Supporting Information

For

A Highly Diastereoselective MgI_2 Mediated Ring Expansion of
Methylenecyclopropanes

Mark E. Scott, Wooseok Han and Mark Lautens*

Davenport Research Laboratories, Department of Chemistry, University of Toronto,
80 St. George Street, Toronto, Ontario, M5S 3H6, Canada
mlautens@chem.utoronto.ca

General:

Melting points were recorded using a Fisher-Johns melting point apparatus and are uncorrected. ^1H , ^{19}F and ^{13}C NMR spectra were recorded using either a Varian Gemini 300, Varian Unity 400 MHz or Varian Unity 500 MHz spectrometer in CDCl_3 with chemical shifts relative to tetramethylsilane (TMS, 0 ppm) unless otherwise reported. No special notation is used for equivalent carbons. IR spectra were obtained using a Nicolet DX FT IR spectrometer as thin films on NaCl plates. Optical rotations were obtained using a Perkin-Elmer 243 B polarimeter. High-resolution mass spectra were obtained using a VG 70-250S (double focusing) mass spectrometer at 70 eV.

Diethyl ether and tetrahydrofuran (THF) were distilled under nitrogen from Na/benzophenone immediately prior to use. Dichloromethane was distilled under nitrogen from CaH_2 immediately before use. All reagents were used as received from Sigma-Aldrich unless otherwise indicated. MgI_2 was weighed out in a glovebox to prevent absorption of water. Neutral silica (Silicycle, Quebec, Canada) for flash chromatography was used as received. All experiments were performed under anhydrous conditions under an atmosphere of nitrogen.

(S)-(+)-*p*-Toluenesulfinamide,¹ (R)-(-)-*p*-toluenesulfinamide,¹ (S)-(+)-*N*-(*p*-nitrobenzylidene)-*p*-toluenesulfinamide,² (S)-(+)-*N*-(*p*-methoxybenzylidene)-*p*-toluenesulfinamide,² (S)-(+)-*N*-(benzylidene)-*p*-toluenesulfinamide,² (R)-(+)-*N*-(benzylidene)-*p*-toluenesulfinamide,² (S)-(+)-*N*-(2-furylmethylidene)-*p*-toluenesulfinamide,² (S)-(+)-*N*-(3-pyridinemethylidene)-*p*-toluenesulfinamide,² (S)-(+)-*N*-(2-pyridinemethylidene)-*p*-toluenesulfinamide,³ (S)-(+)-*N*-(*p*-methylbenzylidene)-*p*-toluenesulfinamide,⁴ (S)-*N*-(benzylidene)-*tert*-butylsulfinamide⁵ and 2-methylenecyclopropane carboxylic acid diphenylamide⁶ were prepared as previously reported.

General Procedure for MgI_2 Mediated Ring Expansion of Methylenecyclopropanes (MCP):

To a flame dried flask was added MCP (0.201 mmol), MgI_2 (0.0565 g, 0.203 mmol, 1 equiv.) and sulfinimine (0.241 mmol, 1.2 equiv.). THF was added (2.0 mL) and the solution was stirred for 20 minutes at room temperature before heating to reflux. Reaction completion was monitored by TLC. The reaction was then cooled to room temperature, diluted with ethyl acetate (2.0 mL), and quenched with saturated aqueous sodium sulfite (2.0 mL). The aqueous layer was separated and 0.5 M tetrasodium ethylenediaminetetraacetic acid salt (EDTA) was added (50 mL). The aqueous phase was then extracted with ethyl acetate (3×50 mL) and the combined organic layers were dried with Na_2SO_4 , filtered and concentrated *in vacuo*.

¹ Davis, F.A.; Zhang, Y.; Andemichael, Y.; Fang, T.; Fanelli, D.L.; Zhang, H. *J. Org. Chem.* **1999**, *64*, 1403-1406.

² Davis, F.A.; Reddy, R.E.; Szewczyk, J.M.; Reddy, G.V.; Portonovo, P.S.; Zhang, H.; Fanelli, D.; Reddy, R.T.; Zhou, P.; Carrol, P.J. *J. Org. Chem.* **1997**, *62*, 2555-2563.

³ García Ruano, J.L.; Alemán, J. *Org. Lett.* **2003**, *23*, 4513-4516.

⁴ Balasubramanian, T.; Hassner, A. *Tetrahedron Lett.* **1996**, *37*, 5755-5758.

⁵ Liu, G.; Cogan, D.A.; Ellman, J.A. *J. Am. Chem. Soc.* **1997**, *119*, 9913-9914.

⁶ Lautens, M.; Han, W. *J. Am. Chem. Soc.* **2002**, *124*, 6312-6316.

(2R, 3R, SS)- 4-Methylene-2-phenyl-1-(toluene-4-sulfinyl)-pyrrolidine-3-carboxylic acid diphenylamide

Following the general procedure outlined above (refluxed for 3.25 hours) for the MgI_2 -mediated ring expansion of 2-methylenecyclopropane carboxylic acid diphenylamide in the presence of (S)-(+)-*N*-(benzylidene)-*p*-toluenesulfinamide. Following workup, chromatography on silica gel using 1:2 ethyl acetate:hexanes ($R_f = 0.16$) gave the title compound (0.0910 g, 89%) as an amorphous white foam. $[\alpha]_D^{20} = +44.5^\circ$ ($c = 0.55$, CH_2Cl_2) IR (neat, cm^{-1}) 3061, 3034, 2918, 1675, 1594, 1489, 1452, 1364, 1293, 1228, 1155, 1087, 1067, 1030, 1013, 982, 911, 809, 782, 748, 728, 698; δ_H (400 MHz, CDCl_3) 7.50 (d, 2H, $J = 8.0$ Hz), 7.44 (s, 4H), 7.31-7.06 (m, 11H), 6.6 (bs, 2H), 5.13 (d, 2H, $J = 2.4$ Hz), 5.11 (d, 1H, $J = 10.4$ Hz), 5.00 (d, 1H, $J = 2.4$ Hz), 4.20 (d, 1H, $J = 14.4$ Hz), 3.72 (d, 1H, $J = 10.0$ Hz), 3.09 (d, 1H, $J = 14.4$ Hz), 2.39 (s, 3H); δ_C (100 MHz, CDCl_3) 170.0, 144.5, 142.5, 142.3, 141.4, 140.9, 138.5, 130.0, 129.8, 129.1, 128.9, 128.7, 128.5, 128.2, 126.5, 126.3, 125.6, 67.8, 57.6, 45.5, 21.5; $\text{C}_{31}\text{H}_{28}\text{N}_2\text{O}_2\text{S}$ (M^+) Requires 493.1950 Found: 493.1961.

(2R, 3R, SS)-4-Methylene-1-(2-methyl-propane-2-sulfinyl)-2-phenyl-pyrrolidine-3-carboxylic acid diphenylamide

Following the general procedure outlined above (refluxed for 3.83 hours) for the MgI_2 -mediated ring expansion of 2-methylenecyclopropane carboxylic acid diphenylamide in the presence of (S)-*N*-(benzylidene)-*tert*-butylsulfinamide. Following workup, chromatography on silica gel using 1:1 ethyl acetate:hexanes ($R_f = 0.15$) gave the title compound (0.0728 g, 79%) as an amorphous white foam. $[\alpha]_D^{20} = +123.9^\circ$ ($c = 0.92$, CHCl_3) IR (neat, cm^{-1}) 2960, 1677, 1593, 1491, 1456, 1364, 1295, 1229, 1156, 1066, 978, 911, 822, 782, 754, 730, 701; δ_H (400 MHz, CDCl_3) 7.37-7.07 (m, 13H), 6.62 (bs, 2H), 5.15 (d, 1H, $J = 2.5$ Hz), 5.13 (d, 1H, $J = 2.5$ Hz), 5.01 (d, 1H, $J = 9.9$ Hz), 4.42 (dd, 1H, $J = 2.2, 14.3$ Hz), 3.66 (d, 1H, $J = 9.3$ Hz), 3.58 (d, 1H, $J = 14.3$ Hz), 1.09 (s, 9H); δ_C (125 MHz, CDCl_3) 169.9, 145.3, 142.5, 142.3, 139.7, 129.9, 129.1, 128.7, 128.7, 128.6, 128.5, 128.2, 126.4, 126.3, 107.7, 71.0, 57.6, 56.6, 46.3, 24.2, 22.6; $\text{C}_{28}\text{H}_{30}\text{N}_2\text{O}_2\text{S}$ (M^+) Requires 459.2106 Found: 459.2116.

(2R, 3R, SS)-2-(2-Bromo-phenyl)-4-methylene-1-(toluene-4-sulfinyl)-pyrrolidine-3-carboxylic acid diphenylamide

Following the general procedure outlined above (refluxed for 6.5 hours) for the MgI_2 -mediated ring expansion of 2-methylenecyclopropane carboxylic acid diphenylamide in the presence of (S)-(+)-*N*-(2-bromo-benzylidene)-*p*-toluenesulfinamide. Following workup, chromatography on

silica gel using 1:2 ethyl acetate:hexanes ($R_f = 0.13$) gave the title compound (0.0724 g, 63%) as a white solid, mp 157-160°C. $[\alpha]_D^{20} = +16.1^\circ$ ($c = 0.90$, CHCl_3) IR (neat, cm^{-1}) 3060, 2922, 2855, 1678, 1593, 1491, 1374, 1297, 1090, 1069, 910, 754, 730, 702; δ_H (300 MHz, CDCl_3) 7.67 (d, 1H, $J = 7.2$), 7.50 (d, 2H, $J = 7.7$ Hz), 7.35-7.16 (m, 13H), 6.84 (bs, 2H), 5.66 (bs, 1H), 5.07 (bs, 1H), 5.02 (bs, 1H), 4.23 (d, 1H, $J = 13.7$ Hz), 3.96 (bs, 1H), 3.12 (d, 1H, $J = 14.0$ Hz), 2.38 (s, 3H); δ_C (100 MHz, CDCl_3) 169.9, 144.5, 142.5, 141.3, 141.0, 133.9, 130.0, 129.7, 129.1, 128.8, 128.1, 126.4, 125.6, 108.9, 46.1, 21.6; $\text{C}_{31}\text{H}_{27}\text{N}_2\text{O}_2\text{SBr}$ (M^+) Requires 571.1055 Found: 571.1048.

(2R, 3R, SS)-2-(3-Bromo-phenyl)-4-methylene-1-(toluene-4-sulfinyl)-pyrrolidine-3-carboxylic acid diphenylamide

Following the general procedure outlined above (refluxed for 7.5 hours) for the MgI_2 -mediated ring expansion of 2-methylenecyclopropane carboxylic acid diphenylamide in the presence of (S)-(+)-*N*-(3-bromo-benzylidene)-*p*-toluenesulfinamide. Following workup, chromatography on silica gel using 1:2 ethyl acetate:hexanes ($R_f = 0.38$) gave the title compound (0.0827 g, 72%) as an amorphous white foam. $[\alpha]_D^{20} = +19.8^\circ$ ($c = 1.20$, CHCl_3) IR (neat, cm^{-1}) 3060, 2922, 1676, 1594, 1490, 1378, 1294, 1093, 1069, 1016, 889, 812, 756, 731, 694; δ_H (300 MHz, CDCl_3) 7.60-7.10 (m, 16H), 6.65 (bs, 2H), 5.15 (s, 1H), 5.06 (d, 1H, $J = 10.2$ Hz), 5.01 (s, 1H), 4.17 (d, 1H, $J = 14.4$ Hz), 3.70 (d, 1H, $J = 9.6$ Hz), 3.08 (d, 1H, $J = 14.3$ Hz), 2.40 (s, 3H); δ_C (125 MHz, CDCl_3) 169.5, 143.9, 142.2, 142.1, 141.6, 141.0, 140.4, 132.0, 131.0, 130.7, 130.0, 129.8, 129.1, 128.6, 128.4, 127.7, 126.6, 126.2, 125.5, 123.3, 108.3, 67.2, 57.5, 45.5; $\text{C}_{31}\text{H}_{27}\text{N}_2\text{O}_2\text{SBr}$ (M^+) Requires 571.1055 Found: 571.1034.

(2R, 3R, SS)-2-(4-Bromo-phenyl)-4-methylene-1-(toluene-4-sulfinyl)-pyrrolidine-3-carboxylic acid diphenylamide

Following the general procedure outlined above (refluxed for 7.5 hours) for the MgI_2 -mediated ring expansion of 2-methylenecyclopropane carboxylic acid diphenylamide in the presence of (S)-(+)-*N*-(4-bromo-benzylidene)-*p*-toluenesulfinamide. Following workup, chromatography on silica gel using 1:1 ethyl acetate:hexanes ($R_f = 0.45$) gave the title compound (0.0919 g, 80%) as an amorphous white foam. $[\alpha]_D^{20} = +53.3^\circ$ ($c = 1.26$, CHCl_3) IR (neat, cm^{-1}) 3060, 2922, 1676, 1592, 1490, 1379, 1295, 1091, 1069, 1011, 909, 833, 812, 755, 730, 702; δ_H (500 MHz, CDCl_3) 7.58 (d, 2H, $J = 10.9$ Hz), 7.47 (d, 2H, $J = 12.1$ Hz), 7.33-7.09 (m, 12H), 6.67 (bs, 2H), 5.15 (d, 1H, $J = 2.4$ Hz), 5.08 (d, 1H, $J = 10.0$ Hz), 5.00 (d, 1H, $J = 2.6$ Hz), 4.16 (dd, 1H, $J = 14.4$, 2.4 Hz), 3.70 (dd, 1H, $J = 10.0$, 1.5 Hz), 3.08 (dd, 1H, $J = 14.3$, 1.0 Hz), 2.39 (s, 3H); δ_C (125 MHz, CDCl_3) 169.6, 144.1, 142.4, 142.2, 141.6, 140.6, 137.8, 132.3, 130.2, 130.0, 129.8, 129.2, 128.7, 128.3, 126.6, 126.3, 125.5, 122.8, 108.3, 67.2, 57.5, 45.6, 21.6; $\text{C}_{31}\text{H}_{27}\text{N}_2\text{O}_2\text{SBr}$ (M^+) Requires 571.1055 Found: 571.1066.

**(2R, 3R, SS)-4-Methylene-1-(toluene-4-sulfinyl)-
2-o-tolyl-pyrrolidine-3-carboxylic acid diphenylamide**

Following the general procedure outlined above (refluxed for 6 hours) for the MgI_2 -mediated ring expansion of 2-methylenecyclopropane carboxylic acid diphenylamide in the presence of (S)-(+)-*N*-(2-methyl-benzylidene)-*p*-toluenesulfinamide. Following workup, chromatography on silica gel using 1:1 ethyl acetate:hexanes ($R_f = 0.3$) gave the title compound (0.0662 g, 65%) as an amorphous white foam. $[\alpha]_D^{20} = +57.2^\circ$ ($c = 0.94$, CHCl_3) IR (neat, cm^{-1}) 3061, 2922, 1676, 1654, 1594, 1490, 1456, 1363, 1295, 1157, 1092, 1068, 910, 813, 753, 729, 702; δ_H (400 MHz, CDCl_3) 7.45 (d, 2H, $J = 8.2$ Hz), 7.33-7.01 (m, 14H), 6.67 (bs, 2H), 5.44 (d, 1H, $J = 9.9$ Hz), 5.14 (dd, 1H, $J = 2.5, 2.5$ Hz), 5.00 (dd, 1H, $J = 2.5, 2.5$ Hz), 4.16 (ddd, 1H, $J = 2.2, 2.5, 14.3$ Hz), 3.85 (dd, 1H, $J = 1.6, 10.2$ Hz), 3.07 (d, 1H, $J = 14.8$ Hz), 2.52 (s, 3H), 2.38 (s, 3H); δ_C (100 MHz, CDCl_3) 170.2, 144.9, 142.5, 142.3, 141.3, 140.9, 138.5, 136.1, 131.1, 129.9, 129.7, 129.1, 128.8, 128.3, 128.4, 128.2, 126.6, 126.5, 126.2, 125.5, 107.9, 63.4, 56.5, 45.7, 21.6, 20.0; $\text{C}_{32}\text{H}_{30}\text{N}_2\text{O}_2\text{S}$ (M^+) Requires 507.2106 Found: 507.2091.

**(2R, 3R, SS)-4-Methylene-1-(toluene-4-sulfinyl)-
2-*p*-tolyl-pyrrolidine-3-carboxylic acid diphenylamide**

Following the general procedure outlined above (refluxed for 7 hours) for the MgI_2 -mediated ring expansion of 2-methylenecyclopropane carboxylic acid diphenylamide in the presence of (S)-(+)-*N*-(4-methyl-benzylidene)-*p*-toluenesulfinamide. Following workup, chromatography on silica gel using 1:1 ethyl acetate:hexanes ($R_f = 0.33$) gave the title compound (0.0866 g, 85%) as a white solid, mp 175-177°C. $[\alpha]_D^{20} = +64.1^\circ$ ($c = 0.91$, CHCl_3) IR (neat, cm^{-1}) 3037, 2923, 1676, 1594, 1491, 1452, 1375, 1295, 1156, 1091, 1068, 910, 830, 812, 758, 731, 702; δ_H (300 MHz, CDCl_3) 7.49 (d, 2H, $J = 8.2$ Hz), 7.34-7.09 (m, 14H), 6.62 (bs, 2H, $J = 5.8$ Hz), 5.13 (d, 1H, $J = 2.2$ Hz), 5.08 (d, 1H, $J = 10.2$ Hz), 4.99 (d, 1H, $J = 2.2$ Hz), 4.16 (dd, 1H, $J = 2.5, 14.3$ Hz), 3.73 (dd, 1H, $J = 1.6, 9.9$ Hz), 3.08 (d, 1H, $J = 14.3$ Hz), 2.45 (s, 3H), 2.38 (s, 3H); δ_C (125 MHz, CDCl_3) 170.0, 144.5, 142.5, 142.3, 141.3, 140.9, 138.6, 135.3, 129.9, 129.7, 129.7, 129.1, 128.7, 128.5, 128.1, 126.5, 126.3, 125.6, 107.9, 67.7, 57.4, 45.5, 21.5; $\text{C}_{32}\text{H}_{30}\text{N}_2\text{O}_2\text{S}$ (M^+) Requires 507.2106 Found: 507.2109.

**(2R, 3R, SS)-2-(4-Methoxy-phenyl)-4-methylene-
1-(toluene-4-sulfinyl)-pyrrolidine-3-carboxylic acid diphenylamide**

Following the general procedure outlined above (refluxed for 7 hours) for the MgI_2 -mediated ring expansion of 2-methylenecyclopropane carboxylic acid diphenylamide in the presence of (S)-(+)-*N*-(4-methoxy-benzylidene)-*p*-toluenesulfinamide. Following workup, chromatography on silica gel using 1:1 ethyl acetate:hexanes ($R_f = 0.39$) gave the title compound (0.0866 g, 85%) as a white solid, mp 175-177°C. $[\alpha]_D^{20} = +55.2^\circ$ ($c = 1.11$, CHCl_3) IR (neat, cm^{-1}) 3004, 2933, 1675, 1612, 1594, 1513, 1491, 1454, 1364, 1296, 1250, 1173, 1156, 1091, 1068, 1031, 984, 884, 837, 812, 755, 703; δ_H (400 MHz, CDCl_3) 7.47 (d, 2H, $J = 8.4$ Hz), 7.34 (d, 2H, $J = 8.4$ Hz), 7.32-7.04 (m, 10H), 6.97 (d, 2H, $J = 8.8$ Hz), 6.68 (bs, 2H), 5.13 (d, 1H, $J = 2.4$ Hz), 5.05 (d, 1H, $J = 10.0$ Hz), 4.98 (d, 1H, $J = 2.4$ Hz), 4.15 (dd, 1H, $J = 14.4, 2.4$ Hz), 3.89 (s, 3H), 3.73 (dm, 1H, $J = 10.0$ Hz), 3.06 (d, 1H, $J = 14.4$ Hz), 2.38 (s, 3H); δ_C (100 MHz, CDCl_3) 170.1, 160.2, 144.5, 142.5, 142.4, 141.3, 140.9, 130.2, 129.9, 129.8, 129.7, 129.1, 128.8, 128.8, 128.2, 126.5, 126.3, 125.6, 114.4, 107.9, 67.4, 57.3, 55.6, 45.5, 21.6; $\text{C}_{32}\text{H}_{30}\text{N}_2\text{O}_3\text{S}$ (M)⁺ Requires 523.2055 Found: 523.2040.

(2R, 3R, SS)-4-Methylene-1-(toluene-4-sulfinyl)-2-(4-trifluoromethyl-phenyl)-pyrrolidine-3-carboxylic acid diphenylamide

Following the general procedure outlined above (refluxed for 4 hours) for the MgI_2 -mediated ring expansion of 2-methylenecyclopropane carboxylic acid diphenylamide in the presence of (S)-(+)-*N*-(4-(trifluoromethyl)-benzylidene)-*p*-toluenesulfinamide. Following workup, chromatography on silica gel using 1:9 ethyl acetate:toluene ($R_f = 0.17$) gave the title compound (0.1059 g, 94%) as an amorphous white foam. $[\alpha]_D^{20} = +52.7^\circ$ ($c = 1.04$, CHCl_3) IR (neat, cm^{-1}) 3061, 1676, 1594, 1491, 1456, 1420, 1375, 1325, 1165, 1125, 1090, 1067, 1018, 909, 844, 812, 758, 732, 702; δ_H (400 MHz, CDCl_3) 7.72 (d, 2H, $J = 8.4$ Hz), 7.57 (d, 2H, $J = 8.1$ Hz), 7.49 (d, 2H, $J = 8.1$ Hz), 7.30-7.09 (m, 10H), 6.60 (bs, 2H), 5.19 (d, 1H, $J = 9.9$ Hz), 5.16 (d, 1H, $J = 2.2$ Hz), 5.03 (d, 1H, $J = 2.2$ Hz), 4.21 (dd, 1H, $J = 14.3, 2.2$ Hz), 3.72 (d, 1H, $J = 9.9$ Hz), 3.12 (d, 1H, $J = 14.3$ Hz), 2.39 (s, 3H); δ_C (100 MHz, CDCl_3) 169.5, 143.9, 143.1, 142.3, 142.1, 141.7, 140.4, 131.1 (q, $^2J_{\text{CF}} = 32.4$ Hz), 130.0, 129.9, 129.2, 128.8, 128.5, 128.3, 126.7, 126.2, 126.1 (q, $^3J_{\text{CF}} = 3.8$ Hz), 125.5, 124.3 (q, $^1J_{\text{CF}} = 272.4$ Hz), 108.4, 67.1, 57.6, 45.6, 21.6; δ_F (376 MHz, CDCl_3) -62.4; $\text{C}_{32}\text{H}_{27}\text{N}_2\text{O}_2\text{SF}_3$ (M)⁺ Requires 561.1824 Found: 561.1822.

(2R, 3R, SS)-4-Methylene-2-(4-nitro-phenyl)-1-(toluene-4-sulfinyl)-pyrrolidine-3-carboxylic acid diphenylamide

Following the general procedure outlined above (refluxed for 4.5 hours) for the MgI_2 -mediated ring expansion of 2-methylenecyclopropane carboxylic acid diphenylamide in the presence of (S)-(+)-*N*-(4-nitro-benzylidene)-*p*-toluenesulfinamide. Following workup, chromatography on silica gel using 1:1 ethyl acetate:hexanes ($R_f = 0.27$) gave the title compound (0.0778 g, 72%) as an amorphous white foam. $[\alpha]_D^{20} = +46.7^\circ$ ($c = 1.15$, CHCl_3) IR (neat, cm^{-1}) 3009, 2922, 2852,

1674, 1654, 1597, 1522, 1490, 1456, 1374, 1348, 1294, 1091, 1070, 1016, 856, 813, 753, 702, 668; δ_{H} (400 MHz, CDCl_3) 8.32 (d, 2H, $J = 8.6$ Hz), 7.64 (d, 2H, $J = 8.6$ Hz), 7.48 (d, 2H, $J = 8.1$ Hz), 7.30-7.09 (m, 10H), 6.68 (bd, 2H, $J = 5.7$ Hz), 5.26 (d, 1H, $J = 9.9$ Hz), 5.19 (d, 1H, $J = 2.0$ Hz), 5.05 (d, 1H, $J = 2.0$ Hz), 4.21 (dd, 1H, $J = 14.3, 2.2$ Hz), 3.75 (d, 1H, $J = 9.7$ Hz), 3.12 (d, 1H, $J = 14.3$ Hz), 2.40 (s, 3H); δ_{C} (100 MHz, CDCl_3) 169.1, 148.3, 146.4, 143.5, 142.1, 142.1, 141.9, 140.2, 130.1, 129.9, 129.4, 129.2, 128.5, 128.5, 126.8, 126.2, 125.4, 124.3, 108.7, 66.7, 57.4, 45.6, 21.6; $\text{C}_{31}\text{H}_{28}\text{N}_3\text{O}_4\text{S}$ (MH^+) Requires 538.1795 Found: 538.1772.

2-Furan-2-yl-4-methylene-1-(toluene-4-sulfinyl)-pyrrolidine-3-carboxylic acid diphenylamide

Following the general procedure outlined above (refluxed for 11 hours) for the MgI_2 -mediated ring expansion of 2-methylenecyclopropane carboxylic acid diphenylamide in the presence of (S)-(+)-N-(2-furylmethylidene)-p-toluenesulfinamide. Following workup, chromatography on silica gel using 1:1 ethyl acetate:hexanes gave the title compound (0.0796 g, 82%) in a 1.1:1 mixture of diastereomers (trans:cis).

(2R, 3R, SS)-2-Furan-2-yl-4-methylene-1-(toluene-4-sulfinyl)-pyrrolidine-3-carboxylic acid diphenylamide was isolated by flash chromatography ($R_f = 0.38$) as an amorphous white foam.

$[\alpha]_{\text{D}}^{20} = +90.1^\circ$ ($c = 0.73$, CHCl_3) IR (neat, cm^{-1}) 3060, 2923, 1676, 1654, 1593, 1507, 1490, 1374, 1292, 1151, 1092, 1069, 1012, 812, 758, 734, 703; δ_{H} (500 MHz, CDCl_3) 7.50 (d, 2H, $J = 7.1$ Hz), 7.47 (s, 1H), 7.34-7.14 (m, 9H), 6.86 (bs, 2H), 6.59 (dd, 1H, $J = 3.3, 0.8$ Hz), 6.48 (dd, 1H, $J = 1.9, 3.3$ Hz), 5.24 (d, 1H, $J = 9.8$ Hz), 5.15 (d, 1H, $J = 2.5$ Hz), 5.00 (d, 1H, $J = 2.5$ Hz), 4.10 (m, $2 \times 1\text{H}$), 3.07 (d, 1H, $J = 14.6$ Hz), 2.38 (s, 3H); δ_{C} (125 MHz, CDCl_3) 170.1, 150.0, 144.1, 143.3, 142.4, 141.3, 140.5, 130.0, 129.7, 129.1, 128.6, 128.3, 126.5, 126.3, 125.7, 111.4, 110.9, 108.4, 61.4, 53.6, 45.5, 21.6; $\text{C}_{29}\text{H}_{26}\text{N}_2\text{O}_3\text{S}$ (M^+) Requires 483.1742 Found: 483.1735.

cis (SS)-2-Furan-2-yl-4-methylene-1-(toluene-4-sulfinyl)-pyrrolidine-3-carboxylic acid diphenylamide was isolated by flash chromatography ($R_f = 0.45$) as an amorphous white foam.

$[\alpha]_{\text{D}}^{20} = +33.6^\circ$ ($c = 1.01$, CHCl_3) IR (neat, cm^{-1}) 3060, 2923, 2857, 1673, 1594, 1491, 1372, 1284, 1156, 1088, 1068, 911, 814, 754, 733, 703; δ_{H} (500 MHz, CDCl_3) 7.61 (d, 2H, $J = 6.8$ Hz), 7.50 (s, 1H), 7.42-7.06 (m, 9H), 6.92 (bs, 2H), 6.64 (d, 1H, $J = 3.4$ Hz), 6.55 (dd, 1H, $J = 2.0, 3.4$ Hz), 5.08 (s, 1H), 5.03 (s, 1H), 4.96 (d, 1H, $J = 7.3$ Hz), 4.07 (d, 1H, $J = 7.3$ Hz), 3.94 (d, 1H, $J = 14.2$ Hz), 3.59 (dd, 1H, $J = 14.2, 1.5$ Hz), 2.39 (s, 3H); δ_{C} (125 MHz, CDCl_3) 169.6, 151.6, 144.2, 142.7, 142.5, 142.4, 141.2, 140.7, 130.2, 130.0, 129.1, 129.0, 128.4, 126.7, 126.6, 126.3, 111.4, 110.3, 110.0, 60.8, 52.7, 45.7, 21.6; $\text{C}_{29}\text{H}_{26}\text{N}_2\text{O}_3\text{S}$ (M^+) Requires 483.1742 Found: 483.1746.

(2R, 3R, SS)-4-Methylene-2-pyridin-4-yl-1-(toluene-4-sulfinyl)-pyrrolidine-3-carboxylic acid diphenylamide

Following the general procedure outlined above (refluxed for 3.25 hours) for the MgI_2 -mediated ring expansion of 2-methylenecyclopropane carboxylic acid diphenylamide in the presence of (S)-(+)-*N*-(4-pyridinemethylidene)-*p*-toluenesulfinamide. Following workup, chromatography on silica gel using 3:1 ethyl acetate:toluene ($R_f = 0.15$) gave the title compound (0.0764 g, 77%) as an amorphous white foam. $[\alpha]_D^{20} = +77.8^\circ$ ($c = 0.64$, CHCl_3) IR (neat, cm^{-1}) 3036, 2922, 1676, 1597, 1491, 1452, 1417, 1368, 1316, 1294, 1234, 1157, 1092, 1069, 1015, 992, 910, 832, 812, 757, 731, 703; δ_H (500 MHz, CDCl_3) 8.72 (m, 2H), 7.50 (d, 2H, $J = 8.1$ Hz), 7.43 (d, 2H, $J = 6.6$ Hz), 7.30-7.17 (m, 8H), 7.11 (d, 1H, $J = 7.7$ Hz), 6.69 (bs, 2H), 5.18 (d, 1H, unable to determine coupling constant), 5.17 (d, 1H, $J = 14.4$ Hz), 5.04 (d, 1H, $J = 2.1$ Hz), 4.21 (dd, 1H, $J = 14.4$, 2.1 Hz), 3.71 (d, 1H, $J = 9.8$ Hz), 3.12 (d, 1H, $J = 14.4$ Hz), 2.40 (s, 3H); δ_C (125 MHz, CDCl_3) 169.1, 150.1, 143.5, 142.2, 142.0, 141.8, 140.2, 130.1, 129.9, 129.5, 129.2, 128.5, 126.7, 126.2, 125.7, 125.4, 123.4, 108.7, 66.4, 57.3, 45.6, 21.6; $\text{C}_{30}\text{H}_{27}\text{N}_3\text{O}_2\text{S}$ (M) $^+$ Requires 494.1902 Found: 494.1899.

(2R, 3R, SS)-4-Methylene-2-pyridin-3-yl-1-(toluene-4-sulfinyl)-pyrrolidine-3-carboxylic acid diphenylamide

Following the general procedure outlined above (refluxed for 16 hours) for the MgI_2 -mediated ring expansion of 2-methylenecyclopropane carboxylic acid diphenylamide in the presence of (S)-(+)-*N*-(3-pyridinemethylidene)-*p*-toluenesulfinamide. Following workup, chromatography on silica gel using 3:1 ethyl acetate:hexanes ($R_f = 0.1$) gave the title compound (0.0814 g, 82%) as an amorphous white foam. $[\alpha]_D^{20} = +57.4^\circ$ ($c = 0.61$, CHCl_3) IR (neat, cm^{-1}) 3006, 2931, 1674, 1594, 1491, 1453, 1430, 1379, 1294, 1229, 1157, 1090, 1069, 1028, 1006, 985, 883, 813, 755, 704; δ_H (500 MHz, CDCl_3) 8.71 (bs, 2H), 7.85 (d, 1H, $J = 7.8$ Hz), 7.48 (d, 2H, $J = 8.1$ Hz), 7.29-7.10 (m, 11H), 6.71 (bs, 2H), 5.19 (d, 1H, $J = 2.2$ Hz), 5.18 (d, 1H, $J = 10.0$ Hz), 5.04 (d, 1H, $J = 2.2$ Hz), 4.19 (dd, 1H, $J = 14.3$, 2.2 Hz), 3.77 (d, 1H, $J = 9.6$ Hz), 3.12 (d, 1H, $J = 14.4$ Hz), 2.39 (s, 3H); δ_C (125 MHz, CDCl_3) 169.4, 150.2, 149.9, 143.7, 142.2, 142.1, 141.7, 140.3, 136.5, 134.4, 130.1, 129.8, 129.2, 128.5, 126.7, 126.2, 125.5, 123.9, 108.5, 65.6, 57.4, 45.6, 21.6; $\text{C}_{30}\text{H}_{28}\text{N}_3\text{O}_2\text{S}$ (M) $^+$ Requires 494.1902 Found: 494.1900.

2-Furan-3-yl-4-methylene-1-(toluene-4-sulfinyl)-pyrrolidine-3-carboxylic acid diphenylamide

Following the general procedure outlined above (refluxed for 3.25 hours) for the MgI_2 -mediated ring expansion of 2-methylenecyclopropane carboxylic acid diphenylamide in the presence of (S)-(+)-*N*-(3-furylmethylidene)-*p*-toluenesulfinamide. Following workup, chromatography on silica gel using 1:1 ethyl acetate:hexanes gave the title compound (0.0825 g, 85%) in a 84:16 mixture of diastereomers (trans:cis).

(2R, 3R, SS)-2-Furan-3-yl-4-methylene-1-(toluene-4-sulfinyl)-pyrrolidine-3-carboxylic acid diphenylamide

was isolated by flash chromatography ($R_f = 0.26$) as an amorphous white foam. $[\alpha]_D^{20} = +99.3^\circ$ ($c = 0.96$, CHCl_3) IR (neat, cm^{-1}) 3061, 2923, 1674, 1595,

1506, 1491, 1455, 1375, 1347, 1294, 1234, 1158, 1092, 1067, 1019, 988, 965, 910, 874, 826, 810, 794, 758, 732, 703; δ_{H} (400 MHz, CDCl_3) 7.63 (s, 1H), 7.54 (m, 1H), 7.46 (d, 2H, $J = 8.3$ Hz), 7.38-7.11 (m, 10H), 6.96 (bs, 2H), 6.33 (m, 1H), 5.17 (d, 1H, $J = 2.2$ Hz), 5.12 (d, 1H, $J = 10.2$ Hz), 5.00 (d, 1H, $J = 2.0$ Hz), 4.11 (dd, 1H, $J = 14.3, 2.2$ Hz), 3.80 (d, 1H, $J = 9.9$ Hz), 3.04 (d, 1H, $J = 14.3$ Hz), 2.37 (s, 3H); δ_{C} (100 MHz, CDCl_3) 169.9, 144.2, 144.1, 142.3, 141.3, 140.6, 130.0, 129.7, 129.1, 128.7, 128.3, 126.8, 126.3, 125.5, 122.7, 109.0, 108.2, 102.6, 59.3, 55.6, 45.3, 21.5; $\text{C}_{29}\text{H}_{26}\text{N}_2\text{O}_3\text{S}$ (MH)⁺ Requires 483.1742 Found: 483.1731.

cis (SS)-2-Furan-3-yl-4-methylene-1-(toluene-4-sulfinyl)

-pyrrolidine-3-carboxylic acid diphenylamide was inseparable from an impurity using flash chromatography ($R_f = 0.32$) or preparative HPLC.

(S)-(+)-N-(4-Bromobenzylidene)-p-toluenesulfinamide

Following the general procedure outlined by Davis and coworkers⁷ (refluxed for 5 hours), the residue was purified by flash chromatography on silica gel using 10% ethyl acetate/90% hexanes ($R_f = 0.22$) to give an off white product that was recrystallized from CH_2Cl_2 /pentane to give the title compound (0.3964 g, 80%) as a white solid, mp 108.5-110°C. $[\alpha]_{\text{D}}^{20} = +29.8^\circ$ ($c = 1.03$, CHCl_3) IR (neat, cm^{-1}) 2918, 1606, 1586, 1562, 1483, 1399, 1351, 1217, 1172, 1097, 1071, 1009, 860, 819, 807, 724, 645; δ_{H} (400 MHz, CDCl_3) 8.69 (s, 1H), 7.70 (d, 2H, $J = 9.6$ Hz), 7.61 (m, 4H), 7.31 (d, 2H, $J = 7.6$ Hz), 2.40 (s, 3H); δ_{C} (100 MHz, CDCl_3) 159.7, 142.1, 141.7, 133.0, 132.5, 131.1, 130.1, 127.6, 125.0, 21.6; $\text{C}_{14}\text{H}_{12}\text{NOSBr}$ (M^+) Requires 320.9823 Found: 320.9835.

(S)-(+)-N-(3-Bromobenzylidene)-p-toluenesulfinamide

Following the general procedure outlined by Davis and coworkers⁷ (refluxed for 5 hours) gave analytically pure title compound (0.4937 g, 99%) as a white solid, mp 93-95°C. $[\alpha]_{\text{D}}^{20} = +19.1^\circ$ ($c = 1.33$, CHCl_3) IR (neat, cm^{-1}) 3058, 3024, 2920, 1597, 1558, 1467, 1428, 1350, 1207, 1080, 817, 788, 728, 682; δ_{H} (400 MHz, CDCl_3) 8.68 (s, 1H), 8.02 (m, 1H), 7.72 (d, 1H, $J = 7.6$ Hz), 7.63 (m, 3H), 7.32 (m, 3H), 2.40 (s, 3H); δ_{C} (100 MHz, CDCl_3) 159.4, 142.1, 141.6, 135.9, 135.6, 132.0, 130.6, 130.1, 128.8, 124.9, 123.4, 21.6; $\text{C}_{14}\text{H}_{12}\text{NOSBr}$ (M^+) Requires 320.9823 Found: 320.9827.

⁷ Fanelli, D.L.; Szewczyk, J.M.; Zhang, Y.; Reddy, G.V.; Burns, D.M.; Davis, F.A. *Org. Synth.* Vol. 77, 50-63.

(S)-(+)-N-(2-Bromobenzylidene)-*p*-toluenesulfinamide

Following the general procedure outlined by Davis and coworkers⁷ (refluxed for 5 hours), the residue was purified by flash chromatography on silica gel using 10% ethyl acetate/90% hexanes ($R_f = 0.22$) to give the title compound (0.3707 g, 94%) as a white solid, mp 98-100°C. $[\alpha]_D^{22} = +349.9^\circ$ ($c = 1.2$, CHCl_3) IR (neat, cm^{-1}) 2918, 1592, 1580, 1558, 1490, 1460, 1446, 1428, 1348, 1265, 1210, 1174, 1098, 1074, 1022, 982, 812, 765, 728, 658, 626; δ_H (400 MHz, CDCl_3) 9.16 (s, 1H), 8.03 (m, 1H), 7.63 (m, 3H), 7.34 (m, 4H), 2.40 (s, 3H); δ_C (100 MHz, CDCl_3) 160.2, 142.0, 141.7, 133.8, 133.7, 132.9, 130.1, 130.1, 127.9, 126.9, 125.0, 21.7; $\text{C}_{14}\text{H}_{12}\text{NOSBr}$ (M^+) Requires 320.9823 Found: 320.9813.

(S)-(+)-N-(2-Methylbenzylidene)-*p*-toluenesulfinamide

Following the general procedure outlined by Davis and coworkers⁷ (refluxed for 5 hours), the residue was purified by flash chromatography on silica gel using 10% ethyl acetate/90% hexanes ($R_f = 0.41$) to give the title compound (0.5057 g, 91%) as a white solid, mp 63-65°C. $[\alpha]_D^{20} = +153.5^\circ$ ($c = 1.62$, CHCl_3) IR (neat, cm^{-1}) 3055, 2922, 1589, 1567, 1490, 1457, 1361, 1287, 1224, 1097, 1073, 1017, 986, 810, 758, 704, 626; δ_H (400 MHz, CDCl_3) 9.03 (s, 1H), 7.91 (d, 1H, $J = 7.6$ Hz), 7.64 (d, 2H, $J = 8.0$), 7.39-7.22 (m, 5H), 2.60 (s, 3H), 2.39 (s, 3H); δ_C (100 MHz, CDCl_3) 159.5, 142.2, 141.8, 139.9, 132.4, 132.2, 131.5, 130.0, 129.6, 126.5, 125.0, 21.6, 20.0; $\text{C}_{15}\text{H}_{15}\text{NOS}$ (M^+) Requires 257.0874 Found: 257.0871.

(S)-(+)-N-(3-Furylmethylene)-*p*-toluenesulfinamide

Following the general procedure outlined by Davis and coworkers⁷ (refluxed for 5 hours), the residue was purified by flash chromatography on silica gel using 10% ethyl acetate/90% hexanes ($R_f = 0.41$ in 1:2 ethyl acetate:hexanes) to give the title compound (0.5839 g, 93%) as a white solid, mp 75-77°C. $[\alpha]_D^{20} = +308.6^\circ$ ($c = 1.01$, CHCl_3) IR (neat, cm^{-1}) 3127, 3054, 2921, 1610, 1551, 1513, 1341, 1155, 1097, 1071, 1013, 976, 872, 808, 784, 742.4, 704, 686, 622, 598; δ_H (500 MHz, CDCl_3) 8.72 (s, 1H), 7.92 (m, 1H), 7.61 (d, 2H, $J = 7.5$ Hz), 7.46 (m, 1H), 7.31 (d, 2H, $J = 7.9$ Hz), 6.82 (m, 1H), 2.41 (s, 3H); δ_C (125 MHz, CDCl_3) 152.6, 148.1, 144.9, 141.9, 130.0, 125.0, 124.3, 108.2, 21.7; $\text{C}_{12}\text{H}_{11}\text{NO}_2\text{S}$ (M^+) Requires 233.0511 Found: 233.0506.

(S)-(+)-N-(4-Pyridinemethylidene)-*p*-toluenesulfinamide

Following the general procedure outlined by Davis and coworkers¹ (refluxed for 24 hours using 4A molecular sieves), the residue was purified by flash chromatography on silica gel using 3:1 ethyl acetate:hexanes ($R_f = 0.35$) to give the title compound (0.4703 g, 71%) as a white solid, mp 110-112°C. $[\alpha]_D^{20} = +150.5^\circ$ ($c = 0.73$, CHCl_3) IR (neat, cm^{-1}) 3036, 1610, 1557, 1490, 1408, 1319, 1231, 1105, 1074, 1016, 984, 804, 718; δ_H (400 MHz, CDCl_3) 8.76 (d, 2H, $J = 5.9$ Hz), 8.74 (s, 1H), 7.67 (d, 2H, $J = 5.9$ Hz), 7.63 (d, 2H, $J = 8.1$ Hz), 7.33 (d, 2H, $J = 8.1$ Hz), 2.41 (s, 3H); δ_C (100 MHz, CDCl_3) 159.2, 151.0, 142.3, 140.9, 140.3, 130.2, 124.9, 122.8, 21.6; $\text{C}_{13}\text{H}_{12}\text{N}_2\text{OS}$ (M^+) Requires 244.0670 Found: 244.0677.

(S)-(+)-N-(4-(Trifluoromethyl)benzylidene)-*p*-toluenesulfinamide

Following the general procedure outlined by Davis and coworkers⁷ (refluxed for 5 hours) gave analytically pure title compound (0.5334 g, 96%) as a white solid, mp 99-101°C. $[\alpha]_D^{20} = +86.2^\circ$ ($c = 1.15$, CHCl_3) IR (neat, cm^{-1}) 2924, 1607, 1576, 1490, 1412, 1324, 1218, 1170, 1120, 1104, 1066, 1017, 908, 840, 810, 736, 642; δ_H (400 MHz, CDCl_3) 7.96 (d, 2H, $J = 8.4$ Hz), 7.71 (d, 2H, $J = 8.1$ Hz), 7.63 (d, 2H, $J = 8.1$ Hz), 7.33 (d, 2H, $J = 8.1$ Hz), 2.41 (s, 3H); δ_C (125 MHz, CDCl_3) 159.5, 142.2, 141.4, 137.0, 134.1 (q, $^2J_{\text{CF}} = 32.6$ Hz), 130.2, 130.0, 126.1 (q, $^3J_{\text{CF}} = 3.8$ Hz), 125.0, 123.8 (q, $^1J_{\text{CF}} = 272.7$ Hz), 21.6; δ_F (376 MHz, CDCl_3) -63.0; $\text{C}_{15}\text{H}_{12}\text{NOSF}_3$ (M^+) Requires 311.0592 Found: 311.0600.

(2R, 3R)-4-Methylene-2-phenyl-pyrrolidine-3-carboxylic acid diphenylamide

Following the general procedure outlined by Davis and coworkers,⁷ removal of the sulfoxide auxiliary from (2R, 3R, SS)-4-methylene-2-phenyl-1-(toluene-4-sulfinyl)-pyrrolidine-3-carboxylic acid diphenylamide (0.1533 g, 0.311 mmol) was achieved under acidic conditions (25°C, 1.5 hours). The reaction mixture was then diluted in dichloromethane and water and solid NaHCO_3 was added until the reaction mixture was pH = 8.0. The organic phase was removed and the aqueous phase was extracted with ethyl acetate ($\times 3$). The combined organic layers were then dried over MgSO_4 and reduced *in vacuo* and purified by flash chromatography on SiO_2 using 84% ethyl acetate:16% hexanes ($R_f = 0.14$) to give pure title compound (0.1047 g, 95%) as a white opaque oil. $[\alpha]_D^{20} = +103.0^\circ$ ($c = 1.00$, CHCl_3) IR (neat, cm^{-1}) 3326, 3062, 3034, 2936, 2852, 1674, 1593, 1490, 1453, 1361, 1270, 1154, 1074, 1028, 1004, 885, 758, 701; δ_H (300 MHz, CDCl_3) 7.38-7.12 (m, 13H), 6.73 (bs, 2H), 5.09 (d, 1H, $J = 2.2$ Hz), 5.06 (d, 1H, $J = 2.2$ Hz), 4.67 (d, 1H, $J = 8.5$ Hz), 3.86 (dd, 1H, $J = 14.6, 2.4$ Hz), 3.74 (d, 1H, $J = 14.6$ Hz), 3.55 (dd,

1H, J = 8.6, 2.4 Hz), 2.3 (bs, N-H, D₂O exchanged); δ_{C} (125 MHz, CDCl₃) 172.5, 150.5, 142.7, 142.5, 141.2, 129.9, 129.0, 128.8, 128.7, 128.0, 127.8, 127.1, 127.0, 126.4, 106.3, 67.8, 57.0, 52.5; δ_{F} (376 MHz, CDCl₃) -63.0; C₂₄H₂₃N₂O (M⁺) Requires 355.1810 Found: 355.1814.