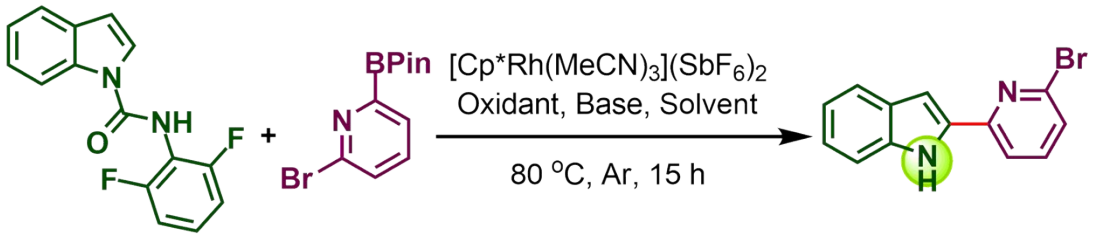
Rh^{III}-Catalyzed C–H Heteroarylation and C–N Cleavage: Direct Access to C2-heteroarylated (NH)-indoles

Zhen-Ang Liu, Xiao Guan, Xiao-Wen Su, Yu-Tong Dong, Huai-Wei Wang*

Shandong Provincial Key Laboratory of Chemical Energy Storage and Novel Cell Technology, School of Chemistry and Chemical Engineering, Liaocheng University, Liaocheng 252000, China.

1. Optimizations of the model reaction with 2 equivalents of oxidants[a,b]

Table S1 Optimizations of reaction conditions with 2 equivalents of oxidants[a,b]

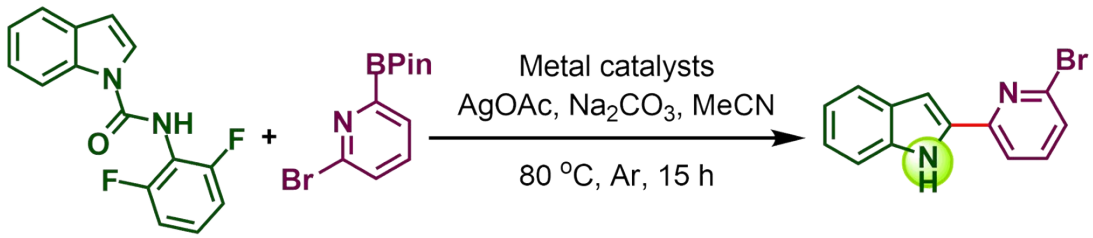


1a **2a** **3a**

Entry	Oxidant	Base	Solvent	Yield[a,b]
1	AgOAc	Na_2CO_3	MeCN	81
2	AgOAc	Na_2CO_3	DCM	28
3	AgOAc	Na_2CO_3	DCE	32
4	AgOAc	Na_2CO_3	DMF	12
5	AgOAc	Na_2CO_3	THF	70
6	AgOAc	Na_2CO_3	Dioxane	71
7	AgOAc	Na_2CO_3	Toluene	79
8	AgOAc	Na_2CO_3	PhCl	72
9	AgOAc	Na_2CO_3	MeOH	11
10	AgOAc	Li_2CO_3	MeCN	8
11	AgOAc	K_2CO_3	MeCN	77
12	AgOAc	Rb_2CO_3	MeCN	27
13	AgOAc	Cs_2CO_3	MeCN	23
14	AgOAc	NaOAc	MeCN	58
15	AgOAc	$NaHCO_3$	MeCN	64
16	AgOAc	$KHCO_3$	MeCN	74
17	AgOAc	CsOAc	MeCN	59
18	Ag_2CO_3	Na_2CO_3	MeCN	20
19	Ag_2O	Na_2CO_3	MeCN	nr
20	AgF	Na_2CO_3	MeCN	48
21	Ag_3PO_4	Na_2CO_3	MeCN	67
22	AgOPiv	Na_2CO_3	MeCN	71
23	CF_3CO_2Ag	Na_2CO_3	MeCN	50
24	$Cu(OAc)_2$	Na_2CO_3	MeCN	nr
25[c]	AgOAc	Na_2CO_3	MeCN	70

[a]Reaction conditions: **1a** (0.1 mmol), **2a** (0.3 mmol), $[Cp^*Rh(MeCN)_3](SbF_6)_2$ (10 mol%), Oxidant (0.2 mmol), Base (0.2 mmol) and dry solvent (2 mL), Ar, 15 h, 80 °C. [b]isolated yields. [c]**2a** (0.2 mmol).

Table S2 The reactivity efficiency of other metal catalysts under the optimal conditions[a,b]

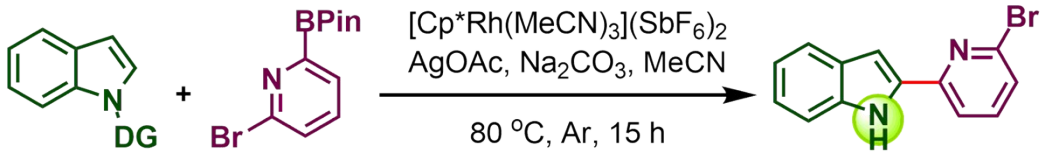


1a 2a 3a

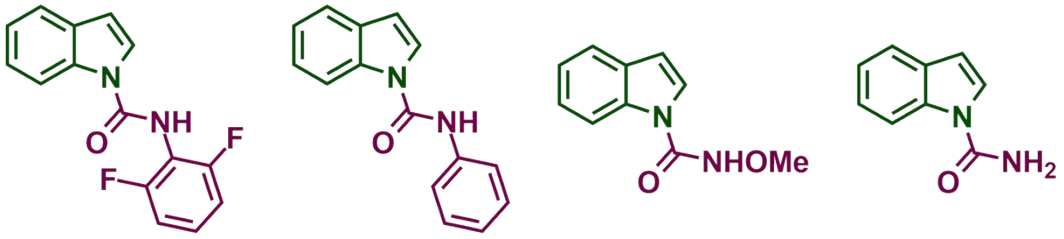
Entry	Catalysts	Yield[a,b]
1	$Pd(OAc)_2$	nr
2	$[RuCl_2(p\text{-cymene})]_2$	nr
3	$Cp^*Co(CO)I_2$	nr
4	$[Cp^*Co(MeCN)_3](SbF_6)_2$	nr
5	$[Cp^*Ir(MeCN)_3](SbF_6)_2$	nr
6	$[Cp^*RhCl_2]_2$	65
7	$[Cp^*Rh(MeCN)_3](SbF_6)_2$	95

[a]Reaction conditions: **1a** (0.1 mmol), **2a** (0.3 mmol), metal catalysts (10 mol%) or $[RuCl_2(p\text{-cymene})]_2$ (5 mol%) or $[Cp^*RhCl_2]_2$ (5 mol%), AgOAc (0.3 mmol), Na_2CO_3 (0.2 mmol) and dry solvent (2 mL), Ar, 15 h, 80 °C. [b]isolated yields.

Table S3 The reactivity efficiency of alternative directing groups[a,b]



2a 3a

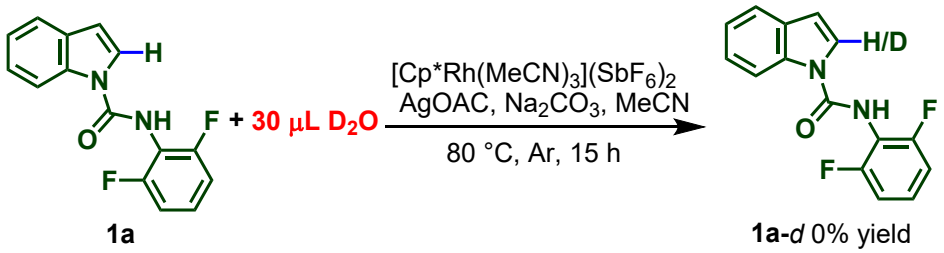


DG1 95% **DG2** 61% **DG3** 21% **DG4** 69%

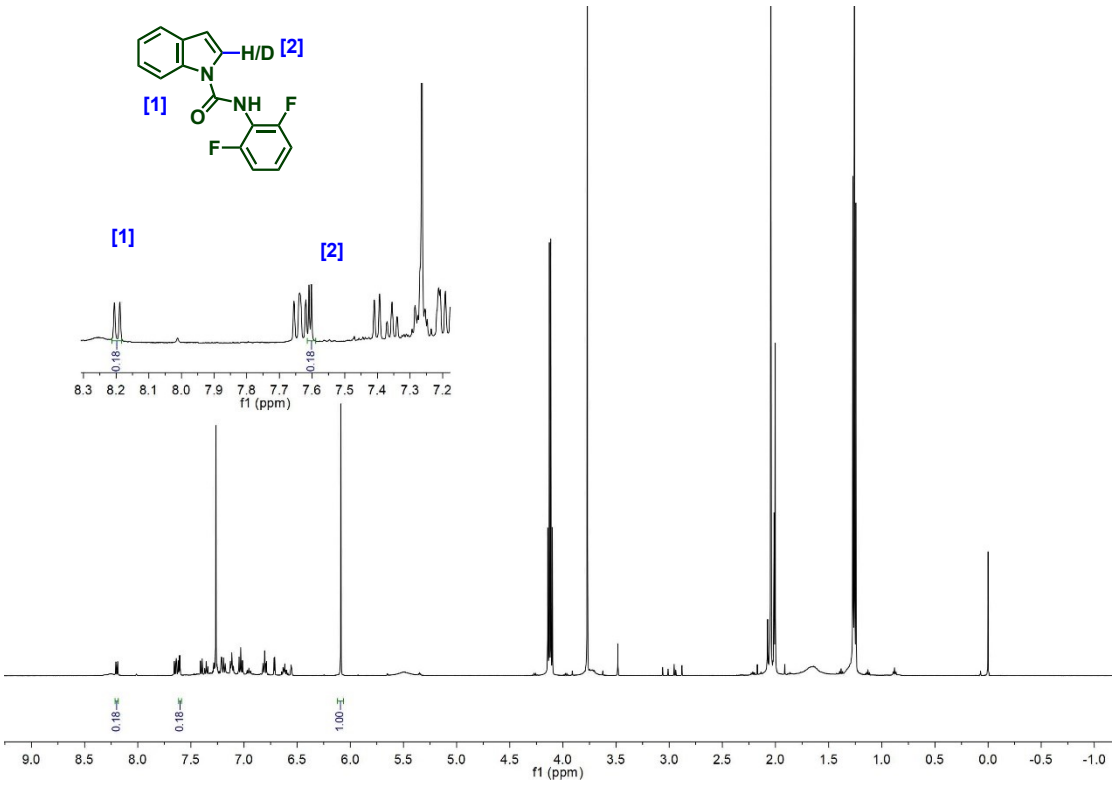
[a]Reaction conditions: **1a** (0.1 mmol), **2a** (0.3 mmol), $[Cp^*Rh(MeCN)_3](SbF_6)_2$ (10 mol%), AgOAc (0.3 mmol), Na_2CO_3 (0.2 mmol) and dry solvent (2 mL), Ar, 15 h, 80 °C. [b]isolated yields.

2. Control experiments

2.1 Deuterium incorporation experiment

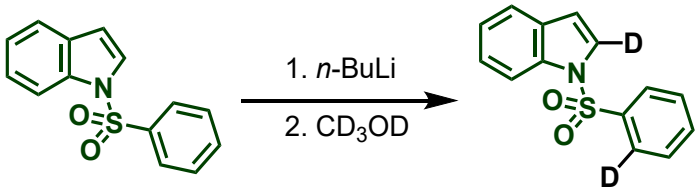


To a 25 mL Schlenk-type sealed tube equipped with a magnetic stirring bar was added the substrate **1a** (27.2 mg, 0.1 mmol), $[Cp^*Rh(MeCN)_3](SbF_6)_2$ (8.3 mg, 0.01 mmol, 10 mol %), AgOAc (50.1 mg, 0.3 mmol, 3 equiv), Na_2CO_3 (21.2 mg, 0.2 mmol, 2 equiv), 30 μL D_2O and dry MeCN (2.0 mL) under Ar atmosphere. The tube was capped and subjected to a 80 °C preheated oil bath for 15 h. After cooled to room temperature, the reaction mixture was filtered through a pad of Celite. The filtrate was concentrated in vacuo to afford crude products, which was determined by ^1H NMR analysis of the crude product using 1,3,5-trimethoxybenzene as the internal standard.



2.2 Kinetic isotope effect (KIE) studies

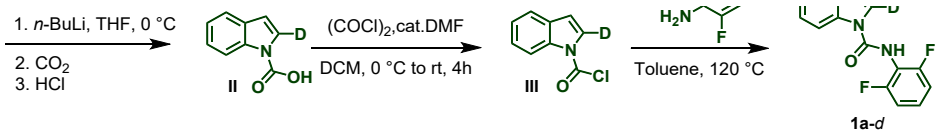
Preparation of **1a-*d***:



According to the procedures in the literature Step 1:[1] An oven-dried round-bottom flask (100 ml) was charged with 1-phenylsulfonyl-indole (2.1 g, 8.0 mmol), a magnetic stirbar, and dry THF (40 ml). The flask was sealed with a septum and placed under a nitrogen gas atmosphere. The solution was cooled to -78 °C, and a 2.5 M solution of *n*-BuLi in hexane (6.4 ml, 16 mmol) was slowly added to the solution via syringe. The -78 °C bath was removed, and the solution was allowed to warm to room temperature. The resulting orange solution was allowed to stir at room temperature. After 1 h, the solution was cooled to -78 °C and CD_3OD (1.0 ml) was added to the solution. The solution was allowed to warm to room temperature. The brown solution was diluted with ether (50 ml), and K_2CO_3 (4 g) was added. The liquor was collected after filtering and washing the solids with ether on a fritted funnel. The liquor was concentrated by rotary evaporation to yield a dark brown residue. The crude material was purified by flash column chromatography with 10 % ethyl acetate in hexanes. The solvent removed by rotary evaporation to yield the title compound as a white solid (1.97 g, 95 %). NMR spectral data matched published data.

Step 2: A round-bottom flask (100 ml) was charged with 1-(ortho-D-phenylsulfonyl)-2-D-indole (1.9 g, 7.5 mmol), methanol (18 ml), a 2.0 M solution of NaOH in water (25 ml, 50 mmol), and a magnetic stirbar. The flask was sealed with a

septum, and the solution was sparged with nitrogen gas for 15 minutes. Once the solution was under a nitrogen atmosphere, the solution was heated to reflux at 90 °C. Complete consumption of the starting material was observed by gas chromatography after 21 h. The solvent was removed by gently blowing nitrogen gas over the solution. The products were extracted with ether (15 ml, x3), dried over $MgSO_4$, and run through a silica plug with diethyl ether as eluent. Hexanes (30 ml) were added to the solution, and the solvents were removed by rotary evaporation to yield a light brown solid. The light brown solid was washed with hexane (10 ml) to yield title compound as a white solid (602 mg, 68 %). NMR spectral data match published data.

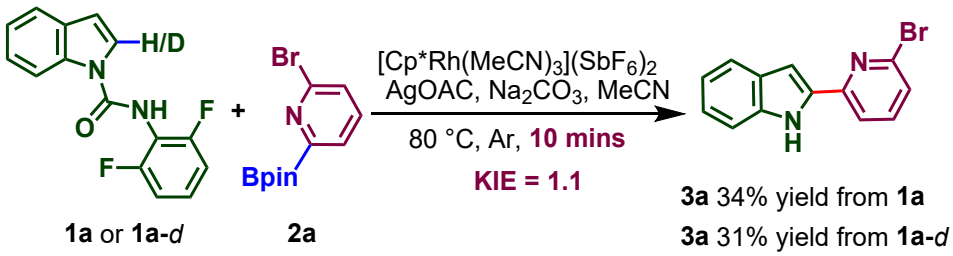


Step 3: The procedure was according to the reference:[2,3] In a 250 mL three-neck flask, a solution of *n*-BuLi (14.4 mL, 2.5 M in hexane, 1.2 equiv) was added dropwise to a solution of indole **I** (30.0 mmol, 1.0 equiv) in dry THF (100 mL) over 30 min at 0 °C under an N_2 atmosphere. After stirring at 0 °C with for 2 h, CO_2 (using dry ice to produce CO_2) was bubbled to the solution for 1 h at 0 °C, and then H_2O (20 mL) was to quench the reaction. The solution was concentrated to 10 mL under vacuum. Aqueous HCl (3 M) was added dropwise to adjust the pH value of the solution to 3. After the solution was extracted with EtOAc, the combined organic layer was dried over anhydrous Na_2SO_4, filtered, and evaporated under reduced pressure to afford crude N-carboxyl indole **II**.

Step 4: To a solution of the carboxylic acid **I** (20.0 mmol, 1.0 equiv) in dry CH_2Cl_2 (20 mL) at 0 °C was added dropwise $(COCl)_2$ (24 mmol, 1.2 equiv) followed by several drops dry DMF. The reaction mixture was allowed to stir at room temperature for 4 h. The solvent was then removed under reduce pressure to afford the corresponding crude acid chloride **III**.

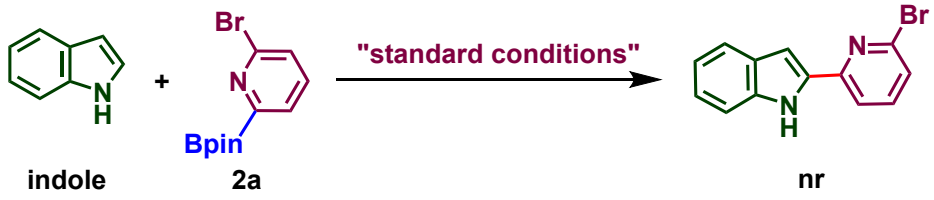
Step 5: An acid chloride was added to a vigorously stirring solution of 2,6-difluoroaniline (22 mmol) in toluene (20 mL). The reaction mixture was stirred for 4 h

under 120 °C oil bath. After cooling to room temperature, the crude reaction mixture was then removed under reduce pressure and purified by flash column chromatography (PE/EA=4:1) to afford the products **1a**-*d*.



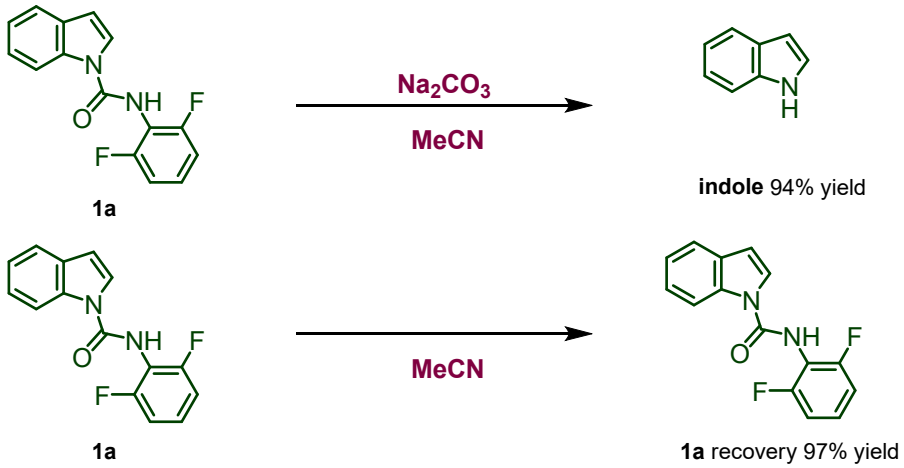
To two 25 mL Schlenk-type sealed tube equipped with a magnetic stirring bar was added the substrate **1a** (0.1 mmol) or **1a**-*d* (0.1 mmol), **2a** (0.3 mmol), $[Cp^*Rh(MeCN)_3](SbF_6)_2$ (8.3 mg, 0.01 mmol, 10 mol %), AgOAc (50.1 mg, 0.3 mmol, 3 equiv), Na_2CO_3 (21.2 mg, 0.2 mmol, 2 equiv), dry MeCN (2.0 mL) under Ar atmosphere. The tube was capped, and subjected to a 80 °C preheated oil bath for the indicated time (two parallel runs). After cooled to room temperature, the reaction mixtures were filtered through a pad of Celite. Both reaction mixtures were determined by ^{1}H NMR analysis of the crude product using 1,3,5-trimethoxybenzene as the internal standard.

2.3 Investigating the reactivity of indole with 2a



To a 25 mL Schlenk-type sealed tube equipped with a magnetic stirring bar was added the substrate **indole** (11.7 mg, 0.1 mmol), **2a** (85.2 mg, 0.3 mmol), $[Cp^*Rh(MeCN)_3](SbF_6)_2$ (8.3 mg, 0.01 mmol, 10 mol %), AgOAc (50.1 mg, 0.3 mmol, 3 equiv), Na_2CO_3 (21.2 mg, 0.2 mmol, 2 equiv), dry MeCN (2.0 mL) under Ar atmosphere. The tube was capped and subjected to a 80 °C preheated oil bath for 15 h. After cooled to room temperature, the reaction mixture was filtered through a pad of Celite. No desired heteroarylated product was detected by ^{1}H NMR analysis of the crude product.

2.4 Investigating the stability of the substrate 1a



To a 25 mL Schlenk-type sealed tube equipped with a magnetic stirring bar was added the substrate **1a** (27.2 mg, 0.1 mmol), with or without Na_2CO_3 (21.2 mg, 0.2 mmol, 2 equiv), dry MeCN (2.0 mL) under Ar atmosphere. The tube was capped and subjected to a 80 °C preheated oil bath for 15 h. After cooled to room temperature, the reaction mixture was filtered through a pad of Celite. The filtrate was concentrated in vacuo and purified by flash column chromatography (PE/EA=8:1) to afford the products **indole** or **1a**.

3. X-ray single crystal data for compound 3d

General Procedure for Crystal Preparation:

Compound **3d** (around 30 mg) were dissolved in $CDCl_3$ (1 mL), respectively and the NMR tubes were capped with a closed-top cap. The single crystal was grown by slow evaporation of solvents at room temperature.

X-ray structure determination of compound 3d:

Single-crystal X-ray data for Cd-CP were collected on a Siemens Smart CCD diffractometer with graphite-monochromatic Mo Kα radiation (λ = 0.71073 Å) at 298 K. The raw data frames were integrated into SHELX-format reflection files and corrected using SAINT program.[4] The structure was solved by direct methods and refined by full-matrix least-squares methods with SHELX program.[5] Displacement parameters were refined anisotropically, and the positions of the H-atoms were generated geometrically, assigned isotropic thermal parameters, and allowed to ride on their parent carbon atoms before the final cycle of refinement. Basic information pertaining to crystal parameters and structure refinement are summarized in Table S1, and selected bond lengths and angles are listed in Table S2. CCDC **2502377** (**3d**) contains the supplementary crystallographic data for this paper.

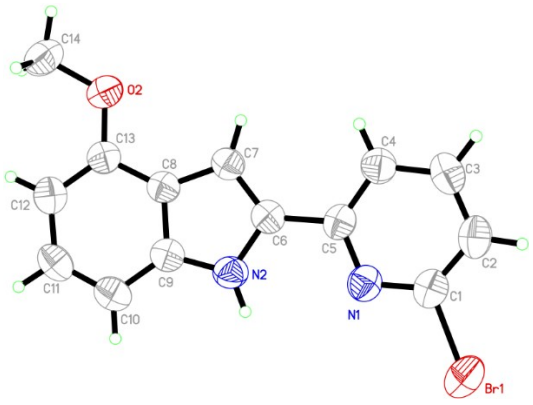


Figure S1. Single crystals of compound **3d**

Table S1. Crystal data and structure refinements for **3d**

Empirical formula	$C_{14}H_{11}BrN_2O$
Formula weight	303.16
Temperature/K	298.15
Crystal system	monoclinic
Space group	$P2_1/n$
a/Å	10.027(14)
b/Å	11.291(16)
c/Å	11.805(16)
α/°	90
β/°	109.228(17)
γ/°	90
Volume/Å^3	1262(3)
Z	4
ρ_{calc}g/cm^3	1.596
F(000)	608.0
2Θ range for data collection/°	4.638 to 50.028
Reflections collected	5986
Independent reflections	2221 [R_{int} = 0.0856, R_{sigma} = 0.0804]
Data/restraints/parameters	2221/438/164
Goodness-of-fit on F^2	0.821
Final R indexes [I>=2σ (I)]	R_1 = 0.0523, wR_2 = 0.1301
Final R indexes [all data]	R_1 = 0.0929, wR_2 = 0.1482

Table S2. Bond lengths [Å] and angles [°] for **3d**

Br1-C1	1.911(5)	C8-C9	1.409(7)
N2-C6	1.383(6)	C8-C13	1.401(6)
N2-C9	1.360(6)	C5-C4	1.384(6)
O2-C13	1.371(5)	C1-C2	1.367(7)
O2-C14	1.430(6)	C9-C10	1.398(7)
N1-C5	1.346(6)	C10-C11	1.367(7)
N1-C1	1.328(6)	C12-C13	1.382(6)
C6-C5	1.468(6)	C12-C11	1.401(7)
C6-C7	1.367(6)	C3-C2	1.385(7)
C8-C7	1.426(6)	C3-C4	1.382(7)
C9-N2-C6	109.3(4)	C2-C1-Br1	119.5(4)
C13-O2-C14	117.6(4)	C6-C7-C8	107.6(4)
C1-N1-C5	116.1(4)	N2-C9-C8	108.1(4)

N2-C6-C5	120.2(4)	N2-C9-C10	129.9(4)
C7-C6-N2	108.7(4)	C10-C9-C8	121.9(4)
C7-C6-C5	131.1(4)	C11-C10-C9	116.6(5)
C9-C8-C7	106.4(4)	C13-C12-C11	120.0(4)
C13-C8-C7	134.0(4)	O2-C13-C8	116.0(4)
C13-C8-C9	119.6(4)	O2-C13-C12	125.3(4)
N1-C5-C6	115.9(4)	C12-C13-C8	118.7(4)
N1-C5-C4	123.4(4)	C4-C3-C2	119.9(5)
C4-C5-C6	120.7(4)	C1-C2-C3	116.9(5)
N1-C1-Br1	114.7(4)	C3-C4-C5	118.0(5)
N1-C1-C2	125.8(5)	C10-C11-C12	123.1(5)

4. References

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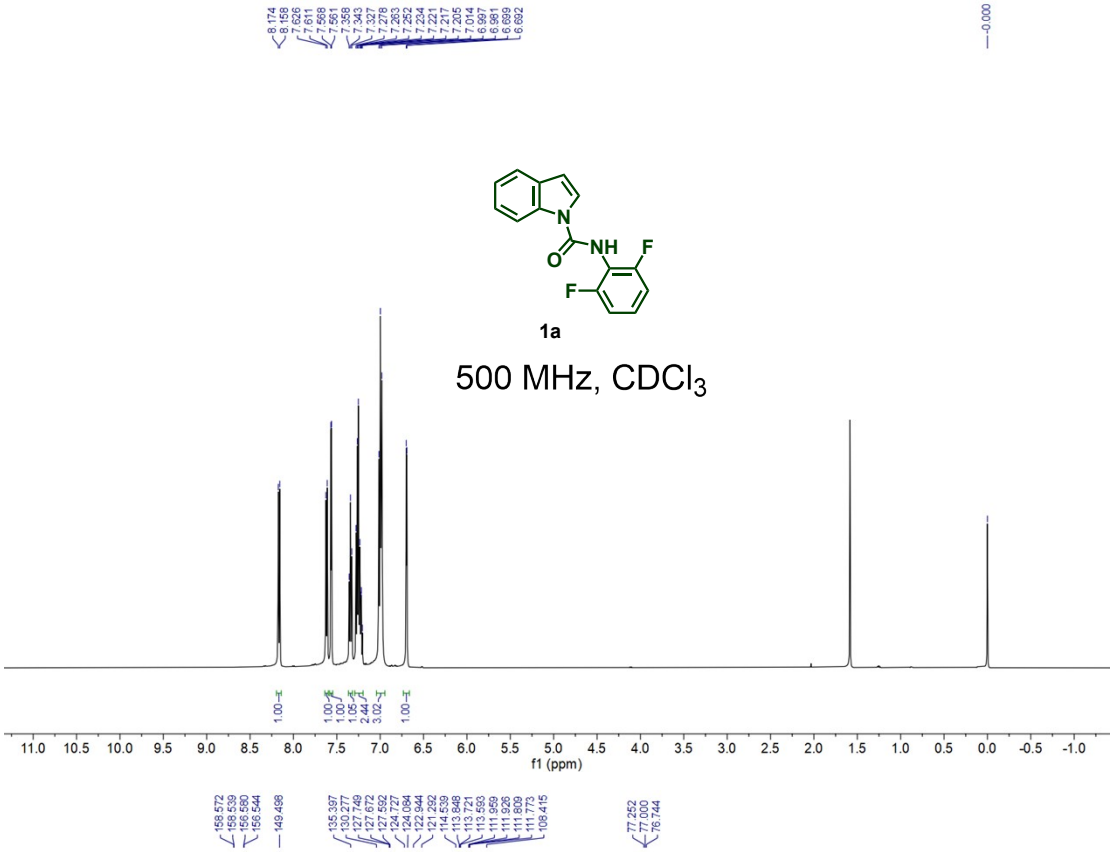
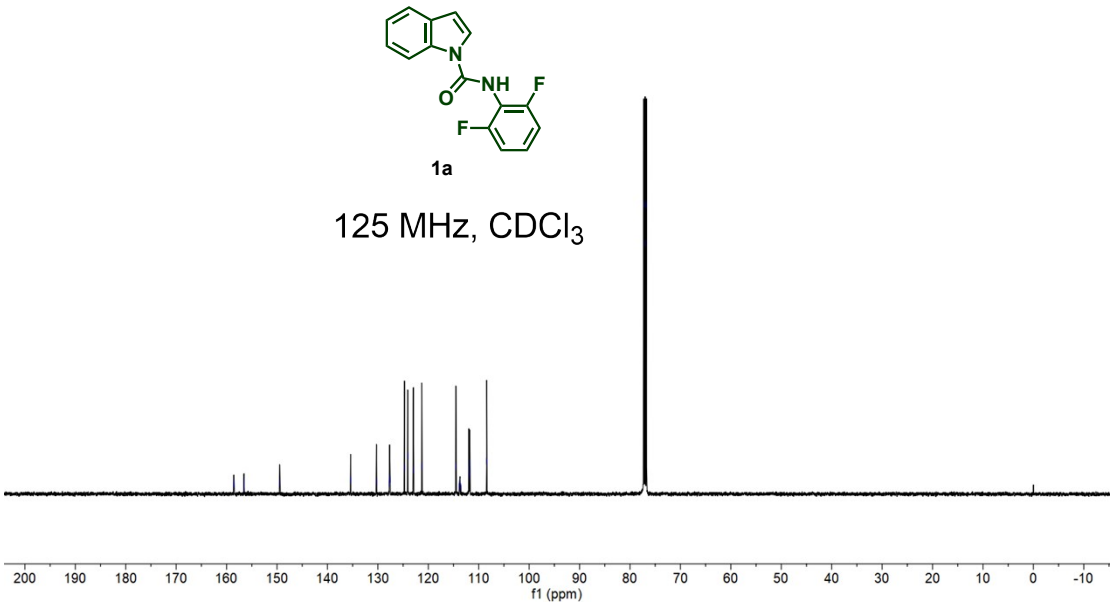
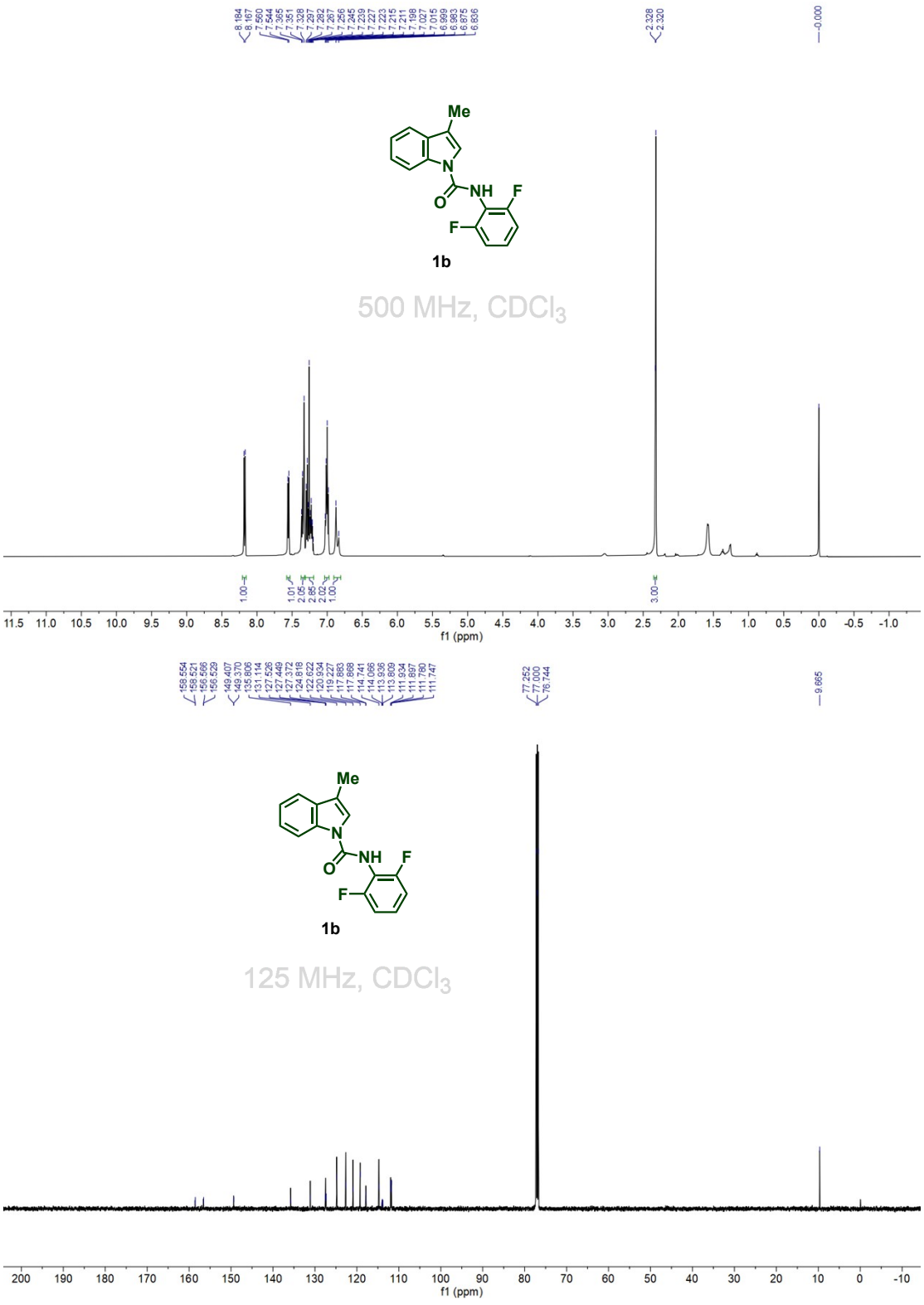
5. (a) Sheldrick, G. M. *SHELXS-97, Program for Crystal Structure Solution,* Göttingen University, Göttingen, Germany, **1997**; (b) Sheldrick, G. M. Crystal structure refinement with SHELXL. *Acta Crystallogr. Sec. C: Struct. Chem.* **2015**, *71*, 3.

5. NMR Spectra



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N
O
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F
F
1b
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f1 (ppm)
Me
N
O
NH
F
F
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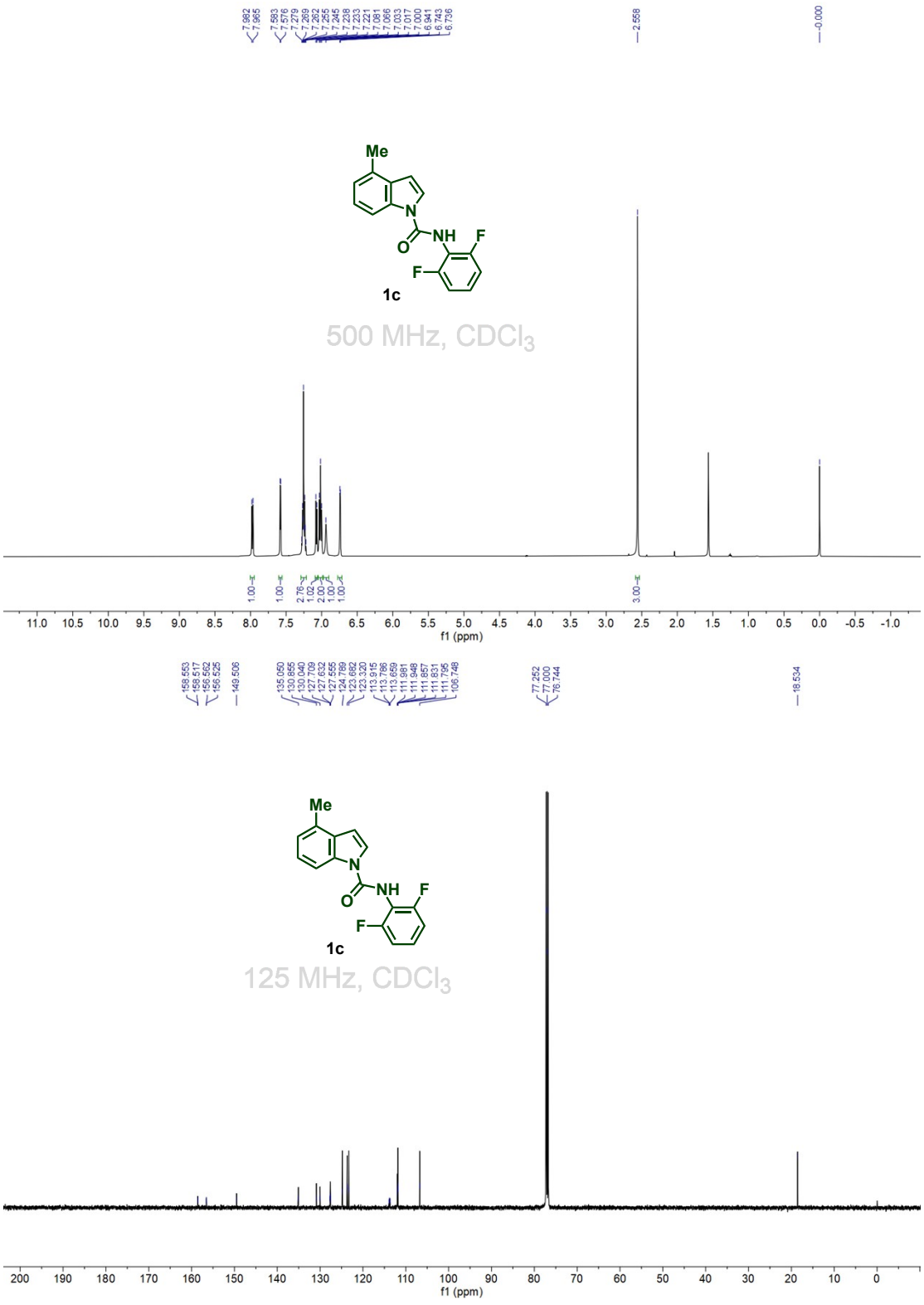
f1 (ppm)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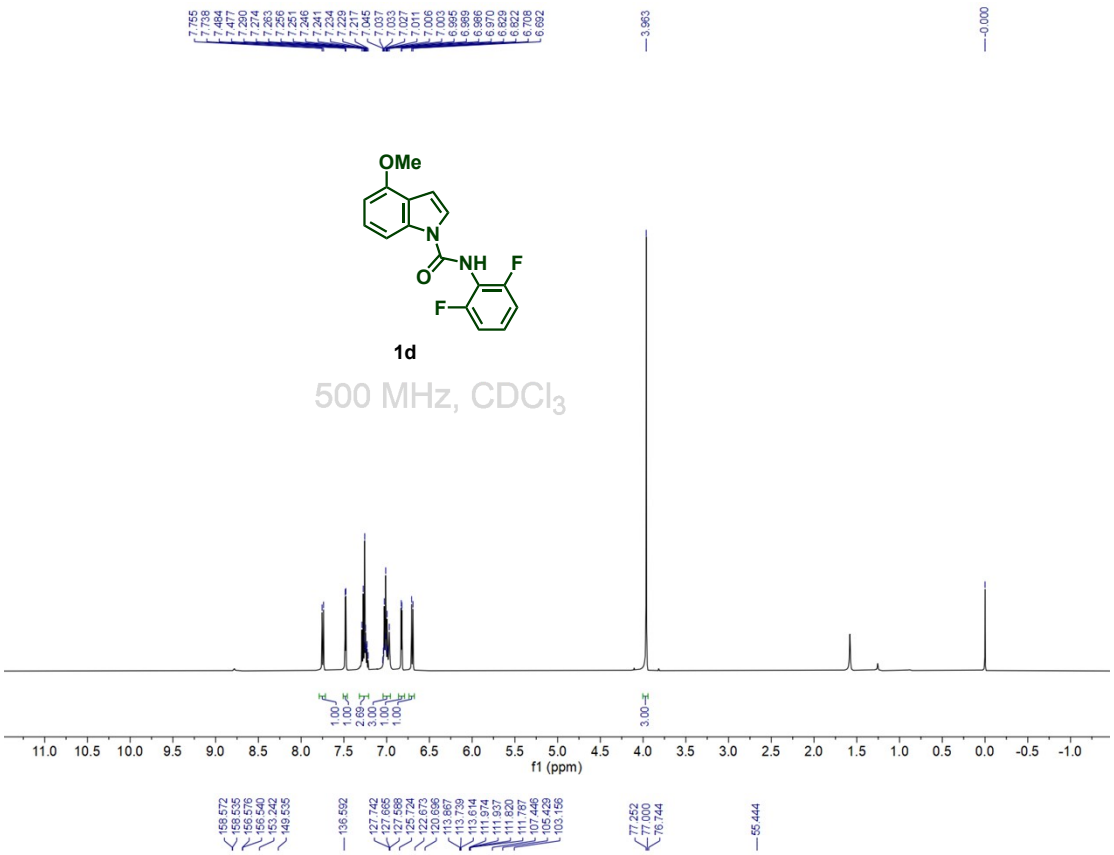
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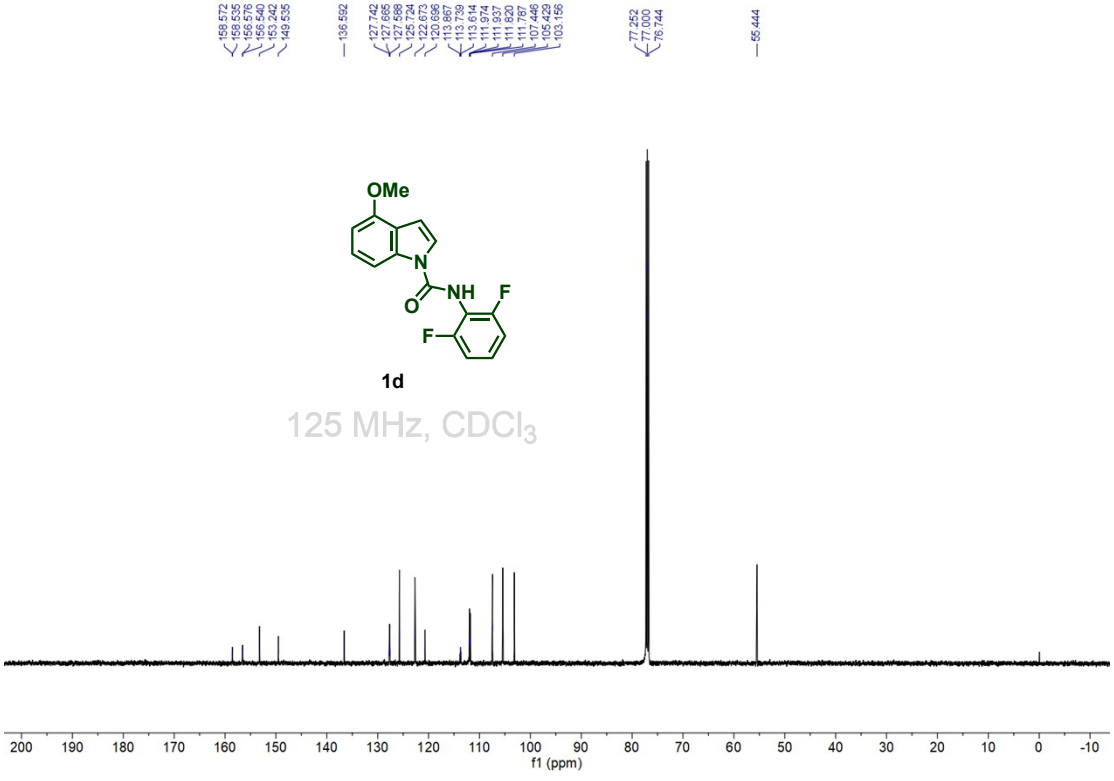
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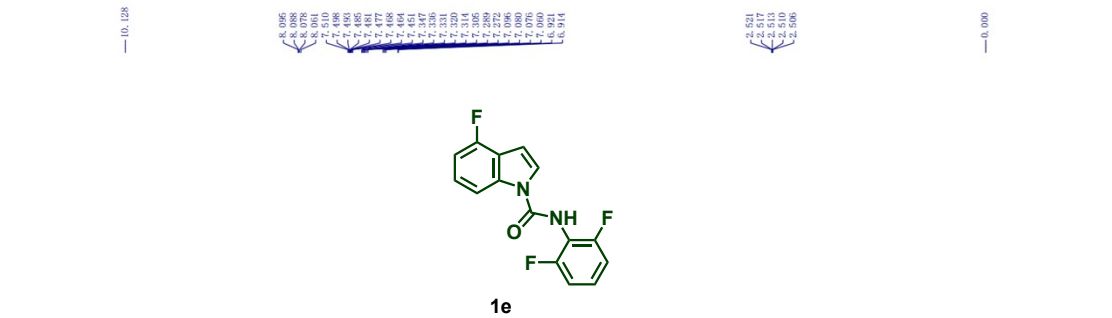
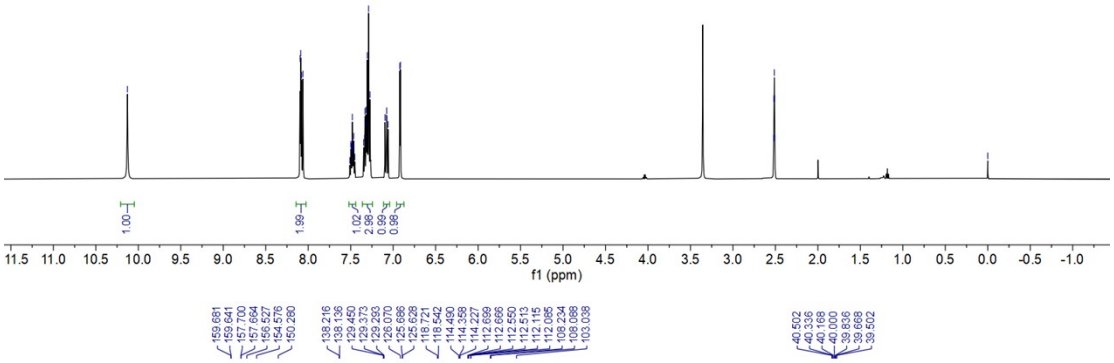
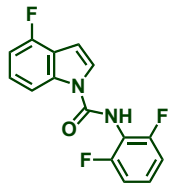


1e

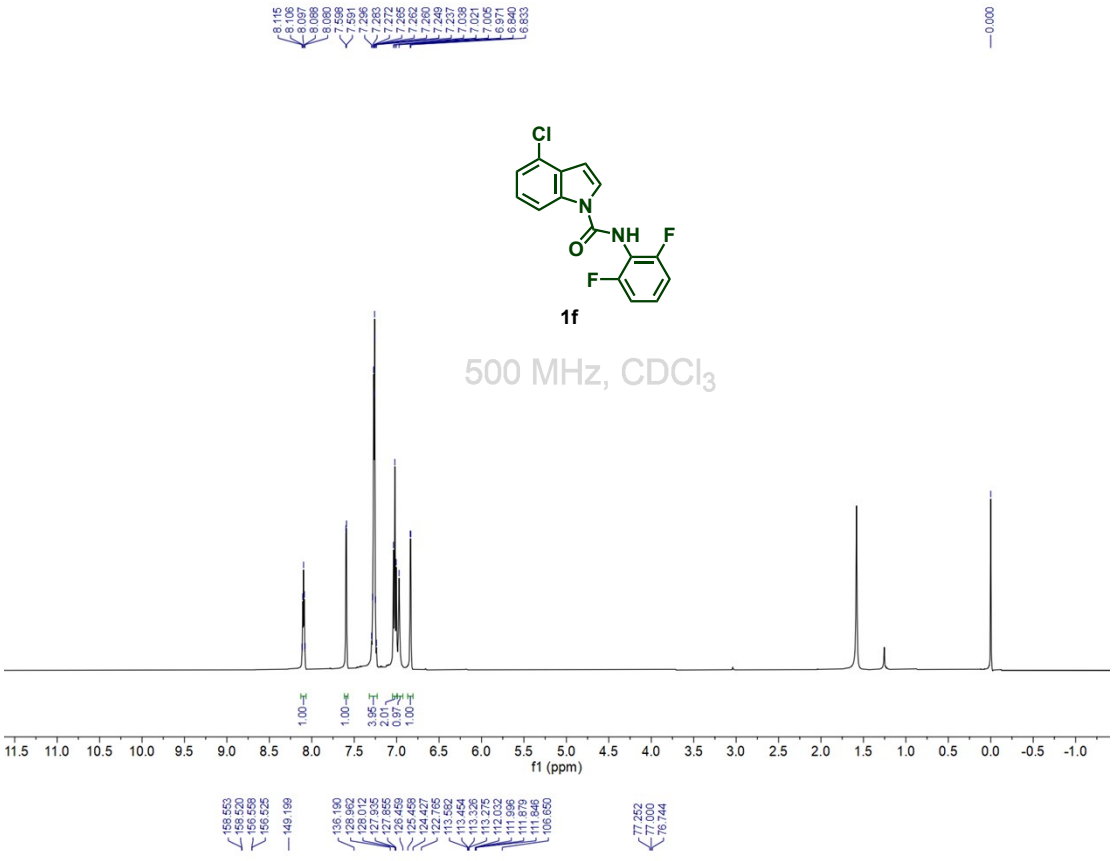
500 MHz, DMSO-d_6





1e

125 MHz, DMSO-d_6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6.840
6.833
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O
NH
F
F
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2.01
0.97
1.00
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f1 (ppm)
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156.568
156.525
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127.935
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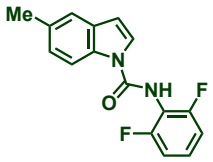
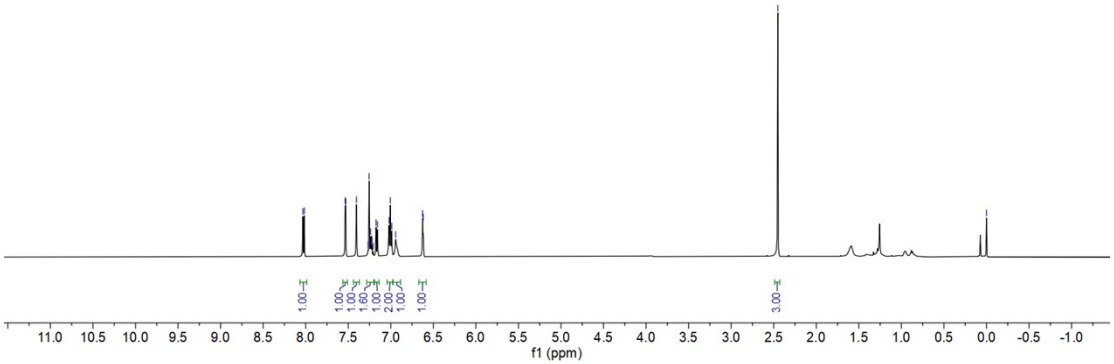
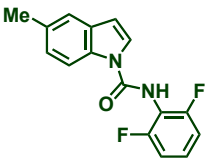
125.468
124.427
123.755
113.582
113.454
113.326
113.275
112.032
111.996
111.879
111.846
108.650
77.252
77.000
76.744
Cl
N
O
NH
F
F
1f
125 MHz, CDCl3
200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
f1 (ppm)



1g

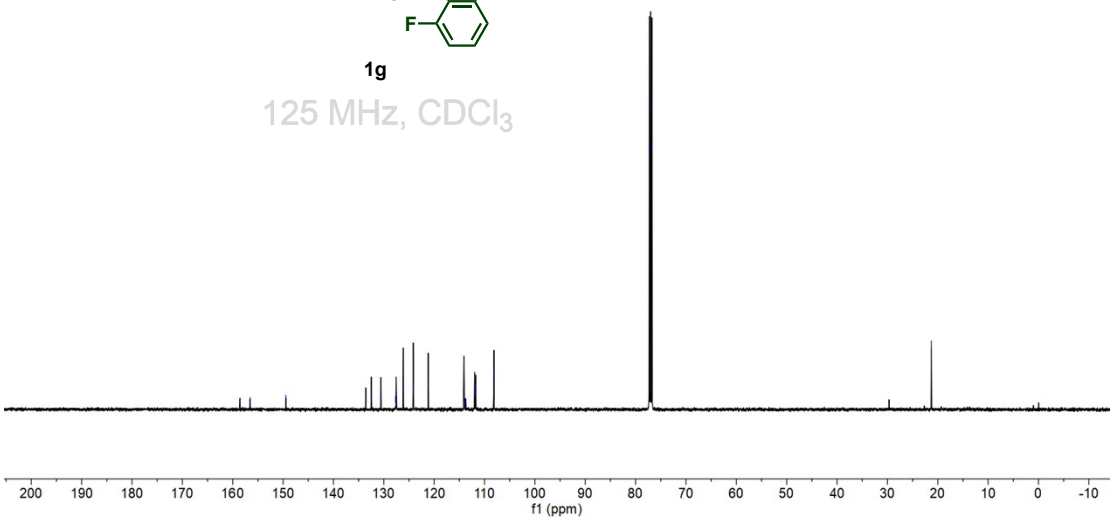
500 MHz, $CDCl_3$

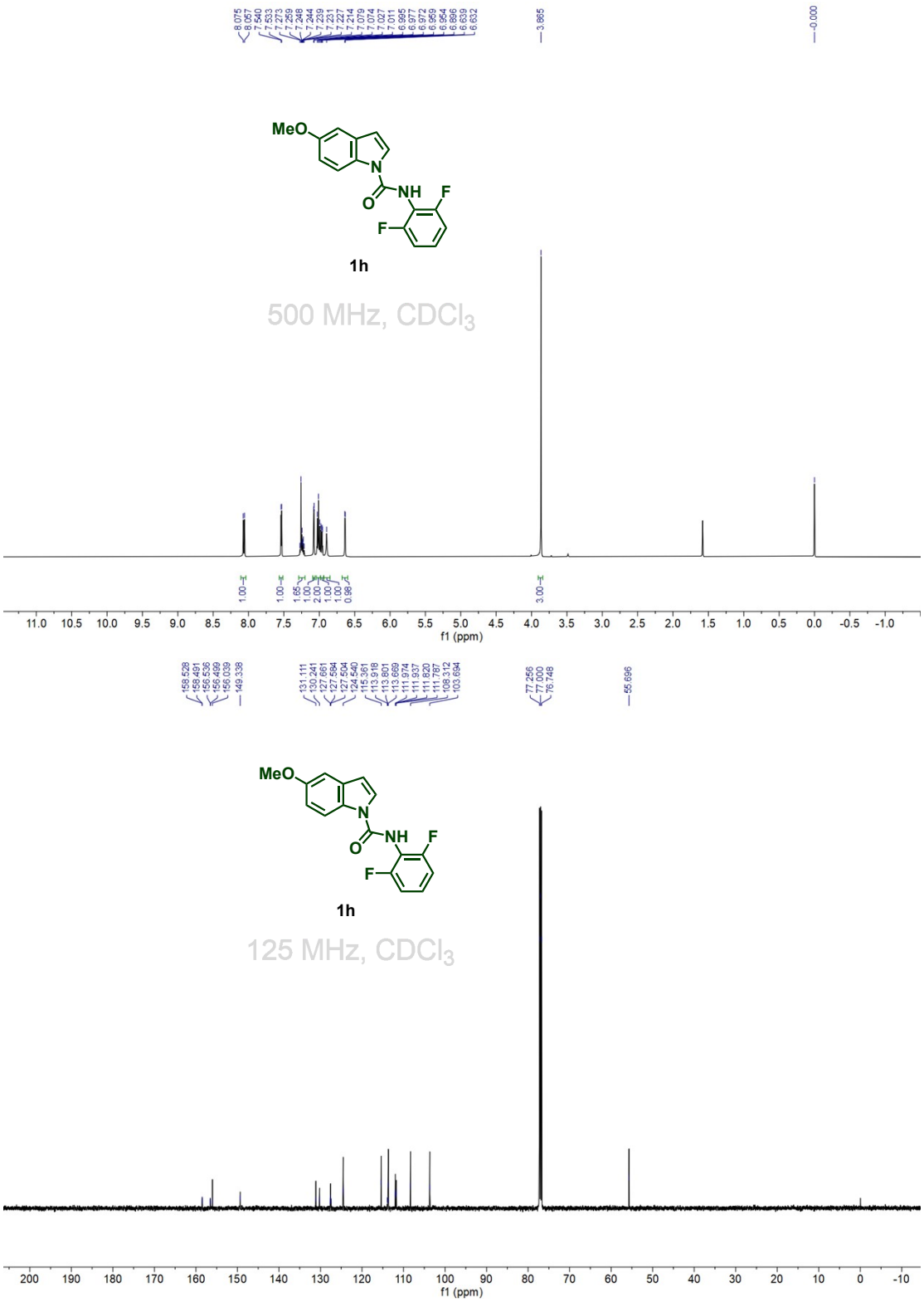


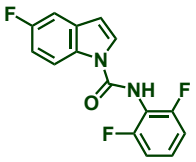


1g

125 MHz, $CDCl_3$

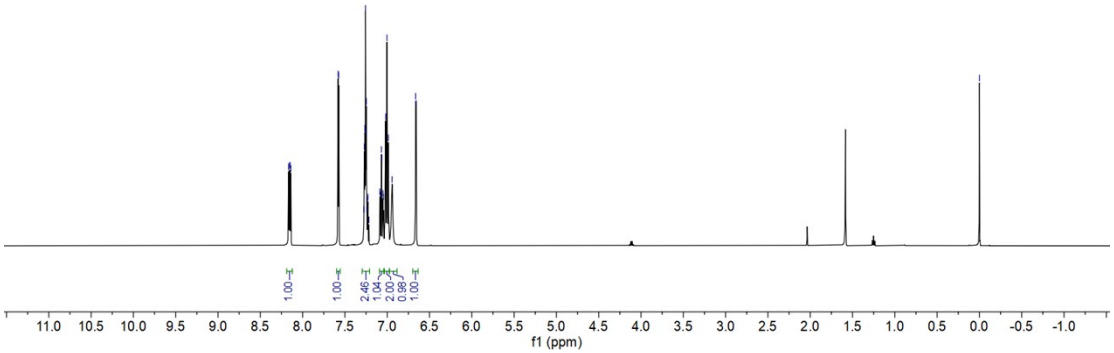


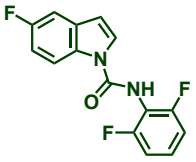

8.075
8.057
7.540
7.533
7.273
7.259
7.248
7.244
7.239
7.231
7.227
7.214
7.079
7.074
7.027
7.011
6.995
6.977
6.972
6.959
6.954
6.896
6.886
6.839
6.832
3.865
0.000
MeO
N
O
NH
F
F
1h
500 MHz, CDCl3
1.00
1.00
1.85
1.00
2.00
1.00
0.98
3.00
11.0 10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5 -1.0
f1 (ppm)
158.528
158.491
156.536
156.499
156.039
149.338
131.111
130.241
127.661
127.584
127.504
124.540
115.361
113.918
113.901
113.669
111.974
111.937
111.820
111.787
108.312
103.694
77.256
77.000
76.748
55.696
MeO
N
O
NH
F
F
1h
125 MHz, CDCl3
200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
f1 (ppm)



1i

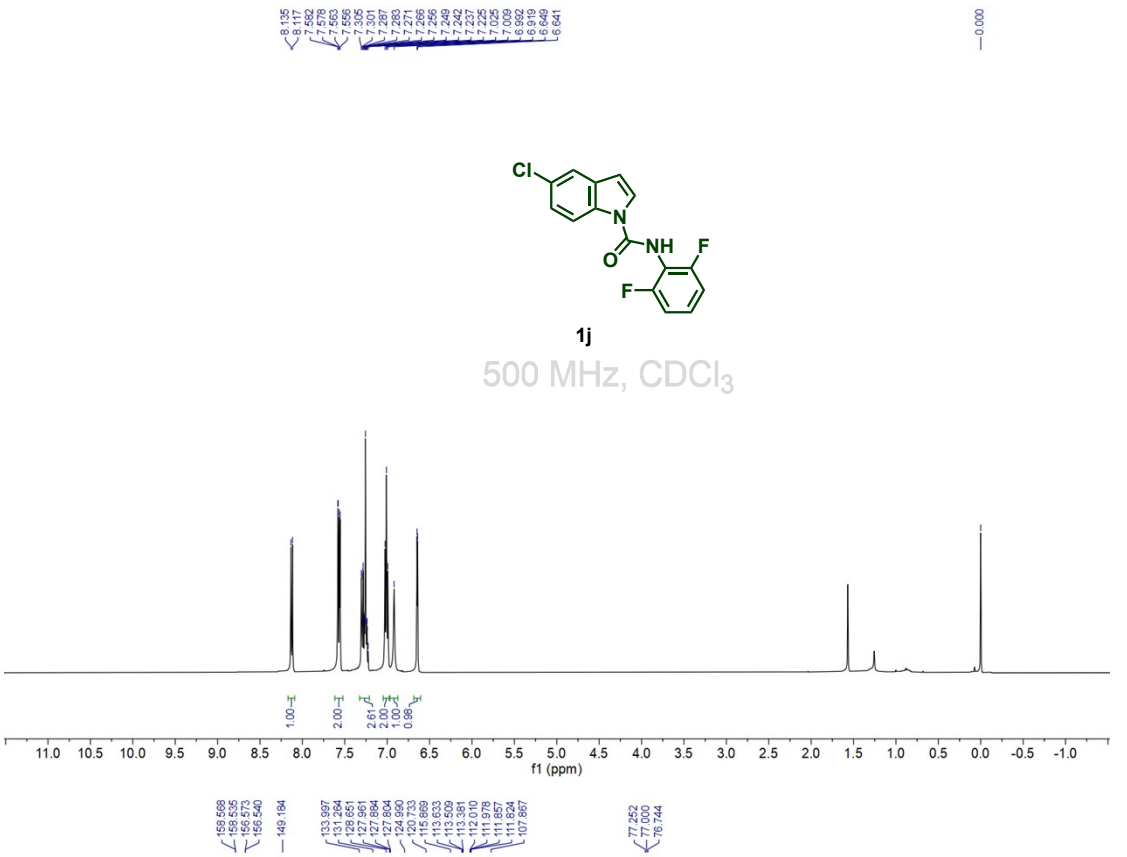
500 MHz, $CDCl_3$

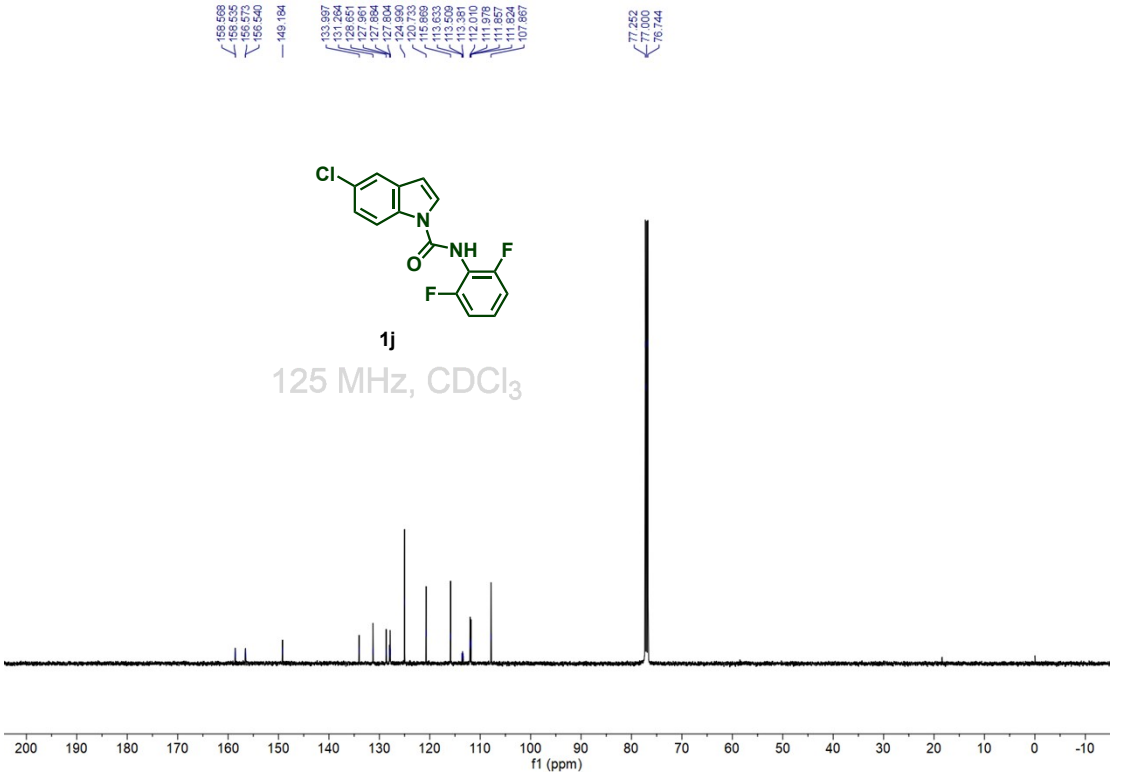


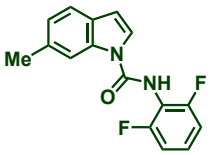


1i

125 MHz, $CDCl_3$

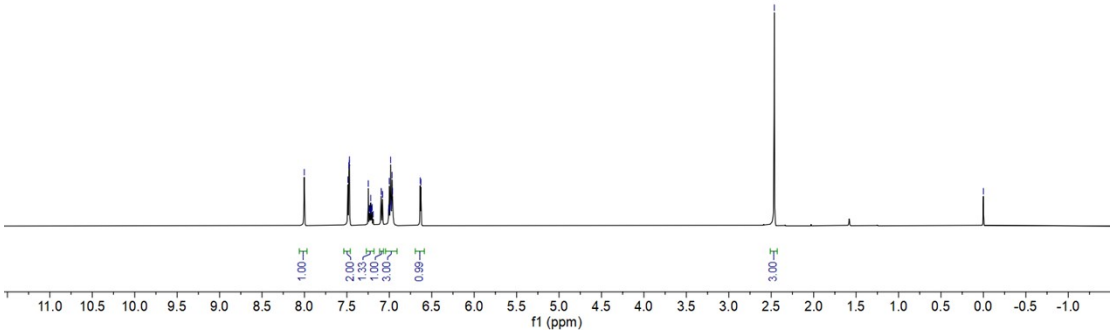

8.135
8.117
7.582
7.578
7.563
7.556
7.305
7.301
7.287
7.283
7.271
7.266
7.256
7.249
7.242
7.237
7.225
7.025
7.009
6.992
6.919
6.649
6.641
0.000
Cl
N
O
NH
F
F
1j
500 MHz, CDCl3
1.00
2.00
2.61
2.00
1.00
0.98
11.0 10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5 -1.0
f1 (ppm)

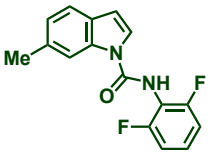

158.569
158.535
156.573
156.540
149.184
133.997
133.264
128.651
127.961
127.884
127.804
124.990
120.733
115.669
115.633
113.539
113.381
112.010
111.978
111.857
111.824
107.867
77.252
77.000
76.744
Cl
N
O
NH
F
F
1j
125 MHz, CDCl3
200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
f1 (ppm)



1k

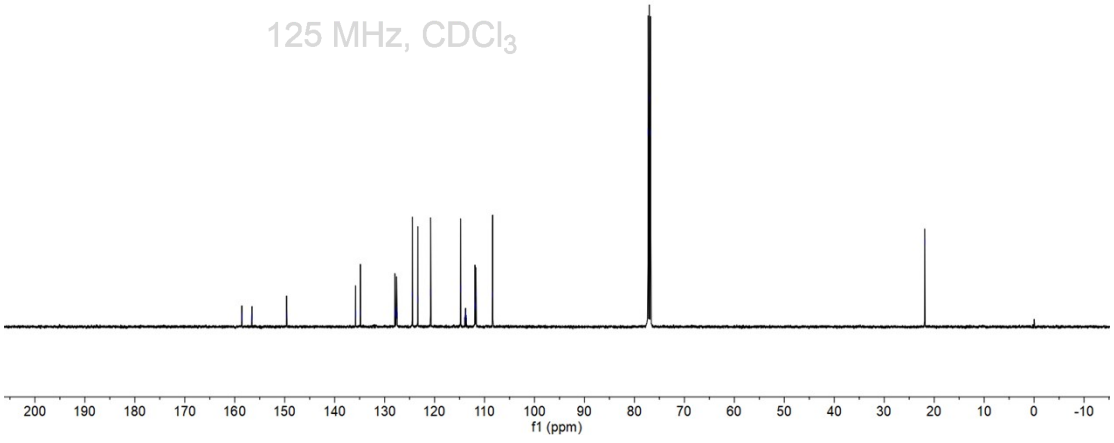
500 MHz, $CDCl_3$

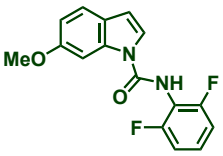




1k

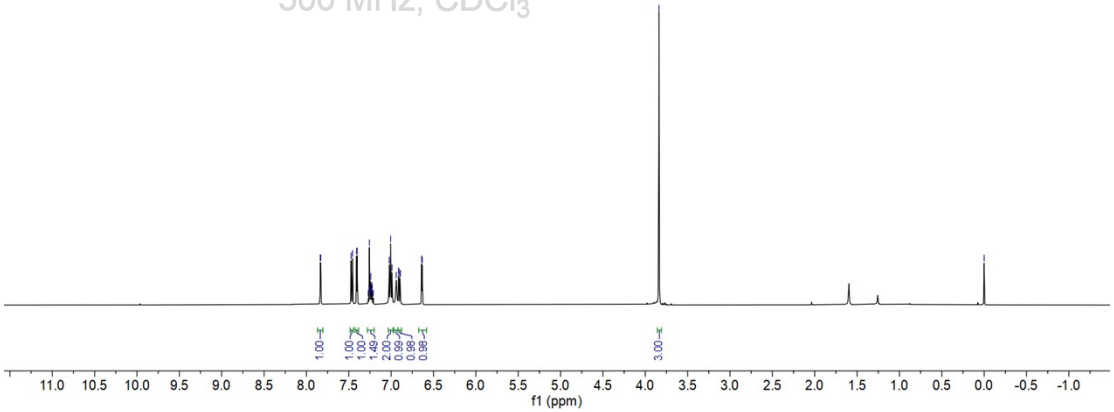
125 MHz, $CDCl_3$

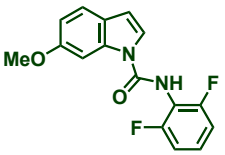




1l

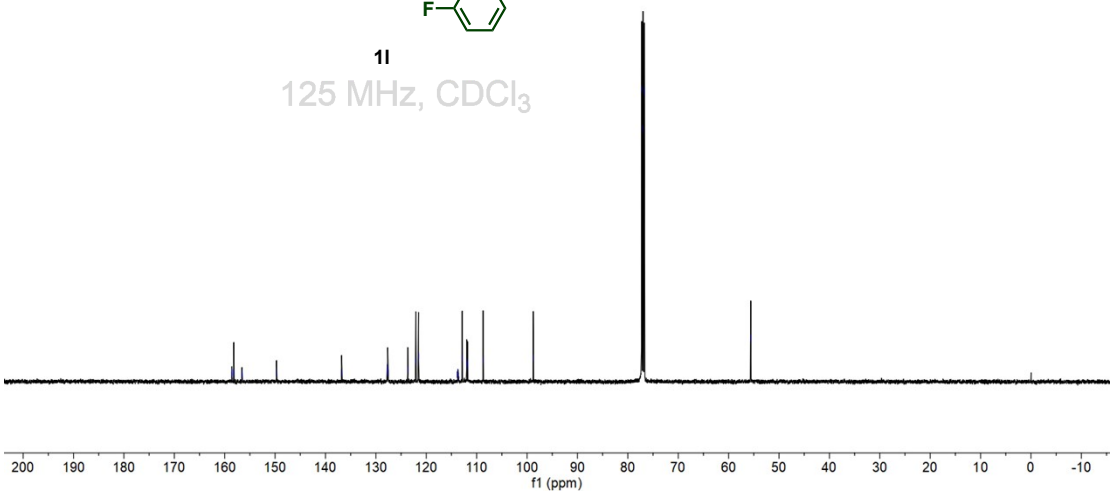
500 MHz, $CDCl_3$

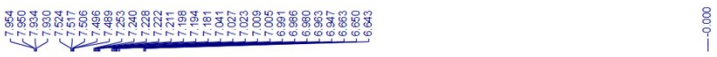


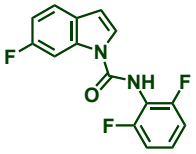


1l

125 MHz, $CDCl_3$

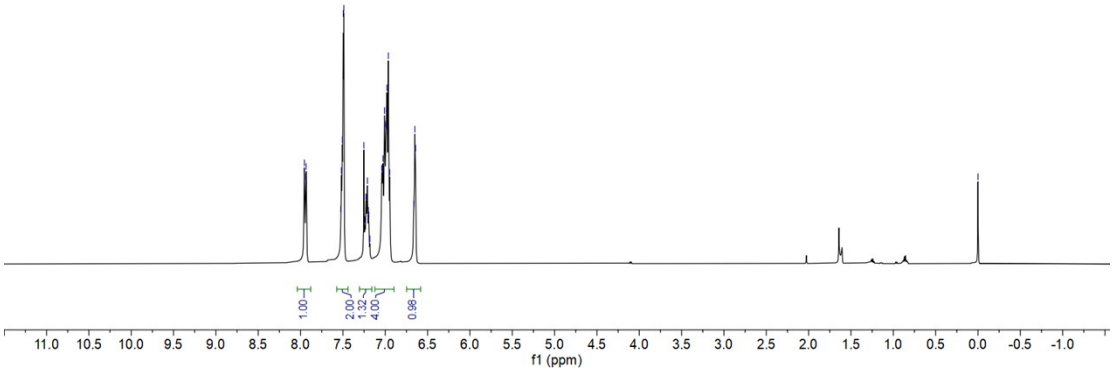


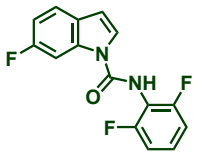




1m

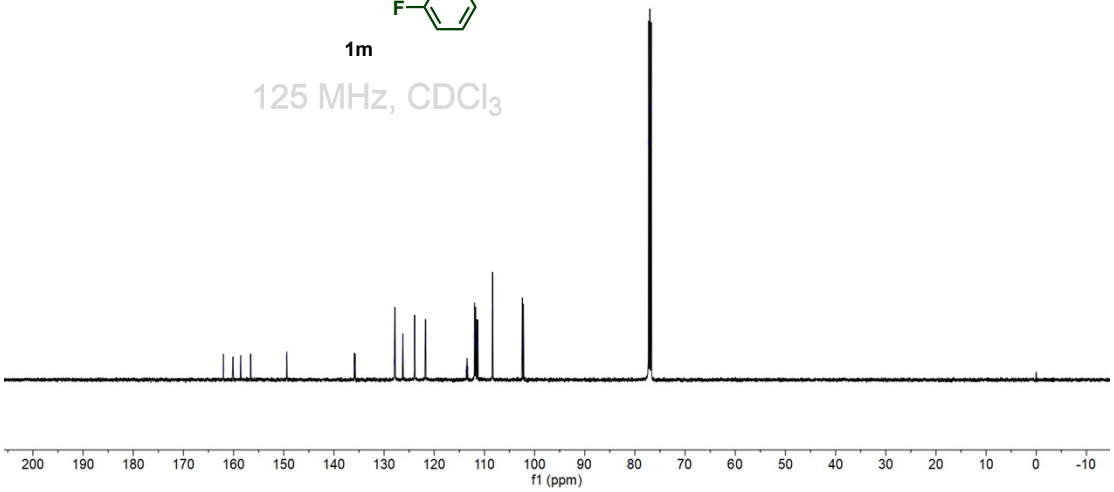
500 MHz, $CDCl_3$

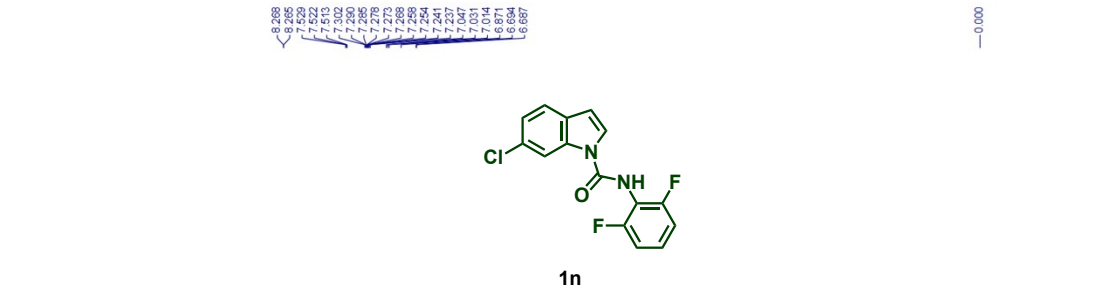




1m

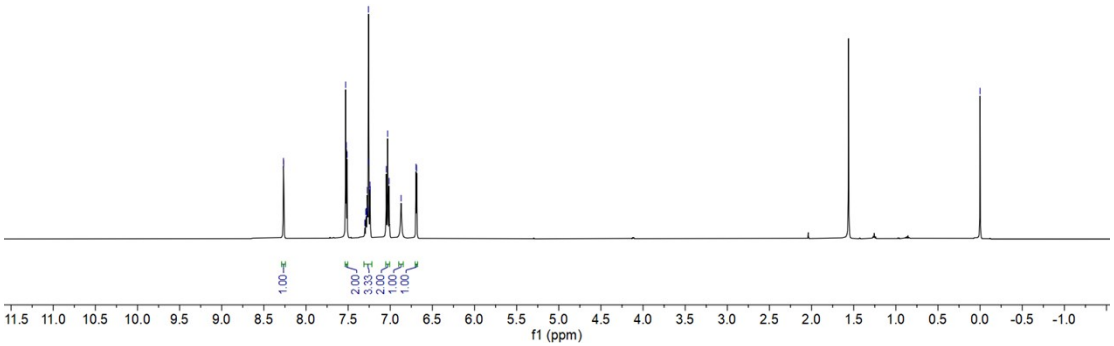
125 MHz, $CDCl_3$

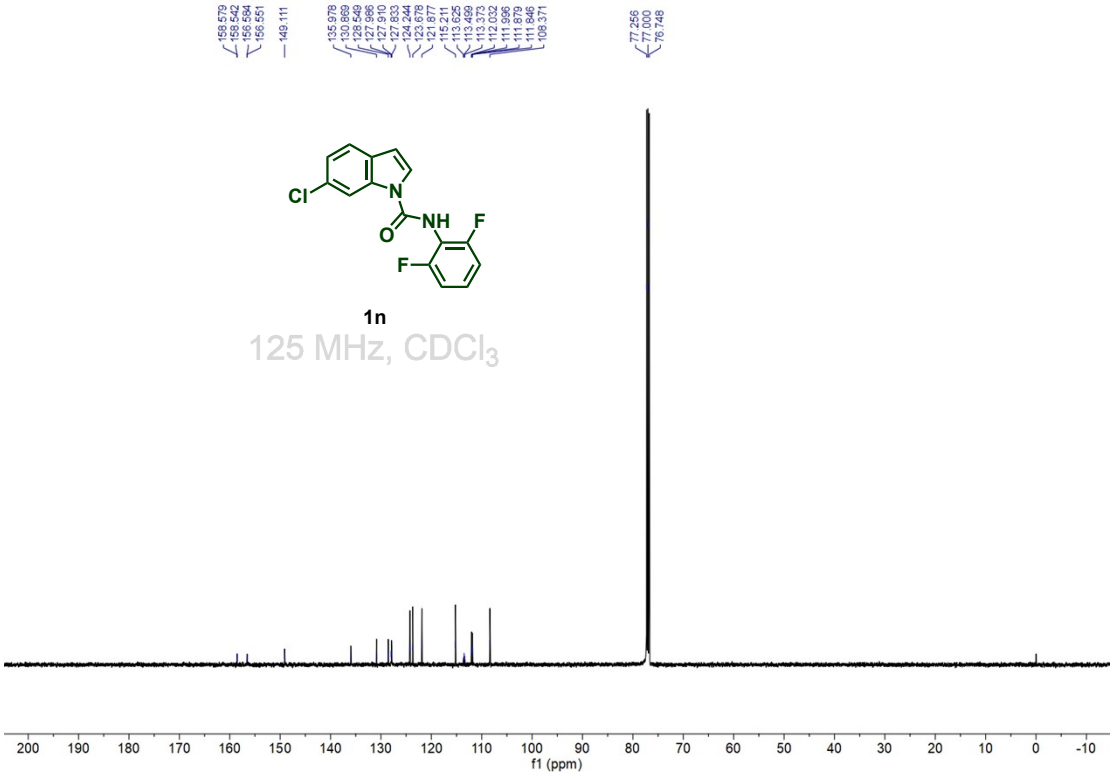




1n

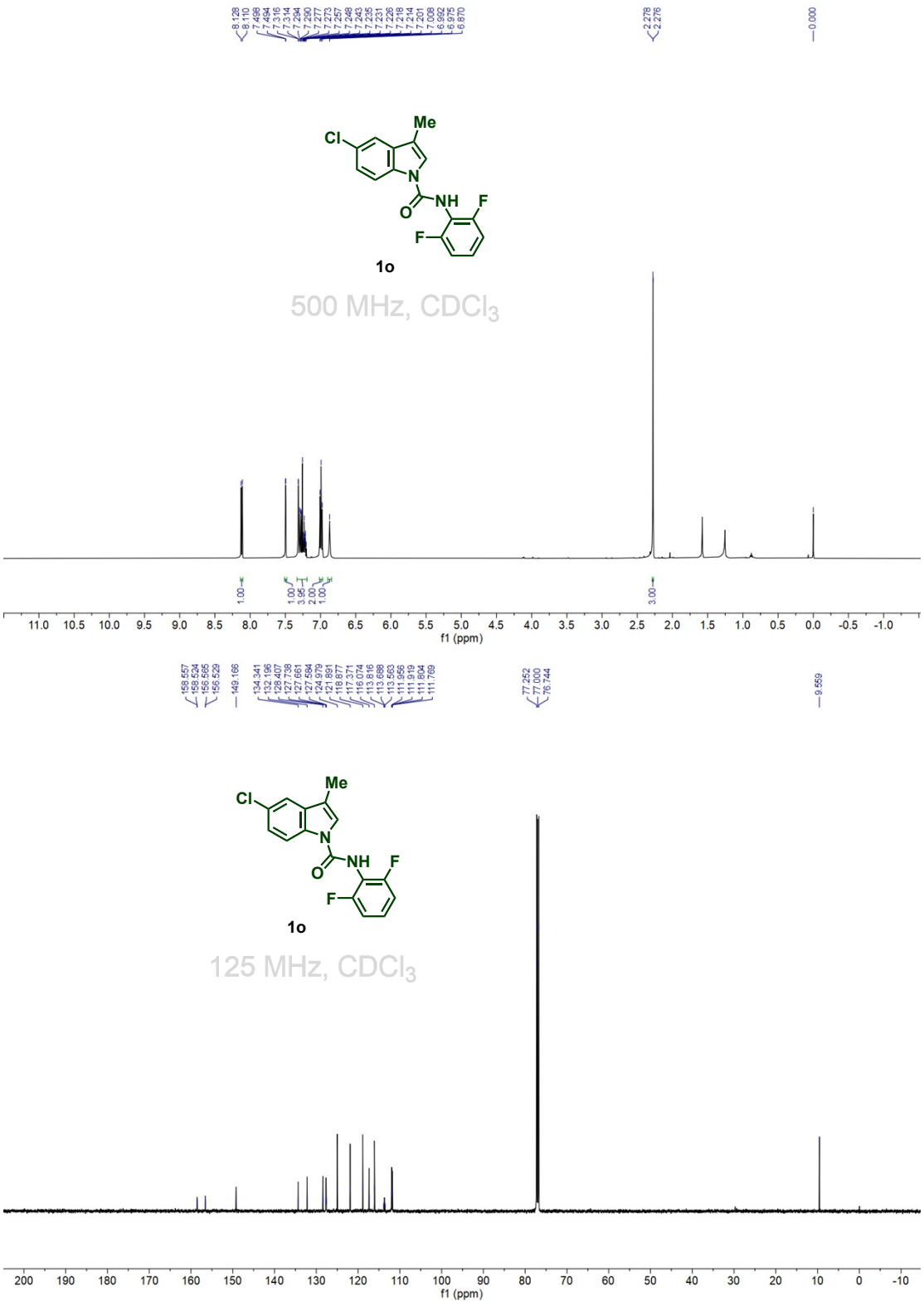
500 MHz, $CDCl_3$

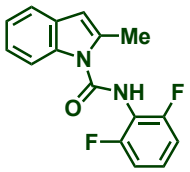




1n

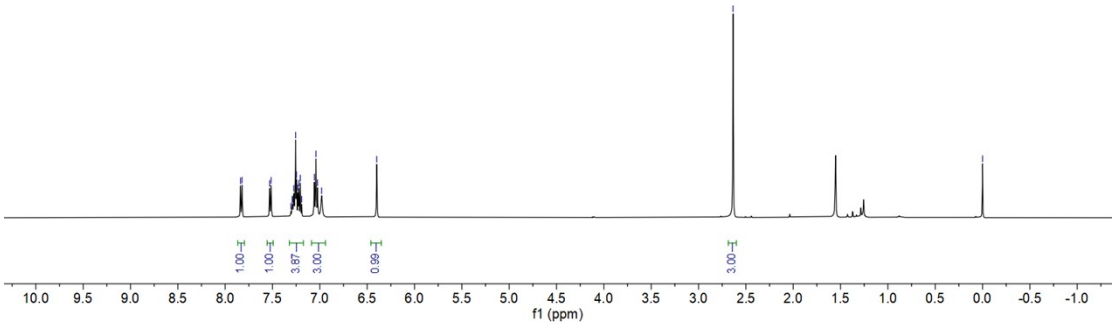
125 MHz, $CDCl_3$

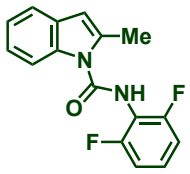

Me
Cl
N
NH
O
F
F
1o
500 MHz, CDCl3
f1 (ppm)
Me
Cl
N
NH
O
F
F
1o
125 MHz, CDCl3
f1 (ppm)



1p

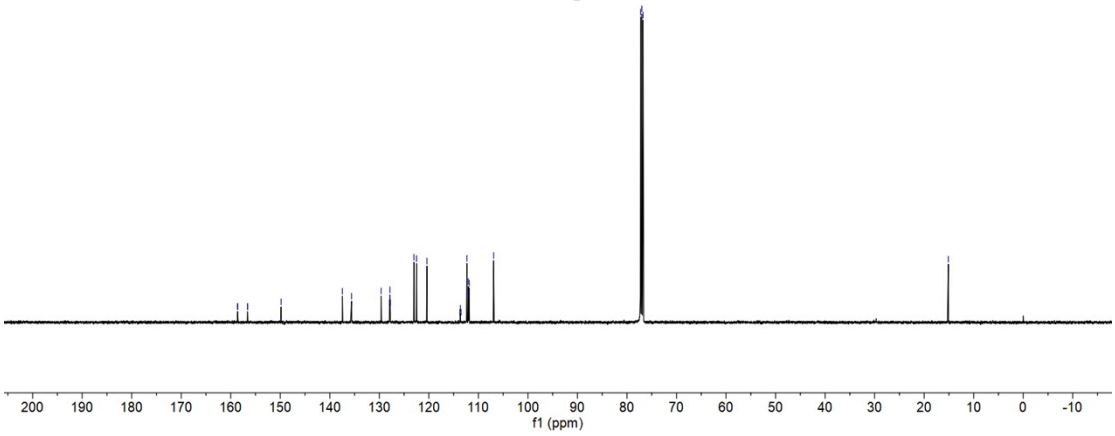
500 MHz, $CDCl_3$

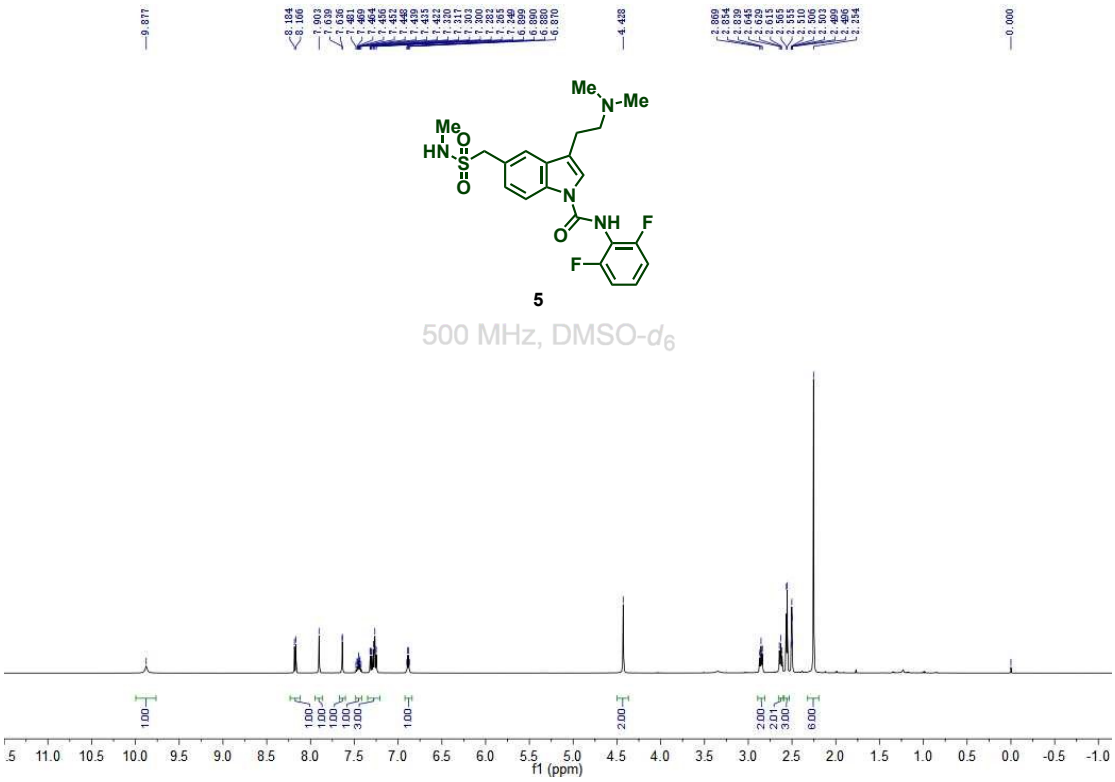


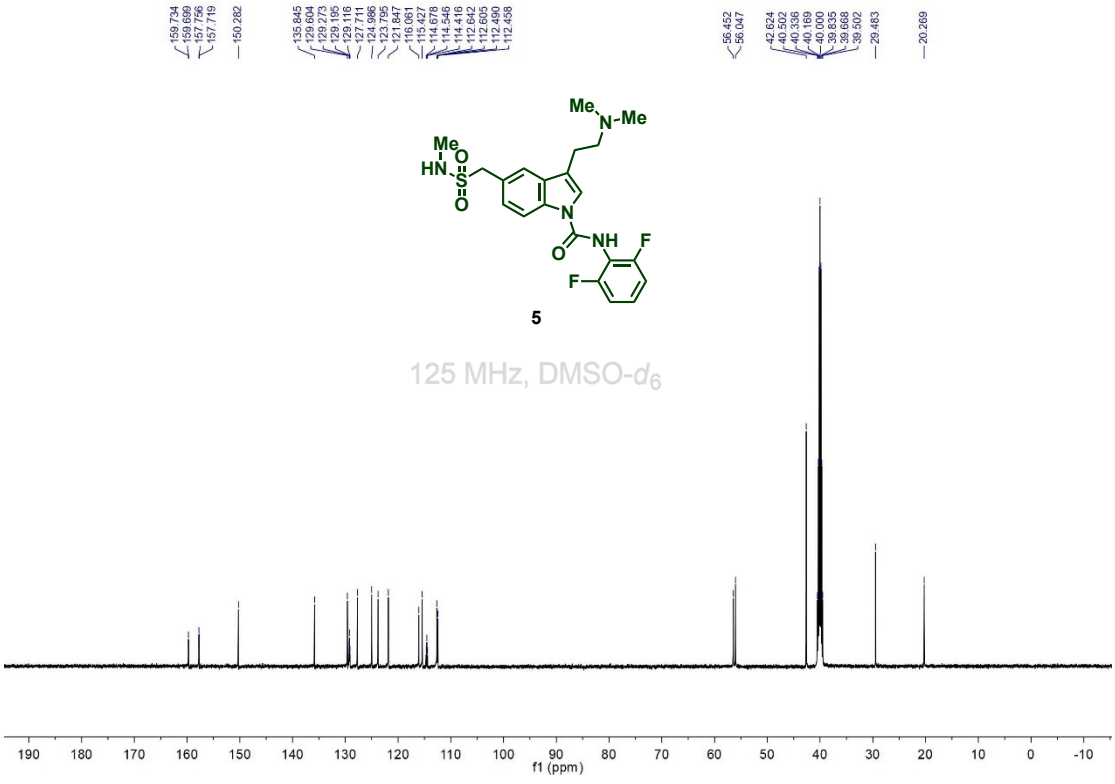


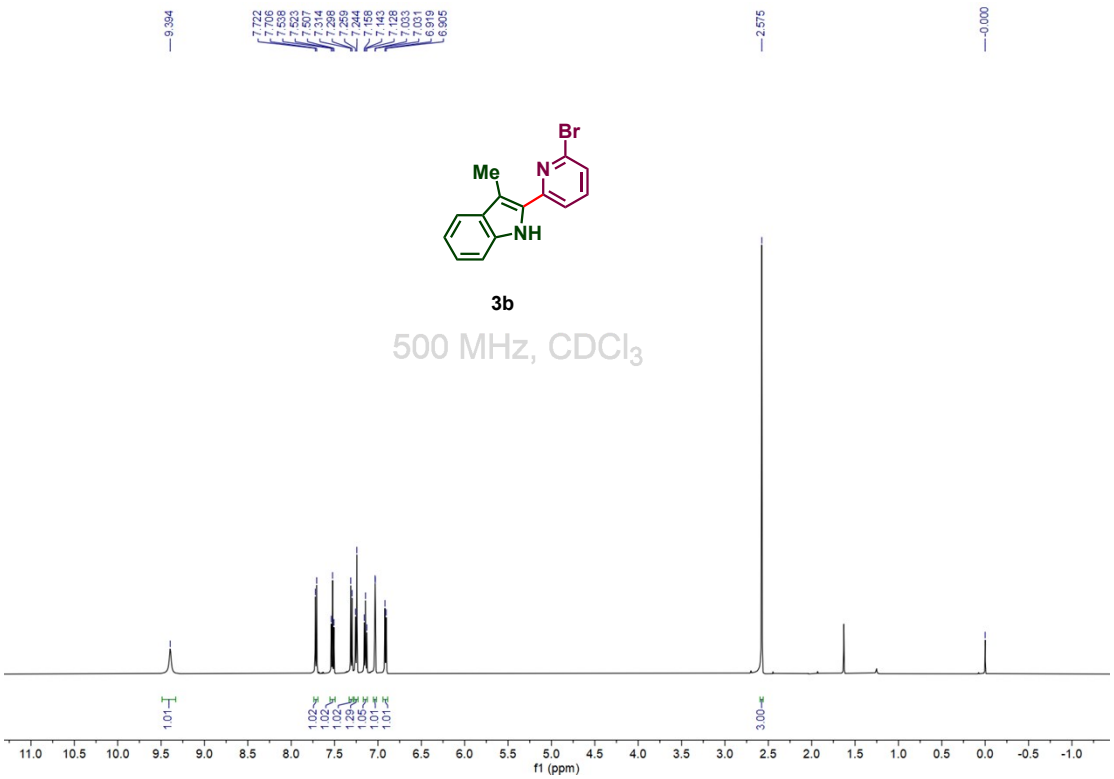
1p

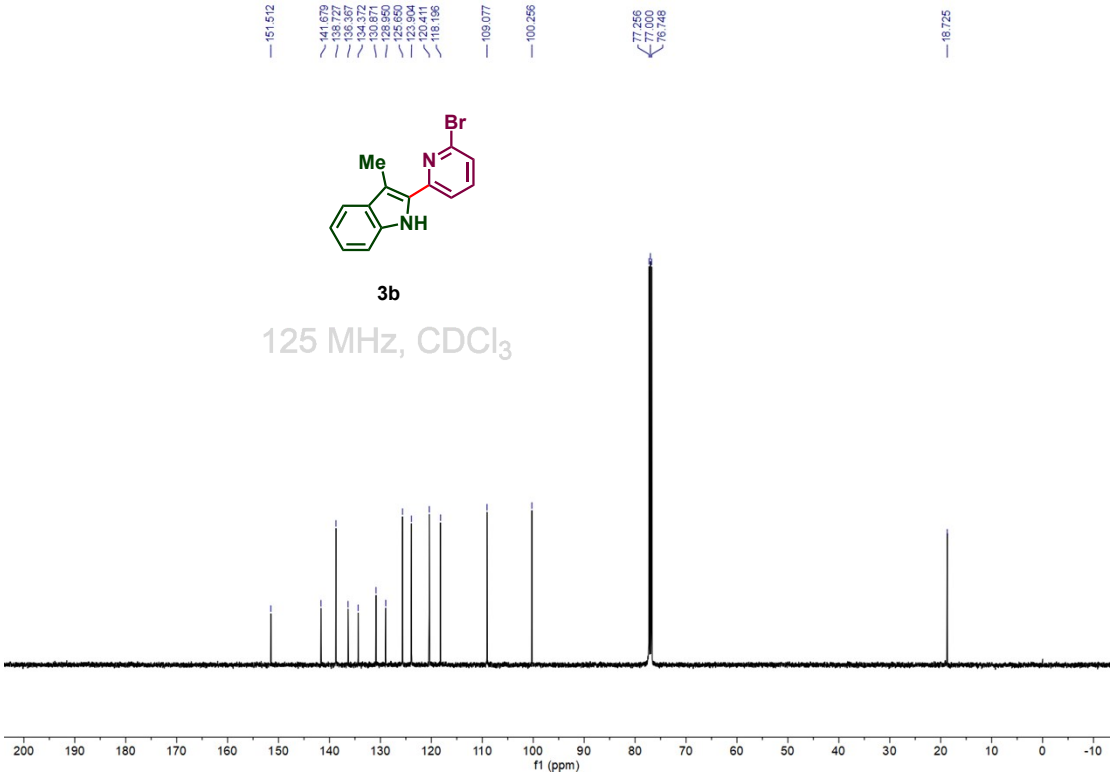
125 MHz, $CDCl_3$

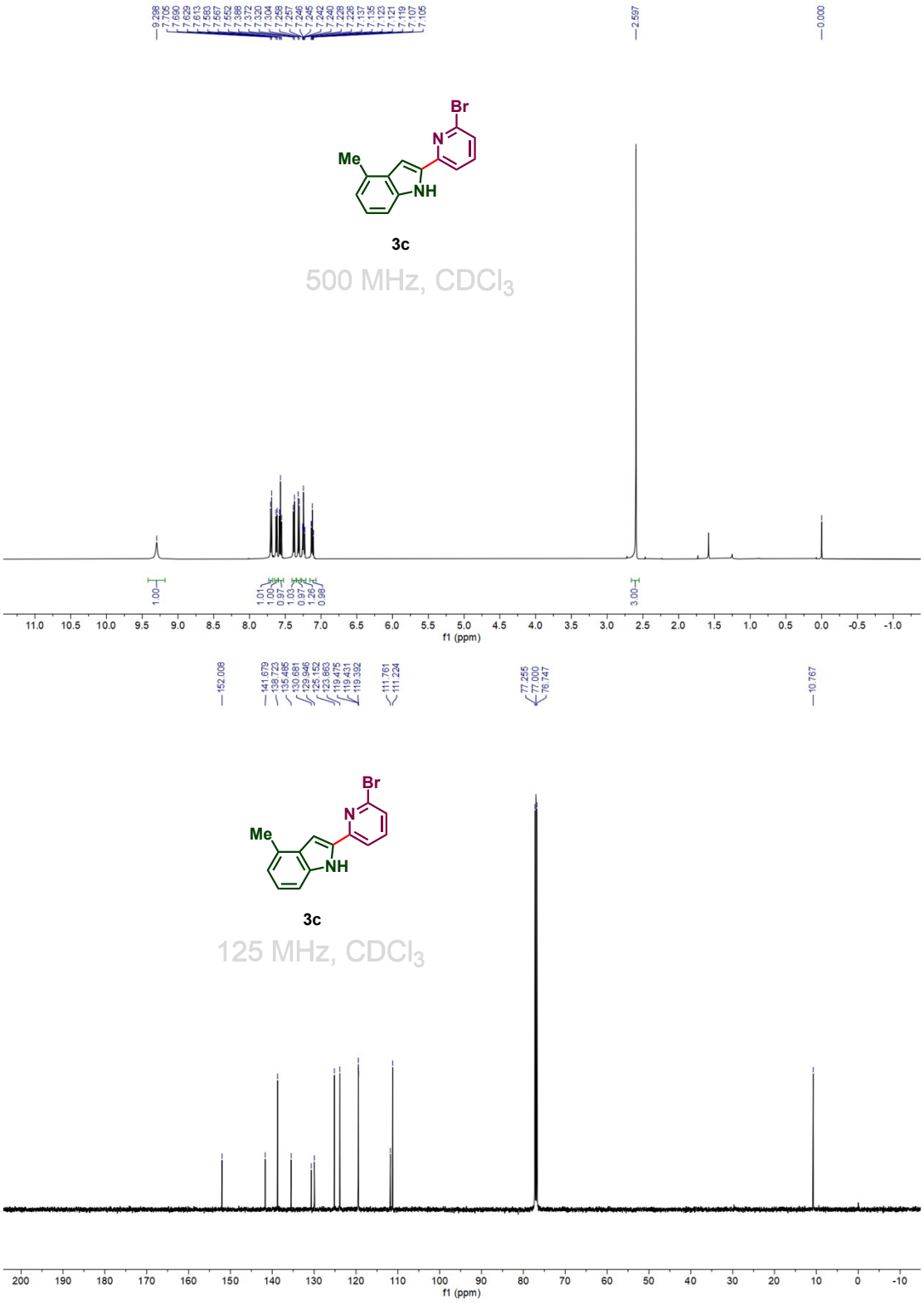


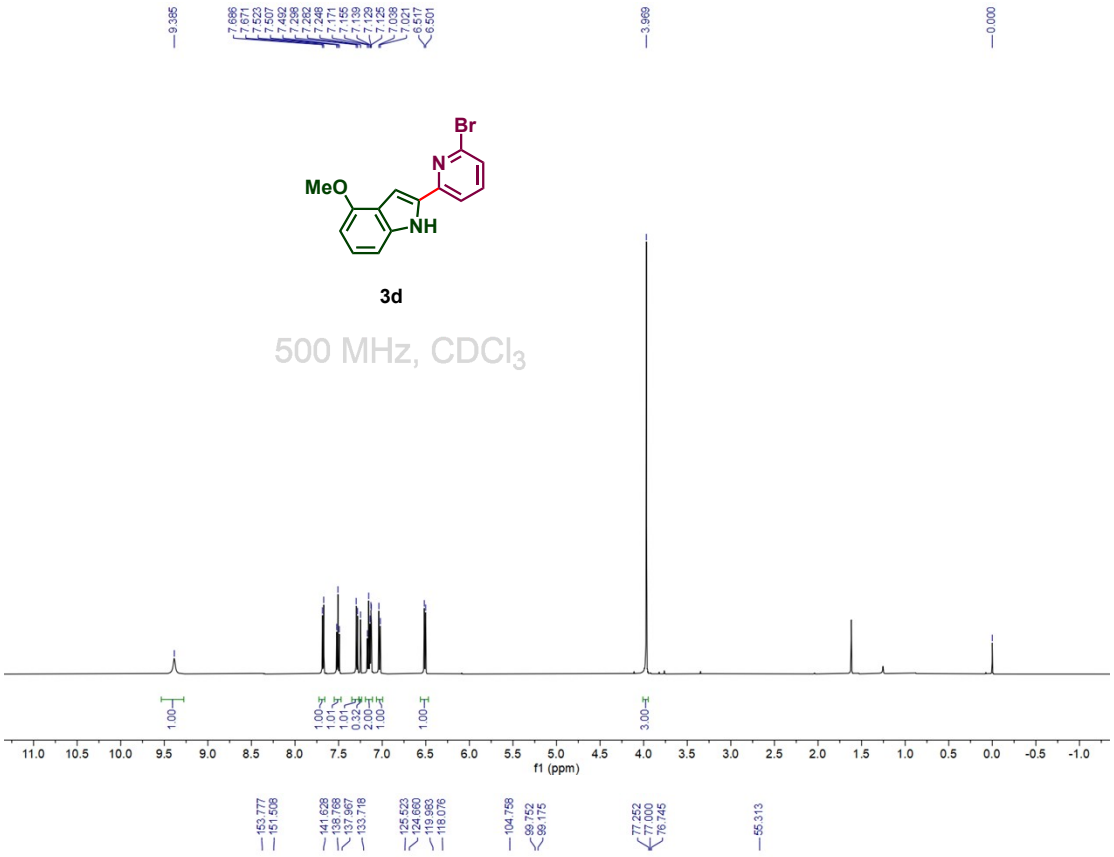

Me
N-Me
Me
HN
O
S
O
N
NH
O
F
F
5
500 MHz, DMSO-d_6
f1 (ppm)

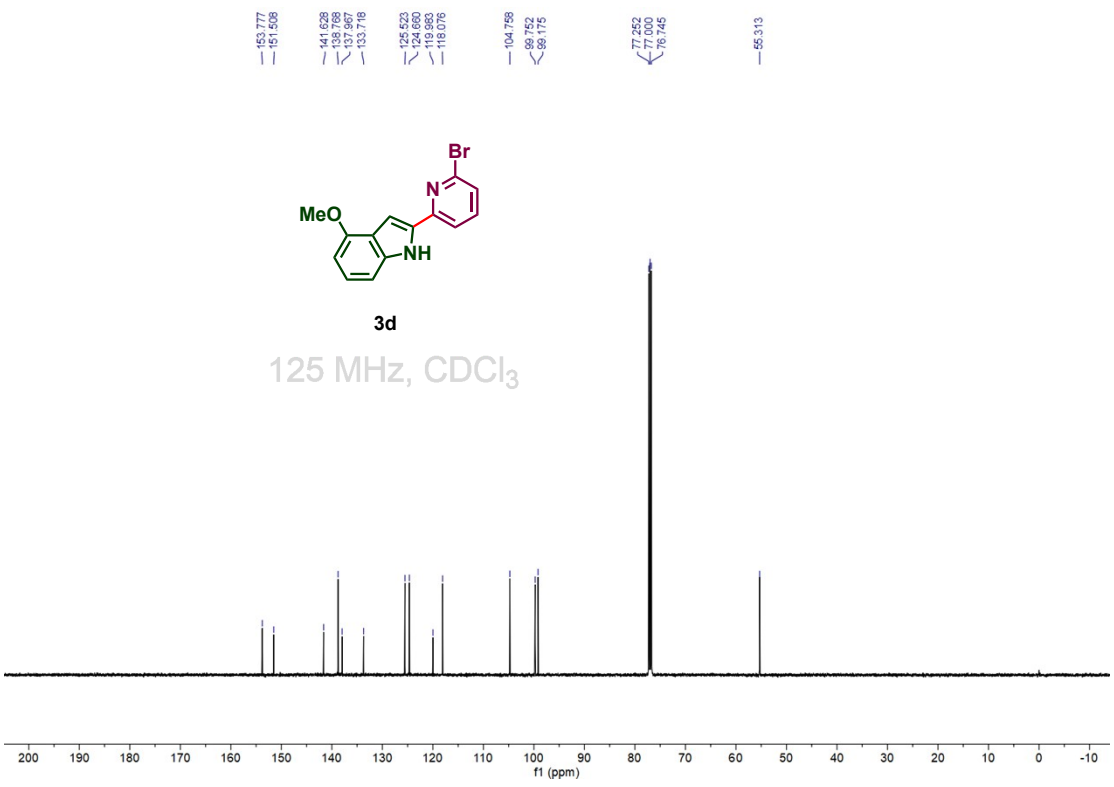

Me
N-Me
Me
HN
O
S
O
N
NH
O
F
F
5
125 MHz, DMSO-d_6
f1 (ppm)

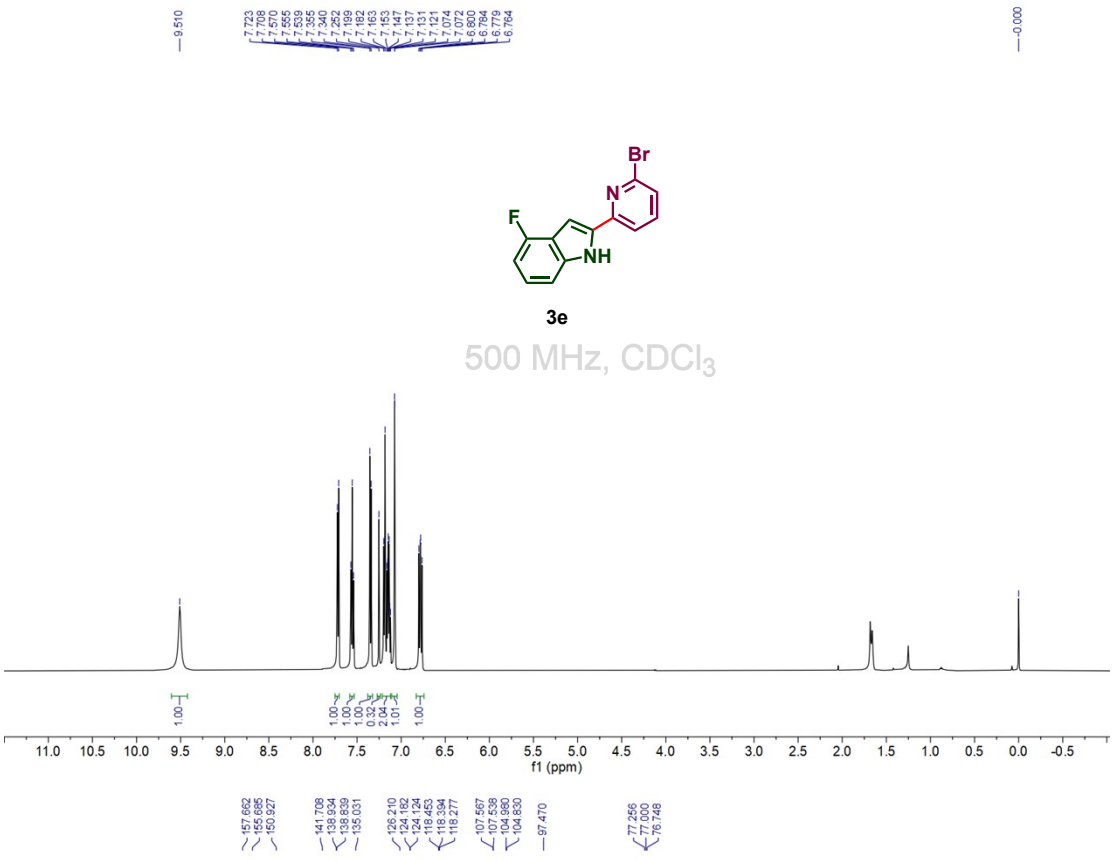

9.394
7.722
7.706
7.589
7.523
7.507
7.314
7.298
7.259
7.244
7.168
7.143
7.128
7.033
7.031
6.919
6.905
2.575
0.000
Br
Me
N
NH
3b
500 MHz, CDCl3
1.01
1.02
1.02
1.03
1.05
1.01
1.01
3.00
11.0 10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5 -1.0
f1 (ppm)

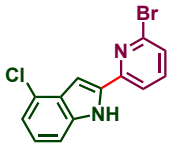

151.512
141.679
139.727
136.367
134.372
130.871
128.960
125.660
123.904
123.411
116.186
109.077
100.256
77.256
77.000
76.748
18.725
Br
Me
N
NH
3b
125 MHz, CDCl3
200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
f1 (ppm)


9.298
7.705
7.690
7.679
7.613
7.583
7.567
7.552
7.388
7.372
7.320
7.304
7.295
7.257
7.246
7.245
7.242
7.240
7.228
7.226
7.137
7.135
7.123
7.121
7.119
7.107
7.105
2.597
0.000
Br
N
Me
NH
3c
500 MHz, CDCl3
1.00
1.01
1.00
1.01
0.97
1.26
0.98
3.00
11.0 10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5 -1.0
f1 (ppm)
152.008
141.679
138.723
135.486
130.681
129.946
125.652
123.863
119.475
119.431
119.392
111.761
111.224
77.255
77.000
76.747
10.767
Br
N
Me
NH
3c
125 MHz, CDCl3
200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
f1 (ppm)


9.385
7.686
7.671
7.523
7.507
7.492
7.296
7.282
7.246
7.171
7.155
7.139
7.125
7.098
7.021
6.517
6.501
3.969
0.000
Br
N
MeO
NH
3d
500 MHz, CDCl3
1.00
1.00
1.01
1.01
0.32
2.00
1.00
1.00
3.00
11.0 10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5 -1.0
f1 (ppm)

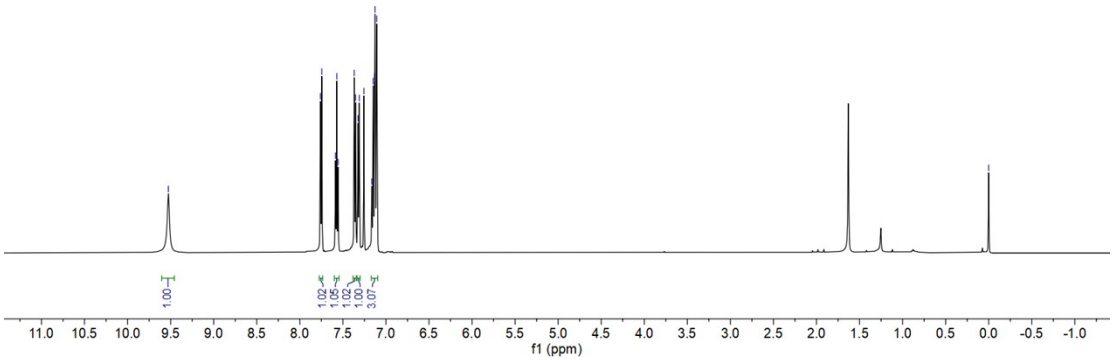

153.777
151.508
141.628
139.788
137.967
133.718
125.523
124.680
119.983
118.076
104.758
99.752
99.175
77.252
77.000
76.745
55.313
Br
N
MeO
NH
3d
125 MHz, CDCl3
200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
f1 (ppm)

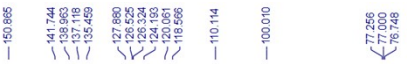

9.510
7.723
7.708
7.570
7.556
7.539
7.365
7.340
7.262
7.199
7.182
7.163
7.153
7.147
7.137
7.131
7.121
7.074
7.072
6.800
6.784
6.779
6.764
-0.000
Br
N
F
NH
3e
500 MHz, CDCl3
1.00
1.00
1.00
1.00
0.32
2.04
1.01
1.00
11.0 10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5
f1 (ppm)
157.662
155.665
150.927
141.708
138.934
138.839
135.031
126.210
124.182
124.124
118.453
118.394
118.277
107.567
107.538
104.969
104.830
97.470
77.256
77.000
76.748
Br
N
F
NH
3e
125 MHz, CDCl3
200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
f1 (ppm)

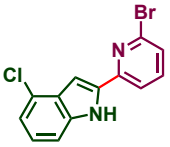


3f

500 MHz, $CDCl_3$

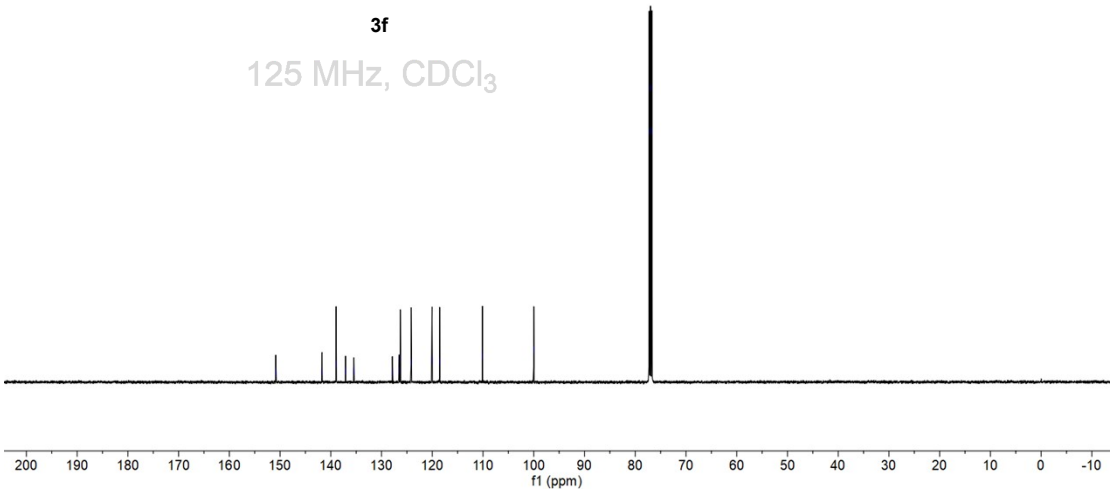


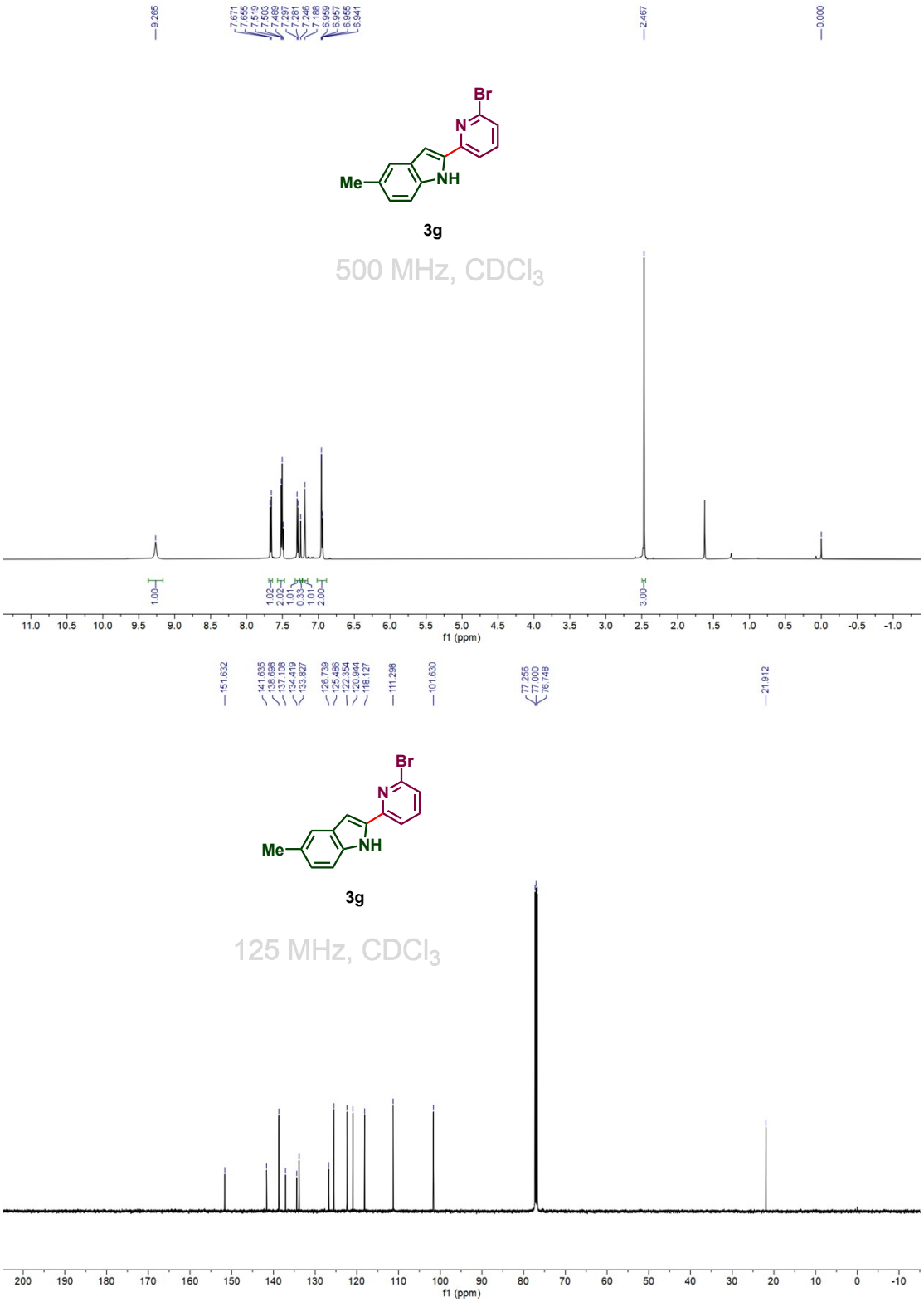


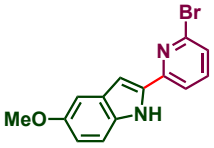


3f

125 MHz, $CDCl_3$

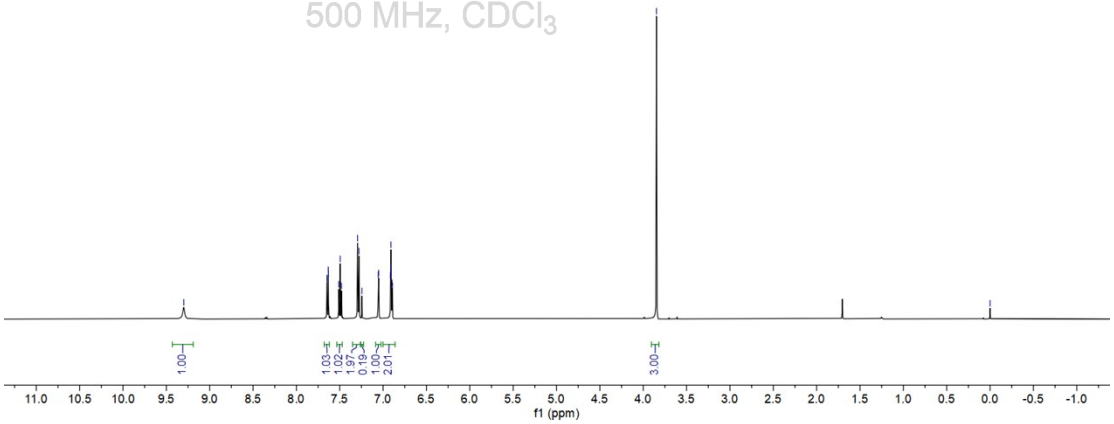


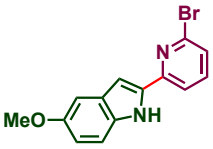

9.265
7.671
7.655
7.519
7.503
7.489
7.297
7.281
7.246
7.168
6.959
6.957
6.955
6.941
2.467
0.000
Br
N
NH
Me
3g
500 MHz, CDCl3
1.00
1.02
2.01
1.01
0.33
1.01
2.00
3.00
f1 (ppm)
151.632
141.635
138.686
137.108
134.419
133.827
126.739
125.486
122.354
120.944
118.127
111.298
101.630
77.256
77.000
76.748
21.912
Br
N
NH
Me
3g
125 MHz, CDCl3
f1 (ppm)



3h

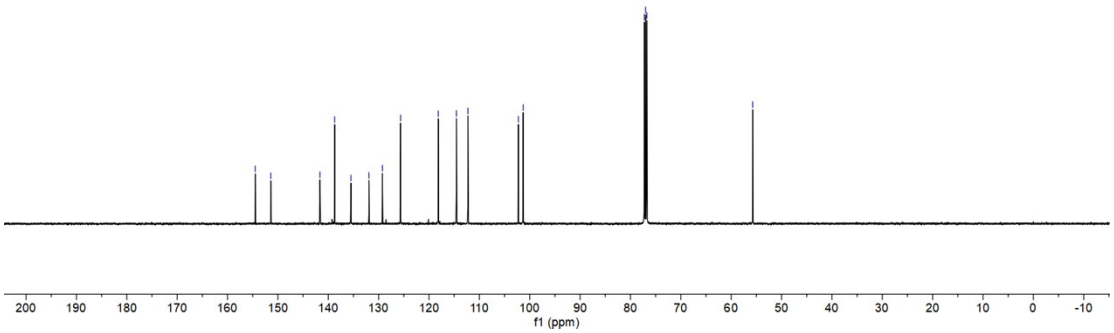
500 MHz, $CDCl_3$

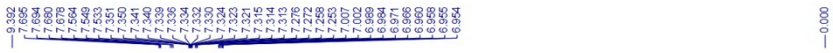


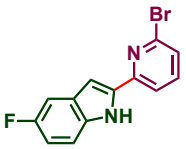


3h

125 MHz, $CDCl_3$

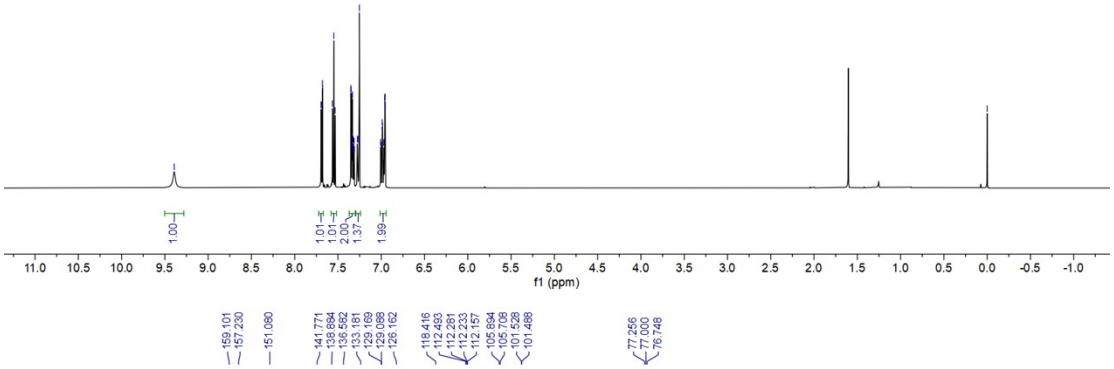


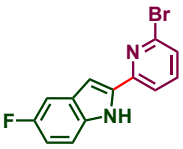




3i

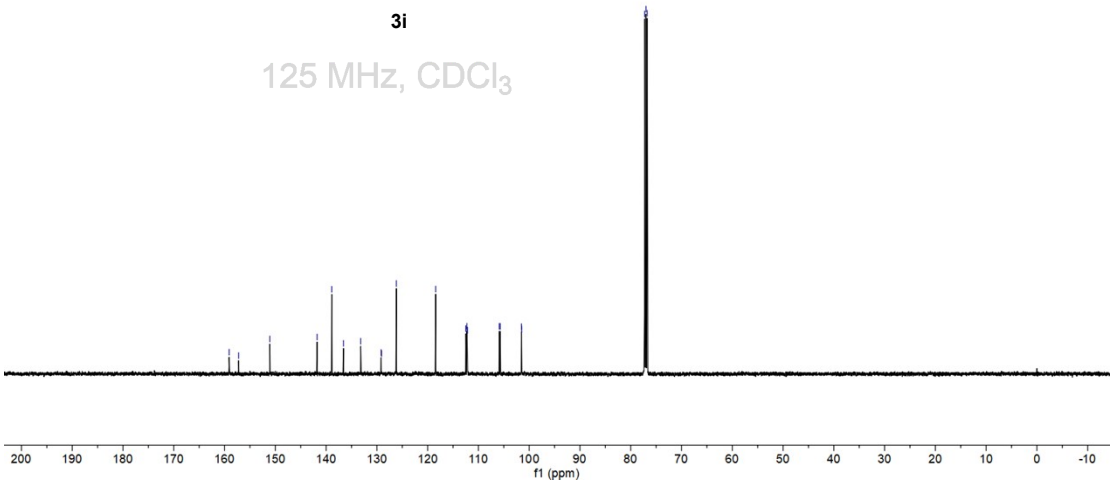
500 MHz, $CDCl_3$

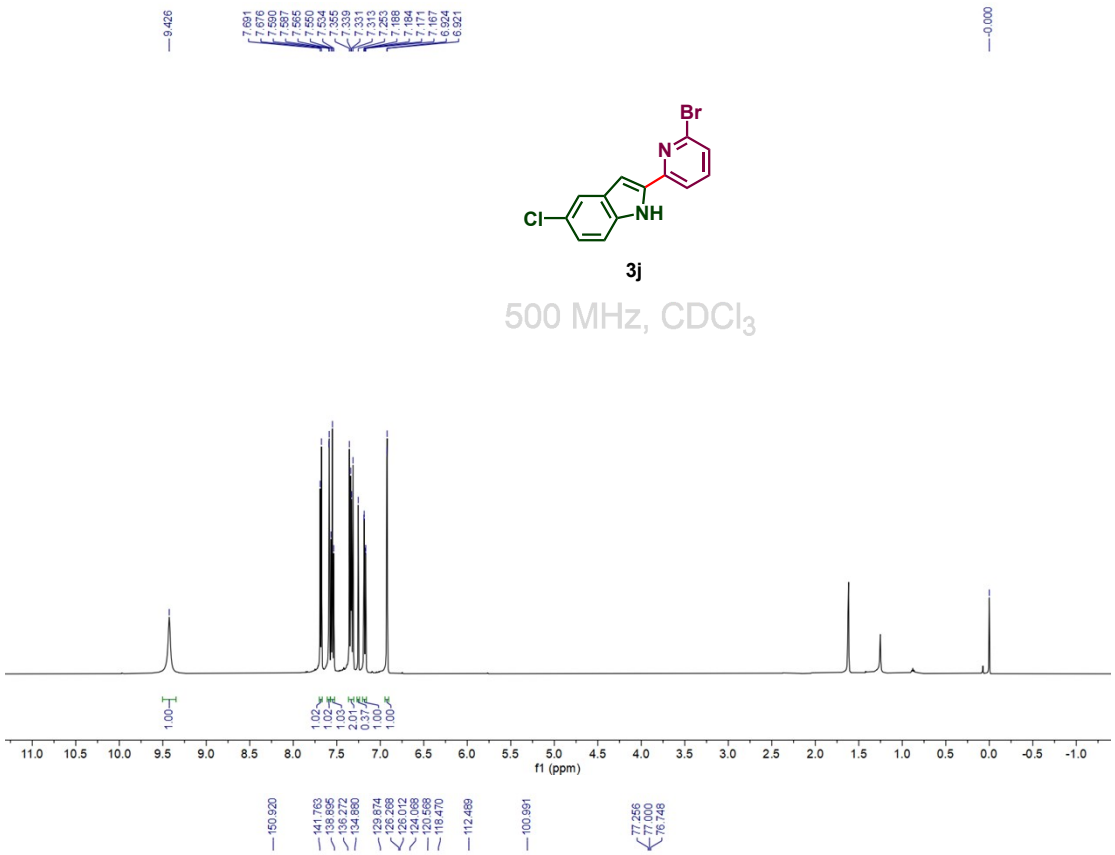


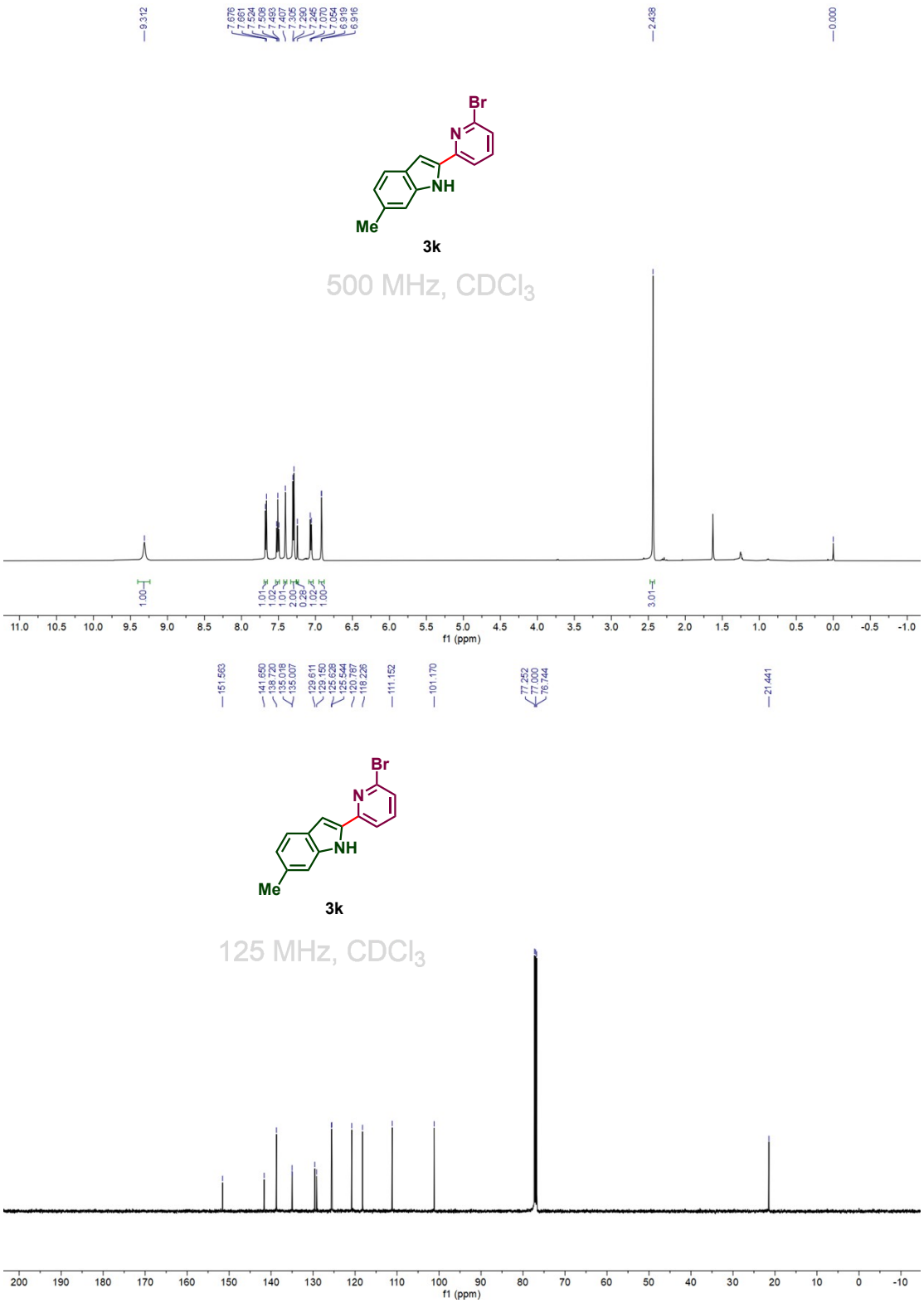


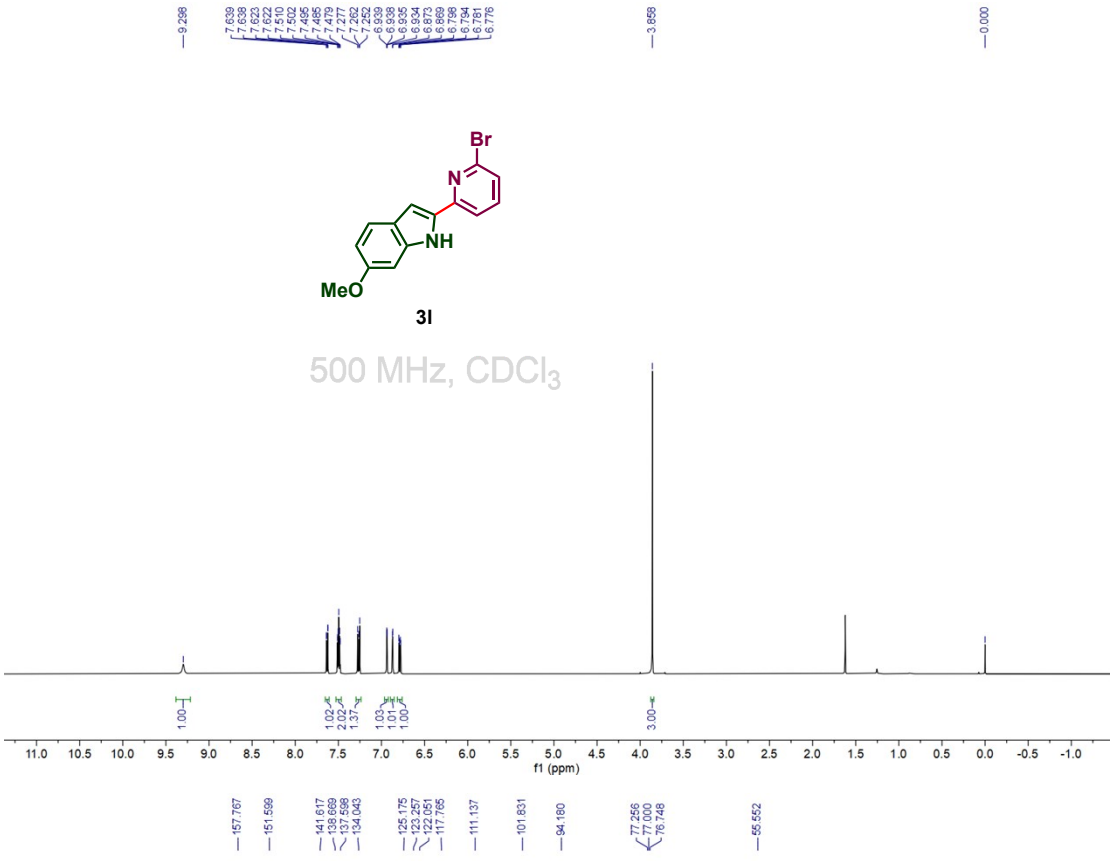
3i

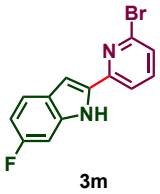
125 MHz, $CDCl_3$




9.426
7.691
7.676
7.590
7.587
7.565
7.560
7.534
7.355
7.339
7.331
7.313
7.253
7.188
7.184
7.171
7.167
6.924
6.921
0.000
Br
N
NH
Cl
3j
500 MHz, CDCl3
1.00
1.02
1.02
1.03
0.37
1.00
1.00
11.0 10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5 -1.0
f1 (ppm)
150.920
141.763
138.895
136.272
134.880
129.874
126.288
126.012
124.068
120.568
118.470
112.469
100.991
77.256
77.000
76.748
Br
N
NH
Cl
3j
125 MHz, CDCl3
200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
f1 (ppm)

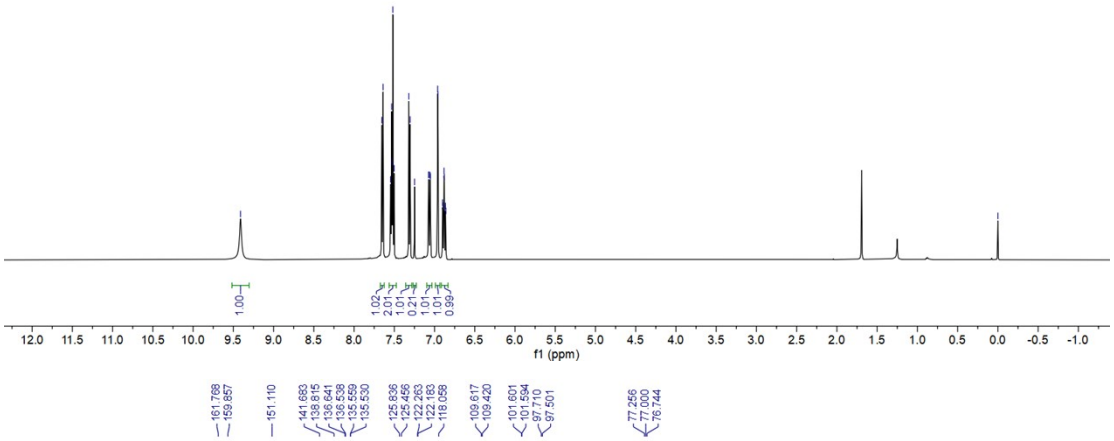

9.312
7.676
7.661
7.524
7.508
7.493
7.407
7.395
7.390
7.245
7.070
7.054
6.919
6.916
2.438
0.000
Br
N
NH
Me
3k
500 MHz, CDCl3
1.00
1.01
1.02
1.01
2.00
1.02
1.00
3.01
11.0 10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5 -1.0
f1 (ppm)
151.563
141.650
138.720
135.018
135.007
129.611
129.150
125.628
125.544
120.787
118.226
111.152
101.170
77.252
77.000
76.744
21.441
Br
N
NH
Me
3k
125 MHz, CDCl3
200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
f1 (ppm)

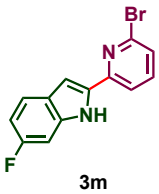

9.296
7.639
7.638
7.623
7.622
7.510
7.502
7.495
7.485
7.479
7.277
7.262
7.252
6.939
6.938
6.935
6.934
6.873
6.869
6.798
6.794
6.781
6.776
3.858
0.000
Br
N
NH
MeO
3l
500 MHz, CDCl3
1.00
1.02
2.02
1.37
1.03
1.01
1.00
3.00
11.0 10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5 -1.0
f1 (ppm)
157.767
151.599
141.617
138.669
137.598
134.043
125.175
123.257
122.051
117.765
111.137
101.831
94.180
77.256
77.000
76.748
55.552
Br
N
NH
MeO
3l
125 MHz, CDCl3
200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
f1 (ppm)



3m

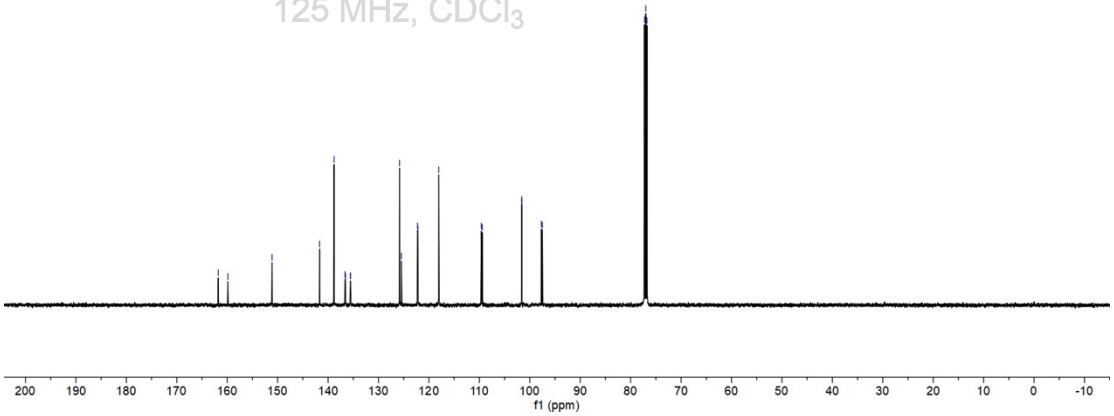
500 MHz, $CDCl_3$

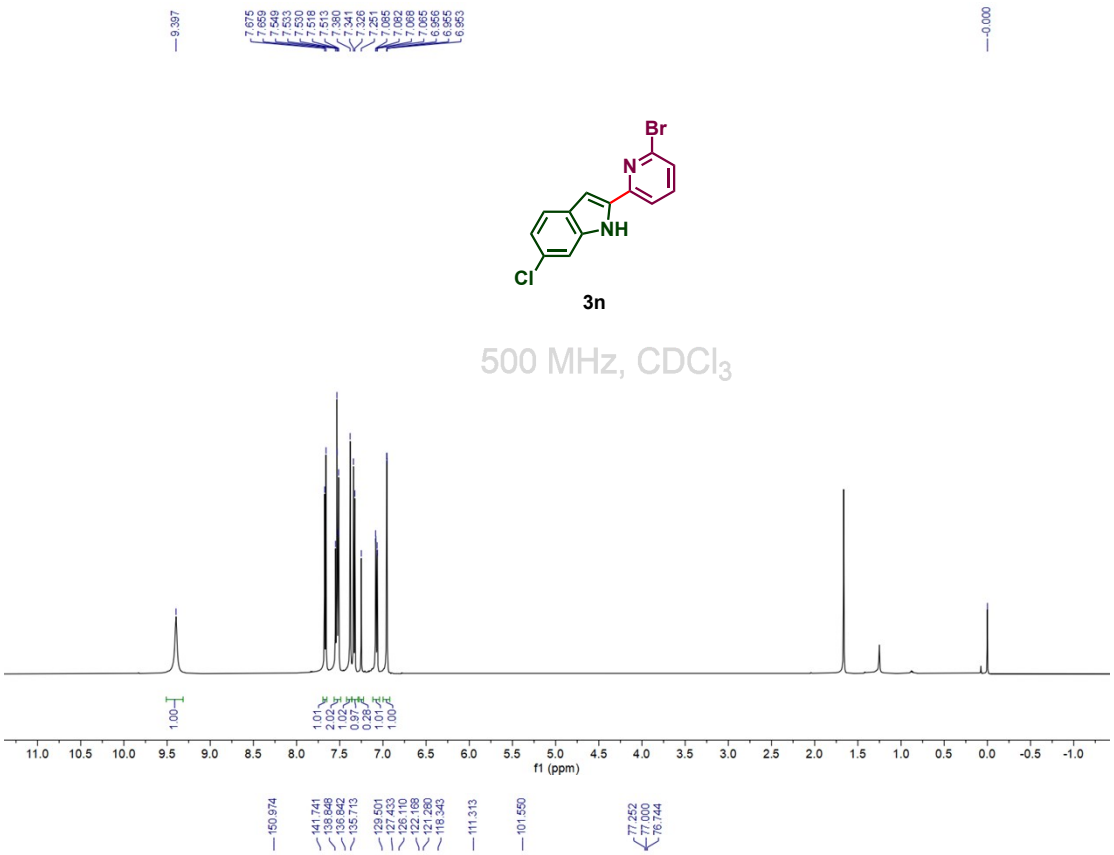


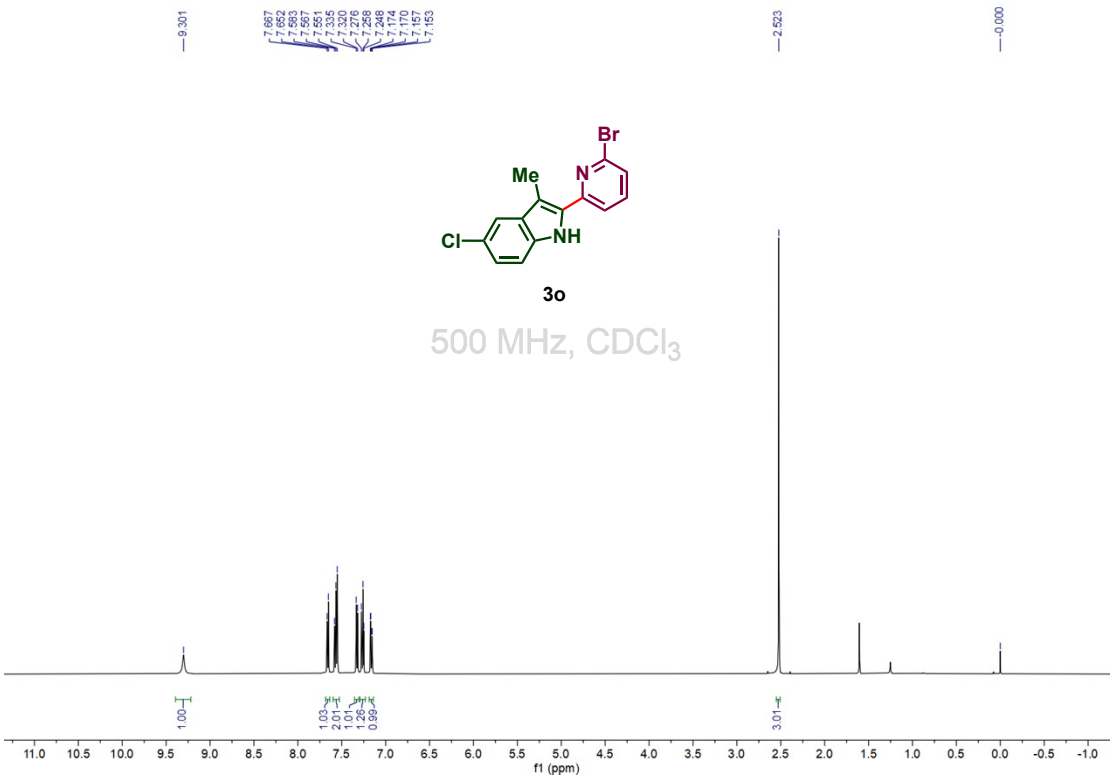


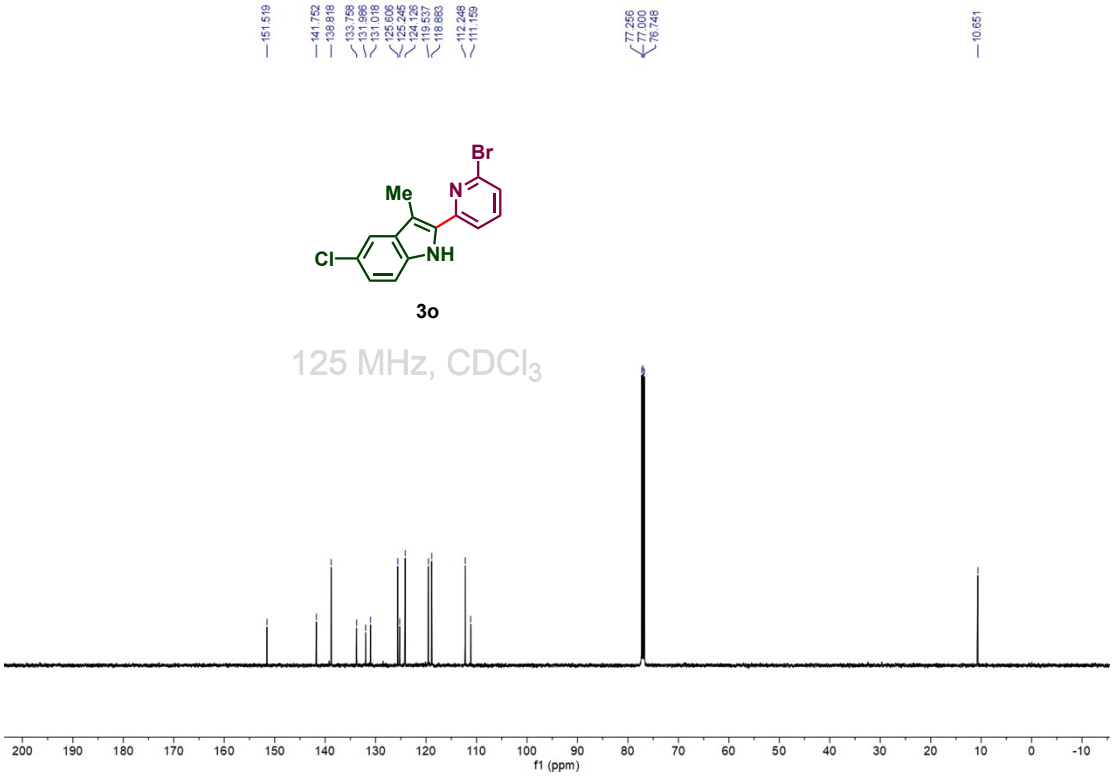
3m

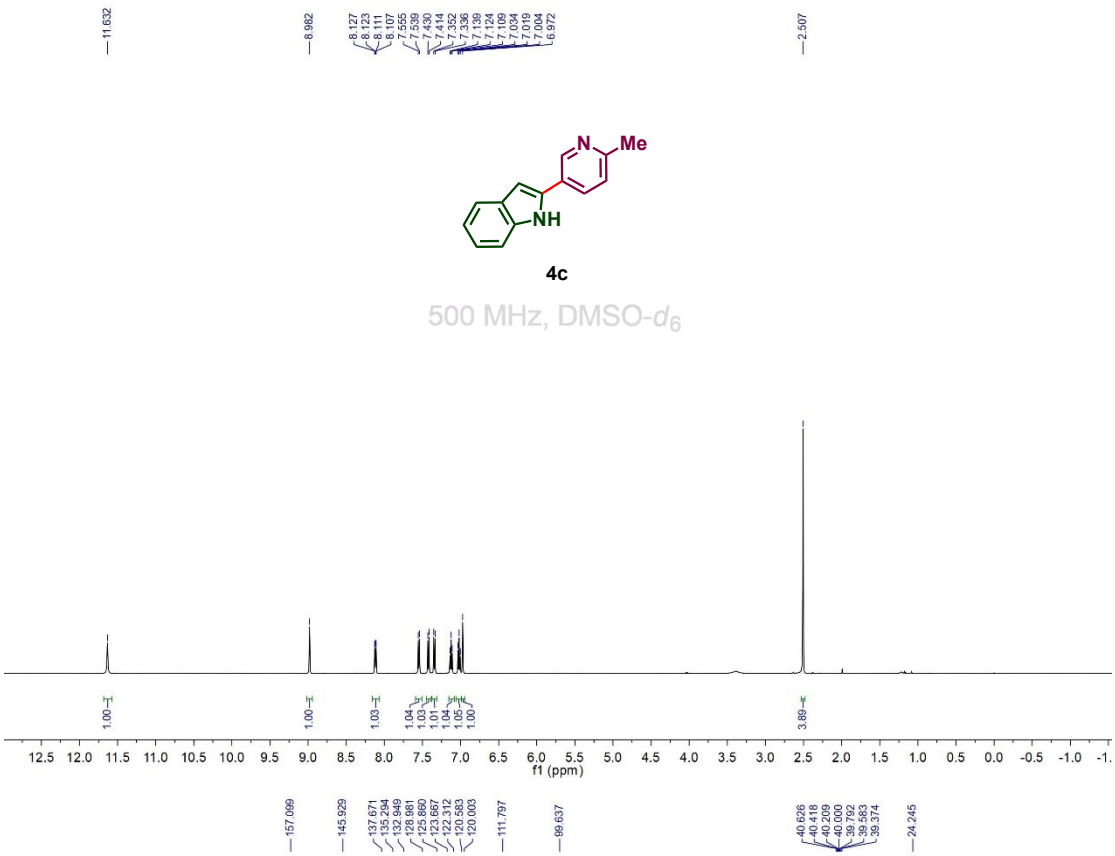
125 MHz, $CDCl_3$

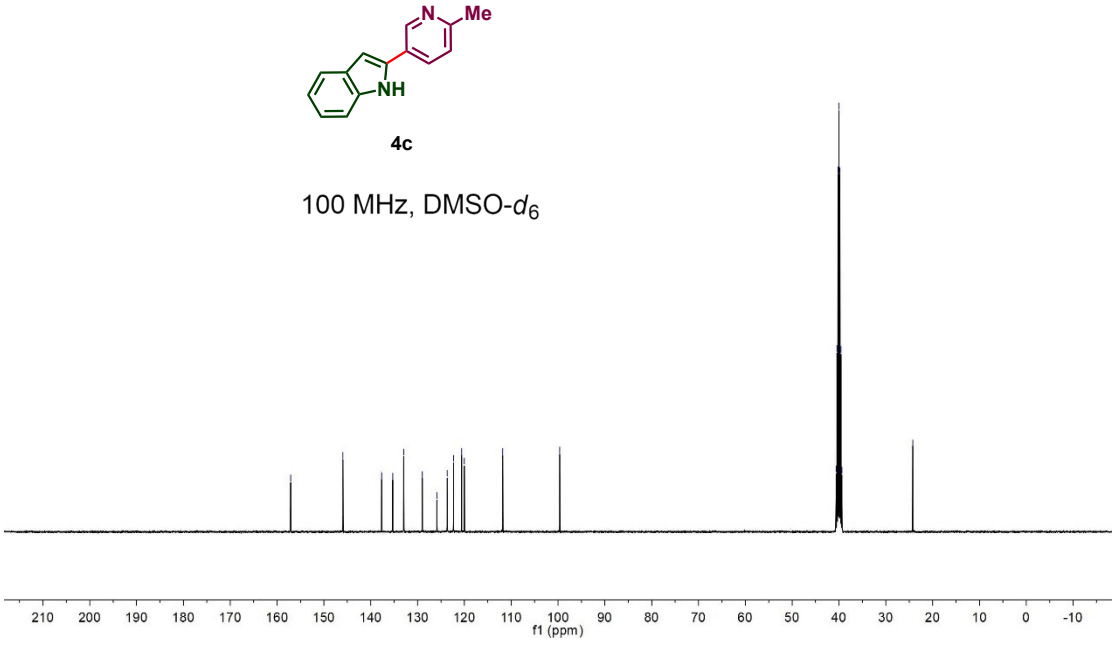


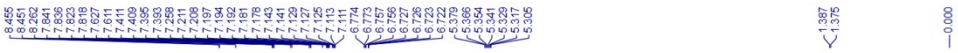

9.397
7.675
7.659
7.549
7.533
7.530
7.516
7.513
7.390
7.341
7.326
7.251
7.085
7.082
7.068
7.065
6.955
6.955
6.953
0.000
Br
N
NH
Cl
3n
500 MHz, CDCl3
1.00
1.01
2.02
1.02
0.97
0.89
1.01
1.00
11.0 10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5 -1.0
f1 (ppm)
150.974
141.741
138.848
136.842
135.713
129.501
127.433
126.110
122.169
121.280
118.343
111.313
101.550
77.252
77.000
76.744
Br
N
NH
Cl
3n
125 MHz, CDCl3
200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
f1 (ppm)

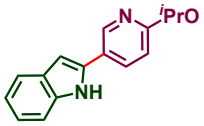

9.301
7.687
7.682
7.593
7.567
7.551
7.335
7.320
7.276
7.258
7.248
7.174
7.170
7.157
7.153
2.523
0.000
Br
Me
N
Cl
NH
3o
500 MHz, CDCl3
1.00
1.03
2.01
1.01
1.26
0.99
3.01
11.0 10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5 -1.0
f1 (ppm)


151.519
141.752
138.818
133.758
131.986
131.018
125.606
125.245
124.126
119.537
118.863
112.248
111.159
77.256
77.000
76.748
10.651
Br
Me
N
Cl
NH
3o
125 MHz, CDCl3
200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
f1 (ppm)


11.632
8.982
8.127
8.123
8.111
8.107
7.555
7.539
7.430
7.414
7.352
7.336
7.139
7.124
7.109
7.034
7.019
7.004
6.972
2.507
N
Me
NH
4c
500 MHz, DMSO-d_6
1.00
1.00
1.03
1.04
1.03
1.01
1.04
1.05
1.00
3.89
f1 (ppm)

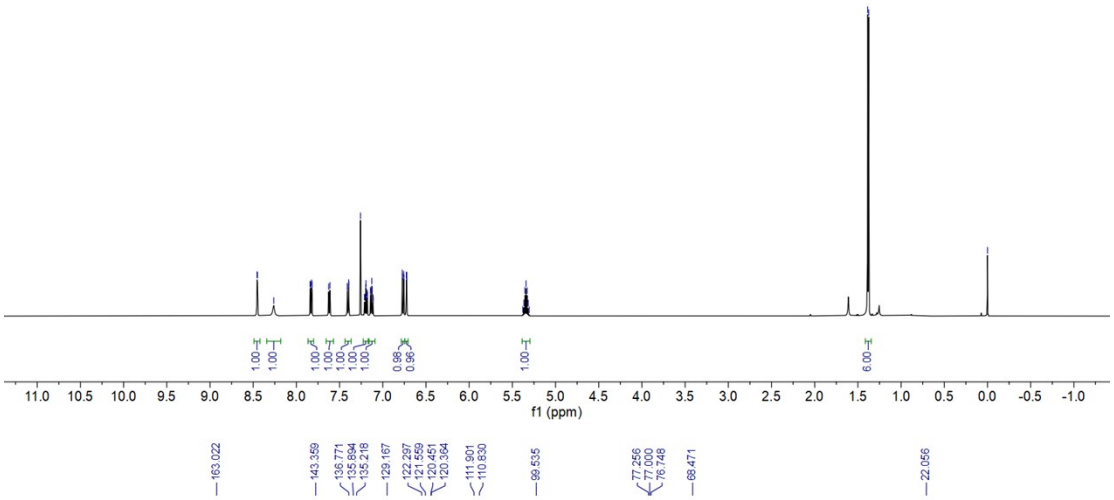

157.099
145.929
137.671
135.294
132.949
128.981
123.880
123.667
122.312
120.583
120.003
111.797
99.637
40.626
40.418
40.209
40.000
39.792
39.583
39.374
24.245
N
Me
NH
4c
100 MHz, DMSO-d_6
f1 (ppm)

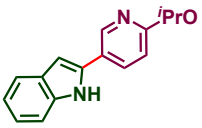




4d

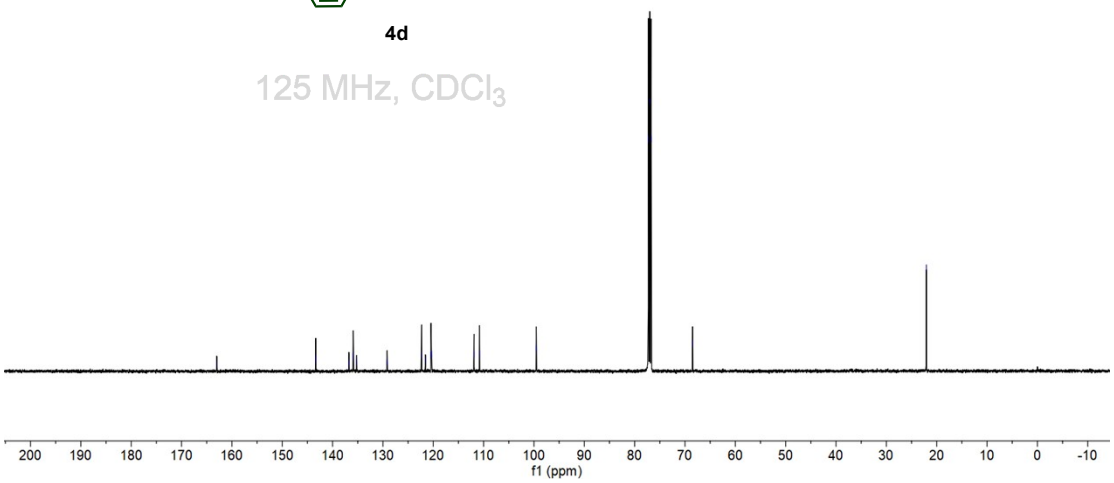
500 MHz, $CDCl_3$

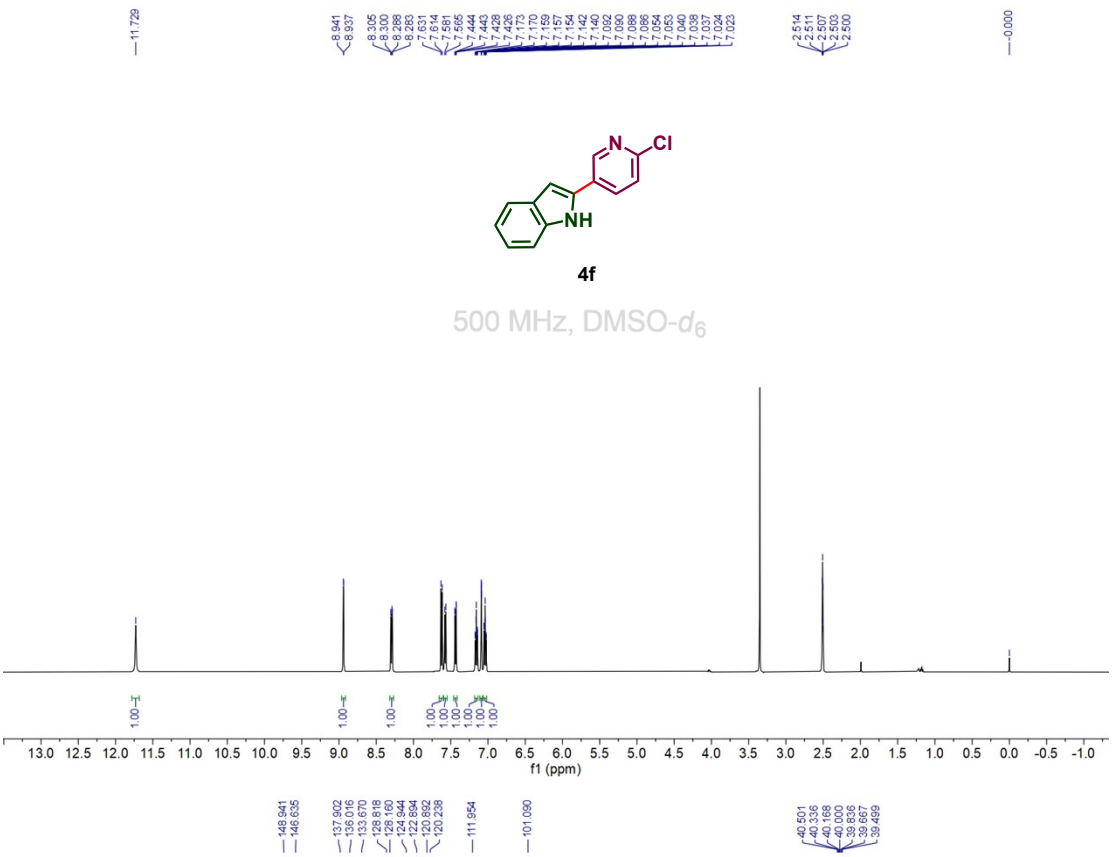


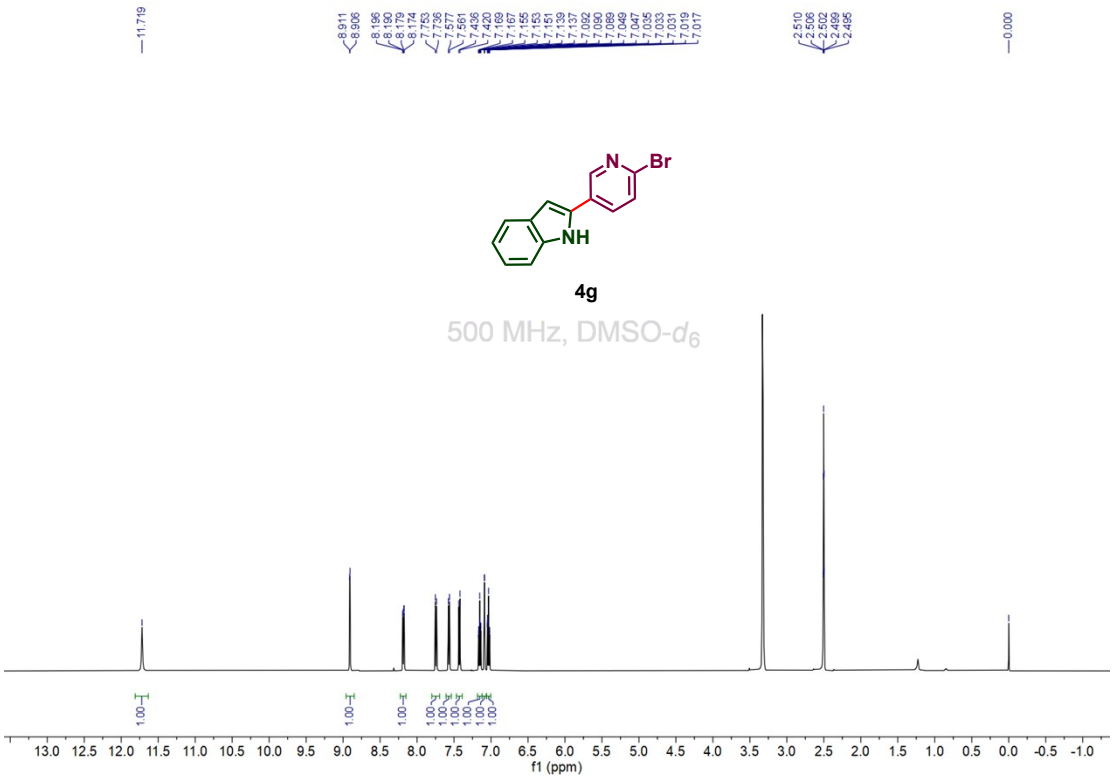


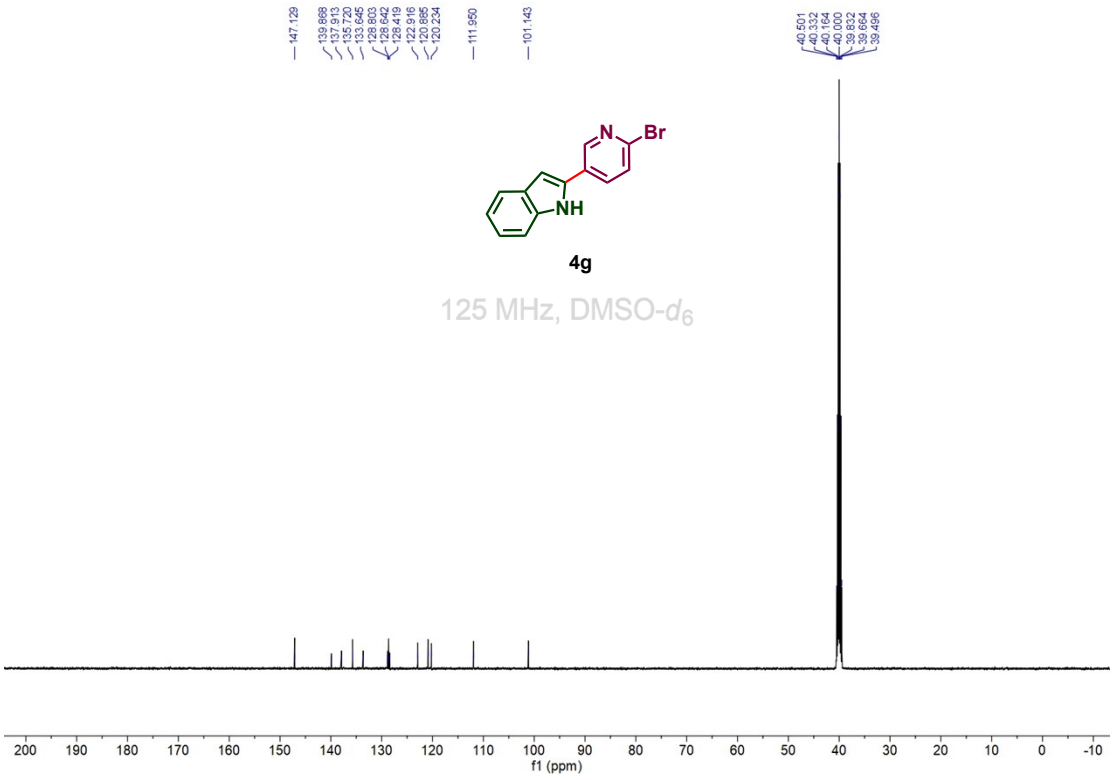
4d

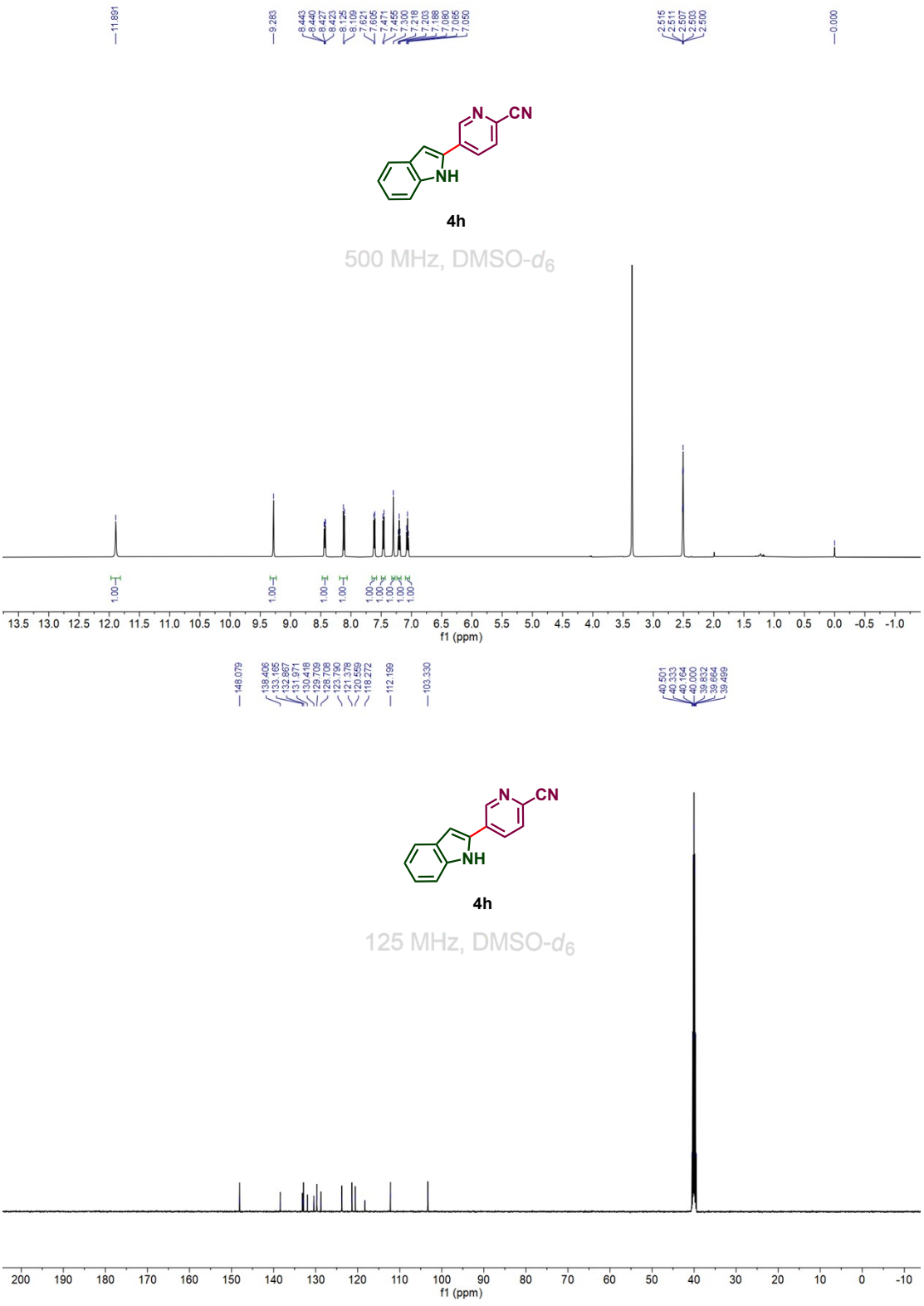
125 MHz, $CDCl_3$

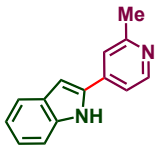



11.729
8.941
8.937
8.305
8.300
8.288
8.283
7.631
7.614
7.581
7.565
7.444
7.443
7.428
7.426
7.173
7.170
7.159
7.157
7.154
7.142
7.140
7.092
7.090
7.088
7.086
7.054
7.053
7.040
7.038
7.037
7.024
7.023
2.514
2.511
2.507
2.503
2.500
0.000
N
Cl
NH
4f
500 MHz, DMSO-d_6
1.00
1.00
1.00
1.00
1.00
1.00
1.00
1.00
13.0 12.5 12.0 11.5 11.0 10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5 -1.0
f1 (ppm)
148.941
146.635
137.902
136.016
133.670
128.818
128.160
124.944
122.894
120.892
120.238
111.954
101.090
40.501
40.336
40.168
40.000
39.836
39.667
39.499
N
Cl
NH
4f
125 MHz, DMSO-d_6
200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
f1 (ppm)


11.719
8.911
8.906
8.196
8.190
8.179
8.174
7.753
7.736
7.577
7.561
7.436
7.420
7.169
7.167
7.155
7.153
7.151
7.139
7.137
7.092
7.090
7.089
7.049
7.047
7.035
7.033
7.031
7.019
7.017
2.510
2.506
2.502
2.499
2.495
0.000
N
Br
NH
4g
500 MHz, DMSO-d_6
1.00
1.00
1.00
1.00
1.00
1.00
1.00
1.00
1.00
13.0 12.5 12.0 11.5 11.0 10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5 -1.0
f1 (ppm)

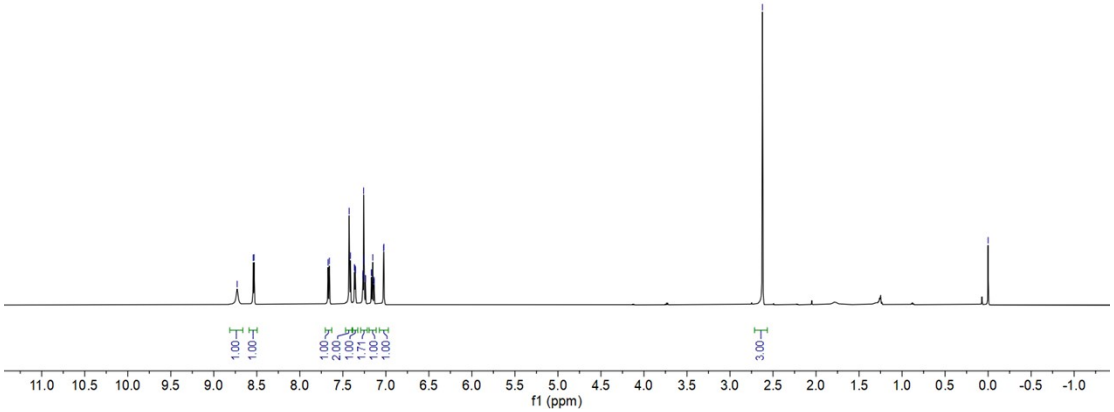

147.129
139.868
137.913
135.720
133.645
128.803
128.642
128.419
122.916
120.885
120.234
111.950
101.143
40.501
40.332
40.164
40.000
39.832
39.664
39.496
N
Br
NH
4g
125 MHz, DMSO-d_6
200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
f1 (ppm)

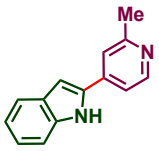

11.891
9.283
8.443
8.440
8.427
8.423
8.125
8.109
7.621
7.605
7.471
7.455
7.300
7.218
7.203
7.188
7.080
7.065
7.050
2.515
2.511
2.507
2.503
2.500
0.000
N
CN
NH
4h
500 MHz, DMSO-d_6
1.00
1.00
1.00
1.00
1.00
1.00
1.00
1.00
13.5 13.0 12.5 12.0 11.5 11.0 10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5 -1.0
f1 (ppm)
148.079
138.406
133.165
132.867
131.971
130.418
129.709
128.708
123.730
121.378
120.559
118.272
112.199
103.330
40.501
40.333
40.164
40.000
39.832
39.664
39.499
N
CN
NH
4h
125 MHz, DMSO-d_6
200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
f1 (ppm)



4i

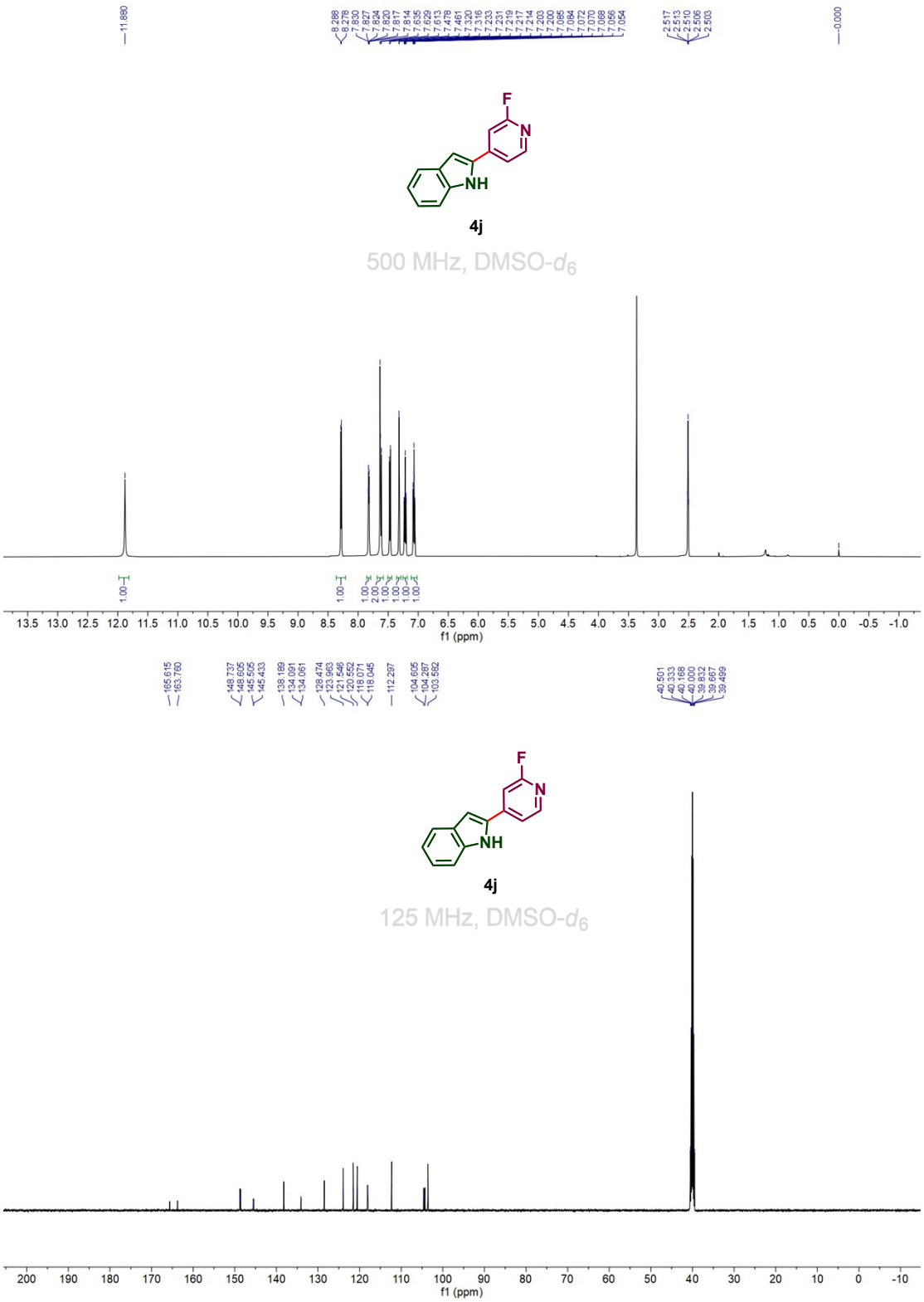
500 MHz, $CDCl_3$

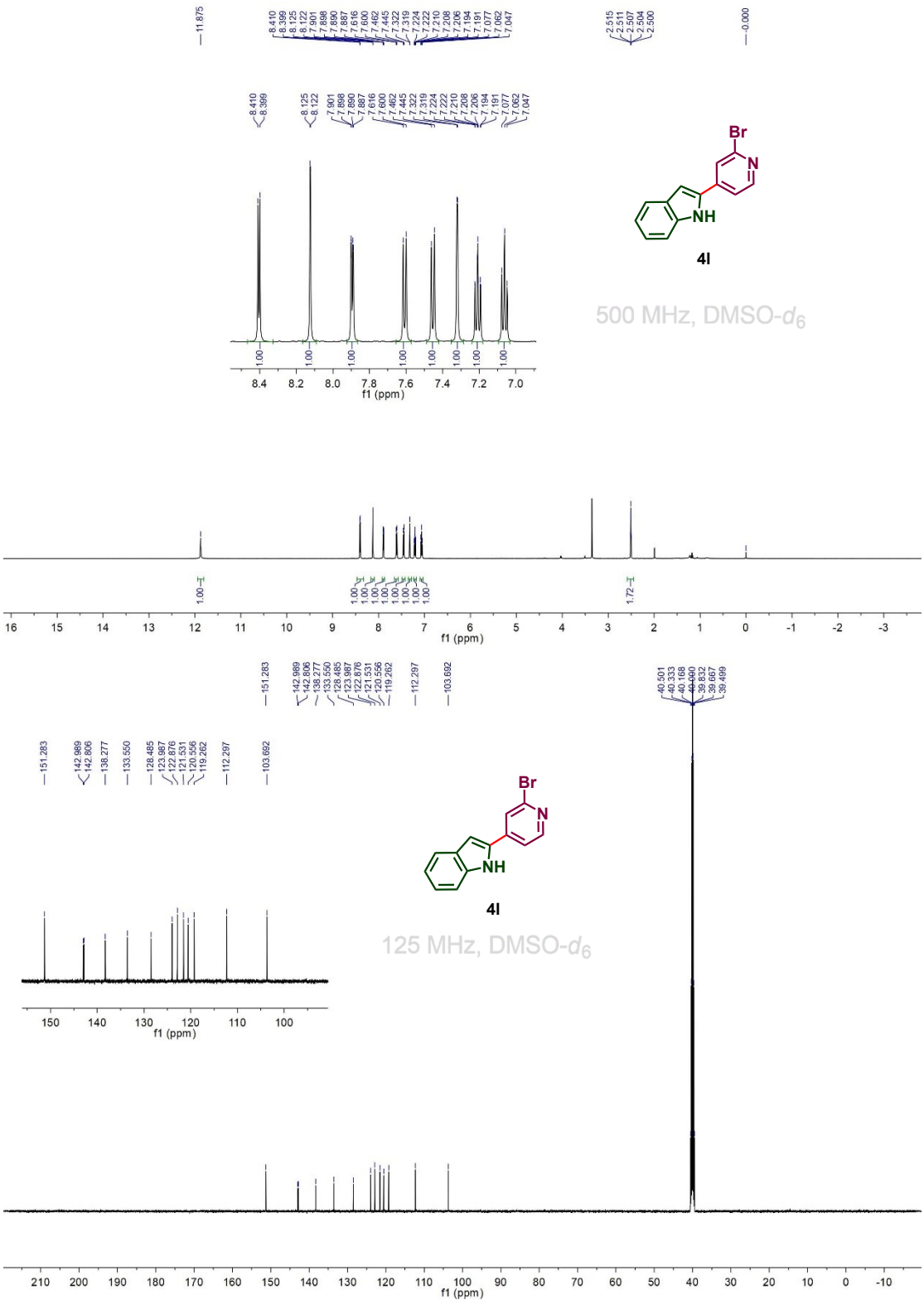


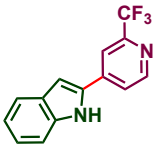


4i

125 MHz, $CDCl_3$

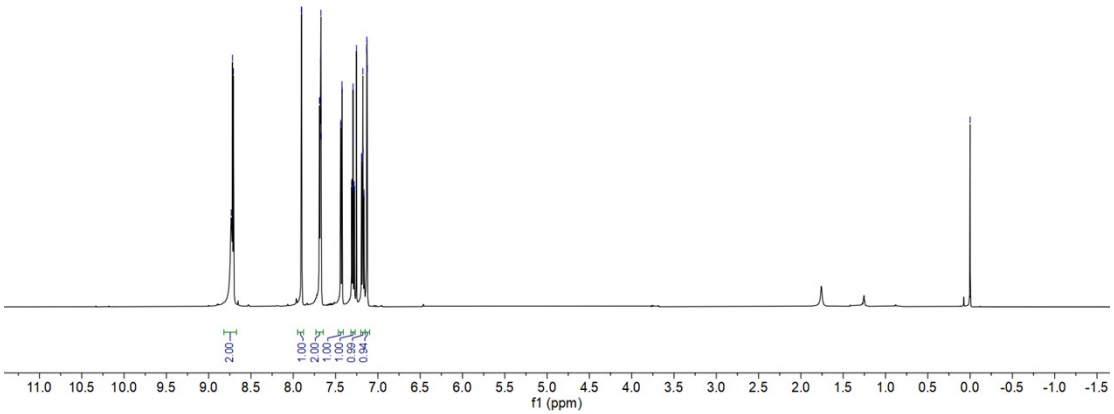

11.880
8.288
8.278
7.830
7.827
7.824
7.820
7.817
7.814
7.635
7.629
7.613
7.478
7.461
7.320
7.316
7.233
7.231
7.219
7.217
7.214
7.203
7.200
7.085
7.084
7.072
7.070
7.068
7.056
7.054
2.517
2.513
2.510
2.506
2.503
0.000
F
N
NH
4j
500 MHz, DMSO-d_6
1.00
1.00
2.00
1.00
1.00
1.00
1.00
13.5 13.0 12.5 12.0 11.5 11.0 10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5 -1.0
f1 (ppm)
165.615
163.760
148.737
148.605
145.505
145.433
138.189
134.061
134.051
128.474
123.963
121.546
121.532
119.071
118.045
112.297
104.605
104.287
103.582
40.501
40.333
40.168
40.000
39.832
39.667
39.499
F
N
NH
4j
125 MHz, DMSO-d_6
200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
f1 (ppm)

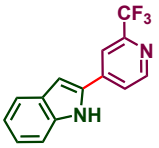

11.875
8.410
8.399
8.125
8.122
7.901
7.898
7.890
7.887
7.616
7.600
7.462
7.445
7.322
7.319
7.224
7.222
7.210
7.208
7.206
7.194
7.191
7.077
7.062
7.047
2.515
2.511
2.507
2.504
2.500
-0.000
Br
N
NH
4l
500 MHz, DMSO-d_6
f1 (ppm)
151.283
142.989
142.806
138.277
133.550
128.485
123.987
122.876
121.531
120.556
119.262
112.297
103.692
40.501
40.333
40.168
40.000
39.832
39.667
39.499
125 MHz, DMSO-d_6



4m

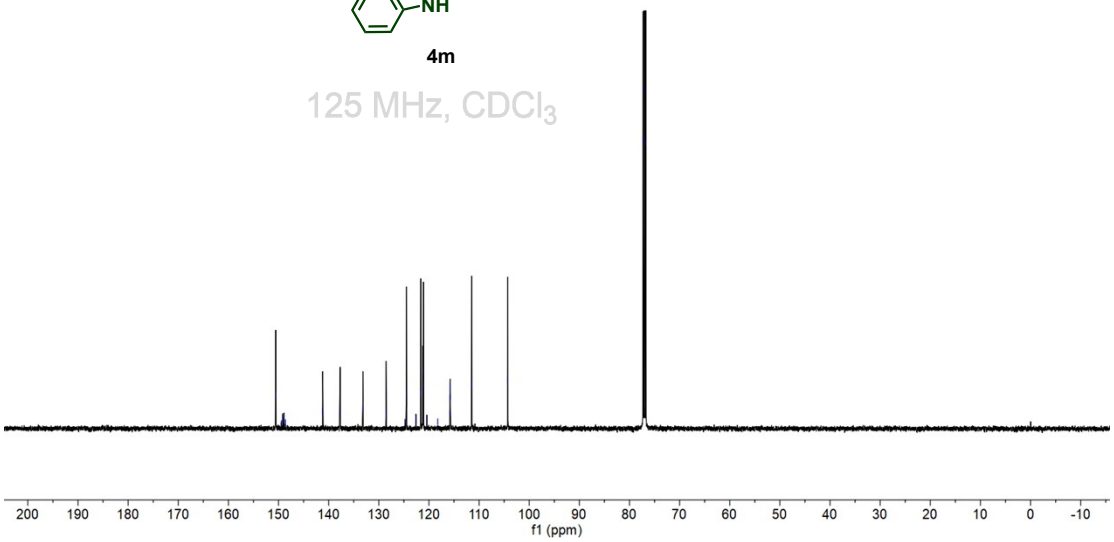
500 MHz, $CDCl_3$

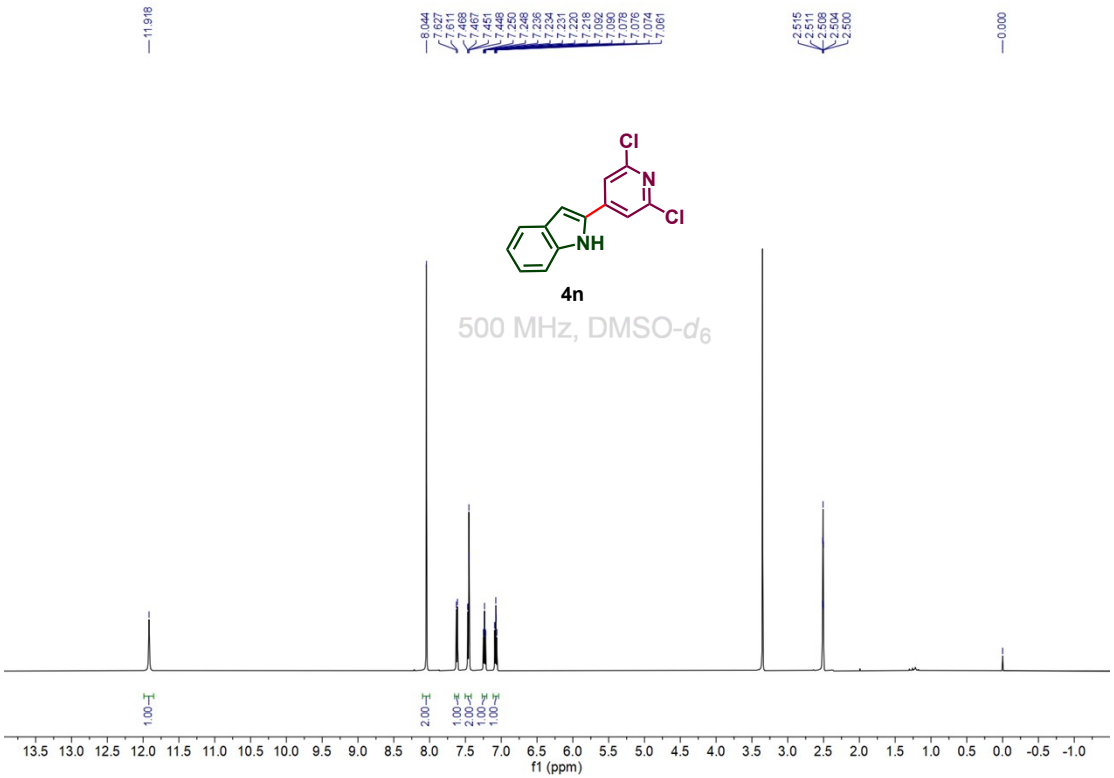


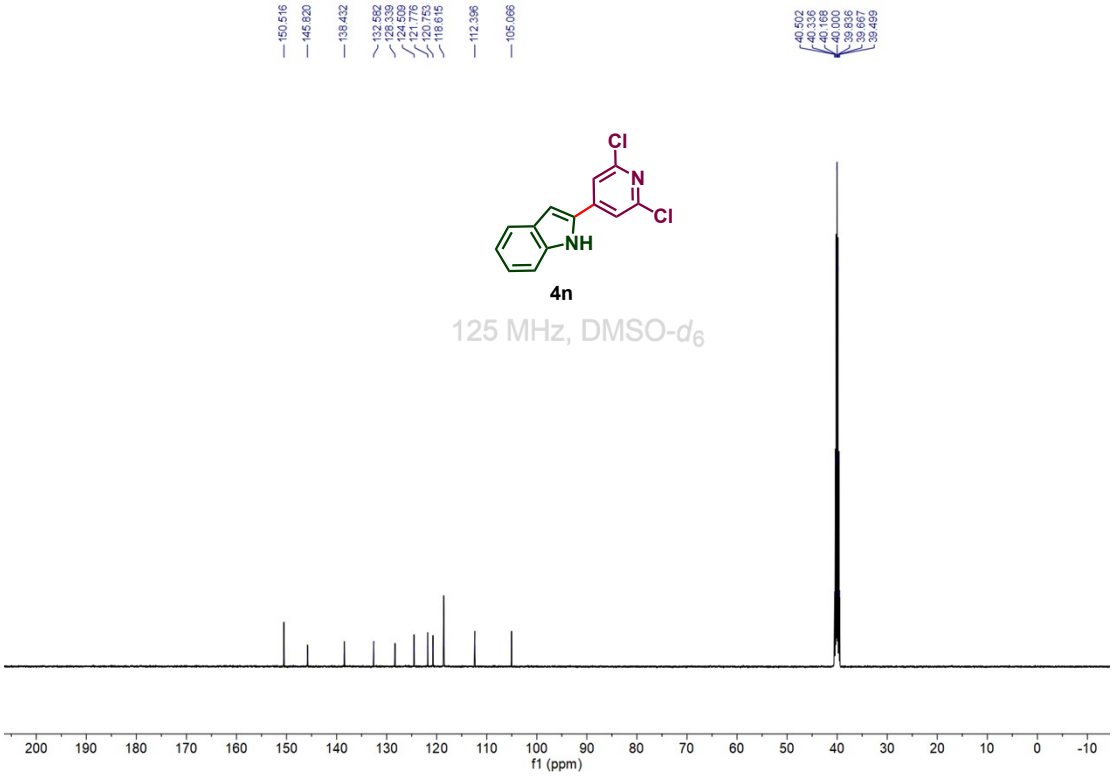


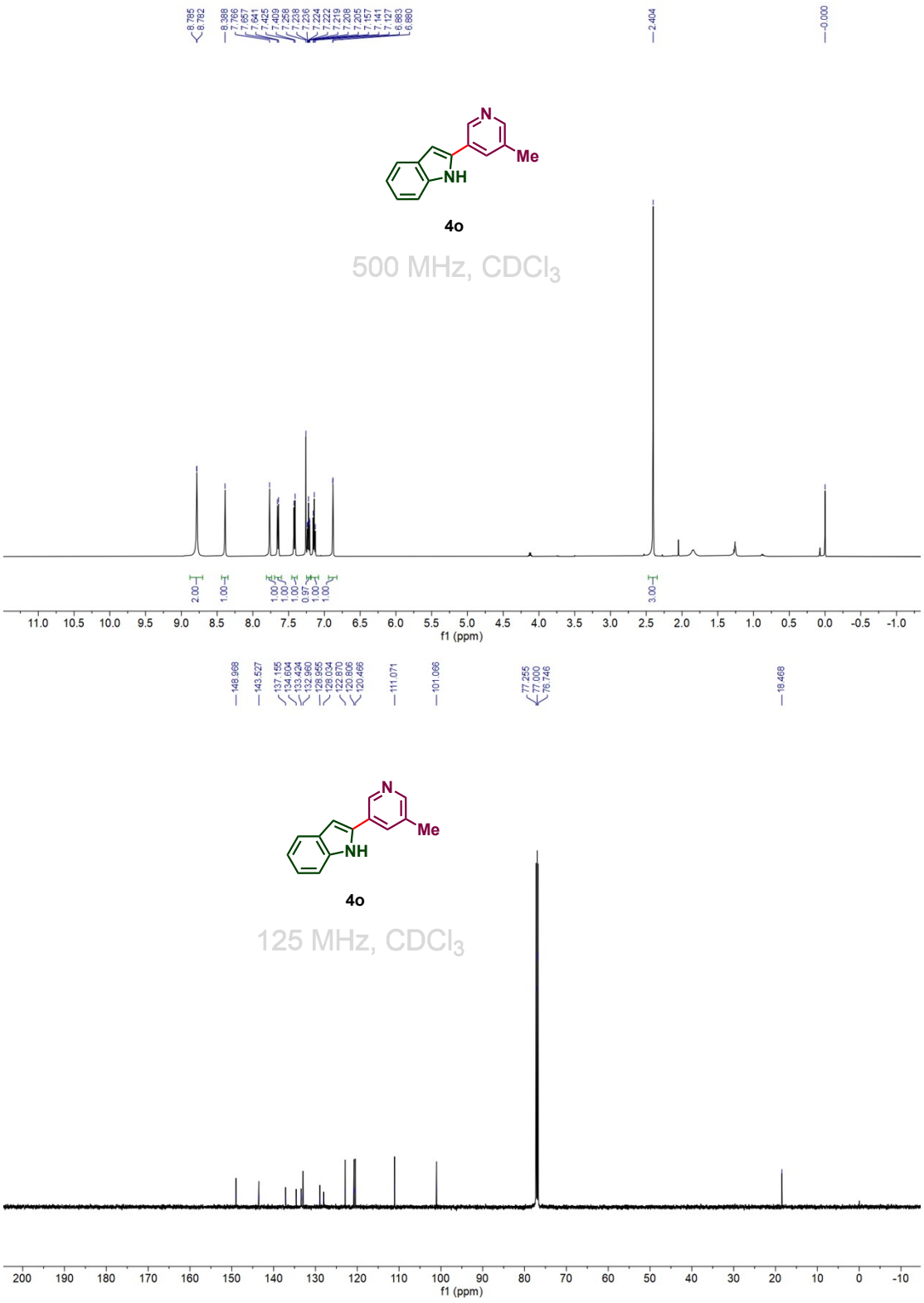
4m

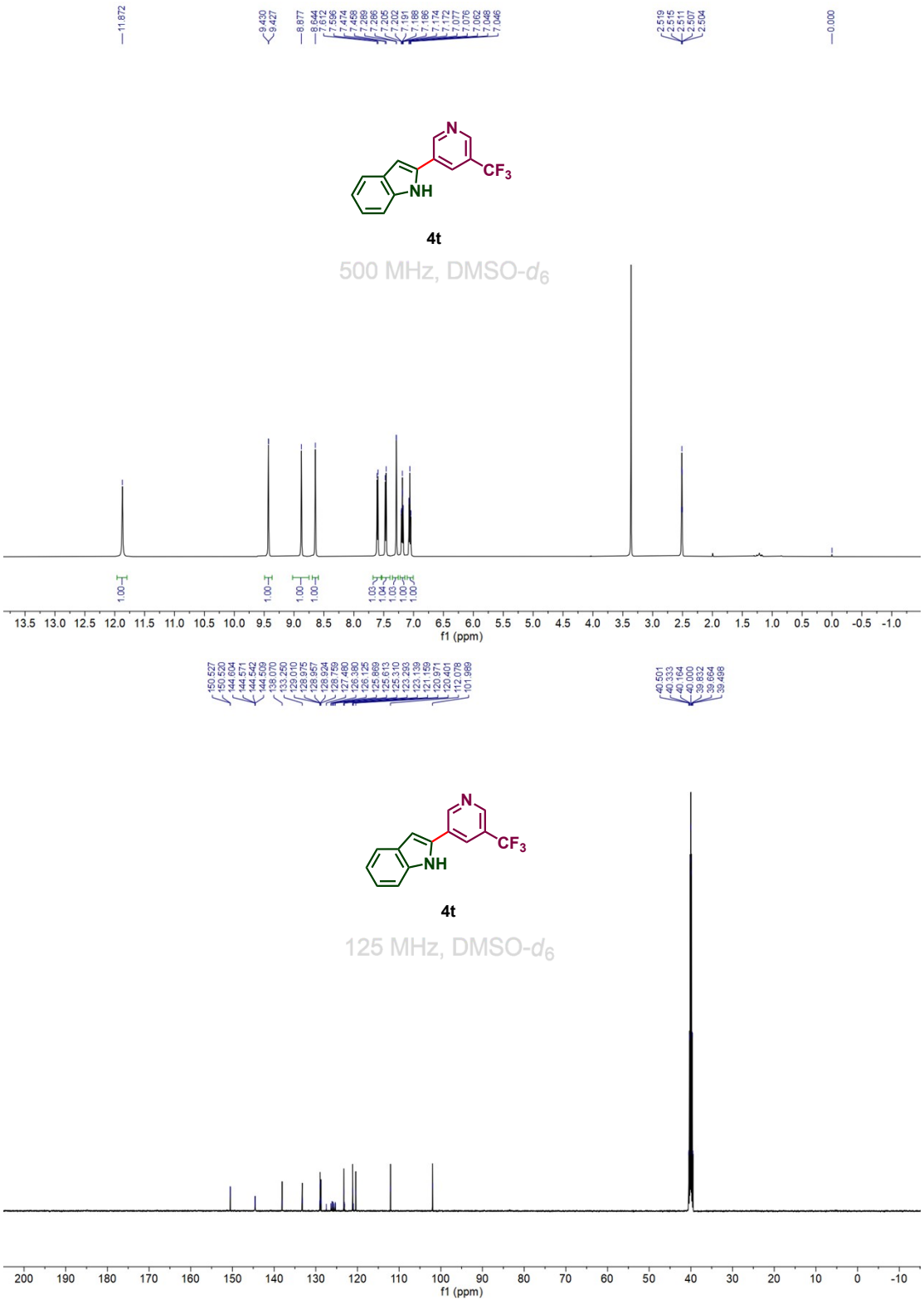
125 MHz, $CDCl_3$

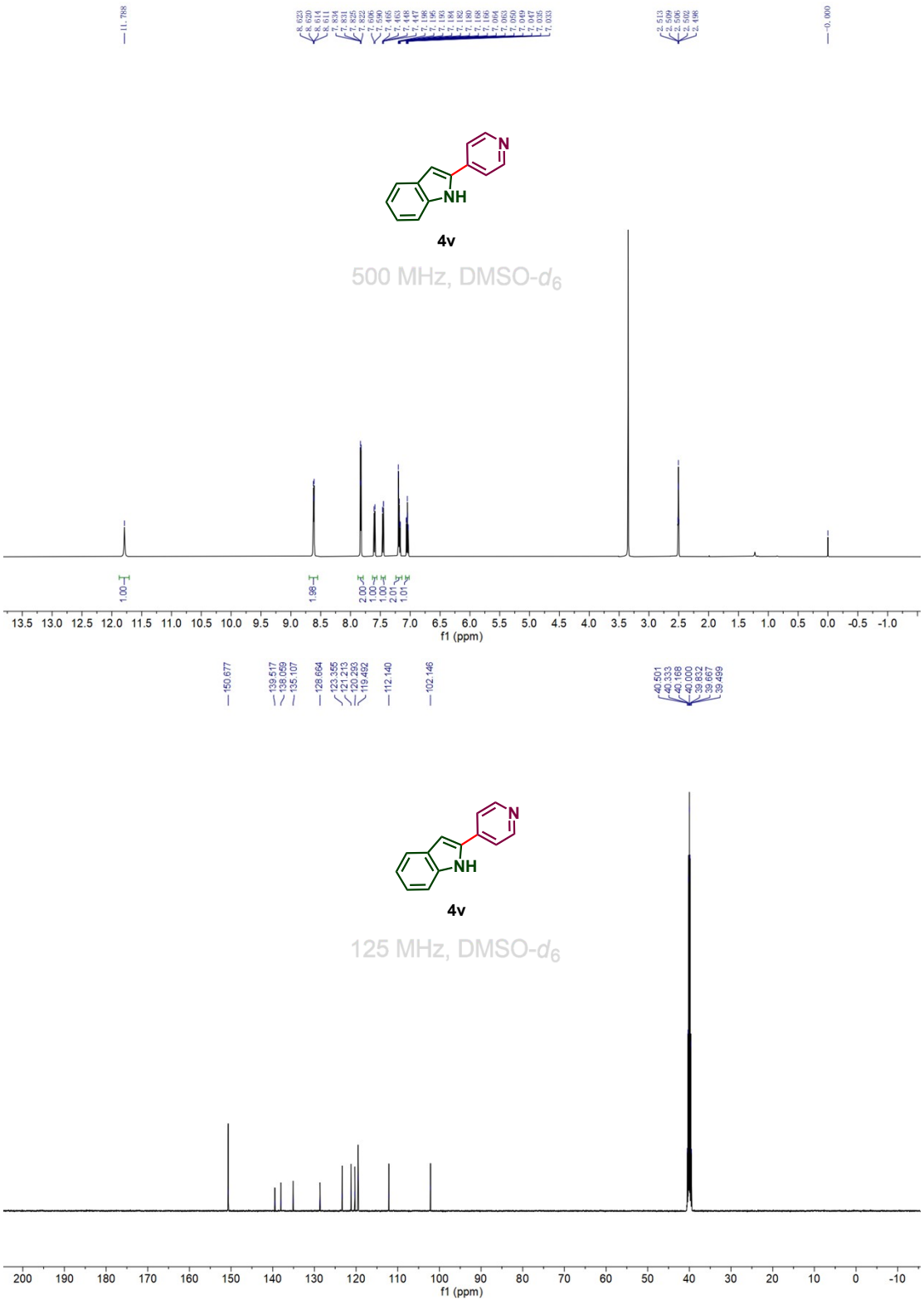


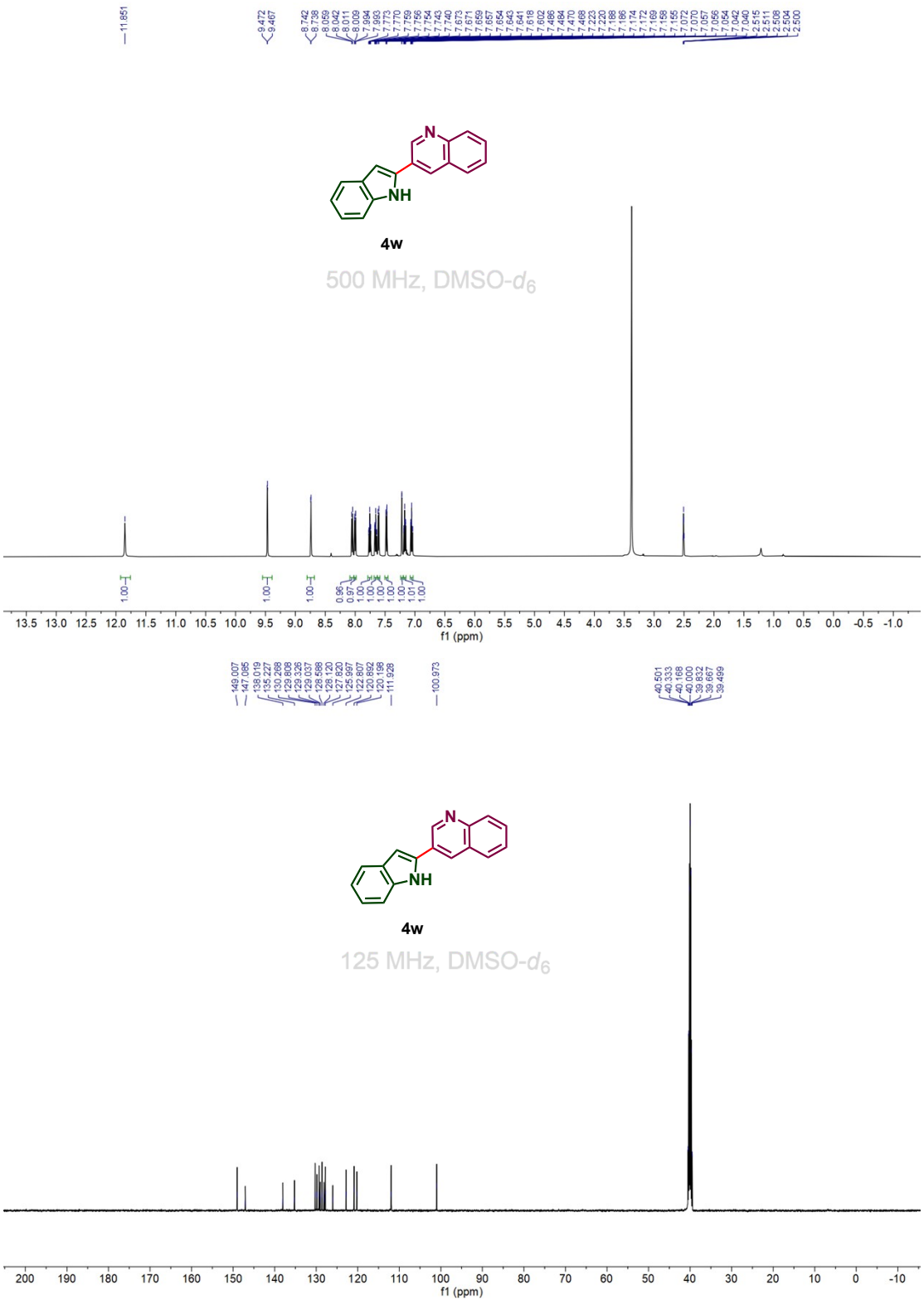

11.918
8.044
7.627
7.611
7.488
7.467
7.451
7.448
7.250
7.248
7.236
7.234
7.231
7.220
7.218
7.092
7.090
7.078
7.076
7.074
7.061
2.515
2.511
2.508
2.504
2.500
0.000
Cl
N
Cl
NH
4n
500 MHz, DMSO-d_6
1.00
2.00
1.00
2.00
1.00
1.00
f1 (ppm)

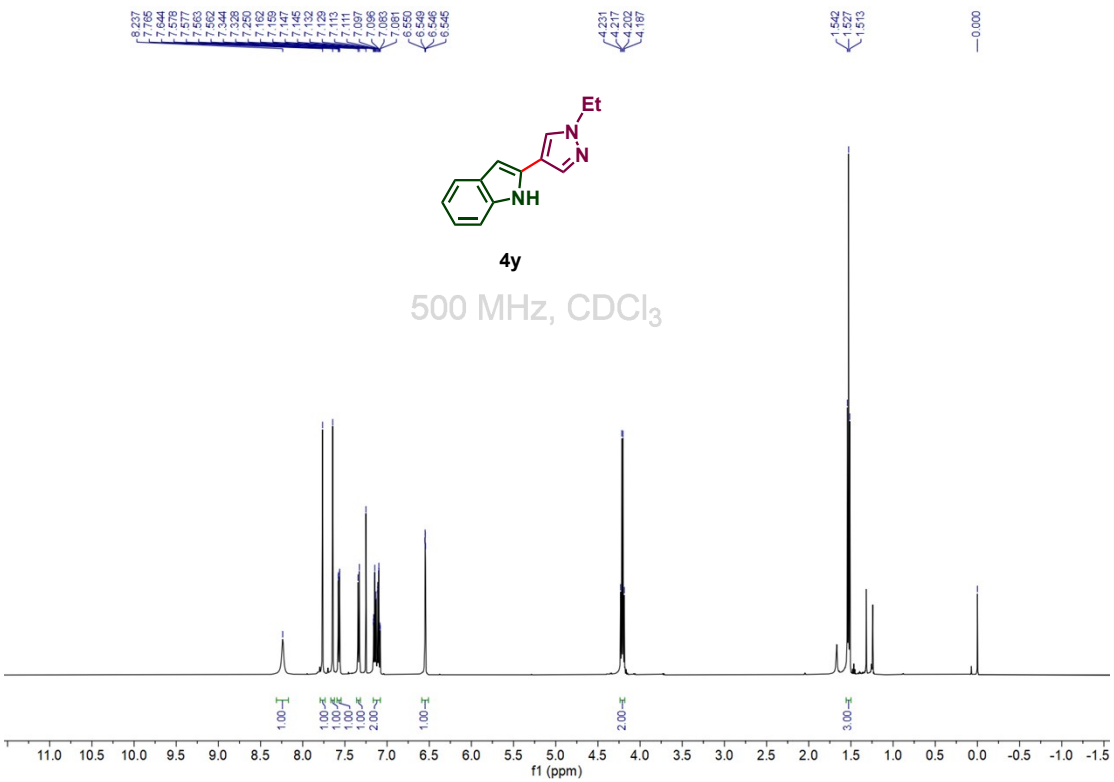

150.516
145.820
138.432
132.582
128.339
124.509
121.776
120.753
118.615
112.396
105.066
40.502
40.336
40.168
40.000
39.836
39.667
39.499
Cl
N
Cl
NH
4n
125 MHz, DMSO-d_6
f1 (ppm)

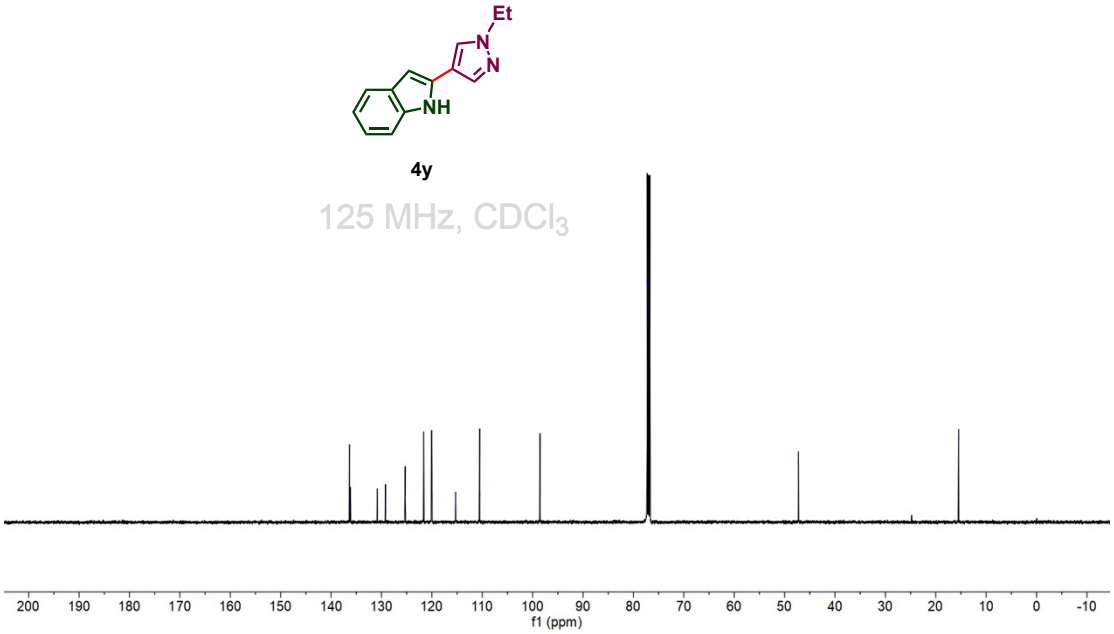

8.765
8.762
8.388
7.866
7.857
7.641
7.425
7.409
7.258
7.238
7.236
7.224
7.222
7.219
7.208
7.205
7.157
7.141
7.127
6.883
6.880
2.404
-0.000
N
Me
NH
4o
500 MHz, CDCl3
2.00
1.00
1.00
1.00
0.97
1.00
1.00
3.00
11.0 10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5 -1.0
f1 (ppm)
148.988
143.527
137.155
134.604
133.424
132.960
128.955
128.034
123.870
123.695
120.466
111.071
101.066
77.255
77.000
76.746
18.468
N
Me
NH
4o
125 MHz, CDCl3
200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
f1 (ppm)

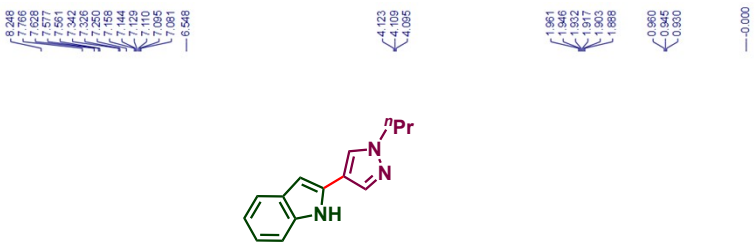

11.872
9.430
9.427
8.877
8.644
7.612
7.596
7.474
7.468
7.289
7.286
7.205
7.202
7.191
7.188
7.186
7.174
7.172
7.077
7.076
7.062
7.048
7.046
2.519
2.515
2.511
2.507
2.504
0.000
N
CF3
NH
4t
500 MHz, DMSO-d6
1.00
1.00
1.00
1.00
1.03
1.04
1.03
1.00
1.00
13.5 13.0 12.5 12.0 11.5 11.0 10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5 -1.0
f1 (ppm)
150.527
150.520
144.604
144.571
144.542
144.509
138.070
133.250
129.010
128.975
128.957
128.924
128.759
127.480
126.380
126.125
125.869
125.613
125.510
123.293
123.139
121.159
120.971
120.401
112.078
101.989
40.501
40.333
40.164
40.000
39.832
39.664
39.496
N
CF3
NH
4t
125 MHz, DMSO-d6
200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
f1 (ppm)


11.788
8.623
8.620
8.614
8.611
7.834
7.831
7.625
7.622
7.602
7.599
7.590
7.465
7.463
7.448
7.447
7.196
7.195
7.185
7.184
7.182
7.180
7.168
7.166
7.064
7.063
7.059
7.049
7.047
7.035
7.033
2.513
2.509
2.506
2.502
2.498
-0.000
N
NH
4v
500 MHz, DMSO-d_6
1.00
1.98
2.00
1.00
1.00
2.01
1.01
13.5 13.0 12.5 12.0 11.5 11.0 10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5 -1.0
f1 (ppm)
150.677
139.517
138.059
135.107
128.664
123.355
121.213
120.293
119.492
112.140
102.146
40.501
40.333
40.168
40.000
39.832
39.667
39.499
N
NH
4v
125 MHz, DMSO-d_6
200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
f1 (ppm)


4w
500 MHz, DMSO-d_6
f1 (ppm)
4w
125 MHz, DMSO-d_6
f1 (ppm)

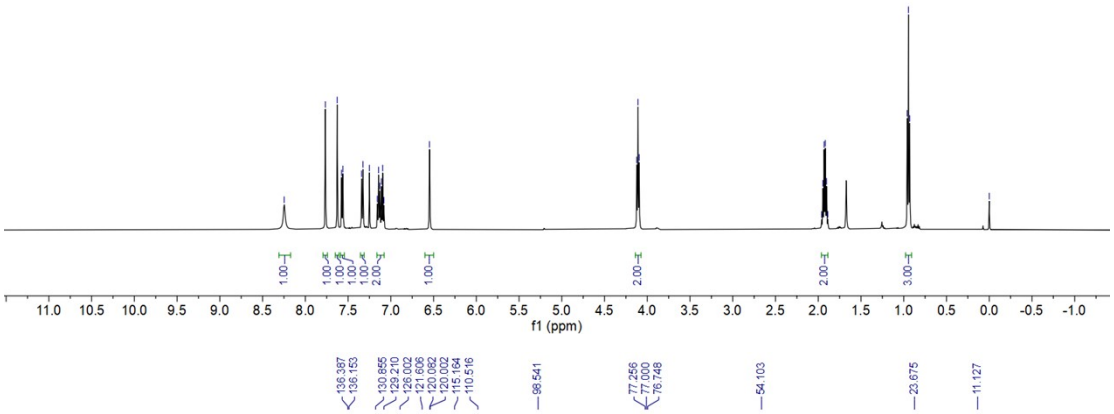

Et
N
N
NH
4y
500 MHz, CDCl3
f1 (ppm)

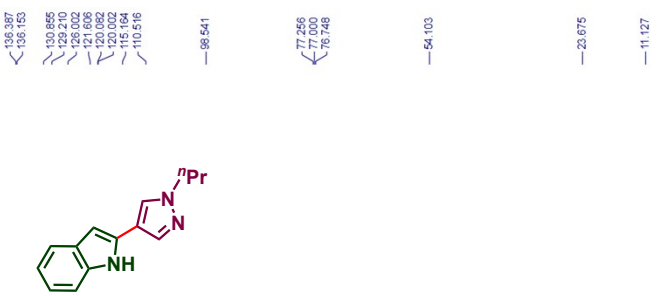

Et
N
N
NH
4y
125 MHz, CDCl3
f1 (ppm)



4z

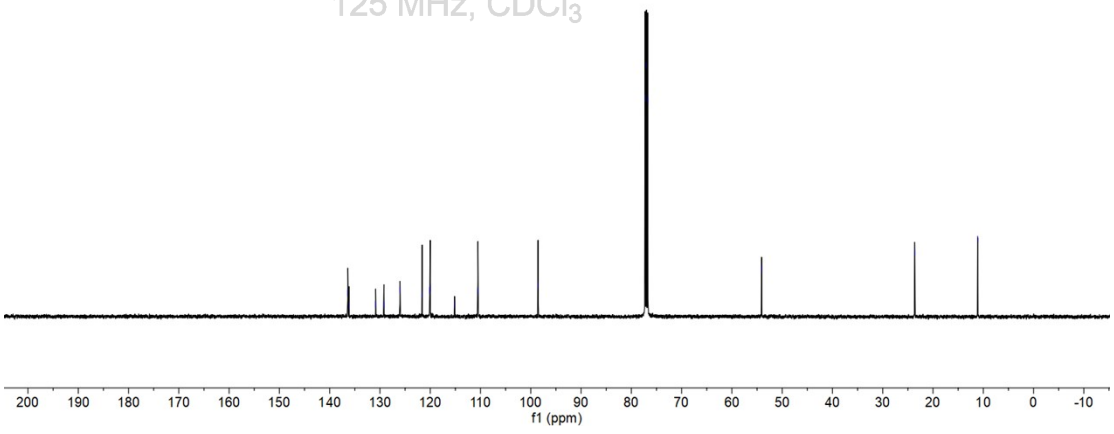
500 MHz, $CDCl_3$

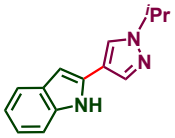




4z

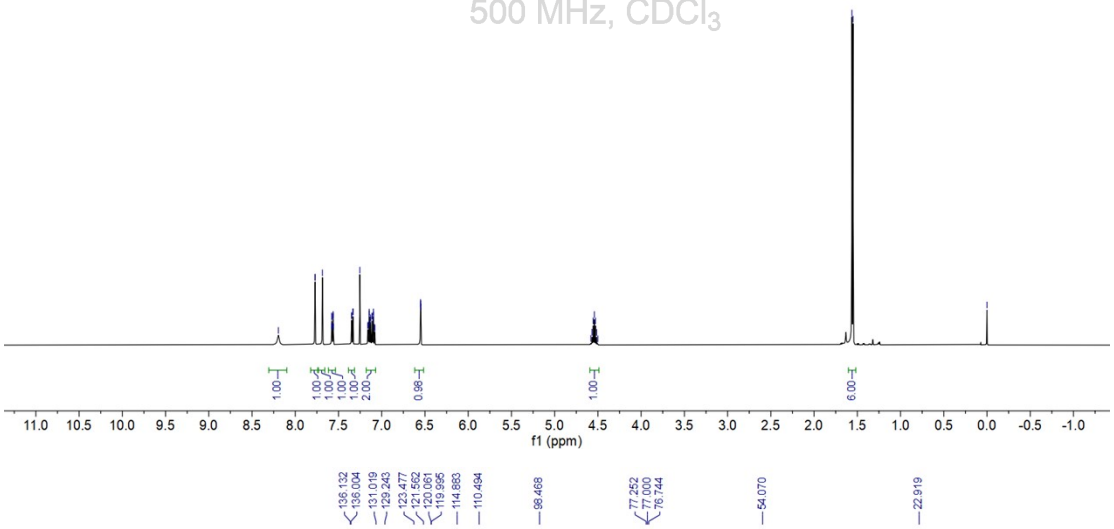
125 MHz, $CDCl_3$

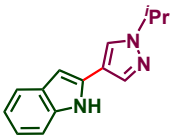




4aa

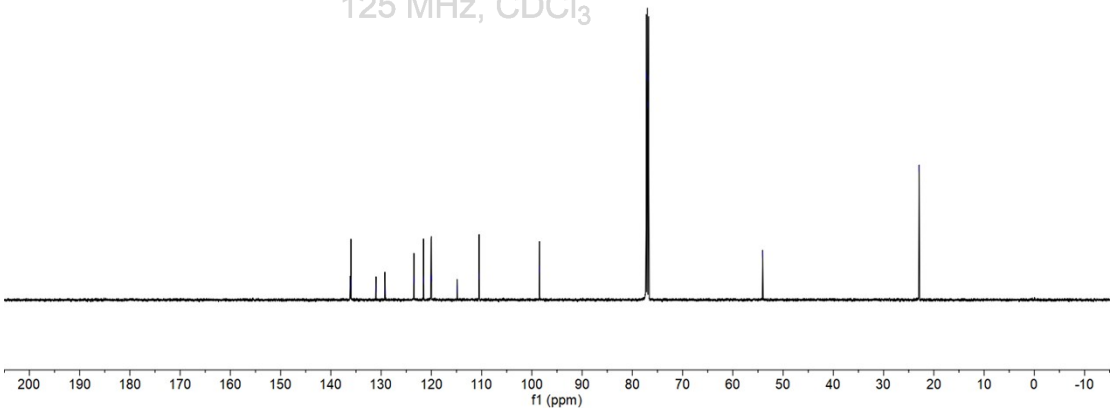
500 MHz, $CDCl_3$

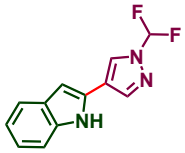




4aa

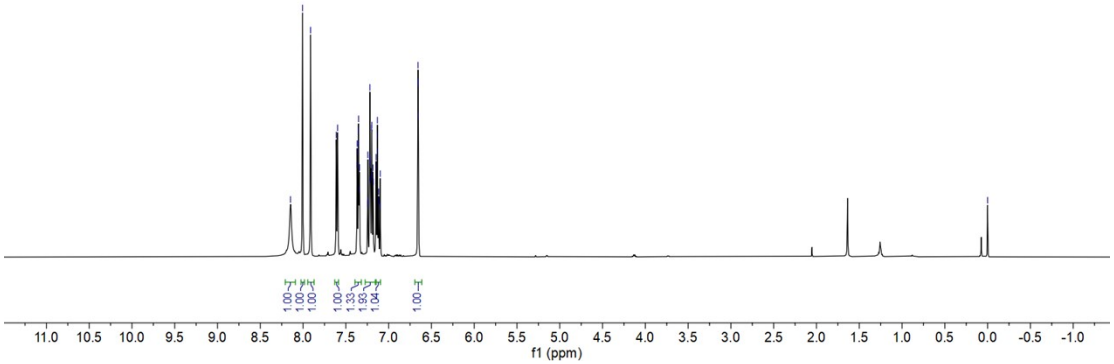
125 MHz, $CDCl_3$

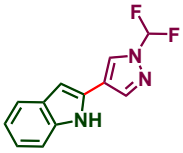




4ab

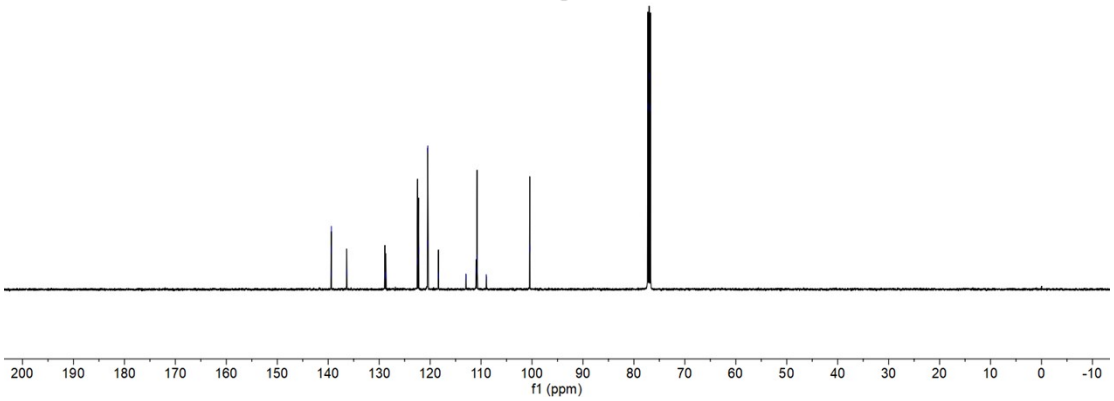
500 MHz, $CDCl_3$

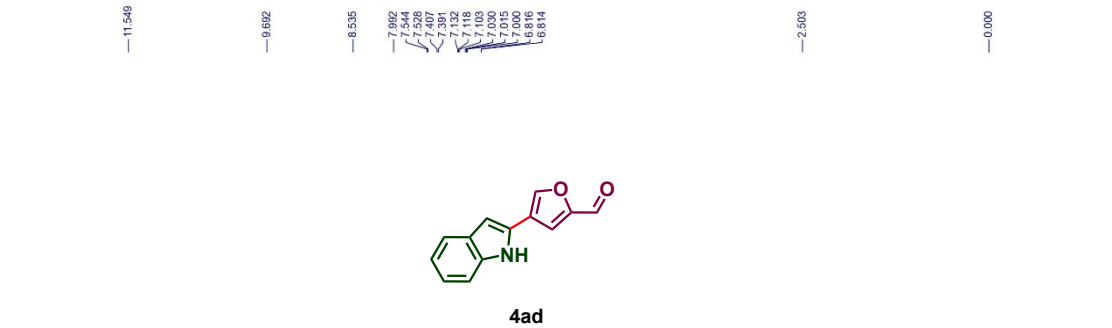




4ab

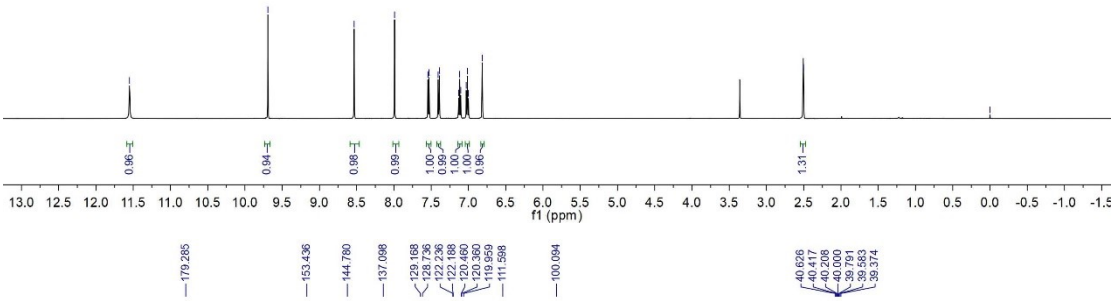
125 MHz, $CDCl_3$

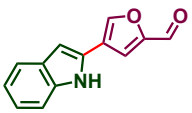




4ad

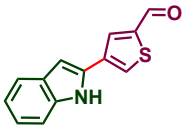
500 MHz, DMSO-d_6





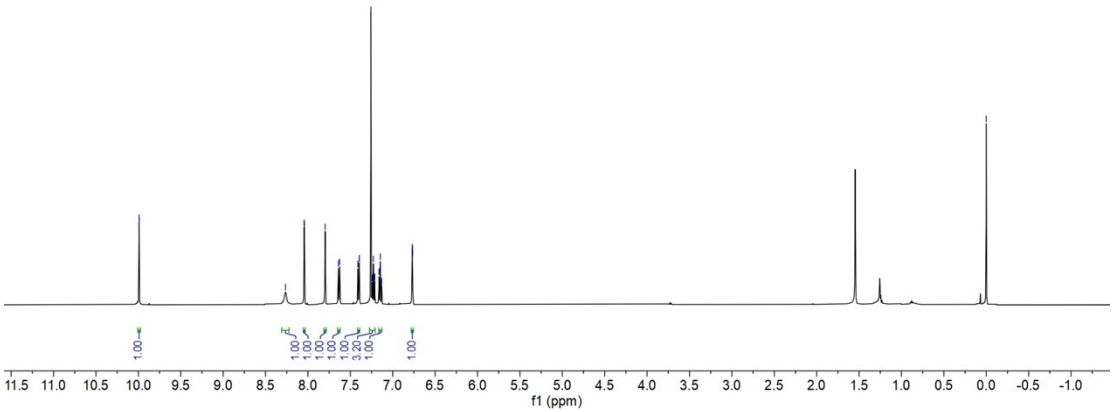
4ad

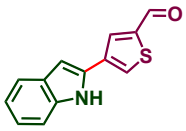
100 MHz, DMSO-d_6



4ah

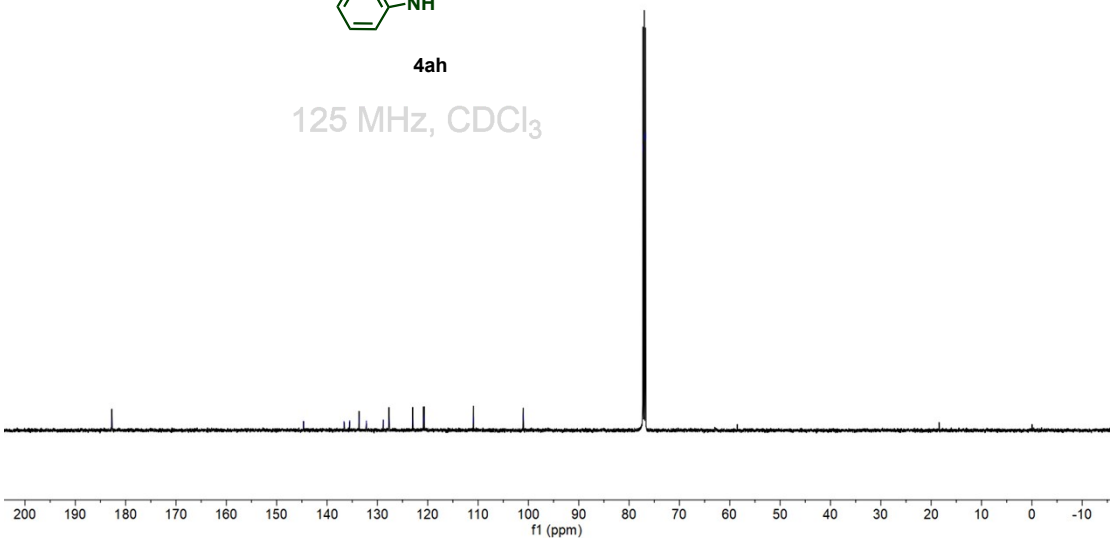
500 MHz, $CDCl_3$

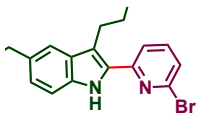




4ah

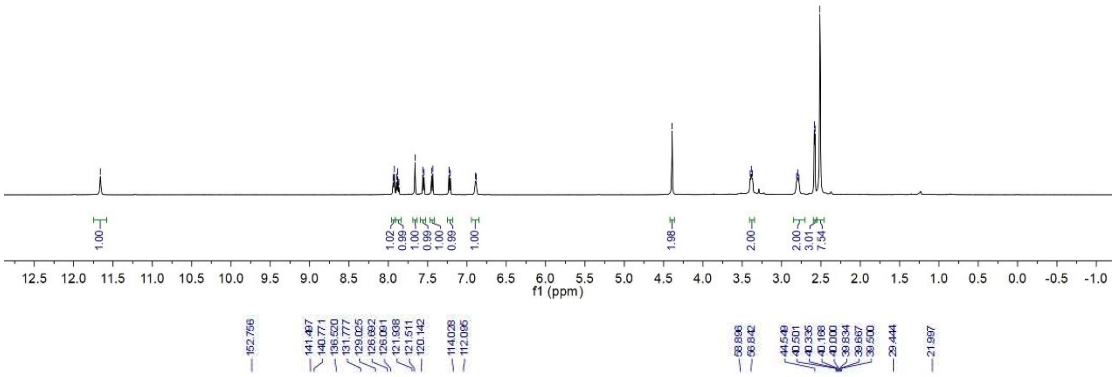
125 MHz, $CDCl_3$

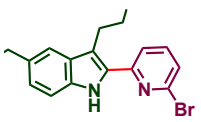




6

500 MHz, DMSO-d_6





6

125 MHz, DMSO-d_6