Electronic Supplementary Material (ESI) for Organic & Biomolecular Chemistry

Enantioselective Morita–Baylis–Hillman Reaction Promoted by L-Threonine-Derived Phosphine–Thiourea Catalysts

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Supporting Information

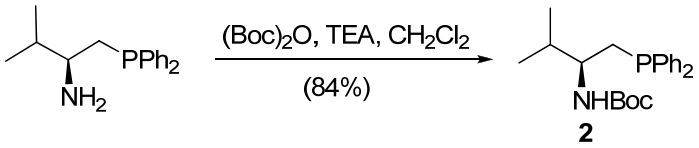
A. General Information

All the starting materials were obtained from commercial sources and used without further purification unless otherwise stated. Toluene, THF and diethyl ether were dried and distilled from sodium benzophenone ketyl prior to use. $CHCl_3$ and CH_2Cl_2 were distilled from CaH_2 prior to use. Dioxane was dried and distilled from Na prior to use. All the solvents used in reactions involving phosphorous-containing compounds were de-gassed by N_2. ^1H and ^{13}C NMR spectra were recorded on a Bruker ACF300 or AMX500 (500 MHz) spectrometer. Chemical shifts were reported in parts per million (ppm), and the residual solvent peak was used as an internal reference: proton (chloroform δ 7.26), carbon (chloroform δ 77.0). Multiplicity was indicated as follows: s (singlet), d (doublet), t (triplet), q (quartet), m (multiplet), dd (doublet of doublet), br s (broad singlet). Coupling constants were reported in Hertz (Hz). Low resolution mass spectra were obtained on a Finnigan/MAT LCQ spectrometer in ESI mode, and a Finnigan/MAT 95XL- T mass spectrometer in FAB mode. All high resolution mass spectra were obtained on a Finnigan/MAT 95XL- T spectrometer. For thin layer chromatography (TLC), Merck pre- coated TLC plates (Merck 60 F254) were used, and compounds were visualized with a UV light at 254 nm. Further visualization was achieved by staining with iodine, or ceric ammonium molybdate followed by heating on a hot plate. Flash chromatographic separations were performed on Merck 60 (0.040- 0.063 mm) mesh silica gel. The enantiomeric excesses of products were determined by chiral-phase HPLC analysis.

The absolute configuration of **12a** was assigned by comparing its specific rotation with that of known compound reported in the literature.[1] The configurations of other MBH adducts were assigned by analogy.

B. Preparation of the Catalysts

(*S*)-*tert*-Butyl 1-(diphenylphosphino)-3-methylbutan-2-ylcarbamate 2

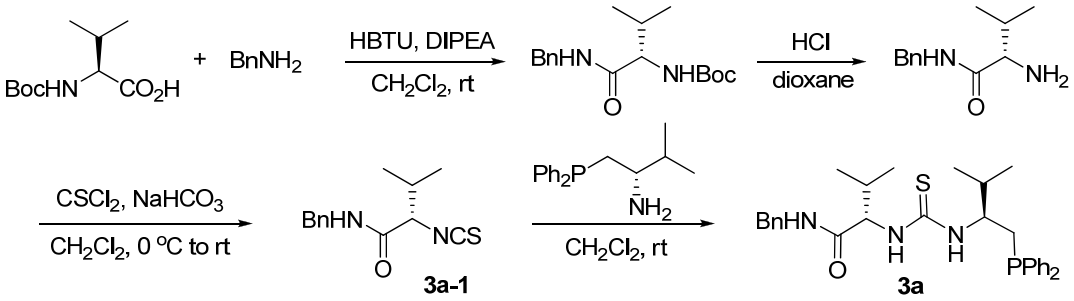


2

To a solution of (*S*)-1-(diphenylphosphino)-3-methylbutan-2-amine (150 mg, 0.55 mmol) and Et_3N (153 μL, 1.10 mmol) in CH_2Cl_2 (5 mL) under N_2 was added $(Boc)_2O$ (143 mg, 0.66 mmol). The reaction mixture was stirred at room temperature for 2 hrs, solvent was then removed under reduced pressure, and the residue was directly purified by column chromatography on silica gel (hexane/ethyl acetate = 15:1 to 10: 1) to afford catalyst **2** as a white solid (171 mg, 84% yield).

^{1}H NMR (300 MHz, $CDCl_3$) δ 7.44-7.32 (m, 10H), 4.40-4.38 (m, 1H), 3.59 (br, 1H), 2.30-2.12 (m, 2H), 1.93-1.87 (m, 1H), 1.43 (s, 9H), 0.88 (d, *J* = 4.4 Hz, 3H), 0.86 (d, *J* = 4.4 Hz, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 115.3, 146.8, 138.9, 138.8, 138.5, 133.1, 132.9, 132.8, 132.7, 128.7, 128.5, 128.5, 128.5, 128.5, 128.4, 85.2, 78.8, 53.6 (d), 32.5, 28.4, 27.4, 18.9, 17.6; ^{31}P NMR (121 MHz, $CDCl_3$) δ -22.2; HRMS (ESI) m/z calcd for $C_{22}H_{31}NO_2P$ $[M+H]^+$ = 372.2087, found = 372.2079.

Prepartion of serine-derived dipeptidic phosphinothiourea catalyst 3a

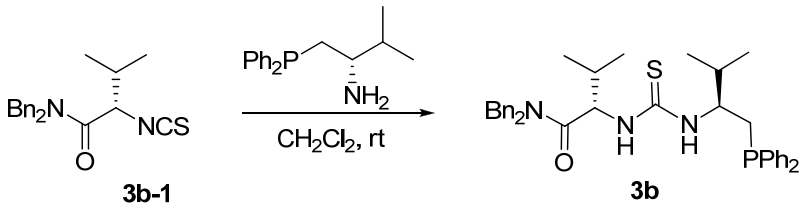


(*S*)-*N*-Benzyl-4-((*S*)-1-(diphenylphosphino)-3-methylbutan-2-ylamino)-2-isopropyl-4-thioxobutanamide 3a

To a solution of isothiocyanide **3a-1**[2] (82 mg, 0.33 mmol) in CH_2Cl_2 (1 mL) under N_2 was added (*S*)-1 (diphenylphosphino)-3-methylbutan-2-amine (81.4 mg, 0.3 mmol). The mixture was stirred at room temperature for 24 h, the solvent was then removed under reduced pressure, and the residue was directly subjected to column chromatographic separation on silica gel (hexane/ethyl acetate =15:1 to 8: 1) to afford catalyst **3a** as a white solid (135 mg, 79% yield).

^{1}H NMR (500 MHz, $CDCl_3$) δ 7.44-7.40 (m, 4H), 7.31-7.24 (m, 11H), 6.84 (br, 1H), 4.81 (s, 1H), 4.46-4.42 (m, 3H), 2.40-2.36 (m, 1H), 2.28-2.13 (m, 1H), 2.07 (s, 1H), 2.03-1.98 (m, 1H), 0.98-0.89 (m, 6H), 0.83(s, 6H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 137.3, 132.8 (dd), 128.6, 128.4 (d), 127.4, 64.1, 57.6 (d), 43.5, 31.9 (d), 30.9, 19.4, 18.8, 18.1; ^{31}P NMR (121 MHz, $CDCl_3$) δ -23.1; HRMS (ESI) m/z calcd for $C_{30}H_{39}N_3OPS$ $[M+H]^+$ = 520.2551, found = 520.2550.

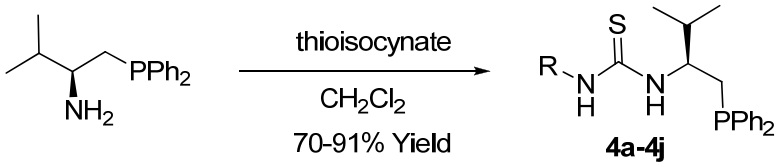
(*S*)-*N*,*N*-Dibenzyl-4-((*S*)-1-(diphenylphosphino)-3-methylbutan-2-ylamino)-2-isopropyl-4-thioxobutanamide 3b



Catalyst **3b** was prepared from *N*-Boc-L-Valine, following the same procedure described for the synthesis of **3a**.

A white solid (67% yield); ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.71 (br, 1H), 7.41-7.27(m, 18H), 7.25 (d, *J* = 5.1 Hz, 2H), 5.80 (br, 1H), 4.72 (s, 4H), 4.38 (d, *J* = 13.8 Hz, 1H), 2.38-2.35 (m, 1H), 2.34-2.22 (m, 2H), 2.14-1.97 (m, 1H), 0.98 (d, *J* = 6.3 Hz, 3H), 0.88 (d, *J* = 7.0 Hz, 3H), 0.81 (d, *J* = 5.7 Hz, 6H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 138.9, 136.3 (d), 132.9 (dd), 132.8, 128.6 (d), 128.3 (d), 127.9 (d), 127.4, 57.3 (d), 50.5, 47.9, 31.9 (dd), 19.6 (d), 18.8, 17.9; ^{31}P NMR (202 MHz, $CDCl_3$) δ -23.4; HRMS (ESI) m/z calcd for $C_{37}H_{45}N_3OPS$ $[M+H]^+$ = 610.3021, found = 610.3023.

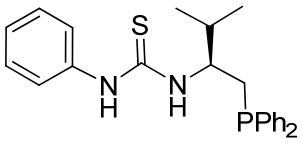
Typical procedure for preparation of catalysts 4a-4j



4a-4j

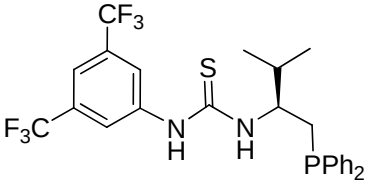
To a solution of (*S*)-1-(diphenylphosphino)-3-methylbutan-2-amine[3] (81 mg, 0.30 mmol) in CH_2Cl_2 (2 mL) under N_2 was added isothiocyanate (1.1 eq., 0.33 mmol), and the reaction mixture was stirred at room temperature for 24 hrs. Solvent was then removed under reduced pressure, and the residue was directly subjected to column chromatographic separation on silica gel (hexane/ethyl acetate = 12:1 to 8: 1) to afford catalyst **4a-4j** as a white solid (71-95% yield).

(*S*)-1-(1-(Diphenylphosphino)-3-methylbutan-2-yl)-3-phenylthiourea 4a



A white solid (86% yield); ^{1}H NMR (300 MHz, $CDCl_3$) δ 8.05 (br, 1H), 7.42-7.16(m, 13H), 7.00 (d, *J* = 10.3 Hz, 2H), 5.92 (d, *J* = 11.4 Hz, 1H), 4.50 (br, 1H), 2.36-2.30 (m, 1H), 2.24-2.17 (m, 1H), 2.09-2.00 (m, 1H), 0.80 (d, *J* = 9.0 Hz, 3H), 0.75 (d, *J* = 9.0 Hz, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 180.1, 135.9, 132.9 (d), 132.7 (d), 130.1, 128.5 (dd), 127.1, 125.2, 58.5 (d), 31.7 (d), 31.2 (d), 18.8, 17.9; ^{31}P NMR (121 MHz, $CDCl_3$) δ -23.9; HRMS (ESI) m/z calcd for $C_{24}H_{28}N_2PS$ $[M+H]^+$ = 407.1711, found = 407.1711.

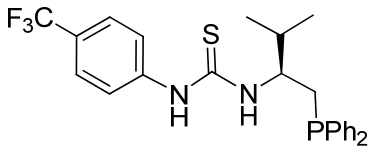
(*S*)-1-(3,5-Bis(trifluoromethyl)phenyl)-3-(1-(diphenylphosphino)-3-methylbutan-2-yl)thiourea 4b



A white solid (86% yield); ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.23 (br, 1H), 7.66 (d, *J* = 12.6 Hz, 3H), 7.44 (t, *J* = 2.9 Hz, 4H), 7.42-7.29 (m, 6H), 6.22 (br, 1H), 4.62(br, 1H), 2.54-2.52 (m, 1H), 2.51-2.49 (m, 1H), 2.34-2.16 (m, 1H), 0.95

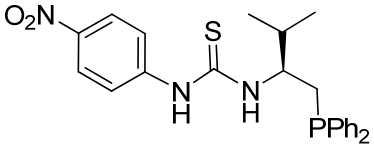
(t, *J* = 7.8 Hz, 6H); ^{31}P NMR (202 MHz, $CDCl_3$) δ -23.2; HRMS (ESI) m/z calcd for $C_{26}H_{26}F_6N_2PS$ $[M+H]^+$ = 543.1459, found = 543.1459. The characterization data were in agreement with the values reported in the literature.[4]

(*S*)-1-(1-(Diphenylphosphino)-3-methylbutan-2-yl)-3-(4-(trifluoromethyl)phenyl)thiourea 4c



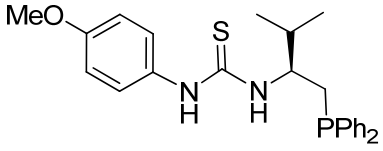
A white solid (81% yield); ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.59 (br, 1H), 7.58 (d, *J* = 8.2 Hz, 2H), 7.47-7.41 (m, 4H), 7.31(d, *J* = 3.8 Hz, 6H), 7.22 (d, *J* = 7.6 Hz, 2H), 6.19 (br, 1H), 4.64 (br, 1H), 2.50-2.46 (m, 1H), 2.32-2.27 (m, 1H), 2.19-2.15 (m, 1H), 0.91 (t, *J* = 7.3 Hz, 6H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 179.6, 139.8, 137.9, 132.8 (d), 132.6, 128.8 (d), 128.5 (dd), 127.9, 127.7, 128.2, 126.9, 124.8, 123.6, 122.7, 58.7 (d), 31.9, 30.8 (d), 18.5 (d); ^{31}P NMR (202 MHz, $CDCl_3$) δ -24.1; HRMS (ESI) m/z calcd for $C_{25}H_{27}F_3N_2PS$ $[M+H]^+$ = 475.1585, found = 475.1582.

(*S*)-1-(1-(Diphenylphosphino)-3-methylbutan-2-yl)-3-(4-nitrophenyl)thiourea 4d



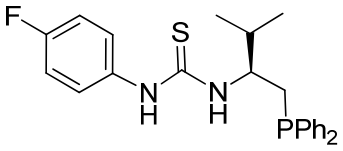
A white solid (86% yield); ^{1}H NMR (300 MHz, $CDCl_3$) δ 8.76 (br, 1H), 8.14-8.11 (m, 2H), 7.46-7.30 (m, 12H), 6.49 (br, 1H), 4.62 (br, 1H), 2.55-2.53 (m, 1H), 2.50-2.48 (m, 1H), 2.35-2.15 (m, 1H), 0.95 (s, 3H), 0.93 (s, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 179.4, 143.9, 143.3, 138.0 (d), 137.4, 132.7 (d), 128.8 (dd), 125.3, 122.1, 58.6 (d), 32.0, 30.7, 18.5; ^{31}P NMR (121 MHz, $CDCl_3$) δ -23.7; HRMS (ESI) m/z calcd for $C_{24}H_{27}N_3O_2PS$ $[M+H]^+$ = 452.1562, found = 452.1560.

(*S*)-1-(1-(Diphenylphosphino)-3-methylbutan-2-yl)-3-(4-methoxyphenyl)thiourea 4e



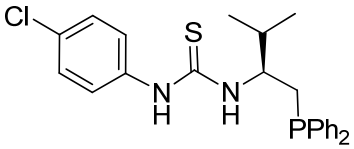
A white solid (75% yield); ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.60 (br, 1H), 7.48-7.41 (m, 4H), 7.36-7.31 (m, 6H), 7.00-6.96 (m, 2H), 6.89-6.84 (m, 2H), 5.78 (d, *J* = 8.2 Hz, 1H), 4.55 (br, 1H), 3.80 (s, 3H), 2.44-2.37 (m, 1H), 2.29-2.21 (m, 1H), 2.16-2.05 (m, 1H), 0.86 (d, *J* = 6.7 Hz, 3H), 0.80 (d, *J* = 6.7 Hz, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 180.7, 158.8, 132.9 (d), 132.6 (d), 128.6, 128.3 (dd), 127.68, 115.1, 58.3 (d), 55.4, 31.7 (d), 31.2 (d), 18.8, 17.9, ^{31}P NMR (121 MHz, $CDCl_3$) δ -24.1; HRMS (ESI) m/z calcd for $C_{25}H_{30}N_2O_3PS$ $[M+H]^+$ = 437.1816, found = 437.1811.

(*S*)-1-(1-(Diphenylphosphino)-3-methylbutan-2-yl)-3-(4-fluorophenyl)thiourea 4f



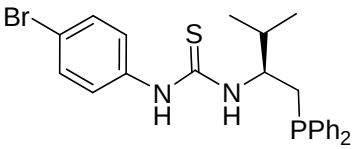
A white solid (91% yield); ^{1}H NMR (300 MHz, $CDCl_3$) δ 8.05 (br, 1H), 7.46-7.40 (m, 4H), 7.32-7.31(m, 6H), 7.04 (d, *J* = 6.8 Hz, 4H), 5.83 (d, *J* = 5.9 Hz, 1H), 4.57 (br, 1H), 2.47-2.44 (m, 1H), 2.42-2.40 (m, 1H), 2.28-2.04 (m, 1H), 0.86 (d, *J* = 6.8 Hz, 3H), 0.83 (d, *J* = 6.8 Hz, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 180.3, 162.9, 159.6, 138.1, 132.9 (d), 132.6 (d), 131.8, 128.7, 128.5 (dd), 127.7, 127.6, 117.0, 116.7, 58.44(d), 31.8 (d), 31.1 (d), 18.7, 18.1; ^{31}P NMR (121 MHz, $CDCl_3$) δ -24.3; HRMS (ESI) m/z calcd for $C_{24}H_{27}FN_2PS$ $[M+H]^+$ = 425.1617, found = 425.1624.

(*S*)-1-(4-Chlorophenyl)-3-(1-(diphenylphosphino)-3-methylbutan-2-yl)thiourea 4g



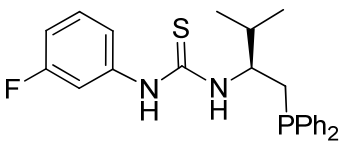
A white solid (81% yield); ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.20 (br, 1H), 7.46-7.41 (m, 4H), 7.32-7.29 (m, 7H), 7.02 (d, *J* = 8.2 Hz, 2H), 5.95 (br, 1H), 4.60 (br, 1H), 2.47-2.45 (m, 1H), 2.44-2.42 (m, 1H), 2.28-2.11 (m, 1H), 0.88 (d, *J* = 6.3 Hz, 3H), 0.85 (d, *J* = 7.0 Hz, 3H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 179.9, 138.2 (d), 132.8 (d), 132.5 (dd), 130.1, 128.8 (d), 128.5 (d), 128.5, 126.3, 58.5 (d), 31.8 (d), 31.0 (d), 18.7, 18.2; ^{31}P NMR (202 MHz, $CDCl_3$) δ -24.2; HRMS (ESI) m/z calcd for $C_{24}H_{27}ClN_2PS$ $[M+H]^+$ = 441.1321, found = 441.1322.

(*S*)-1-(4-Bromophenyl)-3-(1-(diphenylphosphino)-3-methylbutan-2-yl)thiourea 4h



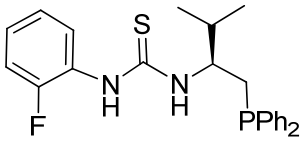
A white solid (75% yield); ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.07 (br, 1H), 7.41-7.36 (m, 6H), 7.27-7.25 (m, 6H), 6.90 (d, *J* = 8.2 Hz, 2H), 5.90 (br, 1H), 4.54 (br, 1H), 2.42-2.38 (m, 1H), 2.23-2.18 (m, 1H), 2.10-2.07 (m, 1H), 0.84 (d, *J* = 7.0 Hz, 3H), 0.81 (d, *J* = 6.9 Hz, 3H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 179.9, 138.2 (d), 135.1, 132.8 (dd), 128.8 (d), 128.5 (d), 126.5, 120.2, 58.6 (d), 31.85 (d), 30.9 (d), 18.7, 18.3; ^{31}P NMR (202 MHz, $CDCl_3$) δ -24.2; HRMS (ESI) m/z calcd for $C_{24}H_{27}BrN_2PS$ $[M+H]^+$ = 485.0816, found = 485.0815.

(*S*)-1-(1-(Diphenylphosphino)-3-methylbutan-2-yl)-3-(3-fluorophenyl)thiourea 4i



A white solid (79% yield); ^{1}H NMR (300 MHz, $CDCl_3$) δ 8.05 (br, 1H), 7.41-7.34 (m, 4H), 7.33-7.17 (m, 7H), 6.88-6.74 (m, 3H), 6.02 (d, *J* = 11.6 Hz, 1H), 4.52 (br, 1H), 2.40-2.38 (m, 1H), 2.36-2.34 (m, 1H), 2.23-2.02 (m, 1H), 0.86 (d, *J* = 2.9 Hz, 3H), 0.82 (d, *J* = 2.9 Hz, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 179.7, 164.8, 161.5, 138.1 (d), 137.8 (d), 132.8 (dd), 131.1 (d), 128.7, 128.5 (dd), 119.9 (d), 113.5 (d), 111.8 (d), 58.6 (d), 31.8 (d), 31.0 (d), 18.7, 18.2; ^{31}P NMR (121 MHz, $CDCl_3$) δ -24.1; HRMS (ESI) m/z calcd for $C_{24}H_{27}FN_2PS$ $[M+H]^+$ = 425.1617, found = 425.1621.

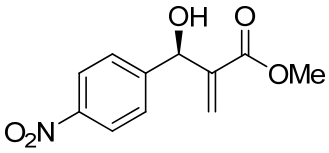
(*S*)-1-(1-(Diphenylphosphino)-3-methylbutan-2-yl)-3-(2-fluorophenyl)thiourea 4j



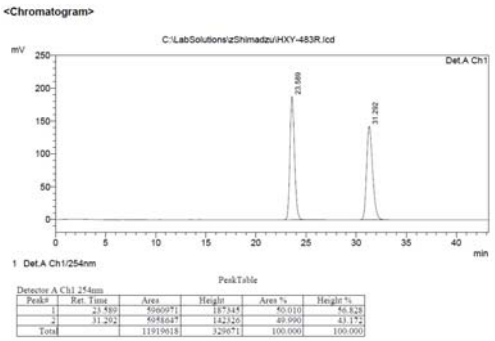
A white solid (82% yield); ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.63 (br, 1H), 7.49-7.40 (m, 4H), 7.33-7.21 (m, 8H), 7.16-7.10 (m, 2H), 6.05 (br, 1H), 4.60 (br, 1H), 2.42-2.39 (m, 1H), 2.38-2.32 (m, 1H), 2.31-2.13 (m, 1H), 0.90 (d, *J* = 7.0 Hz, 3H), 0.86 (d, *J* = 7.0 Hz, 3H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 180.3, 156.9, 154.9, 138.0 (d), 132.8 (d), 132.7 (d), 128.7, 128.4 (dd), 128.1 (d), 126.7, 124.9, 116.8 (d), 58.6 (d), 31.6, 31.1 (d), 18.7, 17.9; ^{31}P NMR (202 MHz, $CDCl_3$) δ -24.1; HRMS (ESI) m/z calcd for $C_{24}H_{27}FN_2PS$ $[M+H]^+$ = 425.1617, found = 425.1617.

C. Analytical Data and HPLC Chromatogram of MBH products

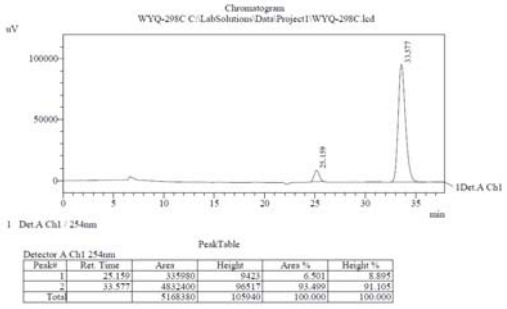
(*R*)-Methyl 2-(hydroxy(4-nitrophenyl)methyl)acrylate **12a**



A yellow solid; $[\alpha]^{27}_D$ = -83.4 (c 1.00, MeOH), (lit.[1]: $[\alpha]^{25}_D$ = -86.6 (c, 0.54, MeOH)); ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.20 (d, *J* = 8.8 Hz, 2H), 7.57 (d, *J* = 8.8 Hz, 2H), 6.39 (s, 1H), 5.87 (s, 1H), 5.29 (d, *J* = 5.1 Hz, 1H), 3.74 (s, 3H), 3.32 (d, *J* = 5.7 Hz, 1H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 166.4, 148.6, 147.5, 140.9, 127.3, 127.2, 123.6, 72.75, 52.19; HRMS (ESI) m/z calcd for $C_{11}H_{12}NO_5$ $[M+H]^+$ = 238.0715, found = 238.0705; the ee value was 87%, t_R (minor) = 25.2 min, t_R (major) = 33.6 min (Chiralcel IC-H, λ = 254 nm, 10% *i*PrOH/hexanes, flow rate = 0.5 mL/min).

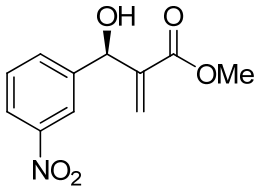


Racemic **12a**

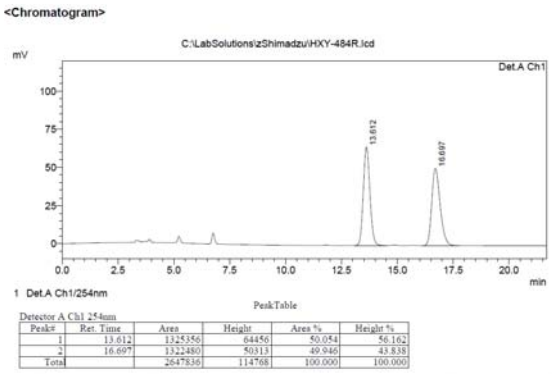


Enantiomerically enriched **12a**

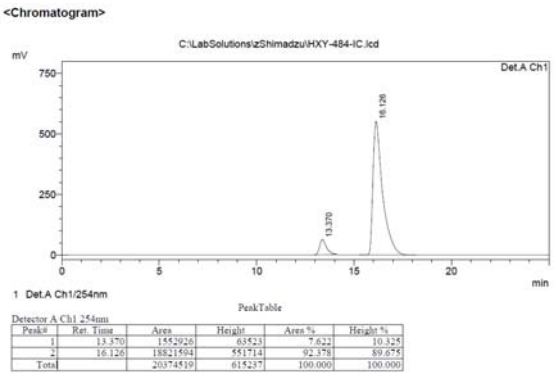
(*R*)-Methyl 2-(hydroxy(3-nitrophenyl)methyl)acrylate **12b**



A yellow solid; $[\alpha]^{27}_{D}$ = -2.7 (c 0.85, $CHCl_3$); ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.13-8.15 (m, 1H), 7.74 (d, *J* = 7.6 Hz, 1H), 7.52 (t, *J* = 7.9 Hz, 1H), 6.41 (s, 1H), 5.90 (s, 1H), 5.64 (d, *J* = 5.1 Hz, 1H), 3.74 (s, 3H), 3.32 (d, *J* = 5.7 Hz, 1H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 166.4, 148.4, 143.6, 140.9, 132.6, 129.3, 127.2, 122.8, 121.5, 72.6, 52. 2; HRMS (ESI) m/z calcd for $C_{11}H_{12}NO_5$ $[M+H]^+$ = 238.0715, found = 238.0706; The ee value was 85%, t_R (minor) = 13.4 min, t_R (major) = 16.1 min (Chiralcel IC-H, λ = 254 nm, 10% *i*PrOH/hexanes, flow rate = 1.0 mL/min).

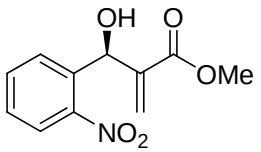


Racemic **12b**



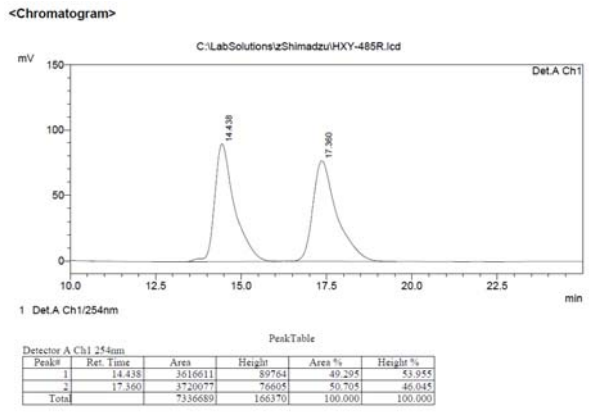
Enantiomerically enriched **12b**

(*R*)-Methyl 2-(hydroxy(2-nitrophenyl)methyl)acrylate **12c**

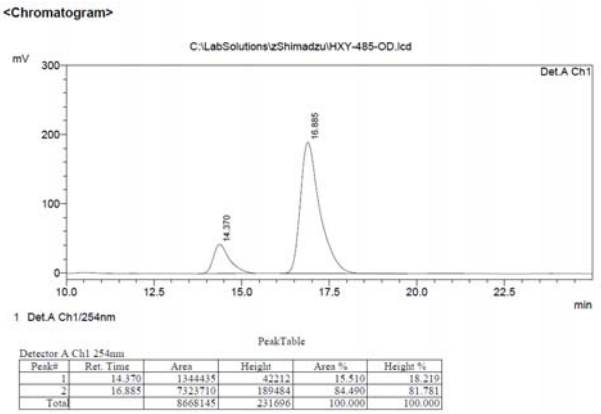


A yellow solid; $[\alpha]^{27}_{D}$ = -16.9 (c 0.80, $CHCl_3$); ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.95 (dd, *J* = 1.3 Hz, 8.2 Hz, 1H), 7.74-7.76 (m, 1H), 7.64 (d, *J* = 7.3 Hz, 1H), 7.44-7.48 (m, 1H), 6.36 (s, 1H), 6.12 (s, 1H), 5.73 (s, 1H), 3.73 (s, 3H), 3.43 (br, 1H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 166.4, 148.3, 140.7, 136.1, 133.4, 128.9, 128.7, 126.5, 124.6, 67.7, 52.1;

HRMS (ESI) m/z calcd for $C_{11}H_{12}NO_5$ $[M+H]^+$ = 238.0715, found = 238.0712; The ee value was 69%, t_R (minor) = 14.4 min, t_R (major) = 16.9 min (Chiralcel OD-H, λ = 254 nm, 10% *i*PrOH/hexanes, flow rate = 1.0 mL/min).

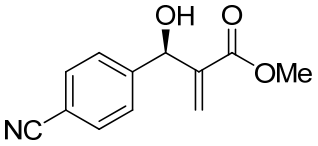


Racemic **12c**

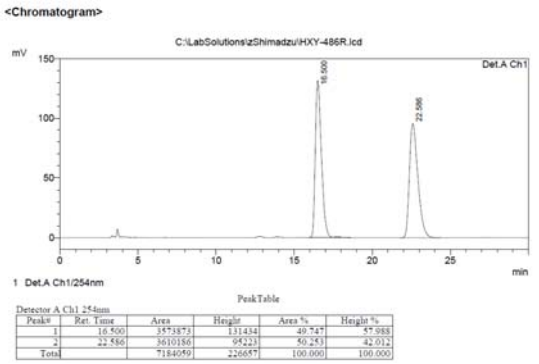


Enantiomerically enriched **12c**

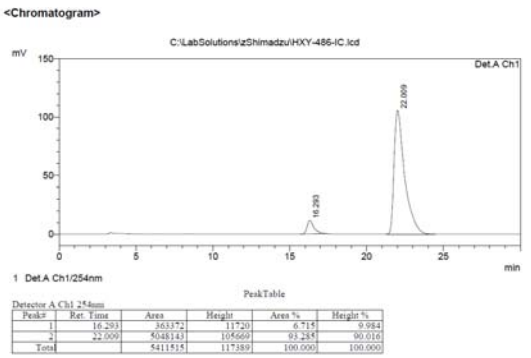
(*R*)-Methyl 2-((4-cyanophenyl)(hydroxy)methyl)acrylate **12d**



A colorless oil; $[\alpha]^{27}_D$ = -4.4 (c 0.85, $CHCl_3$); ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.63 (d, *J* = 8.2 Hz, 2H), 7.51 (d, *J* = 8.2 Hz, 2H), 6.37 (s, 1H), 5.85 (s, 1H), 5.58 (d, *J* = 4.4 Hz, 1H), 3.73 (s, 3H), 3.29 (d, *J* = 5.7 Hz, 1H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 166.4, 146.6, 141.0, 132.2, 127.2, 127.1, 118.7, 111.6, 72.8, 52.1; HRMS (ESI) m/z calcd for $C_{12}H_{12}NO_3$ $[M+H]^+$ = 218.0817, found = 218.0816; The ee value was 87%, t_R (minor) = 16.3 min, t_R (major) = 22.0 min (Chiralcel IC-H, λ = 254 nm, 10% *i*PrOH/hexanes, flow rate = 1.0 mL/min).

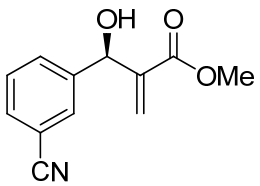


Racemic **12d**

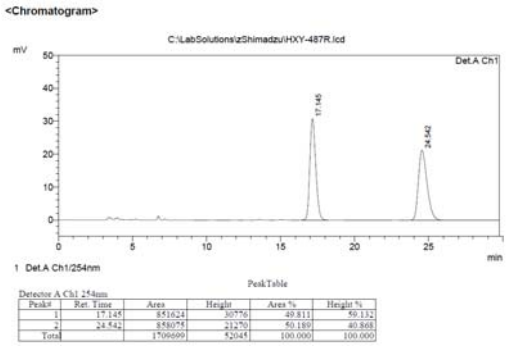


Enantiomerically enriched **12d**

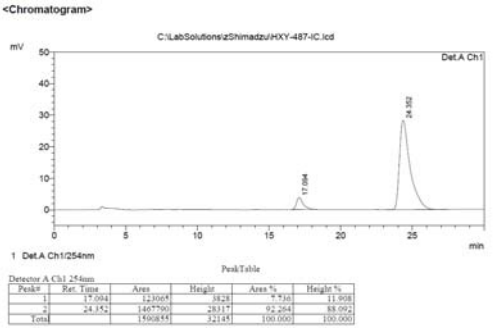
(*R*)-Methyl 2-((3-cyanophenyl)(hydroxy)methyl)acrylate **12e**



A colorless oil; $[\alpha]^{27}_D$ = +11.5 (c 0.87, $CHCl_3$); ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.69 (s, 1H), 7.63 (d, *J* = 7.6 Hz, 1H), 7.57 (d, *J* = 7.6 Hz, 1H), 7.45 (t, *J* = 7.9 Hz, 1H), 6.39 (s, 1H), 5.86 (s, 1H), 5.56 (d, *J* = 5.7 Hz, 1H), 3.74 (s, 3H), 3.28 (d, *J* = 6.3 Hz, 1H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 166.4, 142.9, 141.1, 131.4, 131.0, 130.2, 129.1, 127.0, 118.7, 112.5, 72.5, 52.1; HRMS (ESI) m/z calcd for $C_{12}H_{12}NO_3$ $[M+H]^+$ = 218.0817, found = 218.0824; The ee value was 85%, t_R (minor) = 17.1 min, t_R (major) = 24.4 min (Chiralcel IC-H, λ = 254 nm, 10% *i*PrOH/hexanes, flow rate = 1.0 mL/min).

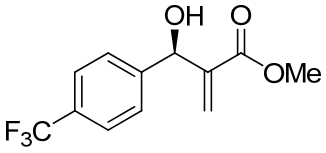


Racemic **12e**

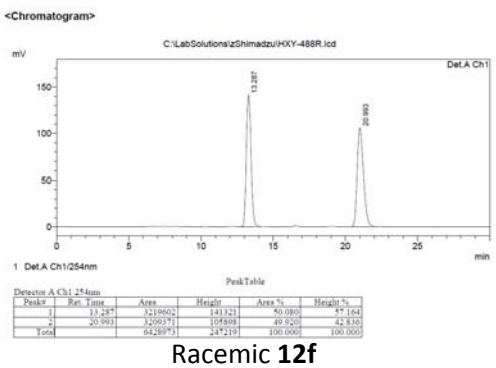


Enantiomerically enriched **12e**

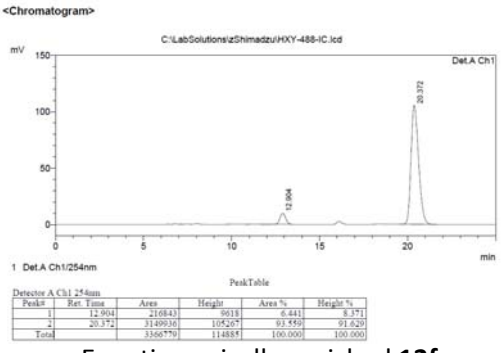
(*R*)-Methyl 2-(hydroxy(4-(trifluoromethyl)phenyl)methyl)acrylate **12f**



A colorless oil; $[\alpha]^{27}_D$ = -4.3 (c 0.71, $CHCl_3$); ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.60 (d, *J* = 8.2 Hz, 2H), 7.50 (d, *J* = 8.2 Hz, 2H), 6.36 (s, 1H), 5.84 (s, 1H), 5.59 (d, *J* = 5.7 Hz, 1H), 3.73 (s, 3H), 3.27 (br, 1H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 166.5, 145.3, 141.4, 129.9 (q), 126.8, 126.8, 125.4 (q), 125.2, 123.0, 72.9, 52.1; HRMS (ESI) m/z calcd for $C_{12}H_{12}F_3O_3$ $[M+H]^+$ = 261.0714, found = 261.0717; The ee value was 87%, t_R (minor) = 12.9 min, t_R (major) = 20.4 min (Chiralcel IC-H, λ = 254 nm, 5% *i*PrOH/hexanes, flow rate = 0.5 mL/min).

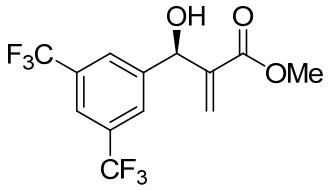


Racemic **12f**

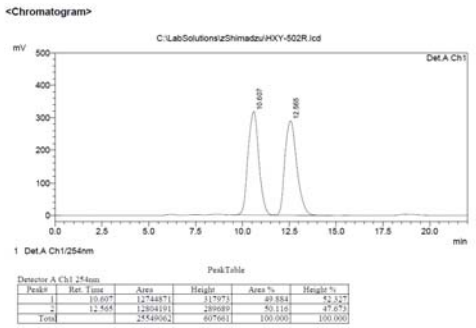


Enantiomerically enriched **12f**

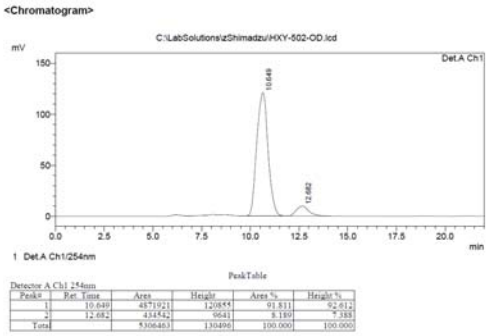
(*R*)-Methyl 2-((3,5-bis(trifluoromethyl)phenyl)(hydroxy)methyl)acrylate **12g**



A colorless oil; $[\alpha]^{27}_D$ = 20.9 (c 1.0, $CHCl_3$); ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.86 (s, 2H), 7.80 (s, 1H), 6.24 (s, 1H), 5.88 (s, 1H), 5.65 (s, 1H), 3.76 (s, 3H), 3.34 (br, 1H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 166.3, 144.0, 140.8, 132.1, 131.6, 127.5, 126.8, 124.4, 122.2, 121.8, 121.7, 121.7, 72.5, 52.3; HRMS (ESI) m/z calcd for $C_{13}H_{11}F_6O_3$ $[M+H]^+$ = 329.0612, found = 329.0620; The ee value was 84%, t_R (minor) = 12.7 min, t_R (major) = 10.7 min (Chiralcel OD-H, λ = 254 nm, 5% *i*PrOH/hexanes, flow rate = 0.5 mL/min).

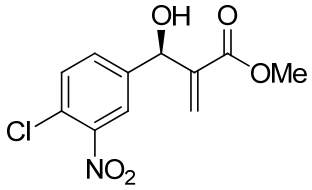


Racemic **12g**

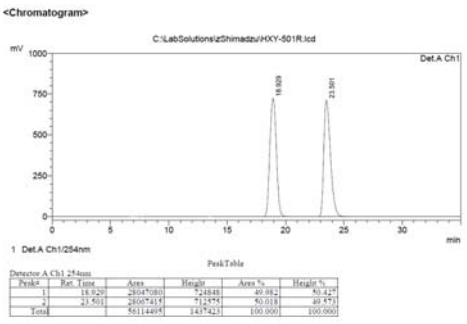


Enantiomerically enriched **12g**

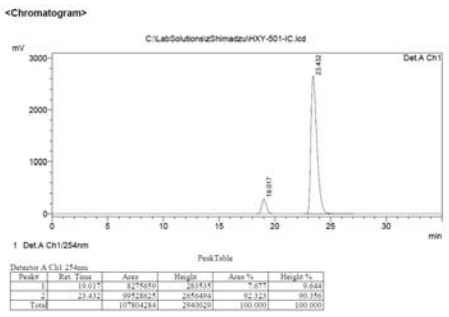
(*R*)-Methyl 2-((4-chloro-3-nitrophenyl)(hydroxy)methyl)acrylate **12h**



A colorless oil; $[\alpha]^{27}_D$ = -7.7 (c 1.10, $CHCl_3$); ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.89 (d, *J* = 1.9 Hz, 1H), 7.49-7.55 (m, 2H), 6.39 (s, 1H), 5.91 (s, 1H), 5.56 (s, 1H), 3.74 (s, 3H), 3.43 (br, 1H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 166.2, 147.8, 142.1, 140.7, 131.7, 131.1, 127.3, 126.0, 123.6, 71.9, 52.2; HRMS (ESI) m/z calcd for $C_{11}H_{11}ClNO_5$ $[M+H]^+$ = 272.0326, found = 272.0329; The ee value was 85%, t_R (minor) = 19.0 min, t_R (major) = 23.4 min (Chiralcel IC-H, λ = 254 nm, 10% *i*PrOH/hexanes, flow rate = 0.5 mL/min).

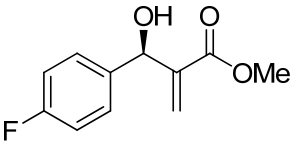


Racemic **12h**

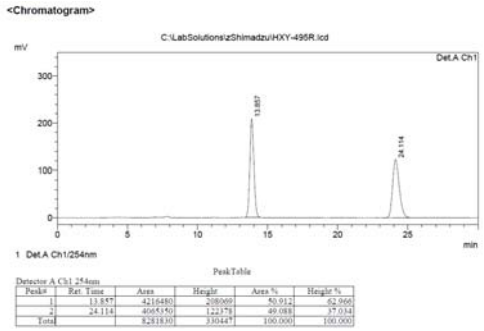


Enantiomerically enriched **12h**

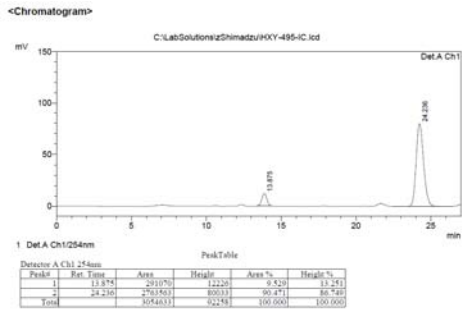
(*R*)-Methyl 2-((4-fluorophenyl)(hydroxy)methyl)acrylate **12i**



A colorless oil; $[\alpha]^{27}_{D}$ = -20.0 (c 0.50, $CHCl_3$); ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.33-7.36 (m, 2H), 7.02 (t, *J* = 8.8 Hz, 2H), 6.33 (s, 1H), 5.82 (s, 1H), 5.54 (d, *J* = 5.1 Hz, 1H), 3.73 (s, 3H), 3.06 (d, *J* = 5.1 Hz, 1H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 166.7, 163.3, 161.4, 141.9, 137.0 (d), 128.3 (d), 126.1, 115.3 (d), 72.6, 52.9; HRMS (ESI) m/z calcd for $C_{11}H_{12}FO_3$ $[M+H]^+$ = 211.0770, found = 211.0772; The ee value was 81%, t_R (minor) = 13.9 min, t_R (major) = 24.2 min (Chiralcel IC-H, λ = 254 nm, 10% *i*PrOH/hexanes, flow rate = 0.5 mL/min).

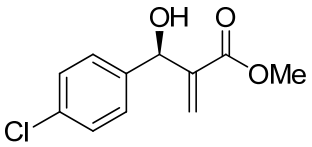


Racemic **12i**

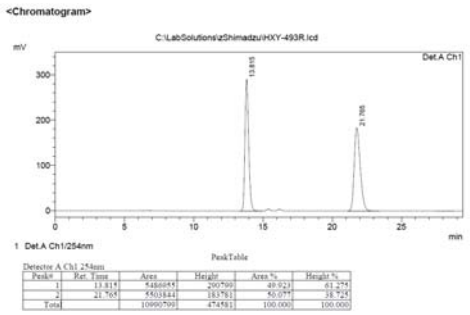


Enantiomerically enriched **12i**

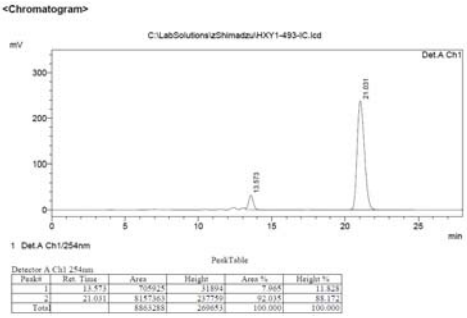
(*R*)-Methyl 2-((4-chlorophenyl)(hydroxy)methyl)acrylate **12j**



A colorless oil; $[\alpha]^{27}_{D}$ = -22.4 (c 1.31, $CHCl_3$); ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.30 (m, 4H), 6.32 (s, 1H), 5.83 (s, 1H), 5.51 (d, *J* = 5.0 Hz, 1H), 3.71 (s, 3H), 3.23 (d, *J* = 5.1 Hz, 1H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 166.6, 141.6, 139.8, 133.5, 128.5, 127.9, 126.2, 72.5, 51.9; (ESI) m/z calcd for $C_{11}H_{12}ClO_3$ $[M+H]^+$ = 227.0475, found = 227.0480; The ee value was 84%, t_R (minor) = 13.6 min, t_R (major) = 21.0 min (Chiralcel IC-H, λ = 254 nm, 10% *i*PrOH/hexanes, flow rate = 0.5 mL/min).

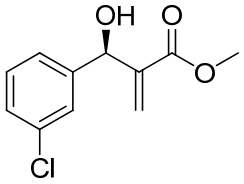


Racemic **12j**

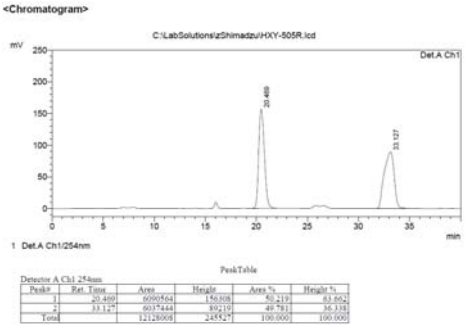


Enantiomerically enriched **12j**

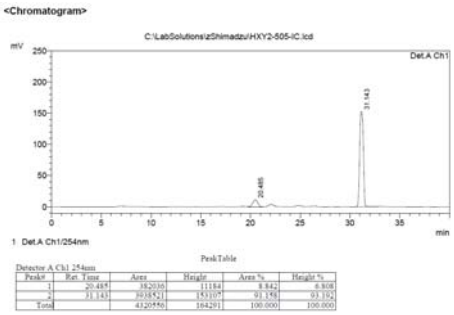
(*R*)-Methyl 2-((3-chlorophenyl)(hydroxy)methyl)acrylate **12k**



A colorless oil; $[\alpha]^{27}_{D}$ = -6.6 (c 0.63, $CHCl_3$); ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.55 (dd, *J* = 1.9 Hz, 7.6 Hz, 1H), 7.22-7.36 (m, 3H), 6.33 (s, 1H), 5.98 (s, 1H), 5.58 (s, 1H), 3.77 (s, 3H), 3.33 (br, 1H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 166.9, 140.6, 138.2, 132.8, 129.4, 129.0, 128.1, 127.0, 126.9, 69.3, 52.1; HRMS (ESI) m/z calcd for $C_{11}H_{11}ClO_3$ $[M+H]^+$ = 227.0475, found = 227.0476; The ee value was 82%, t_R (minor) = 20.5 min, t_R (major) = 31.1 min (Chiralcel IC-H, λ = 254 nm, 5% *i*PrOH/hexanes, flow rate = 0.5 mL/min).

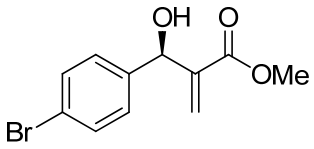


Racemic **12k**

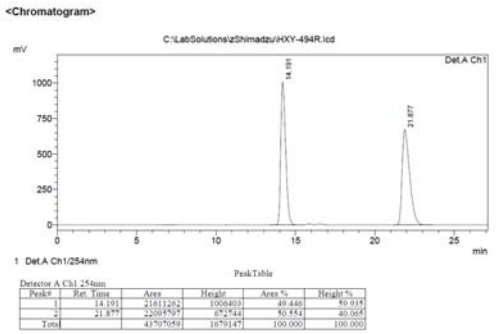


Enantiomerically enriched **12k**

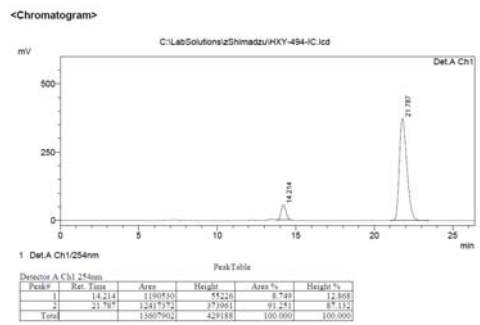
(*R*)-Methyl 2-((4-bromophenyl)(hydroxy)methyl)acrylate **12l**



A colorless oil; $[\alpha]^{27}_{D}$ = +7.9 (c 1.0, $CHCl_3$); ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.84 (d, *J* = 8.2 Hz, 2H), 7.45 (dd, *J* = 2.6 Hz, 8.9 Hz, 2H), 6.33 (s, 1H), 5.82 (s, 1H), 5.49 (d, *J* = 5.1 Hz, 1H), 3.71 (s, 3H), 3.22 (d, *J* = 5.1 Hz, 1H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 166.5, 141.6, 140.3, 131.5, 128.3, 126.3, 121.7, 72.6, 51.9; (ESI) m/z calcd for $C_{11}H_{12}BrO_3$ $[M+H]^+$ = 270.9970, found = 270.9961; The ee value was 83%, t_R (minor) = 14.2 min, t_R (major) = 21.8 min (Chiralcel IC-H, λ = 254 nm, 10% *i*PrOH/hexanes, flow rate = 0.5 mL/min).

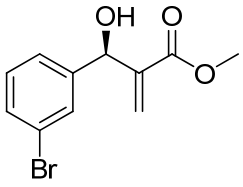


Racemic **12l**

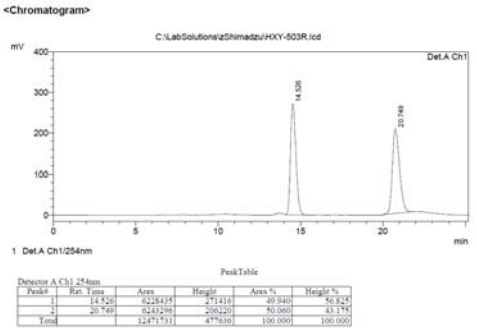


Enantiomerically enriched **12l**

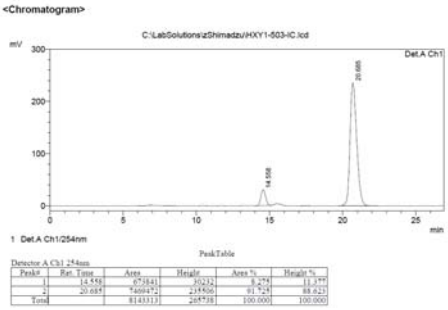
(*R*)-Methyl 2-((3-bromophenyl)(hydroxy)methyl)acrylate **12m**



A colorless oil; $[\alpha]^{27}_{D}$ = -14.9 (c 0.80, $CHCl_3$); ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.52 (s, 1H), 7.40 (d, *J* = 8.2 Hz, 1H), 7.29 (d, *J* = 7.6 Hz, 1H), 7.20 (t, *J* = 8.2 Hz, 1H), 6.35 (s, 1H), 5.84 (s, 1H), 5.50 (s, 1H), 3.73 (s, 3H), 3.22 (br, 1H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 166.5, 143.6, 141.4, 130.8, 129.9, 129.6, 126.6, 125.2, 122.5, 72.6, 52.0; HRMS (ESI) m/z calcd for $C_{11}H_{12}BrO_3$ $[M+H]^+$ = 270.9949, found = 270.9952; The ee value was 84%, t_R (minor) = 14.6 min, t_R (major) = 20.7 min (Chiralcel IC-H, λ = 254 nm, 10% *i*PrOH/hexanes, flow rate = 0.5 mL/min).

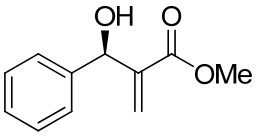


Racemic **12m**

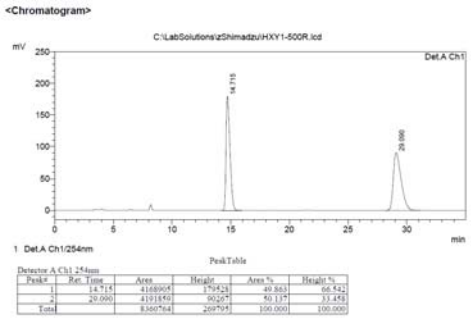


Enantiomerically enriched **12m**

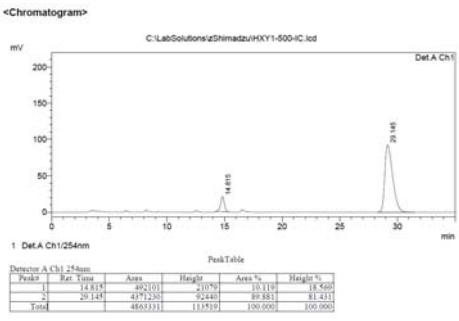
(*R*)-Methyl 2-(hydroxy(phenyl)methyl)acrylate **12n**



A colorless oil; $[\alpha]^{27}_{D}$ = -94.3 (c 0.42, MeOH), (lit.[5]: $[\alpha]^{28}_{D}$ = -109.3 (c, 0.54, MeOH)); ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.32-7.38 (m, 4H), 7.26-7.29 (m, 1H), 6.33 (s, 1H), 5.84 (s, 1H), 5.56 (s, 1H), 3.71 (s, 3H), 3.15 (br, 1H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 166.8, 142.0, 141.3, 128.4, 127.8, 126.6, 126.1, 73.2, 51.9; HRMS (ESI) m/z calcd for $C_{11}H_{13}O_3$ $[M+H]^+$ = 193.0865, found = 193.0866; The ee value was 80%, t_R (minor) = 14.8 min, t_R (major) = 29.1 min (Chiralcel IC-H, λ = 254 nm, 5% *i*PrOH/hexanes, flow rate = 1.0 mL/min).

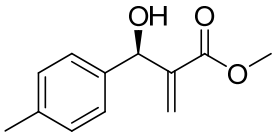


Racemic **12n**

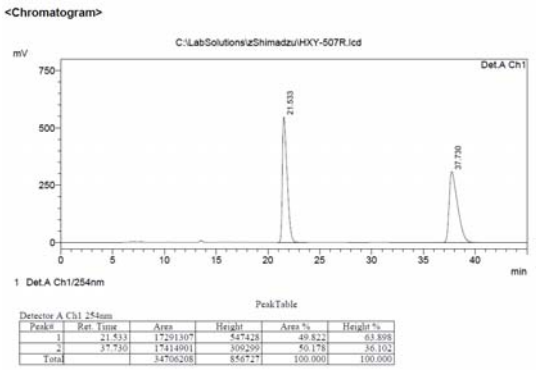


Enantiomerically enriched **12n**

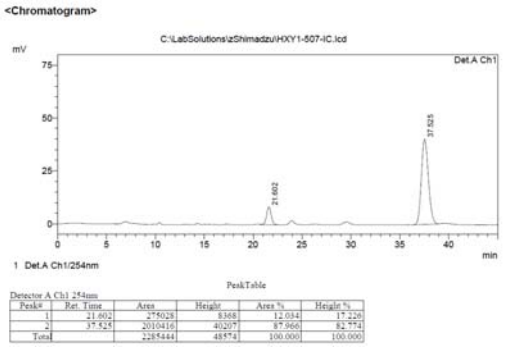
(*R*)-Methyl 2-(hydroxy(p-tolyl)methyl)acrylate **12o**



A colorless oil; $[\alpha]^{27}_{D}$ = -57.4 (c 0.52, $CHCl_3$); ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.26 (d, *J* = 6.6 Hz, 2H), 7.15 (d, *J* = 8.2 Hz, 2H), 6.33 (s, 1H), 5.85 (d, *J* = 1.3 Hz, 1H), 5.53 (s, 1H), 3.71 (s, 3H), 2.99 (br, 1H), 2.34 (s, 1H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 166.7, 142.1, 138.3, 137.5, 129.1, 126.5, 125.8, 73.0, 51.9, 21.1; HRMS (ESI) m/z calcd for $C_{12}H_{15}O_3$ $[M+H]^+$ = 207.1021, found = 207.1022; The ee value was 76%, t_R (minor) = 21.6 min, t_R (major) = 37.5 min (Chiralcel IC-H, λ = 254 nm, 10% *i*PrOH/hexanes, flow rate = 0.5 mL/min).

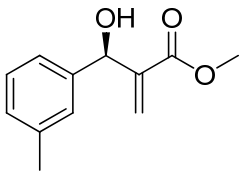


Racemic **12o**

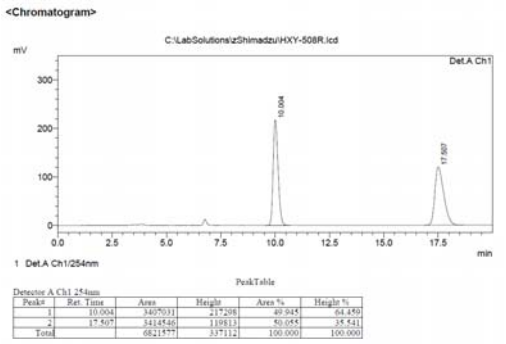


Enantiomerically enriched **12o**

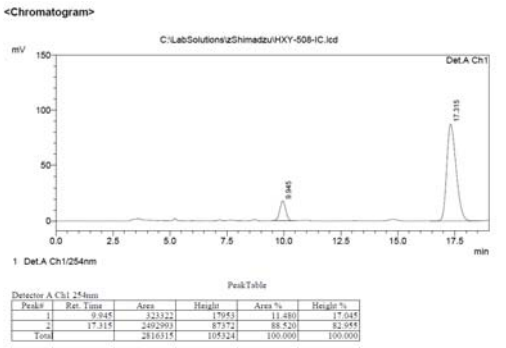
(*R*)-Methyl 2-(hydroxy(m-tolyl)methyl)acrylate **12p**



A colorless oil; $[\alpha]^{27}_{D}$ = -46.7 (c 0.45, $CHCl_3$); ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.15-7.26 (m, 3H), 7.10 (d, *J* = 6.9 Hz, 2H), 6.34 (s, 1H), 5.85 (s, 1H), 5.53 (s, 1H), 3.72 (s, 3H), 3.05 (br, 1H), 2.35 (s, 1H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 166.7, 141.9, 141.2, 138.0, 128.5, 128.3, 127.2, 125.9, 123.6, 73.2, 51.9, 21.4; HRMS (ESI) m/z calcd for $C_{12}H_{15}O_3$ $[M+H]^+$ = 207.1021, found = 207.1015; The ee value was 77%, t_R (minor) = 9.9 min, t_R (major) = 17.3 min (Chiralcel IC-H, λ = 254 nm, 10% *i*PrOH/hexanes, flow rate = 1.0 mL/min).

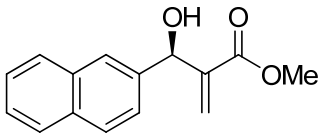


Racemic **12p**

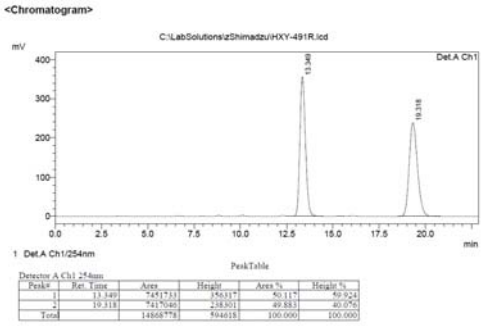


Enantiomerically enriched **12p**

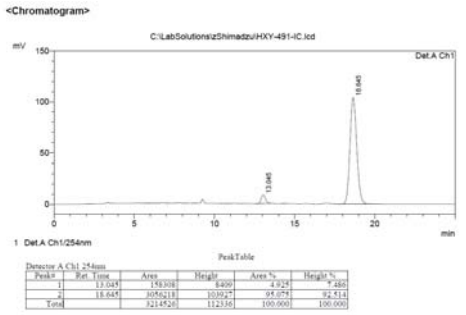
(*R*)-Methyl 2-(hydroxy(naphthalen-2-yl)methyl)acrylate **12q**



A white solid; $[\alpha]^{27}_{D}$ = -12.6 (c 0.43, $CHCl_3$); ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.82-7.86 (m, 4H), 7.48 (d, *J* = 7.6 Hz, 3H), 6.38 (s, 1H), 5.88 (s, 1H), 5.75 (d, *J* = 3.2 Hz, 1H), 3.72 (s, 3H), 3.15 (d, *J* = 5.1 Hz, 1H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 166.8, 141.9, 138.6, 133.2, 133.0, 128.2, 128.1, 127.6, 126.4, 126.1, 126.0, 125.5, 124.6, 73.4, 52.9; HRMS (ESI) m/z calcd for $C_{15}H_{15}O_3$ $[M+H]^+$ = 243.1021, found = 243.1021; the ee value was 90%, t_R (minor) = 13.0 min, t_R (major) = 18.6 min (Chiralcel IC-H, λ = 254 nm, 10% *i*PrOH/hexanes, flow rate = 1.0 mL/min).

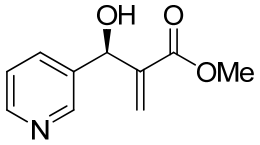


Racemic **12q**

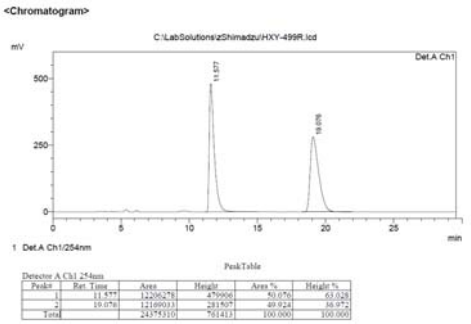


Enantiomerically enriched **12q**

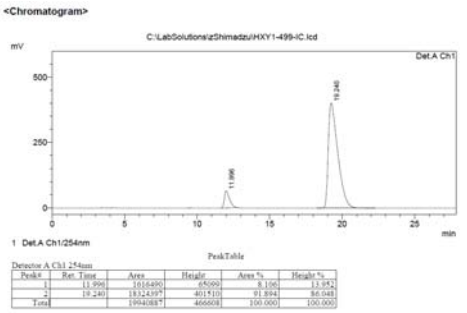
(*R*)-Methyl 2-(hydroxy(pyridin-3-yl)methyl)acrylate **12r**



A colorless oil; $[\alpha]^{27}_{D}$ = -44.5 (c 1.2, $CHCl_3$); ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.49 (s, 1H), 8.41 (d, *J* = 4.4 Hz, 1H), 7.71-7.73 (m, 1H), 7.23-7.26 (m ,1H), 6.37 (s, 1H), 5.95 (s, 1H), 5.59 (m, 1H), 3.70 (s, 3H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 166.3, 148.6, 148.3, 141.6, 137.4, 134.5, 126.2, 123.4, 70.7, 51.9; HRMS (ESI) m/z calcd for $C_{10}H_{12}NO_3$ $[M+H]^+$ = 194.0817, found = 194.0813; the ee value was 84%, t_R (minor) = 12.0 min, t_R (major) = 19.2 min (Chiralcel IC-H, λ = 254 nm, 30% *i*PrOH/hexanes, flow rate = 1.0 mL/min).

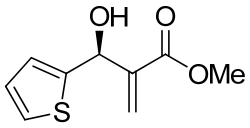


Racemic **12r**

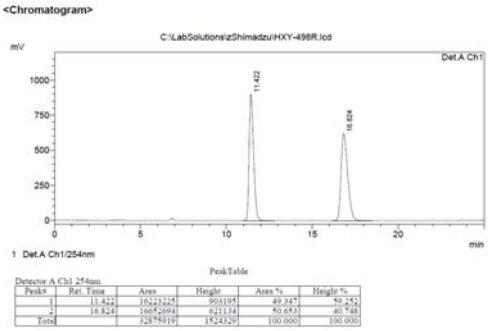


Enantiomerically enriched **12r**

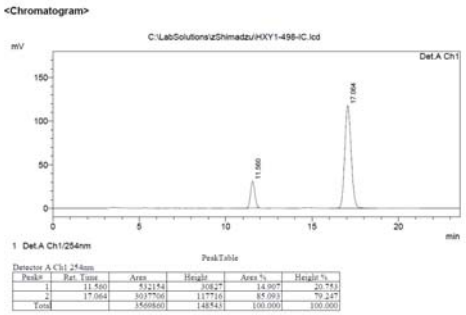
(*S*)-Methyl 2-(hydroxy(thiophen-2-yl)methyl)acrylate **12s**



A colorless oil; $[\alpha]^{27}_{D}$ = +46.7 (c 0.5, $CHCl_3$); ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.24-7.26 (m, 1H), 6.94 (m, 2H), 6.35 (s, 1H), 5.95 (s, 1H), 5.76 (d, *J* = 6.3 Hz, 1H), 3.74 (s, 3H), 3.44 (br, 1H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 166.5, 145.7, 141.3, 126.8, 126.1, 125.2, 124.7, 69.6, 51.9; HRMS (ESI) m/z calcd for $C_9H_{11}O_3S$ $[M+H]^+$ = 199.0429, found = 199.0427; The ee value was 70%, t_R (minor) = 11.6 min, t_R (major) = 17.1 min (Chiralcel IC-H, λ = 254 nm, 10% *i*PrOH/hexanes, flow rate = 1.0 mL/min).



Racemic **12s**



Enantiomerically enriched **12s**

References

[1] A. Nakano, S. Kawahara, S. Akamatsu, K. Morokuma, M. Nakatani, Y. Iwabuchi, K. Takahashi, J. Ishihara, S. Hatakeyama, *Tetrahedron* **2006**, *62*, 381.

[2] Y. Q. Fang, E. N. Jacobsen, *J. Am. Chem. Soc.* **2008**, *130*, 5660.

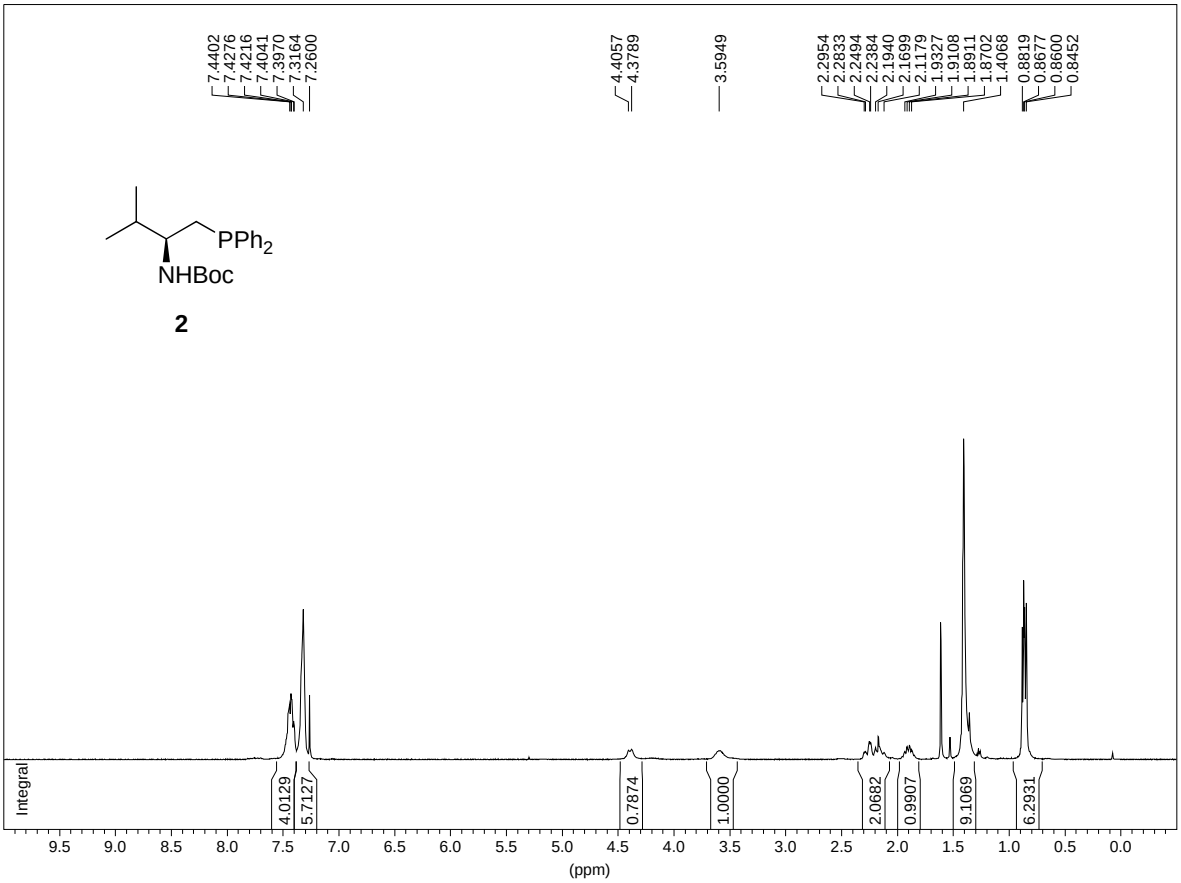
[3] K. Kawamura, H. Fukuzawa, M. Hayashi, *Org. Lett.* **2008**, *10*, 3509.

[4] J.-J. Gong, K. Yuan, X.-Y. Wu, *Tetrahedron: Asymmetry* **2009**, *20*, 2117.

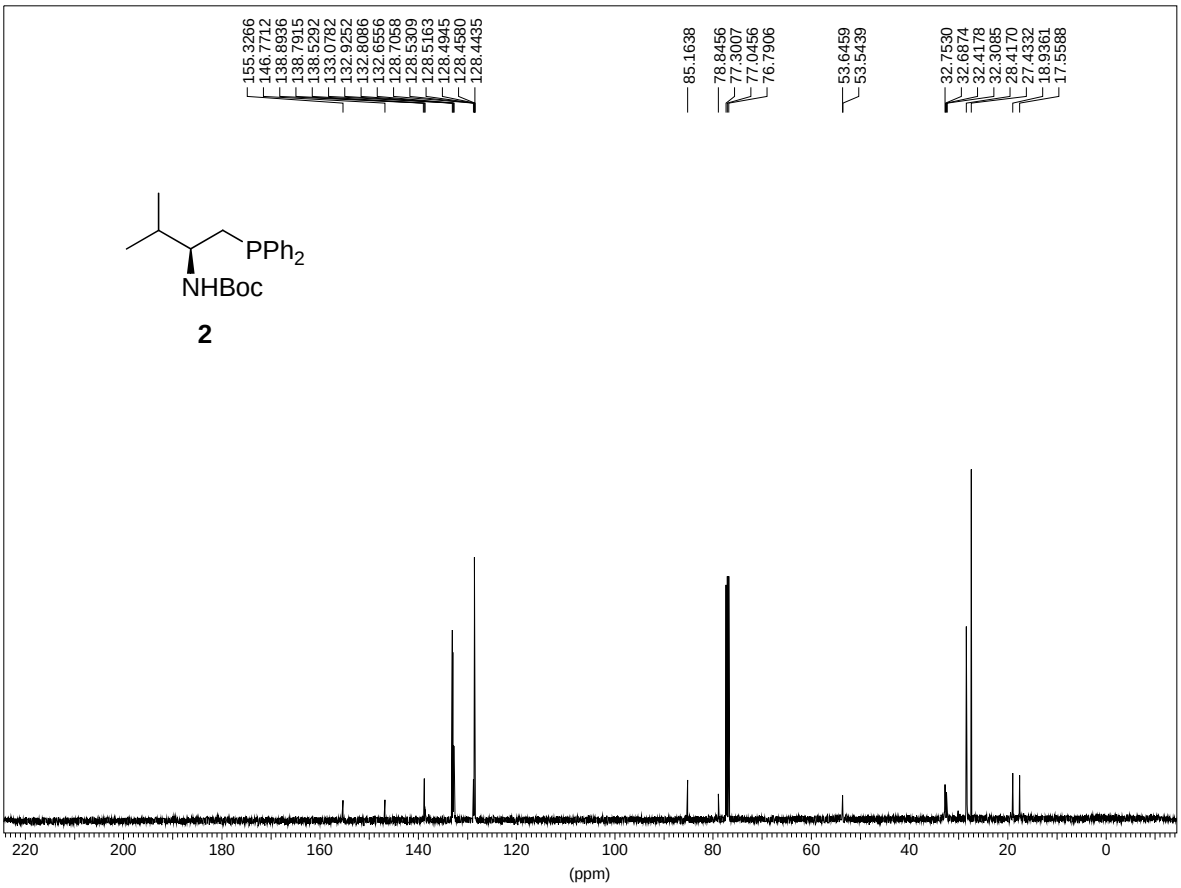
[5] Y. Iwabuchi, M.Nakatani, N. Yodoyama, S. Hatakeyama, *J. Am. Chem. Soc.* **1999**, *121*, 10219.

D. NMR Spectra of the Catalyst and the Products

zfr-valine-Boc



zfr-646



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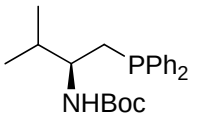

2

*** Current Data Parameters ***

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PROCNO	:	1

*** Acquisition Parameters ***

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BF3	:	121.4948510 MHz
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DATE_d	:	Sep 11 2009
NS	:	14
SOLVENT	:	Acetone

*** Processing Parameters ***

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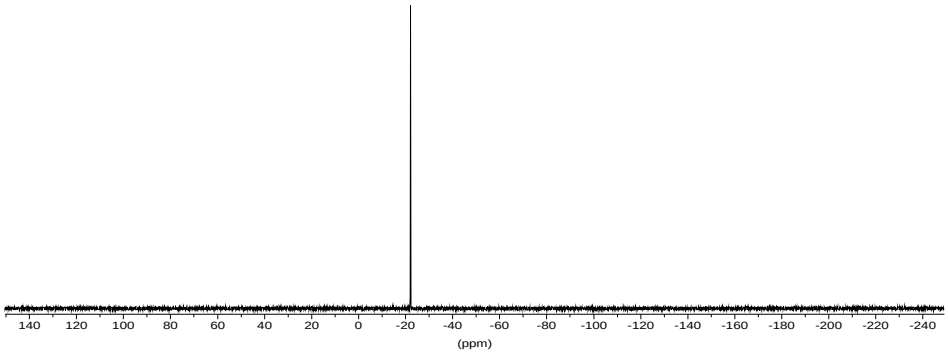
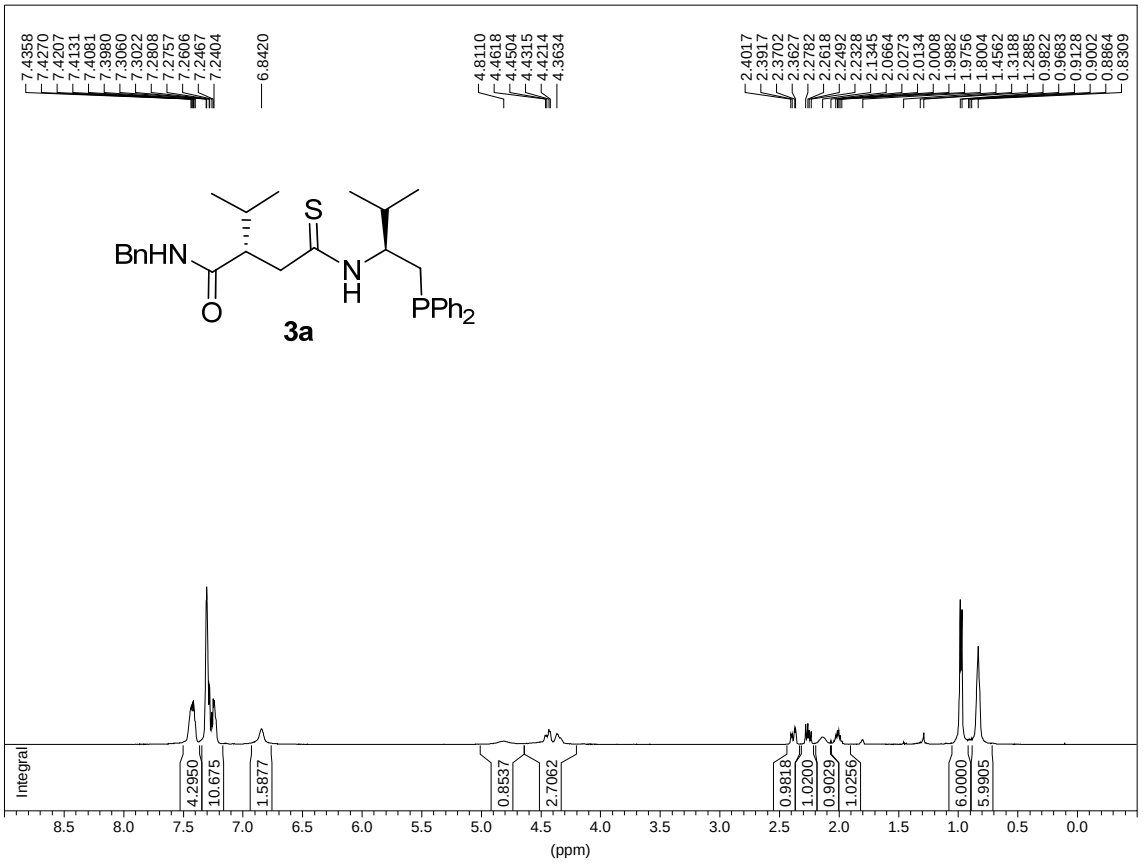
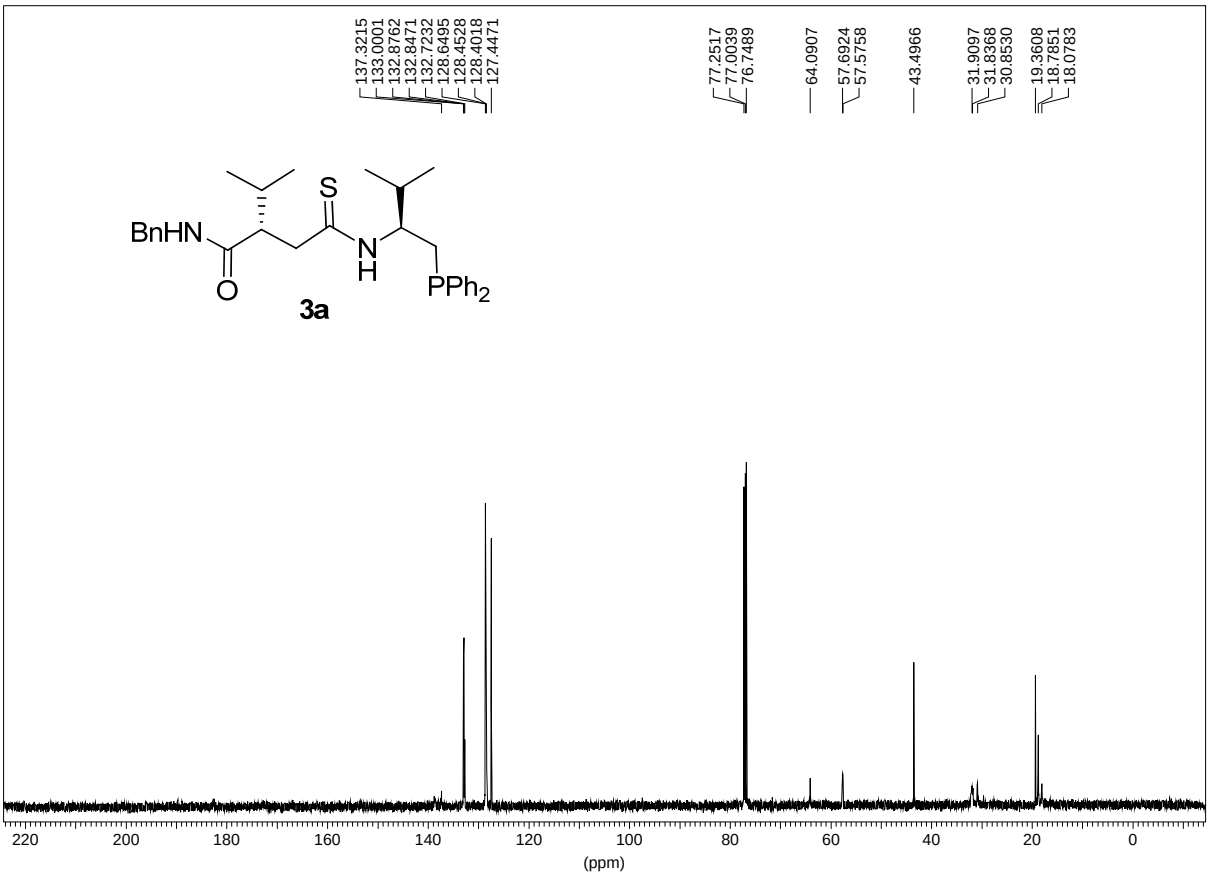


1H AMX500 hxy-479

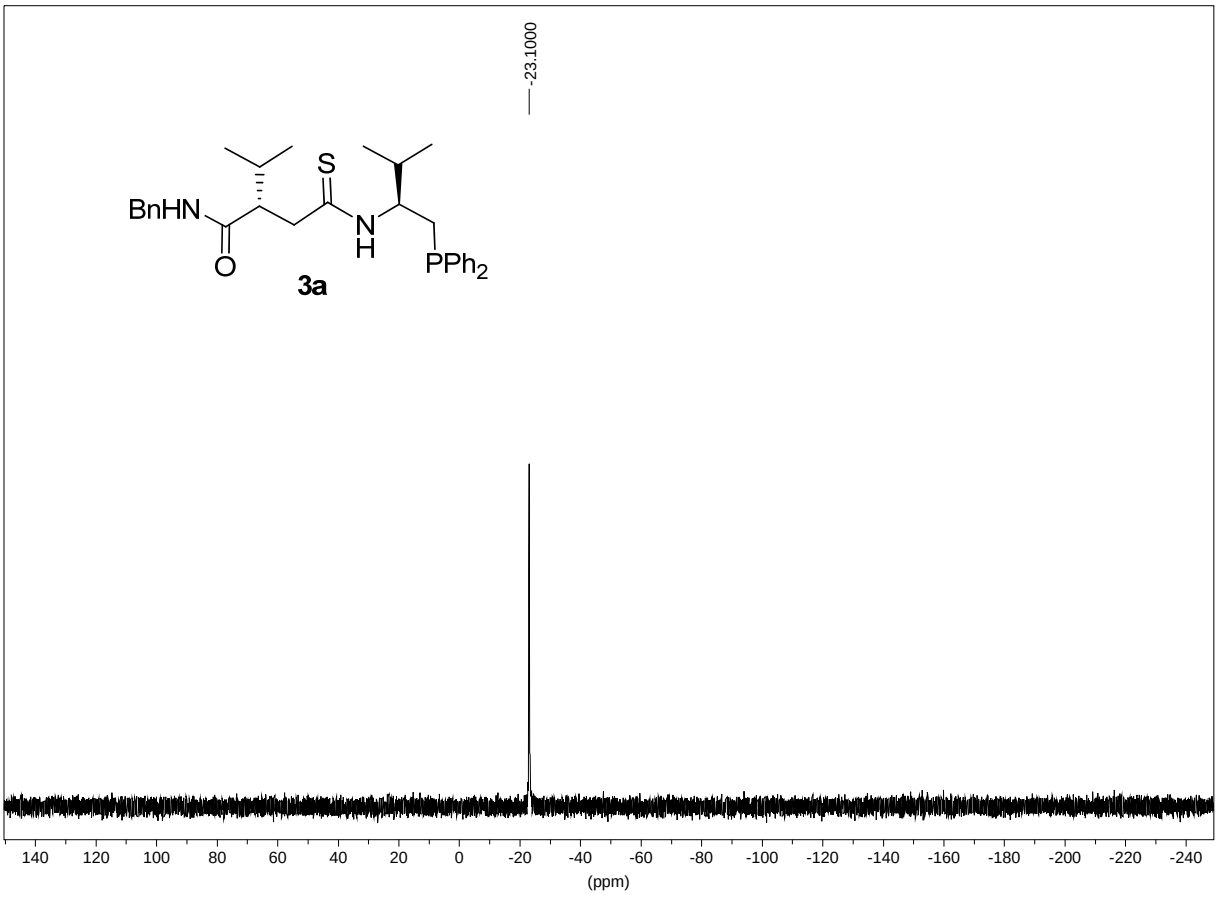


3a

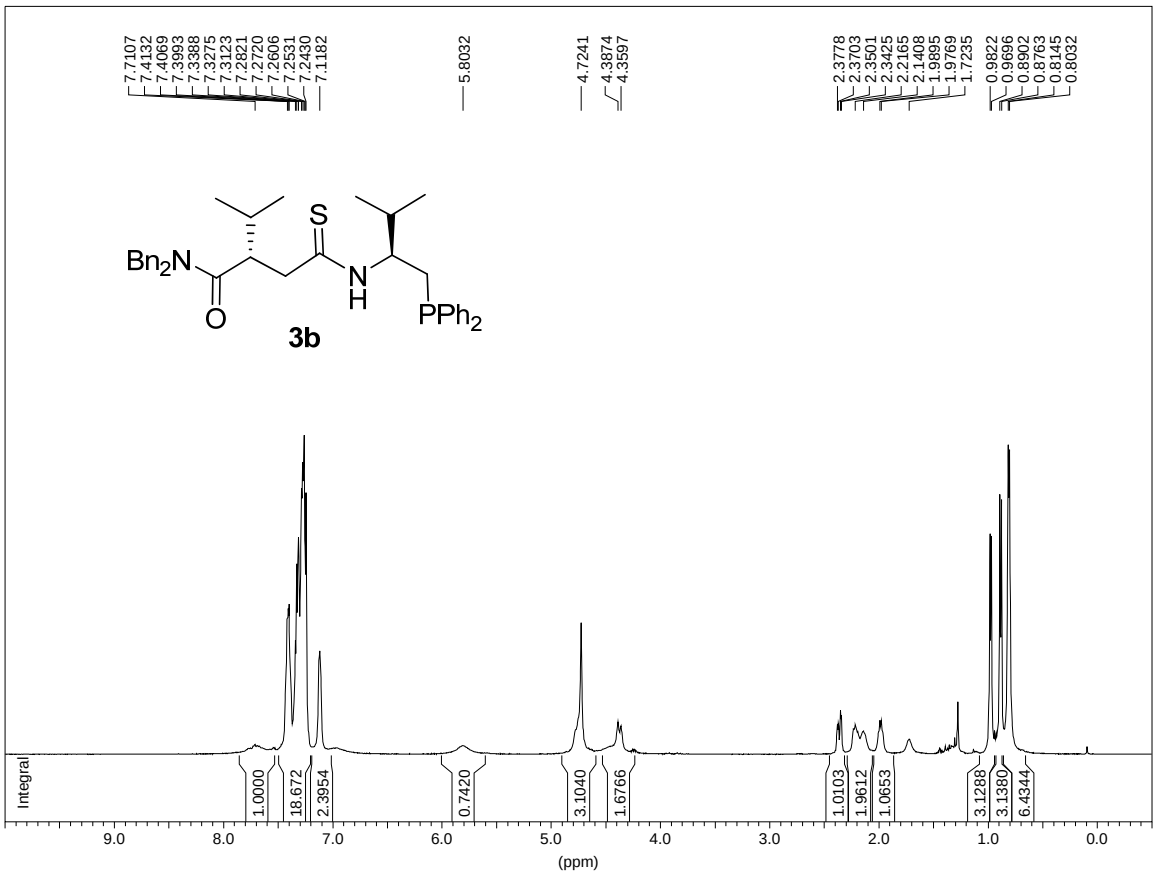
13C AMX500 hxy-479



31P AC300 hxy-479



1H AMX500 hxy-L-V-Cat



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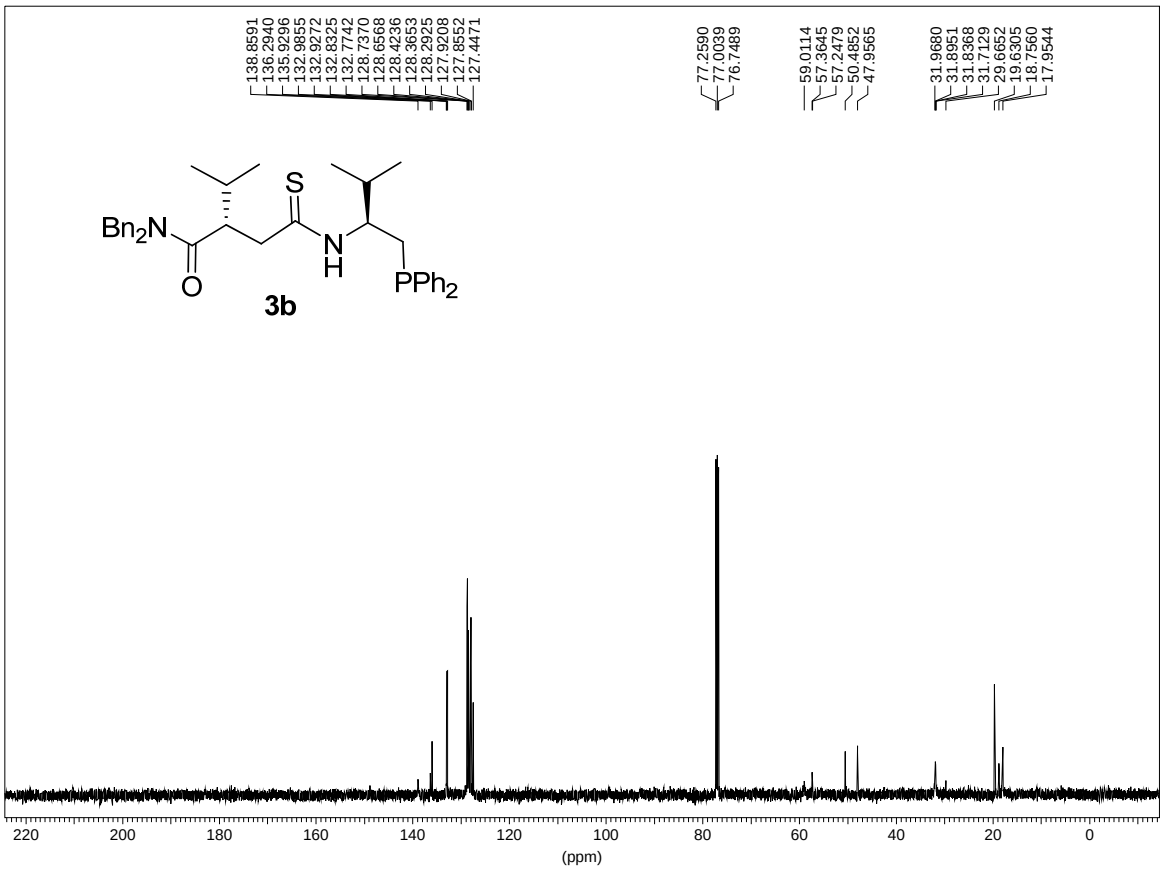

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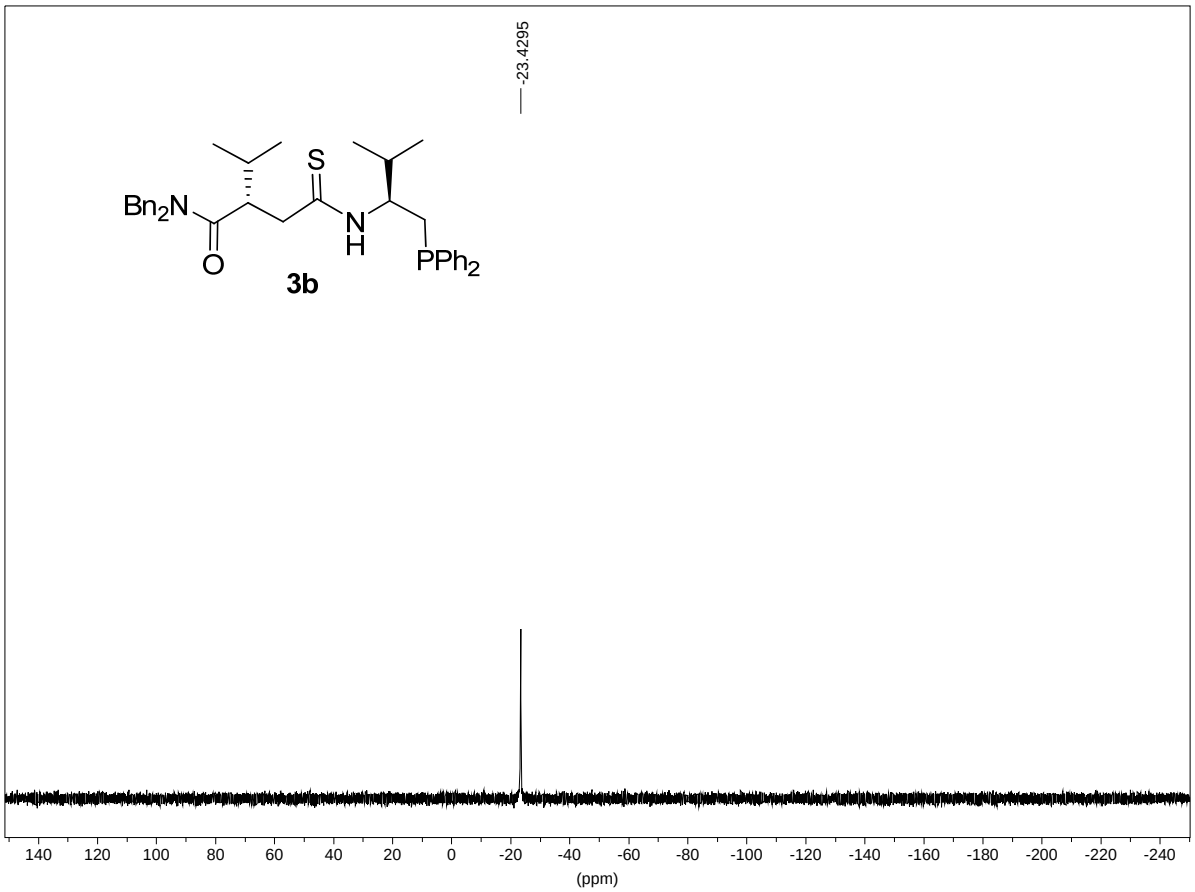
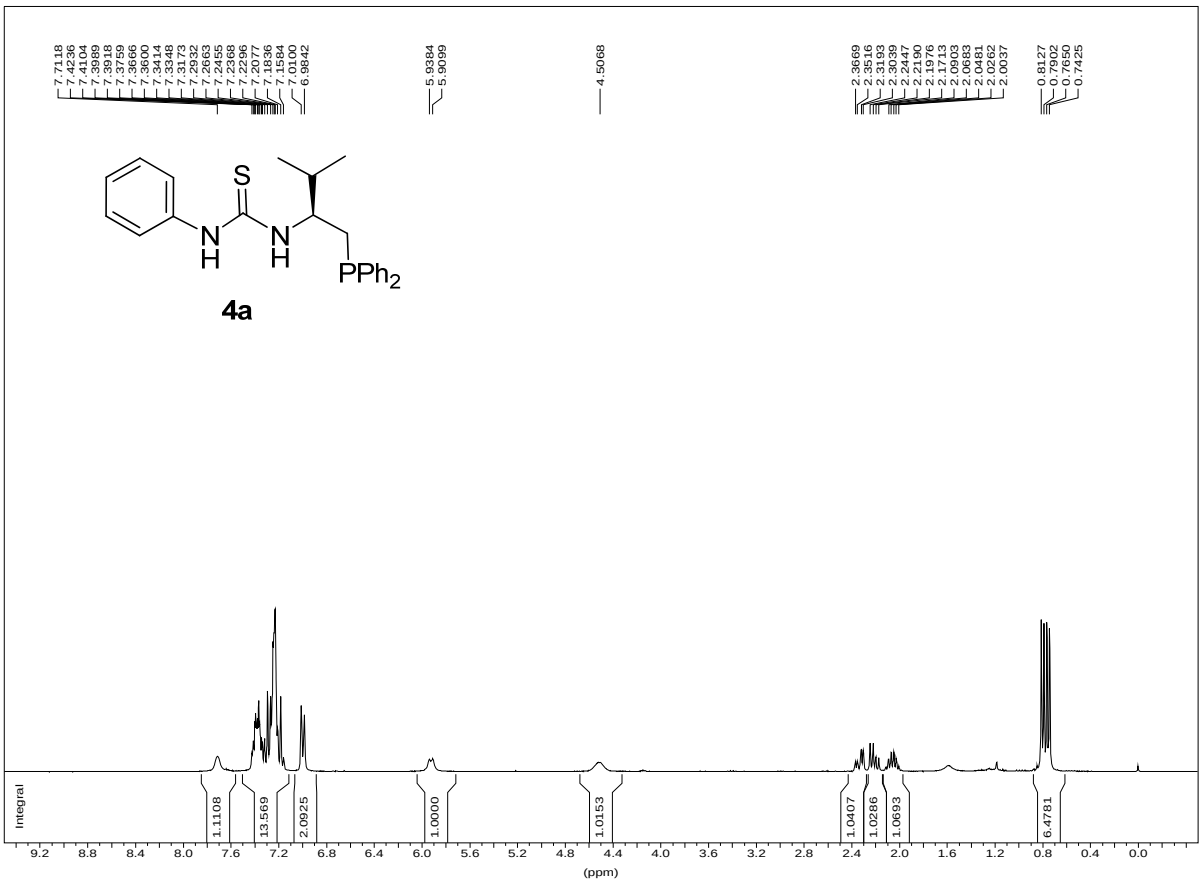
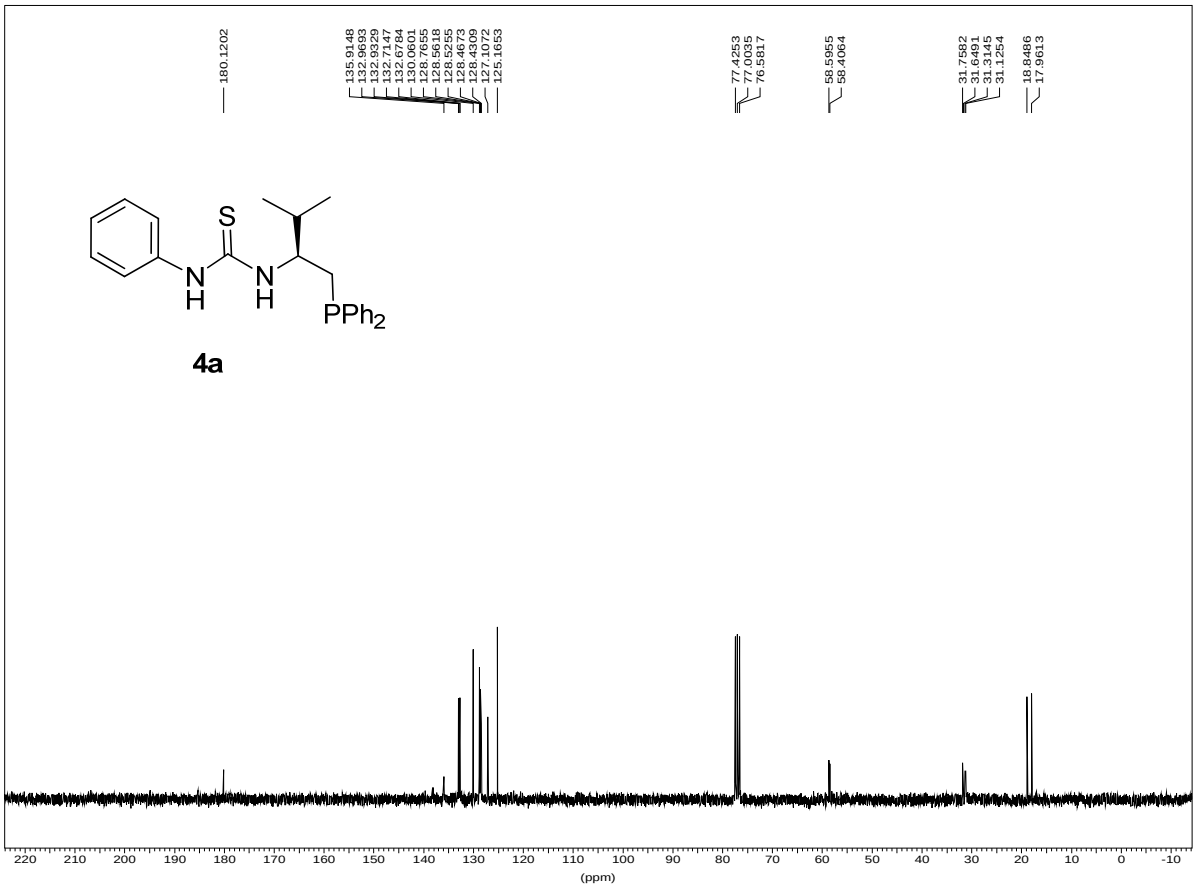


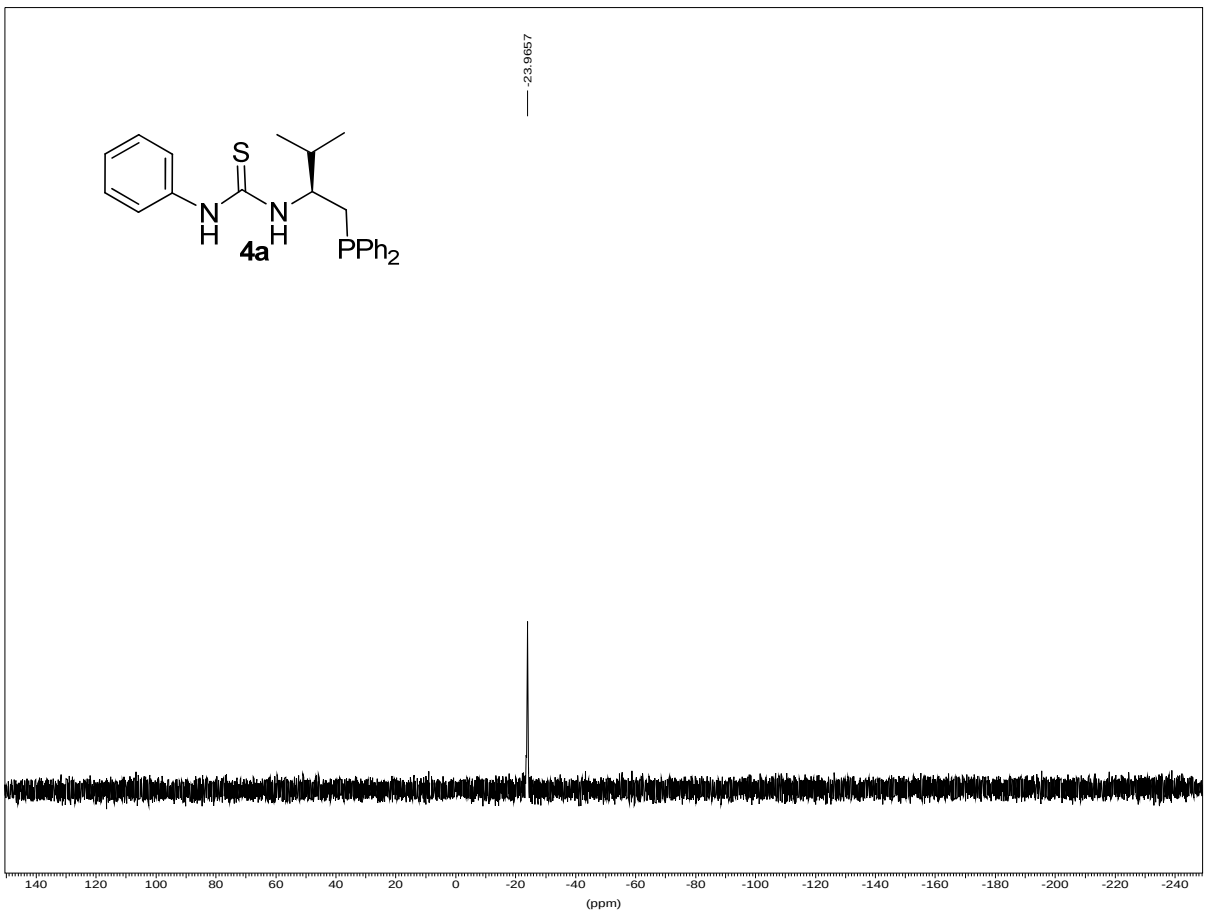
wyq-139A 1H normal range AC300



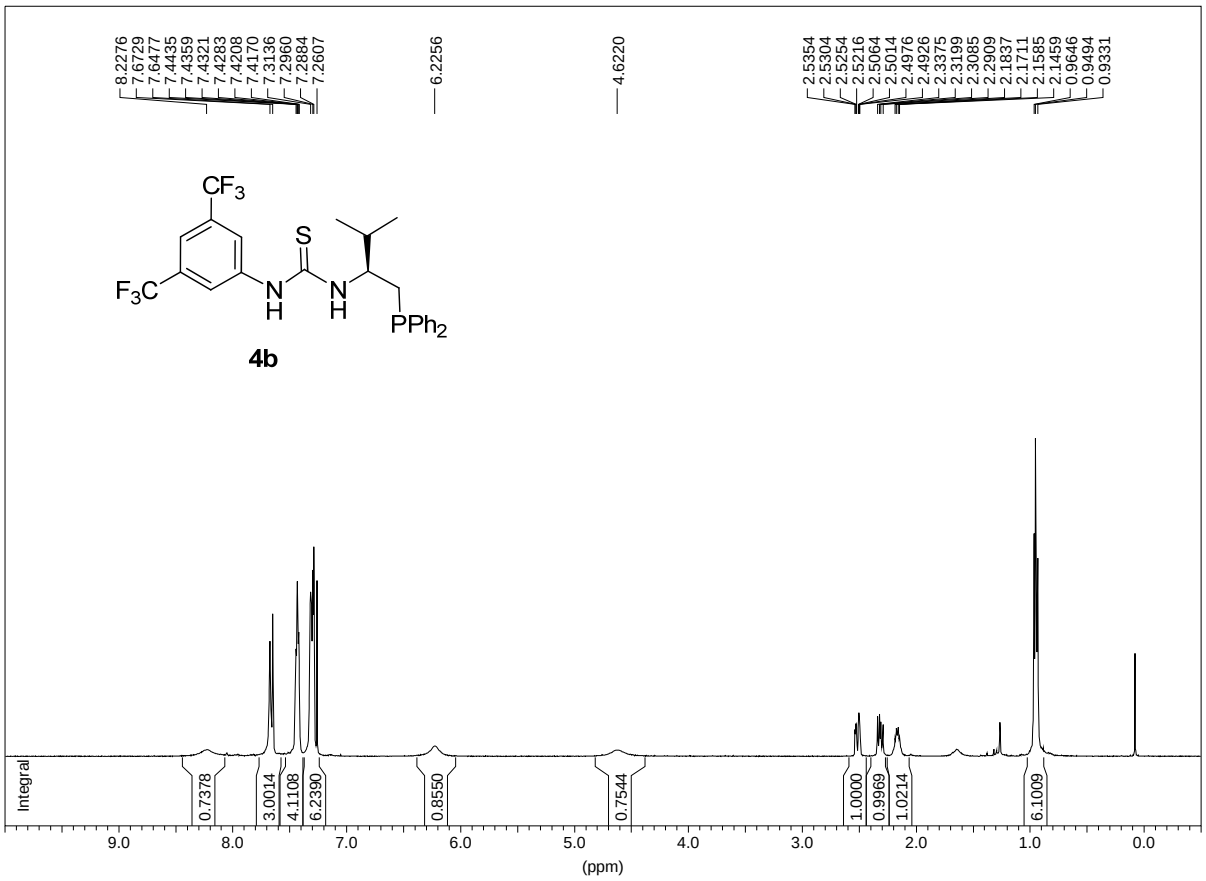
wyq-139A 13C Standard AC300



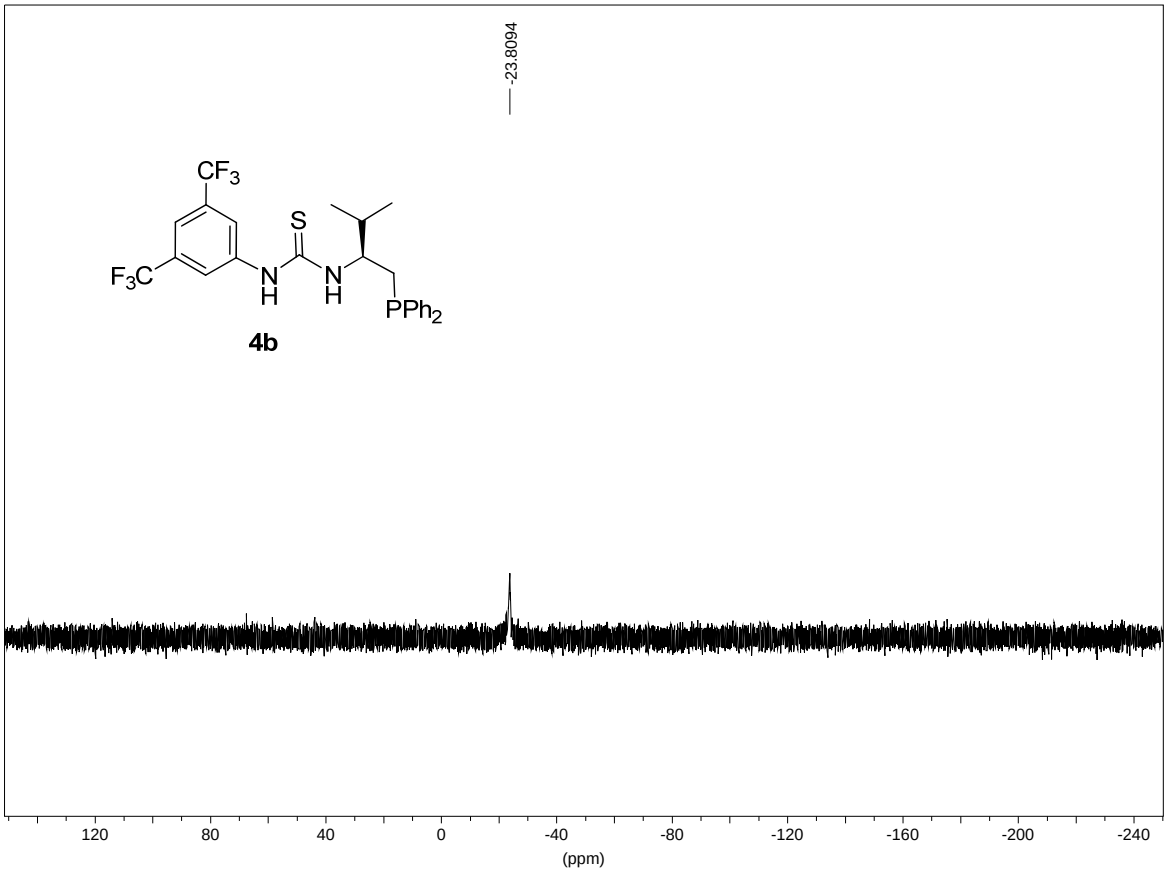
wyq-139A 31P AC300



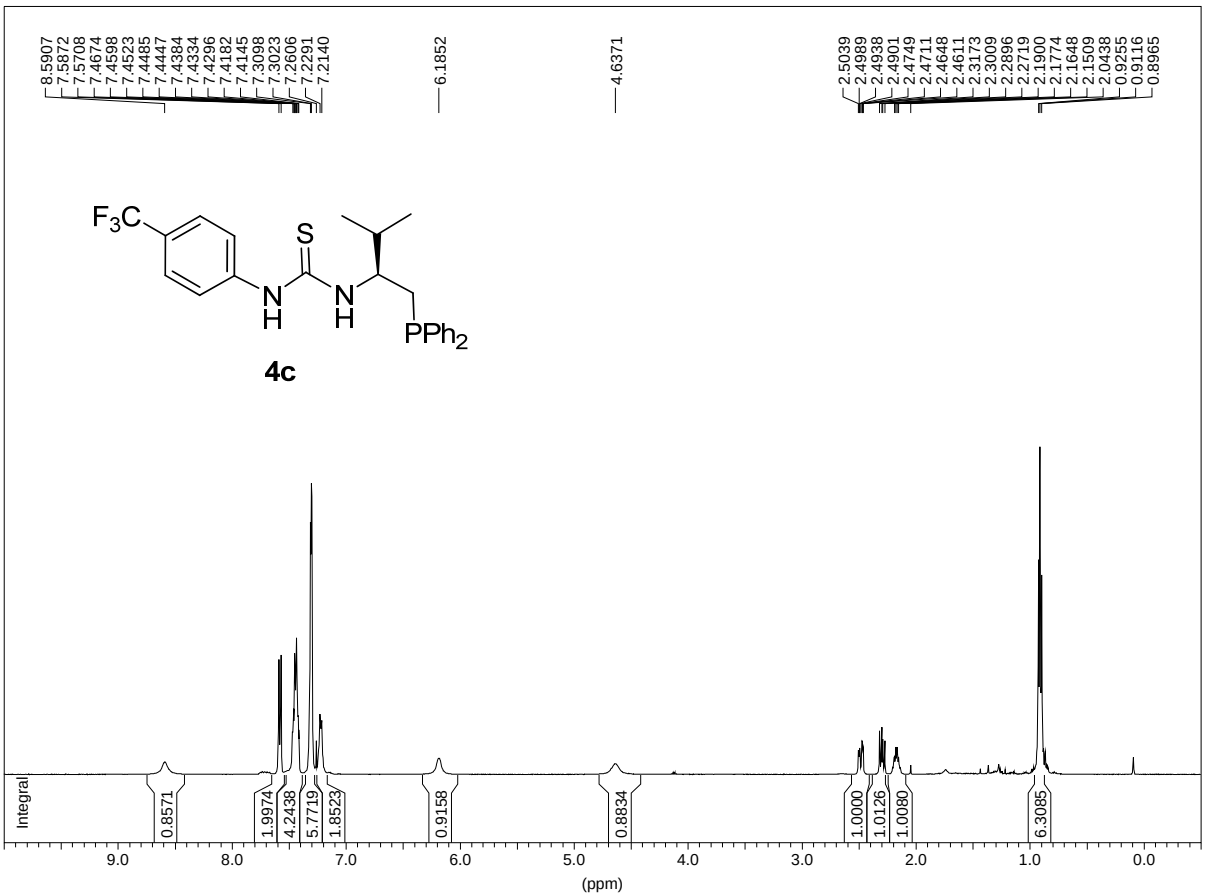
1H AMX500 hxy-2CF3-Cat



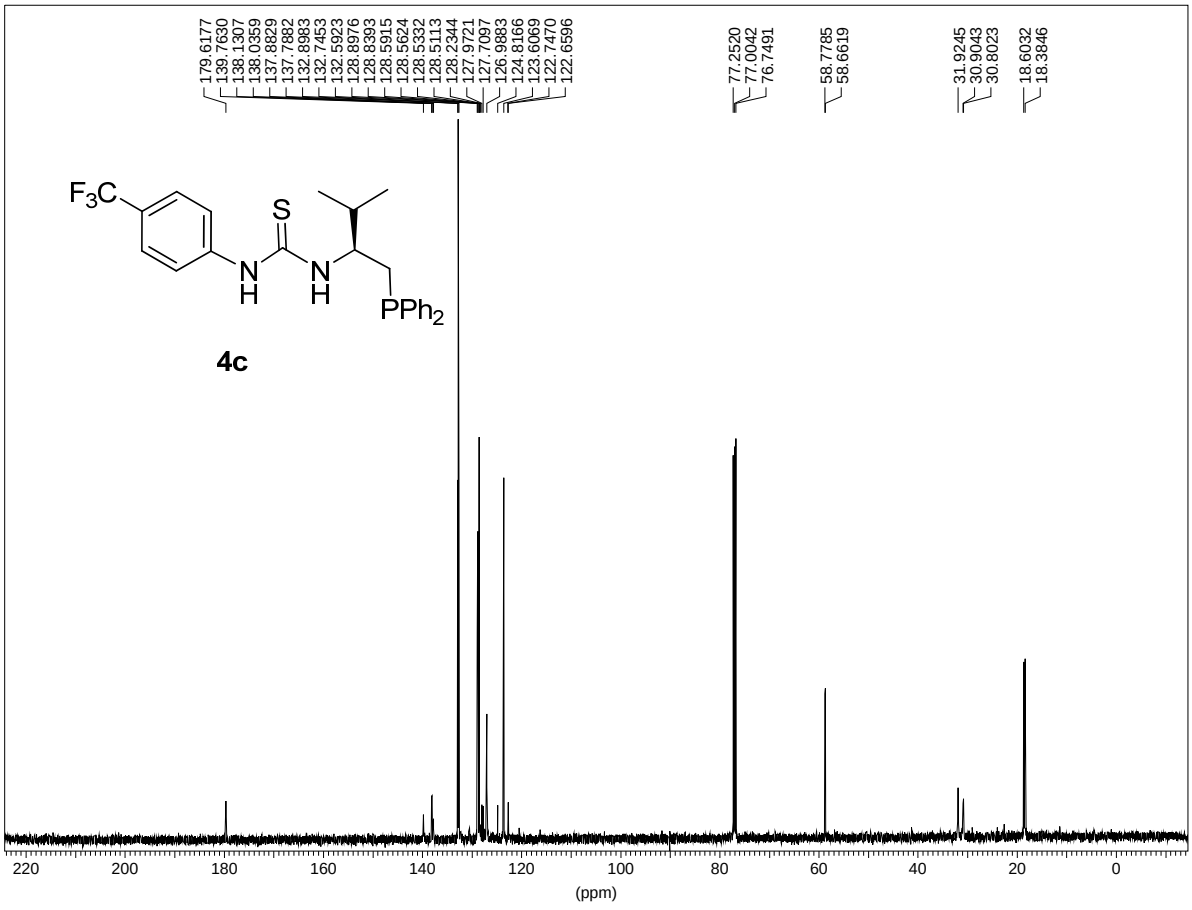
31p AMX500



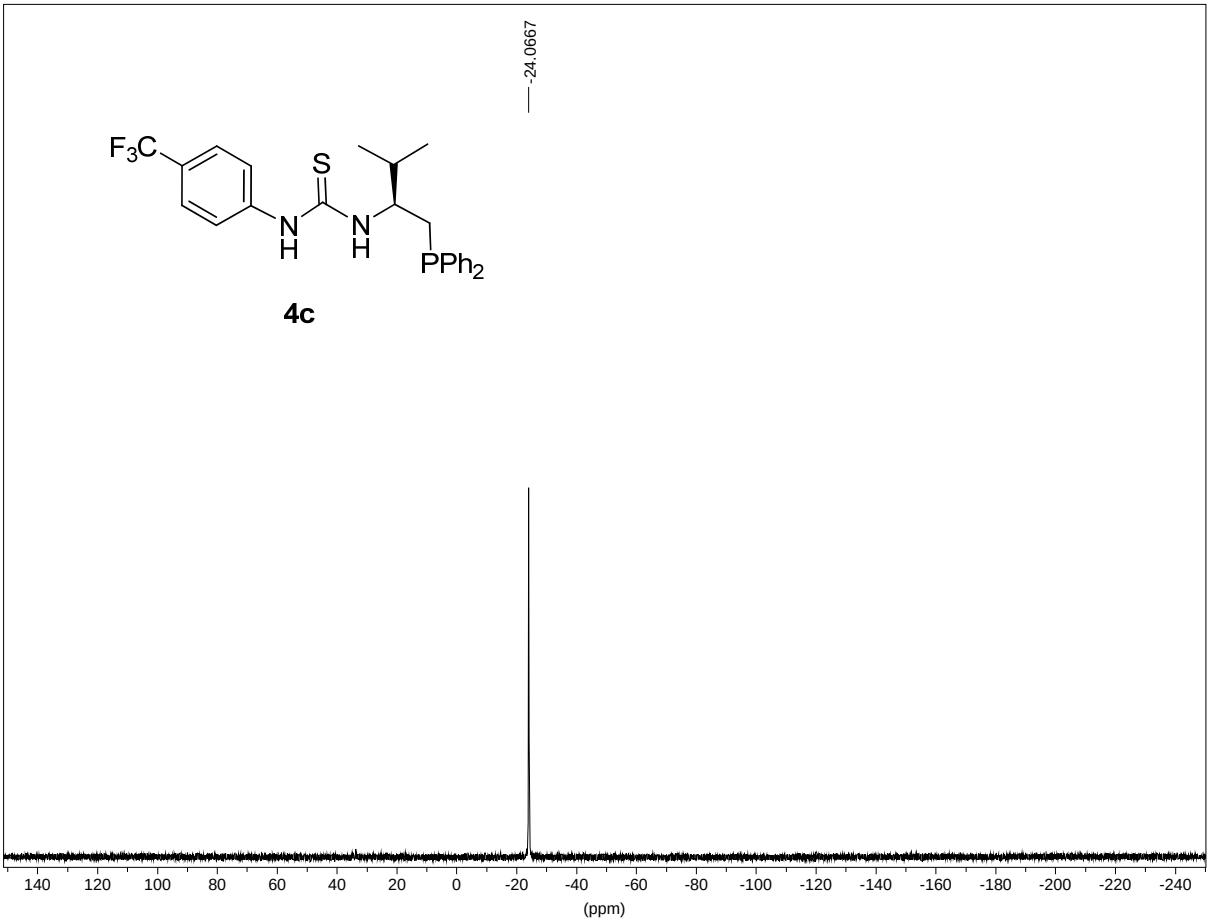
1H AMX500 hxy-444



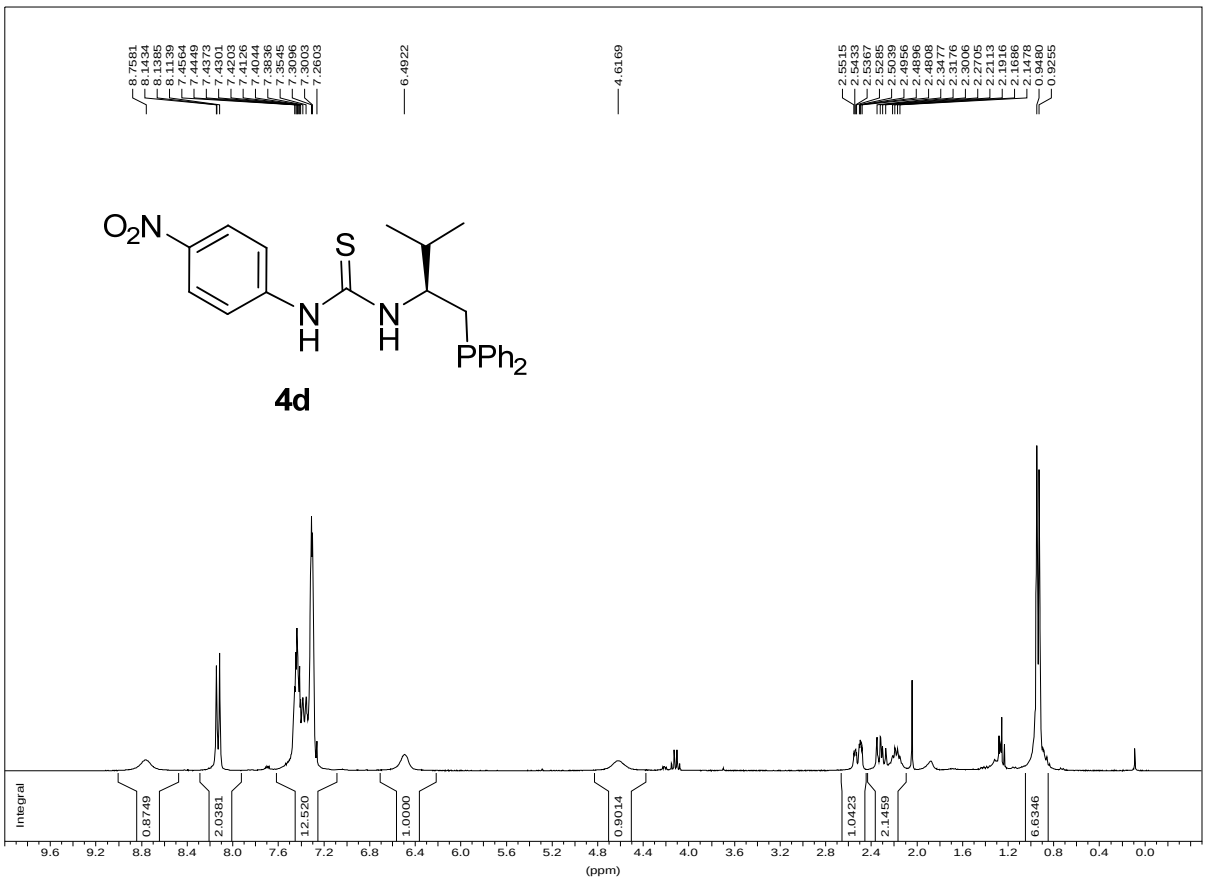
13C AMX500 hxy-444



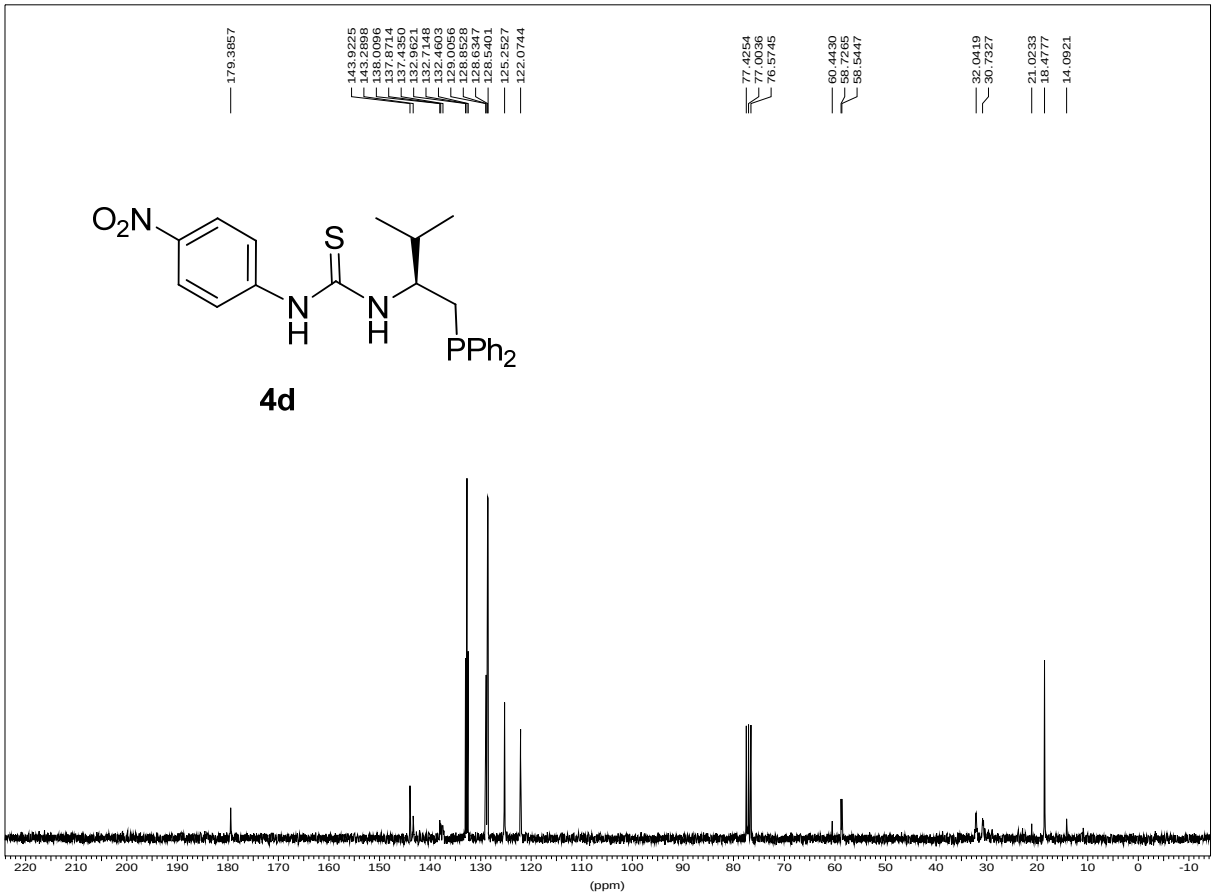
31p AMX500 hxy-444



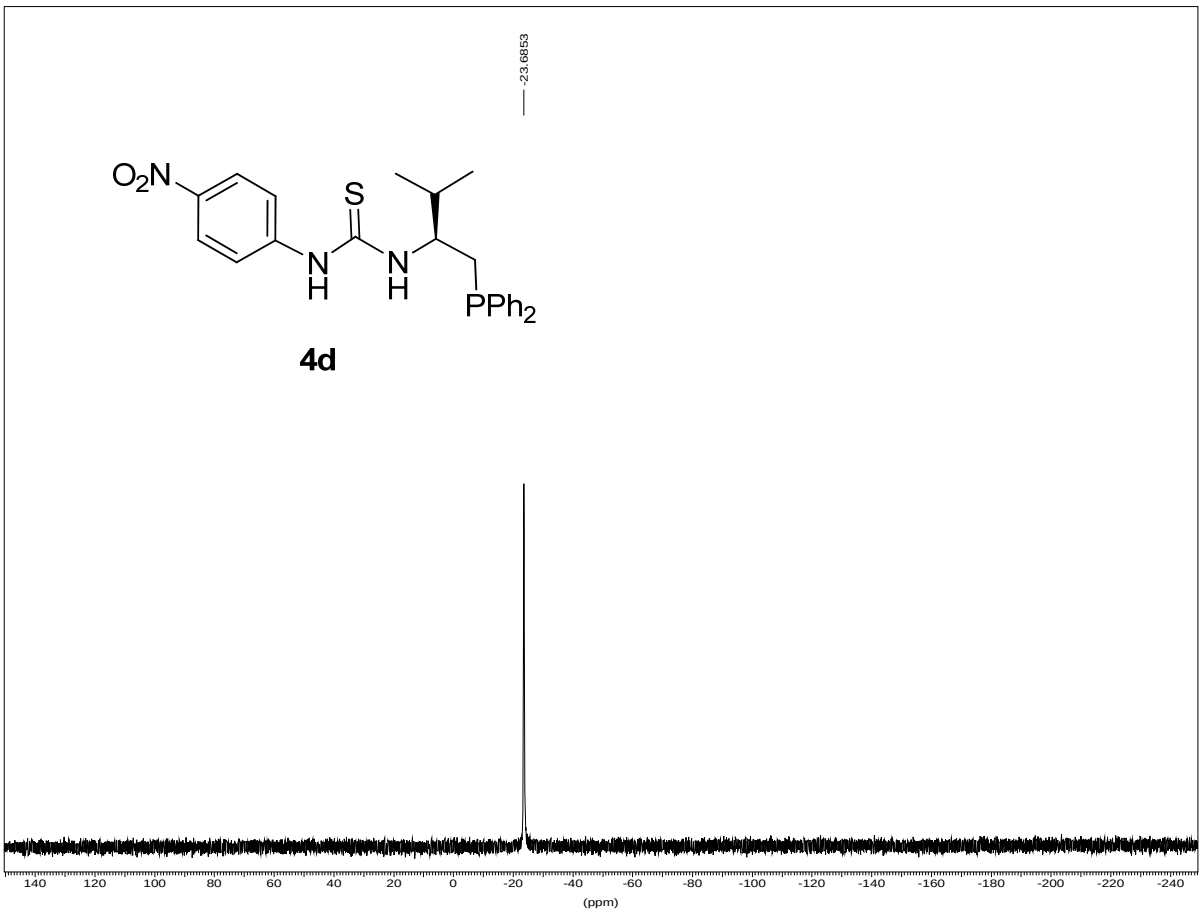
wyq-145B 1H normal range AC300



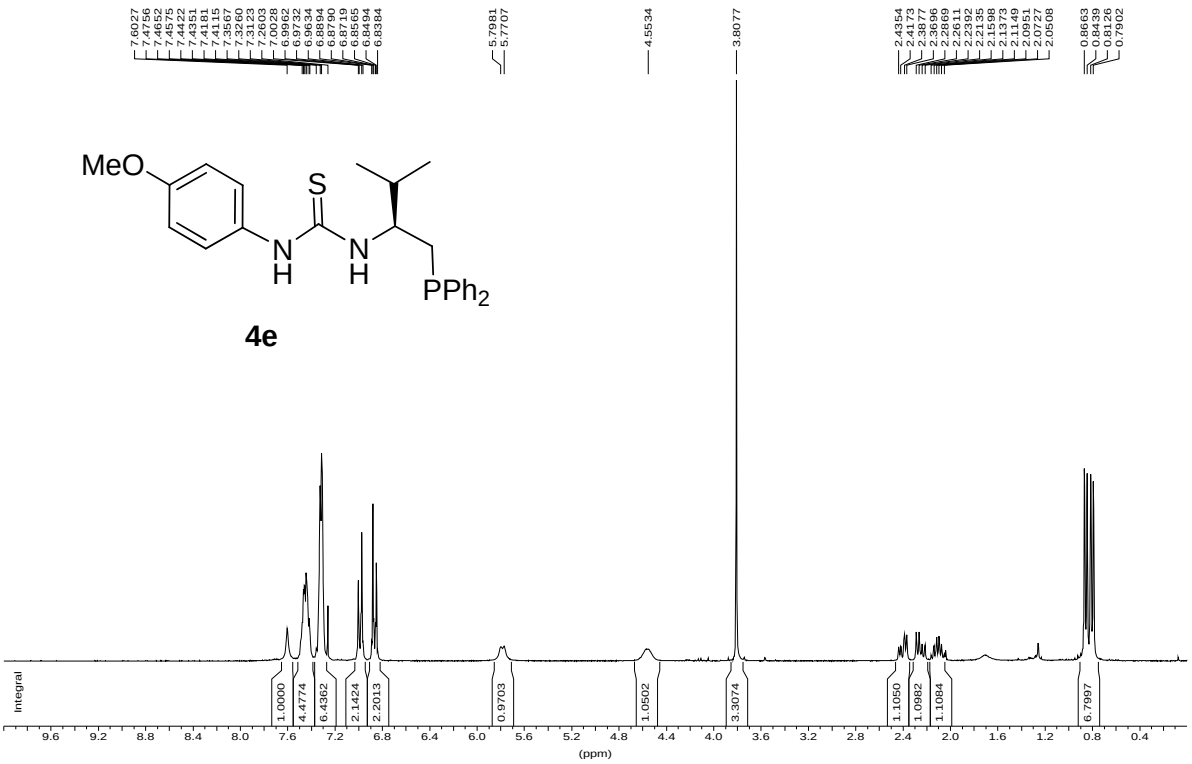
wyq-145B 13C Standard AC300



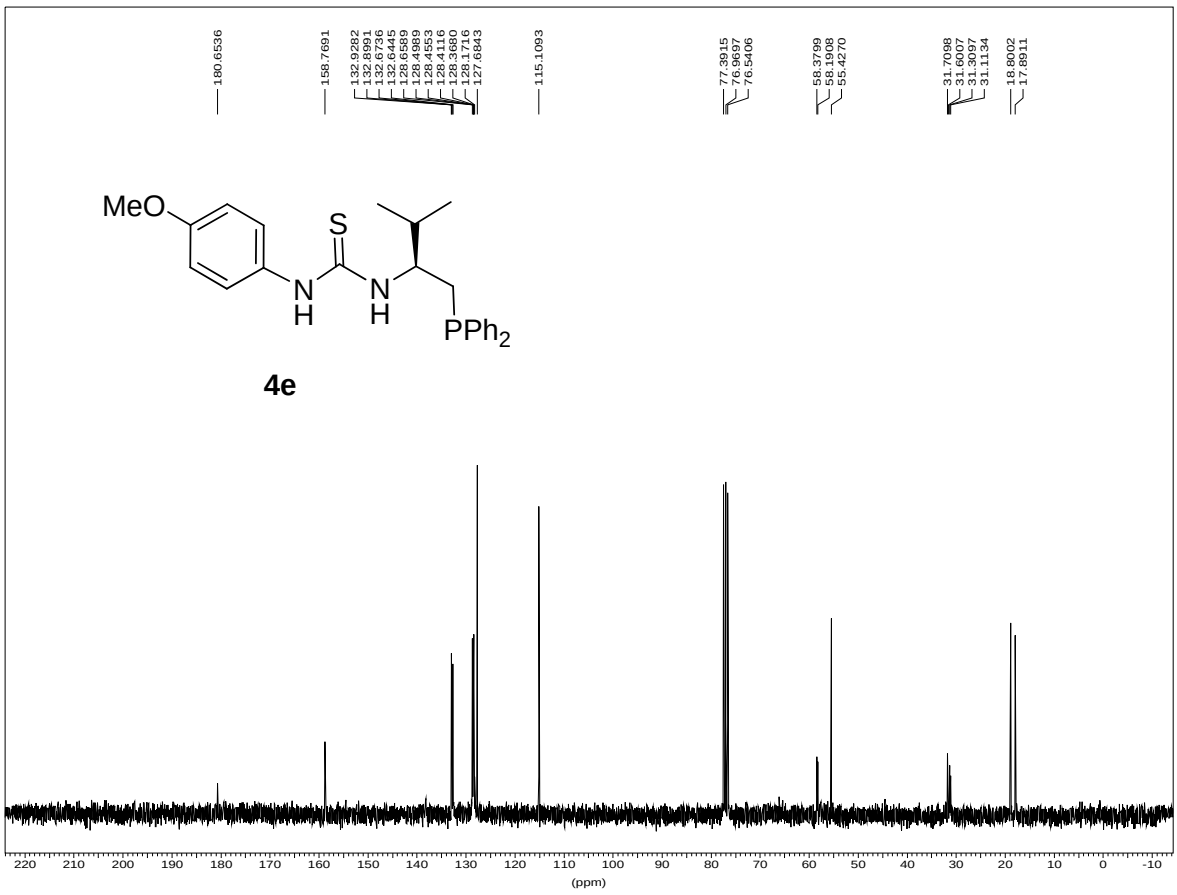
wyq-145B 31P AC300



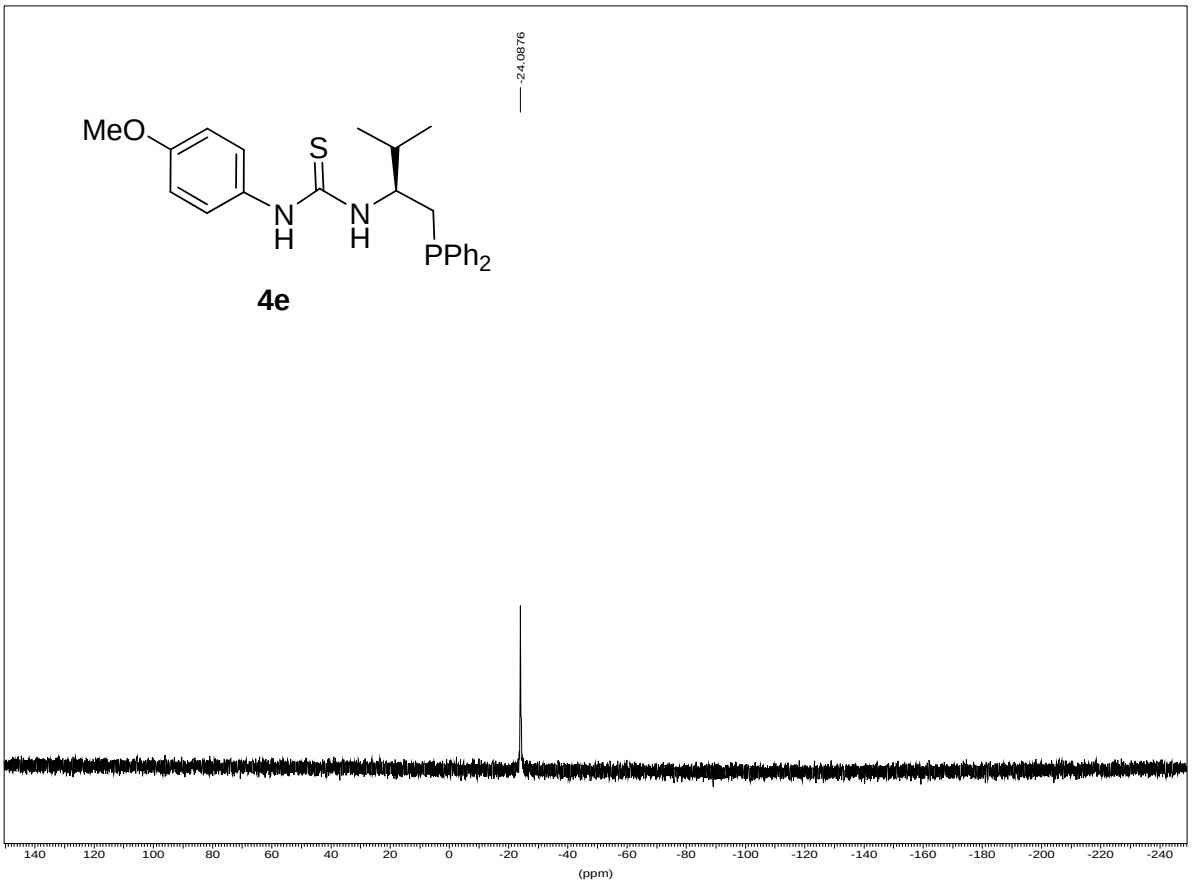
wyq-143A 1H normal range AC300



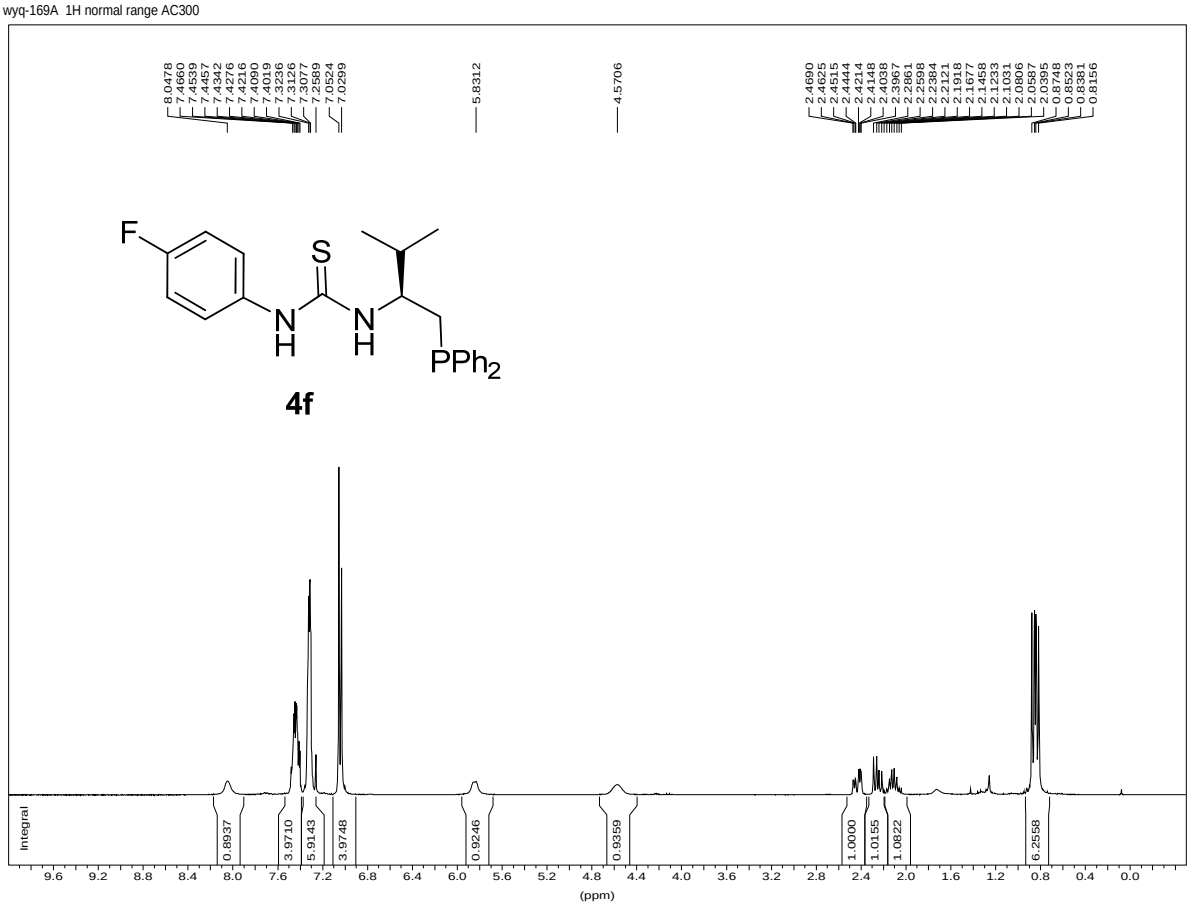
wyq-143A 13C Standard AC300



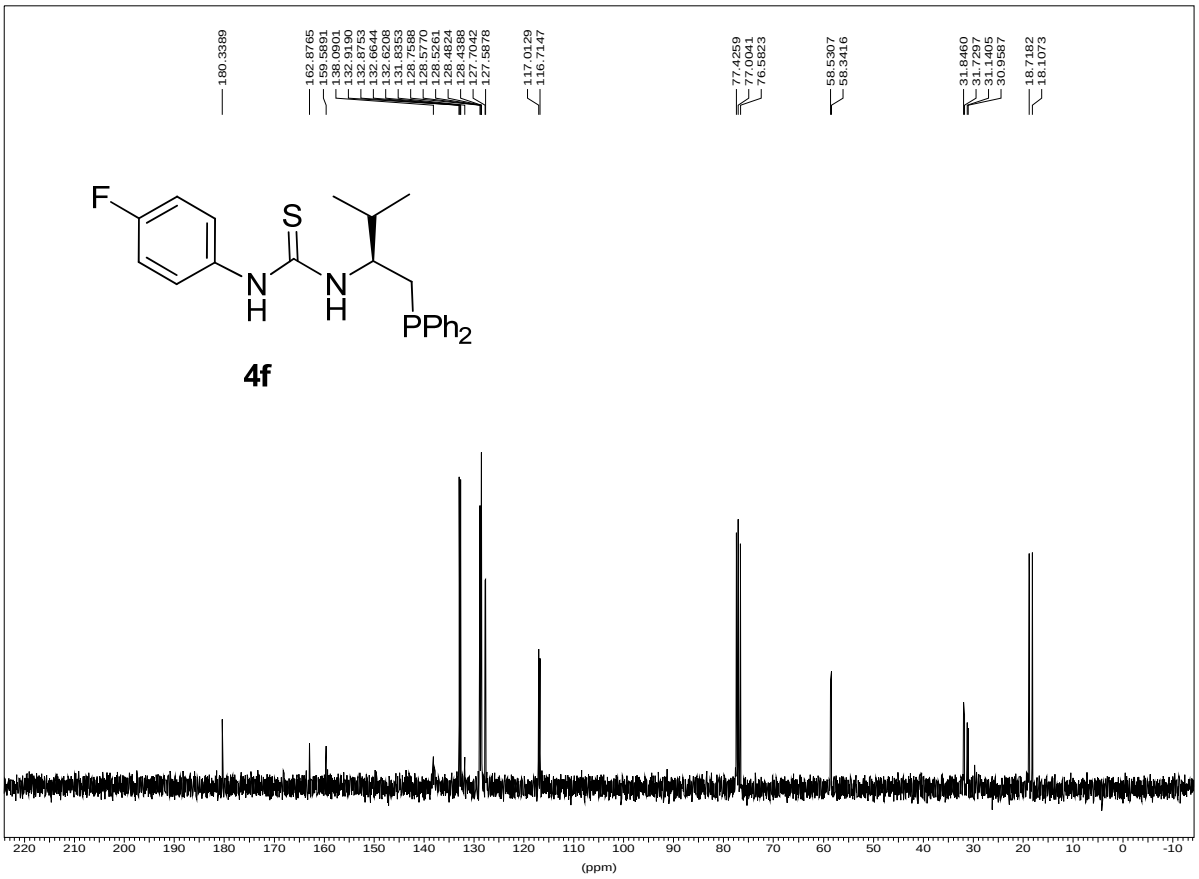
wyq-143A 31P AC300



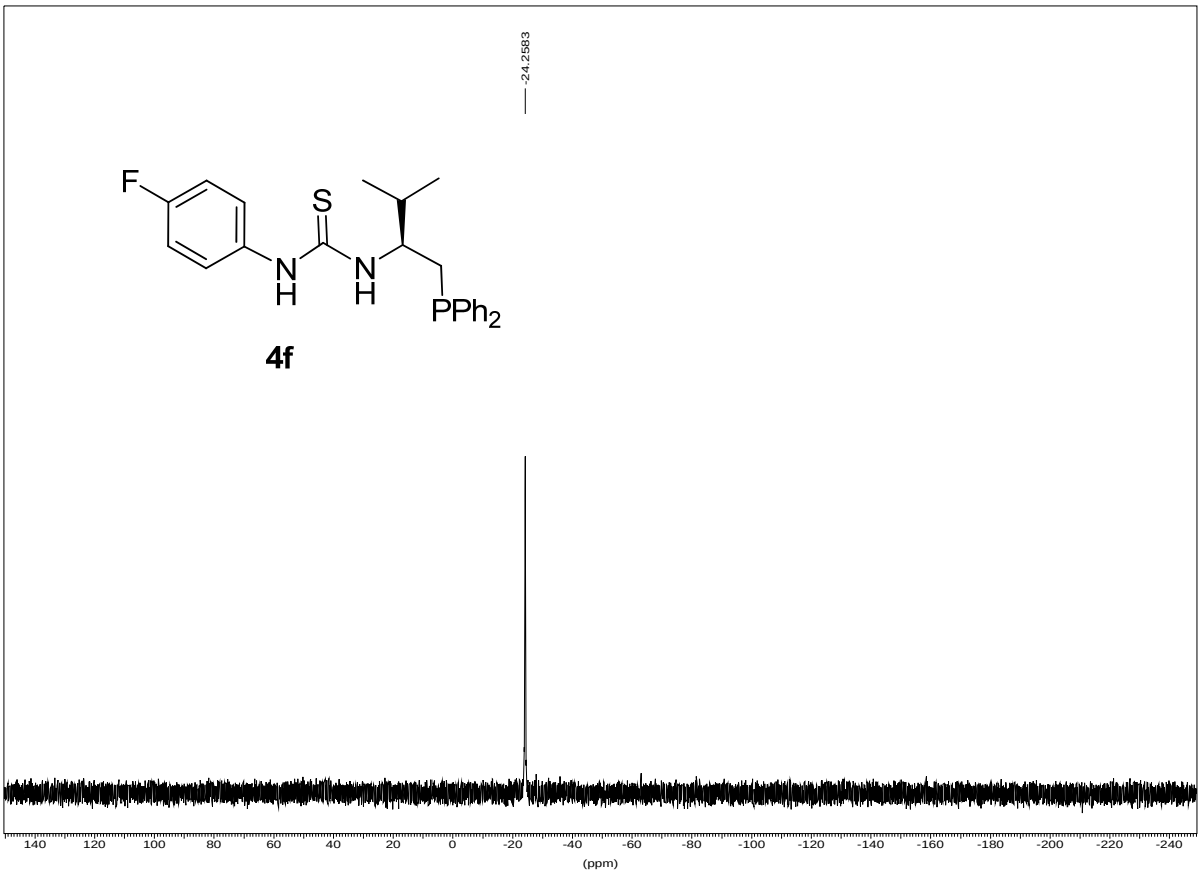
wyq-169A 1H normal range AC300



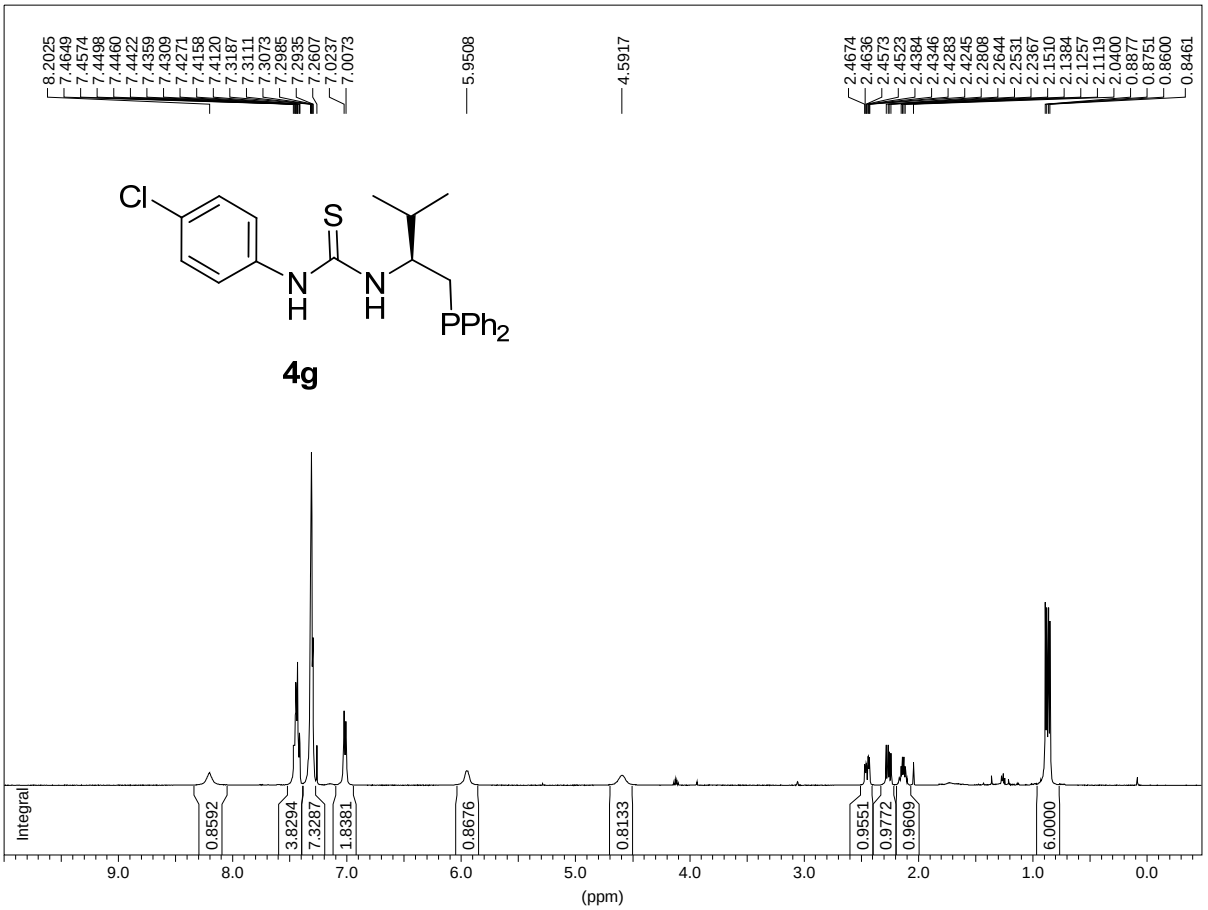
wyq-169A 13C Standard AC300



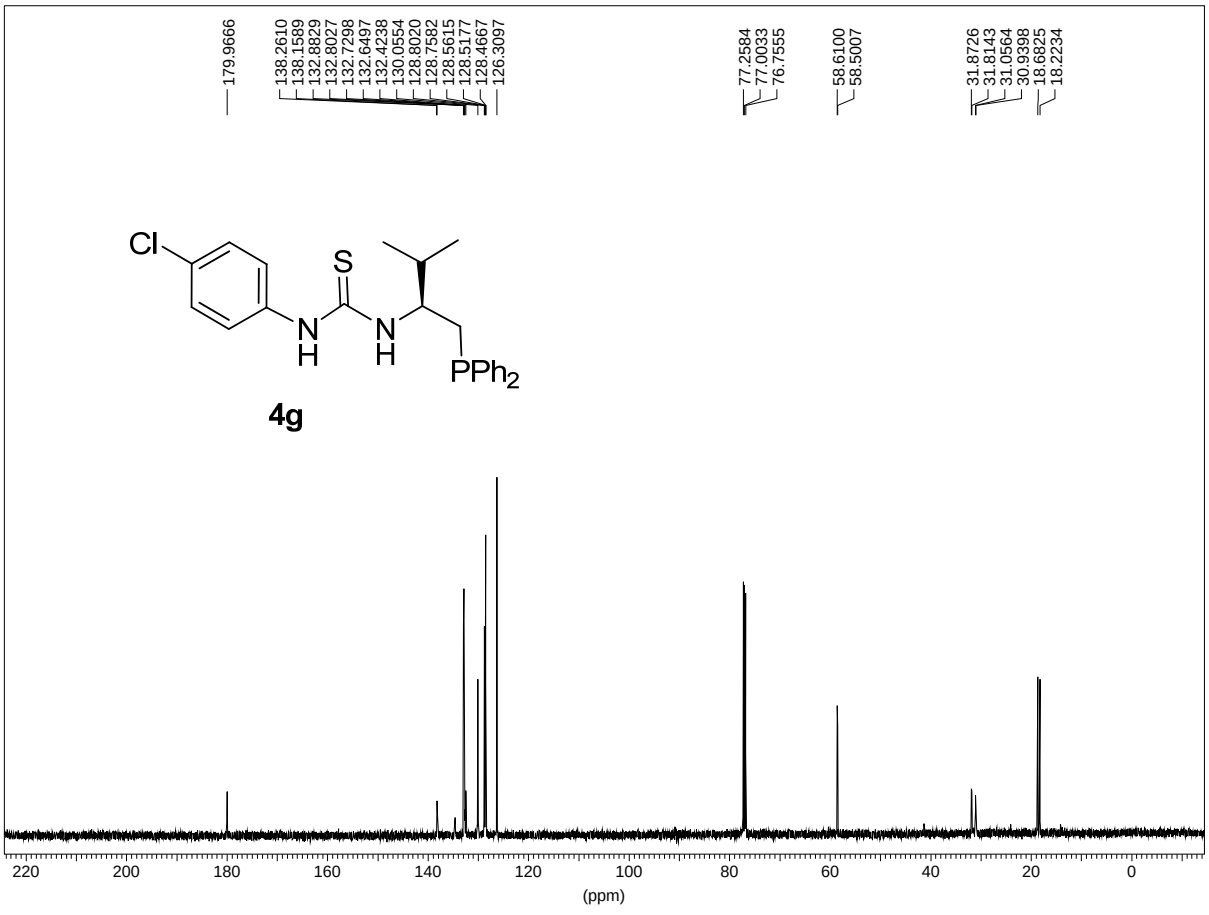
wyq-169A 31P AC300



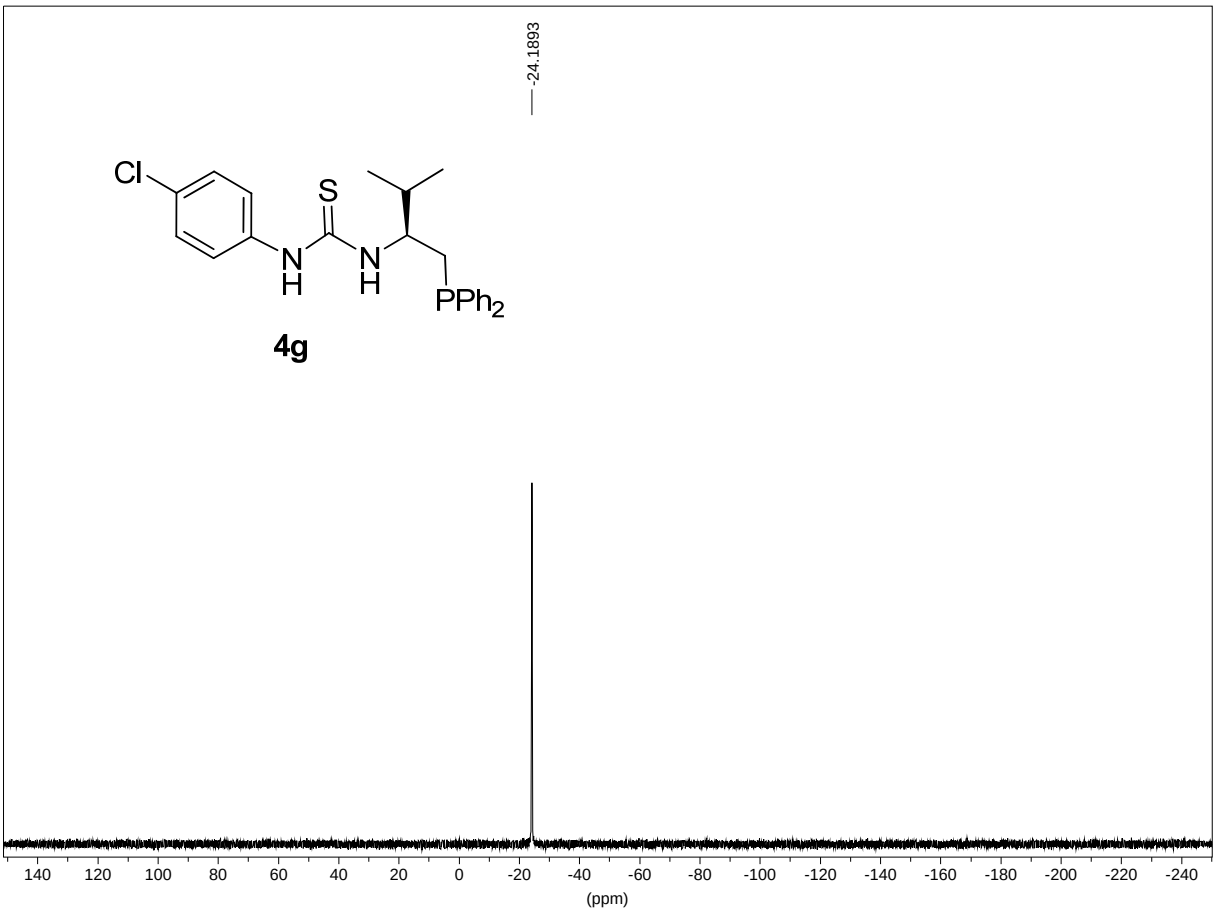
1H AMX500 hxy-439



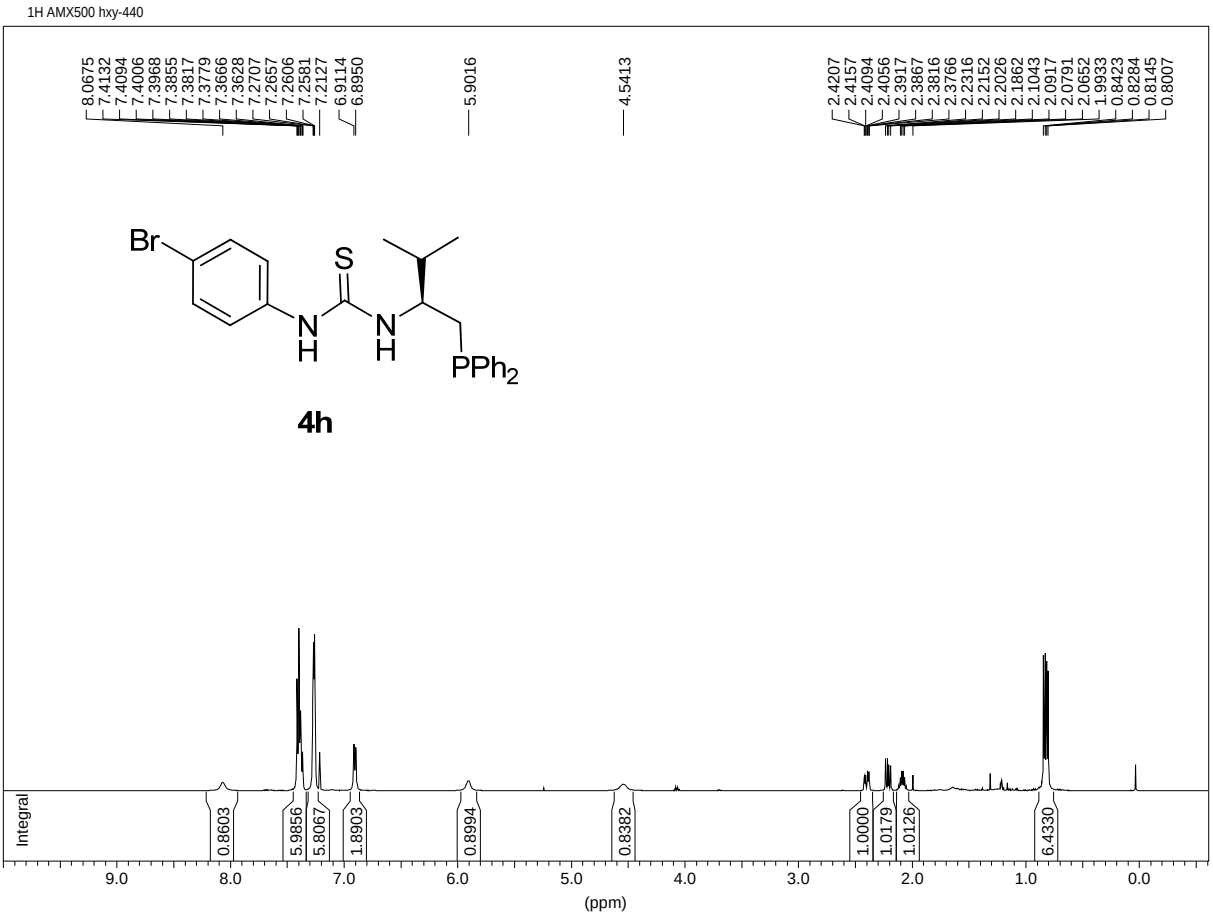
13C AMX500 hxy-439



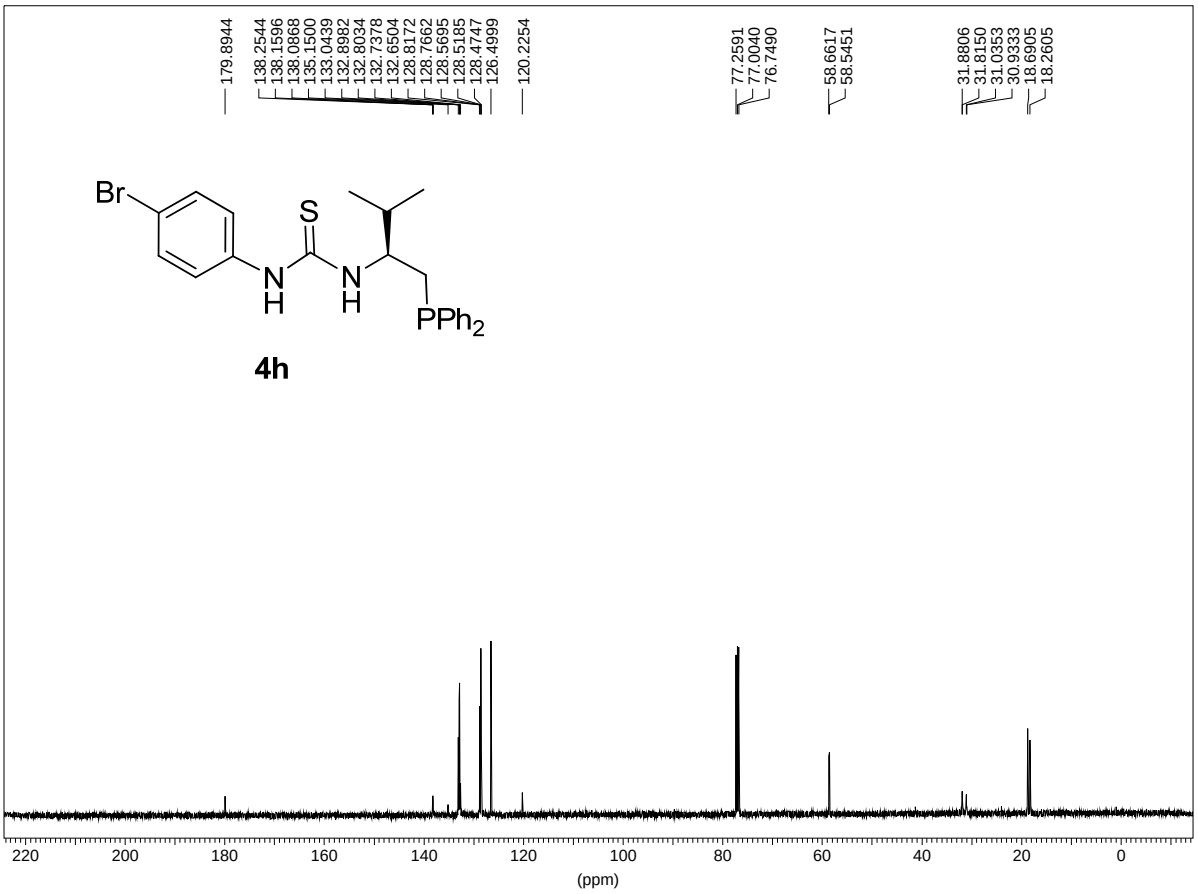
31p AMX500 hxy-439



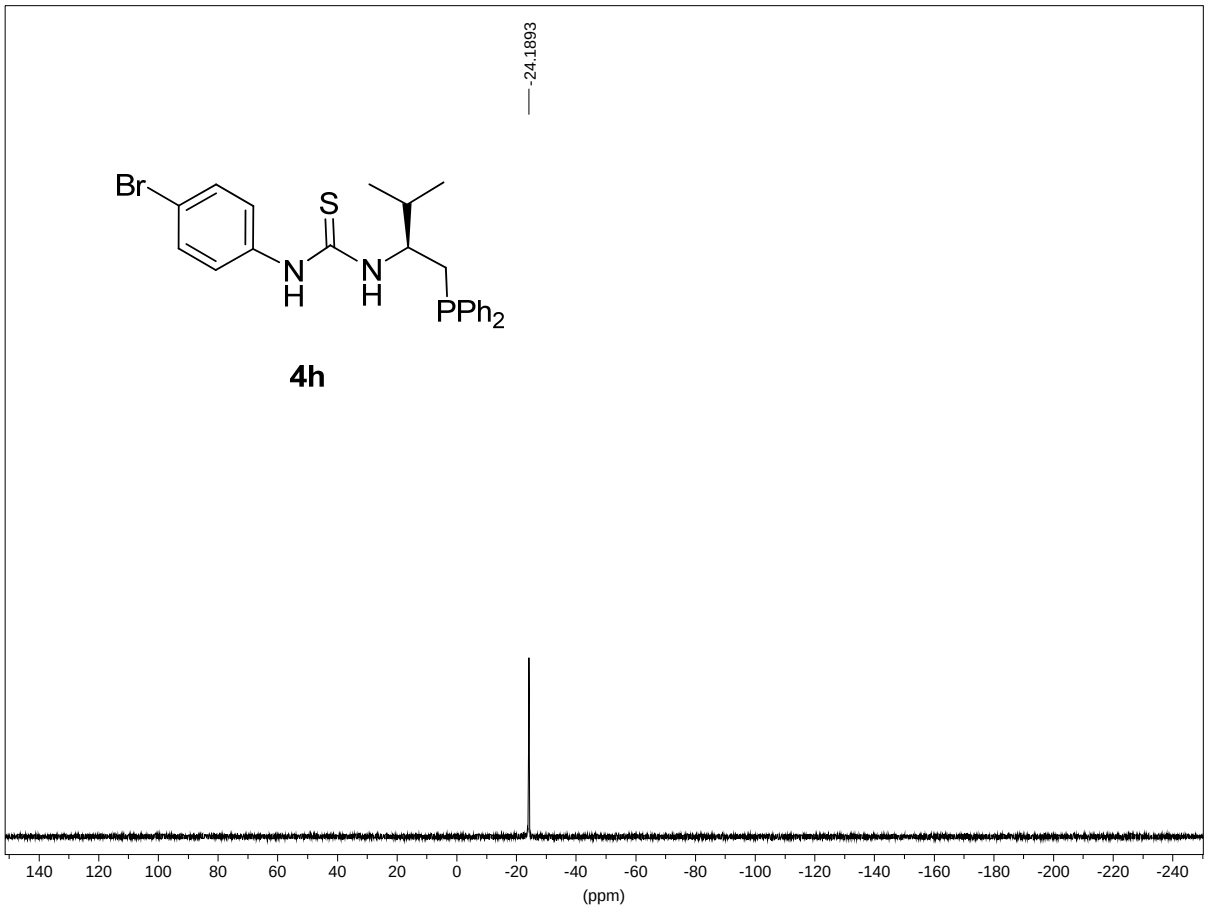
1H AMX500 hxy-440



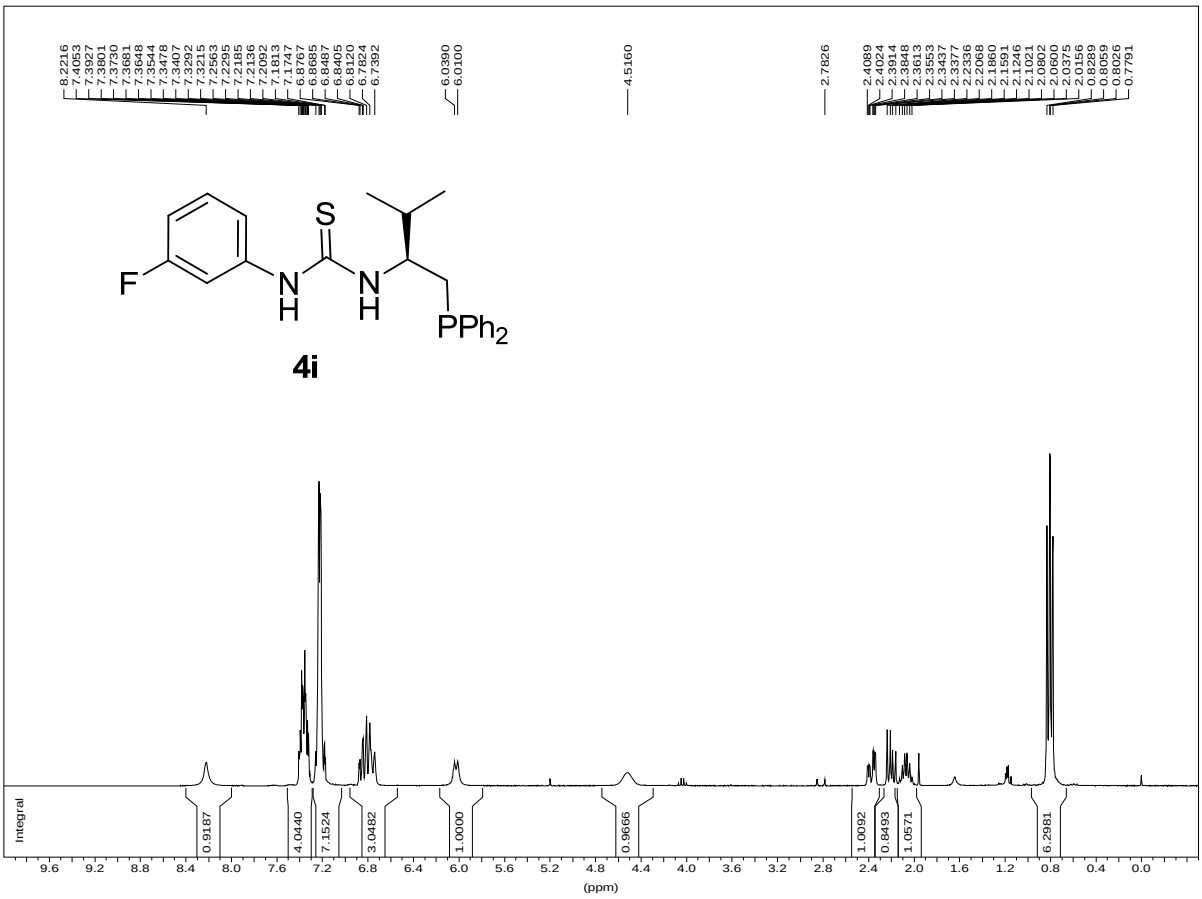
13C AMX500 hxy-440



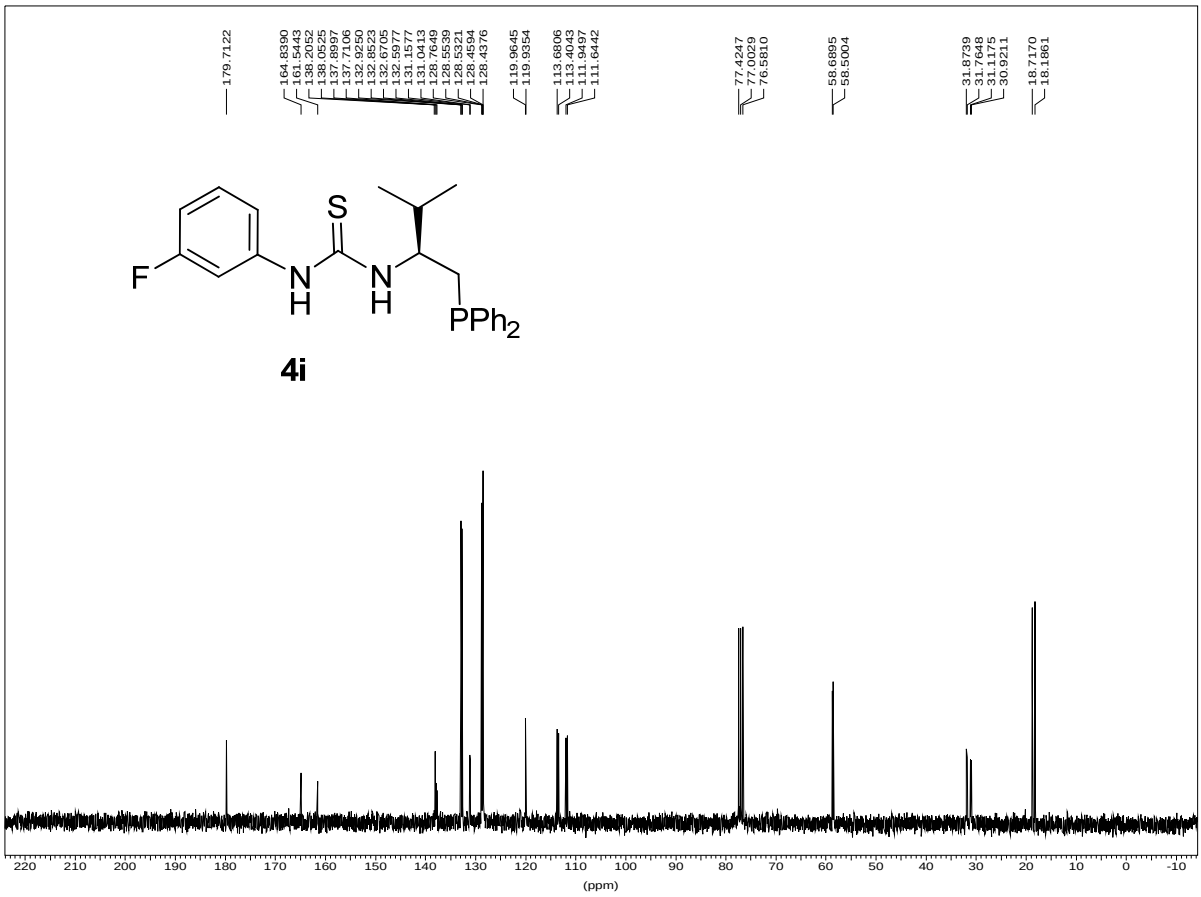
31p AMX500 hxy-440



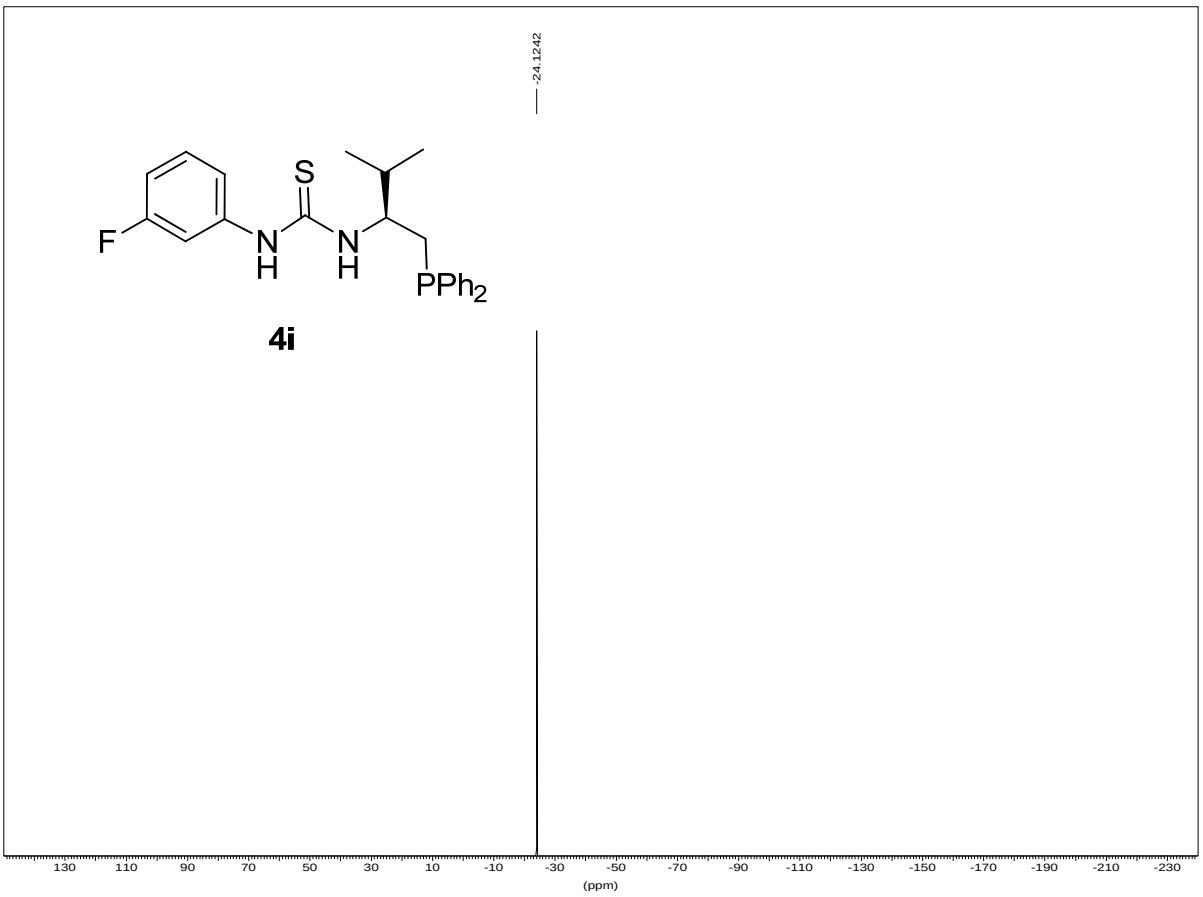
wyq-142B 1H normal range AC300



wyq-142B 13C Standard AC300

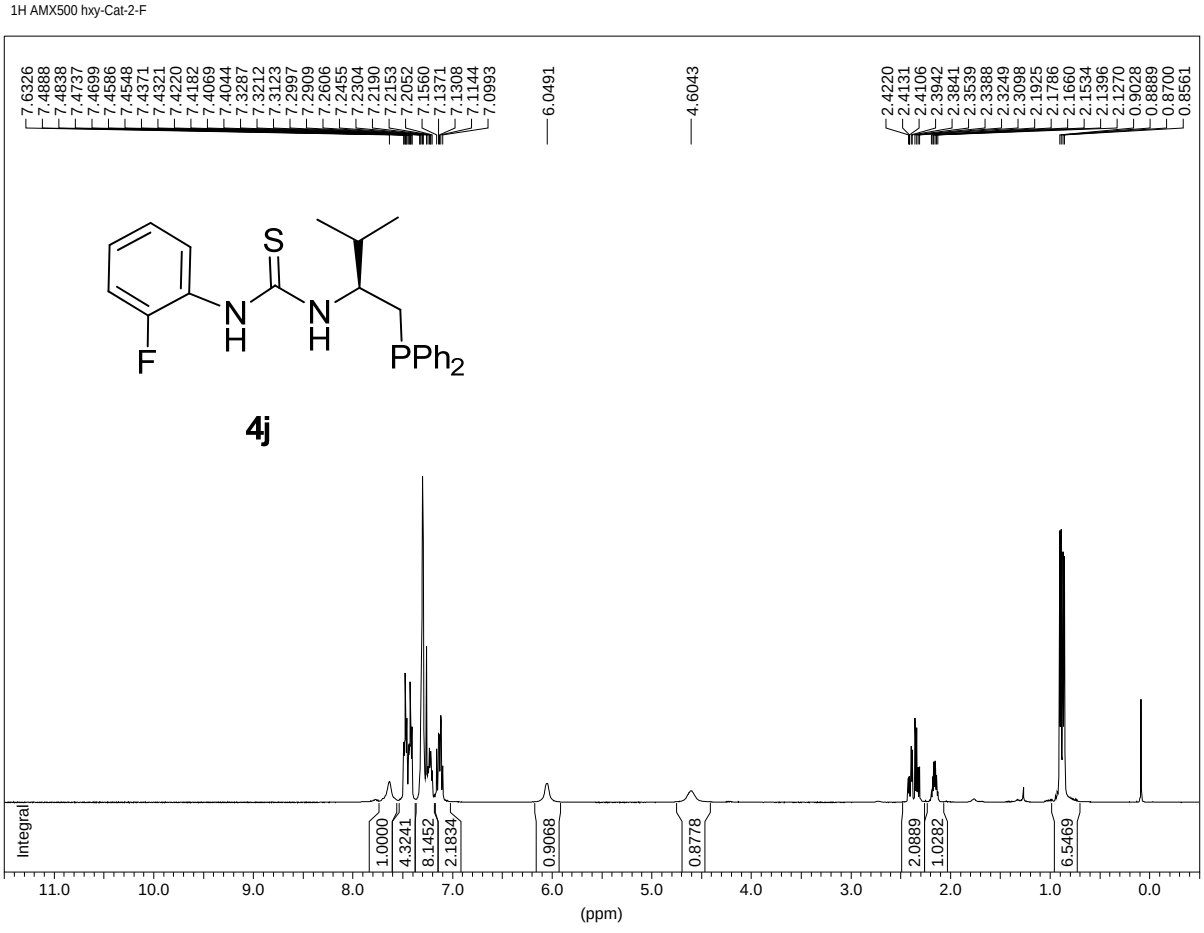


wyq-142B 31P AC300



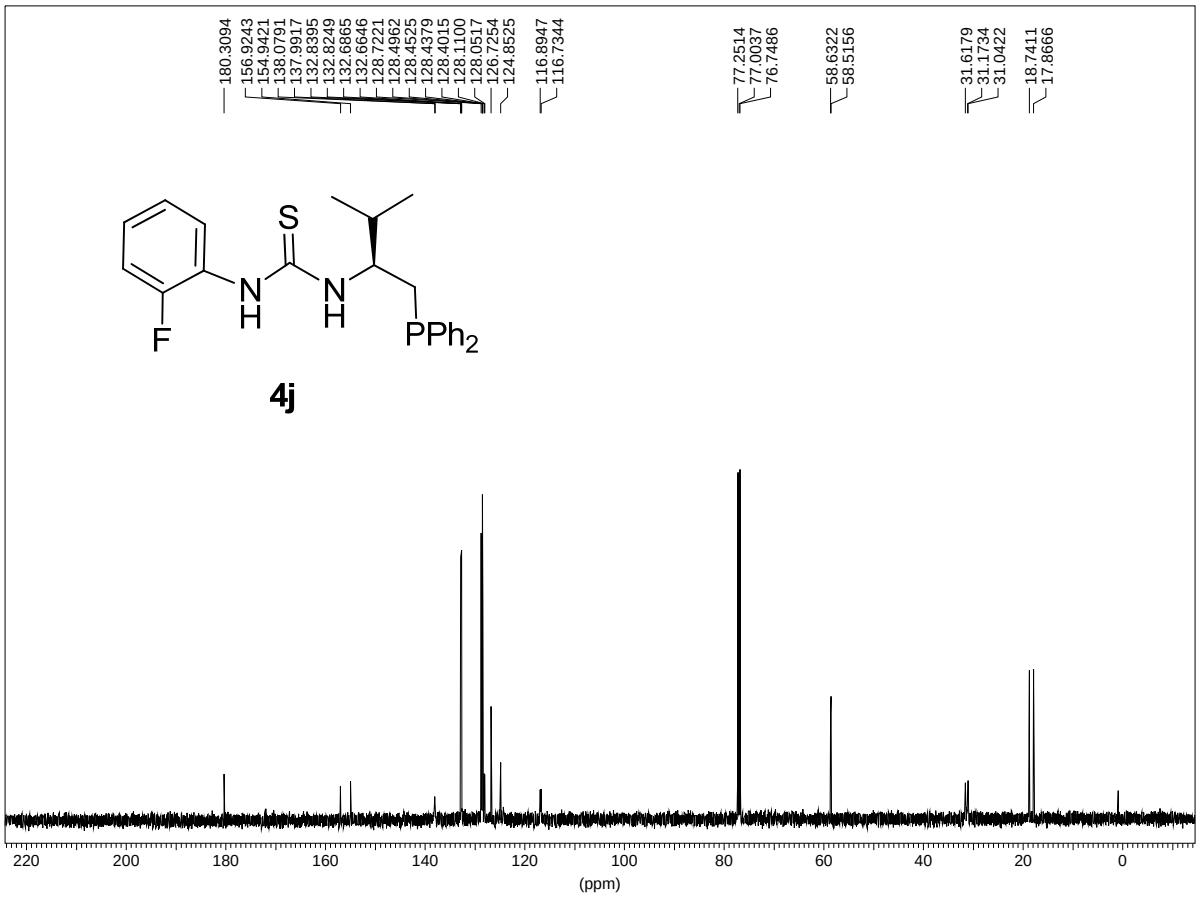
4i

1H AMX500 hxy-Cat-2-F



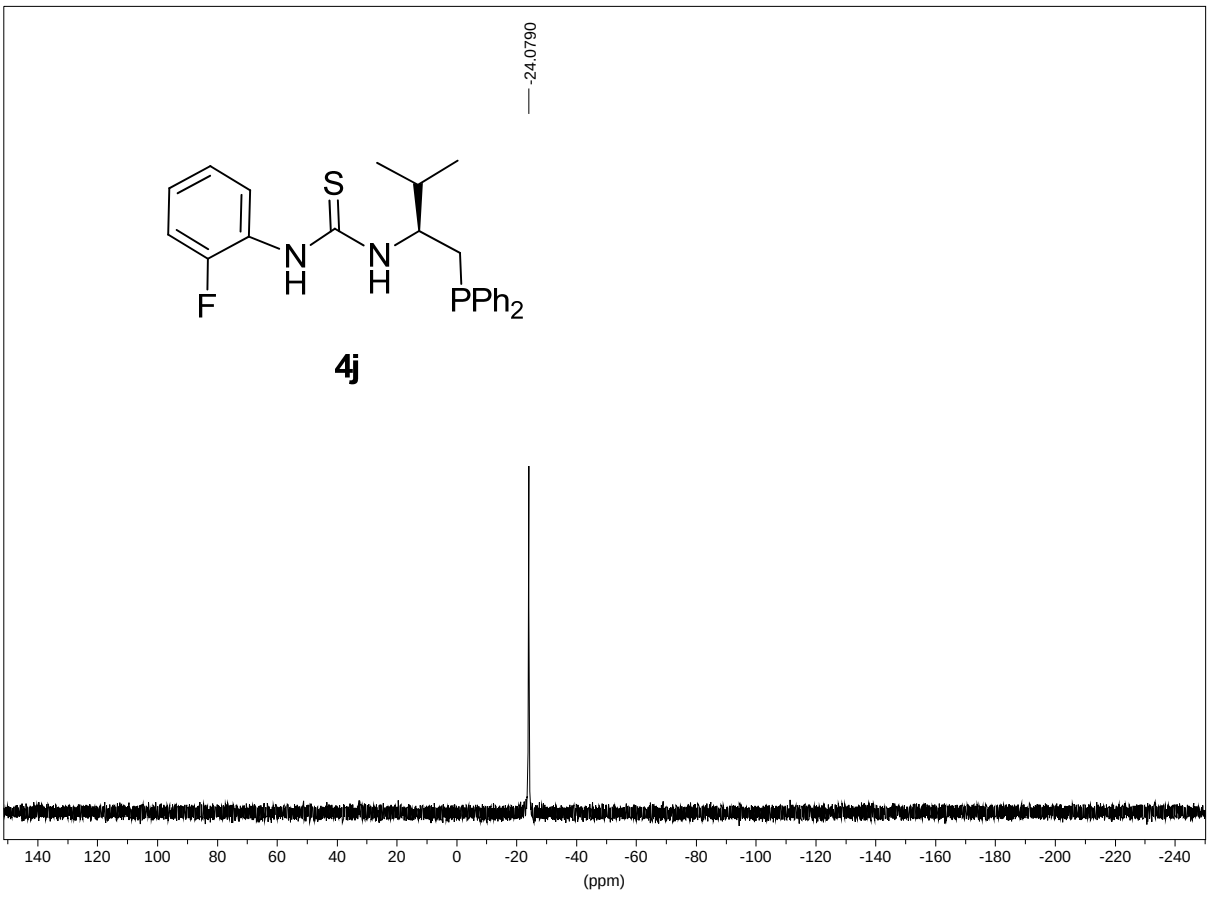
4j

13C AMX500 hxy-Cat-2-F



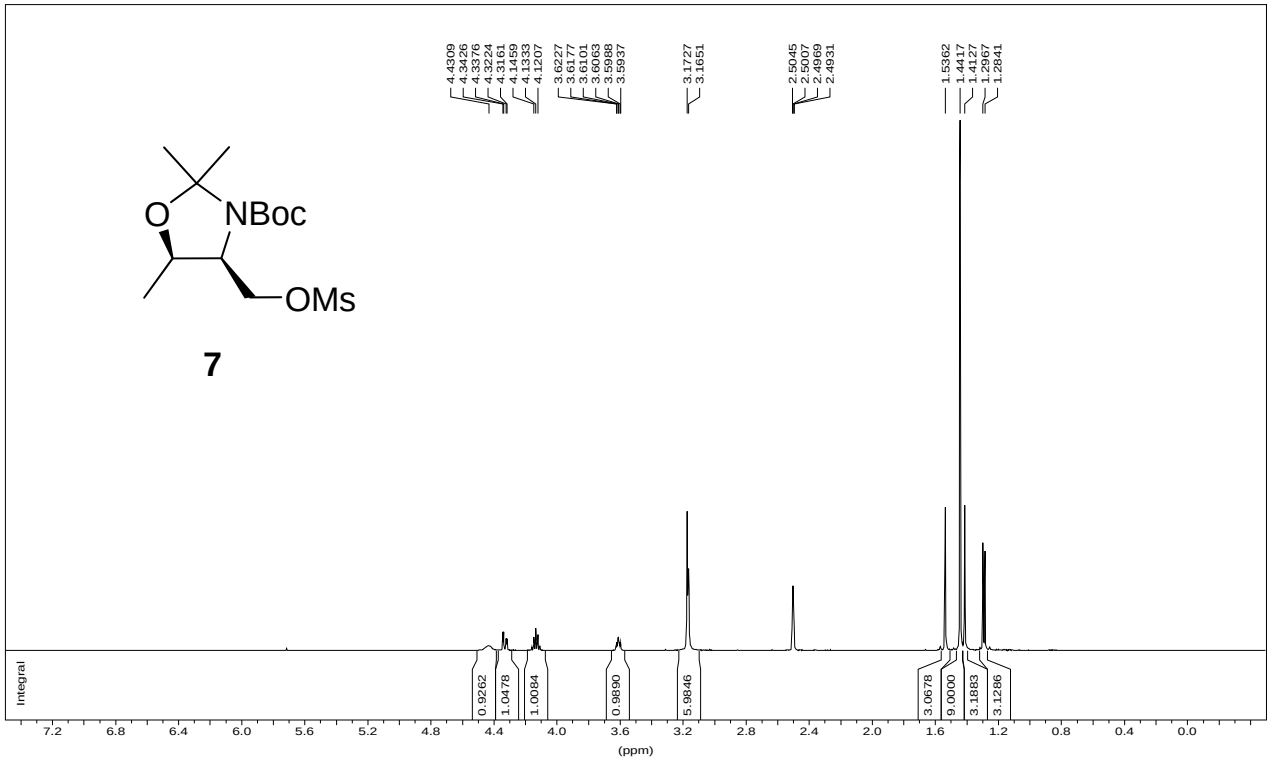
4j

31p AMX500 hxy-Cat-2-F



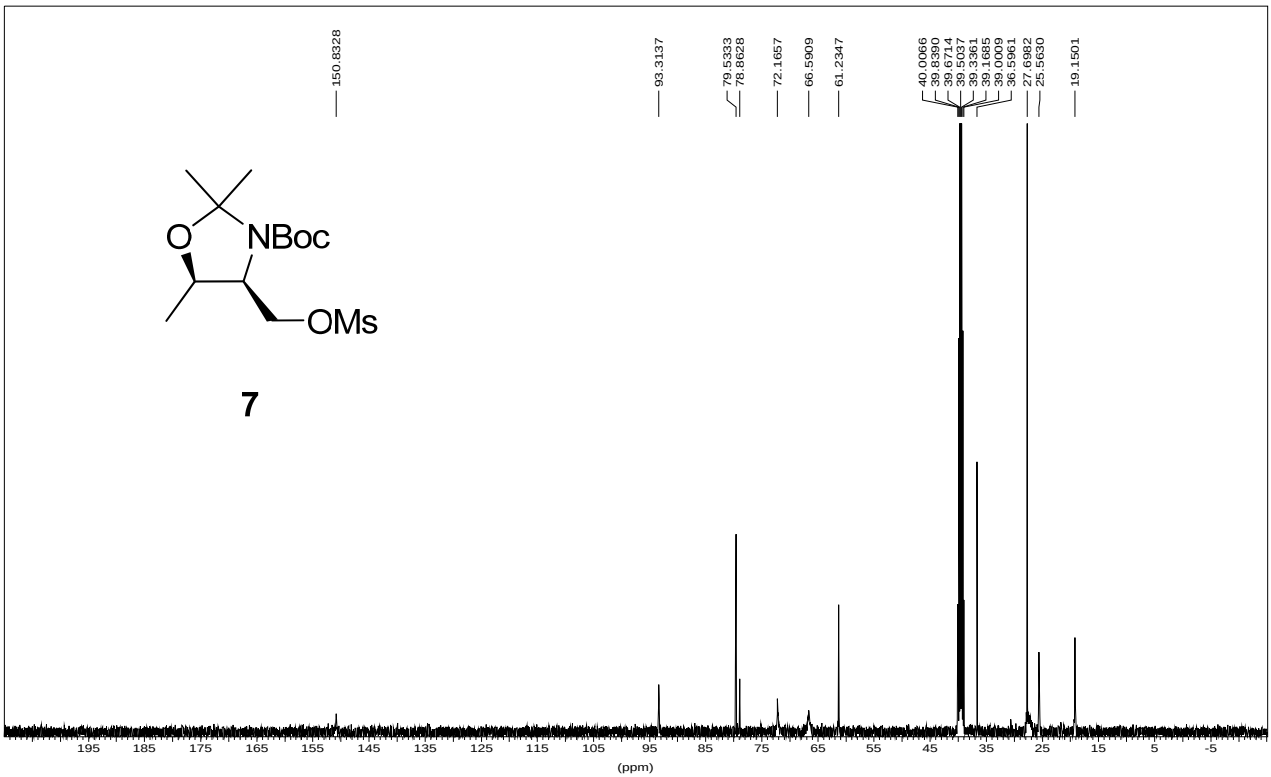
4j

1H AMX500 hxy-258



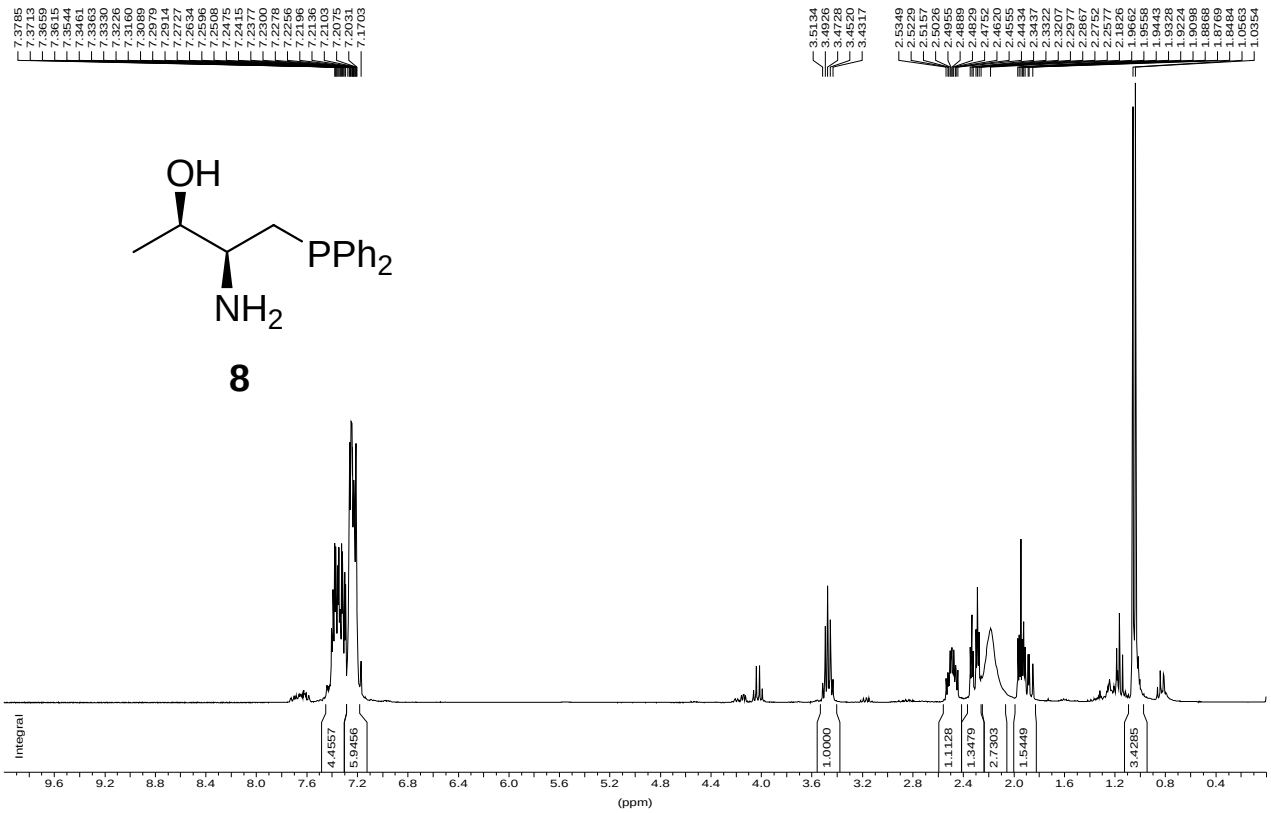
7

13C AMX500 hxy-258

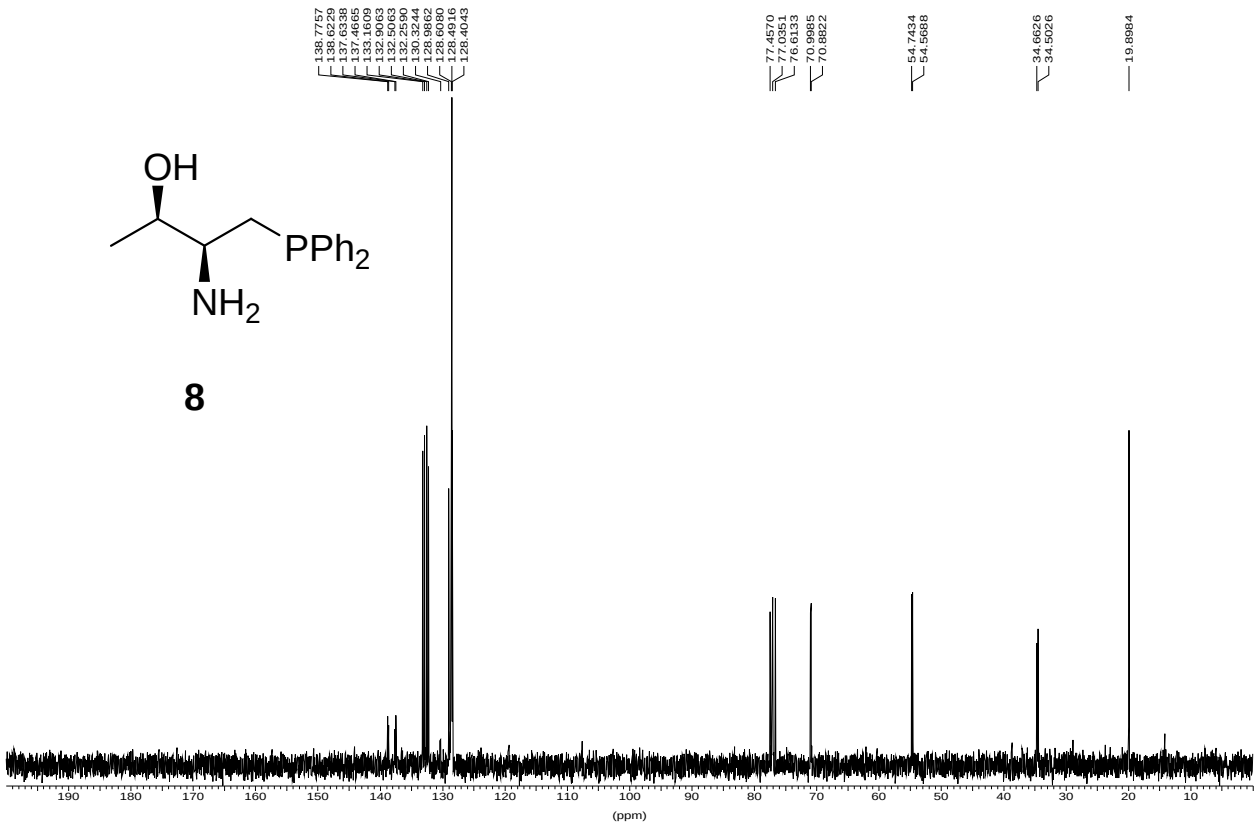


7

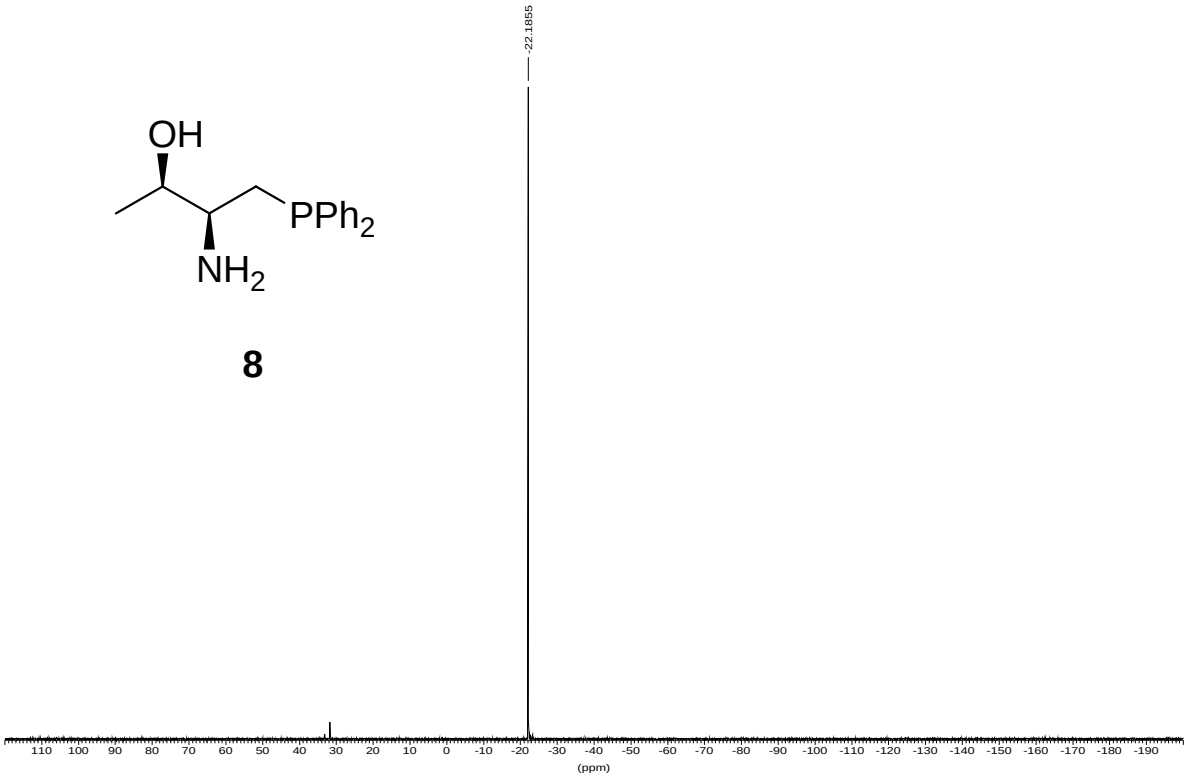
1H normal range AC300 wyq-s3



13C Standard AC300 wyq-s3

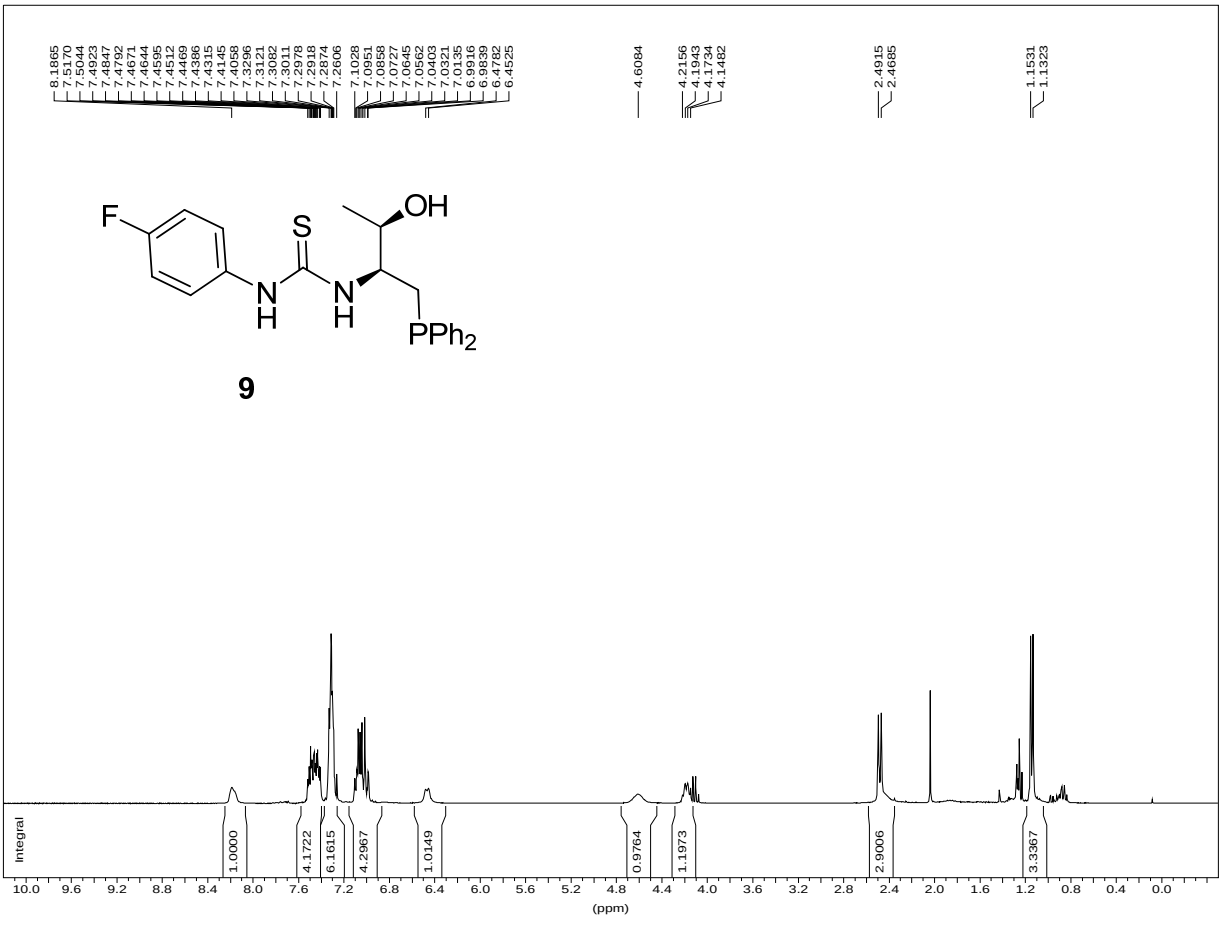


31P AC300 wyq-s3



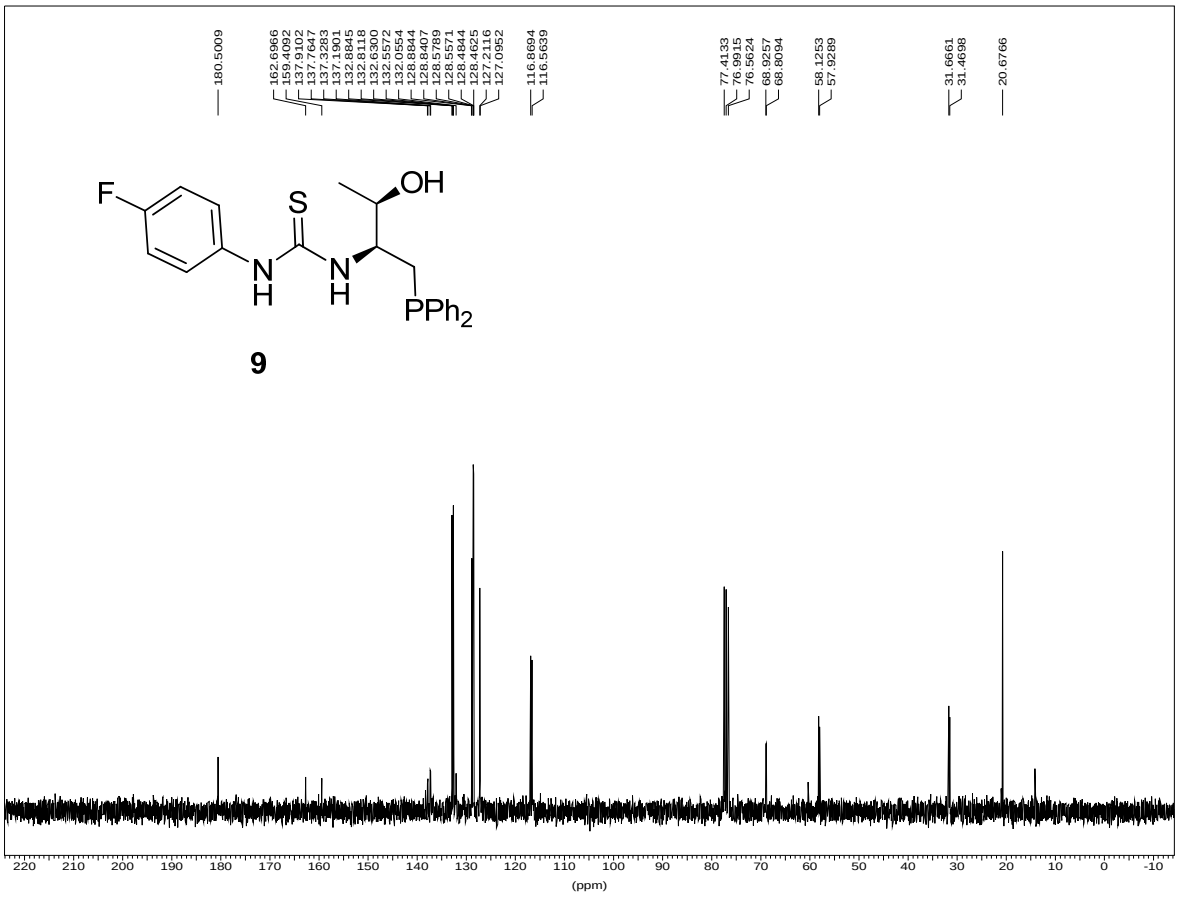
8

wyq-197 1H normal range AC300



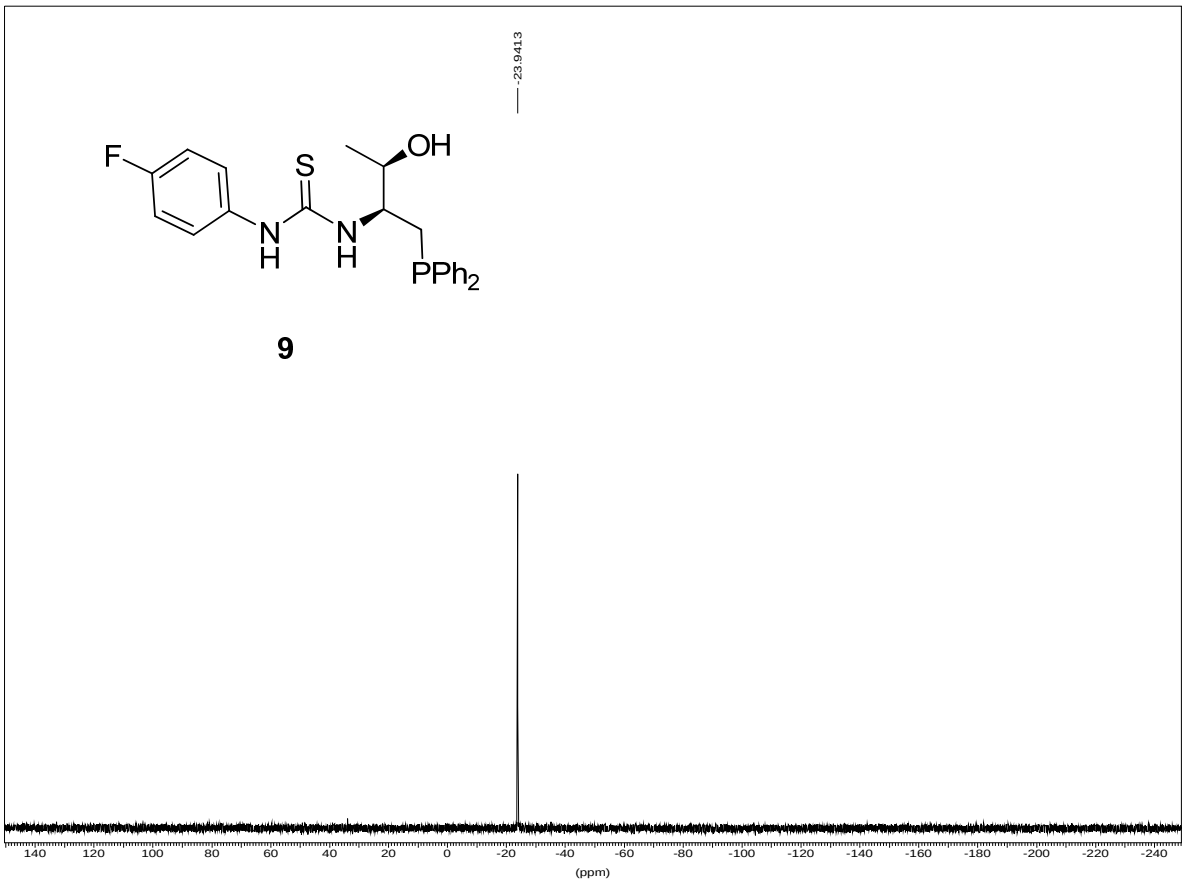
9

wyq-197 13C Standard AC300



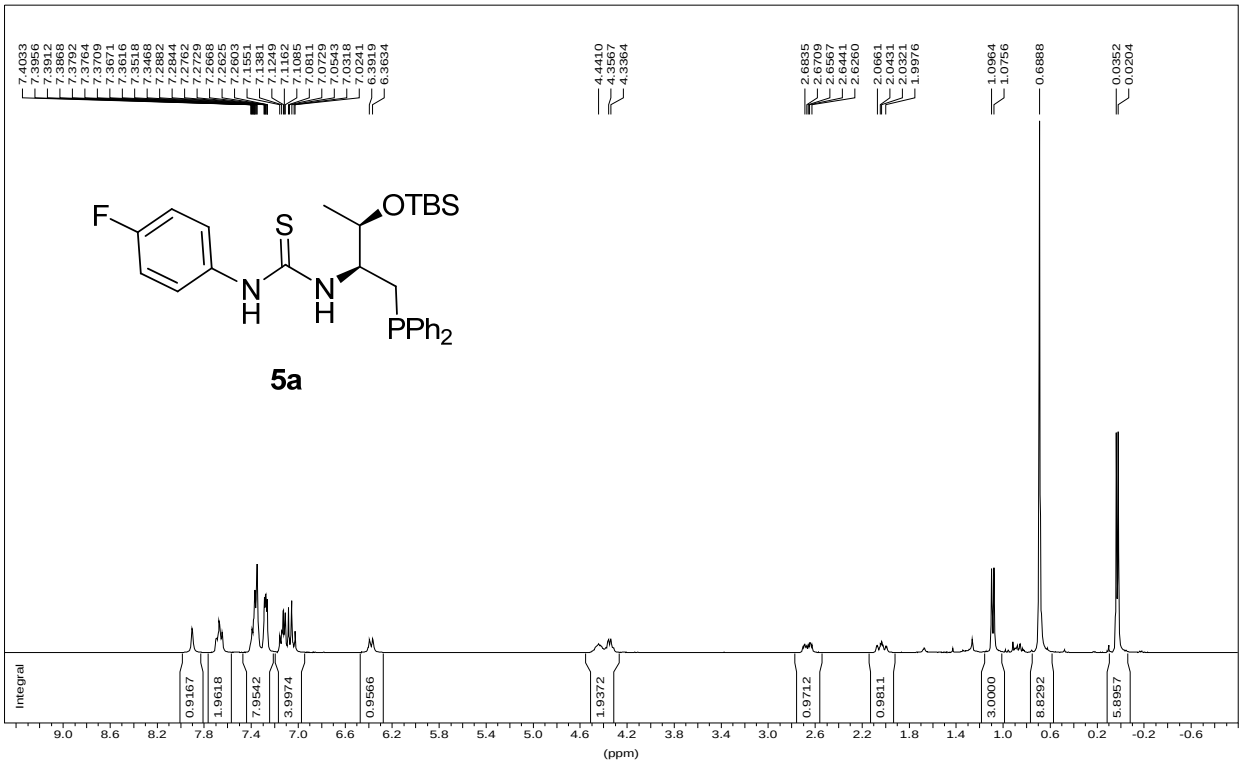
9

wyq-197 31P AC300

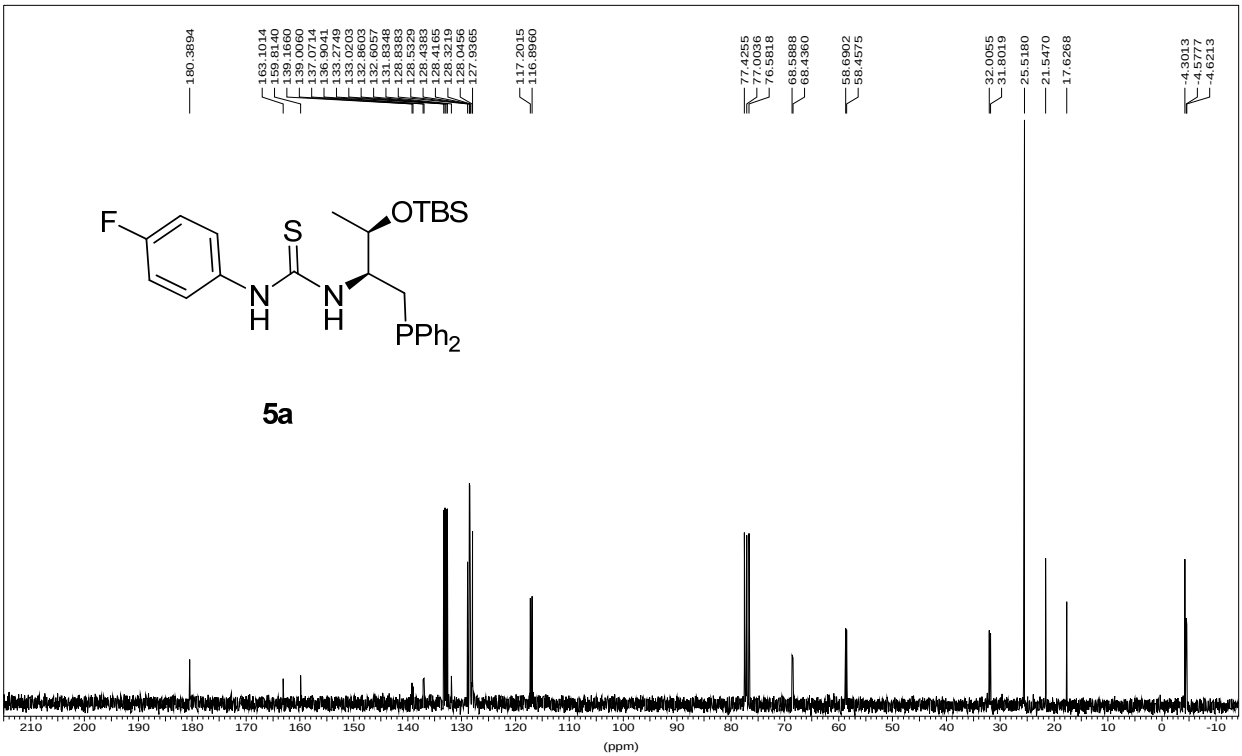


9

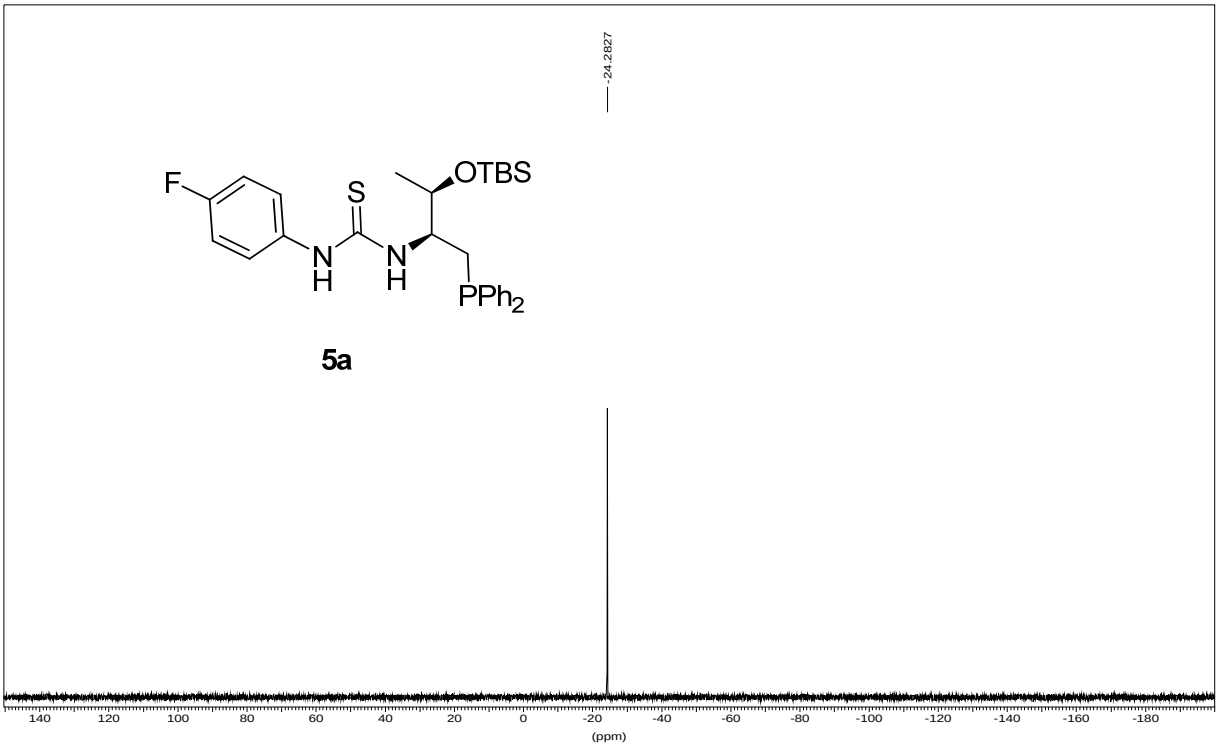
1H normal range AC300 hxy-262-H



13C Standard AC300 hxy-262

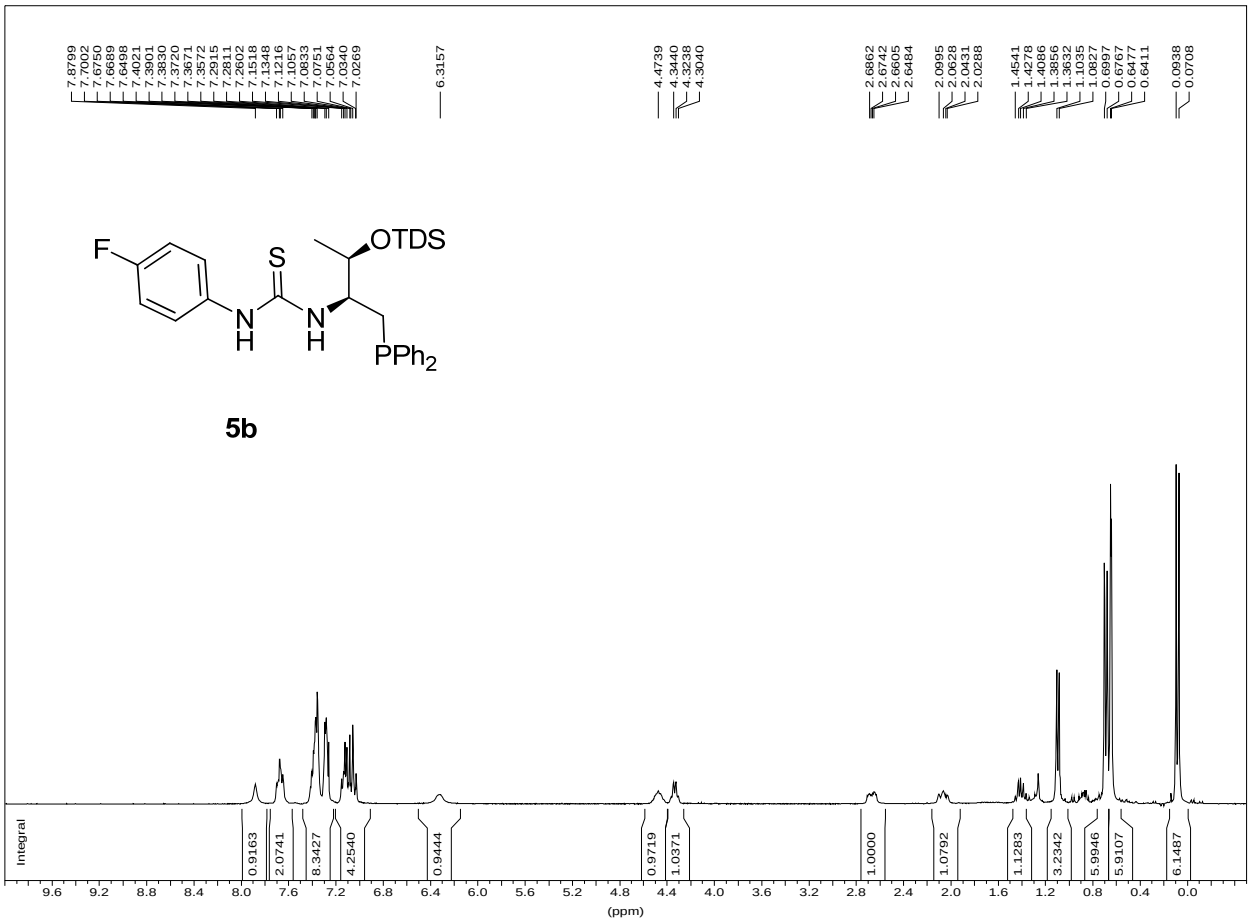


31P AC300 hxy-262-P



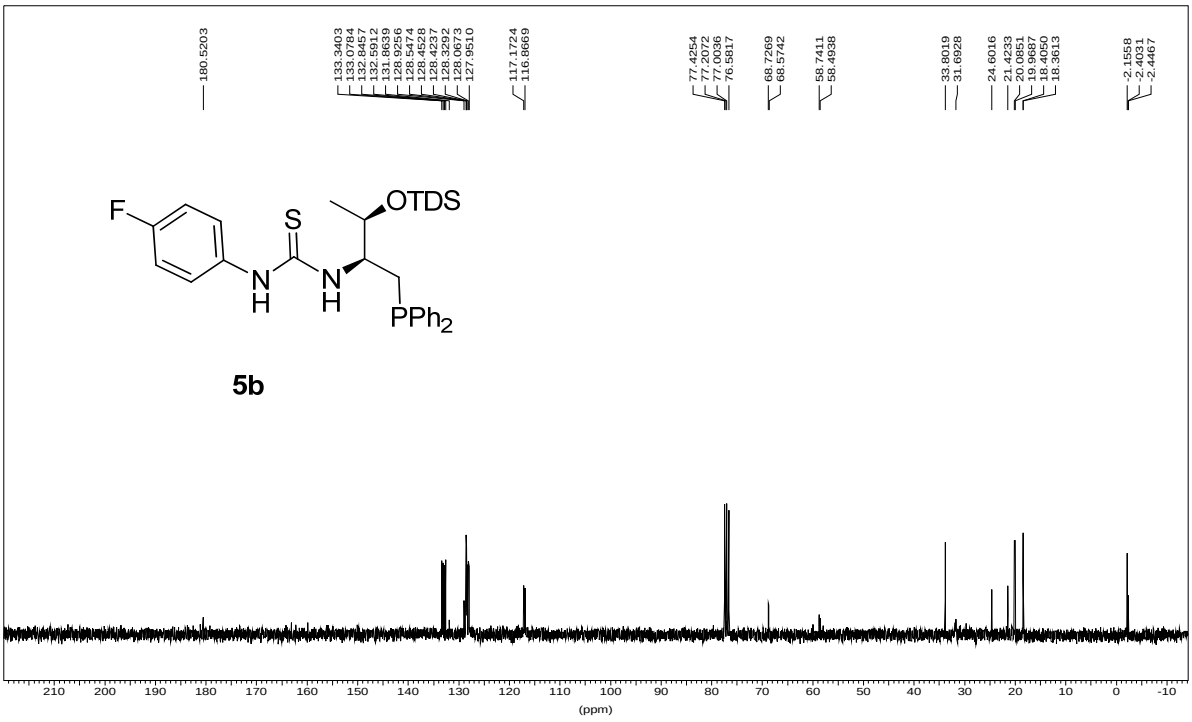
5a

1H normal range AC300 hxy-326

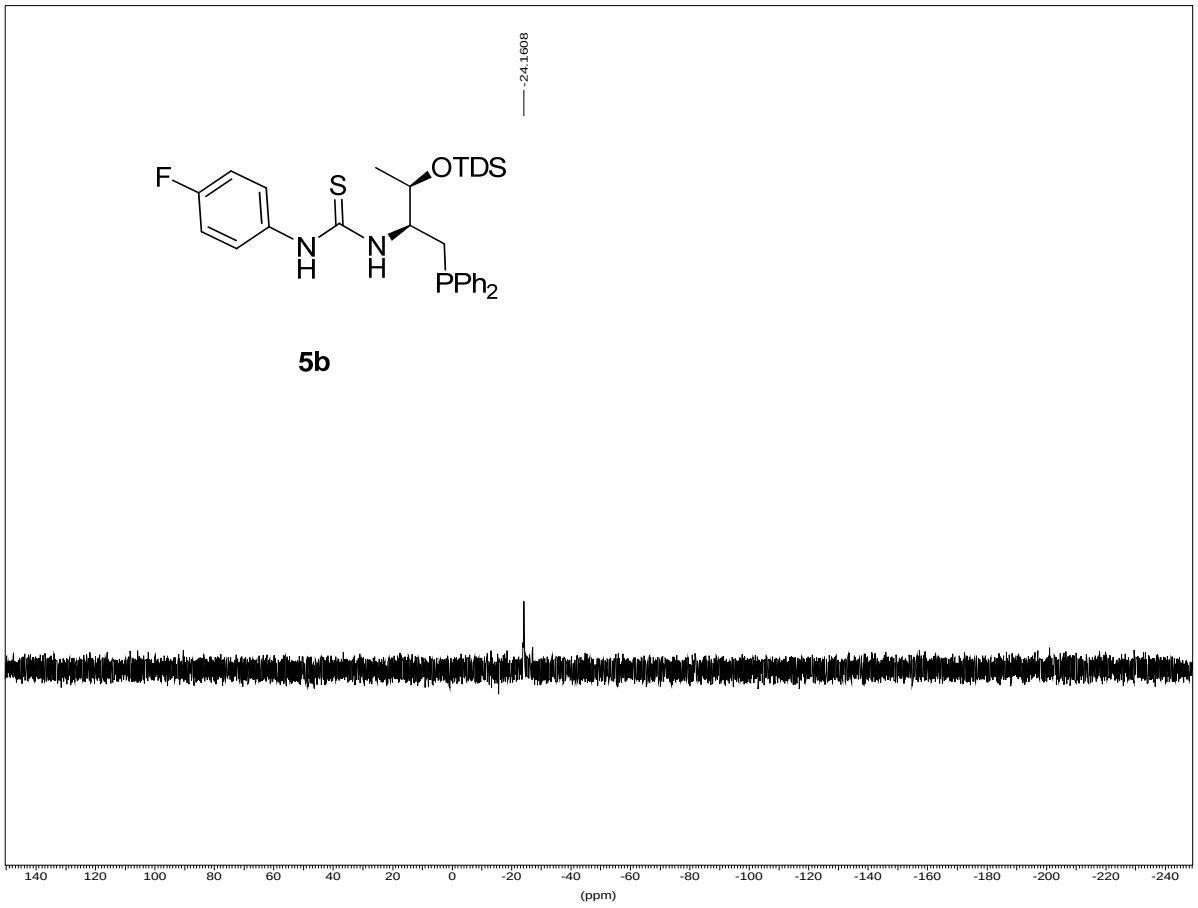


5b

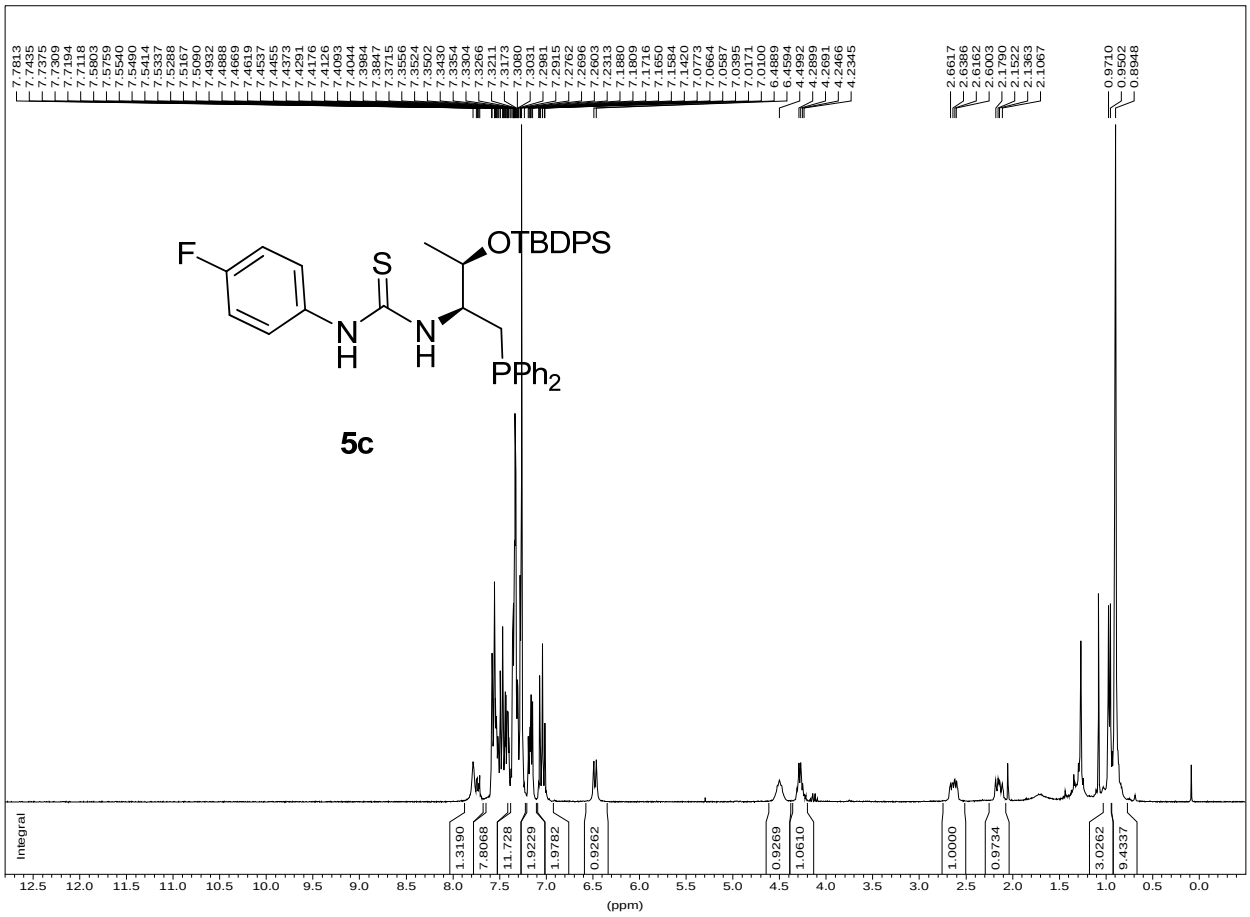
13C Standard AC300 hxy-326



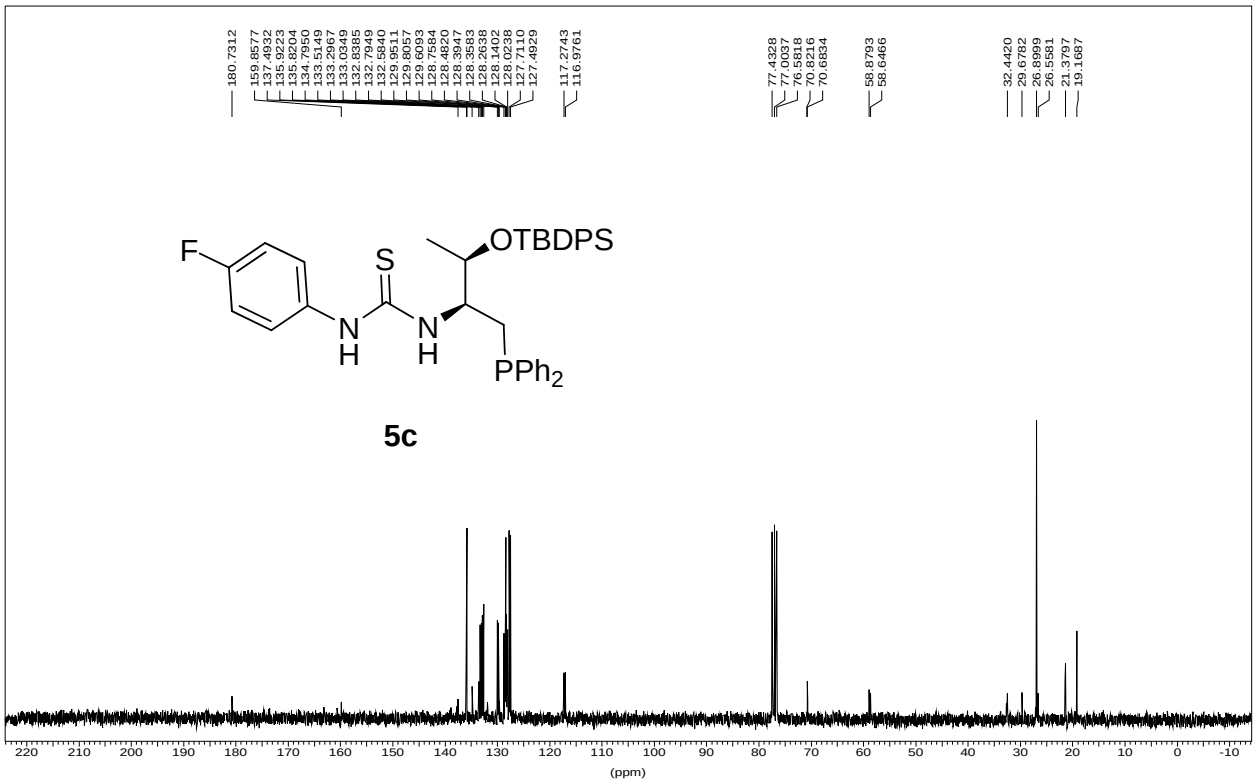
31P AC300 hxy-326



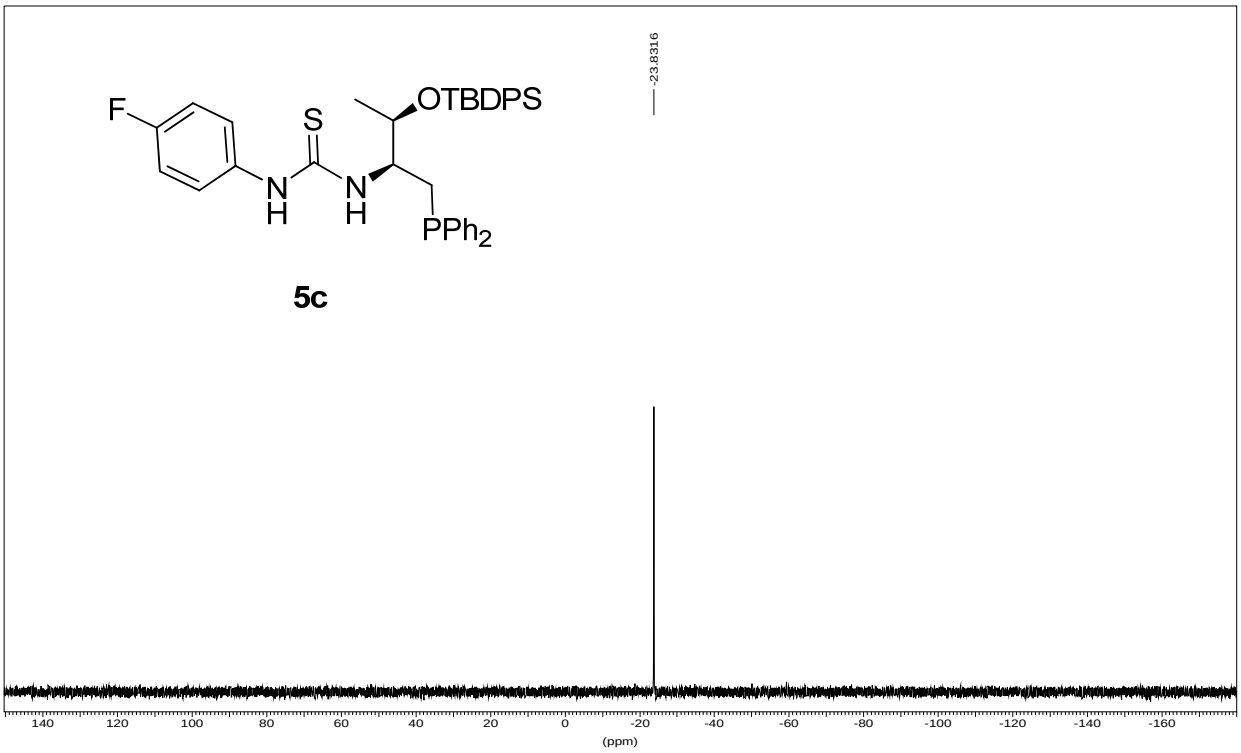
1H normal range AC300 hxy-LTBDPS



13C Standard AC300 hxy-LTBDPS

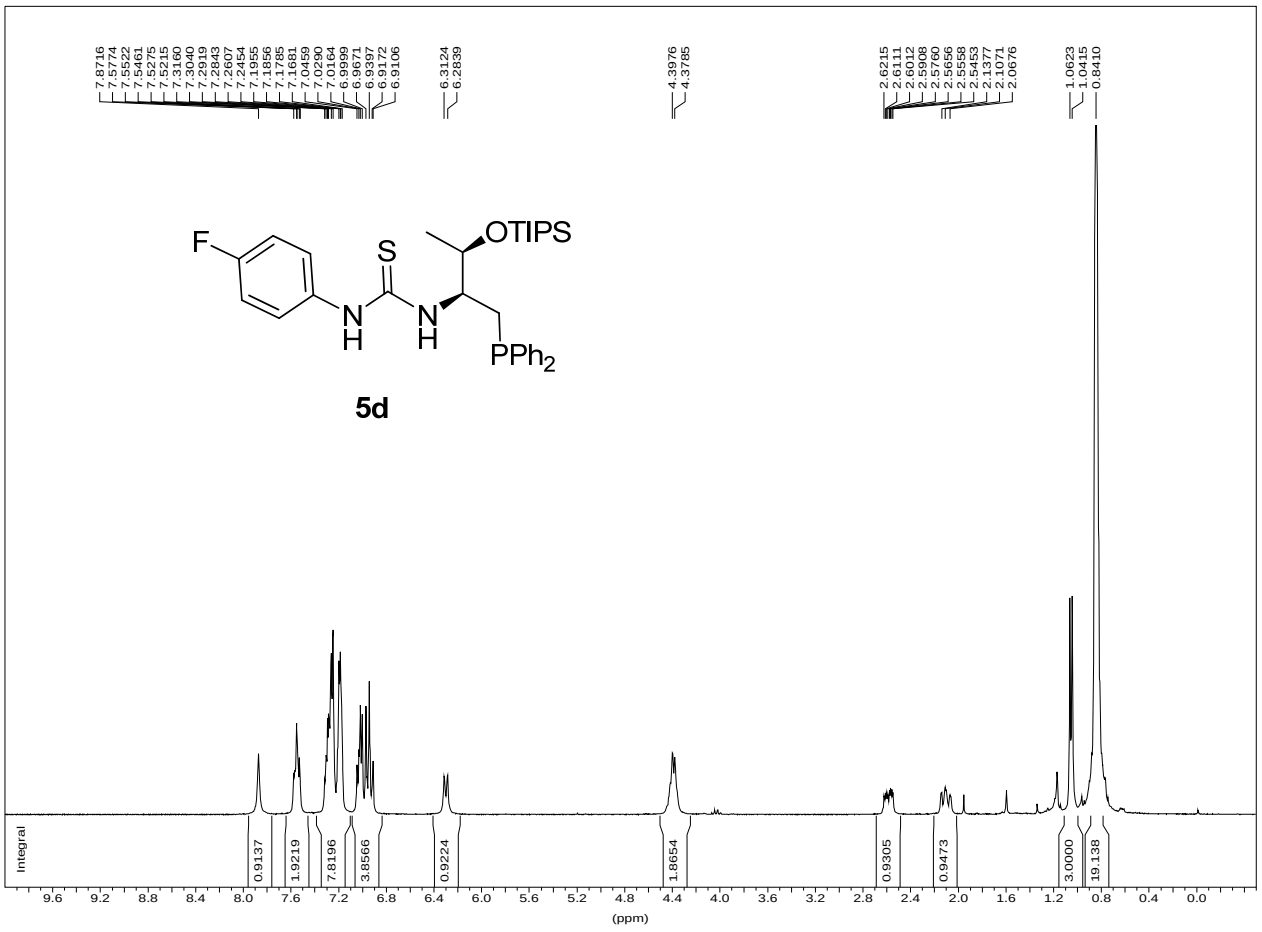


31P AC300 hxy-LTBDPS



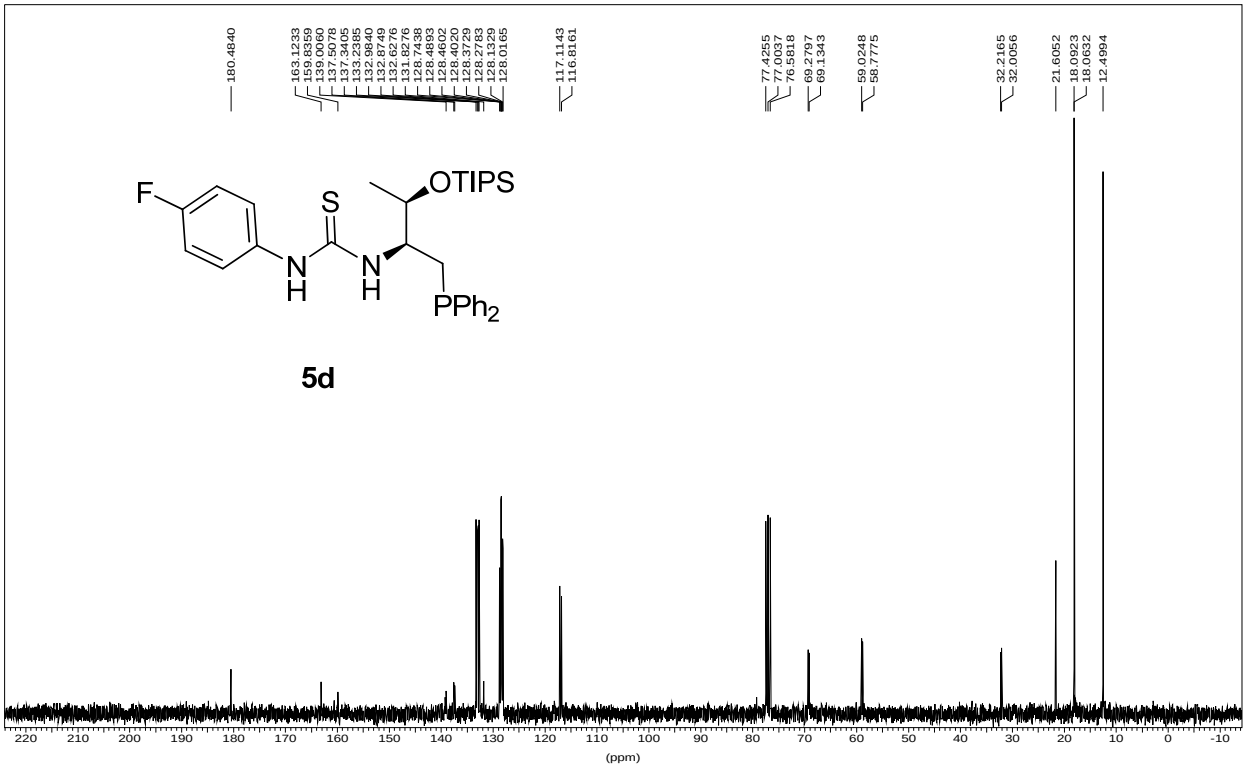
5c

1H normal range AC300 hxy-327

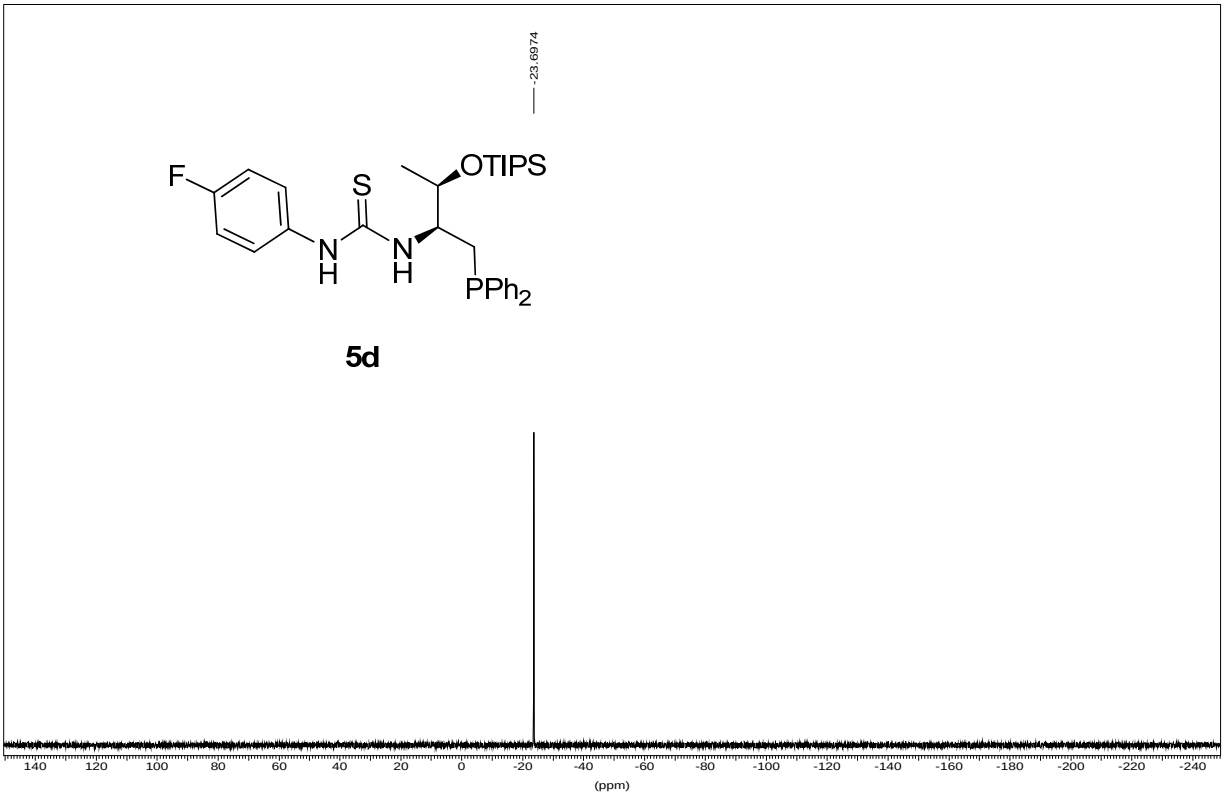


5d

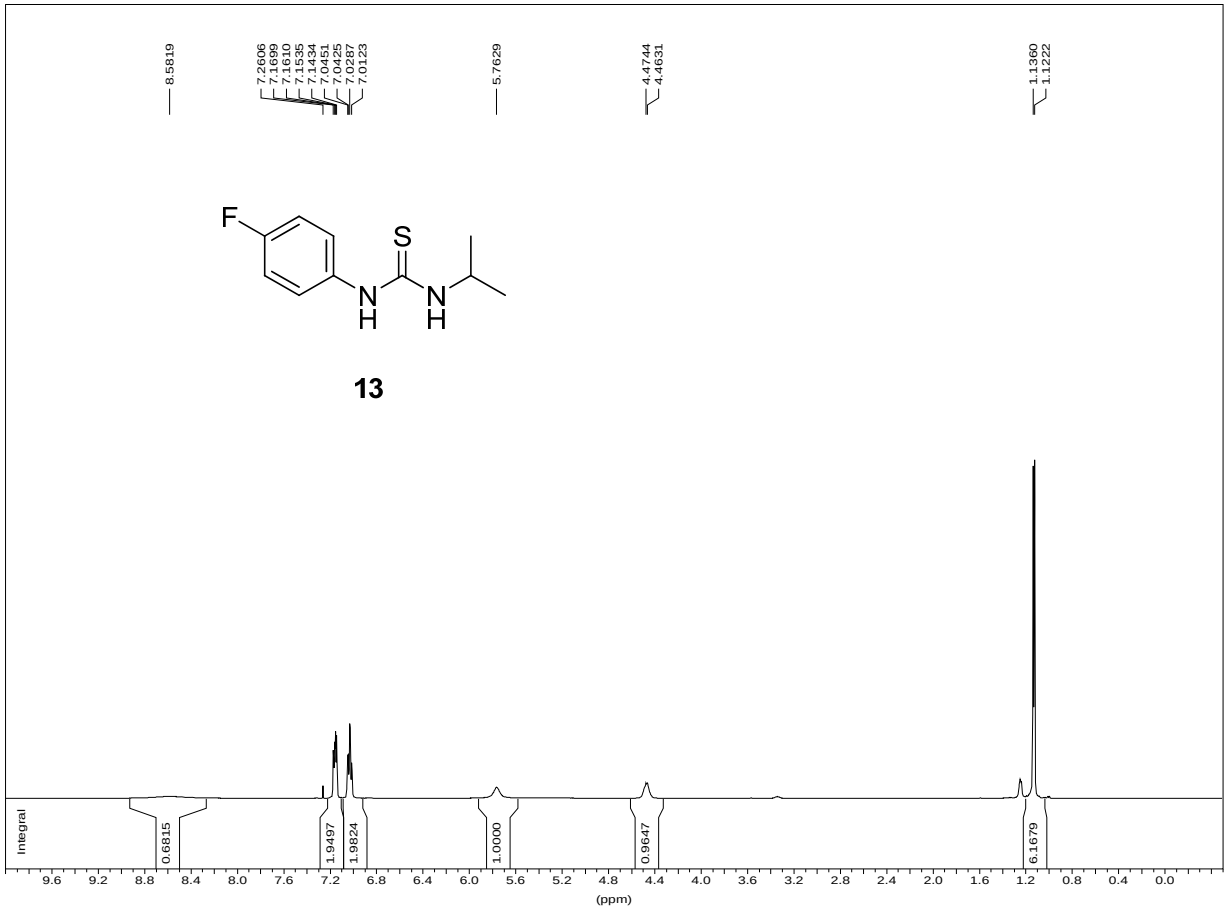
13C Standard AC300 hxy-327



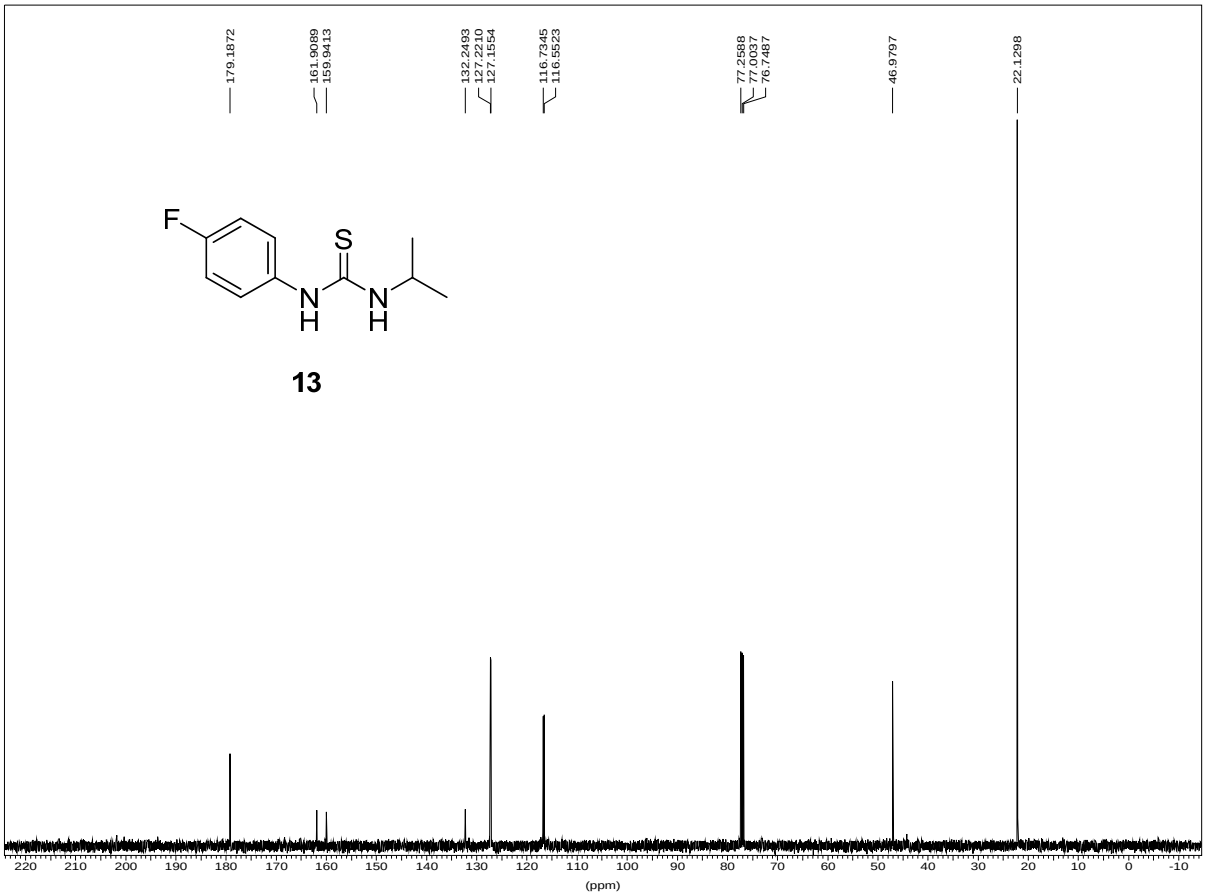
31P AC300 hxy-327



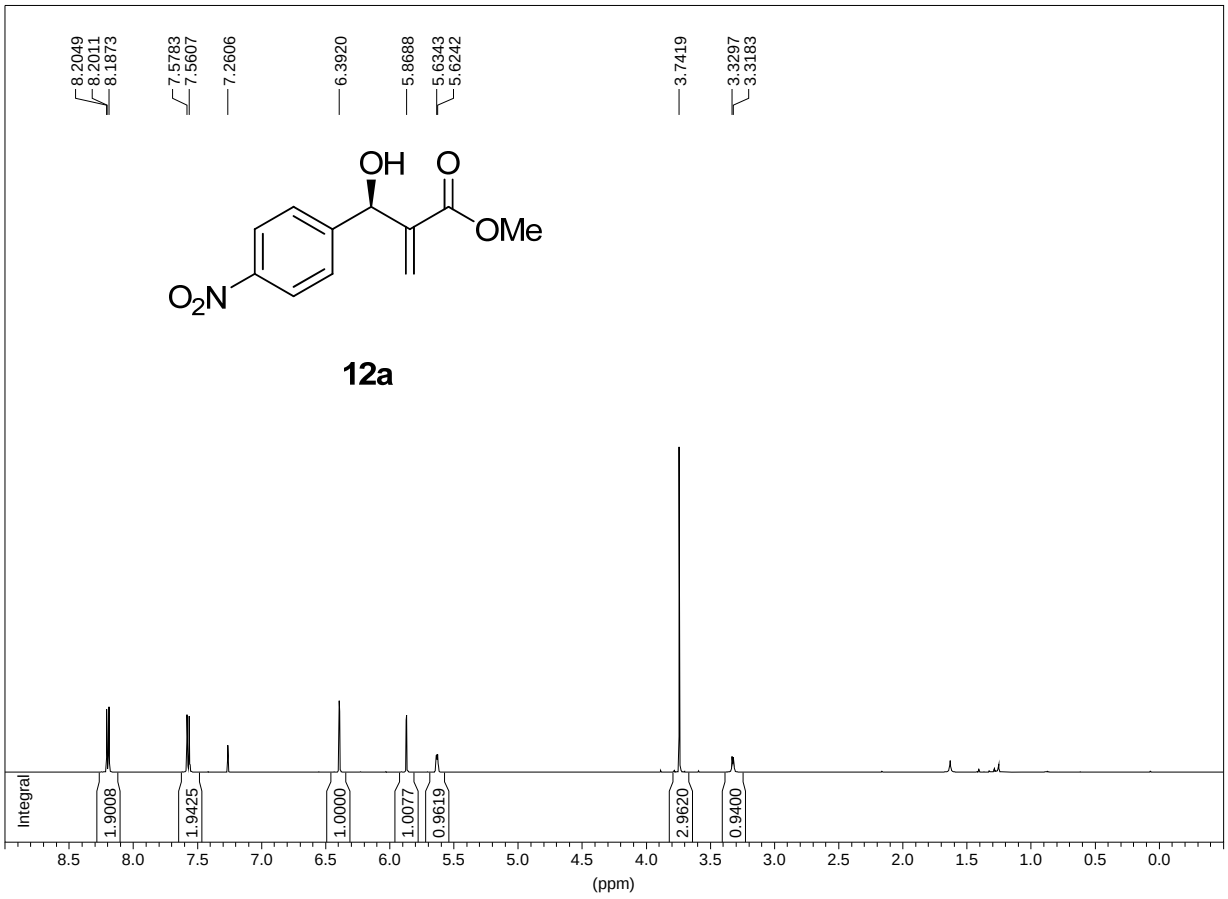
1H AMX500 hxy-515



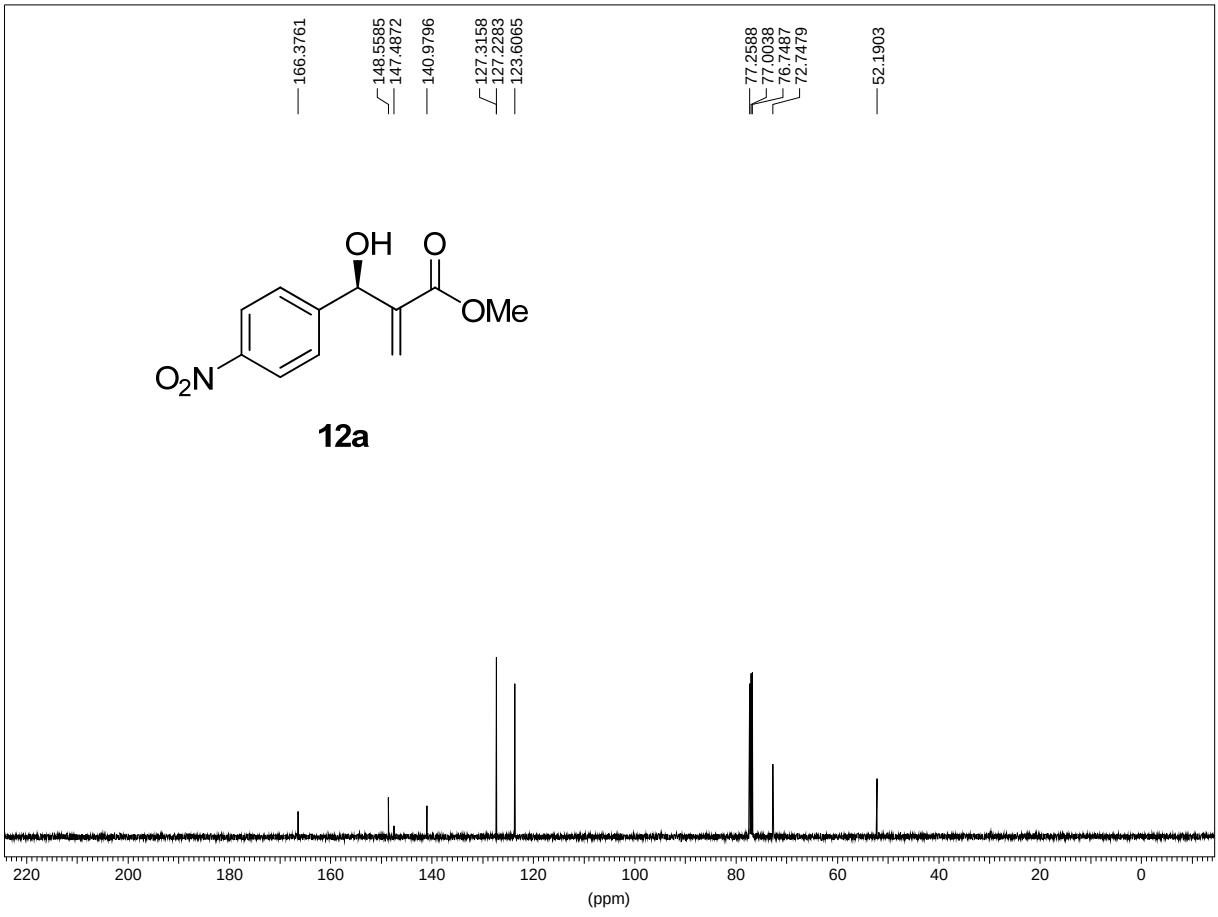
13C AMX500 hxy-515



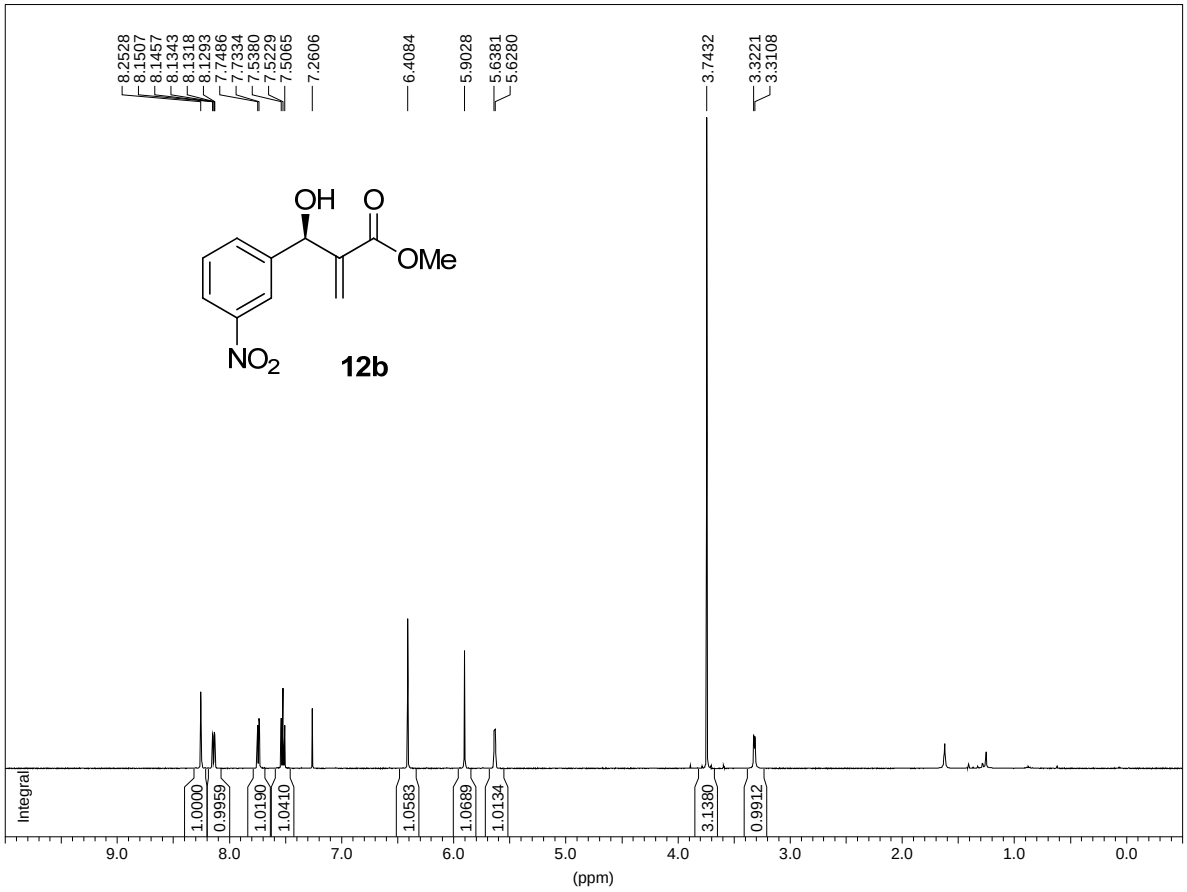
1H AMX500 hxy-483



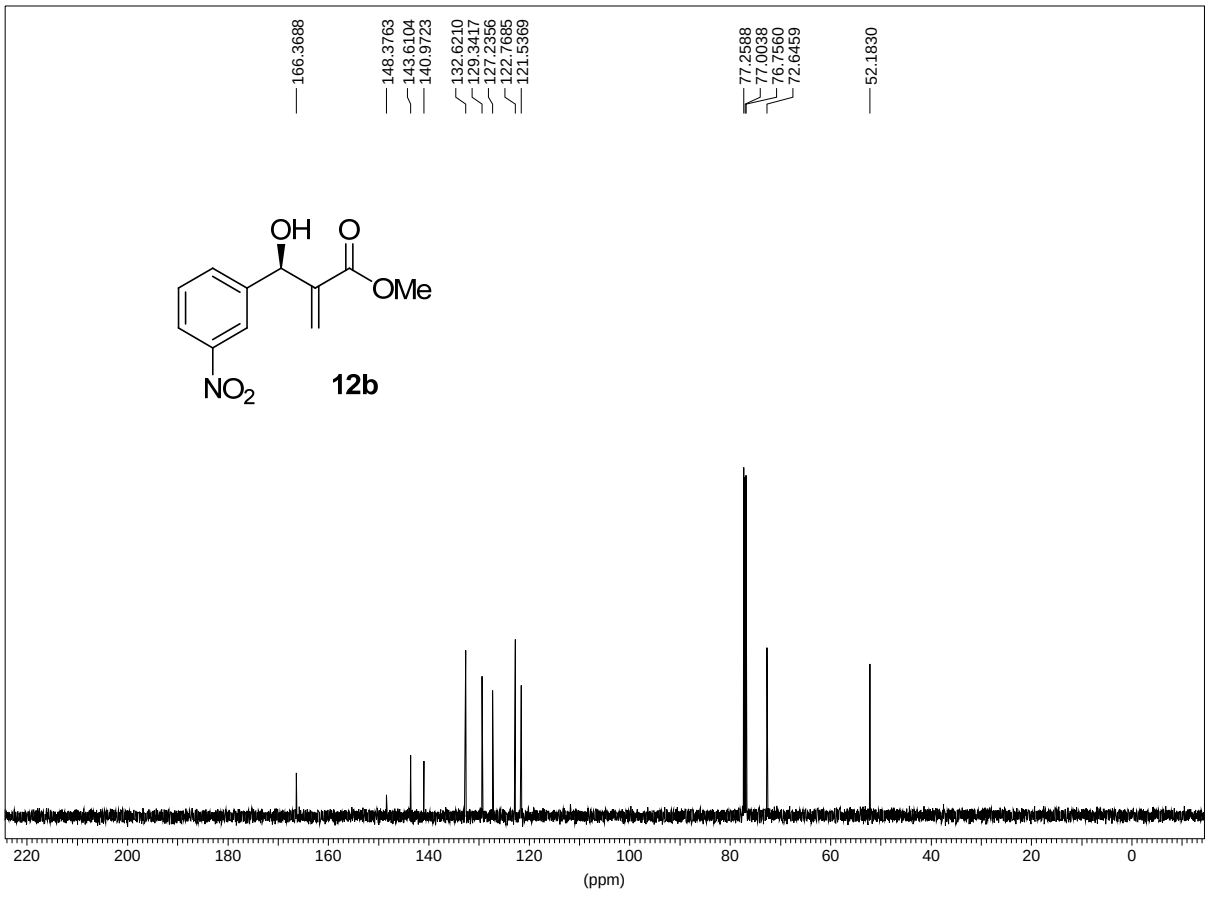
13C AMX500 hxy-483



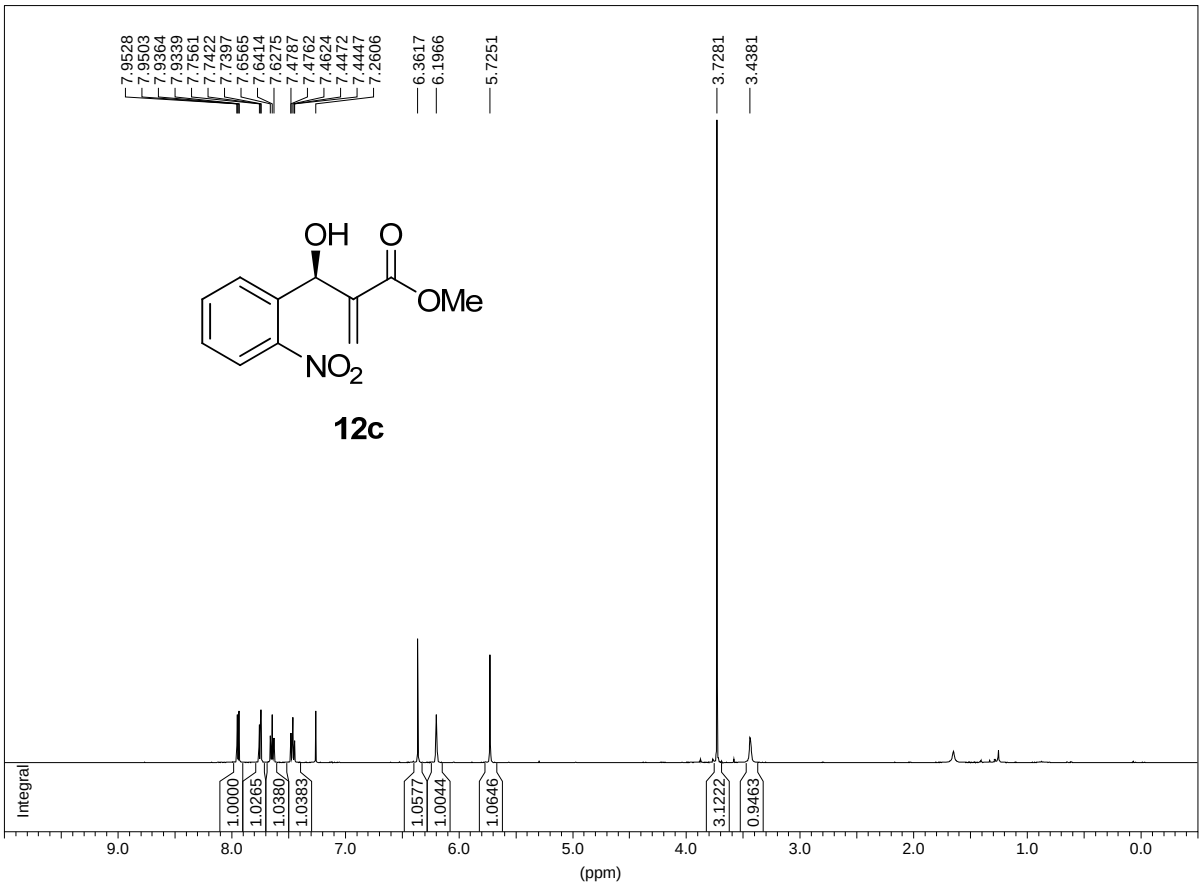
1H AMX500 hxy-484



13C AMX500 hxy-484

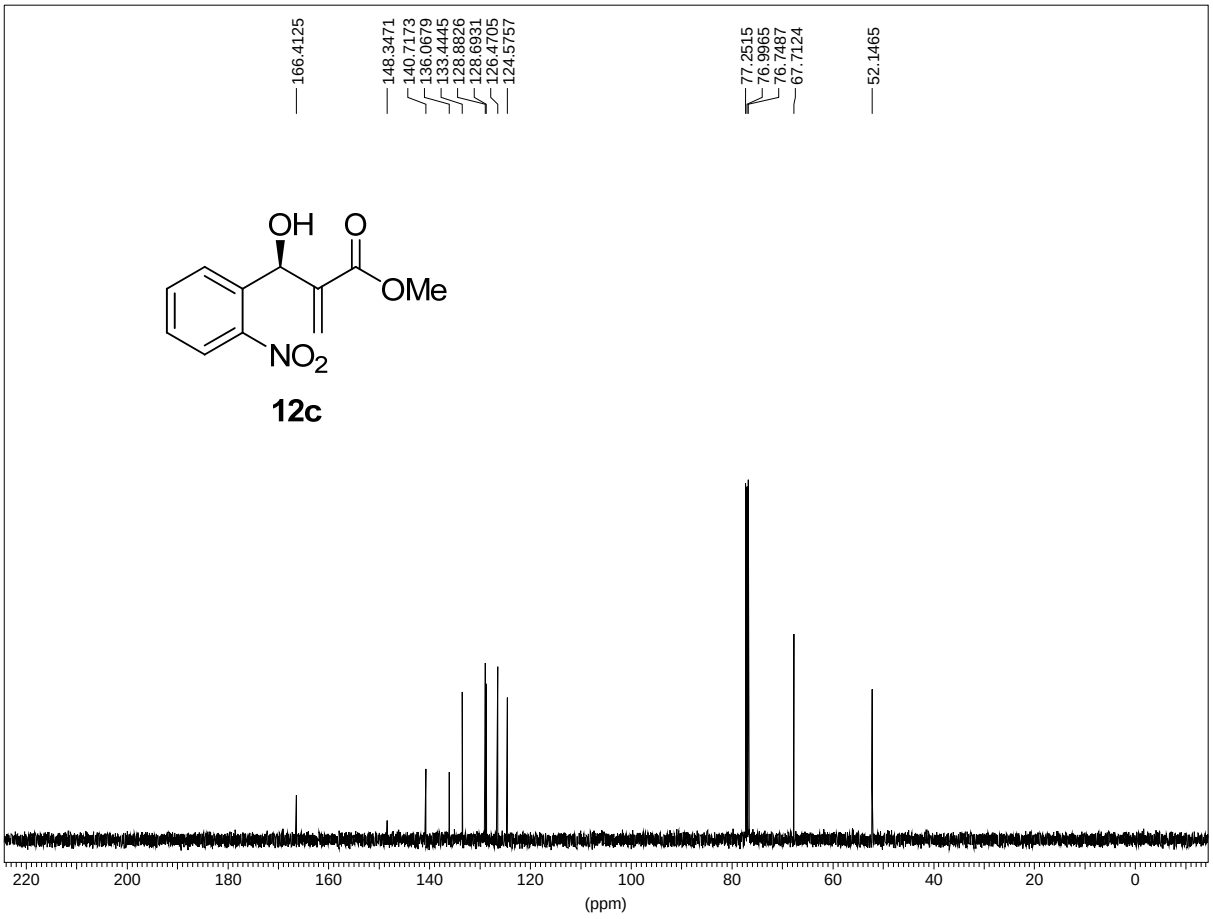


1H AMX500 hxy-485



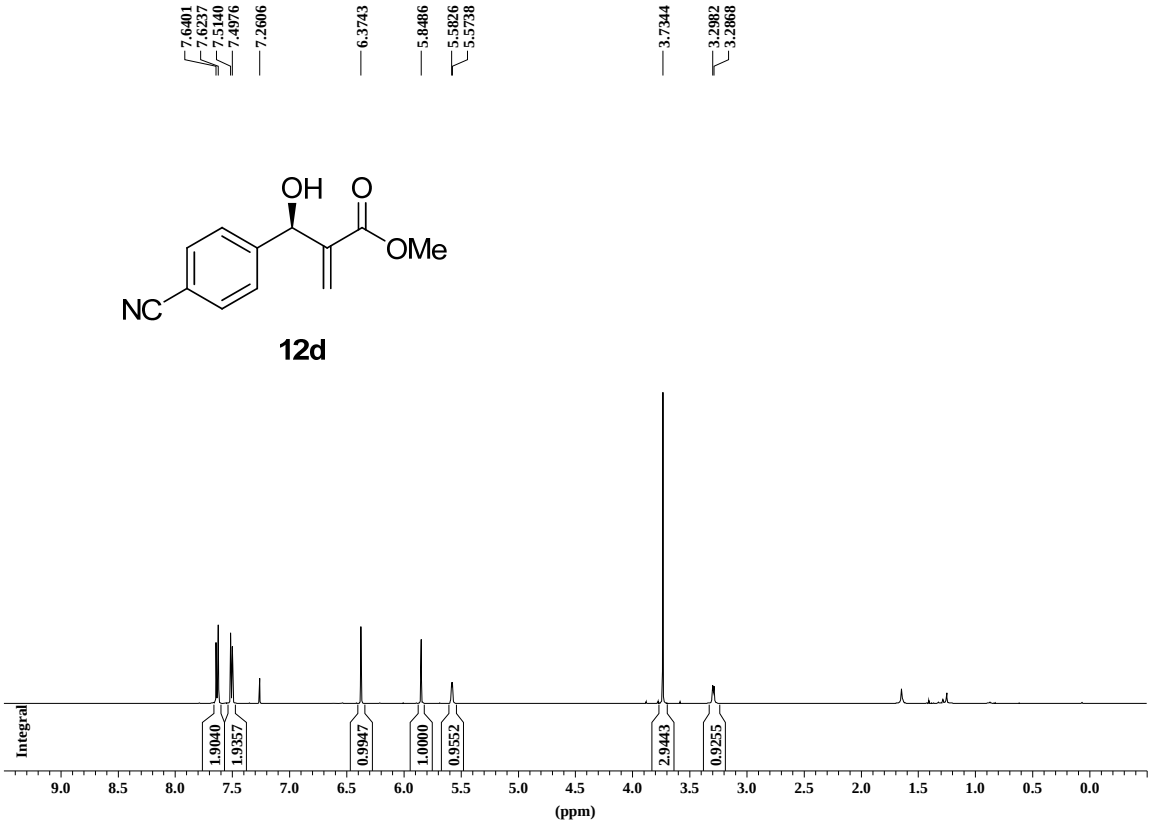
12c

13C AMX500 hxy-485

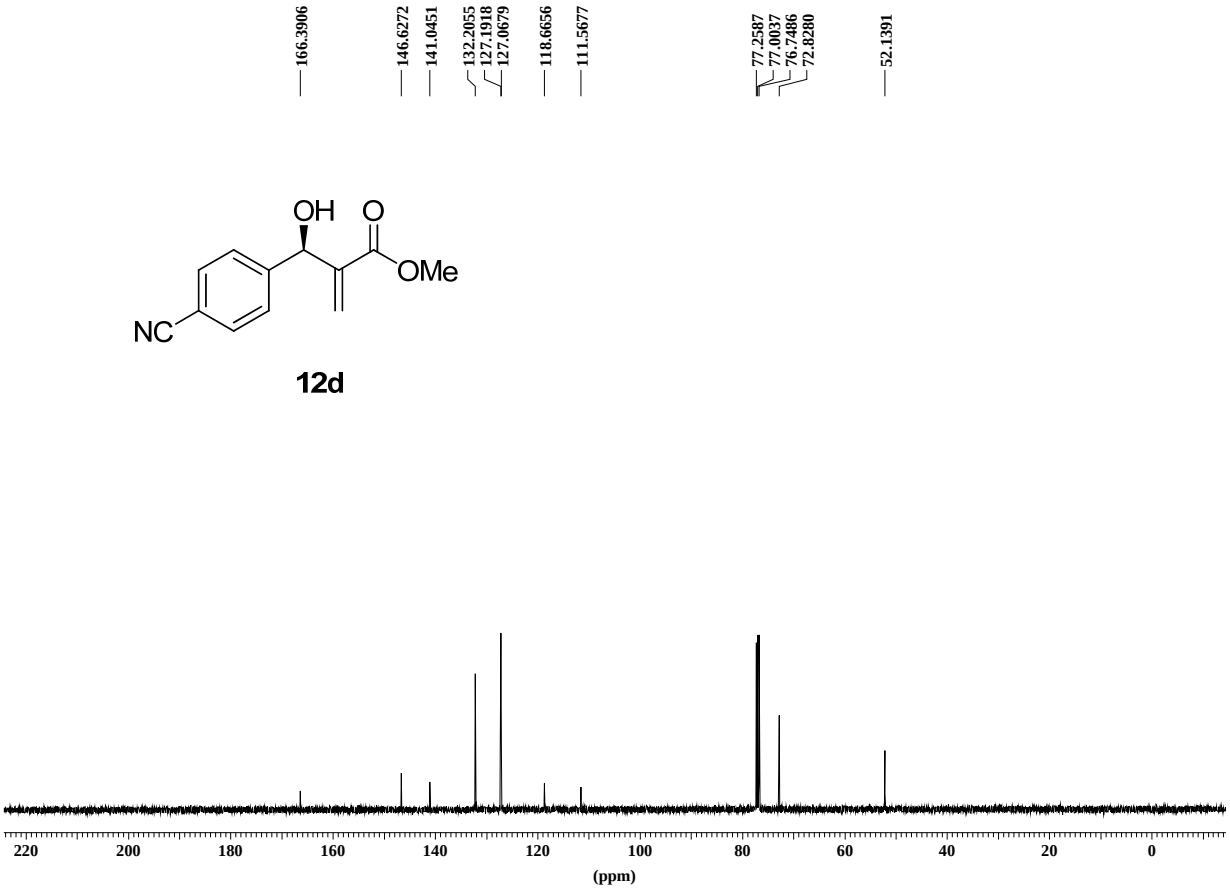


12c

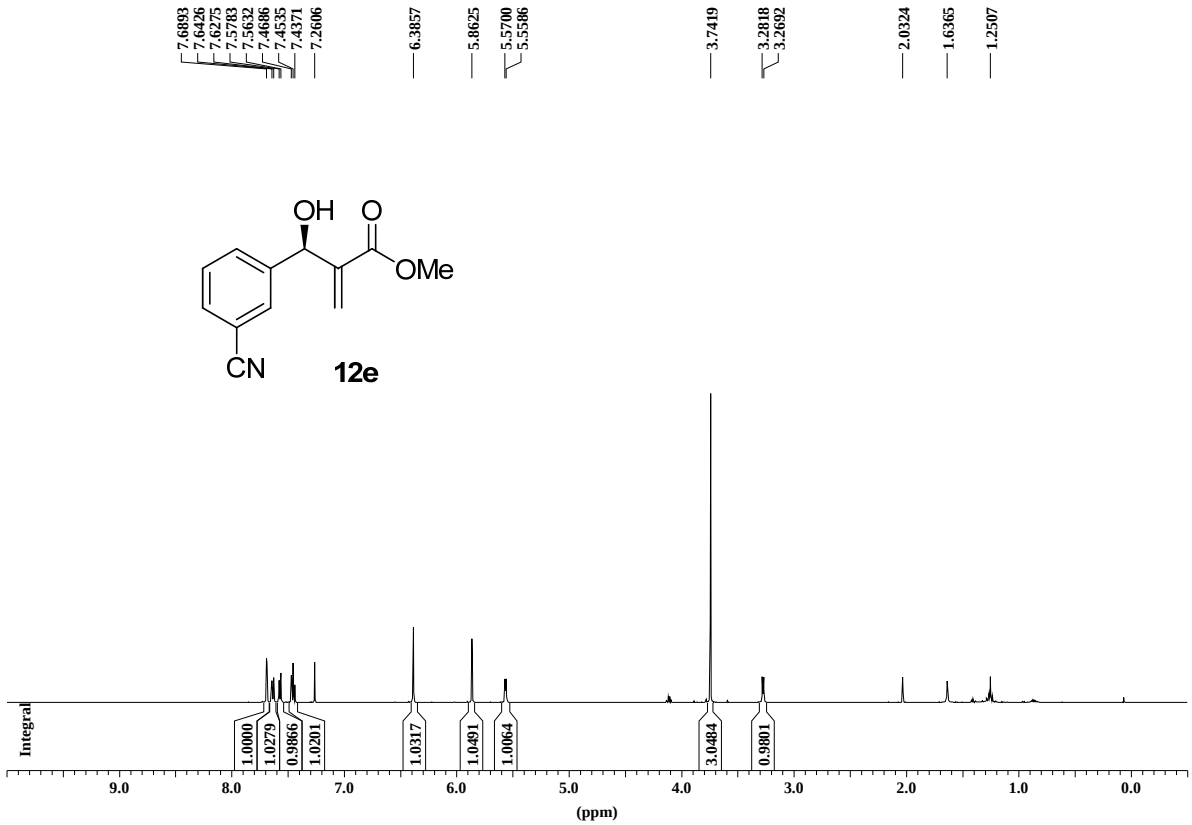
1H AMX500 hxy-486



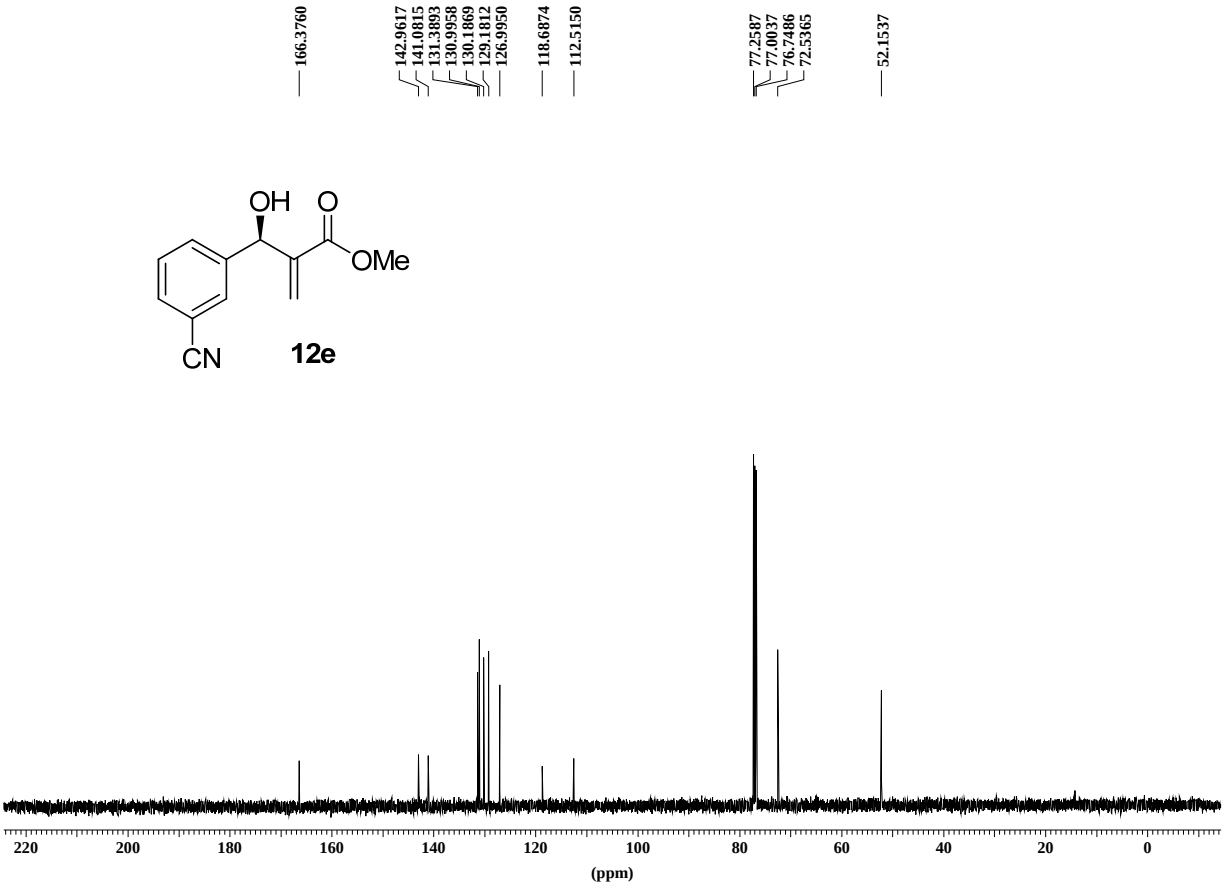
13C AMX500 hxy-486



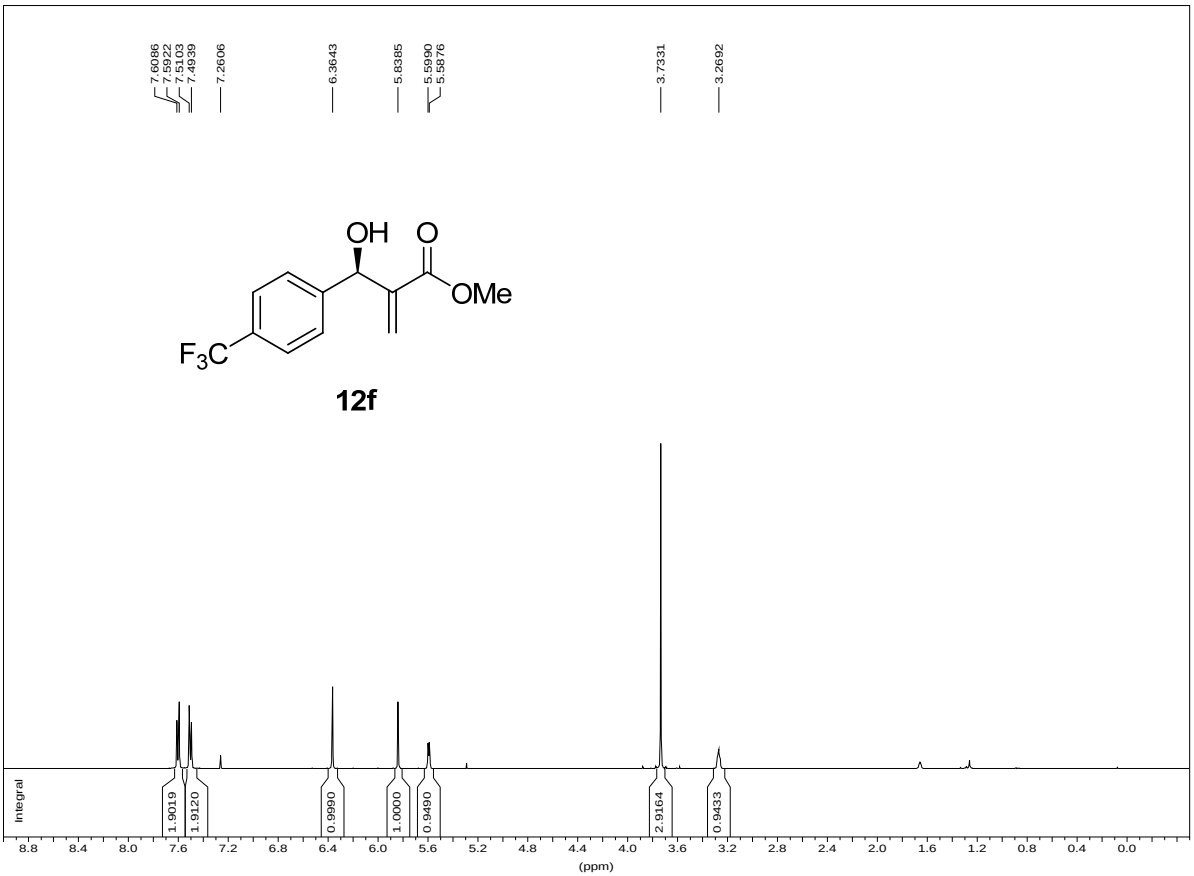
1H AMX500 hxy-487



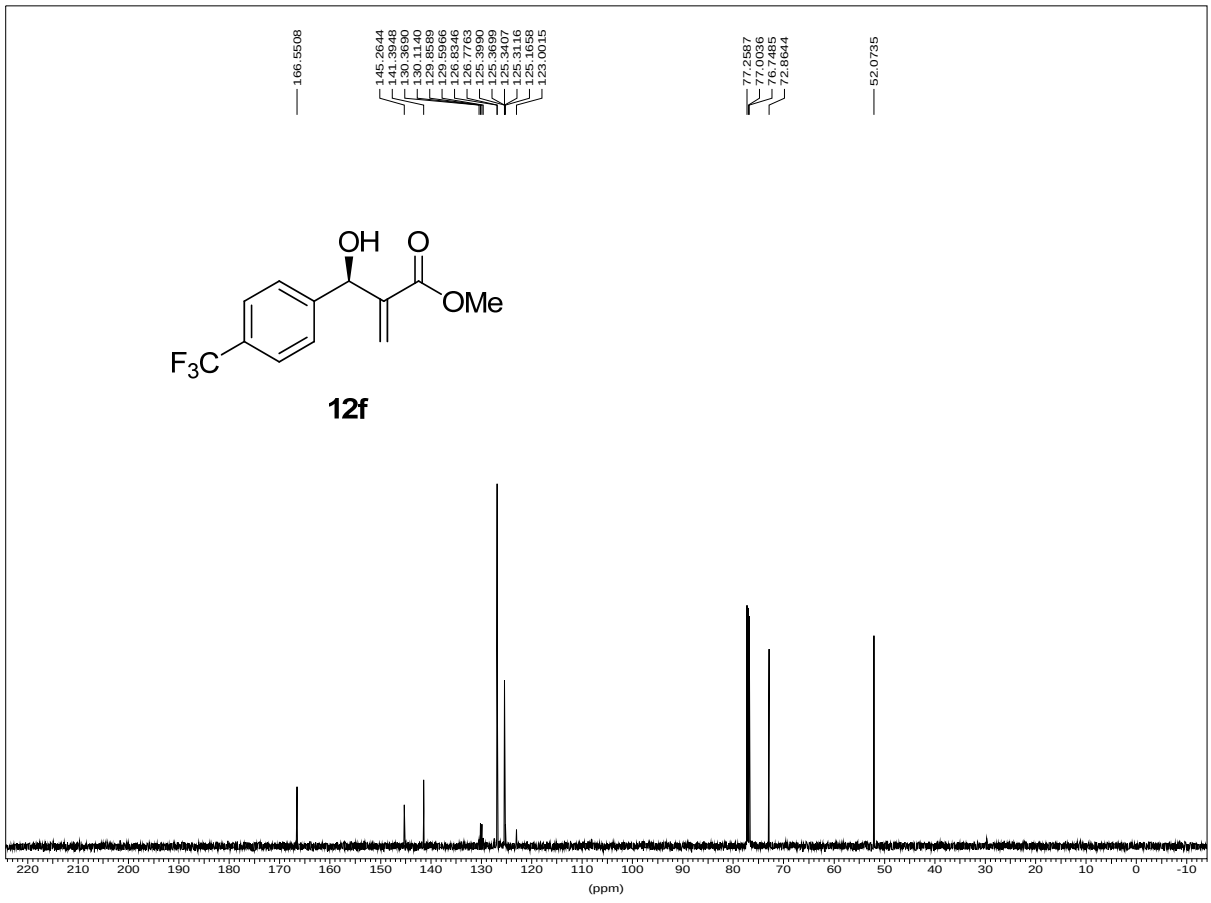
13C AMX500 hxy-487



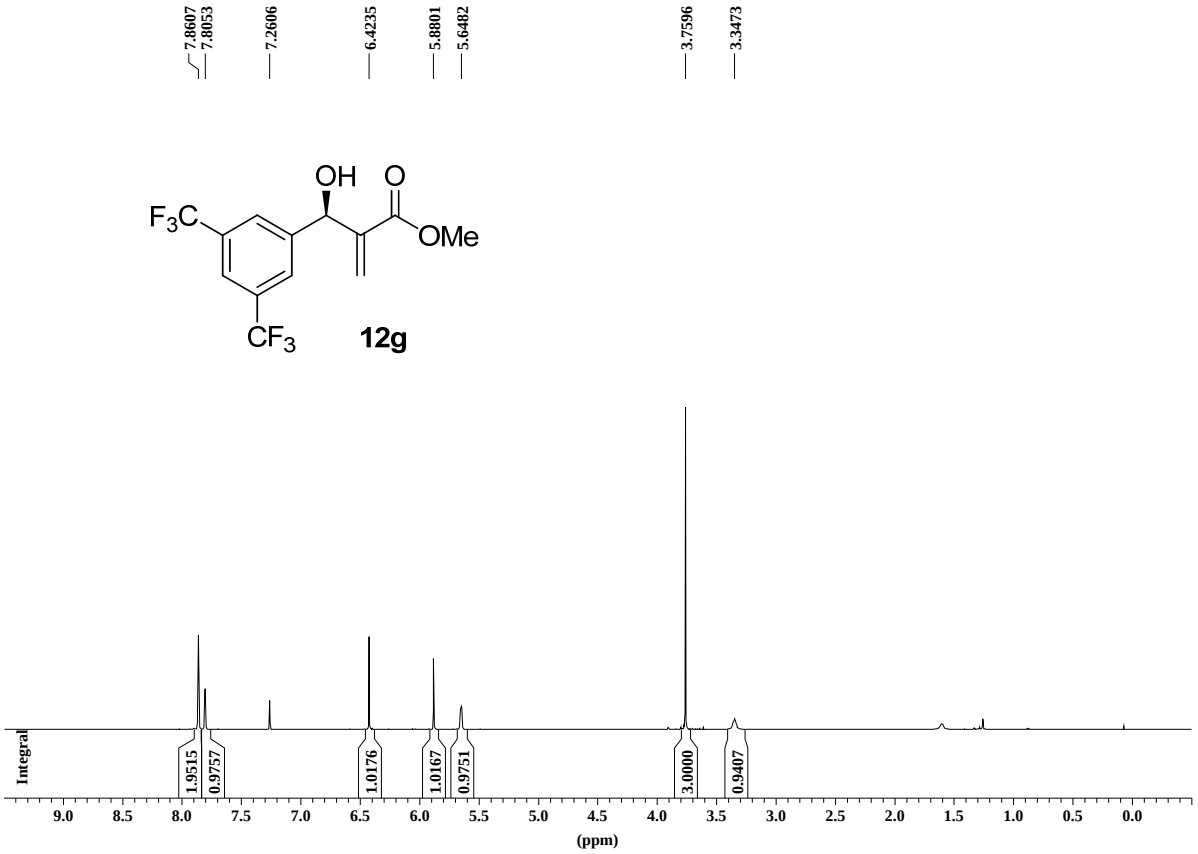
1H AMX500 hxy-488



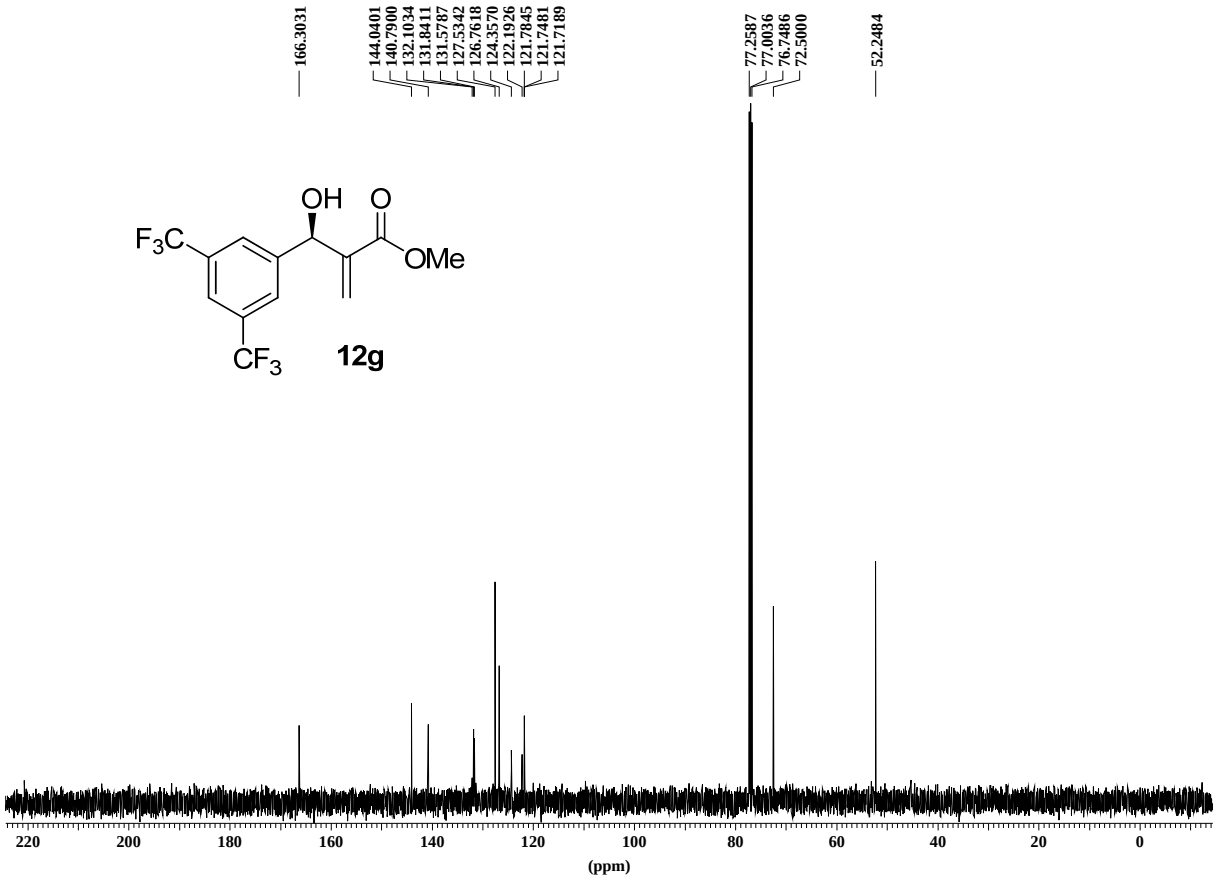
13C AMX500 hxy-488



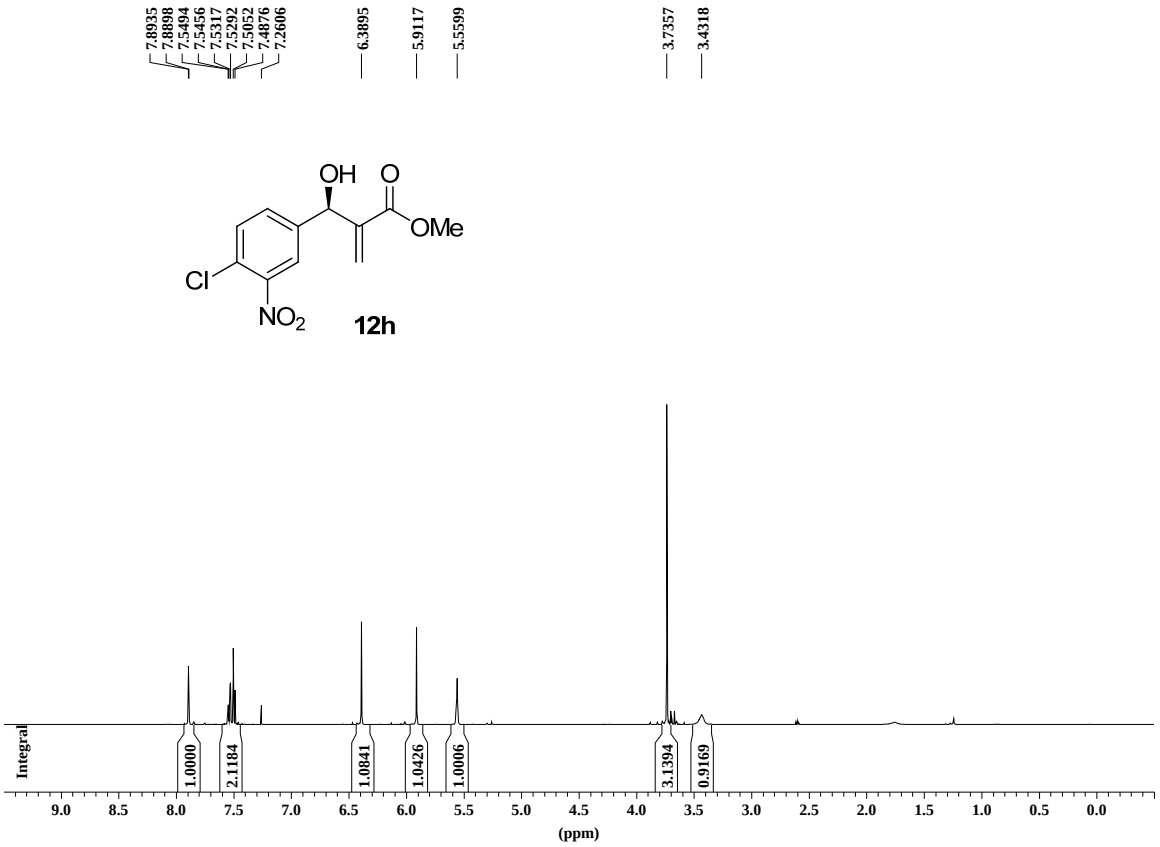
1H AMX500 hxy-502



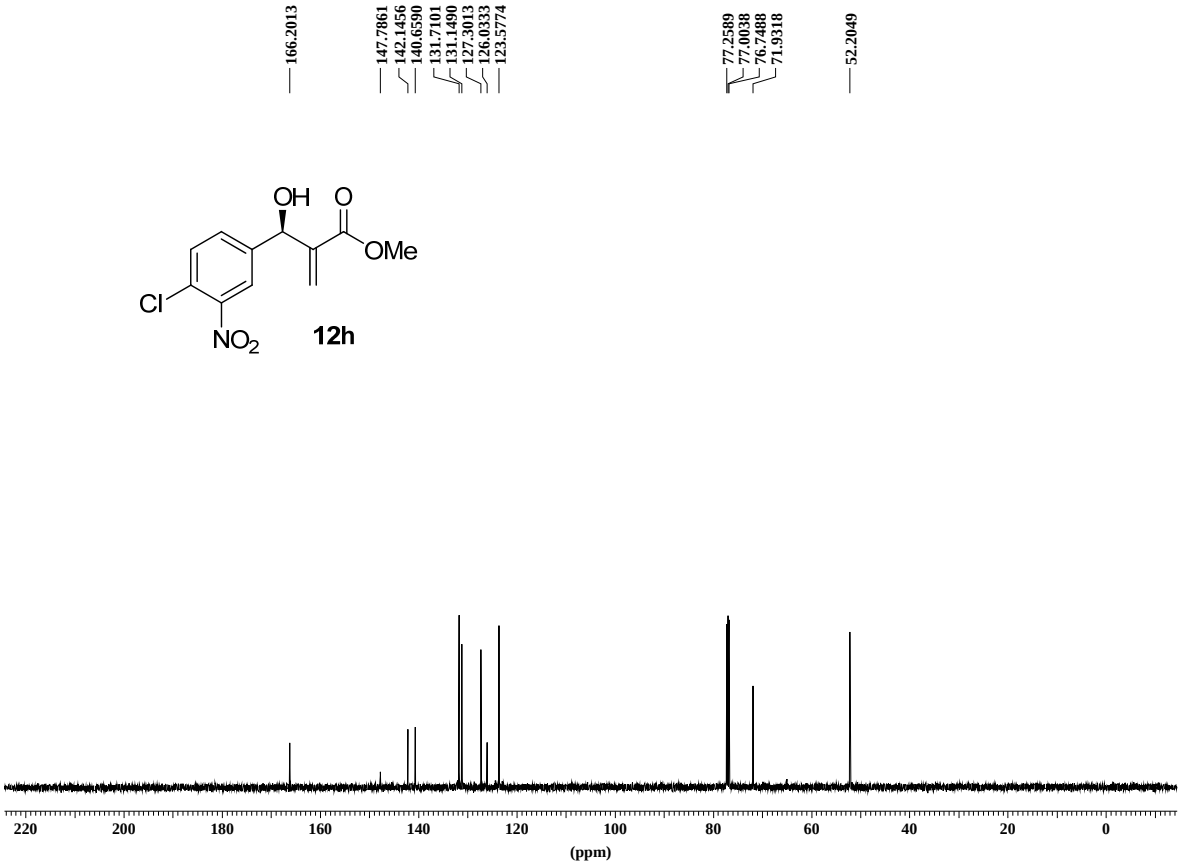
13C AMX500 hxy-502

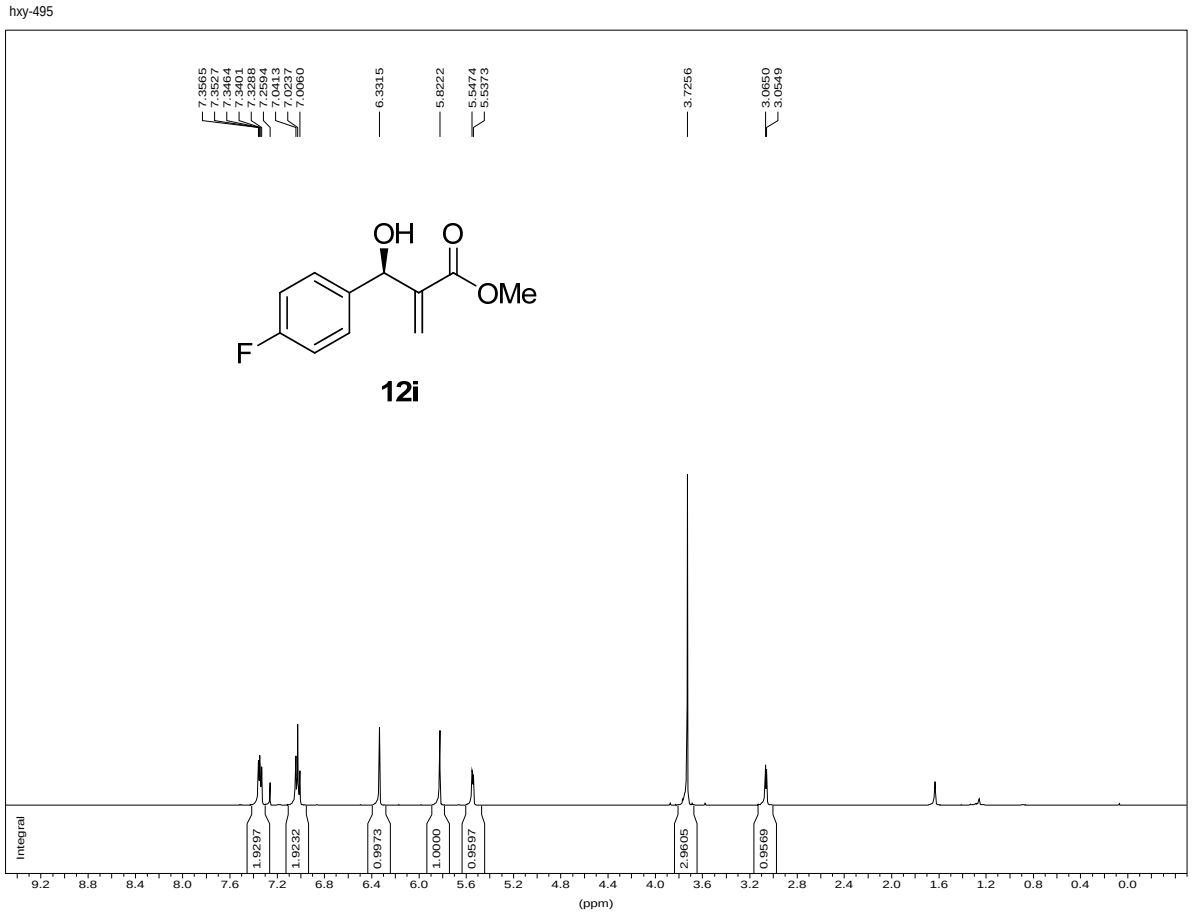


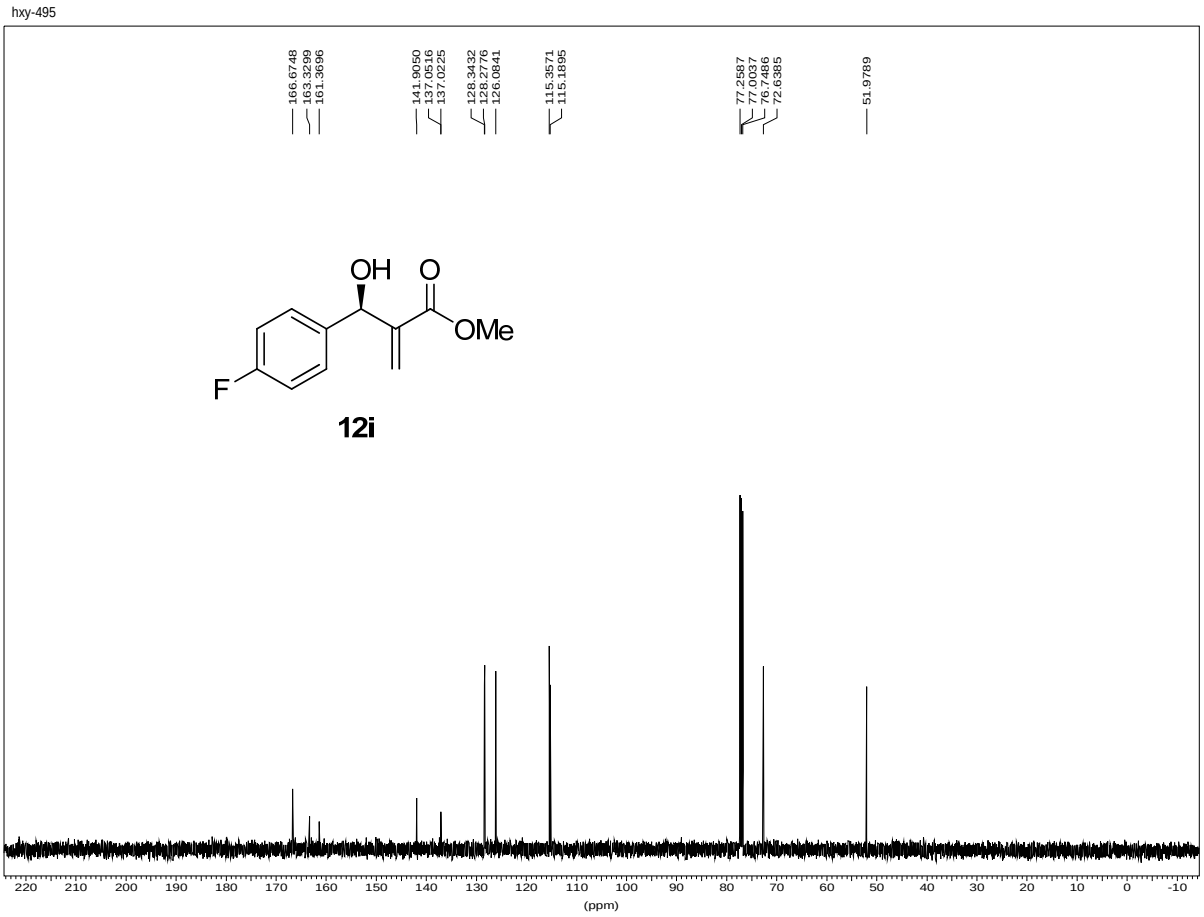
1H AMX500 hxy-501



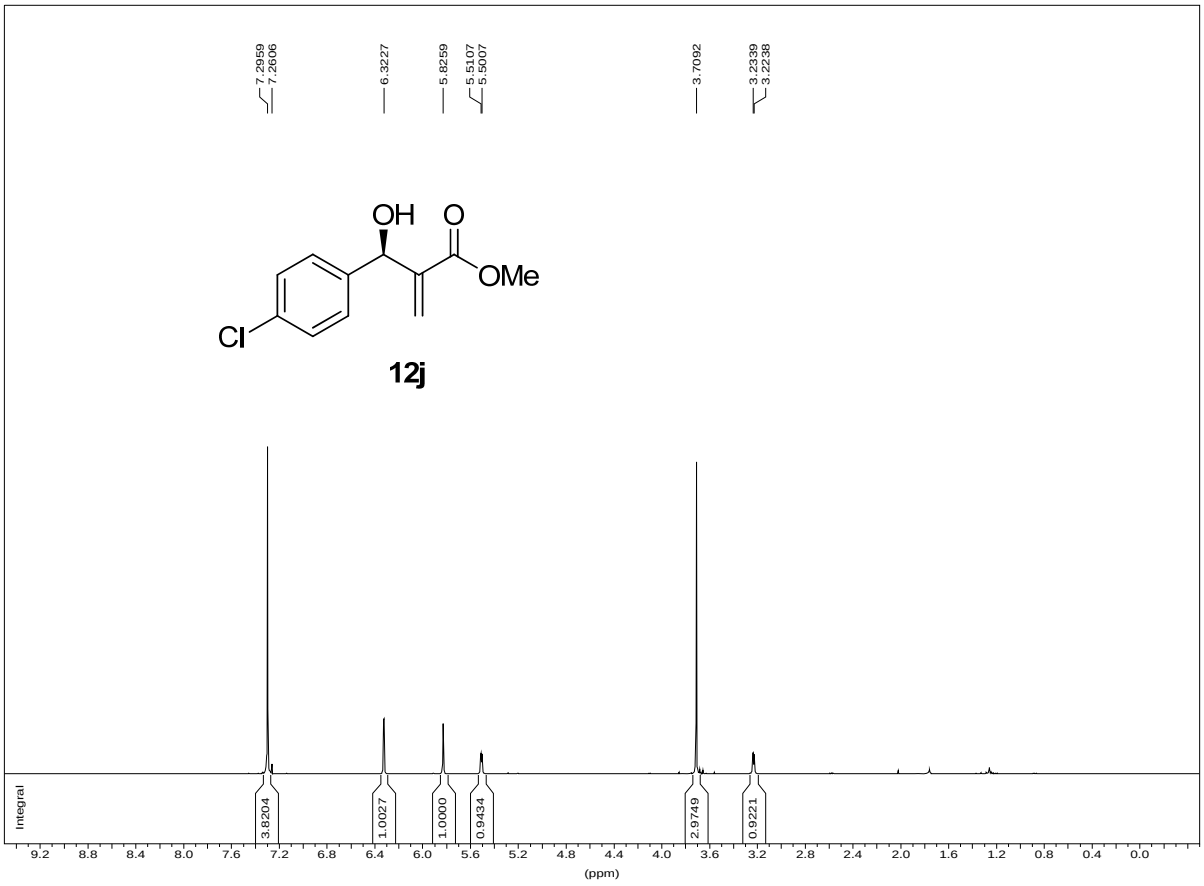
13C AMX500 hxy-501



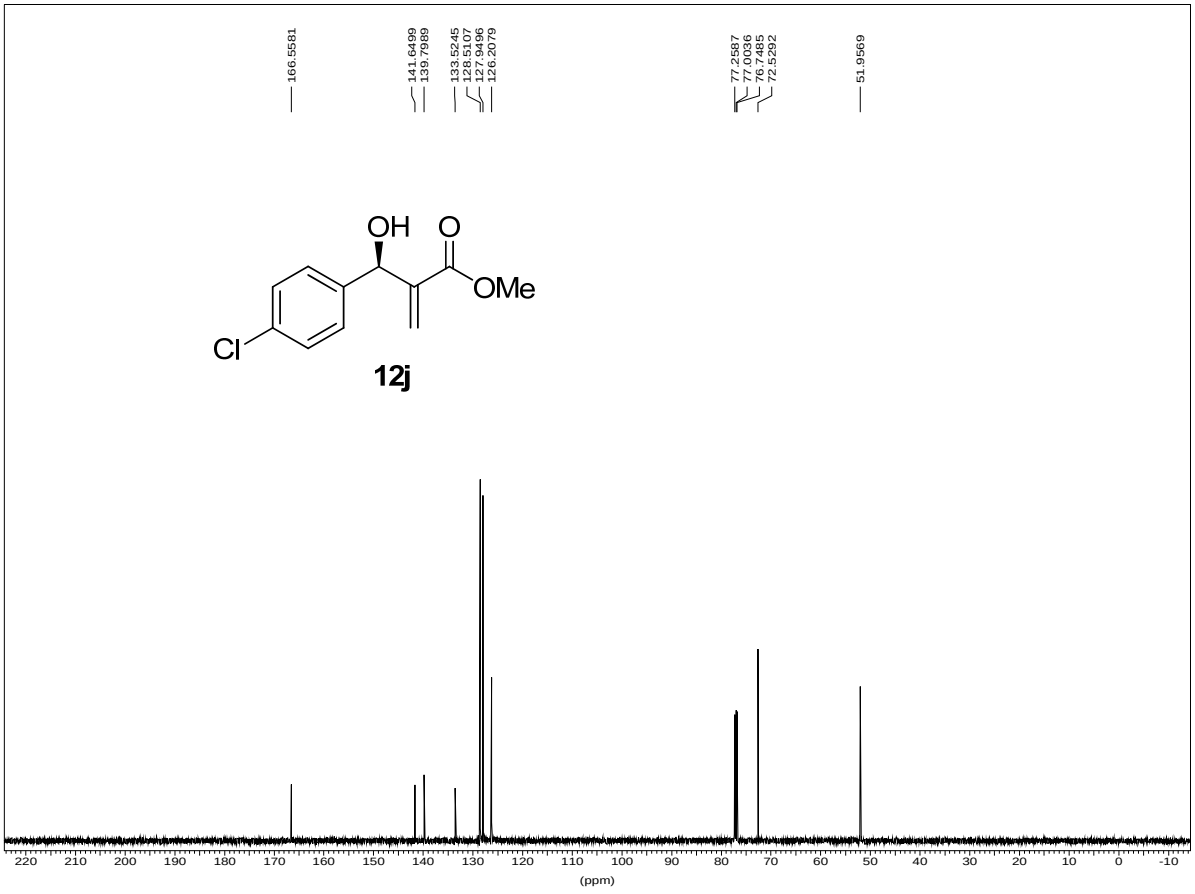

hxy-495
7.3565
7.3527
7.3464
7.3401
7.3288
7.2984
7.0413
7.0237
7.0060
6.3315
5.8222
5.5474
5.5373
3.7256
3.0650
3.0549
OH
O
OMe
F
12i
Integral
1.9297
1.9232
0.9973
1.0000
0.9597
2.9605
0.9569
9.2 8.8 8.4 8.0 7.6 7.2 6.8 6.4 6.0 5.6 5.2 4.8 4.4 4.0 3.6 3.2 2.8 2.4 2.0 1.6 1.2 0.8 0.4 0.0
(ppm)


hxy-495
166.6748
163.3299
161.3696
141.9050
137.0516
137.0225
128.3432
128.2776
126.0841
115.3571
115.1895
77.2587
77.0037
76.7486
72.6385
51.9789
OH
O
OMe
F
12i
220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
(ppm)

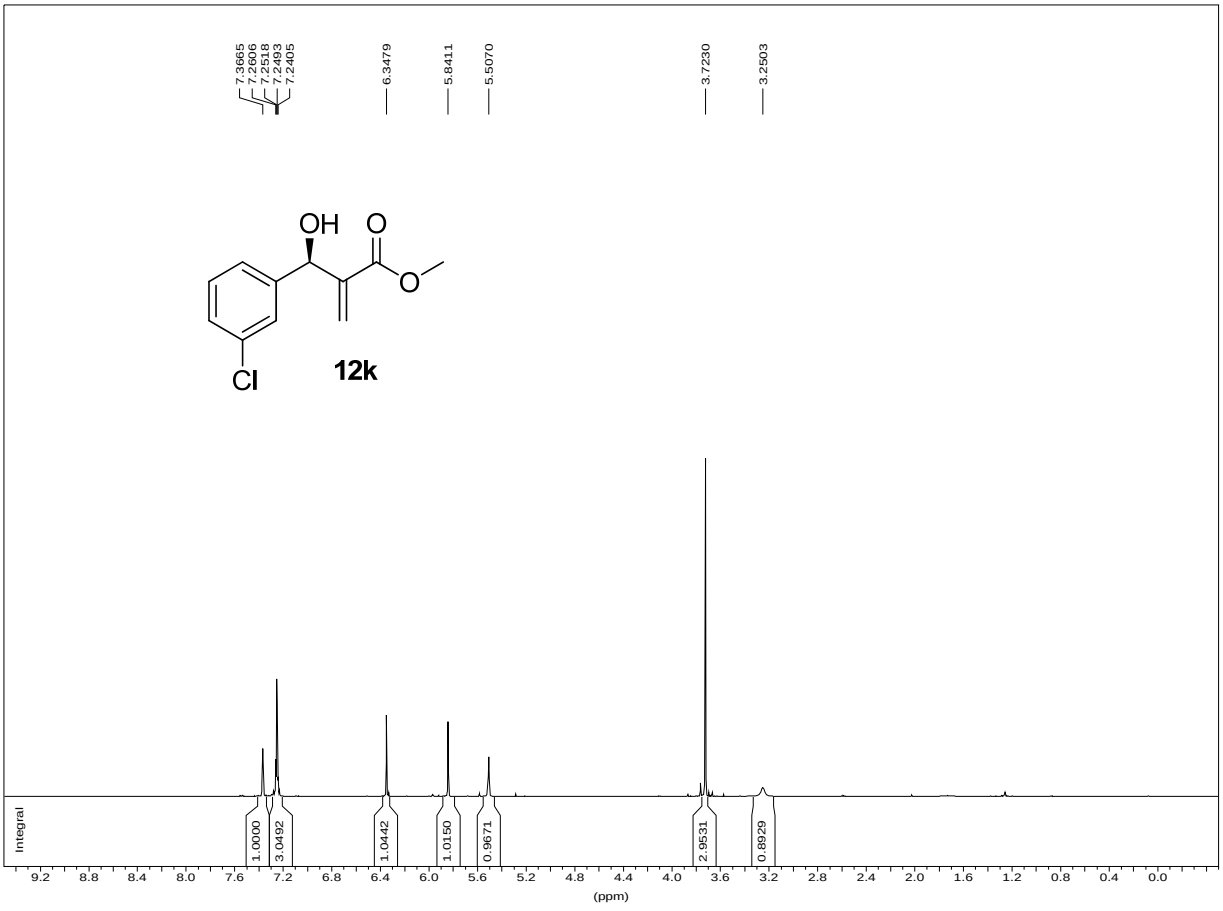
1H AMX500 hxy-493



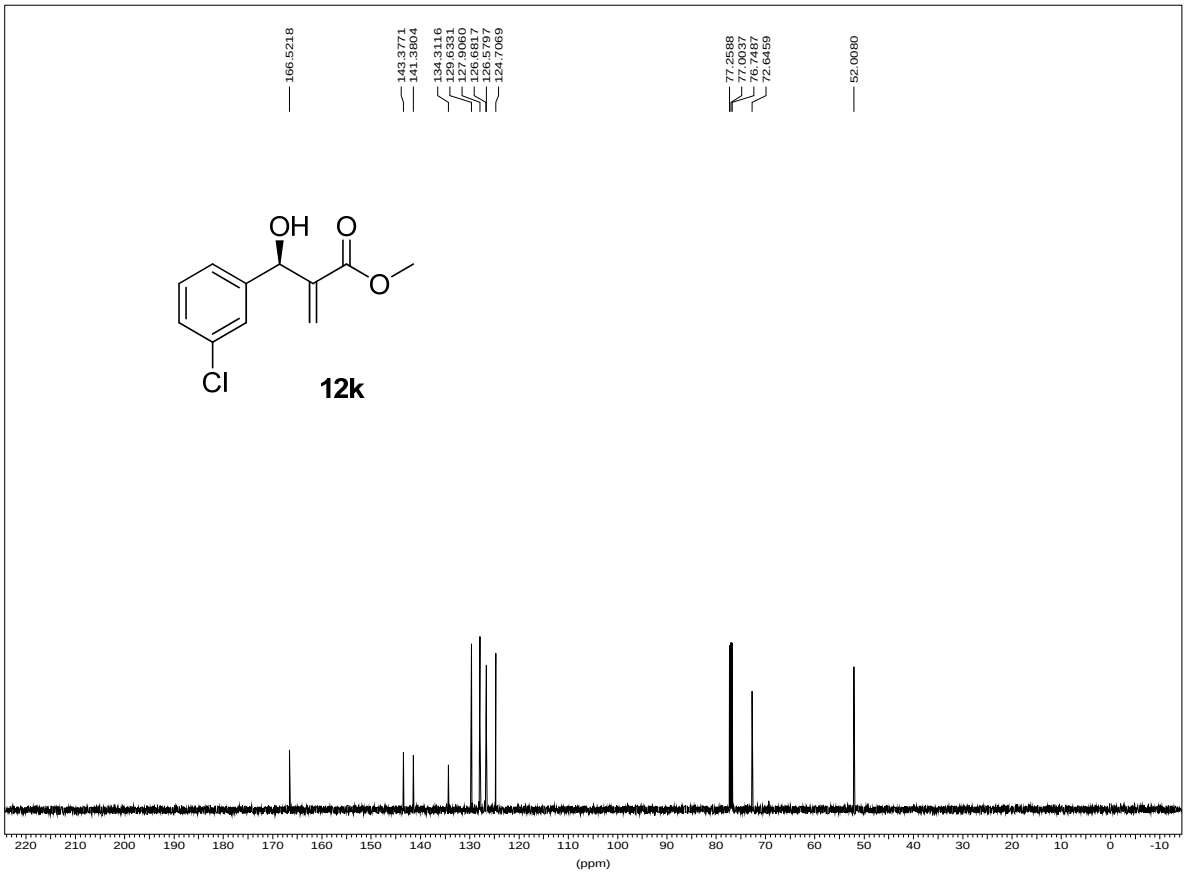
13C AMX500 hxy-493



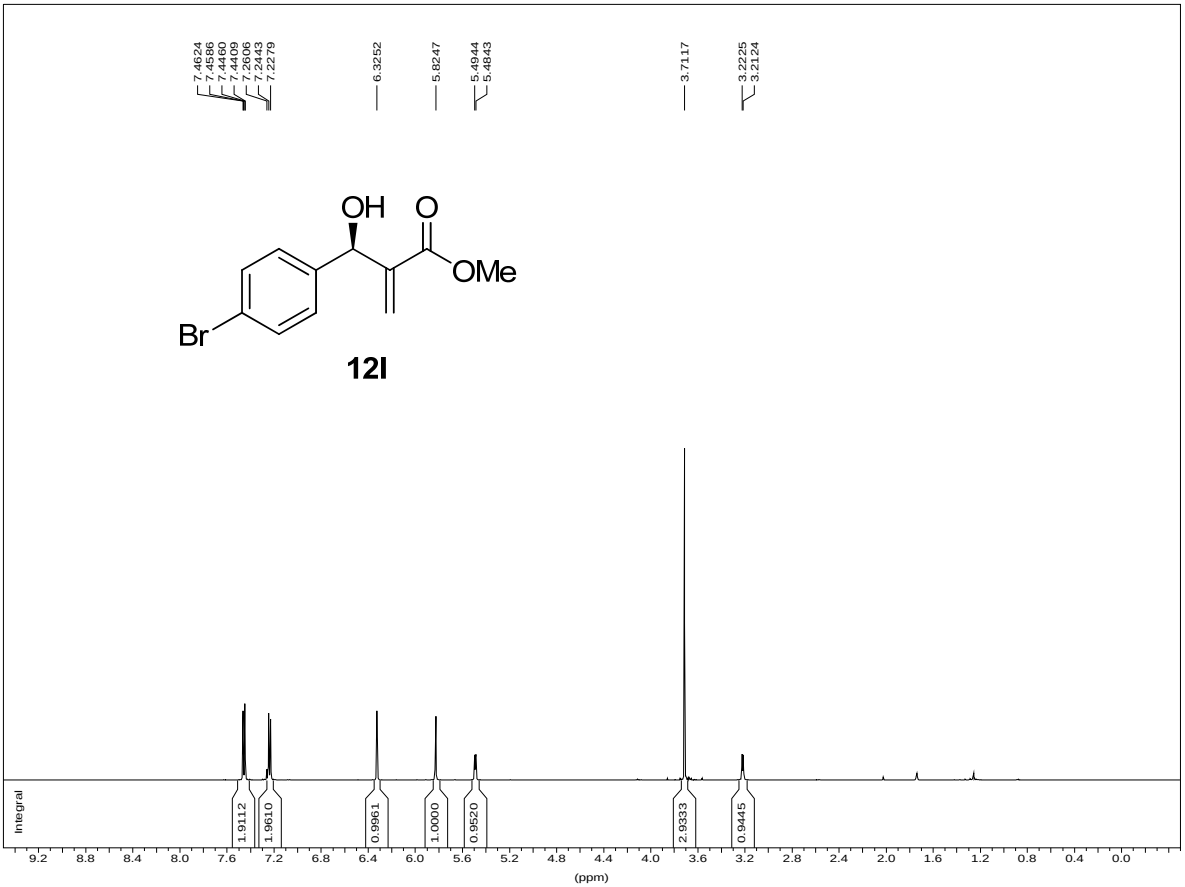
1H AMX500 hxy-506



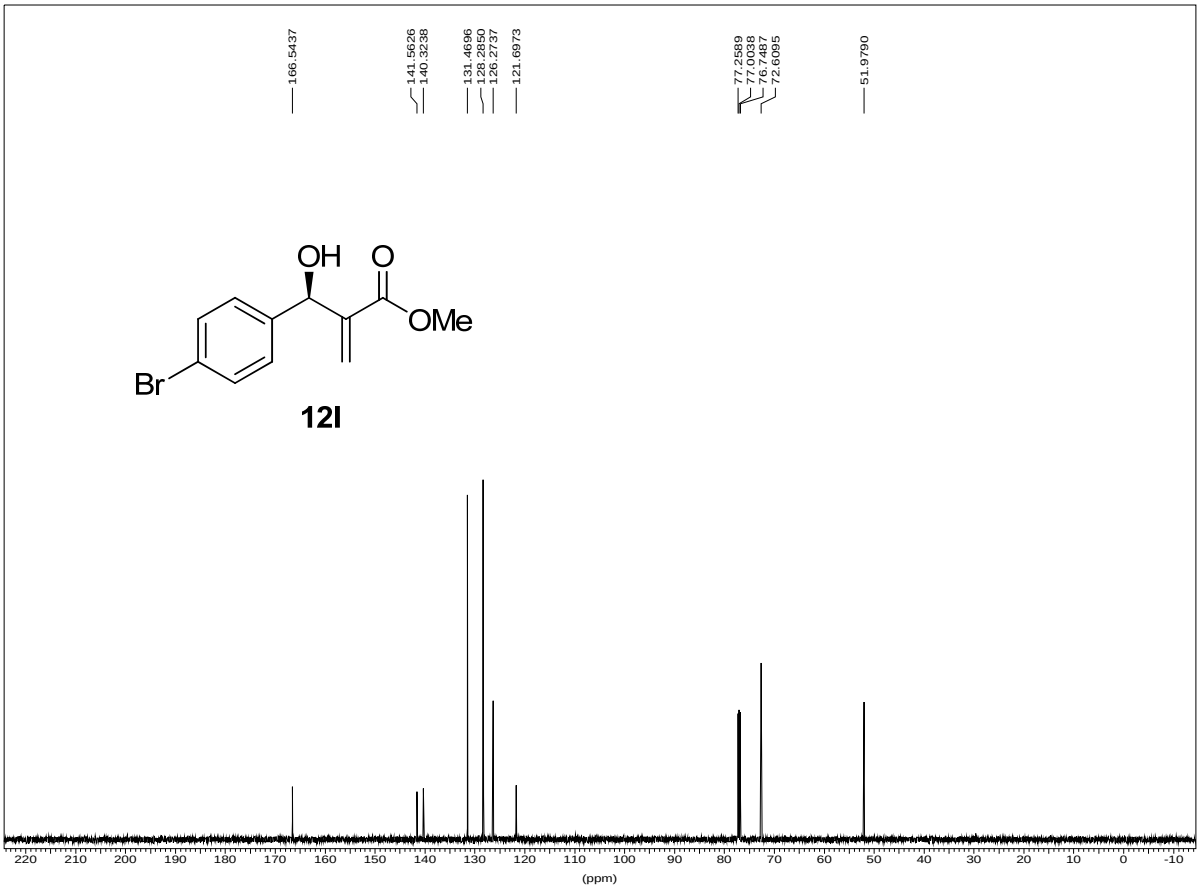
13C AMX500 hxy-506

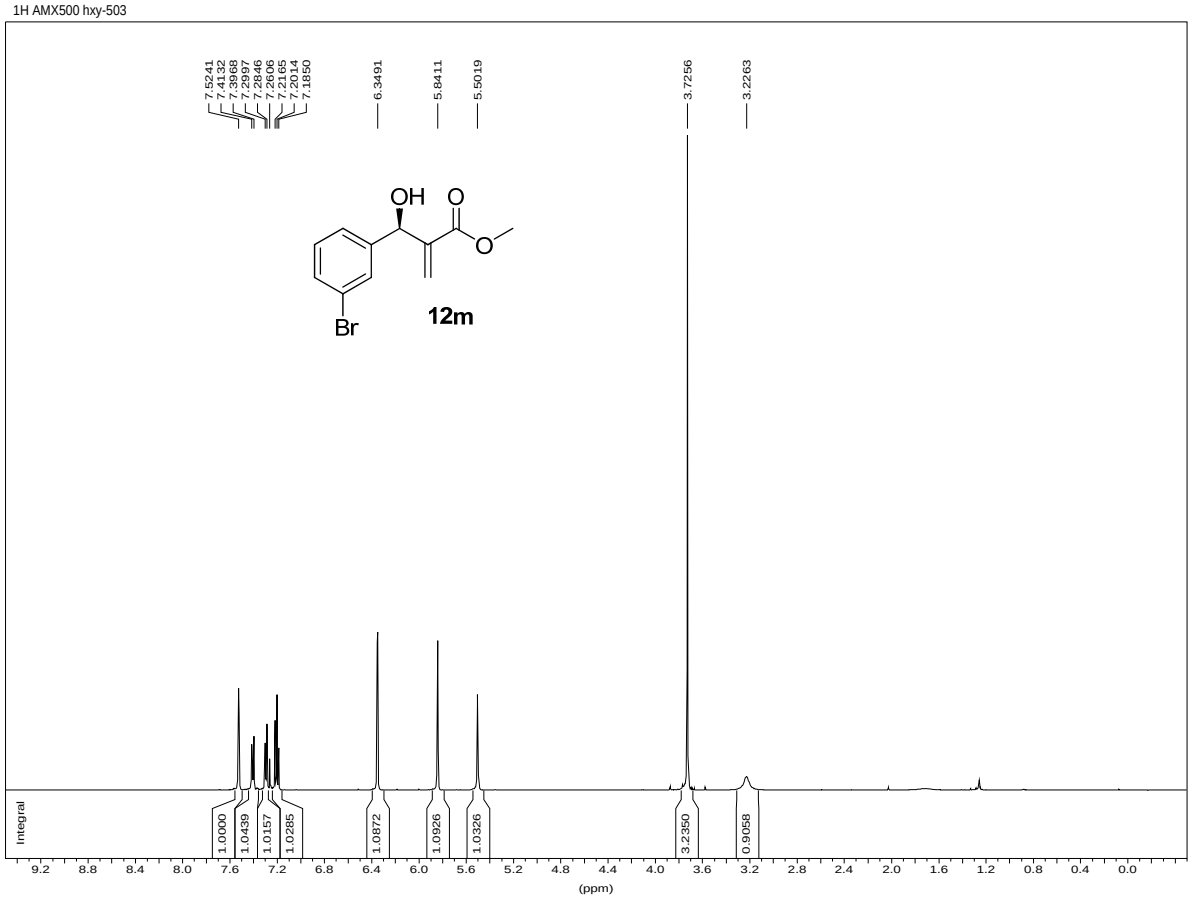


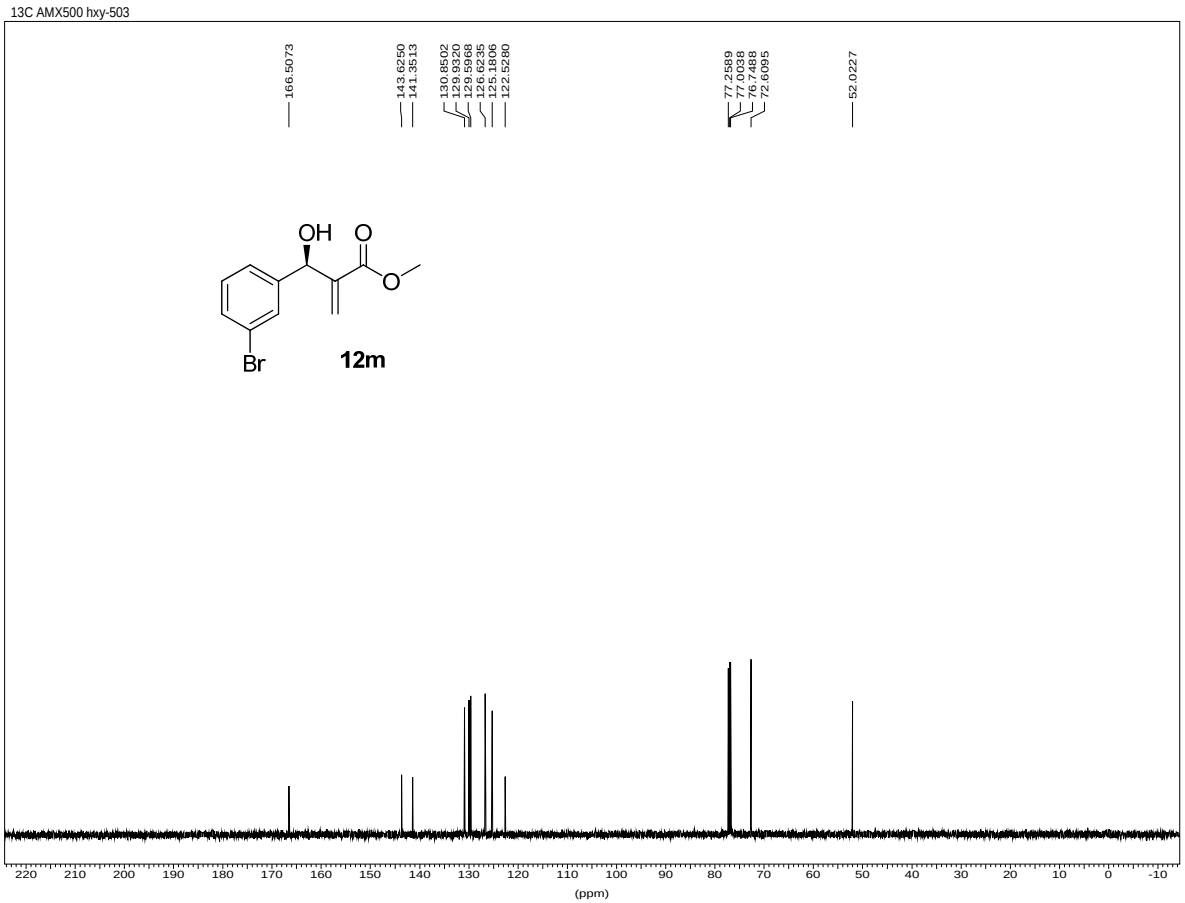
1H AMX500 hxy-494



13C AMX500 hxy-494

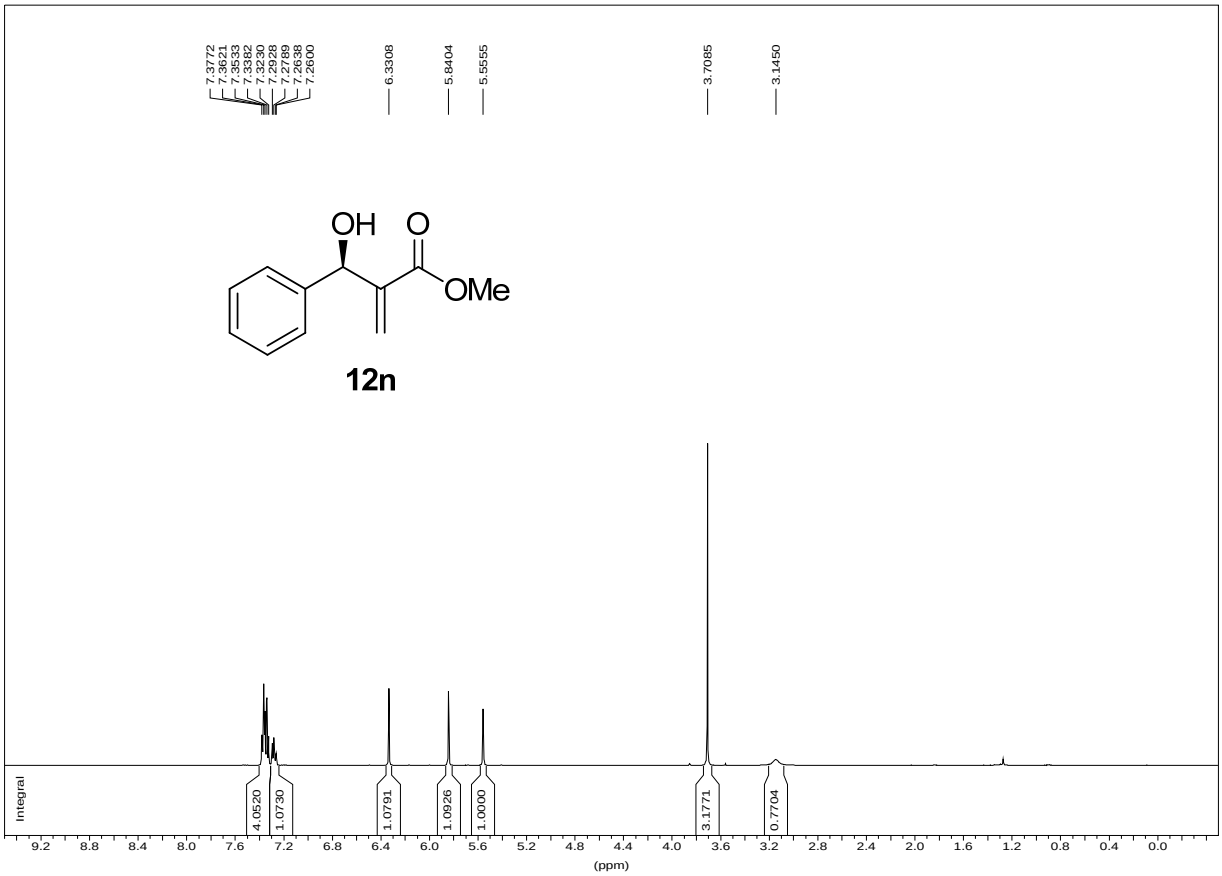



1H AMX500 hxy-503
7.5241
7.4132
7.3968
7.2997
7.2846
7.2606
7.2165
7.2014
7.1850
6.3491
5.8411
5.5019
3.7256
3.2263
OH
O
O
Br
12m
Integral
1.0000
1.0439
1.0157
1.0285
1.0872
1.0926
1.0326
3.2350
0.9058
(ppm)


13C AMX500 hxy-503
166.5073
143.6250
141.3513
130.8502
129.9320
129.5998
126.6235
125.1806
122.5280
77.2589
77.0038
76.7488
72.6095
52.0227
OH
O
O
Br
12m
(ppm)

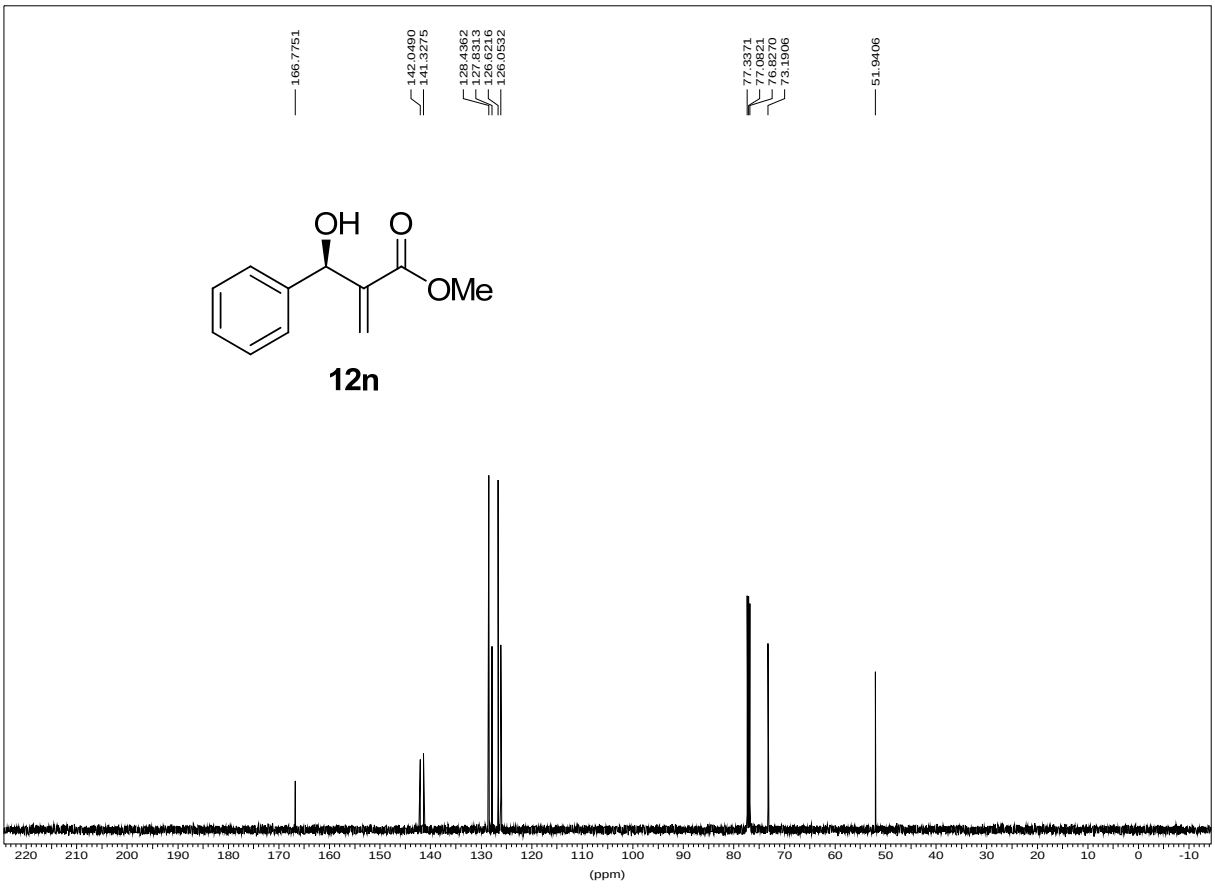
1H AMX500

hxy

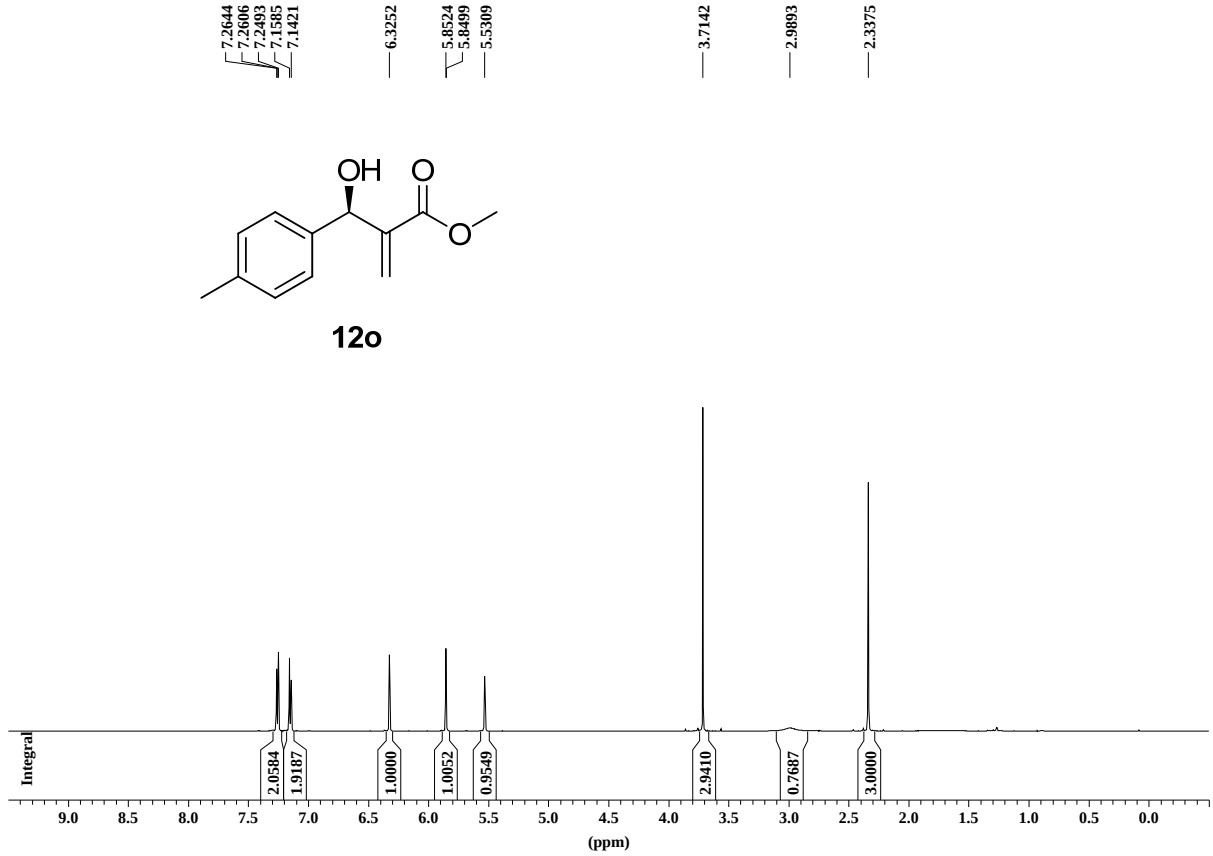


13C AMX500

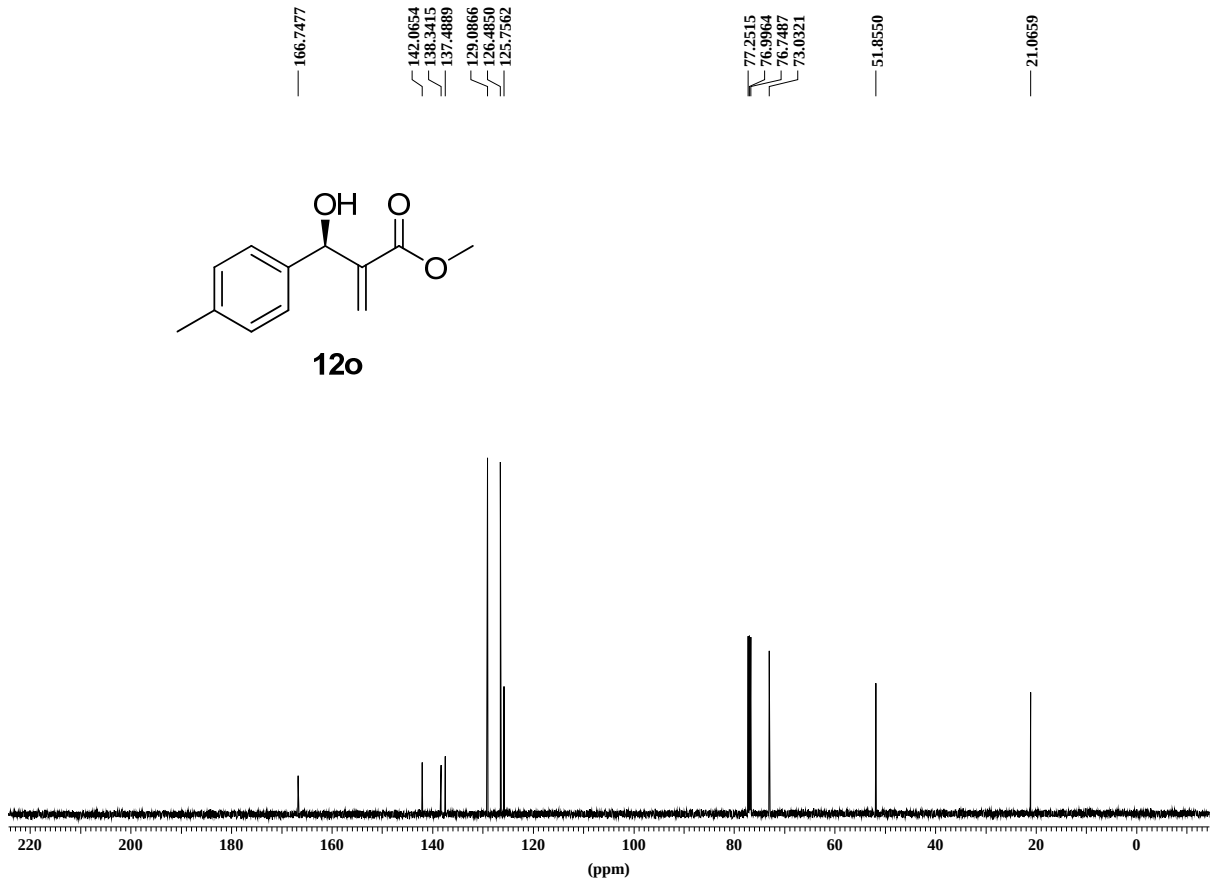
hxy



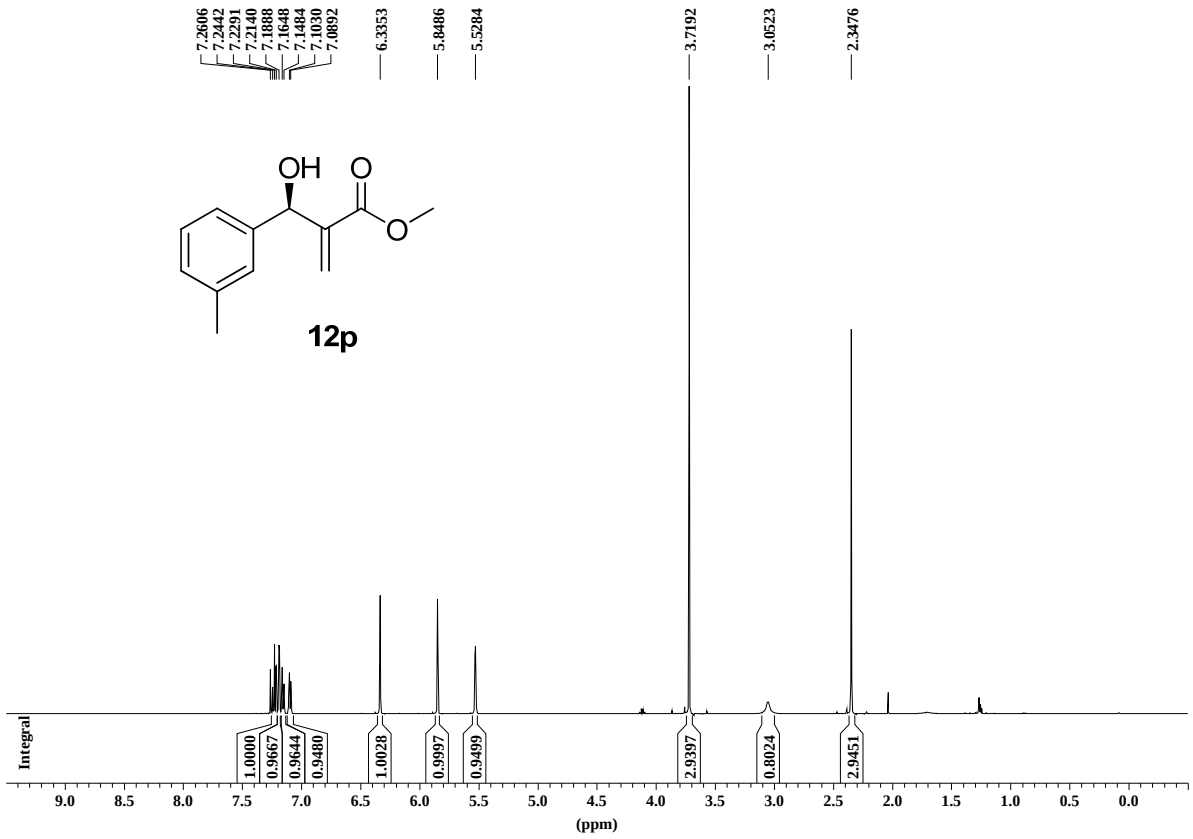
1H AMX500 hxy-507



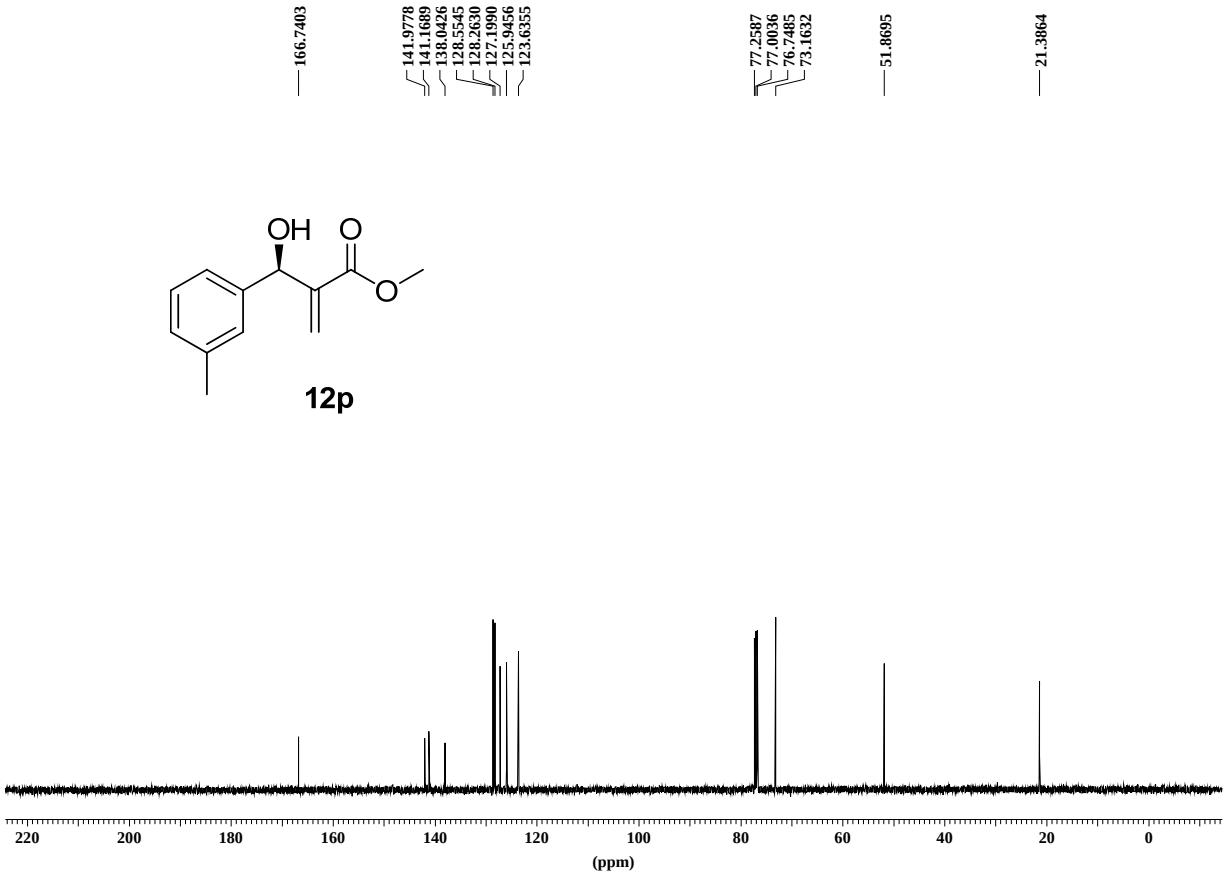
13C AMX500 hxy-507



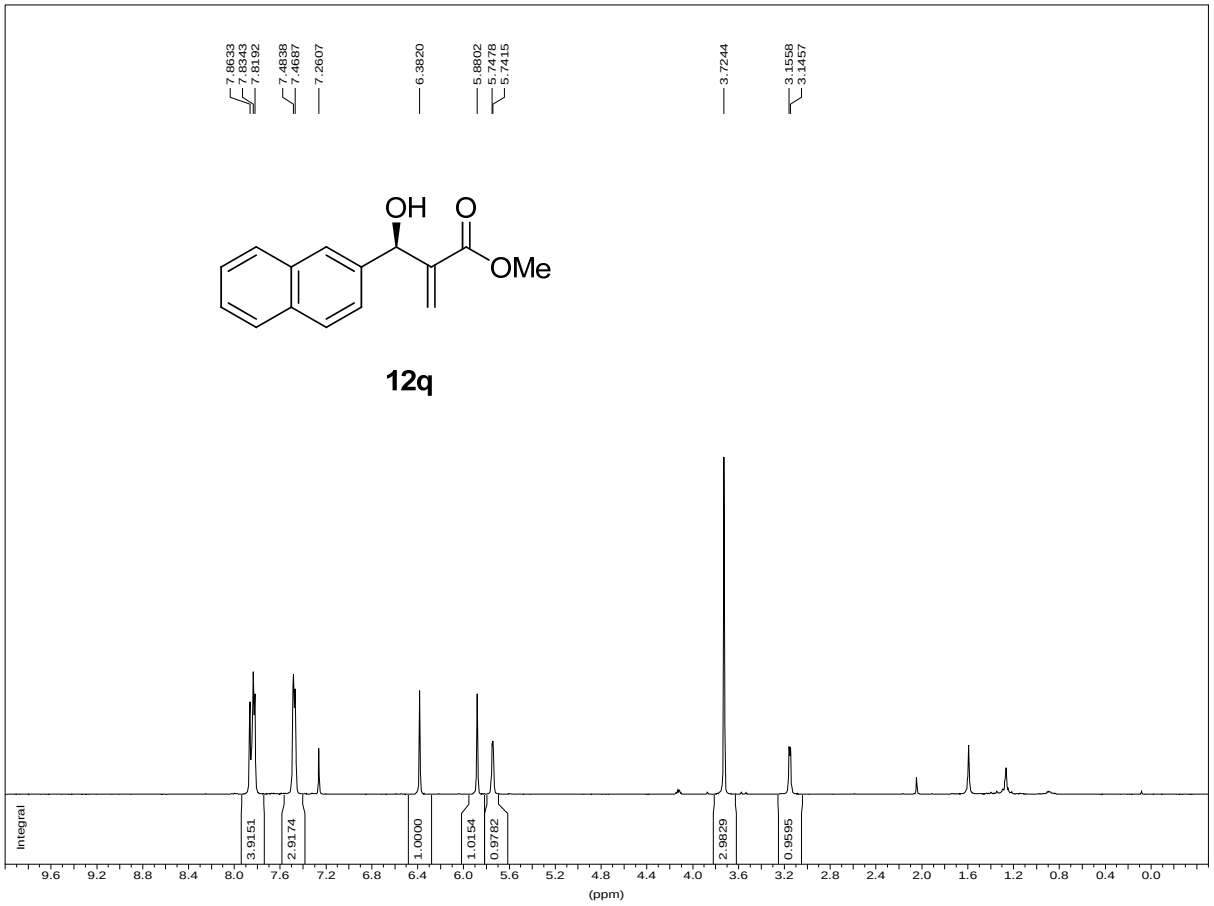
1H AMX500 hxy-508



13C AMX500 hxy-508

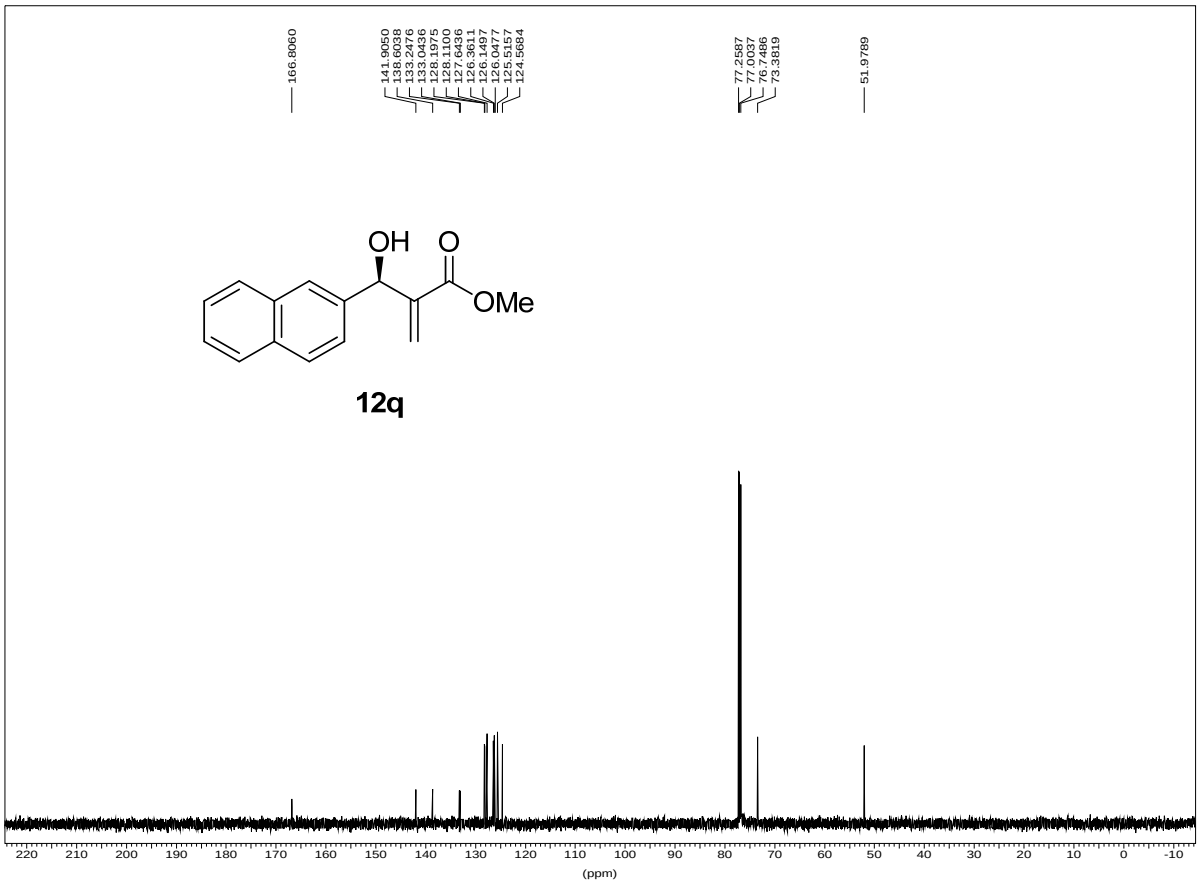


hxy-491



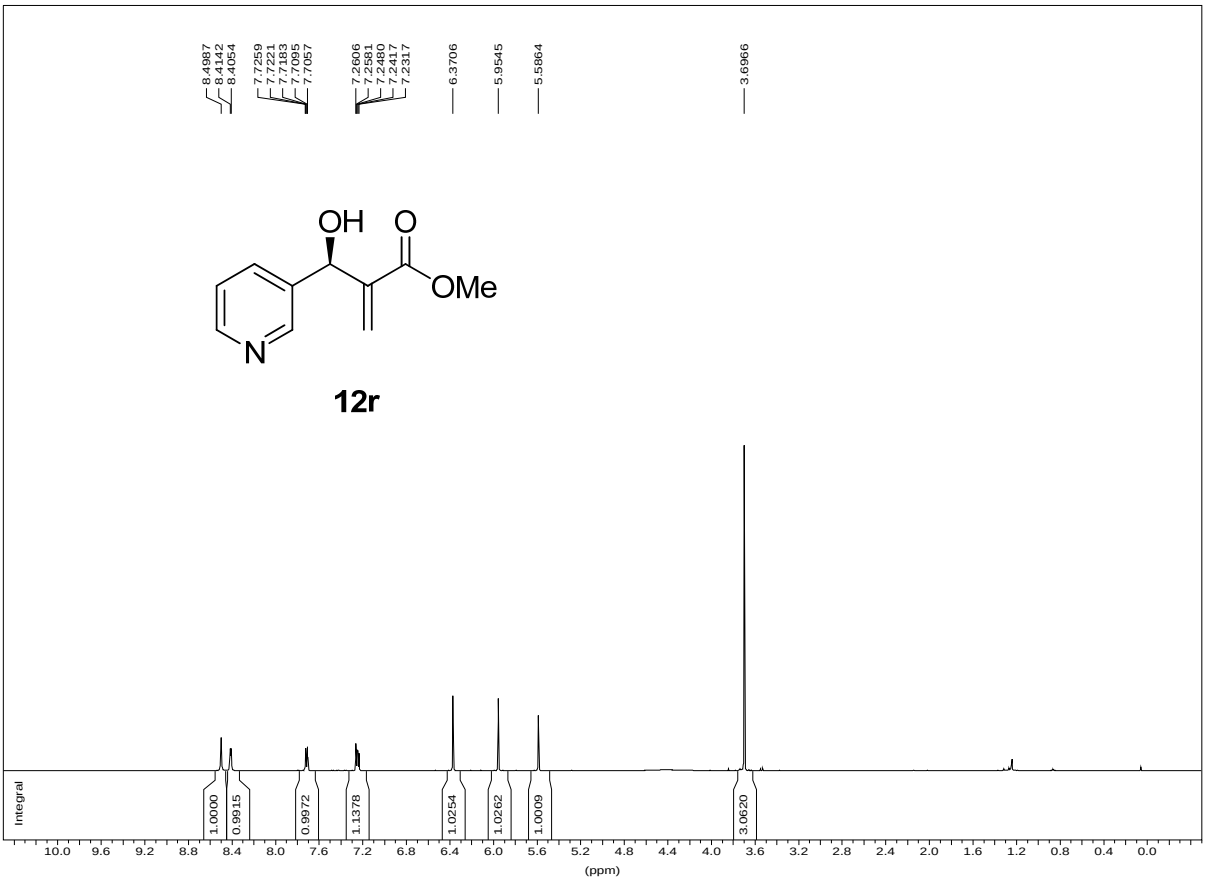
12q

hxy-491

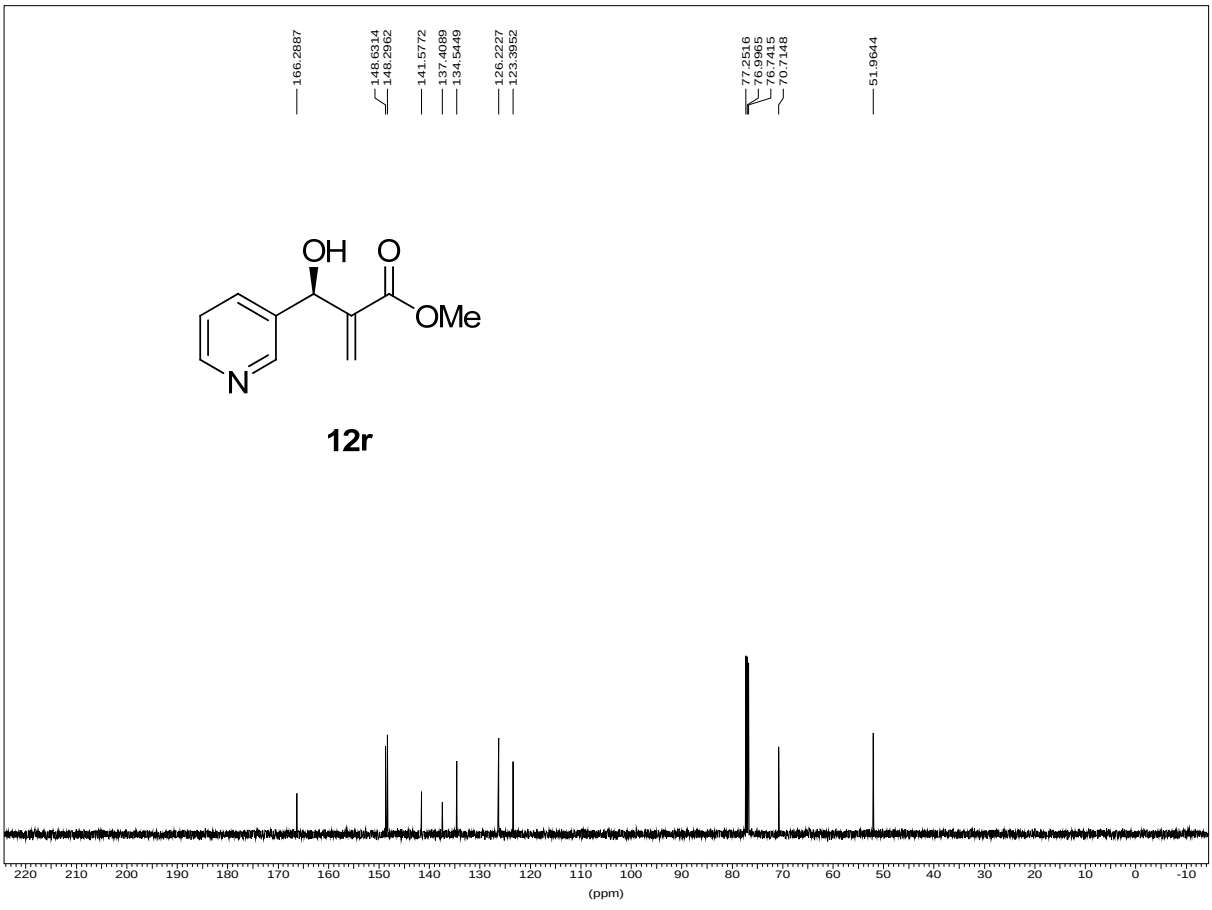


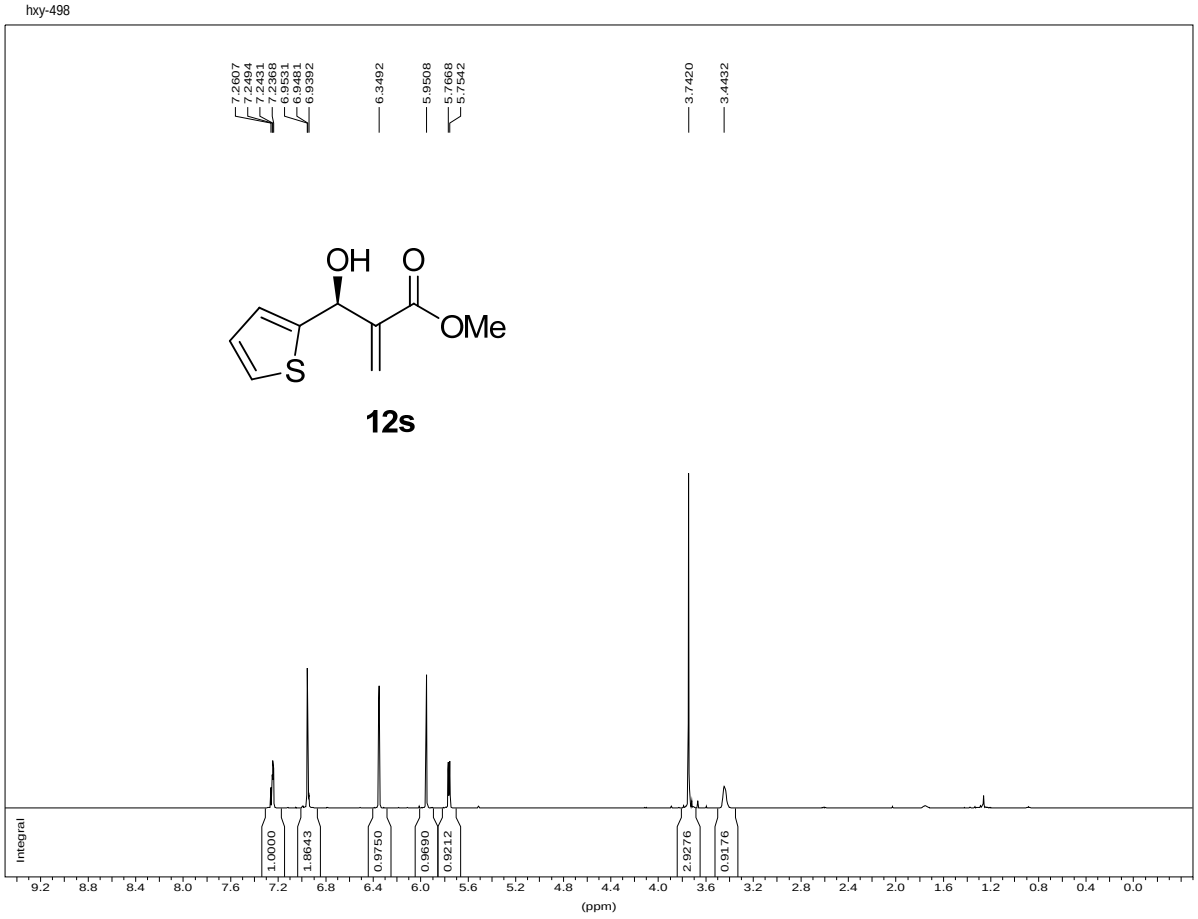
12q

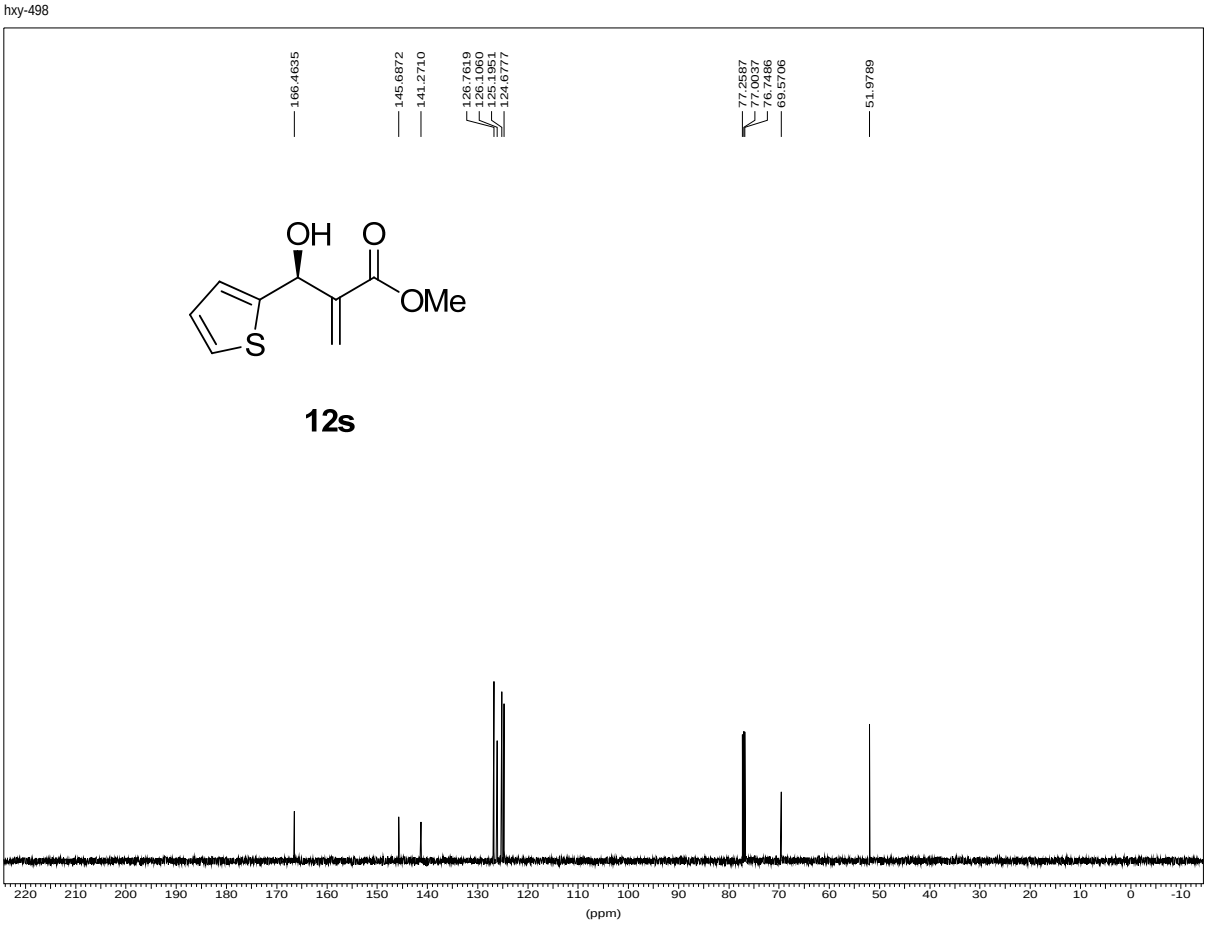
1H AMX500 hxy-499



13C AMX500 hxy-499




hxy-498
7.2607
7.2494
7.2431
7.2368
6.9531
6.9481
6.9392
6.3492
5.9508
5.7668
5.7542
3.7420
3.4432
OH
O
OMe
S
12s
Integral
1.0000
1.8643
0.9750
0.9690
0.9212
2.9276
0.9176
9.2 8.8 8.4 8.0 7.6 7.2 6.8 6.4 6.0 5.6 5.2 4.8 4.4 4.0 3.6 3.2 2.8 2.4 2.0 1.6 1.2 0.8 0.4 0.0
(ppm)


hxy-498
166.4635
145.6872
141.2710
126.7619
126.1060
125.1951
124.6777
77.2587
77.0037
76.7486
69.5706
51.9789
OH
O
OMe
S
12s
220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
(ppm)