Synthesis of aryl-heteroaryl derivatives *via* Rh^{III}-catalyzed heteroarylation of arenes and heteroaromatic boronates

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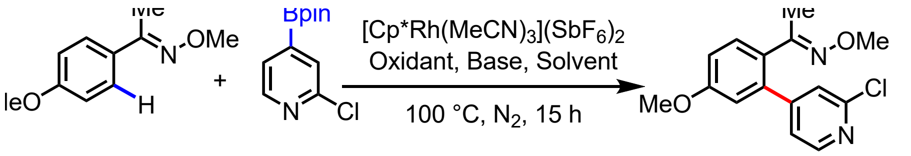
1. Experimental Sections

Table S1. Further supplementary data for optimizing the reaction conditions



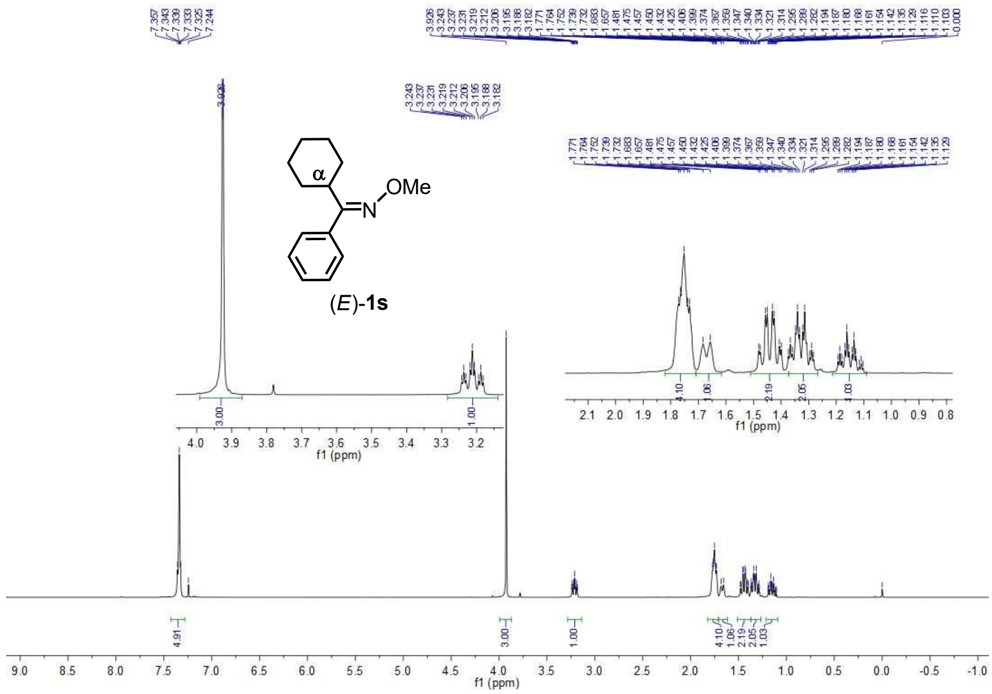
1a **2a** **3a**

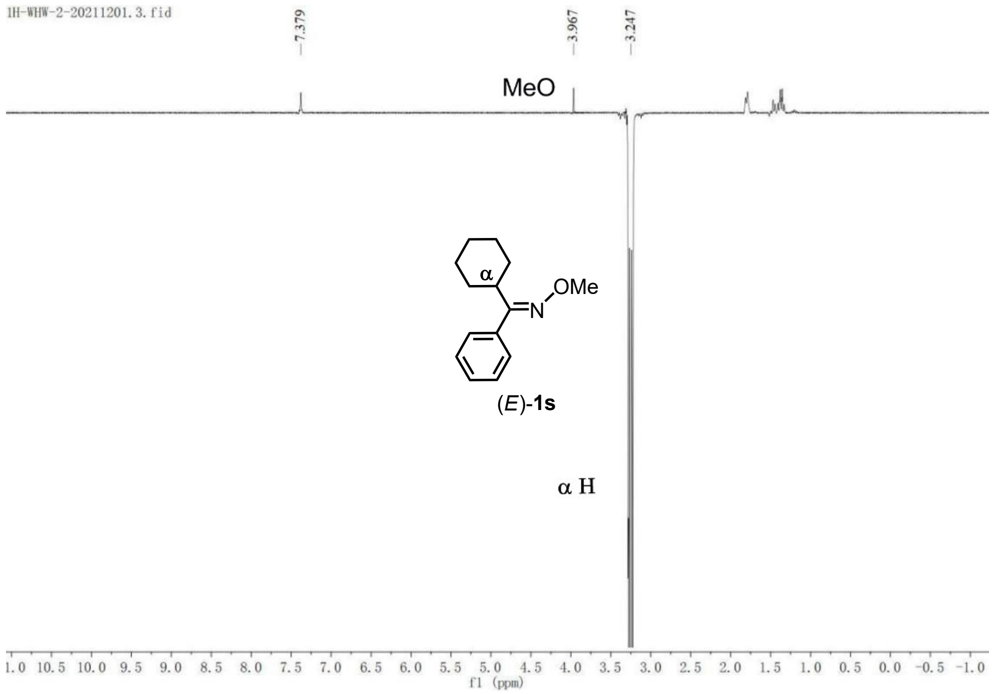
Entry	Oxidant	Base	Solvent	T	Yield[%]
1	Ag_2CO_3	LiF	PhCl	100 °C	78
2	AgOAc	LiF	PhCl	100 °C	12
3	AgOPiv	LiF	PhCl	100 °C	3
4	$Cu(OAc)_2$	LiF	PhCl	100 °C	nr
5	$PhI(OAc)_2$	LiF	PhCl	100 °C	nr
6	Ag_2O	KF	PhCl	100 °C	5
7	Ag_2O	$KHCO_3$	PhCl	100 °C	31
8	Ag_2O	$NaHCO_3$	PhCl	100 °C	83
9	Ag_2O	LiF	Toluene	100 °C	44
10	Ag_2O	LiF	DCE	100 °C	80
11	Ag_2O	LiF	MeCN	100 °C	nr

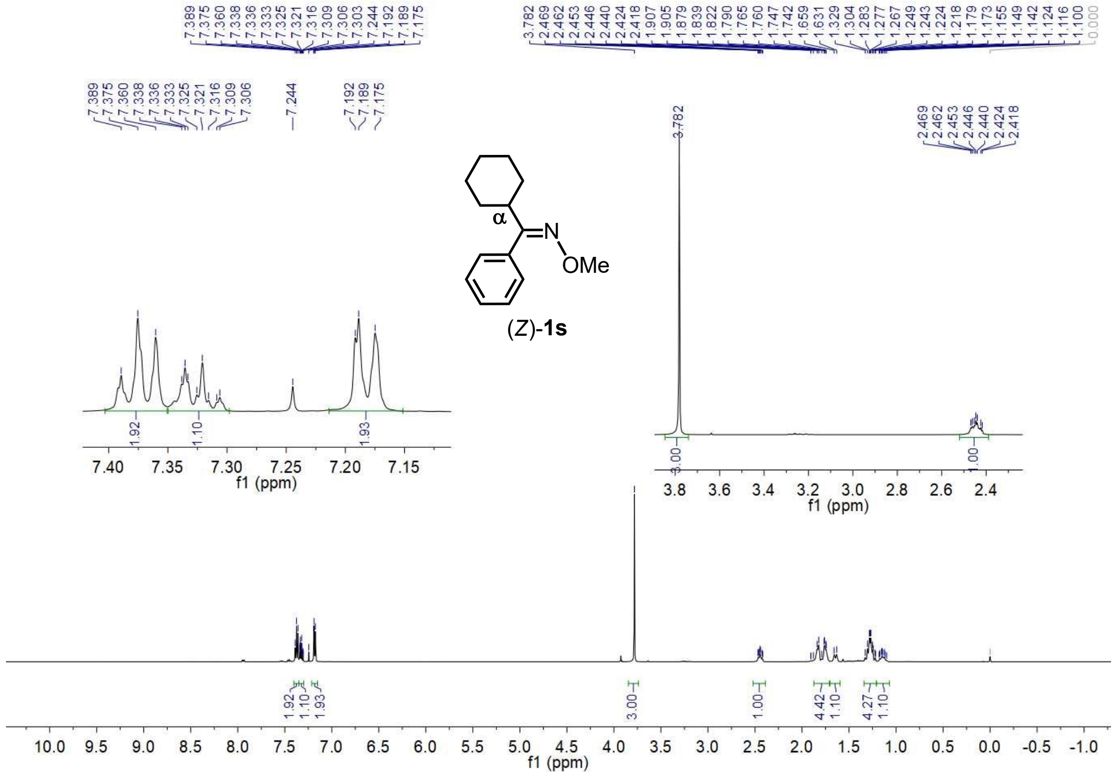
Conditions: **1a** (0.1 mmol), **2a** (0.2 mmol), $[Cp^*Rh(MeCN)_3](SbF_6)_2$ (10 mol %), Ag_2O (0.2 mmol), Base (0.2 mmol) and Solvent (2 mL) under N_2, 15 h, 100 °C. The yield was determined by ^1H NMR analysis of crude product using 1,3,5-Trimethoxybenzene as an internal standard.

The determination of *E*/*Z*-stereochemistry of the substrates (*E*)-1s and (*Z*)-1s

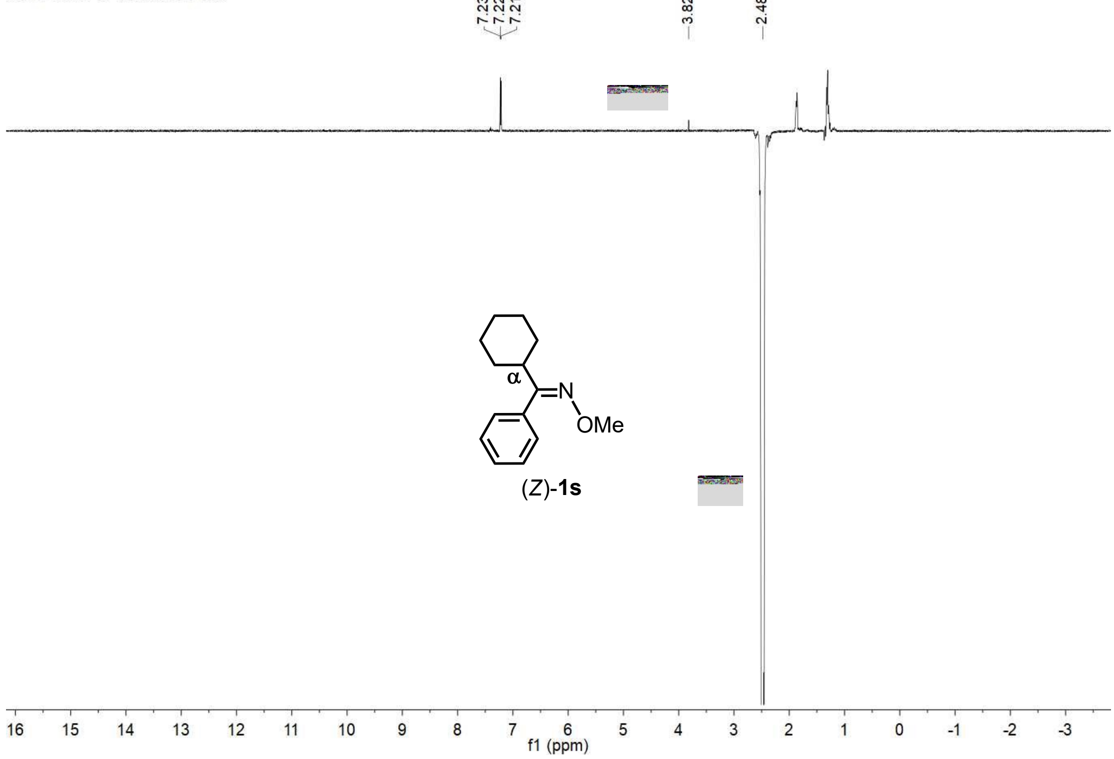
The substrates (*E*)-**1s** and (*Z*)-**1s** were prepared according to the literature.[1] The configurations of them were determined by comparing the strength of the ^{1}H NOE NMR signal between the αH and OMe groups: (*E*)-**1s** demonstrates a strong correlation, whereas (*Z*)-**1s** shows a weak correlation.



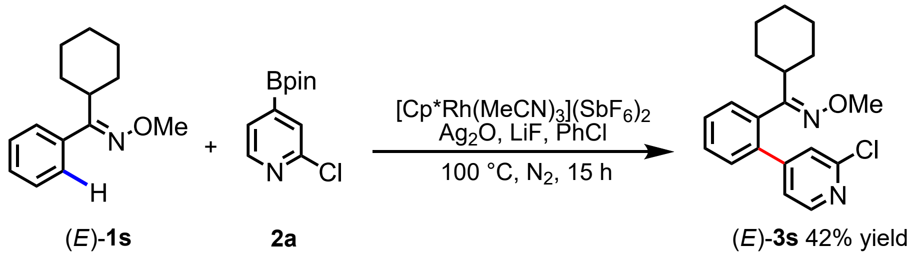


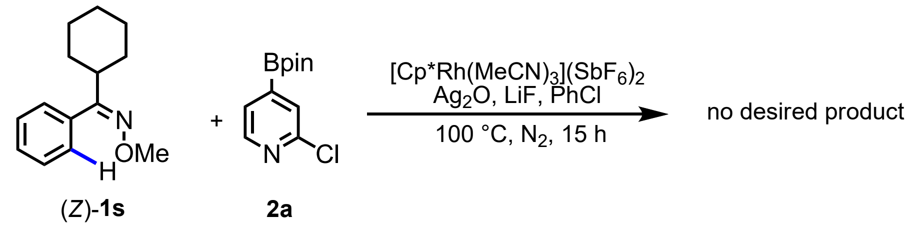


NOE-WHW-3--20211202.4.fid

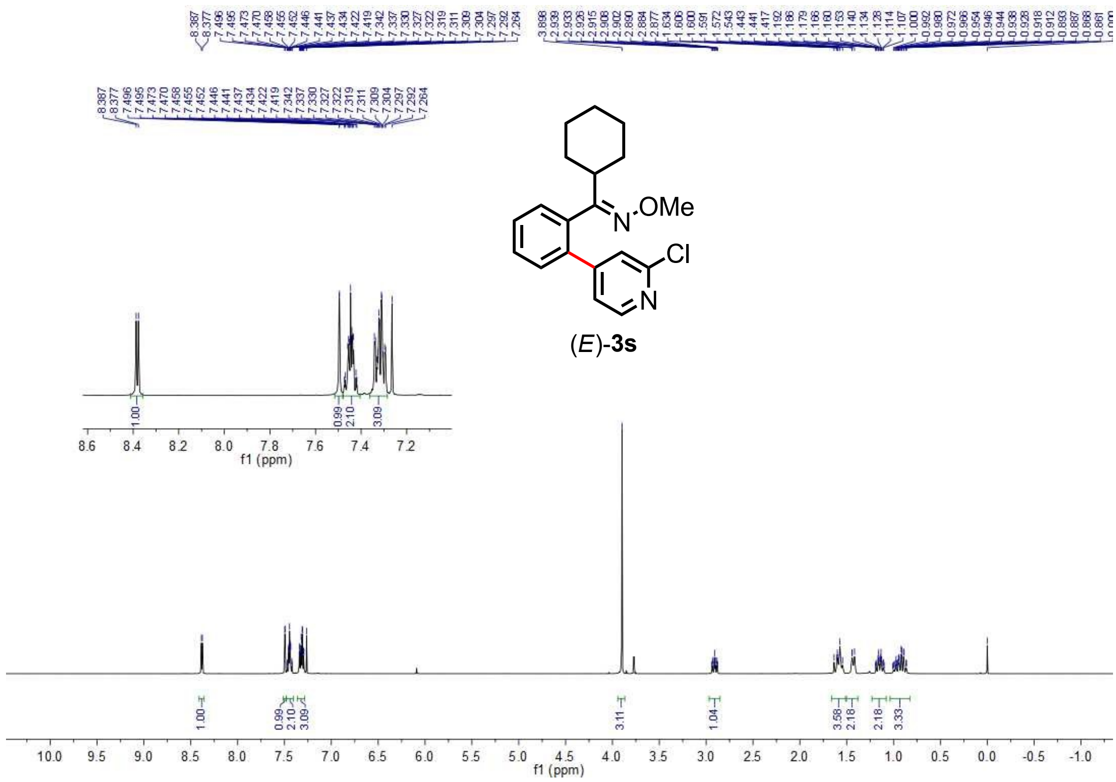


The heteroarylation reaction of the substrates (*E*)-**1s** and (*E*)-**1s** with **2a**





(*E*)-(2-(2-chloropyridin-4-yl)phenyl)(cyclohexyl)methanone *O*-methyl oxime ((*E*)-**3s**): Colorless (13.8 mg, 42%). ^{1}H NMR (500 MHz, $CDCl_3$): δ 8.38 (d, *J* = 5.0 Hz, 1H), 7.50 (d, *J* = 0.5 Hz, 1H), 7.47-7.43 (m, 2H), 7.34-7.29 (m, 3H), 3.90 (s, 3H), 2.91 (tt, J_1 = 12.5 Hz, J_2 = 3.0 Hz, 1H), 1.63-1.54 (m, 3H), 1.44-1.42 (m, 2H), 1.19-1.10 (m, 2H), 1.01-0.86 (m, 3H); ^{13}C{^{1}H} NMR (125 MHz, $CDCl_3$): δ 163.0, 152.4, 151.2, 149.1, 137.0, 134.5, 130.2, 129.6, 128.7, 128.5, 125.5, 123.7, 61.8, 39.5, 29.0, 26.0, 25.8. HRMS (ESI) m/z: $[M+H]^+$ Calcd for $C_{19}H_{22}ClN_2O$ 329.1421; Found 329.1428.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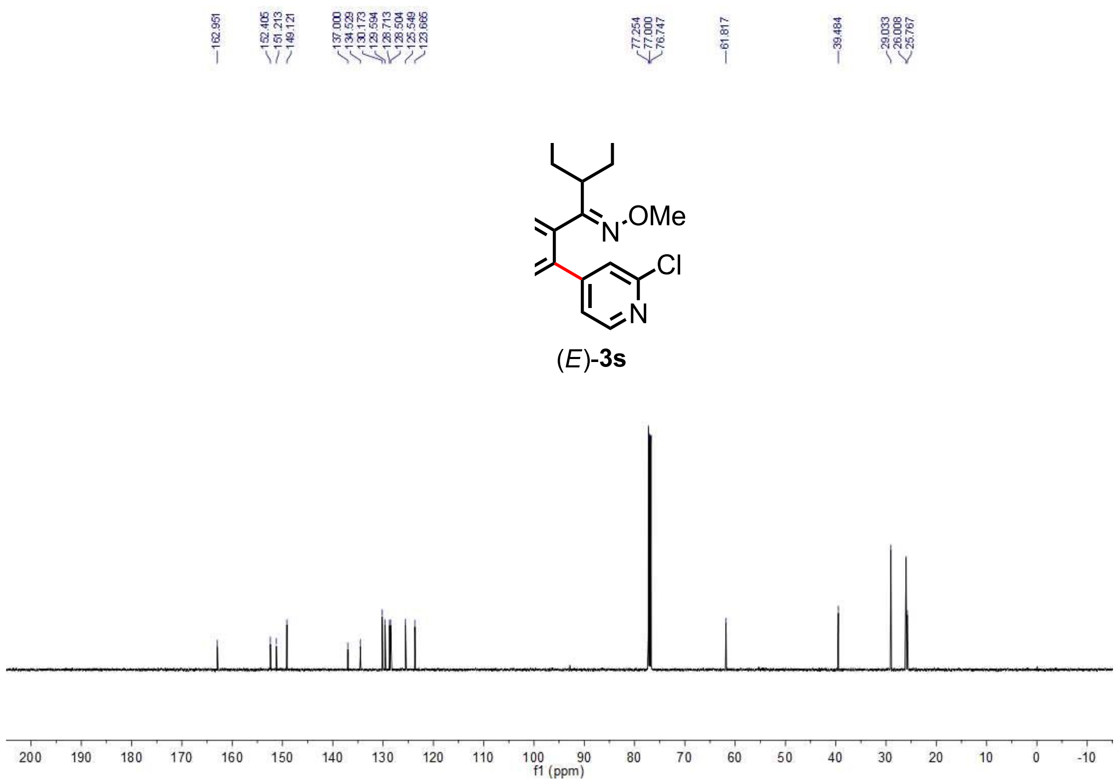
3.898 2.939 2.933 2.926 2.915 2.908 2.902 2.890 2.884 2.877 1.634 1.606 1.600 1.591 1.572 1.543 1.441 1.443 1.417 1.192 1.186 1.179 1.166 1.160 1.153 1.140 1.134 1.128 1.114 1.107 1.000 0.992 0.980 0.972 0.966 0.954 0.946 0.944 0.938 0.928 0.918 0.912 0.893 0.887 0.868 0.861 0.000
OMe
N
Cl
N
(E)-3s
1.00
0.99
2.10
3.09
3.11
1.04
3.58
2.18
2.18
3.33
f1 (ppm)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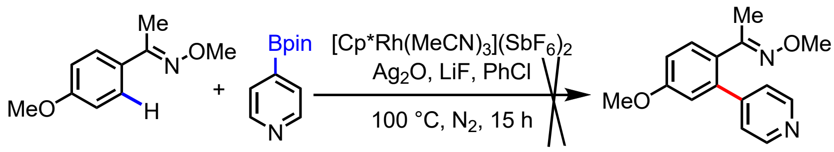
152.405 151.213 149.121
137.000 134.529 130.173 129.594 128.713 128.504 125.549 123.665
77.254 77.000 76.747
61.817
39.484
29.033 26.008 25.767
OMe
N
Cl
N
(E)-3s
f1 (ppm)

Scheme S1. The reaction of the substrate **1a** and 4-pyridine boronic acid pinacol ester

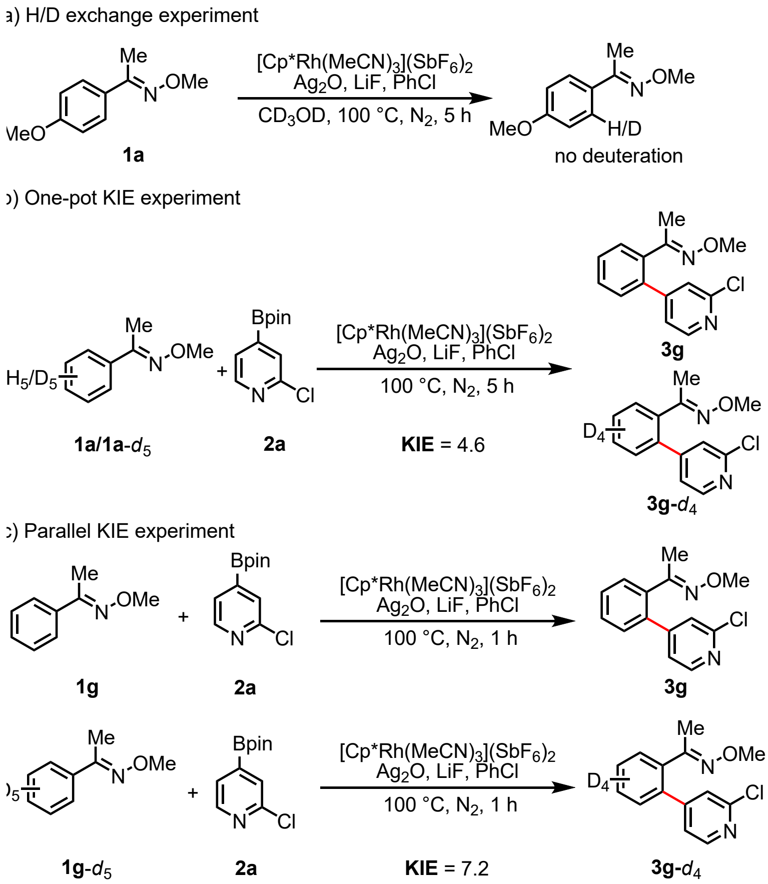


1a **nr**

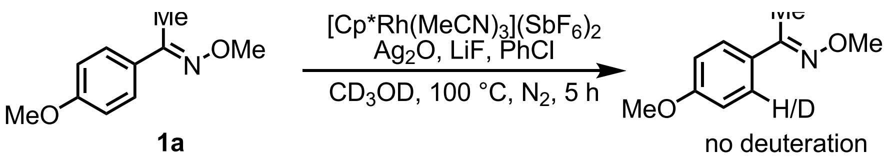
To a 25 mL Schlenk-type sealed tube equipped with a magnetic stirring bar was added the substrate **1a** (0.1 mmol), $[Cp^*Rh(MeCN)_3](SbF_6)_2$ (8.3 mg, 0.01 mmol), 4-pyridine boronic acid pinacol ester (0.2 mmol), Ag_2O (46.3 mg, 0.2 mmol), LiF (5.2 mg, 0.2 mmol) and dry PhCl (2.0 mL) under N_2 atmosphere. The tube was capped and subjected to a 100 °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 no desired product was afforded.

Control experiments

Scheme S2. Mechanism studies

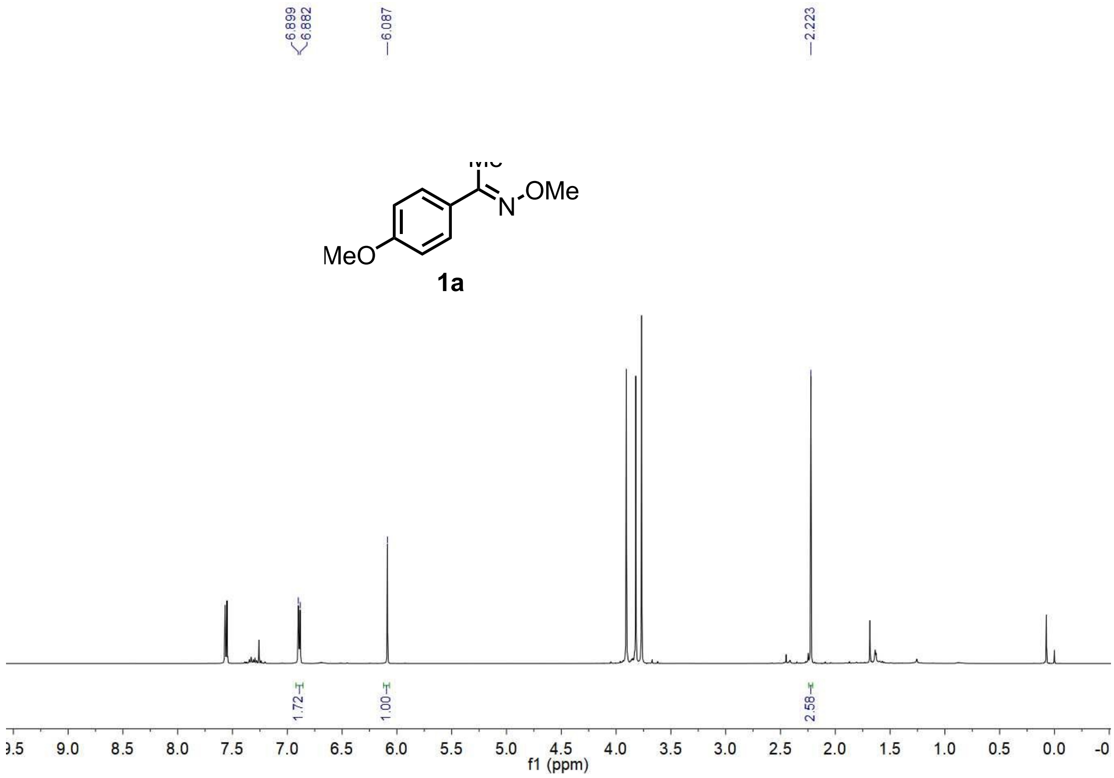


H/D exchange experiment

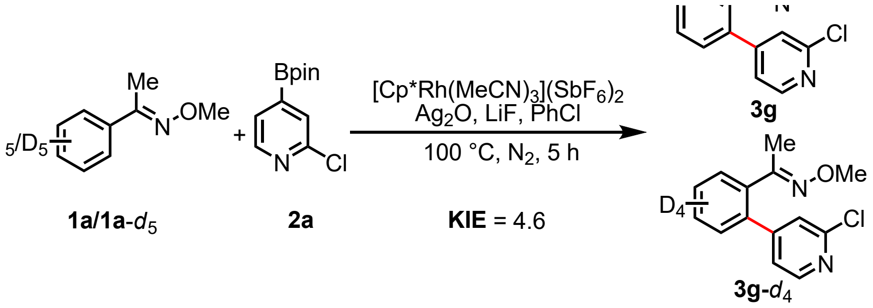


To a 25 mL Schlenk-type sealed tube equipped with a magnetic stirring bar was added the substrate **1a** (0.1 mmol), $[Cp^{*}Rh(MeCN)_3](SbF_6)_2$ (8.3 mg, 0.01 mmol), Ag_2O (46.3 mg, 0.2 mmol), LiF (5.2 mg, 0.2 mmol), CD_3OD (1 mmol) and dry PhCl (2.0 mL) under N_2 atmosphere. The tube was capped and subjected to a 100 °C preheated oil bath for 5 h. After cooled to room temperature, the reaction mixture was filtered through a pad of Celite. The ratio was identified by

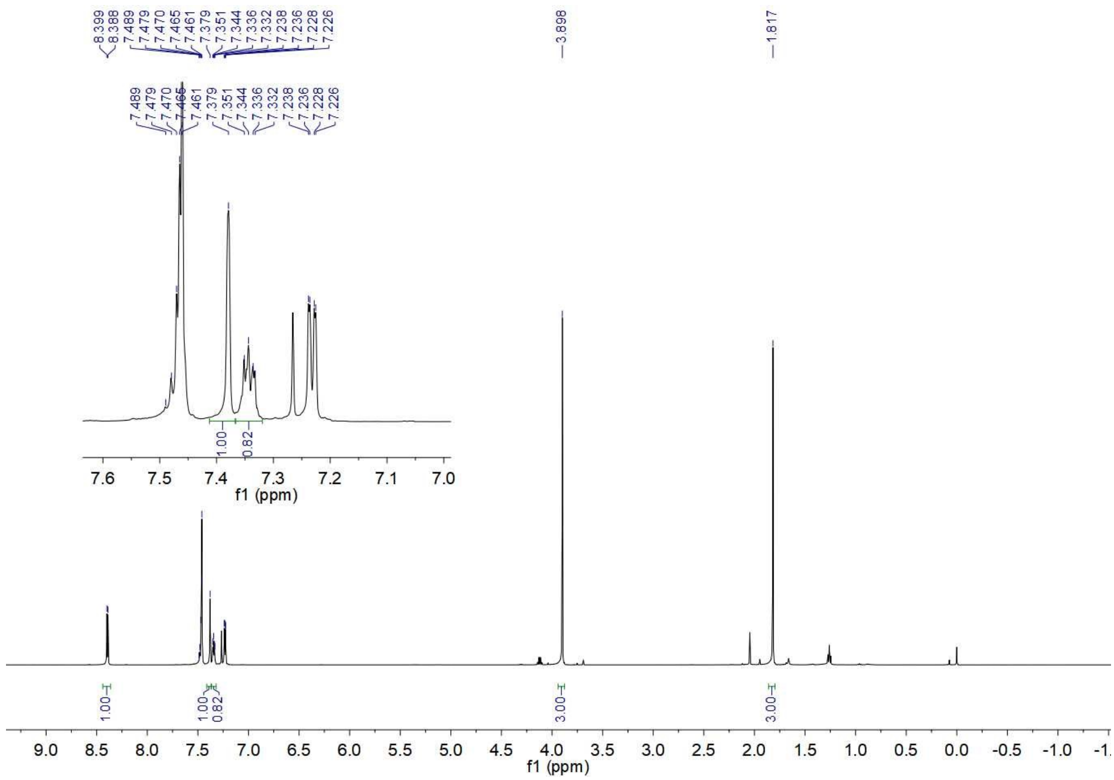
[1]H NMR analysis of the crude product using 1,3,5-trimethoxybenzene as the internal standard.



One-pot KIE experiment

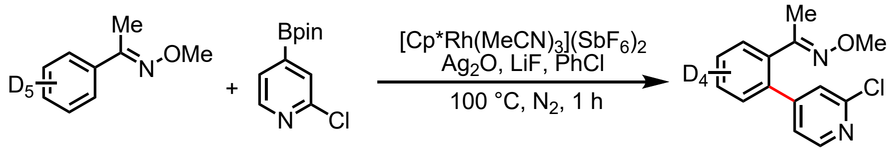


To a 25 mL Schlenk-type sealed tube equipped with a magnetic stirring bar was added the substrate **1a** (0.1 mmol) and **1a**-d_5, $[Cp^*Rh(MeCN)_3](SbF_6)_2$ (8.3 mg, 0.005 mmol), **2a** (0.2 mmol), Ag_2O (46.3 mg, 0.2 mmol), LiF (5.2 mg, 0.2 mmol), and dry PhCl (2.0 mL) under N_2 atmosphere.The tube was capped, and heated to 100 °C for 5 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. The residue was purified by column chromatography with EtOAc/PE (10:1). The ^{1}H NMR analysis showed that ratio of **3g** to **3g**-d_4 is 0.82:0.18 (Compared with the standard ^{1}H NMR spectrum of **3g**, the integration of the peaks at 7.35-7.33 ppm was 0.82 instead of 1.00).



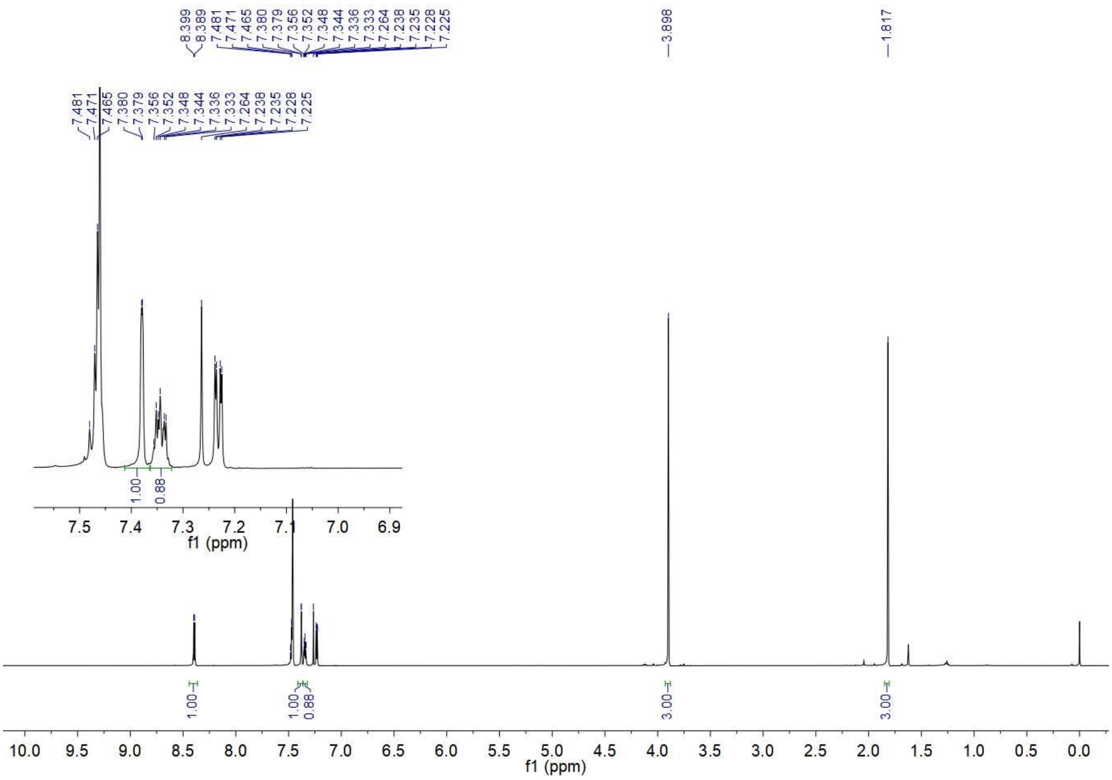
Parallel KIE experiment

1g 2a 3g



1g-d_5 **2a** **KIE** = 7.2 **3g**-d_4

To a 25 mL Schlenk-type sealed tube equipped with a magnetic stirring bar was added the substrate **1g** (0.1 mmol), $[Cp^*Rh(MeCN)_3](SbF_6)_2$ (8.3 mg, 0.005 mmol), **2a** (0.2 mmol), Ag_2O (46.3 mg, 0.2 mmol), LiF (5.2 mg, 0.2 mmol) and dry PhCl (2.0 mL) under N_2 atmosphere. In another tube was added a mixture of the substrate 1**g-*d₅*** (0.1 mmol), $[Cp^*Rh(MeCN)_3](SbF_6)_2$ (8.3 mg, 0.005 mmol), **2a** (0.2 mmol), Ag_2O (46.3 mg, 0.2 mmol), LiF (5.2 mg, 0.2 mmol) and dry PhCl (2.0 mL) under N_2 atmosphere. These two reaction mixtures were stirred side-by-side in the same oil bath at 100 °C for 1 h. These two mixtures were rapidly combined and the combined mixture was diluted with EA, then evaporated under reduced pressure. The purification was performed by flash column chromatography on silica gel (eluent: petroleum ether/EtOAc = 10:1). The ^{1}H NMR analysis showed that ratio of **3g** to **3g**-d_4 is 0.88:0.12 (Compared with the standard ^{1}H NMR spectrum of **3g**, the integration of the peaks at 7.35-7.33 ppm was 0.88 instead of 1.00).



2. X-ray single crystal data for compound 3n

General Procedure for Crystal Preparation:

Compounds **3n** (around 15 mg) were dissolved in $CDCl_3$ (1 ml) separatively, and the NMR tube was capped with a closed-top cap. The single crystals were grown by slow evaporation of solvents at room temperature.

X-ray structure determination of compounds 3n:

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.[2] The structure was solved by direct methods and refined by full-matrix least-squares methods with SHELX program.[3] 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 S2 and selected bond lengths and angles are listed in Table S3. CCDC **2121317** (**3n**) contains the supplementary crystallographic data for this paper.

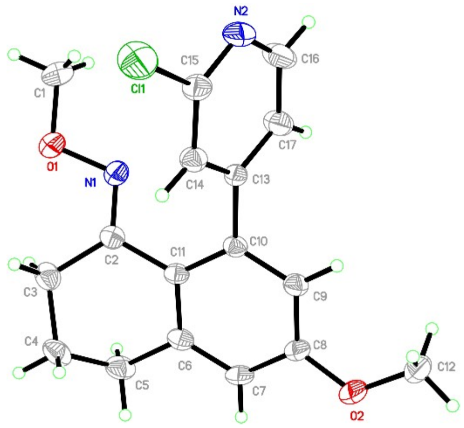


Figure S1. Single crystals of compound **3n** (Thermal ellipsoids are drawn at the 30% probability).

Table S2. Crystal data and structure refinements for **3n**

Formula	$C_{17}H_{17}ClN_2O_2$
Formula weight	316.77
T (K)	293(2)
Crystal system	Monoclinic
Space group	P21/c
a (Å)	10.2910(9)
b (Å)	19.2325(17)
c (Å)	8.6155(7)
α	90°
β	113.623(4)

γ	90°
V	1562.3(2)
Z	4
Dcalc (g cm-3)	1.347
F(000)	664
θ for data collection	4.236-50.026
Reflections collected	7672
Unique reflections	2744
Goodness-of-fit on F2	1.055
R_1, [I > 2σ]	0.0533
wR_2, [I > 2σ]	0.1288

Table S3. Bond lengths [Å] and angles [°] for **3a**

C12-O2	1.417(3)	C10-C13	1.491(3)
O2-C8	1.354(3)	C10-C9	1.376(3)
C7-C8	1.369(4)	C2-C3	1.494(4)
C7-C6	1.377(4)	C13-C14	1.373(3)
C8-C9	1.383(3)	C13-C17	1.373(4)
Cl1-C15	1.740(3)	N2-C15	1.306(4)
O1-N1	1.408(3)	N2-C16	1.332(4)
O1-C1	1.412(4)	C6-C5	1.495(4)
N1-C2	1.272(3)	C14-C15	1.374(4)
C11-C10	1.405(3)	C5-C4	1.511(4)
C11-C2	1.467(4)	C16-C17	1.376(4)
C11-C6	1.405(3)	C4-C3	1.516(4)
C8-O2-C12	118.3(2)		
C8-C7-C6	121.5(2)	C17-C13-C10	122.0(2)
O2-C8-C7	115.9(2)	C17-C13-C14	117.5(2)
O2-C8-C9	124.7(2)	C15-N2-C16	114.8(2)
C7-C8-C9	119.4(2)	C7-C6-C11	119.8(2)
N1-O1-C1	108.8(2)	C7-C6-C5	121.3(2)
C2-N1-O1	110.8(2)	C11-C6-C5	118.8(2)
C10-C11-C2	124.2(2)	C13-C14-C15	118.0(3)
C6-C11-C10	118.4(2)	C10-C9-C8	120.8(2)
C6-C11-C2	117.4(2)	N2-C15-Cl1	115.3(2)
C11-C10-C13	122.5(2)	N2-C15-C14	126.3(3)
C9-C10-C11	120.2(2)	C14-C15-Cl1	118.4(2)
C9-C10-C13	117.2(2)	C6-C5-C4	109.5(2)
N1-C2-C11	116.6(2)	N2-C16-C17	124.2(3)
N1-C2-C3	123.8(2)	C5-C4-C3	109.8(2)
C11-C2-C3	119.5(2)	C2-C3-C4	114.0(2)
C14-C13-C10	120.4(2)	C13-C17-C16	119.2(3)

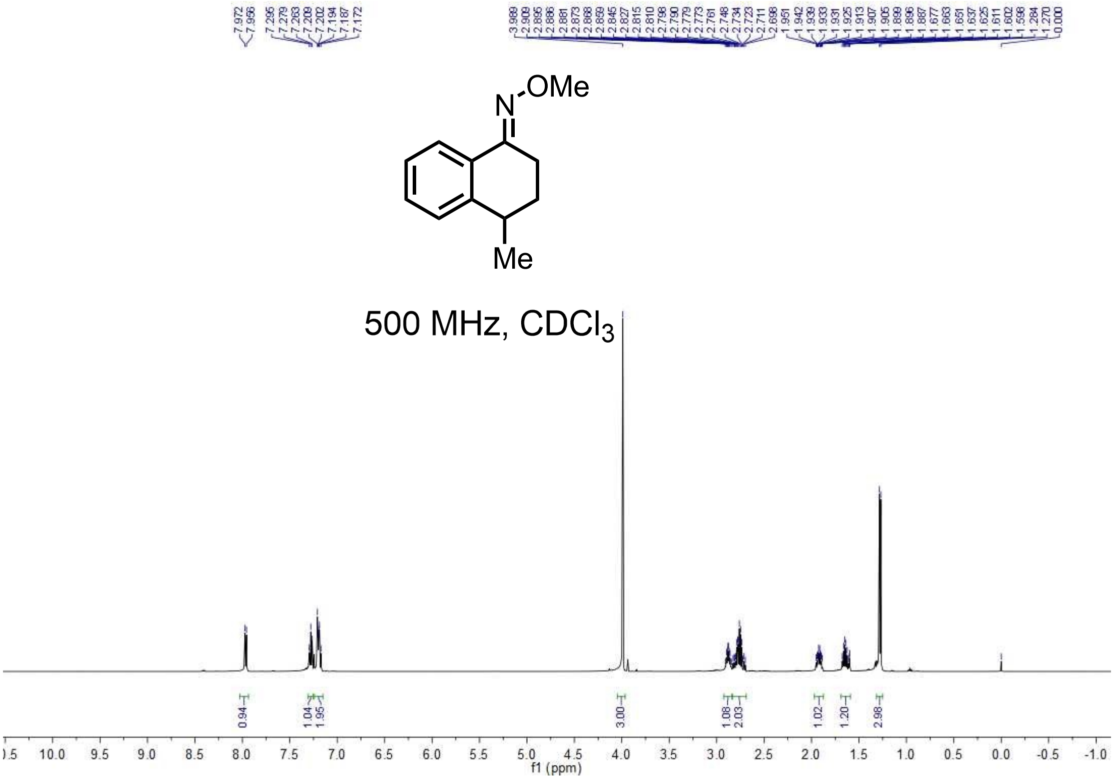
3. References

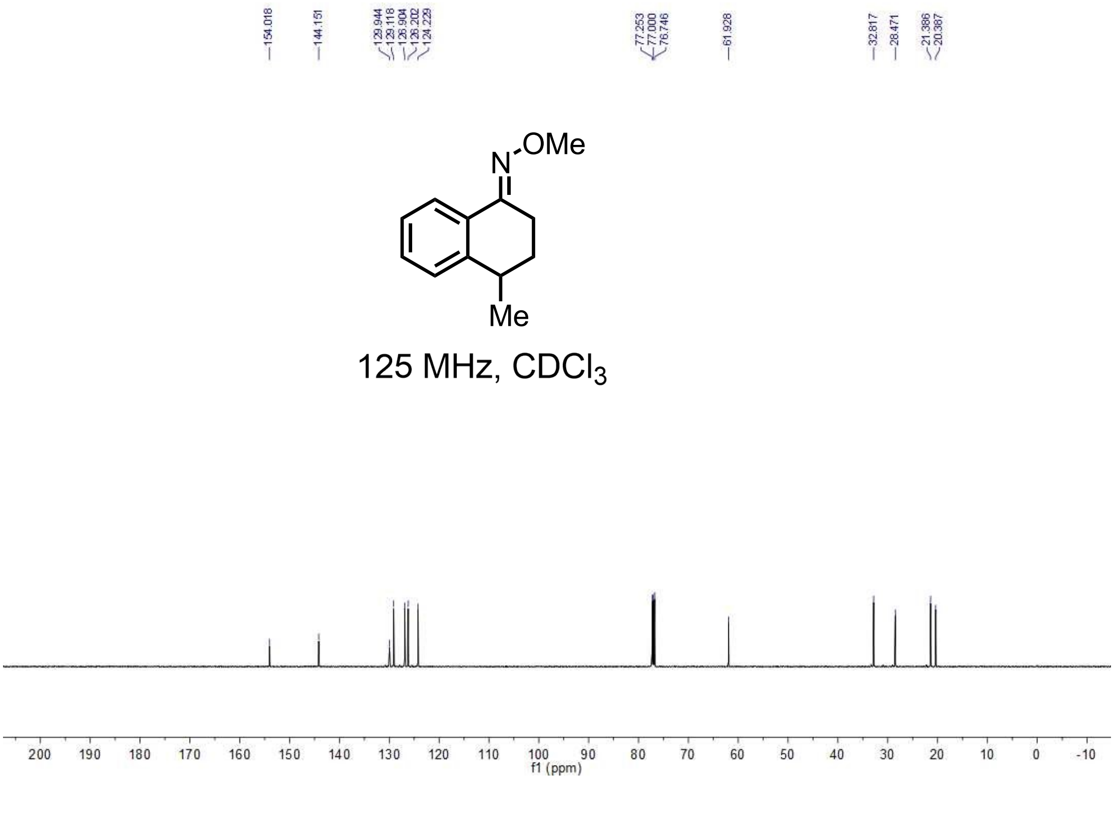
1. J. Mas-Rosell , T. Smejkal and N. Cramer, *Science*, 2020, **368**, 1098-1102.

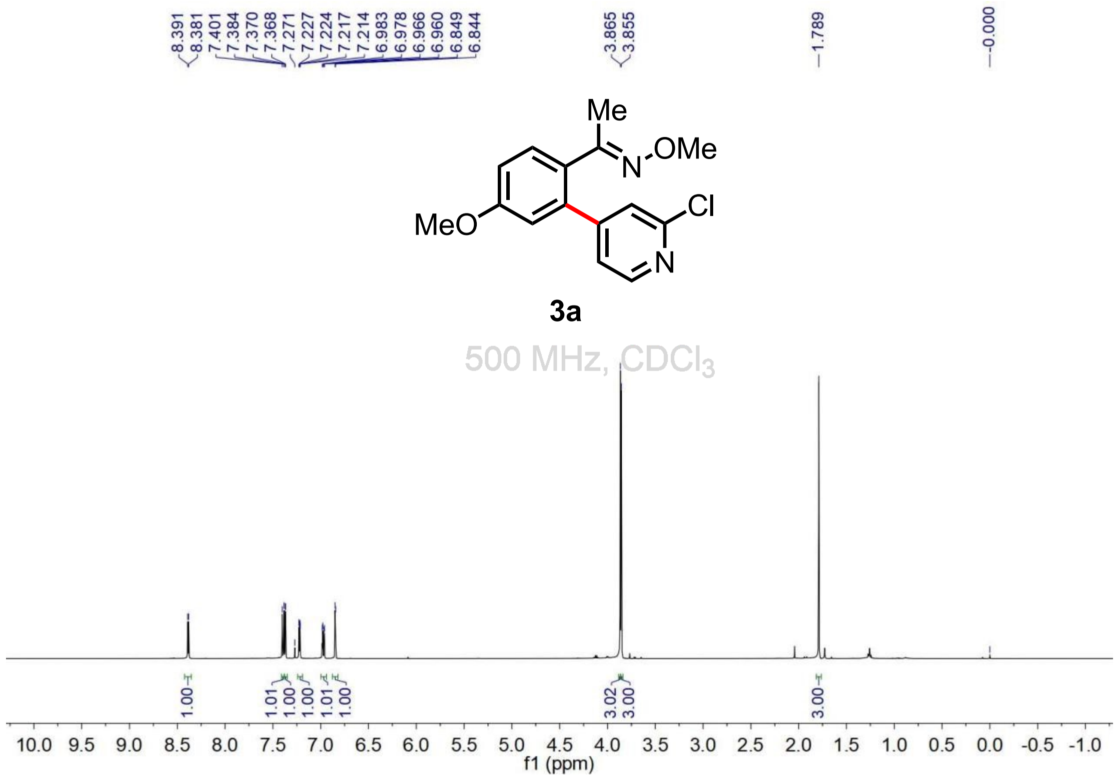
2. SAINT, *Version 6.02a*, Bruker AXS Inc, Madison, WI, **2002**.

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

4. NMR Spectra



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6.978
6.966
6.960
6.849
6.844
3.865
3.855
1.789
-0.000
Me
N
OMe
MeO
Cl
N
3a
500 MHz, $CDCl_3$
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1.01
1.00
1.00
1.01
1.00
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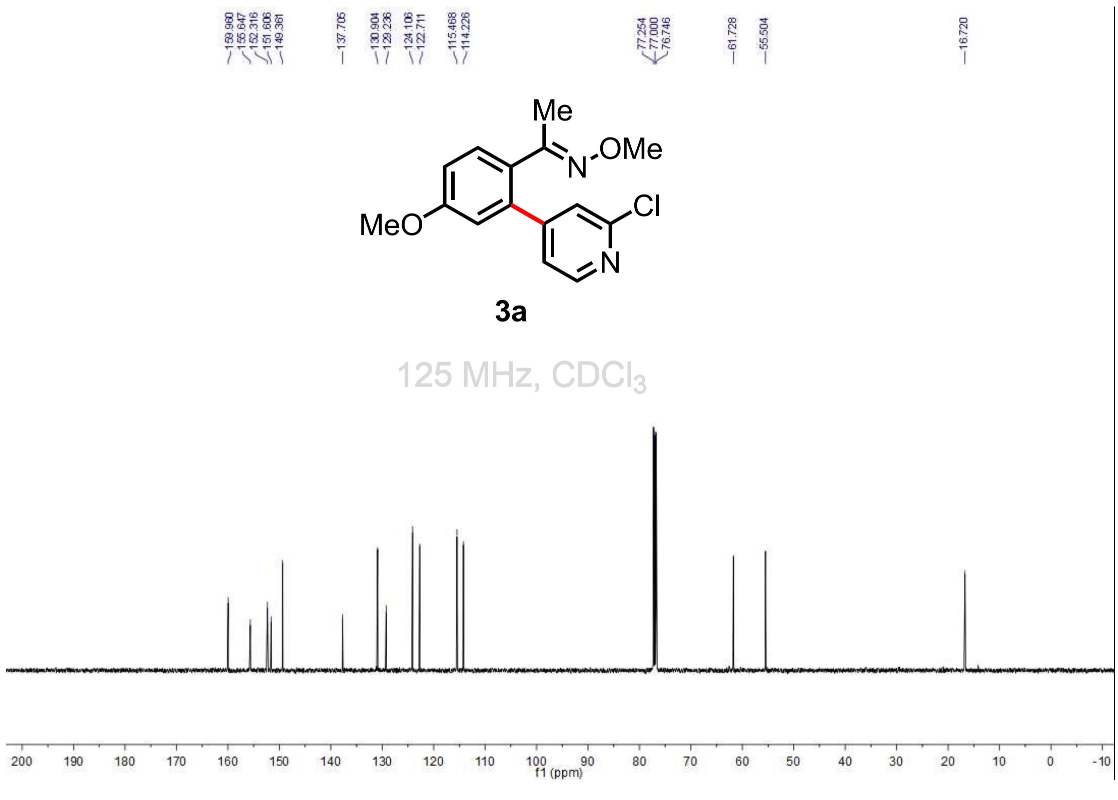
3.00
3.00
f1 (ppm)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77.254
77.000
76.746
61.728
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Me
N
OMe
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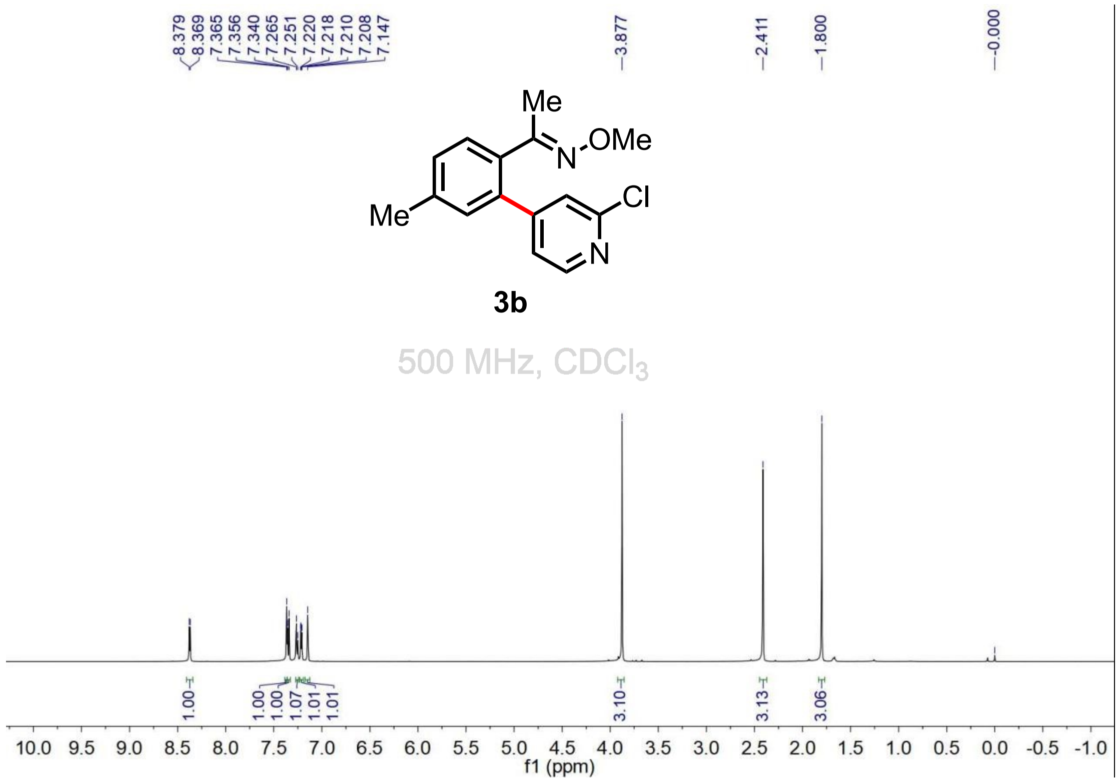
Cl
N
3a
125 MHz, $CDCl_3$
f1 (ppm)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2.411
1.800
0.000
Me
N
OMe
Me
Cl
N
3b
500 MHz, CDCl3
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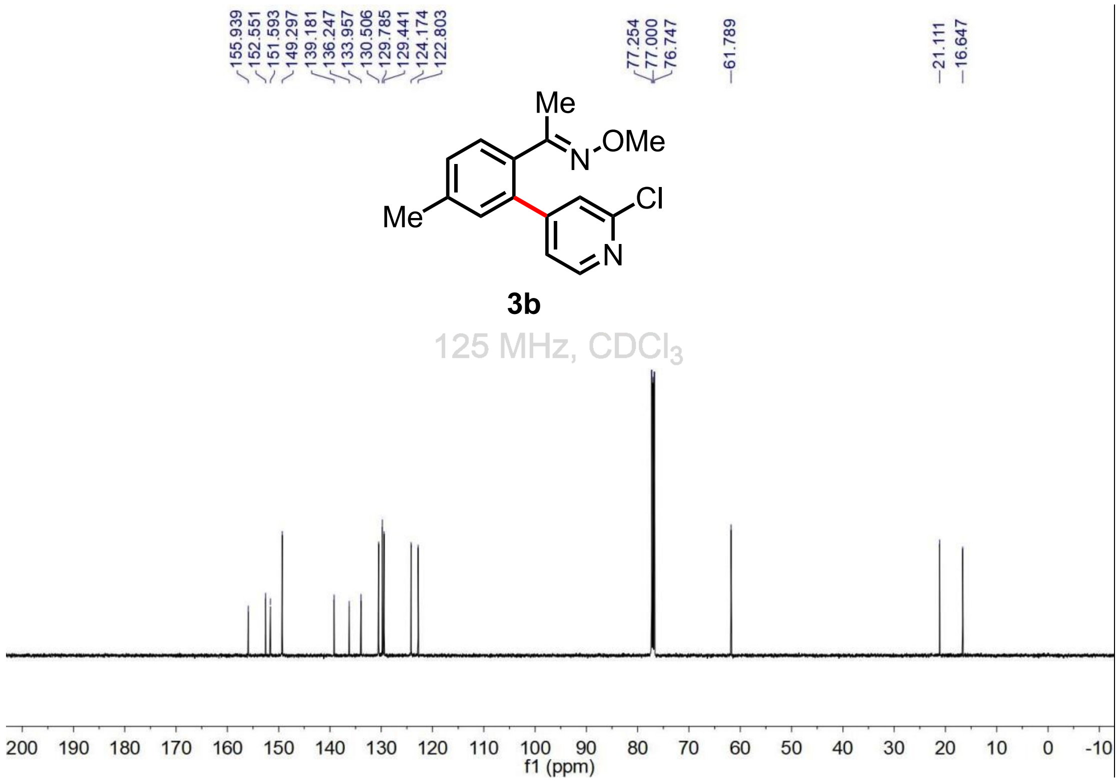
1.00
1.00
1.07
1.01
1.01
3.10
3.13
3.06
f1 (ppm)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77.254
77.000
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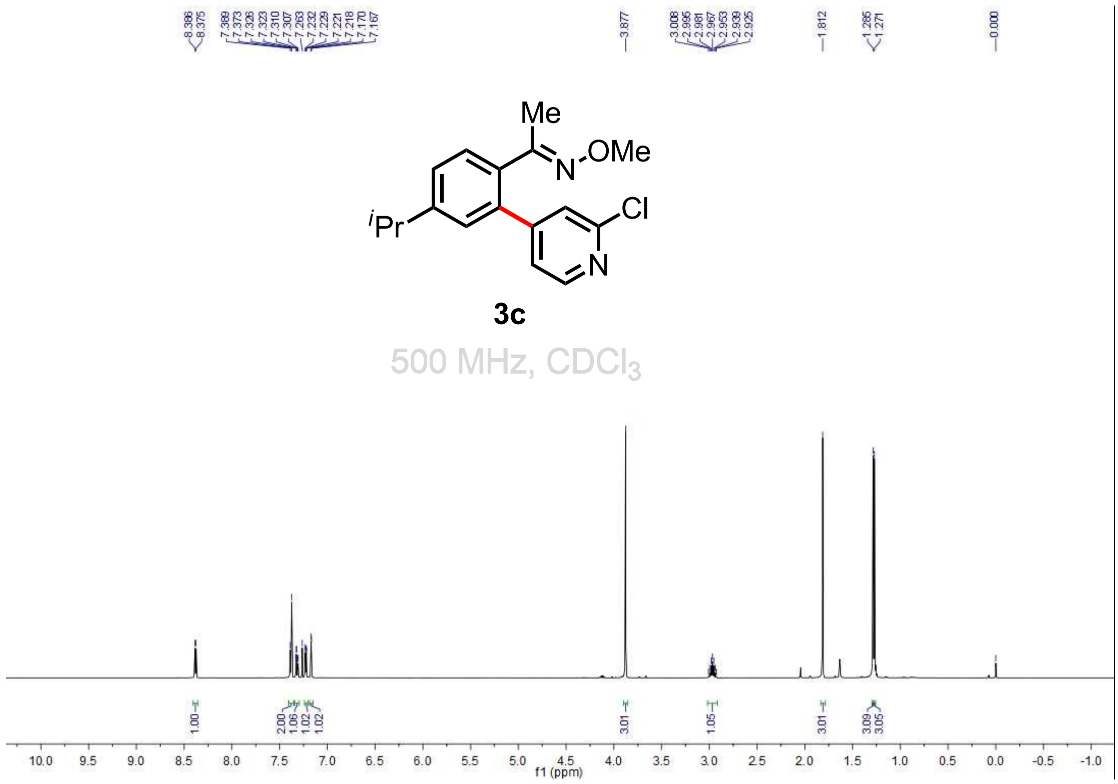
61.789
21.111
16.647
Me
N
OMe
Me
Cl
N
3b
125 MHz, CDCl3
f1 (ppm)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7.170
7.167
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3.008
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2.981
2.967
2.953
2.939
2.925
1.812
1.285
1.271
0.000
Me
N
OMe
Cl
^{i}Pr
N
3c
500 MHz, $CDCl_3$
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1.02
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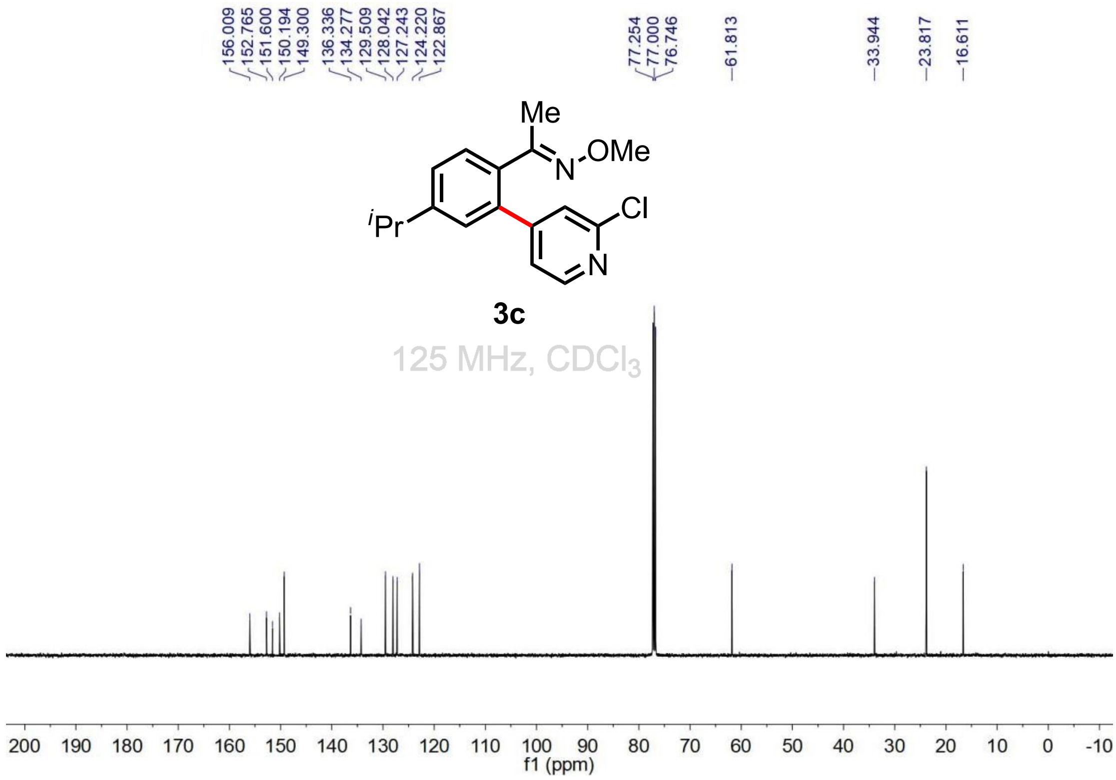
1.05
3.01
3.09
3.05
f1 (ppm)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127.243
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77.254
77.000
76.746
61.813
33.944
23.817
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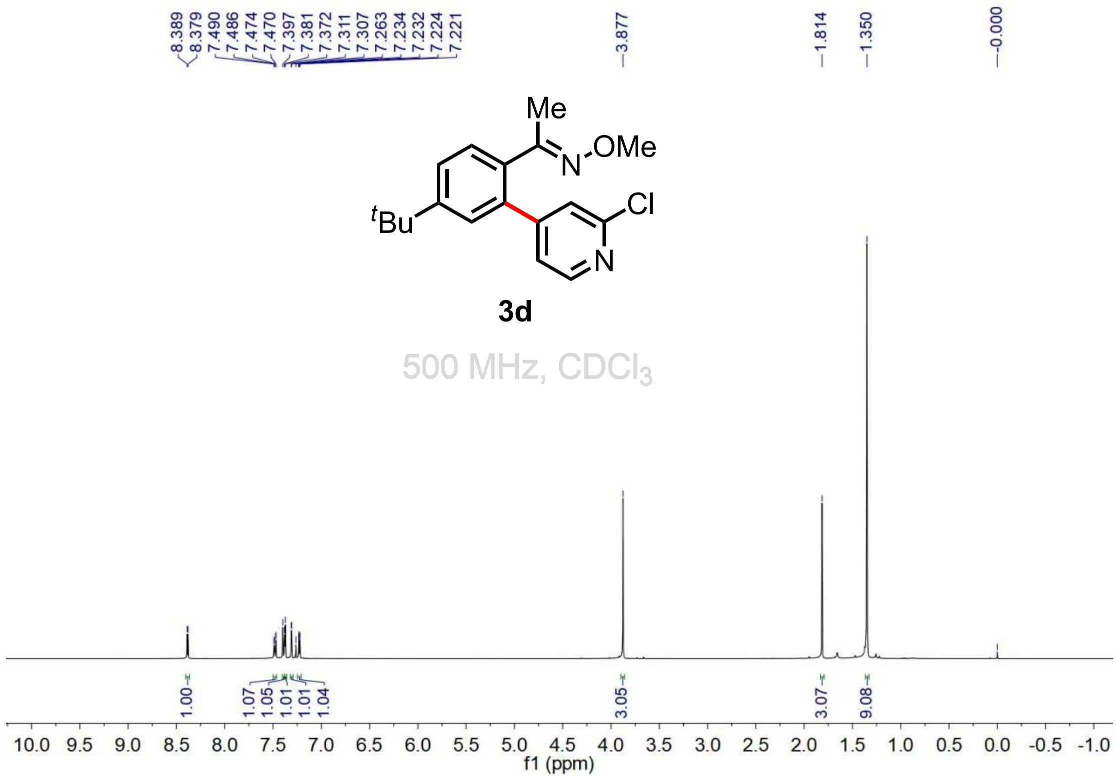
Me
N
OMe
Cl
^{i}Pr
N
3c
125 MHz, $CDCl_3$
f1 (ppm)



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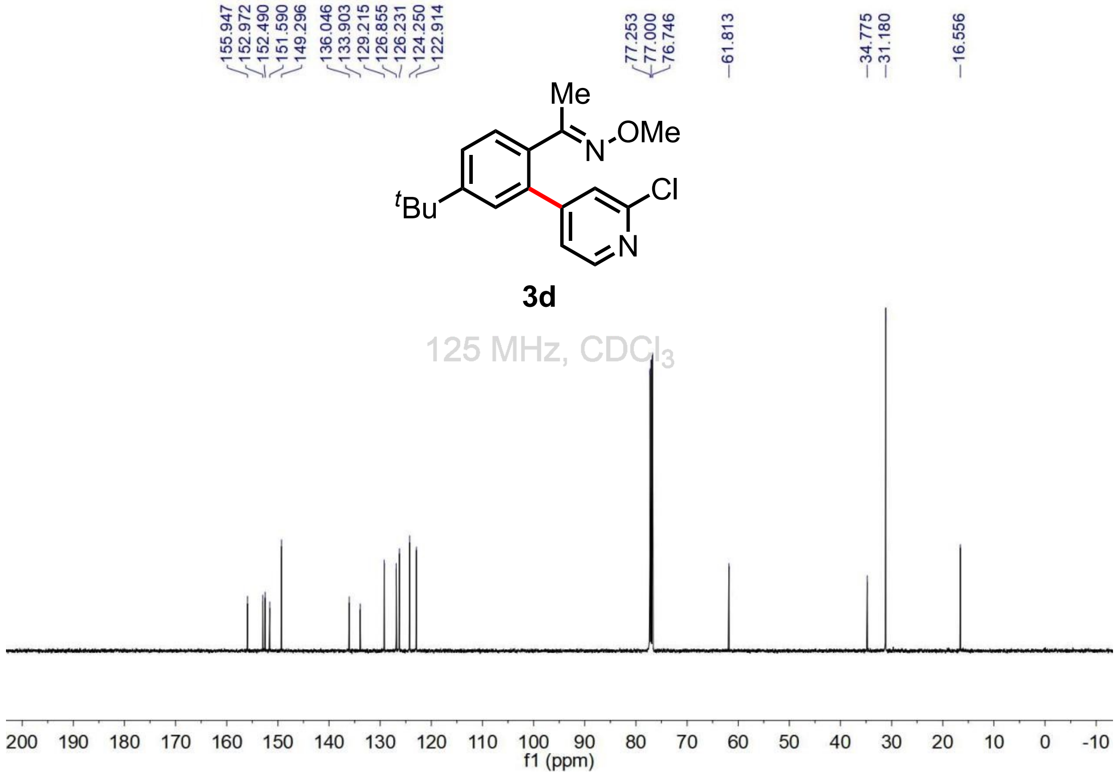
7.232
7.224
7.221
3.877
1.814
1.350
-0.000
Me
N
OMe
Cl
tBu
N
500 MHz, CDCl3
1.00
1.07
1.05
1.01
1.01
1.04
3.05
3.07
9.08
f1 (ppm)

3d



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152.972
152.490
151.590
149.296
136.046
133.903
129.215
126.855
126.231
124.250
122.914
77.253
77.000
76.746
61.813
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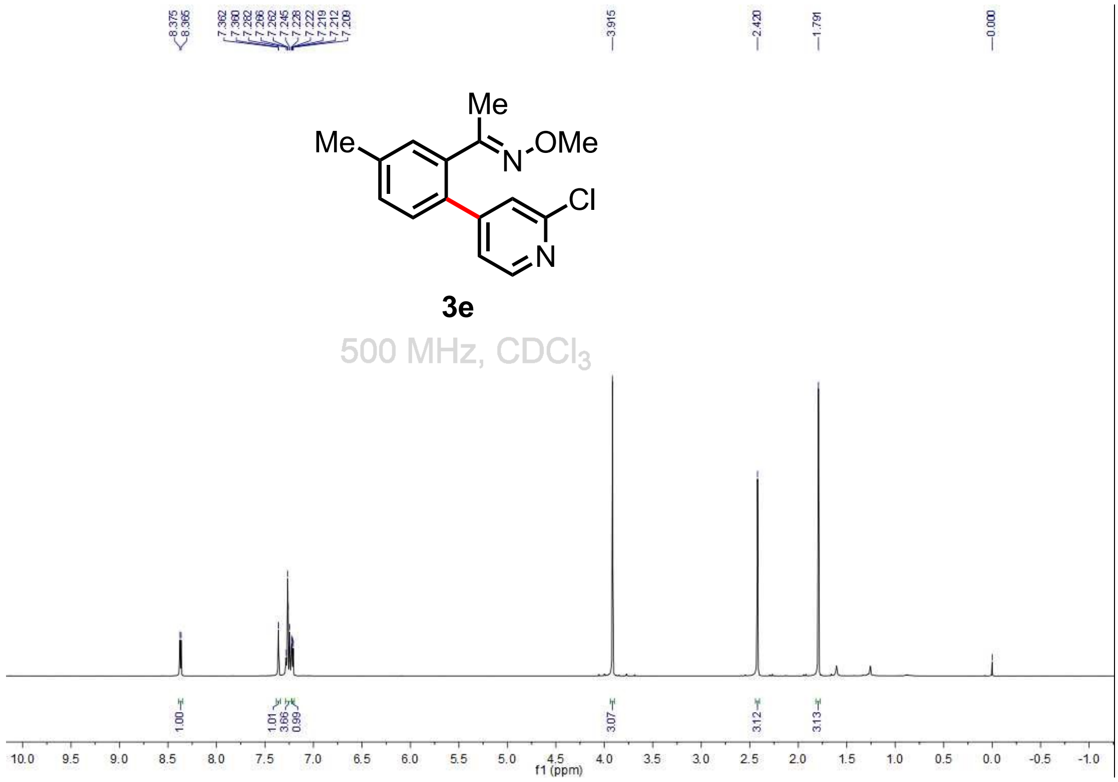
31.180
16.556
Me
N
OMe
Cl
tBu
N
125 MHz, CDCl3
f1 (ppm)

3d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8.365
7.362
7.360
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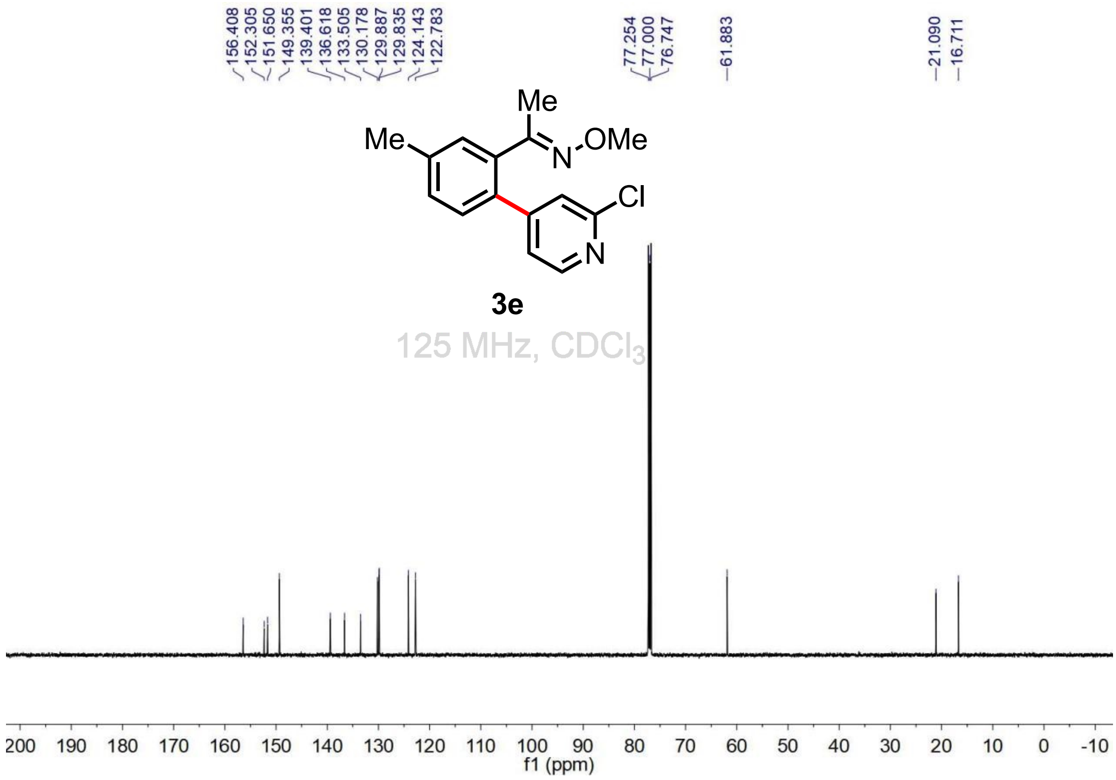
7.266
7.262
7.245
7.228
7.222
7.219
7.212
7.209
3.915
2.420
1.791
0.000
Me
Me
N
OMe
Cl
N
3e
500 MHz, CDCl3
1.00
1.01
3.66
0.99
3.07
3.12
3.13
f1 (ppm)


156.408
152.305
151.650
149.355
139.401
136.618
133.505
130.178
129.887
129.835
124.143
122.783
77.254
77.000
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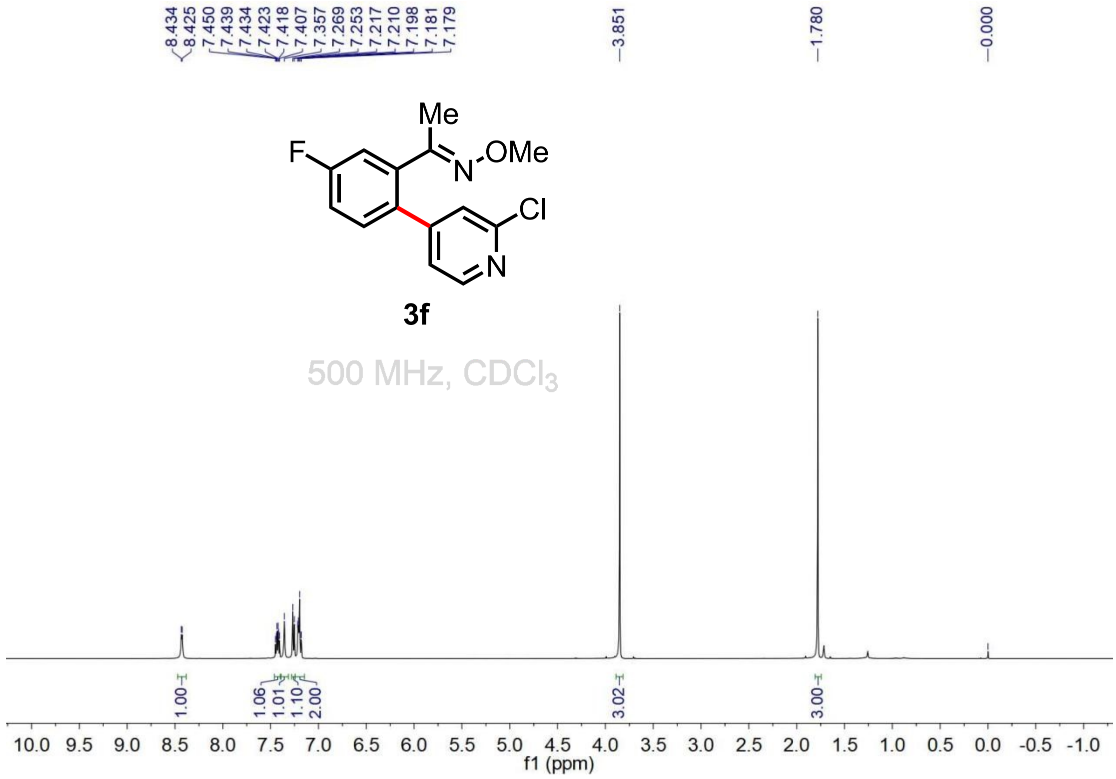
61.883
21.090
16.711
Me
Me
N
OMe
Cl
N
3e
125 MHz, CDCl3
f1 (ppm)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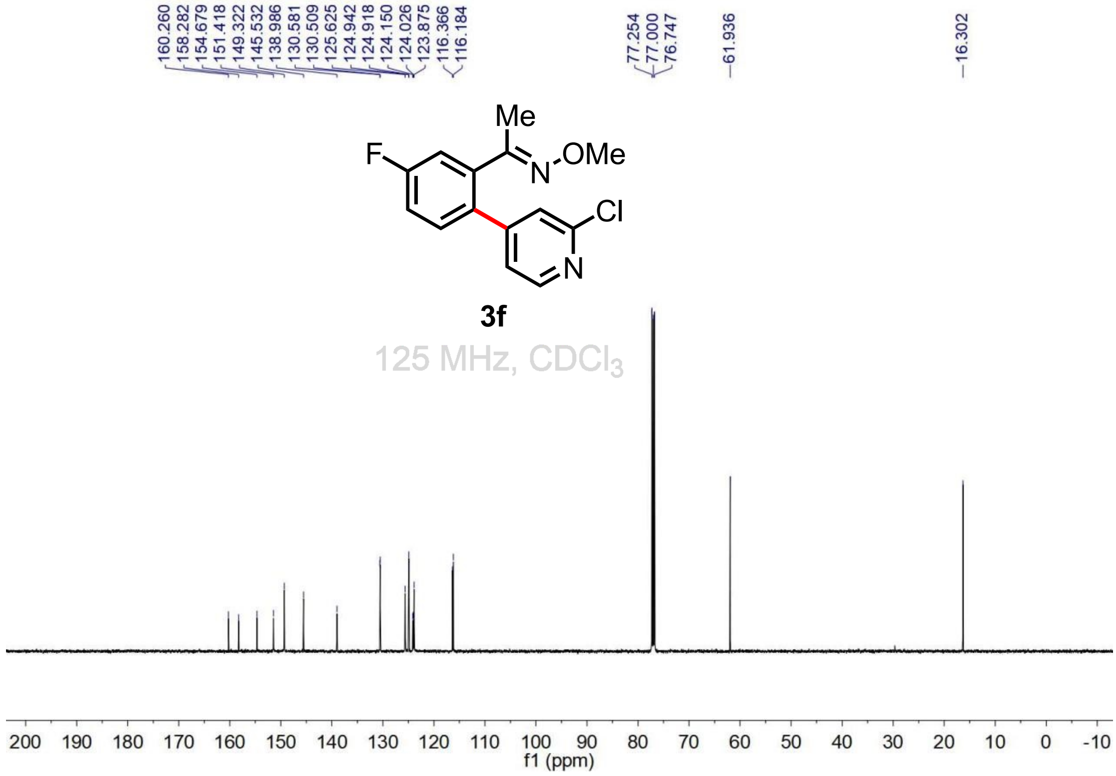
7.450
7.439
7.434
7.423
7.418
7.407
7.357
7.269
7.253
7.217
7.210
7.198
7.181
7.179
3.851
1.780
0.000
Me
F
N
OMe
Cl
N
3f
500 MHz, CDCl3
1.00
1.06
1.01
1.10
2.00
3.02
3.00
f1 (ppm)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158.282
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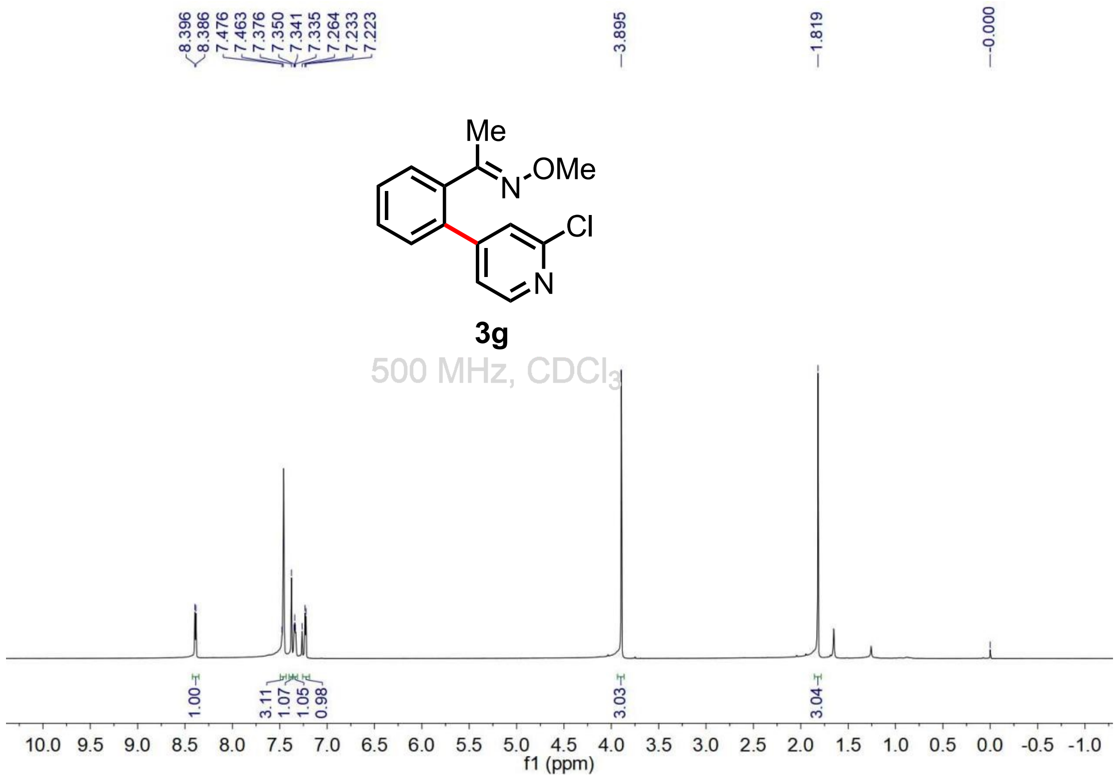
149.322
145.532
138.986
130.581
130.509
125.625
124.942
124.918
124.150
124.026
123.875
116.366
116.184
77.254
77.000
76.747
61.936
16.302
Me
F
N
OMe
Cl
N
3f
125 MHz, CDCl3
f1 (ppm)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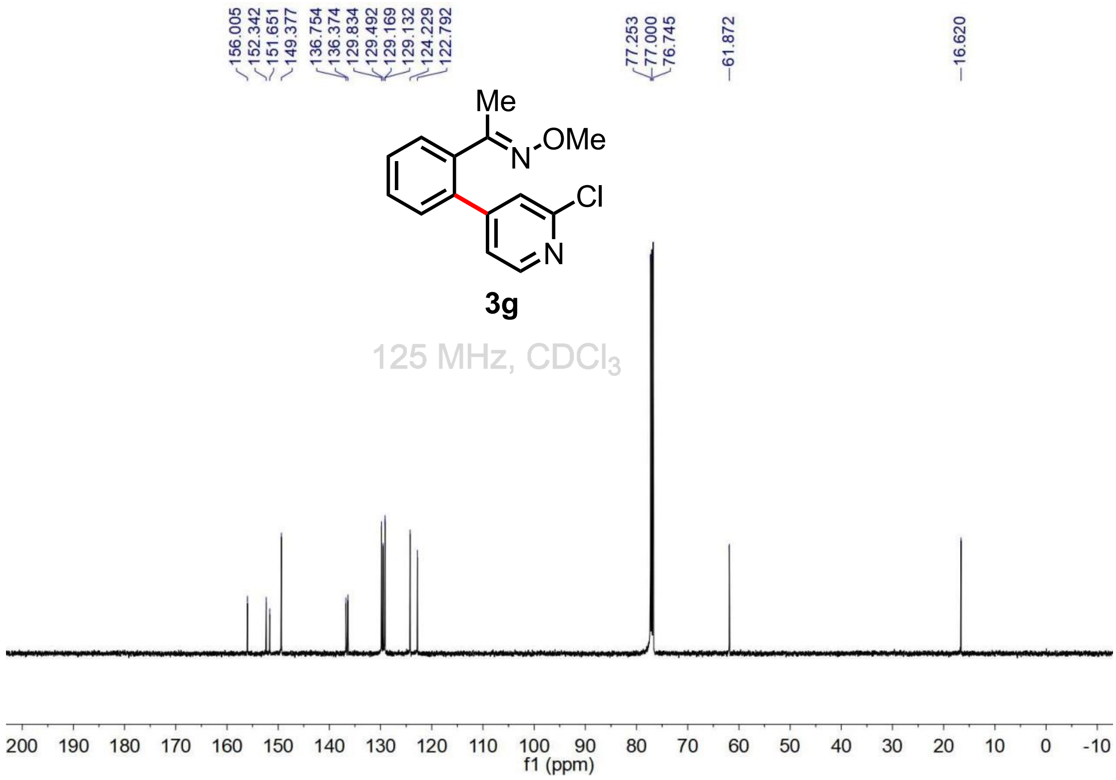
8.386
7.476
7.463
7.376
7.350
7.341
7.335
7.264
7.233
7.223
3.895
1.819
0.000
Me
N
OMe
Cl
N
3g
500 MHz, CDCl3
1.00
3.11
1.07
1.05
0.98
3.03
3.04
10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5 -1.0
f1 (ppm)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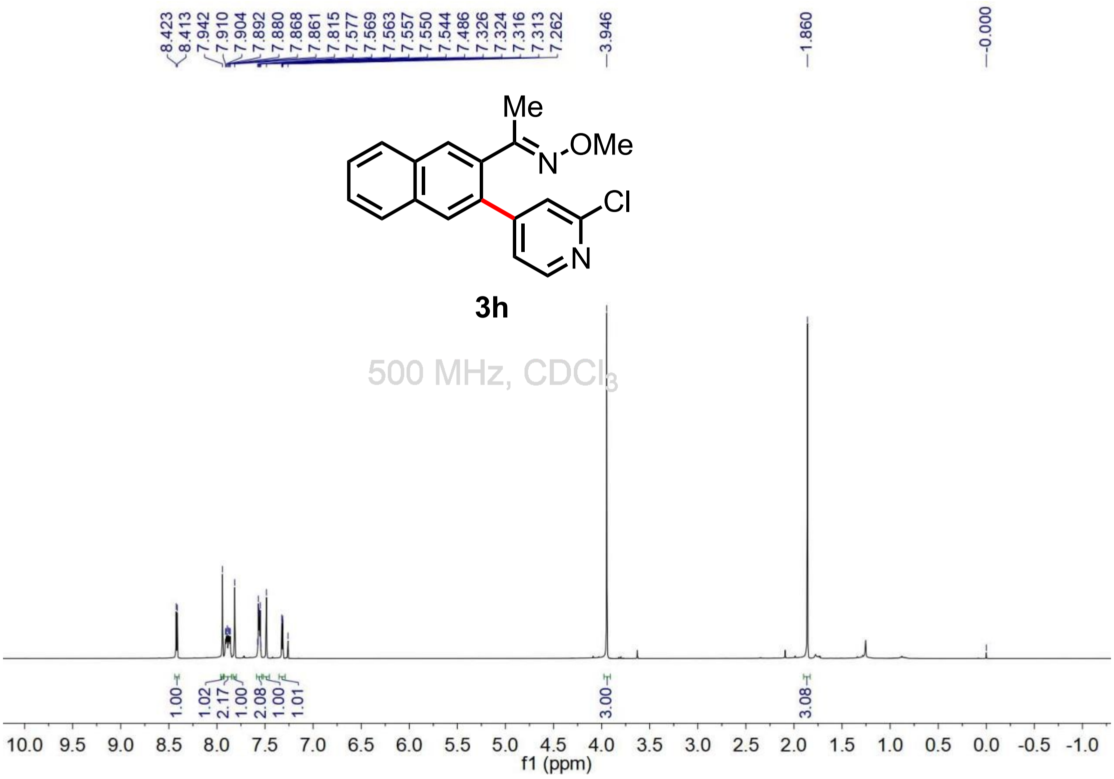
152.342
151.651
149.377
136.754
136.374
129.834
129.492
129.169
129.132
124.229
122.792
77.253
77.000
76.745
61.872
16.620
Me
N
OMe
Cl
N
3g
125 MHz, CDCl3
200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
f1 (ppm)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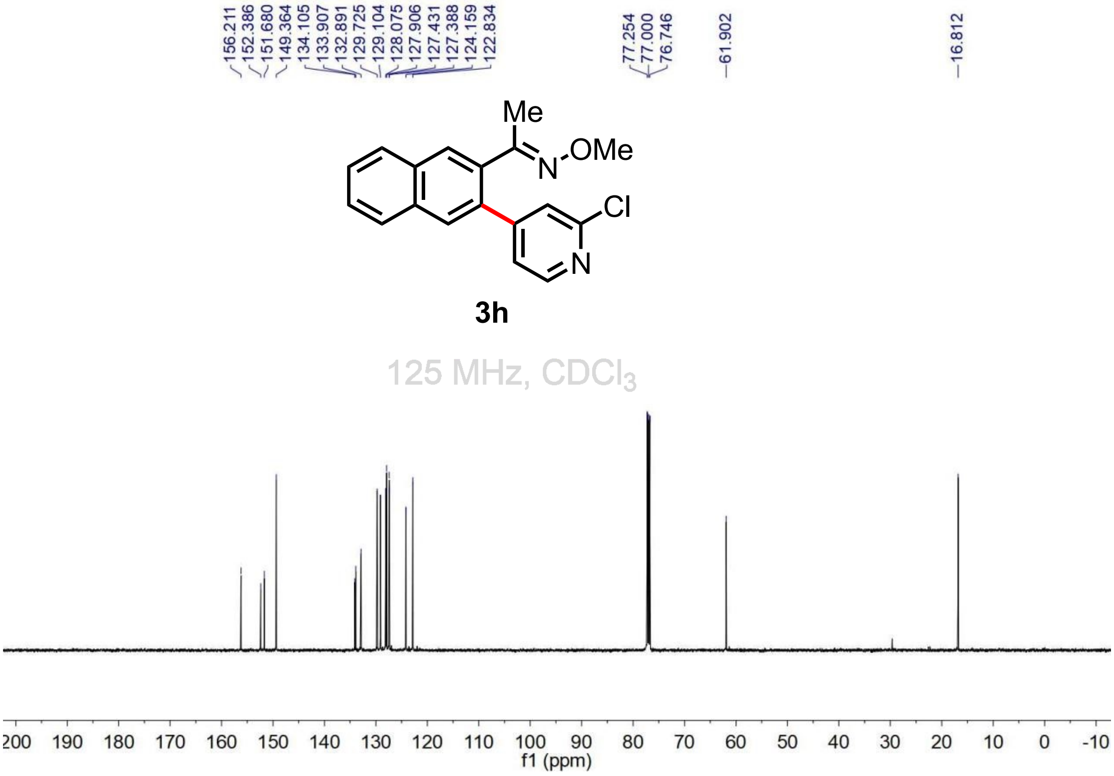
8.413
7.942
7.910
7.904
7.892
7.880
7.868
7.861
7.815
7.577
7.569
7.563
7.557
7.550
7.544
7.486
7.326
7.324
7.316
7.313
7.262
3.946
1.860
0.000
Me
OMe
N
Cl
N
3h
500 MHz, $CDCl_3$
1.00
1.02
2.17
1.00
2.08
1.00
1.01
3.00
3.08
10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5 -1.0
f1 (ppm)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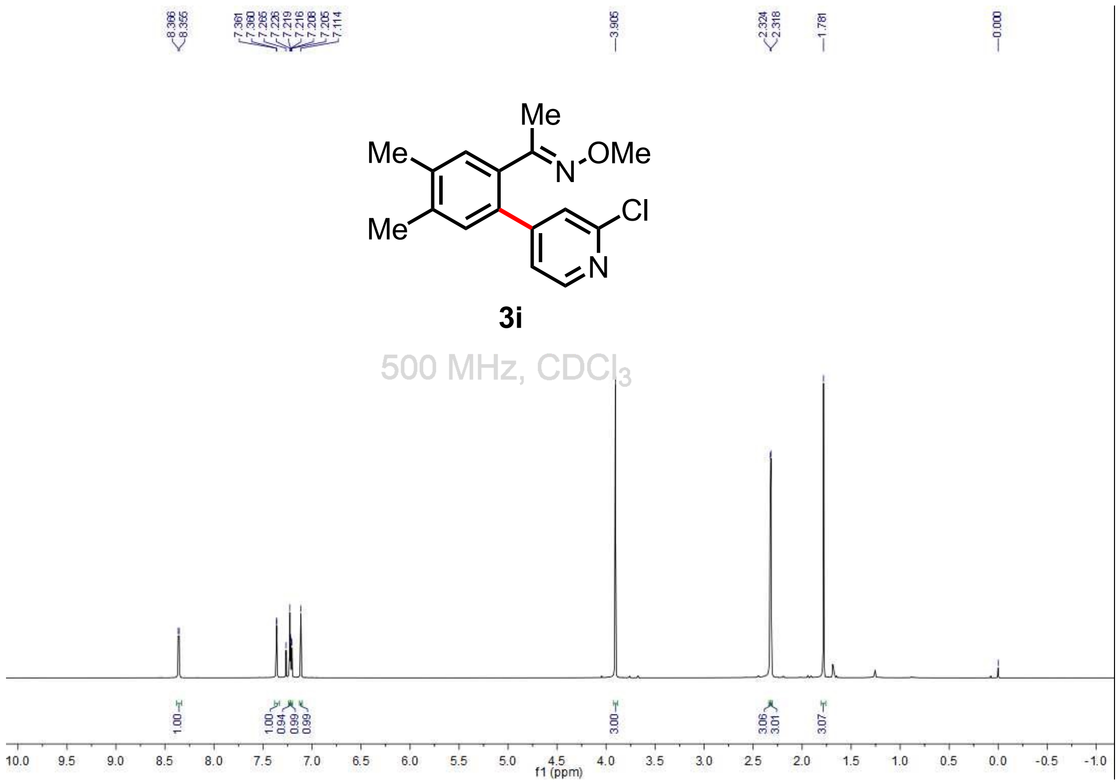
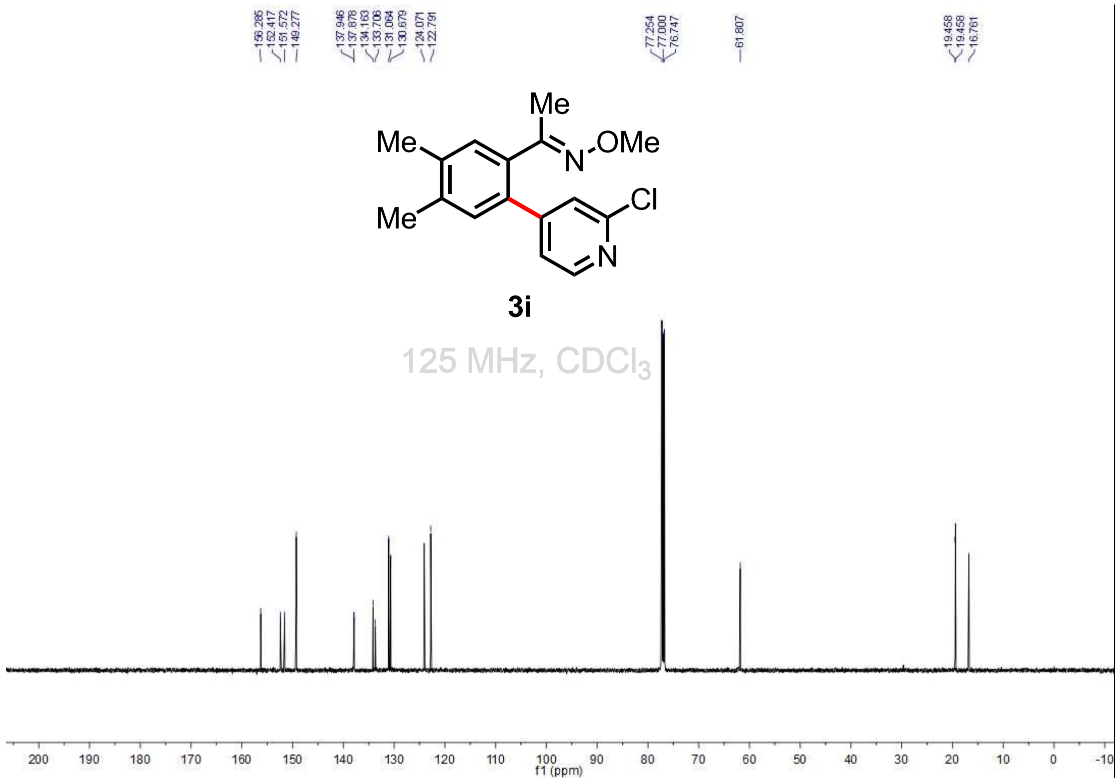
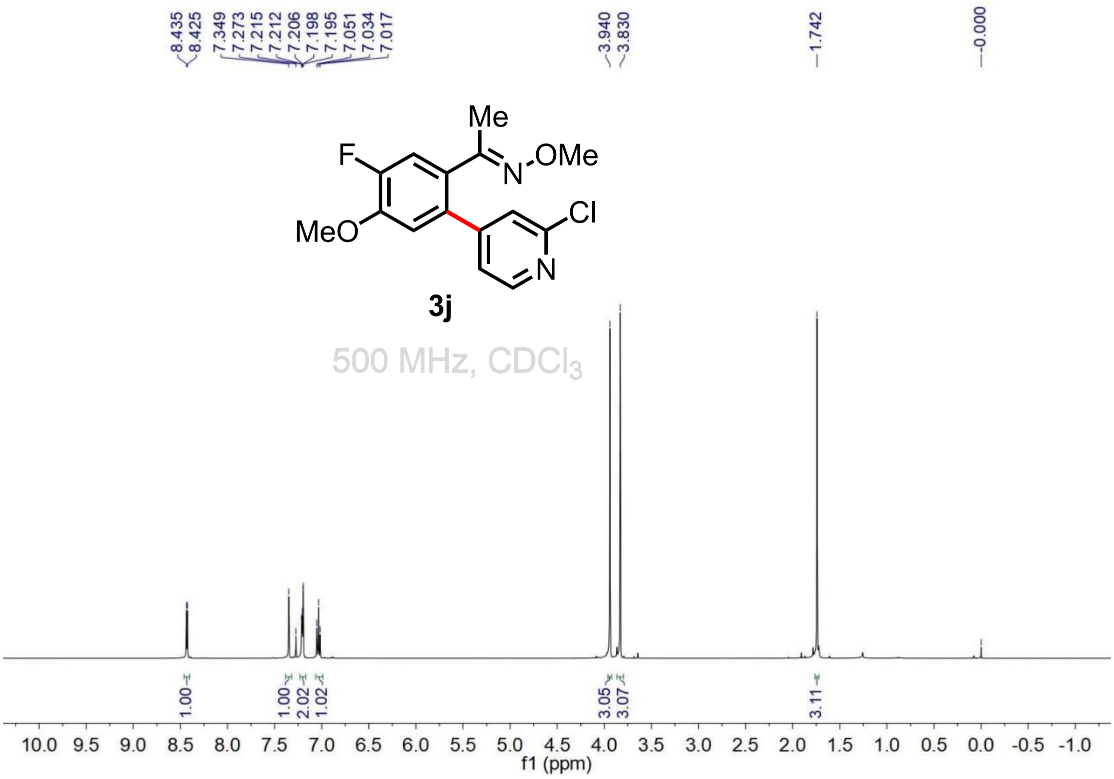
152.386
151.680
149.364
134.105
133.907
132.891
129.725
129.104
128.075
127.906
127.431
127.388
124.159
122.834
77.254
77.000
76.746
61.902
16.812
Me
OMe
N
Cl
N
3h
125 MHz, $CDCl_3$
200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
f1 (ppm)



8.366
8.355
7.361
7.360
7.265
7.226
7.219
7.216
7.208
7.205
7.114
3.905
2.324
2.318
1.781
0.000
Me
Me
N
OMe
Me
Cl
N
3i
500 MHz, CDCl3
1.00
1.00
0.94
0.99
0.99
3.00
3.06
3.01
3.07
f1 (ppm)



156.285
152.417
151.572
149.277
137.946
137.878
134.163
133.706
131.064
130.679
124.071
122.791
77.254
77.000
76.747
61.807
19.458
19.458
16.761
Me
Me
N
OMe
Me
Cl
N
3i
125 MHz, CDCl3
f1 (ppm)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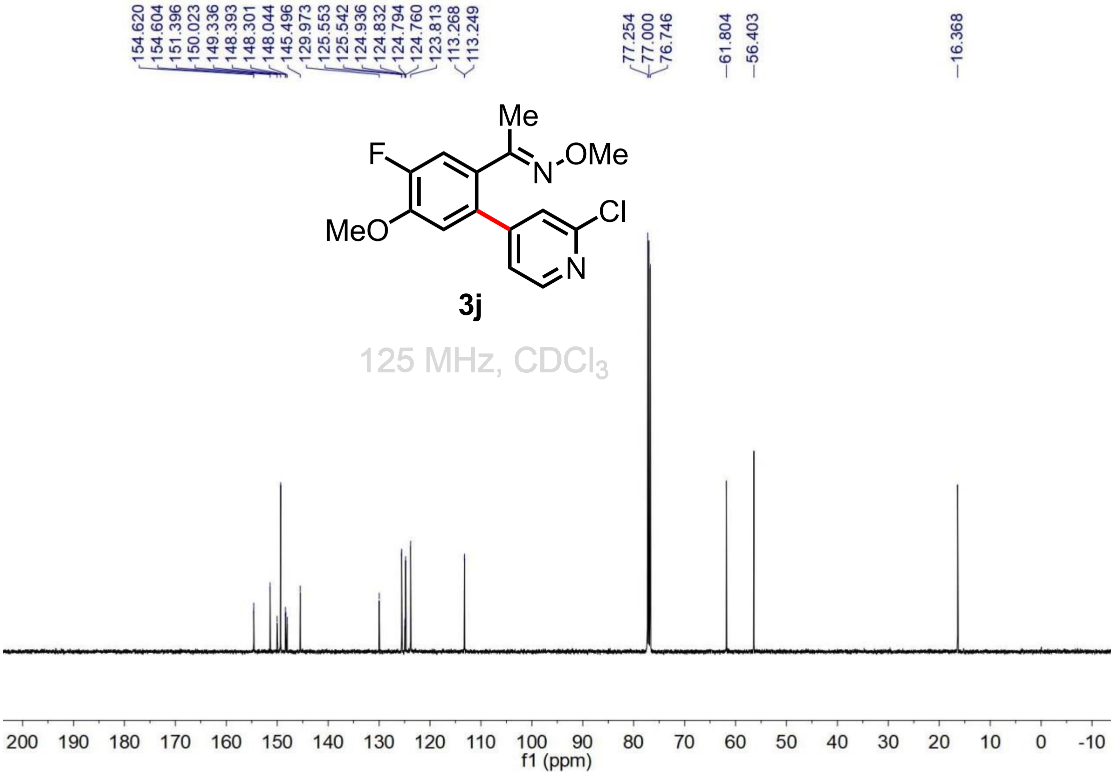
8.425
7.349
7.273
7.215
7.212
7.206
7.198
7.195
7.051
7.034
7.017
3.940
3.830
1.742
0.000
Me
F
N
OMe
MeO
Cl
N
3j
500 MHz, CDCl3
1.00
1.00
2.02
1.02
3.05
3.07
3.11
10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5 -1.0
f1 (ppm)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154.604
151.396
150.023
149.336
148.393
148.301
148.044
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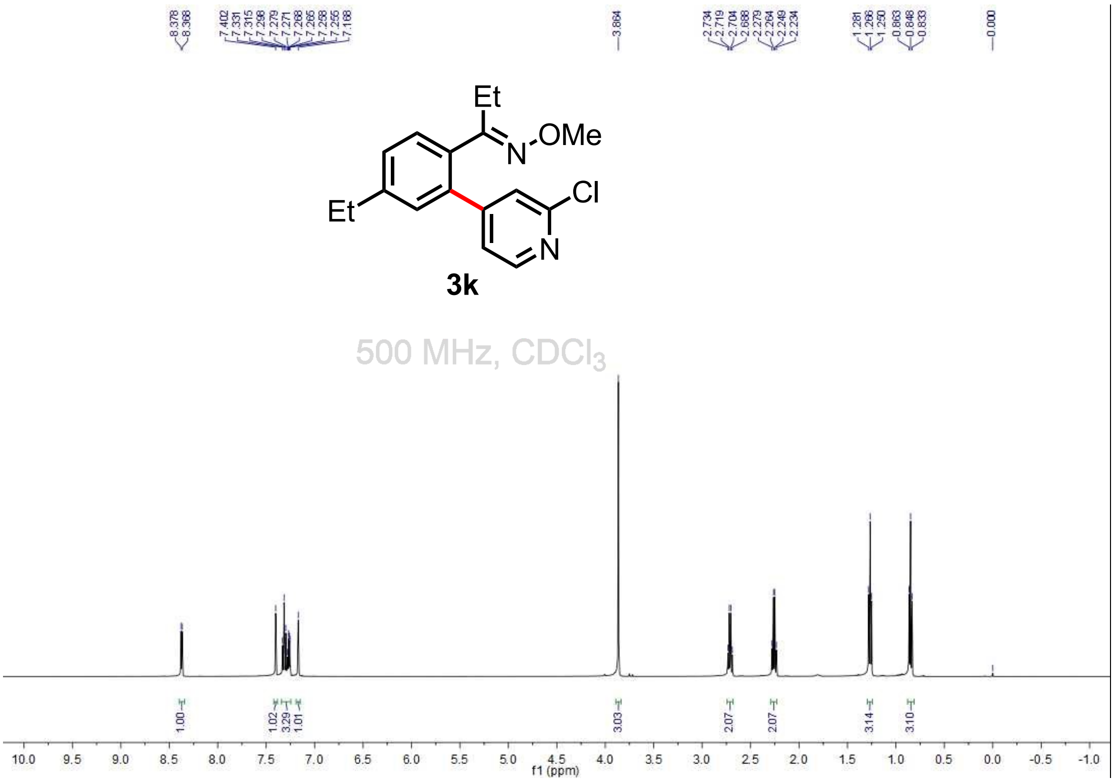
129.973
125.553
125.542
124.936
124.832
124.794
124.760
123.813
113.268
113.249
77.254
77.000
76.746
61.804
56.403
16.368
Me
F
N
OMe
MeO
Cl
N
3j
125 MHz, CDCl3
200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
f1 (ppm)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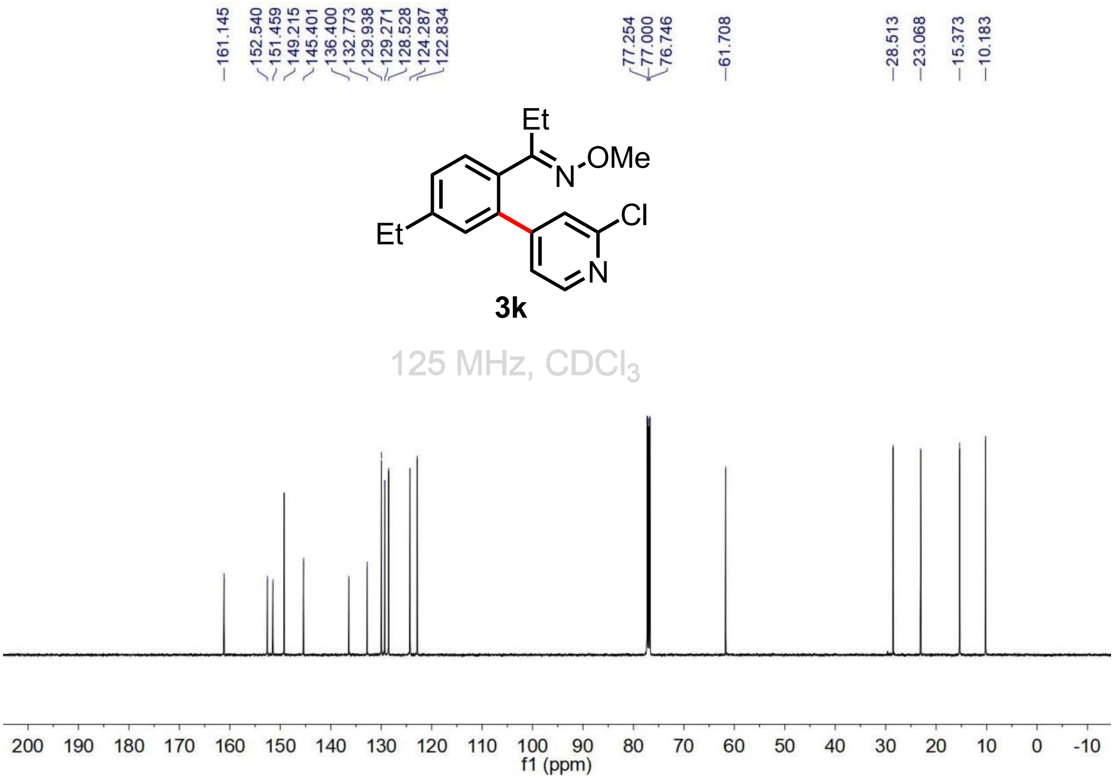
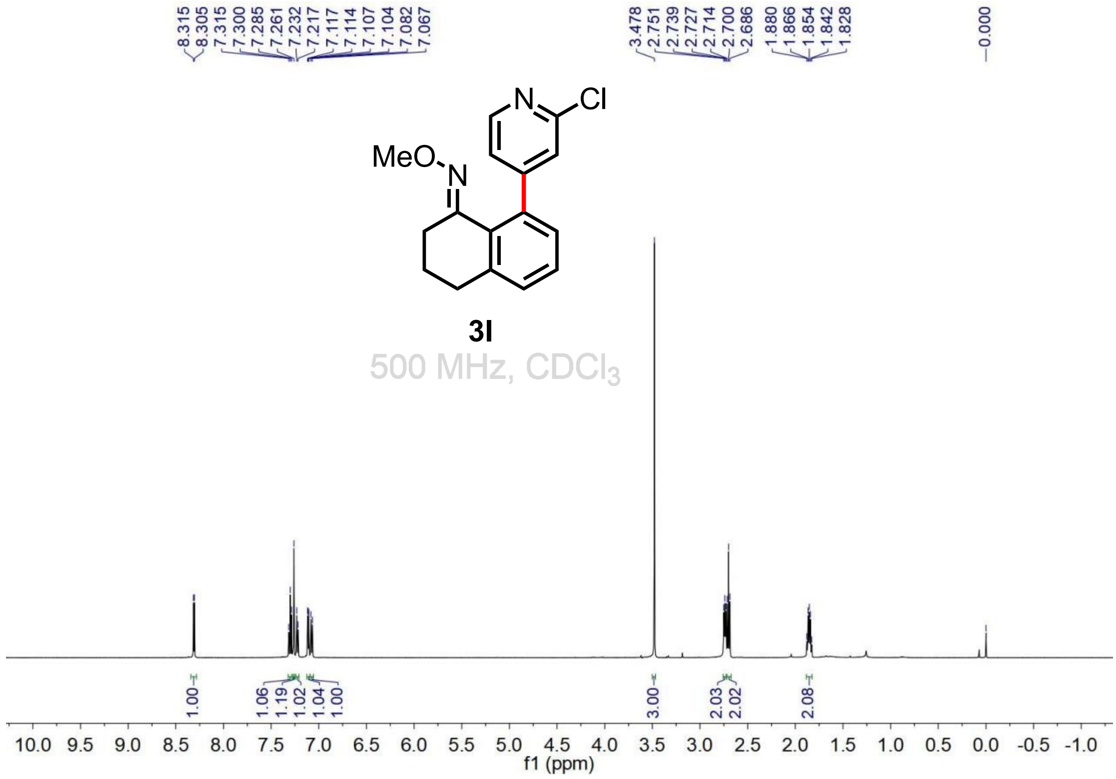
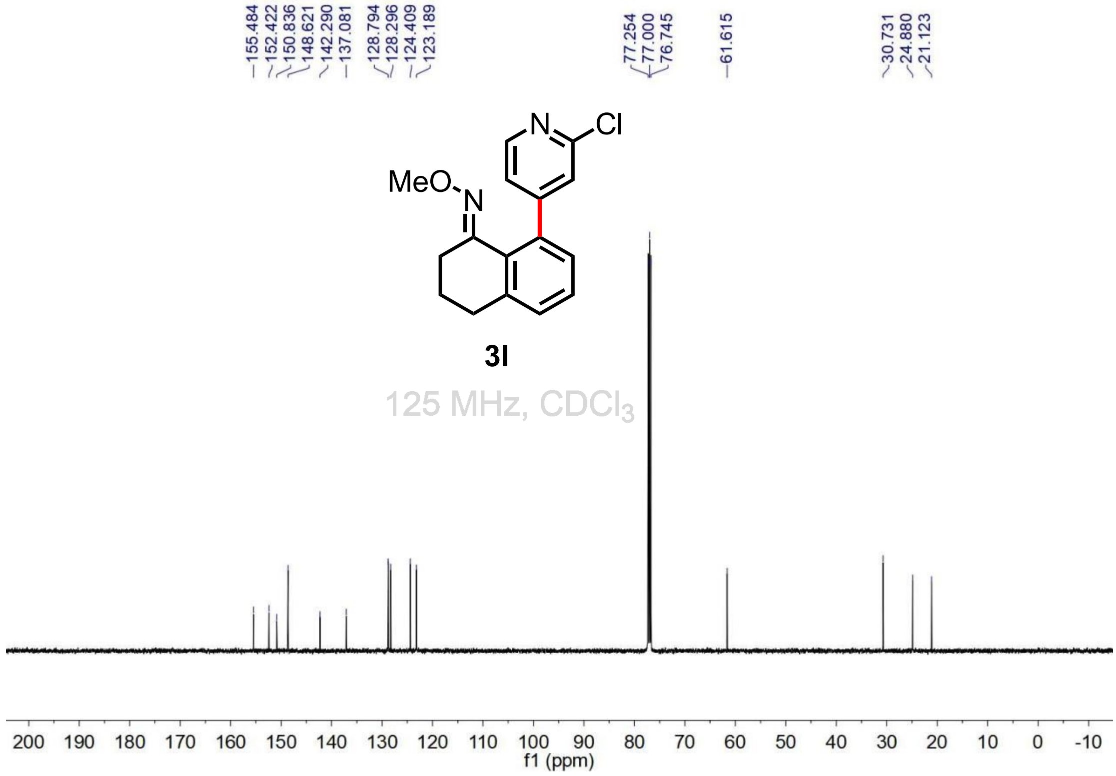
8.368
7.402
7.331
7.315
7.298
7.279
7.271
7.268
7.265
7.258
7.255
7.168
3.864
2.734
2.719
2.704
2.688
2.279
2.264
2.249
2.234
1.281
1.266
1.250
0.863
0.848
0.833
0.000
Et
N
OMe
Cl
Et
N
3k
500 MHz, CDCl3
1.00
1.02
3.29
1.01
3.03
2.07
2.07
3.14
3.10
10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5 -1.0
f1 (ppm)


161.145
152.540
151.459
149.215
145.401
136.400
132.773
129.938
129.271
128.528
124.287
122.834
77.254
77.000
76.746
61.708
28.513
23.068
15.373
10.183
Et
N
OMe
Cl
Et
N
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)



8.315
8.305
7.315
7.300
7.285
7.261
7.232
7.217
7.117
7.114
7.107
7.104
7.082
7.067
3.478
2.751
2.739
2.727
2.714
2.700
2.686
1.880
1.866
1.854
1.842
1.828
0.000
MeO
N
N
Cl
3l
500 MHz, CDCl3
1.00
1.06
1.19
1.02
1.04
1.00
3.00
2.03
2.02
2.08
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)



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150.836
148.621
142.290
137.081
128.794
128.296
124.409
123.189
77.254
77.000
76.745
61.615
30.731
24.880
21.123
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N
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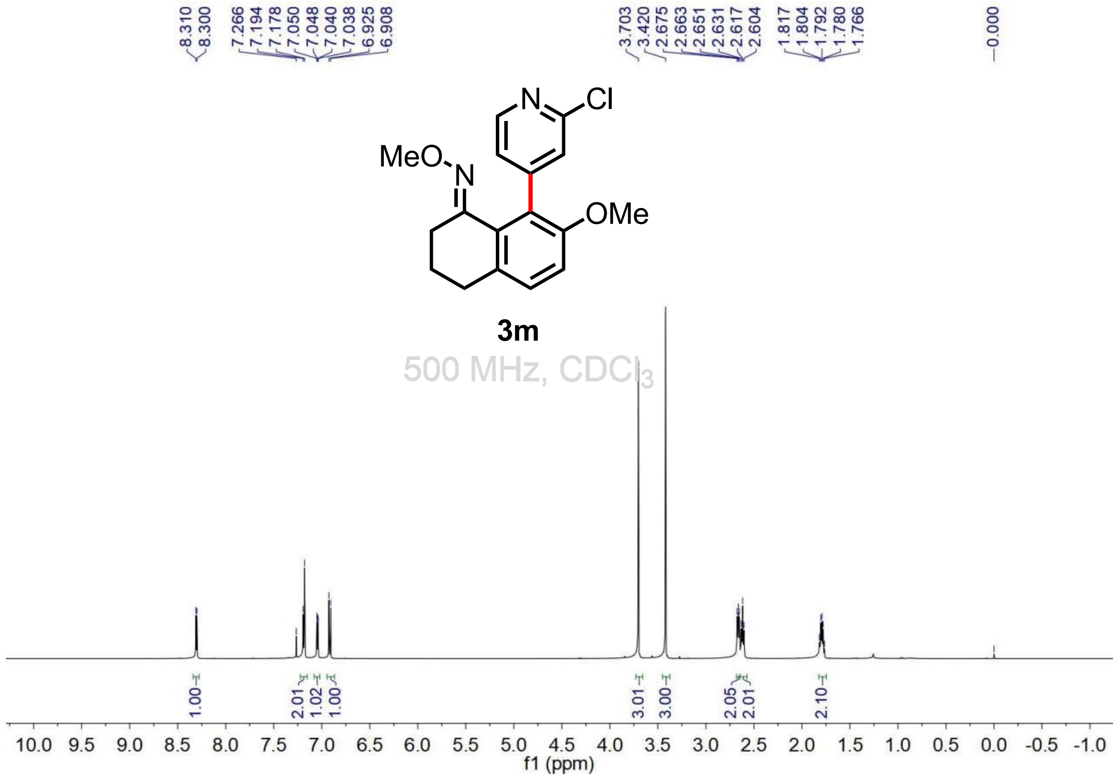
Cl
3l
125 MHz, CDCl3
200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
f1 (ppm)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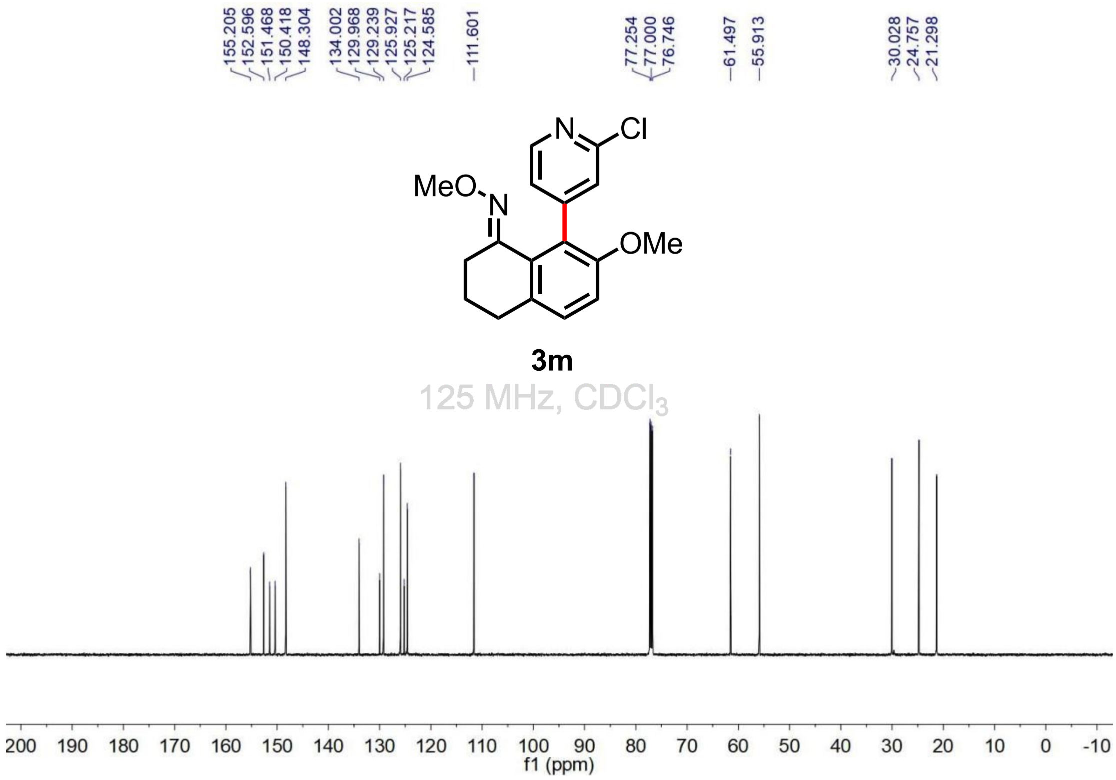
8.300
7.266
7.194
7.178
7.050
7.048
7.040
7.038
6.925
6.908
3.703
3.420
2.675
2.663
2.651
2.631
2.617
2.604
1.817
1.804
1.792
1.780
1.766
0.000
MeO
N
Cl
OMe
3m
500 MHz, CDCl3
1.00
2.01
1.02
1.00
3.01
3.00
2.05
2.01
2.10
10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5 -1.0
f1 (ppm)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150.418
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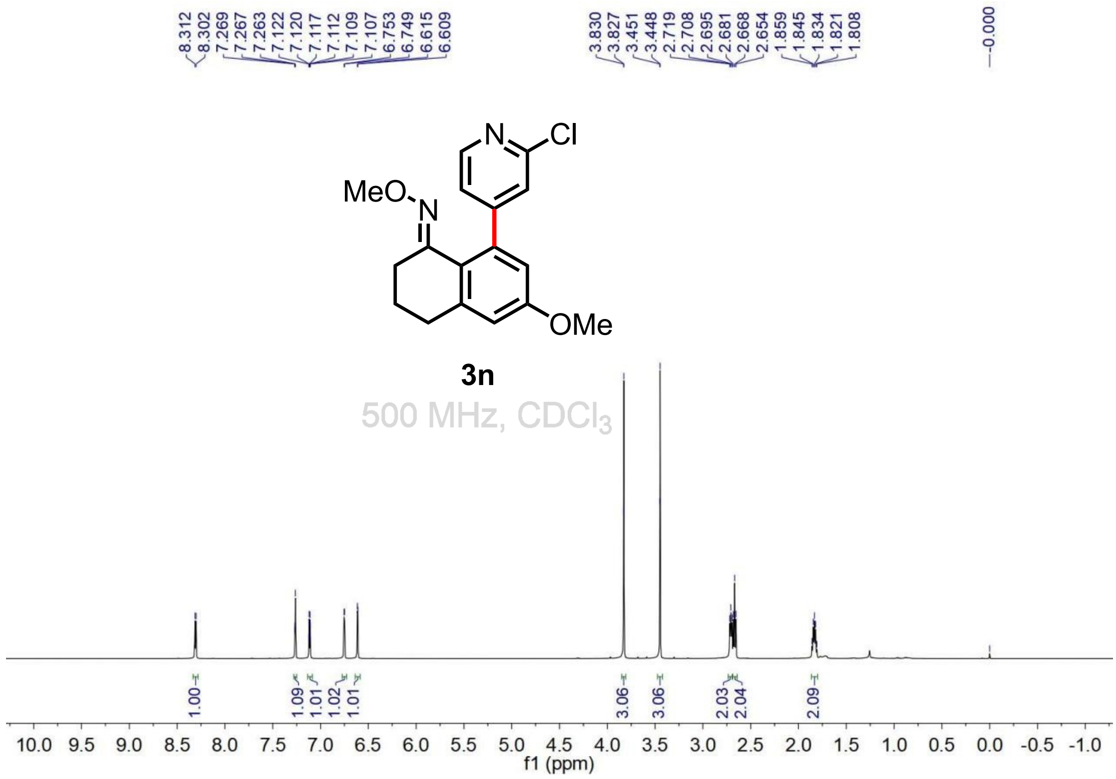
129.239
125.927
125.217
124.585
111.601
77.254
77.000
76.746
61.497
55.913
30.028
24.757
21.298
MeO
N
Cl
OMe
3m
125 MHz, CDCl3
200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
f1 (ppm)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7.267
7.263
7.122
7.120
7.117
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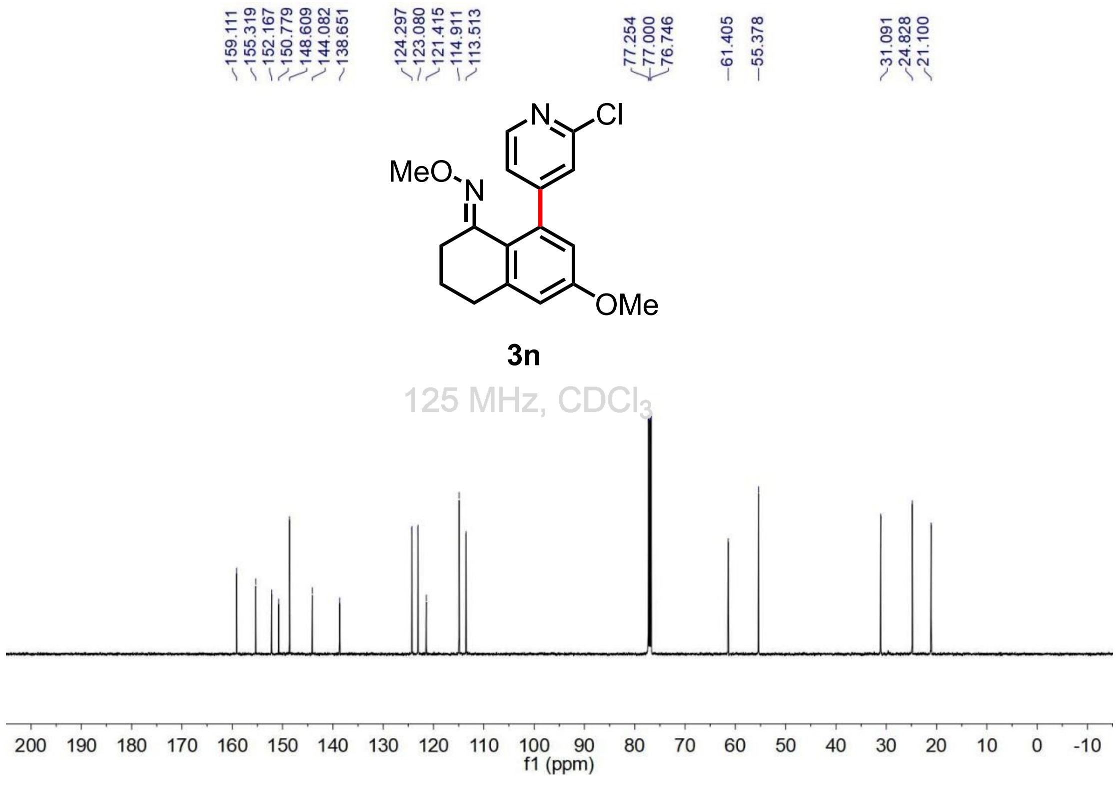
7.109
7.107
6.753
6.749
6.615
6.609
3.830
3.827
3.451
3.448
2.719
2.708
2.695
2.681
2.668
2.654
1.859
1.845
1.834
1.821
1.808
0.000
MeO
N
N
Cl
OMe
3n
500 MHz, CDCl3
1.00
1.09
1.01
1.02
1.01
3.06
3.06
2.03
2.04
2.09
10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5 -1.0
f1 (ppm)


159.111
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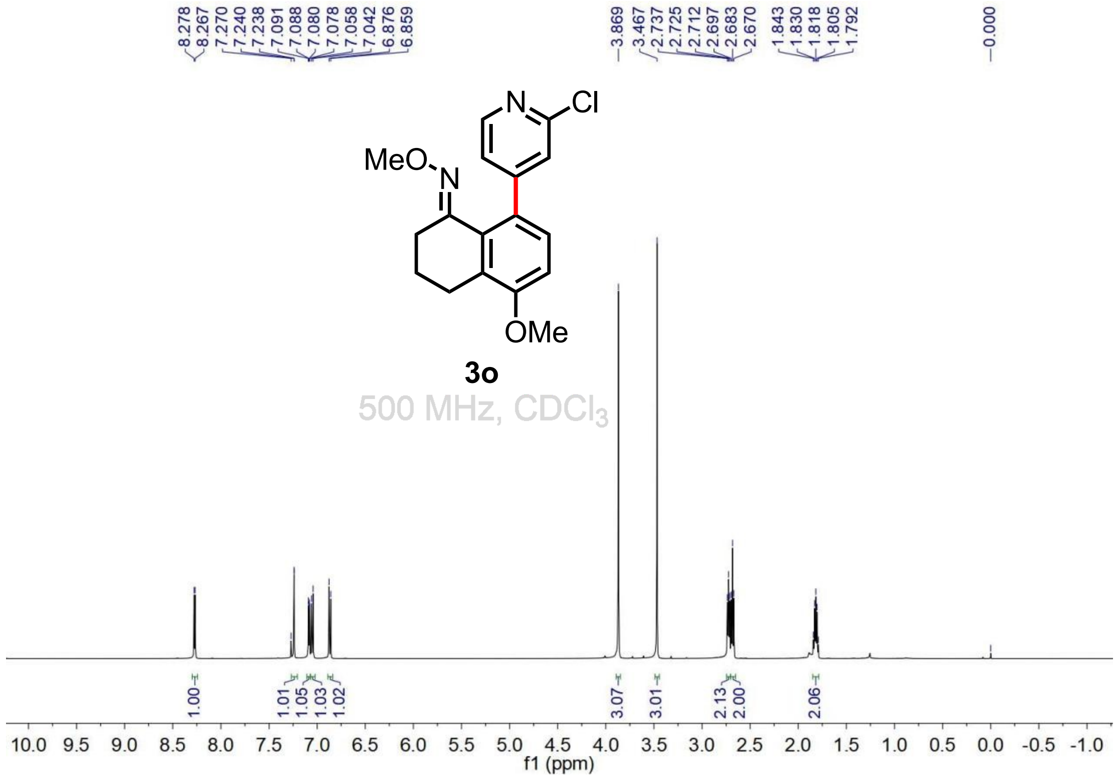
152.167
150.779
148.609
144.082
138.651
124.297
123.080
121.415
114.911
113.513
77.254
77.000
76.746
61.405
55.378
31.091
24.828
21.100
MeO
N
N
Cl
OMe
3n
125 MHz, CDCl3
200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
f1 (ppm)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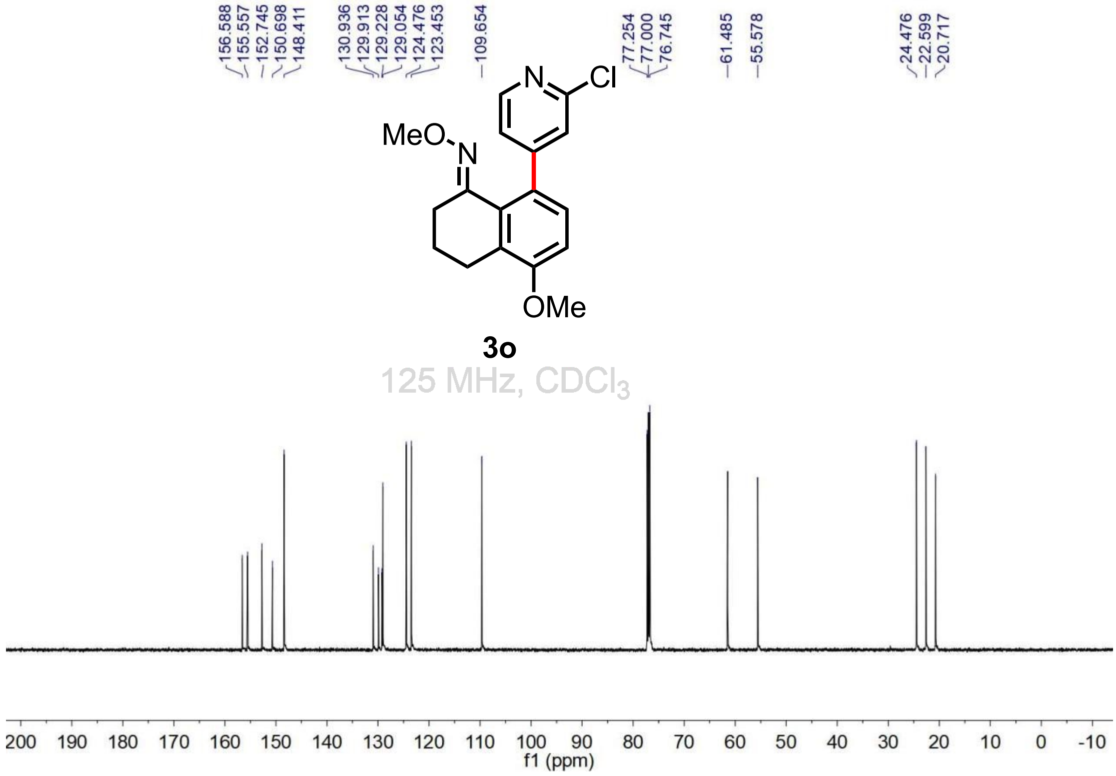
7.240
7.238
7.091
7.088
7.080
7.078
7.058
7.042
6.876
6.859
3.869
3.467
2.737
2.725
2.712
2.697
2.683
2.670
1.843
1.830
1.818
1.805
1.792
0.000
N
Cl
MeO
N
OMe
3o
500 MHz, CDCl3
1.00
1.01
1.05
1.03
1.02
3.07
3.01
2.13
2.00
2.06
10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5 -1.0
f1 (ppm)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129.228
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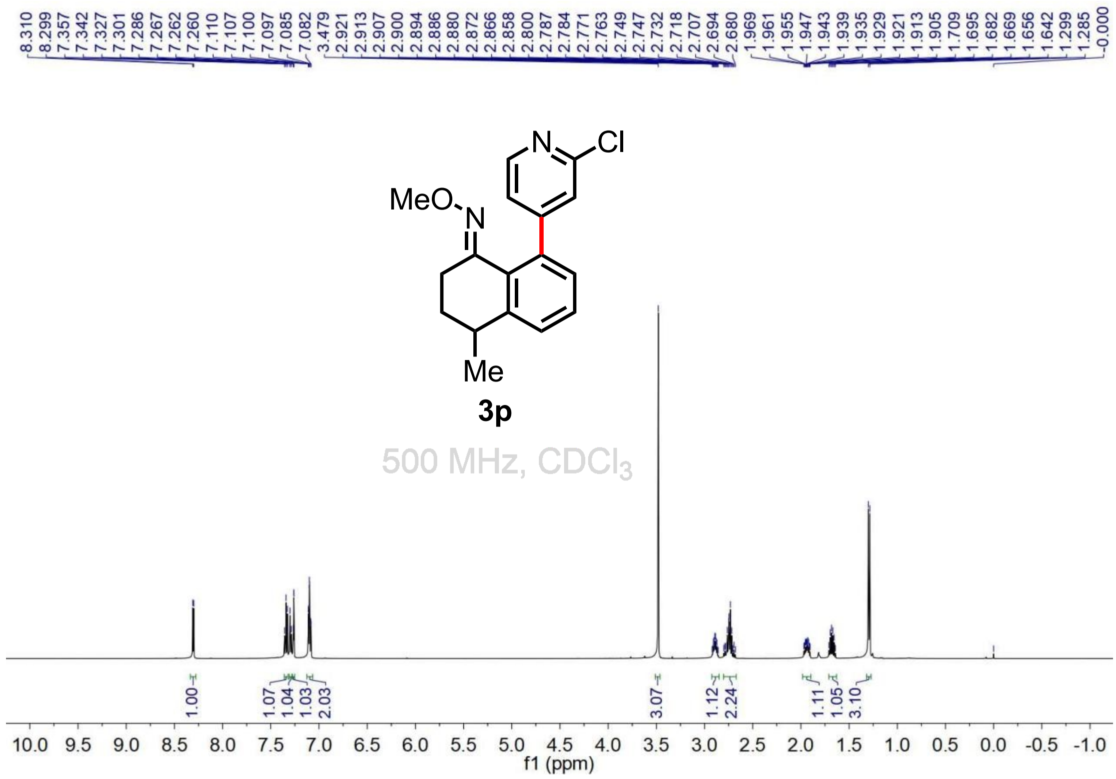
124.476
123.453
109.654
77.254
77.000
76.745
61.485
55.578
24.476
22.599
20.717
N
Cl
MeO
N
OMe
3o
125 MHz, CDCl3
200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
f1 (ppm)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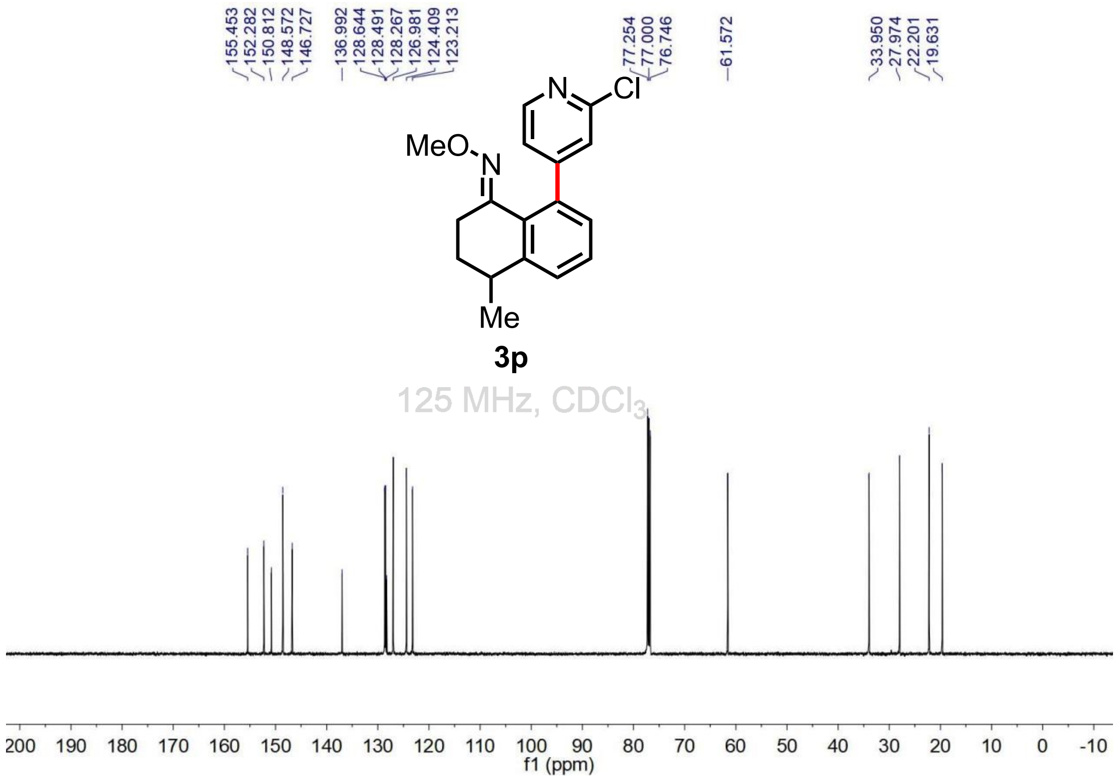
MeO
N
N
Cl
Me
3p
500 MHz, CDCl3
1.00
1.07
1.04
1.03
2.03
3.07
1.12
2.24
1.11
1.05
3.10
10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5 -1.0
f1 (ppm)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MeO
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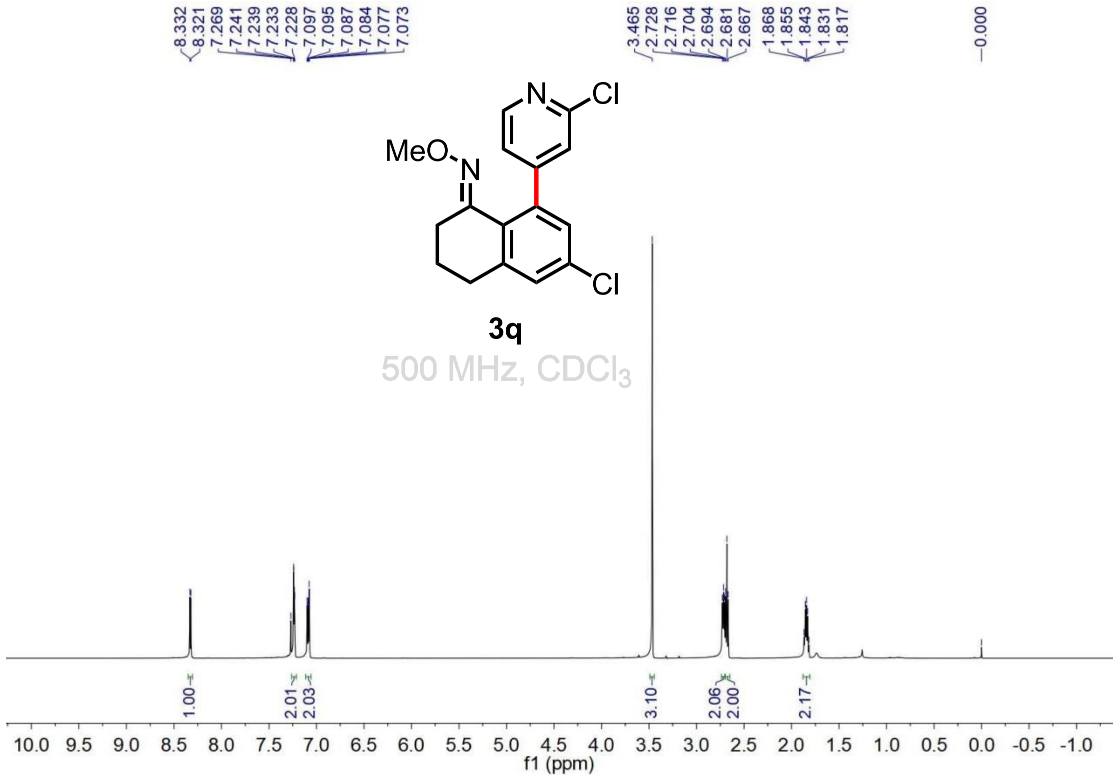
N
Cl
Me
3p
125 MHz, CDCl3
200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
f1 (ppm)


8.332
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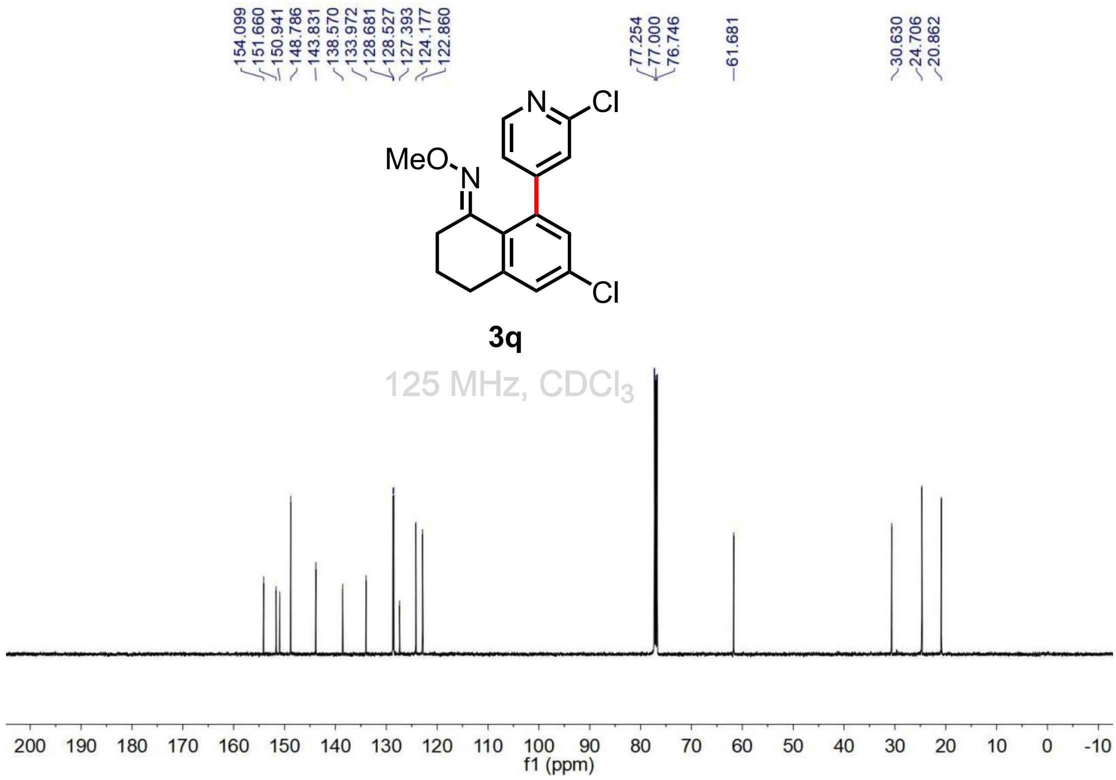
7.097
7.095
7.087
7.084
7.077
7.073
3.465
2.728
2.716
2.704
2.694
2.681
2.667
1.868
1.855
1.843
1.831
1.817
0.000
MeO
N
N
Cl
Cl
3q
500 MHz, CDCl3
1.00
2.01
2.03
3.10
2.06
2.00
2.17
10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5 -1.0
f1 (ppm)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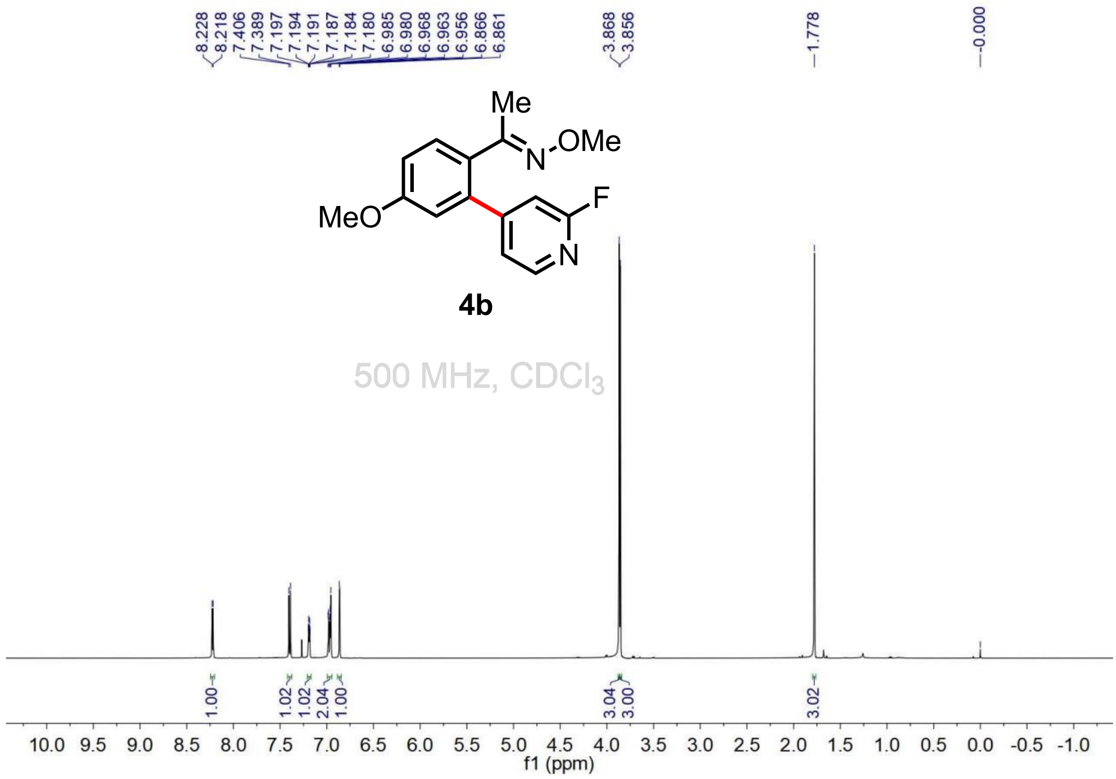
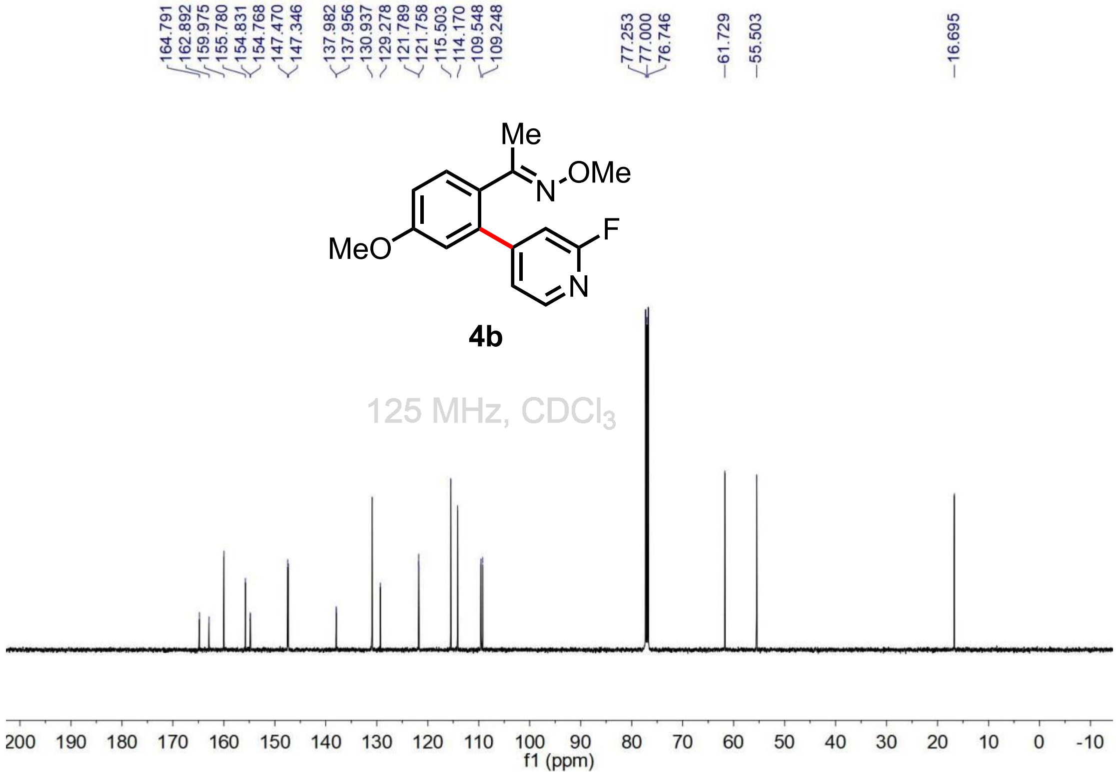
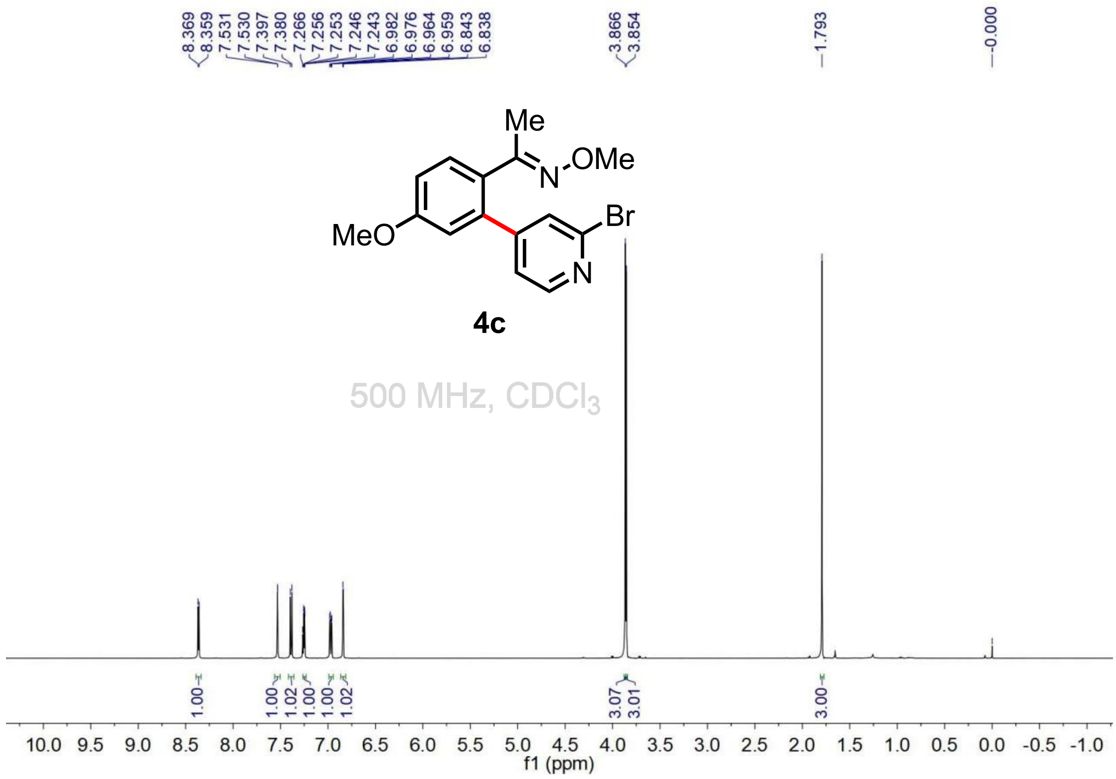
143.831
138.570
133.972
128.681
128.527
127.393
124.177
122.860
77.254
77.000
76.746
61.681
30.630
24.706
20.862
MeO
N
N
Cl
Cl
3q
125 MHz, CDCl3
200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
f1 (ppm)

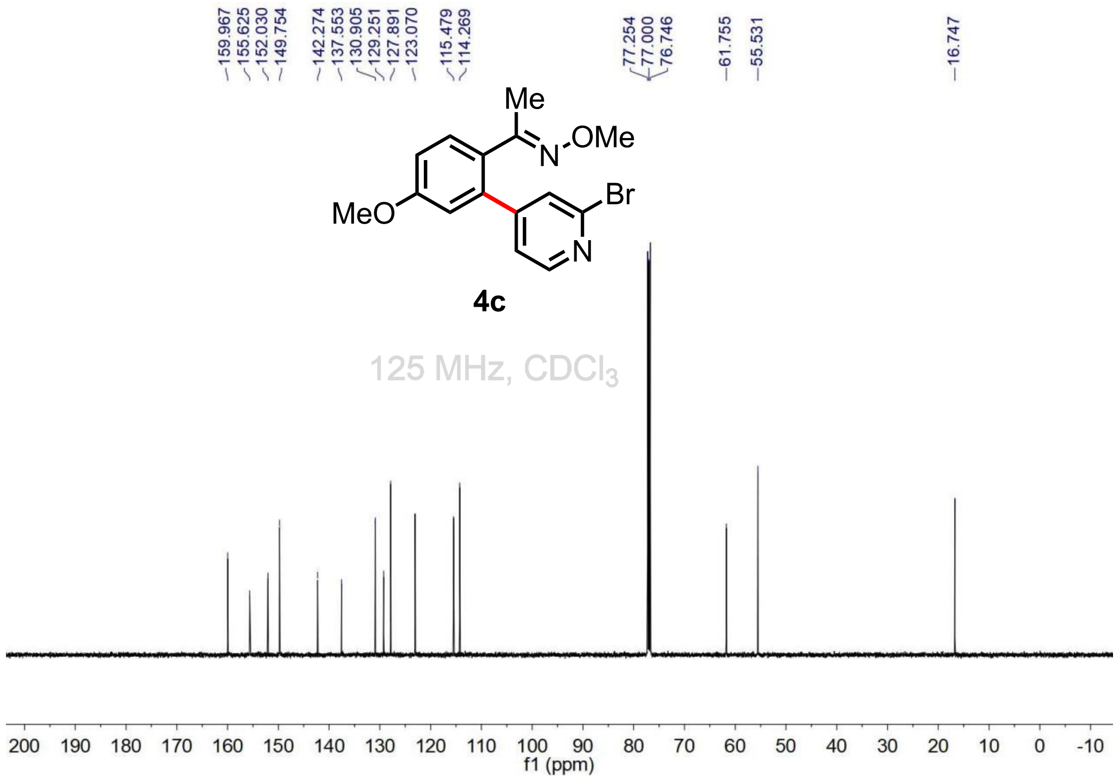


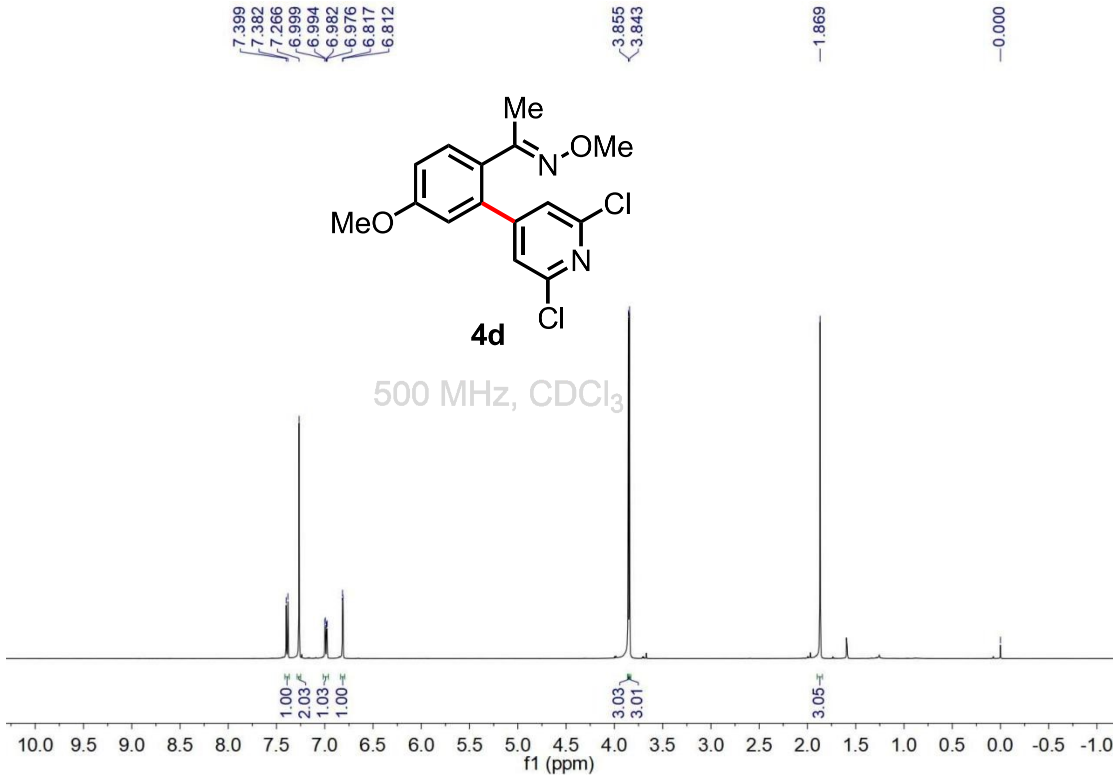
8.228
8.218
7.406
7.389
7.197
7.194
7.191
7.187
7.184
7.180
6.985
6.980
6.968
6.963
6.956
6.866
6.861
3.868
3.856
1.778
0.000
Me
OMe
N
MeO
F
N
4b
500 MHz, CDCl3
1.00
1.02
1.02
2.04
1.00
3.04
3.00
3.02
10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5 -1.0
f1 (ppm)



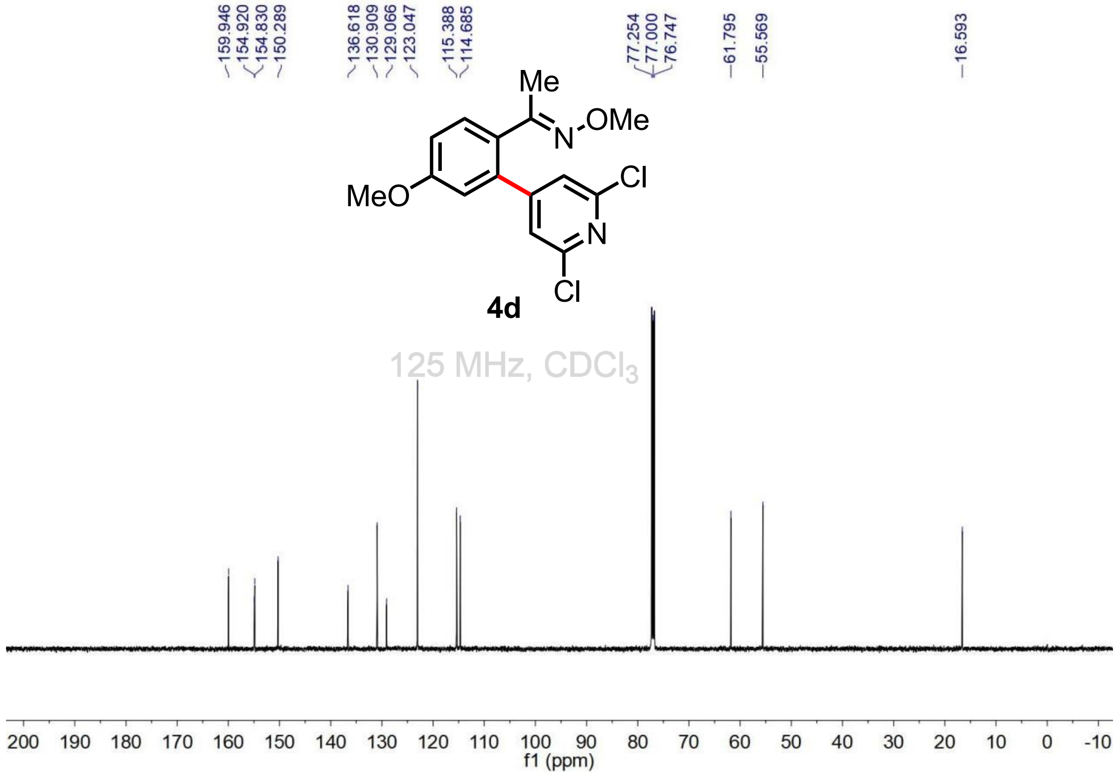
164.791
162.892
159.975
155.780
154.831
154.768
147.470
147.346
137.982
137.956
130.937
129.278
121.789
121.758
115.503
114.170
109.548
109.248
77.253
77.000
76.746
61.729
55.503
16.695
Me
OMe
N
MeO
F
N
4b
125 MHz, CDCl3
200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
f1 (ppm)


8.369
8.359
7.531
7.530
7.397
7.380
7.266
7.256
7.253
7.246
7.243
6.982
6.976
6.964
6.959
6.843
6.838
3.866
3.854
1.793
0.000
Me
N
OMe
MeO
Br
N
4c
500 MHz, CDCl3
1.00
1.00
1.02
1.00
1.00
1.02
3.07
3.01
3.00
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)

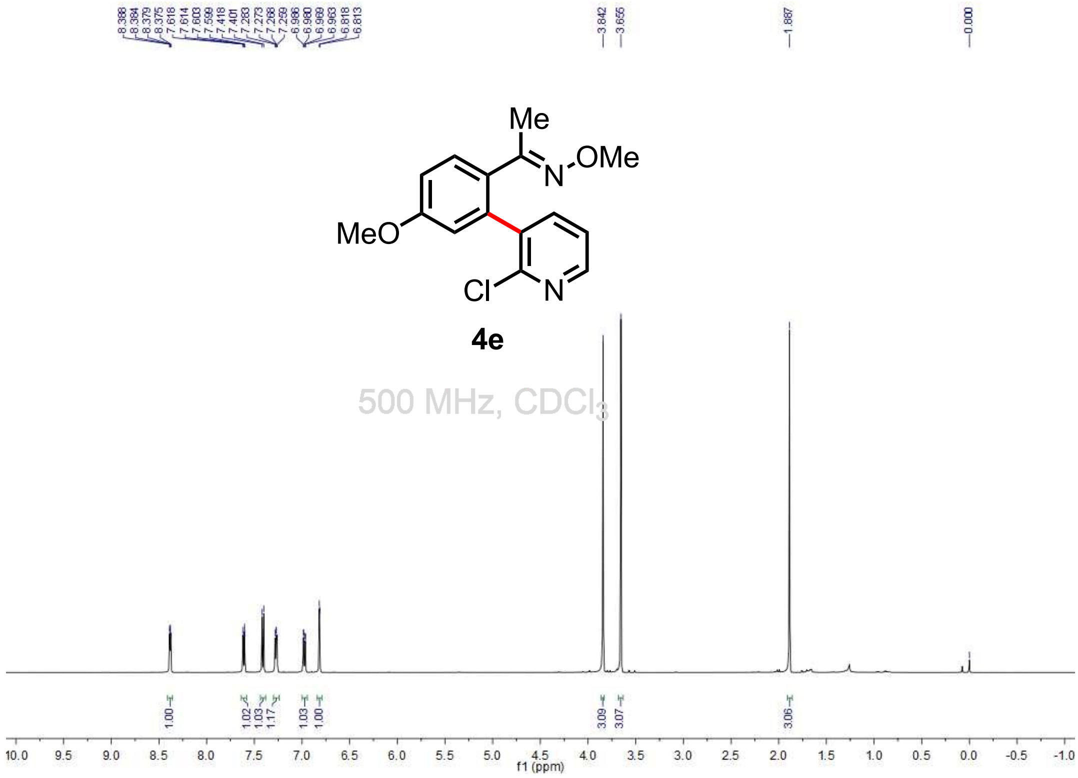

159.967
155.625
152.030
149.754
142.274
137.553
130.905
129.251
127.891
123.070
115.479
114.269
77.254
77.000
76.746
61.755
55.531
16.747
Me
N
OMe
MeO
Br
N
4c
125 MHz, CDCl3
200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
f1 (ppm)

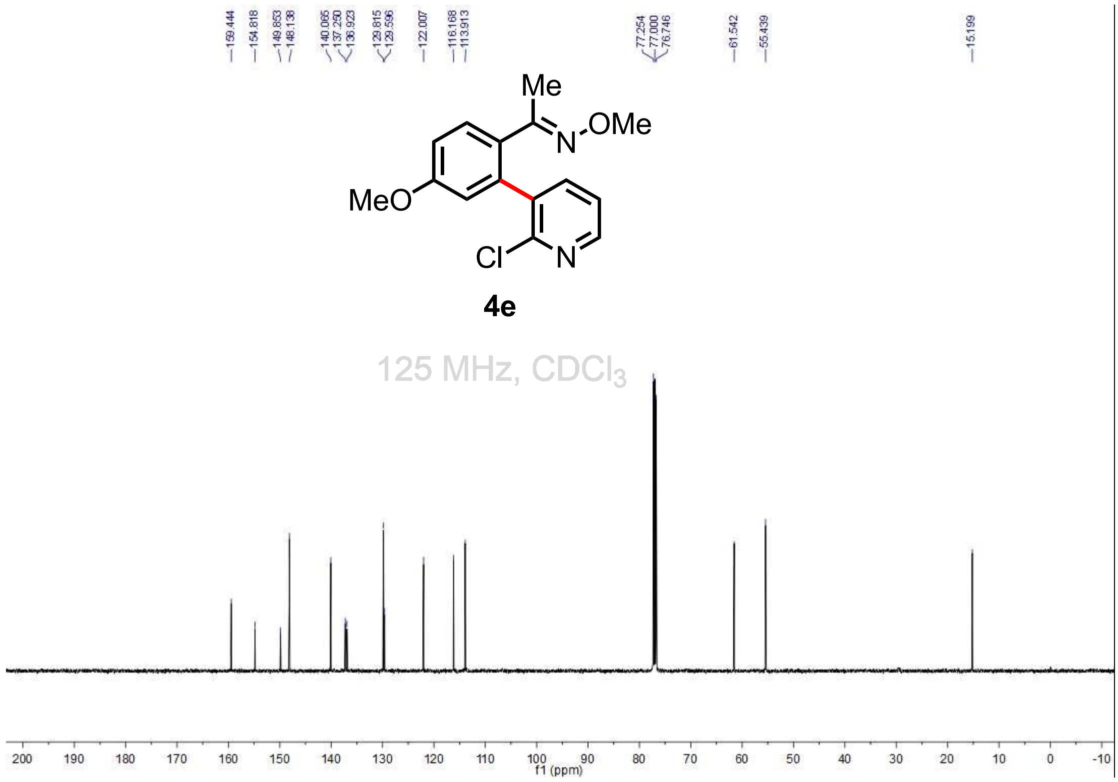


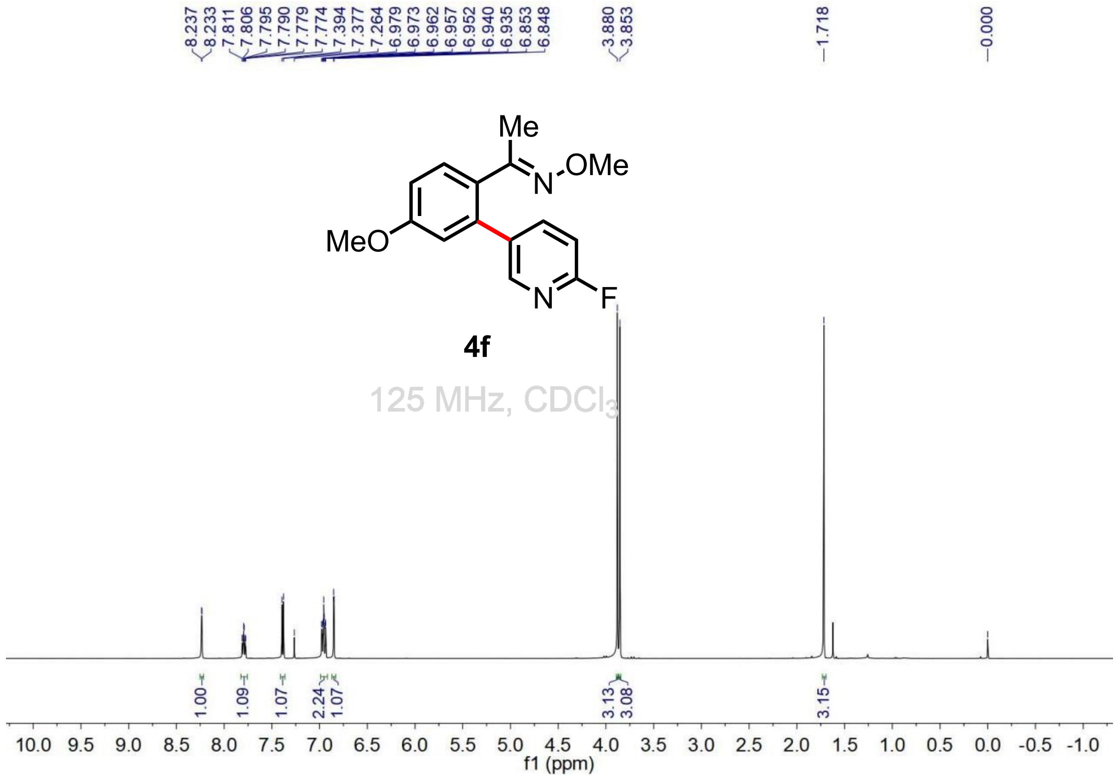
7.399
7.382
7.266
6.999
6.994
6.982
6.976
6.817
6.812
3.855
3.843
1.869
0.000
Me
OMe
N
MeO
Cl
N
Cl
4d
500 MHz, CDCl3
1.00
2.03
1.03
1.00
3.03
3.01
3.05
10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5 -1.0
f1 (ppm)

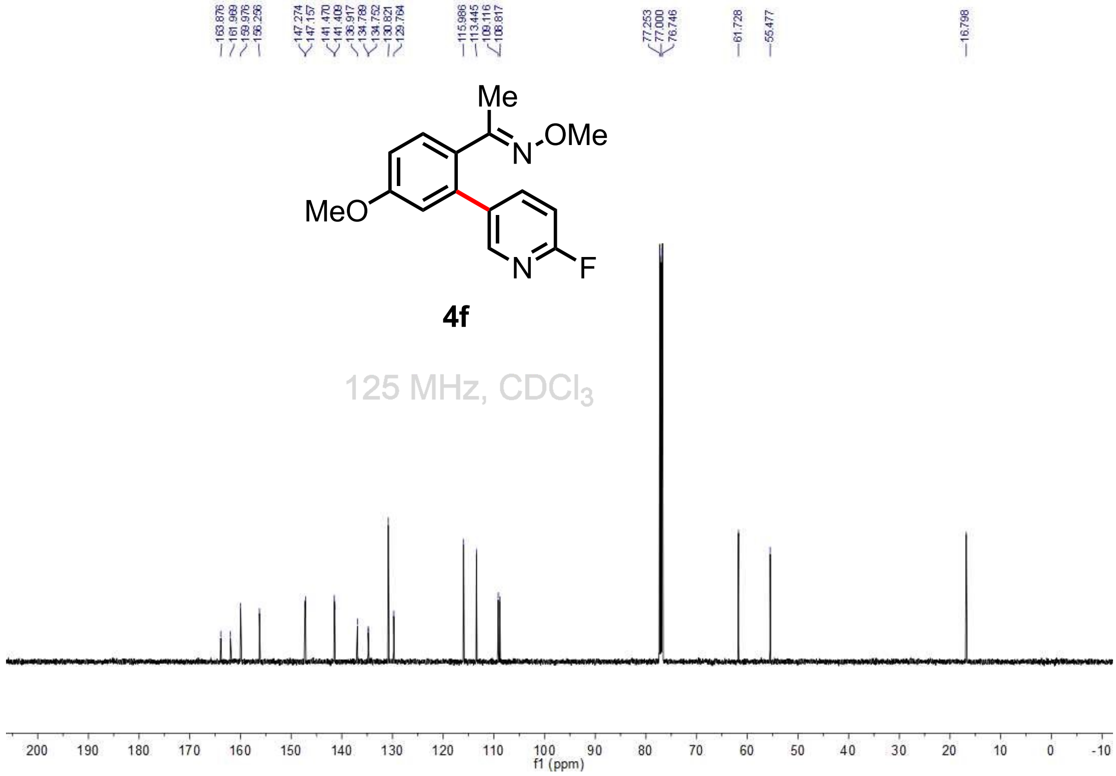


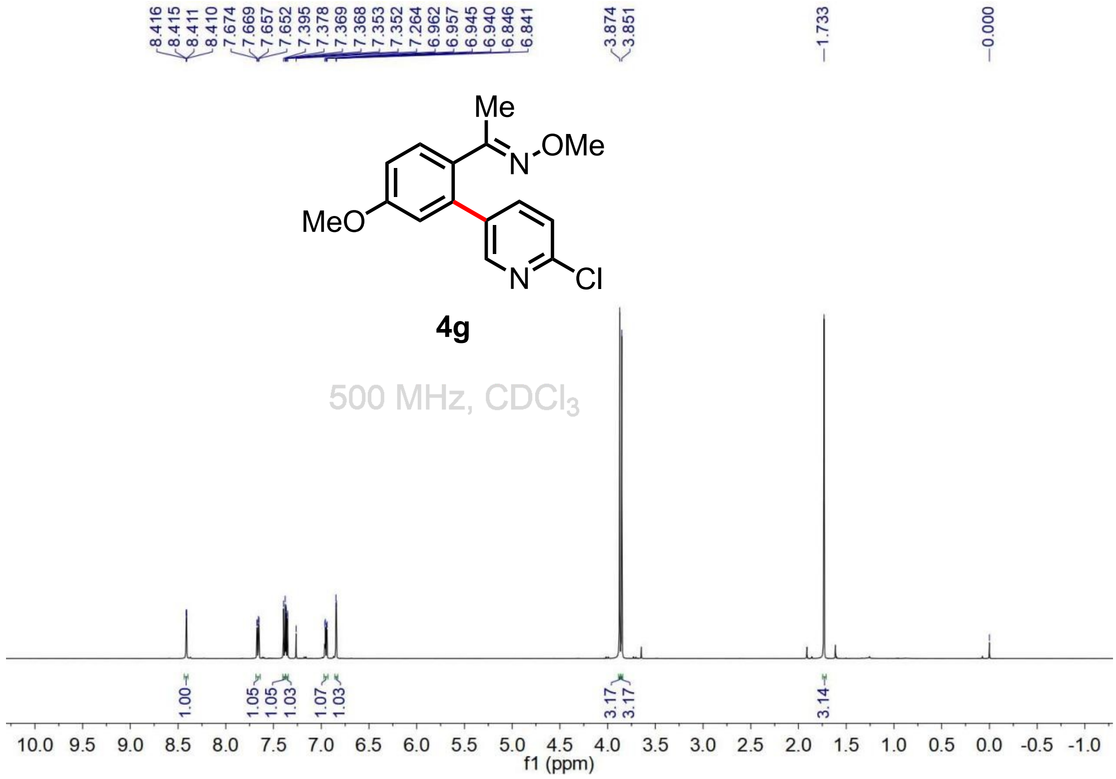
159.946
154.920
154.830
150.289
136.618
130.909
129.066
123.047
115.388
114.685
77.254
77.000
76.747
61.795
55.569
16.593
Me
OMe
N
MeO
Cl
N
Cl
4d
125 MHz, CDCl3
200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
f1 (ppm)

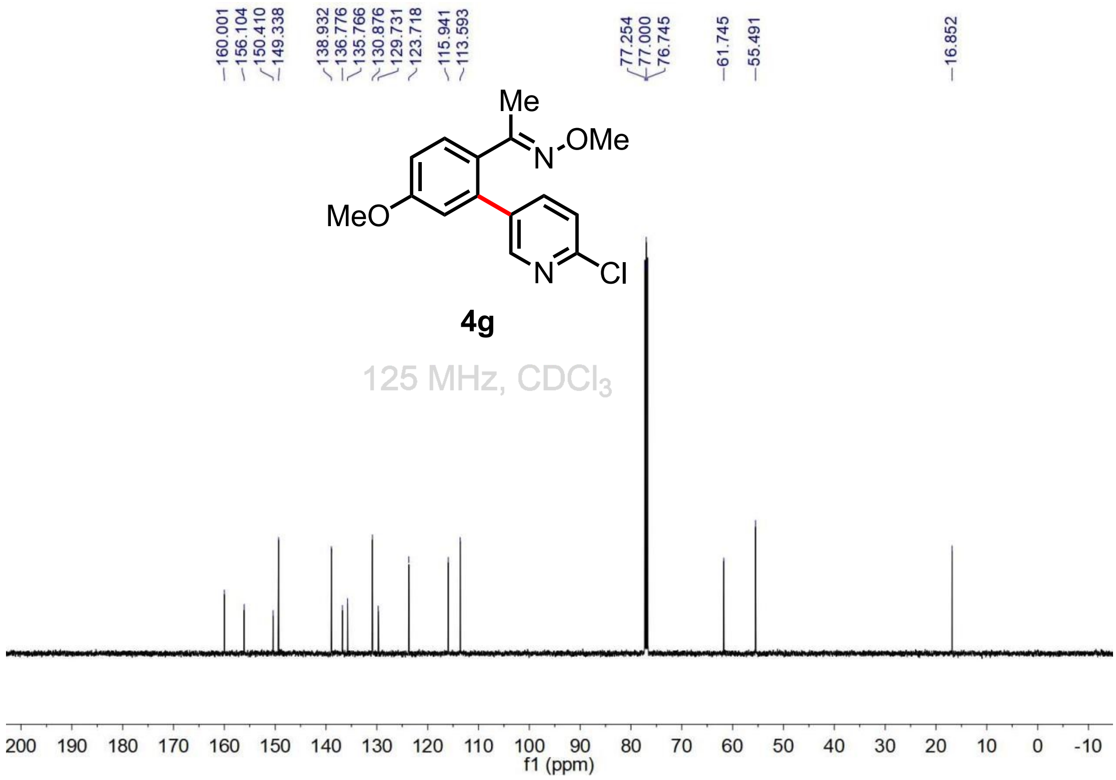

Me
N
OMe
MeO
Cl
N
4e
500 MHz, CDCl3
f1 (ppm)

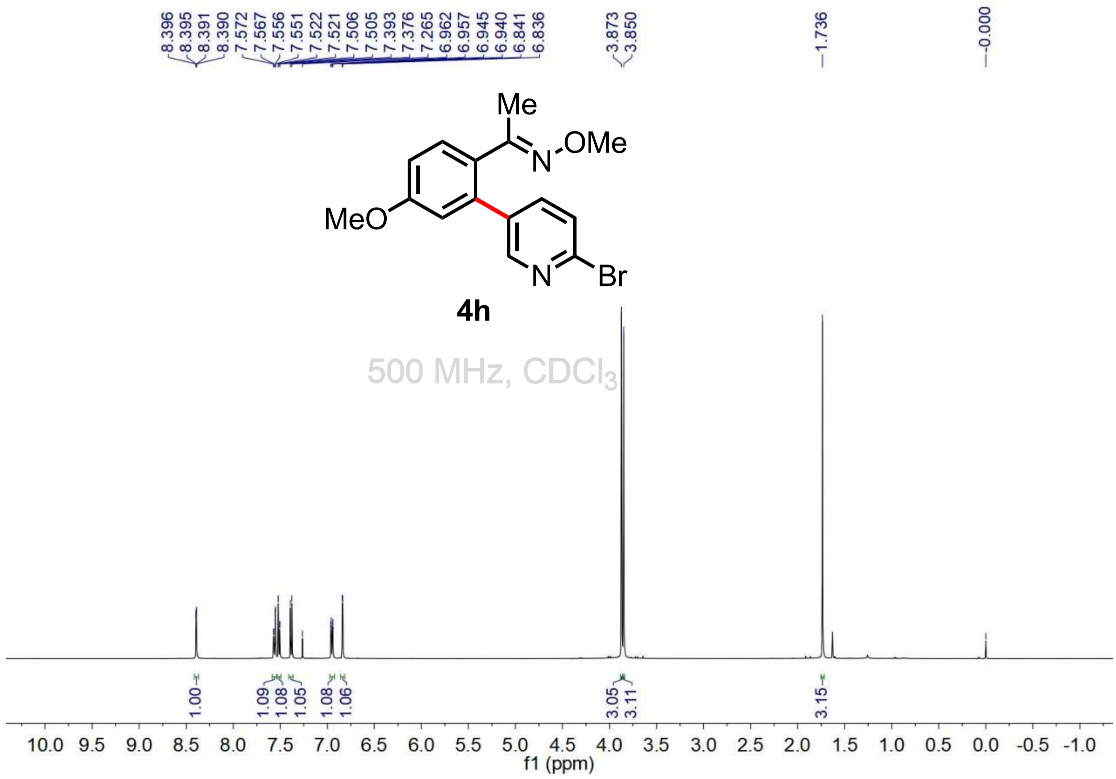

Me
N
OMe
MeO
Cl
N
4e
125 MHz, CDCl3
f1 (ppm)


8.237
8.233
7.811
7.806
7.795
7.790
7.779
7.774
7.394
7.377
7.264
6.979
6.973
6.962
6.957
6.952
6.940
6.935
6.853
6.848
3.880
3.853
1.718
0.000
Me
N
OMe
MeO
N
F
4f
125 MHz, CDCl3
1.00
1.09
1.07
2.24
1.07
3.13
3.08
3.15
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)

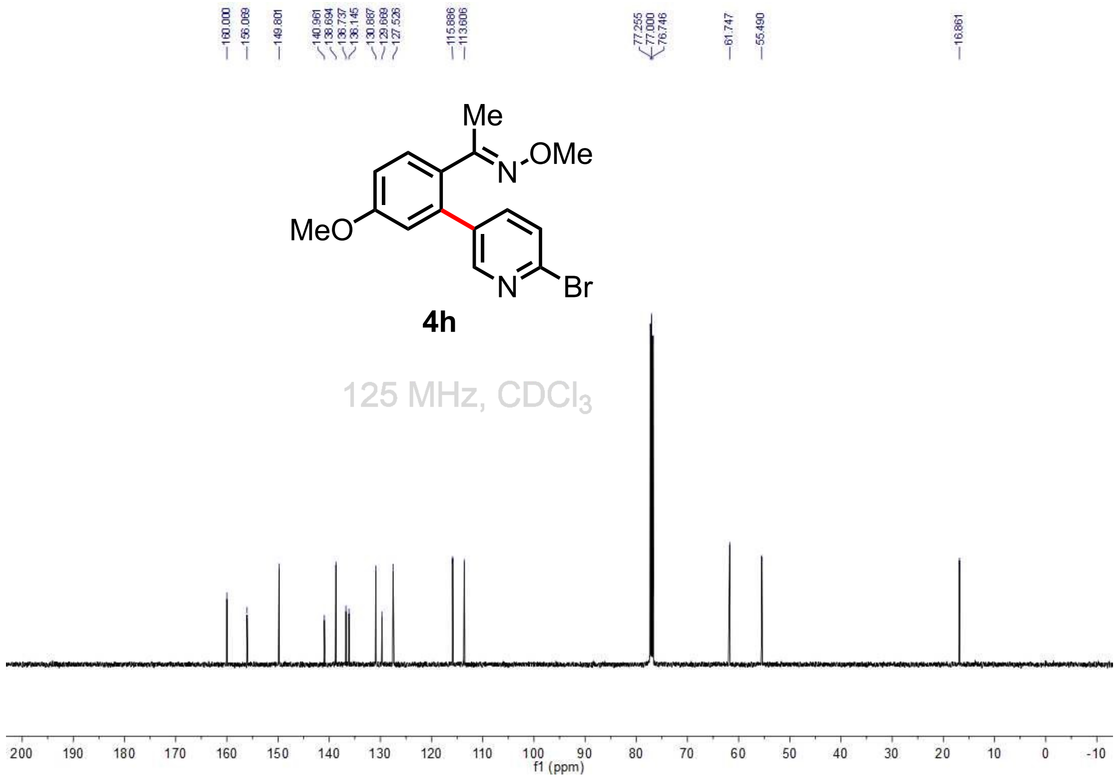

163.876
161.969
159.976
156.256
147.274
147.157
141.470
141.409
136.917
134.789
134.752
130.821
129.764
115.986
113.445
109.116
108.817
77.253
77.000
76.746
61.728
55.477
16.798
Me
N
OMe
MeO
N
F
4f
125 MHz, CDCl3
200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
f1 (ppm)


8.416
8.415
8.411
8.410
7.674
7.669
7.657
7.652
7.395
7.378
7.369
7.368
7.353
7.352
7.264
6.962
6.957
6.945
6.940
6.846
6.841
3.874
3.851
1.733
0.000
Me
OMe
N
MeO
N
Cl
4g
500 MHz, CDCl3
1.00
1.05
1.05
1.03
1.07
1.03
3.17
3.17
3.14
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)

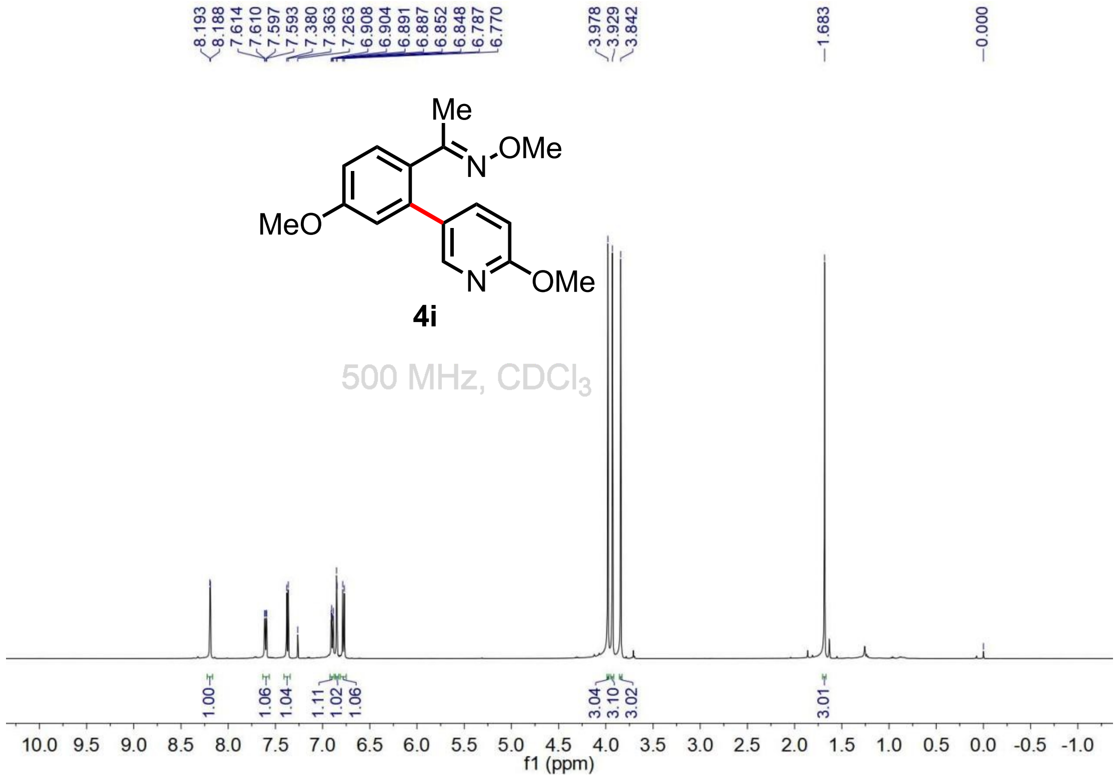

160.001
156.104
150.410
149.338
138.932
136.776
135.766
130.876
129.731
123.718
115.941
113.593
77.254
77.000
76.745
61.745
55.491
16.852
Me
OMe
N
MeO
N
Cl
4g
125 MHz, CDCl3
200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
f1 (ppm)

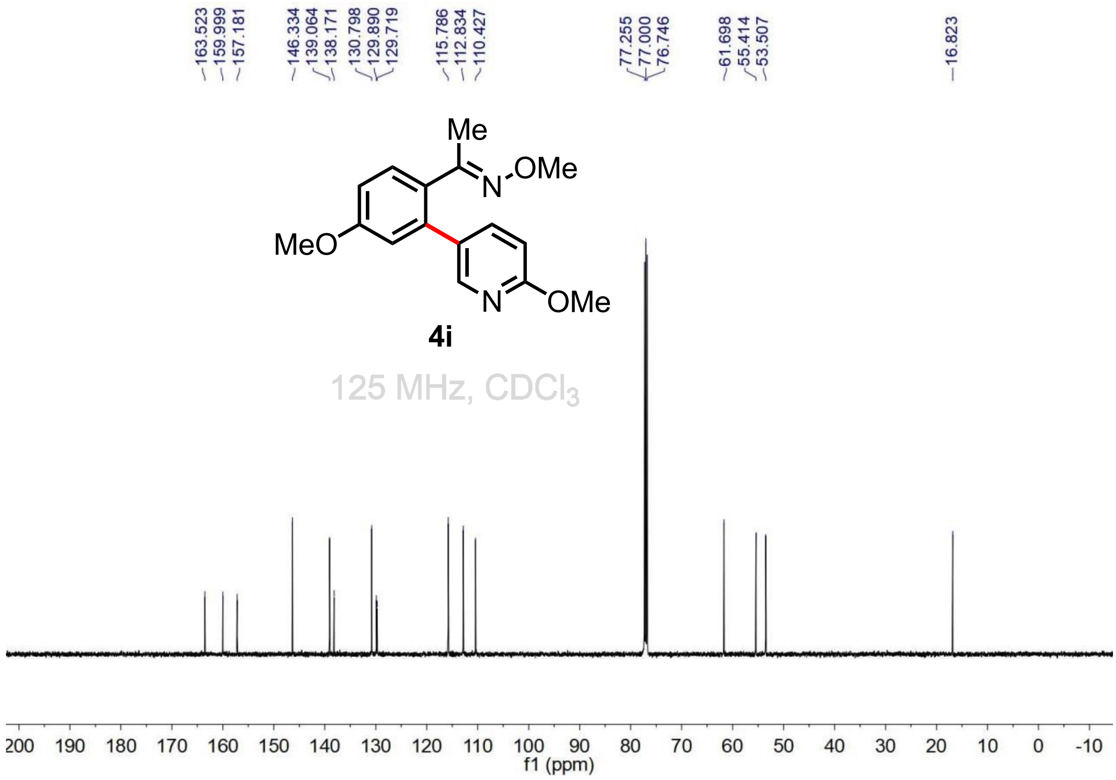


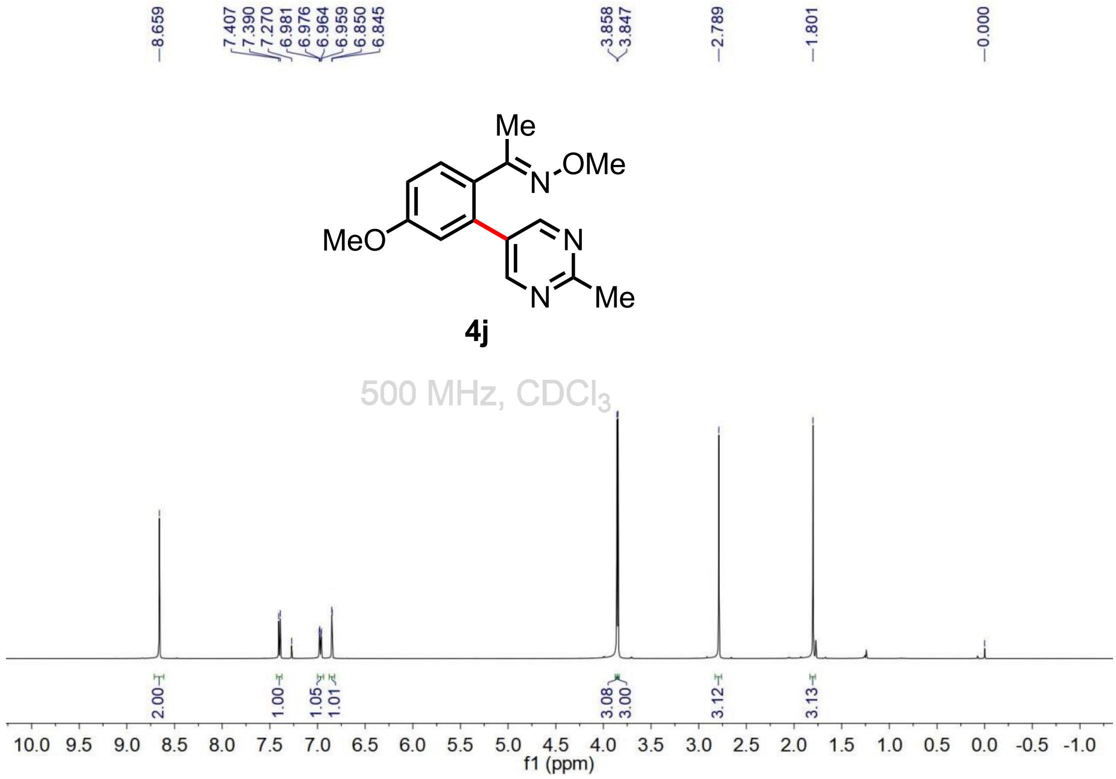
8.396 8.395 8.391 8.390 7.572 7.567 7.556 7.551 7.522 7.521 7.506 7.505 7.393 7.376 7.265 6.962 6.957 6.945 6.940 6.841 6.836
3.873 3.850
1.736
0.000
Me
OMe
N
MeO
N
Br
4h
500 MHz, CDCl3
1.00
1.09 1.08 1.05
1.08 1.06
3.05 3.11
3.15
10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5 -1.0
f1 (ppm)

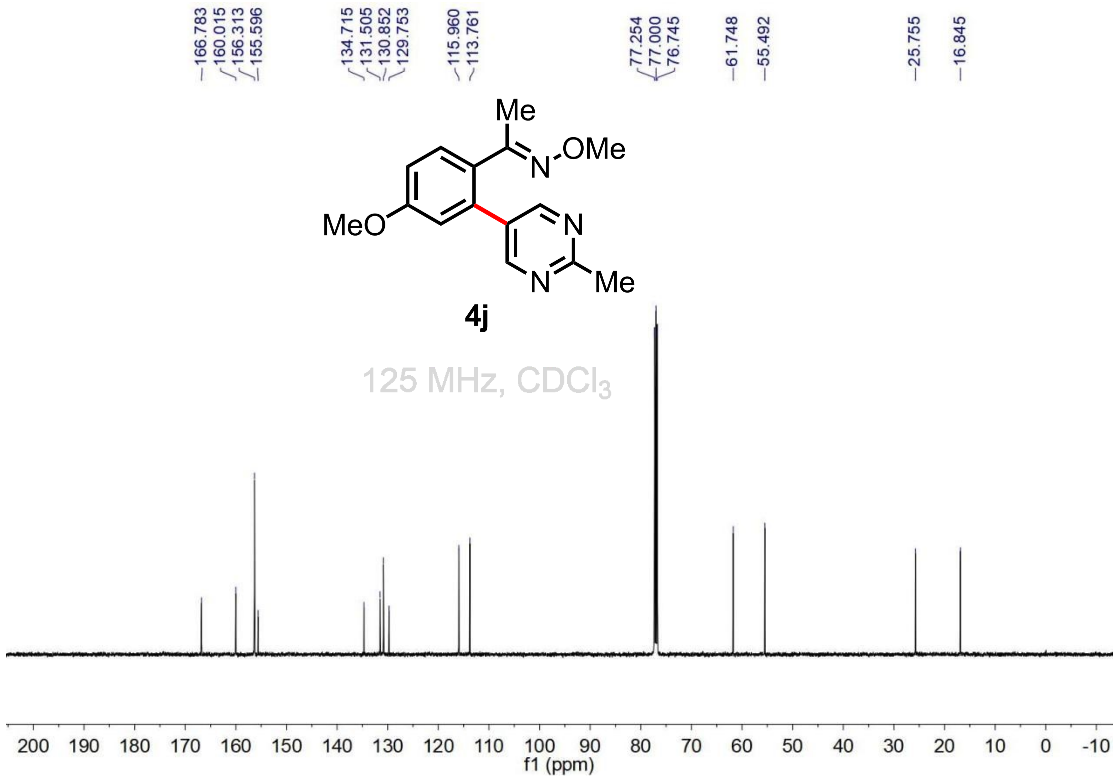


160.000 156.089 149.801 140.961 138.694 136.737 136.145 130.887 129.669 127.526 115.886 113.606 77.255 77.000 76.746 61.747 55.490 16.861
Me
OMe
N
MeO
N
Br
4h
125 MHz, CDCl3
200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
f1 (ppm)


8.193
8.188
7.614
7.610
7.597
7.593
7.380
7.363
7.263
6.908
6.904
6.891
6.887
6.852
6.848
6.787
6.770
3.978
3.929
3.842
1.683
0.000
Me
N
OMe
MeO
N
OMe
4i
500 MHz, CDCl3
1.00
1.06
1.04
1.11
1.02
1.06
3.04
3.10
3.02
3.01
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)


163.523
159.999
157.181
146.334
139.064
138.171
130.798
129.890
129.719
115.786
112.834
110.427
77.255
77.000
76.746
61.698
55.414
53.507
16.823
Me
N
OMe
MeO
N
OMe
4i
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)


8.659
7.407
7.390
7.270
6.981
6.976
6.964
6.959
6.850
6.845
3.858
3.847
2.789
1.801
0.000
Me
OMe
N
MeO
N
N
Me
4j
500 MHz, CDCl3
2.00
1.00
1.05
1.01
3.08
3.00
3.12
3.13
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)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155.596
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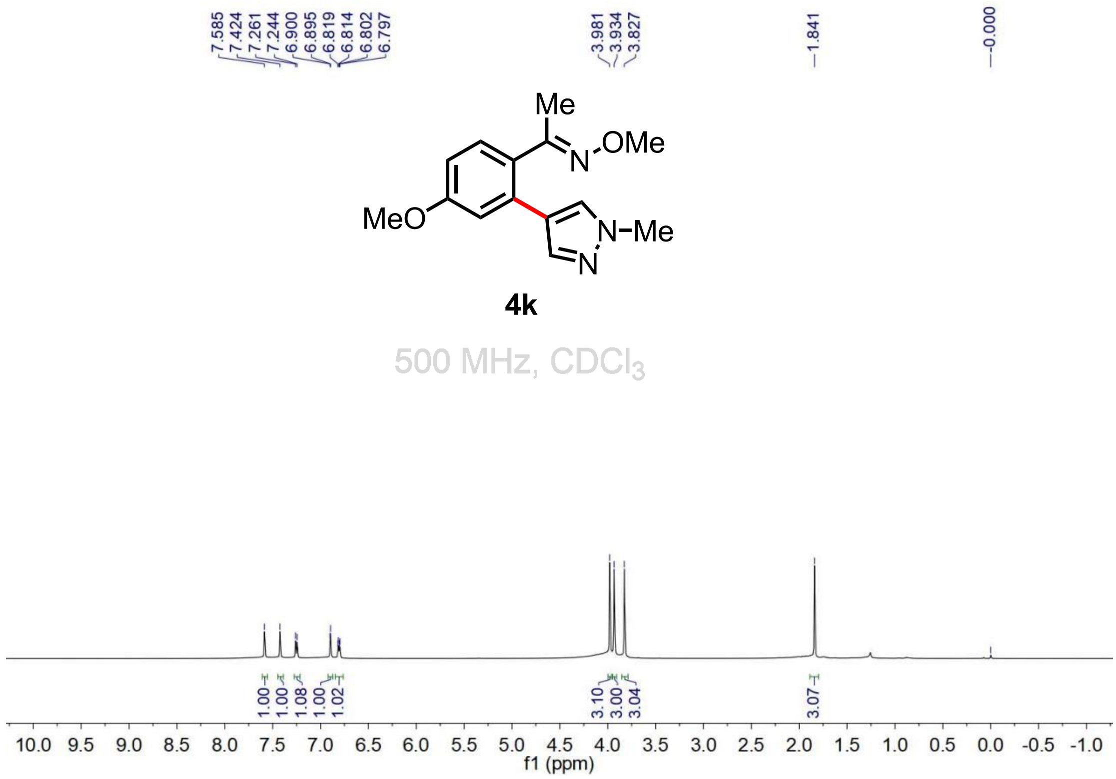
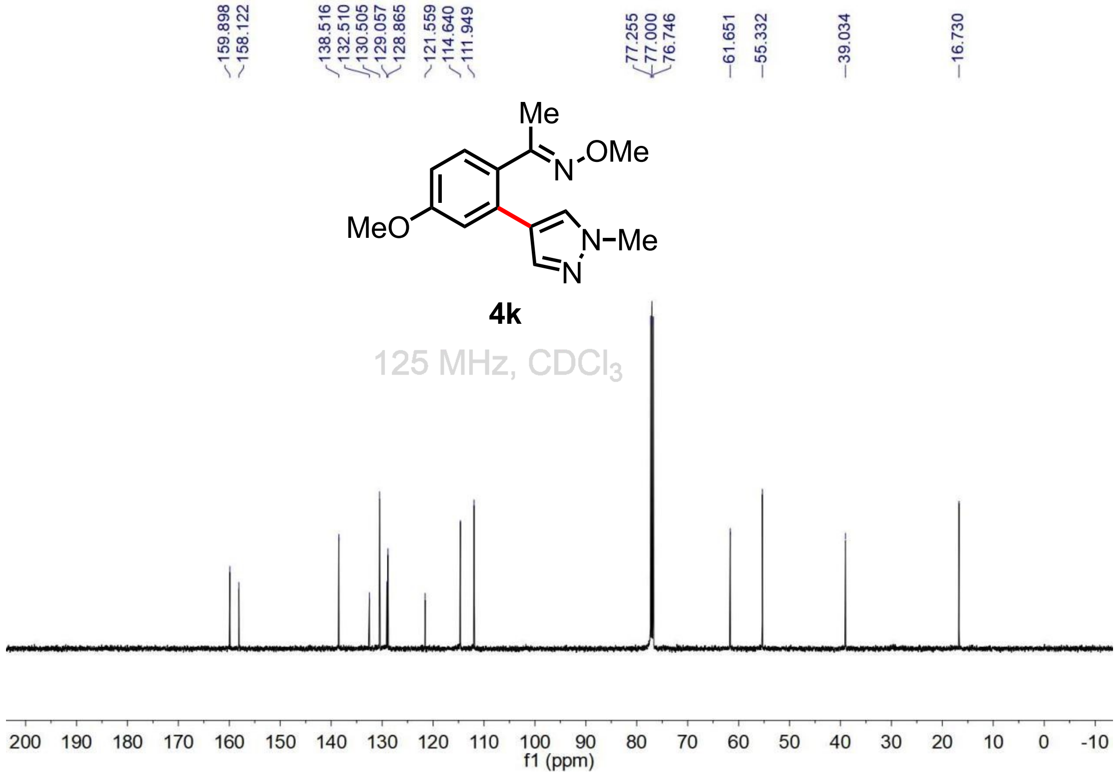
131.505
130.852
129.753
115.960
113.761
77.254
77.000
76.745
61.748
55.492
25.755
16.845
Me
OMe
N
MeO
N
N
Me
4j
125 MHz, CDCl3
200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
f1 (ppm)


7.585
7.424
7.261
7.244
6.900
6.895
6.819
6.814
6.802
6.797
3.981
3.934
3.827
1.841
-0.000
Me
OMe
N
MeO
N-Me
N
4k
500 MHz, CDCl3
1.00
1.00
1.08
1.00
1.02
3.10
3.00
3.04
3.07
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)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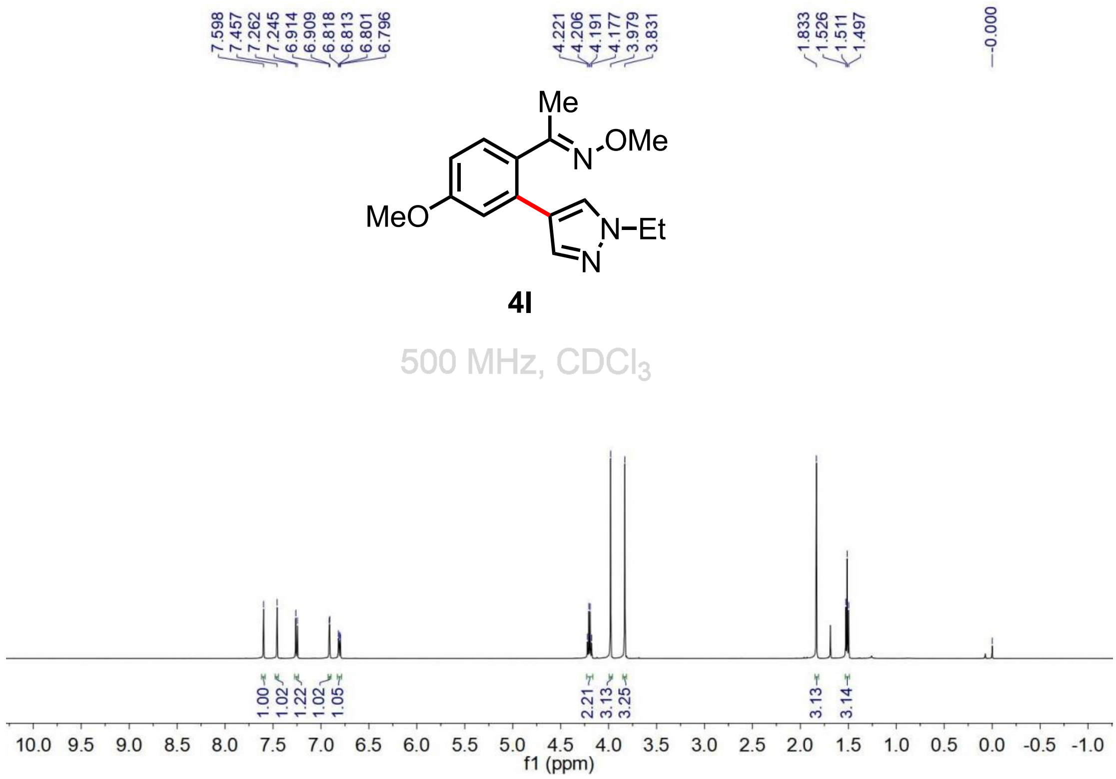
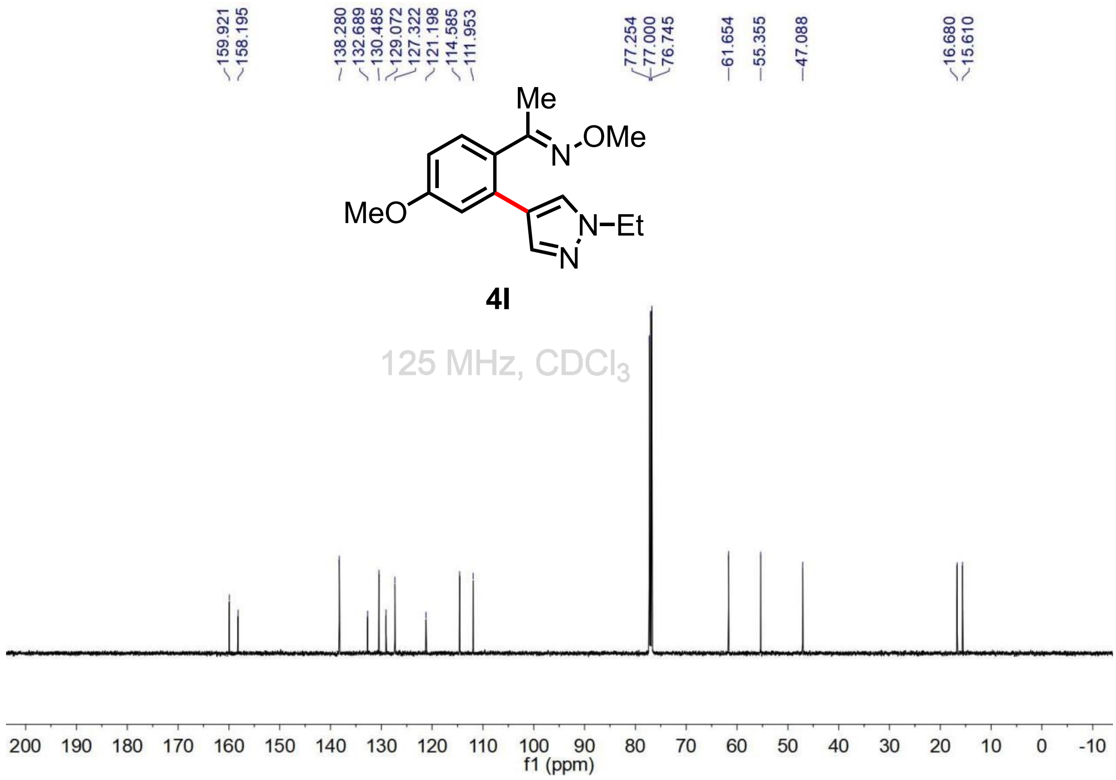
138.516
132.510
130.505
129.057
128.865
121.559
114.640
111.949
77.255
77.000
76.746
61.651
55.332
39.034
16.730
Me
OMe
N
MeO
N-Me
N
4k
125 MHz, CDCl3
200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
f1 (ppm)


7.598
7.457
7.262
7.245
6.914
6.909
6.818
6.813
6.801
6.796
4.221
4.206
4.191
4.177
3.979
3.831
1.833
1.526
1.511
1.497
-0.000
Me
OMe
N
MeO
N-Et
N
4l
500 MHz, CDCl3
1.00
1.02
1.22
1.02
1.05
2.21
3.13
3.25
3.13
3.14
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)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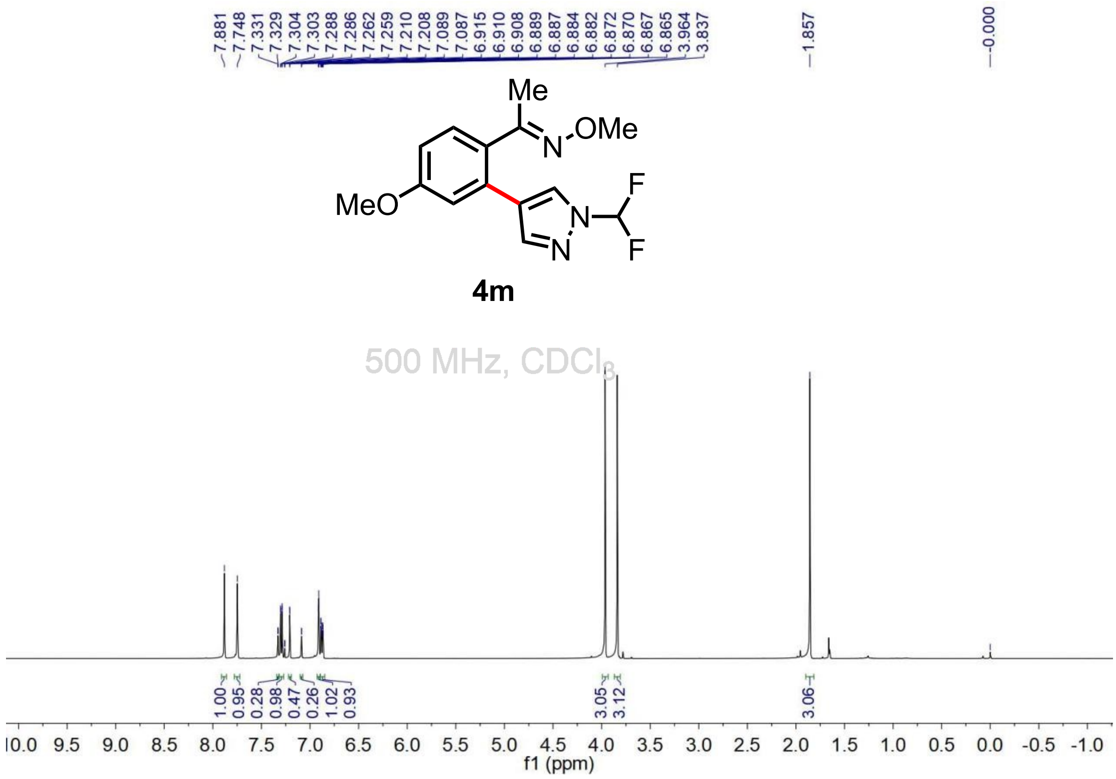
129.072
127.322
121.198
114.585
111.953
77.254
77.000
76.745
61.654
55.355
47.088
16.680
15.610
Me
OMe
N
MeO
N-Et
N
4l
125 MHz, CDCl3
200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
f1 (ppm)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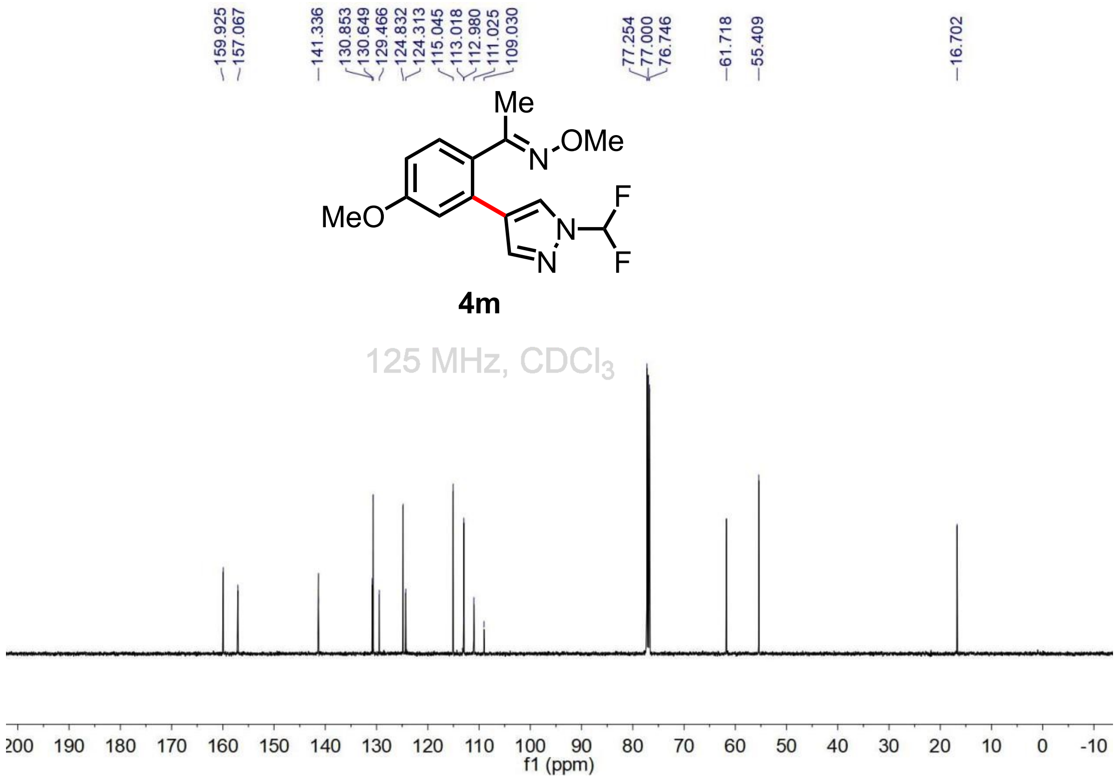
7.329
7.304
7.303
7.288
7.286
7.262
7.259
7.210
7.208
7.089
7.087
6.915
6.910
6.908
6.889
6.887
6.884
6.882
6.872
6.870
6.867
6.865
3.964
3.837
1.857
0.000
Me
N
OMe
MeO
N
N
F
F
4m
500 MHz, CDCl3
1.00
0.95
0.28
0.98
0.47
0.26
1.02
0.93
3.05
3.12
3.06
f1 (ppm)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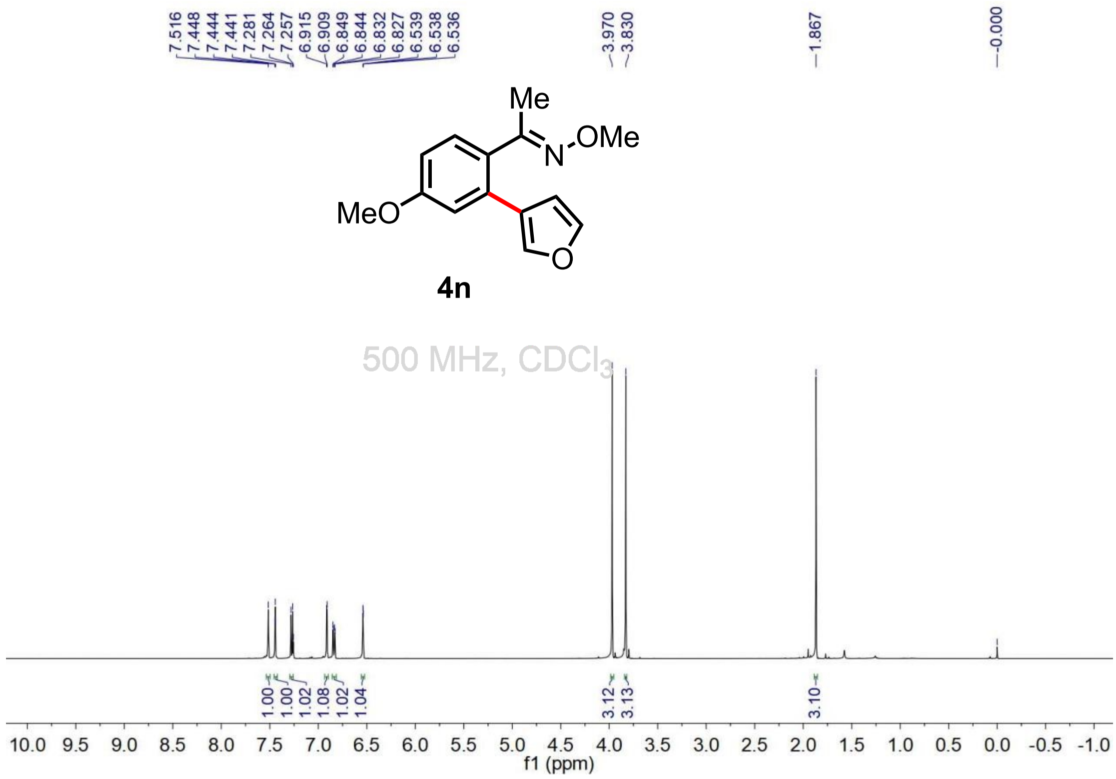
157.067
141.336
130.853
130.649
129.466
124.832
124.313
115.045
113.018
112.980
111.025
109.030
77.254
77.000
76.746
61.718
55.409
16.702
Me
N
OMe
MeO
N
N
F
F
4m
125 MHz, CDCl3
f1 (ppm)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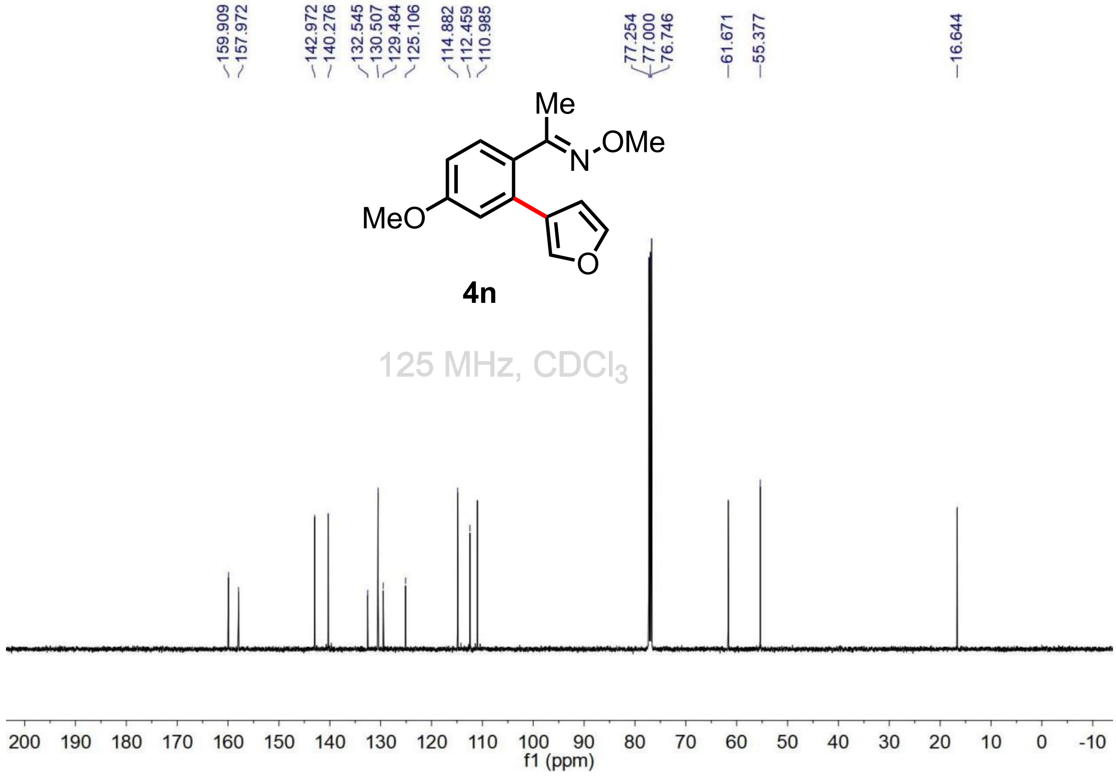
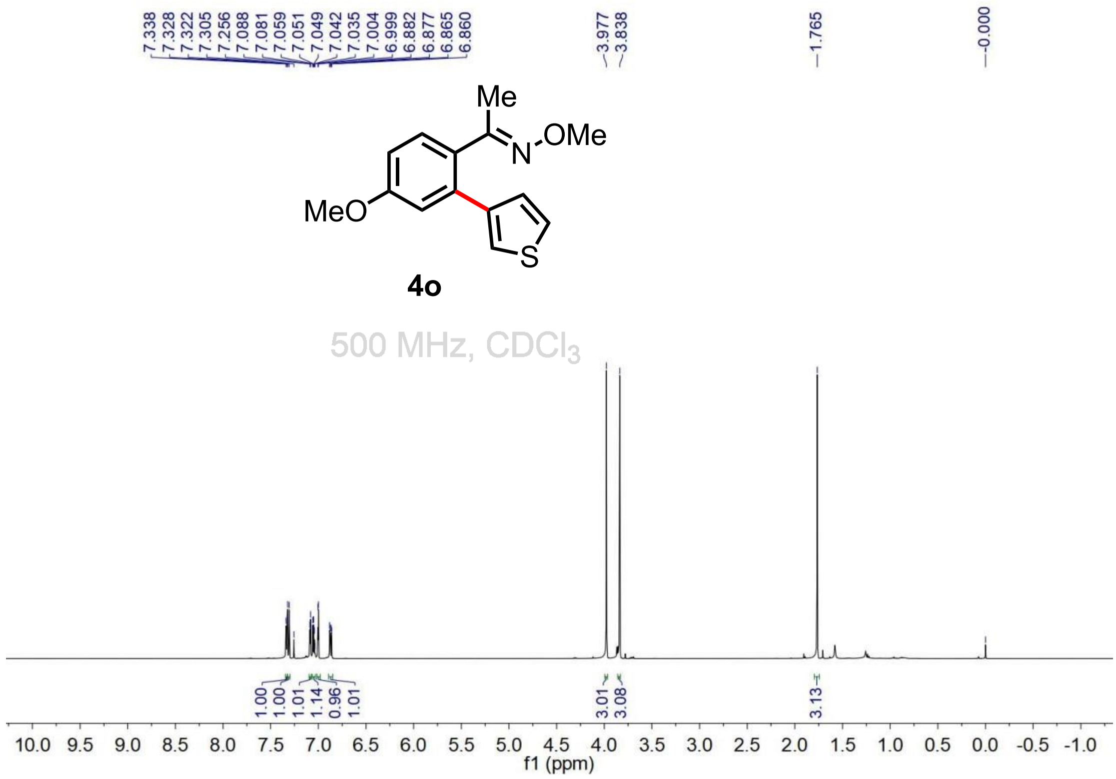
7.441
7.281
7.264
7.257
6.915
6.909
6.849
6.844
6.832
6.827
6.539
6.538
6.536
3.970
3.830
1.867
-0.000
Me
N
OMe
MeO
O
4n
500 MHz, CDCl3
1.00
1.00
1.02
1.08
1.02
1.04
3.12
3.13
3.10
10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5 -1.0
f1 (ppm)


159.909
157.972
142.972
140.276
132.545
130.507
129.484
125.106
114.882
112.459
110.985
77.254
77.000
76.746
61.671
55.377
16.644
Me
N
OMe
MeO
O
4n
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)



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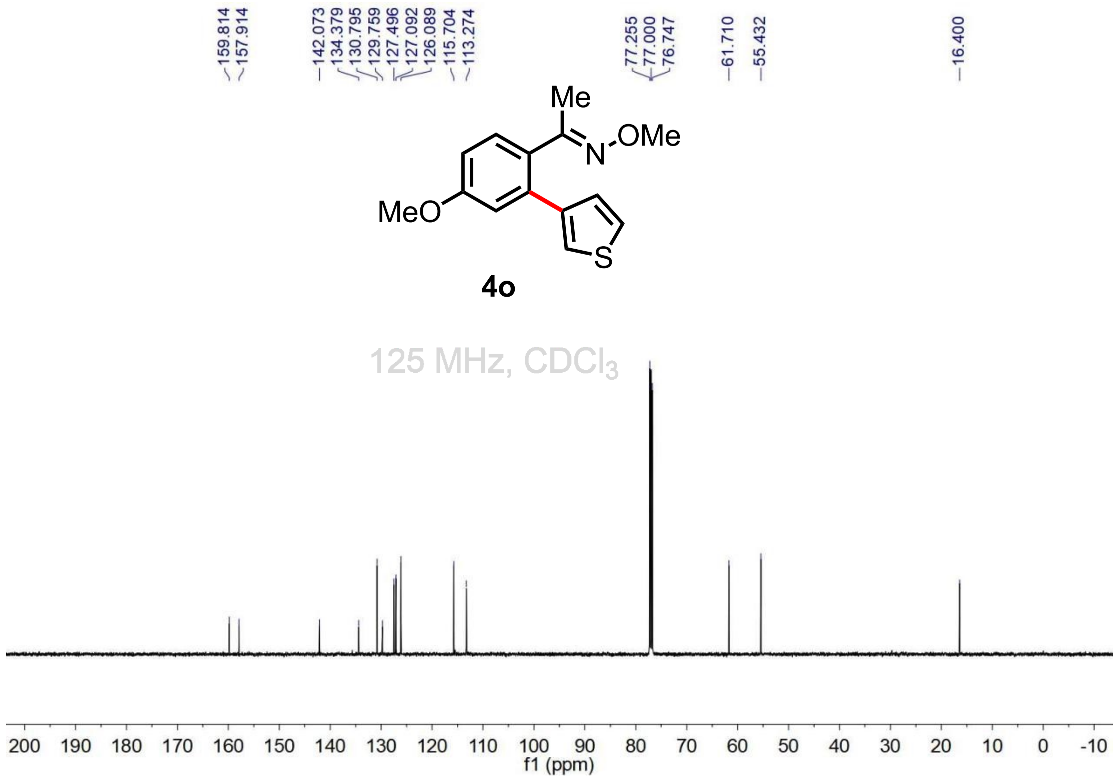
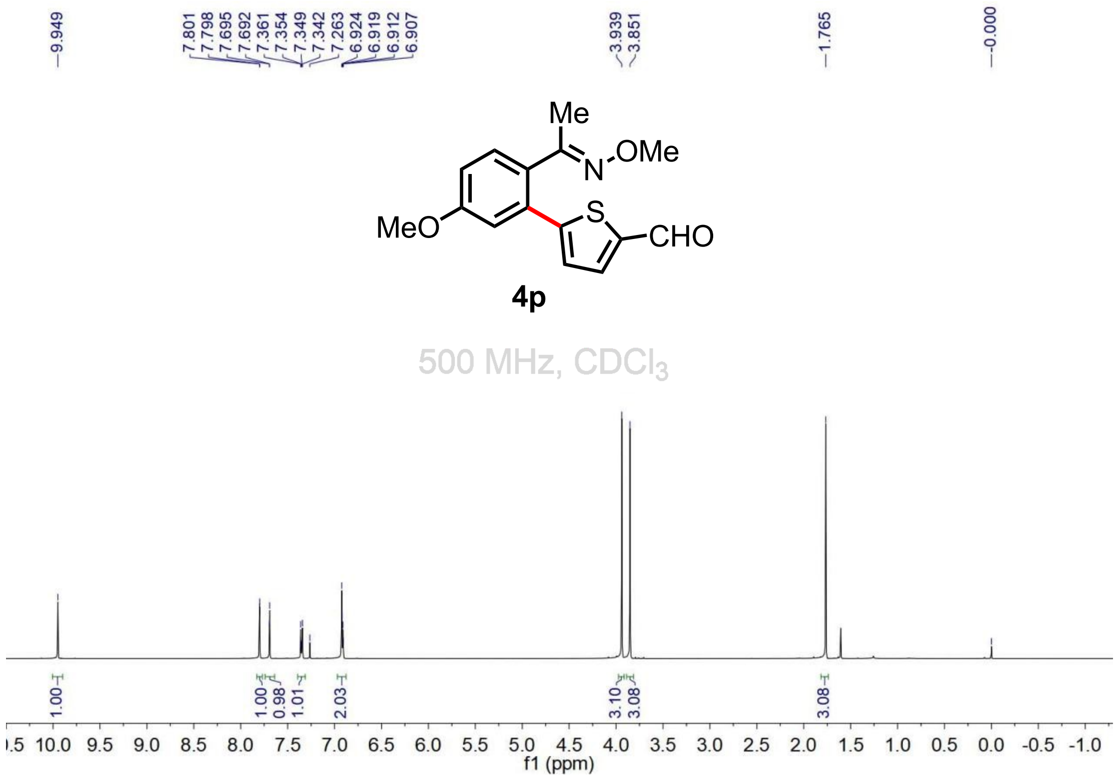
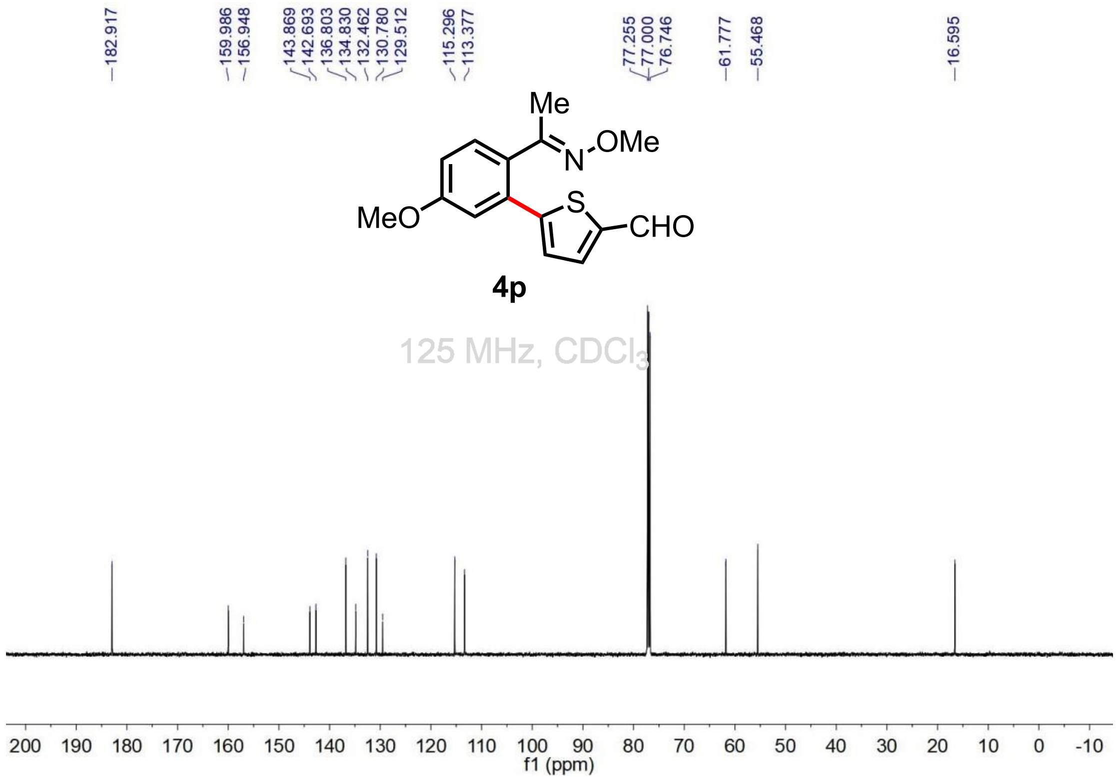
7.328
7.322
7.305
7.256
7.088
7.081
7.059
7.051
7.049
7.042
7.035
7.004
6.999
6.882
6.877
6.865
6.860
3.977
3.838
1.765
0.000
Me
N
OMe
MeO
S
4o
500 MHz, CDCl3
1.00
1.00
1.01
1.14
0.96
1.01
3.01
3.08
3.13
10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5 -1.0
f1 (ppm)



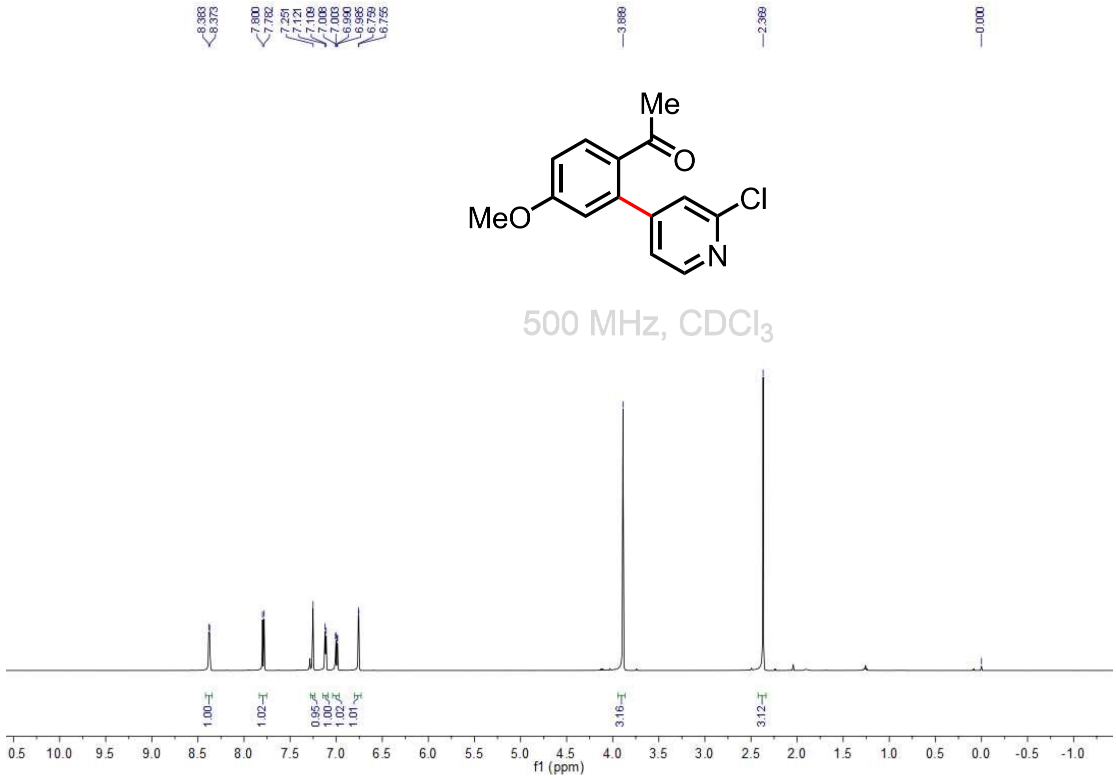
159.814
157.914
142.073
134.379
130.795
129.759
127.496
127.092
126.089
115.704
113.274
77.255
77.000
76.747
61.710
55.432
16.400
Me
N
OMe
MeO
S
4o
125 MHz, CDCl3
200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
f1 (ppm)

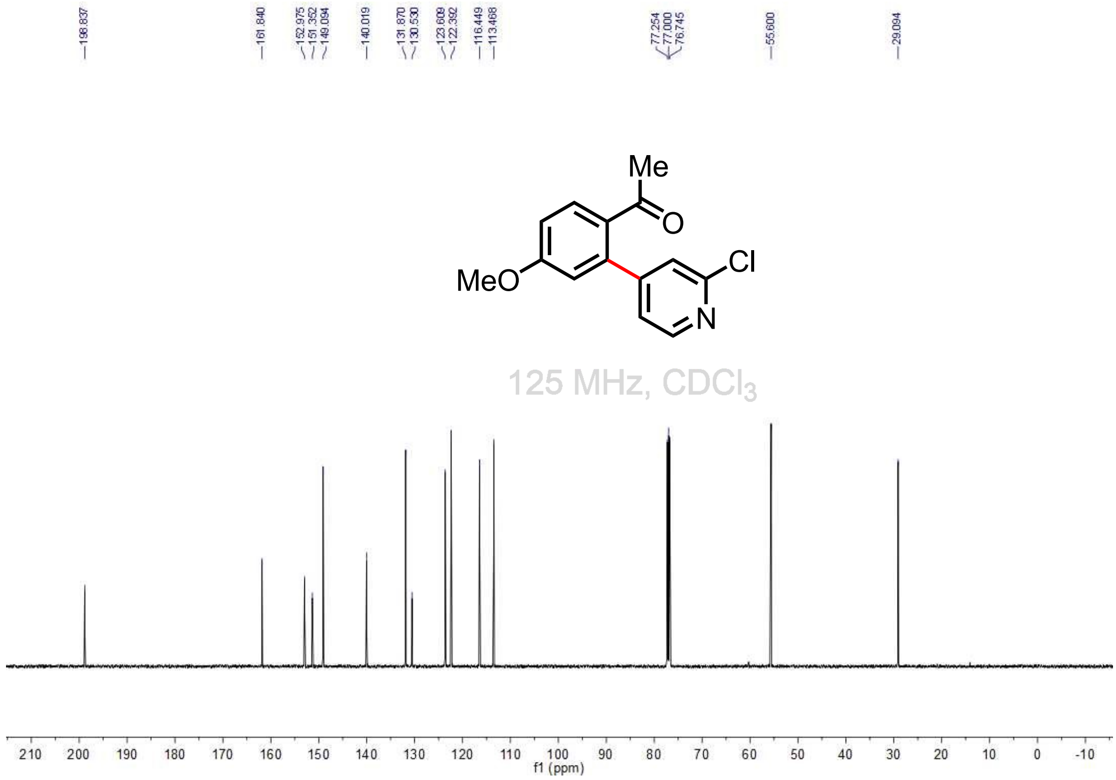


9.949
7.801
7.798
7.695
7.692
7.361
7.354
7.349
7.342
7.263
6.924
6.919
6.912
6.907
3.939
3.851
1.765
0.000
Me
OMe
N
MeO
S
CHO
4p
500 MHz, CDCl3
1.00
1.00
0.98
1.01
2.03
3.10
3.08
3.08
f1 (ppm)



182.917
159.986
156.948
143.869
142.693
136.803
134.830
132.462
130.780
129.512
115.296
113.377
77.255
77.000
76.746
61.777
55.468
16.595
Me
OMe
N
MeO
S
CHO
4p
125 MHz, CDCl3
f1 (ppm)


8.383
8.373
7.800
7.782
7.251
7.121
7.109
7.008
7.003
6.990
6.985
6.759
6.755
3.889
2.369
0.000
Me
O
MeO
Cl
N
500 MHz, CDCl3
1.00
1.02
0.95
1.00
1.02
1.01
3.16
3.12
f1 (ppm)


198.837
161.840
152.975
151.352
149.094
140.019
131.870
130.530
123.609
122.392
116.449
113.468
77.254
77.000
76.745
55.600
29.094
Me
O
MeO
Cl
N
125 MHz, CDCl3
f1 (ppm)