Supporting Information

Asymmetric Synthesis of Remote Quaternary Centers by Copper-Catalyzed Desymmetrization: An Enantioselective Total Synthesis of (+)-Mesembrine

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General Experimental

Reactions requiring anhydrous conditions were performed under an atmosphere of nitrogen or argon in a glovebox or using standard Schlenk techniques with flame or oven dried glassware. Anhydrous tetrahydrofuran (THF) and diethyl ether (Et_2O) were distilled from sodium and benzophenone. Anhydrous toluene was purchased from Sigma-Aldrich and used as received. The concentrations of anionic solutions (e.g., *n*-BuLi and Grignards) were titered by spectroscopic (No-D NMR) methods.[S1] All other solvents and reagents from the commercial sources were used as received. ^{1}H and ^{13}C NMR spectra were recorded on JEOL Eclipse Plus 500 (500 MHz) and JEOL ECX 300 (300 MHz) spectrometers. ^{1}H NMR chemical shifts are referenced to chloroform (7.26 ppm) and benzene-d_6 (7.16 ppm). ^{13}C NMR chemical shifts are referenced to $^{13}CDCl_3$ (77.23 ppm). The following abbreviations are used to describe multiplets: s (singlet), d (doublet), t (triplet), q (quartet), pent (pentet), m (multiplet), nfom (non-first-order multiplet), and br (broad). The following format was used to report peaks: chemical shift in ppm [multiplicity, coupling constant(s) in Hz, integral, and assignment]. ^{1}H NMR assignments are indicated by structure environment, e.g., CH_aH$_b$. Coupling constant analysis was guided by methods described elsewhere.[S2] ^{1}H NMR and ^{13}C NMR were processed with iNMR software program. Infrared (IR) spectra were recorded on a Bruker Alpha-P FT-IR spectrometer using neat (for liquid compound) or a thin film from a concentrated DCM solution. Absorptions are reported in cm^{-1}. Only the most intense and/or diagnostic peaks are reported. MPLC refers to medium pressure liquid chromatography (25-200 psi) using hand-packed columns of Silasorb silica gel (20-45 μm, spherical, 70 Å pore size), a Waters HPLC pump, and a Waters R401 differential refractive index detector. High-resolution mass spectra (HRMS) were recorded in Electrospray ionization time-of-flight (ESI-TOF) mode using a Shimadzu LC/MS IT-TOF. Samples were introduced as solutions in mixed solution of methanol and methylene chloride (DCM). GC/MS data were recorded on a Varian 450-GC/Varian 240-MS System. The methods used are noted parenthetically: 5029017 refers to: 2 min @ 50 °C – 20 °C/min – 3 min @ 290 °C (a 50 °C initial temperature that was held for 2 minutes followed by a 20 °C/min ramp to a final temperature of 250 °C that was held for 3 minutes for a total run time of 17 minutes). 5029027 refers to: 2 min @ 50 °C – 20 °C/min – 5 min @ 290 °C. Analytical TLC experiments were

performed on EMD Merck F254 plate, 250 μm thickness. Detection was performed by UV light or potassium phosphomolybdic acid, permanganate, *p*-anisaldehyde staining.

Supporting Information References

S1. "No-D NMR spectroscopy as a convenient method for titering organolithium (RLi), RMgX, and LDA solutions," Hoye, T. R.; Eklov, B. M.; Voloshin, M. *Org. Lett.* **2004**, *6*, 2567-2570.

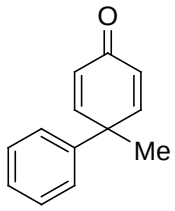
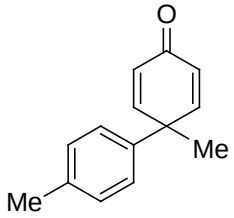
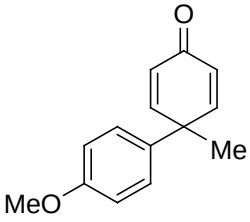
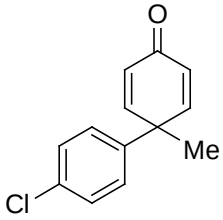
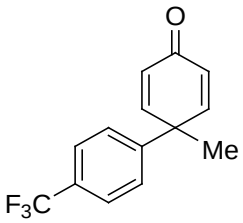
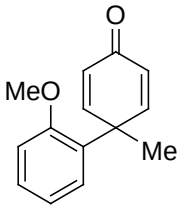
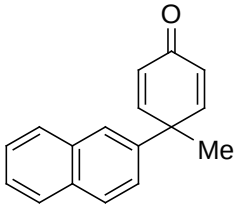
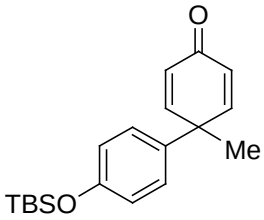
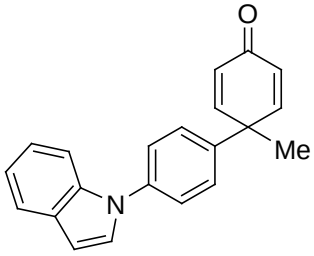
S2. "A method for easily determining coupling constant (*J*) values: An addendum to 'A practical guide to first-order multiplet analysis in ^{1}H NMR spectroscopy'," Hoye, T. R.; Zhao, H. *J. Org. Chem.* **2002**, *67*, 4014-4016.

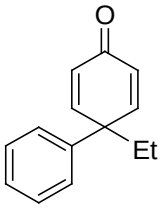
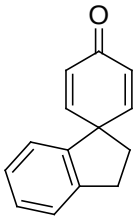
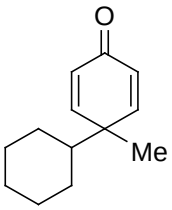
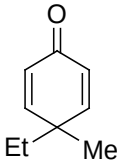
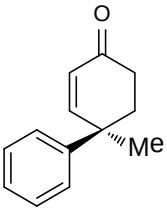
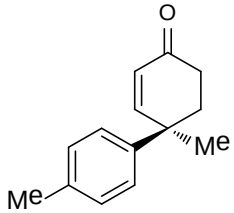
S3. "Total Synthesis of (+)-Mesembrine Applying Asymmetric Gold Catalysis" Spittler, M.; Lutsenko, K.; Czekelius, C. *J. Org. Chem.* **2016**, *81*, 6100.

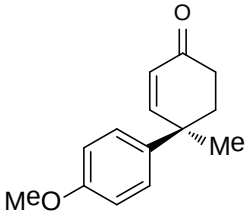
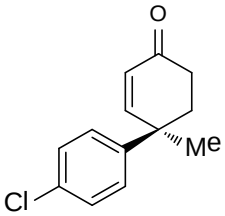
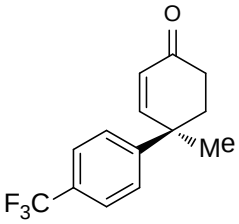
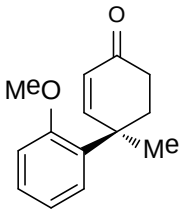
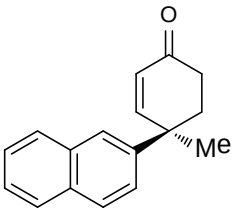
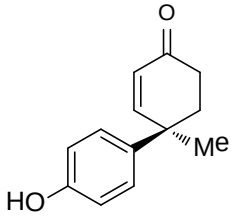
S4. "Efficient Asymmetric Synthesis of (+)-Mesembrine and Related Chiral 4,4-Disubstituted Cyclohexanones" Meyers, A. I.; Hanreich, R.; Wanner, K. T. *J. Am. Chem. Soc.* **1985**, *107*, 7776.

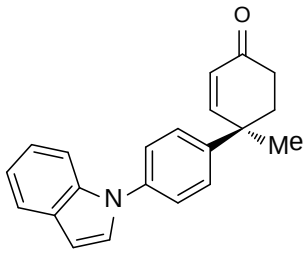
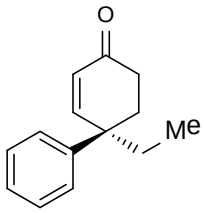
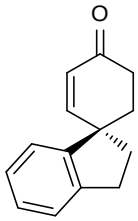
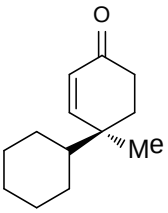
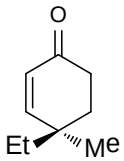
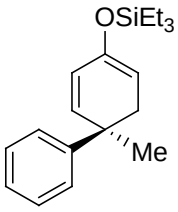
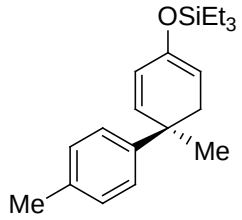
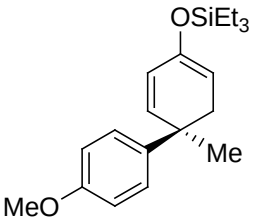
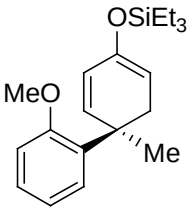
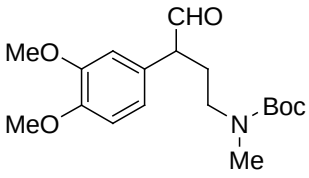
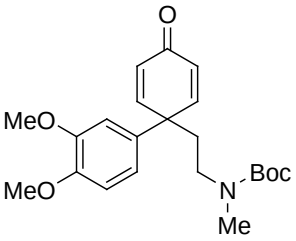
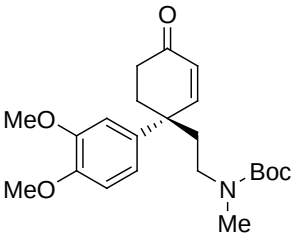
Table of Isolated Compounds

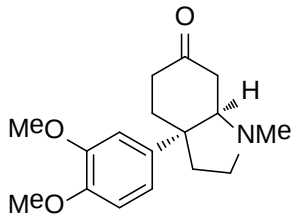
Structures not shown in the main manuscript but described here in the Supporting Information (Methods) and (NMR Spectra) documents are numbered with the form "***SI-##***".

Structure	Compound #	Procedure page:	Characterization page:	NMR spectra page:
	***1a***	7	9	67-68
	***1b***	8	9	69-70
	***1c***	8	10	71-71
	***1d***	8	11	73-74
	***1e***	8	11	75-76
	***1f***	8	12	77-78
	***1g***	8	13	79-80
	***1h***	8	13	81-82
	***1i***	8	14	83-84

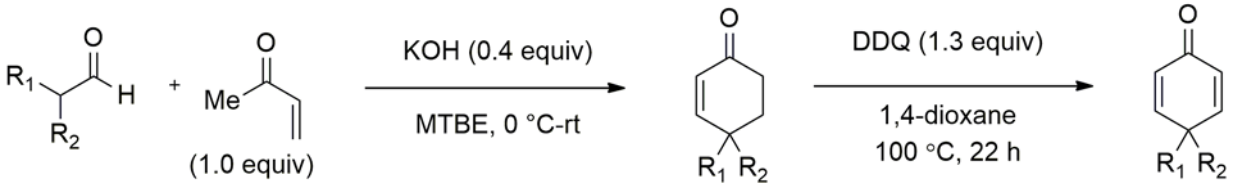
	***1j***	7	15	85-86
	***1k***	8	15	87-88
	***1l***	8	16	89-90
	***1m***	7	17	91-92
	***2a***	17	21	101-102
	***2b***	17	22	103-104

	***2c***	17	22	105-106
	***2d***	17	23	107-108
	***2e***	17	24	109-110
	***2f***	17	25	111-112
	***2g***	17	26	113-114
	***2h***	17	27	115-116

	***2i***	17	28	117-118
	***2j***	17	29	119-120
	***2k***	17	29	121-122
	***2l***	17	30	123-124
	***2m***	17	31	125-126
	***7a***	18	18	93-94
	***7b***	18	19	95-96
	***7c***	18	20	97-98
	***7f***	18	21	99-100
	***11***	32	32	127-128
	***12***	33	34	130-131
	***13***	34	35	132-133

	***8***	36	37	134-135

General Procedure for the Synthesis of γ,γ-disubstituted cyclohexadienone (Method A)

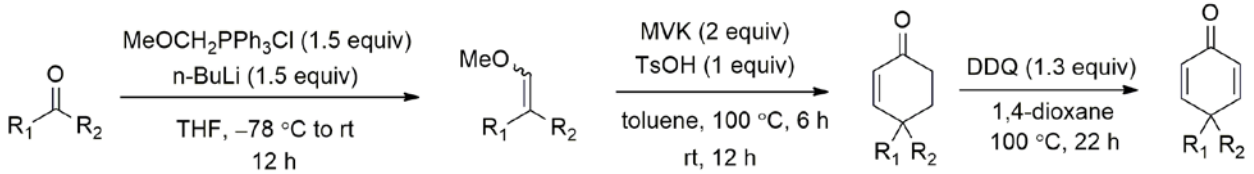


Methyl vinyl ketone (6.3 g, 90 mmol), aldehyde (90 mmol), and methyl *tert*-buthyl ether (MTBE) (300 mL) were added to a 500 mL round bottom flask. The reaction mixture was cooled to 0 °C and an ethanolic solution of KOH (2.1 g in 23 mL ethanol, 36 mmol) was added slowly over 15 min and allowed to stir for 2 h at the same temperature. The reaction mixture was warmed to room temperature and stirred for additional 1 h. The reaction mixture was washed with 1 M HCl (100 mL), water (100 mL), and brine (100 mL). The organic layer was dried over anhydrous Na_2SO_4, filtered through Celite® and the volatiles were removed *in vacuo* to afford the crude cyclohexenone. The resultant mixture was purified by flash column chromatography to furnish racemic cyclohexenone.

Cyclohexenone (8 g, 43 mmol), DDQ (13 g, 56 mmol), and 1,4-dioxane (100 mL) were added to a 3 neck, 250 mL round bottom flask equipped with reflux condenser. The reaction mixture was heated to 100 °C and stirred for 22 h. The reaction mixture was cooled down to room temperature and filtered through Celite®. The filtrates were diluted with diethyl ether, washed with 5% aqueous NaOH, and water sequentially. The organic layer was dried over anhydrous $MgSO_4$, filtered through Celite® and the volatiles were removed *in vacuo* to afford the

crude cyclohexadienone. The resultant mixture was purified by flash column chromatography to furnish cyclohexadienone.

General Procedure for the Synthesis of γ,γ-disubstituted cyclohexadienone (Method B)



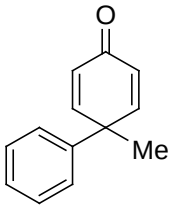
(Methoxymethyl)triphenylposhponium chloride (10.3 g, 30.0 mmol) and THF (200 mL) were added to a 500 mL 3 neck round bottom flask and cooled to –78 °C. *n*-BuLi (2.0 M in hexane, 15 mL, 30 mmol) was added slowly to the reaction mixture and stirred for 1 h at –78 °C and additional 1 h at room temperature. The reaction mixture was cooled to –78 °C. Ketone (20 mmol) in THF (40 mL) was added slowly to the mixture, which was stirred for 30 min at the same temperature. The reaction mixture was warmed to room temperature and stirred for 12 h. The reaction mixture was quenched with water and extracted into Et_2O (3X). The combined organic layers were washed with saturated brine solution, dried over anhydrous $MgSO_4$, filtered through Celite® and concentrated *in vacuo* to afford the crude enol ether. The resultant mixture was purified by flash column chromatography to provide enol ethers.

Enol ether (20 mmol) and *p*-toluenesulfonic acid monohydrate (4.0 g, 21 mmol), and toluene (70 mL) were placed in a 250 mL flask. Methyl vinyl ketone (40 mmol) was added to the mixture, which was stirred at 100 °C for 6 h. The reaction mixture was allowed to cool to room temperature and stirring for 12 h. The mixture was quenched with saturated aqueous $NaHCO_3$. The mixture was extracted with EtOAc (3X). The combined organic layers were dried over anhydrous $MgSO_4$, filtered through Celite® and concentrated *in vacuo* to afford the crude cyclohexenone. The resultant mixture was purified by flash column chromatography to provide racemic cyclohexenone.

Cyclohexenone (43 mmol) and DDQ (13 g, 56 mmol), and 1,4-dioxane (100 mL) were added to a 3 neck 250 mL RBF equipped with reflux condenser. The reaction mixture was heated to 100 °C and stirred for 22 h. Reaction mixture was cooled down to room temperature and filtered through Celite®. The filtrates were diluted with diethyl ether and washed with 5% aqueous NaOH and water sequentially. The organic layer was dried over anhydrous $MgSO_4$,

filtered through Celite® and the volatiles were removed *in vacuo* to afford the crude cyclohexadienone. The resultant mixture was purified by flash column chromatography to provide cyclohexadienone.

1-Methyl-[1,1'-biphenyl]-4(1*H*)-one (1a): Method A



Yield: 9.8 g, 75% (70 mmol scale, off-white solid). Purified by flash column chromatography (hexanes/EtOAc = 10:1). **TLC**: R_f = 0.4 in hexanes/EtOAc = 5:1.

^{1}H NMR ($CDCl_3$, 500 MHz,): δ 7.36-7.26 (m, 5H, Ar-*H*), 6.91 [d, *J* = 10.1 Hz, 2H, C*H*C(O)C*H*], 6.27 [d, *J* = 10.2 Hz, 2H, C*H*CHC(O)CHC*H*], and 1.69 (s, 3H).

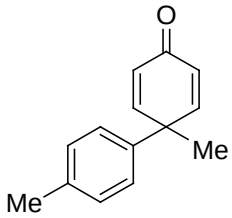
^{13}C NMR ($CDCl_3$, 125 MHz): δ 186.2, 155.6, 140.1, 129.2, 127.8, 127.2, 126.6, 45.2, and 24.0.

GC-MS (5029017): R_t = 10.11 min, m/z 185 [$(M+H)^+$, 100], 169 [$(M–CH_3)^+$, 10], 156 (70), 141 (30), and 128 (25).

IR (neat): 3049 (w), 2976 (m), 1660 (s), 1622 (w), 1491 (m), 1415 (s), 1397 (s), 1245 (s), 1092 (s), 1000 (s), 870 (s), 757 (s), 696 (s) and 541 (s) cm^{-1}.

HRMS (ESI/TOF): Calcd for $(C_{13}H_{13}O)^+$: 185.0961. Found: 185.1006.

1,4'-Dimethyl-[1,1'-biphenyl]-4(1*H*)-one (1b): Method B



Yield: 1.33 g, 68% (10 mmol scale, brown color solid). Purified by flash column chromatography (hexanes/EtOAc = 5:1). **TLC**: R_f = 0.6 in hexanes/EtOAc = 5:1.

^{1}H NMR ($CDCl_3$, 500 MHz,): δ 7.20-7.14 (m, 5H, Ar-*H*), 6.90 [d, *J* = 10.1 Hz, 2H, C*H*C(O)C*H*], 6.26 [d, *J* = 10.1 Hz, 2H, C*H*CHC(O)CHC*H*], 2.33 (s, 3H, Ar-CH_3). and 1.67 (s, 3H, CCH_3).

^{13}C NMR ($CDCl_3$, 125 MHz): δ 185.7, 155.4, 137.2, 136.6, 129.5, 126.7, 126.0, 44.8, 24.0, and

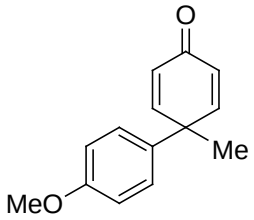
21.2.

GC-MS (5029017): R_t = 10.72 min, m/z 199 [$(M+H)^+$, 100], 183 [$(M–CH_3)^+$, 10], 168 [$(M–2CH_3)^+$, 35], 155 (30), and 128 (20).

IR (neat): 3030 (w), 2971 (m), 2875 (w), 1660 (s), 1620 (s), 1510 (m), 1454 (m), 1361 (s), 1247 (s), 1094 (s), 870 (s), 820 (s), 708 (s), 538 (s) and 460 (s) cm^{-1}.

HRMS (ESI/TOF): Calcd for $(C_{14}H_{15}O)^+$: 199.1117. Found: 199.1154.

4'-Methoxy-1-methyl-[1,1'-biphenyl]-4(1*H*)-one (1c) : Method B



Yield: 1.22 g, 58% (10 mmol scale, pale yellow solid). Purified by flash column chromatography (hexanes/EtOAc = 3:1). **TLC**: R_f = 0.4 in hexanes/EtOAc = 3:1.

^{1}H NMR ($CDCl_3$, 500 MHz,): δ 7.21 (d, *J* = 8.8 Hz, 2H, Ar-*H*), 6.89 [d, *J* = 10.1 Hz, 2H, C*H*C(O)C*H*], 6.86 (d, *J* = 8.8 Hz, 2H, Ar-*H*), 6.25 [d, *J* = 10.1 Hz, 1H, C*H*CHC(O)CHC*H*], 3.79 (s, 3H, Ar-OCH_3), and 1.65 (s, 3H, CCH_3).

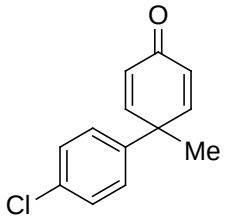
^{13}C NMR ($CDCl_3$, 125 MHz): δ 186.2, 159.1, 155.9, 131.7, 127.6, 126.8, 114.4, 55.4, 44.5, and 24.0

GC-MS (5029017): R_t = 11.58 min, m/z 215 [$(M+H)^+$, 100], 214 [$(M)^+$, 30], 199 [$M-CH_3)^+$, 10], 183 [$(M-OCH_3)^+$, 10], 171 (20), 152(10), and 128 (20).

IR (neat): 3035 (w), 2997 (m), 2835 (w), 1663 (s), 1621 (s), 1507 (s), 1457 (m), 1401 (m), 1301 (m), 1244 (s), 1179 (s), 1098 (s), 1026 (s), 873 (s), 825 (s), 726 (s), 644 (m), 550 (s) 464 (s) cm^{-1}.

HRMS (ESI/TOF): Calcd for $(C_{14}H_{15}O_2)^+$: 215.1067. Found: 215.1105.

4'-Chloro-1-methyl-[1,1'-biphenyl]-4(1*H*)-one (1d) : Method B



Yield: 1.02 g, 47% (10 mmol scale, pale yellow semi solid). Purified by flash column chromatography (hexanes/EtOAc = 3:1)

TLC: R_f = 0.5 in hexanes/EtOAc = 3:1.

^{1}H NMR ($CDCl_3$, 500 MHz,): δ 7.31 (d, *J* = 8.8 Hz, 2H, Ar-*H*), 7.23 (d, *J* = 8.8 Hz, 2H, Ar-*H*), 6.87 [dd, *J* = 10.2 Hz, 2H, C*H*C(O)C*H*], 6.10 [d, *J* = 10.2 Hz, 2H, C*H*CH C(O)CHC*H*], and 1.67 (s, 3H, CCH_3).

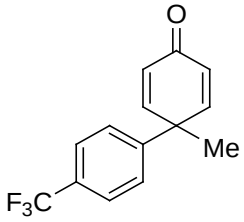
^{13}C NMR ($CDCl_3$, 125 MHz): δ 185.9, 155.0, 138.7, 133.9, 129.3, 128.0, 127.5, 44.7, and 24.1.

GC-MS (5029017): R_t = 11.28 min, m/z 220 [$(M+2)^+$, 30], 219 [$(M+H)^+$, 100], 203 [$(M-CH_3)^+$, 10], 190 (60), 175 (20), 155 (25), 139 (10) and 115 (20).

IR (neat): 3054 (w), 2972 (m), 1660 (s), 1486 (s), 1622 (s), 1489 (s), 1396 (s), 1324 (m), 1246 (m), 1094 (s), 1013 (s), 869 (s), 827 (s), 733 (s), 706 (s), 535 (s), and 458 (s) cm^{-1}.

HRMS (ESI/TOF): Calcd for $(C_{13}H_{12}ClO)^+$: 219.0571. Found: 219.0486.

1-Methyl-4'-(trifluoromethyl)-[1,1'-biphenyl]-4(1*H*)-one (1e) : Method B



Yield: 2.65 g, 53% (20 mmol scale, pale yellow liquid). Purified by flash column chromatography (hexanes/EtOAc = 3:1)

TLC: R_f = 0.4 in hexanes/EtOAc = 3:1.

^{1}H NMR ($CDCl_3$, 500 MHz,): δ 7.59 (d, *J* = 8.2 Hz, 2H, Ar-*H*), 7.42 (d, *J* = 8.2 Hz, 2H, Ar-*H*), 6.88 [d, *J* = 10.2 Hz, 1H, C*H*C(O)C*H*], 6.30 [d, *J* = 10.2 Hz, 1H, C*H*CHC(O)CHC*H*], and 1.71 (s, 3H, CH=CHCCH_3).

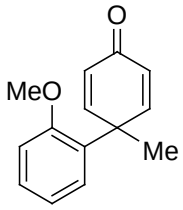
^{13}C NMR ($CDCl_3$, 125 MHz): δ 185.7, 154.4, 144.4, 130 ($^2J_{F\text{-}C}$ = 32.6 Hz), 127.7, 127.0, 126 ($^3J_{F\text{-}C}$ = 3.6 Hz), 124.0 ($^1J_{F\text{-}C}$ = 272 Hz), 45.1, and 24.1.

GC-MS (5029017): R_t = 10.068 min, m/z 253 [$(M+H)^+$, 100], 224 (40), 195 [$(M–3F)^+$, 10], and 183 (20).

IR (neat): 3045 (w), 2977 (w), 1663 (s) 1625 (s), 1397 (m), 1322 (s), 1164 (s), 1117 (s), 1068 (s), 1014 (s), 837 (s), 701 (m), 605 (m), and 462 (m) cm^{-1}..

HRMS (ESI/TOF): Calcd for $(C_{14}H_{12}F_3O)^+$: 253.0991. Found: 253.1025.

2'-methoxy-1-methyl-[1,1'-biphenyl]-4(1*H*)-one (1f) : Method B



Yield: 0.85 g, 40% (10 mmol scale, off-white solid). Purified by flash column chromatography (hexanes/EtOAc = 3:1)

TLC: R_f = 0.4 in hexanes/EtOAc = 3:1.

^{1}H NMR ($CDCl_3$, 500 MHz,): δ 7.29 (dd, *J* = 8.1, 7.6 Hz, 1H, Ar-*H*), 7.27 (d, *J* = 8.1 Hz, 1H, Ar-*H*), 7.08 [d, *J* = 10.1 Hz, 2H, C*H*C(O)C*H*], 6.95 (dd, *J* = 7.6, 7.6 Hz, 1H, Ar-*H*), 6.87 (d, *J* = 8.1 Hz, 1H, Ar-*H*), 6.28 [d, *J* = 10.1 Hz, 2H, C*H*CHC(O)CHC*H*], 3.75 (s, 3H, Ar-OCH_3), and 1.58 (s, 3H, CCH_3).

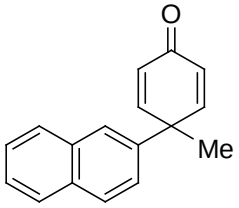
^{13}C NMR ($CDCl_3$, 125 MHz): δ 186.5, 158.5, 155.2, 129.4, 128.9, 127.6, 127.3, 121.1, 112.0, 55.3, 44.3, and 24.9.

GC-MS (5029017): R_t = 11.25 min, m/z 215 [$(M+H)^+$, 100], 191 [$(M–CH_3)^+$, 20], 183 [$(M-OCH_3)^+$, 20], 178 (60), and 128 (15).

IR (neat): 3050 (w), 2956 (w), 2833 (w), 1662 (s), 1616 (s), 1488 (s), 1432 (s), 1399 (s), 1248 (m), 1122 (m), 1089 (m), 1022 (s), 759 (s), 552 (m), and 455 (s) cm^{-1}.

HRMS (ESI/TOF): Calcd for $(C_{14}H_{15}O_2)^+$: 215.1067. Found: 215.1090.

4-methyl-4-(naphthalen-2-yl)cyclohexa-2,5-dienone (1g) : Method B



Yield: 2.8 g, 60% (20 mmol scale, brown color solid). Purified by flash column chromatography (hexanes/EtOAc = 5:1)

TLC: R_f = 0.6 in hexanes/EtOAc = 5:1.

^{1}H NMR ($CDCl_3$, 500 MHz,): δ 7.84-7.79 (m, 4H, Ar-*H*), 7.53-7.46 (m, 2H, Ar-*H*), 7.34 (dd, *J* = 8.5, 2.0 Hz, 1H, Ar), 6.97 [d, *J* = 10.1, Hz, 2H, C*H*C(O)C*H*], 6.34 [d, *J* = 10.1 Hz, 2H, C*H*CHC(O)CHC*H*], and 1.79 (s, 3H, CCH_3).

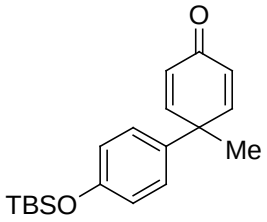
^{13}C NMR ($CDCl_3$, 125 MHz): δ 186.1, 155.5, 137.3, 133.7, 132.7, 128.8, 128.1, 127.7, 127.4, 126.68, 126.56, 125.0, 124.8, 45.3, and 23.9.

GC-MS (5029017): R_t = 13.57 min, m/z 235 [$(M+H)^+$, 80], 234 [$(M)^+$, 234], 219 [$(M-CH_3)^+$, 15], 206 (70), 191 (70), and 178 (20).

IR (neat): 3051 (w), 3030 (m), 2978 (m), 2931 (m), 1662 (s), 1621 (s), 1596 (m), 1499 (m), 1396 (m), 1272 (m), 1092 (m), 863 (s), 814 (s), 752 (s), 475 (s), and 459 (s) cm^{-1}.

HRMS (ESI/TOF): Calcd for $(C_{17}H_{15}O)^+$: 235.1117. Found: 235.1142.

4'-[(*tert*-butyldimethylsilyl)oxy]-1-Methyl-[1,1'-biphenyl]-4(1*H*)-one (1h) : Method B



Yield: 630 mg, 50% (5 mmol scale, off-white solid). Purified by flash column chromatography (hexanes/EtOAc = 5:1)

TLC: R_f = 0.5 in hexanes/EtOAc = 5:1.

^{1}H NMR ($CDCl_3$, 500 MHz,): δ 7.13 (d, *J* = 8.7 Hz, 2H, Ar-*H*), 6.89 (d, *J* = 10.1 Hz, 2H, C*H*C(O)C*H*), 6.79 (d, *J* = 8.7 Hz, 2H, Ar-*H*), 6.25 [d, *J* = 10.1 Hz, 1H, C*H*CHC(O)CHC*H*], 1.65 (s, 3H, CCH_3), 0.97 [s, 9H, SiC(CH_3)$_3$], and –0.18 (s, 3H, Si(CH_3)$_2$).

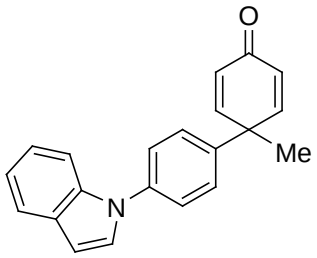
^{13}C NMR ($CDCl_3$, 125 MHz): δ 186.2, 156.0, 155.2, 132.2, 127.5, 126.7, 120.5, 44.6, 25.7, 24.0, 18.3, and –4.3.

GC-MS (5029017): R_t = 13.59 min, m/z 315 [$(M+H)^+$, 100], 199 [$(M-CH_3)^+$, 10], 286 (20), 258 (10), and 230 (10).

IR (neat): 2510 (m), 2856 (m), 1656 (s), 1622 (m), 1603 (m), 1506 (s), 1403 (m), 1284 (s), 1174 (s), 912 (s), 837 (s), 781 (s), 702 (m), 550 (m), and 461 (s) cm^{-1}.

HRMS (ESI/TOF): Calcd for $(C_{19}H_{27}O_2S_i)^+$: 315.1775. Found: 315.1796.

4'-(1*H*-indol-1-yl)-1-Methyl-[1,1'-biphenyl]-4(1*H*)-one (1i)



Yield: 550 mg, 46% (4 mmol scale, brown color solid). Purified by flash column chromatography (hexanes/EtOAc = 3:1)

TLC: R_f = 0.5 in hexanes/EtOAc = 3:1.

^{1}H NMR ($CDCl_3$, 500 MHz,): δ 7.69 (d, *J* = 7.8 Hz, 1H, indole-*H4* or *H7*), 7.56 (d, *J* = 8.2 Hz, 1H, indole-*H7* or *H4*), 7.51-7.44 (m, 4H, Ar-*H*), 7.32 (d, *J* = 3.3 Hz, 1H, indole-*H2*), 7.23 (dd, *J* = 8.2, 7.8 Hz, 1H, indole-*H5* or *H6*), 7.18 (dd, *J* = 7.8 Hz, 1H, indole-*H6* or *H5*), 6.97 [d, *J* = 10.1 Hz, 2H, C*H*C(O)C*H*], 6.69 (d, *J* = 3.3 Hz, 1H, indole-*H3*), 6.34 [d, *J* = 10.1 Hz, 2H, C*H*CHC(O)CHC*H*], and 1.76 (s, 3H, CCH_3).

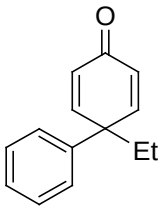
^{13}C NMR ($CDCl_3$, 125 MHz): δ 186.0, 155.2, 139.4, 138.1, 135.9, 129.6, 127.91, 127.90, 127.4, 124.8, 122.7, 121.4, 120.7, 110.6, 104.2, 44.9, and 24.2.

GC-MS (5029027): R_t = 25.37 min, m/z 300 $[(M+H)^+$, 30], 299 $[(M)^+$, 100], 284 $[(M-CH_3)^+$, 40], 271 (70), 256 (60), 228 (10), and 191 (10).

IR (neat): 3044 (w), 2971 (w), 2871 (w), 1659 (s), 1623 (m), 1515 (s), 1454 (s), 1231 (m), 1211 (m), 1133 (m), 850 (s), 762 (m), 744 (s), 586 (s), and 428 (s) cm^{-1}.

HRMS (ESI/TOF): Calcd for $(C_{21}H_{18}NO)^+$: 300.1383. Found: 300.1420.

1-Ethyl-[1,1'-biphenyl]-4(1*H*)-one (1j) : Method B



Yield: 1.05 g, 53% (10 mmol scale, pale yellow color liquid). Purified by flash column chromatography (hexanes/EtOAc = 5:1).

TLC: R_f = 0.5 in hexanes/EtOAc = 5:1.

^{1}H NMR ($CDCl_3$, 500 MHz,): δ 7.36-7.11 (m, 5H, Ar-*H*), 6.88 [d, *J* = 10.3 Hz, 2H, C*H*C(O)C*H*], 6.37 [d, *J* = 10.3, Hz, 2H, C*H*CHC(O)CHC*H*], 2.17 (q, *J* = 7.5 Hz, 2H, CCH_2CH_3), and 0.9 (t, *J* = 7.5 Hz, 3H, CCH_2CH_3).

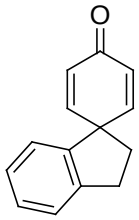
^{13}C NMR ($CDCl_3$, 125 MHz): δ 186.6, 154.5, 140.2, 129.22, 129.05, 127.7, 126.8, 49.7, 30.3, and 9.2.

GC-MS (5029017): R_t = 10.72 min, m/z 199 [$(M+H)^+$, 100], 169 [$(M-CH_2CH_3)^+$, 25], 155 (20), 128 (10) and 115 (30).

IR (neat): 3030 (w), 2968 (m), 1659 (s), 1624 (s), 1491 (m), 1398 (m), 853 (s), 752 (s), 696 (s), and 569 (m) cm^{-1}.

HRMS (ESI/TOF): Calcd for $(C_{14}H_{15}O)^+$: 199.1117, Found: 199.1139.

2',3'-Dihydrospiro[cyclohexa[2,5]diene-1,1'-inden]-4-one (1k) : Method B



Yield: 1.33g, 66% (10 mmol scale, brown color solid). Purified by flash column chromatography (hexanes/EtOAc = 3:1).

TLC: R_f = 0.5 in hexanes/EtOAc = 3:1.

^{1}H NMR ($CDCl_3$, 500 MHz,): δ 7.33 (d, *J* = 7.4 Hz, 1H, Ar-*H*), 7.26 (dd, *J* = 7.4, 7.4 Hz, 1H, Ar-*H*), 7.17 (dd, *J* = 7.7, 7.4 Hz, 1H, Ar-*H*), 6.94 (d, *J* = 7.7 Hz, 1H, Ar-*H*), 6.91 [d, *J* = 10.0 Hz, 2H, C*H* C(O)C*H*], 6.29 [d, *J* = 10.0 Hz, 1H, C*H*CHC(O)CHC*H*], 3.17 (t, *J* = 7.3 Hz, 2H, CCH_2CH_2), and 2.35 (t, *J* = 7.3 Hz, 2H, CCH_2CH_2).

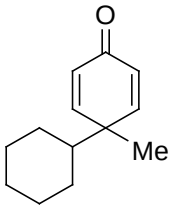
^{13}C NMR ($CDCl_3$, 125 MHz): δ 186.5, 152.9, 144.1, 142.4, 128.5, 127.7, 127.4, 125.6, 124.3, 54.1, 37.6, and 31.3.

GC-MS (5029017): R_t = 11.04 min, m/z 197 [$(M+H)^+$, 100], 168 (25), 152 (20), and 141 (10).

IR (neat): 3020 (w), 2973 (s), 1651 (s), 1615 (s), 1471 (m), 1455 (m), 1402 (m), 1249 (m), 1073 (m), 865 (s), 754 (s), 687 (m), and 573 (s) cm^{-1}.

HRMS (ESI/TOF): Calcd for $(C_{14}H_{15}O)^+$: 197.0961, Found: 197.0925.

1-Methyl-[1,1'-bi(cyclohexane)]-2,5-dien-4-one (1l) : Method B



Yield: 2.3 g, 66% (20 mmol scale, pale yellow color liquid). Purified by flash column chromatography (hexanes/EtOAc = 5:1).

TLC: R_f = 0.5 in hexanes/EtOAc = 5:1.

^{1}H NMR ($CDCl_3$, 500 MHz,): δ 6.81 [d, *J* = 10.2 Hz, 1H, C*H* C(O)C*H*], 6.26 [d, *J* = 10.2 Hz, 1H, C*H*CHC(O)CHC*H*], 1.79-1.71 (m, 4H, Cy*H*), 1.67-1.61 (m, 1H, Cy*H*), 1.45 (ddd, *J* = 12.2, 3.1, 3.1 Hz, 1H, Cy*H*), 1.21 (s, 3H, CCH_3), 1.25-1.17 (m, 1H, Cy*H*), 1.17 (ddd, *J* = 12.9, 3.4, 3.4 Hz, 1H, Cy*H*), 1.07 (ddd, *J* = 12.9, 3.4, 3.4 Hz, 1H, Cy*H*), 0.96 (ddd, *J* = 12.5, 12.5, 3.1 Hz, 1H, Cy*H*), and 0.93 (ddd, *J* = 13.4, 13.4, 4.0 Hz, 1H, Cy*H*).

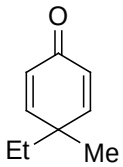
^{13}C NMR ($CDCl_3$, 125 MHz): δ 186.8, 155.9, 129.1, 47.0, 45.0, 28.2, 26.9, 26.4, and 23.7.

GC-MS (5029017): R_t = 10.26 min, m/z 191 $[(M+H)^+$, 20], 175 $[(M-CH_3)^+$, 10], and 107[(M-Cy)$^+$, 100].

IR (neat): 2924 (s), 2852 (s), 1659 (s), 1624 (s), 1449 (m), 1254 (m), 1078 (m), 860 (s), 699 (m) and 448 (m) cm^{-1}.

HRMS (ESI/TOF): Calcd for $(C_{13}H_{19}O)^+$: 191.1430, Found: 191.1395.

4-ethyl-4-methylcyclohexa-2,5-dienone (1m) : Method A



Yield: 326 mg, 40% (6 mmol, pale yellow color liquid). Purified by flash column chromatography (hexanes/EtOAc = 5:1).

TLC: R_f = 0.5 in hexanes/EtOAc = 5:1.

^{1}H NMR ($CDCl_3$, 500 MHz,): δ 6.74 [d, *J* = 10.0 Hz, 1H, C*H*C(O)C*H*], 6.27 [d, *J* = 10.0 Hz, 1H, C*H*CHC(O)C*H*CH], 1.65 (q, *J* = 7.5 Hz, 2H, CCH_2CH$_3$), 1.23 (s, 3H, CCH_3) and 0.74 (t, *J* = 7.5 Hz, CCH$_2$CH_3).

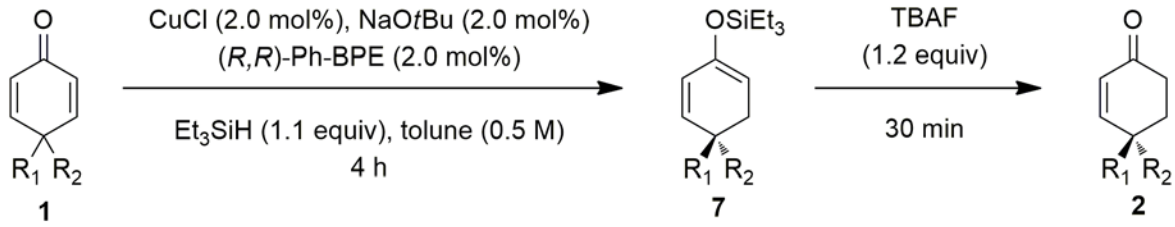
^{13}C NMR ($CDCl_3$, 125 MHz): δ 186.7, 156.1, 129.3, 77.5, 77.2, 77.0, 42.6, 33.5, 25.8, and 9.5.

GC-MS (5029017): R_t = 6.76 min, m/z 137 [$(M+H)^+$, 100], 107 [$(M-CH_2CH_3)^+$, 10], and 91 (10).

IR (neat): 2967 (m), 2930 (m), 1728 (br), 1658 (s), 1615 (s), 1459 (m), 1402 (m), 1261 (m), 1187 (m), 1108 (m), 858 (s), 702 (m), and 461 (s) cm^{-1}.

HRMS (ESI/TOF): Calcd for $(C_9H_{13}O)^+$: 137.0961, Found: 137. 0999.

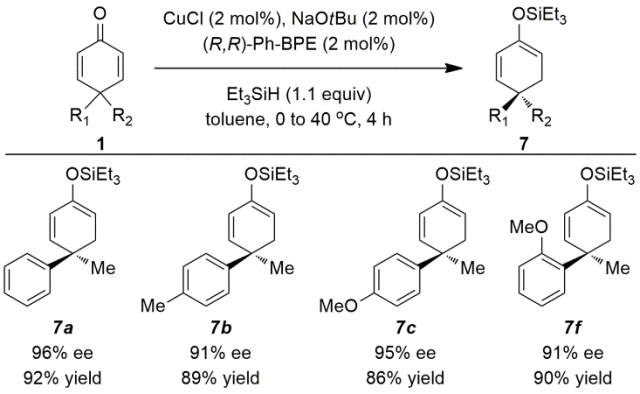
General Procedure for Cu-H Catalyzed desymmetrization of disubstituted cyclohexadienones:



CuCl (1.24 mg, 2.5 mol %), NaO^{t}Bu (1.2 mg, 2.5 mol %) and (*R*,*R*)-Ph-BPE (6.3 mg, 2.5 mol %) were added to an oven dried vial equipped with PTFE red rubber septa lined cap in a glove box. The vial was taken back to a hood and toluene (0.5 mL) was added under a N_2 atmosphere. The reaction mixture was stirred for 10 min at room temperature prior to cooled to ice bath temperature. Silane (0.55 mmol) and cyclohexadienone (0.5 mmol, 1M solution in toluene) was added to the reaction mixture. The reaction mixture was stirred for 4 h at 40 °C and the reaction progress was monitored by TLC and ^{1}H NMR (30 µL aliquot in 500 µL $CDCl_3$). The reaction mixture was cooled to ice bath temperature, quenched with brine. The mixture was extracted into diethyl ether (3X), and volatiles were removed *in vacuo* to afford the crude (4-methyl-4-phenylcyclohexa-1,5-dienyloxy)triethylsilane. The crude mixture was purified by MPLC (hexanes:EtOAc) to provide enantio-enriched 2-oxysilyl cyclohexadiene. A few

representative siloxy dienes were isolated in high yields (86-92%) and excellent enantioselectivities (91-96% ee, **7a**, **7b**, **7c** and **7f**, Scheme 1).

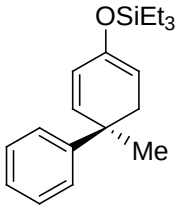
Scheme 1. Examples of Isolated 2-Siloxy Diene[a, b, c]



[a] Conditions: Dienone (0.5 mmol), silane (0.55 mmol), toluene (1.0 mL). [b] Yields of isolated products. [c] The % *ee* values were determined by chiral HPLC analysis of its enone derivatives.

To directly access enantio-enriched cyclohexenone, the reaction mixture was treated with TBAF (600 µL, 0.6 mmol, 1 M solution in THF) and stirred for 30 min at room temperature. The crude mixture was quenched with brine and extracted into ether (3X). The organic layer was dried over anhydrous $MgSO_4$, filtered through Celite® and the volatiles were removed *in vacuo* to afford the crude 4-methyl-4-phenylcyclohex-2-enone. The crude mixture was purified by MPLC (hexanes:EtOAc) to provide enantio-enriched cyclohexenone.

(*R*)-Triethyl((1-methyl-1,2-dihydro-[1,1'-biphenyl]-4-yl)oxy)silane (7a)



Yield: 138 mg, 92% (colorless clear liquid). Purified by MPLC (hexanes/EtOAc = 100:1)

TLC: R_f = 0.8 in hexanes/EtOAc = 100:1.

^{1}H NMR (C_6D_6, 500 MHz,): δ 7.29-7.26 (m, 2H, Ar-*H*), 7.13-7.09 (m, 2H, Ar-*H*), 7.03-7.00 (m, 1H, Ar-*H*), 5.86 [dd, *J* = 10.0, 2.0 Hz, 1H, CH=*CH*C($OSiEt_3$)], 5.71 [d, *J* = 10.2 Hz, 1H, C*H*=CHC($OSiEt_3$)], 4.76 [ddd, *J* = 4.4, 4.4, 2.0 Hz, 1H, ($OSiEt_3$)C=C*H*CH_2], 2.57 [dd, *J* = 16.7, 4.4 Hz, 1H, ($OSiEt_3$)C=CHC*H*$_a$H$_b$], 2.24 [dd, *J* = 16.7, 4.4 Hz, 1H, ($OSiEt_3$)C=CHCH$_a$*H*$_b$], 1.29

(s, 3H, CC*H*$_3$), 0.92 [app t, *J* = 8.0 Hz, 9H, OSi(CH$_2$C*H*$_3$)$_3$], and 0.92 [m, 6H, OSi(C*H*$_2$CH$_3$)$_3$].

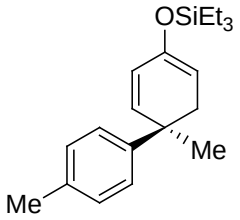
^{13}C NMR (C_6D_6, 125 MHz): δ 149.1, 148.2, 138.5, 128.4, 126.5, 126.3, 125.8, 100.5, 39.2, 38.6, 26.6, 6.9, and 5.3.

GC-MS (5029017): R_t = 15.91 min, m/z 300 [$(M)^+$, 100], 285 [$(M–CH_3)^+$, 40], 256 (50), 228 (10), and 191 (10).

IR (neat): 3056 (w), 2955 (m), 2823 (m), 1650 (s), 1599 (w), 1493 (m), 1457 (w), 1399 (m), 1225 (s), 1189 (s), 1004 (s), 890 (s), 724 (s), and 695 (s) cm^{-1}.

HRMS (ESI/TOF): Calcd for $(C_{19}H_{29}OSi)^+$: 301.1982. Found: 301.2021.

(*R*)-((1,4'-Dimethyl-1,2-dihydro-[1,1'-biphenyl]-4-yl)oxy)triethylsilane (7b)



Yield: 140 mg, 89% (colorless clear liquid). Purified by MPLC (hexanes/EtOAc = 100:1)

TLC: R_f = 0.8 in hexanes/EtOAc = 100:1.

^{1}H NMR (C_6D_6, 500 MHz,): δ 7.28 (d, *J* = 8.2 Hz, 2H, Ar-*H*), 7.02 (d, *J* = 8.2 Hz, 2H, Ar-*H*), 5.93 [dd, *J* = 10.0, 2.0 Hz, 1H, CH=*CH*C(OSiEt$_3$)], 5.80 [d, *J* = 10.2 Hz, 1H, C*H*=CHC(OSiEt$_3$)], 4.76 [ddd, *J* = 4.4, 4.4, 2.0 Hz, 1H, (OSiEt$_3$)C=C*H*CH$_2$], 2.61 [dd, *J* = 16.7, 4.4 Hz, 1H, (OSiEt$_3$)C=CHC*H*$_a$H$_b$], 2.27 [dd, *J* = 16.7, 4.4 Hz, 1H, (OSiEt$_3$)C=CHCH$_a$*H*$_b$], 2.15 (s, 3H, ArC*H*$_3$), 1.38 (s, 3H, CC*H*$_3$), 0.99 [app t, *J* = 8.0 Hz, 9H, OSi(CH$_2$C*H*$_3$)$_2$], and 0.65 [m, 6H, OSi(CH$_2$CH$_3$)$_2$].

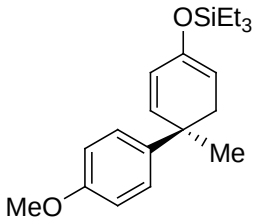
^{13}C NMR (C_6D_6, 125 MHz): δ 148.2, 146.3, 138.8, 135.4, 129.1, 126.4, 125.6, 100.5, 38.87, 38.73, 26.6, 20.9, 7.0, and 5.4.

GC-MS (5029017): R_t = 12.47 min, m/z 314 [$(M)^+$, 100], 299 [$(M–CH_3)^+$, 40], 284 (40), 271 (70), 241 (10) and 191 (10).

IR (neat): 3021 (w), 2955 (m), 2875 (m), 1650 (s), 1595 (w), 1512 (m), 1457 (m), 1398 (m), 1218 (s), 1187 (s), 1016 (m), 891 (s), 812 (s), 722 (s), and 536 (m) cm^{-1}.

HRMS (ESI/TOF): Calcd for $(C_{19}H_{29}OSi)^+$: 301.1982. Found: 301.2021.

(*R*)-Triethyl((4'-methoxy-1-methyl-1,2-dihydro-[1,1'-biphenyl]-4-yl)oxy)silane (7c)



Yield: 141 mg, 86% (colorless clear liquid). Purified by MPLC (hexanes/EtOAc = 100:1)

TLC: R_f = 0.8 in hexanes/EtOAc = 100:1.

^{1}H NMR (C_6D_6, 500 MHz,): δ 7.27 (d, *J* = 8.8 Hz, 1H, Ar-*H*), 6.81 (d, *J* = 8.8 Hz, 1H, Ar-*H*), 5.95 [dd, *J* = 10.0, 2.1 Hz, 1H, CH=*CH*C(OSiEt$_3$)], 5.80 [d, *J* = 10.0 Hz, 1H, C*H*=CHC(OSiEt$_3$)], 4.86 [ddd, *J* = 4.8, 4.5, 2.1 Hz, 1H, (OSiEt$_3$)C=C*H*CH$_2$], 3.35 (s, 3H, Ar-OC*H*$_3$), 2.66 [dd, *J* = 16.8, 4.5 Hz, 1H, (OSiEt$_3$)C=CHC*H*$_a$H$_b$], 2.34 [dd, *J* = 16.8, 4.8 Hz, 1H, (OSiEt$_3$)C=CHCH$_a$*H*$_b$], 1.38 (s, 3H, CC*H*$_3$), 1.0 [app t, *J* = 8.0 Hz, 9H, OSi(CH$_2$C*H*$_3$)$_2$], and 0.66 [m, 6H, OSi(CH$_2$CH$_3$)$_2$].

^{13}C NMR (C_6D_6, 125 MHz): δ 158.5, 148.2, 141.1, 138.9, 127.5, 125.6, 113.8, 100.5, 54.8, 38.8, 38.5, 26.8, 7.0, and 5.4.

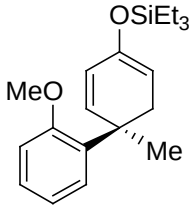
This NMR includes corresponding over-reduced silyl enol ether (ca. 10%).

GC-MS (5029017): R_t = 12.88 min, m/z 330[$(M)^+$, 100], 316 [$(M–CH_3)^+$, 40], 300 [$(M–OCH_3)^+$, 40], , 258 (50), 222 (10), and 196 (10).

IR (neat): 3037 (w), 2911 (m), 2875 (m), 1650 (s), 1609 (w), 1510 (s), 1459 (m), 1398 (m), 1246 (s), 1179 (s), 1035 (s), 890 (s), 825 (s), and 726 (s) cm^{-1}.

HRMS (ESI/TOF): Calcd for $(C_{19}H_{29}OSi)^+$: 301.1982. Found: 301.2021.

(*R*)-Triethyl((2'-methoxy-1-methyl-1,2-dihydro-[1,1'-biphenyl]-4-yl)oxy)silane (7f)



Yield: 148 mg, 90% (colorless clear liquid). Purified by MPLC (hexanes/EtOAc = 100:1)

TLC: R_f = 0.8 in hexanes/EtOAc = 100:1.

^{1}H NMR (C_6D_6, 500 MHz,): δ 7.31 (dd, *J* = 7.5, 1.3 Hz, 1H, Ar-*H*), 7.09 (ddd, *J* = 8.0, 7.5, 1.3 Hz, 1H, Ar-*H*), 6.85 (ddd, *J* = 7.5, 7.5, 1.3 Hz, 1H, Ar-*H*), 6.57 (dd, *J* = 8.0, 1.3 Hz, 1H, Ar-

H), 6.1 [d, *J* = 10.0 Hz, 1H, C*H*=CHC(OSiEt$_3$)], 5.89 [dd, *J* = 10.0, 2.1 Hz, 1H, CH=C*H*C(OSiEt$_3$)], 4.98 [ddd, *J* = 4.6, 4.4, 2.1 Hz, 1H, (OSiEt$_3$)C=C*H*CH$_2$], 3.29 (s, 3H, Ar-OC*H*$_3$), 3.03 [dd, *J* = 16.6, 4.6 Hz, 1H, (OSiEt$_3$)C=CHC*H*$_a$H$_b$], 2.38 [dd, *J* = 16.7, 4.4 Hz, 1H, (OSiEt$_3$)C=CHCH$_a$*H*$_b$], 1.59 (s, 3H, CC*H*$_3$), 0.97 [app t, *J* = 8.0 Hz, 9H, OSi(CH$_2$C*H*$_3$)$_2$], and 0.63 [m, 6H, OSi(CH$_2$CH$_3$)$_2$].

^{13}C NMR (C$_6$D$_6$, 125 MHz): δ 158.4, 148.2, 139.6, 135.7, 127.80, 127.68, 123.8, 120.5, 112.0, 101.4, 54.6, 38.5, 35.7, 25.6, 7.0, and 5.4.

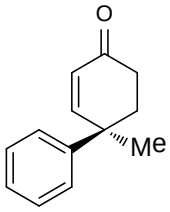
This NMR includes corresponding over-reduced silyl enol ether (ca. 10%).

GC-MS (5029017): R$_t$ = 15.91 min, m/z 331 [(M+H)$^+$, 100], 316 [(M–CH$_3$)$^+$, 40], 300 [(M–OCH$_3$)$^+$, 40], , 273 (10), 223 (10), and 196 (10).

IR (neat): 3046 (w), 2910 (m), 2833 (m), 1650 (s), 1597 (w), 1488 (m), 1459 (m), 1398 (m), 1234 (m), 1185 (m), 1028 (m), 877 (m), and 741 (s) cm^{-1}.

HRMS (ESI/TOF): Calcd for (C$_{19}$H$_{29}$OSi)$^+$: 301.1982. Found: 301.2021.

(*R*)-1-Methyl-2,3-dihydro-[1,1'-biphenyl]-4(1*H*)-one (2a)



Procedure for reaction at 1.0 mmol scale: CuCl (2.5 mg, 2.5 mol %), NaO^{t}Bu (2.4 mg, 2.5 mol %) and (*R*,*R*)-Ph-BPE (12.6 mg, 2.5 mol %) were added to an oven dried vial equipped with PTFE red rubber septa lined cap in a glove box. The vial was taken back to a hood and toluene (1.0 mL) was added under a N$_2$ atmosphere. The reaction mixture was stirred for 10 min at room temperature prior to cooled to ice bath temperature. Silane (1.1 mmol) and cyclohexadienone (1.0 mmol, 1M solution in toluene) was added to the reaction mixture. The reaction mixture was stirred for 4 h at 40 °C (reaction progress was monitored by HPLC) before cooled down to room temperature and treated with TBAF (1.2 mL, 1.2 mmol, 1 M solution in THF) and stirred for 30 min at room temperature. The crude mixture was quenched with brine and extracted into ether (3X). The organic layer was dried over anhydrous MgSO$_4$, filtered through Celite® and the volatiles were removed *in vacuo* to afford the crude product. The crude mixture was purified by MPLC (hexanes:EtOAc = 5:1) to provide enantio-enriched 4-methyl-4-phenylcyclohex-2-enone

(162 mg, 87%, colorless clear liquid). Separation of enantiomers by Chiral HPLC [Daicel ChiralPak IA column, 250 x 4.6 mm, 5 um, flow rate 1.0 mL/min, 1% iPrOH, 99% hexane, Tminor: 13.3 min (S), Tmajor: 16.2 min (R),] provided the product with 96% ee.

TLC: R_f = 0.5 in hexanes/EtOAc = 5:1.

^{1}H NMR ($CDCl_3$, 500 MHz,): δ 7.37-7.32 (m, 4H, Ar-*H*), 7.28-7.24 (m, 1H, Ar-*H*), 6.94 [d, *J* = 10.1 Hz, 1H, C(O)CH=C*H*], 6.13 [d, *J* = 10.2 Hz, 1H, C(O)C*H*=CH], 2.41[ddd, *J* = 16.9, 6.9, 4.0 Hz, 1H, C(O)C$H_a$$H_b$$CH_2$], 2.12-2.45 [m, 2H, C(O)$CH_a$$H_bCH_a$$H_b$], 2.14 [ddd, *J* = 13.2, 10.3, 3.7 Hz, 1H, C(O)$CH_2$$CH_a$$H_b$], and 1.56 (s, 3H, CH=CHCCH_3).

^{13}C NMR ($CDCl_3$, 125 MHz): δ 199.7, 157.3, 145.5, 128.82, 128.77, 127.0, 126.4, 40.8, 38.3, 34.8, and 27.8.

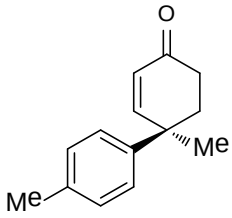
$[\alpha]_D^{25}$ = +79.9 (c = 1.3, MeOH)

GC-MS (5029017): R_t = 10.11 min, m/z 187 [$(M+H)^+$, 100], 186 [$(M)^+$, 30], 171 [$(M–CH_3)^+$, 20], 158 (40), 144 (50), and 128 (45).

IR (neat): 3057 (w), 2961 (m), 1676 (s), 1599 (w), 1493 (m), 1415 (m), 1372 (w), 1206 (m), 1071 (m), 1029 (m), 864(m), 761 (s), 689 (s) and 544 (s) cm^{-1}.

HRMS (ESI/TOF): Calcd for $(C_{13}H_{15}O)^+$: 187.1117. Found: 187.1089.

(*R*)-Triethyl((1-methyl-1,2-dihydro-[1,1'-biphenyl]-4-yl)oxy)silane (2b)



Yield: 85 mg, 85% (colorless clear liquid). Purified by MPLC (hexanes/EtOAc = 5:1) Separation of enantiomers by Chiral HPLC [Daicel ChiralPak IE column, 250 x 4.6 mm, 5 um, flow rate 1.0 mL/min, 10% EtOH, 90% hexane, Tminor: 11.2 min (S), Tmajor: 13.3 min (S),] provided the product with 91% ee.

TLC: R_f = 0.5 in hexanes/EtOAc = 5:1.

^{1}H NMR ($CDCl_3$, 500 MHz,): δ 7.23 (d, *J* = 8.3 Hz, 2H, Ar-*H*), 7.16 (d, *J* = 8.1 Hz, 2H, Ar-*H*), 6.93 [d, *J* = 10.2 Hz, 1H, C(O)CH=C*H*], 6.12 [d, *J* = 10.2 Hz, 1H, C(O)C*H*=CH], 2.39 [ddd, *J* = 16.9, 6.9, 4.8 Hz, 1H, C(O)C$H_a$$H_b$$CH_2$], 2.34 (s, 3H, Ar-C$H_3$), 2.32-2.21 [m, 2H,

C(O)CH$_a$*H*$_b$C*H*$_a$H$_b$], 2.12 [ddd, *J* = 13.4, 10.5, 4.9 Hz, 1H, C(O)CH$_2$CH$_a$*H*$_b$], and 1.54 (s, 3H, CH=CHCC*H*$_3$).

^{13}C NMR (CDCl$_3$, 125 MHz): δ 199.8, 157.6, 142.4, 136.6, 129.5, 128.6, 126.3, 40.5, 38.3, 34.8, 27.9, and 21.1.

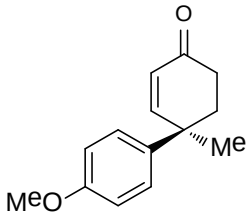
$[\alpha]_D^{25}$ = +110.8 (c = 1.3, MeOH)

GC-MS (5029017): R$_t$ = 10.56 min, m/z 201 [(M+H)$^+$, 100], 185 [(M–CH$_3$)$^+$, 20], 170 [(M–2CH$_3$)$^+$, 20], 158 (30), and 142 (30).

IR (neat): 3022 (w), 2959 (m), 2892 (m), 1677 (s), 1580 (w), 1512 (m), 1415 (s), 1370 (m), 1204 (s), 1070 (s), 991 (s), 814 (s), and 551 (s) cm^{-1}.

HRMS (ESI/TOF): Calcd for (C$_{14}$H$_{17}$O)$^+$: 200.1201. Found: 201.1234.

(*R*)-4'-methoxy-1-methyl-2,3-dihydro-[1,1'-biphenyl]-4(1*H*)-one (2c)



Yield: 86 mg, 80% (colorless clear liquid). Purified by MPLC (hexanes/EtOAc = 3:1)
Separation of enantiomers by Chiral HPLC [Daicel ChiralPak IA column, 250 x 4.6 mm, 5 um, flow rate 1.0 mL/min, 1% iPrOH, 99% hexane, Tminor: 14.3 min (S), Tmajor: 15.1 min (R),] provided the product with 95% ee.

TLC: R$_f$ = 0.5 in hexanes/EtOAc = 3:1.

^{1}H NMR (CDCl$_3$, 500 MHz,): δ 7.25 (d, *J* = 8.8 Hz, 2H, Ar-*H*), 6.90 [d, *J* = 10.1 Hz, 1H, C(O)CH=C*H*], 6.88 (d, *J* = 8.8 Hz, 2H, Ar-*H*), 6.10 [d, *J* = 10.1 Hz, 1H, C(O)C*H*=CH], 3.8 (s, 3H, Ar-OC*H*$_3$), 2.39 [ddd, *J* = 16.9, 6.9, 4.6 Hz, 1H, C(O)C*H*$_a$H$_b$CH$_2$], 2.28 [ddd, *J* = 16.9, 10.5, 4.6 Hz, 1H, C(O) CH$_a$*H*$_b$CH$_2$], 2.31-2.18 [m, 1H, C(O) CH$_2$CH$_b$*H*$_a$], 2.11 [ddd, *J* = 13.5, 10.5, 4.6 Hz, 1H, C(O)CH$_2$CH$_a$*H*$_b$], and 1.53 (s, 3H, CH=CHCC*H*$_3$).

The NMR includes cyclohexanone (reduction product, 6%).

^{13}C NMR (CDCl$_3$, 125 MHz): δ 199.8, 158.5, 157.6, 137.3, 128.6, 127.4, 114.1, 55.5, 40.2, 38.4, 34.8, and 27.9.

$[\alpha]_D^{25}$ = +128.8 (c = 1.07, MeOH)

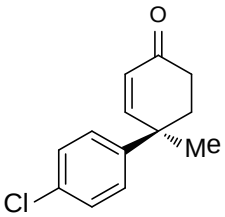
Melting range: 45-47 °C.

GC-MS (5029017): R_t = 11.45 min, m/z 217 [$(M+H)^+$, 100], 201 [$M-CH_3)^+$, 60], 185 [$(M-OCH_3)^+$, 20], 188 (35), 173 (60), 158(40), and 131 (10).

IR (neat): 2944 (w), 1663 (s), 1607 (s), 1509 (s), 1459 (m), 1406 (m), 1300 (m), 1268 (s), 1247 (s), 1180 (s), 1111 (s), 1027 (s), 928 (m), 868 (s), 774 (s), 650 (m), 554 (s) 470 9m), and 399 (s) cm^{-1}.

HRMS (ESI/TOF): Calcd for $(C_{14}H_{17}O_2)^+$: 217.1223. Found: 217.1198.

(*R*)-4'-Chloro-1-methyl-2,3-dihydro-[1,1'-biphenyl]-4(1*H*)-one (2d)



Yield: 75 mg, 68% (colorless clear liquid). Purified by MPLC (hexanes/EtOAc = 3:1)
Separation of enantiomers by Chiral HPLC [Daicel ChiralPak IE column, 250 x 4.6 mm, 5 um, flow rate 1.0 mL/min, 10% EtOH, 90% hexane, Tmajor: 8.0 min (R), Tminor: 10.6 min (S),] provided the product with 88% ee.

TLC: R_f = 0.4 in hexanes/EtOAc = 3:1.

^{1}H NMR ($CDCl_3$, 500 MHz,): δ 7.29 (d, *J* = 8.8 Hz, 2H, Ar-*H*), 7.25 (d, *J* = 8.8 Hz, 2H, Ar-*H*), 6.87 [d, *J* = 10.2 Hz, 1H, C(O)CH=C*H*], 6.10 [d, *J* = 10.2 Hz, 1H, C(O)CH=C*H*], 2.38 [ddd, *J* = 16.9, 6.7, 4.0 Hz, 1H, C(O)C$H_a$$H_b$$CH_2$], 2.26-2.17 [m, 2H, C(O) $CH_a$$H_bCH_a$$H_b$], 2.11 [ddd, *J* = 13.5, 10.5, 4.0 Hz, 1H, C(O)$CH_2$$CH_a$$H_b$], and 1.52 (s, 3H, CH=CHCCH_3).

^{13}C NMR ($CDCl_3$, 125 MHz): δ 199.2, 156.5, 144.0, 132.9, 129.0, 128.0, 127.8, 40.5, 38.2, 34.7, and 27.7.

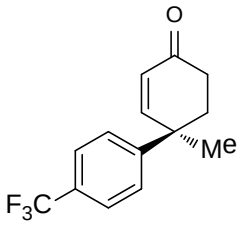
$[\alpha]_D^{25}$ = +99.6 (c = 1.5, MeOH)

GC-MS (5029017): R_t = 11.21 min, m/z 221 [$(M+H)^+$, 100], 205 [$(M–CH_3)^+$, 10], 192 (30), 178 (40), 157 (30), 142 (30) and 128 (50).

IR (neat): 3022 (m), 2977 (m), 2937 (m), 1675 (s), 1486 (s), 1417 (m), 1373 (m), 1324 (m), 1221 (s), 1179 (m), 1118 (m), 1093 (s), 1008 (s), 820 (s), 804 (s), 730 (s), 547 (s), 490 (s), 460 (s) and 417 (s) cm-1.

HRMS (ESI/TOF): Calcd for $(C_{13}H_{14}ClO)^+$: 221.0728. Found: 221.0717.

(*R*)-1-Methyl-4'-(trifluoromethyl)-2,3-dihydro-[1,1'-biphenyl]-4(1*H*)-one (2e)



Yield: 105 mg, 83% (colorless clear liquid). Purified by MPLC (hexanes/EtOAc = 3:1) Separation of enantiomers by Chiral HPLC [Daicel ChiralPak IA column, 250 x 4.6 mm, 5 um, flow rate 1.0 mL/min, 1% iPrOH, 99% hexane, Tminor: 11.0 min (S), Tmajor: 11.9 min (R),] provided the product with 87% ee.

TLC: R_f = 0.5 in hexanes/EtOAc = 3:1.

^{1}H NMR ($CDCl_3$, 500 MHz,): δ 7.60 (d, *J* = 8.2 Hz, 2H, Ar-*H*), 7.40 (d, *J* = 8.2 Hz, 2H, Ar-*H*), 6.91 [d, *J* = 10.2, Hz, 1H, C(O)CH=C*H*], 6.16 [d, *J* = 10.2 Hz, 1H, C(O)C*H*=CH], 2.43 [ddd, *J* = 12.9, 9.1, 6.3, Hz, 1H, C(O)C$H_a$$H_b$$CH_2$], 2.28-2.21 [m, 2H, C(O) $CH_a$$H_bCH_a$$H_b$], 2.17 [ddd, *J* = 12.9, 9.1, 6.3 Hz, 1H, C(O)$CH_2$$CH_a$$H_b$], and 1.58 (s, 3H, CH=CHCCH_3).

^{13}C NMR ($CDCl_3$, 125 MHz): δ 199.0, 156.0, 149.7, 129.4 ($^2J_{F\text{-}C}$ = 32.5 Hz), 129.3, 126.8, 125.8 ($^3J_{F\text{-}C}$ = 3.6 Hz), 124.3 ($^1J_{F\text{-}C}$ = 271.8 Hz), 40.9, 38.2, 34.7, and 27.7.

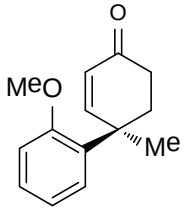
$[\alpha]_D^{25}$ = +68.5 (c = 1.2, MeOH)

GC-MS (5029017): R_t = 9.99 min, m/z 255 [$(M+H)^+$, 100], 235 [$(M–F)^+$, 10], 226 (20), 212 (40), 191 (20), 157 (20), and 128 (30).

IR (neat): 2967 (w), 1680 (s) 1616 (m), 1410 (w), 1322 (s), 1163 (s), 1115 (s), 1076 (s), 1014 (s), 837 (s), 793 (m), 696 (m), 607 (m) and 406 (m) cm-1.

HRMS (ESI/TOF): Calcd for $(C_{14}H_{14}F_3O)^+$: 255.0991. Found: 255.0934.

(*R*)-2'-Methoxy-1-methyl-2,3-dihydro-[1,1'-biphenyl]-4(1*H*)-one (2f)



Yield: 91 mg, 85% (colorless clear liquid). Purified by MPLC (hexanes/EtOAc = 5:1)

Separation of enantiomers by Chiral HPLC [Daicel ChiralPak IA column, 250 x 4.6 mm, 5 um, flow rate 1.0 mL/min, 1% iPrOH, 99% hexane, Tminor: 9.6 min (S), Tmajor: 10.3 min (R),] provided the product with 91% ee.

TLC: R_f = 0.5 in hexanes/EtOAc = 5:1.

^{1}H NMR ($CDCl_3$, 500 MHz,): δ 7.28-7.21 (m, 2H, Ar-*H*), 7.08 [d, *J* = 10.1 Hz, 1H, C(O)CH=C*H*], 6.93-6.90 (m, 2H, Ar-*H*), 6.0 [d, *J* = 10.1 Hz, 1H, C(O)C*H*=CH], 3.82 (s, 3H, Ar-OCH_3), 2.76 [ddd, *J* = 12.3, 7.7, 4.5, Hz, 1H, C(O)CH_aH$_b$CH$_2$], 2.45 [ddd, *J* = 12.3, 7.7, 4.5, Hz, 1H, C(O)CH$_a$$H_bCH_2$], 2.31 [ddd, *J* = 14.3, 9.6, 4.6 Hz, 1H, C(O)CH$_2$CH_aH$_b$], 1.96 [ddd, *J* = 13.6, 9.6, 4.6 Hz, 1H, C(O)CH$_2$CH$_a$$H_b$], and 1.58 (s, 3H, CH=CHCCH_3).

^{13}C NMR ($CDCl_3$, 125 MHz): δ 200.3, 159.8, 158.1, 132.9, 128.5, 128.0, 126.9, 120.7, 112.0, 55.2, 40.3, 35.3, 34.3, and 26.1.

$[\alpha]_D^{25}$ = +79.9 (c = 1.0, MeOH)

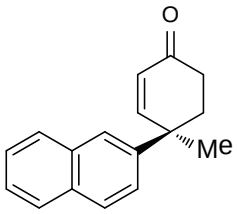
Melting range: 64-66 °C.

GC-MS (5029017): R_t = 11.45 min, m/z 217 [$(M+H)^+$, 100], 201 [$(M–CH_3)^+$, 60], 185 [$(M-OCH_3)^+$, 20], 174 (15), 158 (10), and 131 (15).

IR (neat): 2955 (m), 2869 (m), 1674 (s), 1596 (m), 1580 (m), 1488 (s), 1459 (s), 1435 (s), 1367 (m), 1289 (m), 1241 (s), 1231 (s), 1179 (s), 1109 (m), 1072 (m), 1023 (s), 865 (m), 801 (m), and 751 (s) cm-1.

HRMS (ESI/TOF): Calcd for $(C_{14}H_{17}O_2)^+$: 217.1223. Found: 217.1190.

(*R*)-4-Methyl-4-(naphthalen-2-yl)cyclohex-2-enone (2g)



Yield: 85 mg, 72% (colorless clear liquid). Purified by MPLC (hexanes/EtOAc = 5:1)

Separation of enantiomers by Chiral HPLC [Daicel ChiralPak IA column, 250 x 4.6 mm, 5 um, flow rate 1.0 mL/min, 1% iPrOH, 99% hexane, Tminor: 13.3 min (S), Tmajor: 16.2 min (R),] provided the product with 92% ee.

TLC: R_f = 0.5 in hexanes/EtOAc = 5:1.

^{1}H NMR ($CDCl_3$, 500 MHz,): δ 7.80-7.89 (m, 3H, Ar-*H*), 7.73 (d, *J* = 1.8 Hz, 2H, Ar-*H*), 7.52-7.47 (m, 3H, 1H, Ar-*H*), 7.07 [d, *J* = 10.2 Hz, 1H, C(O)CH=C*H*], 6.21 [d, *J* = 10.2 Hz, 1H, C(O)C*H*=CH], 2.36-2.46 (ddd, *J* = 15.9, 6.2, 3.7 Hz, 1H, C(O) C$H_aH_bCH_2$], 2.41-2.35 (m, 1H, C(O) C$H_aH_bCH_2$), 2.33-2.27 [nfom, 1H, C(O)CH_2CH_aH_b], 2.21 [ddd, *J* = 12.6, 9.6, 3.7 Hz, 1H, C(O)CH_2 CH_aH_b), and 1.65 (s, 3H, CH=CHCCH_3).

^{13}C NMR ($CDCl_3$, 125 MHz): δ 199.7, 157.2, 142.6, 133.3, 132.3, 128.9, 128.7, 128.1, 127.6, 126.5, 126.2, 125.1, 124.5, 40.9, 38.0, 34.8, and 27.9.

The NMR includes cyclohexanone (reduction product, 5% by HPLC analysis).

$[\alpha]_D^{25}$ = +203.8 (c = 1.0, MeOH).

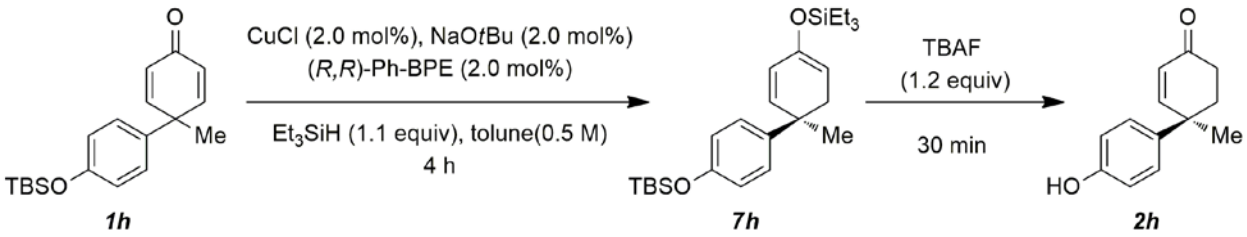
Melting range: 60-62 °C.

GC-MS (5029017): R_t = 13.37 min, m/z 217 $[(M+H)^+$, 100], 221 $[(M-CH_3)^+$, 25], 208 (25), 194 (30), 178 (80), 165 (60), and 152 (25).

IR (neat): 3051 (w), 3022 (m), 2961 (m), 2924 (m), 1702 (m), 1672 (s), 1503 (m), 1457 (m), 1412 (m), 1387 (m), 1321 (m), 1212 (m), 1195 (s), 1129 (s), 1063 (m), 962 (m), 885 (s), 821 (s), 753 (s), 653 (m), 477 (s), and 424 (s) cm-1.

HRMS (ESI/TOF): Calcd for $(C_{17}H_{17}O)^+$: 237.1274. Found: 237.1225.

(*R*)-4'-Hydroxy-1-methyl-2,3-dihydro-[1,1'-biphenyl]-4(1*H*)-one (2h)



Yield: 62 mg, 62% (off-white solid). Purified by MPLC (hexanes/EtOAc = 3:1)

Separation of enantiomers by Chiral HPLC [Daicel ChiralPak IE column, 250 x 4.6 mm, 5 um, flow rate 1.0 mL/min, 15% EtOH, 85% hexane, Tmajor: 9.9 min (R), Tminor: 10.8 min (S),] provided the product with 77% ee.

TLC: R_f = 0.3 in hexanes/EtOAc = 3:1.

^{1}H NMR ($CDCl_3$, 500 MHz,): δ 7.18 (d, *J* = 8.6 Hz, 2H, Ar-*H*), 6.93 (d, *J* = 8.6 Hz, 2H, Ar-*H*), 6.82 [d, *J* = 10.1 Hz, 1H, C(O)CH=C*H*], 6.12 [d, *J* = 10.1 Hz, 1H, C(O)C*H*=CH], 5.83 (br s,

O*H*), 2.41 [ddd, *J* = 17.1, 6.6, 4.6 Hz, 1H, C(O)C*H*$_a$H$_b$CH$_2$], 2.30 [ddd, *J* = 17.1, 10.5, 4.6 Hz, 1H, C(O) CH$_a$*H*$_b$CH$_2$], 2.27-2.22 [m, 1H, C(O)CH$_2$C*H*$_a$H$_b$], 2.11 [ddd, *J* = 13.5, 10.6, 4.6 Hz, 1H, C(O)CH$_2$CH$_a$*H*$_b$], and 1.53 (s, 3H, CH=CHCC*H*$_3$).

^{13}C NMR ($CDCl_3$, 125 MHz): δ 200.6, 158.3, 154.8, 137.0, 128.3, 127.5, 115.6, 40.1, 38.2, 34.7, and 27.8

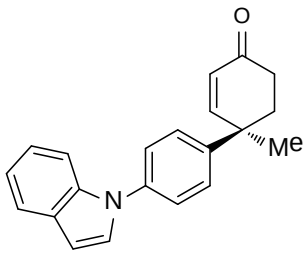
$[\alpha]_D^{25}$ = +78.6 (c = 1.0, MeOH)

GC-MS (5029017): R_t = 11.80 min, m/z 203 [$(M+H)^+$, 100], 187 [$(M-CH_3)^+$, 45], 174 (25), 159 (30), 145 (30), and 131 (30).

IR (neat): 3247 (b), 2960 (m), 1646 (s), 1613 (s), 1594 (s), 1510 (s), 1442 (s), 1391 (m), 1260 (s), 1230 (s), 1207 (s), 1174 (s), 1116 (s), 870 (m), 835 (s), 780 (s), 717 (b), 557 (s), 533 (m), and 403 (s) cm-1.

HRMS (ESI/TOF): Calcd for $(C_{17}H_{17}O)^+$: 202.0994. Found: 202.0961

(*R*)-4'-(1*H*-indol-1-yl)-1-Methyl-2,3-dihydro-[1,1'-biphenyl]-4(1*H*)-one (2i)



Yield: 90 mg, 60% (off-white solid). Purified by MPLC (hexanes/EtOAc = 3:1)

Separation of enantiomers by Chiral HPLC [Daicel ChiralPak IE column, 250 x 4.6 mm, 5 um, flow rate 1.0 mL/min, 15% EtOH, 85% hexane, Tmajor: 9.9 min (R), Tminor: 14.0 min (S),] provided the product with 90% ee.

TLC: R_f = 0.4 in hexanes/EtOAc = 3:1.

^{1}H NMR ($CDCl_3$, 500 MHz,): δ 7.69 (d, *J* = 7.8 Hz, 1H, indole-*H4* or *H7*), 7.57 (d, *J* = 8.2 Hz, 1H, indole-*H7* or *H4*), 7.53-7.47 (m, 4H, Ar-*H*), 7.33 (d, *J* = 3.3 Hz, 1H, indole-*H2*), 7.23 (dd, *J* = 8.1, 8.1 Hz, 1H, indole-*H5* or *H6*), 7.18 (dd, *J* = 7.6 Hz, 1H, indole-*H6* or *H5*), 6.97 [d, *J* = 10.1 Hz, 1H, C(O)CH=C*H*], 6.69 (d, *J* = 3.3 Hz, 1H, indole-*H3*), 6.18 [d, *J* = 10.1 Hz, 1H, C(O)C*H*=CH], 2.47 [ddd, *J* = 17.0, 6.9, 4.0 Hz, 1H, C(O)C*H*$_a$H$_b$CH$_2$], 2.39-2.29 [m, 2H, C(O)CH$_a$*H*$_b$C*H*$_a$H$_b$], 2.21 [ddd, *J* = 14.7, 10.4, 4.0 Hz, 1H, C(O)CH$_2$CH$_a$*H*$_b$], and 1.63 (s, 3H, CH=CHCC*H*$_3$).

The NMR includes cyclohexanone (reduction product, 15% by HPLC analysis).

^{13}C NMR ($CDCl_3$, 100 MHz): δ 199.35, 156.72, 143.69, 138.67, 135.98, 129.53, 129.03, 128.00, 127.65, 124.53, 122.61, 121.38, 120.63, 110.64, 103.93, 40.63, 38.33, 34.82, 27.86.

$[\alpha]_D^{25}$ = +68.7 (c = 1.2, MeOH).

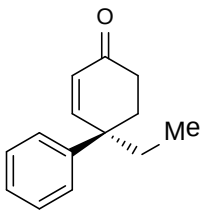
Melting range: 129- 131 °C.

GC-MS (5029017): R_t = 24.23 min, m/z 302 [$(M+H)^+$, 25], 301 [$(M)^+$, 100], 286 [$(M-CH_3)^+$, 80], 273 (15), 258 (25), 243 (15), and 230 (10).

IR (neat): 3042 (w), 2956 (m), 1708 (m), 1674 (s), 1601 (m), 1517 (s), 1455 (s), 1331 (s), 1230 (s), 1211 (s), 1133 (m), 1109 (m), 1008 (m), 838 (s), 762 (m), 744 (s), 719 (s), 586 (s), and 429 (s) cm-1.

HRMS (ESI/TOF): Calcd for $(C_{21}H_{20}NO)^+$: 302.1539. Found: 302.1501.

(*R*)-1-Ethyl-2,3-dihydro-[1,1'-biphenyl]-4(1*H*)-one (2j)



Yield: 78 mg, 78% (colorless clear liquid). Purified by MPLC (hexanes/EtOAc = 5:1)

Separation of enantiomers by Chiral HPLC [Daicel ChiralPak IA column, 250 x 4.6 mm, 5 um, flow rate 1.0 mL/min, 1% iPrOH, 99% hexane, Tminor: 10.5 min (S), Tmajor: 13.8 min (R),] provided the product with 99% ee.

TLC: R_f = 0.4 in hexanes/EtOAc = 5:1.

^{1}H NMR ($CDCl_3$, 500 MHz,): δ 7.37-7.32 (m, 2H, Ar-*H*), 7.29-7.27 (m, 2H, Ar-*H*), 7.26-7.23 (tt, *J* = 7.2, 1.3 Hz, 1H, Ar-*H*), 7.11 [dd, *J* = 10.3, 1.3 Hz, 1H, C(O)CH=C*H*], 6.18 [dd, *J* = 10.3, 0.7 Hz, 1H, C(O)C*H*=CH], 2.39-2.32 [m, 1H, C(O)C$H_a$$H_b$$CH_2$], 2.27-2.17 [m, 3H, C(O) $CH_a$$H_bCH_2$], 1.94 (dq, *J* = 14.1, 7.4 Hz, 1H, $CH_a$$H_b$$CH_3$), 1.85 (dq, *J* = 14.1, 7.4 Hz, 1H, $CH_a$$H_b$$CH_3$), and 0.82 (t, 3H, CCH_2CH_3).

^{13}C NMR ($CDCl_3$, 125 MHz): δ 200.0, 155.8, 143.6, 129.7, 128.8, 126.98, 126.82, 44.4, 35.8, 34.8, 34.4, and 8.9.

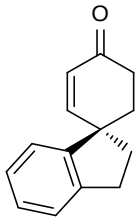
$[\alpha]_D^{25}$ = +56.7 (c = 1.0, MeOH)

GC-MS (5029017): R_t = 10.54 min, m/z 201 [$(M+H)^+$, 100], 171 [$(M-CH_2CH_3)^+$, 20], 158 (25), 128 (60) and 115 (25).

IR (neat): 3057 (w), 2964 (m), 1713 (m), 1678 (s), 1415 (m), 1198 (s), 891 (m), 757 (s), 698 (s), and 563 (s) cm-1.

HRMS (ESI/TOF): Calcd for $(C_{14}H_{17}O)^+$: 201.1274, Found: 201.1241.

(*R*)-2',3'-Dihydrospiro[cyclohex[2]ene-1,1'-inden]-4-one (2k)



Yield: 61 mg, 62% (colorless clear liquid). Purified by MPLC (hexanes/EtOAc = 3:1) Separation of enantiomers by Chiral HPLC [Daicel ChiralPak IA column, 250 x 4.6 mm, 5 um, flow rate 1.0 mL/min, 1% iPrOH, 99% hexane, Tminor: 11.6 min (S), Tmajor: 12.1 min (R),] provided the product with 86% ee.

TLC: R_f = 0.4 in hexanes/EtOAc = 3:1.

^{1}H NMR ($CDCl_3$, 500 MHz,): δ 7.29 (d, *J* = 7.3 Hz, 1H, Ar-*H*), 7.25-7.19 (m, 2H, Ar-*H*), 7.11 (d, *J* = 7.3 Hz, 1H, Ar-*H*), 6.79 [d, *J* = 10.0 Hz, 1H, C(O)CH=C*H*], 6.08 [d, *J* = 10.0 Hz, 1H, C(O)C*H*=CH], 3.07 (ddd, *J* = 16, 9.8, 7.4 Hz, 1H, ArC$H_a$$H_b$$CH_2$), 2.98 (ddd, *J* = 16, 8.7, 2.6 Hz, 1H, ArC$H_a$$H_b$$CH_2$), 2.58-2.46 (m, 2H, Ar$CH_2CH_2$), 2.30 [ddd, *J* = 10.2, 7.5, 2.7 Hz, 1H, C(O)C$H_a$$H_b$$CH_2$], and 2.20-2.08 [m, 3H, C(O)C$H_a$$H_bCH_2$].

^{13}C NMR ($CDCl_3$, 125 MHz): δ 199.9, 156.7, 147.4, 143.3, 128.7, 127.9, 126.9, 125.4, 123.8, 49.8, 37.9, 35.1, 34.0, and 30.6.

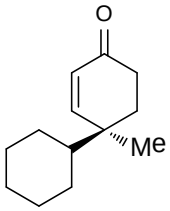
$[\alpha]_D^{25}$ = +111.0 (c = 1.8, MeOH)

GC-MS (5029017): R_t = 10.92 min, m/z 199 [$(M+H)^+$, 100], 170 (70), 156 (35), 141 (80), 128 (25), and 115 (40).

IR (neat): 2964 (s), 1678 (s), 1415 (m), 1198 (s), 891 (m), 757 (s), 698 (s), and 563 (s) cm-1.

HRMS (ESI/TOF): Calcd for $(C_{14}H_{15}O)^+$: 199.1117, Found: 199.1072.

(*S*)-1-Methyl-[1,1'-bi(cyclohexan)]-2-en-4-one (2l)



Yield: 78 mg, 82% (colorless clear liquid). Purified by MPLC (hexanes/EtOAc = 5:1) Separation of enantiomers by Chiral HPLC [Daicel ChiralPak IA column, 250 x 4.6 mm, 5 um, flow rate 0.8 mL/min, 1% iPrOH, 99% hexane, Tmajor: 12.5 min (S), Tminor: 15.1 min (R),] provided the product with 94% ee.

TLC: R_f = 0.4 in hexanes/EtOAc = 5:1.

^{1}H NMR ($CDCl_3$, 500 MHz,): δ 6.72 [d, *J* = 10.3 Hz, 1H, C(O)CH=C*H*], 5.87 [d, *J* = 10.3 Hz, 2H, C(O)C*H*=CH], 2.49-2.38 [m, 2H, C(O)CH_aCH_b], 2.04 [ddd, *J* = 13.5, 10.3, 5.7 Hz, 1H, C(O)CH_2C$H_a$$H_b$], 1.82-1.75 (m, 3H), 1.69-1.62 (m, 3H), 1.37-1.31 (m, 1H, Cy*H*), 1.27-1.17 (m, 2H), 1.66-0.96 (m, 3H), and 1.09 (s, 3H, CH=CHCCH_3).

^{13}C NMR ($CDCl_3$, 125 MHz): δ 200.2, 160.5, 127.4, 47.0, 38.5, 34.3, 30.3, 28.2, 27.3, 27.1, 27.1, 26.7, and 22.4

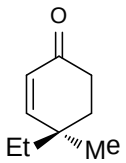
$[\alpha]_D^{25}$ = +31.9 (c = 1.0, MeOH)

GC-MS (5029017): R_t = 10.25 min, m/z 193 [$(M+H)^+$, 100], 177 [$(M-CH_3)^+$, 10], and 110[$(M-Cy)^+$, 30].

IR (neat): 2924 (s), 2851 (s), 1678 (s), 1642 (s), 1448 (m), 1389 (m), 1229 (m), 1182 (m), 1134 (m), 1023 (m), 953 (m), 891 (m) 807 (s), 517 (m) and 413 (w) cm-1.

HRMS (ESI/TOF): Calcd for $(C_{13}H_{21}O)^+$: 193.1587, Found: 193.1547.

(*R*)-4-Ethyl-4-methylcyclohex-2-enone (2m)



Yield: 36 mg, 52% (colorless clear liquid). Purified by MPLC (hexanes/EtOAc = 5:1). Separation of enantiomers by Chiral HPLC [Daicel ChiralPak IA column, 250 x 4.6 mm, 5 um, flow rate 1.0 mL/min, 1% iPrOH, 99% hexane, Tmajor: 8.26 min (R), Tminor: 8.60 min (S),] provided the product with 54% ee.

TLC: R_f = 0.4 in hexanes/EtOAc = 5:1.

^{1}H NMR ($CDCl_3$, 500 MHz,): δ 6.67 [d, *J* = 10.2 Hz, 1H, C(O)CH=C*H*], 5.86 [d, *J* = 10.3 Hz, 1H, C(O)C*H*=CH], 2.49-2.38 [m, 2H, C(O)CH_2CH_2], 1.93 [ddd, *J* = 13.8, 9.3, 5.6 Hz, 1H, C(O)CH_2CH_aH$_b$], 1.75-1.70 [ddddd, *J* = 13.6, 7.1, 5.5, 1.1, 1.1 Hz, 1H, C(O)CH_2CH_a*H*$_b$], 1.54-1.41 (m, 2H, CH_2CH_3), 1.10 (s, CCH_3) and 0.90 (t, *J* = 7.5 Hz, 3H, CH_2C*H*$_3$).

^{13}C NMR ($CDCl_3$, 125 MHz): δ 200.0, 159.6, 127.6, 35.9, 34.3, 33.6, 33.1, 24.4, and 8.6.

$[\alpha]_D^{25}$ = +4.48 (c = 1.0, MeOH)

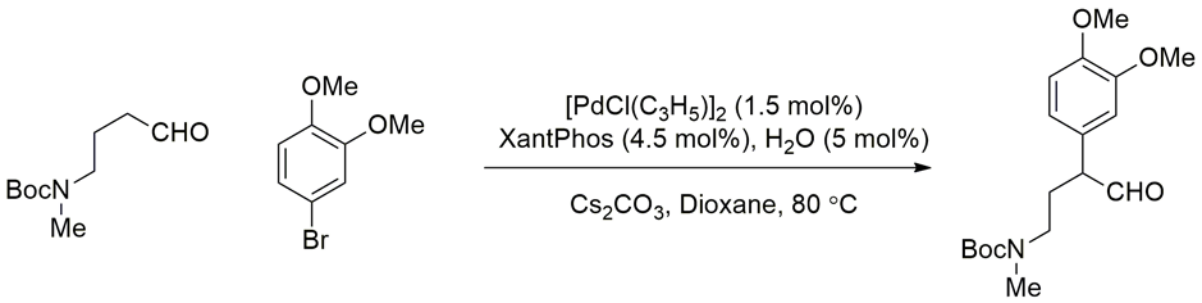
GC-MS (5029017): R_t = 6.77 min, m/z 139 [$(M+H)^+$, 100], 109 [$(M-CH_2CH_3)^+$, 20], 95 (25), and 81 (10).

IR (neat): 2962 (s), 2929 (s), 1672 (s), 1460 (s), 1375 (s), 1262 (s), 1190 (s), 1092 (m), and 802 (s) cm-1.

HRMS (ESI/TOF): Calcd for $(C_9H_{15}O)^+$: 139.1117, Found: 139.1139.

Total Synthesis of (+)-Mesembrine Procedures

Synthesis of *t*-Butyl 3-formyl-3-(3,4-dimethoxyphenyl)propylmethylcarbamate (11)



A two-necked flask containing a stirring bar was charged with $[Pd(allyl)Cl]_2$: (66 mg, 1.5 mol%); XantPhos (312 mg, 4.5 mol%), and anhydrous Cs_2CO_3 (5.47 g, 1.4 eq). The flask was then evacuated and back-filled with nitrogen (this sequence was repeated for total three times). The aldehyde (3.14 g, 15.6 mmol, 1.3 eq), the aryl bromide (2.60 g, 12 mmol, 1.0 eq), dioxane (48 mL) and water (10.8 mg, 5 mol%) were then added by syringe. The resulting mixture was then stirred in a preheated oil bath (80 °C) for 8 h. The mixture was then allowed to cool down to room temperature and diluted with ethyl acetate (30 mL) and filtered through a Celite® plug, eluting with additional ethyl acetate (20 mL). The filtrate was concentrated on rotatory evaporator and the crude was purified by column chromatography on silica gel (Teledyne ISCO 80 g column, eluted with n-heptane/ethyl acetate, gradient 0-80% EtOAc in n-heptane). Product was obtained as colorless oil (2.1 g, 52% yield).

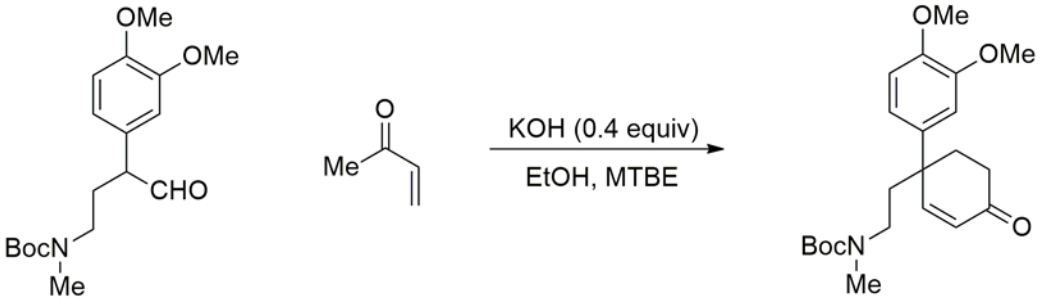
1H NMR (400 MHz, $CDCl_3$) δ 9.65 (s, 1H), 6.88 (d, J = 8.0 Hz, 1H), 6.76 (d, J = 8.0 Hz, 1H), 6.67 (s, 1H), 3.88 (s, 6H), 3.49 (t, J = 6.0 Hz, 1H), 3.23 (s, 2H), 2.82 (s, 3H), 2.37-2.28 (m, 1H); 1.91-1.82 (m, 1H); 1.44 (s, 9H)

13C NMR (100 MHz, $CDCl_3$) δ 199.2, 155.7, 149.4, 148.5, 127.8, 120.9, 111.6, 100.9, 79.3, 55.8, 46.7, 34.2, 34.1, 28.3, 27.5.

IR (thin film): 3054, 2987, 1686, 1422, 1266 cm^{-1}

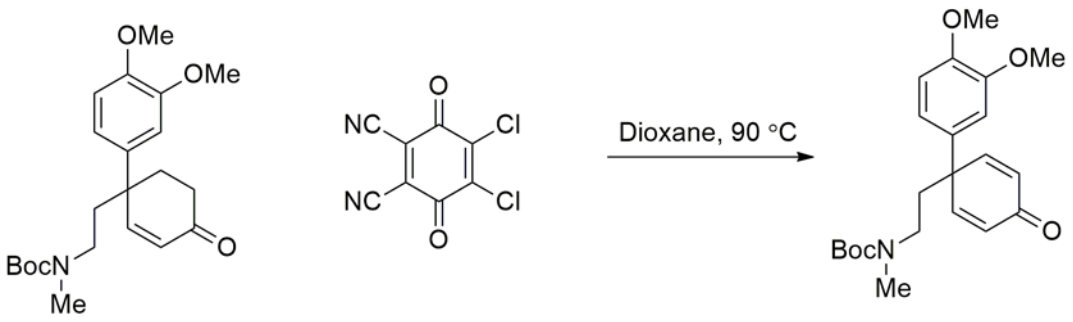
HRMS m/z calcd for C18H27NNaO5 ($M+Na^+$): 360.1787; found: 360.1705.

Synthesis of *t*-Butyl 2-(1-(3,4-dimethoxyphenyl)-4-oxocyclohexa-2,5-dienyl)ethylmethylcarbamate (12)



Freshly prepared potassium hydroxide ethanol solution: dissolving 2.0 g of KOH in 10.0 mL of EtOH. Freshly prepared potassium hydroxide ethanol solution (350 uL, contains 70 mg of KOH, 1.27 mmol, 0.4 eq) was added dropwise under nitrogen at 0 °C to a solution of MVK (212 mg, 3.02 mmol, 1.0 eq) and tert-butyl (3-(3,4-dimethoxyphenyl)-4-oxobutyl)(methyl)carbamate (1.02 g, 3.02 mmol, 1.0 eq) in 5.6 mL of MTBE. The mixture was stirred at 0°C for 2 h then room temperature for 2 h. The reaction mixture was diluted with MTBE (30 mL), washed with aq NH_4Cl (20 mL), water (15 mL) and saturated brine (20 mL). Organic layer was dried over Na_2SO_4. The filtrate was concentrated on rotatory evaporator and the crude product was purified by column chromatography on silica gel (Teledyne ISCO 40 g column, eluted with EtOAc and n-heptane, gradient from 0 to 80% EtOAc in n-heptane). Product was obtained as colorless oil (824 mg, 70%). ^{1}HNMR was included for this known compound.

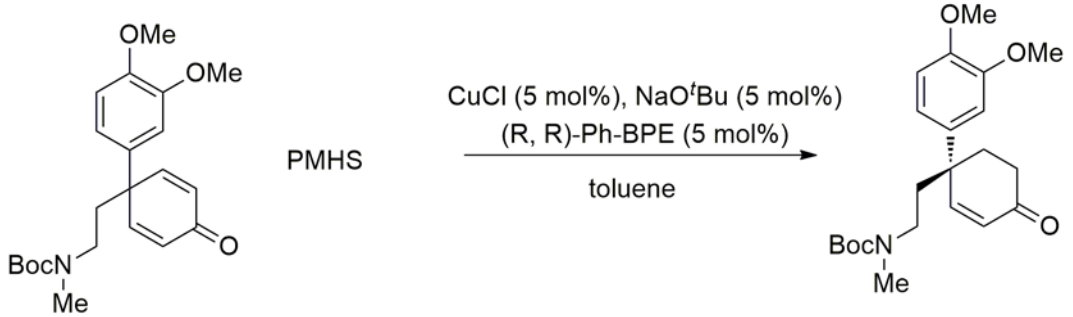
1H NMR (400 MHz, $CDCl_3$): δ 7.09 (d, J = 12.0 Hz, 1H), 6.82 (s, 2H), 6.80 (br, 1H), 6.16 (d, J = 12.0 Hz, 1H), 3.87 (s, 3H), 3.86 (s, 3H), 3.17 (br, 1H), 3.02 (br, 1H), 2.77 (s, 3H), 2.31−2.39 (m, 1H), 2.20−2.31 (m, 3H), 2.05−2.14 (m, 1H), 1.95−2.03 (m, 1H), 1.42 (s, 9H).



To a solution of 2-enone (350 mg, 0.899 mmol) in dioxane (2.2 mL) was added DDQ (306 mg, 1.348 mmol, 1.5 eq) and the resulting mixture was stirred at 90°C for 10 h. The reaction mixture was cooled down to room temperature and diluted with MTBE (30 mL), then washed with NaOH (5% aqueous, 20 mL), water (20 mL) and brine (20 mL). The organic layer was dried over Na_2SO_4. The filtrate was concentrated on rotatory evaporator and the crude product was purified by column chromatography on silica gel (Teledyne ISCO 24 g column, eluted with EtOAc and n-heptane, gradient from 0 to 100% EtOAc in heptane). Product was obtained as yellow oil (279 mg, 80%).

1H NMR (400 MHz, $CDCl_3$) δ 6.90-6.82 (m, 4H), 6.75 (br, 1H), 6.35 (d, J = 8.0 Hz, 2H), 3.86 (s, 3H), 3.84 (s, 3H), 3.15 (br, 2H), 2.84 (s, 3H), 2.31 (t, J = 8.0 Hz, 2H); 1.44 (s, 9H)
13C NMR (100 MHz, $CDCl_3$) δ 186.0, 155.6, 153.7, 149.5, 148.9, 131.5, 128.8, 118.7, 111.7, 110.0, 79.9, 56.2, 56.1, 47.4, 45.4, 34.9, 34.6, 28.6.
IR (thin film): 3054, 2987, 1687, 1667, 1422, 1266 cm^-
HRMS m/z calcd for C22H29NNaO5 ($M+Na^+$): 410.1943; found: 410.1912.

Synthesis of *t*-Butyl 2-((S)-1-(3,4-dimethoxyphenyl)-4-oxocyclohex-2-enyl)ethylmethylcarbamate (13)



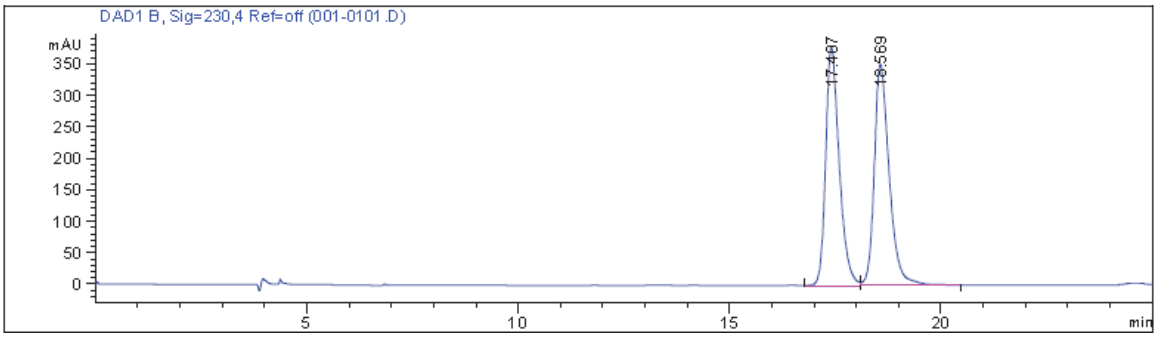
To a vial was added (R, R)-Ph-BPE (12.67 mg, 0.025 mmol) then the vial was transferred to a glovebox, Copper chloride (2.5 mg, 0.025 mmol) and Sodium tert-butoxide (2.4 mg, 0.025 mmol) were added. The vial was sealed before it was removed from the glovebox. Then toluene (0.50 mL) was injected into the vial and the resulting mixture was stirred at room temperature for 20 min. PMHS (36 uL, 0.75 mmol) was added to the solution under nitrogen, the solution was stirred at room temperature for 10 min.

In another vial, a solution of tert-butyl (2-(3',4'-dimethoxy-4-oxo-1,4-dihydro-[1,1'-biphenyl]-1-yl)ethyl)(methyl)carbamate (72 mg, 0.19 mmol) in toluene (0.30 mL) was prepared under N2. The above CuH catalyst solution (200 uL) was added to the substrate solution. The mixture was then stirred at room temperature for 20 h. The reaction mixture was diluted with MTBE (10 mL) and brine (4 mL). Layer was separated; aqueous layer was extracted with MTBE (4 mL). Combined organic extracts were concentrated on rotatory evaporator to about 1 mL. To this was added TBAF (0.22 mmol, 1M in THF) and the resulting solution stirred at room temperature for 1h. The solution was then washed with brine, back-extracted with MTBE and the organic extracts were dried over Na_2SO_4. The filtrate was concentrated on rotatory evaporator and the crude product was purified by column chromatography on silica gel (Teledyne ISCO 4g column, eluted with EtOAc and n-heptane, gradient from 0-80% EtOAc in n-Heptane). Product (59 mg) was obtained as colorless oil (82% yield). Separation of enantiomers by Chiral HPLC [Daicel ChiralPak IB column, 250 x 4.6 mm, 5 um, flow rate 0.60 mL/min, 5% EtOH, 95% hexane, Tminor: 17.0 min (R), Tmajor: 18.0 min (S)] provided the product with (97% ee).

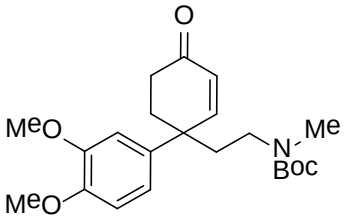
1H NMR (400 MHz, $CDCl_3$): δ 7.09 (d, J = 12.0 Hz, 1H), 6.82 (s, 2H), 6.80 (br, 1H), 6.16 (d, J = 12.0 Hz, 1H), 3.87 (s, 3H), 3.86 (s, 3H), 3.17 (br, 1H), 3.02 (br, 1H), 2.77 (s, 3H), 2.31−2.39 (m, 1H), 2.20−2.31 (m, 3H), 2.05−2.14 (m, 1H), 1.95−2.03 (m, 1H), 1.42 (s, 9H).

13C NMR (100 MHz, $CDCl_3$): δ 199.4, 155.6, 154.7, 149.3, 148.2, 135.2, 129.8, 119.2, 111.3, 110.1, 79.7, 56.2, 56.1, 45.2, 42.7, 39.3, 38.8, 36.4, 34.6, 28.6.

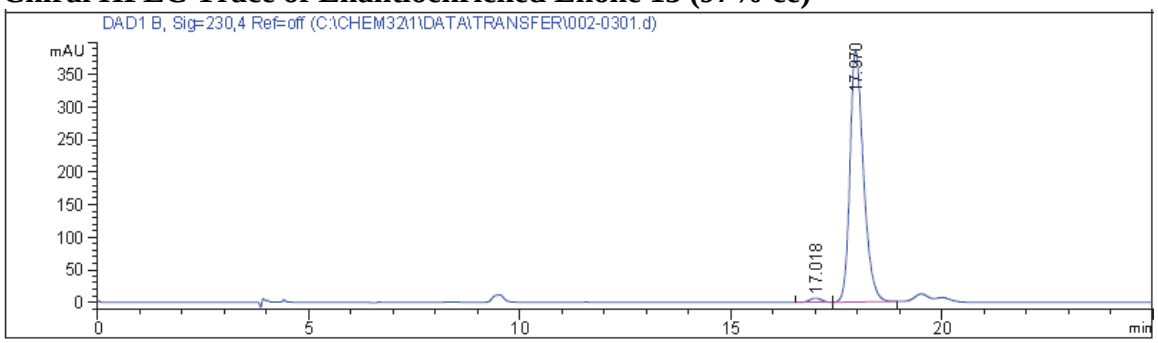
Chiral HPLC Trace of Racemic Enone 13



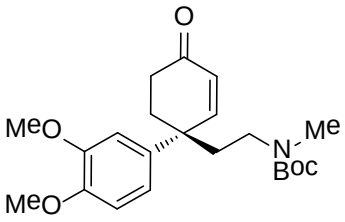
Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	17.407	VV	0.3381	1.37127e4	615.17487	49.5173
2	18.569	VB	0.3697	1.39801e4	570.85040	50.4827



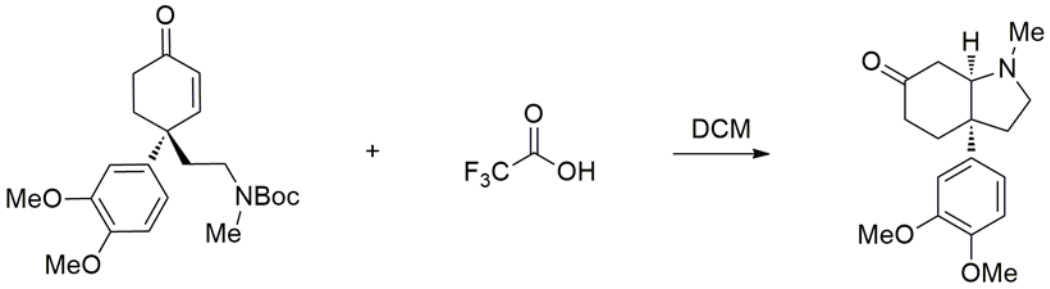
Chiral HPLC Trace of Enantioenriched Enone 13 (97% ee)



Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	17.018	BB	0.2981	123.47170	6.42782	1.4194
2	17.970	BB	0.3366	8575.40625	386.89191	98.5806



Synthesis of (+)-Mesembrine (8)

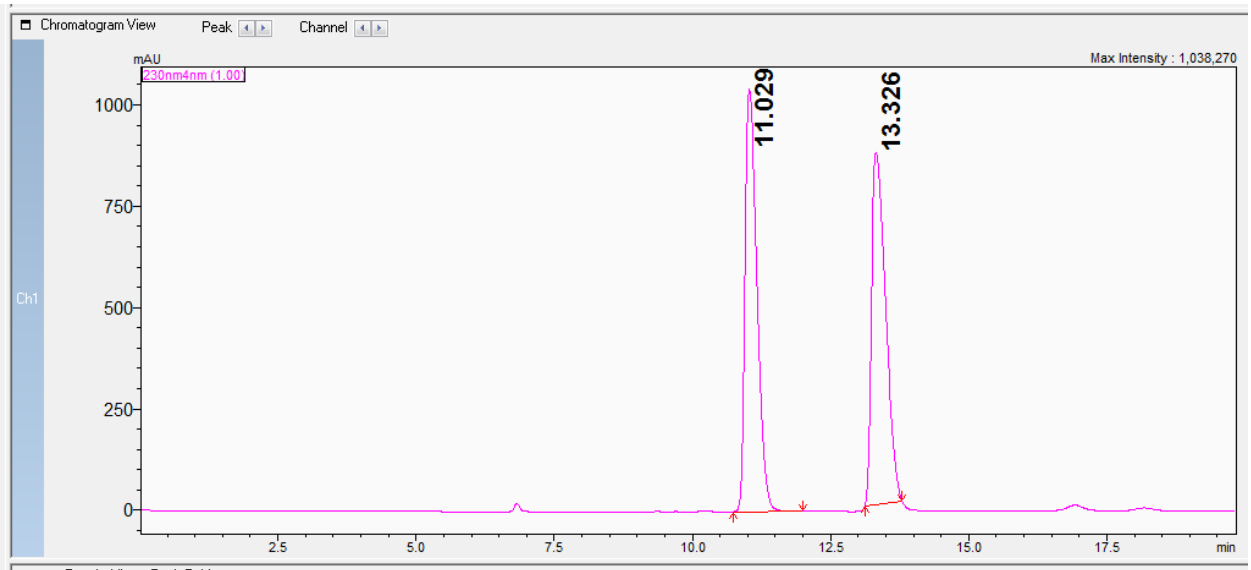


To a solution of tert-butyl (2-(3',4'-dimethoxy-4-oxo-1,2,3,4-tetrahydro-[1,1'-biphenyl]-1-yl)ethyl)(methyl)carbamate (35 mg) in DCM (1.0 mL) was added TFA (400 uL) at 0 °C and the resulting mixture was kept at 0 °C for 20 min before warm to room temperature and incubated for 1 h. Reaction mixture was diluted with DCM (5 mL), basified with sat. $NaHCO_3$ (3 mL), the organic layer was washed with brine (2 mL) and dried over Na_2SO_4. The filtrate was concentrated on rotatory evaporator and the crude product was purified by column chromatography on silica gel (Teledyne ISCO 4g column, eluted with DCM and MeOH, gradient from 0-10%MeOH in DCM). Product (+)-Mesembrine (21 mg) was obtained as colorless oil (81% yield). $[\alpha]_D^{22}$ = +60.5 (c = 0.85, MeOH) (lit[S3] $[\alpha]_D^{23}$ = +56; c = 0.37, MeOH; lit[S4] $[\alpha]_D$ = +58.5; c = 0.04, MeOH).

1H NMR (400 MHz, $CDCl_3$) δ 6.92 (dd, J = 8.0, 4.0 Hz, 1H), 6.89 (d, J = 4.0 Hz, 1H), 6.83 (d, J = 8.0 Hz, 1H), 3.88 (s, 3H), 3.86 (s, 3H), 3.14 (ddd, J = 9.3, 8.0, 4.0 Hz, 1H), 2.94 (t, J = 4.0 Hz, 1H), 2.59 (d, J = 4.0 Hz, 2H), 2.45−2.28 (m, 2H), 2.30 (s, 3H), 2.23−2.02 (m, 5H).

13C NMR (100 MHz, $CDCl_3$) δ 211.5, 149.2, 147.7, 140.4, 118.1, 111.2, 110.2, 70.5, 56.2, 56.1, 55.0, 47.7, 40.7, 40.2, 39.0, 36.4, 35.4.

Chiral HPLC Trace of Racemic 2a

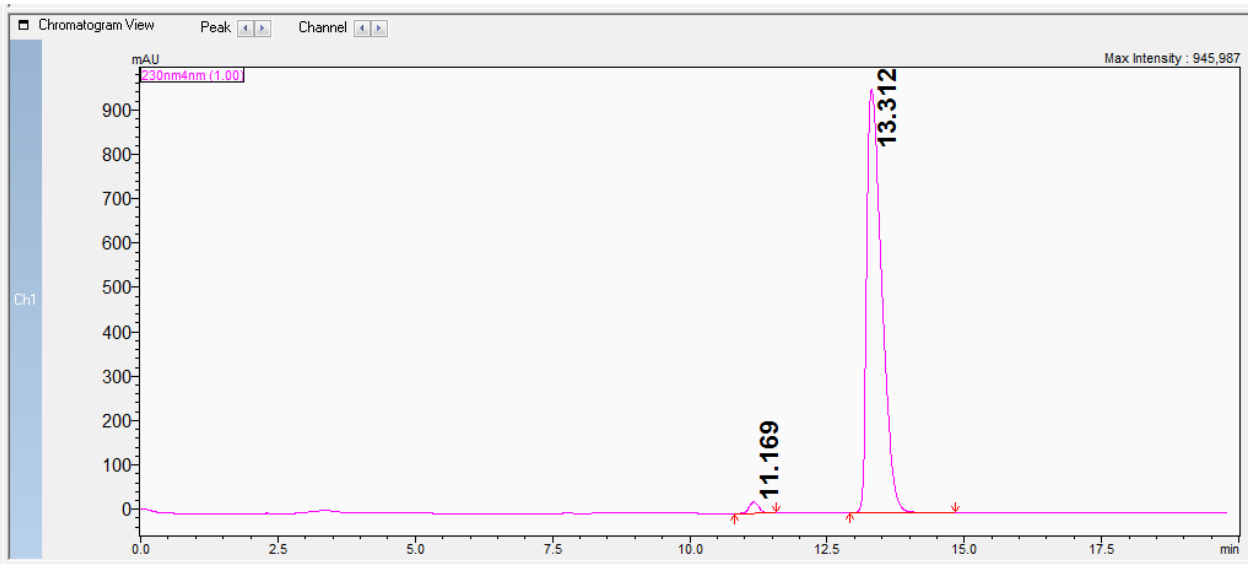


Results View - Peak Table

Peak Table | Compound | Group | Calibration Curve

Peak#	Ret. Time	Area	Height	Peak Start	Peak End	Width(5%)	NTP(USP)	HETP(USP)	Width(50%)	M	Area%
1	11.029	15722515	1041455	10.731	12.000	0.482	11920	12.584	0.237		50.507
2	13.326	15406617	868407	13.120	13.792	0.558	11947	12.555	0.283		49.493
Total		31129132	1909863								100.00

Chiral HPLC Trace of Enantioenriched 2a (96% ee)

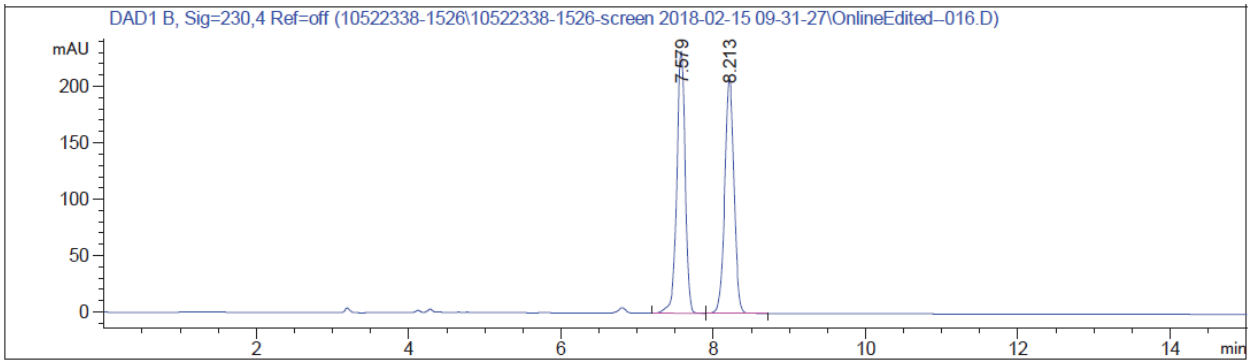


Results View - Peak Table

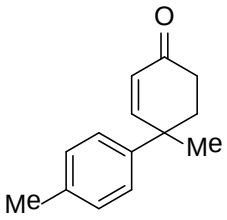
Peak Table | Compound | Group | Calibration Curve

Peak#	Ret. Time	Area	Height	Peak Start	Peak End	Width(5%)	NTP(USP)	HETP(USP)	Width(50%)	M	Area%
1	11.169	308847	25381	10.827	11.573	0.412	18296	8.199	0.187		1.676
2	13.312	18114346	954209	12.917	14.848	0.614	10894	13.769	0.297		98.324
Total		18423193	979589								100.00

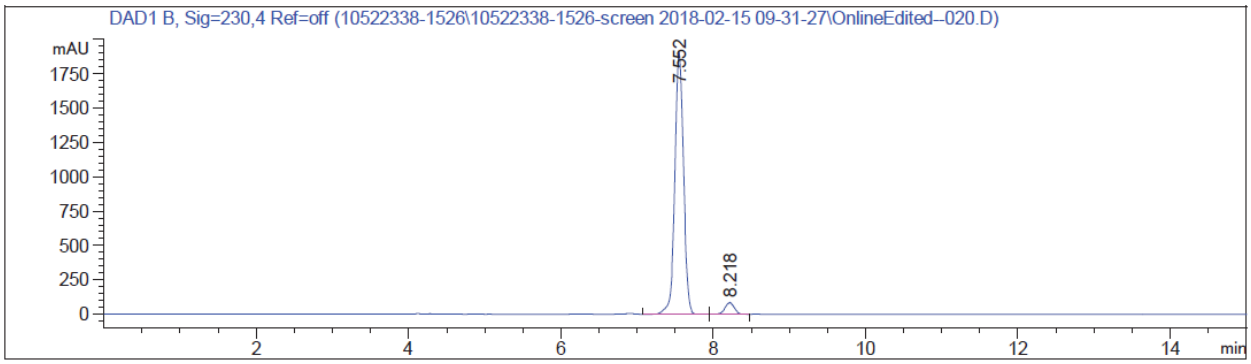
Chiral HPLC Trace of Racemic 2b



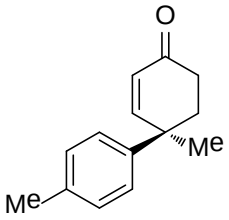
Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	7.579	BV	0.1195	1780.21826	232.07030	50.3862
2	8.213	VB	0.1324	1752.92749	207.84474	49.6138



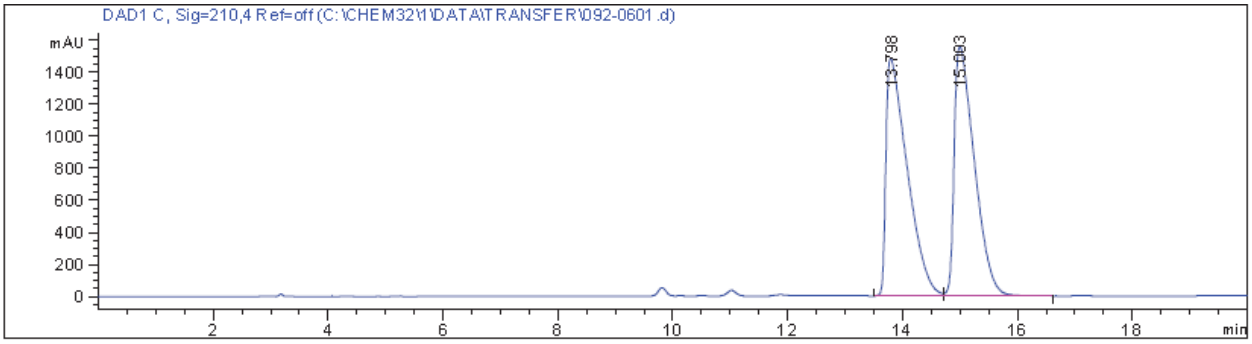
Chiral HPLC Trace of Enantioenriched 2b (91% ee)



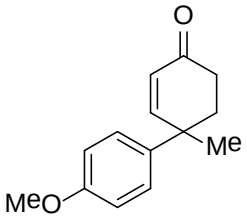
Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	7.552	VV	0.1226	1.52101e4	1915.33569	95.4491
2	8.218	VV	0.1313	725.20209	85.24358	4.5509



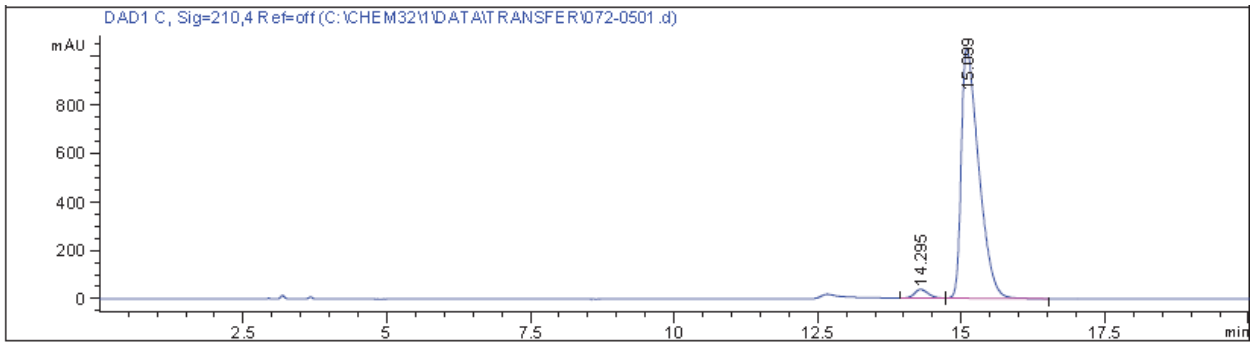
Chiral HPLC Trace of Racemic 2c



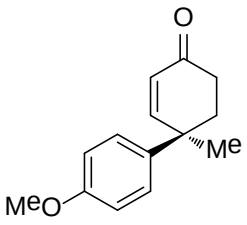
Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	13.798	BV	0.3546	3.81301e4	1479.88940	50.0715
2	15.003	VB	0.3488	3.80213e4	1557.28479	49.9285



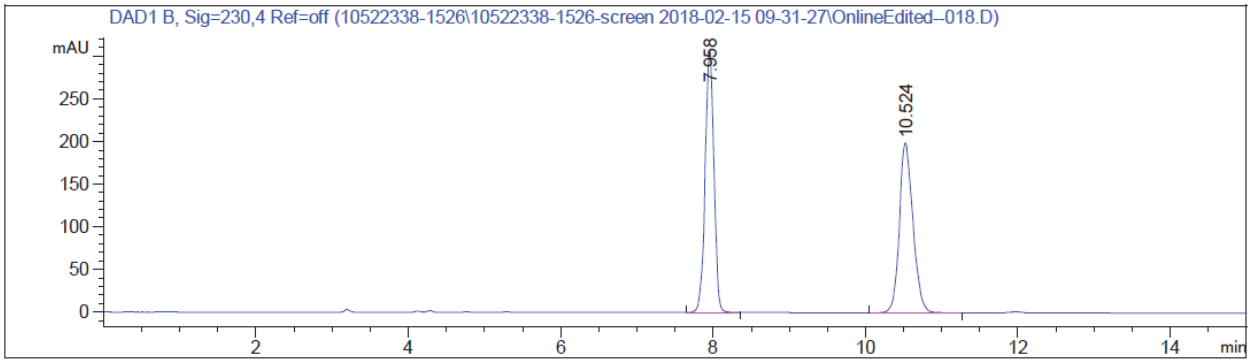
Chiral HPLC Trace of Enantioenriched 2c (95% ee)



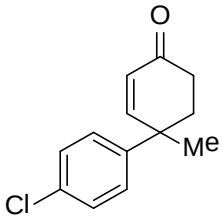
Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	14.295	BV	0.2535	611.60272	36.86956	2.7334
2	15.099	VB	0.3206	2.17632e4	1029.77710	97.2666



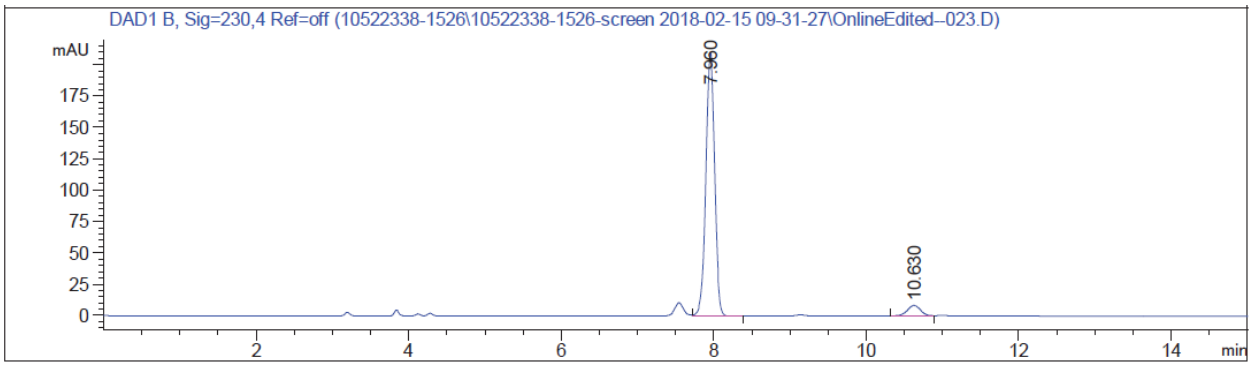
Chiral HPLC Trace of Racemic 2d



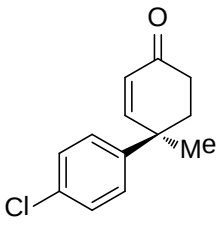
Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	7.958	VV	0.1237	2467.96851	307.42160	50.0565
2	10.524	VB	0.1884	2462.39966	198.95979	49.9435



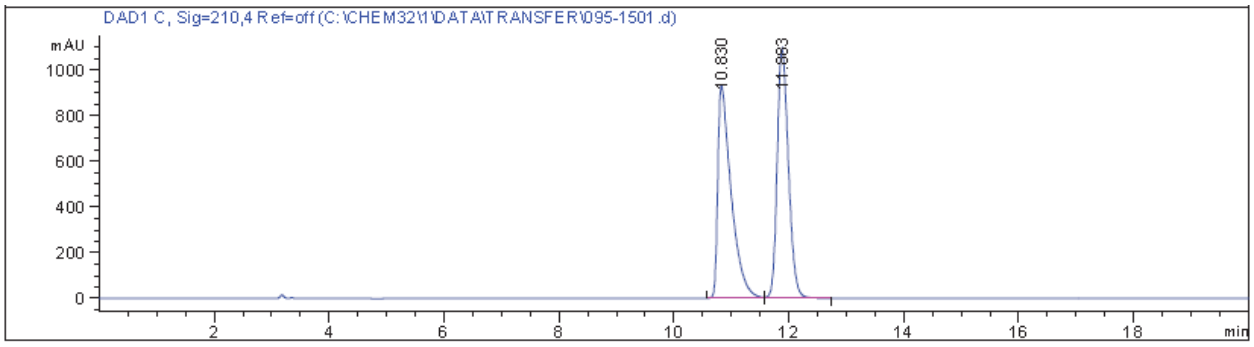
Chiral HPLC Trace of Enantioenriched 2d (88% ee)



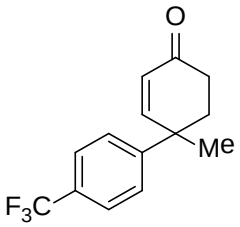
Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	7.960	VB	0.1254	1681.19678	209.98389	94.2125
2	10.630	BV	0.1872	103.27691	8.41621	5.7875



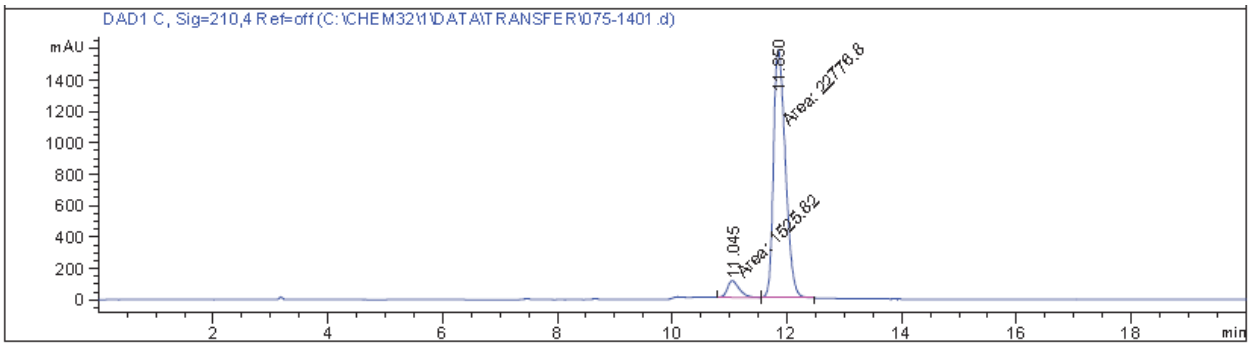
Chiral HPLC Trace of Racemic 2e



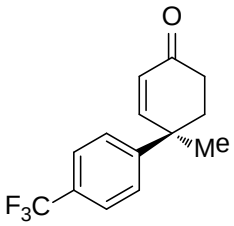
Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	10.830	BV	0.2297	1.49792e4	930.95544	50.2438
2	11.883	VB	0.2086	1.48338e4	1090.95093	49.7562



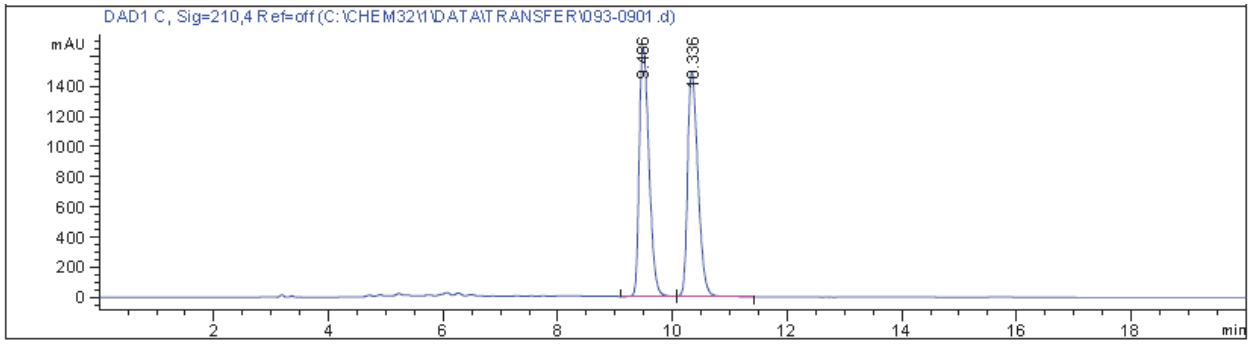
Chiral HPLC Trace of Enantioenriched 2e (87% ee)



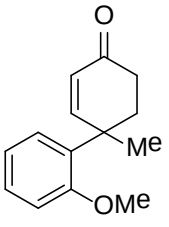
Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	11.045	MF	0.2415	1525.82007	105.32303	6.2784
2	11.850	FM	0.2407	2.27768e4	1576.86475	93.7216



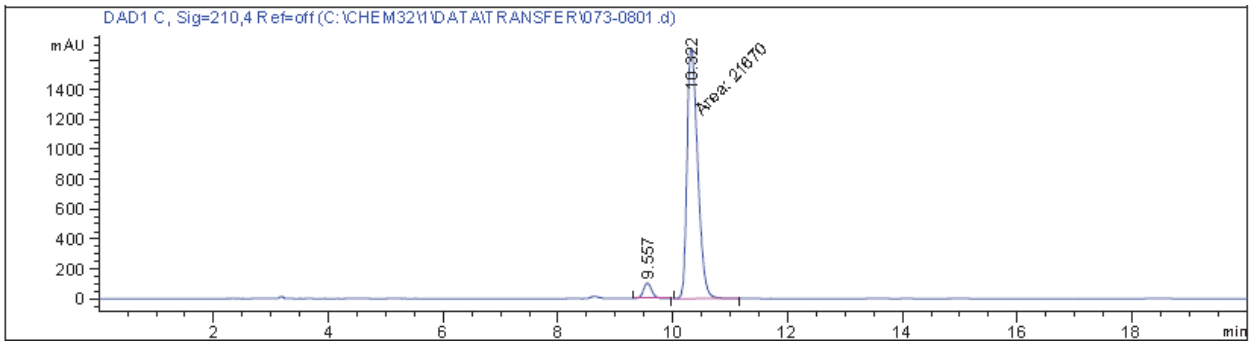
Chiral HPLC Trace of Racemic 2f



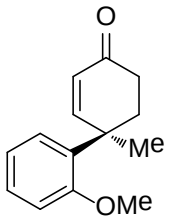
Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	9.486	BV	0.1821	1.95642e4	1653.10559	51.0259
2	10.336	VV R	0.1944	1.87775e4	1496.07141	48.9741

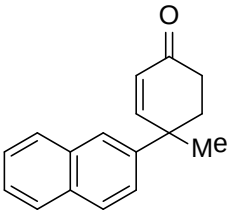


Chiral HPLC Trace of Enantioenriched 2f (91% ee)

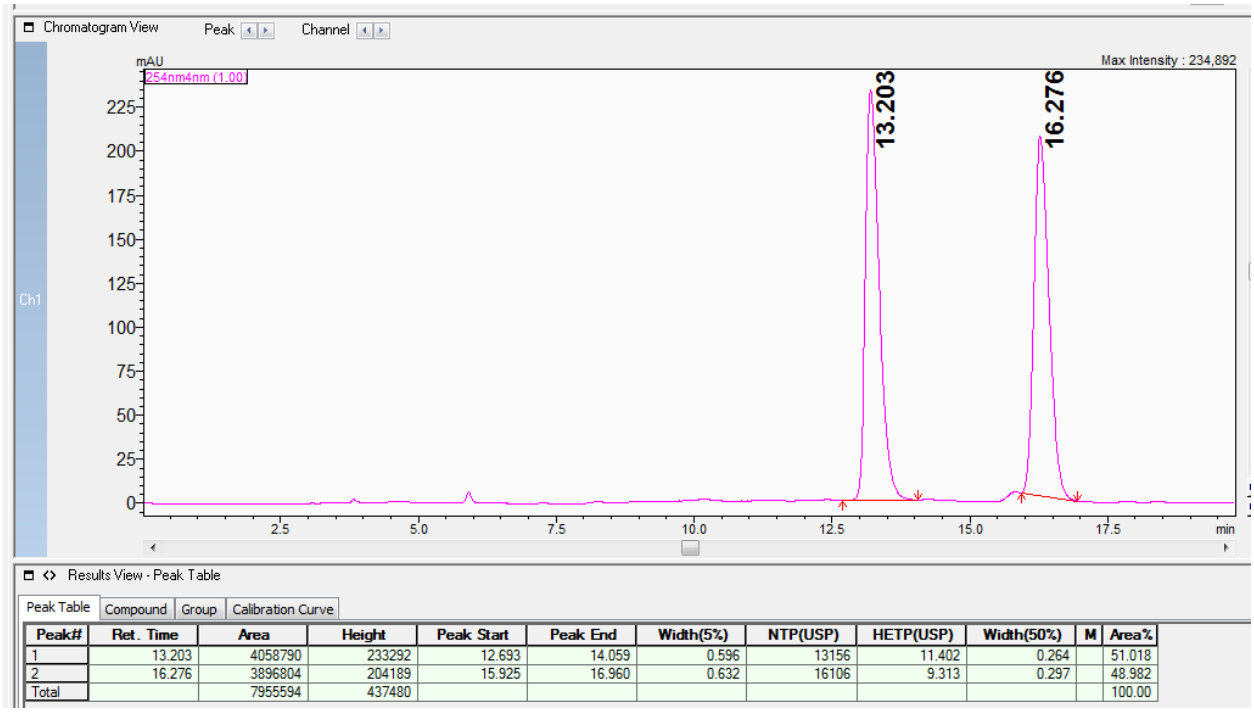


Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	9.557	BB	0.1554	1041.55505	103.46586	4.5860
2	10.322	MM	0.2156	2.16700e4	1675.53076	95.4140

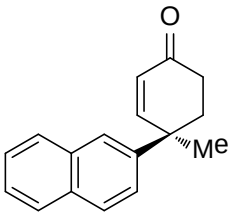




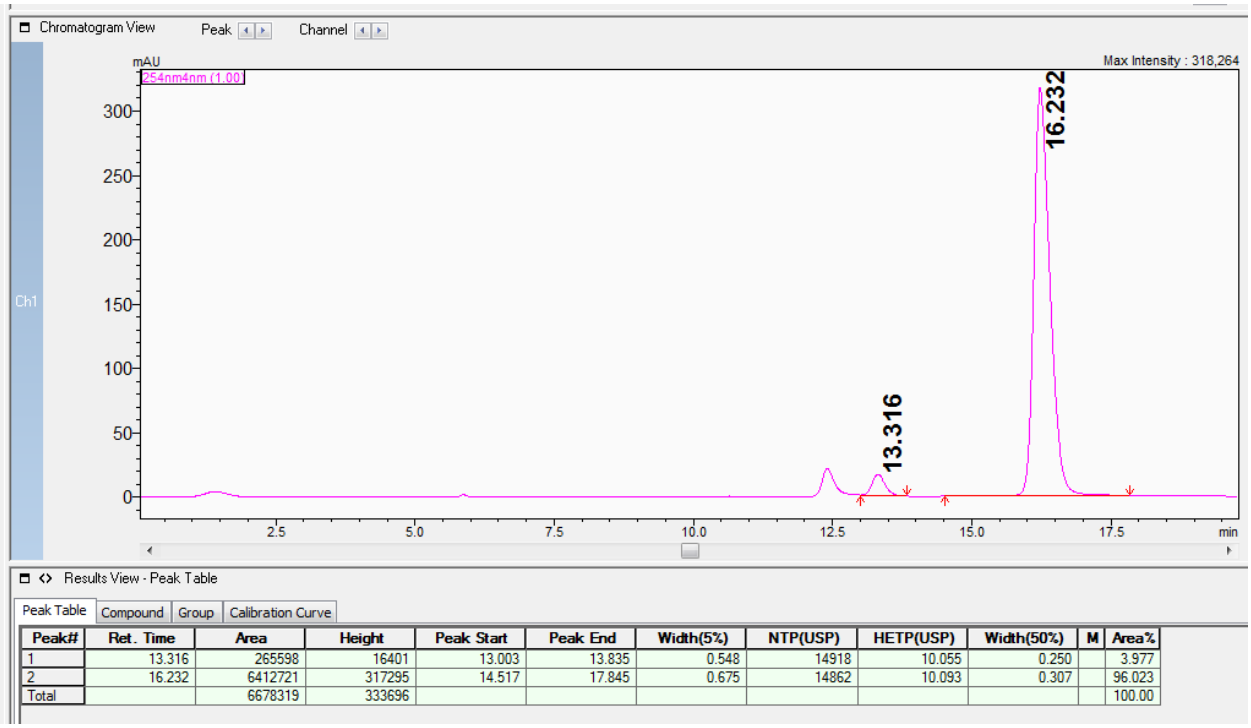
Chiral HPLC Trace of Racemic 2g



Peak#	Ret. Time	Area	Height	Peak Start	Peak End	Width(5%)	NTP(USP)	HETP(USP)	Width(50%)	M	Area%
1	13.203	4058790	233292	12.693	14.059	0.596	13156	11.402	0.264		51.018
2	16.276	3896804	204189	15.925	16.960	0.632	16106	9.313	0.297		48.982
Total		7955594	437480								100.00

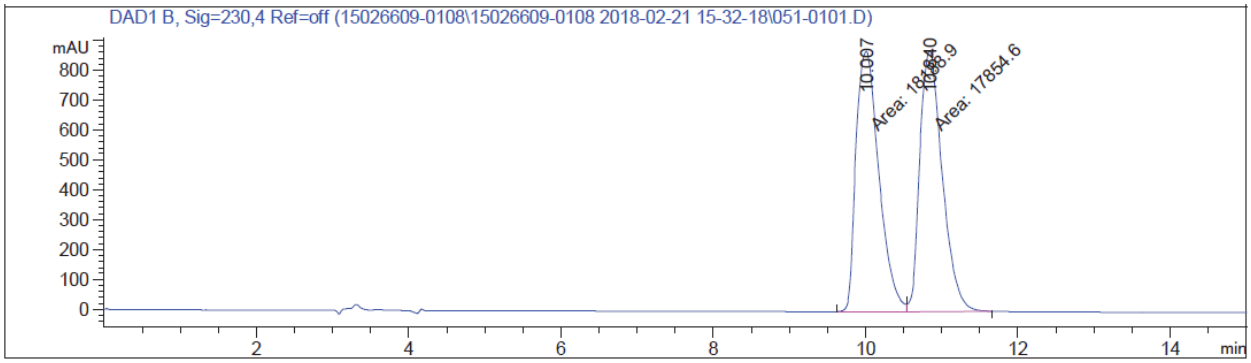


Chiral HPLC Trace of Enantioenriched 2g (92% ee)

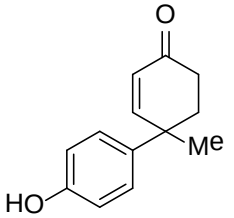


Peak#	Ret. Time	Area	Height	Peak Start	Peak End	Width(5%)	NTP(USP)	HETP(USP)	Width(50%)	M	Area%
1	13.316	265598	16401	13.003	13.835	0.548	14918	10.055	0.250		3.977
2	16.232	6412721	317295	14.517	17.845	0.675	14862	10.093	0.307		96.023
Total		6678319	333696								100.00

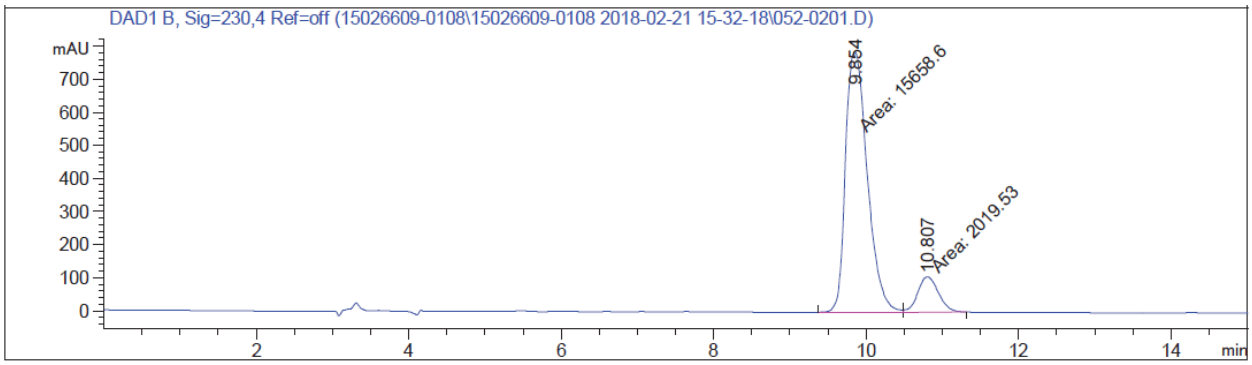
Chiral HPLC Trace of Racemic 2h



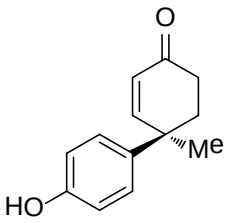
Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	10.007	MF	0.3488	1.81889e4	869.24347	50.4638
2	10.840	FM	0.3417	1.78546e4	870.83594	49.5362



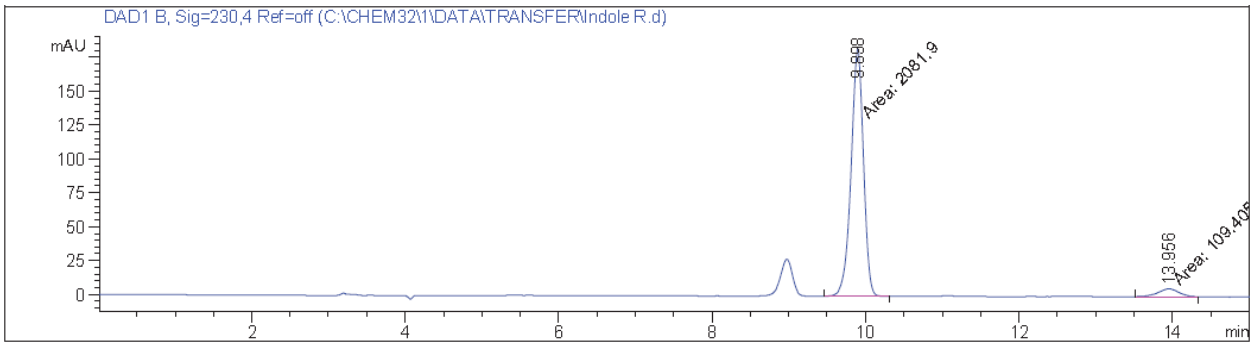
Chiral HPLC Trace of Enantioenriched 2h (77% ee)



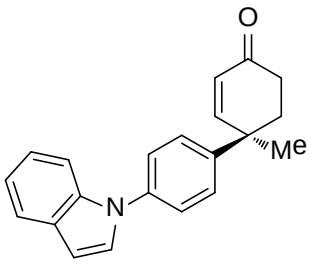
Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	9.854	MF	0.3319	1.56586e4	786.33563	88.5761
2	10.807	FM	0.3164	2019.53064	106.37265	11.4239



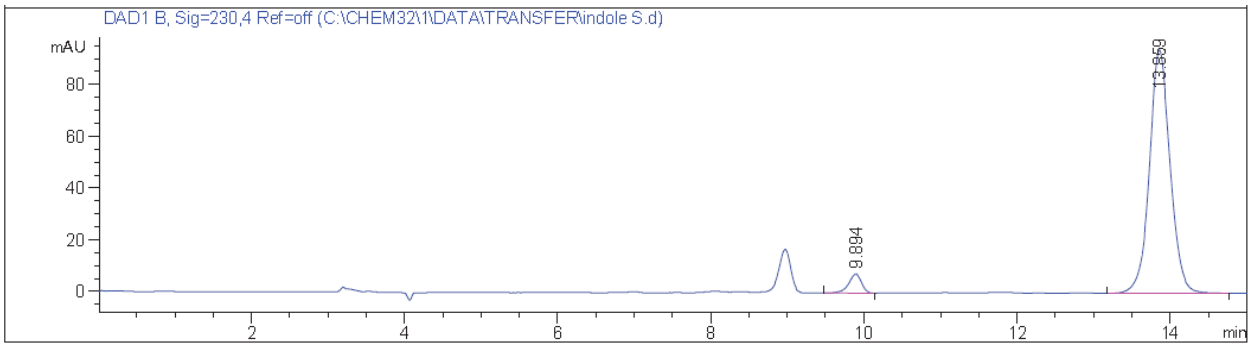
Chiral HPLC Trace of Enantioenriched 2i (90% ee) [Generated from (*R*, *R*)-Ph-BPE]



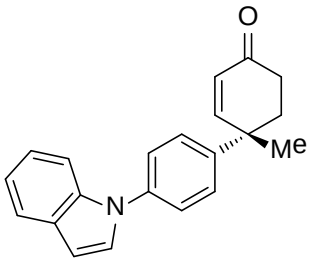
Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	9.898	MM	0.1898	2081.89771	182.78145	95.0073
2	13.956	MM	0.3148	109.40543	5.79215	4.9927



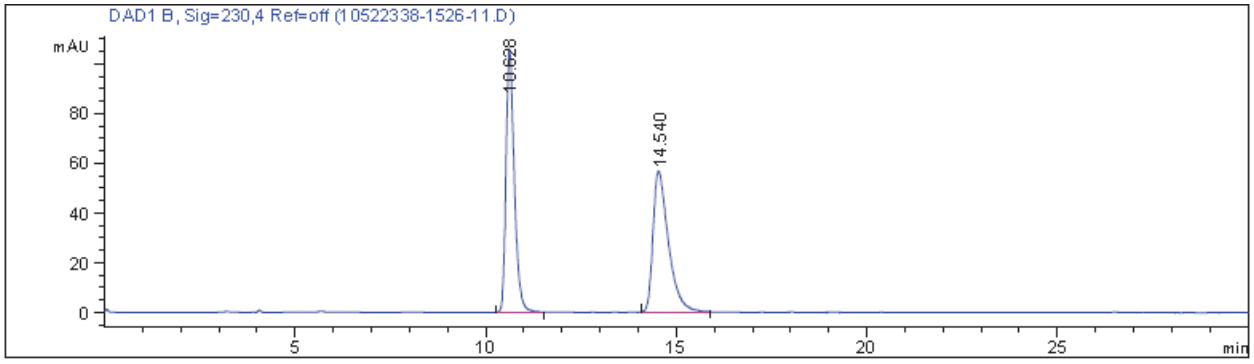
Chiral HPLC Trace of Enantioenriched 2i (91% ee) [Generated from (*S*, *S*)-Ph-BPE]



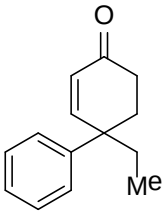
Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	9.894	BB	0.1779	86.56931	7.43182	4.6624
2	13.859	BB	0.2855	1770.19299	94.10175	95.3376



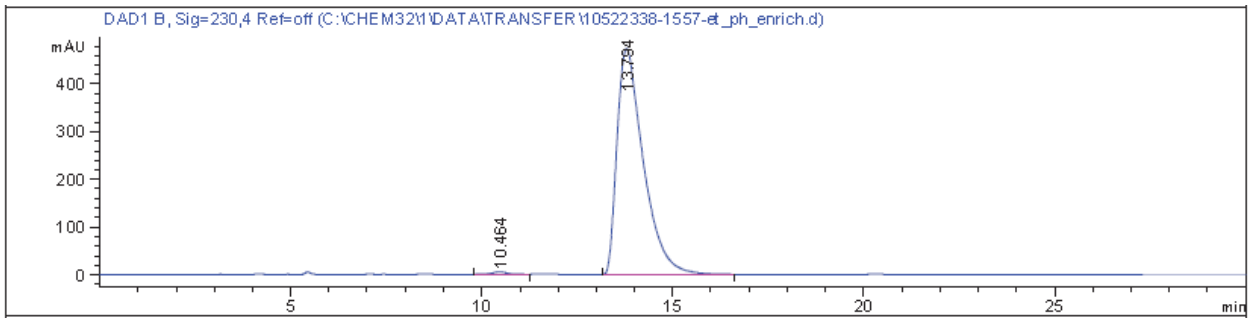
Chiral HPLC Trace of Racemic 2j



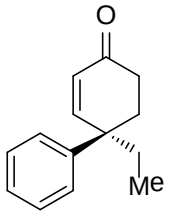
Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	10.628	BB	0.2320	1613.30029	105.73660	50.3051
2	14.540	BB	0.4196	1593.73035	56.75232	49.6949

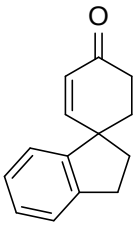


Chiral HPLC Trace of Enantioenriched 2j (99% ee)

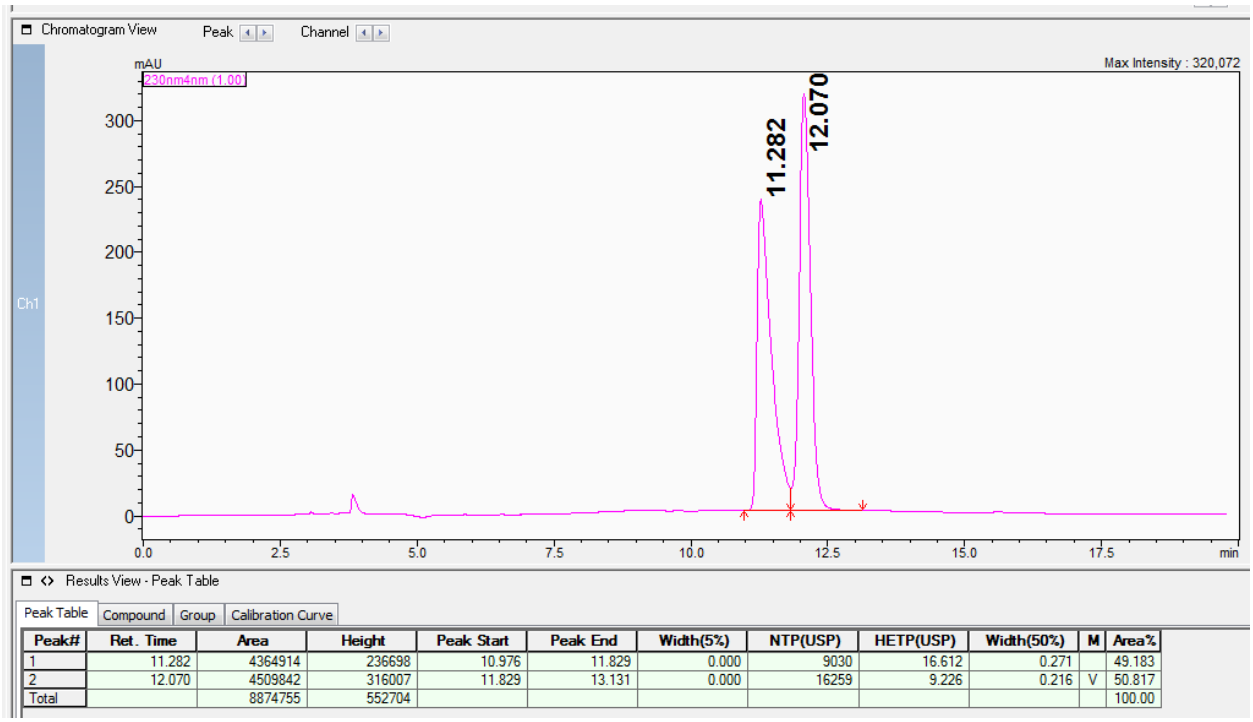


Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	10.464	BB	0.3845	141.92953	5.19929	0.6221
2	13.794	BB	0.7101	2.26720e4	473.93600	99.3779

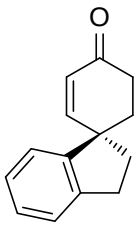




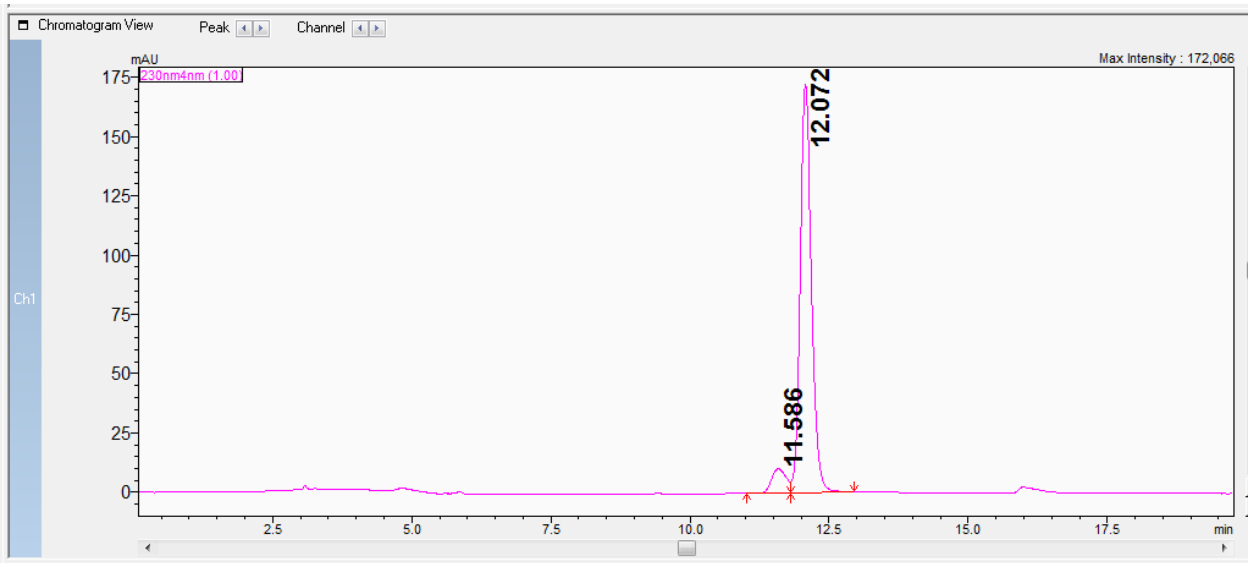
Chiral HPLC Trace of Racemic 2k



Peak#	Ret. Time	Area	Height	Peak Start	Peak End	Width(5%)	NTP(USP)	HETP(USP)	Width(50%)	M	Area%
1	11.282	4364914	236698	10.976	11.829	0.000	9030	16.612	0.271		49.183
2	12.070	4509842	316007	11.829	13.131	0.000	16259	9.226	0.216	V	50.817
Total		8874755	552704								100.00

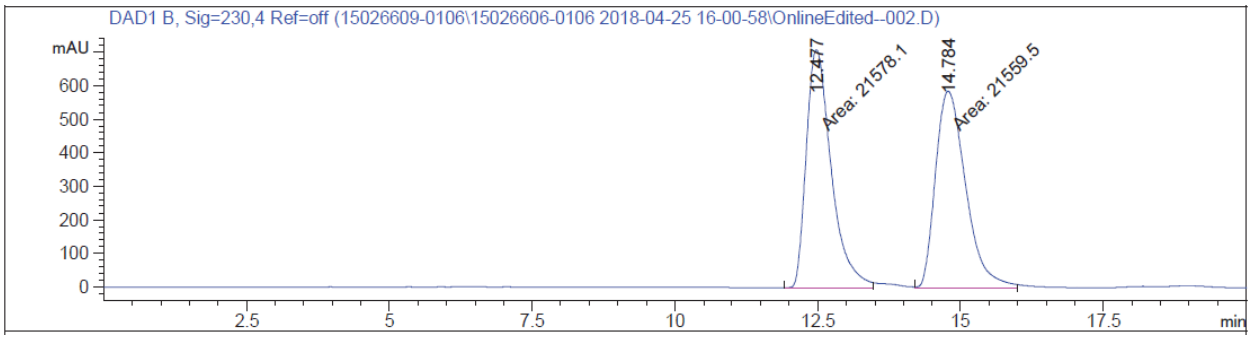


Chiral HPLC Trace of Enantioenriched 2k (86% ee)

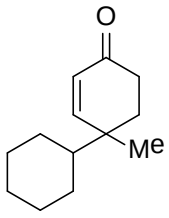


Peak#	Ret. Time	Area	Height	Peak Start	Peak End	Width(5%)	NTP(USP)	HETP(USP)	Width(50%)	M	Area%
1	11.586	185159	10177	11.019	11.808	0.000	7223	20.768	0.316		7.081
2	12.072	2429763	172205	11.808	12.960	0.483	16497	9.093	0.214	V	92.919
Total		2614922	182382								100.00

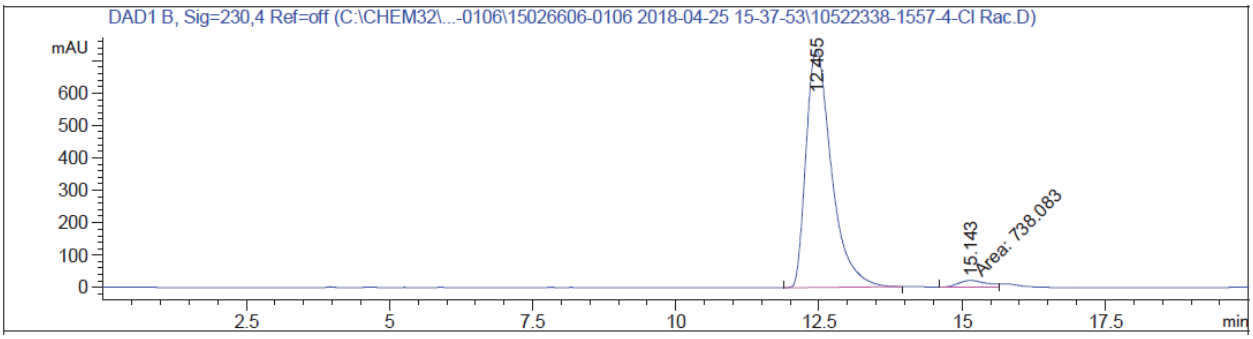
Chiral HPLC Trace of Racemic 2l



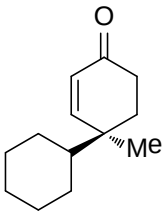
Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	12.477	MF	0.5067	2.15781e4	709.80487	50.0215
2	14.784	MF	0.6129	2.15595e4	586.24304	49.9785



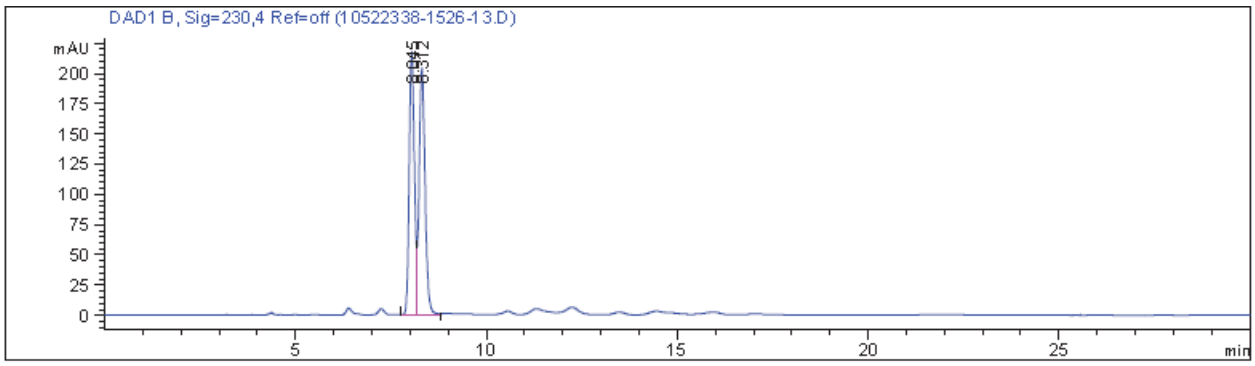
Chiral HPLC Trace of Enantioenriched 2l (94% ee)



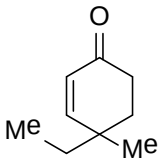
Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	12.455	BB	0.4693	2.26284e4	734.80499	96.8413
2	15.143	MF	0.5956	738.08258	20.65338	3.1587



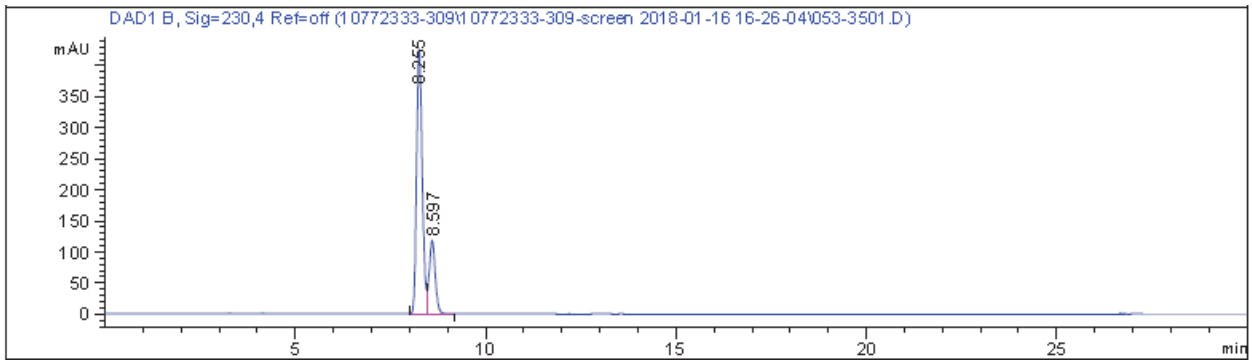
Chiral HPLC Trace of Racemic 2m



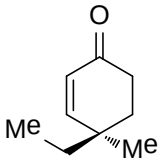
Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	8.045	BV	0.1489	2071.46680	217.98347	48.3684
2	8.312	VV	0.1641	2211.21509	204.65134	51.6316

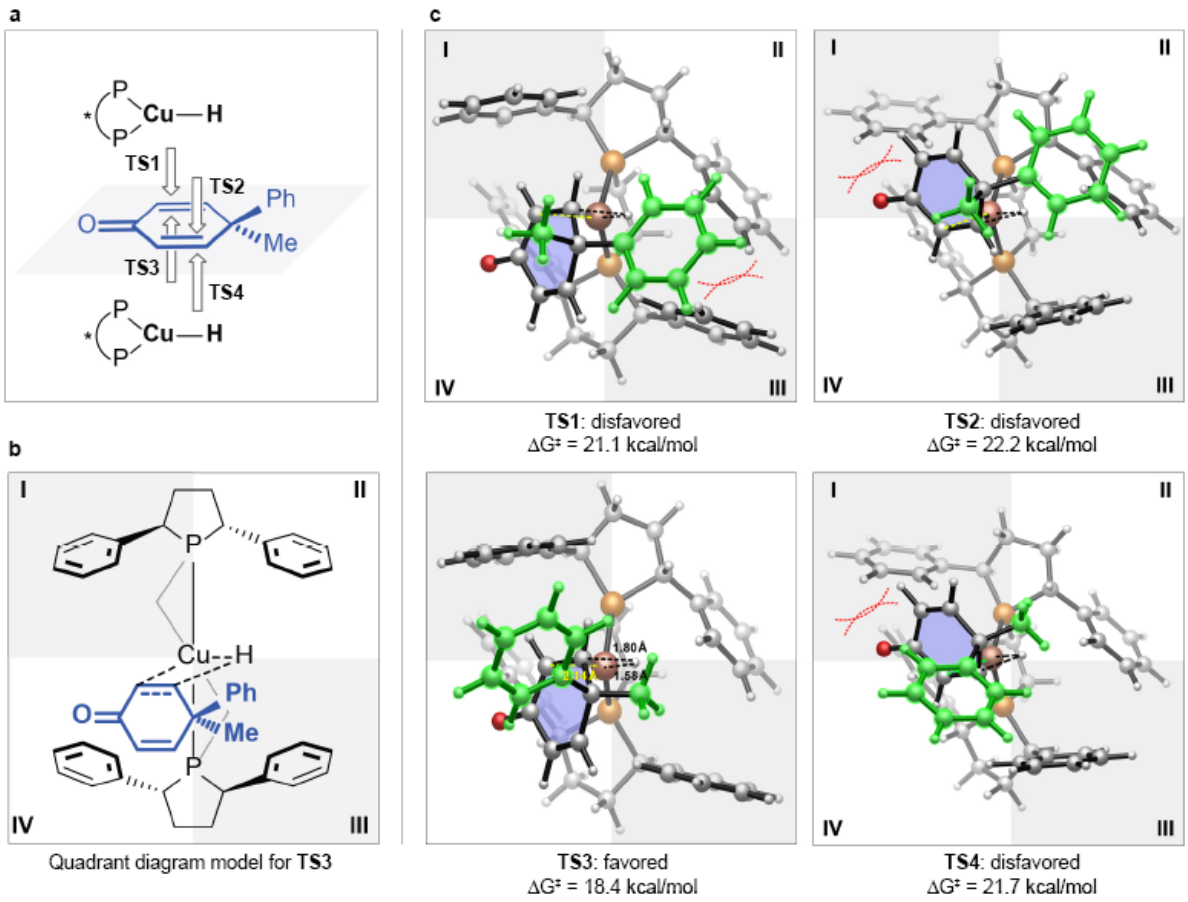


Chiral HPLC Trace of Enantioenriched 2m (54% ee)



Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	8.255	BV	0.1617	4414.89355	423.28308	76.8771
2	8.597	VB	0.1712	1327.89954	118.05677	23.1229





Computational Details

Calculations were performed using the Gaussian 09 program [1] at the High Performance Computing center of The University of Texas at Arlington. All molecular structures were optimized at B3LYP[2]-D3(BJ)[3, 4]/SDD[5] - 6-31G(d)[6] level, followed by frequency analysis to confirm they are either an energy minimum (no imaginary frequency) or a transition states (one unique corresponding imaginary frequency). The energies of optimized geometries were re-evaluated at M06-2X[7]-D3[8]/SDD - Def2TZVP[9] level, and corrected by the free energy calculated from B3LYP/6-31G(d) level and the solvation energy calculated by SMD(toluene)[10] model.

Cartesian Coordinates (Å) and Energies of the Optimized Structures

```
TS1:
B3LYP-D3(BJ) SCF energy: -2776.0570095 a.u.
B3LYP-D3(BJ) free energy: -2775.299573 a.u.
M06-2X-D3 SCF energy: -2774.94041 a.u.
Three lowest frequencies (cm-1): -553.8446, 17.1263, 18.8218
```

Cartesian coordinates

ATOM	X	Y	Z
P	0.16035	-1.42547	-1.11469
C	1.19474	-1.48624	-2.70326
C	0.48324	-2.50633	-3.61215
C	-1.02132	-2.39080	-3.32890
C	-1.18925	-2.54284	-1.80060
H	0.72378	-2.31993	-4.66481
H	0.80499	-3.52955	-3.38223
H	-1.60705	-3.14952	-3.85998
H	-1.39427	-1.40784	-3.64441
P	1.48513	-0.19863	1.56232
C	0.75852	-0.57797	3.26202
C	1.98626	-0.70891	4.17223
C	2.90860	0.46957	3.82663
C	3.06529	0.55363	2.28478
H	1.70679	-0.71068	5.23269
H	2.50950	-1.65272	3.97651
H	3.88830	0.38096	4.30845
H	2.45759	1.39646	4.19814
H	1.07478	-0.49229	-3.14331
H	-0.88206	-3.56620	-1.54591
C	2.05562	-1.86926	0.95693
H	2.35314	-2.51417	1.79131
H	2.94620	-1.68000	0.34934
C	0.98281	-2.56709	0.10635
H	0.22144	0.33946	3.53665
H	3.89132	-0.09212	1.96712
C	-0.23343	-1.70905	3.17089
C	-2.04837	-3.80324	2.68106
C	-1.48374	-1.45663	2.58132
C	0.07947	-3.02318	3.53787
C	-0.82320	-4.06299	3.29579
C	-2.38009	-2.49167	2.33072
H	-1.73098	-0.44686	2.26814
H	1.03262	-3.24551	4.00755
H	-0.56141	-5.07755	3.58446
H	-3.32530	-2.27617	1.84488
H	-2.74287	-4.61312	2.47659
C	3.27737	1.93522	1.71466
C	3.55601	4.45124	0.47900
C	2.42500	2.99839	2.04849
C	4.26907	2.15660	0.75314
C	4.40798	3.40121	0.13658
C	2.56464	4.24517	1.44155
H	1.62919	2.84607	2.77319

H 4.92402 1.33703 0.47155
H 5.17715 3.54662 -0.61650
H 1.89086 5.05387 1.71095
H 3.65733 5.41865 -0.00362
C -2.57849 -2.32472 -1.25498
C -5.17659 -1.98349 -0.23011
C -3.35823 -3.43098 -0.89355
C -3.12352 -1.04299 -1.09940
C -4.40786 -0.87182 -0.58368
C -4.64992 -3.26657 -0.39196
H -2.94400 -4.43102 -1.00046
H -2.52875 -0.17367 -1.35168
H -4.79895 0.13161 -0.44969
H -5.23815 -4.13842 -0.11800
H -6.17686 -1.84957 0.17278
C 2.66020 -1.66443 -2.39846
C 5.35096 -1.89916 -1.59615
C 3.25909 -2.92330 -2.25439
C 3.43686 -0.51852 -2.15360
C 4.76932 -0.63934 -1.75891
C 4.59121 -3.04141 -1.85341
H 2.68540 -3.82407 -2.45167
H 2.98901 0.46272 -2.29494
H 5.35820 0.25813 -1.58989
H 5.03494 -4.02758 -1.74542
H 6.38865 -1.99039 -1.28707
H 1.41649 -3.43073 -0.40793
H 0.17232 -2.93258 0.74507
Cu 0.06533 0.56600 -0.04854
H -1.28319 1.09360 0.52675
H -0.90247 1.28234 -3.97470
H -2.90720 2.02615 -2.79295
C -0.83442 1.75957 -2.99998
C -1.92826 2.17423 -2.34744
O 1.52038 1.79023 -3.22489
C 0.54183 1.96967 -2.47382
C -1.85360 2.92901 -1.03347
H -2.60962 4.78568 -1.94388
C -1.73568 4.45176 -1.37673
C 0.62650 2.35886 -1.08802
C -0.55647 2.56143 -0.31344
H -0.83497 4.63379 -1.96871
H 1.60032 2.60171 -0.68050
H -1.68438 5.04011 -0.45374
H -0.40864 3.08871 0.62555
C -3.13208 2.76836 -0.20039

C -4.38647 2.86573 -0.82021
H -4.45203 3.03154 -1.89105
C -5.57108 2.76335 -0.08977
H -6.52575 2.83439 -0.60381
C -5.52841 2.57098 1.29116
H -6.44744 2.48298 1.86350
C -4.28978 2.50725 1.92811
H -4.23668 2.37345 3.00519
C -3.10837 2.61149 1.19207
H -2.16295 2.55328 1.71566

TS2:
B3LYP-D3(BJ) SCF energy: -2776.0555672 a.u.
B3LYP-D3(BJ) free energy: -2775.298538 a.u.
M06-2X-D3 SCF energy: -2774.938742 a.u.
Three lowest frequencies (cm-1): -513.7848, 19.8917, 22.4931

Cartesian coordinates
ATOM X Y Z
P 0.02156 2.11823 -0.31336
C -1.21776 3.21291 -1.21538
C -0.68208 4.63668 -1.01604
C 0.83227 4.56468 -1.26434
C 1.41454 3.39508 -0.42952
H -1.17239 5.35341 -1.68547
H -0.86733 4.97512 0.01089
H 1.33801 5.50408 -1.01570
H 1.01048 4.38179 -2.33003
P -1.04367 -0.54915 1.19657
C 0.09896 -1.40869 2.44975
C -0.81693 -2.26545 3.34195
C -1.97293 -2.75393 2.46123
C -2.56916 -1.50037 1.78576
H -0.25566 -3.09144 3.79425
H -1.22897 -1.66855 4.16453
H -2.74073 -3.28597 3.03432
H -1.60379 -3.44555 1.69226
H -1.09526 2.94192 -2.27251
H 1.59244 3.74637 0.59322
C -1.44921 1.13358 1.89427
H -1.52251 1.08345 2.98600
H -2.44768 1.35979 1.50771
C -0.46366 2.23548 1.48284
H 0.68536 -2.08015 1.81617
H -3.00452 -0.88329 2.58359
C 1.05522 -0.45299 3.11488
C 2.82974 1.45680 4.19151

C 2.30485 -0.21549 2.52128
C 0.71963 0.27189 4.26779
C 1.59523 1.22030 4.79932
C 3.18253 0.72716 3.05422
H 2.57759 -0.75980 1.62642
H -0.23380 0.10203 4.75909
H 1.31234 1.77189 5.69191
H 4.14557 0.88379 2.57679
H 3.51300 2.19164 4.60849
C -3.64058 -1.76849 0.75943
C -5.66280 -2.28599 -1.12381
C -3.32240 -2.09165 -0.56247
C -4.99098 -1.70333 1.12667
C -5.99604 -1.96684 0.19541
C -4.31995 -2.34210 -1.50387
H -2.28499 -2.10896 -0.86572
H -5.25476 -1.43730 2.14797
H -7.03885 -1.91143 0.49665
H -4.02961 -2.53180 -2.53186
H -6.44575 -2.47321 -1.85354
C 2.68439 2.76655 -0.94944
C 5.01362 1.46264 -1.85251
C 3.74341 2.49874 -0.07436
C 2.80959 2.36419 -2.28660
C 3.96409 1.72451 -2.73686
C 4.89615 1.84950 -0.51688
H 3.65267 2.78700 0.96915
H 1.99232 2.53571 -2.98216
H 4.04086 1.42490 -3.77860
H 5.70365 1.64907 0.18221
H 5.91355 0.96506 -2.20299
C -2.62051 2.86408 -0.79048
C -5.11692 1.98487 0.16025
C -3.33292 3.62124 0.14739
C -3.18754 1.66768 -1.26353
C -4.42380 1.23262 -0.79129
C -4.57329 3.18424 0.62039
H -2.92169 4.55471 0.51917
H -2.65061 1.05886 -1.98727
H -4.83763 0.30052 -1.15708
H -5.11052 3.78399 1.35047
H -6.07478 1.63510 0.53436
H -0.88073 3.22118 1.71917
H 0.47132 2.12459 2.04310
Cu 0.17100 -0.11224 -0.68028
H 1.62808 -0.54465 -0.34588

H 0.05501 0.33970 -3.25714
H 2.23764 -0.29086 -2.31240
C 0.16965 -0.61746 -2.75712
C 1.40522 -0.96147 -2.13002
O -1.97892 -1.34258 -3.48087
C -0.88803 -1.58518 -2.93778
C 1.82728 -2.43269 -2.02569
H 3.51866 -2.14698 -3.41128
C 2.61975 -2.76556 -3.32885
C -0.58803 -2.96700 -2.46124
C 0.62429 -3.34610 -2.03743
H 1.98798 -2.58085 -4.20211
H -1.40573 -3.67882 -2.53954
H 2.92777 -3.81625 -3.33101
H 0.80685 -4.38972 -1.78852
H 5.71191 -1.53066 0.42511
C 4.78512 -2.09637 0.38000
C 4.42919 -2.94749 1.42908
H 5.07572 -3.05431 2.29513
C 3.22465 -3.64394 1.35785
H 2.92408 -4.29859 2.17145
C 2.38739 -3.49632 0.24826
H 1.44143 -4.02641 0.23024
C 2.73680 -2.65519 -0.81414
C 3.95088 -1.95776 -0.72647
H 4.23442 -1.26597 -1.51240

TS3:
B3LYP-D3(BJ) SCF energy: -2776.0564438 a.u.
B3LYP-D3(BJ) free energy: -2775.301137 a.u.
M06-2X-D3 SCF energy: -2774.943436 a.u.
Three lowest frequencies (cm-1): -623.6681, 14.6901, 19.7790

Cartesian coordinates
ATOM X Y Z
P -1.67053 0.20048 -1.16943
C -1.42129 -0.49543 -2.91507
C -2.45464 0.23502 -3.79123
C -2.55908 1.66781 -3.25536
C -2.84770 1.55825 -1.74105
H -2.15718 0.20675 -4.84552
H -3.44011 -0.24177 -3.71925
H -3.34174 2.24899 -3.75577
H -1.61023 2.19733 -3.41027
P -0.61664 -1.55964 1.32232
C -1.27311 -1.27501 3.06802
C -1.35003 -2.68256 3.67307

C -0.03271 -3.38222 3.30879
C 0.25146 -3.17647 1.79619
H -1.50834 -2.65028 4.75781
H -2.19120 -3.23862 3.24169
H -0.05205 -4.44952 3.55443
H 0.78116 -2.93919 3.89349
H -0.42237 -0.15169 -3.20074
H -3.86007 1.14904 -1.62691
C -2.12757 -2.13425 0.39219
H -2.82839 -2.66155 1.04876
H -1.76884 -2.84948 -0.35379
C -2.84262 -0.96720 -0.30891
H -0.46834 -0.72402 3.57197
H -0.23273 -3.97307 1.22076
C -2.50353 -0.40545 3.03399
C -4.74155 1.26145 2.66253
C -2.34578 0.96374 2.76017
C -3.80100 -0.91873 3.14589
C -4.91209 -0.09035 2.96242
C -3.45050 1.78894 2.56919
H -1.34479 1.36874 2.64639
H -3.95408 -1.96980 3.36976
H -5.91164 -0.50768 3.05085
H -3.30229 2.83648 2.32898
H -5.60543 1.90172 2.50733
C 1.70977 -3.10710 1.40814
C 4.36725 -2.81898 0.52180
C 2.58541 -2.21013 2.03872
C 2.19364 -3.86420 0.33613
C 3.51057 -3.72332 -0.10594
C 3.90060 -2.06483 1.60103
H 2.22691 -1.59612 2.86133
H 1.52263 -4.55289 -0.16905
H 3.86190 -4.31184 -0.94879
H 4.55504 -1.34374 2.08270
H 5.38628 -2.69301 0.16898
C -2.76574 2.84968 -0.96949
C -2.65582 5.27611 0.45134
C -3.93051 3.43681 -0.46219
C -1.54019 3.49707 -0.75596
C -1.48704 4.69892 -0.05215
C -3.88086 4.64180 0.24110
H -4.88566 2.93999 -0.61507
H -0.62292 3.04760 -1.12132
H -0.52818 5.18465 0.10683
H -4.79723 5.08059 0.62667

H -2.61081 6.21216 1.00092
C -1.39913 -2.00266 -2.91804
C -1.29067 -4.80835 -2.68703
C -2.55884 -2.77884 -3.05002
C -0.17546 -2.65540 -2.69197
C -0.12545 -4.04478 -2.58043
C -2.50730 -4.16898 -2.93099
H -3.51474 -2.30141 -3.24378
H 0.73192 -2.05940 -2.62778
H 0.83262 -4.53175 -2.42171
H -3.41907 -4.75157 -3.03287
H -1.24961 -5.89050 -2.59784
H -3.58347 -1.35265 -1.01707
H -3.37335 -0.35195 0.42450
Cu 0.14252 0.26632 0.15740
H 0.59530 1.39985 1.15662
H 1.51466 2.32605 -3.21281
H 2.18388 3.89475 -1.43122
H 2.63047 4.32026 1.06046
C 1.81211 1.97308 -2.22808
H 1.03178 3.52863 1.01397
C 2.17497 2.81962 -1.25549
C 2.10171 3.36497 1.15600
O 1.85148 -0.22751 -3.08614
C 1.90704 0.49318 -2.06991
C 2.62361 2.35904 0.11208
H 2.23759 2.99451 2.17599
C 2.07771 0.00867 -0.72474
C 2.14386 0.92368 0.37005
H 2.29597 -1.04213 -0.58084
H 2.52204 0.51344 1.30058
H 4.48427 2.10611 -1.93608
C 4.95427 2.09217 -0.95968
C 4.16845 2.25096 0.18741
C 4.80678 2.20752 1.43597
H 4.22687 2.31393 2.34687
C 6.18507 2.01921 1.53456
H 6.65418 1.99130 2.51457
C 6.95785 1.87013 0.38198
H 8.03200 1.72523 0.45617
C 6.33461 1.90786 -0.86466
H 6.92084 1.78911 -1.77181

TS4:
B3LYP-D3(BJ) SCF energy: -2776.0508007 a.u.
B3LYP-D3(BJ) free energy: -2775.295051 a.u.
M06-2X-D3 SCF energy: -2774.93839 a.u.

Three lowest frequencies (cm-1): -576.2028, 18.5722, 19.9598

Cartesian coordinates
ATOM X Y Z
P 0.18507 1.49987 1.37517
C 0.78521 0.99761 3.08884
C 0.57023 2.25067 3.94803
C -0.82175 2.78746 3.58754
C -0.93897 2.87280 2.04240
H 0.65885 2.02770 5.01786
H 1.32547 3.01063 3.71327
H -1.02110 3.76398 4.04222
H -1.58241 2.09835 3.97162
P 1.72694 0.25833 -1.18030
C 1.37527 1.05759 -2.86997
C 2.54987 0.65905 -3.78164
C 3.00107 -0.74093 -3.34760
C 3.24211 -0.67051 -1.82440
H 2.25516 0.69698 -4.83663
H 3.39125 1.35130 -3.65823
H 3.90942 -1.06684 -3.86661
H 2.21966 -1.48112 -3.56472
H 0.06896 0.23053 3.41152
H -0.50510 3.81986 1.70226
C 2.57197 1.55925 -0.14363
H 3.22417 2.17479 -0.77271
H 3.21250 0.99409 0.54095
C 1.61167 2.45642 0.65236
H 0.48277 0.52046 -3.20714
H 4.08833 0.01161 -1.66523
C 1.01990 2.51745 -2.74687
C 0.29779 5.20738 -2.30106
C -0.31453 2.87417 -2.49453
C 1.98208 3.53612 -2.78544
C 1.62609 4.86759 -2.56233
C -0.67265 4.20314 -2.27468
H -1.06495 2.09263 -2.43495
H 3.02118 3.29578 -2.98751
H 2.38979 5.63987 -2.59574
H -1.71248 4.44872 -2.08206
H 0.02133 6.24416 -2.13076
C 3.56688 -1.98182 -1.15618
C 4.22065 -4.41923 0.08038
C 2.56901 -2.90057 -0.81722
C 4.89971 -2.30055 -0.86573
C 5.22814 -3.51363 -0.26064
C 2.88749 -4.10641 -0.19377

H 1.53256 -2.65294 -1.01032
H 5.68409 -1.58766 -1.11000
H 6.26747 -3.74482 -0.04281
H 2.08638 -4.76542 0.12270
H 4.47143 -5.35479 0.57248
C -2.33957 2.75352 1.49208
C -4.89674 2.46756 0.34544
C -2.83616 3.70948 0.59947
C -3.15291 1.65640 1.81122
C -4.41937 1.51249 1.24647
C -4.10204 3.56948 0.02721
H -2.21709 4.56481 0.34254
H -2.78435 0.89037 2.48900
H -5.02436 0.64455 1.49303
H -4.46684 4.32319 -0.66559
H -5.88169 2.35521 -0.09886
C 2.15330 0.37125 3.00588
C 4.67871 -0.78134 2.55201
C 3.32463 1.08984 3.27666
C 2.26435 -0.94585 2.52781
C 3.51615 -1.51444 2.30268
C 4.57946 0.51785 3.05047
H 3.26635 2.10373 3.66024
H 1.37465 -1.53400 2.31501
H 3.57790 -2.52635 1.92042
H 5.47710 1.09239 3.26415
H 5.65156 -1.22546 2.36206
H 2.16413 2.99713 1.42902
H 1.15997 3.19949 -0.01267
Cu -0.25823 -0.13071 -0.16326
H -1.44717 0.23329 -1.12984
H -1.31151 -1.35394 1.88655
H -2.85633 -0.38005 0.24389
H -3.38887 -0.20182 -2.39047
C -1.29299 -1.70304 0.85868
H -1.91685 -0.93195 -3.01987
C -2.13680 -1.10051 -0.12402
C -2.88949 -1.15638 -2.57552
O 0.15176 -3.50928 1.41871
C -0.58537 -2.93408 0.59969
C -2.69450 -1.95481 -1.27018
H -3.48640 -1.73464 -3.29007
C -0.81717 -3.54240 -0.74328
C -1.78330 -3.12137 -1.56937
H -0.20117 -4.40384 -0.98839
H -1.96956 -3.64284 -2.50778

H -5.08850 -0.60176 -1.19453
C -5.17450 -1.59211 -0.75982
C -4.06244 -2.44796 -0.73559
C -4.20829 -3.70384 -0.13672
H -3.35784 -4.37464 -0.09049
C -5.43139 -4.10180 0.40680
H -5.51893 -5.08385 0.86355
C -6.53137 -3.24618 0.37020
H -7.48278 -3.55518 0.79395
C -6.39587 -1.98559 -0.21444
H -7.24294 -1.30531 -0.24851

(R,R)-Ph-BPE:
B3LYP-D3(BJ) SCF energy: -2198.185836 a.u.
B3LYP-D3(BJ) free energy: -2197.631293 a.u.
M06-2X-D3 SCF energy: -2197.9212205 a.u.
Three lowest frequencies (cm-1): 25.8085, 28.0008, 33.6101

Cartesian coordinates
ATOM X Y Z
P 1.12737 1.11267 0.05456
C 0.39195 2.85568 0.10914
C 1.44856 3.71280 0.82037
C 2.80340 3.25731 0.26425
C 2.88027 1.71793 0.41934
H 1.27122 4.78270 0.65897
H 1.42532 3.53977 1.90382
H 3.64917 3.73650 0.76999
H 2.87410 3.51705 -0.79958
P -1.12709 -1.11253 0.05450
C -0.39214 -2.85577 0.10928
C -1.44884 -3.71246 0.82085
C -2.80360 -3.25682 0.26466
C -2.88015 -1.71739 0.41924
H -1.27175 -4.78244 0.65968
H -1.42548 -3.53919 1.90426
H -3.64946 -3.73569 0.77054
H -2.87434 -3.51684 -0.79909
H 0.36871 3.15789 -0.94512
H 3.05915 1.49565 1.47862
C -0.68088 -0.35600 1.70379
H -0.71413 -1.11153 2.49756
H -1.47870 0.36646 1.90275
C 0.68130 0.35583 1.70373
H -0.36913 -3.15821 -0.94492
H -3.05898 -1.49466 1.47843
C 1.02503 -2.82891 0.62014

C 3.66920 -2.49948 1.52998
C 2.04137 -2.40273 -0.25144
C 1.36163 -3.10978 1.94921
C 2.67457 -2.94470 2.40106
C 3.34965 -2.23699 0.19491
H 1.79492 -2.17598 -1.28665
H 0.59982 -3.45253 2.64244
H 2.91577 -3.16415 3.43780
H 4.11371 -1.89406 -0.49367
H 4.68737 -2.36141 1.88213
C -3.96821 -1.05852 -0.39304
C -6.02508 0.17670 -1.86098
C -3.81142 -0.80136 -1.76202
C -5.17127 -0.69622 0.22483
C -6.19458 -0.08440 -0.50002
C -4.83056 -0.18600 -2.48848
H -2.87421 -1.04509 -2.25492
H -5.30001 -0.88355 1.28839
H -7.11874 0.19454 -0.00108
H -4.68430 0.01967 -3.54507
H -6.81536 0.66112 -2.42748
C 3.96823 1.05876 -0.39279
C 6.02473 -0.17709 -1.86074
C 5.17084 0.69534 0.22524
C 3.81166 0.80232 -1.76196
C 4.83060 0.18667 -2.48841
C 6.19399 0.08322 -0.49962
H 5.29944 0.88208 1.28892
H 2.87470 1.04682 -2.25497
H 4.68453 -0.01839 -3.54514
H 7.11780 -0.19656 -0.00051
H 6.81484 -0.66171 -2.42730
C -1.02513 2.82879 0.62024
C -3.66916 2.49941 1.53054
C -1.36154 3.10989 1.94930
C -2.04160 2.40245 -0.25112
C -3.34981 2.23674 0.19546
C -2.67441 2.94483 2.40138
H -0.59966 3.45281 2.64238
H -1.79530 2.17552 -1.28632
H -4.11395 1.89371 -0.49298
H -2.91542 3.16443 3.43813
H -4.68727 2.36141 1.88288
H 0.71471 1.11121 2.49765
H 1.47920 -0.36662 1.90241
Cu 0.00019 -0.00013 -1.64361

H 0.00011 0.00078 -3.19226

Dienone 1a:
B3LYP-D3(BJ) SCF energy: -577.8588079 a.u.
B3LYP-D3(BJ) free energy: -577.682873 a.u.
M06-2X-D3 SCF energy: -577.7703884 a.u.
Three lowest frequencies (cm-1): 38.6465, 48.9049, 105.7454

Cartesian coordinates
ATOM X Y Z
H 0.54700 -0.73369 2.18770
H 2.68948 0.49478 2.17614
C 1.03213 -0.46289 1.25155
C -3.57134 1.08851 0.00006
H -4.53130 1.59676 0.00008
C -3.51369 -0.30315 0.00008
C 2.19375 0.20527 1.25403
H -4.42970 -0.88739 0.00006
C -2.38453 1.82552 -0.00004
H -0.29415 -2.80652 0.88837
C -2.27946 -0.95898 0.00007
H -2.41590 2.91142 -0.00012
C -1.15653 1.17073 -0.00006
C -1.08737 -0.22992 0.00008
H -2.26178 -2.04292 -0.00001
C 0.30611 -0.89330 -0.00003
H -0.23533 1.74596 -0.00016
C 0.22947 -2.43941 -0.00017
C 2.87495 0.59236 0.00003
H 1.24060 -2.85486 -0.00047
O 3.94166 1.19955 0.00009
H -0.29463 -2.80635 -0.88849
C 1.03207 -0.46269 -1.25157
C 2.19375 0.20540 -1.25401
H 0.54690 -0.73333 -2.18776
H 2.68950 0.49489 -2.17612

References for the computational study

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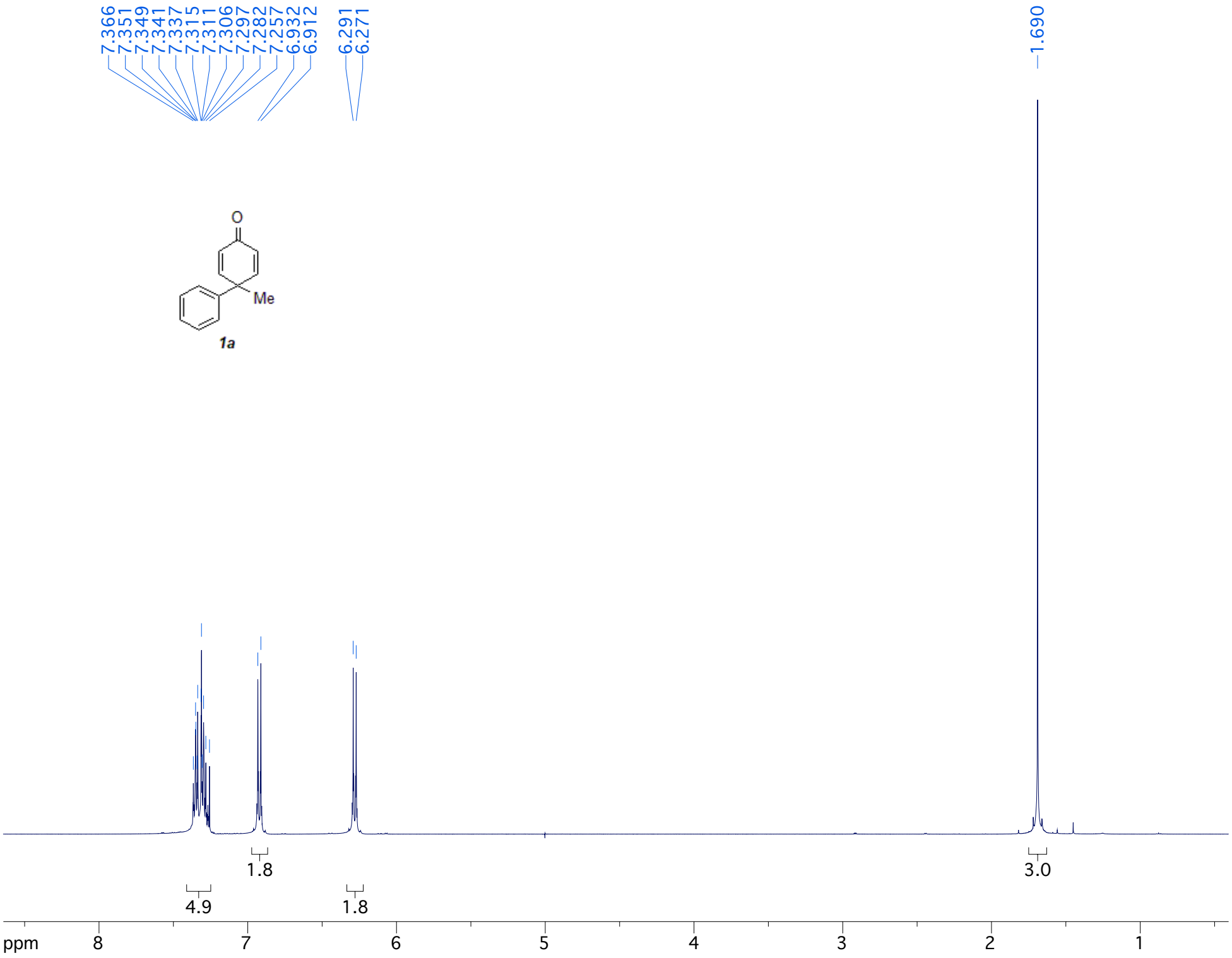
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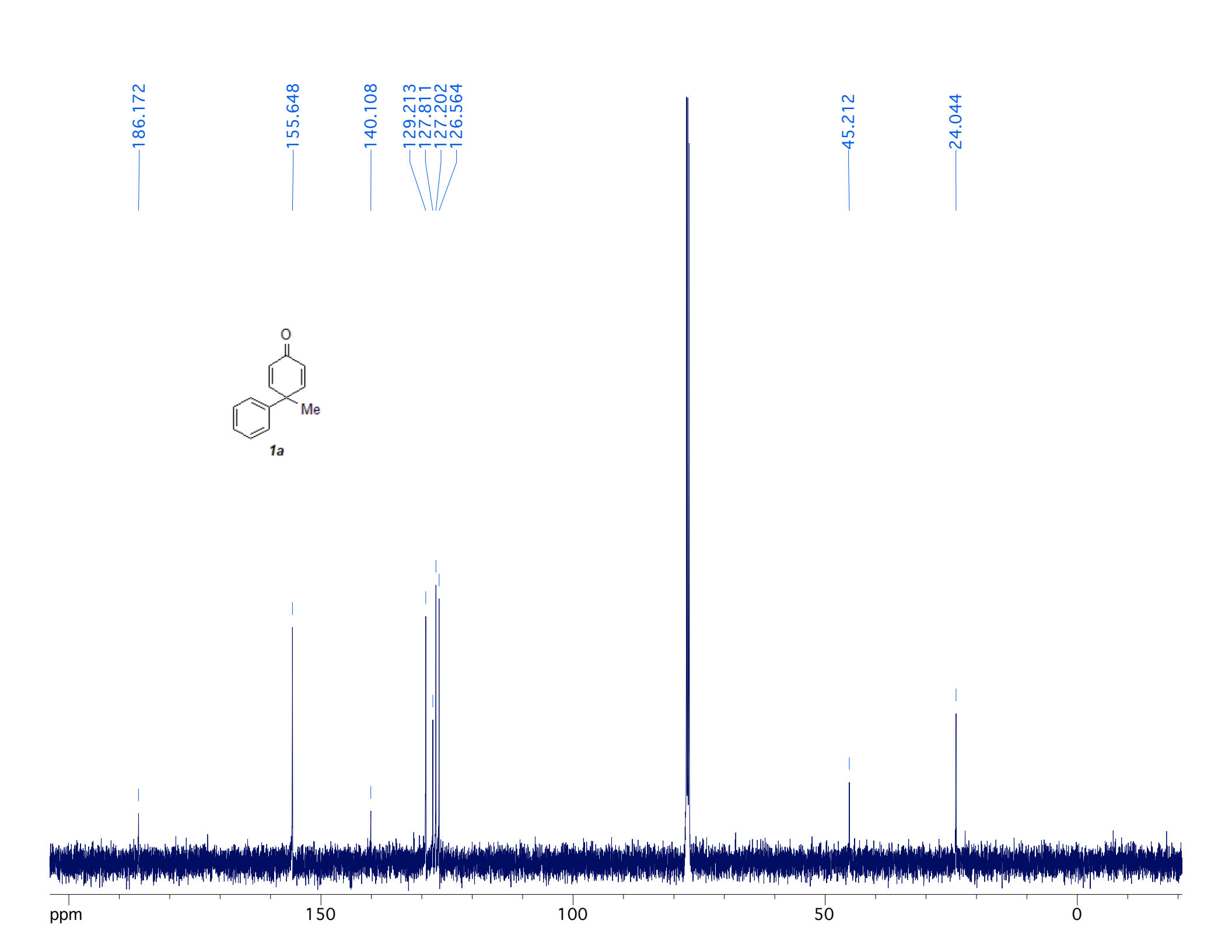
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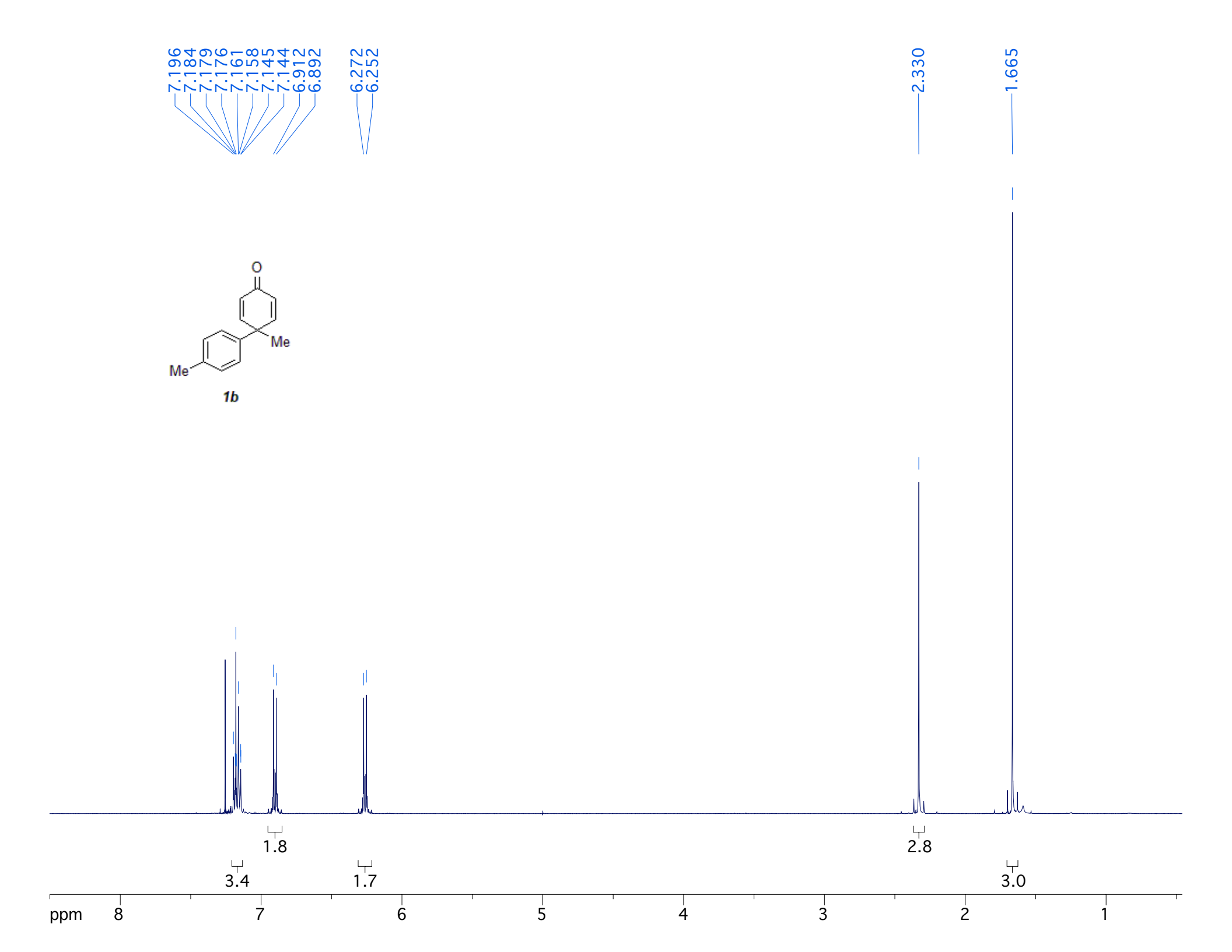
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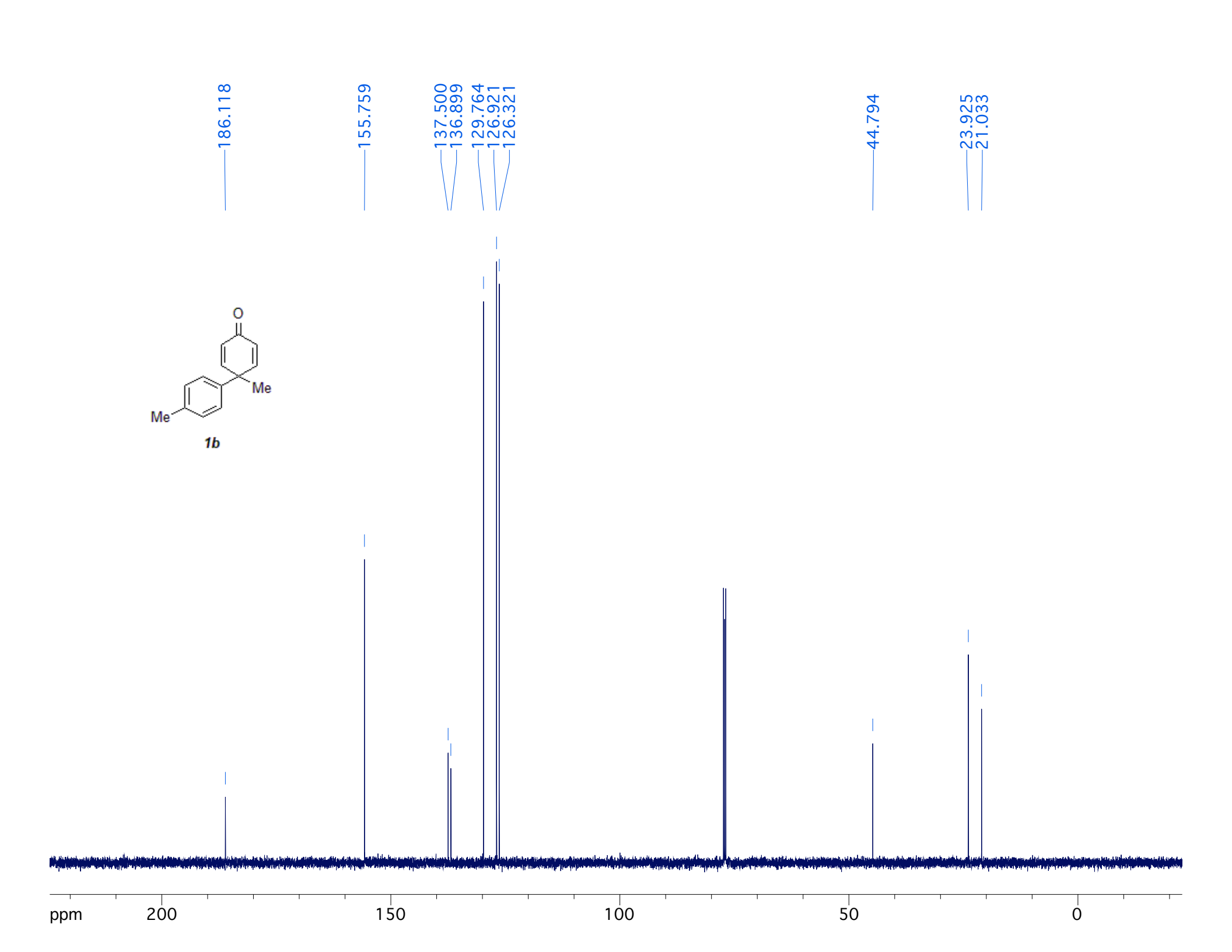
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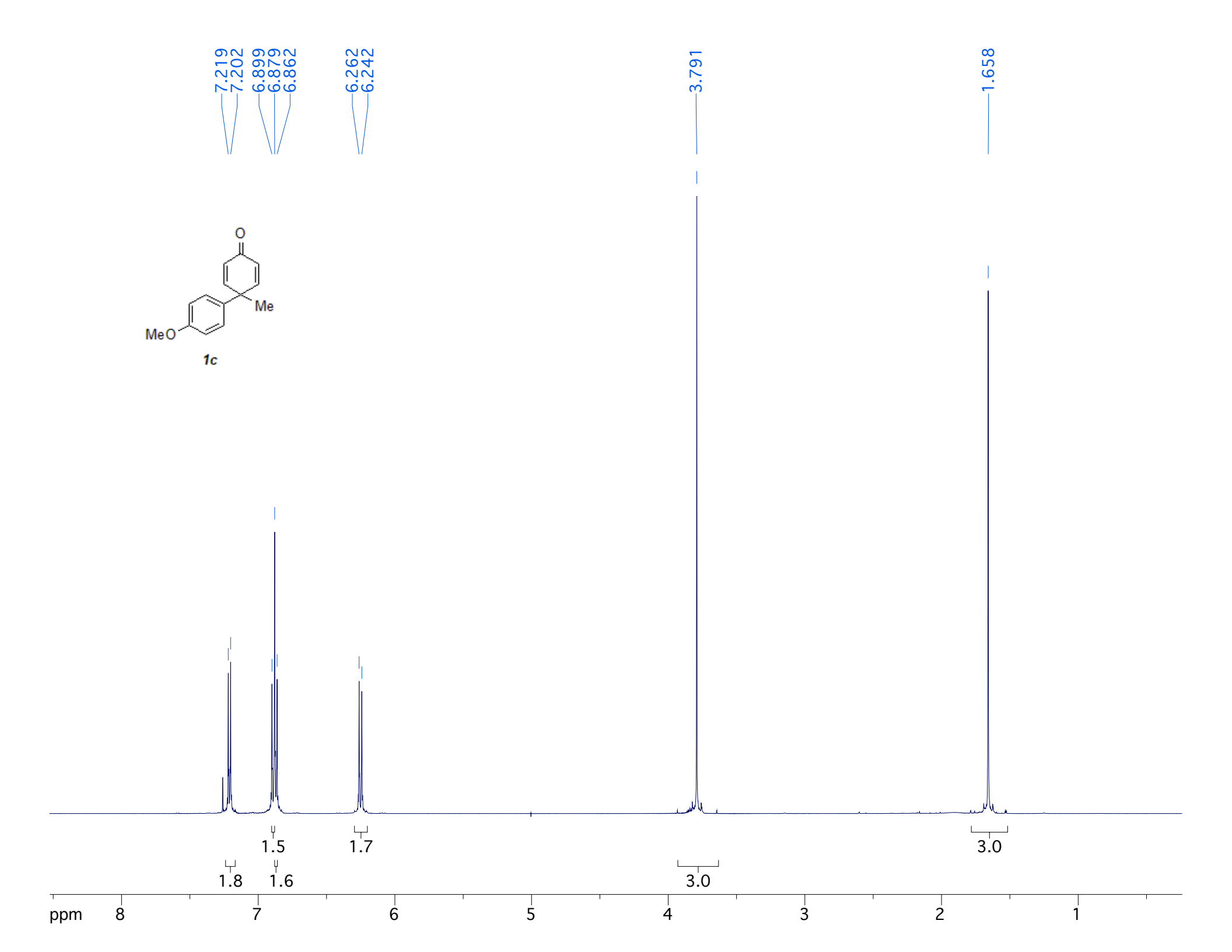
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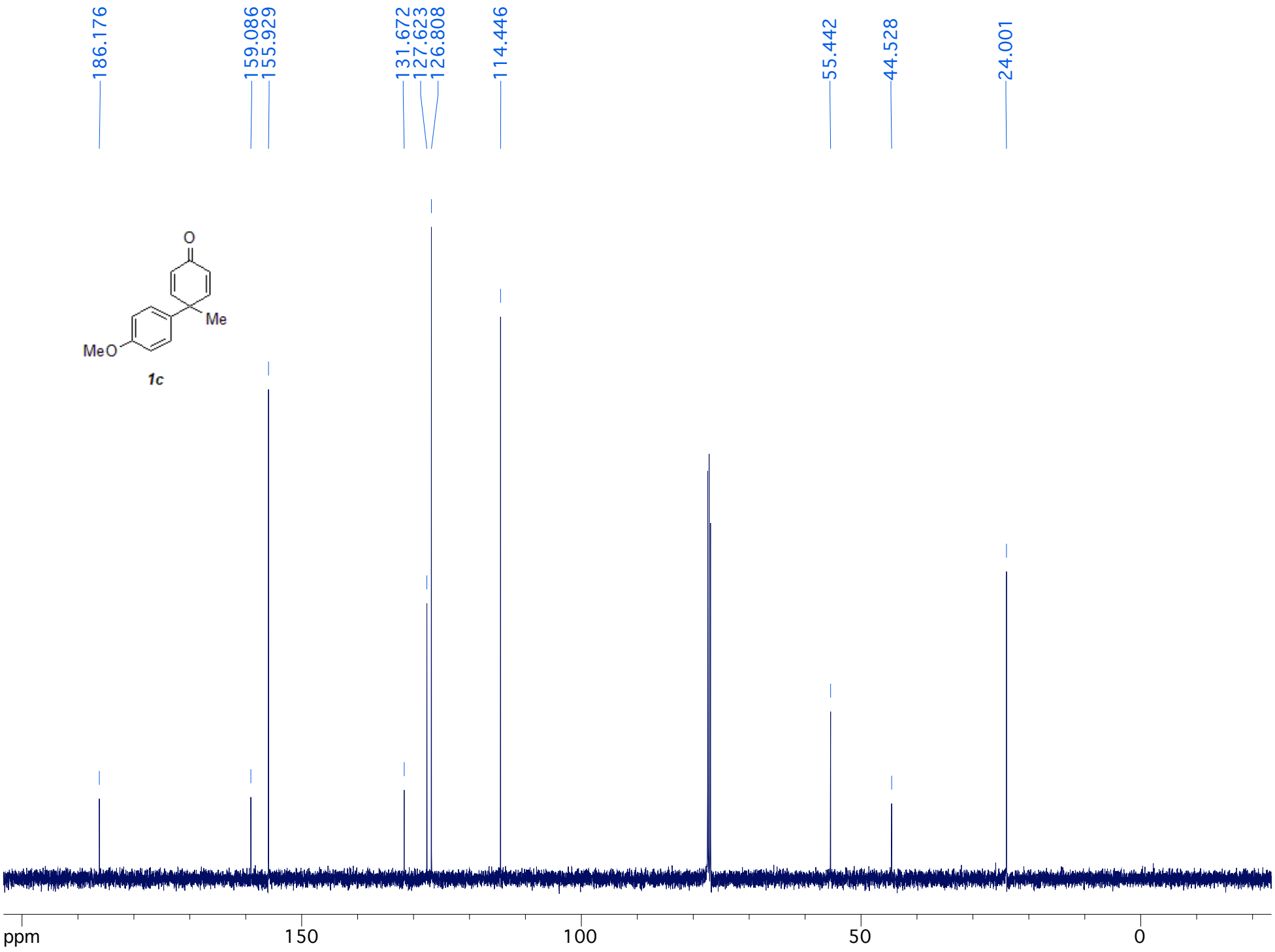
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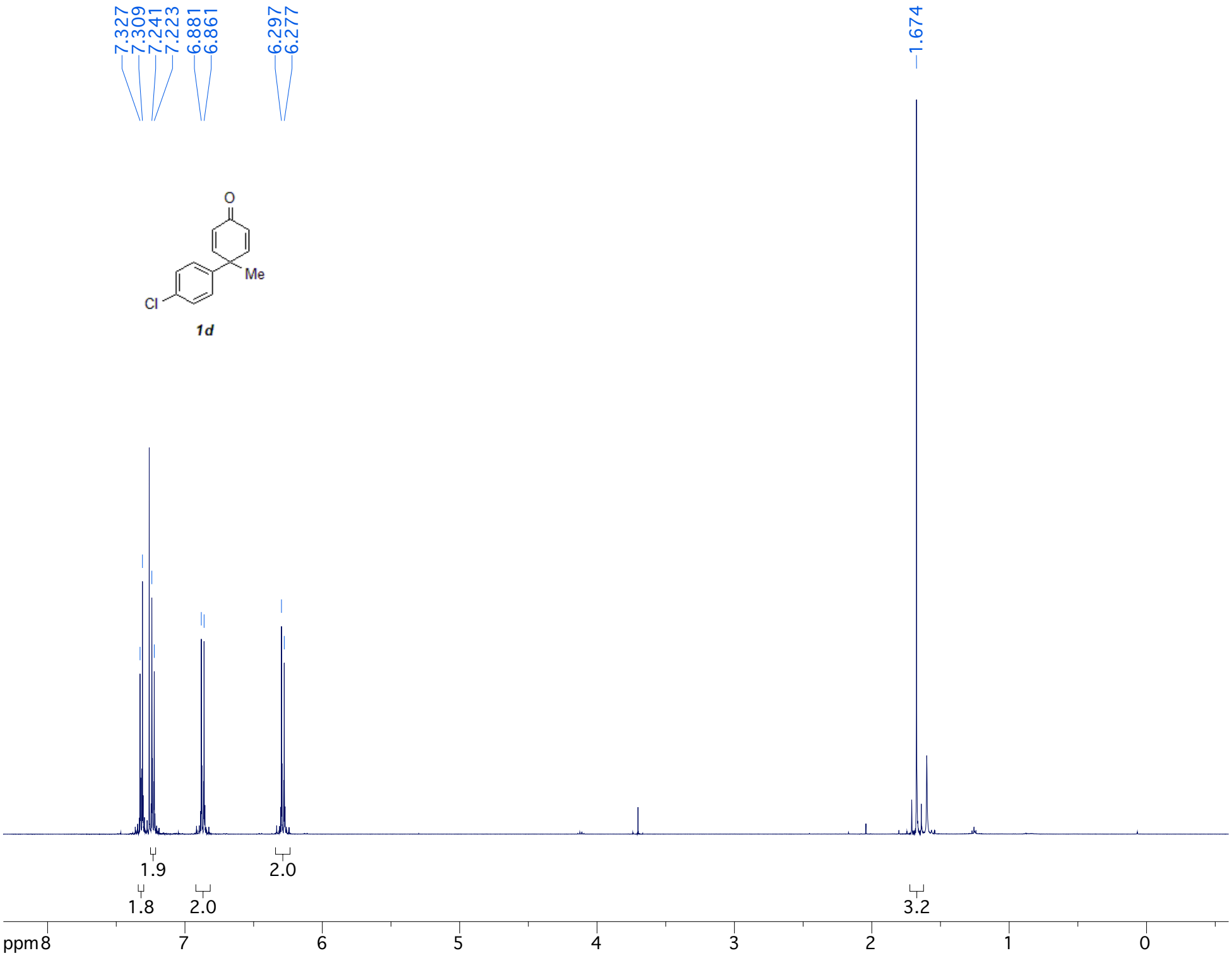
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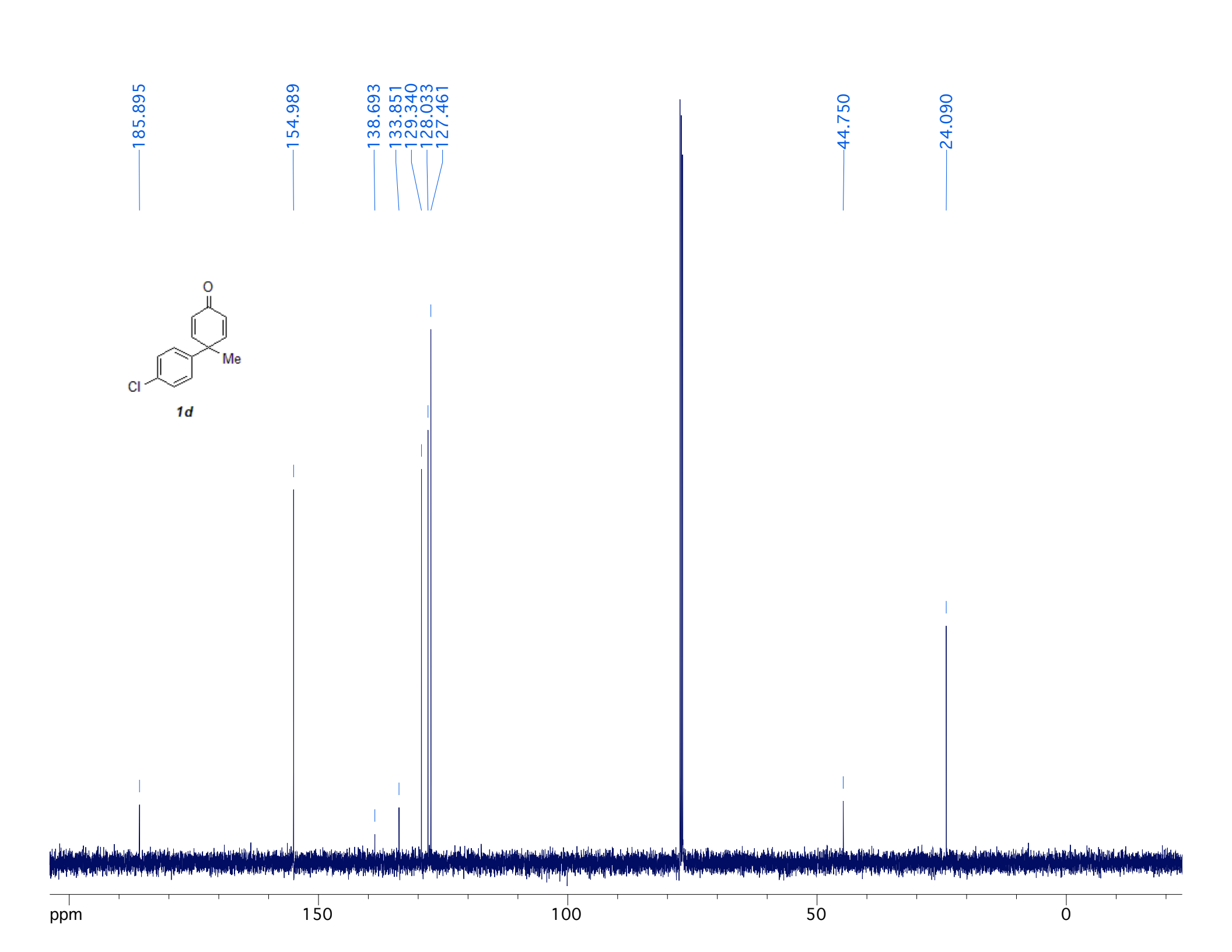
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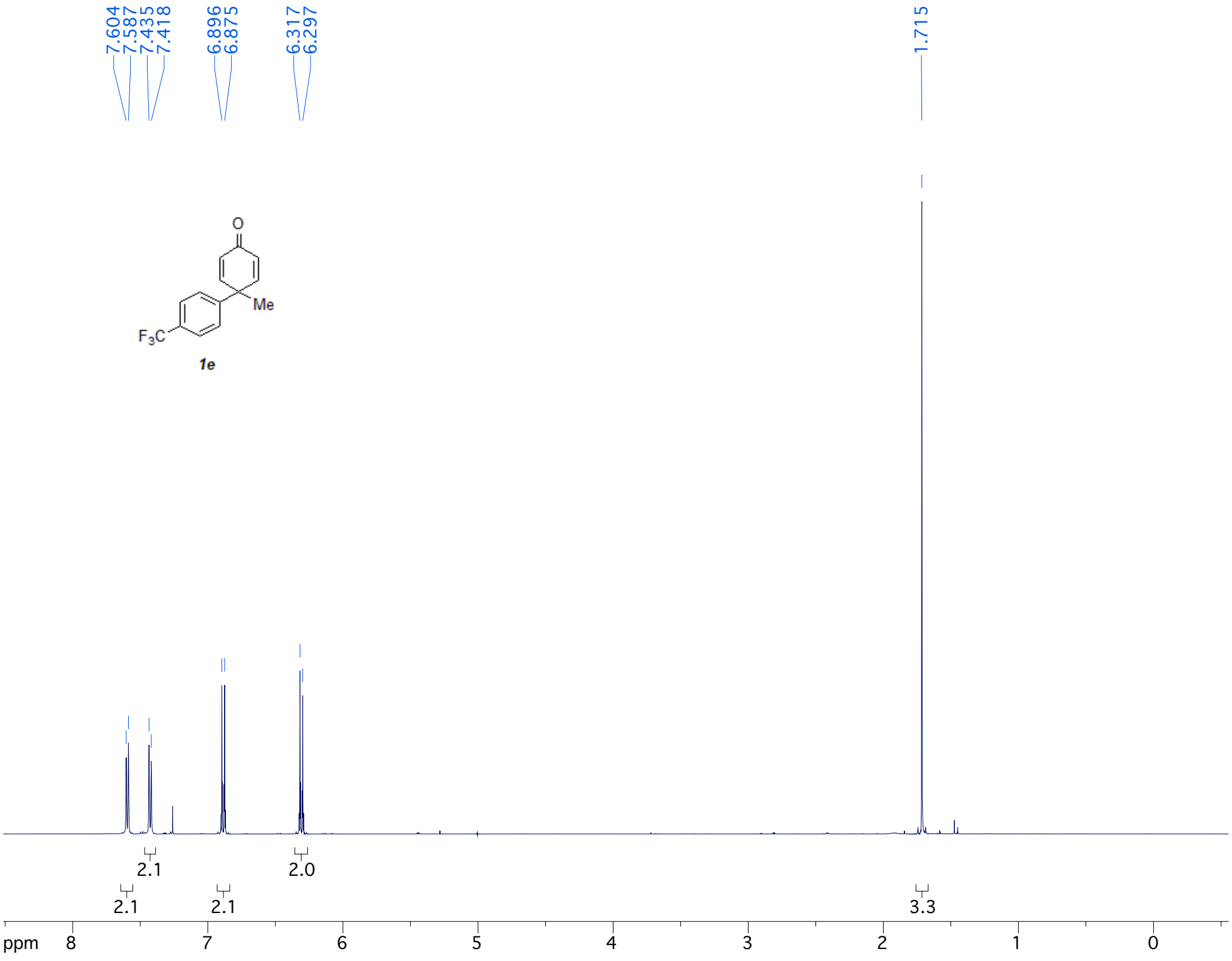
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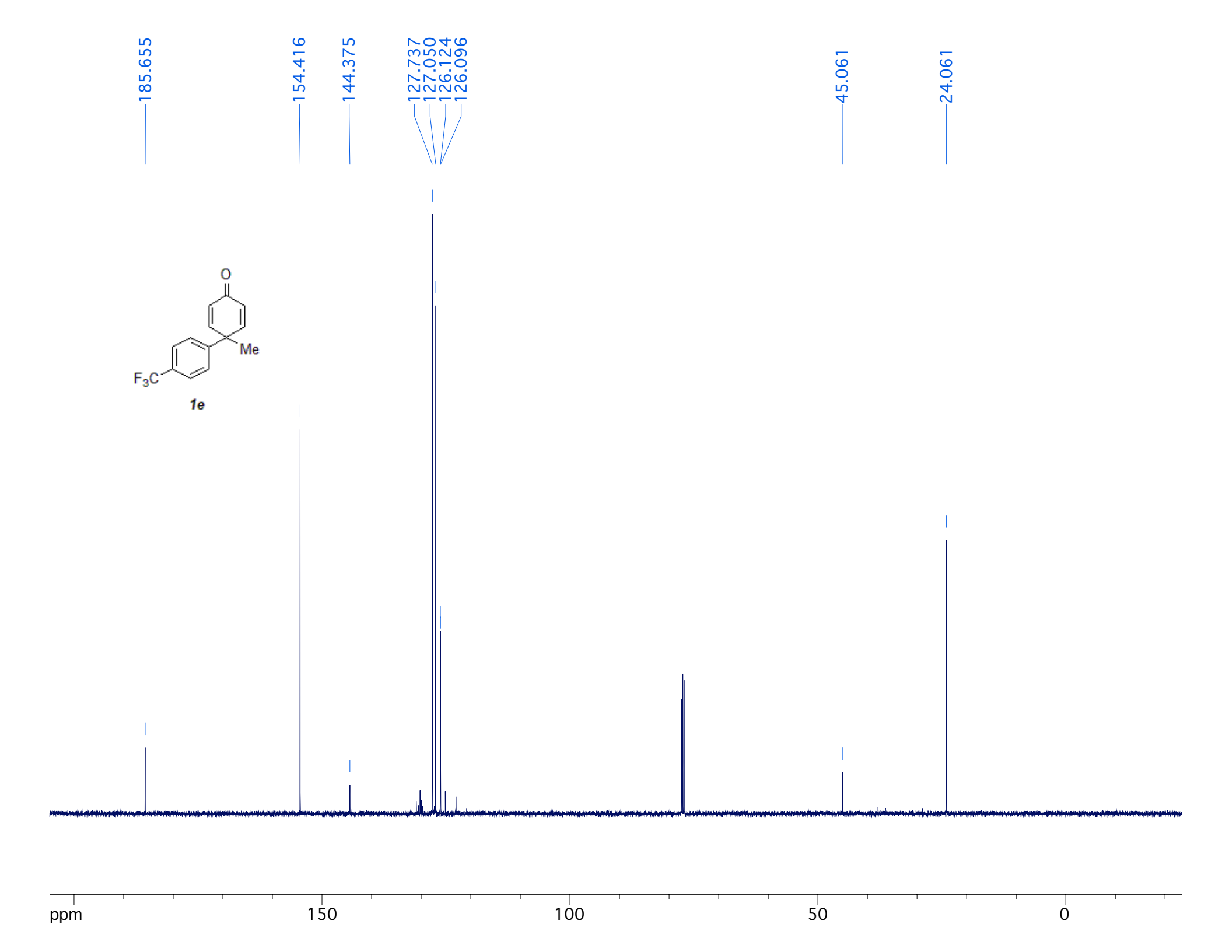
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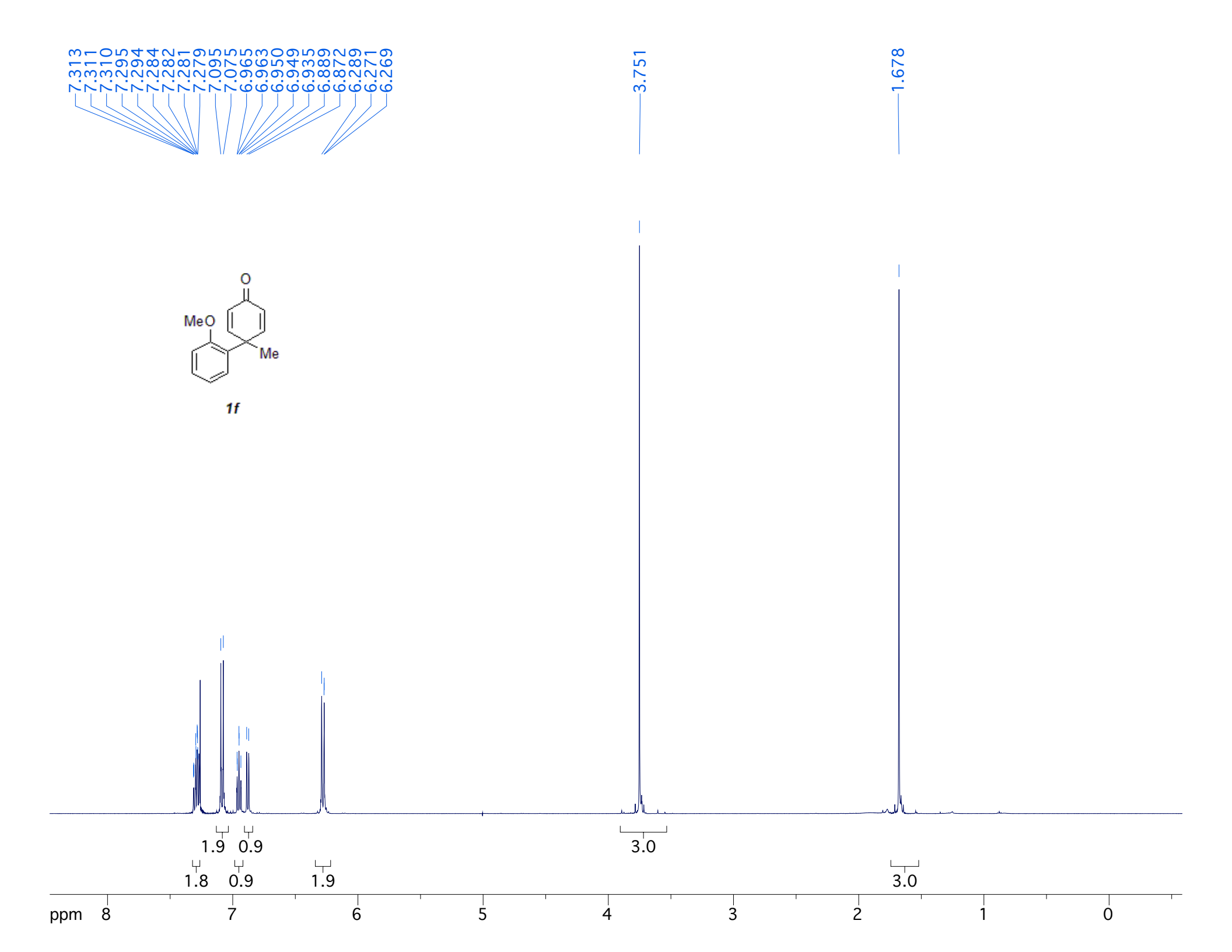
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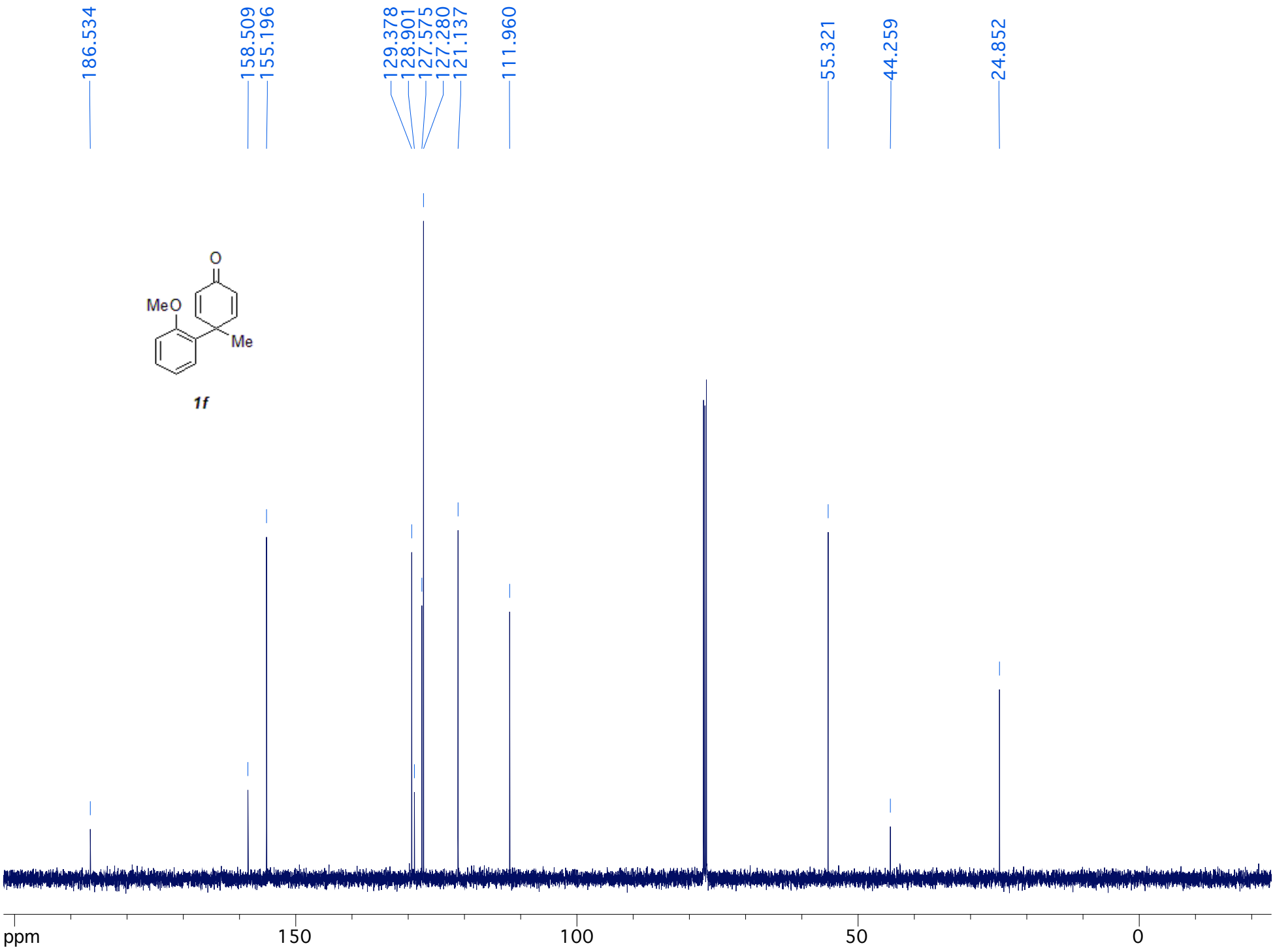
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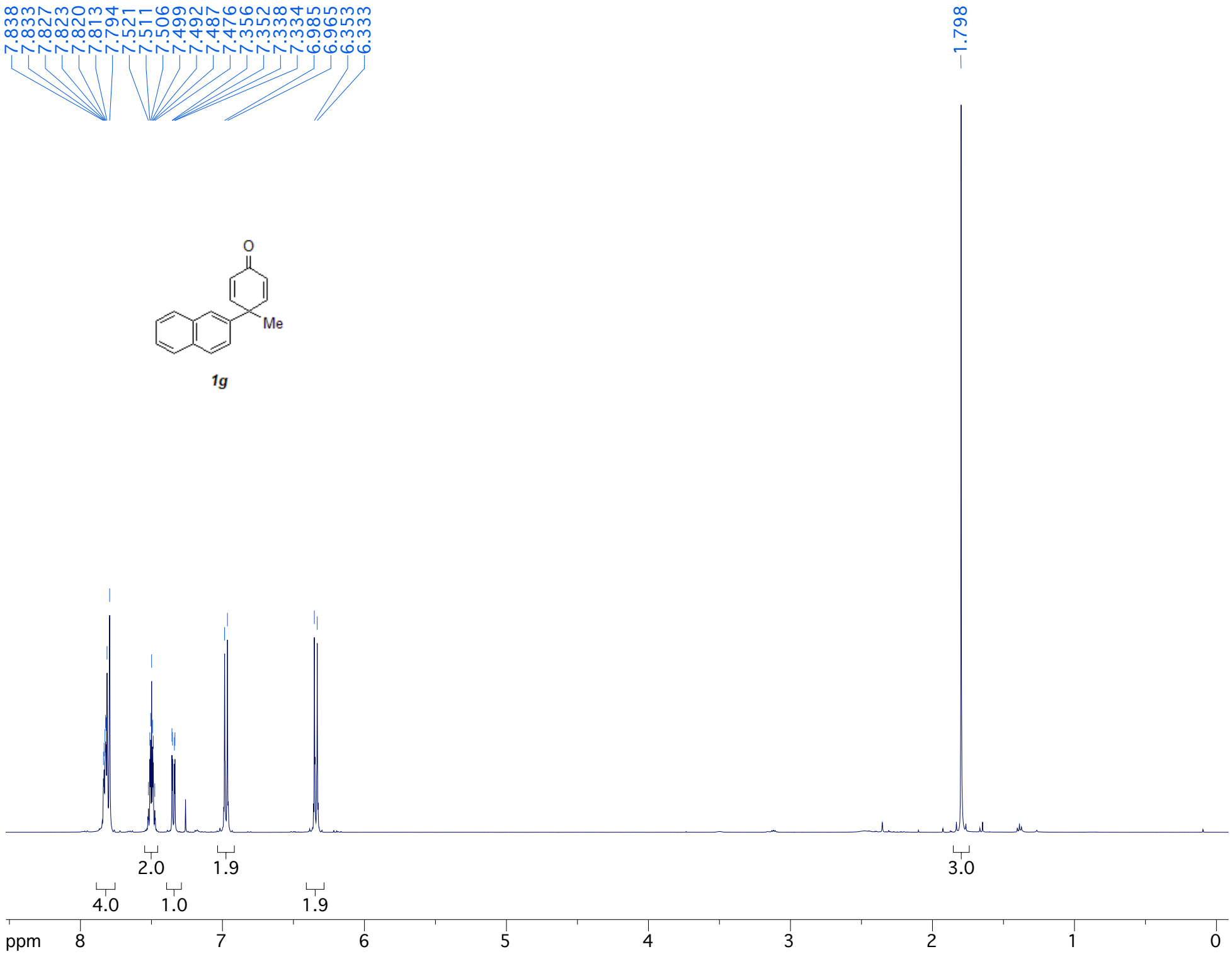
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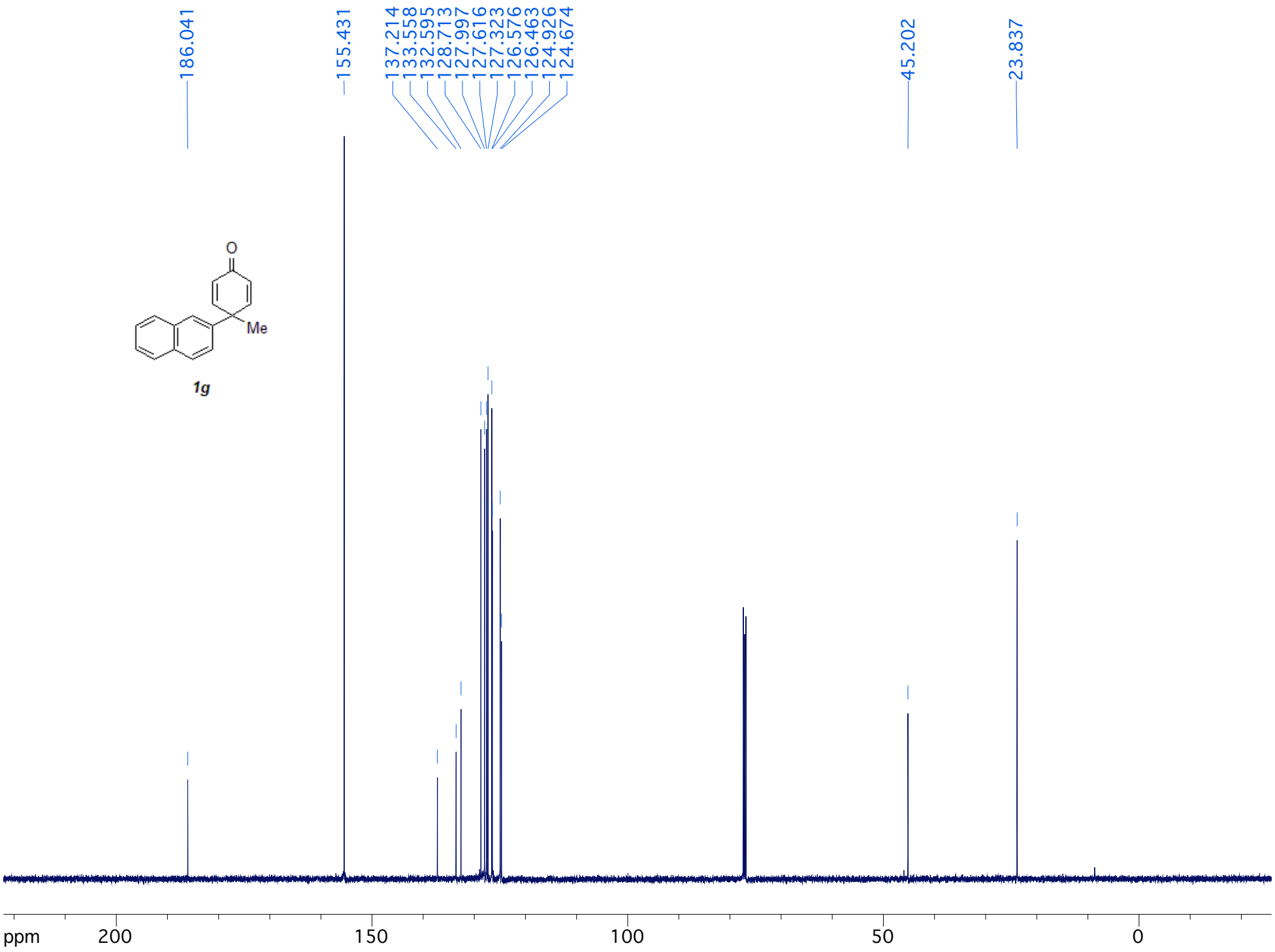
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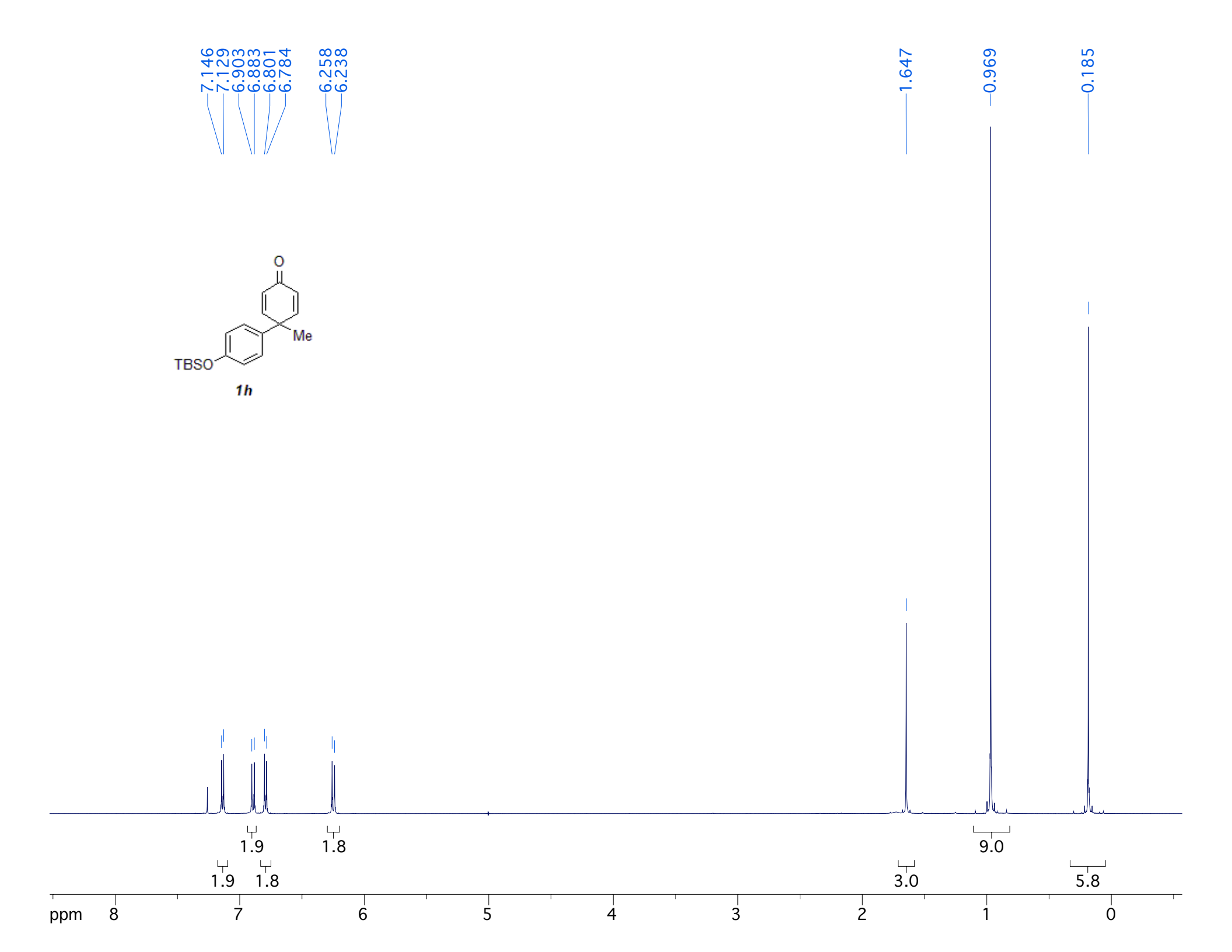
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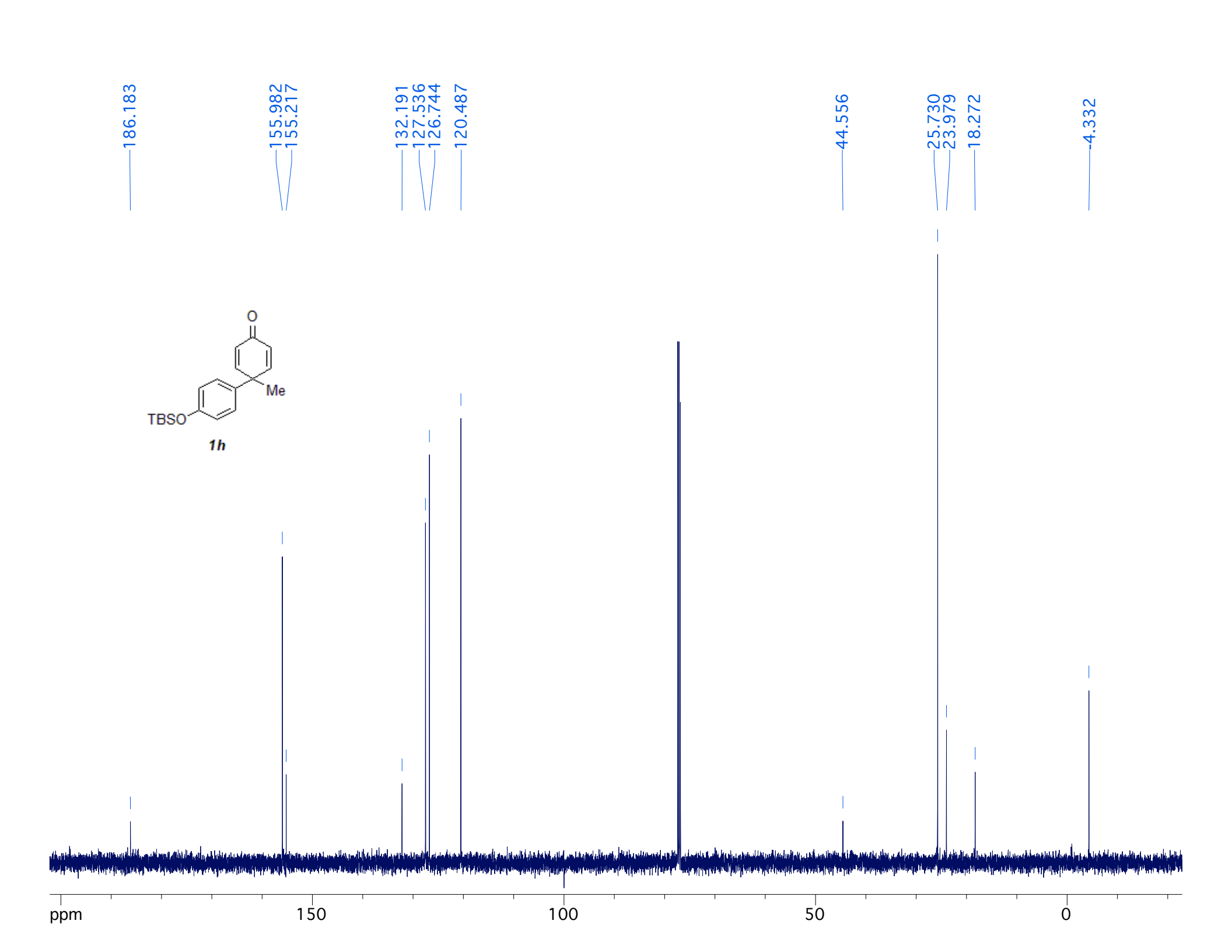
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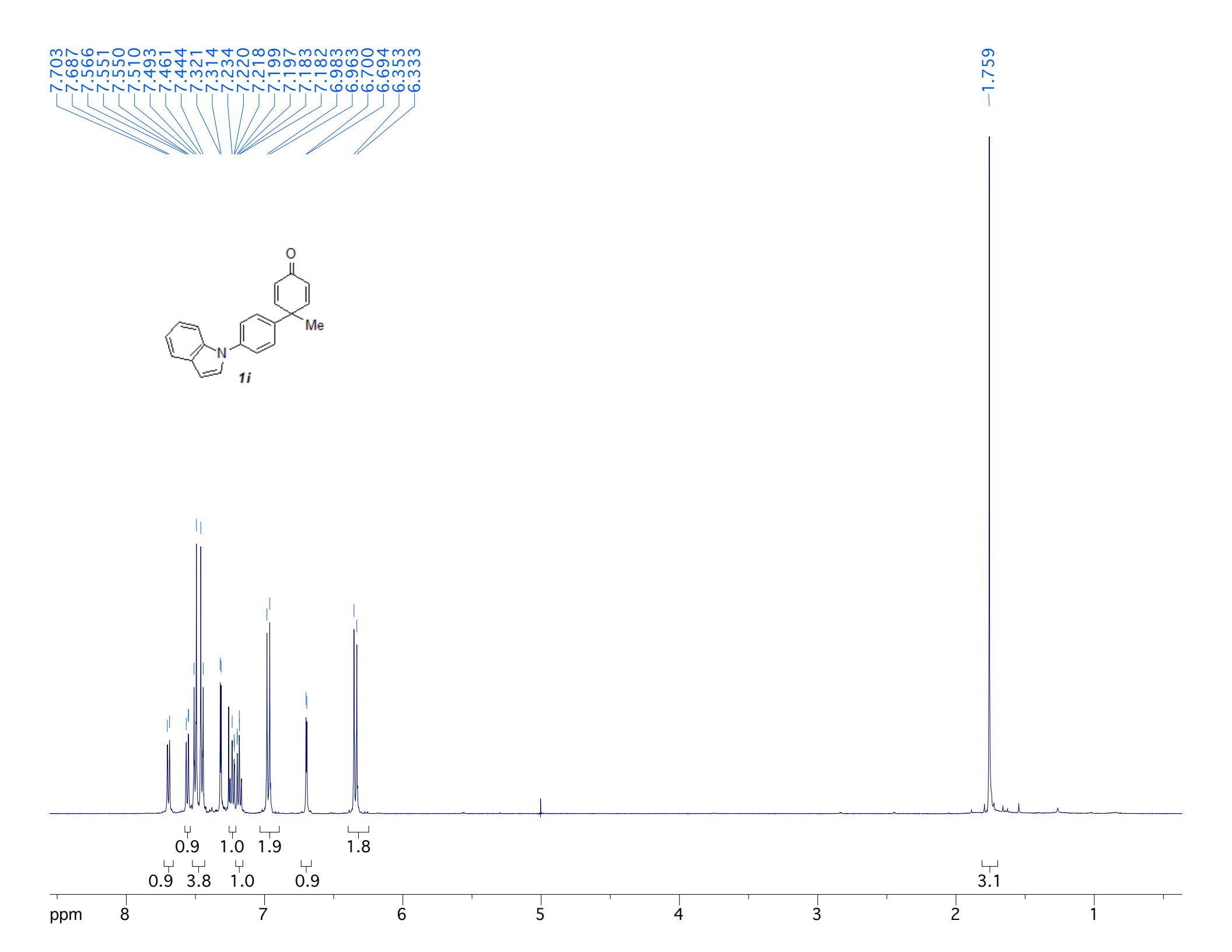
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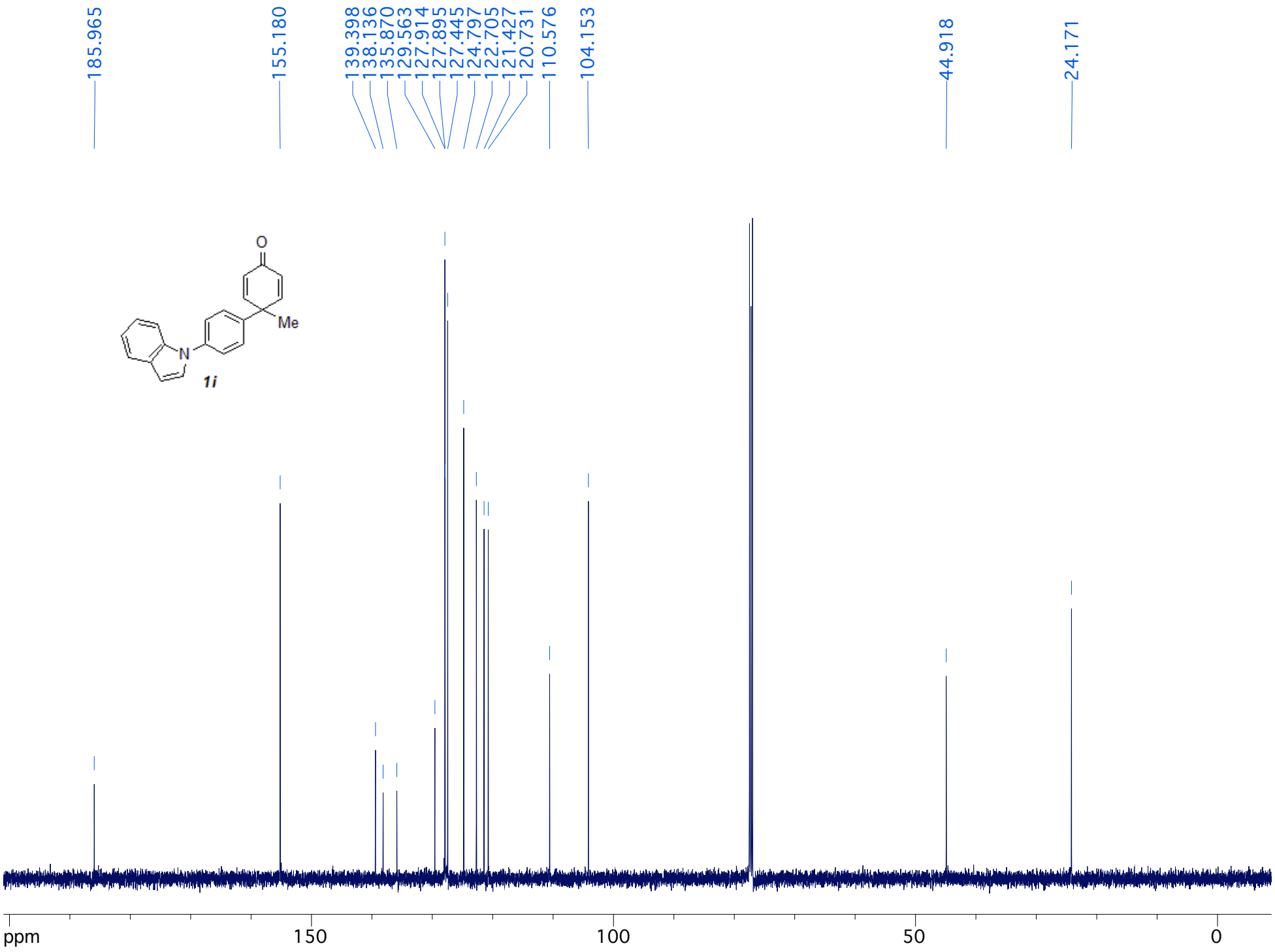
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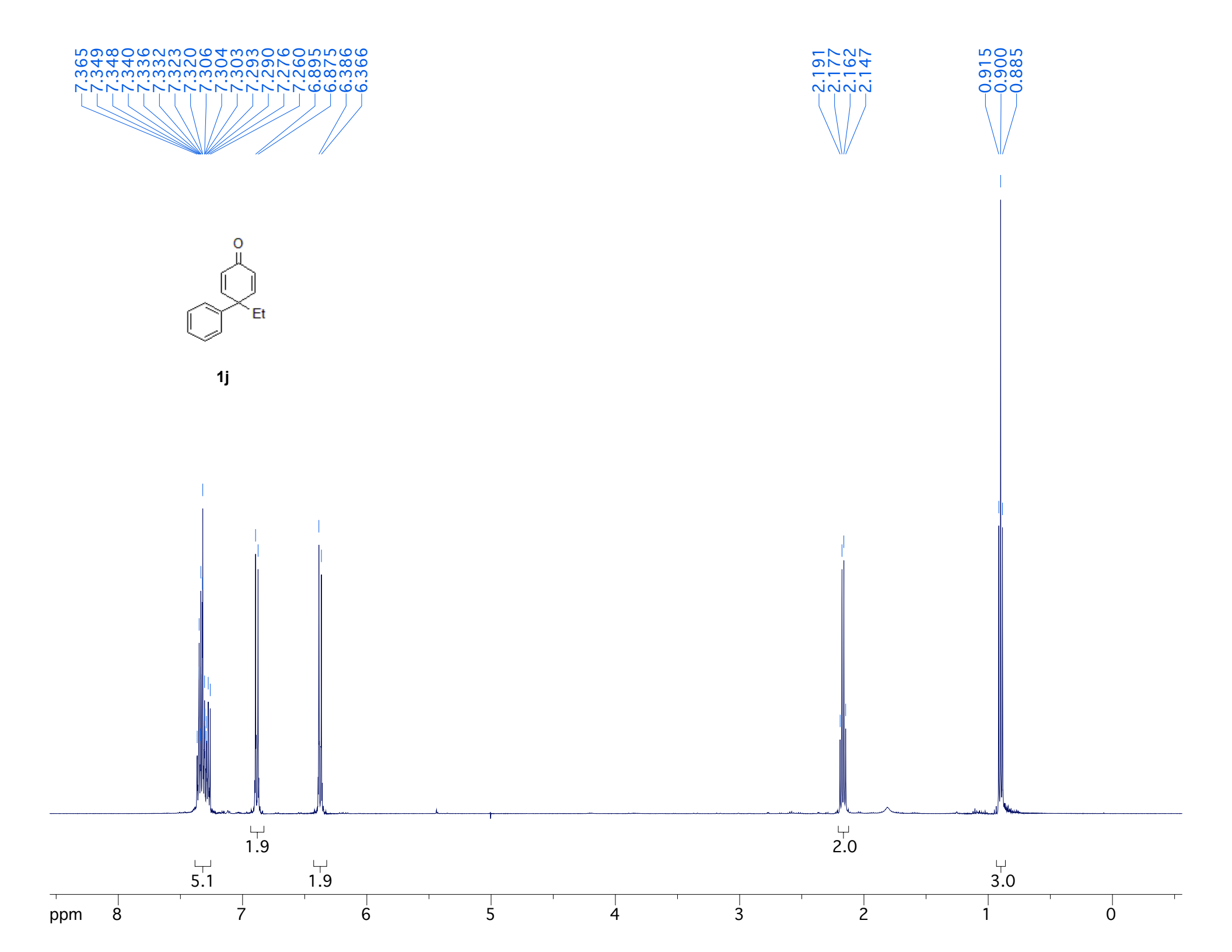
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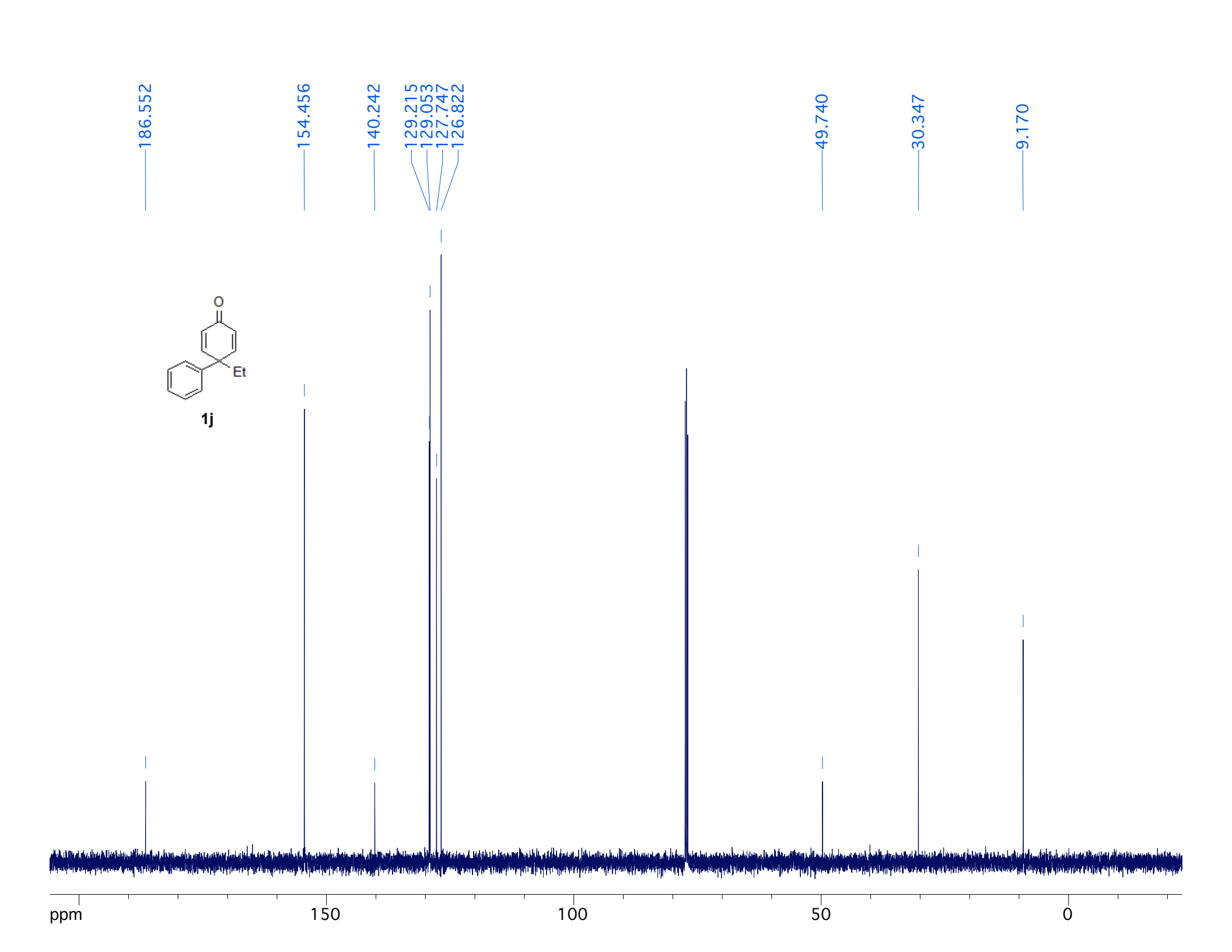
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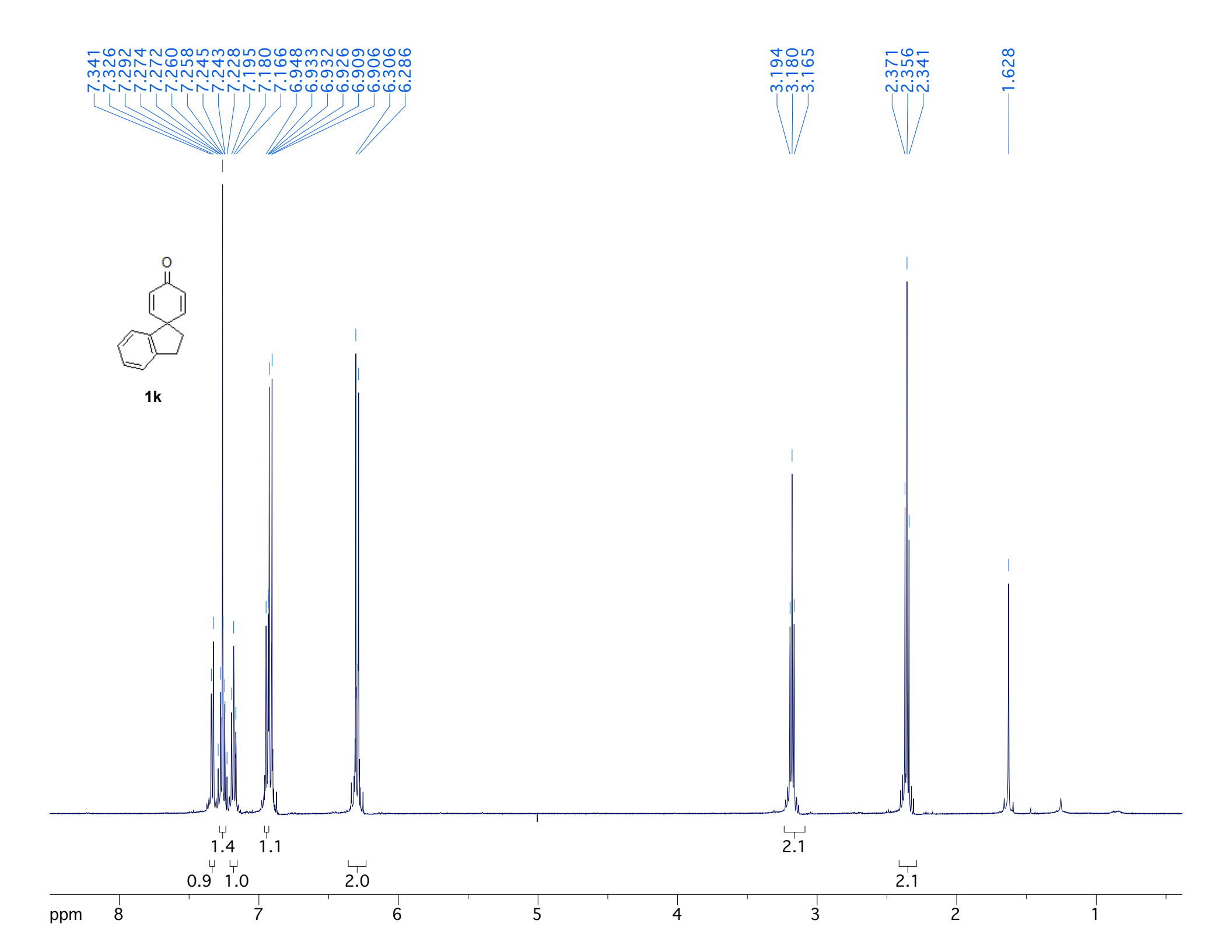
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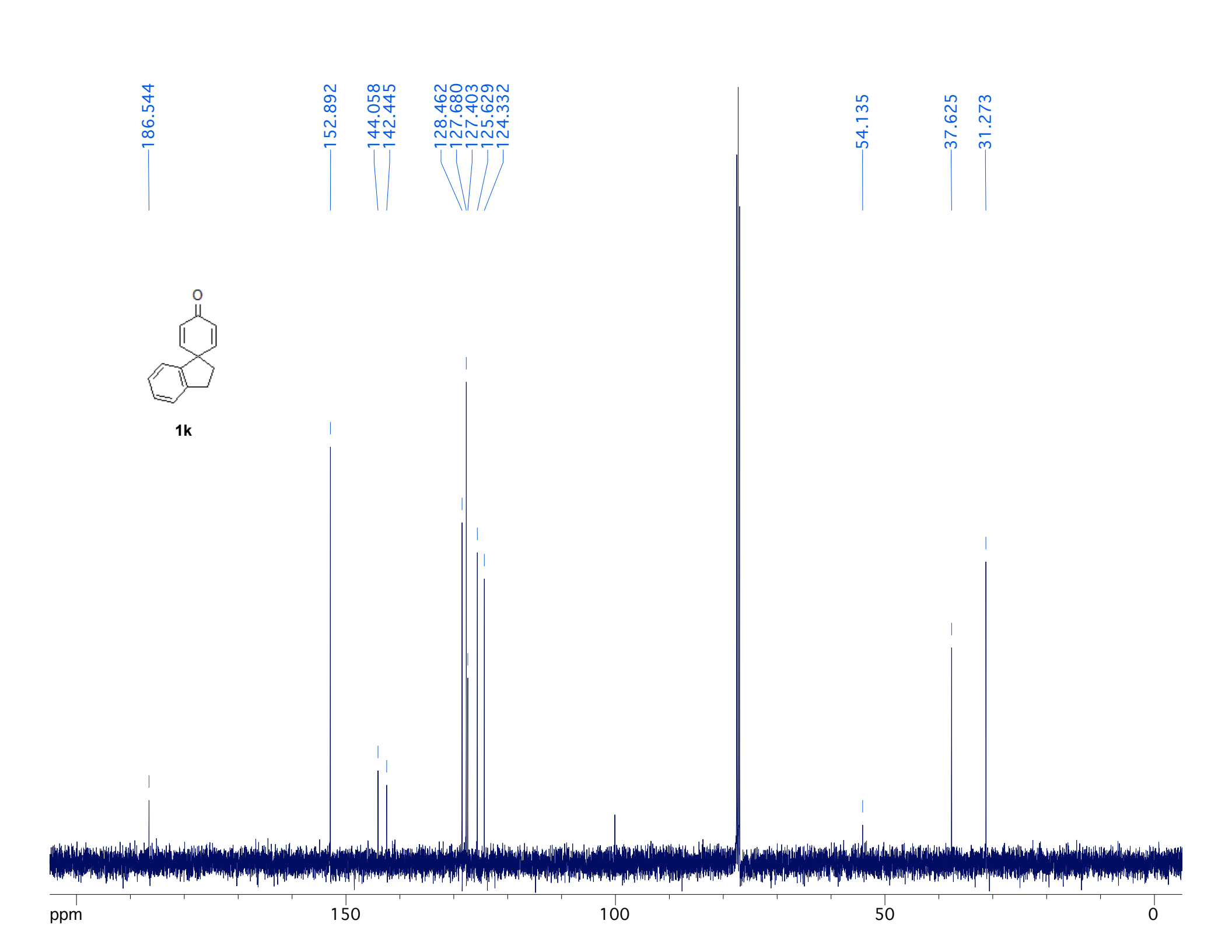
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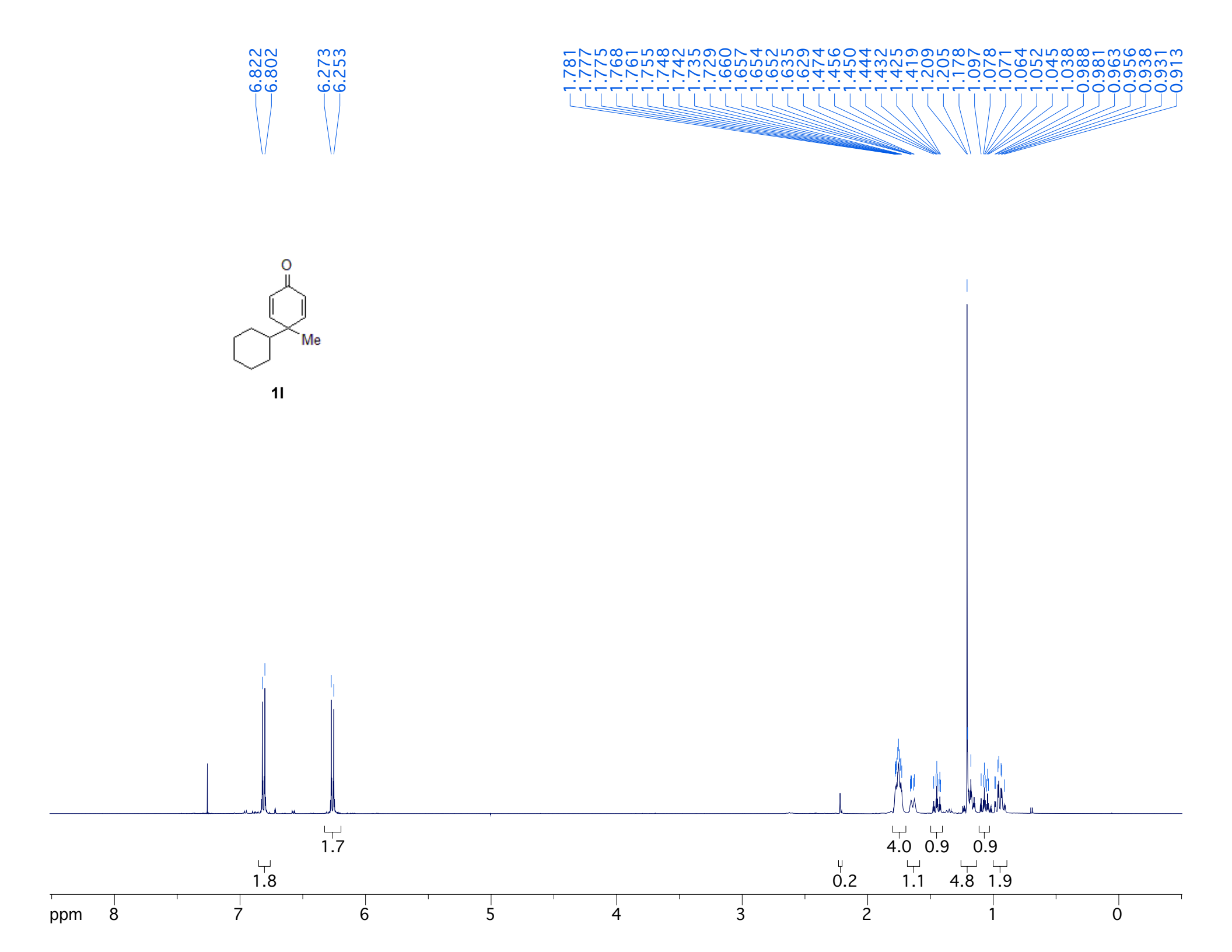
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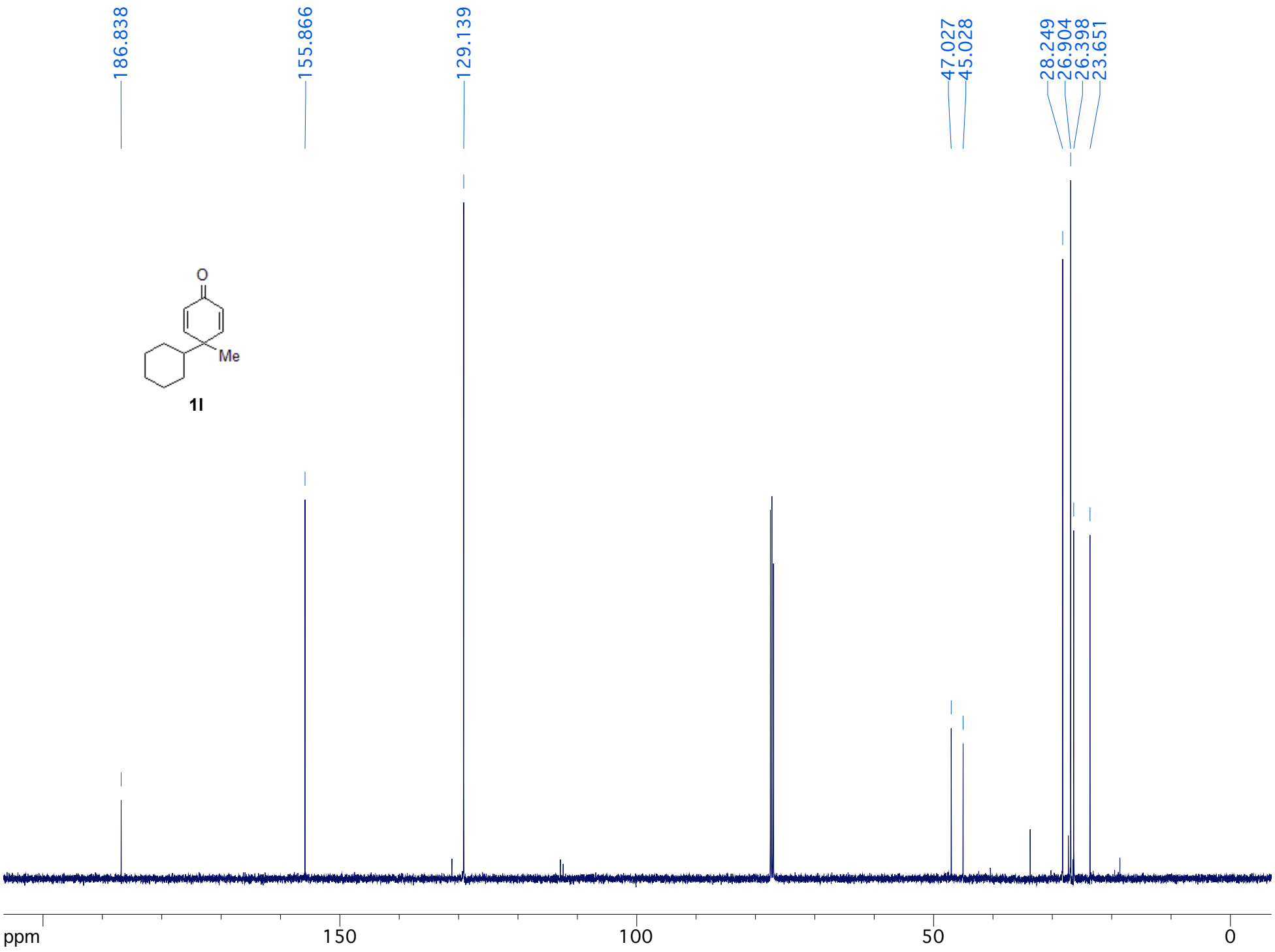
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Me
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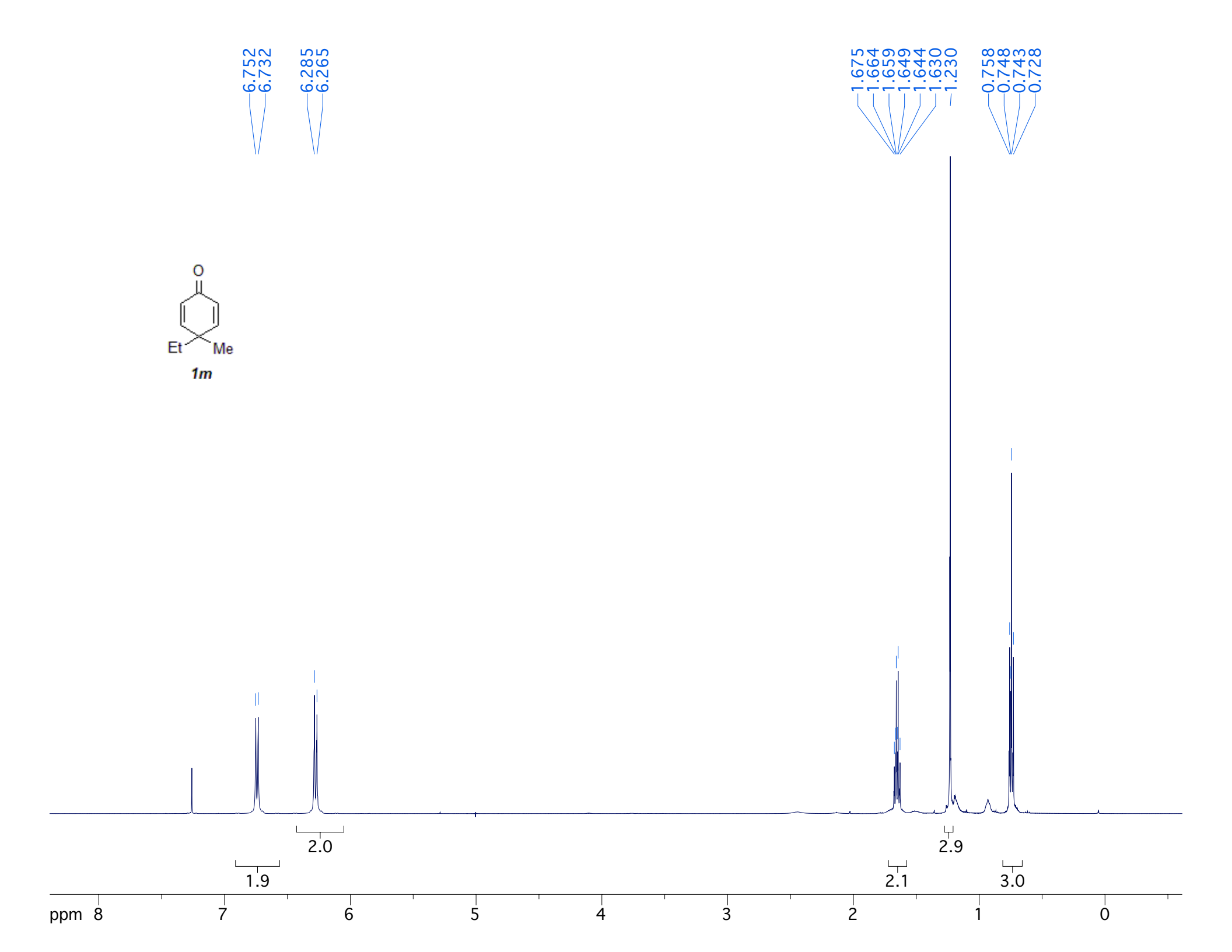
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1.649
1.644
1.630
1.230
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0.748
0.743
0.728
O
Et
Me
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1.9
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3
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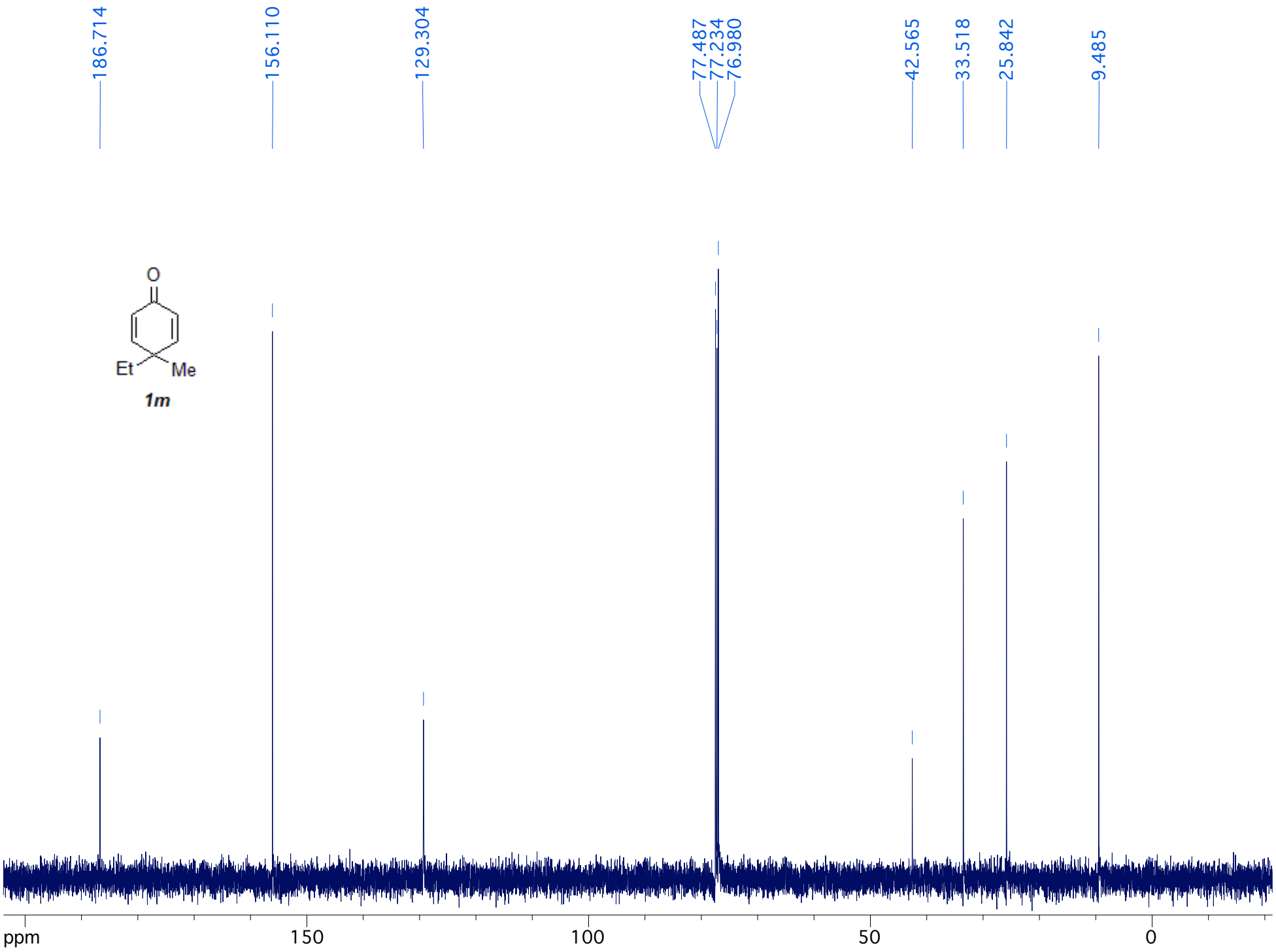
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Et
Me
1m
ppm
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50
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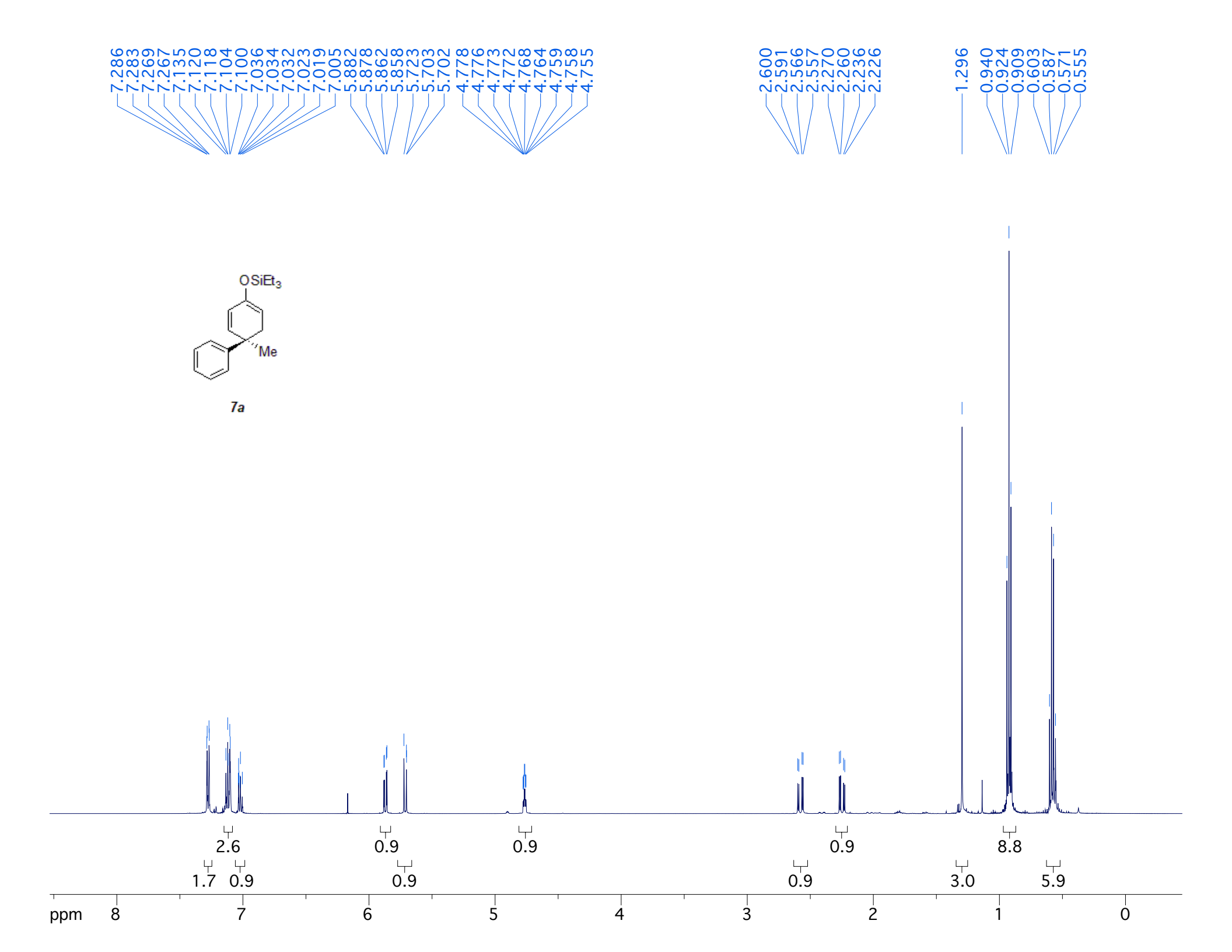
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7.019
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5.858
5.723
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5.702
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4.776
4.773
4.772
4.768
4.764
4.759
4.758
4.755
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2.591
2.566
2.557
2.270
2.260
2.236
2.226
1.296
0.940
0.924
0.909
0.603
0.587
0.571
0.555
OSiEt3
Me
7a
2.6
0.9
0.9
0.9
8.8
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0.9
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ppm
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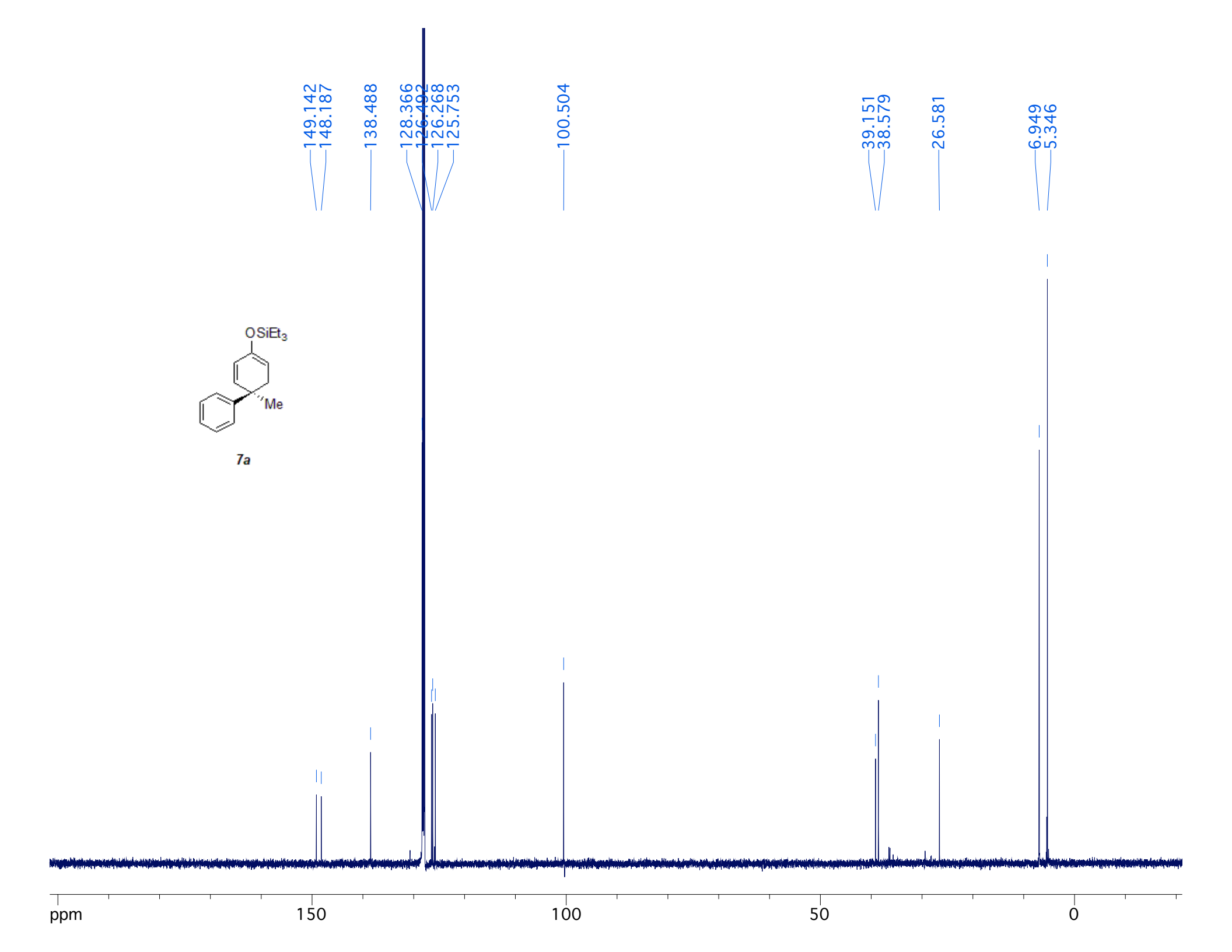
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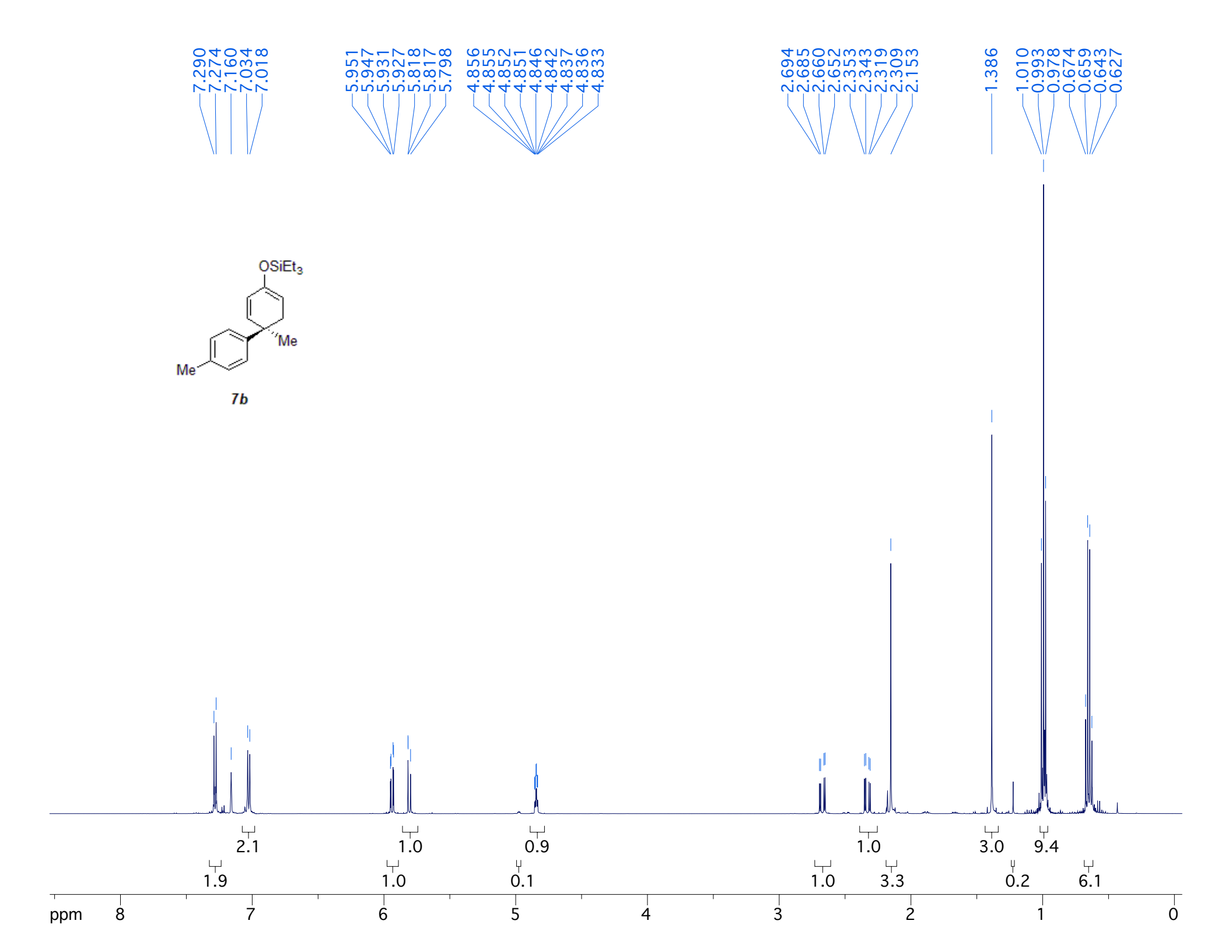
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4.856
4.855
4.852
4.851
4.846
4.842
4.837
4.836
4.833
2.694
2.685
2.660
2.652
2.353
2.343
2.319
2.309
2.153
1.386
1.010
0.993
0.978
0.674
0.659
0.643
0.627
OSiEt3
Me
Me
7b
2.1
1.0
0.9
1.0
3.0
9.4
1.9
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ppm
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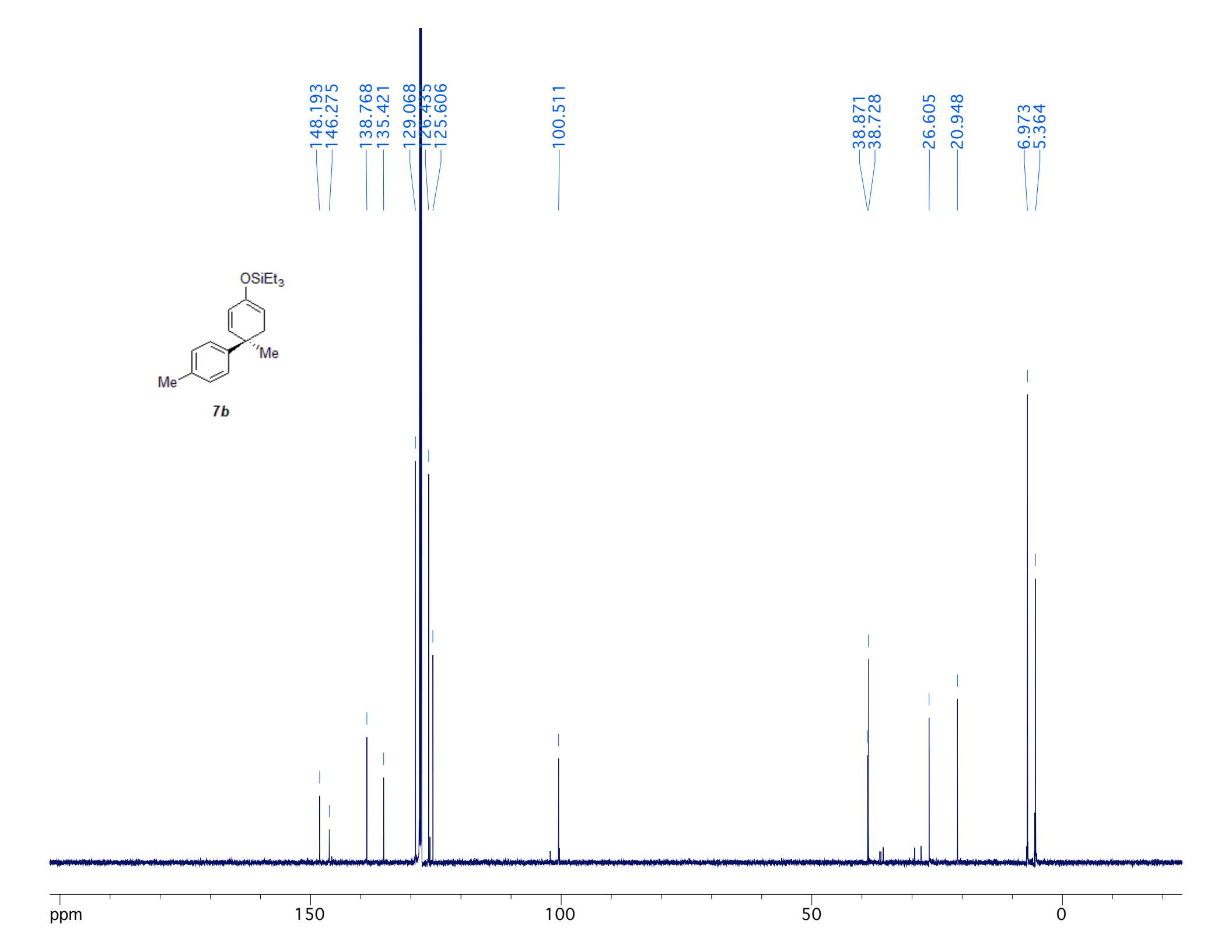
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100.511
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6.973
5.364
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Me
Me
7b
ppm
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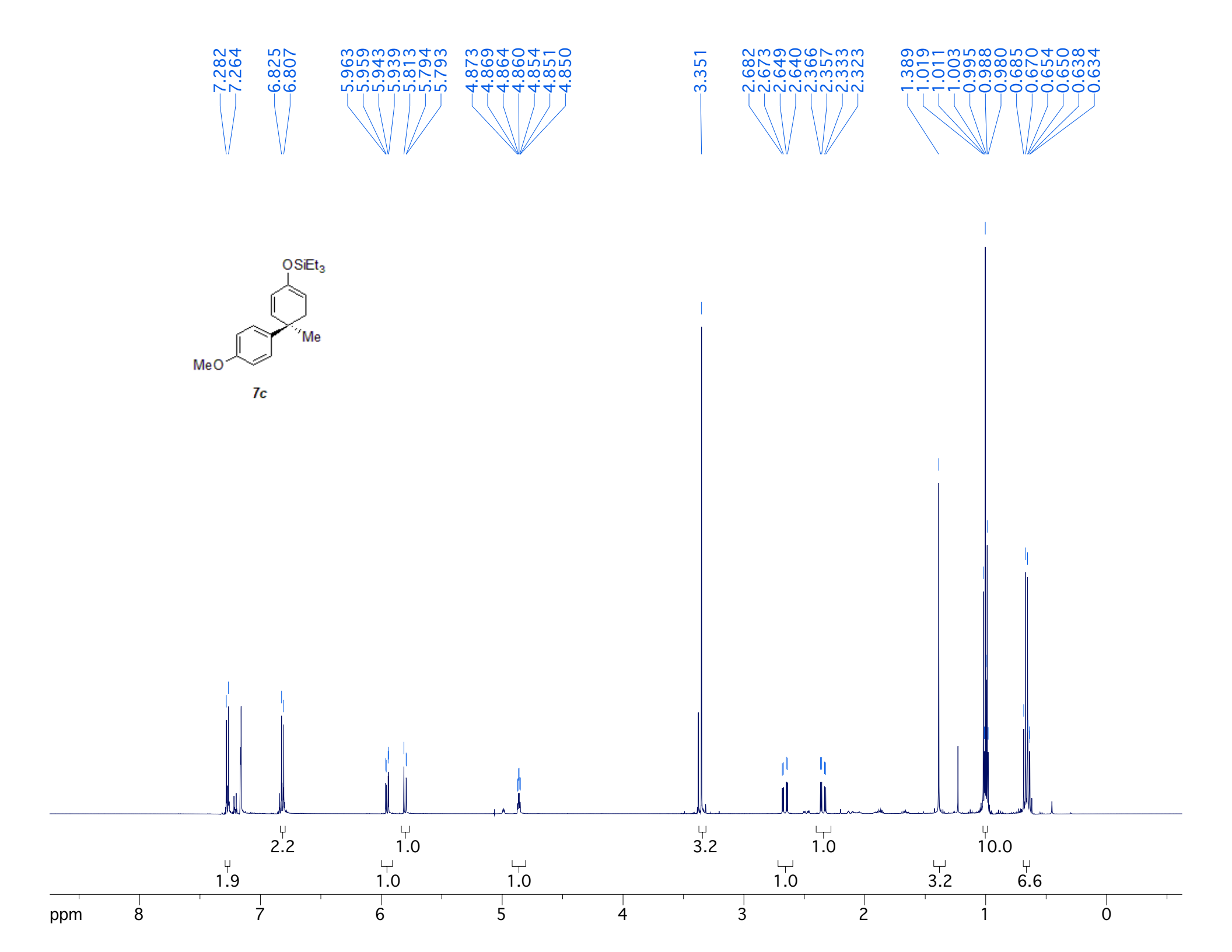
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6.825
6.807
5.963
5.959
5.943
5.939
5.813
5.794
5.793
4.873
4.869
4.864
4.860
4.854
4.851
4.850
3.351
2.682
2.673
2.649
2.640
2.366
2.357
2.333
2.323
1.389
1.019
1.011
1.003
0.995
0.988
0.980
0.685
0.670
0.654
0.650
0.638
0.634
OSiEt3
Me
MeO
7c
2.2
1.0
3.2
1.0
10.0
1.9
1.0
1.0
1.0
3.2
6.6
ppm
8
7
6
5
4
3
2
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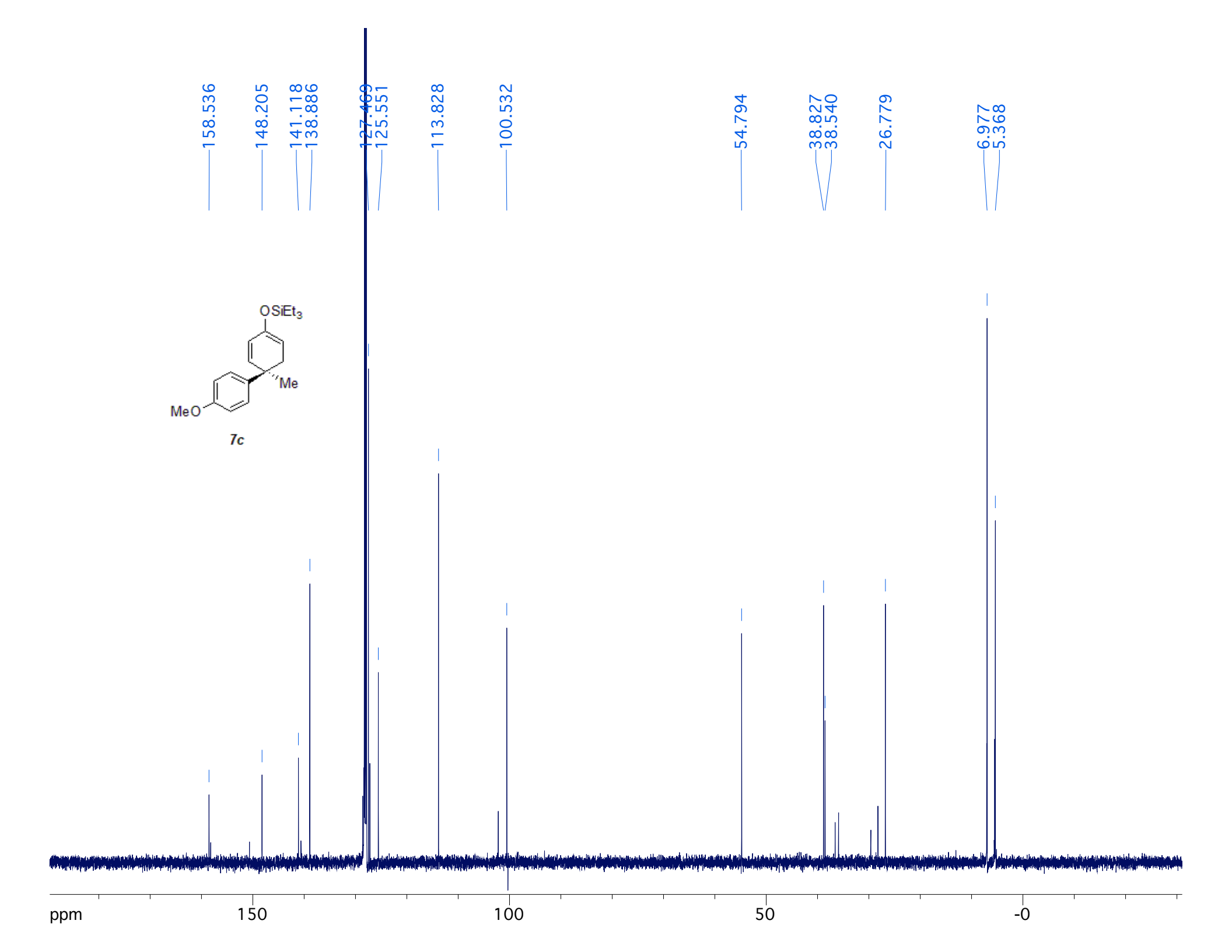
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141.118
138.886
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113.828
100.532
54.794
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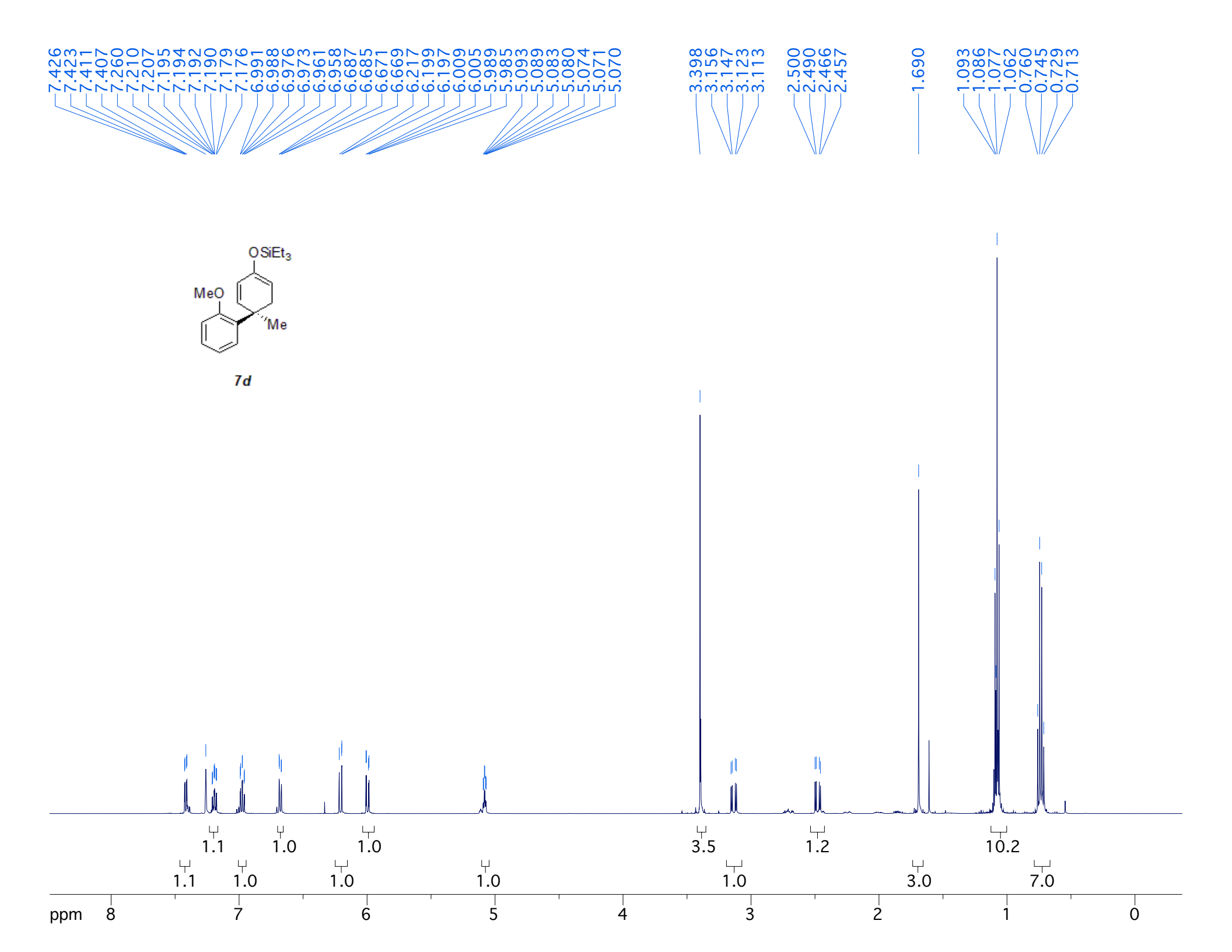
26.779
6.977
5.368
OSiEt3
Me
MeO
7c
ppm
150
100
50
-0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7.407
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7.195
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7.190
7.179
7.176
6.991
6.988
6.976
6.973
6.961
6.958
6.687
6.685
6.671
6.669
6.217
6.199
6.197
6.009
6.005
5.989
5.985
5.093
5.089
5.083
5.080
5.074
5.071
5.070
3.398
3.156
3.147
3.123
3.113
2.500
2.490
2.466
2.457
1.690
1.093
1.086
1.077
1.062
0.760
0.745
0.729
0.713
OSiEt3
MeO
Me
7d
1.1
1.0
1.0
3.5
1.2
10.2
1.1
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1.0
1.0
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ppm
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7
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3
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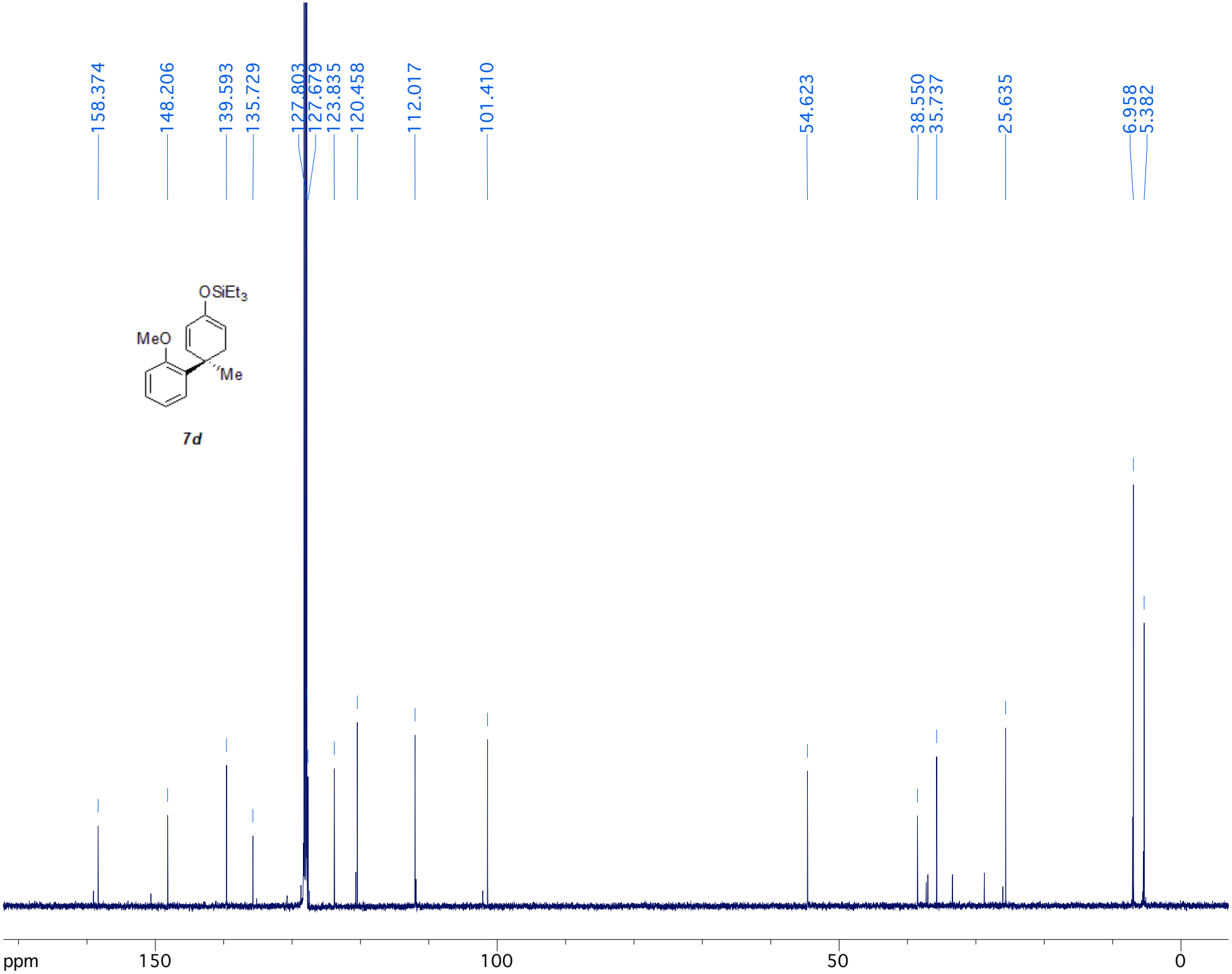
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120.458
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25.635
6.958
5.382
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MeO
Me
7d
ppm
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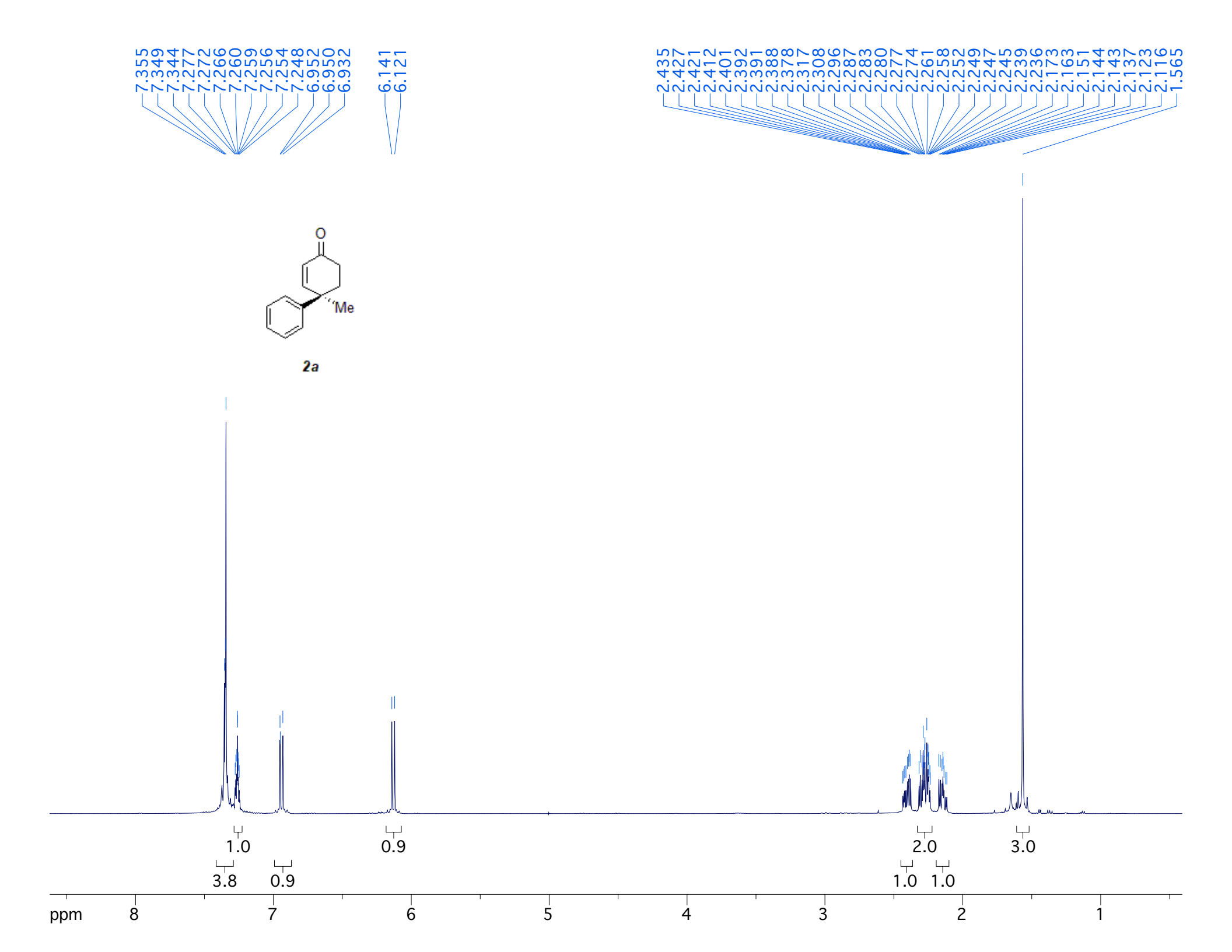
100
50
0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7.259
7.256
7.254
7.248
6.952
6.950
6.932
6.141
6.121
2.435
2.427
2.421
2.412
2.401
2.392
2.391
2.388
2.378
2.317
2.308
2.296
2.287
2.283
2.280
2.277
2.274
2.261
2.258
2.252
2.249
2.247
2.245
2.239
2.236
2.173
2.163
2.151
2.144
2.143
2.137
2.123
2.116
1.565
O
Me
2a
1.0
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3.8
0.9
1.0
1.0
ppm
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5
4
3
2
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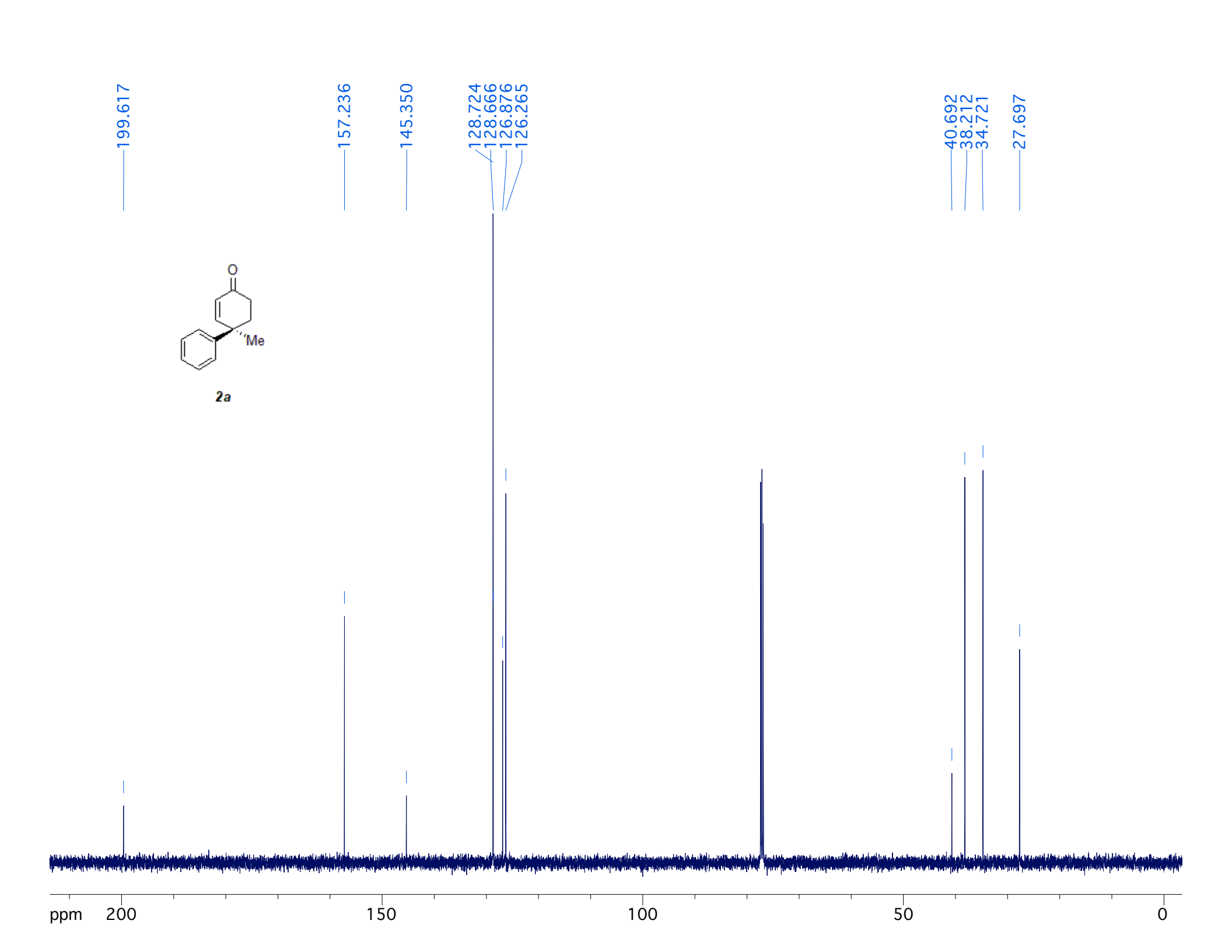
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40.692
38.212
34.721
27.697
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Me
2a
ppm
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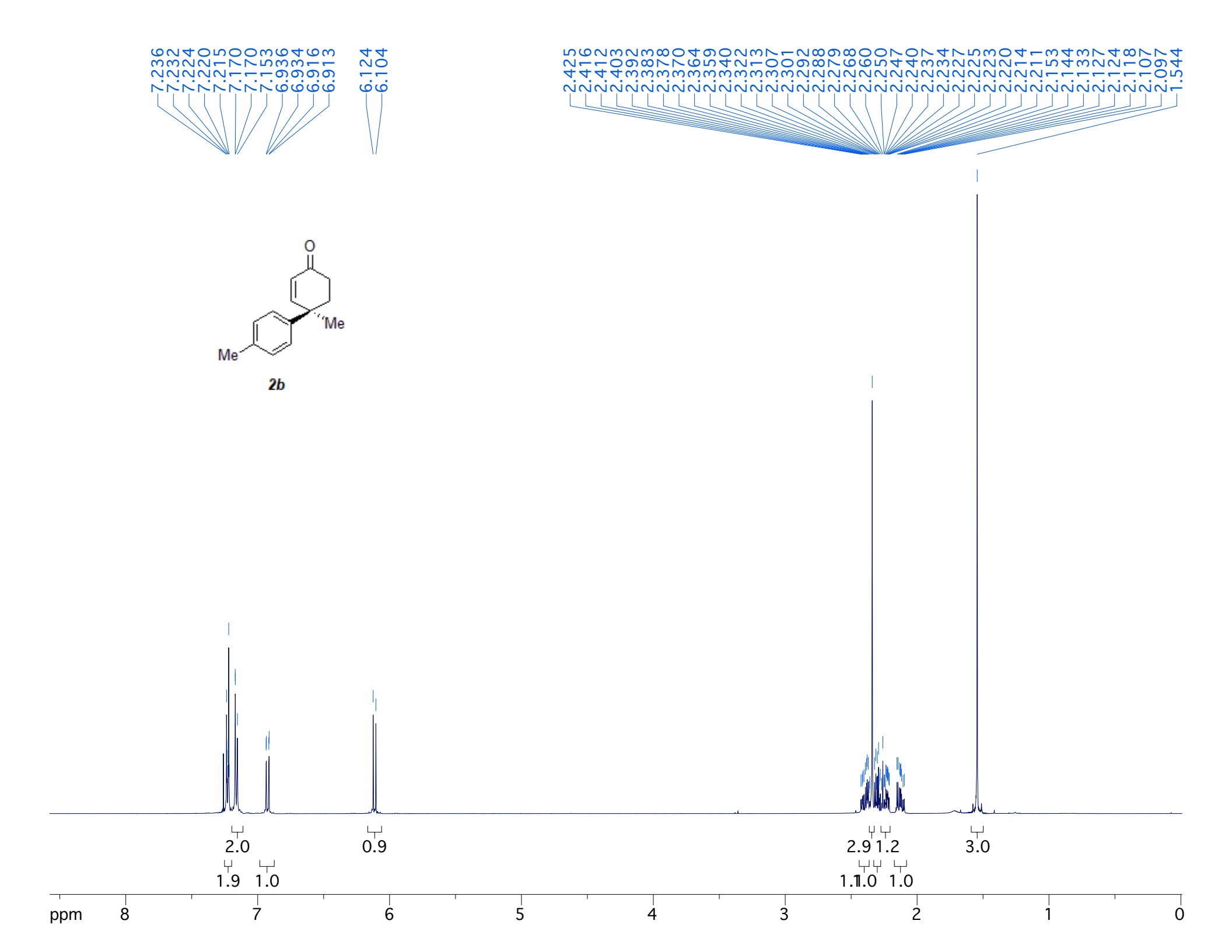
150
100
50
0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7.220
7.215
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7.170
7.153
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6.916
6.913
6.124
6.104
2.425
2.416
2.412
2.403
2.392
2.383
2.378
2.370
2.364
2.359
2.340
2.322
2.313
2.307
2.301
2.292
2.288
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2.268
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2.250
2.247
2.240
2.237
2.234
2.227
2.225
2.223
2.220
2.214
2.211
2.153
2.144
2.133
2.127
2.124
2.118
2.107
2.097
1.544
O
Me
Me
2b
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0.9
2.9
1.2
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1.1
1.0
1.0
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7
6
5
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2
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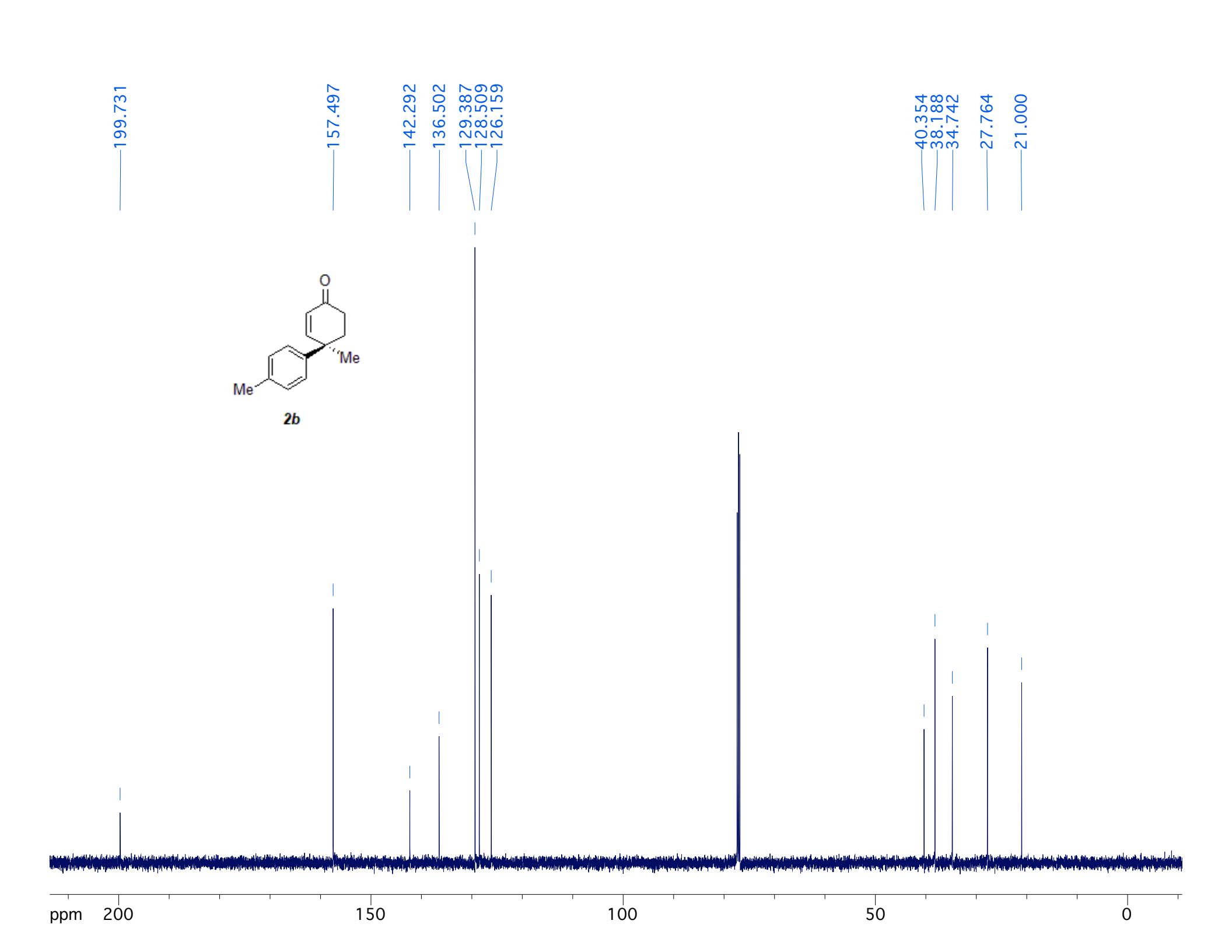
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O
Me
Me
2b
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50
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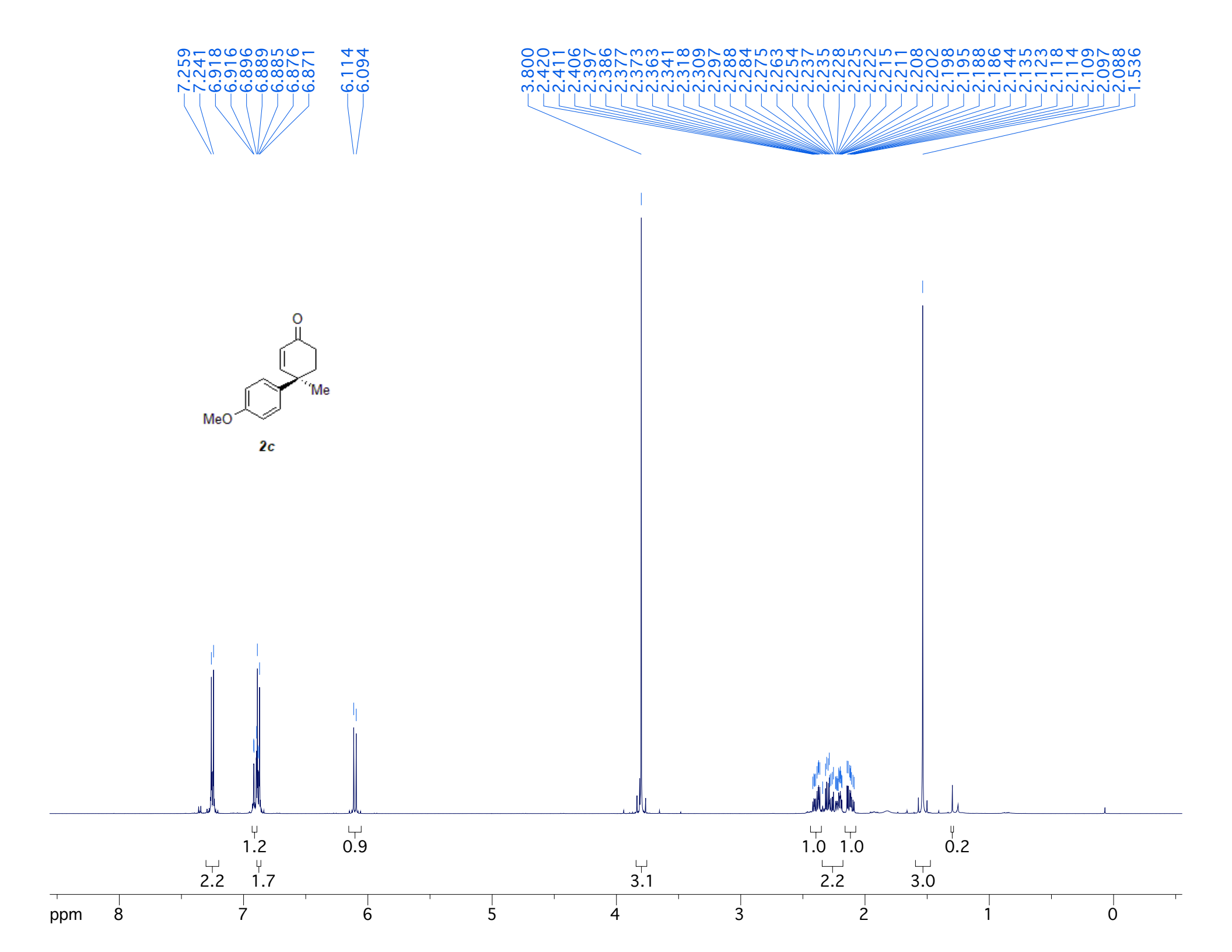
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6.885
6.876
6.871
6.114
6.094
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2.420
2.411
2.406
2.397
2.386
2.377
2.373
2.363
2.341
2.318
2.309
2.297
2.288
2.284
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2.254
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2.222
2.215
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2.208
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2.188
2.186
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2.114
2.109
2.097
2.088
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O
Me
MeO
2c
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1.0
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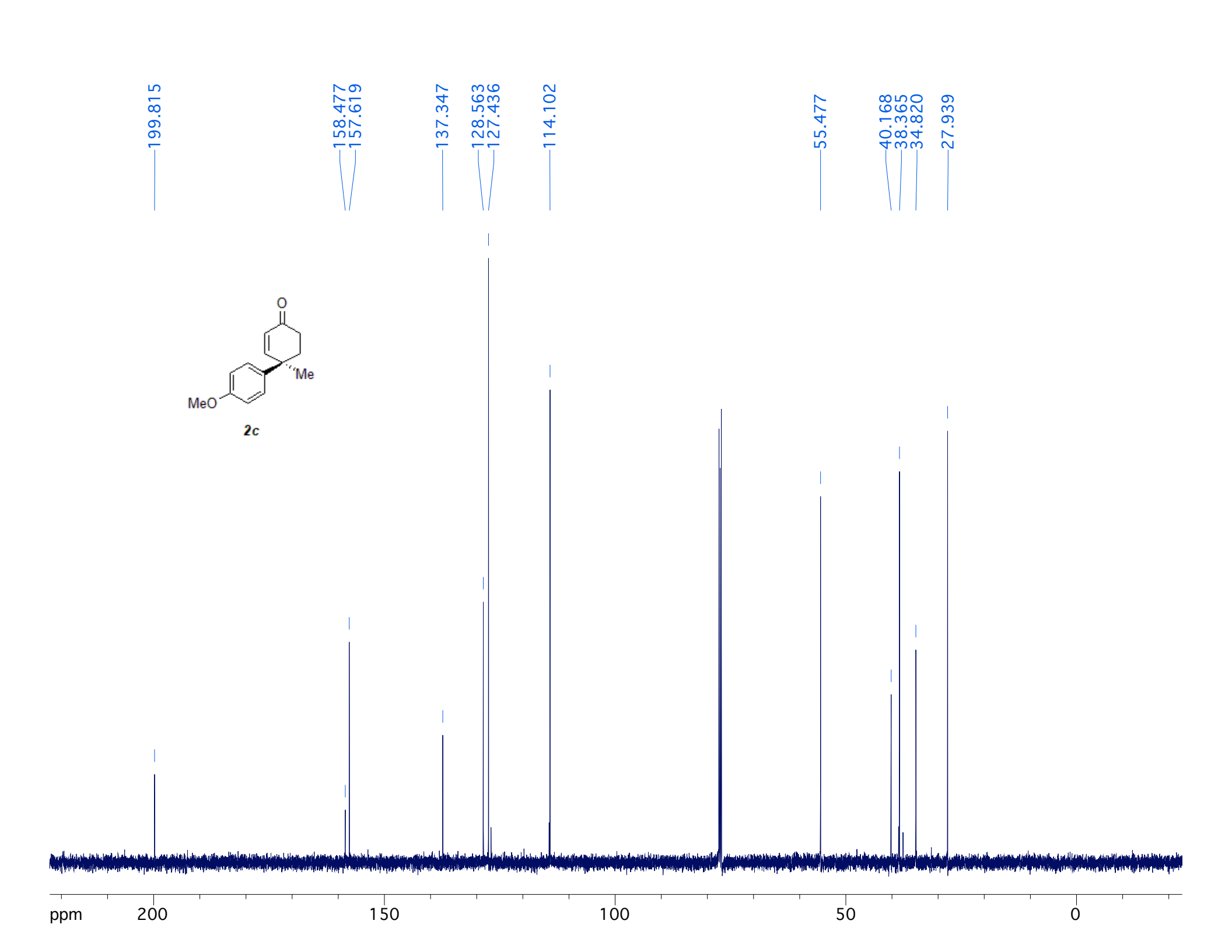
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MeO
2c
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100
50
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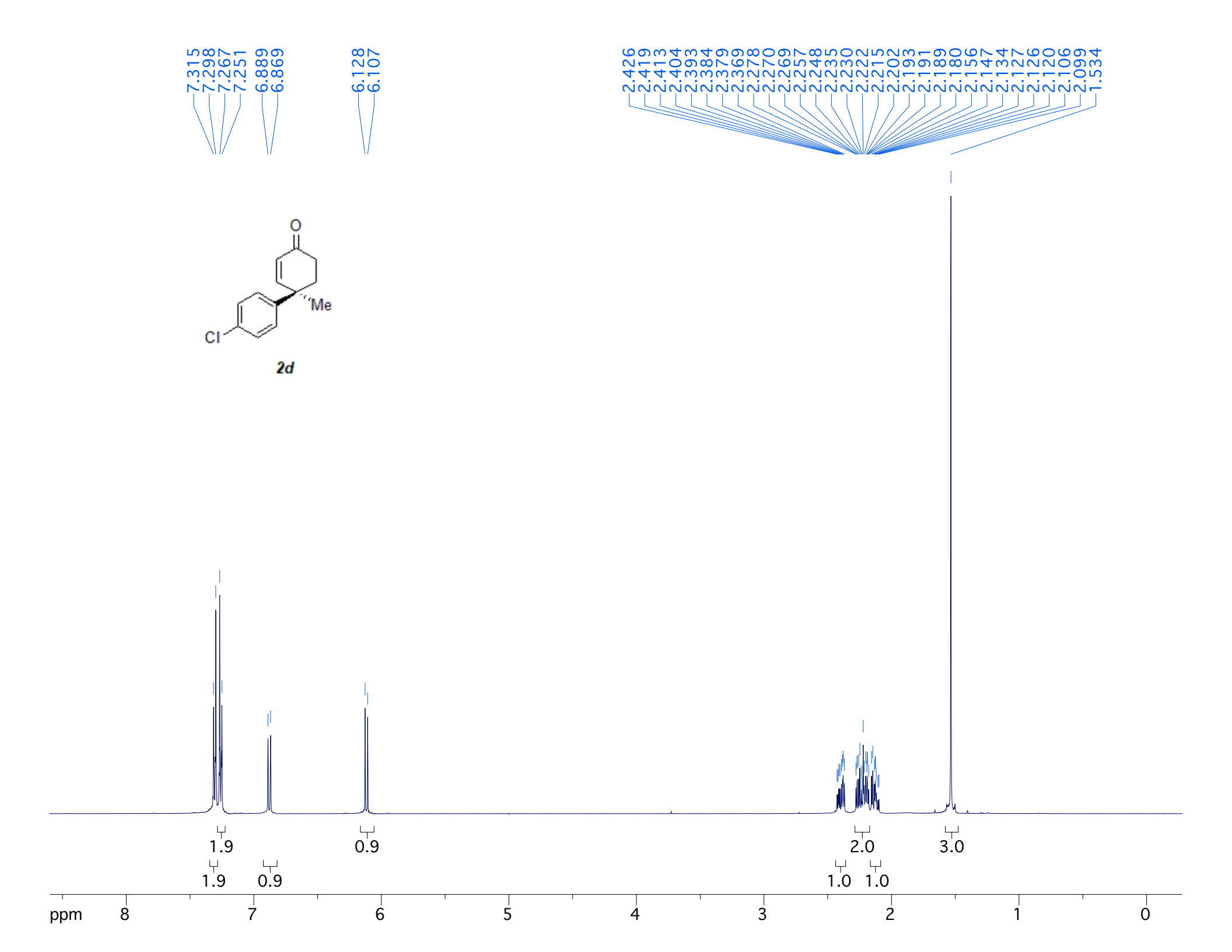
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2.393
2.384
2.379
2.369
2.278
2.270
2.269
2.257
2.248
2.235
2.230
2.222
2.215
2.202
2.193
2.191
2.189
2.180
2.156
2.147
2.134
2.127
2.126
2.120
2.106
2.099
1.534
O
Me
Cl
2d
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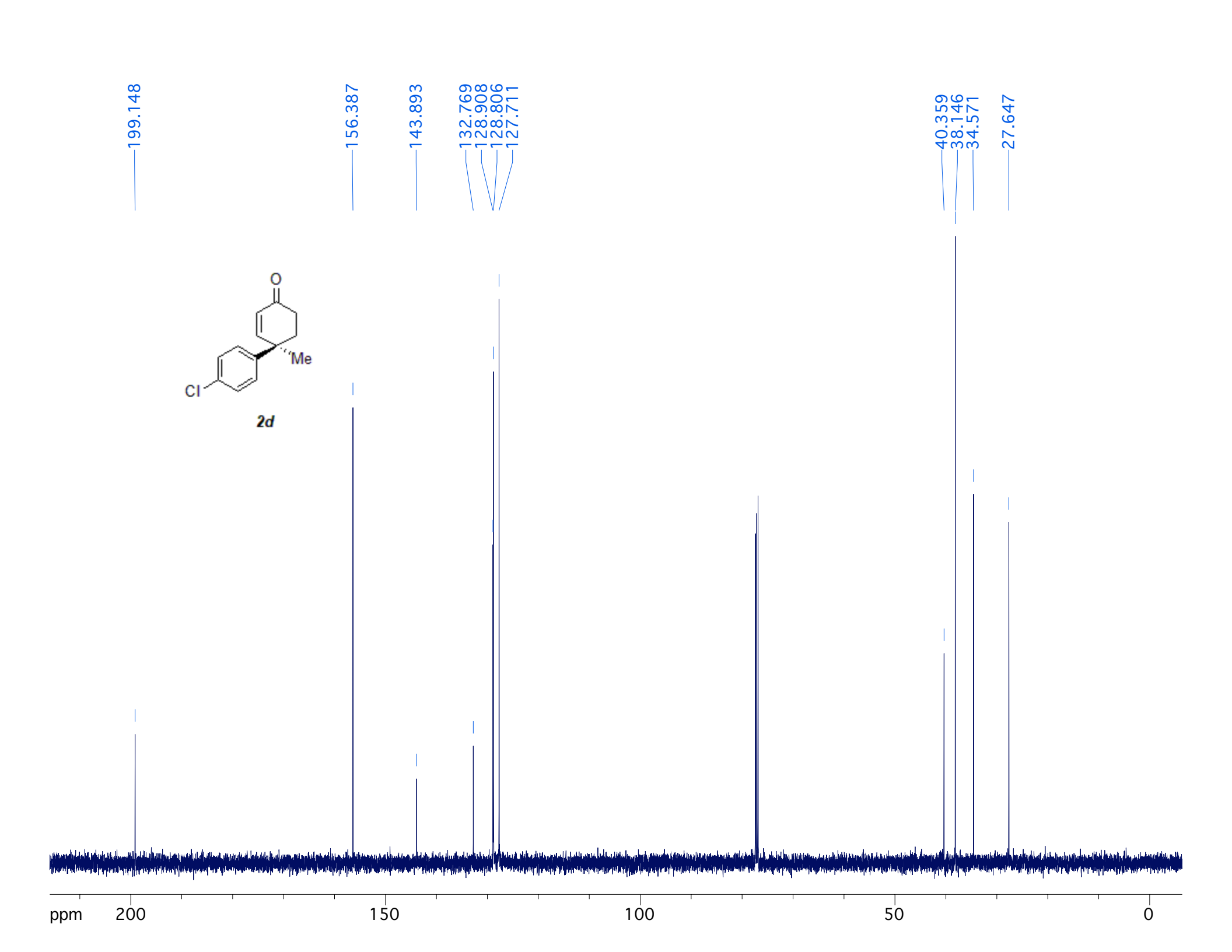
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Cl
2d
ppm
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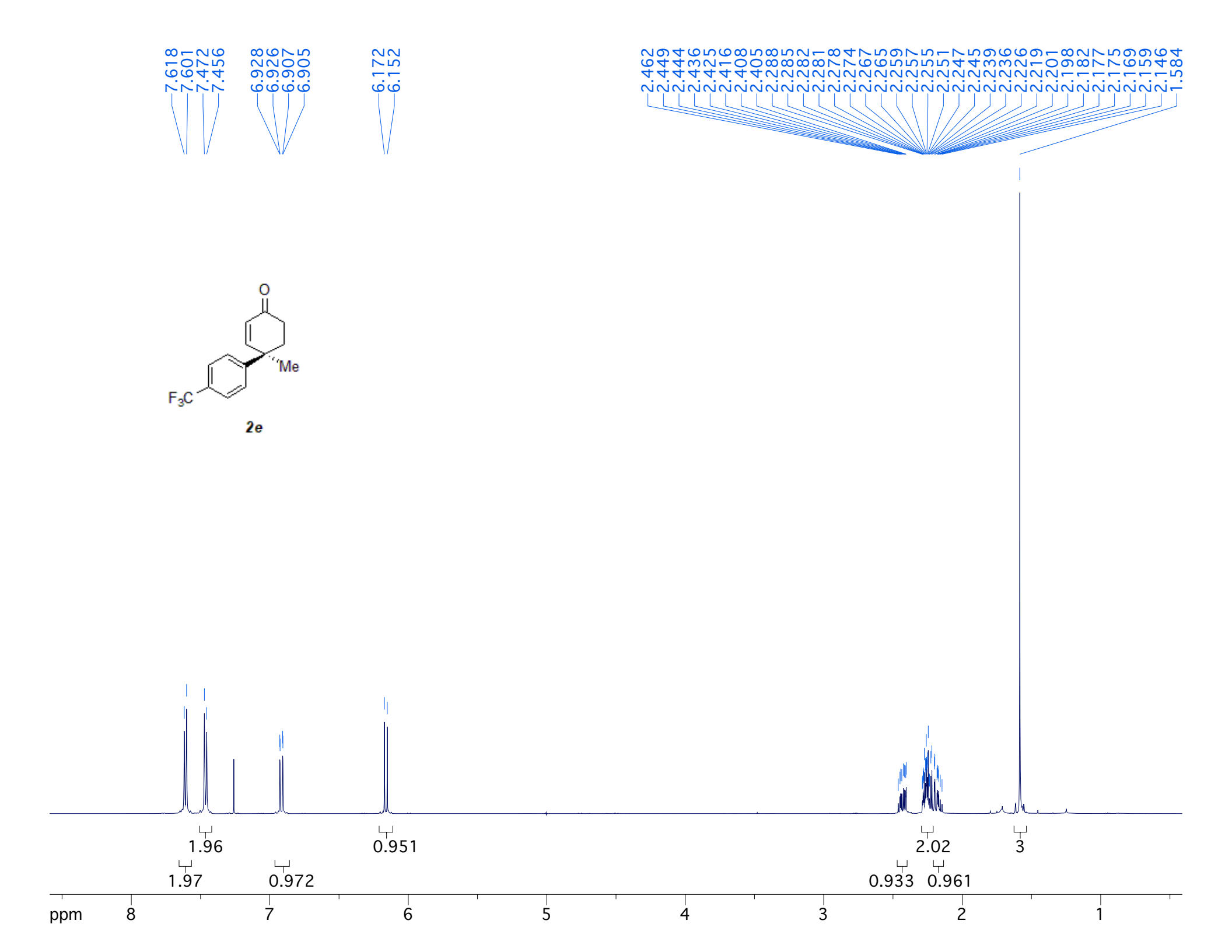
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2.436
2.425
2.416
2.408
2.405
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2.245
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2.236
2.226
2.219
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2.175
2.169
2.159
2.146
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O
Me
F3C
2e
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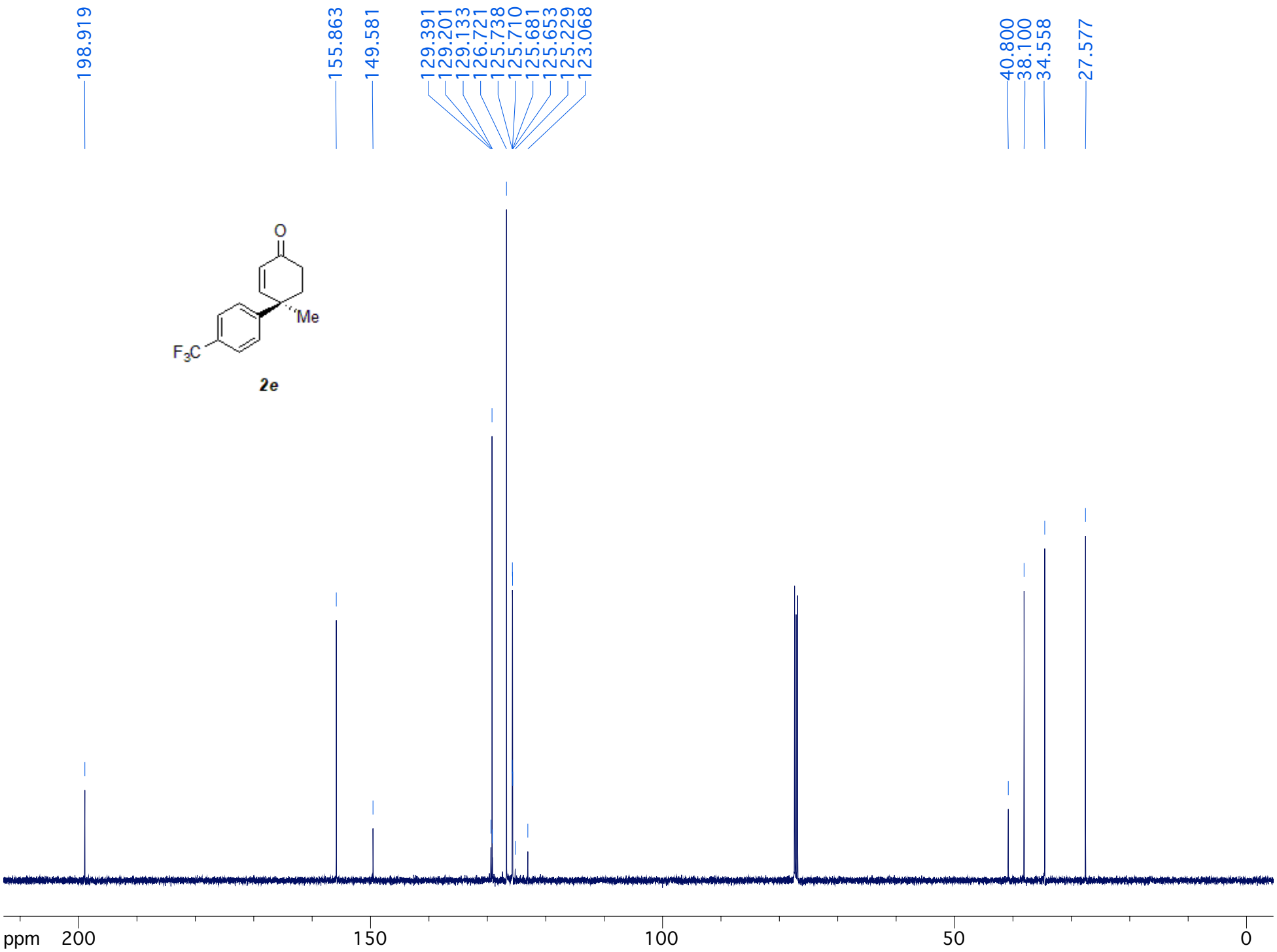
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38.100
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27.577
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Me
F3C
2e
ppm
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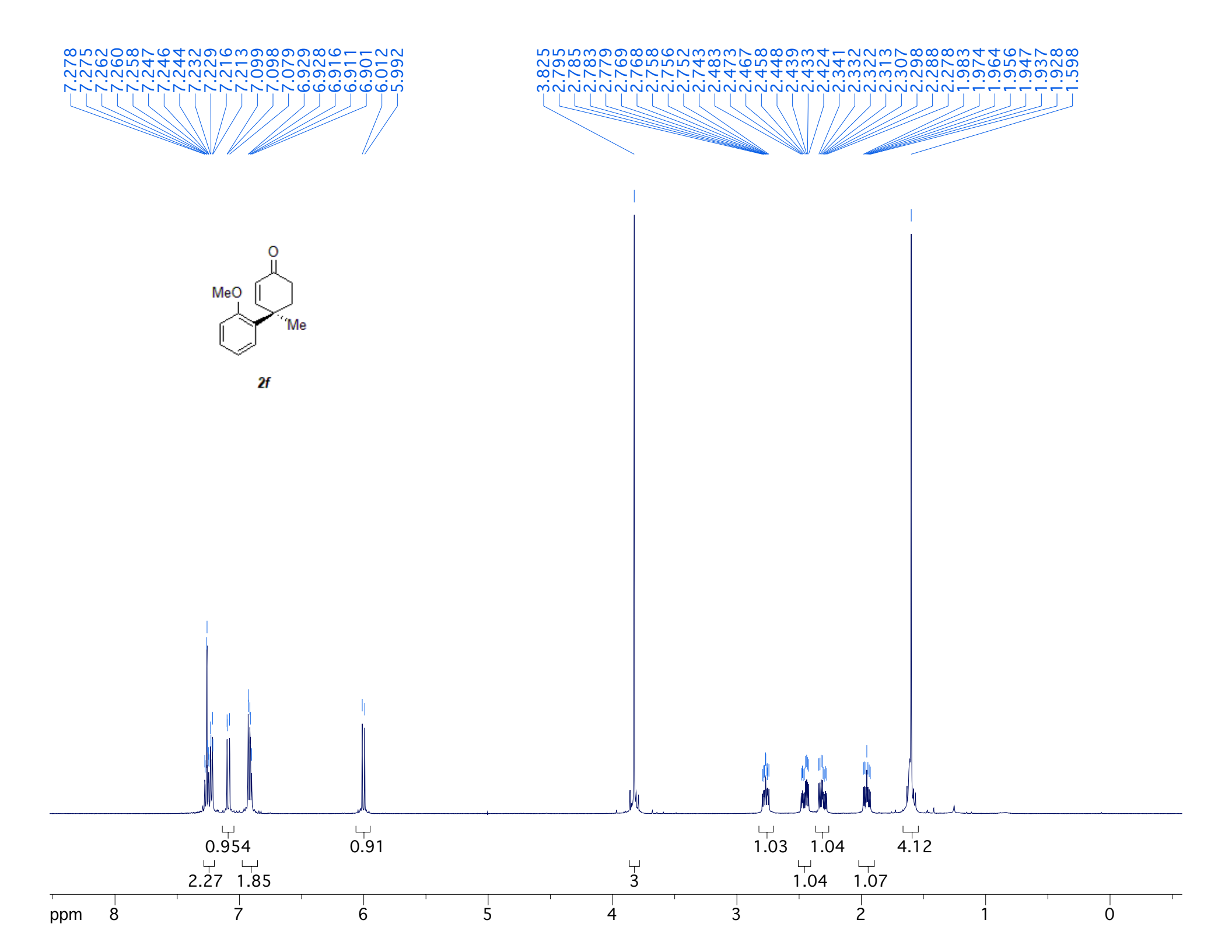
150
100
50
0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7.098
7.079
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6.911
6.901
6.012
5.992
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2.785
2.783
2.779
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2.768
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2.307
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1.947
1.937
1.928
1.598
O
MeO
Me
2f
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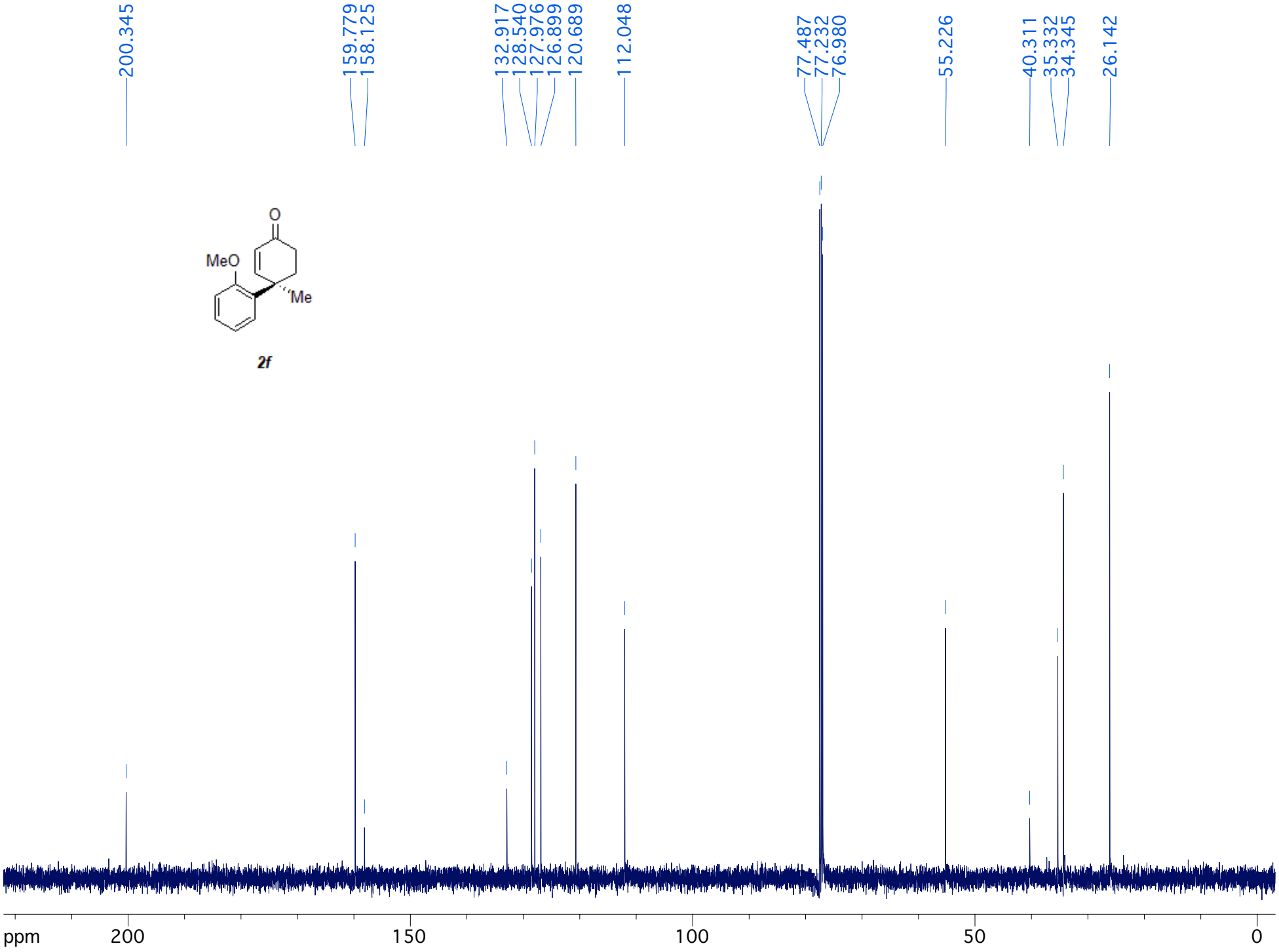
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35.332
34.345
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MeO
Me
2f
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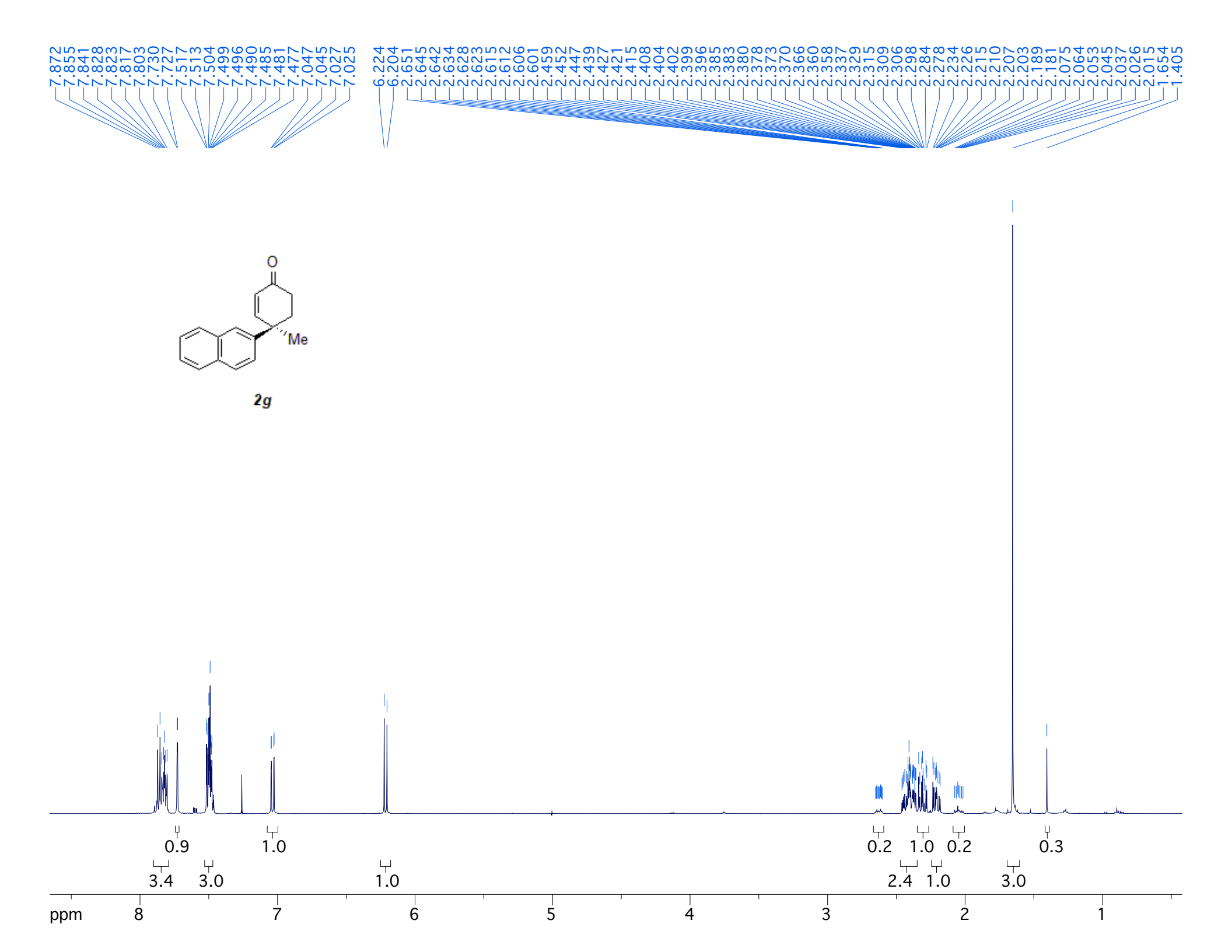
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7.496
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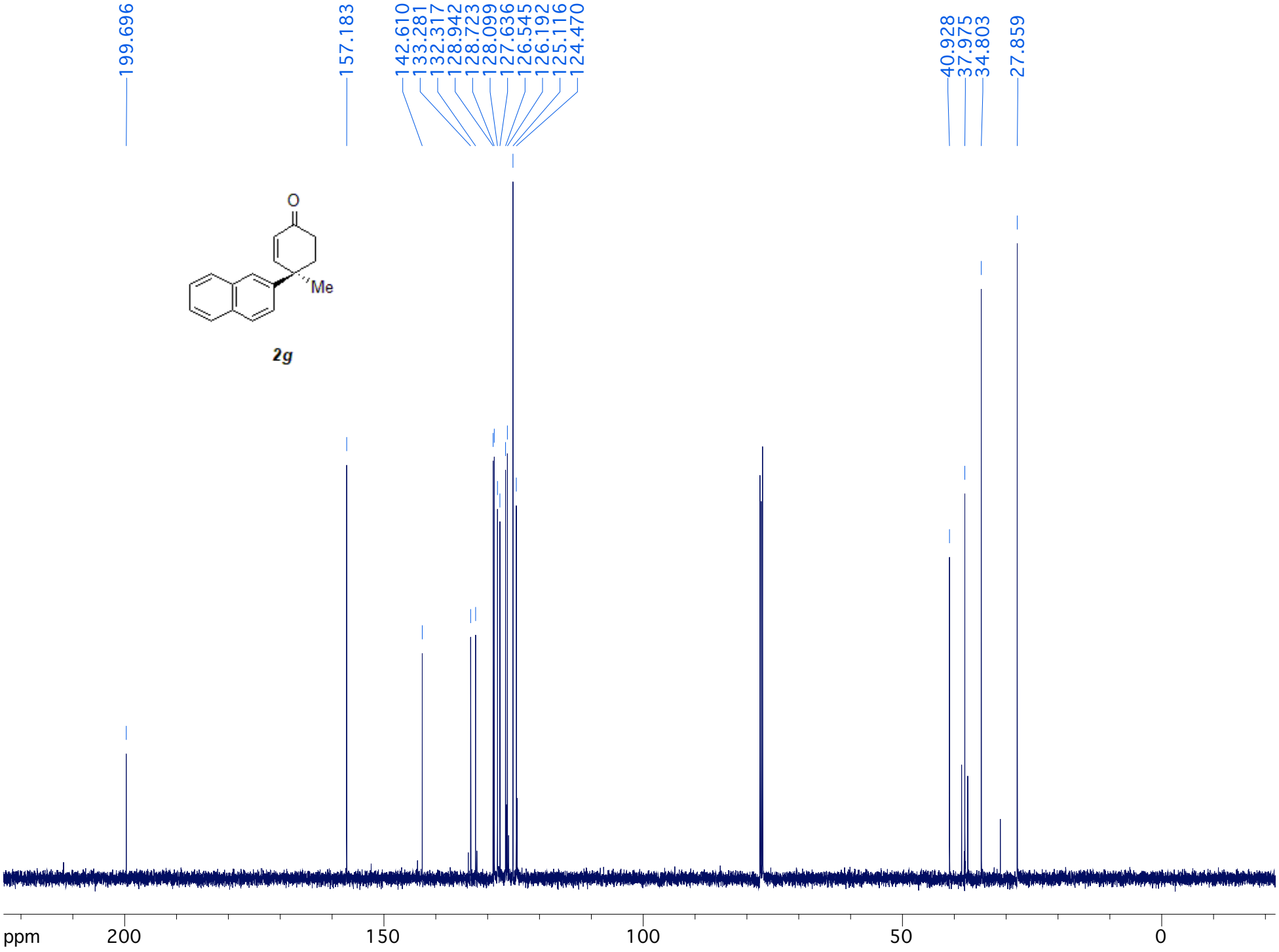
O
Me
2g
0.9
1.0
0.2
1.0
0.2
0.3
3.4
3.0
1.0
2.4
1.0
3.0
ppm
8
7
6
5
4
3
2
1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157.183
142.610
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132.317
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128.099
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126.545
126.192
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40.928
37.975
34.803
27.859
O
Me
2g
ppm
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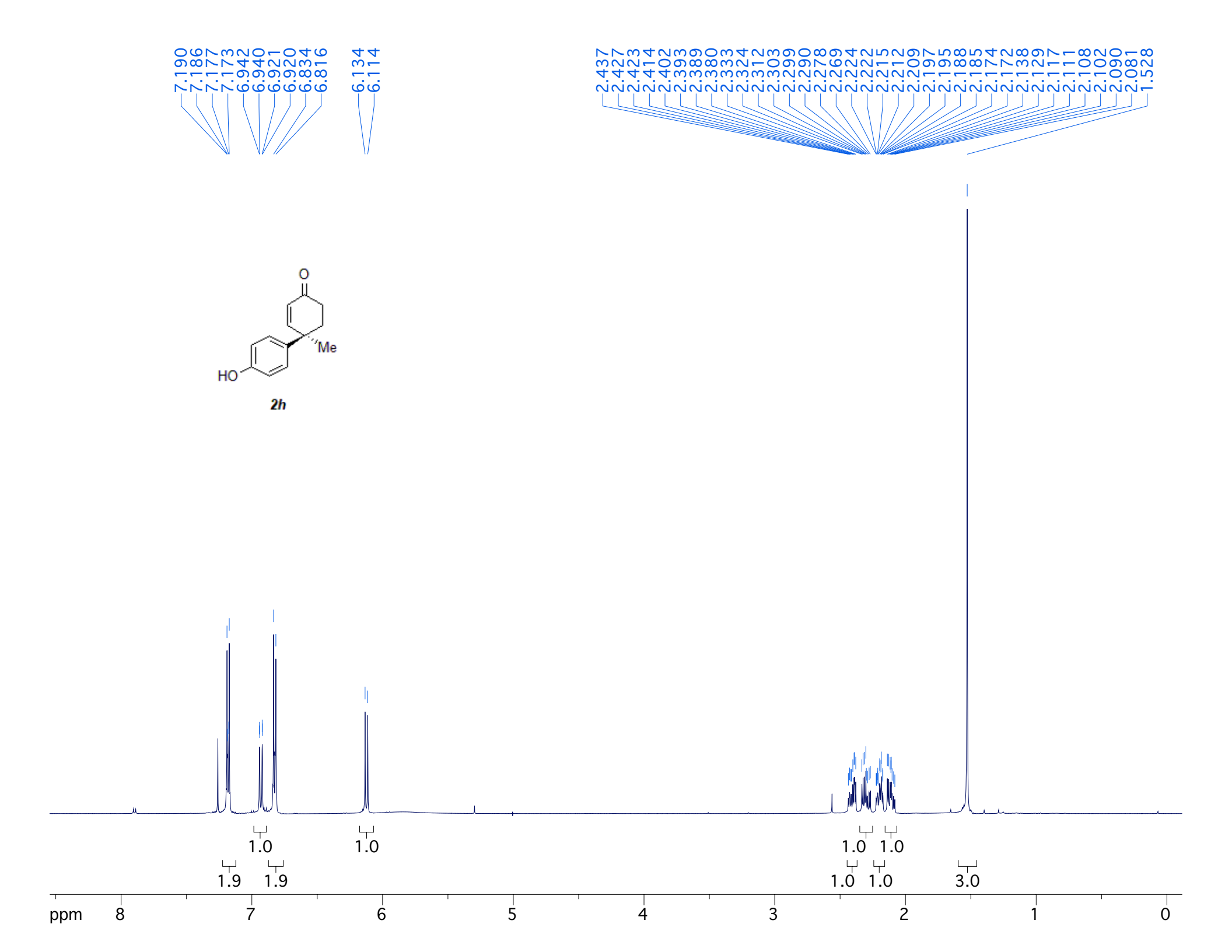
150
100
50
0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7.186
7.177
7.173
6.942
6.940
6.921
6.920
6.834
6.816
6.134
6.114
2.437
2.427
2.423
2.414
2.402
2.393
2.389
2.380
2.333
2.324
2.312
2.303
2.299
2.290
2.278
2.269
2.224
2.222
2.215
2.212
2.209
2.197
2.195
2.188
2.185
2.174
2.172
2.138
2.129
2.117
2.111
2.108
2.102
2.090
2.081
1.528
O
Me
HO
2h
1.0
1.0
1.0
1.0
1.9
1.9
1.0
1.0
3.0
ppm
8
7
6
5
4
3
2
1
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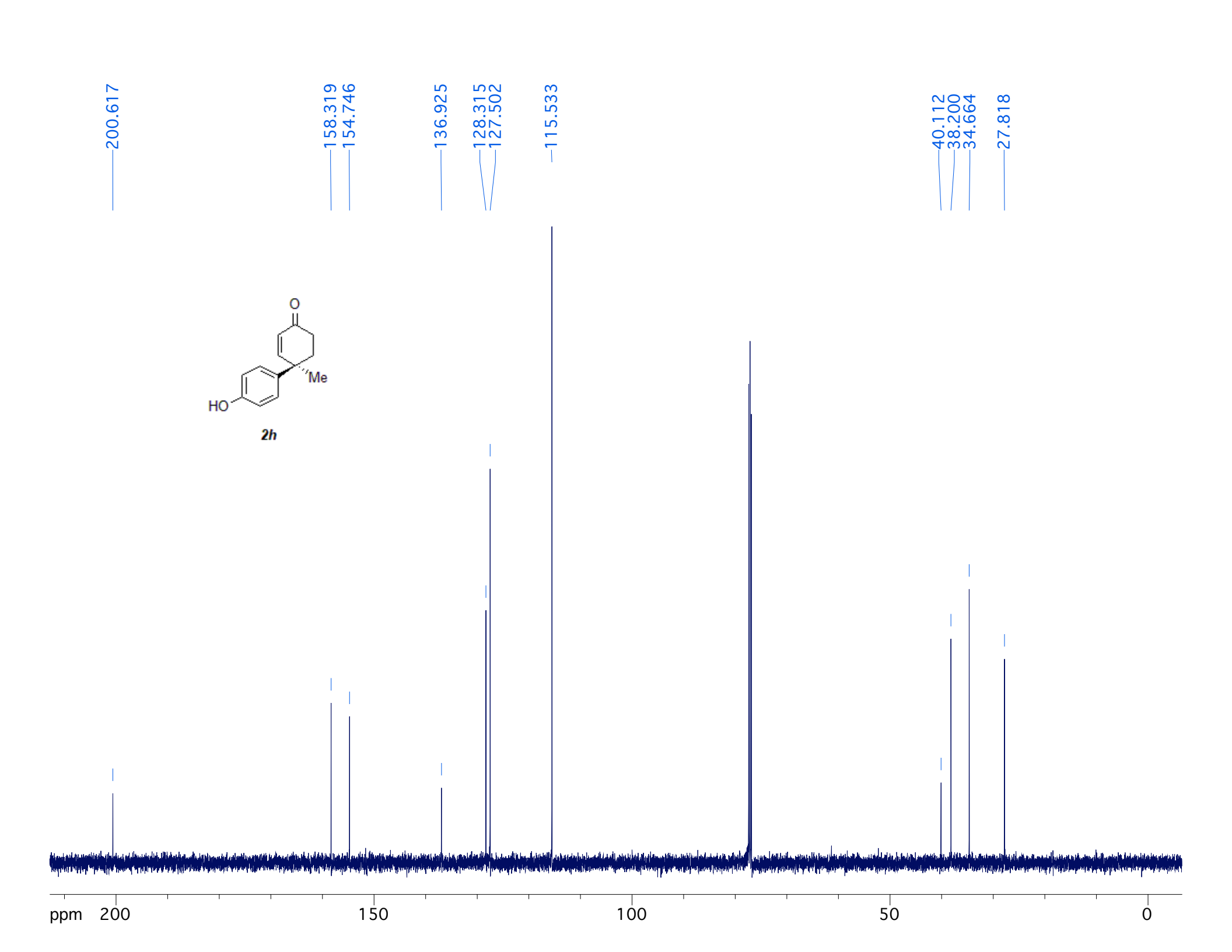
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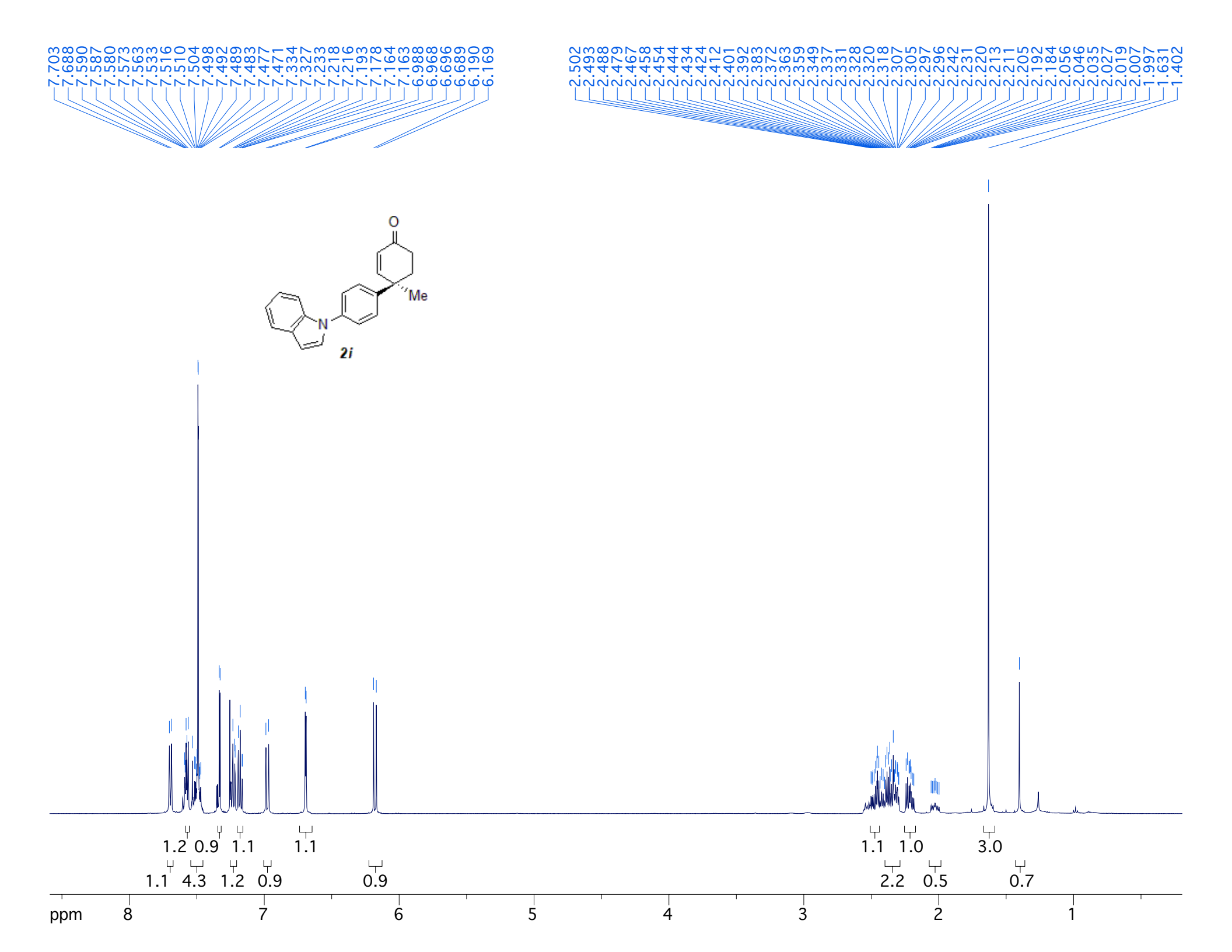
158.319
154.746
136.925
128.315
127.502
115.533
40.112
38.200
34.664
27.818
O
Me
HO
2h
ppm
200
150
100
50
0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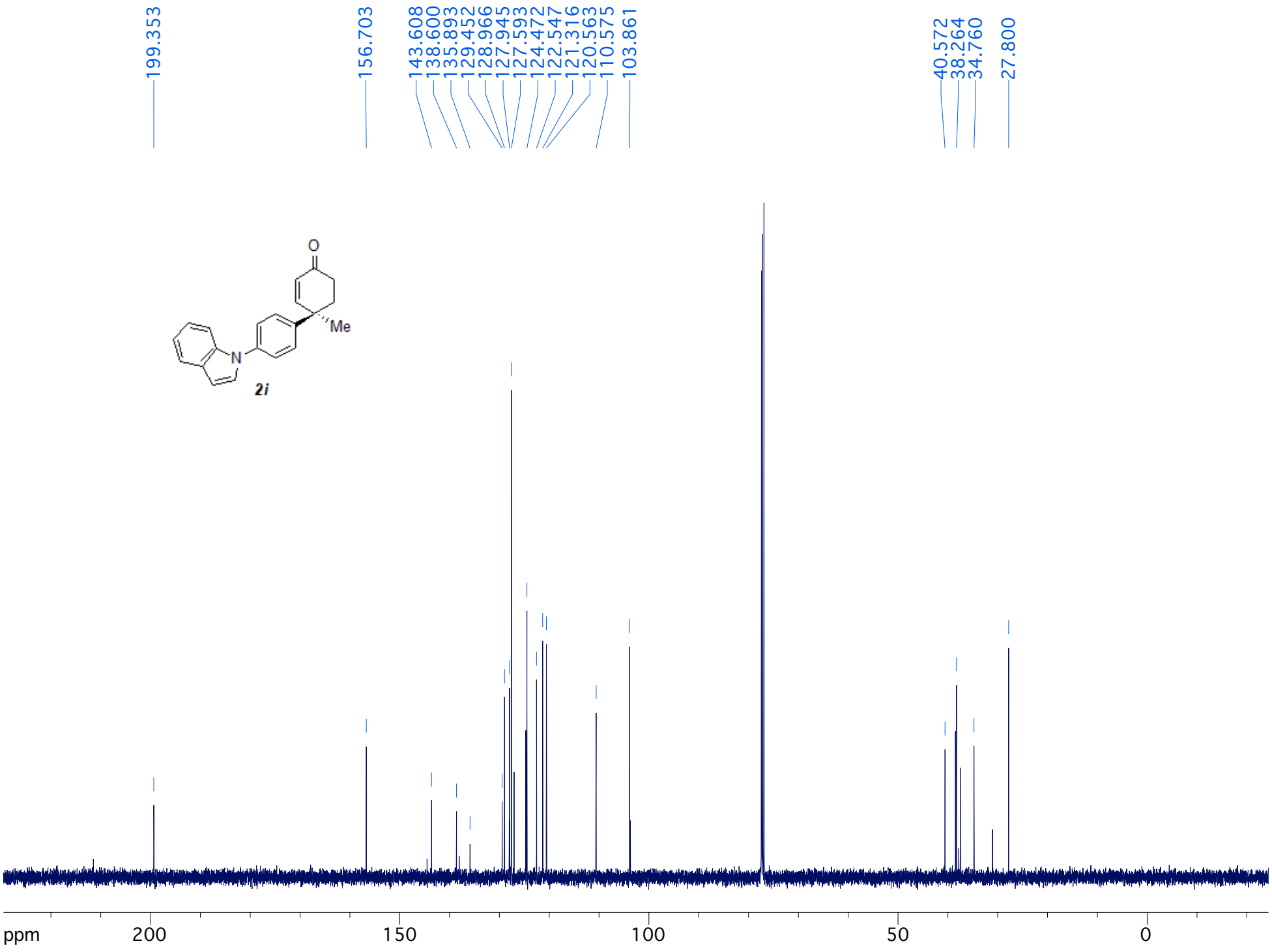
7.688
7.590
7.587
7.580
7.573
7.563
7.533
7.516
7.510
7.504
7.498
7.492
7.489
7.483
7.477
7.471
7.334
7.327
7.233
7.218
7.216
7.193
7.178
7.164
7.163
6.988
6.968
6.696
6.689
6.190
6.169
2.502
2.493
2.488
2.479
2.467
2.458
2.454
2.444
2.434
2.424
2.412
2.401
2.392
2.383
2.372
2.363
2.359
2.349
2.337
2.331
2.328
2.320
2.318
2.307
2.305
2.297
2.296
2.242
2.231
2.220
2.213
2.211
2.205
2.192
2.184
2.056
2.046
2.035
2.027
2.019
2.007
1.997
1.631
1.402
O
Me
N
2i
1.2
0.9
1.1
1.1
1.1
4.3
1.2
0.9
0.9
1.1
1.0
3.0
2.2
0.5
0.7
ppm
8
7
6
5
4
3
2
1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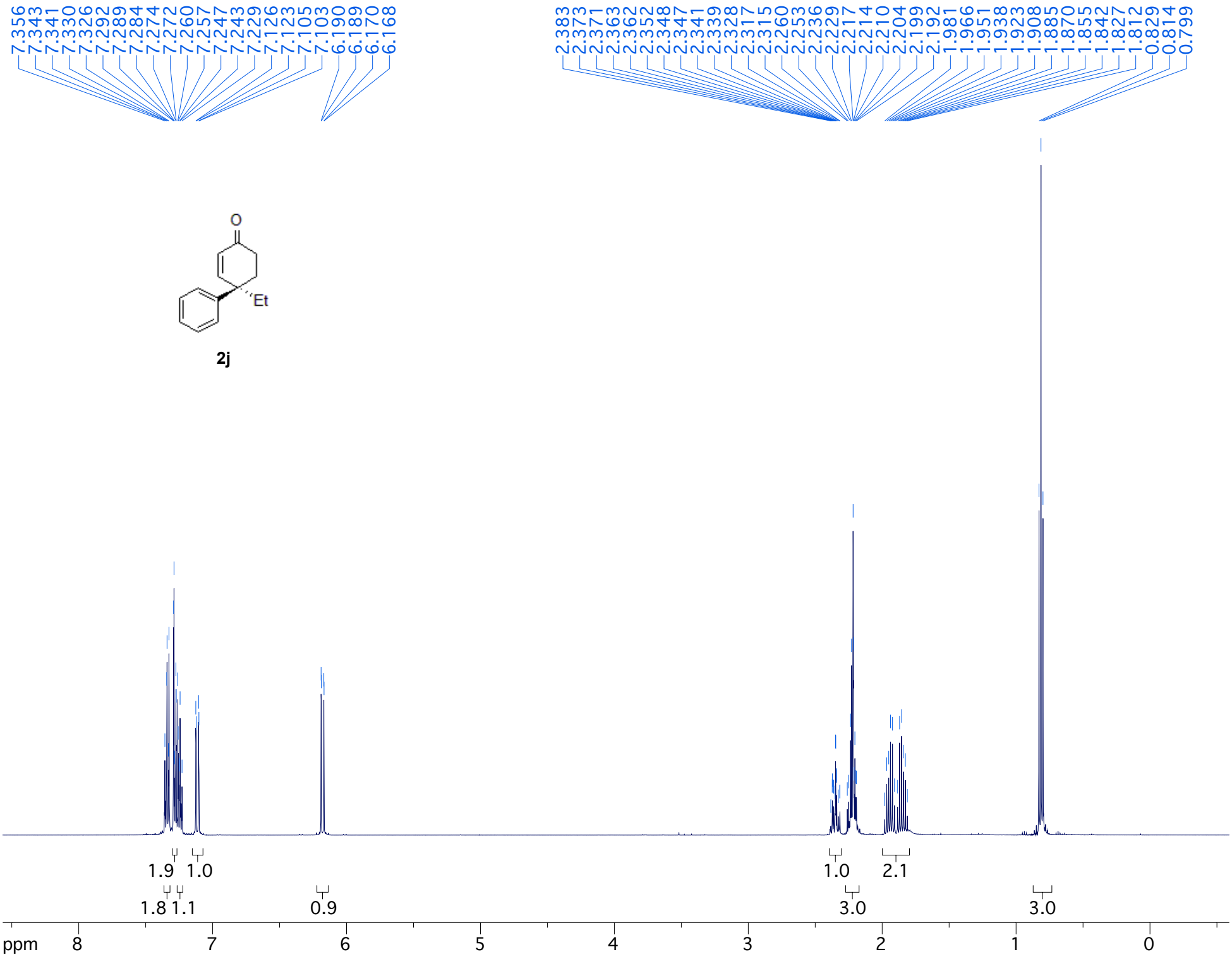
156.703
143.608
138.600
135.893
129.452
128.966
127.945
127.593
124.472
122.547
121.316
120.563
110.575
103.861
40.572
38.264
34.760
27.800
O
Me
N
2i
ppm
200
150
100
50
0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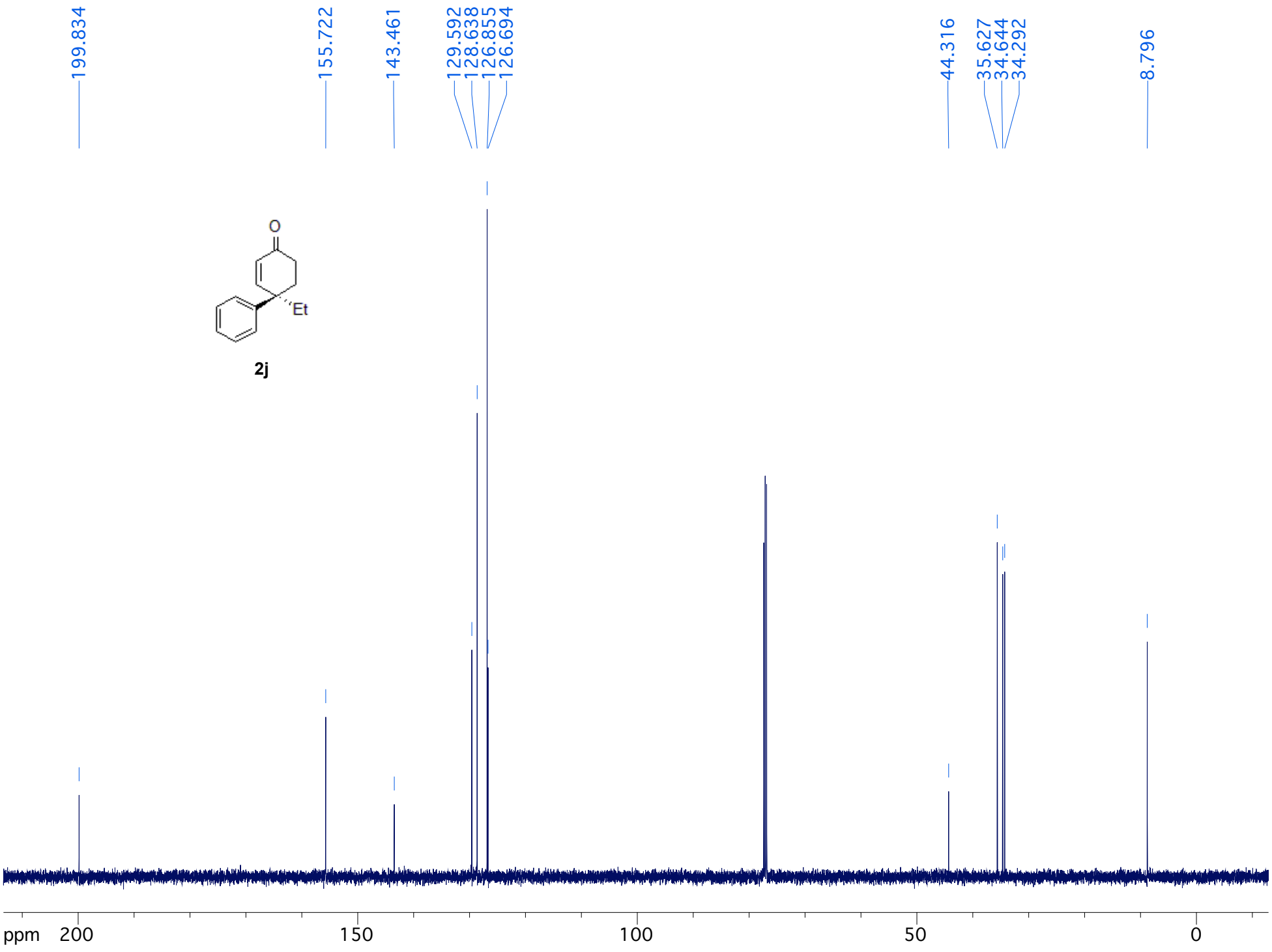
7.343
7.341
7.330
7.326
7.292
7.289
7.284
7.274
7.272
7.260
7.257
7.247
7.243
7.229
7.126
7.123
7.105
7.103
6.190
6.189
6.170
6.168
2.383
2.373
2.371
2.363
2.362
2.352
2.348
2.347
2.341
2.339
2.328
2.317
2.315
2.260
2.253
2.236
2.229
2.217
2.214
2.210
2.204
2.199
2.192
1.981
1.966
1.951
1.938
1.923
1.908
1.885
1.870
1.855
1.842
1.827
1.812
0.829
0.814
0.799
O
Et
1.9
1.0
1.8
1.1
0.9
1.0
2.1
3.0
3.0
ppm
8
7
6
5
4
3
2
1
0

2j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155.722
143.461
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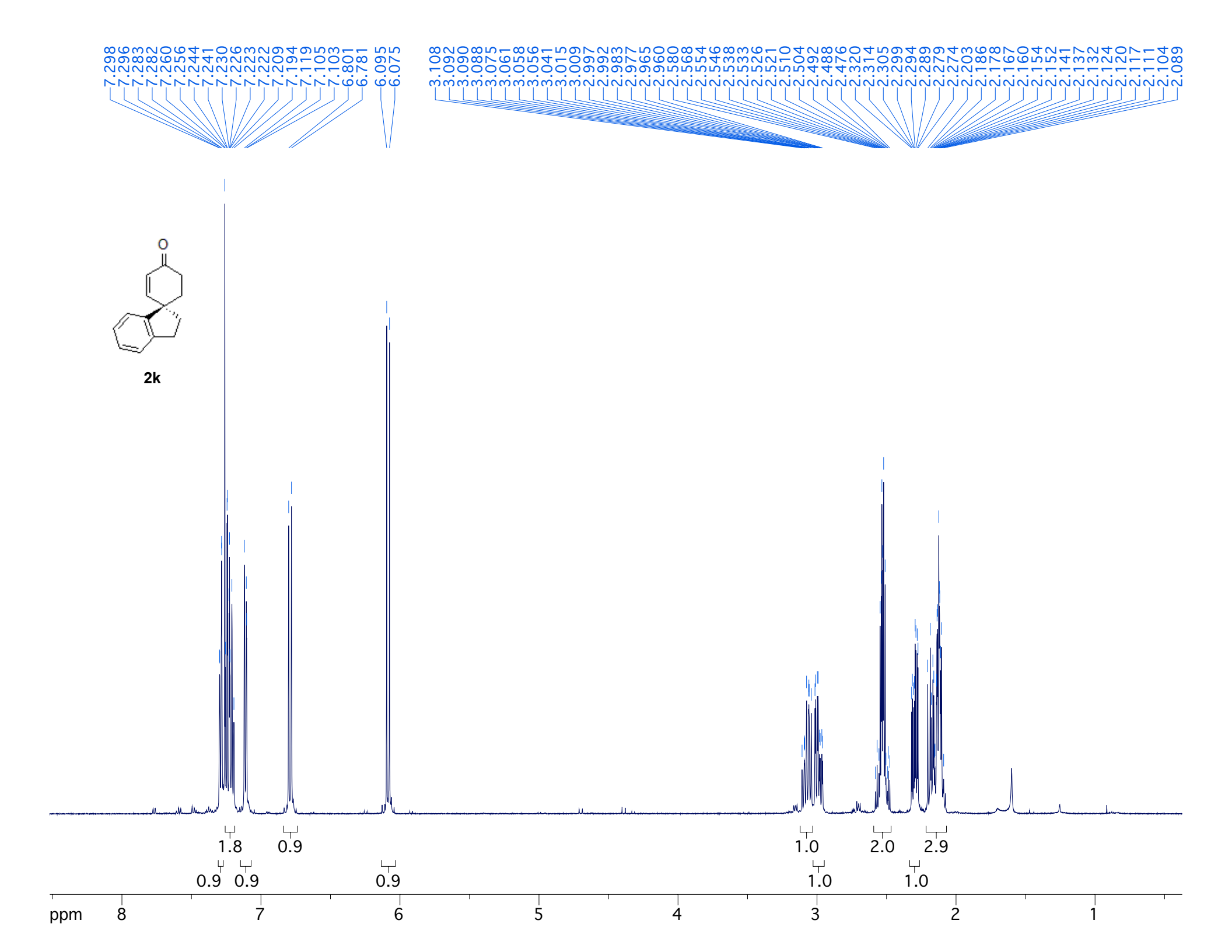
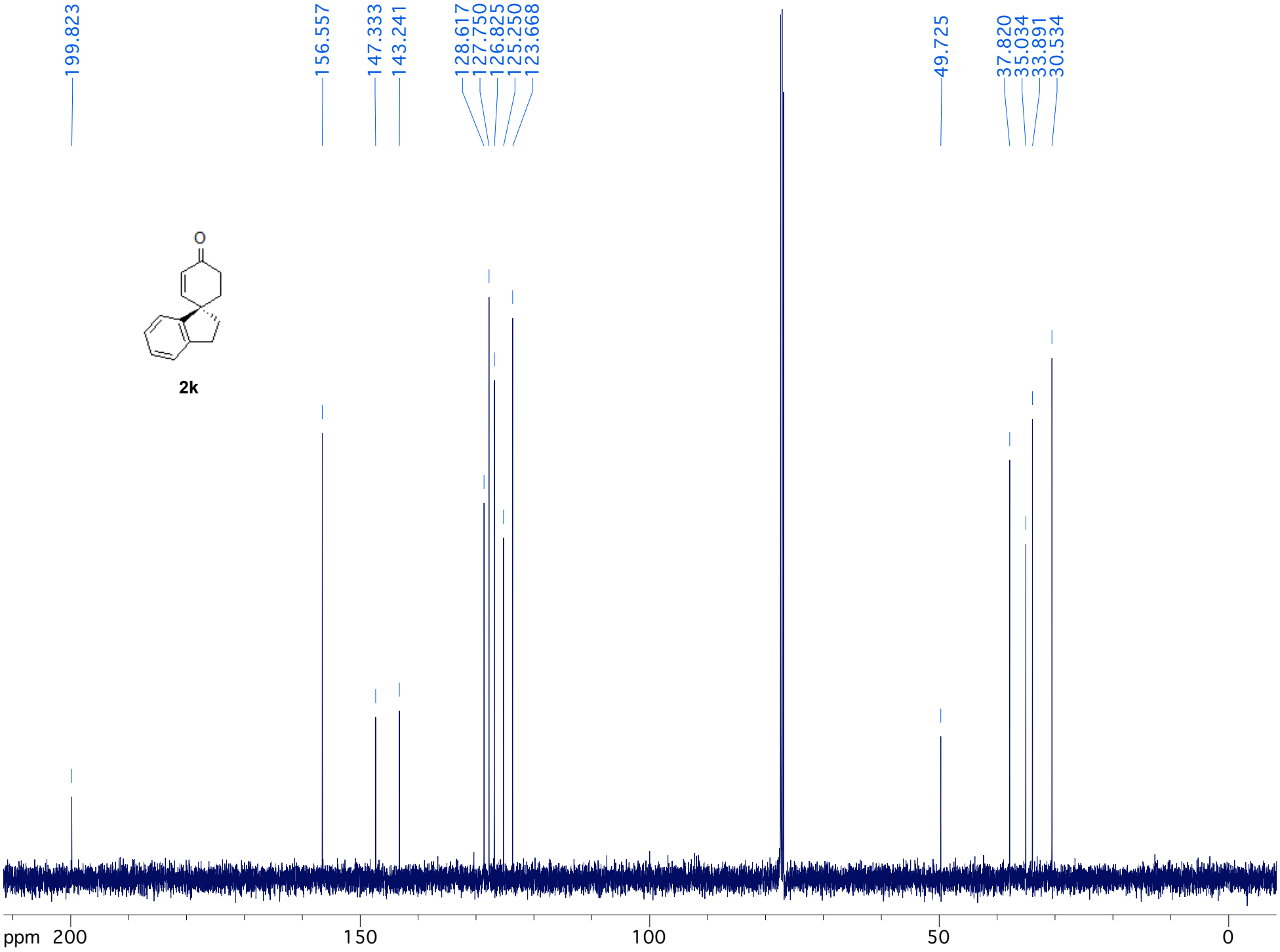
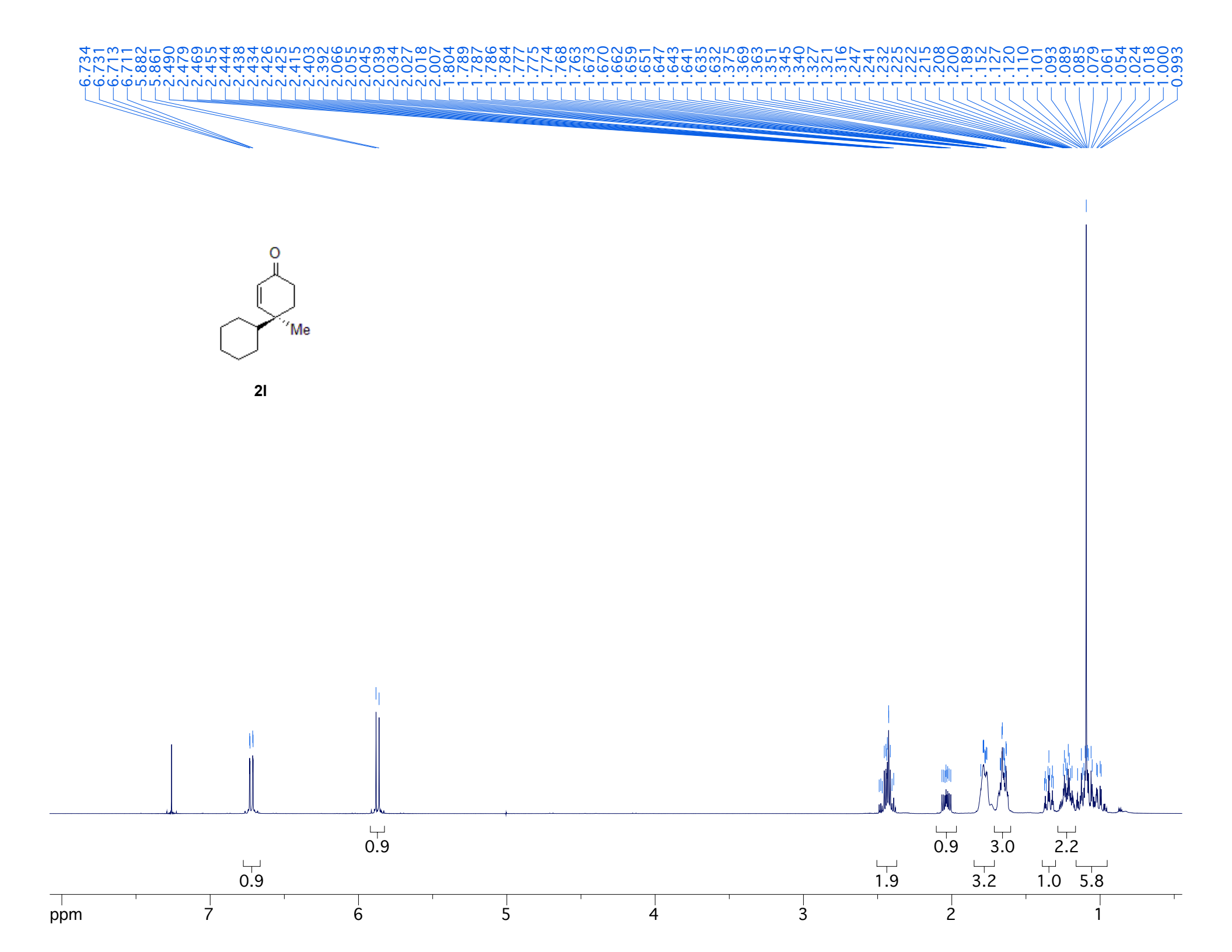
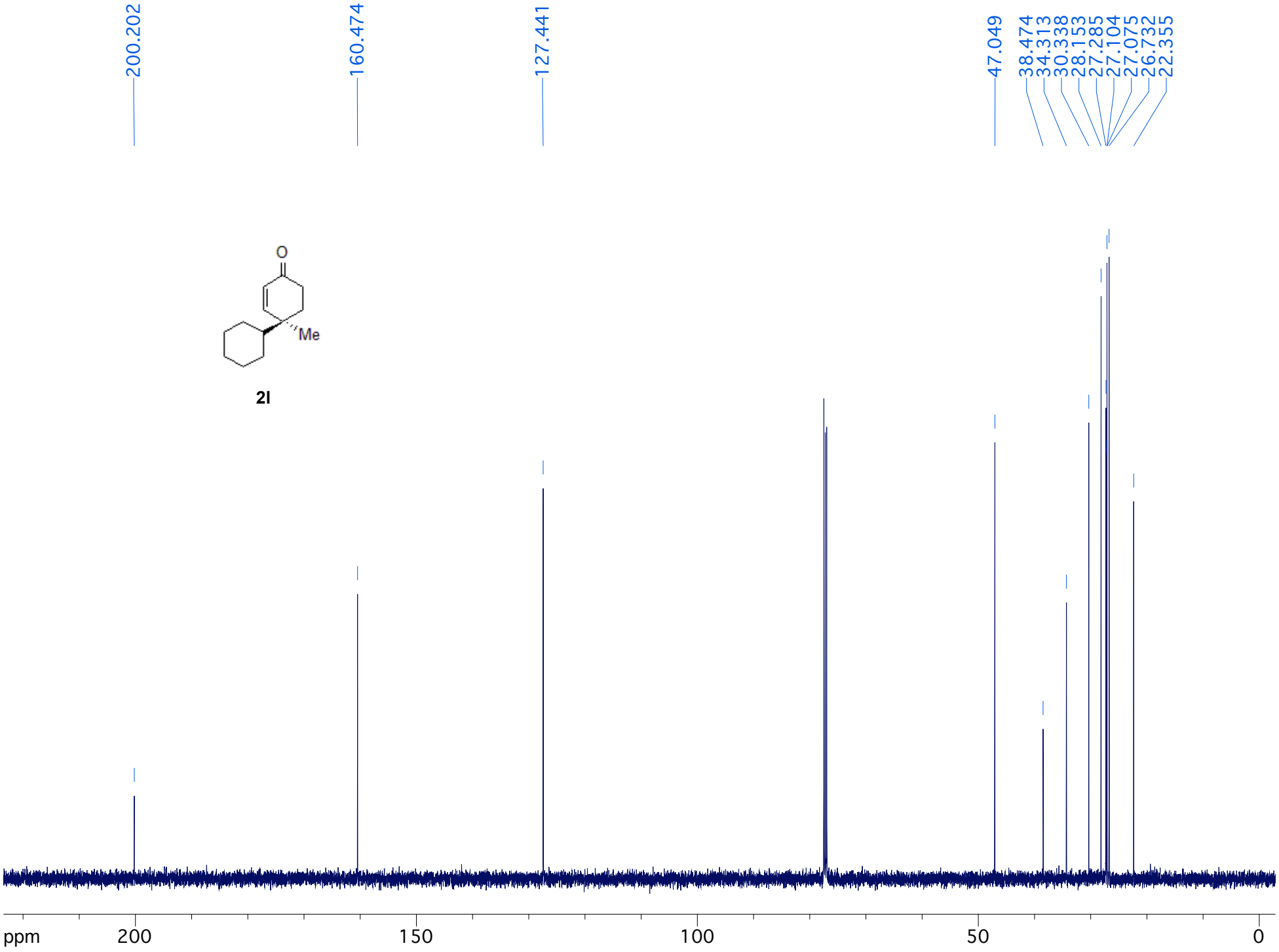
128.638
126.855
126.694
44.316
35.627
34.644
34.292
8.796
O
Et
2j
ppm
200
150
100
50
0

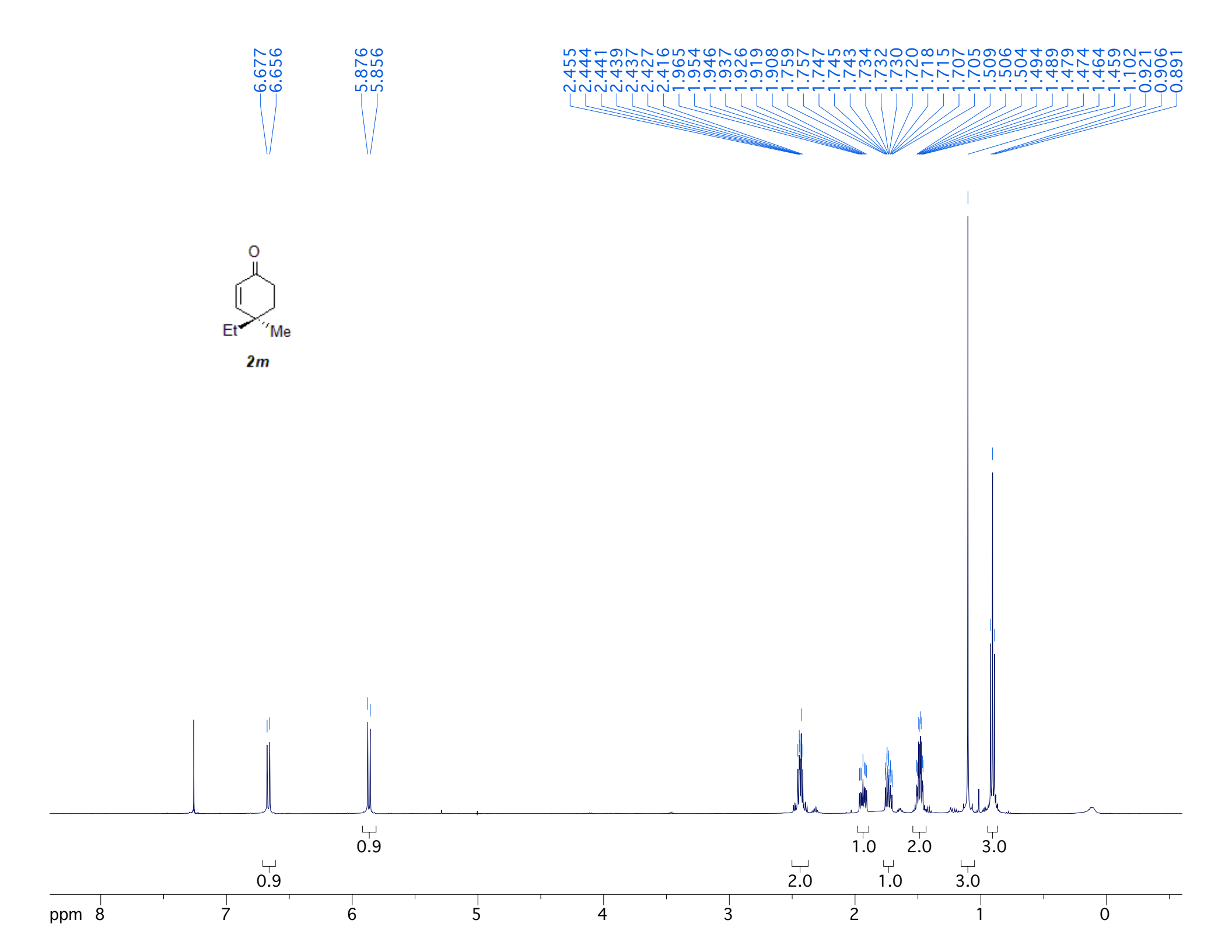

7.298
7.296
7.283
7.282
7.260
7.256
7.244
7.241
7.230
7.226
7.223
7.222
7.209
7.194
7.119
7.105
7.103
6.801
6.781
6.095
6.075
3.108
3.092
3.090
3.088
3.075
3.061
3.058
3.056
3.041
3.015
3.009
2.997
2.992
2.983
2.977
2.965
2.960
2.580
2.568
2.554
2.546
2.538
2.533
2.526
2.521
2.510
2.504
2.492
2.488
2.476
2.320
2.314
2.305
2.299
2.294
2.289
2.279
2.274
2.203
2.186
2.178
2.167
2.160
2.154
2.152
2.141
2.137
2.132
2.124
2.120
2.117
2.111
2.104
2.089
O
2k
1.8
0.9
0.9
0.9
0.9
1.0
1.0
2.0
2.9
1.0
ppm
8
7
6
5
4
3
2
1

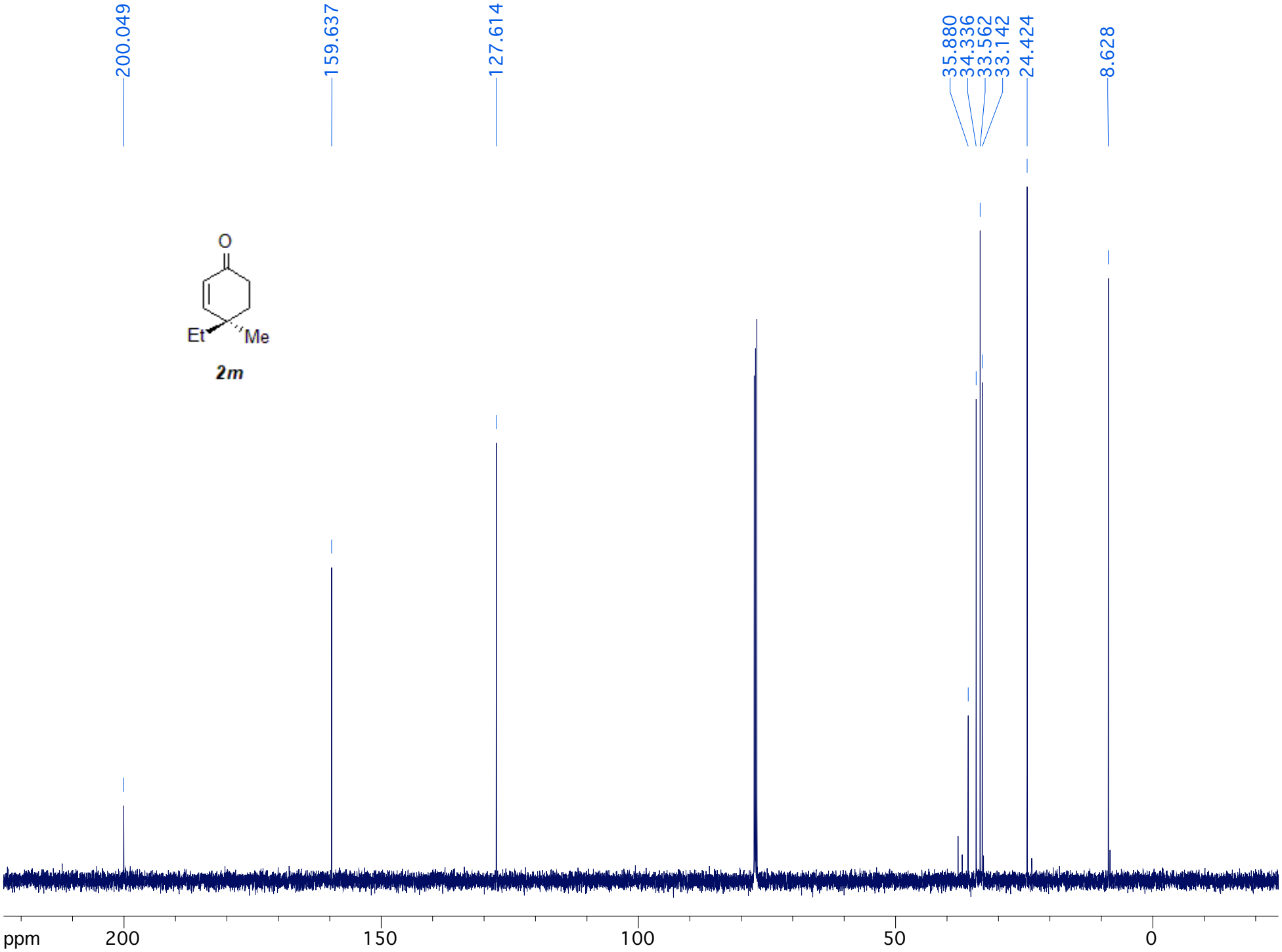

199.823
156.557
147.333
143.241
128.617
127.750
126.825
125.250
123.668
49.725
37.820
35.034
33.891
30.534
O
2k
ppm
200
150
100
50
0

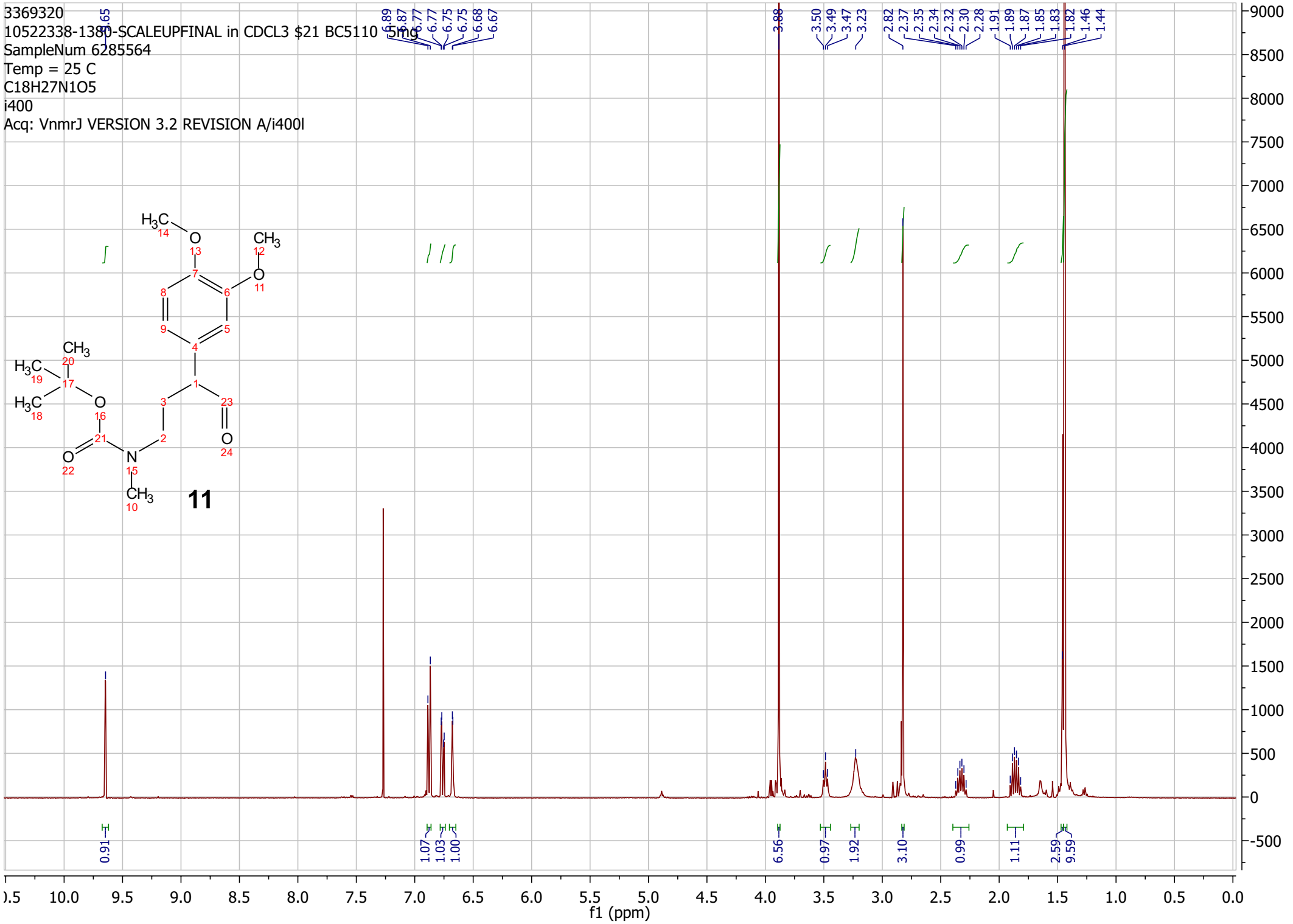

6.734
6.731
6.713
6.711
5.882
5.861
2.490
2.479
2.469
2.455
2.444
2.438
2.434
2.426
2.425
2.415
2.403
2.392
2.066
2.055
2.045
2.039
2.034
2.027
2.018
2.007
1.804
1.789
1.787
1.786
1.784
1.777
1.775
1.774
1.768
1.763
1.673
1.670
1.662
1.659
1.651
1.647
1.643
1.641
1.635
1.632
1.375
1.369
1.363
1.351
1.345
1.340
1.327
1.321
1.316
1.247
1.241
1.232
1.225
1.222
1.215
1.208
1.200
1.189
1.152
1.127
1.120
1.110
1.101
1.093
1.089
1.085
1.079
1.061
1.054
1.024
1.018
1.000
0.993
O
Me
0.9
0.9
0.9
3.0
2.2
1.9
3.2
1.0
5.8
ppm
7
6
5
4
3
2
1

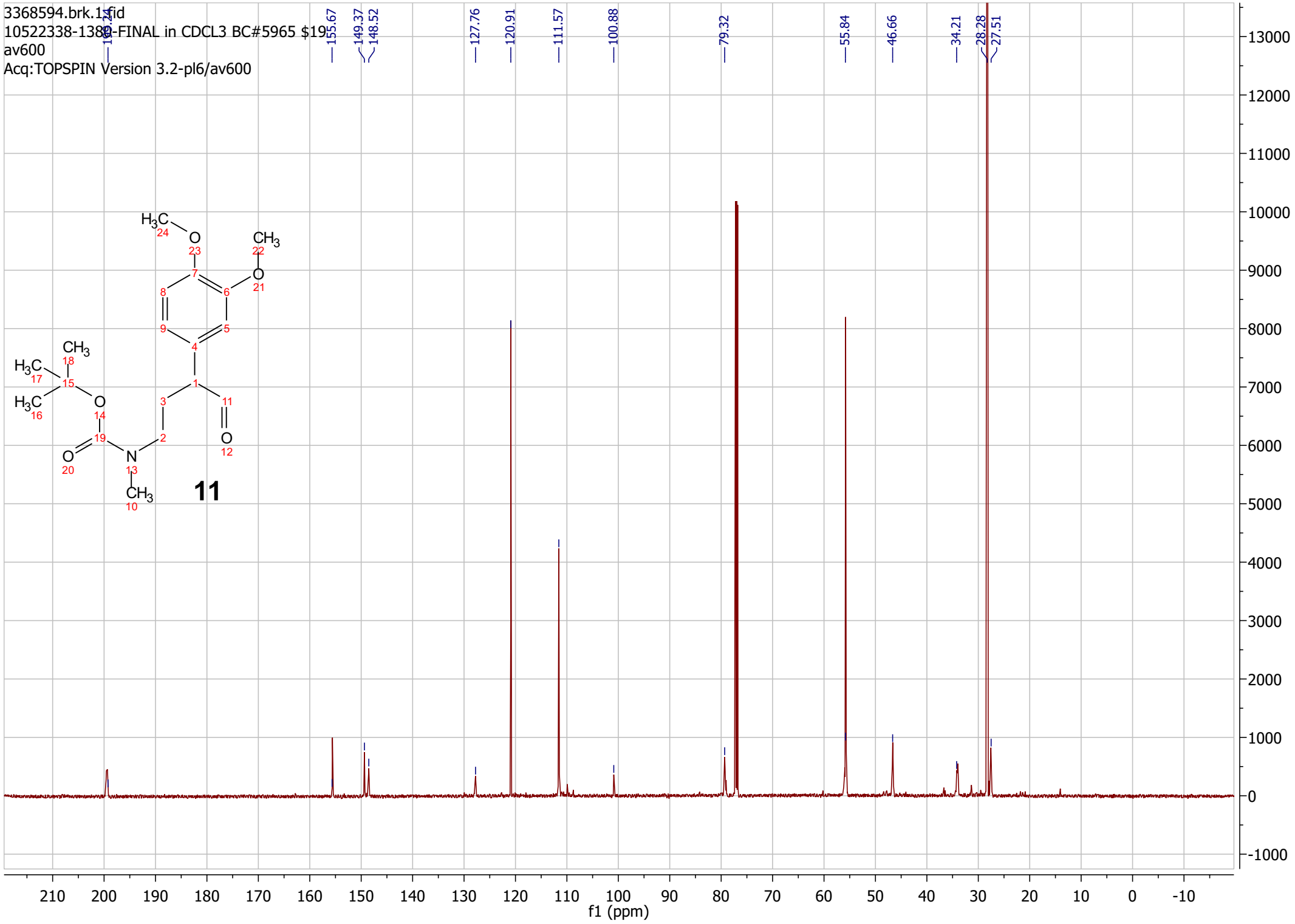
2l


200.202
160.474
127.441
47.049
38.474
34.313
30.338
28.153
27.285
27.104
27.075
26.732
22.355
O
Me
2l
ppm
200
150
100
50
0

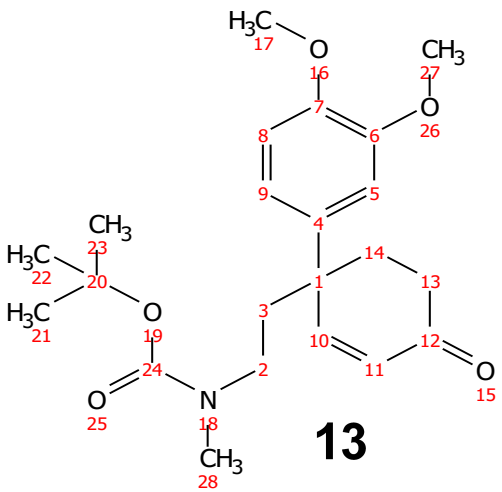

6.677
6.656
5.876
5.856
2.455
2.444
2.441
2.439
2.437
2.427
2.416
1.965
1.954
1.946
1.937
1.926
1.919
1.908
1.759
1.757
1.747
1.745
1.743
1.734
1.732
1.730
1.720
1.718
1.715
1.707
1.705
1.509
1.506
1.504
1.494
1.489
1.479
1.474
1.464
1.459
1.102
0.921
0.906
0.891
O
Et
Me
2m
0.9
1.0
2.0
3.0
0.9
2.0
1.0
3.0
ppm
8
7
6
5
4
3
2
1
0


200.049
159.637
127.614
35.880
34.336
33.562
33.142
24.424
8.628
O
Et
Me
2m
ppm
200
150
100
50
0


3369320
10522338-1380-SCALEUPFINAL in CDCL3 $21 BC5110 5mg
SampleNum 6285564
Temp = 25 C
C18H27N1O5
i400
Acq: VnmrJ VERSION 3.2 REVISION A/i400l
11
f1 (ppm)

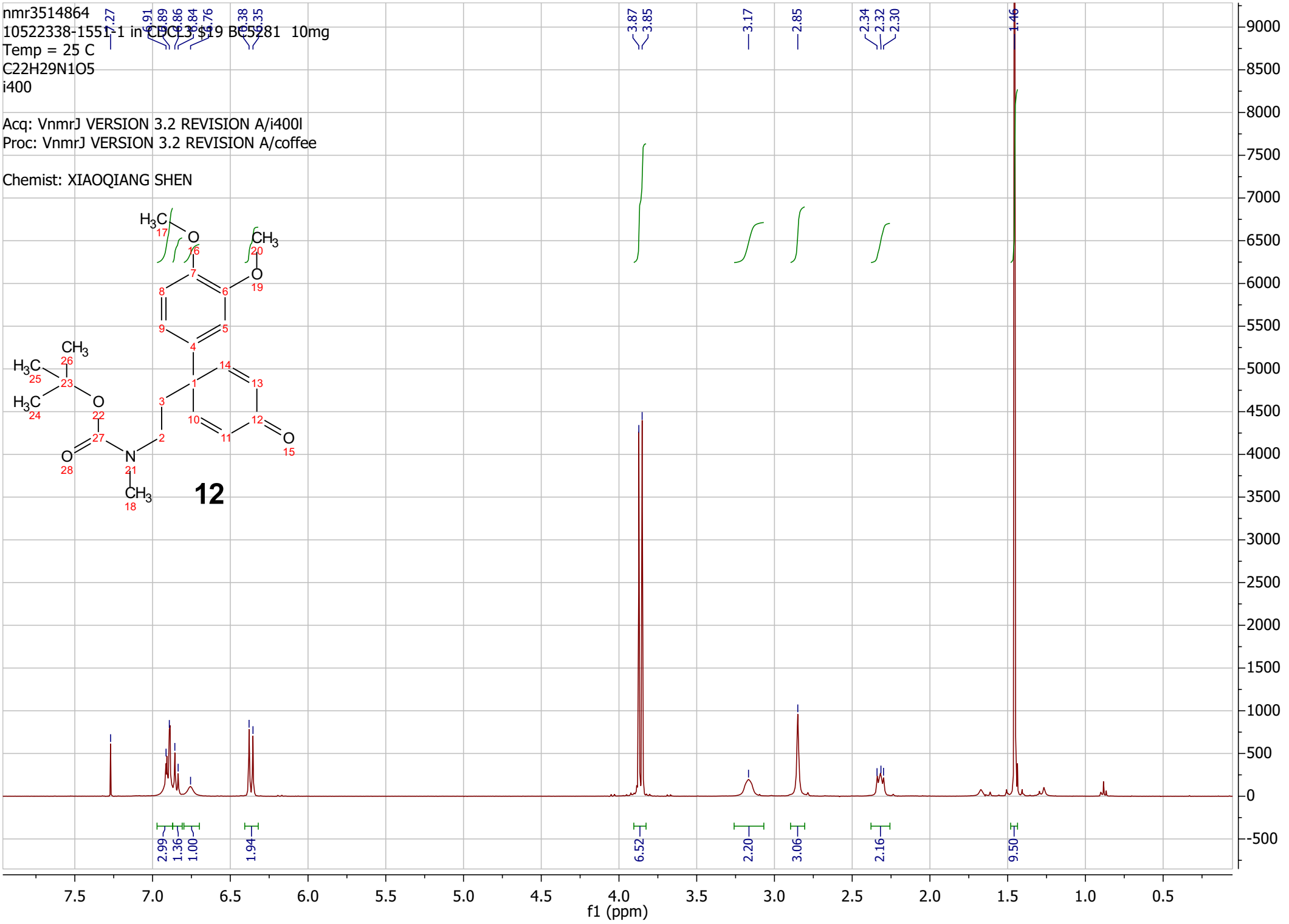

3368594.brk.1.fid
10522338-1380-FINAL in CDCL3 BC#5965 $19
av600
Acq:TOPSPIN Version 3.2-pl6/av600
199.24
155.67
149.37
148.52
127.76
120.91
111.57
100.88
79.32
55.84
46.66
34.21
28.28
27.51
11
f1 (ppm)

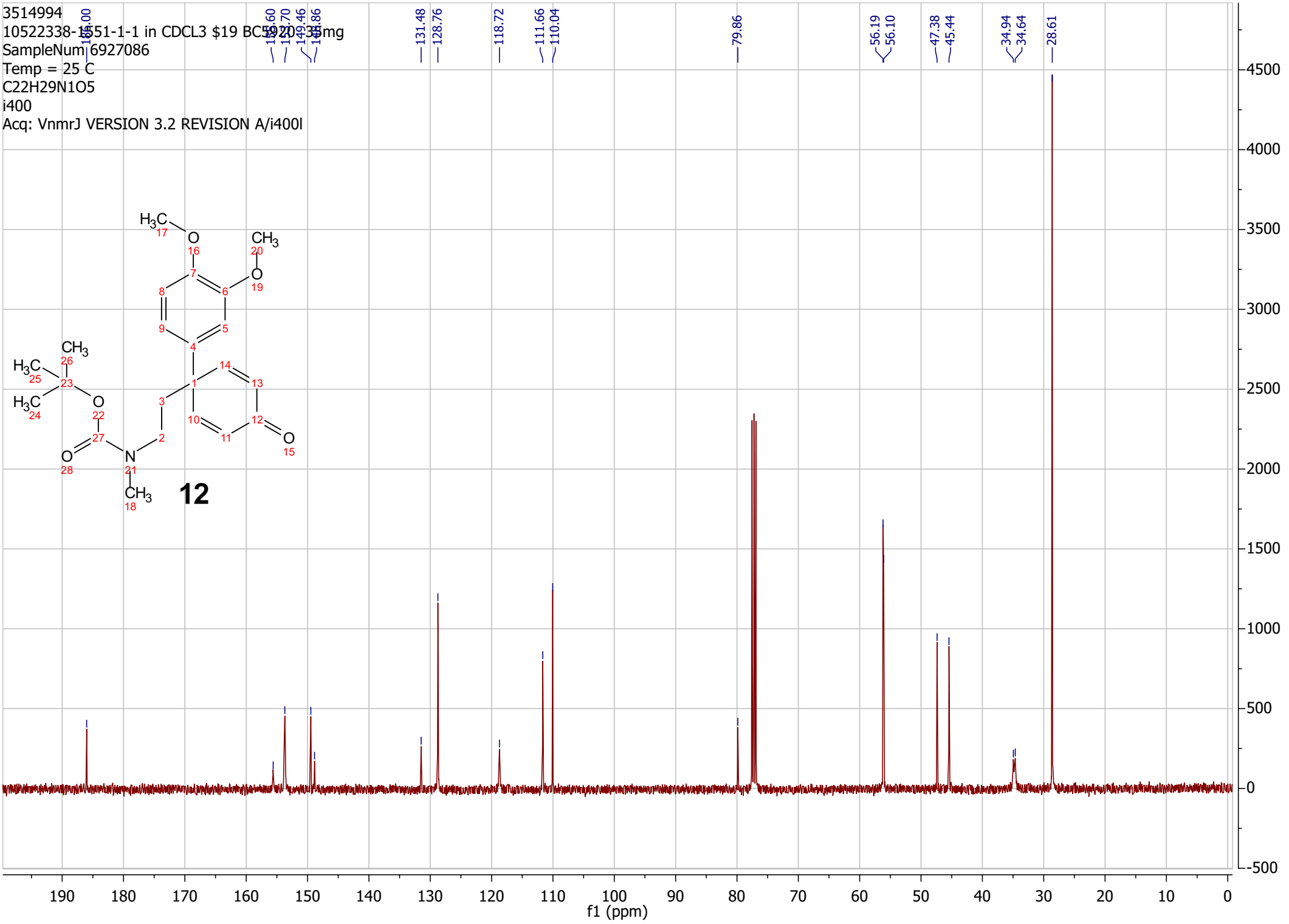
nmr3524761
10522338-1462-1-5 in CDCL3 $16 BC5697 10mg
SampleNum 6967529
Temp = 25 C
C22H31N1O5
i400
Acq: VnmrJ VERSION 3.2 REVISION A/i400l



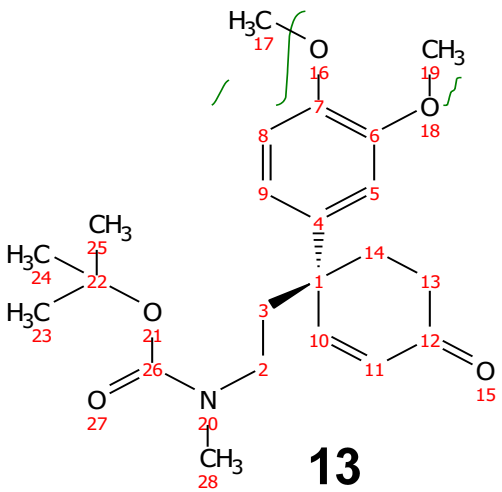
13

f1 (ppm)

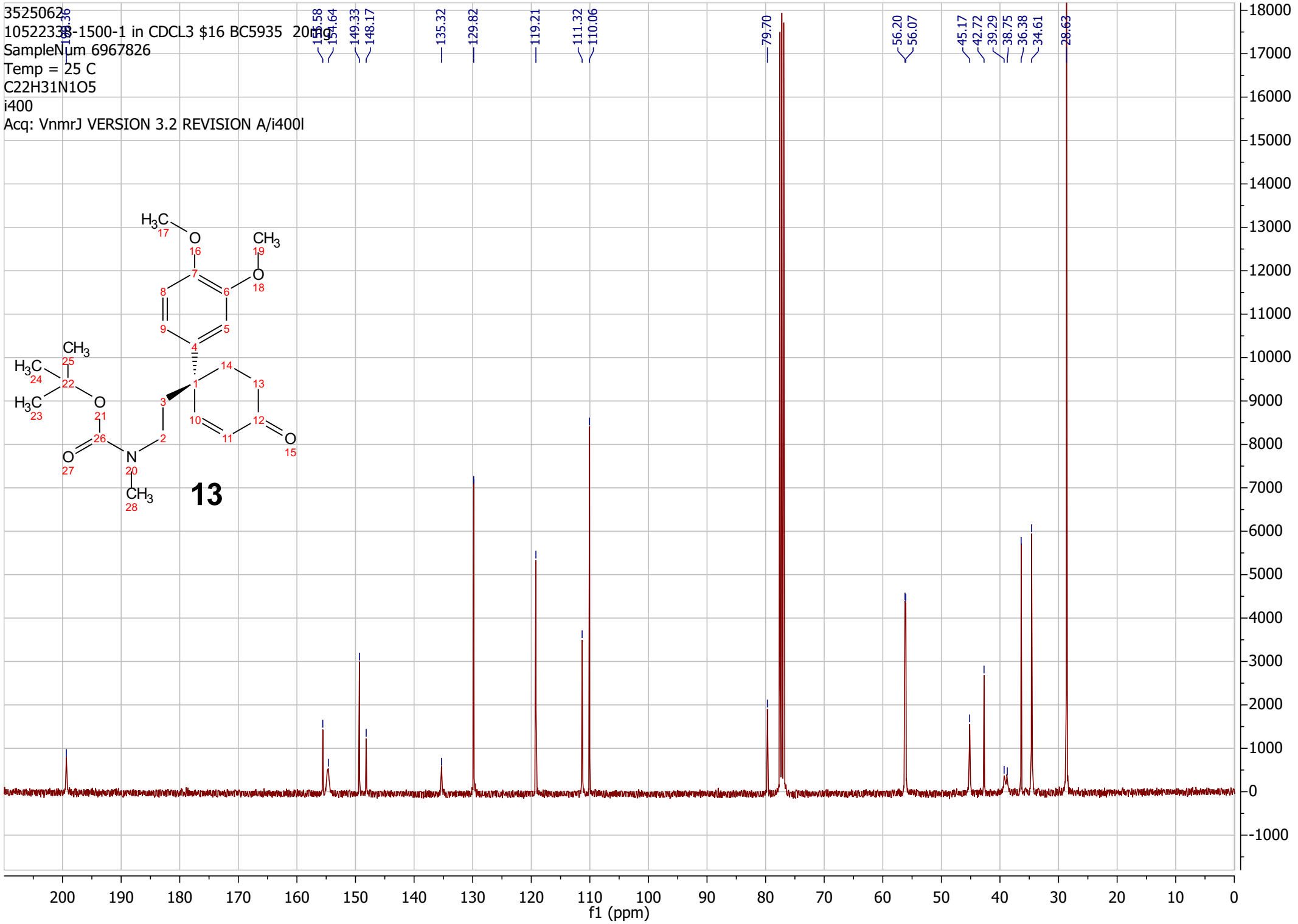

nmr3514864
10522338-1551-1 in CDCL3 $19 BC5281 10mg
Temp = 25 C
C22H29N1O5
i400
Acq: VnmrJ VERSION 3.2 REVISION A/i400l
Proc: VnmrJ VERSION 3.2 REVISION A/coffee
Chemist: XIAOQIANG SHEN
12
7.27
6.91
6.89
6.86
6.84
6.76
6.38
6.35
3.87
3.85
3.17
2.85
2.34
2.32
2.30
1.46
2.99
1.36
1.00
1.94
6.52
2.20
3.06
2.16
9.50
f1 (ppm)


3514994
10522338-1551-1-1 in CDCL3 $19 BC5920 38mg
SampleNum: 6927086
Temp = 25 C
C22H29N1O5
i400
Acq: VnmrJ VERSION 3.2 REVISION A/i400l
166.00
153.60
153.70
149.46
148.86
131.48
128.76
118.72
111.66
110.04
79.86
56.19
56.10
47.38
45.44
34.94
34.64
28.61
12
f1 (ppm)

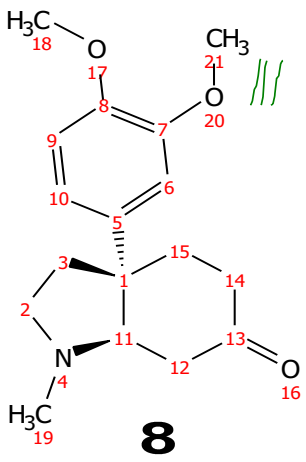
nmr3525064
10522338-1500-1 in CDCL3 $16 BC5935 20mg
SampleNum 6967826
Temp = 25 C
C22H31N1O5
i400
Acq: VnmrJ VERSION 3.2 REVISION A/i400l



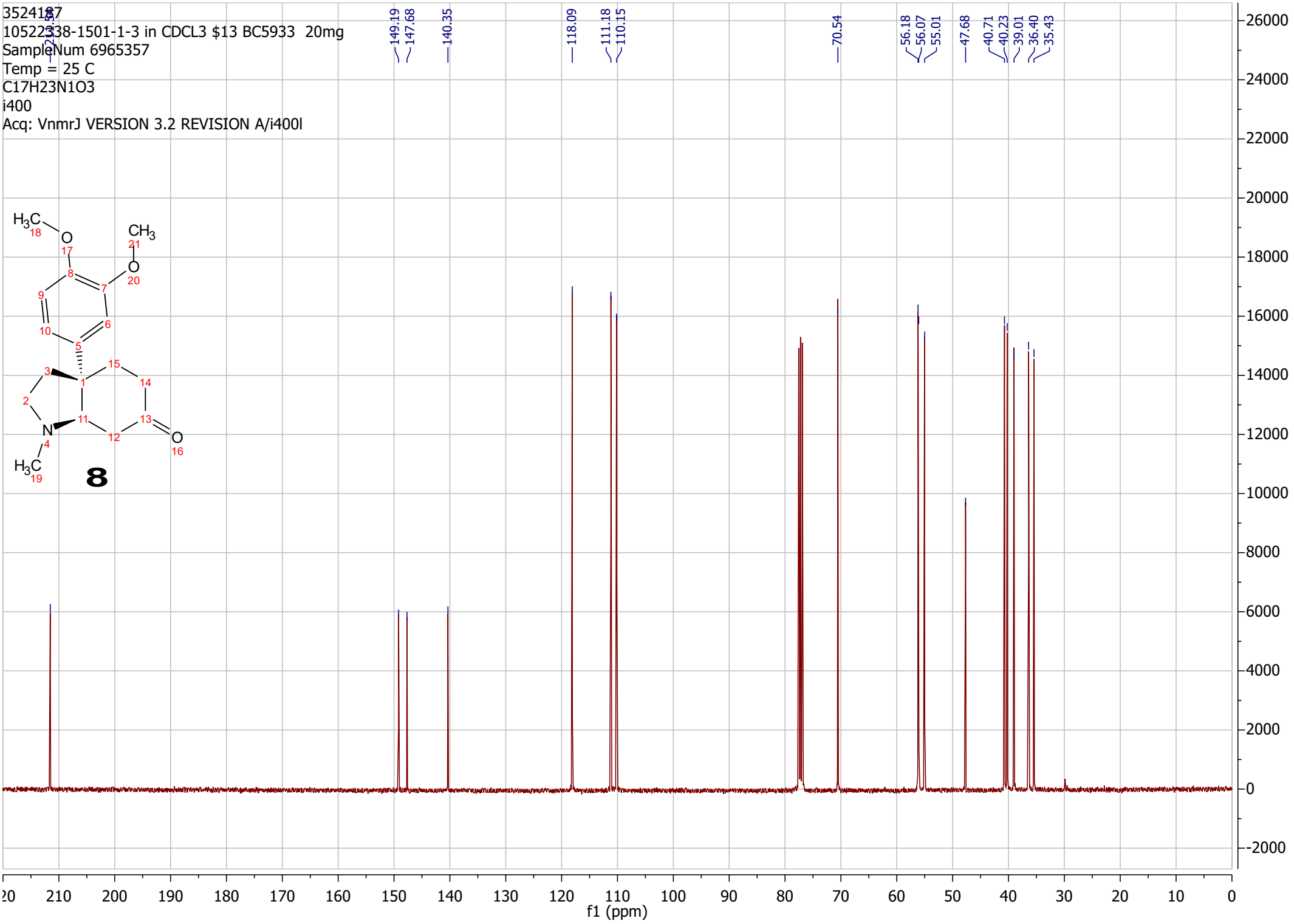
13


3525062
10522338-1500-1 in CDCL3 $16 BC5935 20mg
SampleNum 6967826
Temp = 25 C
C22H31N1O5
i400
Acq: VnmrJ VERSION 3.2 REVISION A/i400l
13
f1 (ppm)

nmr3524055
10522338-1501-1-2 in CDCL3 $13 BC5673 5mg
SampleNum 6965217
Temp = 25 C
C17H23N1O3
i400
Acq: VnmrJ VERSION 3.2 REVISION A/i400l



8


3524187
10522338-1501-1-3 in CDCL3 $13 BC5933 20mg
SampleNum 6965357
Temp = 25 C
C17H23N1O3
i400
Acq: VnmrJ VERSION 3.2 REVISION A/i400l
149.19
147.68
140.35
118.09
111.18
110.15
70.54
56.18
56.07
55.01
47.68
40.71
40.23
39.01
36.40
35.43
8
f1 (ppm)