CH_2Cl_2 (14:1) furnished 87% of the product (0.109 g, 0.383 mmol), which was shown by chiral HPLC to have 92% ee.

^1H NMR (300 MHz, $CDCl_3$) δ 7.23-7.38 (m, 4H), 7.07-7.13 (m, 1H), 3.81 (s, 3H), 3.61 (d, 1H, J=13.2), 2.36 (d, 1H, J=13.2), 2.23 (s, 3H), 1.46 (s, 3H), 1.33 (s, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 201.9, 173.7, 137.6, 127.6, 125.3, 122.5, 120.2, 119.3, 112.3, 109.9, 83.3, 63.1, 42.8, 33.1, 29.6, 28.9, 25.7. FTIR (CH_2Cl_2) 3125, 3056, 2978, 2934, 1751, 1716, 1540, 1473, 1457, 1375, 1272, 1146, 1071, 965 cm^{-1}. HRMS (EI, *m/z*) calcd. for $C_{17}H_{19}NO_3$ (M^+) 285.1360, found 285.1357. $[\alpha]^{20}_D = –348°$ (c=0.62, CH_2Cl_2; for product with 92% ee). mp 84-87 °C.

Eq 3. The silyl ketene acetal (0.116 g, 0.397 mmol), a solution of (**+**)-**4** (0.0545 g, 0.0794 mmol) in CH_2Cl_2 (8.8 mL), and Ac_2O (0.0936 mL, 0.993 mmol) were added to a

screwcap vial, and the resulting solution was stirred for 72 hours at room temperature. Workup and purification furnished 81% (0.0842 g, 0.321 mmol) of a clear, colorless oil, which was shown by chiral GC (Chiraldex G-TA, 20 m x 0.25 mm, 100 °C, 1.0 mL/min, retention times of enantiomers: 14.0 min (minor), 15.2 min (major)) to have 91% ee.

For run 2, the silyl ketene acetal (0.110 g, 0.375 mmol), Ac_2O (0.0885 mL, 0.938 mmol), and (–)-**4** (0.0516 g, 0.0751 mmol) in 8.5 mL of CH_2Cl_2 furnished 83% of the product (0.0814 g, 0.310 mmol), which was shown by chiral GC to have 90% ee.

^{1}H NMR (500 MHz, $CDCl_3$) δ 7.27-7.38 (m, 5H), 2.33 (dq, 1H, J=14.0, J=7.5), 2.13 (dq, 1H, J=14.0, J=7.5), 2.08 (s, 3H), 1.51 (s, 9H), 0.86 (app t, 3H, J=7.5). ^{13}C NMR (125 MHz, $CDCl_3$) δ 204.0, 170.2, 137.4, 128.7, 128.3, 127.6, 82.6, 69.7, 28.5, 28.1, 27.9, 9.5. FTIR (thin film) 2978, 1737, 1713, 1495, 1370, 1248, 1156, 1126, 841, 700 cm^{-1}. $[\alpha]^{20}_D$ = – 69.9° (c=0.70, $CHCl_3$; for product with 91% ee).

VI. Mechanistic Studies (Table 2)

Table 2, entry 1. A solution of the silyl ketene acetal (0.020 g, 0.066 mmol) and 1,4-dioxane (internal standard; 0.0011 mL, 0.013 mmol) in CD_2Cl_2 (0.80 mL) was added to a screwcap NMR tube. Immediately prior to data acquisition, Ac_2O (0.0062 mL, 0.066 mmol) was added. The reaction was monitored by ^1H NMR spectroscopy after reaction times of 5 minutes, 30 minutes, 3.5 hours, 30 hours, 60 hours, and 100 hours. All of the spectra showed only unreacted starting materials.

Table 2, entry 2. A solution of the silyl ketene acetal (0.020 g, 0.066 mmol) in CD_2Cl_2 (0.30 mL) and a solution of (–)-**4** (0.0023 mg, 0.0033 mmol) and 1,4-dioxane (internal standard; 0.56 μL, 0.0066 mmol) in CD_2Cl_2 (0.40 mL) were added in turn to a screwcap NMR tube. Immediately prior to data acquisition, a solution of Ac_2O (0.0063 mL, 0.0662 mmol) in CD_2Cl_2 (0.10 mL) was added. The reaction was monitored by ^1H NMR. Spectra were collected every 2 minutes for the first 50 minutes; the data showed a $t_{1/2}$ of 17 minutes.

The reaction mixture was passed through a plug of silica gel (CH_2Cl_2 as the eluent) and concentrated. The product was shown by chiral GC (Chiraldex G-TA, 20 m x 0.25 mm, 150 °C, 1.0 mL/min, retention times of enantiomers: 9.48 min (major), 12.9 min (minor)) to have 87% ee.

Table 2, entry 3.[2] Inside a glove box, acetyl chloride (0.0010 mL, 0.13 mmol) was added to a deep-purple solution of (+)-**4** (0.035 g, 0.051 mmol) in CH_2Cl_2 (5 mL). After ~15 minutes, the CH_2Cl_2 and excess acetyl chloride were removed by vacuum. The resulting blue-green solid was dissolved in CH_2Cl_2 (2 mL) and then evaporated to dryness (to remove residual acetyl chloride). A solution of $AgSbF_6$ (0.018 g, 0.052 mmol) in acetonitrile (3 mL) was added. The resulting mixture was filtered through an acrodisc to remove the AgCl, then evaporated to provide a green residue, which was

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(2) The DMAP analogue of this complex has been prepared and fully characterized, including an X-ray crystal structure: Tao, B.; Ruble, J. C.; Hoic, D. A.; Fu, G. C. *J. Am. Chem. Soc.* **1999**, *121*, 5091-5092.

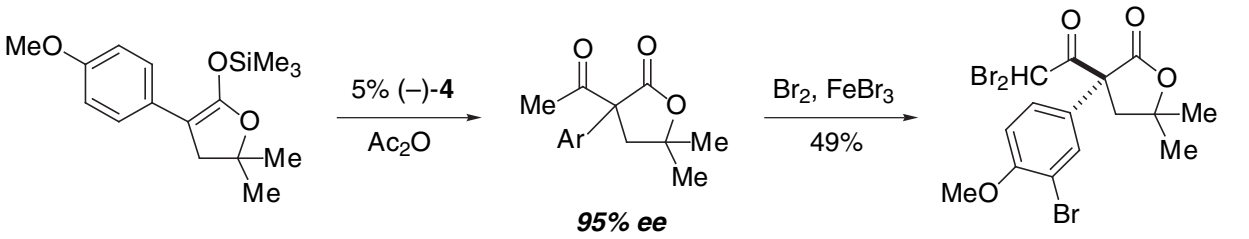
washed several times with CH_2Cl_2/pentane (1:1) to afford a crystalline green solid (0.049 g, 0.051 mmol) in quantitative yield.

^{1}H NMR (300 MHz, CD_2Cl_2) δ 8.15 (d, 1H, J=8.1), 7.26 (t, 5H, J=7.5), 7.12 (t, 10H, J=7.5), 6.86 (d, 10H, J=7.5), 6.41 (dd, 1H, J=3.0, J=1.2), 6.28 (d, 1H, J=8.4), 5.10 (dd, 1H, J=3.0, J=1.2), 4.89 (t, 1H, J=3.0), 3.63-3.90 (m, 4H), 2.45 (s, 3H), 2.05-2.31 (m, 4H). ^{13}C NMR (75 MHz, $CDCl_3$) δ 170.3, 165.6, 141.1, 133.5, 132.4, 128.0, 127.9, 101.5, 100.4, 88.4, 82.7, 71.8, 70.4, 70.2, 54.5, 53.9, 26.2, 24.8, 23.6. FTIR (KBr) 3056, 1735, 1609, 1560, 1507, 1219, 1173, 990, 702, 658 cm^{-1}. Anal. Calcd. for $C_{49}H_{41}F_6FeN_2OSb$ (965.5): C, 60.96; H, 4.28; N, 2.90. Found: C, 60.66; H, 3.90; N, 2.76. $[\alpha]^{25}_D$ = +72° (c=0.09, CH_2Cl_2; for product with >99% ee). mp 242-244 °C.

A solution of (+)-**9** (0.049 g, 0.051 mmol) and 1,4-dioxane (internal standard; 0.0011 mL, 0.013 mmol) in CD_2Cl_2 (0.50 mL) was added to a screwcap NMR tube. Immediately prior to data acquisition, a solution of the silyl ketene acetal (0.015 g, 0.051 mmol) in CD_2Cl_2 (0.30 mL) was added. The reaction was monitored by ^{1}H NMR spectroscopy after reaction times of 5 minutes, 72 minutes, 10 hours, and 60 hours. All of the spectra showed only unreacted starting materials.

Table 2, entry 4. A stock solution of the silyl ketene acetal was prepared by the addition of CD_2Cl_2 (1.0 mL) and 1,4-dioxane (internal standard; 6.0 μL) to the silyl ketene acetal (42.0 mg, 0.138 mmol). Another stock solution was prepared by the addition of CD_2Cl_2 (1 mL) to Me_4N[OAc] (5.3 mg, 0.040 mmol). To a screwcap NMR tube was added 0.35 mL of the stock solution of the silyl ketene acetal, then CD_2Cl_2 (0.40 mL), and then 62 μL of the stock solution of Me_4N[OAc]. After ~10 minutes, neat Ac_2O (6.1 μL, 0.064 mmol) was added. A ^{1}H NMR spectrum after 2 minutes indicated ~80% conversion to product (versus 1,4-dioxane).

VII. Determination of the Absolute Configuration of the Product



stereochemistry determined by X-ray crystallography

$FeBr_3$ (0.0100 g, 0.0330 mmol) and a solution of bromine (0.0569 mL, 1.12 mmol) in $CHCl_3$ (1.50 mL) were added in turn to a solution of the lactone (0.0975 g, 0.372 mmol) in $CHCl_3$ (2.0 mL). The resulting mixture was stirred at room temperature for 34 hours, after which additional $FeBr_3$ (0.0150 g, 0.0507 mmol) and bromine (0.0300 mL, 0.588 mmol) were added. The mixture was stirred at room temperature for 30 hours, and then it was poured into saturated aqueous $Na_2S_2O_3$ and extracted with Et_2O (3 x 20 mL). The organic layer was washed with water (1 x 30 mL) and dried over Na_2SO_4. The solvent was removed, and the resulting off-white solid was purified by flash chromatography (25% Et_2O/75% pentane), which furnished 49% of a white crystalline solid (0.0890 g, 0.212 mmol).

^1H NMR (300 MHz, $CDCl_3$) δ 7.60 (d, 1H, J=2.7), 7.37 (dd, 1H, J=9.0, J=3.0), 6.92 (d, 1H, J=8.7), 6.57 (s, 1H), 3.94 (s, 3H), 3.43 (d, 1H, J=13.5), 2.36 (d, 1H, J=13.5), 1.50 (s, 3H), 1.36 (s, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 191.1, 171.5, 156.7, 132.4, 128.5, 127.8, 113.2, 112.5, 83.7, 65.2, 56.6, 45.2, 36.1, 29.1, 28.7. FTIR (CH_2Cl_2) 3029, 2982, 2943, 2904, 2483, 1749, 1733, 1559, 1540, 1497, 1457, 1388, 1273, 1199 cm^{-1}. HRMS (ESI, *m/z*) calcd. for $C_{15}H_{15}Br_3O_4$ $(M+H)^+$ 496.8613, found 496.8613. $[\alpha]^{20}_D$ = +235° (c=0.25, CH_2Cl_2; for product with 95% ee). mp 148-152 °C.

X-ray quality crystals were grown from Et_2O/pentane, and the configuration of the quaternary center was assigned as (R) by single crystal X-ray diffraction.

X-ray Crystal Structure

A colorless solution of the lactone in Et_2O was prepared. Crystals suitable for X-ray structural analysis were obtained by pentane diffusion. A clear, colorless block of dimensions 0.57 x 0.18 x 0.09 mm^3 was mounted under STP and transferred to a Bruker AXS/CCD three-circle diffractometer (χ fixed at 54.78°) equipped with a cold stream of N_2 gas. An initial unit cell was determined by harvesting reflections $I > 20\ \sigma(I)$ from 45 x 10-s frames of 0.30° ω scan data with monochromated Mo $K\alpha$ radiation (λ = 0.71073 Å). The cell thus determined was orthorhombic.

A hemisphere of data was then collected using ω scans of 0.30° and 10-s frames. The raw data frames were integrated using the Bruker program SAINT+ for NT version 6.01. Actual integration was performed with constant spot sizes of 1.6° in the detector plane and 0.6° in ω. The data that were collected (6854 total reflections, 2473 unique, R_{int} = 0.2631) had the following Miller index ranges: –7 to 7 in h, –13 to 12 in k, and –13 to 22 in l. The data were corrected for Lorentz and polarization effects. No absorption correction was applied.

All aspects of the solution and refinement were handled by SHELXTL NT version 5.10.[3] The structure was solved by direct methods in the orthorhombic space group P2(1)2(1)2(1), a = 6.7476(8) Å; b = 12.5932(15) Å; c = 20.305(2) Å; α = 90°; β = 90°; γ = 90°, and refined using standard difference Fourier techniques. Final, full-matrix least-squares refinement (2473 data for 203 parameters) on F^2 yielded residuals of R_1 and wR_2 of 0.0878 and 0.2031 for data $I > 2\sigma(I)$, and 0.0906 and 0.2070, respectively, for all data. During the final refinement, all non-hydrogen atoms were treated anisotropically. Hydrogen atoms were included in calculated positions and refined isotropically on a riding model. A secondary extinction coefficient of 0.021(3) was used in the refinement. Residual electron density amounted to a maximum of 1.886 e/$Å^3$ and a minimum of –2.216 e/$Å^3$.

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(3) SHELXTL: Bruker AXS, Inc., SHELXTLTM Reference Manual Version 5.1, 1997.

Crystallographic data (excluding structure factors) have been deposited with the Cambridge Crystallographic Data Centre as supplementary publication no. CCDC-178106. Copies of the data can be obtained free of charge on application to CCDC, 12 Union Road, Cambridge CB2 1EZ, UK (fax: (+44)1223-336-033; E-mail: deposit@ccdc.cam.ac.uk).

Tables 1-6 provide the full crystallographic data for the X-ray structure.

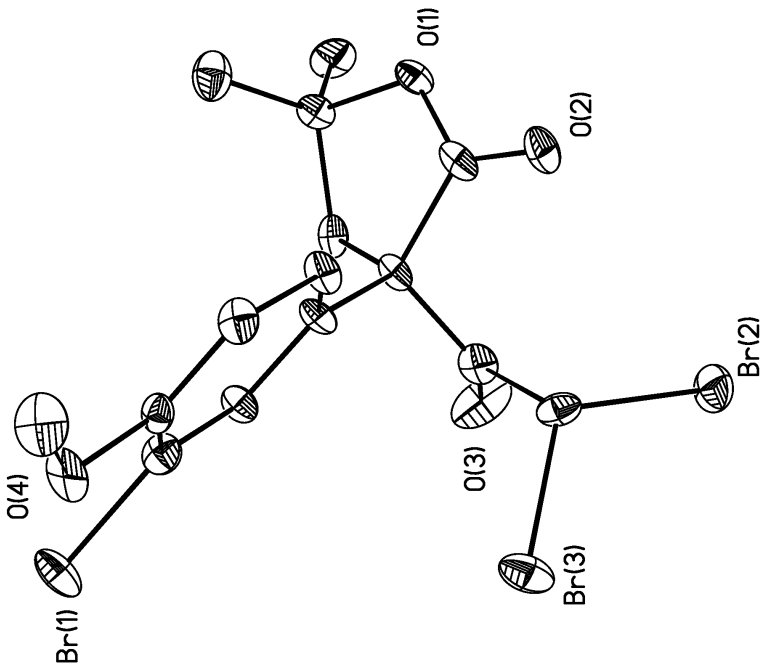
O(1)
O(2)
Br(2)
O(3)
Br(3)
O(4)
Br(1)

Table 1. Crystal data and structure refinement for 02015am2.

Identification code	02015am2	
Empirical formula	C15 H15 Br3 O4	
Formula weight	499.00	
Temperature	183(2) K	
Wavelength	0.71073 Å	
Crystal system	Orthorhombic	
Space group	P2(1)2(1)2(1)	
Unit cell dimensions	a = 6.7476(8) Å	α = 90°.
	b = 12.5932(15) Å	β = 90°.
	c = 20.305(2) Å	γ = 90°.
Volume	1725.4(3) $Å^3$	
Z	4	
Density (calculated)	1.921 Mg/m^3	
Absorption coefficient	7.027 mm^{-1}	
F(000)	968	
Crystal size	0.09 x 0.18 x 0.57 mm^3	
Theta range for data collection	3.18 to 23.29°.	
Index ranges	-7<=h<=7, -13<=k<=12, -13<=l<=22	
Reflections collected	6854	
Independent reflections	2473 [R(int) = 0.2631]	
Completeness to theta = 23.29°	99.5 %	
Refinement method	Full-matrix least-squares on F^2	
Data / restraints / parameters	2473 / 0 / 203	
Goodness-of-fit on F^2	1.024	
Final R indices [I>2sigma(I)]	R1 = 0.0878, wR2 = 0.2031	
R indices (all data)	R1 = 0.0906, wR2 = 0.2070	
Absolute structure parameter	0.00(3)	
Extinction coefficient	0.021(3)	
Largest diff. peak and hole	1.886 and -2.216 e.$Å^{-3}$	

Table 2. Atomic coordinates (x 10^4) and equivalent isotropic displacement parameters ($Å^2$x 10^3) for 02015am2.

U(eq) is defined as one third of the trace of the orthogonalized U^{ij} tensor.

	x	y	z	U(eq)
Br(1)	1390(2)	3465(1)	8123(1)	38(1)
Br(2)	10818(2)	2670(1)	5866(1)	43(1)
Br(3)	7911(2)	1921(1)	7011(1)	43(1)
O(4)	4226(15)	4690(7)	8955(3)	33(2)
O(1)	7270(13)	6259(6)	5707(4)	30(2)
O(3)	6186(19)	2986(7)	5694(4)	52(3)
O(2)	9753(12)	5380(7)	6174(4)	33(2)
C(10)	4873(18)	4746(9)	8315(5)	22(2)
C(9)	3690(20)	4192(9)	7855(5)	29(3)
C(8)	4205(18)	4191(9)	7202(5)	24(2)
C(7)	5892(18)	4715(8)	6980(5)	23(2)
C(12)	7078(18)	5243(9)	7433(5)	24(2)
C(11)	6507(17)	5260(9)	8104(5)	27(2)
C(13)	5230(20)	5340(11)	9432(5)	40(3)
C(15)	8790(20)	3108(9)	6485(5)	28(3)
C(14)	7020(20)	3539(10)	6086(5)	29(3)
C(2)	6368(18)	4665(9)	6238(5)	21(2)
C(1)	8017(18)	5464(9)	6051(5)	26(3)
C(4)	5058(19)	6211(9)	5644(5)	25(2)
C(3)	4696(17)	5021(9)	5785(5)	26(2)
C(5)	4160(20)	6940(11)	6127(6)	41(3)
C(6)	4650(20)	6524(10)	4938(6)	40(3)

Table 3. Bond lengths [Å] and angles [°] for 02015am2.

Br(1)-C(9)	1.884(13)
Br(2)-C(15)	1.939(12)
Br(3)-C(15)	1.930(11)
O(4)-C(10)	1.373(13)
O(4)-C(13)	1.437(15)
O(1)-C(1)	1.321(15)
O(1)-C(4)	1.499(16)
O(3)-C(14)	1.198(14)
O(2)-C(1)	1.203(16)
C(10)-C(11)	1.348(17)
C(10)-C(9)	1.412(17)
C(9)-C(8)	1.371(16)
C(8)-C(7)	1.391(17)
C(7)-C(12)	1.388(16)
C(7)-C(2)	1.542(13)
C(12)-C(11)	1.417(15)
C(15)-C(14)	1.543(18)
C(14)-C(2)	1.516(16)
C(2)-C(3)	1.524(17)
C(2)-C(1)	1.548(15)
C(4)-C(5)	1.475(18)
C(4)-C(6)	1.513(15)
C(4)-C(3)	1.544(17)
C(10)-O(4)-C(13)	117.4(11)
C(1)-O(1)-C(4)	113.2(9)
C(11)-C(10)-O(4)	125.8(11)
C(11)-C(10)-C(9)	119.3(10)
O(4)-C(10)-C(9)	114.9(11)
C(8)-C(9)-C(10)	119.8(12)
C(8)-C(9)-Br(1)	119.2(9)
C(10)-C(9)-Br(1)	121.0(9)
C(9)-C(8)-C(7)	121.3(11)
C(12)-C(7)-C(8)	119.0(9)
C(12)-C(7)-C(2)	123.1(10)
C(8)-C(7)-C(2)	117.9(10)
C(7)-C(12)-C(11)	119.2(11)
C(10)-C(11)-C(12)	121.4(10)
C(14)-C(15)-Br(3)	109.0(9)
C(14)-C(15)-Br(2)	107.8(7)
Br(3)-C(15)-Br(2)	110.8(5)
O(3)-C(14)-C(2)	122.9(12)
O(3)-C(14)-C(15)	120.5(11)
C(2)-C(14)-C(15)	116.5(10)

C(14)-C(2)-C(3)	111.5(9)
C(14)-C(2)-C(7)	107.3(9)
C(3)-C(2)-C(7)	115.0(10)
C(14)-C(2)-C(1)	110.5(10)
C(3)-C(2)-C(1)	101.1(9)
C(7)-C(2)-C(1)	111.3(9)
O(2)-C(1)-O(1)	123.3(10)
O(2)-C(1)-C(2)	126.3(11)
O(1)-C(1)-C(2)	110.4(10)
C(5)-C(4)-O(1)	109.2(10)
C(5)-C(4)-C(6)	113.1(10)
O(1)-C(4)-C(6)	104.6(10)
C(5)-C(4)-C(3)	114.5(10)
O(1)-C(4)-C(3)	100.5(10)
C(6)-C(4)-C(3)	113.5(9)
C(2)-C(3)-C(4)	106.3(10)

Table 4. Anisotropic displacement parameters ($Å^2 x\ 10^3$) for 02015am2.

The anisotropic displacement factor exponent takes the form: $-2\pi^2[h^2 a^{*2} U^{11} + ... + 2 h k a^* b^* U^{12}]$

	U^{11}	U^{22}	U^{33}	U^{23}	U^{13}	U^{12}
Br(1)	33(1)	61(1)	19(1)	6(1)	3(1)	-13(1)
Br(2)	46(1)	47(1)	34(1)	-2(1)	15(1)	9(1)
Br(3)	49(1)	48(1)	32(1)	15(1)	-4(1)	-14(1)
O(4)	43(5)	53(5)	3(3)	-2(3)	6(4)	4(4)
O(1)	31(5)	34(4)	24(4)	7(3)	7(3)	-6(4)
O(3)	75(8)	36(4)	45(5)	-23(4)	-42(6)	4(5)
O(2)	19(4)	50(5)	29(4)	4(4)	0(3)	-1(4)
C(10)	24(6)	27(5)	15(5)	0(4)	1(4)	6(5)
C(9)	34(6)	28(5)	24(5)	-5(5)	-1(5)	1(5)
C(8)	27(6)	31(5)	12(5)	-1(4)	1(5)	-4(5)
C(7)	27(6)	34(5)	8(5)	7(5)	3(5)	-4(5)
C(12)	24(6)	39(6)	7(4)	5(4)	-1(5)	1(5)
C(11)	29(6)	31(6)	21(5)	-12(5)	-3(5)	-3(5)
C(13)	49(9)	52(7)	17(6)	-16(6)	-7(5)	-2(7)
C(15)	44(8)	23(5)	19(5)	3(5)	-4(5)	2(6)
C(14)	37(7)	40(6)	10(5)	1(5)	0(5)	0(6)
C(2)	26(6)	31(5)	6(4)	-7(4)	4(4)	-8(5)
C(1)	33(7)	36(6)	9(5)	-11(5)	8(5)	-14(6)
C(4)	28(6)	32(6)	15(5)	6(5)	-6(4)	-3(5)
C(3)	23(6)	40(6)	14(5)	-7(5)	-1(5)	4(5)
C(5)	30(7)	50(7)	43(7)	-11(7)	-3(6)	3(6)
C(6)	53(9)	39(7)	28(6)	15(5)	-8(6)	9(7)

Table 5. Hydrogen coordinates (x 10^4) and isotropic displacement parameters ($Å^2$x 10^3) for 02015am2.

	x	y	z	U(eq)
H(8)	3393	3825	6895	28
H(12)	8257	5589	7294	28
H(11)	7292	5641	8412	32
H(13A)	6663	5266	9377	59
H(13B)	4852	5112	9877	59
H(13C)	4848	6084	9369	59
H(15)	9320	3678	6779	34
H(3A)	3395	4918	6001	31
H(3B)	4714	4609	5370	31
H(5A)	4529	6719	6574	61
H(5B)	2712	6920	6083	61
H(5C)	4633	7663	6047	61
H(6A)	3341	6254	4806	60
H(6B)	5665	6220	4651	60
H(6C)	4662	7299	4899	60

Table 6. Torsion angles [°] for 02015am2.

C(13)-O(4)-C(10)-C(11)	8.2(17)
C(13)-O(4)-C(10)-C(9)	-172.7(11)
C(11)-C(10)-C(9)-C(8)	-0.6(17)
O(4)-C(10)-C(9)-C(8)	-179.7(11)
C(11)-C(10)-C(9)-Br(1)	-179.8(9)
O(4)-C(10)-C(9)-Br(1)	1.0(14)
C(10)-C(9)-C(8)-C(7)	0.9(17)
Br(1)-C(9)-C(8)-C(7)	-179.9(9)
C(9)-C(8)-C(7)-C(12)	0.4(17)
C(9)-C(8)-C(7)-C(2)	179.5(11)
C(8)-C(7)-C(12)-C(11)	-1.8(16)
C(2)-C(7)-C(12)-C(11)	179.1(11)
O(4)-C(10)-C(11)-C(12)	178.2(11)
C(9)-C(10)-C(11)-C(12)	-0.9(17)
C(7)-C(12)-C(11)-C(10)	2.1(17)
Br(3)-C(15)-C(14)-O(3)	-61.2(13)
Br(2)-C(15)-C(14)-O(3)	59.2(14)
Br(3)-C(15)-C(14)-C(2)	116.5(9)
Br(2)-C(15)-C(14)-C(2)	-123.2(9)
O(3)-C(14)-C(2)-C(3)	-5.8(16)
C(15)-C(14)-C(2)-C(3)	176.6(9)
O(3)-C(14)-C(2)-C(7)	121.1(13)
C(15)-C(14)-C(2)-C(7)	-56.5(13)
O(3)-C(14)-C(2)-C(1)	-117.4(13)
C(15)-C(14)-C(2)-C(1)	65.0(11)
C(12)-C(7)-C(2)-C(14)	108.5(12)
C(8)-C(7)-C(2)-C(14)	-70.6(13)
C(12)-C(7)-C(2)-C(3)	-126.8(12)
C(8)-C(7)-C(2)-C(3)	54.2(14)
C(12)-C(7)-C(2)-C(1)	-12.5(15)
C(8)-C(7)-C(2)-C(1)	168.4(10)
C(4)-O(1)-C(1)-O(2)	-177.5(10)
C(4)-O(1)-C(1)-C(2)	4.7(12)
C(14)-C(2)-C(1)-O(2)	-45.6(14)
C(3)-C(2)-C(1)-O(2)	-163.8(11)
C(7)-C(2)-C(1)-O(2)	73.6(14)
C(14)-C(2)-C(1)-O(1)	132.2(9)
C(3)-C(2)-C(1)-O(1)	14.0(11)
C(7)-C(2)-C(1)-O(1)	-108.7(10)
C(1)-O(1)-C(4)-C(5)	99.8(11)
C(1)-O(1)-C(4)-C(6)	-138.8(9)
C(1)-O(1)-C(4)-C(3)	-20.9(11)
C(14)-C(2)-C(3)-C(4)	-143.8(9)
C(7)-C(2)-C(3)-C(4)	93.6(11)

C(1)-C(2)-C(3)-C(4)	-26.4(10)
C(5)-C(4)-C(3)-C(2)	-88.1(13)
O(1)-C(4)-C(3)-C(2)	28.8(10)
C(6)-C(4)-C(3)-C(2)	139.9(11)