Synthesis and Photophysical Properties of Isocoumarin-based D-π-A systems

Valentina Pirovano,[a] Marialaura Marchetti,[b] Jessica Carbonaro,[a]

Elisa Brambilla,[a] Elisabetta Rossi,[a] Luca Ronda,[b,c] and Giorgio Abbiati[a,*]

[a] Dipartimento di Scienze Farmaceutiche, Sezione di Chimica Generale e Organica "A. Marchesini", Università degli Studi di Milano, Via Venezian, 21, 20133 Milano, Italy

[b] Biopharmanet -TEC, Università degli Studi di Parma, Parco Area delle Scienze, 23/A, 43124 Parma, Italy

[c] Dipartimento di Medicina e Chirurgia, Università degli Studi di Parma, Parco Area delle Scienze, 23/A, 43124 Parma, Italy

Supporting Information

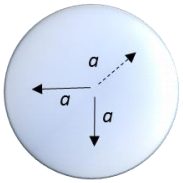
Photophysical Characterization:

Onsager cavity radium

$$a = \sqrt[3]{\frac{3M}{4\pi\delta N_A}}$$

M = molecular weight
NA = Avogadro's number
δ = compound density

Lippert-Mataga equation



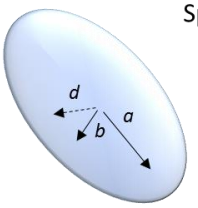
Sphere

$V = \frac{4}{3}\pi a^3$

$$\overline{\nu_a} - \overline{\nu_f} = \frac{2}{hc}\left(\frac{\varepsilon - 1}{2\varepsilon + 1} - \frac{n^2 - 1}{2n^2 + 1}\right)\frac{(\mu^* - \mu)^2}{a^3} + const$$

$\overline{\nu_a}$ and $\overline{\nu_f}$ = wavenumbers in cm^{-1}
h = Planck's constant
c = speed of light
μ* and μ = dipole moment of the molecule in the excited and ground state
a = Onsager cavity radium

Modified Lippert-Mataga equation



Spheroid prolate

$V = \frac{4}{3}\pi abd$

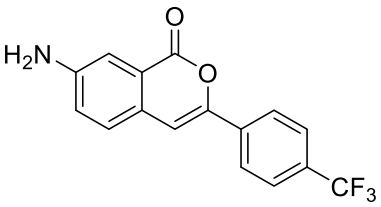
$a > b = d$

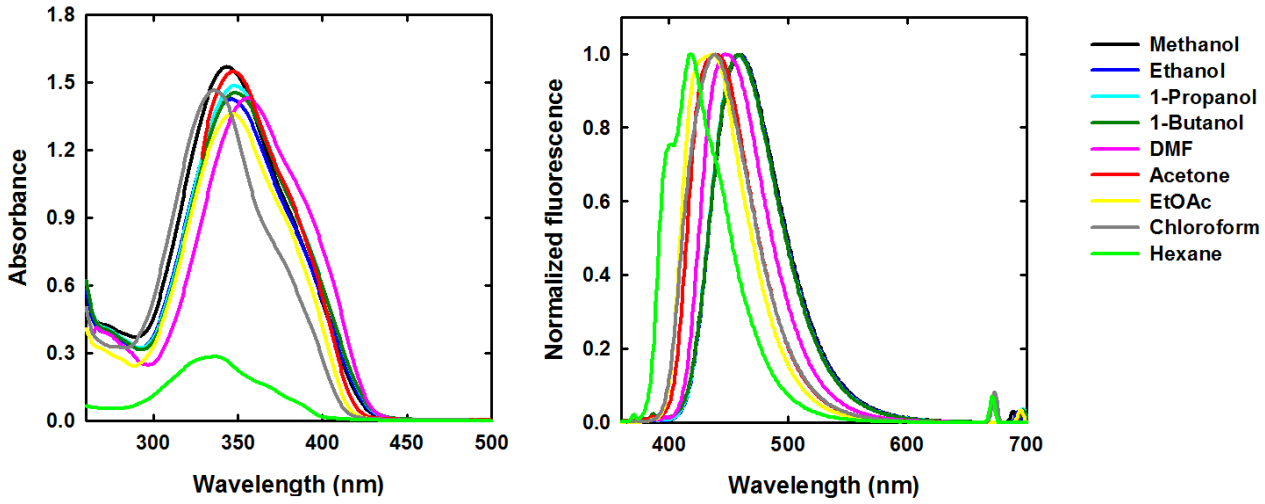
$$\overline{\nu_a} - \overline{\nu_f} = \frac{3}{hc}\left(\frac{\varepsilon - 1}{2\varepsilon + 1} - \frac{n^2 - 1}{2n^2 + 1}\right)\frac{(\mu^* - \mu)^2}{abd} + const$$

References:

1. Vequi-Suplicy C. C., Coutinho, K.; Lamyet, M. T. *Biophys. Rev.* **2014**, *6*, 63–74.
2. Scholte T.G., *Physica* **1949**, 15, 437–449.

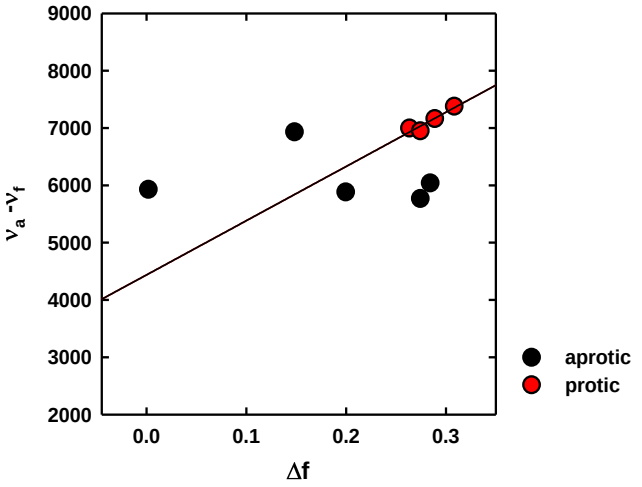
1a





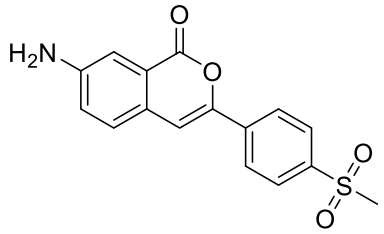
Calculated ε_{346nm} in ethanol = 21764 M^{-1} cm^{-1}
Measurements carried out at 20 °C, l=1 cm
[1a] = 65.52 µM

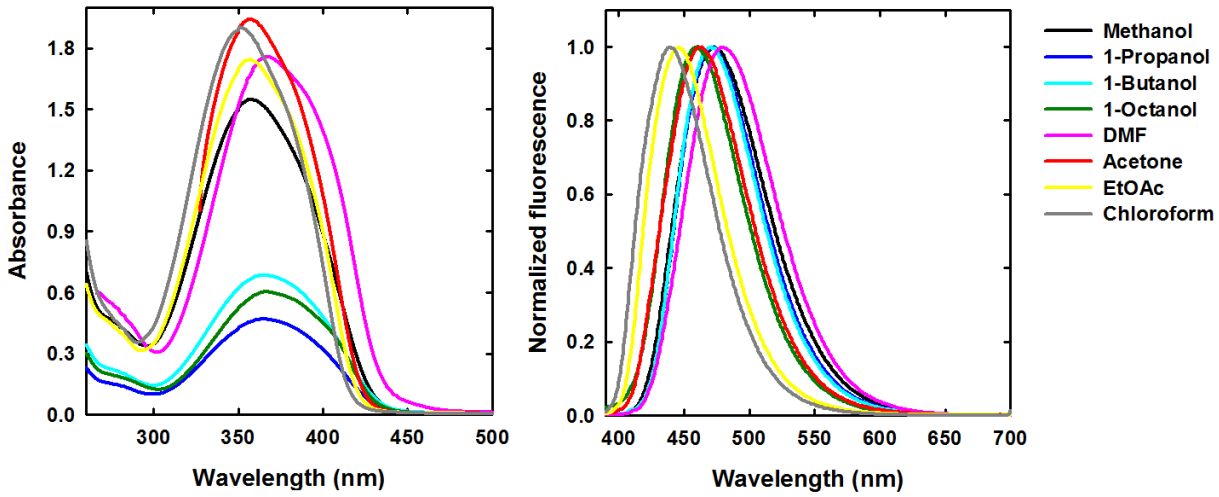
Solvent	λ_{exc} (nm)	λ_{em} (nm)
Methanol	344	461
Ethanol	346	460
1-Propanol	348	459
1-Butanol	348	460
1-Octanol	Not soluble	Not soluble
DMF	356	448
Acetone	347	439
Ethyl Acetate	347	436
Chloroform	336	438
Hexane	335	418



Molecular volume = 357.02 $Å^3$
µ = 3.68 Debye (Discovery Studio)
Sphere - protic
Onsager cavity radius = 4.4 Å
µ *- µ = 8.94±0.04 Debye
Spheroid prolate - protic
a= 5.7 Å
b=d= 1.84 Å
µ *- µ = 3.48±0.42 Debye

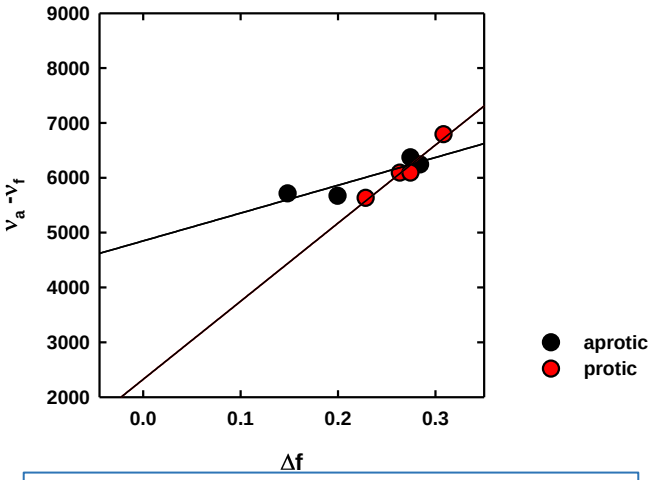
1b





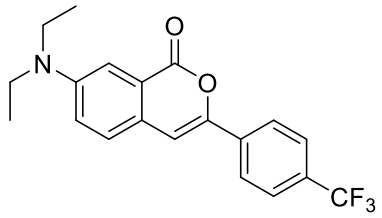
Calculated ε_{358nm} in methanol = 24406 M^{-1} cm^{-1}
Measurements carried out at 20 °C, l=1 cm
[1b] = 63.42 µM

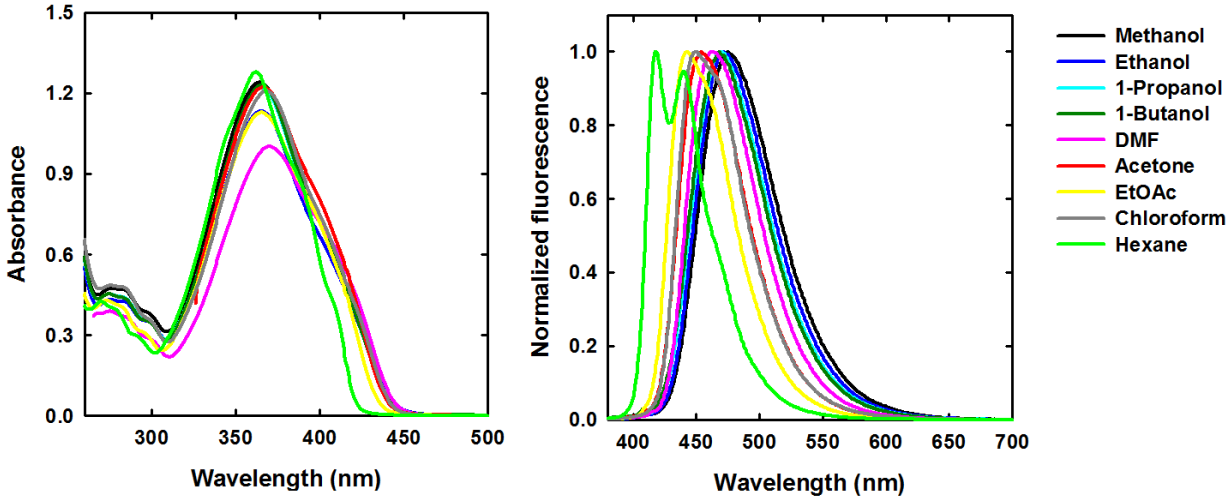
Solvent	λ_{exc} (nm)	λ_{em} (nm)
Methanol	358	473
Ethanol	Not soluble	Not soluble
1-Propanol	366	471
1-Butanol	366	471
1-Octanol	366	461
DMF	367	479
Acetone	358	461
Ethyl Acetate	356	446
Chloroform	351	439
Hexane	Not soluble	Not soluble



Molecular volume = 370.81 $Å^3$
µ = 2.18 Debye (Discovery Studio)
Sphere
Onsager cavity radius = 4.46 Å
aprotic: µ *- µ = 6.69±1.09 Debye
protic: µ *- µ = 11.20±0.82 Debye
Spheroid prolate
a= 6.46 Å
b=d= 2.02 Å
aprotic: µ *- µ = 2.98±0.49 Debye
protic: µ *- µ = 4.99±0.37 Debye

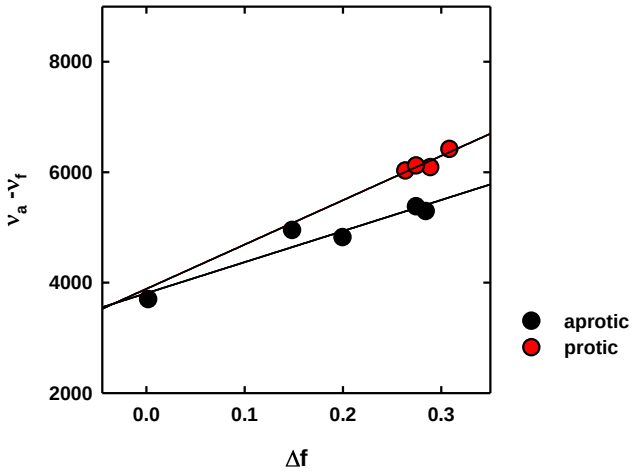
1c





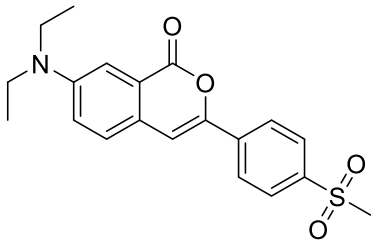
Calculated ε_{366nm} in ethanol = 20488 M^{-1} cm^{-1}
Measurements carried out at 20 °C, l=1 cm
[1c] = 55.35 µM

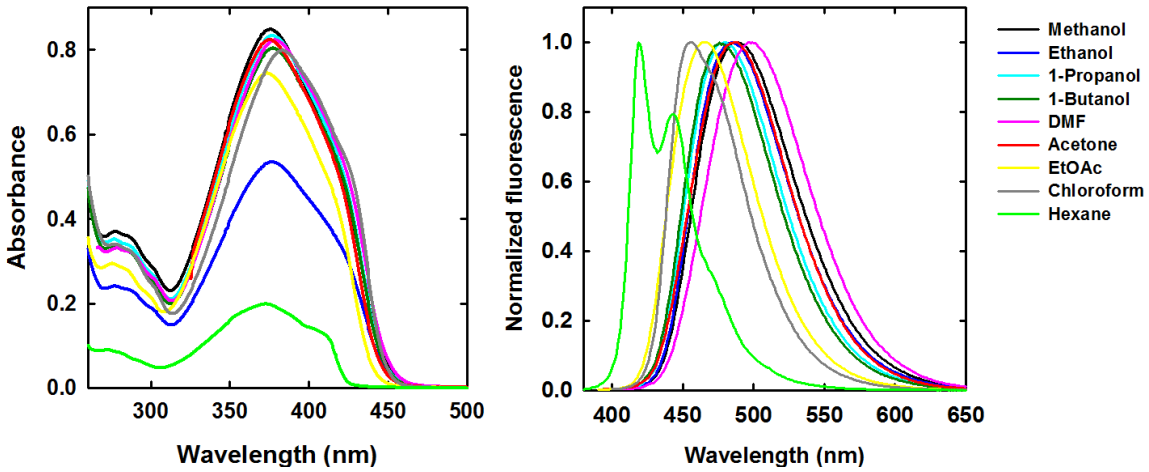
Solvent	λ_{exc} (nm)	λ_{em} (nm)
Methanol	364	475
Ethanol	366	471
1-Propanol	365	470
1-Butanol	365	468
1-Octanol	Not soluble	Not soluble
DMF	370	462
Acetone	366	454
Ethyl Acetate	365	443
Chloroform	368	450
Hexane	362	418



Molecular volume = 471.12 $Å^3$
µ = 4.12 Debye (Discovery Studio)
Sphere
Onsager cavity radius = 4.83 Å
aprotic: µ *- µ = 7.94±0.65 Debye
protic: µ *- µ = 9.48±1.68 Debye
Spheroid prolate
a= 7.62 Å
b=d= 2.02 Å
aprotic: µ *- µ = 3.41±0.28 Debye
protic: µ *- µ = 4.07±0.72 Debye

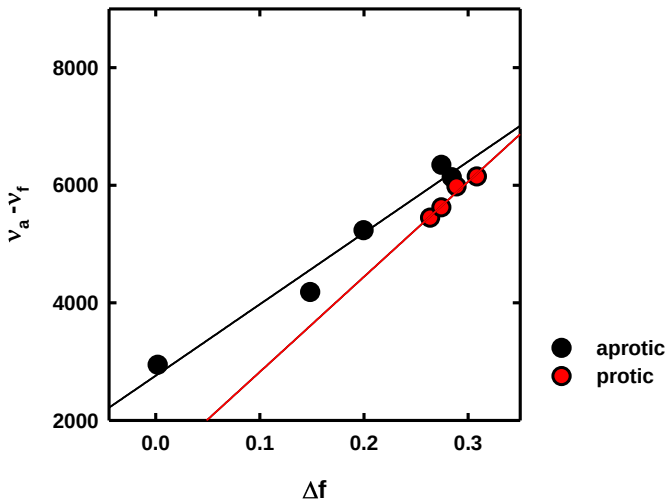
1d





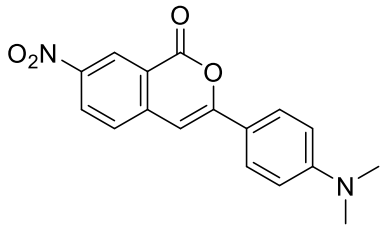
Calculated ε_{376nm} in ethanol = 9937 M^{-1} cm^{-1}
Measurements carried out at 20 °C, l=1 cm
[1d] = 53.84 µM

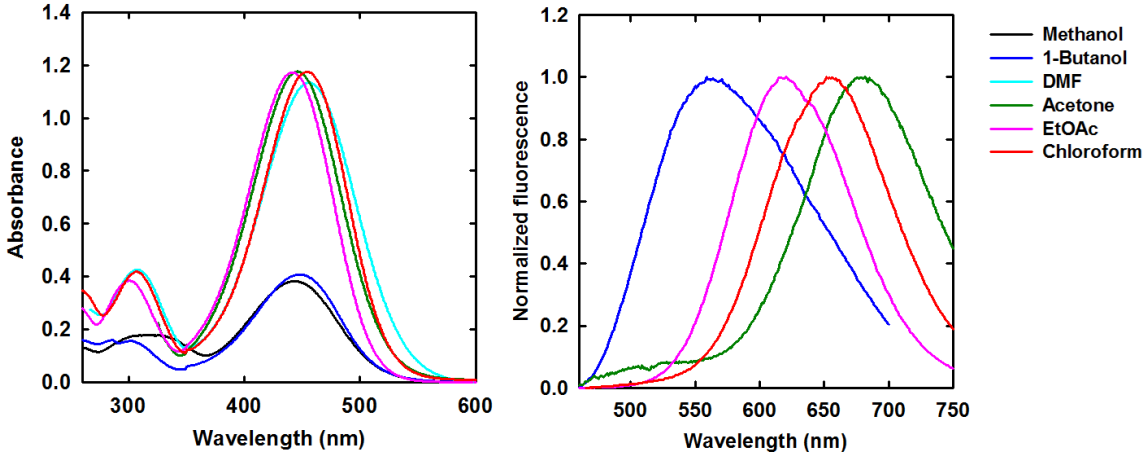
Solvent	λ_{exc} (nm)	λ_{em} (nm)
Methanol	376	489
Ethanol	376	485
1-Propanol	378	480
1-Butanol	378	476
DMF	379	499
Acetone	375	487
Ethyl Acetate	374	465
Chloroform	383	456
Hexane	373	419



Molecular volume = 484.89 $Å^3$
µ = 3.02 Debye (Discovery Studio)
Sphere
Onsager cavity radius = 4.87 Å
aprotic: µ *- µ = 11.80±0.60 Debye
protic: µ *- µ = 13.62±1.02 Debye
Spheroid prolate
a= 7.51 Å
b=d= 2.02 Å
aprotic: µ *- µ = 4.96±0.25 Debye
protic: µ *- µ = 5.73±0.43 Debye

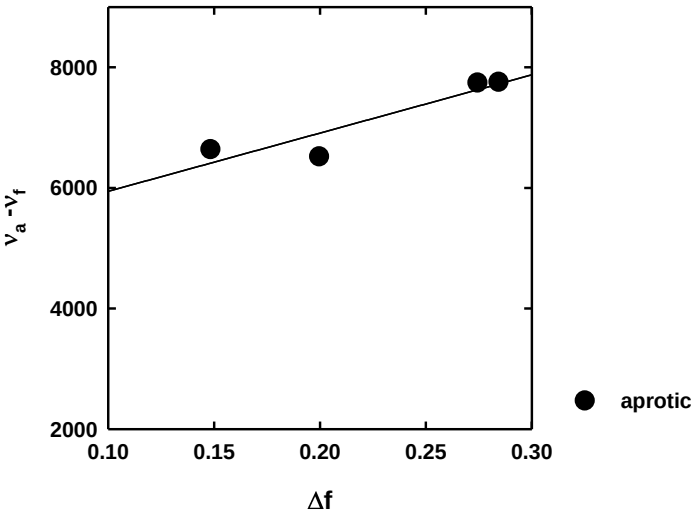
1e





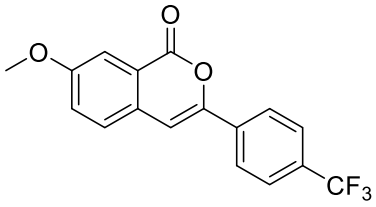
Measurements carried out at 20 °C, l=1 cm
The molecule is poorly fluorescent in methanol and DMF

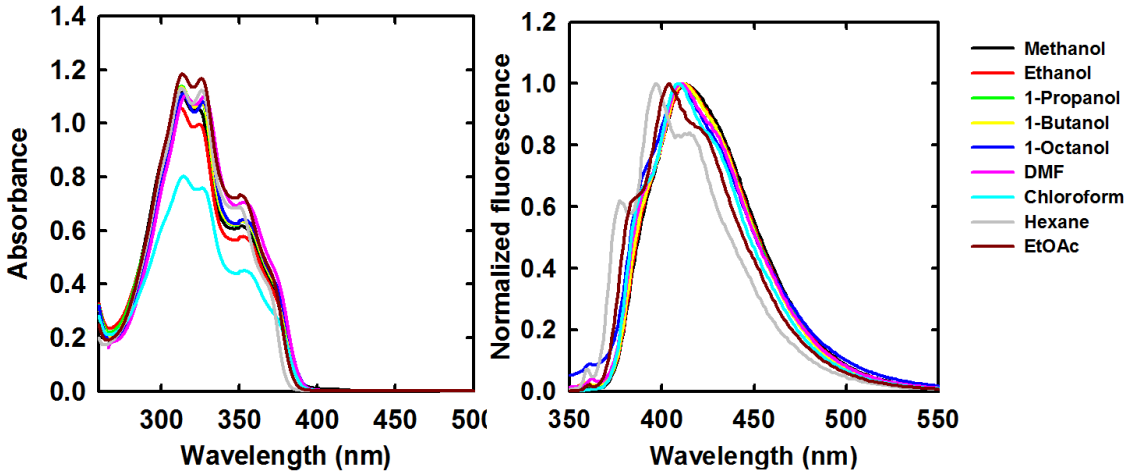
Solvent	λ_{exc} (nm)	λ_{em} (nm)
Methanol	444	(605, poorly fluorescent)
Ethanol	Not soluble	Not soluble
1-Propanol	Not soluble	Not soluble
1-Butanol	448	559
1-Octanol	Not soluble	Not soluble
DMF	456	(605, poorly fluorescent)
Acetone	446	682
Ethyl Acetate	442	621
Chloroform	455	652
Hexane	Not soluble	Not soluble



Molecular volume = 380.44 $Å^3$
μ = 6.17 Debye (Discovery Studio)
Sphere
Onsager cavity radius = 4.495 Å
aprotic: μ *- μ = 9.33±1.42 Debye
Spheroid prolate
a= 7.3 Å
b=d= 2.57 Å
aprotic: μ *- μ = 5.55±0.85 Debye

1f



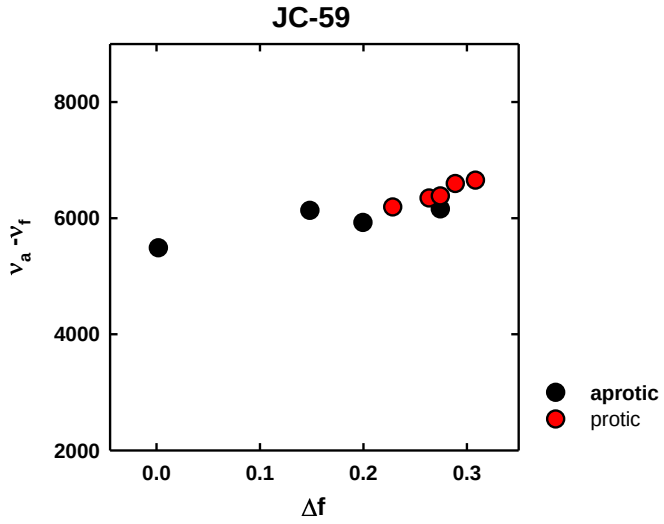


Calculated ε_{324nm} in ethanol = 15957 M^{-1} cm^{-1}

Measurements carried out at 20 °C, l=1 cm

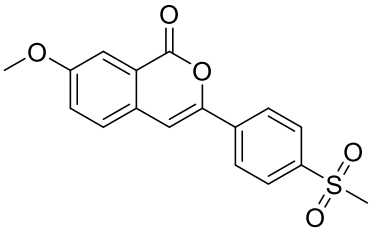
[1f]= 62.45 µM

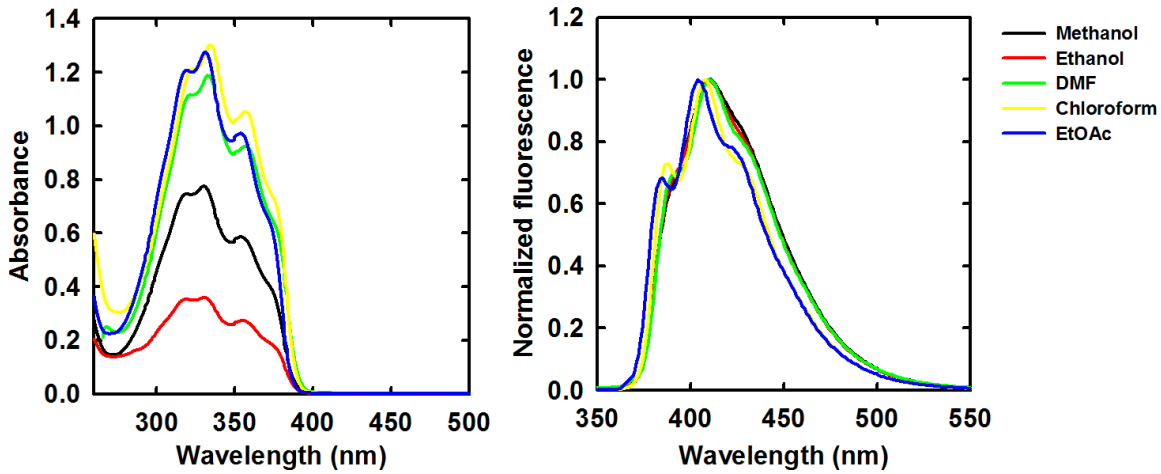
Solvent	λ_{exc} (nm)	λ_{em} (nm)
Methanol	324	413
Ethanol	324	412
1-Propanol	325	410
1-Butanol	326	411
1-Octanol	327	410
DMF	328	411
Acetone	Solvent absorption	-
Ethyl Acetate	326	404
Chloroform	327	409
Hexane	326	397



Molecular volume = 393.06 $Å^3$
µ = 4.984 Debye (Discovery Studio)
Onsager cavity radius = 4.54 Å

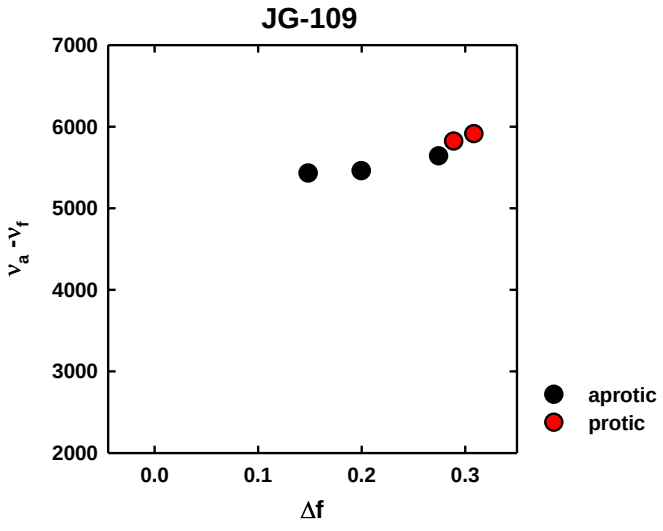
1g





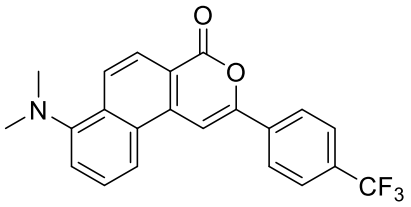
Measurements carried out at 20 °C, l=1 cm
[1g] = 60.54 µM

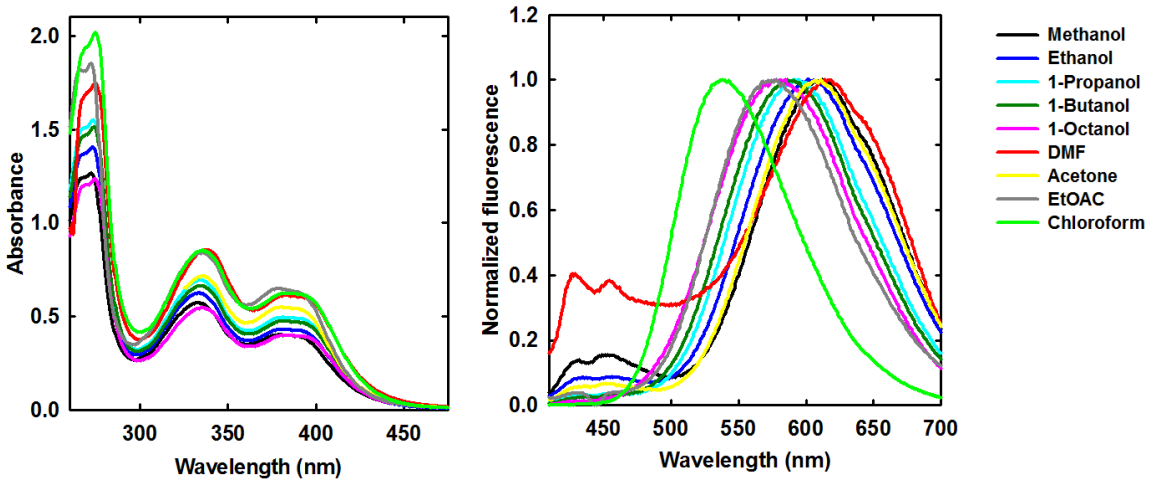
Solvent	λ_{exc} (nm)	λ_{em} (nm)
Methanol	330	410
Ethanol	331	410
1-Propanol	Not soluble	Not soluble
1-Butanol	Not soluble	Not soluble
1-Octanol	Not soluble	Not soluble
DMF	333	410
Acetone	Solvent absorption	-
Ethyl Acetate	331	404
Chloroform	334	408
Hexane	Not soluble	Not soluble



Molecular volume = 406.84 Å^3
µ = 6.323 Debye (Discovery Studio)
Onsager cavity radius = 4.60 Å

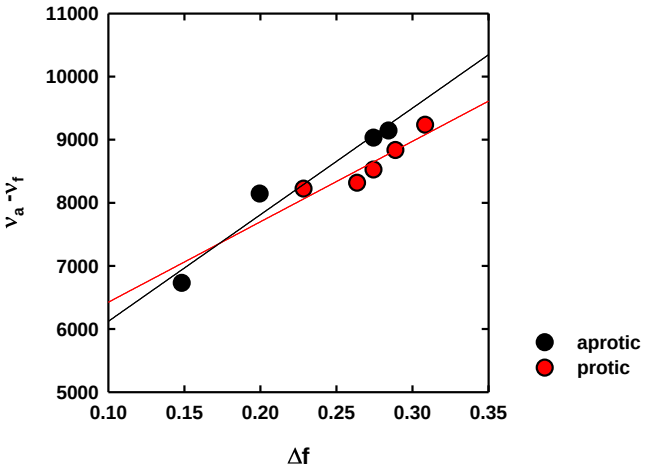
11c





Measurements carried out at 20 °C, l=1 cm

Solvent	λ_{exc} (nm)	λ_{em} (nm)
Methanol	391	612
Ethanol	393	602
1-Propanol	393	591
1-Butanol	394	586
1-Octanol	395	585
DMF	395	614
Acetone	392	611
Ethyl Acetate	393	578
Chloroform	395	538
Hexane	Not soluble	Not soluble



Molecular volume = 472.93 Å^3
μ = 4.113 Debye (Discovery Studio)

Sphere

Onsager cavity radius = 4.833 Å

aprotic: μ *- μ = 13.77±1.06 Debye

protic: μ *- μ = 11.96±1.45 Debye

Spheroid prolate

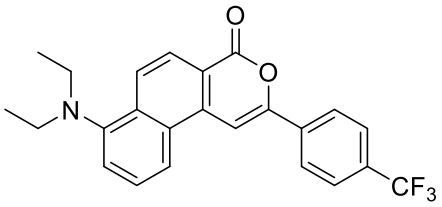
a= 7.7 Å

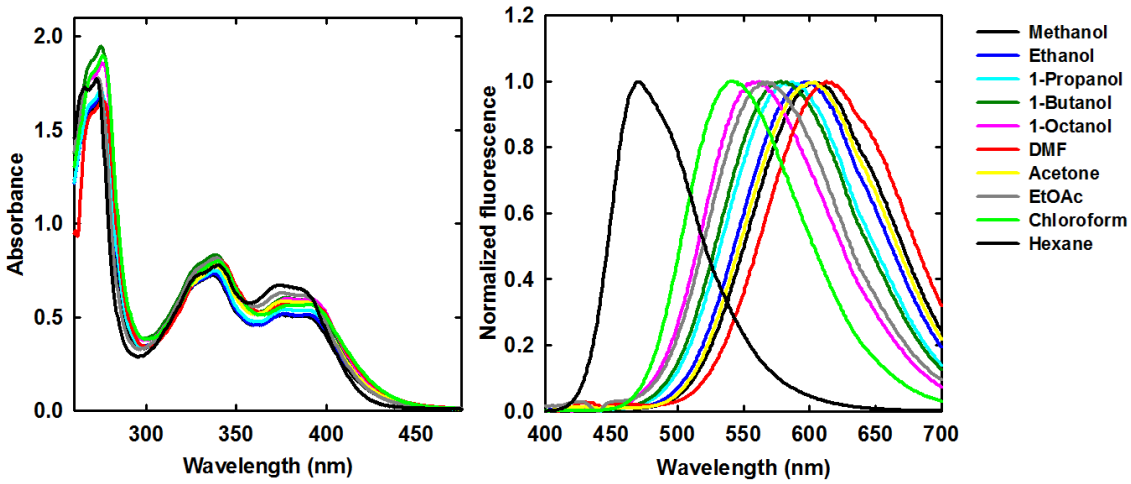
b=d= 3.88 Å

aprotic: μ *- μ = 11.39±0.88 Debye

protic: μ *- μ = 9.90±1.20 Debye

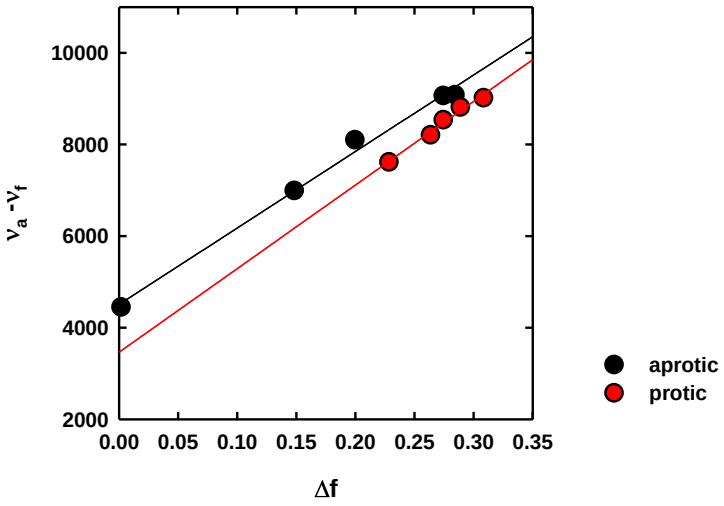
11d





Measurements carried out at 20 °C, l=1 cm

Solvent	λ_{exc} (nm)	λ_{em} (nm)
Methanol	391	604
Ethanol	392	599
1-Propanol	391	587
1-Butanol	392	578
1-Octanol	393	561
DMF	394	613
Acetone	390	604
Ethyl Acetate	389	568
Chloroform	393	542
Hexane	388	469



Molecular volume = 527.9 $Å^3$
μ = 4.267 Debye (Discovery Studio)

Sphere

Onsager cavity radius = 5.014 Å

aprotic: μ *- μ = 11.36±0.28 Debye

protic: μ *- μ = 11.87±0.45 Debye

Spheroid prolate

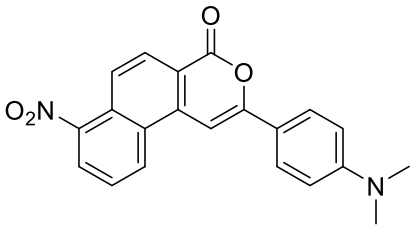
a= 8.3 Å

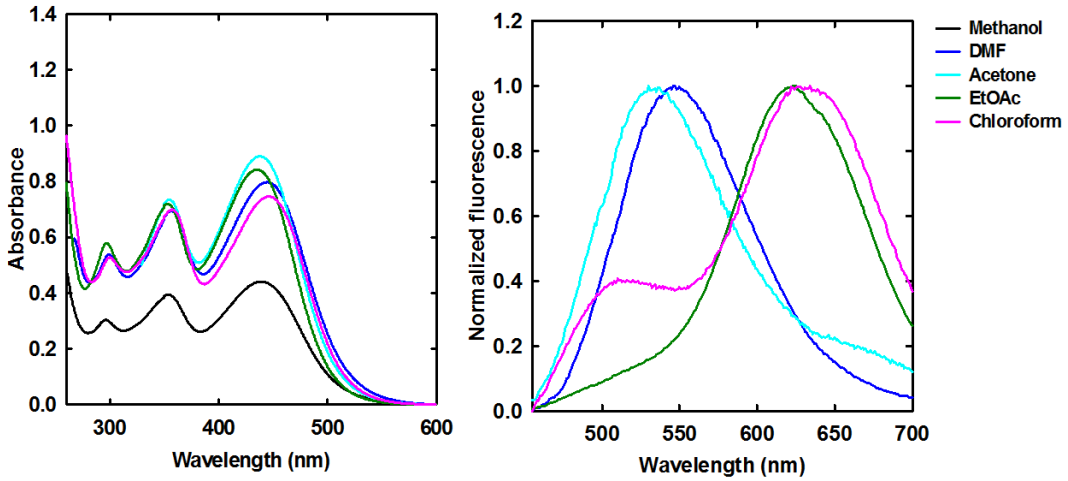
b=d= 3.88 Å

aprotic: μ *- μ = 11.76±0.29 Debye

protic: μ *- μ = 12.29±0.47 Debye

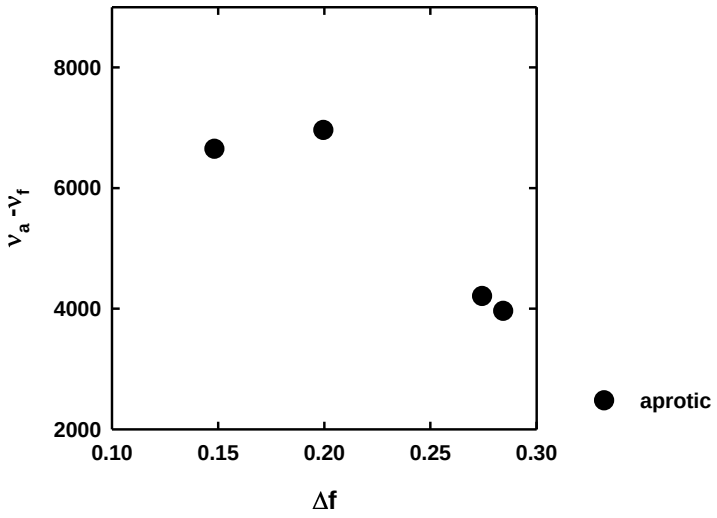
11f





Measurements carried out at 20 °C, l=1 cm
The molecule is poorly fluorescent in methanol.

Solvent	λ_{exc} (nm)	λ_{em} (nm)
Methanol	439	(548, poorly fluorescent)
Ethanol	Not soluble	Not soluble
1-Propanol	Not soluble	Not soluble
1-Butanol	Not soluble	Not soluble
1-Octanol	Not soluble	Not soluble
DMF	444	546
Acetone	438	530
Ethyl Acetate	435	624
Chloroform	446	634
Hexane	Not soluble	Not soluble

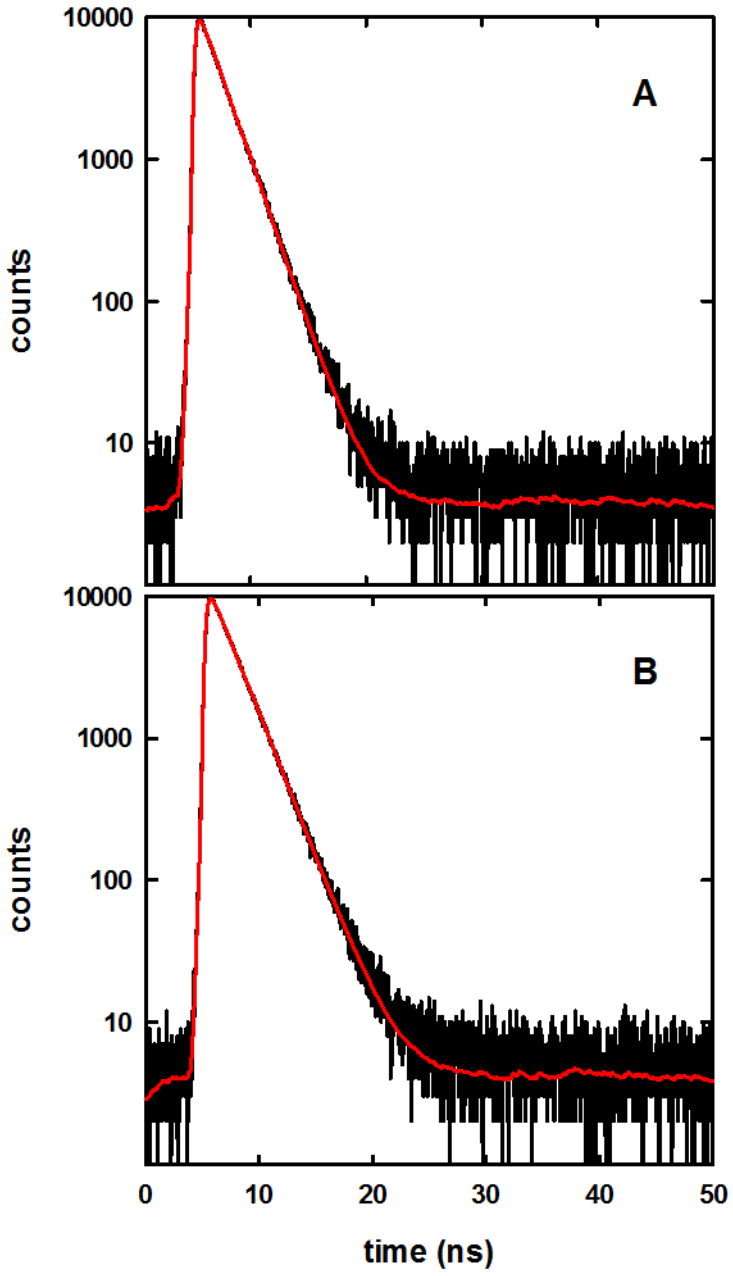


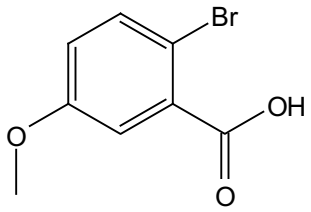
Molecular volume = 437.06 $Å^3$
μ = 6.236 Debye (Discovery Studio)
Sphere
Onsager cavity radius = 4.708 Å

Spheroid prolate
a= 7.85 Å
b=d= 3.86 Å

Fluorescence lifetimes of 1d and 11d

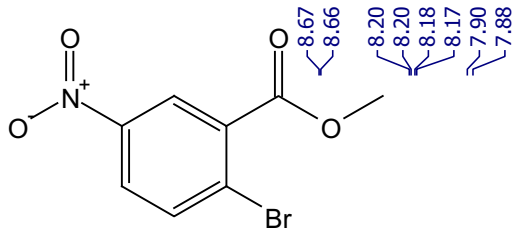
Fluorescence lifetime decays upon 375 nm excitation (0.2 μs repetition rate) of **1d** (panel A) and **11d** (panel B) (black lines). Data, upon IRF correction were fitted to a single exponential decay (red lines).





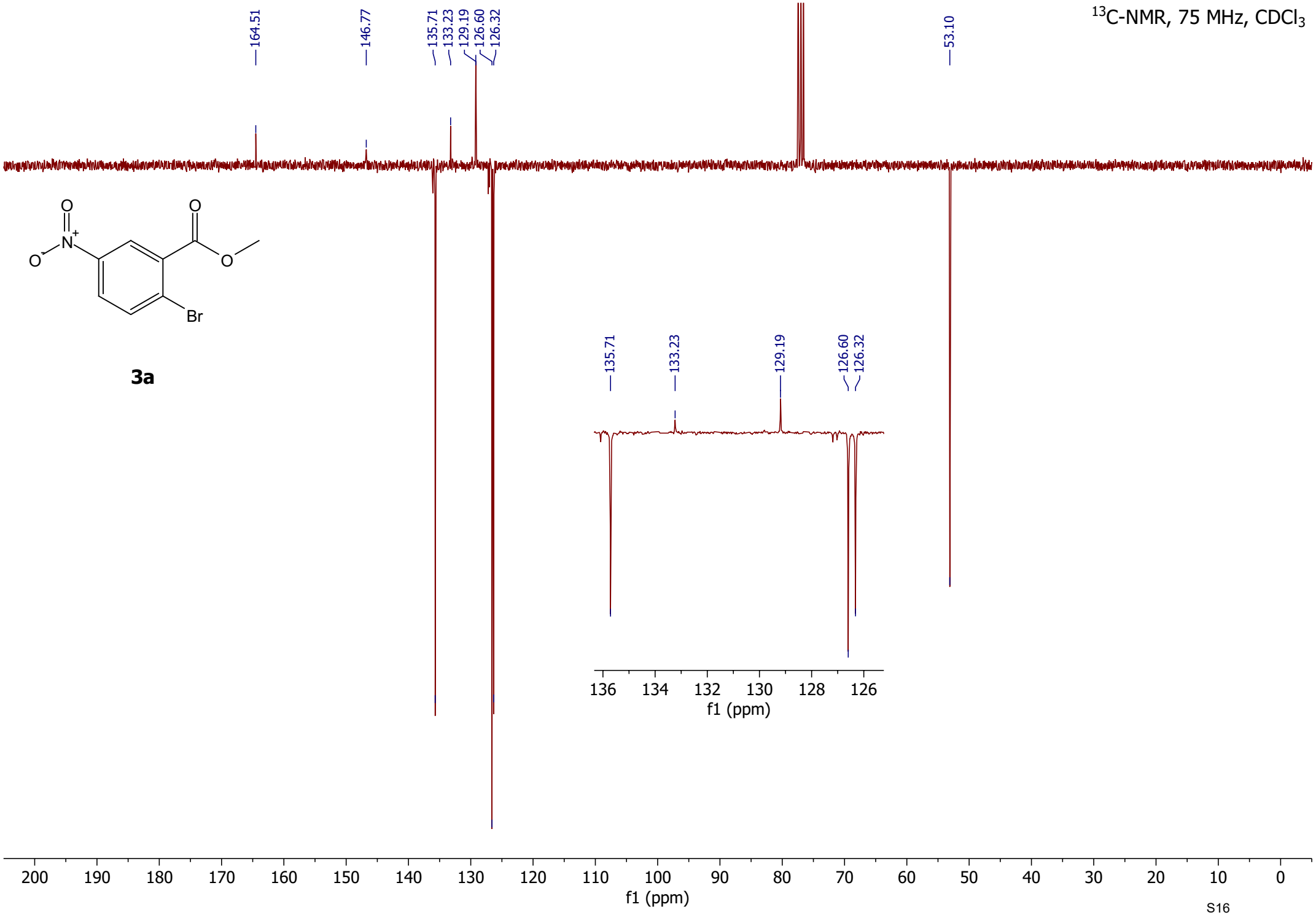
2b

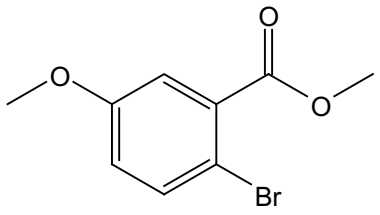
^{1}H-NMR, 300 MHz, $CDCl_3$



3a

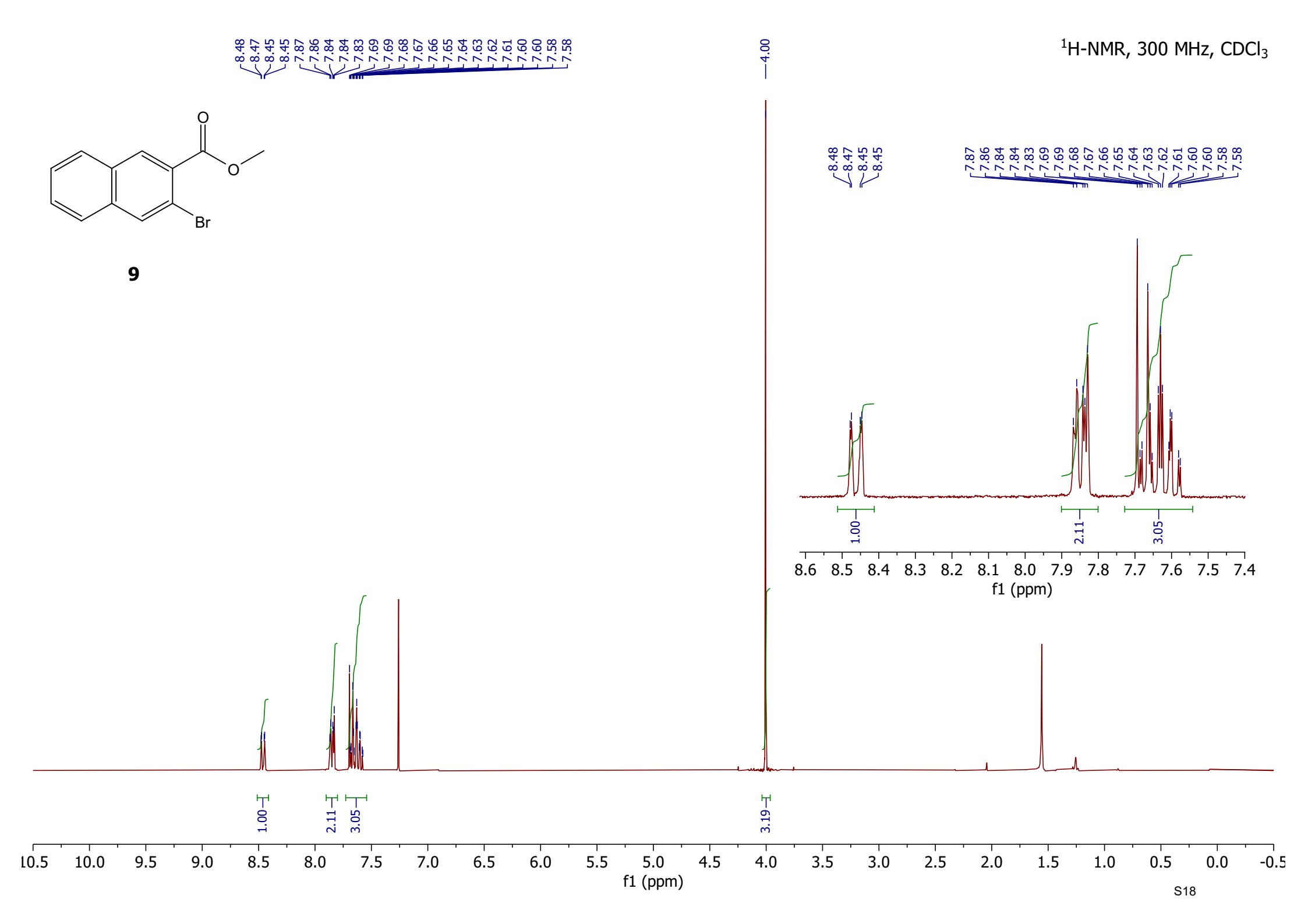
^{1}H-NMR, 300 MHz, $CDCl_3$

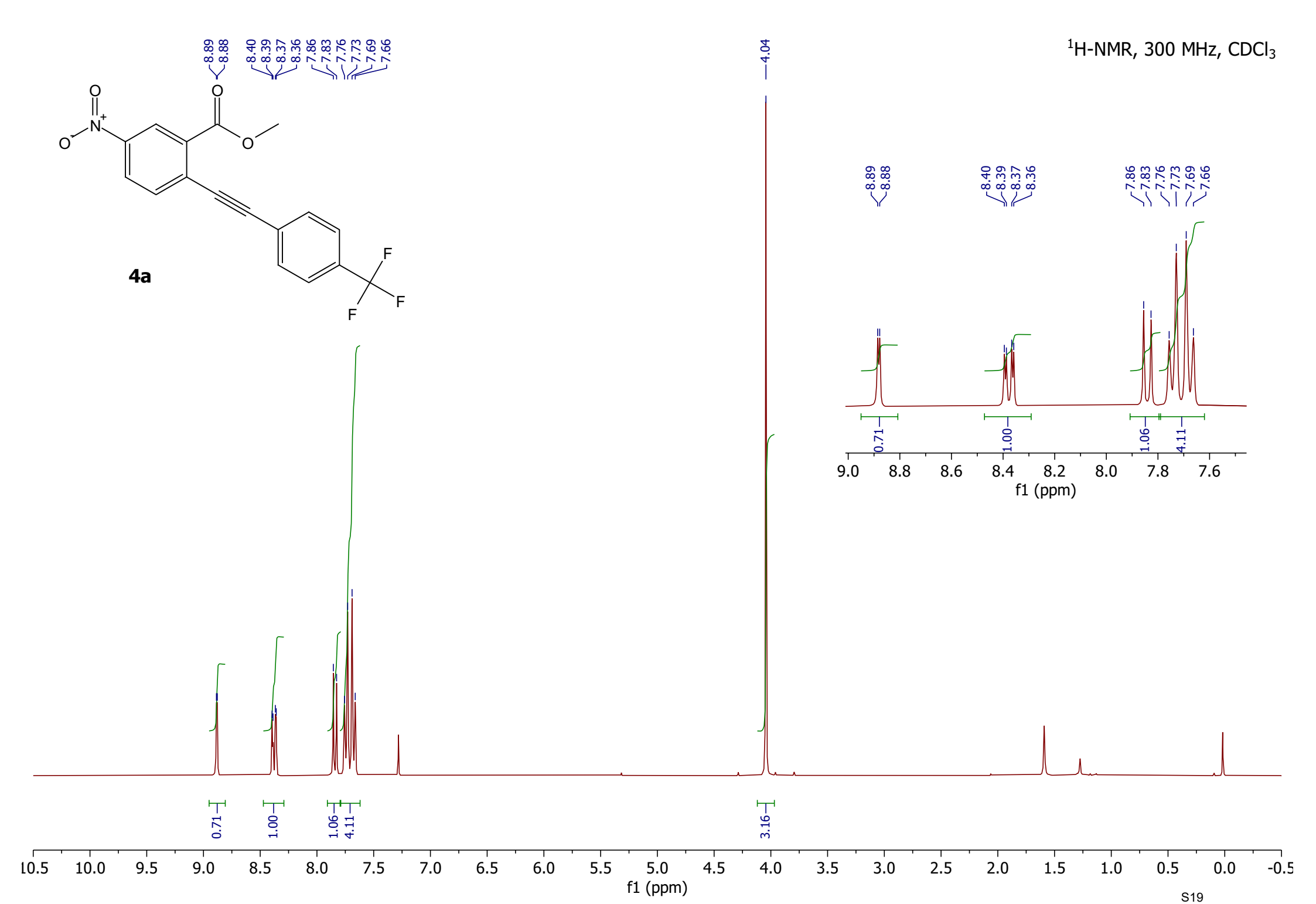

^{13}C-NMR, 75 MHz, $CDCl_3$
164.51
146.77
135.71
133.23
129.19
126.60
126.32
53.10
O
O
N+
O-
O
Br
3a
135.71
133.23
129.19
126.60
126.32
136
134
132
130
128
126
f1 (ppm)
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)

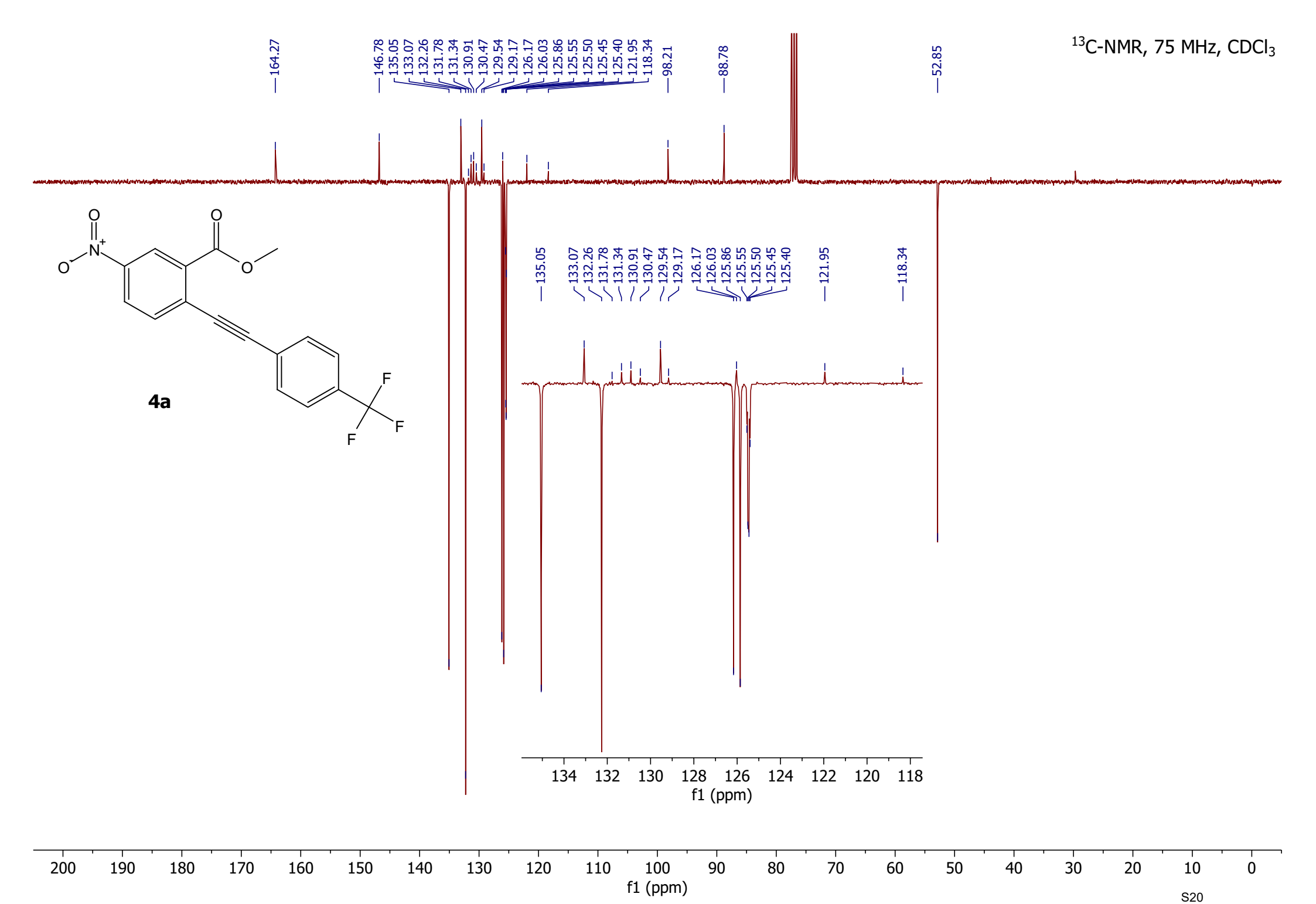


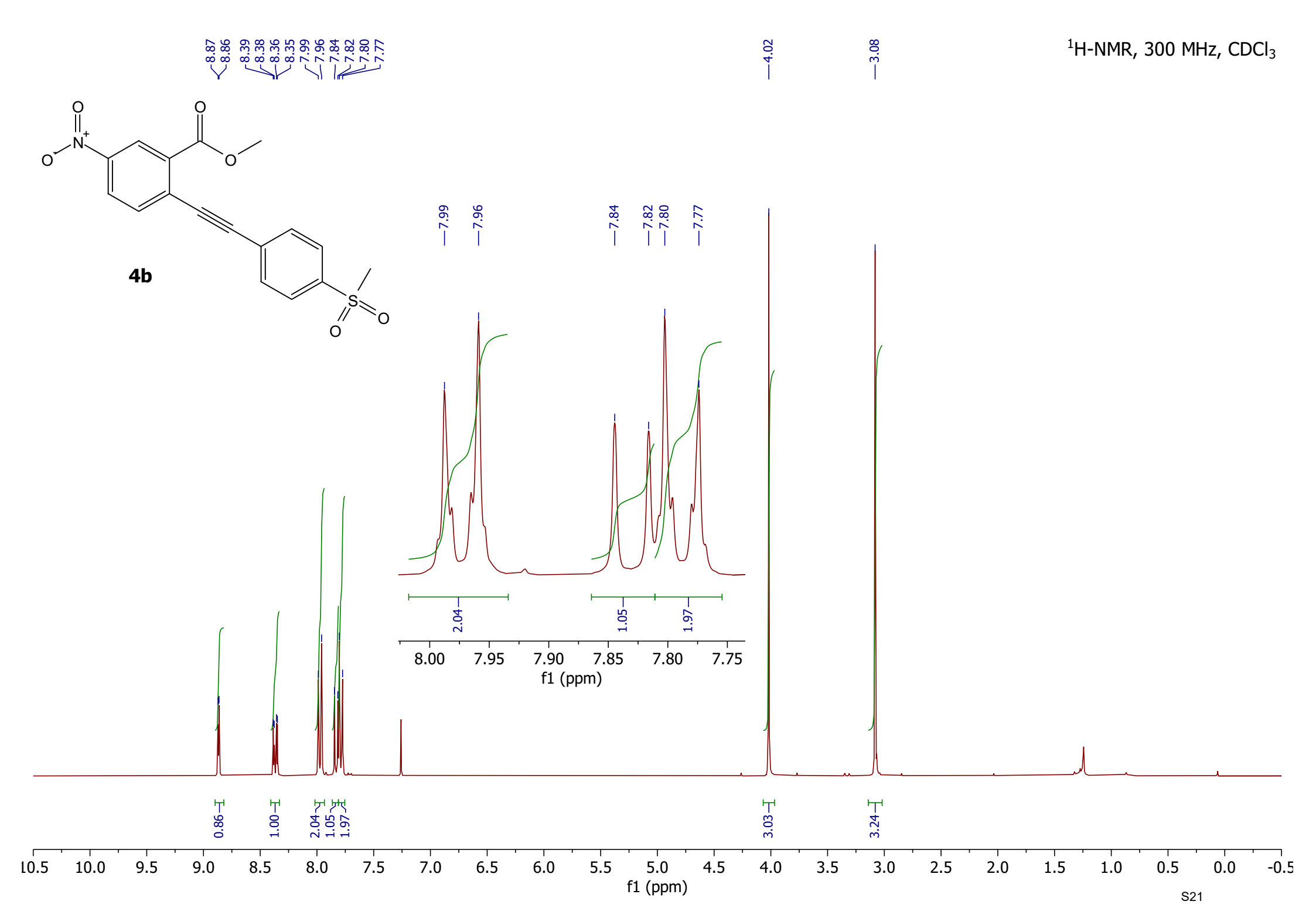
3b

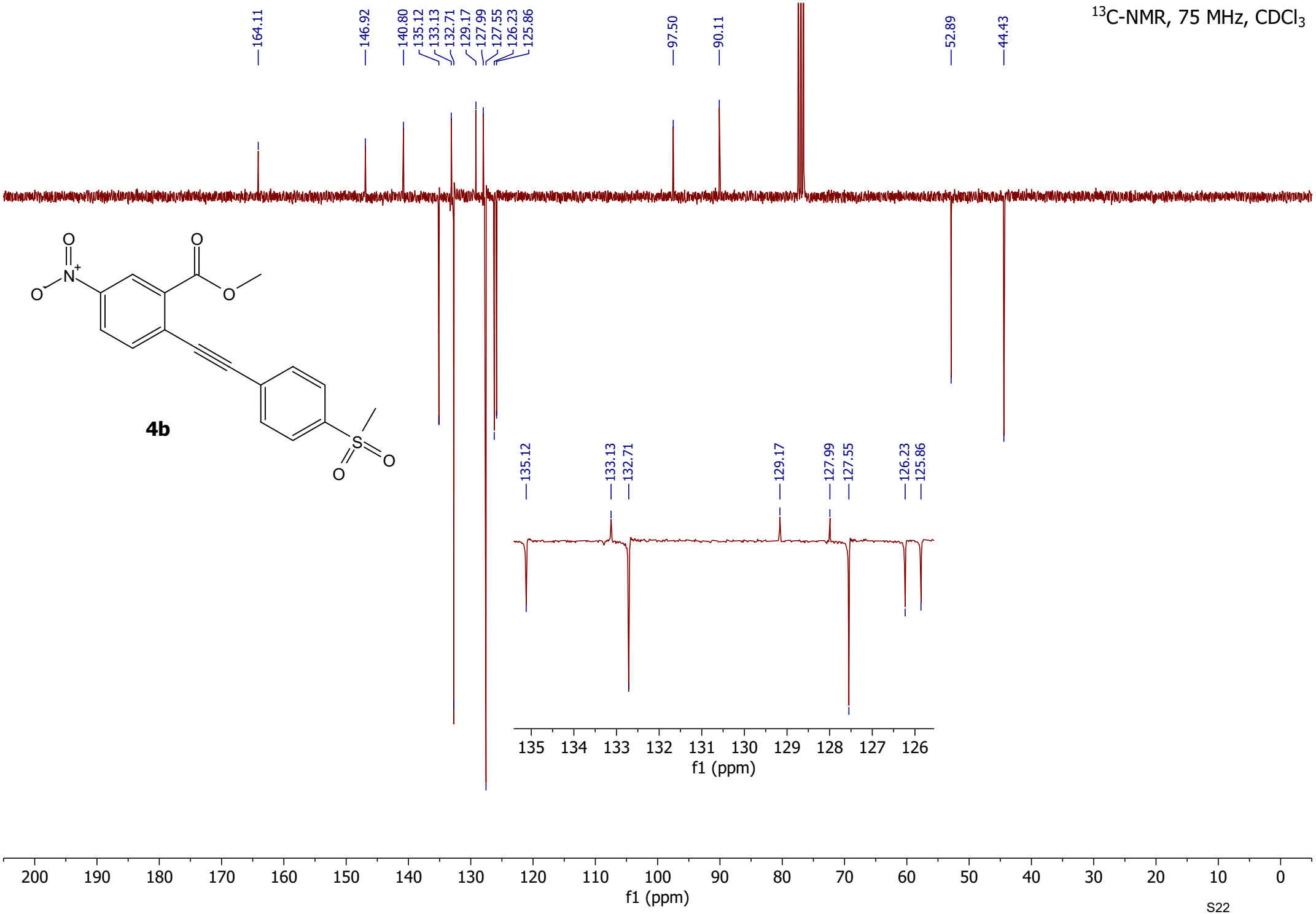
^{1}H-NMR, 300 MHz, $CDCl_3$

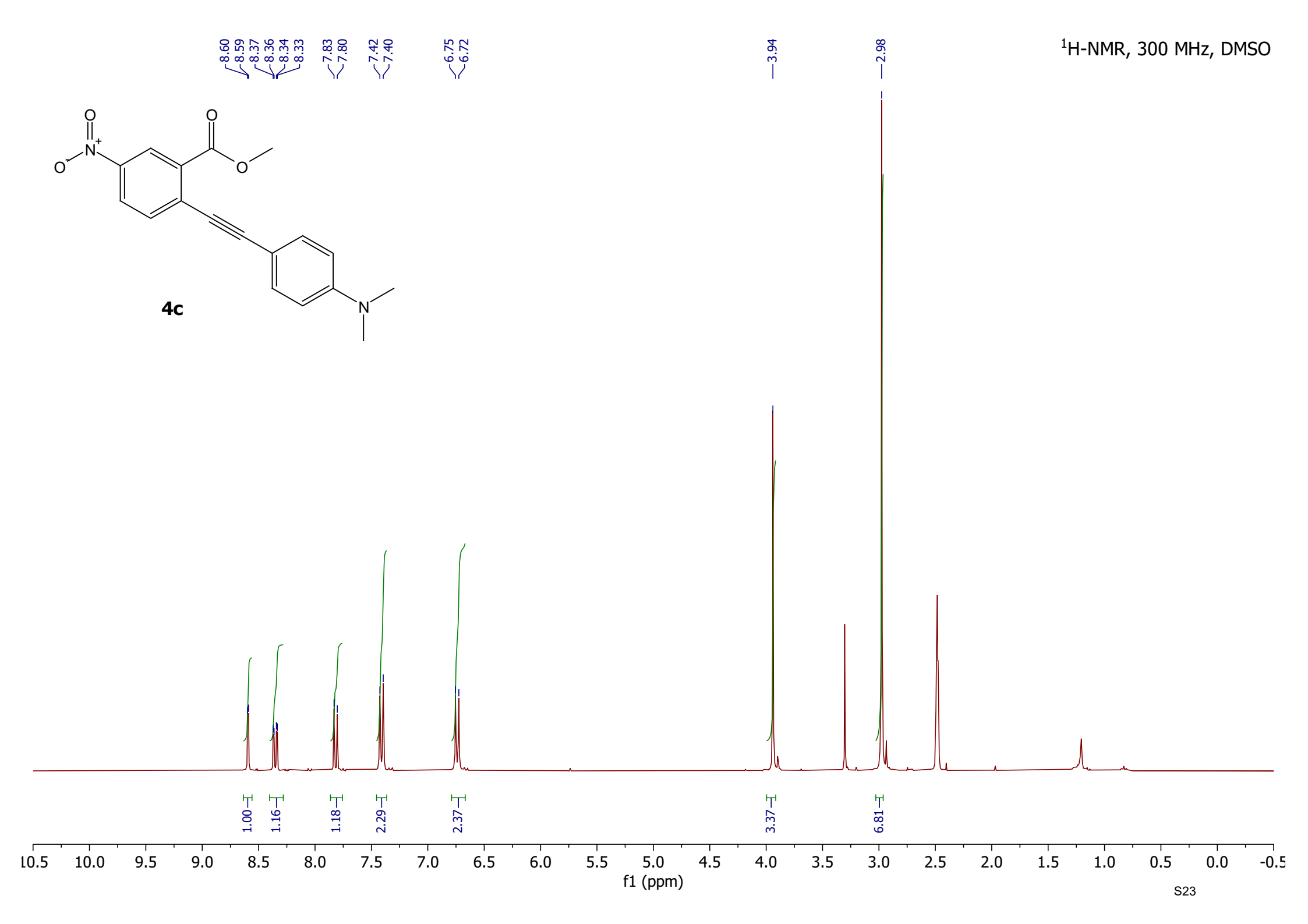

^{1}H-NMR, 300 MHz, $CDCl_3$
8.48 8.47 8.45 8.45 7.87 7.86 7.84 7.84 7.83 7.69 7.69 7.68 7.67 7.66 7.65 7.64 7.63 7.62 7.61 7.60 7.60 7.58 7.58
4.00
O
O
Br
9
1.00
2.11
3.05
3.19
f1 (ppm)

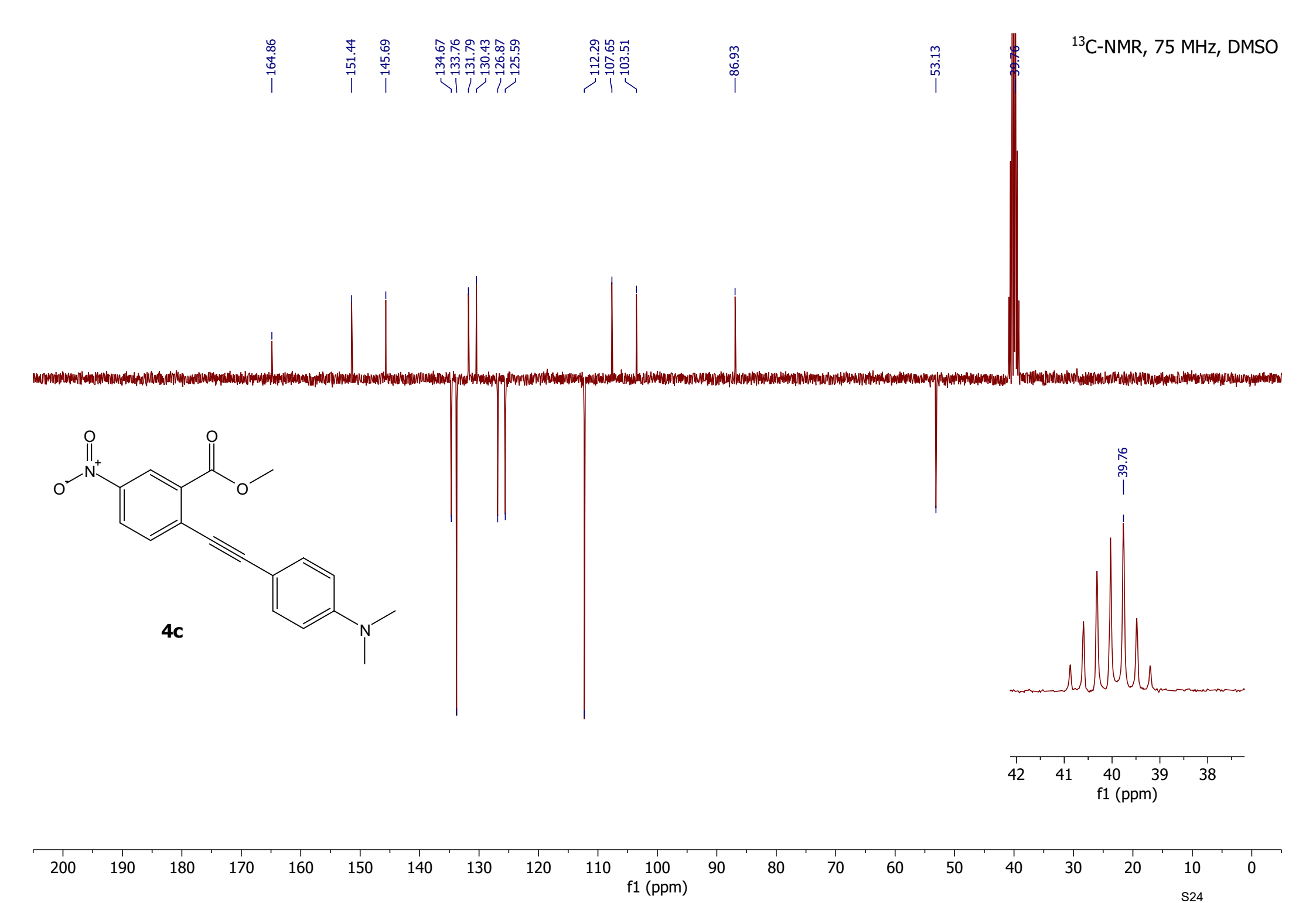

^{1}H-NMR, 300 MHz, $CDCl_3$
8.89
8.88
8.40
8.39
8.37
8.36
7.86
7.83
7.76
7.73
7.69
7.66
4.04
4a
F
F
F
O
O
O
N+
O-
0.71
1.00
1.06
4.11
3.16
f1 (ppm)

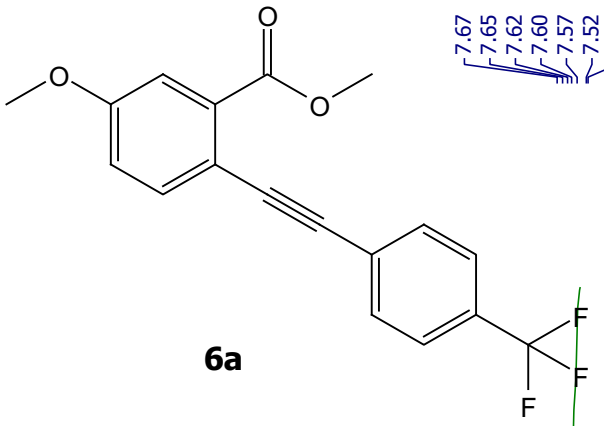

^{13}C-NMR, 75 MHz, $CDCl_3$
164.27
146.78
135.05
133.07
132.26
131.78
131.34
130.91
130.47
129.54
129.17
126.17
126.03
125.86
125.55
125.50
125.45
125.40
121.95
118.34
98.21
88.78
52.85
4a
f1 (ppm)
f1 (ppm)


^{1}H-NMR, 300 MHz, $CDCl_3$
8.87
8.86
8.39
8.38
8.36
8.35
7.99
7.96
7.84
7.82
7.80
7.77
4.02
3.08
4b
2.04
1.05
1.97
8.00
7.95
7.90
7.85
7.80
7.75
f1 (ppm)
0.86
1.00
2.04
1.05
1.97
3.03
3.24
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)


^{13}C-NMR, 75 MHz, $CDCl_3$
164.11
146.92
140.80
135.12
133.13
132.71
129.17
127.99
127.55
126.23
125.86
97.50
90.11
52.89
44.43
4b
135.12
133.13
132.71
129.17
127.99
127.55
126.23
125.86
135 134 133 132 131 130 129 128 127 126
f1 (ppm)
200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0
f1 (ppm)

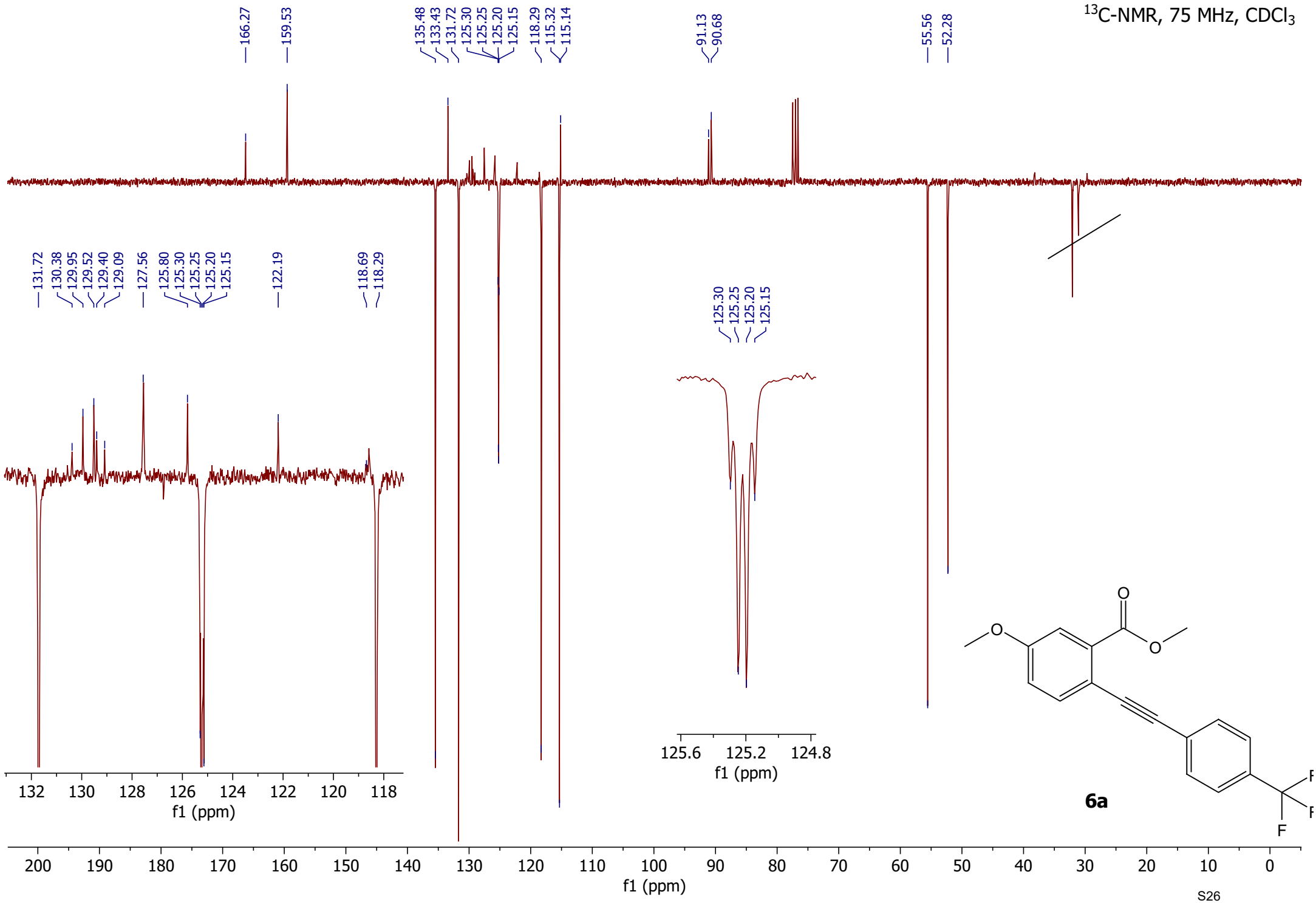

^{1}H-NMR, 300 MHz, DMSO
8.60
8.59
8.37
8.36
8.34
8.33
7.83
7.80
7.42
7.40
6.75
6.72
3.94
2.98
4c
1.00
1.16
1.18
2.29
2.37
3.37
6.81
f1 (ppm)

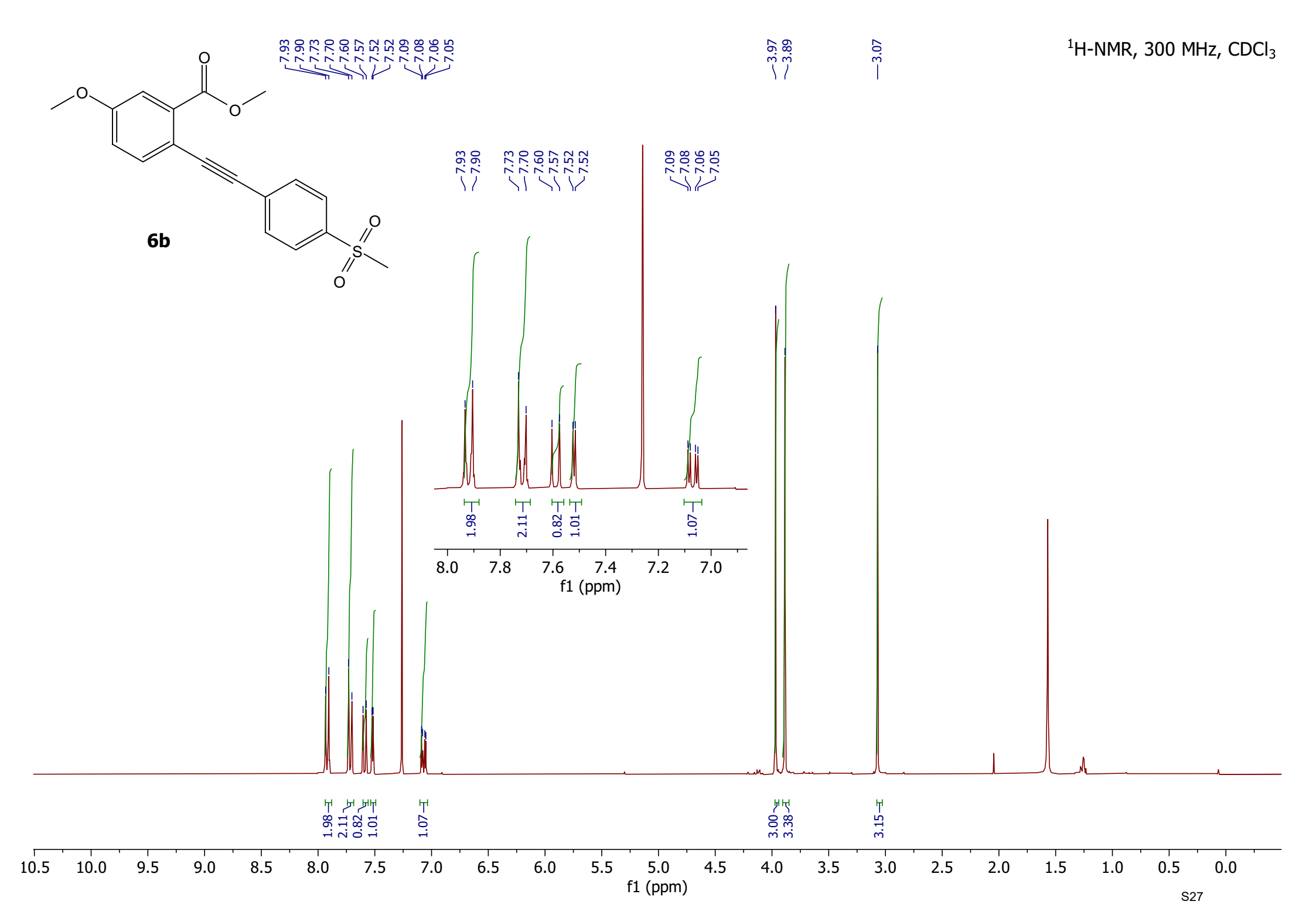

^{13}C-NMR, 75 MHz, DMSO
164.86
151.44
145.69
134.67
133.76
131.79
130.43
126.87
125.59
112.29
107.65
103.51
86.93
53.13
39.76
4c
39.76
42
41
40
39
38
f1 (ppm)
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)

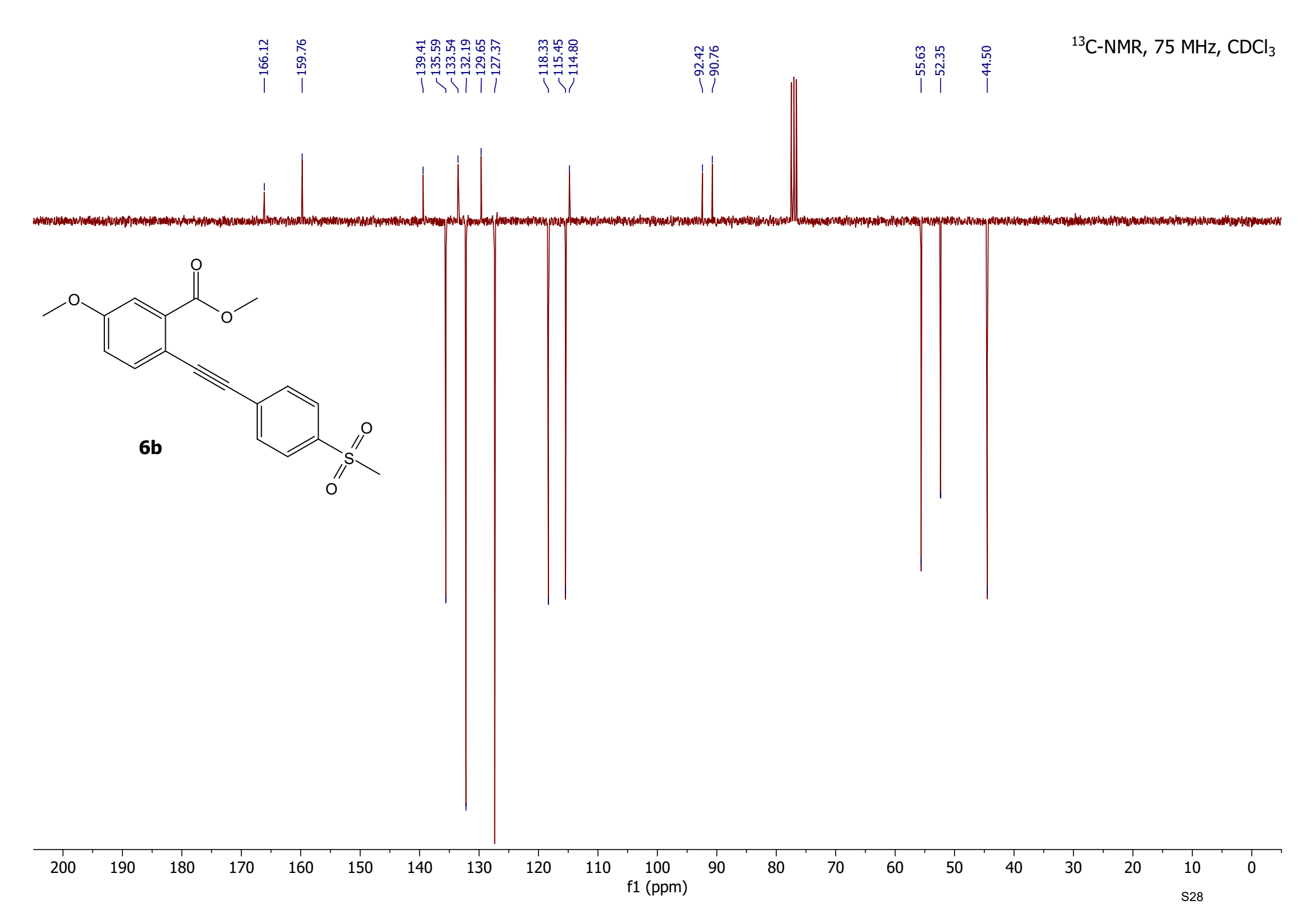


6a

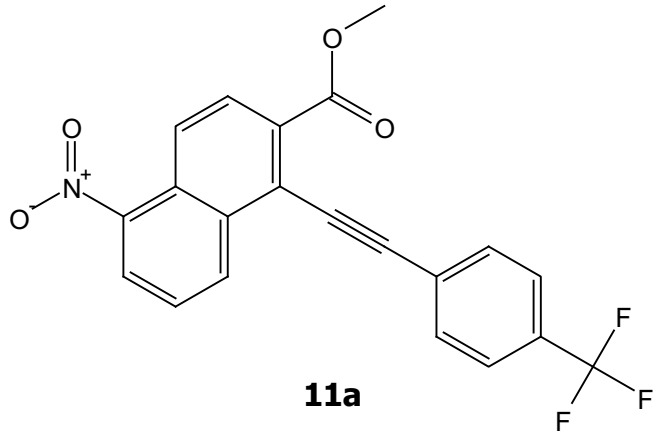
^{1}H-NMR, 300 MHz, $CDCl_3$


^{13}C-NMR, 75 MHz, $CDCl_3$
166.27
159.53
135.48
133.43
131.72
125.30
125.25
125.20
125.15
118.29
115.32
115.14
91.13
90.68
55.56
52.28
131.72
130.38
129.95
129.52
129.40
129.09
127.56
125.80
125.30
125.25
125.20
125.15
122.19
118.69
118.29
132 130 128 126 124 122 120 118
f1 (ppm)
125.30
125.25
125.20
125.15
125.6 125.2 124.8
f1 (ppm)
200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0
f1 (ppm)
O
O
O
F
F
6a

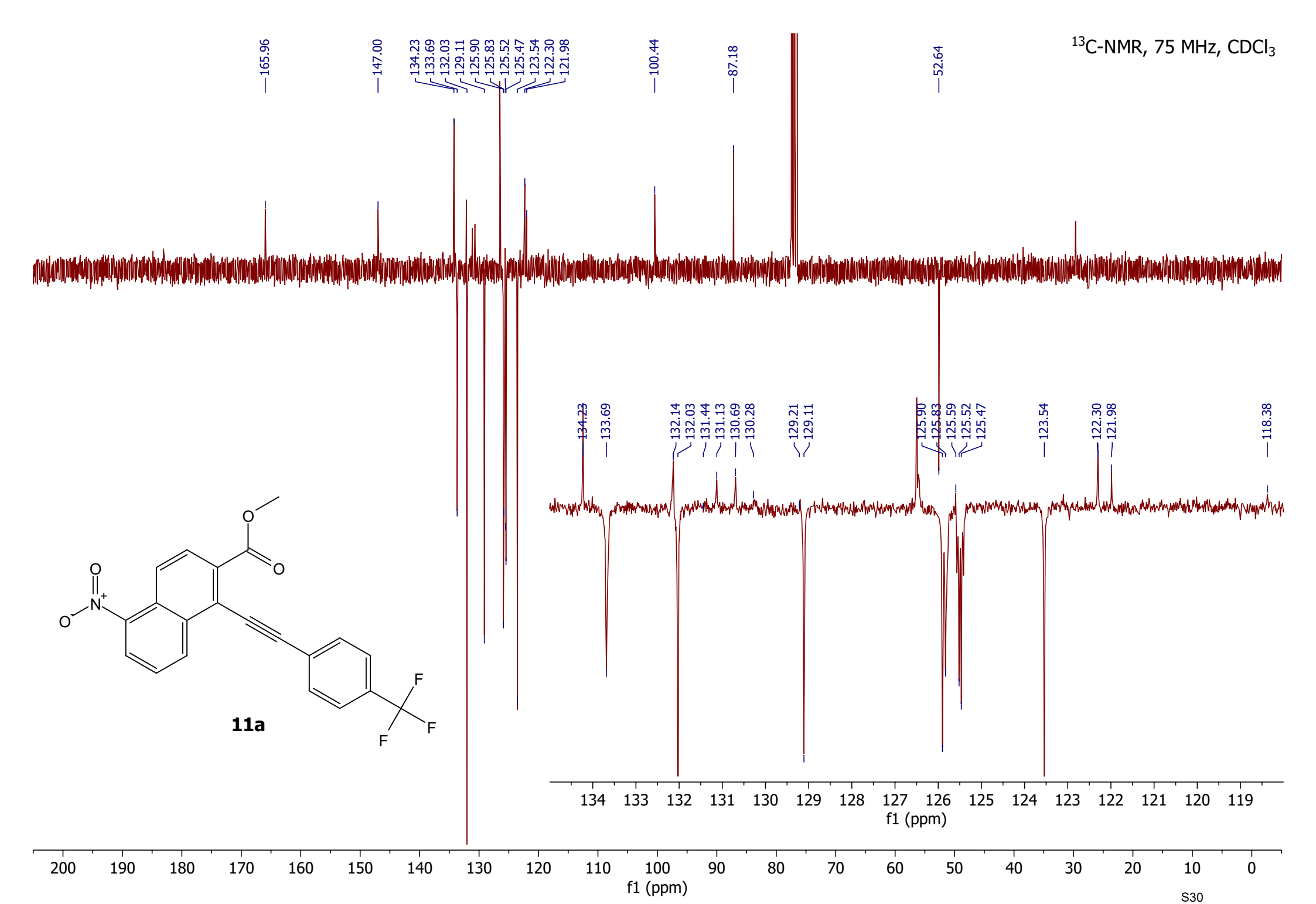

^{1}H-NMR, 300 MHz, $CDCl_3$
6b
7.93
7.90
7.73
7.70
7.60
7.57
7.52
7.52
7.09
7.08
7.06
7.05
3.97
3.89
3.07
1.98
2.11
0.82
1.01
1.07
3.00
3.38
3.15
f1 (ppm)

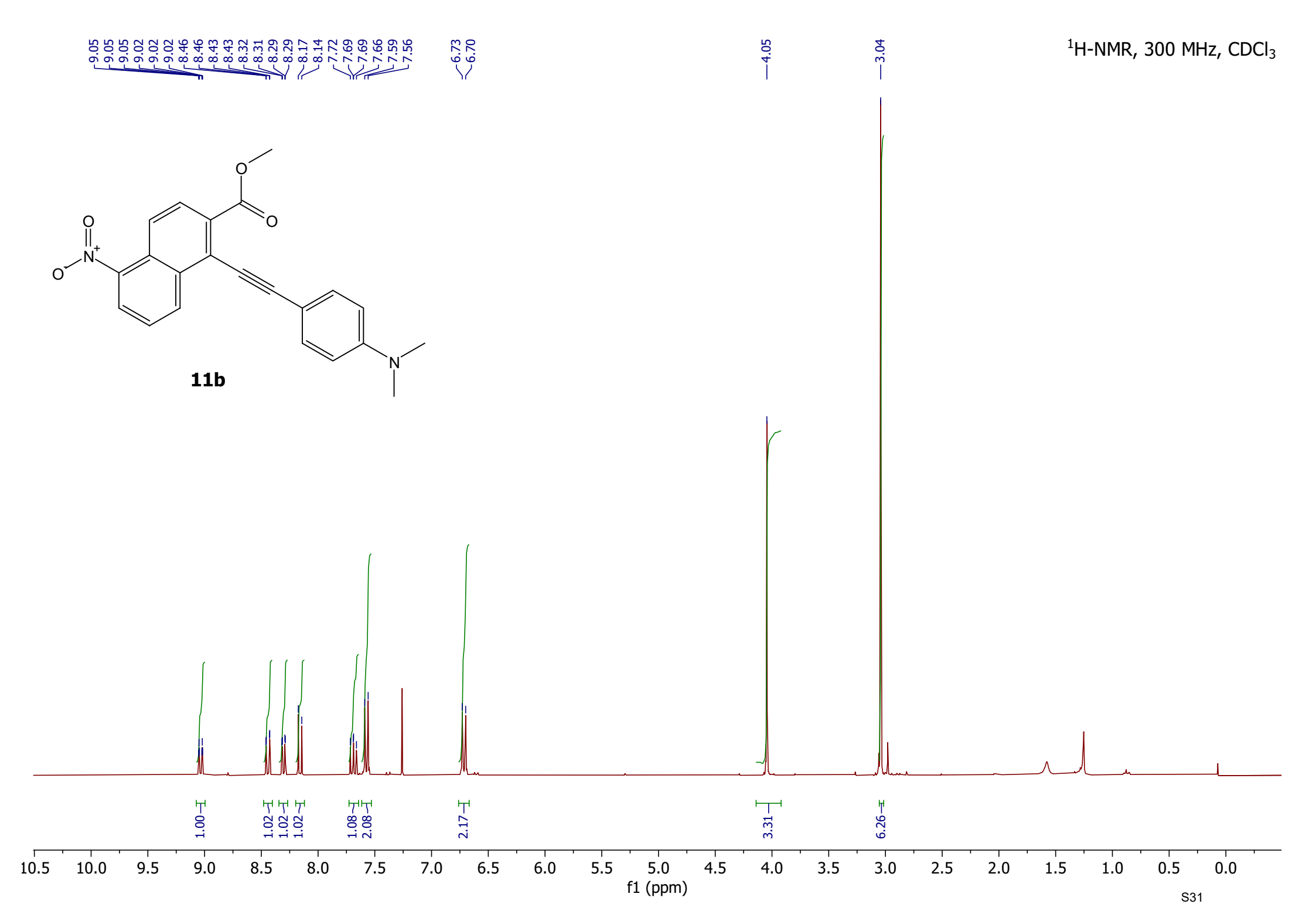

^{13}C-NMR, 75 MHz, $CDCl_3$
166.12
159.76
139.41
135.59
133.54
132.19
129.65
127.37
118.33
115.45
114.80
92.42
90.76
55.63
52.35
44.50
6b
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)

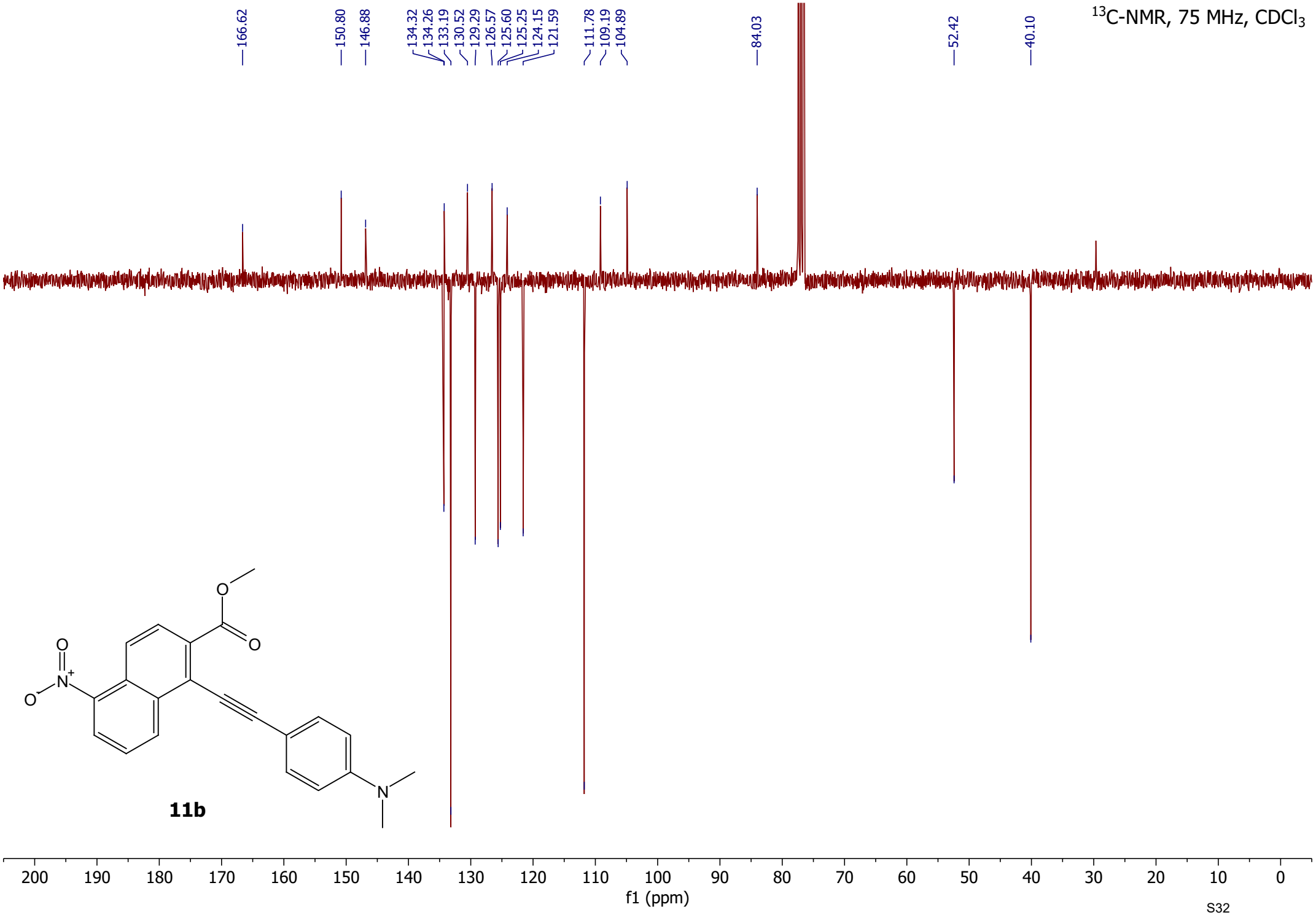
^{1}H-NMR, 300 MHz, $CDCl_3$

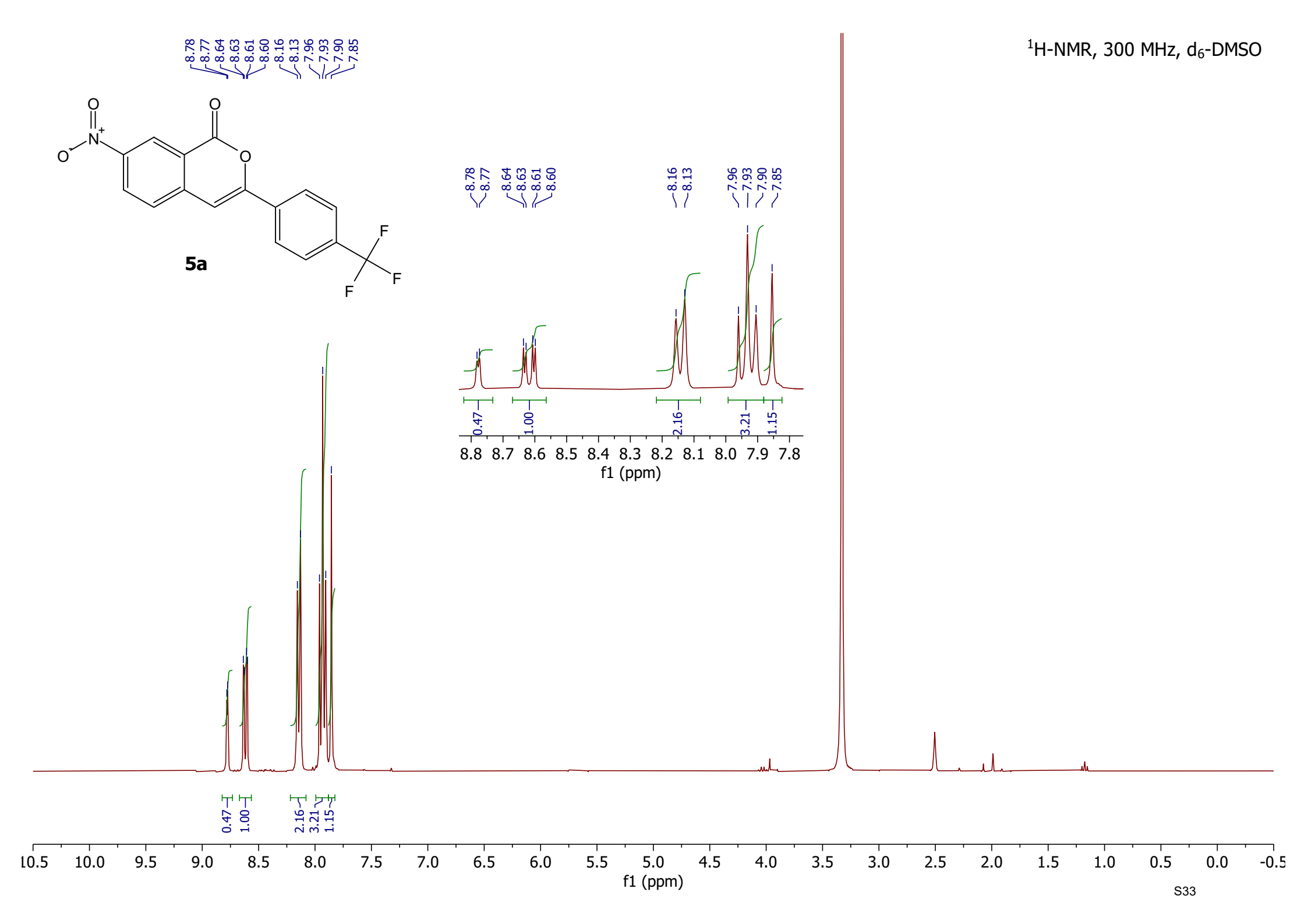


11a

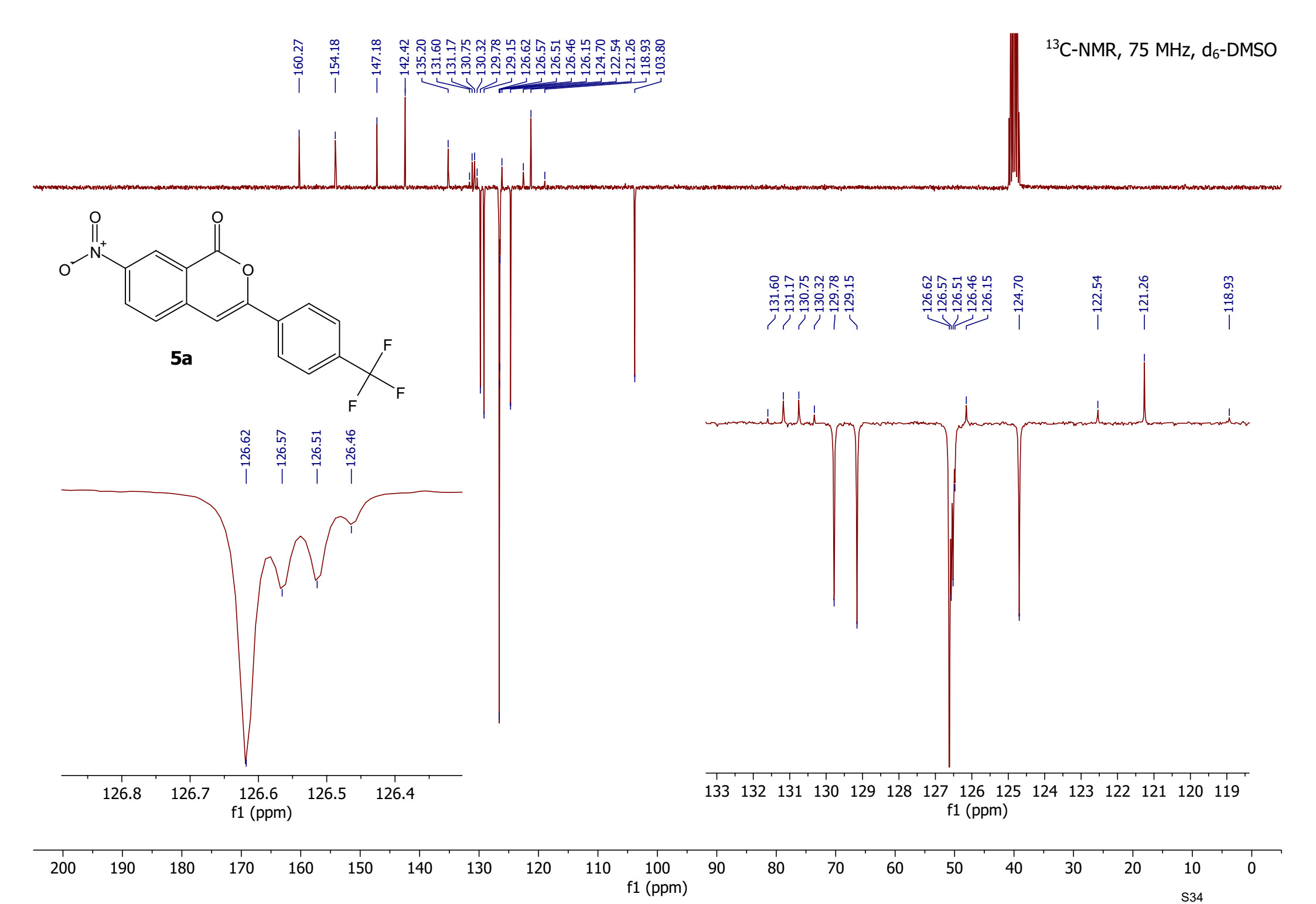

^{13}C-NMR, 75 MHz, $CDCl_3$
165.96
147.00
134.23
133.69
132.03
129.11
125.90
125.83
125.52
125.47
123.54
122.30
121.98
100.44
87.18
52.64
134.23
133.69
132.14
132.03
131.44
131.13
130.69
130.28
129.21
129.11
125.90
125.83
125.59
125.52
125.47
123.54
122.30
121.98
118.38
O
O
O
N+
O-
F
F
F
11a
f1 (ppm)
f1 (ppm)

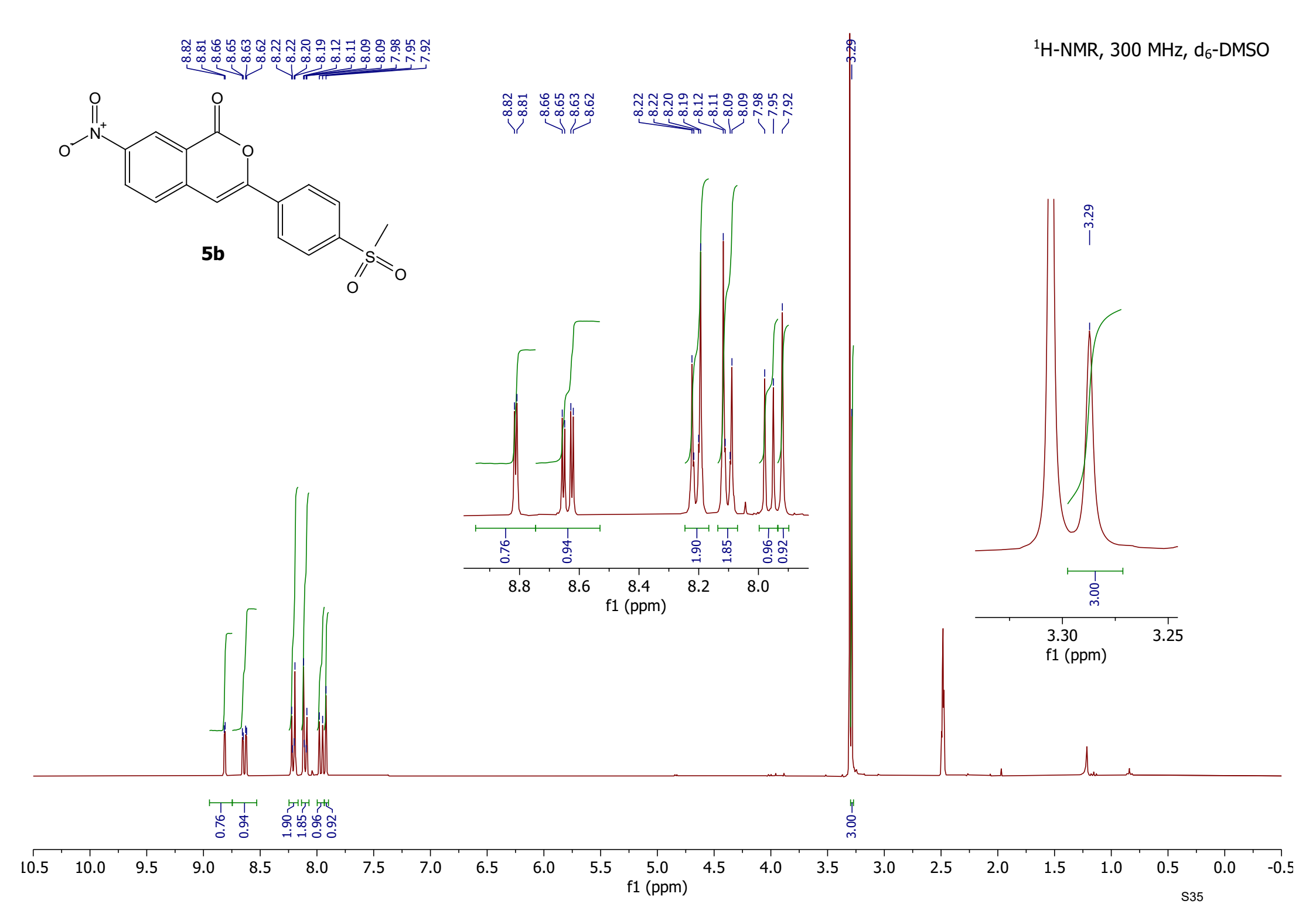

^{1}H-NMR, 300 MHz, $CDCl_3$
9.05
9.05
9.05
9.02
9.02
9.02
8.46
8.46
8.43
8.43
8.32
8.31
8.29
8.29
8.17
8.14
7.72
7.69
7.69
7.66
7.59
7.56
6.73
6.70
4.05
3.04
11b
1.00
1.02
1.02
1.02
1.08
2.08
2.17
3.31
6.26
f1 (ppm)

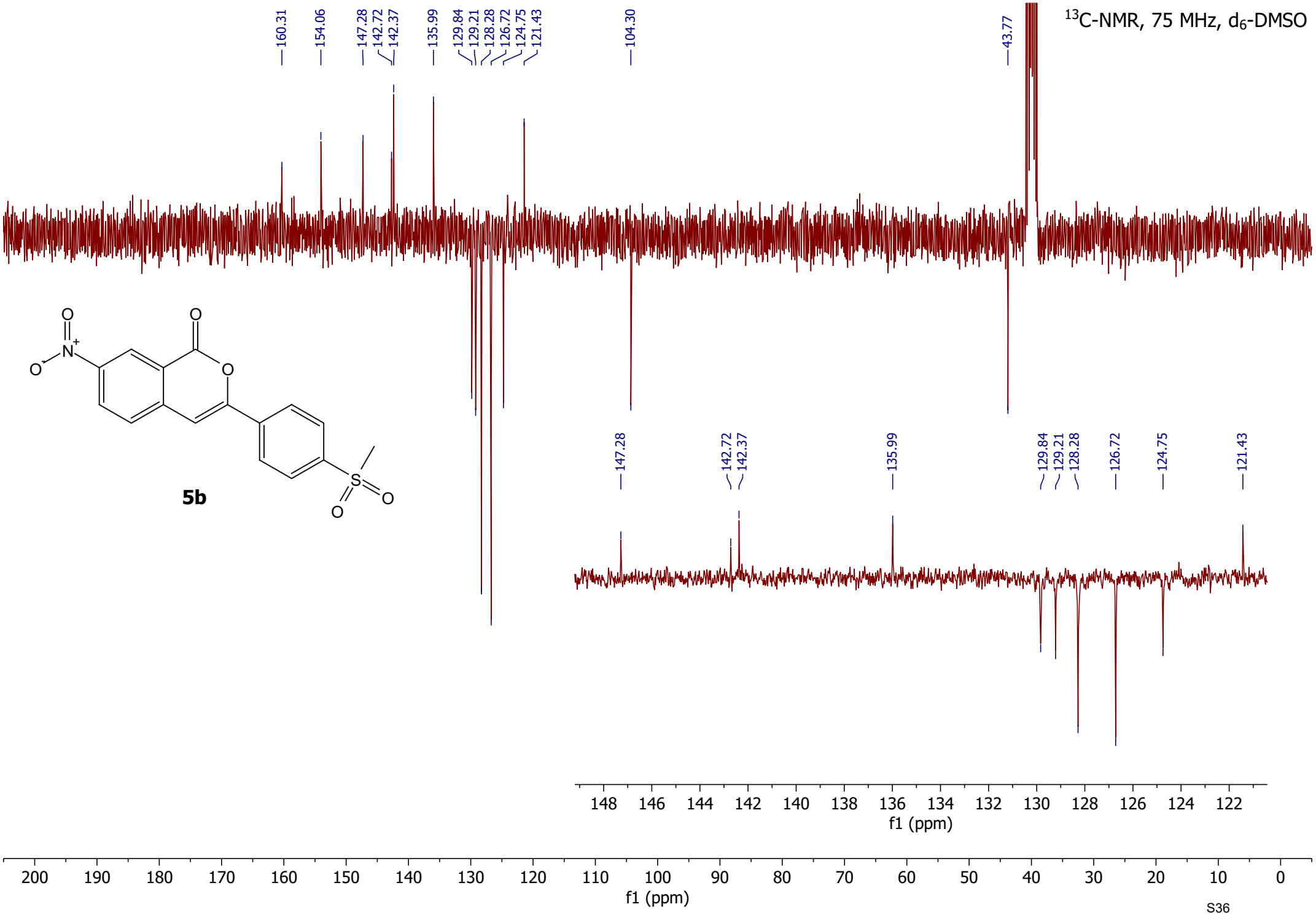

^{13}C-NMR, 75 MHz, $CDCl_3$
166.62
150.80
146.88
134.32
134.26
133.19
130.52
129.29
126.57
125.60
125.25
124.15
121.59
111.78
109.19
104.89
84.03
52.42
40.10
O
O
O
N+
O-
N
11b
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)

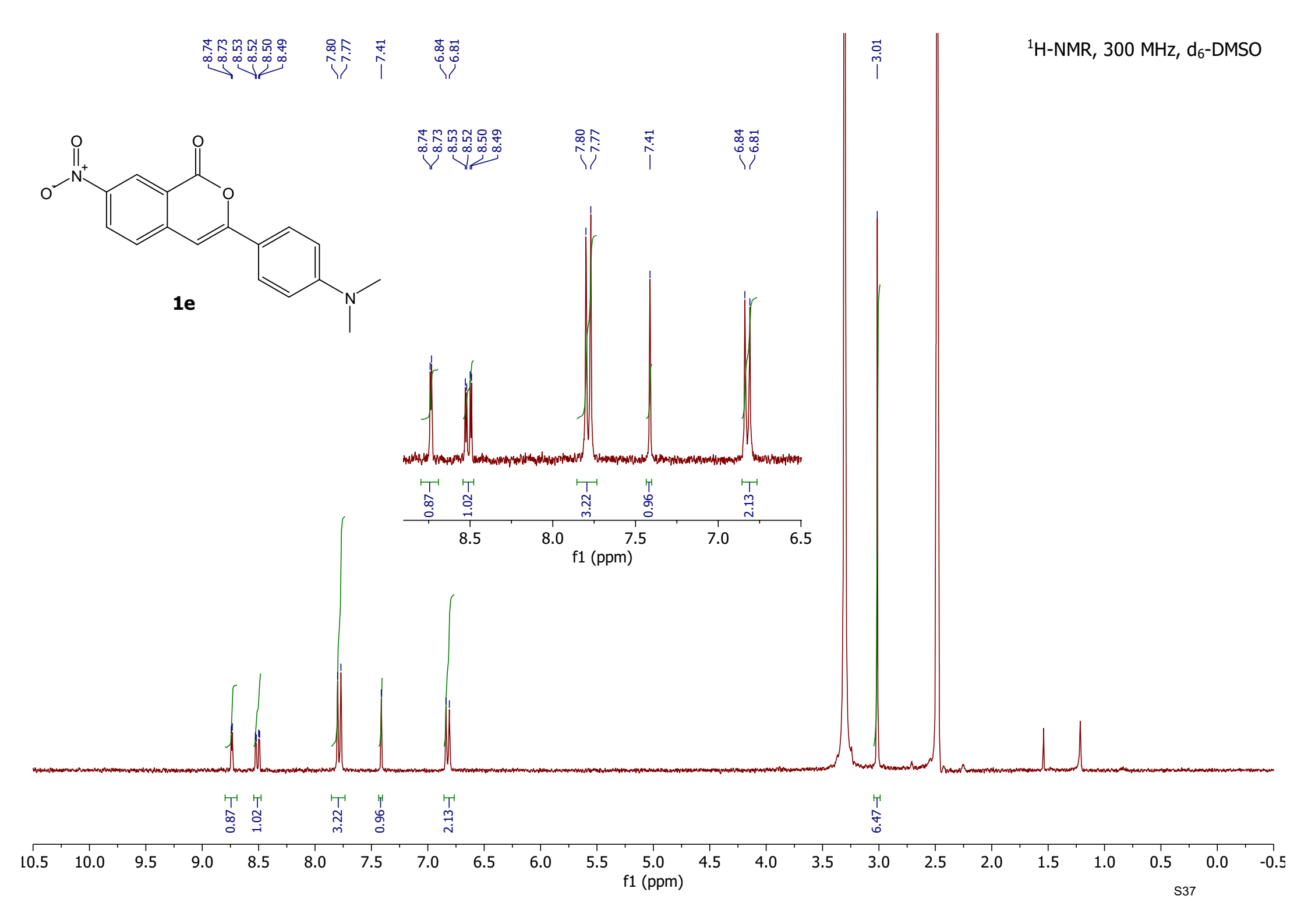


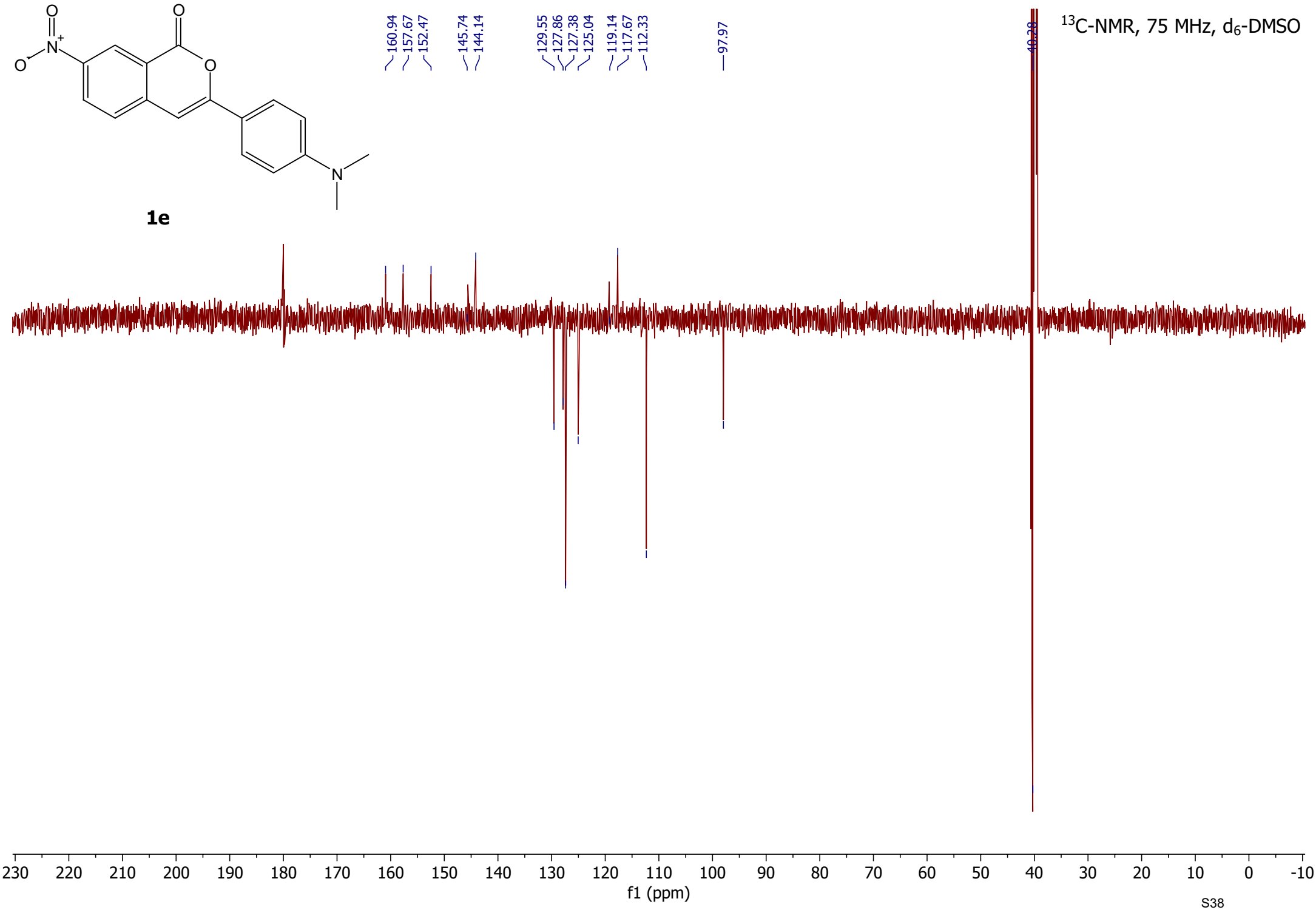
^{1}H-NMR, 300 MHz, d_6-DMSO

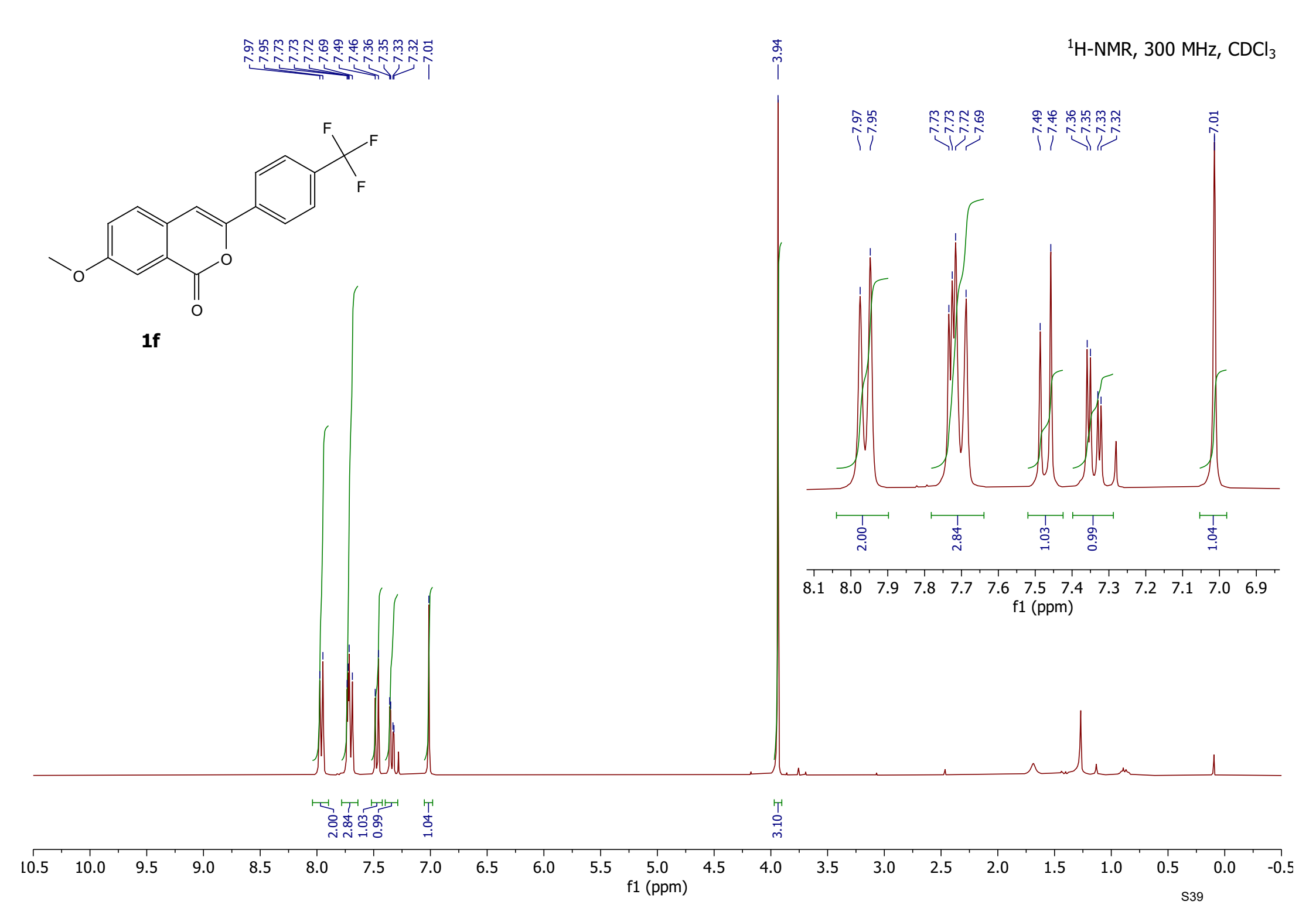

^{13}C-NMR, 75 MHz, d$_6$-DMSO
160.27
154.18
147.18
142.42
135.20
131.60
131.17
130.75
130.32
129.78
129.15
126.62
126.57
126.51
126.46
126.15
124.70
122.54
121.26
118.93
103.80
5a
f1 (ppm)
f1 (ppm)
f1 (ppm)

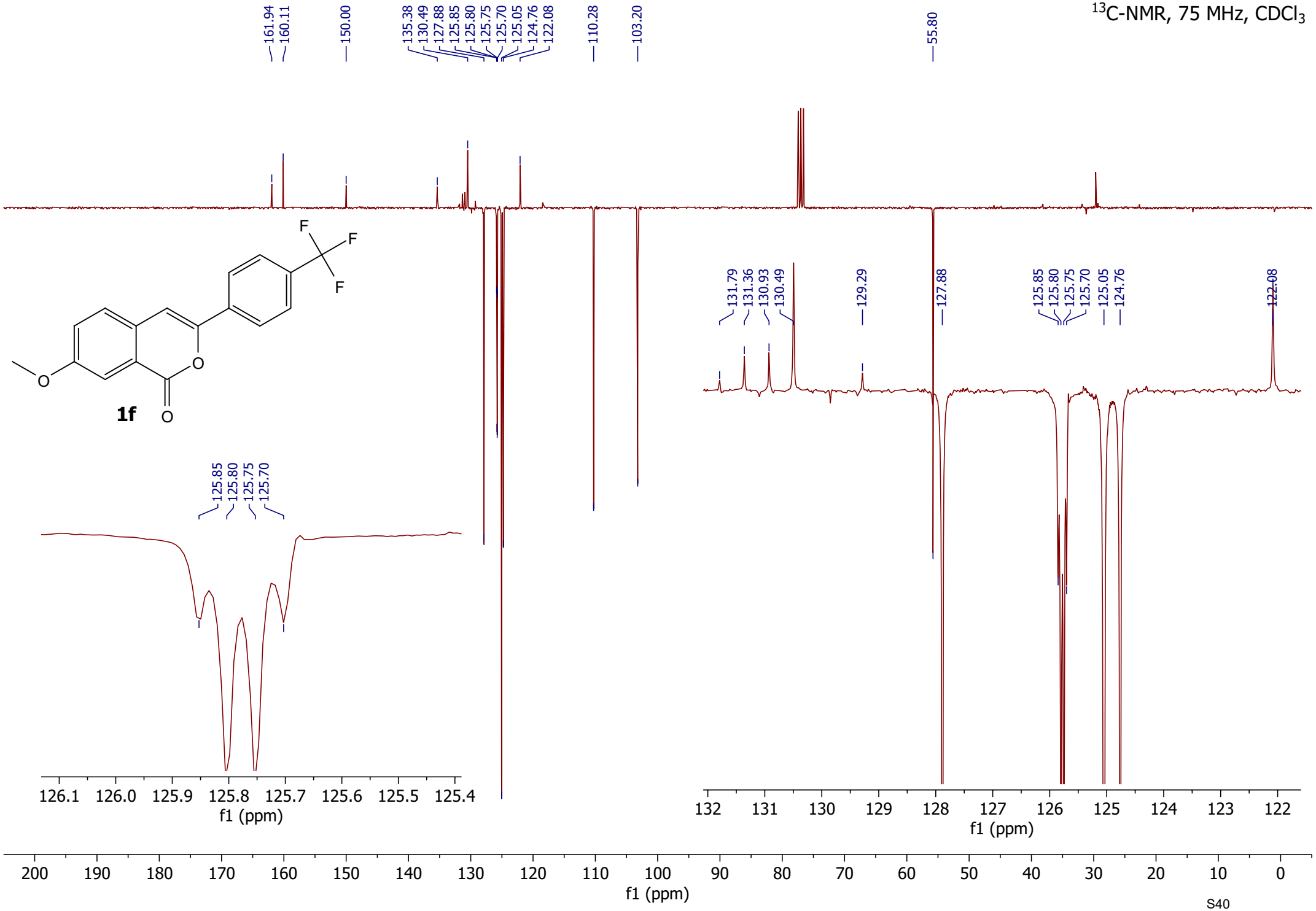

^{1}H-NMR, 300 MHz, d_6-DMSO
8.82
8.81
8.66
8.65
8.63
8.62
8.22
8.22
8.20
8.19
8.12
8.11
8.09
8.09
7.98
7.95
7.92
3.29
5b
0.76
0.94
1.90
1.85
0.96
0.92
3.00
f1 (ppm)

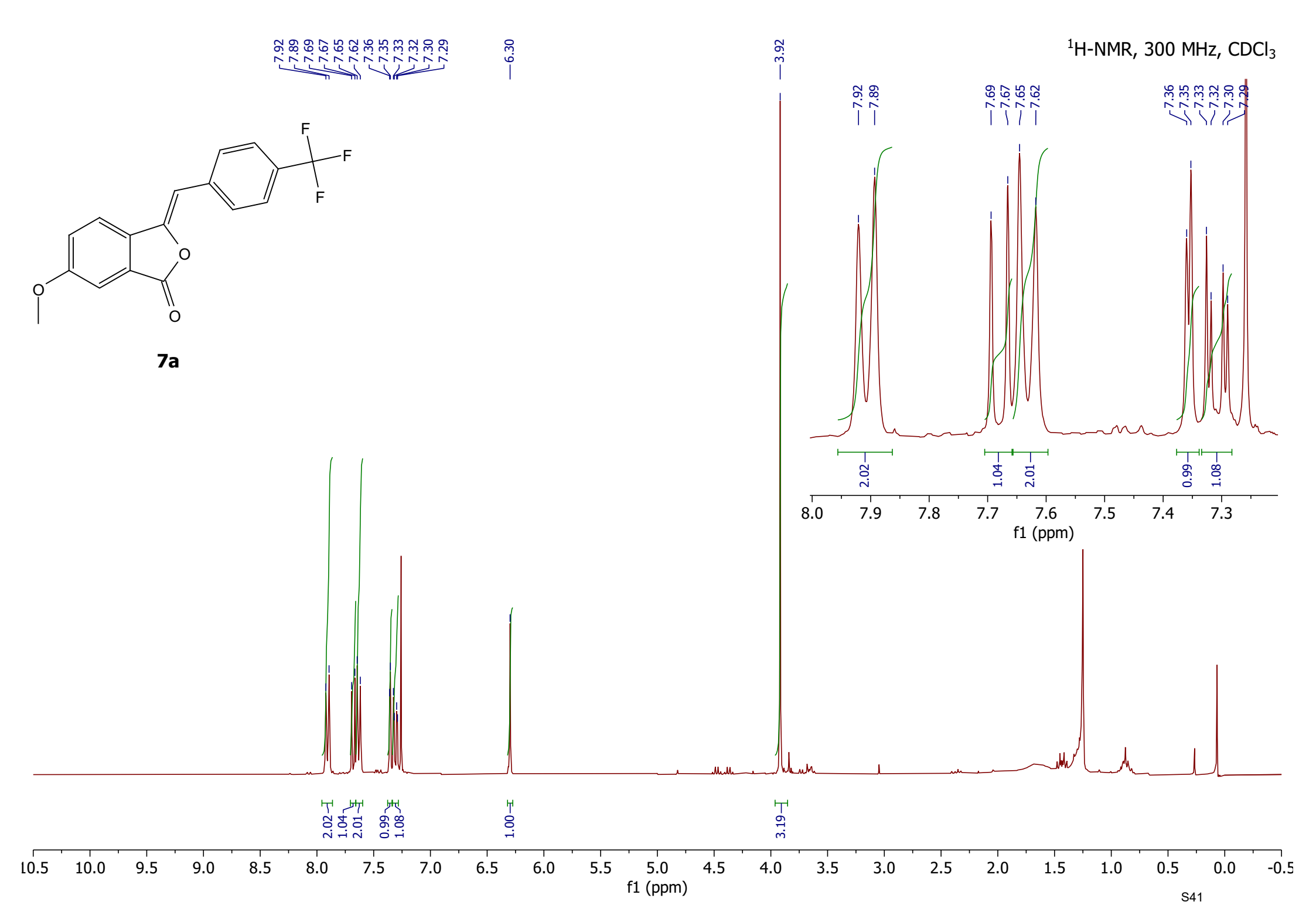

^{13}C-NMR, 75 MHz, d_6-DMSO
160.31
154.06
147.28
142.72
142.37
135.99
129.84
129.21
128.28
126.72
124.75
121.43
104.30
43.77
5b
f1 (ppm)
f1 (ppm)

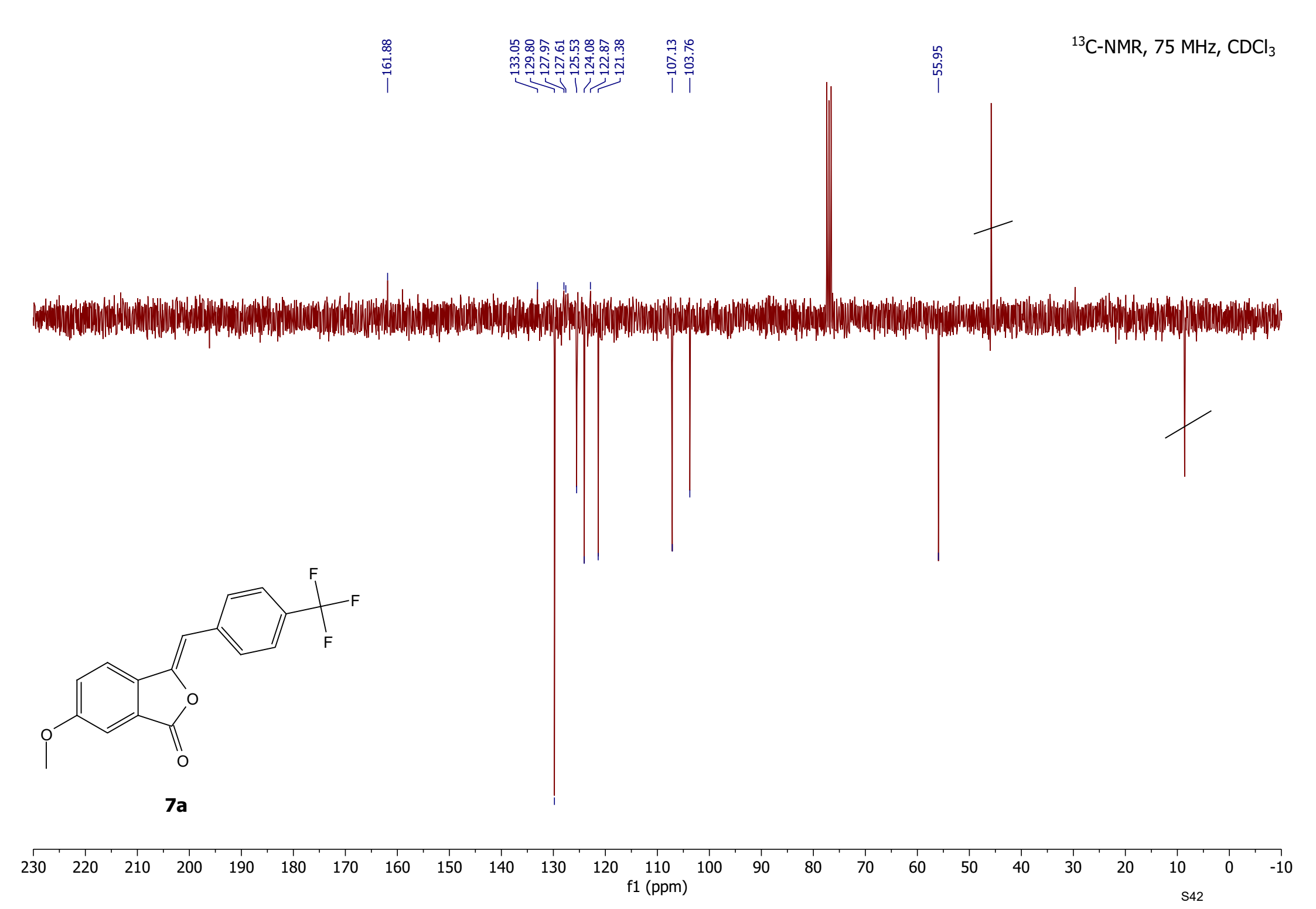

^{1}H-NMR, 300 MHz, d_6-DMSO
8.74
8.73
8.53
8.52
8.50
8.49
7.80
7.77
7.41
6.84
6.81
3.01
1e
0.87
1.02
3.22
0.96
2.13
6.47
f1 (ppm)

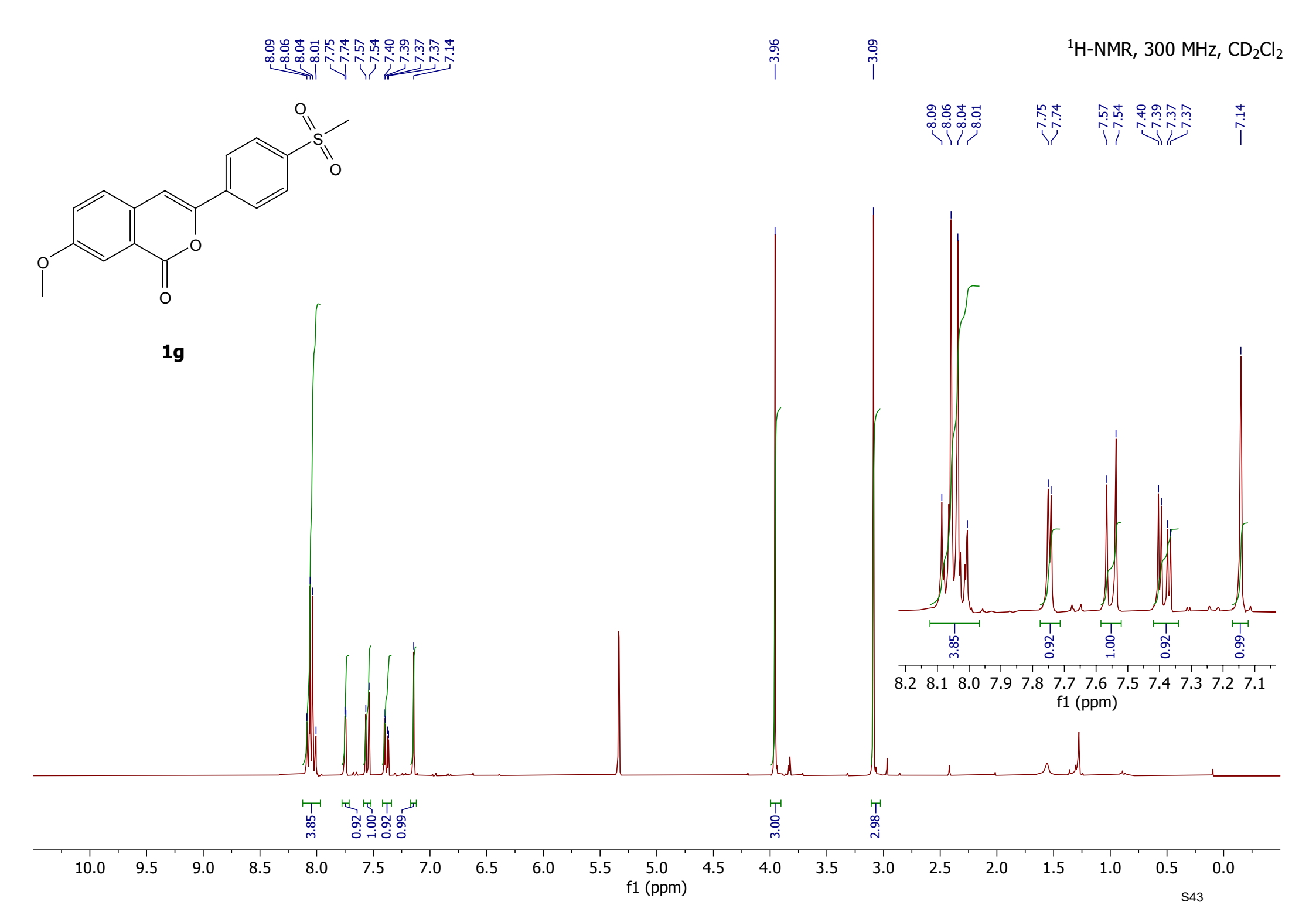

160.94
157.67
152.47
145.74
144.14
129.55
127.86
127.38
125.04
119.14
117.67
112.33
97.97
40.29
^{13}C-NMR, 75 MHz, d_6-DMSO
1e
230 220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
f1 (ppm)

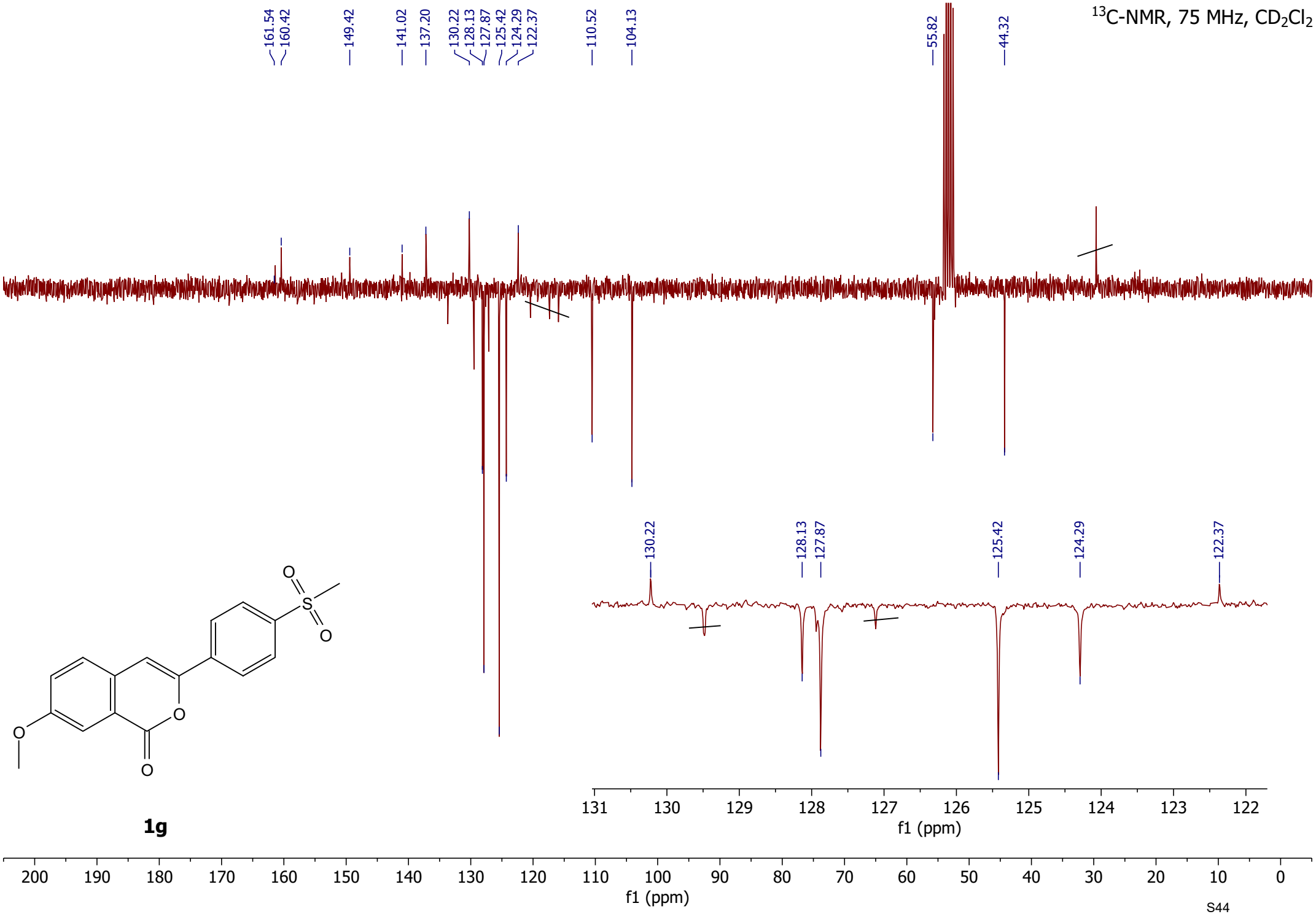

^{1}H-NMR, 300 MHz, $CDCl_3$
7.97
7.95
7.73
7.73
7.72
7.69
7.49
7.46
7.36
7.35
7.33
7.32
7.01
3.94
F
F
F
O
O
O
1f
2.00
2.84
1.03
0.99
1.04
3.10
f1 (ppm)

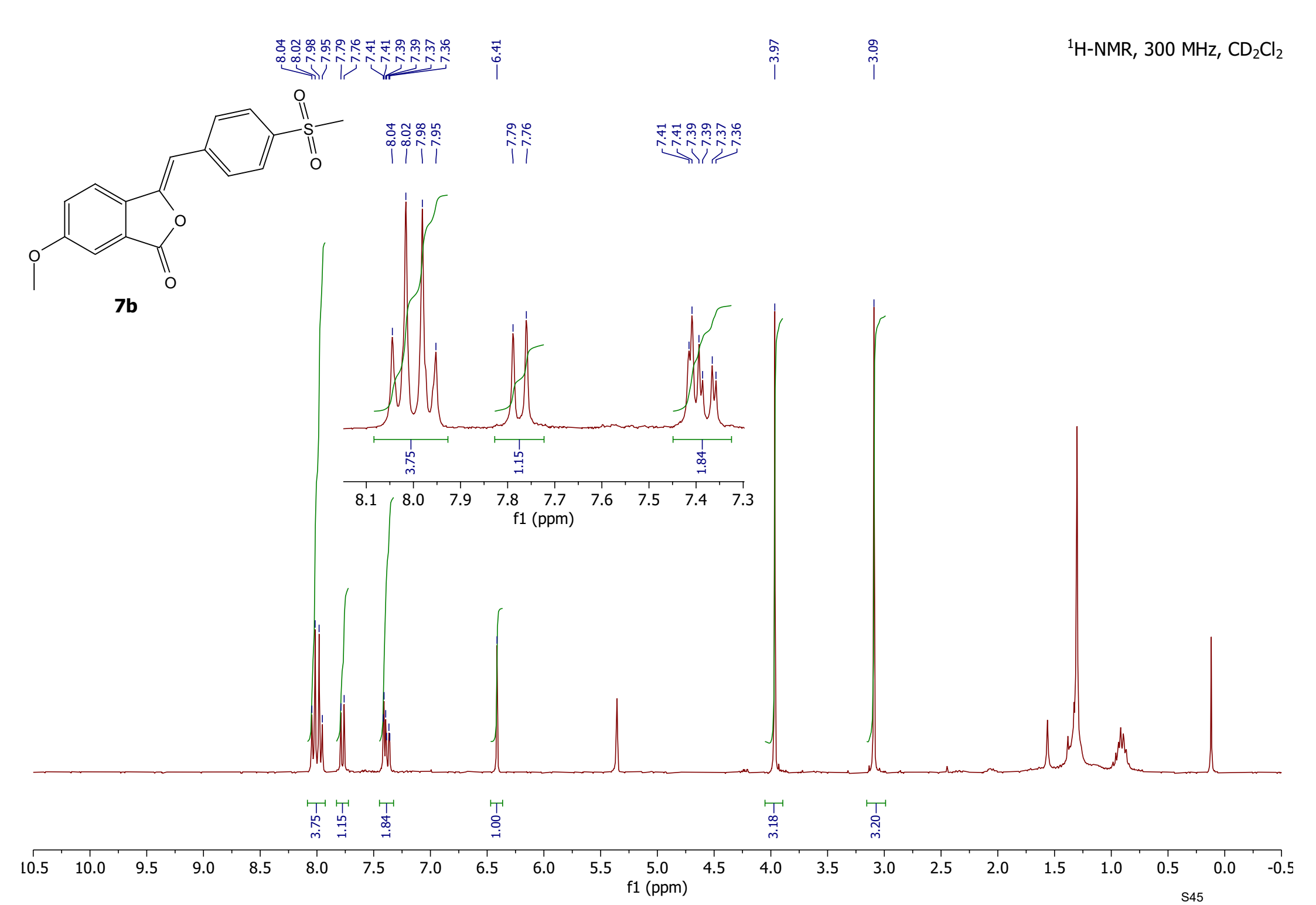

^{13}C-NMR, 75 MHz, $CDCl_3$
161.94
160.11
150.00
135.38
130.49
127.88
125.85
125.80
125.75
125.70
125.05
124.76
122.08
110.28
103.20
55.80
F
F
F
O
O
O
1f
131.79
131.36
130.93
130.49
129.29
127.88
125.85
125.80
125.75
125.70
125.05
124.76
122.08
f1 (ppm)
f1 (ppm)
f1 (ppm)

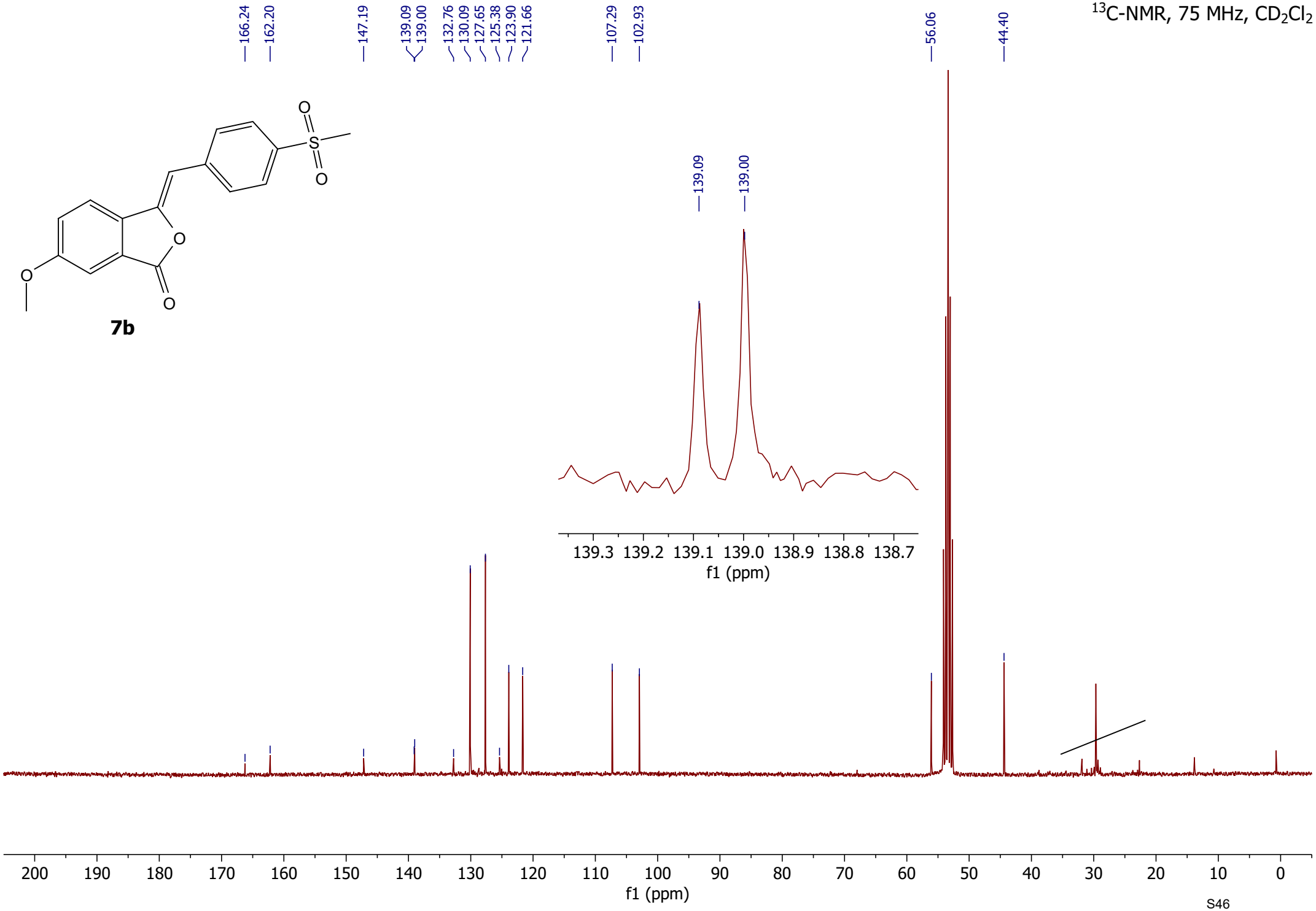

^{1}H-NMR, 300 MHz, $CDCl_3$
7.92
7.89
7.69
7.67
7.65
7.62
7.36
7.35
7.33
7.32
7.30
7.29
6.30
3.92
F
F
F
O
O
O
7a
2.02
1.04
2.01
0.99
1.08
1.00
3.19
f1 (ppm)

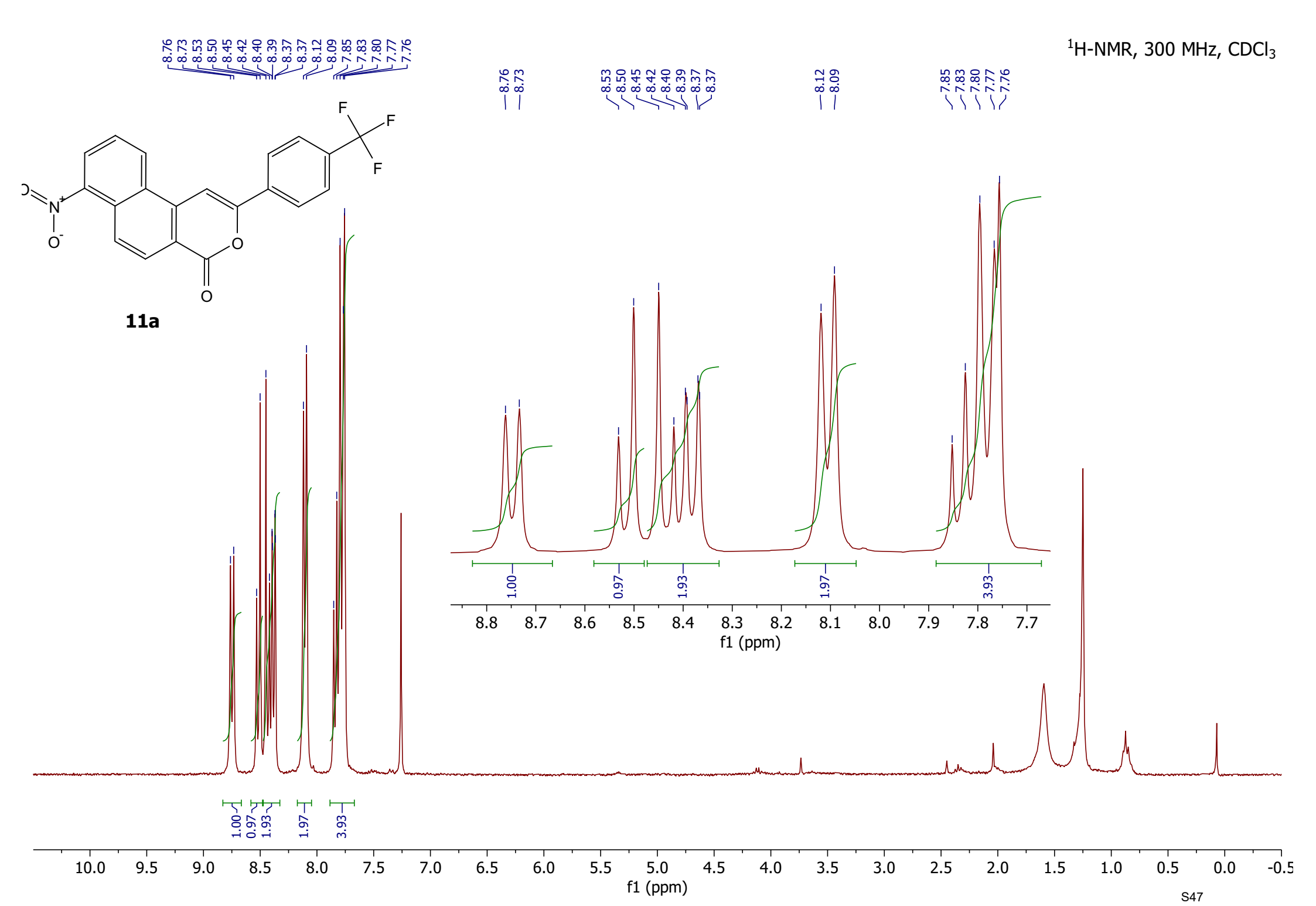

^{13}C-NMR, 75 MHz, $CDCl_3$
161.88
133.05
129.80
127.97
127.61
125.53
124.08
122.87
121.38
107.13
103.76
55.95
F
F
F
O
O
O
7a
230 220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
f1 (ppm)

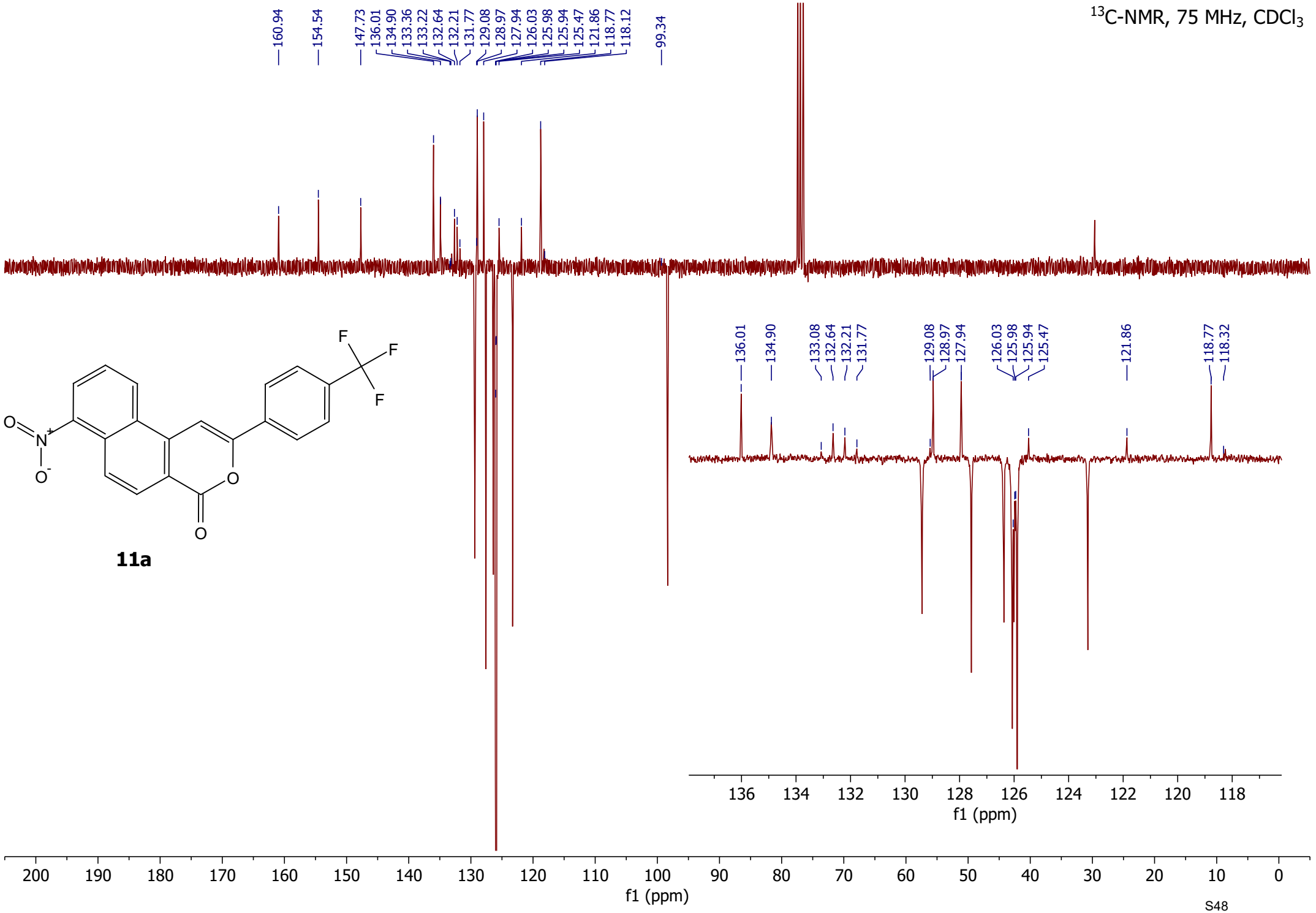

^{1}H-NMR, 300 MHz, CD_2Cl_2
8.09
8.06
8.04
8.01
7.75
7.74
7.57
7.54
7.40
7.39
7.37
7.37
7.14
3.96
3.09
O
S
O
O
O
O
1g
3.85
0.92
1.00
0.92
0.99
3.00
2.98
f1 (ppm)
S43

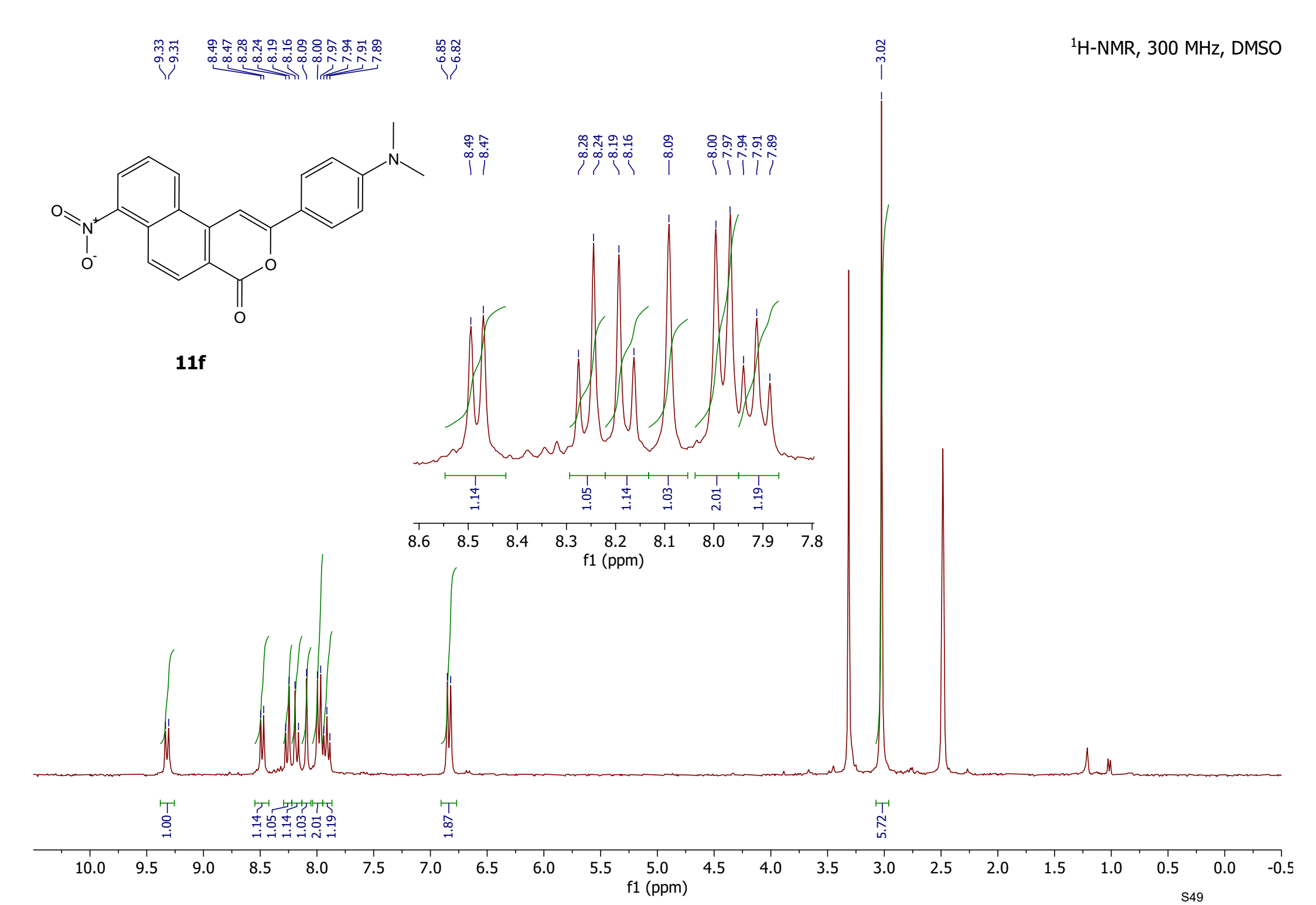

^{13}C-NMR, 75 MHz, CD_2Cl_2
161.54
160.42
149.42
141.02
137.20
130.22
128.13
127.87
125.42
124.29
122.37
110.52
104.13
55.82
44.32
O
S
O
O
O
O
1g
131
130
129
128
127
126
125
124
123
122
f1 (ppm)
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)

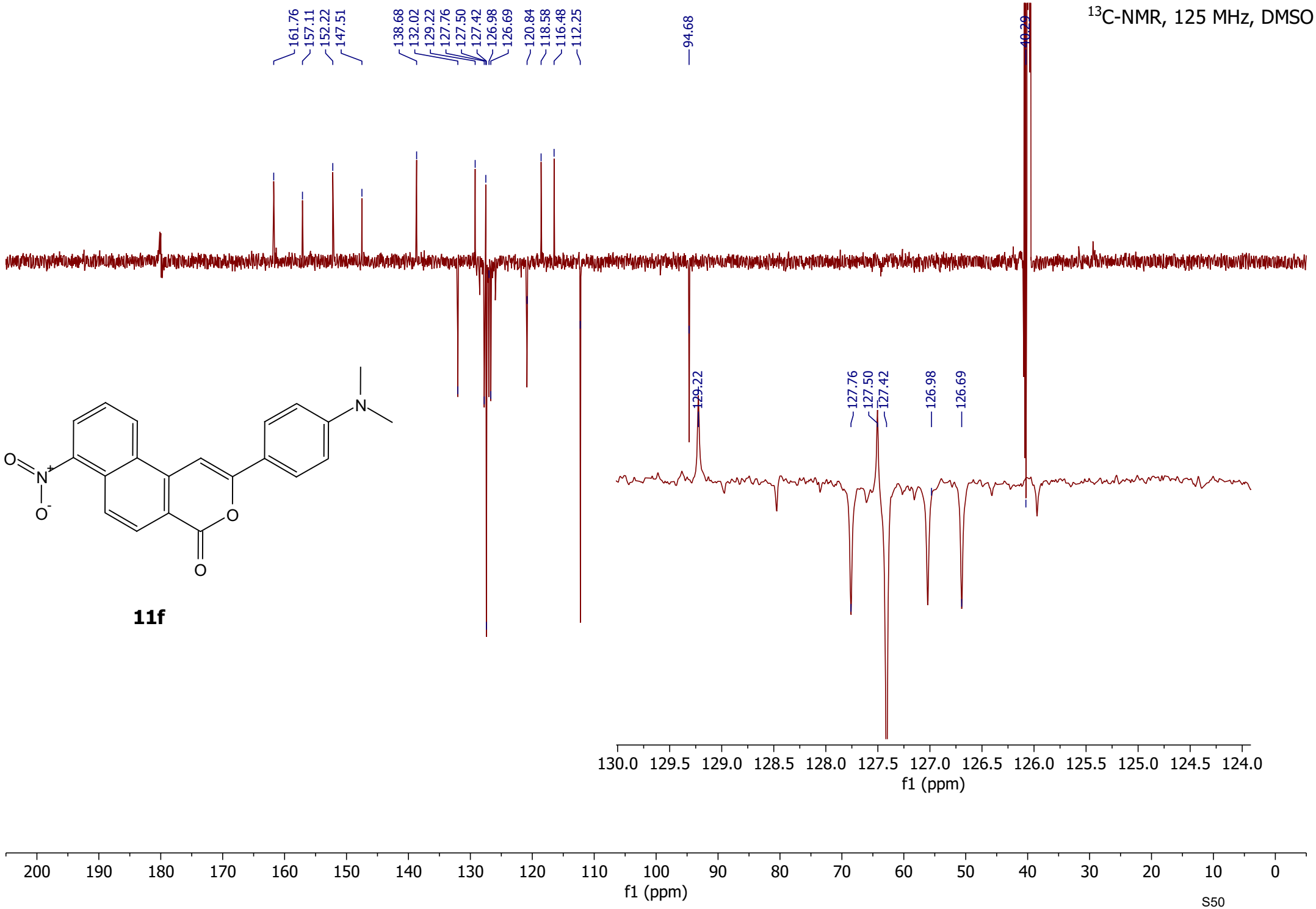

^{1}H-NMR, 300 MHz, CD_2Cl_2
8.04
8.02
7.98
7.95
7.79
7.76
7.41
7.41
7.39
7.39
7.37
7.36
6.41
3.97
3.09
7b
3.75
1.15
1.84
1.00
3.18
3.20
f1 (ppm)
S45

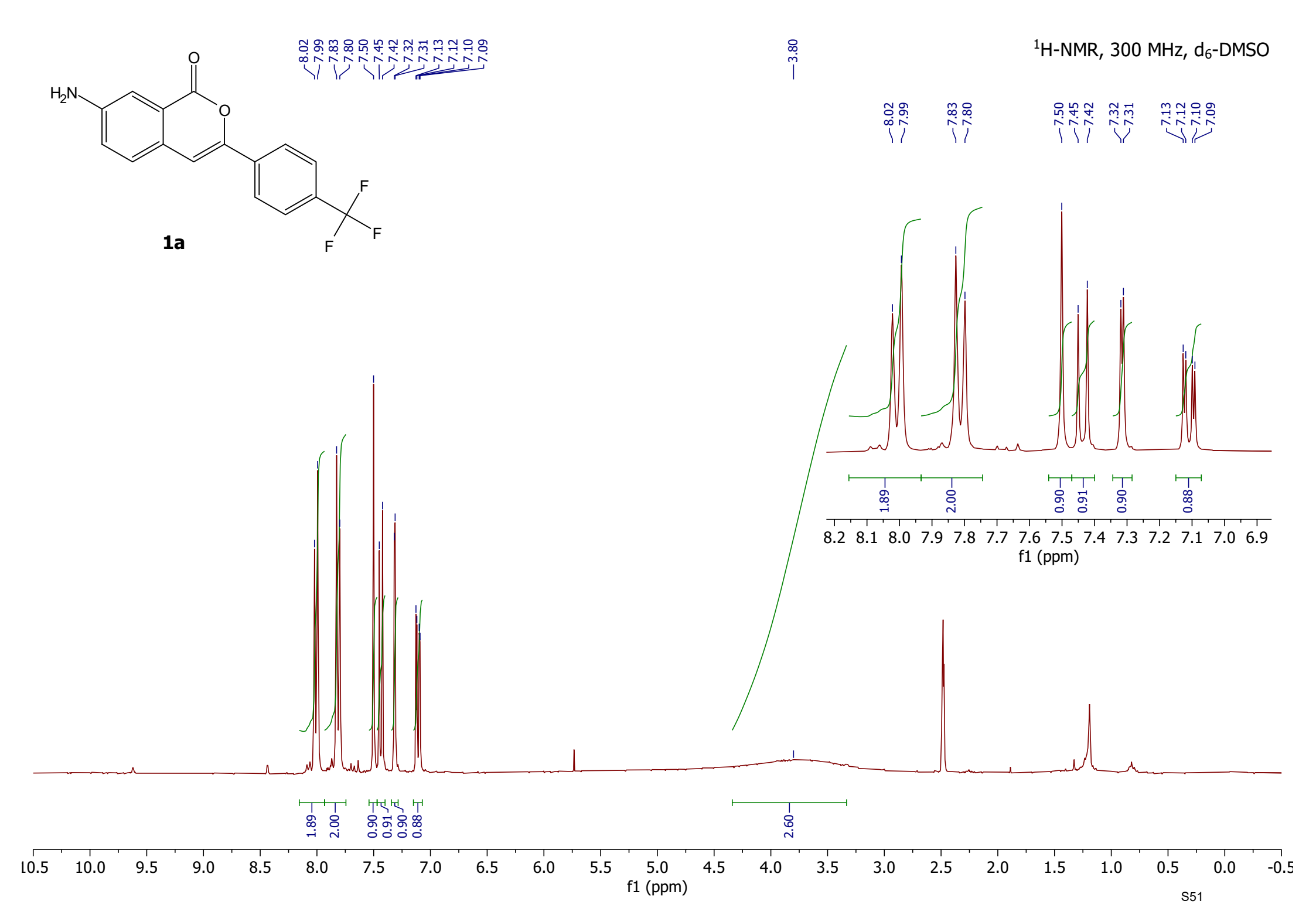

166.24
162.20
147.19
139.09
139.00
132.76
130.09
127.65
125.38
123.90
121.66
107.29
102.93
56.06
44.40
^{13}C-NMR, 75 MHz, CD_2Cl_2
O
S
O
O
O
O
O
7b
139.09
139.00
139.3 139.2 139.1 139.0 138.9 138.8 138.7
f1 (ppm)
200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0
f1 (ppm)

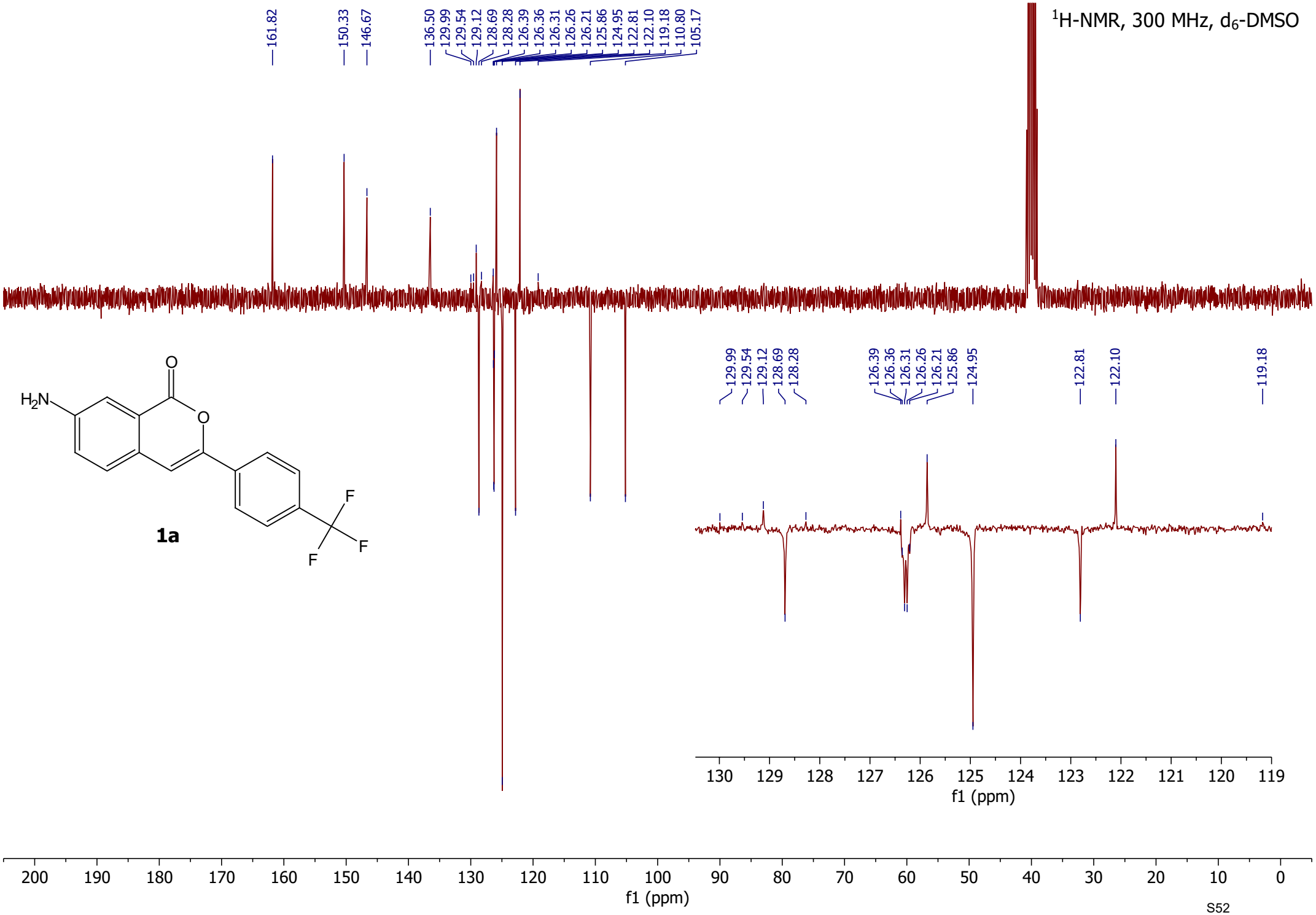

^{1}H-NMR, 300 MHz, $CDCl_3$
8.76 8.73 8.53 8.50 8.45 8.42 8.40 8.39 8.37 8.37 8.12 8.09 7.85 7.83 7.80 7.77 7.76
F F F
N+ O- O O
11a
1.00 0.97 1.93 1.97 3.93
f1 (ppm)

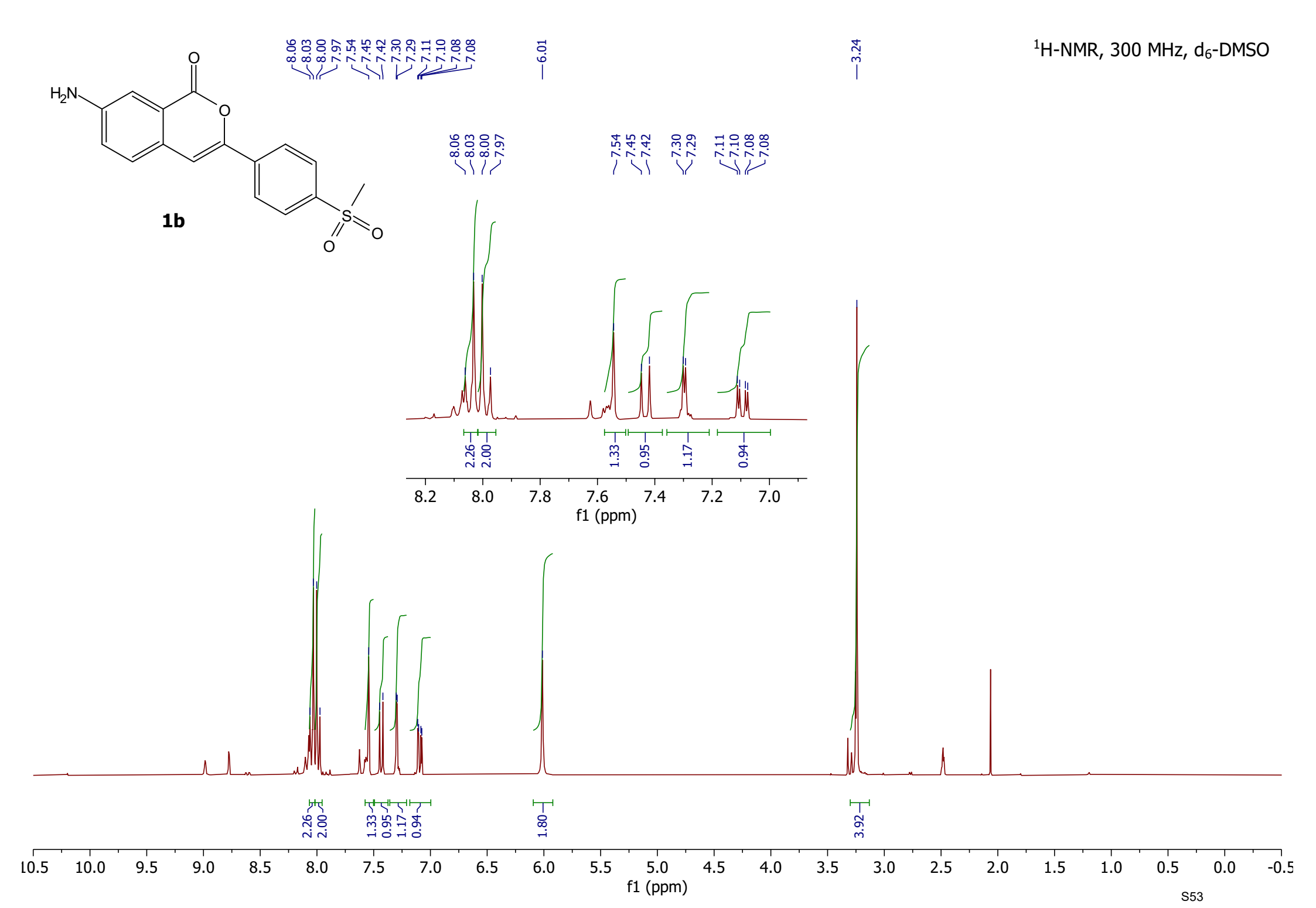

^{13}C-NMR, 75 MHz, $CDCl_3$
160.94
154.54
147.73
136.01
134.90
133.36
133.22
132.64
132.21
131.77
129.08
128.97
127.94
126.03
125.98
125.94
125.47
121.86
118.77
118.12
99.34
F
F
F
O
N
O
O
O
11a
136.01
134.90
133.08
132.64
132.21
131.77
129.08
128.97
127.94
126.03
125.98
125.94
125.47
121.86
118.77
118.32
136
134
132
130
128
126
124
122
120
118
f1 (ppm)
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)

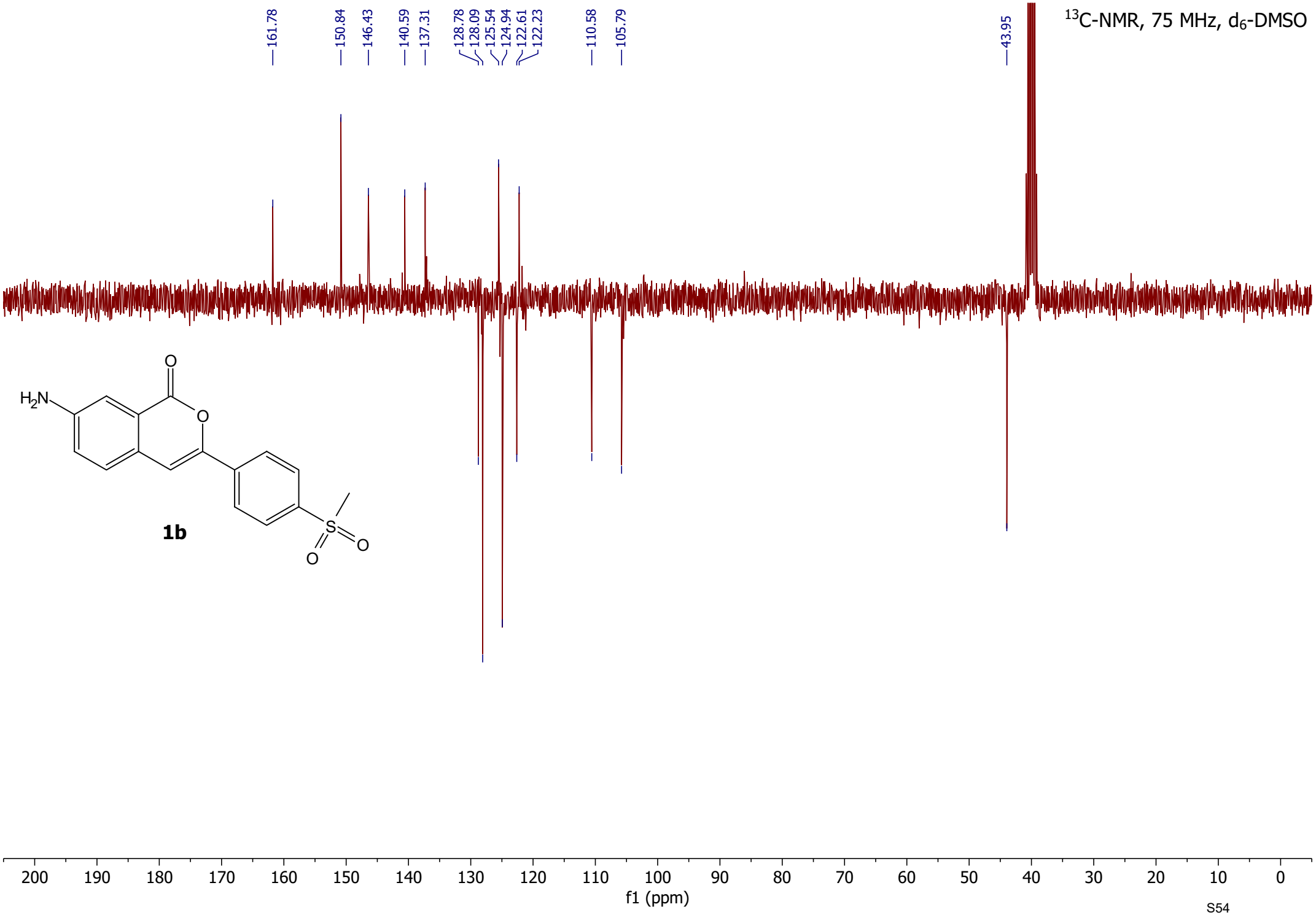

^{1}H-NMR, 300 MHz, DMSO
9.33
9.31
8.49
8.47
8.28
8.24
8.19
8.16
8.09
8.00
7.97
7.94
7.91
7.89
6.85
6.82
3.02
11f
1.00
1.14
1.05
1.14
1.03
2.01
1.19
1.87
5.72
f1 (ppm)

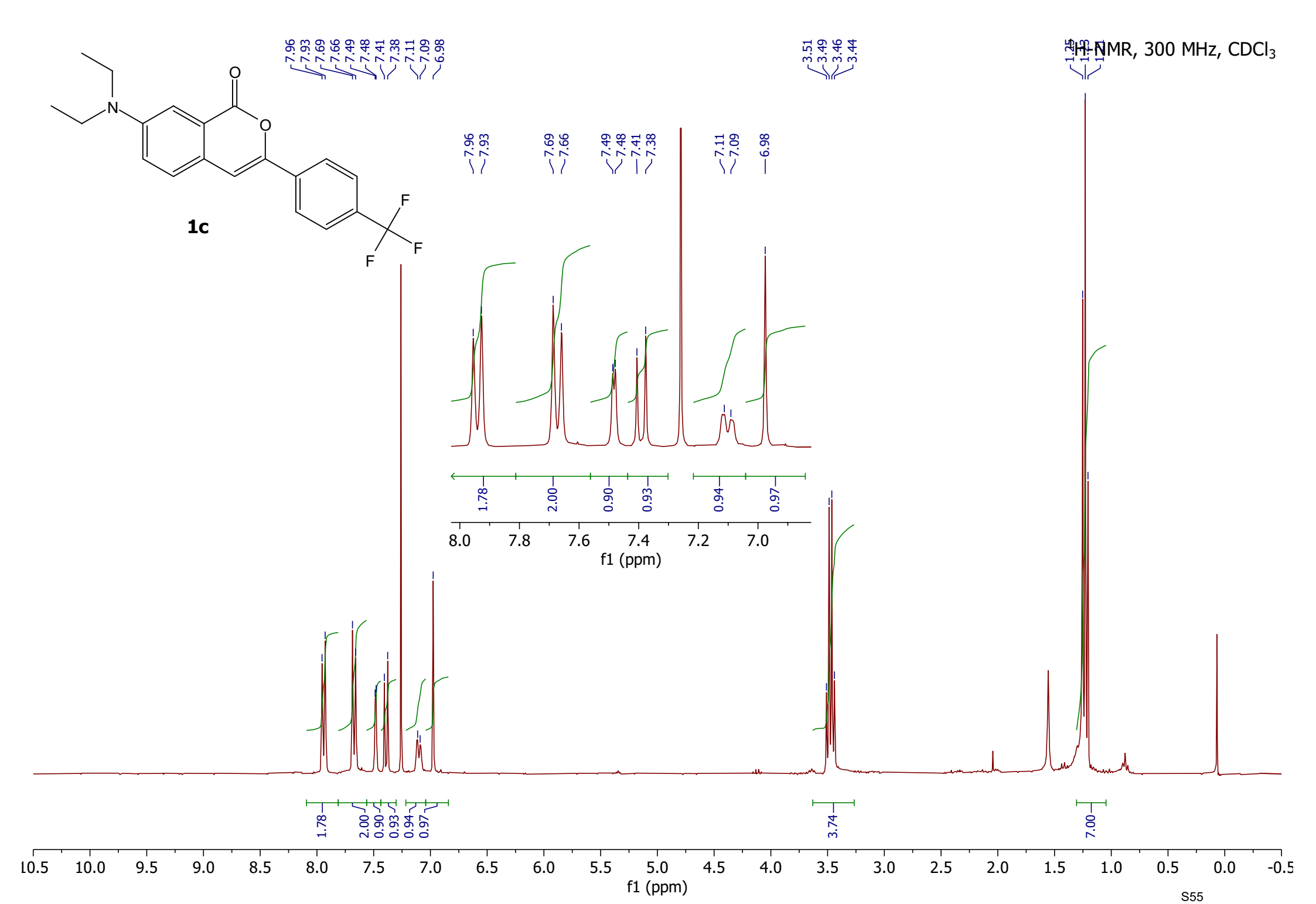

^{13}C-NMR, 125 MHz, DMSO
161.76
157.11
152.22
147.51
138.68
132.02
129.22
127.76
127.50
127.42
126.98
126.69
120.84
118.58
116.48
112.25
94.68
40.29
129.22
127.76
127.50
127.42
126.98
126.69
130.0 129.5 129.0 128.5 128.0 127.5 127.0 126.5 126.0 125.5 125.0 124.5 124.0
f1 (ppm)
200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0
f1 (ppm)
11f

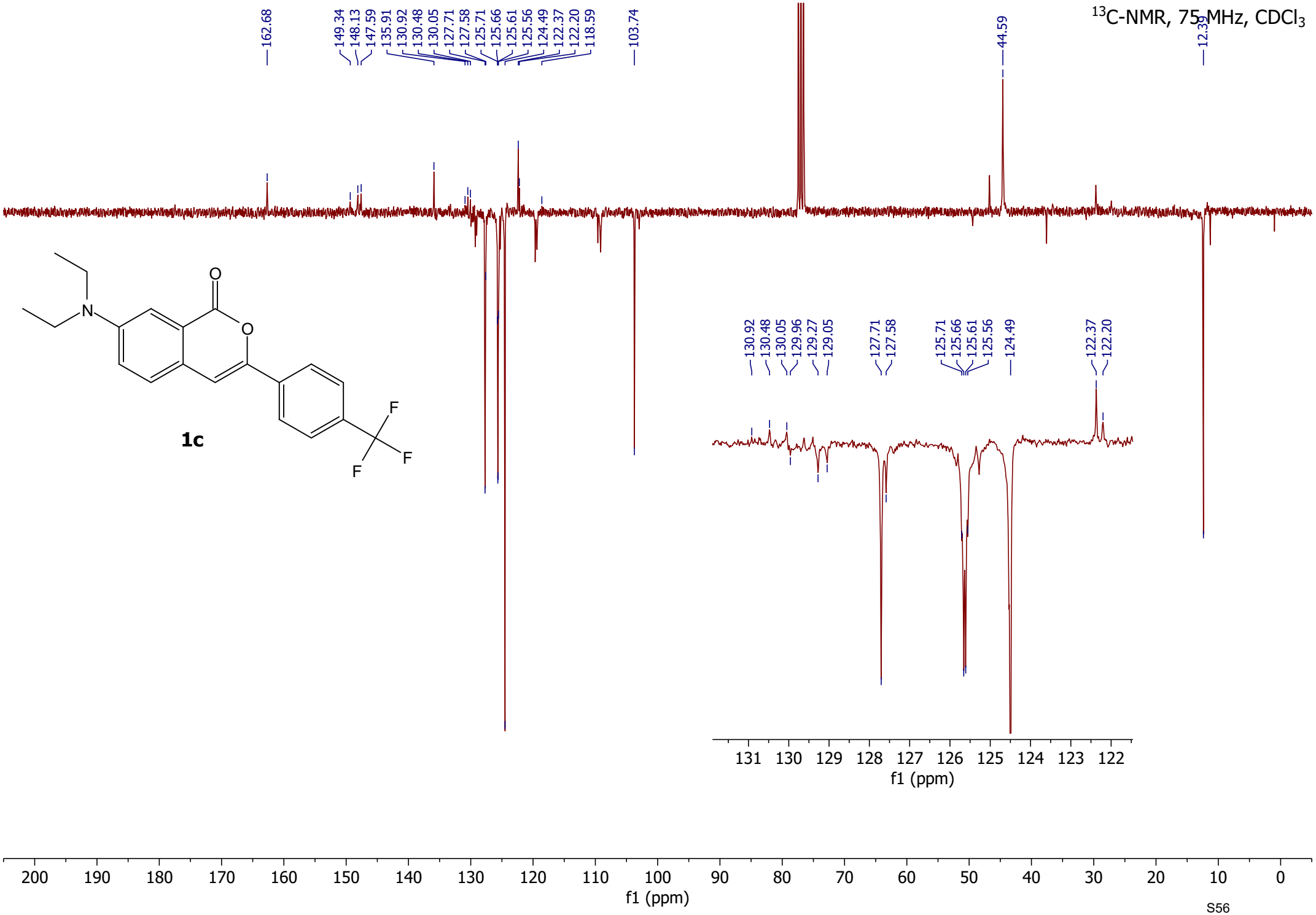

^{1}H-NMR, 300 MHz, d_6-DMSO
8.02
7.99
7.83
7.80
7.50
7.45
7.42
7.32
7.31
7.13
7.12
7.10
7.09
3.80
O
H_2N
O
F
F
F
1a
1.89
2.00
0.90
0.91
0.90
0.88
2.60
f1 (ppm)
S51

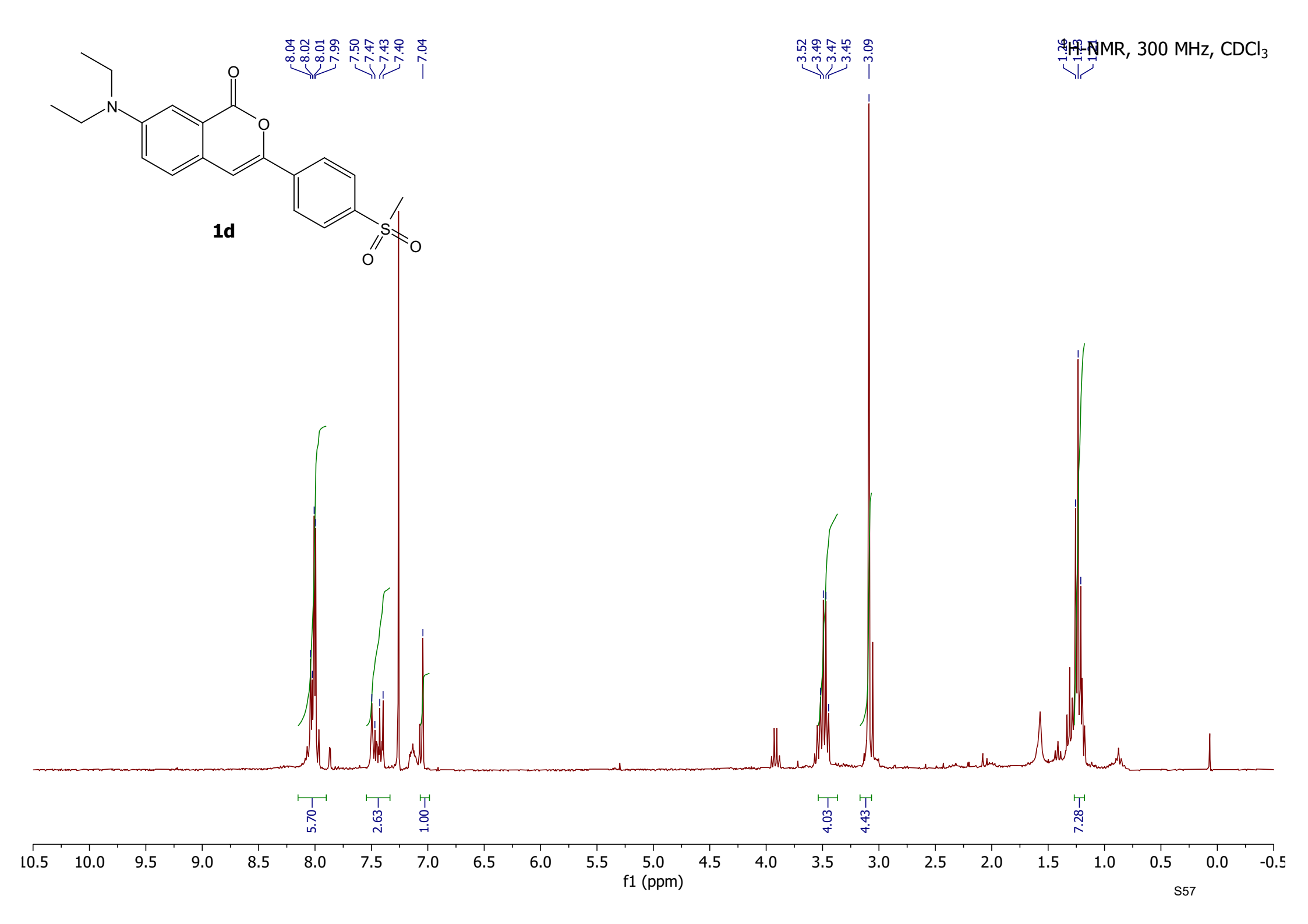

^{1}H-NMR, 300 MHz, d_6-DMSO
161.82
150.33
146.67
136.50
129.99
129.54
129.12
128.69
128.28
126.39
126.36
126.31
126.26
126.21
125.86
124.95
122.81
122.10
119.18
110.80
105.17
H_2N
O
O
F
F
F
1a
f1 (ppm)
f1 (ppm)

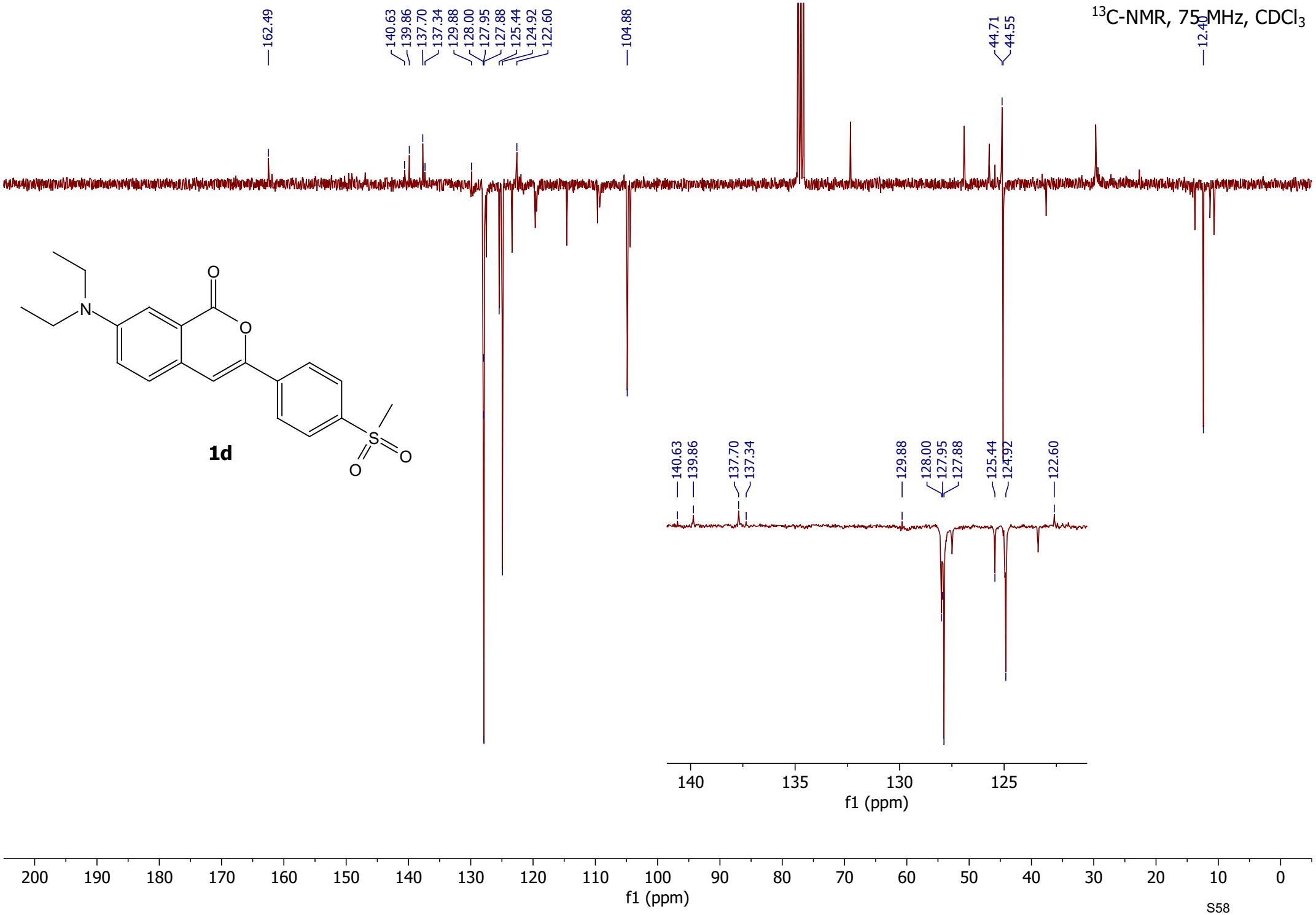

^{1}H-NMR, 300 MHz, d_6-DMSO
1b
f1 (ppm)


161.78
150.84
146.43
140.59
137.31
128.78
128.09
125.54
124.94
122.61
122.23
110.58
105.79
43.95
^{13}C-NMR, 75 MHz, d_6-DMSO
H_2N
O
O
S
O
O
1b
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)

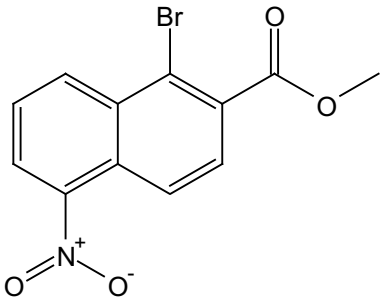

1H-NMR, 300 MHz, CDCl3
1c
O
N
O
F
F
F
7.96
7.93
7.69
7.66
7.49
7.48
7.41
7.38
7.11
7.09
6.98
3.51
3.49
3.46
3.44
1.25
1.23
1.21
1.78
2.00
0.90
0.93
0.94
0.97
3.74
7.00
f1 (ppm)


^{13}C-NMR, 75 MHz, $CDCl_3$
162.68
149.34
148.13
147.59
135.91
130.92
130.48
130.05
127.71
127.58
125.71
125.66
125.61
125.56
124.49
122.37
122.20
118.59
103.74
44.59
12.39
1c
O
N
O
F
F
F
130.92
130.48
130.05
129.96
129.27
129.05
127.71
127.58
125.71
125.66
125.61
125.56
124.49
122.37
122.20
131 130 129 128 127 126 125 124 123 122
f1 (ppm)
200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0
f1 (ppm)

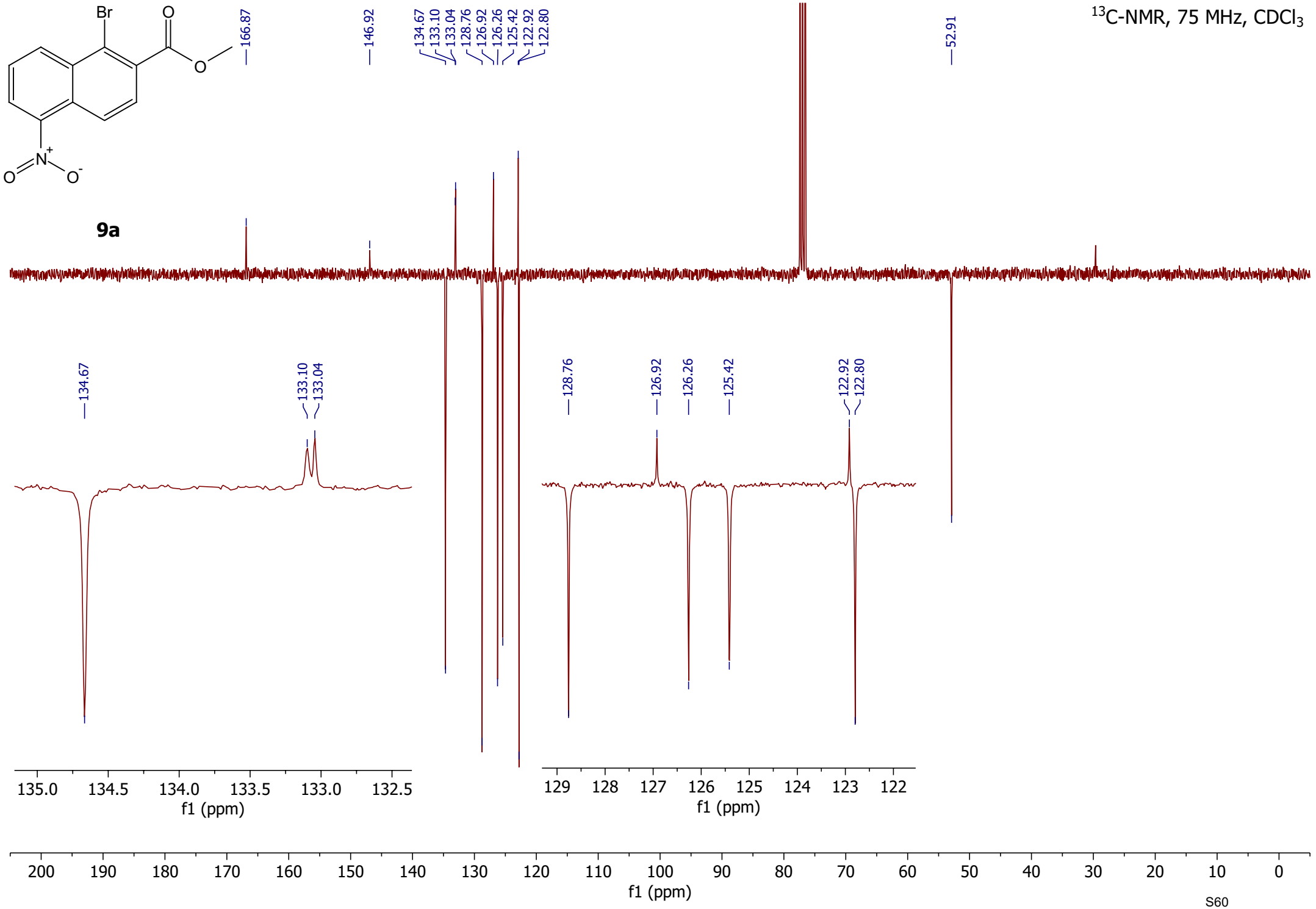

1H-NMR, 300 MHz, CDCl3
1d
8.04
8.02
8.01
7.99
7.50
7.47
7.43
7.40
7.04
3.52
3.49
3.47
3.45
3.09
1.26
1.23
1.21
5.70
2.63
1.00
4.03
4.43
7.28
f1 (ppm)

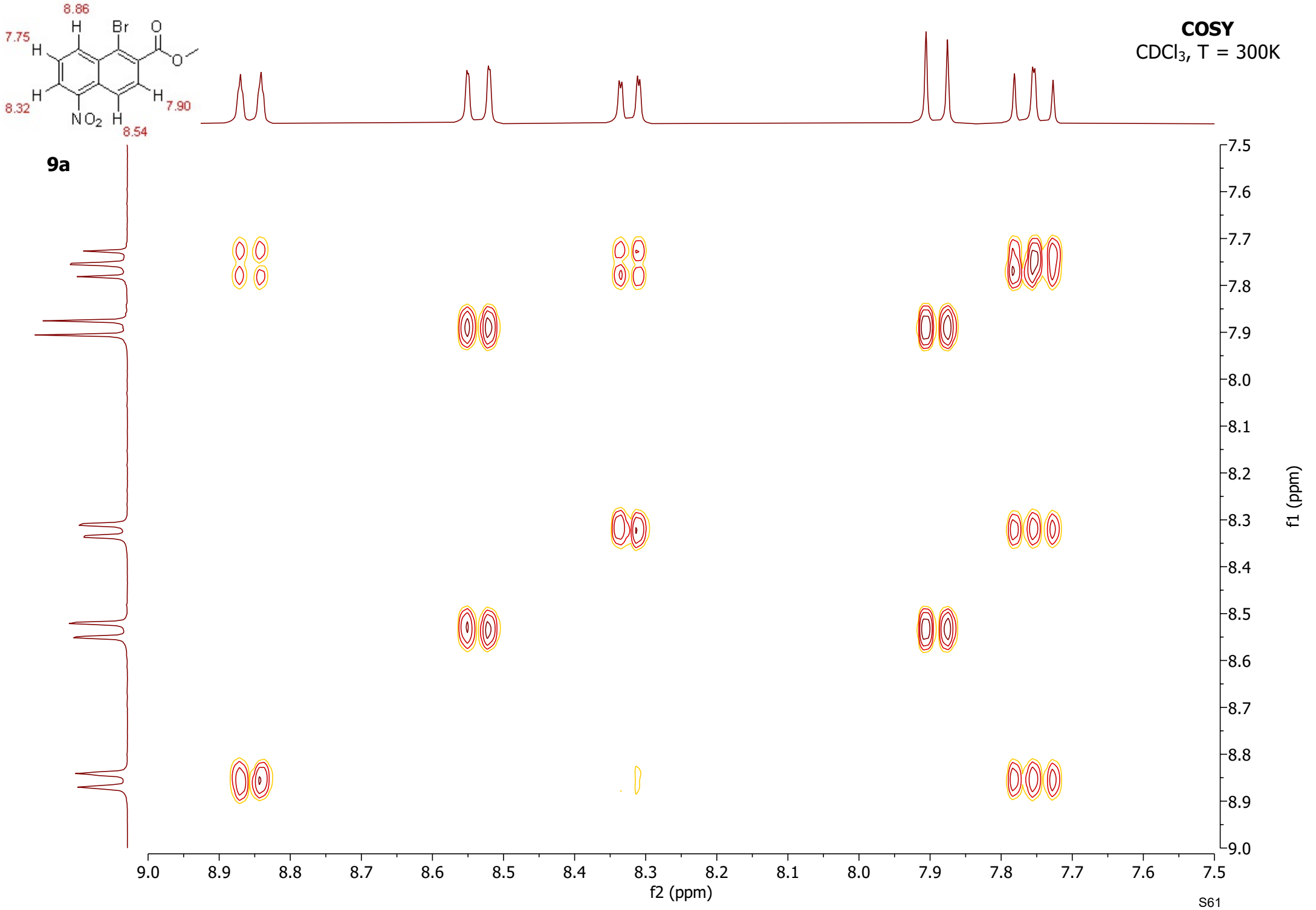

^{13}C-NMR, 75 MHz, $CDCl_3$
162.49
140.63
139.86
137.70
137.34
129.88
128.00
127.95
127.88
125.44
124.92
122.60
104.88
44.71
44.55
12.40
1d
f1 (ppm)
f1 (ppm)

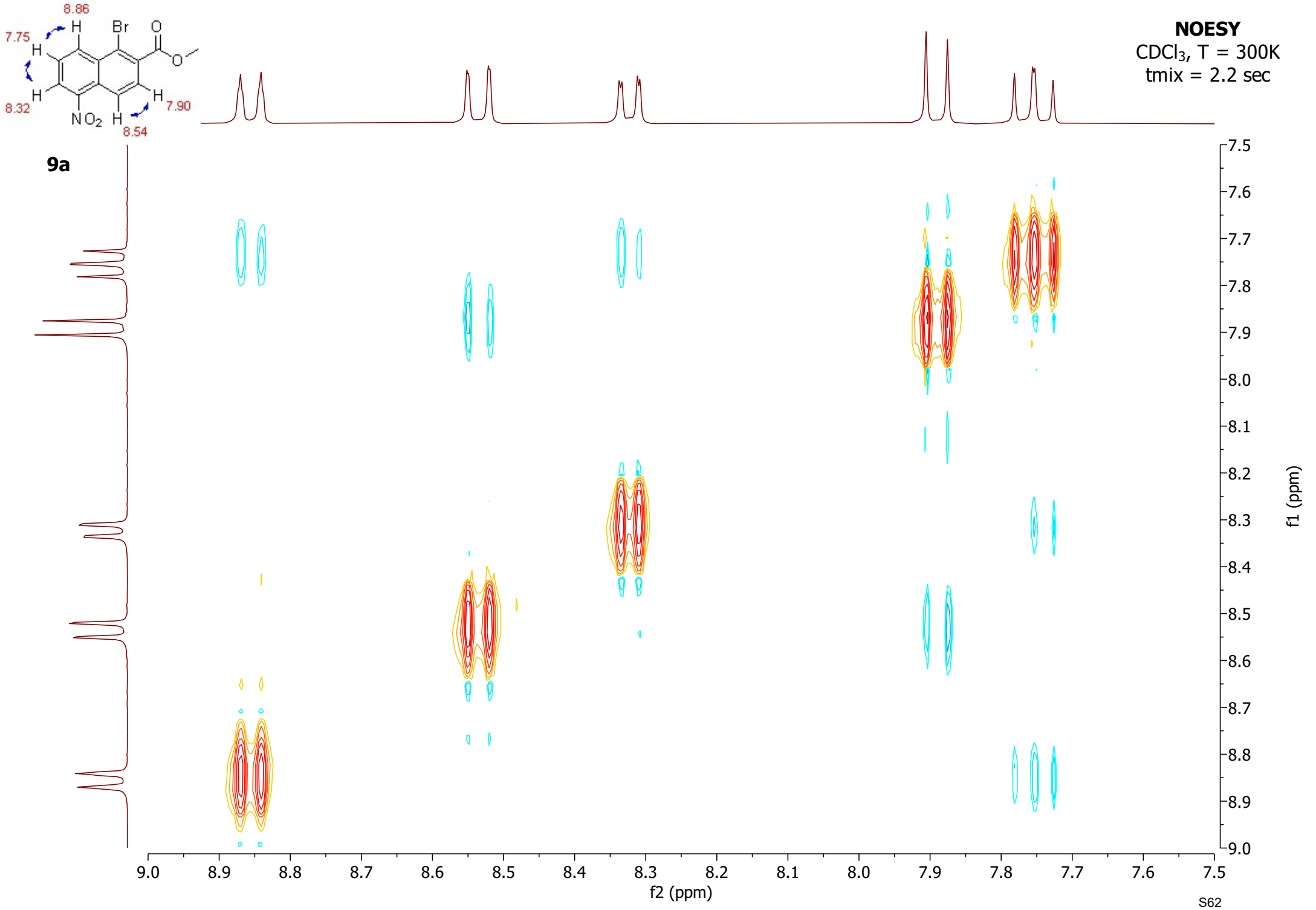
^{1}H-NMR, 300 MHz, $CDCl_3$

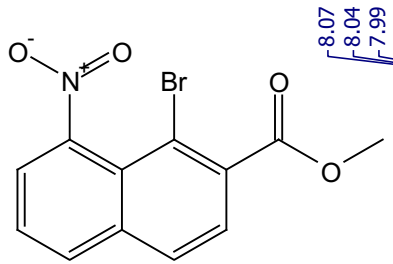


9a


Br
O
O
O
N+
O-
9a
166.87
146.92
134.67
133.10
133.04
128.76
126.92
126.26
125.42
122.92
122.80
52.91
^{13}C-NMR, 75 MHz, $CDCl_3$
135.0
134.5
134.0
133.5
133.0
132.5
f1 (ppm)
129
128
127
126
125
124
123
122
f1 (ppm)
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)

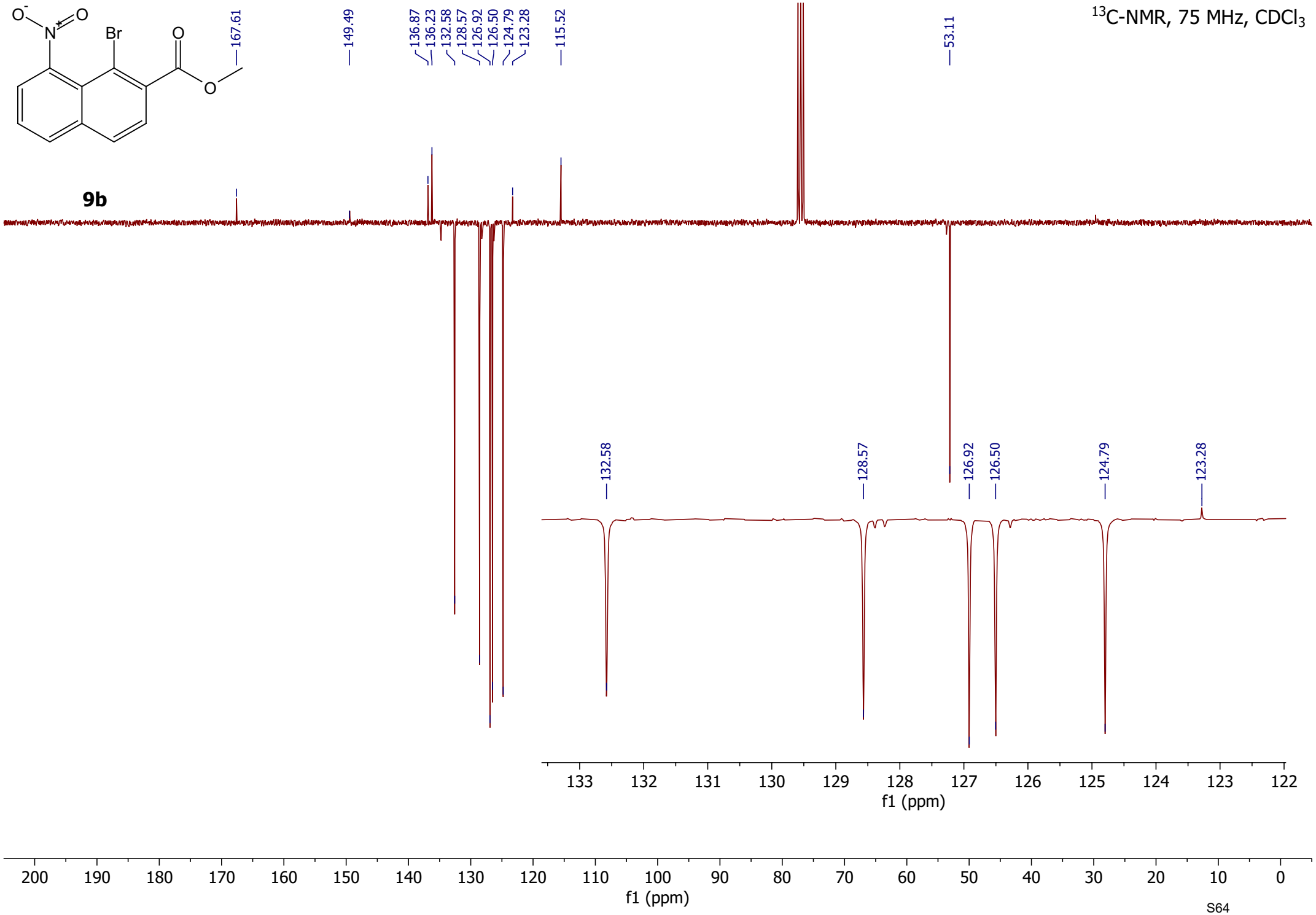

COSY
CDCl3, T = 300K
9a
8.86
7.75
8.32
7.90
8.54
f2 (ppm)
f1 (ppm)

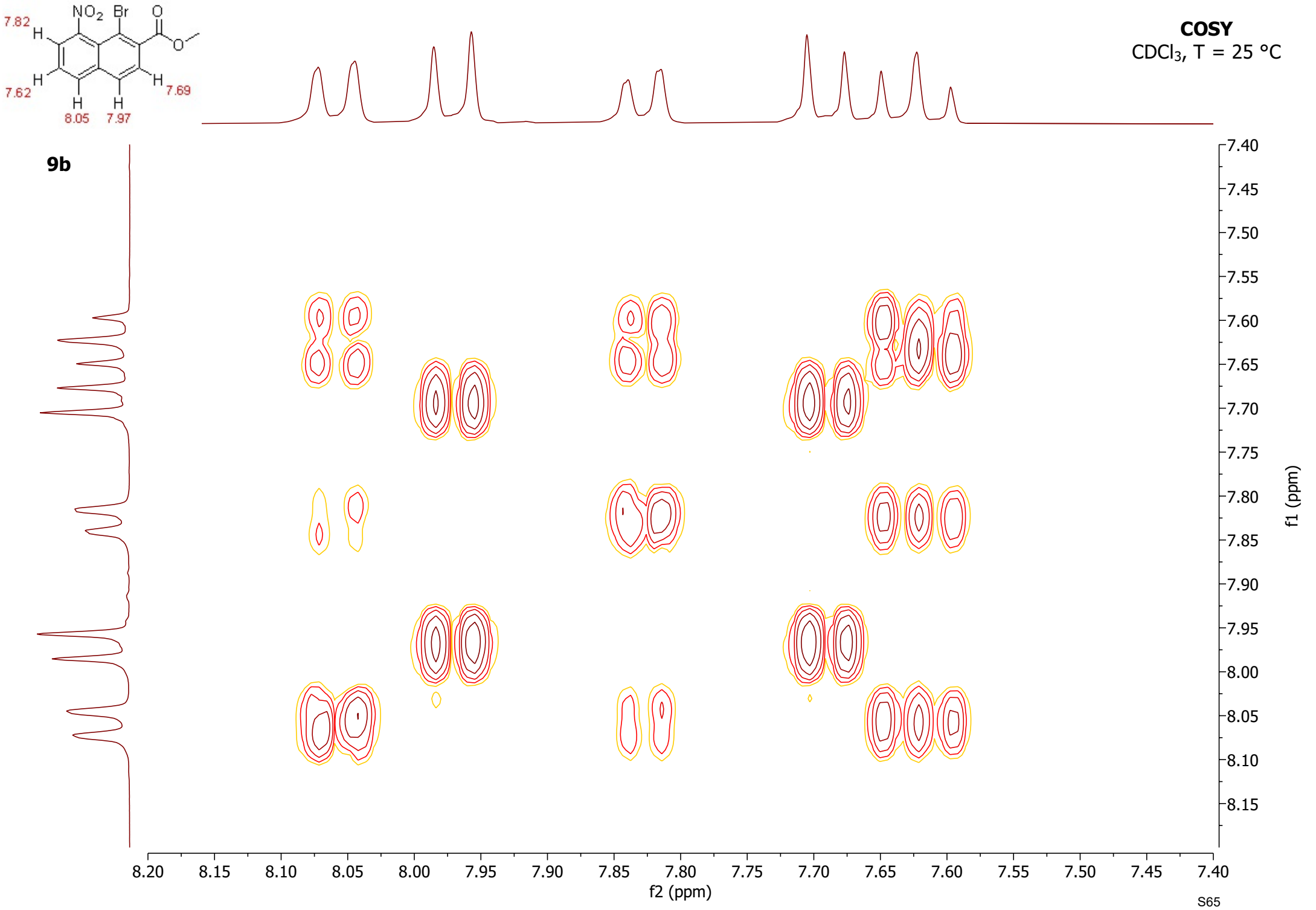

NOESY
CDCl3, T = 300K
tmix = 2.2 sec
9a
8.86
7.75
8.32
7.90
8.54
f2 (ppm)
f1 (ppm)
9.0
8.9
8.8
8.7
8.6
8.5
8.4
8.3
8.2
8.1
8.0
7.9
7.8
7.7
7.6
7.5

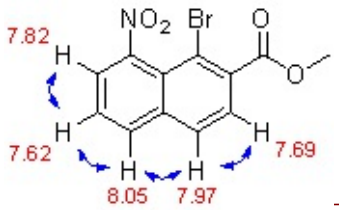


9b

^{1}H-NMR, 300 MHz, $CDCl_3$


^{13}C-NMR, 75 MHz, $CDCl_3$
9b
Br
167.61
149.49
136.87
136.23
132.58
128.57
126.92
126.50
124.79
123.28
115.52
53.11
f1 (ppm)
f1 (ppm)


COSY
CDCl3, T = 25 °C
9b
NO2
Br
O
O
H
H
H
H
7.82
7.62
7.69
8.05
7.97
7.40
7.45
7.50
7.55
7.60
7.65
7.70
7.75
7.80
7.85
7.90
7.95
8.00
8.05
8.10
8.15
f1 (ppm)
8.20
8.15
8.10
8.05
8.00
7.95
7.90
7.85
7.80
7.75
7.70
7.65
7.60
7.55
7.50
7.45
7.40
f2 (ppm)

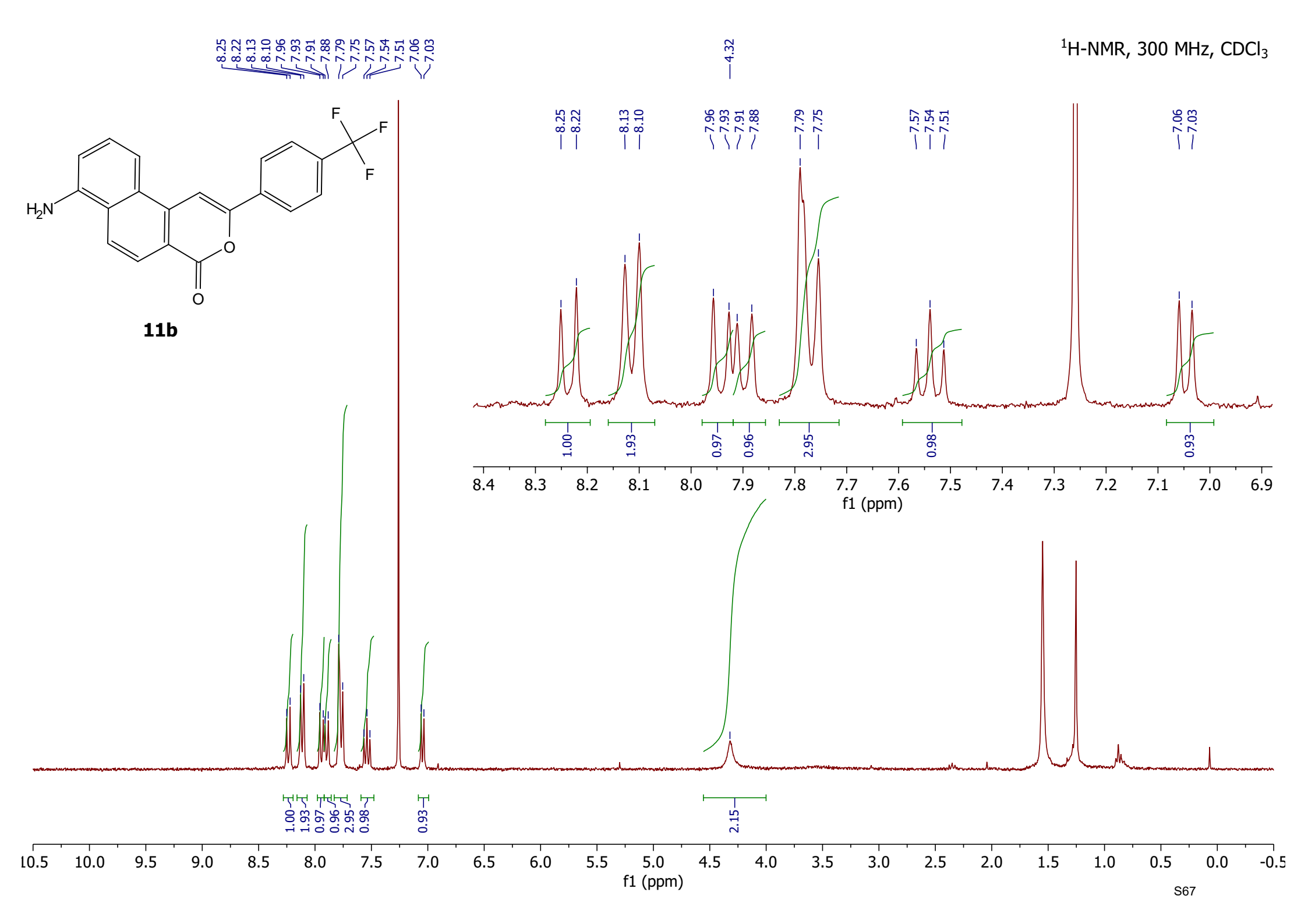


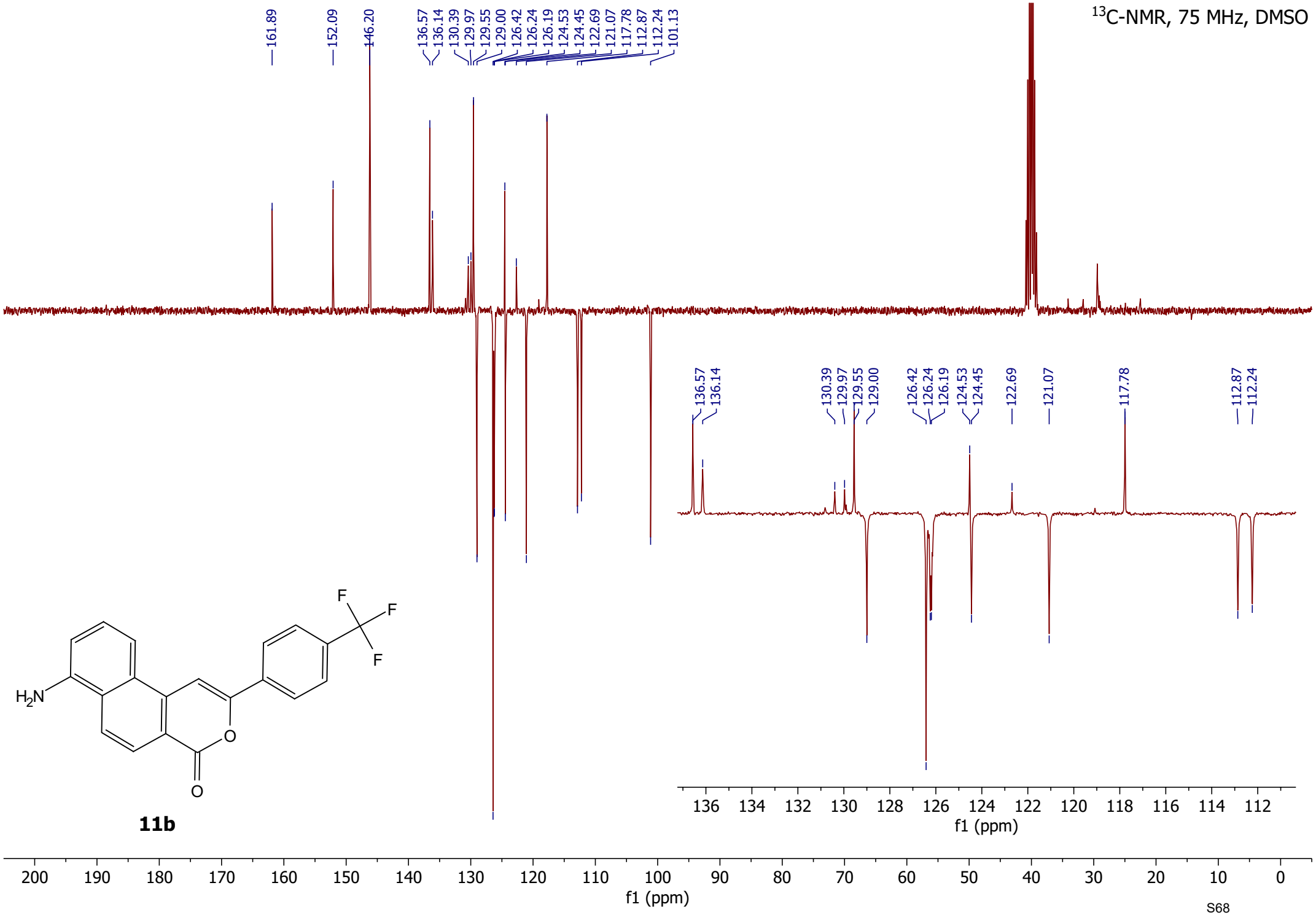
NOESY
$CDCl_3$, T = 25 °C
tmix = 1.4 sec

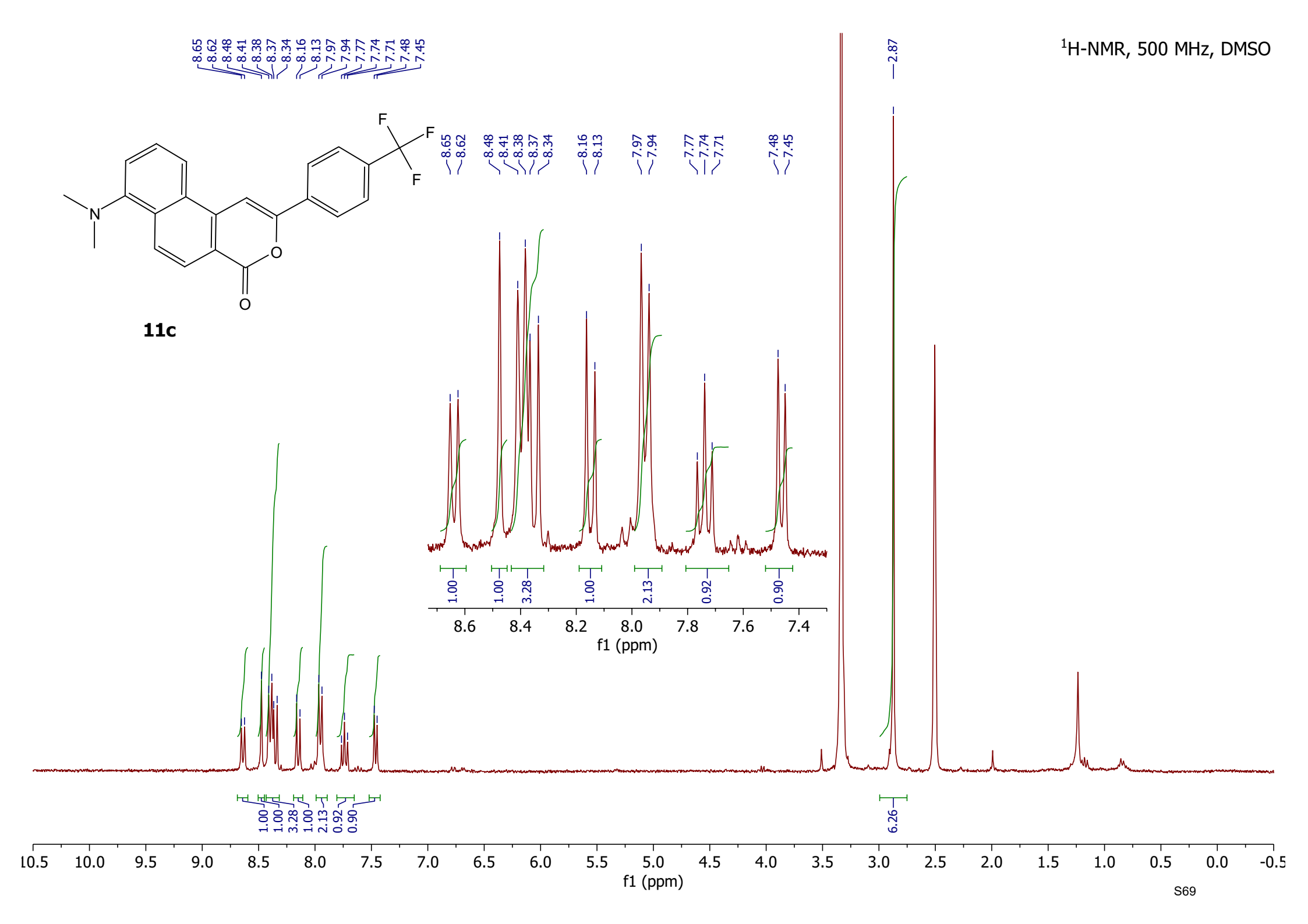
9b

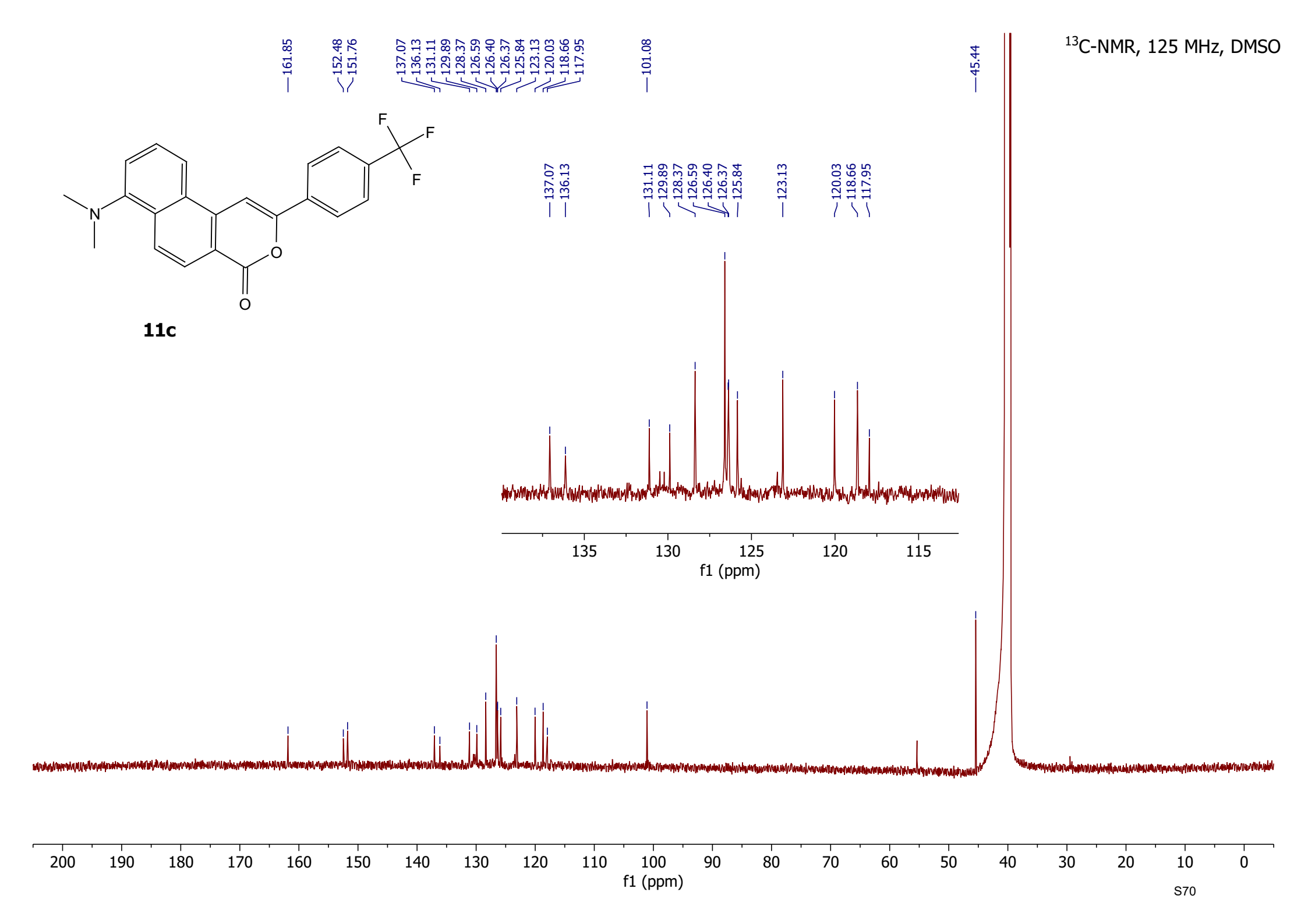
f2 (ppm)

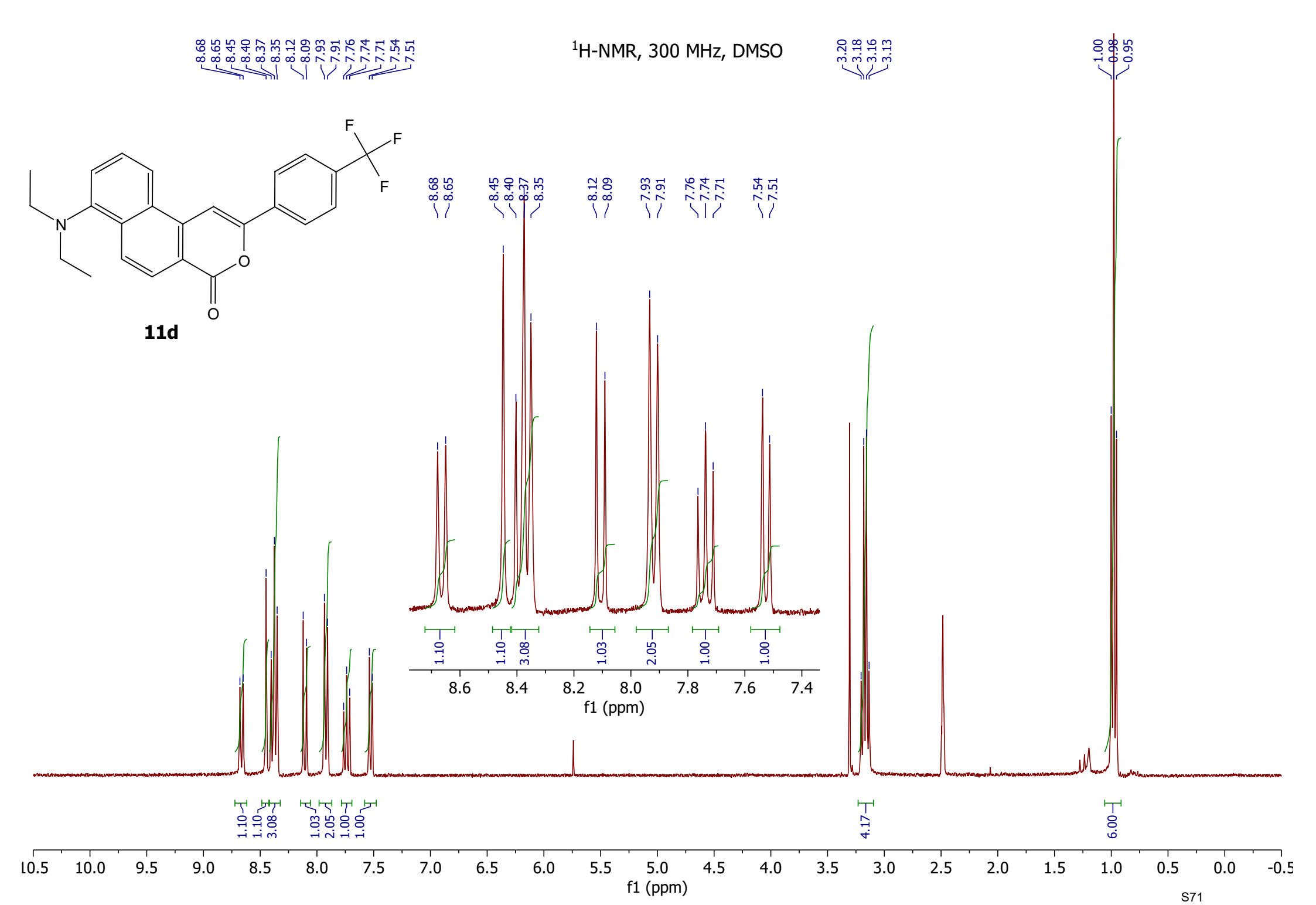
f1 (ppm)

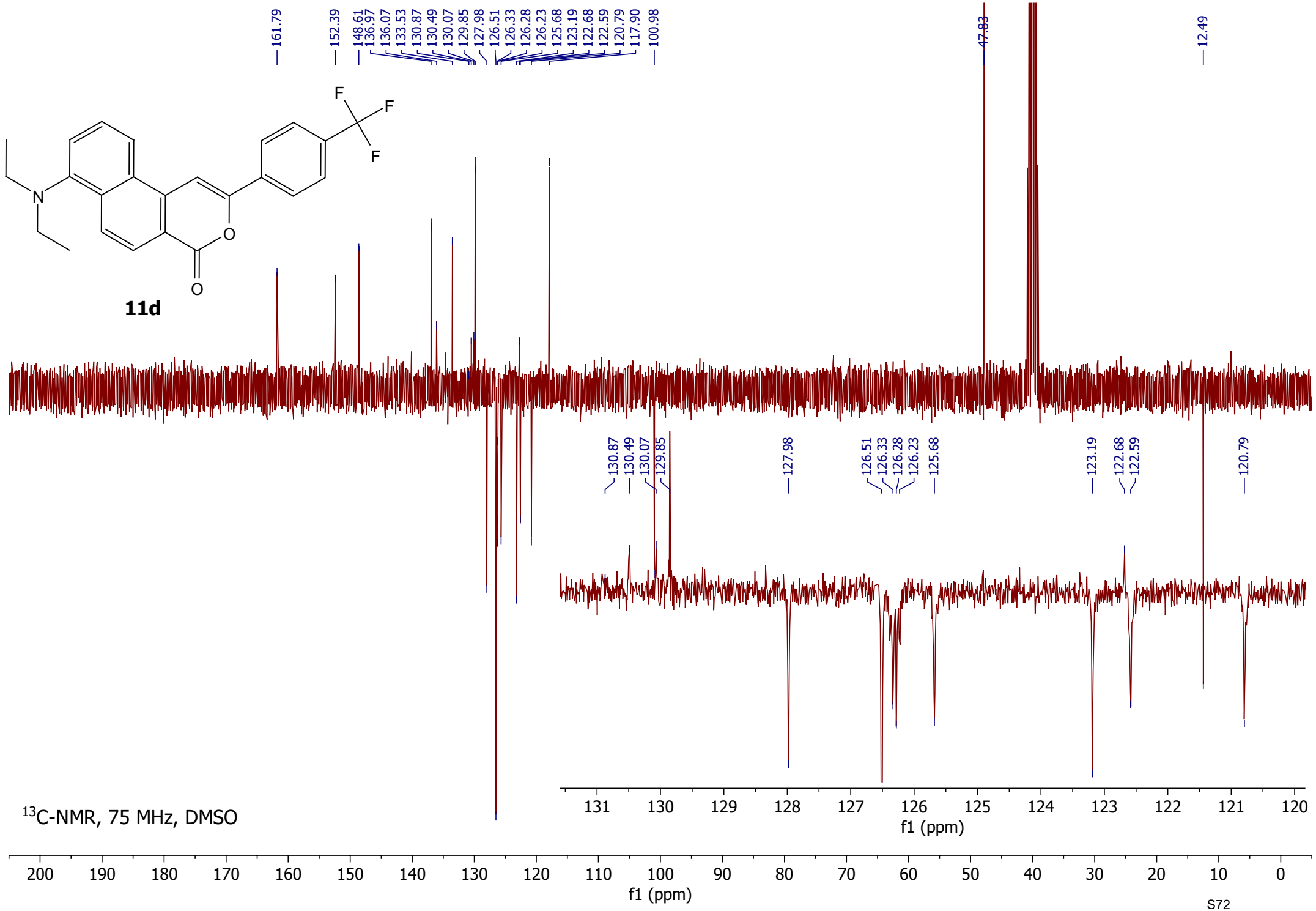

^{1}H-NMR, 300 MHz, $CDCl_3$
8.25
8.22
8.13
8.10
7.96
7.93
7.91
7.88
7.79
7.75
7.57
7.54
7.51
7.06
7.03
4.32
F
F
F
H_2N
O
O
11b
1.00
1.93
0.97
0.96
2.95
0.98
0.93
2.15
f1 (ppm)

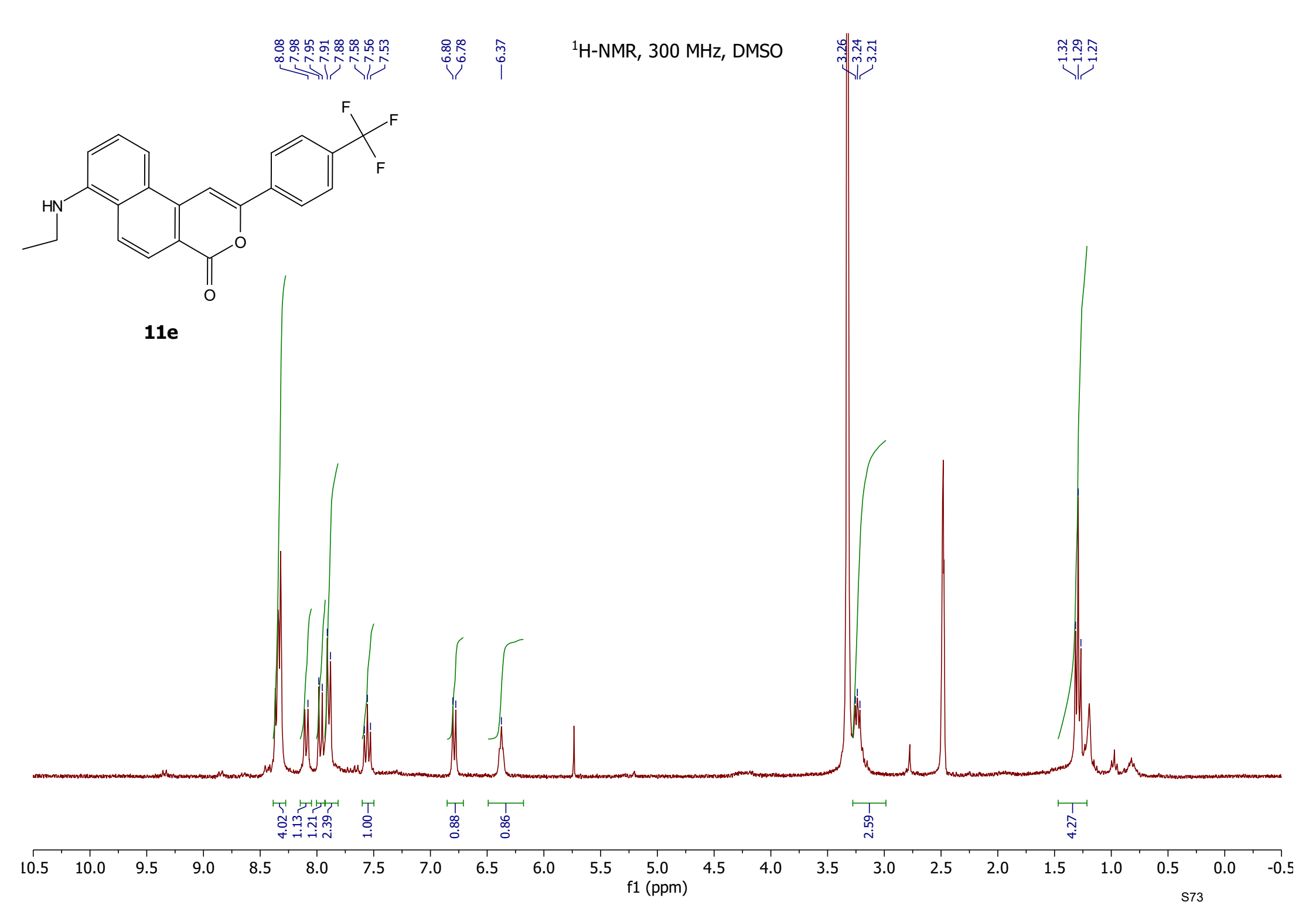

^{13}C-NMR, 75 MHz, DMSO
161.89
152.09
146.20
136.57
136.14
130.39
129.97
129.55
129.00
126.42
126.24
126.19
124.53
124.45
122.69
121.07
117.78
112.87
112.24
101.13
F
F
F
H_2N
O
O
11b
f1 (ppm)
S68

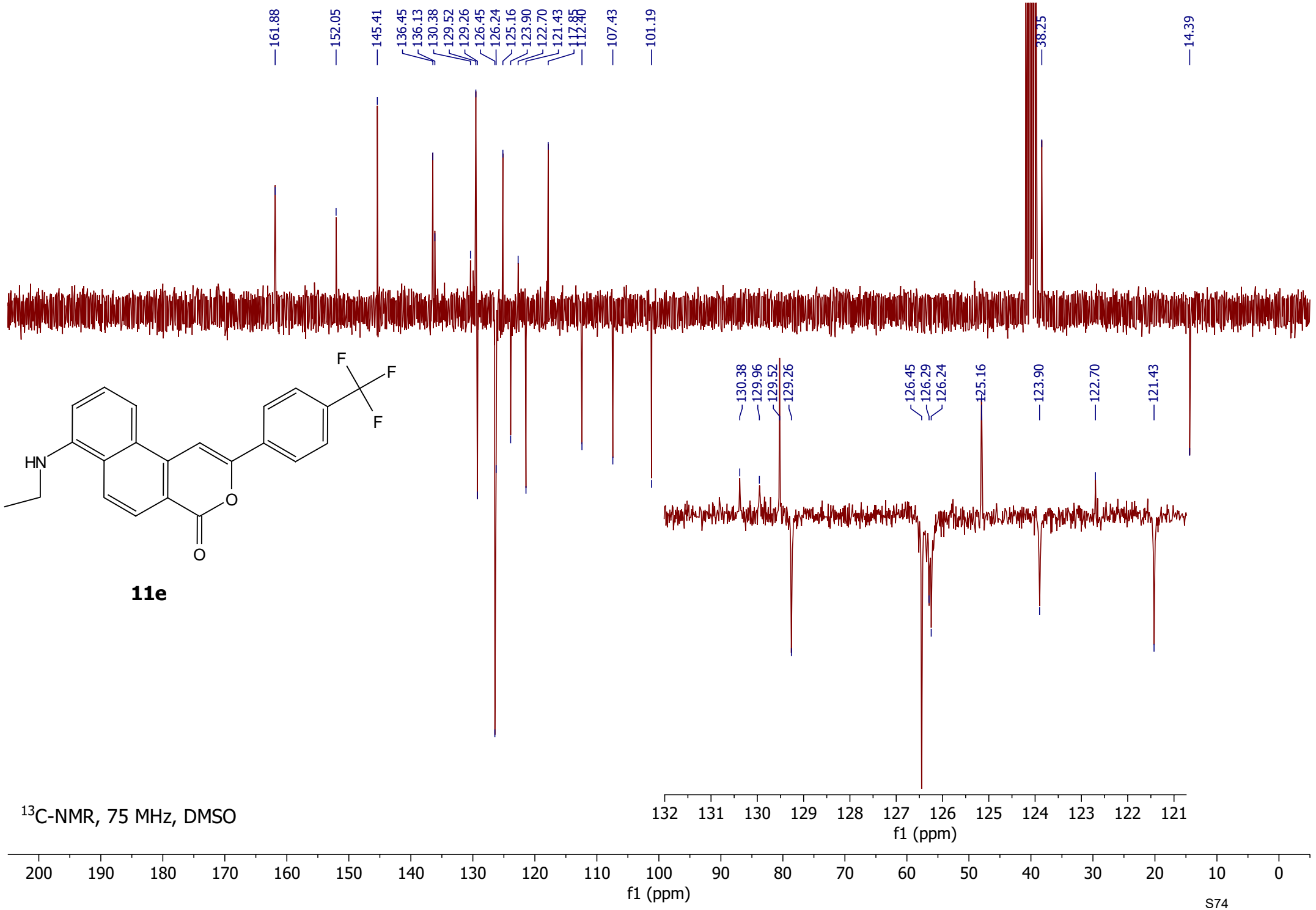

^{1}H-NMR, 500 MHz, DMSO
8.65
8.62
8.48
8.41
8.38
8.37
8.34
8.16
8.13
7.97
7.94
7.77
7.74
7.71
7.48
7.45
2.87
F
F
F
N
O
O
11c
1.00
1.00
3.28
1.00
2.13
0.92
0.90
6.26
f1 (ppm)


^{13}C-NMR, 125 MHz, DMSO
161.85
152.48
151.76
137.07
136.13
131.11
129.89
128.37
126.59
126.40
126.37
125.84
123.13
120.03
118.66
117.95
101.08
45.44
F
F
F
N
O
O
11c
f1 (ppm)
f1 (ppm)


^{1}H-NMR, 300 MHz, DMSO
8.68
8.65
8.45
8.40
8.37
8.35
8.12
8.09
7.93
7.91
7.76
7.74
7.71
7.54
7.51
3.20
3.18
3.16
3.13
1.00
0.98
0.95
F
F
F
N
O
O
11d
1.10
1.10
3.08
1.03
2.05
1.00
1.00
4.17
6.00
f1 (ppm)
f1 (ppm)


161.79
152.39
148.61
136.97
136.07
133.53
130.87
130.49
130.07
129.85
127.98
126.51
126.33
126.28
126.23
125.68
123.19
122.68
122.59
120.79
117.90
100.98
47.83
12.49
F
F
F
N
O
O
11d
130.87
130.49
130.07
129.85
127.98
126.51
126.33
126.28
126.23
125.68
123.19
122.68
122.59
120.79
131
130
129
128
127
126
125
124
123
122
121
120
f1 (ppm)
^{13}C-NMR, 75 MHz, DMSO
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)


^{1}H-NMR, 300 MHz, DMSO
8.08
7.98
7.95
7.91
7.88
7.58
7.56
7.53
6.80
6.78
6.37
3.26
3.24
3.21
1.32
1.29
1.27
F
F
F
HN
O
O
11e
4.02
1.13
1.21
2.39
1.00
0.88
0.86
2.59
4.27
f1 (ppm)


161.88
152.05
145.41
136.45
136.13
130.38
129.52
129.26
126.45
126.24
125.16
123.90
122.70
121.43
117.85
112.40
107.43
101.19
38.25
14.39
130.38
129.96
129.52
129.26
126.45
126.29
126.24
125.16
123.90
122.70
121.43
F
F
F
HN
O
O
11e
13C-NMR, 75 MHz, DMSO
f1 (ppm)
f1 (ppm)