Supporting Information

for

Palladium-Catalyzed Intermolecular Alkynylcarbonylation of Unactivated Alkenes: Easy Access to β-Alkynylcarboxylic Ester

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1. General Consideration.

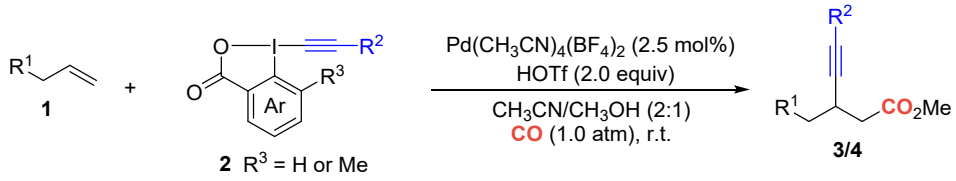
$Pd(CH_3CN)_4(BF_4)_2$ was purchased from Strem Chemical, other commercial reagents with high purity were purchased and used without further purification, unless otherwise noted. ^1H, ^{19}F and ^{13}C NMR spectra were recorded on an Agilent-400 MHz and Bruker-400 MHz spectrometer. The chemical shifts (δ) are given in parts per million relative to internal standard $CDCl_3$ (7.26 ppm for ^1H), $CDCl_3$ (77.0 ppm for ^{13}C). ^1H and ^{19}F multiplicities are reported as follows: singlet (s), doublet (d), doublet of doublets (dd), quartet (q), multiplet (m), and broad resonance (br). Flash column chromatography was performed on silica gel (particle size 230-400 mesh, purchased from Canada) and eluted with petroleum ether/ethyl acetate or dichloromethane/ethyl acetate. High Resolution Mass spectral data were obtained on a Waters Micromass GCT spectrometer in EI mode or on Agilent Technologies 6224 TOF LC MS spectrometer in ESI mode. CH_3CN and DCM were dried by refluxed with CaH_2.

2. Experiments section.

2.1 Preparation of alkene and EBX reagents.

Alkene substrates **1c, 1d, 1f, 1p** and **1u** were commercial available. And other alkenes and EBX reagents were prepared according to literature reports.[1-4]

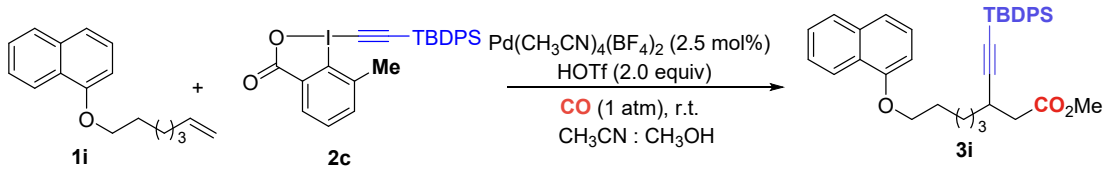
2.2 General procedure for alkynylcarbonylation of alkenes.



In an oven-dried 10.0 mL Schlenk tube, alkene substrate **1** (0.2 mmol, 1.0 equiv.) and EBX reagent **2** (0.4 mmol, 2.0 equiv.) were dissolved in a mixed solvent CH_3CN/toluene (2.0 mL, *v/v* 2:1) at room temperature under a CO atmosphere (1.0 atm). And then, HOTf (35.0 μL, 0.4 mmol, 2.0 equiv.) and $Pd(CH_3CN)_4(BF_4)_2$ (50.0 μL, 0.1 M in CH_3CN, 0.005 mmol, 2.5 mol%) were added to the reaction mixture. The reaction was stirred at room temperature and monitored by TLC. After the alkene substrate was consumed, the solvent was removed under vacuum, and the residue was purified by column chromatography on silica gel with a gradient eluent of petroleum

ether and ethyl acetate to afford products **3** or **4**. The results were shown in Table 2.

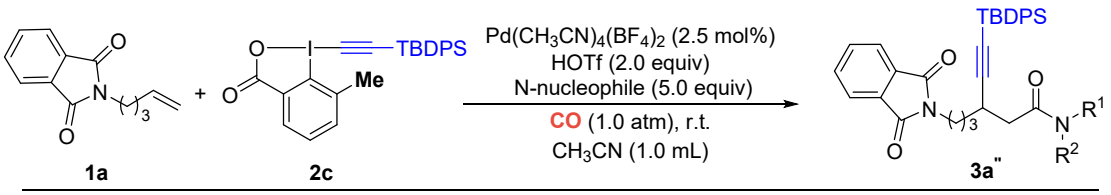
2.3 Scale-up reaction.



In an oven-dried 200.0 mL Schlenk bottom, alkene substrate **1i** (0.7 g, 3.0 mmol, 1.0 equiv.) and EBX reagent **2c** (2.4 g, 4.5 mmol, 1.5 equiv.) were dissolved in a mixed solvent CH_3CN/MeOH (25.0 mL, *v/v* 2:1) at room temperature under a CO atmosphere (1.0 atm). And then, HOTf (0.4 mL, 6.0 mmol, 2.0 equiv.) and $Pd(CH_3CN)_4(BF_4)_2$ (75.0 μL, 1 M in CH_3CN, 0.075 mmol, 2.5 mol%) were added to the reaction mixture. The reaction was stirred at room temperature and monitored by TLC. After the alkene substrate was consumed, the solvent was removed under vacuum, and the residue was purified by column chromatography on silica gel with a gradient eluent of petroleum ether and ethyl acetate (10:1 to 3:1) to afford products **3i** (R_f = 0.61, PE:EA = 3:1) (1.08 g, 75% yield) .

2.4 The reactions with nitrogen nucleophiles.[a]

Table S1 The reactions with nitrogen nucleophiles.



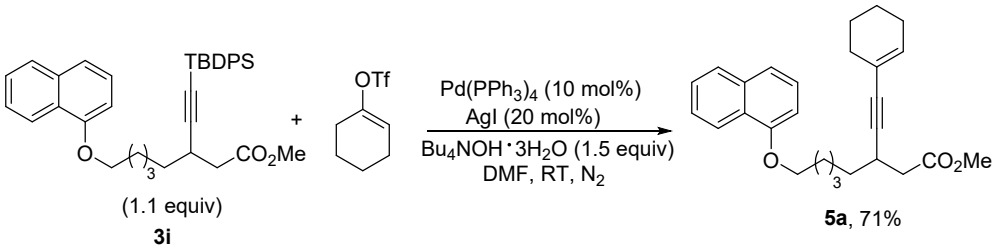
1a **2c** **3a"**

Entry	N-nucleophile	**1a** (%)	**3a"** (%)
1	CH_3ONH_2	100	0
2	CH_3CONH_2	26	0
3	$PhONH_2$	70	0
4	n-$BuNH_2$	22	0
5	$BnNH_2$	68	0
6	$BnNHCH_3$	87	0
7	cyclohexanamine	85	0

[a] The reactions were ran on 0.1 mmol scale, and yields were talken from ^{1}H NMR with CF_3DMA as an internal standard.

2.5 Synthetic applications.

2.5.1. Palladium-catalyzed cross-coupling reaction.



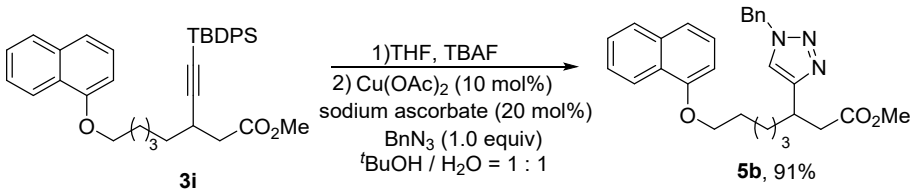
(1.1 equiv)
3i

5a, 71%

According to literature process.[5] $Pd(PPh_3)_4$ (46.2 mg, 0.04 mmol, 10 mol%) and AgI (18.7 mg, 0.08 mmol, 20 mol%) were weighted to an oven-dried sealed tube in glove-box. Then DMF (0.5 mL), **3i** (0.44 mL, 1 M in DMF, 0.44 mmol, 1.1 equiv.) and cyclohex-1-en-1-yl trifluoromethanesulfonate (0.4 mL, 1 M in DMF, 0.4 mmol, 1.0 equiv.) were added in sequence, and the mixture was stirred for 5 minutes under N_2 atmosphere. Then, $Bu_4NOH{\cdot}3H_2O$ (0.6 mL, 1 M in DMF, 0.6 mmol, 1.5 equiv.) was added and the reaction was allowed to stirred at room temperature. When **3i** was consumed, ethyl acetate (10.0 mL) was added and the mixture was washed with water. The combined organic layer was dried over Na_2SO_4, filtered and the filtrate was concentrated under reduced pressure. The residue was purified by column chromatography on silica gel with a gradient eluent of petroleum ether and ethyl acetate

(10:1 to 1:1) to get **5a** (R_f = 0.65, PE:EA = 3:1) (114.7 mg, 71% yield). ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.28 (d, *J* = 8.0 Hz, 1H), 7.79 (d, *J* = 7.6 Hz, 1H), 7.50 – 7.34 (m, 4H), 6.79 (d, *J* = 7.2 Hz, 1H), 6.00 (s, 1H), 4.14 (t, *J* = 6.4 Hz, 2H), 3.69 (s, 3H), 3.00 – 2.96 (m, 1H), 2.55 (dd, *J* = 15.6, 7.6 Hz, 1H), 2.46 (dd, *J* = 15.6, 7.2 Hz, 1H), 2.06 – 2.05 (m, 3H), 1.98 – 1.90 (m, 2H), 1.61 – 1.46 (m, 11H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 172.2, 154.9, 134.5, 133.8, 127.4, 126.3, 125.9, 125.7, 125.0, 122.1, 120.7, 119.9, 104.5, 88.3, 84.0, 67.9, 51.7, 40.2, 34.7, 29.5, 29.2, 28.8, 27.0, 26.0, 25.5, 22.3, 21.5. HRMS: m/z (ESI) calculated $[M+NH_4]^+$: 422.2690, measured: 422.2692. IR (neat): 2929, 2857, 1736, 1579, 1389, 1268, 1155, 1099, 791, 770 cm^{-1}.

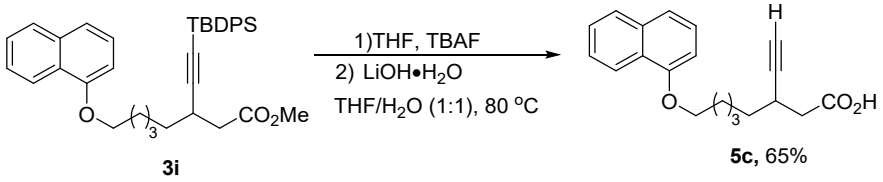
2.5.2. Click reaction.



According to literature process.[6] TBAF (0.4 mL, 1 M in THF, 0.4 mmol, 2.0 equiv.) was added to a solution of **3i** (104.2 mg, 0.2 mmol, 1.0 equiv.) in freshly dried THF, and the mixture was stirred at 80 °C for 2 hours under N_2 atmosphere. When the **3i** was consumed, the reaction was cooled down to room temperature before water (5.0 mL) and ethyl acetate (10.0 mL) were added to the mixture, and the water phase was extracted with ethyl acetate (10.0 mL*2). The combined organic layer was washed with brine and dried over $MgSO_4$. The filtrate was concentrated under vacuum, and the residue was dissolved with tert-butanol and water (1.0 mL, 1:1) in a 10 mL sealed tube, cupric acetate (3.6 mg, 0.02 mmol, 10 mol%), sodium ascorbate (8.0 mg, 0.04 mmol, 20 mol%) and benzyl azide (26.6 mg, 0.2 mmol, 1.0 equiv.) were added to the solution in sequence. The mixture was reacted at room temperature for overnight. Then, the reaction was diluted with ethyl acetate (10.0 mL), dried over $MgSO_4$ and concentrated in vacuum. The residue was purified by column chromatography on silica with a gradient eluent of petroleum ether and ethyl acetate (3:1 to 0:1) gel to get **5b** (R_f = 0.32, PE:EA:Et_3N = 3:3:1) (83.2 mg, 91% yield). ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.26 (d, *J* = 7.6 Hz, 1H), 7.79 (d, *J* = 7.6 Hz, 1H), 7.50 – 7.32 (m, 7H), 7.20 – 7.17 (m, 3H), 6.76

(d, J = 7.2 Hz, 1H), 5.44 (d, J = 15.2 Hz, 1H), 5.39 (d, J = 15.2 Hz, 1H), 4.07 (t, J = 6.4 Hz, 2H), 3.57 (s, 3H), 3.34 – 3.30 (m, 1H), 2.76 (dd, J = 15.6, 8.0 Hz, 1H), 2.68 (dd, J = 16.0, 6.8 Hz, 1H), 1.91 – 1.70 (m, 4H), 1.60 – 1.50 (m, 2H), 1.36 – 1.32 (m, 2H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 172.7, 154.7, 150.3, 134.8, 134.4, 128.9, 128.5, 127.8, 127.4, 126.3, 125.9, 125.6, 125.0, 122.0, 120.9, 119.9, 104.4, 67.7, 53.8, 51.4, 39.5, 34.6, 33.1, 29.1, 26.8, 26.0. HRMS: m/z (ESI) calculated $[M+H]^+$: 458.2438, measured: 458.2435. IR (neat): 3141, 2941, 1727, 1582, 1457, 1333, 1206, 778, 724, 694 cm^{-1}.

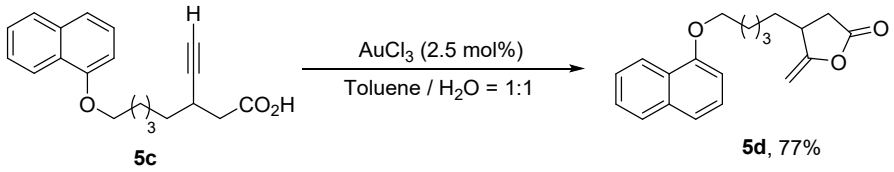
2.5.3. Hydrolysis of ester.



TBAF (2.0 mL, 1 M in THF, 2.0 mmol, 2.0 equiv.) was added to a solution of **3i** (562.3 mg, 1.0 mmol, 1.0 equiv.) in freshly dried THF, and mixture was stirred at 80 °C for 2 hours under N_2 atmosphere. When the **3i** was consumed (detected by TLC), the reaction was cooled down to room temperature before water (10.0 mL) and ethyl acetate (30.0 mL) were added to the mixture, and the water phase was extracted with ethyl acetate (30.0 mL*2). The combined organic layer was washed with brine and dried over $MgSO_4$, and concentrated under reduced pressure. The residue was dissolved with THF/H_2O (1:1, 10.0 mL) and lithium hydroxide monohydrate (125.9 mg, 3.0 mmol, 3.0 equiv.) was added to the solution in sequence. The mixture was allowed to react at 80 °C for overnight. After that, the reaction was cooled down to room temperature, HCl (1 M, 10.0 mL) was added to the mixture and extracted with ethyl acetate (20.0 mL*3). The combined organic phase was washed with brine (40.0 mL) and dried over $MgSO_4$. The filtrate was concentrated under reduced pressure and the residue was purified by column chromatography on silica with a gradient eluent of petroleum ether and ethyl acetate (3:1 to 0:1) gel to get **5c** (R_f = 0.44, PE:EA = 1:3), (201.8 mg, 65% yield). ^{1}H NMR (400 MHz, $CDCl_3$) δ 10.7 (br, 1H), 8.31 (d, J = 9.2 Hz, 1H), 7.81 (d, J = 8.4 Hz, 1H), 7.52 – 7.36 (m, 4H), 6.81 (d, J = 7.2 Hz, 1H), 4.15 (t, J = 6.0 Hz, 2H), 2.94 – 2.88 (m, 1H), 2.64 (dd, J = 15.6, 7.6 Hz, 1H), 2.54 (dd, J =

16.0, 6.8 Hz, 1H), 2.14 (s, 1H), 1.98 – 1.95 (m, 2H), 1.68 – 1.59 (m, 6H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 177.7, 154.7, 134.4, 127.4, 126.3, 125.9, 125.6, 125.0, 122.0, 119.9, 104.5, 85.5, 70.1, 67.8, 39.7, 34.2, 29.1, 27.7, 26.8, 25.9. HRMS: m/z (ESI) calculated $[M+NH_4]^+$: 328.1907, measured: 328.1907. IR (neat): 3310, 2958, 1741, 1579, 1389, 1361, 1155, 770 cm^{-1}.

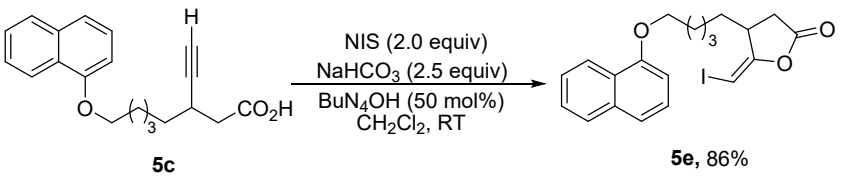
2.5.4 Gold-catalyzed cyclization reaction.



5c **5d**, 77%

According to literature process.[7] $AuCl_3$ (1.2 mg, 0.0035 mmol, 2.5 mol%) and **5c** (43.4 mg, 0.14 mmol, 1.0 equiv.) were dissolved in a mixed solvent (toluene/water, 1:1, 1.0 mL) under N_2 atmosphere. And the mixture was allowed to react at room temperature for overnight. Then, the mixture was diluted with ethyl acetate (10.0 mL), dried over $MgSO_4$ and the filtrate was removed in vacuum. The residue was purified by column chromatography on silica gel with a gradient eluent of petroleum ether and ethyl acetate (20:1 to 5:1) to give **5d** (R_f = 0.75, PE:EA = 5:1) (33.3 mg, 77% yield). ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.28 (d, *J* = 7.6 Hz, 1H), 7.81 (d, *J* = 8.4 Hz, 1H), 7.52 – 7.34 (m, 4H), 6.81 (d, *J* = 7.6 Hz, 1H), 4.77 (s, 1H), 4.32 (s, 1H), 4.15 (t, *J* = 6.4 Hz, 2H), 3.08 – 3.03 (m, 1H), 2.80 (dd, *J* = 18.0, 9.6 Hz, 1H), 2.36 (dd, *J* = 18.0, 6.0 Hz, 1H), 1.98 – 1.91 (m, 2H), 1.78 – 1.73 (m, 1H), 1.66 – 1.45 (m, 5H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 174.1, 160.1, 154.6, 134.4, 127.4, 126.3, 125.9, 125.6, 125.1, 121.9, 120.0, 104.4, 88.4, 67.7, 37.7, 34.1, 29.1, 26.5, 26.1. HRMS: m/z (ESI) calculated $[M+NH_4]^+$: 328.1907, measured: 328.1907. IR (neat): 2942, 2862, 2339, 2307, 1806, 1581, 1269, 1125, 1018, 769 cm^{-1}.

2.5.5. NIS-medaited lactonization.

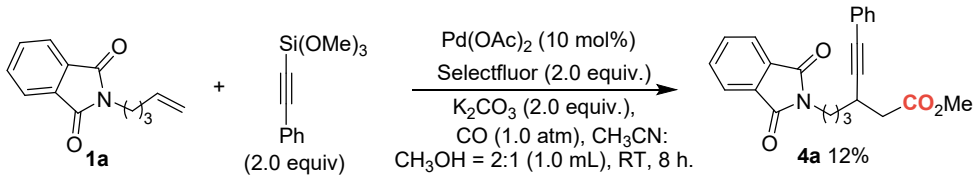


5c **5e**, 86%

According to literature process.[8] In a 10.0 mL oven-dried sealed tube, **5c** (40.3 mg, 0.13 mmol, 1.0 equiv.) was dissolved in CH_2Cl_2, *N*-iodosuccinimide (NIS) (58.5 mg, 0.26 mmol, 2.0 equiv.), sodium bicarbonate (27.3 mg, 0.32 mmol, 2.5 equiv.) and tetrabutylammonium hydroxide (16.9 mg, 0.07 mmol, 50 mol%) were added in sequence. The reaction was stirred vigorously for 30 minutes, H_2O (10.0 mL) and CH_2Cl_2 (10.0 mL) were added to the mixture. The organic layer was washed with sodium thiosulfate (5% *aq*) and saturated brine, dried over Na_2SO_4 and the filtrate was removed in vacuum. The residue was purified by column chromatography on silica gel with a gradient eluent of petroleum ether and ethyl acetate (20:1 to 5:1) to get **5e** (R_f = 0.7, PE:EA = 5:1) (48.8 mg , 86% yield). ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.28 (d, *J* = 7.2 Hz, 1H), 7.80 (d, *J* = 8.4 Hz, 1H), 7.49 – 7.35 (m, 4H), 6.81 (d, *J* = 7.6 Hz, 1H), 5.81 (s, 1H), 4.15 (t, *J* = 6.4 Hz, 2H), 3.23 – 3.21 (m, 1H), 2.85 (dd, *J* = 18.0, 9.2 Hz, 1H), 2.53 (d, *J* = 18.4 Hz, 1H), 1.96 – 1.85 (m, 3H), 1.66 – 1.46 (m, 5H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 173.9, 157.8, 154.7, 134.4, 127.4, 126.3, 125.9, 125.1, 121.9, 120.1, 104.5, 67.7, 53.1, 39.0, 34.0, 32.4, 29.1, 26.0. HRMS: m/z (ESI) calculated $[M+H]^+$: 437.0608, measured: 437.0602. IR (neat): 2934, 2340, 1705, 1579, 1459, 1267, 1237, 1098, 791, 770 cm^{-1}.

2.6 Mechanistic investigations.

2.6.1 Control experiment.



$Pd(OAc)_2$ (2.3 mg, 0.01 mmol, 10 mol%), alkene substrate **1a** (21.5 mg, 0.1 mmol, 1.0 equiv.), Selectfluor (70.8 mg, 0.2 mmol, 2.0 equiv.) and potassium carbonate (27.6 mg, 0.2 mmol, 2.0 equiv.) were dissolved in a mixed solvent (CH_3CN/CH_3OH 2:1, 1.0 mL), and trimethoxy(phenylethynyl)silane (44.4 mg, 0.2 mmol, 2.0 equiv.) was added to the mixture in sequence under a CO atmosphere. Then the reaction was stirred at room temperature for 8 hours. The solvent was removed in vacuum and the residue was

analyzed by ^{1}H NMR with CF_3DMA as internal standard. As shown in **figure S1**, product **4a** was obtained in 12% yield with trimethoxy(phenylethynyl)silane as the alkynylation reagent[9]. The result indicated that alkynyl-Pd^{II} was involved in the alkynylcarbonylation process.

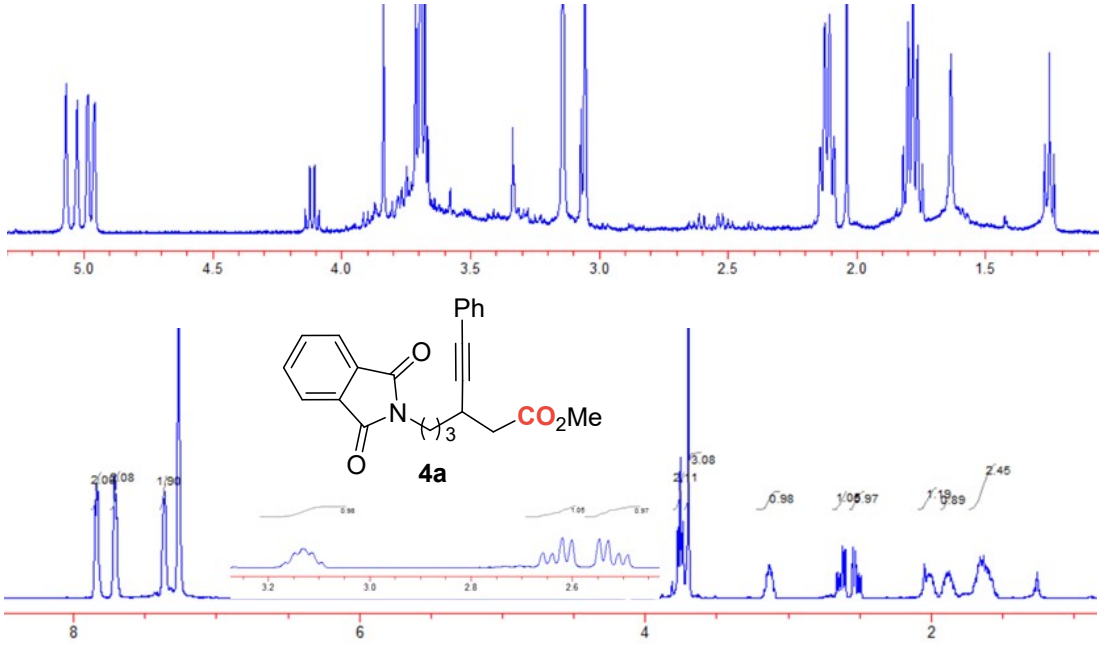
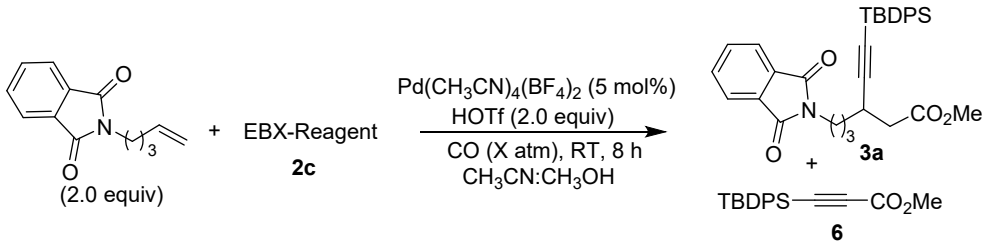


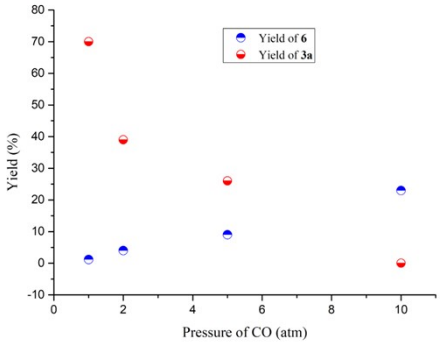
Figure S1 ^{1}H NMR of control experiment

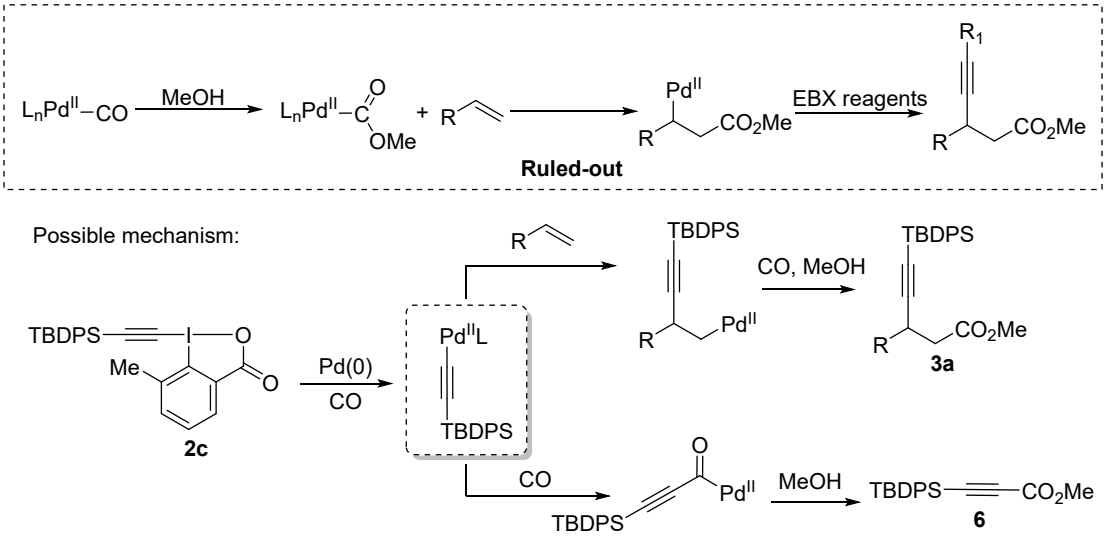
2.6.2 Influence of CO pressure.

Alkene substrate **1a** (43.0 mg, 0.2 mmol, 2.0 equiv.), EBX reagent **2c** (52.4 mg, 0.1 mmol, 1.0 equiv.) and a stirring bar were added into a vial (4.0 mL). Then CH_3CN/CH_3OH (1.0 mL, *v/v* 2:1) was injected by syringe. The vial was then transferred into an autoclave (20.0 mL). At room temperature, the autoclave was flushed with CO gas three times and pressurized with CO gas to 2.0 atm, 5.0 atm and 10.0 atm. 8 hours later, the solvent was removed under reduced pressure and $CDCl_3$ was added to the residue and the product was detected by ^{1}H NMR with CF_3-DMA as an internal standard.



CO (atm)	**3a** (%)	**6** (%)
1	70	1.2
2	39	4
5	26	9
10	--	23

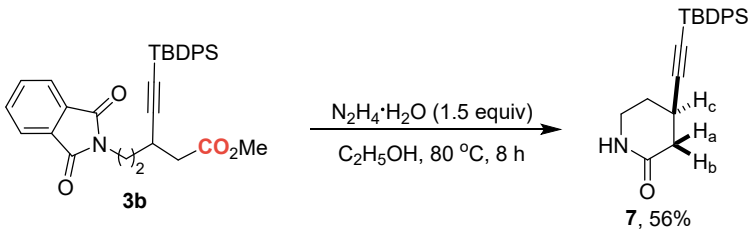




Scheme S1 Influence of CO pressure

The yields of target product **3a** were decreased when increasing CO pressure. Those results ruled out the possibility that CO_2Me-Pd (II) acted as a key intermediate for the target reaction, in which a high CO pressure could be benefited for alkynylcarbonylation products formation. On the other hand, an alkynyl-Pd^{II} species might be involved in the reaction. Alkene insertion by alkynyl-Pd^{II} occurred exclusively at 1 atm CO pressure, whereas the direct carbonylation of alkynyl-Pd^{II} was promoted to a remarkable extent by increasing the CO pressure.

2.6.3 Stereochemistry of alkynylcarbonylation process.



7 was prepared via literature process.[1] ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.77 – 8.75 (m, 4H), 7.42 – 7.34 (m, 6H), 6.01 (br, 1H), 3.63 – 3.57 (m, 1H), 3.40 – 3.33 (m, 1H), 3.13 – 3.07 (m, 1H), 2.73 (dd, *J* = 17.6, 6.0 Hz, 1H), 2.61 (dd, *J* = 17.6, 7.2 Hz, 1H), 2.17 – 1.97 (m, 2H), 1.06 (s, 9H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 170.0, 135.5, 133.2, 129.5, 127.7, 111.0, 82.2, 40.2, 37.4, 27.9, 27.0, 25.8, 18.4. HRMS: m/z (ESI) calculated $[M+Na]^+$: 384.1754 measured:384.1755. Then we turned our attention to confirm the relative The relative configuration of **7**. The NOESY spectroscopy shows that there are stronger NOE between H_b and H_c, and weak NOE with H_c and H_a, which means H_c and H_b in one side of ring, and H_c and H_a in cross sides of ring.

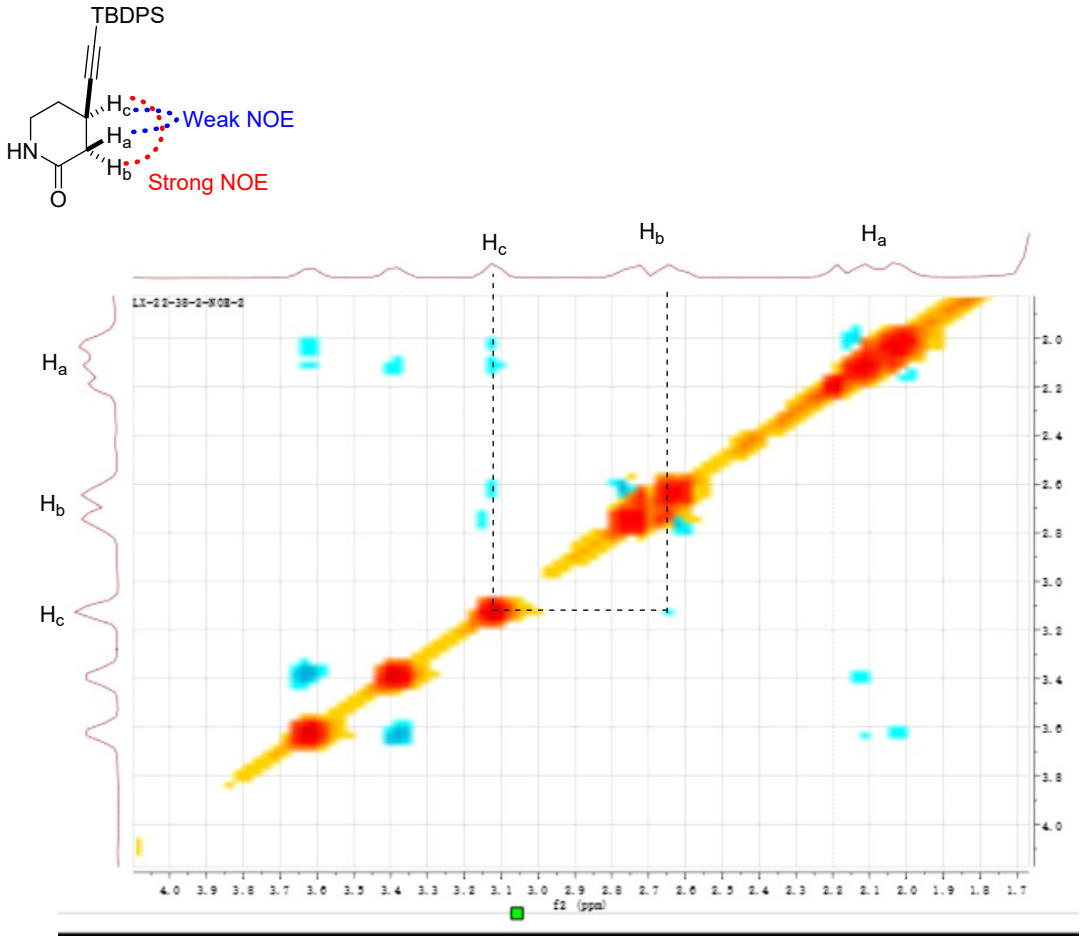


Figure S2 NOE of **7**

The deuterium-labelled substrate *trans*-**1b**-d_1 (90% D containing) was synthesized according to the literature[3] and then subjected to the reaction conditions. The configuration of the corresponding product d_1-**3b** was determined by the further transformation to give six membered-lactam d_1-**7** as a single isomer. This result indicated that the reaction could involve a *cis*-alkynulpalladation followed by CO insertion and nucleophilic attack of acyl Pd(II) intermediate by methanol in sequence to afford the arylcarbonylation products.

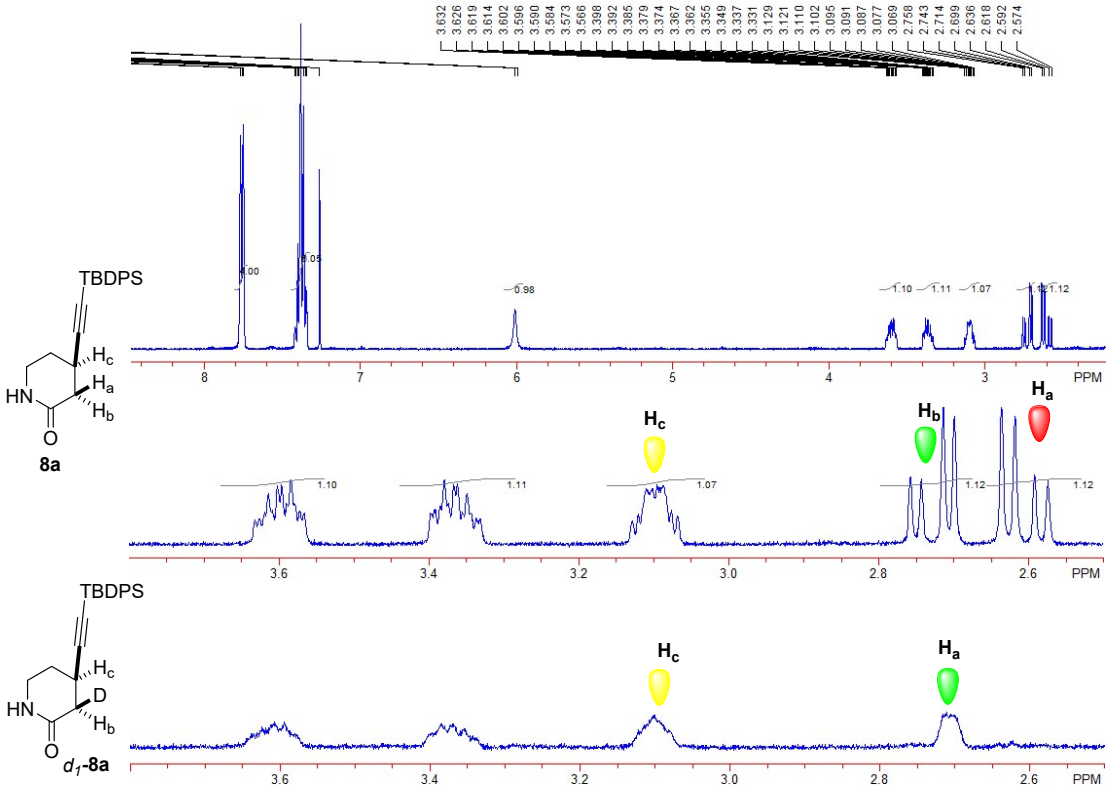
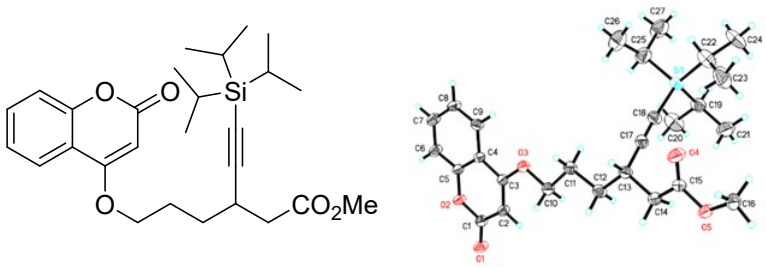


Figure S3 ^{1}H NMR of **8a** and d_1-**8a**

3. X-Ray structure of target product.



3v

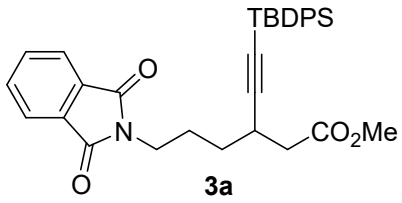
CCDC Number: 2129108

Figure S4 X-Ray structure of 3v

Identification code mo_d8v19162_0m

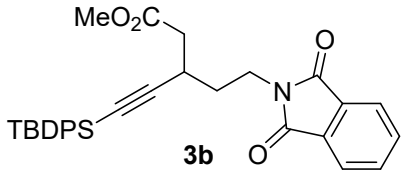
Empirical formula	C27 H38 O5 Si	
Formula weight	470.66	
Temperature	193(2) K	
Wavelength	0.71073 Å	
Crystal system	Triclinic	
Space group	P -1	
Unit cell dimensions	a = 13.9071(10) Å	α= 109.976(2)°.
	b = 14.9140(12) Å	β= 113.932(2)°.
	c = 16.1401(13) Å	γ = 98.587(2)°.
Volume	2709.4(4) $Å^3$	
Z	4	
Density (calculated)	1.154 Mg/m^3	
Absorption coefficient	0.119 mm^{-1}	
F(000)	1016	
Crystal size	0.200 x 0.170 x 0.100 mm^3	
Theta range for data collection	1.700 to 25.500°.	
Index ranges	-16<=h<=16, -18<=k<=18, -19<=l<=19	
Reflections collected	37764	
Independent reflections	10067 [R(int) = 0.0562]	
Completeness to theta = 25.242°	99.8 %	
Absorption correction	Semi-empirical from equivalents	
Max. and min. transmission	0.7456 and 0.6424	
Refinement method	Full-matrix least-squares on F^2	
Data / restraints / parameters	10067 / 132 / 666	
Goodness-of-fit on F^2	1.046	
Final R indices [I>2sigma(I)]	R1 = 0.0727, wR2 = 0.1705	
R indices (all data)	R1 = 0.1098, wR2 = 0.1962	
Extinction coefficient	0.0076(11)	
Largest diff. peak and hole	0.592 and -0.274 $e.Å^{-3}$	

4. New compounds characterization



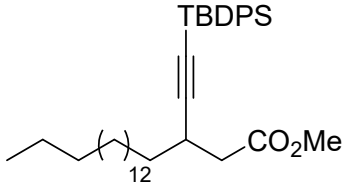
3a

The crude material was purified by column chromatography on silica gel with a gradient eluent of petroleum ether and ethyl acetate (10:1 to 1:1) to get **3a** (R_f = 0.40, PE:EA = 3:1) (Pale yellow oil，85.9 mg of 6:1 mixture, 69%, 6:1). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.86 – 7.83 (m, 2H), 7.78 – 7.76 (m, 4H), 7.72 – 7.67 (m, 2H), 7.40 – 7.34 (m, 6H), 3.77 (t, *J* = 7.2 Hz, 2H), 3.67 (s, 3H), 3.15 – 3.10 (m, 1H), 2.66 (dd, *J* = 15.2, 8.0 Hz, 1H), 2.55 (dd, *J* = 15.2, 6.8 Hz, 1H), 2.10 – 2.04 (m, 1H), 1.95 – 1.89 (m, 1H), 1.78 – 1.62 (m, 2H), 1.03 (s, 9H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 171.6, 168.3, 135.5, 133.8 133.4, 132.0, 129.3, 127.6, 123.2, 111.8, 81.8, 51.7, 39.9, 37.5, 31.7, 29.2, 26.9, 26.6, 18.4. HRMS: m/z (ESI) calculated $[M+NH_4]^+$: 555.2674, measured: 555.2674. IR (neat): 2930, 2855, 2324, 2171, 1772, 1736, 1430, 1394, 1107, 699 cm^{-1}.



3b

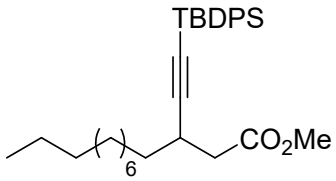
The crude material was purified by column chromatography on silica gel with a gradient eluent of petroleum ether and ethyl acetate (10:1 to 1:1) to get **3b** (R_f = 0.34, PE:EA = 3:1) (Pale yellow oil，86.8 mg of 3:1 mixture, 62%, 3:1). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.85 – 7.62 (m, 8H), 7.61 – 7.35 (m, 6H), 4.02 – 3.81 (m, 2H), 3.66 (s, 3H), 3.17 – 3.13 (m, 1H), 2.77 – 2.63 (m, 2H), 2.04 – 1.99 (m, 2H), 1.04 (s, 9H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 171.4, 168.2, 135.6, 133.8, 133.3, 132.0, 129.4, 127.6, 123.2, 111.0, 82.3, 51.9, 39.7, 36.1, 33.0, 27.6, 26.9, 18.4. HRMS: m/z (ESI) calculated $[M+Na]^+$: 546.2071, measured: 546.2067. IR (neat): 2933, 2934, 2174, 1767, 1743, 1430, 1267, 1107, 699 cm^{-1}.



3c

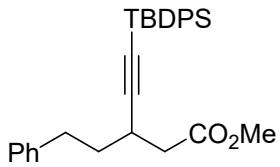
The crude material was purified by column chromatography on silica gel with a gradient eluent of petroleum ether and ethyl acetate (1:0 to 10:1) to get **3c** (R_f = 0.78, PE:EA = 10:1) (Yellow oil，81.5 mg, 71%,

10:1). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.81 – 7.78 (m, 4H), 7.41 – 7.34 (m, 6H), 3.70 (s, 3H), 3.08 – 3.04 (m, 1H), 2.66 (dd, *J* = 15.2, 7.6 Hz, 1H), 2.57 (dd, *J* = 15.2, 6.8 Hz, 1H), 1.60 – 1.52 (m, 4H), 1.37 – 1.26 (m, 26H), 1.06 (s, 9H), 0.88 (t, *J* = 6.8 Hz, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 172.0, 135.5, 133.7, 129.3, 127.6, 112.8, 81.1, 51.7, 40.1, 34.5, 31.9, 29.68, 29.66, 29.62, 29.55, 29.35, 29.26, 27.2, 27.0, 22.7, 18.5, 14.1. HRMS: m/z (ESI) calculated $[M+Na]^+$: 597.4098, measured: 597.4090. IR (neat): 2922, 2853, 2324, 2169, 1744, 1463, 1227, 1163, 1107, 919, 720, 660 cm^{-1}



3d

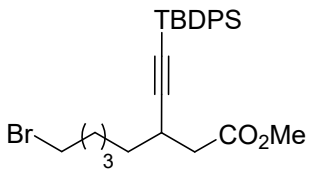
The crude material was purified by column chromatography on silica gel with a gradient eluent of petroleum ether and ethyl acetate (1:0 to 10:1) to get **3d** (R_f = 0.75, PE:EA = 10:1) (Yellow oil, 78.4 mg, 80%, 10:1). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.80 – 7.78 (m, 4H), 7.41 – 7.34 (m, 6H), 3.69 (s, 3H), 3.08 – 3.04 (m, 1H), 2.65 (dd, *J* = 15.2, 7.6 Hz, 1H), 2.56 (dd, *J* = 15.2, 6.8 Hz, 1H), 1.60 – 1.52 (m, 4H), 1.37 – 1.26 (m, 14H), 1.06 (s, 9H), 0.88 (t, *J* = 6.8 Hz, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 172.0, 135.5, 133.7, 129.3, 127.6, 112.8, 81.1, 51.7, 40.1, 34.5, 31.9, 29.62, 29.55, 29.31, 29.26, 27.2, 27.0, 26.9, 22.7, 28.5, 14.1. HRMS: m/z (ESI) calculated $[M+Na]^+$: 513.3159, measured: 513.3168. IR (neat): 2924, 2860, 2324, 2169, 1743, 1462, 1229, 1164, 1107, 918, 674, 660 cm^{-1}.



3e

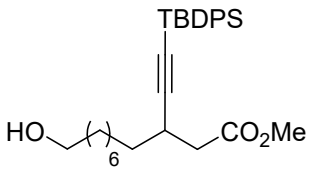
The crude material was purified by column chromatography on silica gel with a gradient eluent of petroleum ether and ethyl acetate (20:1 to 5:1) to get **3e** (R_f = 0.53, PE:EA = 10:1) (Yellow oil, 67.2 mg, 74%, 9:1). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.85 – 7.83 (m, 4H), 7.44 – 7.37 (m, 6H), 7.33 – 7.29 (m, 2H), 7.26 – 7.20 (m, 3H), 3.70 (s, 3H), 3.11 – 2.99 (m, 2H), 2.89 – 2.84 (m, 1H), 2.71 (dd, *J* = 15.6, 8.0 Hz, 1H), 2.57 (dd, *J* = 15.6, 7.2 Hz, 1H), 1.96 – 1.88 (m, 2H), 1.06 (s, 9H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 171.7, 141.4, 135.5, 133.5, 129.4, 128.5, 127.6, 127.62, 126.0, 112.2, 81.9, 51.6, 39.9, 36.4, 33.6, 29.3, 27.0, 18.5. HRMS: m/z (ESI) calculated $[M+NH_4]^+$: 472.2666, measured: 472.2668. IR (neat): 2930, 2856, 2170, 1738, 1428, 1165, 1107,

819, 741, 698 cm^{-1}. **3e'** ^1H NMR (400 MHz, $CDCl_3$) δ 7.80 – 7.82 (m, 4H), 3.72 (s, 3H).



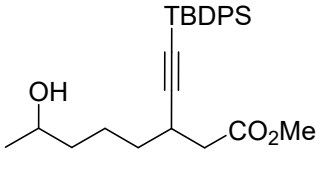
3f

The crude material was purified by column chromatography on silica gel with a gradient eluent of petroleum ether and ethyl acetate (30:1 to 10:1) to get **3f** (R_f = 0.66, PE:EA = 10:1), (Yellow oil，69.4 mg, 70%). ^1H NMR (400 MHz, $CDCl_3$) δ 7.80 – 7.77 (m, 4H), 7.42 – 7.34 (m, 6H), 3.70 (s, 3H), 3.42 (t, *J* = 6.8 Hz, 2H), 3.09 – 3.06 (m, 1H), 2.67 (dd, *J* = 15.2, 8.0 Hz, 1H), 2.56 (dd, *J* = 15.2, 6.8 Hz, 1H), 1.92 – 1.85 (m, 2H), 1.67 – 1.48 (m, 6H), 1.06 (s, 9H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 171.8, 135.5, 133.5, 129.4, 127.6, 112.4, 81.4, 51.8, 40.0, 34.2, 33.7, 32.6, 29.5, 27.7, 27.0, 26.4, 18.4. HRMS: m/z (ESI) calculated $[M+NH_4]^+$: 516.1928, measured: 515.1930. IR (neat): 2930, 2856, 2170, 1738, 1428, 1165, 1107, 819, 741, 698 cm^{-1}



3g

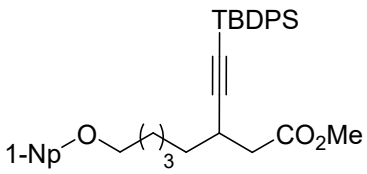
The crude material was purified by column chromatography on silica gel with a gradient eluent of petroleum ether and ethyl acetate (10:1 to 1:1) to get **3g** (R_f = 0.46, PE:EA = 3:1) (Pale yellow oil, 78.5 mg, 82%). ^1H NMR (400 MHz, $CDCl_3$) δ 7.81 – 7.79 (m, 4H), 7.42 – 7.26 (m, 6H), 3.70 (s, 3H), 3.62 (t, *J* = 6.4 Hz, 2H), 3.09 – 3.06 (m, 1H), 2.66 (dd, *J* = 15.6, 8.4 Hz, 1H), 2.56 (dd, *J* = 14.8, 6.8 Hz, 1H), 1.76 (br, 1H), 1.64 – 1.51 (m, 6H), 1.41 - 1.27 (m, 9H), 1.07 (s, 9H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 172.0, 135.5, 133.6, 129.3, 127.6, 112.7, 81.1, 62.9, 51.7, 40.0, 34.4, 32.7, 29.5, 29.4, 29.2, 29.1, 27.1, 26.9, 25.6, 18.4. HRMS: m/z (ESI) calculated $[M+NH_4]^+$: 496.3241, measured: 496.3245. IR (neat): 2928, 2855, 2170, 1738, 1429, 1359, 1107, 741, 698, 630 cm^{-1}



3h

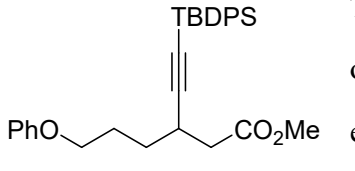
The crude material was purified by column chromatography on silica gel with a gradient eluent of petroleum ether and ethyl acetate (10:1 to 1:1) to get **3h** (R_f = 0.50, PE:EA = 3:1),

(Yellow oil，65.4 mg, 75%, 7:1, dr 1:1). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.79 – 7.77 (m, 4H), 7.41 – 7.34 (m, 6H), 3.84 – 3.79 (m, 1H), 3.69 (s, 3H), 3.09 – 3.06 (m, 1H), 2.67 (dd, *J* = 15.2, 7.6 Hz, 1H), 2.57 (dd, *J* = 15.2, 8.0 Hz, 1H), 1.75 – 1.45 (m, 7H), 1.19 (d, J = 6.4 Hz, 3H), 1.06 (s, 9H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 171.9, 135.5, 133.5, 129.4, 127.6, 112.4, 81.4, 67.9, 51.7, 40.0, 38.8, 34.4, 29.6, 26.9, 23.45, 23.40, 18.4. HRMS: m/z (ESI) calculated $[M+NH_4]^+$: 454.2722, measured: 454.2725. IR (neat): 2930, 2857, 2170, 1737, 1429, 1158, 1107, 819, 714, 699 cm^{-1}



3i

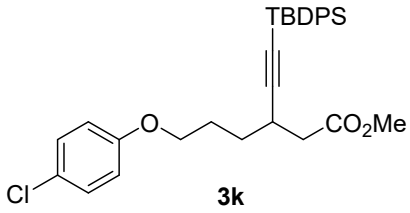
The crude material was purified by column chromatography on silica gel with a gradient eluent of petroleum ether and ethyl acetate (10:1 to 3:1) to afford **3i** (R_f = 0.61, PE:EA = 3:1), (Yellow oil，75.3 mg, 67%, 12:1). ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.36 – 8.34 (m, 1H), 7.88 – 7.82 (m, 5H), 7.54 – 7.37 (m, 10H), 6.80 (d, *J* = 6.8 Hz, 1H), 4.17 (t, *J* = 6.4 Hz, 2H), 3.74 (s, 3H), 3.18 – 3.14 (m, 1H), 2.73 (dd, *J* = 15.2, 7.6 Hz, 1H), 2.62 (dd, *J* = 15.2, 6.8 Hz, 1H), 2.02 – 1.97 (m, 2H), 1.83 – 1.62 (m, 6H), 1.12 (s, 9H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 171.2, 154.7, 135.5, 134.4, 133.5, 129.4, 127.6, 127.4, 126.3, 125.9, 125.7, 125.0, 122.0, 119.9, 112.6, 104.5, 81.3, 67.8, 51.7, 40.0, 34,4, 29.6, 29.2, 27.1, 27.0, 25.9, 18.4. HRMS: m/z (ESI) calculated $[M+NH_4]^+$: 580.3241, measured: 580.3249. IR (neat): 2930, 2856, 2324, 2170, 1737, 1579, 1268, 1238, 1107, 819, 790, 740 cm^{-1}.



3j

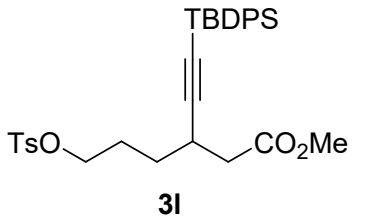
The crude material was purified by column chromatography on silica gel with a gradient eluent of petroleum ether and ethyl acetate (10:1 to 3:1) to get **3j** (R_f = 0.58, PE:EA = 3:1), (Pale yellow oil, 71.6 mg, 74%, 15:1). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.80 – 7.77 (m, 4H), 7.40 – 7.24 (m, 6H), 7.26 (t, *J* = 8.0 Hz, 2H), 6.95 – 6.88 (m, 3H), 4.02 (t, *J* = 6.4 Hz, 2H), 3.68 (s, 3H), 3.16 – 3.12 (m, 1H), 2.69 (dd, *J* = 15.6, 8.4 Hz, 1H), 2.56 (dd, *J* = 15.2, 6.8 Hz, 1H), 2.14 – 2.10 (m, 1H), 2.04 – 1.98 (m, 1H), 1.87 – 1.61 (m, 2H), 1.06 (s, 9H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 171.8, 158.9, 135.5, 133.5, 129.4, 129.38, 127.6, 120.6, 114.4, 112.1, 81.7, 67.2, 51.8, 40.0, 31.2, 29.4, 27.1,

27.0, 18.4. HRMS: m/z (ESI) calculated $[M+NH_4]^+$: 502.2722, measured: 502.2779. IR (neat): 2929, 2856, 2338, 2169, 1738, 1428, 1242, 1079, 752, 693cm^{-1}



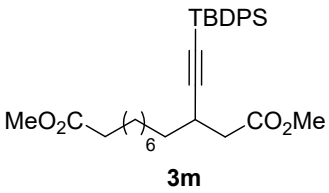
3k

The crude material was purified by column chromatography on silica gel with a gradient eluent of petroleum ether and ethyl acetate (10:1 to 3:1) to get **3k** (R_f = 0.57, PE:EA = 3:1), (Pale yellow oil, 70.5 mg, 68%, 8:1). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.82 – 7.78 (m, 4H), 7.43 – 7.36 (m, 6H), 7.21 (d, *J* = 8.8 Hz, 2H), 6.82 (d, *J* = 8.8 Hz, 2H), 4.00 (t, *J* = 6.0 Hz, 2H), 3.71 (s, 3H), 3.18 – 3.14 (m, 1H), 2.72 (dd, *J* = 15.2, 7.6 Hz, 1H), 2.61 (dd, *J* = 15.6, 6.8 Hz, 1H), 2.16 – 2.10 (m, 1H), 2.05 – 1.97 (m, 1H), 1. 87 – 1.73 (m, 2H), 1.08 (s, 9H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 171.7, 157.5, 135.5, 133.4, 129.4, 129.2, 127.6, 125.4, 115.7, 112.0, 81.9, 67.6, 57.7, 51.2, 40.0, 31.1, 29.4, 27.0, 18.4. HRMS: m/z (ESI) calculated $[M+NH_4]^+$: 536.2382, measured: 536.2379. IR (neat): 2973, 2902, 2348, 1741, 1394, 1252, 1054, 892, 643 cm^{-1}



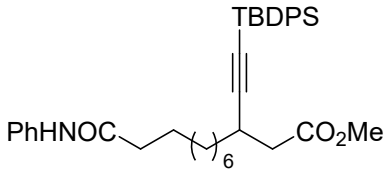
3l

The crude material was purified by column chromatography on silica gel with a gradient eluent of petroleum ether and ethyl acetate (10:1 to 1:1) to **3l** (R_f = 0.42, PE:EA = 3:1), (Yellow oil, 67.4 mg of 7:1 mixture, 53%, 7:1). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.80 – 7.75 (m, 6H), 7.42 – 7.34 (m, 6H), 7.30 (d, *J* = 8.4 Hz, 2H), 4.10 (t, *J* = 6.0 Hz, 2H), 3.69 (s, 3H), 3.05 – 2.99 (m, 1H), 2.65 (dd, *J* = 15.6, 7.6 Hz, 1H), 2.52 (dd, *J* = 15.2, 6.8 Hz, 1H), 2.42 (s, 3H), 2.05 – 1.98 (m, 1H), 1.89 – 1.83 (m, 1H), 1.75 – 1.56 (m, 2H), 1.06 (s, 9H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 171.4, 144.7, 135.4, 133.2, 132.9, 129.8, 129.4, 128.0, 127.6, 111.4, 82.1, 60.9, 51.8, 39.8, 30.3, 29.0, 26.9, 26.7, 21.5, 18.4. HRMS: m/z (ESI) calculated $[M+NH_4]^+$: 580.2547, measured: 580.2549. IR (neat): 2929, 2856, 2171, 1737, 1597, 1429, 1173, 1107, 919, 741 cm^{-1}. **3l'** ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.80 – 7.75 (m, 6H), 7.42 – 7.34 (m, 6H), 7.30 (d, *J* = 8.4 Hz, 2H), 4.07 (t, *J* = 6.0 Hz, 2H), 3.71 (s, 3H).



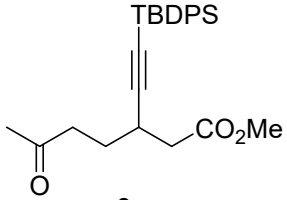
3m

The crude material was purified by column chromatography on silica gel with a gradient eluent of petroleum ether and ethyl acetate (20:1 to 10:1) to get **3m** (R_f = 0.63, PE:EA = 10:1), (Yellow oil，65.5 mg, 63%, 14:1). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.81 – 7.78 (m, 4H), 7.42 – 7.34 (m, 6H), 3.69 (s, 3H), 3.67 (s, 3H), 3.08 – 3.06 (m, 1H), 2.66 (dd, *J* = 15.2, 7.2 Hz, 1H), 2.55 (dd, *J* = 15.2, 8.4 Hz, 1H), 2.30 (t, *J* = 7.6 Hz, 2H), 1.66 – 1.56 (m, 6H), 1.33 – 1.30 (m, 8H), 1.06 (s, 9H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 174.3, 171.9, 135.5, 133.6, 129.3, 127.6, 112.8, 81.1, 51.7, 51.4, 40.0, 34.5, 34.0, 29.6, 29.3, 29.1, 29.08, 27.2, 26.9, 24.9, 18.4. HRMS: m/z (ESI) calculated $[M+NH_4]^+$: 538.3347, measured: 538.3342. IR (neat): 2930, 2856, 2170, 1738, 1428, 1165, 1107, 819, 741, 698 cm^{-1}



3n

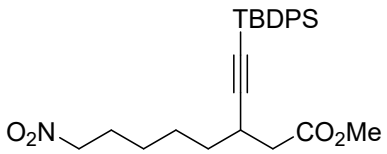
The crude material was purified by column chromatography on silica gel with a gradient eluent of petroleum ether and ethyl acetate (10:1 to 1:1) to get **3n** (R_f = 0.35, PE:EA = 2:1), (Yellow solid, 79.1 mg, 68%, 12:1). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.81 – 7.78 (m, 4H), 7.51 (d, *J* = 8.0 Hz, 2H), 7.41 – 7.26 (m, 9H), 7.09 (t, *J* = 7.2 Hz, 1H), 3.69 (s, 3H), 3.07 – 3.04 (m, 1H), 2.65 (dd, *J* = 15.2, 8.0 Hz, 1H), 2.55 (dd, *J* = 15.2, 6.8 Hz, 1H), 2.31 (t, *J* = 7.2 Hz, 2H), 1.72 – 1.66 (m, 3H), 1.62 – 1.53 (m, 4H), 1.33 – 1.26 (m, 7H), 1.06 (s, 9H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 172.0, 171.4, 135.5, 133.6, 129.3, 128.9, 127.6, 127.5, 124.1, 119.7, 112.8, 81.1, 51.7, 40.1, 37.7, 34.4, 29.5, 29.2, 29.1, 29.0, 27.1, 26.9, 25.5, 18.4. HRMS: m/z (ESI) calculated $[M+NH_4]^+$: 599.3663, measured: 599.3670. IR (neat): 3373, 2927, 2853, 2338, 2172, 1720.3, 1682, 1598, 1534, 1077, 740 cm^{-1}.



3o

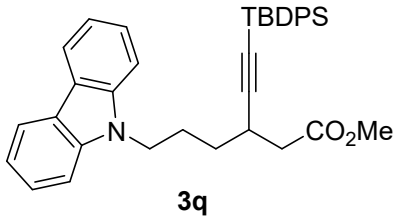
The crude material was purified by column chromatography on silica gel with a gradient eluent of petroleum ether and ethyl acetate (10:1 to 3:1) to get **3o** (R_f = 0.54, PE:EA = 3:1), (Yellow oil, 56.3 mg, 67%, 10:1). ^{1}H NMR (400 MHz,

$CDCl_3$) δ 7.78 – 7.76 (m, 4H), 7.43 – 7.35 (m, 6H), 3.70 (s, 3H), 3.14 – 3.07 (m, 1H), 2.80 – 2.67 (m, 3H), 2.58 (dd, *J* = 15.2, 6.8 Hz, 1H), 2.14 (s, 3H), 2.04 – 1.91 (m, 1H), 1.82 – 1.71 (m, 1H), 1.06 (s, 9H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 207.8, 171.5, 135.4, 133.3, 129.4, 127.6, 111.6, 82.3, 51.8, 41.1, 39.9, 30.0, 28.9, 28.1, 26.9, 18.4. HRMS: m/z (ESI) calculated $[M+NH_4]^+$: 438.2459, measured: 438.2466. IR (neat): 2930, 2856, 2323, 2170, 1737, 1715, 1428, 1166, 1107, 819, 714, 699 cm^{-1}



3p

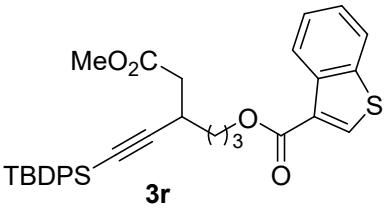
The crude material was purified by column chromatography on silica gel with a gradient eluent of petroleum ether and ethyl acetate (10:1 to 3:1) to get **3p** (R_f = 0.43, PE:EA = 5:1), (Yellow oil, 67.1 mg, 72%). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.79 – 7.77 (m, 4H), 7.43 – 7.35 (m, 6H), 4.35 (t, *J* = 7.2 Hz, 2H), 3.70 (s, 3H), 3.08 – 3.06 (m, 1H), 2.68 (dd, *J* = 15.2, 7.6 Hz, 1H), 2.56 (dd, *J* = 15.6, 7.2 Hz, 1H), 2.06 – 1.98 (m, 2H), 1.71 – 1.57 (m, 4H), 1.51 – 1.40 (m, 2H), 1.07 (s, 9H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 171.7, 135.5, 133.4, 129.4, 127.6, 112.1, 81.6, 75.4, 51.8, 39.9, 34.0, 29.4, 27.2, 26.9, 26.5, 25.8, 18.4. HRMS: m/z (ESI) calculated $[M+NH_4]^+$: 483.2674, measured: 483.2670. IR (neat): 2930, 2857, 2338, 2172, 1739, 1374, 1234, 1143, 1107, 699 cm^{-1}.



3q

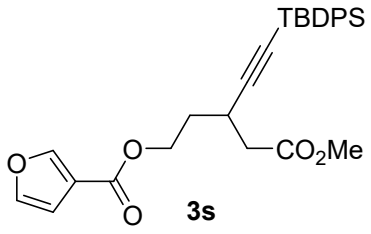
The crude material was purified by column chromatography on silica gel with a gradient eluent of petroleum ether and ethyl acetate (10:1 to 1:1) to get **3q** (R_f = 0.52, PE:EA = 2:1), (Yellow oil, 63.5 mg, 57%, 9:1). ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.08 (d, *J* = 8.0 Hz, 2H), 7.73 (d, *J* = 6.8 Hz, 4H), 7.40 – 7.28 (m, 10H), 7.22 – 7.18 (m, 2H), 4.36 – 4.32 (m, 2H), 3.62 (s, 3H), 3.10 – 3.07 (m, 1H), 2.61 (dd, *J* = 15.2, 8.0 Hz, 1H), 2.47 (dd, *J* = 15.2, 6.4 Hz, 1H), 2.26 – 2.21 (m, 1H), 2.13 – 2.06 (m, 1H), 1.69 – 1.63 (m, 2H), 1.02 (s, 9H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 171.6, 140.3, 135.4, 133.3, 129.4, 127.6, 125.7, 122.8, 120.3, 118.8, 111.7, 108.5, 82.1, 51.7, 42.6, 39.9, 32.0, 29.4, 26.9, 26.8, 18.4. HRMS: m/z

(ESI) calculated $[M+H]^+$: 558.2823, measured: 558.2832. IR (neat): 2928, 2855, 2169, 1735, 1484, 1452, 1326, 1152, 1107, 819, 747, 740 cm^{-1}.



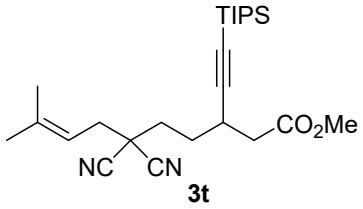
3r

The crude material was purified by column chromatography on silica gel with a gradient eluent of petroleum ether and ethyl acetate (10:1 to 1:1) to get **3r** (R_f = 0.51, PE:EA = 2:1), (Yellow oil, 85.2 mg, 75%, 7:1). ^1H NMR (400 MHz, $CDCl_3$) δ 8.50 (d, *J* = 8.0 Hz, 1H), 8.38 (s, 1H), 7.87 (d, *J* = 8.0 Hz, 1H), 7.81 – 7.79 (m, 4H), 7.48 (t, *J* = 6.8 Hz, 1H), 7.43 – 7.35 (m, 7H), 4.45 (t, *J* = 6.4 Hz, 2H), 3.69 (s, 3H), 3.22 – 3.18 (m, 1H), 2.73 (dd, *J* = 15.2, 7.6 Hz, 1H), 2.61 (dd, *J* = 15.6, 7.2 Hz, 1H), 2.20 – 2.16 (m, 1H), 2.08 – 2.04 (m, 1H), 1.86 – 1.76 (m, 2H), 1.08 (s, 9H). ^1H NMR (400 MHz, $CDCl_3$) δ 171.6, 162.7, 140.0, 136.7, 136.6, 135.5, 133.4, 129.4, 127.7, 127.1, 125.4, 125.0, 124.7, 122.5, 111.9, 82.1, 64.2, 51.8, 40.0, 31.2, 29.4, 27.0, 26.7, 18.4. HRMS: m/z (ESI) calculated $[M+Na]^+$: 591.1996, measured: 591.1996. IR (neat): 2940, 2870, 2338, 2170, 1751, 1737, 1550, 1429, 1170, 700 cm^{-1}.



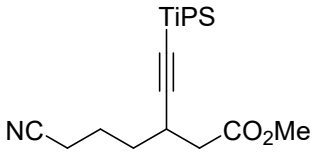
3s

The crude material was purified by column chromatography on silica gel with a gradient eluent of petroleum ether and ethyl acetate (10:1 to 1:1) to get **3s** (R_f = 0.39, PE:EA = 3:1) (Yellow oil, 75.2 mg, 77%, 9:1). ^1H NMR (400 MHz, $CDCl_3$) δ 7.77 – 7.75 (m, 4H), 7.57 (s, 1H), 7.39 – 7.34 (m, 6H), 7.19 (d, *J* = 3.2 Hz, 1H), 6.49 (d, *J* = 2.0 Hz, 1H), 4.61 – 4.52 (m, 2H), 3.69 (s, 3H), 3.32 – 3.28 (m, 1H), 2.73 (dd, *J* = 15.6, 8.0 Hz, 1H), 2.65 (dd, *J* = 15.6, 6.8 Hz, 1H), 2.12 – 2.01 (m, 2H), 1.05 (s, 9H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 171.5, 146.4, 135.5, 134.4, 133.3, 129.5, 127.7, 119.5, 118.1, 111.9, 110.8, 82.6, 62.6, 51.9, 39.8, 33.4, 27.0, 26.7, 18.5. HRMS: m/z (ESI) calculated $[M+Na]^+$: 511.1911, measured: 511.1913. IR (neat): 2928, 2855, 2169, 1735, 1484, 1452, 1326, 1152, 1107, 819, 747, 740 cm^{-1}.



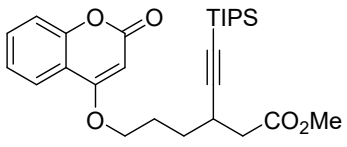
3t

The crude material was purified by column chromatography on silica gel with a gradient eluent of petroleum ether and ethyl acetate (10:1 to 3:1) to get **3t** (R_f = 0.46, PE:EA = 3:1) (Yellow oil, 51.4 mg of 5:1 mixture, 50%, 5:1). ^{1}H NMR (400 MHz, $CDCl_3$) δ 5.26 (t, *J* = 7.6 Hz, 1H), 3.68 (s, 3H), 3.00 – 2.97 (m, 1H), 2.68 – 2.58 (m, 4H), 2.49 (dd, *J* = 15.2, 7.2 Hz, 1H), 2.26 (td, *J* = 8.8, 4.0 Hz, 1H), 2.04 – 1.89 (m, 2H), 1.80 – 1.68 (m, 7H), 1.12 – 0.95 (m, 21H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 171.2, 140.7, 115.4, 114.3, 107.7, 83.9, 51.8, 39.9, 37.5, 36.4, 34.8, 30.4, 28.8, 25.9, 18.5, 11.0. HRMS: m/z (ESI) calculated $[M+NH_4]^+$: 446.3197, measured: 446.3200. IR (neat): 2943, 2865, 2324, 1737, 1458, 1165, 910, 882, 731, 675 cm^{-1}.



3u

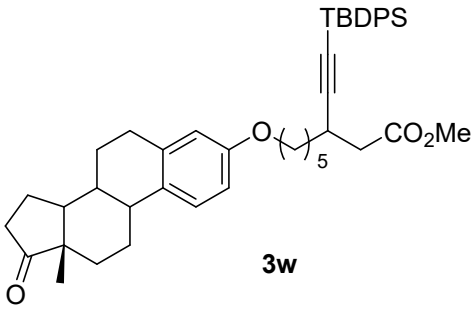
The crude material was purified by column chromatography on silica gel with a gradient eluent of petroleum ether and ethyl acetate (10:1 to 3:1) to get **3u**, (R_f = 0.50, PE:EA = 3:1) (Yellow oil, 46.2 mg of 6:1 mixture, 60%, 7:1). ^{1}H NMR (400 MHz, $CDCl_3$) δ 3.67 (s, 3H), 2.95 – 2.89 (m, 1H), 2.56 (dd, *J* = 15.6, 8.0 Hz, 1H), 2.45 (dd, *J* = 15.6, 8.0 Hz, 1H), 2.40 (t, *J* = 7.2 Hz, 2H), 1.95 – 1.90 (m, 1H), 1.84 – 1.76 (m, 1H), 1.72 – 1.64 (m, 1H), 161 – 1.54 (m, 1H), 1.07 – 0.94 (m, 21H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 171.5, 119.3, 108.5, 83.1, 51.7, 40.1, 33.2, 28.7, 23.2, 18.5, 16.8, 11.0. HRMS: m/z (ESI) calculated $[M+NH_4]^+$: 353.2619, measured: 353.2628. IR (neat): 2943, 2865, 2324, 1737, 1458, 1165, 910, 882, 731, 675 cm^{-1}.



3v

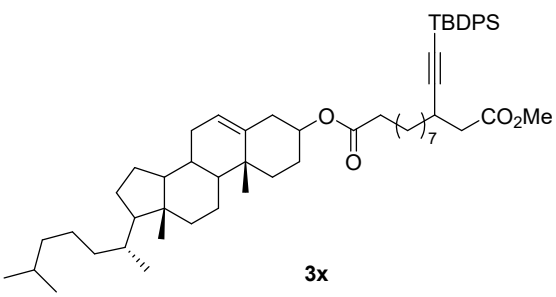
The crude material was purified by column chromatography on silica gel with a gradient eluent of petroleum ether and ethyl acetate (10:1 to 1:1) to get **3v** (R_f = 0.52, PE:EA = 1:1) (Pale yellow solid, 65.8 mg of 6:1 mixture, 60%, 6:1). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.82 (d, *J* = 8.4 Hz, 1 H), 7.55 (t, *J* = 8.4 Hz, 1H), 7.32 (d, *J* = 8.0 Hz, 1H), 7.27 (t, *J* = 8.0 Hz, 1H), 5.68 (s, 1H), 4.19

(t, *J* = 6.0 Hz, 2H), 3.69 (s, 3H), 3.05 – 3.01 (m, 1H), 2.63 (dd, *J* = 15.6, 7.6 Hz, 1H), 2.52 (dd, *J* = 15.6, 7.6 Hz, 1H), 2.22 – 2.18 (m, 1H), 2.11 - 2.06 (m, 1H), 1.83 – 1.77 (m, 1H), 1.72 – 1.65 (m, 1H), 1.12 – 0.95 (m, 21H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 171.6, 165.5, 162.9, 153.3, 132.3, 123.8, 122.9, 116.7, 115.7, 109.0, 90.4, 82.8, 68.8, 51.7, 40.2, 31.1, 29.1, 26.3, 18.5, 11.0. HRMS: m/z (ESI) calculated $[M+H]^+$: 471.2561, measured: 471.2565. IR (neat): 2924, 2860, 2324, 2169, 1743, 1462, 1229, 1164, 1107, 918, 674, 660 cm^{-1}.



3w

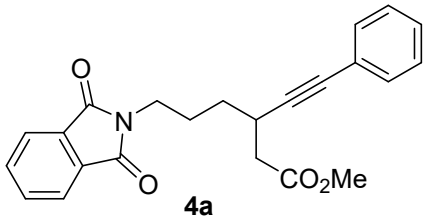
The crude material was purified by column chromatography on silica gel with a gradient eluent of petroleum ether and ethyl acetate (10:1 to 1:1) to get **3w** (R_f = 0.56, PE:EA = 2:1)**,** (Yellow oil, 111.5 mg, 81%). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.83 – 7.81 (m, 4H), 7.43 – 7.36 (m, 6H), 7.20 (d, *J* = 8.8 Hz, 1H), 6.72 (d, *J* = 8.4 Hz, 1H), 6.66 (s, 1H), 3.96 (t, *J* = 6.8 Hz, 2H), 3.72 (s, 3H), 3.13 – 3.10 (m, 1H), 2.92 – 2.88 (m, 2H), 2.69 (dd, *J* = 15.6, 7.2 Hz, 1H), 2.61 – 2.48 (m, 2H), 2.44 – 2.40 (m, 1H), 2.29 – 1.96 (m, 5H), 1.86 – 1.42 (m, 14H), 1.06 (s, 9H), 0.93 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 220.8, 171.8, 157.0, 137.6, 135.4, 133.5, 131.7, 129.3, 127.5, 126.2, 114.4, 112.6, 112.0, 81.2, 67.6, 51.7, 50.3, 47.9, 43.9, 39.9, 38.3, 35.8, 34.3, 31.5, 29.55, 29.5, 29.2, 27.0, 26.9, 26.5, 25.8, 25.7, 21.5, 18.4, 13.8. HRMS: m/z (ESI) calculated $[M+NH_4]^+$: 706.4286, measured: 706.4303. IR (neat): 2929, 2856, 2338, 2170, 1736, 1499, 1429, 1158, 1107, 818, 700 cm^{-1}.



3x

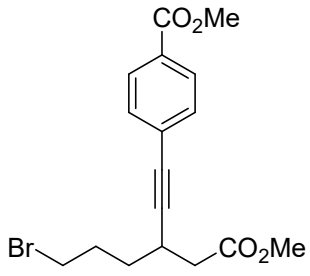
The crude material was purified by column chromatography on silica gel with a gradient eluent of petroleum ether and ethyl acetate (10:1 to 3:1) to get **3x** (R_f = 0.64, PE:EA = 3:1) (Yellow oil, 110.1 mg, 63%). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.80

– 7.78 (m, 4H), 7.41 – 7.34 (m, 6H), 5.38 – 5.37 (m, 1H), 4.63 – 4.61 (m, 1H), 3.69 (s, 3H), 3.09 – 3.04 (m, 1H), 2.65 (dd, *J* = 14.8, 7.6 Hz, 1H), 2.55 (dd, *J* = 15.6, 6.8 Hz, 1H), 2.32 – 2.24 (m, 4H), 2.03 – 1.96 (m, 2H), 1.87 – 1.84 (m, 3H), 1.60 – 0.86 (m, 56H), 0.68 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 173.2, 171.9, 139.7, 135.5, 133.6, 129.3, 127.6, 120.6, 112.8, 81.1, 73.6, 56.6, 56.1, 51.7, 50.0, 42.3, 40.0, 39.7, 39.5, 38.1, 37.0, 36.6, 36.2, 35.8, 34.7, 34.5, 31.9, 31.8, 29.6, 29.3, 29.2, 29.1, 28.2, 28.0, 27.8, 27.2, 27.0, 25.0, 24.3, 23.8, 22.8, 22.6, 21.0, 19.3, 18.7, 18.4, 11.8. HRMS: m/z (ESI) calculated $[M+NH_4]^+$: 892.6634, measured: 892.6656. IR (neat): 2930, 2854, 2171, 1734, 1464, 1430, 1166, 1108, 740, 699 cm^{-1}.



4a

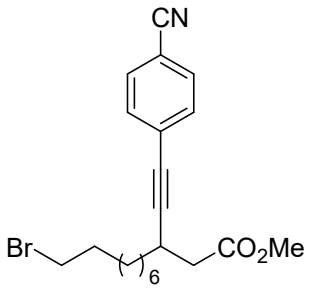
The crude material was purified by column chromatography on silica gel with a gradient eluent of petroleum ether and ethyl acetate (10:1 to 3:1) to get **4a** (R_f = 0.37, PE:EA = 3:1) (Yellow oil, 42.1 mg, 56%). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.85 – 7.83 (m, 2H), 7.72 – 7.70 (m, 2H), 7.37 – 7.36 (m, 2H), 7.26 (br, 3H), 3.75 (t, *J* = 7.2 Hz, 2H), 3.70 (s, 3H), 3.15 – 3.11 (m, 1H), 2.63 (dd, *J* = 15.6, 7.6 Hz, 1H), 2.53 (dd, *J* = 15.2, 6.8 Hz, 1H), 2.02 – 1.98 (m, 1H), 1.91 – 1.84 (m, 1H), 1.70 – 1.57 (m, 2H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 171.8, 168.4, 133.9, 132.1, 131.6, 128.1, 127.9, 123.3, 123.2, 90.4, 82.6, 51.8, 39.9, 37.6, 31.7, 28.6, 26.4. HRMS: m/z (ESI) calculated $[M+NH_4]^+$: 393.1809, measured: 393.1820. IR (neat): 2948, 2321, 1771, 1736, 1707, 1490, 1395, 1361, 882, 719 cm^{-1}.



4b

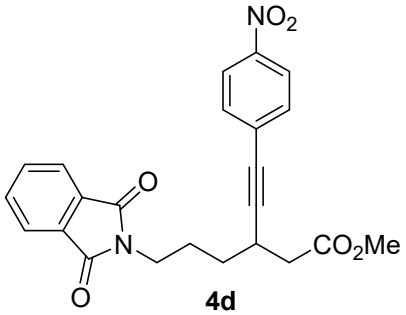
The crude material was purified by column chromatography on silica gel with a gradient eluent of petroleum ether and ethyl acetate (20:1 to 5:1) to get **4b** (R_f = 0.58, PE:EA = 5:1), (Yellow oil, 51.3 mg, 70%). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.95 (d, *J* = 6.4 Hz, 2H), 7.43 (d, *J* = 8.4 Hz, 2H), 3.90 (s, 3H), 3.72 (s, 3H), 3.47 (td, *J* = 6.8, 2.0 Hz, 2H), 3.15 – 3.11 (m, 1H), 2.66 (dd, *J* = 15.6, 7.2 Hz, 1H), 2.55 (dd, *J* = 15.6, 7.2 Hz, 1H), 2.18 – 2.02

(m, 2H), 1.82 – 1.75 (m, 1H), 1.72 – 1.64 (m, 1H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 171.6, 166.5, 131.6, 129.4, 129.2, 127.9, 93.7, 52.2, 51.9, 39.7, 33.2, 32.3, 30.4, 28.3. HRMS: m/z (ESI) calculated $[M+H]^+$: 367.0539, measured: 367.0545. IR (neat): 2950, 1718, 1604, 1434, 1271, 1171, 1107, 857, 768, 695 cm^{-1}.



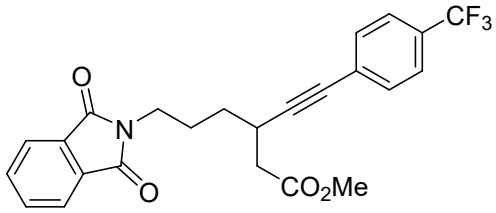
4c

The crude material was purified by column chromatography on silica gel with a gradient eluent of petroleum ether and ethyl acetate (20:1 to 5:1) to get **4c** (R_f = 0.64, PE:EA = 5:1) (Yellow oil, 64.4 mg, 80%). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.56 (d, *J* = 8.0 Hz, 2H), 7.44 (d, *J* = 7.6 Hz, 2H), 3.70 (s, 3H), 3.39 (t, *J* = 6.8 Hz, 2H), 3.09 – 3.06 (m, 1H), 2.60 (dd, *J* = 15.2, 7.6 Hz, 1H), 2.52 (dd, *J* = 15.6, 6.8 Hz, 1H), 1.87 – 1.80 (m, 2H), 1.56 – 1.31 (m, 12H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 171.8, 132.1, 131.8, 128.5, 118.5, 111.0, 96.4, 80.8, 51.8, 39.6, 34.8, 34.0, 32.7, 29.2, 29.0, 28.9, 28.6, 28.0, 27.1. HRMS: m/z (ESI) calculated $[M+H]^+$: 404.1220, measured: 404.1208. IR (neat): 2928, 2855, 2227, 1734, 1711, 1603, 1435, 1203, 1168, 1017, 839, 641 cm^{-1}.



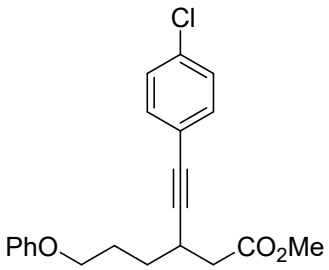
4d

The crude material was purified by column chromatography on silica gel with a gradient eluent of petroleum ether and ethyl acetate (10:1 to 1:1) to get **4d** (R_f = 0.44, PE:EA = 2:1) (Yellow oil, 63.8 mg, 76%). ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.14 (d, *J* = 8.8 Hz, 2H), 7.85 – 7.82 (m, 2H), 7.74 – 7.70 (m, 2H), 7.50 (d, *J* = 9.2 Hz, 2H), 3.75 (t, *J* = 7.2 Hz, 2H), 3.71 (s, 3H), 3.18 – 3.14 (m, 1H), 2.63 (dd, *J* = 16.0, 8.0 Hz, 1H), 2.54 (dd, *J* = 16.0, 8.0 Hz, 1H), 2.02 – 1.95 (m, 2H), 1.69 – 1.57 (m, 2H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 171.4, 168.3, 146.7, 133.9, 132.4, 132.0, 130.2, 123.4, 123.2, 96.4, 81.1. 51.8, 39.7, 37.5, 31.4, 28.6, 26.3. HRMS: m/z (ESI) calculated $[M+NH_4]^+$: 438.1660, measured: 438.1662. IR (neat): 2948, 1771, 1706, 1593, 1515, 1395, 1339, 1168, 853, 718 cm^{-1}.



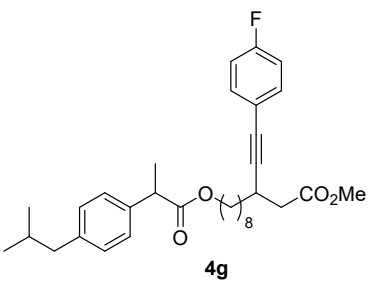
4e

The crude material was purified by column chromatography on silica gel with a gradient eluent of petroleum ether and ethyl acetate (10:1 to 3:1) to get **4e** (R_f = 0.53, PE:EA = 3:1) (Pale yellow oil, 65.6 mg, 74%). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.84 – 7.83 (m, 2H), 7.72 – 7.71 (m, 2H), 7.52 (d, *J* = 8.4 Hz, 2H), 7.46 (d, *J* = 8.0 Hz, 2H), 3.75 (t, *J* = 7.2 Hz, 2H), 3.70 (s, 3H), 3.16 – 3.13 (m, 1H), 2.63 (dd, *J* = 15.2, 7.6 Hz, 1H), 2.53 (dd, *J* = 15.6, 7.6 Hz, 1H), 2.02 – 1.97 (m, 1H), 1.91 – 1.84 (m, 1H), 1.70 – 1.56 (m, 2H). ^{19}F NMR (376 MHz) δ -62.8 (s). ^{13}C NMR (100 MHz, $CDCl_3$) δ 171.5, 168.3, 133.9, 132.0, 131.8, 129.3, 127.1, 125.0 (q, *J* = 3.8 Hz), 123.9 (q, *J* = 271.0 Hz), 123.1, 93.2, 81.4, 51.9, 51.7, 39.5, 37.5, 31.5, 28.5, 26.3. HRMS: m/z (ESI) calculated $[M+NH_4]^+$: 461.1683, measured: 461.1688. IR (neat): 2944, 1712, 1438, 1398, 1324, 1167, 1067, 845, 721 cm^{-1}.



4f

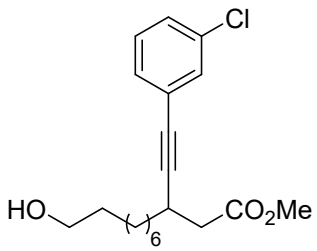
The crude material was purified by column chromatography on silica gel with a gradient eluent of petroleum ether and ethyl acetate (10:1 to 3:1) to get **4f** (R_f = 0.49, PE:EA = 3:1) (Yellow oil，34.9 mg, 49%). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.32 – 7.23 (m, 6H), 6.96 – 6.85 (m, 3H), 4.02 (t, *J* = 6.4 Hz, 2H), 3.71 (s, 3H), 3.18 – 3.11 (m, 1H), 2.65 (dd, *J* = 15.6, 7.6 Hz, 1H), 2.56 (dd, *J* = 15.6, 6.8 Hz, 1H), 2.12 – 2.03 (m, 1H), 1.99 – 1.92 (m, 1H), 1.85 – 1.77 (m, 1H), 1.74 – 1.65 (m, 1H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 171.8, 158.9, 133.8, 132.9, 129.4, 128.5, 121.9, 120.6, 114.4, 91.9, 81.5, 67.2, 51.8, 39.9, 31.1, 28.7, 27.1. HRMS: m/z (ESI) calculated $[M+NH_4]^+$: 374.1517, measured: 374.1522. IR (neat): 2949, 1735, 1599, 1489, 1395, 1241, 1166, 1088, 827, 752, 690 cm^{-1}.



4g

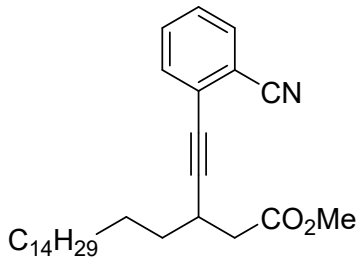
The crude material was purified by column chromatography on silica gel with a gradient eluent of petroleum ether and ethyl acetate (10:1 to 5:1) to

get **4g** (R_f = 0.58, PE:EA = 5:1) (Yellow oil, 50.1 mg, 48%). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.37 – 7.33 (m, 2H), 7.20 (d, *J* = 8.4 Hz, 2H), 7.08 (d, *J* = 8.0 Hz, 2H), 6.96 (dd, *J* = 8.8, 8.4 Hz, 2H), 4.04 (t, *J* = 6.8 Hz, 2H), 3.71 (s, 3H), 3.67 (q, *J* = 7.2 Hz, 1H), 3.07 – 3.06 (m, 1H), 2.66 (dd, *J* = 15.2, 8.0 Hz, 1H), 2.55 (dd, *J* = 15.2, 6.8 Hz, 1H), 2.43 (d, *J* = 7.2 Hz, 2H), 1.85 – 1.82 (m, 1H), 1.60 – 1.49 (m, 9H), 1.34 – 1.25 (m, 8H), 0.89 (d, *J* = 6.4 Hz, 6H). ^{19}F NMR (376 MHz, $CDCl_3$) δ -112.1. ^{13}C NMR (100 MHz, $CDCl_3$) δ 174.8, 172.0, 161.8 (d, *J* = 247.5 Hz), 140.4, 137.9, 133.4 (d, *J* = 7.6 Hz), 129.2, 127.1, 119.6 (d, *J* = 3.8 Hz), 115.3 (d, 22.0 Hz), 91.0, 81.0, 64.7, 51.7, 45.2, 45.0, 40.0, 34.6, 30.1, 29.3, 29.2, 29.1, 28.8, 28.5, 27.2, 25.7, 22.3, 18.4. HRMS: m/z (ESI) calculated $[M+NH_4]^+$: 540.3484, measured: 540.3473. IR (neat): 2929, 2856, 1730, 1506, 1461, 1222, 1157, 1116, 837, 732 cm^{-1}.



4h

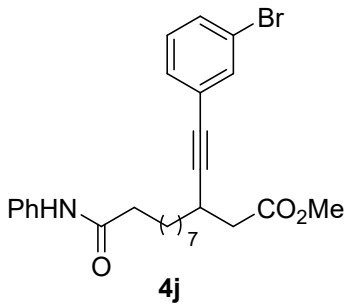
The crude material was purified by column chromatography on silica gel with a gradient eluent of petroleum ether and ethyl acetate (10:1 to 1:1) to get **4h** (R_f = 0.35, PE:EA = 2:1) (Yellow oil, 38.5 mg, 55%). ^{1}H NMR (400 MHz, $CDCl_3$) 7.37 – 7.36 (m, 1H), 7.27 – 7.18 (m, 3H), 3.72 (s, 3H), 3.63 (t, *J* = 6.8 Hz, 2H), 3.07 – 3.04 (m, 1H), 2.61 (dd, *J* = 15.6, 8.0 Hz, 1H), 2.52 (dd, *J* = 15.6, 7.2 Hz, 1H), 1.57 – 1.51 (m, 5H), 1.33 (m, 10H). ^{13}C NMR (100 MHz, $CDCl_3$) 172.0, 133.9, 131.5, 129.7, 129.3, 128.0, 125.3, 92.8, 80.8, 62.9, 51.7, 39.8, 34.5, 32.7, 29.4, 29.3, 29.1, 28.8, 27.1, 25.6. HRMS: m/z (ESI) calculated $[M+NH_4]^+$: 368.1987, measured: 368.1993. IR (neat): 3349, 2926, 2854, 1736, 1592, 1436, 1165, 1054, 879, 682 cm^{-1}.



4i

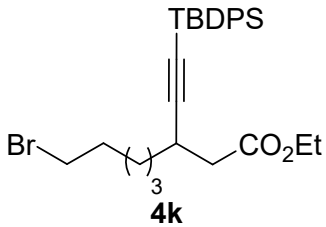
The crude material was purified by column chromatography on silica gel with a gradient eluent of petroleum ether and ethyl acetate (10:1 to 1:1) to get **4i** (R_f = 0.64, PE:EA = 10:1) (Yellow oil, 64.5 mg , 74%). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.60 (d, *J* = 7.6 Hz, 1H), 7.52 – 7.46 (m, 2H), 7.35 (td, *J* = 8.0, 2.4 Hz, 1H), 3.72

(s, 3H), 3.16 – 3.12 (m, 1H), 2.68 (dd, *J* = 15.6, 8.0 Hz, 1H), 2.55 (dd, *J* = 16.0, 6.8 Hz, 1H), 1.68 – 1.48 (m, 4H), 1.29 – 1.24 (m, 26H), 0.87 (t, *J* = 6.4 Hz, 1H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 171.8, 132.4, 132.3, 132.1, 127.8, 127.5, 117.5, 115.4, 98.9, 78.5, 51.8, 39.5, 34.3, 31.9, 29.7, 29.6, 29.57, 29.4, 29.3, 29.2, 29.0, 27.1, 22.6, 14.1. HRMS: m/z (ESI) calculated $[M+NH_4]^+$: 455.3632, measured: 455.3644. IR (neat): 2914, 2849, 1733, 1594, 1469, 1247, 1168, 1021, 766, 736 cm^{-1}.



4j

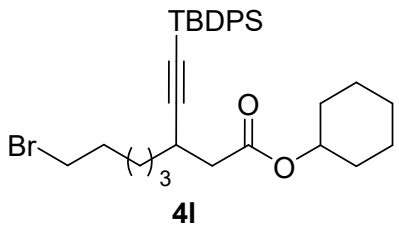
The crude material was purified by column chromatography on silica gel with a gradient eluent of petroleum ether and ethyl acetate (10:1 to 1:1) to get **4j** (R_f = 0.43, PE:EA = 3:1), (Yellow oil, 46.8 mg, 47%). ^{1}H NMR (400 MHz, $CDCl_3$) 7.52 – 7.51 (m, 3H), 7.44 (br, 1H), 7.39 (d, *J* =8.0 Hz, 1H), 7.31 – 7.27 (m, 3H), 7.13 (t, *J* = 8.0 Hz, 1H), 7.08 (t, *J* = 7.6 Hz, 1H), 3.72 (s, 3H), 3.06 – 3.03 (m, 1H), 2.60 (dd, *J* = 15.2, 7.6 Hz, 1H), 2.51 (dd, *J* = 15.6, 7.2 Hz, 1H), 2.33 (t, *J* = 7.6 Hz, 2H), 1.73 – 1.67 (m, 2H), 1.56 – 1.24 (m, 14H). ^{13}C NMR (100 MHz, $CDCl_3$) 172.0, 171.5, 138.0, 134.3, 130.8, 130.2, 129.6, 128.9, 125.5, 124.0, 121.9, 119.7, 92.9, 80.6, 51.7, 39.8, 34.4, 29.2, 29.18, 29.1, 29.09, 28.8, 27.1, 25.5. HRMS: m/z (ESI) calculated $[M+H]^+$: 498.1638, measured: 498.1647. IR (neat): 2949, 1735, 1599, 1489, 1395, 1241, 1166, 1088, 827, 752, 690 cm^{-1}.



4k

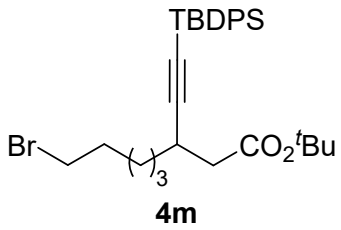
The crude material was purified by column chromatography on silica gel with a gradient eluent of petroleum ether and ethyl acetate (30:1 to 10:1) to get **4k** (R_f = 0.68, PE:EA = 10:1) (Yellow oil, 71.7 mg, 70%). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.82 – 7.79 (m, 4H), 7.43 – 7.36 (m, 6H), 4.17 (q, *J* = 6.8 Hz, 2H), 3.41 (t, *J* = 6.8 Hz, 2H), 3.11 – 3.07 (m, 1H), 2.68 (dd, *J* = 15.6, 8.0 Hz, 1H), 2.55 (dd, *J* = 15.6, 7.2 Hz, 1H), 1.93 – 1.86 (m, 2H), 1.70 – 1.49 (m, 6H), 1.25 (t, *J* = 7.2 Hz, 3H), 1.06 (s, 9H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 171.3, 135.5, 133.5, 129.4, 127.6, 112.6, 81.3, 60.6, 40.2, 34.2, 33.6, 32.6, 29.4, 27.7,

27.0, 26.4, 18.4, 14.2. HRMS: m/z (ESI) calculated $[M+NH_4]^+$: 530.2084, measured: 530.2079. IR (neat): 2928, 2855, 2324, 2169, 1737, 1430, 1166, 1107.



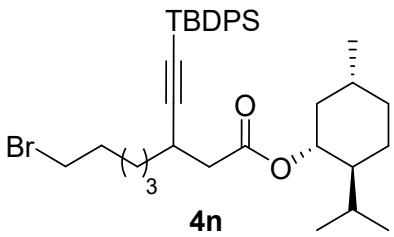
4l

The crude material was purified by column chromatography on silica gel with a gradient eluent of petroleum ether and ethyl acetate (30:1 to 10:1) to get **4l** (R_f = 0.71, PE:EA = 10:1), (Yellow oil, 60.1 mg, 53%). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.78 – 7.76 (m, 4H), 7.41 – 7.34 (m, 6H), 4.79 – 4.76 (m, 1H), 3.40 (t, *J* = 6.4 Hz, 2H), 3.08 – 3.06 (m, 1H), 2.65 (dd, *J* = 15.2, 7.2 Hz, 1H), 2.51 (dd, *J* = 14.8, 7.2 Hz, 1H), 1.92 – 1.81 (m, 2H), 1.68 – 1.11 (m, 16H), 1.07 (s, 9H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 170.8, 135.6, 133.6, 129.4, 127.6, 112.7, 81.3, 73.0, 40.5, 34.3, 33.7, 32.7, 29.5, 27.8, 27.0, 26.4, 21.8, 18.5. HRMS: m/z (ESI) calculated $[M+NH_4]^+$: 584.2554, measured: 584.2552. IR (neat): 2931, 2856, 2170, 1729, 1451, 1172, 1112, 740, 699 cm^{-1}.



4m

The crude material was purified by column chromatography on silica gel with a gradient eluent of petroleum ether and ethyl acetate (30:1 to 10:1) to get **4m** (R_f = 0.69, PE:EA = 10:1) (Yellow oil, 65.9 mg, 61%). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.81 – 7.75 (m, 4H), 7.44 – 7.36 (m, 6H), 3.41 (t, *J* = 6.8 Hz, 2H), 3.05 – 3.01 (m, 1H), 2.60 (dd, *J* = 15.6, 7.6 Hz, 1H), 2.45 (dd, *J* = 15.2, 7.2 Hz, 1H), 1.92 – 1.85 (m, 2H), 1.67 – 1.45 (m, 15H), 1.07 (s, 9H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 170.6, 135.5, 133.6, 129.3, 127.6, 113.0, 81.0, 80.8, 41.3, 34.2, 33.7, 32.7, 29.4, 28.1, 27.8, 27.0, 26.4, 18.5. HRMS: m/z (ESI) calculated $[M+NH_4]^+$: 558.2397, measured: 558.2395. IR (neat): 2930, 2856, 2170, 1728, 1427, 1391, 1149, 1107, 741, 699 cm^{-1}.

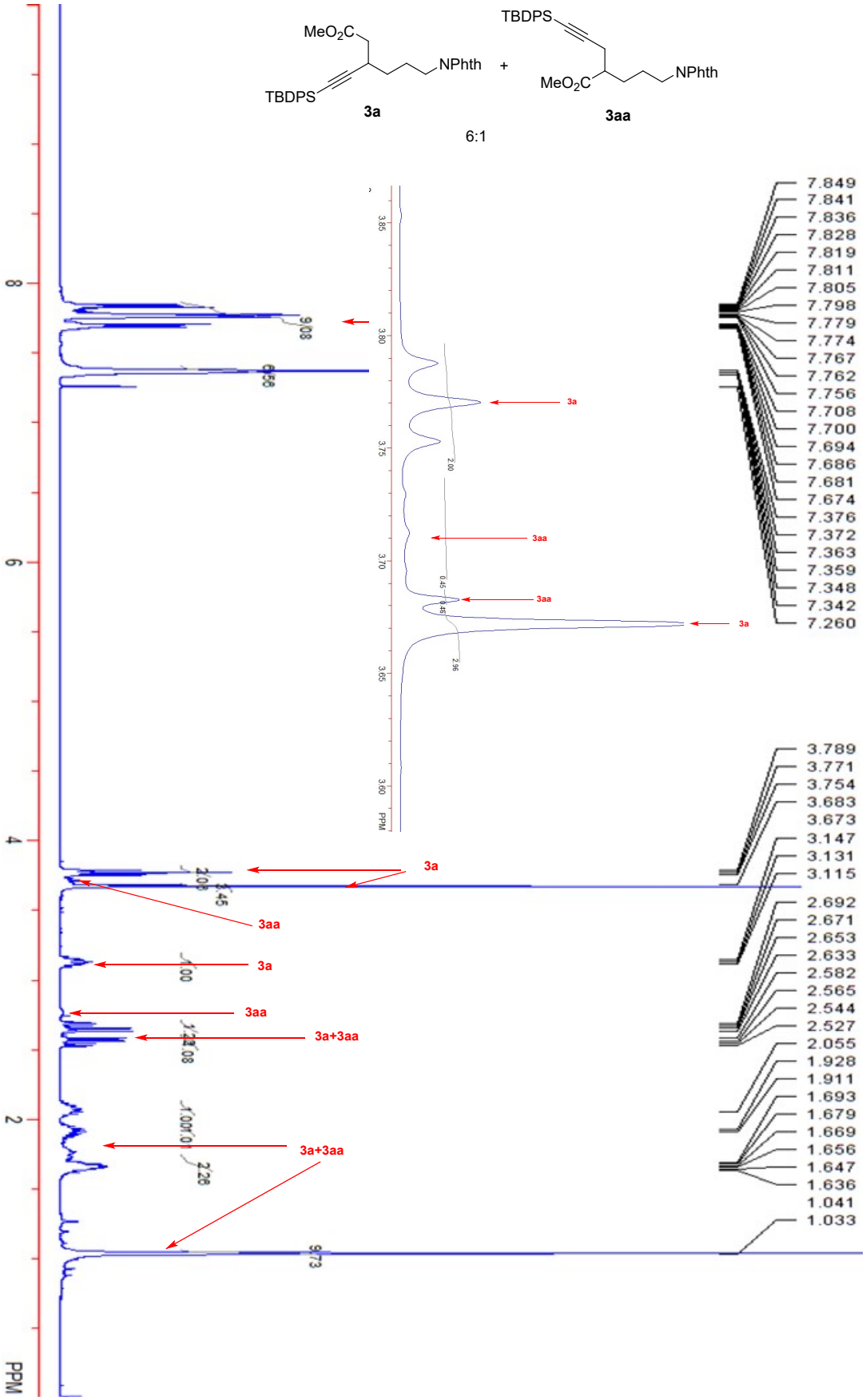


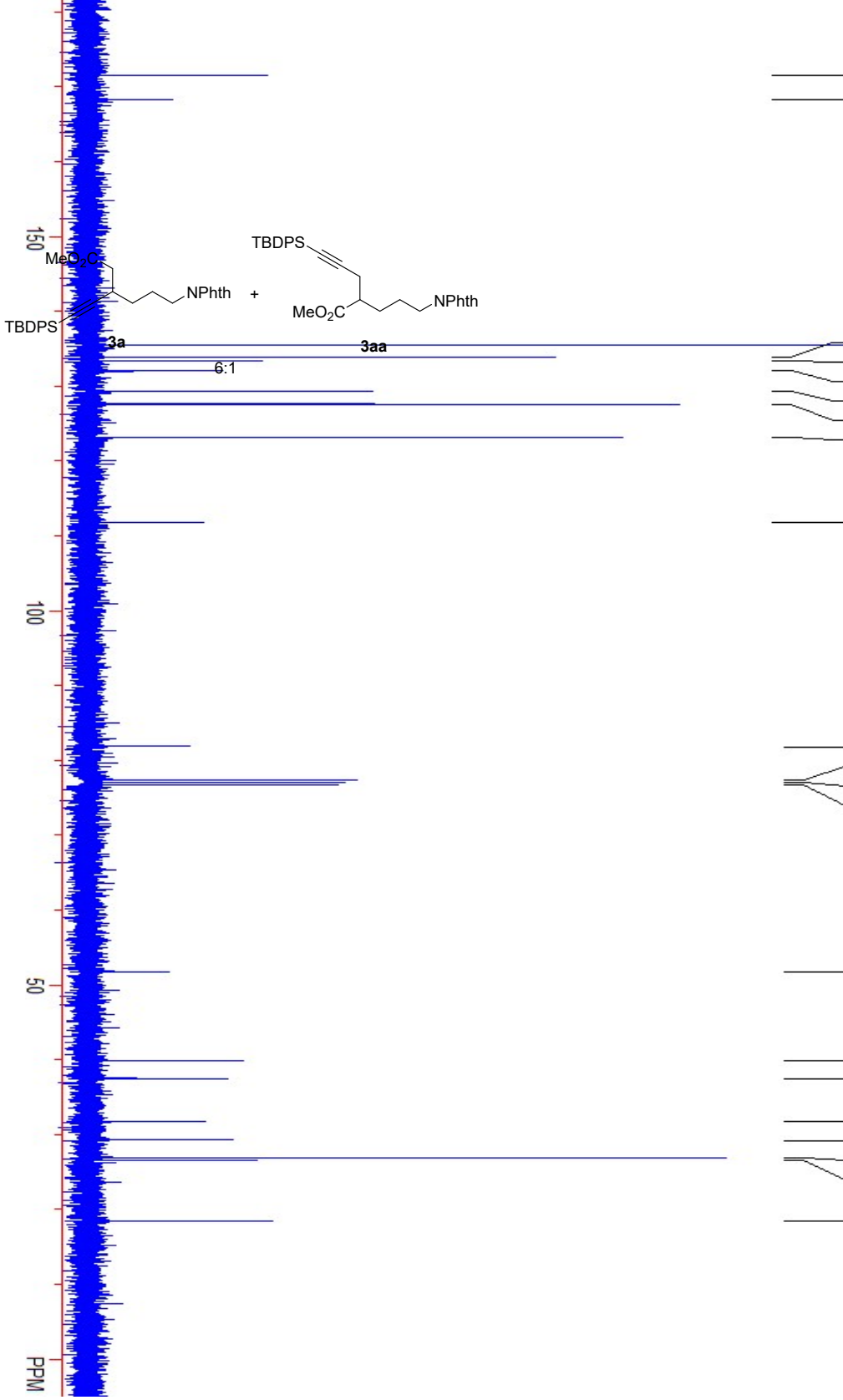
4n

The crude material was purified by column chromatography on silica gel with a gradient eluent of petroleum ether and ethyl acetate (30:1 to 10:1) to get

4n (R_f = 0.72, PE:EA = 10:1) (Yellow oil, 87.2 mg, 70%, dr 1:1). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.81 – 7.78 (m, 4H), 7.44 – 7.36 (m, 6H), 4.76 – 4.69 (m, 1H), 3.40 (t, *J* = 6.8 Hz, 2H), 3.10 – 3.06 (m, 1H), 2.73 – 2.66 (m, 1H), 2.56 – 2.49 (m, 1H), 2.01 – 1.85 (m, 4H), 1.71 – 1.34 (m, 10H), 1.17 – 0.99 (m, 12H), 0.92 – 0.72 (m, 9H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 170.9, 135.5, 133.6, 129.3, 127.6, 112.7, 81.2, 74.6, 46.9, 40.9, 40.4, 34.3, 34.2, 33.6, 32.6, 31.3, 29.4, 27.8, 27.0, 26.4, 26.2, 23.3, 21.9, 20.7, 18.5, 16.2. HRMS: m/z (ESI) calculated $[M+NH_4]^+$: 640.3180, measured: 640.3177. IR (neat): 2929, 2857, 2322, 2172, 1729, 1428, 1175, 1108, 741, 699 cm^{-1}.

5. ^{1}H NMR, ^{13}C NMR and ^{19}F NMR spectra

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3a
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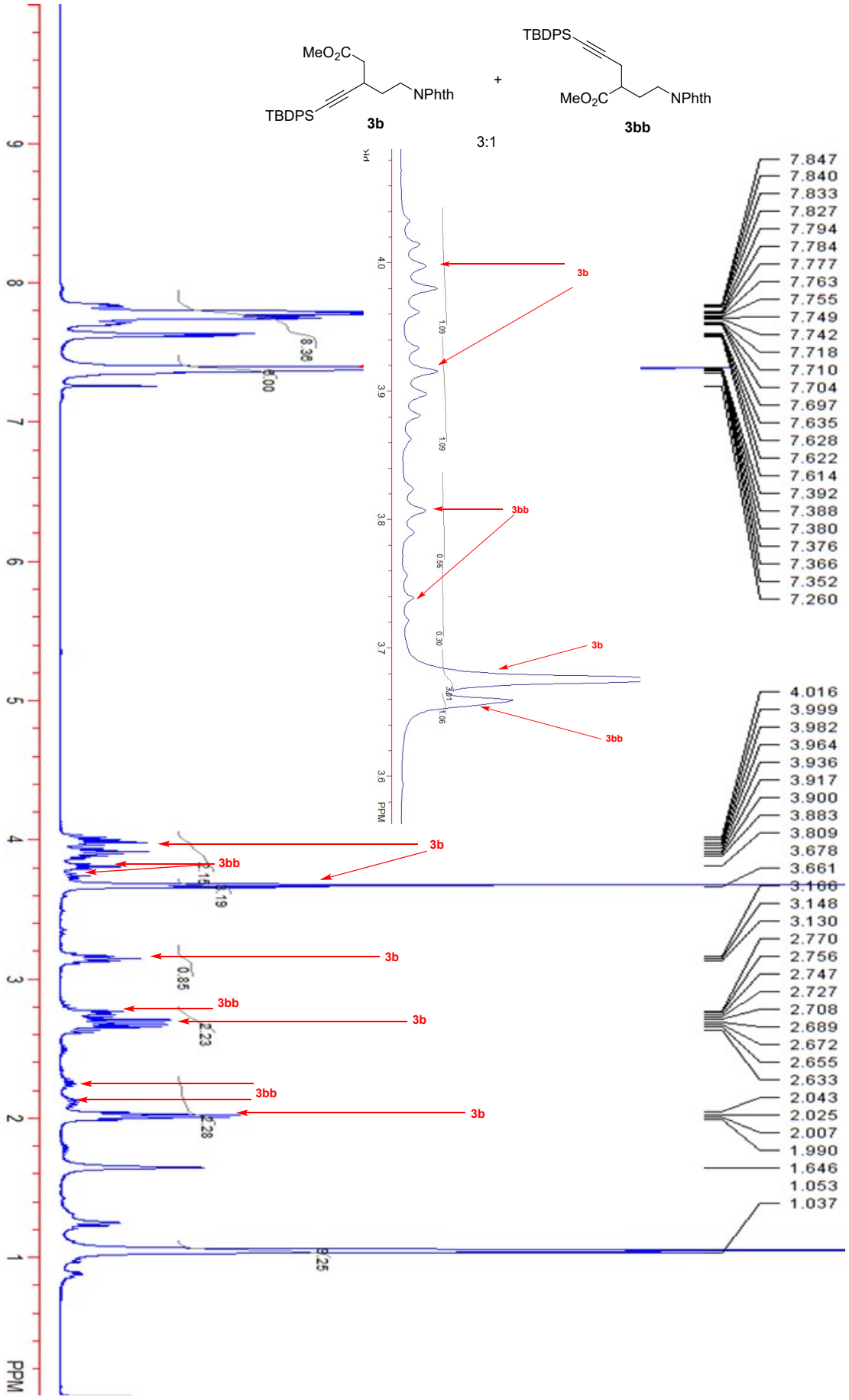
50
PPM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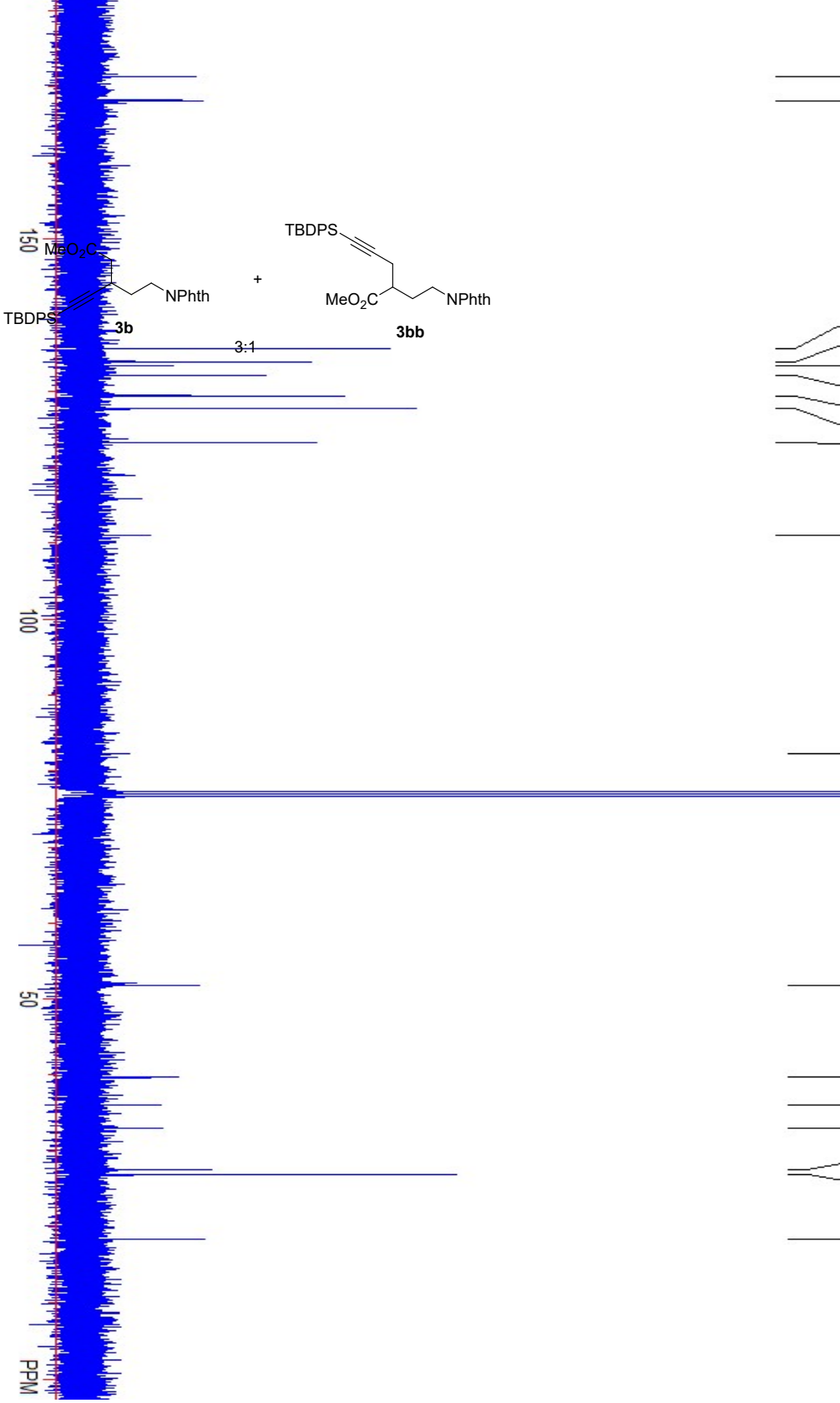
3b
3bb
PPM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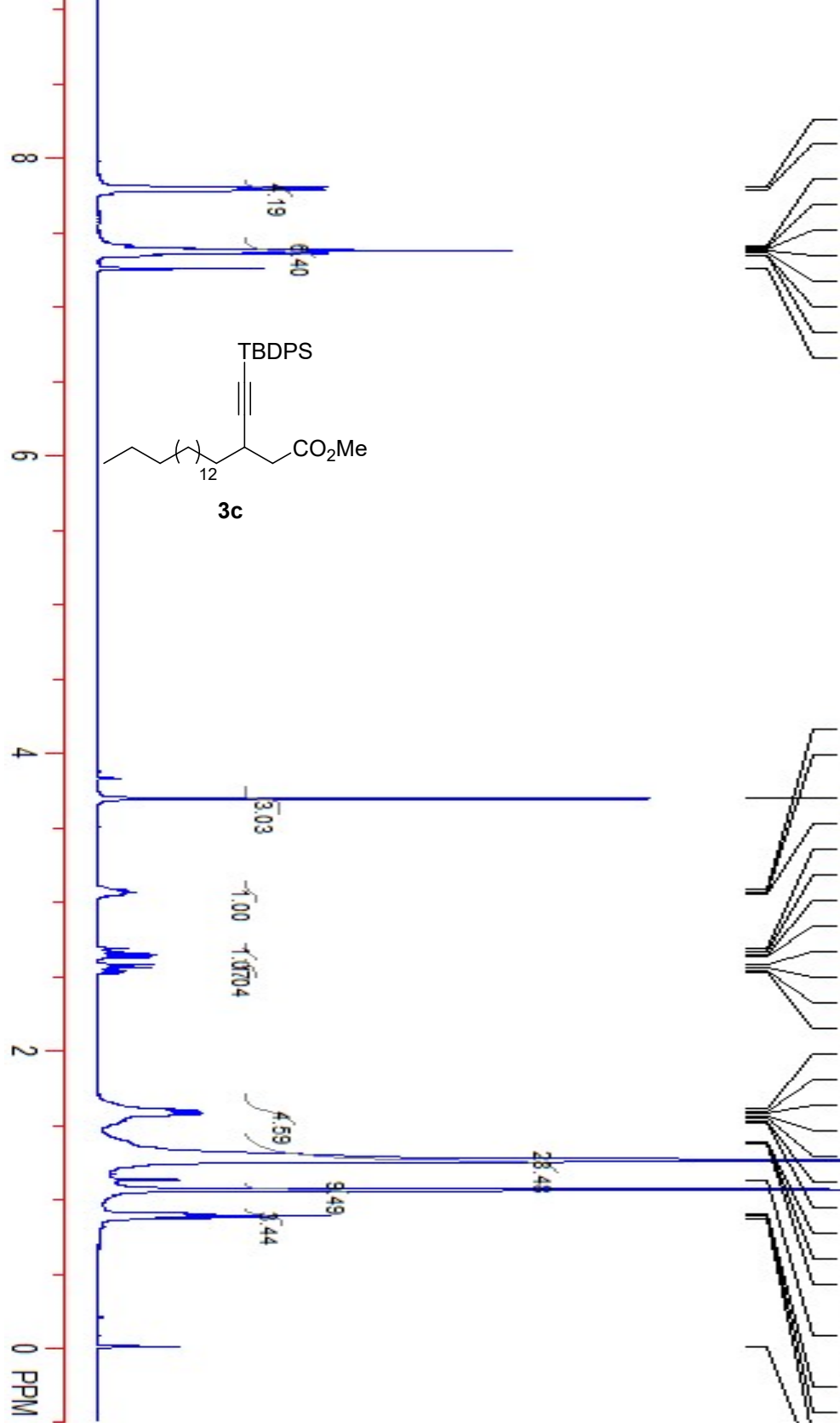
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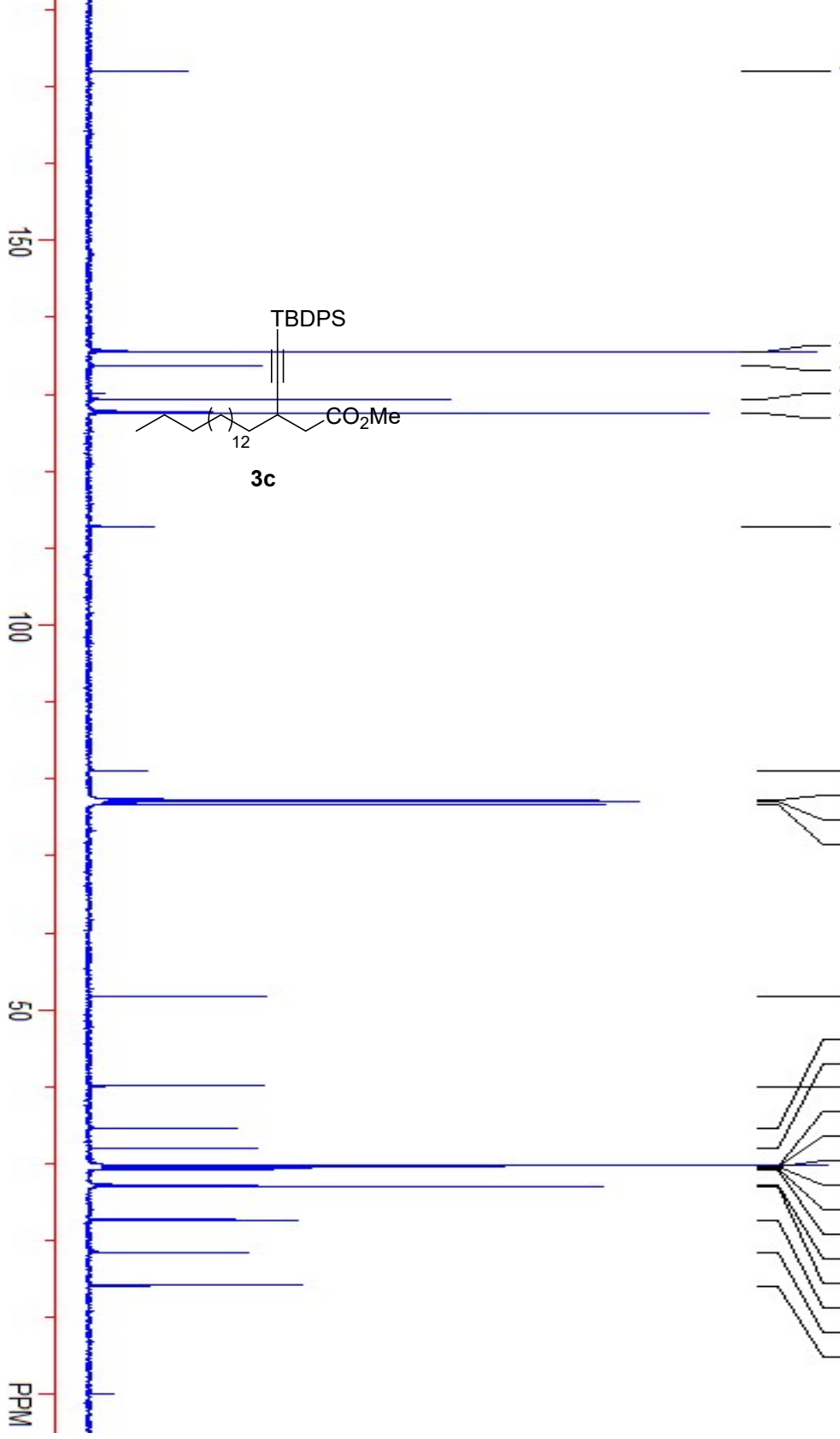
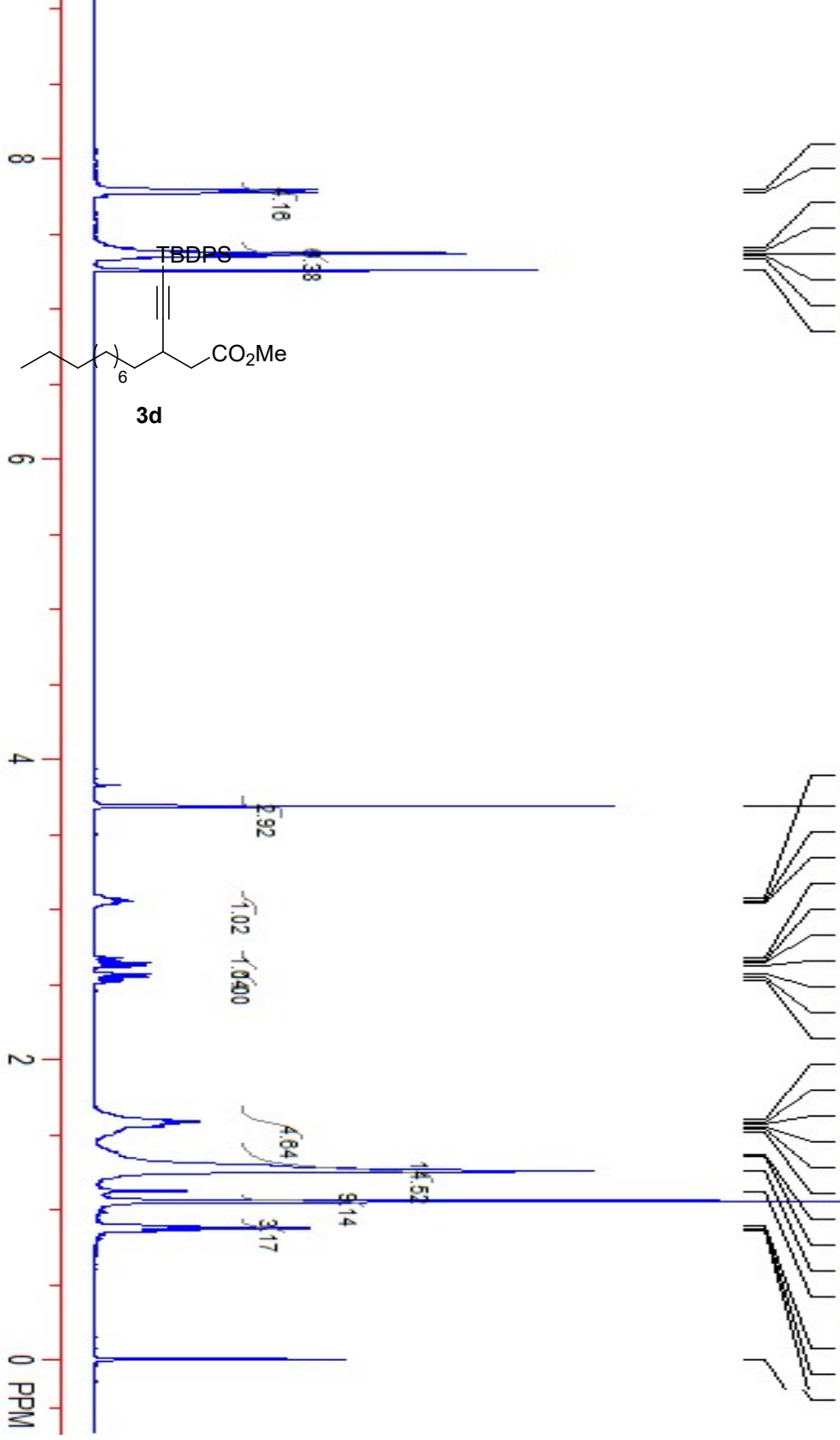
3c



3c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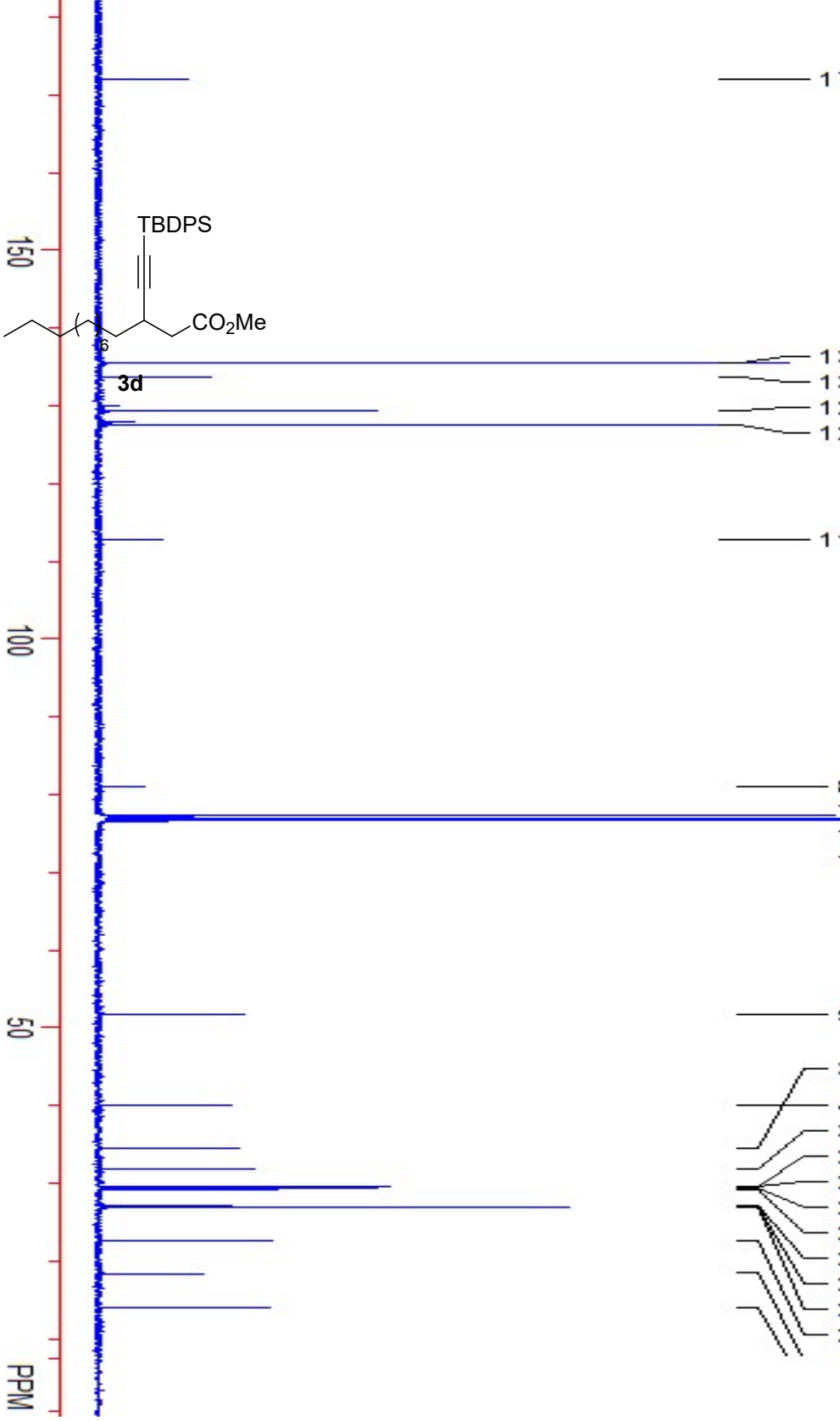
9.14
3.17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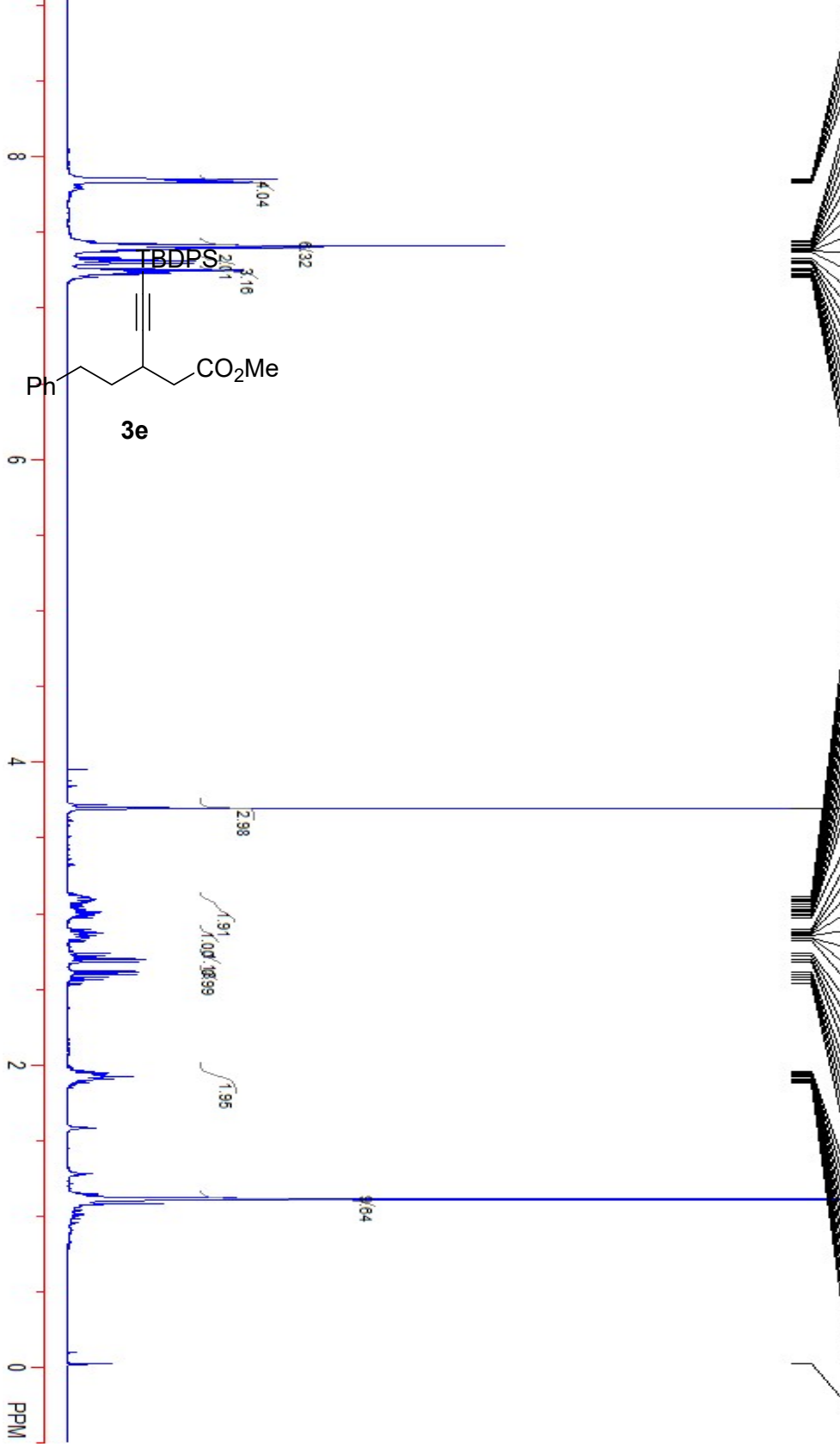
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Ph
CO2Me
3e
8
6
4
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PPM
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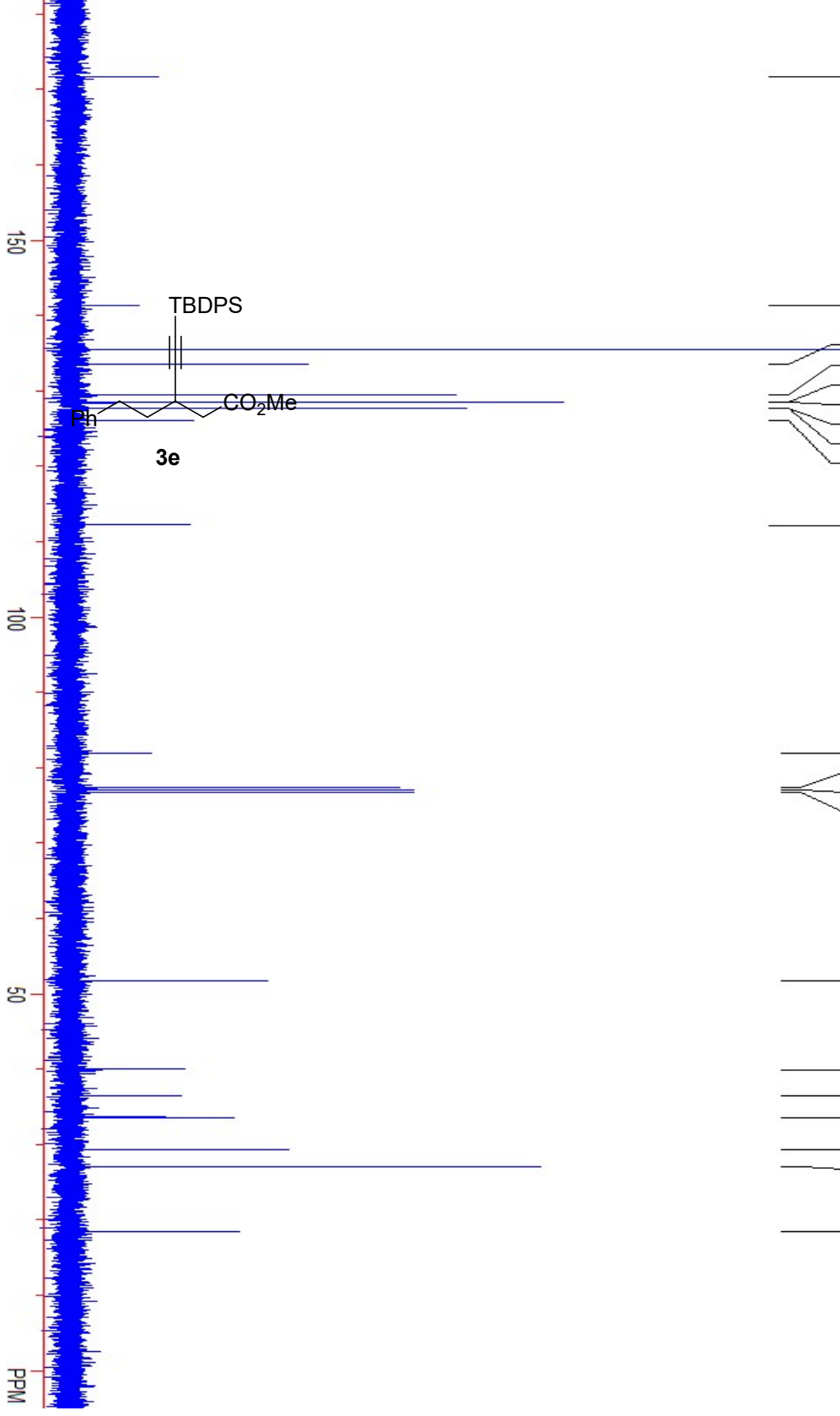
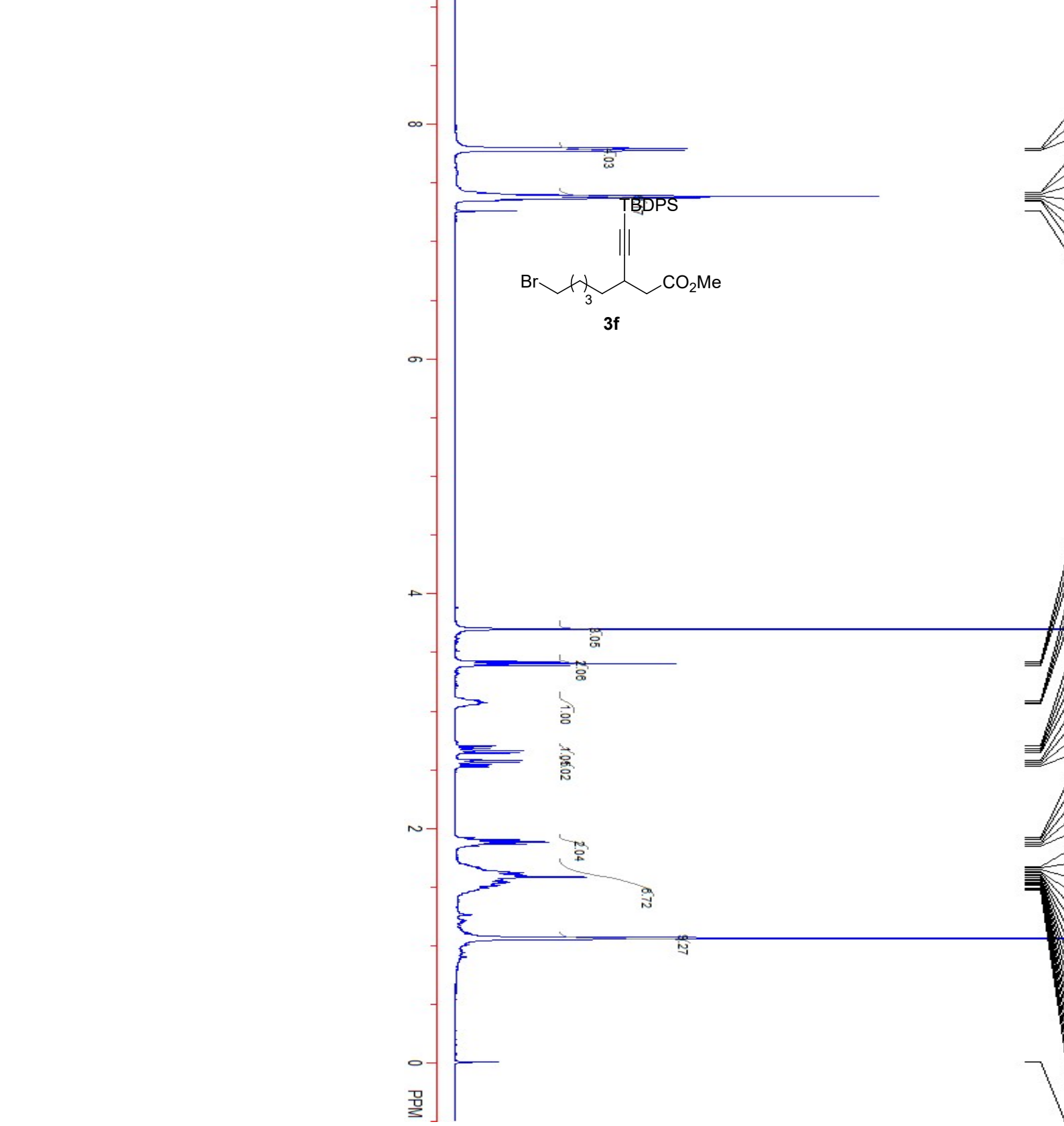
6.32
2.01
3.16
2.98
1.91
1.00
18.99
1.95
9.64



3e


TBDPS
Br
3
CO2Me
3f
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0
PPM
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1.05
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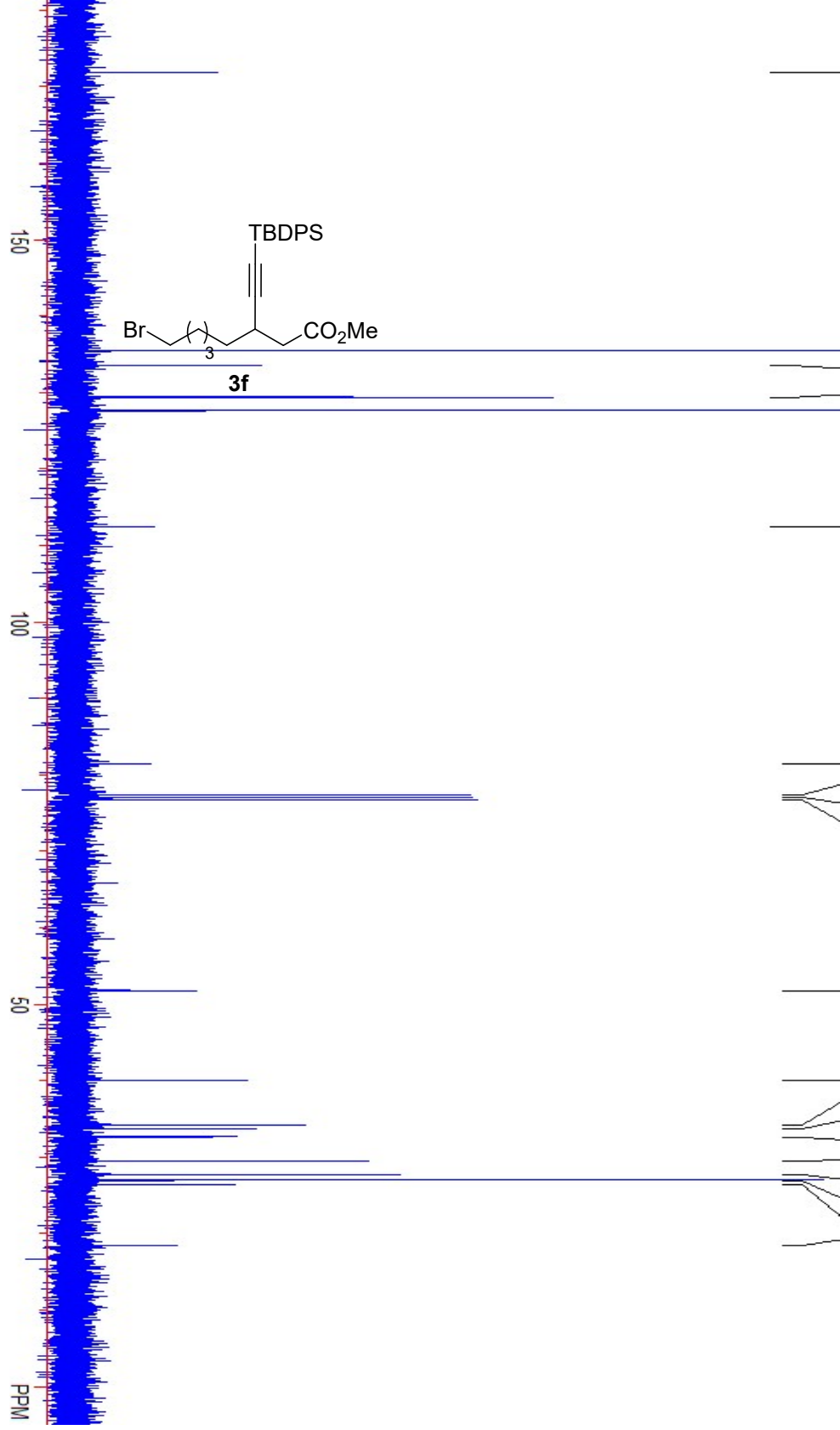
2.04
6.72
9.27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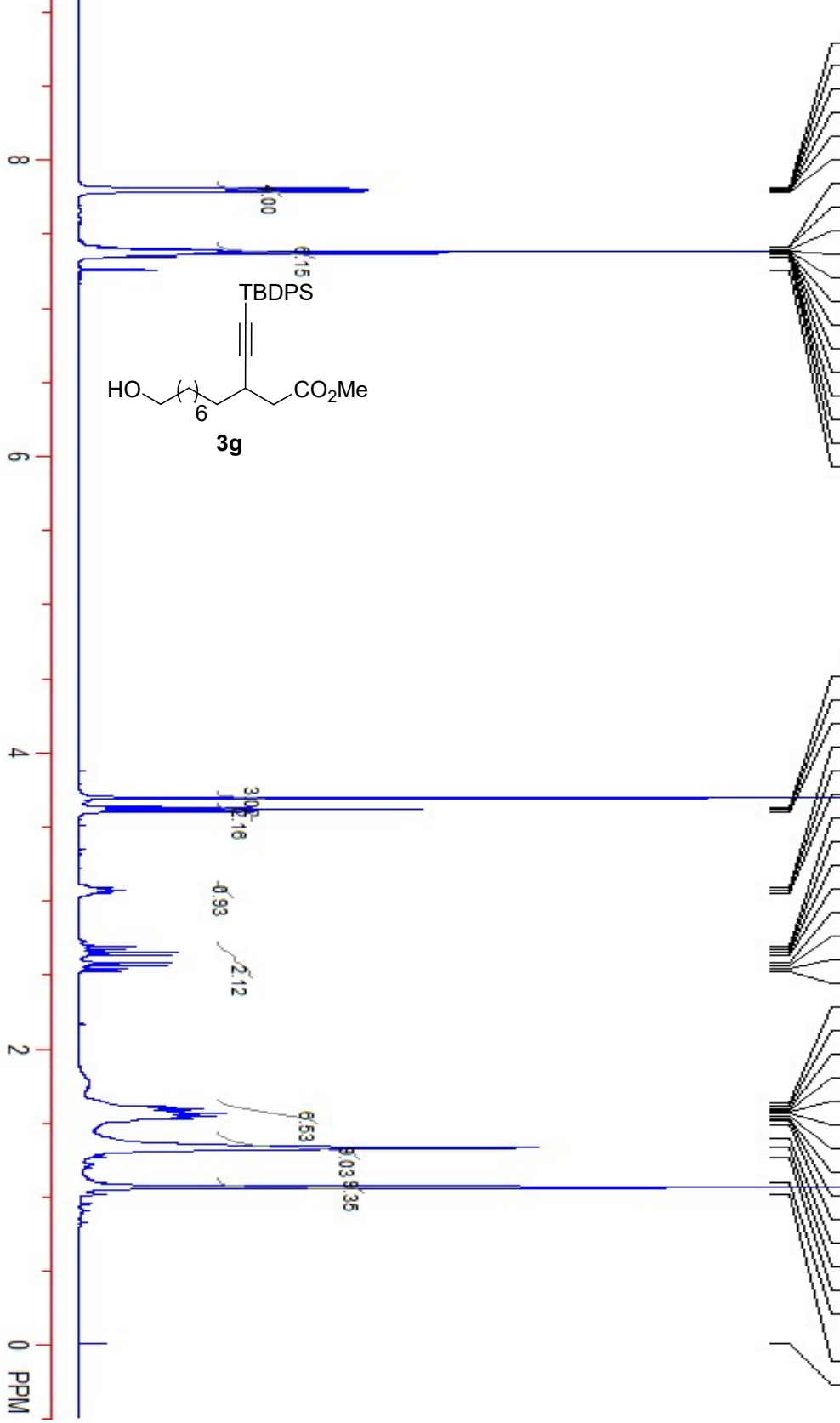
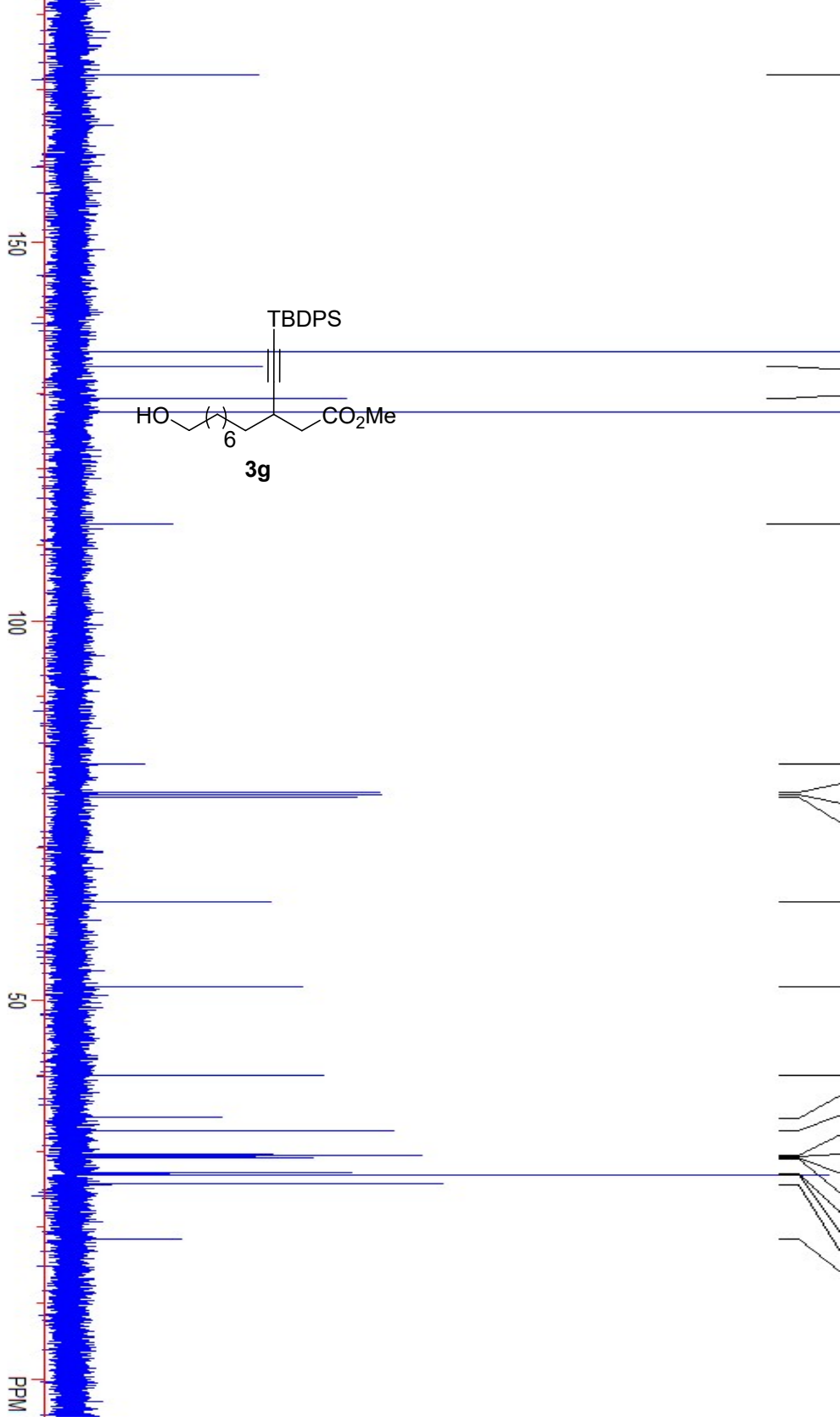
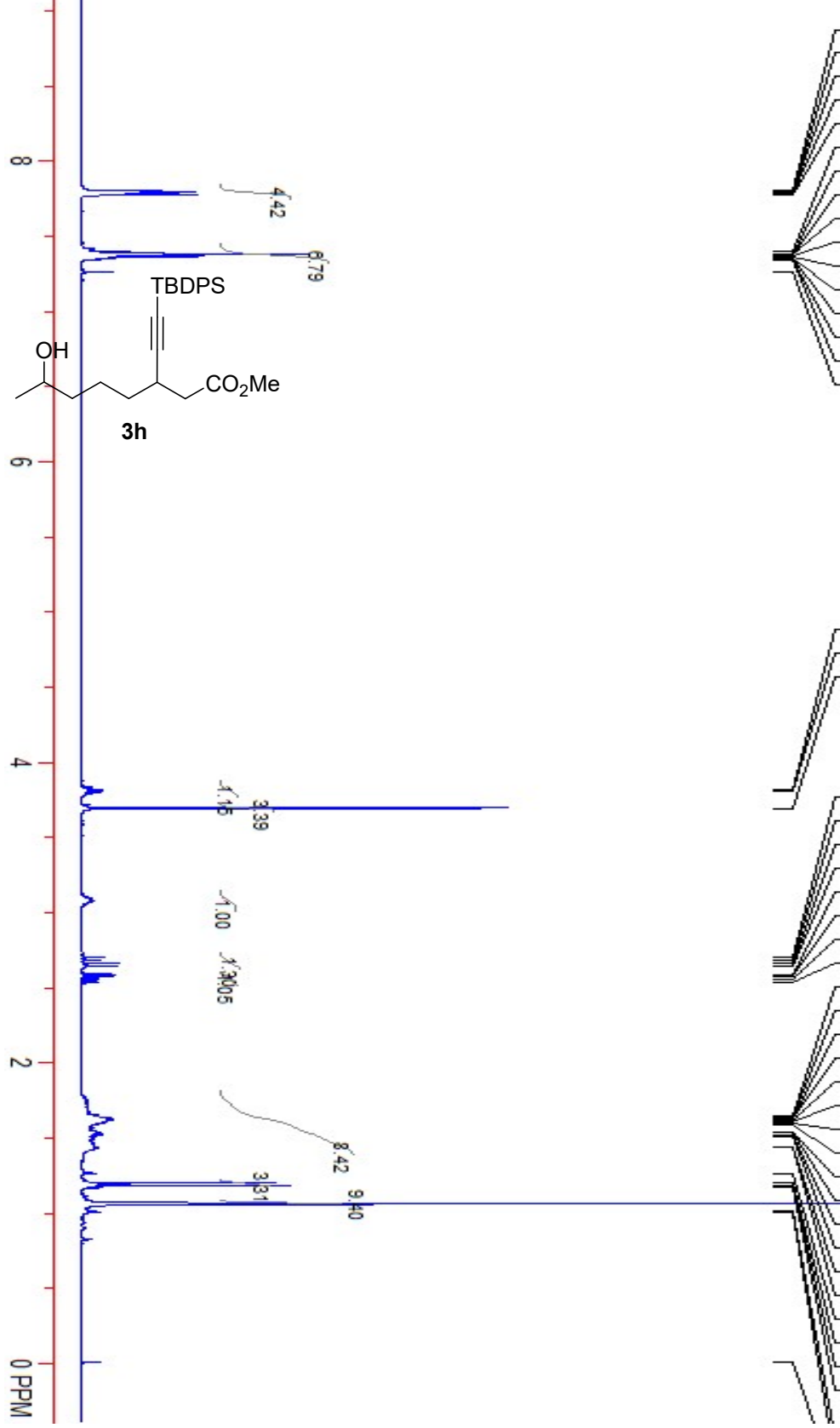
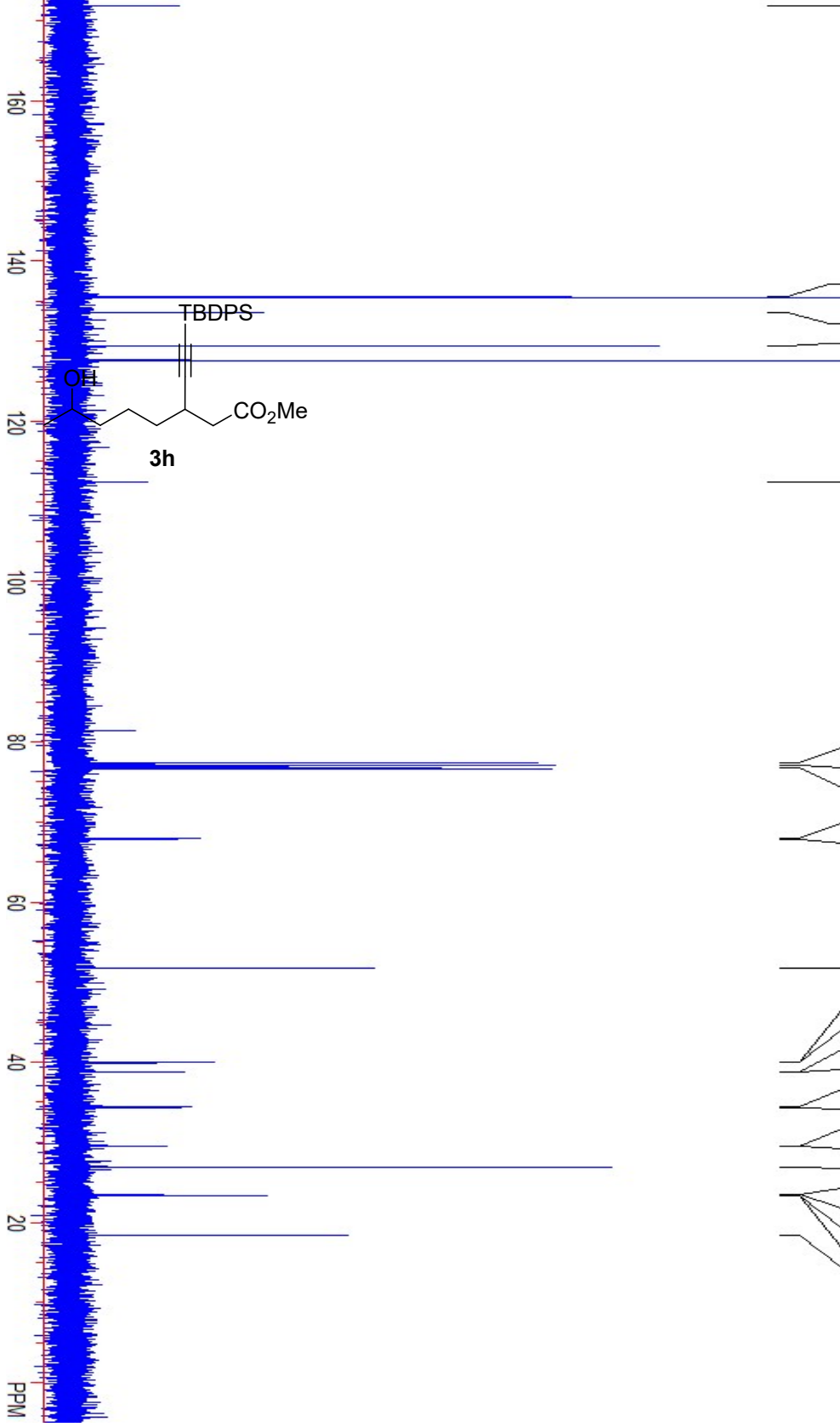
Br
3
CO2Me
3f
150
100
50
PPM


TBDPS
HO
6
CO2Me
3g
8
6
4
2
0 PPM
4.00
6.15
3.05
2.18
0.93
2.12
6.53
9.03
9.35



3g


TBDPS
OH
CO2Me
3h
8
6
4
2
0 PPM
4.42
6.79
1.15
3.39
1.00
3.05
8.42
3.31
9.40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CO2Me
3h
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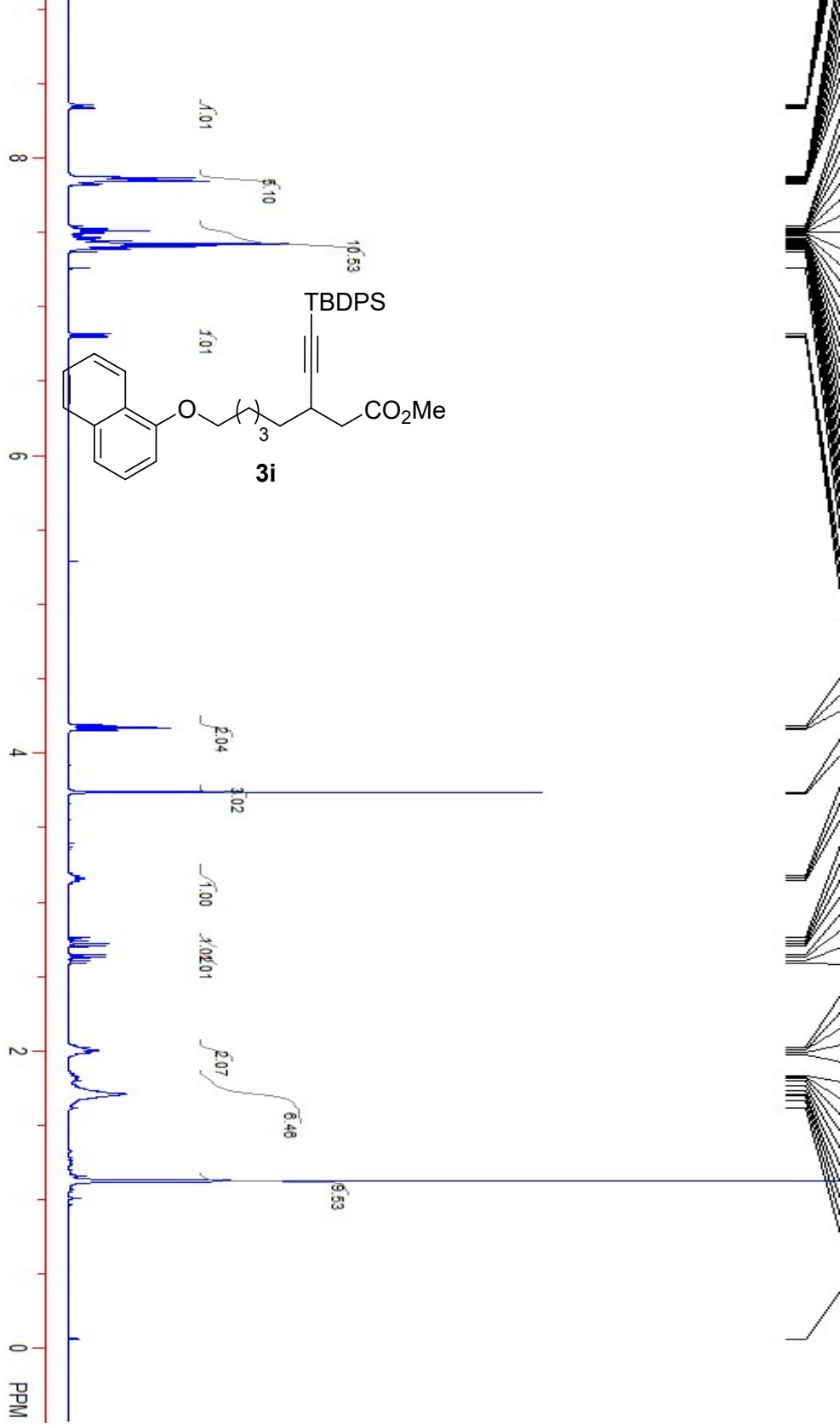
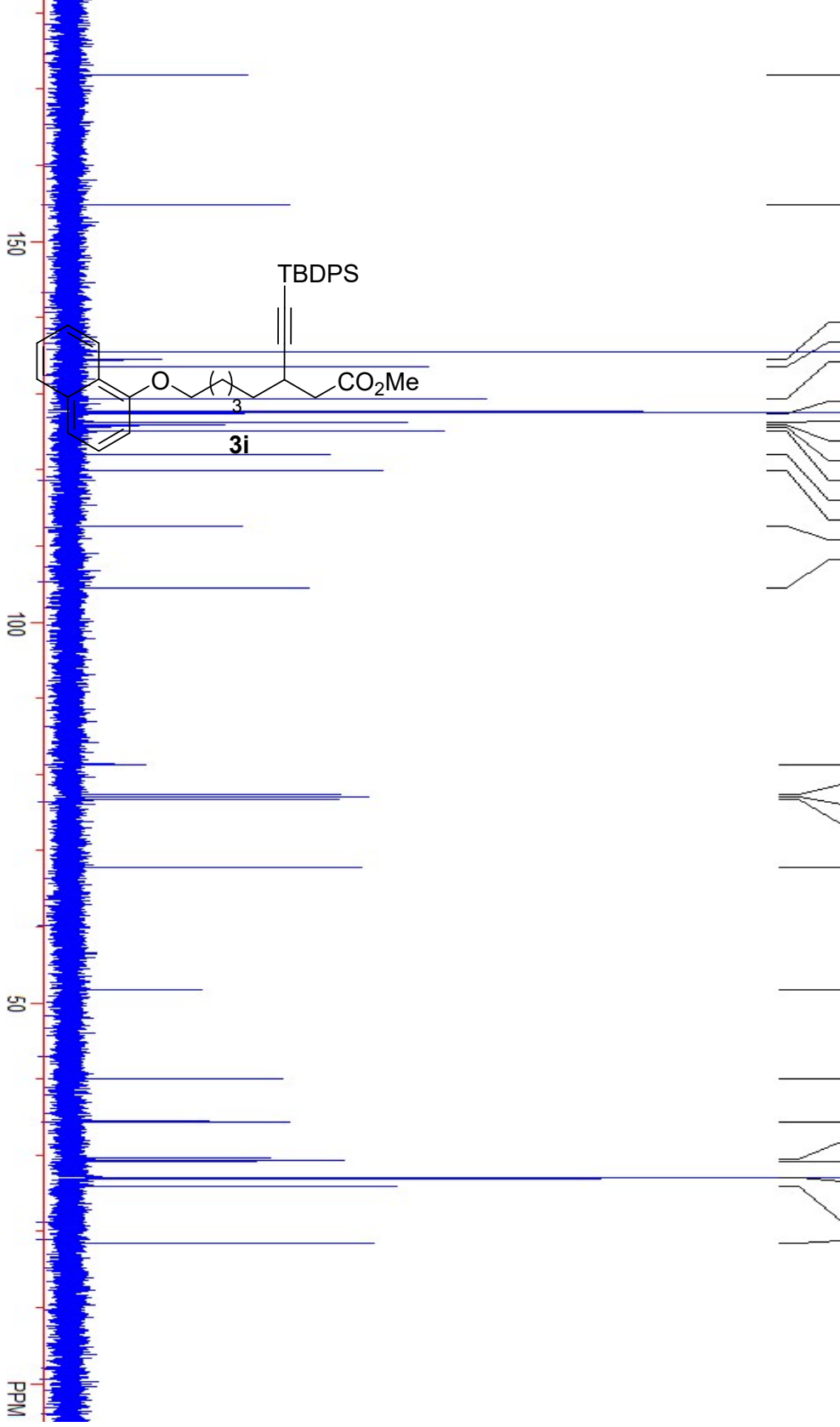
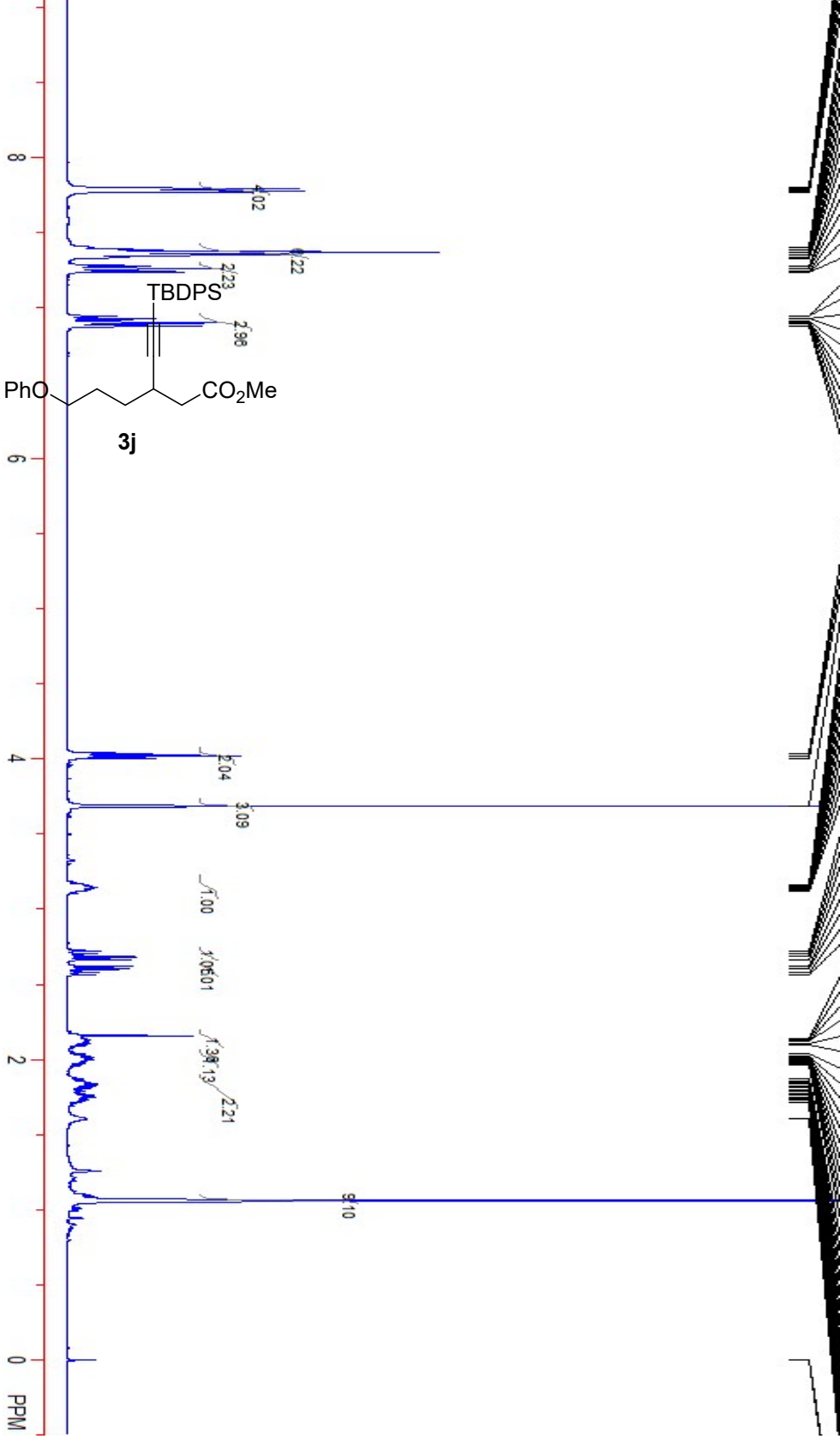
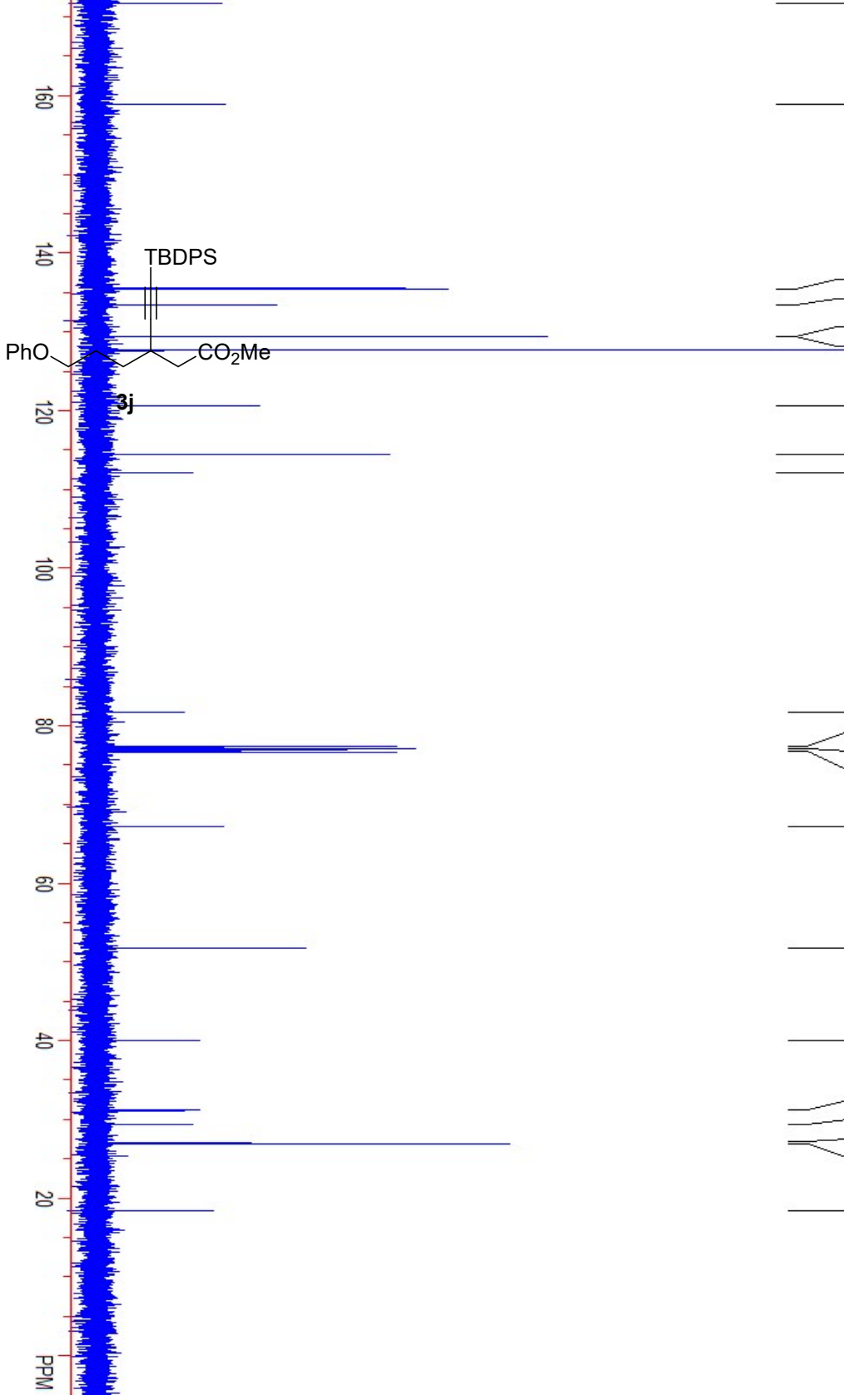
140
120
100
80
60
40
20
PPM


TBDPS
O
3
CO2Me
3i
1.01
5.10
10.53
1.01
2.04
3.02
1.00
1.02
2.01
2.07
6.46
9.53
8
6
4
2
0
PPM


150
100
50
PPM
TBDPS
O
3
CO2Me
3i


TBDPS
PhO
CO2Me
3j
8
6
4
2
0
PPM
4.02
2.22
2.23
2.96
2.04
3.09
1.00
1.06
1.39
1.13
2.21
9.10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CO2Me
3j
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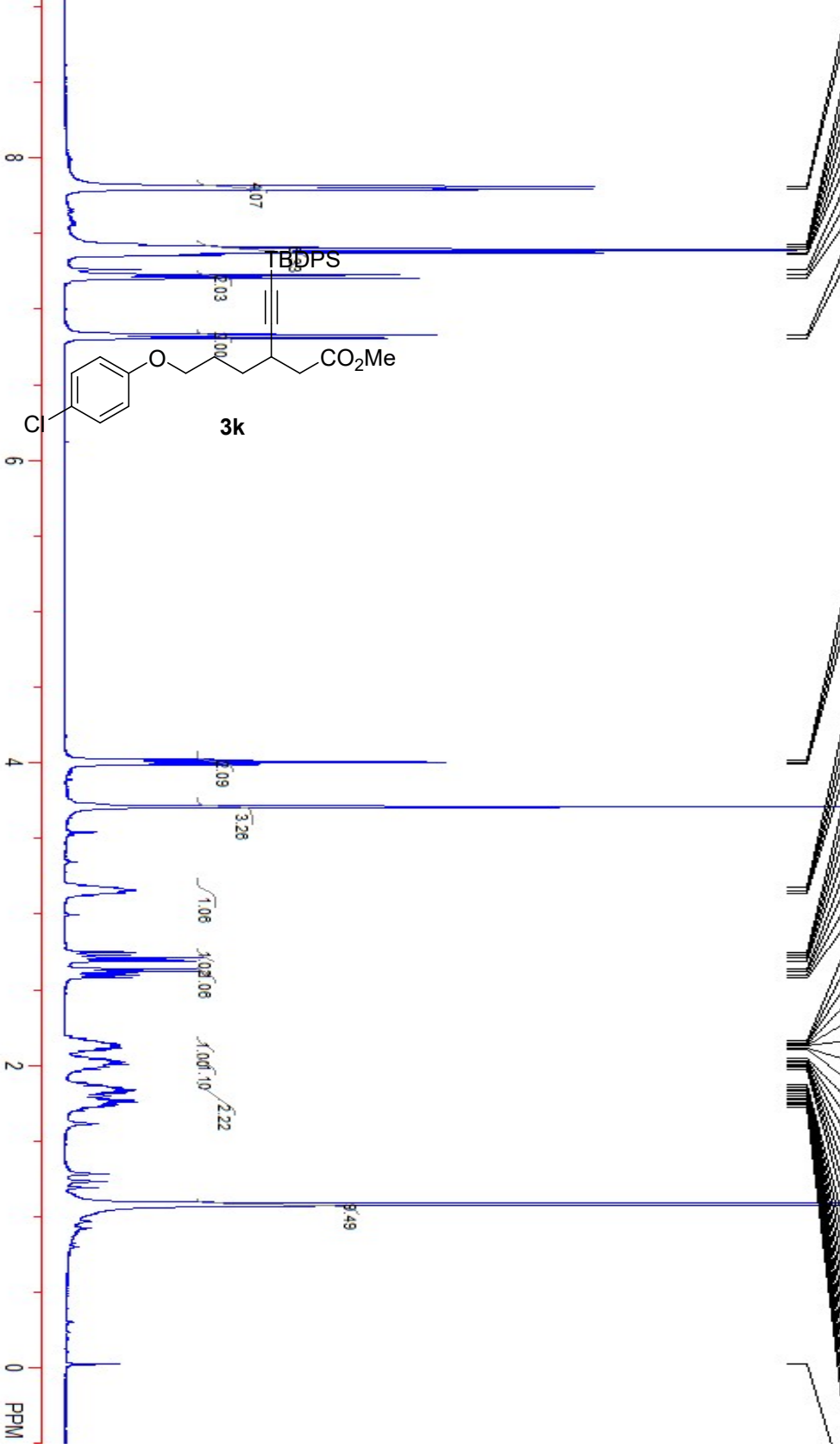
140
120
100
80
60
40
20
PPM


TBDPS
O
CO2Me
Cl
3k
8
6
4
2
0
PPM
4.07
2.03
1.00
2.09
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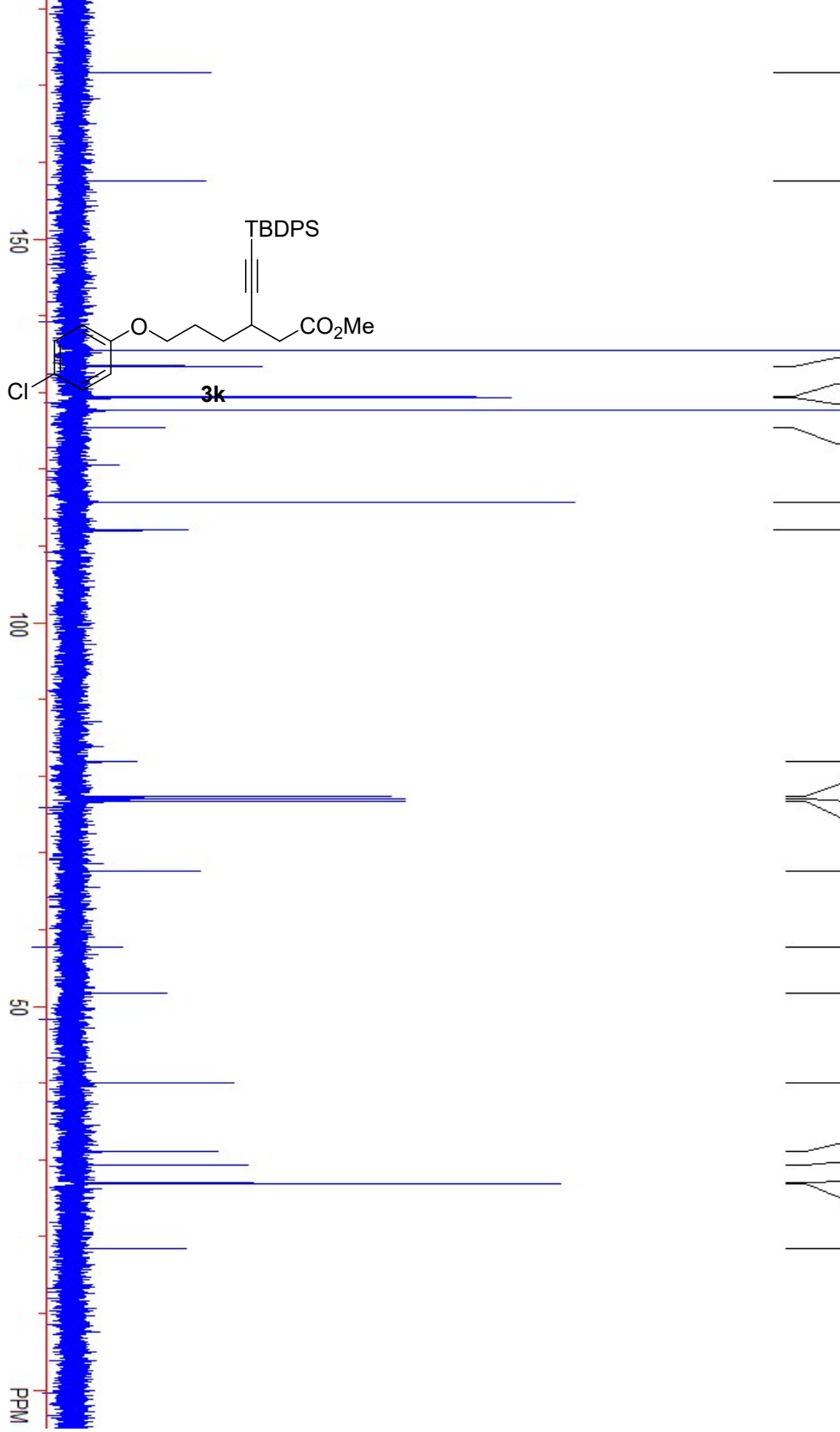
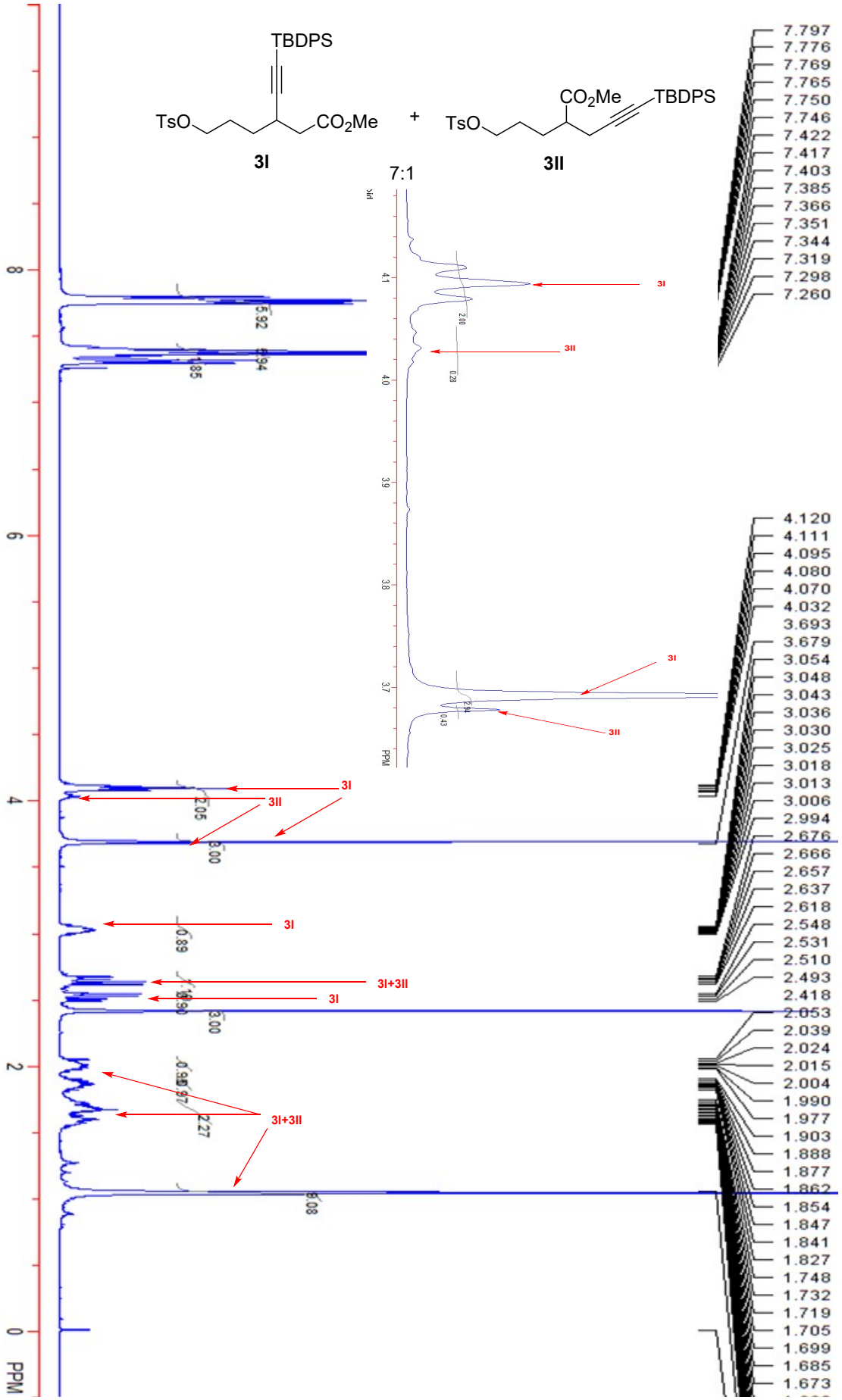
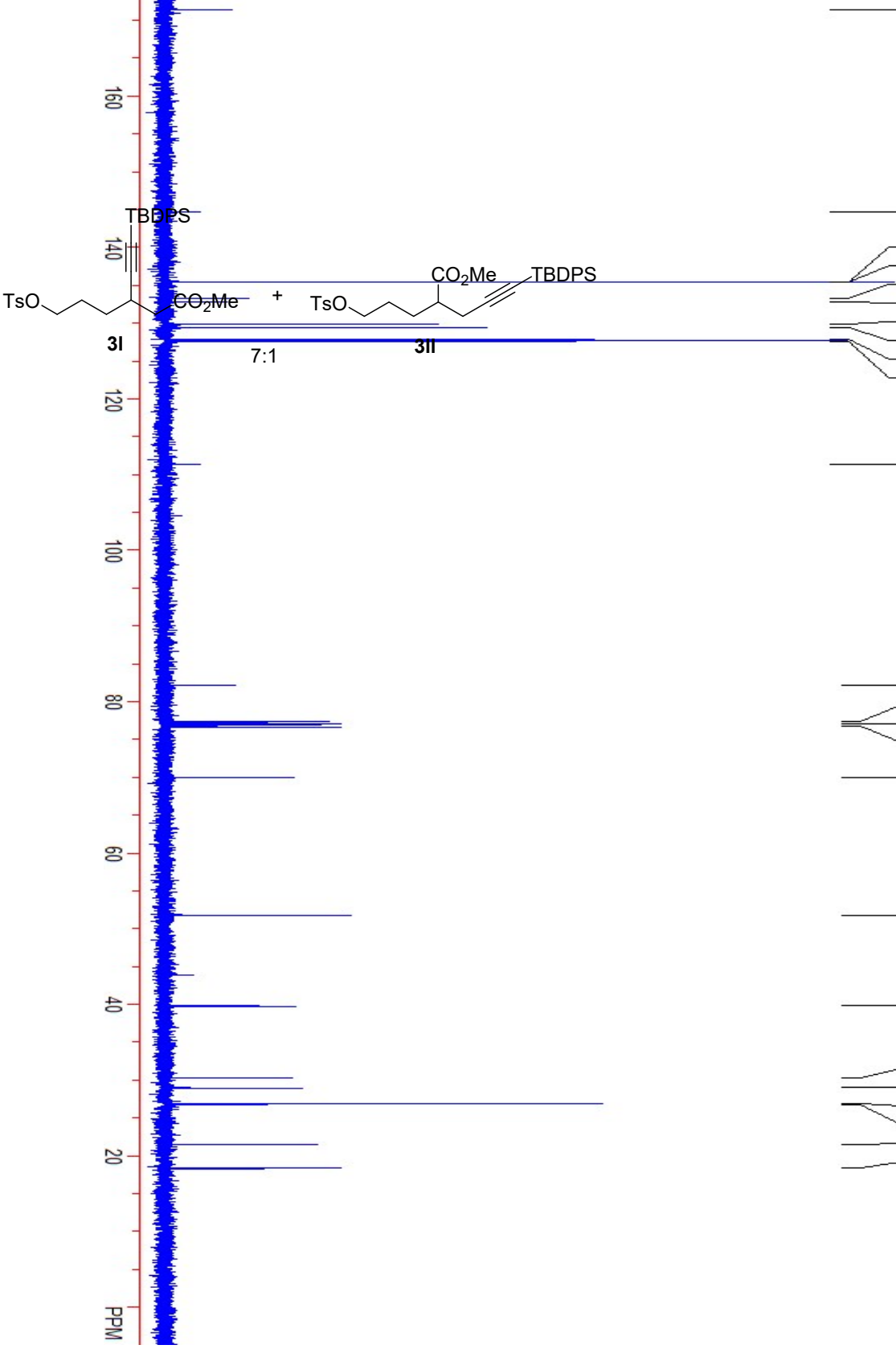
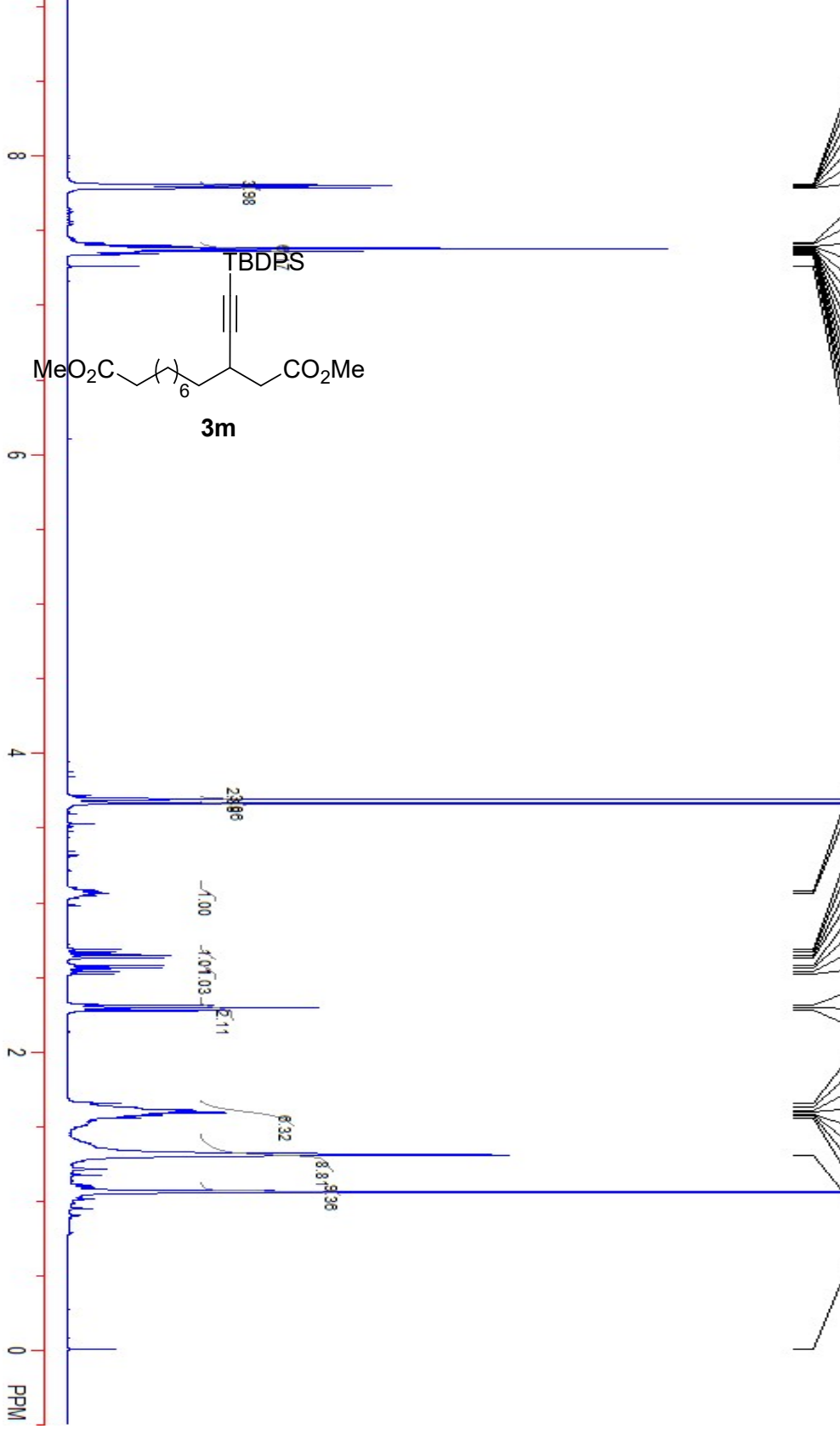
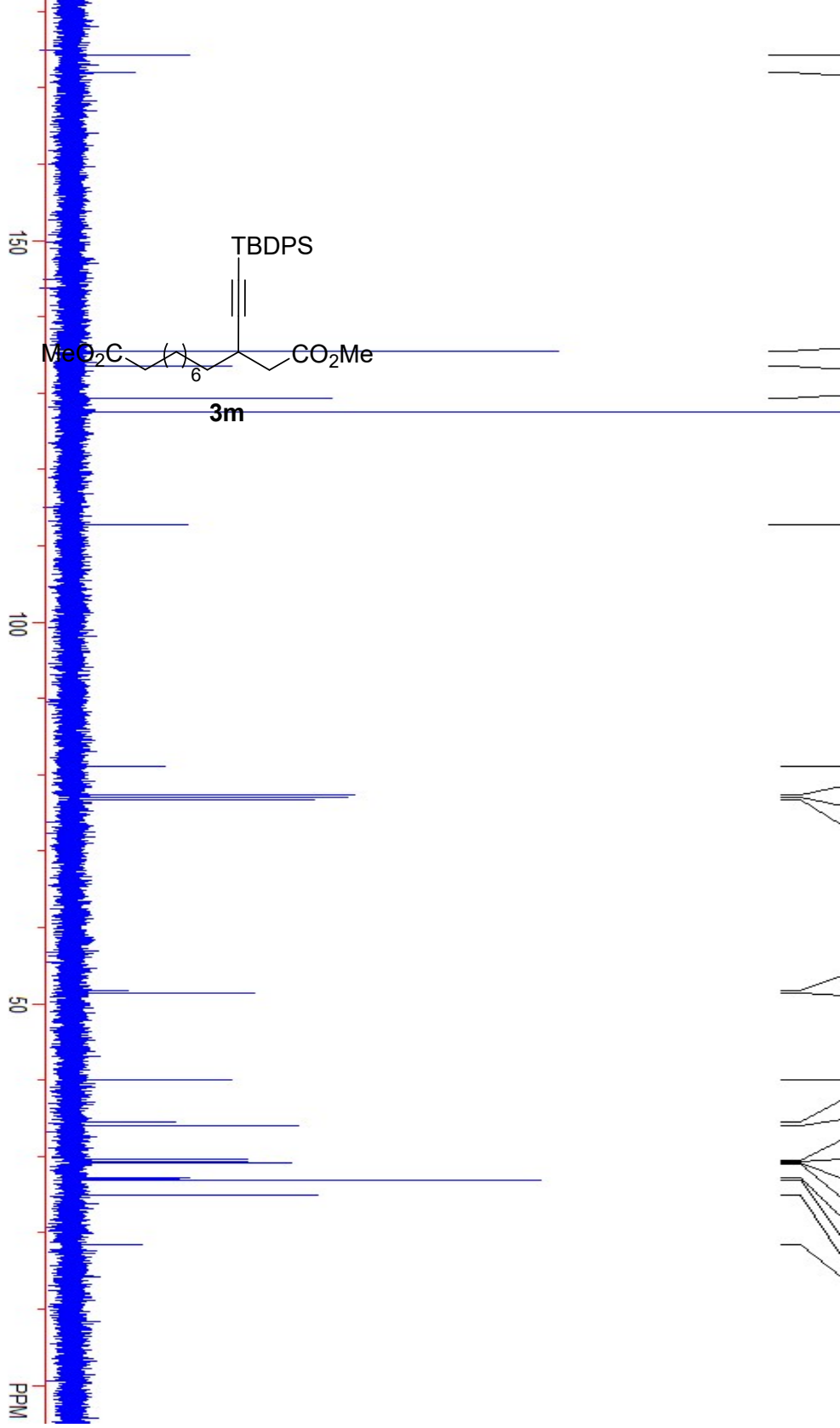
1.06
1.03
3.06
1.00
2.22
3.49

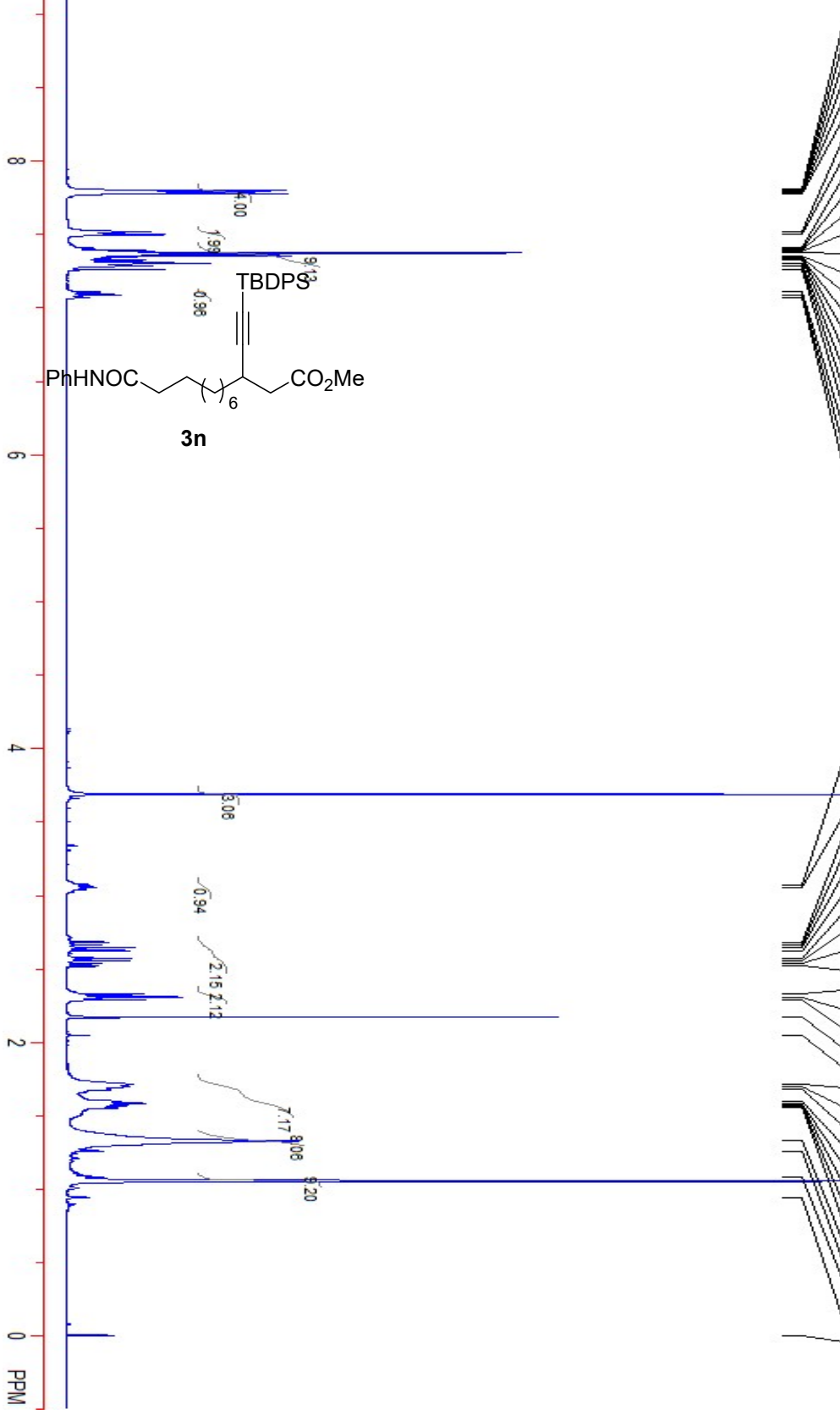

TBDPS
O
CO2Me
Cl
3k
150
100
50
PPM

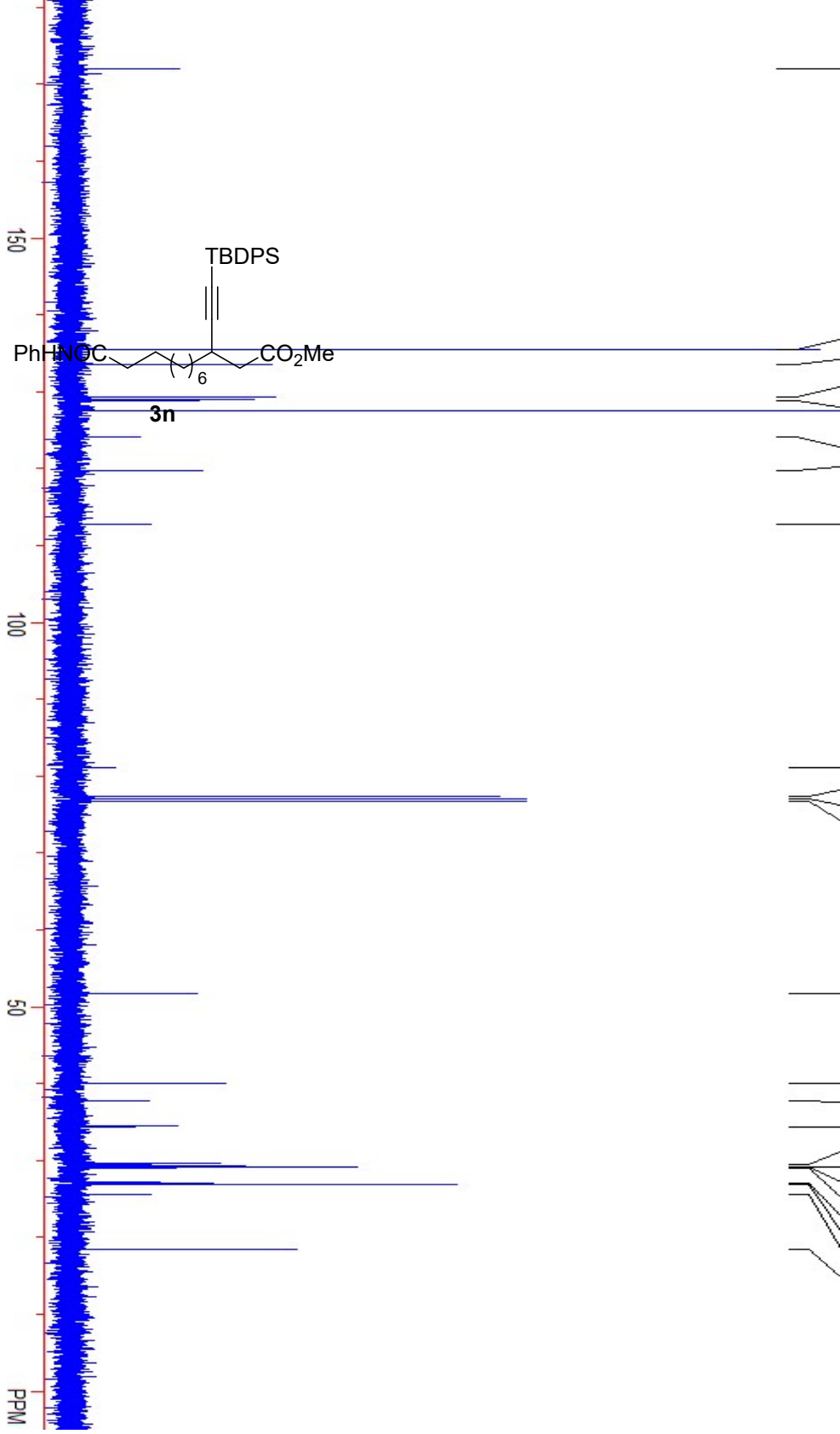

TBDPS
TsO
CO2Me
3I
+
CO2Me
TBDPS
TsO
3II
7:1
3I
3II
3I+3II
PPM

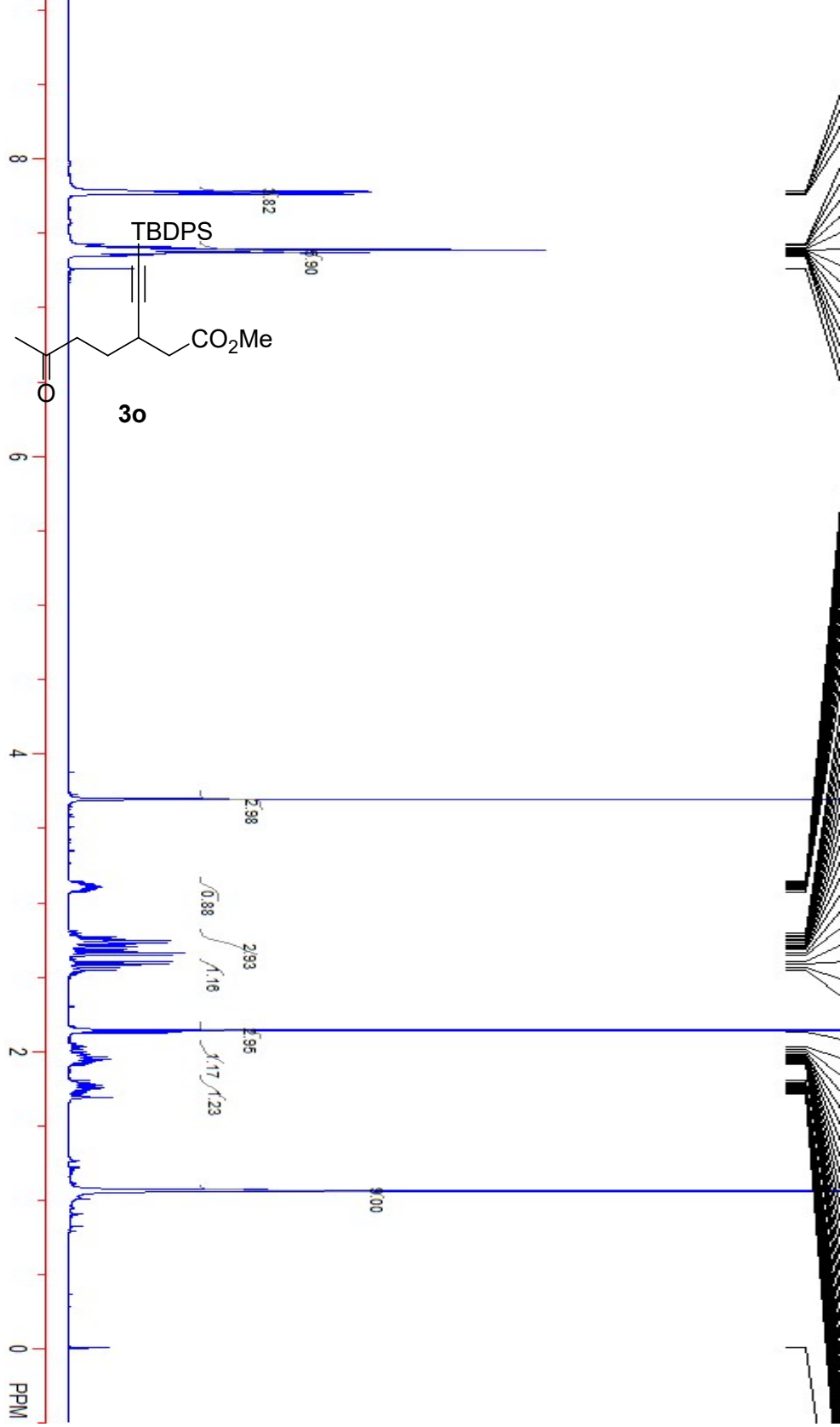

TBDPS
TsO
CO2Me
3I
+
CO2Me
TBDPS
TsO
3II
7:1
160
140
120
100
80
60
40
20
PPM

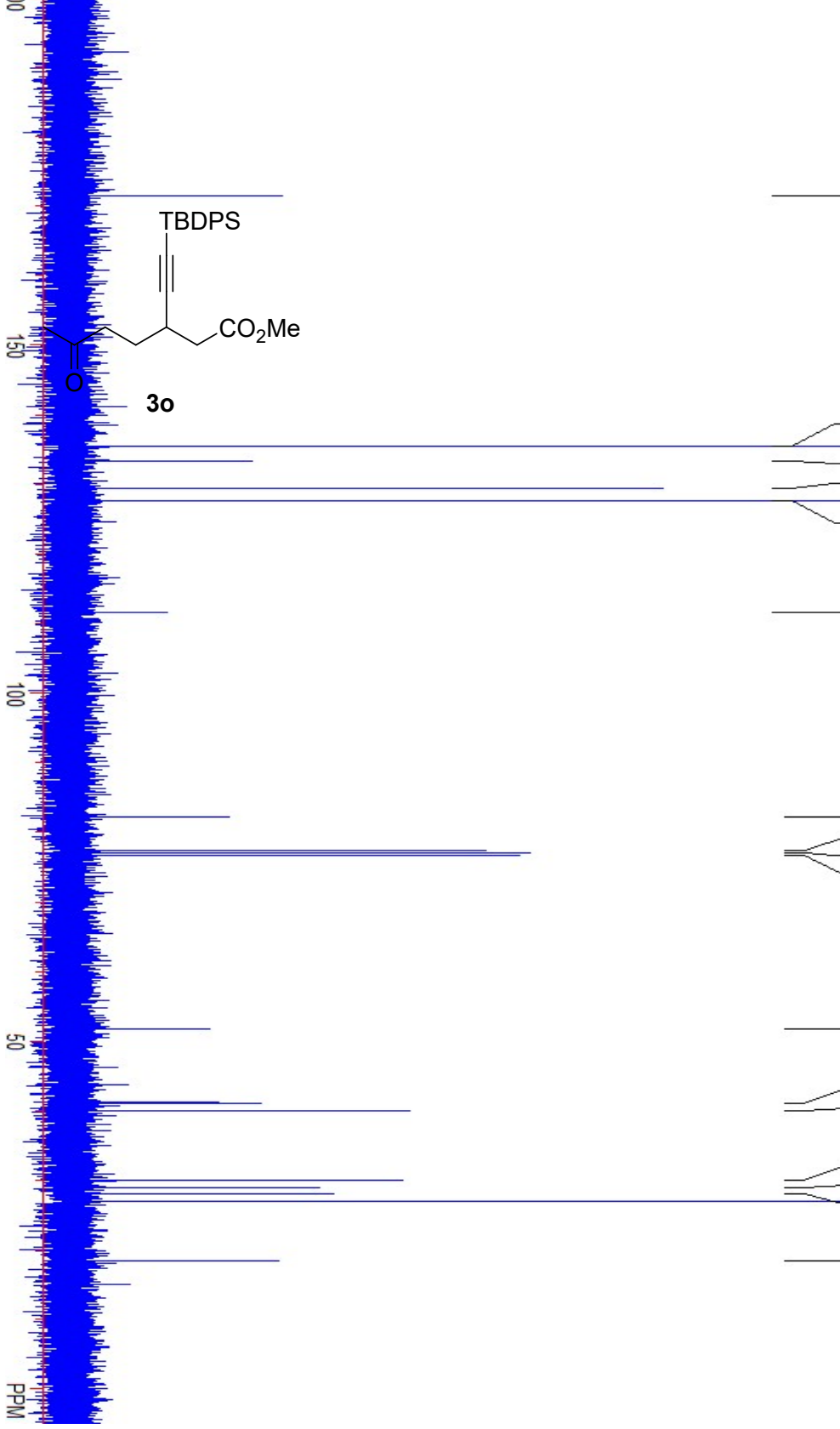

TBDPS
MeO2C
6
CO2Me
3m
8
6
4
2
0
PPM
3.98
2.06
1.00
1.01
1.03
2.11
6.32
8.81
9.36


TBDPS
MeO2C
6
CO2Me
3m
150
100
50
PPM

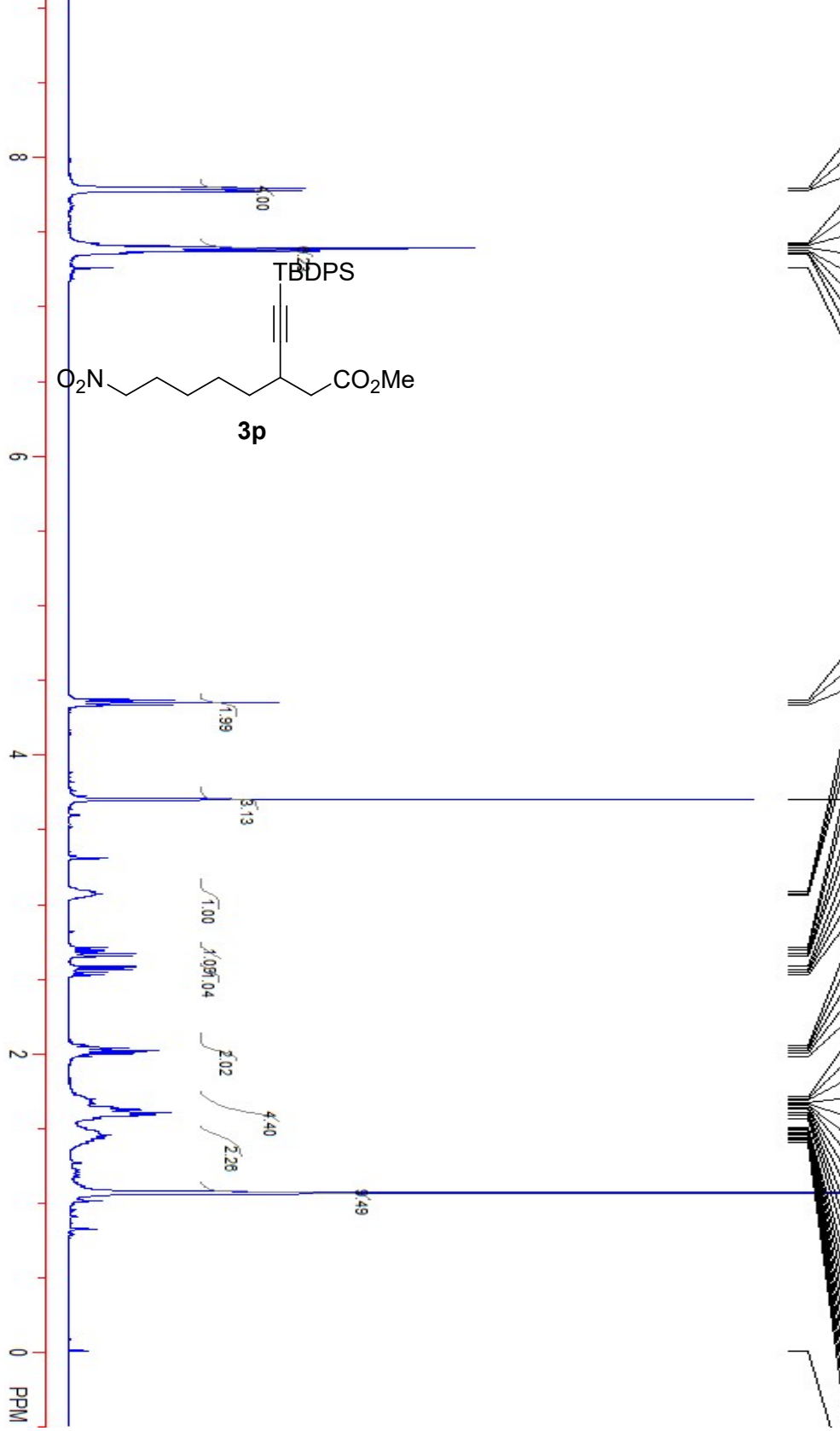

TBDPS
PhHNOC
CO2Me
6
3n
4.00
1.99
9.12
0.96
3.08
0.94
2.15
2.12
7.17
9.08
6.20
8
6
4
2
0
PPM

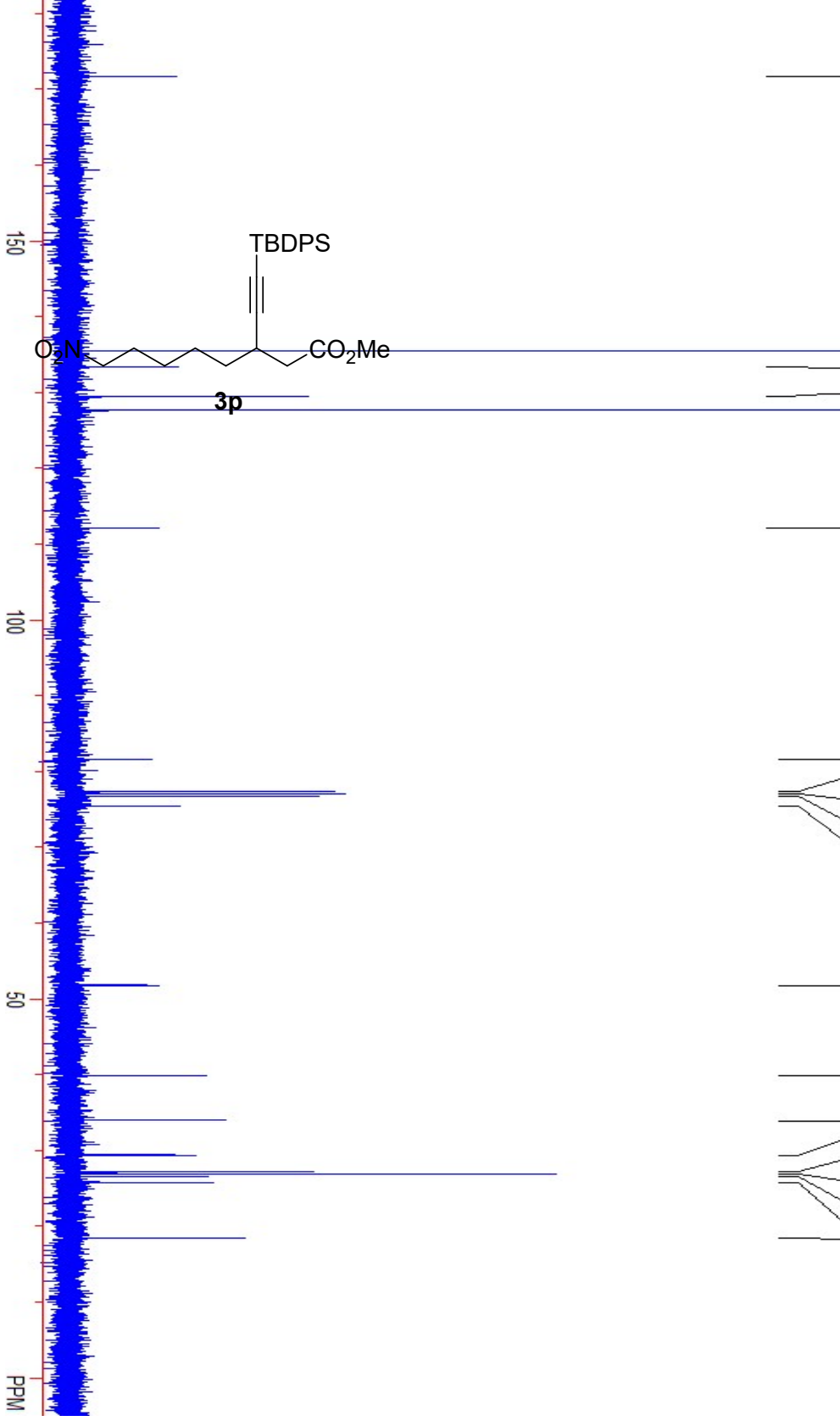

150
100
50
PPM
TBDPS
PhHNOC
CO2Me
6
3n

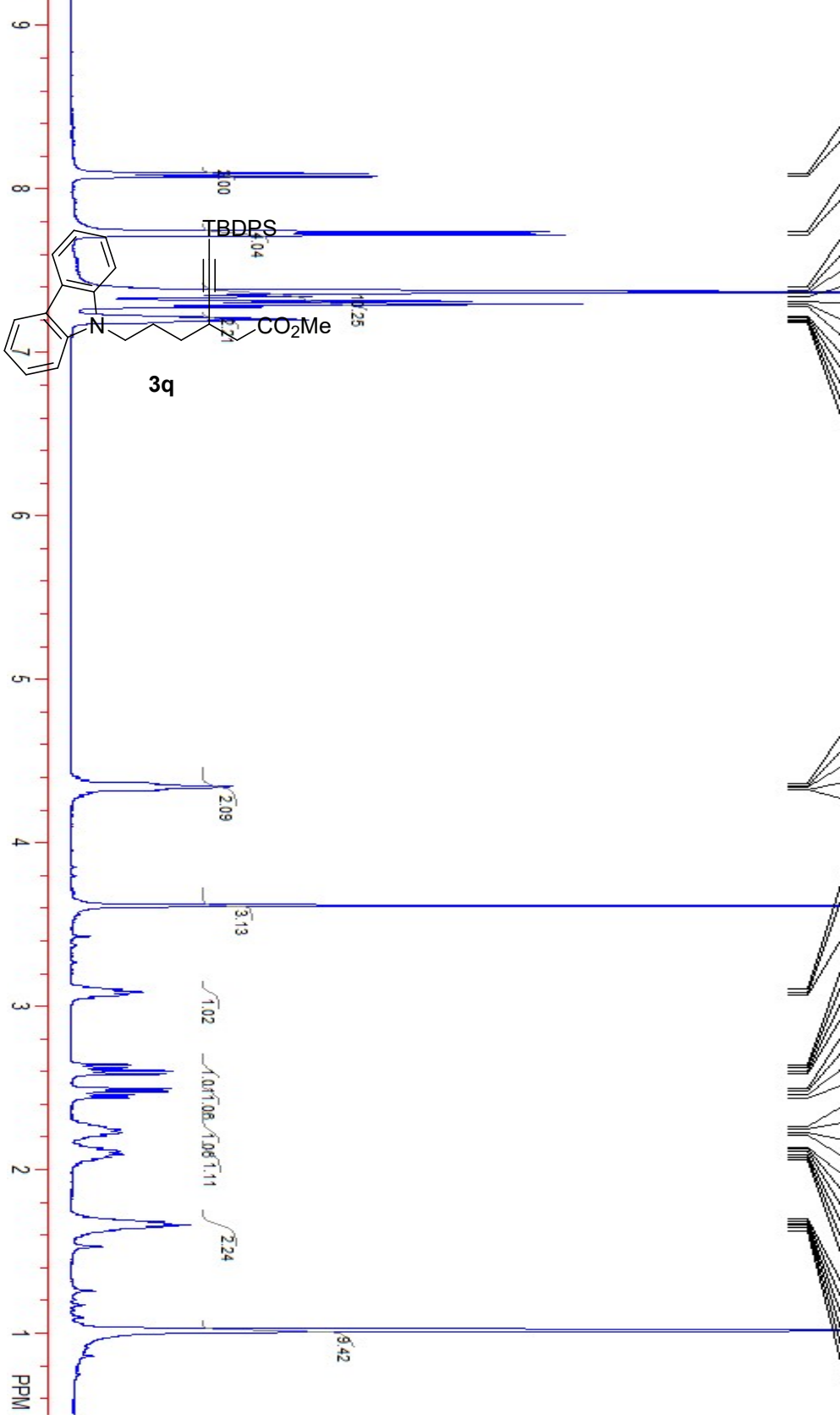

TBDPS
CO2Me
O
3o
8
6
4
2
0
PPM
1.82
1.90
2.98
0.88
2.93
1.18
2.95
1.17
1.23
9.00

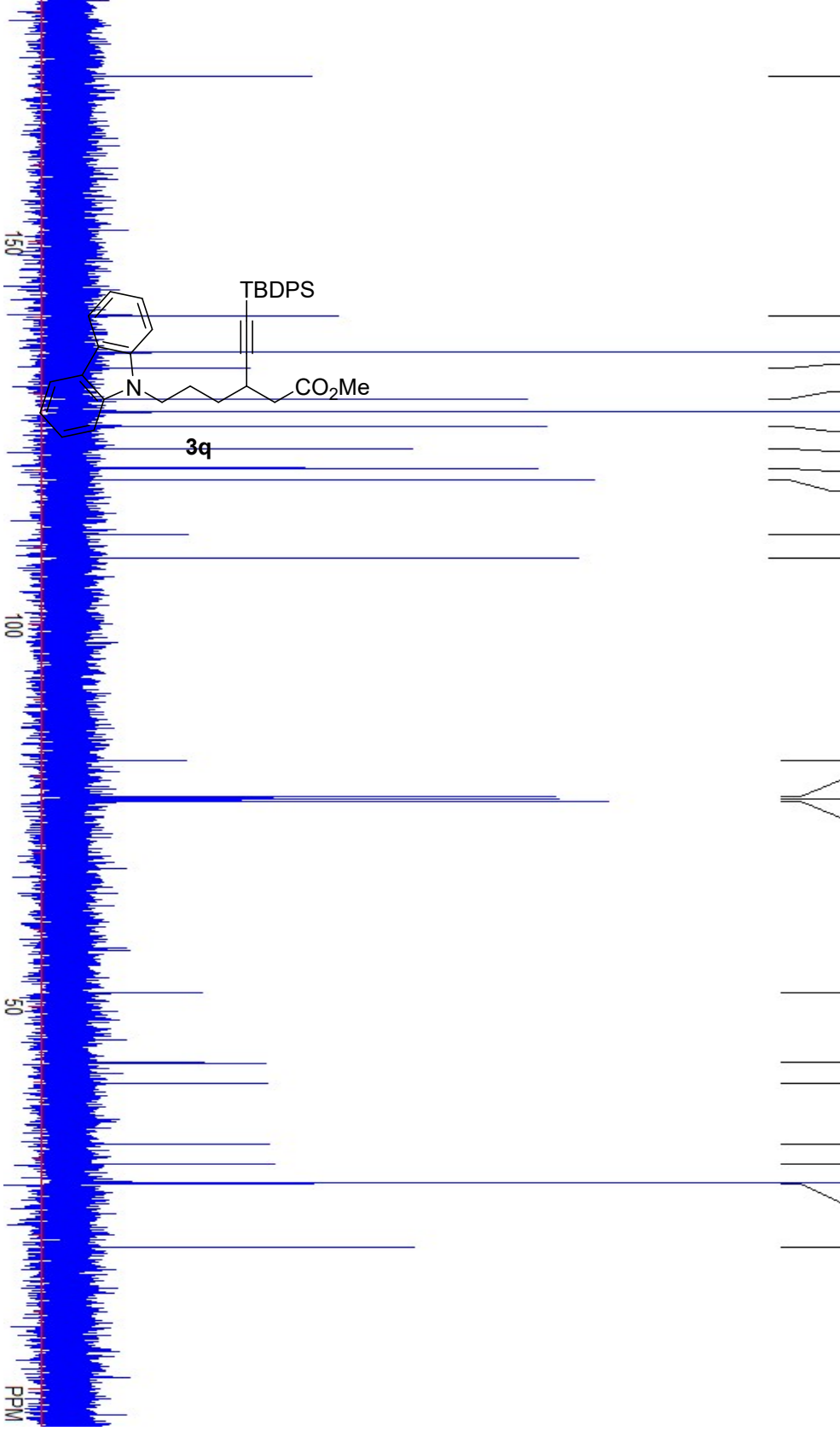


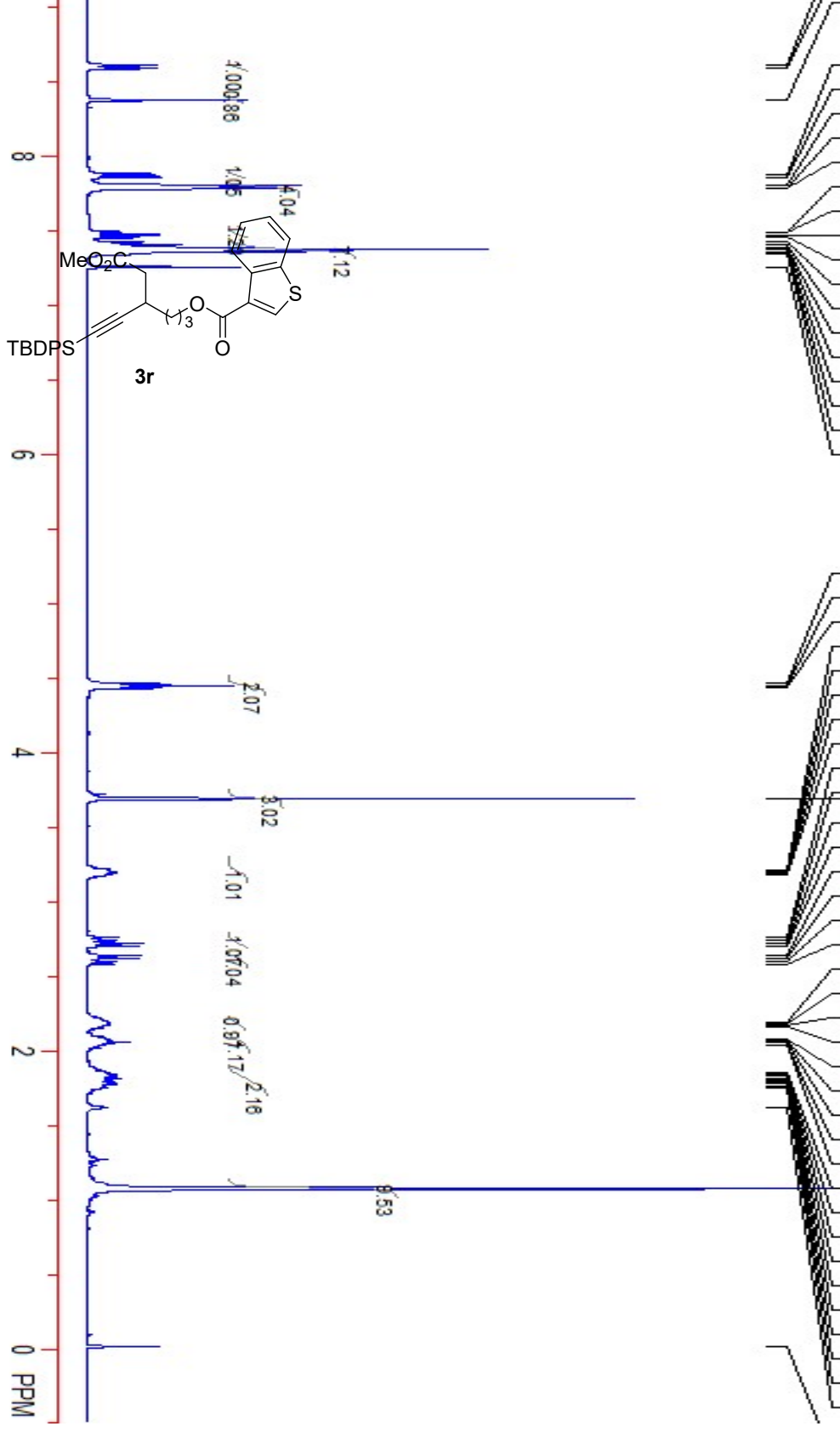
3o

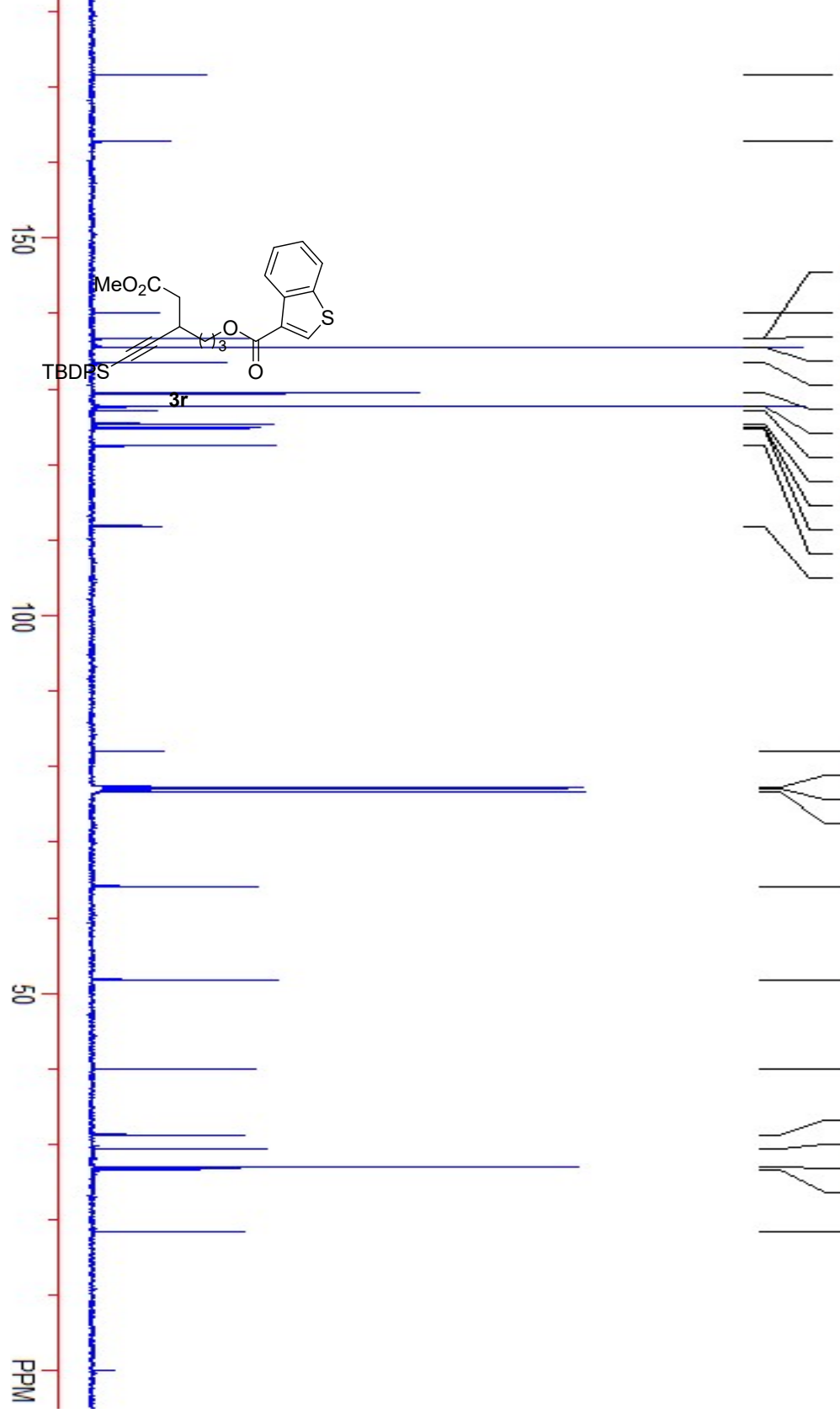

TBDPS
O_2N
CO_2Me
3p
PPM
0
2
4
6
8
4.00
2.22
1.99
3.13
1.00
1.09
1.04
2.02
4.40
2.28
9.49

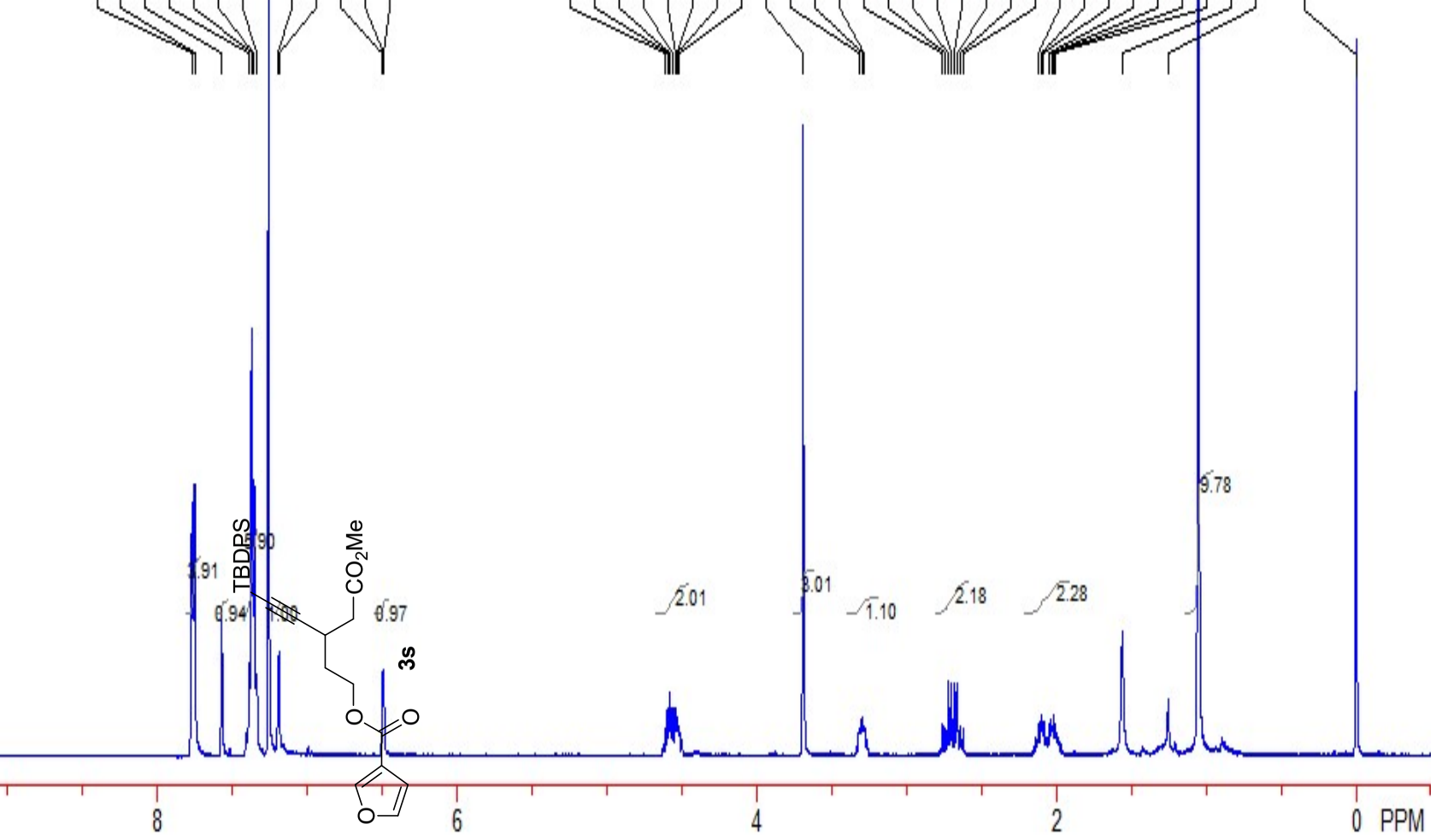

150
100
50
PPM
TBDPS
O2N
CO2Me
3p

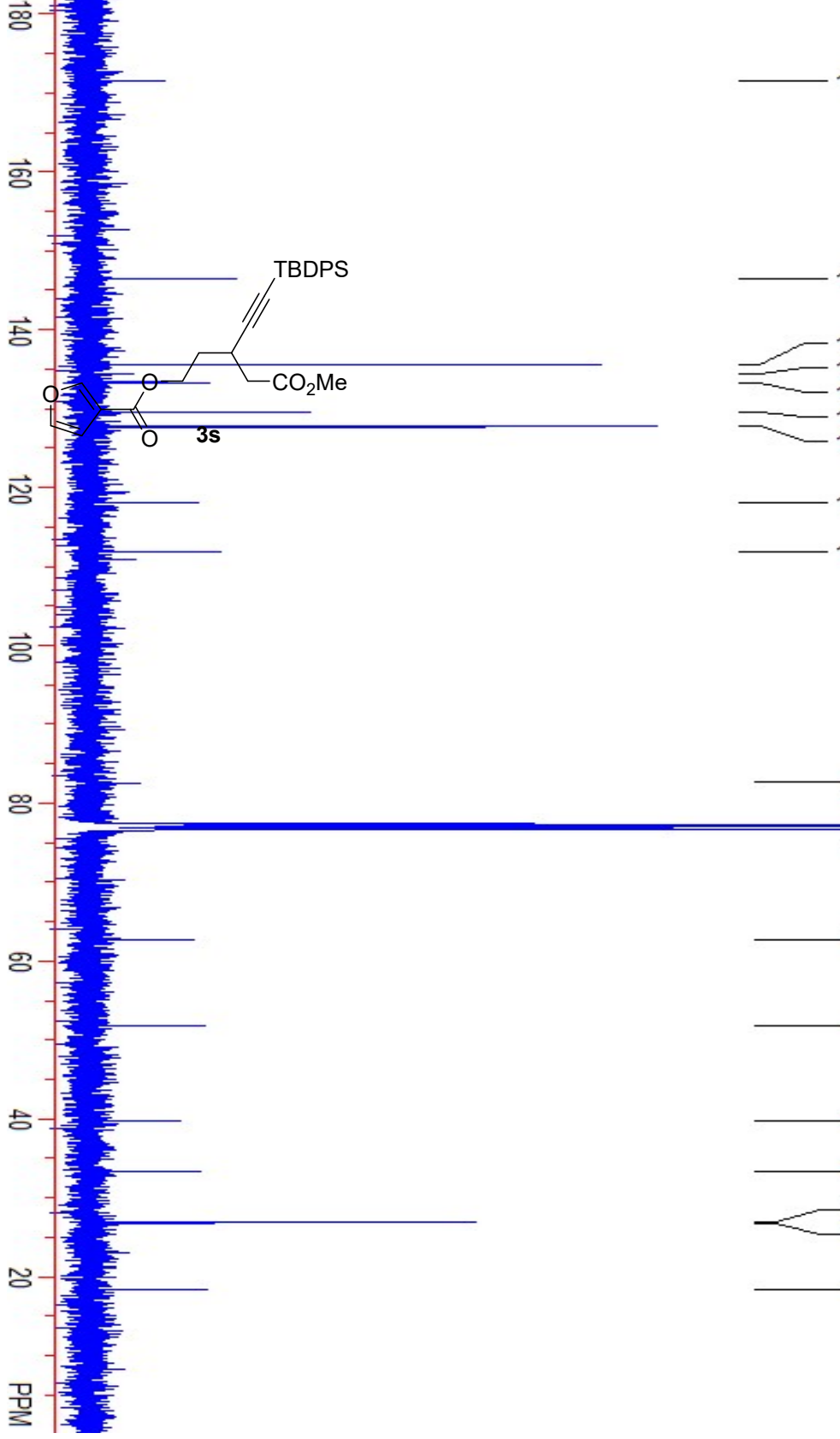

TBDPS
N
CO2Me
3q
2.00
4.04
10.25
2.21
2.09
3.13
1.02
1.07
1.08
1.06
1.11
2.24
9.42
PPM

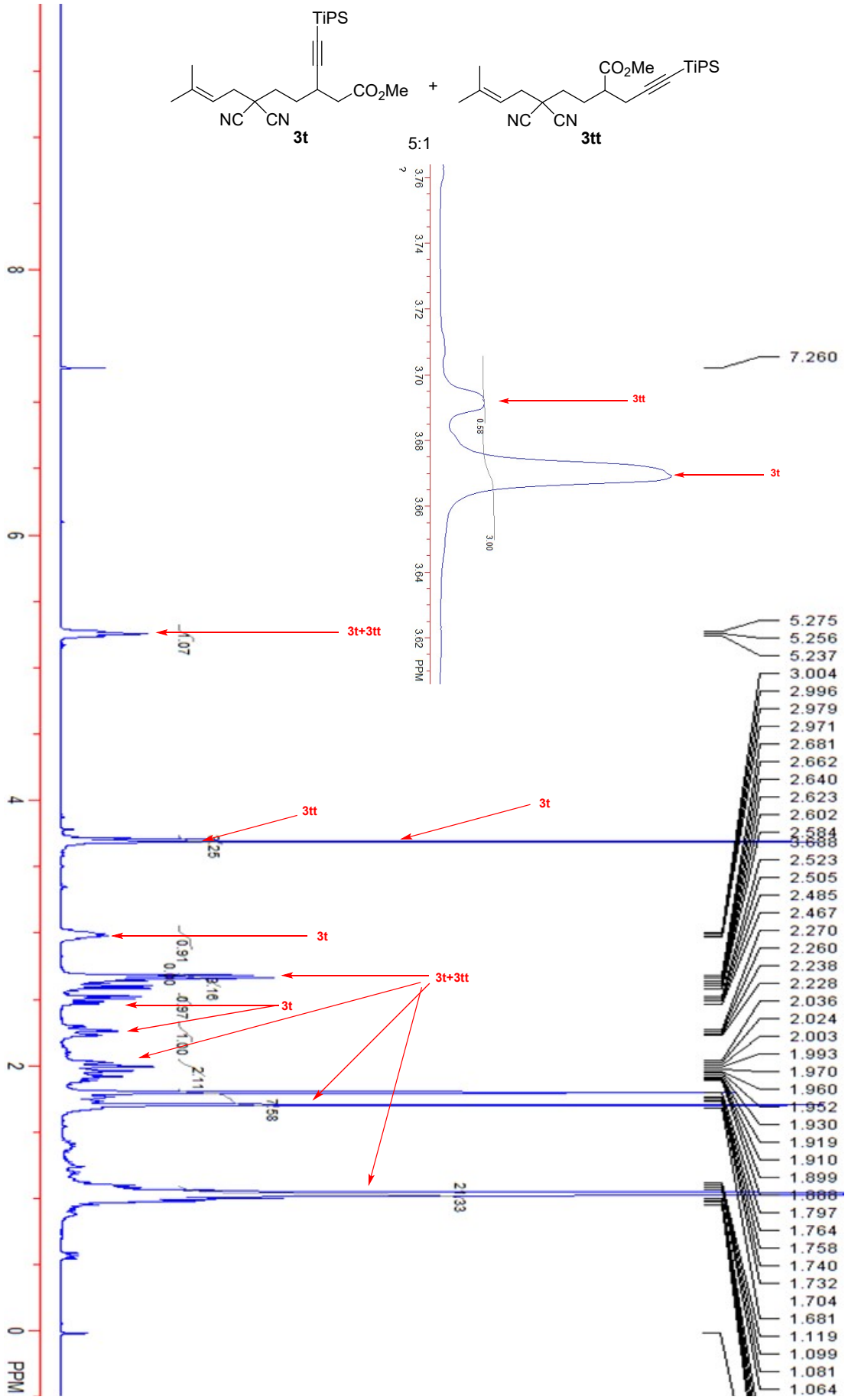

TBDPS
N
CO2Me
3q
150
100
50
PPM


MeO2C
TBDPS
O
O
S
3r
1.00
1.05
4.04
1.12
2.07
3.02
1.01
1.06
0.87
1.17
2.16
9.53
8
6
4
2
0 PPM


150
100
50
PPM
MeO2C
O
3
S
TBDPS
O
3r


TBDPS
CO2Me
O
O
O
3s
1.91
0.94
1.00
0.97
2.01
3.01
1.10
2.18
2.28
9.78
8
6
4
2
0
PPM


TBDPS
O
O
CO2Me
O
O
3s
180
160
140
120
100
80
60
40
20
PPM


TiPS
CO2Me
NC
CN
3t
+
CO2Me
TiPS
NC
CN
3tt
5:1
3tt
3t
3t+3tt
3tt
3t
3t
3t+3tt
3t
7.260
5.275
5.256
5.237
3.004
2.996
2.979
2.971
2.681
2.662
2.640
2.623
2.602
2.584
2.523
2.505
2.485
2.467
2.270
2.260
2.238
2.228
2.036
2.024
2.003
1.993
1.970
1.960
1.952
1.930
1.919
1.910
1.899
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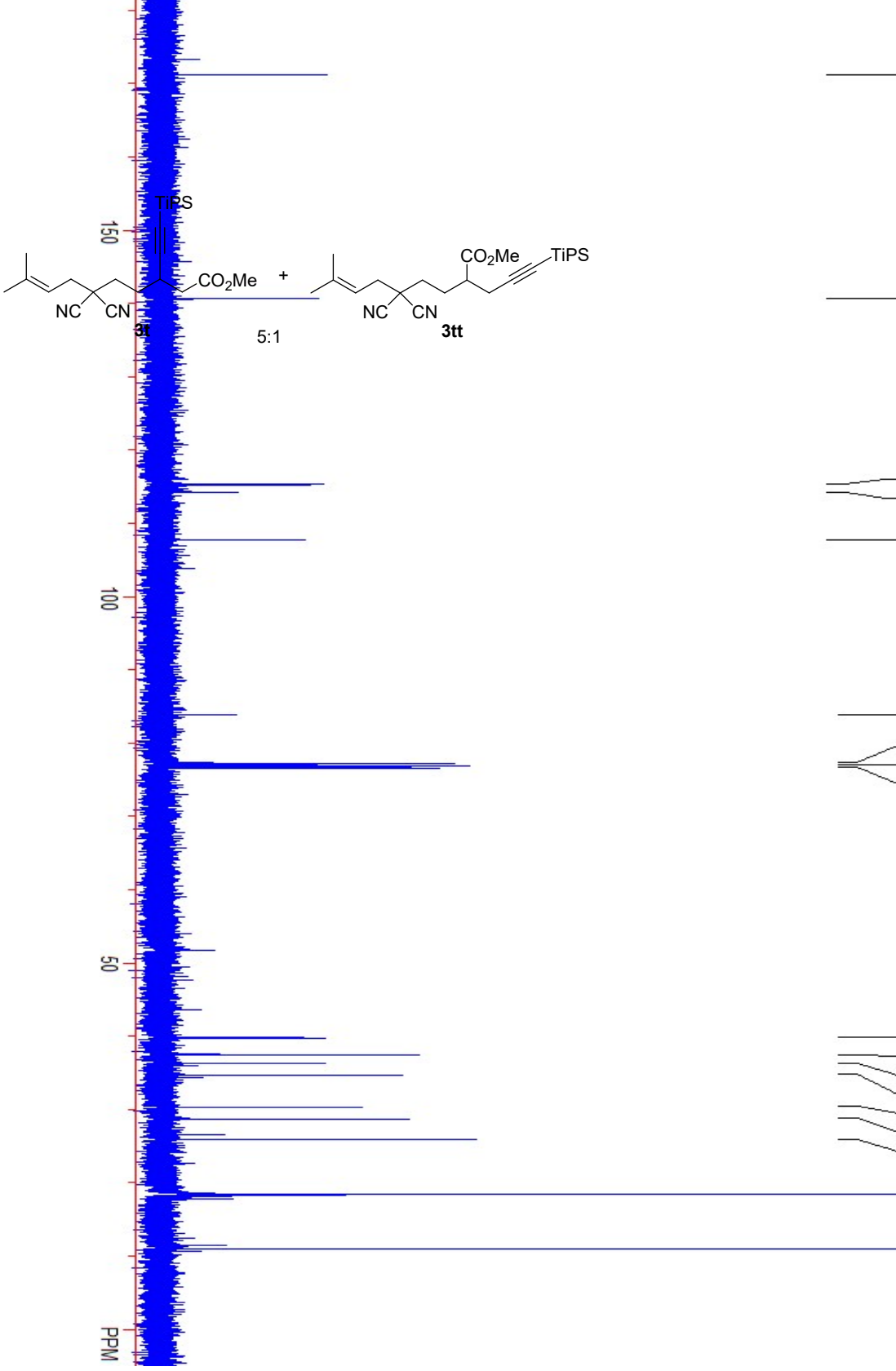
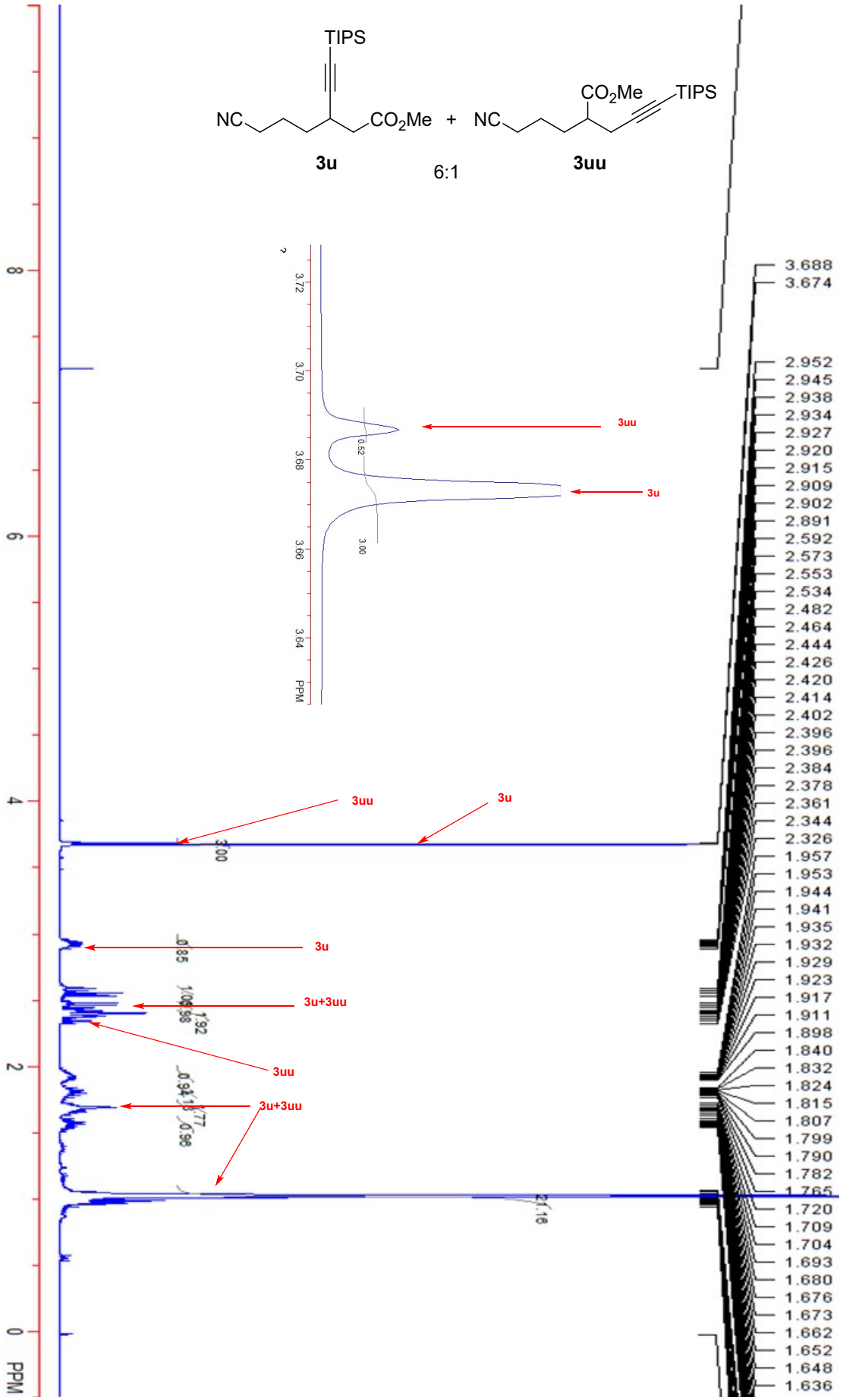
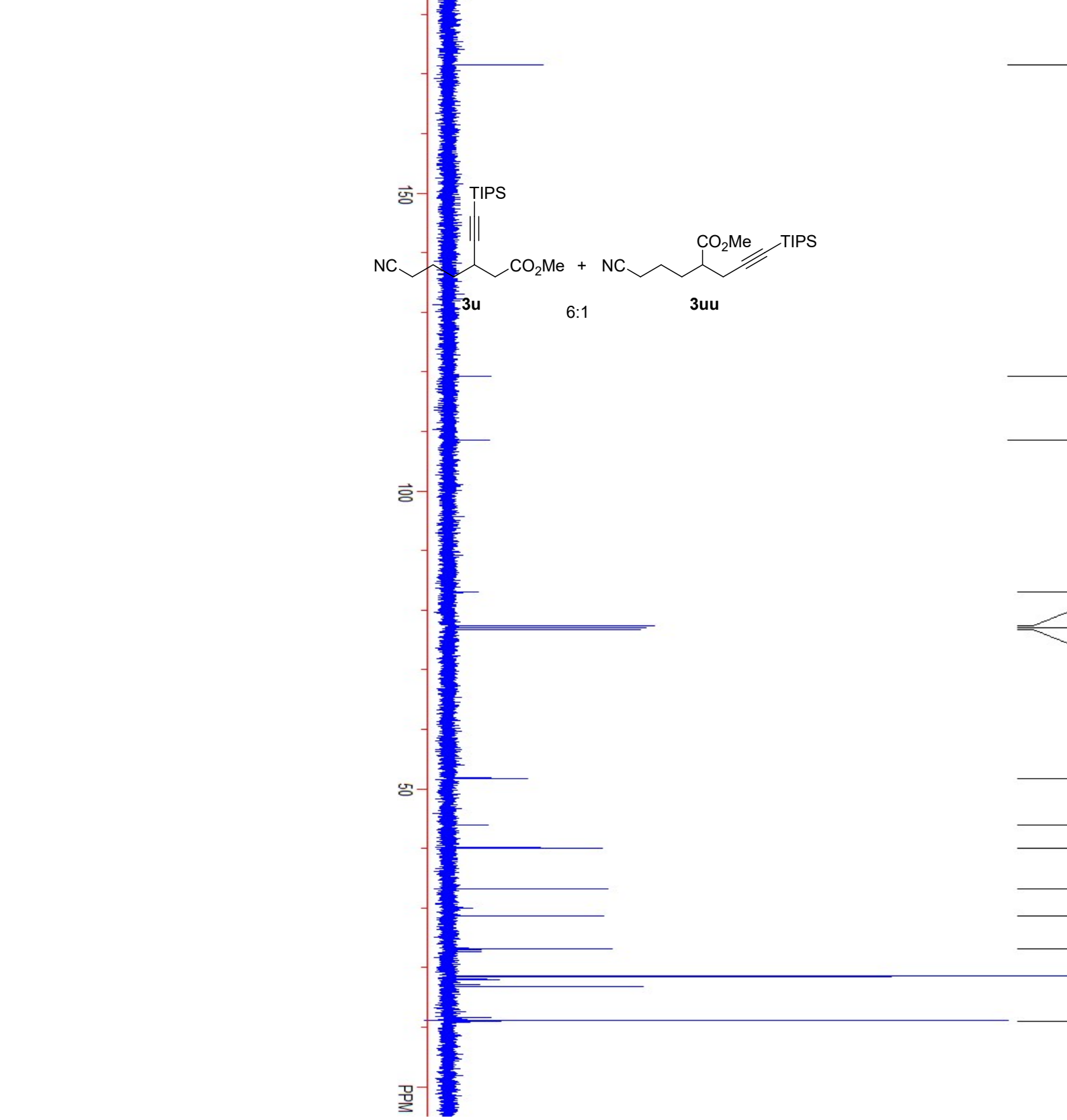
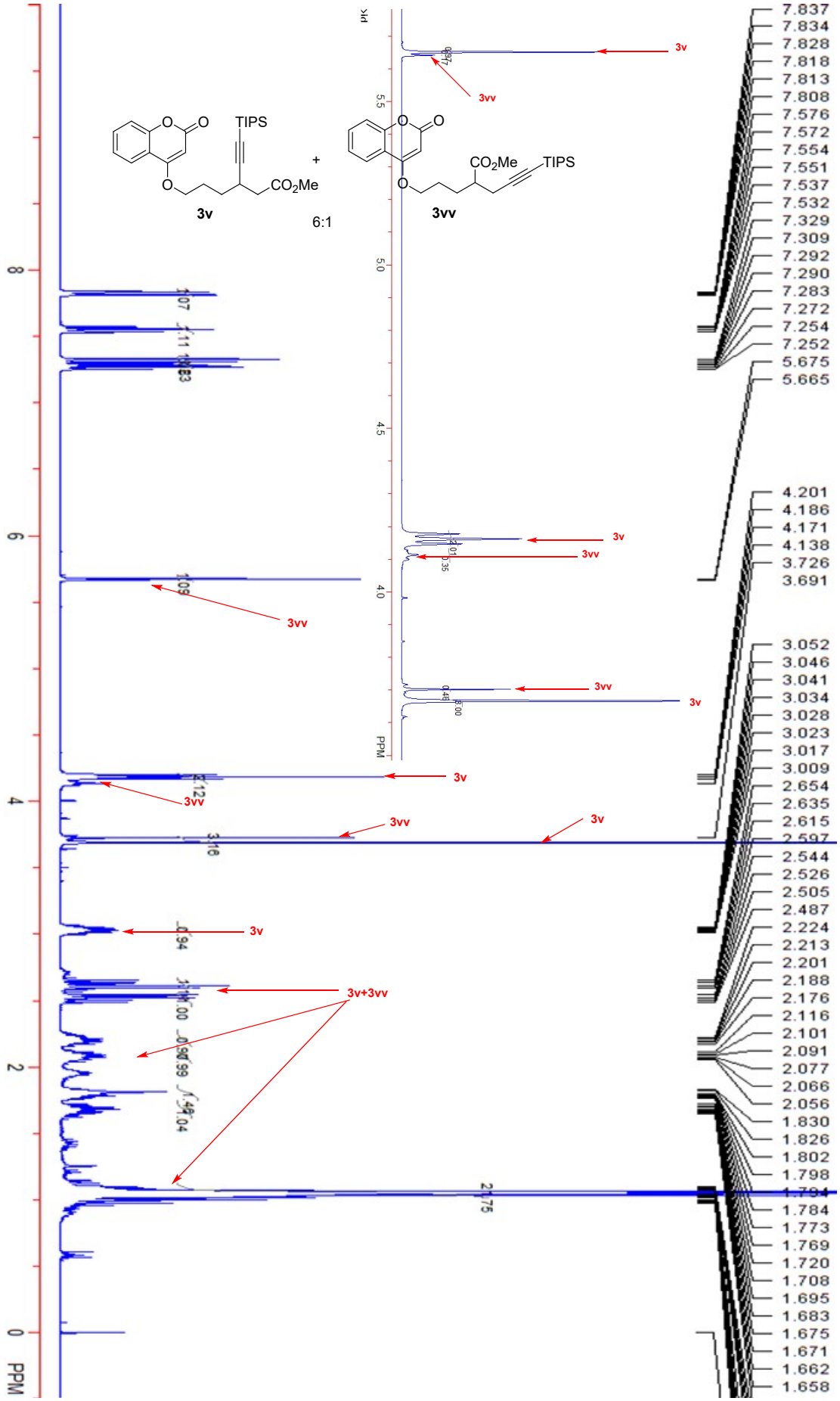
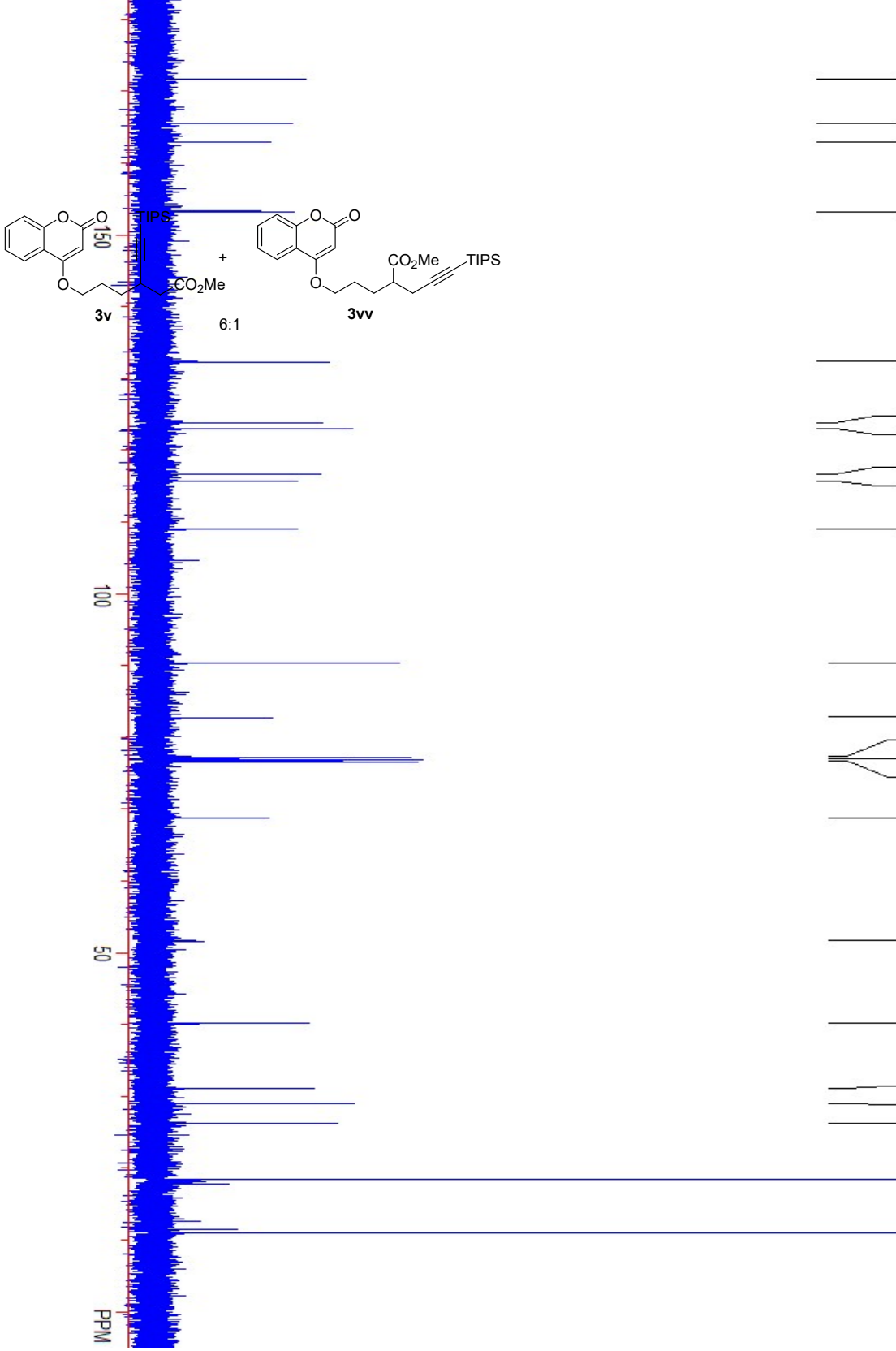
1.740
1.732
1.704
1.681
1.119
1.099
1.081
1.064
PPM

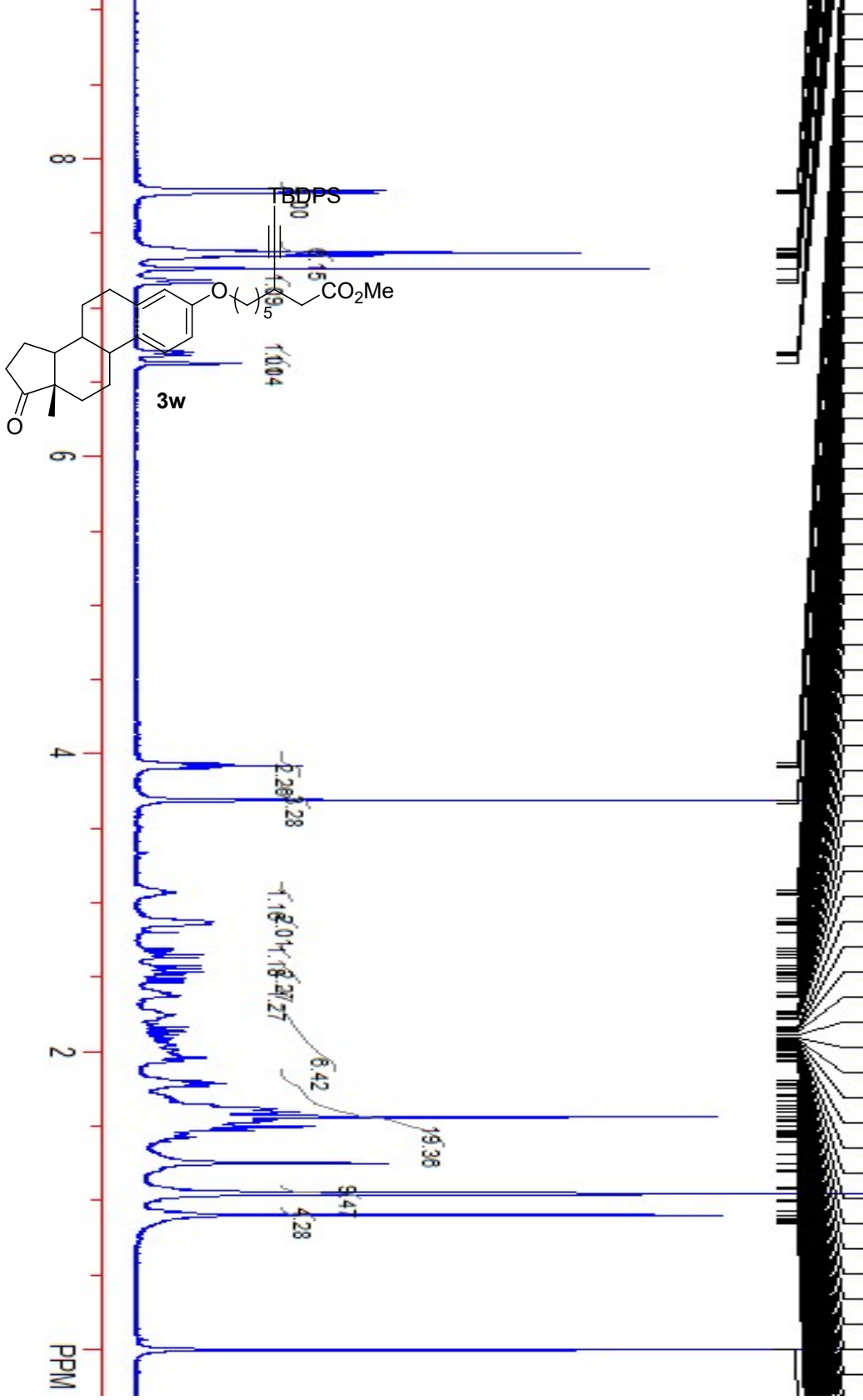

TiPS
CO2Me
NC
CN
3t
+
CO2Me
TiPS
NC
CN
3tt
5:1
150
100
50
PPM

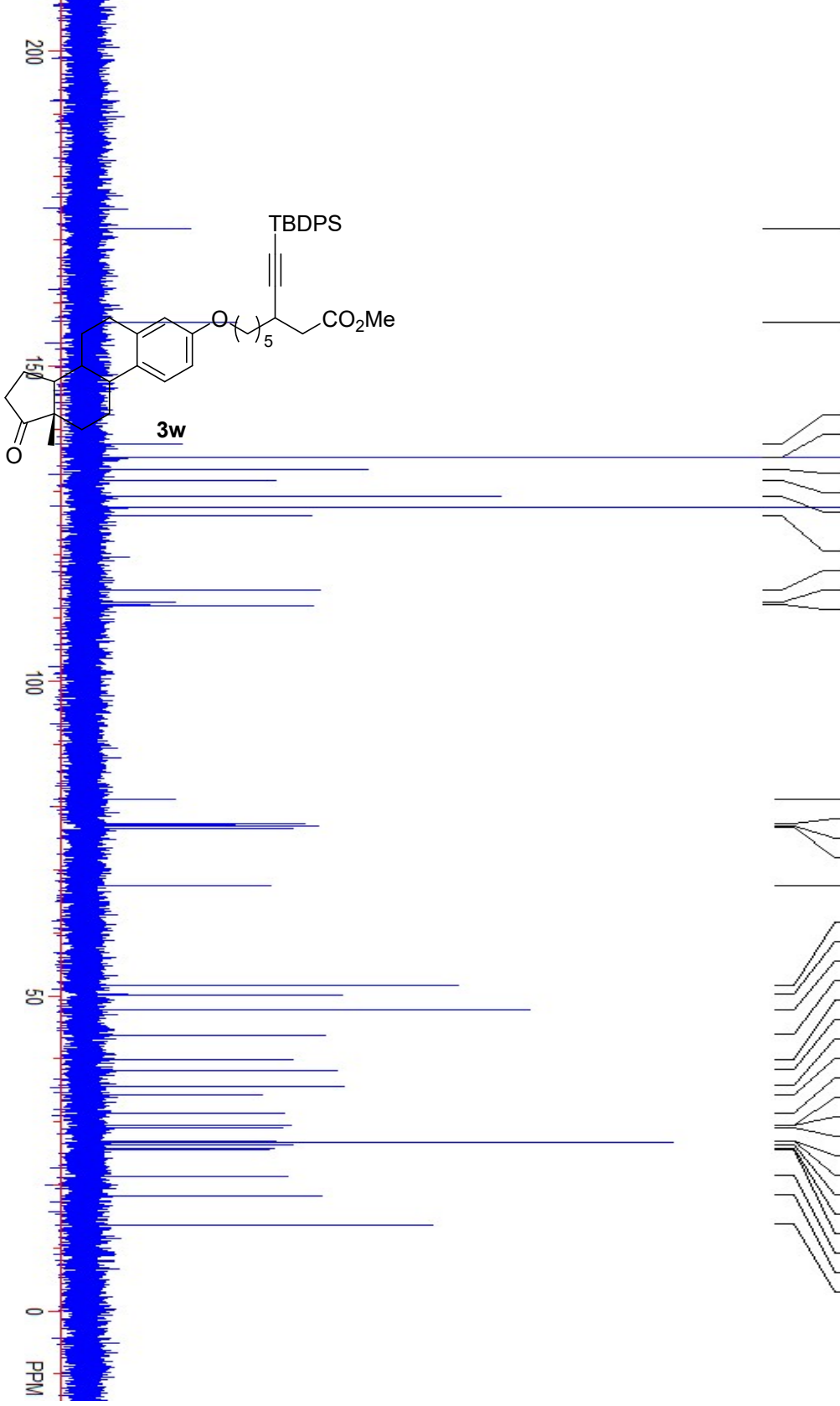

TIPS
NC
CO2Me
3u
6:1
CO2Me
TIPS
NC
3uu
3.688
3.674
2.952
2.945
2.938
2.934
2.927
2.920
2.915
2.909
2.902
2.891
2.592
2.573
2.553
2.534
2.482
2.464
2.444
2.426
2.420
2.414
2.402
2.396
2.396
2.384
2.378
2.361
2.344
2.326
1.957
1.953
1.944
1.941
1.935
1.932
1.929
1.923
1.917
1.911
1.898
1.840
1.832
1.824
1.815
1.807
1.799
1.790
1.782
1.765
1.720
1.709
1.704
1.693
1.680
1.676
1.673
1.662
1.652
1.648
1.636
3uu
3u
3uu
3u
3u
3u+3uu
3uu
3u+3uu
PPM

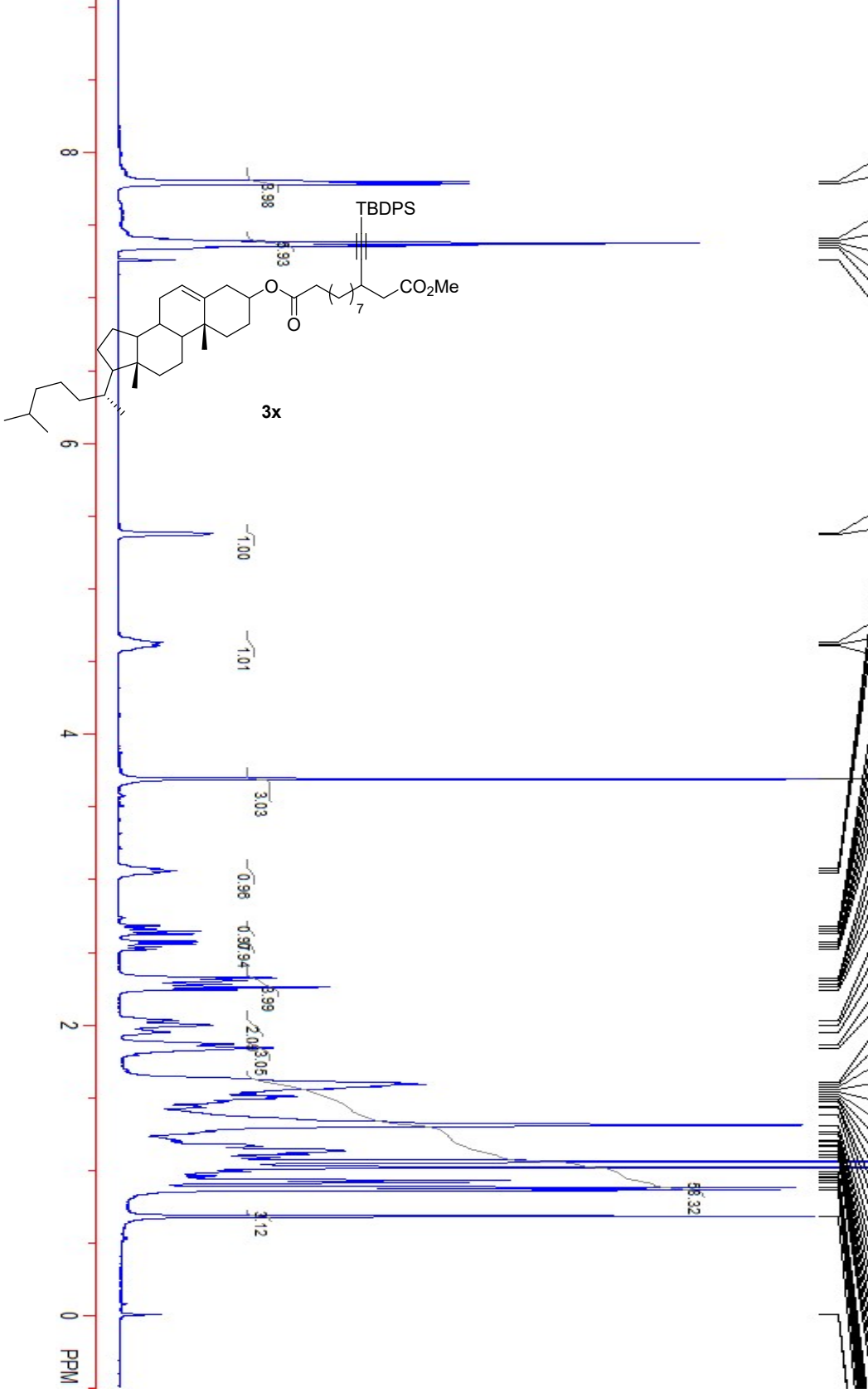

TIPS
NC
CO2Me
3u
6:1
CO2Me
TIPS
NC
3uu
150
100
50
PPM

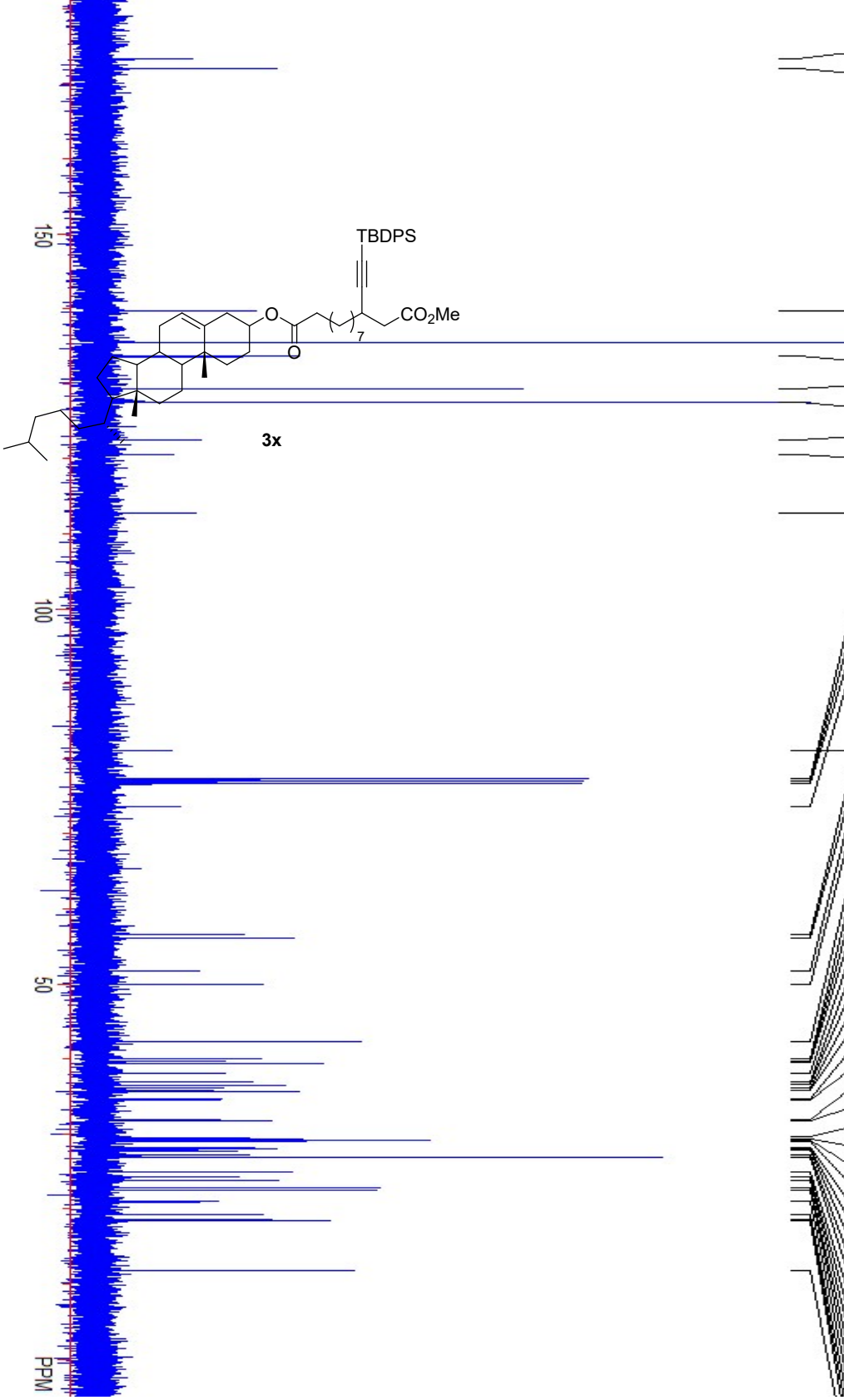

TIPS
CO2Me
3v
+
6:1
3vv
7.837
7.834
7.828
7.818
7.813
7.808
7.576
7.572
7.554
7.551
7.537
7.532
7.329
7.309
7.292
7.290
7.283
7.272
7.254
7.252
5.675
5.665
4.201
4.186
4.171
4.138
3.726
3.691
3.052
3.046
3.041
3.034
3.028
3.023
3.017
3.009
2.654
2.635
2.615
2.544
2.526
2.505
2.487
2.224
2.213
2.201
2.188
2.176
2.116
2.101
2.091
2.077
2.066
2.056
1.830
1.826
1.802
1.798
1.784
1.773
1.769
1.720
1.708
1.695
1.683
1.675
1.671
1.662
1.658
3v+3vv
PPM

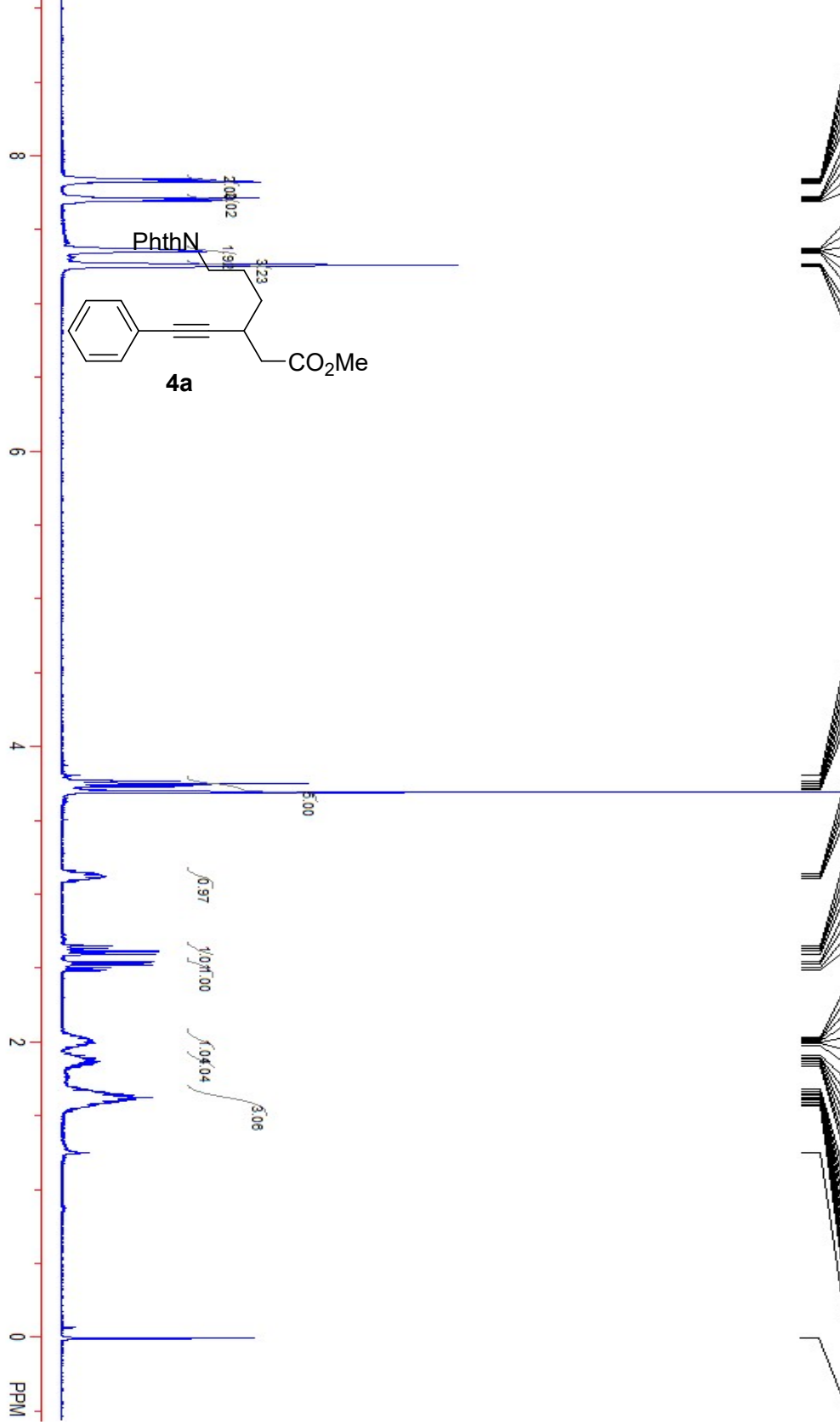

TIPS
CO2Me
3v
+
6:1
CO2Me
TIPS
3vv
150
100
50
PPM

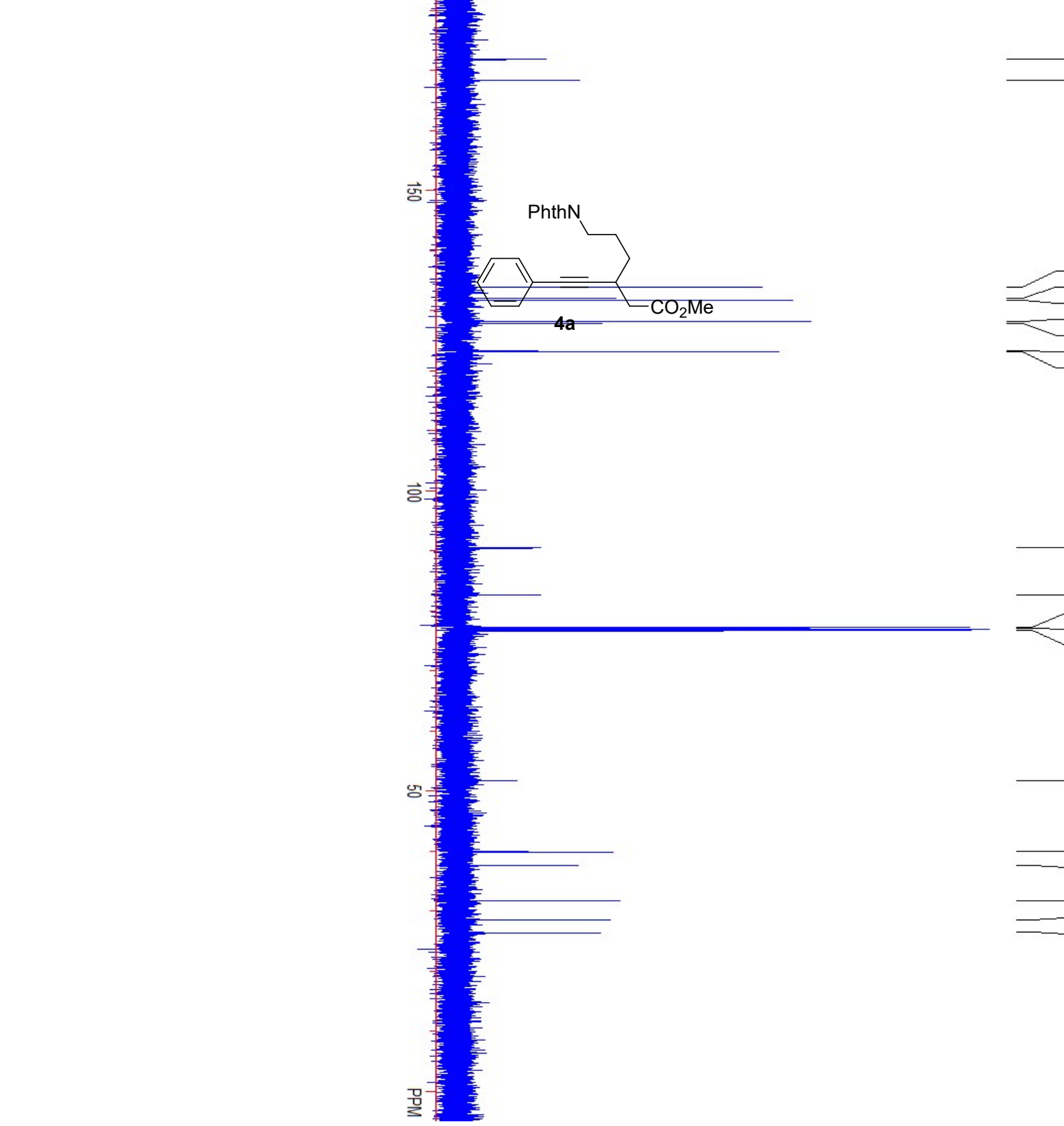

TBDPS
CO2Me
O
5
3w
O
PPM
8
6
4
2
1.00
1.15
1.69
1.00
4
2.28
2.28
1.18
2.01
1.18
4.27
4.27
6.42
19.36
9.47
4.28

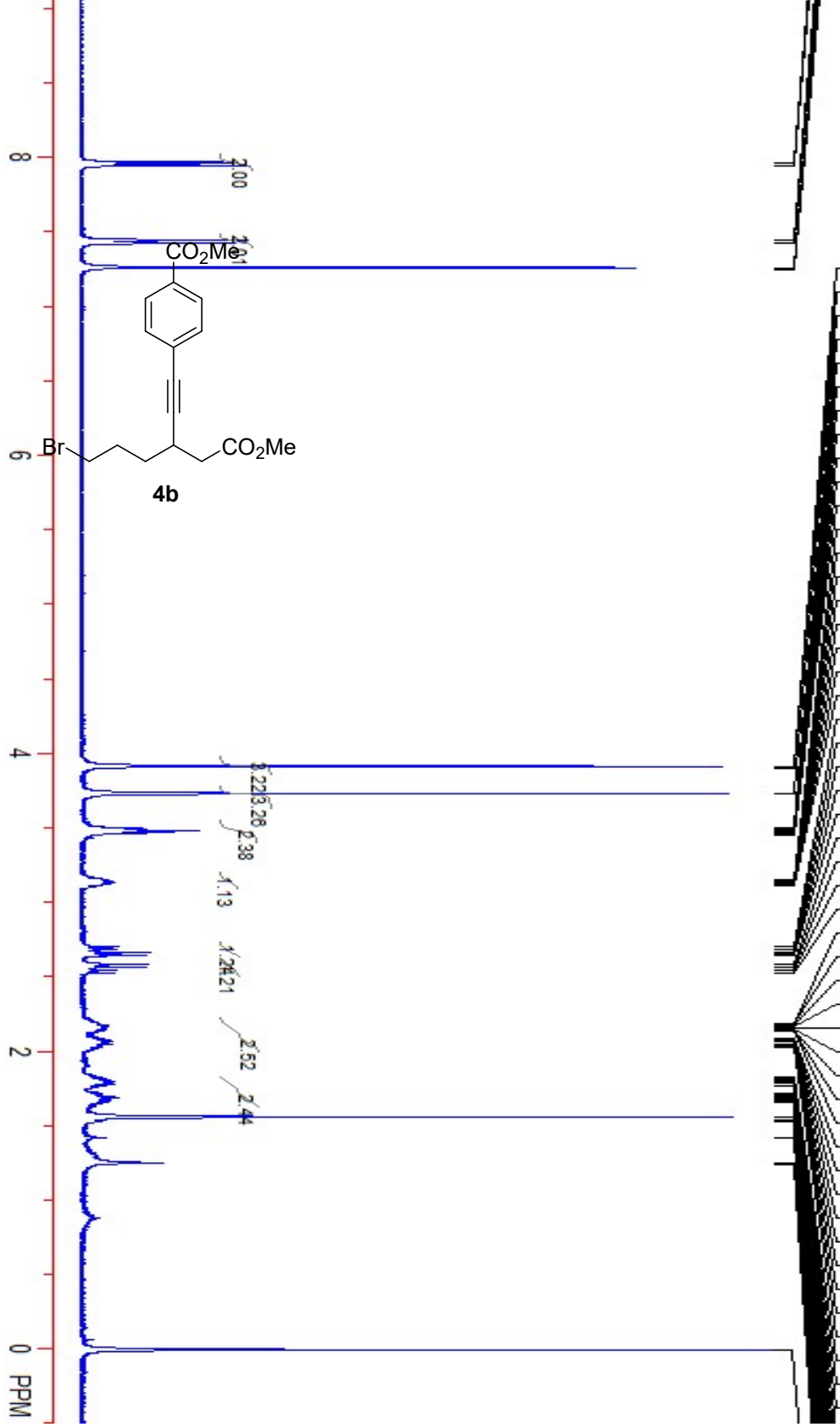

TBDPS
O
5
CO2Me
O
3w
200
150
100
50
0
PPM

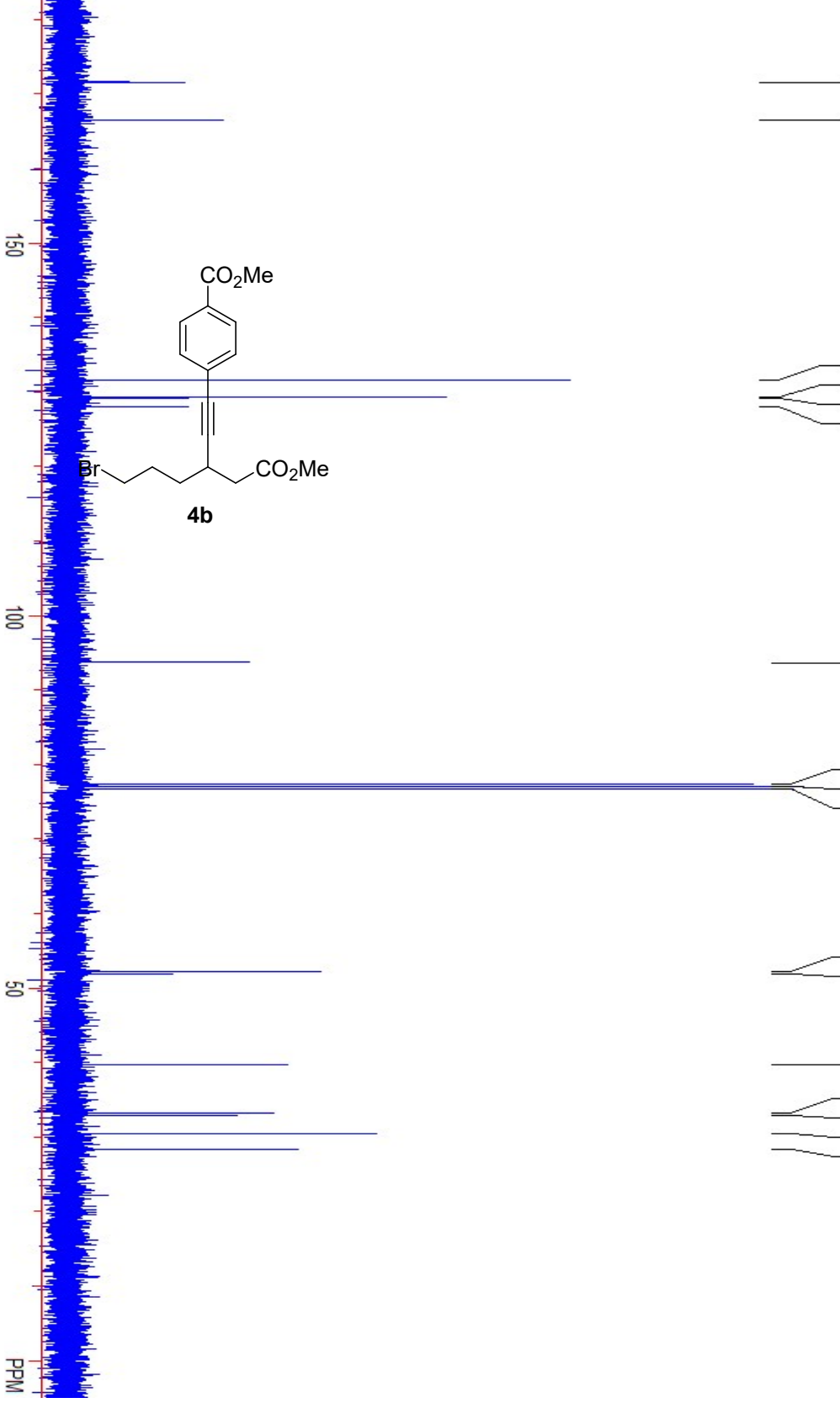

TBDPS
CO2Me
O
O
7
3x
8
6
4
2
0
PPM
3.98
5.93
1.00
1.01
3.03
0.98
0.97
0.94
3.99
2.04
3.05
58.32
3.12


TBDPS
O
O
7
CO2Me
3x
150
100
50
PPM

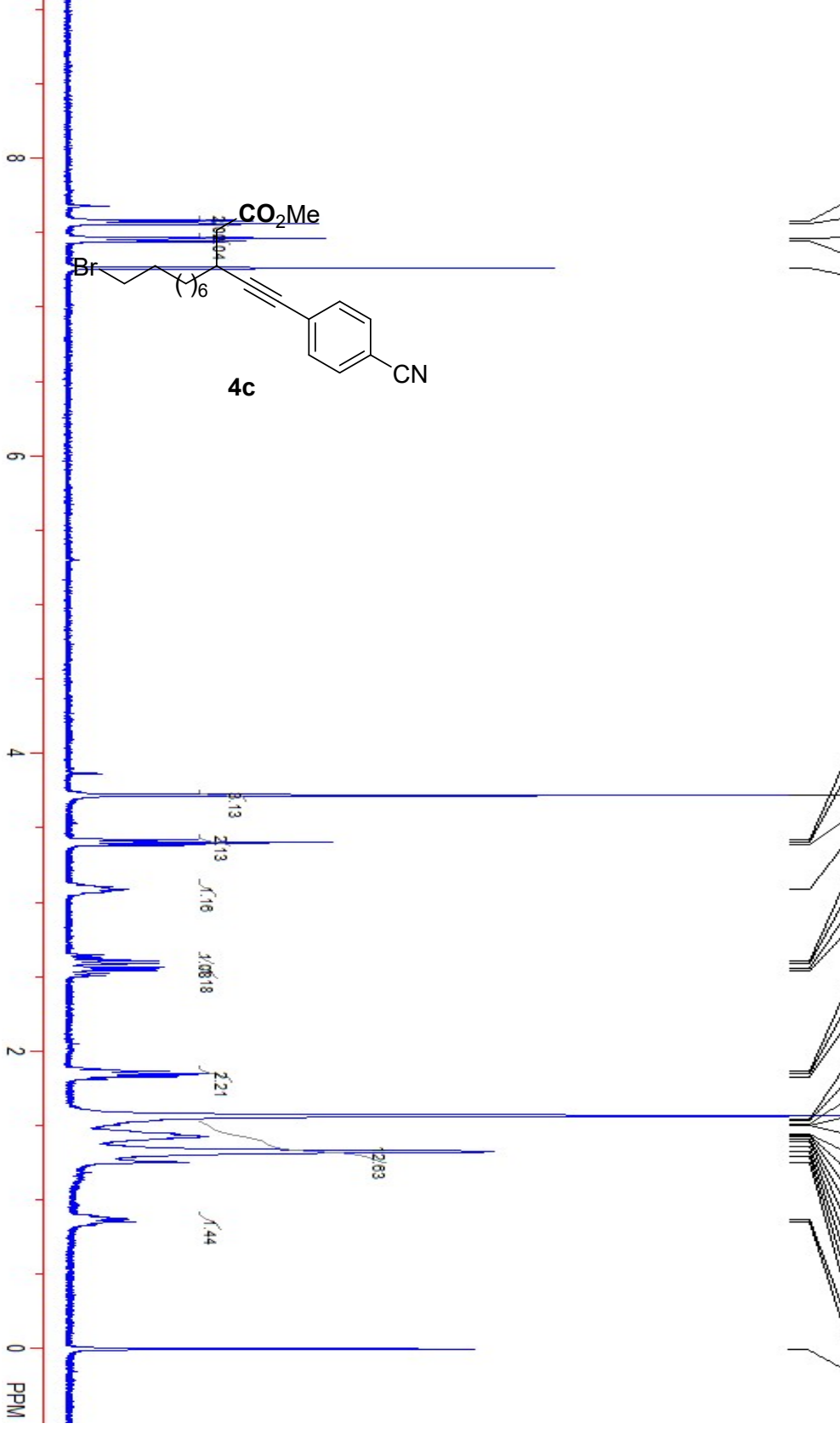

PhthN
CO2Me
4a
8
6
4
2
0
PPM
2.00
2.02
1.91
3.23
5.00
0.97
1.00
1.04
3.08

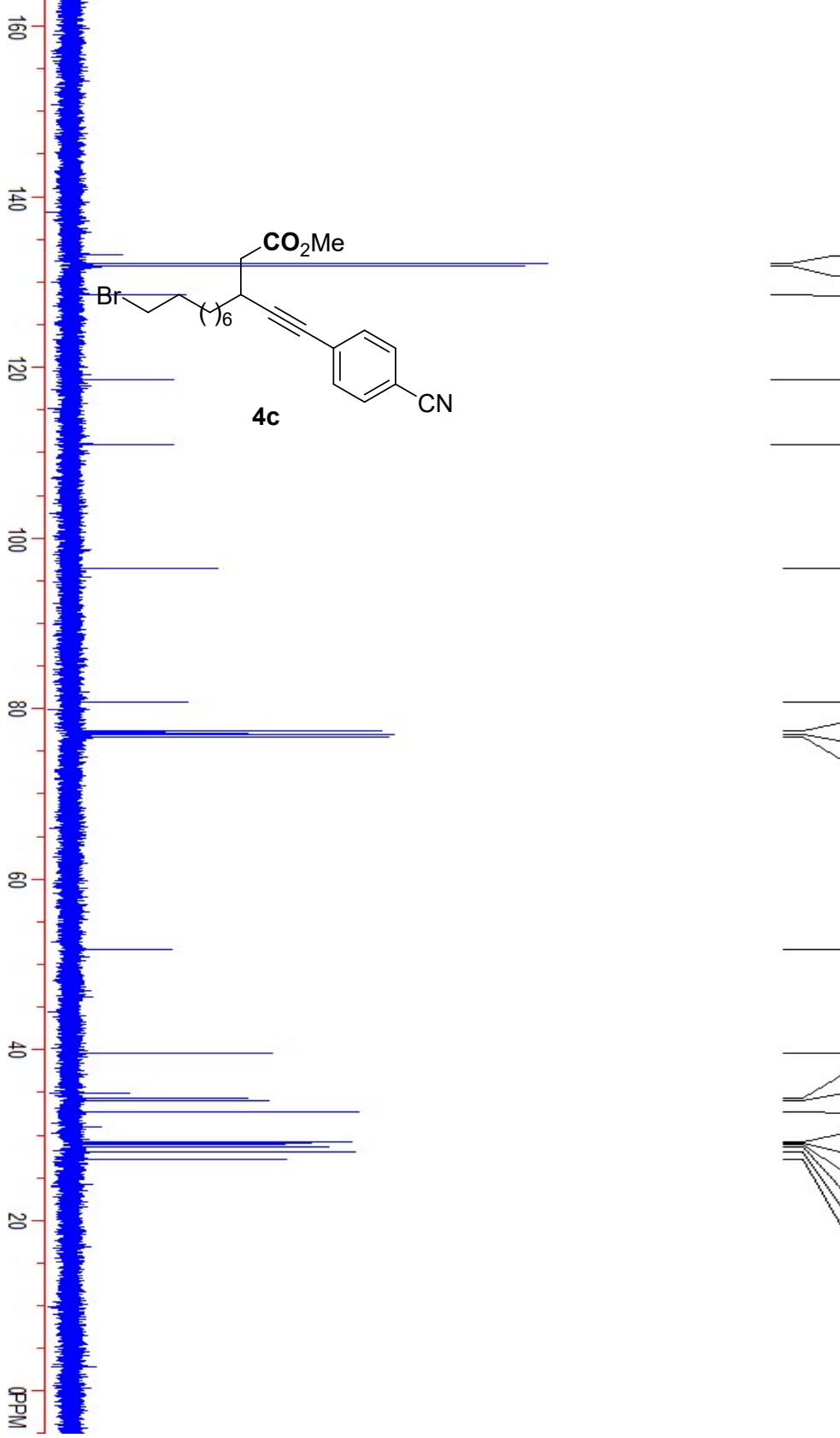

PhthN
CO2Me
4a
150
100
50
PPM


CO2Me
Br
CO2Me
4b
8
6
4
2
0 PPM
2.00
2.01
3.22
3.26
2.38
1.13
1.26
1.21
2.62
2.44

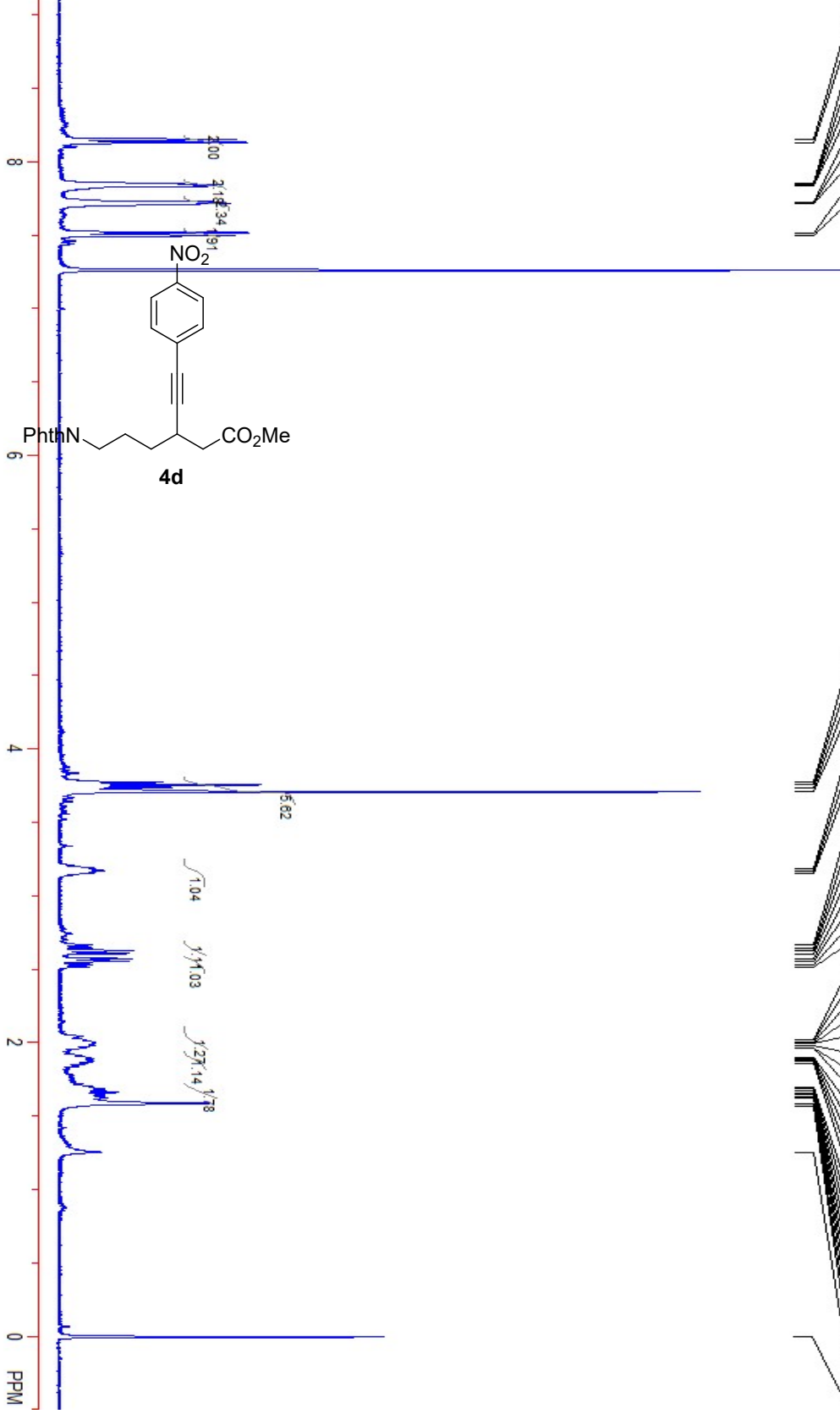


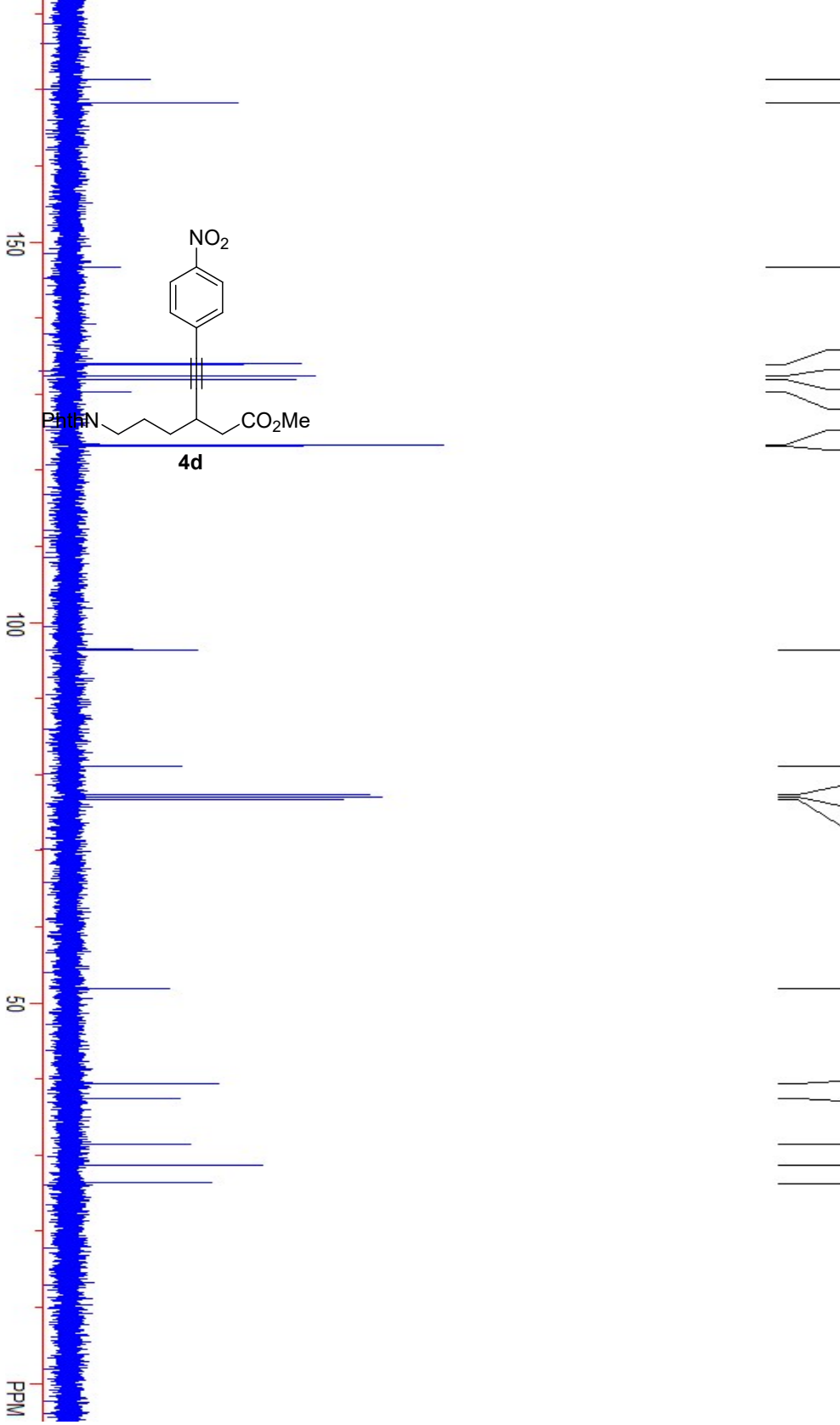
4b


CO2Me
Br
( )6
CN
4c
8
6
4
2
0
PPM
3.13
2.13
1.16
1.06
1.18
2.21
2.63
1.44

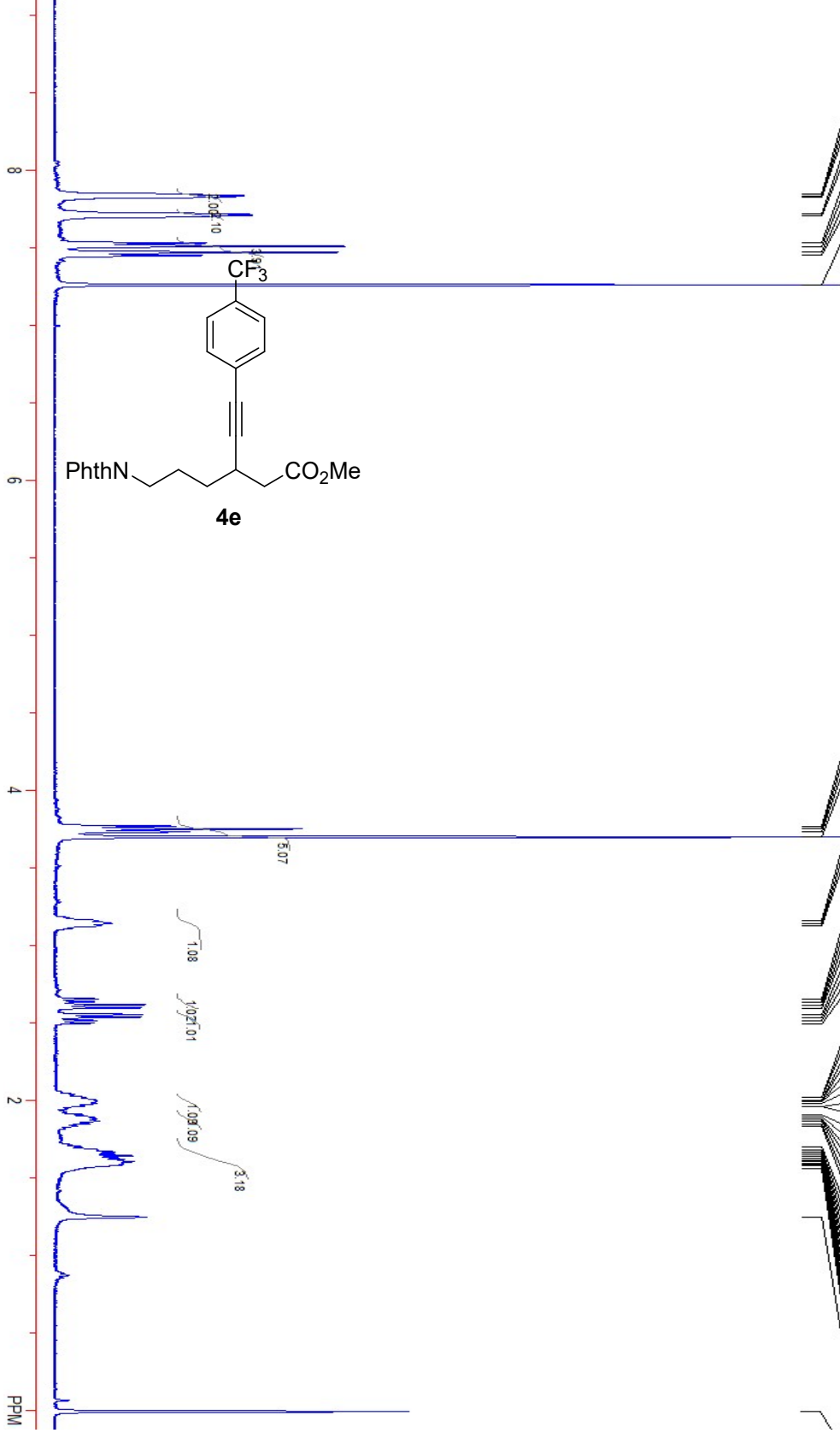


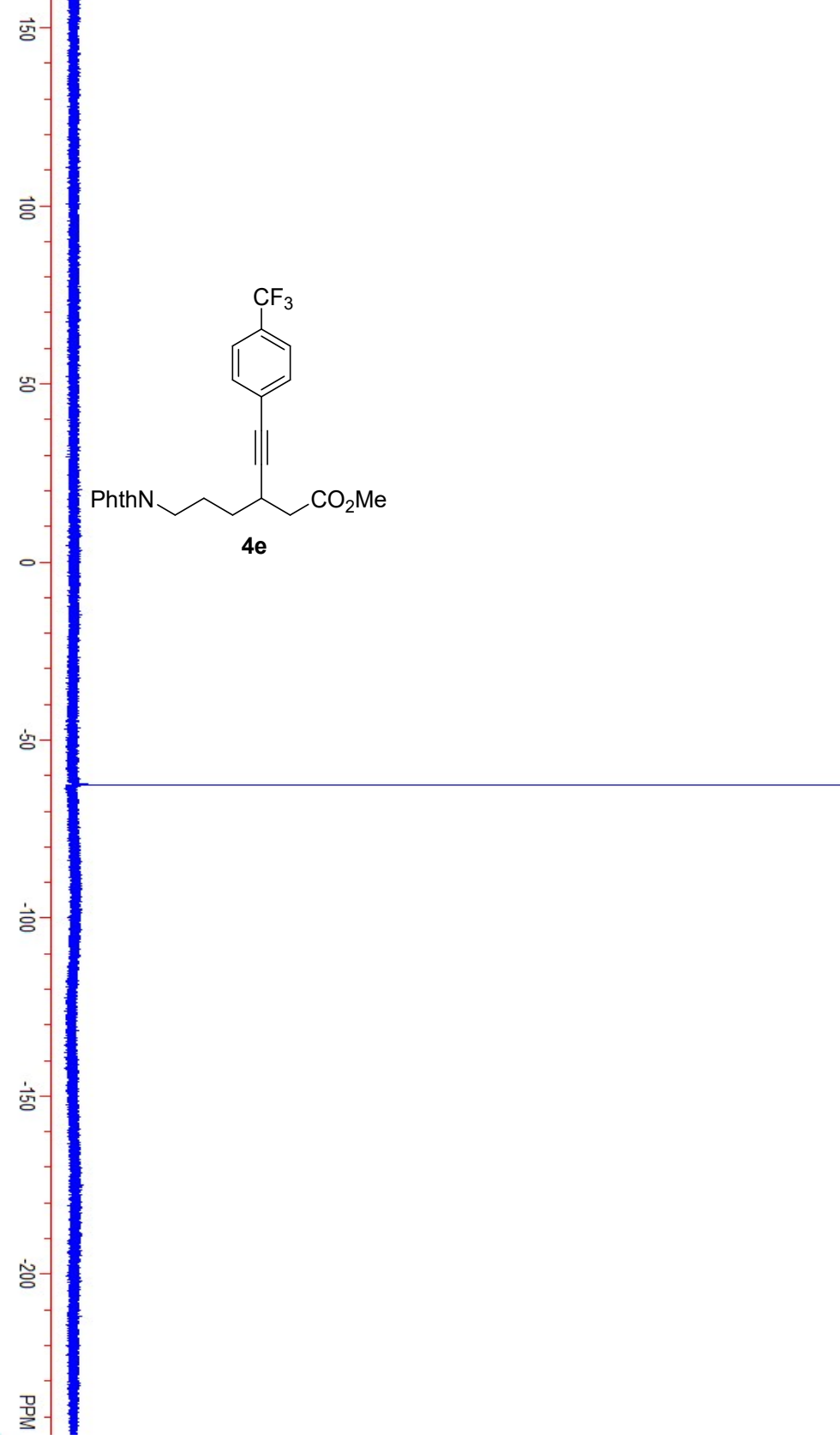
4c


NO2
PhthN
CO2Me
4d
8
6
4
2
0
PPM
2.00
2.12
2.34
1.91
5.62
1.04
1.03
2.27
1.14
1.78

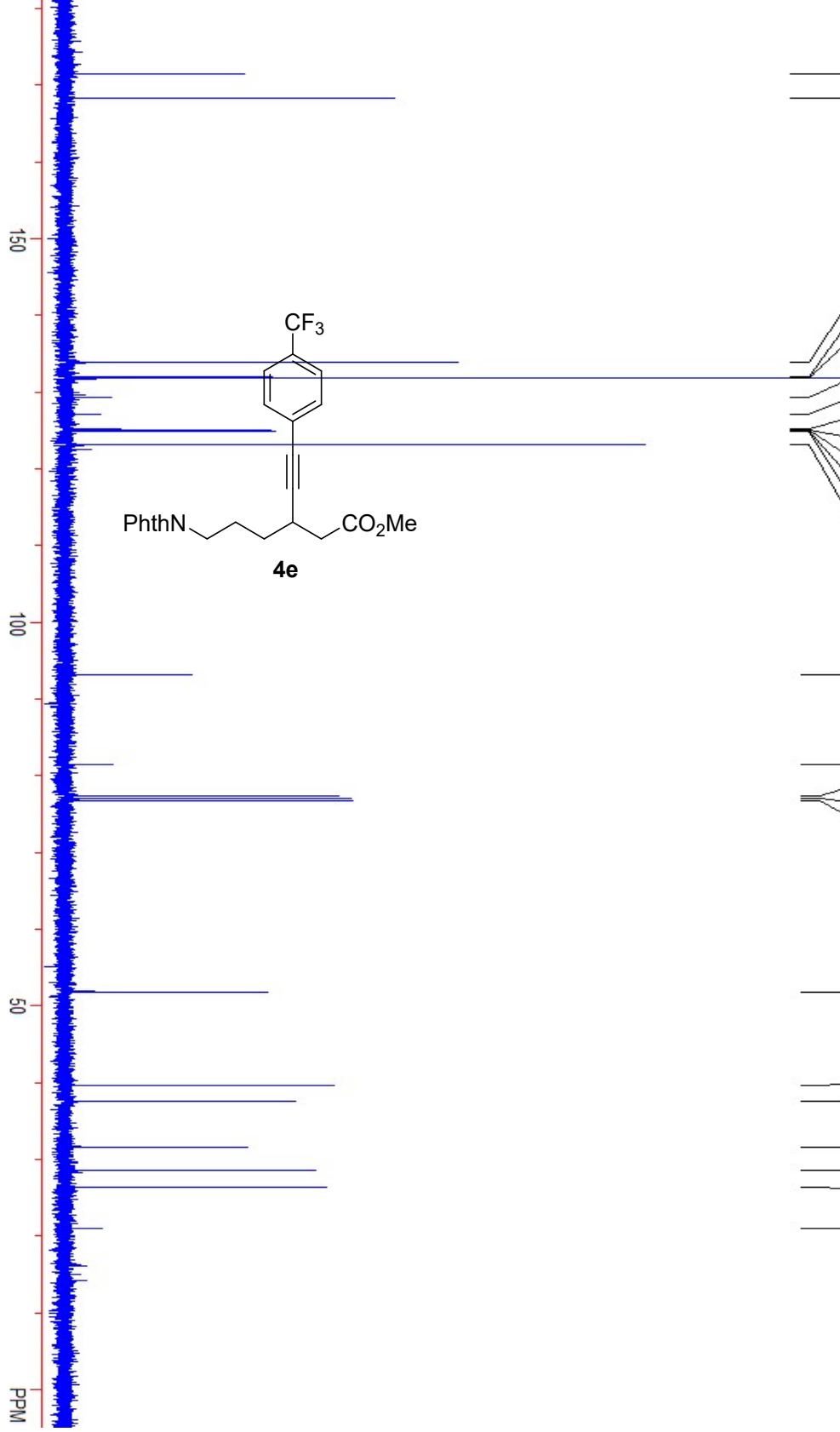


4d

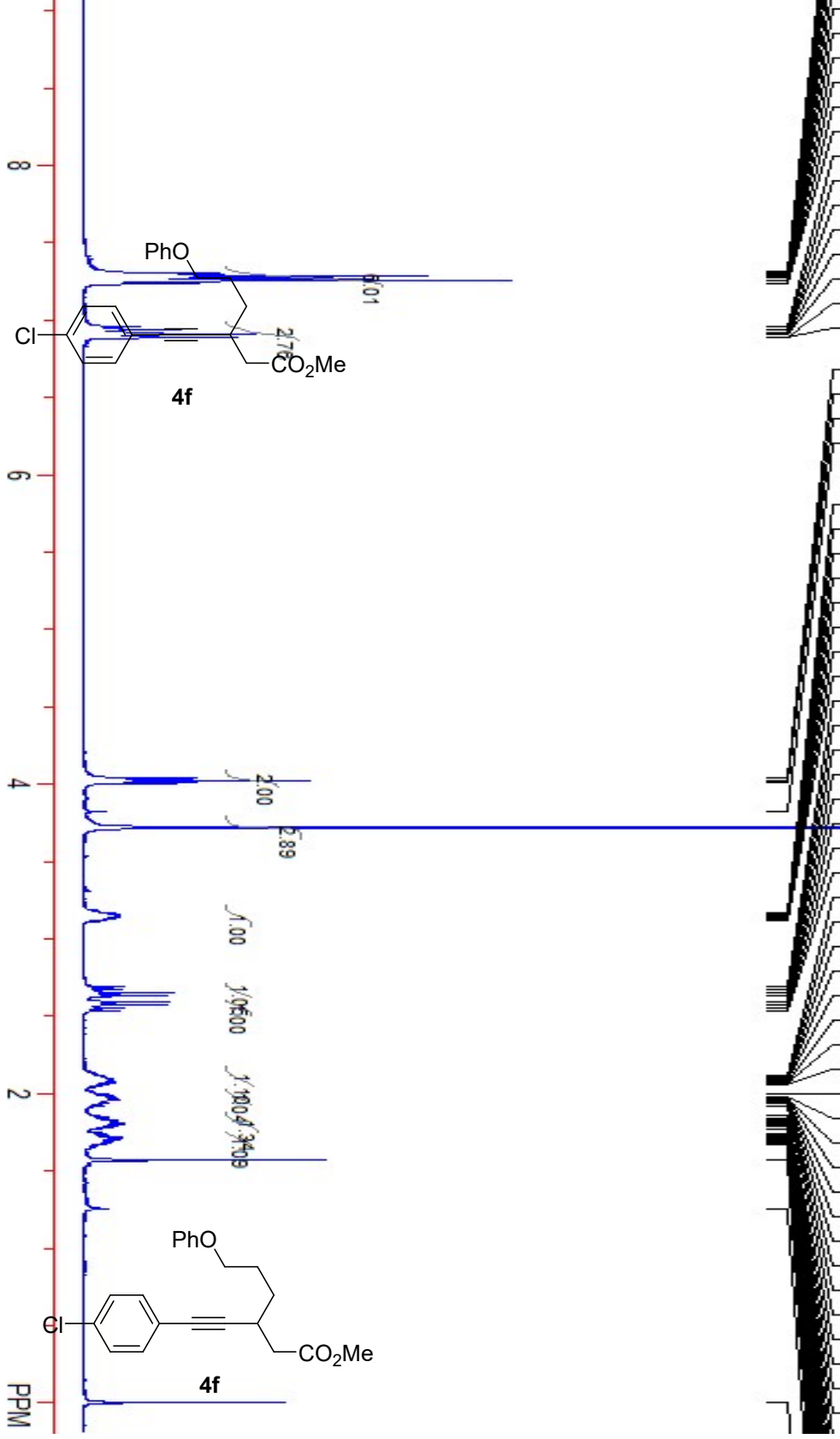

CF3
PhthN
CO2Me
4e
8
6
4
2
PPM
2.04
2.10
5.07
1.08
1.02
1.01
1.09
3.18

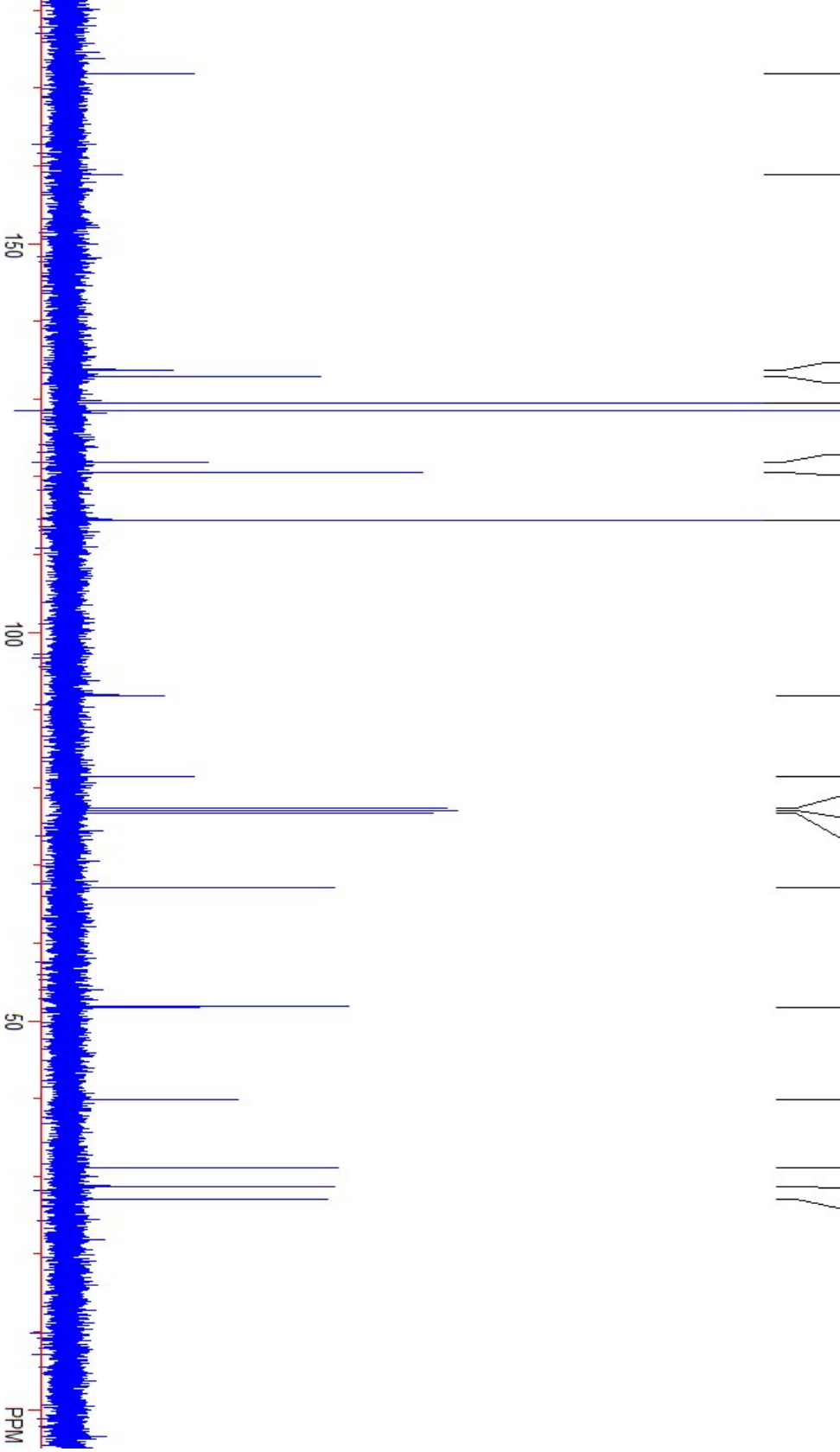


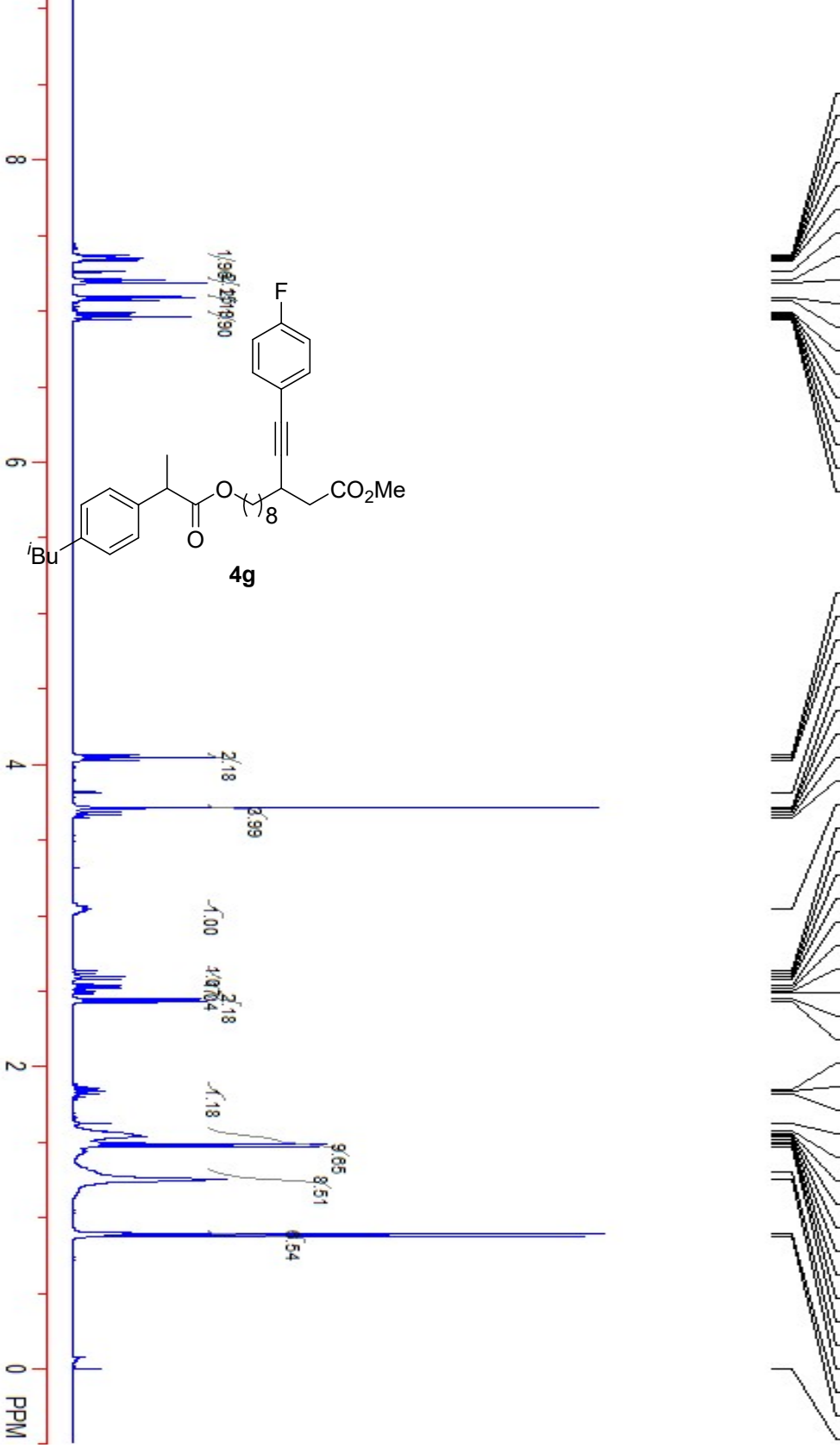
4e

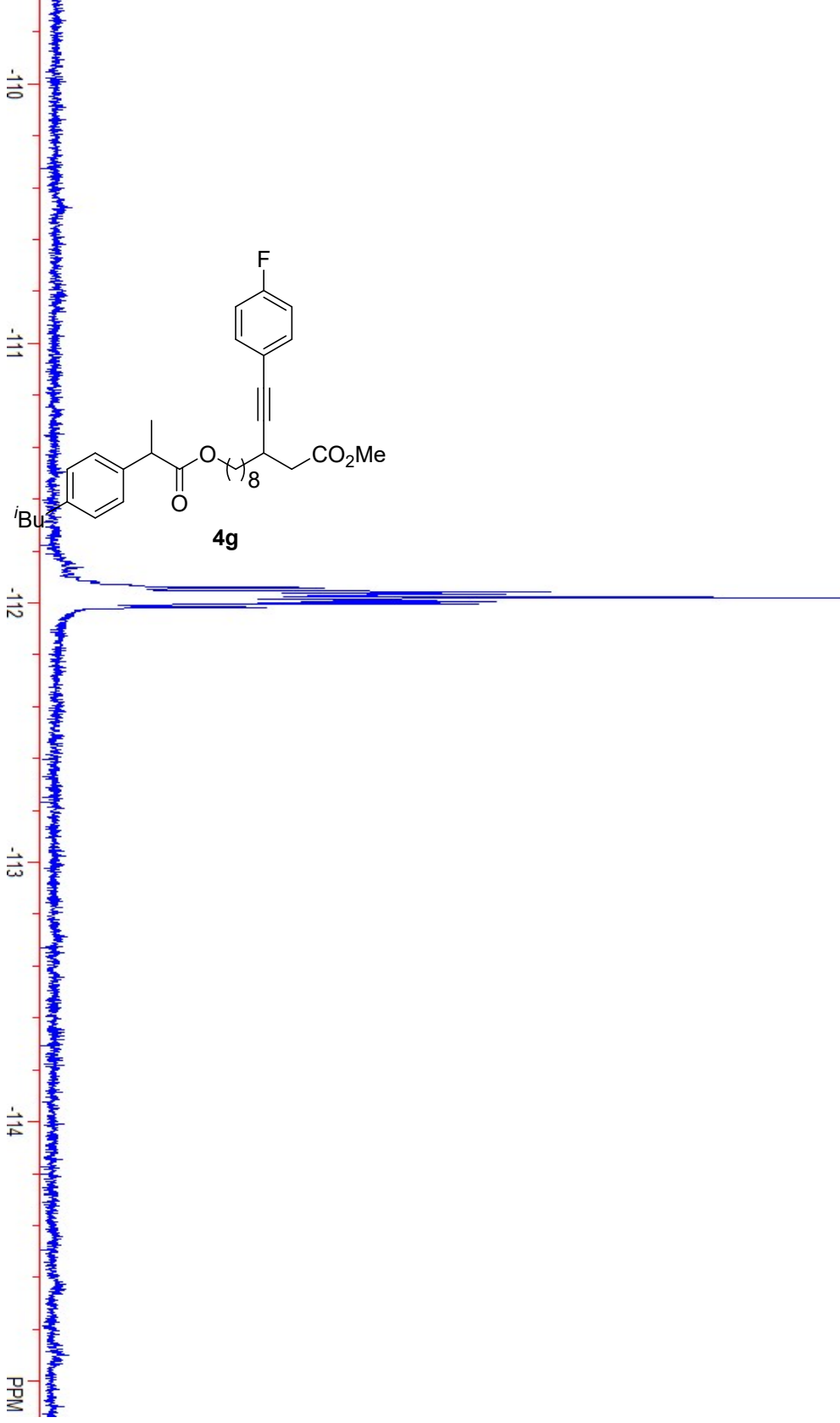


4e

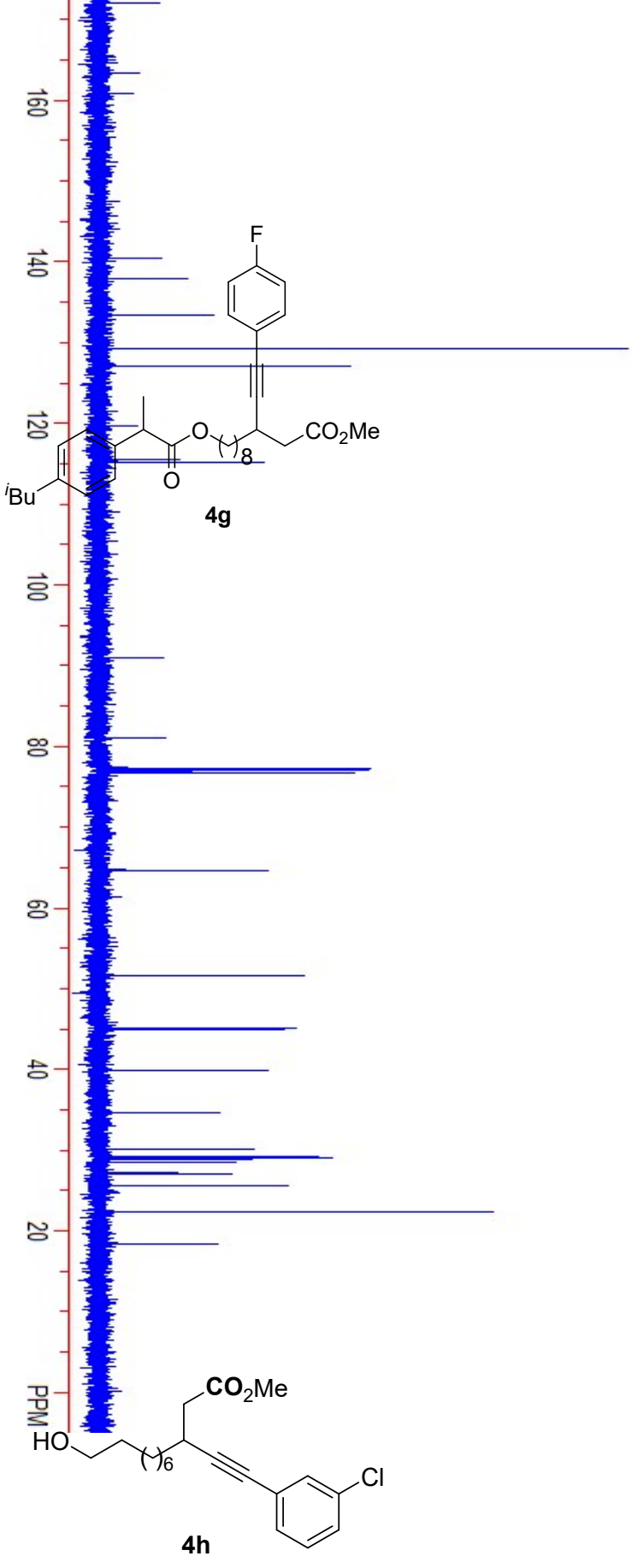

PhO
Cl
CO2Me
4f
8
6
4
2
PPM
2.00
2.89
1.00
PhO
Cl
CO2Me
4f

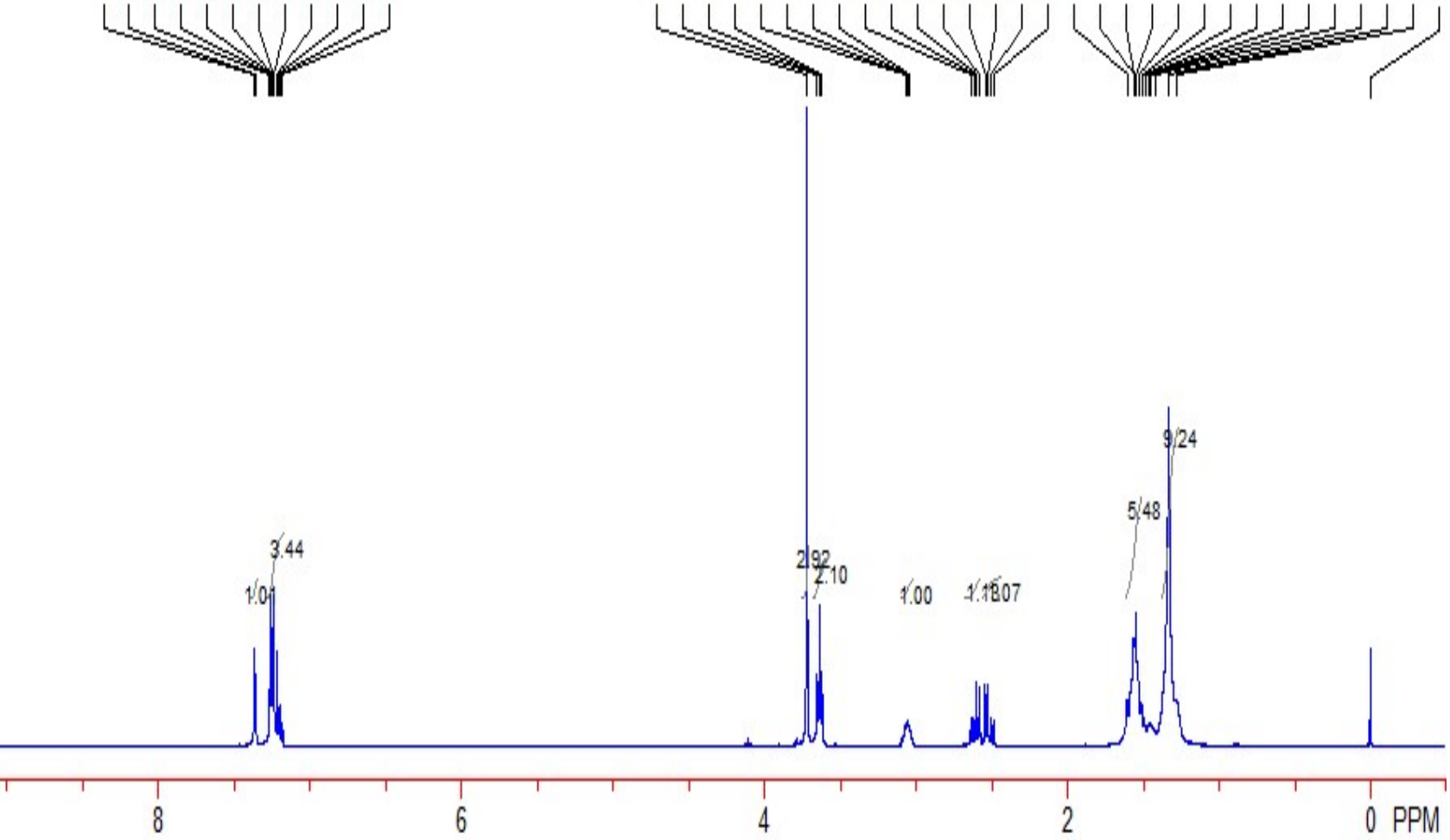

150
100
50
PPM

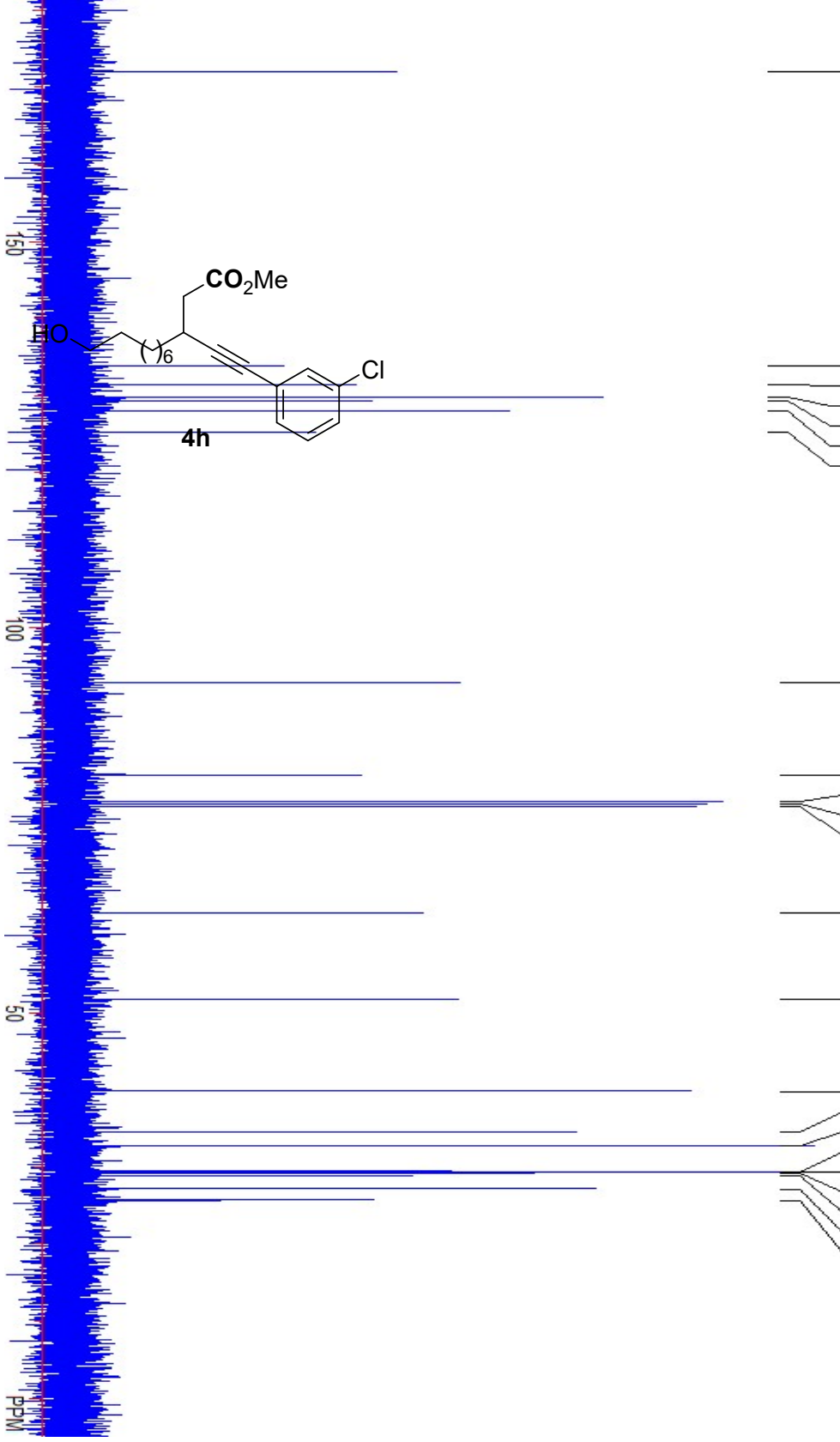

F
O
8
O
CO2Me
iBu
4g
PPM

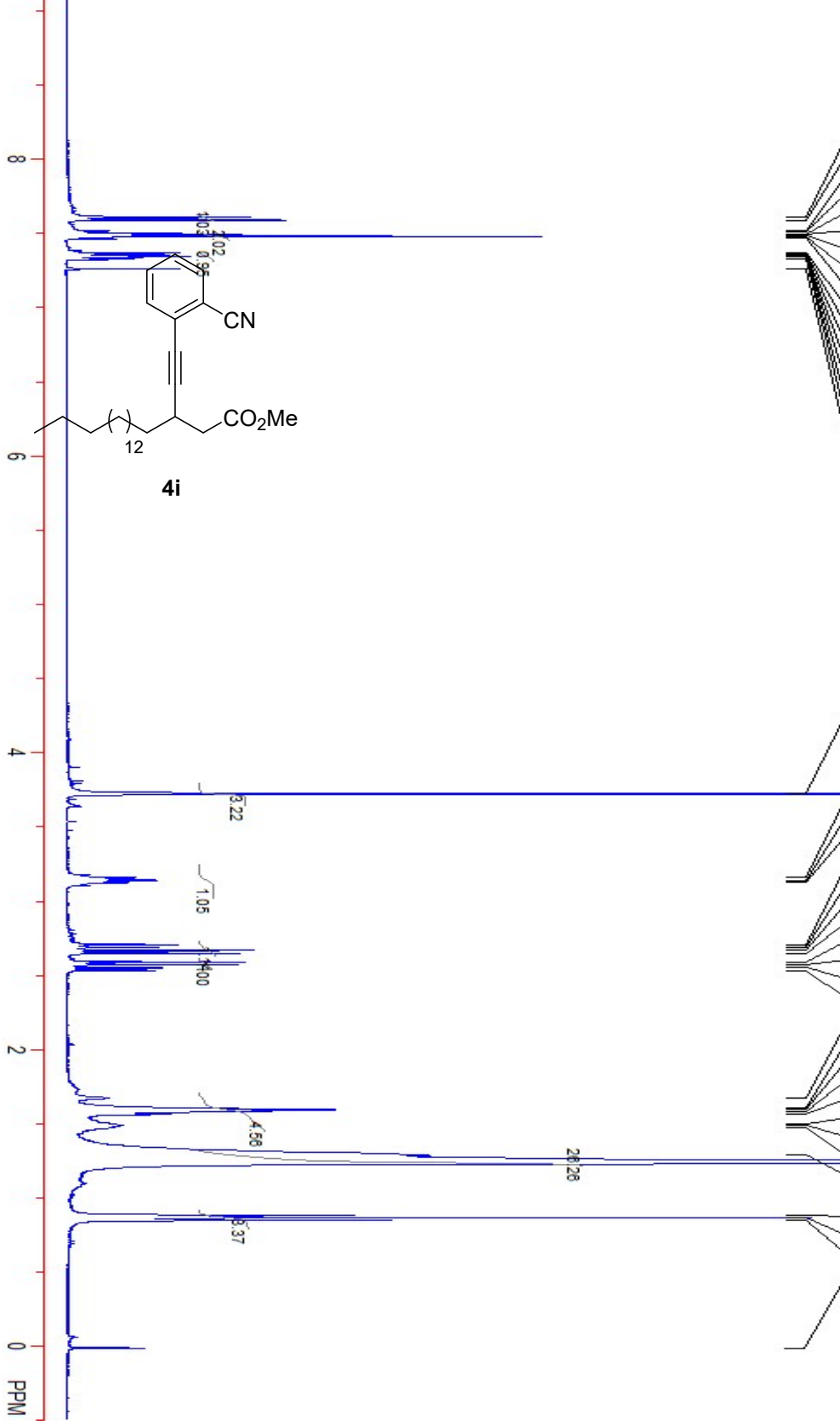


4g

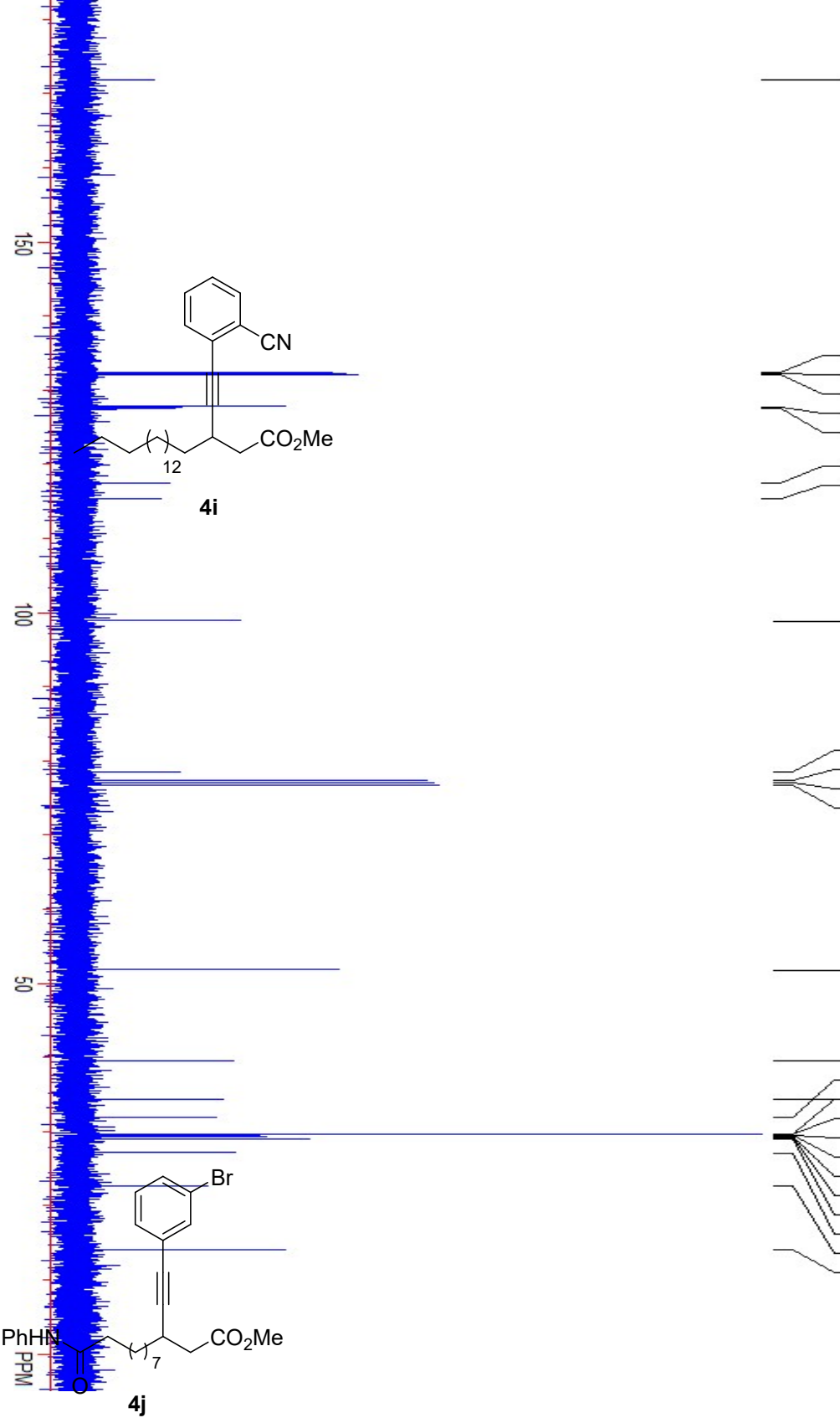

160
140
120
100
80
60
40
20
PPM
F
O
8
O
CO2Me
iBu
4g
CO2Me
HO
6
Cl
4h


3.44
1.01
2.92
2.10
1.00
1.18
1.07
5.48
9.24
8
6
4
2
0 PPM


150
100
50
PPM
CO2Me
HO
6
Cl
4h

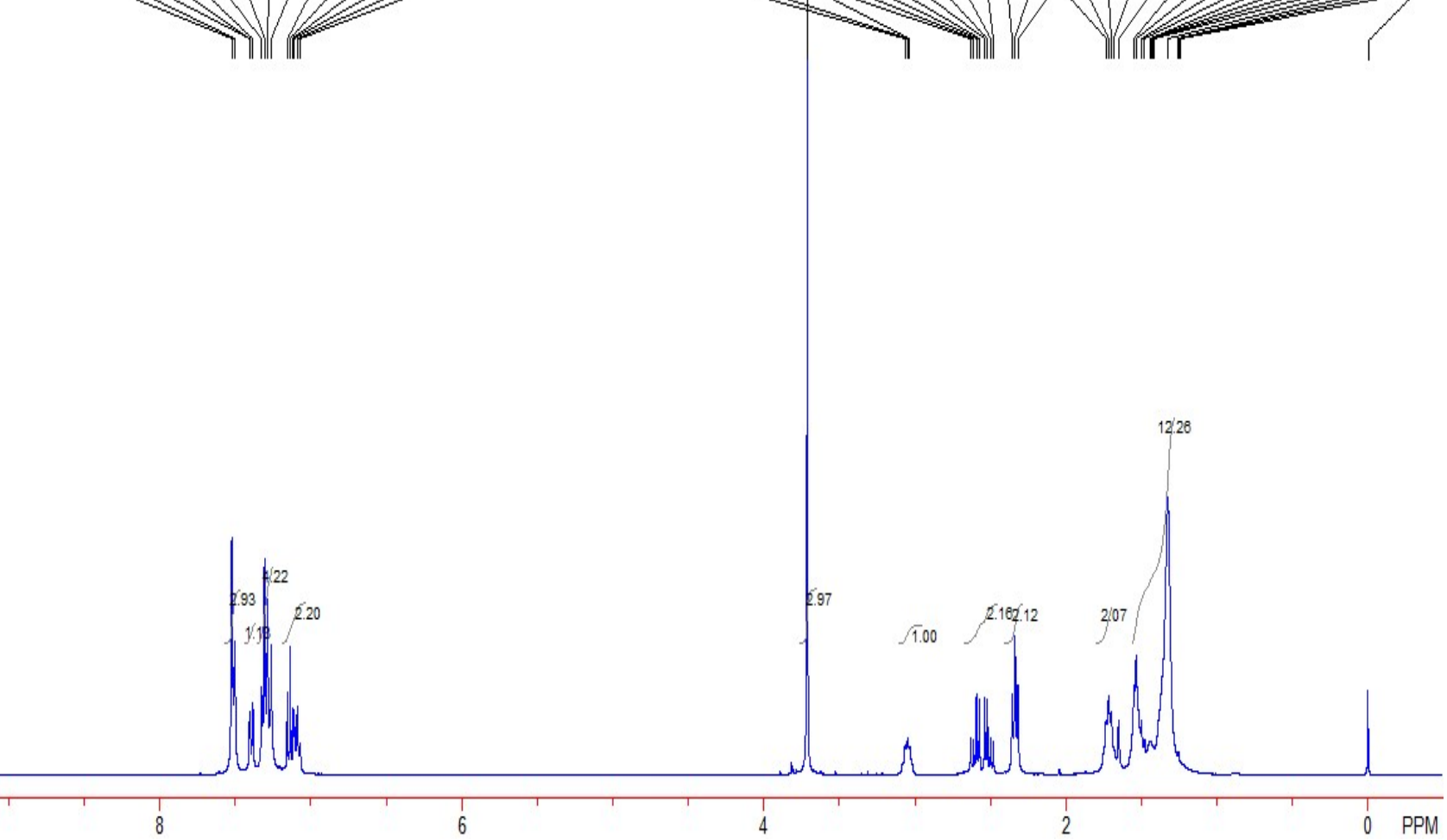


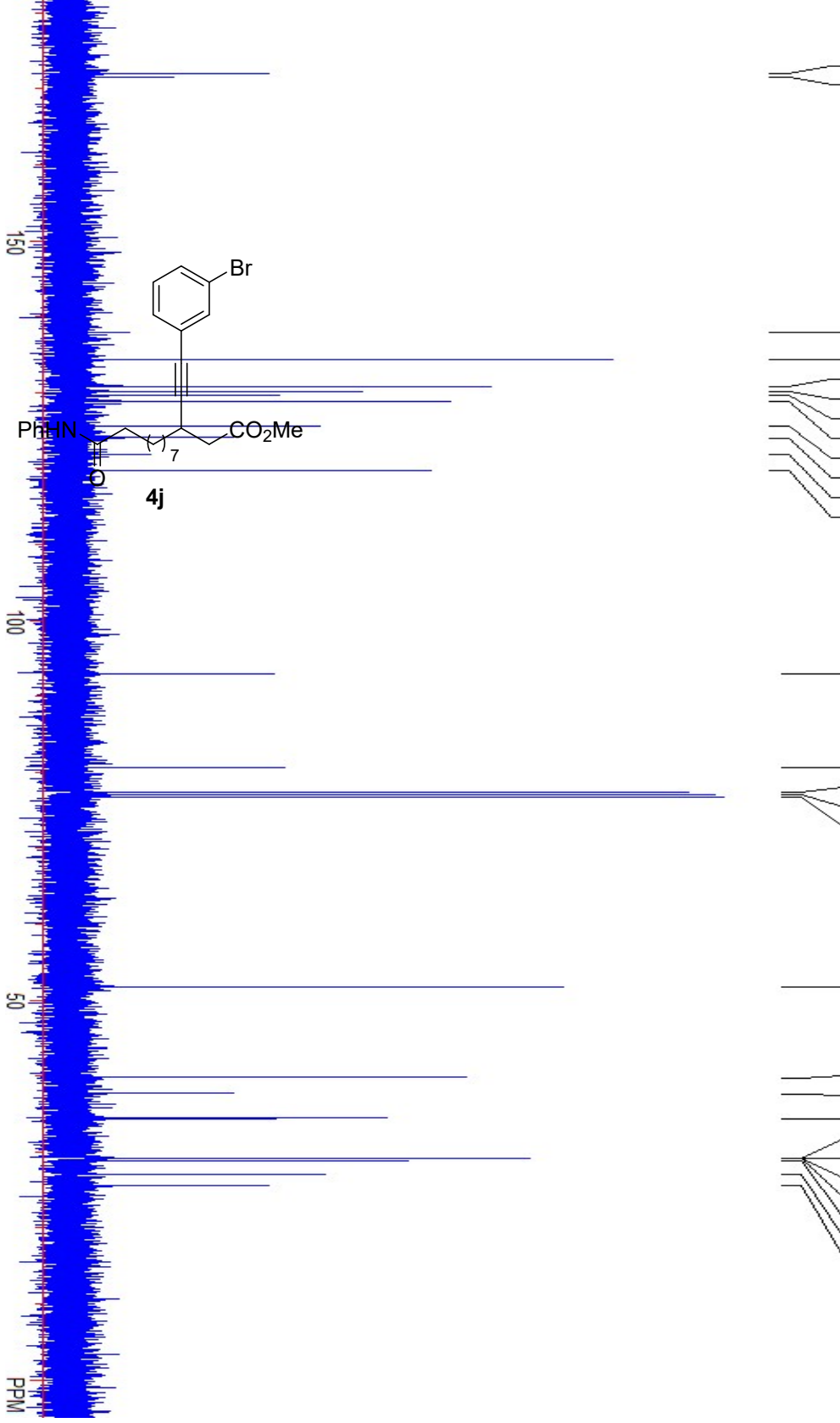
4i



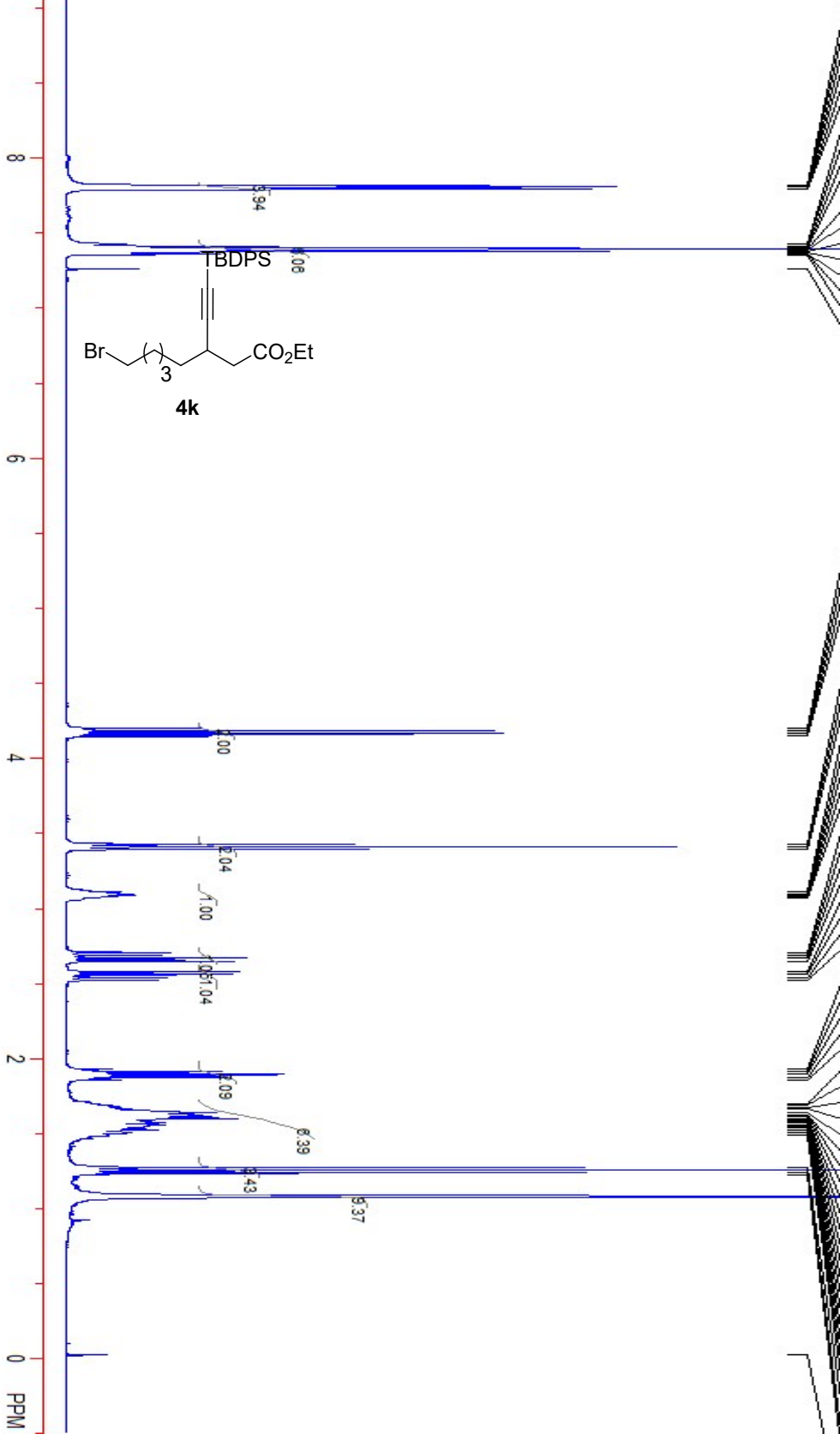
4i

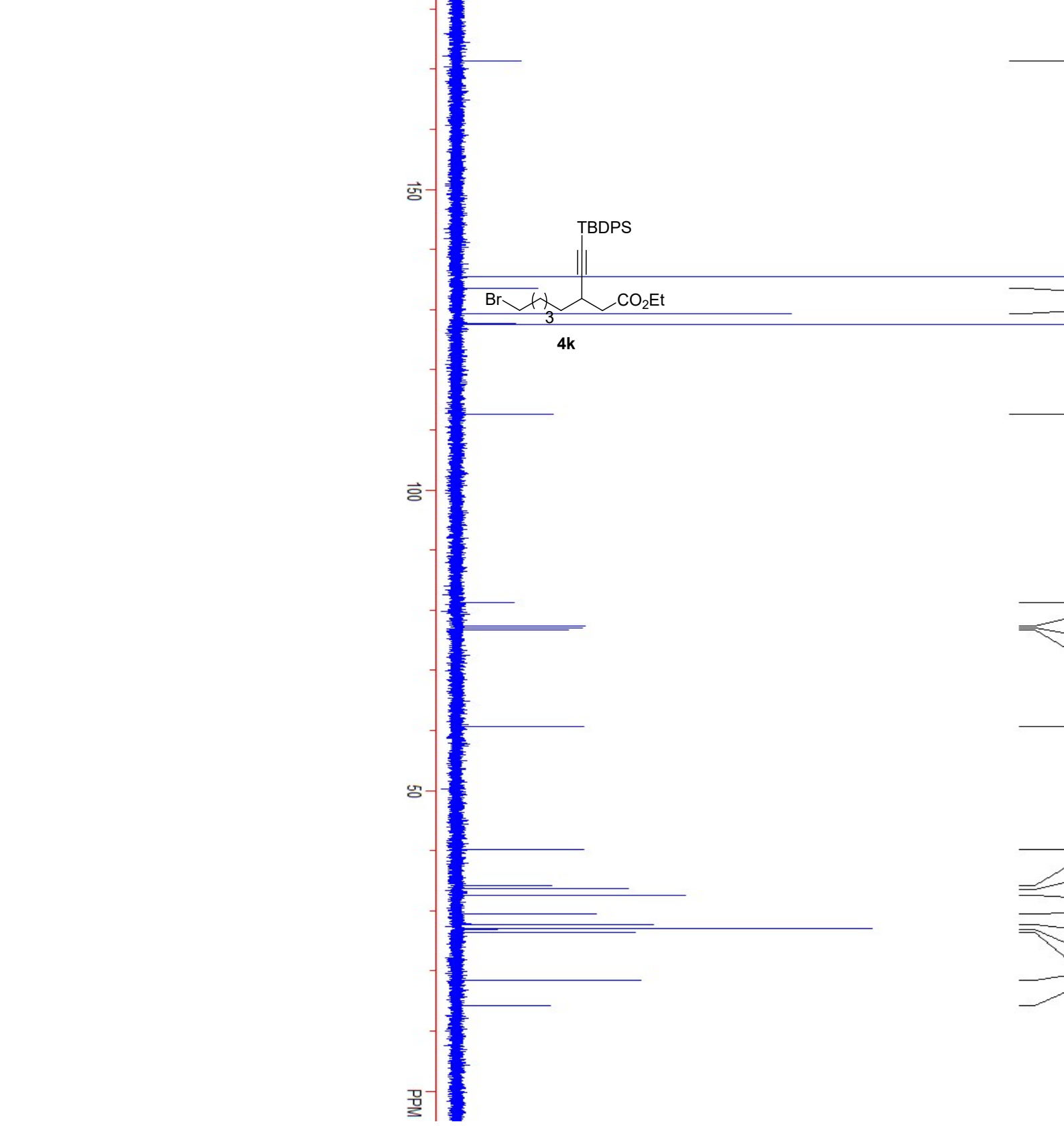
4j

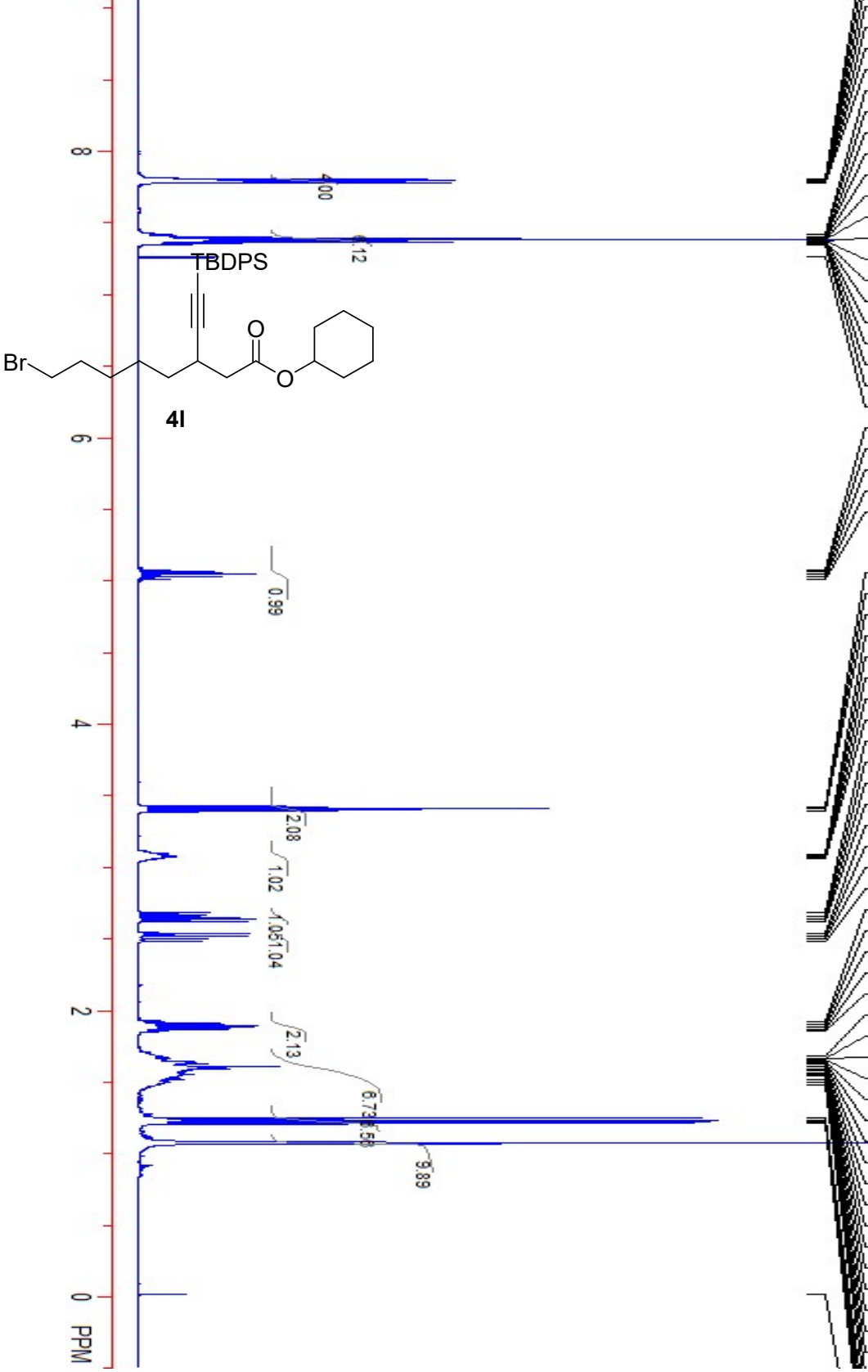

12.26
4.22
2.93
2.20
2.97
1.00
2.16
2.12
2.07
8
6
4
2
0
PPM

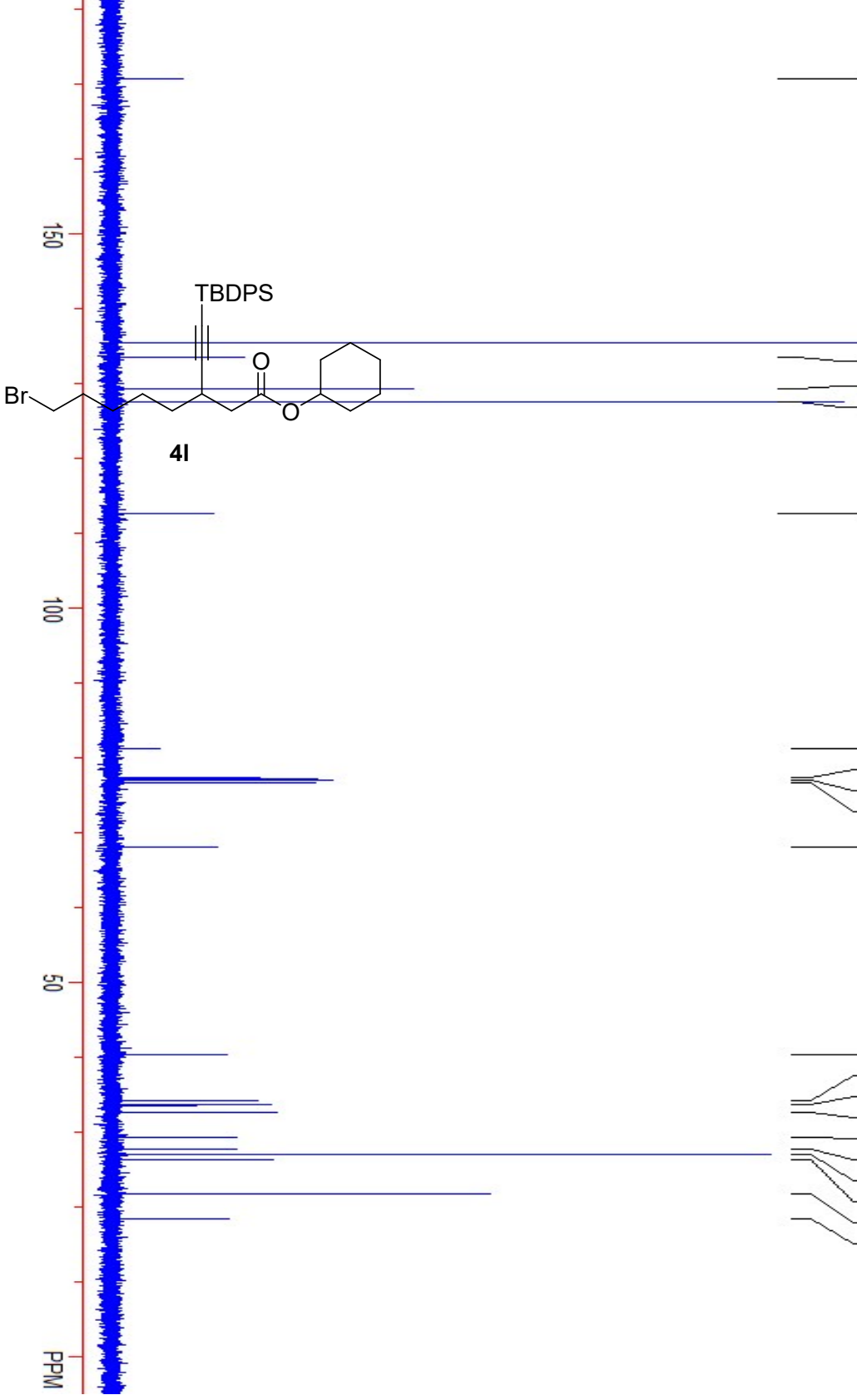


4j

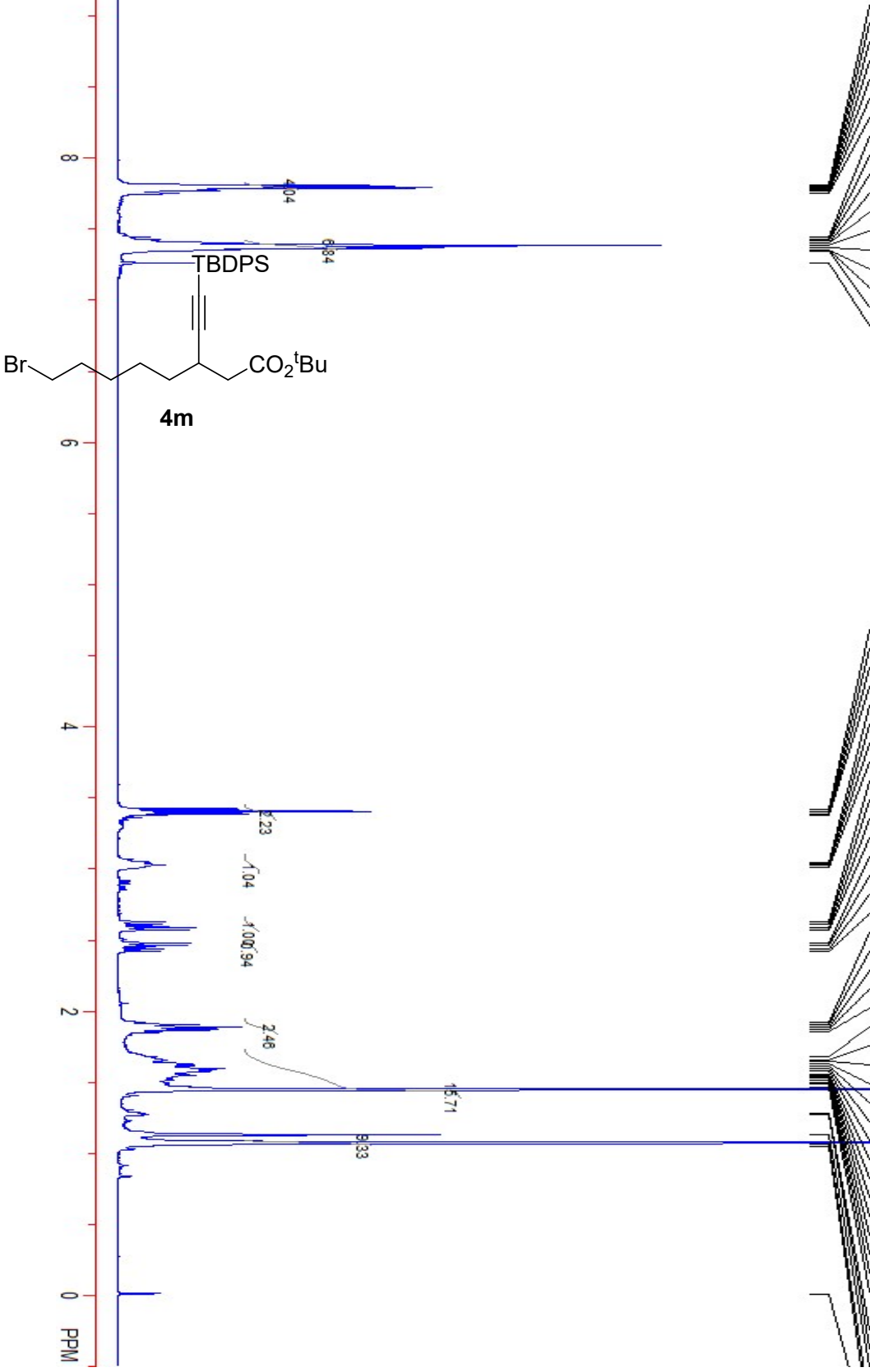

TBDPS
Br
3
CO2Et
4k
8
6
4
2
0
PPM
8.94
8.06
2.00
2.04
1.00
1.04
2.09
8.39
8.43
9.37

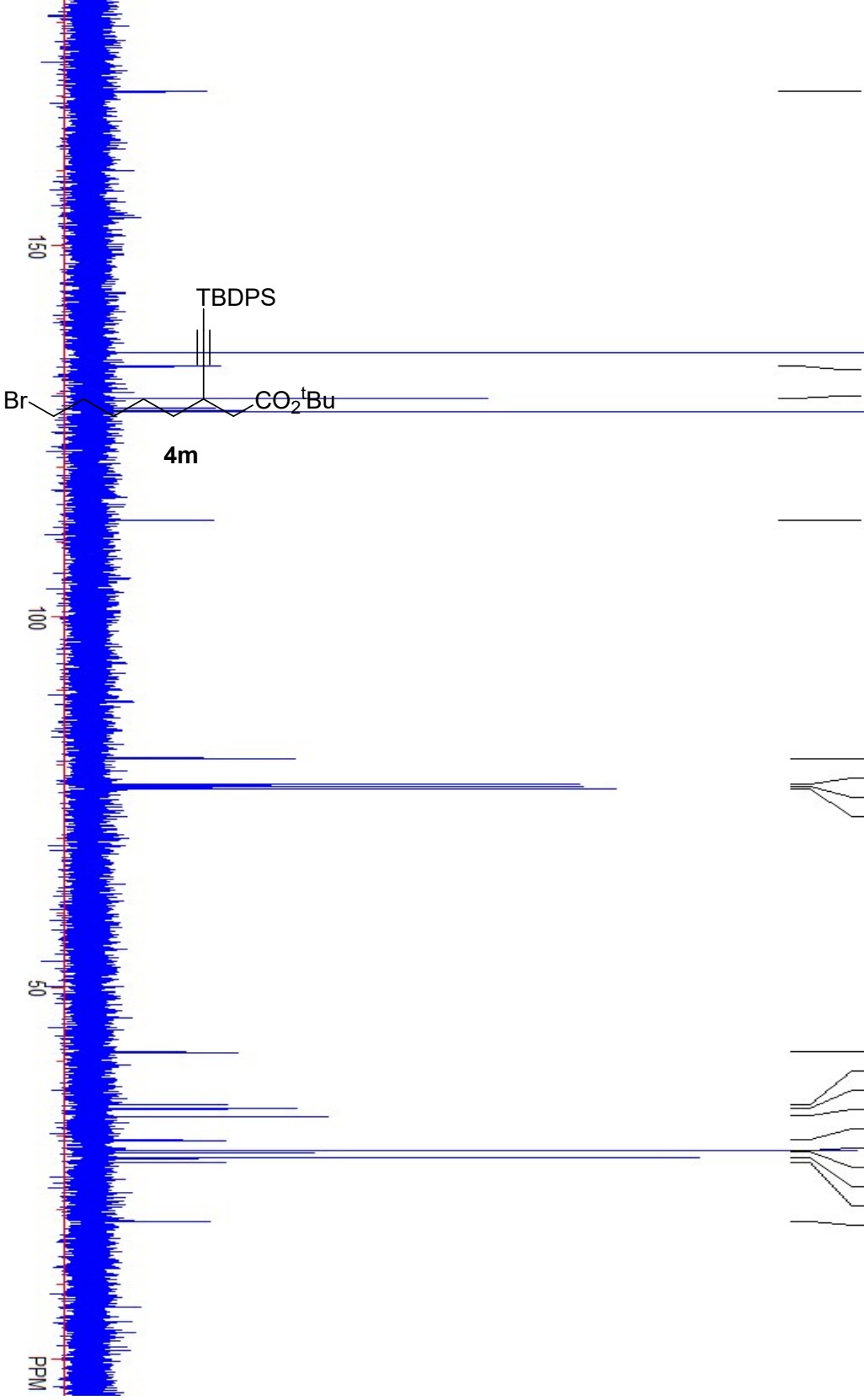

150
100
50
PPM
TBDPS
Br
3
CO2Et
4k


TBDPS
Br
O
O
4l
8
6
4
2
0
PPM
4.00
2.12
0.99
2.08
1.02
1.05
1.04
2.13
6.73
5.58
9.89

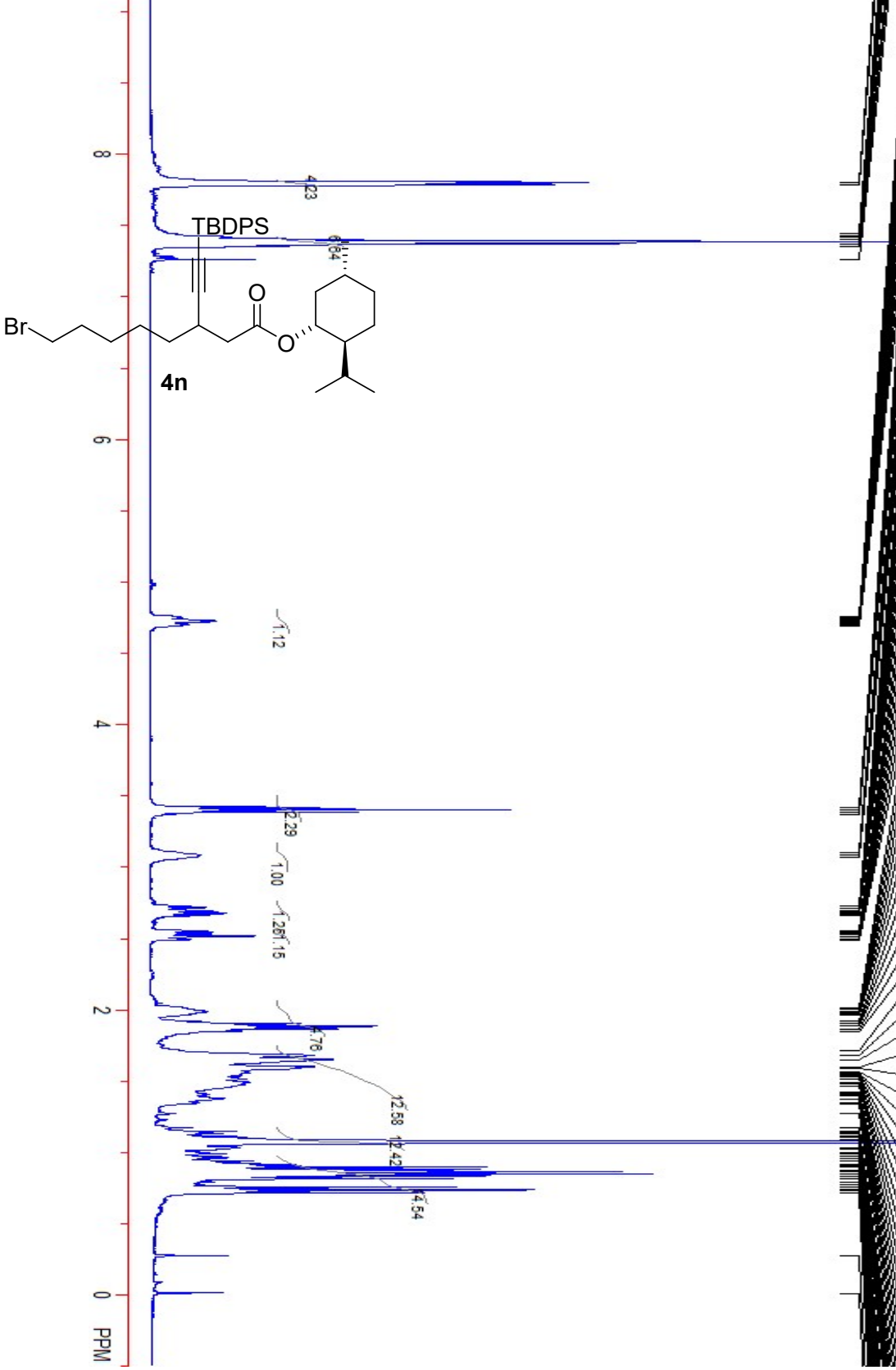


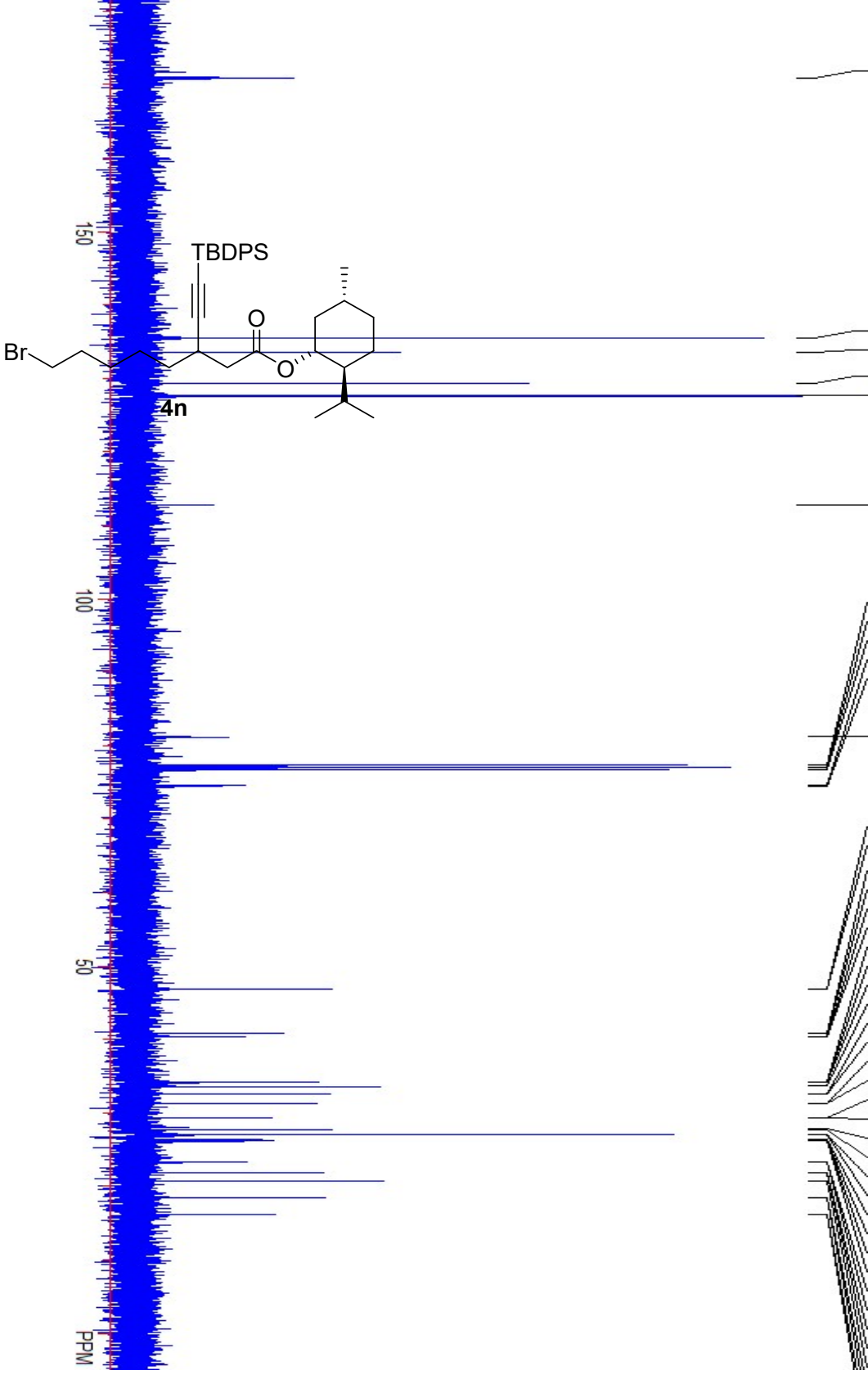
4l

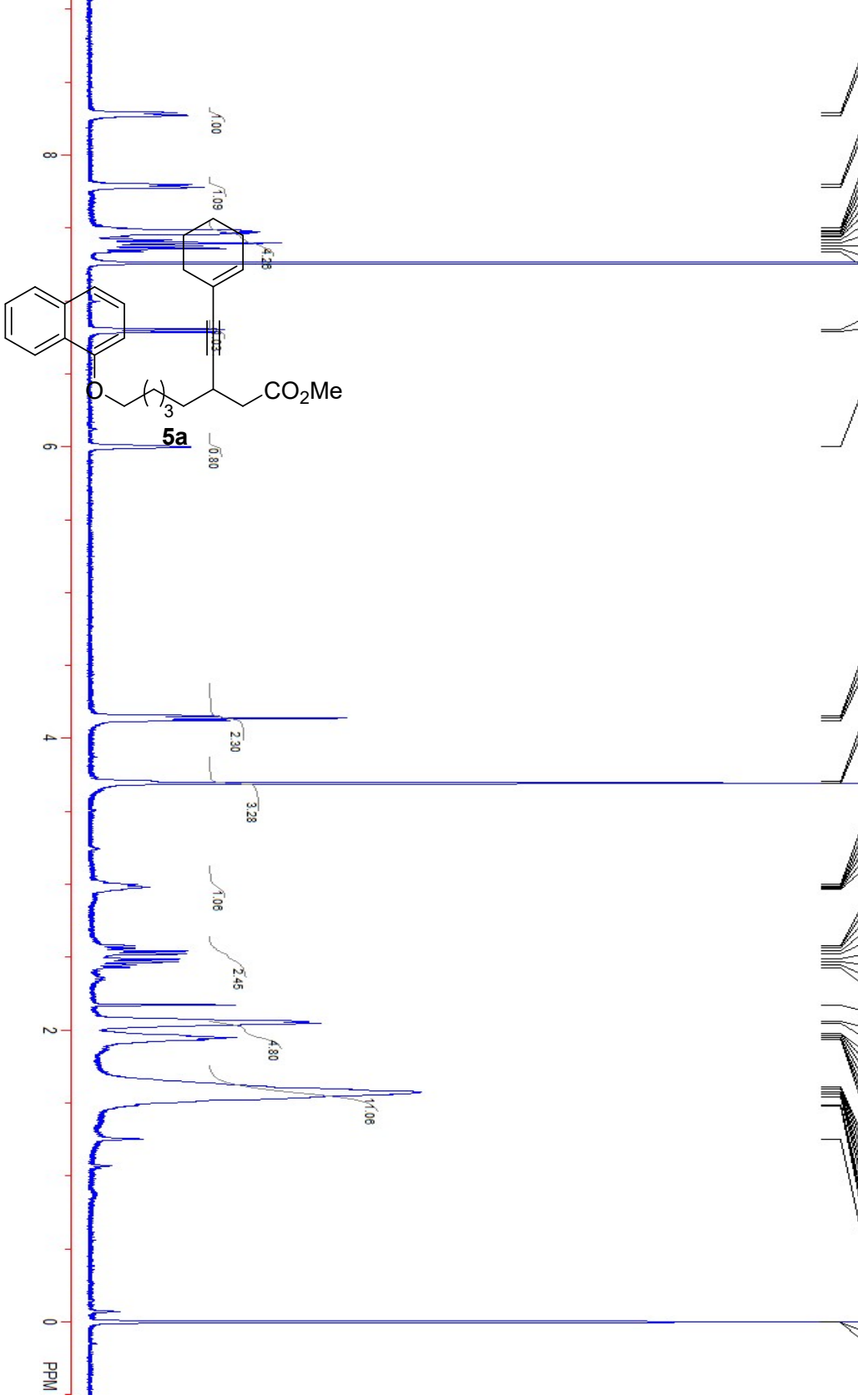

TBDPS
Br
$CO_2{}^tBu$
4m
4.04
6.84
2.23
1.04
1.00
0.94
2.48
15.71
9.33
8
6
4
2
0
PPM

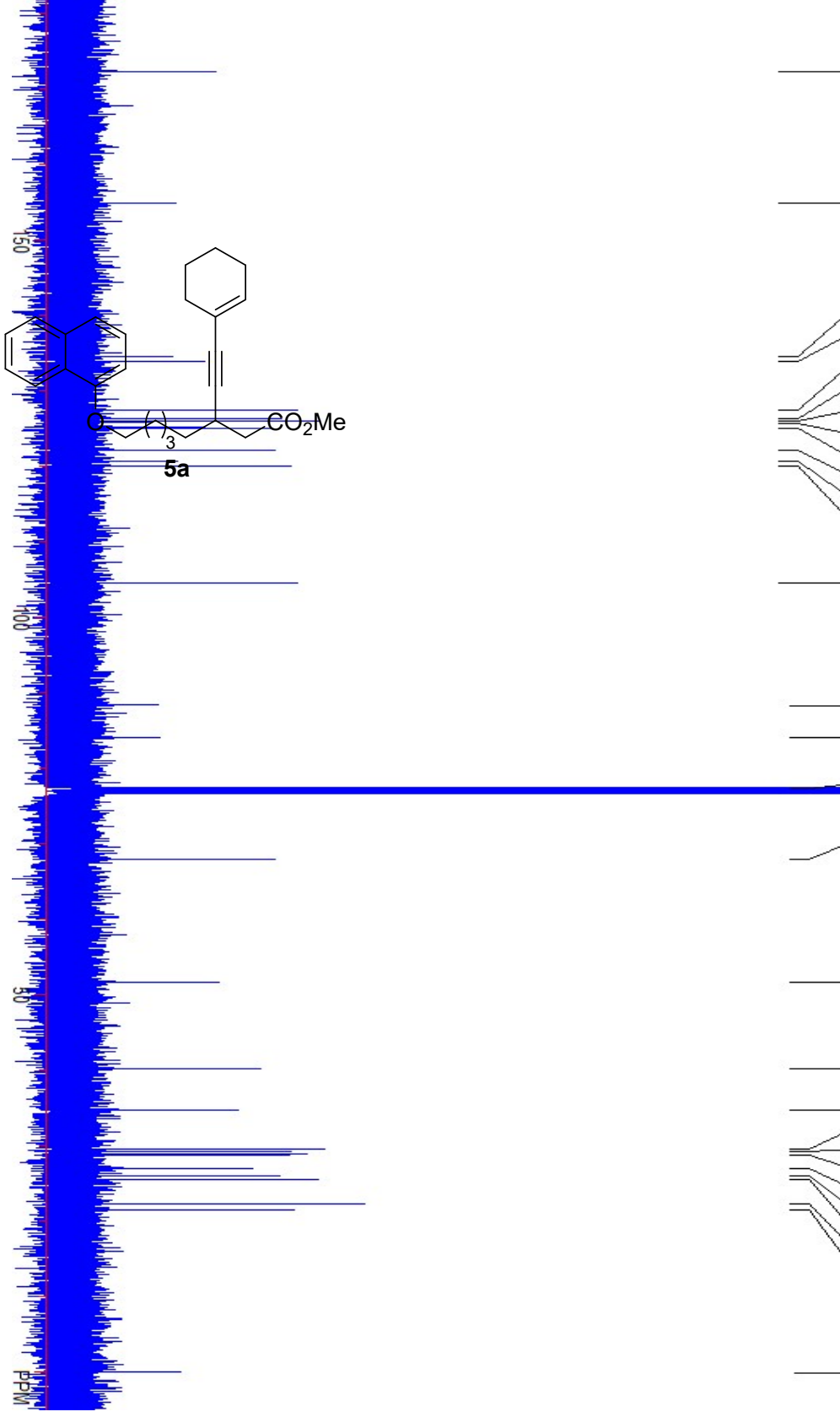


4m

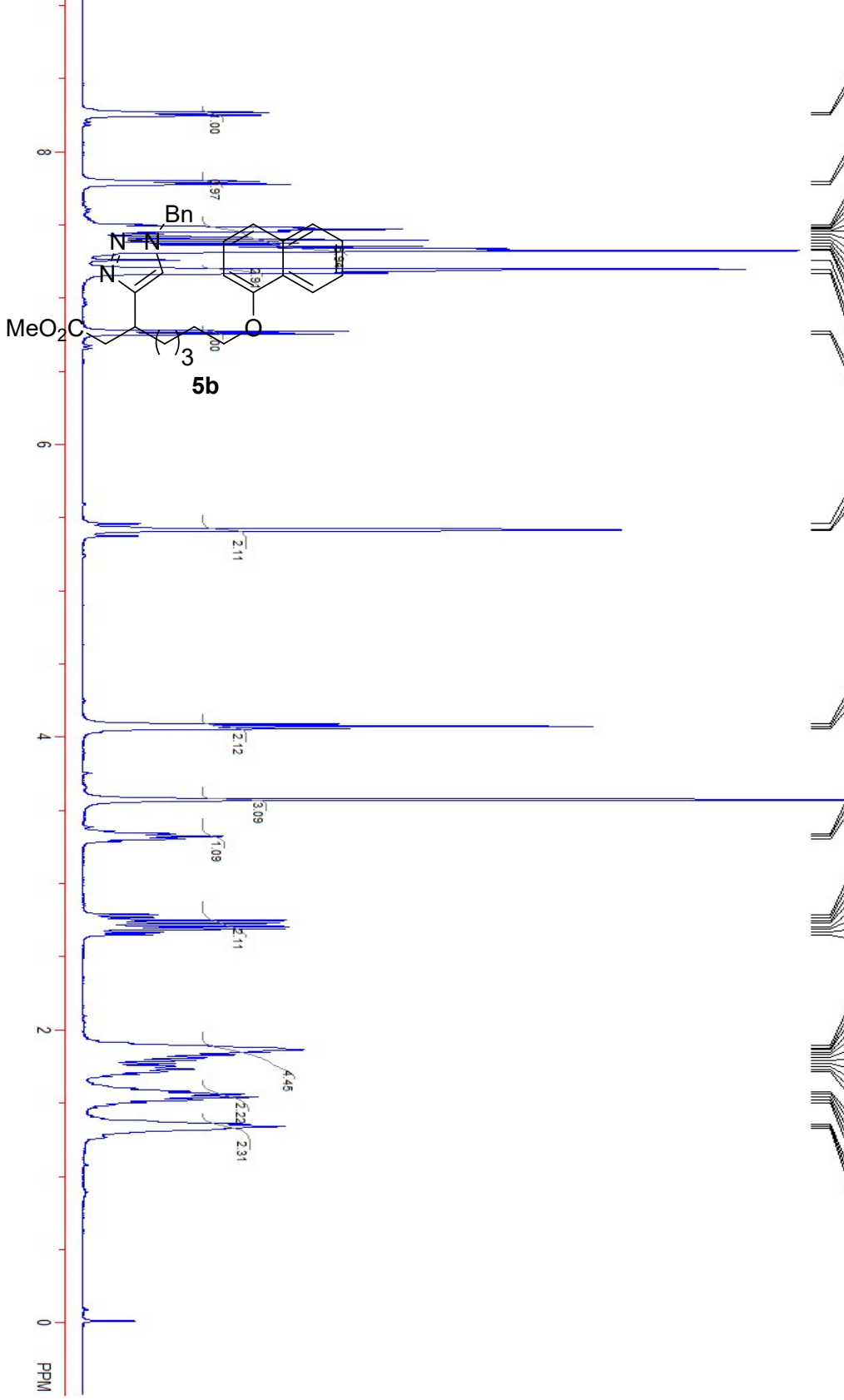

TBDPS
Br
O
O
4n
8
6
4
2
0
PPM
4.23
6.64
1.12
2.29
1.00
1.26
1.15
4.78
12.58
12.42
4.54

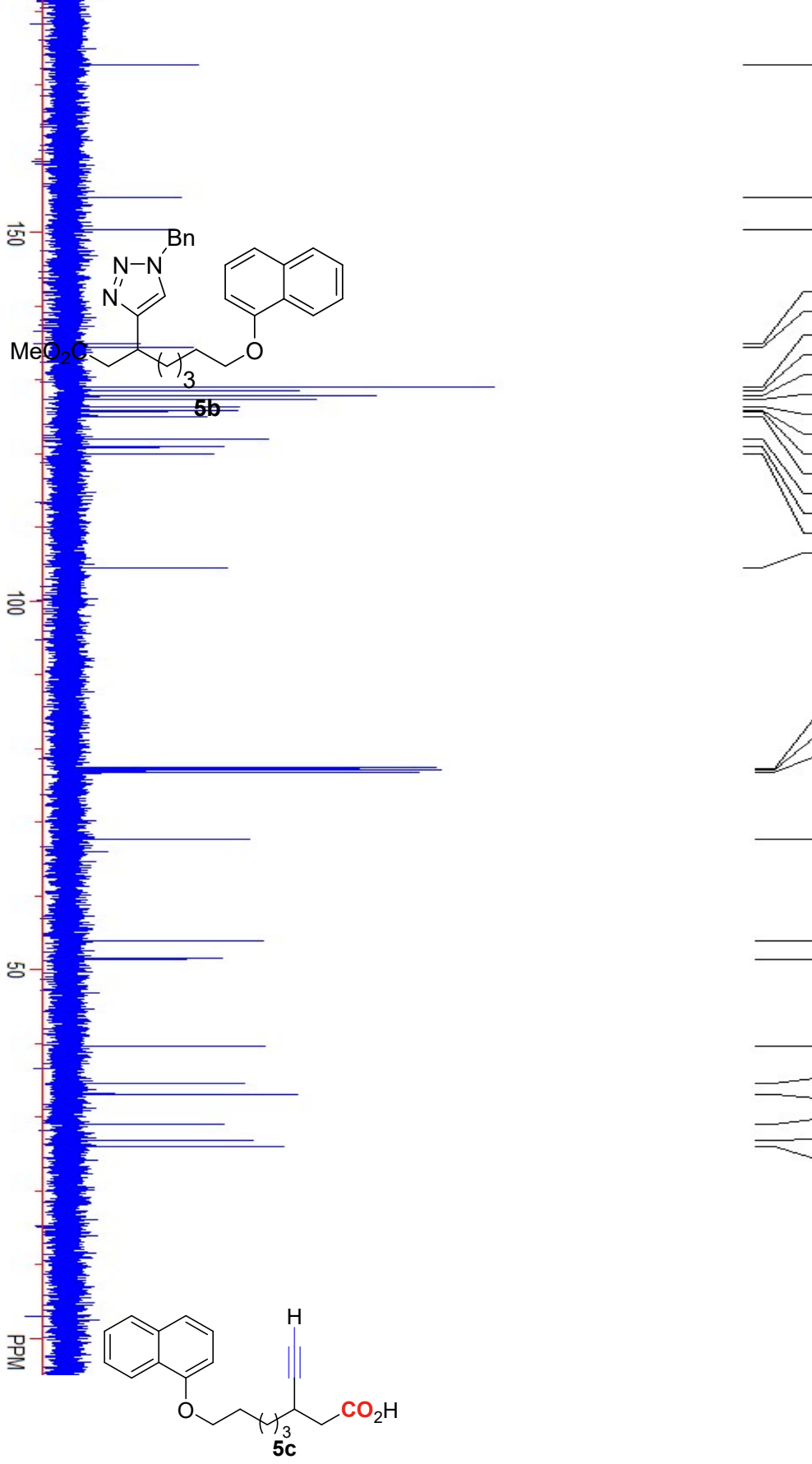

TBDPS
O
Br
O
4n
150
100
50
PPM

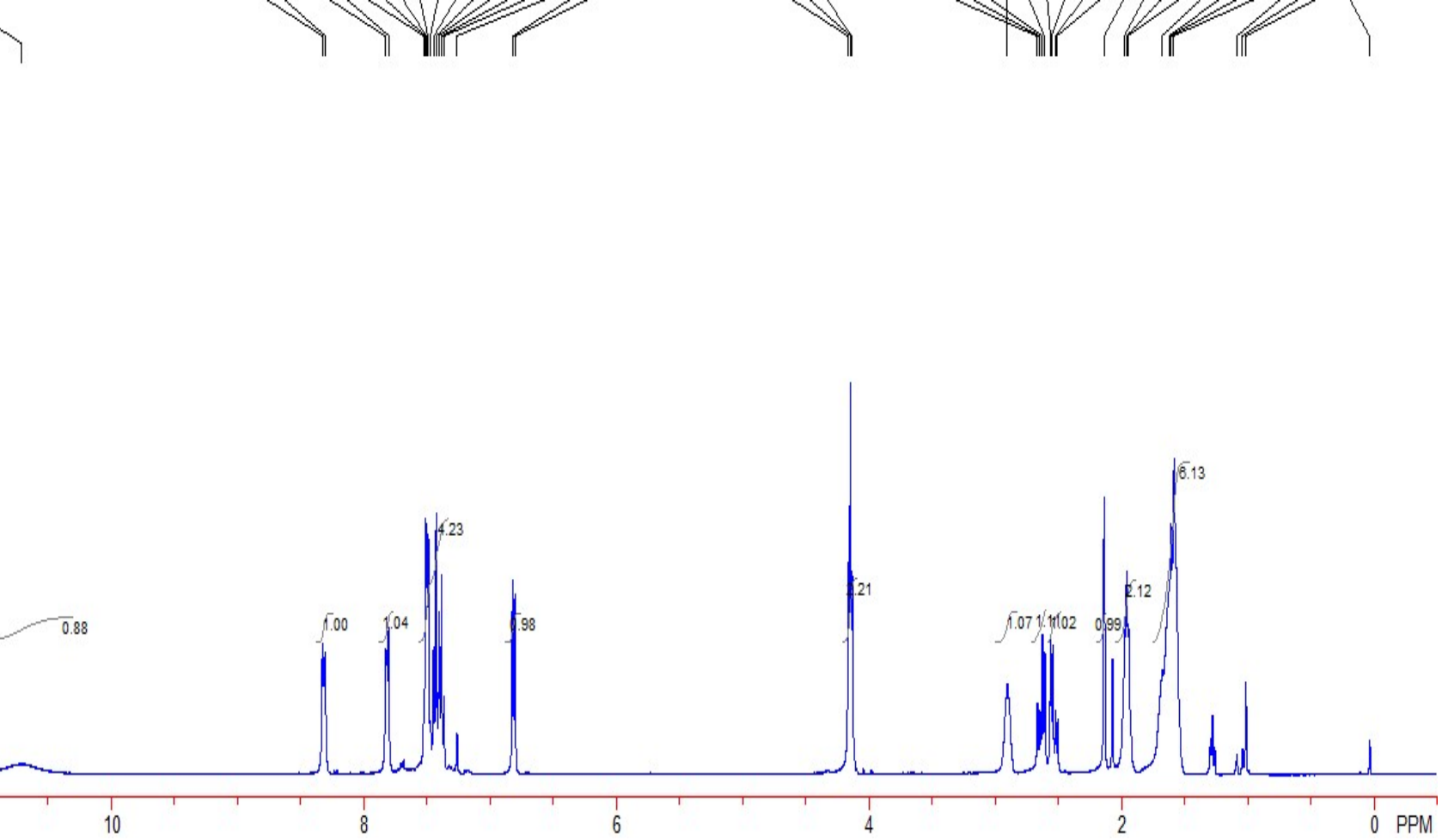

1.00
1.09
4.28
2.03
O
3
CO2Me
5a
0.80
2.30
3.28
1.06
2.45
4.80
11.08
8
6
4
2
0
PPM

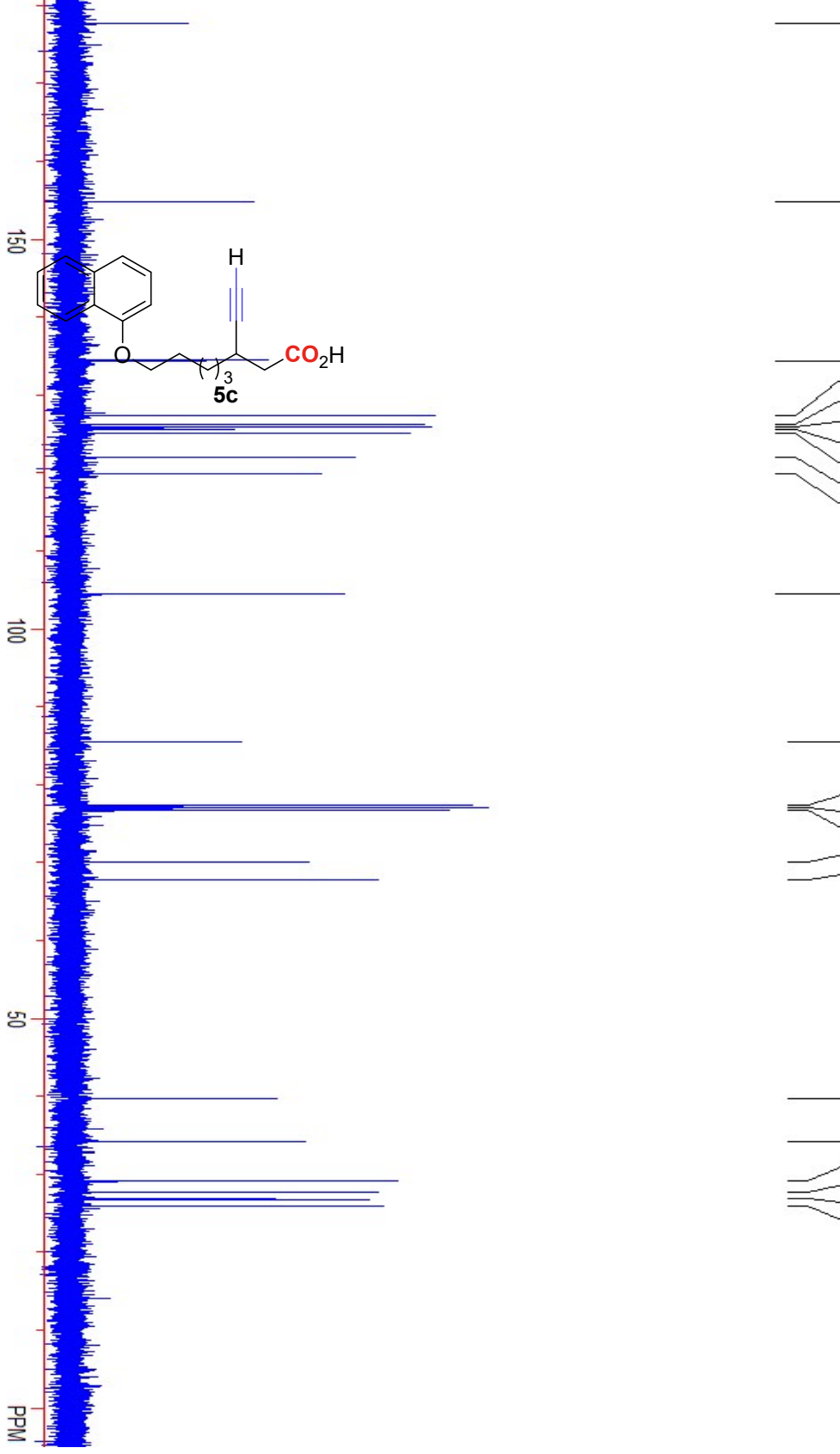


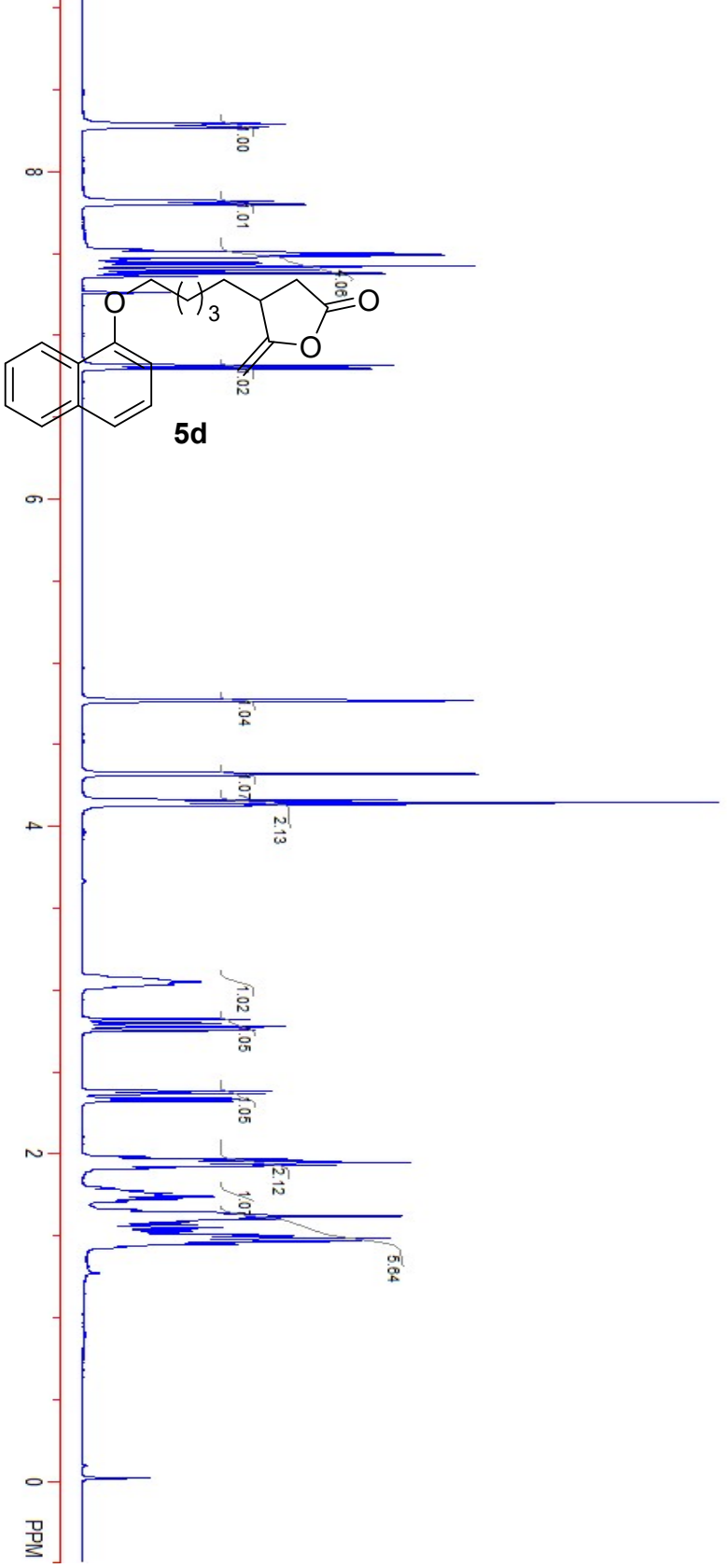
5a


Bn
N
N
N
MeO2C
O
3
5b
8
6
4
2
0
PPM
1.00
0.97
1.51
0.98
1.00
2.11
2.12
3.09
1.09
2.11
4.45
2.22
2.31

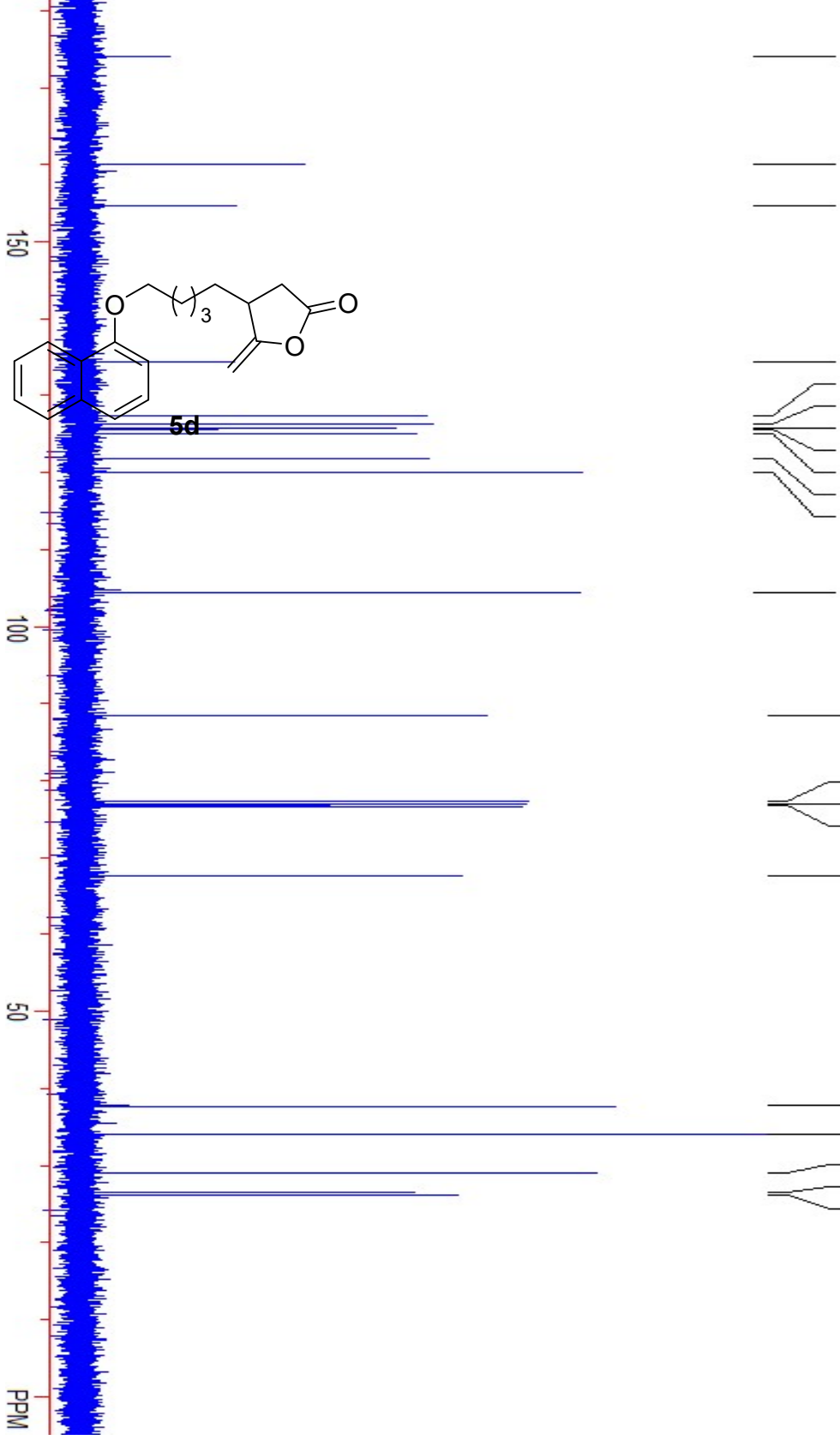

150
100
50
PPM
Bn
N–N
N
MeO2C
O
3
5b
H
O
CO2H
3
5c

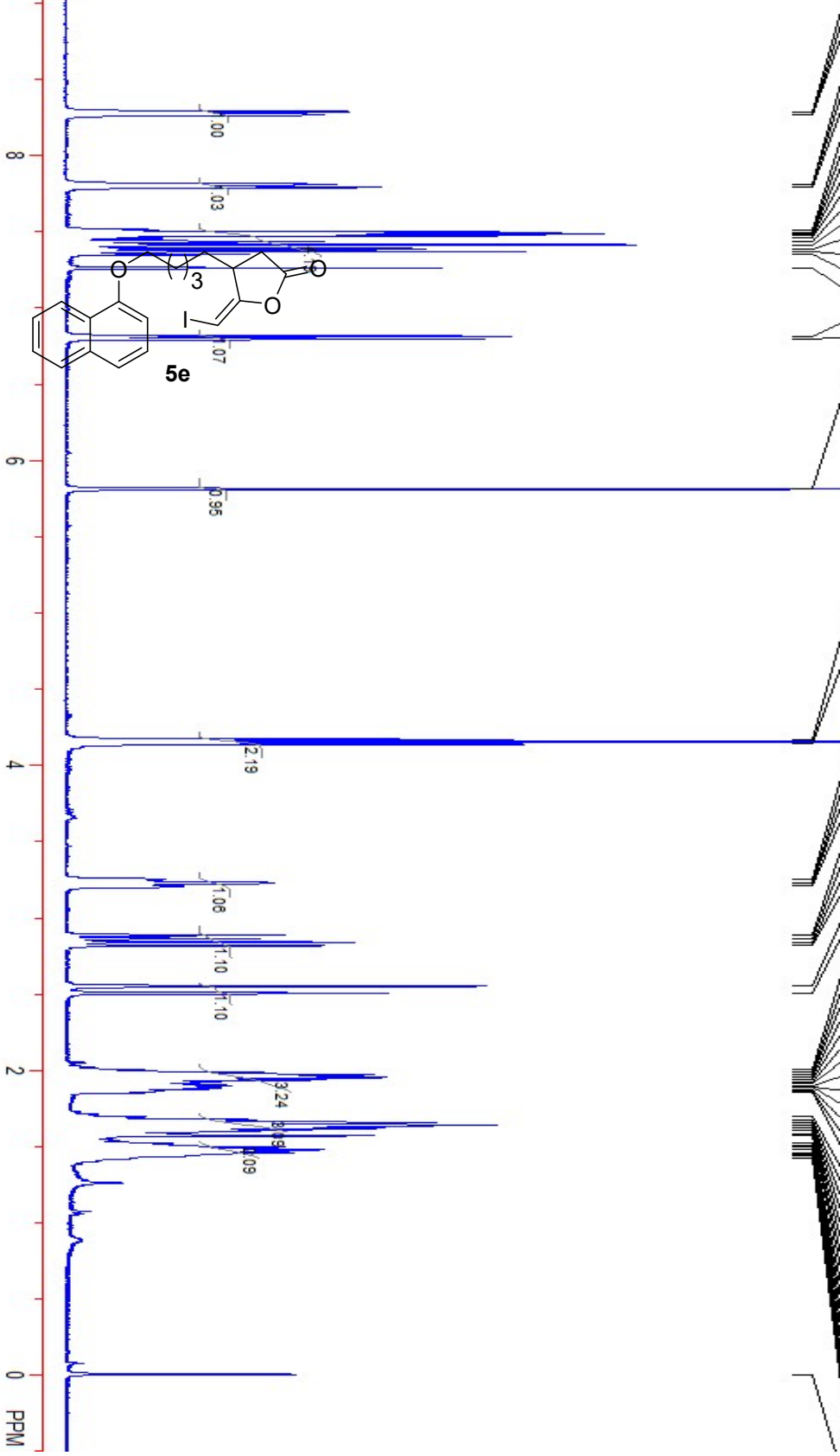

0.88
1.00
1.04
4.23
0.98
3.21
1.07
1.11
1.02
0.99
2.12
6.13
10
8
6
4
2
0
PPM

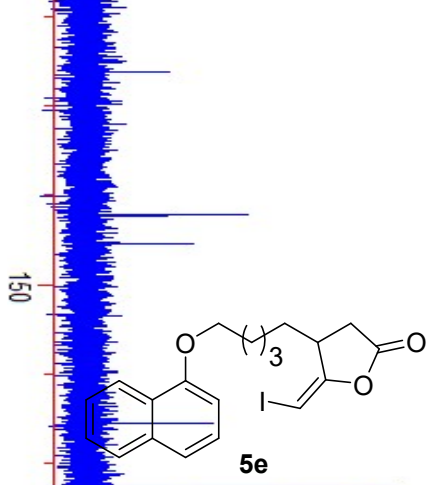

150
100
50
PPM
H
O
CO2H
3
5c


1.00
1.01
1.06
1.02
1.04
1.07
2.13
1.02
1.05
1.05
2.12
1.07
5.84
8
6
4
2
0
PPM
O
3
O
O
O

5d


150
100
50
PPM
O
3
O
O
5d


O
3
O
O
I
5e
8
6
4
2
0
PPM
1.00
1.03
1.07
0.95
2.19
1.08
1.10
1.10
3.24
1.09



5e

6. Supplymentary reference.

1 X. Li, P. Chen and G. Liu, *Angew. Chem., Int. Ed.* 2018, **57**, 15871.

2 X. Qi, F. Yu, P. Chen and G. Liu, *Angew. Chem., Int. Ed.* 2017, **56**, 12692.

3 C. Chen, Y. Luo, L. Fu, P. Chen, Y. Lan and G. Liu, *J. Am. Chem. Soc.* 2018, **140,** 1207.

4 J. P. Brand, C. Chevalley, R. Scopelliti and J. Waser, *Chem. Eur. J.* 2012, **18,** 5655.

5 P. Bertus and P. Pale, *Tetrahedron Lett.* 1996, **37**, 2019.

6 C. Menendez, S. Gau, C. Lherbet, F. Rodriguez, C. Inard, M. R. Pasca and M. Baltas, *Eur. J. Med. Chem.* 2011, **46**, 5524.

7 E. Tomás-Mendivil, P. Y. Toullec, J. Díez, S. Conejero, V. Michelet and V. Cadierno, *Org. Lett.* 2012, **14**, 2520.

8 G. A. Krafft, and J. A. Katzenellenbogen, *J. Am. Chem. Soc.* 1981, **103**, 5459.

9 L. Fu, S. Zhou, X. Wan, P. Chen and G. Liu, *J. Am. Chem. Soc*. 2018, **140**, 10965.