Title: Divergent Synthesis of Cyclopropane-Containing Lead-Like Compounds, Fragments and Building Blocks through a Cobalt Catalyzed Cyclopropanation of Phenyl Vinyl Sulfdide

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General Experimental Considerations

All non-aqueous reactions were run under an inert atmosphere (argon) with flame-dried glassware using standard techniques. Anhydrous solvents were obtained by filtration through drying columns (THF, CH₂Cl₂, toluene, DMF). Where applicable, rt denotes a room temperature of approximately 22 °C, and a specifically noted temperature e.g. "stirred at 25 °C" indicates the stated temperature was accurately maintained.

Flash column chromatography was performed using 230-400 mesh silica with the indicated solvent system according to standard techniques. Analytical thin-layer chromatography (TLC) was performed on precoated, glass-backed silica gel plates. Visualization of the developed chromatogram was performed by UV absorbance (254 nm), aqueous potassium permanganate, vanillin, ninhydrin or p-anisaldehyde stains as appropriate.

Infrared spectra ($v_{\text{max}}$, FTIR ATR) were recorded in reciprocal centimeters (cm⁻¹).

Nuclear magnetic resonance spectra were recorded on 400 or 500 MHz spectrometers. Chemical shifts for $^1$H NMR spectra are recorded in parts per million from tetramethylsilane with the solvent resonance as the internal standard (chloroform: $\delta = 7.27$ ppm, DMSO: $\delta = 2.50$ ppm). Data is reported as follows: chemical shift [multiplicity (s = singlet, d = doublet, t = triplet, m = multiplet and br = broad), coupling constant in Hz, integration, assignment]. $^{13}$C NMR spectra were recorded with complete proton decoupling. Chemical shifts are reported in parts per million from tetramethylsilane with the solvent resonance as the internal standard ($^{13}$CDCl₃: $\delta = 77.0$ ppm, ($^{13}$CD₃)₂SO: $\delta = 39.5$ ppm). $J$ values are reported in Hz. Assignments of $^1$H and $^{13}$C spectra were based upon the analysis of $\delta$ and $J$ values, as well as COSY, HSQC, HMBC and NOESY experiments where appropriate.

Melting points are uncorrected.

Optical rotations ($\alpha'$) were recorded at the indicated temperature (T °C) and were converted to the corresponding specific rotations $[\alpha]^T_D$.

Commercial reagents were used as supplied or purified by standard techniques where necessary.

Use of diazo compounds: Although we have not experienced any problems in the handling or reaction of diazo reagents, extreme care should be taken when manipulating them due to their potentially explosive nature.

Cu⁺-catalyzed cyclopropanation: For the Cu⁺-catalyzed procedure, all catalysts were stored in a dessicator, except for CuOTf which was stored and handled in a glovebox. Reactions were conducted in a sealed microwave vial. Slow addition of the diazo compound solution was achieved with a syringe pump.

Co⁰-catalyzed cyclopropanation: For the Co⁰-catalyzed procedure, no special precautions were taken to exclude air or moisture from the catalyst during storage or handling. After all reagents were added the reaction vessel was sealed with either a crimp seal microwave vial lid with a septum, or a suba seal and the reaction vessel flushed with Ar(g). Ar(g) flushed, deflated balloons were attached to the flask, so that the total potential volume of the balloons when inflated was greater than the volume of N₂(g) evolved from the reaction. On scales where ≥10 mmol of diazo compound were used, a precautionary blast shield was placed between the reaction flask and the fume hood sash.
### SMILES and InChI codes for synthesized compounds

| Compound | SMILES | InChI |
|----------|--------|-------|
| 1        | O=C(OCC)[C@@H]1[C@H]2SC(2=CC=CC=C2) (=O)=O | InChI=1S/C12H14O2S/c1-2-14-12(13)10-8-11(10)15-9-6-4-3-5-7-9/h3-7,10-11H,2,8H2,1H3/t10-11/m0/s1 |
| 2        | O=C(OCC)[C@@H]1C[C@@H]1SC2=CC=CC=C2 | InChI=1S/C12H14O2S/c1-2-14-12(13)10-8-11(10)15-9-6-4-3-5-7-9/h3-7,10-11H,2,8H2,1H3/t10-11/m1/s1 |
| 3        | O=C(OCC)[C@@H]1C[C@@H]1SC2=CC=CC=C2(=O)=O | InChI=1S/C12H14O2S/c1-2-14-12(13)10-8-11(10)15-9-6-4-3-5-7-9/h3-7,10-11H,2,8H2,1H3/t10-11/m0/s1 |
| 4        | O=C(OCC)[C@@H]1C[C@@H]1SC2=CC=CC=C2(=O)=O | InChI=1S/C12H14O2S/c1-2-14-12(13)10-8-11(10)15-9-6-4-3-5-7-9/h3-7,10-11H,2,8H2,1H3/t10-11/m1/s1 |
| 5        | O=C(OCC)[C@@H]1C[C@@H]1SC2=CC=CC=C2(=O)=O | InChI=1S/C12H14O2S/c1-2-14-12(13)10-8-11(10)15-9-6-4-3-5-7-9/h3-7,10-11H,2,8H2,1H3/t10-11/m0/s1 |
| 6        | O=C(OCC)[C@@H]1C[C@@H]1S[C@@+]1[O-]SC2=CC=CC=C2 | InChI=1S/C12H14O2S/c1-2-14-12(13)10-8-11(10)16(14)9-6-4-3-5-7-9/h3-7,10-11H,2,8H2,1H3/t10-11,m1/s1 |
| 7        | O=C(OCC)[C@@H]1C[C@@H]1SC2=CC=CC=C2(=O)=O | InChI=1S/C12H14O2S/c1-2-14-12(13)10-8-11(10)16(14)9-6-4-3-5-7-9/h3-7,10-11H,2,8H2,1H3/t10-11,m1/s1 |
| 8        | O=C(O)1[C@H]1C[C@@H]1SC2=CC=CC=C2 | InChI=1S/C10H10O2S/c11-10(12)8-6-9(8)13-7-4-2-1-3-5-7/h1-5,8-9H,6H2,(H,11,12)8,9,-/m0/s1 |
| 9        | O=C(C@@H)1C[C@@H]1SC2=CC=CC=C2(=O)=O | InChI=1S/C10H10O2S/c11-10(12)8-6-9(8)13-7-4-2-1-3-5-7/h1-5,8-9H,6H2,(H,11,12)8,9,+/-/m1/s1 |
| 10       | OC(C@@H)1C[C@@H]1SC2=CC=CC=C2 | InChI=1S/C10H12O2S/c11-7-8-6-10(8)12-9-4-2-1-3-5-9/h1-5,8-10,11H,6-7H2/t8-,10+/m1/s1 |
| 11       | OC(C@@H)1C[C@@H]1SC2=CC=CC=C2 | InChI=1S/C10H12O2S/c11-7-8-6-10(8)12-9-4-2-1-3-5-9/h1-5,8-10,11H,6-7H2/t8-,10+,m0/s1 |
| 12       | O=C([O-])[C@H]1C[C@@H]1SC2=CC=CC=C2/[N +] | InChI=1S/C10H10O2S.Na/c11-10(12)8-6-9(8)13-7-4-2-1-3-5-7/h1-5,8-9H,6H2,(H,11,12),/q:+1/p-1/-/t8/-,9/-/m0/s1 |
| 13       | OC([C@@H]1C[C@@H]1SC2=CC=CC=C2(=O)=O,[N+Na]) | InChI=1S/C10H9O2S.Na/c11-10(12)8-6-9(8)13-7-4-2-1-3-5-7/h1-5,8-9H,6H2,(H,11,12),/q:+1/p-1/-/t8/-,9/-/m0/s1 |
| 14a      | O=C(NCC1=CC=CC=C1)[C@H]2C[C@@H]1SC2=CC=CC=C3 | InChI=1S/C17H17NOS/c19-17(18-12-13-7-3-1-4-8-13)15-11-16(15)20-14-9-5-2-6-10-14/h1-10,15-16H,11-12H2,(H,18,19),/t15-,16/m0/s1 |
| 14b      | O=C(N1CC([C]CC)1)[C@H]2C[C@@H]2SC3=CC=CC=C3 | InChI=1S/C14H17NOS/c16-14(15-6-8-17-9-7-15)12-10-13(12)18-11-4-2-1-3-5-11/h1-5,12-13H,6-10H2/t12-,13/-/m0/s1 |
| 14c      | O=C(N1CC(C)CC)1[C@H]2C[C@@H]2SC3=CC=CC=C3 | InChI=1S/C15H20N2OS/c16-17-9-10-16(15)18-13-11-14(13)19-12-5-3-2-4-6-12/2-6,13-14H,7-11H2,1H3/t13-,14/-/m0/s1 |
| 14d      | O=C(N1CC(C=CC=C2)=C2CC1)[C@H]3C[C@@H]3SC4=CC=CC=C4 | InChI=1S/C19H19NOS/c21-19(16-13-18(16)22-15-9-2-1-3-10-15)20-12-6-8-14-7-4-11-17(14)20/h1-5,7-9,11,16H,6,8,12-13H2/t16+,18/-/m0/s1 |
| 15a      | O=C(NCC1=CC=CC=C1)[C@H]2C[C@@H]2SC3=CC=CC=C3 | InChI=1S/C17H17NOS/c19-17(18-12-13-7-3-1-4-8-13)15-11-16(15)20-14-9-5-2-6-10-14/h1-10,15-16H,11-12H2,(H,18,19),/t15-,16+/m1/s1 |
| 15b      | O=C(N1CCOC1)[C@H]2C[C@@H]2SC3=CC=CC=C3 | InChI=1S/C14H17NOS/c16-14(15-6-8-17-9-7-15)12-10-13(12)18-11-4-2-1-3-5-11/h1-5,12-13H,6-10H2/t12-,13/+m1/s1 |
| 15c      | O=C(N1CCN(C)CC)1[C@H]2C[C@@H]2SC3=CC=CC=C3 | InChI=1S/C15H20N2OS/c16-17-9-10-16(15)18-13-11-14(13)19-12-5-3-2-4-6-12/2-6,13-14H,7-11H2,1H3/t13-,14/+m1/s1 |
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| 15d  | O=C(N1C(C=CC=C2)=C2CCC1)[C@@H]3C[C@H]3SC4=CC=CC=C4 | InChI=1S/C19H19NOS/c21-19(16-13-18(16)22-15-9-2-1-3-10-15)20-12-6-8-14-7-4-5-11-17(14)20/h1-5,7-9-11,16,18H,6,8,12-13H2/t16-,18+/-m1/s1 |
| 16c  | O=C(N1CCN(C)CC1)[C@@H]2C[C@@H]2S(C3=CC=CC=C3)(=O)=O | InChI=1S/C15H20N2O3S/c1-16-7-9-17(10-8-16)15(18)13-11-14(13)21(19,20)12-5-3-2-4-6-12/h2-6,13-14H,7-11H2,1H3/t13-,14/-m0/s1 |
| 17c  | O=C(N1CCN(C)CC1)[C@@H]2C[C@@H]2S(C3=CC=CC=C3)(=O)=O | InChI=1S/C15H20N2O3S/c1-16-7-9-17(10-8-16)15(18)13-11-14(13)21(19,20)12-5-3-2-4-6-12/h2-6,13-14H,7-11H2,1H3/t13-,14/-m1/s1 |
| 16d  | O=C(N1C(C=CC=C2)=C2CCC1)[C@@H]3C[C@H]3SC4=CC=CC=C4)(=O)=O | InChI=1S/C19H19NOS/c21-19(20-12-6-8-14-7-4-5-11-17(14)20)16-13-18(16)24(22,23)15-9-2-1-3-10-15/h1-5,7-9-11,16,18H,6,8,12-13H2/t16-,18/-m0/s1 |
| 17d  | O=C(N1C(C=CC=C2)=C2CCC1)[C@@H]3C[C@H]3SC4=CC=CC=C4)(=O)=O | InChI=1S/C19H19NOS/c21-19(20-12-6-8-14-7-4-5-11-17(14)20)16-13-18(16)24(22,23)15-9-2-1-3-10-15/h1-5,7-9-11,16,18H,6,8,12-13H2/t16-,18/-m0/s1 |
| 19a  | I[C@H]1C[C@@H]1C(OCC)=O | InChI=1S/C6H9IO2/c1-2-9-6(8)4-3-5(4)/h4-5H,2-3H2,1H3/t4-,5/-m0/s1 |
| 19b  | O[C@H](C1CCCC1)[C@@H]2C[C@H]2S(C3=CC=CC=C3)(=O)=O | InChI=1S/C12H20O3/c1-2-15-12(14)10-7-9(10)11(13)8-5-3-4-6-8/h8-11,13H2,2-7H2,1H3/t9-,10-,11+/m0/s1 |
| 19c  | O[C@H](C1=CC=CC=C1)[C@H]2C[C@H]2S(C3=CC=CC=C3)(=O)=O | InChI=1S/C12H16O3/c1-2-16-13(15)11-8-10(11)12(14)9-6-4-3-5-7-9/h3-7,10-12,14H,2,8H2,1H3/t10-,11-,12+/m0/s1 |
| 19d  | O=C(OCC)[C@H]1C[C@@H]1C[C@H](O)C2=CN=CC=C2 | InChI=1S/C9H14O4/c1-2-13-8(10)6-3-7(6)9(11)4-12-5-9/h6-7,11H2,2-5H2,1H3/t6-,7/-m0/s1 |
| 19f  | O=C(OCC)[C@H]1C[C@@H]1C[C@H]2CC=C(Cl)=C(C2)(C3=CC=C(Cl)C=C3)O | InChI=1S/C19H18Cl2O3/c1-2-24-18(22)16-11-17(16)19(23,12-3-7-14(20)8-4-12)13-5-9-15(21)10-6-13/h3-10,16-17,23H,2,11H2,1H3/t16-,17/-m0/s1 |
| 19g  | O=C(OCC)[C@H]1C[C@@H]1C[C@H]2CC=C(C2)=C(C)NC=CC=C3)O | InChI=1S/C17H18N2O3/c1-2-22-16(20)12-11-13(12)17(21,14-7-3-5-9-18-14)15-8-4-6-10-19-15/h3-10,12-13,32H,2,11H2,1H3/t12-,13+/m0/s1 |
| 19h  | O=C(OCC)[C@H]1C[C@@H]1C[C@H]2CC=C(C2)=C(N2)C3=NC=CC=C3)O | InChI=1S/C13H14O3/c1-2-16-13(15)11-8-10(11)12(14)9-6-4-3-5-7-9/h3-7,10-11H2,2,8H2,1H3/t10-,11-/m0/s1 |
| 19i  | O=C(OCC)[C@H]1C[C@@H]1C[C@H]2CC=C(C2)=O | InChI=1S/C13H15NO3/c1-2-17-13(16)11-8-10(11)12(15)14-9-6-4-3-5-7-9/h3-7,10-11H2,2,8H2,1H3,(H,14,15)/t10-,11-/m0/s1 |
| 19j | O=C(OCC)[C@H]1C[C@@@H]1SC2=CC=C(OC)C=C2 | InChI=1S/C13H16O3S/c1-3-16-13(14)11-8-12(11)17-10-6-4-9(15-2)5-7-10/h4-7,11-12H,3,8H2,1-2H3/t11-,12-/m0/s1 |
| 19k | O=C(OCC)[C@H]1C[C@@@H]1C=O | InChI=1S/C7H10O3/c1-2-10-7(9)6-3-5(6)4-8/h4-6H,2-3H2,1H3/t5+,6+/m1/s1 |
| 19l | O=C(OCC)[C@H]1C[C@@@H]1B2OC(C)(C)(C)(C)O2 | InChI=1S/C12H21BO4/c1-6-15-10(14)8-7-9(8)13-16-11(2,3)12(4,5)17-13/h8-9H,6-7H2,1-5H3/t8-,9-/m0/s1 |
| 19m | O=C(OCC)[C@H]1C[C@@@H]1[Si](OCC)(OCC)OCC | InChI=1S/C12H24OSSi/c1-5-14-12(13)10-9-11(10)18(15-6,2-16-7-3)17-8-4/hJ10-11H,5-9H2,1-4H3/t10-,11-/m0/s1 |
| 20a | l[C@H]1C[C@H]1C(OCC)=O | InChI=1S/C6H9IO2/c1-2-9-6(8)4-3-5/4(7)/h4-5H,2-3H2,1H3/t4+,5+/m1/s1 |
| 20b | O=C10[C@@@H](C2CCCC2)[C@H]3C[C@@@H]31 | InChI=1S/C10H14O2/c11-10-8-5-7(8)9(12-10)6-3-1-2-4-6/h6-9H,1-5H2/t7-,8+,9-/m0/s1 |
| 20c | O=C10[C@@@H](C2=CC=CC=C2)[C@H]3C[C@@@H]31 | InChI=1S/C11H10O2/c12-11-9-6-8(9)10(13-11)7-4-2-1-3-5-7/h1-5-8-10H,6H2/t8-,9+,10-/m0/s1 |
| 20d | O=C(OCC)[C@H]1C[C@@@H]1[C@H](O)C2=CN=CC=C2 | InChI=1S/C12H15NO3/c1-2-16-12(15)10-6-9(10)11(14)8-4-3-5-13-7-8/h3-5,7,9-11,14H,2,6H2,1H3/t9-,10+,11+/m0/s1 |
| 20e | O=C10(CCC)(CC)[C@@@H]2[C@H]21 | InChI=1S/C9H14O2/c1-3-9(4-2)7-5-6(7)8(10)11-9/h6-7H,3-5H2,1-2H3/t6-,7+/m1/s1 |
| 20f | O=C10(C2=CC=CC=CIC=C2)[C@H]3=C=CC=C(CI)C=C=C3[C@H]4[C@@@H]41 | InChI=1S/C17H12Cl2O2/c18-12-5-1-10(2-6-12)17(11-3-7-13(19)8-4-11)15-9-14(15)16(20)21-17/h1-8,14-15H,9H2/t14-,15+/m1/s1 |
| 20g | O=C(OCC)[C@H]1C[C@@@H]1C(C2=NC=CC=C2)(O)C3=NC=CC=C3 | InChI=1S/C17H18N2O3/c1-2-22-16(20)12-11-13(12)17(21,14-7-3-5-9-18-14)15-8-4-6-10-19-15/h3-10,12-13,21H,2,11H2,1H3/t12-,13+/m1/s1 |
| 20g' | O=C10(C2=CC=CC=N2)[C@H]4[C@@@H]41 | InChI=1S/C15H12N2O2/c18-14-10-9-11(10)15(19-14,12-5-1-3-7-16-12)13-6-2-4-8-17-13/h1-8,10-11H,9H2/t10-,11+/m1/s1 |
| 20h | O=C(OCC)[C@@@H]1C[C@@@H]1C(C2=CC=CC=C2)=O | InChI=1S/C13H14O3/c1-2-16-13(15)11-8-10(11)12(14)9-6-4-3-5-7-9/h3-7,10-11H,2,8H2,1H3/t10-,11+/m0/s1 |
| 20i | O=C(OCC)[C@@@H]1C[C@@@H]1B2OC(C)(C)(C)O2 | InChI=1S/C12H21BO4/c1-6-15-10(14)8-7-9(8)13-16-11(2,3)12(4,5)17-13/h8-9H,6-7H2,1-5H3/t8-,9+/m1/s1 |
| 21a | O=C(OCC)[C@H]1C[C@@@H]1C2=CC=CC=C2 | InChI=1S/C12H14O2/c1-2-14-12(13)11-8-10(11)9-6-4-3-5-7-9/h3-7,10-11H,2,8H2,1H3/t10-,11+/m1/s1 |
| 22a | O=C(OCC)[C@@@H]1C[C@@@H]1C2=CC=CC=C2 | InChI=1S/C12H14O2/c1-2-14-12(13)11-8-10(11)9-6-4-3-5-7-9/h3-7,10-11H,2,8H2,1H3/t10-,11-/m1/s1 |
|   |   |   |   |
|---|---|---|---|
| 21b | O=C(OCC)[C@H]1C[C@@H]1C2 =CC=C(Cl)C=C2 | InChI=1S/C12H13ClO2/c1-2-15-12(14)11-7-10(11)8-3-5-9(13)6-4-8/h3-6,10-11H,2,7H2,1H3/t10-,11+/m1/s1 |   |
| 21c | O=C(OCC)[C@H]1C[C@@H]1C2 =CC=C(OCC)C=C2 | InChI=1S/C13H16O3/c1-3-16-14(13)12-8-11(12)9-4-6-10(15-2)7-5-9/h4-7,11-12H,3,8H2,1-2H3/t11-,12+/m1/s1 |   |
| 21d | O=C(OCC)[C@H]1C[C@@H]1C2 =CC=C(Cl)C=C2 | InChI=1S/C14H16O2/c1-3-16-14(15)13-10-12(13)9-8-11-6-4-3-5-7-11/h3-9,12-13H2,10H2,1H3/b9-8+/t12-,13-/m0/s1 |   |
| 21e | O=C(OCC)[C@H]1C[C@@H]1C2 =NC=CC=C2 | InChI=1S/C11H13NO2/c1-2-14-11(13)9-7-8(9)10-5-3-4-6-12-10/h3-6,8-9H,2,7H2,1H3/t8-,9-/m0/s1 |   |
| 21f | O=C(OCC)[C@H]1C[C@@H]1C2 =NC=CC=N2 | InChI=1S/C10H12N2O2/c1-2-14-10(13)8-6-7(8)9-11-4-3-5-12-9/h3-5-7-8H,2,6H2,1H3/t7-,8-/m0/s1 |   |
| 21g | O=C(OCC)[C@H]1C[C@@H]1C2 =CN(C(OC(C)(C)C)=O)C3=C2C=C=C3 | InChI=1S/C19H23NO4/c1-5-23-17(21)14-10-13(14)15-11-20(18,22)24-19(2,3)416-9-7-6-8-12(15)16/h6-9,11,13-14H5,10H2,1-4H3/t13-,14-/m0/s1 |   |
| 22h | O=C(OCC)[C@@H]1C[C@@H]1C2 =CN(S(C3=CC=CC=C3)(=O)=O)C4=C2C=C=C4 | InChI=1S/C20H19NO4S/c1-2-25-20(22)17-12-16(17)18-13-21(19)11-7-6-10-15(18)26(23,24)14-8-4-3-5-9-14/h3-11,13,16-17H2,12H2,1H3/t16-,17+/m0/s1 |   |
| 23 | [O]C([C@H]1C[C@@H]1C2=NC=CC=C2)=O.[Na] | InChI=1S/C9H8NO2.Na/c11-9(12)7-5-6(7)8-3-1-2-4-10-8/h1-4,6-7H,5H2;/t6-,7-/m0./s1 |   |
| 24 | O=C(N1CCCC1)[C@H]2C[C@@H]2C3=NC=CC=C3 | InChI=1S/C13H16N2O/c16-13(15-7-3-4-8-15)11-9-10(11)12-5-1-2-6-14-12/h1-2,5-6,10-11H,3-4-7H2/t10-,11+/m0/s1 |   |
| 25 | O=C(N1CCCC1)[C@H]2C[C@@H]2C3=NC=CC=C3)(=O)=O)C4=C2C=CC=C4 | InChI=1S/C18H17NO3S/c20-12-13-10-16(13)17-11-19(18-9-5-4-8-15(17)23(21,22)14-6-2-1-3-7-14/h1-9,11,13,16,20H,10,12H2/t13-,16-/m0/s1 |   |
Cyclopropanation of phenyl vinyl sulfide: initial catalyst screening

During optimization of the cyclopropanation of phenyl vinyl sulfide and ethyl diazoacetate a variety of transition metals were investigated (Table S1). CuOTf was a good catalyst and gave improved yields on addition of a BOX ligand (BOX1). However, the reaction could not be further optimized to give above approximately 50% yield (entry 10). Therefore, the cyclopropanation was reoptimized for the Co(salen)-type catalyst 3, which gave excellent yields and a convenient reaction set-up (Table S1 entries 15-21 and Table 1 in manuscript). For all reactions the dr (trans:cis) of product cyclopropanes was between 57:43-38:62.

Table S1. Optimization of the transition-metal catalyzed cyclopropanation of phenyl vinyl sulfide and ethyl diazoacetate

| Entry | Catalyst | Solvent   | Ligand | T (°C) | Yield (%) |
|-------|----------|-----------|--------|--------|-----------|
| 1<sup>[a]</sup> | Rh(OAc)<sub>2</sub> | CH<sub>2</sub>Cl<sub>2</sub> | –       | 30     | 0         |
| 2<sup>[a]</sup> | PdCl<sub>2</sub> | CH<sub>2</sub>Cl<sub>2</sub> | –       | 30     | 0         |
| 3<sup>[a]</sup> | Pd(OAc)<sub>2</sub> | CH<sub>2</sub>Cl<sub>2</sub> | –       | 30     | 0         |
| 4<sup>[a]</sup> | Cu(acac)<sub>2</sub> | CH<sub>2</sub>Cl<sub>2</sub> | –       | 30     | 5         |
| 5<sup>[a]</sup> | Cu(OTf)<sub>2</sub> | CH<sub>2</sub>Cl<sub>2</sub> | –       | 30     | 33        |
| 6<sup>[a]</sup> | Cu(OTf) | CH<sub>2</sub>Cl<sub>2</sub> | –       | 30     | 33        |
| 7<sup>[c]</sup> | Cu(OTf) | Toluene | –       | 30     | 12<sup>[f]</sup> |
| 8<sup>[c]</sup> | Cu(OTf) | THF      | –       | 30     | 26<sup>[f]</sup> |
| 9<sup>[c]</sup> | Cu(OTf) | CHCl<sub>3</sub> | –       | 30     | 41<sup>[f]</sup> |
| 10<sup>[a]</sup> | Cu(OTf) | CHCl<sub>3</sub> | BOX1   | 30     | 46-54     |
| 11<sup>[a]</sup> | CuCl | CHCl<sub>3</sub> | BOX1   | 30     | 4<sup>[f]</sup> |
| 12<sup>[a]</sup> | CuBr | CHCl<sub>3</sub> | BOX1   | 30     | 0<sup>[f]</sup> |
| 13<sup>[a]</sup> | Cu | CHCl<sub>3</sub> | BOX1   | 30     | 8<sup>[f]</sup> |
| 14<sup>[e]</sup> | Cu(MeCN)<sub>3</sub>BF<sub>4</sub> | CHCl<sub>3</sub> | BOX1   | 30     | 36<sup>[f]</sup> |
| 15<sup>[e]</sup> | 3 | CH<sub>2</sub>Cl<sub>2</sub> | –       | 40     | 40<sup>[f]</sup> |
| 16<sup>[e]</sup> | 3 | CHCl<sub>3</sub> | –       | 40     | 13<sup>[f]</sup> |
| 17<sup>[e]</sup> | 3 | TBME    | –       | 40     | 69<sup>[f]</sup> |
| 18<sup>[e]</sup> | 3 | Neat    | –       | 40     | 93<sup>[f]</sup> |
| 19<sup>[e]</sup> | 3 | H<sub>2</sub>O | –       | 40     | 100<sup>[f]</sup> |
| 20<sup>[e]</sup> | 3 | H<sub>2</sub>O | –       | 30     | 92<sup>[f]</sup> |
| 21<sup>[e]</sup> | 3 | H<sub>2</sub>O | –       | 20     | 57<sup>[f]</sup> |

<sup>[a]</sup> Cat. (0.5 mol%) added to flame-dried vial, sealed and flushed with Ar<sub>(g)</sub>. A solution of phenyl vinyl sulfide (131 µL, 1.0 mmol) in CH<sub>2</sub>Cl<sub>2</sub> (7.0 mL, 0.14 M) was added and warmed with stirring to 30 °C. A solution of ethyl diazoacetate (118 µL, 1.0 mmol) in CH<sub>2</sub>Cl<sub>2</sub> (118 µL, 8.5 M) was added over 8 h and then stirred for a further 17 h. <sup>[b]</sup> Same method as for [a] but stirred for a total of 48 h. <sup>[c]</sup> CuOTf-toluene complex (2.6 mg, 0.5 mol%) was added to a flame-dried vial, the vial sealed and flushed with Ar<sub>(g)</sub>. A solution of phenyl vinyl sulfide (131 µL, 1.0 mmol) in solvent (3.3 mL, 0.30 M) was added and warmed with stirring to 30 °C. A solution of ethyl diazoacetate (118 µL, 1.0 mmol) in solvent (3.7 mL, 0.27 M) was added over 1.5 h and then stirred for a further 22 h 30 min. <sup>[d]</sup> Ligand (0.55 mol%) was added to a flame-dried vial and flushed with Ar<sub>(g)</sub>. Catalyst (0.5 mol%) was added, the vial sealed and flushed with Ar<sub>(g)</sub>. CHCl<sub>3</sub> (1.85 mL) was added and the mixture stirred at 30 °C for 1 h. Phenyl vinyl sulfide (66 µL, 0.5 mmol) was added to the solution. A solution of ethyl diazoacetate (118 µL, 1.0 mmol) in CHCl<sub>3</sub> (1.65 mL, 0.61 M) was added over 1.5 h and then stirred for a further 22 h 30 min. <sup>[e]</sup> Method used is the same as that detailed for the synthesis of 1 and 2 on page S14. <sup>[f]</sup> Yield was determined using <sup>1</sup>H NMR spectroscopy through comparison to an internal standard (dibenzyl ether or 1,3,5-trimethoxybenzene).
Cyclopropanation of phenyl vinyl sulfide: product purification

With the larger scale cyclopropanation reactions, using EDA and PVS with cobalt catalyst 3, flash chromatography was not successful in separating cyclopropanes 1 and 2 from a catalyst derived impurity. This impurity coeluted with the products in all eluent systems tested. An oxidative work-up was developed that allowed removal of this impurity through simple filtration. Initial observations were made on the addition of iso-hexane to the reaction mixture on small scale, leading to a change in the nature of the impurity so it could be easily removed. This was ascribed to the dissolved O$_2$ in the iso-hexane likely forming a peroxo-bridged dimeric Co-species, resulting in a very deep brown mixture.$^{[1]}$ On larger scales, more O$_2$ was required for the same effect. Various solvents were tested for effectiveness in oxidation of the catalyst, and hence facile removal, by adding O$_2$ (from either an O$_2$ or compressed air cylinder) for approximately 15 minutes. The resulting mixture was then filtered through a pad of silica (size dependant upon the amount of salen-based material being removed), washing with CH$_2$Cl$_2$. i-Hexane was chosen as the most effective solvent as it has a relatively high oxygen permeability,$^{[2]}$ it solubilises the Co-salen-based species, and allows the mixture to be directly filtered through a silica pad without the solvent eluting impurities.

Table S2. Solvent effects on the oxidation of 3 with O$_2$(g).

| Entry | Solvent | Oxidation observed through colour change? | Time |
|-------|---------|------------------------------------------|------|
| 1     | i-Hexane| Yes                                      | <10 s|
| 2     | n-Hexane| Yes                                      | 1 min|
| 3     | Et$_2$O | Yes                                      | 2 min|
| 4     | EtOAc   | No                                       | –    |
| 5     | TBME    | No                                       | –    |
| 6     | CH$_2$Cl$_2$ | Yes                              | 2 h  |
| 7     | Toluene | No                                       | –    |
| 8     | i-Propanol| No                                 | –    |
| 9     | Acetone | No                                       | –    |
| 10    | THF     | Yes                                      | <10 s|
| 11    | 2-MeTHF | Yes                                      | <10 s|
| 12    | DMF     | Yes                                      | <10 s|
Calculated fragment and lead-like properties for cyclopropane derivatives

The compounds synthesized in this work were intended to fit desirable criteria for fragment or lead-like compounds for drug discovery.

Guidelines for fragments as defined by Congreve and co-workers:[3]
- \( M_W < 300 \text{ Da} \)
- cLogP < 3
- Hydrogen bond donors (HBD) \( \leq 3 \)
- Hydrogen bond acceptors (HBA) \( \leq 3 \)

Klebe and co-workers proposed that HBA \( \leq 6 \) is appropriate for fragments to allow for fragment growing/merging due to appropriate functional groups frequently display properties as hydrogen bond acceptors.[4]

Guidelines for lead-like compounds as defined by Churcher and co-workers:[5]
- \( 200 < M_W < 350 \text{ Da} \)
- \(-1 \leq \text{clogP} \leq 3\)

The polar surface area (PSA) of a compound is important to the permeability through biological membranes, and has been correlated with the likelihood of \textit{in vivo} toxicity (ClogP < 3 and PSA > 75 preferred).[6] Finally, recently less planar compounds, more “3-dimensional” as measured by \( F_{sp^3}\), have been investigated to increase the shape diversity of libraries, and with potential benefits of improved developability and linked to reduced biological promiscuity.[7]

Molecular properties for the prepared compounds are below (Figure 1):
Figure S1: Physicochemical properties for the synthesized compounds deemed relevant to drug discovery

Molecular properties were calculated using LLAMA (Lead-Likeness and Molecular Analysis) software, available freely online at https://llama.leeds.ac.uk.⁸
Virtual scaffold decoration and LLAMA compound analysis

The LLAMA software was used to perform a virtual decoration of the synthesized cyclopropyl compounds. The 56 compounds (all 50 compounds shown in Figure S1 plus 19a, 19k, 19l, 19m, 20a and 20l) were utilized as scaffolds, along with the 44 reagents from the ‘LLAMA Default’ reactant set (Figure S2).

The following reactions were enabled for the virtual scaffold functionalization: BOC deprotection, reductive amination, Suzuki-Miyaura cross-coupling, Buchwald-Hartwig amination, sulfonamide formation, urea formation, alcohol alkylation, carbamate formation, secondary amide alkylation, secondary amide arylation, amide formation, alcohol arylation, urea alkylation, urea arylation, esterification and ester hydrolysis.

The reaction for ester hydrolysis to the corresponding carboxylic acid was not present in the default reaction library and so was added via ‘Advanced settings > Add a new reaction to the library’ and using the below SMARTS code as the reaction description:

\[*;$(\text{CX3}(=O));1][\text{OX2\text{H}0}][\#6]>[*:1][\text{OX2\text{H}1}]\]
Elaboration of the scaffolds with LLAMA elaboration generated 1187 compounds. These are represented below through plots of AlogP against molecular weight (Graph S1), and a PMI plot (Graph S2) to indicate the molecular shapes.

Graph S1: AlogP vs. M_w for the decorated cyclopropane-containing compounds

Graph S2: PMI plot for the decorated cyclopropane-containing compounds
Experimental Details and Characterization Data

Synthesis of 1 and 2 by CoII-catalyzed cyclopropanation

(E)-Ethyl 2-(phenylsulfanyl)cyclopropane-1-carboxylate (1) and (Z)-Ethyl 2-(phenylsulfanyl)cyclopropane-1-carboxylate (2)

A flask containing (±)N,N'-bis(3,5-di-tert-butylnsalicylidene)-1,2-cyclohexanediaminocobalt(II) (1.21 g, 2.0 mmol, 5 mol%) was flushed with Ar(g) for 15 min. Water (80 mL, degassed with Ar(g)), phenyl vinyl sulfide (7.84 mL, 60 mmol, 1.5 equiv) and ethyl diazoacetate (4.84 mL, containing 13 wt% CH2Cl2, 40 mmol, 1.0 equiv) were added and the mixture was warmed to 40 °C. After stirring at 40 °C for 24 h, the mixture was cooled to rt. i-Hexane (20 mL) was added and air bubbled through the stirring mixture for 15 min. Filtration of the mixture through a pad of silica, washing with CH2Cl2, followed by purification by flash column chromatography (15:1 pentane:Et2O) gave (E)-ethyl 2-thiophenylcyclopropane carboxylate 1 (3.66 g, 41%) as a yellow oil followed by (Z)-ethyl 2-thiophenylcyclopropane carboxylate 2 (4.25 g, 48%) as a yellow oil.

(E)-Ethyl 2-(phenylsulfanyl)cyclopropane-1-carboxylate (1)

Rf = 0.54 (4:1 n-hexane:Et2O). IR (film)/cm−1 3078 (CH), 3059 (CH), 2981 (CH), 2941 (CH), 2906 (CH), 1725 (C=O), 1584, 1480, 1380. 1H NMR (400 MHz, CDCl3) δ 7.35–7.28 (m, 4 H, 4 × Ph-H), 7.21–7.17 (m, 1 H, Ph-H), 4.25–4.13 (m, 2 H, CH2CH3), 2.77 (dd, J = 8.2, 5.6, 3.6 Hz, 1 H, Hc), 1.92 (dd, J = 8.8, 5.4, 3.6 Hz, 1 H, Hc), 1.67 (dd, J = 8.2, 5.4, 4.9 Hz, 1 H, Hb), 1.29 (t, J = 7.1 Hz, 3 H, CH3), 1.25 (dd, J = 8.8, 5.6, 4.9 Hz, 1 H, Hb). 13C NMR (101 MHz, CDCl3) δ 172.3 (C=O), 136.8 (Ph-C quat), 128.9 (2 × Ph-C), 127.2 (2 × Ph-C), 125.7 (Ph-C), 61.0 (CH2CH3), 24.2 (C(Ha)), 22.3 (C(Hc)), 17.2 (C(Ha)(Hb)), 14.2 (CH3). HRMS (ES) m/z Calcd for C12H15O2S+ [M+H]+: 223.0793; Found: 223.0795.

(Z)-Ethyl 2-(phenylsulfanyl)cyclopropane-1-carboxylate (2)

Rf = 0.35 (4:1 n-hexane:Et2O). IR (film)/cm−1 3074 (CH), 3059 (CH), 2981 (CH), 2937 (CH), 2906 (CH), 2874, 1728 (C=O), 1585, 1480, 1380. 1H NMR (400 MHz, CDCl3) δ 7.37–7.34 (m, 2 H, 2 × Ph-H), 7.30–7.25 (m, 2 H, 2 × Ph-H), 7.17–7.13 (m, 1 H, Ph-H), 4.06 (q, J = 7.1 Hz, 2 H, CH2CH3), 2.70 (ddd, J = 7.8, 7.8, 6.7 Hz, 1 H, Hb), 2.25 (ddd, J = 7.8, 7.8, 6.7 Hz, 1 H, Hb), 1.49–1.45 (m, 2 H, Hs + Hb), 1.11 (t, J = 7.1 Hz, 3 H, CH3). 13C NMR (101 MHz, CDCl3) δ 169.6 (C=O), 137.1 (Ph-C quat), 128.7 (2 × Ph-C), 127.5 (2 × Ph-C), 125.5 (Ph-C), 60.8 (CH2CH3), 22.07 (C(Ha)), 22.05 (C(Hc)), 14.1 (CH3), 13.2 (C(Ha)(Hb)). HRMS (ES) m/z Calcd for C12H15O2S+ [M+H]+: 223.0793; Found: 223.0801.

These compounds display characteristic J-values which have been considered in all assignments.\(^6\)
Synthesis of 4–7 through sulfide oxidation

**(E)-Ethyl-2-(benzenesulfonyl)cyclopropane-1-carboxylate (4)**

![Chemical structure](image1)

mCPBA (62 mg, 0.36 mmol, 2.5 equiv) was added to a solution of (E)-ethyl 2-thiophenecyclopropane carboxylate 1 (32 mg, 0.14 mmol, 1.0 equiv) in CH₂Cl₂ (5.0 mL) and the mixture stirred at 25 °C for 24 h. Water (15 mL) and sat. aq. NaHCO₃ (15 mL) were added and the mixture was extracted with CH₂Cl₂ (3 × 15 mL). The combined organic phases were washed with brine (15 mL), dried (MgSO₄), filtered and concentrated under reduced pressure to give sulfone 4 (39 mg, quant.) as a pale yellow crystalline solid. Rₛ = 0.45 (1:2 n-hexane:Et₂O). mp = 53–56 °C. IR (film) cm⁻¹: 3074 (CH), 3041 (CH), 2991 (CH), 1721 (C=O), 1449, 1306 (S=O), 1147 (S=O).

**Ethyl (Z)-2-(benzenesulfonyl)cyclopropane-1-carboxylate (5)**

![Chemical structure](image2)

mCPBA (56 mg, 0.33 mmol, 2.5 equiv.) was added to a solution of (Z)-ethyl 2-thiophenecyclopropane carboxylate 2 (29 mg, 0.13 mmol, 1.0 equiv) in CH₂Cl₂ (5.0 mL) and the mixture stirred at 25 °C for 25 h. H₂O (10 mL) and sat. aq. NaHCO₃ (15 mL) were added and the mixture was extracted with CH₂Cl₂ (3 × 15 mL). The combined organic phases were washed with brine (20 mL), dried (MgSO₄), filtered and concentrated under reduced pressure to give sulfone 5 (33 mg, quant.) as a pale yellow crystalline solid. Rₛ = 0.33 (1:2 n-hexane:Et₂O). mp = 100–102 °C. IR (film) cm⁻¹: 3098 (CH), 3063 (CH), 3042 (CH), 2984 (CH), 2937 (CH), 2910 (CH), 1733, 1447, 1324 (S=O), 1150 (S=O). ¹H NMR (400 MHz, CDCl₃) 3075, 3042 (CH), 2984 (CH), 2937 (CH), 2910 (CH), 1721 (C=O), 1449, 1306 (S=O), 1147 (S=O). ¹³C NMR (101 MHz, CDCl₃) 3073, 3041 (CH), 2991 (CH), 1723, 1449, 1304 (S=O), 1150 (S=O). HRMS (ES) m/z Calcd for C₇₄H₇₄O₄S [M⁺]: 254.0613; Found: 254.0619.

**(E)-Ethyl 2-(benzenesulfonyl)cyclopropane-1-carboxylate (6)**

![Chemical structure](image3)

mCPBA (2.40 g, 13.9 mmol, 1.05 equiv) was added portionwise (3 × 0.80 g over 30 min) to a solution of (E)-ethyl 2-(phenylsulfanyl)cyclopropane-1-carboxylate 1 (2.95 g, 13.3 mmol, 1.0 equiv) in CH₂Cl₂ (133 mL) at 0 °C. The reaction was stirred at 0 °C for 2 h, then aqueous KOH (3 M, 50 mL) was added and the phases separated. The aqueous phase was extracted with CH₂Cl₂ (5 × 50 mL), then the organic phases were combined, washed with brine (50 mL), dried (MgSO₄), filtered and concentrated under reduced pressure. Purification by flash column chromatography (1:1 to 1:2 n-hexane:Et₂O) afforded a yellow oil which was dissolved in CH₂Cl₂, dried (MgSO₄), filtered and concentrated under reduced pressure to give sulfoxides 6 (2.91 g, 92%, d.r. = 53:47) as a pale yellow oil. Rₛ = 0.24 (1:2 n-hexane:Et₂O). IR (film) cm⁻¹: 3094 (CH), 3055 (CH), 2982 (CH), 2941 (CH), 2910 (CH), 1726 (C=O), 1444, 1381, 1258, 1182, 1048 (S=O). ¹H NMR (400 MHz, CDCl₃) 7.95–7.93 (m, 2 H, 2 × Ph-H), 7.68 (t, J = 7.4 Hz, 1 H, Ph-H), 7.59 (t, J = 7.6 Hz, 2 H, 2 × Ph-H), 4.13 (q, J = 7.1 Hz, 2 H, CH₂CH₃), 2.98 (ddd, J = 8.8, 5.9, 4.1 Hz, 1 H, H₆), 2.52 (ddd, J = 9.7, 5.8, 4.1 Hz, 1 H, H₈), 1.73 (ddd, J = 9.6, 5.5, 5.5 Hz, 1 H, H₄), 1.55 (ddd, J = 8.8, 5.7, 5.7 Hz, 1 H, H₆), 1.25 (t, J = 7.1 Hz, 3 H, CH₃). ¹³C NMR (101 MHz, CDCl₃) 166.9 (C=O), 140.4 (Ph-C quat.), 133.6 (Ph-C), 129.1 (2 × Ph-C), 127.7 (2 × Ph-C), 61.8 (CH₂), 39.6 (C(H₄)), 23.5 (C(H₆)), 13.9 (CH₃), 10.4 (C(H₆)(H₈)). HRMS (EI) m/z Calcd for C₁₃H₁₂O₄S²⁺ [M⁺]: 255.0691; Found: 255.0694.
3 H, CH₃). ¹³C NMR (101 MHz, CDCl₃) δ 171.4 (C=O), 143.9 (Ph-C quat), 131.3 (Ph-C), 129.3 (2 × Ph-C), 123.9 (2 × Ph-C), 61.2 (CH₂CH₃), 41.4 (C(H₃)), 15.8 (C(H₃)), 14.1 (CH₃), 11.7 (C(H₃)(H₆)).

HRMS (ES) m/z Calcld for C₁₂H₁₅O₃S⁺ [M+H⁺]: 239.0742; Found: 239.0731.

(Z)-Ethyl-(benzenesulfonyl)cyclopropane-1-carboxylate (7)

mCPBA (1.21 g, 7.03 mmol, 1.05 equiv) was added portion wise (3 × 0.4 g over 30 min) to a solution of (Z)-ethyl 2-thiophenycyclopropane carboxylate 2 (1.49 g, 6.69 mmol, 1.0 equiv) in CH₂Cl₂ (67 mL) at 0 °C. The reaction was stirred at 0 °C for 3 h then warmed to 25 °C for 16 h 30 min. Aqueous KOH (3M, 50 mL) was added and the phases separated. The aqueous phase was extracted with CH₂Cl₂ (5 × 30 mL), then the organic phases were combined, washed with brine (50 mL), dried (MgSO₄), filtered and concentrated under reduced pressure to give sulfoxides 7 (1.56 g, 98%, d.r = 75:25) as a pale yellow oil. IR (film) cm⁻¹ 3059 (CH), 2983 (CH), 2941 (CH), 1725 (C=O), 1444, 1382, 1188, 1040 (S=O).

Major diastereoisomer: R₁ = 0.23 (Et₂O). ¹H NMR (400 MHz, CDCl₃) δ 7.68–7.64 (m, 2 H, 2 × Ph-H), 7.57–7.50 (m, 3 H, 3 × Ph-H), 4.23 (ddd, J = 7.1, 7.1, 7.1, 0.7 Hz, 2 H, CH₂CH₃), 2.61 (ddd, J = 8.4, 8.4, 6.7 Hz, 1 H, H₆), 2.13 (ddd, J = 8.2, 8.2, 6.5 Hz, 1 H, H₆), 2.07 (ddd, J = 6.5, 6.5, 5.6 Hz, 1 H, H₆), 1.78 (ddd, J = 8.2, 8.2, 5.6 Hz, 1 H, H₆), 1.30 (t, J = 7.1 Hz, 3 H, CH₃). ¹³C NMR (101 MHz, CDCl₃) δ 170.0 (C=O), 145.1 (Ph-C quat.), 131.2 (Ph-C), 129.3 (2 × Ph-C), 124.0 (2 × Ph-C), 61.5 (CH₂CH₃), 43.3 (C(H₃)), 21.2 (C(H₆)), 14.2 (CH₃), 14.1 (C(H₆)(H₇)).

Minor diastereoisomer: R₁ = 0.31 (Et₂O). ¹H NMR (400 MHz, CDCl₃) δ 7.76–7.73 (m, 2 H, 2 × Ph-H), 7.57–7.50 (m, 3 H, 3 × Ph-H), 4.31 (ddd, J = 7.1, 7.1, 7.1, 4.5 Hz, 2 H, CH₂CH₃), 2.68 (ddd, J = 8.7, 8.0, 6.7 Hz, 1 H, H₆), 2.31 (ddd, J = 8.0, 8.0, 6.4 Hz, 1 H, H₆), 1.75 (ddd, J = 6.5, 6.5, 5.7 Hz, 1 H, H₆), 1.38 (ddd, J = 8.8, 8.0, 5.7 Hz, 1 H, H₆), 1.35 (t, J = 7.2 Hz, 3 H, CH₃). ¹³C NMR (101 MHz, CDCl₃) δ 170.1 (C=O), 145.2 (Ph-C quat), 131.0 (Ph-C), 129.3 (2 × Ph-C), 124.0 (2 × Ph-C), 61.7 (CH₂CH₃), 44.3 (C(H₃)), 20.9 (C(H₆)), 13.6 (CH₃), 11.8 (C(H₆)(H₇)).

HRMS (ES) m/z Calcld for C₁₂H₁₅O₃S⁺ [M+H⁺]: 239.0742; Found: 239.0754.

Synthesis of 8–13 through ester derivatization

(E)-2-(Phenylsulfonyl)cyclopropane-1-carboxylic acid (8)

Aqueous NaOH (1.0 M, 0.55 mL, 0.55 mmol, 1.1 equiv) was added to a solution of (E)-ethyl 2-thiophenycyclopropane carboxylate 1 (111 mg, 0.50 mmol, 1.0 equiv) in ethanol (2.5 mL) and the solution stirred at 30 °C for 24 h. HCl(aq) (1.0 M, 10 mL) was added and the mixture extracted with EtOAc (5 × 10 mL). The combined organic phases were dried (MgSO₄), filtered and concentrated under reduced pressure to give carboxylic acid 8 (97 mg, quant) as a white crystalline solid. R₁ = 0.18 (1:1 pentane:Et₂O). mp = 106–110 °C. IR (film)/cm⁻¹ 3008 (CH), 2863 (CH), 2530, 1679 (C=O), 1585, 1440, 1272, 1223, 928. ¹H NMR (400 MHz, CDCl₃) δ 7.37–7.29 (m, 4 H, 4 × Ph-H), 7.25–7.18 (m, 1 H, Ph-H), 2.85 (ddd, J = 8.4, 5.8, 3.5 Hz, 1 H, H₆), 1.95 (ddd, J = 8.7, 5.3, 3.6 Hz, 1 H, H₆), 1.73 (ddd, J = 8.3, 5.1, 5.1 Hz, 1 H, H₆), 1.35 (ddd, J = 8.6, 5.8, 5.0 Hz, 1 H, H₆). ¹³C NMR (101 MHz, CDCl₃) δ 178.3 (C=O), 136.3 (Ph-C quat), 129.0 (2 × Ph-C), 127.6 (2 × Ph-C), 126.0 (Ph-C), 24.1 (C(H₆)), 23.5 (C(H₃)), 17.9 (C(H₆)(H₇)). HRMS (ES) m/z Calcld for C₁₀H₉O₂S⁺ [M⁺]: 193.0332; Found: 193.0332.

(Z)-2-(Phenylsulfonyl)cyclopropane-1-carboxylic acid (9)

Aqueous NaOH (1.0 M, 0.55 mL, 0.55 mmol, 1.1 equiv) was added to a solution of (E)-ethyl 2-thiophenycyclopropane carboxylate 2 (111 mg, 0.50 mmol, 1.0 equiv) in ethanol (2.5 mL) and the solution stirred at 30 °C for 24 h. HCl(aq) (1.0 M, 10 mL) was added and the mixture extracted with EtOAc (5 × 10 mL). The combined organic phases were dried (MgSO₄), filtered and concentrated under reduced pressure to give carboxylic acid 9 (97 mg, quant) as a cream crystalline solid. R₁ = 0.22 (1:1 pentane:Et₂O). mp = 76–79 °C. IR (film)/cm⁻¹ 3044 (CH), 2685 (CH), 2533, 1688 (C=O), 1478, 1436, 1202, 902. ¹H NMR (400 MHz, DMSO-d₆) δ 12.25 (br s, 1 H, CO₂H), 7.36–7.29 (m, 4 H, 4 × Ph-H), 7.18–7.13 (m, 1 H, Ph-H), 2.77 (ddd, J = 8.1, 8.1, 6.4 Hz, 1 H, H₆),
(E)-[2-(Phenylsulfonyl)cyclopropyl]methanol (10)

Lithium aluminum tetrahydride (1.0 M in THF, 1.0 mL, 1.0 mmol, 2.5 equiv) was added dropwise over 5 min to a 0 °C solution of (E)-ethyl 2-thiophenylcyclopropane carboxylate 1 (89 mg, 0.40 mmol, 1.0 equiv) in THF (0.5 mL) and the solution stirred at 0 °C for 10 min. The solution was warmed to 25 °C and stirred for 3 h. The reaction mixture was cooled to 0 °C, EtOAc (5 mL) was added and the mixture stirred for 15 min. The mixture was warmed to 25 °C, sat. aq. potassium sodium tartrate (5.0 mL) was added and the mixture stirred for 1 h. The organic phase was separated, and the aqueous phase extracted with EtOAc (6 × 10 mL). The combined organic phases were washed with brine (20 mL), dried (MgSO₄), filtered and concentrated under reduced pressure. Purification by flash column chromatography (2:1 pentane:Et₂O) gave alcohol 10 (63 mg, 87%) as a yellow oil. Rₐ = 0.13 (2:1 pentane:Et₂O). IR (film)/cm⁻¹ 3340 (OH), 3059 (CH), 3004 (CH), 2923 (CH), 2873 (CH), 1584, 1480, 1271, 1025, 738, 690. ¹H NMR (400 MHz, CDCl₃) δ 7.41–7.39 (m, 2 H, 2 × Ph-H), 7.32–7.28 (m, 2 H, 2 × Ph-H), 7.18–7.14 (m, 1 H, Ph-H), 3.73 (dd, J = 11.4, 6.1 Hz, 1 H, OCH(H)), 3.56 (dd, J = 11.4, 7.1 Hz, 1 H, OCH(H)), 2.17 (dd, J = 8.1, 4.3, 4.3 Hz, 1 H, Hₐ), 1.48–1.40 (m, 1 H, Hₐ), 1.05 (dd, J = 7.8, 5.5, 5.5 Hz, 1 H, Hₐ), 0.95 (dd, J = 8.9, 4.9, 4.9 Hz, 1 H, Hₐ). ¹³C NMR (100 MHz, CDCl₃) δ 138.2 (Ph-C quat), 128.8 (2 × Ph-C), 126.8 (2 × Ph-C), 125.3 (Ph-C), 65.2 (OCH₂), 24.9 (C(Hₐ)), 17.4 (C(Hₐ)), 13.2 (C(Hₐ)), 10.9 (C(Hₐ)). HRMS (EI) m/z Calcd for C₁₀H₉O₂S⁺ [M+H⁺]: 180.0609; Found: 180.0599.

(Z)-[2-(Phenylsulfonyl)cyclopropyl]methanol (11)

Lithium aluminum tetrahydride (1.0 M in THF, 1.0 mL, 1.0 mmol, 2.5 equiv) was added dropwise over 5 min to a solution of (Z)-ethyl 2-thiophenylcyclopropane carboxylate 2 (89 mg, 0.40 mmol, 1.0 equiv) in THF (0.5 mL) at 0 °C. The solution was stirred at 0 °C for 10 min then 25 °C for 3 h. The reaction mixture was cooled to 0 °C, EtOAc (5 mL) was added and the mixture stirred for 15 min. The mixture was warmed to 25 °C, sat. aq. potassium sodium tartrate (5.0 mL) was added and the mixture stirred for 1 h. The organic phase was separated, and the aqueous phase extracted with EtOAc (6 × 10 mL). The combined organic phases were washed with brine (20 mL), dried (MgSO₄), filtered and concentrated under reduced pressure to give cyclopropane 11 (63 mg, 87%) as a colourless oil. Rₐ = 0.40 (1:1 pentane:Et₂O). IR (film)/cm⁻¹ 3245 (OH), 3069 (OH), 3008 (CH), 2928 (CH), 2869 (CH), 1582, 1478, 1438, 1056, 1022, 733. ¹H NMR (400 MHz, CDCl₃) δ 7.41–7.38 (m, 2 H, 2 × Ph-H), 7.19–7.14 (m, 1 H, Ph-H), 3.87 (dd, J = 11.7, 4.4 Hz, 1 H, OCH(H)), 3.69 (dd, J = 11.8, 8.6 Hz, 1 H, OCH(H)), 2.48 (dd, J = 8.0, 7.1, 5.1 Hz, 1 H, Hₐ), 1.71–1.62 (m, 1 H, Hₐ), 1.28 (dd, J = 8.4, 8.4, 5.5 Hz, 1 H, Hₐ), 0.61 (dd, J = 5.4, 5.4, 5.4 Hz, 1 H, Hₐ). ¹³C NMR (101 MHz, CDCl₃) δ 138.2 (Ph-C quat), 129.0 (2 × Ph-C), 126.4 (2 × Ph-C), 125.4 (Ph-C), 62.5 (OCH₂), 21.2 (C(Hₐ)), 18.1 (C(Hₐ)), 10.9 (C(Hₐ)). HRMS (EI) m/z Calcd for C₁₀H₁₀O₂⁺ [M+H⁺]: 162.0503; Found: 162.0507.

(E)-Sodium 2-(phenylsulfonyl)cyclopropane-1-carboxylate (12)

Aqueous NaOH (1.0 M, 2.9 mL, 2.9 mmol, 1.0 equiv) was added to a solution of (E)-ethyl 2-thiophenylcyclopropane carboxylate 3 (646 mg, 2.9 mmol, 1.0 equiv) in ethanol (14.5 mL) and the solution stirred at 30 °C for 24 h. The reaction mixture was concentrated under reduced pressure to give sodium carboxylate salt 12 (622 mg, quant) as a cream solid. mp = 207–212 °C. IR (film)/cm⁻¹ 3521 (OH), 3232 (CH), 1567 (C=O), 1417, 1318, 1251, 955. ¹H NMR (400 MHz, DMSO-d₆) δ 7.34–7.27 (m, 4 H, 4 × Ph-H), 7.15–7.10 (m, 1 H, Ph-H), 2.39 (ddd, J = 7.9, 4.9, 3.7 Hz, 1 H, Hₐ), 1.43 (ddd, J = 8.8, 5.5, 3.6 Hz, 1 H, Hₐ), 1.30 (ddd, J = 7.7, 5.5, 3.8 Hz, 1 H, Hₐ), 0.76 (ddd, J = 8.6, 4.7, 3.9 Hz, 1 H, Hₐ). ¹³C NMR (101 MHz, DMSO-d₆) δ 174.9 (C=O), 138.4 (Ph-C quat), 128.9 (2 × Ph-C), 125.8 (2 × Ph-C), 124.8 (Ph-C), 27.2 (C(Hₐ)), 18.3 (C(Hₐ)), 15.0 (C(Hₐ)). HRMS (ES) m/z Calcd for C₁₀H₉O₂S⁺ [M−Na⁺]: 193.0323; Found: 193.0317.
(Z)-Sodium 2-(phenylsulfanyl)cyclopropane-1-carboxylate (13)

Aqueous NaOH (1.0 M, 4.5 mL, 4.5 mmol, 1.0 equiv) was added to a solution of (Z)-ethyl 2-thiophenecyclopropane carboxylate 2 (1.00 g, 4.50 mmol, 1.0 equiv) in ethanol (22.5 mL) and the solution stirred at 30 °C for 24 h. The reaction mixture was concentrated under reduced pressure to give sodium carboxylate salt 13 (0.98 g, quant) as a cream solid. mp = 236–240 °C. IR (film)/cm⁻¹ 3078 (CH), 3055 (CH), 3016 (CH), 1586 (C=O), 1424, 1315, 1282, 956. ¹H NMR (400 MHz, DMSO-d₆) δ 7.36–7.33 (m, 2 H, 2 × Ph-H), 7.27–7.22 (m, 2 H, 2 × Ph-H), 7.09–7.05 (m, 1 H, Ph-H), 2.24 (dd, J = 8.0, 8.0, 5.9 Hz, 1 H, H₆), 1.77 (dd, J = 8.2, 8.2, 6.5 Hz, 1 H, H₆), 1.10 (dd, J = 8.0, 8.0, 3.9 Hz, 1 H, H₆), 0.90 (dd, J = 6.2, 6.2, 4.0 Hz, 1 H, H₆). ¹³C NMR (101 MHz, DMSO-d₆) δ 173.2 (C=O), 139.8 (Ph-C quat), 128.6 (2 × Ph-C), 126.3 (2 × Ph-C), 124.3 (Ph-C), 24.2 (C(H₆)), 19.4 (C(H₆)), 13.3 (C(H₆)(H₆)). HRMS (ES) m/z Calcd for C₁₀H₇O₂S⁺ [M+Na⁺]: 193.0323; Found: 193.0319.

**Synthesis of 14a–15d through amide bond formation**

(E)-N-Benzyl-2-(phenylsulfanyl)cyclopropane-1-carboxamide (14a)

HATU (183 mg, 0.48 mmol, 1.2 equiv) was added to a solution of (E)-sodium 2-(phenylsulfanyl)cyclopropane-1-carboxylate 12 (87 mg, 0.40 mmol, 1.0 equiv) in N,N-dimethylformamide (2.0 mL) and stirred at 40 °C for 10 min. Benzyllamine (53 µL, 0.48 mmol, 1.2 equiv) was added and the solution stirred for 20 min. Diisopropylethylamine (0.21 mL, 1.20 mmol, 3.0 equiv) was added and the solution stirred for 24 h. Water (100 mL) was added and the mixture extracted with CH₂Cl₂ (5 × 20 mL). The combined organic phases were washed with brine (30 mL), dried (MgSO₄), filtered and concentrated under reduced pressure. Purification by flash column chromatography (2:1 pentane:Et₂O) gave amide 14a (112 mg, 99%) as a white solid. Rf = 0.17 (2:1 pentane:Et₂O). mp = 129–130 °C. IR (film)/cm⁻¹ 3287 (NH), 3092 (CH), 2916 (CH), 1636 (C=O), 1559, 1391, 1222, 736, 695. ¹H NMR (400 MHz, CDCl₃) δ 7.39–7.24 (m, 9 H, 9 × Ph-H), 7.18–7.13 (m, 1 H, Ph-H), 6.04 (br s, 1 H, NH), 4.57 (dd, J = 14.7, 6.1 Hz, 1 H, NC(HH)), 4.41 (dd, J = 14.7, 5.4 Hz, 1 H, NC(HH)), 2.80 (dd, J = 8.3, 5.5, 3.5 Hz, 1 H, H₆), 1.74 (dd, J = 8.3, 5.3, 4.7 Hz, 1 H, H₆), 1.61 (dd, 1 H, J = 8.5, 5.5, 3.6 Hz, H₆), 1.19 (dd, J = 8.5, 5.4, 4.8 Hz, 1 H, H₆). ¹³C NMR (101 MHz, CDCl₃) δ 170.6 (C=O), 138.1 (Ph-C quat), 137.4 (Ph-C quat), 128.9 (2 × Ph-C), 128.8 (2 × Ph-C), 127.8 (2 × Ph-C), 127.6 (Ph-C), 126.7 (2 × Ph-C), 125.4 (Ph-C), 43.9 (PhCH₂), 26.3 (C(H₆)), 21.1 (C(H₆)), 16.5 (C(H₆)(H₆)). HRMS (ES) m/z Calcd for C₁₇H₁₈NOS⁺ [M+H⁺]: 284.1109; Found: 284.1103.

(E)-(Morpholin-4-yl)-2-[(phenylsulfanyl)cyclopropyl]methanone (14b)

HATU (183 mg, 0.48 mmol, 1.2 equiv) was added to a solution of (E)-sodium 2-(phenylsulfanyl)cyclopropane-1-carboxylate 12 (87 mg, 0.40 mmol, 1.0 equiv) in N,N-dimethylformamide (2.0 mL) and stirred at 40 °C for 10 min. Morpholine (42 µL, 0.48 mmol, 1.2 equiv) was added and the solution stirred for 20 min. Diisopropylethylamine (0.21 mL, 1.20 mmol, 3.0 equiv) was added and the solution stirred for 24 h. H₂O (100 mL) was added and the mixture extracted with EtOAc (6 × 20 mL). The combined organic phases were washed with brine (30 mL), dried (MgSO₄), filtered and concentrated under reduced pressure. Purification by flash column chromatography (Et₂O) gave amide 14b (101 mg, 96%) as a white solid. Rf = 0.36 (Et₂O). mp = 77–78 °C. IR (film)/cm⁻¹ 2962 (CH), 2893 (CH), 2856 (CH), 1629 (C=O), 1441, 1233, 1117, 880. ¹H NMR (400 MHz, CDCl₃) δ 7.33–7.28 (m, 4 H, 4 × Ph-H), 7.21–7.16 (m, 1 H, Ph-H), 3.70–3.52 (m, 8 H, 2 × OCH₂ + 2 × NCH₂), 2.80 (dd, J = 8.2, 5.4, 3.6 Hz, 1 H, H₆), 1.94 (dd, J = 8.7, 5.4, 3.6 Hz, 1 H, H₆), 1.74 (dd, J = 8.1, 5.4, 4.6 Hz, 1 H, H₆), 1.22 (dd, J = 8.6, 5.3, 4.6 Hz, 1 H, H₆). ¹³C NMR (101 MHz, CDCl₃) δ 169.4 (C=O), 137.2 (Ph-C quat), 128.9 (2 × Ph-H), 127.3 (2 × Ph-H), 125.7 (Ph-H), 66.8 (OCH₂), 66.7 (OCH₂), 46.0 (NCH₂), 42.6 (NCH₂), 22.6 (C(H₆)), 22.0 (C(H₆)), 16.9 (C(H₆)(H₆)). HRMS (ES) m/z Calcd for C₁₄H₁₈NO₂S⁺ [M+H⁺]: 264.1058; Found: 264.1056.
(E)-(4-Methylpiperazin-1-yl)[2-(phenylsulfanyl)cyclopropyl]methanone (14c)

HATU (183 mg, 0.48 mmol, 1.2 equiv) was added to a solution of (E)-sodium 2-(phenylsulfanyl) cyclopropane-1-carboxylate 12 (87 mg, 0.40 mmol, 1.0 equiv) in N,N-dimethylformamide (2.0 mL) and stirred at 40 °C for 10 min. 1-Methylpiperazine (54 µL, 0.48 mmol, 1.2 equiv) was added and the solution stirred for 20 min. Diisopropylethylamine (0.21 mL, 1.20 mmol, 3.0 equiv) was added and the solution stirred for 24 h. Water (100 mL) was added and the mixture extracted with EtOAc (6 × 20 mL). The combined organic phases were washed with brine (30 mL), dried (MgSO4), filtered and concentrated under reduced pressure. Purification by flash column chromatography (1:19 MeOH:CH2Cl2) gave amide 14c (106 mg, 96%) as a brown gum. Rf = 0.17 (1:19 MeOH:CH2Cl2). IR (film)/cm⁻¹: 3078 (CH), 3005 (CH), 2938 (CH), 2846 (CH), 2791, 1632 (C=O), 1439, 737. ¹H NMR (400 MHz, CDCl3) δ 7.33–7.27 (m, 4 H, 4 × Ph-H), 7.21–7.15 (m, 1 H, Ph-H), 3.76–3.70 (m, 1 H, NCH(H)), 3.63–3.55 (m, 3 H, 3 × NCH(H)), 2.78 (ddd, J = 8.2, 5.4, 3.7 Hz, 1 H, Hα), 2.42–2.37 (m, 3 H, 3 × NCH(H)), 2.34–2.29 (m, 4 H, 1 × NCH(H) + NCH3), 1.98 (ddd, J = 8.8, 5.4, 3.7 Hz, 1 H, Hα), 1.72 (ddd, J = 8.1, 5.4, 4.6 Hz, 1 H, Hβ), 1.20 (ddd, J = 8.8, 5.4, 4.6 Hz, 1 H, Hα). ¹³C NMR (101 MHz, CDCl3) δ 169.2 (C=O), 137.3 (Ph-C quat), 128.9 (2 × Ph-C), 127.1 (2 × Ph-C), 125.6 (Ph-C), 55.2 (NCH2), 54.7 (NCH2), 46.0 (CH3), 45.5 (NCH2), 42.2 (NCH2), 22.7 (C(H2)), 21.8 (C(H2)), 16.8 (C(H3)). HRMS (ES) m/z Calcd for C16H22N2OS [M+H]⁺: 277.1375; Found: 277.1374.

(Z)-N-Benzyl-2-(phenylsulfanyl)cyclopropane-1-carboxamide (15a)

HATU (228 mg, 0.60 mmol, 1.2 equiv) was added to a solution of (Z)-sodium 2-(phenylsulfanyl)cyclopropane-1-carboxylate 13 (108 mg, 0.50 mmol, 1.0 equiv) in N,N-dimethylformamide (2.5 mL) and stirred at 40 °C for 10 min. Benzylamine (66 µL, 0.60 mmol, 1.2 equiv) was added and the solution stirred for 20 min. Diisopropylethylamine (0.27 mL, 1.50 mmol, 3.0 equiv) was added and the solution stirred for 24 h. Water (100 mL) was added and the mixture extracted with EtOAc (5 × 20 mL). The combined organic phases were washed with brine (30 mL), dried (MgSO4), filtered and concentrated under reduced pressure. Purification by flash column chromatography (EtO) gave amide 15a (123 mg, 87%) as a white solid. Rf = 0.32 (EtO). mp = 137–140 °C. IR (film)/cm⁻¹: 3303 (NH), 3060 (CH), 1645 (C=O), 1552, 1244, 687. ¹H NMR (400 MHz, CDCl3) δ 7.36–7.09 (m, 5 H, 5 × Ph-H), 3.82 (t, J = 6.7 Hz, 2 H, CH2), 2.96 (ddd, J = 8.1, 5.5, 3.7 Hz, 1 H, Hα), 2.73 (t, J = 6.6 Hz, 2 H, CH2), 2.26 (ddd, J = 8.8, 5.3, 3.7 Hz, 1 H, Hβ), 1.96 (m, 2 H, CH2), 1.82 (ddd, J = 8.1, 5.4, 4.4 Hz, 1 H, Hβ), 1.17 (ddd, J = 8.7, 4.9, 4.9 Hz, 1 H, Hα). ¹³C NMR (101 MHz, CDCl3) δ 170.6 (C=O), 138.6 (Ar-C quat), 137.1 (2 × Ar-C quat), 128.9 (2 × Ar-C), 128.5 (Ar-C), 127.6 (2 × Ar-C), 126.2 (Ar-C), 125.7 (Ar-C), 125.3 (Ar-C), 124.7 (Ar-C), 43.1 (NCH2), 26.8 (CH2), 24.5 (CH2), 24.1 (C(H2)), 23.3 (C(H3)), 18.1 (C(H3)(H2)). HRMS (ES) m/z Calcd for C19H20NOS [M+H]⁺: 310.1266; Found: 310.1259.
(Z)-(Morpholin-4-yl)-2-[(phenylsulfanyl)cyclopropyl]methanone (15b)

HATU (228 mg, 0.60 mmol, 1.2 equiv) was added to a solution of (Z)-sodium 2-(phenylsulfanyl)cyclopropane-1-carboxylate 13 (108 mg, 0.50 mmol, 1.0 equiv) in \( N,N \)-dimethylformamide (2.5 mL) and stirred at 40 °C for 10 min. Morpholine (52 \( \mu \)L, 0.60 mmol, 1.2 equiv) was added and the solution stirred for 20 min. Diisopropylethylamine (0.27 mL, 1.50 mmol, 3.0 equiv) was added and the solution stirred for 24 h. Water (100 mL) was added and the mixture extracted with EtOAc (5 × 20 mL). The combined organic phases were washed with brine (30 mL), dried (MgSO\(_4\)), filtered and concentrated under reduced pressure. Purification by flash column chromatography (EtOAc) gave amide 15b (98 mg, 74%) as a yellow gum. \( R_t = 0.26 \) (EtOAc). IR (film)/cm\(^{-1}\) 3055 (CH), 2963 (CH), 2855 (CH), 1635 (C=O), 1437, 1291, 1225, 1001, 739. \(^1\)H NMR (400 MHz, CDCl\(_3\)) \( \delta \) 7.39–7.36 (m, 2 H, 2 × Ph-H), 7.31–7.29 (m, 2 H, 2 × Ph-H), 7.21–7.17 (m, 1 H, Ph-H), 3.74–3.58 (m, 3 H, 3 × C(H)(H)), 3.55–3.45 (m, 3 H, 3 × C(H)(H)), 3.38–3.28 (m, 2 H, 2 × C(H)(H)), 2.76 (dd, \( J = 8.0, 8.0, 5.9 \) Hz, 1 H, H\(_c\)), 2.18 (dd, \( J = 8.0, 8.0, 6.2 \) Hz, 1 H, H\(_d\)), 1.61 (ddd, \( J = 5.9, 5.9, 5.9 \) Hz, 1 H, H\(_a\)), 1.43 (ddd, \( J = 8.1, 8.1, 5.3 \) Hz, 1 H, H\(_a\)). \(^1^3\)C NMR (101 MHz, CDCl\(_3\)) \( \delta \) 166.5 (C=O), 137.0 (Ph-C quat), 128.8 (2 × Ph-C), 128.4 (2 × Ph-C), 126.0 (Ph-C), 66.8 (OCH\(_2\)), 66.4 (OCH\(_2\)), 45.7 (NCH\(_2\)), 42.3 (NCH\(_2\)), 21.5 (C(H\(_a\))), 20.9 (C(H\(_c\))), 12.8 (C(H\(_b\))(H\(_a\))). HRMS (ES) m/z Calcd for C\(_{14}\)H\(_{16}\)NO\(_2\)S\(^+\) [M+H\(^+\)]: 264.1058; Found: 264.1058.

(Z)-(4-Methylpiperazin-1-yl)[2-(phenylsulfanyl)cyclopropyl]methanone (15c)

HATU (228 mg, 0.60 mmol, 1.2 equiv) was added to a solution of (Z)-sodium 2-(phenylsulfanyl)cyclopropane-1-carboxylate 13 (108 mg, 0.50 mmol, 1.0 equiv) in \( N,N \)-dimethylformamide (2.5 mL) and stirred at 40 °C for 10 min. 1-Methylpiperazine (67 \( \mu \)L, 0.60 mmol, 1.2 equiv) was added and the solution stirred for 20 min. Diisopropylethylamine (0.27 mL, 1.50 mmol, 3.0 equiv) was added and the solution stirred for 24 h. Water (100 mL) was added and the mixture extracted with EtOAc (5 × 20 mL). The combined organic phases were washed with brine (30 mL), dried (MgSO\(_4\)), filtered and concentrated under reduced pressure. Purification by flash column chromatography (1:1 MeOH:CH\(_2\)Cl\(_2\)) gave amide 15c (125 mg, 90%) as a brown gum. \( R_t = 0.08 \) (1:1 MeOH:CH\(_2\)Cl\(_2\)). IR (film)/cm\(^{-1}\) 3004 (CH), 2937 (CH), 2793 (CH), 1635 (C=O), 1438, 1291, 1225, 1001, 739. \(^1\)H NMR (400 MHz, CDCl\(_3\)) \( \delta \) 7.38–7.36 (m, 2 H, 2 × Ph-H), 7.30–7.26 (m, 2 H, 2 × Ph-H), 7.19–7.15 (m, 1 H, Ph-H), 3.72–3.66 (m, 1 H, NC(H)(H)), 3.59–3.52 (m, 2 H, 2 × NC(H)(H)), 3.41–3.36 (m, 1 H, NCH(H)), 2.74 (ddd, \( J = 8.0, 8.0, 5.9 \) Hz, 1 H, H\(_c\)), 2.44–2.31 (m, 2 H, 2 × NCH(H)), 2.31–2.24 (m, 1 H, NCH(H)), 2.26 (s, 3 H, CH\(_3\)), 2.20 (ddd, \( J = 8.1, 8.1, 6.3 \) Hz, 1 H, H\(_b\)), 2.12 (ddd, \( J = 11.1, 7.6, 3.1 \) Hz, 1 H, NCH(H)), 1.59 (ddd, \( J = 5.8, 5.8, 5.8 \) Hz, 1 H, H\(_b\)), 1.41 (ddd, \( J = 8.2, 8.2, 5.3 \) Hz, 1 H, H\(_a\)). \(^1^3\)C NMR (101 MHz, CDCl\(_3\)) \( \delta \) 166.2 (C=O), 137.1 (Ph-C quat), 128.8 (2 × Ph-C), 128.4 (2 × Ph-C), 125.9 (Ph-C), 54.9 (NCH\(_2\)), 54.6 (NCH\(_2\)), 46.0 (CH\(_3\)), 45.3 (NCH\(_2\)), 41.9 (NCH\(_2\)), 21.6 (C(H\(_b\))), 20.9 (C(H\(_c\))), 12.9 (C(H\(_a\))(H\(_b\))). HRMS (ES) m/z Calcd for C\(_{15}\)H\(_{21}\)N\(_2\)OS\(^+\) [M+H\(^+\)]: 277.1375; Found: 277.1371.

(Z)-(3,4-Dihydroquinolin-1(2H)-yl)[2-(phenylsulfanyl)cyclopropyl]methanone (15d)

HATU (228 mg, 0.60 mmol, 1.2 equiv) was added to a solution of (Z)-sodium 2-(phenylsulfanyl)cyclopropane-1-carboxylate 13 (108 mg, 0.50 mmol, 1.0 equiv) in \( N,N \)-dimethylformamide (2.5 mL) and stirred at 40 °C for 10 min. 1,2,3,4-Tetrahydroquinoline (75 \( \mu \)L, 0.60 mmol, 1.2 equiv) was added and the solution stirred for 20 min. Diisopropylethylamine (0.27 mL, 1.50 mmol, 3.0 equiv) was added and the solution stirred for 24 h. Water (100 mL) was added and the mixture extracted with EtOAc (5 × 20 mL). The combined organic phases were washed with brine (30 mL), dried (MgSO\(_4\)), filtered and concentrated under reduced pressure. Purification by flash column chromatography (2:1 pentane:Et\(_2\)O) gave amide 15d (122 mg, 79%) as a yellow gum. \( R_t = 0.15 \) (2:1 pentane:Et\(_2\)O). IR (film)/cm\(^{-1}\) 3004 (CH), 2937 (CH), 2793 (CH), 1635 (C=O), 1438, 1291, 1225, 1001, 739. \(^1\)H NMR (400 MHz, CDCl\(_3\)) \( \delta \) 7.42–7.40 (m, 2 H, 2 × Ph-H), 7.29–7.26 (m, 2 H, 2 × Ph-H), 7.19–7.07 (m, 5 H, 5 × Ar-H), 4.14–4.12 (m 1 H, 1 × CH(H)), 3.57–3.54 (m, 1 H, CH(H)), 2.68–2.64 (m, 3 H, 2 × CH(H) + H\(_d\)), 2.42 (ddd, \( J = 8.0, 8.0, 6.3 \) Hz, 1 H, H\(_b\)), 2.05–1.98 (m, 1 H, CH(H)), 1.85–1.75 (m, 1 H, CH(H)), 1.70 (ddd, \( J = 6.2, 6.2, 5.3 \) Hz, 1 H, H\(_b\)), 1.44 (ddd, \( J = 8.0, 8.0, 5.1 \) Hz, 1 H, H\(_a\)). \(^1^3\)C NMR (101 MHz, CDCl\(_3\)) \( \delta \) 167.8 (C=O), 138.9 (Ar-C quat), 137.1...
Synthesis of 16c–17d through sulfide oxidation

(E)-[2-(Benzenesulfonyl)cyclopropyl](4-methylpiperazin-1-yl)methanone (16c)

mCPBA (24 mg, 0.14 mmol, 3.0 equiv) was added to a solution of amide 14c (12.6 mg, 0.046 mmol, 1.0 equiv) in CH₂Cl₂ (2.3 mL) and the solution stirred for 6 h at 25 °C. Solid Na₂S₂O₅ (26 mg, 3.0 equiv) was added and the mixture stirred for 30 min before being concentrated under reduced pressure. The mixture was redissolved in acetone containing 5% Et₃N, then filtered. The filtrate was concentrated under reduced pressure then purified by flash column chromatography (2:8 MeOH:CH₂Cl₂ + 2% Et₃N to 3:7 MeOH:CH₂Cl₂ + 2% Et₃N). The material was dissolved in CH₂Cl₂ and filtered to give sulfone 16c (14 mg, quant) as a cream gum. Rₑ = 0.13 (3:7 MeOH:CH₂Cl₂). IR (film)/cm⁻¹ 2958 (CH), 1640 (C=O), 1447, 1306 (S=O), 1150, 1088, 979, 745, 726, 692. ¹H NMR (400 MHz, CDCl₃, 58:42 rotameric mixture, asterisk denotes a rotameric signal) δ 7.92–9.90 (m, 2 H, 2 × Ph-H), 7.71–7.67 (m, 1 H, Ph-H), 7.61–7.58 (m, 2 H, 2 × Ph-H), 4.44 (t, J = 15.1 Hz, 1 H, NC(Ph(H))), 4.22–4.01 (m, 2 H, 2 × NC(Ph(H))H), 3.66–3.63 (m, 1 H, NC(H)H), 3.47–3.23 (m, 4 H, 4 × NC(H)H), 3.01 (ddd, J = 8.2, 5.6, 4.3 Hz, 1 H, H₆), 2.70 (ddd, J = 9.6, 6.0, 4.6 Hz, 1 H, H₅), 1.70–1.57 (m, 1 H, H₄), 1.25 (s, 3 H, CH₃), 0.90–0.83 (m, 1 H, H₃). ¹³C NMR (asterisk denotes minor rotamer, 101 MHz, CDCl₃) δ 166.9 (C=O), 139.5 (Ph-C quat), 134.0 (Ph-C), 129.5 (2 × Ph-C), 127.6 (2 × Ph-C), 65.3 (NCH₂), 65.1 (NCH₂) 60.2 (NCH₂), 40.4 (C(H₆)), 37.0 (NCH₂), 29.7 (CH₃), 18.1* (C(H₅)), 17.6 (C(H₄)), 13.4 (C(H₆)(H₇)), 13.1* (C(H₅)(H₆)). HRMS (ES) m/z Calcd for C₁₅H₂₁N₂O₃S⁺ [M+H]⁺: 309.1273; Found: 309.1278.

(Z)-[2-(Benzenesulfonyl)cyclopropyl](4-methylpiperazin-1-yl)methanone (17c)

mCPBA (28 mg, 0.16 mmol, 3.0 equiv) was added to a 25 °C solution of amide 15c (15 mg, 0.05 mmol, 1.0 equiv) in CH₂Cl₂ (2.7 mL) and the solution stirred for 6 h. Solid Na₂S₂O₅ (31 mg, 3.0 equiv) was added and the mixture stirred for 30 min before being concentrated under reduced pressure. The mixture was redissolved in acetone containing 5% Et₃N, then filtered. The filtrate was concentrated under reduced pressure then purified by flash column chromatography (3:7 MeOH:CH₂Cl₂ + 2% Et₃N). The material was dissolved in CH₂Cl₂, filtered and concentrated under reduced pressure to give sulfone 17c (17 mg, quant) as a golden gum. Rₑ = 0.29 (3:7 MeOH:CH₂Cl₂). IR (film)/cm⁻¹ 3032 (CH), 2947 (CH), 1643 (C=O), 1446, 1290 (S=O), 1147, 730, 690. ¹H NMR (400 MHz, CDCl₃) δ 7.90 (m, 2 H, 2 × Ph-H), 7.72–7.67 (m, 1 H, Ph-H), 7.62–7.58 (m, 2 H, 2 × Ph-H), 4.68–4.64 (m, 1 H, NC(H)H), 4.26–4.22 (m, 2 H, 2 × NC(H)H), 3.80–3.76 (m, 2 H, 2 × NC(H)H), 3.52–3.48 (m, 1 H, NC(H)H), 3.42 (ddd, J = 11.4, 2.2, 1.8 Hz, 1 H, NC(H)H), 3.37 (s, 3 H, CH₃), 3.35–3.23 (m, 1 H, NC(H)H), 2.83 (ddd, J = 8.6, 8.6, 6.6 Hz, 1 H, H₂), 2.34 (ddd, J = 8.6, 8.6, 5.9 Hz, 1 H, H₃). ¹³C NMR (101 MHz, CDCl₃) δ 164.1 (C=O), 139.8 (Ph-C quat), 134.0 (Ph-C), 129.5 (2 × Ph-C), 127.6 (2 × Ph-C), 64.5 (NCH₂), 64.3 (NCH₂), 59.6 (CH₃), 40.4 (NCH₂), 40.2 (C(H₆)), 36.6 (NCH₂), 23.8 (C(H₅)), 11.4 (C(H₆)(H₇)). HRMS (ES) m/z Calcd for C₁₅H₂₁N₂O₃S⁺ [M+H]⁺: 309.1273; Found: 309.1270.

(E)-[2-(Benzenesulfonyl)cyclopropyl](3,4-dihydroquinolin-1(2H)-yl)methanone (16d)

mCPBA (104 mg, 0.60 mmol, 3.0 equiv) was added to a 25 °C solution of amide 14d (62 mg, 0.20 mmol, 1.0 equiv) in CH₂Cl₂ (10 mL) and the solution stirred for 6 h. Water (30 mL) was added and the phases separated. The aqueous phase was extracted with Et₂O (5 × 30 mL). The combined organic phases were washed with brine, dried (MgSO₄), filtered and concentrated under reduced pressure. Purification by flash column chromatography (1:2 pentane:Et₂O) gave sulfone 16d (67 mg, 98%) as a cream oil. Rₑ = 0.29 (1:2 pentane:Et₂O). IR (film)/cm⁻¹ 3040 (CH), 2950 (CH), 1642 (C=O), 1581, 1492, 1402, 1306, 1148, 911, 727. ¹H NMR (400 MHz, CDCl₃) δ 7.85 (d, J = 7.6 Hz, 2 H, 2 × Ph-H), 7.67 (t, J =...
7.4 Hz, 1 H, Ph-H), 7.57 (t, J = 7.7 Hz, 2 H, 2 × Ph-H), 7.25–7.20 (m, 4 H, 4 × Ar-H), 3.80–3.71 (m, 2 H, 2 × NC(H)(H)), 3.14 (ddd, J = 8.8, 5.5, 5.5 Hz, 1 H, Hc), 2.93 (ddd, J = 9.6, 5.7, 4.4 Hz, 1 H, Hg), 2.76–2.63 (m, 2 H, 2 × ArC(H)(H)), 2.01–1.86 (m, 2 H, 2 × NCH₂C(H)(H)), 1.73 (ddd, J = 8.4, 5.8, 4.9 Hz, 1 H, Hb), 1.65–1.63 (m, 1 H, Hg). ¹³C NMR (101 MHz, CDCl₃) δ 168.2 (C=O), 140.1 (Ph-C quat + Ar-C quat), 137.9 (Ar-C quat), 133.7 (Ph-C), 129.4 (2 × Ph-C), 128.6 (Ar-C), 127.6 (2 × Ph-C), 126.7 (Ar-C), 126.0 (Ar-C), 124.8 (Ar-C), 43.3 (CH₂), 41.3 (C(Hg)), 26.7 (CH₃), 24.0 (CH₃), 20.1 (C(Hg)), 14.2 (C(Ha)(Hb)). HRMS (ES) m/z Calcd for C₁₉H₂₀NO₃⁺ [M+H]⁺: 342.1164; Found: 342.1174.

(E)-[2-(Benzenesulfonyl)cyclopropyl][3,4-dihydroquinolin-1(2H)-yl]methanone (17d)

mCPBA (78 mg, 0.45 mmol, 3.0 equiv) was added to a 25 °C solution of amide 15d (47 mg, 0.15 mmol, 1.0 equiv) in CH₂Cl₂ (7.5 mL) and the solution stirred for 6 h. Water (30 mL) was added and the phases separated. The aqueous phase was extracted with Et₂O (5 × 30 mL). The combined organic phases were washed with brine, dried (MgSO₄), filtered and concentrated under reduced pressure. Purification by flash column chromatography (Et₂O) gave the sulfone 17d (44 mg, 86%) as a cream colored gum. R₁ = 0.19 (Et₂O). IR (film)/cm⁻¹: 3030 (CH), 2934 (CH), 1655 (C=O), 1581, 1491, 1403, 1321 (S=O), 1291, 1150 (S=O), 1086, 727. ¹H NMR (400 MHz, CDCl₃) δ 8.00–7.98 (m, 2 H, 2 × Ph-H), 7.63 (t, J = 7.5 Hz, 1 H, Ph-H), 7.57 (t, J = 7.5 Hz, 2 H, 2 × Ph-H), 7.16–7.14 (m, 4 H, 4 × Ar-H), 4.34 (br s, 1 H, NC(H)(H)), 3.40 (br s, 1 H, NC(H)(H)), 2.80–2.70 (m, 3 H, H, + 2 × ArC(H)(H)), 2.41–2.39 (m, 1 H, Hb), 2.18–2.09 (m, 1 H, NCH₂C(H)(H)), 2.02 (br s, 1 H, Hb), 1.85 (br s, 1 H, NCH₂C(H)(H)), 1.39–1.34 (m, 1 H, Hb). ¹³C NMR (101 MHz, CDCl₃) δ 164.8 (C=O), 140.4 (Ph-C quat + Ar-C quat), 133.9 (Ar-C quat), 133.6 (Ph-C), 129.0 (2 × Ph-C), 128.4 (Ar-C), 128.1 (2 × Ph-C), 126.0 (Ar-C), 125.5 (Ar-C), 124.2 (Ar-C), 43.6 (CH₂), 42.6 (CH₂), 26.8 (CH₃), 25.6 (CH₃), 23.8 (CH₃), 13.3 (C(Ha)(Hb)). HRMS (ES) m/z Calcd for C₁₉H₂₀NO₃⁺ [M+H]⁺: 342.1164; Found: 342.1163.

Synthesis of 19a–20l through sulfoxide–magnesium exchange, electrophilic trapping

(E)-Ethyl-2-iodocyclopropanecarboxylate (19a)

i-PrMgCl (0.32 mL, 1.87 M in THF, 0.60 mmol, 1.5 equiv) was added to a −78 °C solution of (E)-ethyl-2-(phenylsulfonyl)cyclopropanecarboxylate 6 (95 mg, 0.40 mmol, 1.0 equiv) in THF (4.0 mL) over 10 s and the solution stirred for 10 min. A solution of I₂ (203 mg, 0.80 mmol, 2.0 equiv) in THF (0.5 mL) was added and the reaction stirred at −78 °C for 1 h. The reaction mixture was warmed to rt, sat. aq NH₄Cl (5 mL) added and the mixture was stirred for 5 min. Water (10 mL) was added and the mixture extracted with CH₂Cl₂ (3 × 30 mL). The combined organic phases were washed with brine, dried (MgSO₄), filtered and concentrated under reduced pressure. Purification by flash column chromatography (100% n-hexane to 10:1 n-hexane:Et₂O) gave cyclopropane 19a (79 mg, 82%) as a yellow oil. IR (film)/cm⁻¹: 2981 (CH), 1721 (C=O), 1396, 1376, 1174, 1033. ¹H NMR (400 MHz, CDCl₃) δ 4.15 (q, J = 7.1 Hz, 2 H, CH₂CH₃), 2.77 (ddd, J = 8.2, 5.6, 3.7 Hz, 1 H, Hb), 1.97 (ddd, J = 9.0, 5.5, 3.7 Hz, 1 H, Hb), 1.63 (ddd, J = 8.2, 5.6, 5.6 Hz, 1 H, Hb), 1.32–1.24 (m, 1 H, Hb), 1.27 (t, J = 7.1 Hz, 3 H, CH₃). ¹³C NMR (101 MHz, CDCl₃) δ 171.9 (C=O), 61.1 (CH₂CH₃), 24.6 (C(Hg)), 19.6 (C(Ha)(Hb)), 14.2 (CH₃), −17.1 (C(Hg)). HRMS (EI) m/z Calcd for C₇H₆O₂⁺ [M⁺]: 239.9647; Found: 239.9651.

(E)-Ethyl 2-[cyclopentyl[(hydroxyl)methyl]]cyclopropane-1-carboxylate (19b)

i-PrMgCl (0.32 mL, 1.87 M in THF, 0.60 mmol, 1.5 equiv) was added to a −78 °C solution of (E)-ethyl-2-(phenylsulfonyl)cyclopropanecarboxylate 6 (95 mg, 0.40 mmol, 1.0 equiv) in THF (4.0 mL) over 10 s and the solution stirred for 10 min. Cyclopentanecarbadoxaldehyde (85 µL, 0.80 mmol, 2.0 equiv) was added and the reaction stirred at 0 °C for 1 h. The reaction was warmed to rt, sat. aq NH₄Cl (5 mL) added and the mixture was stirred for 5 min. Water (10 mL) was added and the mixture extracted with CH₂Cl₂ (5 × 30 mL). The combined organic phases were washed with brine, dried (MgSO₄), filtered and concentrated under reduced pressure. Purification by flash column chromatography (2:1 pentane:Et₂O) gave cyclopropane 19b as a
mixture of two diastereoisomers (d.r = 56:44, 60 mg, 71%) as a colourless oil. Rf = 0.16 (2:1 pentane:EtO).

**Major diastereoisomer: 1H NMR (400 MHz, CDCl₃) δ 4.14–4.08 (m, 2 H, CH₂CH₃), 2.94 (dd, J = 7.3, 7.3 Hz, 1 H, CH(ØH)), 2.06–1.93 (m, 1 H, CH(CH₂)₂), 1.84–1.73 (m, 2 H, CHCH₂CH₃), 1.64–1.54 (m, 4 H, CH(CH₂)₂), 1.67–1.55 (m, 1 H, H₂a), 1.60–1.54 (m, 1 H, H₂c), 1.41–1.30 (m, 4 H, CH(CH₂)CH₂), 1.24 (t, J = 7.2 Hz, 3 H, CH₃), 1.25–1.17 (m, 1 H, H₂d), 0.92–0.87 (m, 1 H, H₂e). 13C NMR (101 MHz, CDCl₃) δ 174.2 (C=O), 77.2 (CH(ØH)), 60.5 (CH₂CH₃), 46.7 (CH₂CH₂), 28.9 (CH₂), 28.6 (CH₃), 28.0 (C(ØH)), 25.5 (CH₂), 25.2 (CH₂), 17.4 (C(H₃)), 14.2 (CH₃), 13.2 (C(H₆)(H₆)).**

**Minor diastereoisomer: 1H NMR (400 MHz, CDCl₃) δ 4.14–4.08 (m, 2 H, CH₂CH₃), 3.07 (dd, J = 7.1, 7.1 Hz, 1 H, CH(ØH)), 2.06–1.93 (m, 1 H, CH(CH₂)₂), 1.84–1.73 (m, 2 H, CHCH₂CH₃), 1.64–1.54 (m, 4 H, CH(CH₂)₂), 1.67–1.55 (m, 1 H, H₂a), 1.60–1.54 (m, 1 H, H₂c), 1.41–1.30 (m, 2 H, CHCH₂CH₂), 1.24 (t, J = 7.2 Hz, 3 H, CH₃), 1.14–1.08 (m, 1 H, H₂b), 0.96–0.92 (m, 1 H, H₂e). 13C NMR (101 MHz, CDCl₃) δ 174.0 (C=O), 76.4 (CH(ØH)), 60.5 (CH₂CH₃), 46.9 (CH₂CH₂), 28.9 (CH₂), 28.8 (CH₂), 27.2 (C(ØH)), 25.5 (CH₂), 25.2 (CH₂), 18.3 (C(H₃)), 14.2 (CH₃), 11.4 (C(H₆)(H₆)).**

HRMS (ES) m/z Calcld for C₁₂H₁₉O₂⁺ [M–OH]⁺: 195.1385; Found: 195.1386.

(E)-Ethyl 2-(hydroxy[pyridine-3-yl]methyl)cyclopropane-1-carboxylate (19c)

![Structure of (E)-Ethyl 2-(hydroxy[pyridine-3-yl]methyl)cyclopropane-1-carboxylate (19c)](image)

-PrMgCl (0.32 mL, 1.87 M in THF, 0.60 mmol, 1.5 equiv) was added to a −78 °C solution of (E)-ethyl 2-(phenylsulfanyl)cyclopropane carboxylate 6 (95 mg, 0.40 mmol, 1.0 equiv) in THF (4.0 mL) over 10 s and the solution stirred for 10 min. Benzaldehyde (81 µL, 0.80 mmol, 2.0 equiv) was added and the reaction stirred at 0 °C for 1 h. The reaction was warmed to rt, sat. aq NH₄Cl (5 mL) added and the mixture stirred for 5 min. H₂O (10 mL) was added and the mixture extracted with CH₂Cl₂ (3 × 30 mL). The combined organic phases were washed with brine, dried (MgSO₄), filtered and concentrated under reduced pressure. Purification by flash column chromatography (10:1 n-hexane:EtO) gave cyclopropane 19c as a mixture of two diastereomers (d.r = 61:39, 83 mg, 94%) as a colourless oil. Rf = 0.16 (2:1 n-hexane:EtO). IR (film)/cm⁻¹: 3458 (OH), 2982 (CH), 1722 (C=O), 1703 (C=O), 1180.

**Major diastereoisomer: 1H NMR (400 MHz, CDCl₃) δ 7.40–7.28 (m, 5 H, 5 × Ph-H), 4.21 (d, J = 7.3 Hz, 1 H, CH(ØH)), 4.16–4.02 (m, 2 H, CH₂CH₃), 2.56 (br s, 1 H, OH), 1.86–1.78 (m, 1 H, H₂a), 1.81 (ddd, J = 8.4, 4.3 Hz, 1 H, H₂c), 1.25 (t, J = 7.1 Hz, 3 H, CH₃), 1.24–1.18 (m, 1 H, H₂b), 0.97 (ddd, J = 8.5, 6.4, 4.5 Hz, 1H, H₂e).**

**Minor diastereoisomer: 1H NMR (400 MHz, CDCl₃) δ 7.40–7.28 (m, 5 H, 5 × Ph-H), 4.47 (d, J = 6.0 Hz, 1 H, CH(ØH)), 4.16–4.02 (m, 2 H, CH₂CH₃), 2.45 (br s, 1 H, OH), 1.89–1.78 (m, 1 H, H₂a), 1.71 (ddd, J = 8.9, 4.6, 4.6 Hz, 1 H, H₂c), 1.24–1.18 (m, 1 H, H₂b), 1.22 (t, J = 7.1 Hz, 3 H, CH₃), 1.10 (ddd, J = 8.6, 6.4, 4.2 Hz, 1 H, H₂e).**

13C NMR (101 MHz, CDCl₃) δ 173.7 (C=O), 142.8 (Ph-C quat), 128.5 (2 × Ph-C), 127.83 (Ph-C), 126.00 (2 × Ph-C), 75.6 (CH(ØH)), 60.6 (CH₂CH₃), 29.2 (C(H₃)), 18.8 (C(H₆)), 14.1 (CH₃), 12.5 (C(H₆)(H₆)).

HRMS (ES) m/z Calcld for C₁₅H₂₁NO₃⁺ [M+H+CH₃CN adduct]: 262.1443; Found: 262.1447. The observed data (IR, 1H, 13C) was consistent with that previously reported.[10]

(E)-Ethyl 2-[hydroxy(pyridine-3-yl)methyl]cyclopropane-1-carboxylate (19d)

![Structure of (E)-Ethyl 2-[hydroxy(pyridine-3-yl)methyl]cyclopropane-1-carboxylate (19d)](image)

i-PrMgCl (0.32 mL, 1.87 M in THF, 0.60 mmol, 1.5 equiv) was added to a −78 °C solution of (E)-ethyl 2-(phenylsulfanyl)cyclopropane carboxylate 6 (95 mg, 0.40 mmol, 1.0 equiv) in THF (4.0 mL) over 10 s and the solution stirred for 10 min. 3-Pyridinecarboxaldehyde (75 µL, 0.80 mmol, 2.0 equiv) was added and the reaction stirred at 0 °C for 1 h. The reaction was warmed to rt, sat. aq NH₄Cl (5 mL) added and the mixture stirred for 5 min. H₂O (10 mL) was added and the mixture extracted with CH₂Cl₂ (6 × 20 mL) then EtOAc (6 × 20 mL). The combined organic phases were concentrated under reduced pressure, dissolved in CH₂Cl₂, washed with brine, dried (MgSO₄), filtered and concentrated under reduced pressure. Purification by flash column chromatography (4:1 EtOAc:toluene) gave cyclopropane 19d as a mixture of two diastereomers (d.r = 52:48, 80 mg, 90%) as a white oil. Rf = 0.26 (4:1 EtOAc:toluene). IR (film)/cm⁻¹: 3169 (OH), 2982 (CH), 1719 (C=O), 1177, 1028, 713.
Major diastereoisomer: $^1$H NMR (400 MHz, CDCl$_3$) δ 8.47 (br s, 1 H, H$_e$), 8.40–8.38 (m, 1 H, H$_h$), 7.79–7.73 (m, 1 H, H$_i$), 7.28–7.24 (m, 1 H, H$_g$), 4.73 (br s, 1 H, OH), 4.26 (d, J = 7.2 Hz, 1 H, CH(OH)), 4.13–4.00 (m, 2 H, CH$_2$CH$_3$), 1.85–1.76 (m, 1 H, H$_d$), 1.83–1.74 (m, 1 H, H$_b$), 1.23–1.18 (m, 1 H, H$_a$). 1.21 (t, J = 7.1 Hz, 3 H, CH$_3$), 0.99 (ddd, J = 8.4, 6.4, 4.5 Hz, 1 H, H$_b$). $^{13}$C NMR (101 MHz, CDCl$_3$) δ 173.5 (C=O), 148.5 (Ar-C), 147.3 (Ar-C), 139.1 (Ar-Cquat), 134.0 (Ar-C), 123.6 (Ar-C), 72.7 (CH(OH)), 60.6 (CH$_2$CH$_3$), 29.0 (CH$_2$), 18.7 (C(H$_d$)), 14.1 (CH$_3$), 12.5 (C(H$_a$)(H$_b$)).

Minor diastereoisomer: $^1$H NMR (400 MHz, CDCl$_3$) δ 8.47 (br s, 1 H, H$_e$), 8.40–8.38 (m, 1 H, H$_h$), 7.79–7.73 (m, 1 H, H$_i$), 7.28–7.24 (m, 1 H, H$_g$), 4.73 (br s, 1 H, OH), 4.50 (d, J = 5.7 Hz, 1 H, CH(OH)), 4.13–4.00 (m, 2 H, CH$_2$CH$_3$), 1.81–1.71 (m, 1 H, H$_d$), 1.78–1.71 (m, 1 H, H$_b$), 1.23–1.18 (m, 1 H, H$_a$), 1.20 (t, J = 7.1 Hz, 3 H, CH$_3$), 1.14 (ddd, J = 8.5, 6.5, 4.3 Hz, 1 H, H$_b$). $^{13}$C NMR (101 MHz, CDCl$_3$) δ 173.6 (C=O), 148.5 (Ar-C), 147.4 (Ar-C), 139.2 (Ar-Cquat), 134.1 (Ar-C), 123.6 (Ar-C), 71.1 (CH(OH)), 60.6 (CH$_2$CH$_3$), 28.3 (C(H$_d$)), 17.7 (C(H$_e$)), 14.1 (CH$_3$), 12.1 (C(H$_a$)(H$_b$)).

HRMS (ES) m/z Calcd for C$_{12}$H$_{16}$NO$_3$ [M+H]+: 222.1130; Found: 222.1131.

(E)-Ethyl 2-(3-hydroxyoxetan-3-yl)cyclopropane-1-carboxylate (19e)

$^1$H NMR (400 MHz, CDCl$_3$) δ 4.58 (d, J = 6.8 Hz, 1 H, oxetane C(H)$_H$), 4.54 (d, J = 6.9 Hz, 1 H, oxetane C(H)$_H$), 4.49 (d, J = 6.8 Hz, 1 H, oxetane C(H)$_H$), 4.47 (d, J = 6.9 Hz, 1 H, oxetane C(H)$_H$), 4.46 (d, J = 6.9 Hz, 1 H, oxetane C(H)$_H$), 4.19–4.07 (m, 2 H, CH$_2$CH$_3$), 3.29 (br s, 1 H, OH), 1.94 (ddd, J = 9.2, 6.5, 4.4 Hz, 1 H, H$_d$), 1.72 (ddd, J = 8.6, 4.9, 4.4 Hz, 1 H, H$_b$), 1.26 (t, J = 7.1 Hz, 3 H, CH$_3$), 1.25–1.18 (m, 1 H, H$_a$), 1.10 (ddd, J = 8.6, 6.5, 4.6 Hz, 1 H, H$_h$). $^{13}$C NMR (101 MHz, CDCl$_3$) δ 173.8 (C=O), 83.3 (oxetane-CH$_2$), 82.5 (oxetane-CH$_2$), 72.8 (oxetane-Cquat), 60.8 (CH$_2$CH$_3$), 27.2 (C(H$_d$)), 16.4 (C(H$_h$)), 14.1 (CH$_3$), 10.8 (C(H$_a$)(H$_b$)). HRMS (Cl+) m/z Calcd for C$_{12}$H$_{16}$NO$_3$ [M+H]+: 204.1236; Found: 204.1226.

(E)-Ethyl-2-[bis(4-chlorophenyl)(hydroxy)methyl]cyclopropane-1-carboxylate (19f)

$^1$H NMR (400 MHz, CDCl$_3$) δ 7.39–7.28 (m, 8 H, 8 × Ar-H), 4.13 (q, J = 7.2 Hz, 2 H, CH$_2$CH$_3$), 2.18 (ddd, J = 9.0, 6.7, 4.5 Hz, 1 H, H$_b$), 1.95 (br s, 1 H, OH), 1.79 (ddd, J = 8.7, 4.8, 4.8 Hz, 1 H, H$_a$), 1.30–1.23 (m, 4 H, H$_h$ + CH$_3$), 1.13 (ddd, J = 8.6, 6.7, 4.3 Hz, 1 H, H$_b$). $^{13}$C NMR (101 MHz, CDCl$_3$) δ 173.8 (C=O), 144.7 (Ar-C-Cl), 144.4 (Ar-C-Cl), 133.5 (2 × Ar-C quat), 128.5 (2 × Ar-C), 128.4 (2 × Ar-C), 128.0 (2 × Ar-C), 127.9 (2 × Ar-C), 75.6 (C(OH)), 60.8 (CH$_2$CH$_3$), 31.5 (C(H$_d$)), 17.5 (C(H$_h$)), 14.2 (CH$_3$), 11.9 (C(H$_a$)(H$_b$)). FTMS (+ p NSI) m/z Calcd for C$_{19}$H$_{14}$O$_3$Cl$_2$Na$^+$ [M+Na]$^+$: 387.0525; Found: 387.0526.
(E)-Ethyl 2-[hydroxydi(pyridin-2-yl)methyl]cyclopropane-1-carboxylate (19g)

i-PrMgCl (0.32 mL, 1.85 M in THF, 0.60 mmol, 1.5 equiv) was added to a –78 °C solution of (E)-ethyl 2-(phenylsulfinyl)cyclopropanecarboxylate 6 (95 mg, 0.40 mmol, 1.0 equiv) in THF (4.0 mL) over 10 s and the solution stirred for 10 min. A solution of di(2-pyridyl)ketone (147 mg, 0.80 mmol, 2.0 equiv) in toluene (1.0 mL) was added and the reaction stirred at 0 °C for 3 h. The reaction was warmed to rt, sat. aq. NH₄Cl (5 mL) added and the mixture stirred for 5 min. Water (10 mL) was added and the mixture extracted with EtOAc (3 × 30 mL). The combined organic phases were washed with brine, dried (MgSO₄), filtered and concentrated under reduced pressure. Purification by flash column chromatography (1:1 pentane:EtO) gave cyclopropane 19g (107 mg, 90%) as a colourless oil. Rf = 0.23 (1:1 pentane:EtO). IR (film)/cm⁻¹ 3319 (OH), 3057 (CH), 2982 (CH), 1718 (C=O), 1587, 1571, 1433, 1177, 749. ¹H NMR (400 MHz, CDCl₃) δ 8.52–8.49 (m, 2 H, 2 × Ar-H), 7.85–7.82 (m, 2 H, 2 × Ar-H), 7.69–7.64 (m, 2 H, 2 × Ar-H), 7.18–7.14 (m, 2 H, 2 × Ar-H), 6.28 (br s, 1 H, OH), 4.11–4.00 (m, 2 H, CH₂CH₃), 2.85 (ddd, J = 9.0, 6.5, 4.4 Hz, 1 H, H3), 1.83–1.79 (m, 1 H, H2), 1.22–1.16 (m, 4 H, H₆ + CH₃), 1.10 (ddd, J = 8.8, 4.8, 3.9 Hz, 1 H, Hb). ¹³C NMR (101 MHz, CDCl₃) δ 174.2 (C=O), 163.0 (Ar-C quat), 162.9 (Ar-C quat), 147.53 (Ar-C), 147.47 (Ar-C), 136.8 (2 × Ar-C), 122.2 (2 × Ar-C), 120.9 (2 × Ar-C), 74.8 (C(OH)), 60.2 (CH₂CH₃), 31.3 (C(H₃)), 16.6 (C(H₃)), 14.2 (CH₃), 11.2 (C(H₆)(H₇)). HRMS (ESI) m/z Calcd for C₁₇H₁₈N₂O₃⁺ [M⁺]: 298.1317; Found: 298.1315.

(E)-Ethyl 2-benzoyleycyclopropane-1-carboxylate (19h)

i-PrMgCl (0.32 mL, 1.85 M in THF, 0.60 mmol, 1.5 equiv) was added to a –78 °C solution of (E)-ethyl 2-(phenylsulfinyl)cyclopropanecarboxylate 6 (95 mg, 0.40 mmol, 1.0 equiv) in THF (4.0 mL) over 10 s and the solution stirred for 10 min. Benzoyl chloride (119 µL, 0.80 mmol, 2.0 equiv) was added and the reaction stirred at 0 °C for 3 h. The reaction was warmed to rt, sat. aq NH₄Cl (5 mL) added and the mixture extracted with EtOAc (5 × 30 mL). The combined organic phases were washed with brine, dried (MgSO₄), filtered and concentrated under reduced pressure. Purification by flash chromatography (9:1–2:1 n-hexane:EtOAc) gave cyclopropane 19h (44 mg, 38%) as a colourless oil. Rf = 0.22 (9:1 n-hexane:EtOAc). IR (film)/cm⁻¹ 3063 (CH), 2982 (CH), 1724 (C=O), 1672, 1332, 1207, 1004. ¹H NMR (400 MHz, CDCl₃) δ 8.40–8.02 (m, 2 H, 2 × Ph-H), 7.62–7.58 (m, 1 H, Ph-H), 7.50 (t, J = 7.6 Hz, 2 H, 2 × Ph-H), 4.19 (q, J = 7.2 Hz, 2 H, CH₂CH₃), 3.20 (ddd, J = 8.7, 5.8, 3.9 Hz, 1 H, H2), 2.39 (ddd, J = 8.7, 5.9, 3.9 Hz, 1 H, H3), 1.66–1.58 (m, 2 H, H₆ + H₇), 1.30 (t, J = 7.1 Hz, 3 H, CH₃). ¹³C NMR (101 MHz, CDCl₃) δ 197.0 (C=O ketone), 172.3 (C=O ester), 137.0 (Ph-C quat), 133.3 (Ph-C), 128.6 (2 × Ph-C), 128.2 (2 × Ph-C), 61.1 (CH₂CH₃), 25.9 (C(H₃)), 24.7 (C(H₄)), 17.9 (C(H₆)(H₇)), 14.2 (CH₃). FTMS (+p APCl) m/z Calcd for C₁₅H₁₉O₃⁺ [M+H⁺]: 219.1016; Found: 219.1016. The observed data (¹H) was consistent with that previously reported.¹”

(E)-Ethyl 2-(phenylcarbamoyl)cyclopropane-1-carboxylate (19i)

i-PrMgCl (0.32 mL, 1.85 M in THF, 0.60 mmol, 1.5 equiv) was added to a –78 °C solution of (E)-ethyl 2-(phenylsulfinyl)cyclopropanecarboxylate 6 (95 mg, 0.40 mmol, 1.0 equiv) in THF (4.0 mL) over 10 s and the solution stirred for 10 min. Phenyl isocyanate (87 µL, 0.80 mmol, 2.0 equiv) was added and the reaction stirred at 0 °C for 6 h. The reaction was warmed to rt, sat. aq. NH₄Cl (5 mL) added and the mixture stirred for 5 min. Water (20 mL) was added and the mixture extracted with Et₂O (5 × 30 mL). The combined organic phases were washed with brine, dried (MgSO₄), filtered and concentrated under reduced pressure. Purification by flash column chromatography (1:1 pentane:EtO) gave cyclopropane 19i (70 mg, 75%) as a white solid. Rf = 0.31 (1:1 pentane:EtO). mp = 90–91°C. IR (film)/cm⁻¹ 3282 (NH), 2977 (CH), 2934 (CH), 1722 (C=O), 1652, 1440, 1365, 1338, 1257, 1206, 1185, 1172, 988, 939, 750, 693. ¹H NMR (400 MHz, CDCl₃) δ 7.97 (br s, 1 H, NH), 7.53–7.51 (m, 2 H, 2 × Ph-H), 7.33–7.30 (m, 2 H, 2 × Ph-H), 7.13–7.09 (t, J = 7.4 Hz, 1 H, Ph-H), 4.19 (q, J = 7.1 Hz, 2 H, CH₂CH₃), 2.28 (ddd, J = 9.1, 5.7, 3.7 Hz, 1 H, H₁), 2.12 (ddd, J = 9.0, 5.8, 3.9 Hz, 1 H, H₂), 1.58 (ddd, J = 9.0, 5.8, 3.8 Hz, 1 H, H₃), 1.43 (ddd, J = 8.9, 5.7, 3.9 Hz, 1 H, H₄), 1.30 (t, J = 7.1 Hz, 3 H, CH₃). ¹³C NMR (101 MHz, CDCl₃) δ 173.0 (C=O ester), 168.4 (C=O amide), 137.8 (Ph-C quat), 129.0 (2 × Ph-C), 124.3 (Ph-C), 119.7 (2 × Ph-C), 61.3 (CH₂CH₃), 25.1
(C(H$_{3}$)), 22.0 (C(H$_{2}$)), 15.3 (C(H$_{a}$)(H$_{b}$)), 14.2 (C$_{3}$H$_{3}$). HRMS (ES) m/z Calcd for C$_{13}$H$_{16}$NO$_{_3}$: [M+H]$^+$: 234.1130; Found: 234.1137.

(E)-Ethyl 2-[(4-methoxyphenyl)sulfonyl]cyclopropane-1-carboxylate (19j)

i-PrMgCl (0.32 mL, 1.85 M in THF, 0.60 mmol, 1.5 equiv) was added to a −78 °C solution of (E)-ethyl 2-(phenylsulfonyl)cyclopropanecarboxylate 6 (95 mg, 0.40 mmol, 1.0 equiv) in THF (4.0 mL) over 10 s and the solution stirred for 10 min. A solution of bis(4-methoxyphenyl)disulfide (223 mg, 0.80 mmol, 2.0 equiv) in THF (0.5 mL) was added and the reaction stirred at 0 °C for 6 h. The reaction was warmed to rt, sat. aq. NH$_4$Cl (5 mL) added and the mixture stirred for 5 min. Water (20 mL) was added and the mixture extracted with EtOAc (5 × 30 mL). The combined organic phases were washed with brine, dried (MgSO$_4$), filtered and concentrated under reduced pressure. Purification by flash column chromatography (15:1 pentane:Et$_2$O) gave cyclopropane 19j (55 mg, 55%) as a yellow oil. R$_f$ = 0.24 (9:1 pentane:Et$_2$O). IR (film)/cm$^{-1}$ 2981 (CH), 2961 (CH), 2836 (CH), 1721 (C=O), 1494, 1242, 1173, 1030, 821. $^1$H NMR (400 MHz, CDCl$_3$) δ 7.34–7.31 (m, 2 H, 2 × Ar-H), 6.89–6.85 (m, 2 H, 2 × Ar-H), 4.20–4.09 (m, 2 H, CH$_2$CH$_3$), 3.81 (s, 3 H, OCH$_3$), 2.74 (ddd, J = 8.3, 5.7, 3.6 Hz, 1 H, H$_{c}$), 1.90 (ddd, J = 8.8, 5.3, 3.5 Hz, 1 H, H$_{d}$), 1.57 (ddd J = 8.3, 5.1, 5.1 Hz, 1H, H$_{b}$), 1.27 (t, J = 7.2 Hz, 3H, CH$_3$), 1.21 (ddd, J = 8.8, 5.6, 4.9 Hz, 1 H, H$_{a}$). $^{13}$C NMR (101 MHz, CDCl$_3$) δ 172.3 (C=O), 158.8 (Ar-C-OCH$_3$), 131.2 (2 × Ar-C), 126.5 (Ar-C quat), 114.7 (2 × Ar-C), 60.8 (CH$_2$CH$_3$), 55.3 (OCH$_3$), 24.5 (C(H$_{d}$)), 24.2 (C(H$_{c}$)), 17.2 (C(H$_{a}$)(H$_{b}$)), 14.2 (CH$_2$CH$_3$). FTMS (+p APCLI) m/z Calcd for C$_{18}$H$_{17}$O$_3$S$^+$ [M+H]$^+$: 253.0893; Found: 253.0891.

(E)-Ethyl 2-formylcyclopropane-1-carboxylate (19k)

i-PrMgCl (0.32 mL, 1.85 M in THF, 0.60 mmol, 1.5 equiv) was added to a −78 °C solution of (E)-ethyl 2-(phenylsulfonyl)cyclopropanecarboxylate 6 (95 mg, 0.40 mmol, 1.0 equiv) in THF (4.0 mL) over 10 s and the solution stirred for 10 min. N,N-Dimethylformamide (62 µL, 0.80 mmol, 2.0 equiv) was added and the reaction stirred at 0 °C for 6 h. The reaction was warmed to rt, sat. aq. NH$_4$Cl (5 mL) added and the mixture stirred for 5 min. H$_2$O (20 mL) was added and the mixture extracted with ether (5 × 30 mL). The combined organic phases were washed with brine, with the aqueous being extracted with Et$_2$O (30 mL). The combined organic phases were dried (MgSO$_4$), filtered and concentrated under reduced pressure. Purification by flash column chromatography (5:1 pentane:Et$_2$O) gave cyclopropane 19k (48 mg, 85%) as a colourless oil. R$_f$ = 0.17 (5:1 pentane:Et$_2$O). IR (film)/cm$^{-1}$ 2984 (CH), 2849 (CH), 2738 (CH), 1182, 980. $^1$H NMR (400 MHz, CDCl$_3$) δ 9.31 (d, J = 4.2 Hz, 1 H, CO(OH)), 4.18 (q, J = 7.1 Hz, 2 H, CH$_2$CH$_3$), 2.44 (ddd, J = 8.5, 5.8, 4.2, 4.0 Hz, 1H, H$_d$), 2.26 (ddd, J = 8.9, 6.0, 3.9 Hz, 1 H, H$_c$), 1.61 (ddd, J = 8.5, 5.9, 4.3 Hz, 1 H, H$_b$), 1.51 (ddd, J = 8.9, 5.7, 4.4 Hz, 1 H, H$_a$), 1.28 (t, J = 7.2 Hz, 3H, CH$_3$). $^{13}$C NMR (101 MHz, CDCl$_3$) δ 198.1 (C=O aldehyde), 171.0 (C=O ester), 61.3 (CH$_2$CH$_3$), 30.6 (C(H$_{a}$)), 22.2 (C(H$_{b}$)), 14.8 (C(H$_{c}$)(H$_{d}$)), 14.1 (C$_3$H$_3$). The observed data ($^1$H, $^{13}$C) was consistent with that previously reported.$^{[12,13]}$

(E)-Ethyl 2-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)cyclopropane-1-carboxylate (19l)

i-PrMgCl (0.32 mL, 1.85 M in THF, 0.60 mmol, 1.5 equiv) was added to a −78 °C solution of (E)-ethyl 2-(phenylsulfonyl)cyclopropanecarboxylate 6 (95 mg, 0.40 mmol, 1.0 equiv) in THF (4.0 mL) over 10 s and the solution stirred for 10 min. 2-Isopropoxy-4,4,5,5-tetramethyl-1,3,2-dioxaborolan (163 µL, 0.80 mmol, 2.0 equiv) was added and the reaction stirred at 0 °C for 6 h. The reaction was warmed to rt, MeOH (1 mL) added and stirred for 5 min. Et$_2$O (10 mL) was added and the mixture filtered, then concentrated under reduced pressure. Purification by flash column chromatography (4:1 pentane:Et$_2$O) gave cyclopropane 19l (52 mg, 54%) as a colourless oil. IR (film)/cm$^{-1}$ 2980 (CH), 2932 (CH), 1727 (C=O), 1424, 1370, 1325, 1177, 1141, 855. $^1$H NMR (400 MHz, CDCl$_3$) δ 4.17–4.05 (m, 2 H, CH$_2$CH$_3$), 1.75 (ddd, J = 7.7, 4.9, 4.9 Hz, 1 H, H$_{d}$), 1.26–1.19 (m, 16 H, H$_d$ + 5 × CH$_3$), 0.98 (ddd, J = 7.6, 7.6, 3.0 Hz, 1 H, H$_b$), 0.57 (ddd, J = 10.1, 7.3, 5.3 Hz, 1 H, H$_a$). $^{13}$C NMR (101 MHz, CDCl$_3$) δ 174.2 (C=O), 83.4 (2 × C(CH$_3$)$_2$), 60.5 (CH$_2$CH$_3$), 29.7 (C(H$_a$)), 24.7 (2 × CH$_3$), 24.6 (2 × CH$_3$), 18.5 (C(H$_c$)), 14.2 (CH$_2$CH$_3$), 13.0 (C(H$_b$)(H$_a$)). $^1$B NMR (128 MHz, CDCl$_3$) δ 32.58 (B(pin)). HRMS (EI) m/z Calcd for C$_{19}$H$_{21}$BO$_4^-$ [M]$: 240.1533; Found: 240.1528.
(E)-Ethyl 2-(triethoxysilyl)cyclopropane-1-carboxylate (19m)

\[ \text{CH}_3\text{CH}_{2}\text{OH} + \text{Si(OC}2\text{H}_3)_2\text{Cl} \rightarrow \text{CH}_3\text{CH}_2\text{Si(OC}2\text{H}_3)_2\text{Cl} \]

Purification by flash column chromatography (4:1 pentane:EtO) gave cyclopropane 19m (55 mg, 43%) as a pale yellow oil. IR (film)/cm\(^{-1}\): 2976 (CH), 2934 (CH), 1722 (C=O), 1389, 1264, 1166, 1100, 1073, 953, 776.

(Z)-Ethyl-2-iodocyclopropanecarboxylate (20a)

\[ \text{CH}_3\text{CH}_2\text{OH} + \text{Cl}_2\text{Si(OC}2\text{H}_3)_2\text{H} \rightarrow \text{CH}_3\text{CH}_2\text{Si(OC}2\text{H}_3)_2\text{Cl} \]

Purification by flash column chromatography (100% n-hexane to 10:1 n-hexane:EtO) gave cyclopropane 20a (56 mg, 58%) as a yellow oil. IR (film)/cm\(^{-1}\): 2981 (CH), 2934 (CH), 1726 (C=O), 1396, 1380, 1248, 1175.

(Z)-4-Cyclopentyl-3-oxabicyclo[3.1.0]hexan-2-one (20b)

\[ \text{CH}_3\text{CH}_2\text{OH} + \text{Cl}_2\text{Si(OC}2\text{H}_3)_2\text{H} \rightarrow \text{CH}_3\text{CH}_2\text{Si(OC}2\text{H}_3)_2\text{Cl} \]

Purification by flash column chromatography (2:1 pentane:EtO) gave cyclopropane 20b as a mixture of two diastereoisomers (d.r = 60:40, 57 mg, 86%) as a yellow oil. R\(_f\) = 0.24 (2:1 pentane:EtO). IR (film)/cm\(^{-1}\): 2953 (CH), 2869 (CH), 1760 (C=O), 1345, 1302, 1280, 1230, 1183, 959.

Major diastereisomer: \(^1^H\) NMR (400 MHz, CDCl\(_3\)) \(\delta\) 4.18 (d, \(J = 7.5\) Hz, 1 H, CH(CH\(_2\))\(_2\)), 2.12–2.03 (m, 1 H, CH(CH\(_2\))\(_2\)), 2.06–2.03 (m, 2 H, H\(_a\) + H\(_b\)), 1.88–1.76 (m, 2 H, CH\(_2\)), 1.69–1.53 (m, 4 H, 2 × CH\(_2\)), 1.45–1.35 (m, 2 H, CH\(_2\)), 1.28–1.19 (m, 1 H, H\(_a\)), 0.84 (dd, \(J = 4.7, 4.0\) Hz, 1 H, H\(_b\)). \(^1^C\) NMR (101 MHz, CDCl\(_3\)) \(\delta\) 176.2 (C=O), 84.7 (CH(CH\(_2\))\(_2\)), 45.0 (CH(CH\(_2\))\(_2\)), 28.0 (CH\(_2\)), 27.7 (CH\(_2\)), 25.5 (CH\(_2\)), 25.3 (CH\(_2\)), 21.5 (C(H\(_3\))), 17.8 (C(H\(_3\))), 12.2 (C(H\(_6\))(H\(_7\))).

Minor diastereisomer: \(^1^H\) NMR (400 MHz, CDCl\(_3\)) \(\delta\) 4.28 (dd, \(J = 9.6, 4.4\) Hz, 1 H, CH(CH\(_2\))\(_2\)), 2.21–2.16 (m, 1 H, H\(_a\)), 2.06–2.03 (m, 1 H, H\(_a\)), 1.97–1.88 (m, 1 H, CH(CH\(_2\))\(_2\)), 1.88–1.76 (m, 2 H, CH\(_2\)), 1.69–1.53 (m, 4 H, 2 × CH\(_2\)), 1.45–1.35 (m, 2 H, CH\(_2\)), 1.11–1.06 (m, 1 H, H\(_a\)), 0.96 (ddd, \(J = 4.7, 4.7, 3.2\) Hz, 1 H, H\(_b\)). \(^1^C\) NMR (101 MHz, CDCl\(_3\)) \(\delta\) 176.3 (C=O), 84.1 (CH(CH\(_2\))\(_2\)), 42.2 (CH(CH\(_2\))\(_2\)), 30.5 (CH\(_2\)), 28.1 (CH\(_2\)), 25.4 (CH\(_2\)), 25.1 (CH\(_2\)), 20.8 (C(H\(_6\))), 18.5 (C(H\(_3\))), 8.8 (C(H\(_6\))(H\(_7\)))).
FTMS (APCI) m/z Calcd for C_{10}H_{16}O_{2}^{+} [M+H]^{+}: 167.1067; Found: 167.1068.

(Z)-4-Phenyl-3-oxabicyclo[3.1.0]hexan-2-one (20c)

\[
\text{i-PrMgCl (0.32 mL, 1.87 M in THF, 0.60 mmol, 1.5 equiv) was added to a −78 °C solution of (Z)-ethyl 2-(phenylsulfinyl)cyclopropanecarboxylate 7 (95 mg, 0.40 mmol, 1.0 equiv) in THF (4.0 mL) over 10 s and the solution stirred for 10 min. Benzaldehyde (81 μL, 0.80 mmol, 2.0 equiv) was added and the reaction stirred at 0 °C for 1 h. The reaction was warmed to rt, sat. aq. NH₄Cl (5 mL) added and the mixture was stirred for 5 min. H₂O (10 mL) was added and the mixture extracted with CH₂Cl₂ (3 × 30 mL). The combined organic phases were washed with brine, dried (MgSO₄), filtered, and concentrated under reduced pressure. Purification by flash column chromatography (10:1 n-hexane:Et₂O) gave cyclopropane 20c as a mixture of two diastereoisomers (d.r. = 56:44, 48 mg, 69%) as a white solid. R_f = 0.59 (1:1 pentane:EtOAc). mp = 33–34 °C. IR (film)/cm⁻¹ 3034 (CH), 3008 (CH), 2930 (CH), 1762 (C=O), 1454, 1312, 1180, 969.

Major diastereoisomer: ¹H NMR (400 MHz, CDCl₃) δ 7.44–7.32 (m, 5 H, 5 × Ph-H), 5.34 (s, 1 H, CH(CHO)), 2.31–2.24 (m, 1 H, H_d), 2.29–2.21 (m, 1 H, H_c), 1.37 (ddd, J = 8.9, 7.6, 4.9 Hz, 1 H, H_a), 1.10 (ddd, J = 4.7, 4.7, 3.5 Hz, 1 H, H_b). ¹³C NMR (101 MHz, CDCl₃) δ 175.9 (C=O), 139.7 (Ph-C quat), 128.9 (2 × Ph-C), 128.8 (Ph-C), 125.5 (2 × Ph-C), 81.6 (CH(CHO)), 24.7 (CH(H)), 17.8 (CH(H)), 12.9 (CH₃(H)).

Minor diastereoisomer: ¹H NMR (400 MHz, CDCl₃) δ 7.44–7.32 (m, 5 H, 5 × Ph-H), 5.75 (d, J = 4.9 Hz, 1 H, CH(CHO)), 2.57 (ddd, J = 7.5, 4.9, 4.9 Hz, 1 H, H_d), 2.31–2.21 (m, 1 H, H_c), 1.44 (ddd, J = 9.0, 7.5, 5.1 Hz, 1 H, H_a), 0.89 (dd, J = 5.1, 4.9, 3.3 Hz, 1 H, H_b). ¹³C NMR (101 MHz, CDCl₃) δ 175.6 (C=O), 137.4 (Ph-Cquat), 128.5 (2 × Ph-C), 128.1 (Ph-C), 125.4 (2 × Ph-C), 79.2 (CH(CHO)), 22.2 (CH₃), 19.1 (CH₃(H)), 9.7 (CH₃(H)).

HRMS (EI) m/z Calcd for C_{11}H_{12}O_{2}⁺ [M⁺]: 174.0681; Found: 174.0674. The observed data (IR, ¹H, ¹³C) was consistent with that previously reported.¹⁶

(Z)-Ethyl 2-[hydroxy(pyridine-3-yl)methyl]cyclopropane-1-carboxylate (20d)

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i-\text{PrMgCl (0.32 mL, 1.87 M in THF, 0.60 mmol, 1.5 equiv) was added to a −78 °C solution of (Z)-ethyl 2-(phenylsulfinyl)cyclopropanecarboxylate 7 (95 mg, 0.40 mmol, 1.0 equiv) in THF (4.0 mL) over 10 s and the solution stirred for 10 min. 3-Pyridinecarboxaldehyde (75 μL, 0.80 mmol, 2.0 equiv) was added and the reaction stirred at 0 °C for 1 h. The reaction was warmed to rt, sat. aq. NH₄Cl (5 mL) added and the mixture stirred for 5 min. Water (10 mL) was added and the mixture extracted with CH₂Cl₂ (6 × 20 mL) then EtOAc (6 × 20 mL). The combined organic phases were concentrated under reduced pressure, dissolved in CH₂Cl₂, washed with brine, dried (MgSO₄), filtered and concentrated under reduced pressure. Purification by flash column chromatography (3:1 EtOAc:toluene) gave cyclopropane 20d as a mixture of two diastereomers (d.r. = 57:43, 76 mg, 86%) as a colourless oil. R_f = 0.23 (3:1 EtOAc:toluene). IR (film)/cm⁻¹ 3184 (OH), 2981 (CH), 2929, 2848 (CH), 1774 (C=O), 1183.

Major diastereoisomer: ¹H NMR (400 MHz, CDCl₃) δ 8.62–8.45 (m, 2 H, 2 × Ar-H), 7.80–7.63 (m, 1 H, Ar-H), 7.34–7.24 (m, 1 H, Ar-H), 5.72 (d, J = 4.8 Hz, 1 H, CH(OH)), 4.16–4.07 (m, 2 H, CH₂CH₃), 1.90 (ddd, J = 8.3, 8.3, 5.8 Hz, 1 H, H_d), 1.70–1.62 (m, 1 H, H_c), 1.26–1.09 (m, 4 H, H₆ + CH₃), 0.80–0.79 (m, 1 H, H_b). ¹³C NMR (101 MHz, CDCl₃) δ 173.2 (C=O), 149.4 (Ar-C), 147.5 (Ar-C), 139.8 (Ar-C quat), 133.6 (Ar-C), 123.4 (Ar-C), 77.1 (CH(OH)), 60.8 (CH₂CH₃), 28.8 (CH₃), 19.0 (CH₃), 12.5 (CH₃).

Minor diastereoisomer: ¹H NMR (400 MHz, CDCl₃) δ 8.62–8.45 (m, 2 H, 2 × Ar-H), 7.80–7.63 (m, 1 H, Ar-H), 7.34–7.24 (m, 1 H, Ar-H), 4.81 (d, J = 9.2 Hz, 1 H, CH(OH)), 4.16–4.07 (m, 2 H, CH₂CH₃), 2.62–2.57 (m, 1 H, H_b), 2.25 (ddd, J = 6.4, 4.1, 3.6 Hz, 1 H, H_c), 1.46–1.36 (m, 1 H, H_a), 1.24 (t, J = 6.8 Hz, 3 H, CH₃), 1.17–1.09 (m, 1 H, H_b). ¹³C NMR (101 MHz, CDCl₃) δ 174.9 (C=O), 148.5 (Ar-C), 146.9 (Ar-C), 135.1 (Ar-Cquat), 133.4 (Ar-C), 123.7 (Ar-C), 79.1 (CH(OH)), 69.6 (CH₂CH₃), 21.6 (CH₃), 18.5 (CH₃), 14.1 (CH₃), 12.8 (CH₃).

HRMS (APCI) m/z Calcd for C_{12}H_{16}NO₃⁺ [M+H]⁺: 222.1125; Found: 222.1124.
(Z)-4,4-Diethyl-3-oxabicyclo[3.1.0]hexan-2-one (20e)

i-PrMgCl (0.32 mL, 1.82 M in THF, 0.60 mmol, 1.5 equiv) was added to a −78 °C solution of (Z)-ethyl 2-(phenylsulfinyl)cyclopropanecarboxylate 7 (95 mg, 0.40 mmol, 1.0 equiv) in THF (4.0 mL) over 10 s and the solution stirred for 10 min. Pentan-3-one (85 μL, 0.80 mmol, 2.0 equiv) was added and the reaction stirred at 0 °C for 3 h. The reaction was warmed to rt, sat. aq. NH₄Cl (5 mL) added and the mixture stirred for 5 min. Water (20 mL) was added and the mixture extracted with EtOAc (5 × 20 mL). The combined organic phases were washed with brine, dried (MgSO₄), filtered and concentrated under reduced pressure. Purification by flash column chromatography (2:1 pentane:Et₂O) gave cyclopropane 20e (30 mg, 49%) as a pale yellow oil. Rᵣ = 0.23 (2:1 pentane:Et₂O).

IR (film)/cm⁻¹ 2973 (CH), 2942 (CH), 2885 (CH), 1766 (C=O), 1463, 1233, 1000, 941. ¹H NMR (400 MHz, CDCl₃) δ 2.12 (dd, J = 8.9, 5.7, 3.1 Hz, 1 H, H₂), 1.99–1.95 (m, 1 H, H₃), 1.87–1.71 (m, 3 H, 3 × C(H)), 1.61–1.52 (m, 1 H, C(H₃)), 1.11 (dd, J = 8.9, 7.6, 5.1 Hz, 1 H, H₄), 1.01–0.94 (m, 7 H, H₅ + 2 × CH₃). ¹³C NMR (101 MHz, CDCl₃) δ 176.0 (C=O), 87.7 (C(CH₃)₂), 30.9 (CH₂CH₃), 28.1 (CH₂CH₃), 24.7 (C(H₄)), 19.1 (C(H₄)), 9.7 (CH₃), 8.4 (CH₃), 7.1 (CH₃). HRMS (Cl⁺) m/z Calcd for C₈H₁₅O₂ [M+H⁺]: 155.1072; Found: 155.1071.

(E)-4,4-Bis(4-chlorophenyl)-3-oxabicyclo[3.1.0]hexan-2-one (20f)

i-PrMgCl (0.32 mL, 1.87 M in THF, 0.60 mmol, 1.5 equiv) was added to a −78 °C solution of (Z)-ethyl 2-(phenylsulfinyl)cyclopropanecarboxylate 7 (95 mg, 0.40 mmol, 1.0 equiv) in THF (4.0 mL) over 10 s and the solution stirred for 10 min. 4,4-Dichlorobenzophenone (201 mg, 0.80 mmol, 2.0 equiv) in toluene (1.0 mL) was added and the reaction stirred for 0 °C 3 h. The reaction was warmed to rt, sat. aq. NH₄Cl (5 mL) added and the mixture stirred for 5 min. Water (20 mL) was added and the mixture extracted with EtOAc (5 × 20 mL). The combined organic phases were washed with brine, dried (MgSO₄), filtered and concentrated under reduced pressure. Purification by flash column chromatography (2:1 pentane:Et₂O–100% Et₂O) gave cyclopropane 20f (83 mg, 65%) as a white solid.

mp = 153–155 °C. Rᵣ = 0.17 (1:2 pentane:Et₂O). IR (film)/cm⁻¹ 2968 (CH), 2932 (CH), 1644 (C=O), 1583, 1443, 1365, 1087, 1020, 748, 691. ¹H NMR (400 MHz, CDCl₃) δ 7.42–7.26 (m, 8 H, 8 × Ar-H), 2.75 (dd, J = 7.5, 5.5, 4.6 Hz, 1 H, H₁), 2.35 (dd, J = 9.0, 5.5, 3.4 Hz, 1 H, H₂), 1.43 (dd, J = 9.0, 7.5, 5.3 Hz, 1 H, H₃), 0.94 (dd, J = 5.2, 4.7, 3.4 Hz, 1 H, H₄). ¹³C NMR (101 MHz, CDCl₃) δ 174.5 (C=O), 142.4 (Ar-C quat), 139.4 (Ar-C quat), 134.3 (Ar-C quat), 134.2 (Ar-C quat), 128.9 (2 × Ar-C), 128.8 (2 × Ar-C), 128.0 (2 × Ar-C), 126.7 (2 × Ar-C), 87.6 (C(Ar)₂), 27.9 (C(H₄)), 19.8 (C(H₄)), 13.1 (C(H₄)). HRMS (ASAP⁺) m/z Calcd for C₁₇H₁₅O₂Cl₂⁺ [M+H⁺]: 319.0293; Found: 319.0290.

(Z)-Ethyl 2-[hydroxydi(pyridin-2-yl)methyl]cyclopropane-1-carboxylate (20g)

and (Z)-4,4-Di(pyridin-2-yl)-3-oxabicyclo[3.1.0]hexan-2-one (20g’)

i-PrMgCl (0.32 mL, 1.85 M in THF, 0.60 mmol, 1.5 equiv) was added to a −78 °C solution of (Z)-ethyl 2-(phenylsulfinyl)cyclopropanecarboxylate 7 (95 mg, 0.40 mmol, 1.0 equiv) in THF (4.0 mL) over 10 s and the solution stirred for 10 min. A solution of di(2-pyridyl)ketone (147 mg, 0.80 mmol, 2.0 equiv) in toluene (1.0 mL) was added and the reaction stirred at 0 °C for 3 h. The reaction was warmed to rt, sat. aq. NH₄Cl (5 mL) added and the mixture stirred for 5 min. Water (10 mL) was added and the mixture extracted with EtOAc (3 × 30 mL). The combined organic phases were washed with brine, dried (MgSO₄), filtered and concentrated under reduced pressure. Purification by flash column chromatography (EtOAc) gave alcohol 20g (51 mg, 43%) as a white oil followed by lactone 20g’ (15 mg, 15%) as a yellow gum.

(Z)-Ethyl 2-[hydroxydi(pyridin-2-yl)methyl]cyclopropane-1-carboxylate (20g)

Rᵣ = 0.54 (EtOAc). IR (film)/cm⁻¹ 3339 (OH), 3058 (CH), 2982 (CH), 2935 (CH), 1728 (C=O), 1587, 1432, 1187, 1083, 994, 769, 749. ¹H NMR (400 MHz, CDCl₃) δ 8.54 (dddd, J = 8.2, 4.8, 1.7, 0.9 Hz, 2 H, 2 × Ar-H), 7.89 (dd, J = 8.0, 0.9, 0.9 Hz, 1 H, Ar-H), 7.75 (ddd, J = 8.0, 0.9, 0.9 Hz, 1 H, Ar-H), 7.65 (m, 2 H, 2 × Ar-H), 7.14–7.10 (m, 2 H, 2 × Ar-H), 6.08 (br s, 1 H, OH), 3.96–3.82 (m, 2 H, CH₂CH₃), 3.00 (ddd, J = 9.0, 9.0,
7.6 Hz, 1 H, Hc), 1.91 (dd, J = 8.7, 8.7, 6.2 Hz, 1 H, Hd), 1.69 (dd, J = 7.4, 6.2, 4.9 Hz, 1 H, Hb), 1.15 (dd, J = 8.7, 8.7, 4.9 Hz, 1 H, Hb), 1.02 (t, J = 7.1 Hz, 3 H, CH3). 13C NMR (101 MHz, CDCl3) δ 174.8 (C=O), 164.6 (Ar-C quat), 164.0 (Ar-C quat), 148.2 (Ar-C), 147.9 (Ar-C), 136.7 (Ar-C), 136.2 (Ar-C), 121.9 (Ar-C), 121.8 (Ar-C), 121.1 (Ar-C), 120.3 (Ar-C), 77.2 (C(OH)), 60.7 (CH2CH3), 30.9 (C(H)), 19.6 (C(H)), 13.9 (CH3), 9.9 (C(H)(Hb)). HRMS (ES) m/z Calcd for C17H19N2O4+ [M]+: 299.1396; Found: 299.1397.

(Z)-4,4-Di(pyridin-2-yl)-3-oxabicyclo[3.1.0]hexan-2-one (20g)

Rf = 0.22 (EtOAc). IR (film)/cm−1 3059 (CH), 3005 (CH), 2926 (CH), 2854 (CH), 1773 (C=O), 1587, 1572, 1465, 1433, 1201, 1028, 948, 749, 675. 1H NMR (400 MHz, CDCl3) δ 8.67–8.65 (m, 2 H, 2 × Ar-H), 7.73–7.64 (m, 2 H, 2 × Ar-H), 7.58 (d, J = 7.9 Hz, 1 H, Ar-H), 7.45 (d, J = 7.9 Hz, 1 H, Ar-H), 7.24–7.20 (m, 2 H, 2 × Ar-H), 3.47 (d, d, J = 7.7, 5.4, 4.7 Hz, 1 H, Hc) 2.09 (d, d, J = 7.9, 5.5, 3.3 Hz, 1 H, Hb), 1.36 (dd, J = 8.8, 7.7, 5.2 Hz, 1 H, Hb), 0.82 (dd, J = 4.8, 4.8, 3.3 Hz, 1 H, Hb). 13C NMR (101 MHz, CDCl3) δ 175.2 (C=O), 160.1 (Ar-C quat), 159.3 (Ar-C quat), 149.6 (Ar-C quat), 149.3 (Ar-C), 136.9 (Ar-C), 136.7 (Ar-C), 136.1 (Ar-C), 121.9 (Ar-C), 120.7 (Ar-C), 88.8 (C(Ar)), 26.3 (C(H)), 19.3 (C(H)), 12.3 (C(Ha)(Hb)). HRMS (ES) m/z Calcd for C15H13N2O3 [M]+: 253.0977; Found: 253.0986.

(Z)-Ethyl 2-benzoylcyclopropane-1-carboxylate (20h)

i-PrMgCl (0.32 mL, 1.85 M in THF, 0.60 mmol, 1.5 equiv) was added to a –78 °C solution of (Z)-ethyl 2-(phenylsulfonyl)cyclopropane carboxylate 7 (95 mg, 0.40 mmol, 1.0 equiv) in THF (4.0 mL) over 10 s and the solution stirred for 10 min. Benzoyl chloride (119 µL, 0.80 mmol, 2.0 equiv) was added and the reaction stirred at 0 °C for 3 h. The reaction was warmed to rt, sat. aq. NH4Cl (5 mL) added and the mixture stirred for 5 min. Water (10 mL) was added and the mixture extracted with EtOAc (5 × 30 mL). The combined organic phases were washed with brine, dried (MgSO4), filtered and concentrated under reduced pressure. Purification by flash column chromatography (9:1 n-hexane:EtOAc) gave cyclopropane 20h (73 mg, 64%) as a golden oil. Rf = 0.07 (9:1 n-hexane:EtOAc). IR (film)/cm−1 3063 (CH), 2983 (CH), 1727 (C=O), 1681, 1382, 1226, 1185. 1H NMR (400 MHz, CDCl3) δ 8.05–8.02 (m, 2 H, 2 × Ph-H), 7.58–7.54 (m, 1 H, Ph-H), 7.48–7.44 (m, 2 H, 2 × Ph-H), 3.99 (ddd, J = 7.1, 7.1, 7.1, 1.5 Hz, 2 H, CH2CH3). 2.79 (ddd, J = 9.2, 8.3, 7.0 Hz, 1 H, Hc), 2.31 (ddd, J = 9.3, 8.3, 6.4 Hz, 1 H, Hd), 1.92 (ddd, J = 6.6, 6.6, 4.8 Hz, 1 H, Hb), 1.37 (ddd, J = 8.3, 8.3, 4.8 Hz, 1 H, Hb), 1.05 (t, J = 7.1 Hz, 3 H, CH3). 13C NMR (101 MHz, CDCl3) δ 194.5 (C=O ketone), 169.9 (C=O ester), 137.1 (Ph-C quat), 133.1 (Ph-C), 128.5 (2 × Ph-C), 128.3 (2 × Ph-C), 60.8 (CH2CH3), 26.2 (C(Hc)), 23.0 (C(Hd)), 13.9 (CH3), 11.5 (C(Ha)(Hb)). FTMS (+p APCI) m/z Calcd for C13H13O5+[M]+: 219.1016; Found: 219.1014. The observed data (IR, 1H, 13C) was consistent with that previously reported.[17,15]

(Z)-Ethyl 2-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)cyclopropane-1-carboxylate (20l)

i-PrMgCl (0.32 mL, 1.85 M in THF, 0.60 mmol, 1.5 equiv) was added to a –78 °C solution of (Z)-ethyl 2-(phenylsulfonyl)cyclopropane carboxylate 7 (95 mg, 0.40 mmol, 1.0 equiv) in THF (4.0 mL) over 10 s and the solution stirred for 10 min. 2-Isopropoxy-4,4,5,5-tetramethyl-1,3,2-dioxaborolane (163 µL, 0.80 mmol, 2.0 equiv) was added and the reaction stirred at 0 °C for 6 h. The reaction was warmed to rt, MeOH (1 mL) added and stirred for 5 min. The mixture was concentrated under reduced pressure, dissolved in acetonitrile (10 mL) and extracted with pentane (5 × 10 mL). The combined pentane phases were washed with acetonitrile (10 mL), then concentrated under reduced pressure to give cyclopropane 20l (79 mg, 82%) as a colourless oil. IR (film)/cm−1 2978 (CH), 2927 (CH), 2852 (CH), 1724 (C=O), 1300, 1319, 1142, 854. 1H NMR (400 MHz, CDCl3) δ 4.24–4.05 (m, 2 H, CH2CH3), 1.83 (ddd, J = 9.3, 7.8, 4.8 Hz, 1 H, Hc), 1.35–1.23 (m, 15 H, 5 × CH3), 1.12 (ddd, J = 8.5, 4.7, 3.7 Hz, 1 H, Hb), 1.06 (ddd, J = 9.9, 7.9, 3.6 Hz, 1 H, Hb), 0.42 (ddd, J = 9.7, 8.8, 8.8 Hz, 1 H, Hb). 13C NMR (101 MHz, CDCl3) δ 174.4 (C=O), 83.5 (2 × C(CH3)2), 60.5 (CH2CH3), 29.7 (C(Hd)), 24.89 (2 × CH3), 24.87 (2 × CH3), 17.8 (C(Hc)), 14.3 (CH2CH3), 11.2 (C(Ha)(Hb)). 11B NMR (128 MHz, CDCl3) δ 32.06 (B(pin)). HRMS (EI) m/z Calcd for C11H1811B04+[M−CH3]: 225.1298; Found: 225.1302.
Synthesis of 21a–22h through sulfoxide–magnesium exchange, Negishi cross-coupling

(E)-Ethyl 2-phenylcyclopropane-1-carboxylate (21a)

\[
\text{C}_{22}H_{22}O_2 \text{Calcd: } C 74.09; H 8.88; } \text{Found: } C 74.06; H 8.91.
\]

| Compound | Molecular Formula | Calcd | Found |
|-----------|------------------|-------|-------|
| 21a       | C₂₂H₂₂O₂          | 346.50 | 346.50 |

Ethyl 2-phenylcyclopropane-1-carboxylate (21a) was synthesized by the reaction of \( \text{PhMgCl} \) (0.32 mL, 1.85 M in THF, 0.60 mmol, 1.5 equiv) with \( \text{PhC} = \text{CPh} \) in THF (4.0 mL) over 10 s and the solution stirred for 10 min. A mixture of \( \text{Pd}_2(\text{dba})_3 \) (9 mg, 0.01 mmol, 2.5 mol%), \( \text{t-Bu}_3\text{P} \) (4.5 mg, 0.022 mmol, 5.5 mol%) and \( \text{ZnCl}_2 \) (82 mg, 0.60 mmol, 1.5 equiv) in THF (1.5 mL) was added and the solution stirred at 0 °C for 1 h. Bromobenzene (84 µL, 0.80 mmol, 2.0 equiv) was added and the reaction stirred at 25 °C for 15 h. MeOH (1 mL) was added and the mixture stirred for 15 min. The mixture was filtered through a pad of silica, washing with \( \text{CH}_2\text{Cl}_2 \) (200 mL). Concentration under reduced pressure followed by purification by flash column chromatography (9:1 n-hexane:EtOAc) gave cyclopropane 21a (56 mg, 74%) as a colourless oil. Rf = 0.21 (19:1 n-hexane:EtOAc). IR (film)/cm⁻¹: 3086 (CH), 3063 (CH), 2932 (CH), 2981 (CH), 2938 (CH), 2907 (CH), 1721 (C=O), 1178, 755, 698. ¹H NMR (400 MHz, CDCl₃) δ 7.31–7.28 (m, 2 H, 2 × Ph-H), 7.22 (t, J = 7.4, 1.3 Hz, 1 H, Ph-H), 7.13–7.11 (m, 2 H, 2 × Ph-H), 1.32 (t, J = 6.0 Hz, 3 H, CH₃), 0.98 (t, J = 7.1 Hz, 3 H, CH₃). ¹³C NMR (101 MHz, CDCl₃) δ 173.4 (C=O), 140.1 (Ph-C quat), 128.4 (2 × Ph-C), 126.4 (Ph-C), 1261 (2 × Ph-C), 60.7 (CH₂CH₃), 26.2 (C(H₃)), 24.2 (C(H₉)), 17.1 (C(H₉)(H₉)), 14.3 (CH₃). HRMS (ES) m/z Calcd for C₁₂H₁₅O₂⁺ [M+H]⁺: 191.1072; Found: 191.1071. The observed data (¹H, ¹³C) was consistent with that previously reported.¹⁶

(Z)-Ethyl 2-phenylcyclopropane-1-carboxylate (22a)

| Compound | Molecular Formula | Calcd | Found |
|-----------|------------------|-------|-------|
| 22a       | C₂₂H₂₀O₂          | 348.50 | 348.50 |

(Z)-Ethyl 2-phenylcyclopropane-1-carboxylate (22a) was synthesized by the reaction of \( \text{PhMgCl} \) (0.32 mL, 1.85 M in THF, 0.60 mmol, 1.5 equiv) with \( \text{PhC} = \text{CPh} \) in THF (4.0 mL) over 10 s and the solution stirred for 10 min. A mixture of \( \text{Pd}_2(\text{dba})_3 \) (9 mg, 0.01 mmol, 2.5 mol%), \( \text{t-Bu}_3\text{P} \) (4.5 mg, 0.022 mmol, 5.5 mol%) and \( \text{ZnCl}_2 \) (82 mg, 0.60 mmol, 1.5 equiv) in THF (1.5 mL) was added and the solution stirred at 0 °C for 1 h. Bromobenzene (84 µL, 0.80 mmol, 2.0 equiv) was added and the reaction stirred at 25 °C for 15 h. MeOH (1 mL) was added and the mixture stirred for 15 min. The mixture was filtered through a pad of silica, washing with \( \text{CH}_2\text{Cl}_2 \) (200 mL). Concentration under reduced pressure followed by purification by flash column chromatography (9:1 pentane:EtOAc) gave cyclopropane 22a (58 mg, 76%) as a yellow oil. Rf = 0.27 (9:1 pentane:EtOAc). IR (film)/cm⁻¹: 3028 (CH), 2982 (CH), 2934 (CH), 1726 (C=O), 1382, 1179, 1157. ¹H NMR (400 MHz, CDCl₃) δ 7.29–7.18 (m, 5 H, 5 × Ph-H), 3.88 (q, J = 7.1 Hz, 2 H, CH₂CH₃), 2.59 (dd, J = 9.0, 9.0, 7.5 Hz, 1 H, H₆), 2.09 (dd, J = 9.4, 7.8, 5.7 Hz, 1 H, H₆), 1.73 (dd, J = 7.5, 5.3, 5.3 Hz, 1 H, H₆), 1.34 (dd, J = 8.7, 7.8, 5.1 Hz, 1 H, H₆), 0.98 (t, J = 7.1 Hz, 3 H, CH₃). ¹³C NMR (101 MHz, CDCl₃) δ 171.0 (C=O), 136.6 (Ph-C quat), 129.3 (2 × Ph-C), 127.9 (2 × Ph-C), 126.6 (Ph-C), 60.2 (CH₂CH₃), 25.5 (C(H₉)), 21.8 (C(H₉)), 14.0 (CH₃), 11.1 (C(H₉)(H₉)). HRMS (ES) m/z Calcd for C₁₂H₁₄O₂⁺ [M+H]⁺: 190.0994; Found: 190.0988. The observed data (¹H, ¹³C) was consistent with that previously reported.¹⁷

(E)-Ethyl 2-(4-chlorophenyl)cyclopropane-1-carboxylate (21b)

| Compound | Molecular Formula | Calcd | Found |
|-----------|------------------|-------|-------|
| 21b       | C₂₁H₁₉ClO₂        | 353.83 | 353.83 |

(E)-Ethyl 2-(4-chlorophenyl)cyclopropane-1-carboxylate (21b) was synthesized by the reaction of \( \text{PhMgCl} \) (0.32 mL, 1.85 M in THF, 0.60 mmol, 1.5 equiv) with \( \text{PhC} = \text{CPh} \) in THF (4.0 mL) over 10 s and the solution stirred for 10 min. A mixture of \( \text{Pd}_2(\text{dba})_3 \) (9 mg, 0.01 mmol, 2.5 mol%), \( \text{t-Bu}_3\text{P} \) (4.5 mg, 0.022 mmol, 5.5 mol%) and \( \text{ZnCl}_2 \) (82 mg, 0.60 mmol, 1.5 equiv) in THF (1.5 mL) was added and the solution stirred at 0 °C for 1 h. 1-Bromo, 4-chlorobenzene (153 mg, 0.80 mmol, 2.0 equiv) in THF (0.5 mL) was added and the reaction stirred at 25 °C for 15 h. MeOH (1 mL) was added and the mixture stirred for 15 min. The mixture was filtered through a pad of silica, washing with \( \text{CH}_2\text{Cl}_2 \) (200 mL). Concentration under reduced pressure followed by purification by flash chromatography (9:1 pentane:EtOAc) gave cyclopropane 21b (76 mg, 85%) as a pale yellow oil. Rf = 0.31 (9:1 pentane:EtOAc). IR (film)/cm⁻¹: 2983 (CH), 2938 (CH), 1724 (C=O), 1497, 1328, 1186. ¹H NMR (400 MHz, CDCl₃) δ 7.27–7.23 (m, 2 H, 2 × Ar-H), 7.05–7.02 (m, 2 H, 2 × Ar-H), 4.18 (q, J = 7.1 Hz, 2 H, CH₂CH₃), 2.50 (dd, J = 9.3, 6.5, 4.2 Hz, 1 H, H₆), 1.87 (dd, J = 8.5, 5.4, 4.2 Hz, 1 H, H₆), 1.64–1.58 (m, 1 H, H₆), 1.29 (t, J = 7.1 Hz, 3 H, CH₃), 1.28 (dd, J = 8.5, 6.4, 4.6 Hz, J = 6.5, 4.2 Hz, 1 H, H₆).
1 H, Hβ). 13C NMR (101 MHz, CDCl3) δ 173.1 (C=O), 138.6 (Ar-C-Cl), 132.2 (Ar-C quat), 128.5 (2 × Ph-C), 127.6 (2 × Ph-C), 60.8 (CH2CH3), 25.5 (CH2), 24.2 (CH3), 17.0 (CH3(H2)), 14.2 (CH3). HRMS (El) m/z Calcd for C12H12O2Cl+ [M]+: 224.0604; Found: 224.0608. The observed data (IR, 1H, 13C) was consistent with that previously reported.[18,19]

(E)-Ethyl 2-(4-methoxyphenyl)cyclopropane-1-carboxylate (21c)

\[
\text{O} \quad \text{H} \\
\text{H} \quad \text{H} \\
\text{H} \quad \text{H} \\
\text{OMe}
\]

i-PrMgCl (0.32 mL, 1.85 M in THF, 0.60 mmol, 1.5 equiv) was added to a –78 °C solution of (E)-ethyl 2-(phenylsulfinyl)cyclopropanecarboxylate 6 (95 mg, 0.40 mmol, 1.0 equiv) in THF (4.0 mL) over 10 s and the solution stirred for 10 min. A mixture of Pd2(dba)3 (9 mg, 0.01 mmol, 2.5 mol%), (t-Bu)3P (4.5 mg, 0.022 mmol, 5.5 mol%) and ZnCl2 (82 mg, 0.60 mmol, 1.5 equiv) in THF (1.5 mL) was added and the solution stirred at 0 °C for 1 h. 4-Bromoanisole (100 µL, 0.80 mmol, 2.0 equiv) in THF (0.5 mL) was added and the reaction stirred at 25 °C for 15 h. MeOH (1 mL) was added and the mixture stirred for 15 min. The mixture was filtered through a pad of silica, washing with CH2Cl2 (200 mL). Concentration under reduced pressure followed by purification by flash column chromatography (15:1 pentane:Et2O) gave cyclopropane 21c (77 mg, 73%) as a cream crystalline solid. \(R_f = 0.24\) (9:1 pentane:Et2O). IR (film)/cm\(^{-1}\) 2988 (CH), 2953 (CH), 2911 (CH), 2837 (CH), 1719 (C=O), 1516, 1252, 1186. 1H NMR (400 MHz, CDCl3) δ 7.06–7.03 (m, 2 H, 2 × Ar-H), 6.85–6.81 (m, 2 H, 2 × Ar-H), 4.18 (q, J = 7.1 Hz, 2 H, CH2CH3), 3.79 (s, 3 H, OCH3), 2.49 (dd, J = 9.3, 6.5, 4.2 Hz, 1 H, Hβ), 1.83 (dd, J = 8.4, 5.2, 4.2 Hz, 1 H, Hδ), 1.58–1.54 (m, 1 H, Hb), 1.29 (t, J = 7.1 Hz, 3 H, CH3), 1.27–1.24 (m, 1 H, Hδ). 13C NMR (101 MHz, CDCl3) δ 173.5 (C=O), 158.3 (Ph-C-OMe), 132.0 (Ph-C quat), 127.3 (2 × Ar-H), 113.9 (2 × Ar-H), 60.6 (CH2CH3), 55.3 (OCH3), 25.6 (CH2), 23.8 (CH2), 16.7 (CH3(H2)), 14.3 (CH3). FTMS (+p APCI) m/z Calcd for C13H13O2+ [M]+: 221.1172; Found: 221.1182. The observed data (IR, 1H, 13C) was consistent with that previously reported.[18,20]

(E)-Ethyl 2-[(E)-2-phenylethenyl]cyclopropane-1-carboxylate (21d)

\[
\text{O} \quad \text{H} \\
\text{H} \quad \text{H} \\
\text{H} \quad \text{H} \\
\text{H}
\]

i-PrMgCl (0.32 mL, 1.85 M in THF, 0.60 mmol, 1.5 equiv) was added to a –78 °C solution of (E)-ethyl 2-(phenylsulfinyl)cyclopropanecarboxylate 6 (95 mg, 0.40 mmol, 1.0 equiv) in THF (4.0 mL) over 10 s and the solution stirred for 10 min. A mixture of Pd2(dba)3 (9 mg, 0.01 mmol, 2.5 mol%), (t-Bu)3P (4.5 mg, 0.022 mmol, 5.5 mol%) and ZnCl2 (82 mg, 0.60 mmol, 1.5 equiv) in THF (1.5 mL) was added and the solution stirred at 0 °C for 1 h. β-Bromostyrene (103 µL, 0.80 mmol, 2.0 equiv) was added and the reaction stirred at 25 °C for 15 h. MeOH (1 mL) was added and the mixture stirred for 15 min. The mixture was filtered through a pad of silica, washing with CH2Cl2 (200 mL). Concentration under reduced pressure followed by purification by flash column chromatography (19:1 pentane:Et2O) gave cyclopropane 21d (73 mg, 84%) as a golden oil. \(R_f = 0.46\) (9:1 pentane:Et2O). IR (film)/cm\(^{-1}\) 3027 (CH), 3000 (CH), 2983 (CH), 2911 (CH), 1718 (C=O), 1650 (C=C), 1341, 1175, 1036, 964, 754. 1H NMR (400 MHz, CDCl3) δ 7.33–7.28 (m, 4 H, 4 × Ph-H), 7.25–7.20 (m, 1 H, Ph-H), 6.55 (d, J = 15.8 Hz, 1 H, Hj), 5.77 (dd, J = 15.8, 8.7 Hz, 1 H, Hg), 4.17 (q, J = 7.1 Hz, 2 H, CH2CH3), 2.19 (dd, J = 8.9, 8.7, 6.3, 3.9 Hz, 1 H, Hg), 1.77 (dd, J = 8.4, 5.2, 3.9 Hz, 1 H, Hj), 1.49 (dd, J = 8.9, 5.2, 4.5 Hz, 1 H, Hg), 1.29 (t, J = 7.1 Hz, 3 H, CH3), 1.11 (dd, J = 8.4, 6.2, 4.4 Hz, 1 H, Hg). 13C NMR (101 MHz, CDCl3) δ 173.3 (C=O), 137.0 (Ph-C quat), 130.3 (alkene CH), 130.1 (alkene CH), 128.5 (2 × Ph-C), 127.2 (Ph-C), 125.8 (2 × Ph-C), 60.7 (CH2CH3), 25.5 (CH3), 22.3 (CH3), 16.0 (CH3(H2)), 14.3 (CH3). The observed data (1H) was consistent with that previously reported.[21]

(E)-Ethyl 2-(pyridin-2-yl)cyclopropane-1-carboxylate (21e)

\[
\text{O} \quad \text{H} \\
\text{H} \quad \text{H} \\
\text{H} \\
\text{N}
\]

i-PrMgCl (0.32 mL, 1.85 M in THF, 0.60 mmol, 1.5 equiv) was added to a –78 °C solution of (E)-ethyl 2-(phenylsulfinyl)cyclopropanecarboxylate 6 (95 mg, 0.40 mmol, 1.0 equiv) in THF (4.0 mL) over 10 s and the solution stirred for 10 min. A mixture of Pd2(dba)3 (9 mg, 0.01 mmol, 2.5 mol%), (t-Bu)3P (4.5 mg, 0.022 mmol, 5.5 mol%) and ZnCl2 (82 mg, 0.60 mmol, 1.5 equiv) in THF (1.5 mL) was added and the solution stirred at 0 °C for 1 h. 2-Bromopyridine (76 µL, 0.80 mmol, 2.0 equiv) was added and the reaction stirred at 25 °C for 15 h. MeOH (1 mL) was added and the mixture stirred for 15 min. The mixture was filtered through a pad
of silica, washing with CH₂Cl₂ (200 mL). Concentration under reduced pressure followed by flash column chromatography (4:1 pentane:Et₂O) gave cyclopropane 21f (46 mg, 60%) as a yellow oil. Rf = 0.17 (4:1 pentane:Et₂O). IR (film)/cm⁻¹ 2981 (CH), 2930 (CH), 1723 (C=O), 1595, 1476, 1330, 1179, 1049, 775. ¹H NMR (400 MHz, CDCl₃) δ 8.46–8.44 (dd, J = 4.9, 1.8, 1.0 Hz, 1 H, Ar-H), 7.59–7.56 (dd, J = 7.6, 7.6, 1.8 Hz, 1 H, Ar-H), 7.25–7.22 (dd, J = 7.6, 1.0, 1.0 Hz, 1 H, Ar-H), 7.11–7.07 (dd, J = 7.6, 4.9, 1.0 Hz, 1 H, Ar-H), 4.17 (q, J = 7.2 Hz, 2 H, CH₂CH₃), 2.59 (dd, J = 9.0, 6.1, 3.9 Hz, 1 H, Hβ), 2.25 (dd, J = 8.3, 5.6, 3.9 Hz, 1 H, Hδ), 1.65–1.57 (m, 2 H, Hα + Hδ), 1.28 (t, J = 7.2 Hz, 3 H, CH₃). ¹³C NMR (101 MHz, CDCl₃) δ 173.4 (C=O), 158.9 (Ar-Cquat), 149.4 (Ar-C), 136.0 (Ar-C), 122.5 (Ar-C), 121.3 (Ar-C), 60.7 (CH₂CH₃), 27.2 (C(Hδ)), 24.3 (C(Hδ)), 17.3 (C(Hα)(Hδ)), 14.2 (CH₃). HRMS (El) m/z Calcd for C₁₁H₁₃NO₂⁺ [M⁺]: 191.0946; Found: 191.0941. The observed data (¹H, ¹³C) was consistent with that previously reported.¹⁸

(E)-Ethyl 2-(pyrimidin-2-yl)cyclopropane-1-carboxylate (21f)

\[ \text{i-PrMgCl (0.32 mL, 1.85 M in THF, 0.60 mmol, 1.5 equiv) was added to a –78 °C solution of (E)-ethyl 2-(phenylsulfinyl)cyclopropanecarboxylic acid 6 (95 mg, 0.40 mmol, 1.0 equiv) in THF (4.0 mL) over 10 s and the solution stirred for 10 min. A mixture of Pd₂(db₃) (9 mg, 0.01 mmol, 25 mol%), (t-Bu₃)P (4.5 mg, 0.022 mmol, 5.5 mol%) and ZnCl₂ (82 mg, 0.60 mmol, 1.5 equiv) in THF (1.5 mL) was added and the solution stirred at 0 °C for 1 h. 2-Bromopyrimidine (127 mg, 0.80 mmol, 2.0 equiv) in toluene (2.0 mL) was added and the reaction stirred at 25 °C for 15 h. MeOH (1 mL) was added and the mixture stirred for 15 min. The mixture was filtered through a pad of silica, washing with CH₂Cl₂ (200 mL). Concentration under reduced pressure followed by flash column chromatography (4:1 pentane:Et₂O) gave cyclopropane 21f (45 mg, 59%) as a yellow oil. Rf = 0.28 (1:2 pentane:Et₂O). IR (film)/cm⁻¹ 2982 (CH), 2938 (CH), 1725 (C=O), 1561, 1425, 1331, 1118. ¹H NMR (400 MHz, CDCl₃) δ 8.60 (d, J = 4.9 Hz, 2 H, 2 × ArNCH), 7.11 (t, J = 4.9 Hz, 1 H, ArNCHCH), 4.17 (q, J = 7.2 Hz, 2 H, CH₂CH₃), 2.82 (ddd, J = 8.7, 6.2, 3.9 Hz, 1 H, Hδ), 2.31 (ddd, J = 8.5, 5.7, 3.8 Hz, 1 H, Hα), 1.71–1.64 (m, 2 H, Hα + Hδ), 1.28 (t, J = 7.1 Hz, 3 H, CH₃). ¹³C NMR (101 MHz, CDCl₃) δ 172.5 (C=O), 168.8 (Ar-Cquat), 156.9 (2 × Ar-C), 118.6 (Ar-C), 60.8 (CH₂CH₃), 28.0 (C(CH₃)), 25.0 (C(CH₂)), 17.7 (C(Hα)(Hδ)), 14.2 (CH₃). HRMS (El) m/z Calcd for C₁₁H₁₃NO₂⁺ [M⁺]: 192.0899; Found: 192.0908.

(E)-tert-Butyl 3-[2-(ethoxycarbonyl)cyclopropyl]-1H-indole-1-carboxylate (21g)

\[ \text{i-PrMgCl (0.32 mL, 1.85 M in THF, 0.60 mmol, 1.5 equiv) was added to a –78 °C solution of (E)-ethyl 2-(phenylsulfinyl)cyclopropanecarboxylic acid 6 (95 mg, 0.40 mmol, 1.0 equiv) in THF (4.0 mL) over 10 s and the solution stirred for 10 min. A mixture of Pd₂(db₃) (9 mg, 0.01 mmol, 25 mol%), (t-Bu₃)P (4.5 mg, 0.022 mmol, 5.5 mol%) and ZnCl₂ (82 mg, 0.60 mmol, 1.5 equiv) in THF (1.5 mL) was added and the solution stirred at 0 °C for 1 h. A solution of 3-Bromoindole-1-carboxylic acid tert-butyl ester (237 mg, 0.80 mmol, 2.0 equiv) in toluene (1.0 mL) was added and the reaction stirred at 25 °C for 15 h. MeOH (1 mL) was added and the mixture stirred for 15 min. The mixture was filtered through a pad of silica, washing with CH₂Cl₂ (200 mL). Concentration under reduced pressure followed by purification by flash column chromatography (19:1 pentane:Et₂O) gave cyclopropane 21g (119 mg, 94%) as a yellow gum. Rf = 0.15 (19:1 pentane:Et₂O). IR (film)/cm⁻¹ 2980 (CH), 2934 (CH), 1722 (C=O), 1451, 1369, 1345, 1254, 1152, 1079, 743. ¹H NMR (400 MHz, CDCl₃) δ 8.12 (d, J = 6.7 Hz, 1 H, ArNCH), 7.62 (d, J = 7.6 Hz, 1 H, Ar-H), 7.36–7.25 (m, 3 H, 3 × Ar-H), 4.23 (q, J = 7.1 Hz, 2 H, CH₂CH₃), 2.55 (ddd, J = 9.0, 6.5, 4.2, 1.1 Hz, 1 H, Hc), 1.92 (ddd, J = 8.4, 5.1, 4.4 Hz, 1 H, Hδ), 1.68 (s, 9 H, C(CH₃)₃), 1.61 (ddd, J = 9.1, 5.0, 4.3 Hz, 1 H, Hβ), 1.34–1.29 (m, 4 H, Hα + CH₂CH₃). ¹³C NMR (101 MHz, CDCl₃) δ 173.6 (C=O ester), 149.6 (C=O carbamate), 135.4 (Ar-Cquat), 130.4 (Ar-Cquat), 124.6 (Ar-C), 122.6 (Ar-C), 122.0 (Ar-C), 120.3 (Ar-Cquat), 119.0 (Ar-C), 115.3 (Ar-C), 83.7 (C(CH₃)₃), 60.7 (CH₂CH₃), 28.2 (C(CH₃)₃), 21.7 (C(CH₃)), 17.1 (C(Hδ)), 15.3 (C(Hα)(Hδ)), 14.3 (CH₂CH₃). HRMS (El) m/z Calcd for C₁₉H₁₃NO₂⁺ [M⁺]: 329.1627; Found: 329.1635. The observed data (¹H, ¹³C) was consistent with that previously reported.¹⁹}
(Z)-Ethyl 2-[1-(benzenesulfonyl)-1H-indol-3-yl]cyclopropane-1-carboxylate (22h)

\[ i\text{-PrMgCl (1.20 mL, 1.85 M in THF, 2.25 mmol, 1.5 equiv) added to a −78 °C solution of (Z)-ethyl 2-(phenylsulfinyl)cyclopropanecarboxylate 7 (358 mg, 1.5 mmol, 1.0 equiv) in THF (15 mL) over 10 s and the solution stirred for 10 min. A mixture of Pd}(dba)\(_2\) (35 mg, 0.04 mmol, 2.5 mol%), (t-Bu)\(_3\)P (17 mg, 0.08 mmol, 5.5 mol%) and ZnCl\(_2\) (308 mg, 2.25 mmol, 1.5 equiv) in THF (1.9 mL) was added and the solution stirred at 0 °C for 1 h. A solution of 3-bromo-(1-phenylsulfonyl)indole (1.00 g, 3.00 mmol, 2.0 equiv) in THF (2.0 mL) was added and the reaction stirred at 25 °C for 15 h. MeOH (5 mL) was added and the mixture stirred for 15 min. The mixture was filtered through a pad of silica, washing with CH\(_2\)Cl\(_2\) (200 mL). Concentration under reduced pressure followed by purification by flash column chromatography (5:1 pentane:EtOAc) gave cyclopropane 22h (414 mg, 75%) as a colourless gum. \(R\)\(_f\) = 0.24 (5:1 pentane:EtOAc). IR (film)/cm\(^{-1}\) 3065 (CH), 2931 (CH), 1721 (C=O), 1447, 1366 (S=O), 1170 (S=O), 1124, 1092, 980, 734, 684. \(^1H\) NMR (400 MHz, CDCl\(_3\)) \(\delta\) 7.92 (d, \(J = 8.2\) Hz, 1 H, Ar-H), 7.87–7.84 (m, 2 H, 2 × Ar-H), 7.59–7.57 (m, 1 H, Ar-H), 7.52–7.48 (m, 1 H, Ar-H), 7.44–7.40 (m, 3 H, 3 × Ar-H), 7.30–7.26 (dd, \(J = 7.4, 7.4, 1.3\) Hz, 1 H, Ar-H), 7.24–7.20 (dd, \(J = 7.4, 7.4, 1.0\) Hz, 1 H, Ar-H), 3.78–3.63 (m, 2 H, CH\(_2\)CH\(_3\)), 2.43 (dd, \(J = 8.6, 8.6, 1.2\) Hz, 1 H, H\(_b\)), 2.18 (ddd, \(J = 8.9, 7.9, 5.7\) Hz, 1 H, H\(_a\)), 1.65 (dd, \(J = 7.2, 5.6, 5.1\) Hz, 1 H, H\(_b\)). 13C NMR (101 MHz, CDCl\(_3\)) \(\delta\) 170.4 (C=O), 138.1 (Ar-C quat), 135.0 (Ar-C quat), 131.5 (Ar-C quat), 129.1 (2 × Ar-C), 126.8 (2 × Ar-C), 125.0 (Ar-C), 124.7 (Ar-C), 123.1 (Ar-C), 119.4 (Ar-C), 118.9 (Ar-C quat), 113.6 (Ar-C), 60.1 (CH\(_2\)CH\(_3\)), 20.7 (CH\(_3\)), 15.5 (CH\(_3\)), 13.7 (CH\(_3\)), 11.1 (CH\(_3\)(H\(_b\))). HRMS (ES) \(m/z\) Calcd for C\(_{20}\)H\(_{19}\)NO\(_2\)S\(_2\) [M+H\(^+\)]: 370.1113; Found: 370.1114. The observed data \(\left[^{13}\text{C}\right]\) was consistent with that previously reported.\[^{[22]}\]

Synthesis of 23, 24 and 25

(E)-Sodium 2-(pyridin-2-yl)cyclopropane-1-carboxylate (23)

\(\text{NaOH}_{\text{aq}}\) (1.0 M, 0.29 mL, 0.29 mmol, 1.2 equiv) was added to a 30 °C solution of (E)-ethyl 2-(pyridin-2-yl)cyclopropane-1-carboxylate 21e (46 mg, 0.24 mmol, 1.0 equiv) in EtOH (1.2 mL) and the solution was stirred at 30 °C for 24 h. The red reaction mixture was concentrated under reduced pressure, then filtered, washing with acetone (50 mL). The filtrate was concentrated under reduced pressure to give cyclopropane 23 (44 mg, quant) as a red gum. IR (film)/cm\(^{-1}\) 1644, 1560 (C=O), 1420, 1371. \(^1H\) NMR (400 MHz, DMSO-d\(_6\)) \(\delta\) 8.36 (d, \(J = 4.1\) Hz, 1 H, Ar-H), 7.59 (dd, \(J = 7.7, 7.7, 1.6\) Hz, 1 H, Ar-H), 7.21 (d, \(J = 7.8\) Hz, 1 H, Ar-H), 7.08 (dd, \(J = 7.0, 5.2\) Hz, 1 H, Ar-H), 2.25 (dd, \(J = 8.8, 5.2, 5.2\) Hz, 1 H, H\(_d\)), 1.70 (ddd, \(J = 8.4, 5.5, 4.1\) Hz, 1 H, H\(_a\)), 1.21 (ddd, \(J = 8.0, 5.5, 2.4\) Hz, 1 H, H\(_b\)), 1.16–1.07 (m, 1 H, H\(_b\)). 13C NMR (101 MHz, DMSO-d\(_6\)) \(\delta\) 176.1 (C=O), 161.7 (Ar-C quat), 148.9 (Ar-C), 135.9 (Ar-C), 121.4 (Ar-C), 120.4 (Ar-C), 29.2 (CH\(_3\)), 25.2 (CH\(_3\)), 16.2 (CH\(_3\)(H\(_b\))). HRMS (ES) \(m/z\) Calcd for C\(_9\)H\(_{11}\)NO\(_2\) \([\text{M+Na}^+\text{H}]^+\): 164.0712; Found: 164.0718.

(E)-2-(Pyridin-2-yl)cyclopropyl(pyrrolidin-1-yl)methanone (24)

HATU (49 mg, 0.13 mmol, 1.2 equiv) was added to a solution of (E)-sodium 2-(pyridin-2-yl)cyclopropane-1-carboxylate 23 (20 mg, 0.11 mmol, 1.0 equiv) in N,N-dimethylformamide (540 \(\mu\)L) and the resultant red solution was stirred at 40 °C for 10 min. Pyrrolidine (11 \(\mu\)L, 0.13 mmol, 1.2 equiv) was added and the solution stirred for 20 min. Disopropylethylamine (56 \(\mu\)L, 0.32 mmol, 3.0 equiv) was added and the solution stirred for 24 h. H\(_2\)O (10 mL) was added and the mixture extracted with EtOAc (5 × 10 mL). The combined organic phases were washed with brine (10 mL), dried (MgSO\(_4\)), filtered and concentrated under reduced pressure. Purification by flash column chromatography (1:2 pentane:EtOAc) gave cyclopropane 24 (19 mg, 82%) as a yellow gum. \(R\)\(_f\) = 0.27 (1:2 pentane:EtOAc). IR (film)/cm\(^{-1}\) 2954 (CH), 2923 (CH), 2854 (CH), 1741 (C=O), 1596, 1460, 1375, 1220, 964, 803. \(^1H\) NMR (400 MHz, CDCl\(_3\)) \(\delta\) 8.45 (d, \(J = 4.4\) Hz, 1 H, Ar-H), 7.56 (ddd, \(J = 7.7, 7.7, 1.5\) Hz, 1 H, Ar-H), 7.29 (d, \(J = 8.1\) Hz, 1 H, Ar-H), 7.09–7.06 (m, 1 H, Ar-H), 2.58 (ddd, \(J = 9.1, 5.5, 4.4\) Hz, 1 H, H\(_c\)), 2.41 (ddd, \(J = 9.0, 5.7, 4.1\) Hz, 1 H, H\(_d\)), 1.58 (ddd, \(J = 8.8, 5.5, 3.3\) Hz, 1 H, H\(_d\)), 1.48 (ddd, \(J = 8.9, 5.7, 3.4\) Hz, 1 H, H\(_b\)), 1.34–1.22 (m, 8 H, 4 × CH\(_2\)). 13C NMR (101 MHz, CDCl\(_3\)) \(\delta\) 160.2
(C=O), 149.3 (Ar-C), 135.9 (Ar-C), 125.5 (Ar-C quat), 122.9 (Ar-C), 120.9 (Ar-C), 45.6 (NCH$_2$), 29.7 (NCH$_2$), 25.8 (C(H$_3$)), 25.3 (C(H$_3$)), 21.6 (NCH$_2$CH$_2$), 20.7 (NCH$_2$CH$_2$), 17.2 (C(H$_a$)(H$_b$)). FTMS (+p NSI) m/z Calcd for C$_{18}$H$_{18}$NO$_3$S$^+$ [M+H]$^+$: 328.1007; Found: 328.1007.

(Z)-(2-[1-(Benzonesulfonyl)-1H-indol-3-yl]cyclopropyl)methanol (25)

Lithium aluminum tetrahydride (1.0 M in THF, 1.35 mL, 1.35 mmol, 2.5 equiv) was added dropwise over 5 min to a 0 °C solution of (Z)-ethyl 2-[1-(benzenesulfonyl)-1H-indol-3-yl]cyclopropane-1-carboxylate (22h) (200 mg, 0.54 mmol, 1.0 equiv) in THF (0.68 mL) and the solution stirred at 0 °C for 10 min. The solution was warmed to 25 °C and stirred for 3 h. The reaction mixture was cooled to 0 °C, EtOAc (7 ml) was added and the mixture stirred for 15 min. The mixture was warmed to 25 °C, sat. aq. potassium sodium tartrate (15 mL) was added and the mixture stirred for 1 h. The organic phase was separated, and the aqueous phase extracted with Et$_2$O (5 × 10 mL). The combined organic phases were washed with brine (20 mL), dried (MgSO$_4$), filtered and concentrated under reduced pressure. Purification by flash column chromatography (1:3 pentane:Et$_2$O) gave cyclopropane 25 (166 mg, 94%) as a yellow gum. R$_r$ (Et$_2$O) = 0.44. IR (film)/cm$^{-1}$ 3387 (OH), 3117 (CH), 3067 (CH), 2923 (CH), 1447, 1366 (S=O), 1173 (S=O), 1124, 1096, 739, 685. $^1$H NMR (400 MHz, CDCl$_3$) δ 8.00 (d, J = 8.2 Hz, 1 H, Ar-H), 7.86–7.84 (m, 2 H, 2 × Ar-H), 7.65 (d, J = 7.6 Hz, 1 H, Ar-H), 7.54 (t, J = 7.4 Hz, 1 H, Ar-H), 7.44 (t, J = 7.7 Hz, 2 H, 2 × Ar-H), 7.37–7.33 (m, 1 H, Ar-H), 7.30–7.29 (m, 2 H, Ar-H), 3.51–3.48 (m, 1 H, CH(H)OH), 3.12–3.07 (m, 1 H, CH(H)OH), 2.12–2.06 (m, 1 H, H$_a$), 1.64–1.55 (m, 1 H, H$_b$), 1.15 (ddd, J = 8.3, 8.3, 5.1 Hz, 1 H, H$_a$), 0.88 (br s, 1 H, OH), 0.75 (ddd, J = 5.5, 5.5, 5.5 Hz, 1 H, H$_b$). $^{13}$C NMR (101 MHz, CDCl$_3$) δ 138.0 (Ar-C quat), 135.5 (Ar-C quat), 133.8 (Ar-C), 131.7 (Ar-C quat), 129.2 (2 × Ar-C), 126.6 (2 × Ar-C), 125.2 (Ar-C), 124.0 (Ar-C), 123.6 (Ar-C), 121.1 (Ar-C quat), 119.4 (Ar-C), 113.9 (Ar-C), 62.7 (CH$_2$OH), 19.9 (C(H$_3$)), 10.8 (C(H$_a$)), 7.6 (C(H$_a$)(H$_b$)). HRMS (ES) m/z Calcd for C$_{12}$H$_{17}$N$_2$O$^+$ [M+H]$^+$: 217.1335; Found: 217.1336.
Optimization of an enantioselective cyclopropanation of phenyl vinyl sulfide

Enantiopure ligands were applied to the cyclopropanation of phenyl vinyl sulfide and ethyl diazoacetate towards an asymmetric cyclopropanation. A range of BOX and PyBOX ligands were investigated in the CuOTf-catalyzed protocol, that give high yields and ee on styrene substrates. However, all gave low yields, dr and ee with PVS. Following the success of the Co-catalyzed reaction, several enantiopure Co\textsuperscript{II}(salen)-type complexes were prepared (see below) to probe a variety of steric and electronic effects (Table S3). The best results were achieved using commercial complex 3 (Table S3, entry 1), which gave a quantitative yield and showed moderate and good enantioselectivity for the trans- and cis-cyclopropane products, respectively. Other variations in catalyst structure were not advantageous.

Table S3. Asymmetric induction using Co\textsuperscript{II}(salen)-type complexes

| Entry | Complex | dr\textsuperscript{[a]} | ee trans (%) | ee cis (%) | Yield\textsuperscript{[b]} trans + cis (%) |
|-------|---------|----------------|--------------|------------|----------------------------------|
| 1     | 3       | 47:53          | 40           | 64         | 100                              |
| 2     | 26      | 50:50          | 29           | 23         | 9                                |
| 3     | 27      | 44:56          | 32           | 42         | 6                                |
| 4     | 28      | 49:51          | 51           | 57         | 17                               |

\textsuperscript{[a]} Calculated from the crude reaction mixture by \textsuperscript{1}H NMR. \textsuperscript{[b]} Yields were calculated using \textsuperscript{1}H NMR by comparison with an internal standard (dibenzyl ether).

A brief optimization of the solvent, reaction temperature and examination of additives, was undertaken (Table S4). Conducting the reaction in cyclohexane at 40 °C (Table S4, entry 7) or on H\textsubscript{2}O at 20 °C (Table S4, entry 9) gave the highest levels of ee observed.
Table S4. Asymmetric induction optimization using Co\textsuperscript{II}(salen)-type complex 3

| Entry | Additive (5 mol\% ) | Solvent | Temperature (°C) | dr\textsuperscript{[a]} trans:cis | ee trans | ee cis | Yield\textsuperscript{[b]} trans + cis (%) |
|-------|----------------------|---------|------------------|-------------------------------|----------|--------|----------------------------------|
| 1     | None                 | H\textsubscript{2}O | 40               | 47:53                         | 40       | 64     | 100                              |
| 2     | KSAc                 | H\textsubscript{2}O | 40               | 48:52                         | 48       | 63     | 100                              |
| 3     | DMSO                 | H\textsubscript{2}O | 40               | 48:52                         | 46       | 66     | 100                              |
| 4     | Br\textsubscript{2}   | H\textsubscript{2}O | 40               | -                             | -        | -      | 0                                |
| 5     | None                 | Benzene | 40               | 48:52                         | 44       | 60     | 73                               |
| 6     | None                 | Toluene | 40               | 45:55                         | 47       | 63     | 53                               |
| 7     | None                 | TBME    | 40               | 48:52                         | 49       | 66     | 69                               |
| 8     | None                 | Cyclohexane | 40           | 45:55                         | 53       | 73     | 55                               |
| 9     | None                 | H\textsubscript{2}O | 30               | 47:53                         | 48       | 65     | 92                               |

\textsuperscript{[a]} Calculated from the crude reaction mixture by \textsuperscript{1}H NMR. \textsuperscript{[b]} Yields were calculated using \textsuperscript{1}H NMR by comparison with an internal standard (dibenzyl ether).
Synthesis of enantiopure C₂-symmetric Co²⁺-(salen)-type complexes

General procedure for tetradentate Schiff base synthesis
A solution of the enantiopure chiral diamine (1.0 equiv) in EtOH (0.2 M) was added to a solution of the salicylaldehyde derivative (2.0 equiv) in EtOH (0.17 M) and the solution refluxed for 3–20 h. Filtration and recrystallization from ethanol gave the desired tetradentate Schiff bases. The observed data was consistent with that previously reported for the tetradentate Schiff base ligands for complexes 26, 27, 25 and 28.

\[ N,N'-\text{Bis}[(E)-(3,5-di-iodo)-2-hydroxyphenylmethylenediamino]-(1R,2R)-1,2-cyclohexanediamino]cobalt(II) \] (26)

\[ \text{A mixture of } \text{Co}^{\text{II}}(\text{OAc})_2 \text{ (33 mg, 0.18 mmol, 1.0 equiv), H}_2\text{O (1.0 mL) and ethanol (2.5 mL) was added to a solution of } N,N'-\text{bis}[(E)-(3,5-di-iodo)-2-hydroxyphenylmethylenediamine]-(1R,2R)-1,2-cyclohexanediamine \text{ (148 mg, 0.18 mmol, 1.0 equiv) in toluene (1.5 mL). The reaction mixture was refluxed for 3 h, cooled to rt, concentrated under reduced pressure, then recrystallized in 3:2 ethanol:CHCl}_3 (v/v) to give 26 (151 mg, 95%) as a vivid orange solid. mp > 250 °C. IR (film)/cm\(^{-1}\) 3003 (CH), 2938 (CH), 2858 (CH), 1738, 1599, 1568, 1490, 1422, 1398, 1160, 1031. FTMS (+ p NSI) m/z Calcd for C\(_{26}\)H\(_{18}\)CoN\(_2\)O\(_4\)\(^{+}\) [M]: 882.677; Found: 882.6714.}

\[ N,N'-\text{Bis}[(E)-(3,5-di-tert-butyl)-2-hydroxyphenylmethylenediamino]-[(1R,2R)-1,2-diphenylethylenediamino]cobalt(II) \] (27)

\[ \text{A mixture of } \text{Co(OAc)}_2 \text{ (123 mg, 0.70 mmol, 1.0 equiv), H}_2\text{O (2.0 mL) and ethanol (4.0 mL) was added to a solution of } N,N'-\text{bis}[(E)-(3,5-di-tert-butyl)-2-hydroxyphenylmethylenediamine]-(1R,2R)-1,2-diphenylethylenediamine \text{ (450 mg, 0.70 mmol, 1.0 equiv) in toluene (4.0 mL, 0.18 M). The reaction mixture was refluxed for 3 h, cooled to rt, concentrated under reduced pressure, then recrystallized from ethanol to obtain 27 (327 mg, 67%) as a vivid red solid. mp > 250 °C. IR (film)/cm\(^{-1}\) 2951 (CH), 2904 (CH), 2867 (CH), 1589 (C=N), 1525, 1454, 1319, 1250, 1179, 787, 698. FTMS (+ p NSI) m/z Calcd for C\(_{44}\)H\(_{54}\)CoN\(_2\)O\(_2\)\(^{+}\) [M]: 701.3512; Found: 701.3505. The observed data was consistent with that previously reported.}\]

\[ N,N'-\text{Bis}[(E)-3-ethoxy-2-hydroxybenzylidene]-[(1R,2R)-1,2-cyclohexanediamino]cobalt(II) \] (28)

\[ \text{A mixture of } \text{Co}^{\text{II}}(\text{OAc})_2 \text{ (33 mg, 0.18 mmol), H}_2\text{O (1.0 mL) and ethanol (2.5 mL) was added to a solution of } N,N'-\text{bis}[(E)-3-ethoxy-2-hydroxybenzylidene]-(1R,2R)-1,2-cyclohexanediamine \text{ (74 mg, 0.18 mmol) in toluene (1.5 mL, 0.12 M). The reaction mixture was refluxed for 3 h, cooled to rt, concentrated under reduced pressure, then recrystallized from CHCl}_3 \text{ to give 28 (74 mg, quant) as a brown solid. mp > 250 °C. IR (film)/cm\(^{-1}\) 3250 (CH), 2980 (CH), 2935 (CH), 2864 (CH), 1635 (C=N), 1603, 1561, 1469, 1447, 1390, 1247, 1222. FTMS (+ p NSI) m/z Calcd for C\(_{20}\)H\(_{20}\)CoN\(_2\)O\(_4\)\(^{+}\) [M]: 411.0750; Found: 411.0750.}\]
HPLC and SFC traces and conditions
Racemic and enantioselective cyclopropanation

Enantioenriched cyclopropanes 1 and 2 were obtained from an asymmetric cyclopropanation (reaction conditions: Table S1, entry 21). The ee was calculated using chiral HPLC, and compared to the corresponding racemic material. HPLC traces were obtained using apparatus consisting of JASCO AS-1555 Intelligent Sampler, 2 × JASCO PU-1580 HPLC Pump, JASCO HG-1580-32 Dynamic Mixer, JASCO MD-1510 Multiwavelength Detector and JASCO LC-Net II/ADC.

(±)-Ethyl 2-(phenylsulfanyl)-cyclopropane-1-carboxylate

**HPLC Conditions:** Chiralpak IB-3 column, 100% n-hexane, flow rate: 1.0 mL min⁻¹, 25 °C, UV detection wavelength: 220 nm. Retention times: 19.4 min (1R,2S enantiomer), 25.0 min (1S,2R enantiomer).

![Chromatogram](image_url)

**Peak results:**

| Index | Name     | Time [Min] | Quantity [% Area] | Height [mAU] | Area [mAU·Min] | Area [%] |
|-------|----------|------------|-------------------|--------------|----------------|----------|
| 1     | UNKNOWN  | 19.372     | 50.21             | 357.5        | 482.9          | 50.214   |
| 2     | UNKNOWN  | 24.972     | 49.57             | 270.9        | 476.7          | 49.569   |
| 3     | UNKNOWN  | 50.303     | 0.22              | 3.0          | 2.1            | 0.217    |
| Total |          |            | 100.00            | 631.4        | 961.6          | 100.00   |
Enantioenriched $E$-ethyl 2-(phenylsulfanyl)-cyclopropane-1-carboxylate

**HPLC Conditions:** Chiralpak IB-3 column, 100% $n$-hexane, flow rate: 1.0 mL min$^{-1}$, 25 °C, UV detection wavelength: 220 nm. Retention times: 22.2 min (1$R,2S$ enantiomer), 27.9 min (1$S,2R$ enantiomer).

\[ \text{ee} = 54.5\% \]
(±)-Z-Ethyl 2-(benzenesulfonyl)cyclopropane-1-carboxylate ((±)-Z-Ethyl 2-(phenylsulfanyl)-cyclopropane-1-carboxylate was oxidized to the corresponding sulfone to facilitate separation of the enantiomers.

**Conditions:** Chiralpak IB-3 column, 90:10 n-hexane:IPA, flow rate: 1.0 mL min⁻¹, 25 °C, UV detection wavelength: 254 nm. Retention times: 23.1 min (1R,2R enantiomer), 25.9 min (1S,2S enantiomer).

### Peak results:

| Index | Name     | Time [Min] | Quantity [% Area] | Height [mAU] | Area [mAU.Min] | Area [%]   |
|-------|----------|------------|-------------------|--------------|----------------|------------|
| 1     | UNKNOWN  | 23.065     | 50.78             | 25.7         | 14.0           | 50.777     |
| 2     | UNKNOWN  | 25.931     | 49.22             | 21.9         | 13.6           | 49.223     |
| Total |          |            | 100.00            | 47.5         | 27.5           | 100.000    |
Enantioenriched Z-Ethyl 2-(benzenesulfonyl)cyclopropane-1-carboxylate (Z-Ethyl 2-(phenylsulfanyl)-cyclopropane-1-carboxylate) was oxidised to the corresponding sulfone to facilitate separation of the enantiomers.

**Conditions:** Chiralpak IB-3 column, 95:5 *n*-hexane:IPA, flow rate: 1.0 mL min\(^{-1}\), 25 °C, UV detection wavelength: 254 nm. Retention times: 23.1 min (1R,2R enantiomer), 25.9 min (1S,2S enantiomer).

**Peak results:**

| Index | Name       | Time [Min] | Quantity [% Area] | Height [mAU] | Area [mAU Min] | Area % [%] |
|-------|------------|------------|-------------------|--------------|----------------|------------|
| 1     | UNKNOWN    | 37.267     | 11.40             | 47.1         | 48.5           | 11.397     |
| 2     | UNKNOWN    | 41.252     | 88.60             | 283.3        | 377.3          | 88.603     |
|       | Total      | 100.00     | 330.4             | 425.8        | 100.000        |            |

\[ ee = 77.2\% \]
Preparative chiral supercritical fluid chromatography (SFC) to obtain highly enantioenriched cyclopropanes

Compounds 1 and 2 were obtained in high ee through preparative chiral SFC using an SFC Minigram. Using this technique, approximately 100-300 mg of each enantiomer was obtained.

Preparative chiral SFC of E-ethyl 2-(phenylsulfanyl)-cyclopropane-1-carboxylate

Conditions: ADH column, 94:6 CO₂:MeOH, flow = 5.0 mL min⁻¹, pressure = 100 bar, temperature = 35 °C, UV detection at 220 nm.

Ethyl (1S,2R)-2-(phenylsulfanyl)-cyclopropane-1-carboxylate

![Graph](image)

| Index | Time   | Width 10% | Height  | Area  | Area [%] |
|-------|--------|-----------|---------|-------|----------|
|       | [Min]  | [Min]     | [mAU]   | [mAU*min] | [%]      |
| 1     | 0.78   | 0.09      | 446.95  | 23.25 | 100.000  |
| Total |        |           |         | 23.25 | 100.000  |

Ethyl (1R,2S)-2-(phenylsulfanyl)-cyclopropane-1-carboxylate

![Graph](image)

| Index | Time   | Width 10% | Height  | Area  | Area [%] |
|-------|--------|-----------|---------|-------|----------|
|       | [Min]  | [Min]     | [mAU]   | [mAU*min] | [%]      |
| 1     | 0.78   | 0.09      | 8.30    | 0.40  | 1.451    |
| 2     | 0.91   | 0.10      | 489.30  | 27.14 | 88.549   |
| Total |        |           |         | 27.54 | 100.000  |
Preparative chiral SFC of Z-ethyl 2-(phenylsulfanyl)-cyclopropane-1-carboxylate

**Conditions:** ADH column, 92:8 CO₂:EtOH + 1% (2M NH₃ in MeOH), flow = 5.0 mL min⁻¹, pressure = 100 bar, temperature = 35 °C, UV detection at 220 nm.

**Ethyl (1S,2S)-2-(phenylsulfanyl)-cyclopropane-1-carboxylate**

![Ethyl (1S,2S)-2-(phenylsulfanyl)-cyclopropane-1-carboxylate chromatogram](image1)

| Index | Time  | Width 10% | Height | Area | Area % |
|-------|-------|-----------|--------|------|--------|
| 1     | 0.79  | 0.08      | 535.19 | 25.65| 100.000|
| Total |       |           |        |      | 25.65  | 100.000|

**Ethyl (1R,2R)-2-(phenylsulfanyl)-cyclopropane-1-carboxylate**

![Ethyl (1R,2R)-2-(phenylsulfanyl)-cyclopropane-1-carboxylate chromatogram](image2)

| Index | Time  | Width 10% | Height | Area | Area % |
|-------|-------|-----------|--------|------|--------|
| 1     | 0.76  | 0.08      | 1.60   | 0.06 | 0.294  |
| 2     | 1.16  | 0.12      | 310.43 | 21.50| 99.706 |
| Total |       |           |        |      | 21.57  | 100.000|
Optical rotation data for enantiopure cyclopropanes 1, 2, 4 and 5

The $[\alpha]^{20}_{D}$ data for each enantiopure compound generated in this work is reported below (Figure S3). Optical rotations ($\alpha'$) were recorded at 20 °C and were converted to the corresponding specific rotations $[\alpha]^{20}_{D}$.

![Chemical structures and optical rotation data](image)

**Figure S3:** Specific optical rotation data and stereochemical configuration for enantiopure synthesized compounds.
$^1$H, $^{13}$C and $^{11}$B NMR spectra
$^{1}$$H$ NMR (400 MHz, CDCl$_3$)

$^{13}$$C$ NMR (101 MHz, CDCl$_3$)
$^1$H NMR (400 MHz, CDCl₃)

$^{13}$C NMR (101 MHz, CDCl₃)

5
$^1$H NMR (400 MHz, CDCl$_3$)
dr = 53:47

$^1$C NMR (101 MHz, CDCl$_3$)
dr = 53:47
\[ ^1H \text{NMR (400 MHz, CDCl}_3) \]
dr = 75:25

\[ ^13C \text{NMR (101 MHz, CDCl}_3) \]
dr = 75:25
$^{1}H$ NMR (400 MHz, CDCl$_3$)

$^{13}$C NMR (101 MHz, CDCl$_3$)
$^1$H NMR (400 MHz, DMSO-$d_6$)

$^{13}$C NMR (101 MHz, DMSO-$d_6$)
$^1$H NMR (400 MHz, CDCl$_3$)

$^{13}$C NMR (101 MHz, CDCl$_3$)
**1H NMR (400 MHz, CDCl₃)**

**13C NMR (101 MHz, CDCl₃)**
$\text{H NMR (400 MHz, DMSO-$d_6$)}$

$\text{C NMR (101 MHz, DMSO-$d_6$)}$
$\text{S. J. Chawner, M. Cases-Thomas and J. A. Bull}$

$^{13}\text{C NMR (101 MHz, DMSO-d$_6$)}$

$^{1}\text{H NMR (400 MHz, DMSO-d$_6$)}$
14a

$^1$H NMR (400 MHz, CDCl$_3$)

14a

$^{13}$C NMR (101 MHz, CDCl$_3$)
$^{1}H$ NMR (400 MHz, CDCl$_3$)

$^{13}$C NMR (101 MHz, CDCl$_3$)
$^{1}H$ NMR (400 MHz, CDCl$_3$)

$^{13}$C NMR (101 MHz, CDCl$_3$)
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15a

$^1$H NMR (400 MHz, CDCl$_3$)

15a

$^{13}$C NMR (101 MHz, CDCl$_3$)
$^{1}$H NMR (400 MHz, CDCl$_3$)

$^{13}$C NMR (101 MHz, CDCl$_3$)
15d

$^1$H NMR (400 MHz, CDCl$_3$)

15d

$^{13}$C NMR (101 MHz, CDCl$_3$)
$^{1}H$ NMR (400 MHz, CDCl$_3$)

$^{13}C$ NMR (101 MHz, CDCl$_3$)
1H NMR (400 MHz, CDCl₃)

13C NMR (400 MHz, CDCl₃)
$^{1}$H NMR (400 MHz, CDCl$_3$)

$^{13}$C NMR (101 MHz, CDCl$_3$)
$^{1}H$ NMR (400 MHz, CDCl$_3$)

$^{13}$C NMR (400 MHz, CDCl$_3$)
19a

1H NMR (400 MHz, CDCl₃)

19a

13C NMR (101 MHz, CDCl₃)
1H NMR (400 MHz, CDCl₃)

$\text{dr} = 56:44$

13C NMR (101 MHz, CDCl₃)

$\text{dr} = 56:44$
$^{1}H$ NMR (400 MHz, CDCl$_3$)

$^{13}C$ NMR (101 MHz, CDCl$_3$)

$\text{dr} = 61:39$
H NMR (400 MHz, CDCl₃)

\[ \text{dr} = 59:41 \]

13C NMR (101 MHz, CDCl₃)

\[ \text{dr} = 59:41 \]
$^{1}H$ NMR (400 MHz, CDCl$_3$)

$^{13}C$ NMR (101 MHz, CDCl$_3$)
$^{1}H$ NMR (400 MHz, CDCl$_3$)



$^{13}C$ NMR (101 MHz, CDCl$_3$)
\[1^1\text{H NMR (400 MHz, CDCl}_3\text{)}\]

\[1^3\text{C NMR (101 MHz, CDCl}_3\text{)}\]
$^{19}$B NMR (128 MHz, CDCl$_3$)
$^{1}H$ NMR (400 MHz, CDCl$_3$)

$^{13}C$ NMR (101 MHz, CDCl$_3$)
20a

$^1$H NMR (400 MHz, CDCl$_3$)



20a

$^{13}$C NMR (101 MHz, CDCl$_3$)
$^{1}H$ NMR (400 MHz, CDCl$_3$)
$\text{dr} = 60:40$

$^{13}C$ NMR (101 MHz, CDCl$_3$)
$\text{dr} = 60:40$
$^{1}$H NMR (400 MHz, CDCl$_3$)

$^{13}$C NMR (101 MHz, CDCl$_3$)
$^{1}H$ NMR (400 MHz, CDCl$_3$)

$^{13}$C NMR (101 MHz, CDCl$_3$)


H NMR (400 MHz, CDCl₃)

^1^H NMR (400 MHz, CDCl₃)

C NMR (400 MHz, CDCl₃)

^1^C NMR (400 MHz, CDCl₃)
$^{1}H$ NMR (400 MHz, CDCl$_3$)

$^{13}C$ NMR (101 MHz, CDCl$_3$)
20h

$^1$H NMR (400 MHz, CDCl$_3$)

20h

$^{13}$C NMR (101 MHz, CDCl$_3$)
$^1$H NMR (400 MHz, CDCl$_3$)

$^{13}$C NMR (101 MHz, CDCl$_3$)
$^{11}$B NMR (128 MHz, CDCl$_3$)
22a

$^1$H NMR (400 MHz, CDCl$_3$)

22a

$^{13}$C NMR (101 MHz, CDCl$_3$)
21b  
$^1$H NMR (400 MHz, CDCl$_3$)

21b  
$^{13}$C NMR (101 MHz, CDCl$_3$)
$^{13}$C NMR (101 MHz, CDCl$_3$)
$^{1}H$ NMR (400 MHz, CDCl$_3$)

$^{13}$C NMR (101 MHz, CDCl$_3$)
$^{13}$C NMR (101 MHz, CDCl$_3$)

$^1$H NMR (400 MHz, CDCl$_3$)

...
$^{1}H$ NMR (400 MHz, CDCl$_3$)

$^{13}C$ NMR (101 MHz, CDCl$_3$)
$^1$H NMR (400 MHz, CDCl$_3$)

$^{13}$C NMR (101 MHz, CDCl$_3$)
$^{1}H$ NMR (400 MHz, CDCl$_{3}$)

$^{13}C$ NMR (101 MHz, CDCl$_{3}$)
$^1$H NMR (400 MHz, DMSO-$d_6$)

$^{13}$C NMR (101 MHz, DMSO-$d_6$)
1H NMR (400 MHz, CDCl₃)

24

13C NMR (101 MHz, CDCl₃)
$^{1}H$ NMR (400 MHz, CDCl$_3$)

$^{13}$C NMR (101 MHz, CDCl$_3$)
X-ray crystallography data
X-ray crystallography data
Single crystals were grown by dissolving the compound in the minimum volume of ethyl acetate and allowing the solvent to slowly evaporate from a loosely capped vial. CCDC 1548245, CCDC 1548246, CCDC 1550178 and CCDC 1550151 contain the supplementary crystallographic data for compounds (+)-4, (−)-4, (−)-5 and (+)-5, respectively, for this paper. The data can be obtained free of charge from the Cambridge Crystallographic Data Centre via www.ccdc.cam.ac.uk/structures.

Ethyl (1R,2S)-2-(benzenesulfonyl)cyclopropane-1-carboxylate (+)-4

Table S5. Crystal data and structure refinement for ethyl (1R,2S)-2-(benzenesulfonyl)cyclopropane-1-carboxylate (+)-4.

| Property                            | Value                        |
|-------------------------------------|------------------------------|
| Identification code                 | cu_16094_0m_a                |
| Empirical formula                   | C12 H14 O4 S                 |
| Formula weight                      | 254.29                       |
| Temperature                         | 100(2) K                     |
| Wavelength                          | 1.54178 Å                    |
| Crystal system                      | Monoclinic                   |
| Space group                         | P2₁                          |
| Unit cell dimensions                | a = 5.3506(4) Å, b = 14.0370(10) Å, c = 8.5086(9) Å | 90°, 104.317(5)°, 90°. |
| Volume                              | 619.20(9) Å³                 |
| Z                                    | 2                            |
| Density (calculated)                | 1.364 Mg/m³                  |
| Absorption coefficient              | 2.349 mm⁻¹                   |
| F(000)                              | 268                          |
| Crystal size                        | 0.230 x 0.097 x 0.056 mm³    |
| Theta range for data collection     | 5.365 to 72.241°.            |
Index ranges
-6<=h<=6, -17<=k<=17, -10<=l<=10

Reflections collected
9885

Independent reflections
2386 [R(int) = 0.0322]

Completeness to \( \theta = 67.679^\circ \) 99.6 %

Refinement method
Full-matrix least-squares on \( F^2 \)

Data / restraints / parameters
2386 / 1 / 156

Goodness-of-fit on \( F^2 \) 1.049

Final R indices [I>2\sigma(I)]
R1 = 0.0274, wR2 = 0.0691

R indices (all data)
R1 = 0.0277, wR2 = 0.0694

Absolute structure parameter
0.070(6)

Extinction coefficient
0.058(5)

Largest diff. peak and hole
0.248 and -0.341 e.Å^-3

Table S6. Atomic coordinates \((x \times 10^4)\) and equivalent isotropic displacement parameters \((Å^2 \times 10^3)\) for ethyl \((1R,2S)-(\text{benzenesulfonyl})\text{cyclopropane-1-carboxylate (}\pm\text{-}4\). U(eq) is defined as one third of the trace of the orthogonalized \(U_{ij}\) tensor.

|     | x     | y     | z     | U(eq) |
|-----|-------|-------|-------|-------|
| S(1)| 5421(1)| 4071(1)| 4387(1)| 20(1) |
| O(1)| 3961(3)| 3293(1)| 3504(2)| 29(1) |
| O(5)| 2322(3)| 6212(1)| -105(2)| 26(1) |
| O(2)| 7992(3)| 4241(1)| 4207(2)| 30(1) |
| O(4)| 146(3) | 6490(1)| 1798(2)| 36(1) |
| C(1)| 4250(4)| 5721(2)| 2517(3)| 24(1) |
| C(8)| 5591(4)| 3918(1)| 6479(2)| 21(1) |
| C(2)| 3627(4)| 5121(1)| 3863(2)| 21(1) |
| C(4)| 2000(4)| 6181(1)| 1396(3)| 24(1) |
| C(13)| 7643(4)| 4315(2)| 7611(3)| 29(1) |
| C(9)| 3697(4)| 3398(2)| 6940(3)| 27(1) |
| C(3)| 4954(5)| 6063(2)| 4248(3)| 30(1) |
| C(6)| 346(4) | 6711(2)| -1309(3)| 28(1) |
| C(10)| 3866(5)| 3278(2)| 8592(3)| 32(1) |
| C(12)| 7756(5)| 4209(2)| 9255(3)| 36(1) |
| C(11)| 5862(5)| 3692(2)| 9733(3)| 33(1) |
| C(7)| 1274(5)| 6724(2)| -2838(3)| 33(1) |
Table S7. Bond lengths [Å] and angles [°] for ethyl (1R,2S)-2-(benzenesulfonyl)cyclopropane-1-carboxylate (+)-4.

| Bond                  | Distance [Å] |
|-----------------------|--------------|
| S(1)-O(1)             | 1.4406(16)   |
| S(1)-O(2)             | 1.4414(14)   |
| S(1)-C(2)             | 1.755(2)     |
| S(1)-C(8)             | 1.7724(19)   |
| O(5)-C(4)             | 1.331(3)     |
| O(5)-C(6)             | 1.457(3)     |
| O(4)-C(4)             | 1.207(3)     |
| C(1)-C(4)             | 1.486(3)     |
| C(1)-C(3)             | 1.506(3)     |
| C(1)-C(2)             | 1.523(3)     |
| C(1)-H(1)             | 1.0000       |
| C(8)-C(9)             | 1.382(3)     |
| C(8)-C(13)            | 1.386(3)     |
| C(2)-C(3)             | 1.499(3)     |
| C(2)-H(2)             | 1.0000       |
| C(13)-C(12)           | 1.393(3)     |
| C(13)-H(13)           | 0.9500       |
| C(9)-C(10)            | 1.396(3)     |
| C(9)-H(9)             | 0.9500       |
| C(3)-H(3A)            | 0.9900       |
| C(3)-H(3B)            | 0.9900       |
| C(6)-C(7)             | 1.502(3)     |
| C(6)-H(6A)            | 0.9900       |
| C(6)-H(6B)            | 0.9900       |
| C(10)-C(11)           | 1.381(4)     |
| C(10)-H(10)           | 0.9500       |
| C(12)-C(11)           | 1.387(4)     |
| C(12)-H(12)           | 0.9500       |
| C(11)-H(11)           | 0.9500       |
| C(7)-H(7A)            | 0.9800       |
| C(7)-H(7B)            | 0.9800       |
| C(7)-H(7C)            | 0.9800       |
| O(1)-S(1)-O(2)        | 118.60(10)   |
| O(1)-S(1)-C(2)        | 108.16(9)    |
| Bond                  | Angle (deg) |
|-----------------------|-------------|
| O(2)-S(1)-C(2)        | 108.07(10)  |
| O(1)-S(1)-C(8)        | 108.59(9)   |
| O(2)-S(1)-C(8)        | 108.26(10)  |
| C(2)-S(1)-C(8)        | 104.23(9)   |
| C(4)-O(5)-C(6)        | 116.57(16)  |
| C(4)-C(1)-C(3)        | 117.11(18)  |
| C(4)-C(1)-C(2)        | 115.46(17)  |
| C(3)-C(1)-C(2)        | 59.31(13)   |
| C(4)-C(1)-H(1)        | 117.4       |
| C(3)-C(1)-H(1)        | 117.4       |
| C(2)-C(1)-H(1)        | 117.4       |
| C(9)-C(8)-C(13)       | 121.69(19)  |
| C(9)-C(8)-S(1)        | 119.32(16)  |
| C(13)-C(8)-S(1)       | 118.98(16)  |
| C(3)-C(2)-C(1)        | 59.79(14)   |
| C(3)-C(2)-S(1)        | 119.08(15)  |
| C(1)-C(2)-S(1)        | 116.61(14)  |
| C(3)-C(2)-H(2)        | 116.5       |
| C(1)-C(2)-H(2)        | 116.5       |
| S(1)-C(2)-H(2)        | 116.5       |
| O(4)-C(4)-O(5)        | 124.75(19)  |
| O(4)-C(4)-C(1)        | 124.5(2)    |
| O(5)-C(4)-C(1)        | 110.72(16)  |
| C(8)-C(13)-C(12)      | 119.0(2)    |
| C(8)-C(13)-H(13)      | 120.5       |
| C(12)-C(13)-H(13)     | 120.5       |
| C(8)-C(9)-C(10)       | 118.7(2)    |
| C(8)-C(9)-H(9)        | 120.6       |
| C(10)-C(9)-H(9)       | 120.6       |
| C(2)-C(3)-C(1)        | 60.90(14)   |
| C(2)-C(3)-H(3A)       | 117.7       |
| C(1)-C(3)-H(3A)       | 117.7       |
| C(2)-C(3)-H(3B)       | 117.7       |
| C(1)-C(3)-H(3B)       | 117.7       |
| H(3A)-C(3)-H(3B)      | 114.8       |
| O(5)-C(6)-C(7)        | 106.10(19)  |
| O(5)-C(6)-H(6A)       | 110.5       |
| C(7)-C(6)-H(6A)       | 110.5       |
O(5)-C(6)-H(6B)    110.5
C(7)-C(6)-H(6B)    110.5
H(6A)-C(6)-H(6B)   108.7
C(11)-C(10)-C(9)   120.2(2)
C(11)-C(10)-H(10)  119.9
C(9)-C(10)-H(10)   119.9
C(11)-C(12)-C(13)  119.8(2)
C(11)-C(12)-H(12)  120.1
C(13)-C(12)-H(12)  120.1
C(10)-C(11)-C(12)  120.6(2)
C(10)-C(11)-H(11)  119.7
C(12)-C(11)-H(11)  119.7
C(6)-C(7)-H(7A)    109.5
C(6)-C(7)-H(7B)    109.5
H(7A)-C(7)-H(7B)   109.5
C(6)-C(7)-H(7C)    109.5
H(7A)-C(7)-H(7C)   109.5
H(7B)-C(7)-H(7C)   109.5

Symmetry transformations used to generate equivalent atoms:
Table S8. Anisotropic displacement parameters (Å² x 10³) for ethyl (1R,2S)-2-(benzenesulfonyl) cyclopropane-1-carboxylate (†)-4. The anisotropic displacement factor exponent takes the form: 

\[-2 \sum h^2 a^* U_{11} + \ldots + 2hk a^* b^* U_{12}\]

|   | u_{11} | u_{22} | u_{33} | u_{23} | u_{13} | u_{12} |
|---|--------|--------|--------|--------|--------|--------|
| S(1) | 20(1)  | 22(1)  | 21(1)  | 1(1)   | 9(1)   | 2(1)   |
| O(1)  | 35(1)  | 24(1)  | 28(1)  | -5(1)  | 9(1)   | 0(1)   |
| O(5)  | 26(1)  | 28(1)  | 24(1)  | 4(1)   | 6(1)   | 5(1)   |
| O(2)  | 21(1)  | 40(1)  | 32(1)  | 10(1)  | 12(1)  | 5(1)   |
| O(4)  | 32(1)  | 43(1)  | 35(1)  | 9(1)   | 14(1)  | 14(1)  |
| C(1)  | 23(1)  | 25(1)  | 25(1)  | 4(1)   | 8(1)   | 0(1)   |
| C(8)  | 23(1)  | 18(1)  | 24(1)  | 1(1)   | 9(1)   | 2(1)   |
| C(2)  | 20(1)  | 20(1)  | 22(1)  | 1(1)   | 7(1)   | 0(1)   |
| C(4)  | 24(1)  | 22(1)  | 28(1)  | 2(1)   | 8(1)   | 1(1)   |
| C(13) | 31(1)  | 27(1)  | 30(1)  | 2(1)   | 7(1)   | -8(1)  |
| C(9)  | 26(1)  | 27(1)  | 30(1)  | -1(1)  | 10(1)  | -3(1)  |
| C(3)  | 35(1)  | 22(1)  | 30(1)  | -1(1)  | 2(1)   | -4(1)  |
| C(6)  | 26(1)  | 25(1)  | 28(1)  | 3(1)   | 1(1)   | 2(1)   |
| C(10) | 37(1)  | 30(1)  | 34(1)  | 6(1)   | 19(1)  | -1(1)  |
| C(12) | 47(1)  | 31(1)  | 26(1)  | -1(1)  | 1(1)   | -8(1)  |
| C(11) | 50(1)  | 28(1)  | 22(1)  | 2(1)   | 14(1)  | 5(1)   |
| C(7)  | 38(1)  | 32(1)  | 26(1)  | 4(1)   | 4(1)   | -7(1)  |
Table S9. Hydrogen coordinates (x 10^4) and isotropic displacement parameters (Å^2 x 10^3) for ethyl (1R,2S)-2-(benzenesulfonyl)cyclopropane-1-carboxylate (+)-4.

|   | x    | y    | z    | U(eq) |
|---|------|------|------|-------|
| H(1) | 5686 | 5498 | 2047 | 29    |
| H(2) | 1774 | 5094 | 3898 | 25    |
| H(13) | 8953 | 4655 | 7271 | 35    |
| H(9) | 2308 | 3128 | 6149 | 32    |
| H(3A) | 6801 | 6059 | 4830 | 36    |
| H(3B) | 3944 | 6597 | 4537 | 36    |
| H(6A) | 122  | 7368 |-945  | 33    |
| H(6B) | -1326| 6373 |-1491 | 33    |
| H(10) | 2605 | 2910 | 8933 | 38    |
| H(12) | 9127 | 4490 | 10046| 43    |
| H(11) | 5937 | 3623 | 10854| 39    |
| H(7A) | 2949 | 7046 | -2630| 49    |
| H(7B) | 25   | 7066 |-3687 | 49    |
| H(7C) | 1453 | 6069 |-3193 | 49    |
Table S10. Torsion angles [*] for ethyl (1R,2S)-2-(benzenesulfonyl)cyclopropane-1-carboxylate (+)-4.

| Torsion Angle | Torsion Angle | Torsion Angle | Torsion Angle |
|---------------|---------------|---------------|---------------|
| O(1)-S(1)-C(8)-C(9) | -24.98(19) | O(2)-S(1)-C(8)-C(9) | -154.98(17) |
| C(2)-S(1)-C(8)-C(9) | 90.14(18) | O(1)-S(1)-C(8)-C(13) | 154.26(17) |
| O(2)-S(1)-C(8)-C(13) | 24.26(19) | C(2)-S(1)-C(8)-C(13) | -90.62(18) |
| C(4)-C(1)-C(2)-C(3) | -107.7(2) | C(4)-C(1)-C(2)-S(1) | 142.57(17) |
| C(3)-C(1)-C(2)-S(1) | -109.71(18) | O(1)-S(1)-C(2)-C(3) | -163.86(15) |
| O(2)-S(1)-C(2)-C(3) | -34.30(18) | C(8)-S(1)-C(2)-C(3) | 80.72(17) |
| O(1)-S(1)-C(2)-C(1) | -95.29(16) | O(2)-S(1)-C(2)-C(1) | 34.27(18) |
| C(8)-S(1)-C(2)-C(1) | 149.28(15) | C(6)-O(5)-C(4)-O(4) | 4.0(3) |
| C(6)-O(5)-C(4)-C(1) | -175.52(19) | C(3)-C(1)-C(4)-O(4) | -31.5(3) |
| C(2)-C(1)-C(4)-O(4) | 35.5(3) | C(3)-C(1)-C(4)-O(5) | 148.05(18) |
| C(2)-C(1)-C(4)-O(5) | -144.98(18) | C(9)-C(8)-C(13)-C(12) | -1.8(3) |
| S(1)-C(8)-C(13)-C(12) | 178.96(17) | C(13)-C(8)-C(9)-C(10) | 0.3(3) |
| S(1)-C(8)-C(9)-C(10) | 179.54(16) | S(1)-C(2)-C(3)-C(1) | 105.62(17) |
| C(4)-C(1)-C(3)-C(2) | 104.9(2) | C(4)-O(5)-C(6)-C(7) | 174.78(17) |
| C(8)-C(9)-C(10)-C(11) | 1.5(3) | C(8)-C(13)-C(12)-C(11) | 1.5(4) |
| C(9)-C(10)-C(11)-C(12) | -1.8(4) | C(13)-C(12)-C(11)-C(10) | 0.3(4) |

Symmetry transformations used to generate equivalent atoms:
### Table S11. Crystal data and structure refinement for lot ethyl (1S,2R)-2-(benzenesulfonyl)cyclopropane-1-carboxylate (−)-4.

| Identification code        | cu_16082_0m_a                        |
|----------------------------|--------------------------------------|
| Empirical formula          | C12 H14 O4 S                         |
| Formula weight             | 254.29                               |
| Temperature                | 100(2) K                             |
| Wavelength                 | 1.54178 Å                            |
| Crystal system             | Monoclinic                           |
| Space group                | P2₁                                  |
| Unit cell dimensions       |                                      |
| a                          | 5.3421(7) Å                         |
| b                          | 14.016(2) Å                         |
| c                          | 8.4966(15) Å                        |
| Volume                     | 616.41(17) Å³                       |
| Z                          | 2                                    |
| Density (calculated)       | 1.370 Mg/m³                         |
| Absorption coefficient     | 2.360 mm⁻¹                          |
| F(000)                     | 268                                  |
| Crystal size               | 0.349 x 0.319 x 0.117 mm³           |
| Theta range for data collection | 5.373 to 72.390°.                |
| Index ranges               | -6<=h<=6, -17<=k<=17, -10<=l<=10     |
| Reflections collected      | 8416                                 |
| Independent reflections    | 2356 [R(int) = 0.0592]               |
| Completeness to theta      | 67.679° 99.7 %                      |
| Absorption correction      | Multi-scan                           |
| Refinement method          | Full-matrix least-squares on F²     |
| Data / restraints / parameters | 2356 / 1 / 156                     |
Goodness-of-fit on $F^2$ 1.037
Final R indices [$I>2\sigma(I)$] R1 = 0.0388, wR2 = 0.1006
R indices (all data) R1 = 0.0406, wR2 = 0.1020
Absolute structure parameter 0.163(13)
Extinction coefficient 0.022(3)
Largest diff. peak and hole 0.433 and -0.396 eÅ$^{-3}$

Table S12. Atomic coordinates (x $10^4$) and equivalent isotropic displacement parameters (Å$^2x10^3$) for ethyl (1$S$,2$R$)-2-(benzenesulfonyl)cyclopropane-1-carboxylate (−)-4. U(eq) is defined as one third of the trace of the orthogonalized $U_{ij}$ tensor.

|     | x    | y    | z    | U(eq) |
|-----|------|------|------|-------|
| S(1)| 5418(1) | 5931(1) | 4393(1) | 21(1) |
| O(2)| 3956(5) | 6709(2) | 3513(3) | 29(1) |
| O(1)| 7986(5) | 5763(2) | 4216(3) | 30(1) |
| O(5)| 2335(5) | 3789(2) | -99(3)  | 25(1) |
| O(4)| 159(6)  | 3512(2) | 1801(4) | 36(1) |
| C(2)| 4260(7) | 4281(2) | 2526(4) | 23(1) |
| C(4)| 2007(6) | 3817(2) | 1406(4) | 23(1) |
| C(8)| 5590(7) | 6083(2) | 6477(4) | 22(1) |
| C(1)| 3634(6) | 4881(3) | 3871(4) | 22(1) |
| C(6)| 343(7)  | 3290(3) | -1308(5)| 27(1) |
| C(9)| 7637(7) | 5681(3) | 7617(5) | 29(1) |
| C(13)| 3692(7) | 6603(3) | 6948(4) | 26(1) |
| C(3)| 4961(8) | 3938(3) | 4252(5) | 30(1) |
| C(10)| 7743(8) | 5789(3) | 9256(5)| 36(1) |
| C(11)| 5855(8) | 6302(3) | 9742(5)| 31(1) |
| C(7)| 1286(8) | 3274(3) | -2829(5)| 31(1) |
| C(12)| 3862(8) | 6722(3) | 8594(5)| 32(1) |
Table S13. Bond lengths [Å] and angles [°] for ethyl (1S,2R)-2-(benzenesulfonyl)cyclopropane-1-carboxylate (–)-4.

| Bond                  | Length [Å]   |
|-----------------------|--------------|
| S(1)-O(1)             | 1.436(2)     |
| S(1)-O(2)             | 1.438(3)     |
| S(1)-C(1)             | 1.751(4)     |
| S(1)-C(8)             | 1.763(4)     |
| O(5)-C(4)             | 1.334(4)     |
| O(5)-C(6)             | 1.462(4)     |
| O(4)-C(4)             | 1.197(4)     |
| C(2)-C(4)             | 1.487(5)     |
| C(2)-C(3)             | 1.500(5)     |
| C(2)-C(1)             | 1.521(5)     |
| C(2)-H(2)             | 1.0000       |
| C(8)-C(13)            | 1.386(5)     |
| C(8)-C(9)             | 1.389(5)     |
| C(1)-C(3)             | 1.497(5)     |
| C(1)-H(1)             | 1.0000       |
| C(6)-C(7)             | 1.498(5)     |
| C(6)-H(6A)            | 0.9900       |
| C(6)-H(6B)            | 0.9900       |
| C(9)-C(10)            | 1.388(5)     |
| C(9)-H(9)             | 0.9500       |
| C(13)-C(12)           | 1.389(5)     |
| C(13)-H(13)           | 0.9500       |
| C(3)-H(3A)            | 0.9900       |
| C(3)-H(3B)            | 0.9900       |
| C(10)-C(11)           | 1.382(6)     |
| C(10)-H(10)           | 0.9500       |
| C(11)-C(12)           | 1.385(6)     |
| C(11)-H(11)           | 0.9500       |
| C(7)-H(7A)            | 0.9800       |
| C(7)-H(7B)            | 0.9800       |
| C(7)-H(7C)            | 0.9800       |
| C(12)-H(12)           | 0.9500       |

| Bond                  | Angle [°]    |
|-----------------------|--------------|
| O(1)-S(1)-O(2)        | 118.68(16)   |
| O(1)-S(1)-C(1)        | 108.02(16)   |
O(2)-S(1)-C(1)  108.30(16)
O(1)-S(1)-C(8)  108.15(17)
O(2)-S(1)-C(8)  108.50(16)
C(1)-S(1)-C(8)  104.26(16)
C(4)-O(5)-C(6)  116.3(3)
C(4)-C(2)-C(3)  116.9(3)
C(4)-C(2)-C(1)  115.4(3)
C(3)-C(2)-C(1)  59.4(2)
C(4)-C(2)-H(2)  117.5
C(3)-C(2)-H(2)  117.5
C(1)-C(2)-H(2)  117.5
O(4)-C(4)-O(5)  124.8(3)
O(4)-C(4)-C(2)  124.8(3)
O(5)-C(4)-C(2)  110.4(3)
C(13)-C(8)-C(9)  121.2(3)
C(13)-C(8)-S(1)  119.6(3)
C(9)-C(8)-S(1)  119.2(3)
C(3)-C(1)-C(2)  59.6(2)
C(3)-C(1)-S(1)  119.2(3)
C(2)-C(1)-S(1)  116.6(2)
C(3)-C(1)-H(1)  116.4
C(2)-C(1)-H(1)  116.4
S(1)-C(1)-H(1)  116.4
O(5)-C(6)-C(7)  105.8(3)
O(5)-C(6)-H(6A)  110.6
C(7)-C(6)-H(6A)  110.6
O(5)-C(6)-H(6B)  110.6
C(7)-C(6)-H(6B)  110.6
H(6A)-C(6)-H(6B)  108.7
C(10)-C(9)-C(8)  119.0(3)
C(10)-C(9)-H(9)  120.5
C(8)-C(9)-H(9)  120.5
C(8)-C(13)-C(12)  118.9(3)
C(8)-C(13)-H(13)  120.5
C(12)-C(13)-H(13)  120.5
C(1)-C(3)-C(2)  61.0(2)
C(1)-C(3)-H(3A)  117.7
C(2)-C(3)-H(3A)  117.7
Symmetry transformations used to generate equivalent atoms:
Table S14. Anisotropic displacement parameters (Å² x 10³) for ethyl (1S,2R)-2-(benzenesulfonyl) cyclopropane-1-carboxylate (–)-4. The anisotropic displacement factor exponent takes the form: 
\[-2\sum h^2 a^* u_{11} + \ldots + 2hk a^* b^* u_{12}\]

|     | u₁₁  | u₂₂  | u₃₃  | u₂₃  | u₁₃  | u₁₂  |
|-----|------|------|------|------|------|------|
| S(1)| 19(1)| 23(1)| 24(1)| -2(1)| 12(1)| -2(1)|
| O(2)| 34(1)| 26(1)| 29(1)|  1(1)| 13(1)| -1(1)|
| O(1)| 23(1)| 39(2)| 34(1)| -9(1)| 16(1)| -6(1)|
| O(5)| 26(1)| 28(1)| 23(1)| -4(1)| 10(1)| -7(1)|
| O(4)| 30(2)| 44(2)| 38(2)| -9(1)| 18(1)|-14(1)|
| C(2)| 20(2)| 24(2)| 28(2)| -4(1)| 12(1)|-2(1)|
| C(4)| 22(2)| 21(2)| 29(2)|  0(1)| 12(1)|  0(1)|
| C(8)| 23(2)| 19(2)| 29(2)|  0(1)| 13(1)| -2(1)|
| C(1)| 19(2)| 24(2)| 25(2)| -1(1)| 11(1)| -1(1)|
| C(6)| 22(2)| 26(2)| 32(2)| -3(2)|  5(2)|-1(1)|
| C(9)| 29(2)| 27(2)| 34(2)| -2(1)| 11(2)|  8(1)|
| C(13)|26(2)| 26(2)| 29(2)| -1(1)| 13(2)|  2(1)|
| C(3)| 34(2)| 22(2)| 32(2)| -1(1)|  7(2)|  3(2)|
| C(10)|43(2)| 35(2)| 27(2)|  2(2)|  4(2)|  7(2)|
| C(11)|42(2)| 28(2)| 26(2)| -2(1)| 15(2)|-4(2)|
| C(7)| 35(2)| 30(2)| 28(2)| -3(2)|  8(2)|  6(2)|
| C(12)|37(2)| 30(2)| 35(2)| -7(2)| 24(2)|-1(2)|
Table S15. Hydrogen coordinates (x 10⁴) and isotropic displacement parameters (Å² x 10³) for ethyl (1S,2R)-2-(benzenesulfonyl)cyclopropane-1-carboxylate (−)-4.

|       | x    | y    | z    | U(eq) |
|-------|------|------|------|-------|
| H(2)  | 5698 | 4504 | 2055 | 28    |
| H(1)  | 1777 | 4906 | 3904 | 26    |
| H(6A) | -1327| 3631 | -1494| 32    |
| H(6B) | 110  | 2632 | -944 | 32    |
| H(9)  | 8946 | 5337 | 7280 | 35    |
| H(13) | 2296 | 6873 | 6158 | 31    |
| H(3A) | 3949 | 3402 | 4539 | 35    |
| H(3B) | 6811 | 3941 | 4836 | 35    |
| H(10) | 9121 | 5510 | 10048| 43    |
| H(11) | 5924 | 6366 | 10865| 37    |
| H(7A) | 1456 | 3930 | -3190| 47    |
| H(7B) | 47   | 2927 | -3679| 47    |
| H(7C) | 2970 | 2956 | -2612| 47    |
| H(12) | 2605 | 7093 | 8935 | 38    |
Table S16. Torsion angles [°] for ethyl (1S,2R)-2-(benzenesulfonyl)cyclopropane-1-carboxylate (−)-4.

| Bond Sequence                  | Torsion Angle [°] |
|--------------------------------|-------------------|
| C(6)-O(5)-C(4)-O(4)            | -4.2(5)           |
| C(6)-O(5)-C(4)-C(2)            | 175.8(3)          |
| C(3)-C(2)-C(4)-O(4)            | 31.9(5)           |
| C(1)-C(2)-C(4)-O(4)            | -35.1(5)          |
| C(3)-C(2)-C(4)-O(5)            | -148.1(3)         |
| C(1)-C(2)-C(4)-O(5)            | 144.9(3)          |
| O(1)-S(1)-C(8)-C(13)           | 155.1(3)          |
| O(2)-S(1)-C(8)-C(13)           | 25.1(3)           |
| C(1)-S(1)-C(8)-C(13)           | -90.1(3)          |
| O(1)-S(1)-C(8)-C(9)            | -24.7(3)          |
| O(2)-S(1)-C(8)-C(9)            | -154.7(3)         |
| C(1)-S(1)-C(8)-C(9)            | 90.0(3)           |
| C(4)-C(2)-C(1)-C(3)            | 107.5(3)          |
| C(4)-C(2)-C(1)-S(1)            | -142.6(3)         |
| C(3)-C(2)-C(1)-S(1)            | 109.9(3)          |
| O(1)-S(1)-C(1)-C(3)            | 34.1(3)           |
| O(2)-S(1)-C(1)-C(3)            | 163.8(3)          |
| C(8)-S(1)-C(1)-C(3)            | -80.8(3)          |
| O(1)-S(1)-C(1)-C(2)            | -34.3(3)          |
| O(2)-S(1)-C(1)-C(2)            | 95.4(3)           |
| C(8)-S(1)-C(1)-C(2)            | -149.2(3)         |
| C(4)-O(5)-C(6)-C(7)            | -174.5(3)         |
| C(13)-C(8)-C(9)-C(10)          | 1.2(5)            |
| S(1)-C(8)-C(9)-C(10)           | -178.9(3)         |
| C(9)-C(8)-C(13)-C(12)          | 0.2(5)            |
| S(1)-C(8)-C(13)-C(12)          | -179.6(3)         |
| S(1)-C(1)-C(3)-C(2)            | -105.5(3)         |
| C(4)-C(2)-C(3)-C(1)            | -105.0(3)         |
| C(8)-C(9)-C(10)-C(11)          | -0.9(6)           |
| C(9)-C(10)-C(11)-C(12)         | -0.9(7)           |
| C(10)-C(11)-C(12)-C(13)        | 2.4(7)            |
| C(8)-C(13)-C(12)-C(11)         | -2.0(6)           |

Symmetry transformations used to generate equivalent atoms:
Table S17. Crystal data and structure refinement for lot ethyl (1S,2S)-2-(benzenesulfonyl)cyclopropane-1-carboxylate (−)-5.

| Property                                      | Value                                      |
|-----------------------------------------------|--------------------------------------------|
| Identification code                           | cu_16003_0m_a                              |
| Empirical formula                             | C12 H14 O4 S                               |
| Formula weight                                | 254.29                                     |
| Temperature                                   | 100(2) K                                   |
| Wavelength                                    | 1.54178 Å                                  |
| Crystal system                                | Orthorhombic                               |
| Space group                                   | P2₁2₁2₁                                    |
| Unit cell dimensions                          | a = 5.516(2) Å = 90°.                      |
|                                              | b = 14.424(7) Å = 90°.                     |
|                                              | c = 15.436(9) Å = 90°.                     |
| Volume                                        | 1228.1(10) Å³                              |
| Z                                             | 4                                          |
| Density (calculated)                          | 1.375 Mg/m³                                |
| Absorption coefficient                        | 2.369 mm⁻¹                                 |
| F(000)                                        | 536                                        |
| Crystal size                                  | 0.250 x 0.070 x 0.050 mm³                  |
| Theta range for data collection               | 6.505 to 72.585°.                          |
| Index ranges                                  | -6≤h≤6, -15≤k≤17, -18≤l≤18                 |
| Reflections collected                         | 12802                                      |
| Independent reflections                       | 2389 [R(int) = 0.0281]                     |
| Completeness to theta = 67.679°              | 99.2 %                                     |
| Absorption correction                         | Multi-scan                                 |
| Refinement method                             | Full-matrix least-squares on F²           |
Data / restraints / parameters 2389 / 0 / 156
Goodness-of-fit on F² 1.066
Final R indices [I>2sigma(I)] R1 = 0.0272, wR2 = 0.0763
R indices (all data) R1 = 0.0276, wR2 = 0.0766
Absolute structure parameter 0.047(4)
Extinction coefficient 0.0119(16)
Largest diff. peak and hole 0.682 and -0.281 e.Å⁻³

Table S18. Atomic coordinates ( x 10⁴) and equivalent isotropic displacement parameters (Å² x 10³) for ethyl (1S,2S)-2-(benzenesulfonyl)cyclopropane-1-carboxylate (–)-5. U(eq) is defined as one third of the trace of the orthogonalized Uᵢⱼ tensor.

|     | x     | y     | z     | U(eq) |
|-----|-------|-------|-------|-------|
| S(1)| 3737  | 5244  | 1731  | 18    |
| O(2)| 1167  | 5418  | 1670  | 24    |
| O(1)| 4754  | 4484  | 1254  | 27    |
| O(4)| -60   | 7483  | 1424  | 29    |
| O(5)| 1839  | 7479  | 2709  | 28    |
| C(8)| 4501  | 5102  | 2833  | 19    |
| C(2)| 4225  | 7203  | 1495  | 21    |
| C(3)| 4455  | 6757  | 625   | 24    |
| C(13)| 2914 | 5413  | 3465  | 25    |
| C(1)| 5296  | 6245  | 1418  | 20    |
| C(4)| 1751  | 7386  | 1847  | 22    |
| C(10)| 7278 | 4581  | 3913  | 28    |
| C(11)| 5716 | 4895  | 4553  | 30    |
| C(9)| 6683  | 4684  | 3044  | 24    |
| C(12)| 3533 | 5304  | 4331  | 30    |
| C(6)| -460  | 7704  | 3124  | 43    |
| C(7)| 37    | 7809  | 4059  | 61    |
Table S19. Bond lengths [Å] and angles [°] for ethyl (1S,2S)-2-(benzenesulfonyl)cyclopropane-1-carboxylate (−)-5.

| Bond                        | Distance [Å]     |
|-----------------------------|------------------|
| S(1)-O(1)                   | 1.4345(17)       |
| S(1)-O(2)                   | 1.4427(17)       |
| S(1)-C(1)                   | 1.749(2)         |
| S(1)-C(8)                   | 1.764(2)         |
| O(4)-C(4)                   | 1.201(3)         |
| O(5)-C(4)                   | 1.339(3)         |
| O(5)-C(6)                   | 1.457(3)         |
| C(8)-C(9)                   | 1.385(3)         |
| C(8)-C(13)                  | 1.386(3)         |
| C(2)-C(4)                   | 1.492(3)         |
| C(2)-C(3)                   | 1.494(3)         |
| C(2)-C(1)                   | 1.507(3)         |
| C(2)-H(2)                   | 1.0000           |
| C(3)-C(1)                   | 1.503(3)         |
| C(3)-H(3A)                  | 0.9900           |
| C(3)-H(3B)                  | 0.9900           |
| C(13)-C(12)                 | 1.388(3)         |
| C(13)-H(13)                 | 0.9500           |
| C(1)-H(1)                   | 1.0000           |
| C(10)-C(11)                 | 1.387(4)         |
| C(10)-C(9)                  | 1.389(3)         |
| C(10)-H(10)                 | 0.9500           |
| C(11)-C(12)                 | 1.383(4)         |
| C(11)-H(11)                 | 0.9500           |
| C(9)-H(9)                   | 0.9500           |
| C(12)-H(12)                 | 0.9500           |
| C(6)-C(7)                   | 1.477(5)         |
| C(6)-H(6A)                  | 0.9900           |
| C(6)-H(6B)                  | 0.9900           |
| C(7)-H(7A)                  | 0.9800           |
| C(7)-H(7B)                  | 0.9800           |
| C(7)-H(7C)                  | 0.9800           |
| O(1)-S(1)-O(2)              | 118.92(10)       |
| O(1)-S(1)-C(1)              | 107.29(10)       |
O(2)-S(1)-C(1) 108.76(10)
O(1)-S(1)-C(8) 108.22(11)
O(2)-S(1)-C(8) 108.51(10)
C(1)-S(1)-C(8) 104.16(11)
C(4)-O(5)-C(6) 115.3(2)
C(9)-C(8)-C(13) 121.6(2)
C(9)-C(8)-S(1) 119.04(17)
C(13)-C(8)-S(1) 119.40(19)
C(4)-C(2)-C(3) 118.7(2)
C(4)-C(2)-C(1) 123.30(18)
C(3)-C(2)-C(1) 60.11(15)
C(4)-C(2)-H(2) 114.6
C(3)-C(2)-H(2) 114.6
C(1)-C(2)-H(2) 114.6
C(2)-C(3)-C(1) 60.39(16)
C(2)-C(3)-H(3A) 117.7
C(1)-C(3)-H(3A) 117.7
C(2)-C(3)-H(3B) 117.7
C(1)-C(3)-H(3B) 117.7
H(3A)-C(3)-H(3B) 114.9
C(8)-C(13)-C(12) 119.1(2)
C(8)-C(13)-H(13) 120.4
C(12)-C(13)-H(13) 120.4
C(3)-C(1)-C(2) 59.50(15)
C(3)-C(1)-S(1) 118.59(17)
C(2)-C(1)-S(1) 122.88(16)
C(3)-C(1)-H(1) 114.9
C(2)-C(1)-H(1) 114.9
S(1)-C(1)-H(1) 114.9
O(4)-C(4)-O(5) 123.9(2)
O(4)-C(4)-C(2) 125.7(2)
O(5)-C(4)-C(2) 110.27(18)
C(11)-C(10)-C(9) 120.4(2)
C(11)-C(10)-H(10) 119.8
C(9)-C(10)-H(10) 119.8
C(12)-C(11)-C(10) 120.3(2)
C(12)-C(11)-H(11) 119.9
C(10)-C(11)-H(11) 119.9
| Bond                        | θ (°) |
|-----------------------------|-------|
| C(8)-C(9)-C(10)            | 118.7(2) |
| C(8)-C(9)-H(9)             | 120.7 |
| C(10)-C(9)-H(9)            | 120.7 |
| C(11)-C(12)-C(13)          | 120.0(2) |
| C(11)-C(12)-H(12)          | 120.0 |
| C(13)-C(12)-H(12)          | 120.0 |
| O(5)-C(6)-C(7)             | 106.9(3) |
| O(5)-C(6)-H(6A)            | 110.3 |
| C(7)-C(6)-H(6A)            | 110.3 |
| O(5)-C(6)-H(6B)            | 110.3 |
| C(7)-C(6)-H(6B)            | 110.3 |
| H(6A)-C(6)-H(6B)           | 108.6 |
| C(6)-C(7)-H(7A)            | 109.5 |
| C(6)-C(7)-H(7B)            | 109.5 |
| H(7A)-C(7)-H(7B)           | 109.5 |
| C(6)-C(7)-H(7C)            | 109.5 |
| H(7A)-C(7)-H(7C)           | 109.5 |
| H(7B)-C(7)-H(7C)           | 109.5 |

Symmetry transformations used to generate equivalent atoms:
Table S20. Anisotropic displacement parameters ($A^2 \times 10^3$) for ethyl (1S,2S)-2-(benzenesulfonyl) cyclopropane-1-carboxylate (−)-5. The anisotropic displacement factor exponent takes the form:

$$-2 \sum_{h,k} h^2 a^* U_{11} + \ldots + 2hk a^* b^* U_{12}$$

|        | U11  | U22  | U33  | U23  | U13  | U12  |
|--------|------|------|------|------|------|------|
| S(1)   | 19(1)| 20(1)| 15(1)| 2(1) | -1(1)| -2(1)|
| O(2)   | 19(1)| 30(1)| 22(1)| 5(1) | -3(1)| -4(1)|
| O(1)   | 35(1)| 24(1)| 22(1)| -3(1)| -1(1)| 1(1) |
| O(4)   | 20(1)| 34(1)| 32(1)| 6(1) | -2(1)| 1(1) |
| O(5)   | 26(1)| 35(1)| 23(1)| 0(1) | 4(1) | 7(1) |
| C(8)   | 21(1)| 19(1)| 17(1)| 3(1) | -1(1)| -3(1)|
| C(2)   | 18(1)| 20(1)| 26(1)| 2(1) | 2(1) | -2(1)|
| C(3)   | 26(1)| 26(1)| 21(1)| 7(1) | 4(1) | 0(1) |
| C(13)  | 25(1)| 28(1)| 21(1)| 2(1) | 2(1) | 3(1) |
| C(1)   | 18(1)| 21(1)| 20(1)| 1(1) | 3(1) | -1(1)|
| C(4)   | 22(1)| 20(1)| 25(1)| 4(1) | 1(1) | -1(1)|
| C(10)  | 25(1)| 32(1)| 26(1)| 7(1) | -7(1)| 1(1) |
| C(11)  | 37(1)| 33(1)| 20(1)| 5(1) | -4(1)| -6(1)|
| C(9)   | 23(1)| 26(1)| 22(1)| 4(1)| 1(1) | 1(1) |
| C(12)  | 38(1)| 36(1)| 18(1)| 1(1)| 5(1) | 2(1) |
| C(6)   | 36(1)| 56(2)| 36(2)| 2(1)| 12(1)| 15(1)|
| C(7)   | 70(2)| 70(2)| 41(2)| -12(2)| 17(2)| 18(2)|
Table S21. Hydrogen coordinates ($x \times 10^4$) and isotropic displacement parameters ($\text{Å}^2 \times 10^3$) for ethyl (1S,2S)-2-(benzenesulfonyl)cyclopropane-1-carboxylate (−)-5.

|        | x    | y    | z    | U(eq) |
|--------|------|------|------|-------|
| H(2)   | 5433 | 7705 | 1611 | 25    |
| H(3A)  | 5708 | 7001 | 226  | 29    |
| H(3B)  | 2952 | 6540 | 340  | 29    |
| H(13)  | 1424 | 5697 | 3309 | 30    |
| H(1)   | 7095 | 6215 | 1492 | 24    |
| H(10)  | 8765 | 4294 | 4070 | 33    |
| H(11)  | 6146 | 4830 | 5146 | 36    |
| H(9)   | 7752 | 4473 | 2604 | 28    |
| H(12)  | 2457 | 5509 | 4772 | 36    |
| H(6A)  | -1652| 7202 | 3025 | 51    |
| H(6B)  | -1125| 8288 | 2884 | 51    |
| H(7A)  | 759  | 7236 | 4282 | 91    |
| H(7B)  | -1483| 7934 | 4366 | 91    |
| H(7C)  | 1163 | 8325 | 4149 | 91    |
Table S22. Torsion angles [°] for ethyl (1S,2S)-2-(benzenesulfonyl)cyclopropane-1-carboxylate (−)-5.

| Torsion Angle | Torsion Angle | Torsion Angle |
|---------------|---------------|---------------|
| O(1)-S(1)-C(8)-C(9) | 32.2(2)        |               |
| O(2)-S(1)-C(8)-C(9) | 162.56(17)     |               |
| C(1)-S(1)-C(8)-C(9) | -81.71(19)     |               |
| O(1)-S(1)-C(8)-C(13) | -148.10(18)    |               |
| O(2)-S(1)-C(8)-C(13) | -17.8(2)       |               |
| C(1)-S(1)-C(8)-C(13) | 98.0(2)        |               |
| C(4)-C(2)-C(3)-C(1) | -114.0(2)      |               |
| C(9)-C(8)-C(13)-C(12) | 0.0(4)         |               |
| S(1)-C(8)-C(13)-C(12) | -179.62(19)    |               |
| C(2)-C(3)-C(1)-S(1) | 113.4(2)       |               |
| C(4)-C(2)-C(1)-C(3) | 106.6(2)       |               |
| C(4)-C(2)-C(1)-S(1) | 0.3(3)         |               |
| C(3)-C(2)-C(1)-S(1) | -106.3(2)      |               |
| O(1)-S(1)-C(1)-C(3) | 85.59(19)      |               |
| O(2)-S(1)-C(1)-C(3) | -44.2(2)       |               |
| C(8)-S(1)-C(1)-C(3) | -159.81(18)    |               |
| O(1)-S(1)-C(1)-C(2) | 155.96(18)     |               |
| O(2)-S(1)-C(1)-C(2) | 26.1(2)        |               |
| C(8)-S(1)-C(1)-C(2) | -89.4(2)       |               |
| C(6)-O(5)-C(4)-O(4) | 0.5(3)         |               |
| C(6)-O(5)-C(4)-C(2) | 177.2(2)       |               |
| C(3)-C(2)-C(4)-O(4) | -24.5(3)       |               |
| C(1)-C(2)-C(4)-O(4) | -95.9(3)       |               |
| C(3)-C(2)-C(4)-O(5) | 158.81(19)     |               |
| C(1)-C(2)-C(4)-O(5) | 87.5(2)        |               |
| C(9)-C(10)-C(11)-C(12) | 0.9(4)      |               |
| C(13)-C(8)-C(9)-C(10) | -0.1(3)       |               |
| S(1)-C(8)-C(9)-C(10) | 179.52(17)    |               |
| C(11)-C(10)-C(9)-C(8) | -0.3(3)       |               |
| C(10)-C(11)-C(12)-C(13) | -1.0(4)    |               |
| C(8)-C(13)-C(12)-C(11) | 0.5(4)       |               |
| C(4)-O(5)-C(6)-C(7) | -178.0(3)     |               |

Symmetry transformations used to generate equivalent atoms:
Table S23. Crystal data and structure refinement for lot ethyl (1R,2R)-2-(benzenesulfonyl)cyclopropane-1-carboxylate (+)-5.

| Property                                      | Value                        |
|-----------------------------------------------|------------------------------|
| Identification code                           | cu_16002_a                   |
| Empirical formula                            | C12 H14 O4 S                 |
| Formula weight                                | 254.29                       |
| Temperature                                   | 100(2) K                     |
| Wavelength                                    | 1.54178 Å                    |
| Crystal system                                | Orthorhombic                 |
| Space group                                   | P2₁2₁2₁                       |
| Unit cell dimensions                          | a = 5.5189(16) Å = 90°.      |
|                                              | b = 14.454(6) Å = 90°.       |
|                                              | c = 15.447(5) Å = 90°.       |
| Volume                                        | 1232.3(7) Å³                 |
| Z                                             | 4                             |
| Density (calculated)                          | 1.371 Mg/m³                  |
| Absorption coefficient                        | 2.361 mm⁻¹                   |
| F(000)                                        | 536                           |
| Crystal size                                  | 0.180 x 0.035 x 0.015 mm³    |
| Theta range for data collection               | 4.189 to 72.547°.            |
| Index ranges                                  | -6<=h<=6, -17<=k<=17, -19<=l<=17 |
| Reflections collected                         | 11656                        |
| Independent reflections                       | 2425 [R(int) = 0.0832]        |
| Completeness to theta                         | 67.679° 99.5 %               |
| Absorption correction                         | Multi-scan                   |
| Refinement method                             | Full-matrix least-squares on F²|
| Data / restraints / parameters                 | 2425 / 0 / 156               |
S. J. Chawner, M. Cases-Thomas and J. A. Bull

Goodness-of-fit on $F^2$ 1.035

Final R indices $[I>2\sigma(I)]$ $R_1 = 0.0463$, $wR_2 = 0.1147$

R indices (all data) $R_1 = 0.0525$, $wR_2 = 0.1203$

Absolute structure parameter 0.067(17)

Extinction coefficient 0.0067(14)

Largest diff. peak and hole 0.528 and -0.526 e.Å$^{-3}$

Table S24. Atomic coordinates ($\times 10^4$) and equivalent isotropic displacement parameters ($\text{Å}^2 \times 10^3$) for ethyl ($1R,2R$)-2-(benzenesulfonfonyl)cyclopropane-1-carboxylate (+)-5. $U_{eq}$ is defined as one third of the trace of the orthogonalized $U_{ij}$ tensor.

|       | x    | y    | z    | $U_{eq}$ |
|-------|------|------|------|----------|
| S(1)  | 3736(2) | 4758(1) | 1729(1) | 19(1)    |
| O(2)  | 1178(5) | 4587(2) | 1669(2) | 24(1)    |
| O(4)  | -62(5) | 2514(2) | 1426(2) | 28(1)    |
| O(1)  | 4751(6) | 5517(2) | 1254(2) | 27(1)    |
| O(5)  | 1839(5) | 2521(2) | 2708(2) | 29(1)    |
| C(2)  | 4221(7) | 2796(3) | 1495(2) | 21(1)    |
| C(4)  | 1759(7) | 2613(3) | 1841(3) | 22(1)    |
| C(8)  | 4509(7) | 4897(3) | 2836(3) | 20(1)    |
| C(1)  | 5300(7) | 3756(3) | 1417(3) | 20(1)    |
| C(3)  | 4444(8) | 3240(3) | 625(3)  | 24(1)    |
| C(13) | 2906(8) | 4590(3) | 3463(3) | 26(1)    |
| C(10) | 7285(7) | 5416(3) | 3914(3) | 27(1)    |
| C(9)  | 6687(7) | 5318(3) | 3042(3) | 25(1)    |
| C(11) | 5713(8) | 5103(3) | 4552(3) | 30(1)    |
| C(12) | 3532(9) | 4694(3) | 4326(3) | 31(1)    |
| C(6)  | -460(9) | 2301(4) | 3116(3) | 41(1)    |
| C(7)  | 27(12) | 2190(5) | 4060(4) | 60(2)    |
Table S25. Bond lengths [Å] and angles [°] for ethyl (1R,2R)-2-(benzenesulfonyl)cyclopropane-1-carboxylate (+)-5.

| Bond                  | Length/Angle   |
|-----------------------|----------------|
| S(1)-O(1)             | 1.435(3)       |
| S(1)-O(2)             | 1.436(3)       |
| S(1)-C(1)             | 1.753(4)       |
| S(1)-C(8)             | 1.773(4)       |
| O(4)-C(4)             | 1.201(5)       |
| O(5)-C(4)             | 1.345(5)       |
| O(5)-C(6)             | 1.453(5)       |
| C(2)-C(4)             | 1.484(5)       |
| C(2)-C(3)             | 1.495(6)       |
| C(2)-C(1)             | 1.516(5)       |
| C(2)-H(2)             | 1.0000         |
| C(8)-C(13)            | 1.385(6)       |
| C(8)-C(9)             | 1.385(5)       |
| C(1)-C(3)             | 1.509(6)       |
| C(1)-H(1)             | 1.0000         |
| C(3)-H(3A)            | 0.9900         |
| C(3)-H(3B)            | 0.9900         |
| C(13)-C(12)           | 1.385(6)       |
| C(13)-H(13)           | 0.9500         |
| C(10)-C(11)           | 1.389(6)       |
| C(10)-C(9)            | 1.393(6)       |
| C(10)-H(10)           | 0.9500         |
| C(9)-H(9)             | 0.9500         |
| C(11)-C(12)           | 1.386(6)       |
| C(11)-H(11)           | 0.9500         |
| C(12)-H(12)           | 0.9500         |
| C(6)-C(7)             | 1.492(8)       |
| C(6)-H(6A)            | 0.9900         |
| C(6)-H(6B)            | 0.9900         |
| C(7)-H(7A)            | 0.9800         |
| C(7)-H(7B)            | 0.9800         |
| C(7)-H(7C)            | 0.9800         |
| O(1)-S(1)-O(2)        | 118.85(17)     |
| O(1)-S(1)-C(1)        | 107.36(18)     |
| Bond                        | Angle (°)       |
|-----------------------------|-----------------|
| O(2)-S(1)-C(1)              | 108.93 (18)     |
| O(1)-S(1)-C(8)              | 108.21 (18)     |
| O(2)-S(1)-C(8)              | 108.58 (17)     |
| C(1)-S(1)-C(8)              | 103.91 (18)     |
| C(4)-O(5)-C(6)              | 115.1 (3)       |
| C(4)-C(2)-C(3)              | 118.4 (3)       |
| C(4)-C(2)-C(1)              | 123.4 (3)       |
| C(3)-C(2)-C(1)              | 60.2 (3)        |
| C(4)-C(2)-H(2)              | 114.6           |
| C(3)-C(2)-H(2)              | 114.6           |
| C(1)-C(2)-H(2)              | 114.6           |
| O(4)-C(4)-O(5)              | 123.2 (4)       |
| O(4)-C(4)-C(2)              | 126.5 (4)       |
| O(5)-C(4)-C(2)              | 110.2 (3)       |
| C(13)-C(8)-C(9)             | 122.3 (4)       |
| C(13)-C(8)-S(1)             | 119.0 (3)       |
| C(9)-C(8)-S(1)              | 118.7 (3)       |
| C(3)-C(1)-C(2)              | 59.2 (3)        |
| C(3)-C(1)-S(1)              | 118.5 (3)       |
| C(2)-C(1)-S(1)              | 122.8 (3)       |
| C(3)-C(1)-H(1)              | 115.0           |
| C(2)-C(1)-H(1)              | 115.0           |
| S(1)-C(1)-H(1)              | 115.0           |
| C(2)-C(3)-C(1)              | 60.6 (3)        |
| C(2)-C(3)-H(3A)             | 117.7           |
| C(1)-C(3)-H(3A)             | 117.7           |
| C(2)-C(3)-H(3B)             | 117.7           |
| C(1)-C(3)-H(3B)             | 117.7           |
| H(3A)-C(3)-H(3B)            | 114.8           |
| C(12)-C(13)-C(8)            | 118.6 (4)       |
| C(12)-C(13)-H(13)           | 120.7           |
| C(8)-C(13)-H(13)            | 120.7           |
| C(11)-C(10)-C(9)            | 120.3 (4)       |
| C(11)-C(10)-H(10)           | 119.8           |
| C(9)-C(10)-H(10)            | 119.8           |
| C(8)-C(9)-C(10)             | 118.2 (4)       |
| C(8)-C(9)-H(9)              | 120.9           |
| C(10)-C(9)-H(9)             | 120.9           |
| Bond                  | Angle (°)  |
|----------------------|------------|
| C(12)-C(11)-C(10)   | 120.1(4)   |
| C(12)-C(11)-H(11)   | 119.9      |
| C(10)-C(11)-H(11)   | 119.9      |
| C(13)-C(12)-C(11)   | 120.4(4)   |
| C(13)-C(12)-H(12)   | 119.8      |
| C(11)-C(12)-H(12)   | 119.8      |
| O(5)-C(6)-C(7)      | 106.9(4)   |
| O(5)-C(6)-H(6A)     | 110.3      |
| C(7)-C(6)-H(6A)     | 110.3      |
| O(5)-C(6)-H(6B)     | 110.3      |
| C(7)-C(6)-H(6B)     | 110.3      |
| H(6A)-C(6)-H(6B)    | 108.6      |
| C(6)-C(7)-H(7A)     | 109.5      |
| C(6)-C(7)-H(7B)     | 109.5      |
| H(7A)-C(7)-H(7B)    | 109.5      |
| C(6)-C(7)-H(7C)     | 109.5      |
| H(7A)-C(7)-H(7C)    | 109.5      |
| H(7B)-C(7)-H(7C)    | 109.5      |

Symmetry transformations used to generate equivalent atoms:
Table S26. Anisotropic displacement parameters (Å$^2 \times 10^3$) for ethyl (1$R$,2$R$)-2-(benzenesulfonyl) cyclopropane-1-carboxylate (+)-5. The anisotropic displacement factor exponent takes the form:

$$-2 \left[ h^2 a^2 U_{11} + ... + 2 h k a^* b^* U_{12} \right]$$

|   | $U_{11}$  | $U_{22}$ | $U_{33}$ | $U_{23}$ | $U_{13}$ | $U_{12}$ |
|---|-----------|-----------|-----------|---------|---------|---------|
| S(1) | 18(1) | 19(1) | 19(1) | -1(1) | 0(1) | 2(1) |
| O(2) | 18(1) | 26(1) | 26(1) | -4(1) | -2(1) | 4(1) |
| O(4) | 18(1) | 32(2) | 34(2) | -6(1) | -1(1) | 0(1) |
| O(1) | 35(2) | 21(1) | 25(2) | 4(1) | 1(1) | -2(1) |
| O(5) | 26(2) | 35(2) | 26(1) | 2(1) | 4(1) | -7(1) |
| C(2) | 18(2) | 20(2) | 26(2) | -1(1) | 3(1) | 4(2) |
| C(4) | 21(2) | 18(2) | 27(2) | -4(2) | 1(2) | 2(1) |
| C(8) | 17(2) | 19(2) | 24(2) | -2(1) | -1(1) | 3(1) |
| C(1) | 17(2) | 21(2) | 23(2) | -2(2) | 1(2) | 0(2) |
| C(3) | 22(2) | 26(2) | 25(2) | -4(2) | 3(2) | -1(2) |
| C(13) | 26(2) | 25(2) | 27(2) | -3(2) | 1(2) | -5(2) |
| C(10) | 22(2) | 28(2) | 31(2) | -7(2) | -4(2) | -1(2) |
| C(9) | 25(2) | 23(2) | 26(2) | -4(2) | 1(2) | -2(2) |
| C(11) | 34(2) | 32(2) | 25(2) | -7(2) | -4(2) | -4(2) |
| C(12) | 38(2) | 36(2) | 20(2) | -2(2) | 5(2) | -2(2) |
| C(6) | 35(2) | 52(3) | 37(3) | 1(2) | 9(2) | -14(2) |
| C(7) | 68(4) | 71(4) | 40(3) | 11(3) | 16(3) | -19(4) |
Table S27. Hydrogen coordinates ($x \times 10^4$) and isotropic displacement parameters ($\AA^2 \times 10^3$) for ethyl (1R,2R)-2-(benzenesulfonyl)cyclopropane-1-carboxylate (+)-5.

|   | x    | y    | z    | U(eq) |
|---|------|------|------|-------|
| H(2) | 5427 | 2294 | 1610 | 26    |
| H(1) | 7099 | 3787 | 1488 | 24    |
| H(3A) | 2939 | 3457 | 341  | 29    |
| H(3B) | 5691 | 2996 | 225  | 29    |
| H(13) | 1408 | 4314 | 3305 | 31    |
| H(10) | 8775 | 5698 | 4072 | 32    |
| H(9)  | 7746 | 5534 | 2602 | 30    |
| H(11) | 6133 | 5170 | 5145 | 36    |
| H(12) | 2461 | 4483 | 4765 | 37    |
| H(6A) | -1131| 1721 | 2873 | 50    |
| H(6B) | -1643| 2805 | 3018 | 50    |
| H(7A) | 1004 | 1633 | 4155 | 90    |
| H(7B) | -1512| 2132 | 4372 | 90    |
| H(7C) | 909  | 2732 | 4274 | 90    |
Table S28. Torsion angles [°] for ethyl (1R,2R)-2-(benzenesulfonyl)cyclopropane-1-carboxylate (+)-5.

| Torsion Angle                          | Torsion Angle                          |
|----------------------------------------|----------------------------------------|
| C(6)-O(5)-C(4)-O(4)                   | -0.6(6)                                |
| C(6)-O(5)-C(4)-C(2)                   | -177.5(4)                              |
| C(3)-C(2)-C(4)-O(4)                   | 24.5(6)                                |
| C(1)-C(2)-C(4)-O(4)                   | 95.8(5)                                |
| C(3)-C(2)-C(4)-O(5)                   | -158.8(3)                              |
| C(1)-C(2)-C(4)-O(5)                   | -87.5(4)                               |
| O(1)-S(1)-C(8)-C(13)                  | 147.6(3)                               |
| O(2)-S(1)-C(8)-C(13)                  | 17.3(4)                                |
| C(1)-S(1)-C(8)-C(13)                  | -98.5(4)                               |
| O(1)-S(1)-C(8)-C(9)                   | -31.8(4)                               |
| O(2)-S(1)-C(8)-C(9)                   | -162.1(3)                              |
| C(1)-S(1)-C(8)-C(9)                   | 82.1(3)                                |
| C(4)-C(2)-C(1)-C(3)                   | -106.2(4)                              |
| C(4)-C(2)-C(1)-S(1)                   | -0.1(5)                                |
| C(3)-C(2)-C(1)-S(1)                   | 106.1(4)                               |
| O(1)-S(1)-C(1)-C(3)                   | -86.1(3)                               |
| O(2)-S(1)-C(1)-C(3)                   | 43.8(4)                                |
| C(8)-S(1)-C(1)-C(3)                   | 159.4(3)                               |
| O(1)-S(1)-C(1)-C(2)                   | -156.1(3)                              |
| O(2)-S(1)-C(1)-C(2)                   | -26.2(4)                               |
| C(8)-S(1)-C(1)-C(2)                   | 89.4(3)                                |
| C(4)-C(2)-C(3)-C(1)                   | 114.3(4)                               |
| S(1)-C(1)-C(3)-C(2)                   | -113.2(3)                              |
| C(9)-C(8)-C(13)-C(12)                 | -1.2(6)                                |
| S(1)-C(8)-C(13)-C(12)                 | 179.4(3)                               |
| C(13)-C(8)-C(9)-C(10)                 | 1.2(6)                                 |
| S(1)-C(8)-C(9)-C(10)                  | -179.4(3)                              |
| C(11)-C(10)-C(9)-C(8)                 | -0.5(6)                                |
| C(9)-C(10)-C(11)-C(12)                | -0.2(7)                                |
| C(8)-C(13)-C(12)-C(11)                | 0.5(7)                                 |
| C(10)-C(11)-C(12)-C(13)               | 0.2(7)                                 |
| C(4)-O(5)-C(6)-C(7)                   | 177.7(4)                               |

Symmetry transformations used to generate equivalent atoms:
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