Supplementary Information

Metal-Catalyzed Methylthiolation of Chloroarenes and Diverse Aryl Electrophiles

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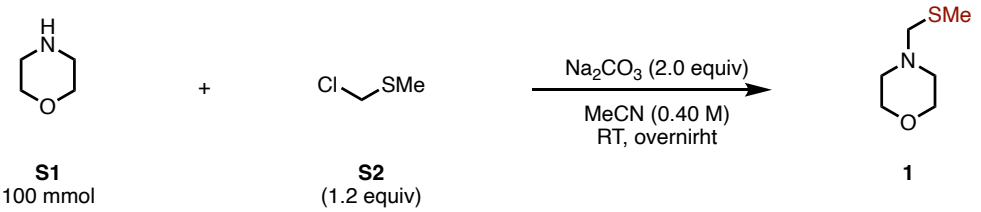
1. General

Unless otherwise noted, all reactants or reagents including drying solvents were obtained from commercial suppliers and used as received. 2-Naphthoic acid (**CO_2H-2c**), toluene, diethyl ether (Et_2O) and acetonitrile (MeCN) were obtained from KANTO Chemical. Palladium(II) acetate ($Pd(OAc)_2$), Xantphos, 1,1'-bis(diphenylphosphino)ferrocene (dppf), zinc (powder), morpholine (**S1**), chloromethyl methyl sulfide (**S2**), 6-hydroxy-4-methylcoumarin, 1-bromonaphthalene (**Br-2a**), 1-chloronaphthalene (**Cl-2a**), 1-bromo-2-methylnaphthalene (**2b**), 1-naphthol, 2-bromonaphthalene (**Br-2c**), 2-chloronaphthalene (**Cl-2c**), 2-naphthol, 2-naphthonitrile (**CN-2c**), 2-naphthoic acid, 2-chloroanthracene (**2d**), 9-bromoanthracene (**2e**), 4-bromopyrene (**Br-2g**), 1-(*tert*-butyl)-4-chlorobenzene (**2h**), 1-bromo-3,5-di-*tert*-butylbenzene (**2i**), 4-bromo-1,1'-biphenyl (**Br-2j**), 4-chloro-1,1'-biphenyl (**Cl-2j**), 4-cyanobiphenyl (**CN-2j**), [1,1'-biphenyl]-4-ol, 3-bromo-1,1'-biphenyl (**Br-2k**), 2-bromo-1,1'-biphenyl (**Br-2l**), 1-chloro-3,5-dimethoxybenzene (**2m**), 1-(4'-bromo-[1,1'-biphenyl]-4-yl)ethan-1-one (**2n**), ethyl 3-chlorobenzoate (**2o**), methyl 3-hydroxybenzoate, 1-chloro-4-nitronaphthalene (**2r**), chlorobenzhydrol (**2s**), 2-chloropyridine (**3t**), 5-acetyl-2-chloropyridine (**2u**), 2-chloroquinoline (**Cl-2v**), 2-quinolinecarbonitrile (**CN-2v**), 3-bromoquinoline (**2w**), 4-bromodibenzothiophene (**2x**), 2-(5-bromothiophen-2-yl)pyridine (**2y**), 5-chloro-2-methylbenzoxazole (**2z**), 6-chloroflavone (**2A**), fenofibrate (**2C**), vanillin, eugenol, chlorpromazine hydrochloride (**2F**), estrone, ticlopidine hydrochloride, diphenyl disulfide, dimethyl disulfide, methyl mercaptan sodium salt (**S7**, ca. 15% in water), 4-methoxyphenol (**S8**) and *p*-toluenesulfonic acid monohydrate (PTSA) were obtained from Tokyo Chemical Industry (TCI). Na_2CO_3, 9-bromophenanthrene (**2f**) and *N,N'*-dimorpholinomethane (**S6**) were obtained from FUJIFILM Wako Chemicals. Cs_2CO_3 was obtained from Iwatani Corporation. Naphthalen-1-yl 4-methylbenzenesulfonate (**OTs-2a**), naphthalen-1-yl methanesulfonate (**OMs-2a**), naphthalen-2-yl pivalate (**OPiv-2c**), naphthalen-2-yl 4-methylbenzenesulfonate (**OTs-2c**), naphthalen-2-yl methanesulfonate (**OMs-2c**), pyrene-4-carbonitrile (**CN-2g**) and [1,1'-biphenyl]-4-yl 4-methylbenzenesulfonate (**OTs-2j**) were obtained in our laboratory. Naphthalen-1-yl trifluoromethanesulfonate (**OTf-2a**),[1,2] naphthalen-2-yl trifluoromethanesulfonate (**OTf-2c**),[1,3] [1,1'-biphenyl]-4-yl trifluoromethanesulfonate (**OTf-2j**),[1,4] [1,1'-biphenyl]-4-yl pivalate (**OPiv-2j**),[5] [1,1'-biphenyl]-2-yl trifluoromethanesulfonate (**OTf-2l**),[1,4] methyl 3-(((trifluoromethyl)sulfonyl)oxy)benzoate (**2p**),[1,6] methyl 6-(((trifluoromethyl)sulfonyl)oxy)-2-naphthoate (**OTf-3q**),[1,7] methyl 6-(pivaloyloxy)-2-naphthoate **(OPiv-3q)**,[5] 4-formyl-2-methoxyphenyl trifluoromethanesulfonate **(2D),**[1,3] 4-allyl-2-methoxyphenyl trifluoromethanesulfonate **(2E)**[1,3] and 2-bromo-5-(2-chlorobenzyl)-4,5,6,7-tetrahydrothieno[3,2-*c*]pyridine (**2J** and **2K**)[8] were synthesized according to procedures and the spectra matched with those of compounds reported in the literatures. Unless otherwise noted, all reactions were performed with drying solvents under an atmosphere of N_2 in dried glassware using standard vacuum-line techniques. All coupling reactions were performed in 20-mL glass vessel tubes equipped with J. Young® O-ring tap and heated (IKA Plate RCT

digital) in a nine-well aluminum reaction block (IKA H 135.103 Block 9 × 16 mL) unless otherwise noted. All work-up and purification procedures were carried out with reagent-grade solvents in air.

Analytical thin-layer chromatography (TLC) was performed using Silica-gel 70 TLC Plate-Wako (0.25 mm). The developed chromatogram was analyzed by UV lamp (254 nm). Flash column chromatography was performed with a Biotage Isolera® instrument equipped with Biotage Sfär Cartridge Silica (HD) D Duo columns. Preparative thin-layer chromatography (PTLC) was performed using Wakogel B5-F silica coated plates (0.75 mm) prepared in our laboratory. Preparative recycling gel permeation chromatography (GPC) was performed with a JAI LaboACE LC-5060 instrument equipped with JAIGEL-2HR columns using $CHCl_3$ as an eluent. High-resolution mass spectra were conducted on Bruker Compact QTOF (ESI and APCI). Nuclear magnetic resonance (NMR) spectra were recorded on a JEOL JNM-ECS-400 and a JNM-ECZ-400S (^{1}H 400 MHz, ^{13}C 101 MHz, ^{19}F 376 MHz) spectrometer. Chemical shifts for ^{1}H NMR are expressed in parts per million (ppm) relative to tetramethylsilane (δ 0.00 ppm). Chemical shifts for ^{13}C NMR are expressed in ppm relative to $CDCl_3$ (δ 77.0 ppm). Chemical shifts for ^{19}F NMR are expressed in ppm relative to PhF (δ –113.15 ppm). Data are reported as follows: chemical shift, multiplicity (s = singlet, d = doublet, dd = doublet of doublets, ddd = doublet of doublets of doublets, dt = doublet of triplets, tt = triplet of triplets, td = triplet of doublets, q = quartet, ddt = doublet of doublets of triplets, m = multiplet), coupling constant (Hz), and integration.

2. Preparation of 4-((Methylthio)methyl)morpholine 1



S1
100 mmol

S2
(1.2 equiv)

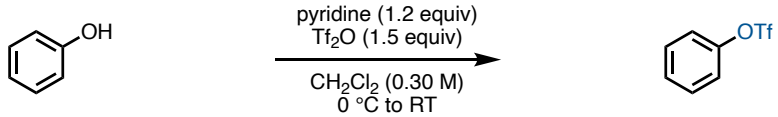
1

To a round-bottom flask containing a magnetic stirring bar and sodium carbonate (20.8 g, 200 mmol, 2.0 equiv) in acetonitrile (MeCN, 250 mL, 0.40 M) were added morpholine (**S1**: 8.8 mL, 100 mmol, 1.0 equiv) and chloromethyl methyl sulfide (**S2**: 9.9 mL, 120 mmol, 1.2 equiv). After stirring the mixture at room temperature overnight, the reaction was quenched with water. The mixture was extracted three times with EtOAc. The combined organic layer was dried over Na_2SO_4 and then filtered. The filtrate was distilled (45 Torr, 160 °C). to provide **1** as a colorless liquid (10.6 g, 72% yield).

Compound **1**: ^{1}H NMR (400 MHz, $CDCl_3$) δ 3.86 (s, 2H), 3.75–3.67 (m, 4H), 2.63–2.57 (m, 4H), 2.18 (s, 3H); $^{13}C\{^1H\}$ NMR (101 MHz, $CDCl_3$) δ 66.7, 65.0, 51.1, 16.9; HRMS (APCI) *m/z*: $[M+H]^+$ Calcd for $C_6H_{14}NOS$ 148.0791; Found 148.0788.

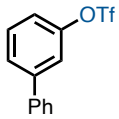
3. Preparation of Starting Materials 2

3-1. Preparation of Aryl Triflates OTf-2k, 2B, 2D, 2E and 2G′



OTf-2k, 2B, 2D, 2E, 2G′

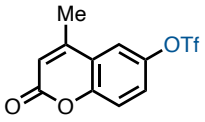
To a solution of arenol (1.0 equiv) in CH_2Cl_2 (0.30 M) was added pyridine (1.2 equiv) at room temperature. Then, trifluoromethanesulfonic anhydride (Tf_2O: 1.5 equiv) was added dropwise at 0 °C. After stirring the mixture for several hours at room temperature while the reaction progress was being monitored the reaction progress by TLC, the reaction mixture was added saturated $NaHCO_3$ aq. and extracted three times with CH_2Cl_2. The combined organic layer was dried over Na_2SO_4, filtered, and then concentrated *in vacuo*. The residue was purified by Isolera® to afford aryl triflates **OTf-2k**, **2B**, **2D**, **2E** and **2G′**.



[1,1'-Biphenyl]-3-yl trifluoromethanesulfonate (OTf-2k)

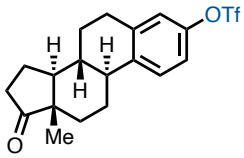
[1,1'-Biphenyl]-3-ol (171.9 mg, 1.0 mmol) was used. Purification by Isolera® (hexane/EtOAc = 90:10 to 70:30) afforded **OTf-2k** as a colorless liquid (276.8 mg, 91% yield). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.87–7.38 (m, 8H), 7.32–7.23 (m, 1H); $^{13}C\{^1H\}$ NMR (101 MHz, $CDCl_3$) δ 150.0, 143.9, 138.9, 130.4,

129.0, 128.3 127.1, 127.0, 119.9, 119.7, 118.8 (q, J_{CF} = 323.0 Hz); ^{19}F NMR (377 MHz, $CDCl_3$) δ –72.9 (s, 3F); HRMS (APCI) *m/z*: $[M+H]^+$ Calcd for $C_{13}H_{10}F_3O_3S$ 303.0297; Found 303.0290.



4-Methyl-2-oxo-2H-chromen-6-yl trifluoromethanesulfonate (2B)

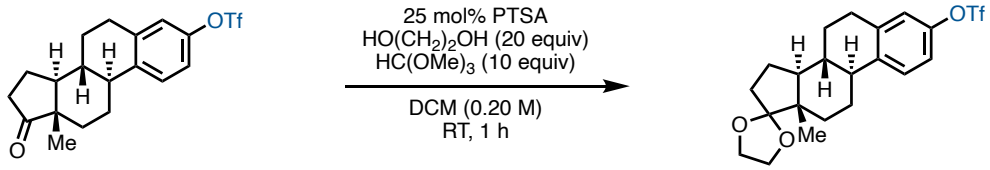
6-Hydroxy-4-methylcoumarin (486.0 mg, 1.0 mmol) was used. Purification by Isolera® (hexane/EtOAc = 90:10 to 70:30) afforded **2B** as a brown solid (275.4 mg, 89% yield). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.51–7.49 (m, 1H), 7.45–7.42 (m, 2H), 6.41 (d, *J* = 1.2 Hz, 1H), 2.46 (d, *J* = 1.2 Hz, 3H); ^{13}C{^{1}H} NMR (101 MHz, $CDCl_3$) δ 159.4, 152.5, 150.9, 145.1, 124.4, 121.2 119.0, 118.6 (q, J_{CF} = 323.1 Hz), 117.4, 116.7, 18.5; ^{19}F NMR (377 MHz, $CDCl_3$) δ –72.7 (s, 3F); HRMS (APCI) *m/z*: $[M+H]^+$ Calcd for $C_{11}H_8F_3O_5S$ 309.0039; Found 309.0040.



(8R,9S,13S,14S)-13-Methyl-17-oxo-7,8,9,11,12,13,14,15,16,17-decahydro-6*H*-cyclopenta[a]phenanthren-3-yl trifluoromethanesulfonate (2G′)

Estrone (537.6 mg, 1.8 mmol) was used. Purification by Isolera® (hexane/EtOAc = 90:10 to 60:40) afforded **2G′** as a white solid (702.6 mg, 87% yield). The spectra are in accordance with those reported in the literature.[9]

3-2. Preparation of Estrone Derivatives 2G and 2H

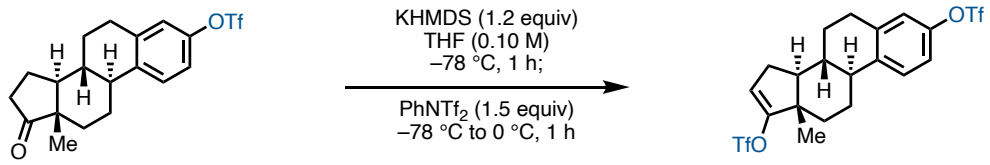


2G′
1.0 mmol

2G

To a solution of **2G′** (198.5 mg, 0.50 mmol, 1.0 equiv) in CH_2Cl_2 (2.5 mL, 0.20 M) were added *p*-toluenesulfonic acid (PTSA: 22.2 mg, 0.13 mmol, 25 mol%), ethylene glycol (0.56 mL, 10 mmol, 20 equiv) and trimethyl orthoformate (0.50 mL, 5.0 mmol, 10 equiv). After stirring the mixture at room temperature for 1 hour, the reaction mixture was saturated added $NaHCO_3$ aq. and extracted three times with CH_2Cl_2. The combined organic layer was washed with brine, dried over Na_2SO_4, filtered, and concentrated *in vacuo*. The residue was purified by Isolera® (hexane/EtOAc = 90:10 to 60:40) to afford (8*R*,9*S*,13*S*,14*S*)-13-methyl-6,7,8,9,11,12,13,14,15,16-decahydrospiro[cyclopenta[*a*]phenanthrene-17,2'-[1,3]dioxolan]-3-yl trifluoromethanesulfonate **2G** as a colorless liquid (189.4 mg, 84% yield).

Compound **2G**: ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.33 (d, J = 8.8 Hz, 1H), 7.01 (dd, J = 8.8, 2.8 Hz, 1H), 6.96 (d, J = 2.8 Hz, 1H), 4.00–3.84 (m, 4H), 2.92–2.83 (m, 2H), 2.36–2.21 (m, 2H), 2.08–1.98 (m, 1H), 1.96–1.72 (m, 4H), 1.69–1.28 (m, 6H), 0.89 (s, 3H); ^{13}C{^{1}H} NMR (101 MHz, $CDCl_3$) δ 147.4, 140.9, 139.5, 127.1, 121.1, 119.2, 118.7 (q, J_{CF} = 322.1 Hz), 118.0, 65.2, 64.6, 49.3, 46.0, 43.7, 38.4, 34.1, 30.5, 29.5, 26.5, 25.9, 22.3, 14.2; ^{19}F NMR (377 MHz, $CDCl_3$) δ –73.1 (s, 3F); HRMS (APCI) *m/z*: $[M+H]^+$ Calcd for $C_{21}H_{26}F_3O_5S$ 447.1448; Found 447.1444.



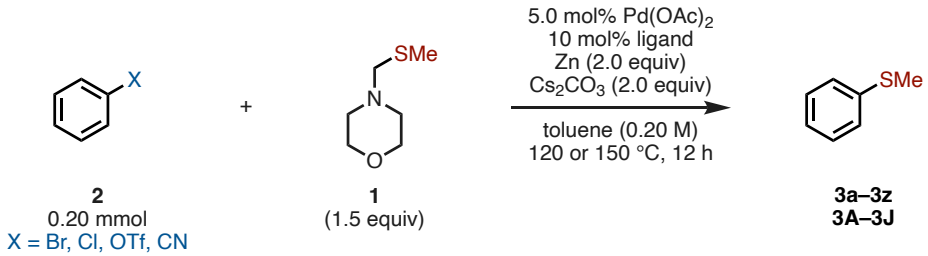
2G′
1.0 mmol

2H

A 20-mL glass vessel containing a magnetic stirring bar was dried with a heat gun *in vacuo* and filled with N_2 gas after cooling to room temperature. To this vessel was added **2G′** (279.5 mL, 0.80 mmol, 1.0 equiv) and placed under vacuum and refilled three times with N_2 gas. After cooling the vessel to –78 °C, the vessel were added THF (5.0 mL, 0.10 M) and KHMDS (0.50 M in toluene, 1.9 mL, 0.96 mmol, 1.2 equiv). After stirring the mixture for 1 hour at –78 °C, the vessel was warmed to room temperature, added *N*-phenylbis(trifluoromethanesulfonimide) ($PhNTf_2$: 428.7 mg, 1.2 mmol, 1.5 equiv) and stirred for 1 hour while the reaction progress was being monitored the reaction progress by TLC. The reaction mixture was added saturated $NaHCO_3$ aq. and extracted three times with EtOAc. The combined organic layer was dried over Na_2SO_4, filtered, and then concentrated *in vacuo*. The residue was purified by Isolera® (hexane/EtOAc = 98:2 to 70:30) to afford **2H** as a colorless liquid (221.6 mg, 83% yield).

Compound **2H**: ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.31 (d, J = 8.4 Hz, 1H), 7.03 (dd, J = 8.4, 2.8 Hz, 1H), 6.99 (d, J = 2.8 Hz, 1H), 5.65–5.61 (m, 1H), 2.94 (dd, J = 8.8, 4.4 Hz, 2H), 2.43–2.29 (m, 3H), 2.11 (ddd, J = 14.8, 11.2, 2.0 Hz, 1H), 2.00–1.88 (m, 2H), 1.80 (td, J = 11.2, 6.4 Hz, 1H), 1.72–1.53 (m, 3H), 1.53–1.39 (m, 1H), 1.01 (s, 3H); ^{13}C{^{1}H} NMR (101 MHz, $CDCl_3$) δ 159.0, 147.6, 140.3, 139.2, 126.8, 121.2, 118.7 (q, J_{CF} = 322.1 Hz), 118.6 (q, J_{CF} = 322.1 Hz), 118.3, 114.5, 53.4, 44.9, 44.3, 36.1, 32.6, 29.1, 28.3, 26.3, 25.5, 15.3; ^{19}F NMR (377 MHz, $CDCl_3$) δ –73.1 (s, 3F), –73.6 (s, 3F); HRMS (APCI) *m/z*: $[M+H]^+$ Calcd for $C_{20}H_{21}F_6O_6S_2$ 535.0678; Found 535.0681.

4. Pd or Ni-Catalyzed Methylthiolation of Aryl Electrophiles



2
0.20 mmol
X = Br, Cl, OTf, CN

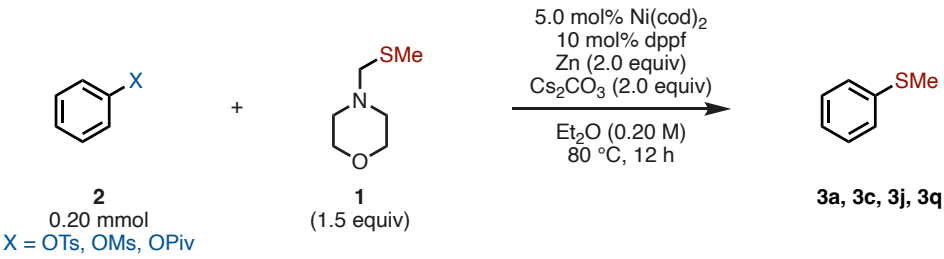
1
(1.5 equiv)

3a–3z
3A–3J

General Procedure 1 (GP-1)

A 20-mL glass vessel equipped with J. Young® O-ring tap containing a magnetic stirring bar and Cs_2CO_3 (130.3 mg, 0.40 mmol, 2.0 equiv) was dried with a heat gun *in vacuo* and filled with N_2 gas after cooling to room temperature. To this vessel were added haloarene or aryltriflate **2** (0.20 mmol, 1.0 equiv), 4-((methylthio)methyl)morpholine (**1** : 44.1 mg, 0.30 mmol, 1.5 equiv), $Pd(OAc)_2$ (2.3 mg, 0.010 mmol, 5.0 mol%), ligand (0.020 mmol, 10 mol%) and zinc (26.2 mg, 0.40 mmol, 2.0 equiv).[a] The vessel was placed under vacuum and refilled three times with N_2 gas. To this was added toluene (1.0 mL). The vessel was sealed with the O-ring tap and then heated at 120 °C or 150 °C for 12 hours in a nine-well aluminum reaction block with stirring. After the reaction mixture had been cooled to room temperature, the mixture was passed through a pad of silica-gel with EtOAc as an eluent. The filtrate was concentrated *in vacuo*, and the residue was purified by PTLC or GPC to afford the corresponding aryl methyl sulfide **3**. The condition details are shown in Table S1.

[a] When using aryl nitriles, NaO^{t}Bu was used instead of Cs_2CO_3.



2
0.20 mmol
X = OTs, OMs, OPiv

1
(1.5 equiv)

3a, 3c, 3j, 3q

General Procedure 2 (GP-2)

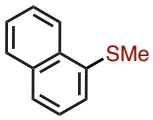
Caution: scaling up reactions in diethyl ether at high temperatures should be avoided unless appropriate equipment is used.

A 20-mL glass vessel equipped with J. Young® O-ring tap containing a magnetic stirring bar and Cs_2CO_3 (130.3 mg, 0.40 mmol, 2.0 equiv) was dried with a heat gun *in vacuo* and filled with N_2 gas after cooling to room temperature. To this vessel were added dppf (11.1 mg, 0.020 mmol, 10 mol%) and zinc (26.2 mg, 0.40 mmol, 2.0 equiv). The vessel was introduced inside an Ar atmosphere glovebox. In the glovebox, the vessel was added $Ni(cod)_2$ (2.8 mg, 0.010 mmol, 5.0 mol%), which was then capped with the O-ring tap and taken out of the glovebox. The vessel was placed under vacuum and refilled three times with N_2 gas. To this was added Et_2O (1.0 mL, 0.20 M), aryl tosylate, aryl mesylate or aryl pivalate **2** (0.20 mmol, 1.0 equiv), and 4-((methylthio)methyl)morpholine (**1** : 44.1 mg, 0.30 mmol, 1.5

equiv), The vessel was sealed with the O-ring tap and then heated at 150 °C for 12 hours in a nine-well aluminum reaction block with stirring. After the reaction mixture had been cooled to room temperature, the mixture was passed through a pad of silica-gel with EtOAc as an eluent. The filtrate was concentrated *in vacuo*, and the residue was purified by PTLC or GPC to afford the corresponding aryl methyl sulfide **3**. The condition details are shown in Table S1.

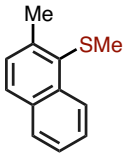
Table S1. Reaction Conditions on each Aryl electrophiles

X	metal	ligand	base	reductant	solvent	temperature, time
Br	5.0 mol% $Pd(OAc)_2$	10 mol% Xantphos	Cs_2CO_3	–	toluene	120 °C, 12 h
Cl, OTf	5.0 mol% $Pd(OAc)_2$	10 mol% dppf	Cs_2CO_3	Zn	toluene	150 °C, 12 h
CN	5.0 mol% $Pd(OAc)_2$	10 mol% dcype	NaO^tBu	Zn	toluene	150 °C, 24 h
OTs	5.0 mol% $Ni(cod)_2$	10 mol% dppf	Cs_2CO_3	Zn	Et_2O	80 °C, 12 h
OMs	10 mol% $Ni(cod)_2$	20 mol% dppf	Cs_2CO_3	Zn	Et_2O	80 °C, 24 h
OPiv	10 mol% $Ni(cod)_2$	20 mol% dcypt	Cs_2CO_3	Zn	toluene	150 °C, 12 h
CO_2H	10 mol% $Ni(cod)_2$	20 mol% dcypt	Cs_2CO_3	Zn	toluene	150 °C, 24 h



Methyl(naphthalen-1-yl)sulfane (3a)

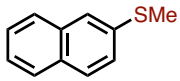
When 1-bromonaphthalene, 1-chloronaphthalene or naphthalen-1-yl trifluoromethanesulfonate was used, compound **3a** was synthesized according to **GP-1**. When naphthalen-1-yl 4-methylbenzenesulfonate or naphthalen-1-yl methanesulfonate was used, compound **3a** was synthesized according to **GP-2**. Purification by PTLC (hexane/EtOAc = 90:10) afforded **3a** as a yellow liquid (X = Br : 19.6 mg, 85% yield; Cl: 39.7 mg, 96% yield; OTf: 27.7 mg, 79% yield; OTs: 12.1 mg, 35% yield; OMs: 14.9 mg, 43% yield). ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.28 (d, J = 8.0 Hz, 1H), 7.85–7.82 (m, 1H), 7.67 (dd, J = 8.0, 0.8 Hz, 1H), 7.57–7.48 (m, 2H), 7.45–7.37 (m, 2H), 2.58 (s, 3H); ^{13}C{^{1}H} NMR (101 MHz, $CDCl_3$) δ 135.8, 133.6, 131.6, 128.5, 126.2, 126.1, 125.8, 125.7, 124.2, 123.6, 16.2. HRMS (APCI) *m/z*: $[M+H]^+$ Calcd for $C_{11}H_{11}S$ 175.0576; Found 175.0577. The spectra are in accordance with those reported in the literature.[10]



Methyl(2-methylnaphthalen-1-yl)sulfane (3b)

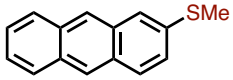
Compound **3b** was synthesized according to **GP-1**. 1-Bromo-2-methylnaphthalene was used. The reaction was conducted using zinc (2.0 equiv) as an additive. Purification by PTLC (hexane/EtOAc = 90:10) afforded **3b** as a colorless liquid (34.2 mg, 91% yield). ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.68 (dd, J = 8.4, 1.2 Hz, 1H), 7.86–7.79 (m, 1H), 7.74 (d, J = 8.4 Hz, 1H), 7.57 (ddd, J = 8.0, 6.8, 1.2 Hz, 1H), 7.45 (ddd, J = 8.0, 6.8, 1.2 Hz, 1H), 7.39 (d, J = 8.4 Hz, 1H), 2.77 (s, 3H), 2.30 (s, 3H); ^{13}C{^{1}H} NMR

(101 MHz, $CDCl_3$) δ 141.1, 135.0, 132.8, 131.8, 128.72, 128.69, 128.4, 126.8, 126.2, 125.1, 22.1, 19.0; HRMS (APCI) *m/z*: $[M+H]^+$ Calcd for $C_{12}H_{13}S$ 189.0732; Found 189.0737. The spectra are in accordance with those reported in the literature.[10]



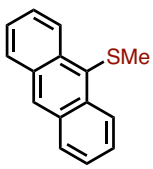
Methyl(naphthalen-2-yl)sulfane (3c)

When 1-bromonaphthalene, 1-chloronaphthalene or naphthalen-1-yl trifluoromethanesulfonate was used, compound **3c** was synthesized according to **GP-1**. When naphthalen-1-yl 4-methylbenzenesulfonate or naphthalen-1-yl methanesulfonate was used, compound **3b** was synthesized according to **GP-2**. Purification by PTLC (hexane/EtOAc = 90:10) afforded **3c** as a white solid (X=Br : 26.6 mg, 86%; Cl:36.4 mg, >99% yield; OTf: 29.6 mg, 85%; OTs: 32.5 mg, 93%; OMs: 31.3 mg, 89% yield; OPiv: 25.5 mg, 73% yield; CN: 27.0 mg, 77% yield; CO_2H: 7.5 mg, 26% yield). ^1H NMR (400 MHz, $CDCl_3$) δ 7.77 (d, *J* = 8.0 Hz, 1H), 7.75–7.71 (m, 2H), 7.60 (d, *J* = 1.2 Hz, 1H), 7.50–7.35 (m, 3H), 2.58 (s, 3H); $^{13}C\{^1H\}$ NMR (101 MHz, $CDCl_3$) δ 136.1, 133.8, 131.2, 128.1, 127.7, 126.8, 126.5, 125.6, 125.2, 123.3, 15.7; HRMS (APCI) *m/z*: $[M+H]^+$ Calcd for $C_{11}H_{11}S$ 175.0576; Found 175.0580. The spectra are in accordance with those reported in the literature.[11]



Anthracen-2-yl(methyl)sulfane (3d)

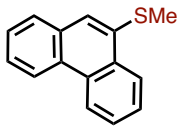
Compound **3d** was synthesized according to **GP-1**. 2-Chloroanthracene was used. Purification by PTLC (hexane/EtOAc = 90:10) afforded **3d** as a yellow solid (43.5 mg, 96% yield). ^1H NMR (400 MHz, $CDCl_3$) δ 8.35 (s, 1H), 8.29 (s, 1H), 8.02–7.93 (m, 2H), 7.89 (d, *J* = 8.8 Hz, 1H), 7.68 (s, 1H), 7.49–7.40 (m, 2H), 7.36–7.27 (m, 1H), 2.63 (s, 3H); $^{13}C\{^1H\}$ NMR (101 MHz, $CDCl_3$) δ 135.8, 132.2, 132.0, 131.3, 129.8, 128.4, 128.2, 128.0, 126.2, 125.6, 125.1, 124.6, 122.0, 15.4 (one peak is missing due to overlapping); HRMS (APCI) *m/z*: $[M+H]^+$ Calcd for $C_{15}H_{13}S$ 225.0732; Found 225.0733.



Anthracen-9-yl(methyl)sulfane (3e)

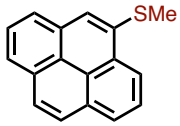
Compound **3e** was synthesized according to **GP-1**. 9-Bromoanthracene was used. Purification by PTLC (hexane/EtOAc = 90:10) afforded **3e** as a yellow liquid (43.9 mg, 98% yield). ^1H NMR (400 MHz, $CDCl_3$) δ 8.95 (d, *J* = 8.4 Hz, 2H), 8.46 (s, 1H), 8.01 (d, *J* = 8.4 Hz, 2H), 7.70–7.56 (m, 2H), 7.56–7.46

(m, 2H), 2.40 (s, 3H); $^{13}C\{^{1}H\}$ NMR (101 MHz, $CDCl_3$) δ 134.0, 131.8, 131.0, 129.0, 128.8, 126.9, 126.7, 125.3, 20.1; HRMS (APCI) *m/z*: $[M+H]^+$ Calcd for $C_{15}H_{13}S$ 225.0732; Found 225.0730.



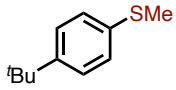
Methyl(phenanthren-9-yl)sulfane (3f)

Compound **3f** was synthesized according to **GP-1**. 9-Bromophenanthrene was used. Purification by PTLC (hexane/EtOAc = 90:10) afforded **3f** as a white solid (42.4 mg, 95% yield). ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.73–8.63 (m, 1H), 8.62–8.54 (m, 1H), 8.38–8.28 (m, 1H), 7.82–7.73 (m, 1H), 7.70–7.60 (m, 2H), 7.59–7.49 (m, 3H), 2.61 (s, 3H); $^{13}C\{^{1}H\}$ NMR (101 MHz, $CDCl_3$) δ 134.4, 131.9, 130.4, 130.3, 128.8, 127.5, 126.90, 126.88, 126.7, 126.0, 124.8, 123.1, 123.0, 122.5, 15.8; HRMS (APCI) *m/z*: $[M+H]^+$ Calcd for $C_{15}H_{13}S$ 225.0732; Found 225.0736. The spectra are in accordance with those reported in the literature.[12]



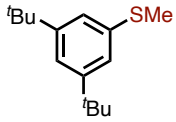
Methyl(pyren-4-yl)sulfane (3g)

Compound **3g** was synthesized according to **GP-1**. 4-Bromopyrene was used. Purification by PTLC (hexane/EtOAc = 90:10) afforded **3g** as a pink solid (X=Br : 41.0 mg, 82% yield, CN: 16.9 mg, 43% yield). ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.57 (dd, *J* = 8.0, 0.8 Hz, 1H), 8.21 (dd, *J* = 7.6, 0.8 Hz, 1H), 8.11 (ddd, *J* = 9.2, 7.6, 1.2 Hz, 2H), 8.06–8.01 (m, 3H), 7.97 (t, *J* = 7.6 Hz, 1H), 7.89 (s, 1H), 2.75 (s, 3H); $^{13}C\{^{1}H\}$ NMR (101 MHz, $CDCl_3$) δ 135.3, 131.3, 131.0, 130.9, 129.6, 127.4, 127.2, 126.1, 125.7, 125.6, 124.55, 124.48, 124.0, 123.0, 122.9, 121.6, 15.7; HRMS (APCI) *m/z*: $[M+H]^+$ Calcd for $C_{17}H_{13}S$ 249.0732; Found 249.0733.



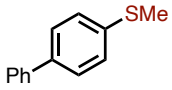
(4-(*tert*-Butyl)phenyl)(methyl)sulfane (3h)

Compound **3h** was synthesized according to **GP-1**. 1-(*tert*-Butyl)-4-chlorobenzene was used. The reaction was conducted at 0.40 mmol scale. Purification by PTLC (hexane/EtOAc = 90:10) afforded **3h** as a colorless liquid (46.0 mg, 65% yield). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.32 (d, *J* = 8.4 Hz, 2H), 7.22 (d, *J* = 8.4 Hz, 2H), 2.47 (s, 3H), 1.30 (s, 9H); $^{13}C\{^{1}H\}$ NMR (101 MHz, $CDCl_3$) δ 148.4, 134.9, 127.0, 126.0, 34.5, 31.4, 16.4; HRMS (APCI) *m/z*: $[M+H]^+$ Calcd for $C_{11}H_{17}S$ 181.1045, Found 181.1041. The spectra are in accordance with those reported in the literature.[11]



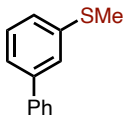
(3,5-Di-*tert*-butylphenyl)(methyl)sulfane (3i)

Compound **3i** was synthesized according to **GP-1**. 1,3-Di-*tert*-butyl-5-chlorobenzene was used. Purification by PTLC (hexane/EtOAc = 90:10) afforded **3i** as a white solid (36.4 mg, 66% yield). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.21 (t, J = 2.0 Hz, 1H), 7.13 (d, J = 2.0 Hz, 2H), 2.50 (s, 3H), 1.32 (s, 18H); $^{13}C\{^{1}H\}$ NMR (101 MHz, $CDCl_3$) δ 151.3, 137.0, 121.3, 119.8, 34.9, 31.4, 16.3; HRMS (APCI) *m/z*: $[M+H]^+$ Calcd for $C_{15}H_{25}S$ 237.1671; Found 237.1680.



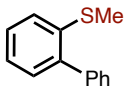
[1,1'-Biphenyl]-4-yl(methyl)sulfane (3j)

When 4-bromo-1,1'-biphenyl, 4-chloro-1,1'-biphenyl or [1,1'-biphenyl]-4-yl trifluoromethanesulfonate (**OTf-2j**) was used, compound **3j** was synthesized according to **GP-1**. When [1,1'-biphenyl]-4-yl 4-methylbenzenesulfonate or [1,1'-biphenyl]-4-yl methanesulfonate was used, compound **3j** was synthesized according to **GP-2**. All except **OTf-3j** was afforded by Purification by PTLC (hexane/EtOAc = 90:10) as a white solid. When using **OTf-2j** as a substrate, purification by GPC afforded **3j** as a white solid (X = Br: 30.1 mg, 91% yield; Cl: 35.4 mg, 88% yield; OTf: 32.2 mg, 80% yield; OTs: 7.4 mg, 18% yield; OPiv: 5.6 mg, 14% yield; CN: 20.3 mg, 51% yield). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.59–7.54 (m, 2H), 7.54–7.50 (m, 2H), 7.45–7.39 (m, 2H), 7.35–7.30 (m, 3H), 2.52 (s, 3H); $^{13}C\{^{1}H\}$ NMR (101 MHz, $CDCl_3$) δ 140.5, 138.0, 137.6, 128.8, 127.5, 127.2, 126.9, 126.8, 15.9; HRMS (APCI) *m/z*: $[M+H]^+$ Calcd for $C_{13}H_{13}S$ 201.0732; Found 201.0735. The spectra are in accordance with those reported in the literature.[11]



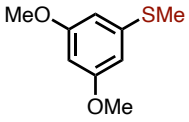
[1,1'-Biphenyl]-3-yl(methyl)sulfane (3k)

Compound **3k** was synthesized according to **GP-1**. 3-Bromo-1,1'-biphenyl was used. Purification by PTLC (hexane/EtOAc = 90:10) afforded **3k** as a yellow liquid (X = Br: 33.2 mg, 82% yield; OTf: 19.1 mg, 54% yield). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.60–7.55 (m, 2H), 7.48–7.47 (m, 1H), δ 7.47–7.41 (m, 2H), 7.39–7.33 (m, 3H), δ 7.26–7.21 (m, 1H), 2.54 (s, 3H); $^{13}C\{^{1}H\}$ NMR (101 MHz, $CDCl_3$) δ 141.9, 140.7, 138.9, 129.1, 128.7, 127.5, 127.1, 125.3, 124.0, 15.8 (One peak is missing due to overlapping.); HRMS (APCI) *m/z*: $[M+H]^+$ Calcd for $C_{13}H_{13}S$ 201.0732; Found 201.0733.



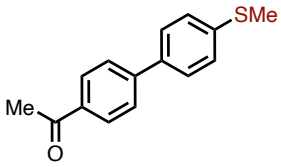
[1,1'-Biphenyl]-2-yl(methyl)sulfane (3l)

Compound **3l** was synthesized according to **GP-1**. When 2-Bromo-1,1'-biphenyl was used, the reaction was conducted using zinc (2.0 equiv) as an additive. Purification by PTLC (hexane/EtOAc = 90:10) afforded **3l** as a yellow liquid (X = Br: 26.3 mg, 65% yield, OTf: 17.1 mg, 49% yield). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.44–7.15 (m, 9H), 2.36 (s, 3H); $^{13}C\{^{1}H\}$ NMR (101 MHz, $CDCl_3$) δ 140.9, 140.5, 137.1, 129.9, 129.3, 128.1, 127.9, 127.5, 125.1, 124.7, 15.9; HRMS (APCI) *m/z*: $[M+H]^+$ Calcd for $C_{13}H_{13}S$ 201.0732; Found 201.0732. The spectra are in accordance with those reported in the literature.[10]



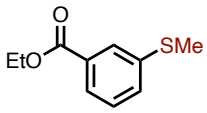
(3,5-Dimethoxyphenyl)(methyl)sulfane (3m)

Compound **3m** was synthesized according to **GP-1**. 1-Chloro-3,5-dimethoxybenzene was used. Purification by PTLC (hexane/EtOAc = 90:10) afforded **3m** as a yellow liquid (36.0 mg, 98% yield). ^{1}H NMR (400 MHz, $CDCl_3$) δ 6.41 (d, *J* = 2.4 Hz, 2H), 6.24 (t, *J* = 2.4 Hz, 1H), 3.78 (s, 6H), 2.47 (s, 3H); $^{13}C\{^{1}H\}$ NMR (101 MHz, $CDCl_3$) δ 160.9, 140.6, 104.3, 97.3, 55.3, 15.5. HRMS (APCI) *m/z*: $[M+H]^+$ Calcd for $C_9H_{13}O_2S$ 185.0631; Found 185.0631. The spectra are in accordance with those reported in the literature.[12]



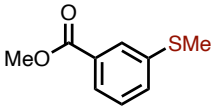
1-(4'-(Methylthio)-[1,1'-biphenyl]-4-yl)ethan-1-one (3n)

Compound **3n** was synthesized according to **GP-1**. 1-(4'-Bromo-[1,1'-biphenyl]-4-yl)ethan-1-one was used. Purification by PTLC (hexane/EtOAc = 90:10) afforded **3n** as a white solid (32.1 mg, 80% yield). ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.02 (d *J* = 8.8 Hz, 2H), 7.67 (d, *J* = 8.8 Hz, 2H), 7.57 (d, *J* = 8.4 Hz, 2H), 7.35 (d, *J* = 8.4 Hz, 2H), 2.64 (s, 3H), 2.54 (s, 3H). $^{13}C\{^{1}H\}$ NMR (101 MHz, $CDCl_3$) δ 197.7, 145.1, 139.1, 136.4, 135.7, 129.0, 127.5, 126.8, 126.7, 26.6, 15.6; HRMS (APCI) *m/z*: $[M+H]^+$ Calcd for $C_{15}H_{15}OS$ 243.0838; Found 243.0841. The spectra are in accordance with those reported in the literature.[13]



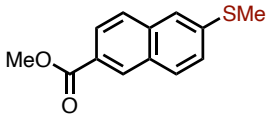
Ethyl 3-(methylthio)benzoate (3o)

Compound **3o** was synthesized according to **GP-1**. Ethyl 3-chlorobenzoate was used. Purification by PTLC (hexane/EtOAc = 90:10) afforded **3o** as a colorless liquid (23.8 mg, 61% yield). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.93–7.90 (m, 1H), 7.80 (dt, *J* = 8.0, 1.2 Hz, 1H), 7.43 (ddd, *J* = 8.0, 2.0, 1.2 Hz, 1H), 7.34 (t, *J* = 8.0 Hz, 1H), 4.38 (q, *J* = 7.2 Hz, 2H), 2.52 (s, 3H), 1.40 (t, *J* = 7.2 Hz, 3H). ^{13}C{^{1}H} NMR (101 MHz, $CDCl_3$) δ 166.2, 139.2, 131.1, 130.7, 128.7, 127.1, 126.0, 61.1, 15.6, 14.3; HRMS (APCI) *m/z*: $[M+H]^+$ Calcd for $C_{10}H_{13}O_2S$ 197.0631; Found 197.0639.



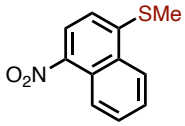
Methyl 4-(methylthio)benzoate (3p)

Compound **3p** was synthesized according to **GP-1**. Methyl 4-(((trifluoromethyl)sulfonyl)oxy)benzoate was used. Purification by PTLC (hexane/EtOAc = 90:10) afforded **3p** as a brown liquid (22.0 mg, 60% yield). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.91 (t, *J* = 1.6 Hz, 1H), 7.80 (dd, *J* = 7.6, 1.6 Hz, 1H), 7.46–7.41 (m, 1H), 7.35 (t, *J* = 7.6 Hz, 1H), 3.92 (s, 3H), 2.52 (s, 3H); ^{13}C{^{1}H} NMR (101 MHz, $CDCl_3$) δ 166.7, 139.3, 130.7, 128.7, 127.0, 126.0, 52.2, 15.6; HRMS (APCI) *m/z*: $[M+H]^+$ Calcd for $C_9H_{11}O_2S$ 183.0474; Found 183.0475. The spectra are in accordance with those reported in the literature.[14]



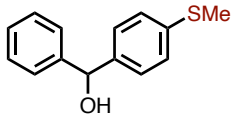
Methyl 6-(methylthio)-2-naphthoate (3q)

When methyl 6-(((trifluoromethyl)sulfonyl)oxy)-2-naphthoate was used, compound **3q** was synthesized according to **GP-1**. When methyl 6-(pivaloyloxy)-2-naphthoate was used, **3q** was synthesized according to **GP-2**. Purification by PTLC (hexane/EtOAc = 90:10) afforded **3q** as a brown solid (X = OTf: 38.0 mg, 82% yield, OPiv: 13.3 mg, 29% yield). ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.52 (s, 1H), 8.04 (dd, *J* = 8.4, 1.6 Hz, 1H), 7.81 (d, *J* = 8.4 Hz, 1H), 7.74 (d, *J* = 8.4 Hz, 1H), 7.58–7.55 (m, 1H), 7.40 (dd, *J* = 8.4, 1.6 Hz, 1H), 3.97 (s, 3H), 2.59 (s, 3H); ^{13}C{^{1}H} NMR (101 MHz, $CDCl_3$) δ 167.2, 139.8, 135.9, 130.8, 130.1, 129.4, 126.8, 126.5, 126.1, 125.9, 122.0, 52.2, 15.2; HRMS (APCI) *m/z*: $[M+H]^+$ Calcd for $C_{13}H_{13}O_2S$ 233.0631; Found 233.0628.



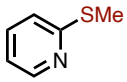
Methyl(4-nitrophenyl)sulfane (3r)

Compound **3r** was synthesized according to **GP-1**. 1-Chloro-4-nitronaphthalene was used. Purification by PTLC (hexane/EtOAc = 90:10) afforded **3r** as a yellow solid (20.8 mg, 47% yield). ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.70 (d, *J* = 8.8 Hz, 1H), 8.31 (d, *J* = 8.4 Hz, 1H), 8.25 (d, *J* = 8.4 Hz, 1H), 7.75 (ddd, *J* = 8.8, 6.8, 1.2 Hz, 1H), 7.65 (ddd, *J* = 8.4, 6.8, 1.2 Hz, 1H), 7.26 (d, *J* = 8.4 Hz, 1H), 2.68 (s, 3H); ^{13}C{^{1}H} NMR (101 MHz, $CDCl_3$) δ 146.5, 143.3, 131.0, 129.7, 127.2, 125.1, 124.3, 124.2, 124.0, 118.2, 15.0; HRMS (APCI) *m/z*: $[M+H]^+$ Calcd for $C_{11}H_{10}NO_2S$ 220.0427; Found 220.0430.



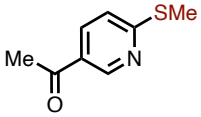
(4-(Methylthio)phenyl)(phenyl)methanol (3s)

Compound **3s** was synthesized according to **GP-1**. (4-Chlorophenyl)(phenyl)methanol was used. Purification by PTLC (hexane/chloroform = 90:10) afforded **3s** as a yellow solid (27.1 mg, 59% yield). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.40–7.30 (m, 4H), 7.30–7.21 (m, 3H), 7.22–7.16 (m, 2H), 5.75 (s, 1H), 2.44 (s, 3H), 2.39 (s, 1H); ^{13}C{^{1}H} NMR (101 MHz, $CDCl_3$) δ 143.6, 140.7, 137.6, 128.5, 127.6, 127.0, 126.6, 126.4, 75.7, 15.8; HRMS (APCI) *m/z*: $[M+H]^+$ Calcd for $C_{14}H_{15}OS$ 231.0838; Found 231.0830. The spectra are in accordance with those reported in the literature.



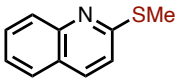
2-(Methylthio)pyridine (3t)

Compound **3t** was synthesized according to **GP-1**. 2-Chloropyridine was used. The yield of **3t** was determined as 65% by ^{1}H NMR analysis of crude material using CH_2Br_2 as an internal standard (2.51 ppm, s, 3H was used). The spectra are in accordance with those reported in the literature.[15]



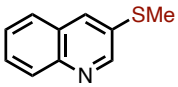
1-(6-(Methylthio)pyridin-3-yl)ethan-1-one (3u)

Compound **3u** was synthesized according to **GP-1**. 1-(6-Chloropyridin-3-yl)ethan-1-one was used. Purification by PTLC (hexane/EtOAc = 90:10) afforded **3u** as a white solid (26.6 mg, 40% yield). ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.98 (dd, *J* = 2.4, 0.8 Hz, 1H), 8.01 (dd, *J* = 8.4, 2.4 Hz, 1H), 7.25 (dd, *J* = 8.4, 0.8 Hz, 1H), 2.61 (s, 3H), 2.59 (s, 3H); ^{13}C{^{1}H} NMR (101 MHz, $CDCl_3$) δ 196.1, 166.0, 150.0, 134.7, 128.2, 121.1, 26.4, 13.2; HRMS (APCI) *m/z*: $[M+H]^+$ Calcd for $C_8H_{10}NOS$ 168.0478; Found 168.0479.



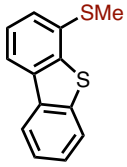
2-(Methylthio)quinoline (3v)

When 2-chloroquinoline or naphthalen-1-yl trifluoromethanesulfonate was used, compound **3v** was synthesized according to **GP-1**. Purification by PTLC (hexane/EtOAc = 90:10) afforded **3v** as a yellow liquid (X = Cl: 27.9 mg, 85% yield, CN: 4.3 mg, 14% yield). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.94 (d, *J* = 8.4 Hz, 1H), 7.85 (d, *J* = 8.4 Hz, 1H), 7.69 (dd, *J* = 8.4, 1.6 Hz, 1H), 7.63 (ddd, *J* = 8.4, 6.8, 1.6 Hz, 1H), 7.40 (ddd, *J* = 8.4, 6.8, 1.2 Hz, 1H), 7.21 (d, *J* =8.4 Hz, 1H), 2.70 (s, 3H); ^{13}C{^{1}H} NMR (101 MHz, $CDCl_3$) δ 159.8, 148.3, 135.1, 129.6, 127.9, 127.6, 125.8, 125.1, 120.6, 12.9; HRMS (APCI) *m/z*: $[M+H]^+$ Calcd for $C_{10}H_{10}NS$ 176.0528; Found 176.0528.



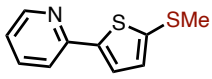
3-(Methylthio)quinoline (3w)

Compound **3w** was synthesized according to **GP-1**. 3-Bromoquinoline was used. Purification by PTLC (hexane/EtOAc = 90:10) afforded **3w** as a colorless liquid (34.1 mg, 93% yield). ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.80 (s, 1H), 8.06 (d, *J* = 8.4 Hz, 1H), 7.90 (s, 1H), 7.73 (d, *J* = 8.0 Hz, 1H), 7.67–7.61 (m, 1H), 7.56–7.50 (m, 1H), 2.61 (s, 3H); ^{13}C{^{1}H} NMR (101 MHz, $CDCl_3$) δ 149.8, 145.8, 132.6, 131.2, 129.2, 128.5, 128.2, 127.1, 126.6, 15.7; HRMS (APCI) *m/z*: $[M+H]^+$ Calcd for $C_{10}H_{10}NS$ 176.0528; Found 176.0528. The spectra are in accordance with those reported in the literature.[16]



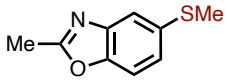
4-(Methylthio)dibenzo[*b*,*d*]thiophene (3x)

Compound **3x** was synthesized according to **GP-1**. 4-Chlorodibenzo[*b*,*d*]thiophene was used. Purification by PTLC (hexane/EtOAc = 90:10) afforded **3x** as a colorless liquid (57.5 mg, 74% yield). ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.11–8.04 (m, 1H), 7.96–7.91 (m 1H), 7.87–7.81 (m, 1H), 7.50–7.33 (m, 4H), 2.57 (s, 3H); ^{13}C{^{1}H} NMR (101 MHz, $CDCl_3$) δ 140.3, 139.3, 135.8, 135.6, 131.7, 126.8, 125.7, 125.1, 124.4, 122.8, 121.8, 119.2, 16.6; HRMS (APCI) *m/z*: $[M+H]^+$ Calcd for $C_{13}H_{11}S_2$ 231.0297; Found 231.0289. The spectra are in accordance with those reported in the literature.[12]



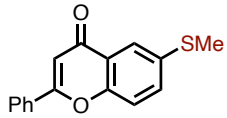
2-(5-(Methylthio)thiophen-2-yl)pyridine (3y)

Compound **3y** was synthesized according to **GP-1**. 2-(5-Bromothiophen-2-yl)pyridine was used. Purification by PTLC (hexane/EtOAc = 90:10) afforded **3y** as a yellow liquid (35.8 mg, 86% yield). ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.55–8.51 (m, 1H), 7.69–7.62 (m, 1H), 7.61–7.55 (m, 1H), 7.40 (d, *J* = 4.0 Hz, 1H), 7.15–7.10 (m, 1H), 7.02 (d, *J* = 4.0 Hz, 1H), 2.56 (s, 3H); ^{13}C{^{1}H} NMR (101 MHz, $CDCl_3$) δ 152.1, 149.5, 145.7, 140.3, 136.6, 130.2, 124.6, 121.8, 118.2, 21.2; HRMS (APCI) *m/z*: $[M+H]^+$ Calcd for $C_{10}H_{10}NS_2$ 208.0249; Found 208.0247.



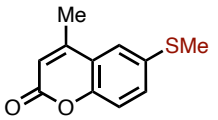
2-Methyl-5-(methylthio)benzo[*d*]oxazole (3z)

Compound **3z** was synthesized according to **GP-1**. 5-Chloro-2-methylbenzo[*d*]oxazole was used. Purification by PTLC (hexane/EtOAc = 90:10) afforded **3z** as a white solid (16.3 mg, 45% yield). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.57 (d, *J* = 2.0 Hz, 1H), 7.37 (d, *J* = 8.4 Hz, 1H), 7.25 (dd, *J* = 8.4, 2.0 Hz, 1H), 2.62 (s, 3H), 2.52 (s, 3H); ^{13}C{^{1}H} NMR (101 MHz, $CDCl_3$) δ 164.5, 149.3, 142.3, 133.8, 124.7, 118.3, 110.4, 17.5, 14.5; HRMS (APCI) *m/z*: $[M+H]^+$ Calcd for $C_9H_{10}NOS$ 180.0478; Found 180.0478.



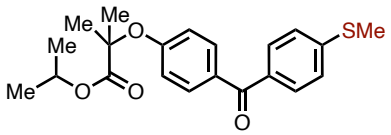
6-(Methylthio)-2-phenyl-4H-chromen-4-one (3A)

Compound **3A** was synthesized according to **GP-1**. Purification by PTLC (hexane/EtOAc = 90:10) afforded **3A** as a yellow solid (52.5 mg, 98% yield). ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.00 (d, *J* = 2.4 Hz, 1H), 7.97–7.89 (m, 2H), 7.61–7.47 (m, 5H), 6.84 (s, 1H), 2.58 (s, 3H); ^{13}C{^{1}H} NMR (101 MHz, $CDCl_3$) δ 177.5, 163.1, 153.9, 136.4, 132.4, 131.5, 128.9, 126.1, 124.2, 121.0, 118.4, 107.4, 15.8 (One peak is missing due to overlapping); HRMS (APCI) *m/z*: $[M+H]^+$ Calcd for $C_{16}H_{13}O_2S$ 269.0631; Found 269.0630.



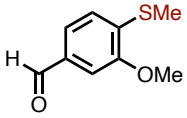
4-Methyl-6-(methylthio)-2*H*-chromen-2-one (3B)

Compound **3B** was synthesized according to **GP-1**. **1B** was used. Purification by PTLC (hexane/EtOAc = 90:10) afforded **3B** as a yellow solid (19.3 mg, 47% yield). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.48 (d, *J* = 2.4 Hz, 1H), 7.45 (dd, *J* = 8.4, 2.4 Hz, 1H), 7.27 (d, *J* = 8.4 Hz, 1H), 6.31 (d, *J* = 1.2 Hz, 1H), 2.53 (s, 3H), 2.44 (d, *J* = 1.2 Hz, 3H); ^{13}C{^{1}H} NMR (101 MHz, $CDCl_3$) δ 160.5, 151.7, 151.5, 134.2, 130.9, 123.0, 120.4, 117.6, 115.6, 18.6, 16.9; HRMS (APCI) *m/z*: $[M+H]^+$ Calcd for $C_{11}H_{11}O_2S$ 207.0474; Found 207.0475.



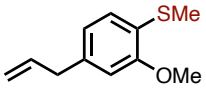
Isopropyl 2-methyl-2-(4-(4-(methylthio)benzoyl)phenoxy)propanoate (3C)

Compound **3C** was synthesized according to **GP-1**. Purification by PTLC (hexane/EtOAc = 90:10) afforded **3C** as a white solid (56.4 mg, 76% yield). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.73 (d, *J* = 8.8 Hz, 2H), 7.70 (d, *J* = 8.8 Hz, 2H), 7.29 (d, *J* = 8.4 Hz, 2H), 6.86 (d, *J* = 8.8 Hz, 2H), 5.14–5.04 (m, 1H), 2.54 (s, 3H), 1.66 (s, 6H), 1.21 (d, *J* = 6.4 Hz, 6H); ^{13}C{^{1}H} NMR (101 MHz, $CDCl_3$) δ 194.6, 173.2, 159.4, 144.6, 134.2, 131.8, 130.8, 130.4, 124.9, 117.2, 79.3, 69.3, 25.3, 21.5, 14.9; HRMS (APCI) *m/z*: $[M+H]^+$ Calcd for $C_{21}H_{25}O_4S$ 373.1468; Found 373.1470. The spectra are in accordance with those reported in the literature.[17]



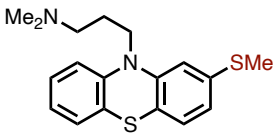
3-Methoxy-4-(methylthio)benzaldehyde (3D)

Compound **3D** was synthesized according to **GP-1**. **1D** was used. Purification by PTLC (hexane/EtOAc = 90:10) afforded **3D** as a yellow liquid (23.5 mg, 65% yield). ^{1}H NMR (400 MHz, $CDCl_3$) δ 9.91 (s, 1H), 7.45 (dd, *J* = 7.6, 1.6 Hz, 1H), 7.31 (d, *J* = 1.6 Hz, 1H), 7.22 (d, *J* = 7.6 Hz, 1H), 3.97 (s, 3H), 2.49 (s, 3H); ^{13}C{^{1}H} NMR (101 MHz, $CDCl_3$) δ 191.3, 155.8, 137.4, 133.8, 125.2, 123.6, 107.1, 56.0, 13.9; HRMS (APCI) *m/z*: $[M+H]^+$ Calcd for $C_9H_{11}O_2S$ 183.0474; Found 183.0474.



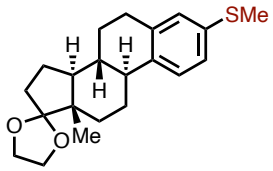
(4-Allyl-2-methoxyphenyl)(methyl)sulfane (3E)

Compound **3E** was synthesized according to **GP-1**. **1E** was used. Purification by PTLC (hexane/EtOAc = 90:10) afforded **3E** as a yellow liquid (37.3 mg, 96% yield). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.10 (d, *J* = 8.0 Hz, 1H), 6.78 (dd, *J* = 8.0, 1.6 Hz, 1H), 6.67 (d, *J* = 1.6 Hz, 1H), 6.01–5.89 (m, 1H), 5.13–5.04 (m, 2H), 3.88 (s, 3H), 3.36 (d, *J* = 6.8 Hz, 2H), 2.41 (s, 3H); ^{13}C{^{1}H} NMR (101 MHz, $CDCl_3$) δ 156.5, 138.5, 137.2, 126.8, 123.9, 121.2, 115.9, 110.6, 55.7, 40.0, 15.1; HRMS (APCI) *m/z*: $[M+H]^+$ Calcd for $C_{11}H_{15}OS$ 195.0838; Found 195.0838.



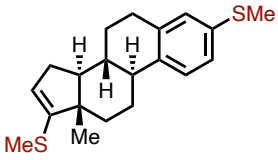
***N*,*N*-Dimethyl-3-(2-(methylthio)-10*H*-phenothiazin-10-yl)propan-1-amine (3F)**

Compound **3F** was synthesized according to **GP-1**. Purification by PTLC (chloroform/methanol = 90:10) afforded **3F** as a brown liquid (53.3 mg, 81% yield). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.17–7.10 (m 2H), 7.04 (d, *J* = 8.4 Hz, 1H), 6.95–6.84 (m, 2H), 6.84–6.79 (m, 2H), 3.90 (t, *J* = 7.2 Hz, 2H), 2.46 (s, 3H), 2.40 (t, *J* = 7.2 Hz, 2H), 2.21 (s, 6H), 1.99–1.89 (m, 2H); ^{13}C{^{1}H} NMR (101 MHz, $CDCl_3$) δ 145.7, 144.9, 137.4, 127.5, 127.4, 127.2, 125.1, 122.5, 122.1, 120.7, 115.7, 114.6, 57.1, 45.5, 45.3, 25.1, 16.4; HRMS (APCI) *m/z*: $[M+H]^+$ Calcd for $C_{18}H_{23}N_2S_2$ 331.1297; Found 331.1294.



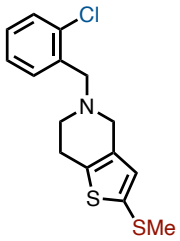
(8*R*,9*S*,13*S*,14*S*)-13-methyl-3-(methylthio)-6,7,8,9,11,12,13,14,15,16-decahydrospiro[cyclopent-a[*a*]phenanthrene-17,2'-[1,3]dioxolane] (3G)

Compound **3G** was synthesized according to **GP-1**. Purification by PTLC (hexane/EtOAc = 90:10) afforded **3G** as a white solid (49.5 mg, 72% yield). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.22 (d, *J* = 8.0 Hz, 1H), 7.06 (dd, *J* = 8.0, 2.0 Hz, 1H), 7.01–6.99 (m, 1H), 3.99–3.85 (m, 4H), 2.88–2.78 (m, 2H), 2.46 (s, 3H), 2.36–2.20 (m, 2H), 2.08–1.98 (m, 1H), 1.94–1.71 (m, 4H), 1.68–1.23 (m, 6H); ^{13}C{^{1}H} NMR (101 MHz, $CDCl_3$) δ 137.7, 137.5, 134.9, 127.5, 125.9, 124.5, 119.4, 65.2, 64.6, 49.4, 46.1, 43.8, 38.8, 34.2, 30.7, 29.5, 26.8, 25.9, 22.3, 16.3, 14.3; HRMS (APCI) *m/z*: $[M+H]^+$ Calcd for $C_{21}H_{29}O_2S$ 345.1883; Found 345.1881.



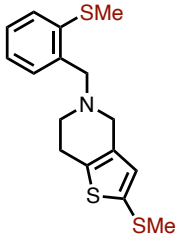
((8R,9S,13S,14S)-13-Methyl-7,8,9,11,12,13,14,15-octahydro-6H-cyclopenta[a]phenanthrene-3,17-diyl)bis(methylsulfane) (3H)

Compound **3H** was synthesized according to **GP-1**. **1** (3.0 equiv) was used. Purification by PTLC (hexane/EtOAc = 80:20) afforded **3H** as a colorless liquid (46.3 mg, 70% yield). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.20 (d, *J* = 8.0 Hz, 1H), 7.06 (dd, *J* = 8.0, 2.0 Hz,1H), 7.02–6.99 (m, 1H), 5.19–5.15 (m, 1H), 2.91–2.84 (m, 2H), 2.46 (s, 3H), 2.40–2.23 (m, 3H), 2.27 (s, 3H), 2.07–1.98 (m, 1H), 1.96–1.87 (m, 2H), 1.73–1.54 (m, 4H), 1.49–1.37 (m, 1H), 0.91 (s, 3H); ^{13}C{^{1}H} NMR (101 MHz, $CDCl_3$) δ 151.6, 137.8, 137.3, 134.9, 127.5, 125.6, 124.4, 116.9, 56.3, 48.4, 44.4, 37.1, 34.2, 31.3, 29.3, 27.5, 26.2, 16.5, 16.2, 14.2; HRMS (APCI) *m/z*: $[M]^+$ Calcd for $C_{20}H_{26}S_2$ 330.1470; Found 331.1499.



5-(2-Chlorobenzyl)-2-(methylthio)-4,5,6,7-tetrahydrothieno[3,2-*c*]pyridine (3I)

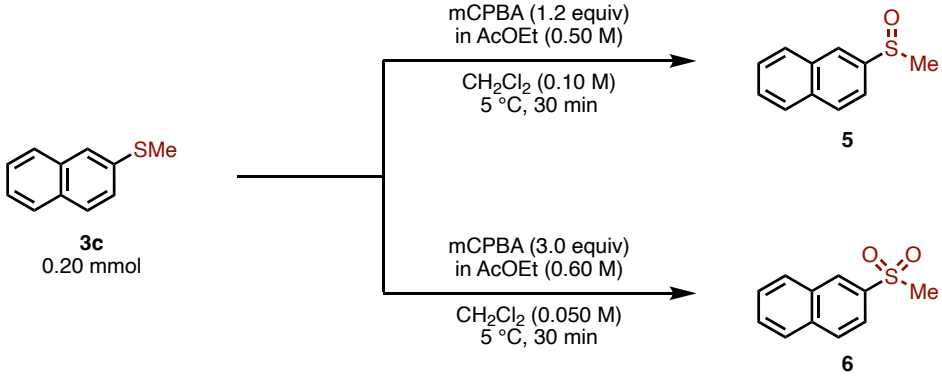
Compound **3I** was synthesized according to **GP-1**. **1** (3.0 equiv) was used. Purification by PTLC (hexane/EtOAc = 90:10) afforded **3I** as a yellow liquid (46.1 mg, 74% yield). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.52 (dd, *J* = 7.6, 2.0 Hz, 1H), 7.36 (dd, *J* = 7.6, 1.6 Hz, 1H),7.27–7.16 (m, 2H), 6.71 (s, 1H), 3.80 (s, 2H), 3.55 (s, 2H), 2.86–2.83 (m, 4H), 2.43 (s, 3H); ^{13}C{^{1}H} NMR (101 MHz, $CDCl_3$) δ 136.7, 135.9, 134.25, 134.20, 134.0, 130.6, 130.1, 129.4, 128.2, 126.7, 58.4, 52.7, 50.5, 25.7, 22.6; HRMS (APCI) *m/z*: $[M+H]^+$ Calcd for $C_{15}H_{17}ClNS_2$ 310.0485; Found 310.0484.



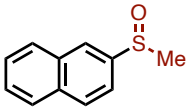
2-(Methylthio)-5-(2-(methylthio)benzyl)-4,5,6,7-tetrahydrothieno[3,2-*c*]pyridine (3J)

Compound **3J** was synthesized according to **GP-1**. **1** (3.0 equiv) was used. The reaction was carried out for 24 hours. Purification by PTLC (hexane/EtOAc = 90:10) afforded **3J** as a yellow liquid (32.3 mg, 52% yield). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.37 (d, *J* = 8.4 Hz, 1H), 7.31–7.21 (m, 2H), 7.16–7.09 (m, 1H), 6.70 (s, 1H), 3.73 (s, 2H), 3.52 (s, 2H), 2.90–2.78 (m, 4H), 2.45 (s, 3H), 2.41 (s, 3H); ^{13}C{^{1}H} NMR (101 MHz, $CDCl_3$) δ 138.7, 136.8, 136.3, 134.4, 133.7, 130.2, 129.4, 127.7, 125.4, 124.5, 59.5, 52.5, 50.2, 25.7, 22.6, 15.9; HRMS (APCI) *m/z*: $[M+H]^+$ Calcd for $C_{16}H_{20}NS_3$ 322.0752; Found 322.0752.

5. Oxidation of Aryl Methyl Sulfides

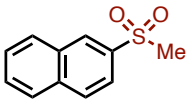


5 and **6** were synthesized according to procedures reported in the literature.[23] To a 20-mL glass vessel containing a magnetic stirring bar and methyl(naphthalen-2-yl)sulfane **3c** (0.20 mmol, 1.0 equiv) in CH_2Cl_2 (10 mL) were added a solution of m-CPBA (0.24 mmol or 0.60 mmol) in EtOAc (2.0 mL) in dropwise. Stirring the mixture for 30 minutes at 5 °C. The reaction mixture was added saturated $NaHCO_3$ aq. and extracted three times with CH_2Cl_2. The combined organic layer was dried over Na_2SO_4, filtered, and then concentrated *in vacuo* to give sulfoxide **5** or sulfone **6**.



2-(Methylsulfinyl)naphthalene (5)

Purification by PTLC (hexane/EtOAc = 50:50) afforded **5** as a white solid (34.7 mg, 84% yield). ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.22 (s, 1H), 7.99 (d, J = 8.4 Hz, 1H), 7.96–7.88 (m, 2H), 7.63–7.56 (m, 3H), 2.79 (s, 3H); $^{13}C\{^1H\}$ NMR (101 MHz, $CDCl_3$) δ 142.7, 134.3, 132.8, 129.5, 128.4, 128.0, 127.7, 127.3, 124.0, 119.4, 43.7; HRMS (APCI) *m/z*: $[M+H]^+$ Calcd for $C_{11}H_{11}OS$ 191.0525; Found 191.0530. The spectra are in accordance with those reported in the literature.[24]

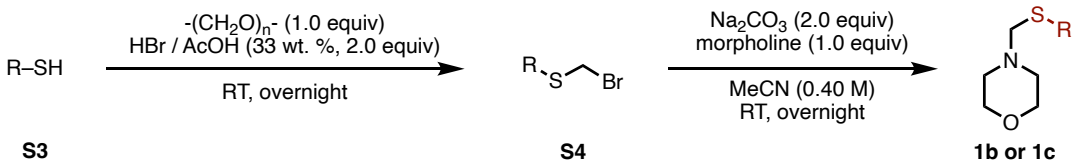


(*S*)-2-(Methylsulfinyl)naphthalene (6)

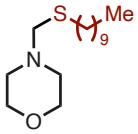
Purification by PTLC (hexane/EtOAc = 50:50) afforded **6** as a white solid (37.5.6 mg, 91% yield). ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.53 (s, 1H), 8.10–7.98 (m, 2H), 7.98–7.88 (m, 2H), 7.77–7.61 (m, 2H), 3.13 (s, 3H); $^{13}C\{^1H\}$ NMR (101 MHz, $CDCl_3$) δ 137.3, 135.2, 132.1, 129.7, 129.3, 129.2, 129.0, 127.9, 127.7, 122.1, 44.5; HRMS (APCI) *m/z*: $[M+H]^+$ Calcd for $C_{11}H_{11}O_2S$ 207.0474; Found 207.0474. The spectra are in accordance with those reported in the literature.[25]

6. Synthesis and Reaction of Thioalkyl/arylating Agents

6-1. Preparation of 4-((Alkyl/Arylthio)methyl)morpholines 1b–1d[18][19]

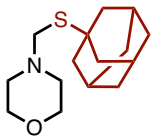


S4 was synthesized according to procedure reported in the literature.[18] To a 20-mL glass vessel containing a magnetic stirring bar and thiol **S3** (2.0 mmol, 1.0 equiv) were added paraformaldehyde (2.0 mmol, 1.0 equiv) and a hydrogen bromide solution 33 wt. % in AcOH (4.0 mmol, 2.0 equiv) in one portion. The reaction mixture was stirred at room temperature while the reaction progress was being monitored the reaction progress by TLC. The reaction mixture was added saturated $NaHCO_3$ aq. and extracted three times with EtOAc. The combined organic layer was dried over Na_2SO_4, filtered, and then concentrated *in vacuo* (**S3** to **S4**). **S4** was added to a round-bottom flask containing a magnetic stirring bar, sodium carbonate (4.0 mmol, 2.0 equiv) and morpholine (2.0 mmol, 1.0 equiv) in MeCN (5.0 mL, 0.40 M). After stirring the mixture at room temperature while the reaction progress was being monitored the reaction progress by TLC. The solution was added saturated $NaHCO_3$ aq. and extracted three times with EtOAc. The combined organic layer was dried over Na_2SO_4, and then filtered. The filtrate was concentrated *in vacuo* and the residue was purified by Isolera® to provide **1b** or **1c**.



4-((Decylthio)methyl)morpholine (1b)

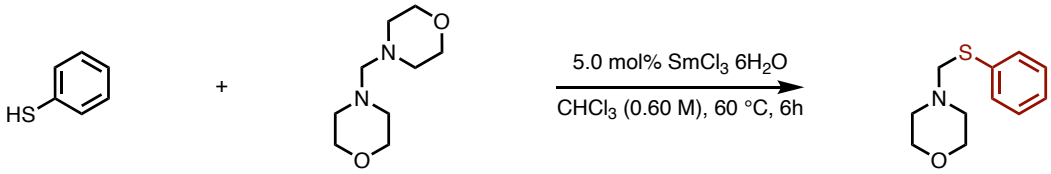
The reaction was conducted on a 2.0 mmol scale. Purification by Isolera® (hexane/EtOAc = 95:5 to 50:50) afforded **1b** as a colorless liquid (102.2 mg, 0.32 mmol, 19% yield). ^{1}H NMR (400 MHz, $CDCl_3$) δ 3.87 (s, 2H), 3.78–3.68 (m, 4H), 2.66–2.54 (m, 6H), 1.65–1.54 (m, 2H), 1.43–1.33 (m, 2H), 1.33–1.16 (m, 12H), 0.88 (t, J = 6.4 Hz, 3H); ^{13}C{^{1}H} NMR (101 MHz, $CDCl_3$) δ 66.6, 62.9, 50.9, 33.2, 31.7, 30.1, 29.41, 29.38, 29.2, 29.1, 28.7, 22.5, 14.0; HRMS (APCI) *m/z*: $[M+H]^+$ Calcd for $C_{15}H_{32}NOS$ 274.2199; Found 274.2199.



4-((((3*s*,5*s*,7*s*)-Adamantan-1-yl)thio)methyl)morpholine (1c)

The reaction was conducted on a 2.0 mmol scale. Purification by Isolera® (hexane/EtOAc = 95:5 to 50:50) afforded **2c** as a white solid (154.2 mg, 0.59 mmol, 30% yield). ^{1}H NMR (400 MHz, $CDCl_3$) δ 3.86 (s, 2H), 3.74–3.66 (m, 4H), 2.63–2.53 (m, 4H), 2.03 (brs, 3H), 1.90 (d, J = 2.4Hz, 6H), 1.69 (s,

6H); $^{13}C\{^{1}H\}$ NMR (101 MHz, $CDCl_3$) δ 66.9, 56.5, 51.4, 44.6, 44.0, 36.3, 29.8; HRMS (APCI) *m/z*: $[M+H]^+$ Calcd for $C_{15}H_{26}NOS$ 268.1730 ;Found 268.1730.



S5
3.0 mmol

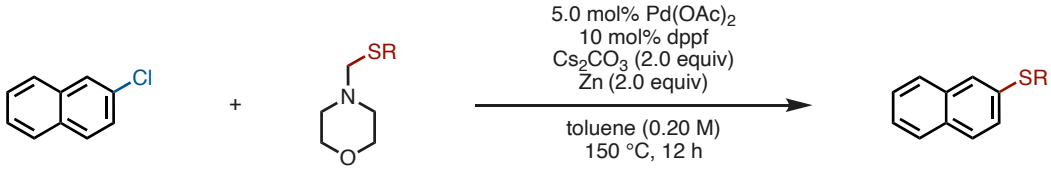
S6
(1.2 equiv)

1d

4-((Phenylthio)methyl)morpholine **(1d)** was synthesized according to procedures reported in the literature.[19] To a round-bottom flask containing a magnetic stirring bar and samarium(III) chloride hexahydrate ($SmCl_3 \cdot 6H_2O$, 40.6 mg, 0.15 mmol, 5 mol%) in $CHCl_3$ (5 mL, 0.60 M) were added dimorpholinomethane **S6** (0.33 mL, 3.6 mmol, 1.2 equiv), thiophenol (**S5**: 0.31 mL, 3.0 mmol, 1.0 equiv). After stirring the mixture at 60 °C for 6 hours, the reaction was quenched with water. The mixture was extracted three times with CH_2Cl_2. The combined organic layer was dried over Na_2SO_4, and then filtered. The filtrate was concentrated *in vacuo* and the residue was purified by Isolera® (hexane/EtOAc = 95:5 to 70:30) to afford **1d** as a yellow liquid (188.0 mg, 30% yield).

Compound **1d**: ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.54–7.46 (m, 2H), 7.36–7.25 (m, 2H), 7.24–7.17 (m, 1H), 4.42 (s, 2H), 3.75–3.63 (m, 4H), 2.70–2.57 (m, 4H); $^{13}C\{^{1}H\}$ NMR (101 MHz, $CDCl_3$) δ 137.5, 131.4, 128.8, 126.4, 67.0, 66.5, 50.5; HRMS (APCI) *m/z*: $[M+H]^+$ Calcd for $C_{11}H_{16}NOS$ 210.0947; Found 210.0949.

6-2. Coupling between haloarene and 1b–1d

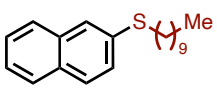


Cl-2c
0.20 mmol

1b–d
(1.5 equiv)

7–9

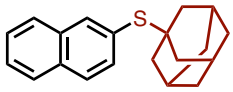
The reactions were carried out according to the method written in **4-2**. Thioalkyl/arylating agents **1b–1d** was used instead of **1**.



Decyl(naphthalen-2-yl)sulfane (7)

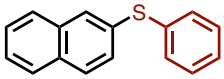
Purification by PTLC (hexane/EtOAc = 90:10) afforded **7** as a yellow liquid (46.1 mg, 77% yield). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.77 (d, J = 8.0 Hz, 1H), 7.75–7.70 (m, 3H), 7.50–7.37 (m, 3H), 3.01 (t, J = 7.2Hz, 2H), 1.75–1.64 (m, 2H), 1.50–1.39 (m, 2H), 1.36–1.18 (m, 12H), 0.87 (t, J = 6.8 Hz, 3H);

$^{13}C\{^{1}H\}$ NMR (101 MHz, $CDCl_3$) δ 134.6, 133.8, 131.5, 128.2, 127.7, 127.1, 126.9, 126.4, 126.2, 125.4, 33.4, 31.9, 29.51, 29.48, 29.3, 29.1, 29.0, 28.9, 22.7, 14.1; HRMS (APCI) *m/z*: $[M+H]^+$ Calcd for $C_{20}H_{29}S$ 301.1984; Found 301.1985.



Adamantan-1-yl(naphthalen-2-yl)sulfane (8)

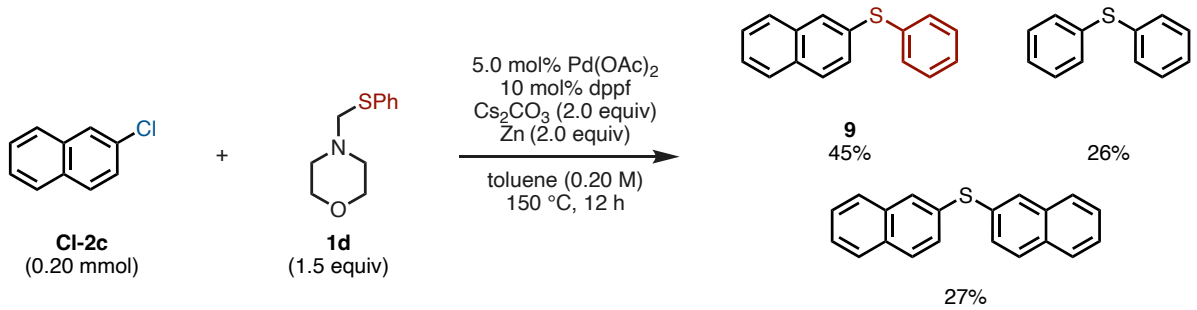
Purification by PTLC (hexane/EtOAc = 90:10) afforded **8** as a white solid (50.3 mg, 85% yield). ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.04 (s, 1H), 7.89–7.80 (m, 2H), 7.76 (d, *J* = 8.4 Hz, 1H), 7.56 (d, *J* = 8.4 Hz, 1H), 7.53–7.44 (m, 2H), 2.00 (s, 3H), 1.87 (s, 6H), 1.72–1.54 (m, 6H); $^{13}C\{^{1}H\}$ NMR (101 MHz, $CDCl_3$) δ 137.2, 134.6, 133.2, 133.0, 128.0, 127.9, 127.6, 127.5, 126.5, 126.2, 48.3, 43.7 36.1, 29.9; HRMS (APCI) *m/z*: $[M+H]^+$ Calcd for $C_{20}H_{23}S$ 295.1515; Found 295.1505. The spectra are in accordance with those reported in the literature.[20]



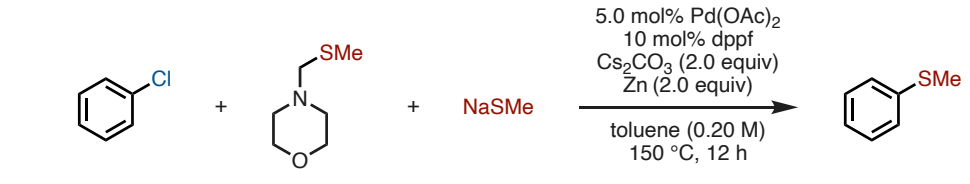
Naphthalen-2-yl(phenyl)sulfane (9)

Purification by PTLC (hexane/EtOAc = 90:10) afforded **9** as a white solid (39.2 mg, 83% yield). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.83 (d, *J* = 2.0 Hz, 1H), 7.81–7.69 (m, 3H), 7.49–7.42 (m, 2H), 7.42–7.34 (m, 3H), 7.34–7.22 (m, 3H); $^{13}C\{^{1}H\}$ NMR (101 MHz, $CDCl_3$) δ 135.8, 133.8, 133.0, 132.3, 130.9, 129.9, 129.2, 128.8, 128.7, 127.7, 127.4, 127.0, 126.6, 126.2; HRMS (APCI) *m/z*: $[M+H]^+$ Calcd for $C_{16}H_{13}S$ 237.0732; Found 237.0728. The spectra are in accordance with those reported in the literature.[21]

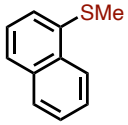
In the thiophenylation of **Cl-2c**, some by-products in which aryl exchange proceeded was obtained.[22]



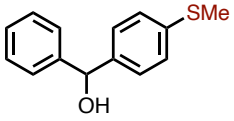
7. Mechanistic Investigations



Cl-2a or **2s** 0.20 mmol | **1** (1.5 equiv) | **S7** (5.8 equiv) | **3**

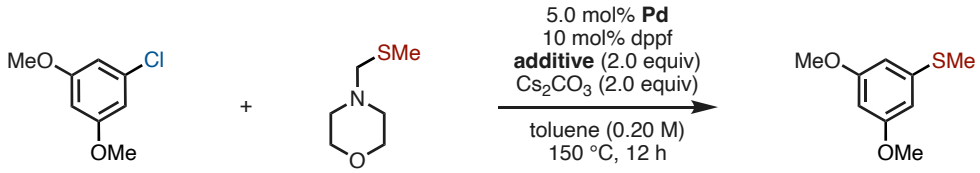


yield of **3a**	condition	yield of **3s**
6%	–	22%
96%	without **S7**	59%



A 20-mL glass vessel equipped with J. Young® O-ring tap containing a magnetic stirring bar and Cs_2CO_3 (130.3 mg, 0.40 mmol, 2.0 equiv) was dried with a heat gun *in vacuo* and filled with N_2 gas after cooling to room temperature. To this vessel were added chloroarene **Cl-2a** or **2s** (0.20 mmol, 1.0 equiv), sodium methanethiolate (**S7**: 81.6 mg, 1.2 mmol, 5.8 equiv), 4-((methylthio)methyl)morpholine (**1**: 44.1 mg, 0.30 mmol, 1.5 equiv), $Pd(OAc)_2$ (2.3 mg, 0.010 mmol, 5.0 mol%), dppf (0.020 mmol, 10 mol%), and zinc (26.2 mg, 0.40 mmol, 2.0 equiv). The vessel was placed under vacuum and refilled three times with N_2 gas. To this was added toluene (1.0 mL). The vessel was sealed with the O-ring tap and then heated at 150 °C for 12 hours in a nine-well aluminum reaction block with stirring. After the reaction mixture had been cooled to room temperature, the mixture was passed through a pad of silica-gel with EtOAc as an eluent. The filtrate was concentrated *in vacuo*, and the residue was purified by PTLC to afford the corresponding aryl methyl sulfide **3**. Although sodium methanethiolate was highly hygroscopic, yield of **3a** was 45% with H_2O (50 μL) instead of sodium methanethiolate, which was enough for the possible water content.

7-1. Effect of zinc

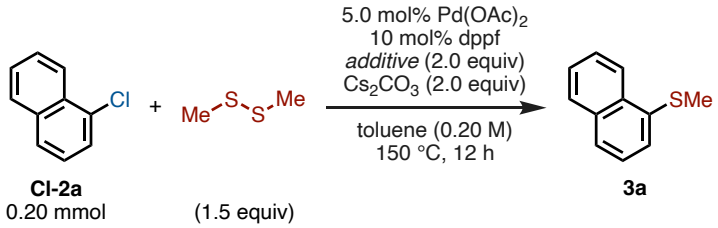


2m 0.20 mmol | **1** (1.5 equiv) | **3m**

entry	Pd	additive	recovery yield of **2m**/ %	yield of **3m**/ %
1	$Pd(OAc)_2$	–	75	5
2	$Pd(OAc)_2$	Zn (2.0 equiv)	trace	98
3	$Pd(dba)_2$	–	46	45
4	$Pd(dba)_2$	Zn (2.0 equiv)	10	90

Yields were determined by ^1H NMR using CH_2Br_2 as an internal standard.

The reactions were carried out according to the method **GP-1**. As results above, zinc works as reduction of compounds generated in the reaction besides reduction of $Pd(OAc)_2$ (entries 3and 4).



Cl-2a
0.20 mmol

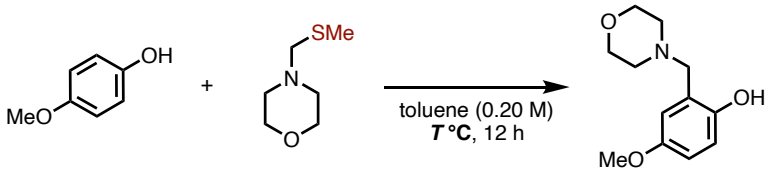
(1.5 equiv)

3a

entry	additive	yield of **3a**/ %
1	Zn (2.0 equiv)	0
2	–	60

The reactions were carried out according to the method **GP-1**. On each reaction, dimethyl disulfide was used as thiolating agent instead of **1**. Purification by PTLC (hexane/EtOAc = 90:10) afford **3a**. The spectra are of **3a** matched with those reported in chapter 4.

7-2. Investigation of the generation of SMe anion



S8
0.20 mmol

1
(1.0 equiv)

4

entry	*T* /°C	**1**/ %	**4**/ %
1	150	0	92
2	120	22	45
3	80	86	29
4	50	<100	8
5	RT	<100	5

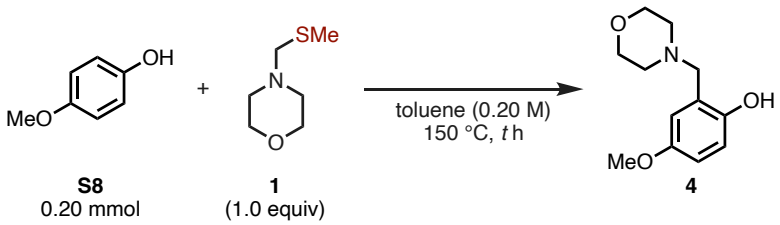
Yields were determined by ^{1}H NMR using CH_2Br_2 as an internal standard.

A 20-mL glass vessel equipped with J. Young® O-ring tap containing a magnetic stirring bar filled with N_2 gas. To this vessel were added 4-methoxyphenol (**S8**, 0.20 mmol, 1.0 equiv) in toluene (0.20 M) and 4-((methylthio)methyl)morpholine (**1**: 0.20 mmol, 1.0 equiv). The vessel was sealed with the O-ring tap and then heated for 12 hours in a nine-well aluminum reaction block with stirring. After the reaction mixture had been cooled to room temperature, the mixture was concentrated *in vacuo*, and yields of **1** and **4** were determined by ^{1}H NMR using CH_2Br_2 as an internal standard.

Compound **4**: ^{1}H NMR (400 MHz, $CDCl_3$) δ 6.78–6.71 (m, 2H), 6.58–6.55 (m, 1H), 3.79–3.71 (m, 7H), 3.66 (brs, 4H); $^{13}C\{^1H\}$ NMR (101 MHz, $CDCl_3$) δ 152.6, 151.2, 121.3, 116.4, 114.6, 113.7, 66.7, 61.9, 55.7, 52.9; HRMS (APCI) *m/z*: $[M+H]^+$ Calcd for $C_{12}H_{18}NO_3$ 224.1281；Found 224.1282.

7-3. Time-course monitoring of the formation of 4

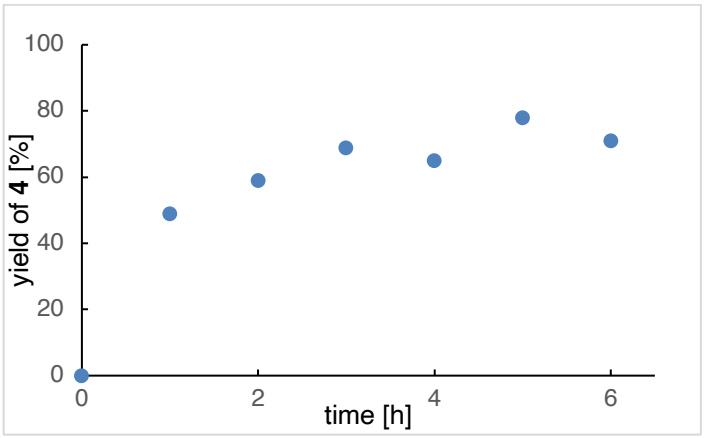
In the experimental procedure described in Section 7.2, the reaction was conducted at 0, 1, 2, 3, 4, 5, and 6 h. To account for experimental variability, each reaction was performed four times, and the average yield at each time point was plotted.



S8
0.20 mmol

1
(1.0 equiv)

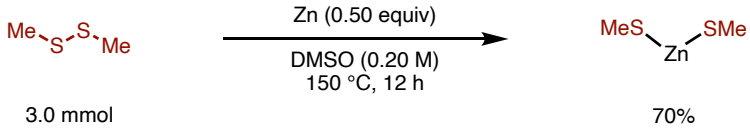
4



time [*t*/ h]	yield of **4**/ %	yield of **4**/ %	yield of **4**/ %	yield of **4**/ %
0	0	0	no data	no data
1	under analysis	49	no data	48
2	48	46	74	66
3	66	74	72	63
4	83	52	65	60
5	73	76	no data	84
6	59	85	68	71

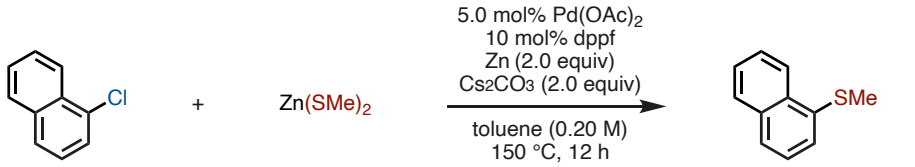
Yields were determined by ^{1}H NMR using CH_2Br_2 as an internal standard.

7-4. Preparation of $Zn(SMe)_2$ and its application in methylthiolation



3.0 mmol　　70%

Dimethyl disulfide (260 µL, 3.0 mmol, 1.0 equiv) and zinc powder (102.5 mg, 1.5 mmol, 0.5 equiv) were stirred in DMSO (0.20 M) at 150 °C for 12 hours. After completion of the reaction, the mixture was filtered, and the resulting solid was washed with ethyl acetate to afford white solid $Zn(SMe)_2$ in 70% yield (168.2 mg, 1.05 mmol). Anal. Calcd for $C_2H_6S_2Zn$: C, 15.05; H, 3.79; S, 40.18. Found: C, 15.00; H, 3.60; S, 37.95.

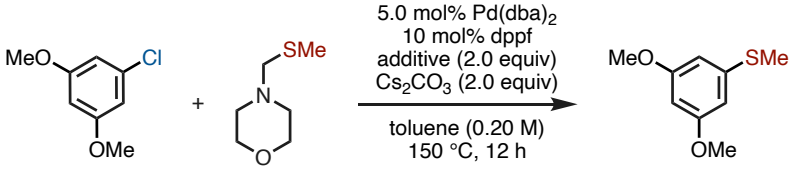


Cl-2a
0.20 mmol　　(0.75 equiv)　　**3a**
80%
recovery of **Cl-2a**: 12%

A 20-mL glass vessel equipped with J. Young® O-ring tap containing a magnetic stirring bar and Cs_2CO_3 (131.0 mg, 0.40 mmol, 2.0 equiv) was dried with a heat gun *in vacuo* and filled with N_2 gas after cooling to room temperature. To this vessel were added haloarene or **Cl-2a** (32.9 mg, 0.20 mmol, 1.0 equiv), $Zn(SMe)_2$ (24.3 mg, 0.15 mmol, 0.75 equiv), $Pd(OAc)_2$ (2.2 mg, 0.010 mmol, 5.0 mol%), dppf (11.4 mg, 0.020 mmol, 10 mol%) and zinc (26.3 mg, 0.40 mmol, 2.0 equiv). The vessel was placed under vacuum and refilled three times with N_2 gas. To this was added toluene (1.0 mL). The vessel was sealed

with the O-ring tap and then heated at 150 °C for 12 hours in a nine-well aluminum reaction block with stirring. After the reaction mixture had been cooled to room temperature, the mixture was passed through a pad of silica-gel with EtOAc as an eluent. The filtrate was concentrated *in vacuo*, and the residue was purified by PTLC to afford t **3a** (80% yield) and recovery of **Cl-2a** (12% yield).

7-5. Effect of Zn, Mn, and Mg using a Pd(0) catalyst

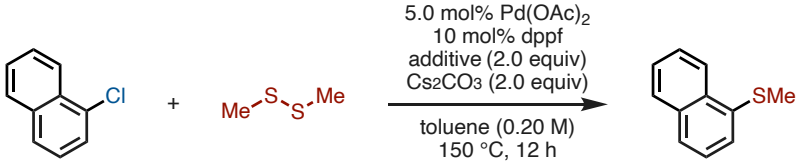


Cl-2m 0.20 mmol — **1** (1.5 equiv) — **3m**

entry	additive	recovery of **Cl-2m**/ %	yield of **3m**/ %
1	–	46	45
2	Zn	10	90
3	Mg (powder)	55	40
4	Mn	51	41

Yields were determined by ^{1}H NMR using CH_2Br_2 as an internal standard.

7-6. Effect of Zn, Mn, and Mg using $(SMe)_2$ as a methylthiolation agent

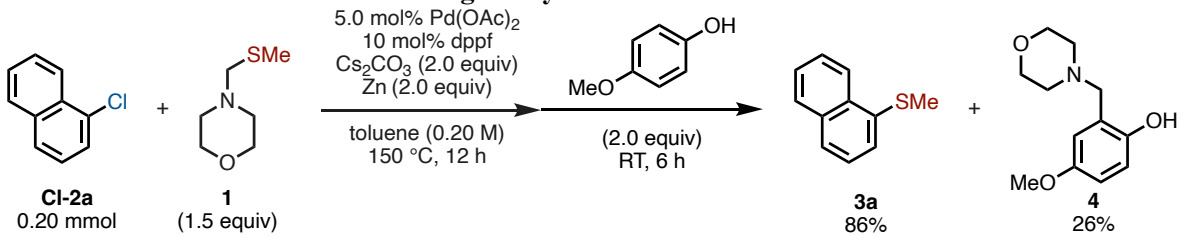


Cl-2a 0.20 mmol — (0.75 equiv) — **3a**

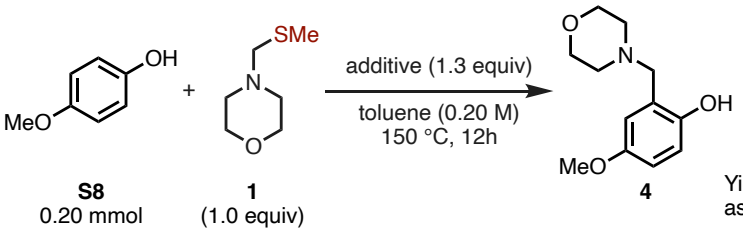
entry	additive	recovery of **Cl-2a**/ %	yield of **3a**/ %
1	–	79	0
2	Zn	28	89(60)
3	Mg	74	0
4	Mn	75	0

Yields were determined by ^{1}H NMR using CH_2Br_2 as an internal standard.

7-7. The fate of the iminium ion during catalysis



Cl-2a 0.20 mmol — **1** (1.5 equiv) — **3a** 86% — **4** 26%



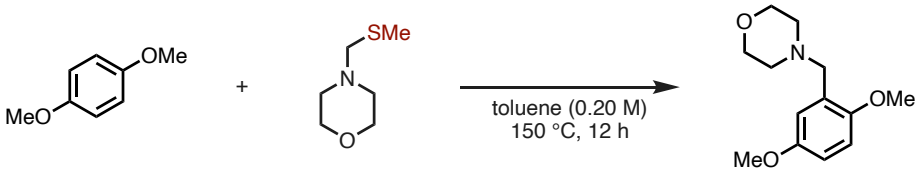
S8
0.20 mmol

1
(1.0 equiv)

4

entry	additive	yield of **4** /%
1	–	92
2	Zn	84
3	Cs_2CO_3	10

Yields were determined by ^{1}H NMR using CH_2Br_2 as an internal standard.



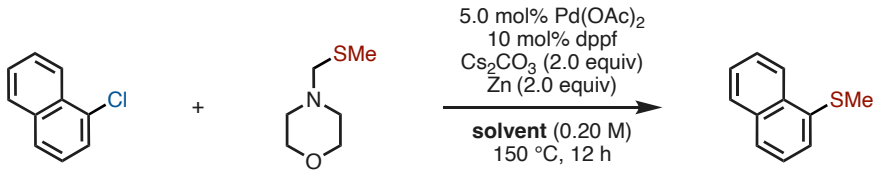
0.20 mmol

1
(1.0 equiv)

0%
recovery of **1**: 85%

8. Effect of Parameters

Effect of solvent



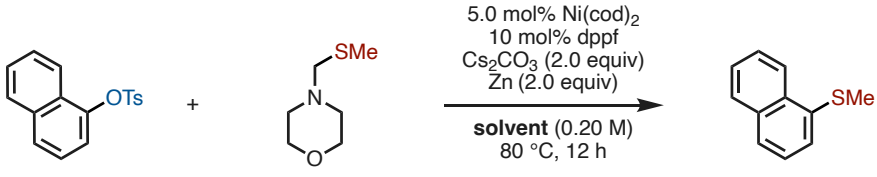
Cl-2a
0.20 mmol

1
(2.0 equiv)

Cl-3a

entry	solvent	recovery of **Cl-2a**/ %	yield of **1**/ %	yield of **Cl-3a**/ %
1	toluene	2	2	96[a]
2	Et_2O	14	3	84
3	^{t}butanol	15	0	77
4	2-methyl-2-butanol	24	0	66
5	MeCN	25	2	65
6	THF	33	7	62
7	DCM	68	0	0

Yields were determined by ^{1}H NMR using CH_2Br_2 as an internal standard. [a] Isolated yield.



OTs-2a
0.20 mmol

1
(1.5 equiv)

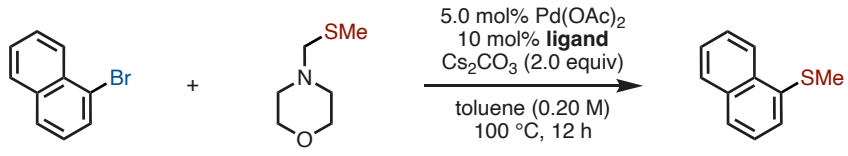
3a

entry	solvent	recovery of **OTs-2a**/ %	yield of **1**/ %	yield of **3a**/ %
1[a]	toluene	6	trace	24
2[a]	dioxane	0	trace	31
3	Et_2O	56	14	43
4	THF	87	53	13
5	MeCN	67	17	7
6	2-methyl-2-butanol	52	9	3
7	toluene	79	4	trace
8	MeOH	0	4	0

Yields were determined by ^{1}H NMR using CH_2Br_2 as an internal standard. A number in parentheses is isolated yield. [a] 150 °C.

Effect of ligand

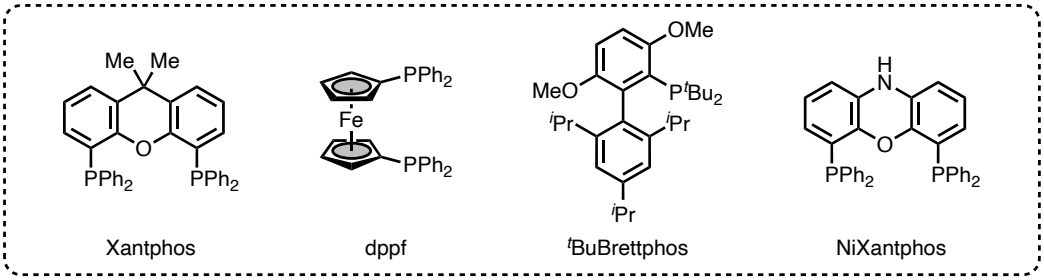
The screening using 1-bromonaphthalene was conducted at 100 °C.



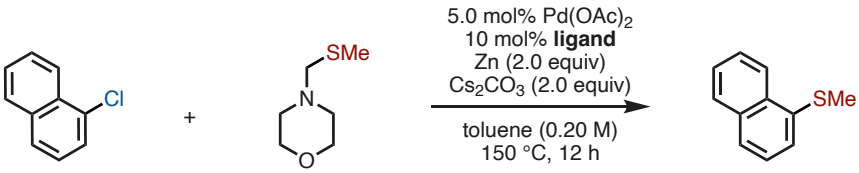
Br-2a 0.20 mmol | **1** (1.5 equiv) | **3a**

entry	ligand	recovery of **Br-2a**/ %	yield of **1**/ %	yield of **3a**/ %
1	Xantphos	64	24	36[a]
2	dppf	80	37	22
3[b]	PPh_3	98	33	0
4[b]	^{t}BuBrettphos	94	51	0
5[b]	PCy_3	96	38	3
6	NiXantphos	93	57	4
7	BINAP	62	14	4
8	dppb	93	62	2

Yields were determined by ^{1}H NMR using CH_2Br_2 as an internal standard.
[a]Isoleted yield. [b]20 mol% ligand.



In the screening using 1-chloronaphthalene, both of dppp and dppf were suitable for conditions. However, we selected dppf as the optimal ligand due to a practical consideration: the 1H NMR signals of dppp overlap significantly with the methylthio product, making accurate yield determination difficult.

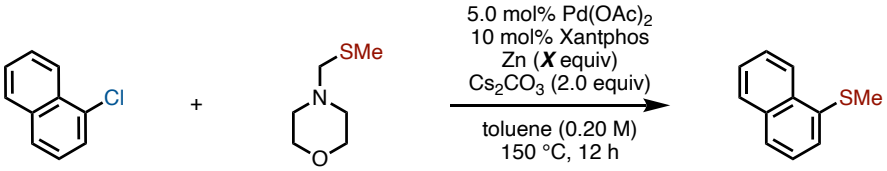


Cl-2a 0.20 mmol | **1** (1.5 equiv) | **3a**

entry	ligand	recovery of **Ci-2a**/ %	yield of **1**/ %	yield of **3a**/ %
1	–	91	2	trace
2	Xantphos	44	24	50[a]
3	dppf	2	trace	96[a]
4	dppp	3	3	97[a]
5	BINAP	13	20	65
6	dppe	68	29	10

Yields were determined by ^{1}H NMR using CH_2Br_2 as an internalstandard. [a] Isolated yield.

Effect of equivalent of zinc

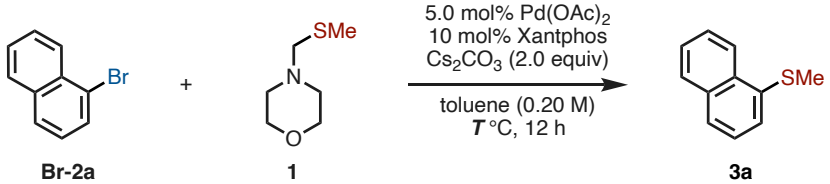


Cl-2a 0.20 mmol + **1** (1.5 equiv) → **3a**

entry	*X*/ equiv	recovery of **Cl-2a**/ %	yield of **1**/ %	yield of **3a**/ %
1	–	73	18	trace
2	0.50	90	41	4
3	1.0	90	33	10
4	2.0	44	24	50[a]
5	2.5	80	19	6

Yields were determined by ^{1}H NMR using CH_2Br_2 as an internal standard.
[a] Isolated yield.

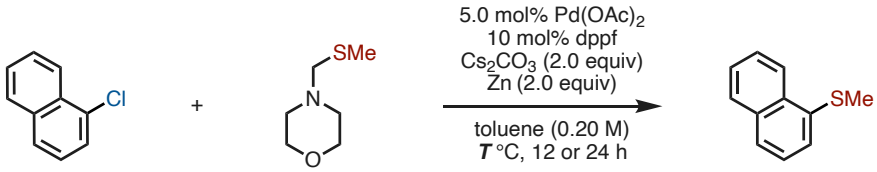
Effect of temperature



Br-2a 0.20 mmol + **1** (1.5 equiv) → **3a**

entry	*T*/ °C	recovery of **Br-2a**/ %	yield of **1**/ %	yield of **3a**/ %
1	100	54	22	46
2	110	25	5	75
3	120	0	trace	98
4	130	0	trace	96

Yields were determined by ^{1}H NMR using CH_2Br_2 as an internal standard.

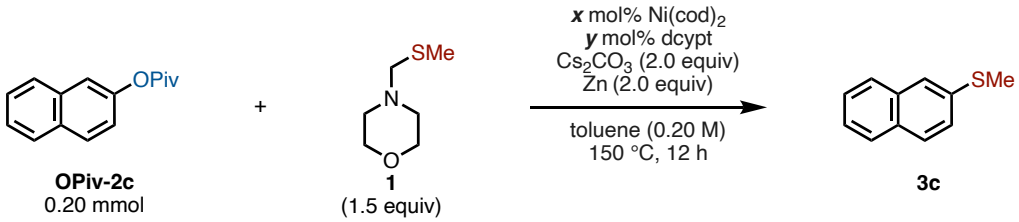


Cl-2a 0.20 mmol + **1** (2.0 equiv) → **3a**

entry	*T*/ °C	time/ h	recovery of **Cl-2a**/ %	yield of **1**/ %	yield of **3a**/ %
1	150	12	trace	trace	96[a]
2	140	12	trace	9	94
3	140	24	15	trace	91
4	120	24	54	trace	32
5	100	24	71	34	14

Yields were determined by ^{1}H NMR using CH_2Br_2 as an internal standard. [a] Isolated tield.

Effect of amount of catalysts



OPiv-2c
0.20 mmol

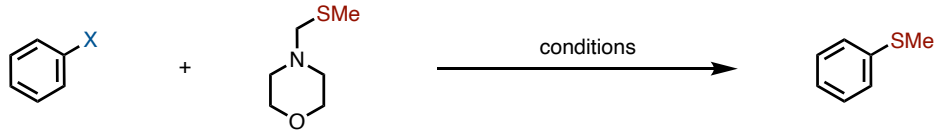
1
(1.5 equiv)

3c

entry	*x*/ mol%	*y*/ mol%	yield of **1**/ %	yield of **3c**/ %
1	5.0	10	3	43
2	10	20	trace	73[a]
3	10	10	trace	32

Yields were determined by ^{1}H NMR using CH_2Br_2 as an internal standard. [a] Isolated yield.

Effect of cesium carbonate



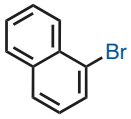
2
0.20 mmol

1
(1.5 equiv)

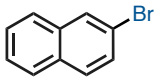
3

Br	Cl	OTf	OPiv	OTs
5.0 mol% $Pd(OAc)_2$ 10 mol% Xantphos Cs_2CO_3 (2.0 equiv) toluene (0.20 M) 120 °C, 12 h	5.0 mol% $Pd(OAc)_2$ 10 mol% dppf Zn (2.0 equiv) Cs_2CO_3 (2.0 equiv) toluene (0.20 M) 150 °C, 24 h	5.0 mol% $Ni(cod)_2$ 10 mol% dppf Zn (2.0 equiv) Cs_2CO_3 (2.0 equiv) toluene (0.20 M) 150 °C, 12 h	10 mol% $Ni(cod)_2$ 20 mol% dcypt Zn (2.0 equiv) Cs_2CO_3 (2.0 equiv) toluene (0.20 M) 150 °C, 12 h	5.0 mol% $Ni(cod)_2$ 10 mol% dppf Zn (2.0 equiv) Cs_2CO_3 (2.0 equiv) Et_2O (0.20 M) 80 °C, 12 h

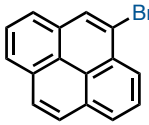
good yields even without Cs_2CO_3



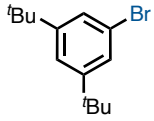
Br-2a
with Cs_2CO_3, **3a** : (75)%
without Cs_2CO_3, **3a** : 70%



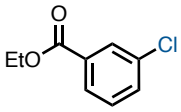
Br-2c
with Cs_2CO_3, **3c** : (86)%
without Cs_2CO_3, **3c** : 100%



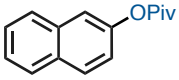
Br-2g
with Cs_2CO_3, **3e** : (82)%
without Cs_2CO_3, **3e** : 70%



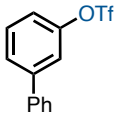
2i
with Cs_2CO_3, **3i** : 66(66)%
without Cs_2CO_3, **3i** : 66%



2o
with Cs_2CO_3, **3o** : 74(61)%
without Cs_2CO_3, **3o** : 67%

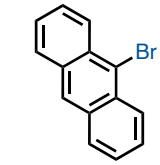


OPiv-2c
with Cs_2CO_3, **3c** : (73)%
without Cs_2CO_3, **3c** : 78%



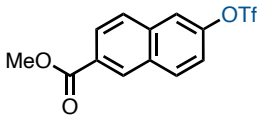
OTf-2k
with Cs_2CO_3, **3k** : 43(54)%
without Cs_2CO_3, **3k** : 50%

decreased yields without Cs_2CO_3



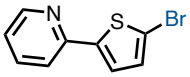
2e

with Cs_2CO_3, **3e** : (98)%
without Cs_2CO_3, **3e** : 55%



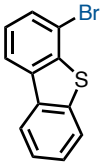
OTf-2q

with Cs_2CO_3, **3q** : 77(82)%
without Cs_2CO_3, **3q** : 62%



2y

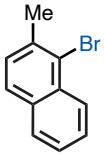
with Cs_2CO_3, **3y** : (86)%
without Cs_2CO_3, **3y** : 68%



2x

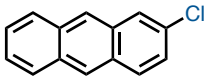
with Cs_2CO_3, **3x** : 89(74)%
without Cs_2CO_3, **3x** : 63%

dramatically decreased yields without Cs_2CO_3



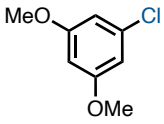
2b

with Cs_2CO_3, **3b** : 99(91)%
without Cs_2CO_3, **3b** : 16%



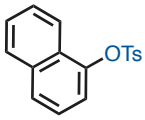
2d

with Cs_2CO_3, **3d** : 96(96)%
without Cs_2CO_3, **3d** : 30%



2m

with Cs_2CO_3, **3m** : 98(98)%
without Cs_2CO_3, **3m** : 23%

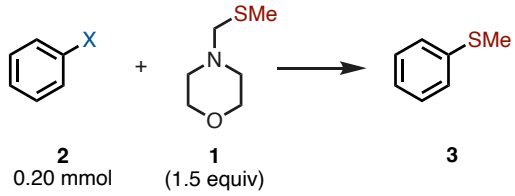


OTs-2a

with Cs_2CO_3, **3a** : 30%
without Cs_2CO_3, **3a** : <3%

Yields were determined by ^{1}H NMR using CH_2Br_2 as an internal standard.
Numbers in parentheses are isolated yields.

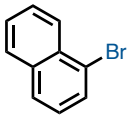
Effect of zinc



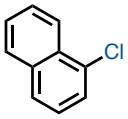
2
0.20 mmol

1
(1.5 equiv)

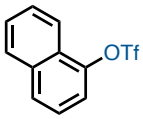
3



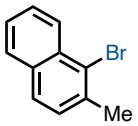
Br-2a
with Zn, **3a**: 91%
without Zn, **3a**: 86%



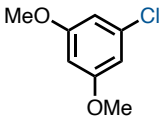
Cl-2a
with Zn, **3a**: 96%
without Zn, **3a**: 91%



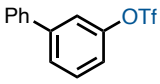
OTf-2a
with Zn, **3a**: 79%
without Zn, **3a**: 80%



2b
with Zn, **3b**: 91%
without Zn, **3b**: trace

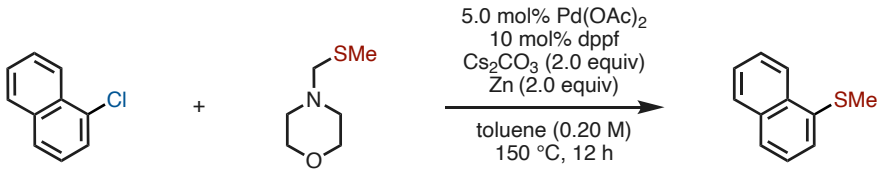


2m
with Zn, **3m**: 98%
without Zn, **3m**: 5%



OTf-2k
with Zn, **3k**: 54%
without Zn, **3k**: 42%

Effect of methylthiolation agent



Cl-2a
0.20 mmol

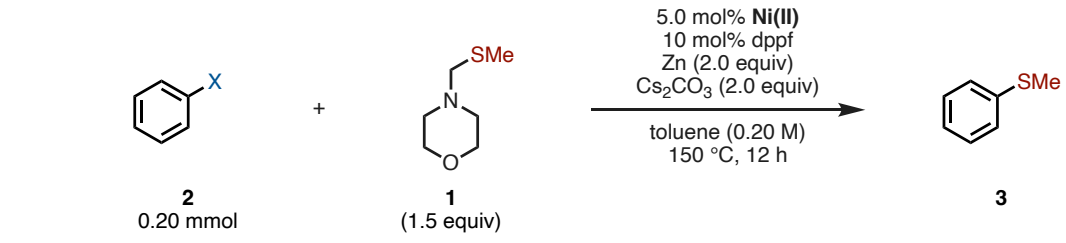
1
(**x** equiv)

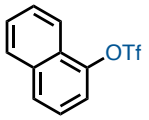
3a

entry	x/ equiv	recovery yield of **Cl-2a**/ %	yield of **3a**/ %
1	1.0	trace	83
2	1.5	trace	96
3	2.0	5	80
4	2.5	17	74[a]
5	5.0	47	53[a]

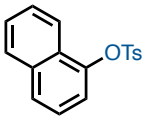
[a] Yields were determined by ^{1}H NMR using CH_2Br_2 as an internal standard.

Using Ni (II) salt instead of $Ni(cod)_2$

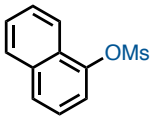




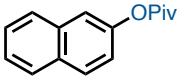
OTf-2a
3a: 41% ($Ni(OAc)_2$)
3a: 44% ($NiCl_2$)



OTs-2a
3a: 0% ($Ni(OAc)_2$)[a]
3a: 0% ($NiCl_2$)[a]



OMs-2a
3a: 0% ($Ni(OAc)_2$)[a,b]
3a: 0% ($NiCl_2$)[a]



OPiv-2c
3d: 65% ($NiCl_2$)

Yields were determined by ^1H NMR using CH_2Br_2 as an internal standard. [a] Et_2O, 80 °C. [b] 10 mol% $Ni(OAc)_2$, 20 mol% dppf were used.

8. References

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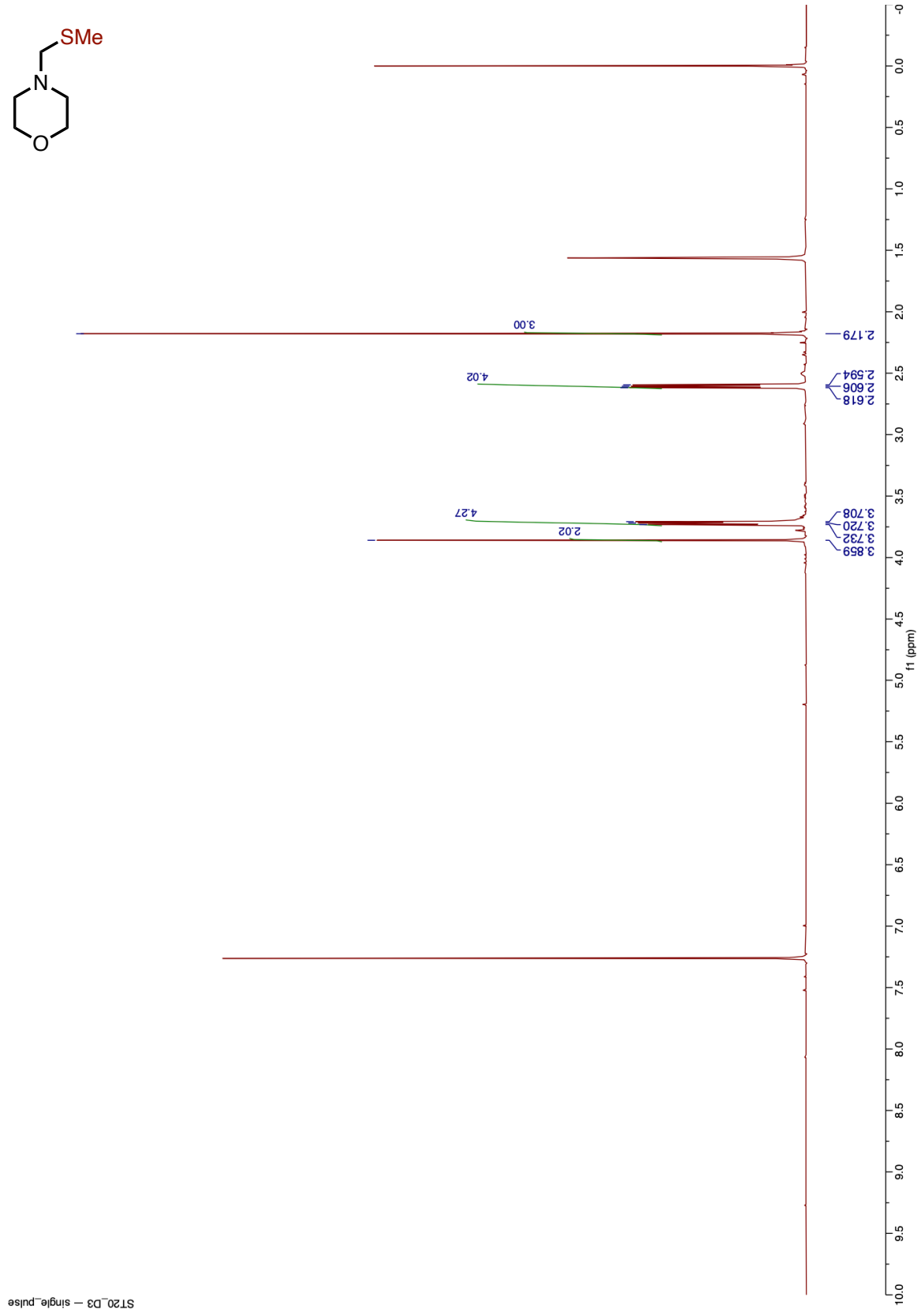
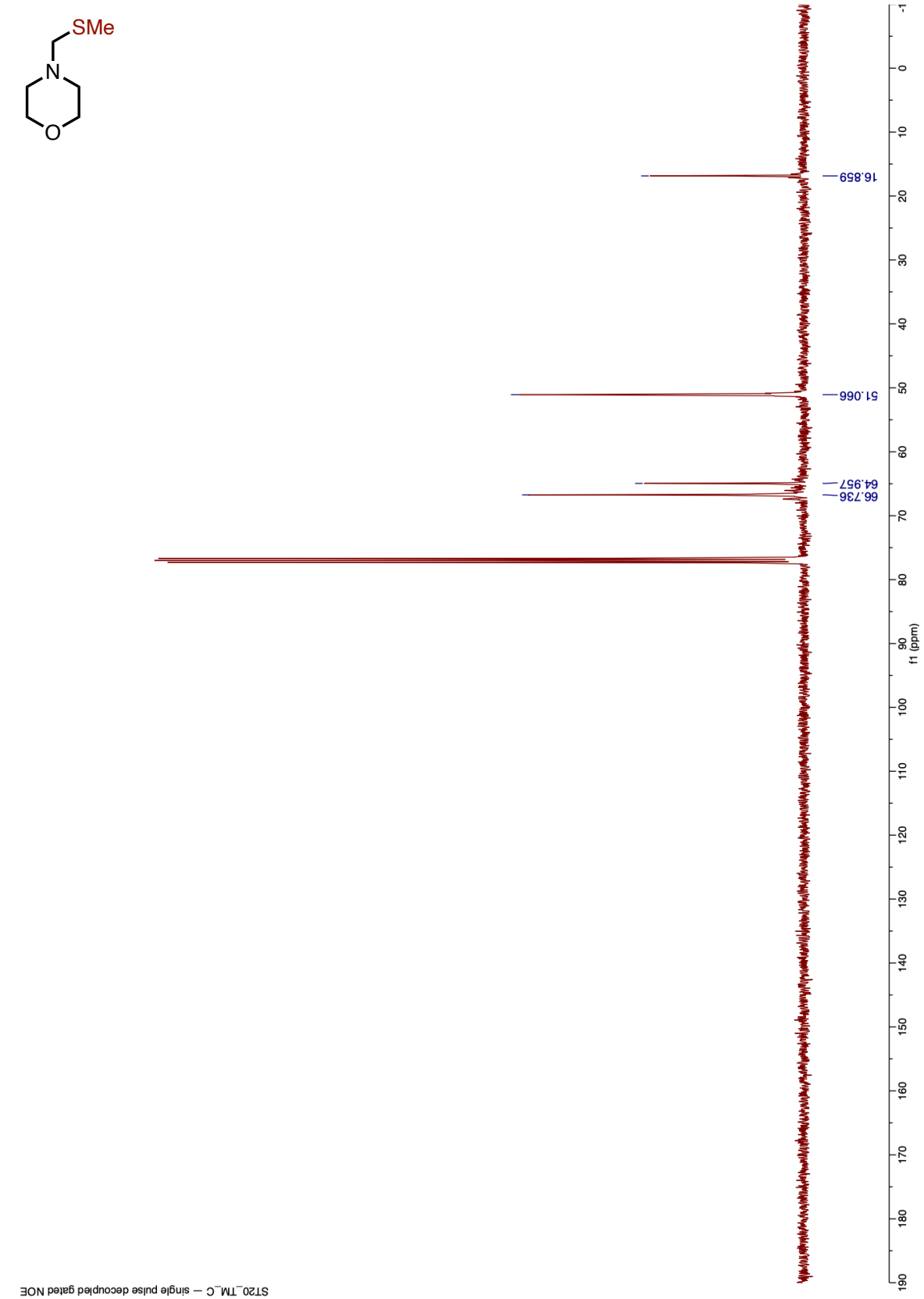
9. ^{1}H, ^{13}C, and ^{19}F NMR Spectra

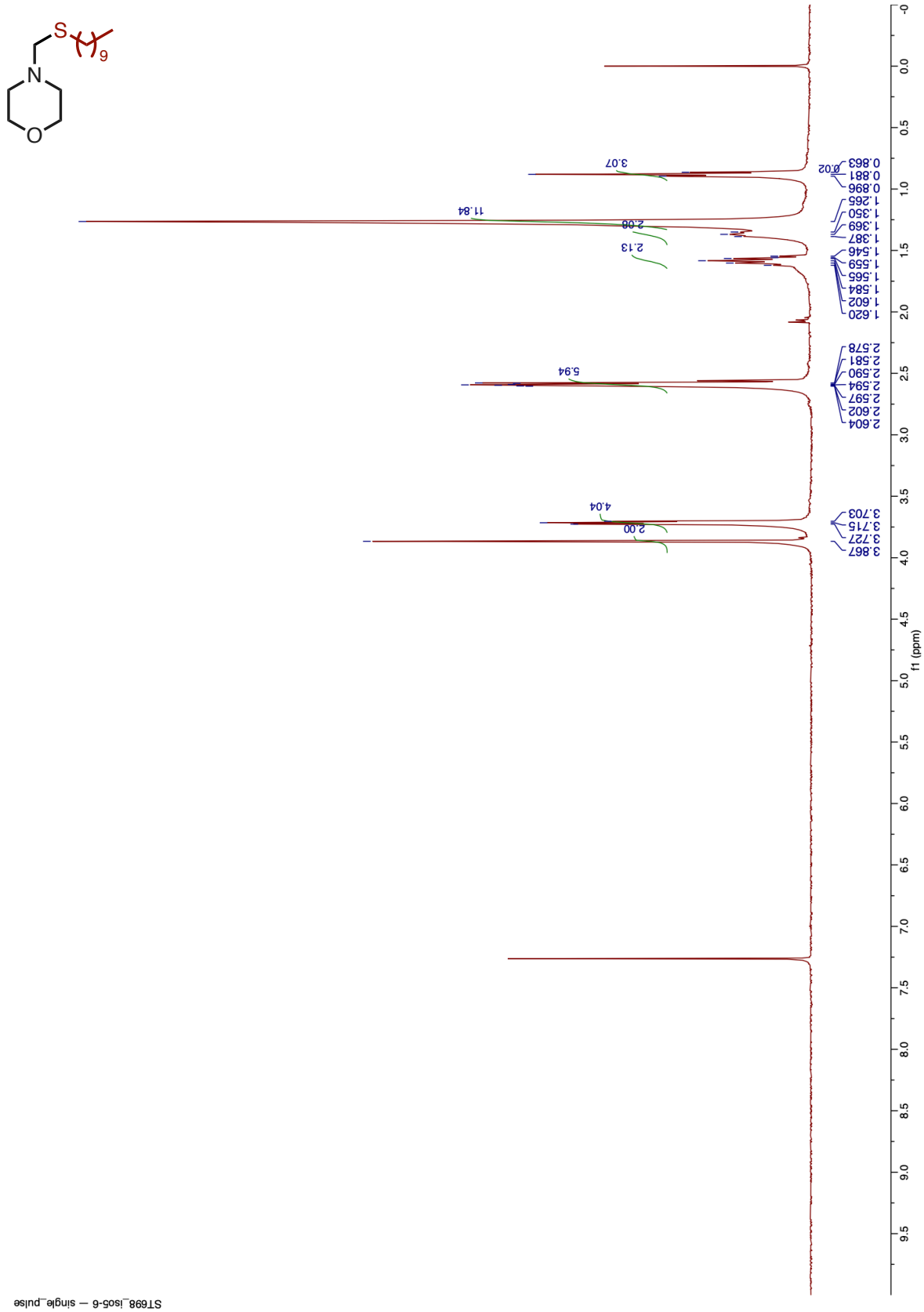
^{1}H NMR of **1** (400 MHz, $CDCl_3$)



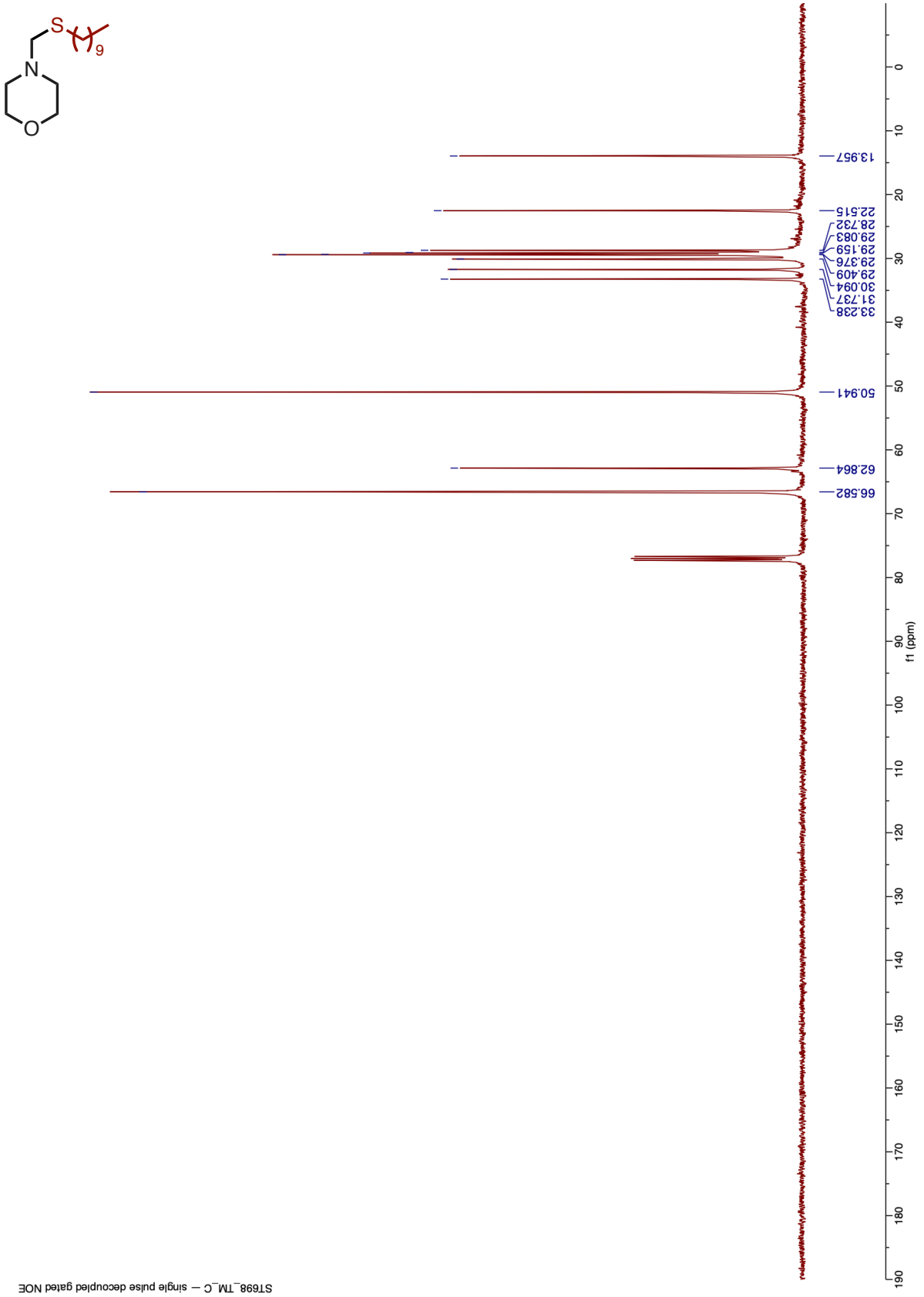
^{13}C NMR of **1** (101 MHz, $CDCl_3$)



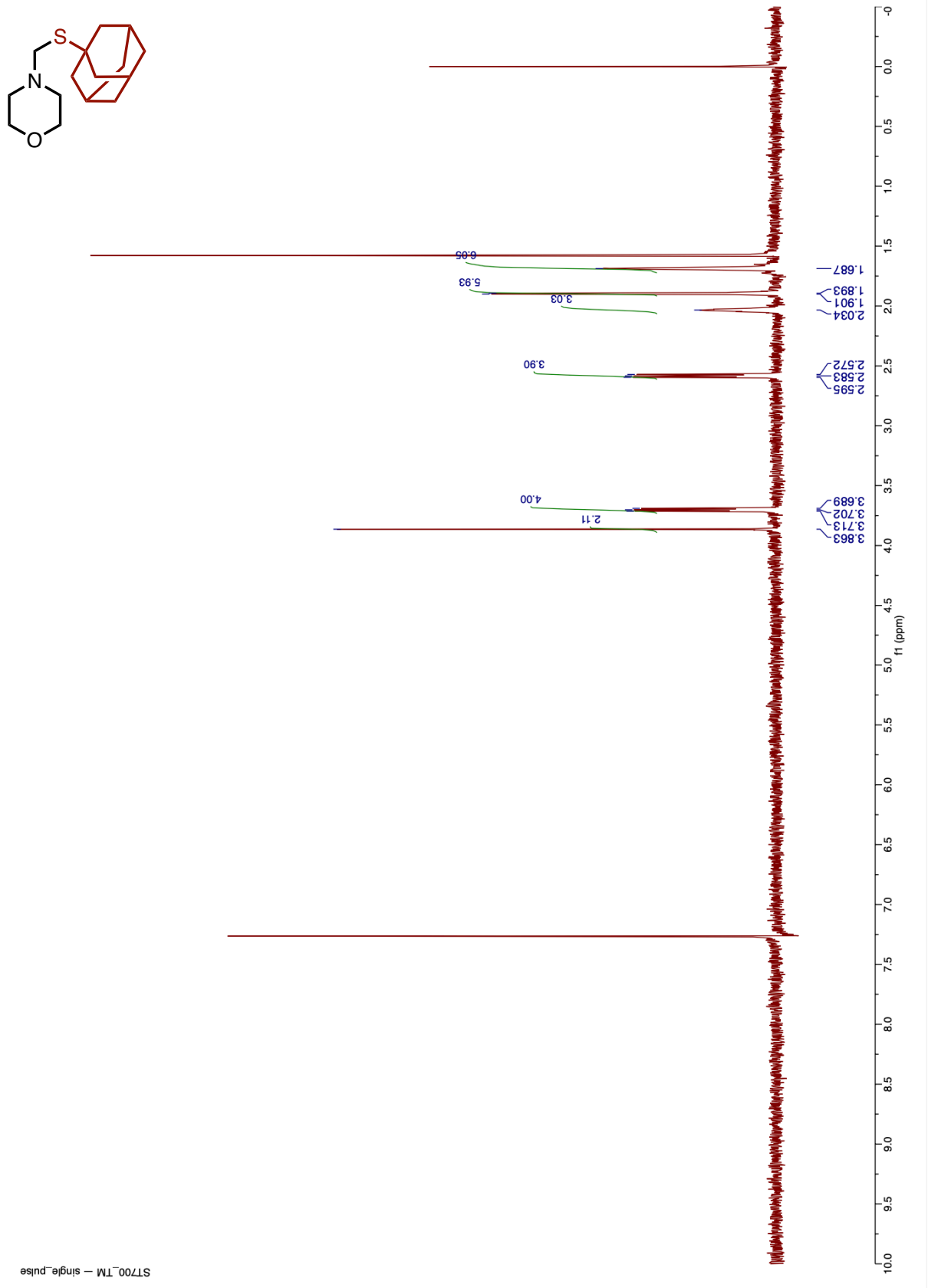
^{1}H NMR of **1b** (400 MHz, $CDCl_3$)



^{13}C NMR of **1b** (101 MHz, $CDCl_3$)



^{1}H NMR of **1c** (400 MHz, $CDCl_3$)



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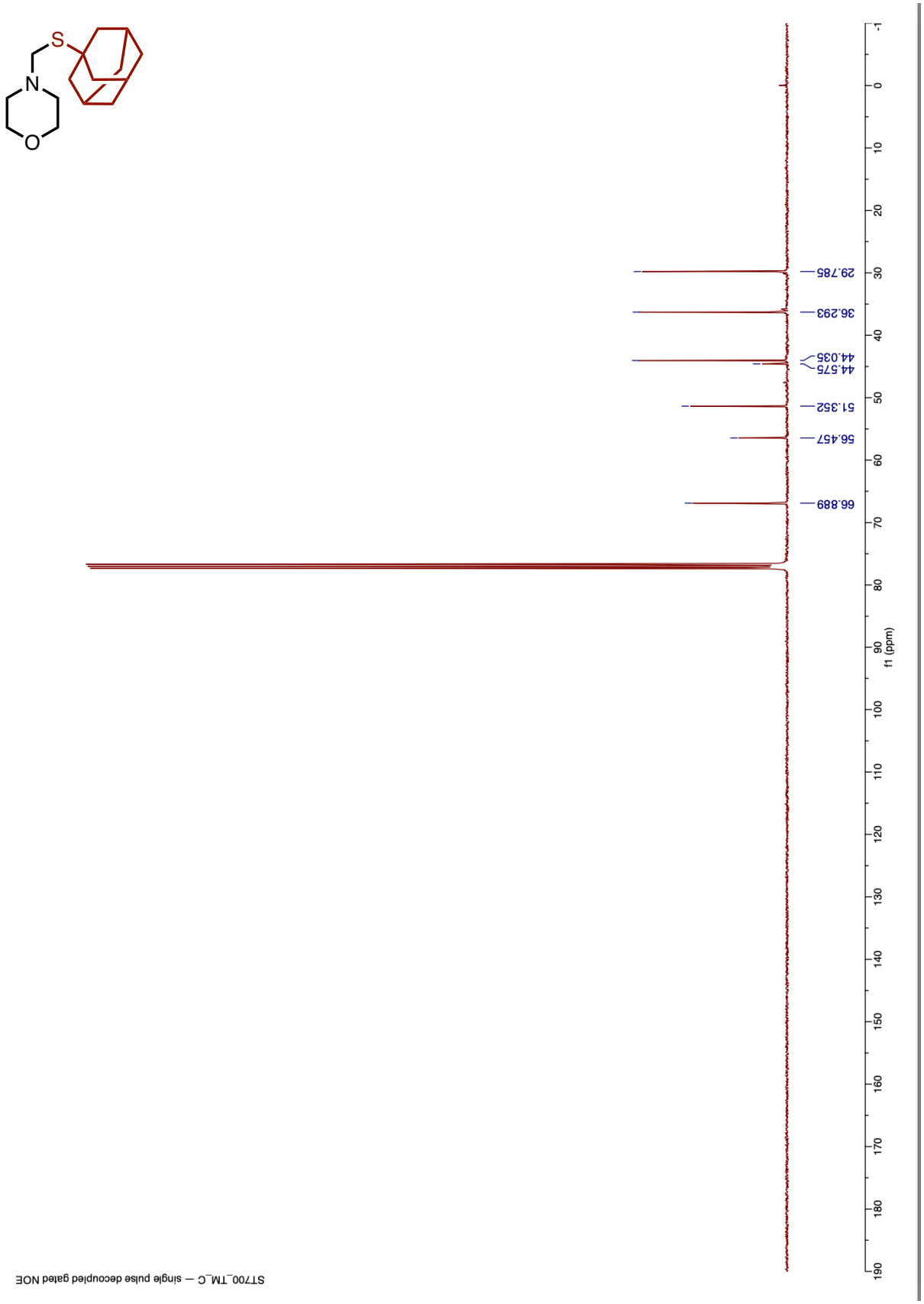
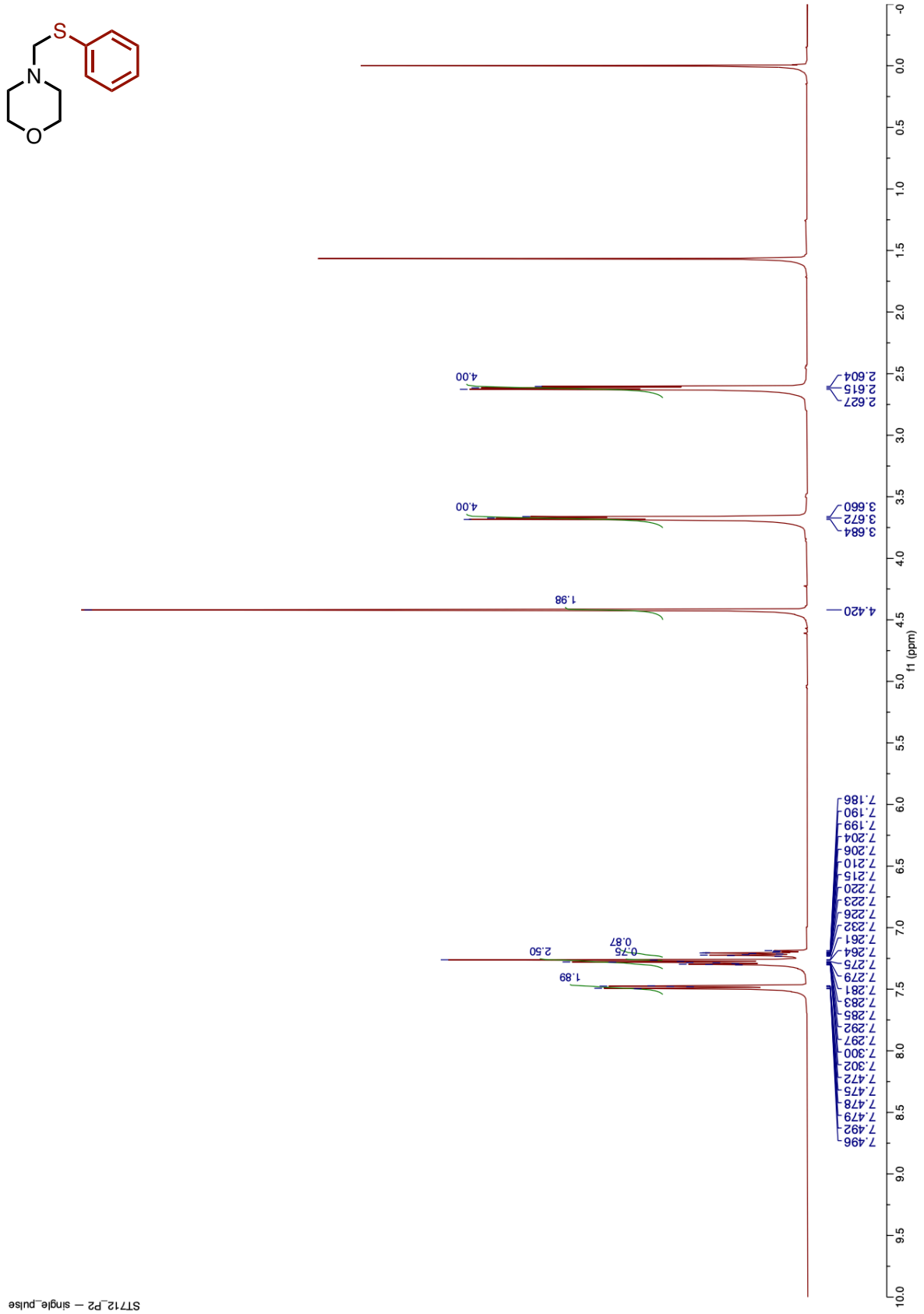
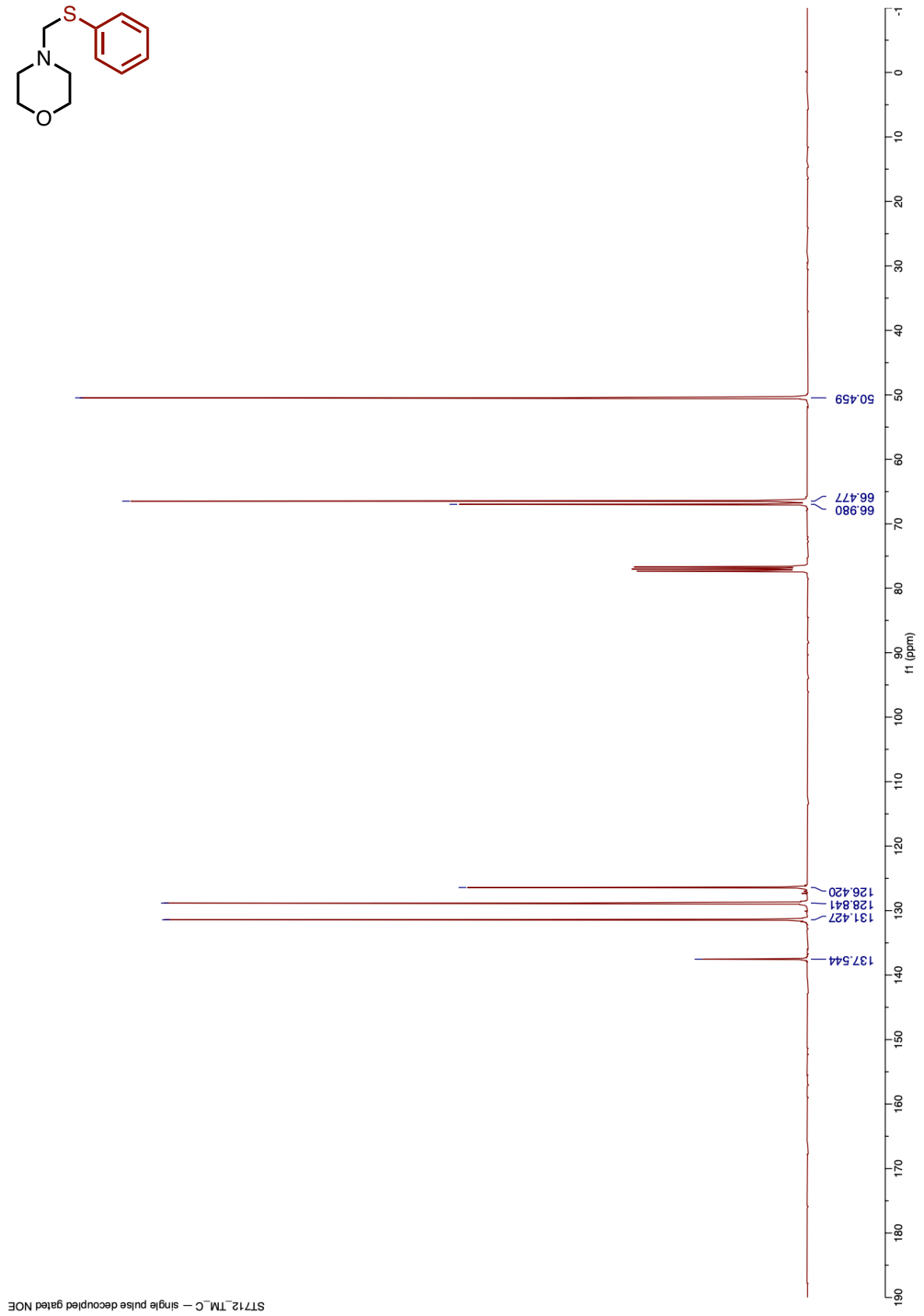


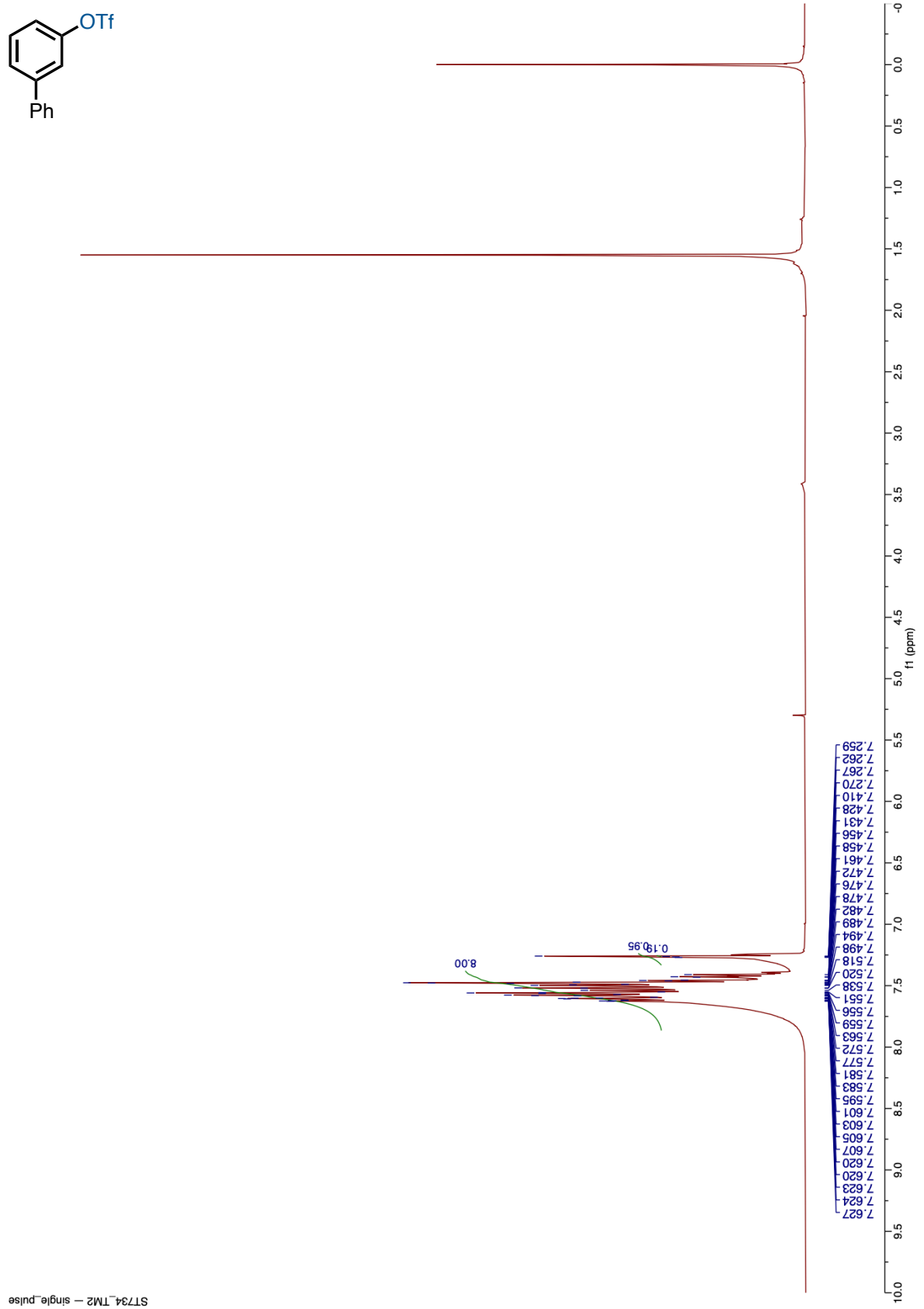
^{1}H NMR of **1d** (400 MHz, $CDCl_3$)



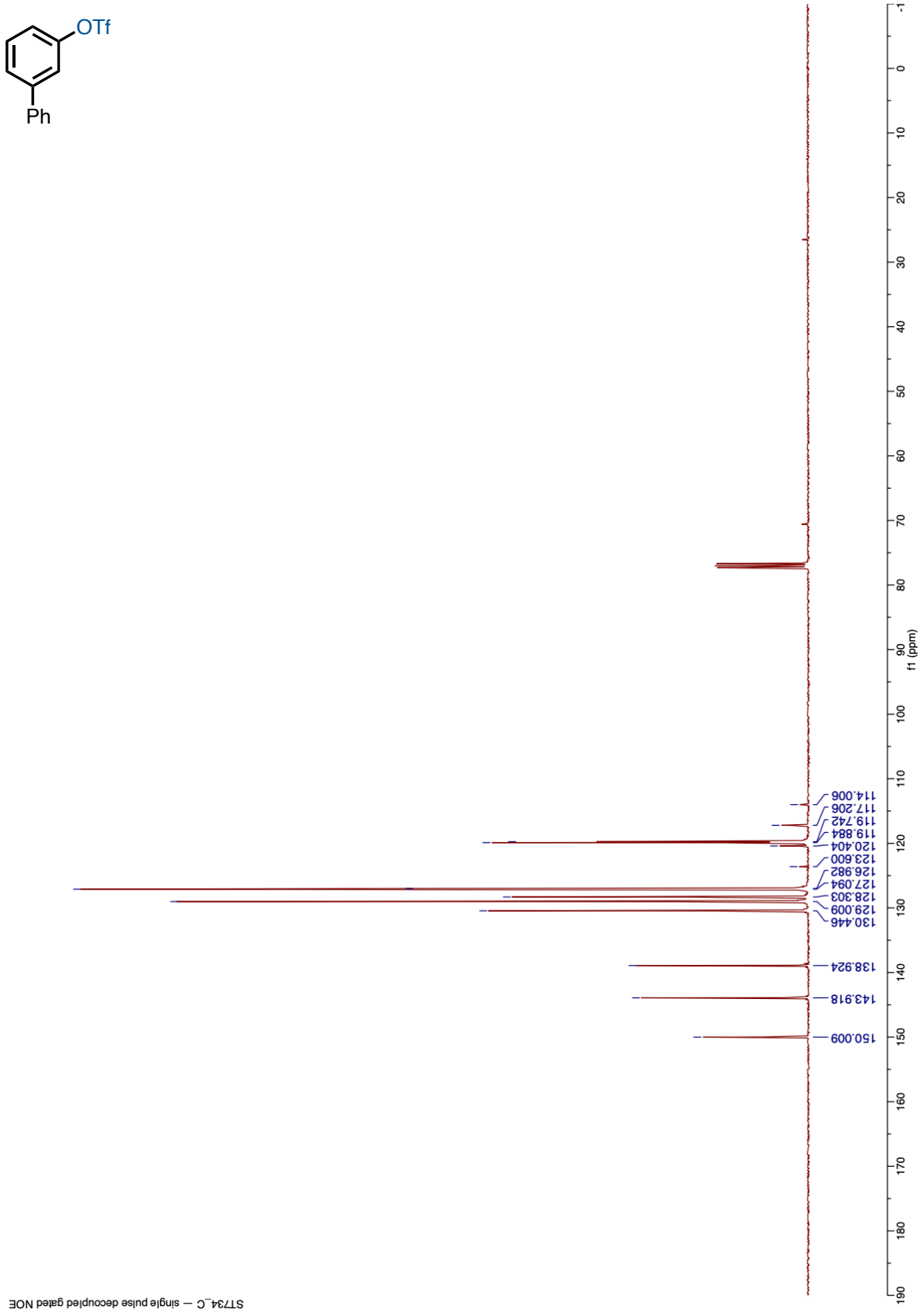
^{13}C NMR of **1d** (101 MHz, $CDCl_3$)



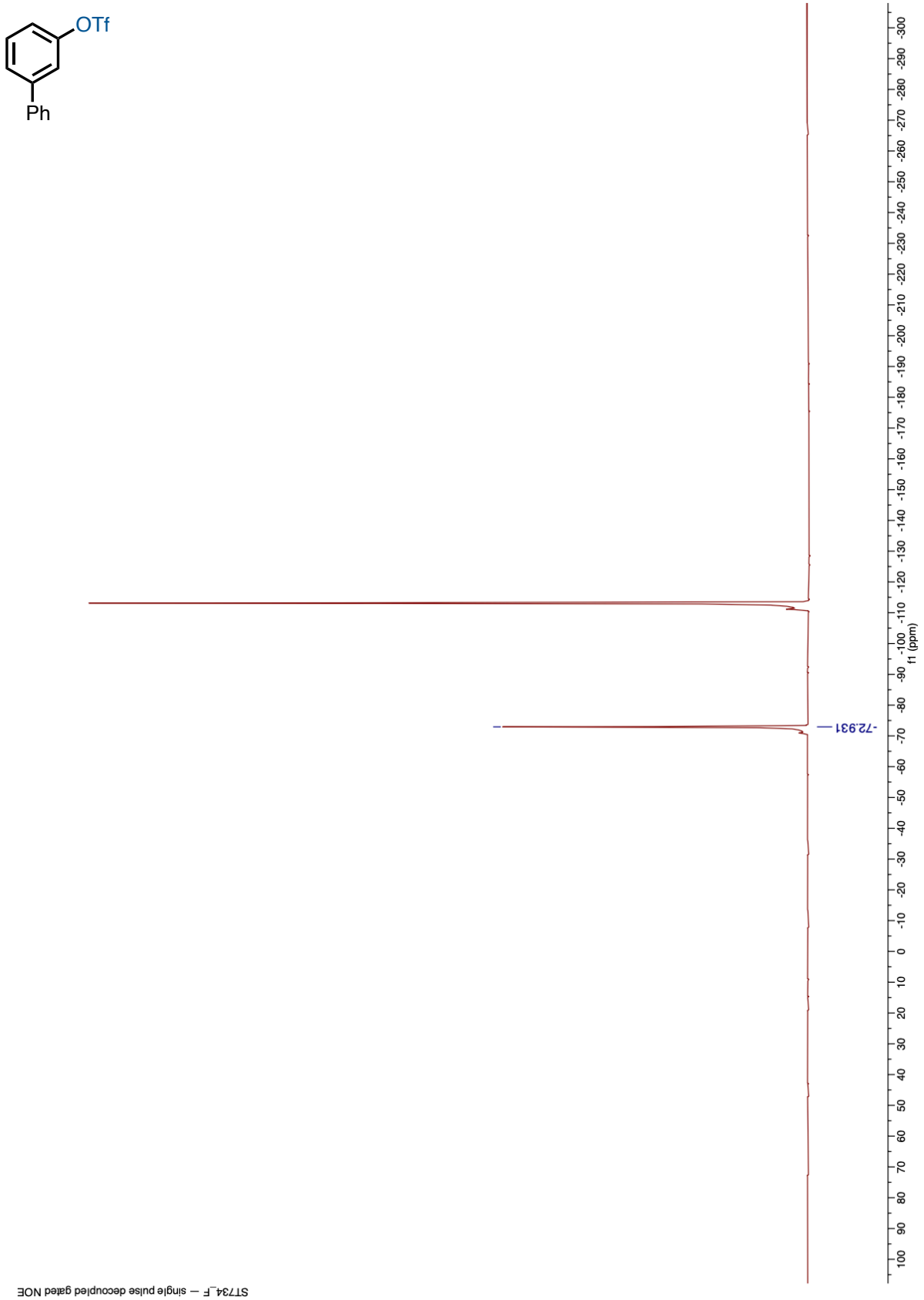
^{1}H NMR of **OTf-2k** (400 MHz, $CDCl_3$)



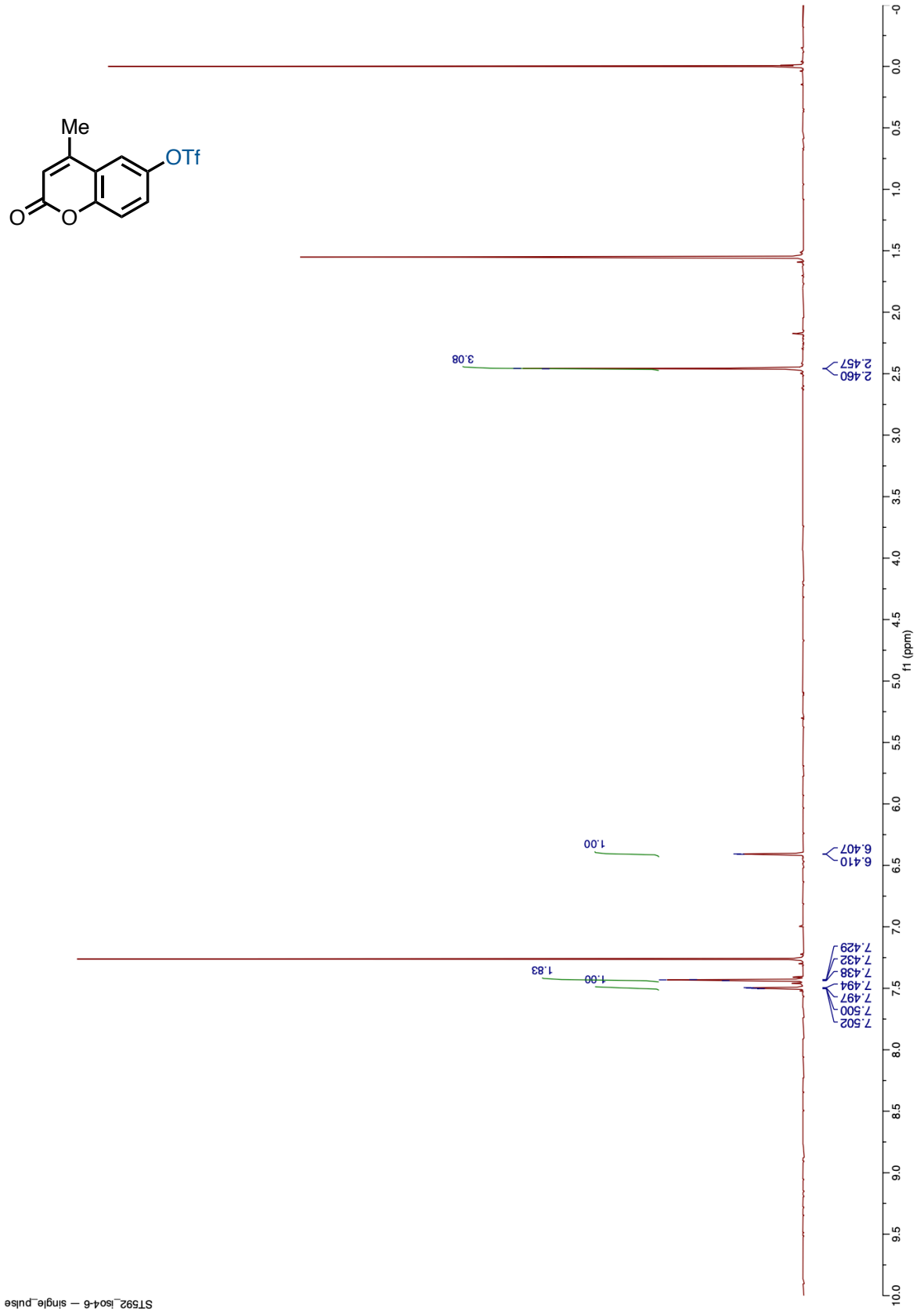
^{13}C NMR of **OTf-2k** (101 MHz, $CDCl_3$)



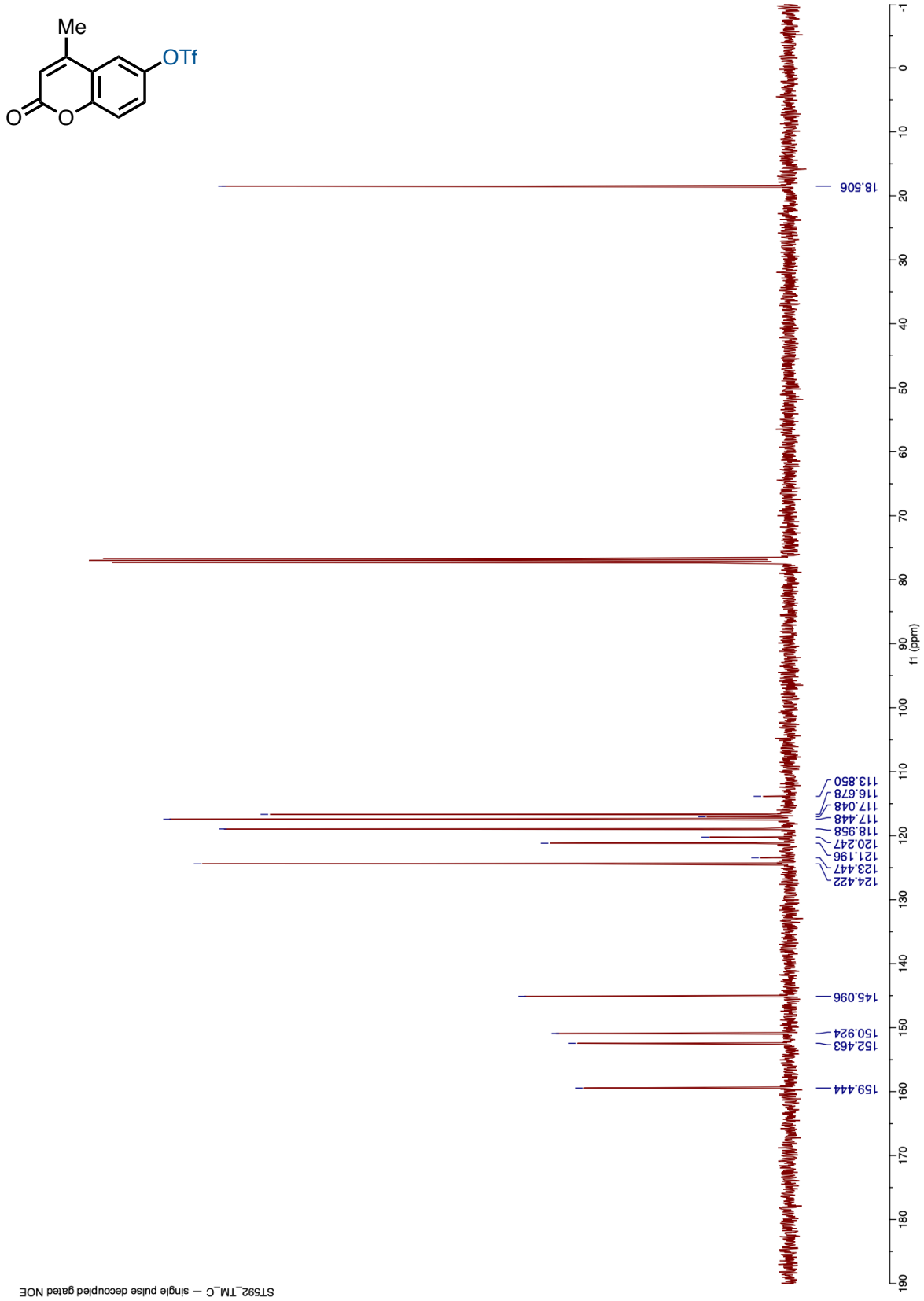
^{19}F NMR of **OTf-2k** (376 MHz, $CDCl_3$)



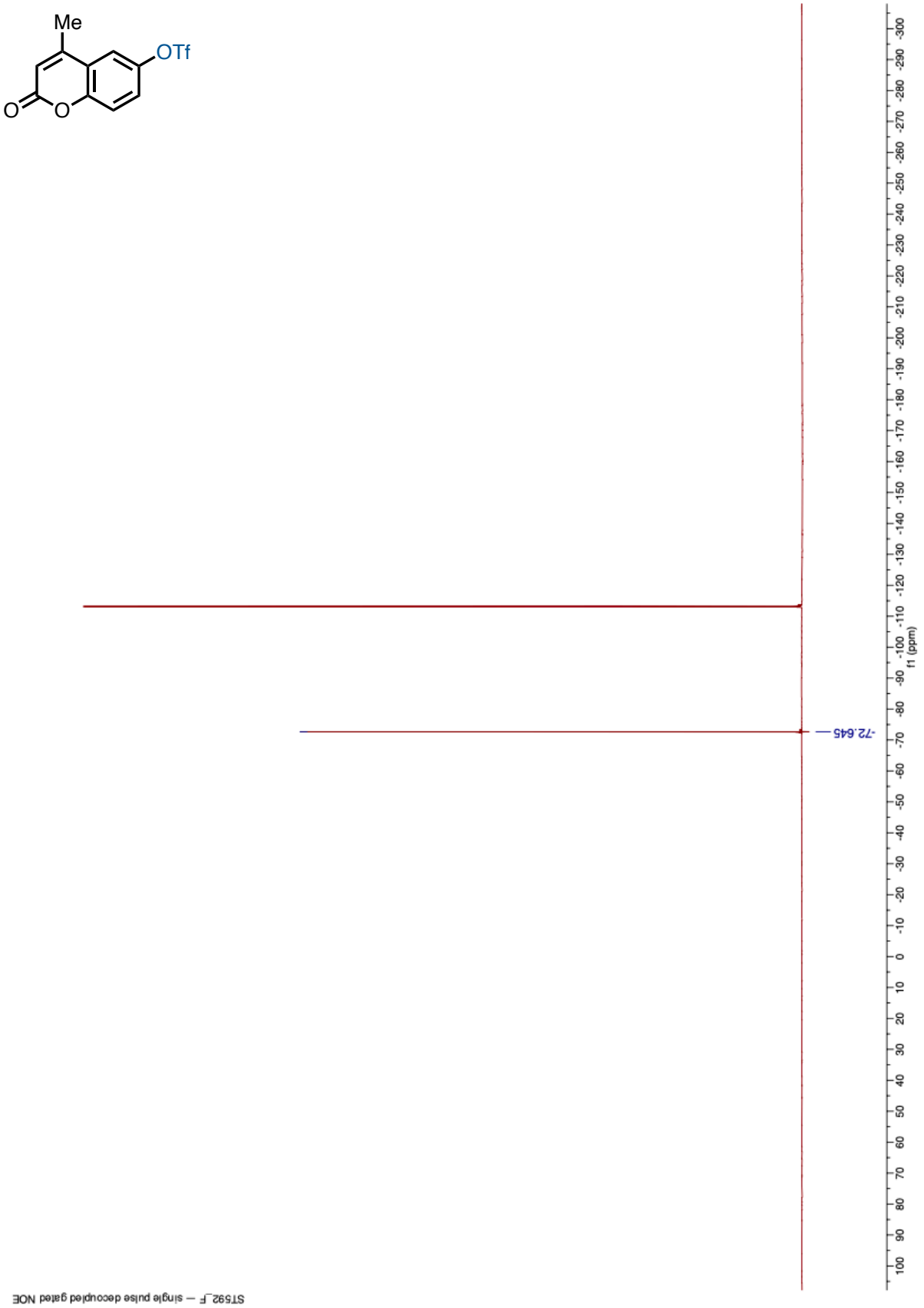
^{1}H NMR of **2B** (400 MHz, $CDCl_3$)



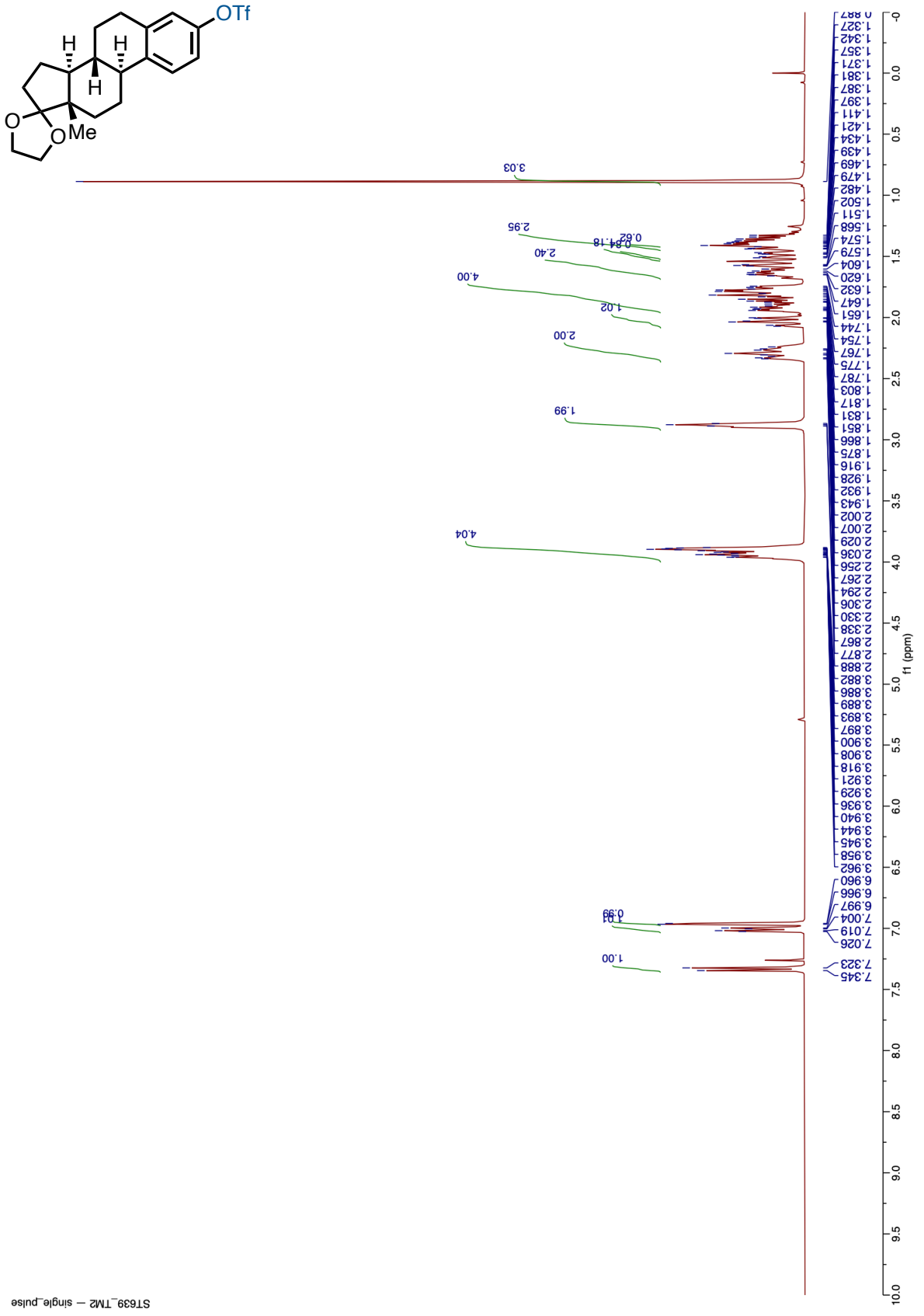
^{13}C NMR of **2B** (101 MHz, $CDCl_3$)



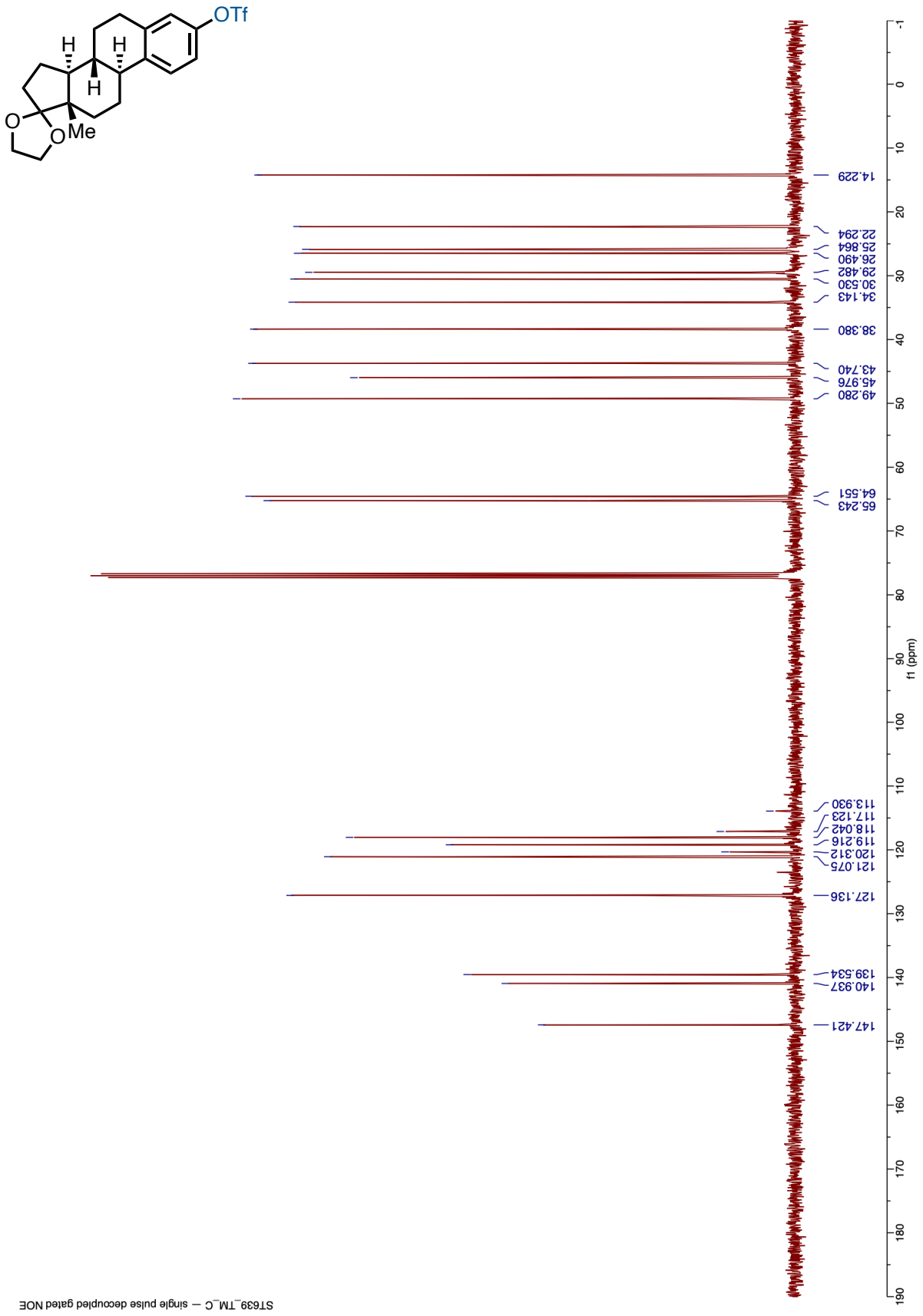
^{19}F NMR of **2B** (376 MHz, $CDCl_3$)



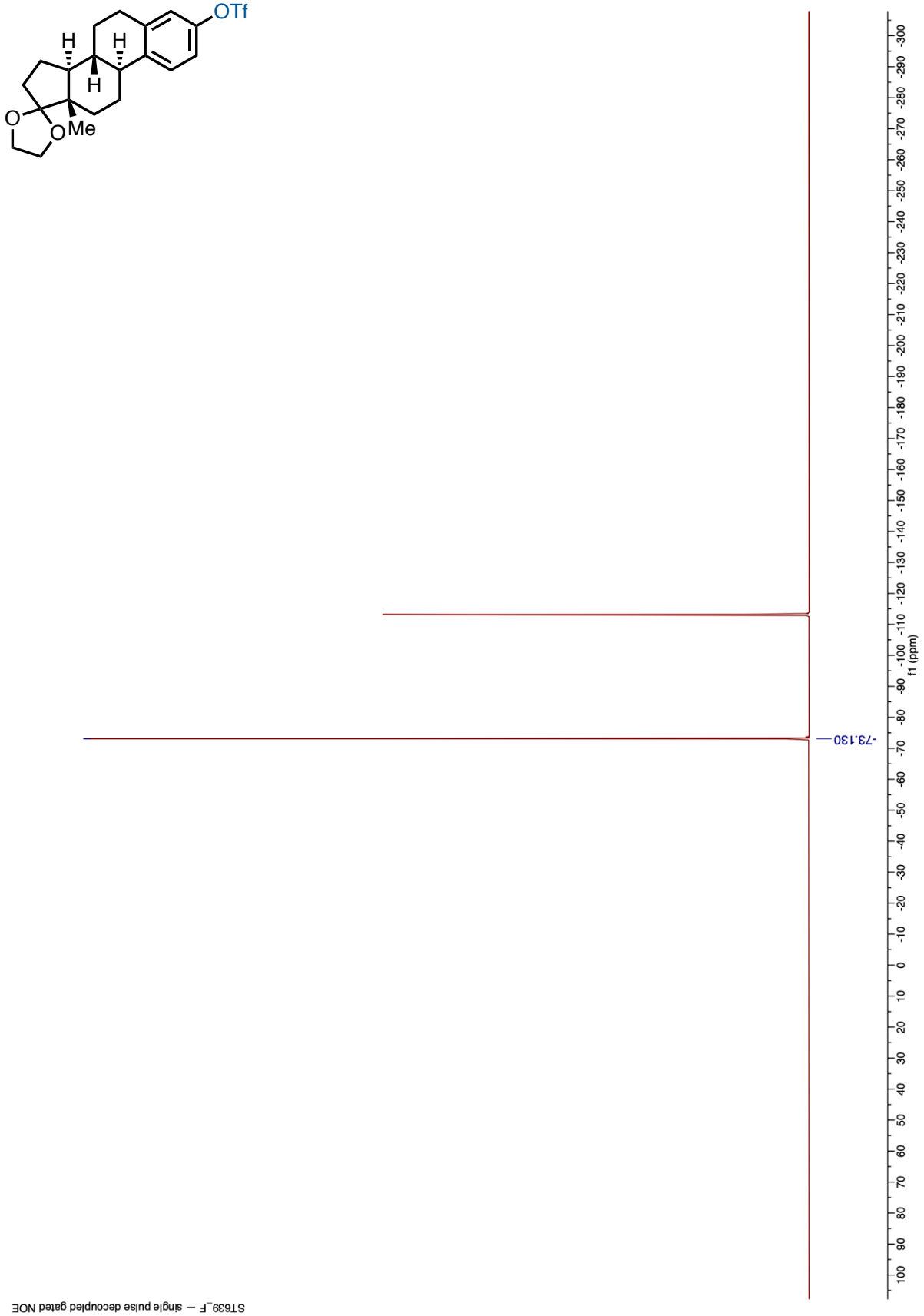
^{1}H NMR of **2G** (400 MHz, $CDCl_3$)



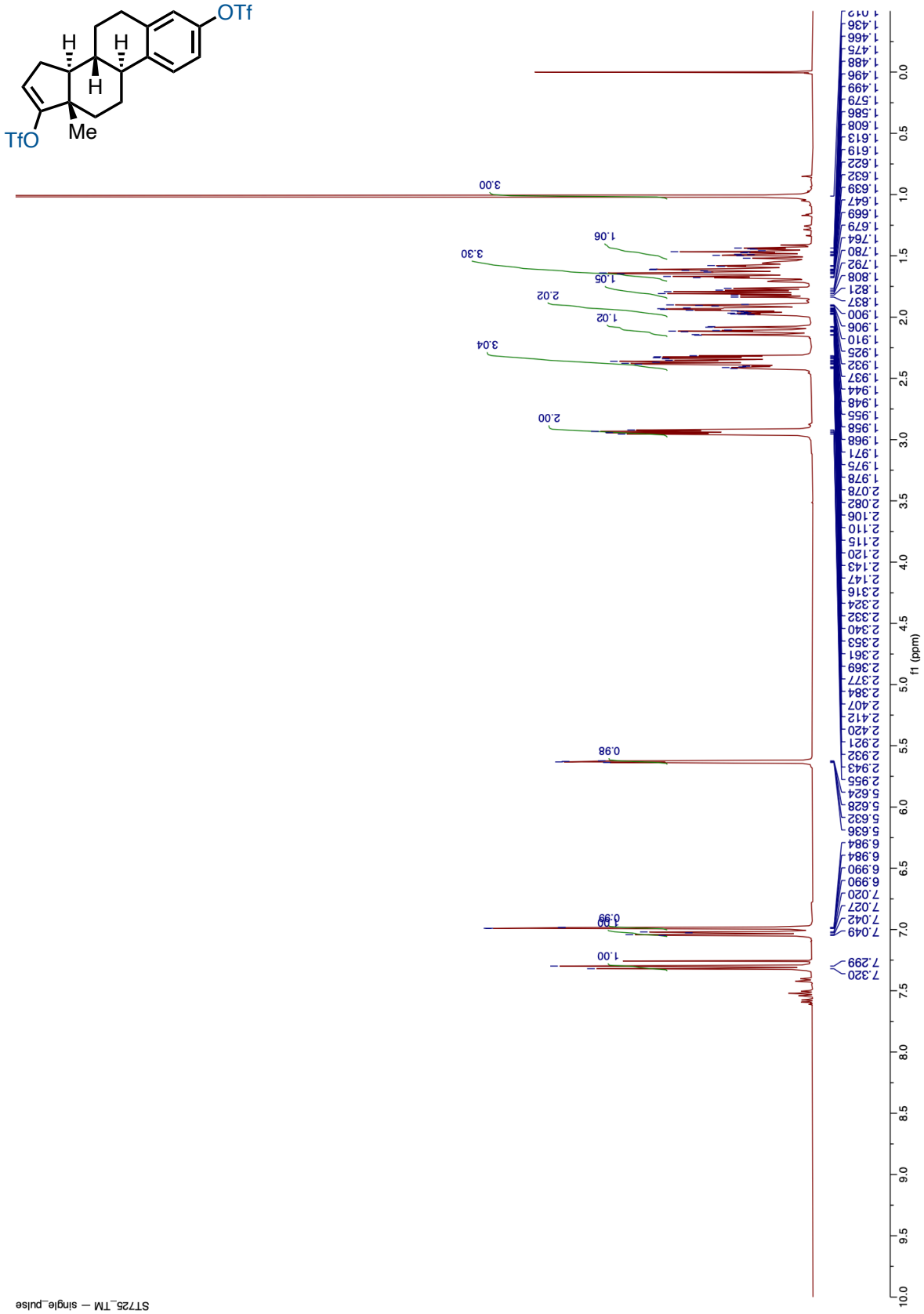
^{13}C NMR of **2G** (101 MHz, $CDCl_3$)



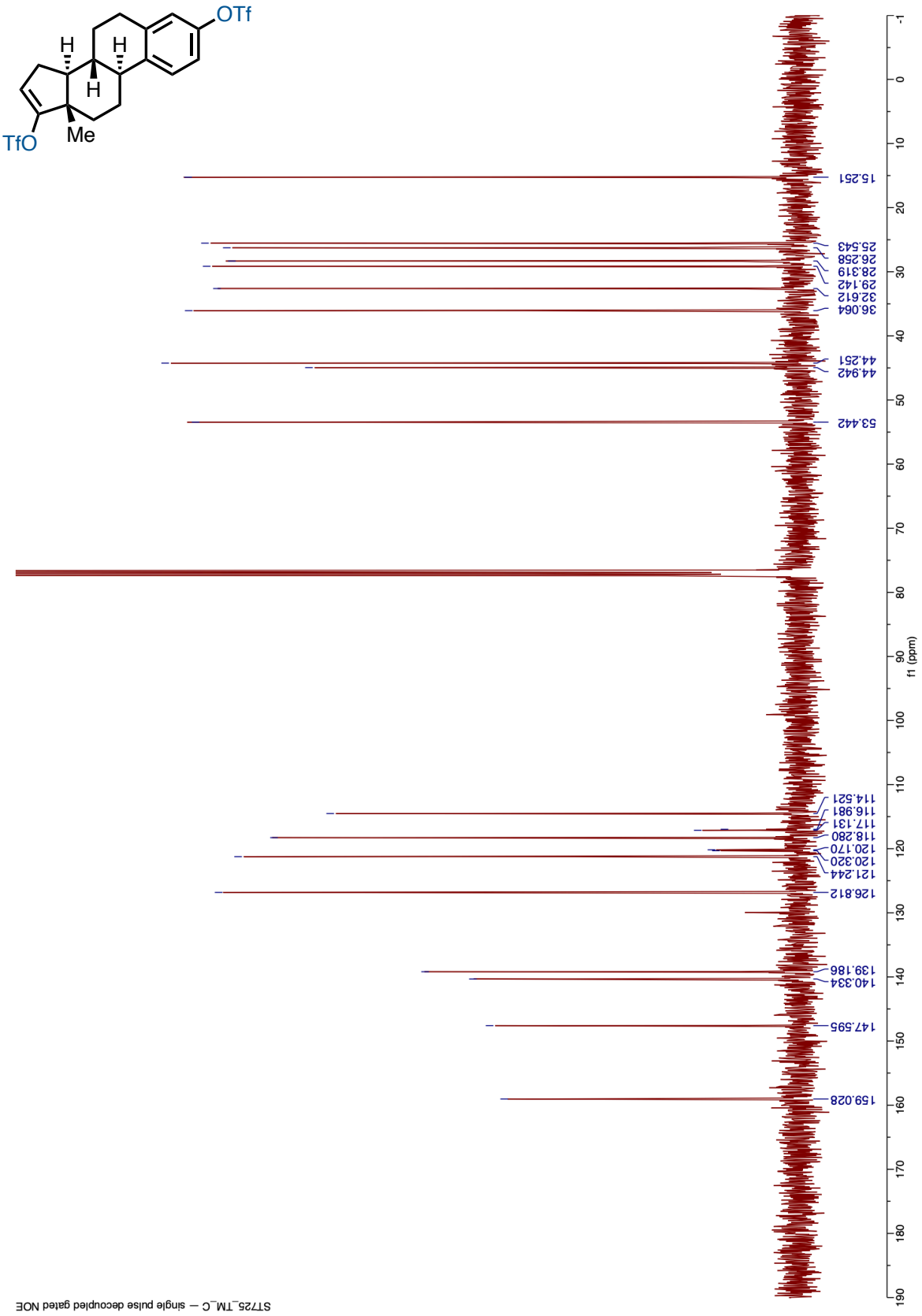
^{19}F NMR of **2G** (376 MHz, $CDCl_3$)



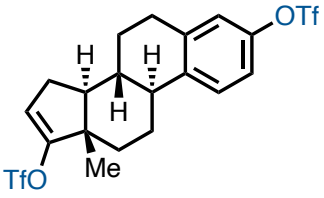
^{1}H NMR of **2H** (400 MHz, $CDCl_3$)



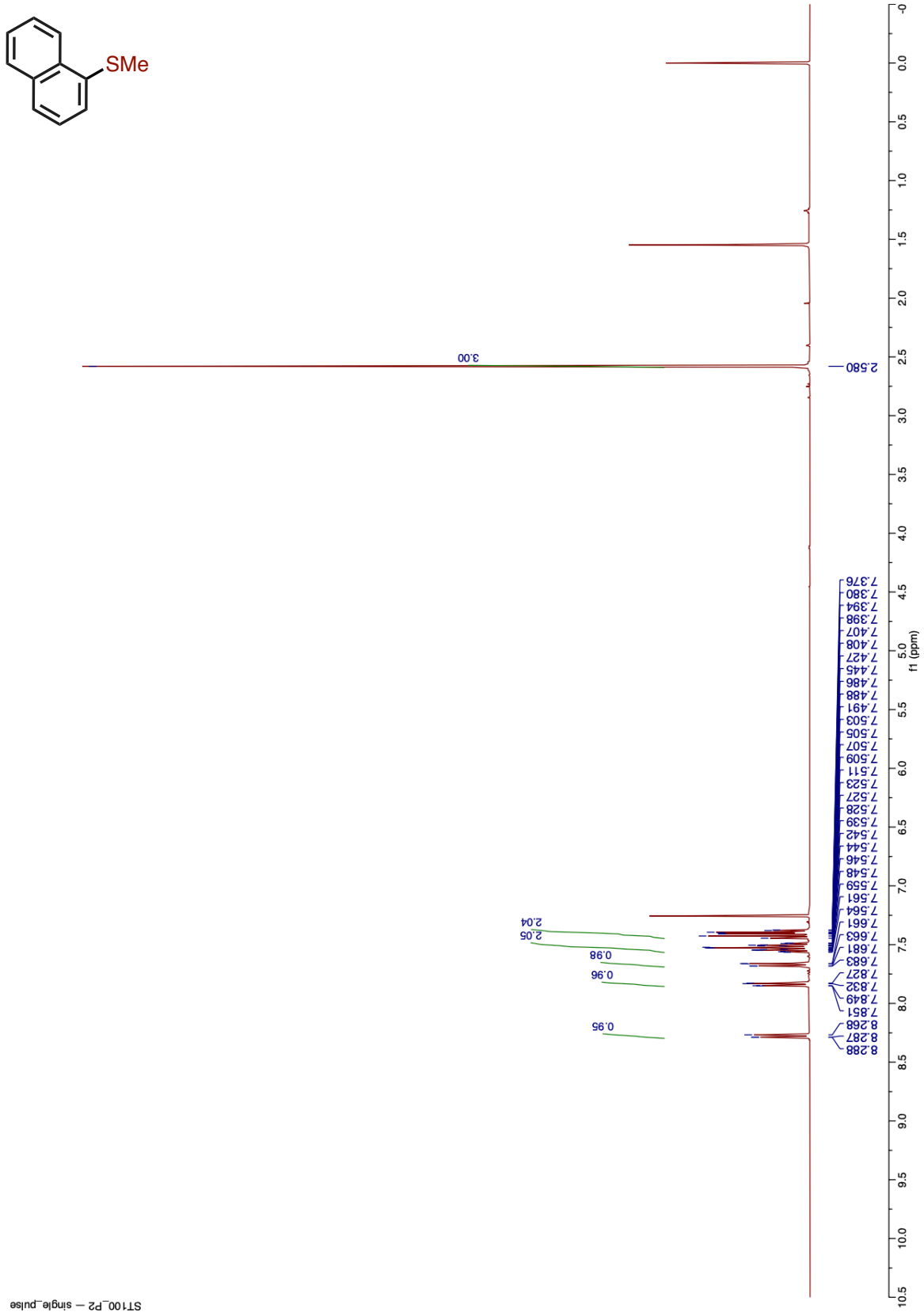
^{13}C NMR of **2H** (101 MHz, $CDCl_3$)



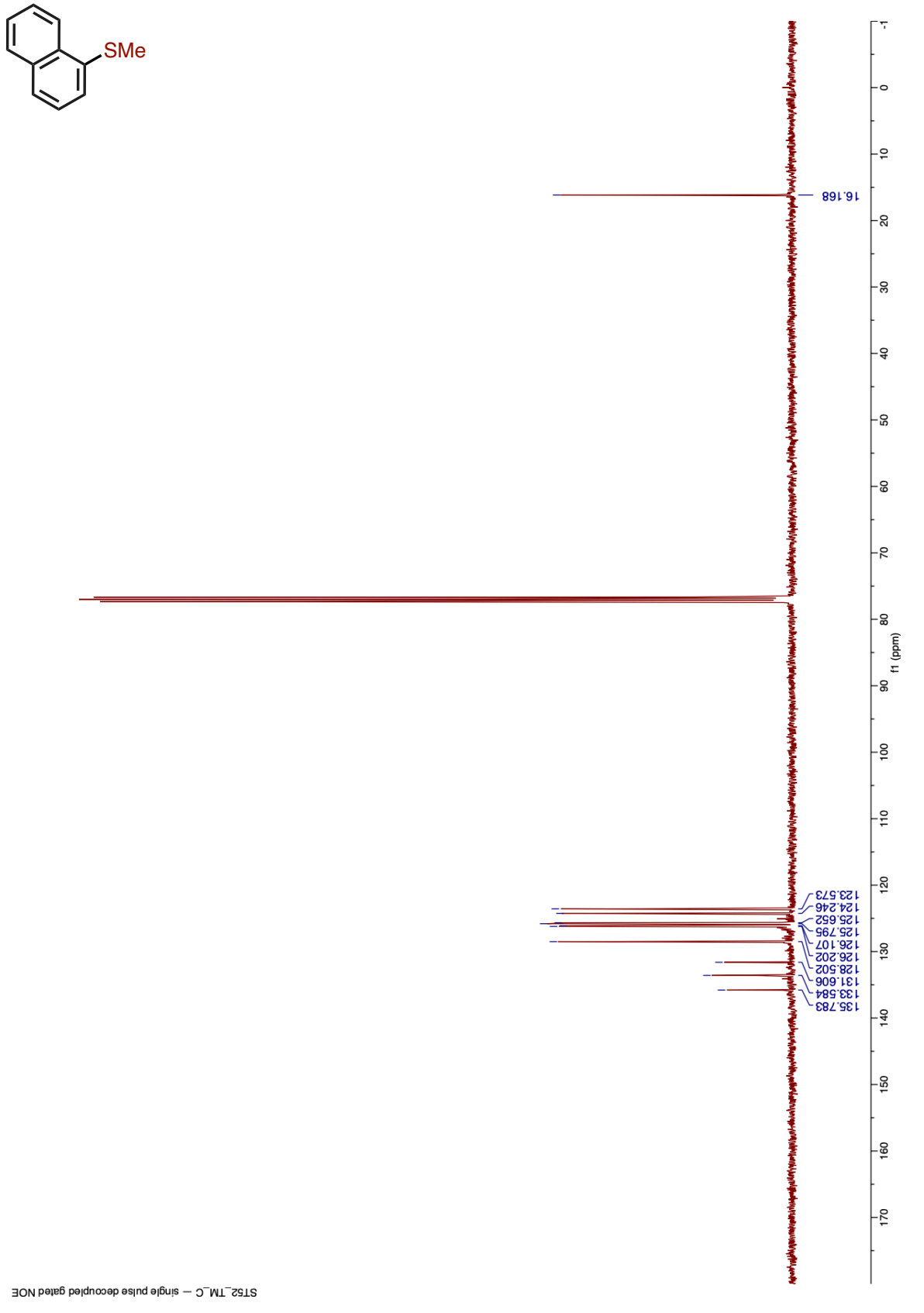
^{19}F NMR of **2H**(376 MHz, $CDCl_3$)



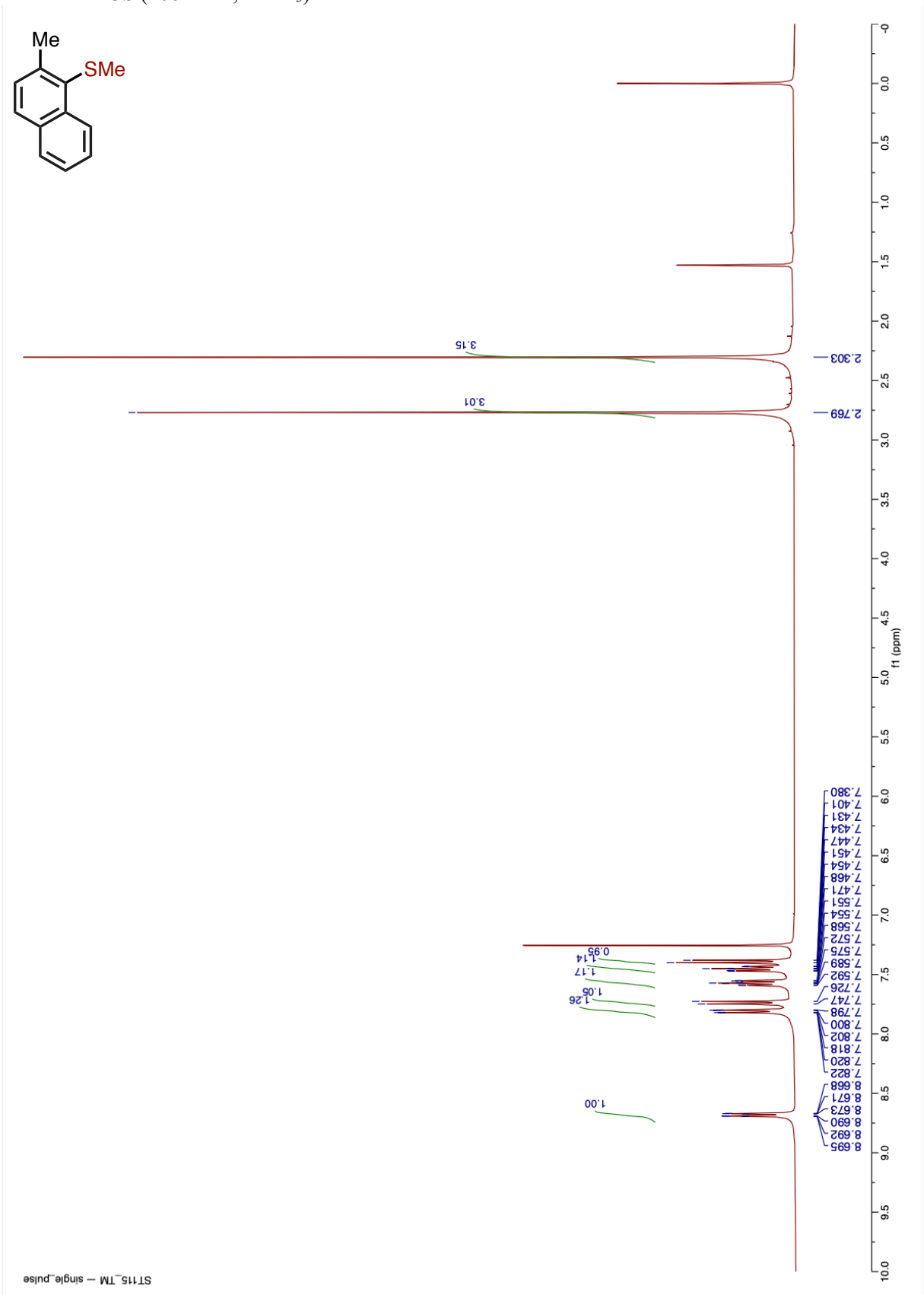
^{1}H NMR of **3a** (400 MHz, $CDCl_3$)



^{13}C NMR of **3a** (101 MHz, $CDCl_3$)



^{1}H NMR of **3b** (400 MHz, $CDCl_3$)



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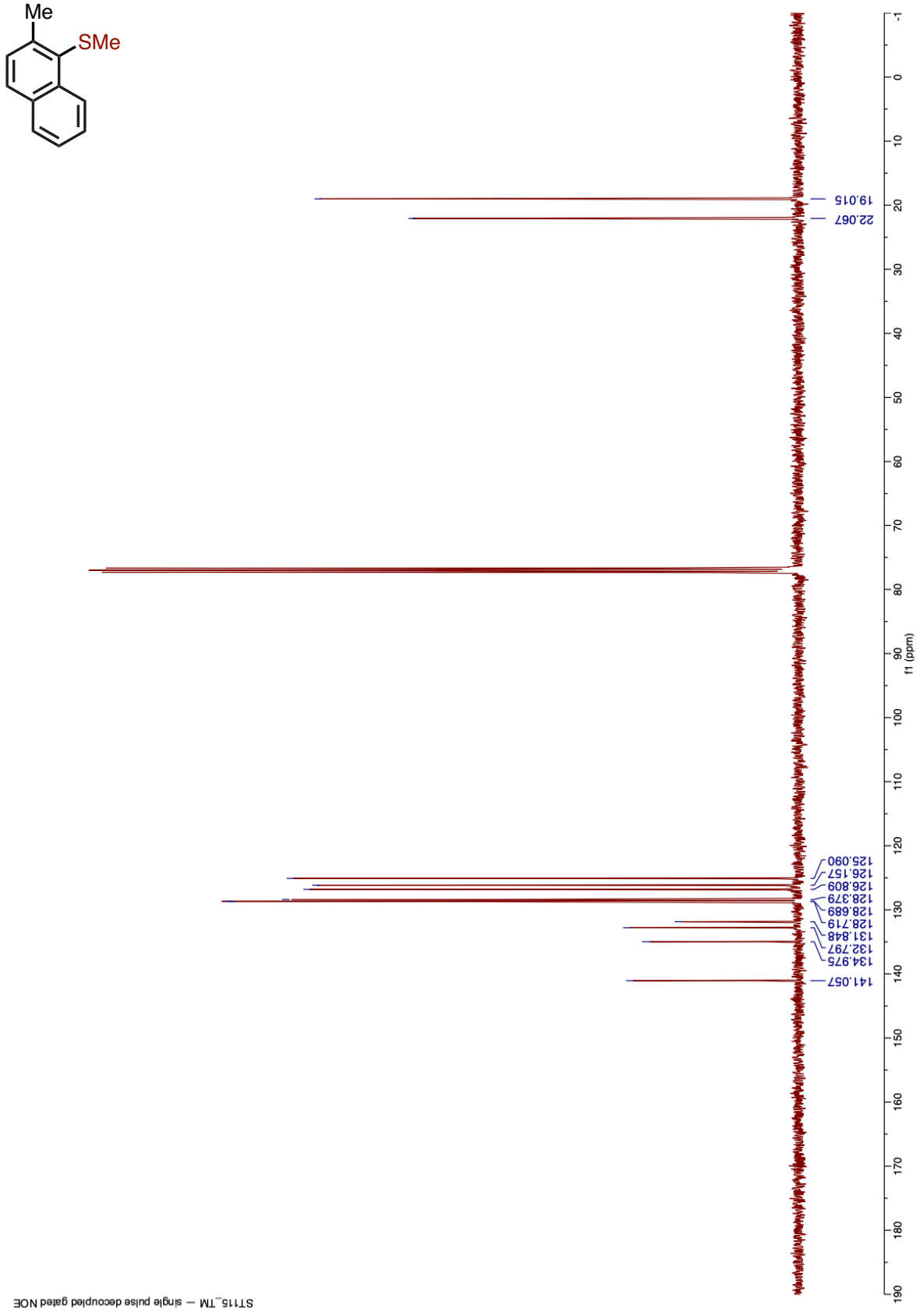

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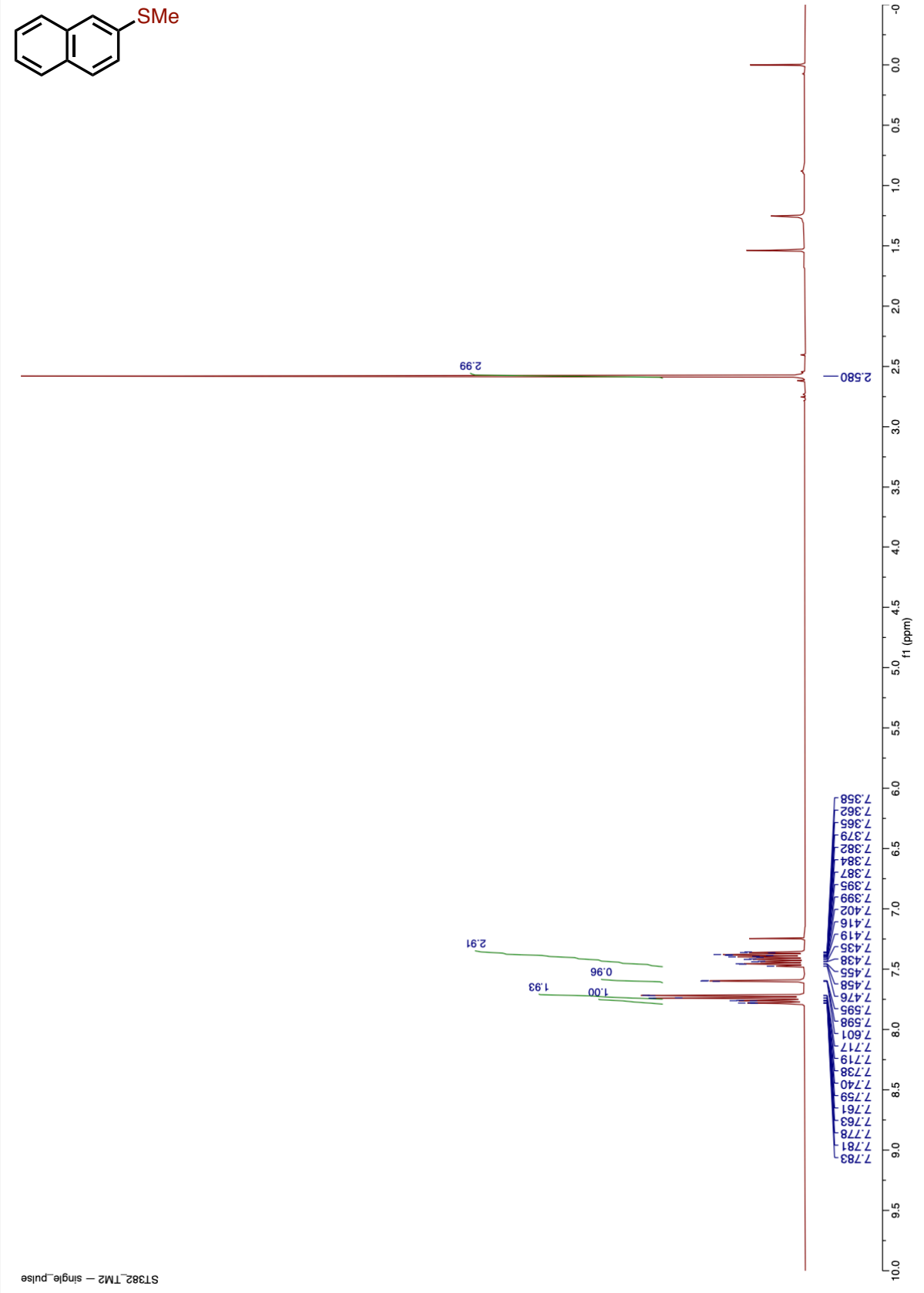

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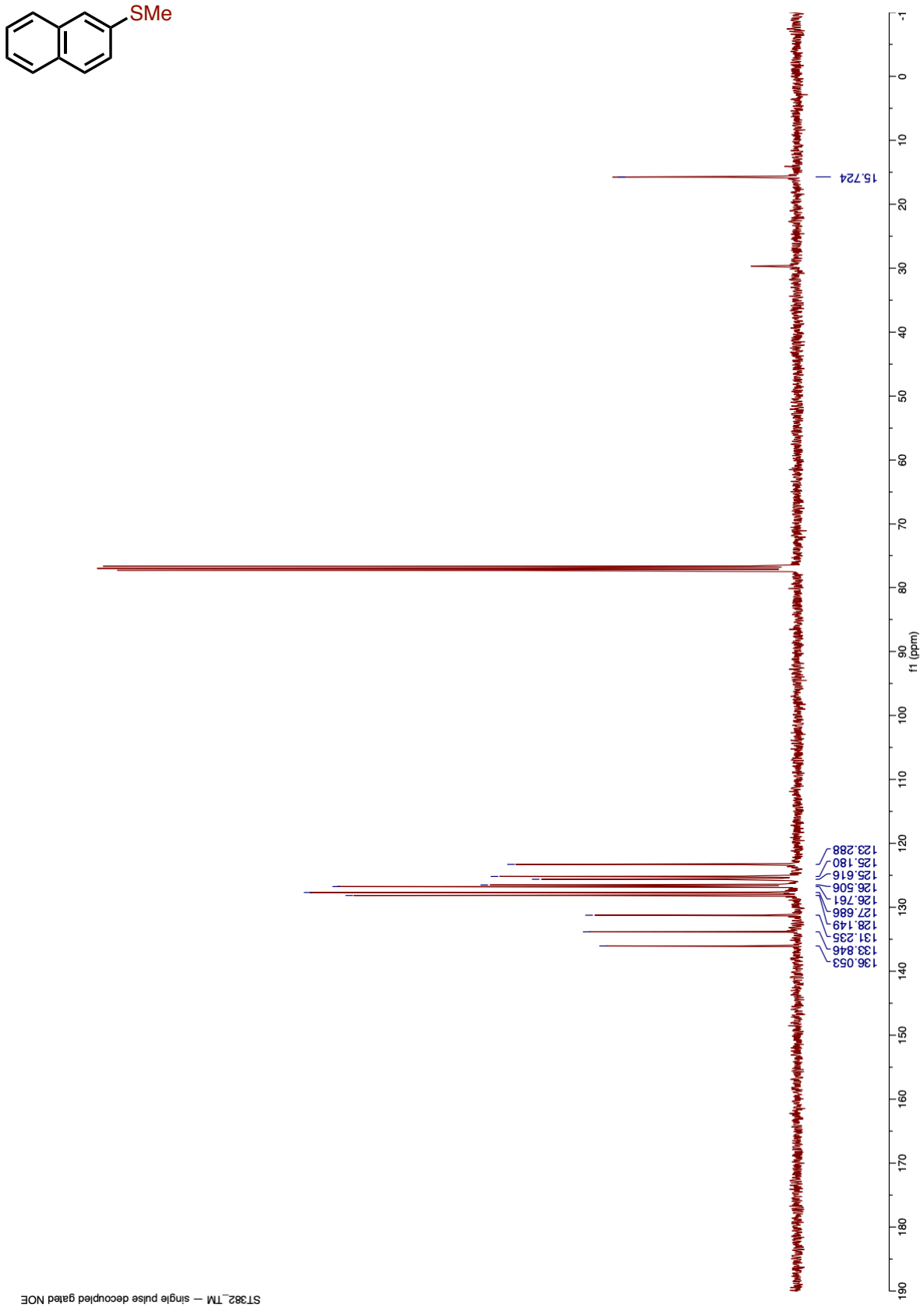
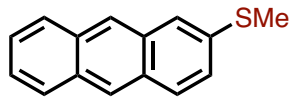
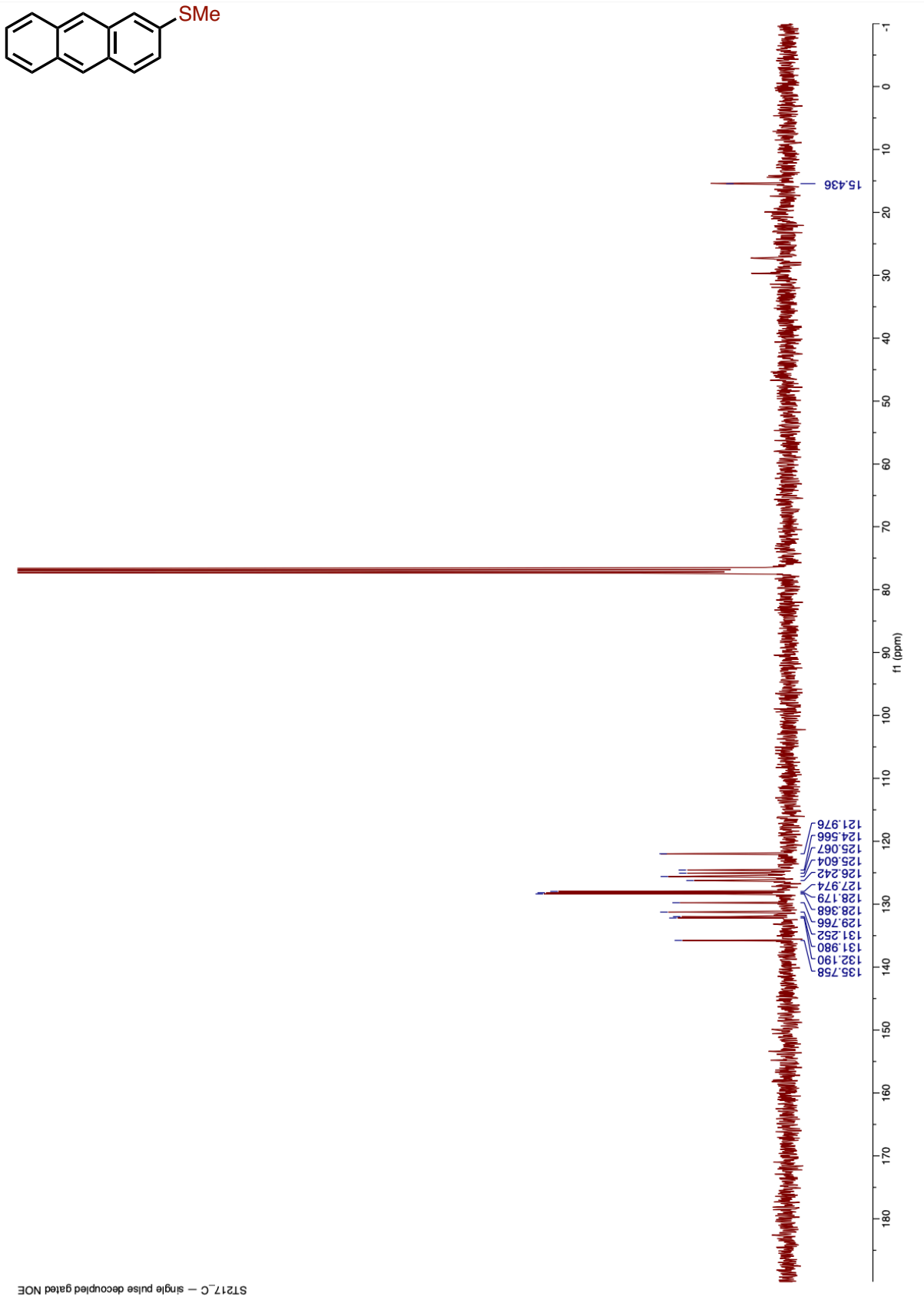


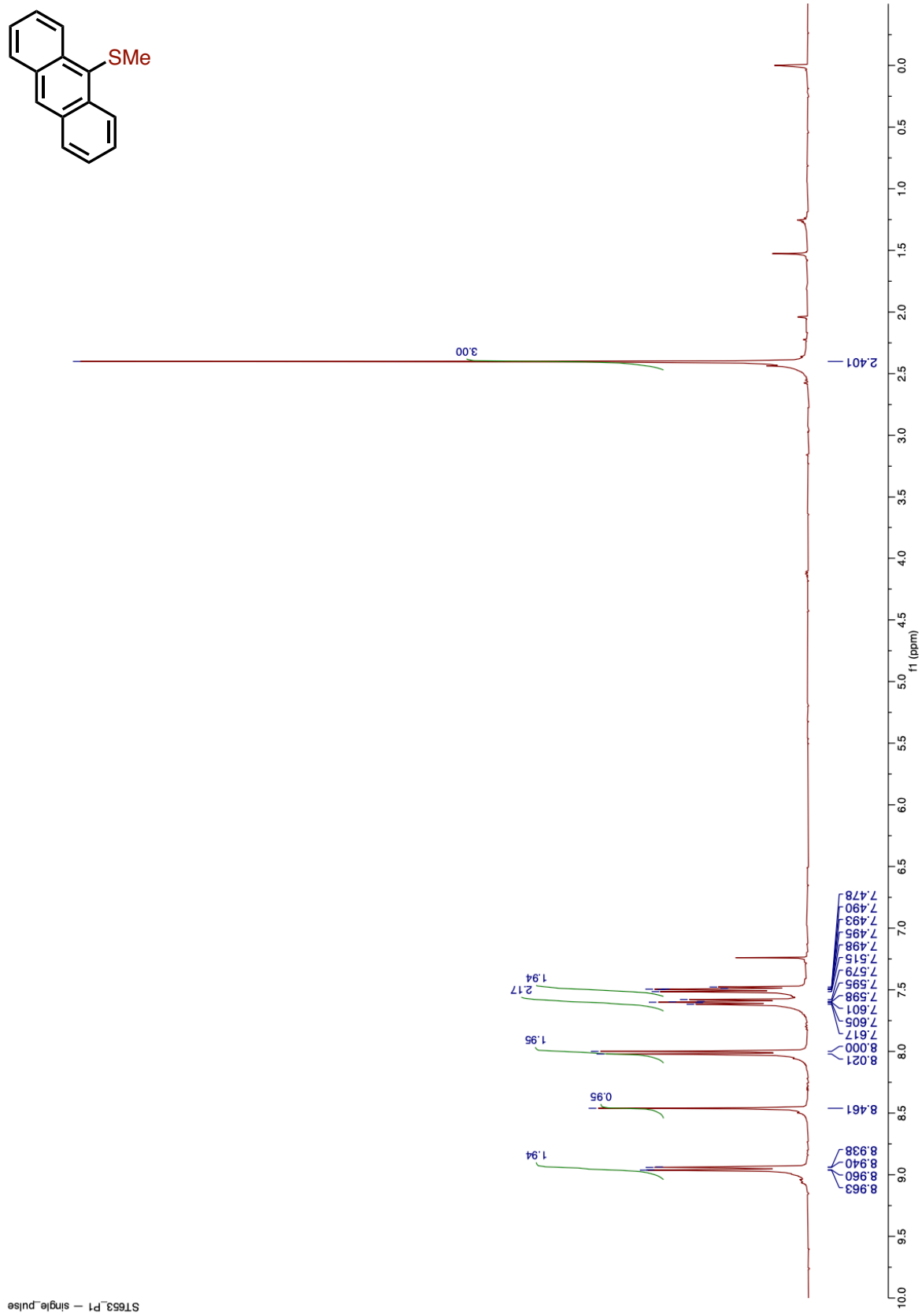
^{1}H NMR of **3d** (400 MHz, $CDCl_3$)



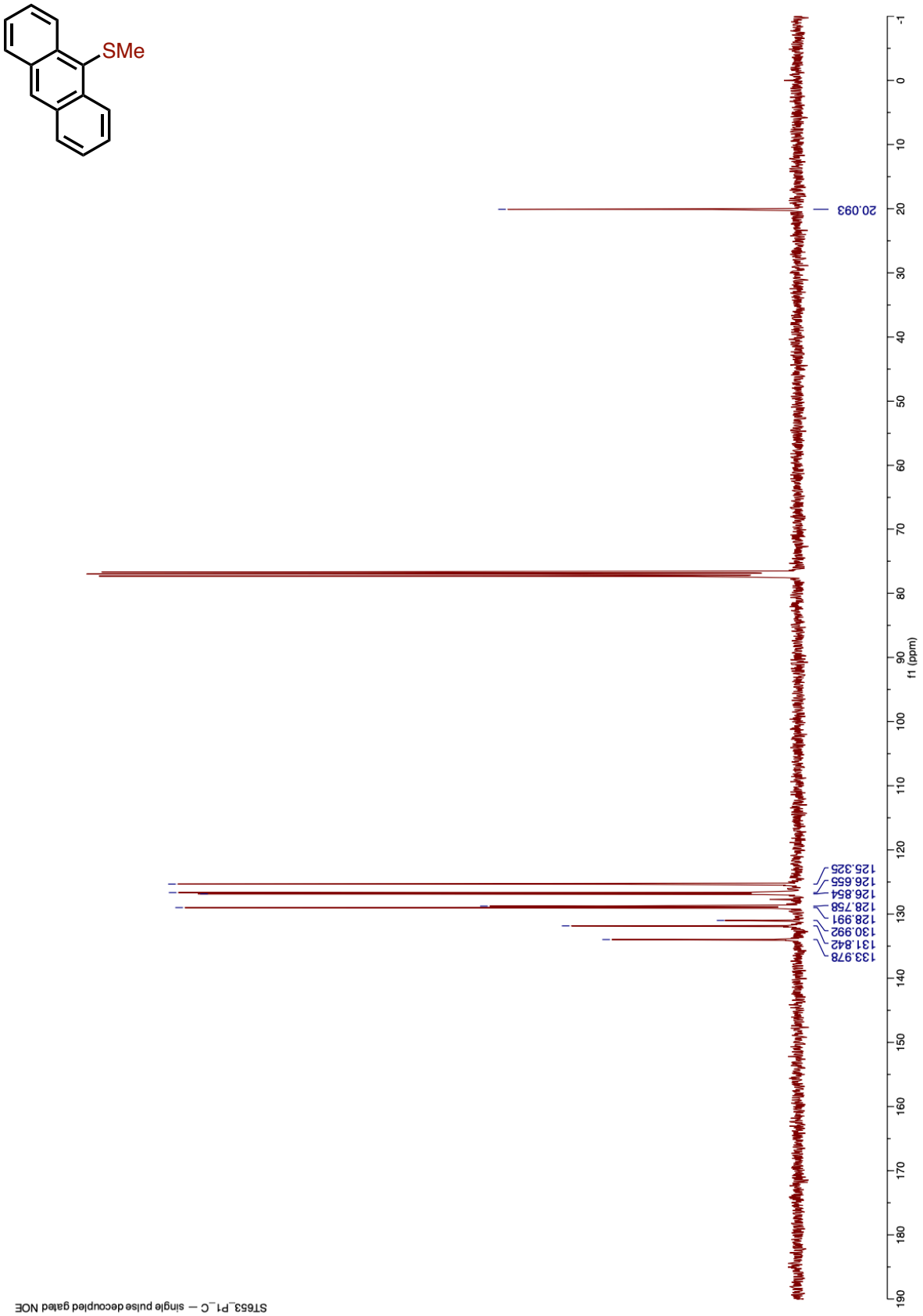
^{13}C NMR of **3d** (101 MHz, $CDCl_3$)



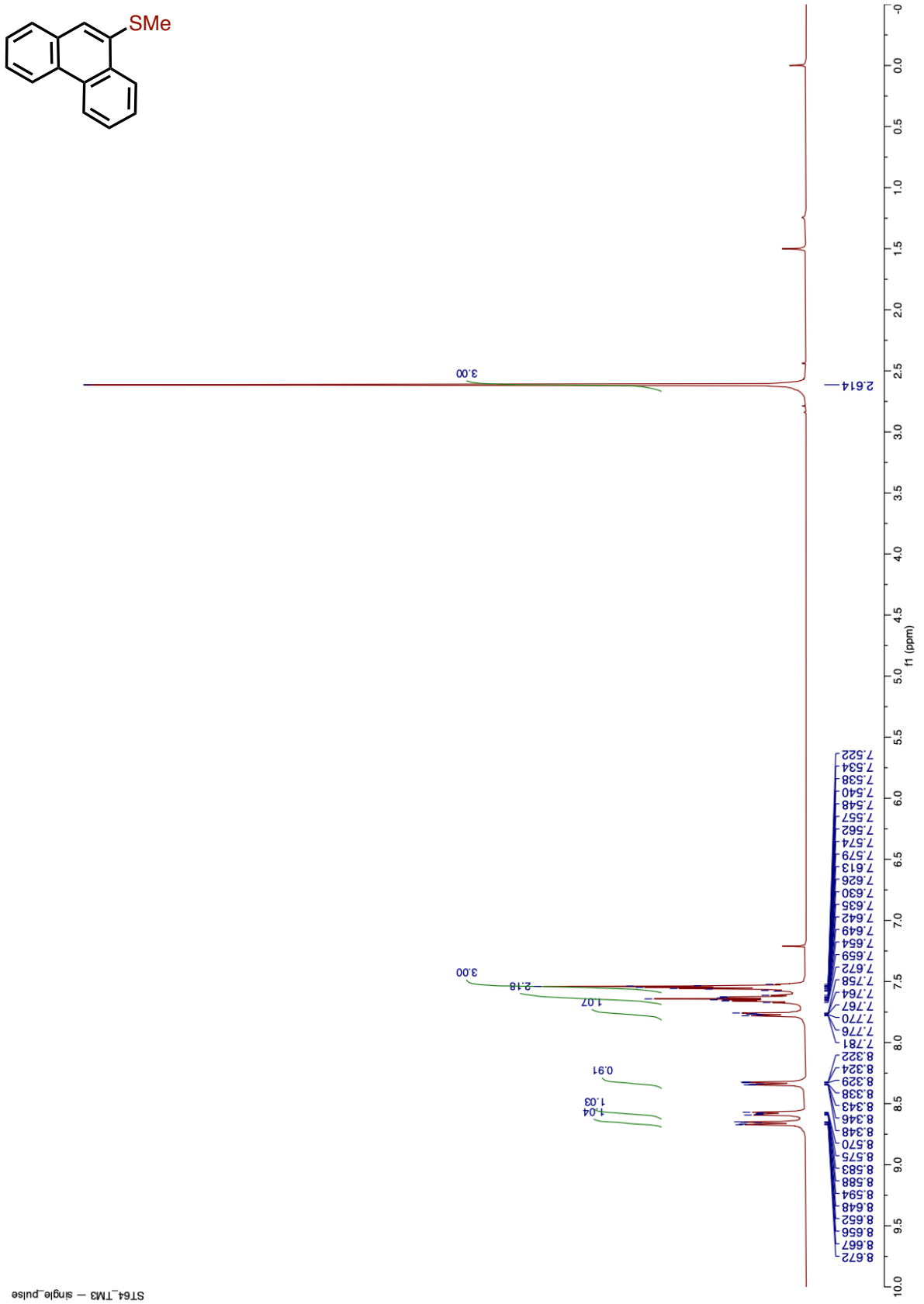
^{1}H NMR of **3e** (400 MHz, $CDCl_3$)



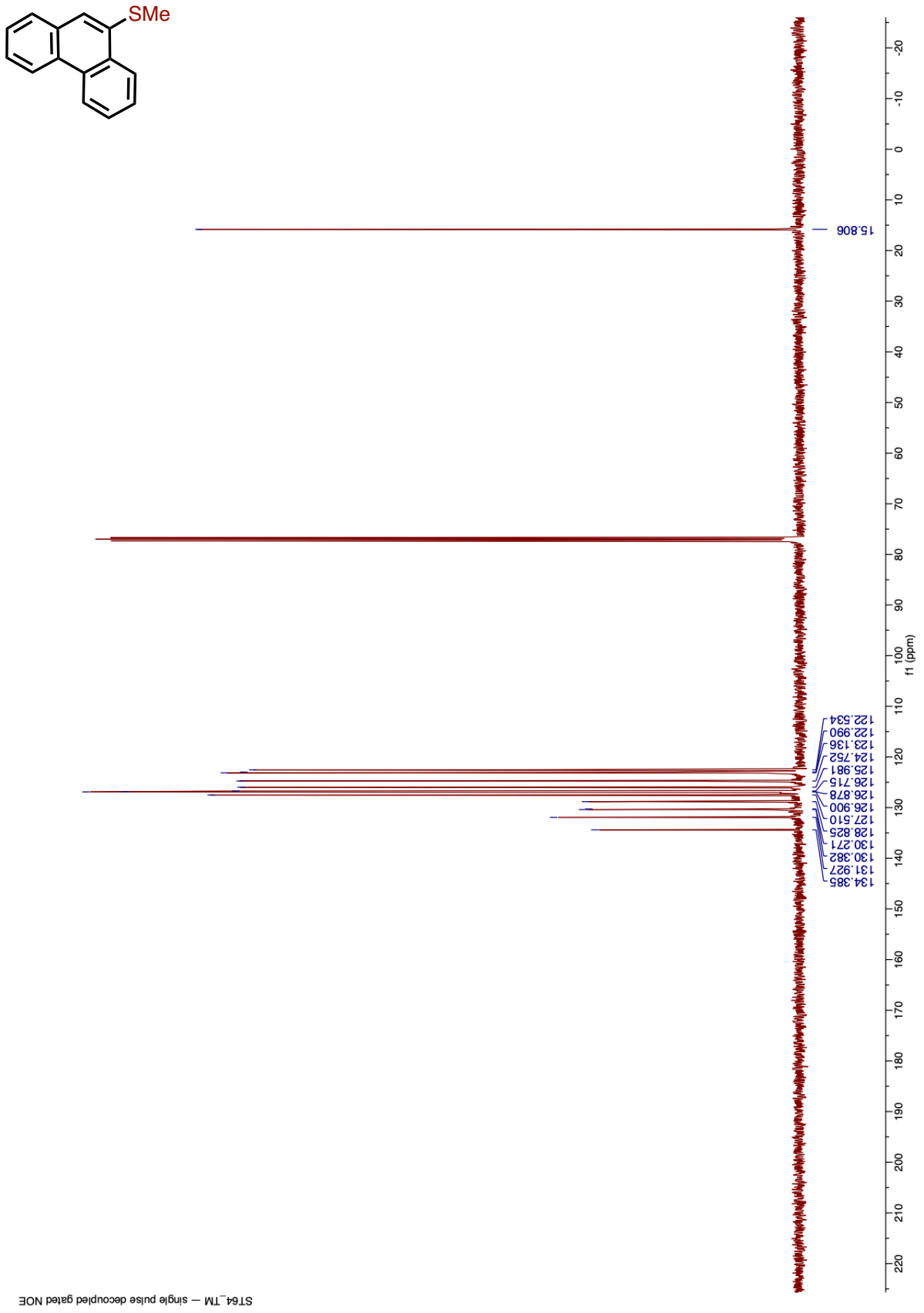
^{13}C NMR of **3e** (101 MHz, $CDCl_3$)



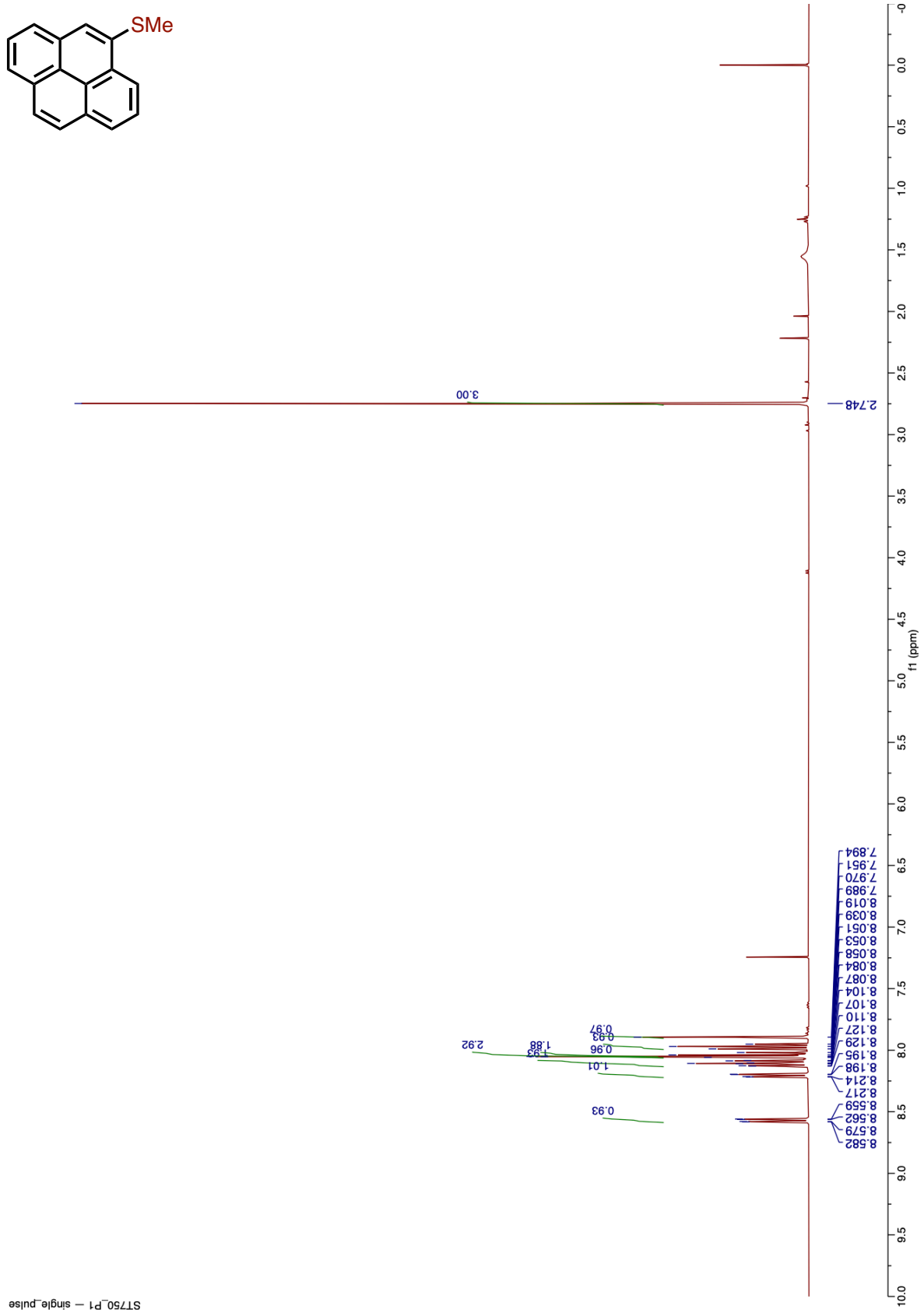
^{1}H NMR of **3f** (400 MHz, $CDCl_3$)



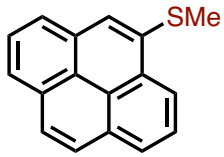
^{13}C NMR of **3f** (101 MHz, $CDCl_3$)



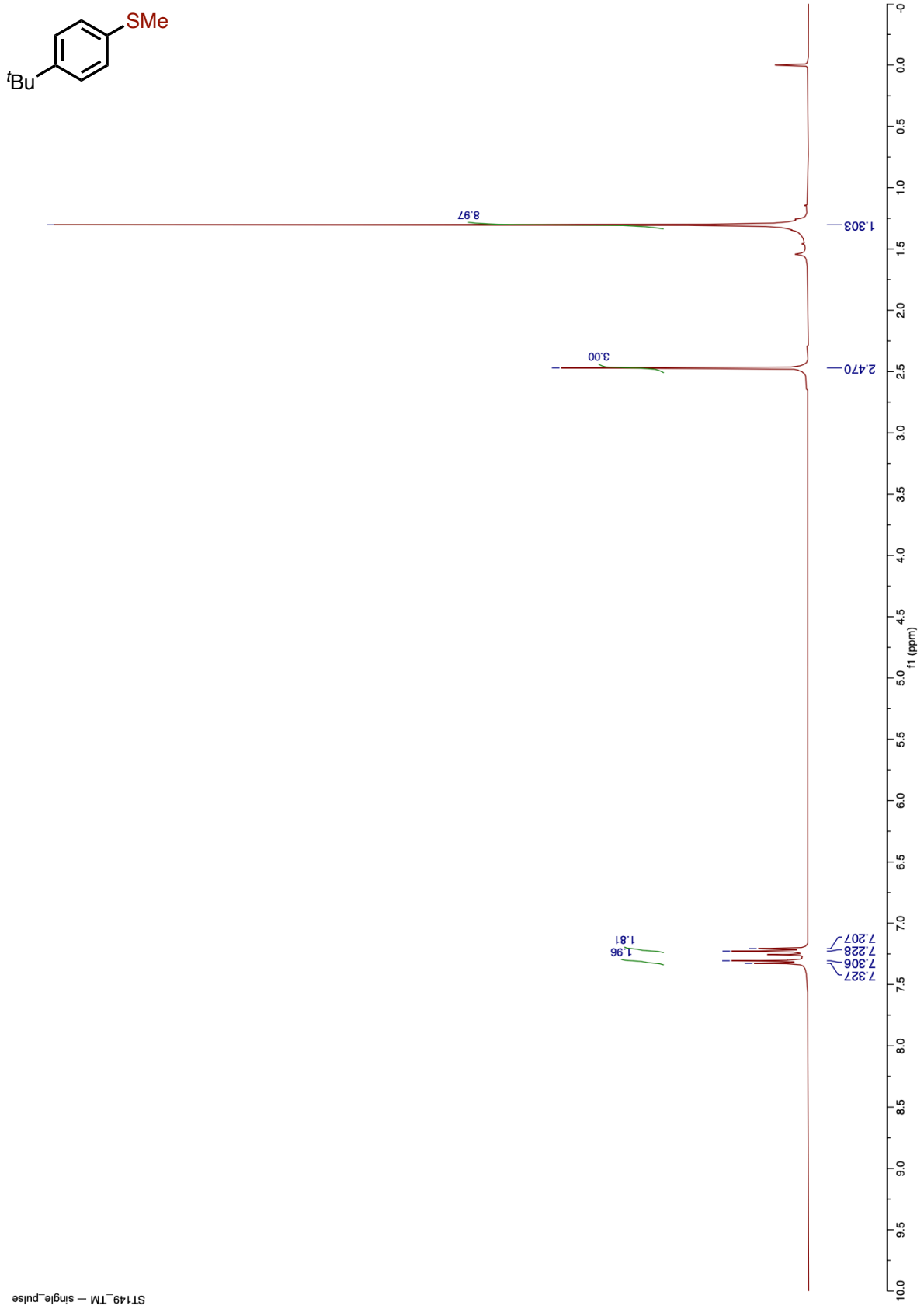
^{1}H NMR of **3g** (400 MHz, $CDCl_3$)



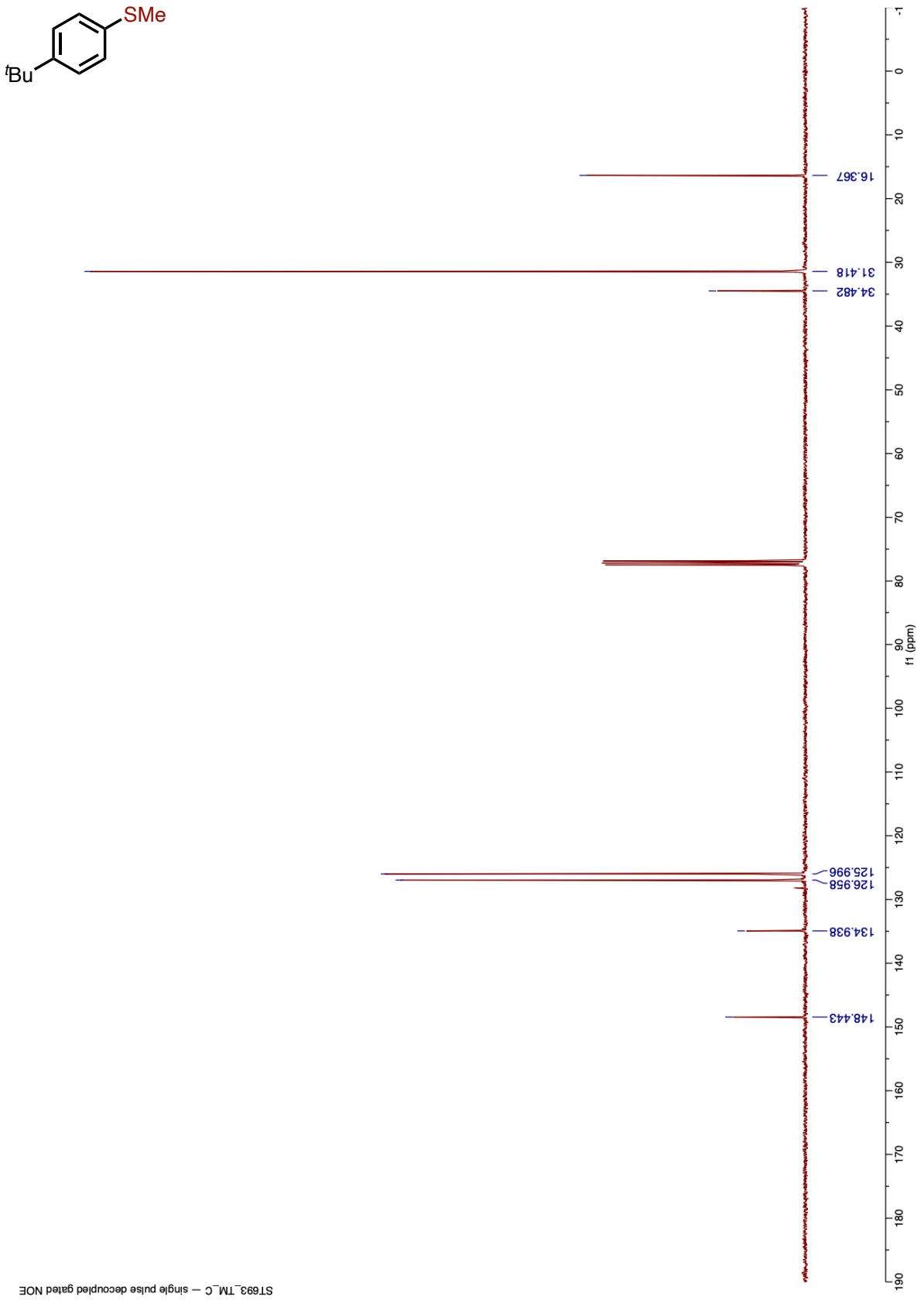
^{13}C NMR of **3g** (101 MHz, $CDCl_3$)



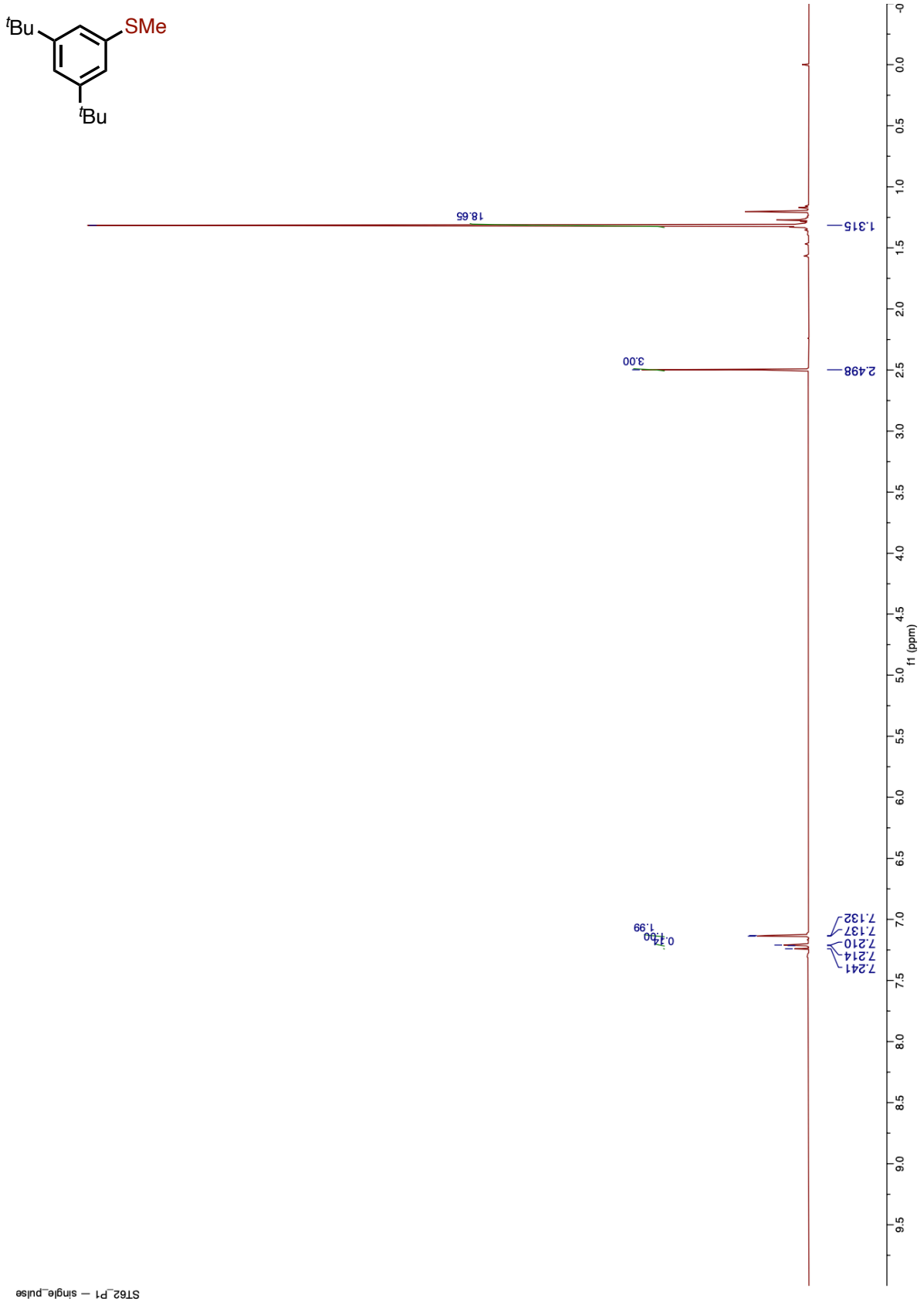
^{1}H NMR of **3h** (400 MHz, $CDCl_3$)



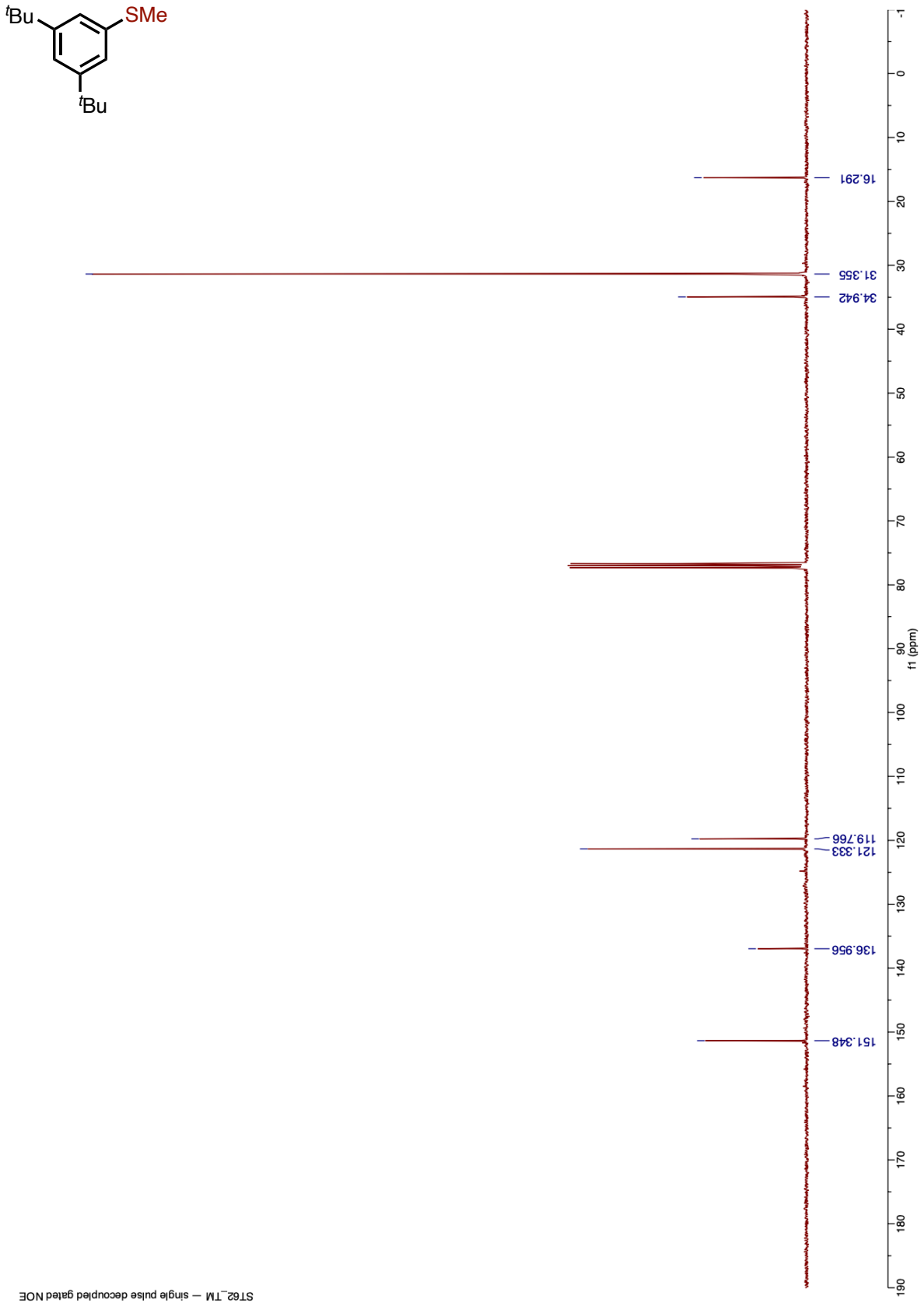
^{13}C NMR of **3h** (101 MHz, $CDCl_3$)



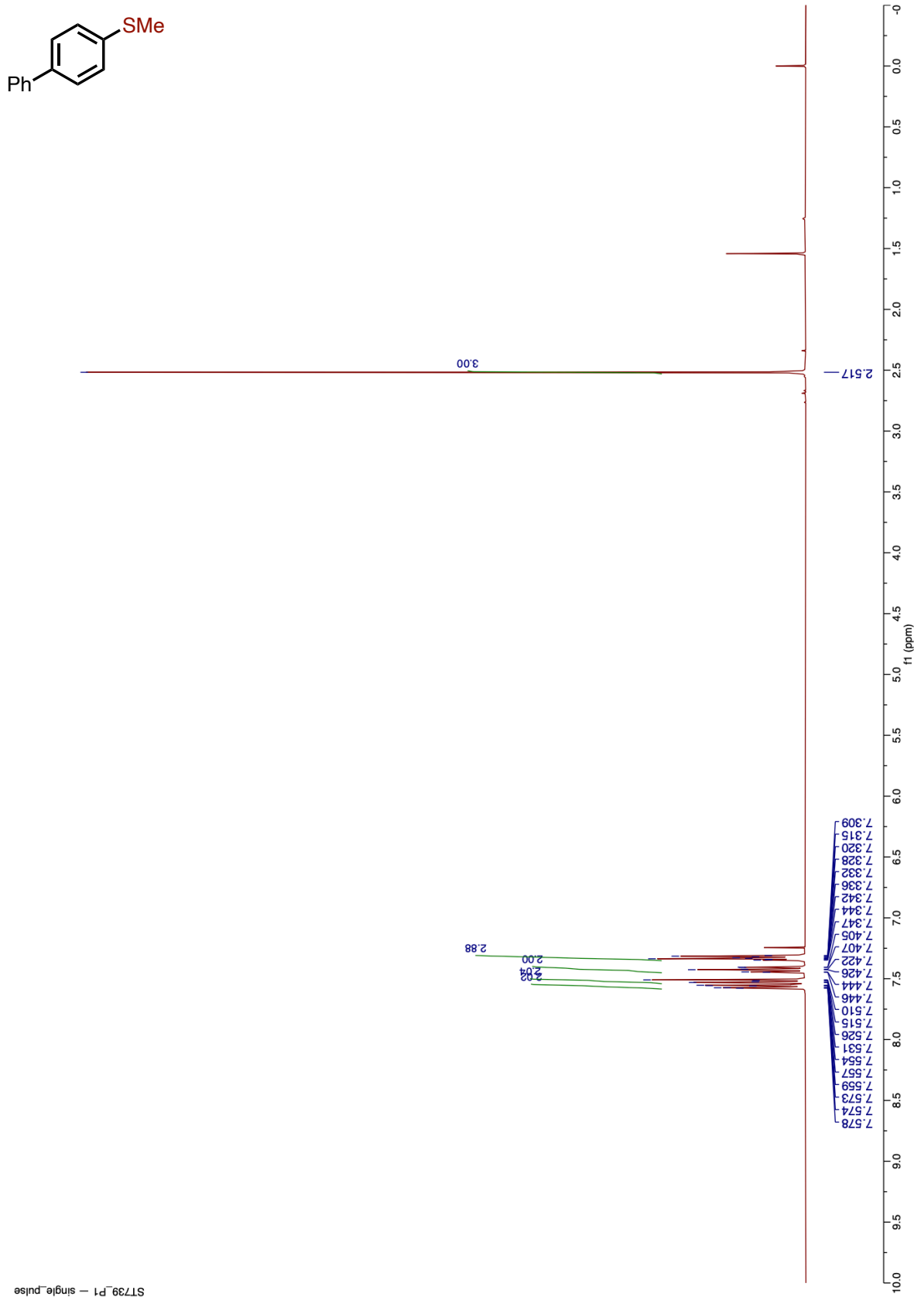
^{1}H NMR of **3i** (400 MHz, $CDCl_3$)



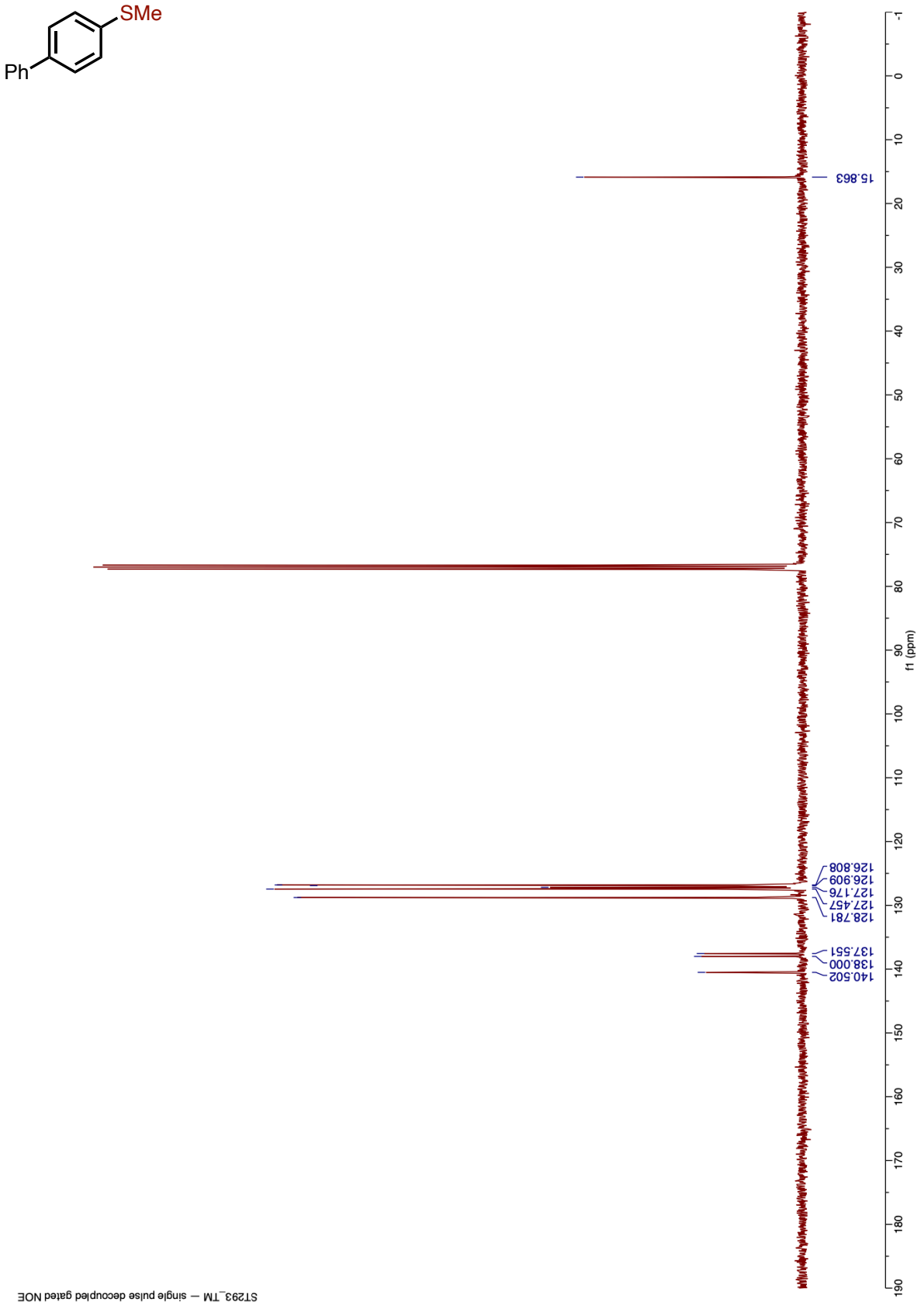
^{13}C NMR of **3i** (101 MHz, $CDCl_3$)



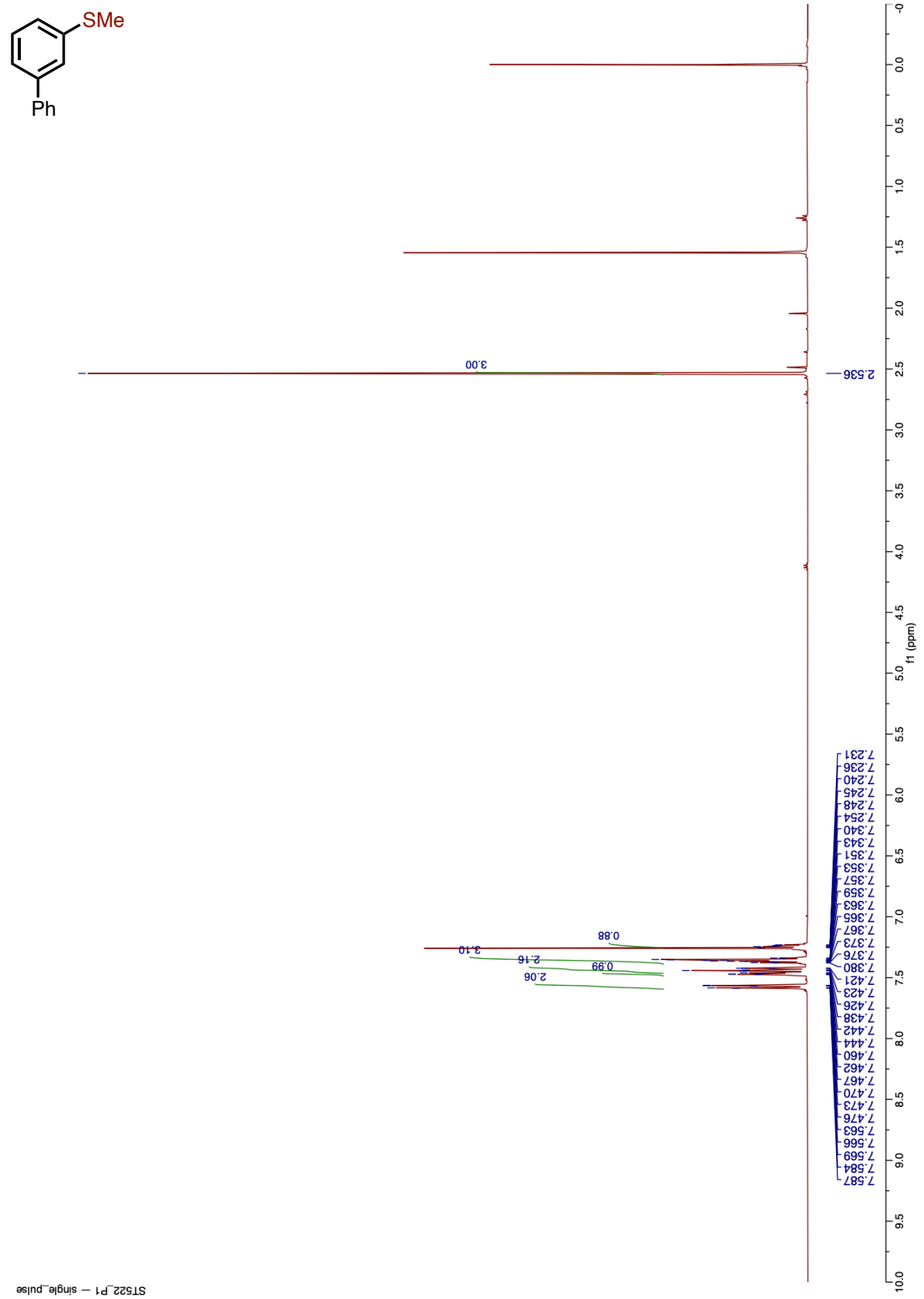
^{1}H NMR of **3j** (400 MHz, $CDCl_3$)



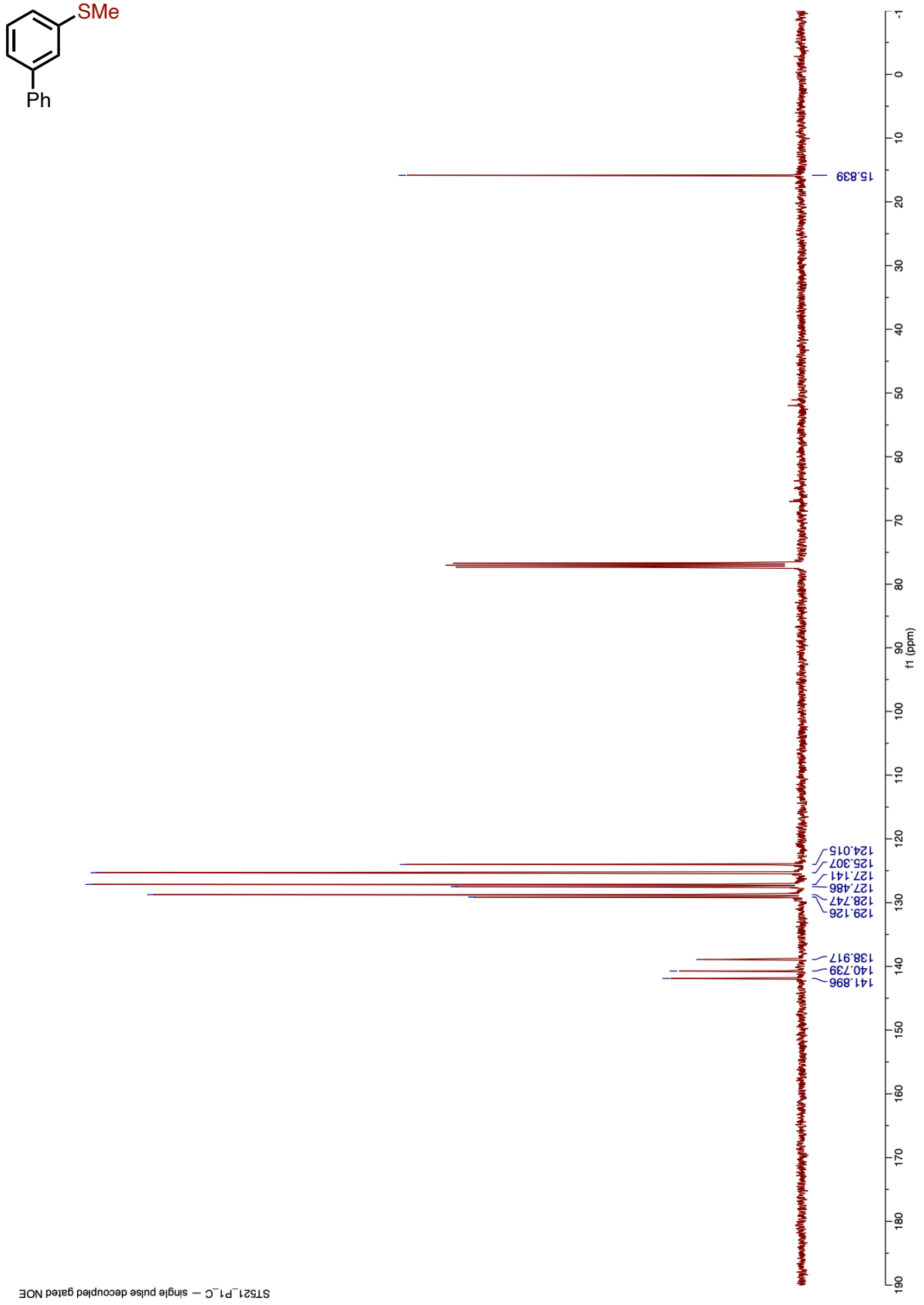
^{13}C NMR of **3j** (101 MHz, $CDCl_3$)



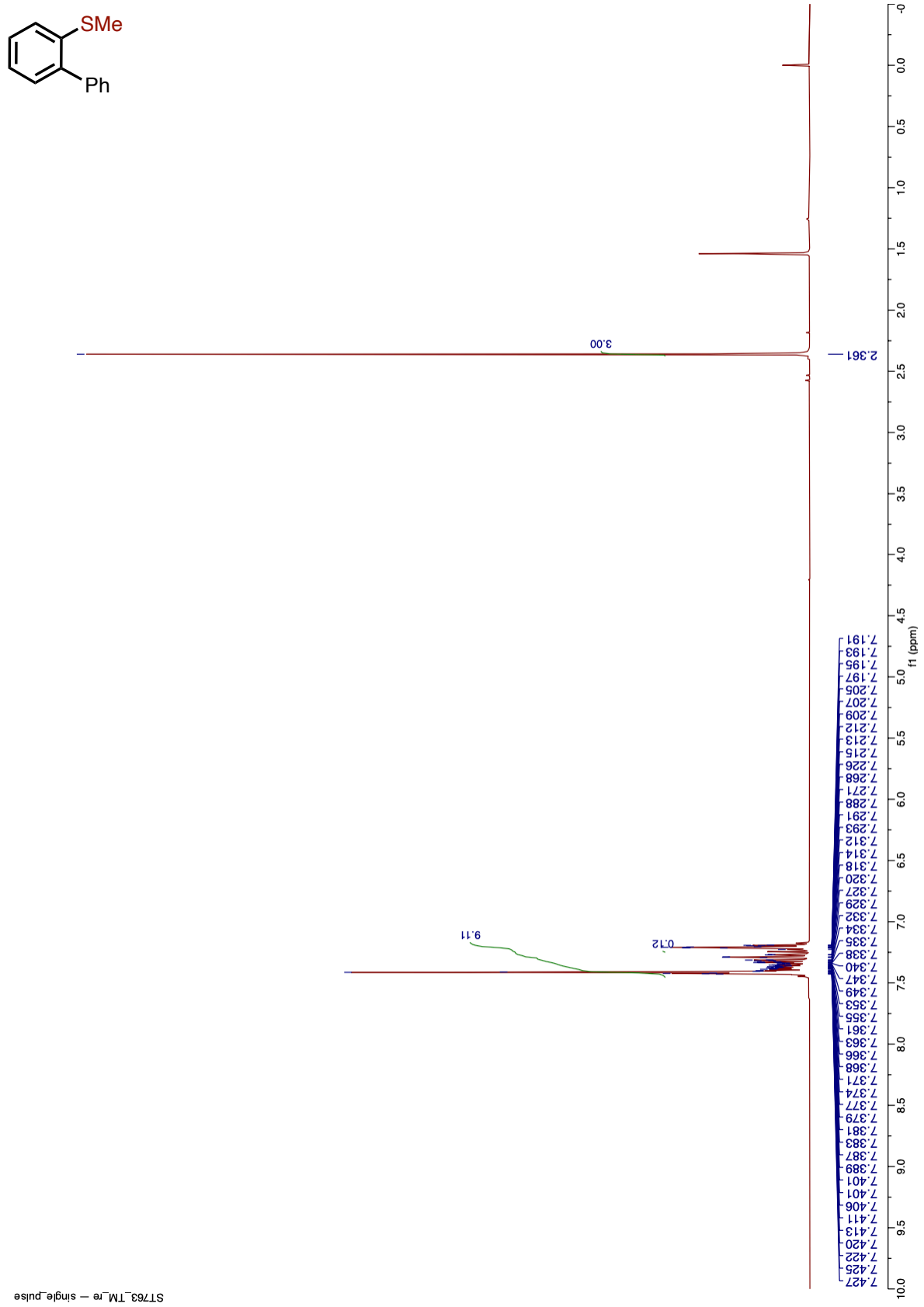
^{1}H NMR of **3k** (400 MHz, $CDCl_3$)



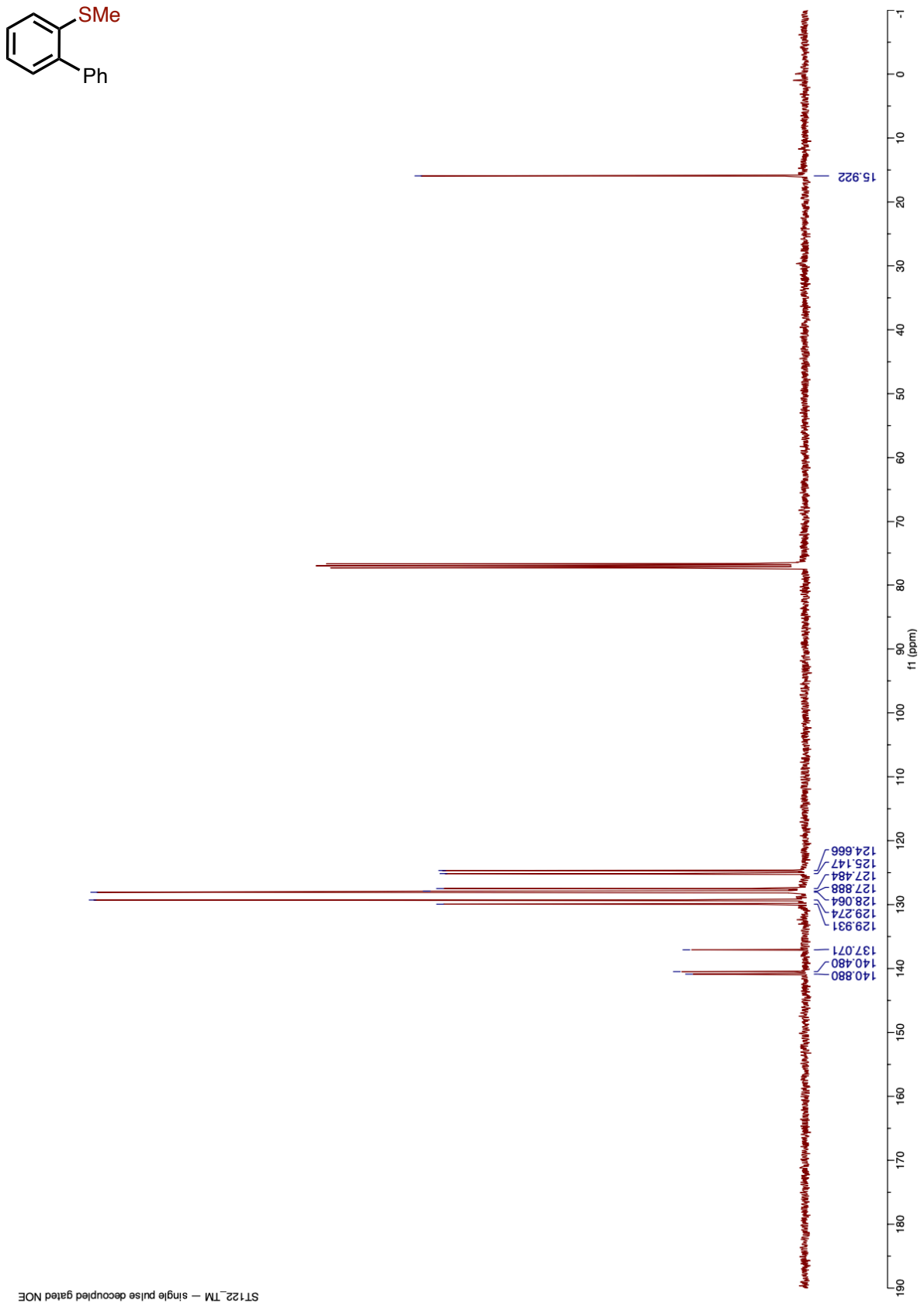
^{13}C NMR of **3k** (101 MHz, $CDCl_3$)



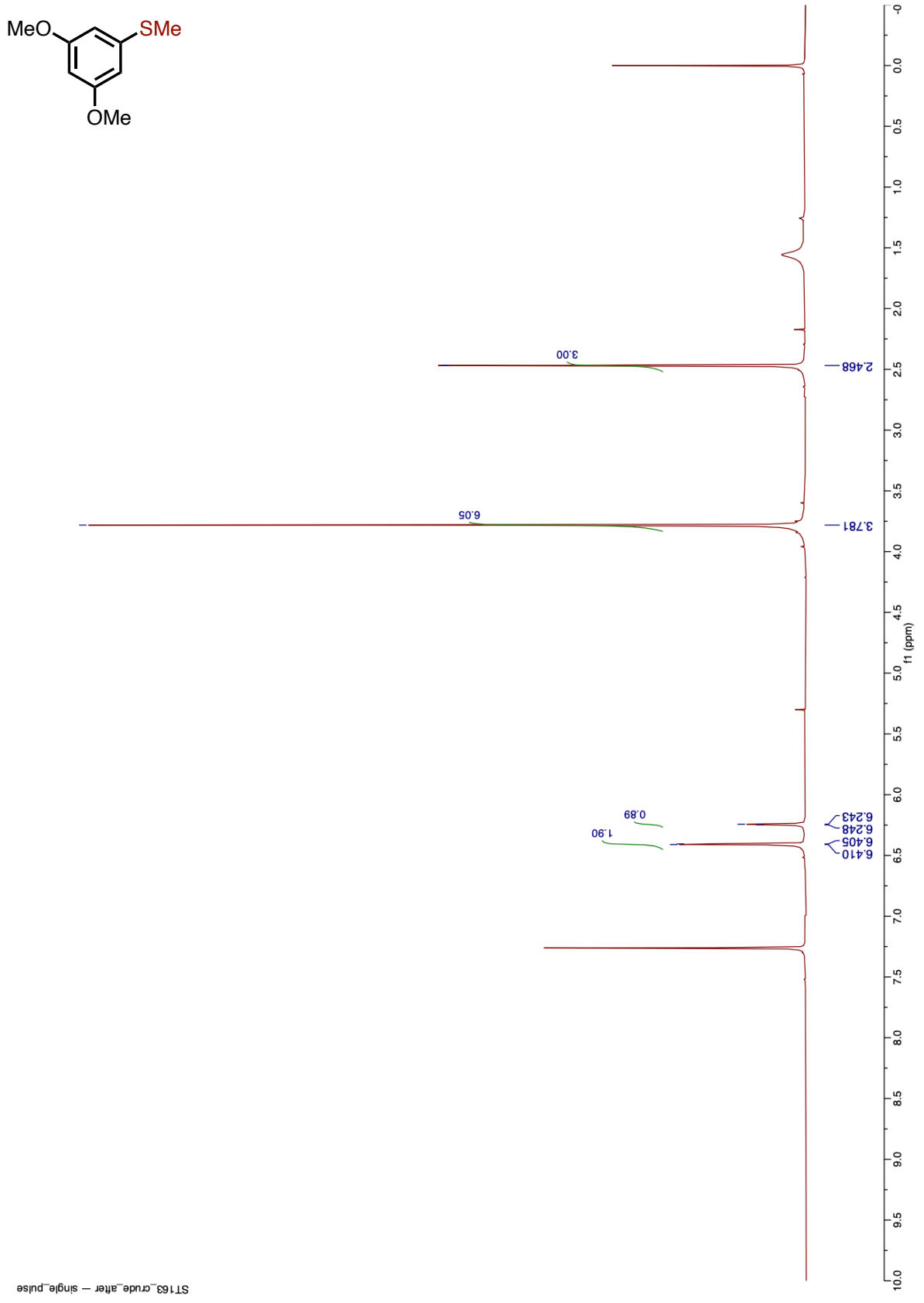
^{1}H NMR of **3l** (400 MHz, $CDCl_3$)



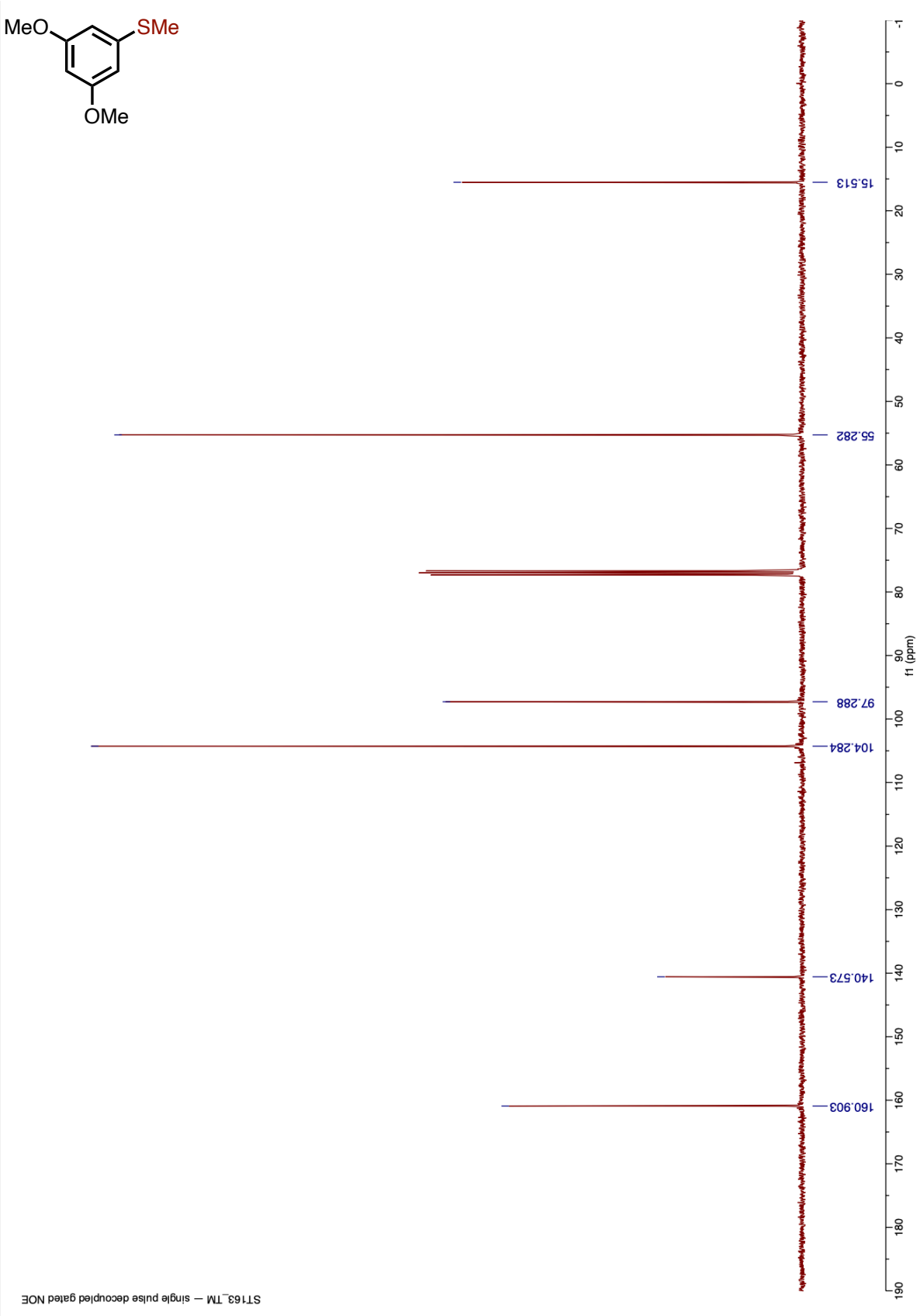
^{13}C NMR of **3l** (101 MHz, $CDCl_3$)



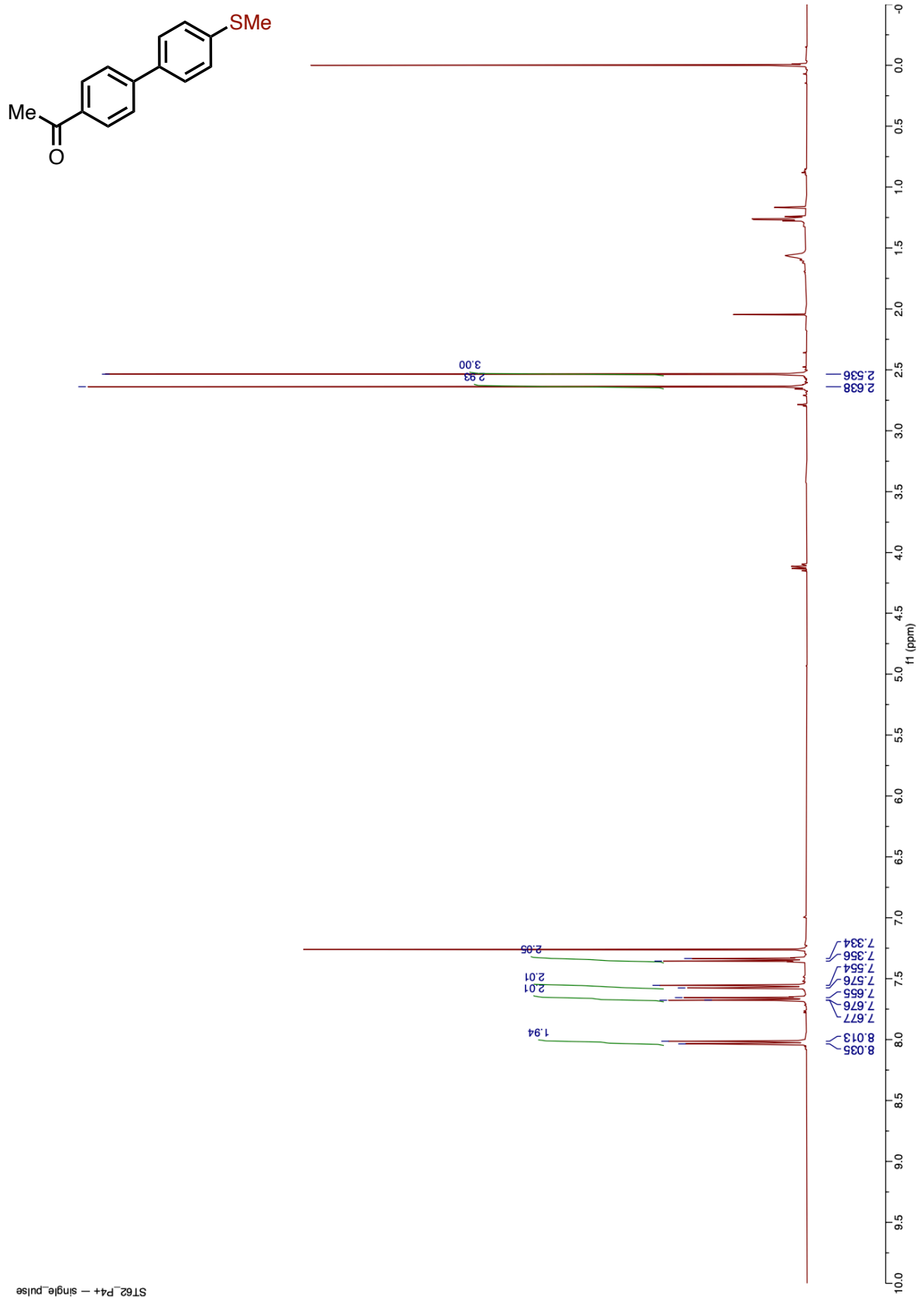
^{1}H NMR of **3m** (400 MHz, $CDCl_3$)



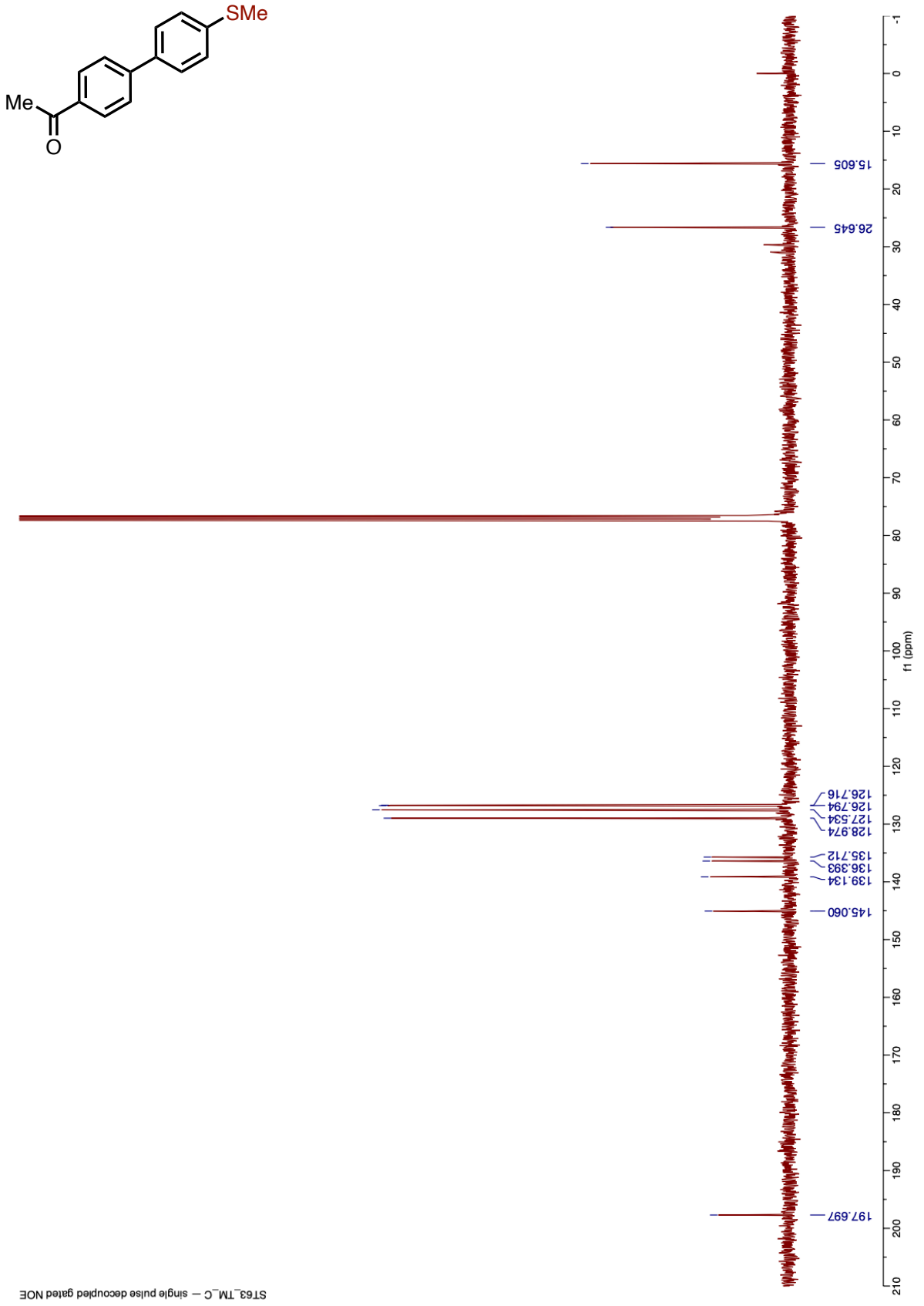
^{13}C NMR of **3m** (101 MHz, $CDCl_3$)



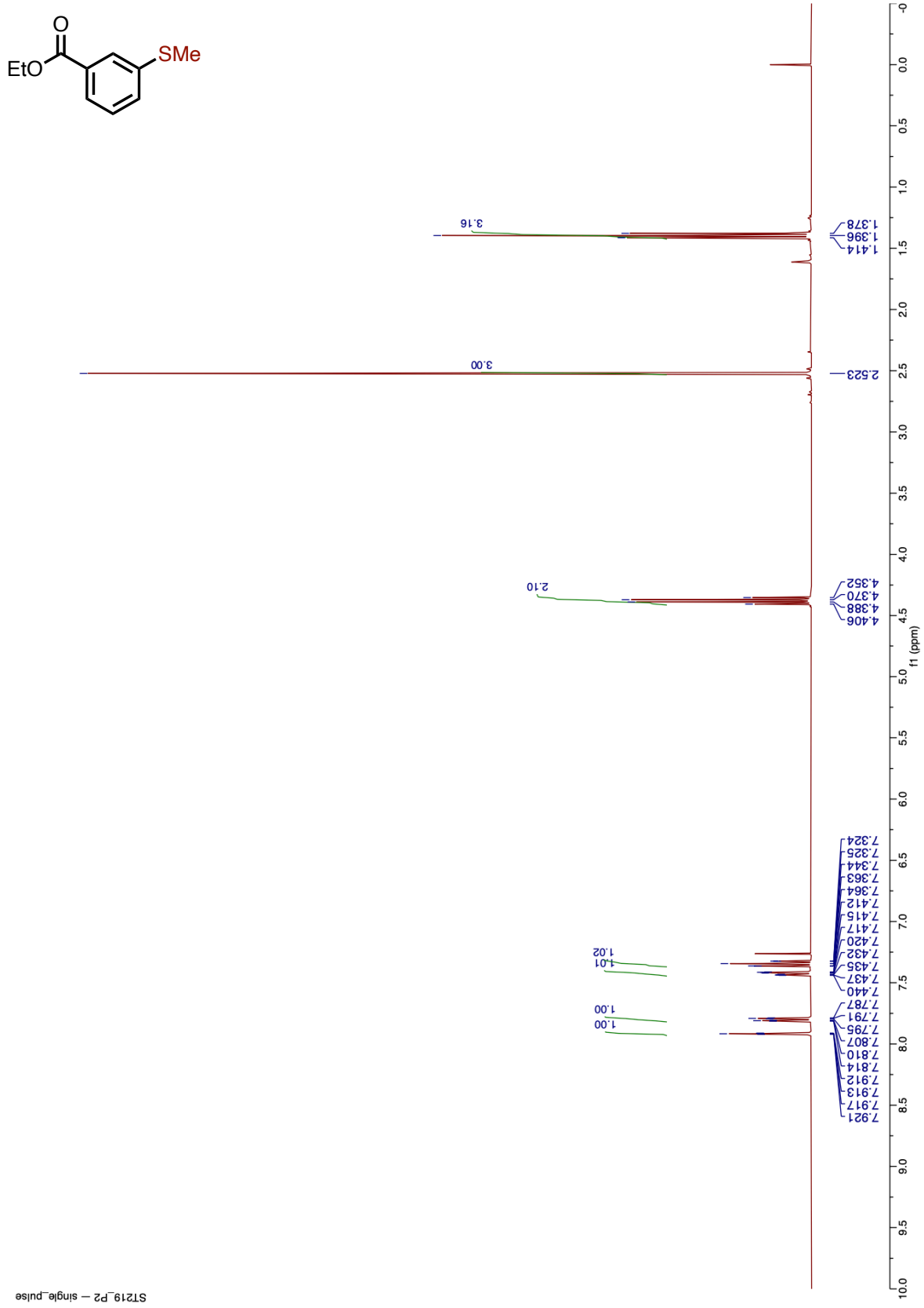
^{1}H NMR of **3n** (400 MHz, $CDCl_3$)



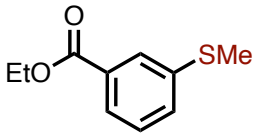
^{13}C NMR of **3n** (101 MHz, $CDCl_3$)



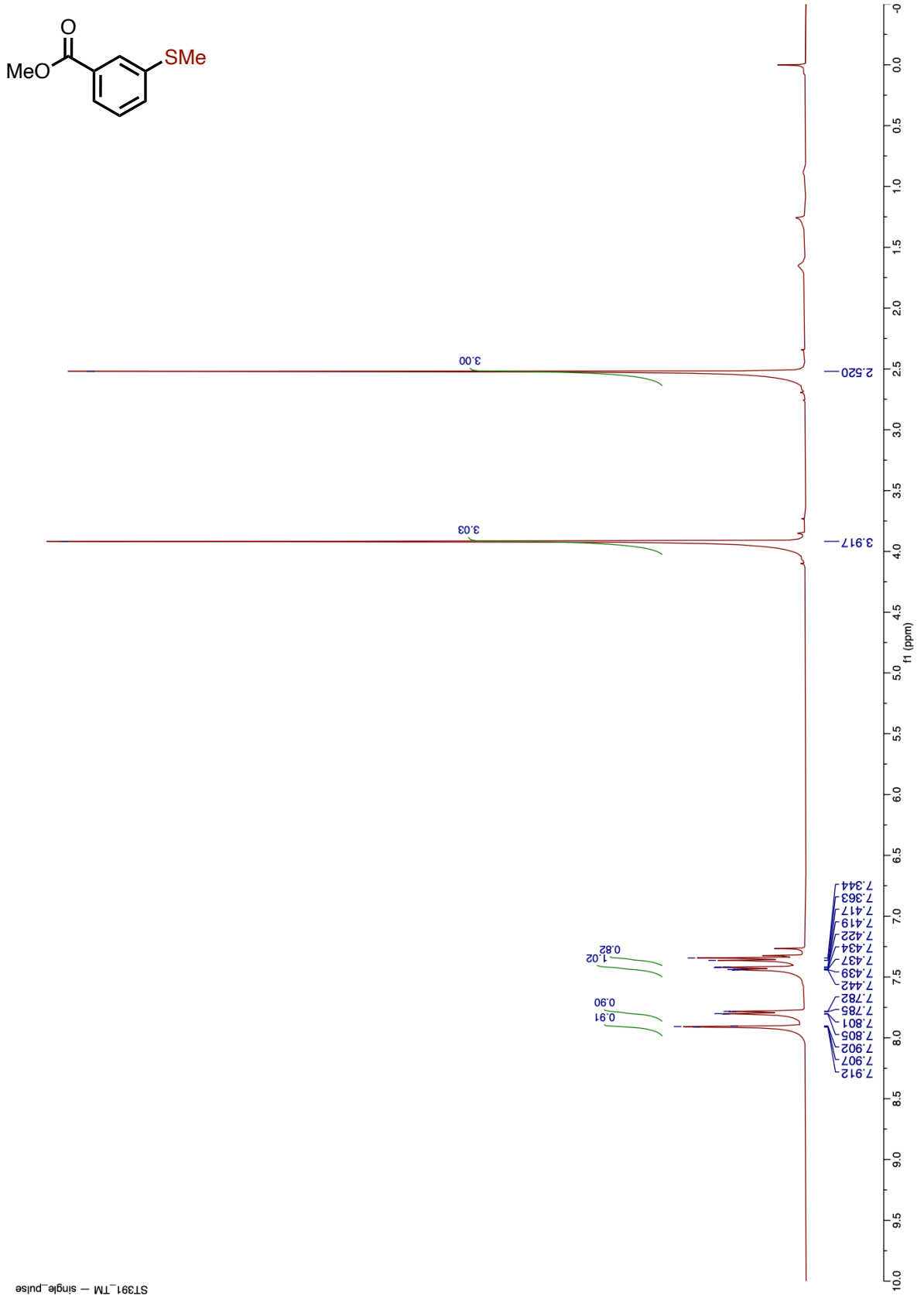
^{1}H NMR of **3o** (400 MHz, $CDCl_3$)



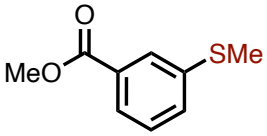
^{13}C NMR of **3o** (101 MHz, $CDCl_3$)



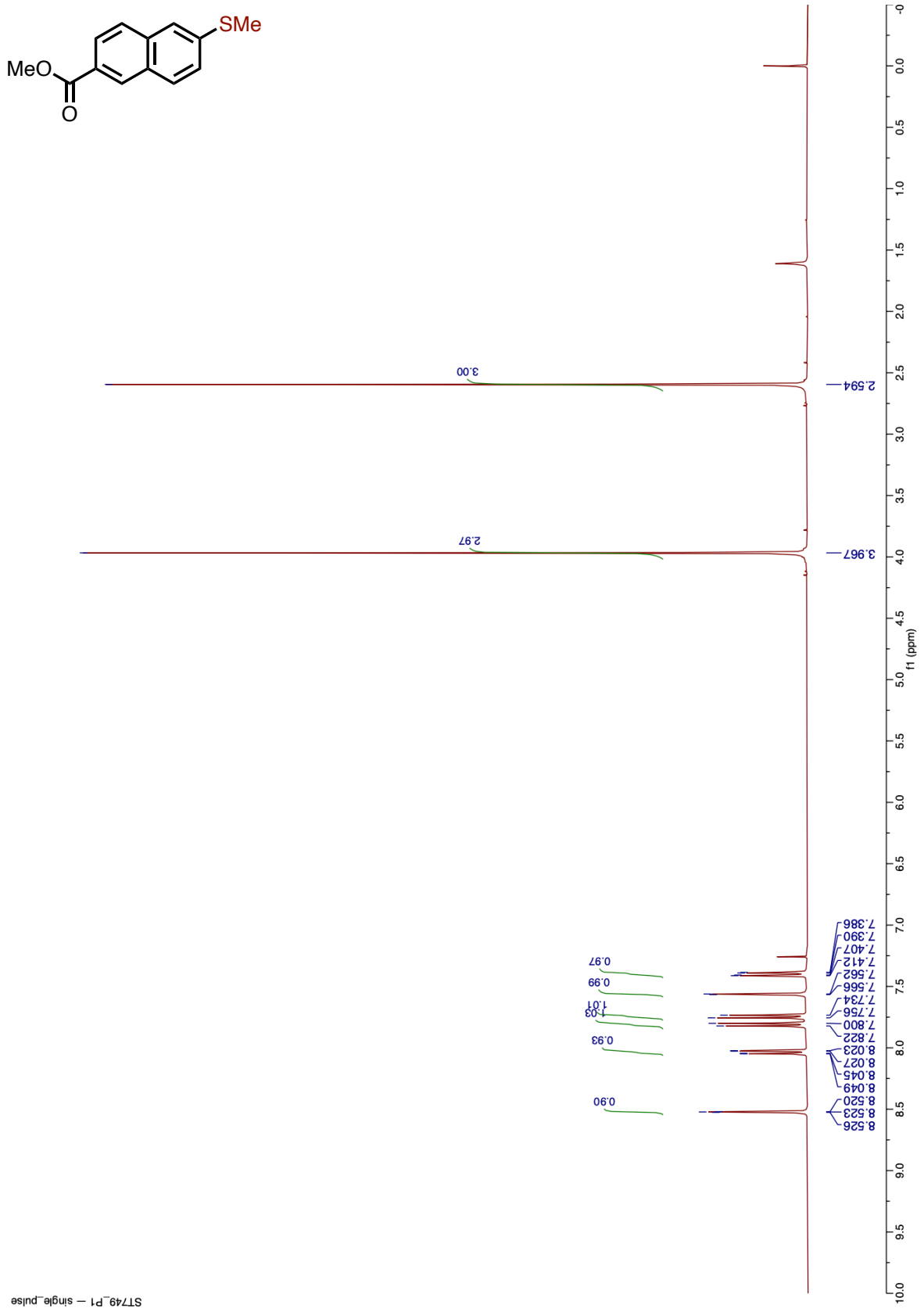
^{1}H NMR of **3p** (400 MHz, $CDCl_3$)



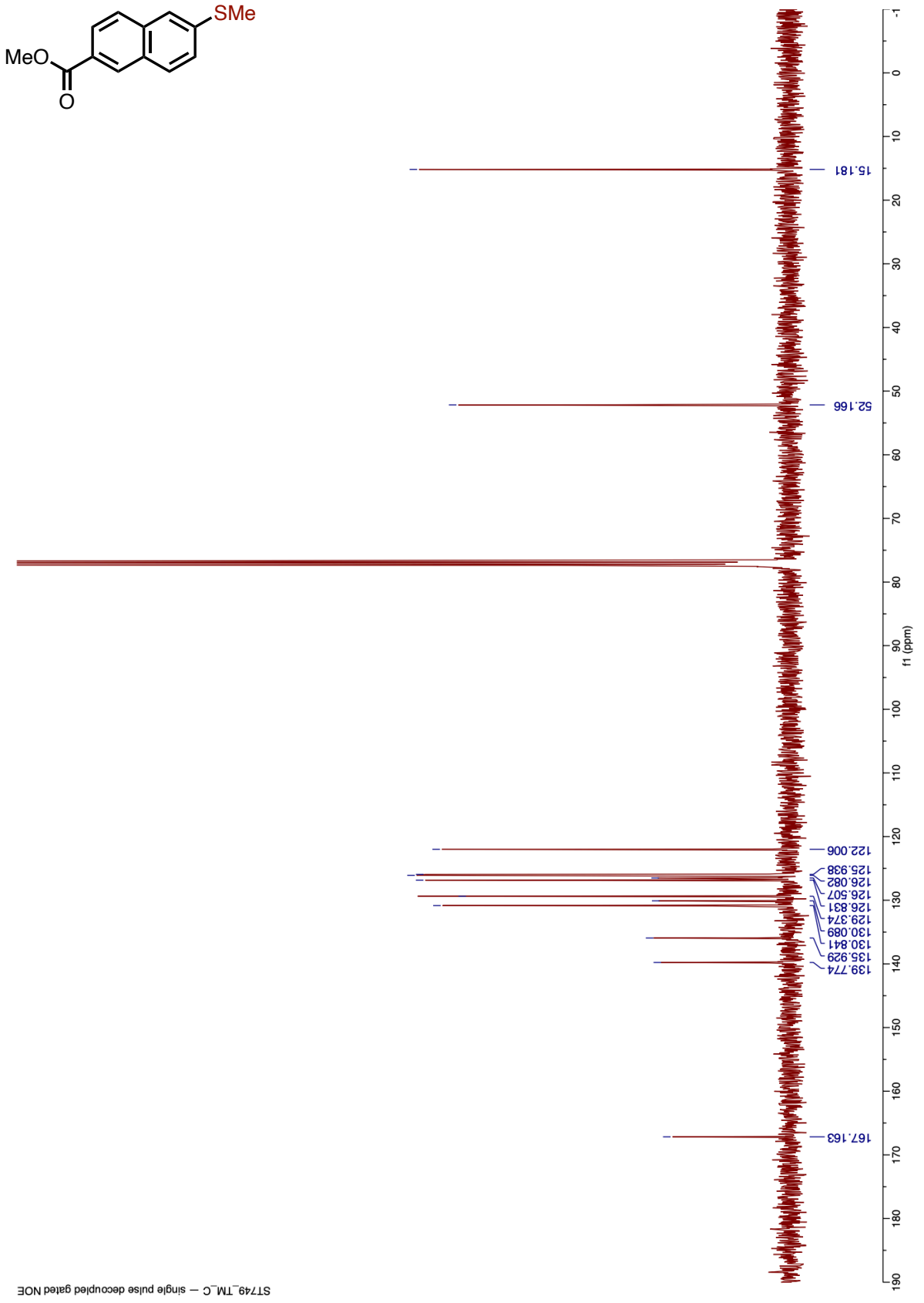
^{13}C NMR of **3p** (101 MHz, $CDCl_3$)



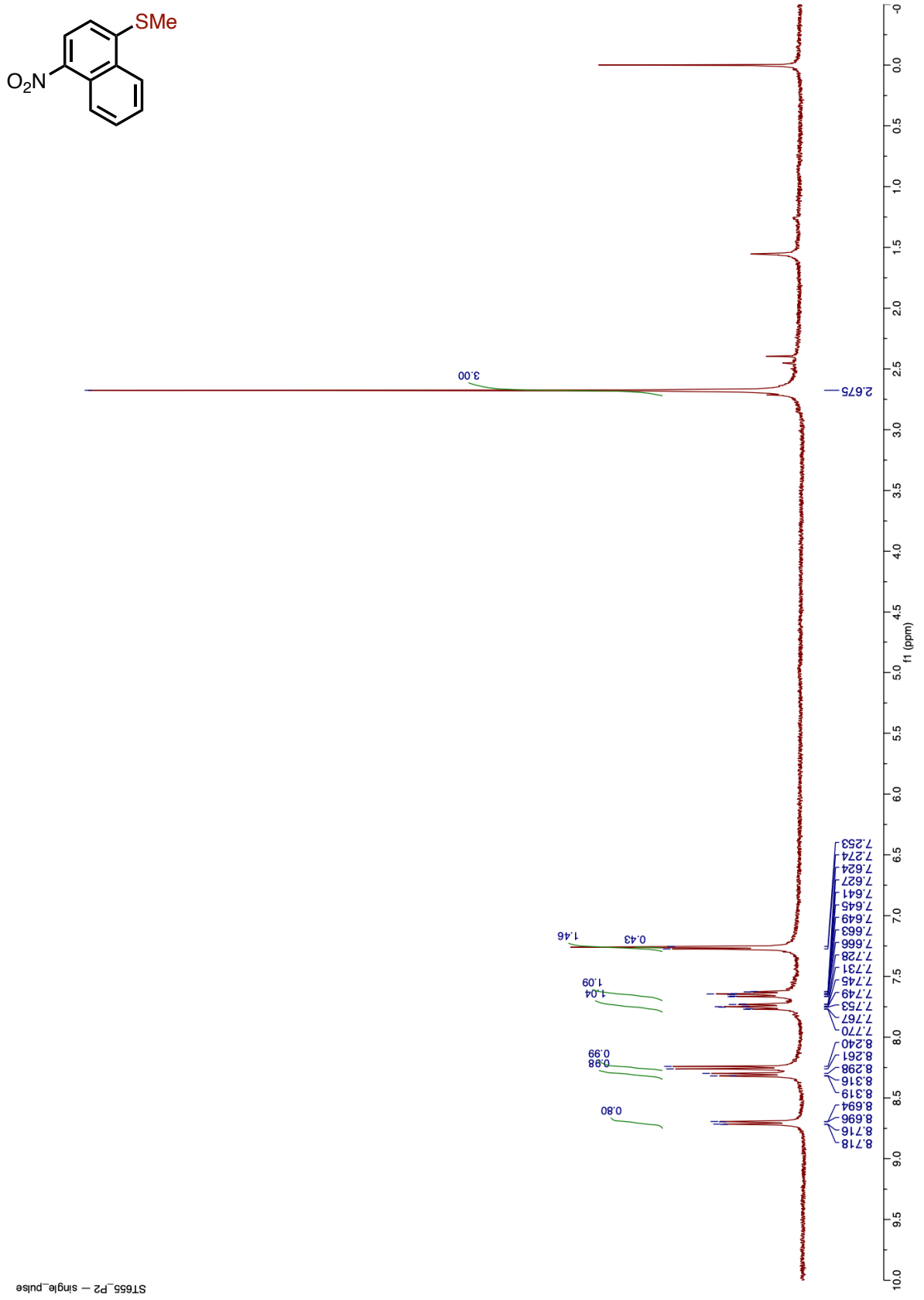
^{1}H NMR of **3q** (400 MHz, $CDCl_3$)



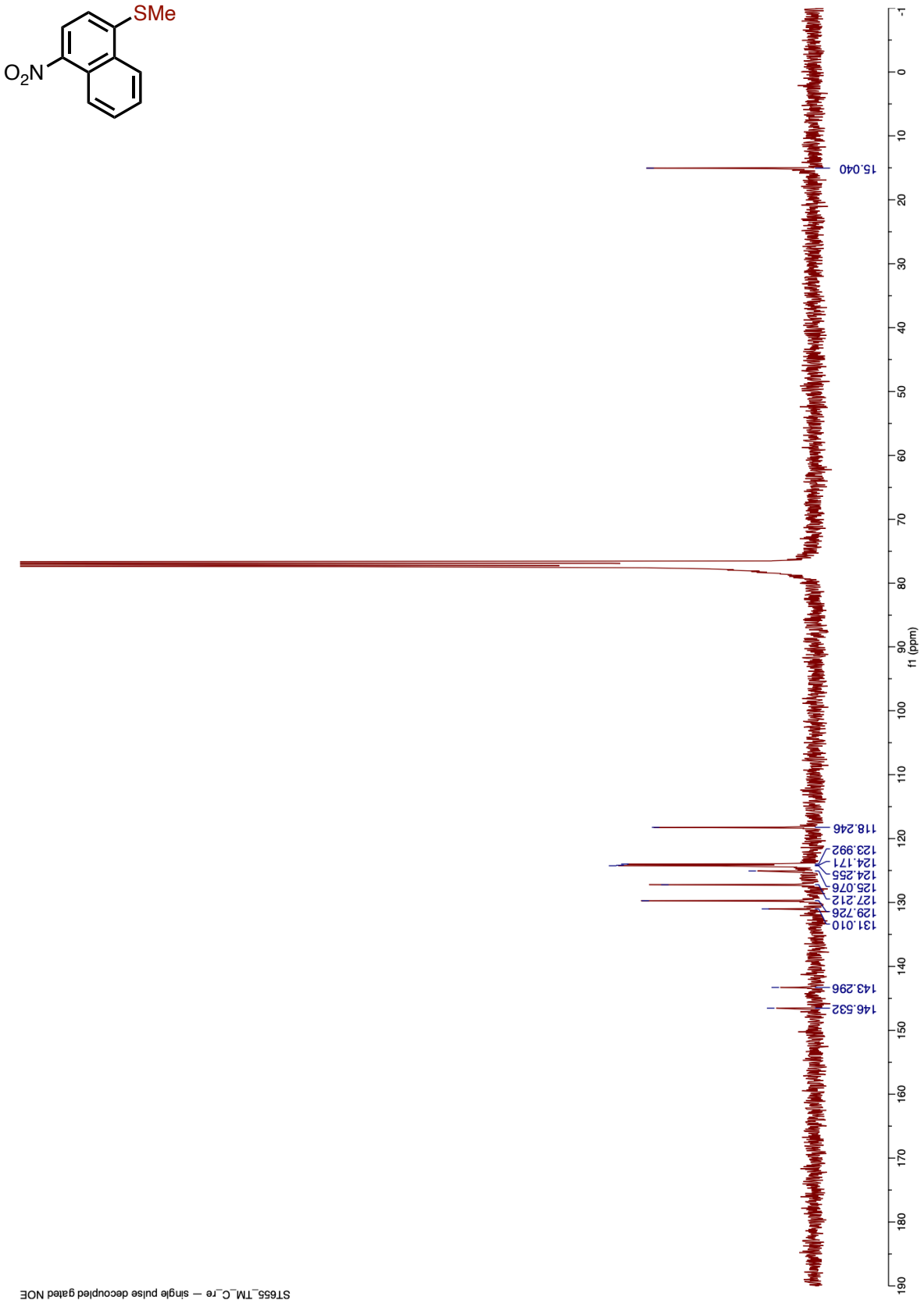
^{13}C NMR of **3q** (101 MHz, $CDCl_3$)



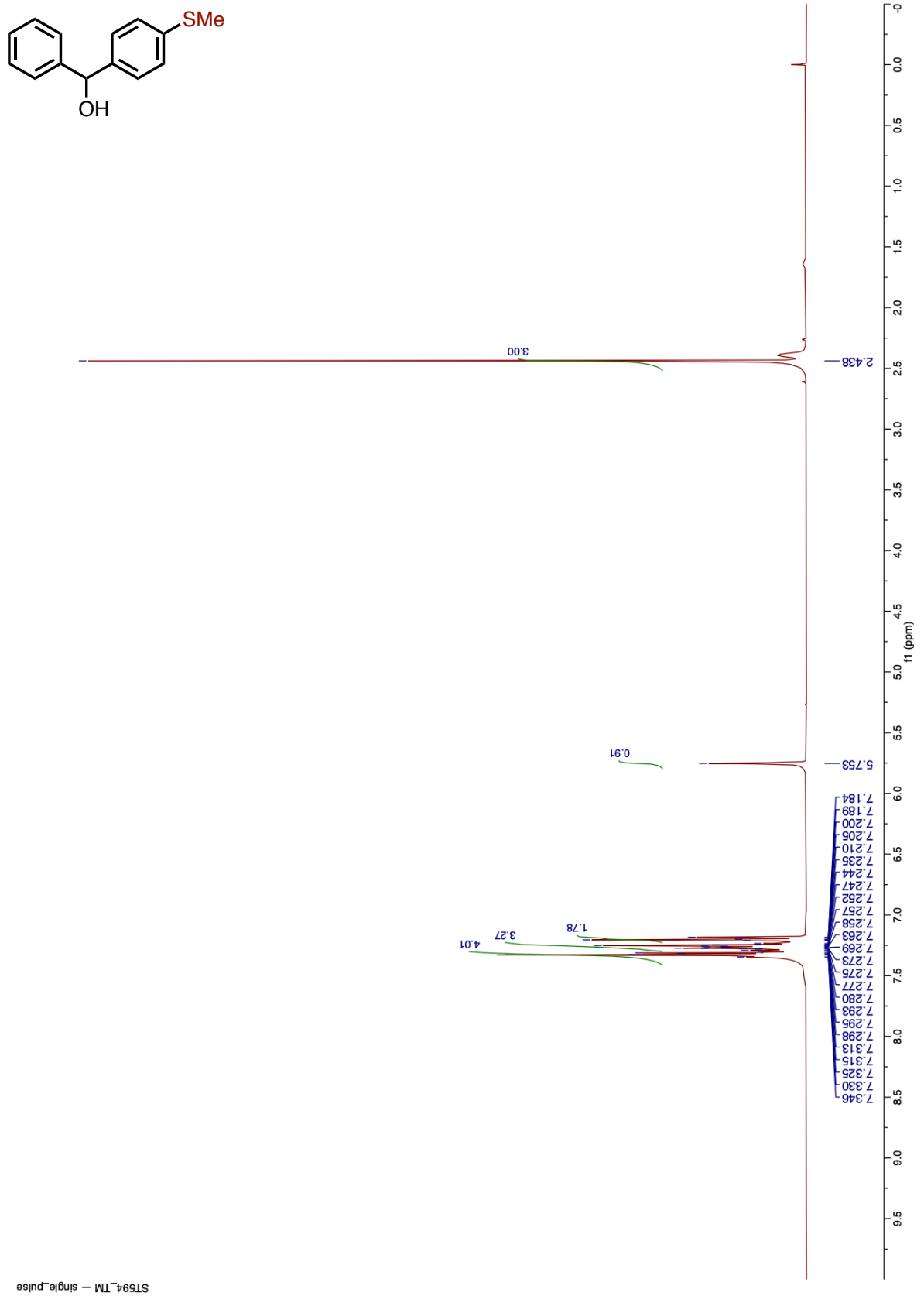
^{1}H NMR of **3r** (400 MHz, $CDCl_3$)



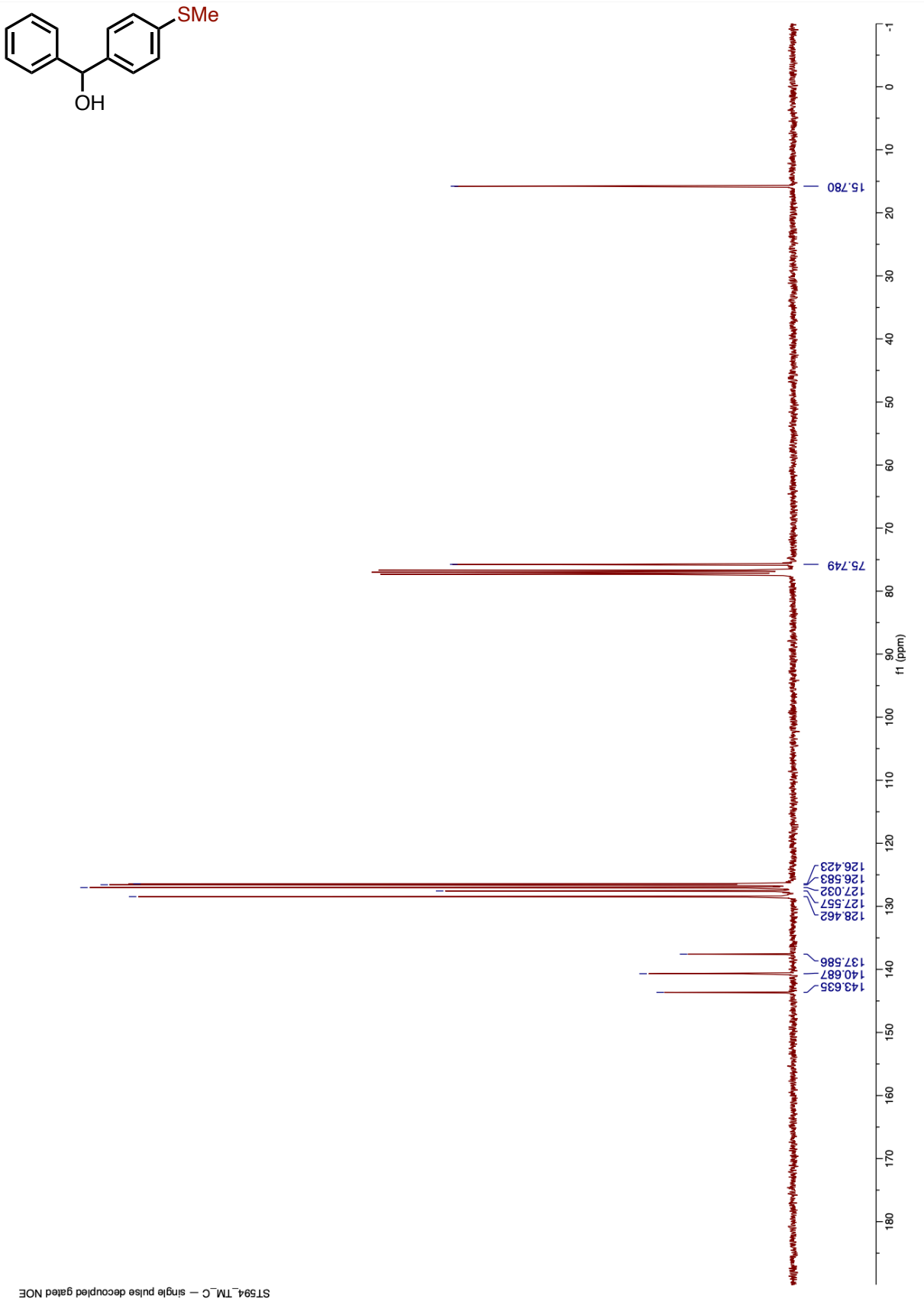
^{13}C NMR of **3r** (101 MHz, $CDCl_3$)



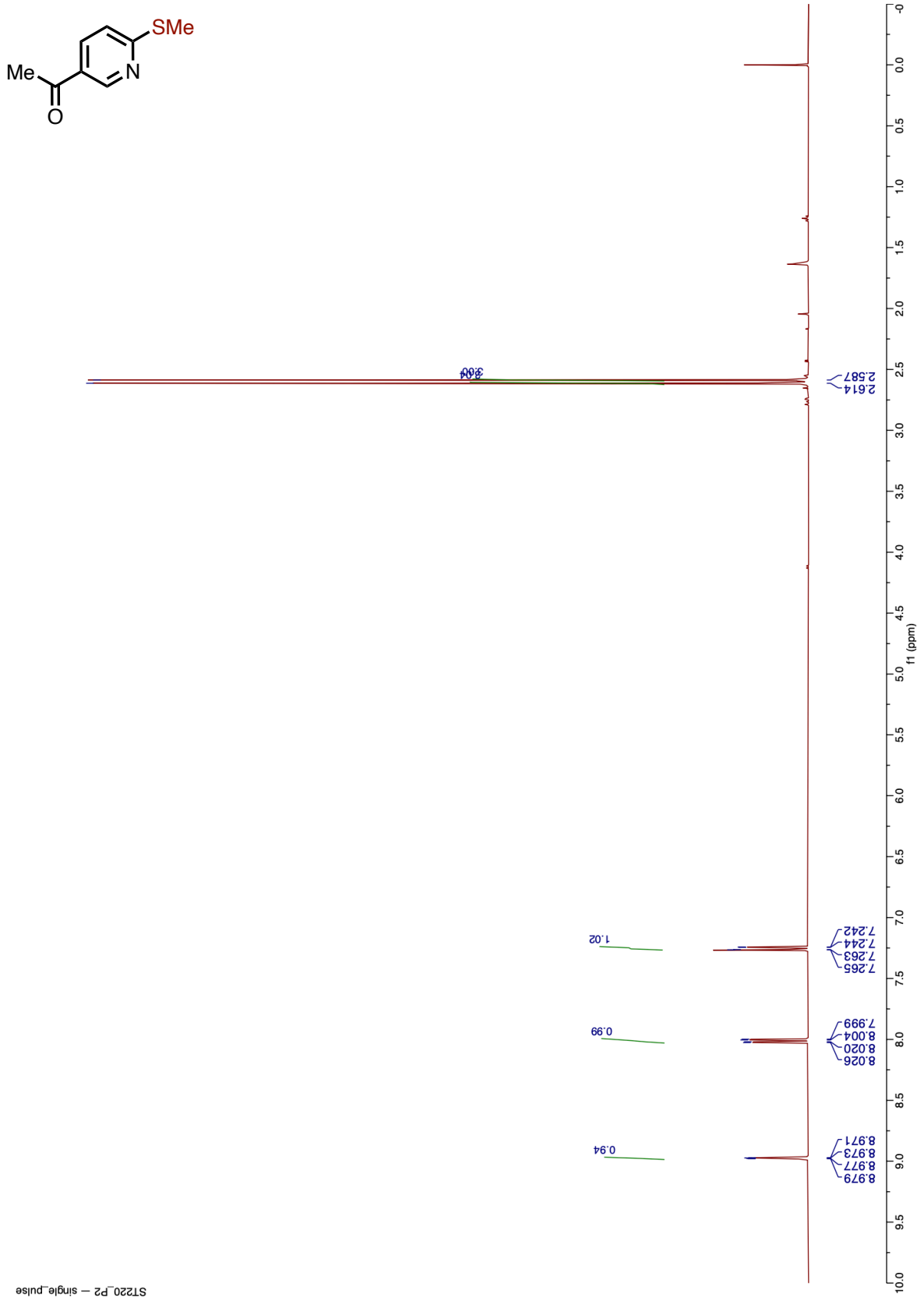
^{1}H NMR of **3s** (400 MHz, $CDCl_3$)



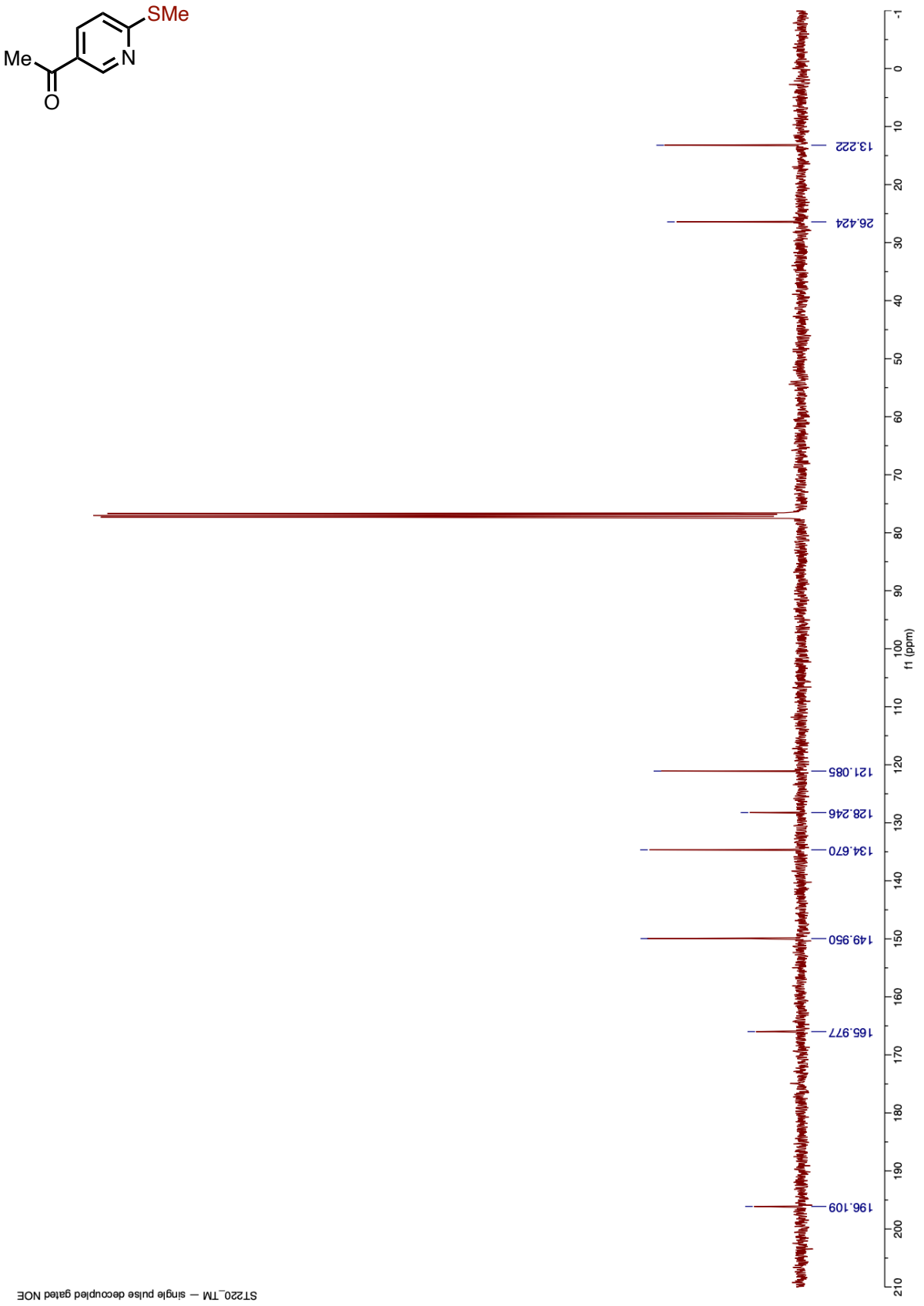
^{13}C NMR of **3s** (101 MHz, $CDCl_3$)



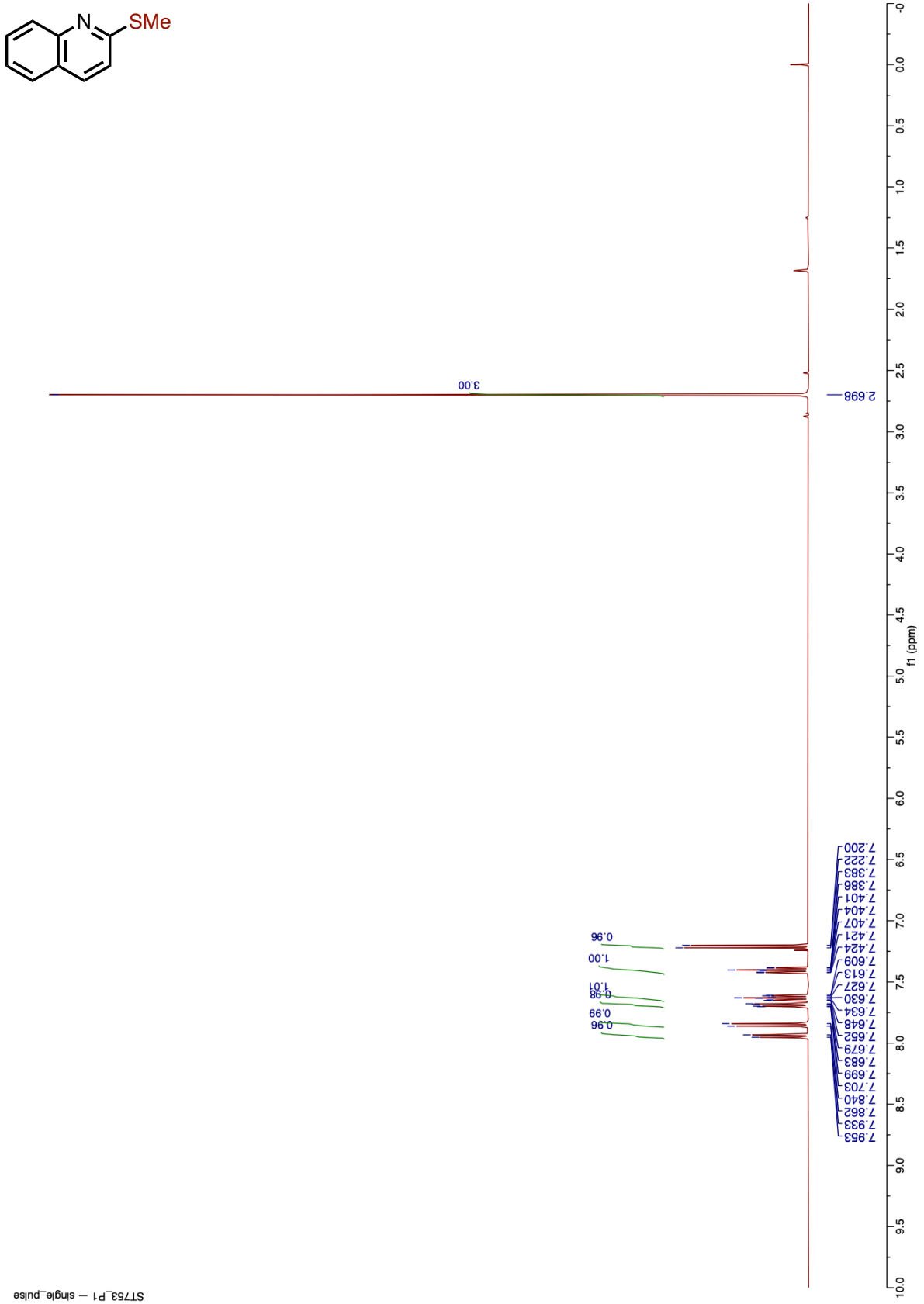
^{1}H NMR of **3u** (400 MHz, $CDCl_3$)



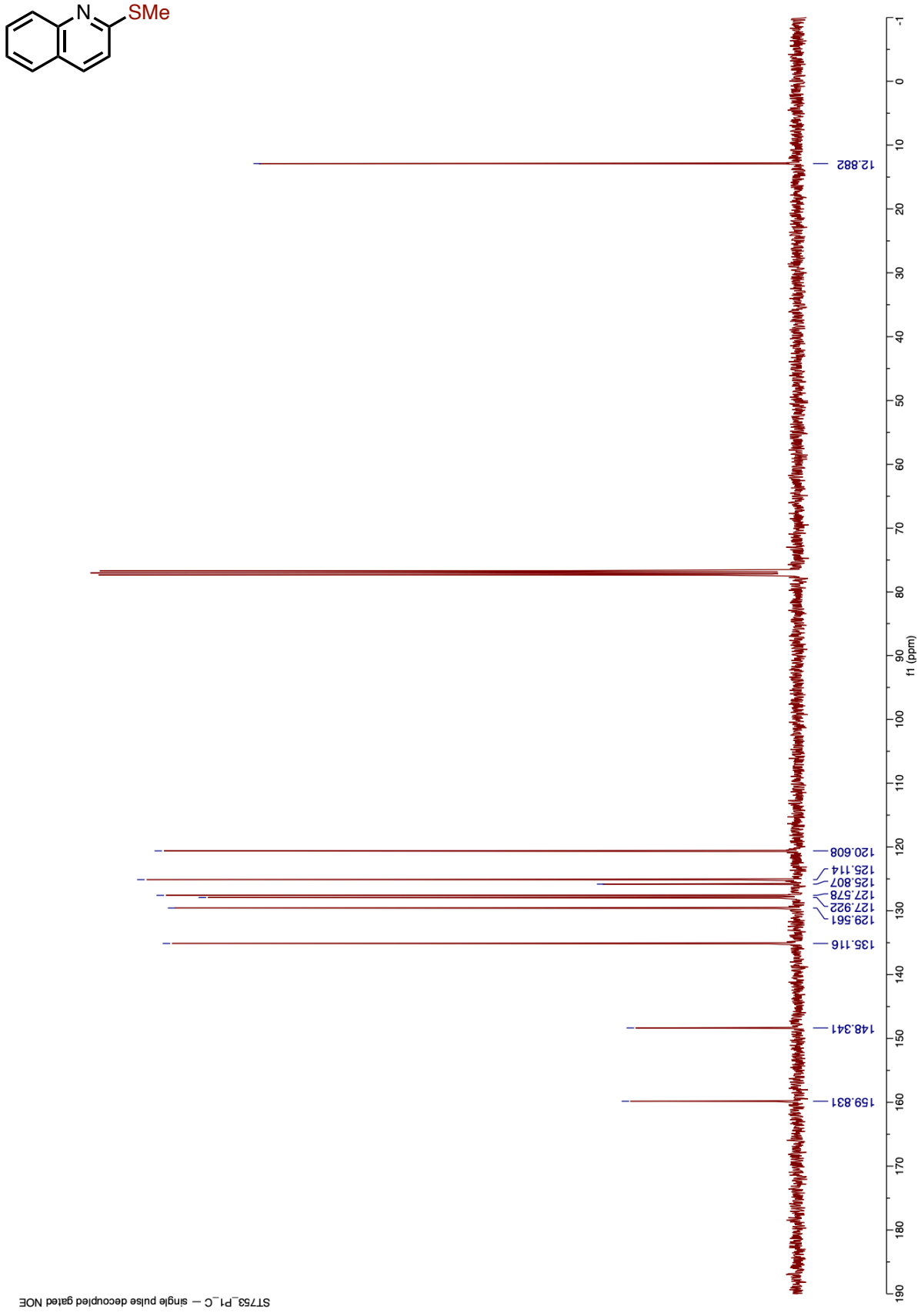
^{13}C NMR of **3u** (101 MHz, $CDCl_3$)



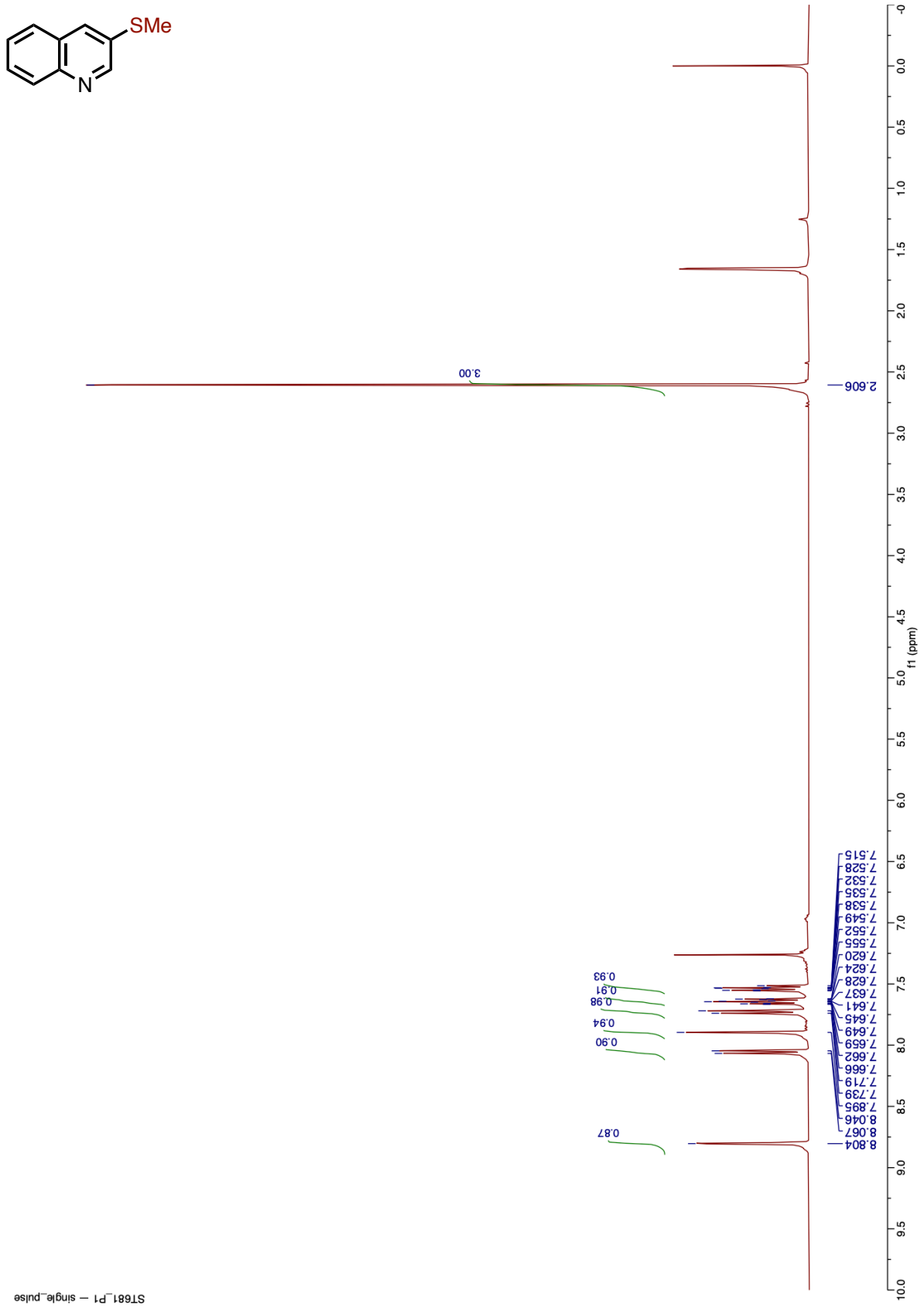
^{1}H NMR of **3v** (400 MHz, $CDCl_3$)



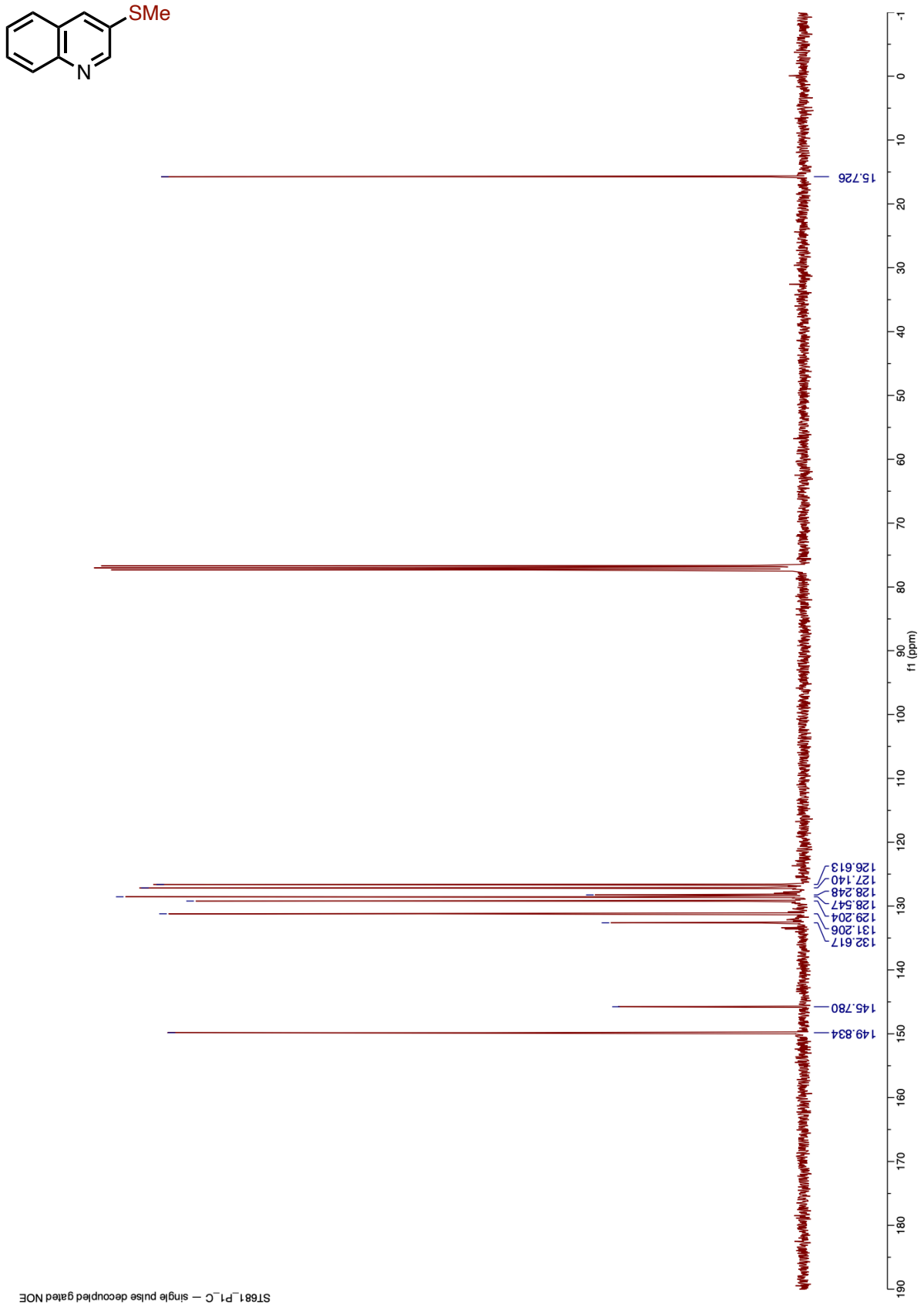
^{13}C NMR of **3v** (101 MHz, $CDCl_3$)



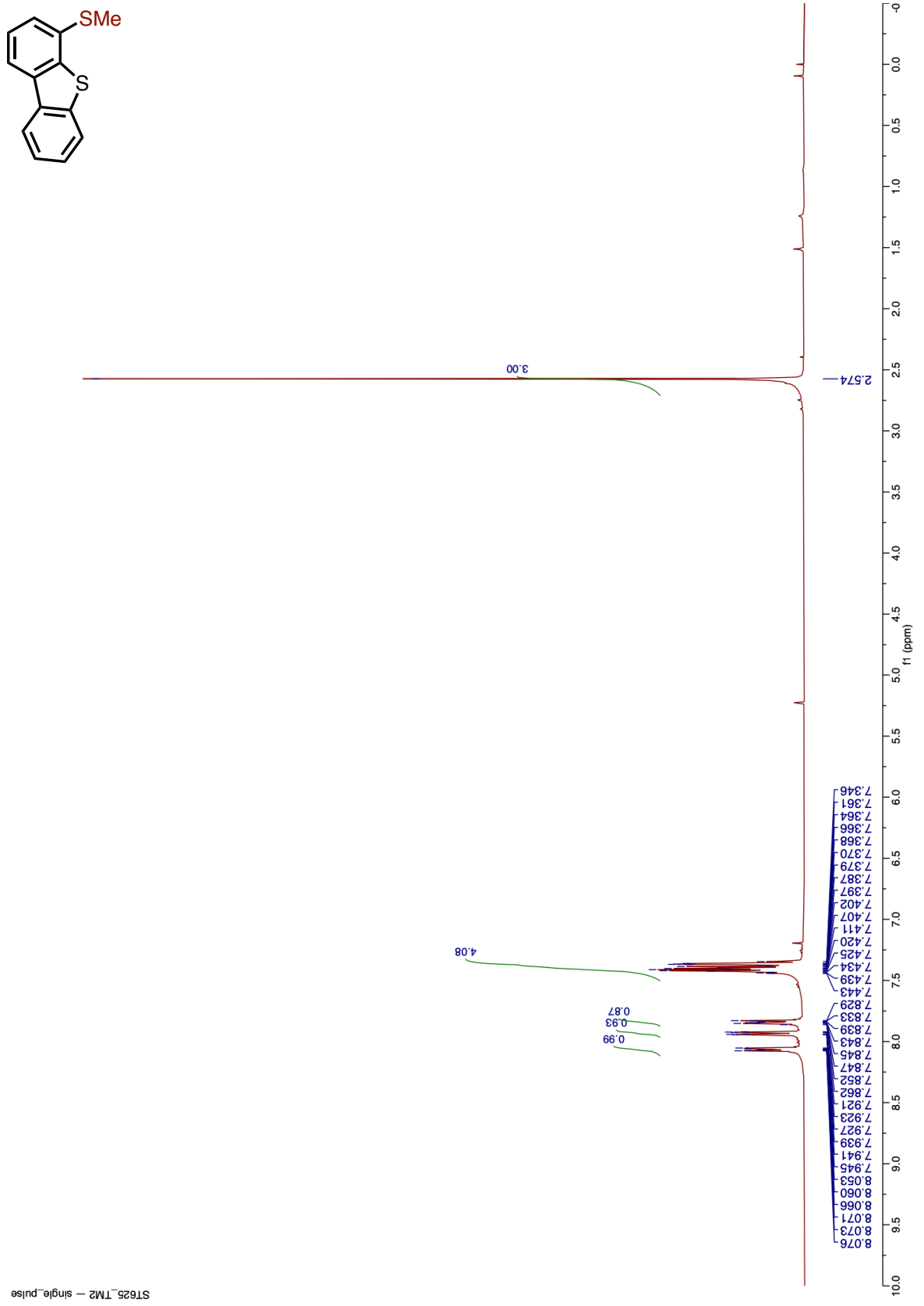
^{1}H NMR of **3w** (400 MHz, $CDCl_3$)



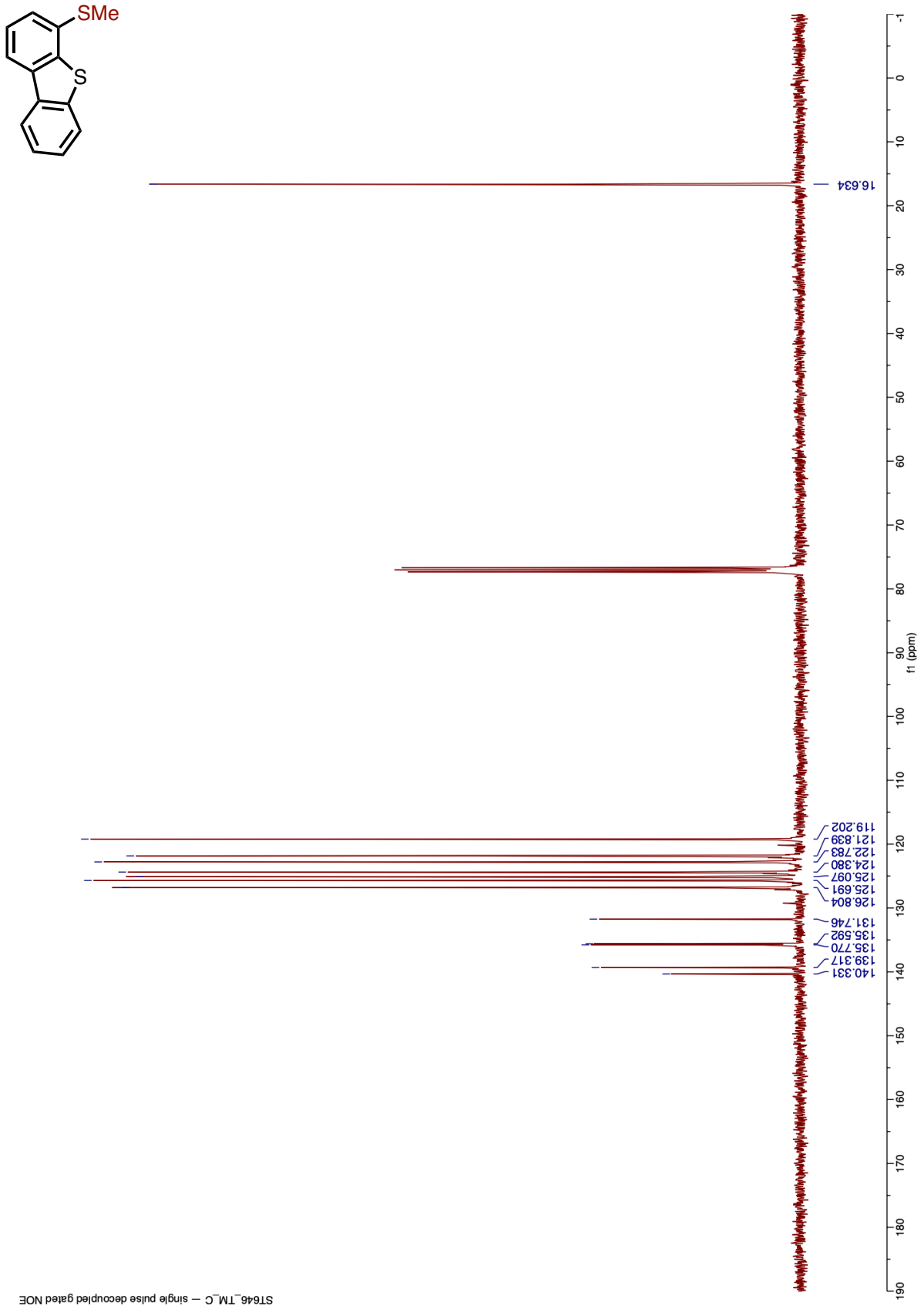
^{13}C NMR of **3w** (101 MHz, $CDCl_3$)



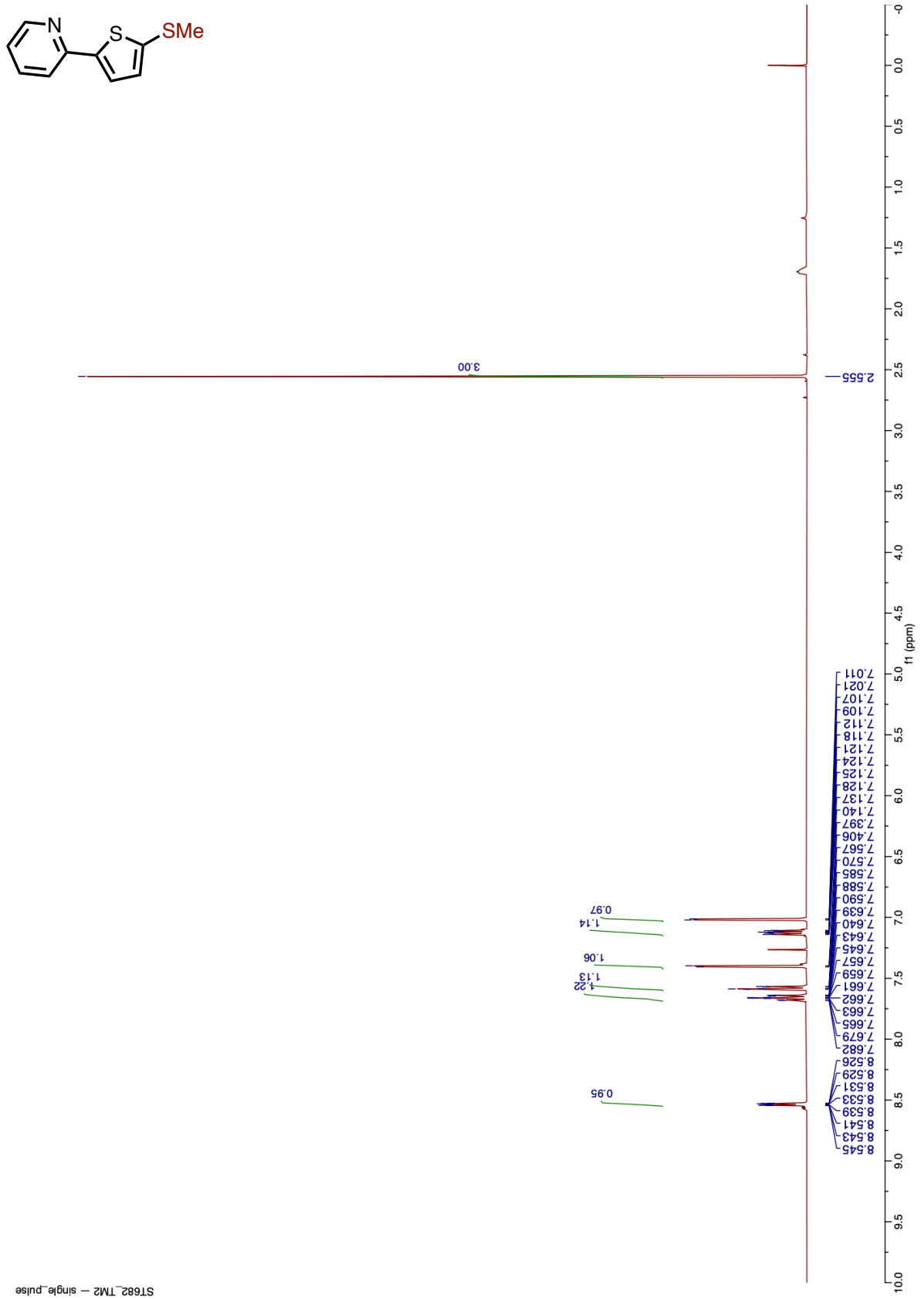
^{1}H NMR of **3x** (400 MHz, $CDCl_3$)



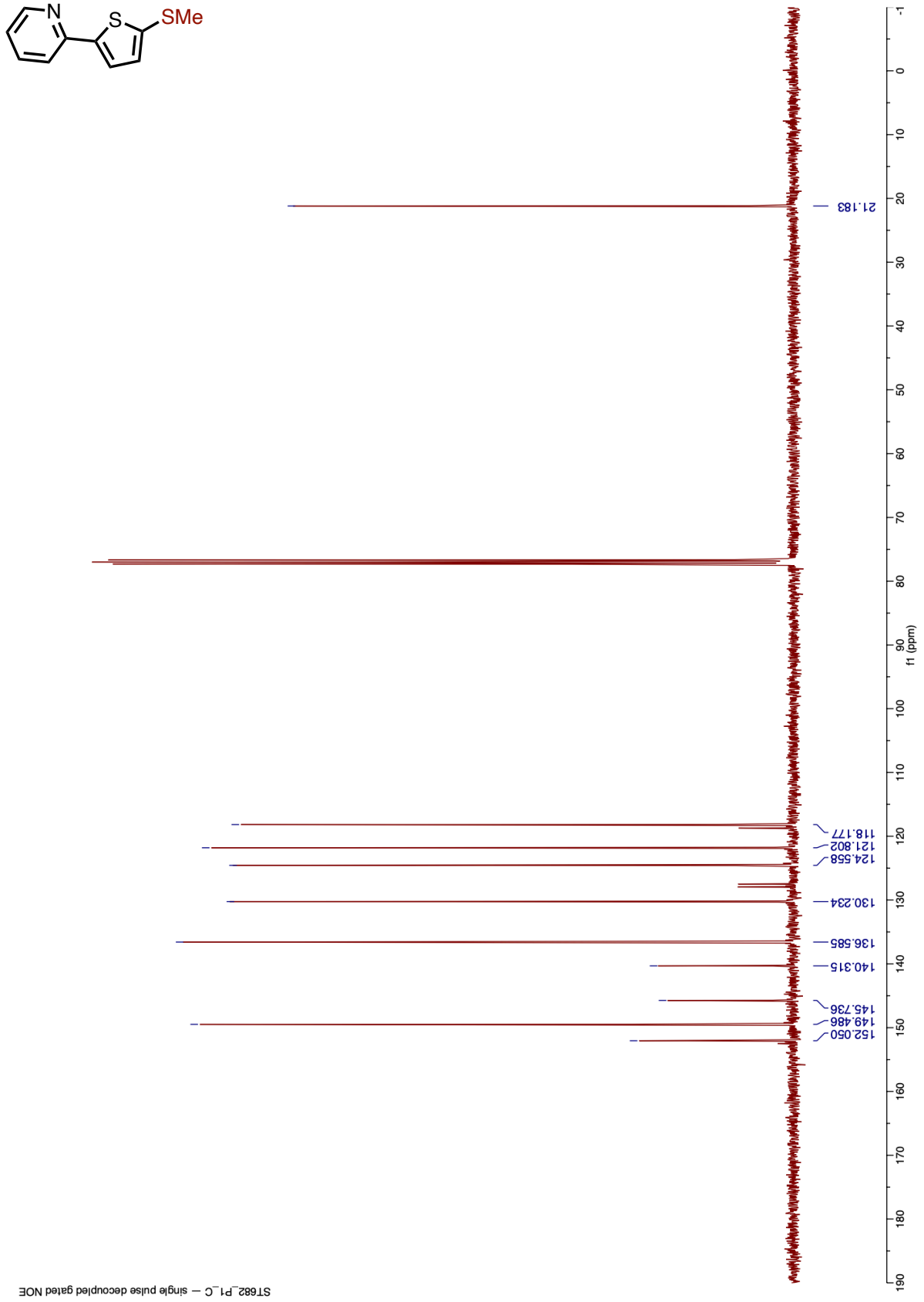
^{13}C NMR of **3x** (101 MHz, $CDCl_3$)



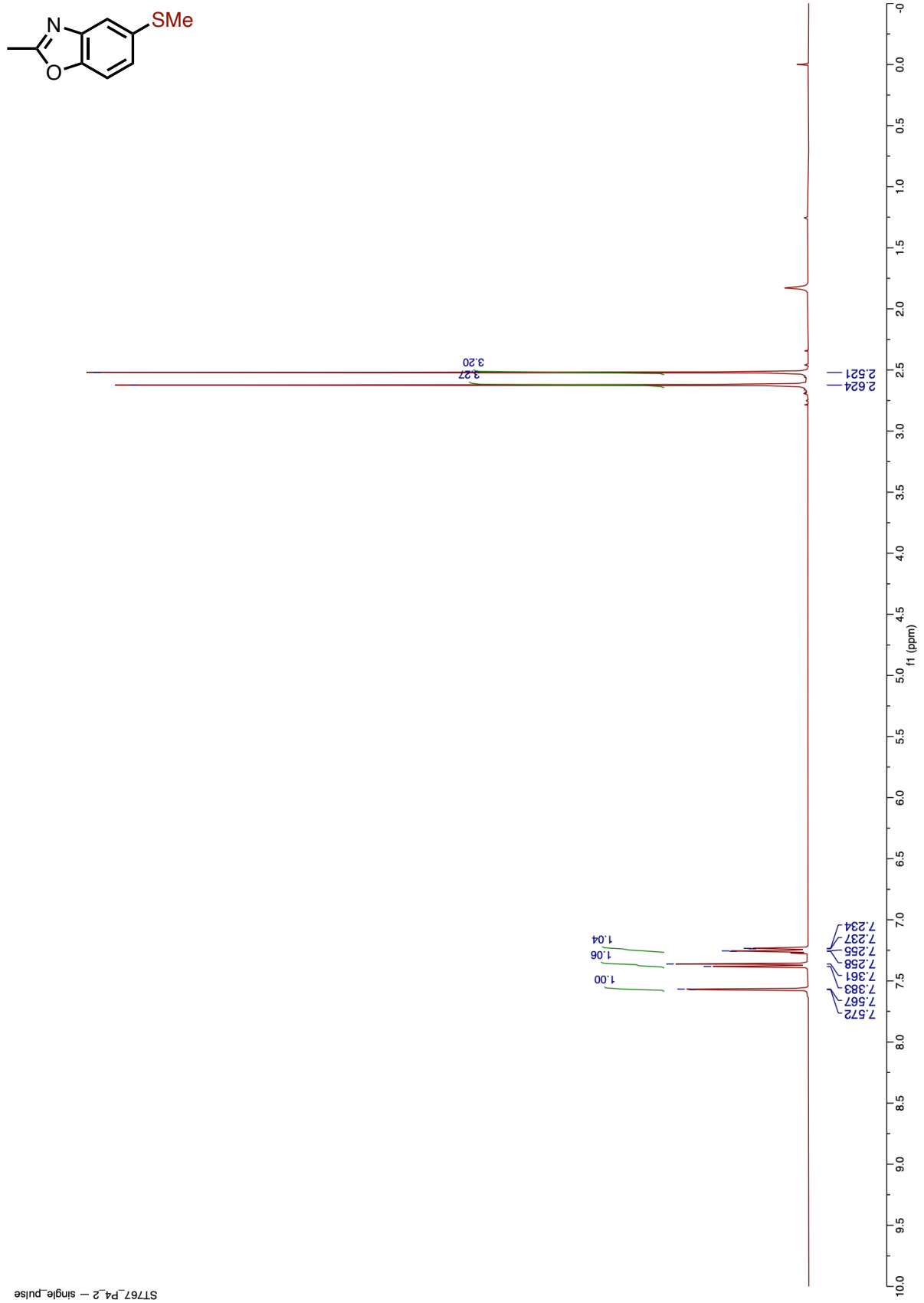
^{1}H NMR of **3y** (400 MHz, $CDCl_3$)



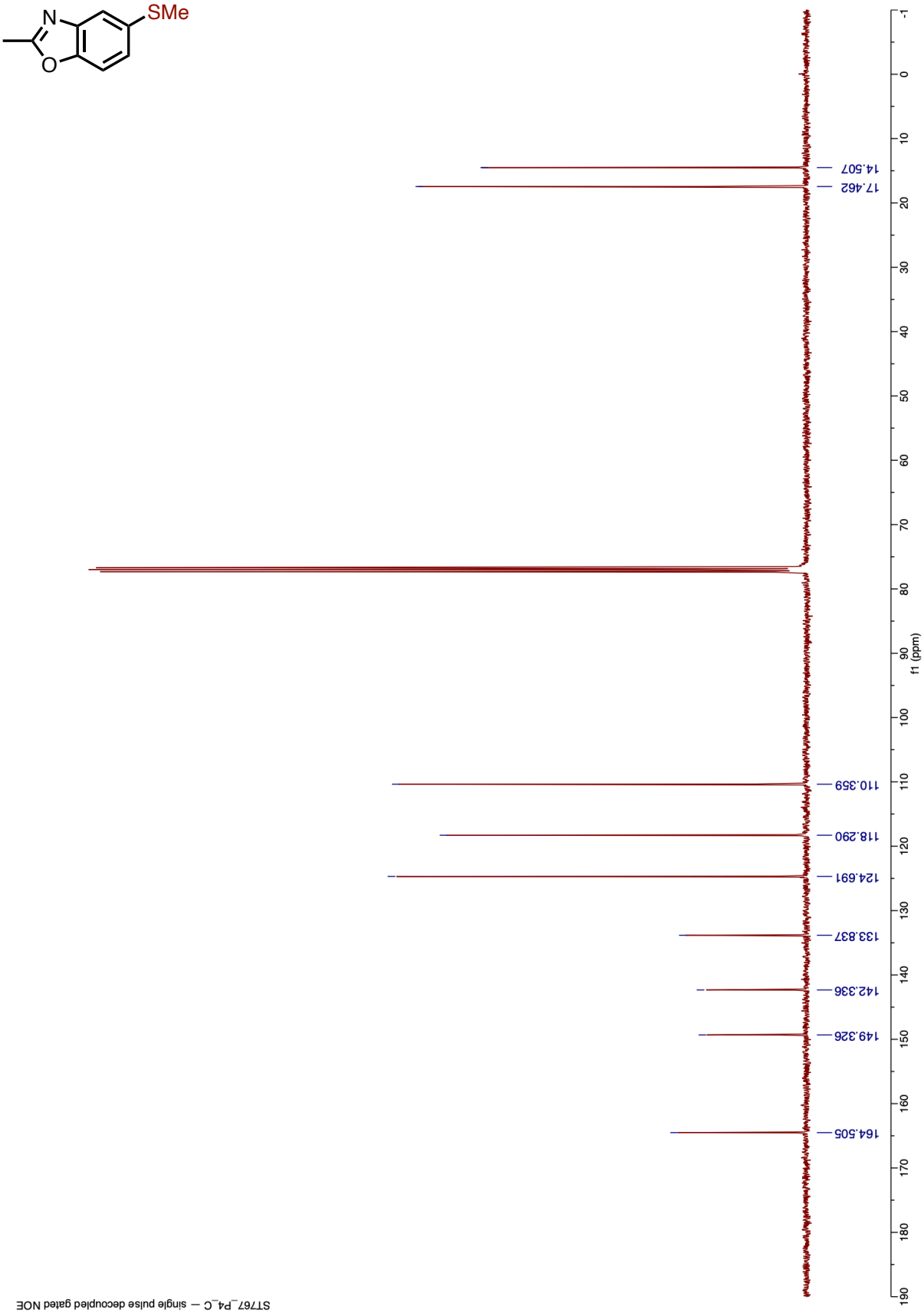
^{13}C NMR of **3y** (101 MHz, $CDCl_3$)



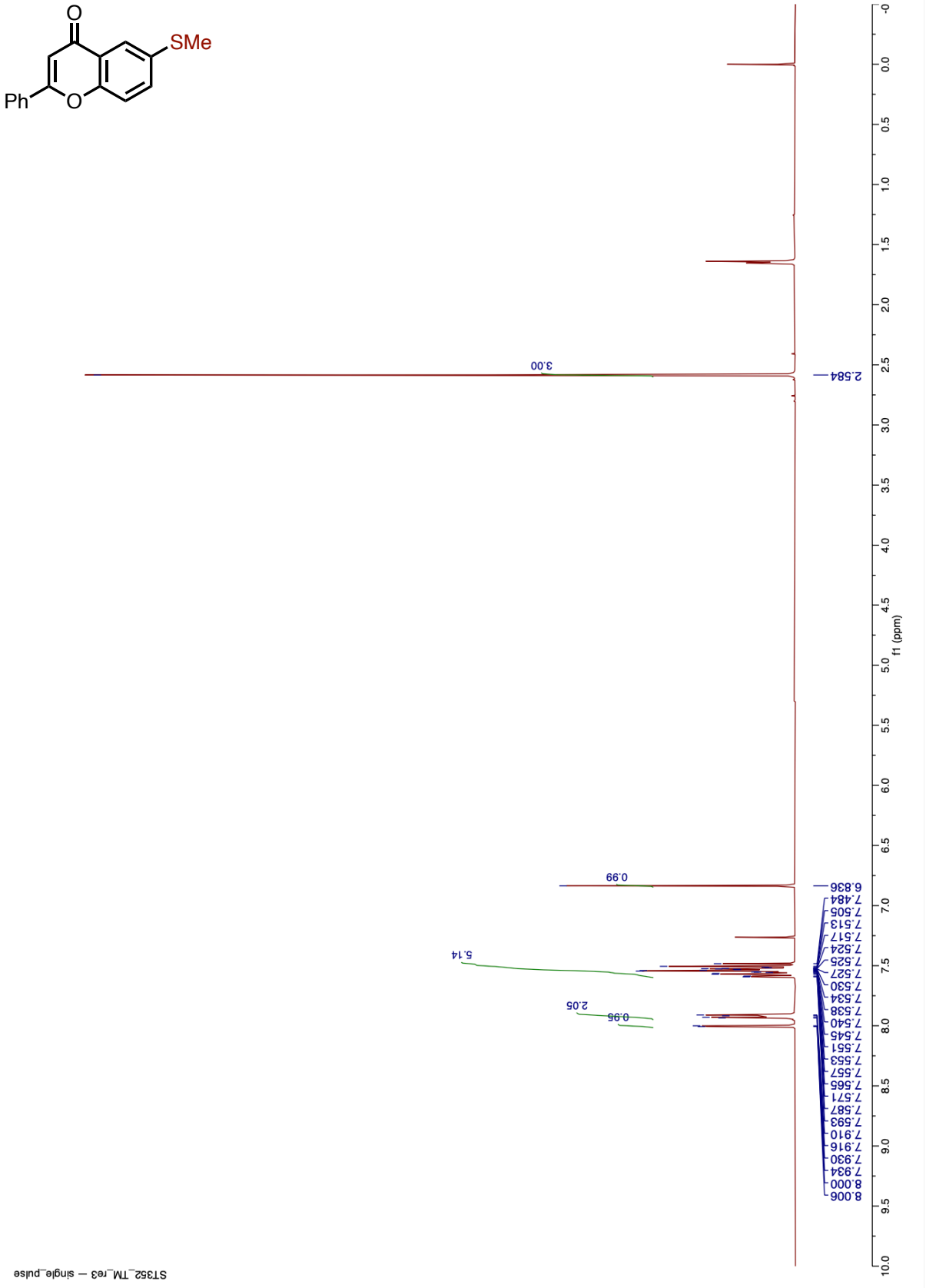
^{1}H NMR of **3z** (400 MHz, $CDCl_3$)



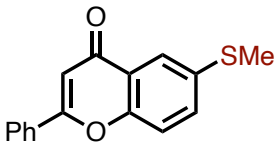
^{13}C NMR of **3z** (101 MHz, $CDCl_3$)



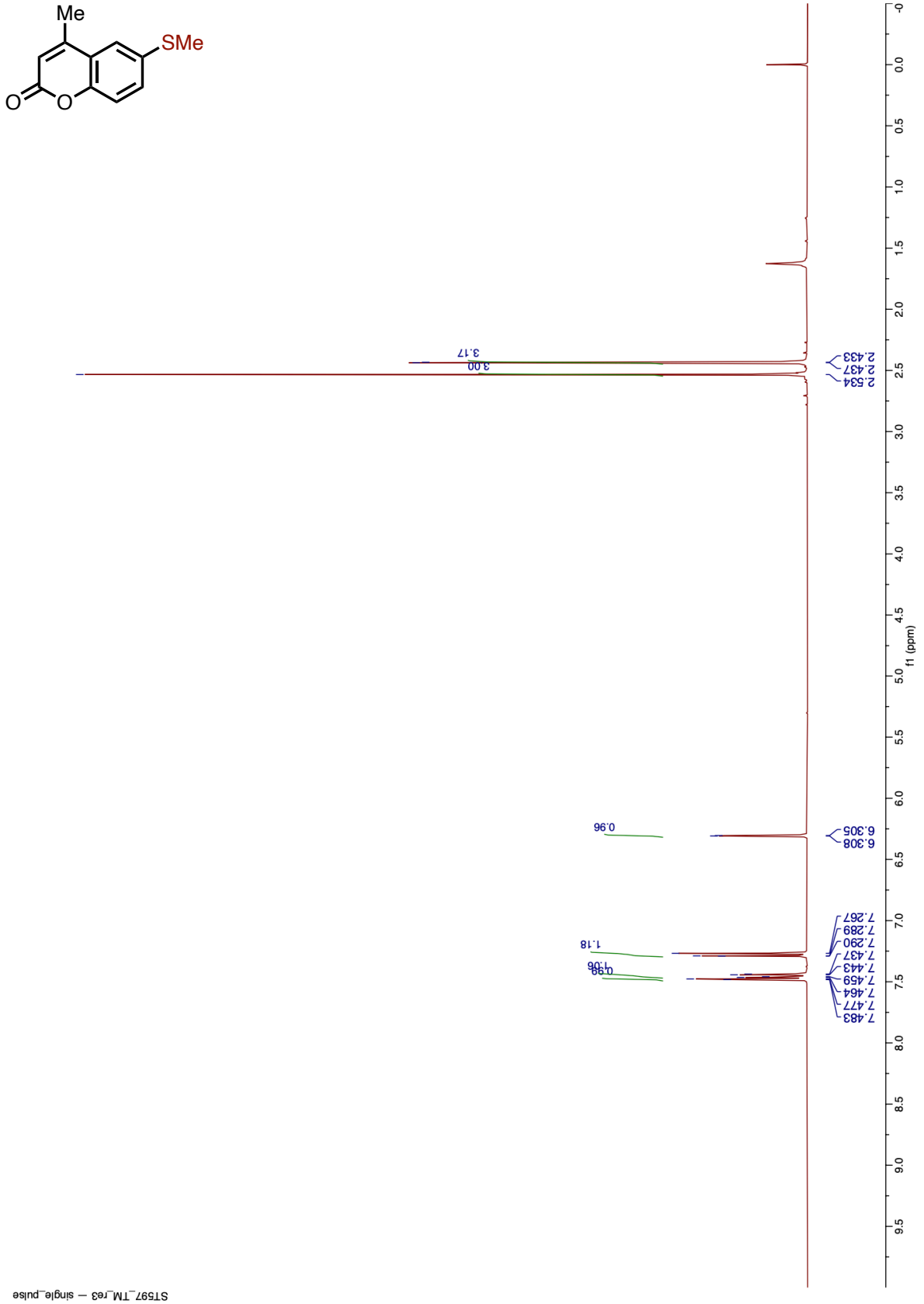
^{1}H NMR of **3A** (400 MHz, $CDCl_3$)



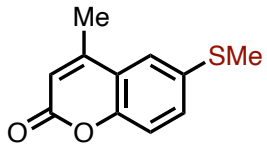
^{13}C NMR of **3A** (101 MHz, $CDCl_3$)



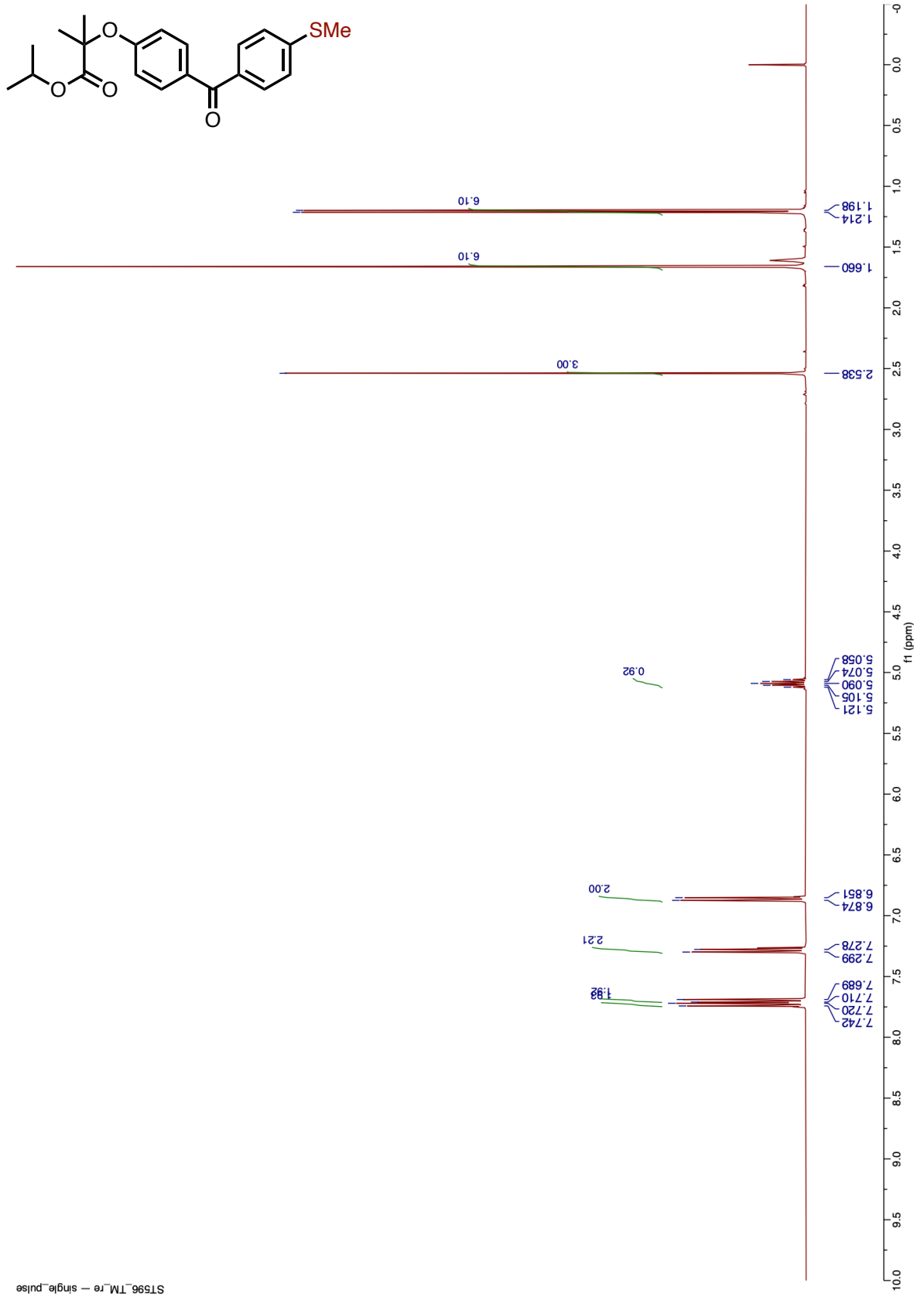
^{1}H NMR of **3B** (400 MHz, $CDCl_3$)



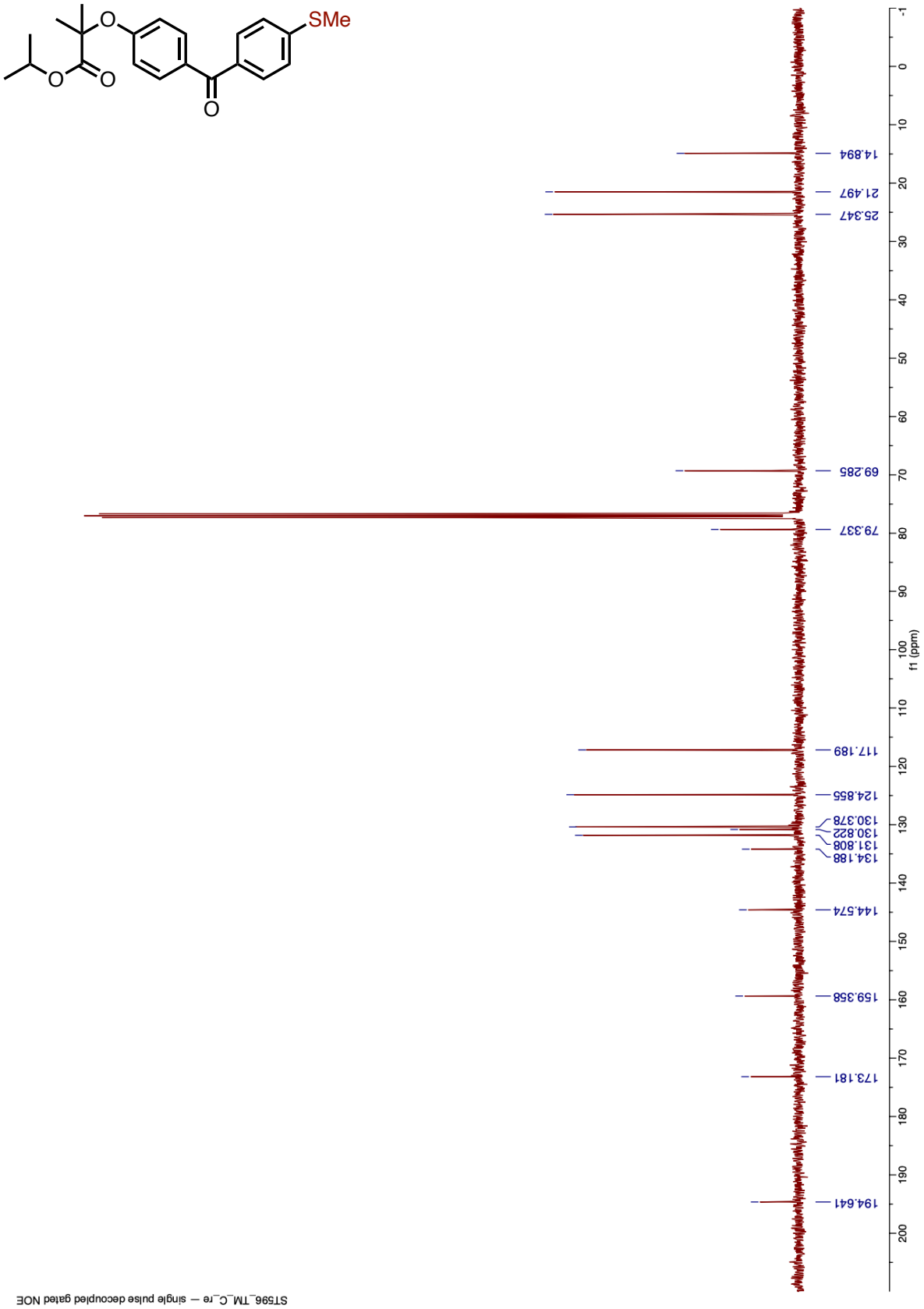
^{13}C NMR of **3B** (101 MHz, $CDCl_3$)



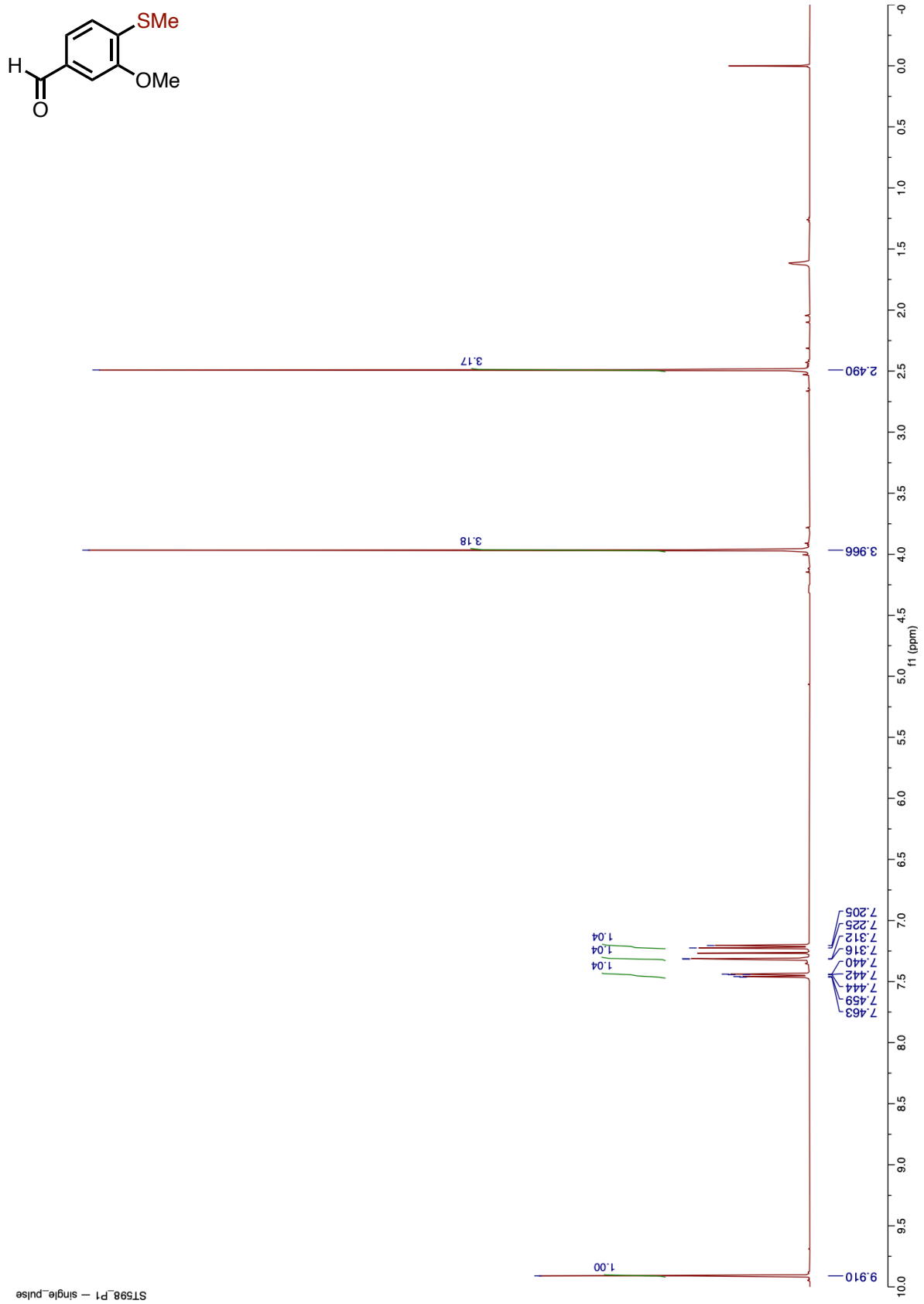
^{1}H NMR of **3C** (400 MHz, $CDCl_3$)



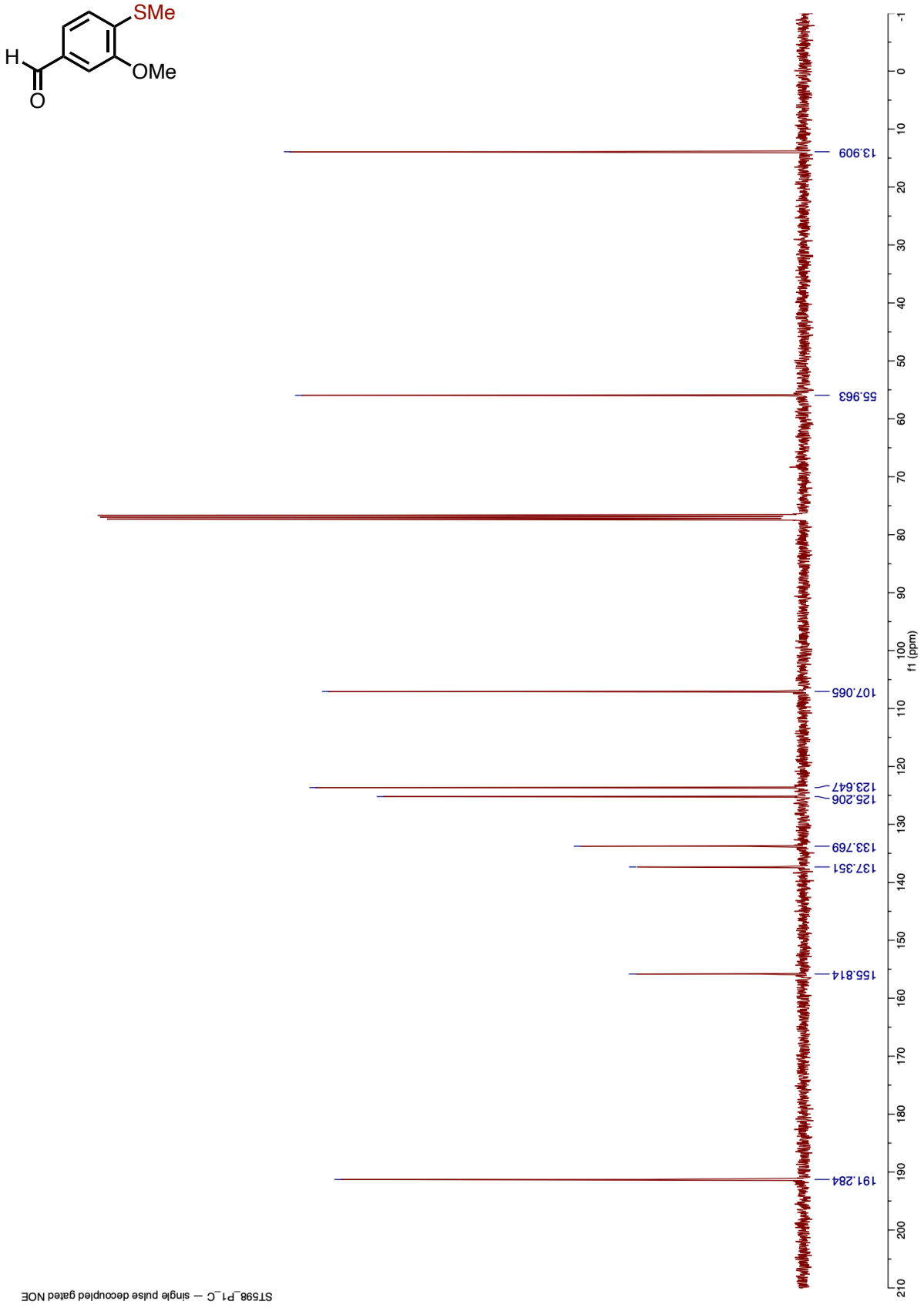
^{13}C NMR of **3C** (101 MHz, $CDCl_3$)



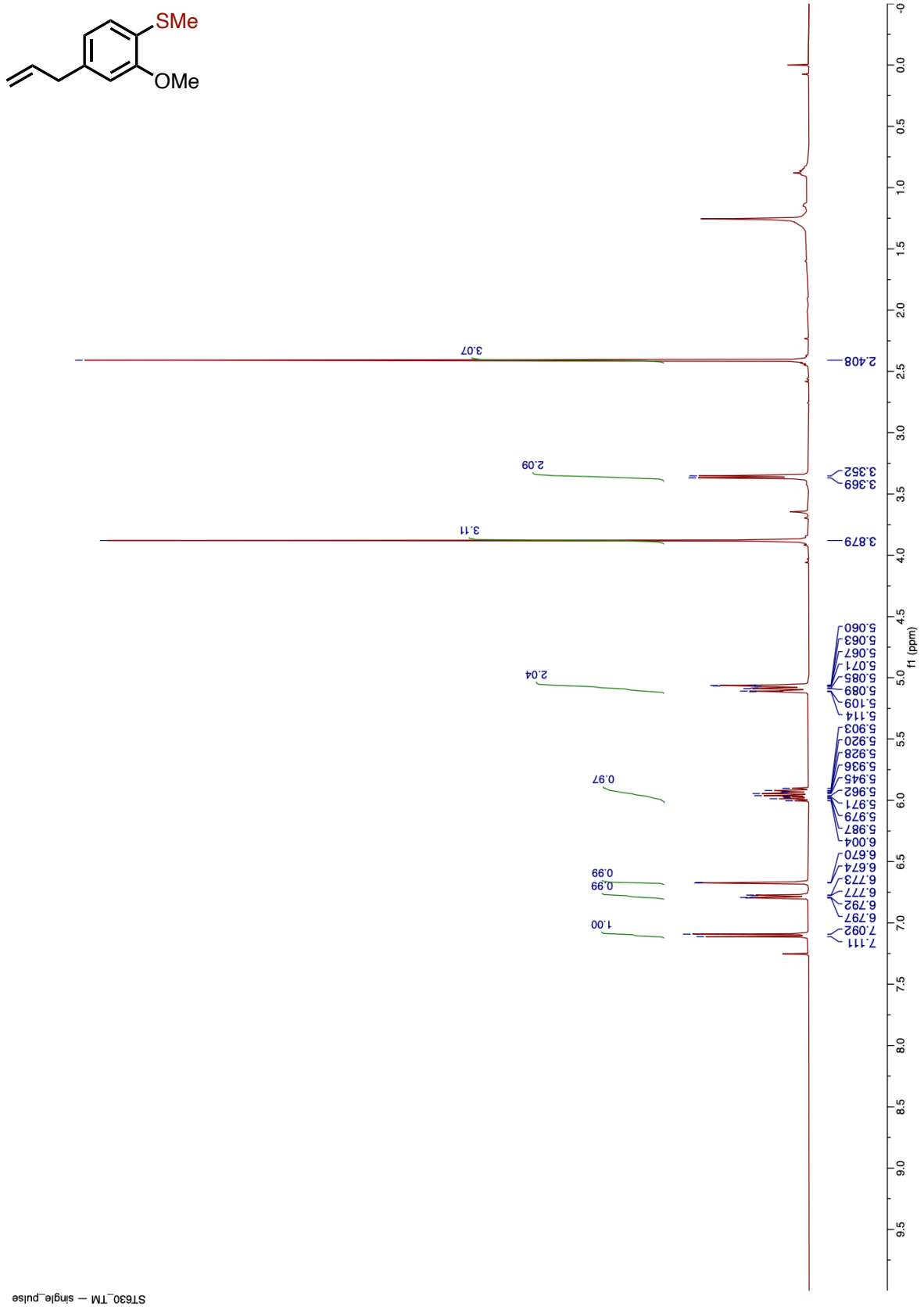
^{1}H NMR of **3D** (400 MHz, $CDCl_3$)



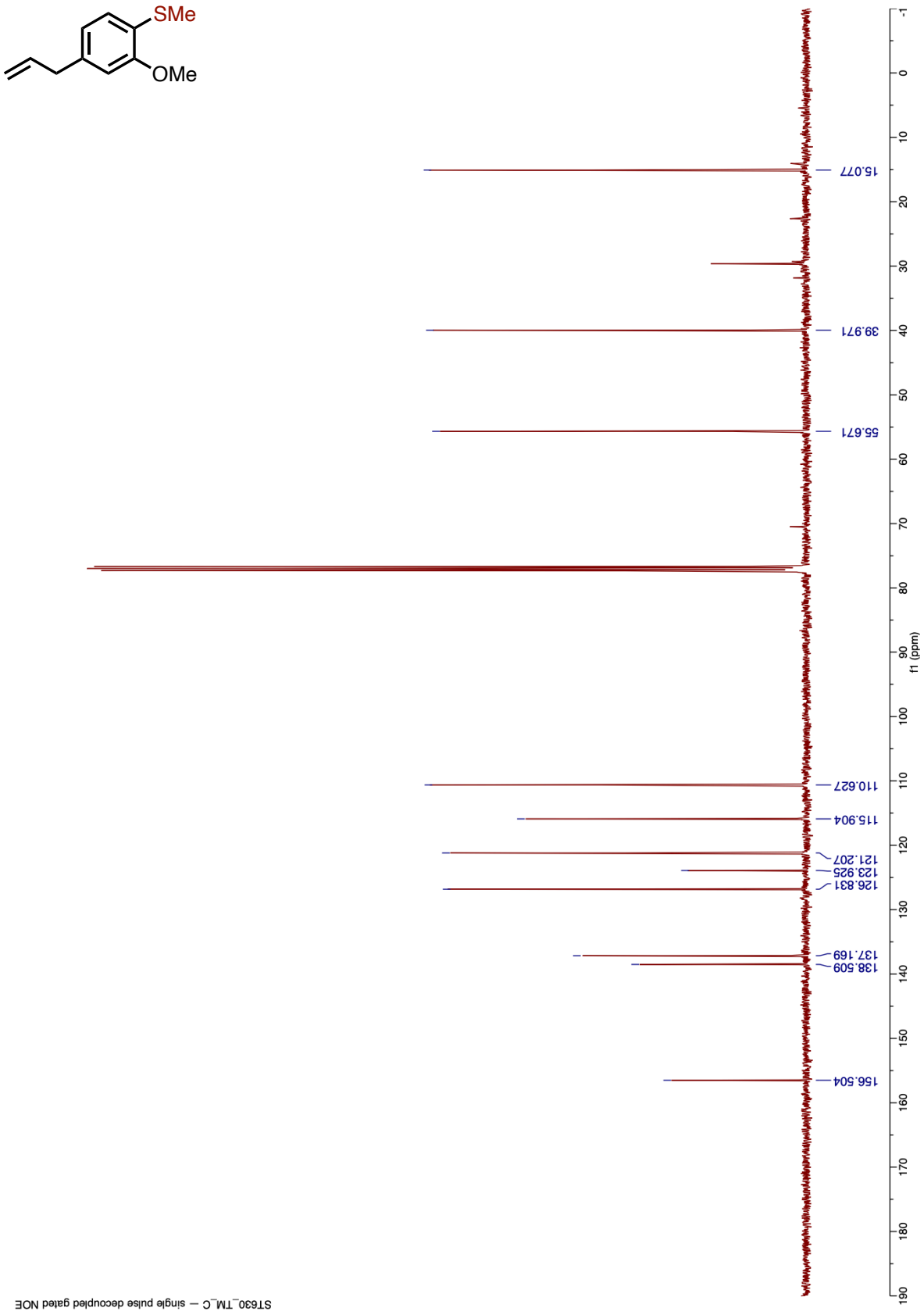
^{13}C NMR of **3D** (101 MHz, $CDCl_3$)



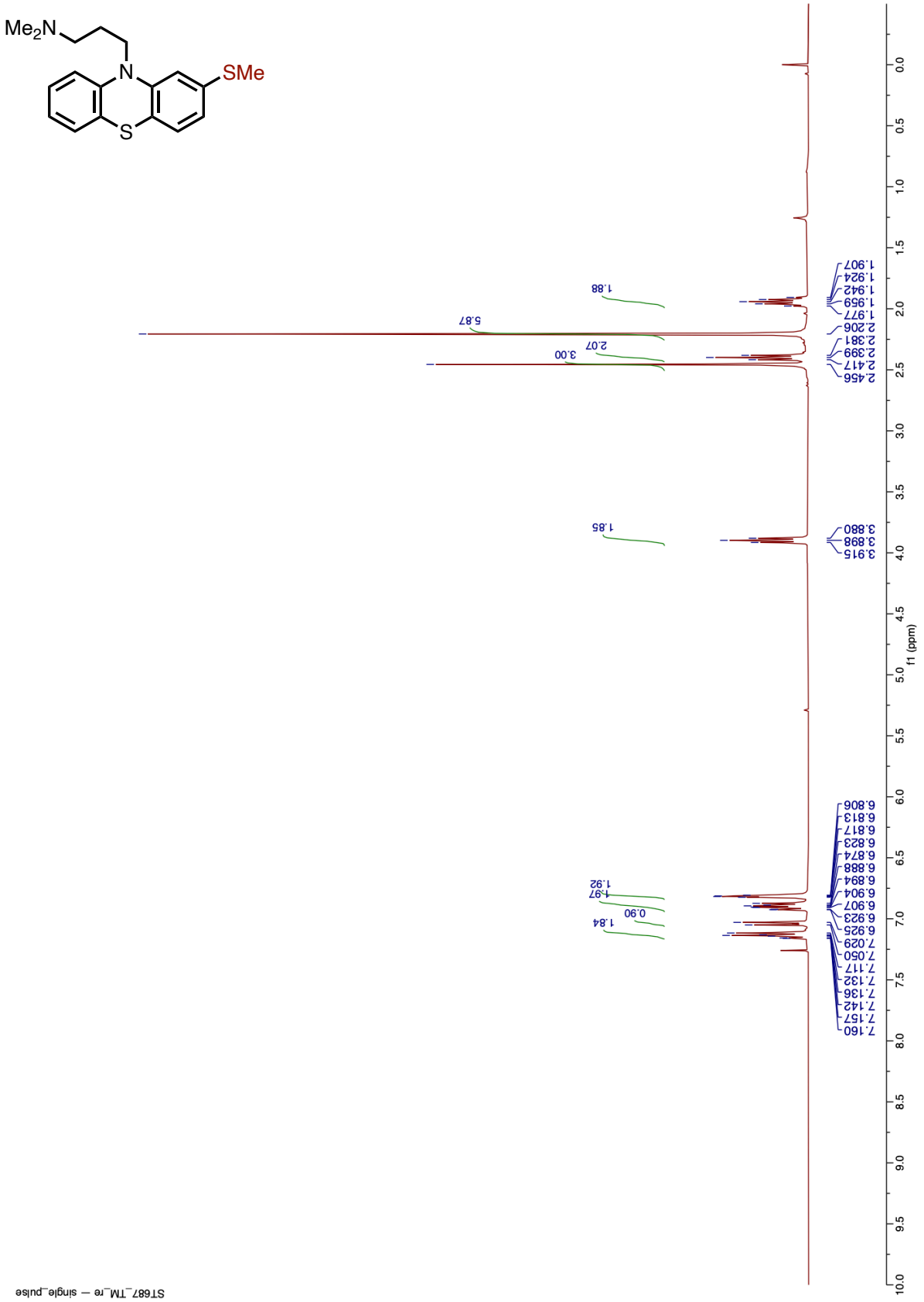
^{1}H NMR of **3E** (400 MHz, $CDCl_3$)



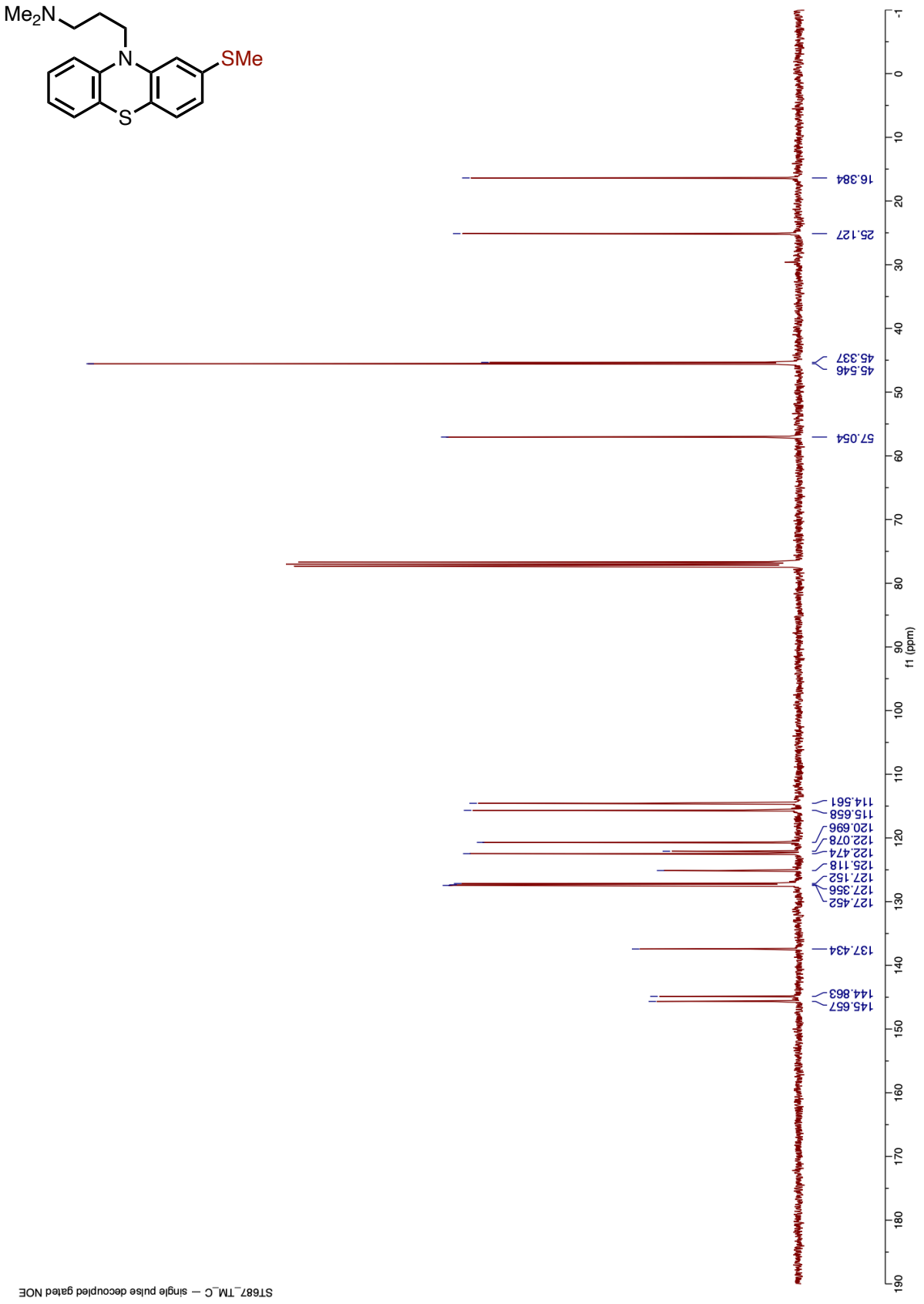
^{13}C NMR of **3E** (101 MHz, $CDCl_3$)



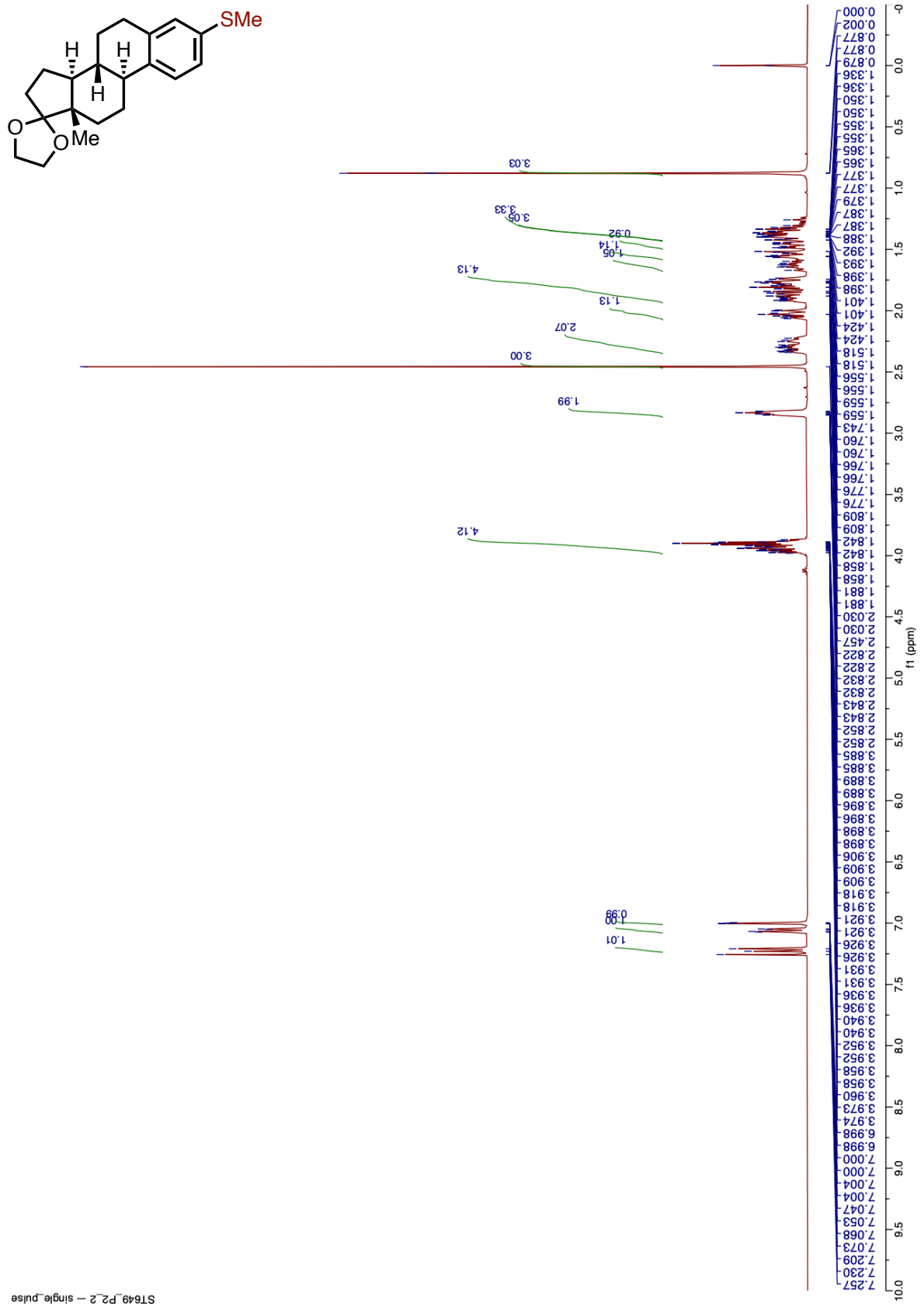
^{1}H NMR of **3F** (400 MHz, $CDCl_3$)



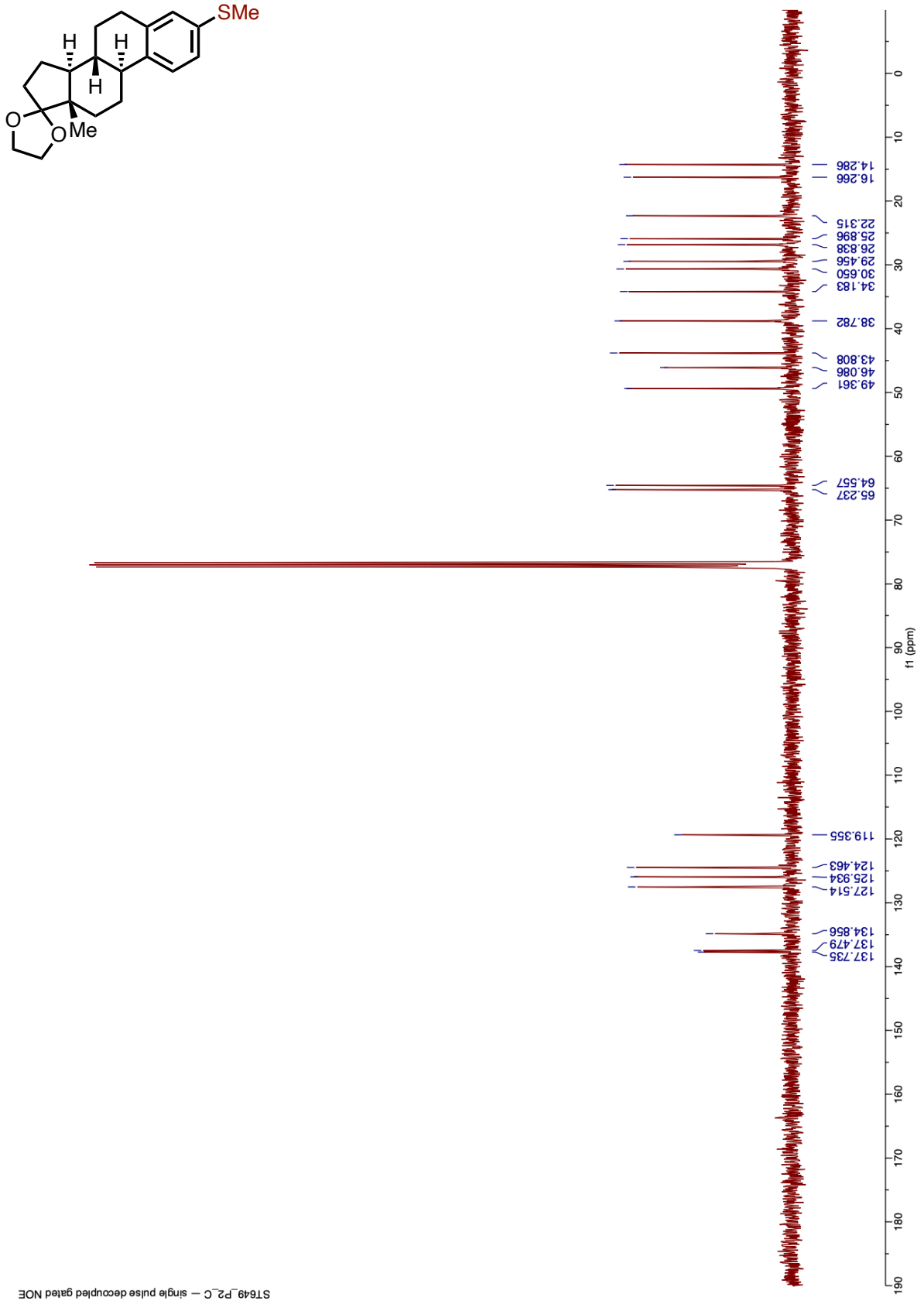
^{13}C NMR of **3F** (101 MHz, $CDCl_3$)



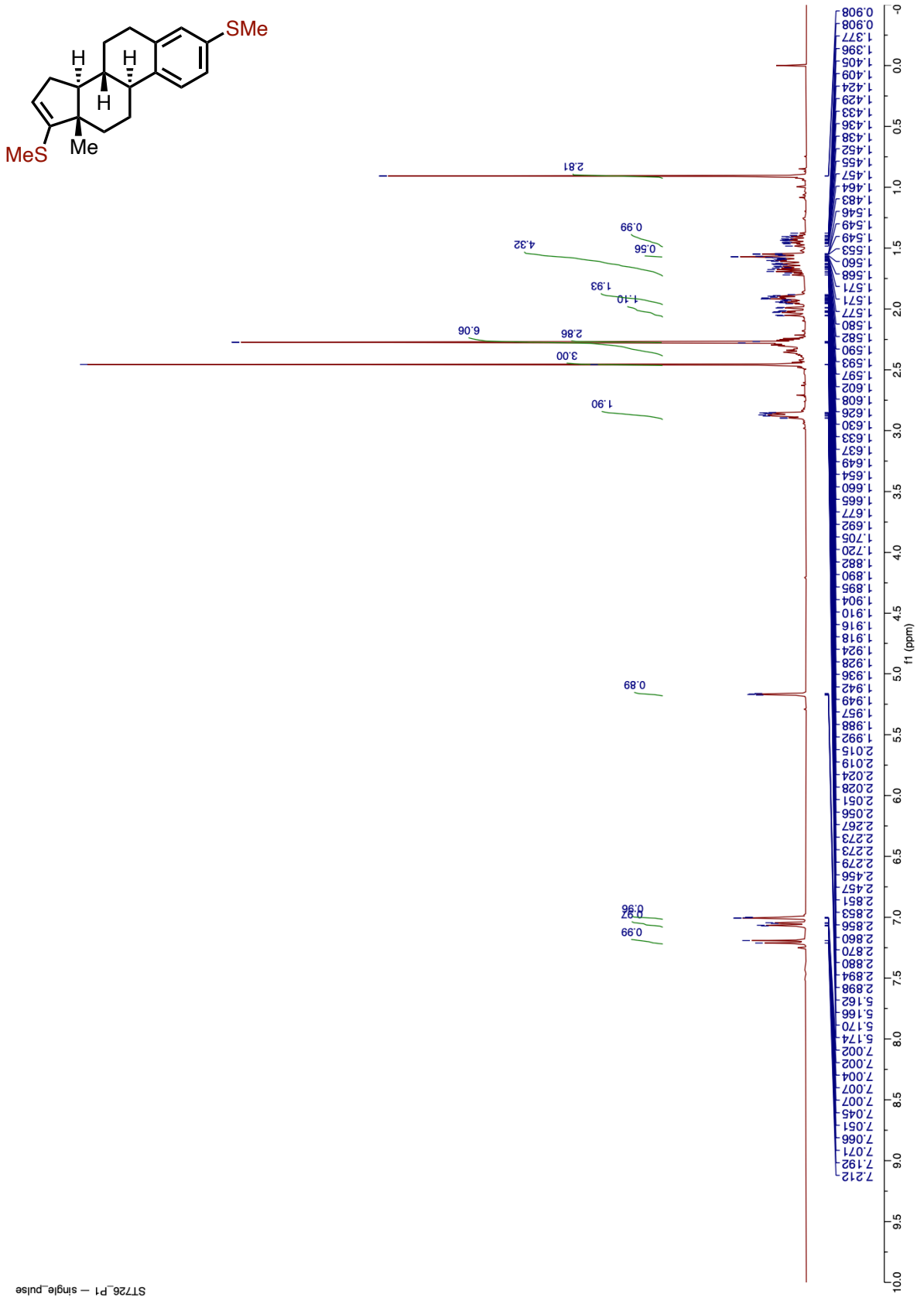
^{1}H NMR of **3G** (400 MHz, $CDCl_3$)



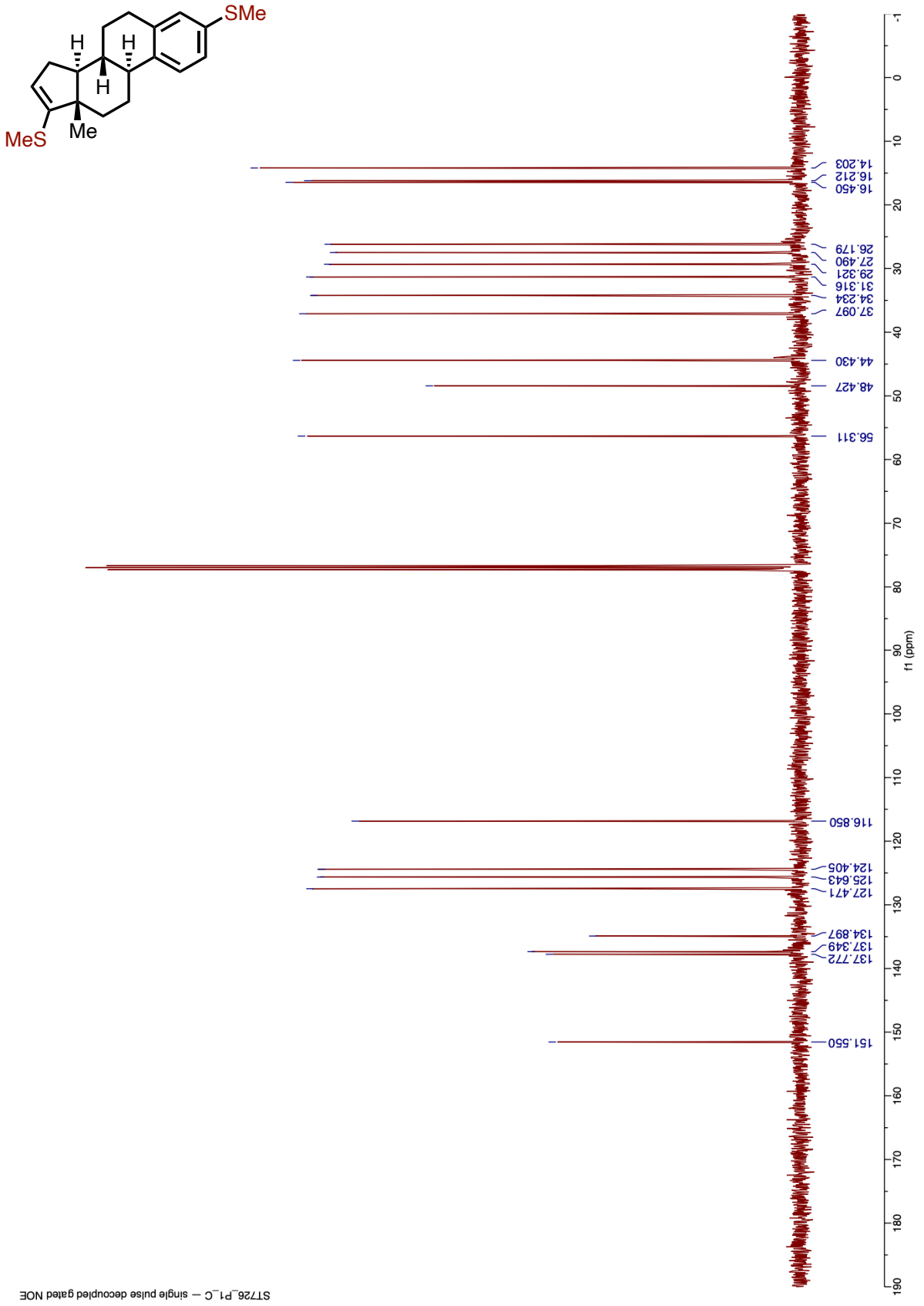
^{13}C NMR of **3G** (101 MHz, $CDCl_3$)



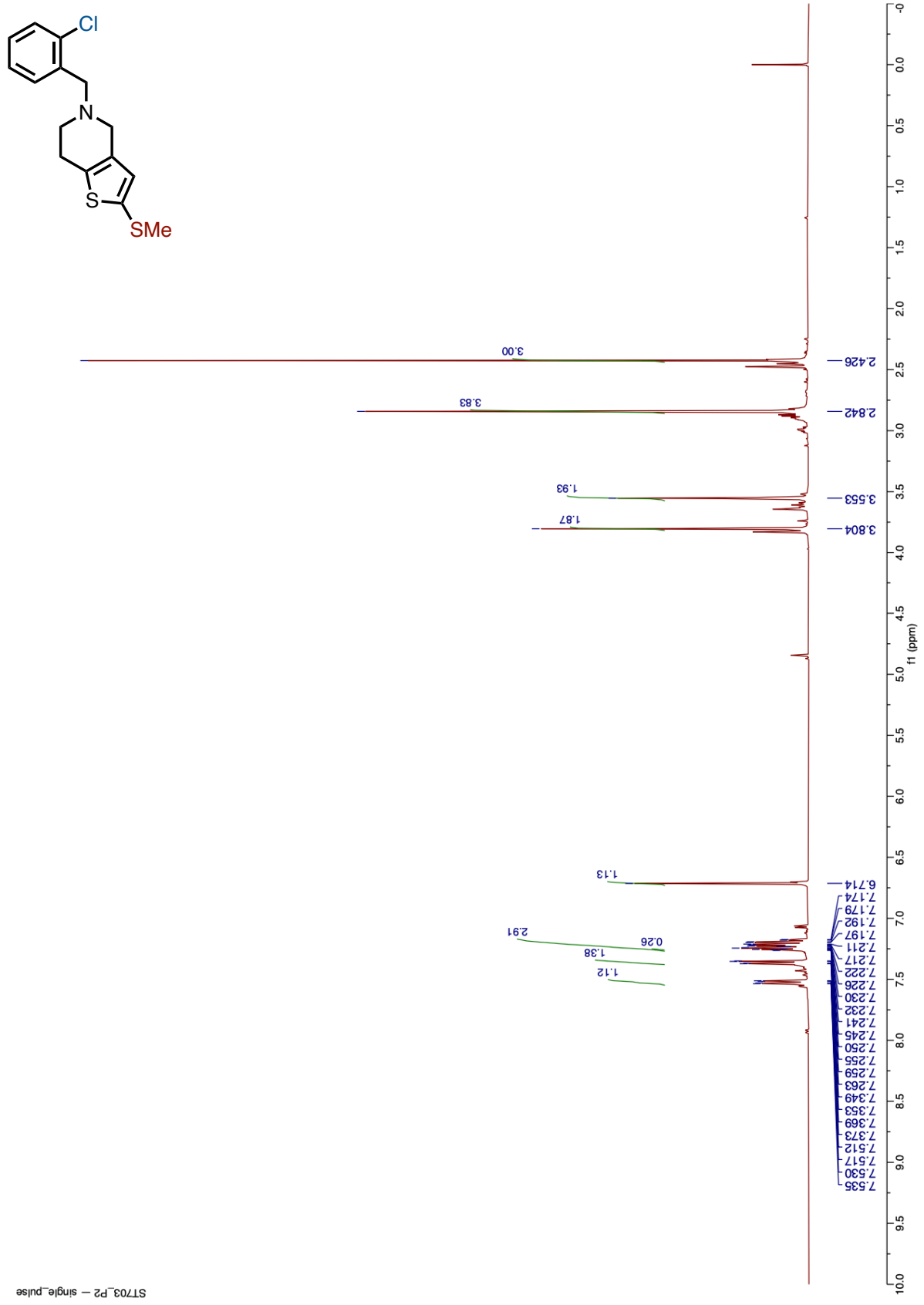
^{1}H NMR of **3H** (400 MHz, $CDCl_3$)



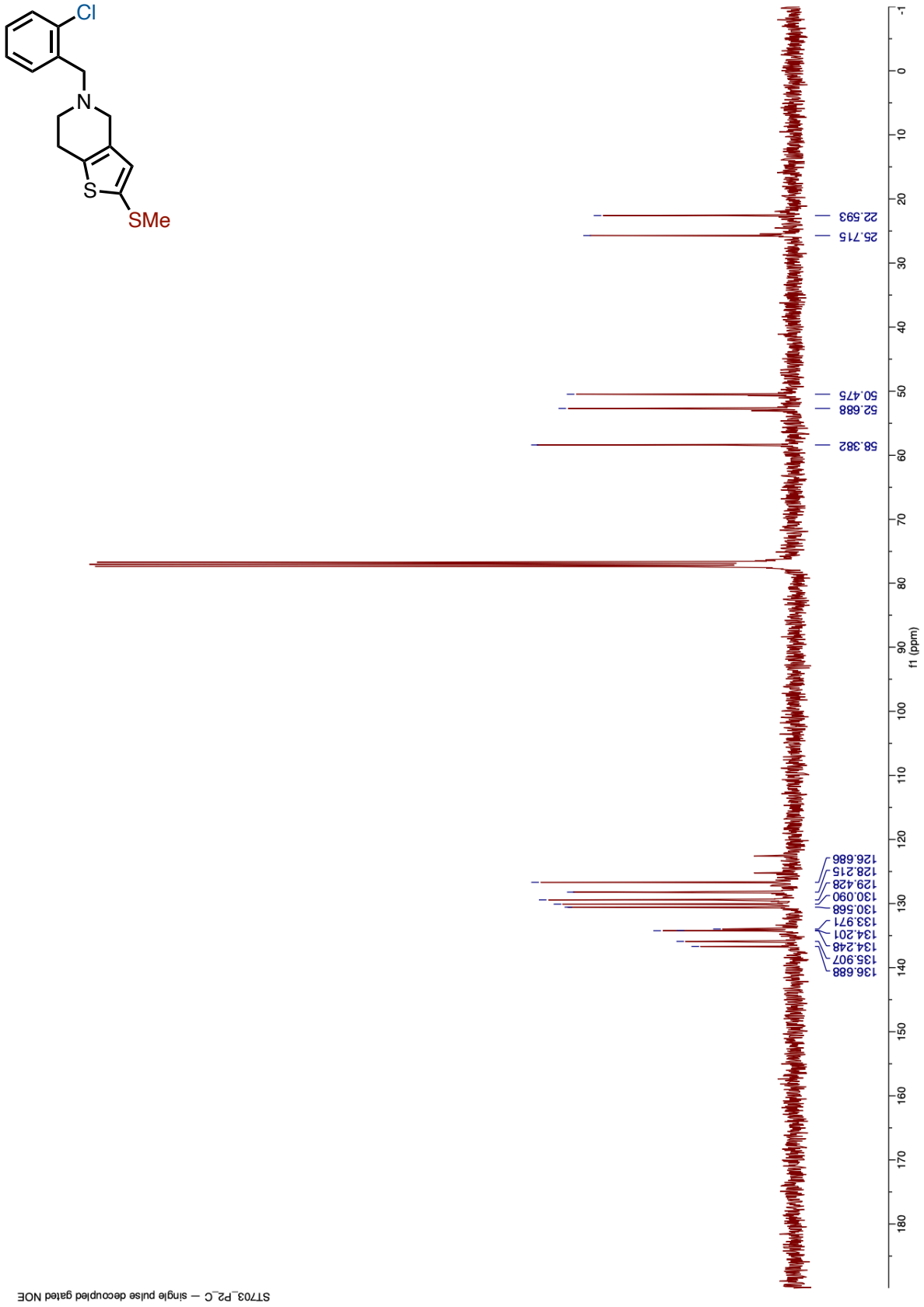
^{13}C NMR of **3H** (101 MHz, $CDCl_3$)



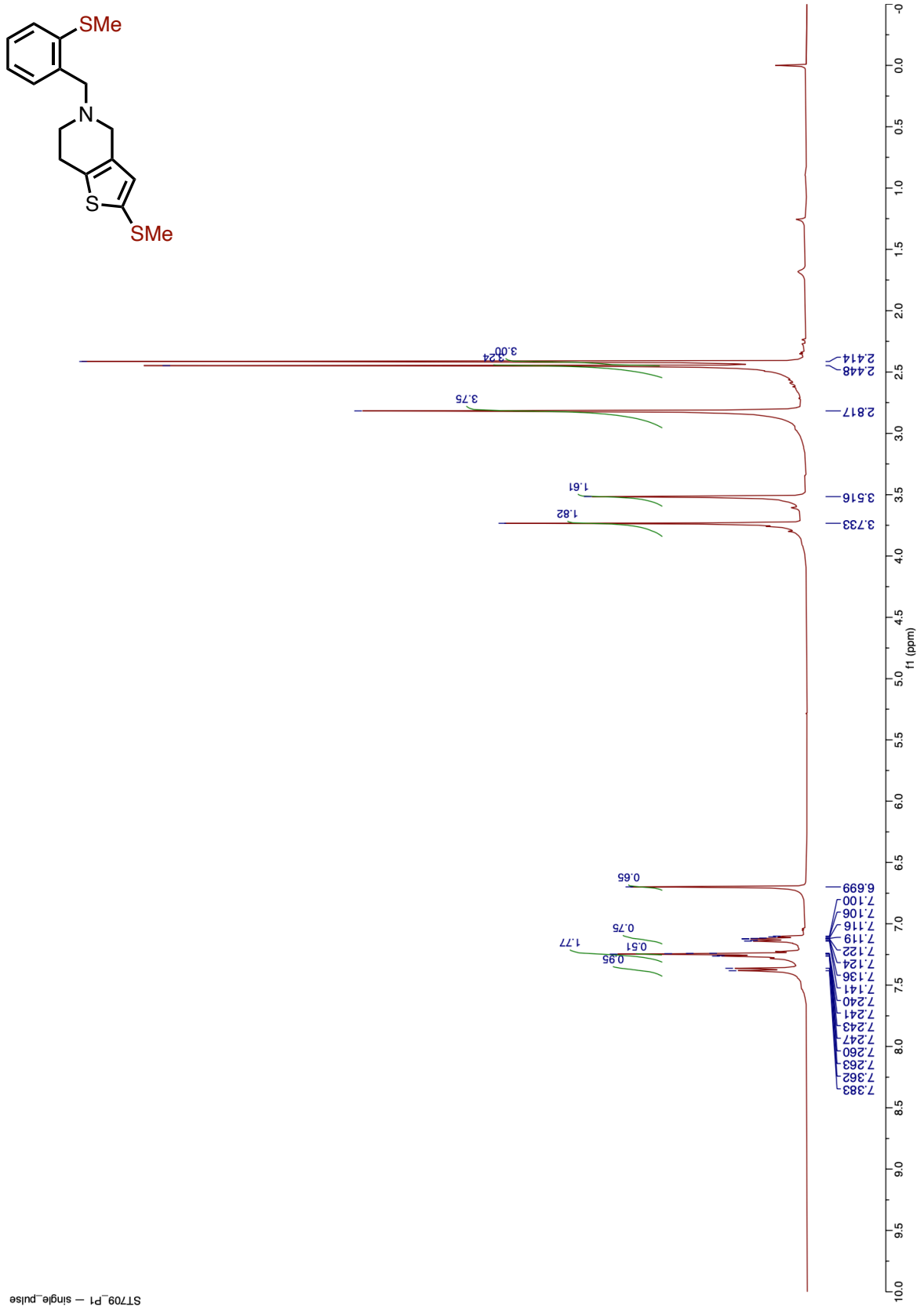
^{1}H NMR of **3I** (400 MHz, $CDCl_3$)



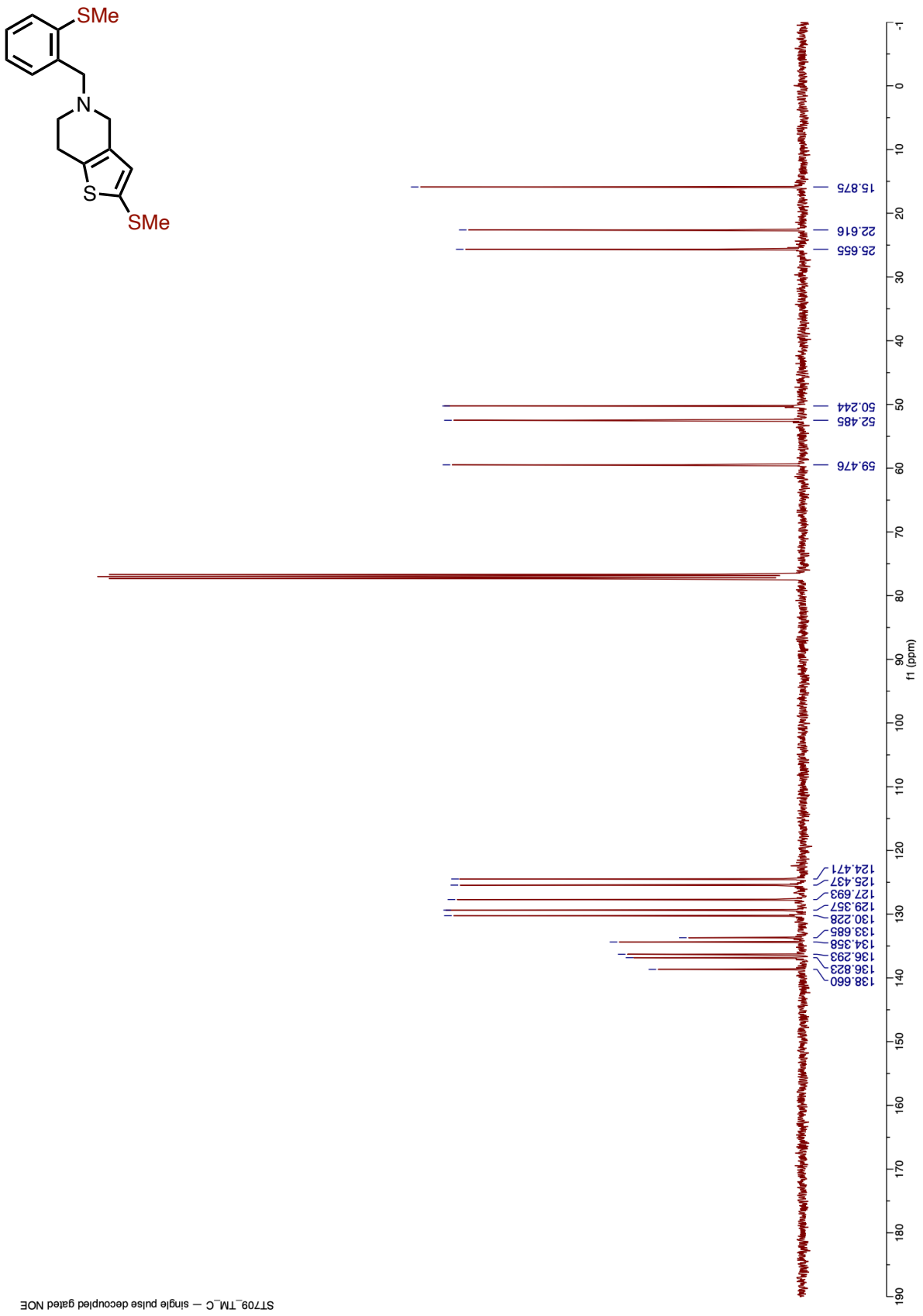
^{13}C NMR of **3I** (101 MHz, $CDCl_3$)



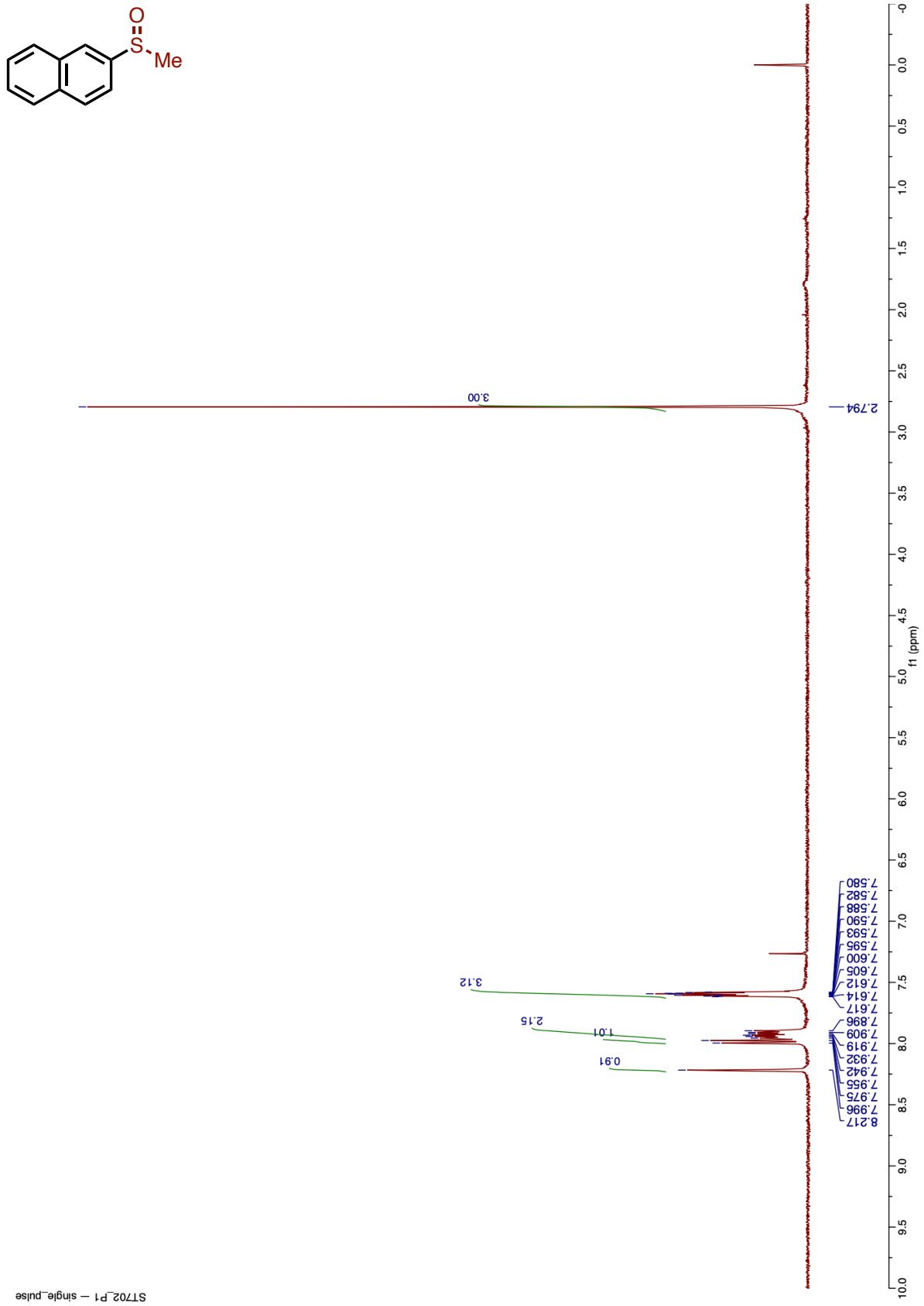
^{1}H NMR of **3J** (400 MHz, $CDCl_3$)



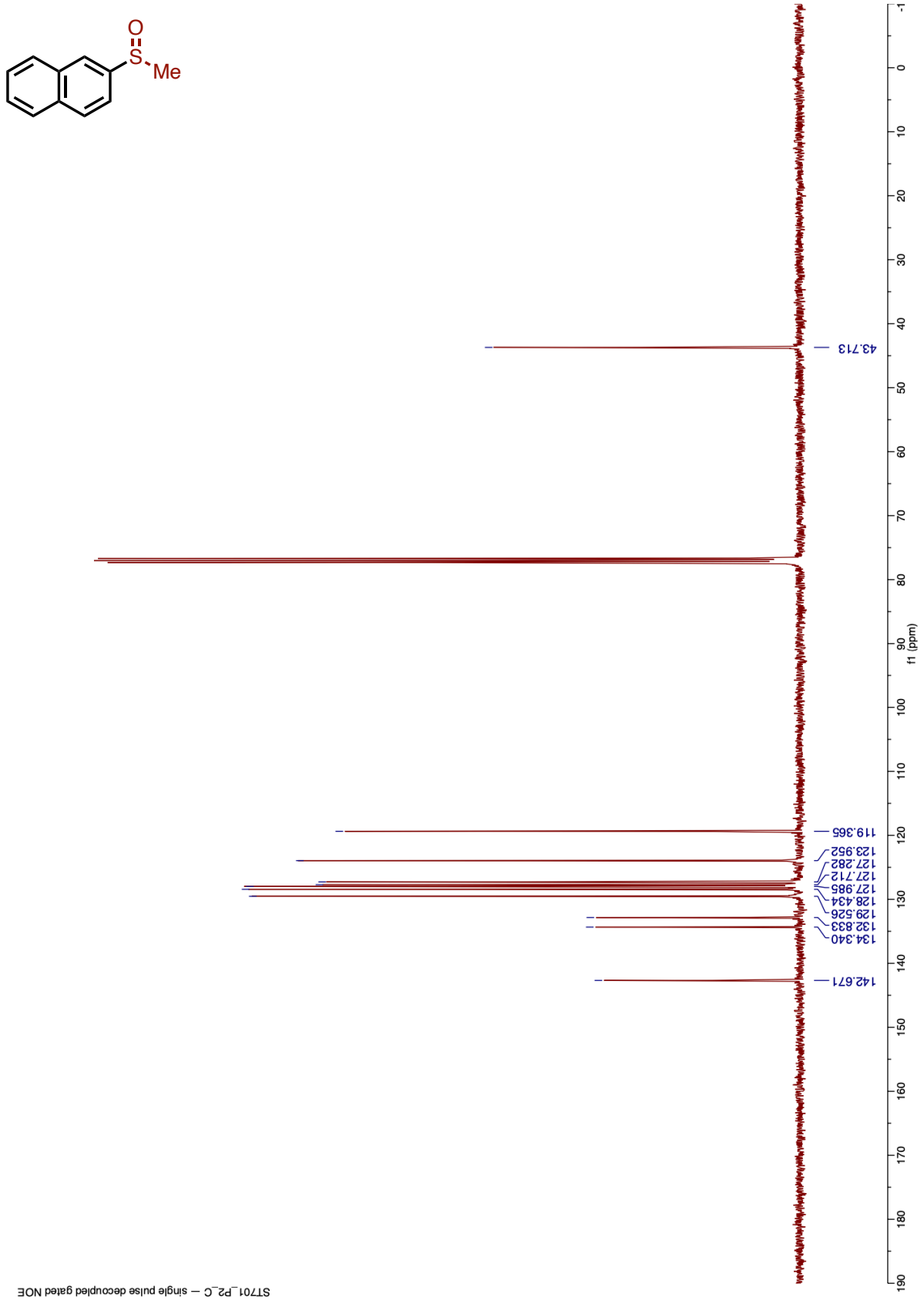
^{13}C NMR of **3J** (101 MHz, $CDCl_3$)



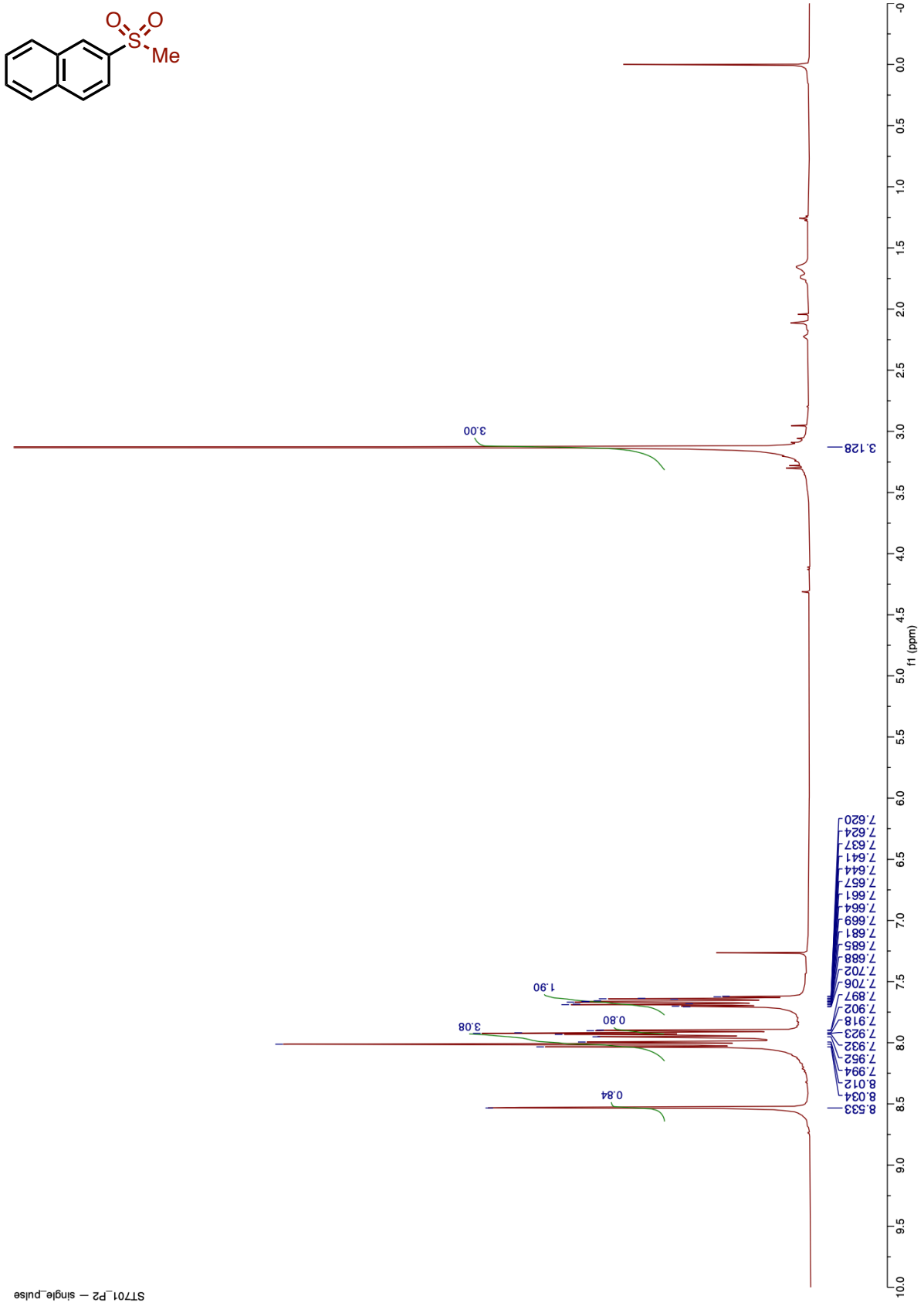
^{1}H NMR of **5** (400 MHz, $CDCl_3$)



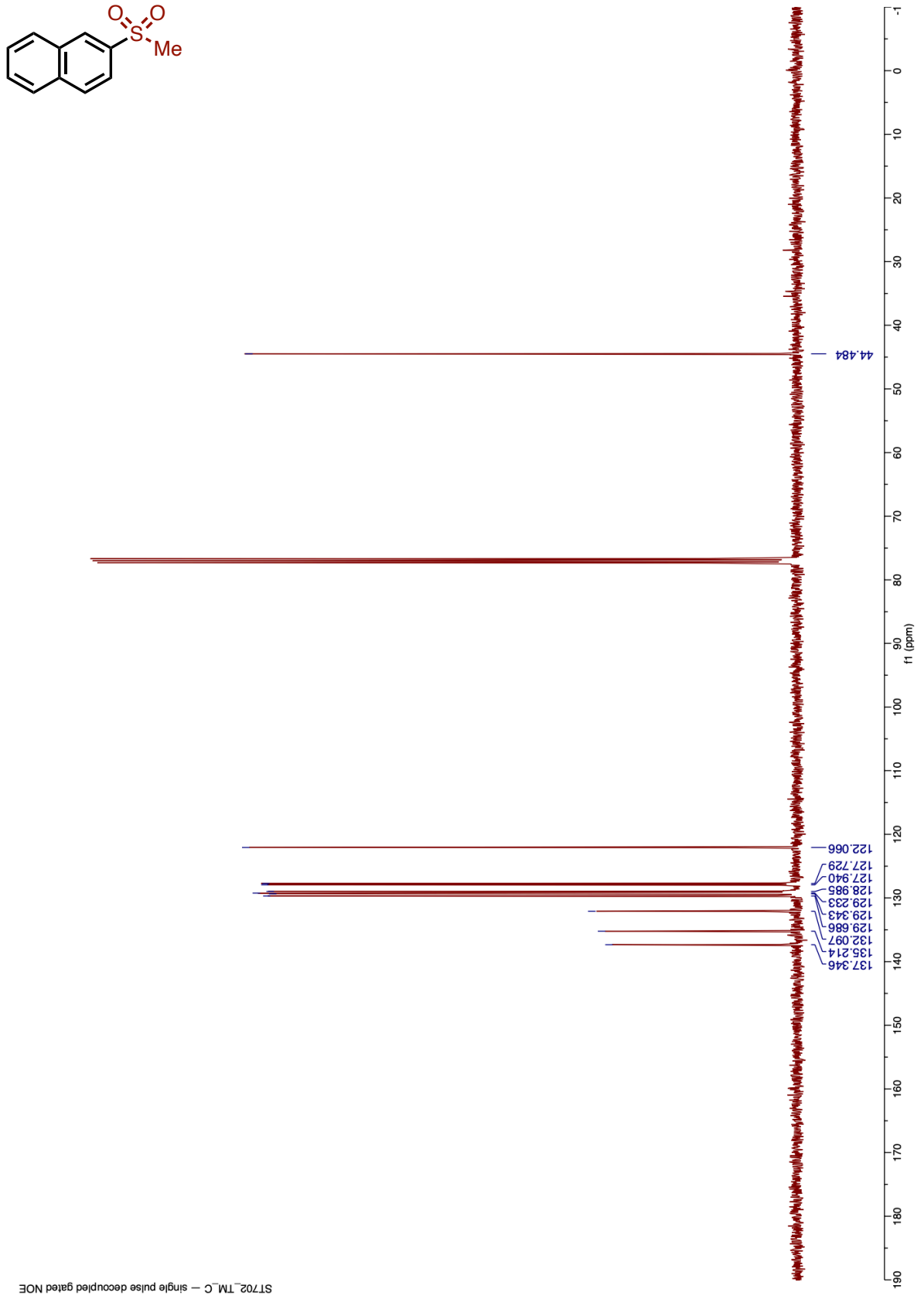
^{13}C NMR of **5** (101 MHz, $CDCl_3$)



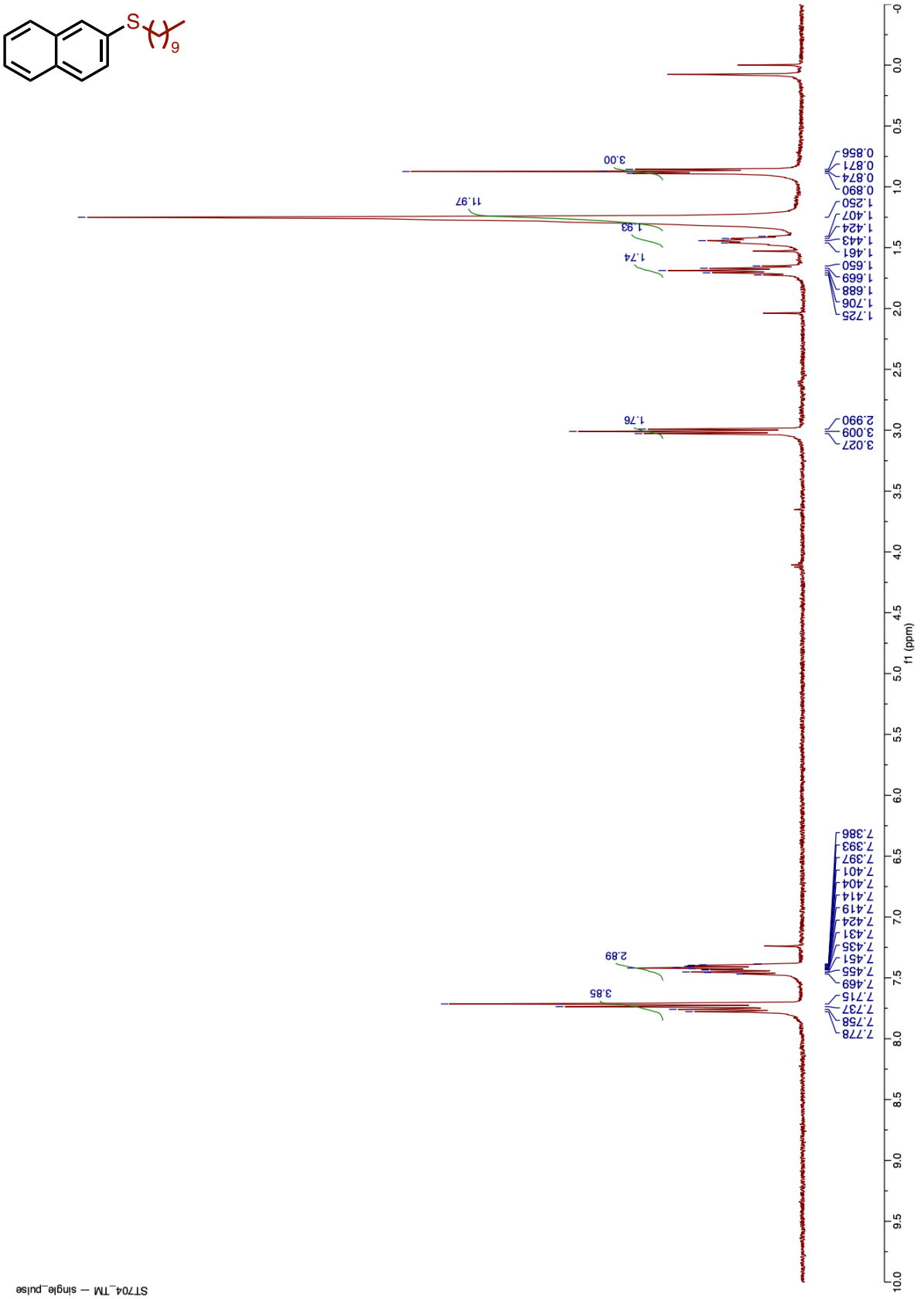
^{1}H NMR of **6** (400 MHz, $CDCl_3$)



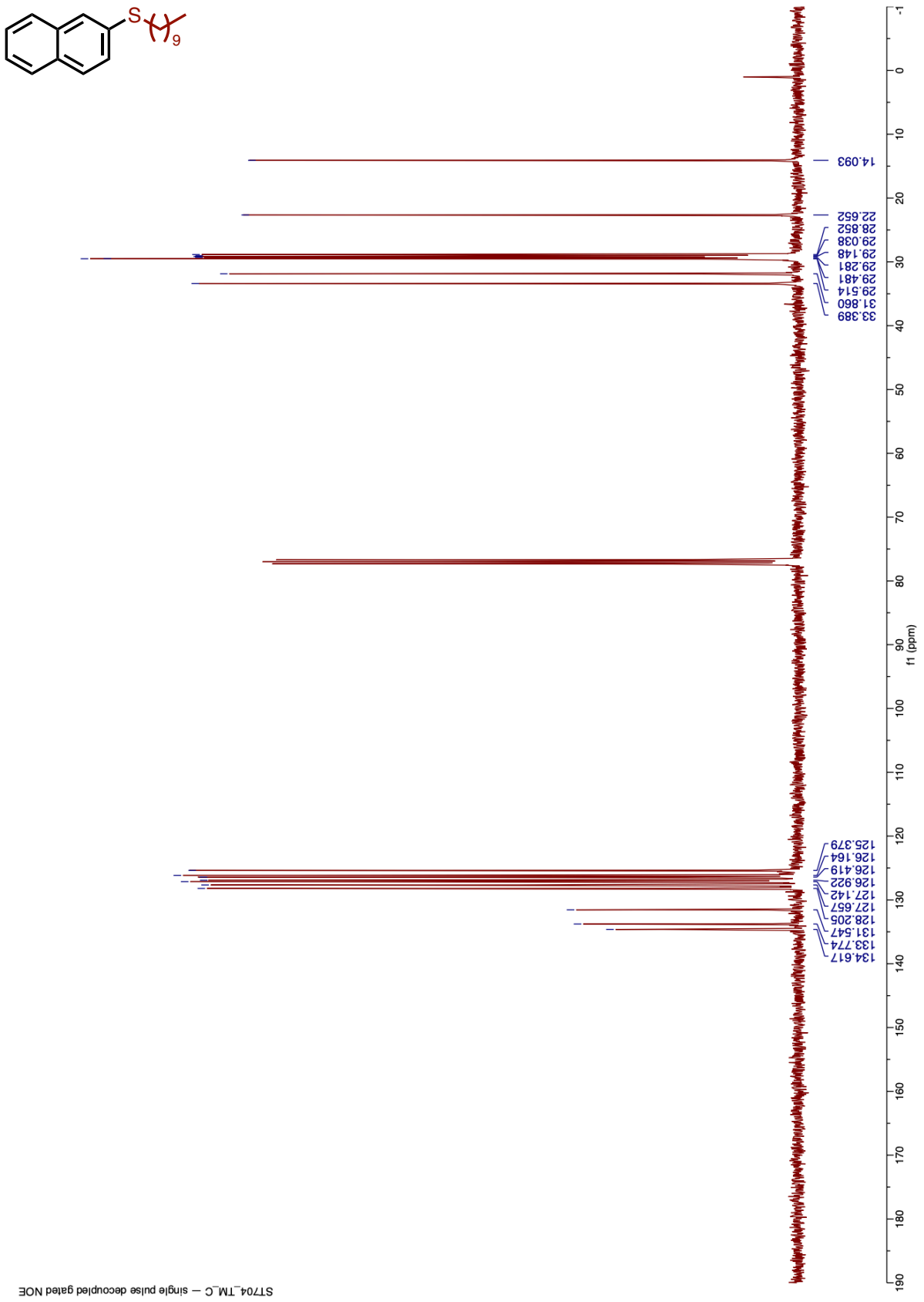
^{13}C NMR of **6** (101 MHz, $CDCl_3$)



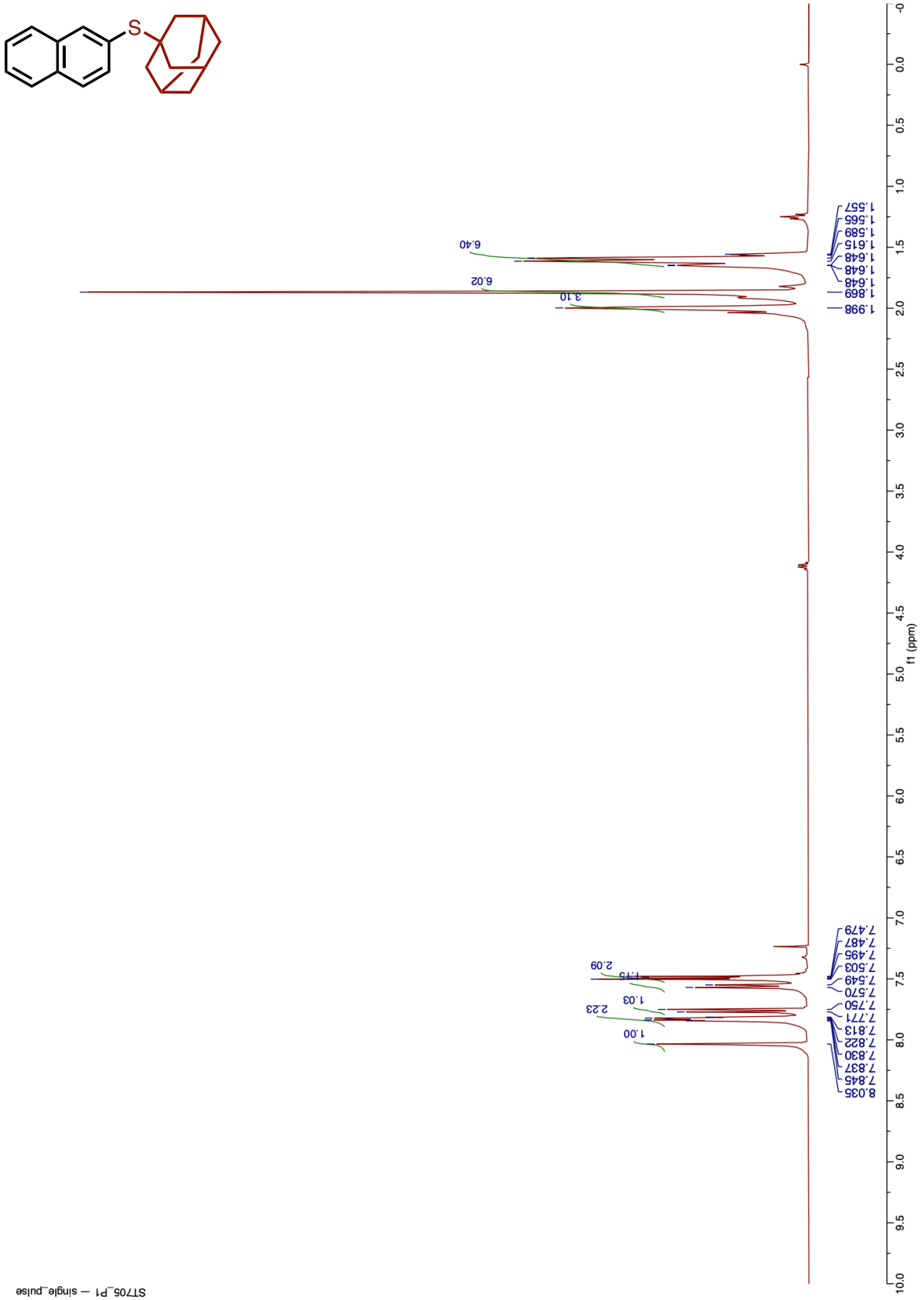
^{1}H NMR of **7** (400 MHz, $CDCl_3$)



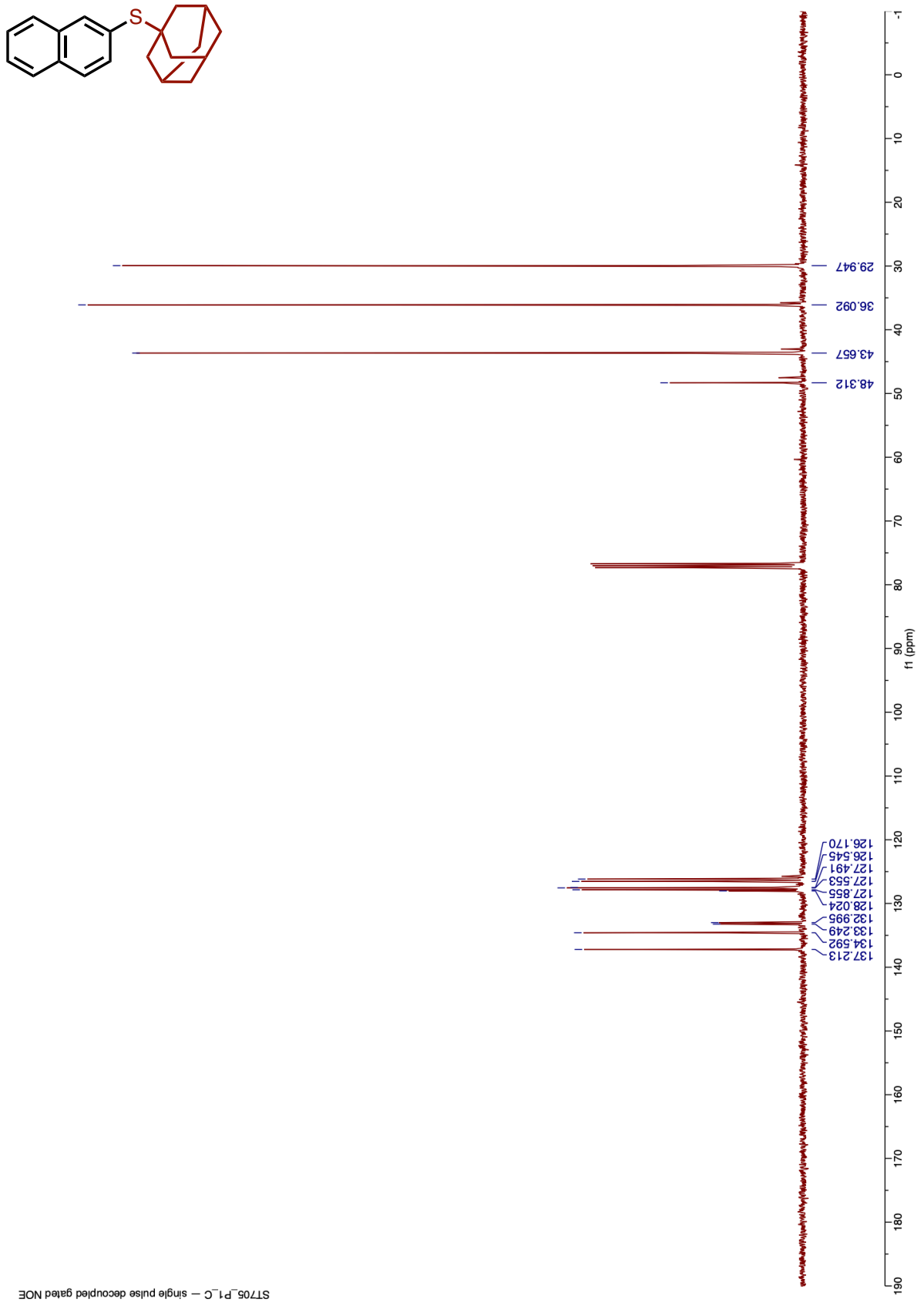
^{13}C NMR of **7** (101 MHz, $CDCl_3$)



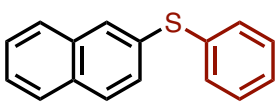
^{1}H NMR of **8** (400 MHz, $CDCl_3$)



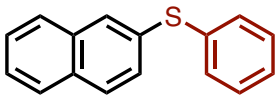
^{13}C NMR of **8** (101 MHz, $CDCl_3$)



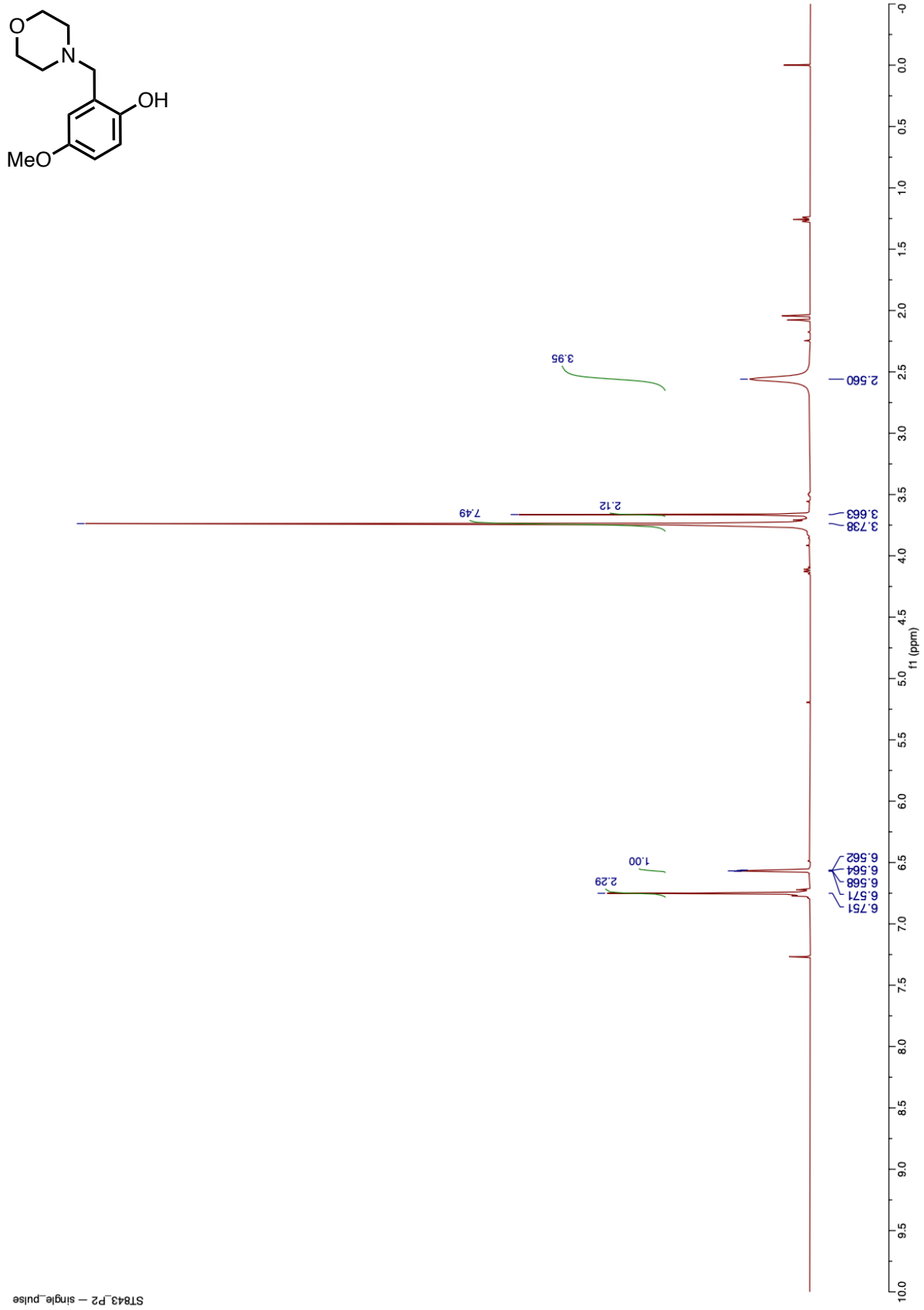
^{1}H NMR of **9** (400 MHz, $CDCl_3$)



^{13}C NMR of **9** (101 MHz, $CDCl_3$)



^{1}H NMR of **4** (400 MHz, $CDCl_3$)



^{13}C NMR of **4** (101 MHz, $CDCl_3$)