Electronic Supplementary Material (ESI) for ChemComm.

SUPPORTING INFORMATION
Experimental procedures, computational details and characterization data

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I. General experimental

All reactions were performed under an inert argon atmosphere in oven- or flame-dried round bottom flasks fitted with rubber septa and using magnetic stirring, unless otherwise stated. Liquids and solutions were transferred via syringe or stainless-steel cannula under inert conditions. Reactions were frequently monitored by thin-layer chromatography (TLC), which was carried out on glass plates coated with 250 μm of 230-400 mesh silica gel that had been saturated with F-254 indicator. TLC plates were visualized using ultraviolet light and/or by exposure to various staining solutions followed by heating. Flash column chromatography was carried out on 230-400 mesh silica gel (Silicycle) using reagent-grade solvents. Room temperature (rt) indicates a temperature of approximately 22 °C.

All commercial reagents were used without further purification with the following exceptions: tetrahydrofuran and diethyl ether were distilled from sodium/benzophenone ketyl radical under a nitrogen atmosphere. Triethylamine was distilled from calcium hydride under a nitrogen atmosphere. Dichloromethane was distilled from calcium hydride under a dry air atmosphere. Pyridine, dimethylformamide, and dimethyl sulfoxide were stored over 4Å molecular sieves. Triphenylphosphine was recrystallized from methanol.

All polyene cyclization reactions were performed under air using reagent-grade solvents out of the bottle.

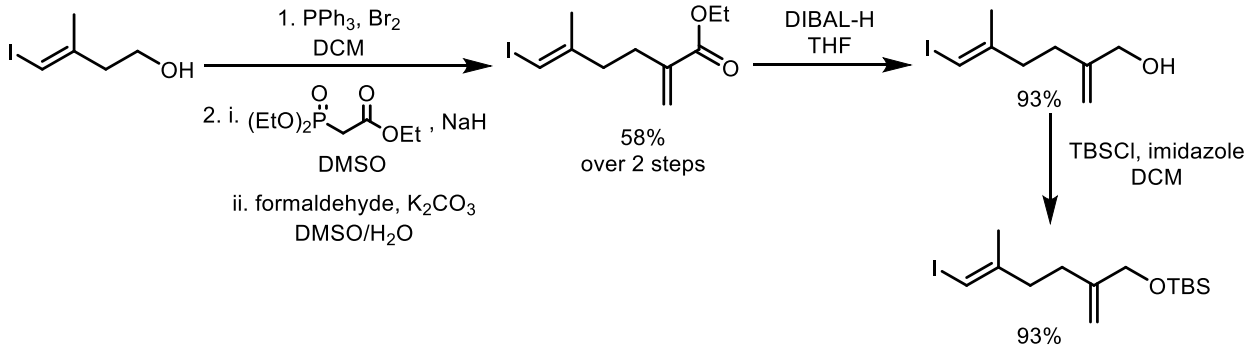
IR spectra were obtained using a Perkin-Elmer Spectrum One FT-IR spectrophotometer. NMR spectra were recorded on 400, 500 MHz Varian or 400, 500, 800 MHz Bruker spectrometers. Some NMR experiments were recorded at the Quebec/Eastern Canada High Field NMR Facility, supported by the Canada Foundation for Innovation, McGill University Faculty of Science and Department of Chemistry. Chemical shifts (δ) were internally referenced to the residual proton resonance of chloroform-*d* (δ 7.26 ppm). The following abbreviations were used for NMR peak multiplicities: s = singlet, d = doublet, t = triplet, q = quartet, sext = sextet, m = multiplet. Coupling constants (*J*) are reported in Hertz (Hz). High-resolution mass spectrometry was conducted by Dr. Nadim Saadé and Dr. Alexander Wahba in the Mass Spectrometry Facility in the Department of Chemistry, McGill University, using Thermo-Fisher Exactive Plus Orbitrap-API and Bruker Maxis API QqTOF mass spectrometers.

The following known compounds were synthesized following literature procedures: ethyl 1,2-diazepane-1-carboxylate[1] and Dess-Martin periodinane[2, 3].

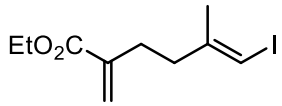
Atom numbering for decalin compounds is based on IUPAC rules for the numbering of steroids, except for the numbering in the compounds' names, which uses general IUPAC nomenclature (as assigned by PerkinElmer ChemDraw).

II. Substrate synthesis

Synthesis of (E)-iodoalkene coupling partner



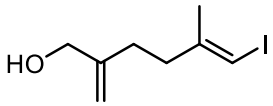
ethyl (*E*)-6-iodo-5-methyl-2-methylenehex-5-enoate



To a stirred solution of PPh_3 (3.369 g, 12.8 mmol) in DCM (10 mL) at 0 °C was added bromine (600 μL, 11.7 mmol). The solution was stirred for 10 minutes, then a solution of (*E*)-4-iodo-3-methylbut-3-en-1-ol[4] (2.079 g, 9.8 mmol) in DCM (40 mL) was added. The solution was stirred for 1 h, then concentrated. The crude bromide was purified by a silica gel plug (eluted with hexanes).

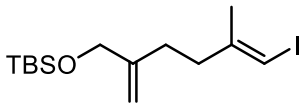
Following the procedure of Serebryakov *et al*[5]: To a stirred solution of NaH (60% dispersion in mineral oil, 622 mg, 15.5 mmol) in DMSO (16 mL) at 0 °C was added triethyl phosphonoacetate (3.0 mL, 15.5 mmol) dropwise. When bubbling ceased, the solution was added to the bromide formed in the previous step. The solution was brought to 50 °C and stirred for 2 h. *The* solution was cooled to room temperature and K_2CO_3 (3.248 g, 23.2 mmol) and formaldehyde (37% in water, 3.5 mL, 47.0 mmol) were added. The mixture was brought to 60 °C and let stir for 1 h. The solution was diluted with water and extracted with Et_2O (3 x 20 mL). The combined organic layers were washed with brine, dried with $MgSO_4$, filtered, and concentrated. The crude extracts were purified by silica gel column chromatography (gradient from hexanes to 95:5 hexanes/ethyl acetate) to obtain ethyl (*E*)-6-iodo-5-methyl-2-methylenehex-5-enoate, which was isolated as a colourless oil (1.673 g, 5.7 mmol, 58% yield over 2 steps. IR (Film) 3057, 2980, 2930, 2854, 1712, 1630, 1445, 1408, 1369, 1306, 1267, 1185, 1134, 1095, 1025, 943, 888, 863, 843, 815, 780, 682, 662 cm^{-1}; ^1H NMR (500 MHz, $CDCl_3$) δ = 6.15 (d, *J* = 1.2 Hz, 1 H), 5.90 (q, *J* = 0.9 Hz, 1 H), 5.51 (d, *J* = 1.2 Hz, 1 H), 4.20 (qt, *J* = 7.1, 1.4 Hz, 2 H), 2.44 (t, *J* = 8.0 Hz, 2 H), 2.37 (t, *J* = 8.0 Hz, 2 H), 1.85 (d, *J* = 0.9 Hz, 3 H), 1.30 (tt, *J* = 7.0, 1.5 Hz, 3 H) ppm; ^{13}C NMR (125 MHz, $CDCl_3$) δ = 166.8, 146.9, 139.7, 125.2, 75.5, 60.7, 38.6, 30.3, 23.8, 14.2 ppm; MS (ESI) exact mass calculated for [M+Na] ($C_{10}H_{15}INaO_2$) requires m/z 317.0009, found m/z 317.0007.

(*E*)-6-iodo-5-methyl-2-methylenehex-5-en-1-ol



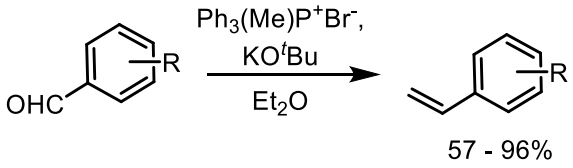
To a stirred solution of ethyl (*E*)-6-iodo-5-methyl-2-methylenehex-5-enoate (1.553 g, 5.3 mmol) in THF (20 mL) at 0 °C was added DIBAL-H (25 wt. % in toluene, 8 mL, 11.6 mmol) dropwise. The solution was stirred for 3 h, then quenched with a saturated solution of Rochelle's salt. The mixture was extracted with EtOAc (3 x 20 mL). The combined organic layers were washed with brine, dried with $MgSO_4$, filtered and concentrated. The crude extracts were purified by silica gel column chromatography (gradient from hexanes to 80:20 hexanes/EtOAc) to obtain (*E*)-6-iodo-5-methyl-2-methylenehex-5-en-1-ol, which was isolated as a colourless oil (1.237 g, 4.9 mmol, 93% yield). IR (Film) 3378, 3058, 2979, 2914, 2853, 1712, 1653, 1629, 1446, 1409, 1374, 1290, 1268, 1189, 1138, 1094, 1065, 1024, 945, 898, 864, 815, 780, 764, 742, 665, 598, 579 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ = 5.93 (d, *J* = 0.9 Hz, 1 H), 5.06 (s, 1 H), 4.88 (d, *J* = 1.1 Hz, 1 H), 4.08 (d, *J* = 5.9 Hz, 2 H), 2.38 (dd, *J* = 8.4, 7.1 Hz, 2 H), 2.22 (dd, *J* = 8.4, 7.1 Hz, 2 H), 1.86 (s, 3 H), 1.39 (t, *J* = 6.1 Hz, 1 H) ppm; ^{13}C NMR (125 MHz, $CDCl_3$) δ = 147.8, 147.4, 110.2, 75.2, 65.9, 37.9, 31.1, 23.9 ppm; MS (ESI) exact mass calculated for [M+Na] ($C_8H_{13}INaO$) requires m/z 274.9903, found m/z 274.9906.

(*E*)-*tert*-butyl((6-iodo-5-methyl-2-methylenehex-5-en-1-yl)oxy)dimethylsilane



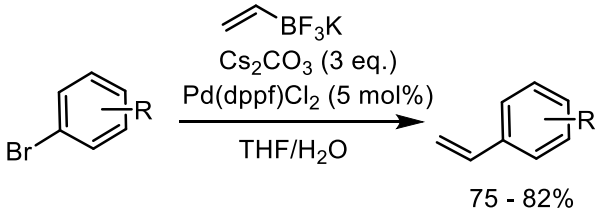
To a stirred solution of (*E*)-6-iodo-5-methyl-2-methylenehex-5-en-1-ol (1.304 g, 5.2 mmol) in DCM (20 mL) was added imidazole (717 mg, 10.5 mmol) and TBSCl (872.5 mg, 10.3 mmol). The resulting solution was stirred for 3 h, then concentrated and purified by silica gel column chromatography (gradient from hexanes to 93:7 hexanes/ethyl acetate) to obtain (*E*)-*tert*-butyl((6-iodo-5-methyl-2-methylenehex-5-en-1-yl)oxy)dimethylsilane, which was isolated as a colourless oil (1.762 g, 4.8 mmol, 93% yield). IR (Film) 3075, 3056, 2953, 2928, 2895, 2856, 1654, 1618, 1471, 1462, 1388, 1377, 1361, 1252, 1141, 1107, 1081, 1006, 939, 899, 834, 774, 738, 705, 667, 583, 509 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ = 5.91 (d, *J* = 1.0 Hz, 1 H), 5.04 (s, 1 H), 4.82 (d, *J* = 1.2 Hz, 1 H), 4.07 (s, 2 H), 2.36 (dd, *J* = 8.8, 6.8 Hz, 2 H), 2.16 (dd, *J* = 8.7, 7.0 Hz, 2 H), 1.86 (d, *J* = 0.6 Hz, 3 H), 0.92 (s, 9 H), 0.09 (s, 6 H) ppm; ^{13}C NMR (125 MHz, $CDCl_3$) δ = 147.6, 147.6, 109.3, 75.0, 65.9, 38.0, 30.9, 25.9, 23.9, 18.4, -5.3 ppm; MS (ESI) exact mass calculated for [M+Na] ($C_{14}H_{27}INaOSi$) requires m/z 389.0768, found m/z 389.0775.

Synthesis of vinylarenes



General procedure A

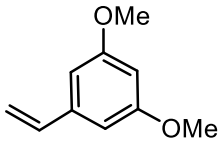
To a stirred suspension of methyltriphenylphosphonium bromide (1.82 g, 5.1 mmol) in Et_2O (20 mL) at 0 °C was added potassium *tert*-butoxide (505 mg, 4.5 mmol). The mixture was stirred 15 minutes and became bright yellow. A solution of aryl aldehyde (3.0 mmol) in Et_2O (10 mL) was added dropwise. The reaction mixture was removed from cooling, stirred overnight, cooled to 0 °C, and quenched with saturated aqueous NH_4Cl (12 mL). The aqueous layer was diluted with water (6 mL) and extracted with Et_2O (2 x 12 mL). The organic layer and ether extracts were combined, washed with water and brine, dried with $MgSO_4$, filtered, concentrated, and purified by flash chromatography to give the vinylarene.



General procedure B

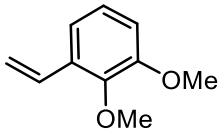
Following a modified procedure of Molander *et al.*[6]: To a 10 mL microwave vial containing aryl bromide, $Pd(dppf)Cl_2$, $CsCO_3$, and vinyl trifluoroborate was added THF:H_2O (9:1). The solution was brought to 85 °C and let stir for 21 h. The reaction quenched with water (5 mL) and extracted with Et_2O (2 x 10 mL). The organic layer and ether extracts were combined, washed with brine, dried with $MgSO_4$, filtered, concentrated, and purified by flash chromatography to give the vinylarene.

1,3-dimethoxy-5-vinylbenzene



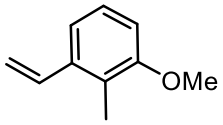
From 3,5-dimethoxybenzaldehyde (6.0 mmol), general procedure A was followed to give, after flash chromatography (gradient from 99:1 to 97:3 hexanes/EtOAc), 950 mg (5.8 mmol) of 1,3-dimethoxy-5-vinylbenzene as a colourless oil (96% yield). Spectroscopic data were in accordance with previously reported literature.[7]

1,2-dimethoxy-3-vinylbenzene



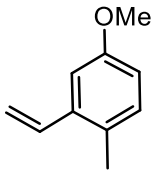
From 2,3-dimethoxybenzaldehyde (2.1 mmol), general procedure A was followed to give, after flash chromatography (gradient from 97:3 to 90:10 hexanes/DCM), 279.4 mg (1.7 mmol) of 1,2-dimethoxy-3-vinylbenzene as a colourless oil (80% yield). Spectroscopic data were in accordance with previously reported literature.[8]

1-methoxy-2-methyl-3-vinylbenzene



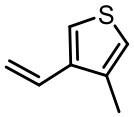
From 3-methoxy-2-methylbenzaldehyde (3.0 mmol), general procedure A was followed to give, after flash chromatography (gradient from 96:4 to 92:8 hexanes/DCM), 384 mg (2.6 mmol) of 1-methoxy-2-methyl-3-vinylbenzene as a colourless oil (86% yield). Spectroscopic data were in accordance with previously reported literature.[9]

4-methoxy-1-methyl-2-vinylbenzene



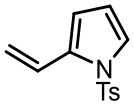
From 5-methoxy-2-methylbenzaldehyde (1.6 mmol), general procedure A was followed to give, after flash chromatography (gradient from 96:4 to 92:8 hexanes/DCM), 217 mg (1.5 mmol) of 4-methoxy-1-methyl-2-vinylbenzene as a colourless oil (89% yield). Spectroscopic data were in accordance with previously reported literature.[10]

3-methyl-4-vinylthiophene



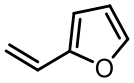
From 3-bromo-4-methylthiophene (2.8 mmol), general procedure B was followed to give, after flash chromatography (pentane), 264.7 mg (2.1 mmol) of 3-methyl-4-vinylthiophene as a colourless oil (75% yield). IR (Film) 3087, 3008, 2971, 2946, 2920, 2862, 1622, 1444, 1381, 985 cm^{-1}; ^{1}H NMR (500 MHz, $CDCl_3$) δ = 7.28 (d, *J* = 3.2 Hz, 1 H), 6.90 (dq, *J* = 3.2, 1.0 Hz, 1 H), 5.58 (dd, *J* = 17.6, 1.4 Hz, 1 H), 5.21 (dd, *J* = 17.6, 1.5 Hz, 1 H), 2.27 (d, *J* = 0.7 Hz, 3 H) ppm; ^{13}C NMR (125 MHz, $CDCl_3$) δ = 139.5, 136.2, 130.1, 121.5, 121.0, 114.4, 15.0 ppm; HRMS (APCI) exact mass calculated for [M+H] (C_7H_9S) requires m/z 125.0423, found m/z 125.0419.

1-tosyl-2-vinyl-1H-pyrrole



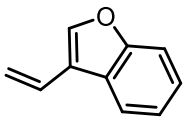
From 1-tosyl-1H-pyrrole-2-carbaldehyde (3.0 mmol), general procedure A was followed to give, after flash chromatography (gradient from 97:3 to 93:7 hexanes/DCM), 655.7 mg (2.7 mmol) of 1-tosyl-2-vinyl-1H-pyrroleas a colourless oil (89% yield). Spectroscopic data were in accordance with previously reported literature.[8]

2-vinylfuran



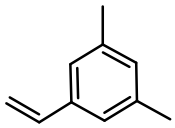
From furan-2-carbaldehyde (12.1 mmol), general procedure A was followed to give, after flash chromatography (90:10 pentane/Et_2O), 844.5 mg (9.0 mmol) of 2-vinylfuran as a colourless oil (57% yield). Spectroscopic data were in accordance with previously reported literature.[11]

3-vinylbenzofuran



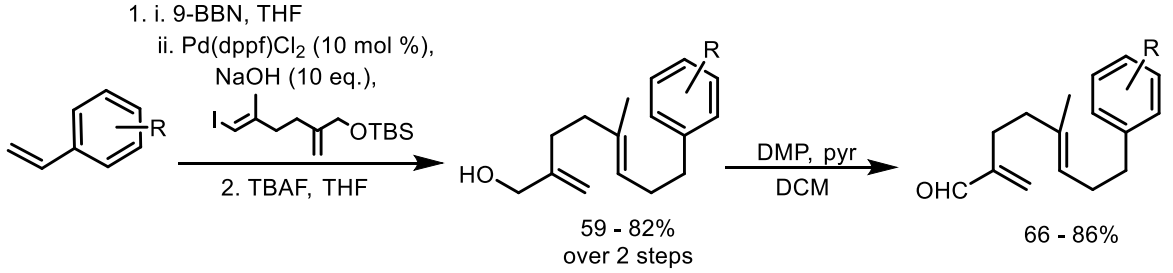
From 3-bromobenzofuran (3.0 mmol), general procedure B was followed to give, after flash chromatography (hexanes), 364.8 mg (2.5 mmol) of 3-vinylbenzofuran as a colourless oil (82% yield). Spectroscopic data were in accordance with previously reported literature.[12]

1,3-dimethyl-5-vinylbenzene



From 3,5-dimethylbenzaldehyde (3.0 mmol), general procedure A was followed to give, after flash chromatography (gradient from 97:3 to 95:5 pentane/DCM), 323 mg (2.4 mmol) of 1,3-dimethyl-5-vinylbenzene as a colourless oil (81% yield). Spectroscopic data were in accordance with previously reported literature.[13]

Synthesis of (E)-polyene substrates (**4**)

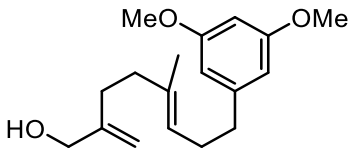


Synthesis of alcohol (general procedure C)

Following the procedure of Zhao *et al*[14]: To a stirred solution of vinylarene (1.1 mmol) in tetrahydrofuran (400 µL) at 0 °C was added a solution of 9-BBN (0.5 M in THF, 2.1 mL, 1.1 mmol). The mixture was brought to room temperature and stirred for 18 h. When the hydroboration was complete, the reaction was cooled to 0 °C and $Pd(dppf)Cl_2$ (40 mg, 0.054 mmol), NaOH (216 mg, 5.4 mmol), and a solution of (*E*)-*tert*-butyl((6-iodo-5-methyl-2-methylenehex-5-en-1-yl)oxy)dimethylsilane (198.0 mg, 0.54 mmol) in THF (400 µL) were added sequentially. The mixture was brought to room temperature and stirred for 22 h. The reaction was quenched with saturated aqueous NH_4Cl and extracted with EtOAc (3 x 10 mL). The combined organic layers were washed with brine, dried with $MgSO_4$, filtered, and concentrated. The crude extracts were purified by silica gel column chromatography (gradient from hexanes to 94:6 hexanes/EtOAc) to obtain coupling product.

To a stirred solution of coupled product in THF was added a solution of TBAF (1.0 M in THF, 1.1 mL, 1.1 mmol) was added and the resulting solution was stirred for 1 h. The reaction was quenched with saturated aqueous $NaHCO_3$ and extracted with EtOAc (3 x 10 mL). The combined organic layers were washed with brine, dried with $MgSO_4$, filtered, and concentrated. The crude extracts were purified by silica gel column chromatography (gradient from hexanes to 70:30 hexanes/EtOAc) to obtain alcohol product.

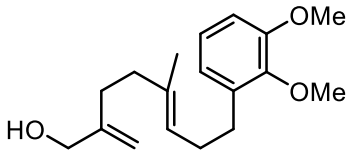
(*E*)-8-(3,5-dimethoxyphenyl)-5-methyl-2-methyleneoct-5-en-1-ol



Followed general procedure C from 3,5-dimethoxystyrene on a 0.54 mmol scale and purified using silica gel column chromatography to give 98 mg (0.38 mmol, 70% yield over 2 steps) of (*E*)-8-(3,5-dimethoxyphenyl)-5-methyl-2-methyleneoct-5-en-1-ol as a colourless oil. IR (Film) 3393, 3083, 2933, 2838, 1594, 1459, 1428, 1204, 1148, 1065, 1026, 896, 829, 736, 694 cm^{-1}; ^1H NMR (500 MHz, $CDCl_3$) δ = 6.36 (d, *J* = 2.2 Hz, 2 H), 6.31 (t, *J* = 2.2 Hz, 1 H), 5.20 (t, *J* = 6.9 Hz, 1 H), 5.02 (d, *J* = 1.1 Hz, 1 H), 4.86 (s, 1 H), 4.05 (s, 2 H), 3.78 (s, 6 H), 2.59 (t, *J* = 7.7 Hz, 2 H), 2.31 (td, *J* = 7.5, 6.8 Hz, 2 H), 2.15 (bs, 4 H), 2.09 (s, 1 H), 1.60 (s, 3 H) ppm; ^{13}C NMR (125 MHz, $CDCl_3$) δ = 160.5, 148.7, 144.6, 135.2, 123.8, 109.0, 106.5, 97.5, 65.6, 55.1, 37.7, 36.2,

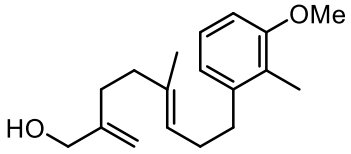
31.4, 29.5, 15.8 ppm; HRMS (ESI) exact mass calculated for [M+Na] ($C_{18}H_{26}NaO_3$) requires m/z 313.1774, found m/z 313.1784.

(*E*)-8-(2,3-dimethoxyphenyl)-5-methyl-2-methyleneoct-5-en-1-ol



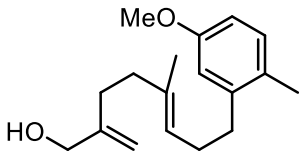
Followed general procedure C from 1,2-dimethoxy-3-vinylbenzene on a 0.81 mmol scale and purified using silica gel column chromatography to give 187 mg (0.64 mmol, 78% yield over 2 steps) of (*E*)-8-(2,3-dimethoxyphenyl)-5-methyl-2-methyleneoct-5-en-1-ol a colourless oil. IR (Film) 3418, 2930, 2856, 1689, 1584, 1475, 1267, 1076, 1009 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ = 6.97 (dd, *J* = 8.1, 8.1 Hz, 1 H), 6.77 (dd, *J* = 8.1, 2.1 Hz, 2 H), 5.23 (t, *J* = 6.9 Hz, 1 H), 5.00 (s, 1 H), 4.84 (s, 1 H), 4.06 (s, 2H), 3.85 (s, 3 H), 3.82 (s, 3 H), 2.64 (t, *J* = 7.4 Hz, 2 H), 2.28 (dt, *J* = 8.1, 7.4 Hz, 2 H), 2.14 (s, 4 H), 1.72 (bs, 1 H), 1.59 (s, 3 H) ppm; ^{13}C NMR (125 MHz, $CDCl_3$) δ = 152.6, 148.9, 147.1, 136.0, 135.1, 124.3, 123.6, 121.9, 110.0, 109.1, 65.8, 60.5, 55.6, 37.8, 31.4, 29.9, 29.1, 15.8 ppm; HRMS (ESI) exact mass calculated for [M+Na] ($C_{18}H_{26}NaO_3$) requires m/z 313.1774, found m/z 313.1770.

(*E*)-8-(3-methoxy-2-methylphenyl)-5-methyl-2-methyleneoct-5-en-1-ol



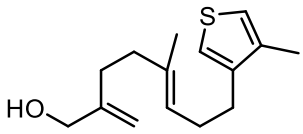
Followed general procedure C from 3-methoxy-2-methylstyrene on a 0.54 mmol scale and purified using silica gel column chromatography to give 101 mg (0.36 mmol, 67% yield over 2 steps) of (*E*)-8-(3-methoxy-2-methylphenyl)-5-methyl-2-methyleneoct-5-en-1-ol as a colourless oil. IR (Film) 3327, 3071, 2932, 2861, 2837, 1653, 1584, 1463, 1438, 1380, 1310, 1252, 1192, 1168, 1142, 1101, 1018, 895, 835, 778, 719, 678 cm^{-1}; ^1H NMR (500 MHz, $CDCl_3$) δ = 7.12 (dd, *J* = 7.8, 7.8 Hz, 1 H), 6.81 (d, *J* = 7.7 Hz, 1 H), 6.74 (d, *J* = 8.0 Hz, 1 H), 5.27 (t, *J* = 7.0 Hz, 1 H), 5.05 (s, 1 H), 4.90 (s, 1 H), 4.09 (s, 2 H), 3.84 (s, 3 H), 2.66 (t, *J* = 7.6 Hz, 2 H), 2.29 (td, *J* = 7.6, 7.1 Hz, 2 H), 2.23 (s, 3 H), 2.18 (s, 4 H), 1.83 (s, 1 H), 1.62 (s, 3 H) ppm; ^{13}C NMR (125 MHz, $CDCl_3$) δ = 157.6, 148.8, 141.7, 135.1, 125.8, 124.4, 124.1, 121.4, 109.2, 107.8, 65.8, 55.4, 37.9, 33.6, 31.4, 28.8, 15.8, 11.2 ppm; HRMS (APCI) exact mass calculated for [M+H] ($C_{18}H_{27}O_2$) requires m/z 267.1390, found m/z 267.1389.

(*E*)-8-(5-methoxy-2-methylphenyl)-5-methyl-2-methyleneoct-5-en-1-ol



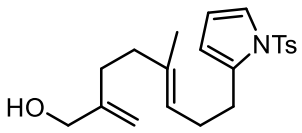
Followed general procedure C from 4-methoxy-2-methylstyrene on a 0.54 mmol scale and purified using silica gel column chromatography to give 102 mg (0.38 mmol, 70% yield over 2 steps) of (*E*)-8-(5-methoxy-2-methylphenyl)-5-methyl-2-methyleneoct-5-en-1-ol as a colourless oil. IR (Film) 3452, 3053, 1936, 2865, 2837, 1652, 1608, 1579, 1498, 1454, 1383, 1303, 1265, 1208, 1161, 1114, 1045, 896, 854, 803, 704 cm^{-1}; ^{1}H NMR (500 MHz, $CDCl_3$) δ = 7.07 (d, *J* = 8.2 Hz, 1 H), 6.74 (d, *J* = 2.3 Hz, 1 H), 6.69 (dd, *J* = 8.2, 2.4 Hz, 1 H), 5.26 (t, *J* = 7.0 Hz, 1 H), 5.06 (s, 1 H), 4.90 (s, 1 H), 4.09 (s, 2 H), 3.80 (s, 3 H), 2.62 (t, *J* = 7.6 Hz, 2 H), 2.30 (m, 5 H), 2.18 (s, 4 H), 2.06 (s, 1 H), 1.62 (s, 3 H) ppm; ^{13}C NMR (125 MHz, $CDCl_3$) δ = 157.6, 148.8, 141.5, 135.2, 130.6, 127.9, 123.9, 114.8, 110.5, 109.1, 65.7, 55.1, 37.8, 33.5, 31.4, 28.4, 18.3, 15.8 ppm; HRMS (ESI) exact mass calculated for [M+Na] ($C_{18}H_{26}NaO_2$) requires m/z 297.1825, found m/z 297.1815.

(*E*)-5-methyl-2-methylene-8-(4-methylthiophen-3-yl)oct-5-en-1-ol



Followed general procedure C from 2-vinylthiophene on a 0.54 mmol scale and purified using silica gel column chromatography to give 82 mg (0.33 mmol, 62% yield over 2 steps) of (*E*)-5-methyl-2-methylene-8-(4-methylthiophen-3-yl)oct-5-en-1-ol as a colourless oil. IR (Film) 3330, 3085, 2921, 2856, 1652, 1445, 1383, 1060, 1022, 896, 861 cm^{-1}; ^{1}H NMR (500 MHz, $CDCl_3$) δ = 6.90 (m, 2 H), 5.25 (t, *J* = 6.8 Hz, 1 H), 5.04 (d, *J* = 1.2 Hz, 1 H), 4.89 (d, *J* = 1.0 Hz, 1 H), 4.08 (s, 2 H), 2.57 (t, *J* = 8.3 Hz, 2 H), 2.33 (td, *J* = 8.3, 6.8 Hz, 2 H), 2.20 (s, 3H), 2.18 (bs, 4 H), 1.75 (s, 1 H), 1.63 (s, 3H) ppm; ^{13}C NMR (125 MHz, $CDCl_3$) δ = 148.8, 141.7, 136.9, 135.3, 124.0, 120.7, 120.2, 109.3, 65.8, 37.8, 31.4, 29.0, 27.8, 15.8, 14.4 ppm; HRMS (ESI) exact mass calculated for [M+Na] ($C_{15}H_{22}NaOS$) requires m/z 273.1284, found m/z 273.1279.

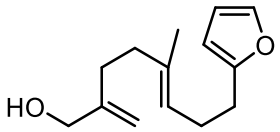
(*E*)-5-methyl-2-methylene-8-(1-tosyl-1H-pyrrol-2-yl)oct-5-en-1-ol



Followed general procedure C from 1-tosyl-2-vinyl-1H-pyrrole on a 0.54 mmol scale and purified using silica gel column chromatography to give 74 mg (0.32 mmol, 59% yield over 2 steps) of (*E*)-5-methyl-2-methylene-8-(1-tosyl-1H-pyrrol-2-yl)oct-5-en-1-ol as a colourless oil. IR (Film) 3555, 3373, 3155, 2922, 2855, 1652, 1597, 1448, 1362, 1185, 10990, 1053 cm^{-1}; ^{1}H NMR (500 MHz, $CDCl_3$) δ = 7.62 (d, *J* = 8.8 Hz, 2 H), 7.27 (m, 3 H), 6.18 (dd, *J* = 3.3, 3.3 Hz, 1 H), 5.97 (m, 1 H), 5.11 (t, *J* = 6.9 Hz, 1 H), 5.01 (d, *J* = 1.1 Hz, 1 H), 4.85 (d, *J* = 1.0 Hz, 1 H), 4.05 (s, 2 H), 2.68 (t,

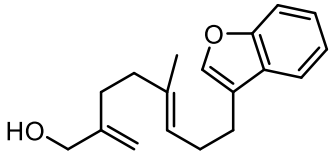
J = 8.0 Hz, 2 H), 2.38 (s, 3 H), 2.25 (td, *J* = 8.0, 7.0 Hz, 2 H), 2.12 (m, 4 H), 1.78 (bs, 1 H), 1.56 (s, 3 H) ppm; ^{13}C NMR (125 MHz, $CDCl_3$) δ = 148.8, 144.6, 136.4, 135.6, 135.3, 128.9, 126.6, 123.5, 122.2, 112.0, 111.2, 109.2, 65.7, 37.8, 31.3, 27.2, 27.0, 21.5, 15.8 ppm; HRMS (ESI) exact mass calculated for [M+Na] ($C_{21}H_{27}NNaO_3S$) requires m/z 396.1604, found m/z 396.1600.

(*E*)-8-(furan-2-yl)-5-methyl-2-methyleneoct-5-en-1-ol



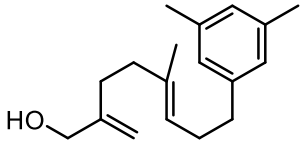
Followed general procedure C from 2-vinylfuran on a 0.54 mmol scale and purified using silica gel column chromatography to give 78 mg (0.35 mmol, 64% yield over 2 steps) of (*E*)-8-(furan-2-yl)-5-methyl-2-methyleneoct-5-en-1-ol (**4.43**) as a colourless oil. IR (Film) 3331, 2915, 2853, 1383, 1072 cm^{-1}; ^{1}H NMR (500 MHz, $CDCl_3$) δ = 7.29 (d, *J* = 2.2 Hz, 1 H), 6.27 (dd, *J* = 3.1, 2.2 Hz, 1 H), 5.97 (d, *J* = 3.1 Hz, 1 H), 5.18 (t, *J* = 7.0 Hz, 1 H), 5.01 (s, 1 H), 4.86 (s, 1 H), 4.06 (s, 2 H), 2.64 (t, *J* = 7.2 Hz, 2 H), 2.33 (dt, *J* = 7.2, 7.0 Hz, 2 H), 2.14 (s, 4 H), 1.60 (s, 4 H) ppm; ^{13}C NMR (125 MHz, $CDCl_3$) δ = 156.0, 148.8, 140.7, 135.6, 123.5, 110.0, 109.3, 104.8, 65.8, 37.8, 21.4, 28.1, 26.4, 15.8 ppm; HRMS (ESI) exact mass calculated for [M+Na] ($C_{14}H_{20}NaO_2$) requires m/z 243.13555, found m/z 243.13547.

(*E*)-8-(benzofuran-3-yl)-5-methyl-2-methyleneoct-5-en-1-ol



Followed general procedure C from 3-vinylbenzofuran on a 0.83 mmol scale and purified using silica gel column chromatography to give 177 mg (0.65 mmol, 79% yield over 2 steps) of (*E*)-8-(benzofuran-3-yl)-5-methyl-2-methyleneoct-5-en-1-ol a colourless oil. IR (Film) 3327, 3062, 2916, 2853, 1652, 1452, 1009 cm^{-1}; ^{1}H NMR (500 MHz, $CDCl_3$) δ = 7.58 (d, *J* = 7.4 Hz, 1 H), 7.48 (d, *J* = 7.9 Hz, 1 H), 7.42 (s, 1 H), 7.30 (dd, *J* = 7.4, 6.2 Hz, 1 H), 7.25 (dd, *J* = 7.9, 6.2 Hz, 1 H), 5.27 (t, *J* = 7.6 Hz, 1 H), 5.04 (s, 1 H), 4.88 (s, 1 H), 4.07 (s, 2 H), 2.72 (t, *J* = 7.3 Hz, 2 H), 2.43 (dt, *J* = 7.6, 7.3 Hz, 2 H), 2.17 (s, 4 H), 1.89 (bs, 1 H), 1.62 (s, 3 H) ppm; ^{13}C NMR (125 MHz, $CDCl_3$) δ = 155.2, 148.7, 141.0, 135.5, 128.2, 123.9, 123.9, 122.0, 120.1, 119.5, 111.2, 109.2, 65.7, 37.8, 31.3, 27.3, 23.6, 15.9 ppm; HRMS (ESI) exact mass calculated for [M+Na] ($C_{18}H_{22}NaO_2$) requires m/z 293.1512, found m/z 293.1514.

(*E*)-8-(3,5-dimethylphenyl)-5-methyl-2-methyleneoct-5-en-1-ol



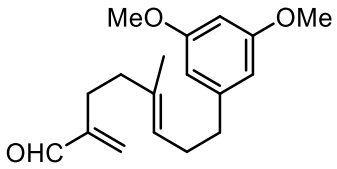
Followed general procedure C from 3,5-dimethylstyrene on a 0.54 mmol scale and purified using silica gel column chromatography to give 119 mg (0.46 mmol, 82% yield over 2 steps) of (*E*)-8-

(3,5-dimethylphenyl)-5-methyl-2-methyleneoct-5-en-1-ol as a colourless oil. IR (Film) 3318, 3012, 2917, 2854, 1653, 1605, 1449, 1378, 1061, 1023, 895, 842, 701 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ = 6.84 (bs, 1H), 6.82 (bs, 2 H), 5.22 (t, *J* = 7.0 Hz, 1 H), 5.02 (d, *J* = 1.2 Hz, 1 H), 4.88 (s, 1 H), 4.07 (d, *J* = 5.0 Hz, 2 H), 2.57 (t, *J* = 7.9 Hz, 2 H), 2.30 (m, 8 H), 2.16 (bs, 4 H), 1.60 (s, 3 H), 1.39 (t, *J* = 5.1 Hz, 1 H) ppm; ^{13}C NMR (125 MHz, $CDCl_3$) δ = 149.0, 142.2, 138.0, 135.1, 127.3, 126.3, 124.3, 109.4, 66.0, 38.0, 35.9, 31.6, 30.0, 21.3, 15.9 ppm; HRMS (ESI) exact mass calculated for [M+Na] ($C_{18}H_{26}NaO$) requires 281.1876, found m/z 281.1867.

Synthesis of aldehydes (general procedure D)

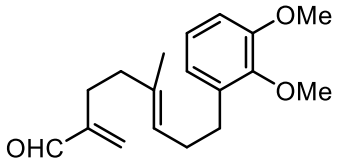
To a solution of alcohol (0.30 mmol) in DCM (3 mL) was added pyridine (40 µL, 0.50 mmol) and Dess-Martin periodinane[3] (170 mg, 0.40 mmol). The mixture was stirred for 1 h. The reaction was quenched with saturated aqueous sodium thiosulphate and extracted with DCM (3 x 10 mL). The combined organic layers were washed with brine, dried with $MgSO_4$, filtered and concentrated. The crude extracts were purified by silica gel column chromatography (gradient from hexanes to 90:10 hexanes/EtOAc) to obtain aldehyde.

(*E*)-8-(3,5-dimethoxyphenyl)-5-methyl-2-methyleneoct-5-enal (4a)



From (*E*)-8-(3,5-dimethoxyphenyl)-5-methyl-2-methyleneoct-5-en-1-ol, general procedure D was followed on a 0.30 mmol scale to give 73 mg (0.23 mmol, 76% yield) of (*E*)-8-(3,5-dimethoxyphenyl)-5-methyl-2-methyleneoct-5-enal as a colourless oil. IR (Film) 3083, 3056, 2992, 2932, 2838, 2694, 1687, 1594, 1460, 1428, 1347, 1315, 1293, 1204, 1150, 1066, 940, 830, 694 cm^{-1}; ^1H NMR (500 MHz, $CDCl_3$) δ = 9.52 (s, 1 H), 6.37 (d, *J* = 2.2 Hz, 2 H), 6.32 (t, *J* = 2.2 Hz, 1 H), 6.22 (s, 1 H), 5.98 (s, 1 H), 5.18 (tq, *J* = 7.1, 0.9 Hz, 1 H), 3.80 (s, 6 H), 2.59 (t, *J* = 7.5 Hz, 2 H), 2.36 (t, *J* = 8.1 Hz, 2 H), 2.31 (td, *J* = 7.6, 7.3 Hz, 2 H), 2.14 (t, *J* = 7.9, 2 H), 1.61 (s, 3 H) ppm; ^{13}C NMR (125 MHz, $CDCl_3$) δ = 194.6, 160.7, 149.8, 144.7, 134.6, 134.2, 124.6, 106.5, 97.7, 55.2, 37.6, 36.3, 29.6, 26.3, 15.9 ppm; HRMS (ESI) exact mass calculated for [M+Na] ($C_{18}H_{24}NaO_3$) requires m/z 311.1618, found m/z 311.1622.

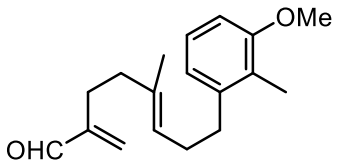
(*E*)-8-(2,3-dimethoxyphenyl)-5-methyl-2-methyleneoct-5-enal (4b)



From (*E*)-8-(2,3-dimethoxyphenyl)-5-methyl-2-methyleneoct-5-en-1-ol, general procedure D was followed on a 0.64 mmol scale to give 148 mg (0.51 mmol, 80% yield) of (*E*)-8-(2,3-dimethoxyphenyl)-5-methyl-2-methyleneoct-5-enal as a colourless oil. IR (Film) 2931, 2855, 2835, 2698, 1687, 1475, 1336, 1267, 1076 cm^{-1}; ^1H NMR (500 MHz, $CDCl_3$) δ = 9.49 (s, 1 H), 6.95 (dd, *J* = 7.6, 7.6 Hz, 1 H), 6.75 (d, *J* = 7.6 Hz, 2 H), 6.19 (s, 1 H), 5.95 (s, 1 H), 5.20 (t, *J* =

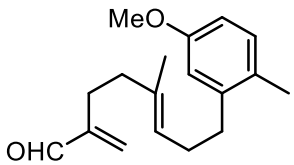
7.7 Hz, 1 H), 3.84 (s, 3 H), 3.81 (s, 3 H), 2.62 (t, *J* = 8.1 Hz, 2 H), 2.34 (t, *J* = 8.1 Hz, 2 H), 2.26 (dt, *J* = 8.1, 7.3 Hz, 2 H), 2.11 (t, *J* = 7.3 Hz, 2 H), 1.59 (s, 3 H) ppm; ^{13}C NMR (125 MHz, $CDCl_3$) δ = 194.4, 152.5, 149.7, 147.0, 135.9, 134.3, 134.0, 124.8, 123.5, 121.8, 110.0, 60.4, 55.5, 37.5, 29.9, 29.0, 26.2, 15.6 ppm; HRMS (ESI) exact mass calculated for [M+Na] ($C_{18}H_{24}NaO_3$) requires m/z 311.1618, found m/z 311.1631.

(*E*)-8-(3-methoxy-2-methylphenyl)-5-methyl-2-methyleneoct-5-enal (4c)



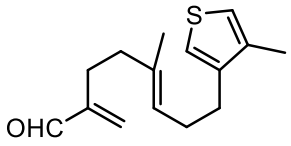
From (*E*)-8-(3-methoxy-2-methylphenyl)-5-methyl-2-methyleneoct-5-en-1-ol, general procedure D was followed on a 0.35 mmol scale to give 72 mg (0.26 mmol, 74% yield) of (*E*)-8-(3-methoxy-2-methylphenyl)-5-methyl-2-methyleneoct-5-enal as a colourless oil. IR (Film) 2937, 2865, 2844, 2699, 1689, 1627, 1584, 1464, 1438, 1378, 1346, 1310, 1256, 1167, 1142, 1101, 1055, 1033, 1014, 942, 870, 838, 778, 720, 678 cm^{-1}; ^{1}H NMR (500 MHz, $CDCl_3$) δ = 9.53 (s, 1 H), 7.10 (t, 7.8 Hz, 1 H), 6.79 (d, *J* = 7.6 Hz, 1 H), 6.72 (d, *J* = 8.0 Hz, 1 H), 6.23 (s, 1 H), 5.98 (s, 1 H), 5.22 (tq, *J* = 7.1, 1.2 Hz, 1 H), 3.83 (s, 3 H), 2.63 (t, *J* = 7.9 Hz, 2 H), 2.37 (t, *J* = 7.6 Hz, 2 H), 2.26 (td, *J* = 8.0, 7.2 Hz, 2 H) 2.20 (s, 3 H), 2.15 (t, *J* = 7.6 Hz, 2 H), 1.61 (s, 3 H) ppm; ^{13}C NMR (125 MHz, $CDCl_3$) δ = 194.6, 157.6, 149.8, 141.7, 134.4, 134.1, 125.8, 124.7, 124.4, 121.4, 107.8, 55.4, 37.6, 33.6, 28.9, 26.3, 15.7, 11.2 ppm; HRMS (APCI) exact mass calculated for [M+H] ($C_{18}H_{25}O_2$) requires m/z 255.1743, found m/z 255.1751.

(*E*)-8-(5-methoxy-2-methylphenyl)-5-methyl-2-methyleneoct-5-enal (4d)



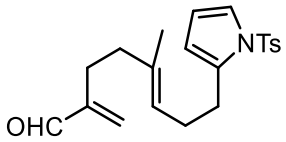
From (*E*)-8-(5-methoxy-2-methylphenyl)-5-methyl-2-methyleneoct-5-en-1-ol, general procedure D was followed on a 0.30 mmol scale to give 72 mg (0.24 mmol, 81% yield) of (*E*)-8-(5-methoxy-2-methylphenyl)-5-methyl-2-methyleneoct-5-enal as a colourless oil. IR (Film) 3060, 2932, 2863, 2834, 2698, 1688, 1609, 1578, 1498, 1452, 1382, 1304, 1284, 1249, 1208, 1160, 1114, 1087, 1045, 997, 942, 868, 848, 801, 778, 713 cm^{-1}; ^{1}H NMR (500 MHz, $CDCl_3$) δ = 9.55 (s, 1 H), 7.07 (d, 7.8 Hz, 1 H), 6.74 (d, *J* = 2.8 Hz, 1 H), 6.69 (dd, 7.8, 2.8 Hz, 1 H), 6.25 (s, 1 H), 6.01 (s, 1 H), 5.24 (tq, *J* = 7.1, 1.0 Hz, 1 H), 3.81 (s, 3 H), 2.61 (t, *J* = 7.7 Hz, 2 H), 2.39 (t, *J* = 7.7 Hz, 2 H), 2.31 – 2.27 (m, 5 H), 2.17 (t, *J* = 7.7 Hz, 2 H), 1.63 (s, 3 H) ppm; ^{13}C NMR (125 MHz, $CDCl_3$) δ = 194.6, 157.8, 149.9, 141.6, 134.6, 134.2, 130.8, 127.9, 124.7, 114.8, 110.8, 55.2, 37.7, 33.6, 28.5, 26.4, 18.4, 15.8 ppm; HRMS (ESI) exact mass calculated for [M+Na] ($C_{18}H_{24}NaO_2$) requires m/z 295.1669, found m/z 295.1678.

(*E*)-5-methyl-2-methylene-8-(4-methylthiophen-3-yl)oct-5-enal (4e)



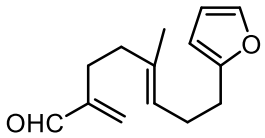
From (*E*)-5-methyl-2-methylene-8-(4-methylthiophen-3-yl)oct-5-en-1-ol, general procedure D was followed on a 0.32 mmol scale to give 58 mg (0.23 mmol, 73% yield) (*E*)-5-methyl-2-methylene-8-(4-methylthiophen-3-yl)oct-5-enal as a colourless oil. IR (Film) 3083, 2922, 2855, 2699, 1688, 1627, 1444, 1383 cm^{-1}; ^{1}H NMR (500 MHz, $CDCl_3$) δ = 9.53 (s, 1H), 6.89 (s, 2H), 6.22 (s, 1 H), 5.98 (s, 1 H) 5.21 (t, *J* = 7.0, 1 H), 2.53 (t, *J* = 8.2 Hz, 2 H), 2.37 (t, *J* = 7.5 Hz, 2 H), 2.30 (td, *J* = 7.6, 7.4 Hz, 2 H), 2.19 (s, 3 H), 2.14 (t, *J* = 7.5 Hz, 2 H), 1.62 (s, 3 H) ppm; ^{13}C NMR (125 MHz, $CDCl_3$) δ = 194.5, 149.8, 141.6, 136.8, 134.6, 134.1, 124.6, 120.7, 120.1, 37.6, 29.0, 27.8, 26.3, 15.8, 14.4 ppm; HRMS (ESI) exact mass calculated for [M+Na] ($C_{15}H_{20}NaOS$) requires m/z 271.1127, found m/z 271.1127.

(*E*)-5-methyl-2-methylene-8-(1-tosyl-1H-pyrrol-2-yl)oct-5-enal (4f)



From (*E*)-5-methyl-2-methylene-8-(1-tosyl-1H-pyrrol-2-yl)oct-5-en-1-ol, general procedure D was followed on a 0.28 mmol scale to give 83 mg (0.22 mmol, 80% yield) of (*E*)-5-methyl-2-methylene-8-(1-tosyl-1H-pyrrol-2-yl)oct-5-enal as a colourless oil. IR (Film) 3151, 3063, 2924, 2854, 2702, 1686, 1596, 1363, 1173, 945 cm^{-1}; ^{1}H NMR (500 MHz, $CDCl_3$) δ = 9.49 (s, 1H), 7.61 (d, *J* = 7.0 Hz, 2 H), 7.27 (m, 3 H), 6.17 (m, 2 H), 5.95 (s, 2 H), 5.06 (t, *J* = 6.4 Hz, 1 H), 2.65 (t, *J* = 8.1 Hz, 2 H), 2.38 (s, 3 H), 2.31 (t, *J* = 8.1 Hz, 2 H), 2.22 (td, *J* = 7.2, 6.9 Hz, 2 H), 2.08 (t, *J* = 7.1 Hz, 2 H), 1.55 (s, 3 H) ppm; ^{13}C NMR (125 MHz, $CDCl_3$) δ = 194.5, 149.7, 144.6, 136.4, 135.3, 134.9, 134.2, 129.9, 126.6, 124.1, 122.2, 112.0, 111.2, 37.5, 27.2, 27.0, 26.2, 21.5, 15.8 ppm; HRMS (ESI) exact mass calculated for [M+Na] ($C_{21}H_{25}NNaO_3S$) requires m/z 394.1447, found m/z 394.1434.

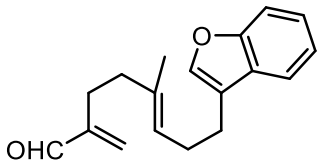
(*E*)-8-(furan-2-yl)-5-methyl-2-methyleneoct-5-enal (4g)



From (*E*)-8-(furan-2-yl)-5-methyl-2-methyleneoct-5-en-1-ol, general procedure D was followed on a 0.20 mmol scale to give 38 mg (0.17 mmol, 86% yield) of (*E*)-8-(furan-2-yl)-5-methyl-2-methyleneoct-5-enal as a colourless oil. IR (Film) 2959, 2921, 2851, 1749, 1689, 1476, 1073 cm^{-1}; ^{1}H NMR (500 MHz, $CDCl_3$) δ = 9.50 (s, 1 H), 7.29 (d, *J* = 1.1 Hz, 1 H), 6.27 (dd, *J* = 3.0, 1.1 Hz, 1 H), 6.20 (s, 1 H), 5.96 (m, 2 H), 5.14 (t, *J* = 7.2 Hz, 1 H), 2.63 (t, *J* = 7.3 Hz, 2 H), 2.36 – 2.30 (m, 4 H), 2.12 (t, *J* = 7.3 Hz, 2 H), 1.60 (s, 3 H) ppm; ^{13}C NMR (125 MHz, $CDCl_3$) δ = 194.6, 155.9, 149.8, 140.7, 134.9, 134.1, 124.1, 110.0, 104.8, 37.6, 28.1, 26.4, 26.2, 15.7 ppm; HRMS

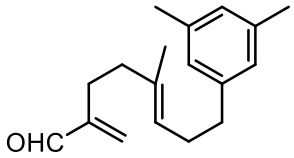
(ESI) exact mass calculated for [M+Na] ($C_{14}H_{18}NaO_2$) requires m/z 241.1199, found m/z 241.1190.

(*E*)-8-(benzofuran-3-yl)-5-methyl-2-methyleneoct-5-enal (4h)



From (*E*)-8-(benzofuran-3-yl)-5-methyl-2-methyleneoct-5-en-1-ol, general procedure D was followed on a 0.45 mmol scale to give 94 mg (0.35 mmol, 77% yield) of (*E*)-8-(benzofuran-3-yl)-5-methyl-2-methyleneoct-5-enal as a colourless oil. IR (Film) 2928, 2854, 2699, 1687, 1452, 1271, 1086, 942 cm^{-1}; ^1H NMR (500 MHz, $CDCl_3$) δ = 9.50 (s, 1 H), 7.56 (d, *J* = 7.5 Hz, 1 H), 7.47 (d, *J* = 7.7 Hz, 1 H), 7.40 (s, 1 H), 7.29 (dd, *J* = 7.5, 6.7 Hz, 1 H), 7.24 (dd, *J* = 7.7, 6.7 Hz, 1 H), 6.18 (s, 1 H), 5.93 (s, 1 H), 5.22 (t, *J* = 7.0 Hz, 1 H), 2.70 (t, *J* = 7.3 Hz, 2 H), 2.41 (td, *J* = 7.3, 7.0 Hz, 2 H), 2.36 (t, *J* = 7.3 Hz, 2 H), 2.14 (t, *J* = 7.3 Hz, 2 H), 1.61 (s, 3 H) ppm; ^{13}C NMR (125 MHz, $CDCl_3$) δ = 194.5, 155.2, 149.7, 141.0, 134.8, 134.0, 128.2, 124.5, 123.9, 122.1, 120.1, 119.5, 111.3, 37.6, 27.3, 26.2, 23.6, 15.8 ppm; HRMS (ESI) exact mass calculated for [M+Na] ($C_{18}H_{20}NaO_2$) requires m/z 291.1356, found m/z 291.1351.

(*E*)-8-(3,5-dimethylphenyl)-5-methyl-2-methyleneoct-5-enal (4i)

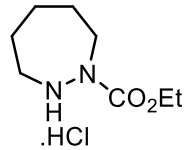


From (*E*)-8-(3,5-dimethylphenyl)-5-methyl-2-methyleneoct-5-en-1-ol, general procedure D was followed on a 0.46 mmol scale to give 78 mg (30 mmol, 66% yield) of (*E*)-8-(3,5-dimethylphenyl)-5-methyl-2-methyleneoct-5-enal as a colourless oil. IR (Film) 3435, 3012, 2921, 2860, 1715, 1605, 1451, 1377, 1265, 1161, 1084, 1038, 946, 845, 734, 702 cm^{-1}; ^1H NMR (500 MHz, $CDCl_3$) δ = 9.54 (s, 1 H), 6.85 (s, 1 H), 6.83 (s, 2 H), 6.23 (d, *J* = 0.7 Hz, 1 H), 6.00 (d, *J* = 0.5 Hz, 1 H), 5.21 (tq, *J* = 7.1, 1.1 Hz, 1 H), 2.57 (t, *J* = 7.8 Hz, 2 H), 2.37 (t, *J* = 7.6 Hz, 2 H), 2.32 – 2.27 (m, 8 H), 2.15 (t, *J* = 7.4 Hz, 2 H) 1.62 (s, 3 H) ppm; ^{13}C NMR (125 MHz, $CDCl_3$) δ = 194.6, 149.9, 142.2, 137.7, 134.4, 134.1, 127.4, 126.2, 124.9, 37.6, 35.9, 30.0, 26.4, 21.3, 15.8 ppm; HRMS (ESI) exact mass calculated for [M+Na] ($C_{18}H_{24}NaO$) requires m/z 279.1719, found m/z 279.1712.

III. Catalyst synthesis

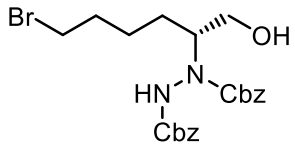
Note: due to restricted bond rotation, some catalyst intermediates display multiple rotamers and broad peaks in their ^{1}H and ^{13}C NMR spectra.

ethyl 1,2-diazepane-1-carboxylate hydrochloride



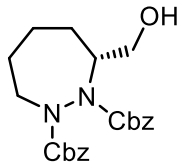
Ethyl 1,2-diazepane-1-carboxylate was synthesized according to literature.[1] Gaseous hydrochloric acid was bubbled through a stirred solution of freebase ethyl 1,2-diazepane-1-carboxylate in hexanes, causing an oil to crash out. The solvent was removed *in vacuo*, the residue was dissolved in a hexanes/dichloromethane mixture, and the solvent was again removed. After three repetitions of this cycle, the oil was left under high vacuum for several days until all the material had solidified, giving an off-white powder.

dibenzyl (*R*)-1-(6-bromo-1-hydroxyhexan-2-yl)hydrazine-1,2-dicarboxylate



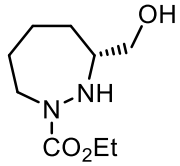
Following a modified procedure of Hamada *et al.*[15, 16]: To a stirred solution of 6-bromohexanal (1.908 g, 10.7 mmol) and dibenzylazodicarboxylate (2.130 g, 7.1 mmol) in MeCN (50 mL) at 0 °C was added (*S*)-proline (181 mg, 1.6 mmol) and the resulting reaction mixture was stirred at -5 °C for 17 h. EtOH (50 mL) and $NaBH_4$ (320 mg, 8.5 mmol) were added and the reaction mixture was stirred at 0 °C for 30 min. The reaction was quenched with saturated aqueous NH_4Cl and extracted with EtOAc (3 x 50 mL). The combined extracts were washed with brine, dried with Na_2SO_4, filtered, concentrated, and purified by flash chromatography (gradient from 80:20 to 60:40 hexanes/EtOAc) to give dibenzyl (*R*)-1-(6-bromo-1-hydroxyhexan-2-yl)hydrazine-1,2-dicarboxylate (2.20 g, 4.6 mmol, 64% yield) which was isolated as a colourless oil. Enantioselectivity was 97:3 to >99:1 *er* (when run at 0 °C or on larger scale, enantioselectivity was decreased, resulting in variations in final catalyst *er*) as determined by HPLC analysis using a CHIRACEL OD column (10% ^{i}PrOH in hexanes 40 min – tr 13.3 and 25.7 min). IR (thin film) ν 3272, 3033, 2956, 1712, 1252 cm^{-1}; ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.43 – 7.20 (m, 10H), 6.64 – 6.48 (m, 1H), 5.35 – 5.02 (m, 4H), 4.55 – 4.00 (m, 2H), 3.64 – 3.21 (m, 4H), 1.96 – 1.60 (m, 2H), 1.48 – 1.16 (m, 4H) ppm; ^{13}C NMR (125 MHz, $CDCl_3$) δ = 157.2, 156.2, 135.8, 135.1, 128.8, 128.8, 128.7, 128.4, 128.2, 127.9, 68.8, 68.4, 62.3, 33.7, 33.4, 32.1, 27.0, 24.5 ppm; HRMS (ESI) exact mass calculated for [M+Na] ($C_{22}H_{27}N_2BrNaO_5$) requires m/z 501.0996, found m/z 501.0975.

dibenzyl (*R*)-3-(hydroxymethyl)-1,2-diazepane-1,2-dicarboxylate



To a stirred solution of dibenzyl (R)-1-(6-bromo-1-hydroxyhexan-2-yl)hydrazine-1,2-dicarboxylate (1.85 g, 3.8 mmol) in tetrahydrofuran (90 mL) was added tetrabutylammonium fluoride hydrate (1M in THF, 11.4 mL, 11.4 mmol). After 48 hours, saturated aqueous ammonium chloride was added, and the mixture was extracted with ethyl acetate. The combined extracts were washed with brine, dried with sodium sulfate, filtered, concentrated, and purified by flash chromatography (gradient from 80:20 to 65:35 hexanes/EtOAc) to give dibenzyl (*R*)-3-(hydroxymethyl)-1,2-diazepane-1,2-dicarboxylate (1.422 g, 3.6 mmol, 92% yield) which was isolated as a colourless oil. Spectroscopic data were in accordance with previously reported literature.[17]

ethyl (*R*)-3-(hydroxymethyl)-1,2-diazepane-1-carboxylate

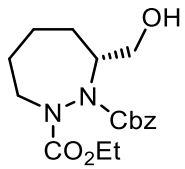


A stirred solution of dibenzyl (*R*)-3-(hydroxymethyl)-1,2-diazepane-1,2-dicarboxylate (1.504 g, 3.8 mmol) in MeOH (40 mL) was submitted to three cycles of vacuum/argon. AcCl (1.1 mL, 15.2 mmol) and 10% Pd/C (454 mg, 0.43 mmol) were added. Argon flow was removed, and a needle attached to a hydrogen-filled balloon was inserted through the septum and into the reaction mixture. A second needle was inserted through the septum to allow gas efflux and the hydrogen was allowed to bubble through the mixture, with the balloon being refilled as needed. After 1 h, the balloon was removed and the mixture was filtered through diatomaceous earth, rinsing with MeOH. The filtrate was concentrated to give crude (*R*)-(1,2-diazepan-3-yl)methanol hydrochloride as a yellow solid. (Note: benzyloxycarbonyl removal is performed under acidic conditions as the unprotected freebase is highly unstable to air oxidation.)

To a stirred suspension of crude (*R*)-(1,2-diazepan-3-yl)methanol in DCM (4.5 mL) at 0 ºC was added Et_3N (1.6 mL, 11.4 mmol) and EtO_2CCl (340 µL, 3.6 mmol). After 1 h, saturated aqueous $NaHCO_3$ was added, and the mixture was extracted with DCM (3 x 5 mL). The combined extracts were washed with water, dried with $MgSO_4$, filtered, concentrated, and purified by flash chromatography (gradient from 70:30 to 20:80 hexanes/EtOAc). ethyl (*R*)-3-(hydroxymethyl)-1,2-diazepane-1-carboxylate was isolated as a colourless oil (582 mg, 2.9 mmol, 76% yield over two steps). IR (Film) ν = 3430, 3329, 2981, 2928, 2864, 1672, 1410, 1380, 1211, 1096, 1034 cm^{-1}; ^1H NMR (500 MHz, $CDCl_3$) δ = 4.93 (bs, 1 H), 4.17 (q, *J* = 7.5 Hz, 2 H), 3.73 – 3.70 (m, 1 H), 3.49 (bs, 2 H), 3.37 – 3.32 (m, 2 H), 3.03 (bs, 1 H), 1.80 – 1.61 (m, 5 H), 1.28 (t, *J* = 7.6 Hz, 3 H), 1.22 – 1.20 (m, 1 H) ppm; ^{13}C NMR (125 MHz, $CDCl_3$) δ = 157.7, 156.7, 64.0, 61.8, 61.4, 49.2, 30.7,

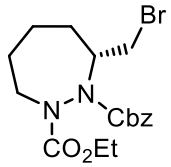
28.1, 27.4, 23.7, 14.4 ppm; HRMS (ESI) exact mass calculated for [M+Na] ($C_9H_{18}N_2NaO_3$) requires m/z 225.1210, found m/z 225.1200.

2-benzyl 1-ethyl (*R*)-3-(hydroxymethyl)-1,2-diazepane-1,2-dicarboxylate



To a stirred solution of ethyl (*R*)-3-(hydroxymethyl)-1,2-diazepane-1-carboxylate (582 mg, 2.9 mmol) and $NaHCO_3$ (874 mg, 10.4 mmol) in $CHCl_3$ (30 mL) was added benzyl chloroformate (0.020 mL, 0.21 mmol). After 19 h, the reaction was quenched with water and extracted with DCM (3 x 30 mL). The combined extracts were dried with $MgSO_4$, filtered, concentrated, and purified by flash chromatography (gradient from 70:30 to 90:10 hexanes/EtOAc) to give 2-benzyl 1-ethyl (*R*)-3-(hydroxymethyl)-1,2-diazepane-1,2-dicarboxylate (947 mg, 2.8 mmol, 95% yield) as a colourless oil. IR (Film) ν = 3429, 2935, 1693, 1320, 1212, 1051 cm^{-1}; ^1H NMR (500 MHz, $CDCl_3$) δ 7.36 – 7.28 (m, 5 H), 5.29 – 5.12 (m, 2 H), 4.27 – 4.13 (m, 3 H), 4.12 – 3.87 (m, 2 H), 3.74 – 3.36 (m, 2 H), 3.11 – 2.92 (m, 1 H), 1.88 – 1.40 (m, 6 H), 1.32 – 1.11 (m, 3H) ppm; ^{13}C NMR (125 MHz, $CDCl_3$) δ 158.1, 157.5, 155.0, 155.0, 136.0, 135.7, 68.0, 67.6, 63.1, 63.0, 62.9, 62.8, 61.5, 61.3, 50.8, 49.7, 28.5, 28.4, 28.2, 27.9, 24.6, 24.3, 14.3, 14.2, 14.0 ppm; HRMS (ESI) exact mass calculated for [M+Na] ($C_{17}H_{24}N_2NaO_5$) requires m/z 359.1577, found m/z 359.1577.

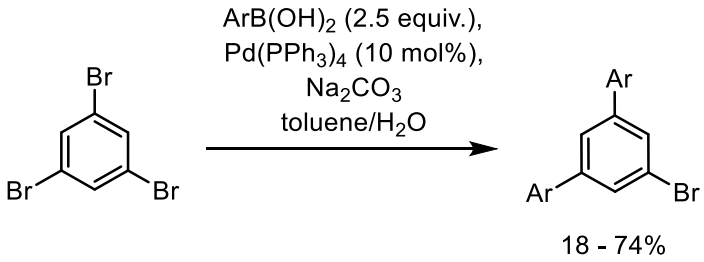
2-benzyl 1-ethyl (*R*)-3-(bromomethyl)-1,2-diazepane-1,2-dicarboxylate



To a stirred solution of PPh_3 (357 mg, 1.4 mmol) in THF (10 mL) at 0 °C was added CBr_4 (412 mg, 1.2 mmol). After 15 minutes, 2-benzyl 1-ethyl (*R*)-3-(hydroxymethyl)-1,2-diazepane-1,2-dicarboxylate (325 mg, 0.97 mmol) was added in THF (5 mL). The solution was brought to room temperature and stirred for 17 h. The reaction was quenched with the addition of saturated aqueous $NaHCO_3$ and extracted with EtOAc (3 x 10 mL). The combined extracts were washed with brine, dried with Na_2SO_4, filtered, concentrated, and purified by flash chromatography (gradient from 90:10 to 80:20 hexanes/EtOAc). 2-benzyl 1-ethyl (*R*)-3-(bromomethyl)-1,2-diazepane-1,2-dicarboxylate was isolated as a colourless oil (367 mg, 0.92 mmol, 95% yield). IR (Film) ν = 2934, 2857, 1705, 1350, 1229, 1210, 1078 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ = 7.37 – 7.28 (m, 5 H), 5.30 – 5.07 (m, 2 H), 4.30 – 3.90 (m, 4 H), 3.85 – 3.54 (m, 1 H), 3.33 – 3.14 (m, 1 H), 3.02 – 2.81 (m, 1 H), 2.56 – 2.34 (m, 1 H), 1.95 – 1.88 (m, 1 H), 1.70 – 1.50 (m, 2 H), 1.40 – 1.29 (m, 2 H), 1.29 – 1.04 (m, 3H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$) δ = 156.2, 156.1, 155.9, 155.7, 154.7, 154.6, 154.2, 154.0, 135.9, 135.8, 135.7, 135.6, 128.4, 128.4, 128.3, 128.3, 128.1, 128.1, 127.8, 127.7, 127.6, 127.3, 68.0, 68.0, 67.6, 62.4, 62.4, 62.2, 61.6, 61.2, 61.1, 60.7, 51.0, 50.4, 50.0, 49.4, 34.2, 33.7, 33.6, 33.3, 30.3, 30.0, 29.8, 29.6, 28.5, 28.3, 28.2, 28.0, 24.4, 24.3, 14.4, 14.4, 14.2,

14.2 ppm; HRMS (ESI) exact mass calculated for [M+Na] ($C_{17}H_{23}BrN_2NaO_4$) requires m/z 421.0733, found m/z 421.0734.

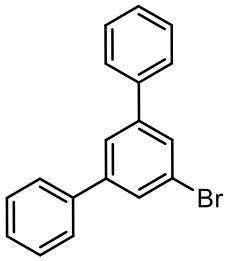
Synthesis of m-terphenyls



General procedure E

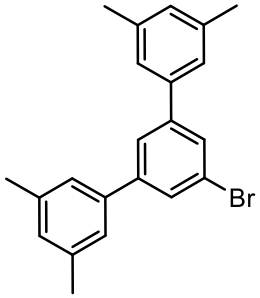
Toluene and 1M aqueous Na_2CO_3 were degassed by bubbling argon through for 1 h. To a solution of 1,3,5-tribromobenzene (1 mmol) and aryl boronic acid (2.2-2.5 mmol) in toluene (4 mL) was added $Pd(PPh_3)_4$ (0.1 mmol) then 1 M aqueous Na_2CO_3 (3.0 mL). The solution was brought to reflux and let stir for 17 h before it was cooled, diluted with water and extracted with DCM (3 x 10 mL). The combined extracts were washed with brine, dried with $MgSO_4$, filtered, concentrated, and purified by flash chromatography (hexanes).

5'-bromo-1,1':3',1''-terphenyl



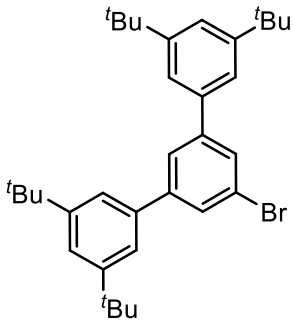
From phenylboronic acid (695 mg, 5.6 mmol), general procedure E was followed to give, after flash chromatography (hexanes), 5'-bromo-1,1':3',1"-terphenyl (227 mg, 0.44 mmol, 18% yield) as a white foam. Spectroscopic data were in accordance with previously reported literature.[18]

5'-bromo-3,3'',5,5''-tetramethyl-1,1':3',1''-terphenyl



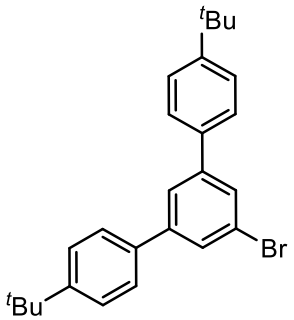
From 3,5-dimethylphenylboronic acid (741 mg, 4.9 mmol), general procedure E was followed to give, after flash chromatography (hexanes), 5'-bromo-3,3'',5,5''-tetramethyl-1,1':3',1''-terphenyl (347 mg, 0.95 mmol, 43% yield) of a white foam. Spectroscopic data were in accordance with previously reported literature.[19]

5'-bromo-3,3'',5,5''-tetra-*tert*-butyl-1,1':3',1''-terphenyl



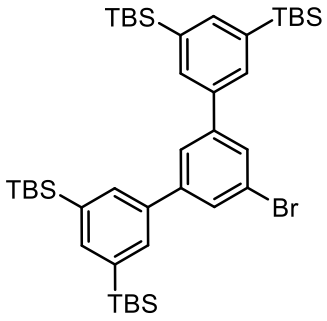
From 3,5-*tert*-butylphenylboronic acid (458 mg, 1.9 mmol), general procedure E was followed to give, after flash chromatography (hexanes), 5'-bromo-3,3'',5,5''-tetra-tert-butyl-1,1':3',1''-terphenyl (187 mg, 0.35 mmol, 37% yield) as a white foam. Spectroscopic data were in accordance with previously reported literature.[20]

5'-bromo-4,4''-di-*tert*-butyl-1,1':3',1''-terphenyl



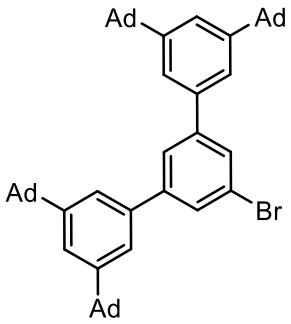
From (4-(*tert*-butyl)phenyl)boronic acid (732 mg, 4.1 mmol), general procedure E was followed to give, after flash chromatography (hexanes), 5'-bromo-4,4''-di-tert-butyl-1,1':3',1''-terphenyl (326 mg, 0.77 mmol, 47% yield) of a white foam. Spectroscopic data were in accordance with previously reported literature.[21]

(5'-bromo-[1,1':3',1''-terphenyl]-3,3'',5,5''-tetrayl)tetrakis(*tert*-butyldimethylsilane)



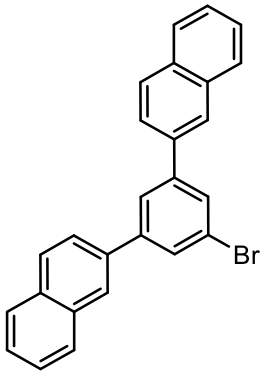
From (3,5-bis(*tert*-butyldimethylsilyl)phenyl)boronic acid (717 mg, 2.0 mmol), general procedure E was followed to give, after flash chromatography (hexanes), (5'-bromo-[1,1':3',1''-terphenyl]-3,3'',5,5''-tetrayl)tetrakis(tert-butyldimethylsilane) (166 mg, 0.22 mmol, 26% yield) as a white foam. IR (Film) ν = 3026, 2952, 2927, 2884, 2955, 1470, 1249, 860, 767cm^{-1}; ^{1}H NMR (500 MHz, $CDCl_3$) δ = 7.72 – 7.70 (m, 9 H), 0.93 (s, 36 H), 0.35 (s, 24 H) ppm; ^{13}C NMR (125 MHz, $CDCl_3$) δ = 144.5, 140.4, 137.8, 137.2, 133.7, 128.8, 125.6, 123.2, 26.5, 16.9, -6.2 ppm. HRMS (APCI) (CH_3CN adduct formed with loss of ^{t}Bu) exact mass calculated for [M+H] ($C_{40}H_{63}BrNSi_4$) requires m/z 748.3221, found m/z 748.3207.

1,1',1'',1'''-(5'-bromo-[1,1':3',1''-terphenyl]-3,3'',5,5''-tetrayl)tetrakis(adamantane)



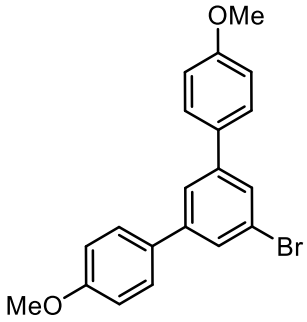
From (3,5-di(adamantan-1-yl)phenyl)boronic acid (732 mg, 1.9 mmol), general procedure E was followed to give, after flash chromatography (hexanes), 1,1',1'',1'''-(5'-bromo-[1,1':3',1''-terphenyl]-3,3'',5,5''-tetrayl)tetrakis(adamantane) (489 mg, 0.58 mmol, 62% yield) as a white foam. IR (Film) ν = 3062, 2900, 2847, 1589, 1449, 1344, 1103 cm^{-1}; ^{1}H NMR (500 MHz, $CDCl_3$) δ = 7.69 (s, 1 H), 7.66 (s, 2 H), 7.44 (s, 2 H), 7.39 (s, 4 H), 2.12 (s, 12 H), 2.00 (s, 24 H), 1.80 (s, 24 H) ppm; ^{13}C NMR (125 MHz, $CDCl_3$) δ = 151.6, 145.1, 139.6, 128.9, 127.4, 125.8, 121.6, 121.2, 43.3, 36.8, 29.0 ppm; HRMS (APCI) exact mass calculated for [M+H] ($C_{58}H_{70}Br$) requires m/z 845.46554, found m/z 845.46425.

2,2'-(5-bromo-1,3-phenylene)dinaphthalene



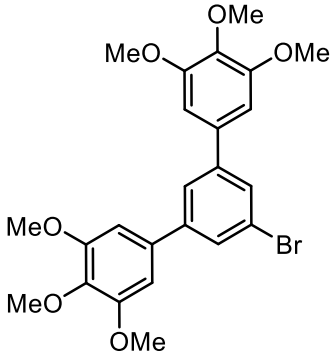
From 2-naphthylboronic acid (493 mg, 2.9 mmol), general procedure E was followed to give, after flash chromatography (98:2 to 95:5 hexanes/EtOAc), 2,2'-(5-bromo-1,3-phenylene)dinaphthalene (123 mg, 0.30 mmol, 25% yield) as a white foam. Spectroscopic data were in accordance with previously reported literature.[22]

5'-bromo-4,4''-dimethoxy-1,1':3',1''-terphenyl



From (4-methoxyphenyl)boronic acid (510 mg, 3.4 mmol), general procedure E was followed to give, after flash chromatography (95:5 to 85:15 hexanes/EtOAc), 5'-bromo-4,4''-dimethoxy-1,1':3',1''-terphenyl (104 mg, 0.28 mmol, 30% yield) as a white foam. Spectroscopic data were in accordance with previously reported literature.[23]

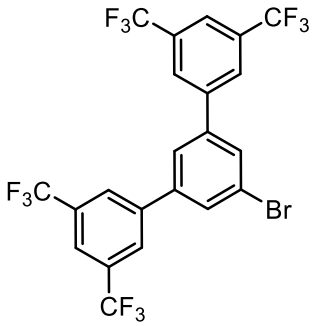
5'-bromo-3,3'',4,4'',5,5''-hexamethoxy-1,1':3',1''-terphenyl



From (3,4,5-trimethoxyphenyl)boronic acid (144 mg, 0.68 mmol), general procedure E was followed to give, after flash chromatography (90:10 to 70:30 hexanes/EtOAc), 5'-bromo-

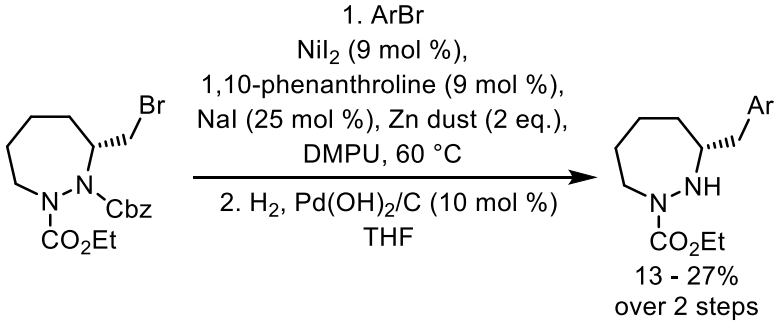
3,3",4,4",5,5"-hexamethoxy-1,1':3',1"-terphenyl (70 mg, 0.15 mmol, 74% yield) as a white foam. IR (Film) ν = 3050, 2935, 2838, 1718, 1508, 1407, 1344, 1124, 1006 cm^{-1}; ^{1}H NMR (500 MHz, $CDCl_3$) δ = 7.64 (s, 2 H), 7.59 (s, 1 H), 6.76 (s, 4 H), 3.93 (s, 12 H), 3.90 (s, 6 H) ppm; ^{13}C NMR (125 MHz, $CDCl_3$) δ = 153.6, 143.9, 138.2, 135.6, 128.9, 124.8, 123.0, 104.6, 61.0, 56.3 ppm; HRMS (ESI) exact mass calculated for [M+Na] ($C_{24}H_{25}BrNaO_6$) requires m/z 511.07267, found m/z 511.07275.

5'-bromo-3,3'',5,5''-tetrakis(trifluoromethyl)-1,1':3',1''-terphenyl



From 3,5-bis(trifluoromethyl)phenylboronic acid (999 mg, 3.9 mmol), general procedure E was followed to give, after flash chromatography (hexanes), 5'-bromo-3,3",5,5"-tetrakis(trifluoromethyl)-1,1':3',1"-terphenyl (252 mg, 0.43 mmol, 43% yield) as a white foam. Spectroscopic data were in accordance with previously reported literature.[24]

Synthesis of m-terphenyl catalysts



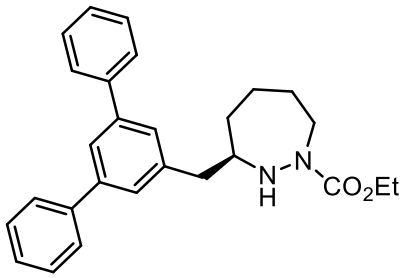
General procedure F

Following a modified procedure of Weix *et al.*[25]: To a 1 mL HPLC vial containing bromo-*m*-terphenyl (0.25 mmol), NiI_2 (0.025 mmol), 1,10-phenanthroline (0.025 mmol), and NaI(0.063 mmol) was added a solution of 2-benzyl 1-ethyl (*R*)-3-(bromomethyl)-1,2-diazepane-1,2-dicarboxylate (0.25 mmol) in DMPU (1 mL). Zn dust (0.50 mmol) was added, vial was capped, and the solution was brought to 60 °C. After 72 h, the reaction was purified by flash chromatography (gradient from 95:5 to 85:15 hexanes/EtOAc) to give coupled product which was isolated as a mixture with the dehalogenated hydrazide.

A stirred solution of the isolated mixture in THF (2.0 mL) was submitted to three cycles of vacuum/argon and 10% $Pd(OH)_2/C$ (0.050 mmol) was added. Argon flow was removed, and a

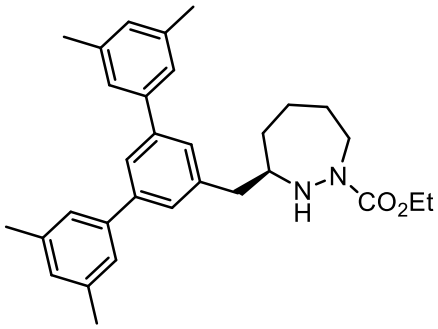
needle attached to a hydrogen-filled balloon was inserted through the septum and into the reaction mixture. A second needle was inserted through the septum to allow gas efflux and the hydrogen was allowed to bubble through the mixture, with the balloon being refilled as needed. After 6 h, the balloon was removed and the mixture was filtered through diatomaceous earth, rinsing with DCM. The filtrate was concentrated and purified by flash chromatography (gradient from 80:20 to 50:50 hexanes/EtOAc) to give desired product.

ethyl (*R*)-3-([1,1':3',1''-terphenyl]-5'-ylmethyl)-1,2-diazepane-1-carboxylate (3a)



Prepared according to general procedure F from 5'-bromo-1,1':3',1"-terphenyl (82 mg, 0.26 mmol). ethyl (*R*)-3-([1,1':3',1"-terphenyl]-5'-ylmethyl)-1,2-diazepane-1-carboxylate was isolated as a colourless oil (22 mg, 0.053 mmol, 22% yield). IR (Film) ν = 3325, 2058, 3033, 2927, 2854, 1688, 1596, 1261, 1028 cm^{-1}; ^{1}H NMR (500 MHz, $CDCl_3$) δ = 7.68 – 7.64 (m, 5 H), 7.48 – 7.44 (m, 6 H), 7.38 – 7.36 (t, *J* = 7.5 Hz, 2 H), 4.62 (bs, 1 H), 4.15 (bs, 1 H), 3.82 (bs, 2 H), 3.39 – 3.14 (m, 2 H), 2.93 – 2.65 (m, 2 H), 1.84 – 1.76 (m, 4 H), 1.42 – 1.26 (m, 3 H), 0.84 (bs, 2 H) ppm; ^{13}C NMR (125 MHz, $CDCl_3$) δ = 156.8, 156.0, 142.0, 141.0, 139.6, 128.8, 127.4, 127.2, 127.1, 124.3, 62.1, 61.3, 60.5, 48.3, 47.4, 41.2, 37.1, 35.0, 27.5, 26.9, 23.8, 14.4 ppm; ^{1}H NMR (400 MHz, DMSO-d_6, 80 °C) δ = 7.75 – 7.72 (m, 5 H), 7.51 – 7.46 (m, 6 H), 7.38 (t, *J* = 7.2 Hz, 2 H), 4.82 (s, 1 H), 3.95 (q, *J* = 6.6 Hz, 2 H), 3.73 – 3.66 (m, 1 H), 3.26 – 3.18 (m, 2 H), 2.83 – 2.73 (m, 2 H), 1.81 – 1.67 (m, 4 H), 1.41 – 1.35 (m, 2 H), 1.05 (t, *J* = 6.6 Hz, 3 H) ppm; ^{13}C NMR (100 MHz, DMSO-d_6, 80 °C) δ = 155.4, 140.6, 140.0, 139.9, 128.3, 127.0, 126.5, 126.3, 122.6, 60.2, 47.9, 40.0, 34.5, 26.6, 23.0, 13.9 ppm; HRMS (ESI) exact mass calculated for [M+Na] ($C_{27}H_{30}N_2NaO_2$) requires m/z 437.2199, found m/z 437.2200.

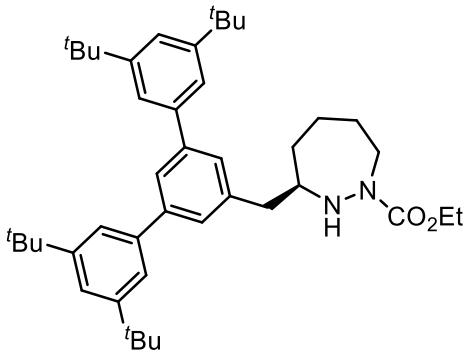
ethyl (*R*)-3-((3,3'',5,5''-tetramethyl-[1,1':3',1''-terphenyl]-5'-yl)methyl)-1,2-diazepane-1-carboxylate (3b)



Prepared according to general procedure F from 5'-bromo-3,3",5,5"-tetramethyl-1,1':3',1"-terphenyl (94 mg, 0.26 mmol). ethyl (*R*)-3-((3,3",5,5"-tetramethyl-[1,1':3',1"-terphenyl]-5'-

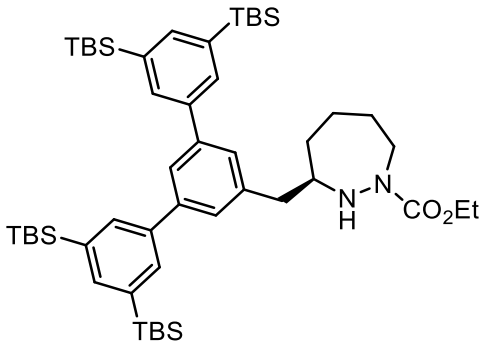
yl)methyl)-1,2-diazepane-1-carboxylate was isolated as a colourless oil (38 mg, 0.080 mmol, 31% yield). IR (Film) ν = 2927, 2865, 1696, 1593, 1447, 1408, 1380, 1336, 1212, 1112, 1025 cm^{-1}; ^1H NMR (500 MHz, $CDCl_3$) δ = 7.65 (s, 1 H), 7.41 (s, 2 H), 7.28 (s, 4 H), 7.02 (s, 2 H), 4.89 – 4.50 (m, 1 H), 4.18 (bs, 1 H), 3.85 (bs, 2 H), 3.41 – 3.15 (m, 2 H), 2.89 – 2.64 (m, 2 H), 2.41 (s, 12 H), 1.95 – 1.69 (m, 4 H), 1.47 – 1.24 (m, 3 H), 0.87 (bs, 2 H) ppm; ^{13}C NMR (125 MHz, $CDCl_3$) δ = 156.8, 156.0, 142.0, 141.1, 139.3, 138.2, 129.0, 126.9, 125.1, 124.3, 62.2, 61.3, 60.4, 48.2, 47.4, 41.2, 37.1, 34.9, 27.5, 27.1, 26.9, 23.8, 23.5, 21.4, 14.7, 14.4 ppm; HRMS (ESI) exact mass calculated for [M+Na] ($C_{31}H_{38}N_2NaO_2$) requires m/z 493.2825, found m/z 493.2822.

ethyl (*R*)-3-((3,3'',5,5''-tetra-*tert*-butyl-[1,1':3',1''-terphenyl]-5'-yl)methyl)-1,2-diazepane-1-carboxylate (3c)



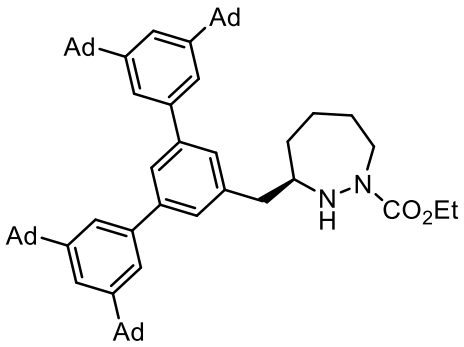
Prepared according to general procedure F from 5'-bromo-3,3",5,5"-tetra-*tert*-butyl-1,1':3',1"-terphenyl (171 mg, 0.32 mmol). ethyl (*R*)-3-((3,3",5,5"-tetra-tert-butyl-[1,1':3',1"-terphenyl]-5'-yl)methyl)-1,2-diazepane-1-carboxylate was isolated as a colourless oil (65 mg, 0.10 mmol, 37% yield). IR (Film) ν = 2962, 2865, 1697, 1590, 1476, 1464, 1408, 1248, 1111 cm^{-1}; ^1H NMR (500 MHz, $CDCl_3$) δ = 7.64 (bs, 1 H), 7.47 – 7.46 (m, 6 H), 7.39 (bs, 2 H), 4.66 (bs, 1 H), 4.16 (bs, 1 H), 3.84 (bs, 2 H), 3.44 – 3.24 (m, 2 H), 2.89 – 2.67 (m, 2 H), 1.85 – 1.77 (m, 4 H), 1.43 – 1.40 (m, 39 H), 0.87 (bs, 2 H) ppm; ^{13}C NMR (125 MHz, $CDCl_3$) δ = 156.8, 156.0, 151.2, 143.3, 140.8, 139.2, 127.2, 125.2, 121.9, 121.6, 62.2, 61.2, 60.1, 48.2, 47.4, 41.1, 37.1, 35.0, 31.5, 27.6, 26.9, 23.8, 14.6 ppm; ^1H NMR (400 MHz, DMSO-d_6, 80 °C) δ = 7.58 (s, 1 H), 7.47 – 7.46 (m, 4 H), 7.45 – 7.43 (m, 4 H), 4.80 (s, 1 H), 3.97 (q, *J* = 7.5 Hz, 2 H), 3.74 – 3.67 (m, 1 H), 3.28 (bs, 1 H), 3.23 – 3.17 (m, 1 H), 2.85 – 2.73 (m, 2 H), 1.82 – 1.65 (m, 4 H), 1.42 – 1.37 (m, 38 H), 1.06 (t, *J* = 7.5 Hz, 3 H) ppm; ^{13}C NMR (100 MHz, DMSO-d_6, 80 °C) δ = 155.4, 150.5, 141.9, 139.8, 139.5, 126.3, 123.4, 120.8, 1206, 60.2, 60.0, 47.8, 40.0, 34.7, 34.2, 30.9, 26.6, 23.0, 14.0 ppm; HRMS (ESI) exact mass calculated for [M+Na] ($C_{43}H_{62}N_2NaO_2$) requires m/z 661.4703, found m/z 661.4710.

ethyl (*R*)-3-((3,3'',5,5''-tetrakis(*tert*-butyldimethylsilyl)-[1,1':3',1''-terphenyl]-5'-yl)methyl)-1,2-diazepane-1-carboxylate (3d)



Prepared according to general procedure F from (5'-bromo-[1,1':3',1"-terphenyl]-3,3",5,5"-tetrayl)tetrakis(*tert*-butyldimethylsilane) (224 mg, 0.29 mmol). ethyl (*R*)-3-((3,3",5,5"-tetrakis(*tert*-butyldimethylsilyl)-[1,1':3',1"-terphenyl]-5'-yl)methyl)-1,2-diazepane-1-carboxylate was isolated as a colourless oil (52 mg, 0.059 mmol, 22% yield). IR (Film) ν = 3027, 2952, 2927, 2884, 2856, 2698, 1597, 1470, 1361, 1249, 1176 cm^{-1}; ^{1}H NMR (500 MHz, $CDCl_3$) δ = 7.74 (s, 4 H), 7.68 (s, 2 H), 7.62 (s, 1 H), 7.40 (s, 2 H), 4.70 – 4.57 (m, 1 H), 4.16 – 4.13 (m, 1 H), 3.92 – 3.76 (m, 2 H), 3.50 – 3.12 (m, 2 H), 2.97 – 2.66 (m, 2 H), 1.95 – 1.75 (m, 4 H), 1.48 – 1.22 (m, 3 H), 0.92 – 0.86 (m, 38 H), 0.33 (s, 24 H) ppm; ^{13}C NMR (125 MHz, $CDCl_3$) δ = 156.8, 156.0, 142.8, 139.8, 139.6, 139.0, 137.0, 133.8, 126.9, 125.2, 62.3, 61.2, 60.1, 48.3, 47.4, 41.1, 37.0, 35.0, 26.5, 23.8, 23.5, 16.9, 14.5, -6.2 ppm; HRMS (ESI) exact mass calculated for [M+Na] ($C_{51}H_{86}N_2NaSi_4O_2$) requires m/z 893.56586, found m/z 893.56383.

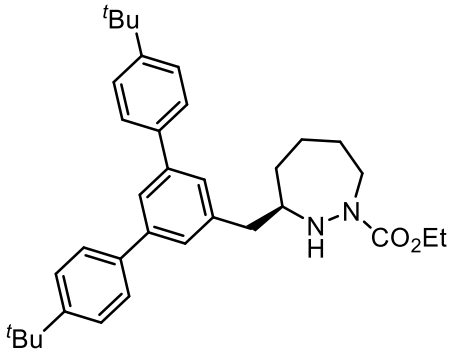
ethyl (*R*)-3-((3,3'',5,5''-tetra(adamantan-1-yl)-[1,1':3',1''-terphenyl]-5'-yl)methyl)-1,2-diazepane-1-carboxylate (3e)



Prepared according to general procedure F from 1,1',1",1'"-(5'-bromo-[1,1':3',1"-terphenyl]-3,3",5,5"-tetrayl)tetrakis(1-adamantane) (198 mg, 0.23 mmol). ethyl (*R*)-3-((3,3",5,5"-tetra(adamantan-1-yl)-[1,1':3',1"-terphenyl]-5'-yl)methyl)-1,2-diazepane-1-carboxylate was isolated as a colourless oil (52 mg, 0.054 mmol, 23% yield). IR (Film) ν = 2979, 2905, 2950, 1731, 1588, 1450, 1374, 1178, 1154 cm^{-1}; ^{1}H NMR (500 MHz, $CDCl_3$) δ = 7.66 (bs, 1 H), 7.43 (s 6 H), 2.08 (s, 2 H), 4.60 (bs, 1 H), 4.16 (bs, 1 H), 3.84 (bs, 2 H), 3.44 – 3.23 (m, 2 H), 2.93 – 2.65 (m, 2 H), 2.13 (s, 12 H), 2.01 (s, 24 H), 1.83 – 1.78 (m, 28 H), 1.44 – 1.41 (m, 2 H), 1.27 – 1.25 (m, 1 H), 0.86 (s, 2 H) ppm; ^{13}C NMR (125 MHz, $CDCl_3$) δ = 156.8, 156.0, 151.4, 143.4, 140.9, 139.0,

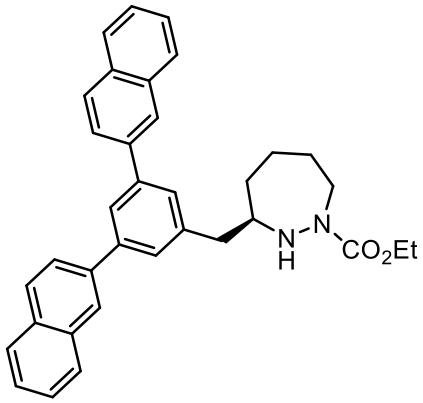
127.0, 126.2, 125.4, 121.6, 120.6, 62.1, 61.3, 60.5, 48.5, 47.3, 43.3, 41.1, 36.8, 29.0, 23.8, 14.6 ppm; HRMS (APCI) exact mass calculated for [M+H] ($C_{67}H_{87}N_2O_8$) requires m/z 951.67621, found m/z 951.67554.

ethyl (*R*)-3-((4,4''-di-*tert*-butyl-[1,1':3',1''-terphenyl]-5'-yl)methyl)-1,2-diazepane-1-carboxylate (3f)



Prepared according to general procedure F from 5'-bromo-4,4''-di-*tert*-butyl-1,1':3',1''-terphenyl (106 mg, 0.25 mmol). ethyl (*R*)-3-((4,4''-di-*tert*-butyl-[1,1':3',1''-terphenyl]-5'-yl)methyl)-1,2-diazepane-1-carboxylate was isolated as a colourless oil (18 mg, 0.034 mmol, 13% yield). IR (Film) ν = 3307, 3031, 2933, 2862, 1709, 1597, 1322, 1308, 1080, 1063 cm^{-1}; ^1H NMR (500 MHz, $CDCl_3$) δ = 7.68 (s, 1 H), 7.58 (d, *J* = 8.0 Hz, 4 H), 7.48 (d, *J* = 8.0 Hz, 4 H), 7.40 (s, 2 H), 4.61 (bs, 1 H), 4.16 (bs, 1 H), 3.84 (bs, 2 H), 3.37 – 3.12 (m, 2 H), 2.86 – 2.63 (m, 2 H), 1.83 – 1.77 (m, 4 H), 1.38 – 1.25 (m, 21 H), 0.84 (bs, 2 H) ppm; ^{13}C NMR (125 MHz, $CDCl_3$) δ = 156.8, 156.0, 150.4, 141.7, 139.5, 138.2, 126.8, 125.7, 124.0, 62.2, 61.3, 48.3, 47.4, 41.2, 37.1, 34.5, 31.4, 27.1, 26.9, 24.0, 23.8, 14.4 ppm; HRMS (ESI) exact mass calculated for [M+Na] ($C_{35}H_{46}N_2NaO_2$) requires m/z 549.3451, found m/z 549.3475.

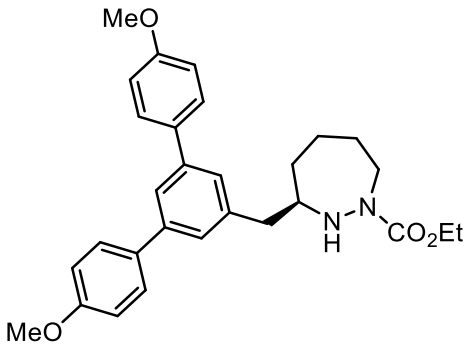
ethyl (*R*)-3-(3,5-di(naphthalen-2-yl)benzyl)-1,2-diazepane-1-carboxylate (3g)



Prepared according to general procedure F from 2,2'-(5-bromo-1,3-phenylene)dinaphthalene (103 mg, 0.25 mmol). ethyl (*R*)-3-(3,5-di(naphthalen-2-yl)benzyl)-1,2-diazepane-1-carboxylate was isolated as a colourless oil (30 mg, 0.059 mmol, 24% yield). IR (Film) ν = 3053, 3017, 2929, 2854, 1693, 1593, 1506, 1447, 1408, 1212, 1112 cm^{-1}; ^1H NMR (800 MHz, $CDCl_3$) δ = 8.10 (s, 2 H), 7.92 – 7.91 (m, 5 H), 7.87 – 7.86 (m, 2 H), 7.79 (s, 2 H), 7.63 (s, 2 H), 7.52 – 7.48 (m, 4 H), 4.28

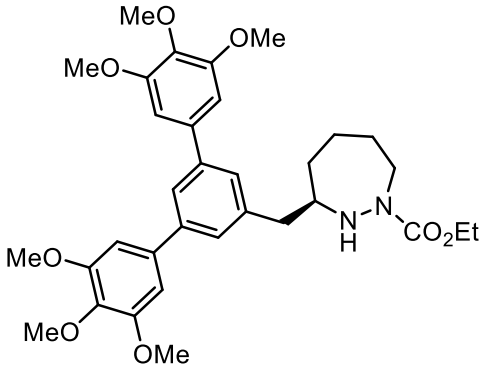
– 3.99 (m, 4 H), 3.84 – 3.46 (m, 2 H), 3.19 (bs, 1 H), 2.00 – 1.92 (m, 4 H), 1.58 (bs, 2 H), 1.28 – 1.18 (m, 3 H) ppm; ^{13}C NMR (200 MHz, $CDCl_3$) δ = 155.2, 153.6, 142.3, 137.9, 133.6, 132.7, 128.5, 128.2, 127.6, 127.3, 126.3, 126.0, 126.0, 125.5, 64.2, 63.6, 47.2, 38.8, 30.6, 26.6, 22.9, 14.4 ppm; HRMS (ESI) exact mass calculated for [M+Na] ($C_{35}H_{34}N_2NaO_2$) requires m/z 537.2512, found m/z 537.2534.

ethyl (*R*)-3-((4,4''-dimethoxy-[1,1':3',1''-terphenyl]-5'-yl)methyl)-1,2-diazepane-1-carboxylate (3h)



Prepared according to general procedure F from 5'-bromo-4,4''-dimethoxy-1,1':3',1''-terphenyl (104 mg, 0.23 mmol). ethyl (*R*)-3-((4,4''-dimethoxy-[1,1':3',1''-terphenyl]-5'-yl)methyl)-1,2-diazepane-1-carboxylate was isolated as a colourless oil (24 mg, 0.12 mmol, 22% yield). IR (Film) ν = 2930, 2836, 1687, 1608, 1512, 1451, 1440, 1247, 1177, 1032 cm^{-1}; ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.58 (d, *J* = 7.9 Hz, 5 H), 7.35 (s, 2 H), 6.99 (d, *J* = 7.9 Hz, 4 H), 4.71 – 4.55 (m, 1 H), 4.15 (bs, 1 H), 3.86 – 3.78 (m, 8 H), 3.39 – 3.13 (m, 2 H), 2.85 – 2.61 (m, 2 H), 1.83 – 1.77 (m, 4 H), 1.41 – 1.26 (m, 3 H), 0.84 (bs, 2 H) ppm; ^{13}C NMR (125 MHz, $CDCl_3$) δ = 159.2, 156.8, 156.0, 141.4, 139.5, 133.6, 128.2, 126.1, 123.4, 114.2, 62.2, 61.3, 60.4, 55.3, 48.2, 47.4, 41.2, 37.1, 34.9, 27.5, 26.9, 23.8, 14.6 ppm; HRMS (ESI) exact mass calculated for [M+Na] ($C_{29}H_{34}N_2NaO_4$) requires m/z 497.2411, found m/z 497.2408.

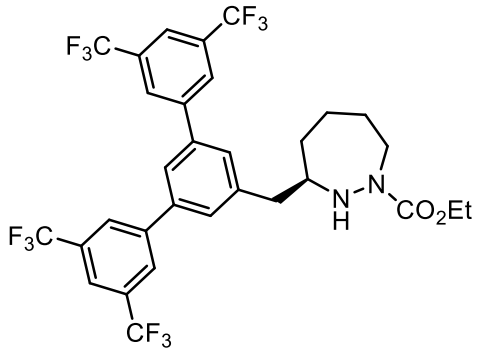
ethyl (*R*)-3-((3,3'',4,4'',5,5''-hexamethoxy-[1,1':3',1''-terphenyl]-5'-yl)methyl)-1,2-diazepane-1-carboxylate (3i)



Prepared according to general procedure F from 5'-bromo-3,3'',4,4'',5,5''-hexamethoxy-1,1':3',1''-terphenyl (202 mg, 0.45 mmol). ethyl (*R*)-3-((3,3'',4,4'',5,5''-hexamethoxy-[1,1':3',1''-terphenyl]-5'-yl)methyl)-1,2-diazepane-1-carboxylate was isolated as a colourless oil (42 mg, 0.071 mmol,

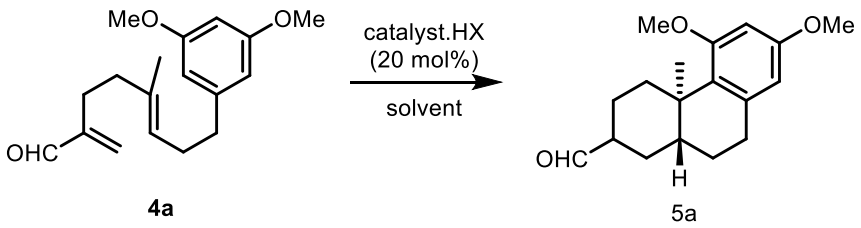
14% yield). IR (Film) ν = 2933, 2865, 1691, 1581, 1430, 1409, 1240, 1127 cm^{-1}; ^{1}H NMR (500 MHz, $CDCl_3$) δ = 7.54 (s, 1 H), 7.40 (s, 2 H), 6.83 (s, 4 H), 4.71 (bs, 1 H), 4.12 (bs, 1 H), 3.94 – 3.84 (m, 20 H), 3.48 – 3.23 (m, 2 H), 2.84 – 2.67 (m, 2 H), 1.84 – 1.75 (m, 4 H), 1.45 – 1.39 (m, 2 H), 1.27 – 1.24 (m, 2 H), 0.91 (bs, 1 H) ppm; ^{13}C NMR (125 MHz, $CDCl_3$) δ = 156.8, 156.0, 153.5, 142.2, 139.3, 137.8, 137.2, 127.1, 124.3, 104.7, 61.9, 61.4, 60.9, 59.5, 56.3, 48.1, 47.5, 41.0, 36.9, 35.7, 27.4, 23.6, 14.6 ppm; HRMS (ESI) exact mass calculated for [M+Na] ($C_{33}H_{42}N_2NaO_8$) requires m/z 617.2833, found m/z 617.2812.

ethyl (*R*)-3-((3,3'',5,5''-tetrakis(trifluoromethyl)-[1,1':3',1''-terphenyl]-5'-yl)methyl)-1,2-diazepane-1-carboxylate (3*J*)



Prepared according to general procedure F from 5'-bromo-3,3",5,5"-tetrakis(trifluoromethyl)-1,1':3',1"-terphenyl (114 mg, 0.20 mmol). ethyl (*R*)-3-((3,3",5,5"-tetrakis(trifluoromethyl)-[1,1':3',1"-terphenyl]-5'-yl)methyl)-1,2-diazepane-1-carboxylate was isolated as a colourless oil (34 mg, 0.050 mmol, 17% yield). IR (Film) ν = 3029, 2933, 1692, 1600, 1410, 1299, 1172, 1130 cm^{-1}; ^{1}H NMR (500 MHz, $CDCl_3$) δ = 8.13 (s, 4 H), 7.91 (s, 2 H), 7.62 (s, 3 H), 4.63 (bs, 1 H), 4.17 – 3.76 (m, 3 H), 3.55 – 3.22 (m, 2 H), 3.02 – 2.95 (m, 1 H), 2.83 – 2.75 (m, 1 H), 1.90 – 1.73 (m, 4 H), 1.50 – 1.20 (m, 4 H), 1.00 – 0.78 (m, 1 H) ppm; ^{13}C NMR (125 MHz, $CDCl_3$) δ = 156.8, 142.8, 140.4, 139.7, 132.2 (q, *J* = 34.7 Hz), 128.8, 127.6, 124.5, 123.5 (q, *J* = 253.1 Hz), 121.3, 61.6, 59.4, 47.7, 40.7, 36.6, 27.2, 23.7, 14.6 ppm; HRMS (ESI) exact mass calculated for [M+Na] ($C_{31}H_{26}F_{12}N_2NaO_2$) requires m/z 709.1695, found m/z 709.1668.

IV. Polyene cyclizations: optimization



4a **5a**

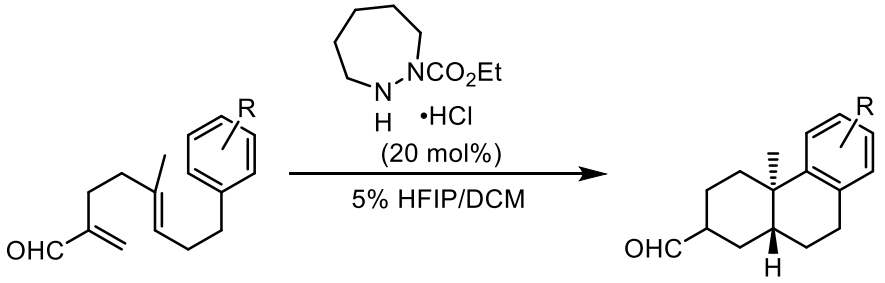
General polyene cyclization procedure during optimization

General procedure for asymmetric polyene cyclization optimization

To a 1.8-mL vial containing aldehyde **4a** (0.035 mmol) was added a solution of catalyst (0.0070 mmol, as the salt or 1:1 freebase:salt) in solvent (140 µL, 0.25M in substrate). The mixture was briefly swirled to homogenize and let stand at the specified temperature until complete. The reaction mixture was concentrated and purified by silica gel column chromatography (gradient from 97:3 to 90:10 hexanes/ethyl acetate) to obtain aldehyde **5a** as a mixture of diastereomers. Where alcoholic solvents were used, the following acetal-cleavage sequence was performed after concentration and prior to chromatography: the material was redissolved in chloroform (0.5 mL); water (0.25 mL) and trifluoroacetic acid (0.25 mL) were added; and the biphasic mixture was stirred for 2 hours, added dropwise to a saturated solution of sodium bicarbonate (5 mL), extracted with dichloromethane (5 mL), and concentrated.

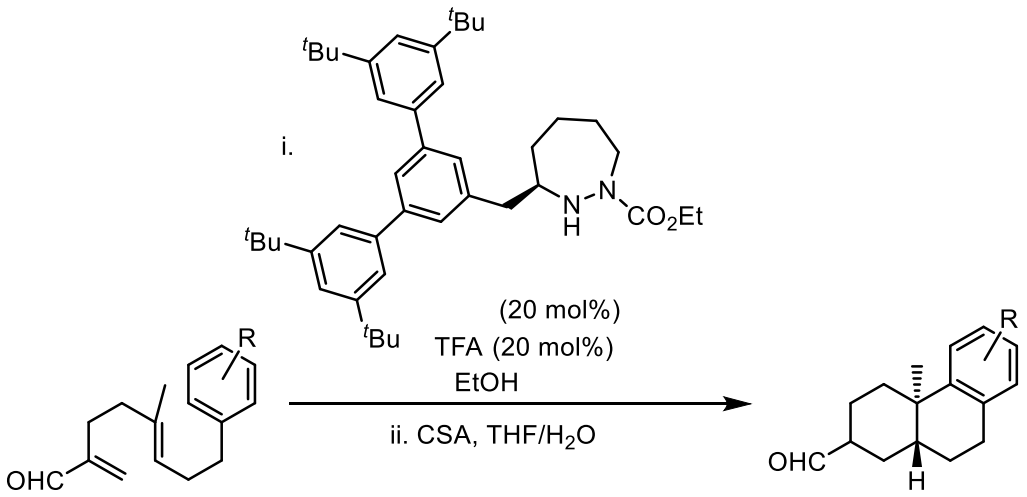
To determine product enantiopurity (where applicable), excess sodium borohydride was added to a stirred sample of the aldehyde product in methanol. After one hour, the reaction was quenched with 1M hydrochloric acid. The resulting mixture was extracted with a small amount of dichloromethane and the extract was purified directly by flash chromatography (gradient from 85:15 to 75:25 hexanes/ethyl acetate) to give a diastereomeric mixture of alcohols. This mixture was submitted to chiral HPLC analysis. For (*E*) cyclizations: Daicel Chiralcel O*J*-H, 1 mL/min, 94:6 hexanes/isopropanol, 220 nm: 10.4 min (4a*R*,10a*R*-α), 11.9 min (4a*R*,10a*R*-β), 15.3 min (4a*S*,10a*S*-β), 23.4 min (4a*S*,10a*S*-α).) Catalyst **3a, 3d-3*J*** had an *er* of >99:1 for screening. Catalyst **3b** and **3c** had an *er* of 97:3 for screening reactions. Reported *er* of product **5a** were ad*J*usted accounting for catalyst enantiopurity, assuming no non-linear effects.

V. Polyene cyclizations: scope



Racemic polyene cyclization (general procedure G)

To a 1.8-mL or 4 mL vial containing aldehyde was added a solution of ethyl 1,2-diazepane-1-carboxylate hydrochloride (0.2 equiv.) in 5% HFIP/DCM (0.25 M in substrate). The mixture was briefly swirled to homogenize and let stand for 5 hours. The reaction mixture was concentrated and purified by silica gel column chromatography (gradient from hexanes to 93:7 hexanes/EtOAc) to obtain *trans*-decalin products as a mixture of diastereomers.



Asymmetric polyene cyclization (general procedure H)

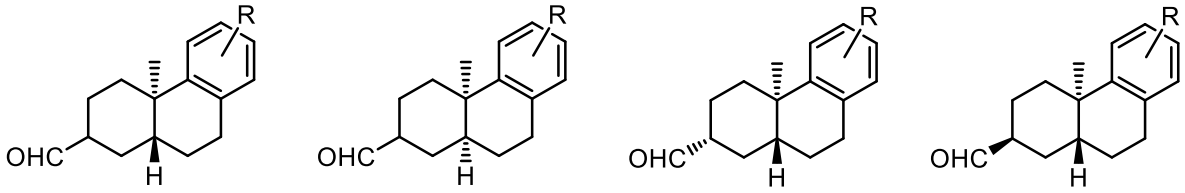
To a 4 mL vial containing aldehyde (0.15 mmol) was added a solution of catalyst **3c** (99:1 *er*, 0.030 mmol, as the premixed 1:1 TFA salt) in ethanol (600 μL, 0.25M in substrate). The mixture was briefly swirled to homogenize and let sit for 24–30 h. Once complete, the reaction mixture was concentrated and redissolved in THF (0.6 mL). Water (0.3 mL) and camphorsulfonic acid (0.30 mmol) were added and the biphasic mixture was stirred for 3 hours, then purified by flash chromatography to obtain aldehyde **5** as a mixture of diastereomers. The enantiomeric excess of the product was determined by reduction to the corresponding alcohol (following the general procedure used for the corresponding racemic product, *vide supra*) and chiral HPLC analysis (see section IX for chromatographic conditions).

^{1}H and ^{13}C peaks for the α diastereomer of *trans*-decalin products are reported with an asterisk (*) where possible to distinguish from the β diastereomer peaks. The integrations are reported as a

proportion of the total signal (i.e. 1 H x 0.8 for a signal that corresponds to one proton of one of the two diastereomers).

Stereochemical nomenclature for polyene cyclization products:

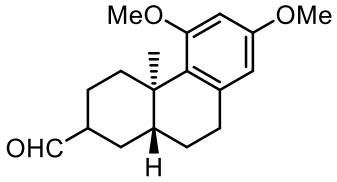
- *trans* and *cis* refer to ring fusion
- α and β refer to stereochemistry at C3



Reduction and separation of polyene cyclization products (general procedure I)

To a stirred sample of aldehyde 5 in methanol was added excess sodium borohydride. After one hour, the reaction was quenched with 1M hydrochloric acid. The resulting mixture was extracted with a small amount of dichloromethane and the extract was purified directly by flash chromatography to give a diastereomeric mixture of alcohols. The mixture of alcohols was submitted to semi-preparative normal phase HPLC to give pure *trans*-α and *trans*-β alcohols. Due to the small amounts of alcohol obtained, complete characterization was done for the ma*J*or *trans*-β alcohols.

(4a*R*,10a*R*)-5,7-dimethoxy-4a-methyl-1,2,3,4,4a,9,10,10a-octahydrophenanthrene-2-carbaldehyde (5a)



Racemic:

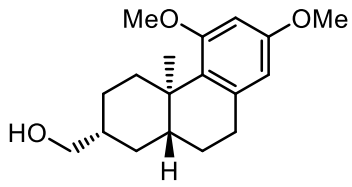
Prepared according to general procedure G from (*E*)-8-(3,5-dimethoxyphenyl)-5-methyl-2-methyleneoct-5-enal (49 mg, 0.17 mmol). The reaction was run for 5 h and (4a*RS*,10a*RS*)-5,7-dimethoxy-4a-methyl-1,2,3,4,4a,9,10,10a-octahydrophenanthrene-2-carbaldehyde was isolated as a colourless oil (35 mg, 0.12 mmol, 72% yield, *trans*:*cis* 95:5, *trans*-α:β 6:1).

Asymmetric:

Prepared according to general procedure H from (*E*)-8-(3,5-dimethoxyphenyl)-5-methyl-2-methyleneoct-5-enal (43 mg, 0.15 mmol). The reaction was run for 24 h and (4a*R*,10a*R*)-5,7-dimethoxy-4a-methyl-1,2,3,4,4a,9,10,10a-octahydrophenanthrene-2-carbaldehyde was isolated as a colourless oil (28 mg, 0.097 mmol, 65% yield, 89:11 *er*, *trans*:*cis* 99:1, *trans*-α:β 6:1).

IR (Film) 2988, 2928, 2861, 2837, 2709, 1721, 1604, 1580, 1459, 1419, 1341, 1325, 1309, 1289, 1268, 1230, 1212, 1194, 1150, 1132, 1119, 1085, 1065, 1046, 1023, 941, 829, 736, 702 cm^{-1}; ^1H NMR (500 MHz, $CDCl_3$) δ = 9.73* (s, 1 H x 0.2), 9.66 (d, *J* = 1.5 Hz, 1 H x 0.8), 6.30 (d, *J* = 2.4 Hz, 1 H x 0.8), 6.30* (d, *J* = 2.4 Hz, 1H x 0.2), 6.22 (d, *J* = 2.4 Hz, 1 H x 0.8), 6.21* (d, *J* = 2.4 Hz, 1 H x 0.2), 3.78 (s, 3 H x 0.8), 3.77 (s, 3 H x 0.8), 3.75* (s, 3 H x 0.2), 3.75* (s, 3 H x 0.2), 3.17 (dt, *J* = 13.4, 3.5 Hz, 1 H x 0.8), 2.99 – 2.91 (m, 1 H x 0.8), 2.99 – 2.91* (m, 2 H x 0.2), 2.77 (dd, *J* = 17.4, 4.5 Hz, 1 H x 0.8), 2.74* (dd, *J* = 17.3, 5.5 Hz, 1 H x 0.2), 2.43* (t, *J* = 6.2 Hz, 1 H x 0.2), 2.40 – 2.34 (m, 1 H x 0.8), 2.13* (d, *J* = 14.8, 1 H x 0.2), 2.01* (d, *J* = 14.0, 1 H x 0.2), 1.96 – 1.88* (m, 1 H x 0.2), 1.86 (m, 1 H x 0.8), 1.82 – 1.74* (m, 1 H x 0.2), 1.74 – 1.39 (m, 6 H x 0.8), 1.74 – 1.39* (m, 3 H x 0.2), 1.25 (td, *J* = 13.4, 3.8 Hz, 1 H x 0.8), 1.20* (s, 3 H x 0.2), 1.17 (s, 3 H x 0.8), 1.13* (td, *J* = 14.1, 4.2, 1 H x 0.2) ppm; ^{13}C NMR (125 MHz, $CDCl_3$) δ = 206.0*, 204.7, 160.0, 159.8*, 158.0, 158.0*, 138.8, 138.8*, 127.6*, 127.5, 105.0, 105.0*, 97.4, 97.4*, 55.1, 55.1*, 55.0, 55.0*, 50.8, 46.6*, 44.2, 41.5*, 37.4, 37.3*, 34.7, 32.8*, 32.2, 32.0*, 28.2, 27.4*, 25.7, 25.7*, 22.0, 21.0*, 16.6, 16.1* ppm; MS (ESI) exact mass calculated for [M+Na] ($C_{18}H_{24}NaO_3$) requires m/z 311.1618, found m/z 311.1611.

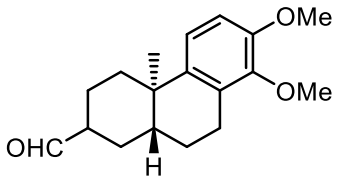
((2*R*,4a*R*,10a*R*)-5,7-dimethoxy-4a-methyl-1,2,3,4,4a,9,10,10a-octahydrophenanthren-2-yl)methanol



From (4a*R*,10a*R*)-5,7-dimethoxy-4a-methyl-1,2,3,4,4a,9,10,10a-octahydrophenanthrene-2-carbaldehyde, general procedure I was followed to give, after flash chromatography (gradient from 85:15 to 75:25 hexanes/ethyl acetate) and semi-preparative HPLC (99:1 hexanes/isopropanol), a white solid.

IR (Film) 3423, 2924, 2858, 2838, 1685, 1597, 1460, 1117 cm^{-1}; ^1H NMR (500 MHz, $CDCl_3$) δ = 6.29 (d, *J* = 3.3 Hz, 1 H), 6.21 (d, *J* = 3.3 Hz, 1 H), 3.76 (s, 3 H), 3.76 (s, 3H), 3.51 (td, *J* = 5.7, 2.3 Hz, 2 H), 3.06 (dt, *J* = 12.1, 3.7 Hz, 1 H), 2.96 – 2.89 (m, 1 H), 2.73 (dd, *J* = 12.1, 5.1 Hz, 1 H), 1.67 – 1.56 (m, 3 H), 1.45 – 1.41 (m, 1 H), 1.30 – 1.22 (m, 4 H), 1.15 (s, 3 H), 0.90 – 0.84 (m, 2 H) ppm; ^{13}C NMR (125 MHz, $CDCl_3$) δ = 160.0, 157.9, 139.0, 128.3, 105.0, 97.4, 68.7, 55.1, 55.0, 44.7, 40.9, 37.8, 35.3, 32.4, 31.9, 31.6, 26.0, 25.4, 22.6, 16.9, 14.1 ppm; MS (ESI) exact mass calculated for [M+Na] ($C_{18}H_{26}NaO_3$) requires m/z 313.1774, found m/z 313.1780.

(4a*R*,10a*R*)-7,8-dimethoxy-4a-methyl-1,2,3,4,4a,9,10,10a-octahydrophenanthrene-2-carbaldehyde (5b)



Racemic:

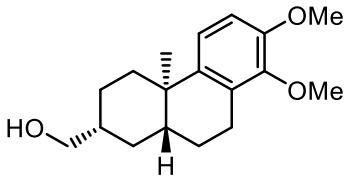
Prepared according to general procedure G from (*E*)-8-(2,3-dimethoxyphenyl)-5-methyl-2-methyleneoct-5-enal (32 mg, 0.11 mmol). The reaction was run for 5 h and (4a*RS*,10a*RS*)-7,8-dimethoxy-4a-methyl-1,2,3,4,4a,9,10,10a-octahydrophenanthrene-2-carbaldehyde was isolated as a colourless oil (26 mg, 0.089 mmol, 81% yield, *trans*-α:β 4:1).

Asymmetric:

Prepared according to general procedure H from (*E*)-8-(2,3-dimethoxyphenyl)-5-methyl-2-methyleneoct-5-enal (43 mg, 0.15 mmol). The reaction was run for 5 h and (4a*R*,10a*R*)-7,8-dimethoxy-4a-methyl-1,2,3,4,4a,9,10,10a-octahydrophenanthrene-2-carbaldehyde was isolated as a colourless oil (33 mg, 0.12 mmol, 77% yield, 93:7 *er*, *trans*-α:β 6:1).

IR (Film) 2928, 2857, 2709, 1721, 1598, 1489, 1451, 1375, 1151, 1077 cm^{-1}; ^{1}H NMR (500 MHz, $CDCl_3$) δ = 9.72* (s, 1 H x 0.2), 9.68 (s, 1 H x 0.8), 6.99 (d, *J* = 8.7 Hz, 1 H x 0.8), 6.94* (d, *J* = 8.5 Hz, 1 H x 0.2), 6.77 (d, *J* = 8.6 Hz, 1 H x 0.8), 6.73* (d, *J* = 8.5 Hz, 1 H x 0.2), 3.84 (s, 3 H x 0.8), 3.82* (s, 3 H x 0.2), 3.80 (s, 3 H x 0.8), 3.78* (s, 3 H x 0.2), 2.99 – 2.89 (m, 1 H), 2.80 – 2.67 (m, 1 H), 2.39 – 2.31 (m, 2 H x 0.8), 2.29 – 2.21* (m, 1 H x 0.2), 2.17 – 2.10* (m, 1 H x 0.2), 2.08 – 2.01* (m, 1 H x 0.2), 2.00 – 1.94 (m, 1 H x 0.8), 1.80 – 1.55 (m, 5 H), 1.49 – 1.39 (m, 2 H), 1.08* (s, 3 H x 0.2), 1.05 (s, 3 H x 0.8) ppm; ^{13}C NMR (125 MHz, $CDCl_3$) δ = 205.4*, 204.3, 150.1, 150.0*, 146.4, 146.3*, 140.8*, 140.7, 130.0, 130.0*, 119.8, 119.7*, 109.8, 109.8*, 59.6, 59.6*, 55.6, 55.6*, 50.5, 46.4*, 40.9, 38.2*, 36.8, 36.2, 36.0*, 34.7*, 28.3, 27.4*, 25.1*, 25.0, 23.3, 23.2*, 21.9, 21.7, 21.2*, 20.8* ppm; MS (ESI) exact mass calculated for [M+Na] ($C_{18}H_{24}NaO_3$) requires m/z 311.1618, found m/z 311.1618.

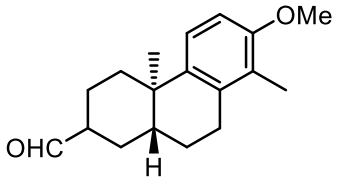
((2*R*,4a*R*,10a*R*)-7,8-dimethoxy-4a-methyl-1,2,3,4,4a,9,10,10a-octahydrophenanthren-2-yl)methanol



From (4a*R*,10a*R*)-7,8-dimethoxy-4a-methyl-1,2,3,4,4a,9,10,10a-octahydrophenanthrene-2-carbaldehyde, general procedure I was followed to give, after flash chromatography (gradient from 85:15 to 75:25 hexanes/ethyl acetate) and semi-preparative HPLC (99:1 hexanes/isopropanol), a white solid.

IR (Film) 3411, 2923, 2855, 1598, 1489, 1273, 1083, 1031 cm^{-1}; ^1H NMR (500 MHz, $CDCl_3$) δ = 7.00 (d, *J* = 8.6 Hz, 1 H), 6.75 (d, *J* = 8.6 Hz, 1 H), 3.83 (s, 3 H), 3.80 (s, 3 H), 3.53 (dd, *J* = 5.8, 5.8 Hz, 2 H), 2.96 – 2.91 (m, 1 H), 2.78 – 2.71 (m, 1 H), 2.28 – 2.24 (m, 1 H), 1.80 – 1.75 (m, 1 H), 1.65 – 1.56 (m, 4 H), 1.47 – 1.29 (m, 3 H), 1.17 – 1.09 (m, 1 H), 1.04 (s, 3 H) ppm; ^{13}C NMR (125 MHz, $CDCl_3$) δ = 150.0, 146.3, 141.5, 130.2, 119.8, 109.7, 68.5, 59.6, 55.7, 41.2, 40.6, 37.5, 36.5, 31.9, 25.4, 25.2, 23.4, 21.9 ppm; MS (ESI) exact mass calculated for [M+Na] ($C_{18}H_{26}NaO_3$) requires m/z 313.1774, found m/z 313.1779.

(4a*R*,10a*R*)-7-methoxy-4a,8-dimethyl-1,2,3,4,4a,9,10,10a-octahydrophenanthrene-2-carbaldehyde (5c)



Racemic:

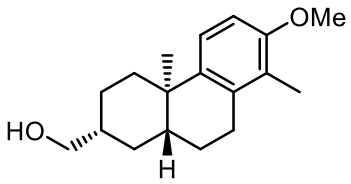
Prepared according to general procedure G from (*E*)-8-(3-methoxy-2-methylphenyl)-5-methyl-2-methyleneoct-5-enal (48 mg, 0.18 mmol). The reaction was run for 5 h and (4a*RS*,10a*RS*)-7-methoxy-4a,8-dimethyl-1,2,3,4,4a,9,10,10a-octahydrophenanthrene-2-carbaldehyde was isolated as a white solid (36 mg, 0.13 mmol, 75% yield, *trans*:*cis* 96:4, *trans*-α:β 4:1).

Asymmetric:

Prepared according to general procedure H from (*E*)-8-(3-methoxy-2-methylphenyl)-5-methyl-2-methyleneoct-5-enal (41 mg, 0.15 mmol). The reaction was run for 30 h and (4a*R*,10a*R*)-7-methoxy-4a,8-dimethyl-1,2,3,4,4a,9,10,10a-octahydrophenanthrene-2-carbaldehyde was isolated as a white solid (30 mg, 0.11 mmol, 73% yield, 92:8 *er* *trans*:*cis* >99:1, *trans*-α:β 6:1).

IR (Film) 3083, 3040, 2928, 2858, 2833, 2709, 1721, 1596, 1583, 1483, 1464, 1438, 1375, 1337, 1291, 1260, 1214, 1192, 1170, 1148, 1109, 1088, 1023, 999, 930, 899, 844, 802, 738, 706 cm^{-1}; ^1H NMR (500 MHz, $CDCl_3$) δ = 9.72* (s, 1 H x 0.2), 9.70 (d, *J* = 1.2 Hz, 1 H x 0.8), 7.15 (d, *J* = 8.6 Hz, 1 H x 0.8), 7.09* (d, *J* = 8.6 Hz, 1 H x 0.2), 6.75 (d, *J* = 8.6 Hz, 1 H x 0.8), 6.72* (d, *J* = 8.6 Hz, 1 H x 0.2), 3.81 (s, 3 H x 0.8), 3.80* (s, 3 H x 0.2), 2.84 – 2.62 (m, 2 H x 0.8), 2.84 – 2.62* (m, 2 H x 0.2), 2.51* (t, *J* = 6.0 Hz, 1 H x 0.2), 2.42 – 2.32 (m, 2 H x 0.8), 2.30 – 2.23* (m, 1 H x 0.2), 2.20 – 2.14* (m, 1 H x 0.2), 2.11 (s, 3 H x 0.8), 2.08* (s, 3 H x 0.2), 2.08 – 2.04* (m, 1 H x 0.2), 2.02 – 1.95 (m, 1 H x 0.8), 1.95 – 1.88* (m, 1 H x 0.2), 1.83 – 1.57 (m, 5 H x 0.8), 1.83 – 1.57* (m, 3 H x 0.2), 1.50 – 1.39 (m, 2 H x 0.8), 1.50 – 1.39* (m, 1 H x 0.2), 1.35* (td, *J* = 13.6, 4.2 Hz, 1 H x 0.2), 1.11* (s, 3 H x 0.2), 1.08 (s, 3 H x 0.8) ppm; ^{13}C NMR (125 MHz, $CDCl_3$) δ = 205.4*, 204.3, 155.2, 155.1*, 139.7*, 139.6, 135.2, 135.1*, 124.4, 124.4*, 122.3, 122.2*, 108.0, 108.0*, 55.5, 55.5*, 50.5, 46.4*, 40.7, 38.0*, 37.1, 36.2, 36.0*, 34.9*, 28.3, 27.4*, 27.3, 27.2*, 25.6*, 25.6, 22.0, 21.8, 21.3*, 20.8*, 11.1, 11.0* ppm; MS (APCI) exact mass calculated for [M-H] ($C_{18}H_{23}O_2$) requires m/z 271.1703, found m/z 271.1701.

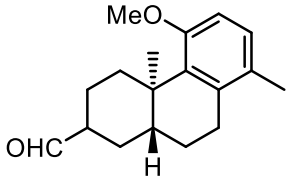
((2*R*,4a*R*,10a*R*)-7-methoxy-4a,8-dimethyl-1,2,3,4,4a,9,10,10a-octahydrophenanthren-2-yl)methanol



From (4a*R*,10a*R*)-7-methoxy-4a,8-dimethyl-1,2,3,4,4a,9,10,10a-octahydrophenanthrene-2-carbaldehyde, general procedure I was followed to give, after flash chromatography (gradient from 85:15 to 75:25 hexanes/ethyl acetate) and semi-preparative HPLC (99:1 hexanes/isopropanol), a white solid.

IR (Film) 3355, 2925, 2856, 1595, 1483, 1463, 1262, 1096 cm^{-1}; ^{1}H NMR (500 MHz, $CDCl_3$) δ = 7.14 (d, *J* = 8.5 Hz, 1 H), 6.73 (d, *J* = 8.5 Hz, 1 H), 3.80 (s, 3 H), 3.53 (dd, *J* = 5.9, 5.9 Hz, 2 H), 2.78 – 2.64 (m, 2 H), 2.30 – 2.28 (m, 1 H), 2.09 (s, 3 H), 1.79 – 1.56 (m, 6 H), 1.46 – 1.26 (m, 3 H), 1.14 (m, 1 H), 1.09 (s, 3 H) ppm; ^{13}C NMR (125 MHz, $CDCl_3$) δ = 155.1, 140.4, 135.4, 124.4, 122.4, 107.9, 68.6, 55.5, 41.1, 40.6, 37.8, 36.5, 31.9, 27.5, 25.8, 25.5, 22.0, 11.1 ppm; MS (ESI) exact mass calculated for [M+Na] ($C_{18}H_{26}NaO_2$) requires m/z 297.1825, found m/z 297.1812.

(4a*R*,10a*R*)-5-methoxy-4a,8-dimethyl-1,2,3,4,4a,9,10,10a-octahydrophenanthrene-2-carbaldehyde (5d)



Racemic:

Prepared according to general procedure G from (*E*)-8-(5-methoxy-2-methylphenyl)-5-methyl-2-methyleneoct-5-enal (48 mg, 0.17 mmol). The reaction was run for 5 h and (4a*RS*,10a*RS*)-5-methoxy-4a,8-dimethyl-1,2,3,4,4a,9,10,10a-octahydrophenanthrene-2-carbaldehyde was isolated as an off-white solid (34 mg, 0.12 mmol, 72% yield, 85:15 *er*, *trans*:*cis* 94:6, *trans*-α:β 4:1).

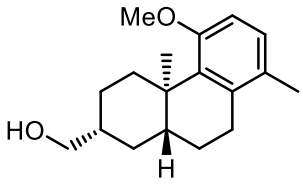
Asymmetric:

Prepared according to general procedure H from (*E*)-8-(5-methoxy-2-methylphenyl)-5-methyl-2-methyleneoct-5-enal (41 mg, 0.15 mmol). The reaction was run for 30 h and (4a*R*,10a*R*)-5-methoxy-4a,8-dimethyl-1,2,3,4,4a,9,10,10a-octahydrophenanthrene-2-carbaldehyde was isolated as an off-white solid (26 mg, 0.095 mmol, 63% yield, *trans*:*cis* 98:2, *trans*-α:β 6:1).

IR (Film) 2927, 2861, 2833, 1708, 1721, 1582, 1461, 1437, 1406, 1374, 1340, 1289, 1244, 1223, 1190, 1166, 1144, 1107, 1085, 1057, 1034, 1007, 948, 922, 907, 888, 801, 736, 722, 702 cm^{-1}; ^{1}H NMR (500 MHz, $CDCl_3$) δ = 9.73* (s, 1 H x 0.2), 9.67 (d, *J* = 1.6 Hz, 1 H x 0.8), 6.97 (d, *J* = 8.1 Hz, 1 H x 0.8), 6.95* (d, *J* = 8.1 Hz, 1 H x 0.2), 6.68 (d, *J* = 8.1 Hz, 1 H x 0.8), 6.64* (d, *J* = 8.1 Hz, 1 H x 0.2), 3.79 (s, 3 H x 0.8), 3.77* (s, 3 H x 0.2), 3.26 (dt, *J* = 13.4, 3.3 Hz, 1 H x 0.8), 3.05* (dt, *J* = 13.7, 3.5 Hz, 1 H x 0.2), 2.70 – 2.64 (m, 2 H x 0.8), 2.65 – 2.60* (m, 2 H x 0.2), 2.46* (t,

J = 6.5 Hz, 1 H x 0.2), 2.41 – 2.33 (m, 1 H x 0.8), 2.15 (s, 3 H x 0.8), 2.13* (s, 3 H x 0.2), 2.05 – 2.00* (m, 1 H x 0.2), 1.99 – 1.90* (m, 1 H x 0.2), 1.90 – 1.83 (m, 1 H x 0.8), 1.84 – 1.76* (m, 1 H x 0.2), 1.77 – 1.54 (m, 6 H x 0.8), 1.77 – 1.54* (m, 3 H x 0.2), 1.48 – 1.39* (m, 1 H x 0.8), 1.27* (s, 3 H x 0.2), 1.26 – 1.20 (m, 1 H x 0.8), 1.23 (s, 3 H), 1.12* (td, *J* = 13.7, 4.1 Hz, 1 H x 0.2) ppm; ^{13}C NMR (125 MHz, $CDCl_3$) δ = 206.0*, 204.7, 157.2, 157.2*, 136.5, 136.5*, 134.9, 134.8*, 128.9, 128.9*, 127.7, 127.6*, 109.0, 109.0*, 55.1, 55.0*, 50.8, 46.5*, 43.5, 40.8*, 38.0, 37.9*, 34.6, 32.6*, 29.4, 29.2*, 28.2, 27.4*, 25.6, 25.6*, 22.0, 21.0*, 19.5, 19.5*, 16.4, 15.8* ppm; MS (ESI) exact mass calculated for [M+Na] ($C_{18}H_{24}NaO_2$) requires m/z 295.1669, found m/z 295.1667.

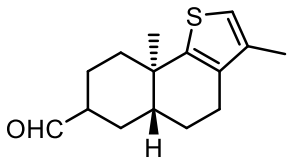
((2*R*,4a*R*,10a*R*)-5-methoxy-4a,8-dimethyl-1,2,3,4,4a,9,10,10a-octahydrophenanthren-2-yl)methanol



From (4a*R*,10a*R*)-5-methoxy-4a,8-dimethyl-1,2,3,4,4a,9,10,10a-octahydrophenanthrene-2-carbaldehyde, general procedure I was followed to give, after flash chromatography (gradient from 85:15 to 75:25 hexanes/ethyl acetate) and semi-preparative HPLC (99:1 hexanes/isopropanol), a white solid.

IR (Film) 3514, 2927, 2855, 1688, 1452, 1222, 1085 cm^{-1}; ^{1}H NMR (500 MHz, $CDCl_3$) δ = 6.95 (d, *J* = 8.2 Hz, 1 H), 6.65 (d, *J* = 8.2 Hz, 1 H), 3.77 (s, 3 H), 3.51 (td, *J* = 6.1, 1.7 Hz, 2 H), 3.12 (dt, *J* = 12.9, 3.5 Hz, 1 H), 2.66 – 2.63 (m, 2 H), 2.14 (s, 3 H), 1.68 – 1.55 (m, 4 H), 1.29 – 1.23 (m, 4 H), 1.21 (s, 3 H), 0.90 – 0.87 (m, 2 H) ppm; ^{13}C NMR (125 MHz, $CDCl_3$) δ 157.4, 136.8, 135.6, 128.9, 127.5, 109.0, 68.7, 55.1, 44.0, 40.8, 38.4, 35.2, 31.9, 29.6, 25.8, 25.4, 19.6, 16.6 ppm; MS (ESI) exact mass calculated for [M+Na] ($C_{18}H_{26}NaO_2$) requires m/z 297.1825, found m/z 297.1824.

(5a*R*,9a*R*)-3,9a-dimethyl-4,5,5a,6,7,8,9,9a-octahydronaphtho[1,2-b]thiophene-7-carbaldehyde (5e)



Racemic:

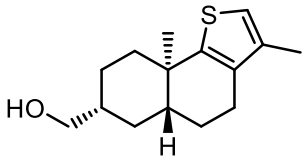
Prepared according to general procedure G from (*E*)-5-methyl-2-methylene-8-(4-methylthiophen-3-yl)oct-5-enal (49 mg, 0.20 mmol). The reaction was run for 5 h and (5a*RS*,9a*RS*)-3,9a-dimethyl-4,5,5a,6,7,8,9,9a-octahydronaphtho[1,2-b]thiophene-7-carbaldehyde was isolated as a white powder (21 mg, 0.084 mmol, 43% yield, *trans*-α:β 4:1).

Asymmetric:

Prepared according to general procedure H from (*E*)-5-methyl-2-methylene-8-(4-methylthiophen-3-yl)oct-5-enal (43 mg, 0.17 mmol). The reaction was run for 30 h and (5a*R*,9a*R*)-3,9a-dimethyl-4,5,5a,6,7,8,9,9a-octahydronaphtho[1,2-b]thiophene-7-carbaldehyde was isolated as white powder (34 mg, 0.14 mmol, 81% yield, 94:6 *er*, *trans*-α:β 4:1).

IR (Film) 3087, 2964, 1928, 1857, 2708, 1724, 1462, 1450, 1438, 1374, 1018 cm^{-1}; ^{1}H NMR (500 MHz, $CDCl_3$) δ = 9.71* (s, 1 H x 0.2), 9.67 (s, 1 H x 0.8), 6.72 (s, 1 H x 0.8), 6.68* (s, 1 H x 0.2), 2.62 – 2.48 (m, 2 H), 2.44 – 2.36 (m, 1 H), 2.10 – 2.06 (m, 4 H), 1.96 – 1.89 (m, 1 H), 1.82 – 1.59 (m, 6 H), 1.52 – 1.42 (m, 1 H), 1.20* (s, 3 H x 0.2), 1.16 (s, 3 H x 0.8) ppm; ^{13}C NMR (125 MHz, $CDCl_3$) δ = 205.2*, 203.9, 148.1*, 147.9, 136.2, 136.2*, 133.1, 133.0*, 116.9, 116.8*, 50.8, 46.8*, 42.7, 40.0*, 38.6, 36.6, 36.6*, 36.5*, 27.4, 26.5*, 25.5*, 25.5, 24.7, 24.6*, 21.9, 21.6, 21.4*, 20.4*, 14.2, 14.2* ppm; MS (ESI) exact mass calculated for [M+Na] ($C_{15}H_{20}NaOS$) requires m/z 271.1127, found m/z 271.1127.

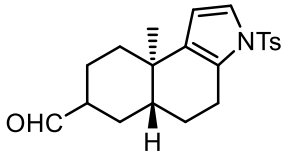
((5a*R*,7*R*,9a*R*)-3,9a-dimethyl-4,5,5a,6,7,8,9,9a-octahydronaphtho[1,2-b]thiophen-7-yl)methanol



From (5a*R*,9a*R*)-3,9a-dimethyl-4,5,5a,6,7,8,9,9a-octahydronaphtho[1,2-b]thiophene-7-carbaldehyde, general procedure I was followed to give, after flash chromatography (gradient from 85:15 to 75:25 hexanes/ethyl acetate) and semi-preparative HPLC (99:1 hexanes/isopropanol), a white solid.

IR (Film) 3424, 2925, 2856, 1685, 1641, 1594, 1460, 1429, 1150, 1058 cm^{-1}; ^{1}H NMR (500 MHz, $CDCl_3$) δ = 6.70 (s, 1 H), 3.53 (dd, *J* = 5.2, 5.2 Hz, 2 H), 2.58 – 2.48 (m, 2 H), 2.08 (s, 3 H), 2.02 – 1.98 (m, 1 H), 1.75 – 1.57 (m, 6 H), 1.41 – 1.25 (m, 3 H), 1.20 – 1.12 (m, 4 H) ppm; ^{13}C NMR (125 MHz, $CDCl_3$) δ = 148.7, 136.2, 133.1, 116.7, 68.4, 43.1, 41.0, 39.2, 36.9, 31.0, 25.6, 25.0, 24.8, 22.1, 14.3 ppm; MS (ESI) exact mass calculated for [M+Na] ($C_{15}H_{22}NaOS$) requires m/z 273.1284, found m/z 273.1273.

(5a*R*,9a*R*)-9a-methyl-3-tosyl-4,5,5a,6,7,8,9,9a-octahydro-3H-benzo[e]indole-7-carbaldehyde (5f)



Racemic:

Prepared according to general procedure G from of (*E*)-5-methyl-2-methylene-8-(1-tosyl-1H-pyrrol-2-yl)oct-5-enal (48 mg, 0.13 mmol). The reaction was run for 5 h and (5a*RS*,9a*RS*)-9a-

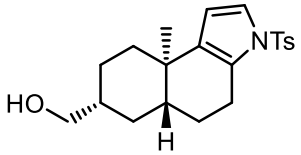
methyl-3-tosyl-4,5,5a,6,7,8,9,9a-octahydro-3H-benzo[e]indole-7-carbaldehyde was isolated as a white powder (31 mg, 0.084 mmol, 65% yield, *trans*-α:β 4:1).

Asymmetric:

Prepared according to general procedure H from (*E*)-5-methyl-2-methylene-8-(1-tosyl-1H-pyrrol-2-yl)oct-5-enal (42 mg, 0.11 mmol). The reaction was run for 24 h and (5a*R*,9a*R*)-9a-methyl-3-tosyl-4,5,5a,6,7,8,9,9a-octahydro-3H-benzo[e]indole-7-carbaldehyde was isolated as a white powder (38 mg, 0.10 mmol, 90% yield, 93:7 *er*, *trans*-α:β 4:1).

IR (Film) 3147, 3058, 2933, 2857, 2713, 1721, 1597, 1365, 1265, 1171, 1139, 1124, 1090, 1037, 813 cm^{-1}; ^{1}H NMR (500 MHz, $CDCl_3$) δ = 9.65* (s, 1 H x 0.2), 9.63 (s, 1 H x 0.8), 7.65 – 7.61 (m, 2 H), 7.29 – 7.28 (m, 2 H), 7.16 (d, *J* = 3.9 Hz, 1 H x 0.8), 7.13* (d, *J* = 3.9 Hz, 1 H x 0.2), 6.12 (d, *J* = 3.9 Hz, 1 H x 0.8), 6.06 (d, *J* = 3.9 Hz, 1 H x 0.2), 2.90 – 2.81 (m, 1 H), 2.65 – 2.57 (m, 1 H x 0.8), 2.51 – 2.46* (m, 2 H x 0.2), 2.41 (s, 3 H), 2.35 – 2.28 (m, 1 H x 0.8), 2.12 – 1.96 (m, 1 H), 1.96 – 1.83 (m, 1 H), 1.71 – 1.52 (m, 4 H), 1.48 – 1.21 (m, 3 H), 0.99* (s, 3 H x 0.2), 0.95 (s, 2 H x 0.8) ppm; ^{13}C NMR (125 MHz, $CDCl_3$) δ = 205.5*, 204.0, 144.6, 144.5*, 136.5, 136.4*, 134.3*, 134.3, 130.0*, 129.9, 127.2(*), 126.8(*), 121.1, 121.0*, 108.3, 108.2*, 50.7, 46.7*, 41.9, 39.2*, 36.3, 34.2*, 33.6, 33.5*, 27.0, 26.1*, 25.4*, 25.3, 23.3, 23.0*, 21.6, 21.2, 20.4(*), 20.0*, 19.9* ppm; MS (ESI) exact mass calculated for [M+Na] ($C_{21}H_{25}NNaO_3S$) requires m/z 394.1447, found m/z 394.1431.

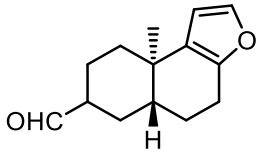
((5a*R*,7*R*,9a*R*)-9a-methyl-3-tosyl-4,5,5a,6,7,8,9,9a-octahydro-3H-benzo[e]indol-7-yl)methanol



From ((5a*R*,9a*R*)-9a-methyl-3-tosyl-4,5,5a,6,7,8,9,9a-octahydro-3H-benzo[e]indole-7-carbaldehyde, general procedure I was followed to give, after flash chromatography (gradient from 85:15 to 75:25 hexanes/ethyl acetate) and semi-preparative HPLC (99:1 hexanes/isopropanol), a white solid.

IR (Film) 3388, 2925, 2854, 1453, 1412, 1261, 1141, 1090 cm^{-1}; ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.64 (d, *J* = 8.5 Hz, 2 H), 7.28 (d, *J* = 8.5 Hz, 2 H), 7.15 (d, *J* = 3.2 Hz, 1 H), 6.12 (d, *J* = 3.2 Hz, 1 H), 3.49 (dd, *J* = 6.4, 6.4 Hz, 2 H), 2.84 – 2.79 (m, 1 H), 2.61 – 2.55 (m, 1 H), 2.41 (s, 3 H), 1.95 – 1.90 (m, 1 H), 1.68 – 1.54 (m, 4 H), 1.50 – 1.26 (m, 4 H), 1.12 – 1.03 (m, 1 H), 0.95 (s, 3 H) ppm; ^{13}C NMR (125 MHz, $CDCl_3$) δ = 144.4, 136.6, 135.0, 129.9, 127.3, 126.8, 121.0, 108.5, 68.5, 42.3, 41.0, 36.9, 33.9, 30.6, 25.6, 24.6, 23.4, 21.6, 20.6 ppm; MS (ESI) exact mass calculated for [M+Na] ($C_{21}H_{27}NNaO_3S$) requires m/z 396.16039, found m/z 396.16057.

(5a*R*,9a*R*)-9a-methyl-4,5,5a,6,7,8,9,9a-octahydronaphtho[2,1-b]furan-7-carbaldehyde (5g)



Racemic:

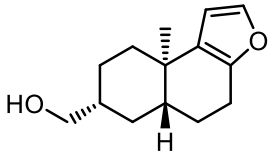
Prepared according to general procedure G from of (*E*)-8-(furan-2-yl)-5-methyl-2-methyleneoct-5-enal (10 mg, 0.045 mmol). The reaction was run for 5 h and (5a*RS*,9a*RS*)-9a-methyl-4,5,5a,6,7,8,9,9a-octahydronaphtho[2,1-b]furan-7-carbaldehyde was isolated as a colourless oil (2.9 mg, 0.013 mmol, 29% yield, *trans*-α:β 4:1).

Asymmetric:

Prepared according to general procedure H from (*E*)-8-(furan-2-yl)-5-methyl-2-methyleneoct-5-enal (47 mg, 0.22 mmol) with catalyst The reaction was run for 24 h and (5a*R*,9a*R*)-9a-methyl-4,5,5a,6,7,8,9,9a-octahydronaphtho[2,1-b]furan-7-carbaldehyde was isolated as a colourless oil (22 mg, 0.10 mmol, 47% yield, 90:10 *er*, *trans*-β:α 4:1).

IR (Film) ν = 2929, 2854, 1721, 1614, 1368, 1279, 1138 cm^{-1}; ^{1}H NMR (500 MHz, $CDCl_3$) δ 9.70* (s, 1 H x 0.2), 9.67 (s, 1 H x 0.8), 7.23 (s, 1 H x 0.8) 7.19* (s, 1 H x 0.2), 6.23 (s, 1 H x 0.8), 6.18* (s, 1 H x 0.2), 2.68 – 2.65 (m, 2 H), 2.40 – 2.33 (m, 1 H), 2.05 – 2.00 (m, 1 H), 1.92 – 1.86 (m, 1 H), 1.84 – 1.56 (m, 5 H), 1.47 – 1.37 (m, 2 H), 1.06* (s, 3 H x 0.2), 1.02 (s, 3 H x 0.8) ppm; ^{13}C NMR (125 MHz, $CDCl_3$) δ = 205.4*, 204.1, 148.9, 148.8*, 140.7, 140.6*, 128.0, 127.9*, 107.1, 107.0*, 50.9, 46.8*, 42.8, 40.1*, 36.4, 34.4*, 33.3, 33.1*, 27.1, 26.2*, 25.6*, 25.5, 23.4, 23.3*, 21.2, 20.2, 20.0*, 19.7* ppm; HRMS (APCI) exact mass calculated for [M+H] ($C_{14}H_{19}O_2$) requires m/z 219.13796, found m/z 219.13728.

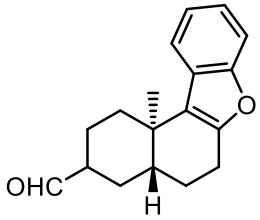
((5a*R*,7*R*,9a*R*)-9a-methyl-4,5,5a,6,7,8,9,9a-octahydronaphtho[2,1-b]furan-7-yl)methanol



From (5a*R*,9a*R*)-9a-methyl-4,5,5a,6,7,8,9,9a-octahydronaphtho[2,1-b]furan-7-carbaldehyde, general procedure I was followed to give, after flash chromatography (gradient from 85:15 to 75:25 hexanes/ethyl acetate) and semi-preparative HPLC (99:1 hexanes/isopropanol), a white solid.

IR (Film) 3435, 2928, 2854, 1683, 1594, 1460, 1429, 1149, 1060 cm^{-1}; ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.23 (m, 1 H), 6.24 (d, *J* = 1.9 Hz, 1 H), 3.54 (t, *J* = 4.5 Hz, 2 H), 2.67 – 2.64 (m, 2 H), 1.94 (dt, *J* = 12.3, 2.9 Hz, 1 H), 1.79 – 1.61 (m, 4 H), 1.44 – 1.26 (m, 4 H), 1.17 – 1.10 (m, 1 H), 1.01 (2, 3 H) ppm; ^{13}C NMR (125 MHz, $CDCl_3$) δ = 149.0, 140.5, 128.4, 107.2, 68.5, 43.2, 41.1, 36.9, 33.5, 30.6, 25.7, 24.5, 23.5, 20.3 ppm; MS (ESI) exact mass calculated for [M+Na] ($C_{14}H_{20}NaO_2$) requires m/z 243.1356, found m/z 243.1346.

(4a*R*,11c*R*)-11c-methyl-1,2,3,4,4a,5,6,11c-octahydronaphtho[2,1-b]benzofuran-3-carbaldehyde (5h)



Racemic:

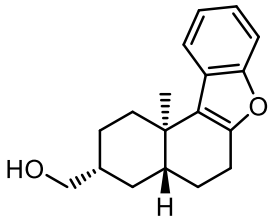
Prepared according to general procedure G from (*E*)-8-(benzofuran-3-yl)-5-methyl-2-methyleneoct-5-enal (31 mg, 0.11 mmol). The reaction was run for 5 h and (4a*RS*,11c*RS*)-11c-methyl-1,2,3,4,4a,5,6,11c-octahydronaphtho[2,1-b]benzofuran-3-carbaldehyde was isolated as a colourless oil (27 mg, 0.10 mmol, 89% yield, *trans*-α:β 4:1).

Asymmetric:

Prepared according to general procedure H from (*E*)-8-(benzofuran-3-yl)-5-methyl-2-methyleneoct-5-enal (43 mg, 0.16 mmol). The reaction was run for 30 h and (4a*R*,11c*R*)-11c-methyl-1,2,3,4,4a,5,6,11c-octahydronaphtho[2,1-b]benzofuran-3-carbaldehyde was isolated as a colourless oil (35 mg, 0.13 mmol, 81% yield, 92:8 *er*, *trans*-α:β 9:1).

IR (Film) 3058, 2930, 2858, 2709, 1721, 1612, 1244, 1153 cm^{-1}; ^{1}H NMR (500 MHz, $CDCl_3$) δ = 9.73* (s, 1 H x 0.1), 9.69 (s, 1 H x 0.9), 7.42 – 7.37 (m, 2 H), 7.23 – 7.17 (m, 2 H), 2.72 – 2.53 (m, 2 H), 2.46 – 2.36 (m, 2 H x 0.9), 2.28 – 2.22* (m, 1 H x 0.1), 2.19 – 2.14* (m, 1 H x 0.1), 2.11 – 2.06* (m, 1 H x 0.1), 2.00 – 1.96 (m, 1 H x 0.9), 1.84 – 1.64 (m, 5 H), 1.60 – 1.49 (m, 2 H), 1.23* (s, 3 H x 0.1), 1.19 (s, 3 H x 0.9) ppm; ^{13}C NMR (125 MHz, $CDCl_3$) δ = 205.1*, 203.8, 161.0, 161.0*, 154.4, 154.4*, 128.8, 128.8*, 123.1, 123.0*, 122.1, 122.1*, 118.6, 118.6*, 111.0, 110.9*, 110.4, 110.4*, 50.7, 46.7*, 43.4, 40.6*, 35.6, 35.4*, 33.6, 31.7*, 26.6, 26.6*, 25.7*, 25.5, 20.9, 20.4, 20.3*, 19.7*, 18.2, 17.7* ppm; MS (ESI) exact mass calculated for [M+Na] ($C_{18}H_{20}NaO_2$) requires m/z 291.1356, found m/z 291.1348.

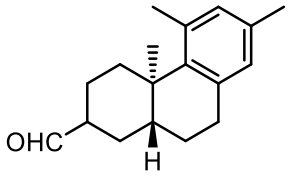
((3*R*,4a*R*,11c*R*)-11c-methyl-1,2,3,4,4a,5,6,11c-octahydronaphtho[2,1-b]benzofuran-3-yl)methanol



From (4a*R*,11c*R*)-11c-methyl-1,2,3,4,4a,5,6,11c-octahydronaphtho[2,1-b]benzofuran-3-carbaldehyde, general procedure I was followed to give, after flash chromatography (gradient from 85:15 to 75:25 hexanes/ethyl acetate) and semi-preparative HPLC (99:1 hexanes/isopropanol), a white solid.

IR (Film) 3373, 2926, 2856, 1690, 1596, 1452, 1152, 1051 cm^{-1}; ^{1}H NMR (500 MHz, $CDCl_3$) δ = 7.40 – 7.39 (m, 2 H), 7.26 – 7.16 (m, 2 H), 3.56 – 3.54 (m, 2 H), 2.68 – 2.60 (m, 2 H), 2.29 – 2.26 (m, 1 H), 1.81 – 1.60 (m, 6 H), 1.58 – 1.51 (m, 1 H), 1.43 – 1.35 (m, 1 H), 1.30 – 1.26 (m, 1 H), 1.18 (s, 3 H) ppm; ^{13}C NMR (125 MHz, $CDCl_3$) δ = 161.9, 154.4, 128.9, 122.9, 122.0, 118.5, 110.9, 110.3, 68.4, 43.8, 41.0, 35.8, 34.2, 30.2, 25.7, 24.3, 20.6, 18.3 ppm; MS (ESI) exact mass calculated for [M+Na] ($C_{18}H_{22}NaO_2$) requires m/z 293.1512, found m/z 293.1507.

(4a*R*,10a*R*)-4a,5,7-trimethyl-1,2,3,4,4a,9,10,10a-octahydrophenanthrene-2-carbaldehyde (5i)



Racemic:

Prepared according to general procedure G from (*E*)-8-(3,5-dimethylphenyl)-5-methyl-2-methyleneoct-5-enal (48 mg, 0.18 mmol). The reaction was run for 5 h and (4a*RS*,10a*RS*)-4a,5,7-trimethyl-1,2,3,4,4a,9,10,10a-octahydrophenanthrene-2-carbaldehyde was isolated as a colourless oil (36, 0.14 mmol, 75% yield, *trans*:*cis* 94:6, *trans*-α:β 5:1).

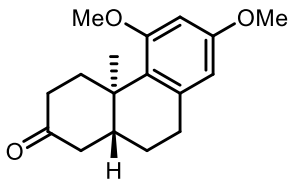
Asymmetric:

Prepared according to general procedure H with catalyst as the HCl salt, from (*E*)-8-(3,5-dimethylphenyl)-5-methyl-2-methyleneoct-5-enal (9.0 mg, 0.035 mmol). The reaction was run for 19 h and (4a*R*,10a*R*)-4a,5,7-trimethyl-1,2,3,4,4a,9,10,10a-octahydrophenanthrene-2-carbaldehyde was isolated as a colourless oil (3.6 mg, 0.014 mmol, 36% yield, 66:34 *er*, *trans*:*cis* 96:4, *trans*-α:β 4:1).

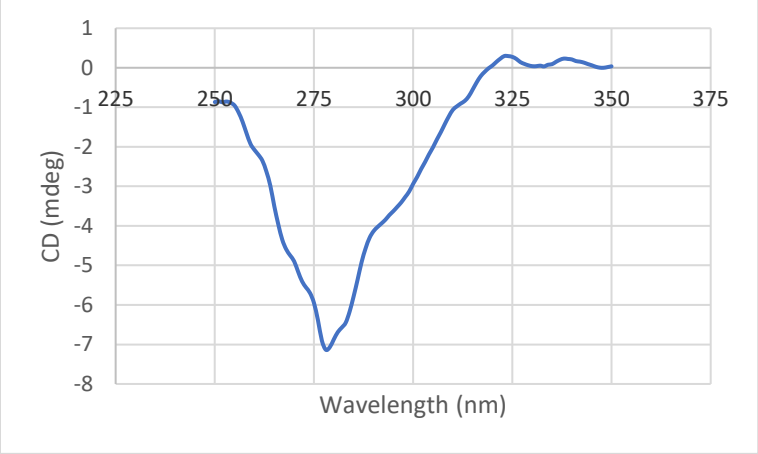
IR (Film) 3050, 2973, 2926, 2860, 2712, 1722, 1611, 1463, 1440, 1382, 1266, 1166, 1044, 1016, 911, 849, 734, 703, 611 cm^{-1}; ^{1}H NMR (500 MHz, $CDCl_3$) δ = 9.73* (s, 1 H x 0.2), 9.68 (d, *J* = 1.5 Hz, 1 H x 0.8), 6.79 (s, 1 H x 0.8), 6.78 (s, 1 H x 0.8), 6.76* (s, 1 H x 0.2), 6.75* (s, 1 H x 0.2), 3.02 – 2.91* (m, 1 H x 0.2), 2.99 (ddd, *J* = 16.9, 12.2, 7.6 Hz, 1 H x 0.8), 2.87 (dt, *J* = 13.4, 3.4 Hz, 1 H x 0.8), 2.80 (dd, *J* = 17.0, 6.0 Hz, 1 H x 0.8), 2.80 – 2.74* (m, 1 H x 0.2), 2.66* (dt, *J* = 13.5, 2.7 Hz, 1 H x 0.2), 2.50 (s, 3 H x 0.8), 2.47* (s, 3 H x 0.2), 2.40 – 2.33 (m, 1 H x 0.8), 2.40 – 2.31* (m, 2 H x 0.2), 2.24 (s, 3 H x 0.8), 2.23 – 2.17* (m, 1 H x 0.2), 2.22* (s, 3 H x 0.2), 2.06 – 2.02* (m, 1 H x 0.2), 1.95 – 1.88* (m, 1 H x 0.2), 1.94 – 1.89 (m, 1 H x 0.8), 1.84 – 1.46* (m, 3 H x 0.2), 1.78 – 1.50 (m, 6 H x 0.8), 1.39 (ddd, *J* = 13.5, 13.5, 3.6 Hz, 1 H x 0.8), 1.31 – 1.27* (m, 1 H x 0.2), 1.27* (s, 3 H x 0.2), 1.24 (s, 3 H x 0.8) ppm; ^{13}C NMR (125 MHz, $CDCl_3$) δ = 205.5*, 204.4, 142.0*, 141.9, 136.8, 136.8*, 136.2, 136.1*, 134.9, 134.8*, 131.8, 131.7*, 128.8, 128.7*, 50.3, 46.1*, 44.4, 41.6*, 38.5, 38.4*, 35.3, 33.2*, 31.7, 31.5*, 28.7, 27.8*, 25.8, 25.7*, 24.3, 24.2*, 22.0, 20.9*, 20.3, 20.3*, 17.4, 16.9* ppm; MS (ESI) exact mass calculated for [M+Na] ($C_{18}H_{24}NaO$) requires m/z 279.1719, found m/z 279.1713.

VI. Additional derivatization and determination of absolute stereochemistry of polyene cyclization products

Absolute stereochemistry of *trans*-decalin via circular dichroism:

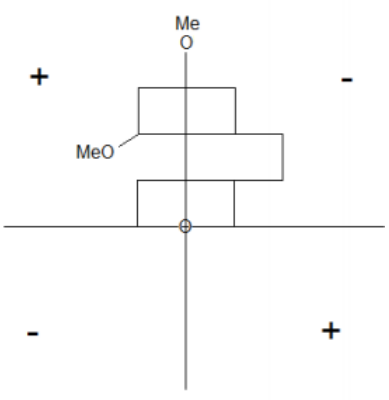


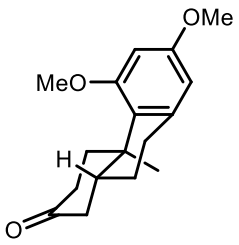
(4a*R*,10a*R*)-5,7-Dimethoxy-4a-methyl-3,4,4a,9,10,10a-hexahydrophenanthren-2(1*H*)-one was derived from enantioenriched **4a** (66:34 er).[26] A sample was dissolved in methanol and submitted to circular dichroism spectroscopy:



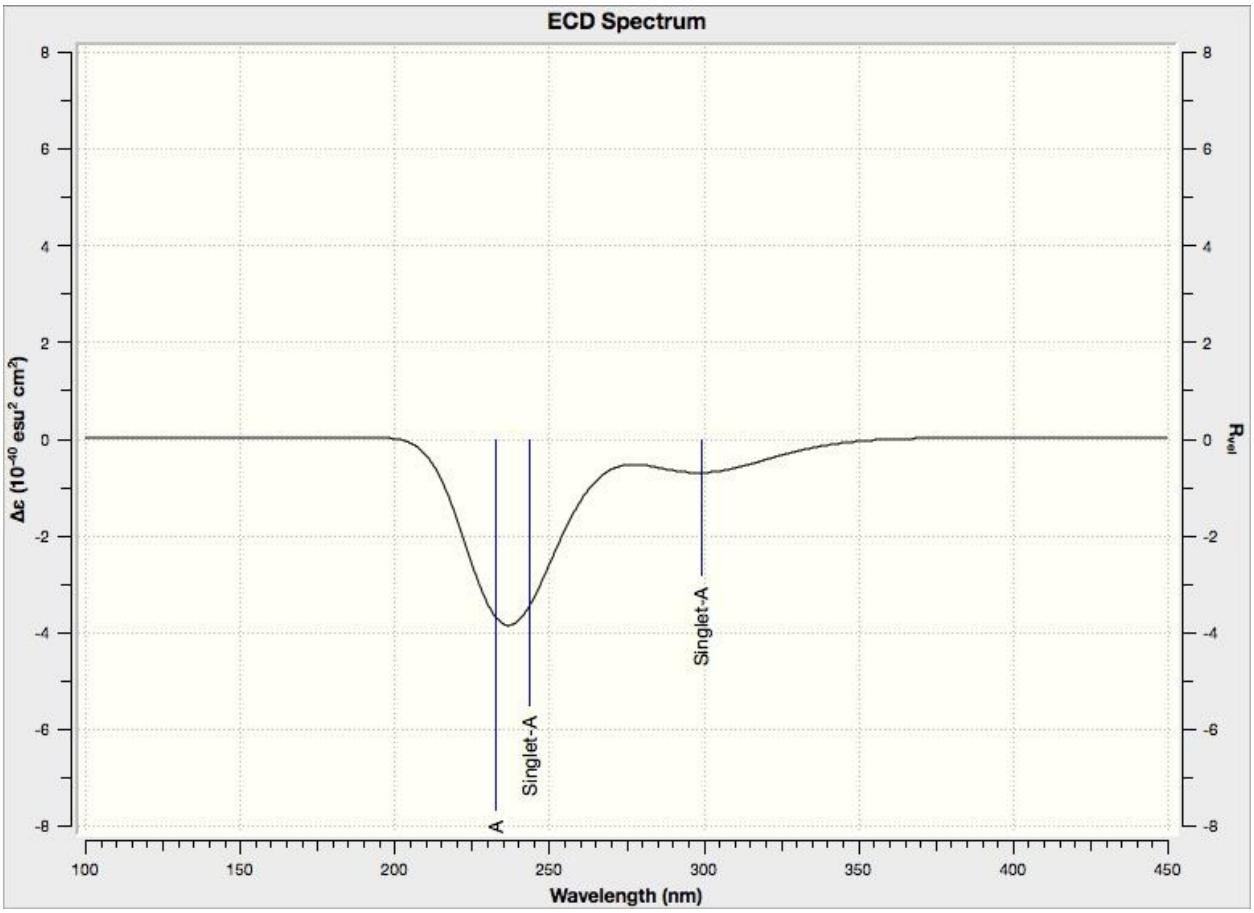
The negative Cotton effect near 275 nm is consistent with that of a *trans*-2-decalone with the absolute stereochemistry shown, as deduced by performing an octant-rule analysis[27]:

Negative Cotton effect (CD):

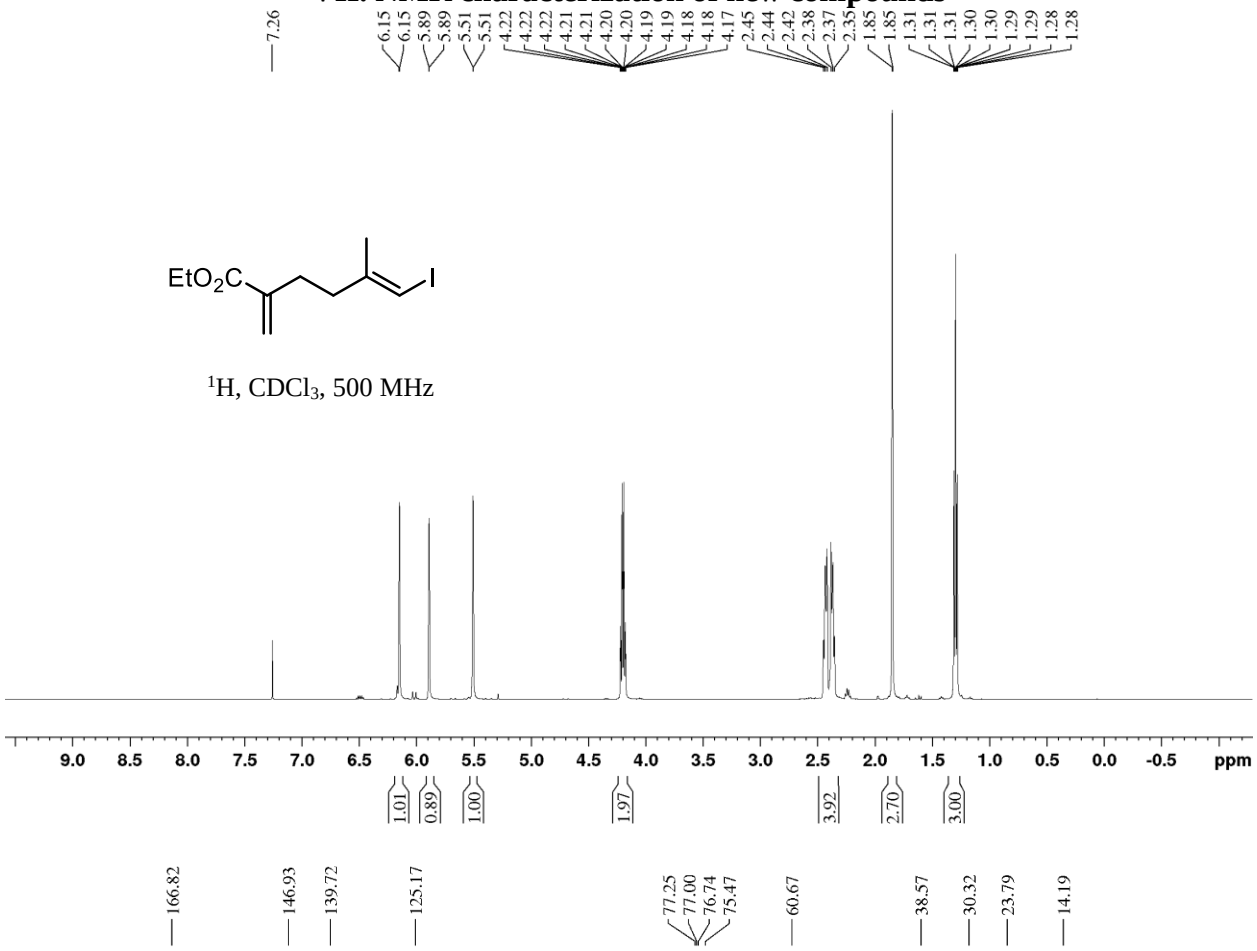




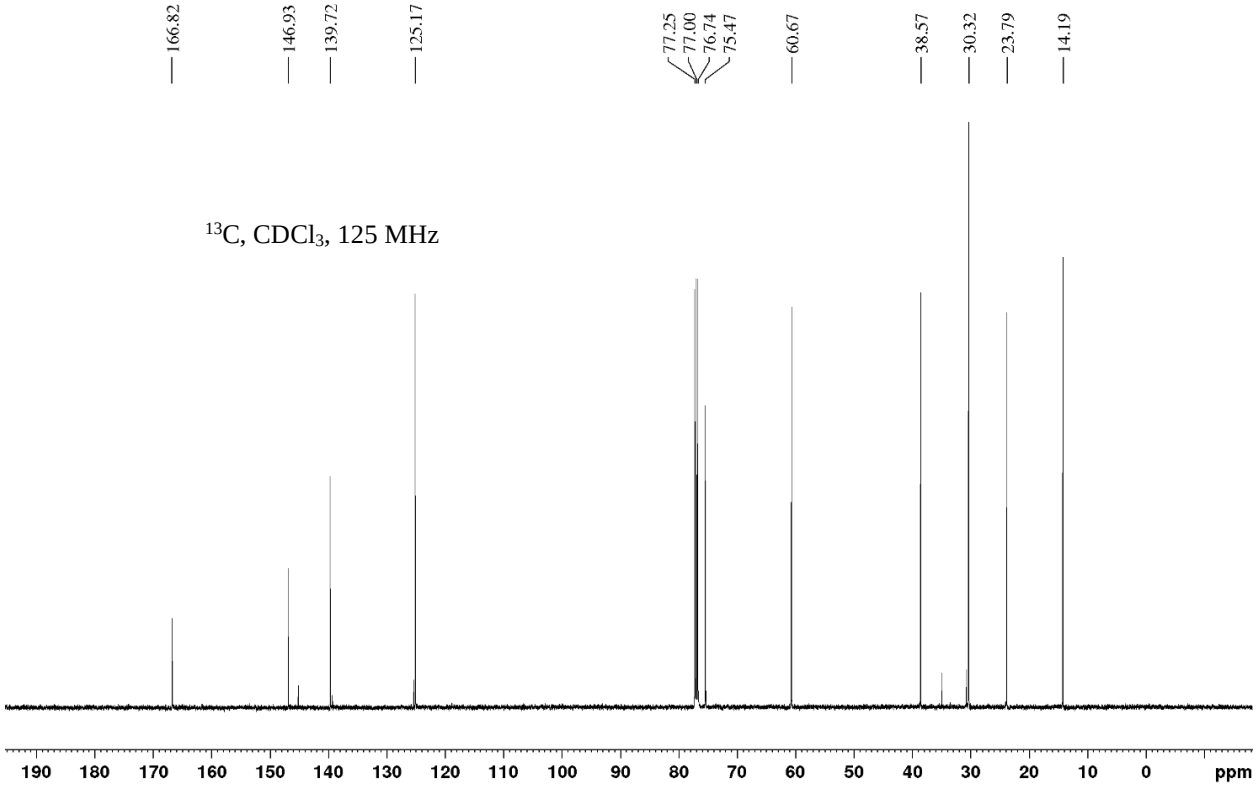
This octant-rule determination was further supported by calculation (td/aug-cc-pvdz//M06-2x/6-311g(d,p) with SCRF=MeOH):



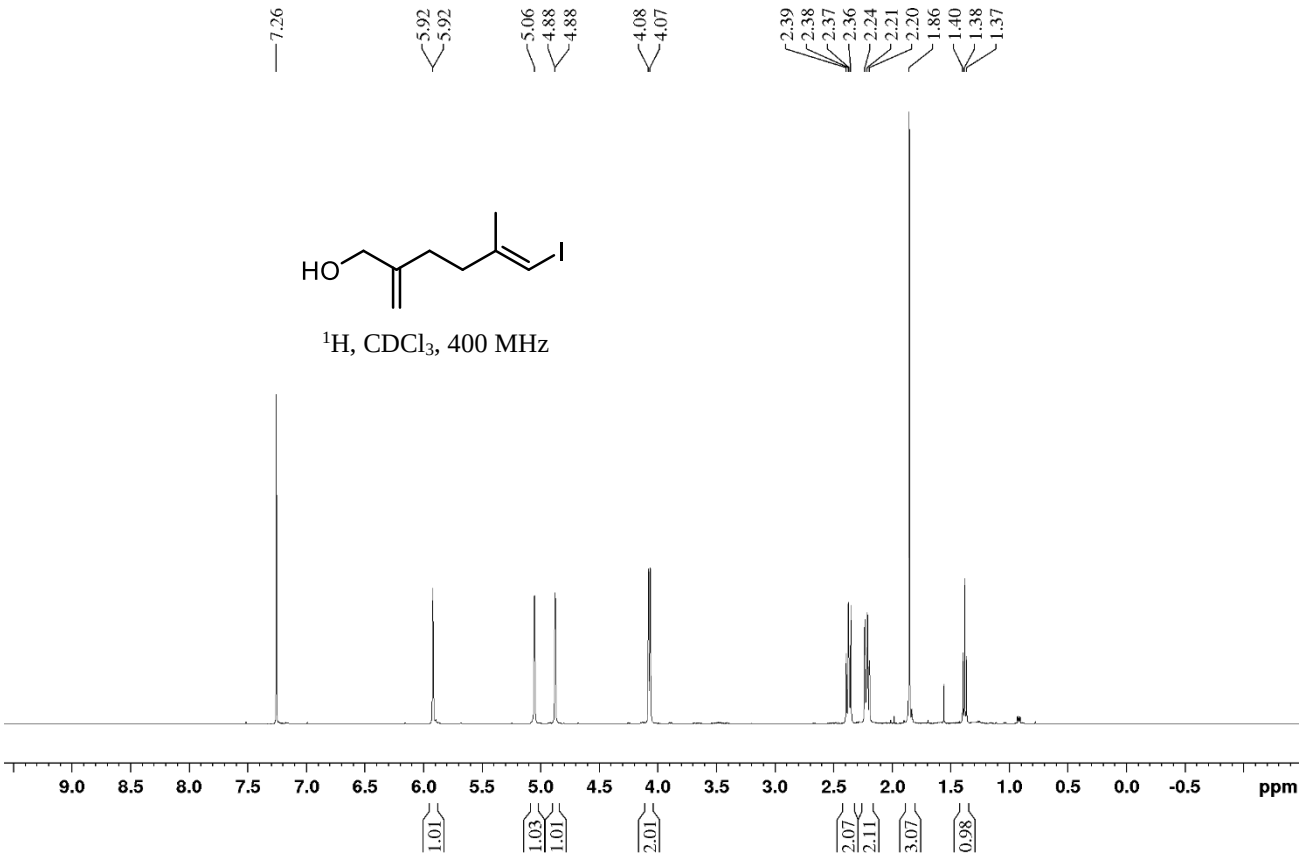
VII. NMR characterization of new compounds



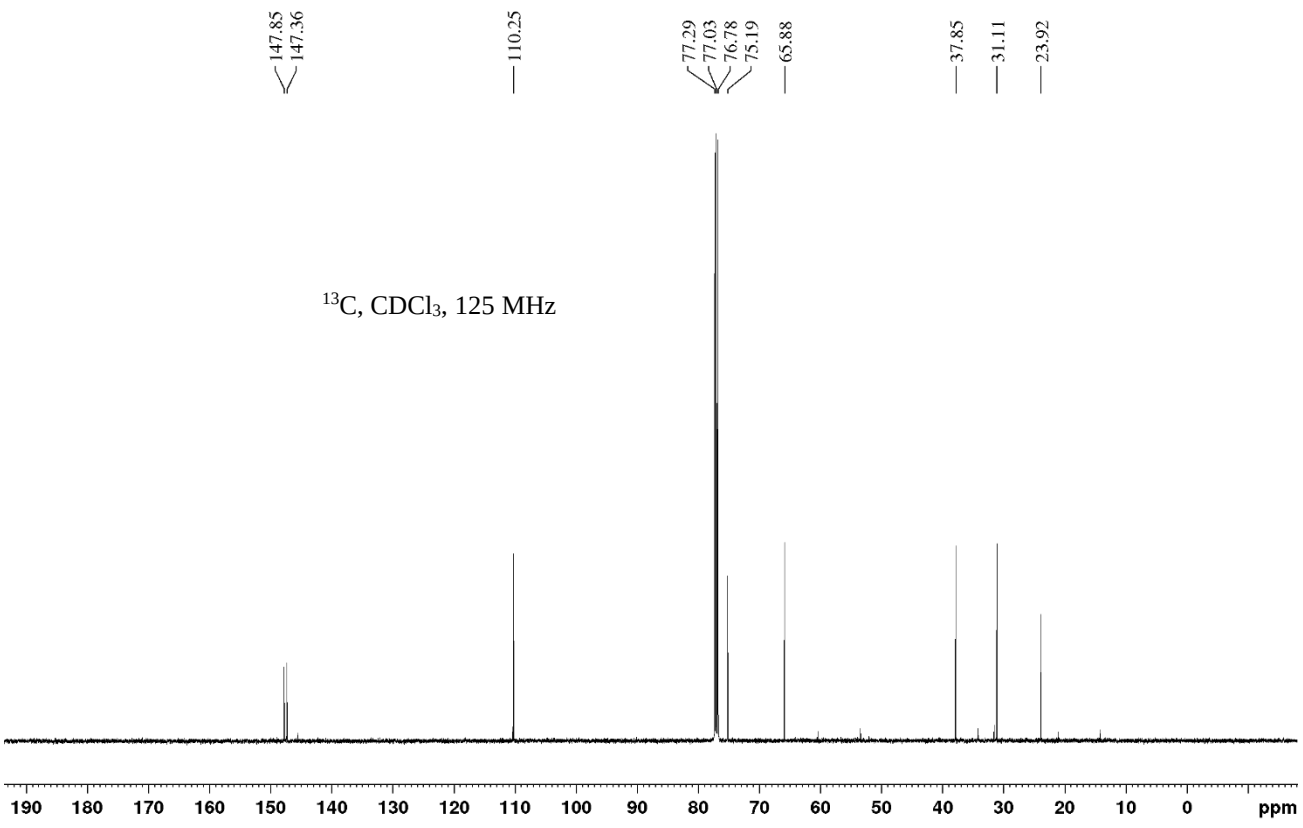
^{1}H, $CDCl_3$, 500 MHz



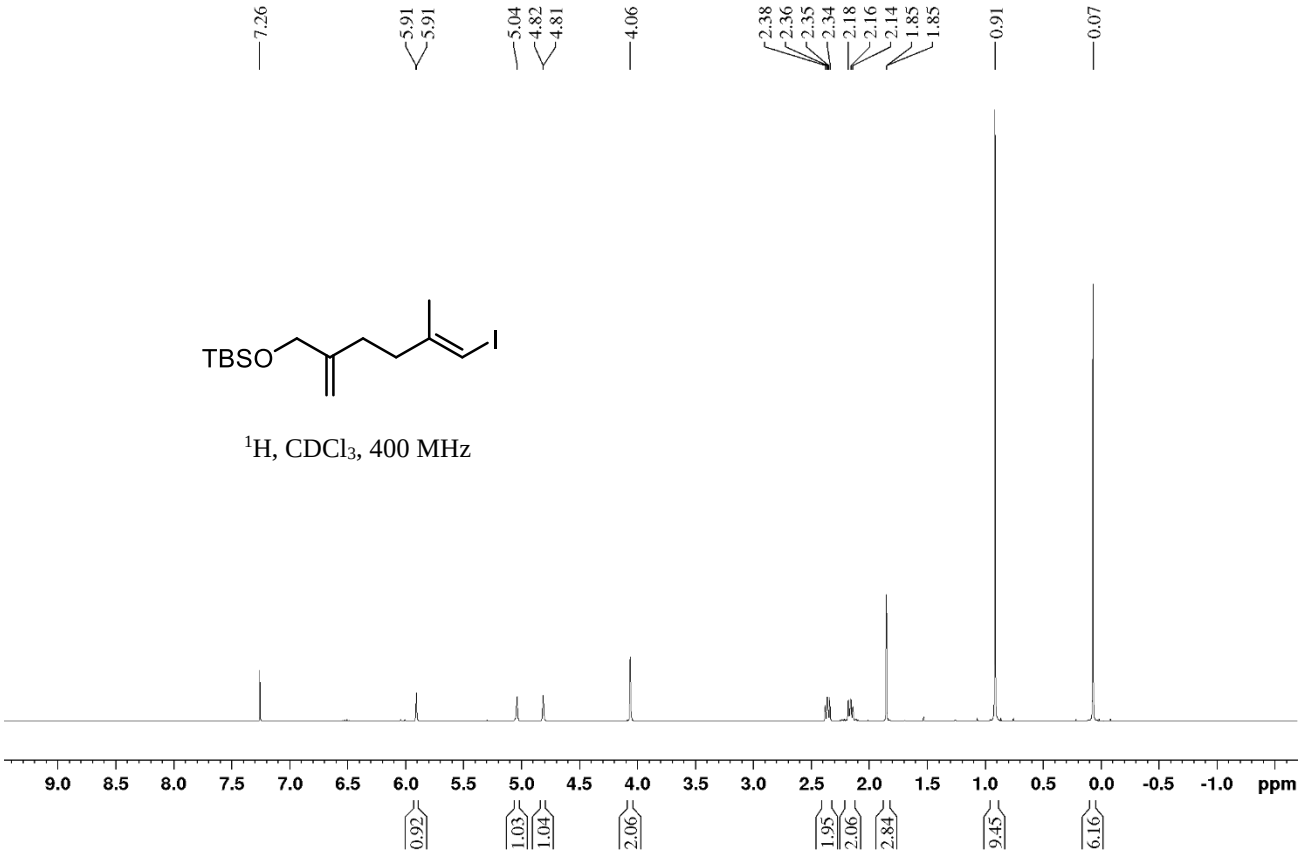
^{13}C, $CDCl_3$, 125 MHz



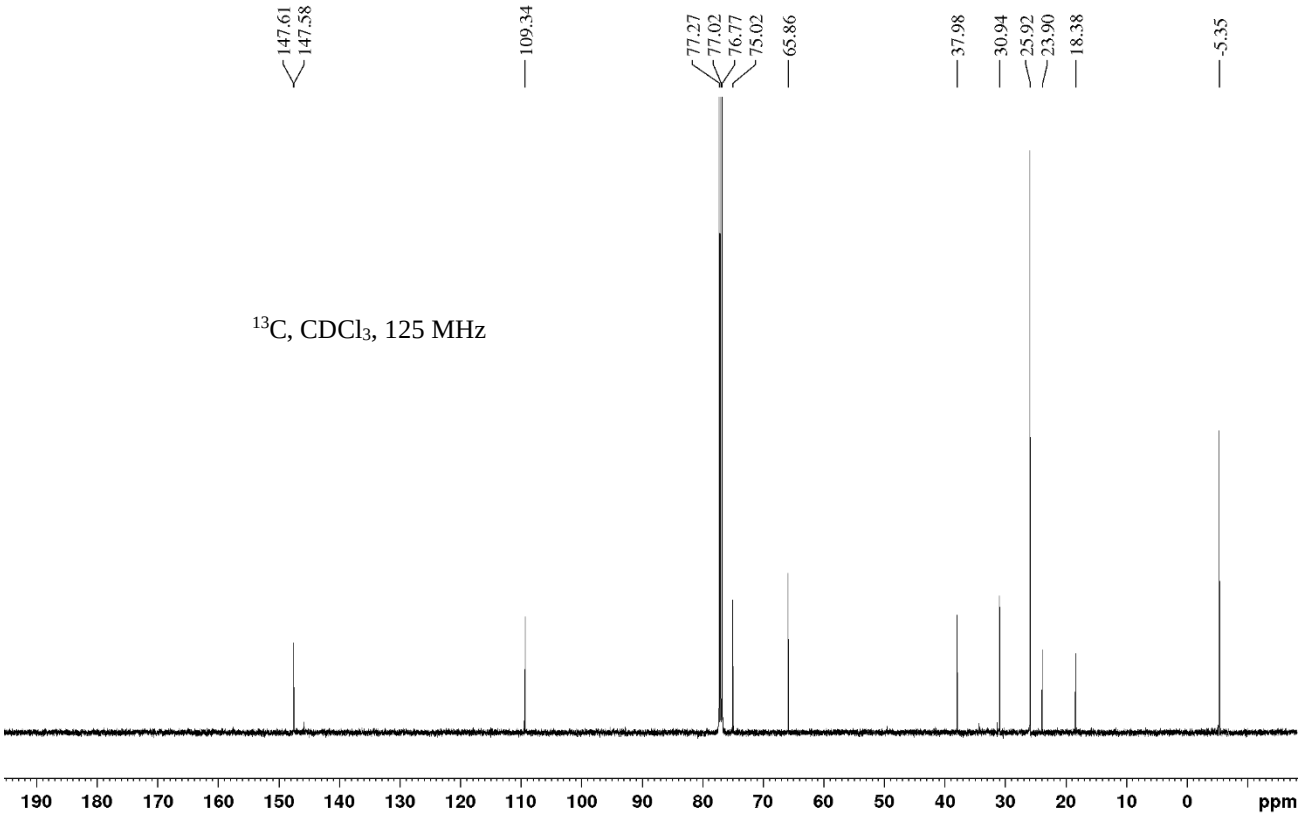
^{1}H, $CDCl_3$, 400 MHz



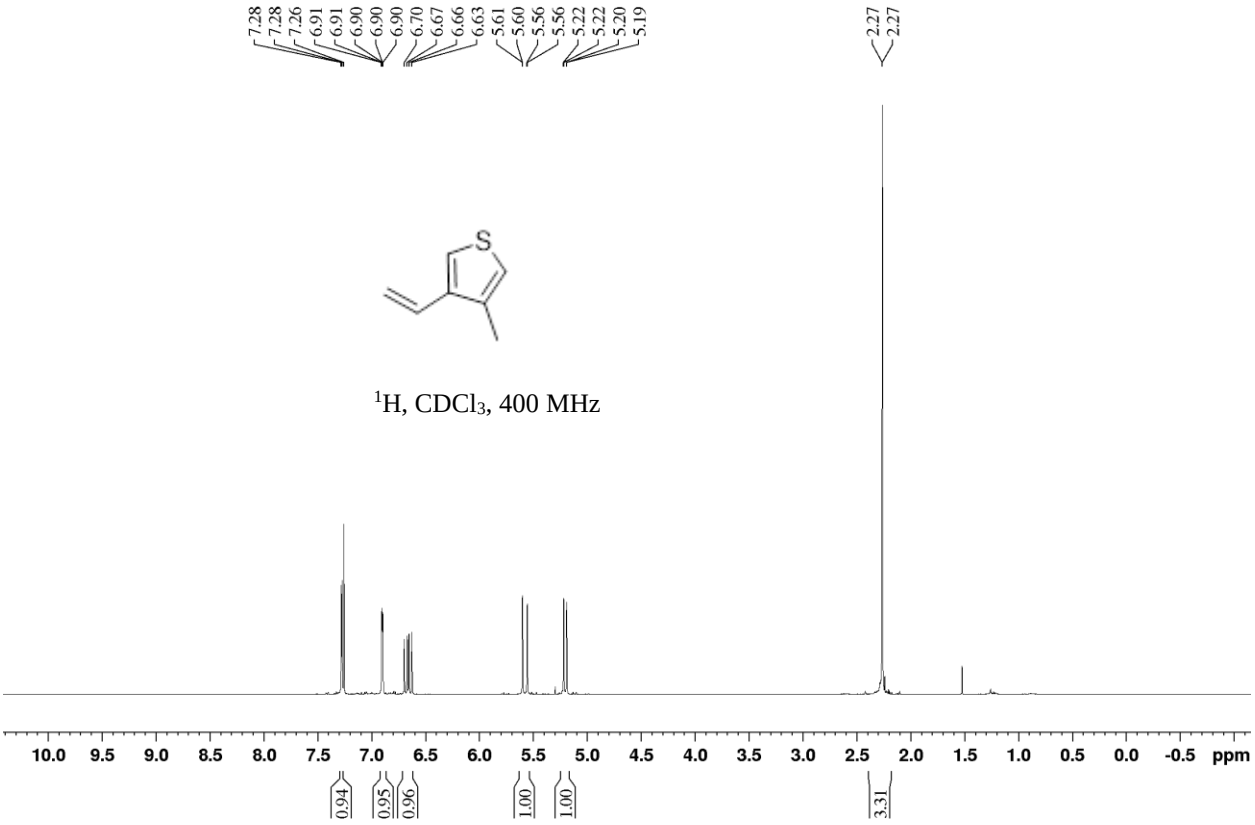
^{13}C, $CDCl_3$, 125 MHz



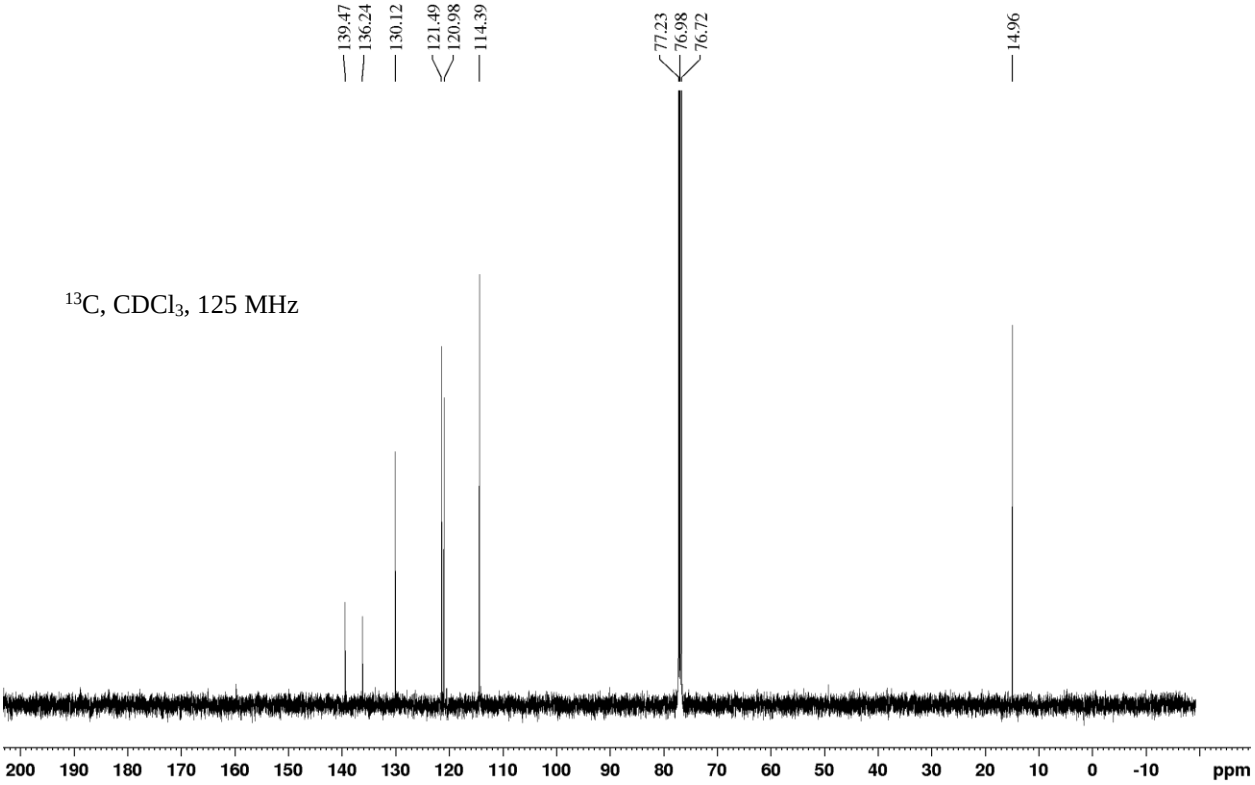
^{1}H, $CDCl_3$, 400 MHz



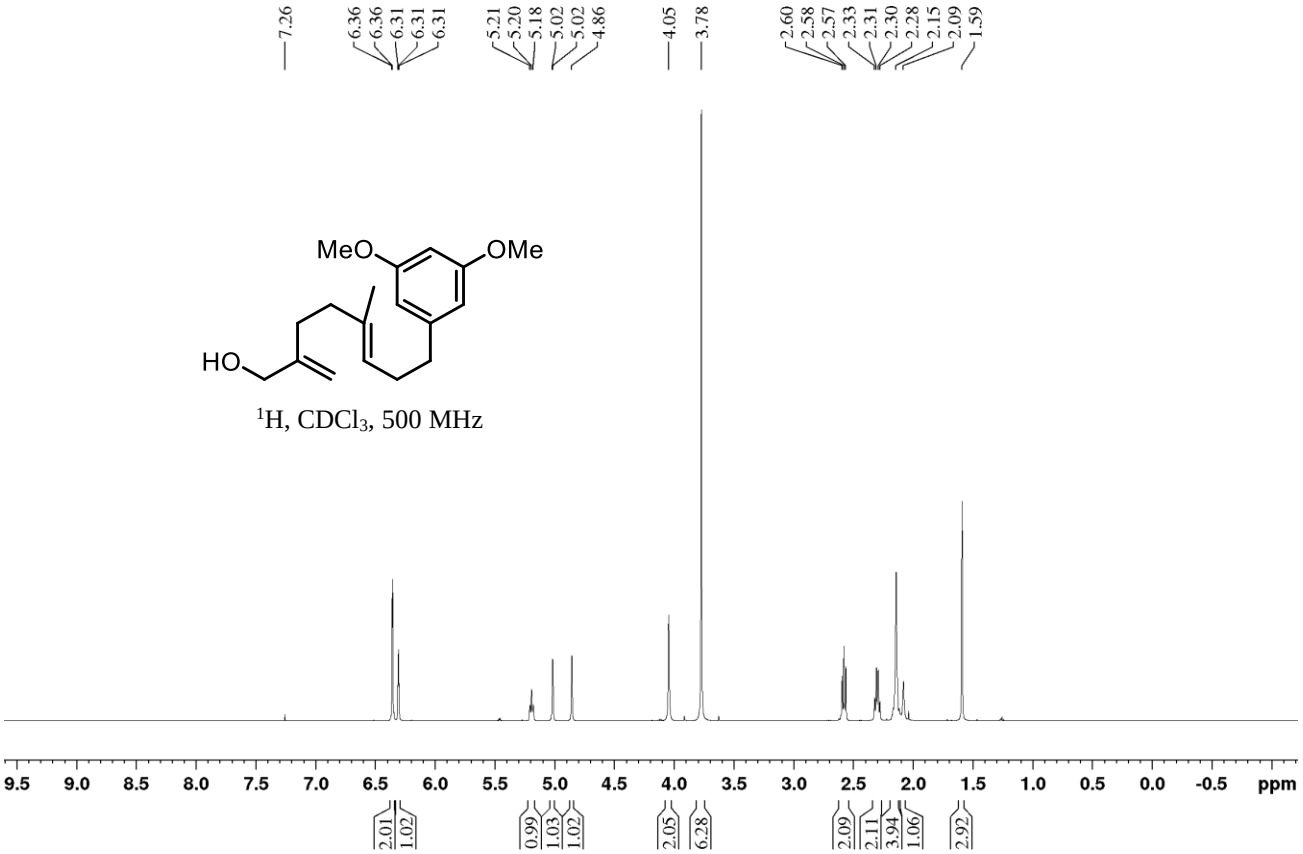
^{13}C, $CDCl_3$, 125 MHz



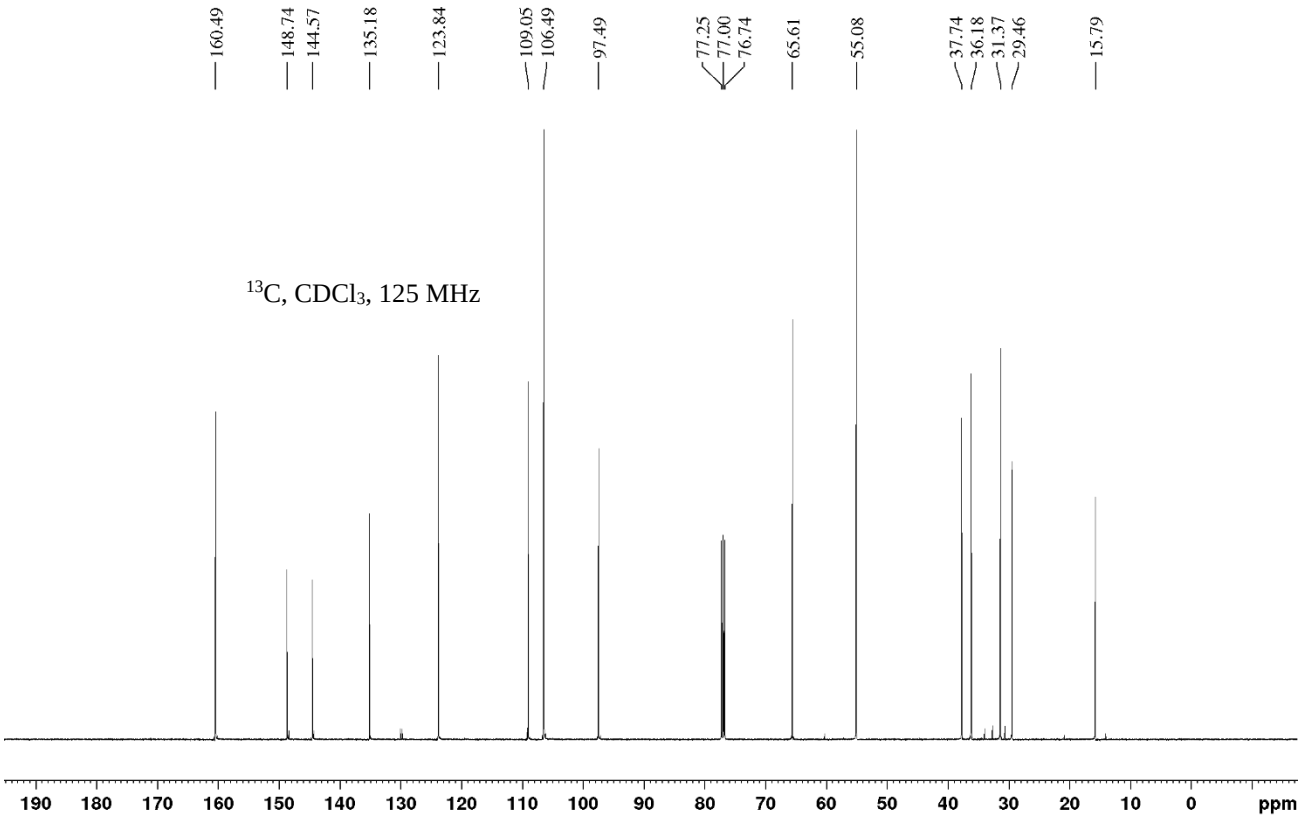
^{1}H, $CDCl_3$, 400 MHz



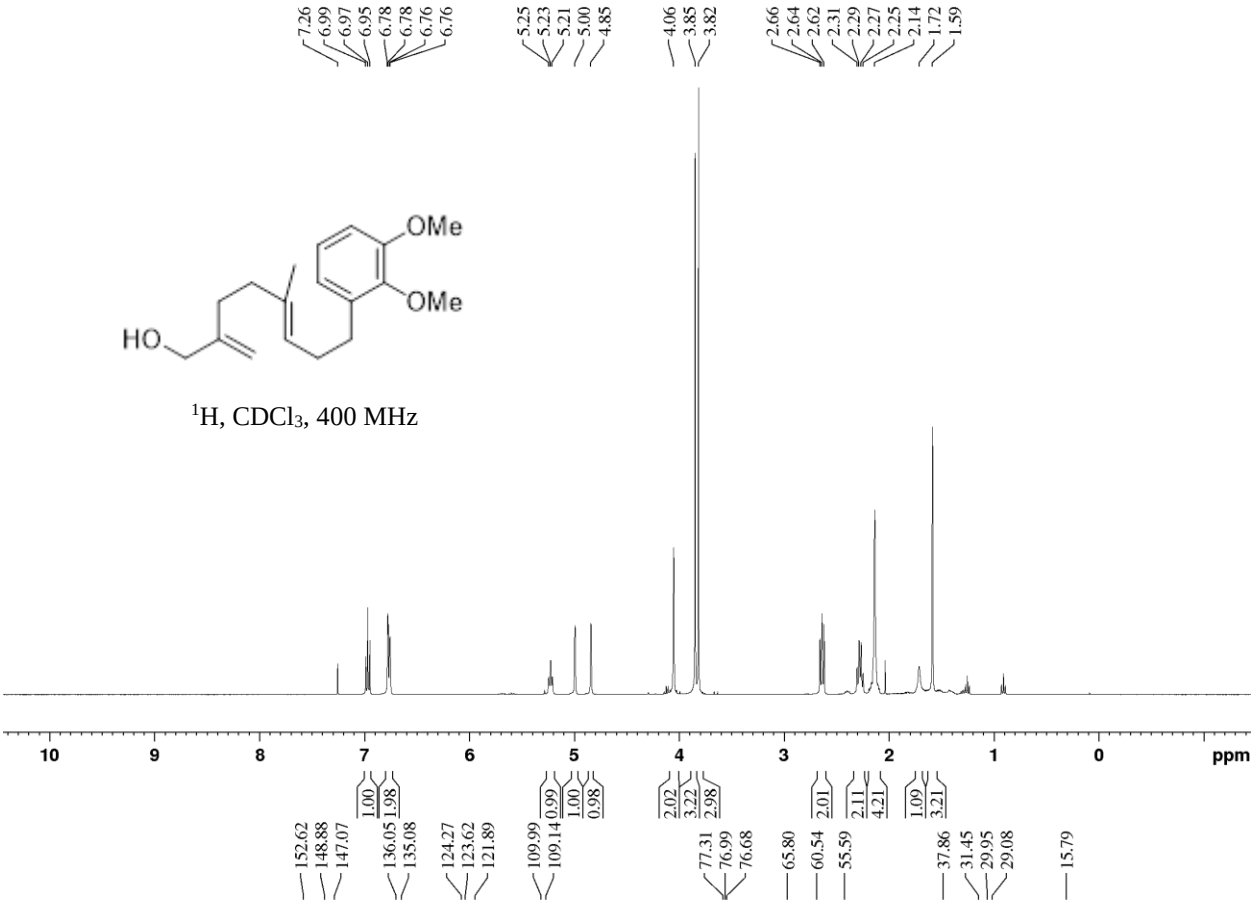
^{13}C, $CDCl_3$, 125 MHz



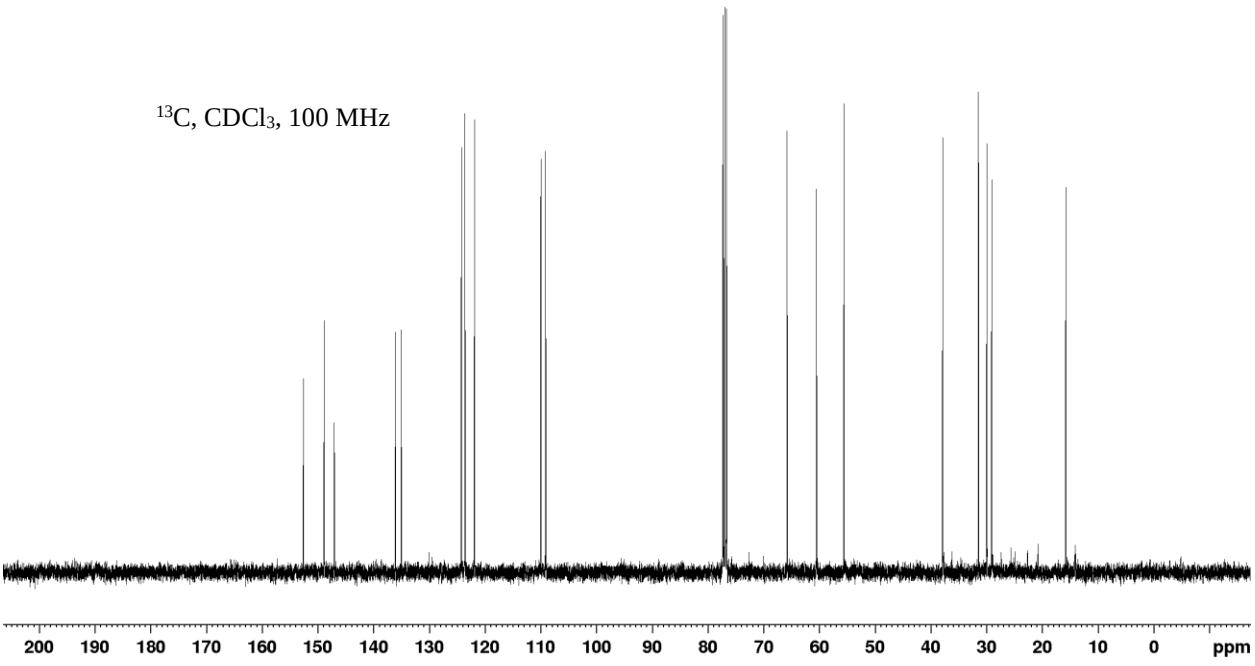
^{1}H, $CDCl_3$, 500 MHz



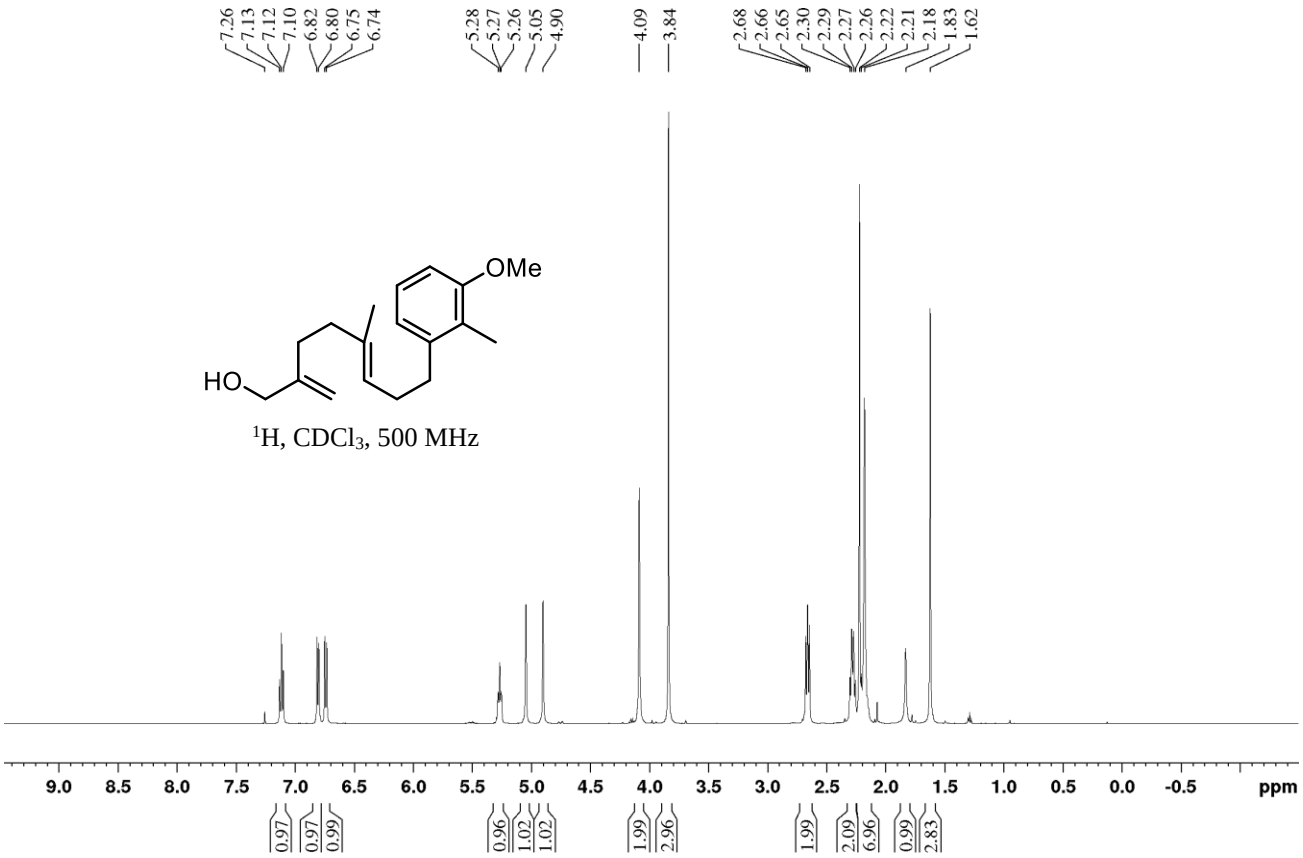
^{13}C, $CDCl_3$, 125 MHz



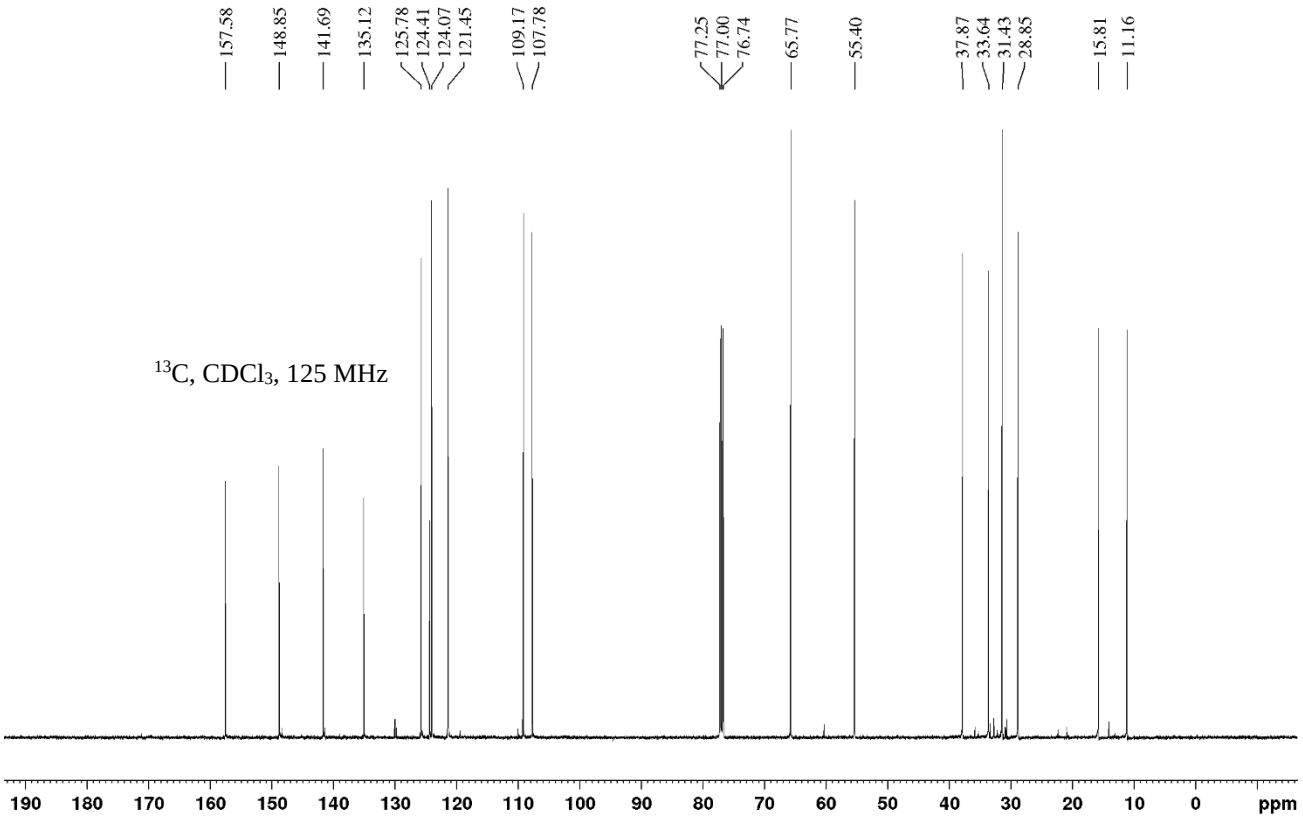
^{1}H, $CDCl_3$, 400 MHz



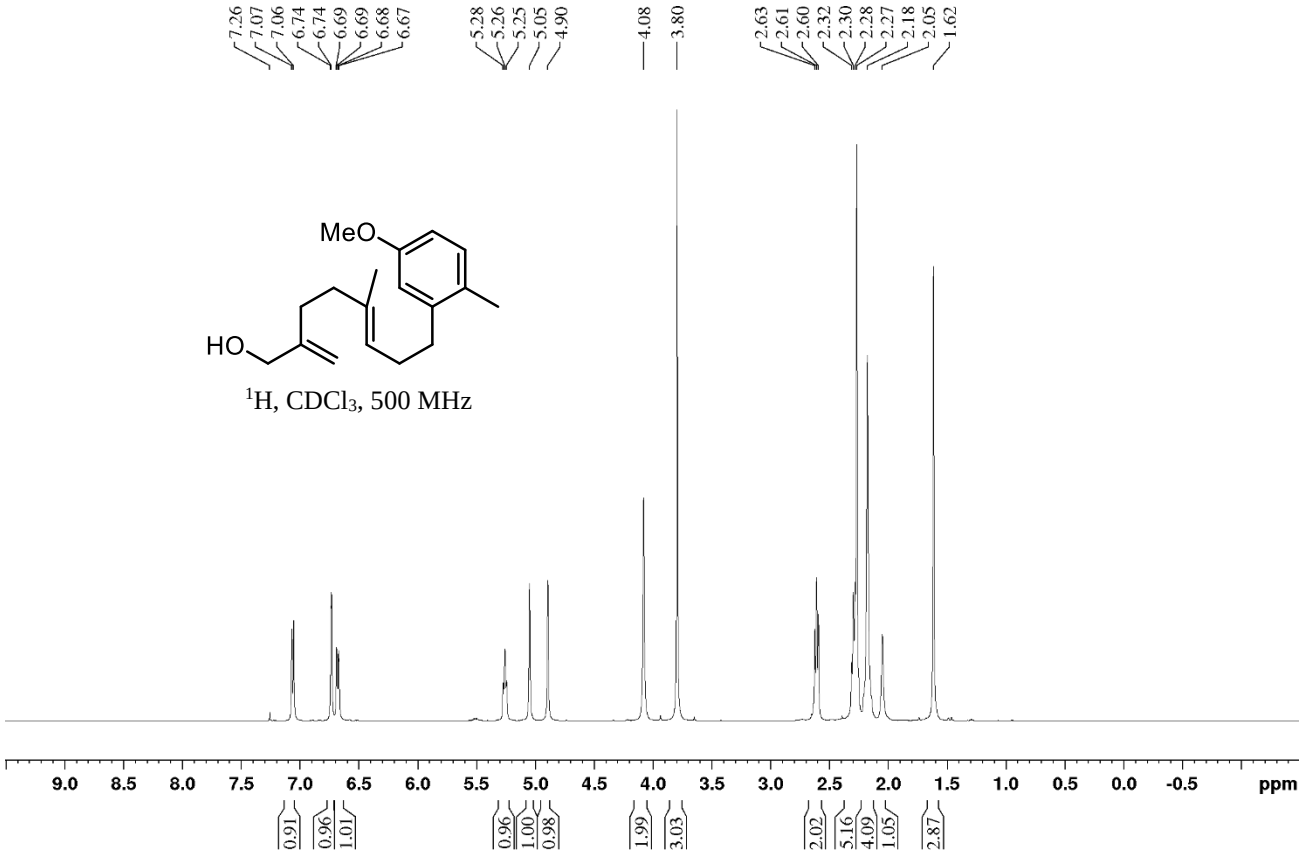
^{13}C, $CDCl_3$, 100 MHz



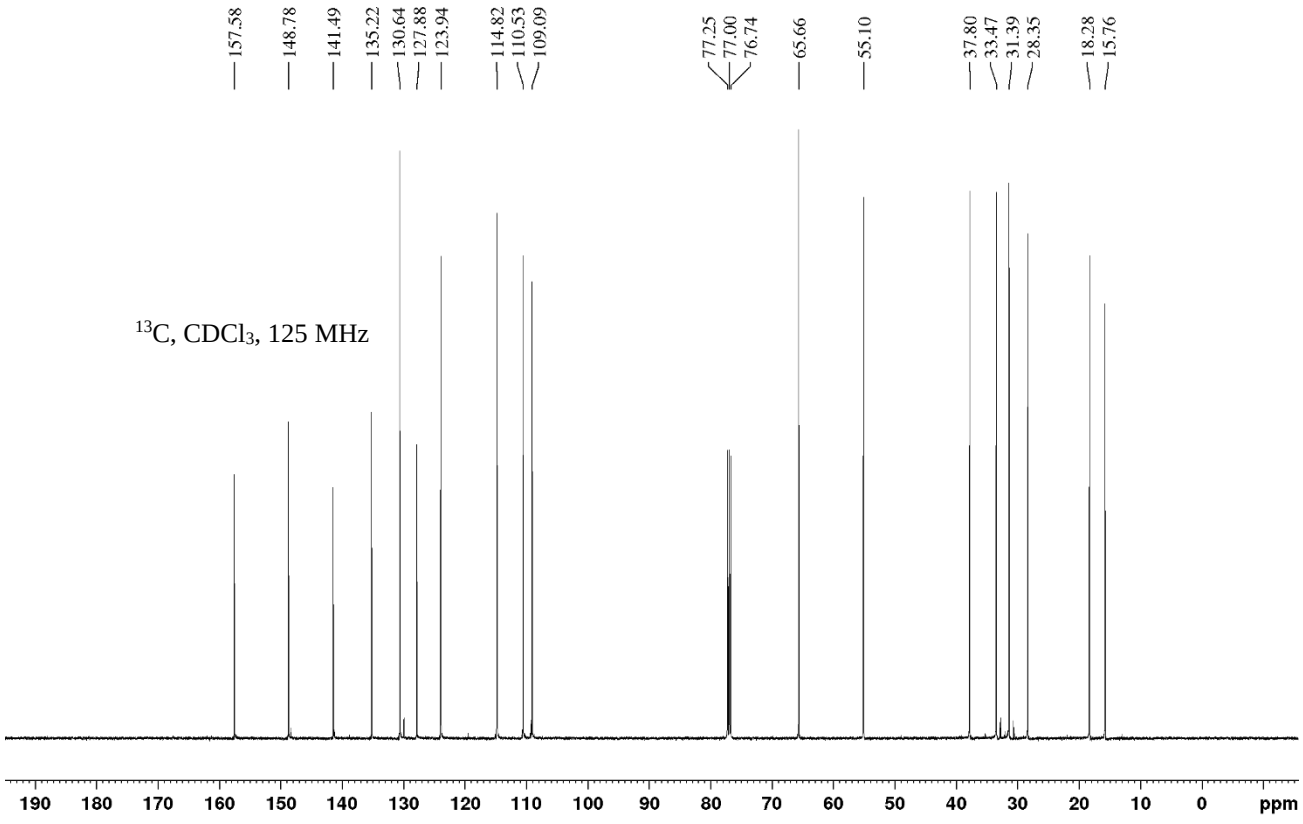
^{1}H, $CDCl_3$, 500 MHz



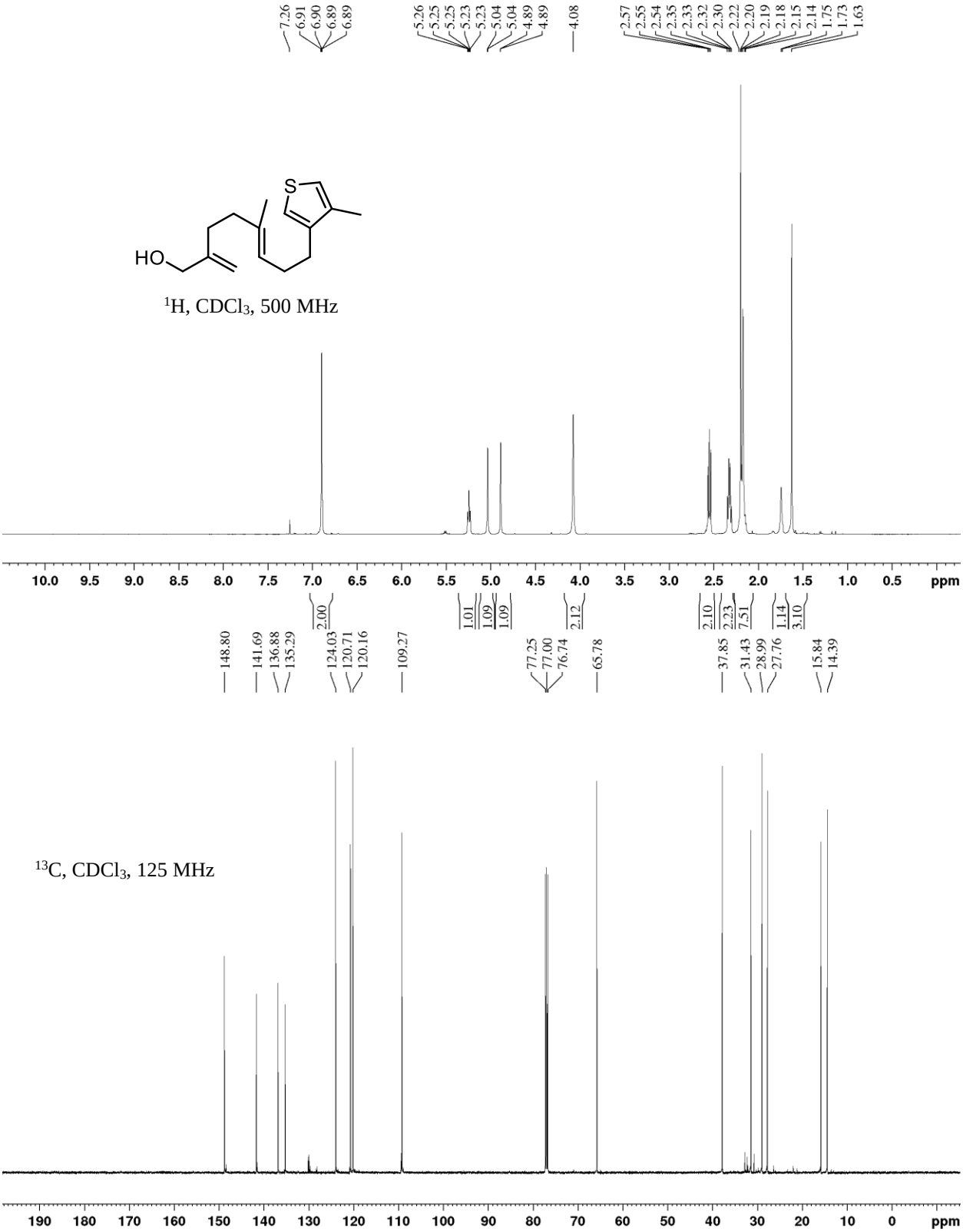
^{13}C, $CDCl_3$, 125 MHz



^{1}H, $CDCl_3$, 500 MHz

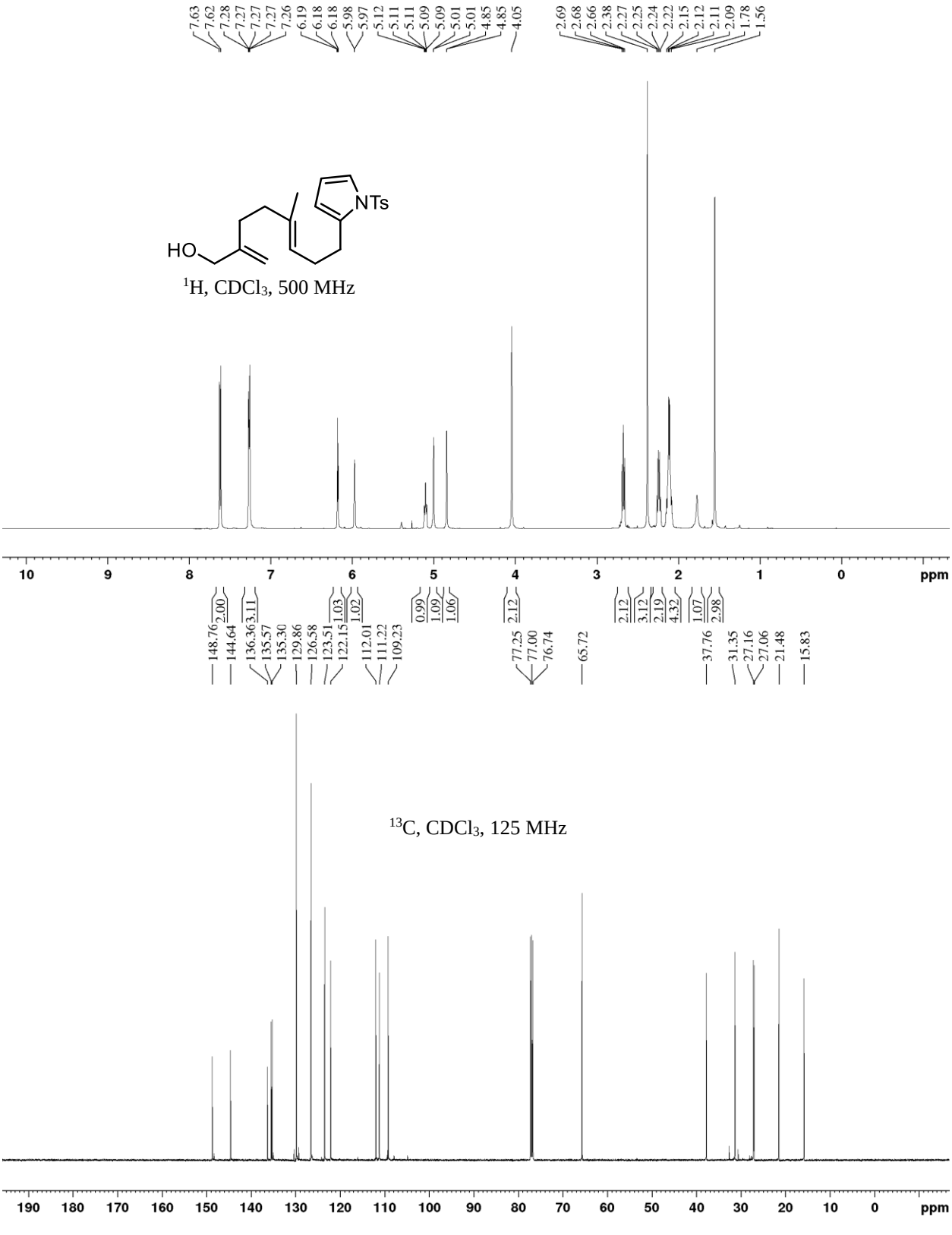


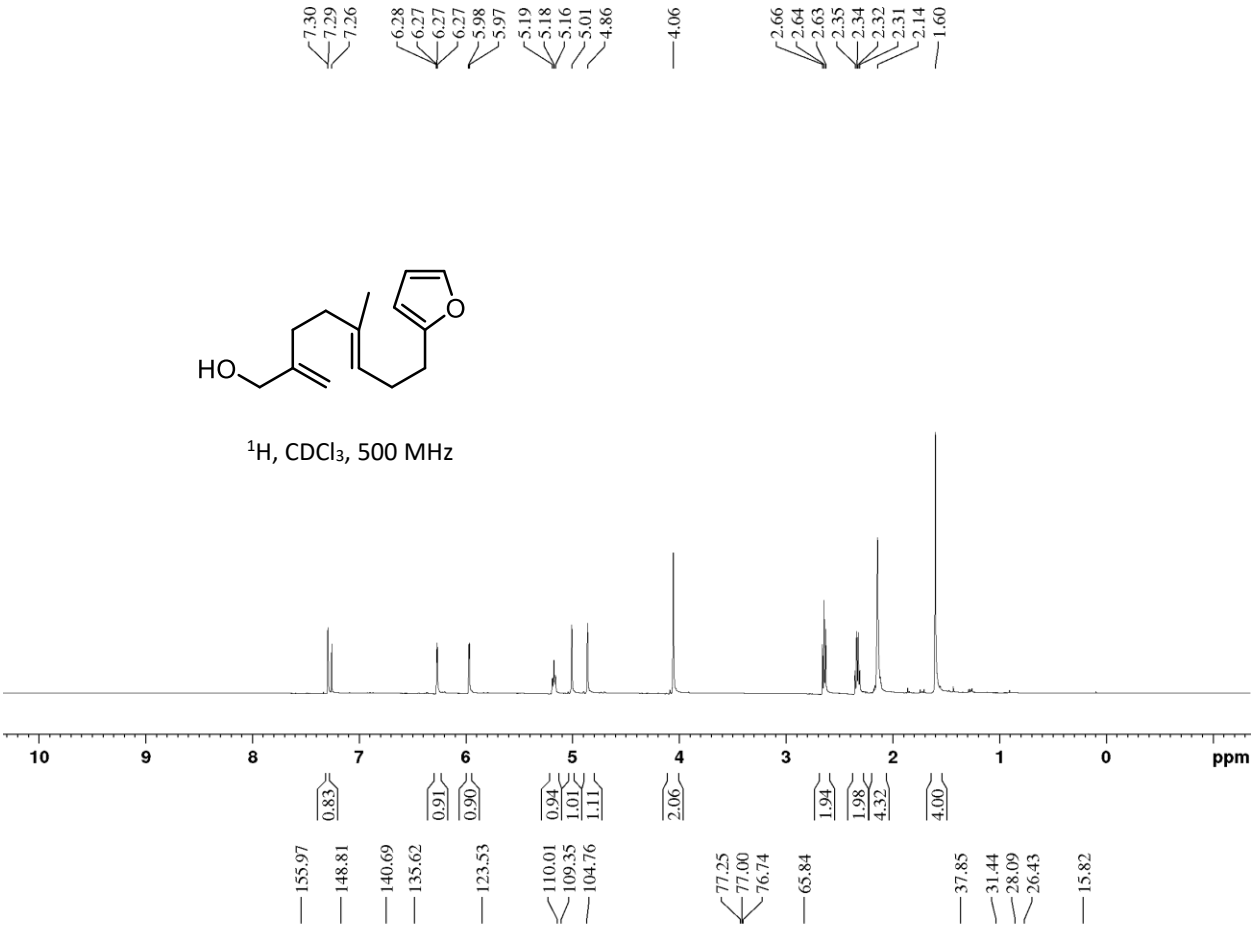
^{13}C, $CDCl_3$, 125 MHz

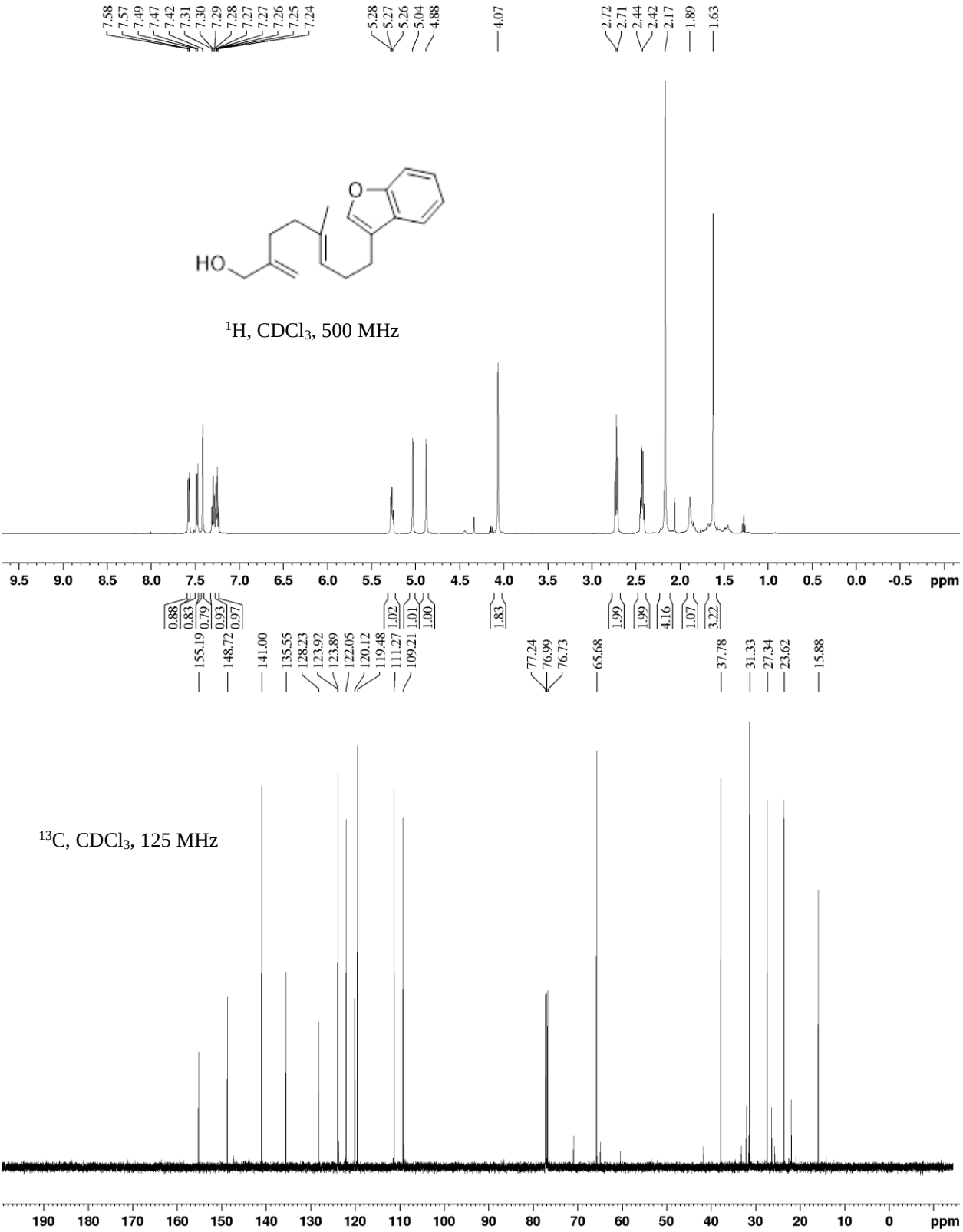


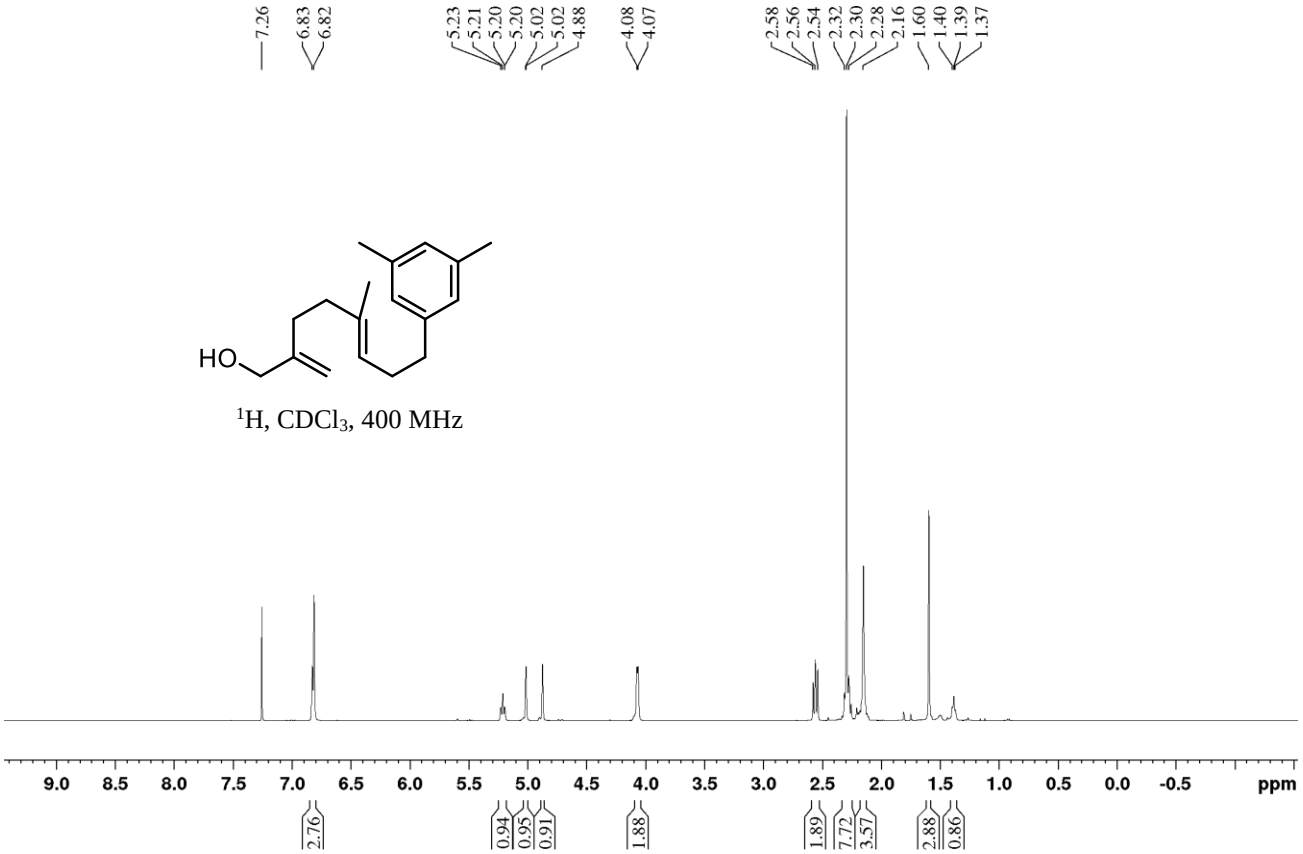
^{1}H, $CDCl_3$, 500 MHz

^{13}C, $CDCl_3$, 125 MHz

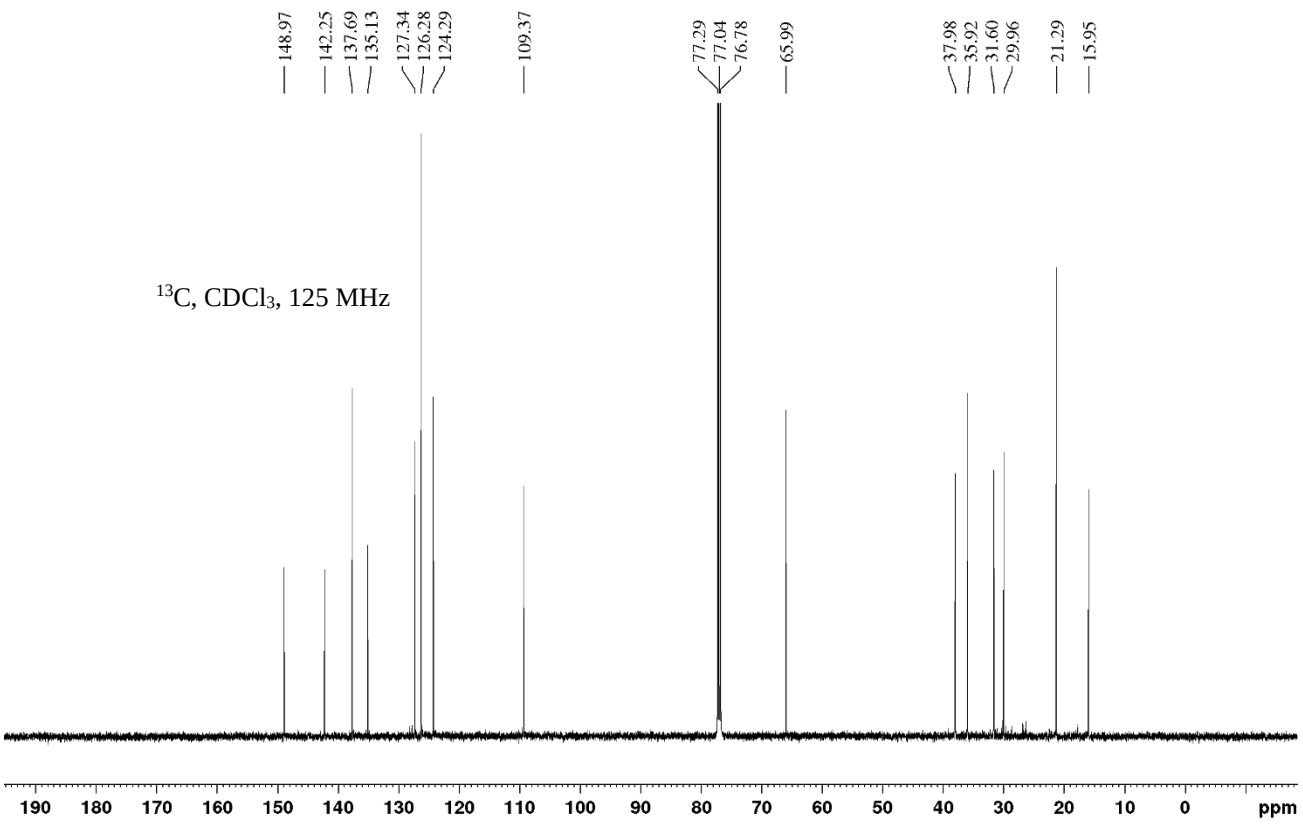

7.63
7.62
7.28
7.27
7.27
7.27
7.26
6.19
6.18
6.18
5.98
5.97
5.12
5.11
5.11
5.09
5.09
5.01
5.01
4.85
4.85
4.05
2.69
2.68
2.66
2.38
2.27
2.25
2.24
2.22
2.15
2.12
2.11
2.09
1.78
1.56
NTs
HO
1H, CDCl3, 500 MHz
10
9
8
7
6
5
4
3
2
1
0
ppm
2.00
3.11
1.03
1.02
0.99
1.09
1.06
2.12
2.12
3.12
2.19
4.32
1.07
2.98
148.76
144.64
136.36
135.57
135.30
129.86
126.58
123.51
122.15
112.01
111.22
109.23
77.25
77.00
76.74
65.72
37.76
31.35
27.16
27.06
21.48
15.83
13C, CDCl3, 125 MHz
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
ppm


7.30
7.29
7.26
6.28
6.27
6.27
6.27
5.98
5.97
5.19
5.18
5.16
5.01
4.86
4.06
2.66
2.64
2.63
2.35
2.34
2.32
2.31
2.14
1.60
HO
O
1H, CDCl3, 500 MHz
10
9
8
7
6
5
4
3
2
1
0
ppm
0.83
0.91
0.90
0.94
1.01
1.11
2.06
1.94
1.98
4.32
4.00
155.97
148.81
140.69
135.62
123.53
110.01
109.35
104.76
77.25
77.00
76.74
65.84
37.85
31.44
28.09
26.43
15.82
13C, CDCl3, 125 MHz
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
ppm

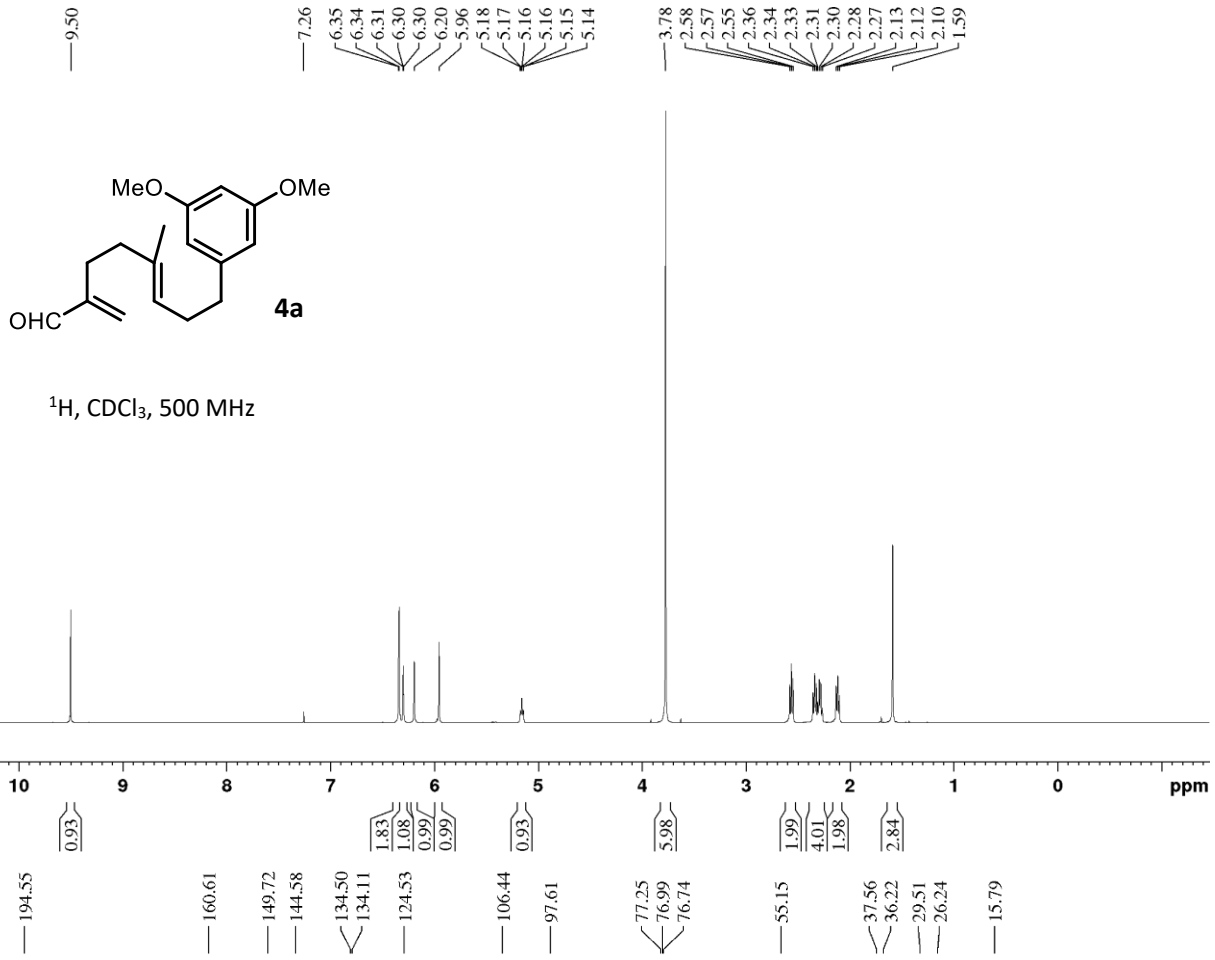

7.58
7.57
7.49
7.47
7.42
7.31
7.30
7.29
7.28
7.27
7.27
7.26
7.25
7.24
5.28
5.27
5.26
5.04
4.88
4.07
2.72
2.71
2.44
2.42
2.17
1.89
1.63
HO
O
1H, CDCl3, 500 MHz
9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5 ppm
0.88
0.83
0.79
0.93
0.97
1.02
1.01
1.00
1.83
1.99
1.99
4.16
1.07
3.22
155.19
148.72
141.00
135.55
128.23
123.92
123.89
122.05
120.12
119.48
111.27
109.21
77.24
76.99
76.73
65.68
37.78
31.33
27.34
23.62
15.88
13C, CDCl3, 125 MHz
190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 ppm



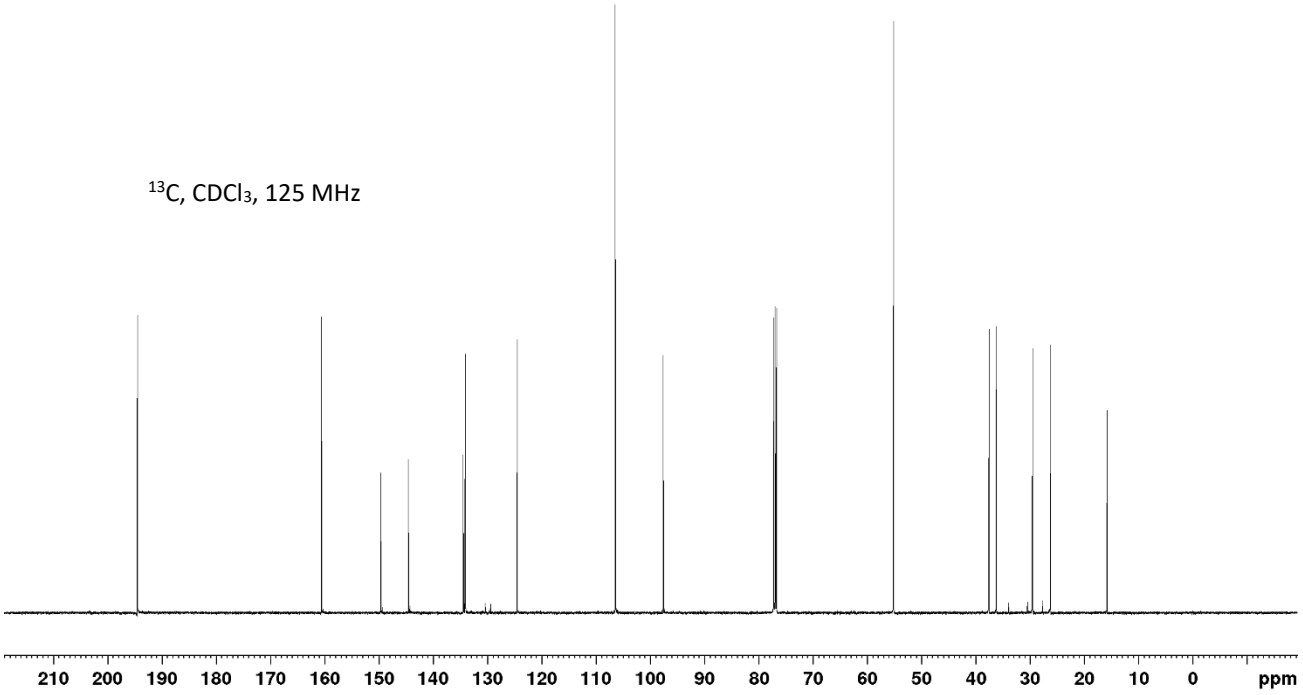
^{1}H, $CDCl_3$, 400 MHz



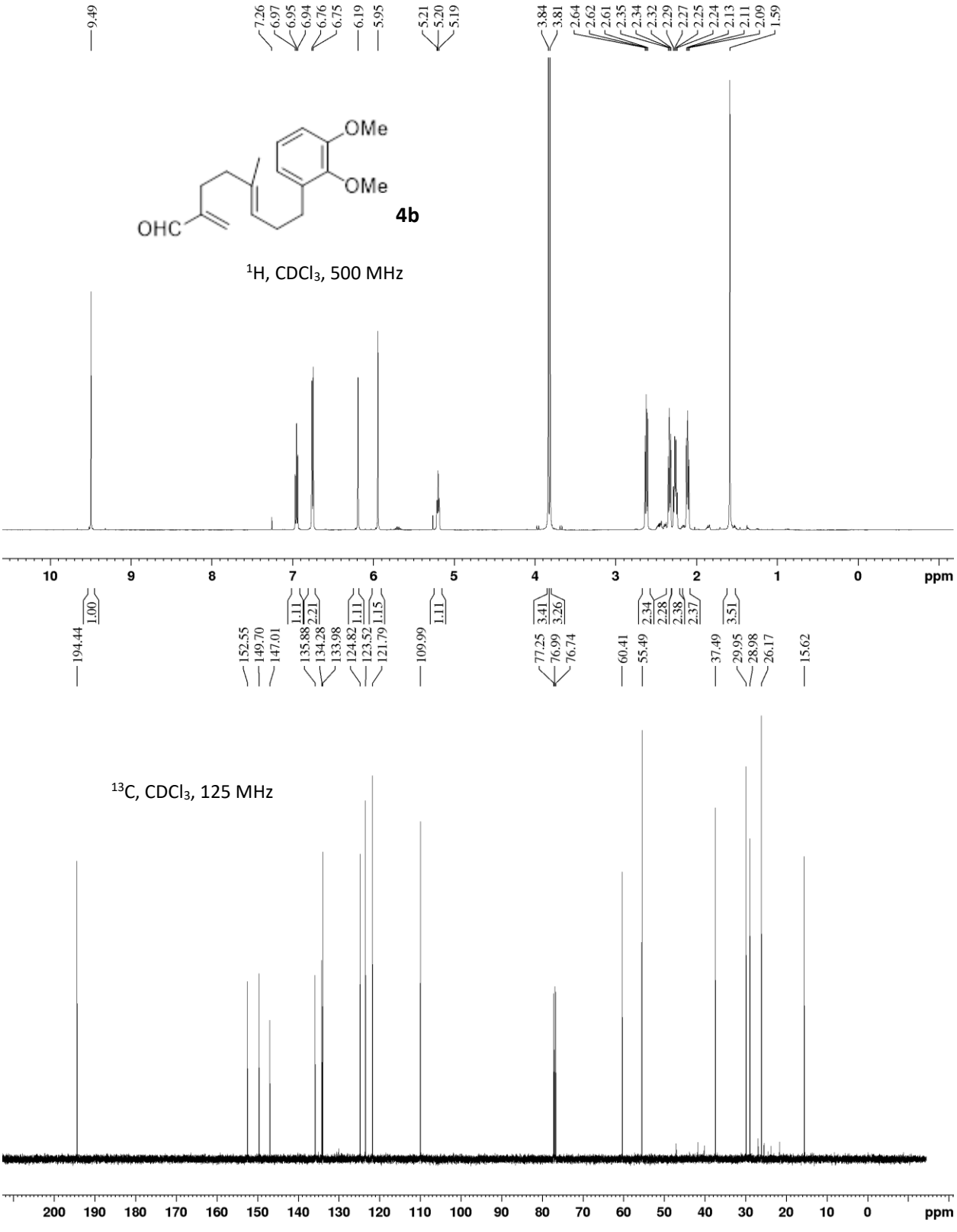
^{13}C, $CDCl_3$, 125 MHz

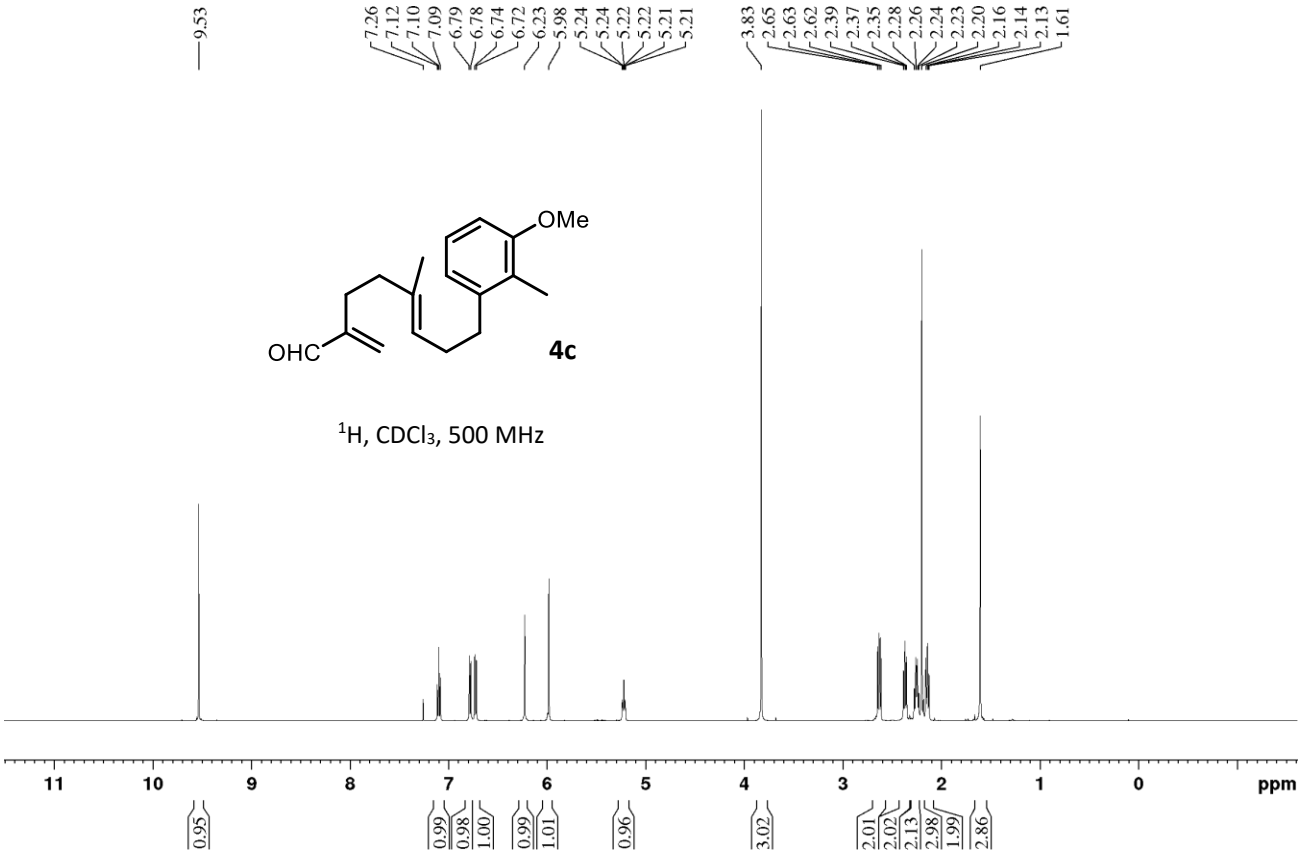


^{1}H, $CDCl_3$, 500 MHz

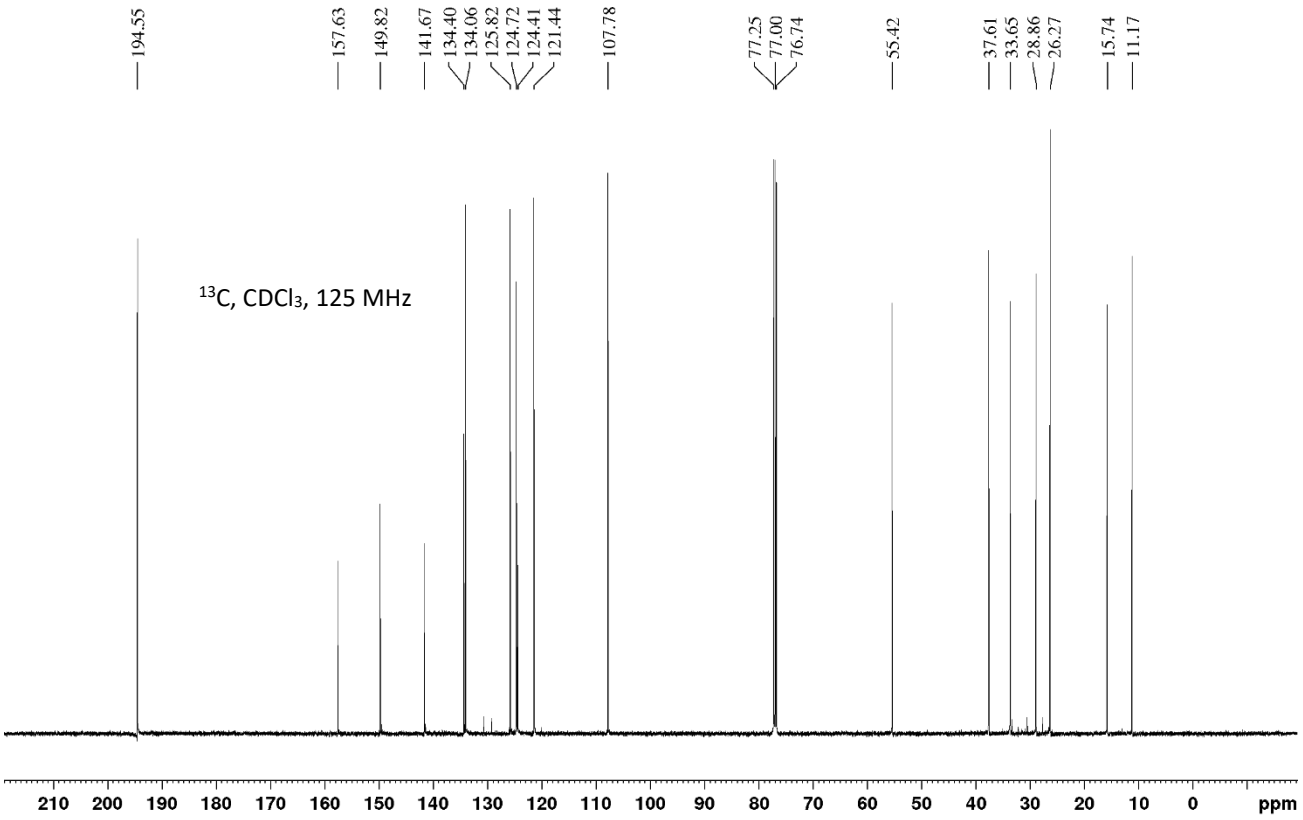


^{13}C, $CDCl_3$, 125 MHz

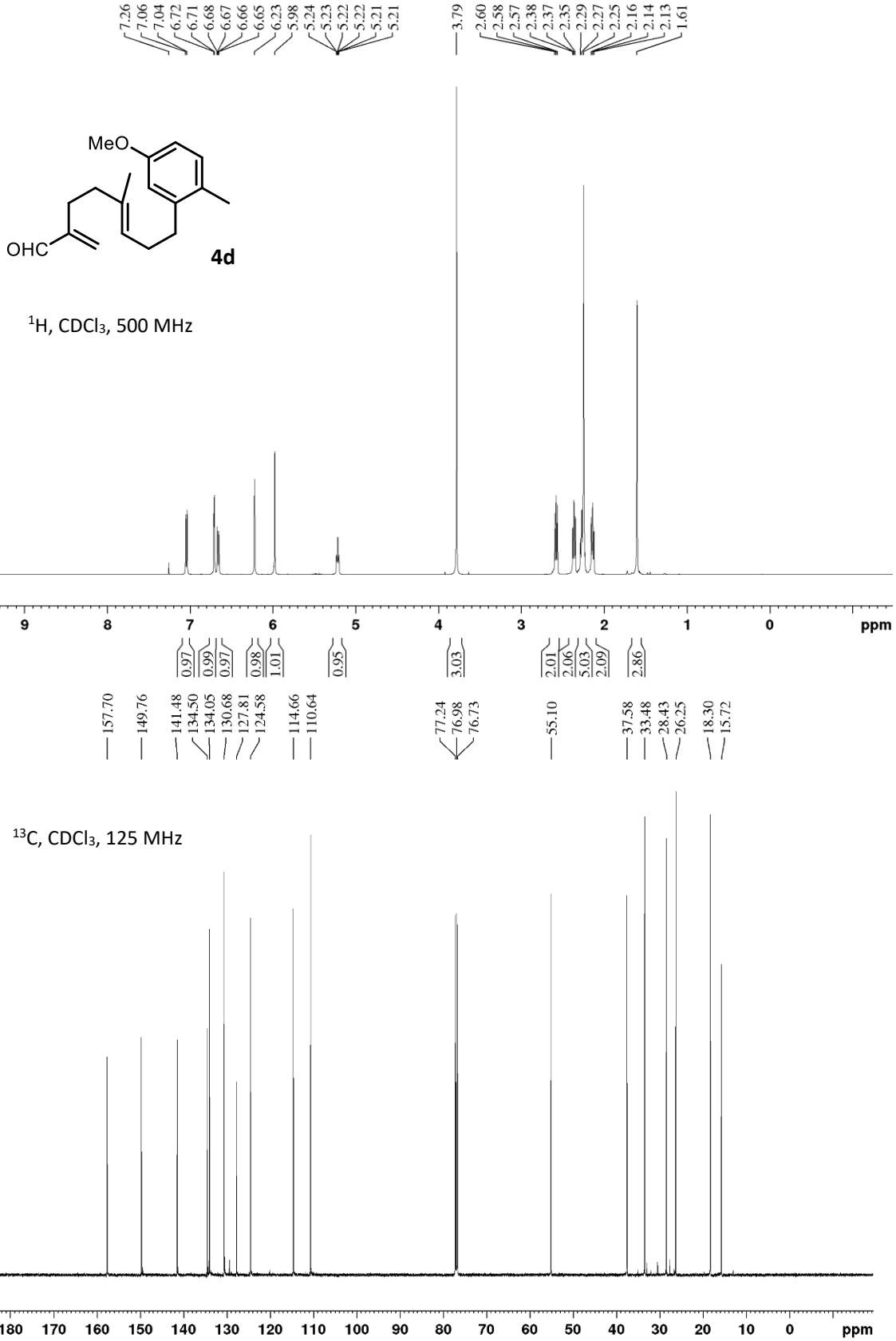

9.49
7.26
6.97
6.95
6.94
6.76
6.75
6.19
5.95
5.21
5.20
5.19
3.84
3.81
2.64
2.62
2.61
2.35
2.34
2.32
2.29
2.27
2.25
2.24
2.13
2.11
2.09
1.59
OMe
OMe
OHC
4b
1H, CDCl3, 500 MHz
10
9
8
7
6
5
4
3
2
1
0
ppm
1.00
1.11
2.21
1.11
1.15
1.11
3.41
3.26
2.34
2.28
2.38
2.37
3.51
194.44
152.55
149.70
147.01
135.88
134.28
133.98
124.82
123.52
121.79
109.99
77.25
76.99
76.74
60.41
55.49
37.49
29.95
28.98
26.17
15.62
13C, CDCl3, 125 MHz
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
ppm

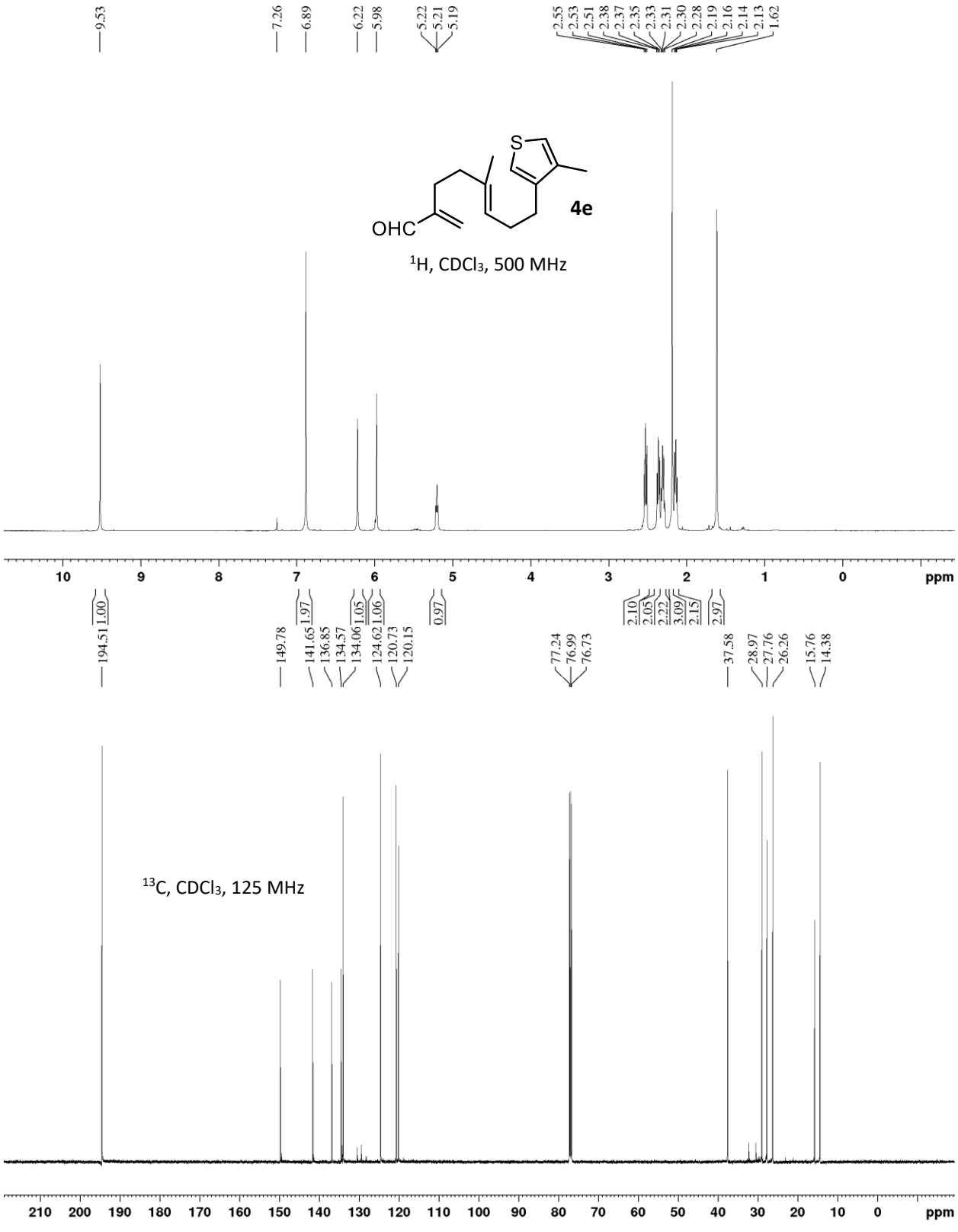


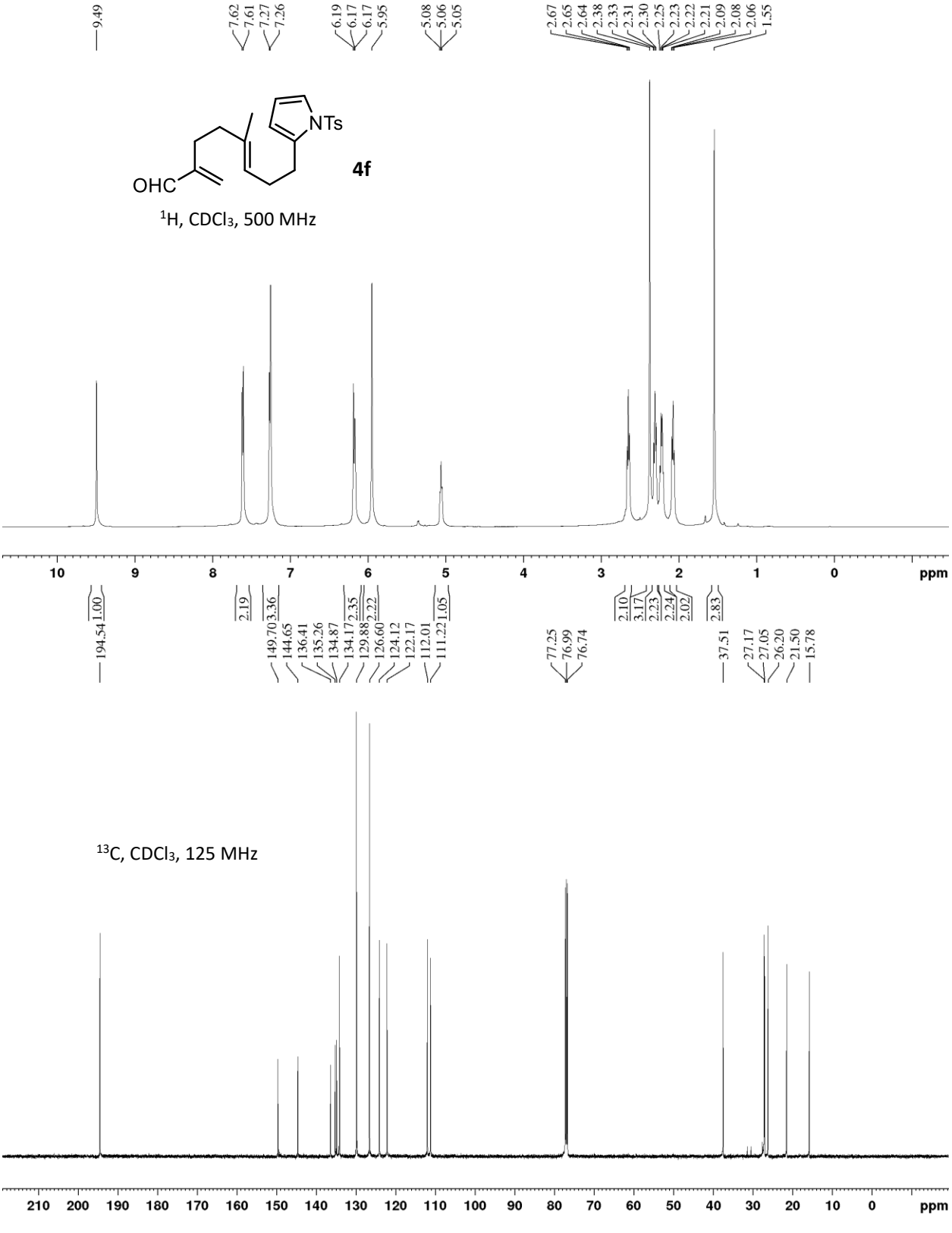
^{1}H, $CDCl_3$, 500 MHz

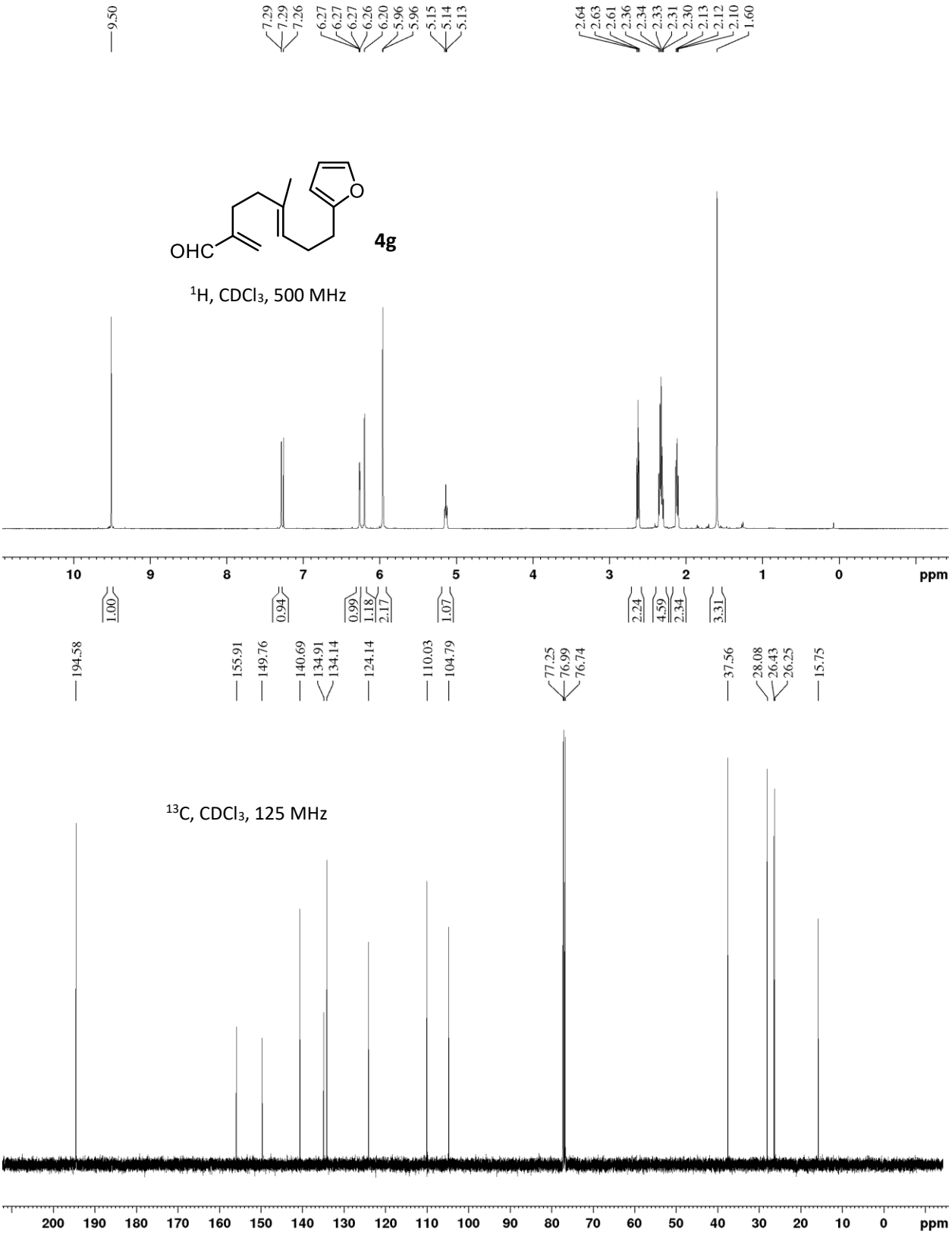


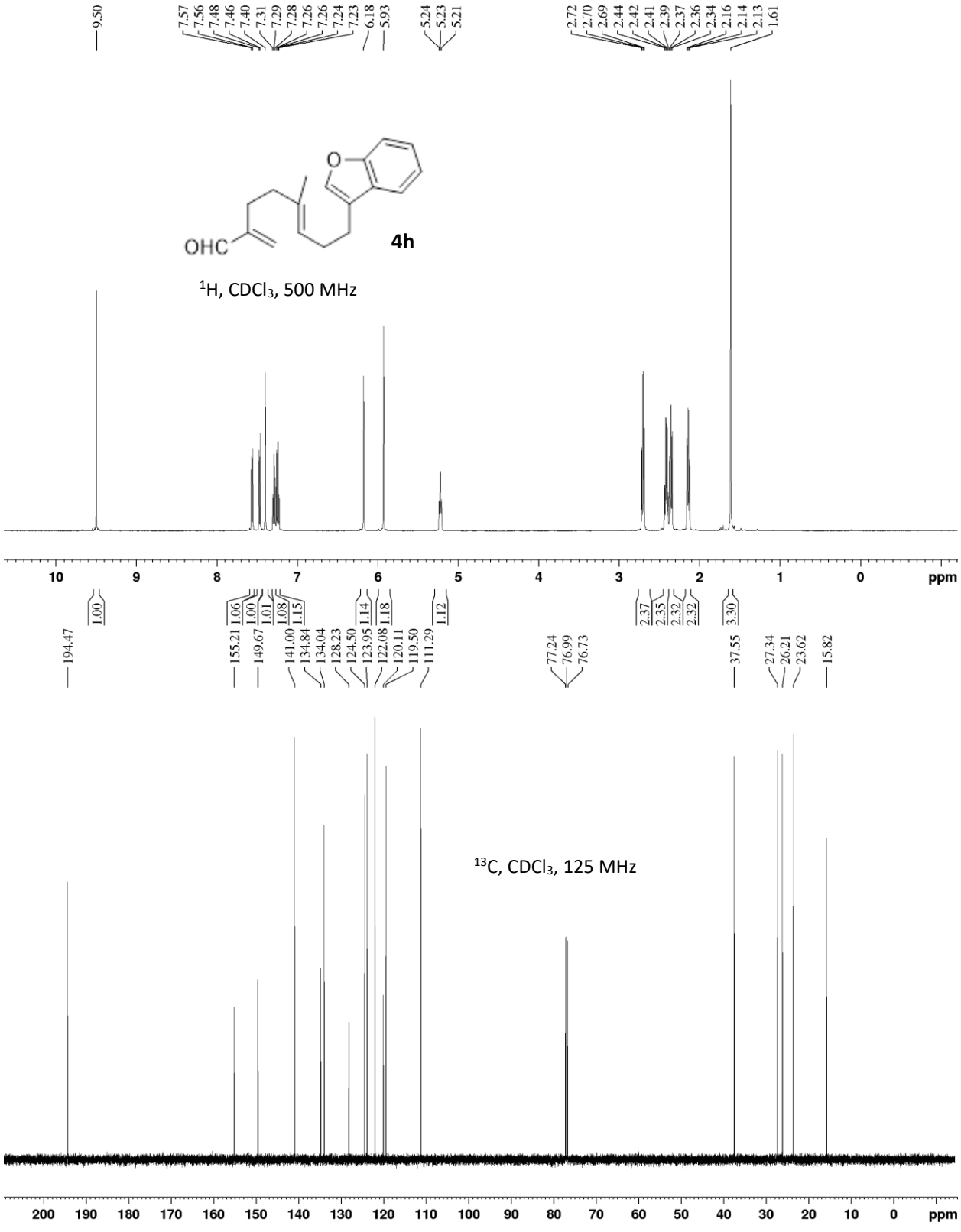
^{13}C, $CDCl_3$, 125 MHz

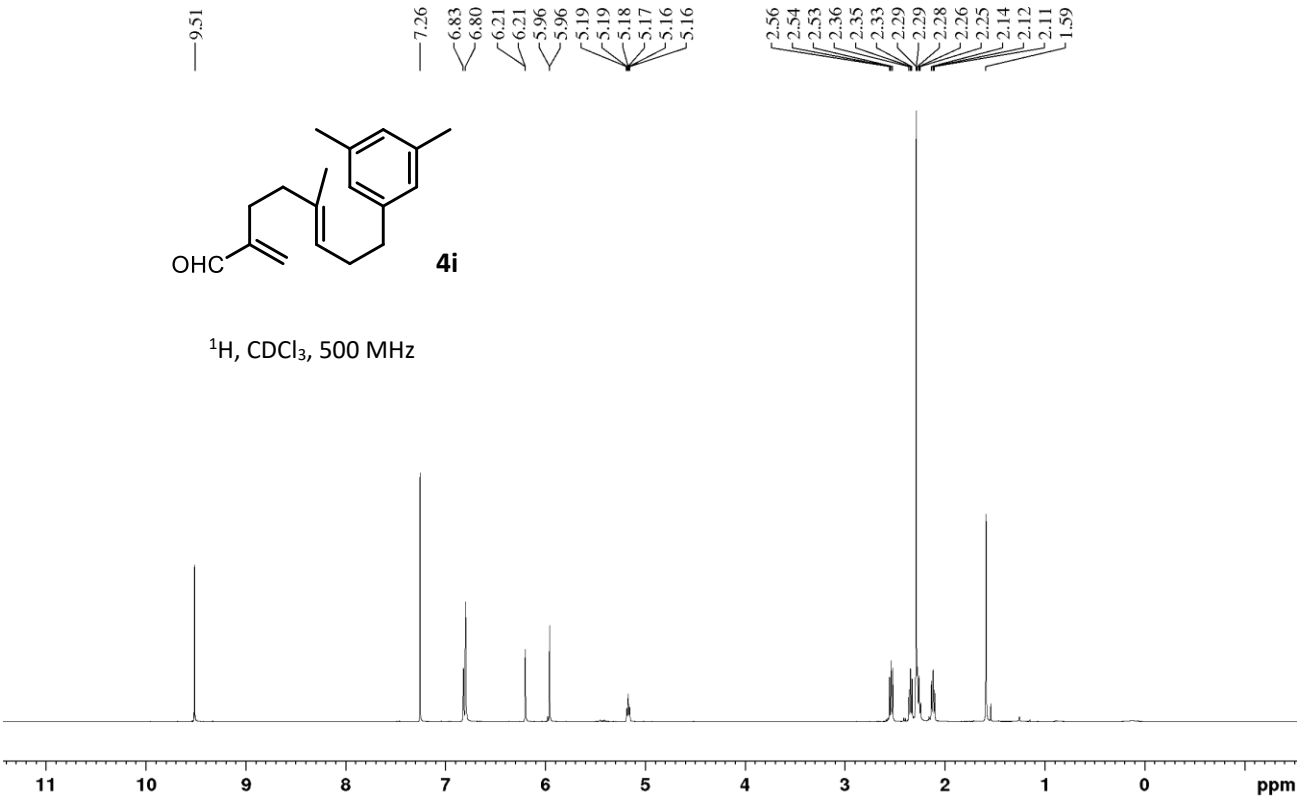

9.52
7.26
7.06
7.04
6.72
6.71
6.68
6.67
6.66
6.65
6.23
5.98
5.24
5.23
5.22
5.21
5.21
3.79
2.60
2.58
2.57
2.38
2.37
2.35
2.29
2.27
2.25
2.16
2.14
2.13
1.61
MeO
OHC
4d
1H, CDCl3, 500 MHz
10
9
8
7
6
5
4
3
2
1
0
ppm
0.94
0.97
0.99
0.97
0.98
1.01
0.95
3.03
2.01
2.06
5.03
2.09
2.86
194.51
157.70
149.76
141.48
134.50
134.05
130.68
127.81
124.58
114.66
110.64
77.24
76.98
76.73
55.10
37.58
33.48
28.43
26.25
18.30
15.72
13C, CDCl3, 125 MHz
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
ppm

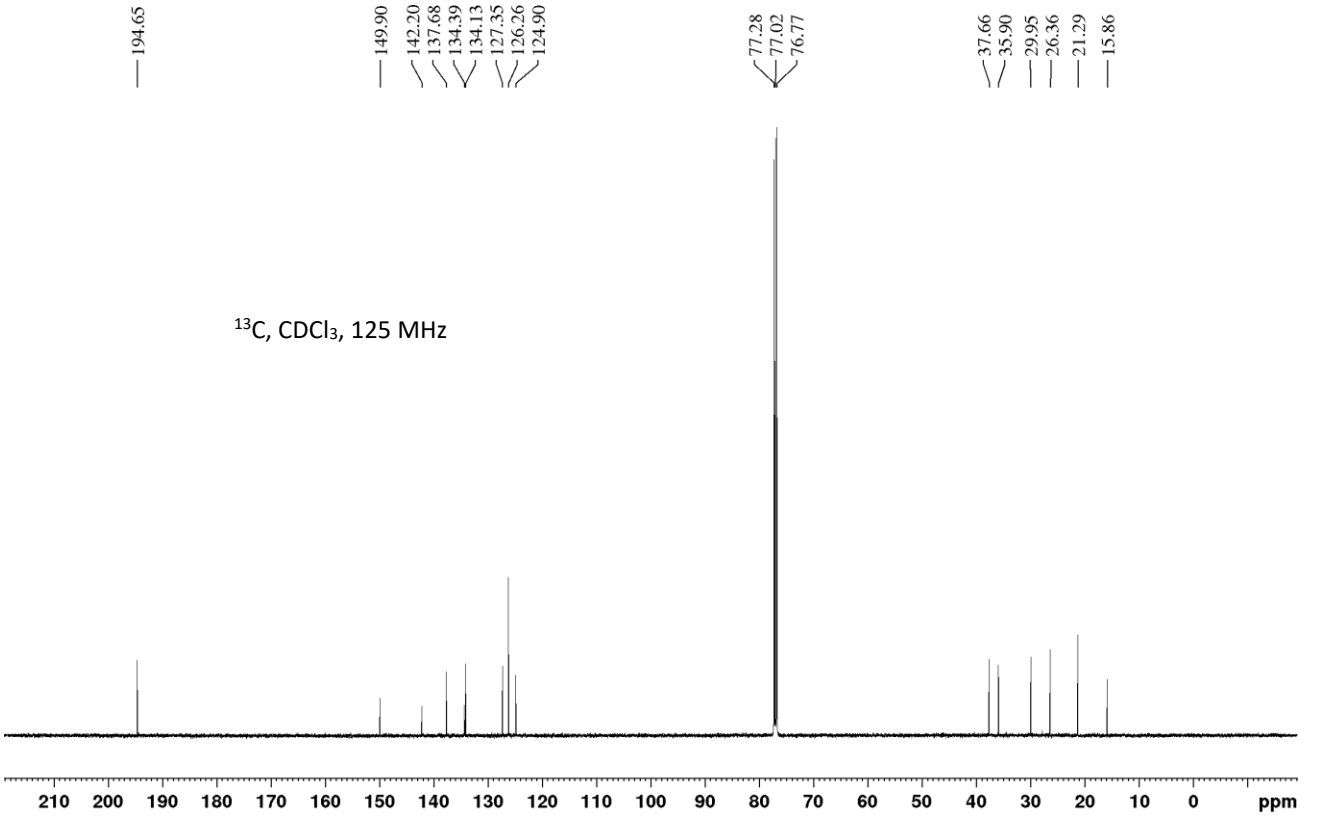

9.53
7.26
6.89
6.22
5.98
5.22
5.21
5.19
2.55
2.53
2.51
2.38
2.37
2.35
2.33
2.31
2.30
2.28
2.19
2.16
2.14
2.13
1.62
S
OHC
4e
1H, CDCl3, 500 MHz
10
9
8
7
6
5
4
3
2
1
0
ppm
1.00
1.97
1.05
1.06
0.97
2.10
2.05
2.22
3.09
2.15
2.97
194.51
149.78
141.65
136.85
134.57
134.06
124.62
120.73
120.15
77.24
76.99
76.73
37.58
28.97
27.76
26.26
15.76
14.38
13C, CDCl3, 125 MHz
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
ppm

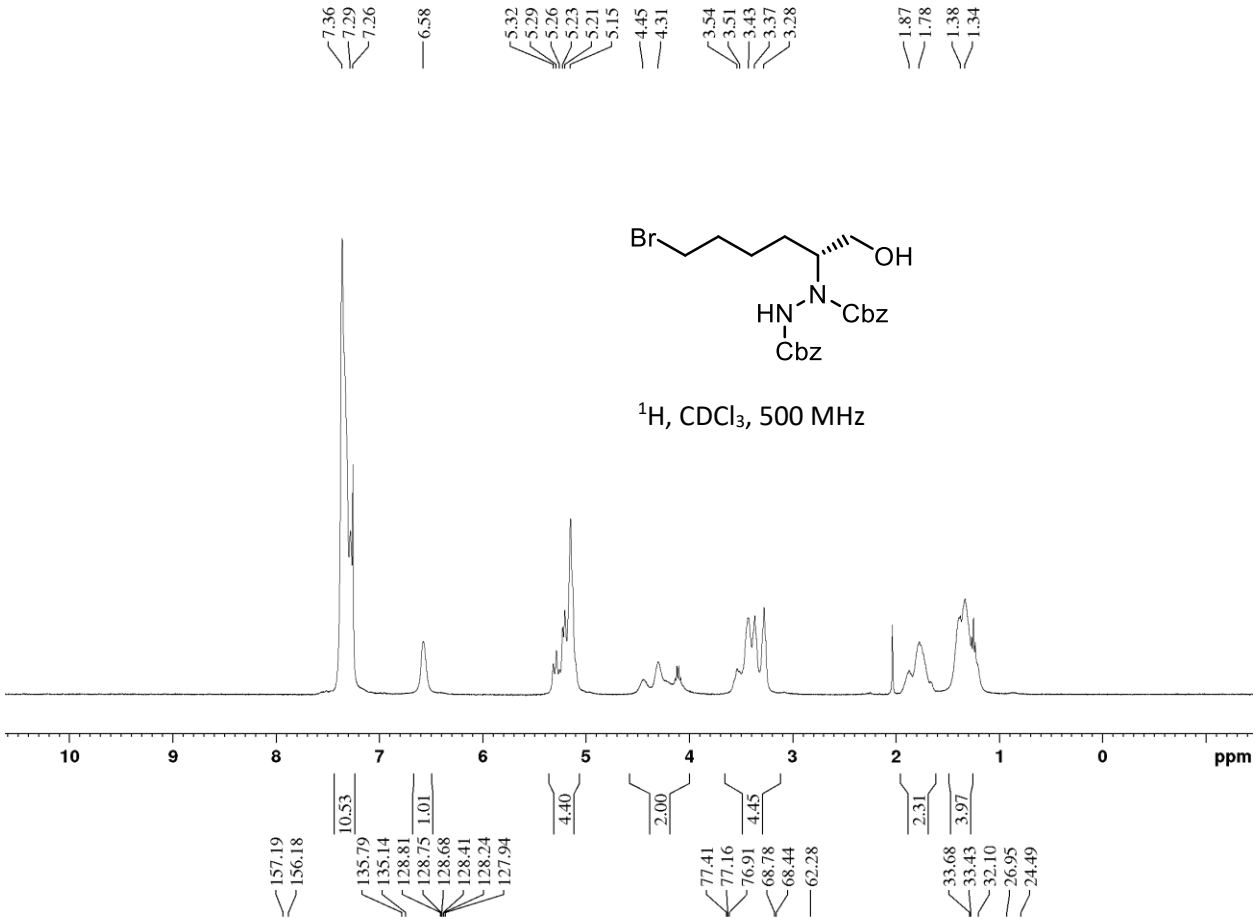

9.49
7.62
7.61
7.27
7.26
6.19
6.17
6.17
5.95
5.08
5.06
5.05
2.67
2.65
2.64
2.38
2.33
2.31
2.30
2.25
2.23
2.22
2.21
2.09
2.08
2.06
1.55
NTs
OHC
4f
1H, CDCl3, 500 MHz
10
9
8
7
6
5
4
3
2
1
0
ppm
1.00
2.19
3.36
2.35
2.22
1.05
2.10
3.17
2.23
2.24
2.02
2.83
194.54
149.70
144.65
136.41
135.26
134.87
134.17
129.88
126.60
124.12
122.17
112.01
111.22
77.25
76.99
76.74
37.51
27.17
27.05
26.20
21.50
15.78
13C, CDCl3, 125 MHz
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
ppm


9.50
7.29
7.29
7.26
6.27
6.27
6.27
6.26
6.20
5.96
5.96
5.15
5.14
5.13
2.64
2.63
2.61
2.36
2.34
2.33
2.31
2.30
2.13
2.12
2.10
1.60
OHC
O
4g
1H, CDCl3, 500 MHz
10
9
8
7
6
5
4
3
2
1
0
ppm
1.00
0.94
0.99
1.18
2.17
1.07
2.24
4.59
2.34
3.31
194.58
155.91
149.76
140.69
134.91
134.14
124.14
110.03
104.79
77.25
76.99
76.74
37.56
28.08
26.43
26.25
15.75
13C, CDCl3, 125 MHz
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
ppm

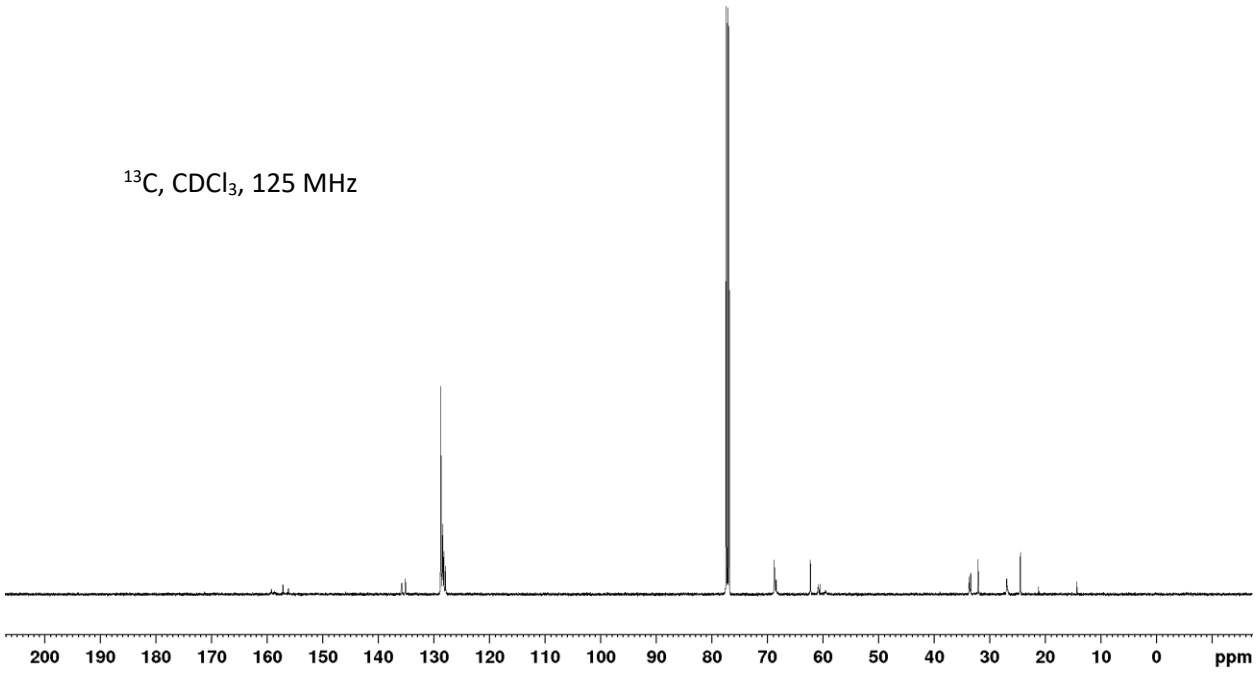

9.50
7.57
7.56
7.48
7.46
7.40
7.31
7.29
7.28
7.26
7.26
7.24
7.23
6.18
5.93
5.24
5.23
5.21
2.72
2.70
2.69
2.44
2.42
2.41
2.39
2.37
2.36
2.34
2.16
2.14
2.13
1.61
O
OHC
4h
1H, CDCl3, 500 MHz
10
9
8
7
6
5
4
3
2
1
0
ppm
1.00
1.06
1.00
1.01
1.08
1.15
1.14
1.18
1.12
2.37
2.35
2.32
2.32
3.30
194.47
155.21
149.67
141.00
134.84
134.04
128.23
124.50
123.95
122.08
120.11
119.50
111.29
77.24
76.99
76.73
37.55
27.34
26.21
23.62
15.82
13C, CDCl3, 125 MHz
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
ppm


9.51
7.26
6.83
6.80
6.21
6.21
5.96
5.96
5.19
5.19
5.18
5.17
5.16
5.16
2.56
2.54
2.53
2.36
2.35
2.33
2.29
2.29
2.28
2.26
2.25
2.14
2.12
2.11
1.59
OHC
4i
1H, CDCl3, 500 MHz
11
10
9
8
7
6
5
4
3
2
1
0
ppm
1.03
3.11
1.07
1.10
1.04
2.18
2.07
8.75
2.25
2.99

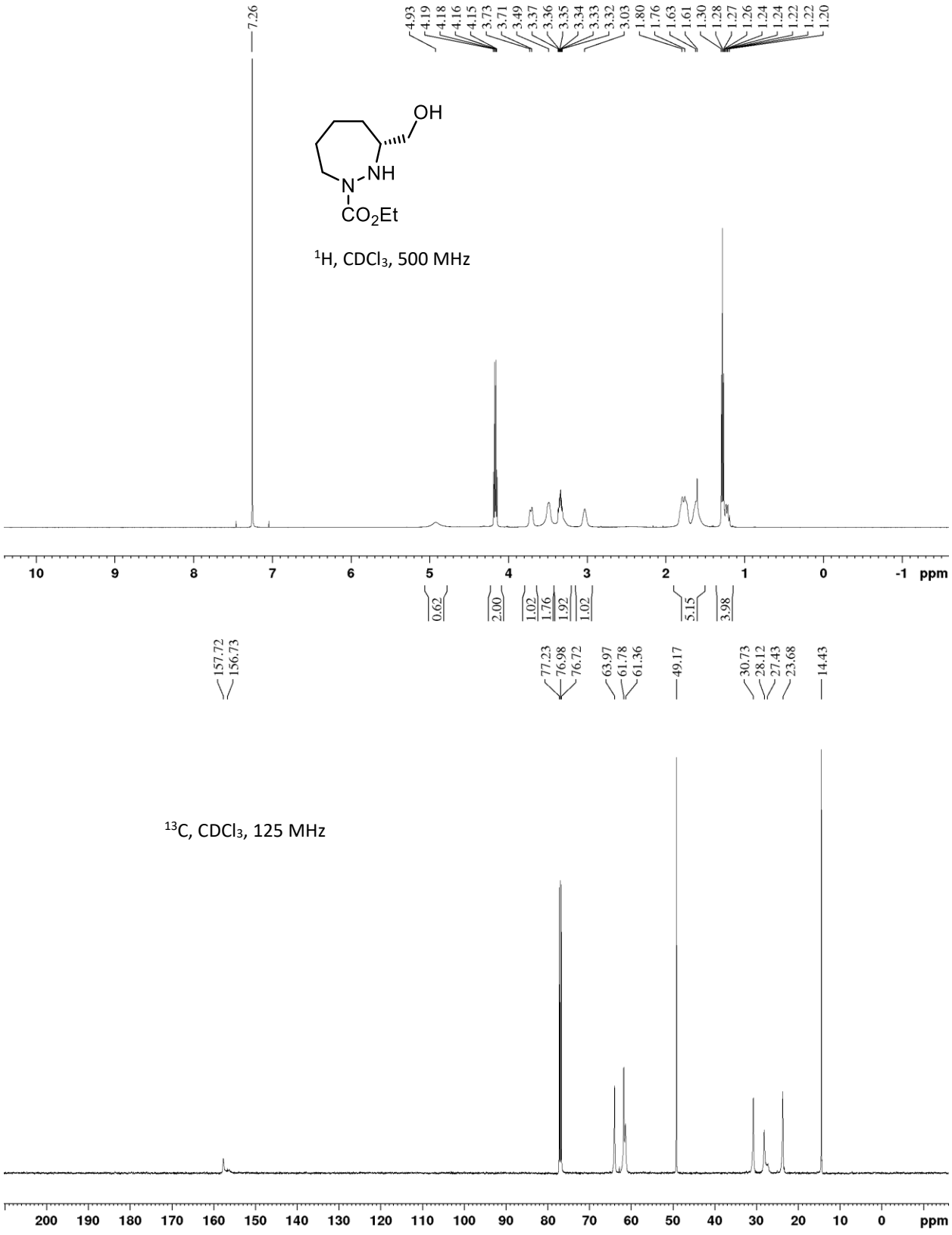

194.65
149.90
142.20
137.68
134.39
134.13
127.35
126.26
124.90
77.28
77.02
76.77
37.66
35.90
29.95
26.36
21.29
15.86
13C, CDCl3, 125 MHz
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
ppm

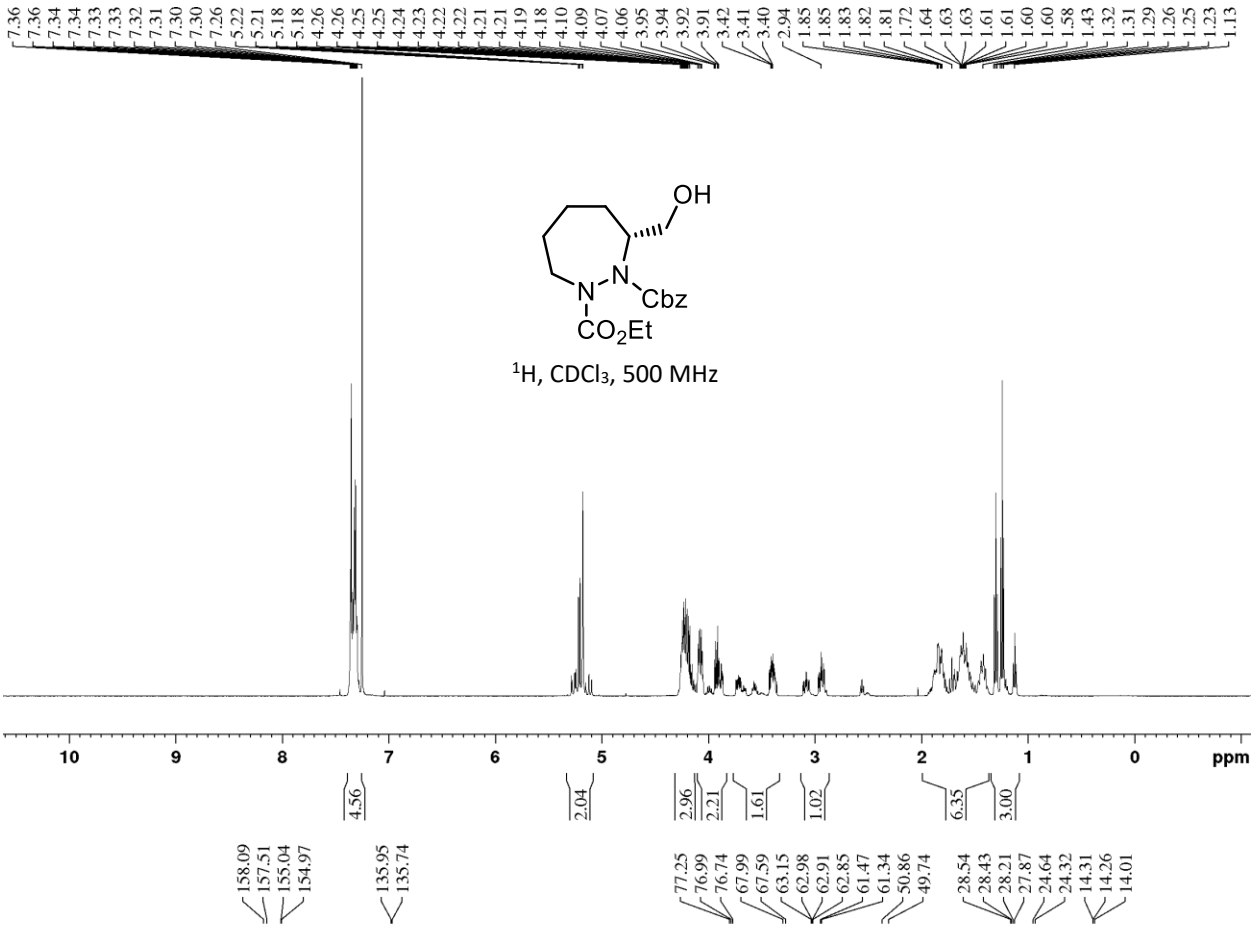


^{1}H, $CDCl_3$, 500 MHz

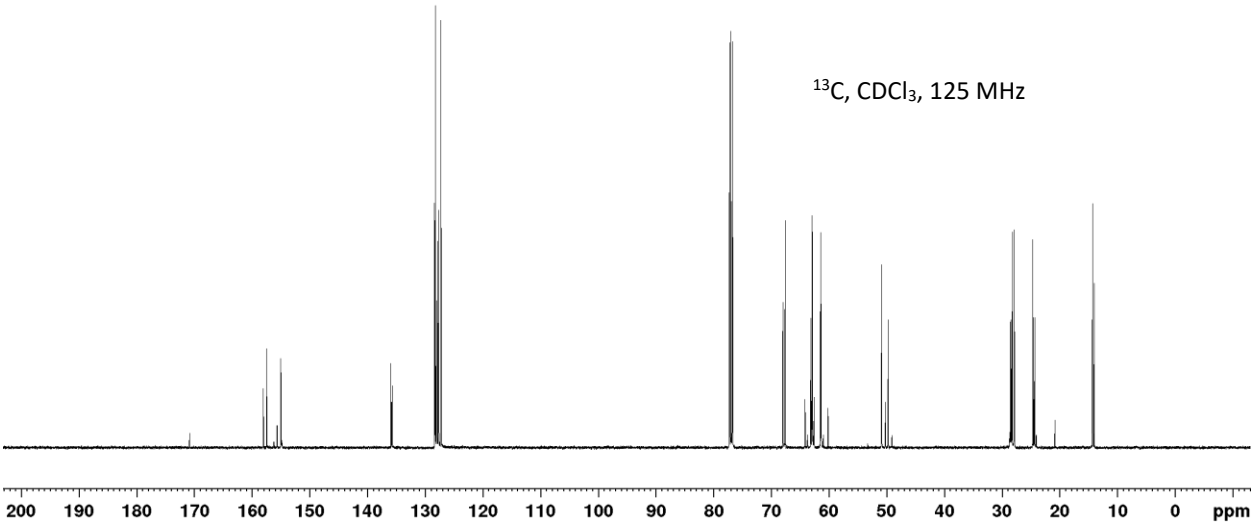


^{13}C, $CDCl_3$, 125 MHz


7.26
4.93
4.19
4.18
4.16
4.15
3.73
3.71
3.49
3.37
3.36
3.35
3.34
3.33
3.32
3.03
1.80
1.76
1.63
1.61
1.30
1.28
1.27
1.26
1.24
1.24
1.22
1.22
1.20
OH
NH
N
CO2Et
1H, CDCl3, 500 MHz
10 9 8 7 6 5 4 3 2 1 0 -1 ppm
0.62
2.00
1.02
1.76
1.92
1.02
5.15
3.98
157.72
156.73
77.23
76.98
76.72
63.97
61.78
61.36
49.17
30.73
28.12
27.43
23.68
14.43
13C, CDCl3, 125 MHz
200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 ppm

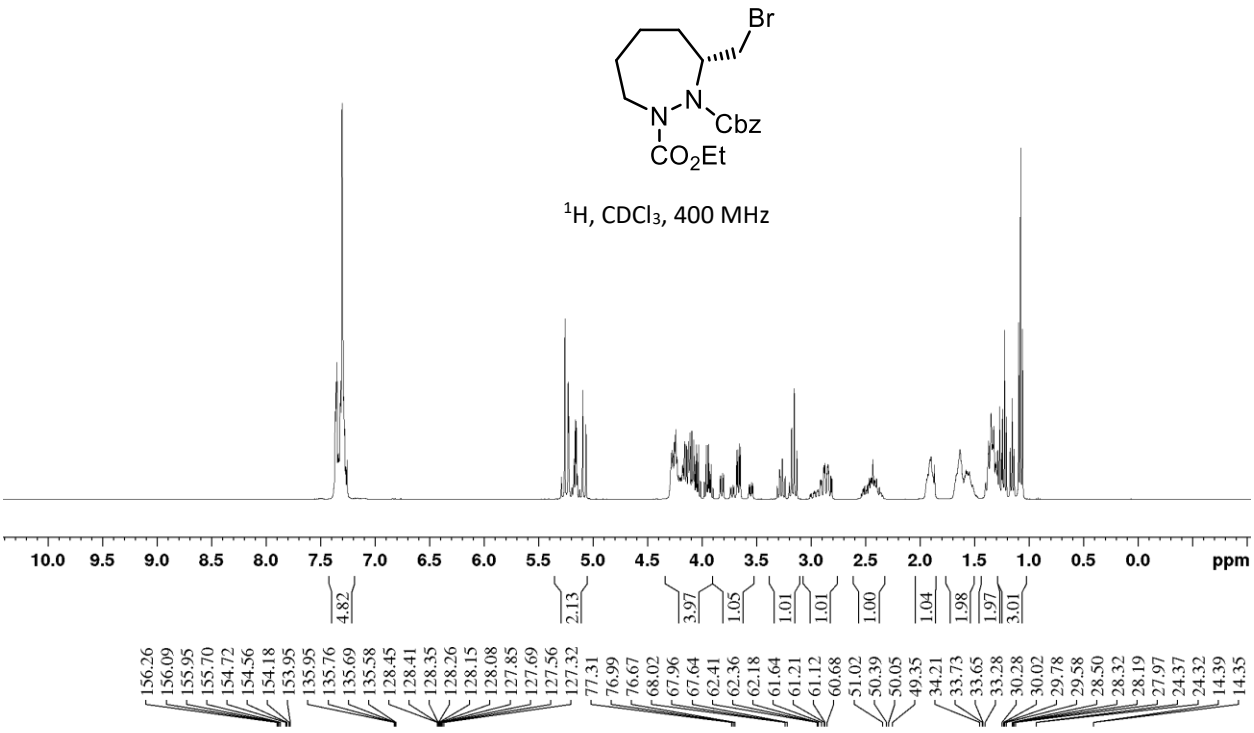


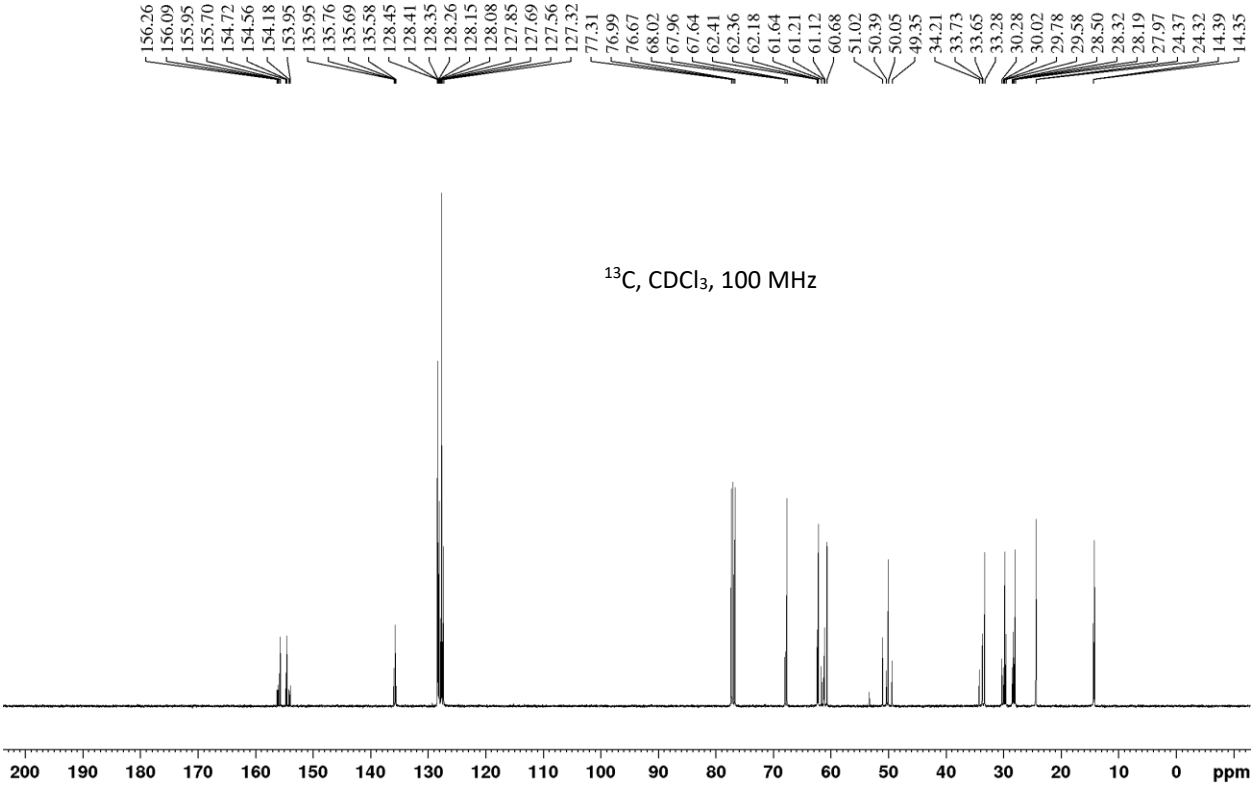
^{1}H, $CDCl_3$, 500 MHz

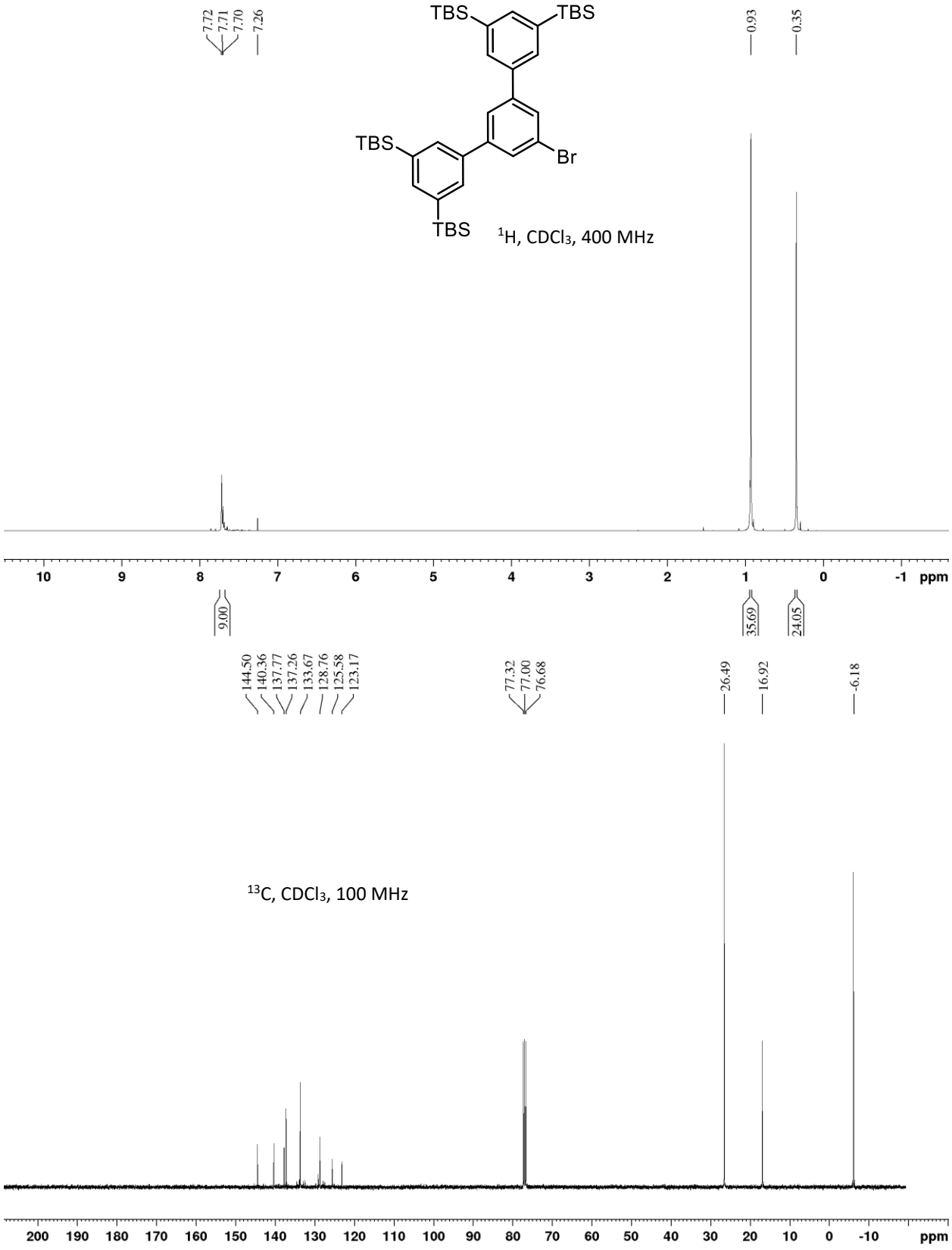


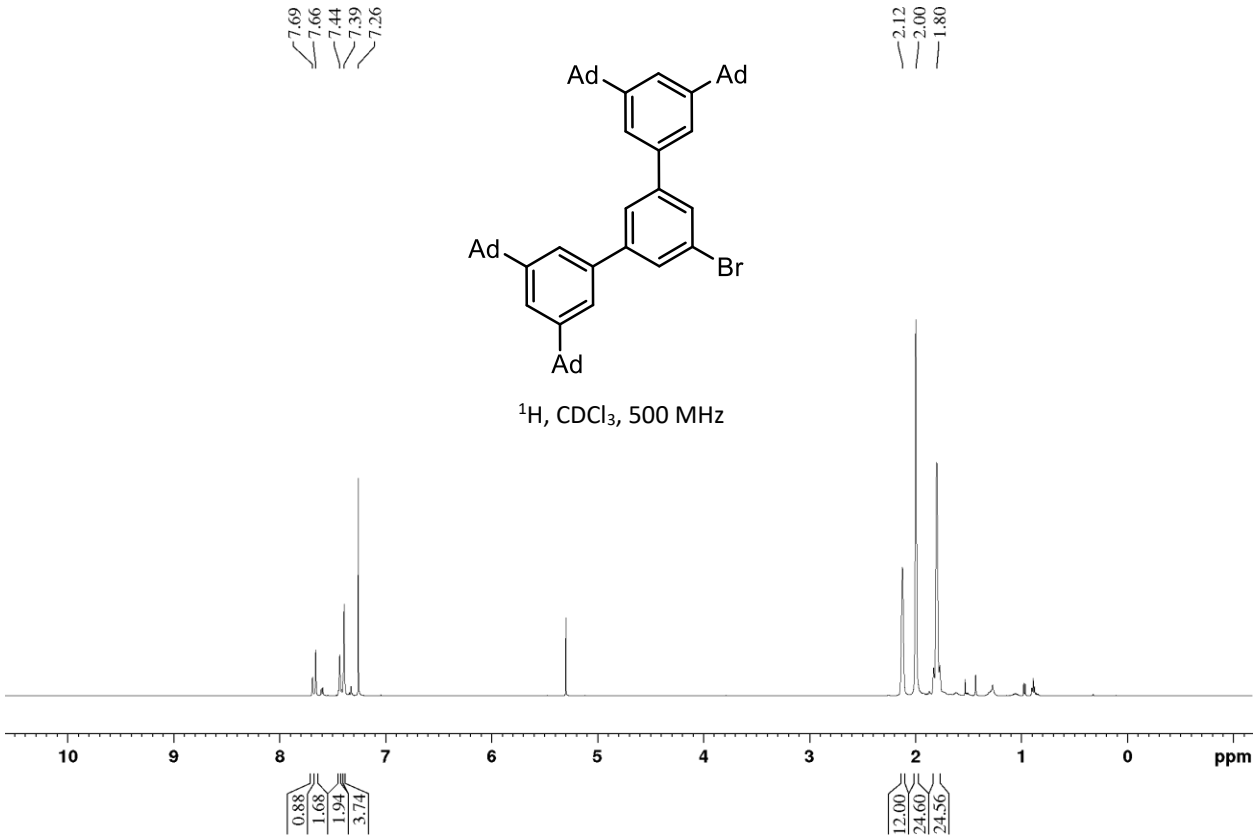
^{13}C, $CDCl_3$, 125 MHz


7.37 7.36 7.35 7.34 7.32 7.32 7.32 7.31 7.30 7.29 7.29 7.28 5.26 5.23 5.22 5.16 5.16 5.10 5.07 4.28 4.27 4.27 4.26 4.25 4.24 4.16 4.15 4.14 4.13 4.11 4.10 4.08 4.05 4.03 3.96 3.95 3.68 3.67 3.66 3.65 3.18 3.16 3.13 1.64 1.38 1.37 1.35 1.34 1.32 1.29 1.27 1.25 1.24 1.23 1.21 1.17 1.16 1.14 1.10 1.08 1.06

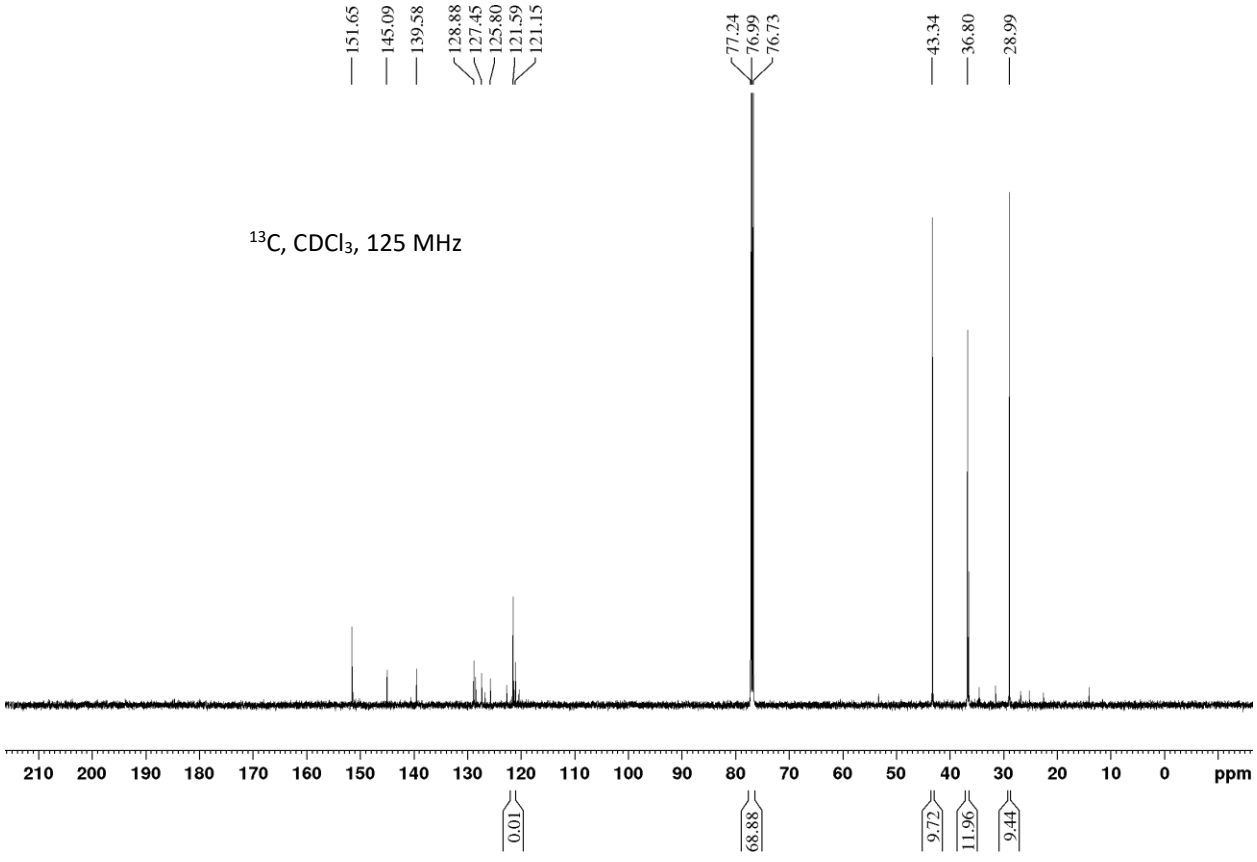

Br
N
N
Cbz
CO2Et
1H, CDCl3, 400 MHz
10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 ppm
4.82 2.13 3.97 1.05 1.01 1.01 1.00 1.04 1.98 1.97 3.01


156.26 156.09 155.95 155.70 154.72 154.56 154.18 153.95 135.95 135.76 135.69 135.58 128.45 128.41 128.35 128.26 128.15 128.08 127.85 127.69 127.56 127.32 77.31 76.99 76.67 68.02 67.96 67.64 62.41 62.36 62.18 61.64 61.21 61.12 60.68 51.02 50.39 50.05 49.35 34.21 33.73 33.65 33.28 30.28 30.02 29.78 29.58 28.50 28.32 28.19 27.97 24.37 24.32 14.39 14.35
13C, CDCl3, 100 MHz
200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 ppm

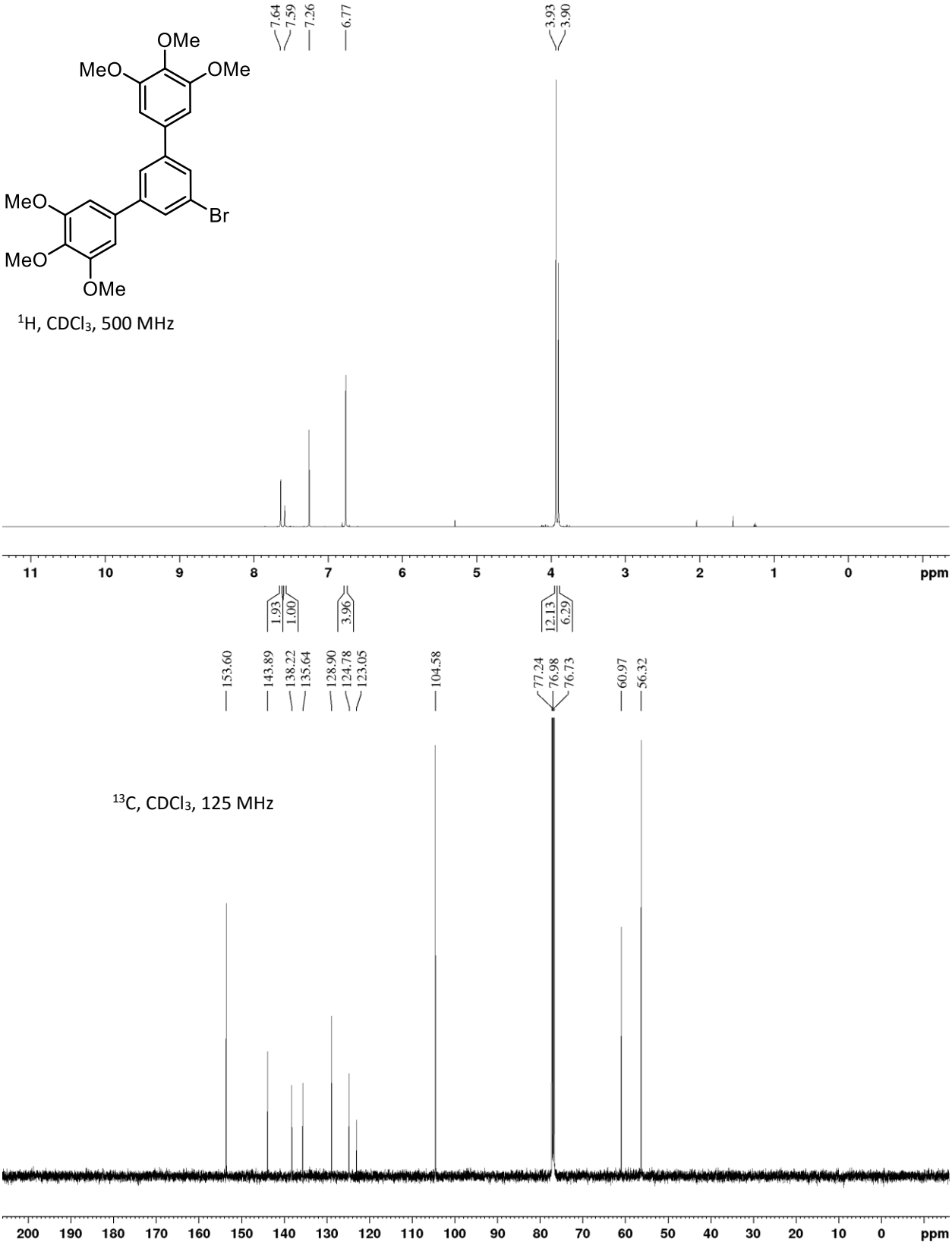

7.72
7.71
7.70
7.26
TBS
TBS
TBS
TBS
Br
0.93
0.35
^{1}H, CDCl$_3$, 400 MHz
10 9 8 7 6 5 4 3 2 1 0 -1 ppm
9.00
35.69
24.05
144.50
140.36
137.77
137.26
133.67
128.76
125.58
123.17
77.32
77.00
76.68
26.49
16.92
-6.18
^{13}C, CDCl$_3$, 100 MHz
200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10 ppm

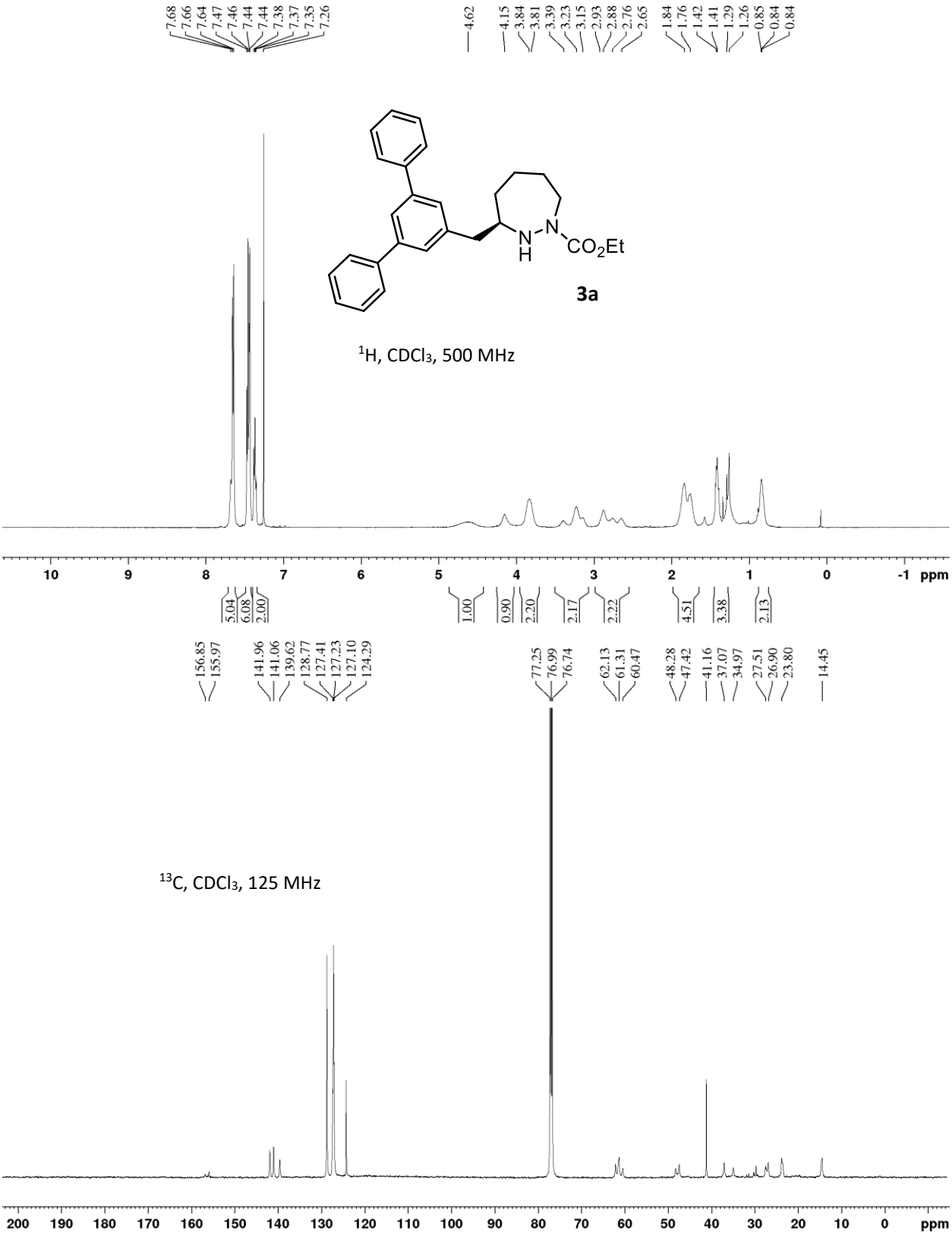


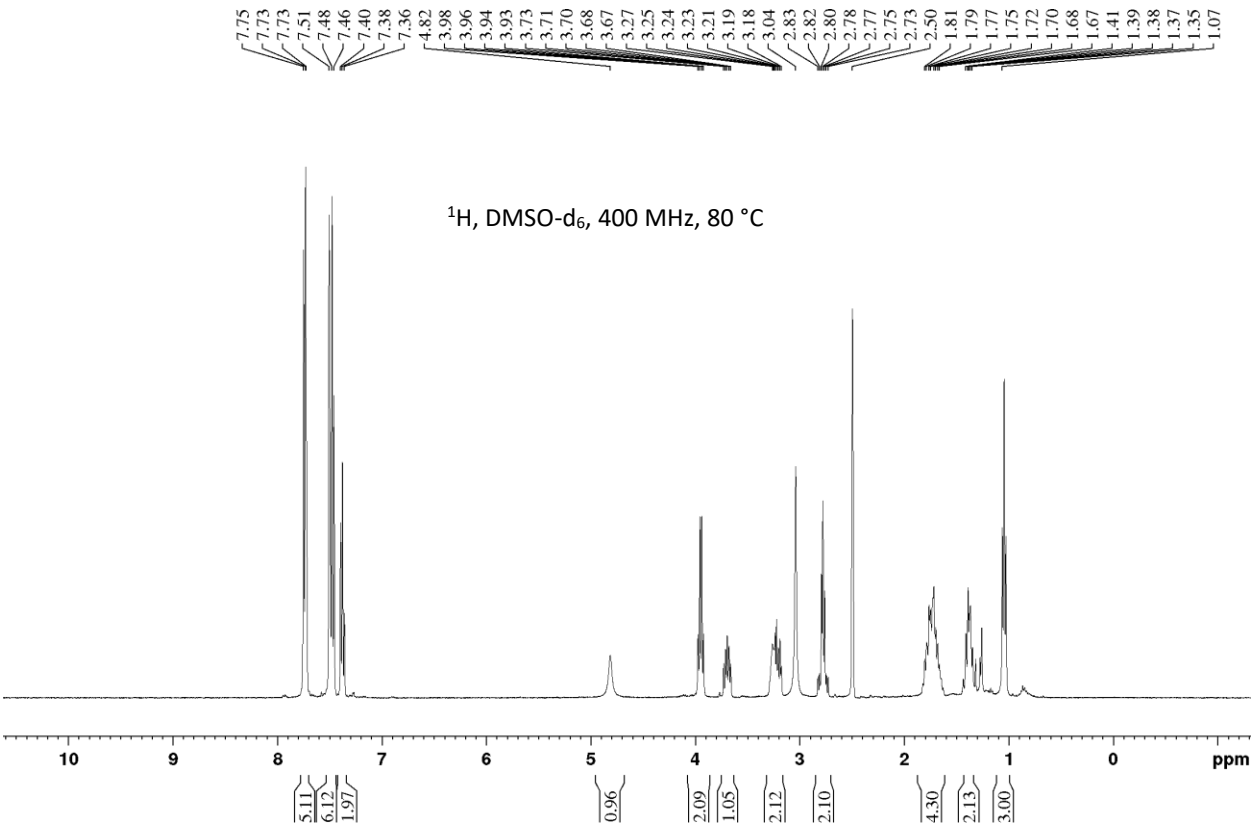
^{1}H, $CDCl_3$, 500 MHz



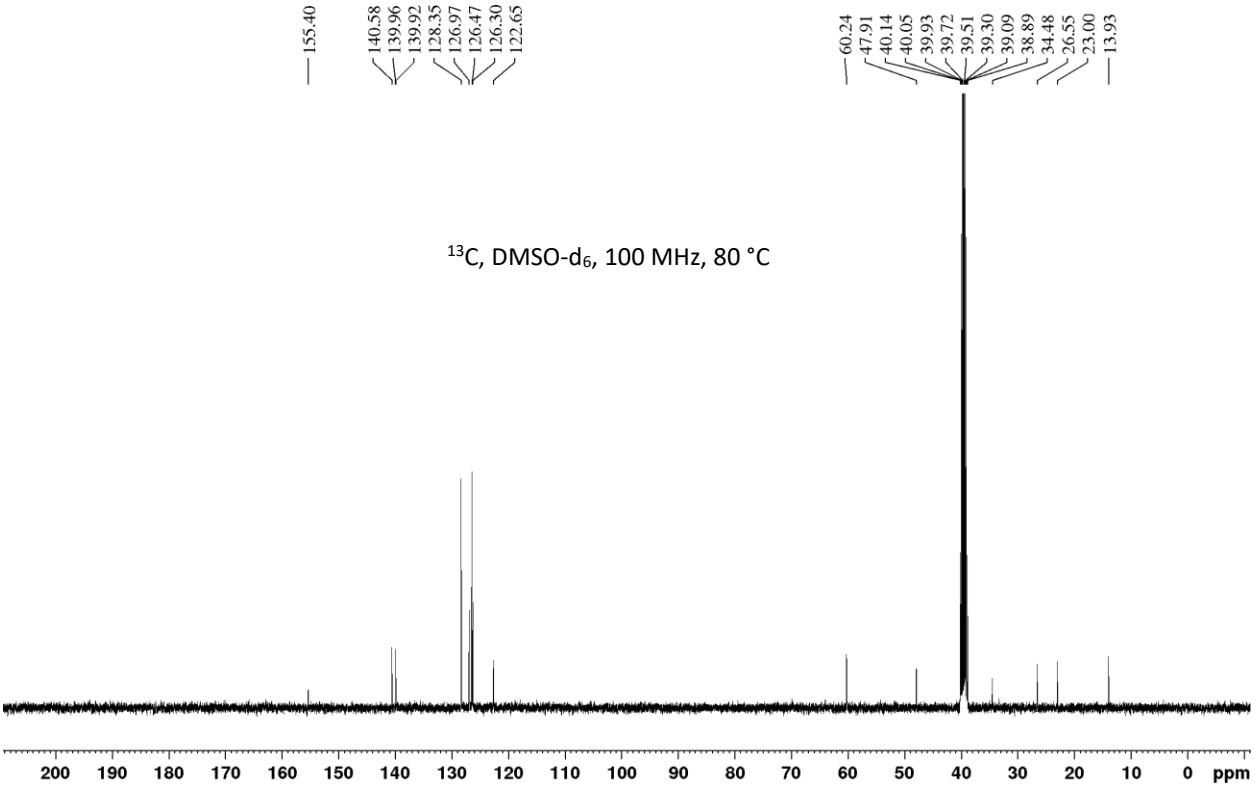
^{13}C, $CDCl_3$, 125 MHz


OMe
MeO
OMe
MeO
Br
MeO
OMe
7.64
7.59
7.26
6.77
3.93
3.90
1H, CDCl3, 500 MHz
11 10 9 8 7 6 5 4 3 2 1 0 ppm
1.93
1.00
3.96
12.13
6.29
153.60
143.89
138.22
135.64
128.90
124.78
123.05
104.58
77.24
76.98
76.73
60.97
56.32
13C, CDCl3, 125 MHz
200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 ppm


7.68
7.66
7.64
7.47
7.46
7.44
7.44
7.38
7.37
7.35
7.26
4.62
4.15
3.84
3.81
3.39
3.23
3.15
2.93
2.88
2.76
2.65
1.84
1.76
1.42
1.41
1.29
1.26
0.85
0.84
0.84
N
N
H
CO2Et
3a
1H, CDCl3, 500 MHz
10
9
8
7
6
5
4
3
2
1
0
-1 ppm
5.04
6.08
2.00
1.00
0.90
2.20
2.17
2.22
4.51
3.38
2.13
156.85
155.97
141.96
141.06
139.62
128.77
127.41
127.23
127.10
124.29
77.25
76.99
76.74
62.13
61.31
60.47
48.28
47.42
41.16
37.07
34.97
27.51
26.90
23.80
14.45
13C, CDCl3, 125 MHz
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
ppm

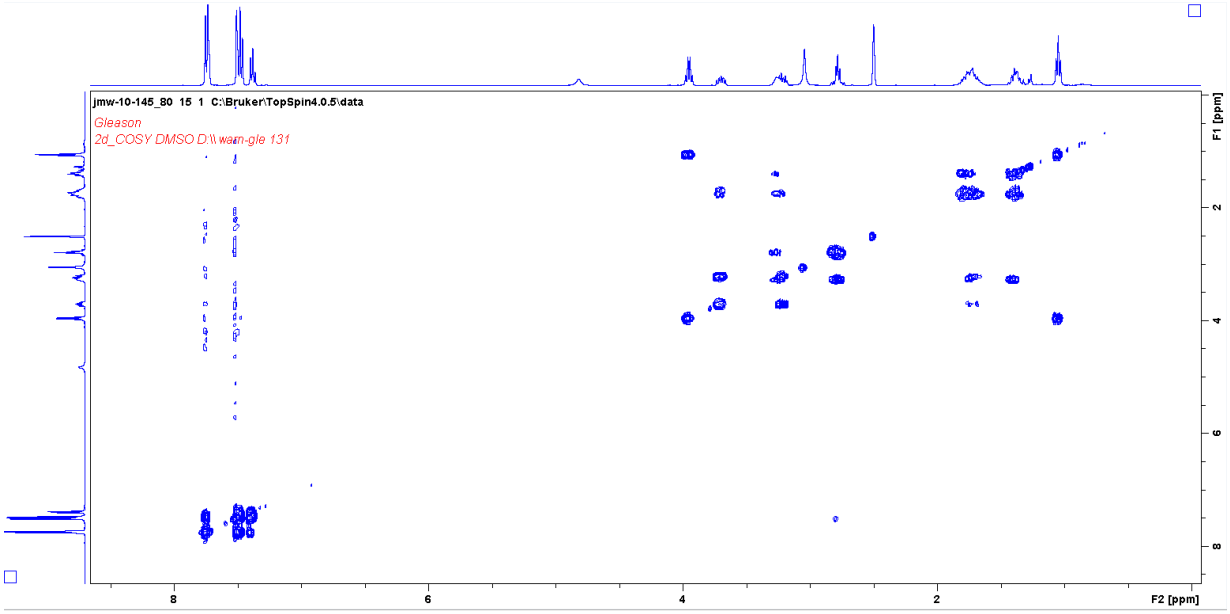


^{1}H, DMSO-d$_6$, 400 MHz, 80 °C

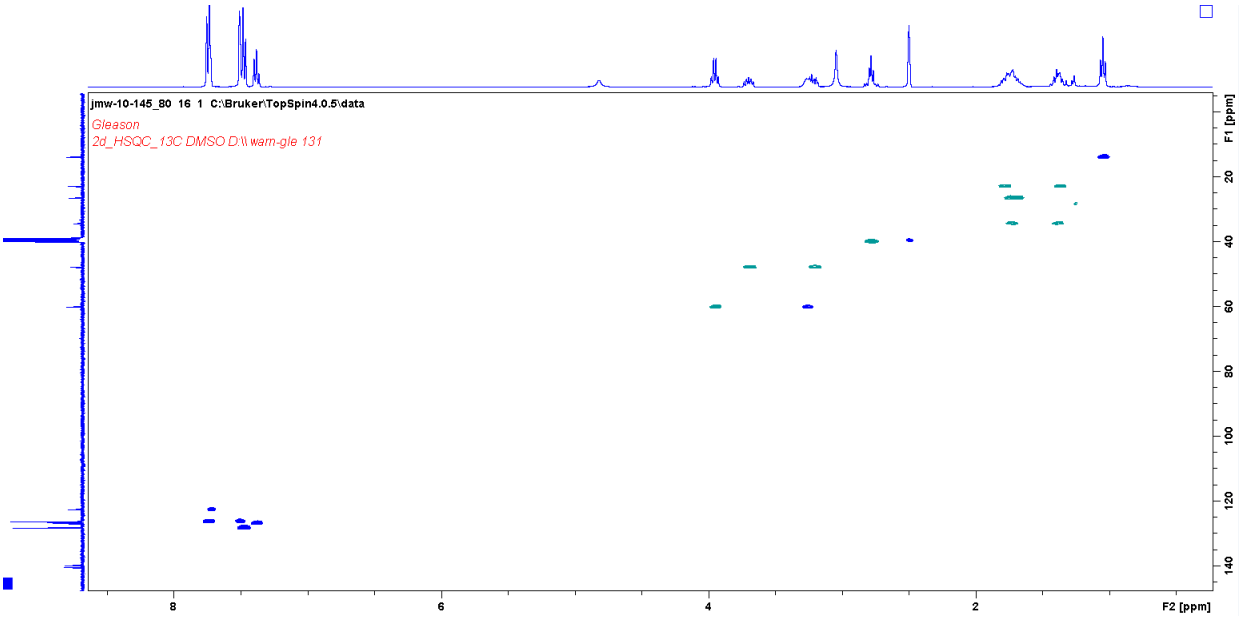


^{13}C, DMSO-d$_6$, 100 MHz, 80 °C

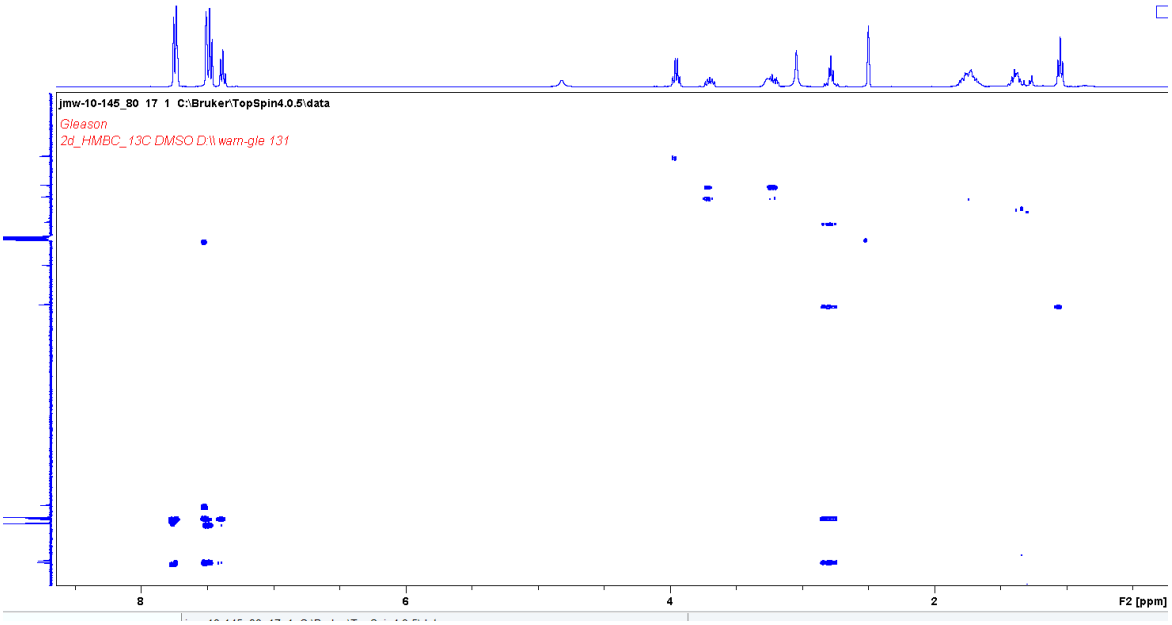
COSY, DMSO-d_6, 80 °C

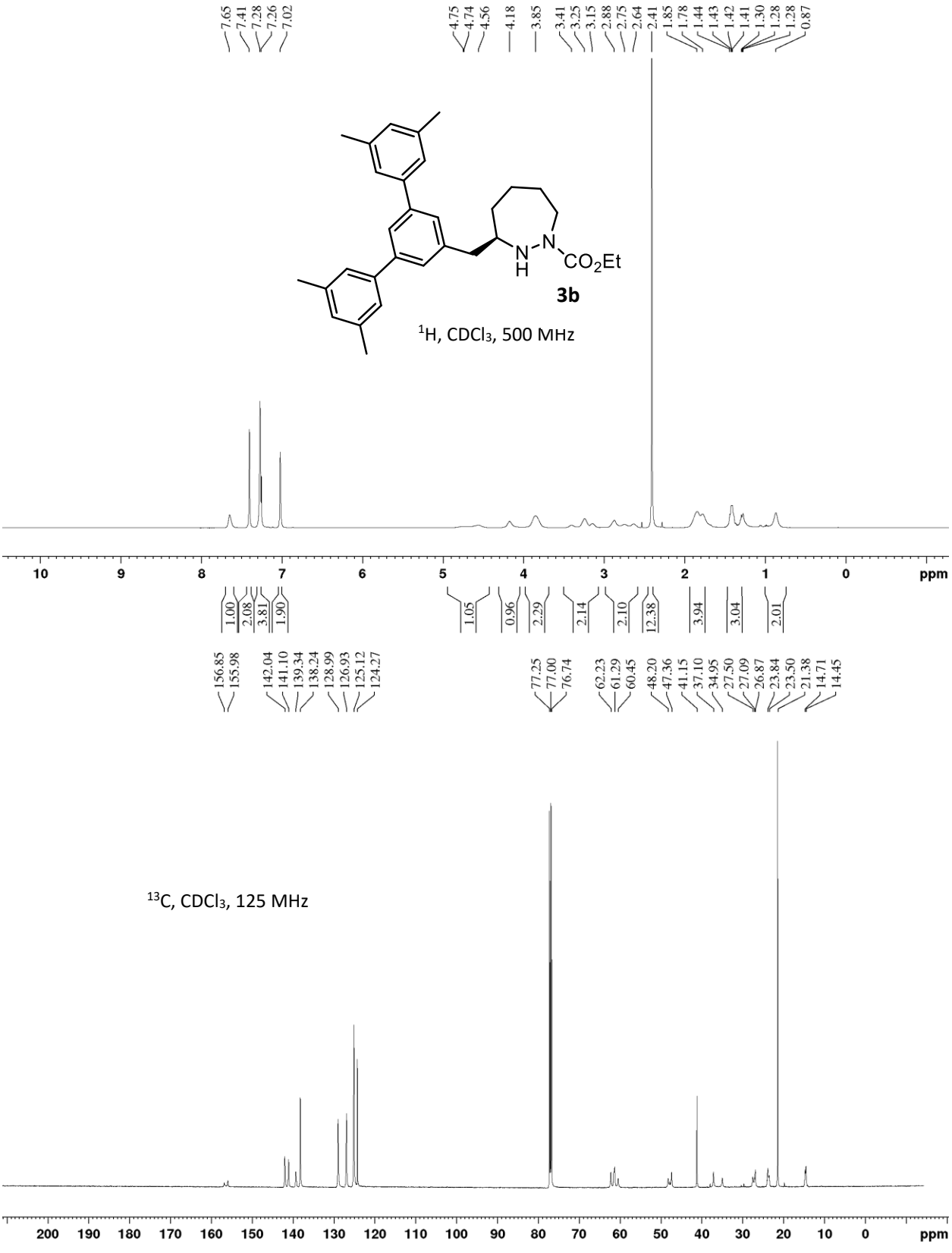


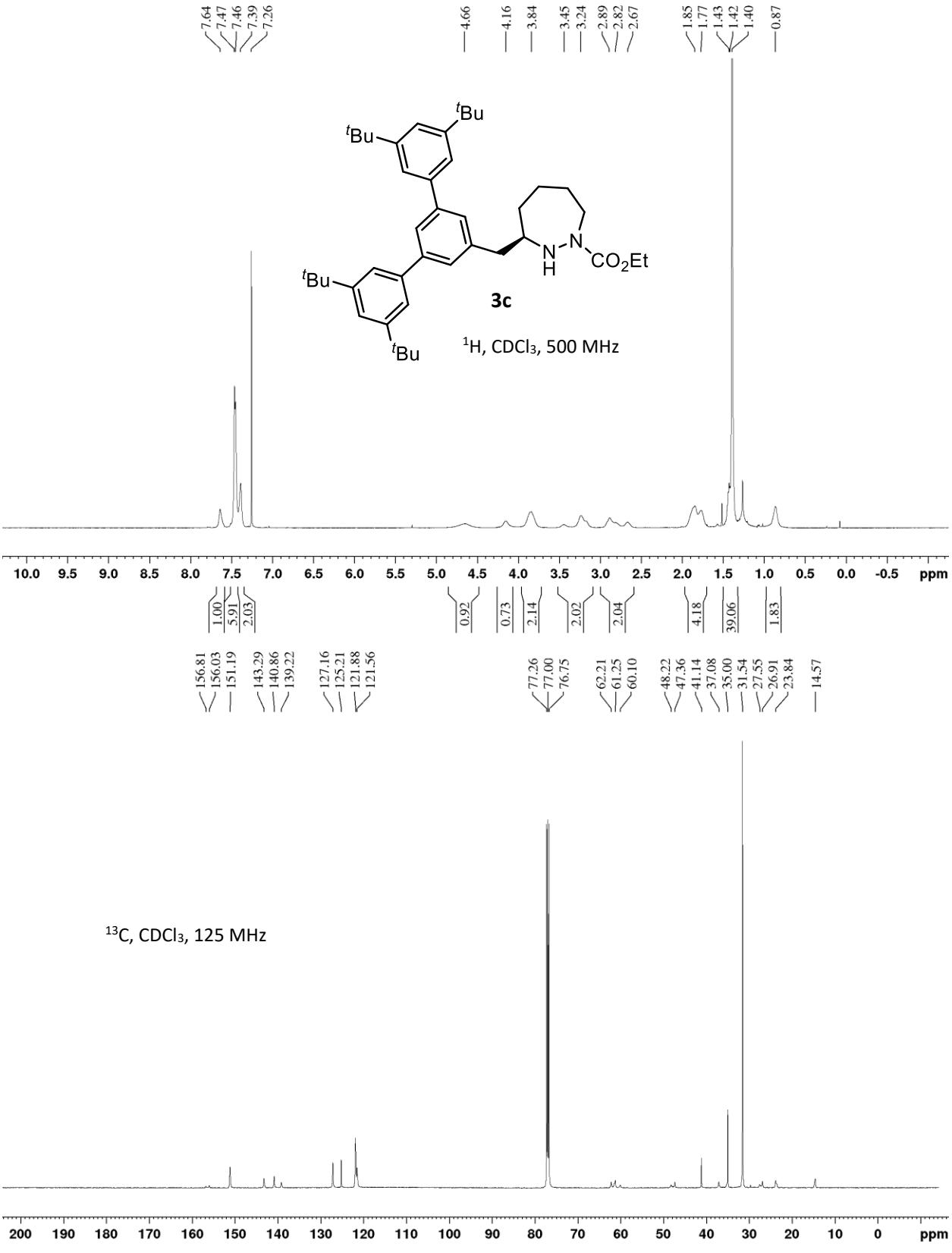
HSQC, DMSO-d_6, 80 °C

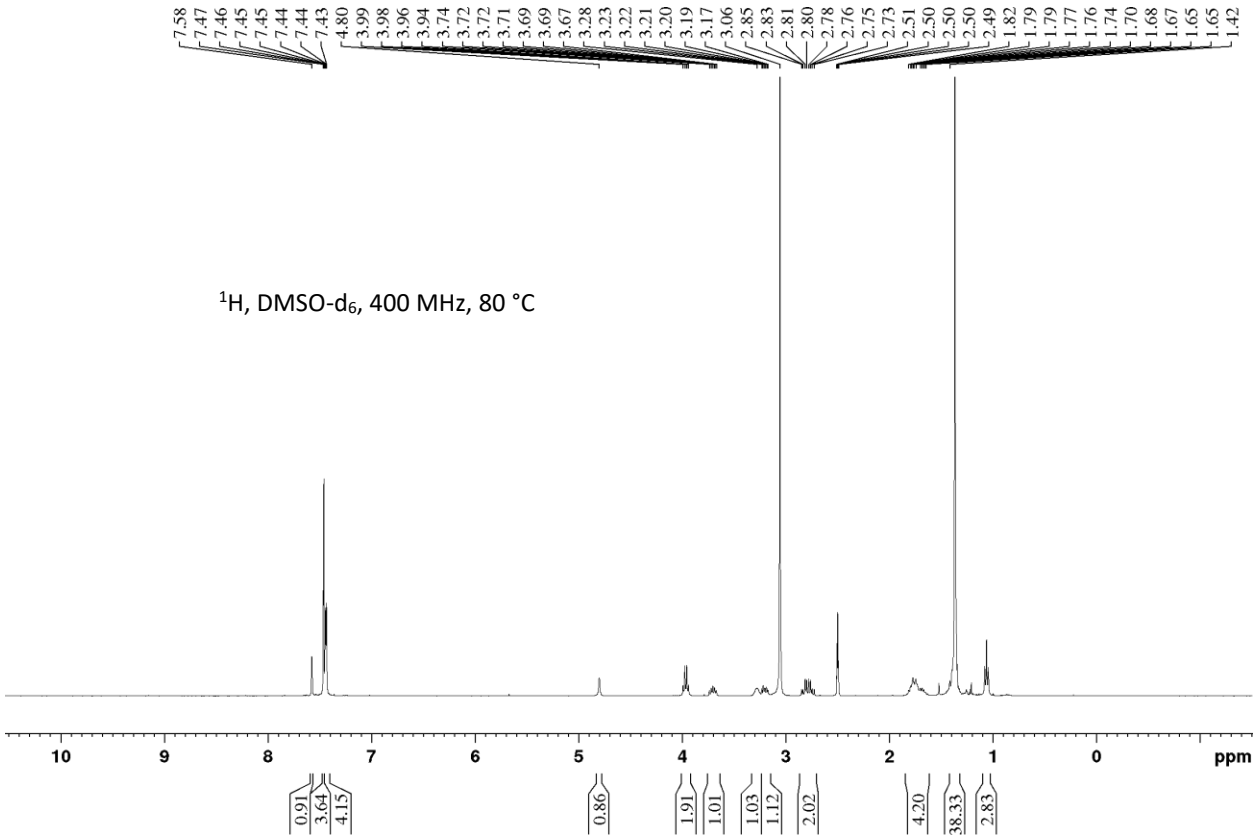


HMBC, DMSO-d_6, 80 °C

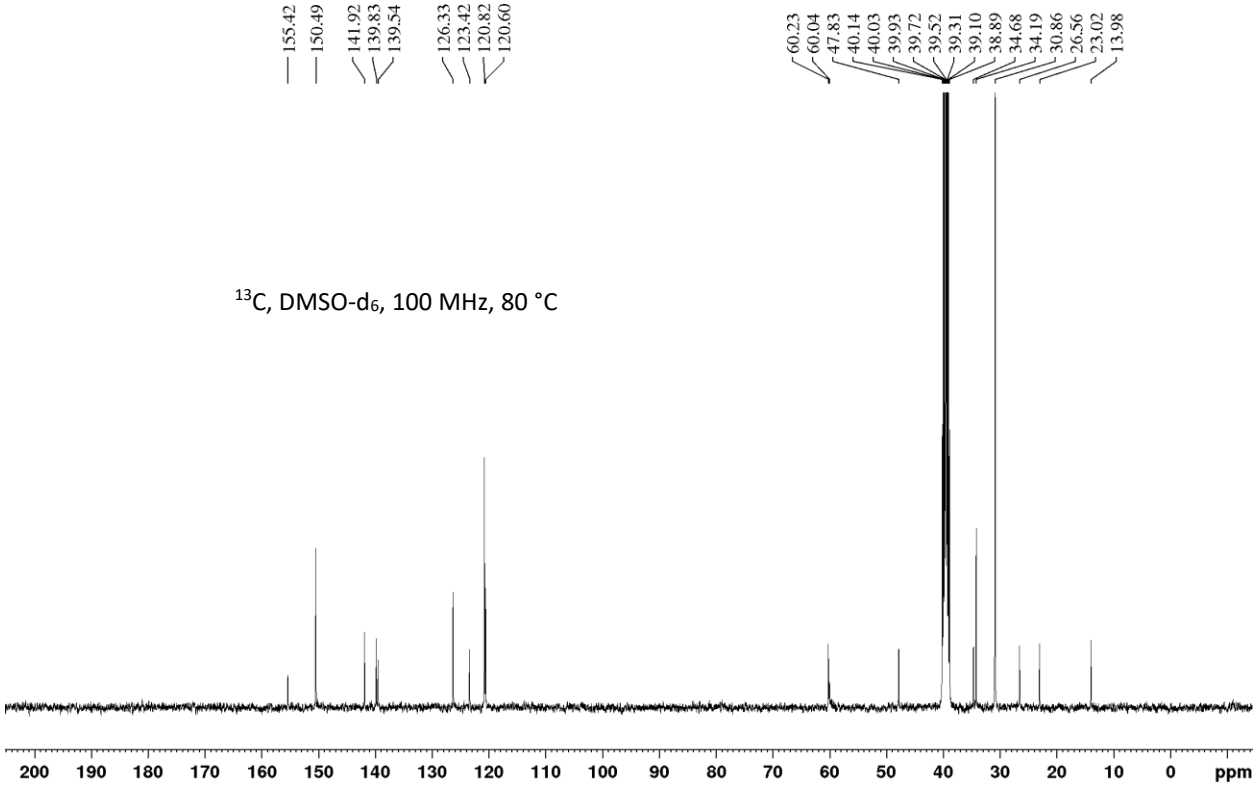



7.65
7.41
7.28
7.26
7.02
4.75
4.74
4.56
4.18
3.85
3.41
3.25
3.15
2.88
2.75
2.64
2.41
1.85
1.78
1.44
1.43
1.42
1.41
1.30
1.28
1.28
0.87
N
N
H
CO2Et
3b
1H, CDCl3, 500 MHz
10
9
8
7
6
5
4
3
2
1
0
ppm
1.00
2.08
3.81
1.90
1.05
0.96
2.29
2.14
2.10
12.38
3.94
3.04
2.01
156.85
155.98
142.04
141.10
139.34
138.24
128.99
126.93
125.12
124.27
77.25
77.00
76.74
62.23
61.29
60.45
48.20
47.36
41.15
37.10
34.95
27.50
27.09
26.87
23.84
23.50
21.38
14.71
14.45
13C, CDCl3, 125 MHz
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
ppm

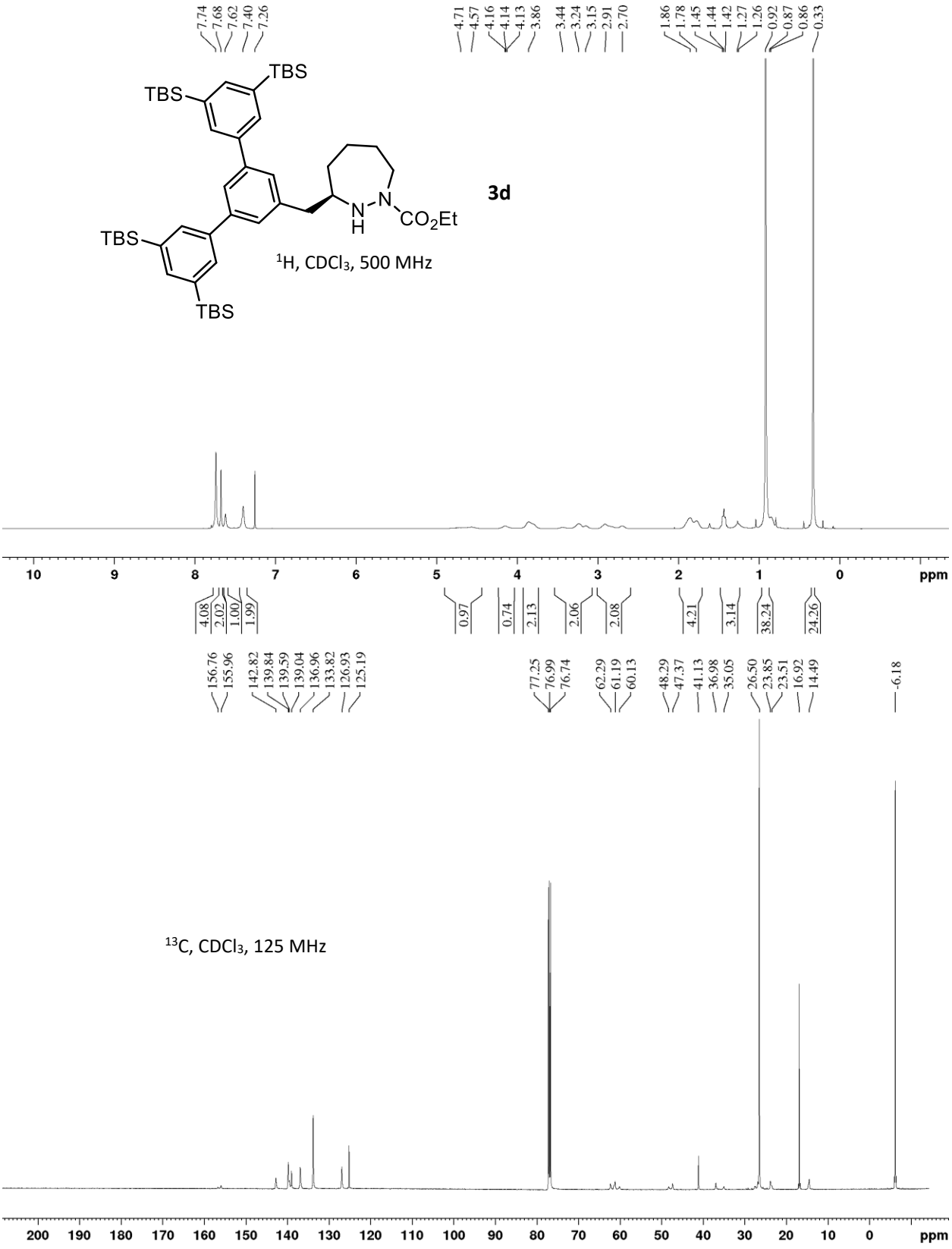

7.64
7.47
7.46
7.39
7.26
4.66
4.16
3.84
3.45
3.24
2.89
2.82
2.67
1.85
1.77
1.43
1.42
1.40
0.87
tBu
tBu
tBu
tBu
N
N
H
CO2Et
3c
1H, CDCl3, 500 MHz
10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5 ppm
1.00
5.91
2.03
0.92
0.73
2.14
2.02
2.04
4.18
39.06
1.83
156.81
156.03
151.19
143.29
140.86
139.22
127.16
125.21
121.88
121.56
77.26
77.00
76.75
62.21
61.25
60.10
48.22
47.36
41.14
37.08
35.00
31.54
27.55
26.91
23.84
14.57
13C, CDCl3, 125 MHz
200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 ppm

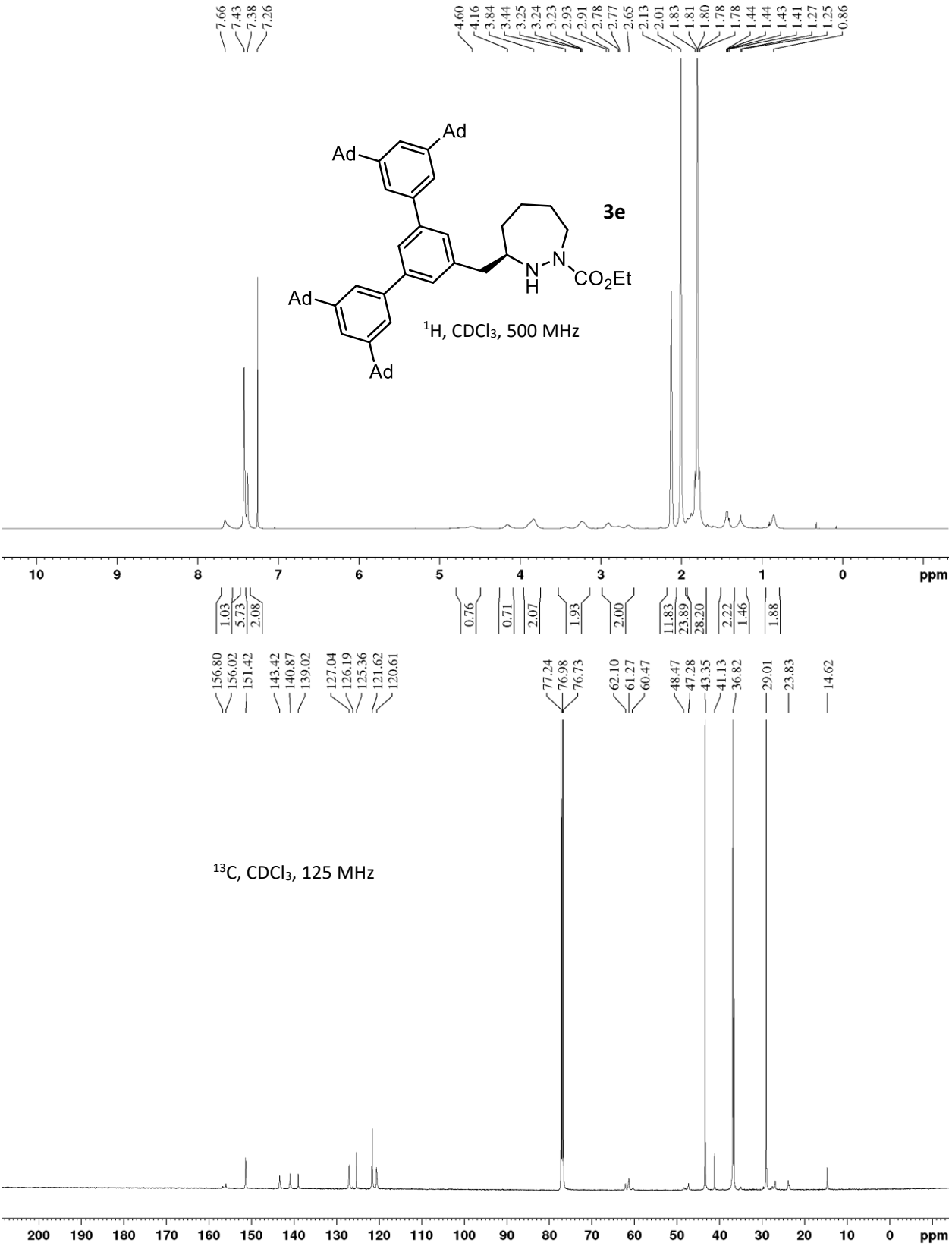


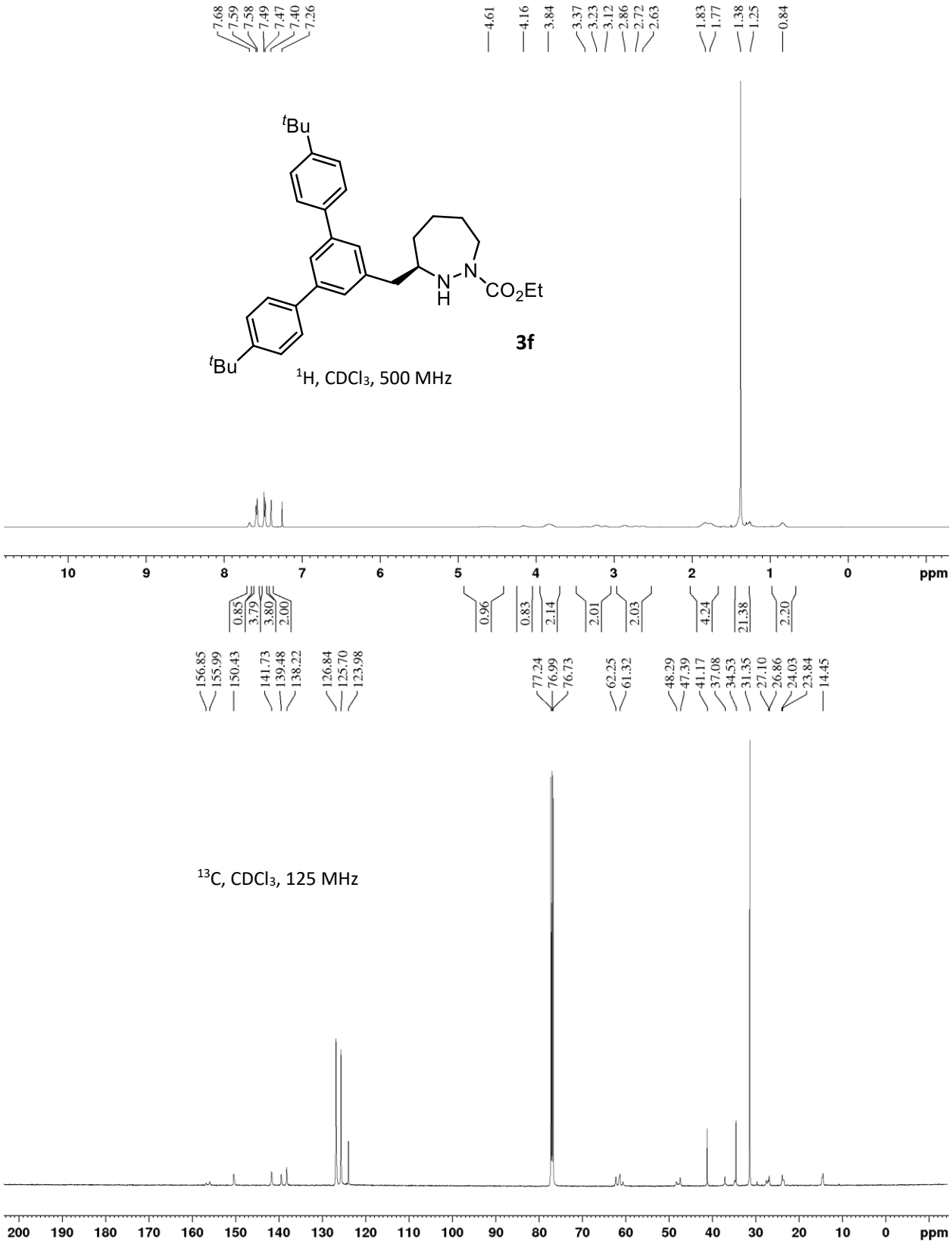
^{1}H, DMSO-d$_6$, 400 MHz, 80 °C

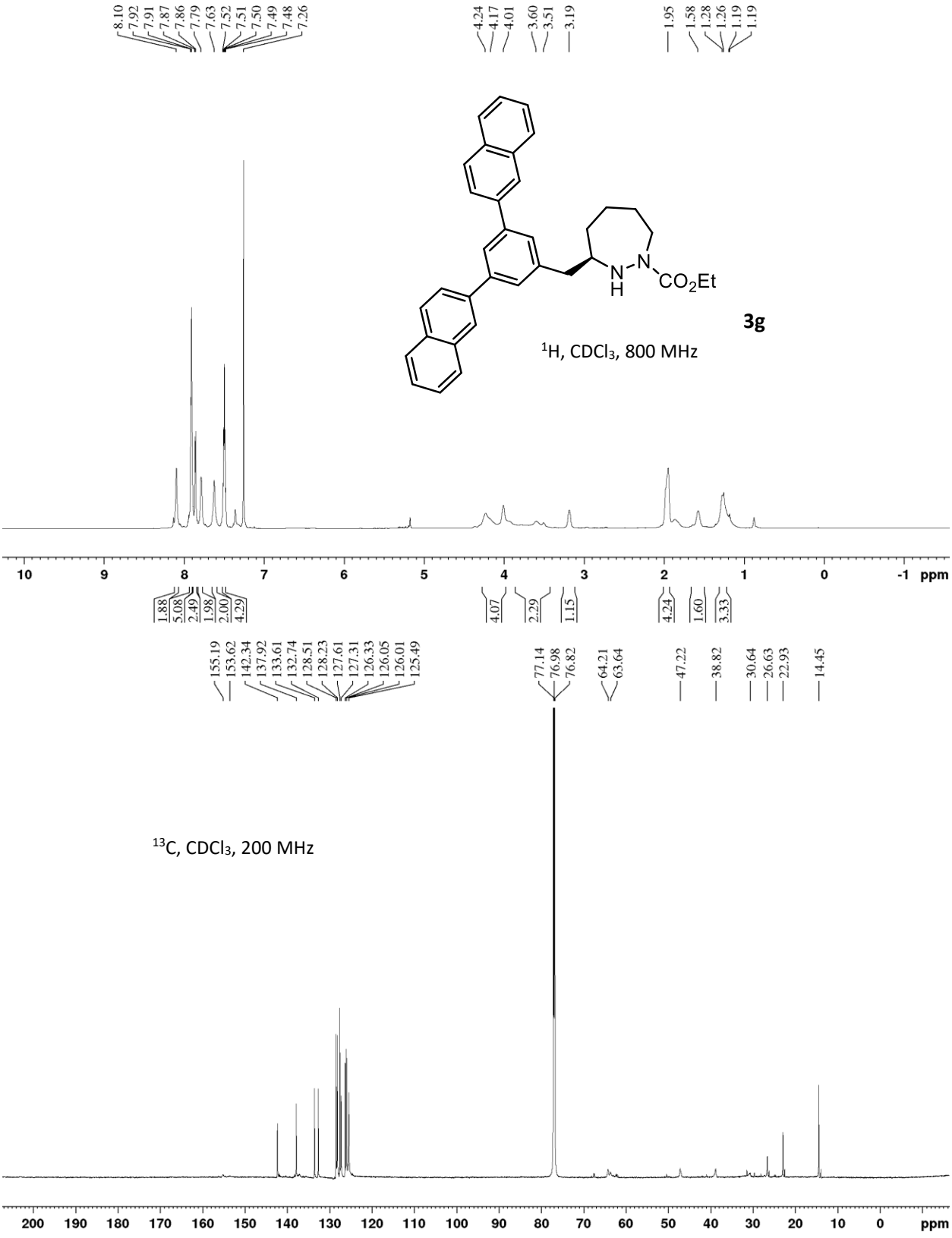


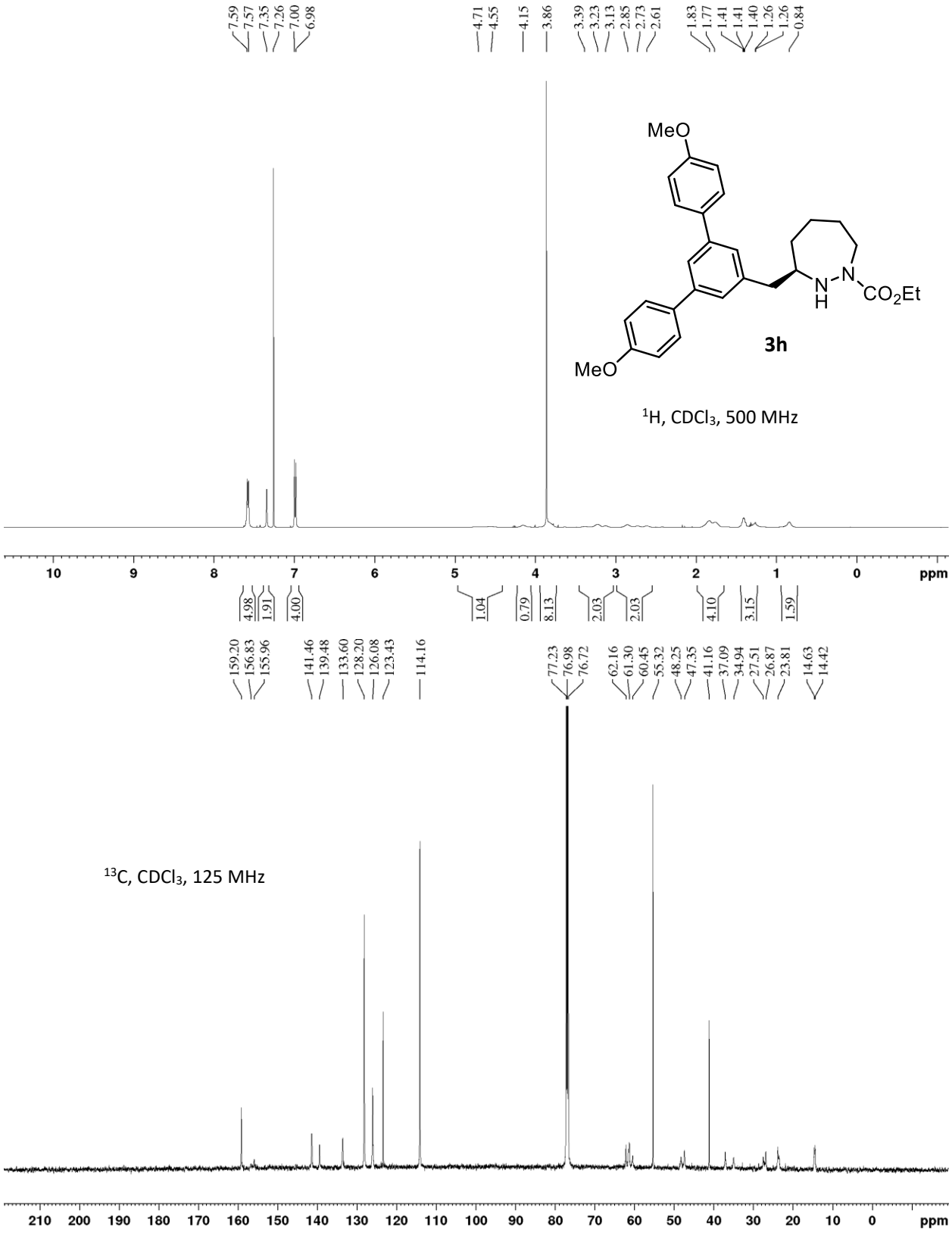
^{13}C, DMSO-d$_6$, 100 MHz, 80 °C

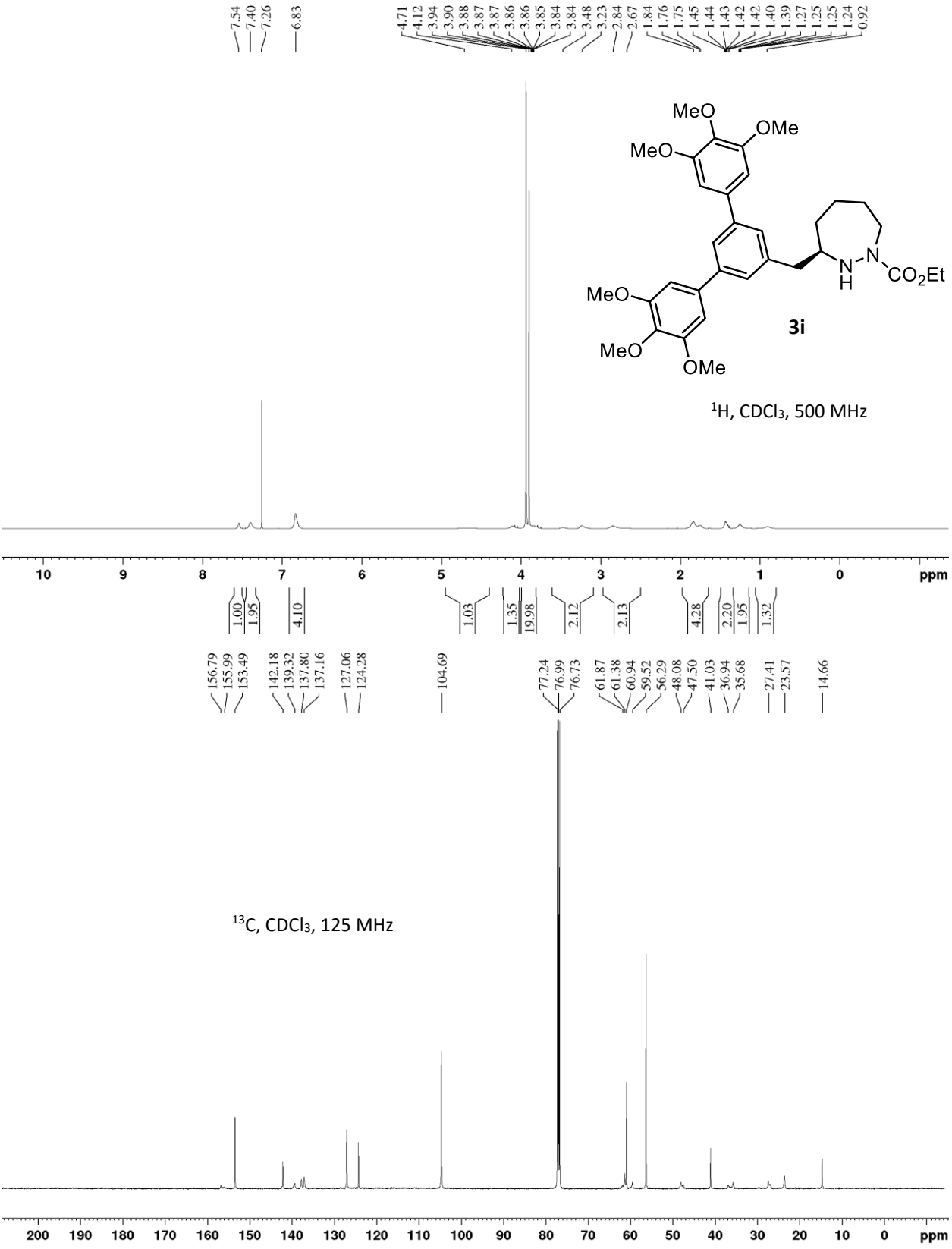

7.74
7.68
7.62
7.40
7.26
4.71
4.57
4.16
4.14
4.13
3.86
3.44
3.24
3.15
2.91
2.70
1.86
1.78
1.45
1.44
1.42
1.27
1.26
0.92
0.87
0.86
0.33
TBS
TBS
TBS
TBS
N
N
H
CO2Et
3d
1H, CDCl3, 500 MHz
10
9
8
7
6
5
4
3
2
1
0
ppm
4.08
2.02
1.00
1.99
0.97
0.74
2.13
2.06
2.08
4.21
3.14
38.24
24.26
156.76
155.96
142.82
139.84
139.59
139.04
136.96
133.82
126.93
125.19
77.25
76.99
76.74
62.29
61.19
60.13
48.29
47.37
41.13
36.98
35.05
26.50
23.85
23.51
16.92
14.49
-6.18
13C, CDCl3, 125 MHz
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
ppm

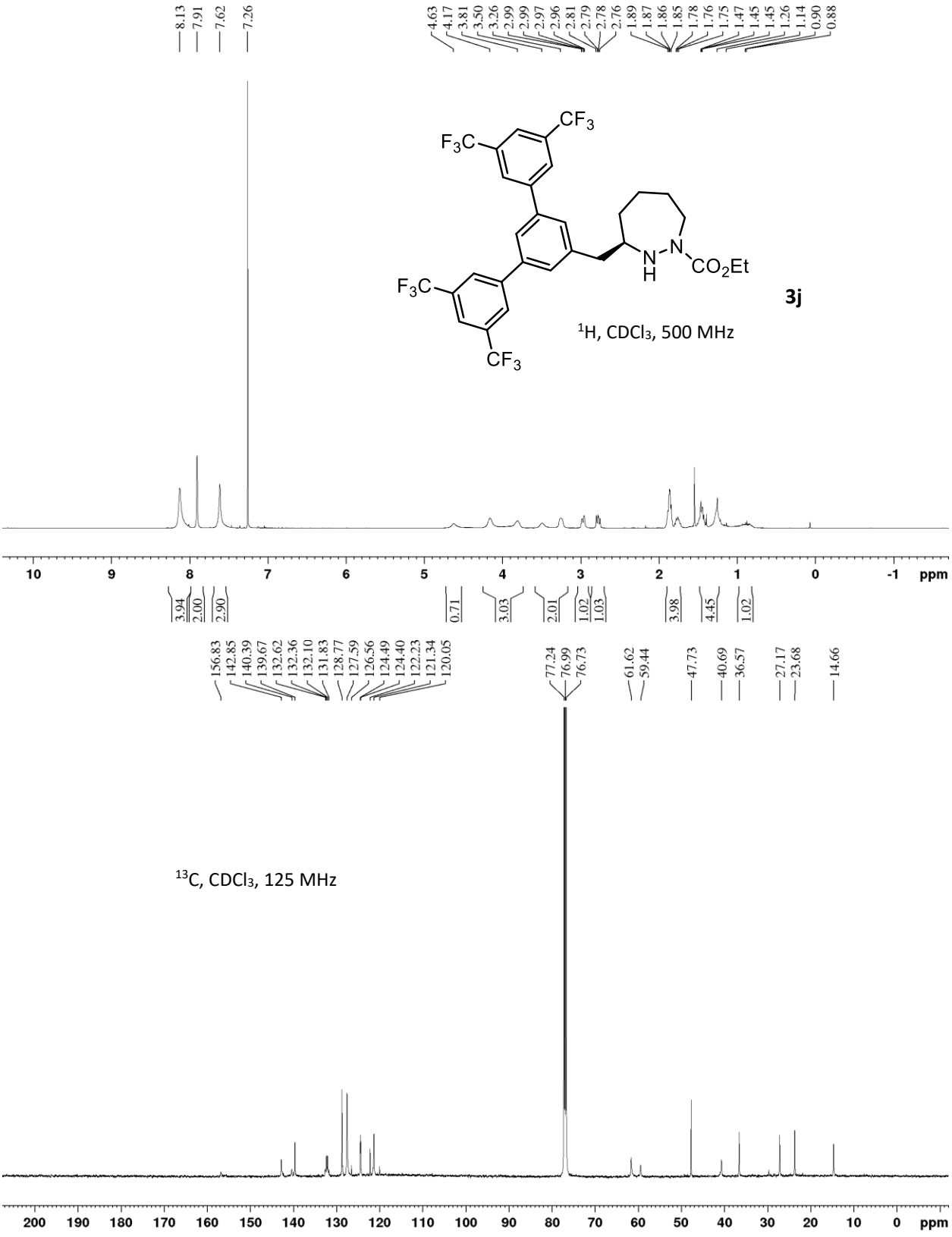

7.66
7.43
7.38
7.26
4.60
4.16
3.84
3.44
3.25
3.24
3.23
2.93
2.91
2.78
2.77
2.65
2.13
2.01
1.83
1.81
1.80
1.78
1.78
1.44
1.44
1.43
1.41
1.27
1.25
0.86
Ad
Ad
Ad
Ad
3e
N
N
H
CO2Et
1H, CDCl3, 500 MHz
10
9
8
7
6
5
4
3
2
1
0
ppm
1.03
5.73
2.08
0.76
0.71
2.07
1.93
2.00
11.83
23.89
28.20
2.22
1.46
1.88
156.80
156.02
151.42
143.42
140.87
139.02
127.04
126.19
125.36
121.62
120.61
77.24
76.98
76.73
62.10
61.27
60.47
48.47
47.28
43.35
41.13
36.82
29.01
23.83
14.62
13C, CDCl3, 125 MHz
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
ppm

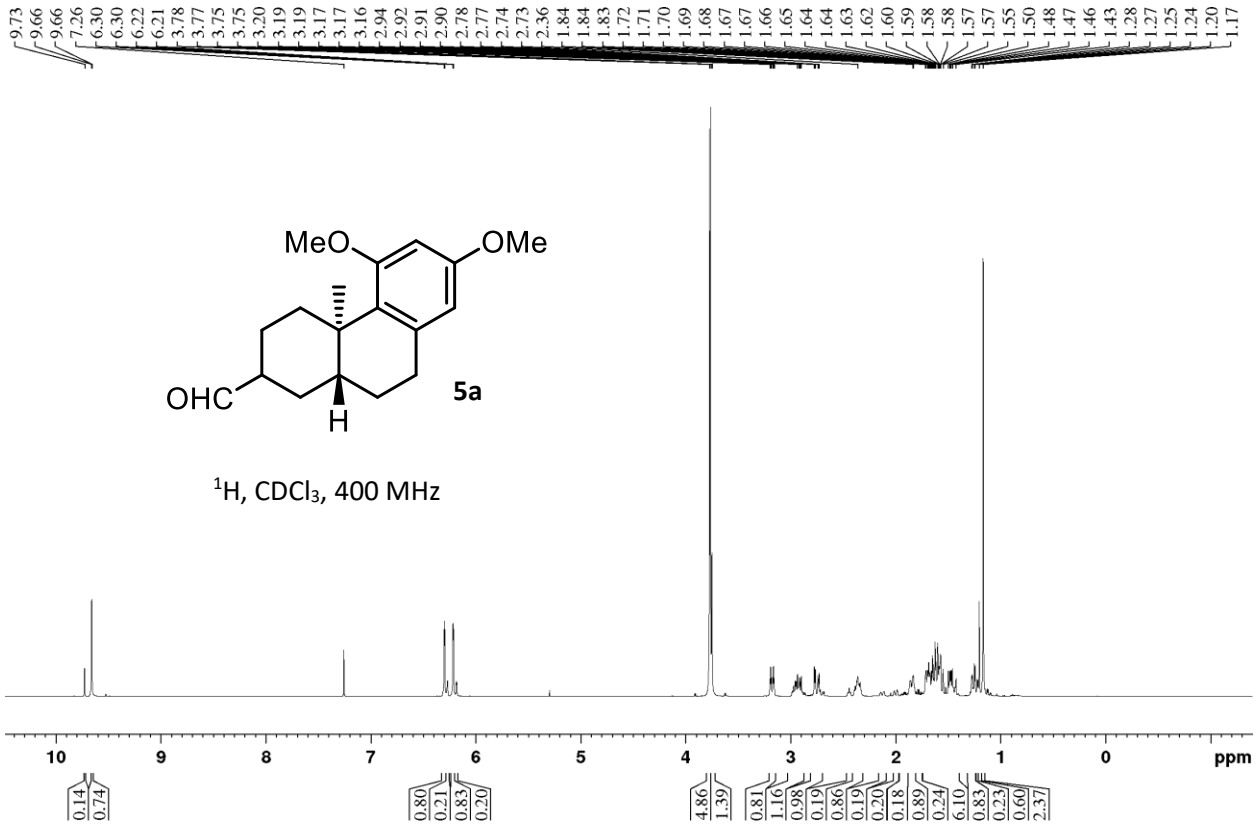

7.68
7.59
7.58
7.49
7.47
7.40
7.26
4.61
4.16
3.84
3.37
3.23
3.12
2.86
2.72
2.63
1.83
1.77
1.38
1.25
0.84
tBu
tBu
N
N
H
CO2Et
3f
1H, CDCl3, 500 MHz
10
9
8
7
6
5
4
3
2
1
0
ppm
0.85
3.79
3.80
2.00
0.96
0.83
2.14
2.01
2.03
4.24
21.38
2.20
156.85
155.99
150.43
141.73
139.48
138.22
126.84
125.70
123.98
77.24
76.99
76.73
62.25
61.32
48.29
47.39
41.17
37.08
34.53
31.35
27.10
26.86
24.03
23.84
14.45
13C, CDCl3, 125 MHz
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
ppm

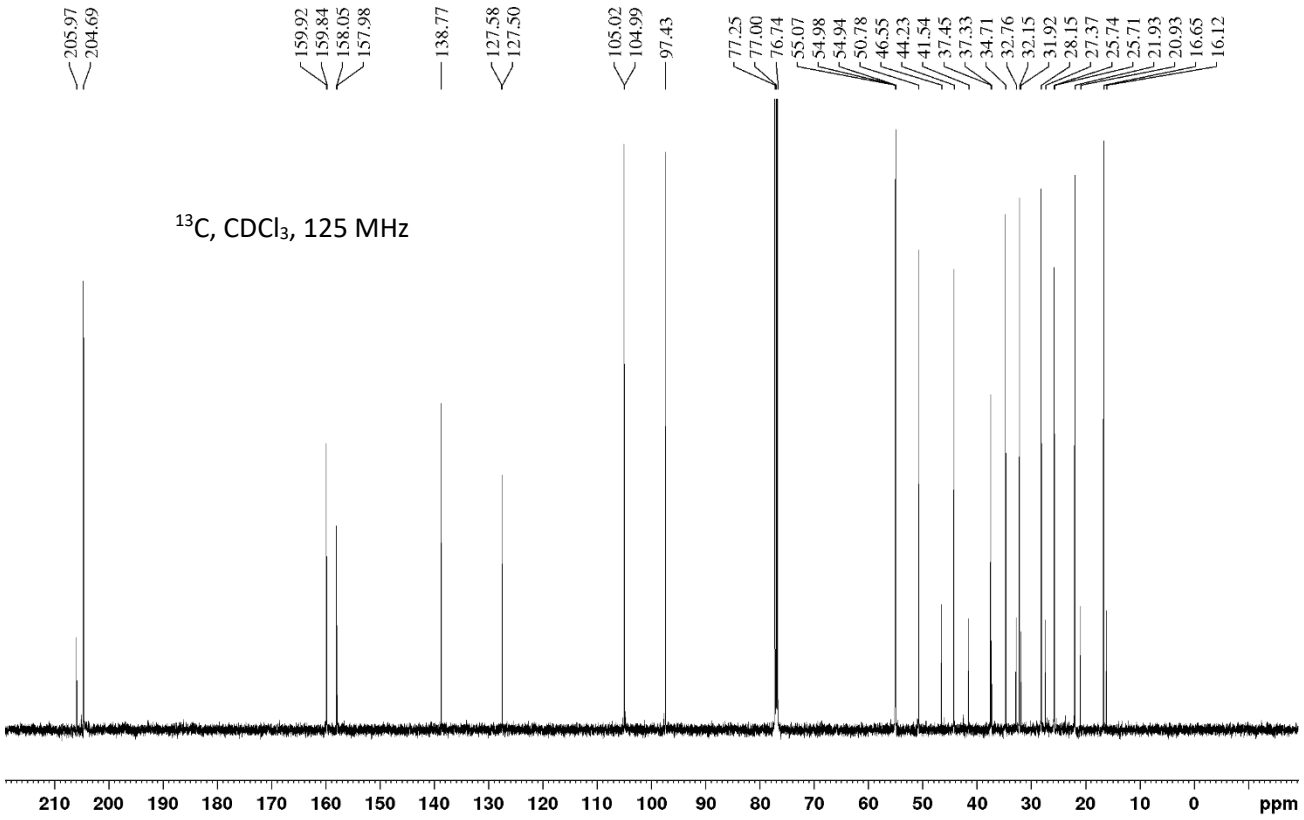

8.10
7.92
7.91
7.87
7.86
7.79
7.63
7.52
7.51
7.50
7.49
7.48
7.26
4.24
4.17
4.01
3.60
3.51
3.19
1.95
1.58
1.28
1.26
1.19
1.19
CO2Et
3g
1H, CDCl3, 800 MHz
10 9 8 7 6 5 4 3 2 1 0 -1 ppm
1.88
5.08
2.49
1.98
2.00
4.29
4.07
2.29
1.15
4.24
1.60
3.33
155.19
153.62
142.34
137.92
133.61
132.74
128.51
128.23
127.61
127.31
126.33
126.05
126.01
125.49
77.14
76.98
76.82
64.21
63.64
47.22
38.82
30.64
26.63
22.93
14.45
13C, CDCl3, 200 MHz
200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 ppm

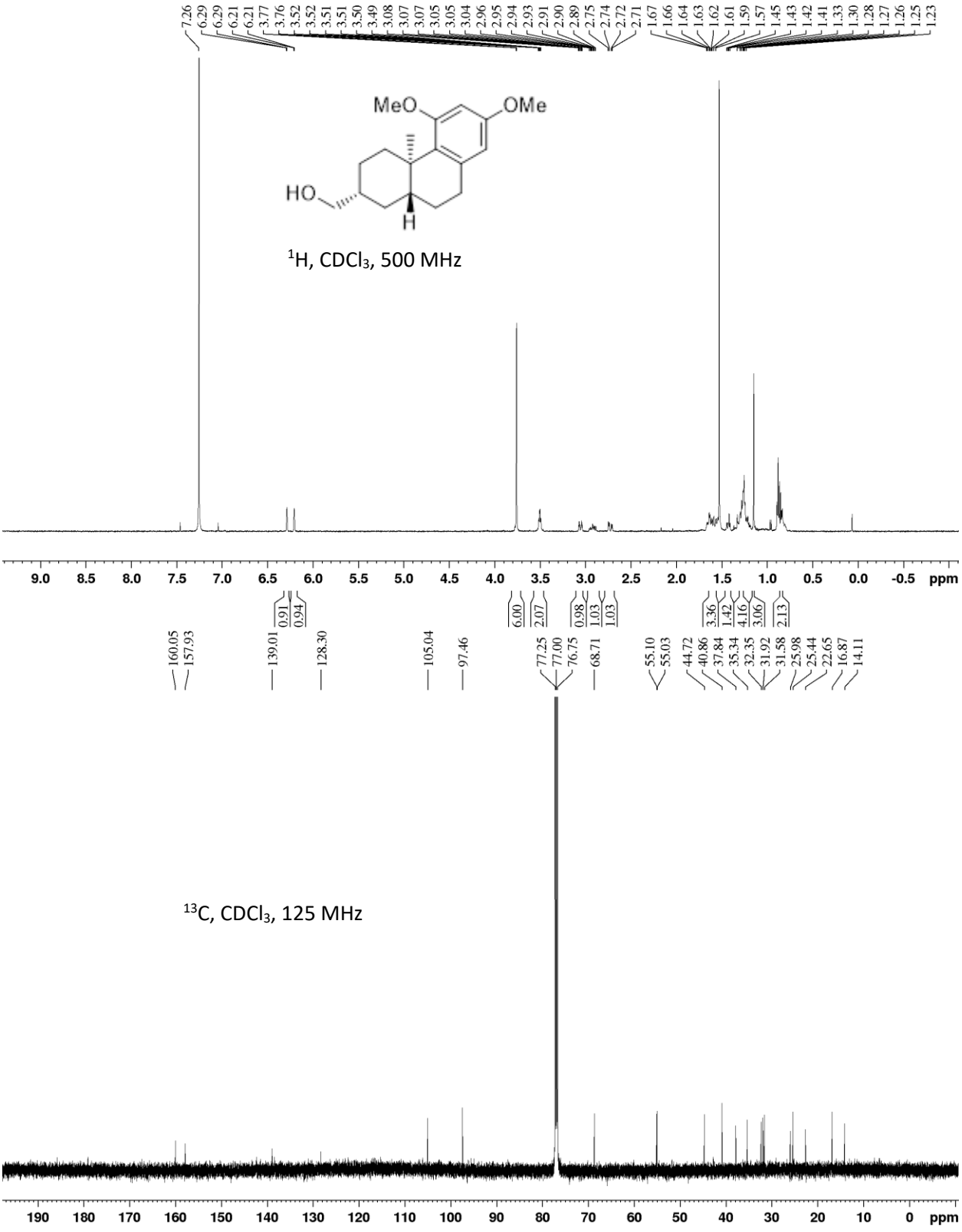

7.59
7.57
7.35
7.26
7.00
6.98
4.71
4.55
4.15
3.86
3.39
3.23
3.13
2.85
2.73
2.61
1.83
1.77
1.41
1.41
1.40
1.26
1.26
0.84
MeO
N
N
H
CO2Et
MeO
3h
1H, CDCl3, 500 MHz
10
9
8
7
6
5
4
3
2
1
0
ppm
4.98
1.91
4.00
1.04
0.79
8.13
2.03
2.03
4.10
3.15
1.59
159.20
156.83
155.96
141.46
139.48
133.60
128.20
126.08
123.43
114.16
77.23
76.98
76.72
62.16
61.30
60.45
55.32
48.25
47.35
41.16
37.09
34.94
27.51
26.87
23.81
14.63
14.42
13C, CDCl3, 125 MHz
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
ppm

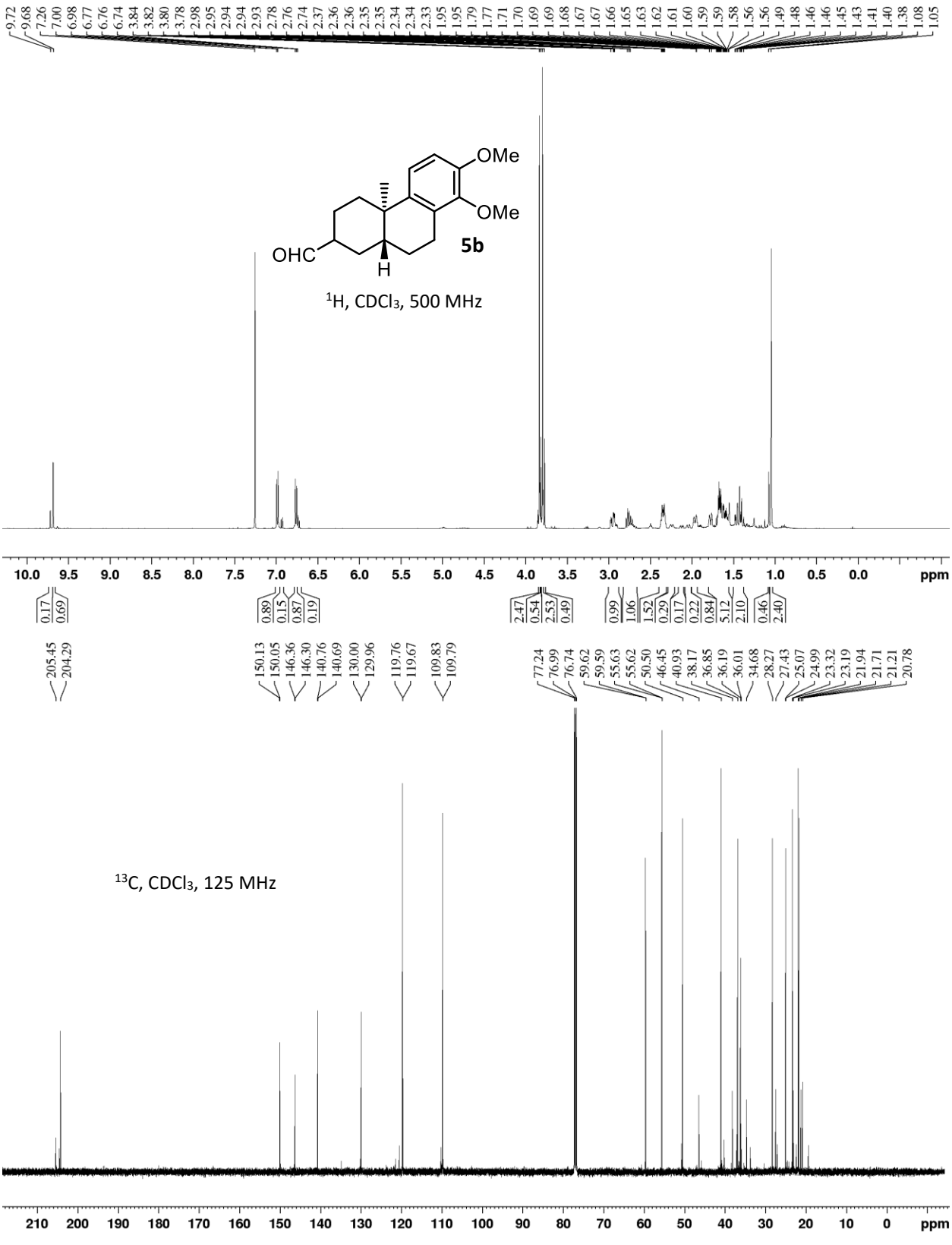

7.54
7.40
7.26
6.83
4.71
4.12
3.94
3.90
3.88
3.87
3.87
3.86
3.86
3.85
3.84
3.84
3.48
3.23
2.84
2.67
1.84
1.76
1.75
1.45
1.44
1.43
1.42
1.42
1.40
1.39
1.27
1.25
1.25
1.24
0.92
MeO
OMe
MeO
N
N
H
CO2Et
MeO
MeO
OMe
3i
1H, CDCl3, 500 MHz
10
9
8
7
6
5
4
3
2
1
0
ppm
1.00
1.95
4.10
1.03
1.35
19.98
2.12
2.13
4.28
2.20
1.95
1.32
156.79
155.99
153.49
142.18
139.32
137.80
137.16
127.06
124.28
104.69
77.24
76.99
76.73
61.87
61.38
60.94
59.52
56.29
48.08
47.50
41.03
36.94
35.68
27.41
23.57
14.66
13C, CDCl3, 125 MHz
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
ppm

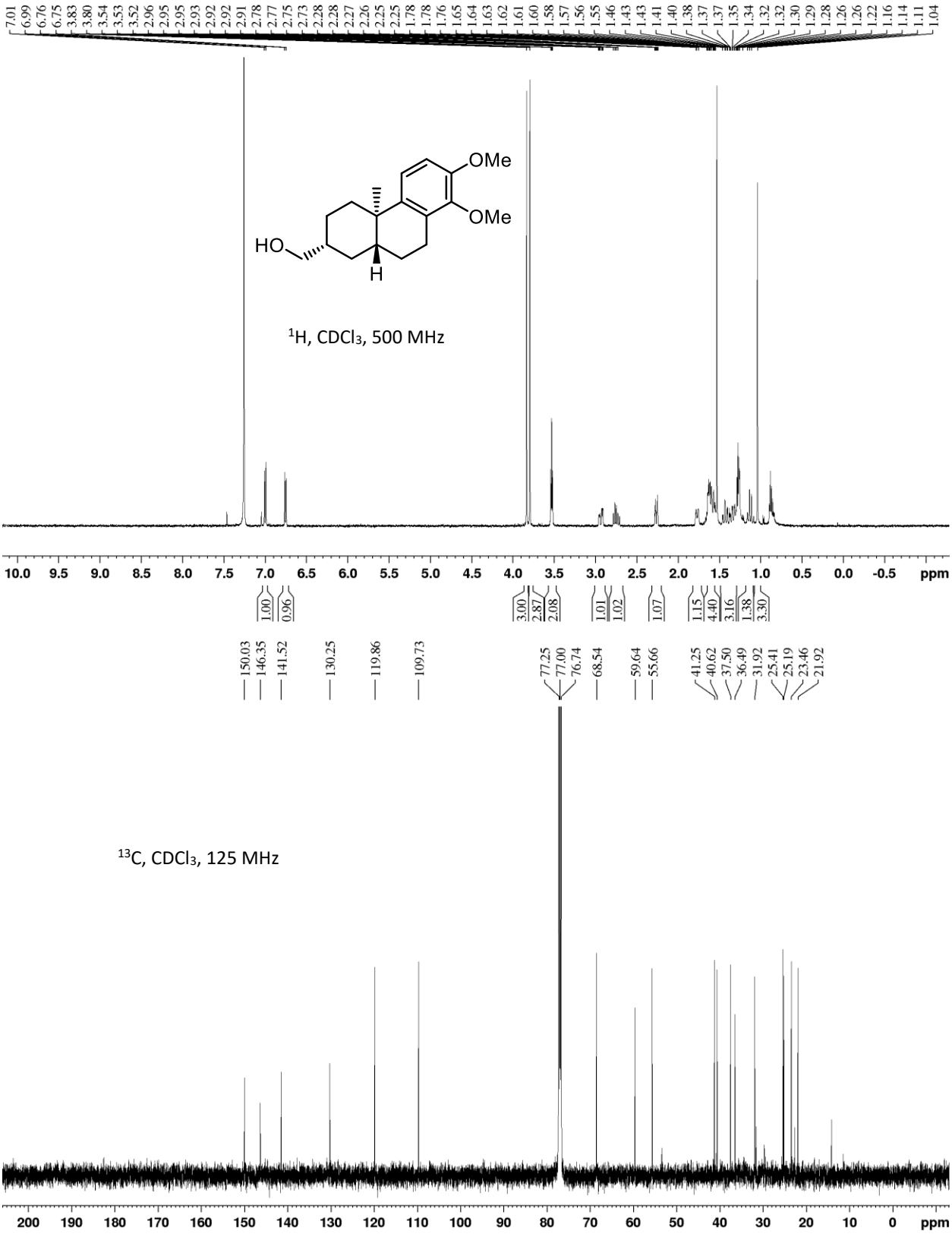

8.13
7.91
7.62
7.26
4.63
4.17
3.81
3.50
3.26
2.99
2.99
2.97
2.96
2.81
2.79
2.78
2.76
1.89
1.87
1.86
1.85
1.78
1.76
1.75
1.47
1.45
1.45
1.26
1.14
0.90
0.88
CF3
F3C
F3C
CF3
N
N
H
CO2Et
3j
1H, CDCl3, 500 MHz
10 9 8 7 6 5 4 3 2 1 0 -1 ppm
3.94
2.00
2.90
0.71
3.03
2.01
1.02
1.03
3.98
4.45
1.02
156.83
142.85
140.39
139.67
132.62
132.36
132.10
131.83
128.77
127.59
126.56
124.49
124.40
122.23
121.34
120.05
77.24
76.99
76.73
61.62
59.44
47.73
40.69
36.57
27.17
23.68
14.66
13C, CDCl3, 125 MHz
200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 ppm

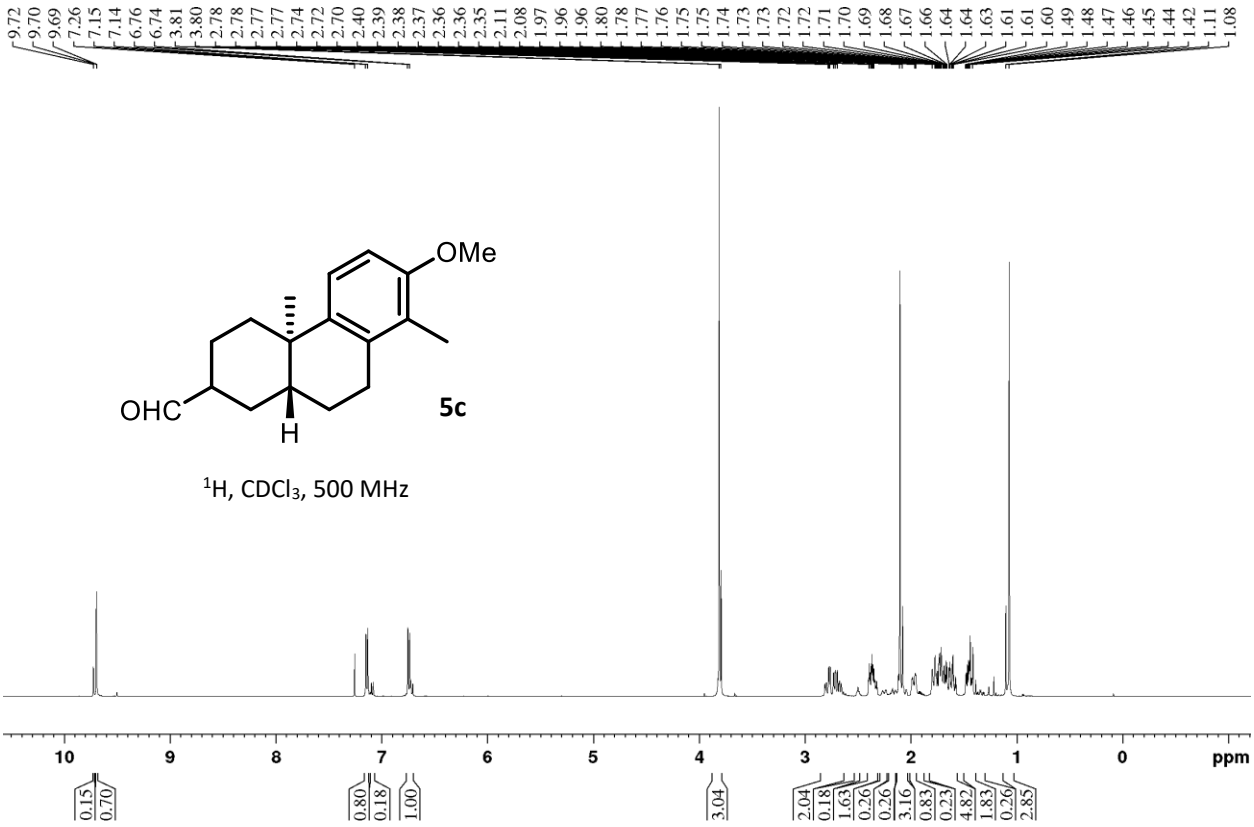

MeO
OMe
OHC
H
5a
^{1}H, CDCl$_3$, 400 MHz
ppm

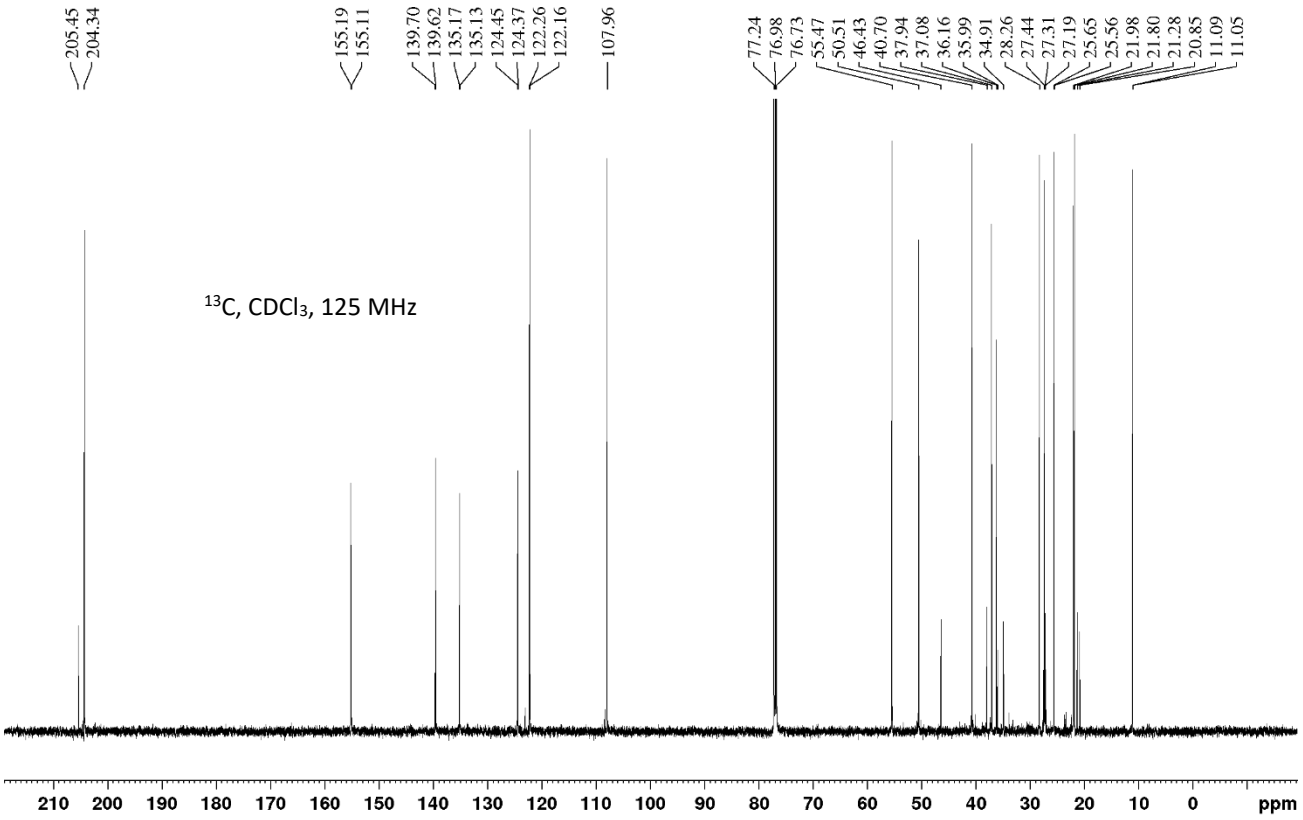

^{13}C, CDCl$_3$, 125 MHz
ppm

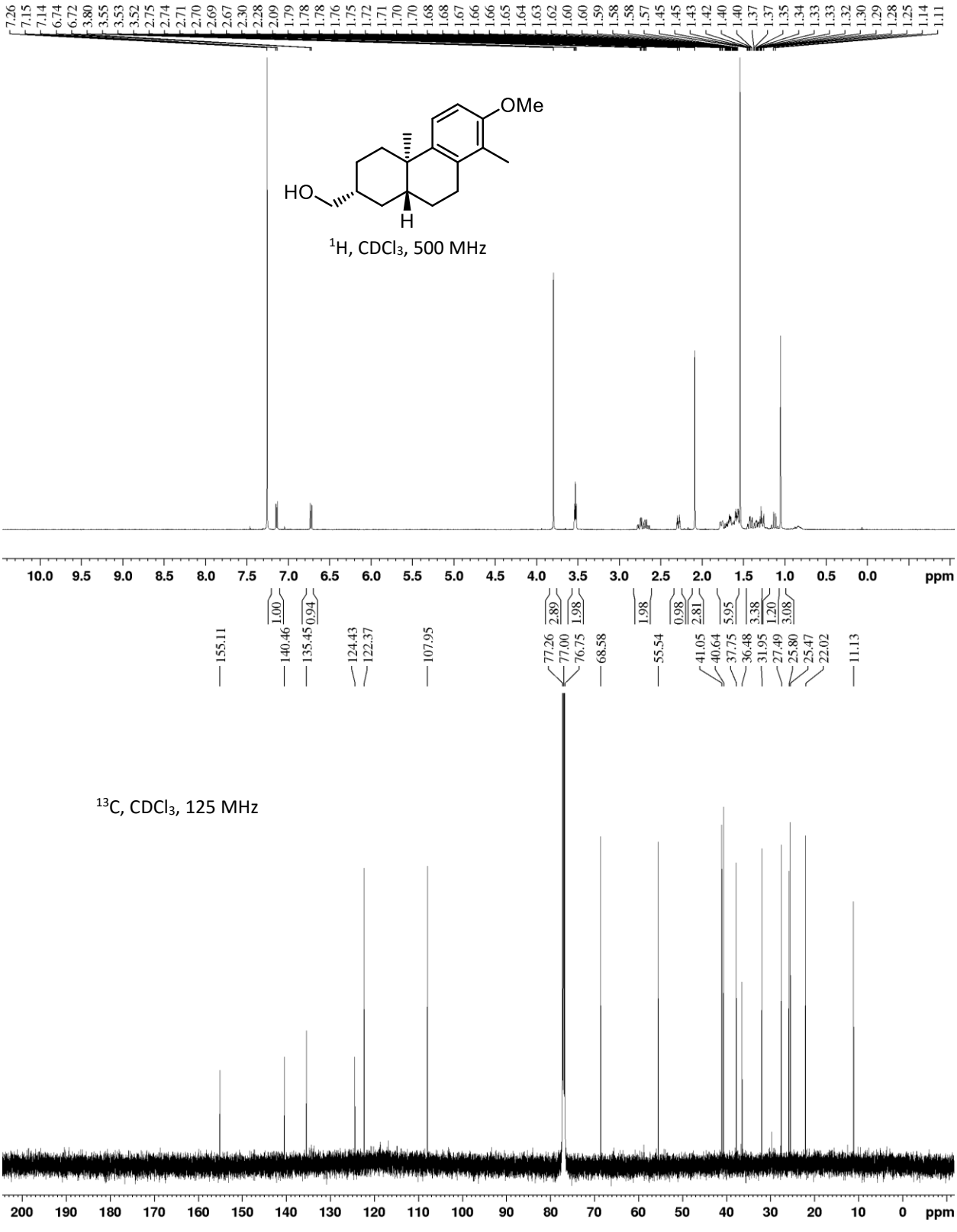

MeO
OMe
HO
H
^{1}H, CDCl$_3$, 500 MHz
^{13}C, CDCl$_3$, 125 MHz


OMe
OMe
OHC
H
5b
^{1}H, CDCl$_3$, 500 MHz
^{13}C, CDCl$_3$, 125 MHz
ppm


7.01 6.99 6.76 6.75 3.83 3.80 3.54 3.53 3.52 2.96 2.95 2.95 2.93 2.92 2.92 2.91 2.78 2.77 2.75 2.73 2.28 2.28 2.27 2.26 2.25 2.25 1.78 1.78 1.76 1.65 1.64 1.63 1.62 1.61 1.60 1.58 1.57 1.56 1.55 1.46 1.43 1.43 1.41 1.40 1.38 1.37 1.37 1.35 1.34 1.32 1.32 1.30 1.29 1.28 1.26 1.26 1.22 1.16 1.14 1.11 1.04
OMe
OMe
HO
H
1H, CDCl3, 500 MHz
10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5 ppm
1.00 0.96 3.00 2.87 2.08 1.01 1.02 1.07 1.15 4.40 3.16 1.38 3.30
150.03 146.35 141.52 130.25 119.86 109.73 77.25 77.00 76.74 68.54 59.64 55.66 41.25 40.62 37.50 36.49 31.92 25.41 25.19 23.46 21.92
13C, CDCl3, 125 MHz
200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 ppm

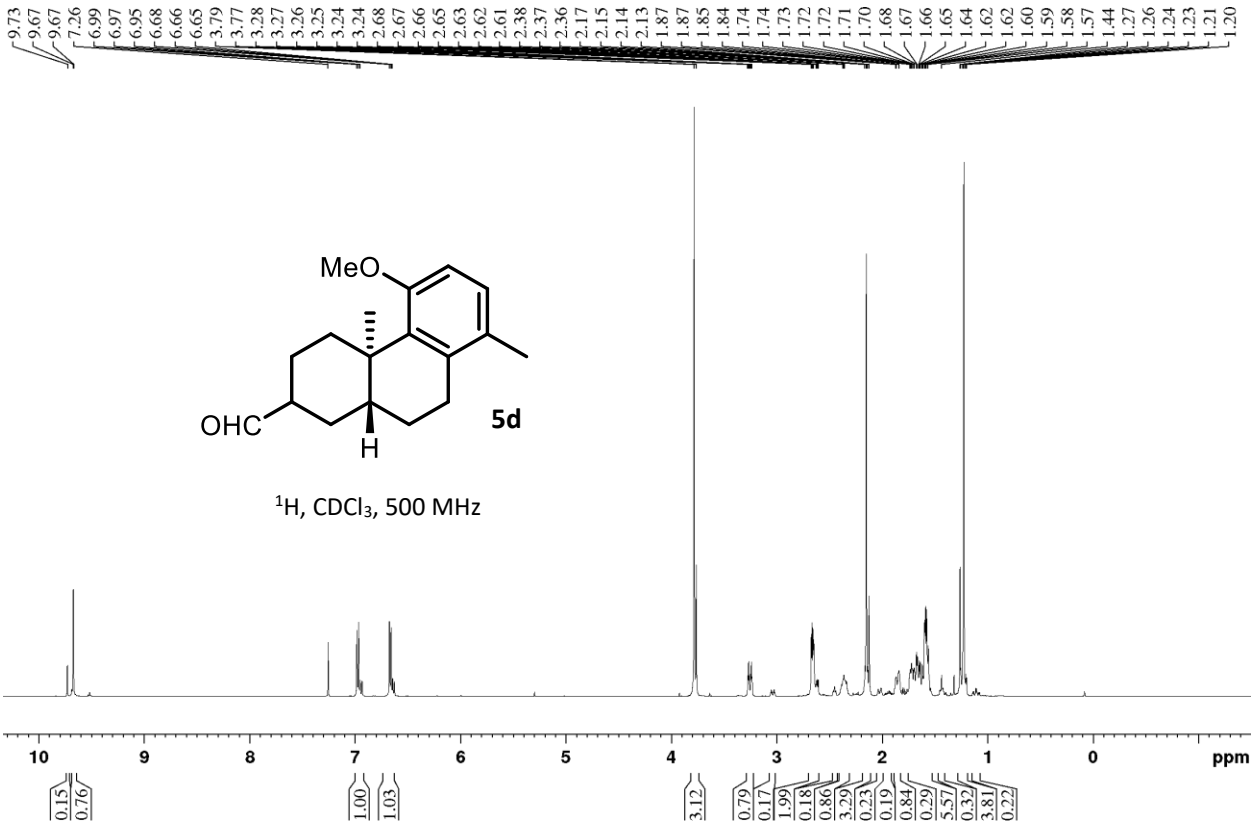

9.72
9.70
9.69
7.26
7.15
7.14
6.76
6.74
3.81
3.80
2.78
2.78
2.77
2.77
2.74
2.72
2.70
2.40
2.39
2.38
2.37
2.36
2.36
2.35
2.11
2.08
1.97
1.96
1.96
1.80
1.78
1.77
1.76
1.75
1.75
1.74
1.73
1.73
1.72
1.72
1.71
1.70
1.69
1.68
1.67
1.66
1.64
1.64
1.63
1.61
1.61
1.60
1.49
1.48
1.47
1.46
1.45
1.44
1.42
1.11
1.08
OMe
OHC
H
5c
^{1}H, CDCl$_3$, 500 MHz
10
9
8
7
6
5
4
3
2
1
0
ppm
0.15
0.70
0.80
0.18
1.00
3.04
2.04
0.18
1.63
0.26
0.26
3.16
0.83
0.23
4.82
1.83
0.26
2.85

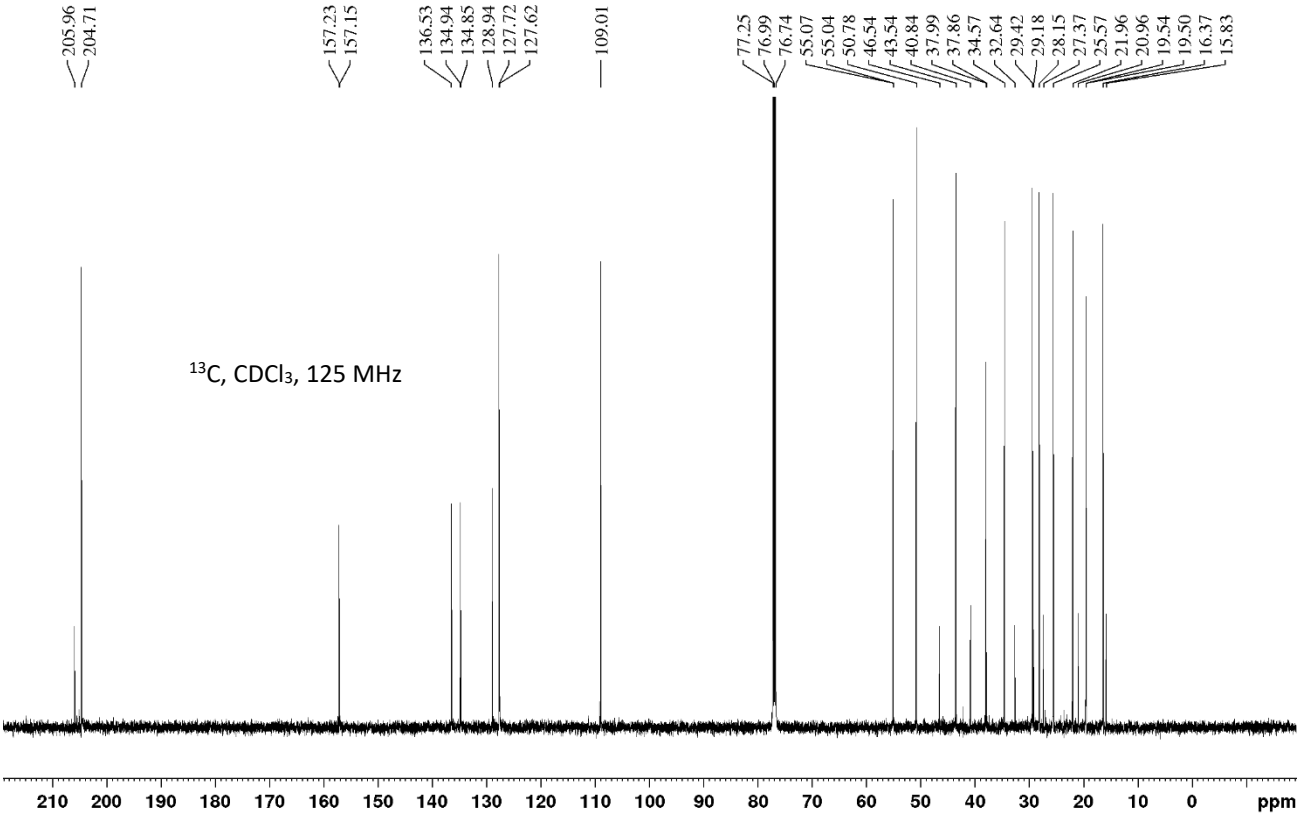

205.45
204.34
155.19
155.11
139.70
139.62
135.17
135.13
124.45
124.37
122.26
122.16
107.96
77.24
76.98
76.73
55.47
50.51
46.43
40.70
37.94
37.08
36.16
35.99
34.91
28.26
27.44
27.31
27.19
25.65
25.56
21.98
21.80
21.28
20.85
11.09
11.05
^{13}C, CDCl$_3$, 125 MHz
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
ppm

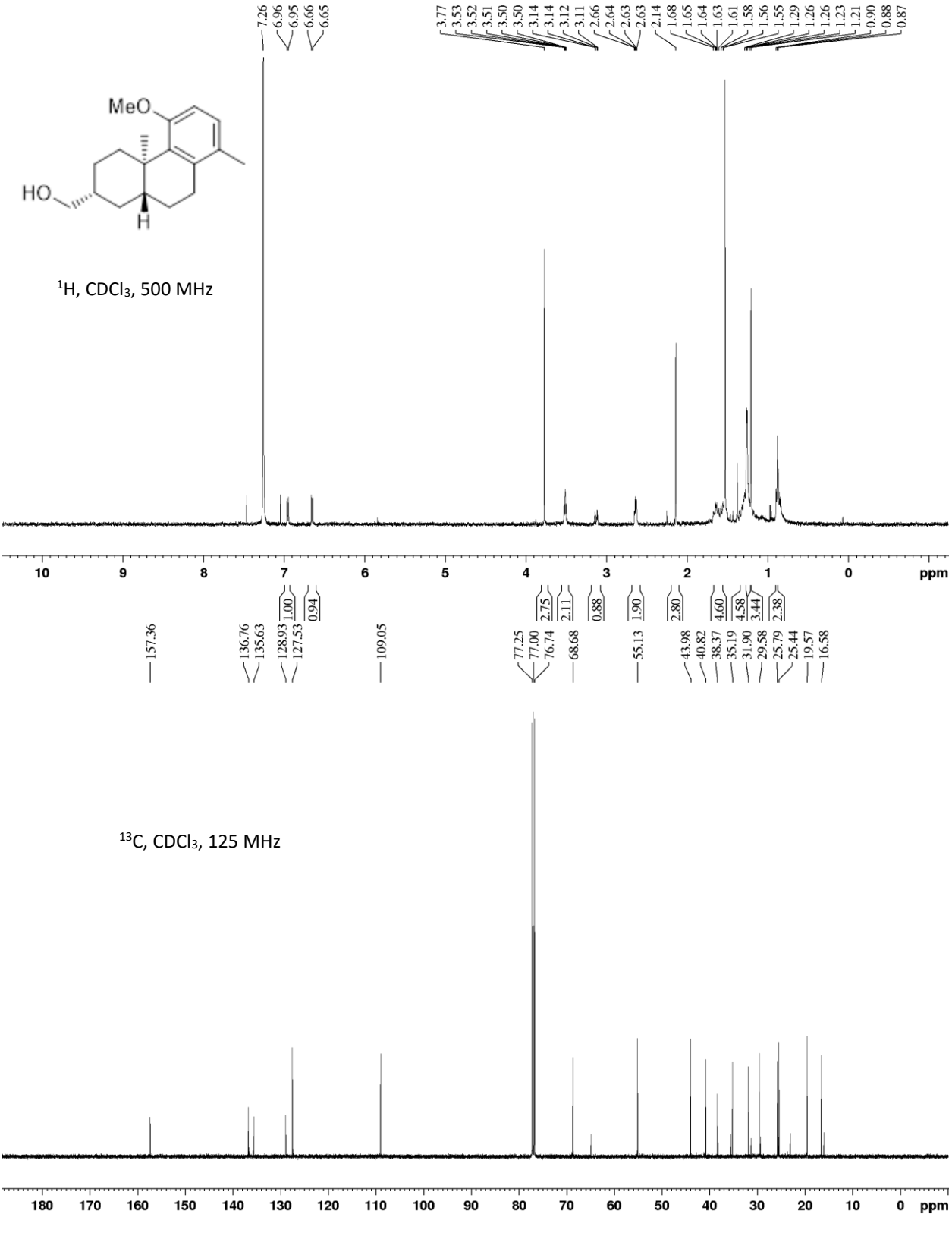


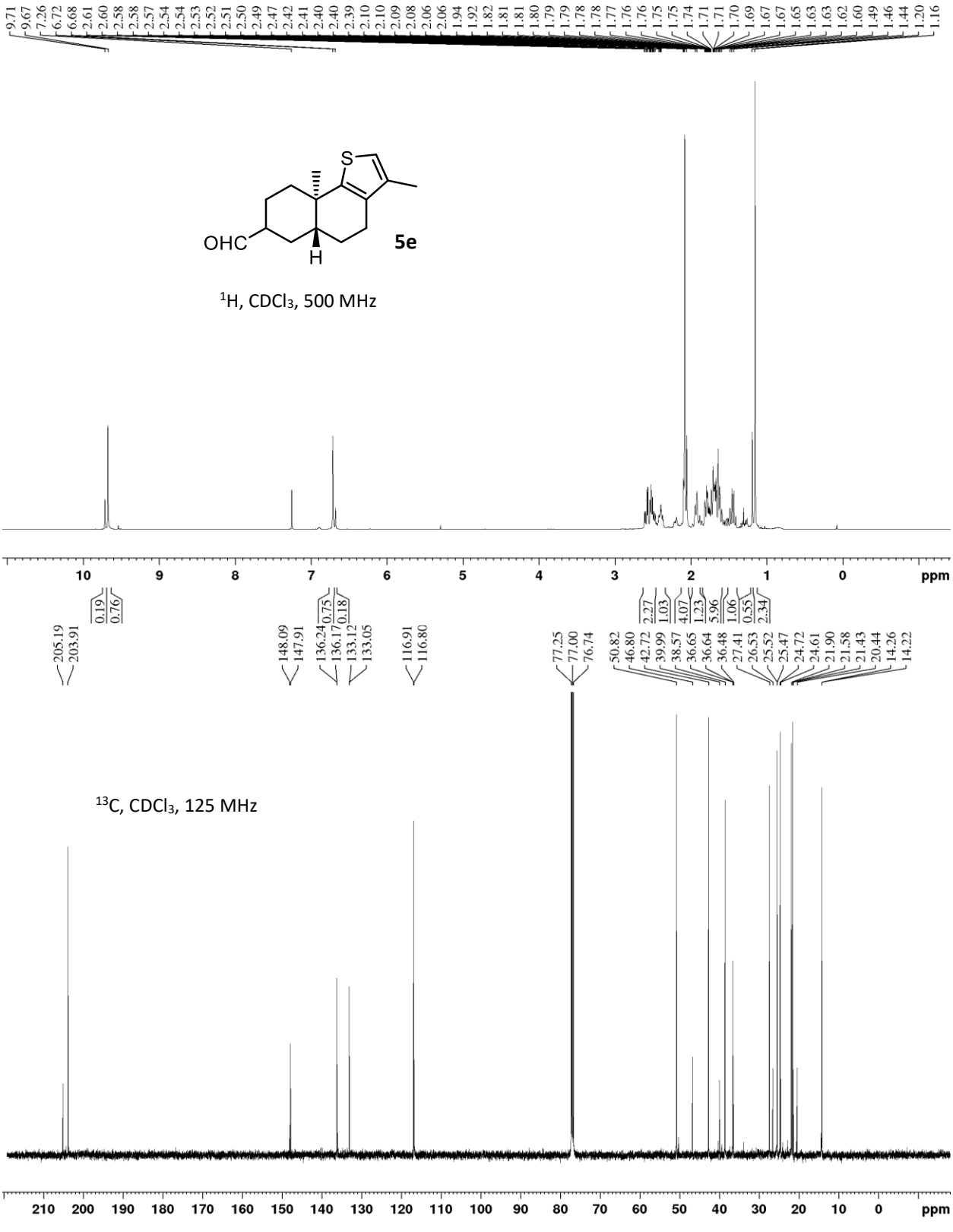
^{1}H, $CDCl_3$, 500 MHz

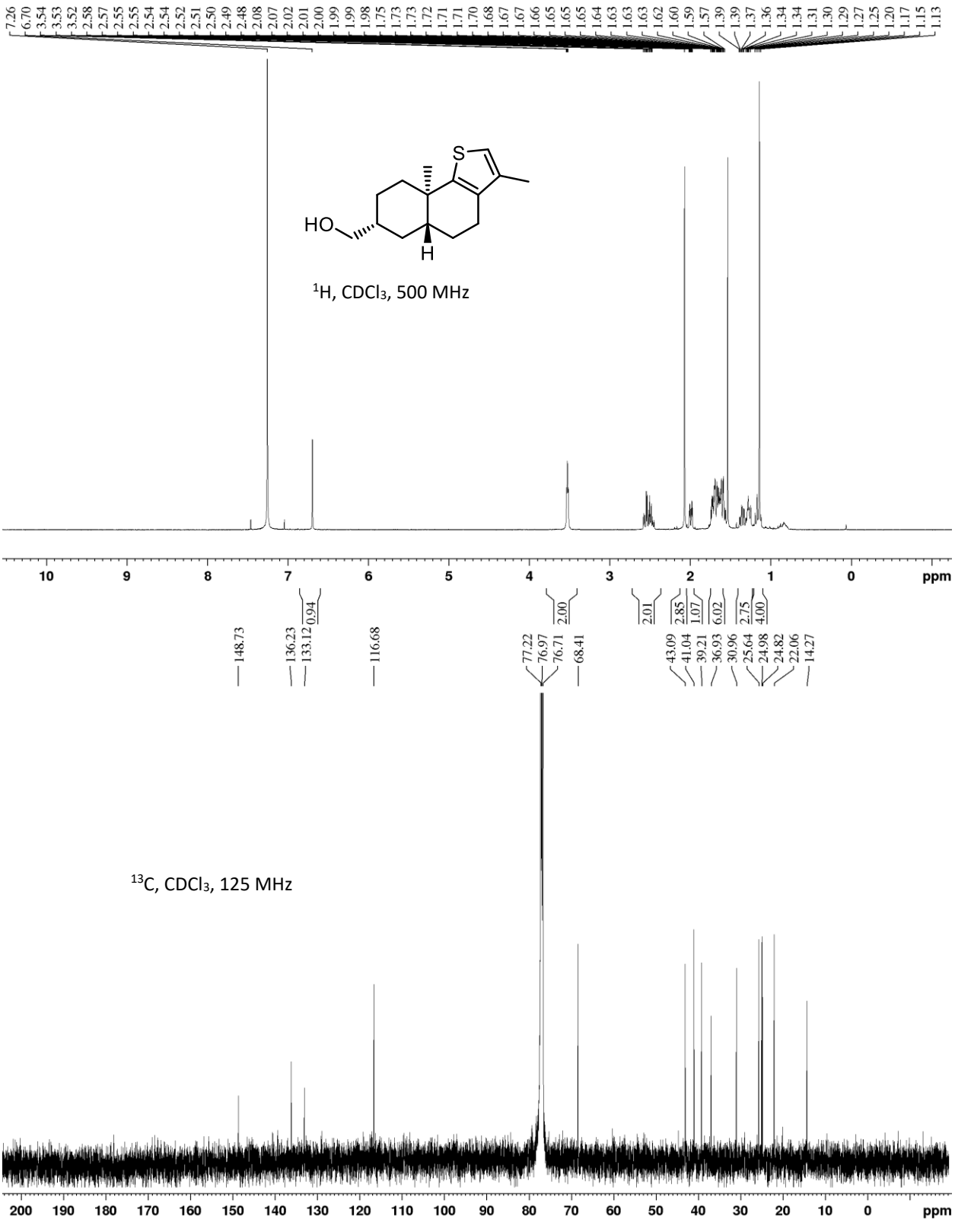
^{13}C, $CDCl_3$, 125 MHz


9.73
9.67
9.67
7.26
6.99
6.97
6.95
6.68
6.66
6.65
3.79
3.77
3.28
3.27
3.26
3.25
3.24
3.24
2.68
2.67
2.66
2.65
2.63
2.62
2.61
2.38
2.37
2.36
2.17
2.15
2.14
2.13
1.87
1.87
1.85
1.84
1.74
1.74
1.73
1.72
1.72
1.71
1.70
1.68
1.67
1.66
1.65
1.64
1.62
1.62
1.60
1.59
1.58
1.57
1.44
1.27
1.26
1.24
1.23
1.21
1.20
MeO
OHC
H
5d
1H, CDCl3, 500 MHz
10
9
8
7
6
5
4
3
2
1
0
ppm
0.15
0.76
1.00
1.03
3.12
0.79
0.17
1.99
0.18
0.86
3.29
0.23
0.19
0.84
0.29
5.57
0.32
3.81
0.22


205.96
204.71
157.23
157.15
136.53
134.94
134.85
128.94
127.72
127.62
109.01
77.25
76.99
76.74
55.07
55.04
50.78
46.54
43.54
40.84
37.99
37.86
34.57
32.64
29.42
29.18
28.15
27.37
25.57
21.96
20.96
19.54
19.50
16.37
15.83
13C, CDCl3, 125 MHz
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
ppm

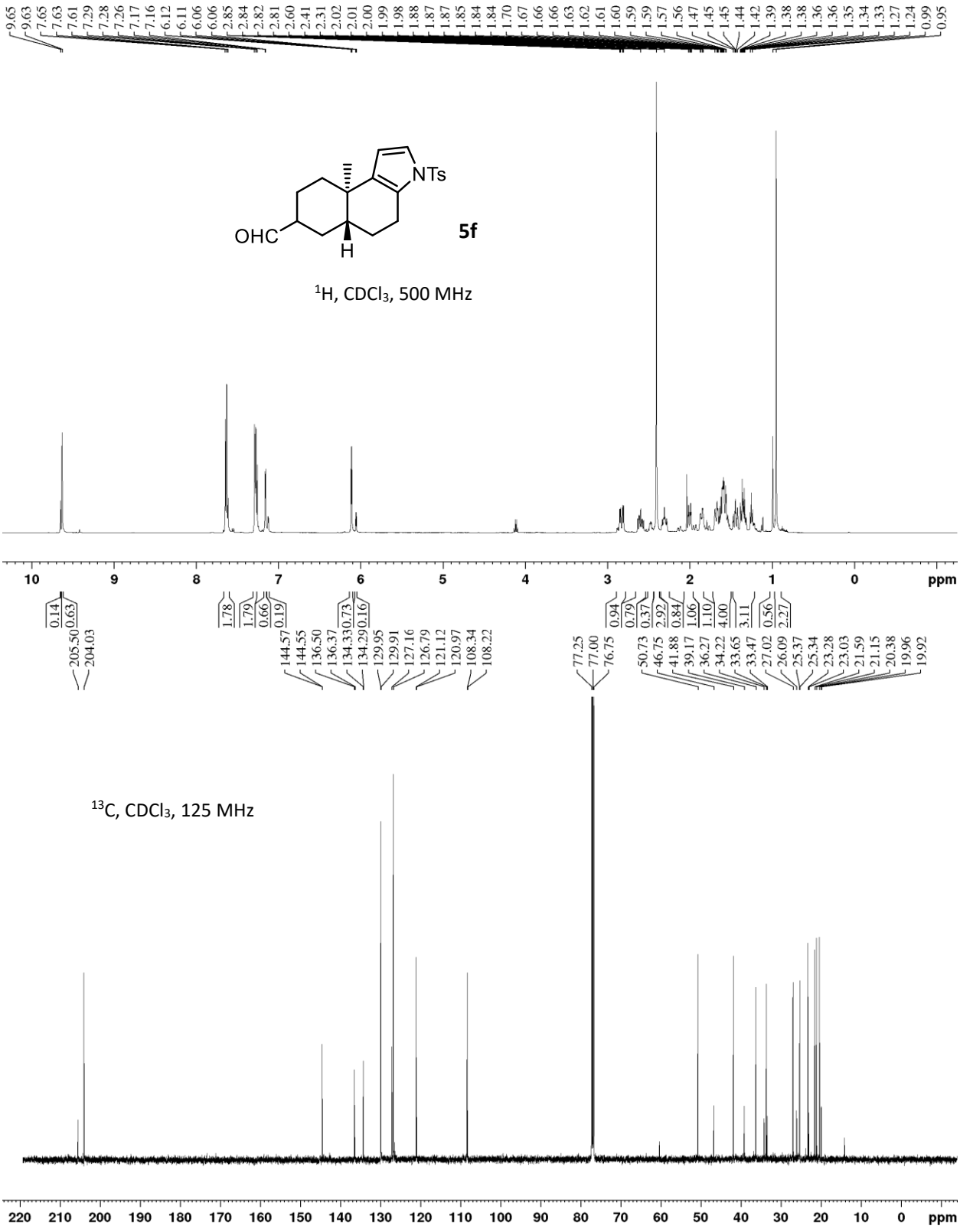

MeO
HO
H
^{1}H, CDCl$_3$, 500 MHz
^{13}C, CDCl$_3$, 125 MHz
ppm

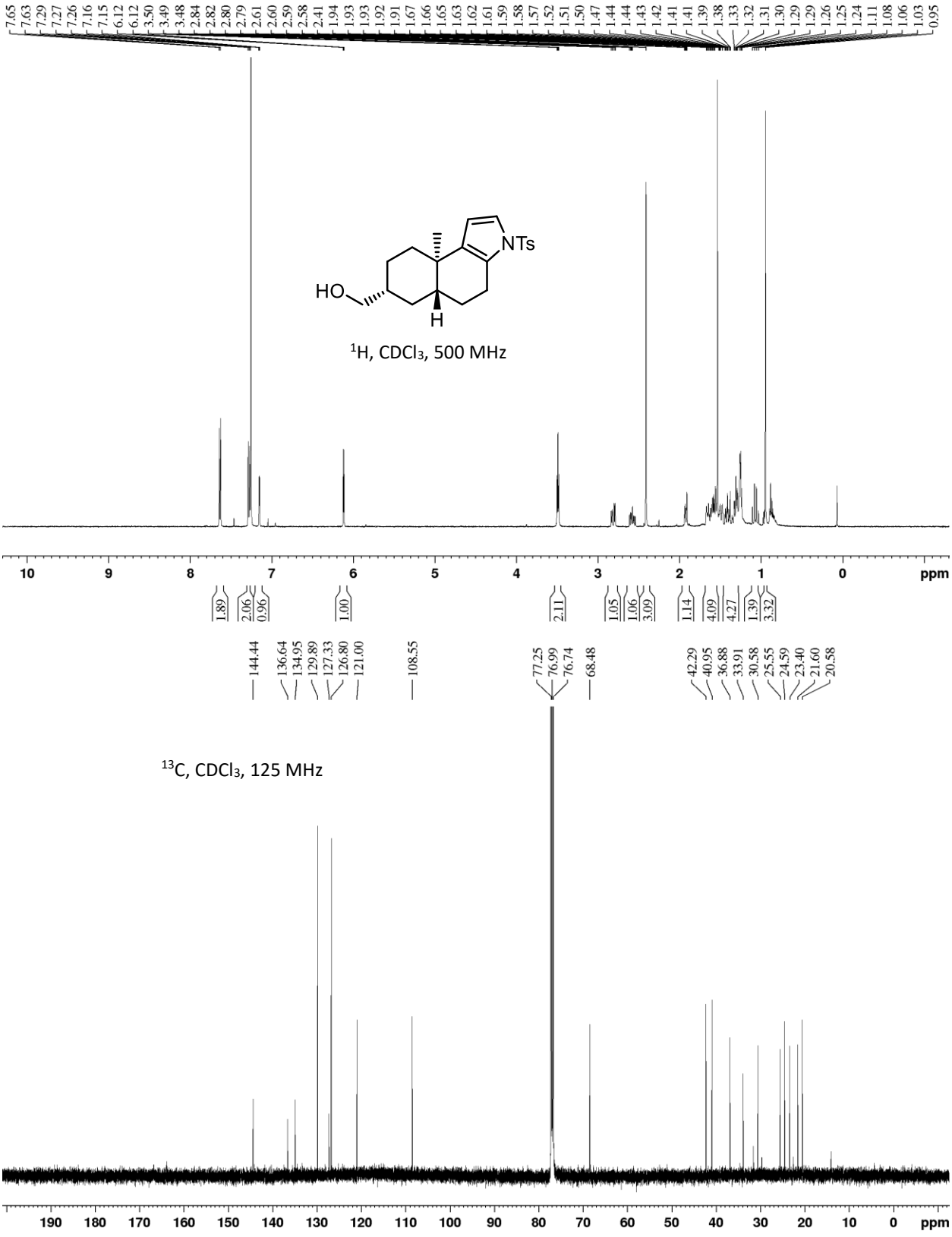

9.71 9.67 7.26 6.72 6.68 2.61 2.60 2.58 2.58 2.57 2.54 2.54 2.53 2.52 2.51 2.50 2.49 2.47 2.42 2.41 2.40 2.40 2.39 2.10 2.10 2.09 2.08 2.06 2.06 1.94 1.92 1.82 1.81 1.81 1.80 1.79 1.79 1.78 1.78 1.77 1.76 1.76 1.75 1.75 1.74 1.71 1.71 1.70 1.69 1.67 1.67 1.65 1.63 1.63 1.62 1.60 1.49 1.46 1.44 1.20 1.16
S
OHC
H
5e
^{1}H, CDCl$_3$, 500 MHz
10 9 8 7 6 5 4 3 2 1 0 ppm
0.19 0.76 0.75 0.18 2.27 1.03 4.07 1.23 5.96 1.06 0.55 2.34
205.19 203.91 148.09 147.91 136.24 136.17 133.12 133.05 116.91 116.80 77.25 77.00 76.74 50.82 46.80 42.72 39.99 38.57 36.65 36.64 36.48 27.41 26.53 25.52 25.47 24.72 24.61 21.90 21.58 21.43 20.44 14.26 14.22
^{13}C, CDCl$_3$, 125 MHz
210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 ppm

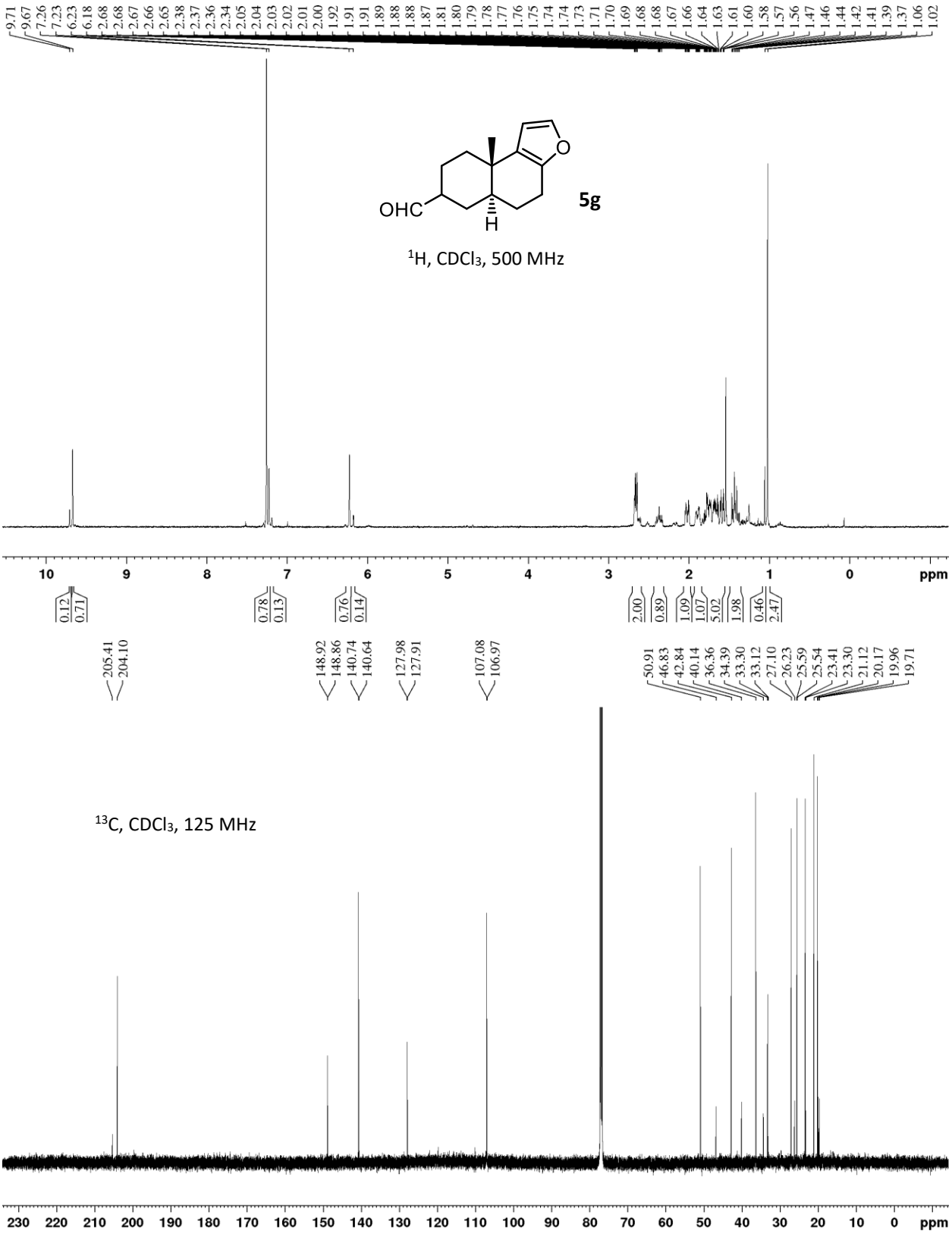


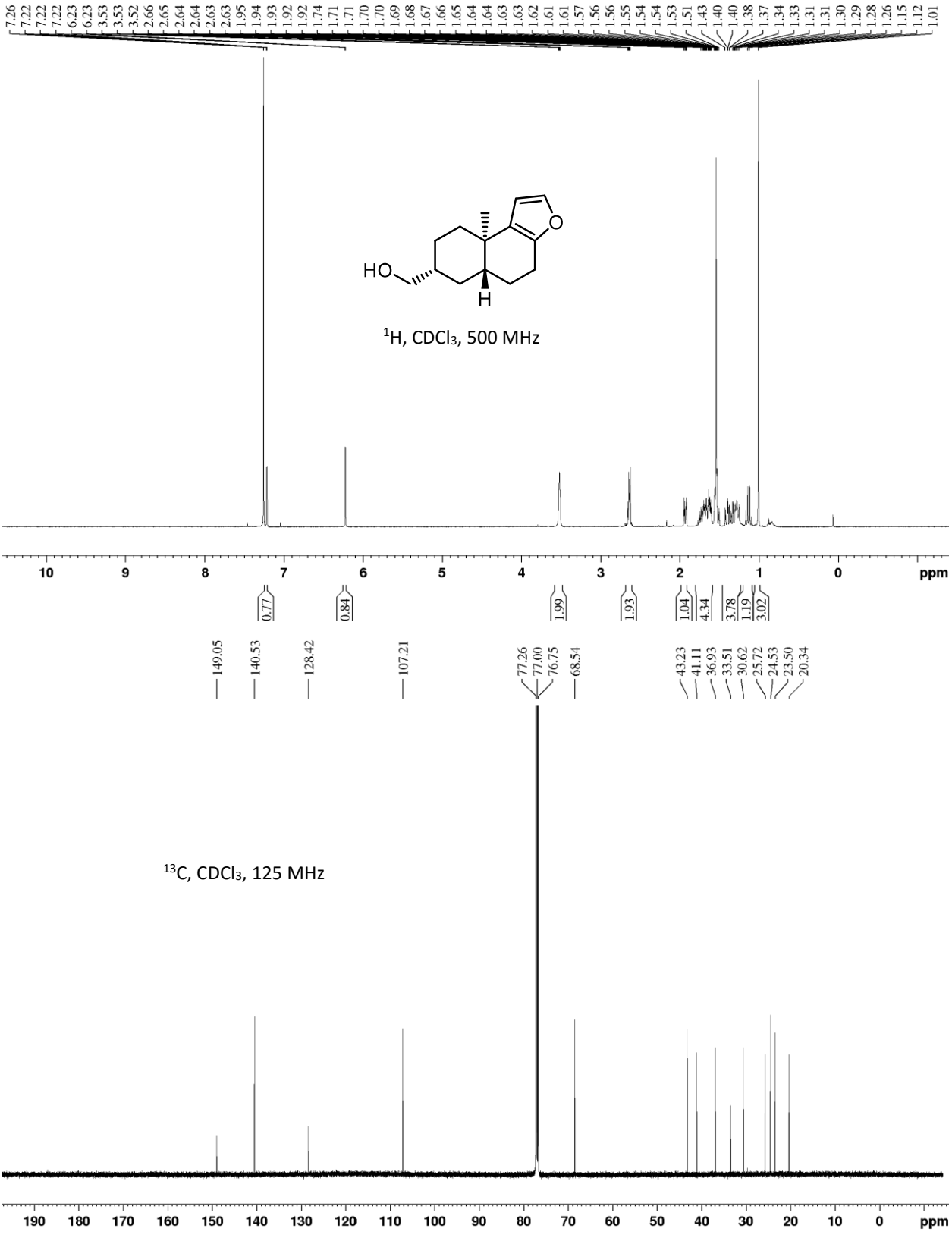
^{1}H, $CDCl_3$, 500 MHz

^{13}C, $CDCl_3$, 125 MHz


9.65 9.63 7.65 7.63 7.61 7.29 7.28 7.26 7.17 7.16 6.12 6.11 6.06 6.06 2.85 2.84 2.82 2.81 2.60 2.41 2.31 2.02 2.01 2.00 1.99 1.98 1.88 1.87 1.87 1.85 1.84 1.84 1.70 1.67 1.66 1.66 1.63 1.62 1.61 1.60 1.59 1.59 1.57 1.56 1.47 1.45 1.45 1.44 1.42 1.39 1.38 1.38 1.36 1.36 1.35 1.34 1.33 1.27 1.24 0.99 0.95
NTs
OHC
H
5f
1H, CDCl3, 500 MHz
10 9 8 7 6 5 4 3 2 1 0 ppm
0.14 0.63 1.78 1.79 0.66 0.19 0.73 0.16 0.94 0.79 0.37 2.92 0.84 1.06 1.10 4.00 3.11 0.56 2.27
205.50 204.03 144.57 144.55 136.50 136.37 134.33 134.29 129.95 129.91 127.16 126.79 121.12 120.97 108.34 108.22 77.25 77.00 76.75 50.73 46.75 41.88 39.17 36.27 34.22 33.65 33.47 27.02 26.09 25.37 25.34 23.28 23.03 21.59 21.15 20.38 19.96 19.92
13C, CDCl3, 125 MHz
220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 ppm

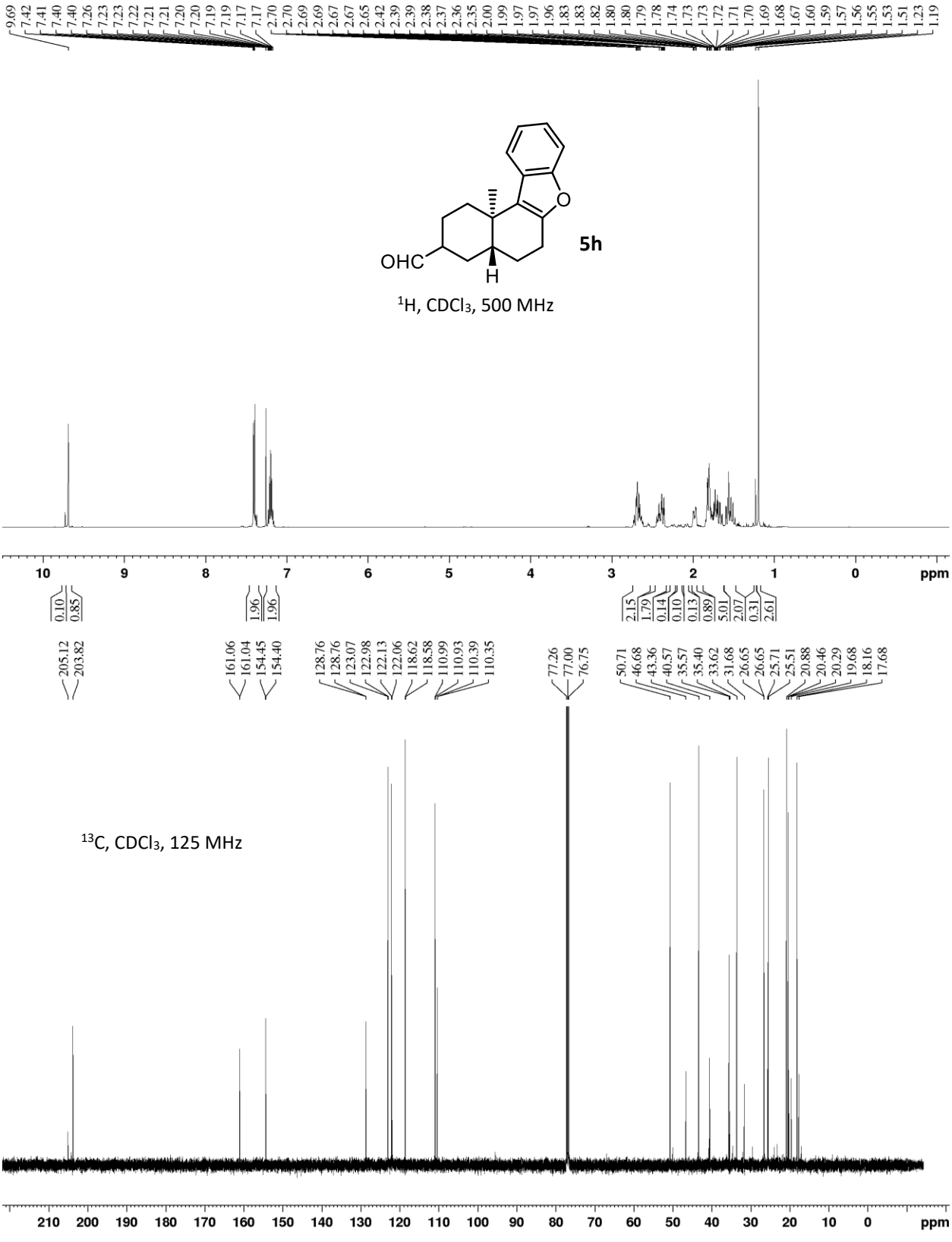

7.65 7.63 7.29 7.27 7.26 7.16 7.15 6.12 6.12 3.50 3.49 3.48 2.84 2.82 2.80 2.79 2.61 2.60 2.59 2.58 2.41 1.94 1.93 1.93 1.92 1.91 1.67 1.66 1.65 1.63 1.62 1.61 1.59 1.58 1.57 1.52 1.51 1.50 1.47 1.44 1.44 1.43 1.42 1.41 1.41 1.39 1.38 1.33 1.32 1.31 1.30 1.29 1.29 1.26 1.25 1.24 1.11 1.08 1.06 1.03 0.95
NTs
HO
H
1H, CDCl3, 500 MHz
10 9 8 7 6 5 4 3 2 1 0 ppm
1.89 2.06 0.96 1.00 2.11 1.05 1.06 3.09 1.14 4.09 4.27 1.39 3.32
144.44 136.64 134.95 129.89 127.33 126.80 121.00 108.55 77.25 76.99 76.74 68.48 42.29 40.95 36.88 33.91 30.58 25.55 24.59 23.40 21.60 20.58
13C, CDCl3, 125 MHz
190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 ppm

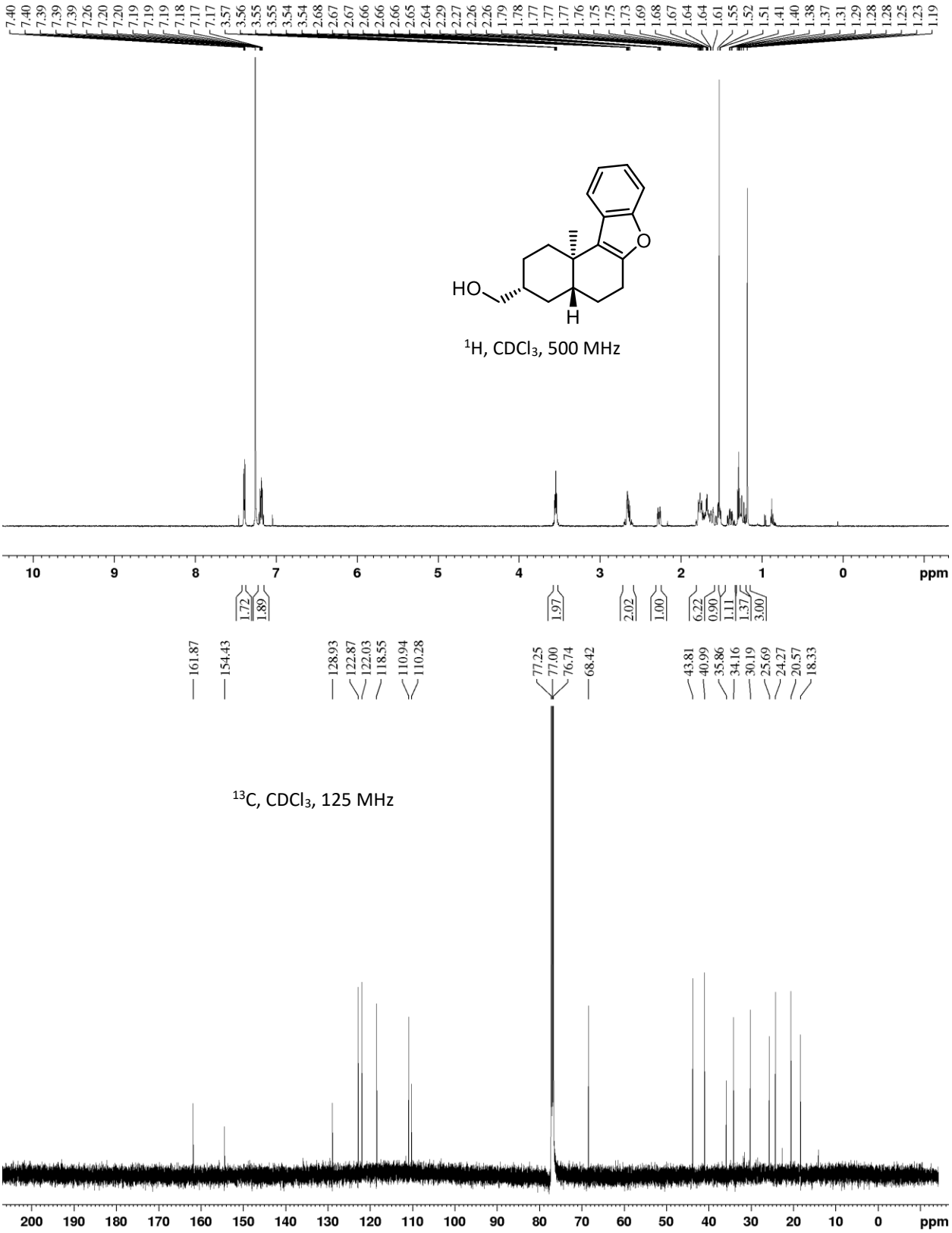

9.71
9.67
7.26
7.23
6.23
6.18
2.68
2.68
2.67
2.66
2.65
2.38
2.37
2.36
2.34
2.05
2.04
2.03
2.02
2.01
2.00
1.92
1.91
1.91
1.89
1.88
1.88
1.87
1.81
1.80
1.79
1.78
1.77
1.76
1.75
1.74
1.74
1.73
1.71
1.70
1.69
1.68
1.68
1.67
1.66
1.64
1.63
1.61
1.60
1.58
1.57
1.56
1.47
1.46
1.44
1.42
1.41
1.39
1.37
1.06
1.02
OHC
H
O
5g
1H, CDCl3, 500 MHz
10
9
8
7
6
5
4
3
2
1
0
ppm
0.12
0.71
0.78
0.13
0.76
0.14
2.00
0.89
1.09
1.07
5.02
1.98
0.46
2.47
205.41
204.10
148.92
148.86
140.74
140.64
127.98
127.91
107.08
106.97
50.91
46.83
42.84
40.14
36.36
34.39
33.30
33.12
27.10
26.23
25.59
25.54
23.41
23.30
21.12
20.17
19.96
19.71
13C, CDCl3, 125 MHz
230
220
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
ppm



^{1}H, $CDCl_3$, 500 MHz

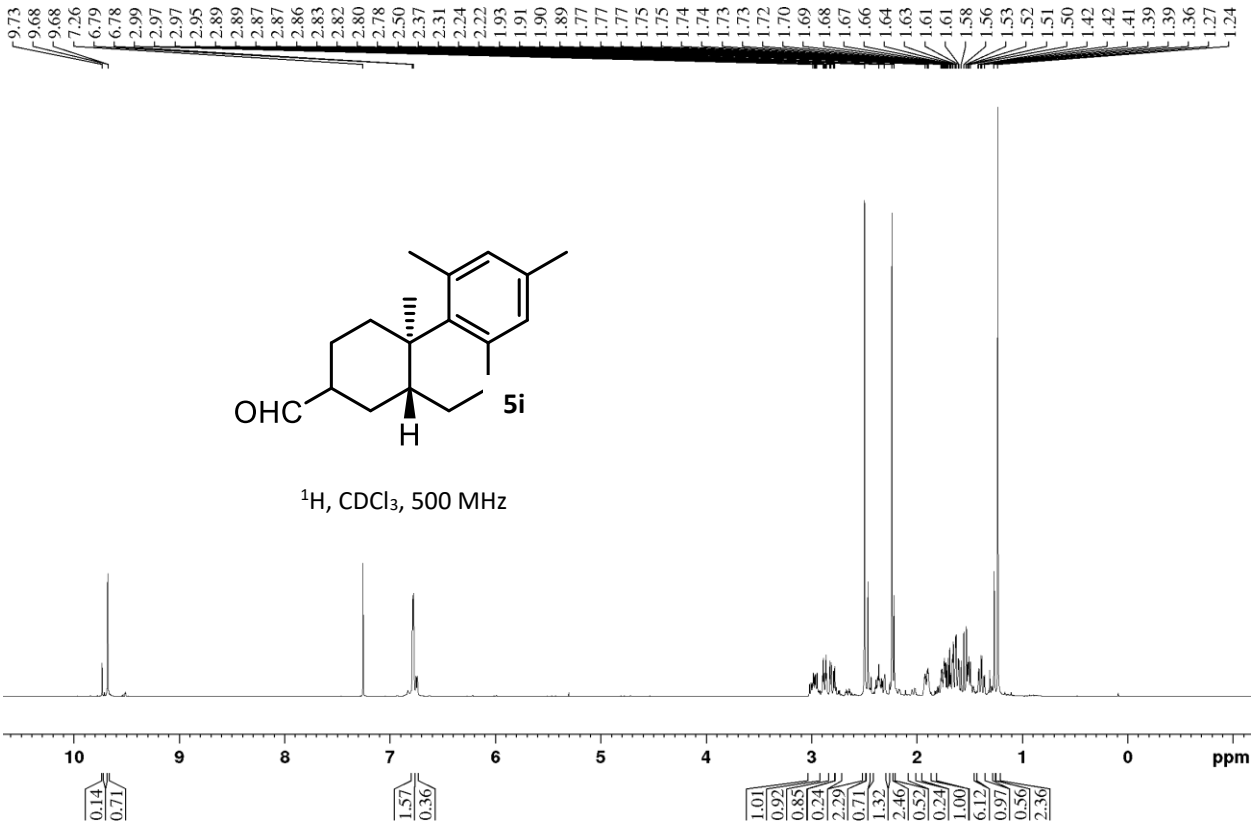
^{13}C, $CDCl_3$, 125 MHz


9.69 7.42 7.41 7.40 7.40 7.26 7.23 7.23 7.22 7.21 7.21 7.20 7.20 7.19 7.19 7.17 7.17 2.70 2.70 2.69 2.69 2.67 2.65 2.42 2.39 2.39 2.38 2.37 2.36 2.35 2.00 1.99 1.97 1.97 1.96 1.83 1.83 1.82 1.80 1.80 1.79 1.78 1.74 1.73 1.73 1.72 1.71 1.70 1.69 1.68 1.67 1.60 1.59 1.57 1.56 1.55 1.53 1.51 1.23 1.19
O
OHC
H
5h
^{1}H, CDCl$_3$, 500 MHz
10 9 8 7 6 5 4 3 2 1 0 ppm
0.10 0.85 1.96 1.96 2.15 1.79 0.14 0.10 0.13 0.89 5.01 2.07 0.31 2.61
205.12 203.82 161.06 161.04 154.45 154.40 128.76 128.76 123.07 122.98 122.13 122.06 118.62 118.58 110.99 110.93 110.39 110.35 77.26 77.00 76.75 50.71 46.68 43.36 40.57 35.57 35.40 33.62 31.68 26.65 26.65 25.71 25.51 20.88 20.46 20.29 19.68 18.16 17.68
^{13}C, CDCl$_3$, 125 MHz
210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 ppm

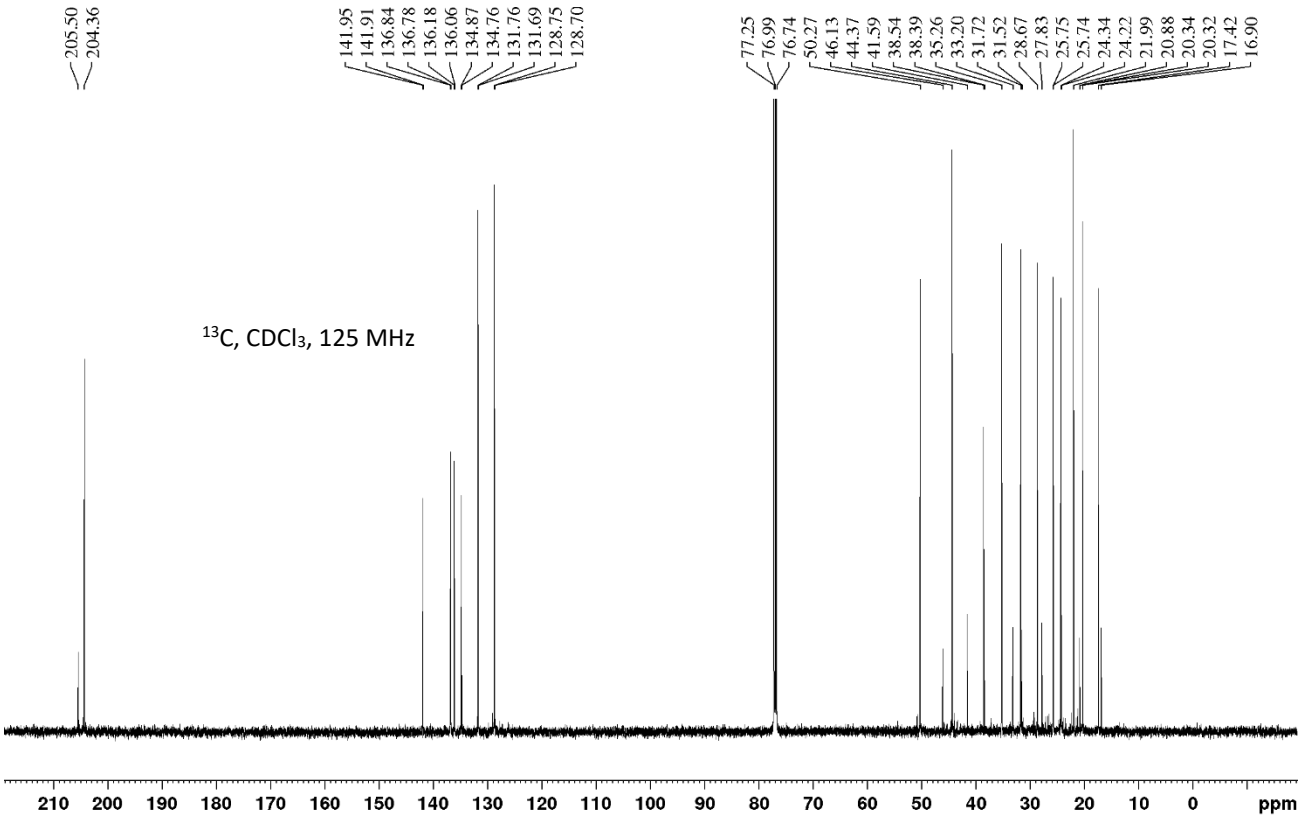


^{1}H, $CDCl_3$, 500 MHz

^{13}C, $CDCl_3$, 125 MHz



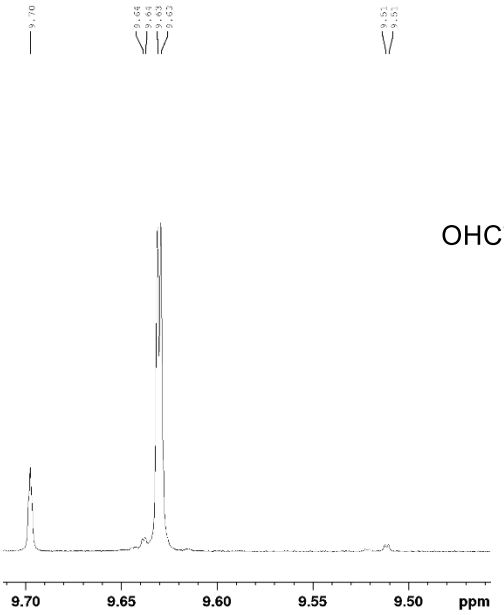
^{1}H, $CDCl_3$, 500 MHz

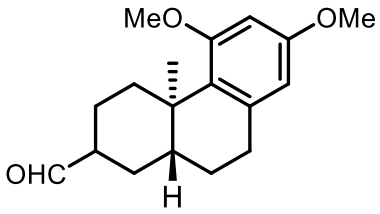


^{13}C, $CDCl_3$, 125 MHz

VIII. Diastereomeric ratios of decalin products

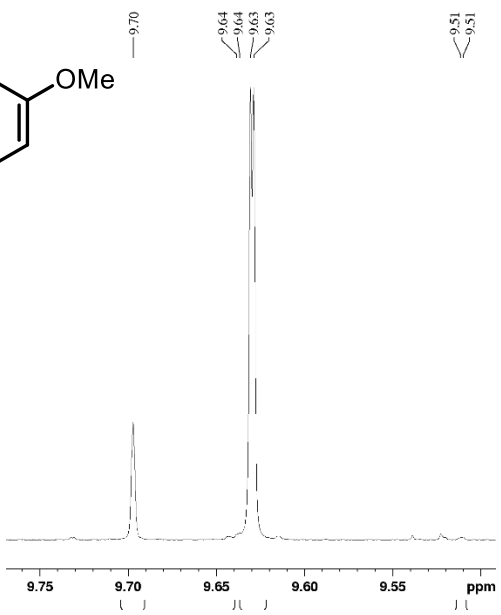
racemic





5a

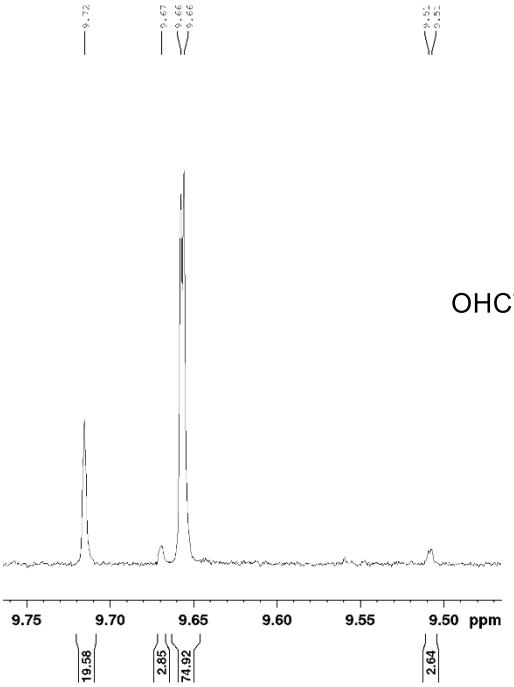
asymmetric

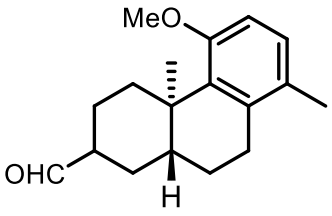


^{1}H NMR (800 MHz, $(CD_3)_2CO$)
trans:*cis* 95:5, *trans*-β:α 6:1

^{1}H NMR (800 MHz, $(CD_3)_2CO$)
trans:*cis* 99:1, *trans*-β:α 6:1

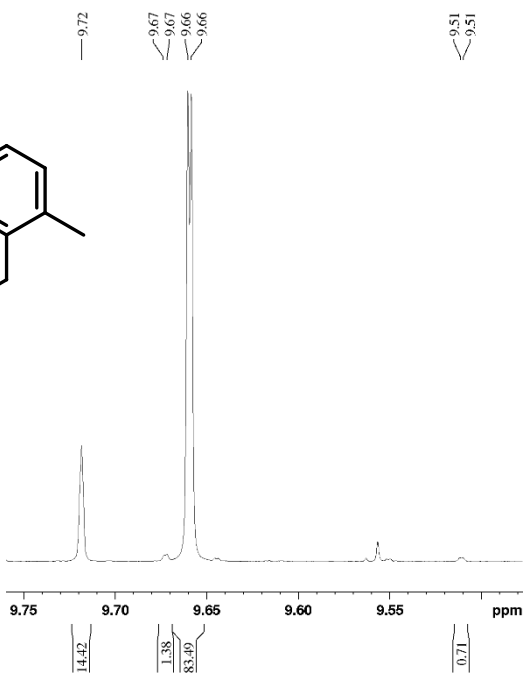
racemic





5d

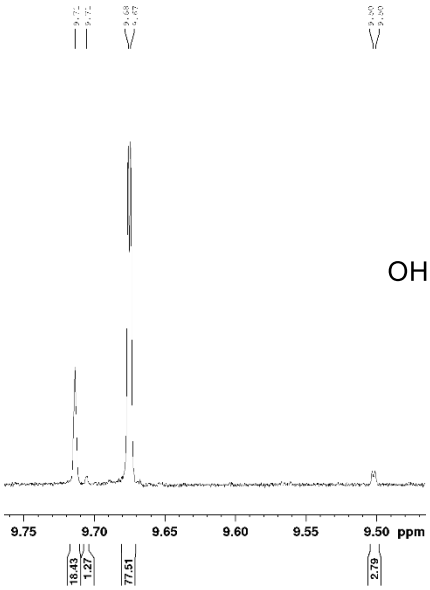
asymmetric



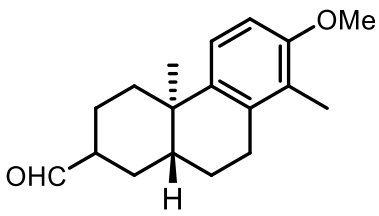
^{1}H NMR (800 MHz, $(CD_3)_2CO$)
trans:*cis* 94:6, *trans*-β:α 4:1

^{1}H NMR (800 MHz, $(CD_3)_2CO$)
trans:*cis* 98:2, *trans*-β:α 6:1

racemic

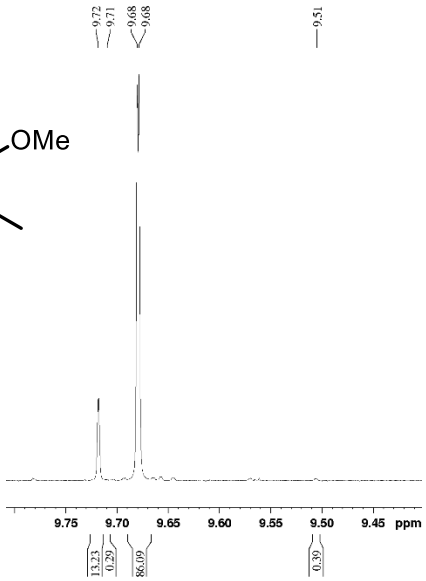


^{1}H NMR (800 MHz, $(CD_3)_2CO$)
trans:*cis* 96:4, *trans*-β:α 4:1



5c

asymmetric



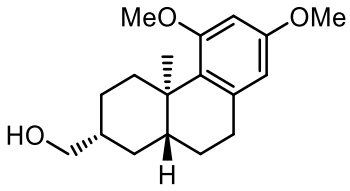
^{1}H NMR (800 MHz, $(CD_3)_2CO$)
trans:*cis* >99:1, *trans*-β:α 6:1

IX. HPLC chromatograms of asymmetric polyene cyclization products

In all cases, HPLC was run on either a Daicel Chiralcel O*J*-H or Chiral OD column, flow rate was 1 mL/min and UV absorbance was observed at 220 nm.

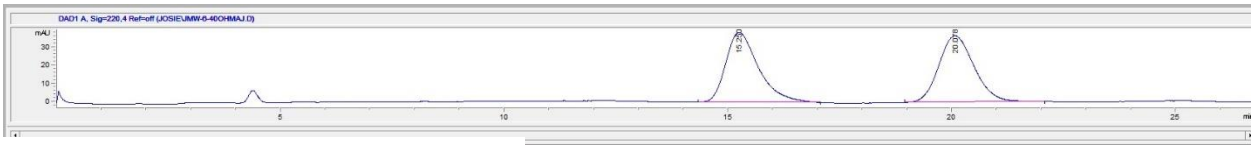
Aldehydes were derivatized to the corresponding α and β alcohols by reduction with $NaBH_4$ in MeOH. As the enantiomeric ratio differed between the α and β alcohols in some cases, the overall enantiomeric ratio was calculated as follows:

Enantiomeric excess = [(area of ma*J*or HPLC peak of α alcohol x ^{1}H NMR ratio of α aldehyde) + (area of ma*J*or HPLC peak of β alcohol x ^{1}H NMR ratio of β aldehyde)) - (area of minor HPLC peak of α alcohol ^{1}H NMR ratio of α aldehyde) + area of minor HPLC peak of β alcohol x ^{1}H NMR ratio of β aldehyde))]/total peak area



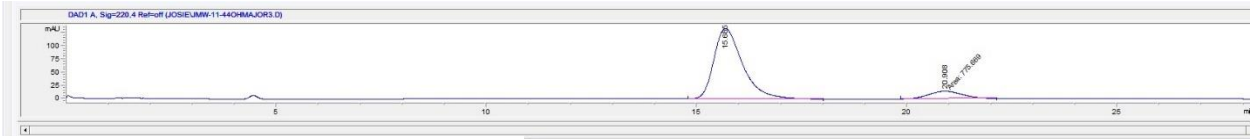
95:5 hexanes/iPrOH, Daicel Chiralcel O*J*-H, 1 mL/min

Racemic:

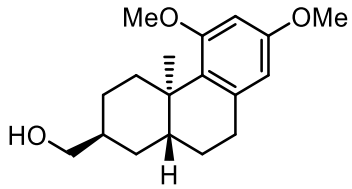


#	Time	Area	Height	Width	Area%	Symmetry
1	15.25	1944.5	38.2	0.7337	49.458	0.65
2	20.078	1987.1	36.3	0.7885	50.542	0.831

Asymmetric:

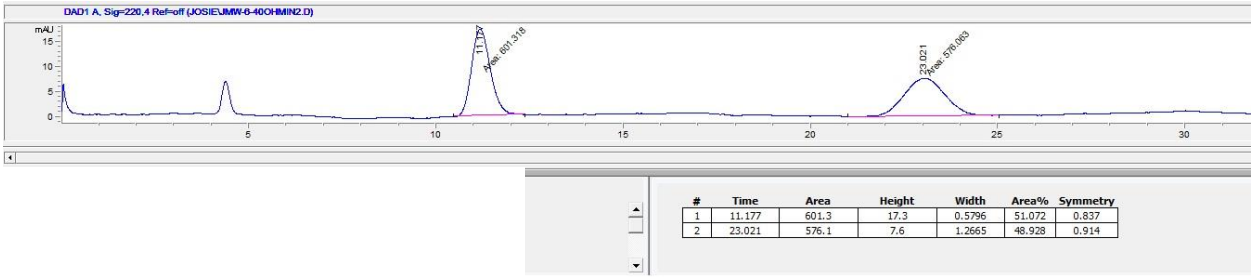


#	Time	Area	Height	Width	Area%	Symmetry
1	15.685	6323.8	133.6	0.7223	89.074	0.624
2	20.908	775.7	14	0.9221	10.926	0.922



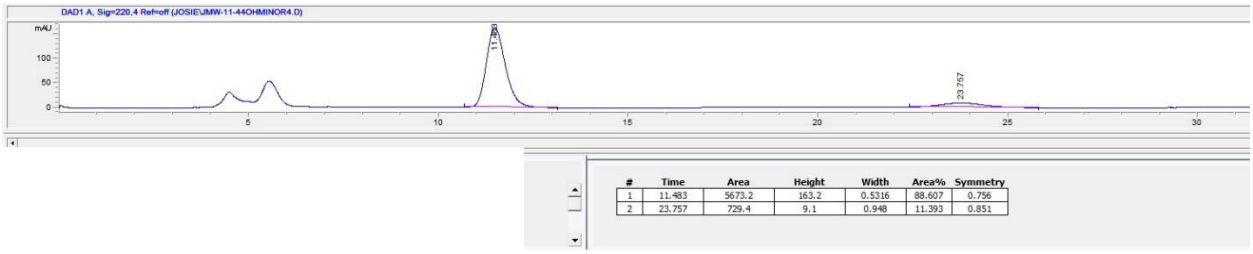
93:7 hexanes/iPrOH, Daicel Chiralcel O*J*-H, 1 mL/min

Racemic:

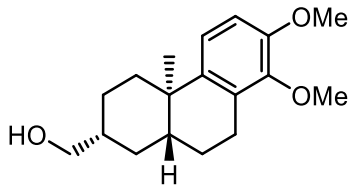


#	Time	Area	Height	Width	Area%	Symmetry
1	11.177	601.3	17.3	0.5796	51.072	0.837
2	23.021	576.1	7.6	1.2665	48.928	0.914

Asymmetric:

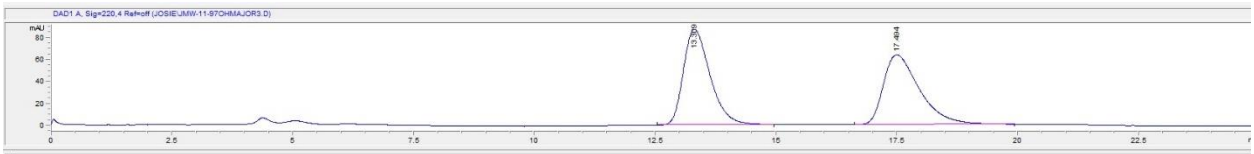


#	Time	Area	Height	Width	Area%	Symmetry
1	11.483	5673.2	163.2	0.5316	88.607	0.756
2	23.757	729.4	9.1	0.948	11.393	0.851



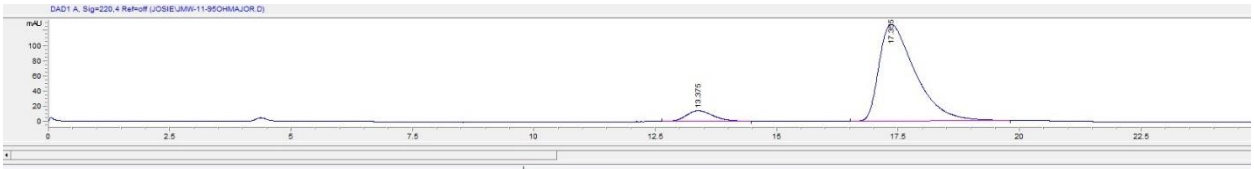
90:10 hexanes/iPrOH, Daicel Chiralcel O*J*-H, 1 mL/min

Racemic:

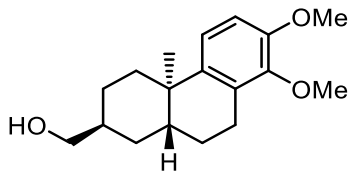


#	Time	Area	Height	Width	Area%	Symmetry
1	13.309	3348.2	87.3	0.5895	50.262	0.666
2	17.494	3313.3	63.5	0.7587	49.738	0.55

Asymmetric:

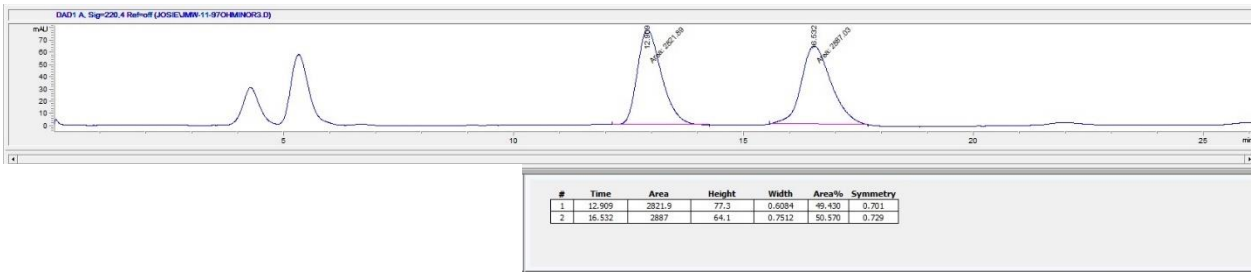


#	Time	Area	Height	Width	Area%	Symmetry
1	13.375	534	14	0.5303	7.480	0.756
2	17.355	6605.1	127.7	0.7633	92.520	0.479



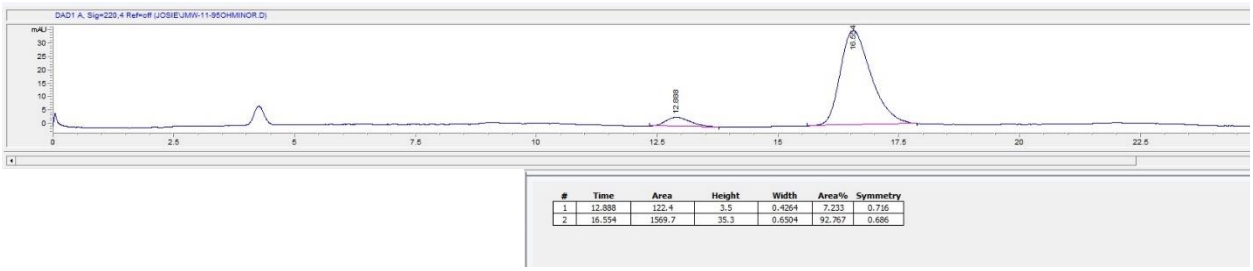
95:5 hexanes/iPrOH, Daicel Chiralcel O*J*-H, 1 mL/min

Racemic:

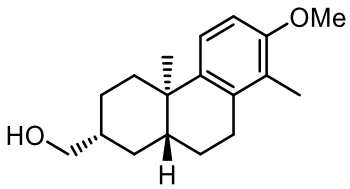


#	Time	Area	Height	Width	Area%	Symmetry
1	12.909	2821.9	77.3	0.6084	49.430	0.701
2	16.532	2887	64.1	0.7512	50.570	0.729

Asymmetric:

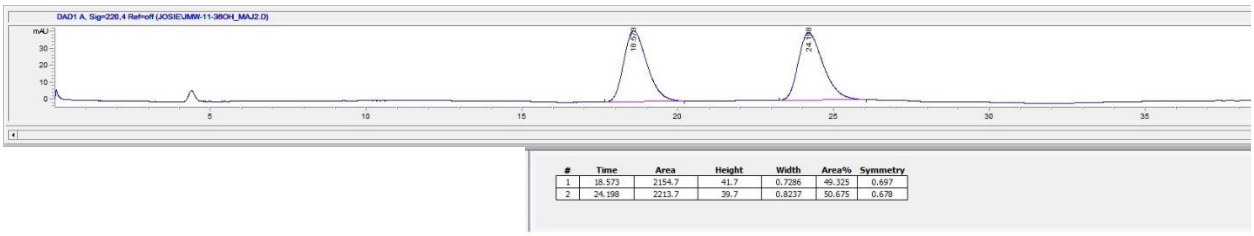


#	Time	Area	Height	Width	Area%	Symmetry
1	12.888	122.4	3.5	0.4264	7.233	0.716
2	16.554	1569.7	35.3	0.6504	92.767	0.686

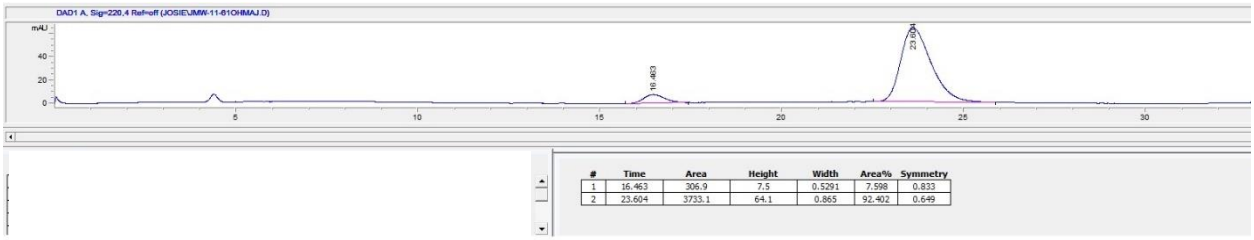


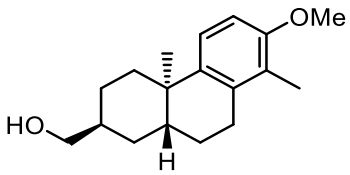
95:5 hexanes/iPrOH, Daicel Chiralcel O*J*-H, 1 mL/min

Racemic:



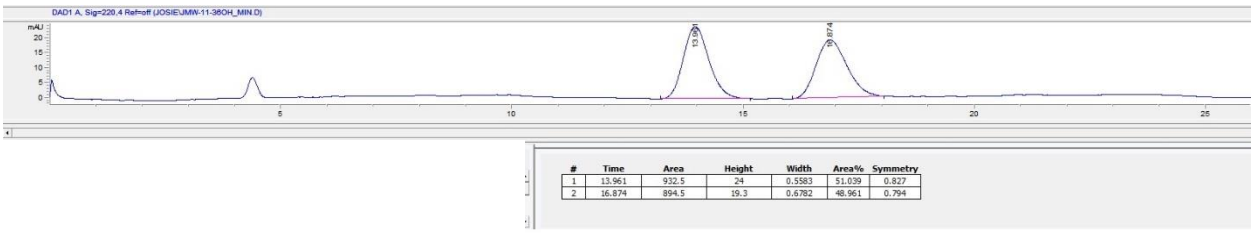
Asymmetric:





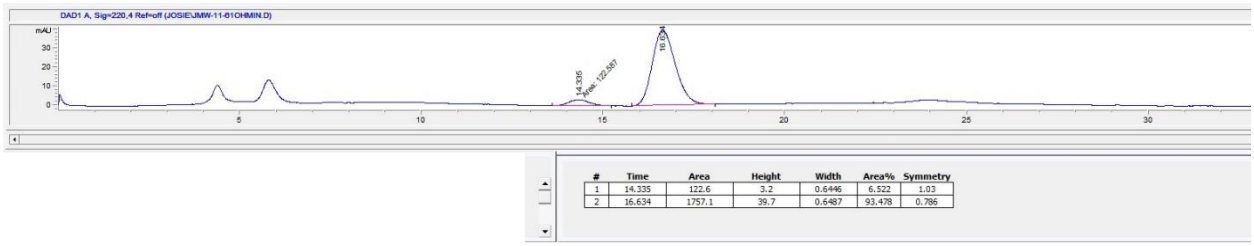
95:5 hexanes/iPrOH, Daicel Chiralcel O*J*-H, 1 mL/min

Racemic:

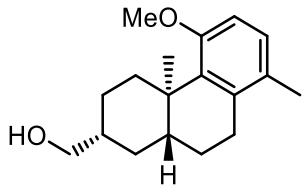


#	Time	Area	Height	Width	Area%	Symmetry
1	13.961	932.5	24	0.5583	51.039	0.827
2	16.874	894.5	19.3	0.6782	48.961	0.794

Asymmetric:

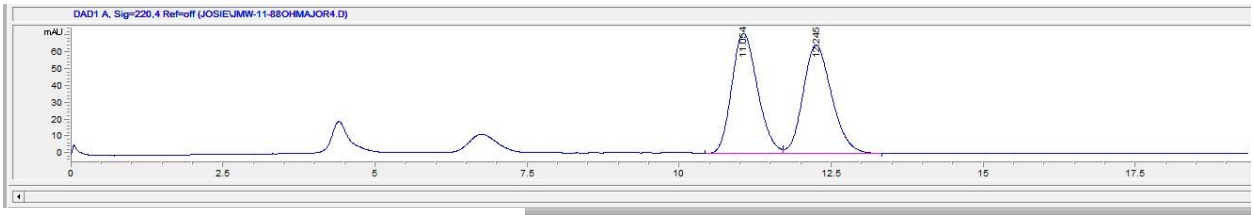


#	Time	Area	Height	Width	Area%	Symmetry
1	14.335	122.6	3.2	0.6446	6.522	1.03
2	16.634	1757.1	39.7	0.6487	93.478	0.786



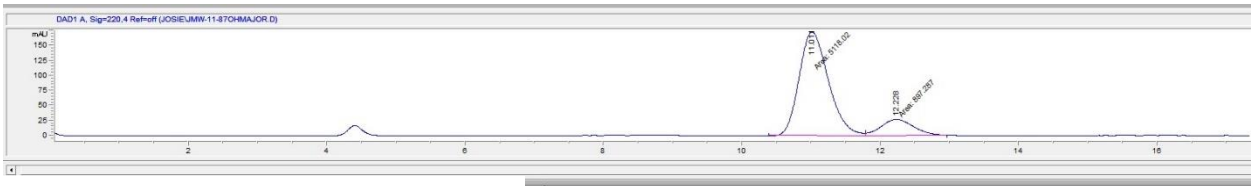
95:5 hexanes/iPrOH, Daicel Chiralcel O*J*-H, 1 mL/min

Racemic:

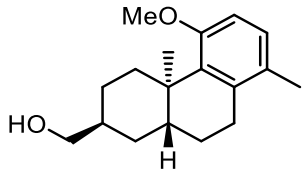


#	Time	Area	Height	Width	Area%	Symmetry
1	11.054	2103.1	71.4	0.4595	49.927	0.804
2	12.245	2109.3	64.4	0.5098	50.073	0.785

Asymmetric:

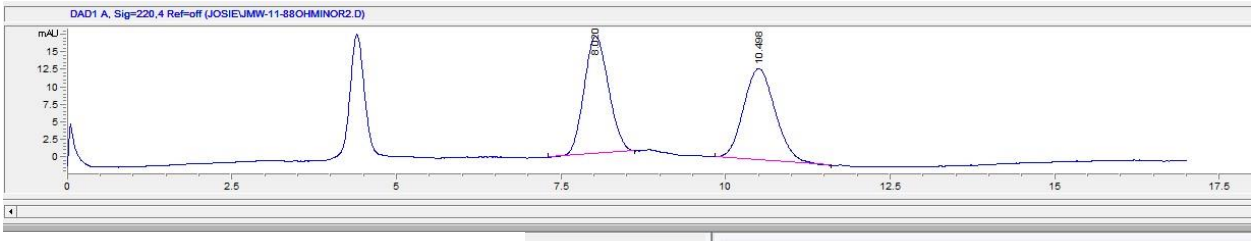


#	Time	Area	Height	Width	Area%	Symmetry
1	11.011	5118	172.9	0.4934	85.083	0.758
2	12.228	897.3	27.2	0.5497	14.917	0.864



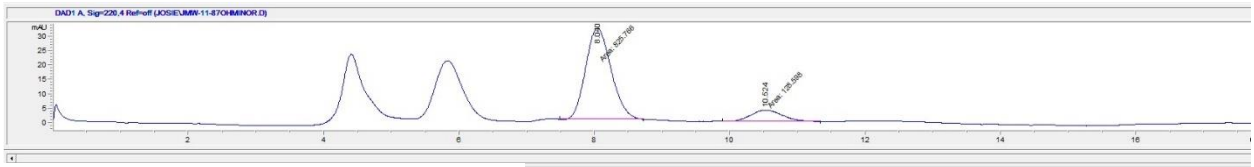
97:3 hexanes/iPrOH, Daicel Chiralcel O*J*-H, 1 mL/min

Racemic:

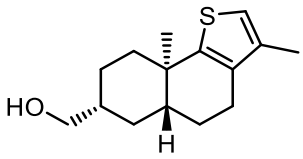


#	Time	Area	Height	Width	Area%	Symmetry
1	8.02	435.3	16.8	0.4048	49.887	0.861
2	10.498	437.3	13.1	0.5066	50.113	0.855

Asymmetric:

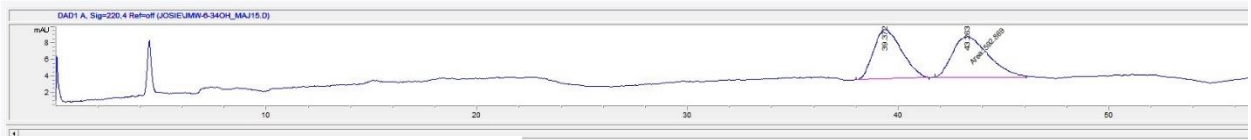


#	Time	Area	Height	Width	Area%	Symmetry
1	8.04	825.8	31.6	0.4353	86.525	0.819
2	10.524	128.6	3.9	0.5451	13.475	0.845



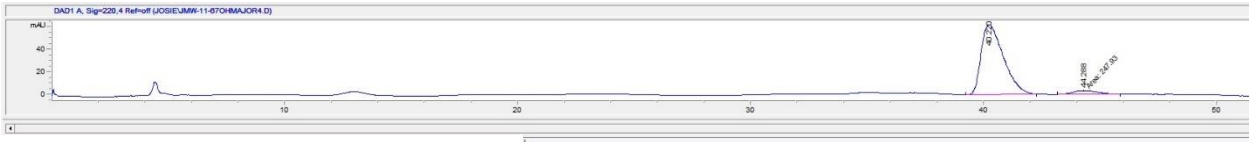
99.4:0.6 hexanes/iPrOH, Daicel Chiralcel O*J*-H, 1 mL/min

Racemic:

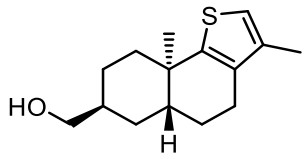


#	Time	Area	Height	Width	Area%	Symmetry
1	39.372	557.7	6	1.1027	48.471	0.7
2	43.263	592.9	4.9	1.9984	51.529	0.671

Asymmetric:

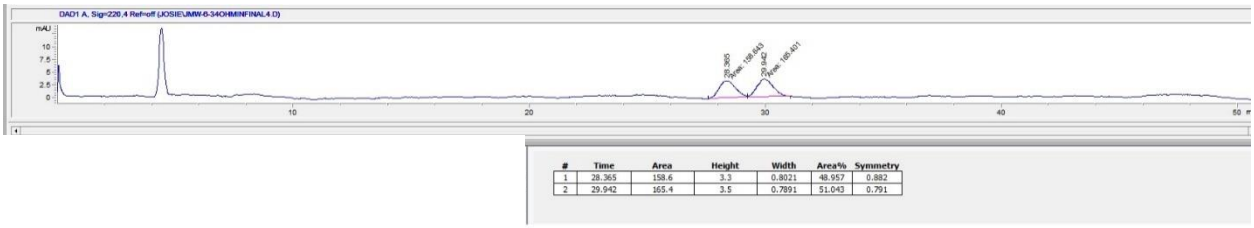


#	Time	Area	Height	Width	Area%	Symmetry
1	40.22	4131.1	62	0.9295	94.338	0.519
2	44.288	247.9	3.4	1.2252	5.662	0.816



99.4:0.6 hexanes/iPrOH, Daicel Chiralcel O*J*-H, 1 mL/min

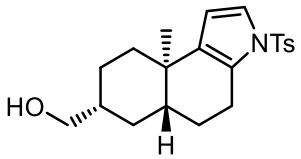
Racemic:



#	Time	Area	Height	Width	Area%	Symmetry
1	28.365	158.6	3.3	0.8021	48.957	0.882
2	29.942	165.4	3.5	0.7891	51.043	0.791

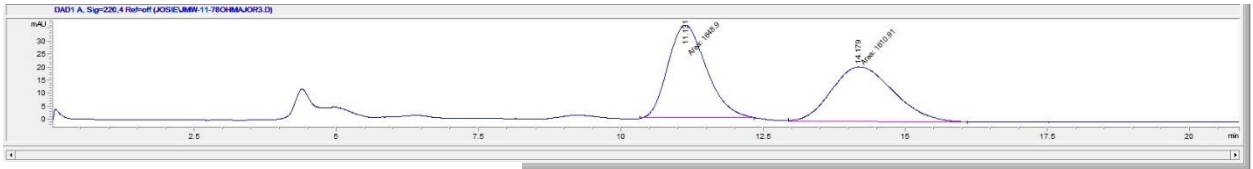
Asymmetric:

#	Time	Area	Height	Width	Area%	Symmetry
1	29.413	8225.7	144.9	0.8404	96.022	0.491
2	33.18	340.8	5.7	0.9901	3.978	0.73



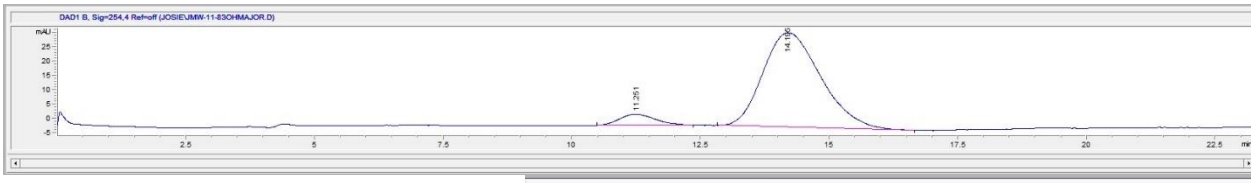
80:20 hexanes/iPrOH, Daicel Chiralcel O*J*-H, 1 mL/min

Racemic:

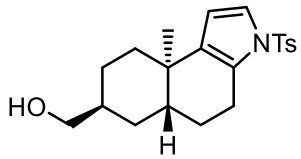


#	Time	Area	Height	Width	Area%	Symmetry
1	11.131	1648.9	35.4	0.7764	50.583	0.792
2	14.179	1610.9	21	1.2779	49.417	0.75

Asymmetric:

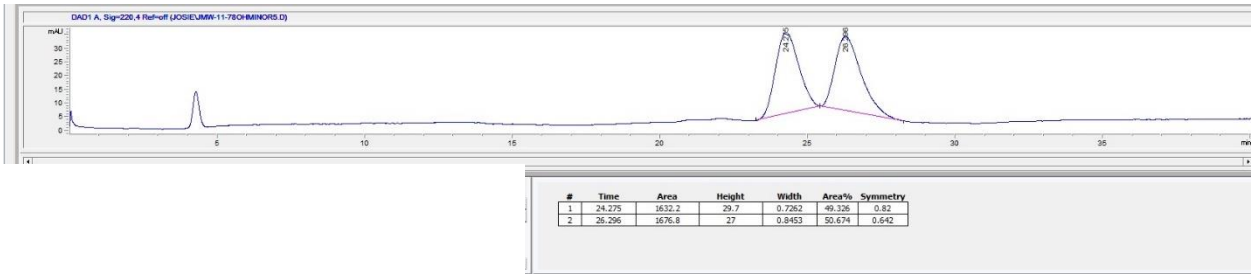


#	Time	Area	Height	Width	Area%	Symmetry
1	11.251	184.7	3.9	0.5619	6.683	0.856
2	14.195	2579.7	32.9	0.9334	93.317	0.732



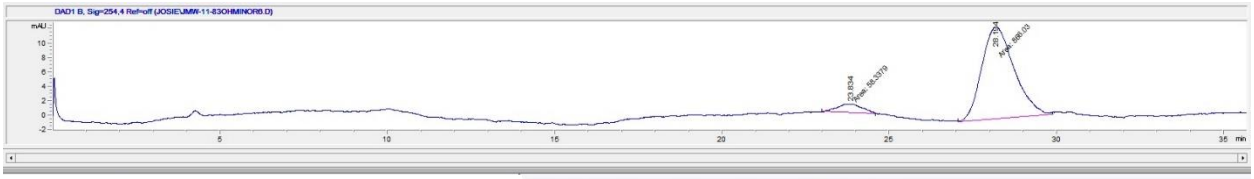
95:5 hexanes/iPrOH, Daicel Chiralcel O*J*-H, 1 mL/min

Racemic:

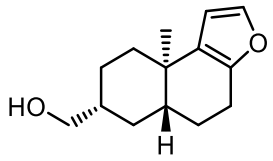


#	Time	Area	Height	Width	Area%	Symmetry
1	24.275	1632.2	29.7	0.7262	49.326	0.82
2	26.296	1676.8	27	0.8453	50.674	0.642

Asymmetric:

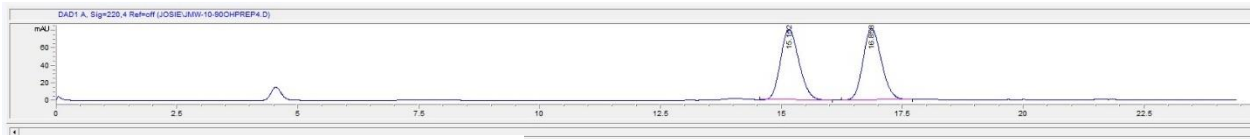


#	Time	Area	Height	Width	Area%	Symmetry
1	23.834	58.3	1.1	0.8496	6.311	0.723
2	28.194	866	12.8	1.1286	93.689	0.798



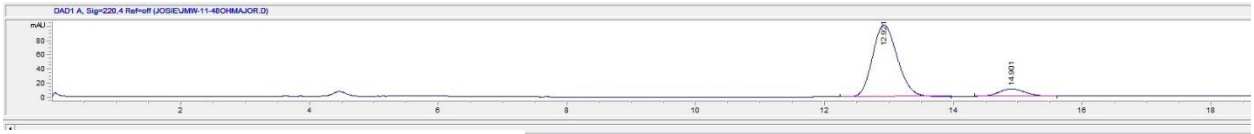
97:3 hexanes/iPrOH, Daicel Chiralcel O*J*-H, 1 mL/min

Racemic:

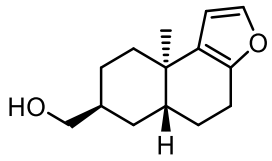


#	Time	Area	Height	Width	Area%	Symmetry
1	15.152	2135.9	80.4	0.4139	49.853	0.816
2	16.858	2148.5	81.4	0.414	50.147	0.82

Asymmetric:

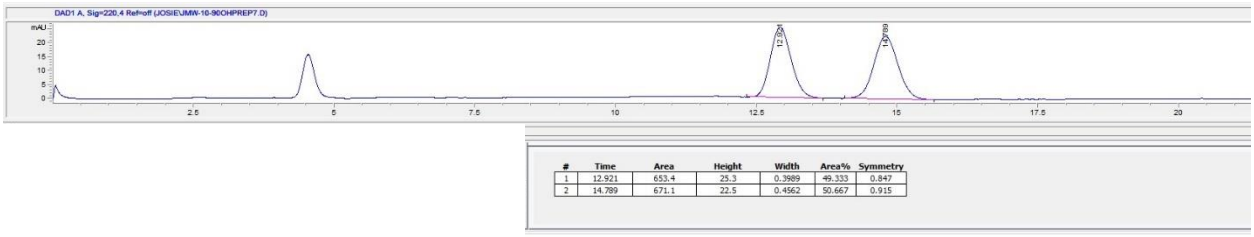


#	Time	Area	Height	Width	Area%	Symmetry
1	12.921	2699.9	101.6	0.4141	90.346	0.815
2	14.901	288.5	10.3	0.3816	9.654	0.884



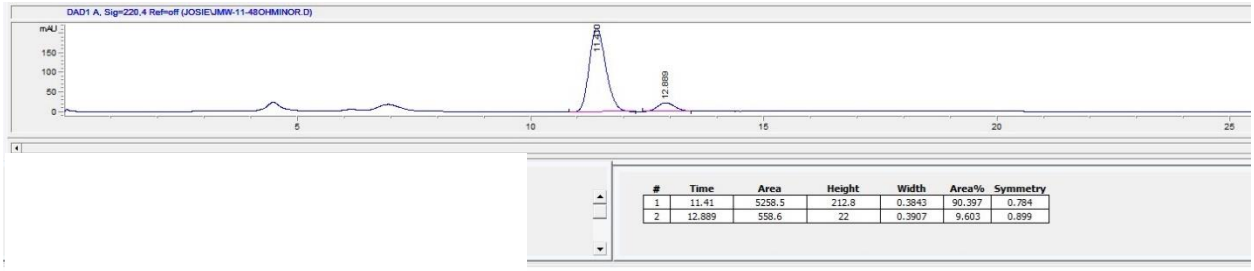
97:3 hexanes/iPrOH, Daicel Chiralcel O*J*-H, 1 mL/min

Racemic:

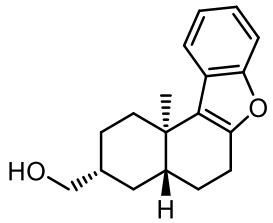


#	Time	Area	Height	Width	Area%	Symmetry
1	12.921	653.4	25.3	0.3989	49.333	0.847
2	14.789	671.1	22.5	0.4562	50.667	0.915

Asymmetric:

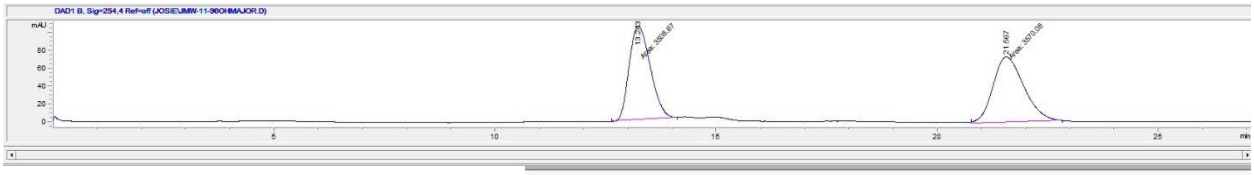


#	Time	Area	Height	Width	Area%	Symmetry
1	11.41	5258.5	212.8	0.3843	90.397	0.784
2	12.889	558.6	22	0.3907	9.603	0.899



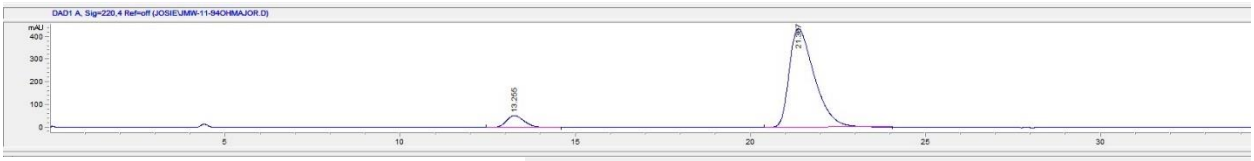
95:5 hexanes/iPrOH, Daicel Chiralcel O*J*-H, 1 mL/min

Racemic:

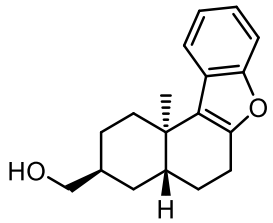


#	Time	Area	Height	Width	Area%	Symmetry
1	13.243	3508.7	105.5	0.554	49.566	0.745
2	21.567	3570.1	73.4	0.8106	50.434	0.745

Asymmetric:

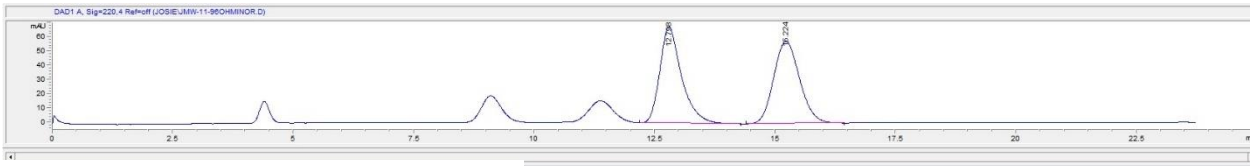


#	Time	Area	Height	Width	Area%	Symmetry
1	13.255	1797.9	51.2	0.55	7.635	0.773
2	21.367	21751.7	435.7	0.7605	92.365	0.538



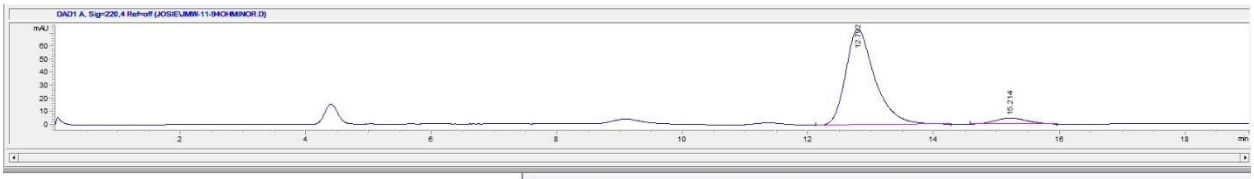
95:5 hexanes/iPrOH, Daicel Chiralcel O*J*-H, 1 mL/min

Racemic:

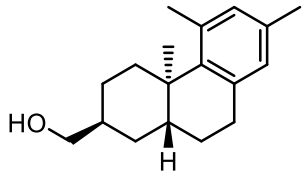


#	Time	Area	Height	Width	Area%	Symmetry
1	12.798	2116.4	67.4	0.4686	49.511	0.677
2	15.224	2158.2	57.7	0.5766	50.489	0.851

Asymmetric:



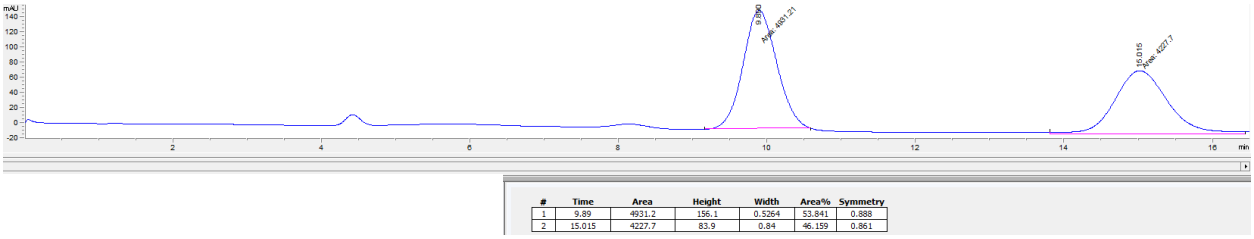
#	Time	Area	Height	Width	Area%	Symmetry
1	12.792	2373.6	73.4	0.4791	93.520	0.677
2	15.214	164.5	4.6	0.4315	6.480	0.849



97:3 hexanes/iPrOH, Daicel Chiralcel O*J*-H, 1 mL/min

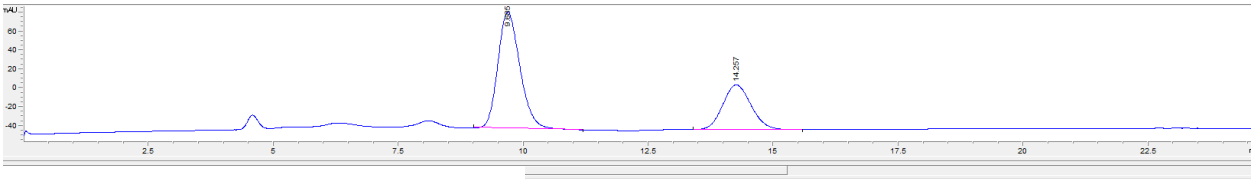
Enantiomeric excess = (area of ma*J*or HPLC peak of α alcohol - area of minor HPLC peak of α alcohol)/total peak area

Racemic:



#	Time	Area	Height	Width	Area%	Symmetry
1	9.89	4931.2	156.1	0.5264	53.841	0.888
2	15.015	4227.7	83.9	0.84	46.159	0.861

Asymmetric:



#	Time	Area	Height	Width	Area%	Symmetry
1	9.685	3797.3	123.2	0.4756	67.187	0.762
2	14.257	1854.5	47.3	0.6057	32.813	0.881

X. References

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