Supporting information

TEMPO-mediated late stage photochemical hydroxylation of biaryl sulfonium salts

Yue Zhao, Congjun Yu, Wenjing Liang, Iuliana L. Atodiresei, and Frederic W. Patureau
Institute of Organic Chemistry, RWTH Aachen University. Landoltweg 1, 52074 Aachen (Deutschland)
E-Mail: Frederic.Patureau@rwth-aachen.de

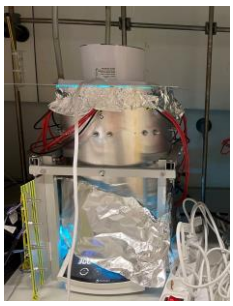
Table of contents

General Information

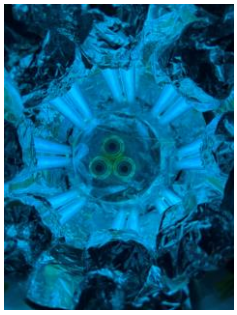
NMR spectra were obtained on an Agilent VNMRS 400 or a Bruker Av 600 using $CDCl_3$ or DMSO-d_6 as solvents. Chemical shifts are given in ppm and coupling constants (*J*) in Hz. The following abbreviations were used for ^1H NMR spectra to indicate the signal multiplicity: s (singlet), d (doublet), t (triplet), q (quartet) and m (multiplet) as well as combinations of them. Flash chromatography was performed on silica gel (60 M, 0.04-0.063 mm) by standard technique. All the chemicals used for synthesis were purchased from Sigma Aldrich, abcr, Alfa Aesar, TCI, Fisher, BLDpharma or ChemPUR. High resolution mass spectra (HRMS) were recorded on ThermoFisher Scientific LTQ Orbitrap XL spectrometer. IR spectra were measured on a PerkinElmer 100 FT-IR spectrometer with an UATR Diamond KRS-5 unit. The absorption spectra were measured from 500 nm to 240 nm with a medium scan speed on an Agilent Cary 60 UV-Vis Spectrophotometer (1 cm, quartz cells).

Crystallographic data were collected on a Bruker Kappa APEX II CCD-diffractometer with monochromatic Mo–Kα radiation (λ = 0.71073 Å) and a CCD detector.

All reactions with UV-light were carried out using a 23 cm diameter steel cylinder photo-reactor equipped with 8 Heissner GmbH UV Lamps (Model: ZF 418, 18W, Type PL-L, 230 V, 4 pins 2G11), thus in total 144W at λ = 254 nm. The cylindrical quartz vials (50 mL) were thus situated at approximatively 11 cm from the light source. In order to avoid overheating of the reaction mixtures, the quartz vials were cooled with a ventilator located on top of the photo-reactor. No filters were utilized:



144 Watt UV reactor



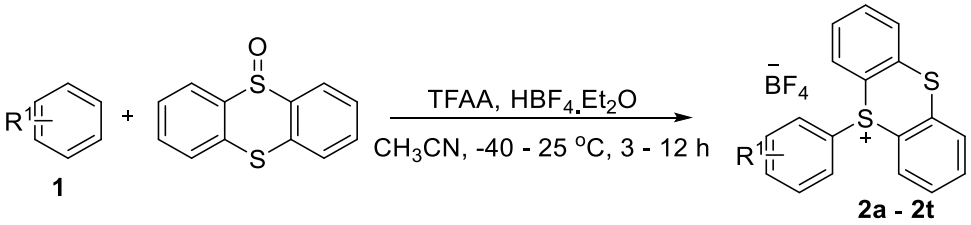
Inside of UV reactor with 8 x 18 W UV lamps

18 W UV lamp

50 mL quartz reaction vial

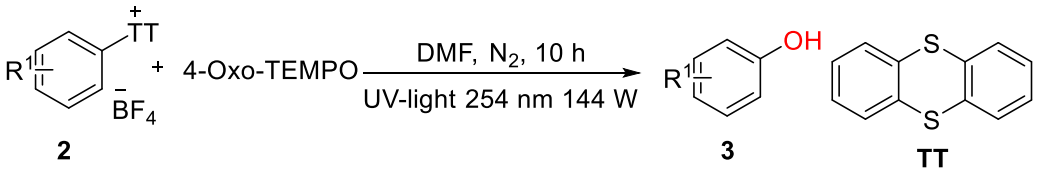
1. Experimental Section

1.1 General procedure **A** for the synthesis of aryl thianthrenium salts **2** [1,2]



Under ambient atmosphere, a 50 mL round-bottom flask equipped with a magnetic stir bar was charged with simple arenes (2 mmol, 1.0 equiv.), thianthrene S-oxide (464 mg, 2 mmol, 1 equiv.) and CH_3CN (5 mL). After cooling to -40 °C, Trifluoroacetic anhydride (0.56 mL, 840mg, 4 mmol, 2.0 equiv.) was added in one portion, followed by the addition of $HBF_4{\cdot}OEt_2$ (0.6 mL, 712 mg, 4.4 mmol, 2.2 equiv.) in one portion. The mixture was stirred at -40 °C for 1 h, then at ambient temperature for 3-12 h. The reaction mixture was concentrated under reduced pressure, and subsequently diluted with DCM (14 mL). The solution was poured onto a saturated aqueous $NaHCO_3$ solution (14 mL), and the layers were separated. The organic phase was washed with aqueous $NaBF_4$ solution (2 × 14 mL, 10%), and with water (2 × 14 mL). The organic phase was dried over Na_2SO_4, and the solvent was removed under reduced pressure. The residue was purified by chromatography on silica gel eluting with DCM / MeOH (20:1 (v/v)) to afford **2a** – **2t**.

1.2 General procedure **B** for the hydroxylation of aryl sulfonium salts

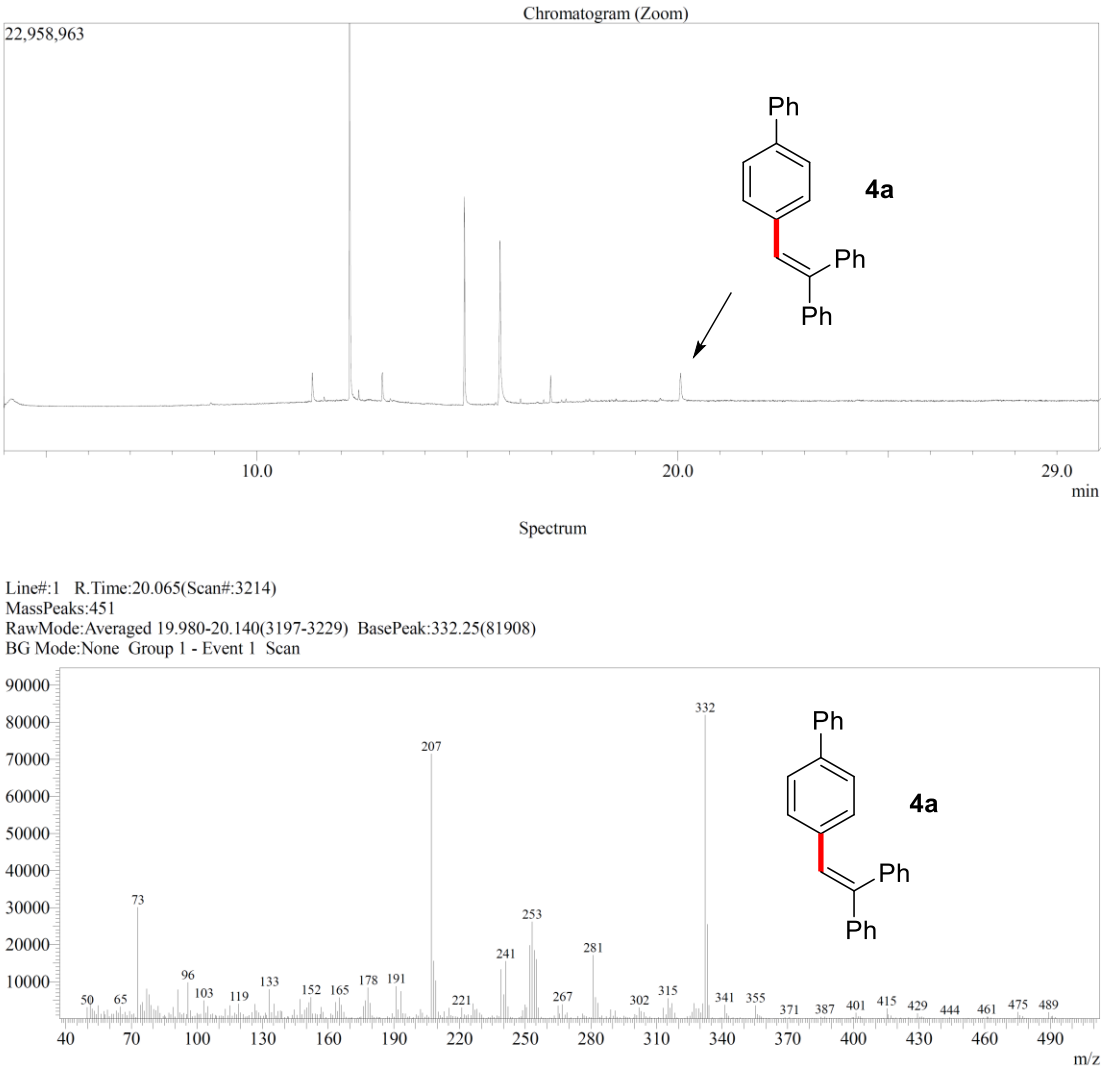


Under N_2 atmosphere, a 50 mL flat-bottom quartz vial equipped with a magnetic stir bar was charged with aryl thianthrenium salts **2** (0.4 mmol, 1.0 equiv.), 4-Oxo-TEMPO (3.2 mmol, 8 equiv.) and DMF (3 mL). The tube was sealed, and the mixture was stirred at room temperature under UV-light (254 nm, 144 W) for 10 h before quenching with aqueous saturated $NaHCO_3$ and dilution with EtOAc. The organic layer was washed with brine, dried using Na_2SO_4, filtered, and concentrated *in vacuo*, to give the crude product **3a** – **3s**, which was purified by column chromatography on silica gel.

1.3 Mechanistic experiments

Mechanistic experiments were carried out along general procedure **B**, with the addition of an additive to the reaction mixture before the start of the reaction (1.4-dinitrobenzene, 1,1-diphenylethylene, or BHT), in 2 equivalents, as noted in the article. The reaction

work-up is otherwise identical. GCMS profile of the crude reaction mixture in the case of 1,1-diphenylethylene (product **4a**):



2. UV-vis absorption spectroscopic measurements

The UV-Vis spectroscopy was used to measure the absorption of **2a** and **2a** with 4-Oxo-TEMPO (medium scan speed on an Agilent Cary 60 UV-Vis Spectrophotometer, 1 cm, quartz cells). As shown in **Figure S1**, **2a** exhibits the main absorption within 260-350 nm and almost no absorption can be seen shorter than 260 nm. In order to eliminate the influence of 4-Oxo-TEMPO to **2a**, 8 equiv. 4-Oxo-TEMPO was added to measure the absorption which is consistent with the amount during the synthesis, and the red line reveals no obvious difference as **2a**.

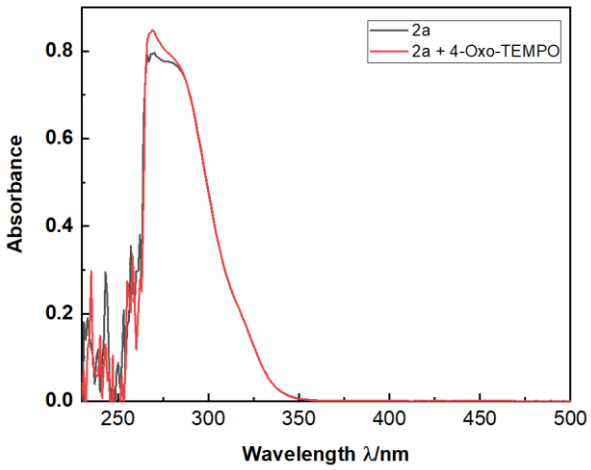


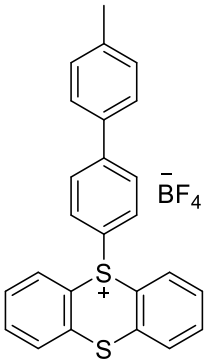
Figure S1 UV absorption spectroscopy

3. Characterization of Products

Thianthrenium salts **2a**, **2m**, and **2s** were prepared as previously described.[3]

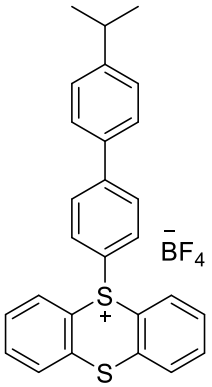
3.1 Characterization of aryl thianthrenium salts

4-Methylbiphenyl derived thianthrenium salt **2b**



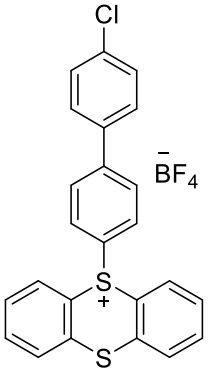
Following the general procedure A afforded the product as a yellow solid (749 mg, 80% yield, 2 mmol); Chromatography column, DCM /MeOH = 20:1.
^{1}H NMR (600 MHz, DMSO-d_6) δ 8.61 (dd, *J* = 7.9, 1.2 Hz, 2H), 8.06 (dd, *J* = 7.9, 1.1 Hz, 2H), 7.93 (td, *J* = 7.7, 1.4 Hz, 2H), 7.88 (td, *J* = 7.7, 1.3 Hz, 2H), 7.82 (d, *J* = 8.8 Hz, 2H), 7.54 (d, *J* = 8.2 Hz, 2H), 7.28 (d, *J* = 8.8 Hz, 2H), 7.25 (d, *J* = 8.1 Hz, 2H), 2.30 (s, 3H). ^{19}F NMR (565 MHz, DMSO-d_6) δ -148.09 (s, 1F), -148.15 (s, 3F). ^{13}C NMR (151 MHz, DMSO-d_6) δ 144.2 (s), 138.6 (s), 135.6 (s), 135.4 (s), 134.9 (s), 134.7 (s), 130.3 (s), 129.8 (s), 129.8 (s), 128.7 (s), 128.3 (s), 126.9 (s), 122.9 (s), 119.3 (s), 20.7 (s). HRMS-ESI (m/z): Calculated for $C_{25}H_{19}S_2$: $[M - BF_4]^+$ 383.0922; Found, 383.0920. IR: 3630, 3083, 2324, 1567, 1482, 1448, 1392, 1287, 1197, 1049, 807, 760, 703 cm^{-1}.

4-Isopropylbiphenyl derived thianthrenium salt **2c**



Following the general procedure A afforded the product as a yellow solid (712 mg, 71% yield, 2 mmol); Chromatography column, DCM /MeOH = 20:1.
^{1}H NMR (600 MHz, DMSO-d_6) δ 8.62 (dd, *J* = 7.9, 1.3 Hz, 2H), 8.08 (dd, *J* = 7.9, 1.2 Hz, 2H), 7.94 (td, *J* = 7.7, 1.4 Hz, 2H), 7.88 (td, *J* = 7.7, 1.3 Hz, 2H), 7.83 (d, *J* = 8.9 Hz, 2H), 7.57 (d, *J* = 8.4 Hz, 2H), 7.33 (d, *J* = 8.3 Hz, 2H), 7.29 (d, *J* = 8.8 Hz, 2H), 2.90 (hept, *J* = 6.9 Hz, 1H), 1.19 (d, *J* = 6.9 Hz, 6H). ^{19}F NMR (565 MHz, DMSO-d_6) δ -148.17 (s, 1F), -148.22 (s, 3F). ^{13}C NMR (151 MHz, DMSO-d_6) δ 149.3 (s), 144.3 (s), 135.6 (s), 135.4 (s), 135.2 (s), 134.8 (s), 130.3 (s), 129.7 (s), 128.7 (s), 128.3 (s), 127.1 (s), 127.0 (s), 123.0 (s), 119.2 (s), 33.1 (s), 23.7 (s). HRMS-ESI (m/z): Calculated for $C_{27}H_{23}S_2$: $[M - BF_4]^+$ 411.1234; Found, 411.1229. IR: 3098, 2956, 2868, 2324, 1991, 1646, 1567, 1485, 1451, 1287, 1092, 1052, 964, 820, 764, 710, 660 cm^{-1}.

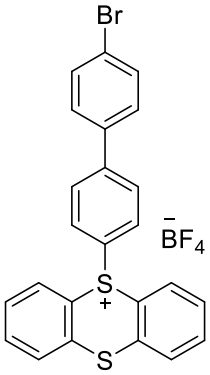
4-Chlorobiphenyl derived thianthrenium salt **2d**



Following the general procedure A afforded the product as a yellow solid (825 mg, 84% yield, 2 mmol); Chromatography column, DCM /MeOH = 20:1.
^{1}H NMR (400 MHz, DMSO-d_6) δ 8.62 (d, *J* = 7.8 Hz, 2H), 8.07 (d, *J* = 7.7 Hz, 2H), 7.97 – 7.91 (m, 2H), 7.88 (td, *J* = 7.7, 1.3 Hz, 2H), 7.84 (d, *J* = 8.7 Hz, 2H), 7.67 (d, *J* = 8.6 Hz, 2H), 7.50 (d, *J* = 8.6 Hz, 2H), 7.30 (d, *J* = 8.7 Hz, 2H). ^{19}F NMR (376 MHz, DMSO-d_6) δ -148.14 (s, 1F), -148.20 (s, 3F). ^{13}C NMR (101 MHz, DMSO-d_6) δ 142.9 (s), 136.5 (s), 135.7 (s), 135.5 (s), 134.9 (s), 133.9 (s), 130.3 (s), 129.8 (s), 129.2 (s), 128.9 (s), 128.8 (s), 128.5 (s), 123.9 (s), 119.2 (s). HRMS-ESI (m/z): Calculated for $C_{24}H_{16}ClS_2$: $[M - BF_4]^+$ 403.0377; Found, 403.0372. IR: 3082, 2925, 2323, 2157, 1814,

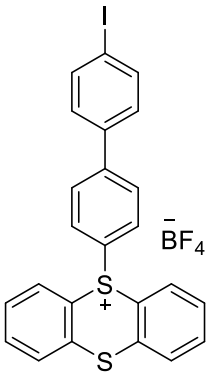
1591, 1566, 1472, 1453, 1384, 1266, 1169, 1027, 813, 751, 701, 659 cm^{-1}.

4-Bromobiphenyl derived thianthrenium salt **2e**



Following the general procedure A afforded the product as a white solid (895 mg, 84% yield, 2 mmol); Chromatography column, DCM /MeOH = 20:1.
^{1}H NMR (600 MHz, DMSO-d_6) δ 8.63 (dd, *J* = 7.9, 1.2 Hz, 2H), 8.07 (dd, *J* = 7.9, 1.1 Hz, 2H), 7.94 (td, *J* = 7.7, 1.4 Hz, 2H), 7.89 (td, *J* = 7.7, 1.3 Hz, 2H), 7.84 (d, *J* = 8.8 Hz, 2H), 7.64 (d, *J* = 8.7 Hz, 2H), 7.60 (d, *J* = 8.7 Hz, 2H), 7.30 (d, *J* = 8.8 Hz, 2H). ^{19}F NMR (565 MHz, DMSO-d_6) δ -148.10 (s, 1F), -148.15 (s, 3F). ^{13}C NMR (151 MHz, DMSO-d_6) δ 142.9 (s), 136.8 (s), 135.6 (s), 135.4 (s), 134.9 (s), 132.0 (s), 130.3 (s), 129.7 (s), 129.1 (s), 128.8 (s), 128.4 (s), 123.9 (s), 122.5 (s), 119.2 (s). HRMS-ESI (m/z): Calculated for $C_{24}H_{16}BrS_2$: $[M - BF_4]^+$ 446.9871; Found, 446.9870. IR: 3632, 3555, 3085, 2683, 2322, 1997, 1630, 1588, 1567, 1474, 1449, 1384, 1288, 1266, 1049, 810, 757, 702, 658 cm^{-1}.

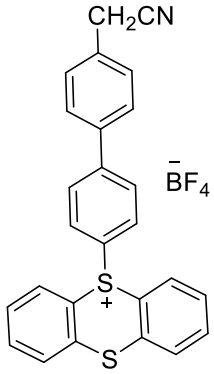
4-Iodobiphenyl derived thianthrenium salt **2f**



Following the general procedure A afforded the product as a white solid (864 mg, 74% yield, 2 mmol); Chromatography column, DCM /MeOH = 20:1.
^{1}H NMR (600 MHz, DMSO-d_6) δ 8.62 (dd, *J* = 7.9, 1.2 Hz, 2H), 8.08 (dd, *J* = 7.9, 1.1 Hz, 2H), 7.94 (td, *J* = 7.7, 1.3 Hz, 2H), 7.88 (td, *J* = 7.8, 1.2 Hz, 2H), 7.83 (dd, *J* = 8.5, 6.0 Hz, 4H), 7.45 (d, *J* = 8.5 Hz, 2H), 7.29 (d, *J* = 8.8 Hz, 2H). ^{19}F NMR (565 MHz, DMSO-d_6) δ -148.17 (s, 1F), -148.23 (s, 3F). ^{13}C NMR (151 MHz, DMSO-d_6) δ 143.1 (s), 137.9 (s), 137.1 (s), 135.7 (s), 135.4 (s), 134.8 (s), 130.3 (s), 129.6 (s), 129.1 (s), 128.8 (s), 128.3 (s), 123.9 (s), 119.2 (s), 95.8 (s). HRMS-ESI (m/z): Calculated for

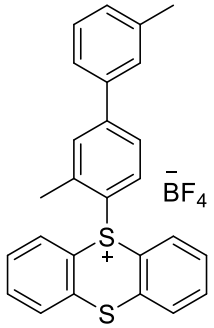
$C_{24}H_{16}IS_2$: $[M - BF_4]^+$ 494.9733; Found, 494.9728. IR: 3828, 3077, 2924, 2325, 2084, 1996, 1818, 1569, 1450, 1380, 1287, 1260, 1199, 1044, 844, 806, 751, 701, 658 cm^{-1}.

4-Biphenylacetonitrile derived thianthrenium salt **2g**



Following the general procedure A afforded the product as a pale yellow solid (868 mg, 88% yield, 2 mmol); Chromatography column, DCM /MeOH = 10:1.
^{1}H NMR (600 MHz, DMSO-d_6) δ 8.62 (dd, *J* = 7.9, 0.9 Hz, 2H), 8.04 (d, *J* = 7.8 Hz, 2H), 7.93 (td, *J* = 7.7, 1.1 Hz, 2H), 7.88 (td, *J* = 7.8, 1.0 Hz, 2H), 7.84 (d, *J* = 8.7 Hz, 2H), 7.67 (d, *J* = 8.3 Hz, 2H), 7.45 (d, *J* = 8.3 Hz, 2H), 7.31 (d, *J* = 8.7 Hz, 2H), 4.08 (s, 2H). ^{19}F NMR (565 MHz, DMSO-d_6) δ -147.95 (s, 1F), -148.00 (s, 3F). ^{13}C NMR (151 MHz, DMSO-d_6) δ 143.6 (s), 137.0 (s), 135.6 (s), 135.5 (s), 134.9 (s), 132.1 (s), 130.3 (s), 129.8 (s), 129.0 (s), 128.7 (s), 128.5 (s), 127.6 (s), 123.6 (s), 119.1 (s), 119.1 (s), 22.2 (s). HRMS-ESI (m/z): Calculated for $C_{26}H_{18}NS_2$: $[M - BF_4]^+$ 408.0875; Found, 408.0870. IR: 3628, 3082, 2925, 2251, 1567, 1483, 1449, 1394, 1288, 1266, 1034, 803, 758, 704, 658 cm^{-1}.

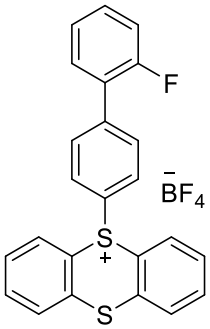
3,3'-Dimethylbiphenyl derived thianthrenium salt **2h**



Following the general procedure A afforded the product as a yellow solid (681 mg, 70% yield, 2 mmol); Chromatography column, DCM /MeOH = 20:1.
^{1}H NMR (600 MHz, DMSO-d_6) δ 8.48 (d, *J* = 8.0 Hz, 2H), 8.12 (d, *J* = 7.9 Hz, 2H), 7.94 – 7.90 (m, 2H), 7.86 (d, *J* = 1.3 Hz, 1H), 7.85 – 7.82 (m, 2H), 7.63 (dd, *J* = 8.6, 1.7 Hz, 1H), 7.48 (s, 1H), 7.44 (d, *J* = 7.9 Hz, 1H), 7.35 (t, *J* = 7.7 Hz, 1H), 7.23 (d, *J* = 7.6 Hz, 1H), 7.05 (d, *J* = 8.6 Hz, 1H), 2.73 (s, 3H), 2.34 (s, 3H). ^{19}F NMR (565 MHz, DMSO-d_6) δ -148.16 (s, 1F), -148.21 (s, 3F). ^{13}C NMR (151 MHz, DMSO-d_6) δ 145.3 (s), 140.2 (s), 138.4 (s), 137.5 (s), 136.2 (s), 134.9 (s), 134.6 (s), 131.7 (s), 130.7 (s), 129.8 (s), 129.8 (s), 129.6 (s), 129.0 (s), 127.7 (s), 125.7 (s), 124.2 (s), 120.9 (s), 118.4

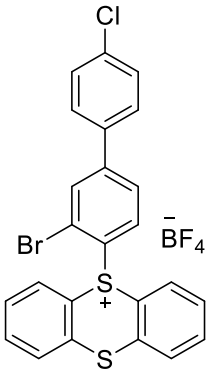
(s), 21.0 (s), 20.2 (s). HRMS-ESI (m/z): Calculated for $C_{26}H_{21}S_2$: $[M - BF_4]^+$ 397.1079; Found, 397.1075. IR: 3632, 3081, 2919, 2333, 1592, 1564, 1447, 1384, 1271, 1050, 881, 760, 698 cm^{-1}.

2-Fluorobiphenyl derived thianthrenium salt **2i**



Following the general procedure A afforded the product as a white solid (779 mg, 82% yield, 2 mmol); Chromatography column, DCM /MeOH = 20:1.
^{1}H NMR (600 MHz, DMSO-d_6) δ 8.64 (d, *J* = 7.8 Hz, 2H), 8.08 (d, *J* = 7.8 Hz, 2H), 7.95 (t, *J* = 7.6 Hz, 2H), 7.89 (t, *J* = 7.6 Hz, 2H), 7.73 (d, *J* = 8.2 Hz, 2H), 7.50 (t, *J* = 7.8 Hz, 1H), 7.46 (dd, *J* = 13.2, 7.2 Hz, 1H), 7.33 (d, *J* = 8.7 Hz, 2H), 7.32 – 7.27 (m, 2H). ^{19}F NMR (565 MHz, DMSO-d_6) δ -118.04 (s, 1F), -148.12 (s, 1F), -148.18 (s, 3F). ^{13}C NMR (151 MHz, DMSO-d_6) δ 159.0 (d, *J* = 247.2 Hz), 139.3 (s), 135.7 (s), 135.5 (s), 134.1 (s), 131.0 (d, *J* = 8.3 Hz), 130.8 (d, *J* = 2.0 Hz), 130.7 (d, *J* = 2.6 Hz), 130.4 (s), 129.7 (s), 128.4 (s), 126.0 (d, *J* = 13.0 Hz), 125.2 (d, *J* = 3.3 Hz), 124.2 (s), 119.1 (s), 116.4 (s), 116.2 (s). HRMS-ESI (m/z): Calculated for $C_{24}H_{16}FS_2$: $[M - BF_4]^+$ 387.0672; Found, 387.0667. IR: 3091, 2700, 2326, 2081, 1614, 1570, 1474, 1450, 1392, 1288, 1260, 1214, 1043, 823, 755, 703, 659 cm^{-1}.

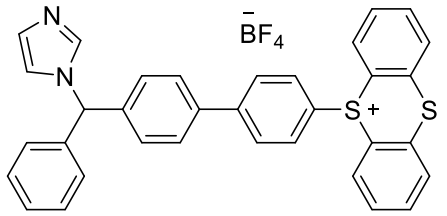
3-Bromo-4'-chloro-1,1'-biphenyl derived thianthrenium salt **2j**



Following the general procedure A afforded the product as a yellow solid (465 mg, 41% yield, 2 mmol); Chromatography column, DCM /MeOH = 20:1.
^{1}H NMR (600 MHz, DMSO-d_6) δ 8.60 (dd, *J* = 8.1, 1.2 Hz, 2H), 8.25 (d, *J* = 2.0 Hz, 1H), 8.12 (dd, *J* = 8.0, 1.1 Hz, 2H), 7.93 (td, *J* = 7.8, 1.3 Hz, 2H), 7.88 – 7.83 (m, 2H), 7.80 (dd, *J* = 8.7, 2.0 Hz, 1H), 7.72 (d, *J* = 8.7 Hz, 2H), 7.51 (d, *J* = 8.7 Hz, 2H), 7.07 (d, *J* = 8.6 Hz, 1H). ^{19}F NMR (565 MHz, DMSO-d_6) δ -148.16 (s, 1F), -148.21 (s, 3F). ^{13}C NMR (151 MHz, DMSO-d_6) δ 145.2 (s), 136.8 (s), 136.5 (s), 135.1 (s), 134.8 (s),

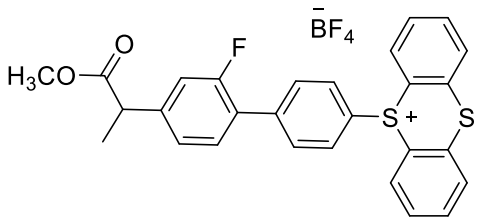
134.5 (s), 133.5 (s), 131.8 (s), 130.7 (s), 129.5 (s), 129.2 (s), 129.1 (s), 126.7 (s), 124.0 (s), 121.9 (s), 117.8 (s). HRMS-ESI (m/z): Calculated for $C_{24}H_{15}BrClS_2$: $[M - BF_4]^+$ 480.9482; Found, 480.9476. IR: 3632, 3084, 2329, 1726, 1620, 1576, 1448, 1370, 1287, 1259, 1170, 1048, 815, 758, 701, 658 cm^{-1}.

Bifonazole derived thianthrenium salt **2k**



Under ambient atmosphere, a 50 mL round-bottom flask equipped with a magnetic stir bar was charged with bifonazole (2 mmol, 1.0 equiv.), thianthrene S-oxide (450 mg, 1.94 mmol, 0.97 equiv.), thianthrene (14 mg, 0.06 mmol, 0.03 equiv.) and CH_3CN (5 mL). After cooling to -40°C, Trifluoroacetic anhydride (0.56 mL, 840mg, 4 mmol, 2.0 equiv.) was added in one portion, followed by the addition of $HBF_4{\cdot}OEt_2$ (0.6 mL, 712 mg, 4.4 mmol, 2.2 equiv.) in one portion. The mixture was stirred at -40 °C for 1 h, then at ambient temperature for 6 h. The reaction mixture was concentrated under reduced pressure, and subsequently diluted with DCM (14 mL). The solution was poured onto a saturated aqueous $NaHCO_3$ solution (14 mL), and the layers were separated. The organic phase was washed with aqueous $NaBF_4$ solution (2 × 14 mL, 10%), and with water (2 × 14 mL). The organic phase was dried over Na_2SO_4, and the solvent was removed under reduced pressure. The residue was purified by chromatography on silica gel eluting with DCM / MeOH (10:1 (v/v)) to afford **2k** as a yellow solid (887 mg, 72% yield, 2 mmol).
^{1}H NMR (400 MHz, DMSO-d_6) δ 8.62 (d, J = 7.7 Hz, 2H), 8.08 (d, J = 7.7 Hz, 2H), 7.98 – 7.82 (m, 6H), 7.76 (d, J = 8.3 Hz, 1H), 7.68 (d, J = 8.2 Hz, 2H), 7.43 – 7.33 (m, 3H), 7.30 (d, J = 8.6 Hz, 2H), 7.24 (d, J = 8.1 Hz, 2H), 7.18 (d, J = 7.2 Hz, 3H), 7.02 (s, 1H), 6.94 (s, 1H). ^{19}F NMR (376 MHz, DMSO-d_6) δ -148.20 (s, 1F), -148.26 (s, 3F). ^{13}C NMR (101 MHz, DMSO-d_6) δ 143.5 (s), 140.5 (s), 139.5 (s), 137.3 (s), 135.7 (s), 135.4 (s), 134.8 (s), 130.3 (s), 129.7 (s), 128.8 (s), 128.7 (s), 128.6 (s), 128.1 (s), 127.9 (s), 127.5 (s), 123.7 (s), 119.2 (s), 63.1 (s). HRMS-ESI (m/z): Calculated for $C_{34}H_{25}N_2S_2$: $[M - BF_4]^+$ 525.1454; Found, 525.1446. IR: 3746, 3394, 3086, 2165, 1831, 1605, 1572, 1447, 1379, 1320, 1252, 1172, 1055, 959, 870, 845, 763 cm^{-1}.

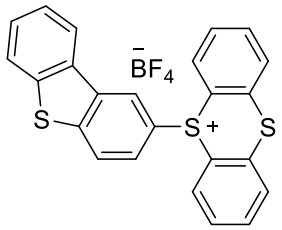
Flurbiprofen derived thianthrenium salt **2l**



Following the general procedure A afforded the product as a white solid (878 mg, 78%

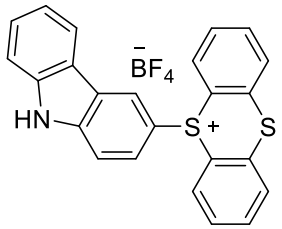
yield, 2 mmol); Chromatography column, DCM /MeOH = 10:1.
^{1}H NMR (400 MHz, DMSO-d_6) δ 8.62 (d, *J* = 7.8 Hz, 2H), 8.09 (d, *J* = 7.8 Hz, 2H), 7.95 (t, *J* = 7.5 Hz, 2H), 7.88 (t, *J* = 7.6 Hz, 2H), 7.73 (d, *J* = 8.1 Hz, 2H), 7.47 (t, *J* = 8.1 Hz, 1H), 7.32 (d, *J* = 8.6 Hz, 2H), 7.24 (dd, *J* = 14.0, 10.3 Hz, 2H), 3.90 (q, *J* = 7.1 Hz, 1H), 3.60 (s, 3H), 1.41 (d, *J* = 7.1 Hz, 3H). ^{19}F NMR (376 MHz, DMSO-d_6) δ -117.85 (s, 1F), -148.24 (s, 1F), -148.30 (s, 3F). ^{13}C NMR (101 MHz, DMSO-d_6) δ 173.6 (s), 158.8 (d, *J* = 247.7 Hz), 144.0 (d, *J* = 8.0 Hz), 139.0 (s), 135.7 (s), 135.5 (s), 134.9 (s), 130.9 (d, *J* = 2.8 Hz), 130.6 (d, *J* = 2.6 Hz), 130.3 (s), 129.7 (s), 128.4 (s), 124.6 (d, *J* = 12.9 Hz), 124.3 (d, *J* = 2.7 Hz), 124.1 (s), 119.1 (s), 115.5 (s), 115.3 (s), 52.0 (s), 43.8 (s), 18.3 (s). HRMS-ESI (m/z): Calculated for $C_{28}H_{22}FO_2S_2$: $[M - BF_4]^+$ 473.1040; Found, 473.1030. IR: 3088, 2945, 2322, 1821, 1734, 1619, 1568, 1431, 1392, 1283, 1196, 1128, 1095, 1050, 919, 835, 764, 703, 658 cm^{-1}.

Dibenzothiophene derived thianthrenium salt **2n**



Following the general procedure A afforded the product as a white solid (650 mg, 67% yield, 2 mmol); Chromatography column, DCM /MeOH = 20:1.
^{1}H NMR (600 MHz, DMSO-d_6) δ 9.14 (d, *J* = 1.9 Hz, 1H), 8.56 (d, *J* = 7.8 Hz, 2H), 8.48 – 8.42 (m, 1H), 8.38 (d, *J* = 8.0 Hz, 2H), 8.20 (d, *J* = 8.7 Hz, 1H), 8.16 – 8.09 (m, 1H), 7.98 (t, *J* = 7.6 Hz, 2H), 7.76 (t, *J* = 8.1 Hz, 2H), 7.70 – 7.55 (m, 2H), 7.14 (dd, *J* = 8.7, 2.0 Hz, 1H). ^{19}F NMR (565 MHz, DMSO-d_6) δ -148.21 (s, 1F), -148.26 (s, 3F). ^{13}C NMR (151 MHz, DMSO-d_6) δ 144.6 (s), 139.5 (s), 139.2 (s), 136.2 (s), 133.9 (s), 133.4 (s), 131.3 (s), 128.6 (s), 128.2 (s), 126.2 (s), 126.1 (s), 125.6 (s), 124.9 (s), 124.6 (s), 124.2 (s), 123.5 (s), 122.6 (s). HRMS-ESI (m/z): Calculated for $C_{24}H_{15}S_3$: $[M - BF_4]^+$ 399.0330; Found, 399.0326. IR: 3087, 2322, 2157, 1986, 1904, 1568, 1430, 1289, 1230, 1048, 911, 874, 808, 759, 727 cm^{-1}.

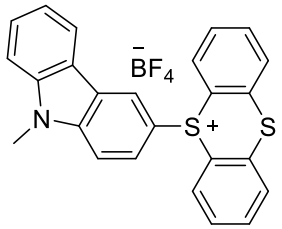
Carbazole derived thianthrenium salt **2o**



Following the general procedure A afforded the product as a white solid (572 mg, 61% yield, 2 mmol); Chromatography column, DCM /MeOH = 10:1.
^{1}H NMR (600 MHz, DMSO-d_6) δ 11.97 (s, 1H), 8.44 (d, *J* = 7.9 Hz, 2H), 8.37 (d, *J* = 1.9 Hz, 1H), 8.13 (d, *J* = 7.9 Hz, 1H), 8.07 (d, *J* = 7.9 Hz, 2H), 7.90 (td, *J* = 7.8, 1.1 Hz,

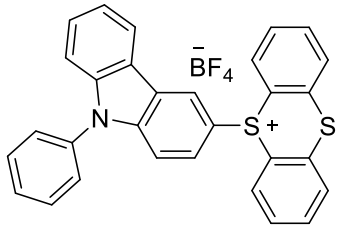
2H), 7.83 (t, *J* = 7.7 Hz, 2H), 7.70 (d, *J* = 8.8 Hz, 1H), 7.57 (d, *J* = 8.1 Hz, 1H), 7.50 (t, *J* = 7.6 Hz, 1H), 7.39 (dd, *J* = 8.8, 2.1 Hz, 1H), 7.25 (t, *J* = 7.5 Hz, 1H). ^{19}F NMR (565 MHz, DMSO-d_6) δ -148.15 (s, 1F), -148.21 (s, 3F). ^{13}C NMR (151 MHz, DMSO-d_6) δ 141.8 (s), 140.5 (s), 134.6 (s), 134.3 (s), 134.1 (s), 130.2 (s), 129.8 (s), 127.5 (s), 125.4 (s), 123.6 (s), 122.6 (s), 121.2 (s), 121.1 (s), 120.9 (s), 120.1 (s), 113.4 (s), 111.9 (s), 111.8 (s). HRMS-ESI (m/z): Calculated for $C_{24}H_{16}NS_2$: $[M - BF_4]^+$ 382.0719; Found, 382.0713. IR: 3356, 3085, 2164, 1603, 1570, 1496, 1329, 1286, 1251, 1069, 1005, 961, 808, 761, 709, 658 cm^{-1}.

9-Methylcarbazole derived thianthrenium salt **2p**



Following the general procedure A afforded the product as a pale green solid (653 mg, 67% yield, 2 mmol); Chromatography column, DCM /MeOH = 10:1.
^{1}H NMR (600 MHz, DMSO-d_6) δ 8.45 (dd, *J* = 8.0, 1.1 Hz, 2H), 8.36 (d, *J* = 2.1 Hz, 1H), 8.15 (d, *J* = 7.8 Hz, 1H), 8.07 (dd, *J* = 7.9, 1.0 Hz, 2H), 7.90 (td, *J* = 7.8, 1.3 Hz, 2H), 7.86 – 7.79 (m, 3H), 7.67 (d, *J* = 8.2 Hz, 1H), 7.57 (t, *J* = 7.3 Hz, 1H), 7.46 (dd, *J* = 8.9, 2.1 Hz, 1H), 7.29 (t, *J* = 7.5 Hz, 1H), 3.89 (s, 3H). ^{19}F NMR (565 MHz, DMSO-d_6) δ -148.14 (s, 1F), -148.19 (s, 3F). ^{13}C NMR (151 MHz, DMSO-d_6) δ 142.4 (s), 141.4 (s), 134.6 (s), 134.3 (s), 134.1 (s), 130.2 (s), 129.8 (s), 127.6 (s), 125.5 (s), 123.1 (s), 122.4 (s), 121.1 (s), 120.9 (s), 120.7 (s), 120.4 (s), 112.0 (s), 111.7 (s), 110.1 (s), 29.4 (s). HRMS-ESI (m/z): Calculated for $C_{25}H_{18}NS_2$: $[M - BF_4]^+$ 396.0875; Found, 396.0870. IR: 3635, 3078, 2329, 2014, 1737, 1585, 1502, 1458, 1429, 1323, 1288, 1254, 1155, 1049, 911, 888, 751, 700, 657 cm^{-1}.

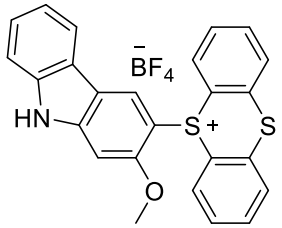
9-Phenylcarbazole derived thianthrenium salt **2q**



Following the general procedure A afforded the product as a pale green solid (795 mg, 82% yield, 2 mmol); Chromatography column, DCM /MeOH = 10:1.
^{1}H NMR (600 MHz, DMSO-d_6) δ 8.52 (d, *J* = 7.6 Hz, 2H), 8.47 (d, *J* = 1.7 Hz, 1H), 8.21 (d, *J* = 7.9 Hz, 1H), 8.01 (d, *J* = 7.6 Hz, 2H), 7.89 (t, *J* = 7.2 Hz, 2H), 7.84 (t, *J* = 7.4 Hz, 2H), 7.60 (t, *J* = 7.7 Hz, 2H), 7.52 (t, *J* = 7.4 Hz, 1H), 7.45 (d, *J* = 7.6 Hz, 2H), 7.43 – 7.40 (m, 1H), 7.39 (d, *J* = 9.0 Hz, 1H), 7.36 (dd, *J* = 9.0, 1.8 Hz, 1H), 7.30 (t, *J* = 7.5 Hz, 1H), 7.21 (d, *J* = 8.2 Hz, 1H). ^{19}F NMR (565 MHz, DMSO-d_6) δ -147.89 (s,

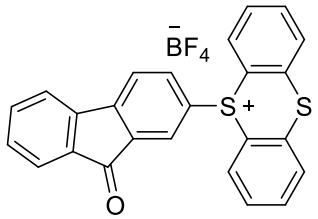
1F), -147.94 (s, 3F). ^{13}C NMR (151 MHz, DMSO-d_6) δ 142.0 (s), 141.0 (s), 135.4 (s), 134.8 (s), 134.5 (s), 134.4 (s), 130.3 (s), 130.2 (s), 129.9 (s), 128.6 (s), 128.0 (s), 126.7 (s), 125.8 (s), 124.0 (s), 122.5 (s), 121.4 (s), 121.3 (s), 120.4 (s), 113.9 (s), 111.9 (s), 110.2 (s). HRMS-ESI (m/z): Calculated for $C_{30}H_{20}NS_2$: $[M - BF_4]^+$ 458.1032; Found, 458.1022. IR: 3948, 3628, 3069, 2806, 2167, 1833, 1590, 1499, 1449, 1284, 1237, 1172, 1048, 801, 754, 698, 661 cm^{-1}.

2-Methoxycarbazole derived thianthrenium salt **2r**



Following the general procedure A afforded the product as a yellow solid (437 mg, 44% yield, 2 mmol); Chromatography column, DCM /MeOH = 10:1.
^{1}H NMR (600 MHz, DMSO-d_6) δ 11.82 (s, 1H), 8.32 (d, *J* = 8.0 Hz, 2H), 8.06 (d, *J* = 7.9 Hz, 2H), 7.94 (d, *J* = 7.8 Hz, 1H), 7.88 (t, *J* = 7.7 Hz, 2H), 7.80 (t, *J* = 7.7 Hz, 2H), 7.60 (s, 1H), 7.51 (d, *J* = 8.1 Hz, 1H), 7.40 (t, *J* = 7.6 Hz, 1H), 7.32 (s, 1H), 7.17 (t, *J* = 7.5 Hz, 1H), 4.02 (s, 3H). ^{19}F NMR (565 MHz, DMSO-d_6) δ -148.18 (s, 1F), -148.24 (s, 3F). ^{13}C NMR (151 MHz, DMSO-d_6) δ 156.1 (s), 144.2 (s), 140.2 (s), 135.6 (s), 134.1 (s), 134.1 (s), 130.3 (s), 129.5 (s), 126.2 (s), 122.6 (s), 121.5 (s), 120.1 (s), 120.1 (s), 119.2 (s), 116.9 (s), 111.5 (s), 98.9 (s), 95.9 (s), 57.1 (s). HRMS-ESI (m/z): Calculated for $C_{25}H_{18}ONS_2$: $[M - BF_4]^+$ 412.0824; Found, 412.0812. IR: 3746, 3394, 3086, 2165, 1831, 1605, 1572, 1447, 1379, 1320, 1252, 1172, 1055, 959, 870, 845, 763 cm^{-1}.

9-Fluorenone derived thianthrenium salt **2t**

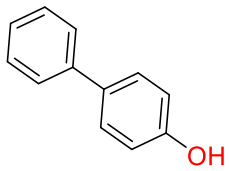


Following the general procedure A afforded the product as a yellow solid (795 mg, 82% yield, 2 mmol); Chromatography column, DCM /MeOH = 10:1.
^{1}H NMR (400 MHz, DMSO-d_6) δ 8.64 (d, *J* = 7.7 Hz, 2H), 8.10 (d, *J* = 7.8 Hz, 2H), 8.00 – 7.83 (m, 6H), 7.66 (dd, *J* = 13.0, 7.6 Hz, 2H), 7.46 (t, *J* = 7.5 Hz, 1H), 7.41 (dd, *J* = 8.1, 1.8 Hz, 1H), 7.35 (s, 1H). ^{19}F NMR (376 MHz, DMSO-d_6) δ -148.23 (s, 1F), -148.29 (s, 3F). ^{13}C NMR (101 MHz, DMSO-d_6) δ 190.7 (s), 147.3 (s), 142.0 (s), 136.0 (s), 135.9 (s), 135.4 (s), 134.9 (s), 134.3 (s), 133.3 (s), 131.1 (s), 130.3 (s), 129.7 (s), 125.8 (s), 124.6 (s), 123.1 (s), 122.7 (s), 122.5 (s), 119.4 (s). HRMS-ESI (m/z): Calculated for $C_{25}H_{15}OS_2$: $[M - BF_4]^+$ 395.0559; Found, 395.0554. IR: 3585, 3094, 2925, 2322, 1873, 1718, 1600, 1567, 1446, 1287, 1267, 1190, 1156, 1025, 961, 938,

834, 748, 705, 662 cm^{-1}.

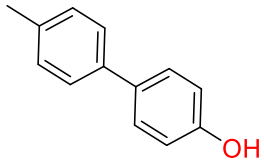
3.2 Characterization for hydroxylation of simple arenes

4-Phenylphenol **3a**



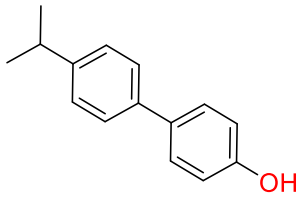
Following the general procedure B afforded the product as a pale yellow solid (56 mg, 82% yield); Chromatography column, pentane / EA = 5:1.
Scale-up experiment: 4mmol scale: Under N_2 atmosphere, a 50 mL flat-bottom quartz vial equipped with a magnetic stir bar was charged with aryl thianthrenium salts **2a** (4 mmol, 1.0 equiv.), 4-Oxo-TEMPO (32 mmol, 8 equiv.) and DMF (10 mL). The tube was sealed, and the mixture was stirred at room temperature under UV-light (254 nm, 144 W) for 24 h before quenching with aqueous saturated $NaHCO_3$ and dilution with EtOAc. The organic layer was washed with brine, dried using Na_2SO_4, filtered, and concentrated *in vacuo*, to give the crude product **4a**, which was purified by column chromatography on silica gel. pentane / EA = 5:1. (446 mg, 66% yield)
^{1}H NMR (600 MHz, $CDCl_3$) δ 7.55 (d, *J* = 7.4 Hz, 2H), 7.49 (d, *J* = 8.5 Hz, 2H), 7.42 (t, *J* = 7.7 Hz, 2H), 7.31 (t, *J* = 7.4 Hz, 1H), 6.91 (d, *J* = 8.5 Hz, 2H), 4.88 (s, 1H). ^{13}C NMR (151 MHz, $CDCl_3$) δ 155.2 (s), 140.9 (s), 134.2 (s), 128.9 (s), 128.5 (s), 126.9 (s), 126.8 (s), 115.8 (s). The characterization of this compound is in accordance with the literature.[4]

4'-methyl-[1,1'-biphenyl]-4-ol **3b**



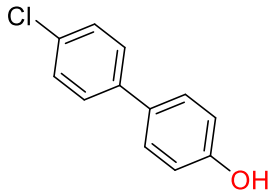
Following the general procedure B afforded the product as a yellow solid (73 mg, 82% yield); Chromatography column, pentane / EA = 4:1.
^{1}H NMR (600 MHz, $CDCl_3$) δ 7.47 (d, *J* = 8.5 Hz, 2H), 7.45 (d, *J* = 8.0 Hz, 2H), 7.24 (d, *J* = 7.9 Hz, 2H), 6.90 (d, *J* = 8.5 Hz, 2H), 4.99 (s, 1H), 2.40 (s, 3H). ^{13}C NMR (151 MHz, $CDCl_3$) δ 155.0 (s), 138.0 (s), 136.5 (s), 134.1 (s), 129.6 (s), 128.3 (s), 126.7 (s), 115.7 (s), 21.2 (s). The characterization of this compound is in accordance with the literature.[5]

4'-isopropyl-[1,1'-biphenyl]-4-ol **3c**



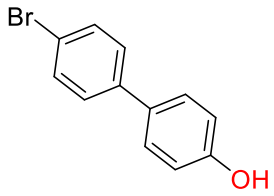
Following the general procedure B afforded the product as a yellow solid (60 mg, 71% yield); Chromatography column, pentane / EA = 4:1.
^{1}H NMR (600 MHz, $CDCl_3$) δ 7.48 (d, *J* = 3.9 Hz, 2H), 7.47 (d, *J* = 4.2 Hz, 2H), 7.29 (d, *J* = 8.1 Hz, 2H), 6.90 (d, *J* = 8.5 Hz, 2H), 4.92 (s, 1H), 2.95 (hept, *J* = 6.9 Hz, 1H), 1.30 (d, *J* = 6.9 Hz, 6H). ^{13}C NMR (151 MHz, $CDCl_3$) δ 155.0 (s), 147.6 (s), 138.4 (s), 134.2 (s), 128.4 (s), 126.9 (s), 126.8 (s), 115.7 (s), 33.9 (s), 24.2 (s). HRMS-APCI (m/z): Calculated for $C_{15}H_{16}O$: [M] 212.1196; Found, 212.1202. IR: 3376, 2962, 2872, 1716, 1609, 1497, 1447, 1367, 1226, 1173, 1108, 1024, 819, 921, 753, 720, 685 cm^{-1}.

4'-chloro-[1,1'-biphenyl]-4-ol **3d**



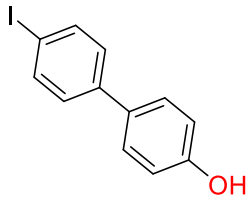
Following the general procedure B afforded the product as a yellow solid (51 mg, 62% yield); Chromatography column, pentane / EA = 4:1.
^{1}H NMR (600 MHz, $CDCl_3$) δ 7.46 (d, *J* = 8.4 Hz, 4H), 7.38 (d, *J* = 8.2 Hz, 2H), 6.92 (s, 2H). ^{13}C NMR (151 MHz, $CDCl_3$) δ 155.3 (s), 139.3 (s), 132.8 (s), 132.8 (s), 128.9 (s), 128.4 (s), 128.0 (s), 116.2 (s). The characterization of this compound is in accordance with the literature.[6]

4'-bromo-[1,1'-biphenyl]-4-ol **3e**



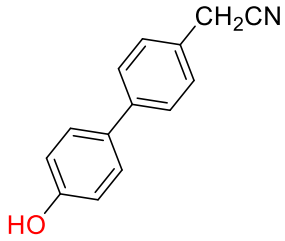
Following the general procedure B afforded the product as a yellow solid (58 mg, 58% yield); Chromatography column, pentane / EA = 5:1.
^{1}H NMR (600 MHz, $CDCl_3$) δ 7.53 (d, *J* = 8.5 Hz, 2H), 7.44 (d, *J* = 8.5 Hz, 2H), 7.40 (d, *J* = 8.5 Hz, 2H), 6.91 (d, *J* = 8.5 Hz, 2H), 5.02 (s, 1H). ^{13}C NMR (151 MHz, $CDCl_3$) δ 155.5 (s), 139.8 (s), 132.9 (s), 131.9 (s), 128.4 (s), 128.4 (s), 121.0 (s), 115.9 (s). The characterization of this compound is in accordance with the literature.[7]

4'-iodo-[1,1'-biphenyl]-4-ol **3f**



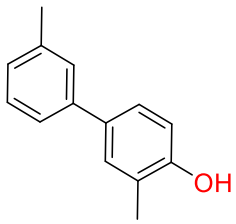
Following the general procedure B afforded the product as a white solid (28 mg, 24% yield); Chromatography column, pentane / EA = 4:1.
^{1}H NMR (600 MHz, $CDCl_3$) δ 7.73 (d, *J* = 8.5 Hz, 2H), 7.43 (d, *J* = 8.6 Hz, 2H), 7.27 (d, *J* = 8.5 Hz, 2H), 6.90 (d, *J* = 8.6 Hz, 2H), 4.88 (s, 1H). ^{13}C NMR (151 MHz, $CDCl_3$) δ 137.8 (s), 128.6 (s), 128.2 (s), 115.8 (s). The characterization of this compound is in accordance with the literature.[8]

2-(4'-hydroxy-[1,1'-biphenyl]-4-yl) acetonitrile **3g**



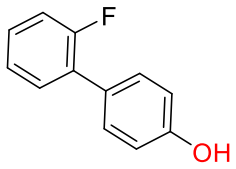
Following the general procedure B afforded the product as a pale yellow solid (54 mg, 64% yield); Chromatography column, pentane / EA = 2:1.
^{1}H NMR (600 MHz, CD_3OD) δ 7.56 (d, *J* = 8.2 Hz, 2H), 7.45 (d, *J* = 8.6 Hz, 2H), 7.37 (d, *J* = 8.2 Hz, 2H), 6.86 (d, *J* = 8.6 Hz, 2H), 3.89 (s, 2H). ^{13}C NMR (151 MHz, CD_3OD) δ 158.4 (s), 142.1 (s), 132.9 (s), 130.2 (s), 129.4 (s), 129.0 (s), 128.0 (s), 119.7 (s), 116.7 (s), 23.1 (s). The characterization of this compound is in accordance with the literature.[9]

3,3'-dimethyl-[1,1'-biphenyl]-4-ol **3h**



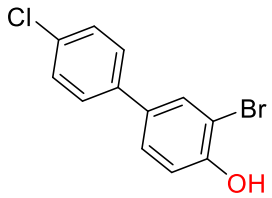
Following the general procedure B afforded the product as a pale yellow solid (41 mg, 52% yield); Chromatography column, pentane / EA = 5:1.
^{1}H NMR (600 MHz, $CDCl_3$) δ 7.38 (s, 2H), 7.37 (d, *J* = 8.0 Hz, 1H), 7.32 (t, *J* = 7.6 Hz, 2H), 7.14 (d, *J* = 7.3 Hz, 1H), 6.85 (d, *J* = 8.2 Hz, 1H), 4.89 (s, 1H), 2.43 (s, 3H), 2.34 (s, 3H). ^{13}C NMR (151 MHz, $CDCl_3$) δ 153.4 (s), 141.1 (s), 134.2 (s), 123.0 (s), 128.7 (s), 127.7 (s), 127.5 (s), 125.9 (s), 124.1 (s), 124.0 (s), 115.3 (s), 21.7 (s), 16.0 (s). HRMS-APCI (m/z): Calculated for $C_{14}H_{15}O$: $[M + H]^+$ 199.1039; Found, 199.1112. IR: 3891, 3410, 3027, 2921, 2859, 2335, 1873, 1606, 1509, 1480, 1387, 1305, 1239, 1183, 1116, 881, 820, 738, 698 cm^{-1}.

2'-fluoro-[1,1'-biphenyl]-4-ol **3i**



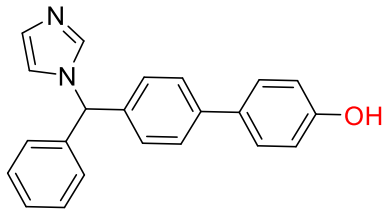
Following the general procedure B afforded the product as a yellow solid (55 mg, 73% yield); Chromatography column, pentane / EA = 5:1.
^{1}H NMR (600 MHz, $CDCl_3$) δ 7.45 (d, *J* = 7.8 Hz, 2H), 7.40 (t, *J* = 7.6 Hz, 1H), 7.28 (d, *J* = 6.0 Hz, 1H), 7.19 (t, *J* = 7.4 Hz, 1H), 7.16 – 7.10 (m, 1H), 6.92 (d, *J* = 8.2 Hz, 2H), 4.95 (s, 1H). ^{19}F NMR (565 MHz, $CDCl_3$) δ -118.25 (s, 1F). ^{13}C NMR (151 MHz, $CDCl_3$) δ 159.9 (d, *J* = 247.0 Hz), 155.3 (s), 130.6 (d, *J* = 3.5 Hz), 130.5 (d, *J* = 3.2 Hz), 128.8 (d, *J* = 13.3 Hz), 128.6 (d, *J* = 8.5 Hz), 124.4 (d, *J* = 3.6 Hz), 116.19 (d, *J* = 22.6 Hz), 115.5 (s). (At least one line overlapped). HRMS-APCI (m/z): Calculated for $C_{12}H_9OF$: [M] 188.0632; Found, 188.0634. IR: 3425, 2925, 1709, 1606, 1517, 1478, 1448, 1363, 1228, 1102, 1035, 1007, 942, 820, 753 cm^{-1}.

3-bromo-4'-chloro-[1,1'-biphenyl]-4-ol **3j**



Following the general procedure B afforded the product as a yellow solid (58 mg, 51% yield); Chromatography column, pentane / EA = 4:1.
^{1}H NMR (600 MHz, $CDCl_3$) δ 7.66 (d, *J* = 2.0 Hz, 1H), 7.43 (d, *J* = 8.5 Hz, 2H), 7.41 (dd, *J* = 8.5, 2.0 Hz, 1H), 7.38 (d, *J* = 8.5 Hz, 2H), 7.09 (d, *J* = 8.4 Hz, 1H), 5.56 (s, 1H). ^{13}C NMR (151 MHz, $CDCl_3$) δ 152.1 (s), 138.0 (s), 134.3 (s), 133.5 (s), 130.5 (s), 129.1 (s), 128.1 (s), 127.9 (s), 116.6 (s), 110.9 (s). HRMS-APCI (m/z): Calculated for $C_{12}H_8OBrCl$: [M] 283.9419; Found, 283.9413. IR: 3394, 3060, 2974, 1898, 1703, 1600, 1477, 1384, 1282, 1183, 1093, 1012, 956, 884, 815, 751, 680 cm^{-1}.

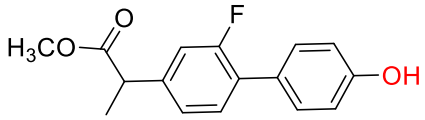
4'-((1H-imidazol-1-yl) (phenyl)methyl)-[1,1'-biphenyl]-4-ol **3k**



Following the general procedure B afforded the product as a white solid (81 mg, 62% yield); Chromatography column, DCM / EA = 1:1.
^{1}H NMR (600 MHz, DMSO-d_6) δ 9.59 (s, 1H), 7.67 (s, 1H), 7.59 (d, *J* = 8.3 Hz, 2H), 7.49 (d, *J* = 8.6 Hz, 2H), 7.40 (t, *J* = 7.4 Hz, 2H), 7.35 (t, *J* = 7.3 Hz, 1H), 7.17 (t, *J* = 7.3 Hz, 4H), 7.13 (s, 1H), 6.97 (s, 1H), 6.88 (s, 1H), 6.84 (d, *J* = 8.6 Hz, 2H). ^{13}C NMR (151 MHz, DMSO-d_6) δ 157.3 (s), 140.0 (s), 139.8 (s), 137.9 (s), 137.2 (s), 130.2 (s),

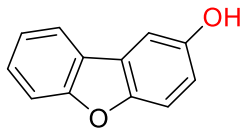
128.7 (s), 128.7 (s), 128.3 (s), 128.0 (s), 127.8 (s), 127.8 (s), 126.2 (s), 119.2 (s), 115.8 (s), 63.1 (s). HRMS-ESI (m/z): Calculated for $C_{22}H_{19}ON_2$: $[M + H]^+$ 327.1492; Found, 327.1491. IR: 3116, 3029, 2934, 2815, 2676, 2606, 2159, 1661, 1605, 1495, 1452, 1387, 1269, 1231, 1173, 1107, 1078, 1025, 921, 826, 795, 736, 702, 660 cm^{-1}.

Methyl 2-(2-fluoro-4'-hydroxy-[1,1'-biphenyl]-4-yl) propanoate **3l**



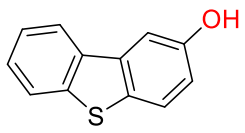
Following the general procedure B afforded the product as a white solid (61 mg, 56% yield); Chromatography column, pentane / EA = 4:1.
^1H NMR (600 MHz, $CDCl_3$) δ 7.40 (d, *J* = 7.6 Hz, 2H), 7.34 (t, *J* = 8.0 Hz, 1H), 7.11 (t, *J* = 10.1 Hz, 2H), 6.88 (d, *J* = 8.4 Hz, 2H), 3.77 (q, *J* = 7.2 Hz, 1H), 3.72 (s, 3H), 1.54 (d, *J* = 7.2 Hz, 3H). ^{19}F NMR (565 MHz, $CDCl_3$) δ -117.67 (s, 1F). ^{13}C NMR (151 MHz, $CDCl_3$) δ 175.1 (s), 159.7 (d, *J* = 247.9 Hz), 155.6 (s), 141.1 (d, *J* = 7.7 Hz), 130.6 (d, *J* = 3.7 Hz), 130.3 (d, *J* = 3.2 Hz), 127.9 (s), 127.6 (d, *J* = 13.7 Hz), 123.6 (d, *J* = 2.6 Hz), 115.6 (s), 115.3 (d, *J* = 23.9 Hz), 52.5 (s), 45.0 (s), 18.4 (s). HRMS-APCI (m/z): Calculated for $C_{16}H_{16}OF$: $[M + H]^+$ 275.1078; Found, 275.1076. IR: 3756, 3366, 2963, 1706, 1611, 1525, 1493, 1433, 1334, 1274, 1210, 1170, 1073, 1009, 968, 918, 871, 825, 786, 715 cm^{-1}.

dibenzo[b,d]furan-2-ol **3m**



Following the general procedure B afforded the product as a white solid (53 mg, 72% yield); Chromatography column, pure DCM.
^1H NMR (600 MHz, $CDCl_3$) δ 7.88 (d, *J* = 7.6 Hz, 1H), 7.54 (d, *J* = 8.2 Hz, 1H), 7.44 (dd, *J* = 15.5, 8.1 Hz, 2H), 7.38 (s, 1H), 7.32 (t, *J* = 7.4 Hz, 1H), 6.96 (d, *J* = 10.1 Hz, 1H), 4.86 (s, 1H). ^{13}C NMR (151 MHz, $CDCl_3$) δ 157.1 (s), 151.6 (s), 151.1 (s), 127.4 (s), 125.2 (s), 124.3 (s), 122.6 (s), 120.8 (s), 115.4 (s), 112.2 (s), 111.9 (s), 106.4 (s). The characterization of this compound is in accordance with the literature.[10]

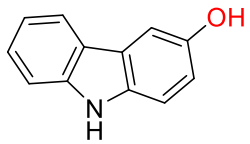
dibenzo[b,d]thiophen-2-ol **3n**



Following the general procedure B afforded the product as a white solid (51 mg, 64% yield); Chromatography column, pentane / EA = 4:1.
^1H NMR (600 MHz, $CDCl_3$) δ 8.05 (dd, *J* = 6.7, 2.0 Hz, 1H), 7.83 (dd, *J* = 6.8, 1.8 Hz, 1H), 7.69 (d, *J* = 8.5 Hz, 1H), 7.59 (d, *J* = 2.4 Hz, 1H), 7.48 – 7.37 (m, 2H), 7.02 (dd, *J* = 8.5, 2.4 Hz, 1H), 5.02 (s, 1H). ^{13}C NMR (151 MHz, $CDCl_3$) δ 153.5 (s), 140.8 (s),

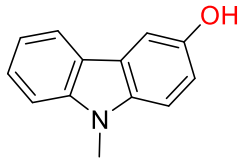
137.0 (s), 135.3 (s), 131.6 (s), 127.0 (s), 124.3 (s), 123.7 (s), 123.1 (s), 121.8 (s), 116.1 (s), 107.7 (s). HRMS-APCI (m/z): Calculated for $C_{12}H_8OS$: [M] 200.0290; Found, 200.0285. IR: 3797, 3485, 3388, 3282, 2923, 2854, 1708, 1602, 1466, 1427, 1330, 1183, 1068, 1020, 892, 850, 807, 756, 725, 658 cm^{-1}.

9H-carbazol-3-ol **3o**



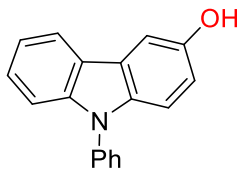
Following the general procedure B afforded the product as a white solid (48 mg, 66% yield); Chromatography column, pentane / EA = 2:1.
^{1}H NMR (600 MHz, DMSO-d_6) δ 10.86 (s, 1H), 8.89 (s, 1H), 7.97 (d, *J* = 7.7 Hz, 1H), 7.41 (d, *J* = 2.2 Hz, 1H), 7.39 (d, *J* = 8.1 Hz, 1H), 7.33 – 7.29 (m, 1H), 7.27 (d, *J* = 8.6 Hz, 1H), 7.06 (t, *J* = 7.8 Hz, 1H), 6.88 (dd, *J* = 8.6, 2.3 Hz, 1H). ^{13}C NMR (151 MHz, DMSO-d_6) δ 150.4 (s), 140.4 (s), 133.7 (s), 125.2 (s), 123.0 (s), 122.3 (s), 120.1 (s), 117.7 (s), 115.0 (s), 111.3 (s), 110.8 (s), 104.8 (s). The characterization of this compound is in accordance with the literature.[11]

9-methyl-9H-carbazol-3-ol **3p**



Following the general procedure B afforded the product as a yellow solid (47 mg, 60% yield); Chromatography column, pentane / EA = 2:1.
^{1}H NMR (600 MHz, $CDCl_3$) δ 8.02 (d, *J* = 7.6 Hz, 1H), 7.58 (s, 1H), 7.49 (t, *J* = 7.5 Hz, 1H), 7.38 (d, *J* = 8.1 Hz, 1H), 7.29 (s, 1H), 7.21 (t, *J* = 7.2 Hz, 1H), 7.10 (s, 1H), 3.82 (s, 3H). ^{13}C NMR (151 MHz, $CDCl_3$) δ 148.0 (s), 141.0 (s), 135.7 (s), 125.2 (s), 122.9 (s), 121.8 (s), 119.8 (s), 117.7 (s), 115.4 (s), 108.6 (s), 107.9 (s), 106.8 (s), 28.6 (s). The characterization of this compound is in accordance with the literature.[12]

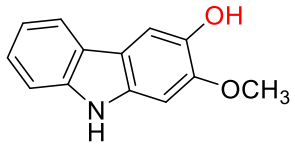
9-phenyl-9H-carbazol-3-ol **3q**



Following the general procedure B afforded the product as a yellow solid (61 mg, 59% yield); Chromatography column, pentane / EA = 2:1.
^{1}H NMR (600 MHz, DMSO-d_6) δ 9.17 (s, 1H), 8.12 (d, *J* = 7.6 Hz, 1H), 7.65 (t, *J* = 7.3 Hz, 2H), 7.58 (d, *J* = 7.6 Hz, 2H), 7.55 (s, 1H), 7.49 (t, *J* = 7.2 Hz, 1H), 7.42 – 7.31 (m, 2H), 7.21 (dd, *J* = 12.7, 7.6 Hz, 2H), 6.92 (d, *J* = 20.5 Hz, 1H). ^{13}C NMR (151 MHz, DMSO-d_6) δ 151.6 (s), 140.4 (s), 137.3 (s), 134.1 (s), 130.1 (s), 127.1 (s), 126.3 (s),

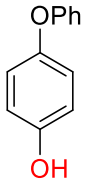
126.0 (s), 123.5 (s), 122.6 (s), 120.5 (s), 119.4 (s), 115.4 (s), 110.1 (s), 109.4 (s), 105.2 (s). HRMS-APCI (m/z): Calculated for $C_{18}H_{14}ON$: $[M + H]^+$ 260.1070; Found, 260.1073. IR: 3315, 2934, 2862, 1627, 1593, 1485, 1450, 1361, 1313, 1234, 1190, 1106, 1024, 931, 875, 803, 744, 696 cm^{-1}.

2-methoxy-9H-carbazol-3-ol **3r**



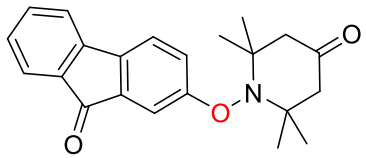
Following the general procedure B afforded the product as a yellow solid (29 mg, 34% yield); Chromatography column, pentane / EA = 2:1.
^1H NMR (600 MHz, DMSO-d_6) δ 10.80 (s, 1H), 8.43 (s, 1H), 7.87 (d, J = 7.7 Hz, 1H), 7.42 (s, 1H), 7.37 (d, J = 8.0 Hz, 1H), 7.22 (t, J = 7.5 Hz, 1H), 7.03 (t, J = 7.4 Hz, 1H), 6.97 (s, 1H), 3.86 (s, 3H). ^{13}C NMR (151 MHz, DMSO-d_6) δ 148.1 (s), 140.7 (s), 139.6 (s), 134.0 (s), 123.5 (s), 122.7 (s), 119.1 (s), 117.8 (s), 114.8 (s), 110.5 (s), 105.5 (s), 94.4 (s), 55.7 (s). HRMS-APCI (m/z): Calculated for $C_{13}H_{12}O_2N$: $[M + H]^+$ 214.0863; Found, 214.0870. IR: 3530, 3391, 2923, 2853, 1715, 1613, 1489, 1453, 1342, 1307, 1178, 1147, 1025, 921, 862, 820, 743, 692 cm^{-1}.

4-Phenoxyphenol **3s**



Following the general procedure B afforded the product as a brown solid (32 mg, 43% yield); Chromatography column, pentane / EA = 4:1.
^1H NMR (600 MHz, $CDCl_3$) δ 7.30 (dd, *J* = 8.5, 7.5 Hz, 2H), 7.05 (t, *J* = 7.4 Hz, 1H), 6.95 (t, *J* = 8.9 Hz, 4H), 6.82 (d, *J* = 8.9 Hz, 2H), 4.79 (s, 1H). ^{13}C NMR (151 MHz, $CDCl_3$) δ 158.4 (s), 151.5 (s), 150.2 (s), 129.6 (s), 122.4 (s), 121.0 (s), 117.5 (s), 117.0 (s). The characterization of this compound is in accordance with the literature.[13]

2,2,6,6-tetramethyl-1-((9-oxo-9H-fluoren-2-yl) oxy) piperidin-4-one **3t**

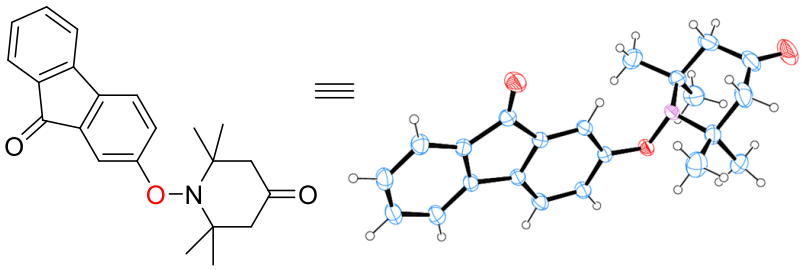


Following the general procedure B afforded the product as a yellow solid (52 mg, 37% yield); Chromatography column, pentane / EA = 4:1.
^1H NMR (600 MHz, $CDCl_3$) δ 7.69 (s, 1H), 7.63 (d, *J* = 7.3 Hz, 1H), 7.46 (td, *J* = 7.3, 1.0 Hz, 1H), 7.43 (d, *J* = 7.2 Hz, 1H), 7.41 (d, *J* = 8.2 Hz, 1H), 7.26 (s, 1H), 7.22 (td, *J* = 7.3, 1.2 Hz, 1H), 2.77 (d, *J* = 13.1 Hz, 2H), 2.39 (d, *J* = 13.1 Hz, 2H), 1.31 (s, 6H), 1.23 (s, 6H). ^{13}C NMR (151 MHz, $CDCl_3$) δ 207.1 (s), 194.1 (s), 164.3 (s), 145.0 (s),

137.4 (s), 135.8 (s), 135.0 (s), 134.5 (s), 128.0 (s), 124.4 (s), 121.1 (s), 119.6 (s), 119.3 (s), 110.7 (s), 63.9 (s), 53.3 (s), 31.9 (s), 23.1 (s). HRMS-ESI (m/z): Calculated for $C_{22}H_{23}O_3NNa$: $[M + Na]^+$ 372.1570; Found, 372.1569. IR: 3417, 3067, 2975, 2927, 2319, 1713, 1600, 1451, 1368, 1298, 1223, 1130, 1072, 947, 922, 886, 850, 761, 732, 671 cm^{-1}.

4. X-ray Experiment

Crystallization of compound **3t** ($C_{22}H_{23}N_1O_3$) from ethyl acetate/hexane at room temperature gave monoclinic crystals of space group P21/n (14) suitable for single crystal X-ray structure determination. Cell constants a = 8.2069(3), b = 26.8100(11), c = 8.7494(4) Å, $\alpha = \gamma = 90°$, β = 105.943(2), Z = 4, and a molecular weight of M_r = 349.41 result in a density of 1.254 gcm^{-3} and a linear absorption coefficient of μ = 0.083 mm^{-1} for MoK$_\alpha$ radiation (λ = 0.71073 Å). 29640 reflections covering the range $-11 \le h \le 10$, $-38 \le k \le 38$, and $-11 \le l \le 12$ (Θ_{max} = 30.7°) were collected (ϕ and ω scans) at 293 K on an Bruker APEX-II CCD diffractometer equipped with a graphite-monochomator and merged to give 5740 independent diffraction data (R_{int} = 0.0364) of which 3827 with $I > 2\sigma(I)$. The data set was corrected for absorption effects using the multi scan absorption correction method SADABS[14] (T_{min} = 0.6788, T_{max} = 0.761). The structure was solved by intrinsic phasing using the ShelXT 2018/2 structure solution program[15] and refined against F^2 on all data by full-matrix least-squares methods using ShelXL-2018/3[16] and ShelXle GUI.[17] 3827 reflexions were used in the final full-matrix least squares refinement including 239 parameters. All non-hydrogen atoms were refined anisotropically. The hydrogen atoms were placed at idealised positions and refined isotropically using the riding model. Refinement converged at $R1$ = 0.0507 for the observed data and w$R2$ = 0.1491 for all data ($w = 1/[\sigma^2(Fo^2)+(0.0672P)^2+0.3135P]$ where $P=(Fo^2+2Fc^2)/3$), a residual electron density of –0.198/+0.270 eÅ^{-3}, and a final goodness of fit of 1.026.



3t **CCDC 2118729**

Figure S2 X-ray for compound **3t**

5. References

(1) Berger, F.; Plutschack, M. B.; Riegger, J.; Yu, W.; Speicher, S.; Ho, M.; Frank, N.; Ritter, T. Site-selective and versatile aromatic C-H functionalization by thianthrenation. *Nature* **2019**, *567*, 223.

(2) Engl, P. S.; Häring, A. P.; Berger, F.; Berger, G.; Perez-Bitrian, A.; Ritter, T. C-N Cross-Couplings for Site-Selective Late-Stage Diversification via Aryl Sulfonium Salts. *J. Am. Chem. Soc.* **2019**, *141*, 13346.

(3) Zhao, Y.; Yu, C.; Liang, W.; Patureau, F. W. Photochemical (Hetero-) Arylation of Aryl Sulfonium Salts. *Org. Lett.* **2021**, *23*, 6232.

(4) See for example: (a) Imahori, T.; Tokuda, T.; Taguchi, T.; Takahata, H. An Alternative Approach to *para*-C–H Arylation of Phenol: Palladium-Catalyzed Tandem γ-Arylation/Aromatization of 2-Cyclohexen-1-one Derivatives. *Org. Lett.* **2012**, *14*, 1172; or: (b) Gao, H.; Zhou, Z.; Kwon, D.-H.; Coombs, J.; Jones, S.; Behnke, N. E.; Ess, D. H.; Kürti, L. Rapid heteroatom transfer to arylmetals utilizing multifunctional reagent scaffolds. *Nat. chem.* **2017**, *9*, 681.

(5) Gondo, K.; Oyamada, J.; Kitamura, T. Palladium-catalyzed desilylative acyloxylation of silicon–carbon bonds on (trimethylsilyl) arenes: synthesis of phenol derivatives from trimethylsilylarenes. *Org. Lett*. **2015**, 17, 4778.

(6) Chadwick, J.; Amewu, R. K.; Marti, F.; Garah, F. B.; Sharma, R.; Berry, N. G.; Stocks, P. A.; Burrell-Saward, H.; Wittlin, S.; Rottmann, M.; Brun, R.; Taramelli, D.; Parapini, S.; Ward, S. A.; O'Neill, P. M. Antimalarial Mannoxanes: Hybrid Antimalarial Drugs with Outstanding Oral Activity Profiles and A Potential Dual Mechanism of Action. *ChemMedChem* **2011**, *6*, 1357.

(7) Cui, J.; Liu, A.; Guan, Y.; Zheng, J.; Shen, Z.; Wan, X. Tuning the Helicity of Self-Assembled Structure of a Sugar-Based Organogelator by the Proper Choice of Cooling Rate. *Langmuir* **2010**, *26*, 3615.

(8) (a) Olshavsky, M. A.; Allcock, H. R. Polyphosphazenes with High Refractive Indices: Synthesis, Characterization, and Optical Properties. *Macromolecules* **1995**, *28*, 6188. (b) Kang, Q.-K.; Lin, Y.; Li, Y.; Xu, L.; Li, K.; Shi, H. Catalytic SNAr Hydroxylation and Alkoxylation of Aryl Fluorides. *Angew. Chem. Int. Ed.* **2021**, *60*, 20391.

(9) Ortar, G.; Morera, E.; De Petrocellis, L.; Ligresti, A.; Moriello, A. S.; Morera, L.; Nalli, M.; Ragno, R.; Pirolli, A.; Di Marzo, V. Biaryl tetrazolyl ureas as inhibitors of endocannabinoid metabolism: modulation at the N-portion and distal phenyl ring. *Eur. J. Med. Chem*. **2013**, *63*, 118.

(10) Purtsas, A.; Kataeva, O.; Knölker, H. J. Iron-Catalyzed Oxidative C− C Cross-Coupling Reaction of Tertiary Anilines with Hydroxyarenes by Using Air as Sole Oxidant. *Chem. Eur. J.* **2020**, 26, 2499.

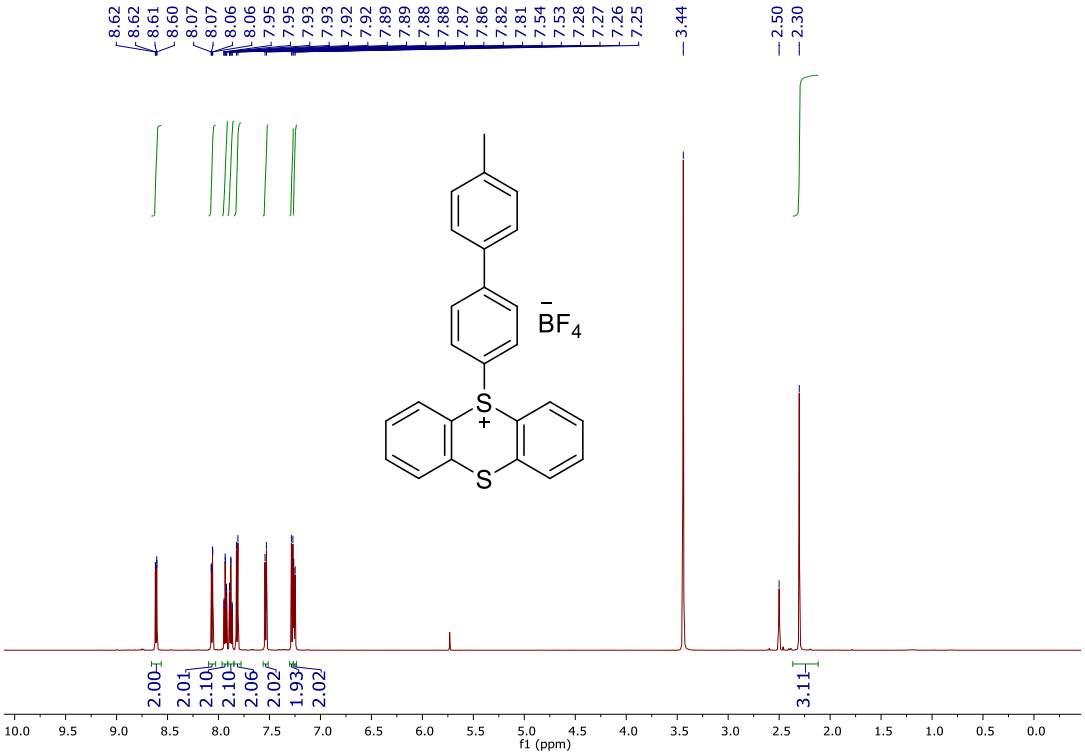
(11) Ku, S. K.; Lee, J. H.; Yuseok, O.; Lee, W.; Song, G. Y.; Bae, J. S. Vascular barrier protective effects of 3-N-or 3-O-cinnamoyl carbazole derivatives. *Bioorg. Med. Chem. Lett*. **2015**, *25*, 4304.

(12) Langendoen, A.; Plug, J. P. M.; Koomen, G. J.; Pandit, U. K. Regiospecific C-9

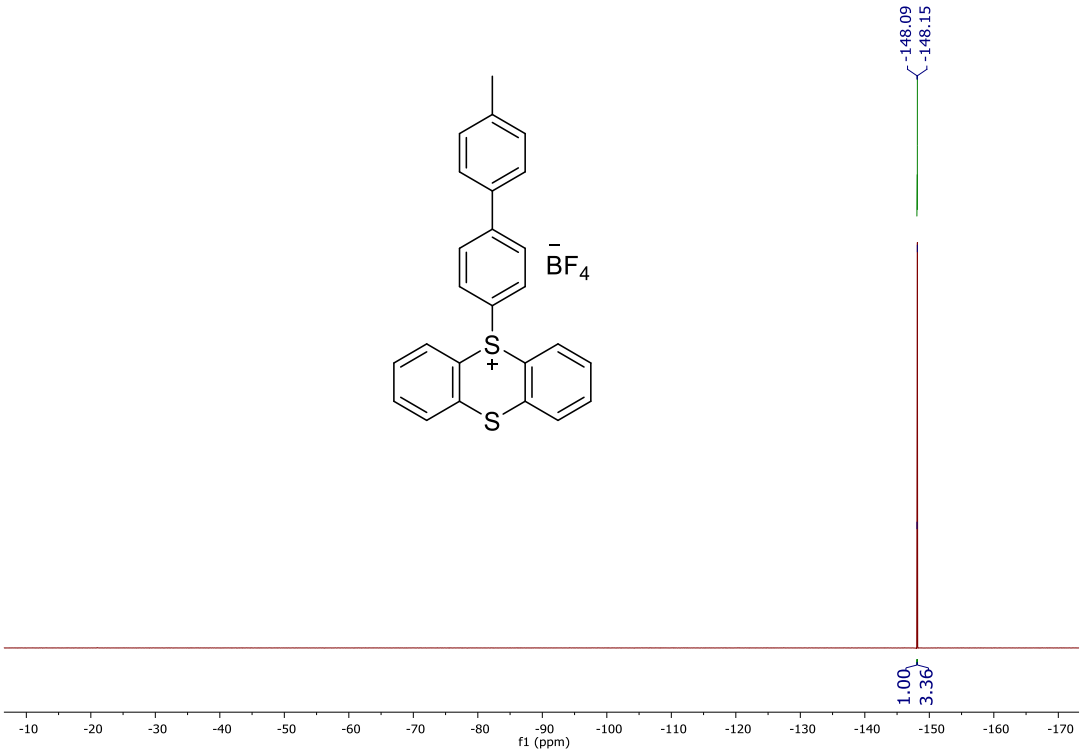
substitution of ellipticine derivatives. *Tetrahedron* **1989**, *45*, 1759.
(13) Song, Z. Q.; Wang, D. H. Palladium-catalyzed hydroxylation of aryl halides with boric acid. *Org. Lett.* **2020**, 22, 8470.
(14) a) SADABS-2016/2 - Bruker AXS area detector scaling and absorption correction. b) Krause, L.; Herbst-Irmer, R.; Sheldrick, G. M.; Stalke, D. Comparison of silver and molybdenum microfocus X-ray sources for single-crystal structure determination. *J. Appl. Cryst*. **2015**, 48, 3.
(15) Sheldrick, G. M. SHELXT - Integrated space-group and crystal-structure determination. *Acta Cryst.* **2015**, A71, 3-8.
(16) Sheldrick, G. M. Crystal Structure Refinement with SHELXL. *Acta Cryst*. **2015**, C71, 3-8.
(17) Hübschle, C. B.; Sheldrick, G. M.; Dittrich, B. ShelXle: a Qt graphical user interface for SHELXL. *J. Appl. Cryst.* **2011**, 44, 1281.

6. Copies of ^{1}H, ^{13}C and ^{19}F NMR Spectra

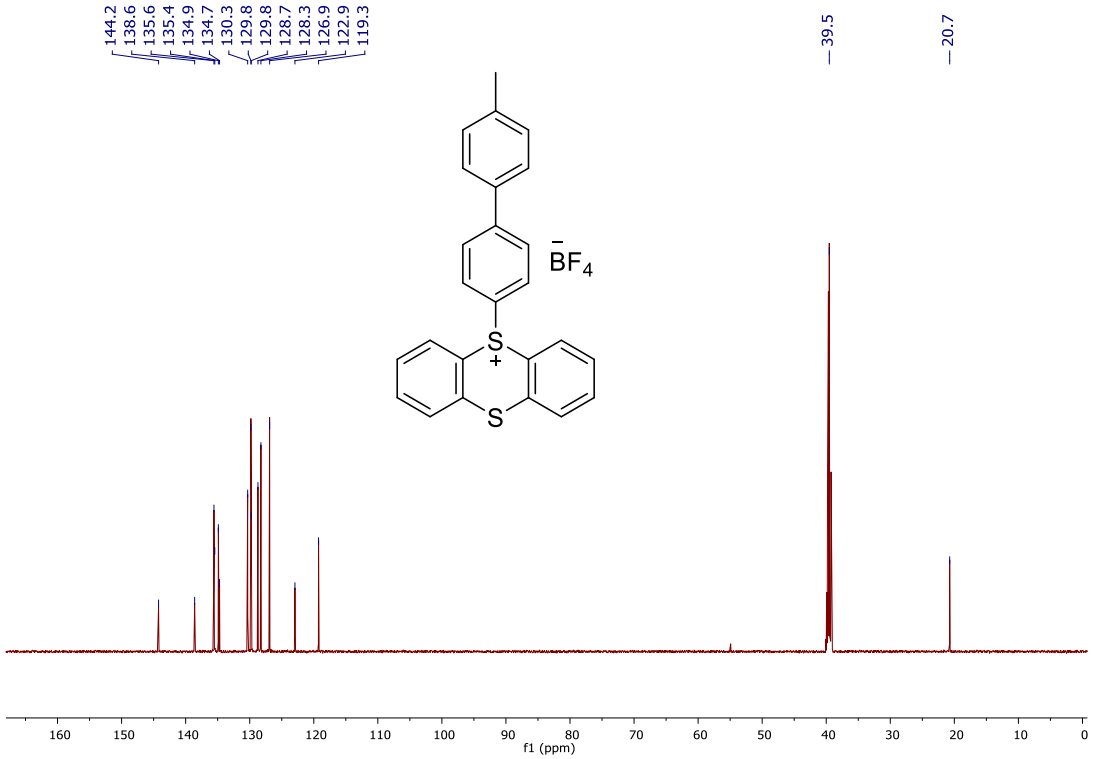
^{1}H NMR spectrum of **2b**



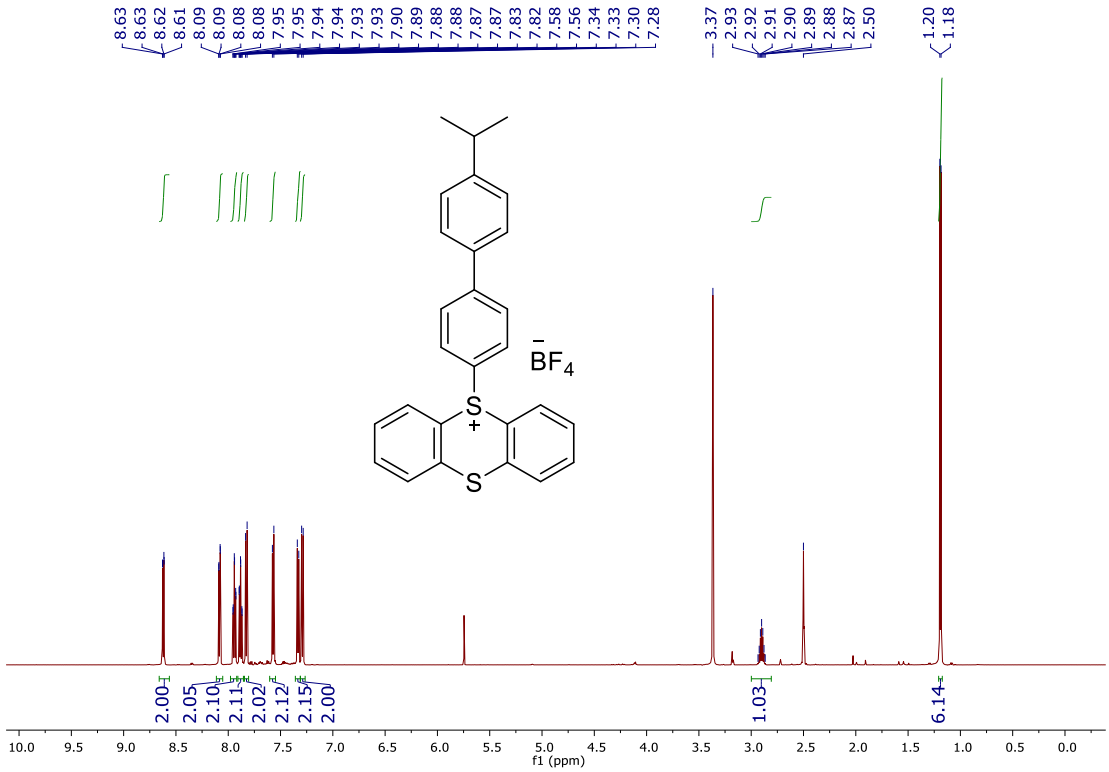
^{19}F NMR spectrum of **2b**



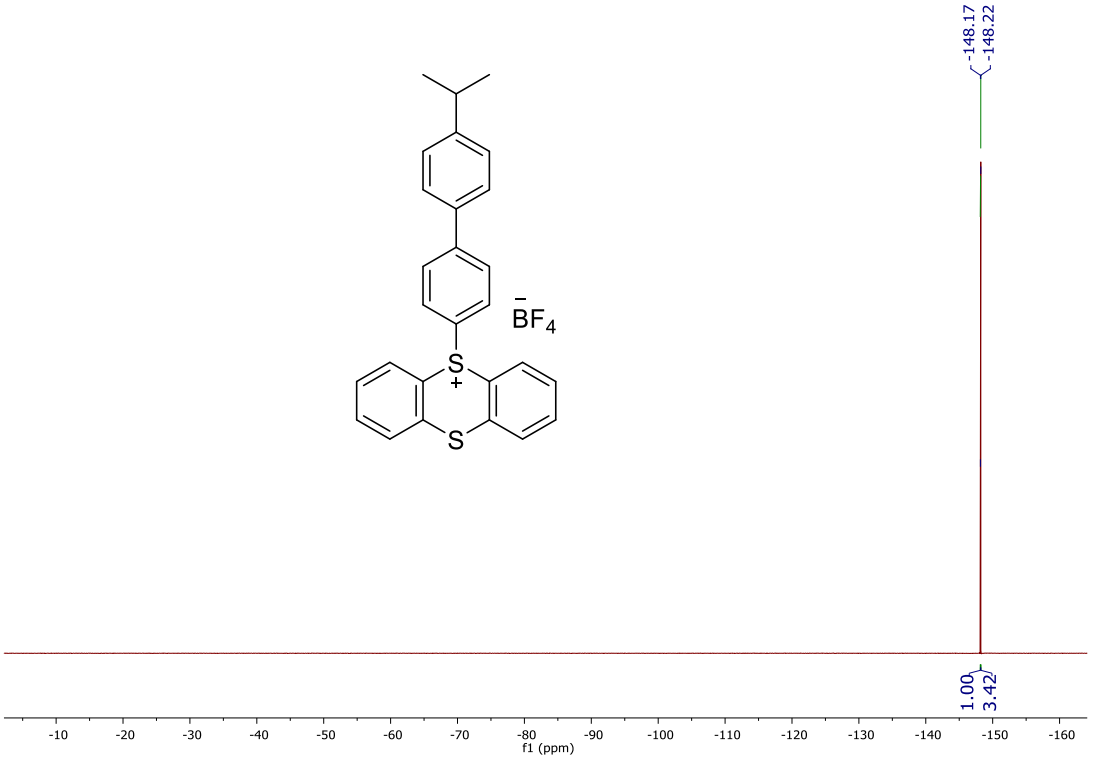
^{13}C NMR spectrum of **2b**



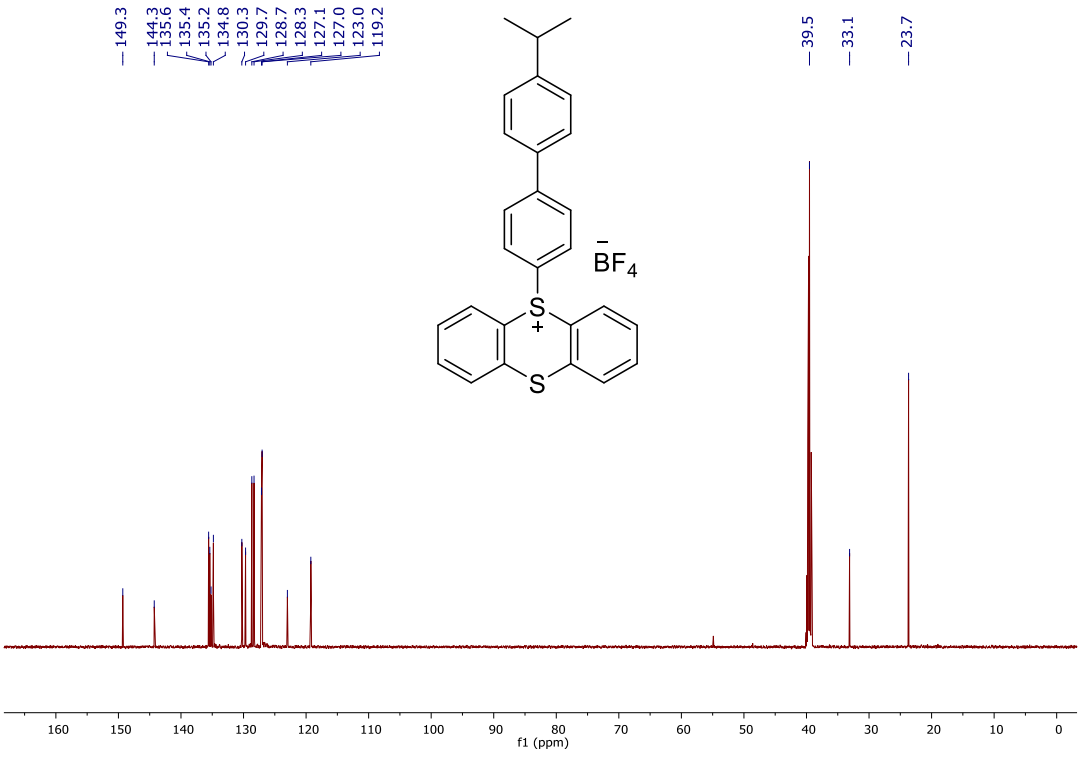
^{1}H NMR spectrum of **2c**



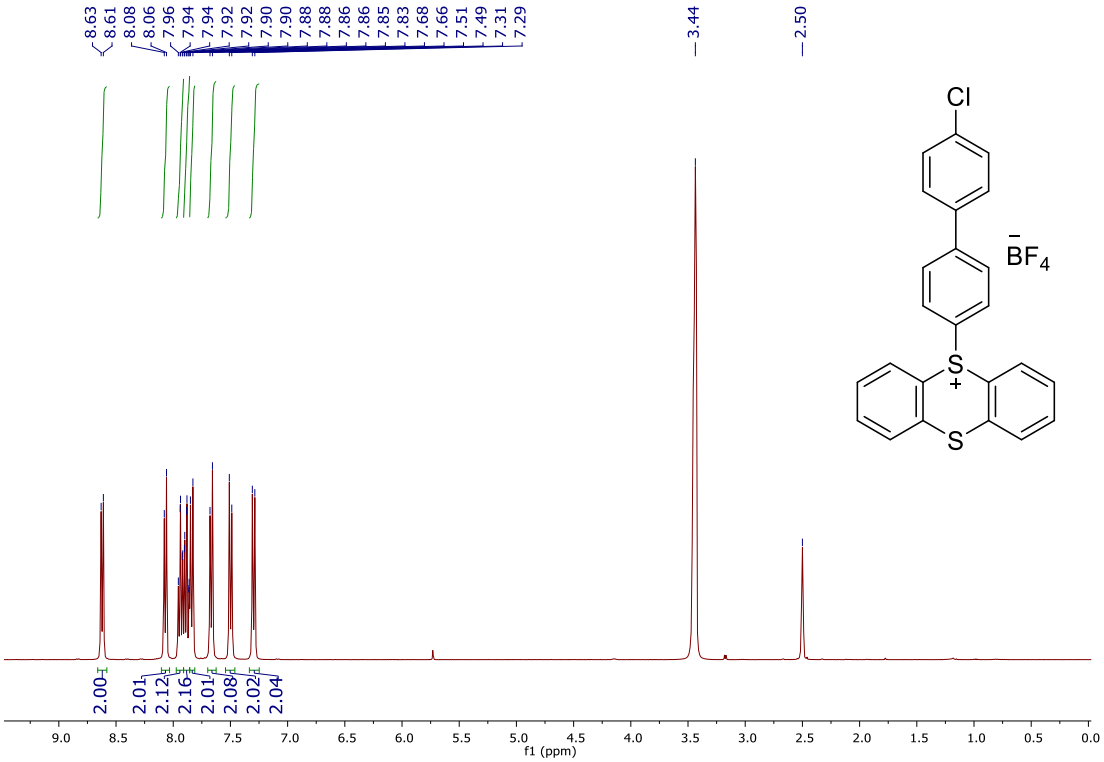
^{19}F NMR spectrum of **2c**



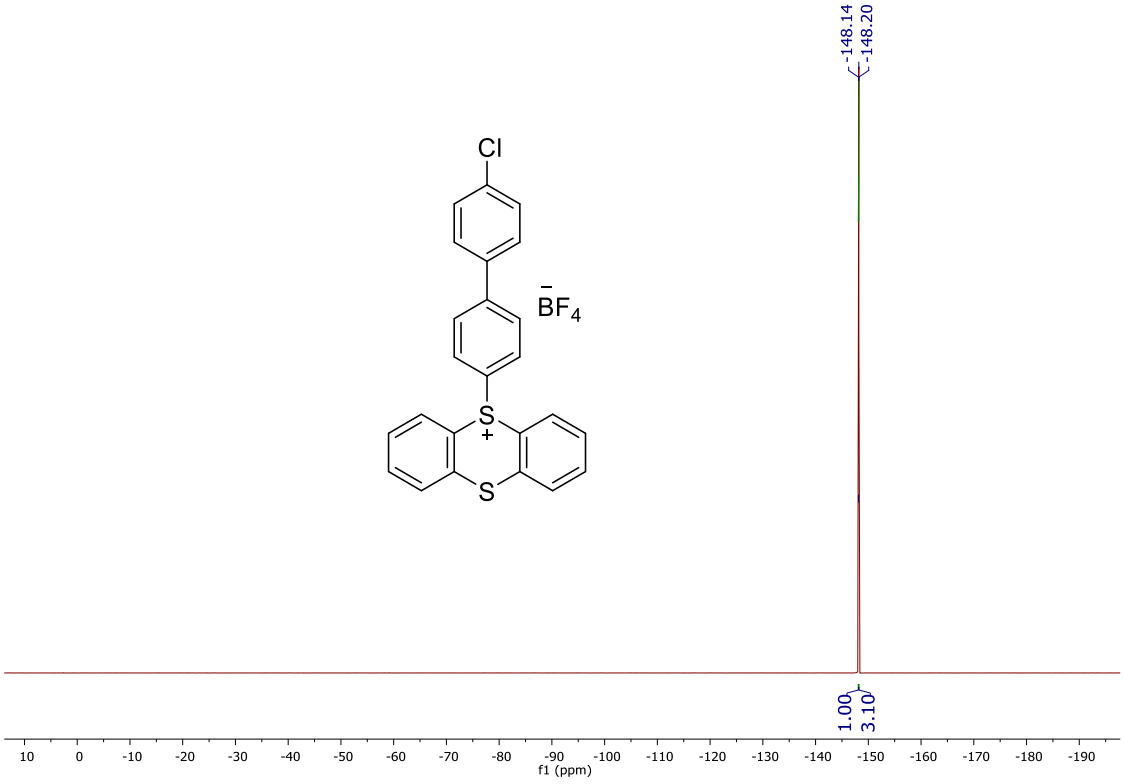
^{13}C NMR spectrum of **2c**



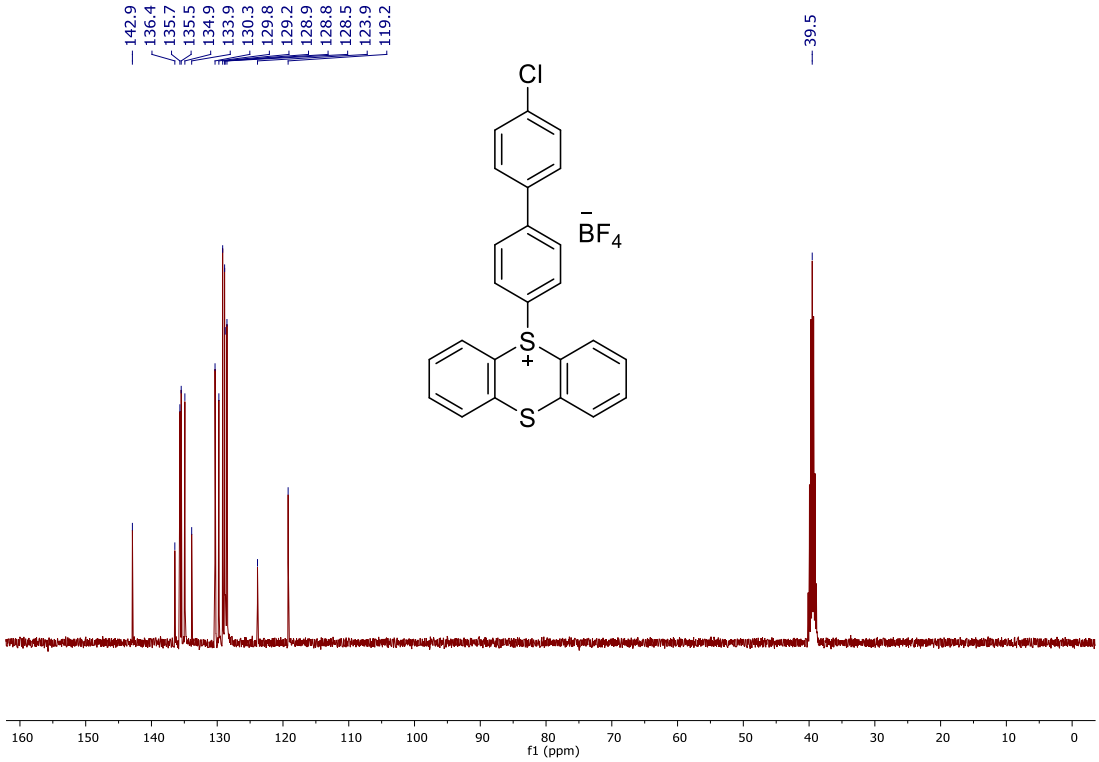
^{1}H NMR spectrum of **2d**



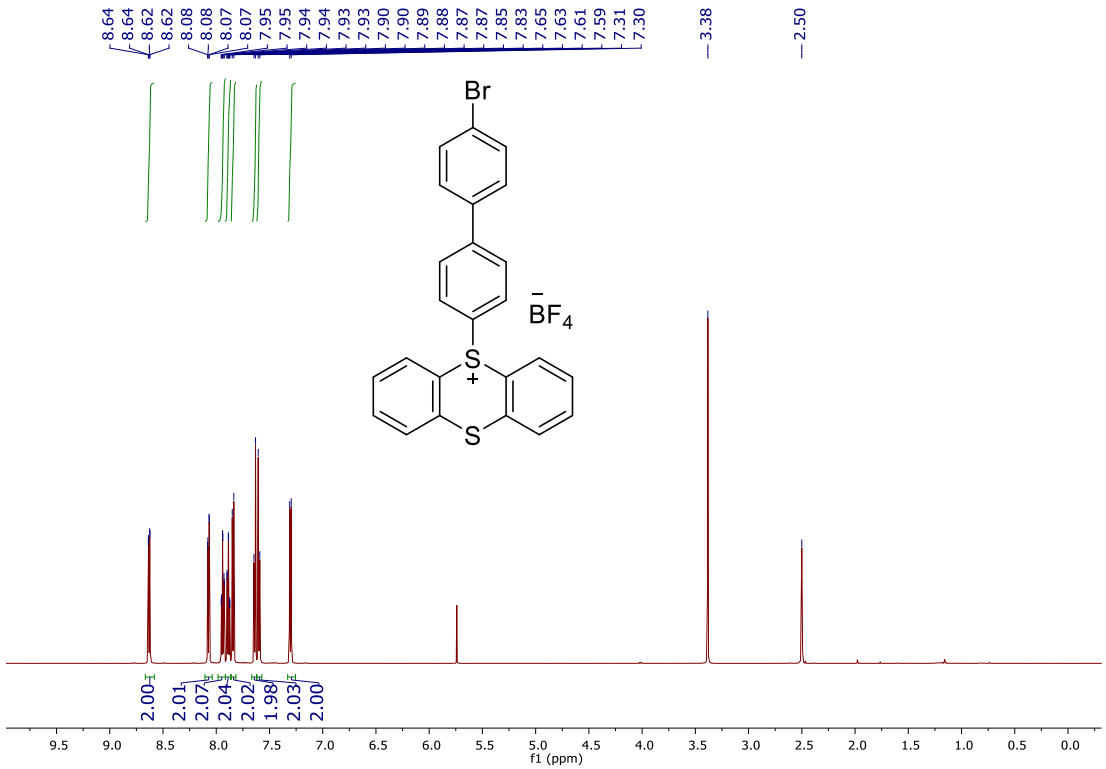
^{19}F NMR spectrum of **2d**



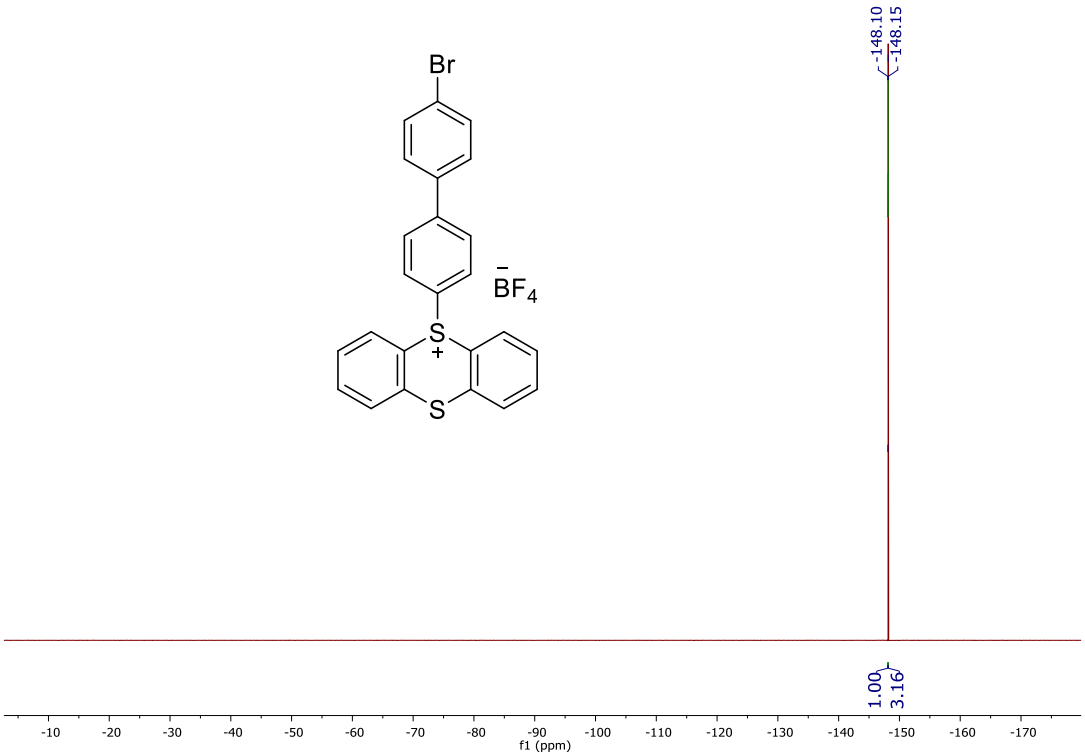
^{13}C NMR spectrum of **2d**



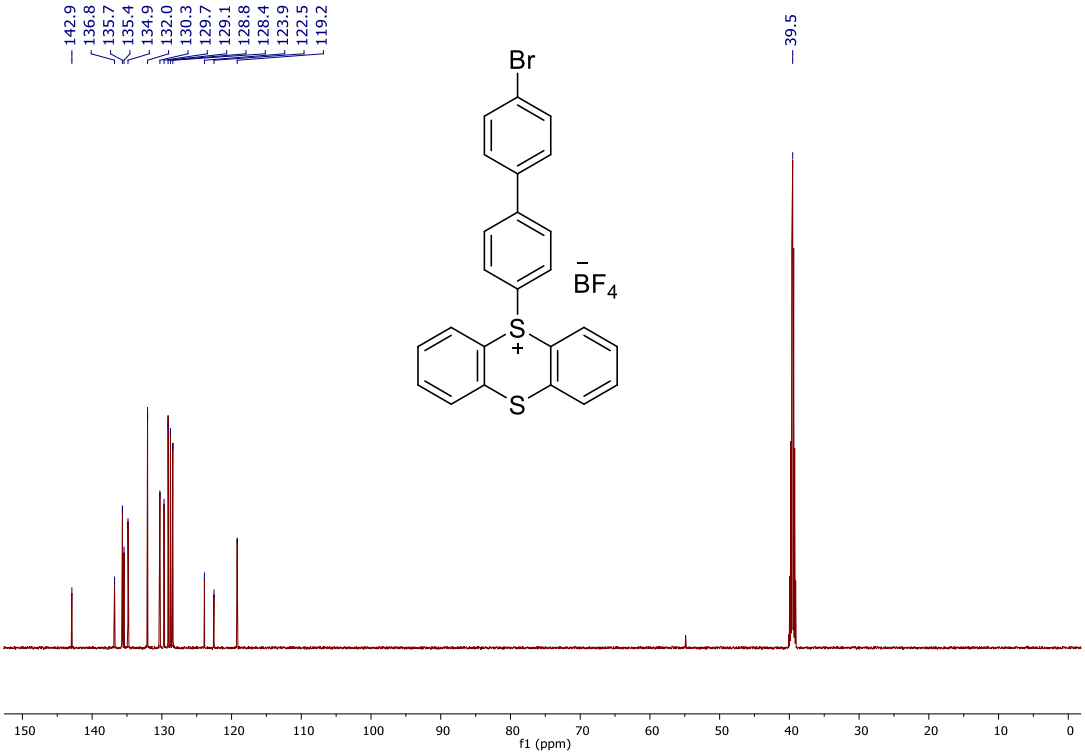
^{1}H NMR spectrum of **2e**



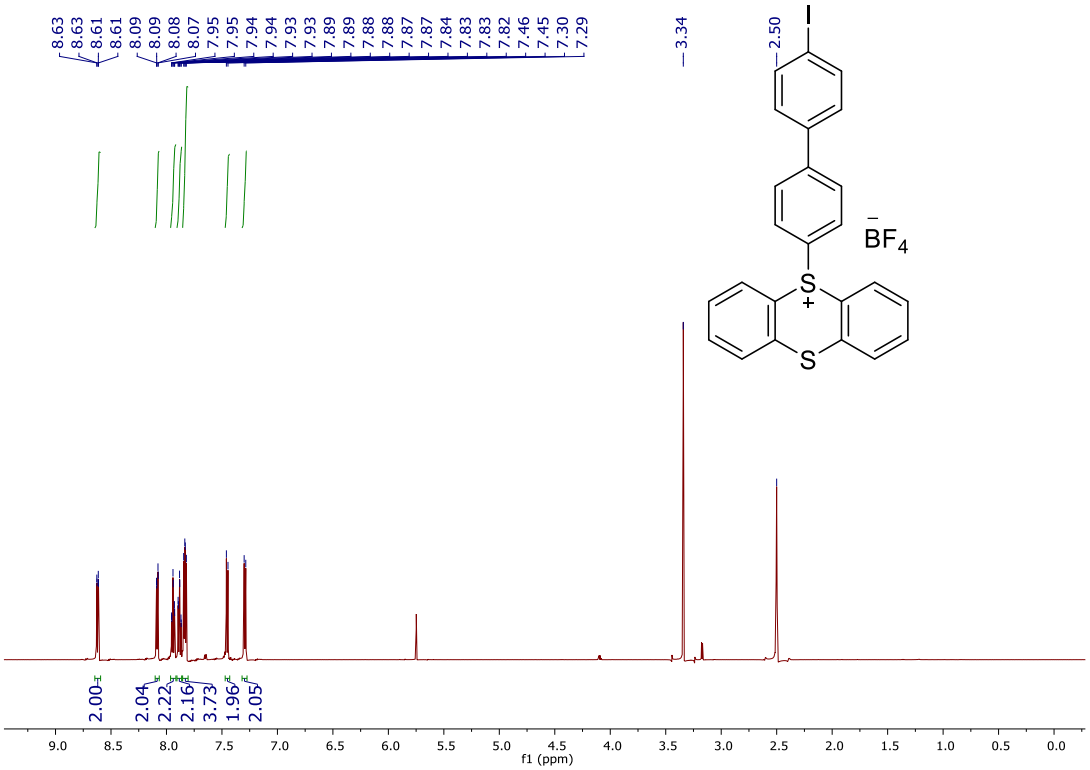
^{19}F NMR spectrum of **2e**



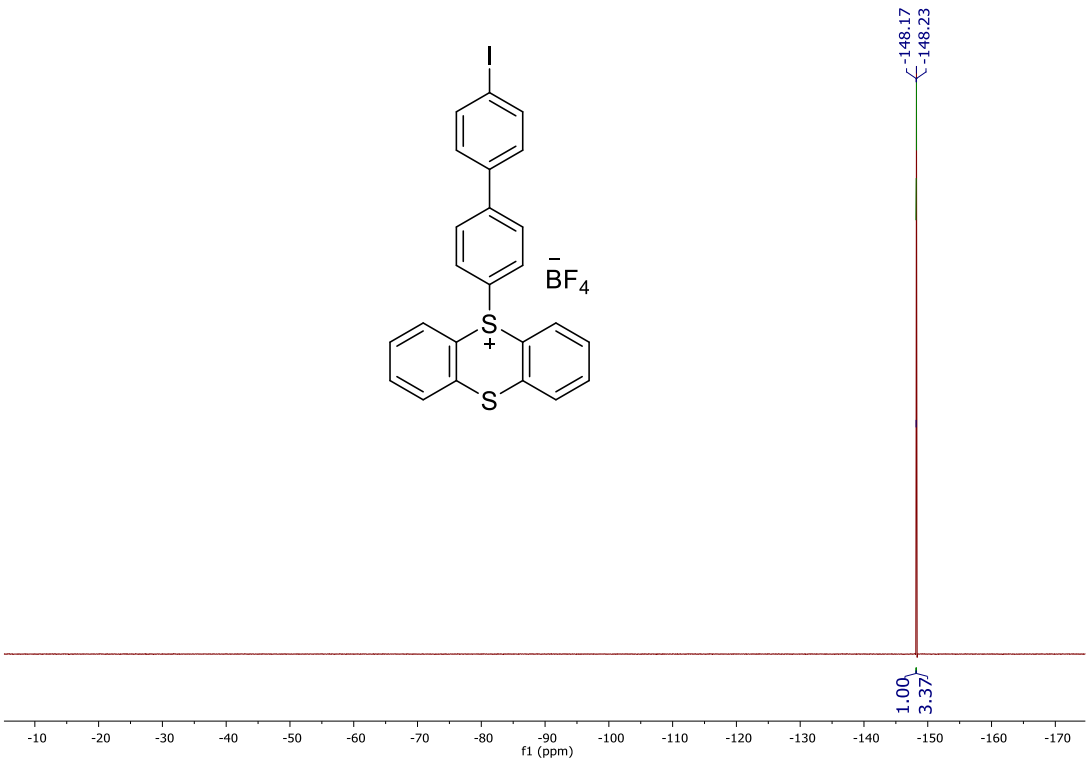
^{13}C NMR spectrum of **2e**



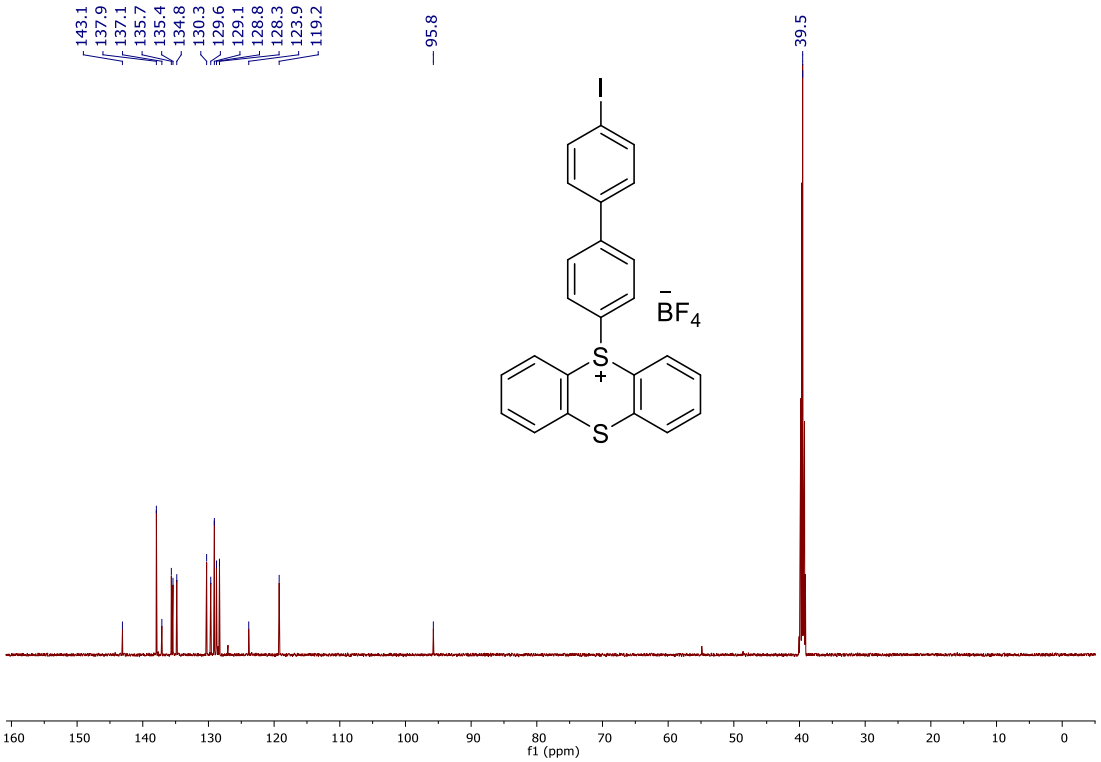
^{1}H NMR spectrum of **2f**



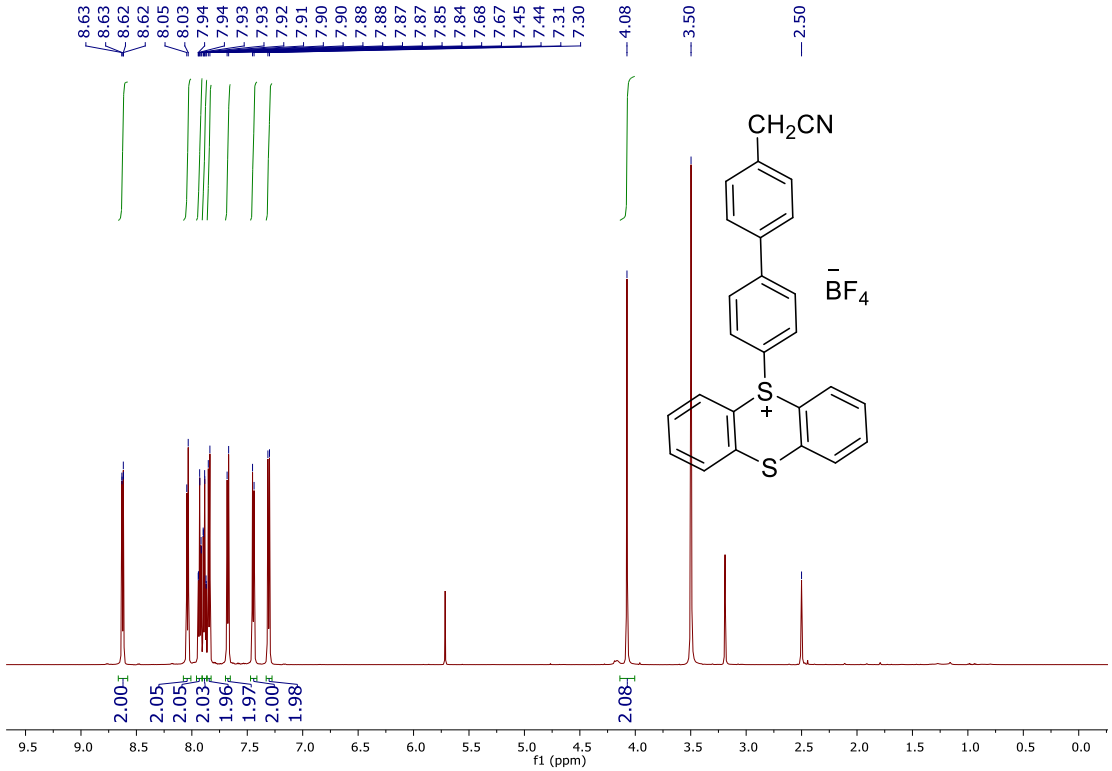
^{19}F NMR spectrum of **2f**



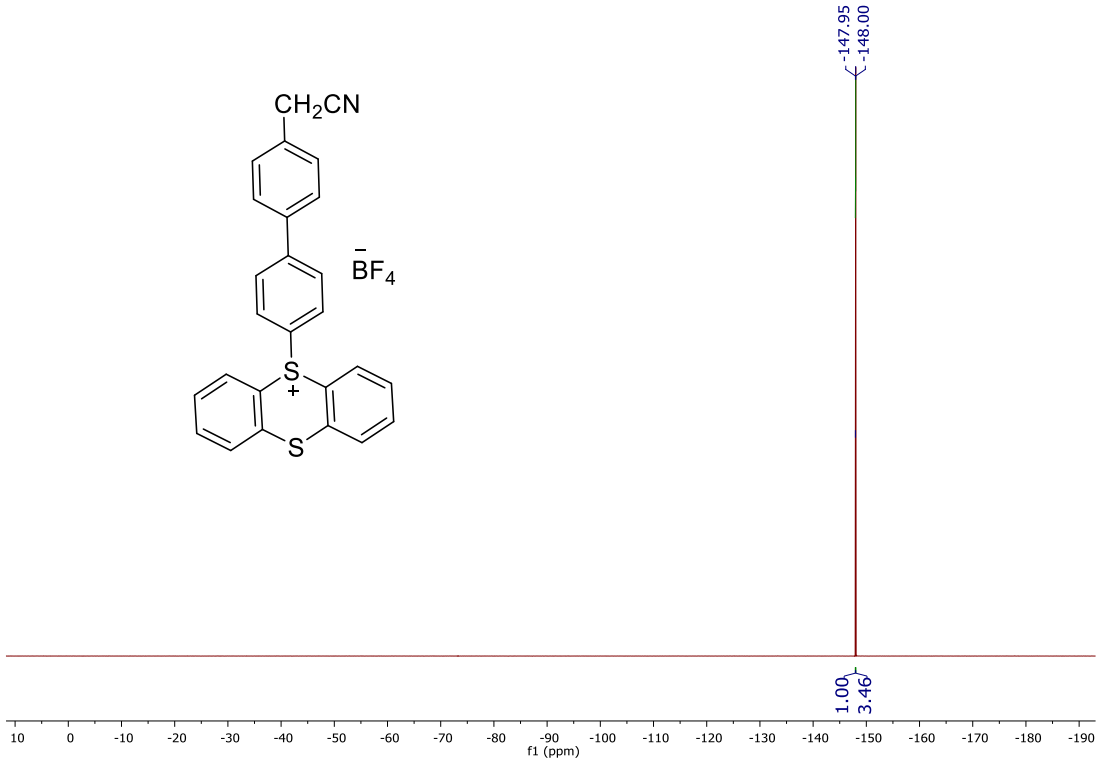
^{13}C NMR spectrum of **2f**



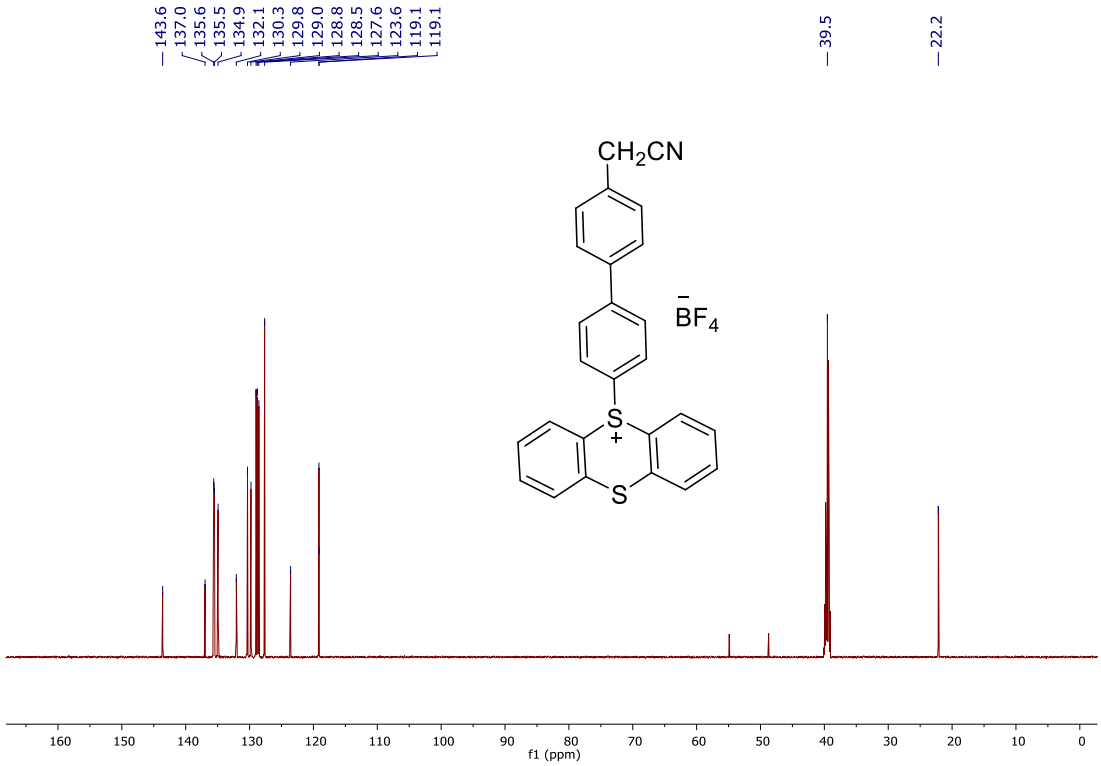
^{1}H NMR spectrum of **2g**



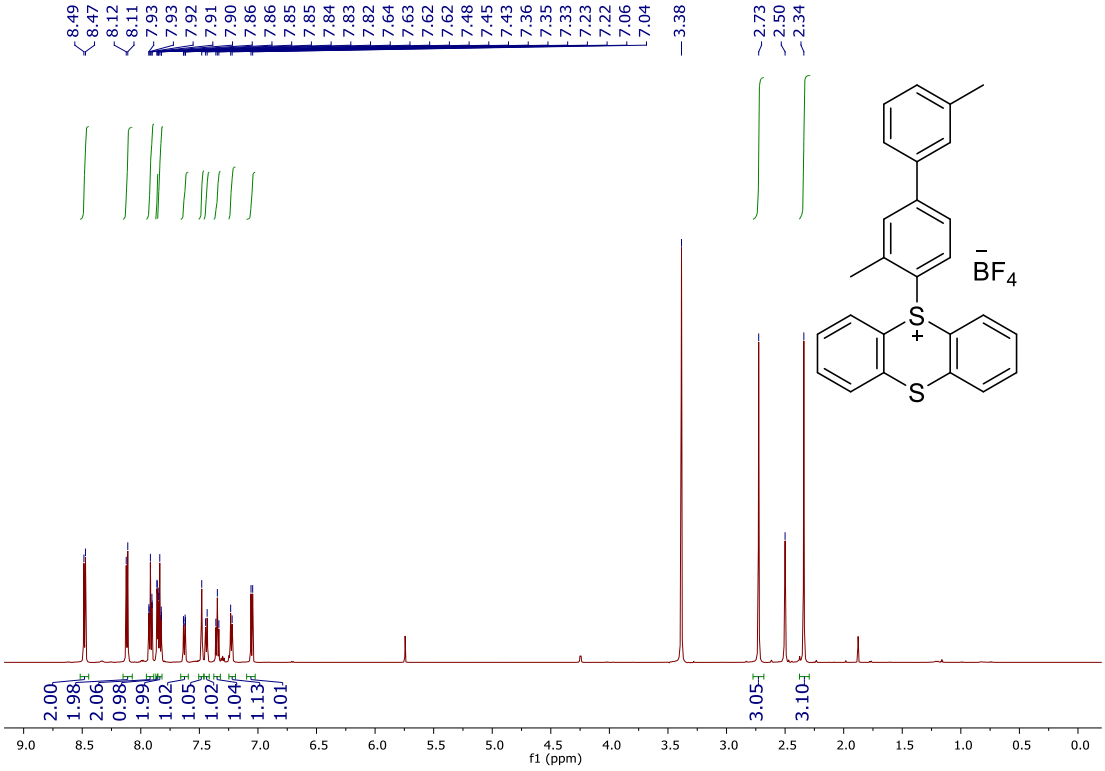
^{19}F NMR spectrum of **2g**



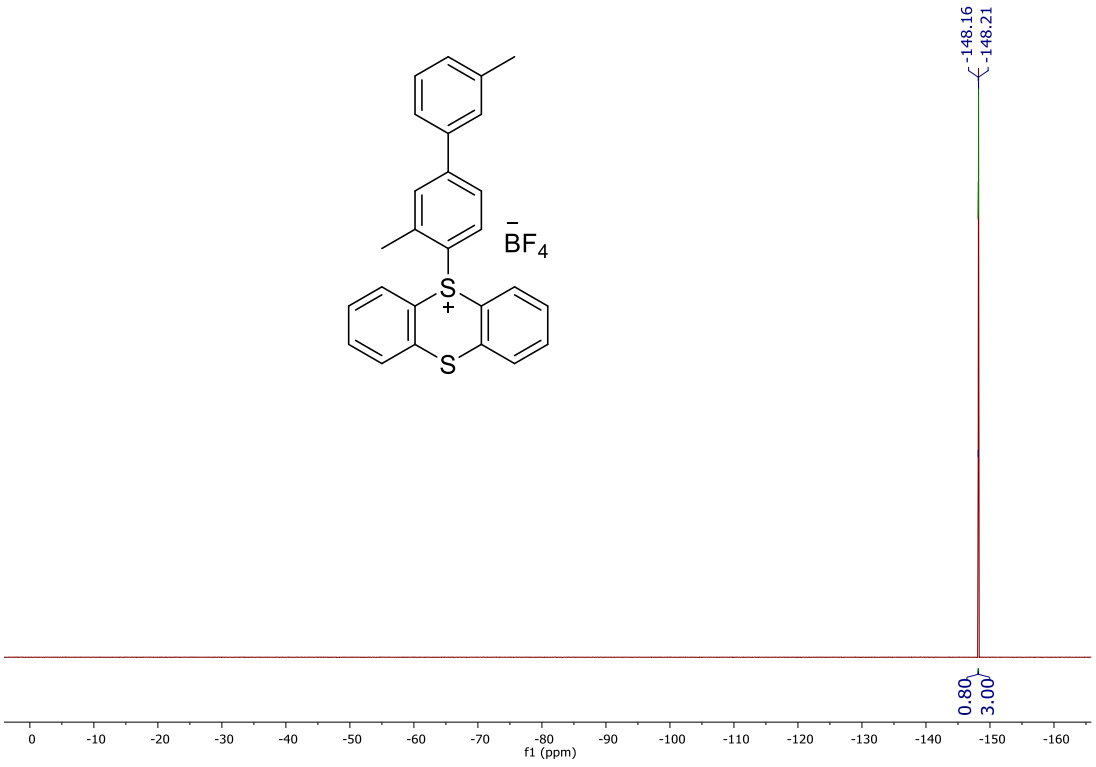
^{13}C NMR spectrum of **2g**



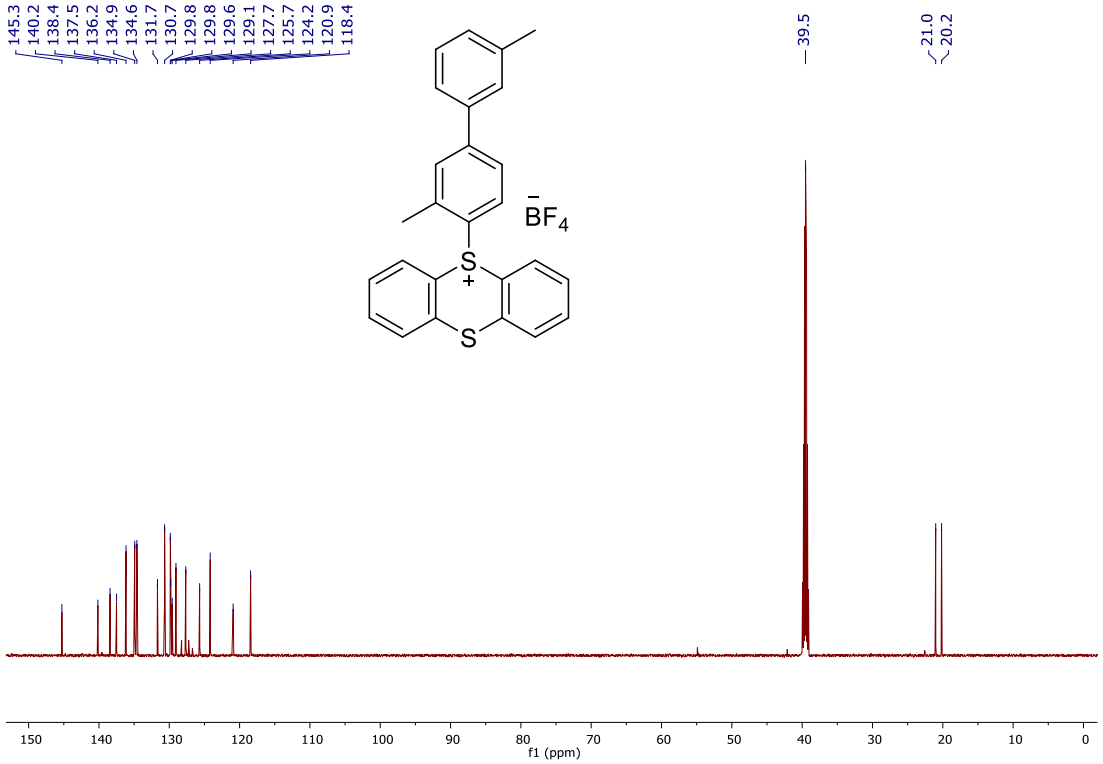
^{1}H NMR spectrum of **2h**



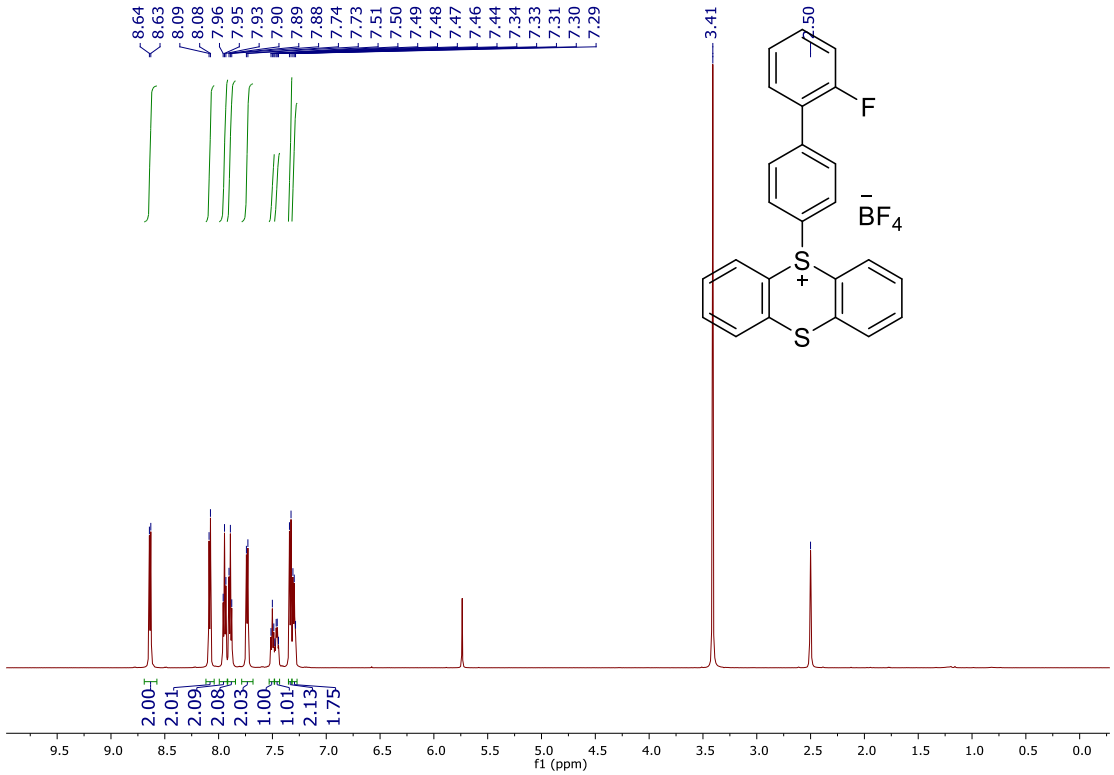
^{19}F NMR spectrum of **2h**



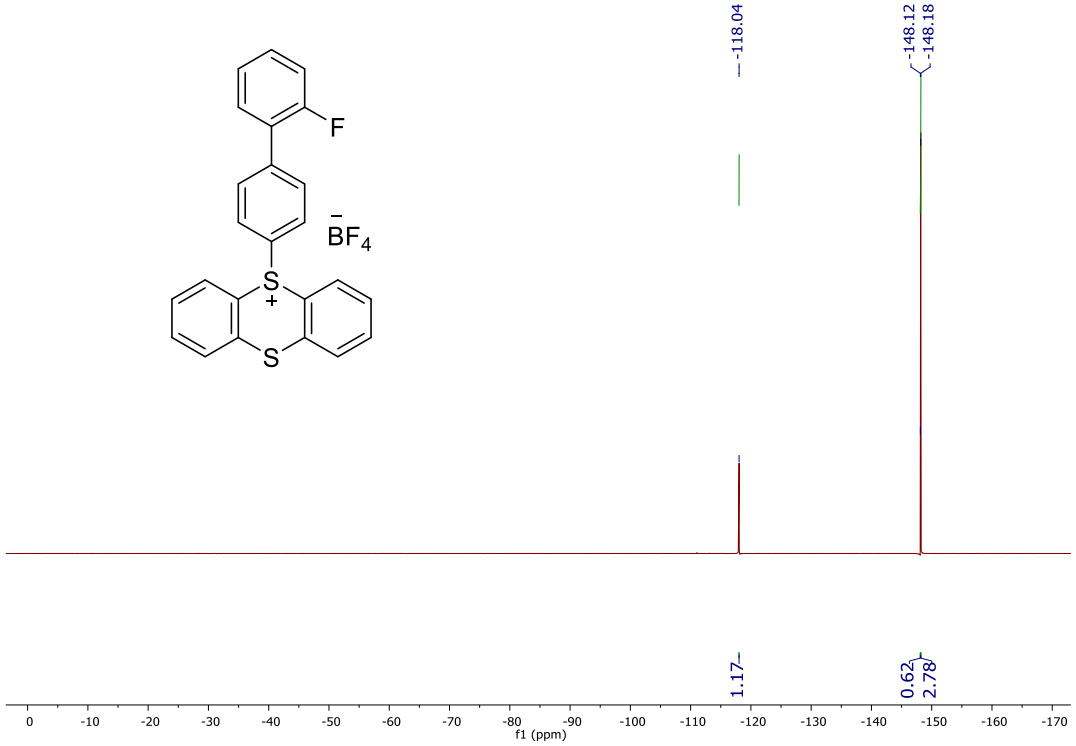
^{13}C NMR spectrum of **2h**



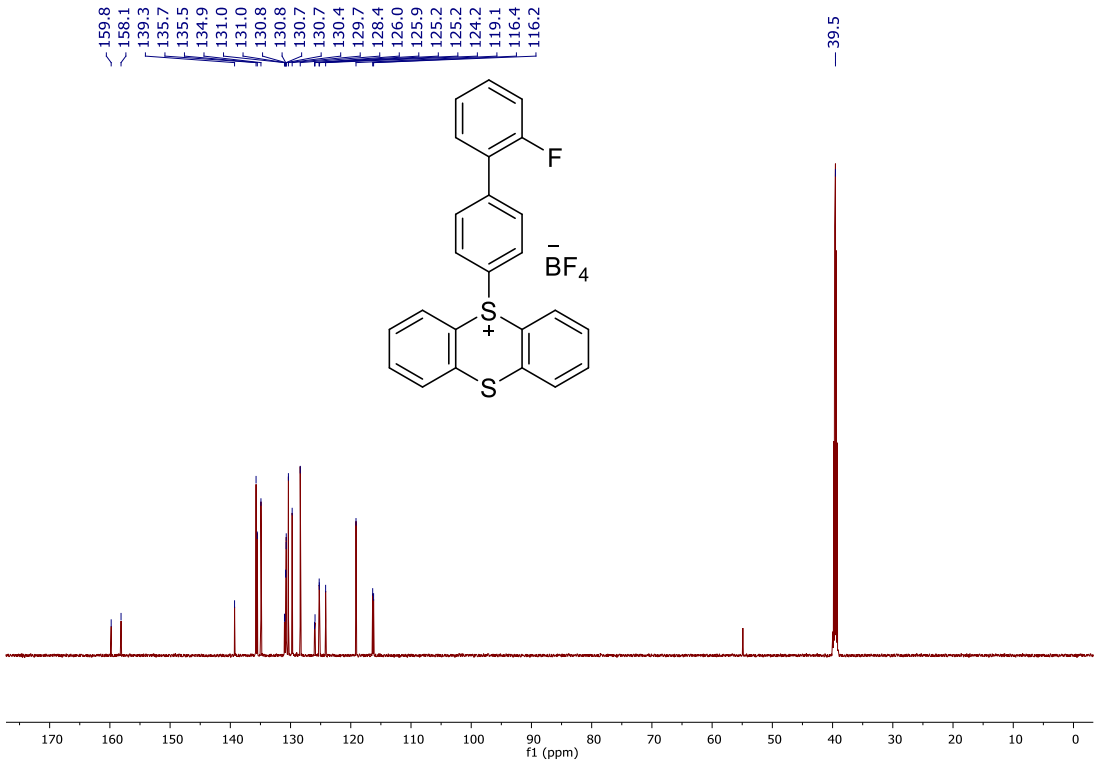
^{1}H NMR spectrum of **2i**



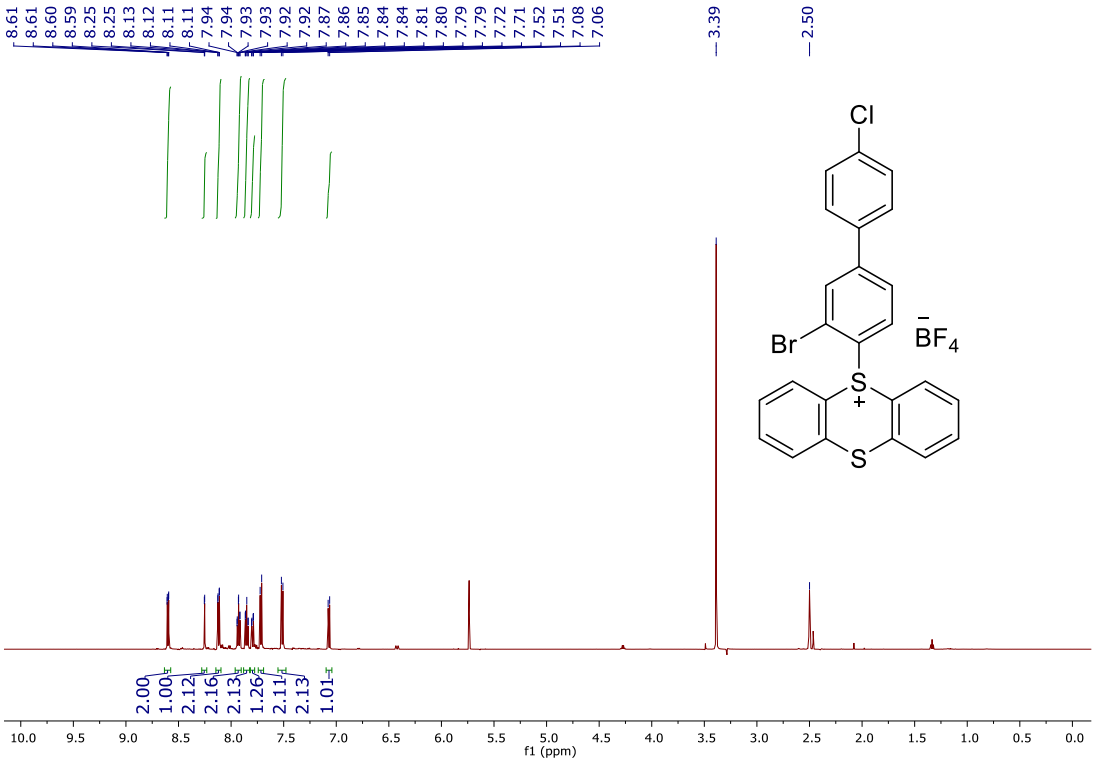
^{19}F NMR spectrum of **2i**



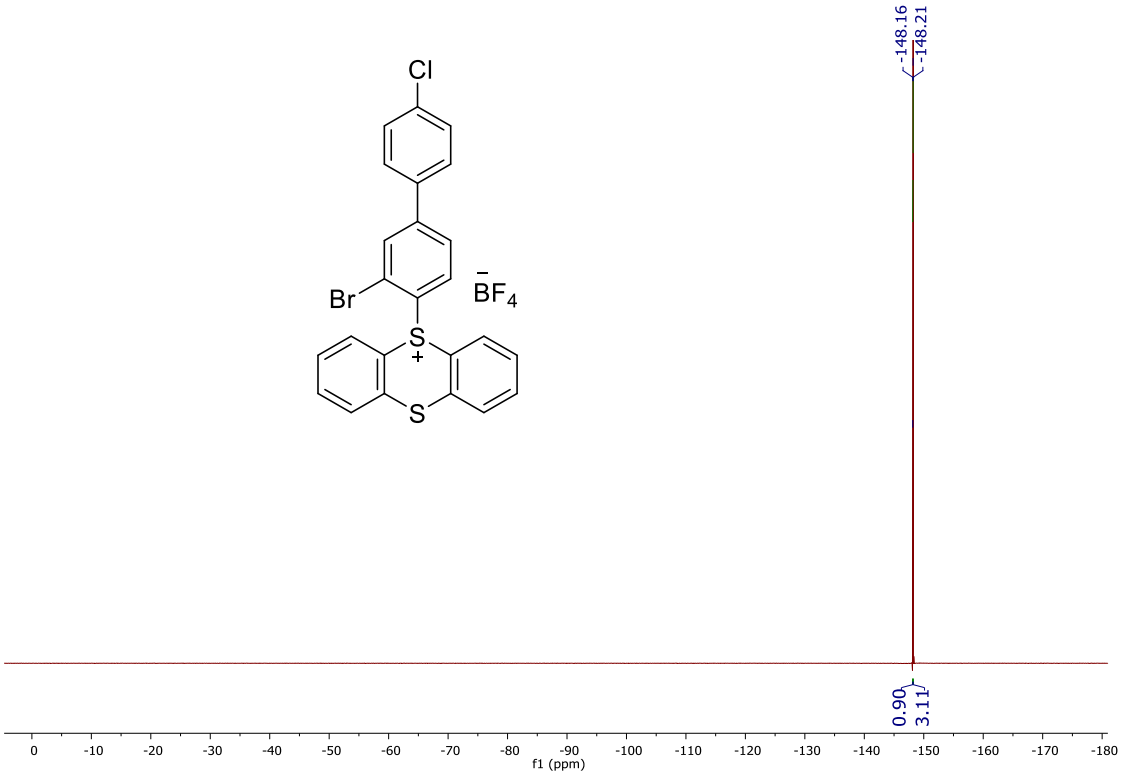
^{13}C NMR spectrum of **2i**



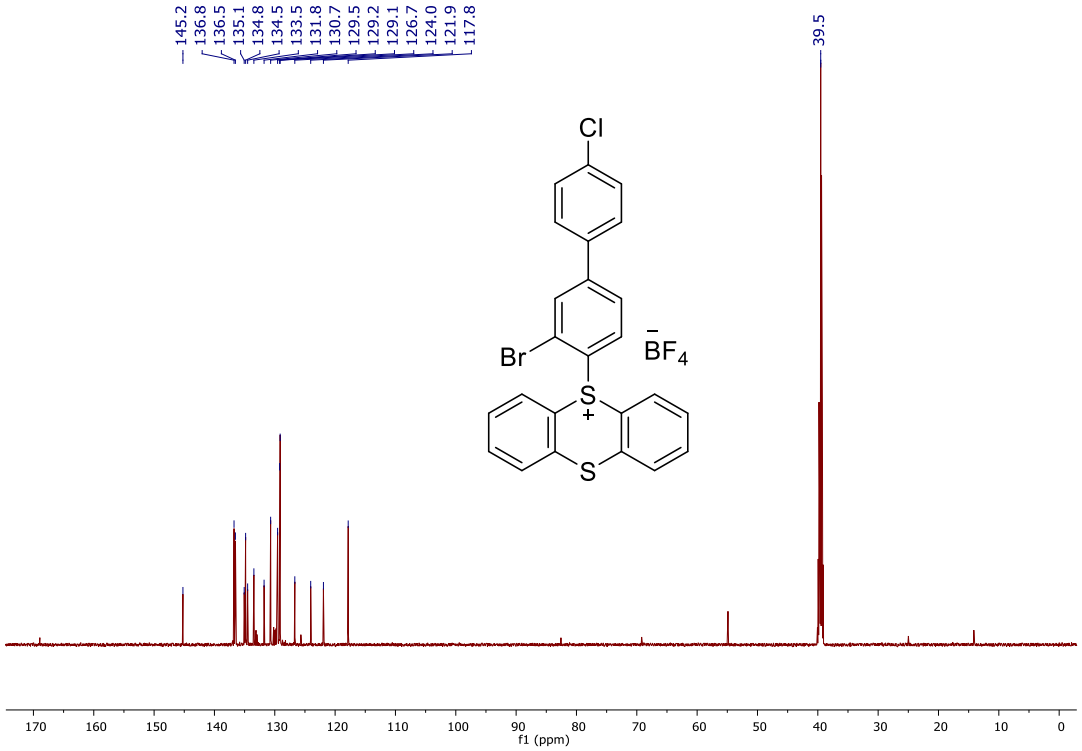
^{1}H NMR spectrum of **2j**



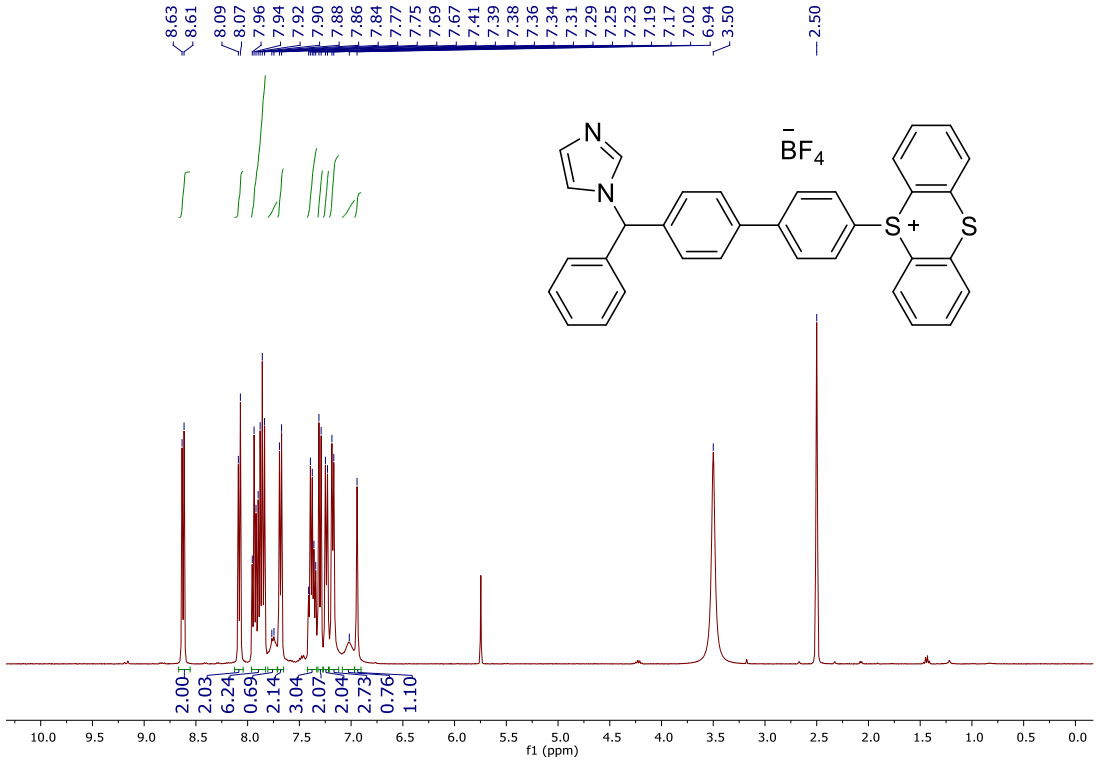
^{19}F NMR spectrum of **2j**



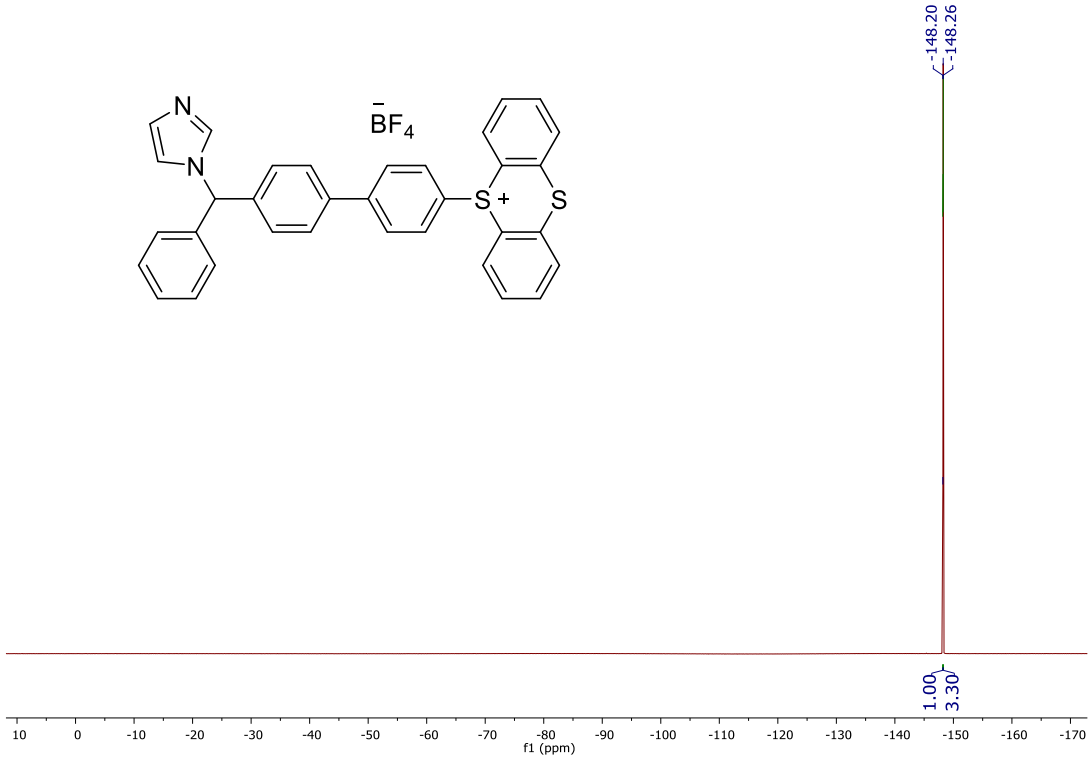
^{13}C NMR spectrum of **2j**



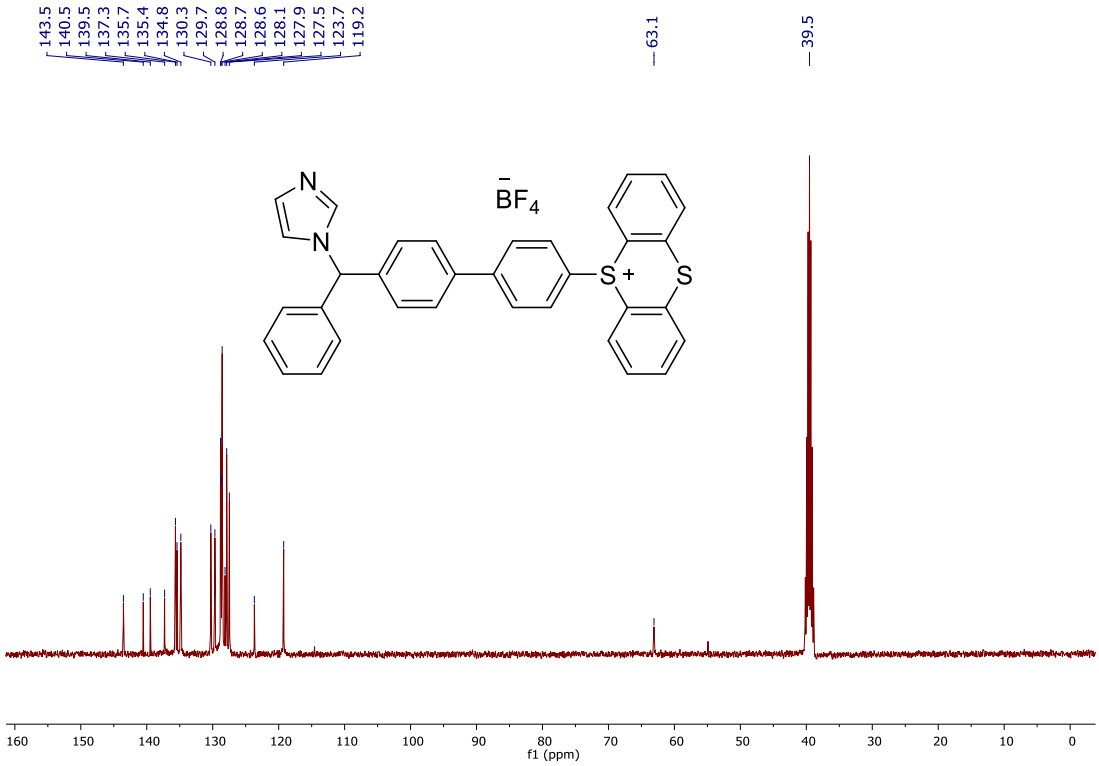
^{1}H NMR spectrum of **2k**



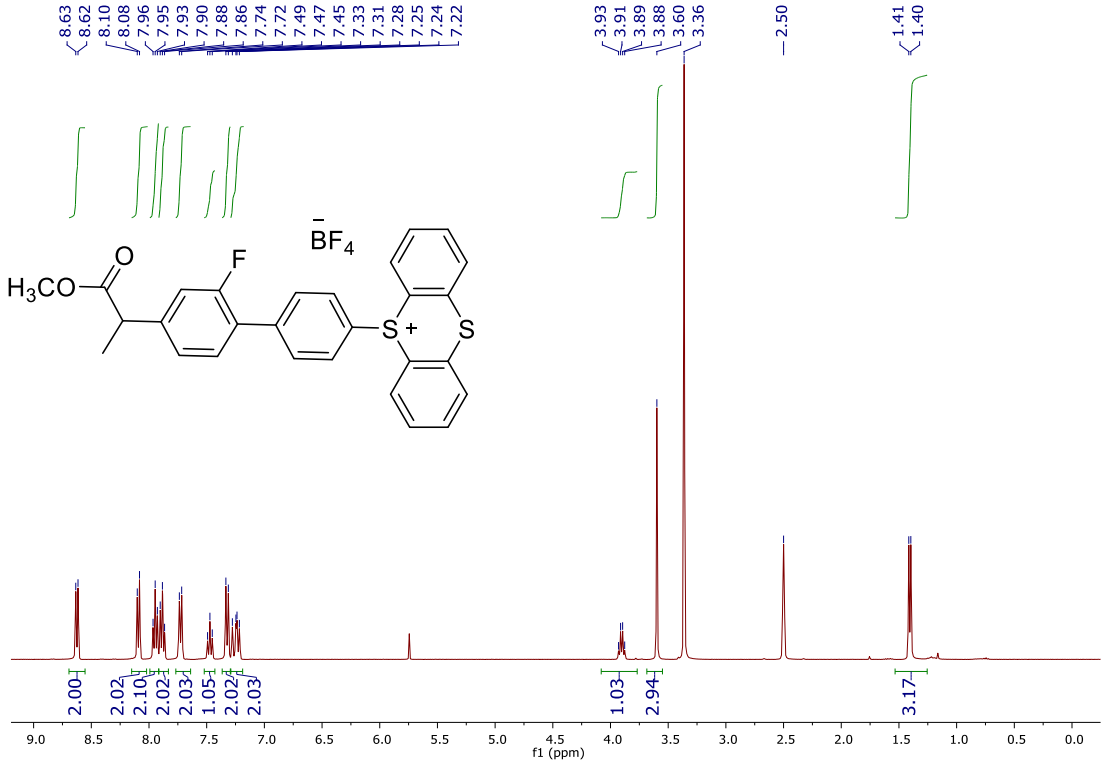
^{19}F NMR spectrum of **2k**



^{13}C NMR spectrum of **2k**

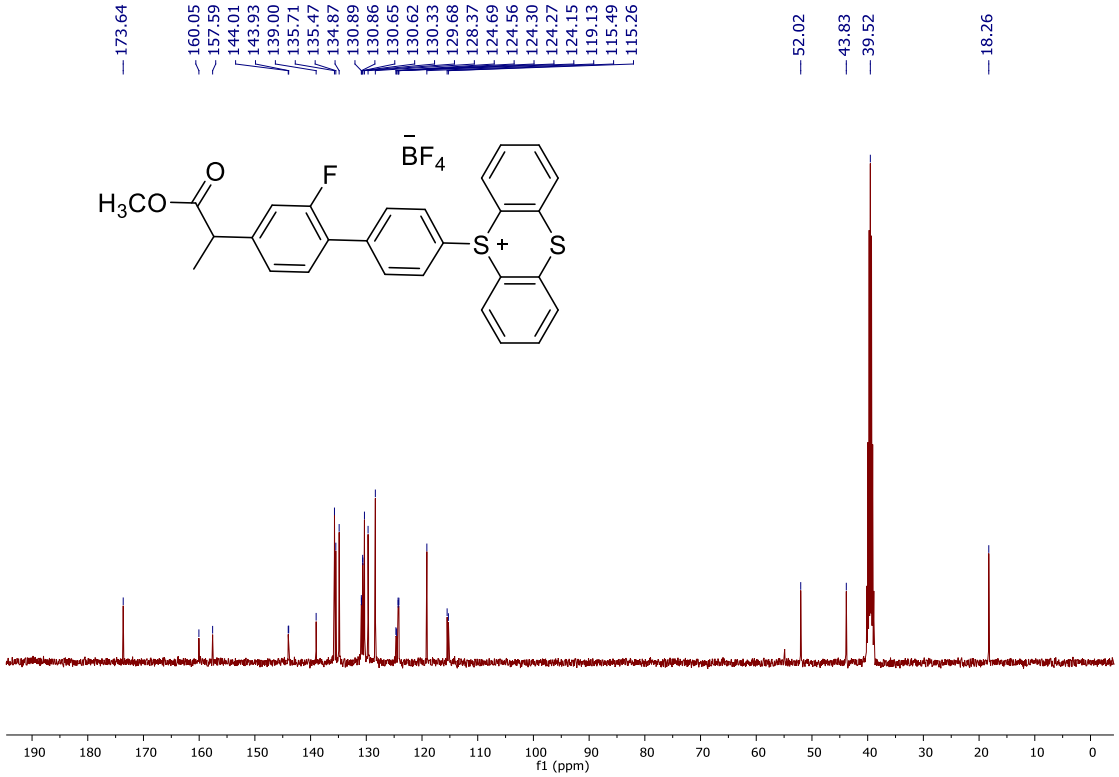


^{1}H NMR spectrum of **2l**

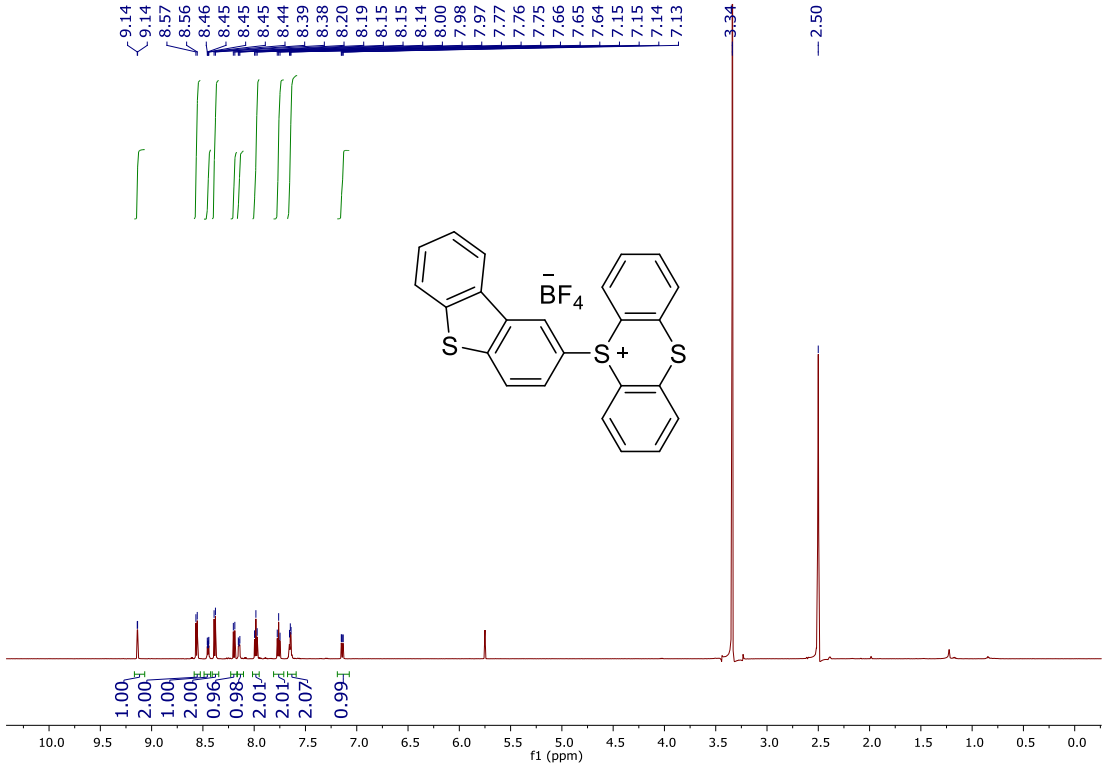


^{19}F NMR spectrum of **2l**

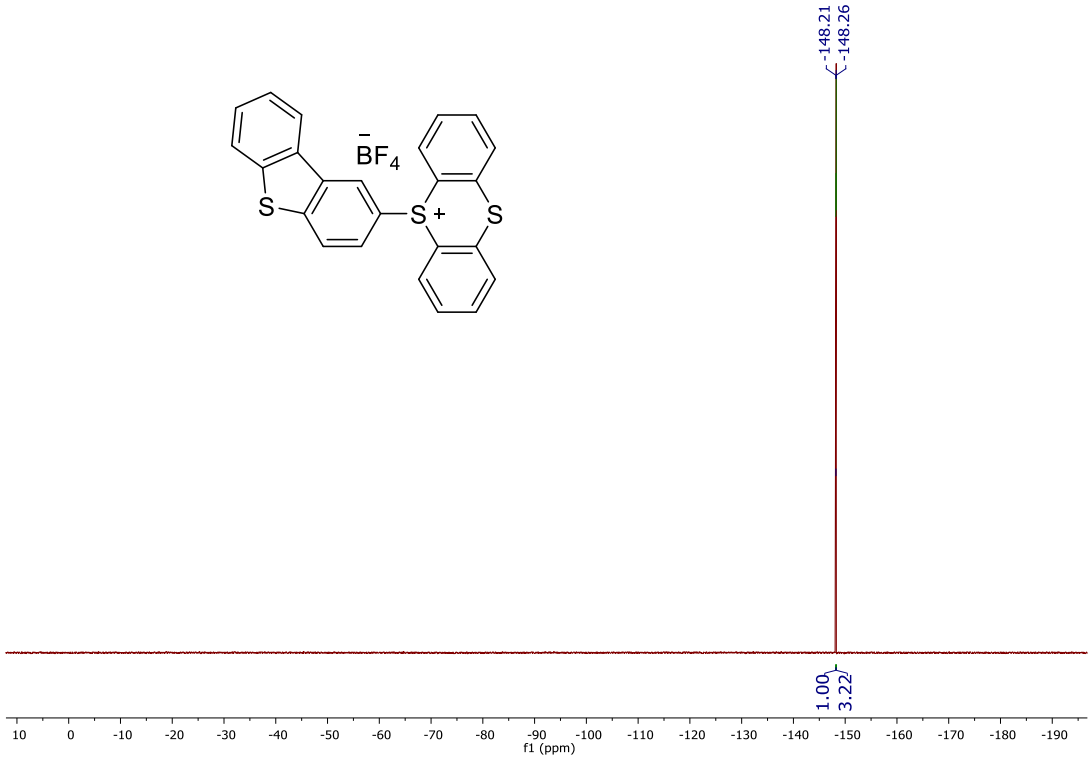
^{13}C NMR spectrum of **2l**



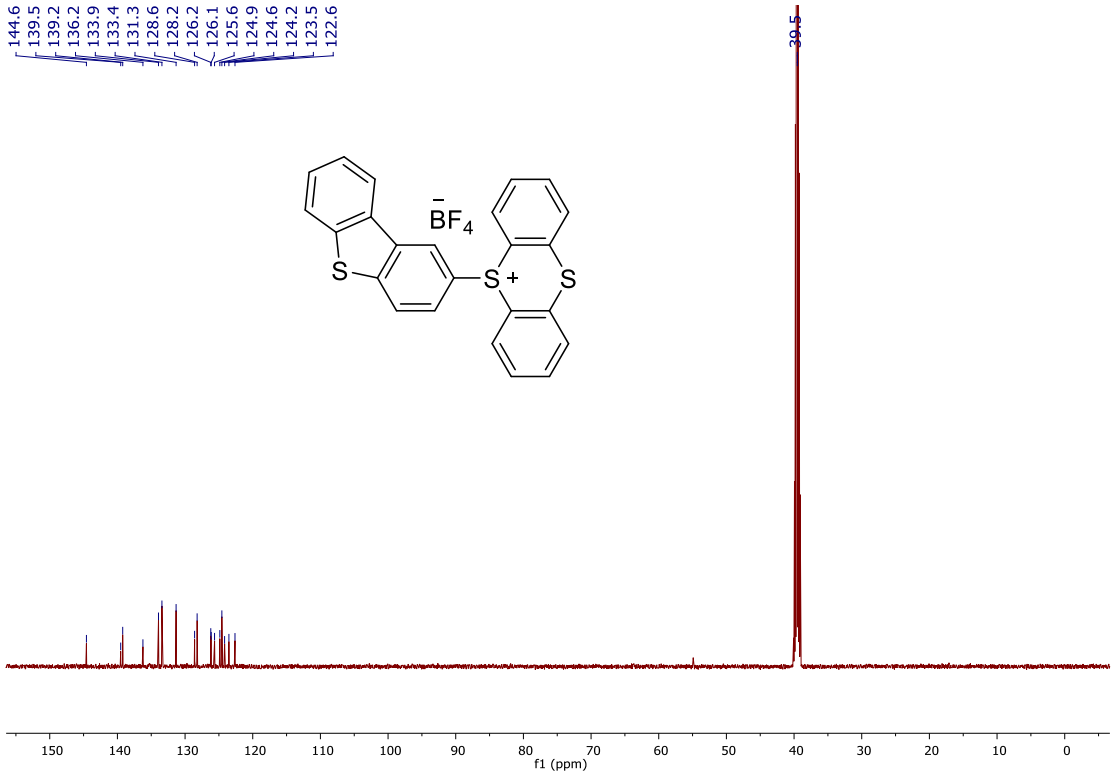
^{1}H NMR spectrum of **2n**



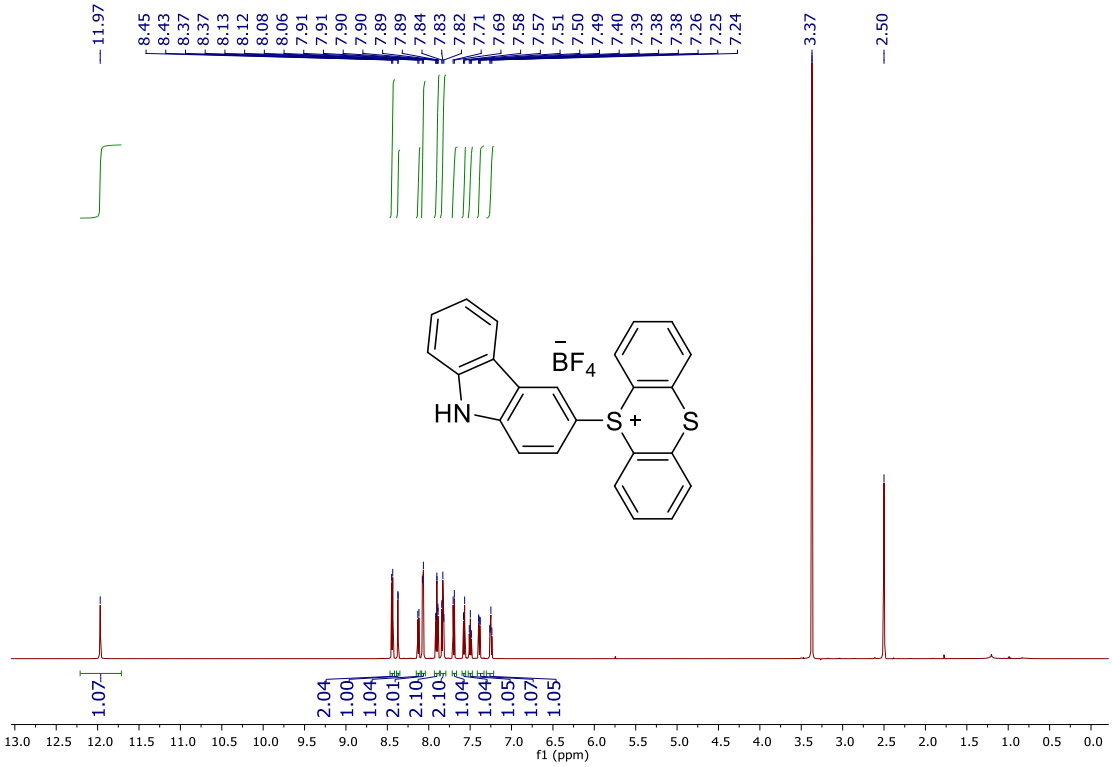
^{19}F NMR spectrum of **2n**



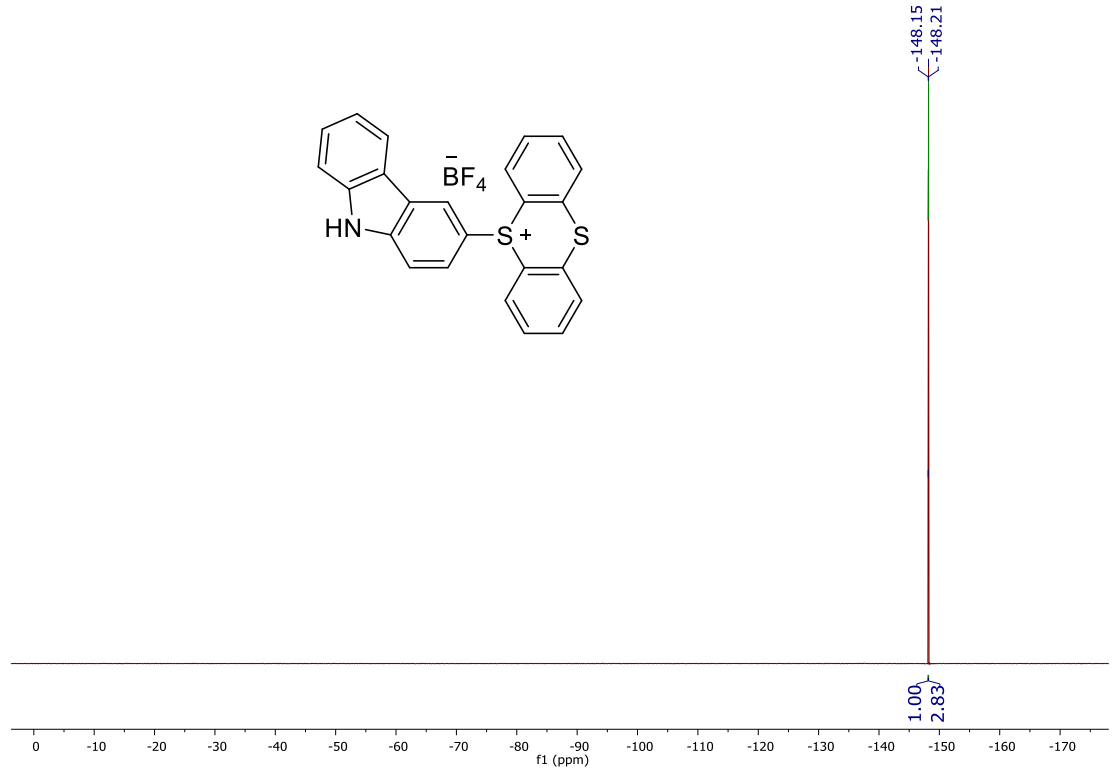
^{13}C NMR spectrum of **2n**



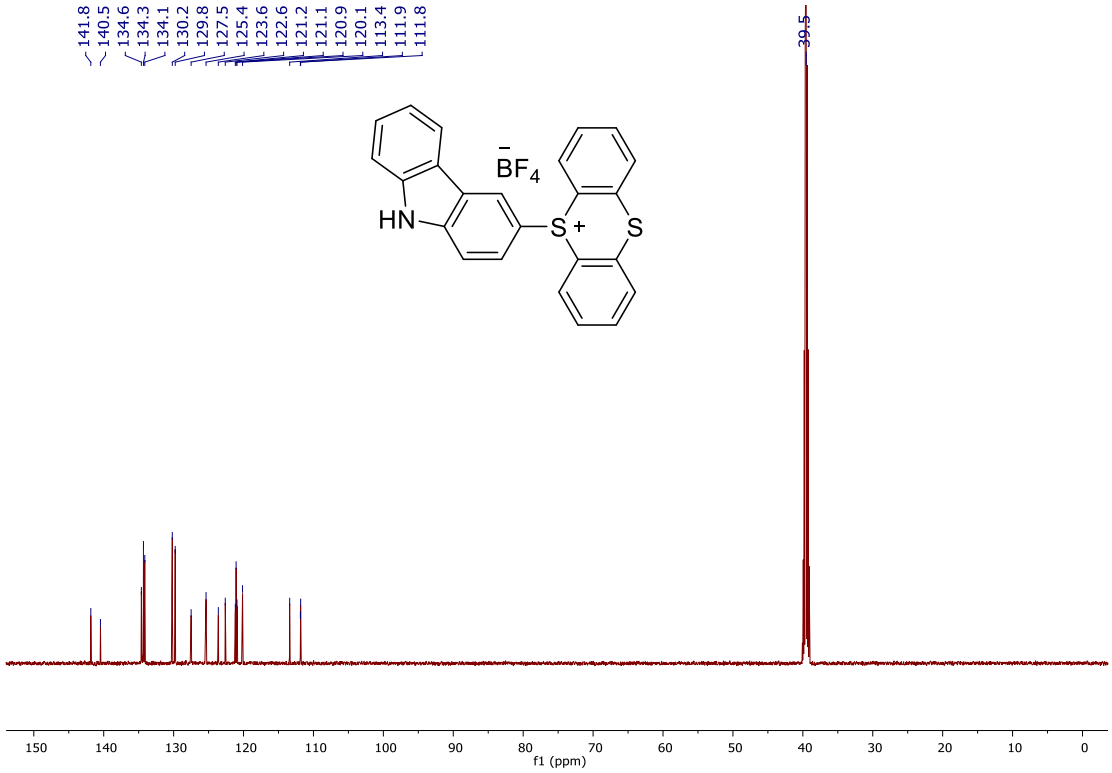
^{1}H NMR spectrum of **2o**



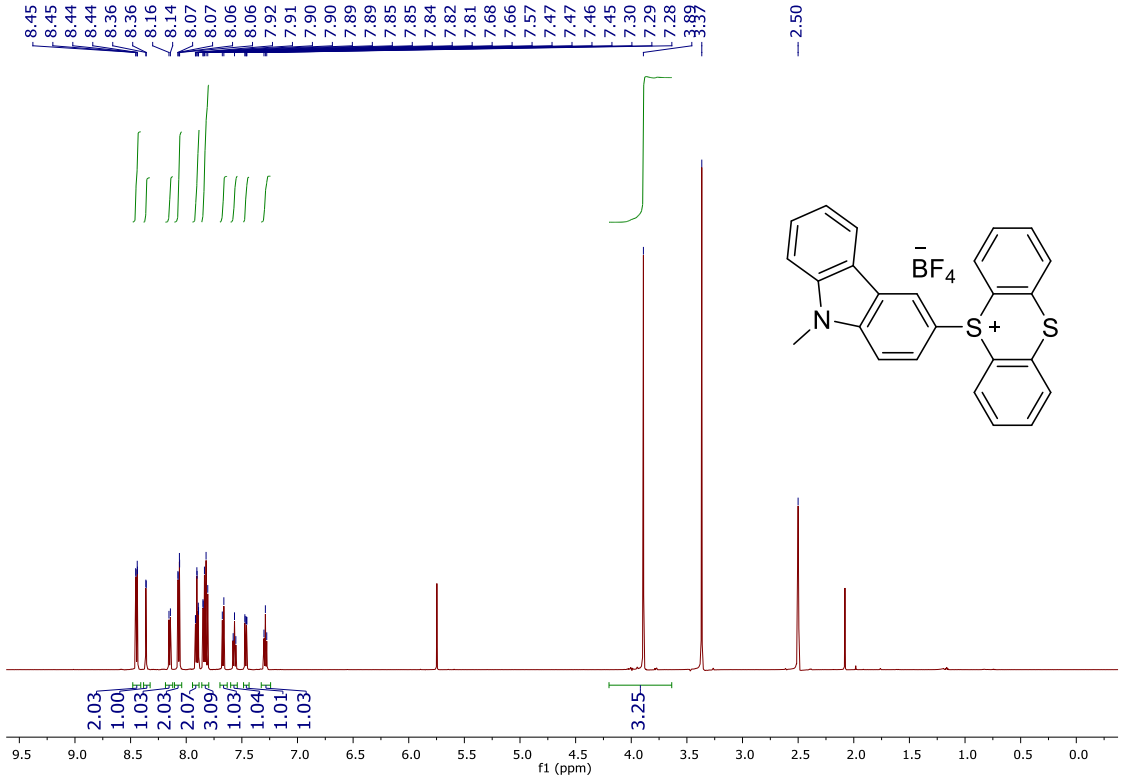
^{19}F NMR spectrum of **2o**



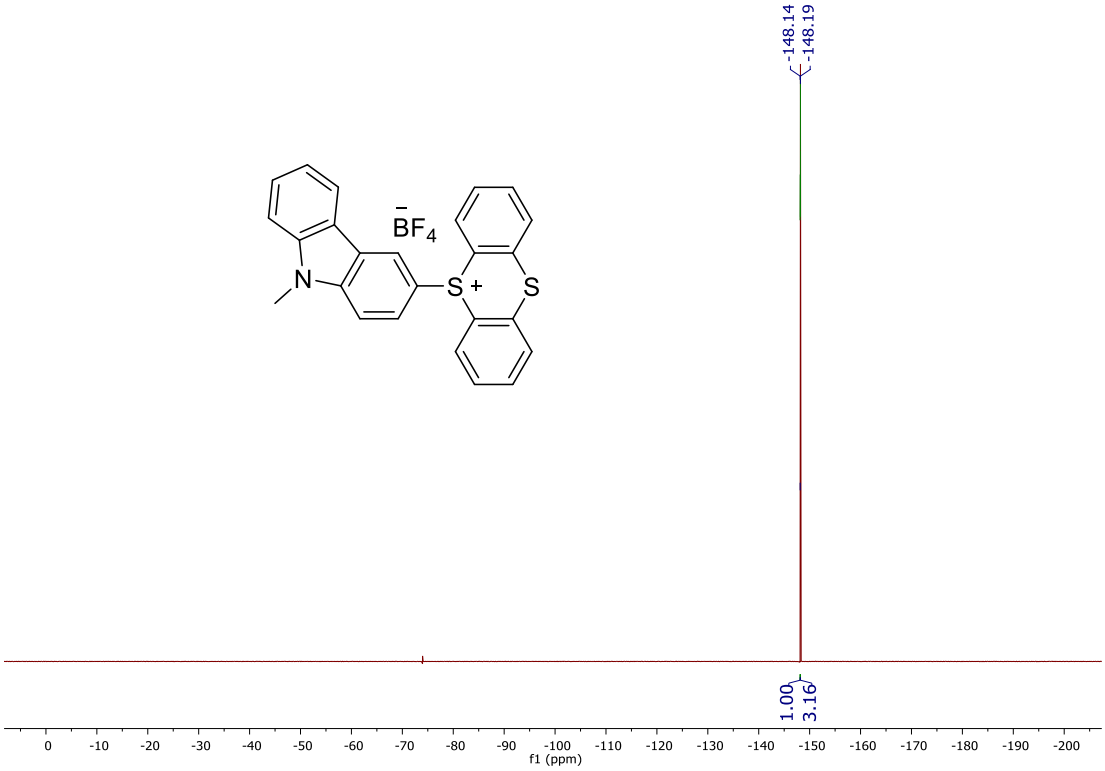
^{13}C NMR spectrum of **2o**



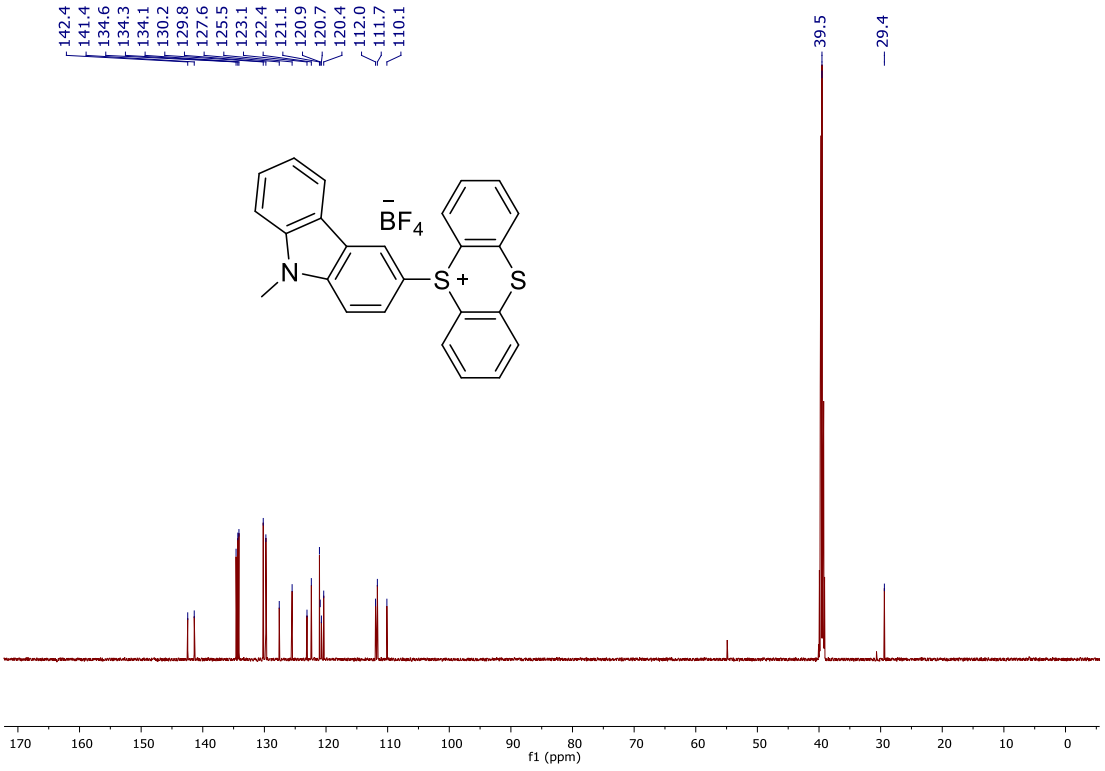
^{1}H NMR spectrum of **2p**



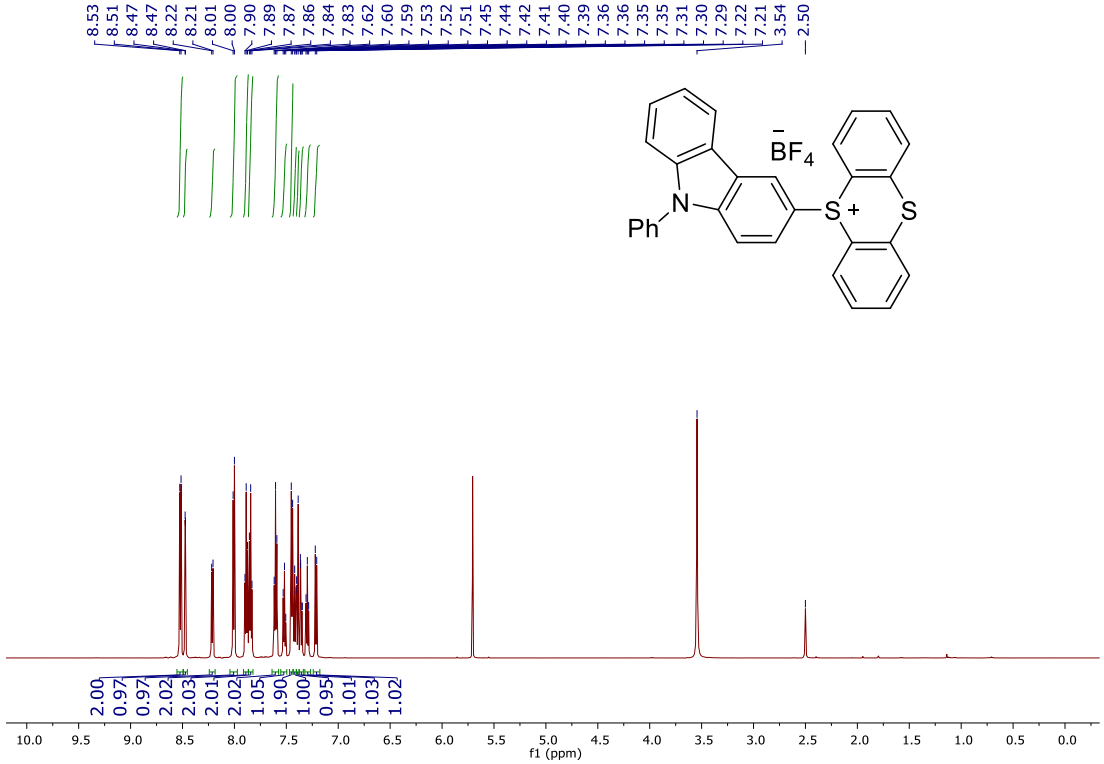
^{19}F NMR spectrum of **2p**



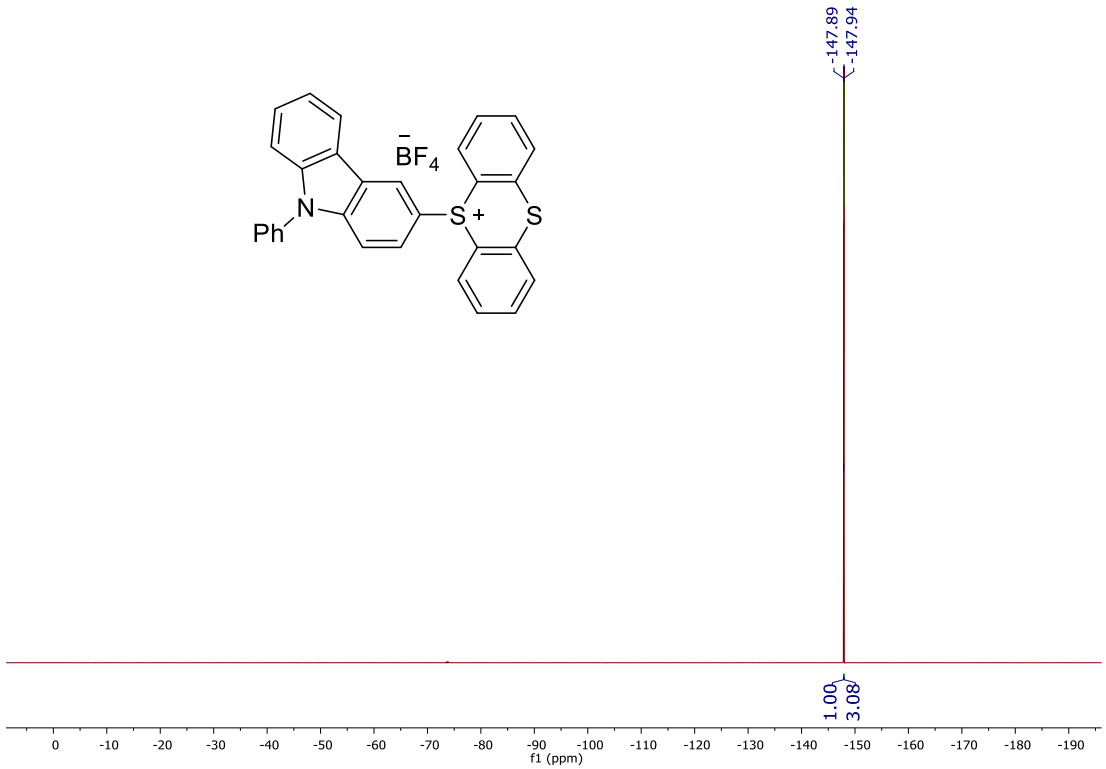
^{13}C NMR spectrum of **2p**



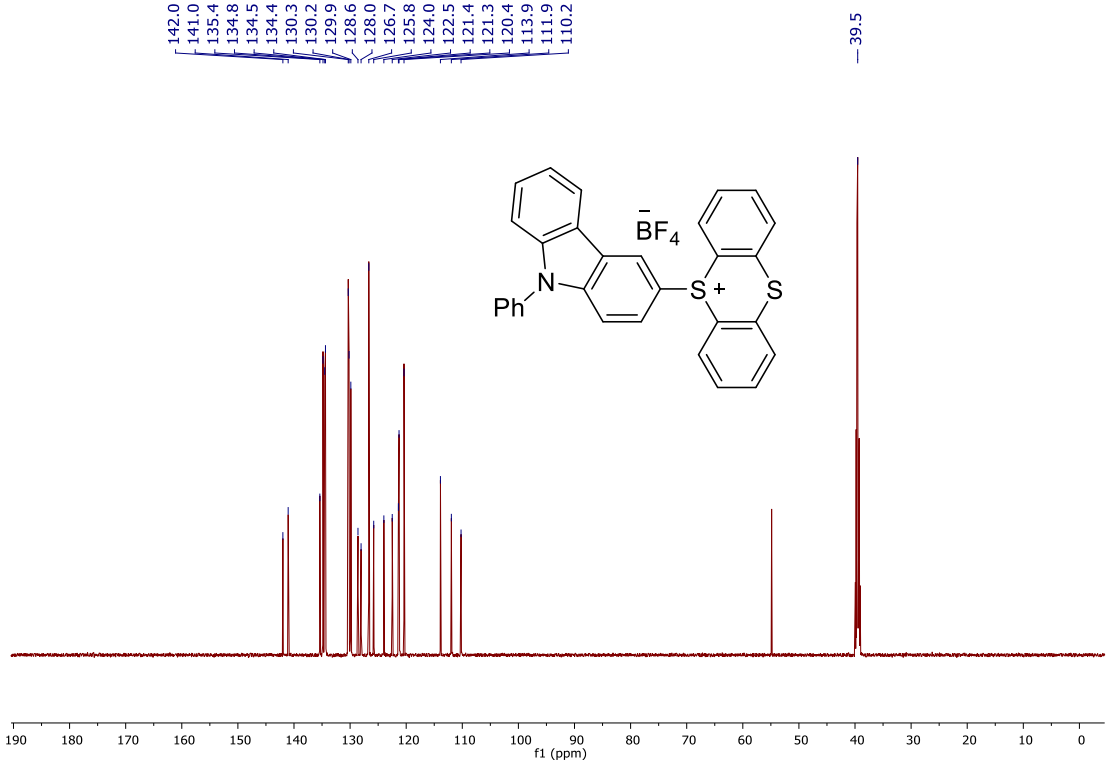
^{1}H NMR spectrum of **2q**



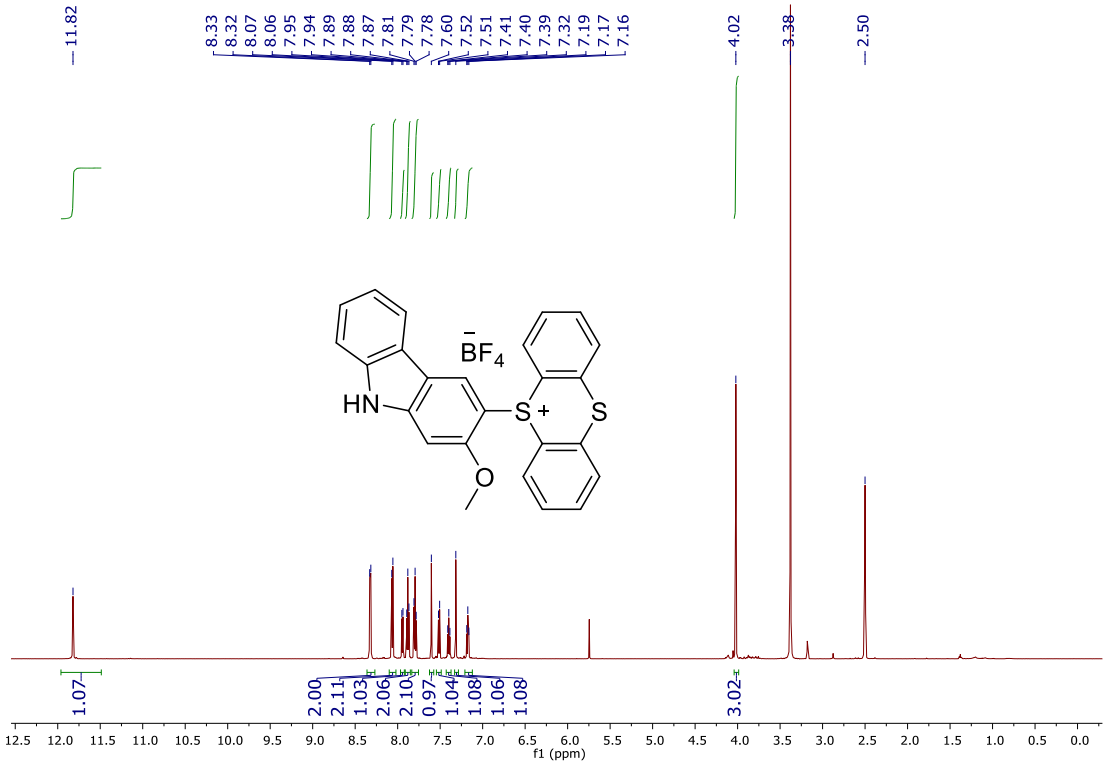
^{19}F NMR spectrum of **2q**



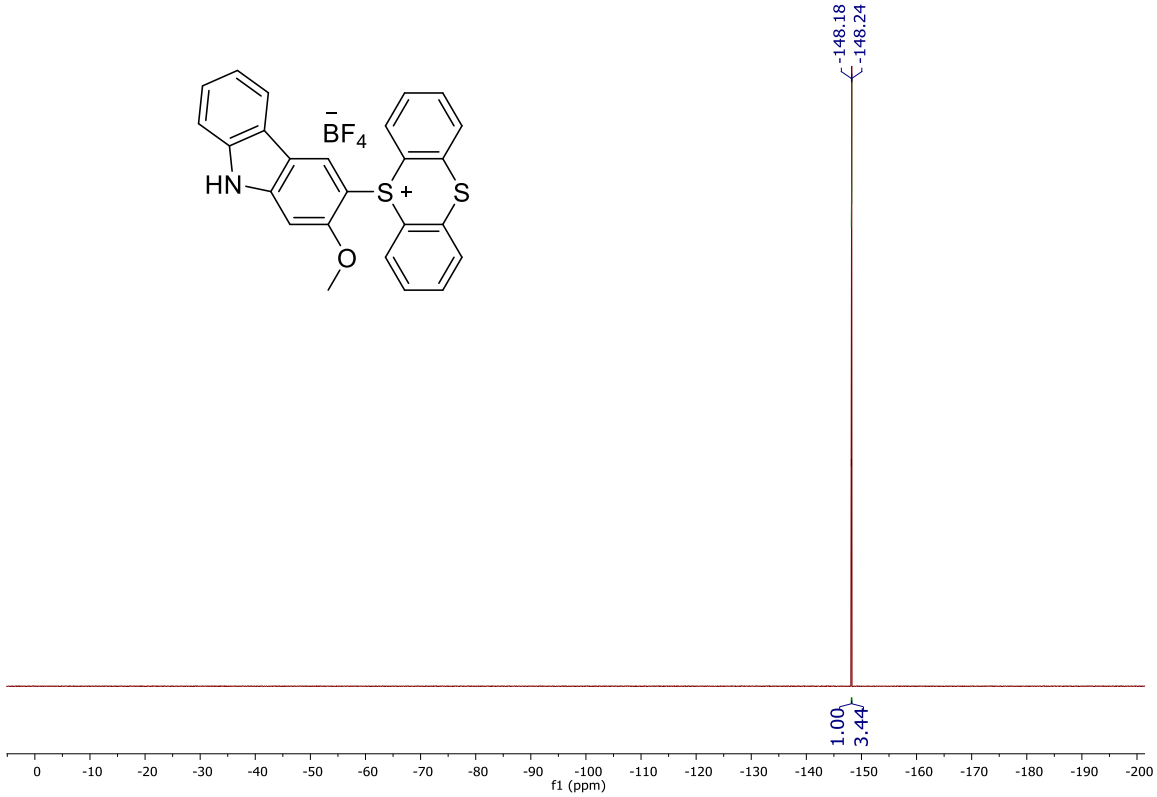
^{13}C NMR spectrum of **2q**



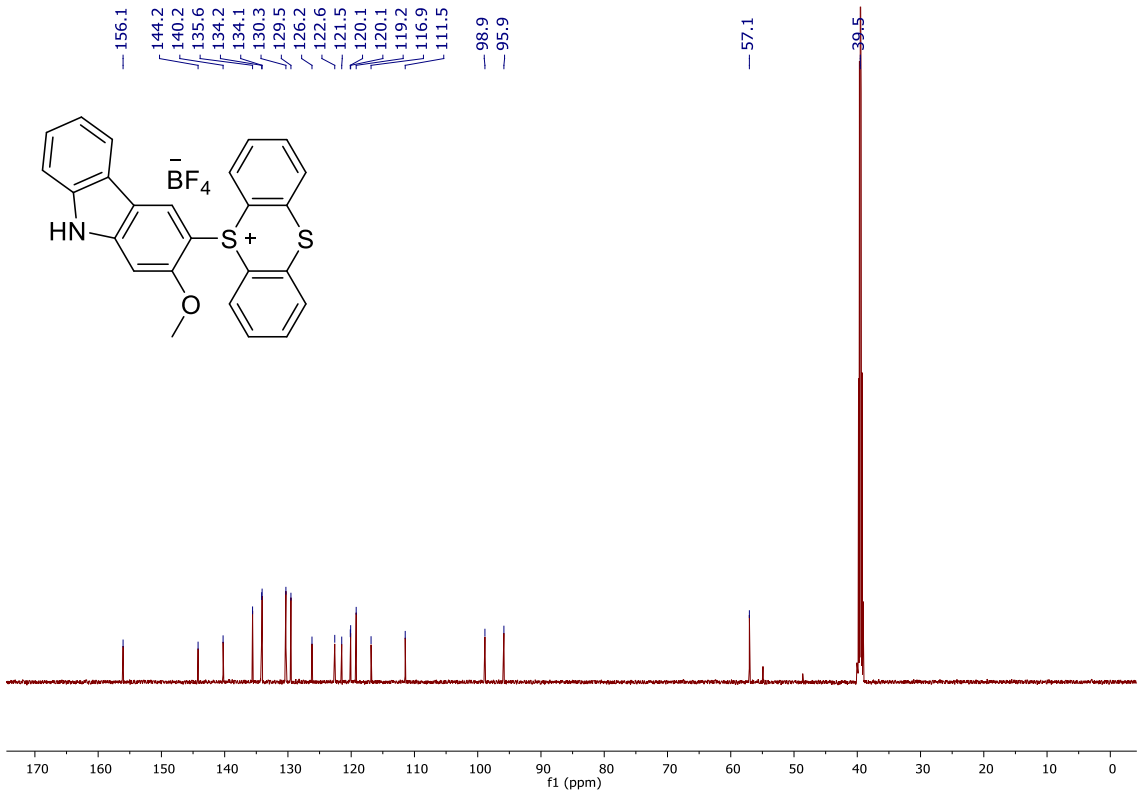
^{1}H NMR spectrum of **2r**



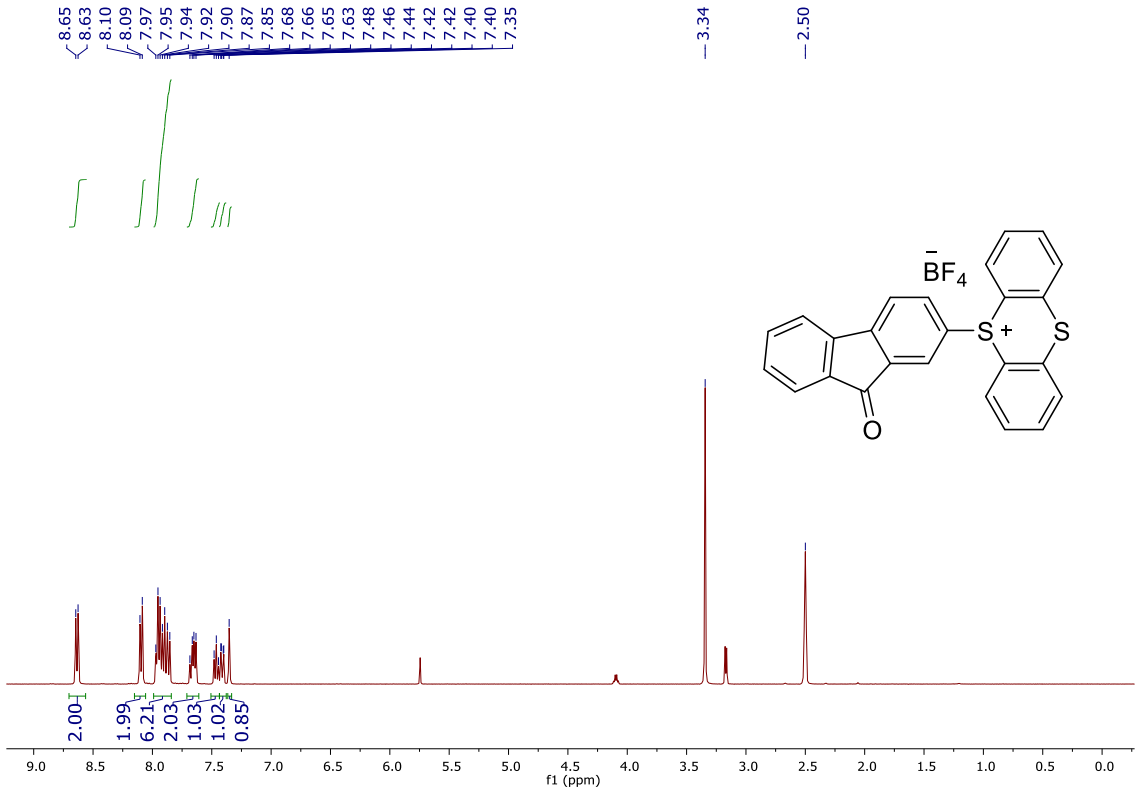
^{19}F NMR spectrum of **2r**



^{13}C NMR spectrum of **2r**

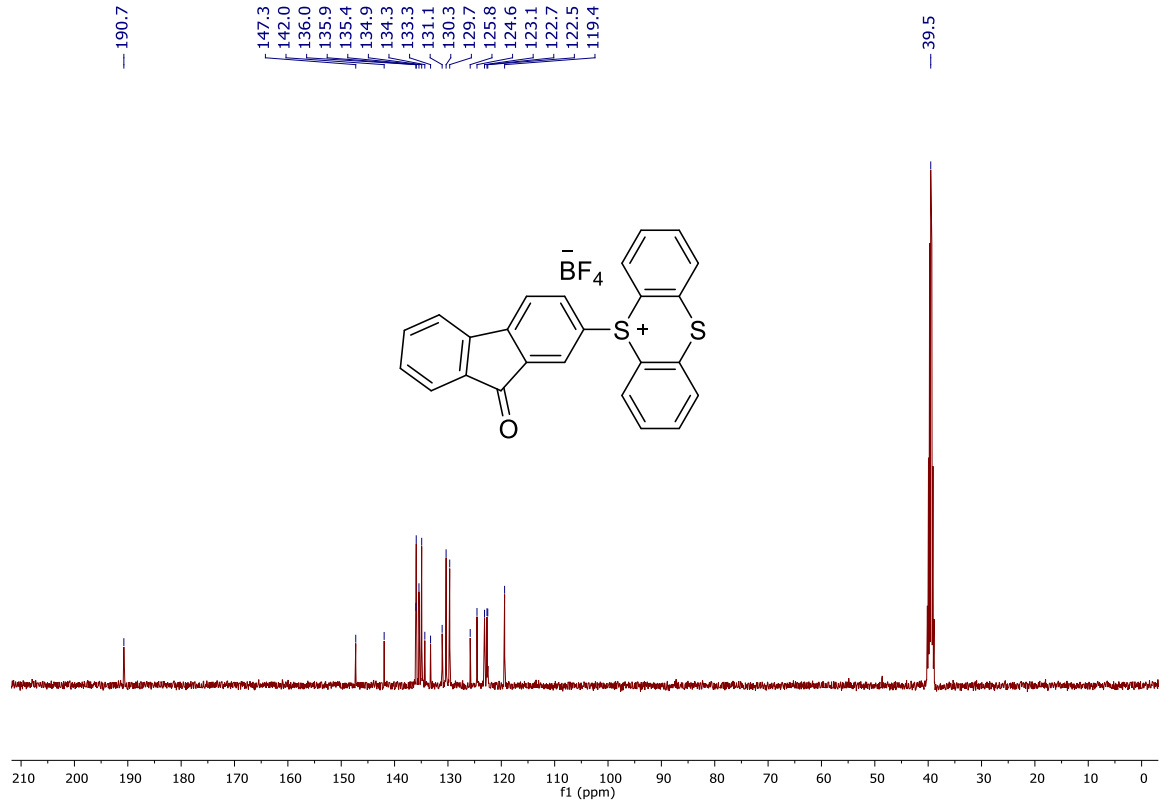


^{1}H NMR spectrum of **2t**

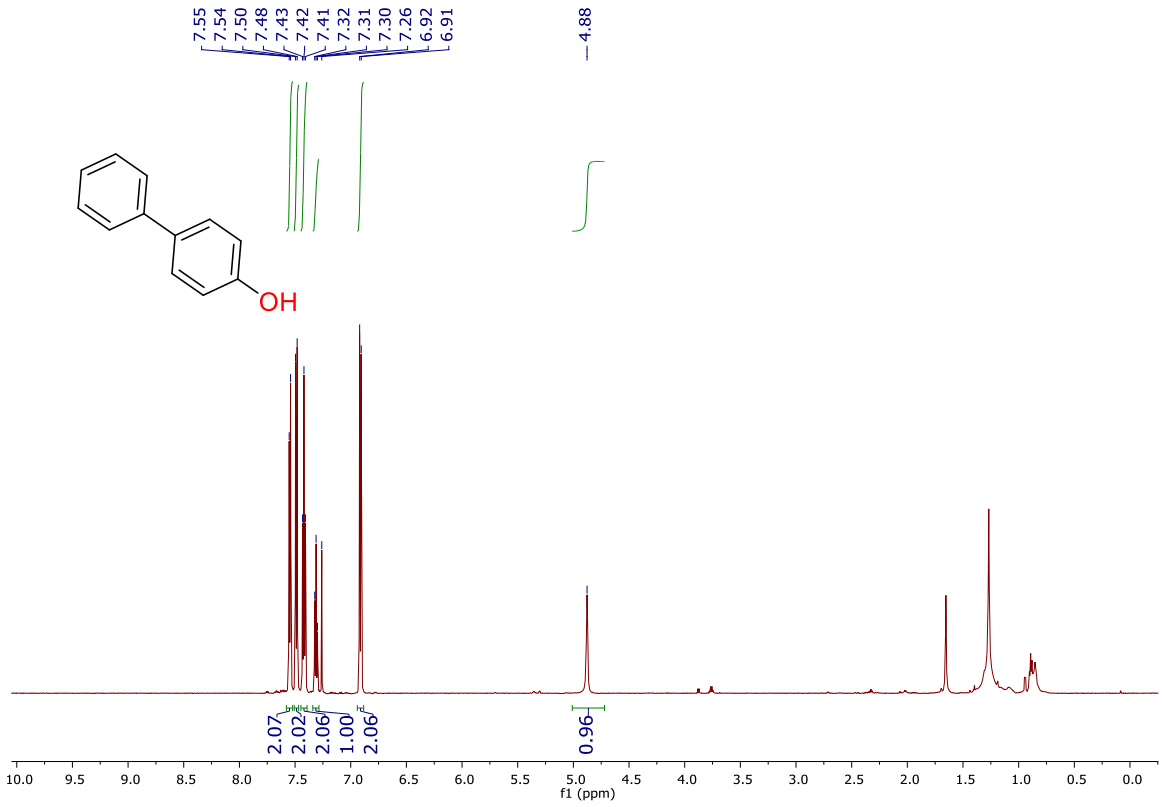


^{19}F NMR spectrum of **2t**

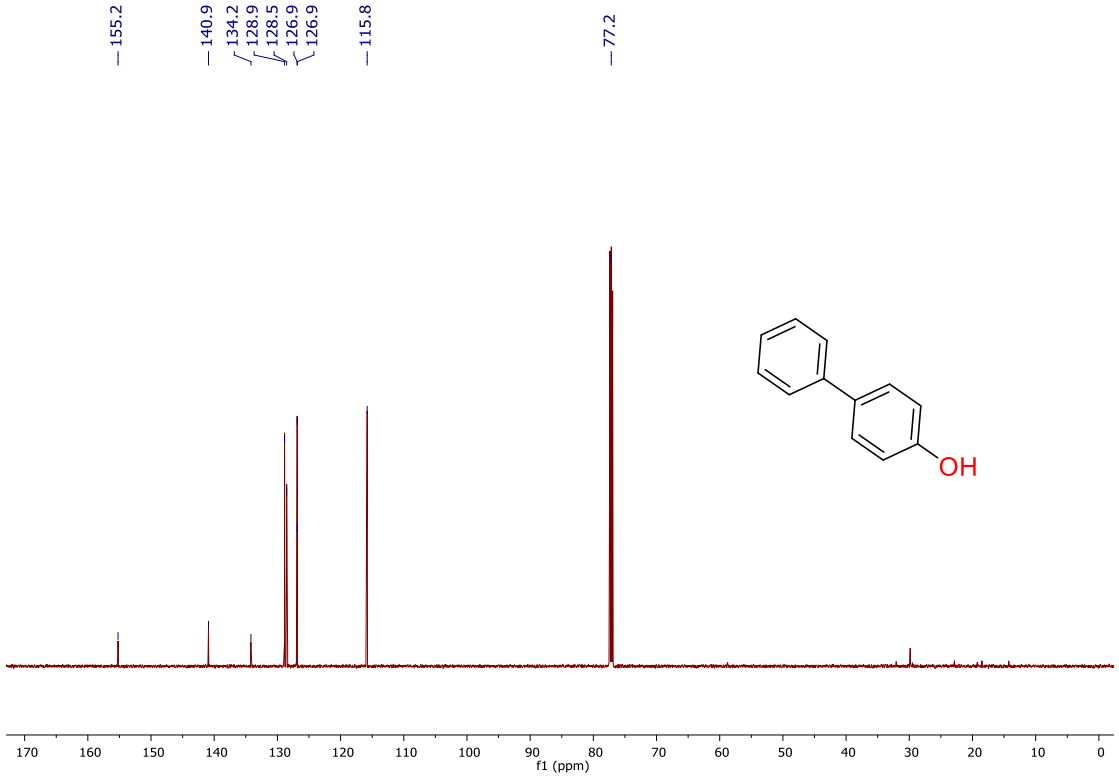
^{13}C NMR spectrum of **2t**



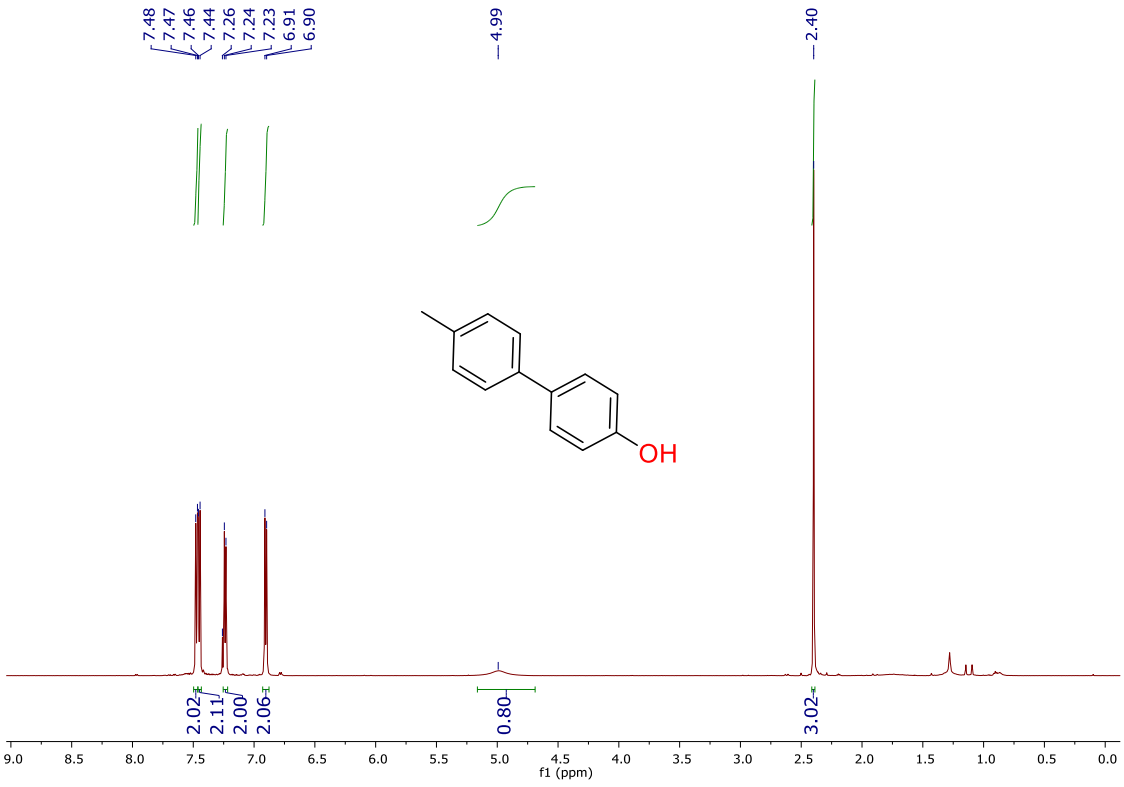
^{1}H NMR spectrum of **3a**



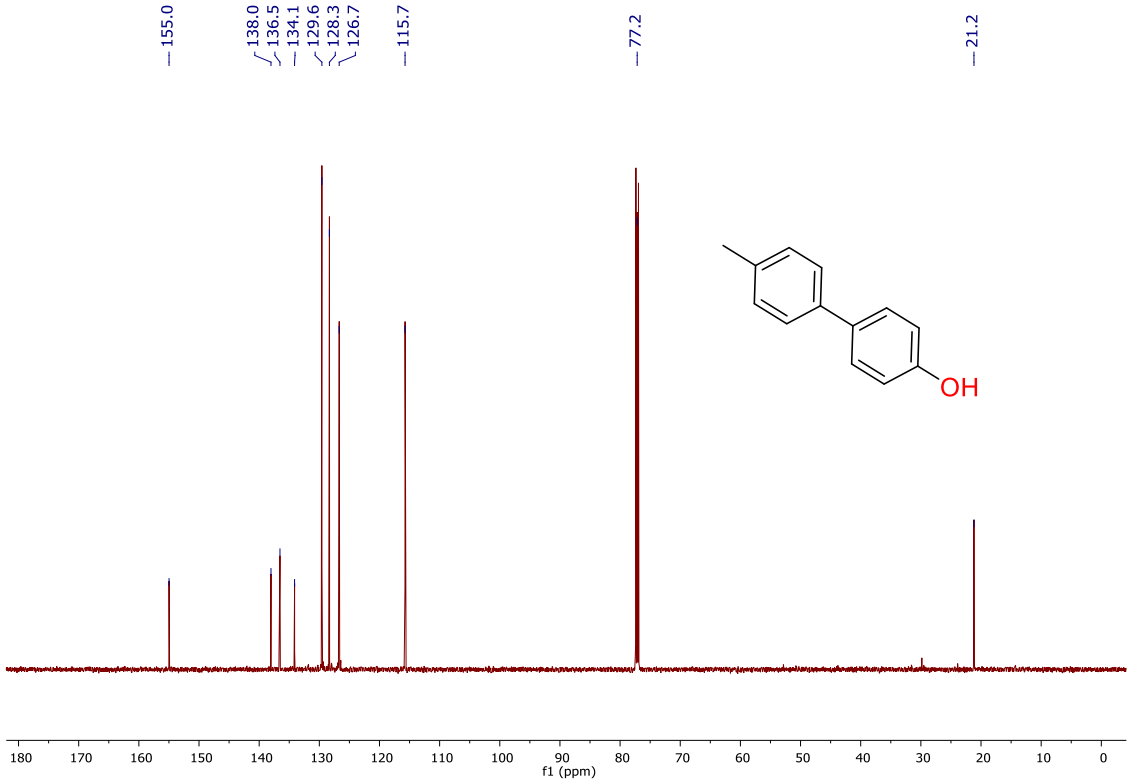
^{13}C NMR spectrum of **3a**



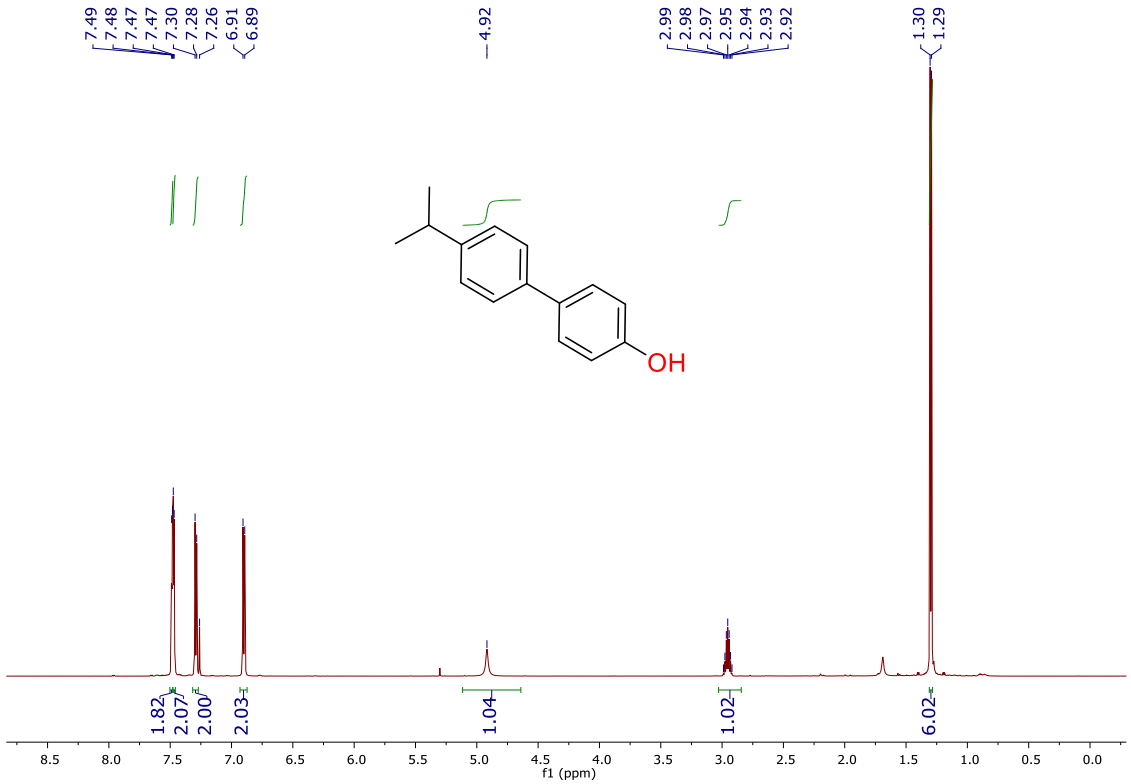
^{1}H NMR spectrum of **3b**



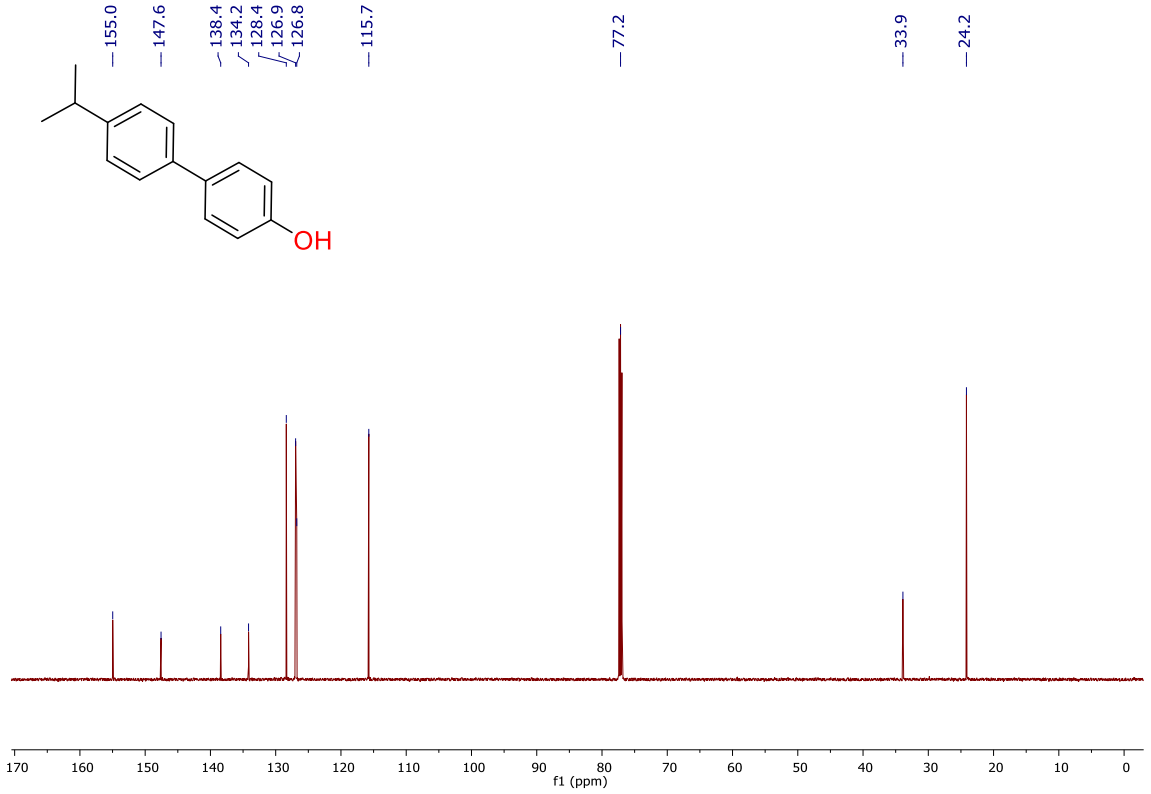
^{13}C NMR spectrum of **3b**



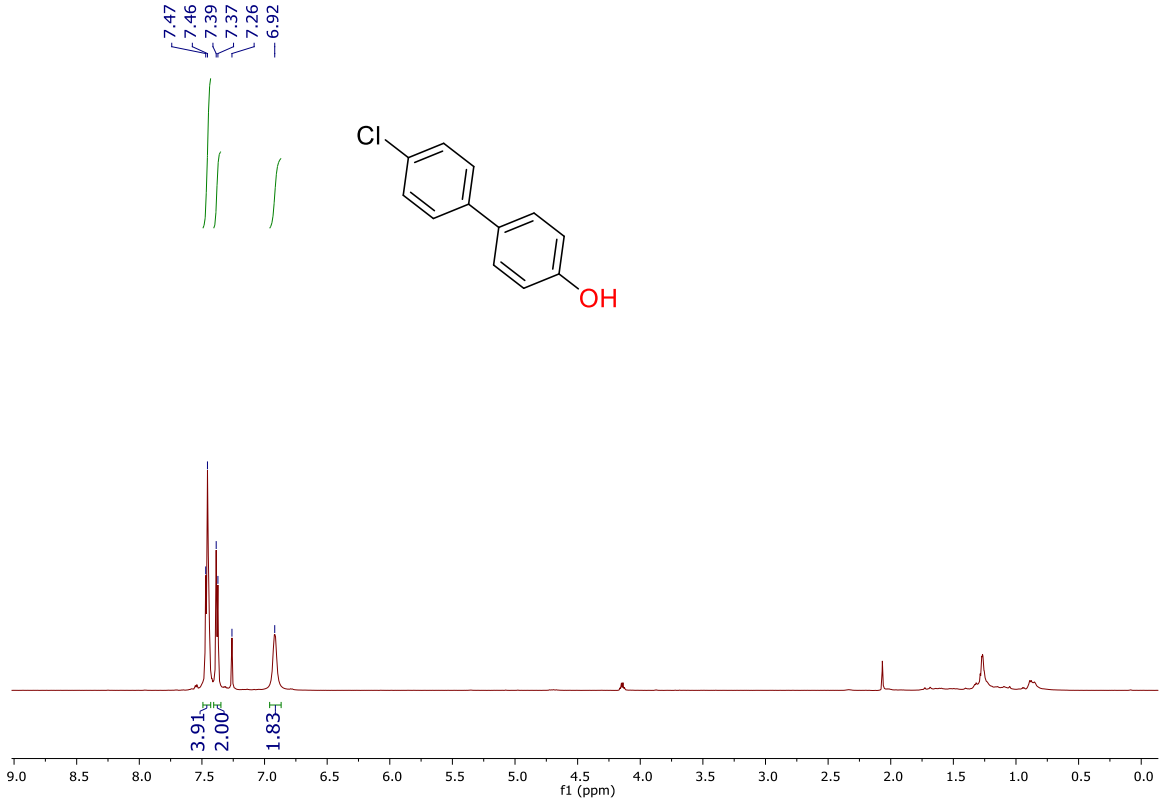
^{1}H NMR spectrum of **3c**



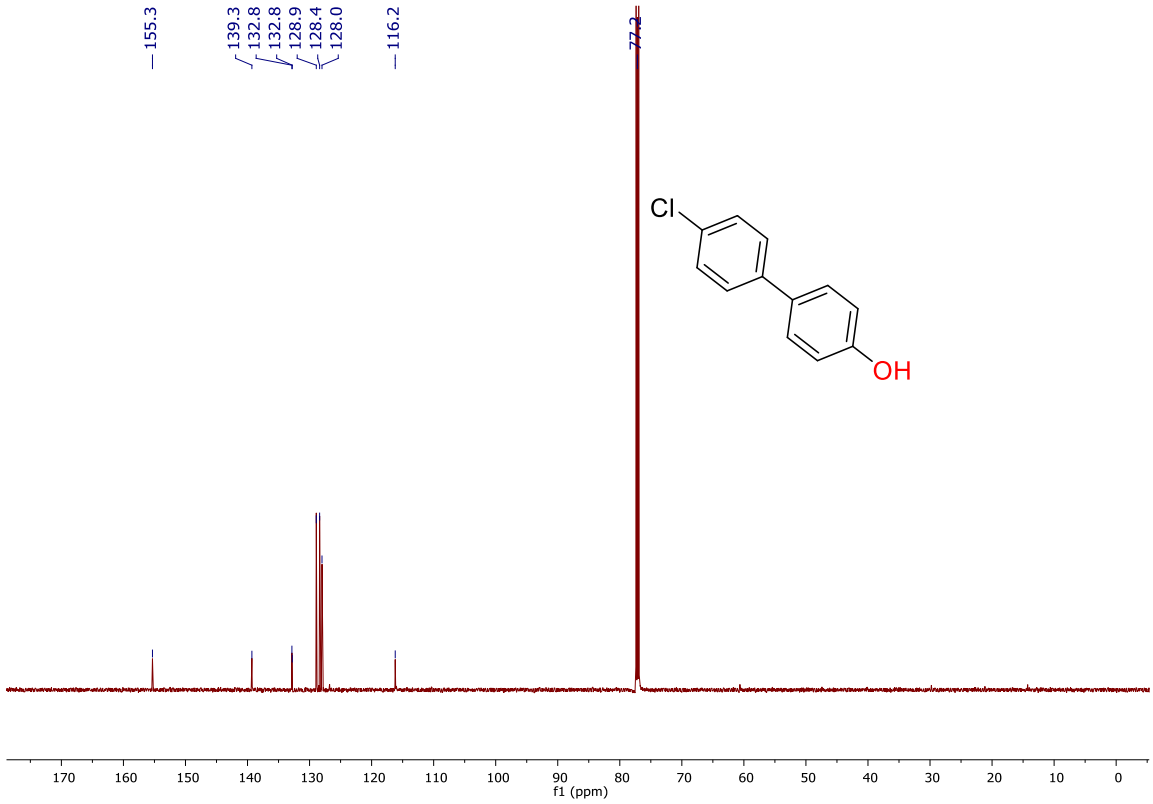
^{13}C NMR spectrum of **3c**



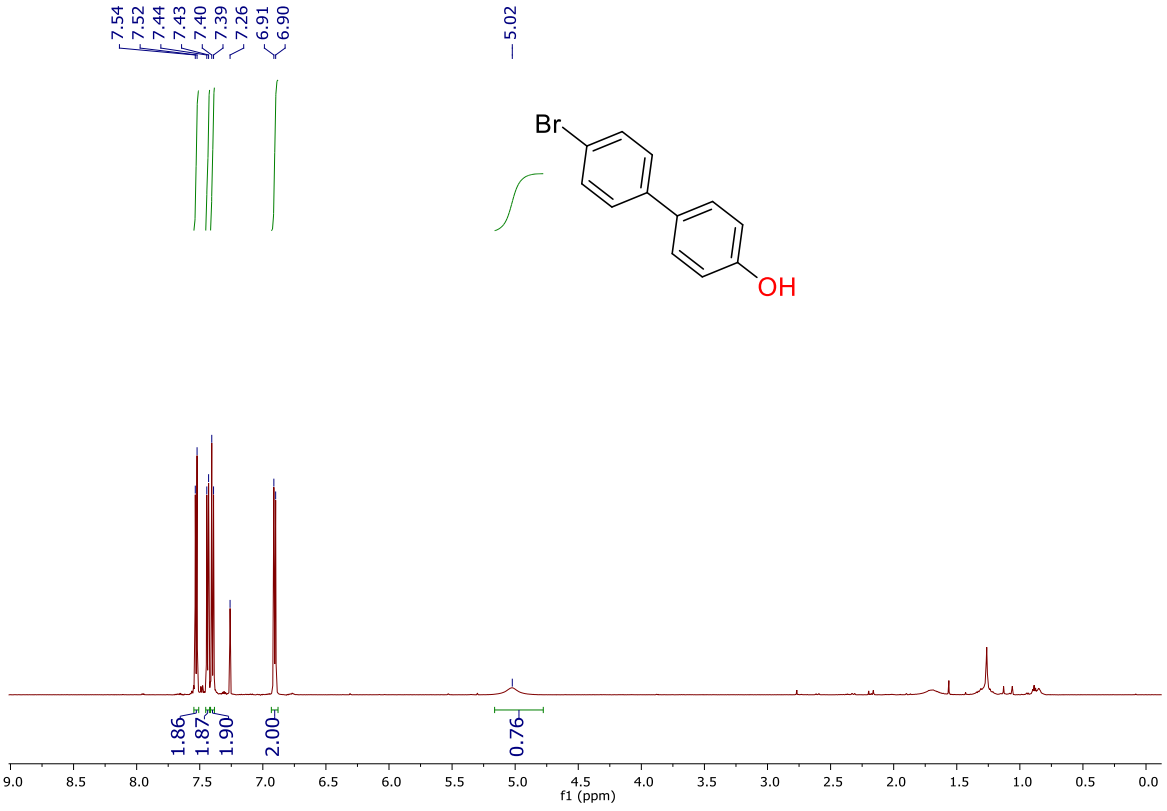
^{1}H NMR spectrum of **3d**



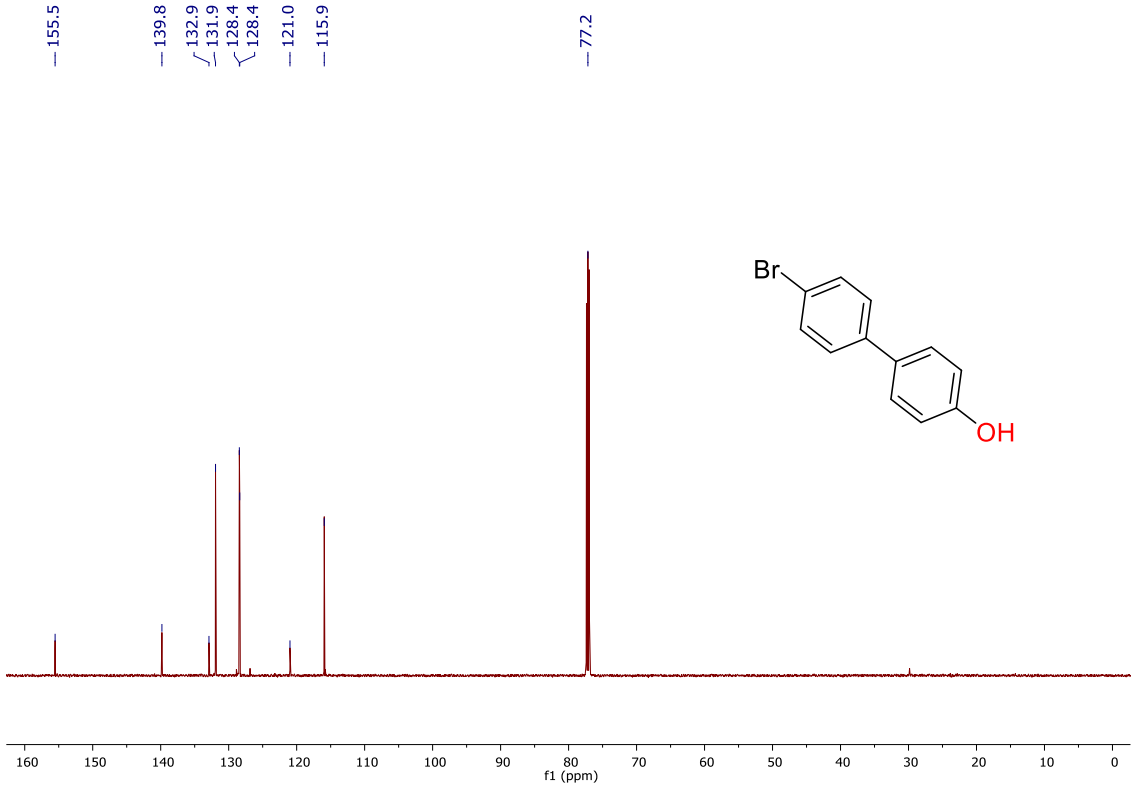
^{13}C NMR spectrum of **3d**



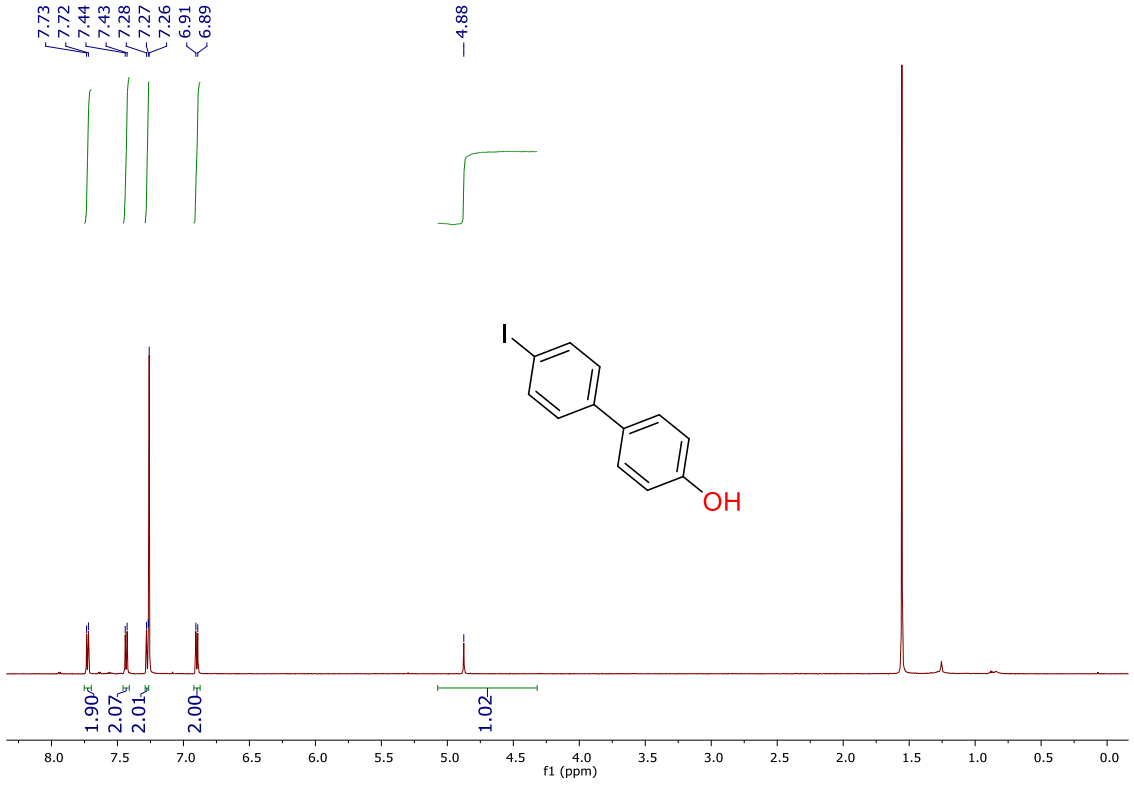
^{1}H NMR spectrum of **3e**



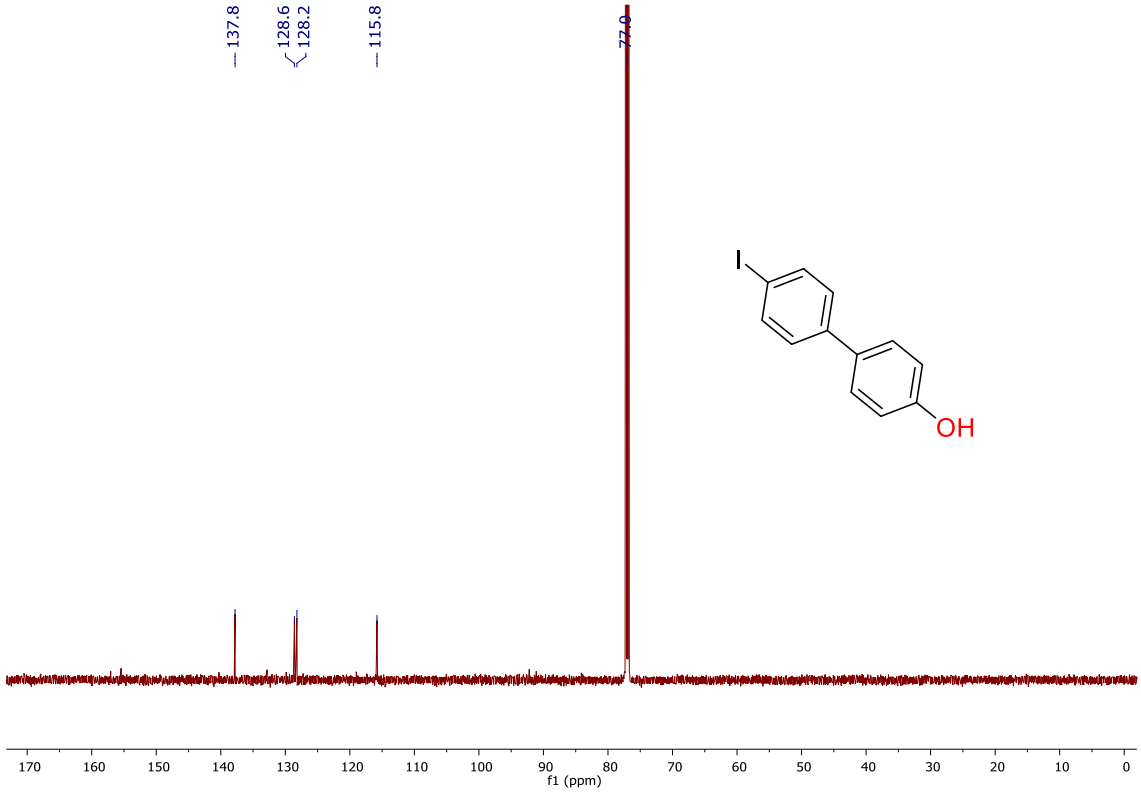
^{13}C NMR spectrum of **3e**



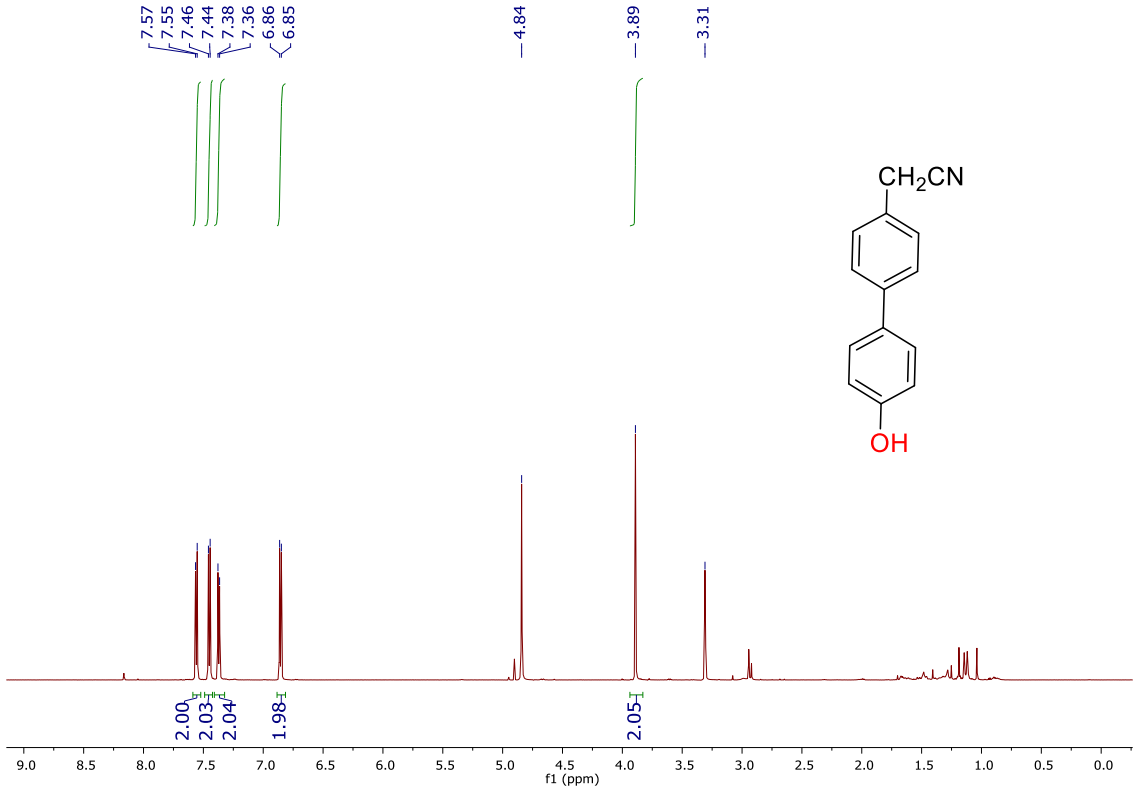
^{1}H NMR spectrum of **3f**



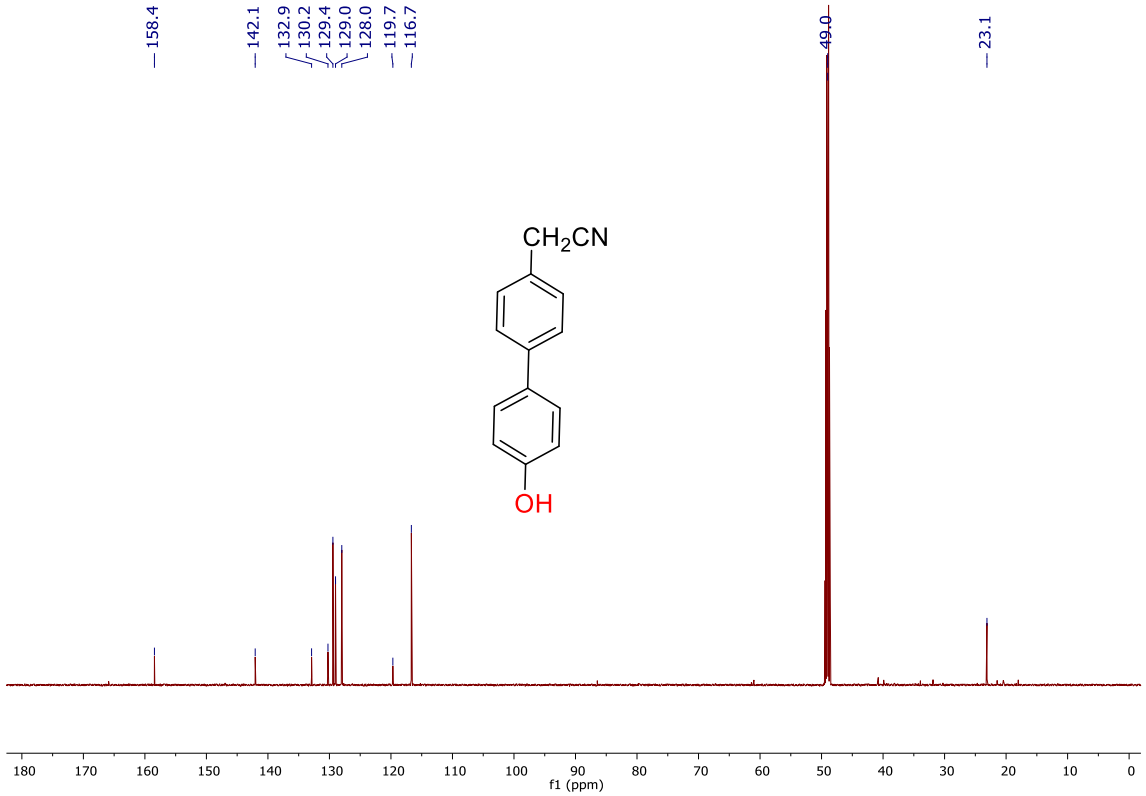
^{13}C NMR spectrum of **3f**



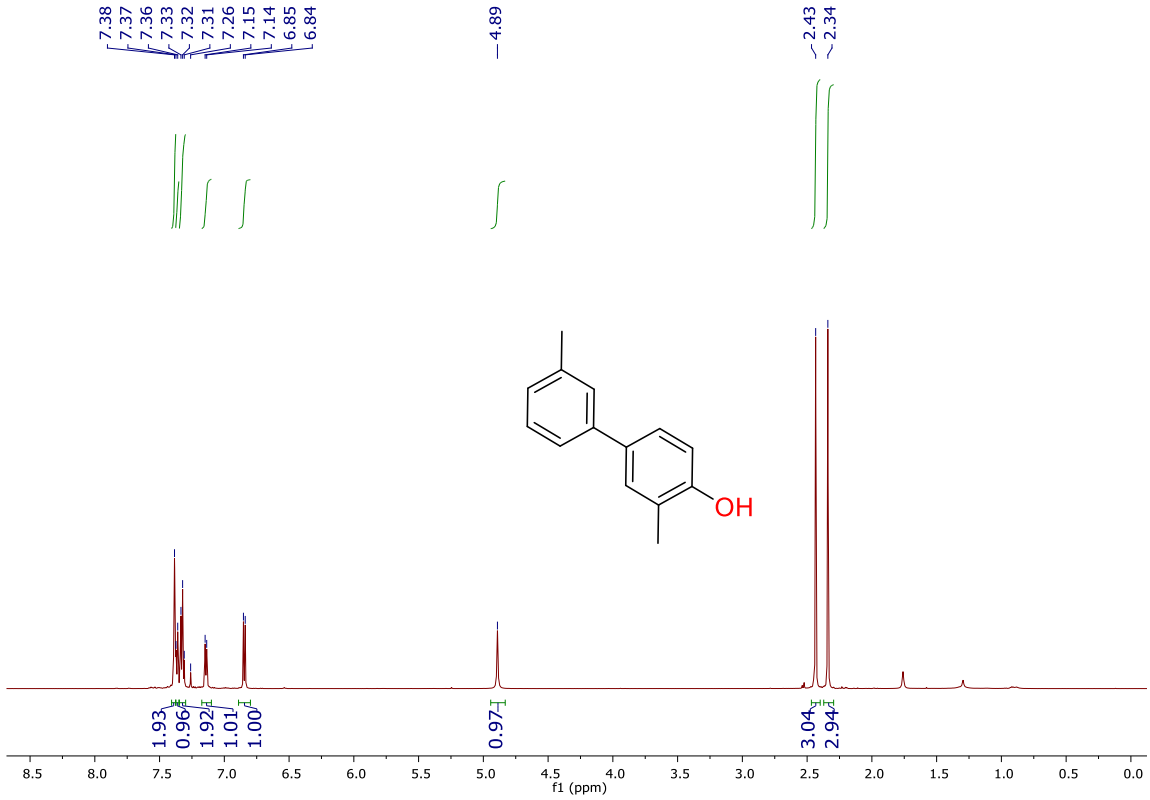
^{1}H NMR spectrum of **3g**



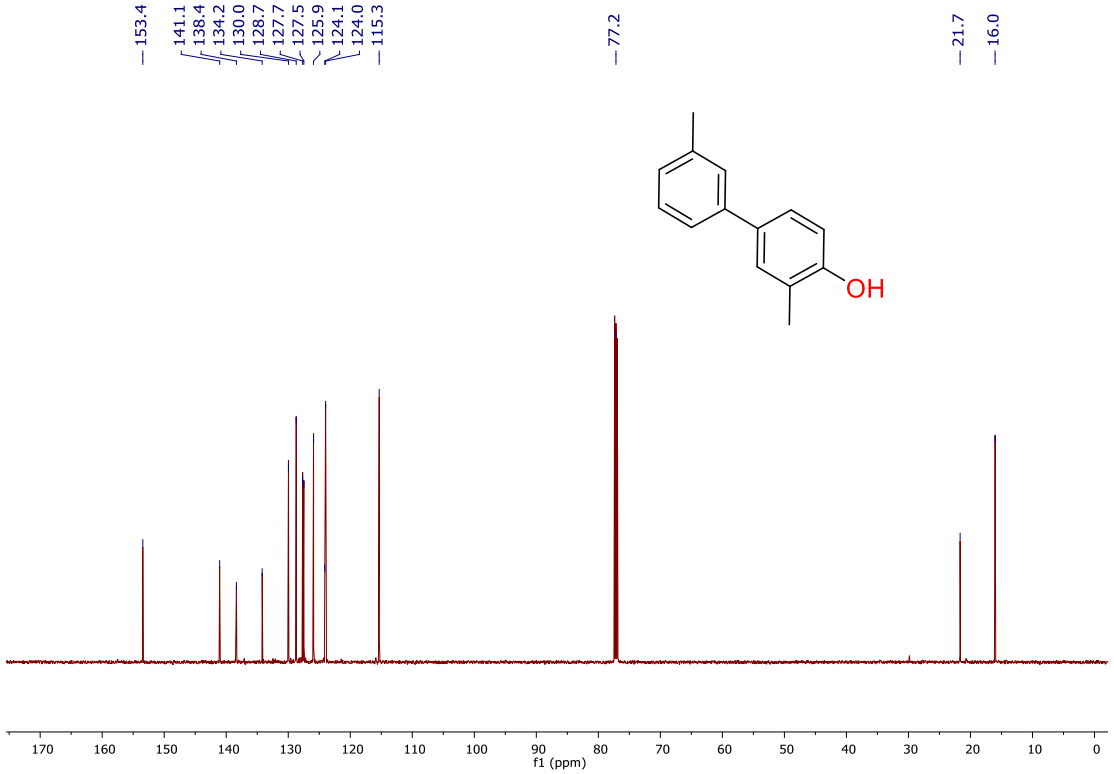
^{13}C NMR spectrum of **3g**



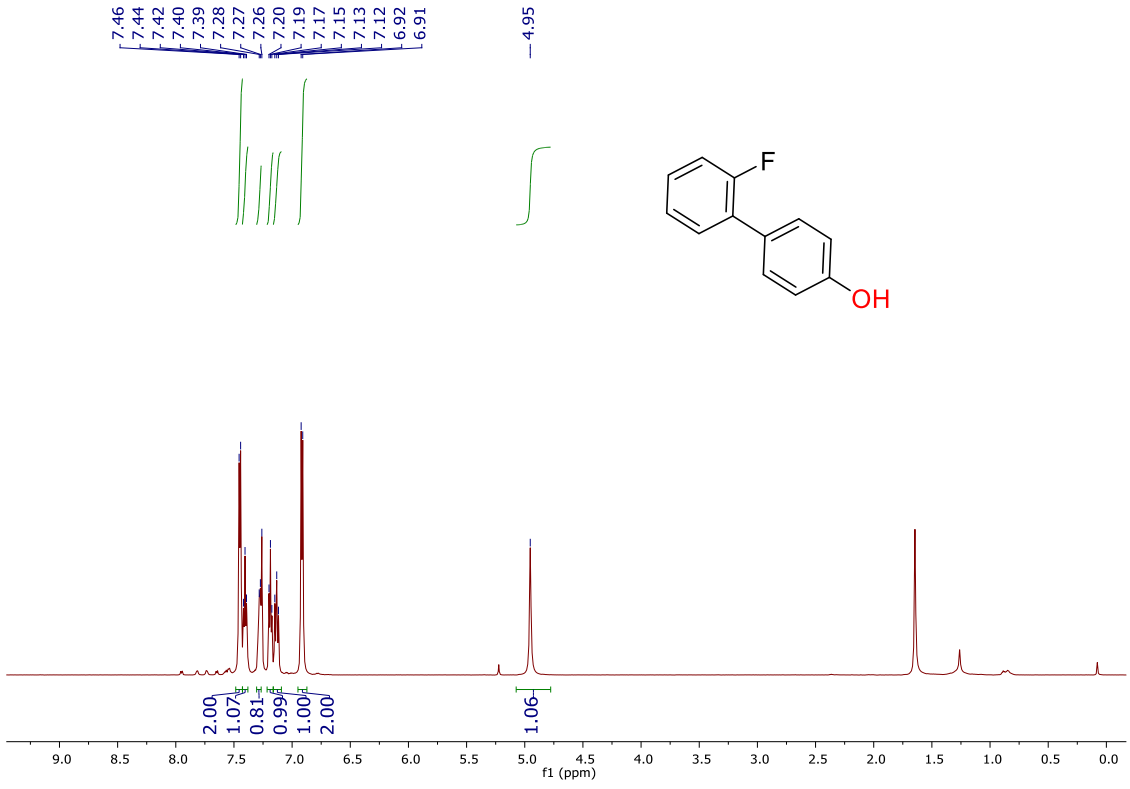
^{1}H NMR spectrum of **3h**



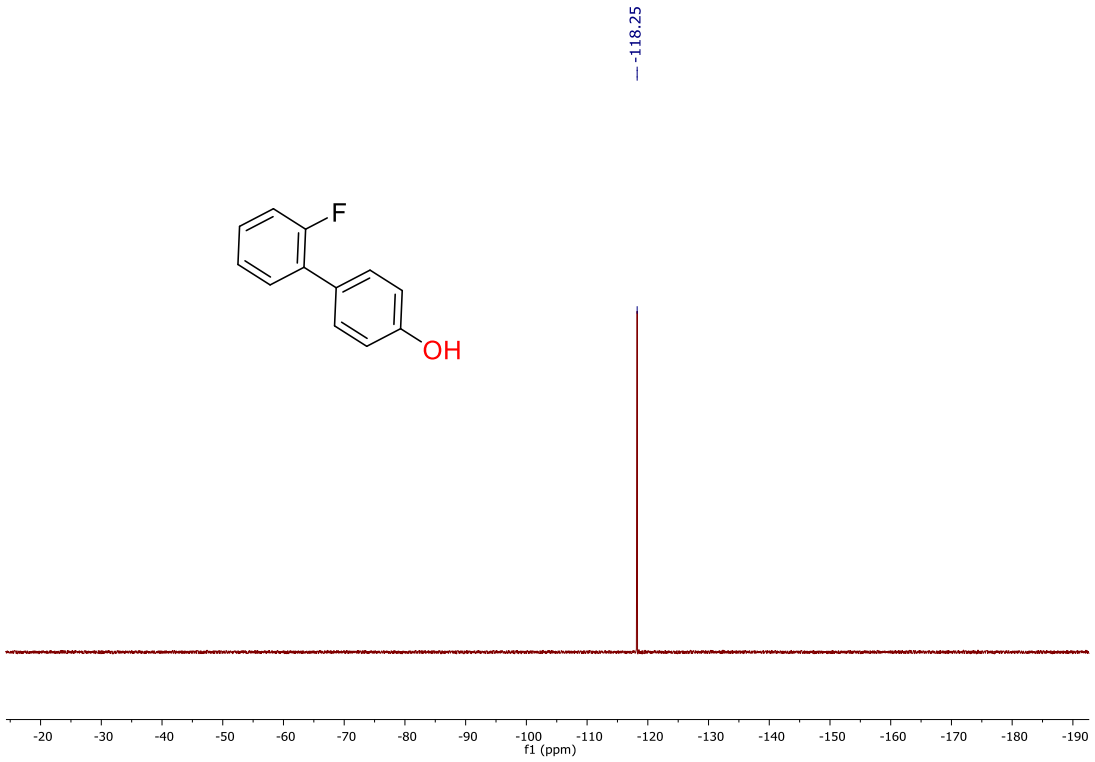
^{13}C NMR spectrum of **3h**



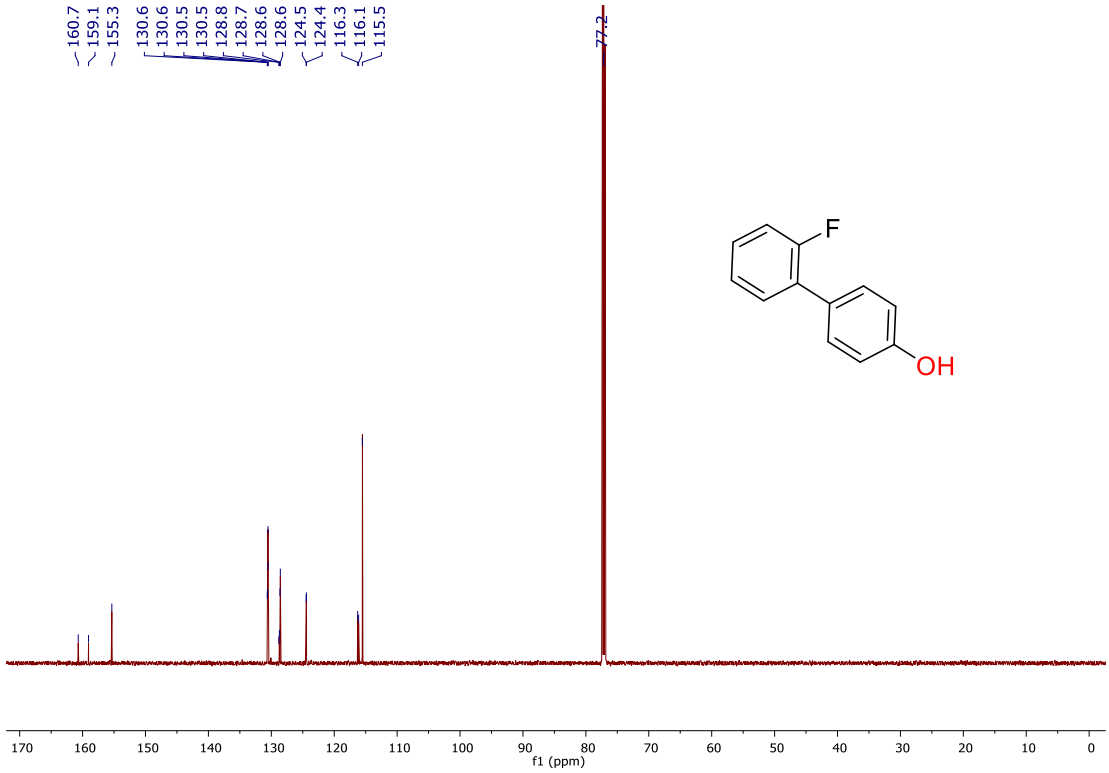
^{1}H NMR spectrum of **3i**



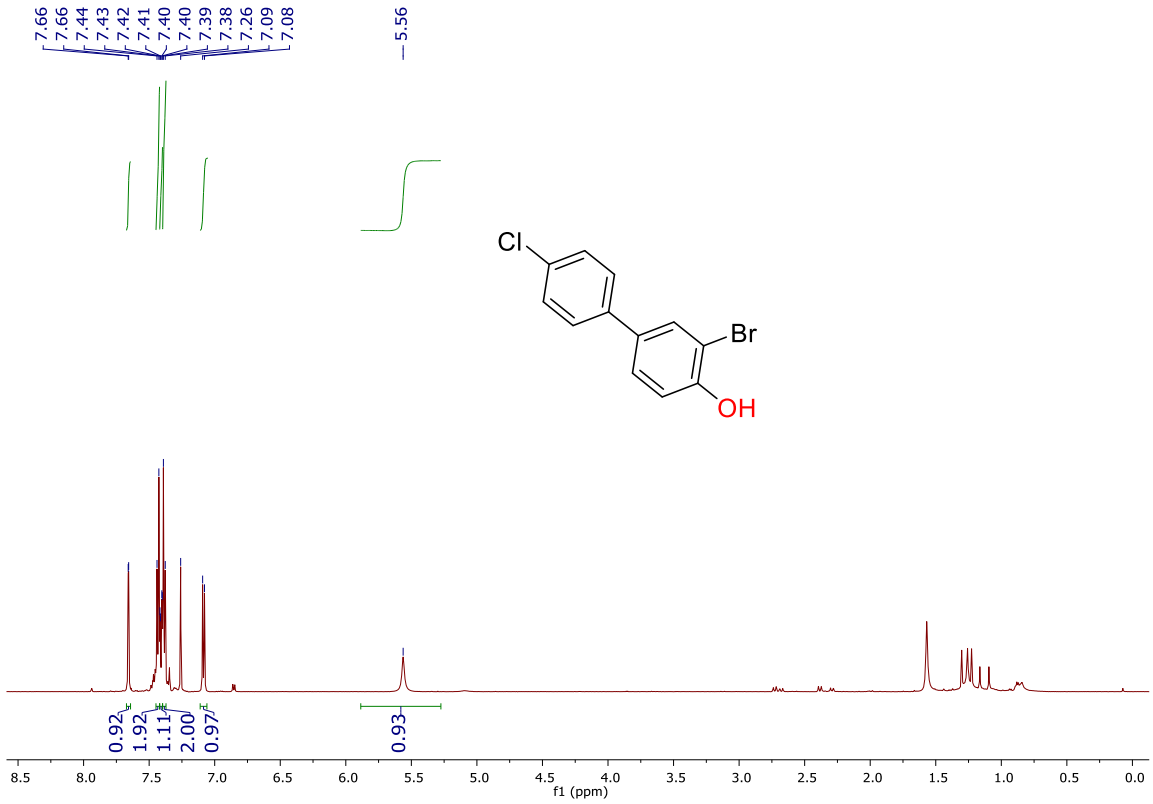
^{19}F NMR spectrum of **3i**



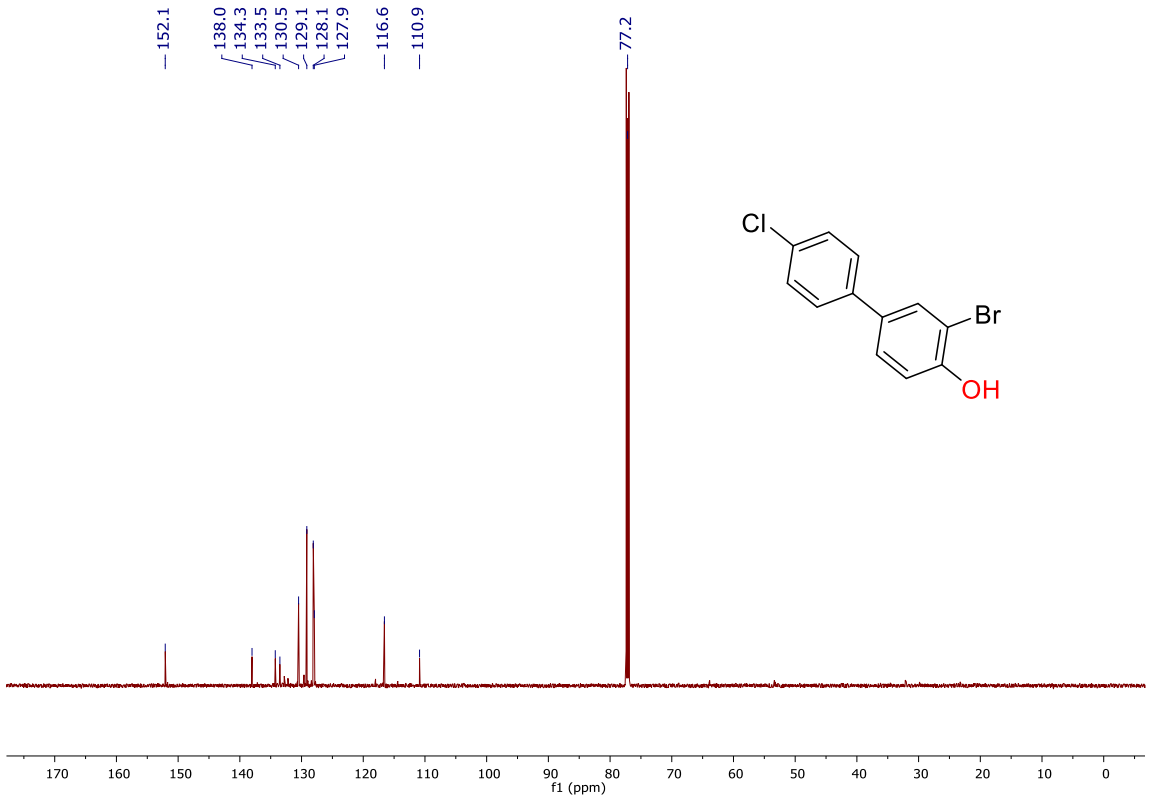
^{13}C NMR spectrum of **3i**



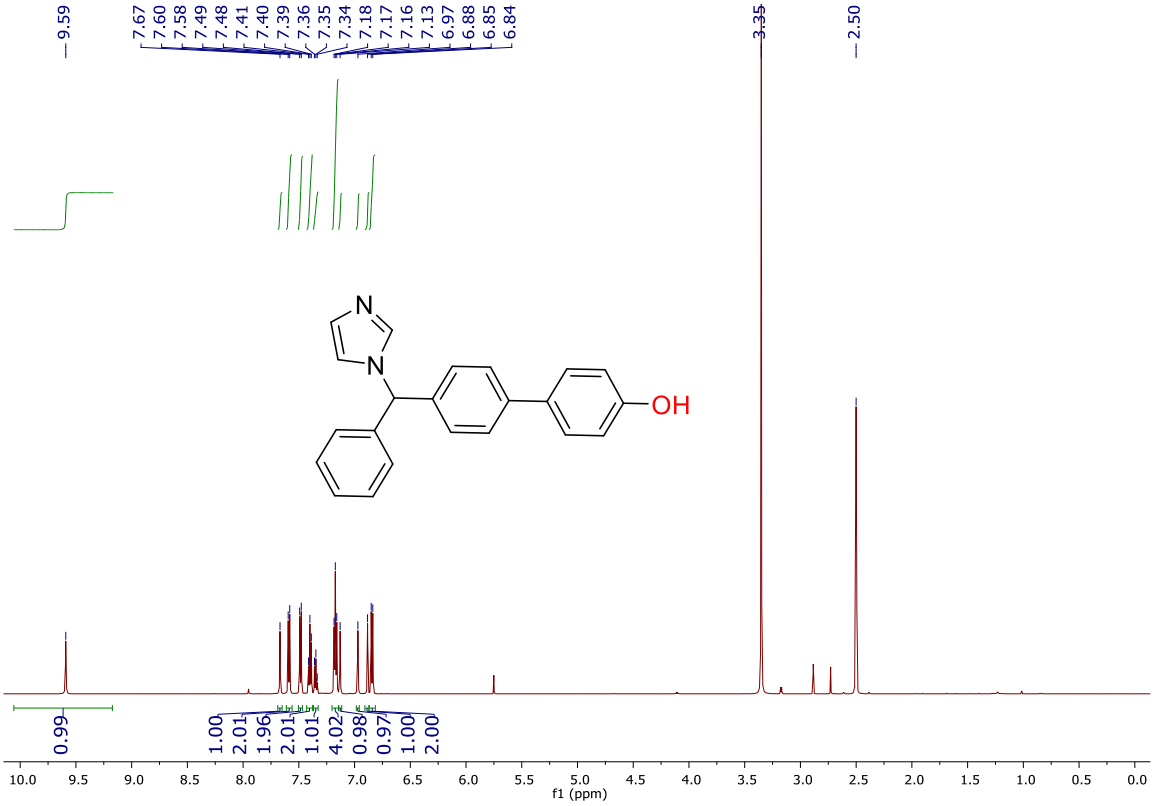
^{1}H NMR spectrum of **3j**



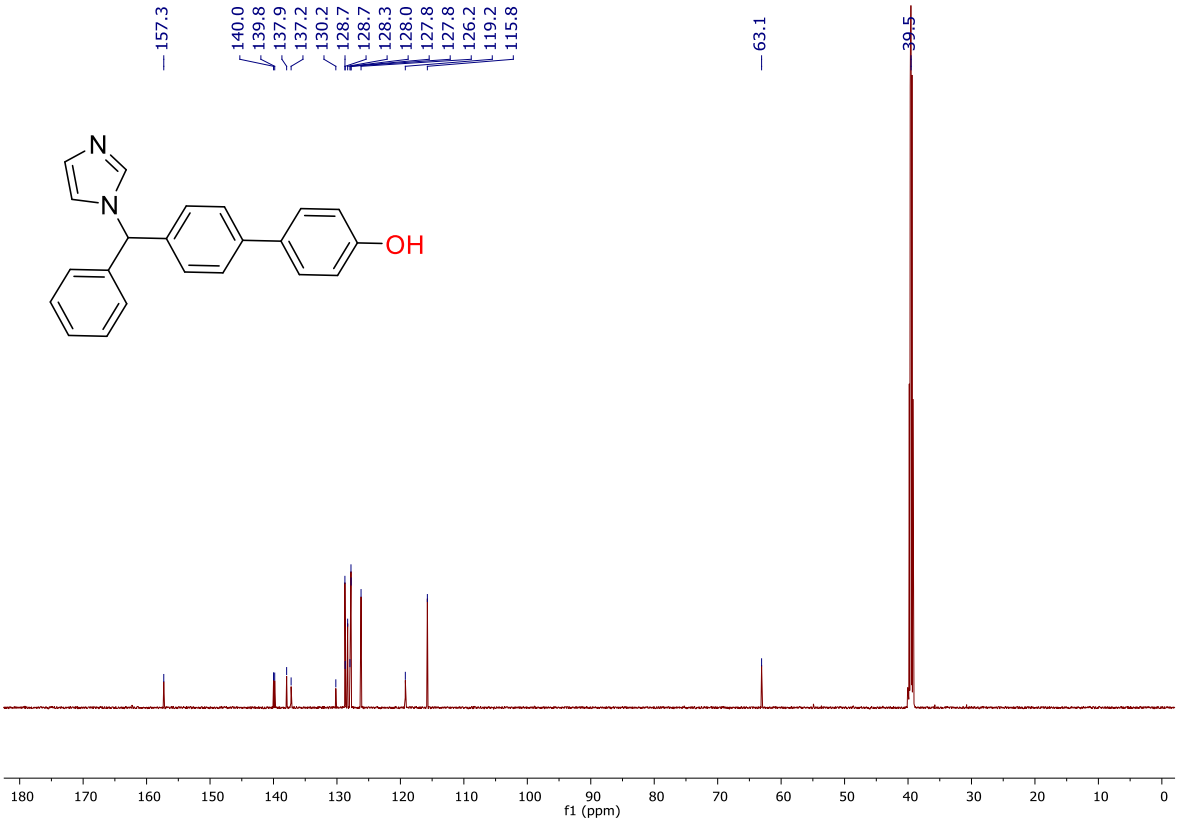
^{13}C NMR spectrum of **3j**



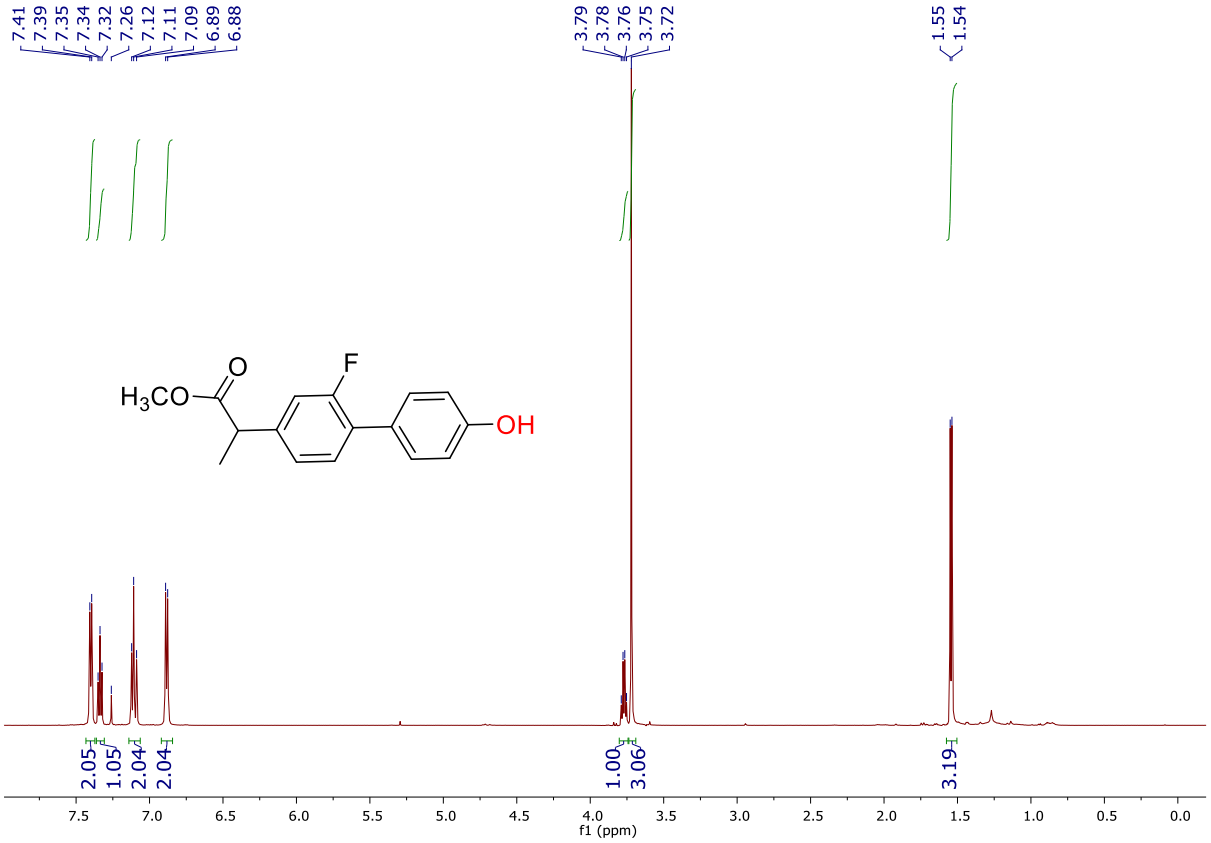
^{1}H NMR spectrum of **3k**



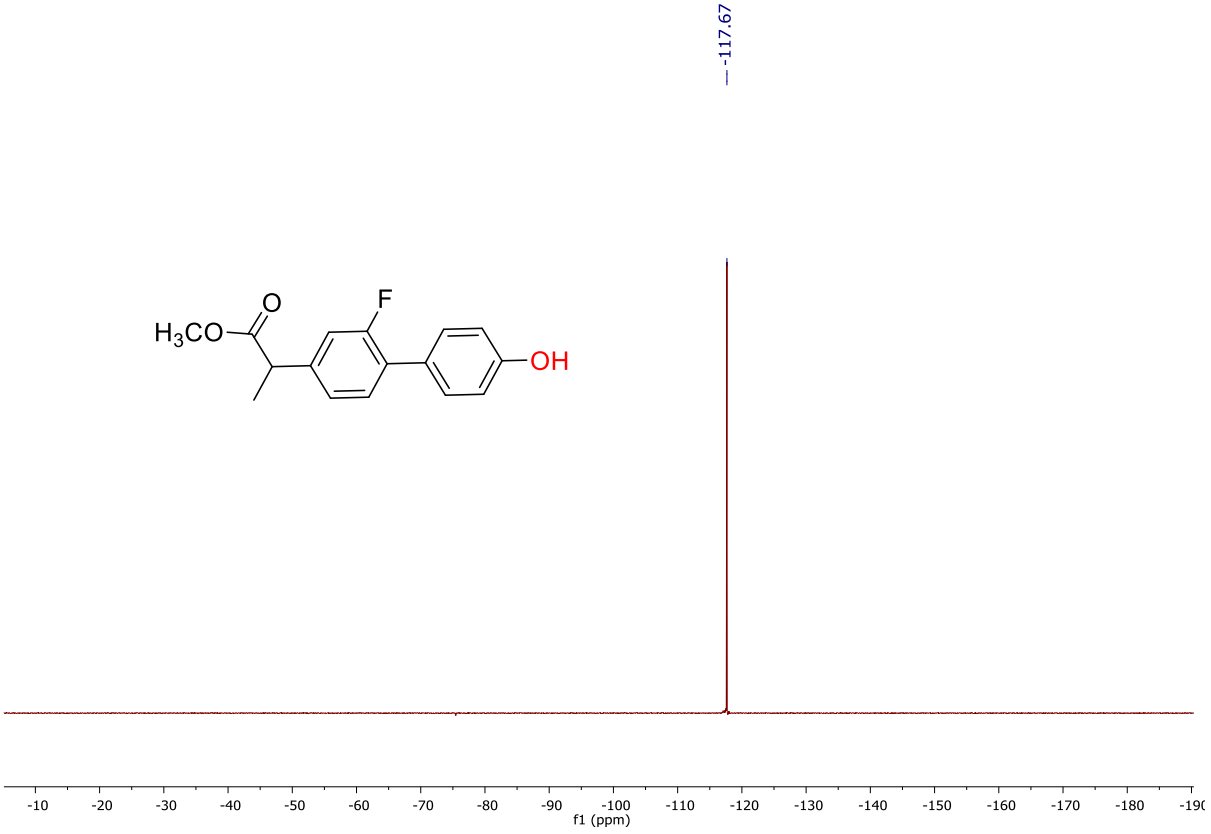
^{13}C NMR spectrum of **3k**



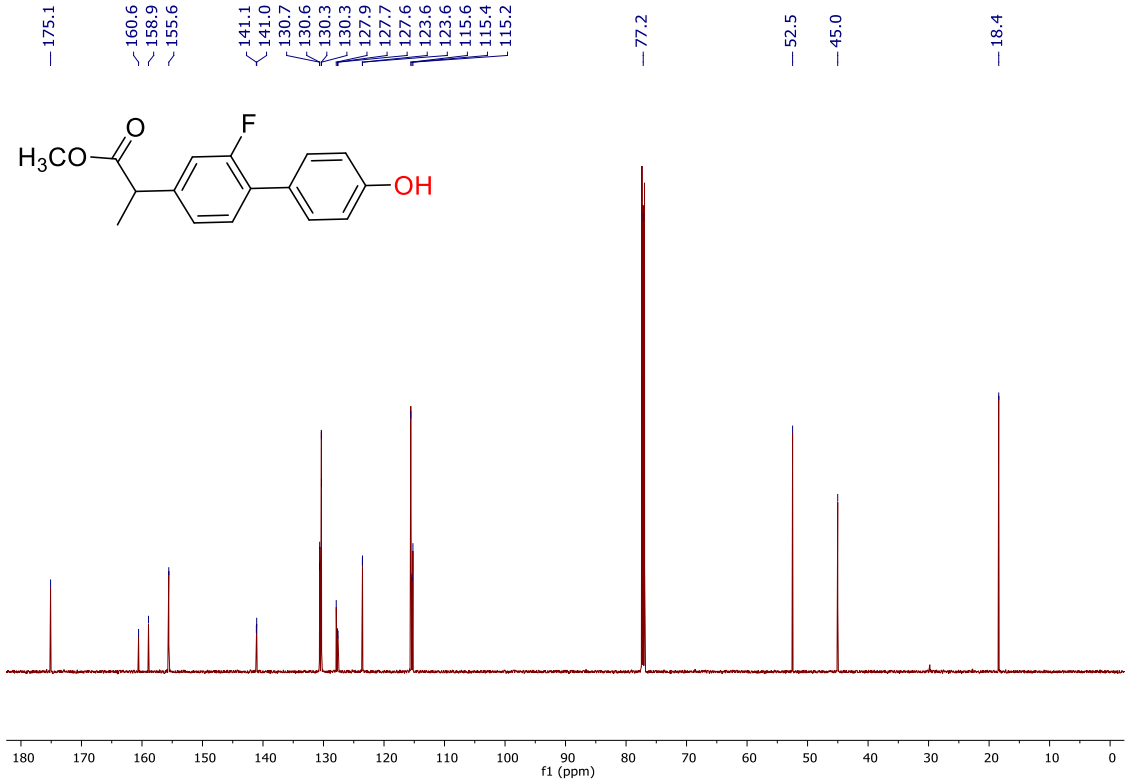
^{1}H NMR spectrum of **3l**



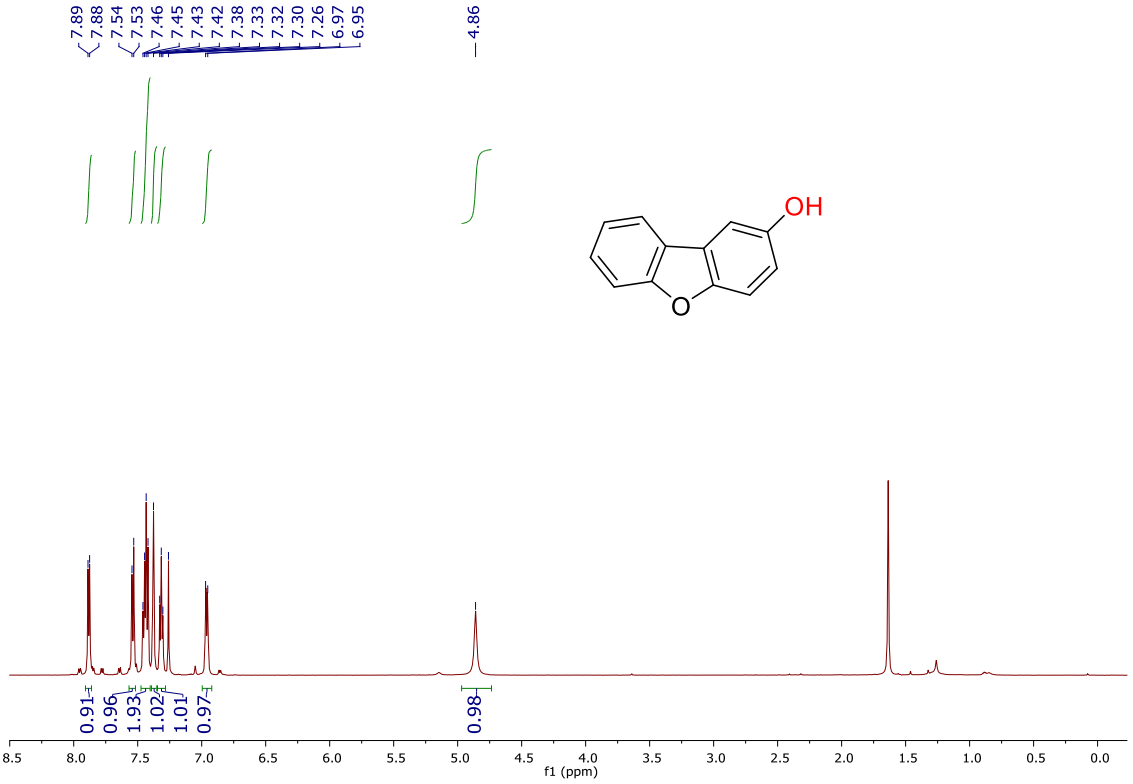
^{19}F NMR spectrum of **3l**



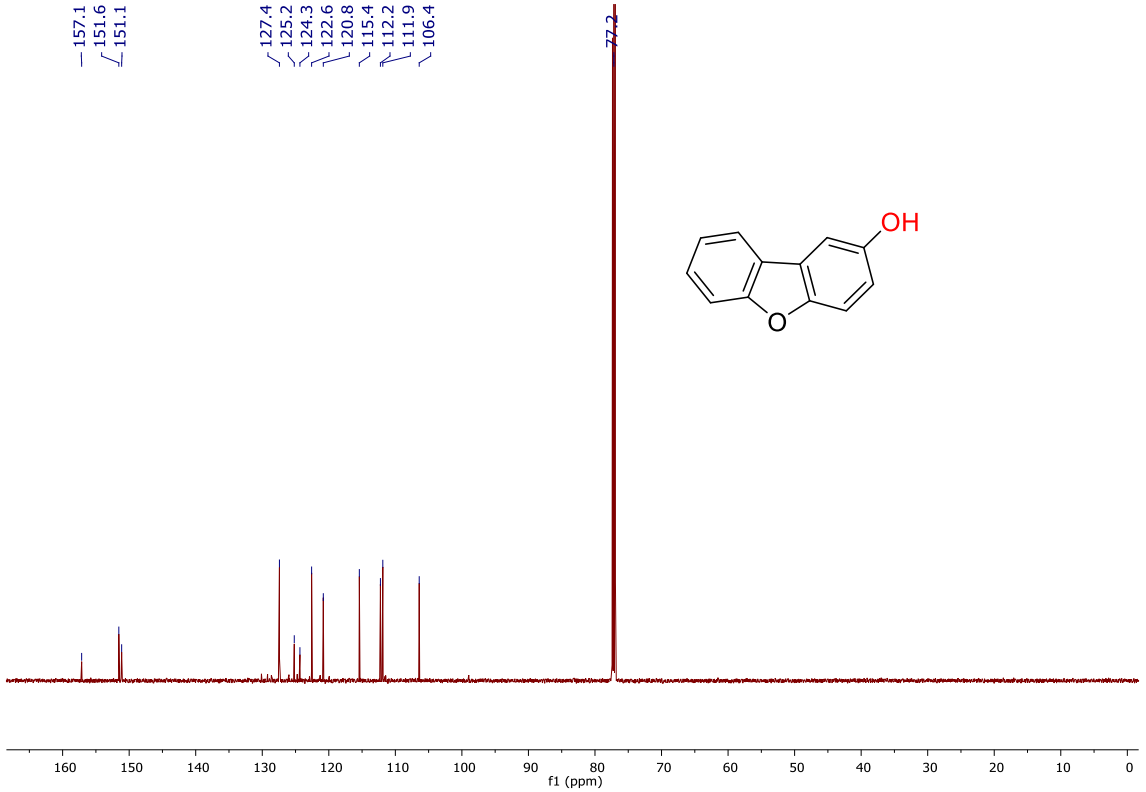
^{13}C NMR spectrum of **3l**



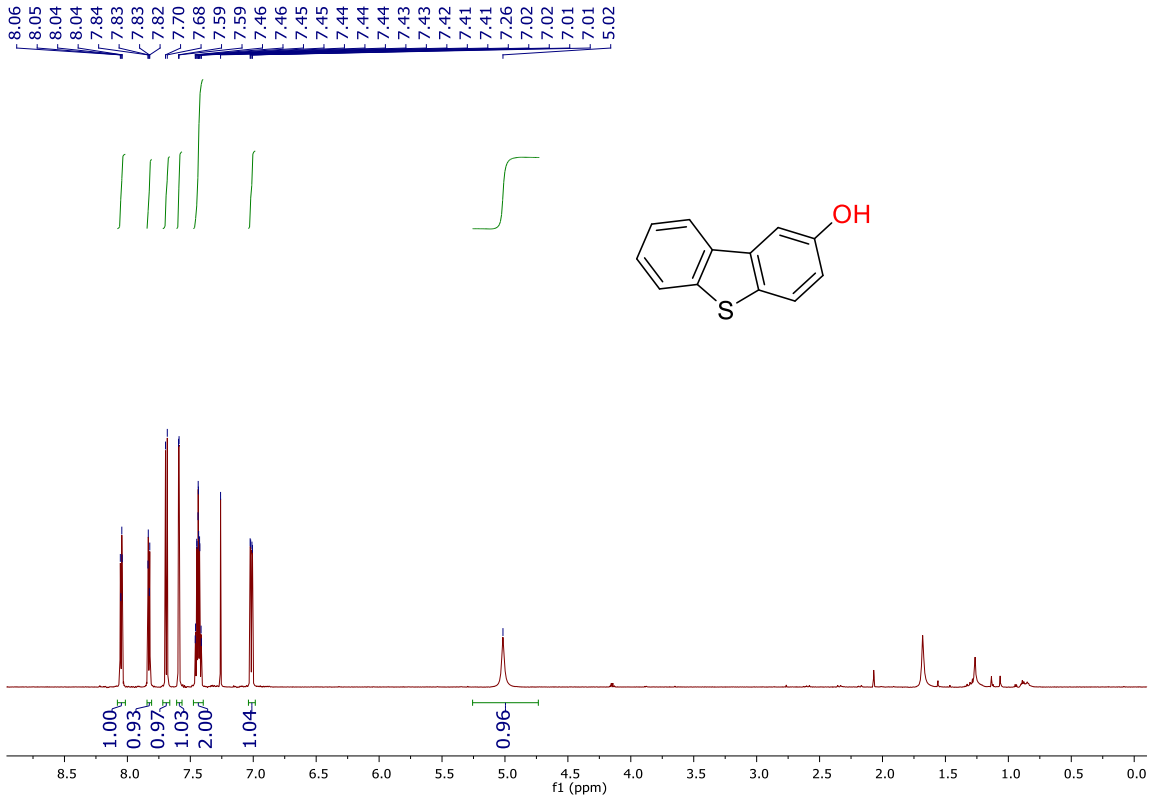
^{1}H NMR spectrum of **3m**



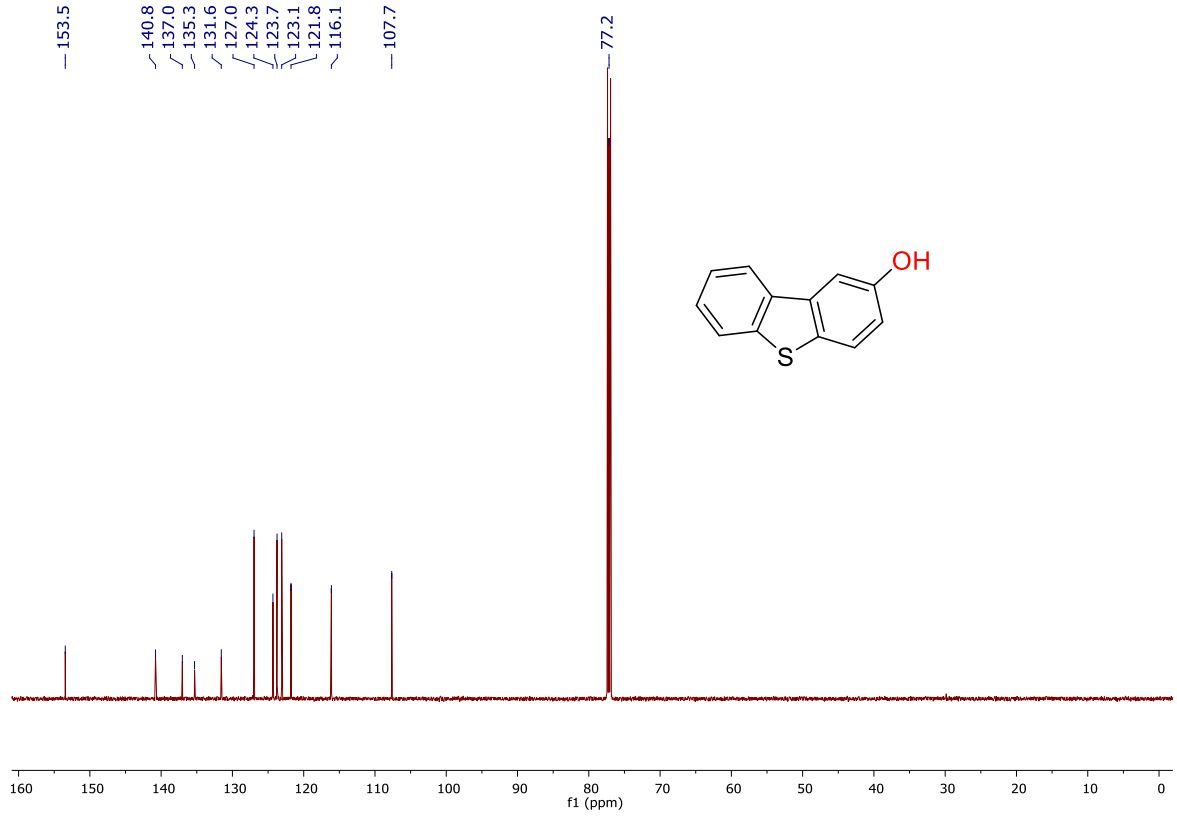
^{13}C NMR spectrum of **3m**



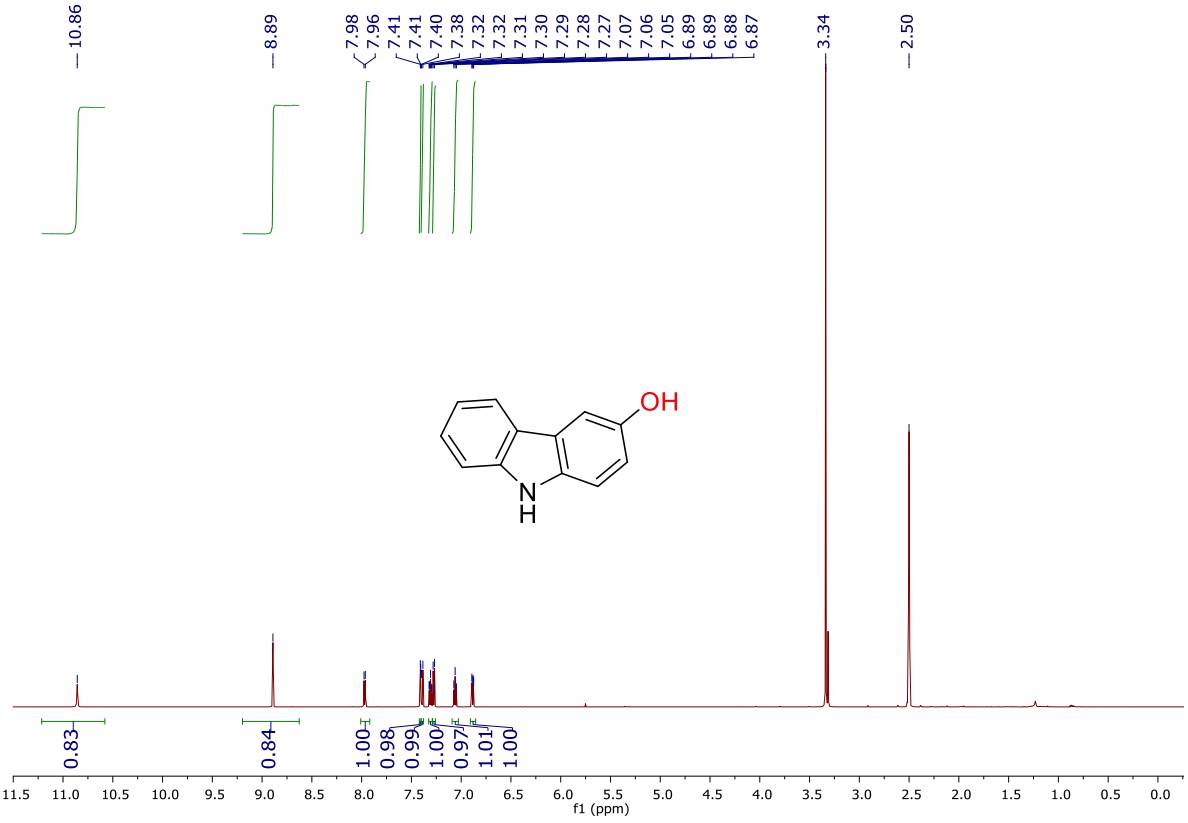
^{1}H NMR spectrum of **3n**



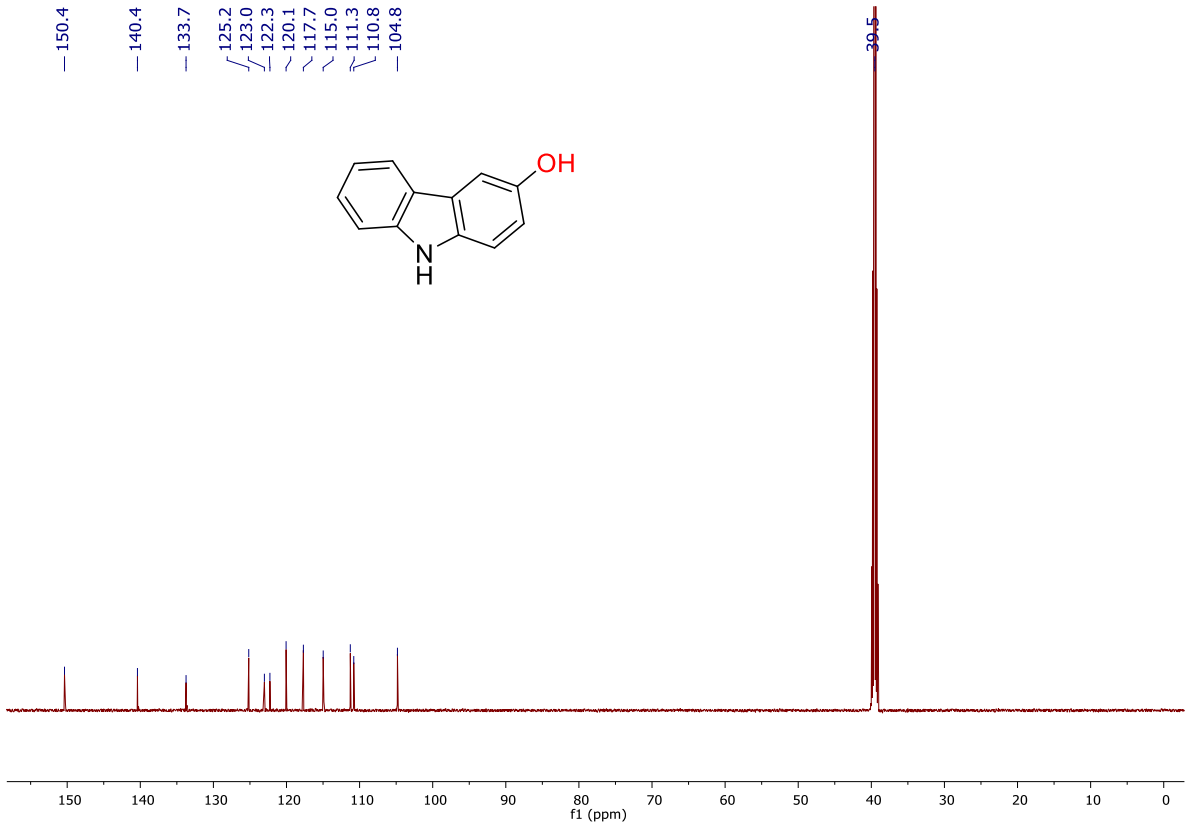
^{13}C NMR spectrum of **3n**



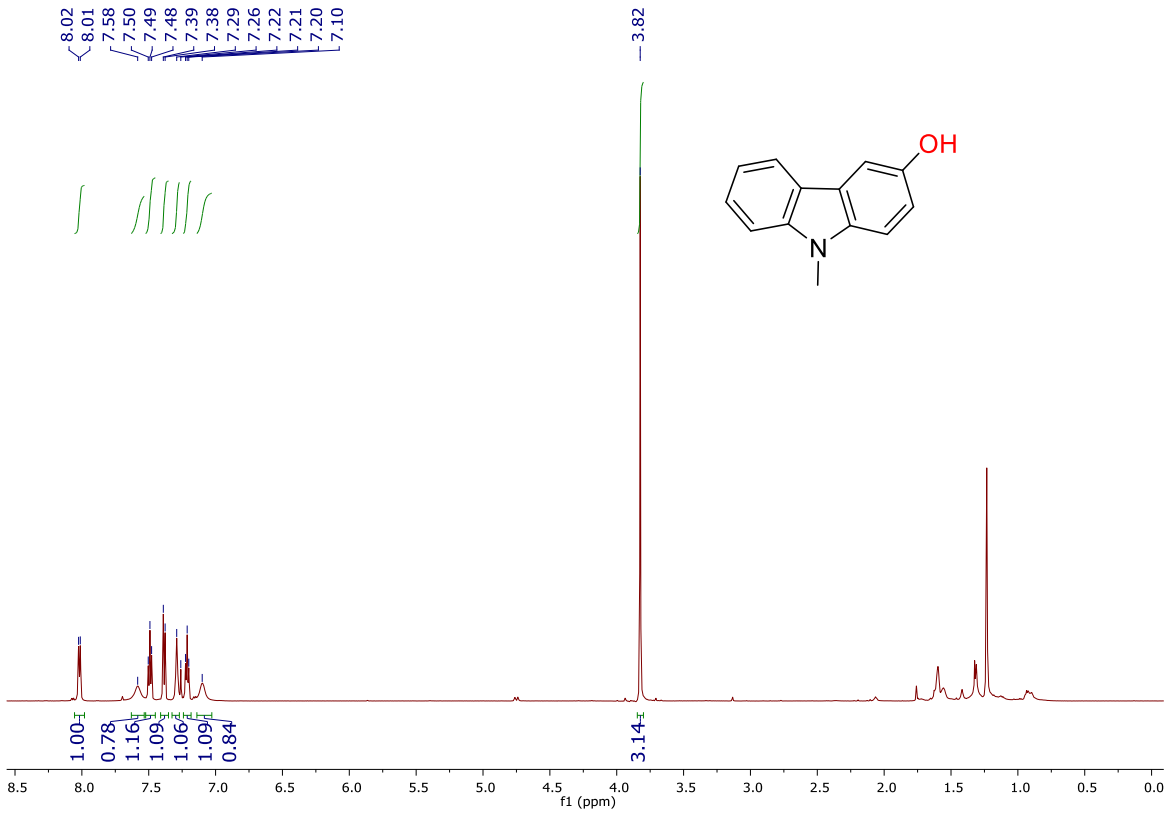
^{1}H NMR spectrum of **3o**



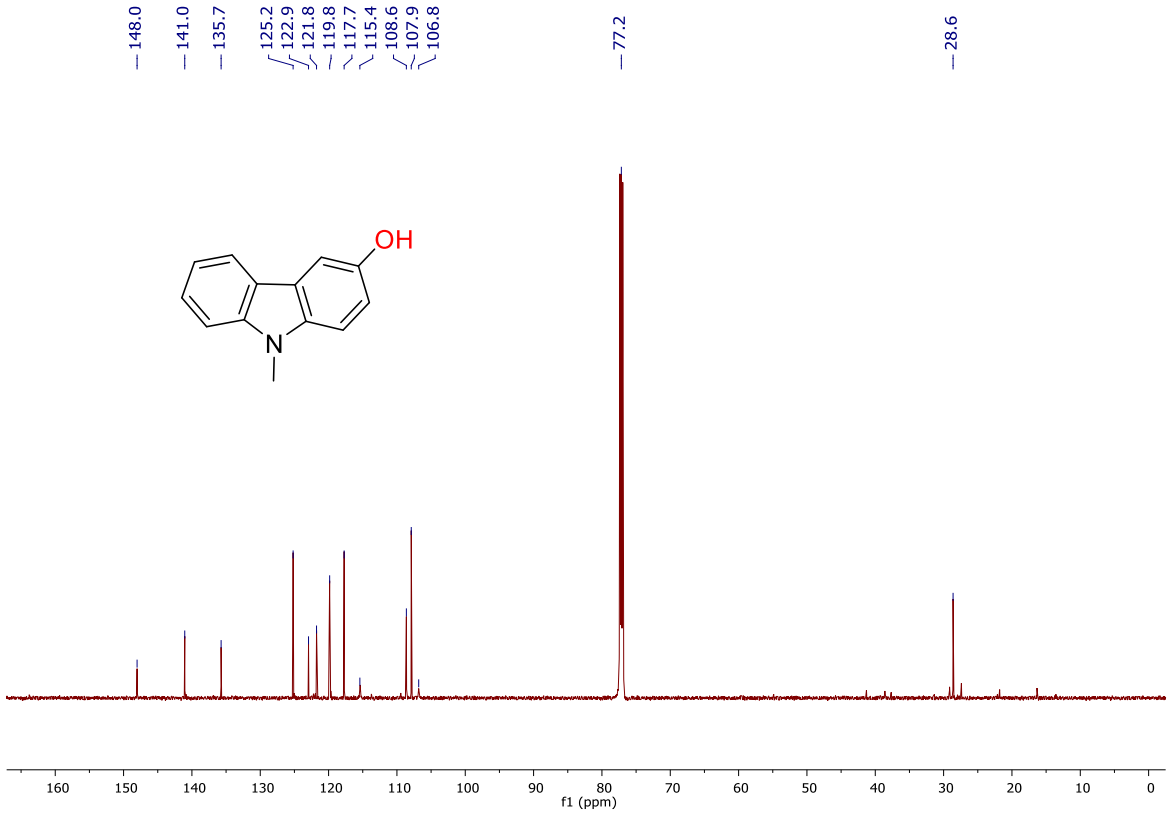
^{13}C NMR spectrum of **3o**



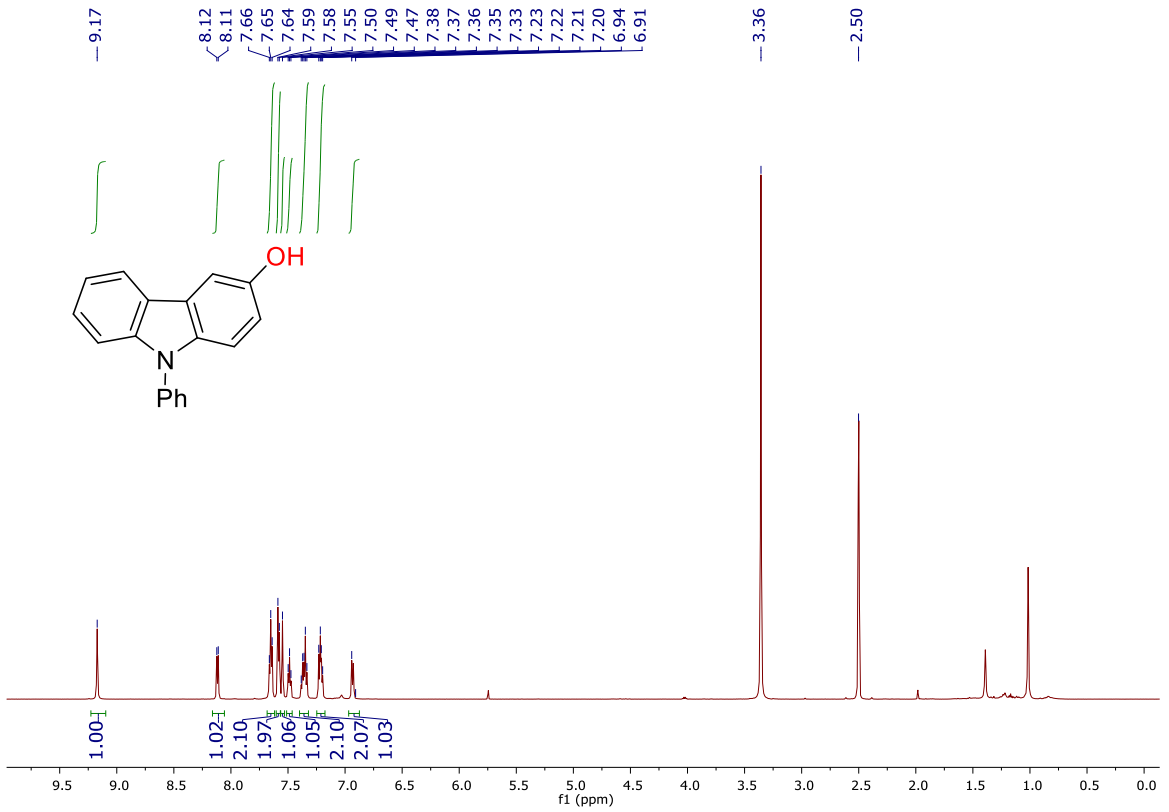
^{1}H NMR spectrum of **3p**



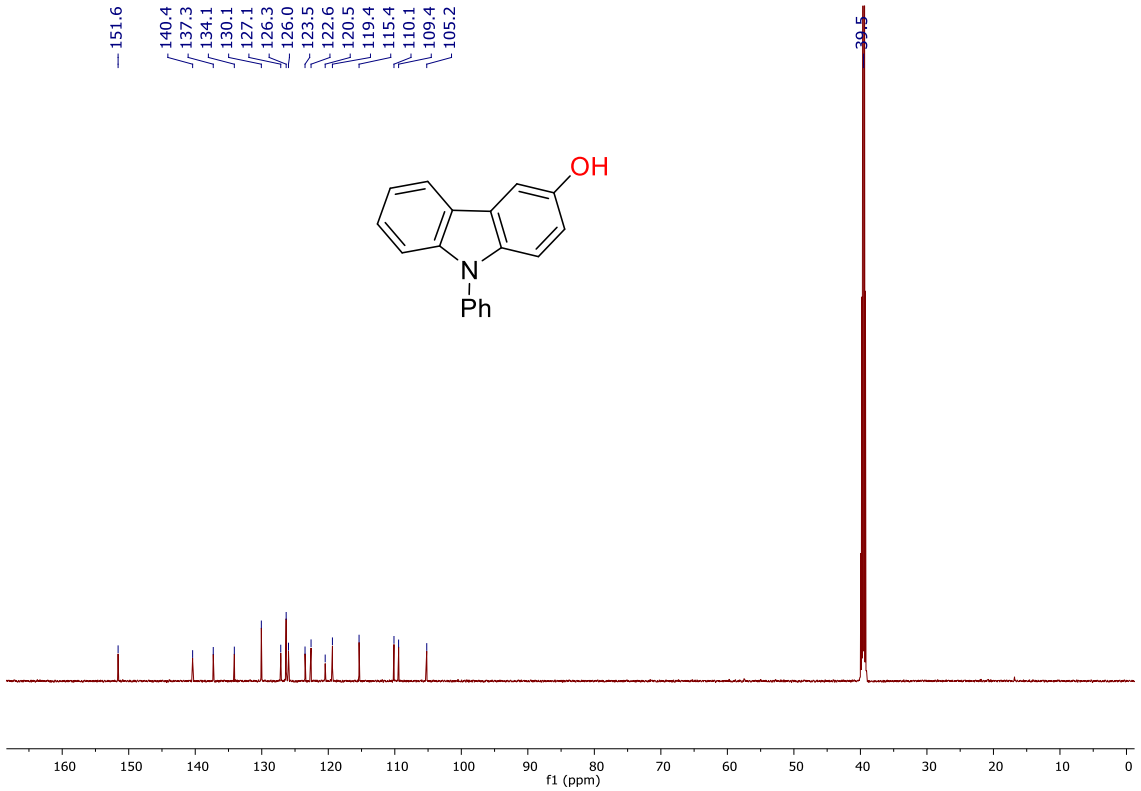
^{13}C NMR spectrum of **3p**



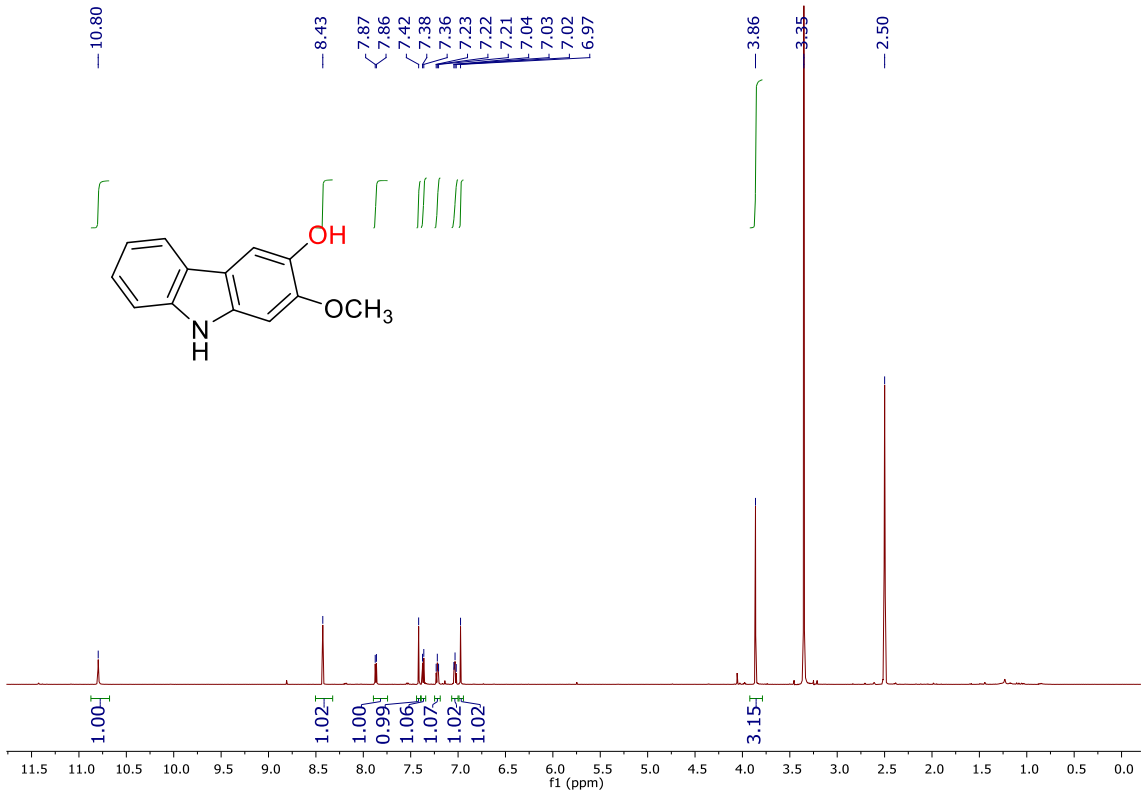
^{1}H NMR spectrum of **3q**



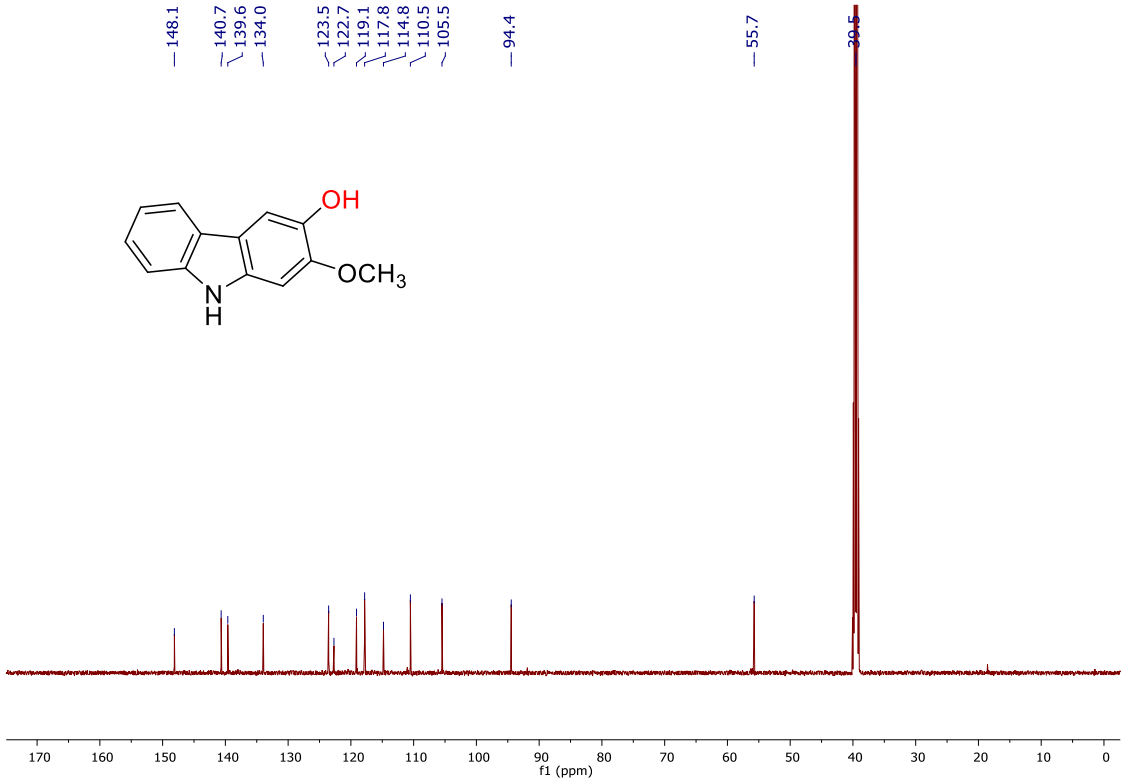
^{13}C NMR spectrum of **3q**



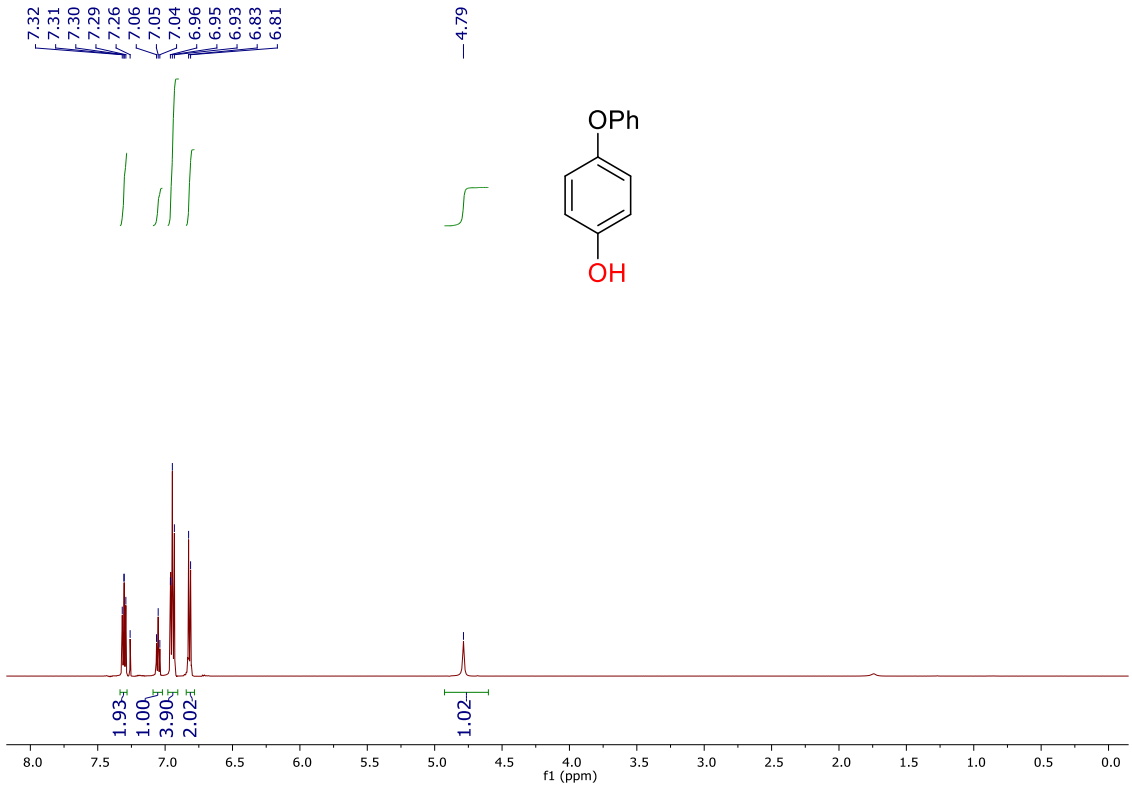
^{1}H NMR spectrum of **3r**



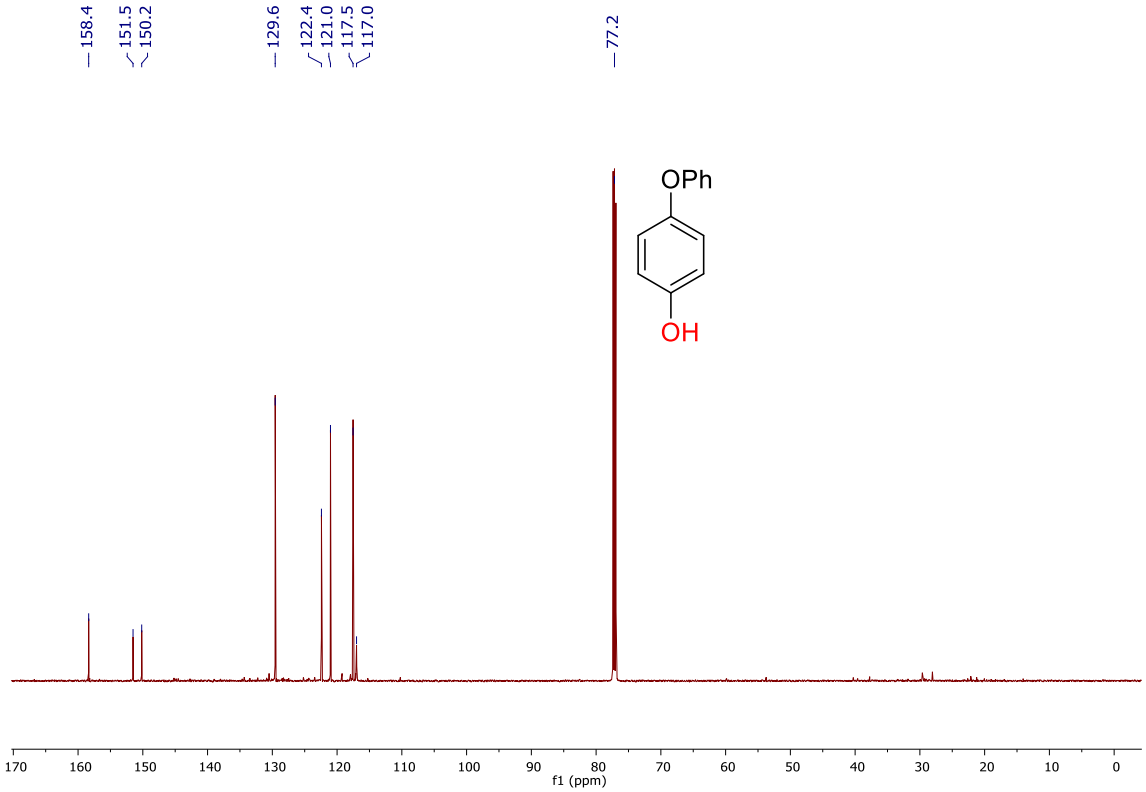
^{13}C NMR spectrum of **3r**



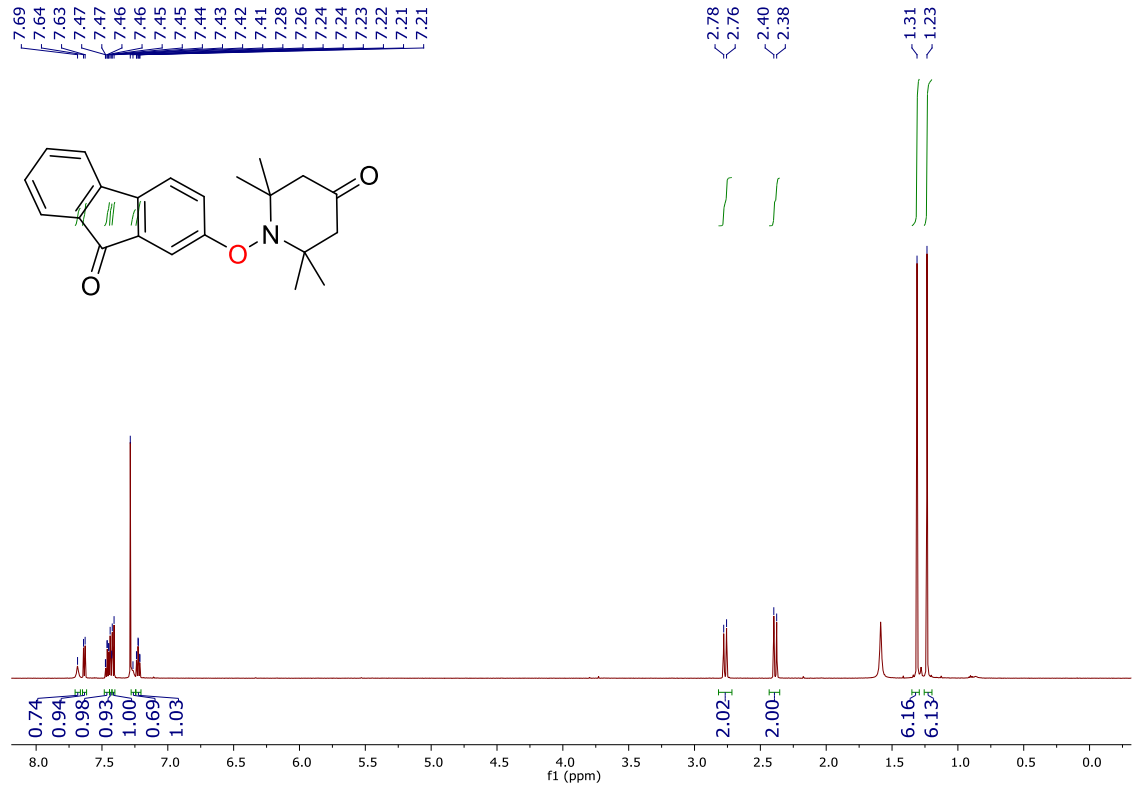
^{1}H NMR spectrum of **3s**



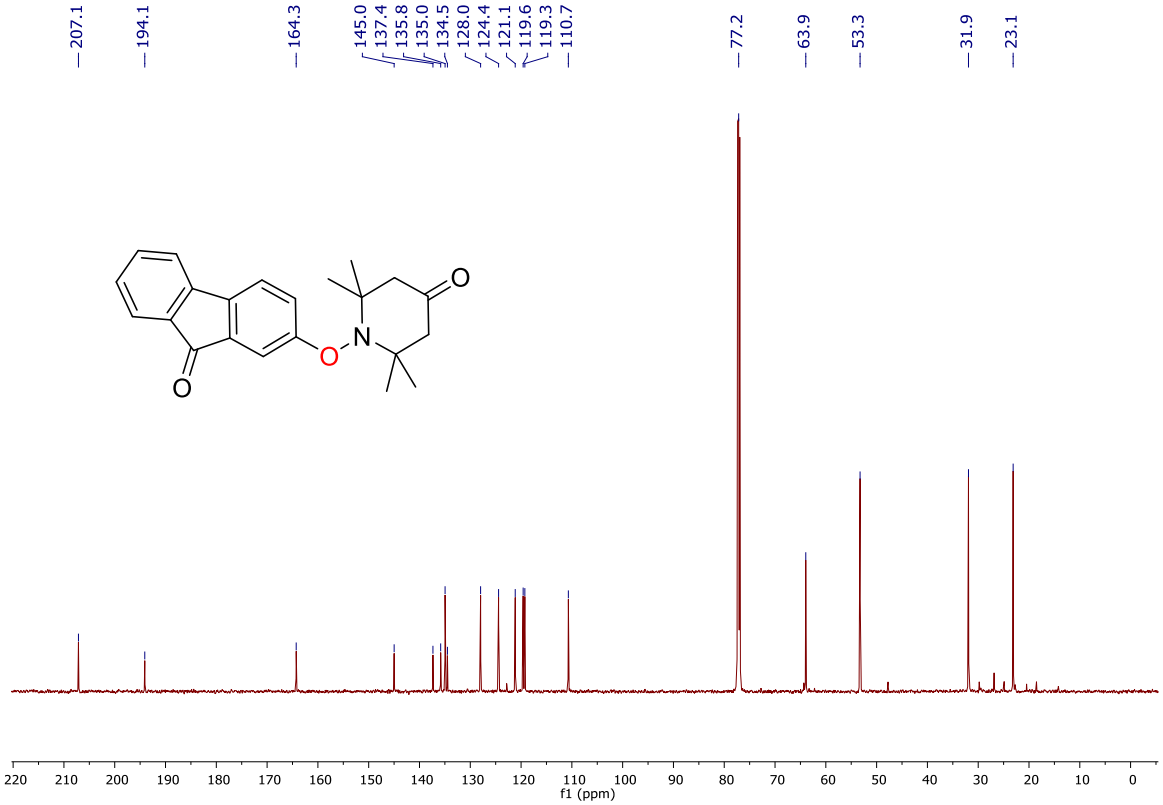
^{13}C NMR spectrum of **3s**



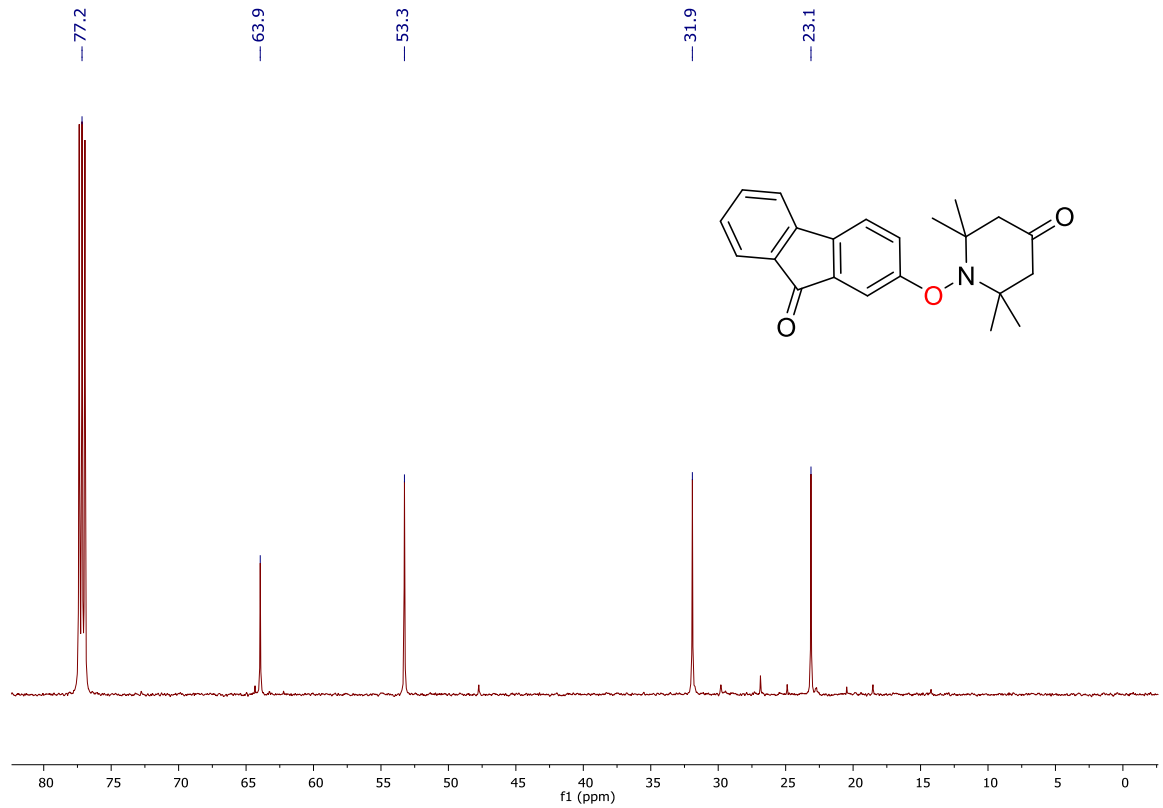
^{1}H NMR spectrum of **3t**



^{13}C NMR spectrum of **3t**



Zoom in section on the ^{13}C NMR spectrum of **3t:**



Zoom in section on the ^{13}C NMR spectrum of **3t:**