Intermolecular Scandium Triflate-Promoted Nitrene-Transfer [5+1] Cycloadditions of Vinylcyclopropanes

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Supporting Information

General Considerations

All reagents and solvents were obtained commercially in reagent grade or better quality and used without further purification. Anhydrous dichloromethane and tetrahydrofuran were obtained by degassing followed by passing through an alumina drying column before use. Anhydrous DMSO was purchased from Acros Organics and used directly. Flash column chromatography was performed using silica gel (230-400 mesh) purchased from Silicycle. ^{1}H and ^{13}C spectra were acquired at 300 K on a Bruker Avance III (600 MHz or 800 MHz) or Varian NMRS (600 MHz) spectrometer. Chemical shifts are reported in parts per million (ppm δ) referenced to the residual ^{1}H resonance of the solvent. The following abbreviations are used singularly or in combination to indicate the multiplicity of signals: s - singlet, d - doublet, t - triplet, q - quartet, m - multiplet and br - broad. IR spectra were recorded on a Shimadzu IRAffinity-1S FTIR spectrophotometer with ATR attachment. High-resolution mass spectrometry was obtained from the University of Illinois at Urbana-Champaign Mass Spectrometry Lab using Waters Q-TOF ESI or Waters oa-TOF EI spectrometers.

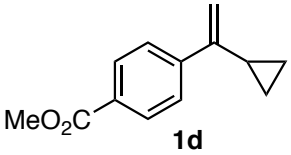
Synthesis of 2-substituted vinylcyclopropanes:

1a-c, 1e,[1] **1i**,[2] and **1l** (R^1 = Ph, R^2 = Cy, R^3 = R^4 = H)[3] were synthesized according to literature procedures.

General procedure for new vinylcyclopropanes:
Methyl triphenylphosphonium iodide (12 mmol) was suspended in anhydrous THF (40 mL) under inert atmosphere. After cooling to 4˚C, ^{t}BuOK (12 mmol) was added and the resulting solution was stirred for 30 minutes. The corresponding cyclopropylketone (10 mmol) was added in a single portion and the reaction mixture was allowed to warm to ambient temperature. Reactions were monitored by TLC until starting material was consumed at which time reaction was quenched with aqueous NH_4Cl, added to aqueous NH_4Cl (50 ml) and extracted with Et_2O (50 ml x 3). The combined organic extracts were washed with aqueous NH_4Cl (40 ml), brine (50 ml x 2) and dried over Na_2SO_4. The organic layer was concentrated and purified by silica gel chromatography (0-3% ethyl acetate in hexanes) to afford the corresponding vinylcyclopropane.

Characterization of 2-substituted vinylcyclopropanes:

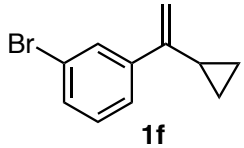
methyl 4-(1-cyclopropylvinyl)benzoate



1d

1.13 g, 56% yield, white crystalline solid. **^{1}H NMR** (600 MHz, $CDCl_3$) δ 8.01 – 7.99 (m, 2H), 7.65 – 7.63, (m, 2H), 5.37 (s, 1H), 5.08 (s, 1H), 3.92 (s, 3H), 1.64 (ttd, J = 8.3, 5.4, 1.3 Hz 1H), 0.87 – 0.84 (m, 2H), 0.61 – 0.58 (m, 2H) ppm.
^{13}C NMR (151 MHz, Chloroform-*d*) δ 167.12, 148.70, 146.25, 129.63 (2C), 129.13, 126.15 (2C), 111.19, 52.17, 15.62, 6.90 (2C) ppm.
IR (film): $\tilde{\nu}$ = 3082 (w), 3001 (w), 2949 (w), 1813 (w), 1708 (s), 1608 (m), 1277 (m), 901 (s), 782 (s), 718 (s) cm^{-1}
HRMS (EI): *m/z* calculated for $[C_{13}H_{14}O_2]^+$: 202.0994; found: 202.0995

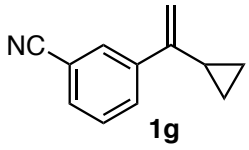
1-bromo-3-(1-cyclopropylvinyl)benzene



1f

1.34 g, 60% yield, clear liquid. **^{1}H NMR** (598 MHz, $CDCl_3$) δ 7.75 – 7.73 (m, 1H), 7.53 – 7.51 (m, 1H), 7.42-7.40 (m, 1H), 7.22 – 7.20 (m, 1H), 5.29 (s, 1H), 4.98 (d, J = 1.2 Hz, 1H), 1.63 – 1.59 (m, 1H), 0.90 – 0.81 (m, 2H), 0.65 – 0.55 (m, 2H) ppm.
^{13}C NMR (150 MHz, Chloroform-*d*) δ 148.26, 143.96, 130.47, 129.79, 129.35, 124.86, 122.55, 110.41, 15.64, 6.86 (2C) ppm.
IR (film): $\tilde{\nu}$ = 3084 (w), 3001 (w), 1591 (m), 1556 (s), 1257 (m), 883 (s), 785 (s) cm^{-1}
HRMS (EI): *m/z* calculated for $[C_{11}H_{11}Br]^+$: 222.0044; found: 222.0046

3-(1-cyclopropylvinyl)benzonitrile



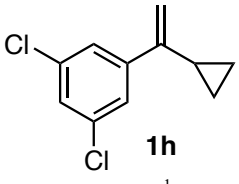
1g

1.13 g, 67% yield, clear liquid. **^{1}H NMR** (600 MHz, $CDCl_3$) δ 7.88 – 7.86 (m, 1H), 7.83 – 7.78 (m, 1H), 7.58 – 7.54 (m, 1H), 7.44 – 7.42 (m, 1H), 5.34 (s, 1H), 5.05 (d, J = 1.3 Hz, 1H), 1.64 – 1.58 (m, 1H), 0.91 – 0.87 (m, 2H), 0.62 – 0.59 (m, 2H) ppm. **^{13}C NMR** (150 MHz, $CDCl_3$) δ 147.53, 142.88, 130.96, 130.52, 129.90, 129.10, 119.15, 112.47, 111.45, 15.51, 6.84 (2C) ppm.

IR (film): $\tilde{\nu}$ = 3089 (w), 3003 (w), 2365 (w), 2229 (w), 1625 (m), 1479 (m), 896 (s), 800 (s) cm^{-1}

HRMS (EI): *m/z* calculated for $[C_{12}H_{11}N]^+$: 168.0813; found: 168.0810

1,3-dichloro-5-(1-cyclopropylvinyl)benzene



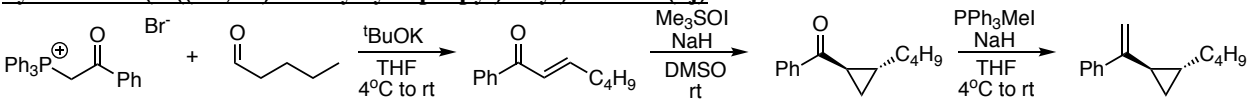
1h

1.75 g, 82% yield, clear liquid. **^{1}H NMR** (600 MHz, $CDCl_3$) δ 7.45 (d, J = 1.9 Hz, 2H), 7.27 (s, 1H), 5.30 (s, 1H), 5.01 (d, J = 1.4 Hz, 1H), 1.60 – 1.53 (m, 1H), 0.89 – 0.83 (m, 2H), 0.61 – 0.57 (m, 2H) ppm. **^{13}C NMR** (151 MHz, $CDCl_3$) δ 147.29, 144.81, 134.83 (2C), 127.41, 124.80 (2C), 111.54, 15.51, 6.89 (2C) ppm.

IR (film): $\tilde{\nu}$ = 3084 (w), 3005 (w), 2362 (w), 1583 (m), 1558 (s), 1379 (m), 1261 (m), 877 (s), 799 (s) cm^{-1}

HRMS (EI): *m/z* calculated for $[C_{11}H_{10}Cl_2]^+$: 212.0160; found: 212.0162

<u>Synthesis of (1-((1*R*,2*R*)-2-butylcyclopropyl)vinyl)benzene (1j)</u>:



1j

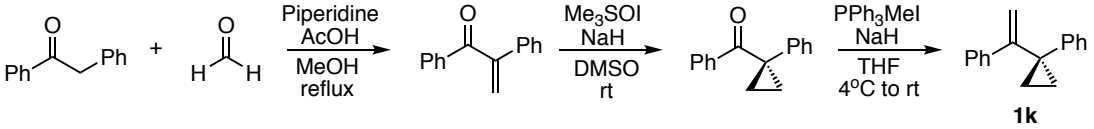
(2-oxo-2-phenylethyl) triphenylphosphonium bromide (12 mmol) was suspended in anhydrous THF (30 mL) under inert atmosphere. After cooling to 4˚C, potassium tert-butoxide (12 mmol) was added and stirred 30 minutes. Valeraldehyde (10 mmol) was added in a single portion and the reaction mixture was allowed to warm to ambient temperature. Reactions were monitored by TLC until starting material was consumed (24 hours) at which time reaction was quenched with aqueous NH_4Cl, added to aqueous NH_4Cl (50 ml) and extracted with Et_2O (50 ml x 3). The combined organic extracts were washed with aqueous NH_4Cl (40 ml), brine (50 ml x 2) and dried over Na_2SO_4. The filtrated was concentrated and purified by silica gel chromatography (3% ethyl acetate in hexanes) to afford (*E*)-1-phenylhept-2-en-1-one as a yellow oil (1.02 g, 54% yield). Product ^{1}H NMR matches previous reports.[4]

Trimethylsulfoxonium iodide (10.8 mmol) was dissolved in 25 mL anhydrous DMSO under inert atmosphere at ambient temperature. Sodium hydride (10.8 mmol) was added portionwise and the mixture was stirred 30 minutes at which time the enone (5.4 mmol) was added in a single portion. The reaction was stirred overnight then quenched with saturated aqueous NH_4Cl (30 mL) before being extracted with Et_2O (50 ml x 2). Combined organic layers were washed with aqueous NH_4Cl (30 ml), then brine (30 ml x 2) and dried over Na_2SO_4. The filtrate was concentrated and purified by silica gel chromatography (3% ethyl acetate in hexanes) to afford ((1*R*,2*R*)-2-butylcyclopropyl)(phenyl)methanone as a yellow oil (460.8 mg, 42% yield). Product ^{1}H NMR matches previous reports.[5]

Methyl triphenylphosphonium iodide (2.8 mmol) was suspended in anhydrous THF (20 mL) under inert atmosphere. After cooling to 4˚C, potassium tert-butoxide (2.8 mmol) was added and stirred 30 minutes. The cyclopropyl ketone (2.3 mmol) was added in a single portion and the reaction mixture was allowed to warm to ambient temperature. After stirring overnight, the reaction was quenched with aqueous NH_4Cl, added to aqueous NH_4Cl (50 ml) and extracted with Et_2O (50 ml x 3). The combined organic extracts were washed with aqueous NH_4Cl (40 ml), brine (50 ml x 2) and dried over Na_2SO_4. The filtrated was concentrated and purified by silica gel chromatography (3% ethyl acetate in hexanes) to afford (1-((1*R*,2*R*)-2-butylcyclopropyl)vinyl)benzene (**1j**) as a clear liquid (257.2 mg, 78% yield). **^{1}H NMR** (600 MHz, $CDCl_3$) δ 7.57 – 7.55 (m, 2H), 7.42 – 7.32 (m, 2H), 7.31 – 7.24 (m, 1H), 5.22 (d, J = 3.0 Hz, 1H), 4.99 – 4.63 (m, 1H), 1.70 – 1.49 (m, 1H), 1.49 – 1.25 (m, 6H), 0.95 – 0.85 (m, 4H), 0.80 – 0.77 (m, 1H), 0.64 – 0.60 (m, 1H). **^{13}C NMR** (151 MHz, $CDCl_3$) δ 149.80, 142.11, 128.25 (2C), 127.47, 126.29 (2C), 108.74, 34.11, 31.77,

23.41, 22.71, 21.69, 14.27, 14.01. **IR** (film): $\tilde{\nu}$ = 3030 (w), 1622 (w), 1494 (w), 1444 (w), 1028 (m), 889 (m), 775 (s), 702 (s) cm^{-1}. **HRMS** (EI): *m/z* calculated for $[C_{15}H_{20}]^+$: 200.1565; found: 200.1567

Synthesis of (1-(1-phenylcyclopropyl)vinyl)benzene (1k):



2-phenyl acetophenone (30 mmol) was dissolved in 100 ml of anhydrous MeOH under inert atmosphere at ambient temperature. Formaldehyde (10.6 ml), piperidine (0.4 ml) and acetic acid (0.4 ml) were subsequently added. The reaction was stirred at reflux overnight then cooled to room temperature and added to brine (80 ml) then extracted with EtOAc (60 ml x 2). The combined organic extracts were washed with 1M HCl (60 ml x 2), aqueous $NaHCO_3$ (60 ml x 2), brine (60 ml x 2), and dried over Na_2SO_4. The organic layers were concentrated and afforded 1,2-diphenylprop-2-en-1-one as a gold liquid (6.21 g, quantitative yield). Product ^{1}H NMR matches previous reports.[6]

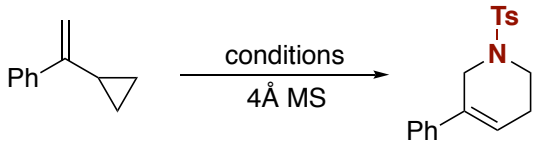
Trimethylsulfoxonium iodide (60 mmol) was dissolved in 100 mL anhydrous DMSO under inert atmosphere at ambient temperature. Sodium hydride (60 mmol) was added portionwise and the mixture was stirred 30 minutes at which time the enone (30 mmol) was added in a single portion. The reaction was stirred overnight then quenched with saturated aqueous NH_4Cl (80 mL) before being extracted with Et_2O (75 ml x 2). Combined organic layers were washed with aqueous NH_4Cl (70 ml), then brine (70 ml x 2) and dried over Na_2SO_4. The organic layers were concentrated and afforded phenyl(1-phenylcyclopropyl)methanone as beige crystals (5.70 g, 85% yield). Product ^{1}H NMR matches previous reports.[7]

Methyl triphenylphosphonium iodide (12 mmol) was suspended in anhydrous THF (60 mL) under inert atmosphere. After cooling to 4˚C, potassium tert-butoxide (12 mmol) was added and stirred 30 minutes. The cyclopropyl ketone (10 mmol) was added in a single portion and the reaction mixture was allowed to warm to ambient temperature. After stirring overnight, the reaction was quenched with aqueous NH_4Cl, added to aqueous NH_4Cl (70 ml) and extracted with Et_2O (50 ml x 3). The combined organic extracts were washed with aqueous NH_4Cl (60 ml), brine (50 ml x 2) and dried over Na_2SO_4. The filtrated was concentrated and purified by silica gel chromatography (1% ethyl acetate in hexanes) to afford (1-(1-phenylcyclopropyl)vinyl)benzene (**1k**) as a clear liquid (1.81 g, 82% yield). **^{1}H NMR** (600 MHz, $CDCl_3$) δ 7.58 – 7.56 (m, 2H), 7.29 – 7.22 (m, 8H), 7.15 – 7.12 (m, 1H), 5.76 (d, *J* = 1.5 Hz, 1H), 5.43 (d, *J* = 1.7 Hz, 1H), 1.34 – 1.29 (m, 2H), 1.29 – 1.27 (m, 2H). **^{13}C NMR** (151 MHz, $CDCl_3$) δ 150.24, 144.71, 139.91, 128.24 (2C), 128.12 (2C), 127.45 (2C), 127.04 (2C), 126.48, 125.53, 115.22, 29.49, 16.91 (2C). **IR** (film): $\tilde{\nu}$ = 3084 (w), 1600 (w), 1494 (w), 1028 (m), 904 (m), 779 (s), 756 (m), 696 (s) cm^{-1}. **HRMS** (EI): *m/z* calculated for $[C_{17}H_{16}]^+$: 220.1252; found: 220.1257

Synthesis of *N*-Tosylphenyimidoliodinane (PhINTs):

p-Toluenesulfonamide (20 mmol) and KOH (50 mmol) were dissolved in 80 ml of MeOH and cooled to 4ºC. To the stirred solution diacetoxyiodobenzene (20 mmol) was added portionwise. The yellow solution was then warmed to room temperature and stirred for 5 hours. The reaction was then cooled to 4ºC, 100 ml of ice water was added, and the reaction was stirred for an additional hour at 4ºC. The mixture was then filtered to collect the precipitate, which was subsequently washed with cold MeOH and cold EtOAc to afford PhINTs as a pale yellow solid (4.46 g, 65% yield). NMR data matched literature values.[8]

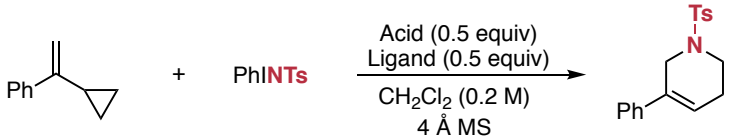
Reaction Optimization:



Entry	PhINTs (Equiv.)	$Sc(OTf)_3$ (Equiv.)	Add. Time[a] (h)	T (˚C)	Solvent (M)	Yield[c]
1	1	1	-	rt	CH_2Cl_2	22*
2	1	0.5	-	rt	CH_2Cl_2	24*
3	1.5	0.5	-	rt	CH_2Cl_2	40
4	1.5	0.5	-	4	CH_2Cl_2	38
5	1.5	0.5	1	4	CH_2Cl_2	41
6	1.5	0.5	1	4	$CHCl_3$	35
7	1.5	0.5	-	4	C_6H_6	17
8	2	0.5	-	rt	CH_2Cl_2	42*
9	2	0.5	1	4	CH_2Cl_2	50
10	2.5	0.5	1	4	CH_2Cl_2	50
11	2.5	0.5	1	4	CH_2Cl_2	58
12	2.5	1	1	4	CH_2Cl_2	48
13	2.5	0.5	1	4	$PhCF_3$	13
14	2.5	0.5	1	4	PhCl	33
15	2.5	0.5	1	4	CH_3CN	14
16	2.5	0.5	1	4	DCE	23
17	2.5	0.5	1	4	iPrOAc	14
18	2.5	0.5	1	4	Propylene carbonate	0
19	2.5	0.5	1	4	MTBE	14
20	2.5	0.5	1	4	THF	0
21	2.5	0.5	1	4	$CHCl_3$	38*
22	3	0.5	1	4	CH_2Cl_2	42*

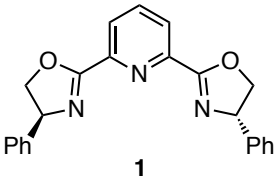
(a) Substrate added as solution in reaction solvent. If no time indicated, reagents were combined sequentially: PhINTs, $Sc(OTf)_3$, 4Å MS, solvent, and substrate. (b) Reactions quenched when substrate appeared consumed or reaction stalled by TLC. (c) Isolated yields with respect to substrate. Parentheses indicate yield with respect to $Sc(OTf)_3$. *NMR Yields.

Investigation into Metal-Ligand Complexes:

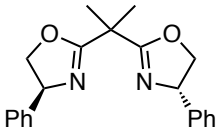


Entry	Equiv VCP	Equiv PhINTs	Acid	Ligand	Yield (brsm) (%)
1	1	1	$Cu(OTf)_2$	**1**	17 (22)
2	1	1	$Cu(OTf)_2$	**2**	24
3	1	1	$Sc(OTf)_3$	**1**	39 (49)
4	3	1	$Sc(OTf)_3$	**1**	28
5	1	2	$Sc(OTf)_3$	**1**	34
6	1	1	$Sc(OTf)_3$	**1**	36 (40)[b]
7	1	1	$Sc(OTf)_3$	**1**	23 (40)[c]
8	1	1	$Sc(OTf)_3$	**1**	33 (53)[d]
9	1	1	$Sc(OTf)_3$	**2**	10 (14)
10	1	1	$Sc(OTf)_3$	**3**	42 (47)
11	1	1	$Sc(OTf)_3$	**4**	40 (48)
12	1	2.5	$Sc(OTf)_3$	**5**	18
13	1	1	$Sc(OTf)_3$	**6**	23 (28)

[a] All reactions were conducted on a 0.2 mmol scale in the limiting reagent. Acid, ligand, 4 Å MS and DCM were combined in the glovebox and stirred for 2 hrs, then substrate and PhINTs were added. [b]Acid, ligand, 4 Å MS and DCM were stirred for 4 hrs before substrate and PhINTs addition. [c]Reaction concentration 0.4M with respect to substrate. [d]Reaction time of 48 hrs.



1



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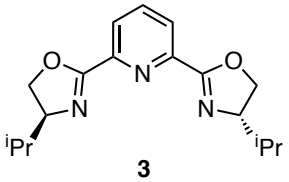

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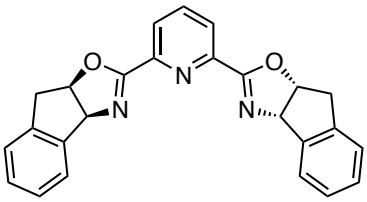

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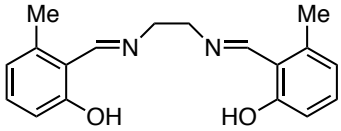

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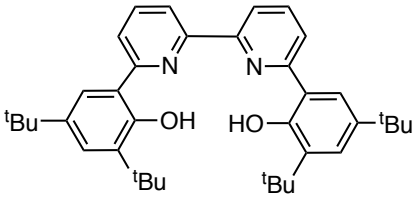
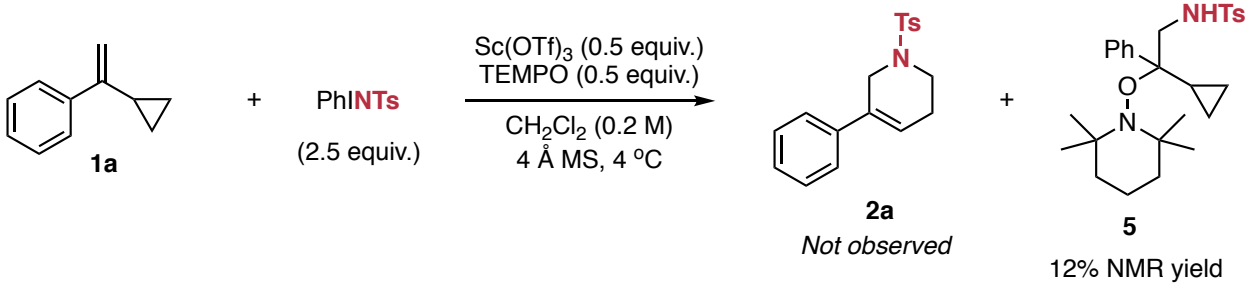
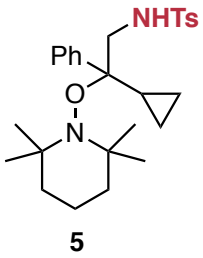


6

Radical Trap Experiment with TEMPO:



***N*-(2-cyclopropyl-2-phenyl-2-((2,2,6,6-tetramethylpiperidin-1-yl)oxy)ethyl)-4-methylbenzenesulfonamide**



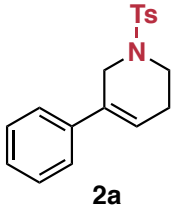
5

12% NMR yield using methyl-3-nitrobenzoate as an internal standard. Product co-eluted with unknown impurity (see ^{1}H NMR), so isolated yield is unavailable. Off-white solid.
Total reaction time: 5 h
Purified by silica gel flash chromatography using 10:1 Hexanes/Ethyl acetate.
^{1}H NMR (600 MHz, Chloroform-*d*) δ 7.67 – 7.65 (m, 2H), 7.54 – 7.52 (m, 2H), 7.25 – 7.15 (m, 6H), 5.59 (s, 1H), 3.82 (d, *J* = 8.6 Hz, 1H), 3.69 (d, *J* = 8.6 Hz, 1H), 2.41 (s, 3H), 1.57 – 1.53 (m, 6H), 1.17 (s, 3H), 1.13 (s, 3H), 0.98 (s, 3H), 0.89 (s, 3H), 0.60 – 0.51 (m, 1H), 0.50 – 0.42 (m, 1H), 0.36 – 0.25 (m, 1H), 0.06 (tt, *J* = 9.1, 5.5 Hz, 1H).
^{13}C NMR (201 MHz, Chloroform-*d*) δ 142.65, 142.18, 140.92, 129.26, 128.59, 127.69, 127.44, 127.20, 126.11, 80.52, 64.91, 60.32, 40.06, 33.28, 32.65, 29.86, 28.52, 26.61, 21.64, 20.77, 20.45, 17.61, 17.05, 3.95, 2.71.
IR (film): $\tilde{\nu}$ = 2972 (w), 1703 (m, br), 1498 (m), 1361 (m), 1321 (m, br), 1246 (w), 1159 (s, br) 1047 (m), 1024 (m), 974 (w), 813 (m), 765 (m), 734 (m), 694 (s), 663 (s), 561 (s) cm^{-1}
HRMS (ESI): *m/z* calculated for $[C_{27}H_{38}N_2O_3S+H]^+$: 471.2686; found: 471.2673

Representative procedure:

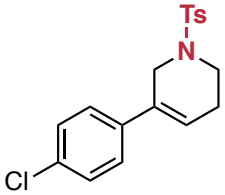
PhINTs (186 mg, 0.5 mmol), $Sc(OTf)_3$ (49 mg, 0.1 mmol) and 4Å molecular sieves (30 mg) were suspended in 600 µL DCM at 4 ℃ under nitrogen atmosphere. The corresponding vinyl cyclopropane (0.2 mmol) was then dissolved in 400 µL DCM and added dropwise over 1 hour via syringe pump. After consumption of starting material by TLC, the mixture was quenched with sat. $NaHCO_3$ and extracted with DCM. The combined extracts were washed with brine and dried over Na_2SO4.

Characterization of [5+1] products:



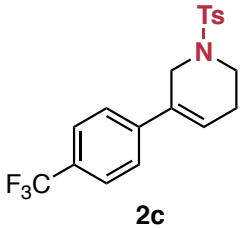
2a

5-phenyl-1-tosyl-1,2,3,6-tetrahydropyridine
36.4 mg isolated, 58% yield. White solid.
Total reaction time: 2 h
Purified by silica gel flash chromatography using 20:1 Hexanes/Acetone.
^{1}H NMR (598 MHz, $CDCl_3$) δ 7.88 – 7.62 (m, 2H), 7.37 – 7.30 (m, 4H), 7.29 – 7.27 (m, 3H), 6.07 (tt, *J* = 4.0, 1.9 Hz, 1H), 3.94 (d, *J* = 2.3 Hz, 2H), 3.24 (t, *J* = 5.8 Hz, 2H), 2.43 (s, 3H), 2.39 – 2.35 (m, 2H). Matches previous reports.[9]



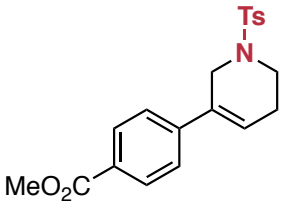
2b

5-(4-chlorophenyl)-1-tosyl-1,2,3,6-tetrahydropyridine
35.3 mg isolated, 48% yield. White solid.
Total reaction time: 2 h
Purified by silica gel flash chromatography using 20:1 Hexanes/Acetone.
^{1}H NMR (598 MHz, $CDCl_3$) δ 7.77 – 7.67 (m, 2H), 7.48 – 7.31 (m, 2H), 7.30 – 7.26 (m, 2H), 7.23 – 7.17 (m, 2H), 6.07 (tt, *J* = 4.0, 1.9 Hz, 1H), 3.91-3.89 (m, 2H), 3.23 (t, *J* = 5.8 Hz, 2H), 2.43 (s, 3H), 2.40 – 2.37 (m, 2H) ppm. Matches previous reports.[9]



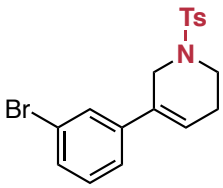
2c

1-tosyl-5-(4-(trifluoromethyl)phenyl)-1,2,3,6-tetrahydropyridine
37.8 mg isolated, 50% yield. White solid
Total reaction time: 2.5 h
Purified by silica gel flash chromatography using 20:1 Hexanes/Acetone.
^{1}H NMR (600 MHz, $CDCl_3$) δ 7.73 – 7.70 (m, 2H), 7.57 (d, *J* = 8.1 Hz, 2H), 7.38 (d, *J* = 8.1 Hz, 2H), 7.35 – 7.31 (m, 2H), 6.19 – 6.15 (m, 1H), 3.96 – 3.92 (m, 2H), 3.26 (t, *J* = 5.8 Hz, 2H), 2.43 – 2.41 (m, 5H). Matches previous reports.[9]



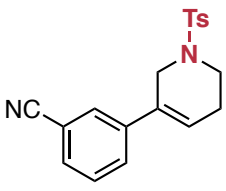
2d

methyl 4-(1-tosyl-1,2,5,6-tetrahydropyridin-3-yl)benzoate
22.4 mg isolated, 30% yield. White solid.
Total reaction time: 5 h
Purified by silica gel flash chromatography using 20:3 Hexanes/Ethyl acetate.
^{1}H NMR (600 MHz, $CDCl_3$) δ 7.99 – 7.97 (m, 2H), 7.73 – 7.71 (m, 2H), 7.35 – 7.32 (m, 4H), 6.21 – 6.19 (m, 1H), 3.96 – 3.95 (m, 2H), 3.91 (s, 3H), 3.25 (t, *J* = 5.8 Hz, 2H), 2.42 (s, 3H), 2.42 – 2.39 (m, 2H) ppm.
^{13}C NMR (151 MHz, $CDCl_3$) δ 166.86, 143.87, 143.11, 133.53, 132.87, 130.00 (2C), 129.90 (2C), 129.40, 127.83 (2C), 125.10 (2C), 124.51, 52.27, 46.24, 42.38, 25.91, 21.68 ppm.
IR (film): $\tilde{\nu}$ = 3045 (w), 2918 (w), 2848 (w), 1721 (s), 1607 (m), 1436 (m), 1338 (m), 1274 (s), 1265 (s), 1161 (m), 1105 (m), 972 (m), 760 (s) cm^{-1}
HRMS (ESI): *m/z* calculated for $[C_{20}H_{21}NO_4S+H]^+$: 372.1270; found: 372.1269



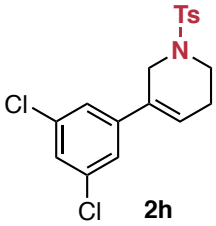
2f

5-(3-bromophenyl)-1-tosyl-1,2,3,6-tetrahydropyridine
37.0 mg isolated, 47% yield. Off-white solid.
Total reaction time: 19 h
Purified by silica gel flash chromatography using 20:1 Hexanes/Acetone.
^{1}H NMR (598 MHz, $CDCl_3$) δ 7.70 (d, *J* = 8.2 Hz, 2H), 7.41 – 7.36 (m, 2H), 7.34 – 7.30 (m, 2H), 7.21 – 7.15 (m, 2H), 6.09 – 6.05 (m, 1H), 3.90 – 3.85 (m, 2H), 3.22 (t, *J* = 5.8 Hz, 2H), 2.42 (s, 3H), 2.38 (m, 2H) ppm. Matches previous literature.[10]



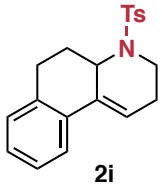
2g

3-(1-tosyl-1,2,5,6-tetrahydropyridin-3-yl)benzonitrile
25.0 mg isolated, 37% yield. Yellow solid.
Total reaction time: 20 h
Purified by silica gel flash chromatography using 20:1 Hexanes/Acetone.
^{1}H NMR (600 MHz, $CDCl_3$) δ 7.74 – 7.69 (m, 2H), 7.57 – 7.49 (m, 3H), 7.45 – 7.40 (m, 1H), 7.35 (d, *J* = 8.0 Hz, 2H), 6.17 – 6.14 (m, 1H), 3.92 – 3.88 (m, 2H), 3.25 (t, *J* = 5.8 Hz, 2H), 2.44 (s, 3H), 2.43 – 2.40 (m, 2H) ppm.
^{13}C NMR (151 MHz $CDCl_3$) δ 143.99, 140.00, 133.31, 131.90, 131.17, 129.95 (2C), 129.54 (2C), 128.92, 127.81 (2C), 124.87, 118.72, 112.93, 46.15, 42.30, 25.85, 21.67 ppm.
IR (film): $\tilde{\nu}$ = 3168 (w), 2980 (w), 2254 (m), 2233 (w), 1598 (m), 1018 (m), 972 (m), 667 (m) cm^{-1}
HRMS (ESI): *m/z* calculated for $[C_{19}H_{18}N_2SO_2+H]^+$: 339.1167; found: 339.1163



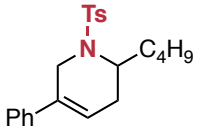
2h

5-(3,5-dichlorophenyl)-1-tosyl-1,2,3,6-tetrahydropyridine
34.0 mg isolated, 44% yield. Off-white solid.
Total reaction time: 20 h
Purified by silica gel flash chromatography using 20:1 Hexanes/Acetone.
^{1}H NMR (600 MHz, $CDCl_3$) δ δ 7.75 – 7.69 (m, 2H), 7.38 – 7.31 (m, 2H), 7.27 – 7.25 (m, 1H), 7.15 – 7.13 (m, 2H), 6.16 – 6.10 (m, 1H), 3.89 – 3.83 (m, 2H), 3.23 (t, J = 5.8 Hz, 2H), 2.44 (s, 3H), 2.42 – 2.36 (m, 2H) ppm.
^{13}C NMR (151 MHz, $CDCl_3$) δ 143.96, 141.74, 135.29, 133.30, 131.66, 129.95 (2C), 127.81 (2C), 127.72 (2C), 124.96, 123.91 (2C), 46.12, 42.30, 25.81, 21.69 ppm.
IR (film): $\tilde{\nu}$ = 3061 (w), 2322 (w), 1739 (w), 1560 (m), 1271 (s), 972 (m) cm^{-1}
HRMS (ESI): *m/z* calculated for $[C_{18}H_{17}Cl_2NO_2S+H]^+$: 382.0435; found: 382.0432



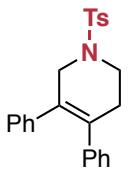
2i

4-tosyl-2,3,4,4a,5,6-hexahydrobenzo[*f*]quinoline
18.8 mg isolated, 27% yield. White solid.
Total reaction time: 17 h
Purified by silica gel flash chromatography using 20:1 Hexanes/Acetone.
^{1}H NMR (600 MHz, $CDCl_3$) δ 7.73 – 7.69 (m, 2H), 7.35 (dd, J = 7.9, 1.4 Hz, 1H), 7.28 – 7.24 (m, 2H), 7.18 – 7.06 (m, 3H), 6.12 – 6.09 (m, 1H), 4.50 – 4.43 (m, 1H), 3.88 (dd, J = 13.9, 5.5 Hz, 1H), 3.19 – 3.08 (m, 2H), 2.96 (dd, J = 17.4, 5.9 Hz, 1H), 2.40 (s, 3H), 2.32 – 2.25 (m, 1H), 2.11 – 1.90 (m, 3H) ppm.
^{13}C NMR (151 MHz, $CDCl_3$) δ 143.22, 138.47, 135.46, 135.16, 134.82, 129.82 (2C), 129.09, 127.62, 126.97 (2C), 126.17, 123.71, 118.98, 54.01, 39.11, 31.07, 29.10, 24.40, 21.64 ppm.
IR (film): $\tilde{\nu}$ = 3082 (w), 2935 (m), 2360 (w), 1577 (s), 1504 (s), 1409 (m), 1006 (m), 842 (m) cm^{-1}
HRMS (ESI): *m/z* calculated for $[C_{20}H_{21}NO_2S+H]^+$: 340.1371; found: 340.1372



2j

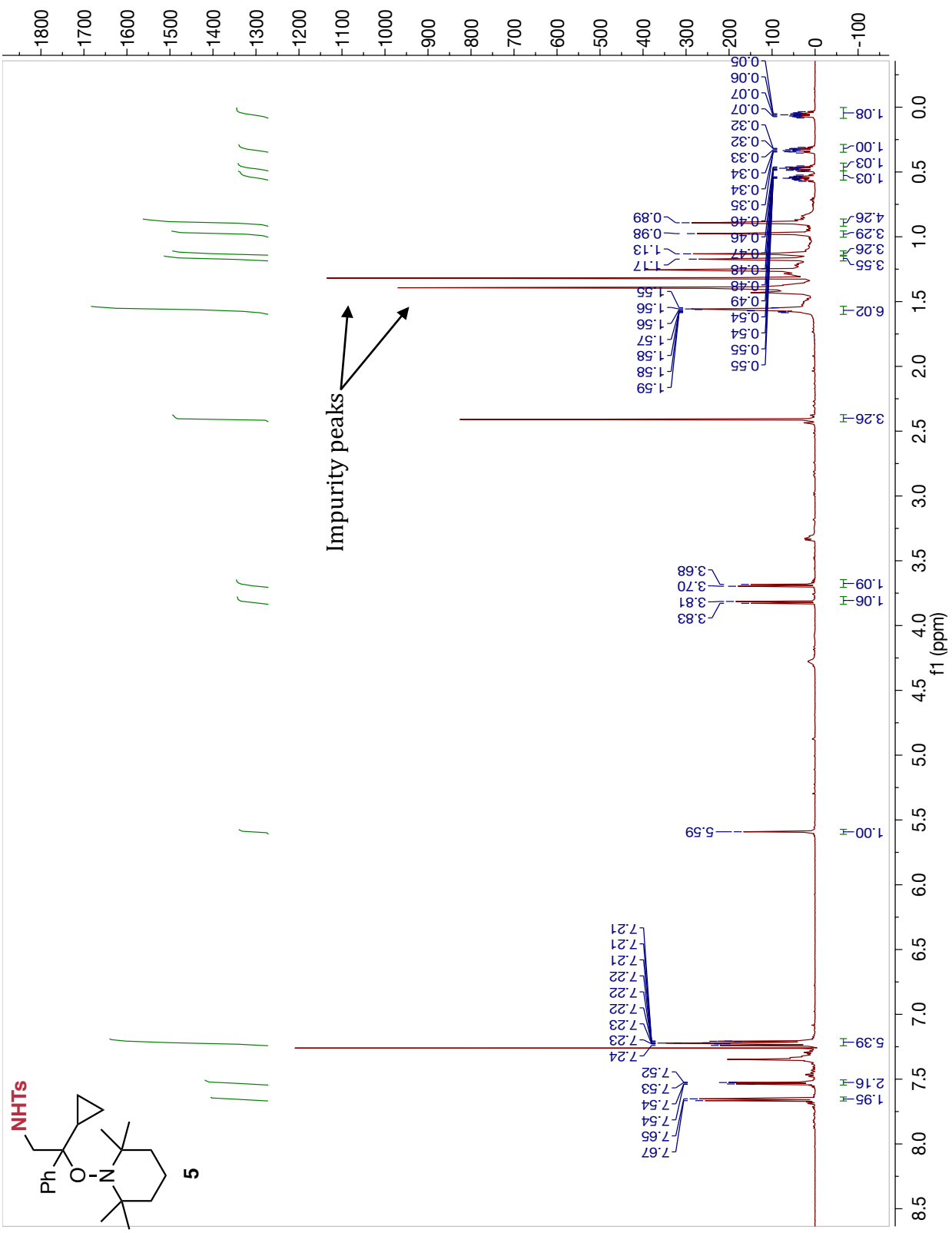
2-butyl-5-phenyl-1-tosyl-1,2,3,6-tetrahydropyridine
30.5 mg isolated, 41% yield. Pale yellow solid.
Total reaction time: 2 h
Purified by silica gel flash chromatography using 20:1 Hexanes/Acetone.
^{1}H NMR (600 MHz, $CDCl_3$) δ 7.73 – 7.68 (m, 2H), 7.37 – 7.31 (m, 2H), 7.31 – 7.26 (m, 3H), 7.24 – 7.19 (m, 2H), 5.97 – 5.81 (m, 1H), 4.59 – 4.55 (m, 1H), 4.13 – 4.08 (m, 1H), 3.94 – 3.89 (m, 1H), 2.39 (s, 3H), 2.29 – 2.13 (m, 1H), 2.02 – 1.86 (m, 1H), 1.43 – 1.16 (m, 5H), 0.92 – 0.82 (m, 4H) ppm.
^{13}C NMR (151 MHz, $CDCl_3$ $CDCl_3$) δ 129.82, 129.68 (2C), 128.80, 128.70 (2C), 128.33, 127.54, 127.08 (2C), 125.95, 125.03 (2C), 120.98, 50.39, 41.83, 31.22, 28.64, 28.49, 22.56, 21.64, 14.15 ppm.
IR (film): $\tilde{\nu}$ = 2954 (w), 2927 (w), 1597 (w), 1494 (w), 1334 (m, br), 1155 (s), 1091 (m), 813 (m), 748 (s), 680 (s), 565 (s) cm^{-1}
HRMS (ESI): *m/z* calculated for $[C_{22}H_{27}NO_2S+H]^+$: 370.1835; found: 370.1834

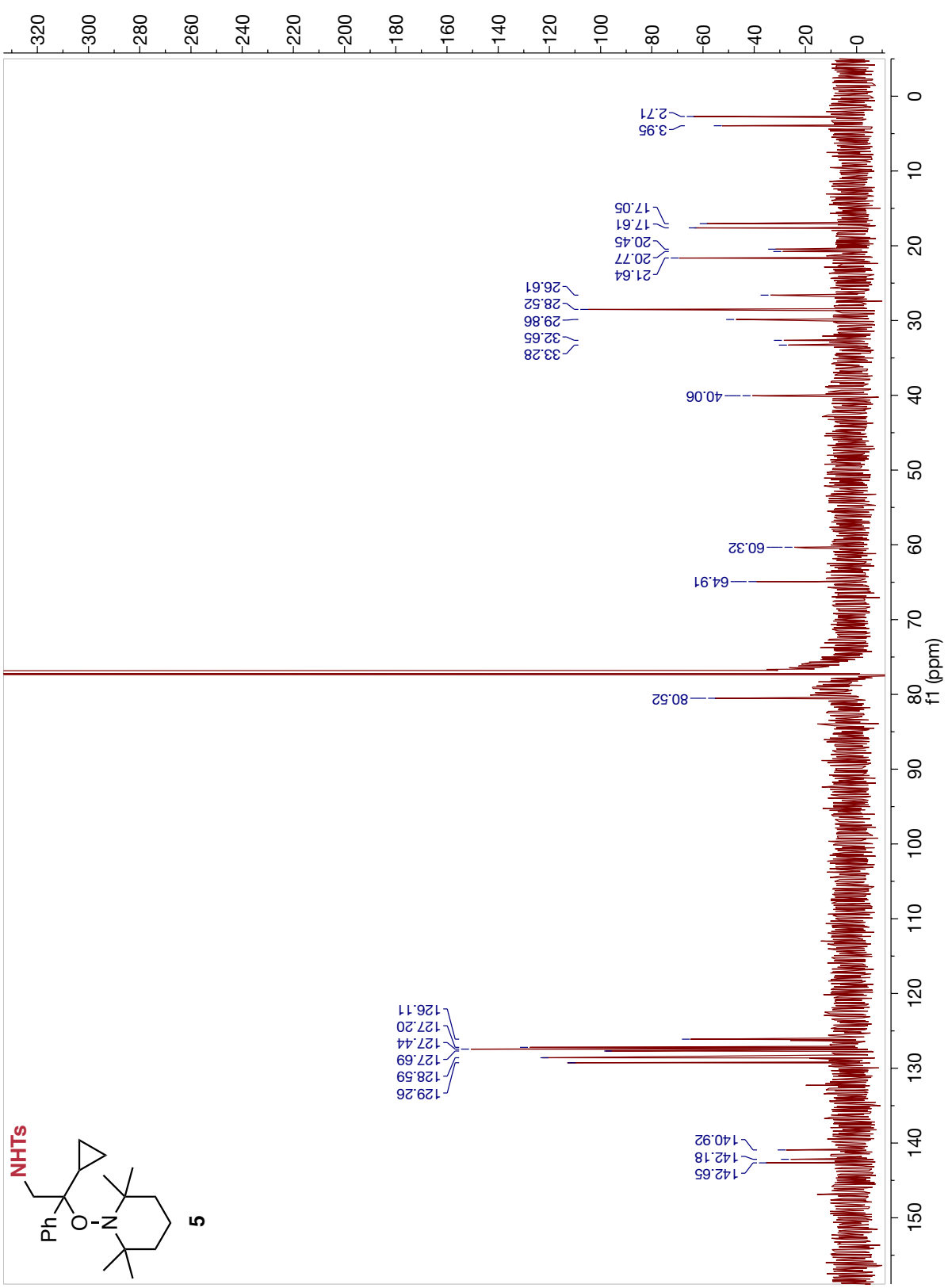


2k

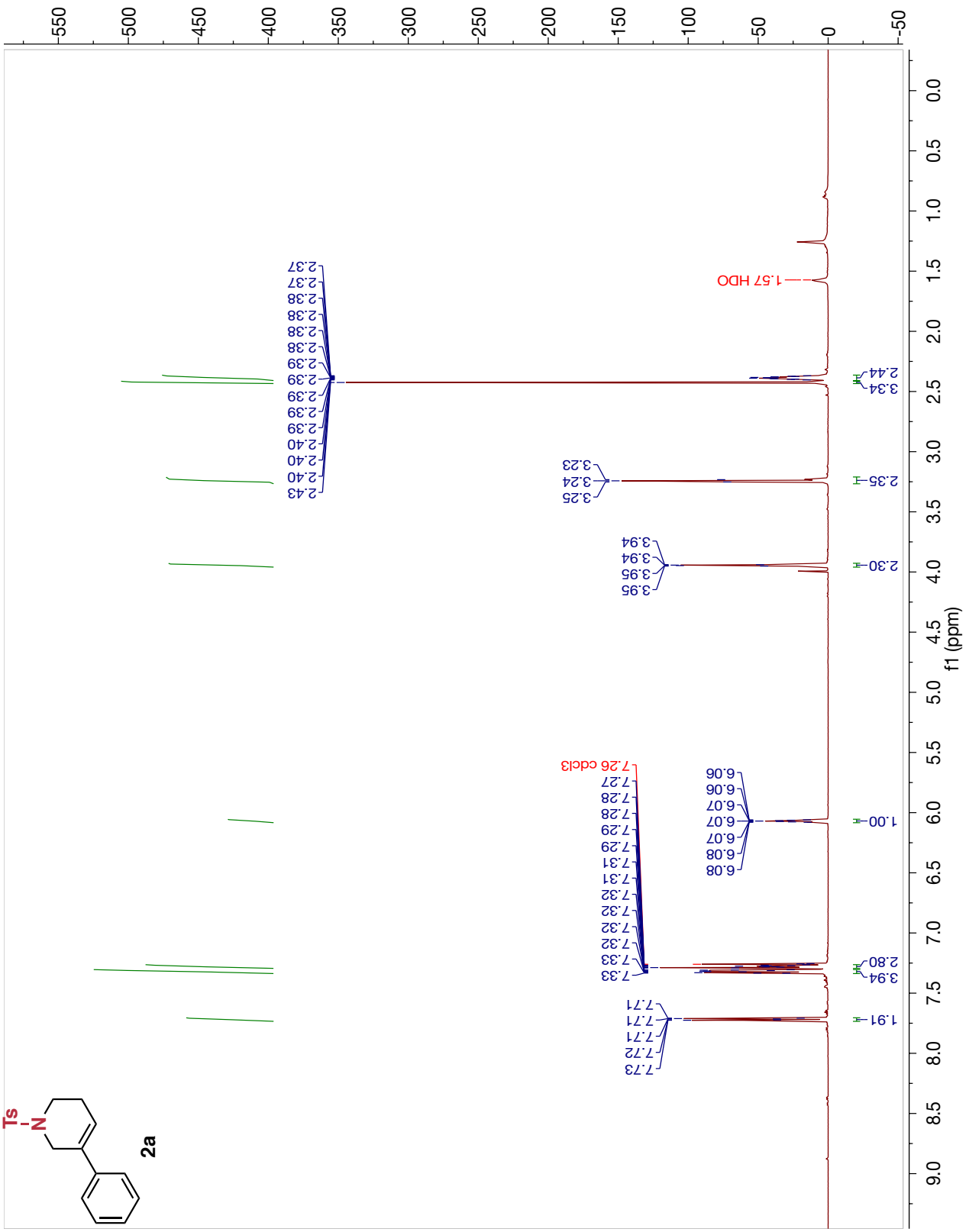
4,5-diphenyl-1-tosyl-1,2,3,6-tetrahydropyridine
23.1 mg isolated, 30% yield. Off white solid.
Total reaction time: 24 h (stirred at room temperature overnight)
Purified by silica gel flash chromatography using 20:2 Hexanes/Ethyl acetate.
^{1}H NMR (598 MHz, $CDCl_3$) δ 7.73 – 7.71 (m, 2H), 7.35 – 7.32 (m, 2H), 7.15 – 7.04 (m, 6H), 6.97 – 6.95 (m, 2H), 6.92 – 6.88 (m, 2H), 3.91 (t, J = 2.5 Hz, 2H), 3.40 (t, J = 5.8 Hz, 2H), 2.67 – 2.63 (m, 2H), 2.43 (s, 3H) ppm.
^{13}C NMR (151 MHz, $CDCl_3$) δ 143.82, 141.18, 139.35, 133.50, 131.07, 129.86 (2C), 129.46 (2C), 129.36 (2C), 128.88 (2C), 128.20 (2C), 128.03 (2C), 127.98, 127.12, 126.75, 49.36, 43.45, 31.44, 21.68 ppm.
IR (film): $\tilde{\nu}$ = 3059 (w), 2922 (w), 1598 (w), 1338 (m, br), 1157 (s), 1091 (m), 759 (s), 698 (s), 665 (s) cm^{-1}
HRMS (ESI): *m/z* calculated for $[C_{24}H_{23}NO_2S+Na]^+$: 412.1342; found: 412.1342

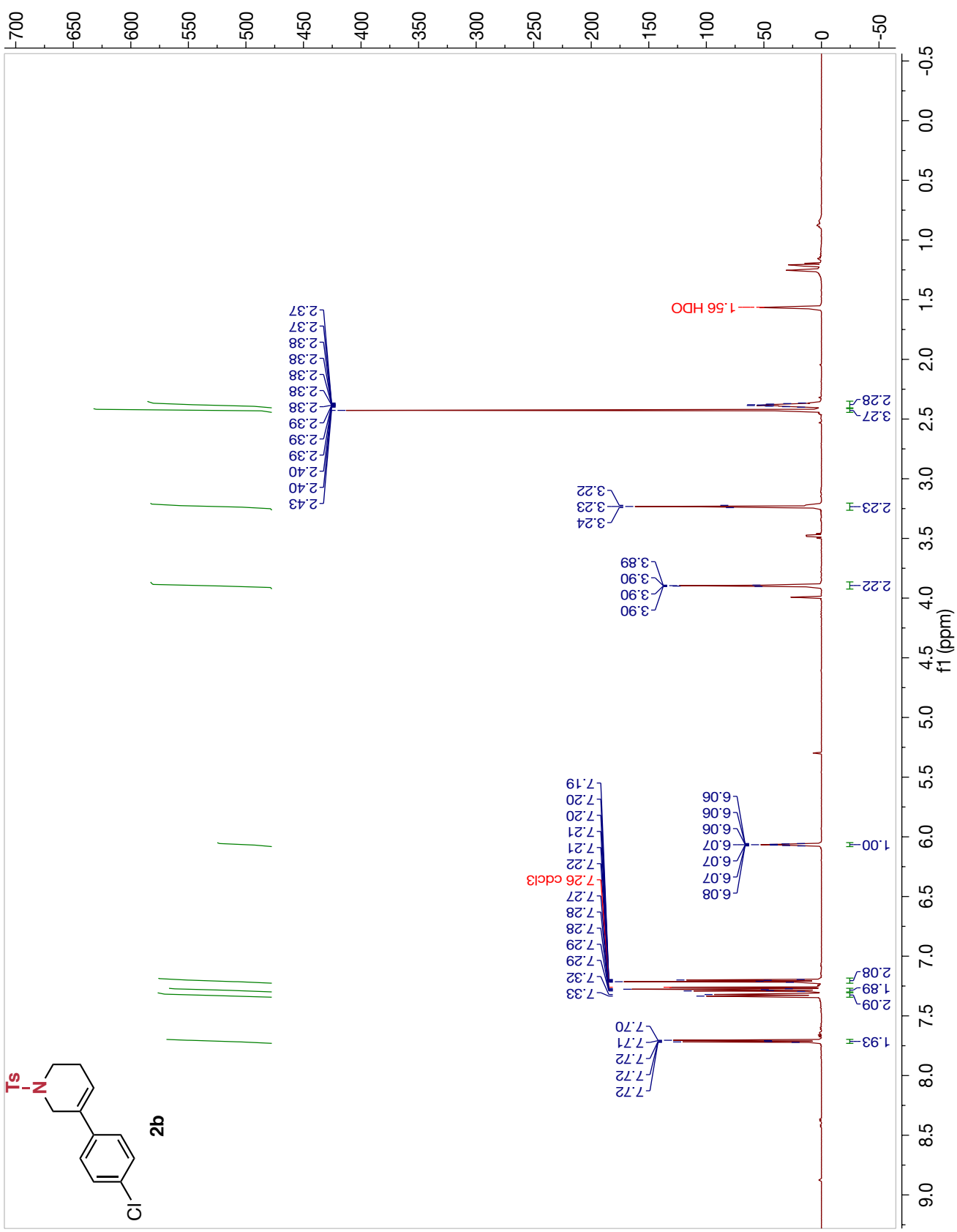
NMR Spectra of TEMPO Adduct:

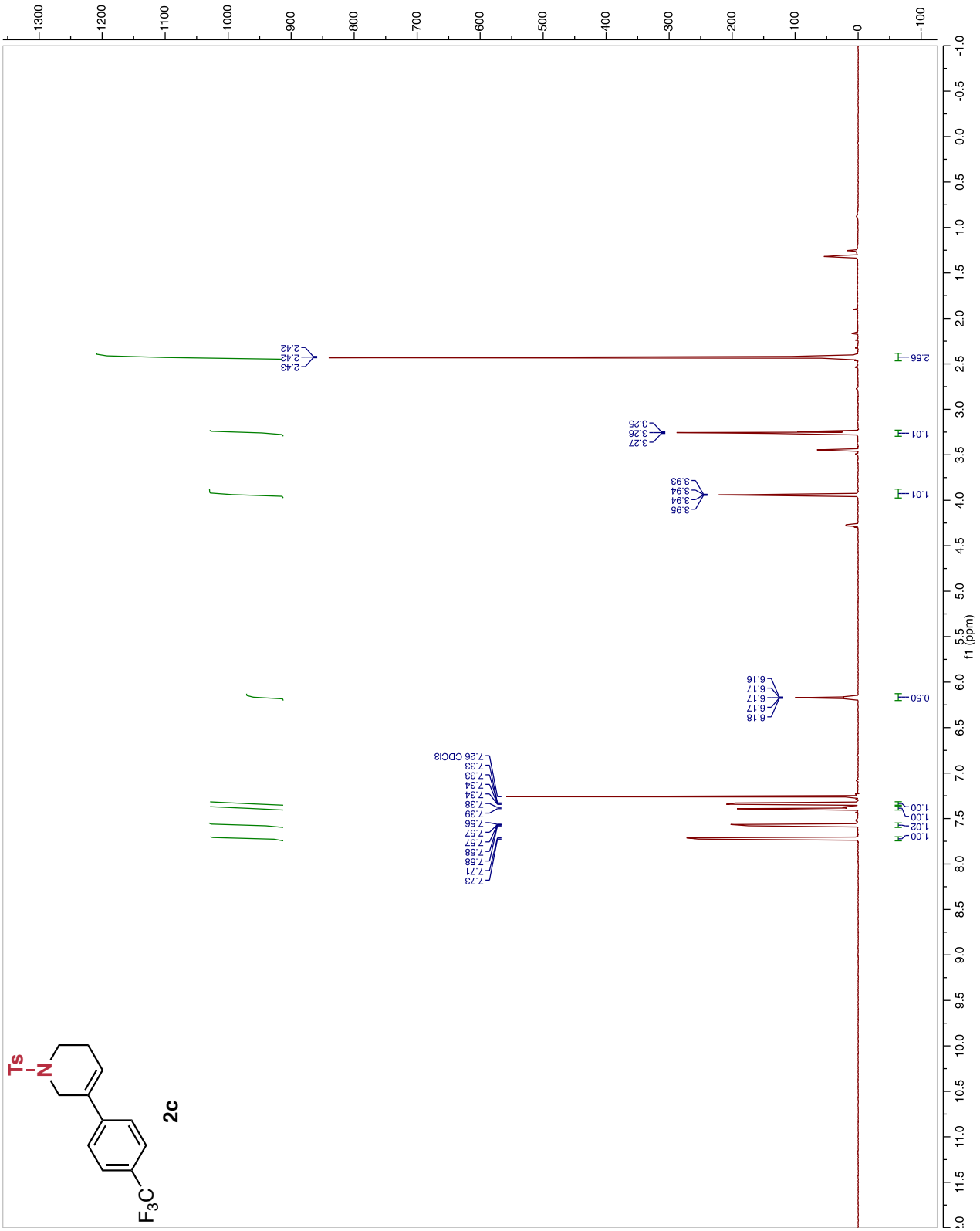


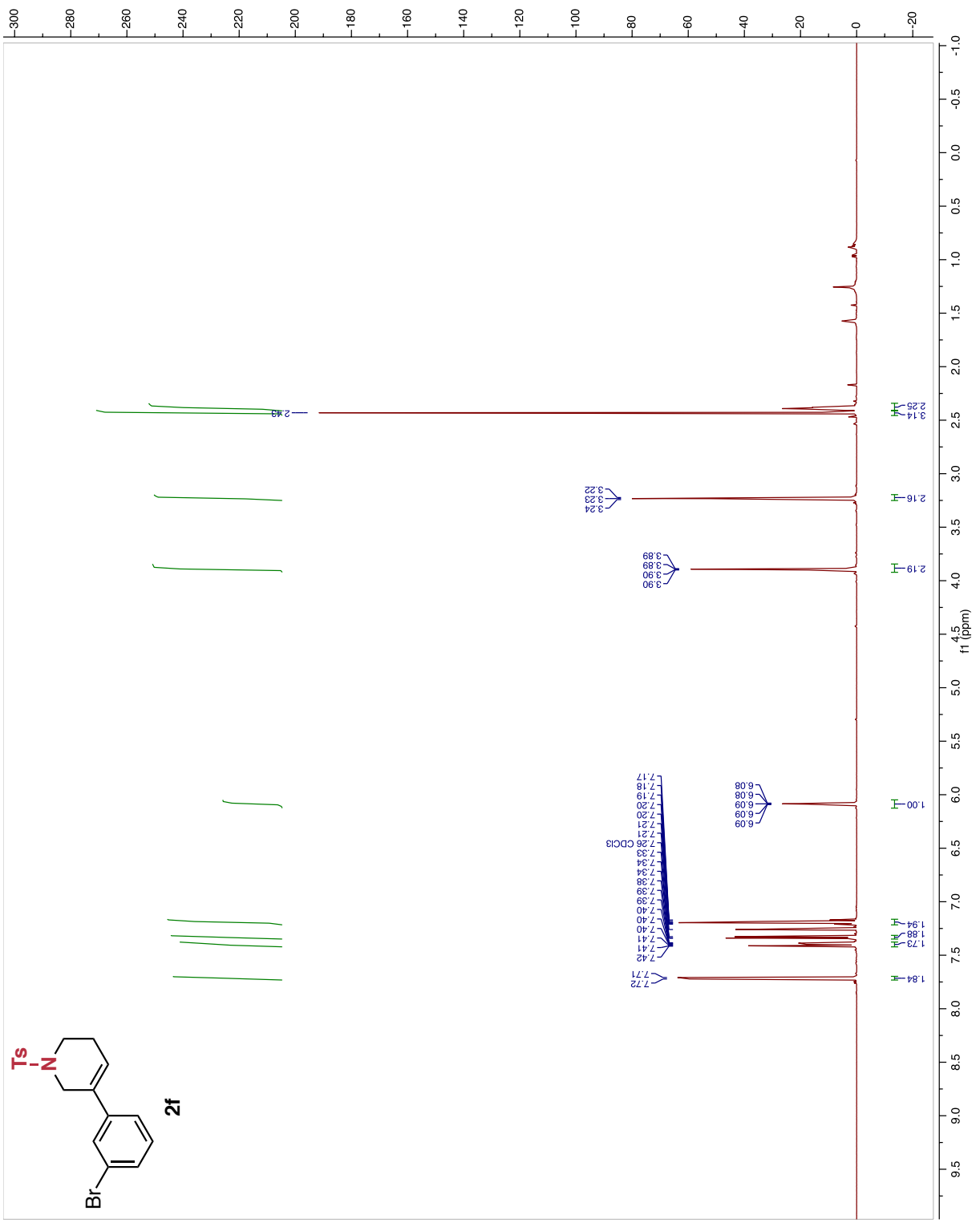

NHTs
Ph
O
N
5
142.65
142.18
140.92
129.26
128.59
127.69
127.44
127.20
126.11
80.52
64.91
60.32
40.06
33.28
32.65
29.86
28.52
26.61
21.64
20.77
20.45
17.61
17.05
3.95
2.71
f1 (ppm)

[1]H NMR spectra of previously reported products:

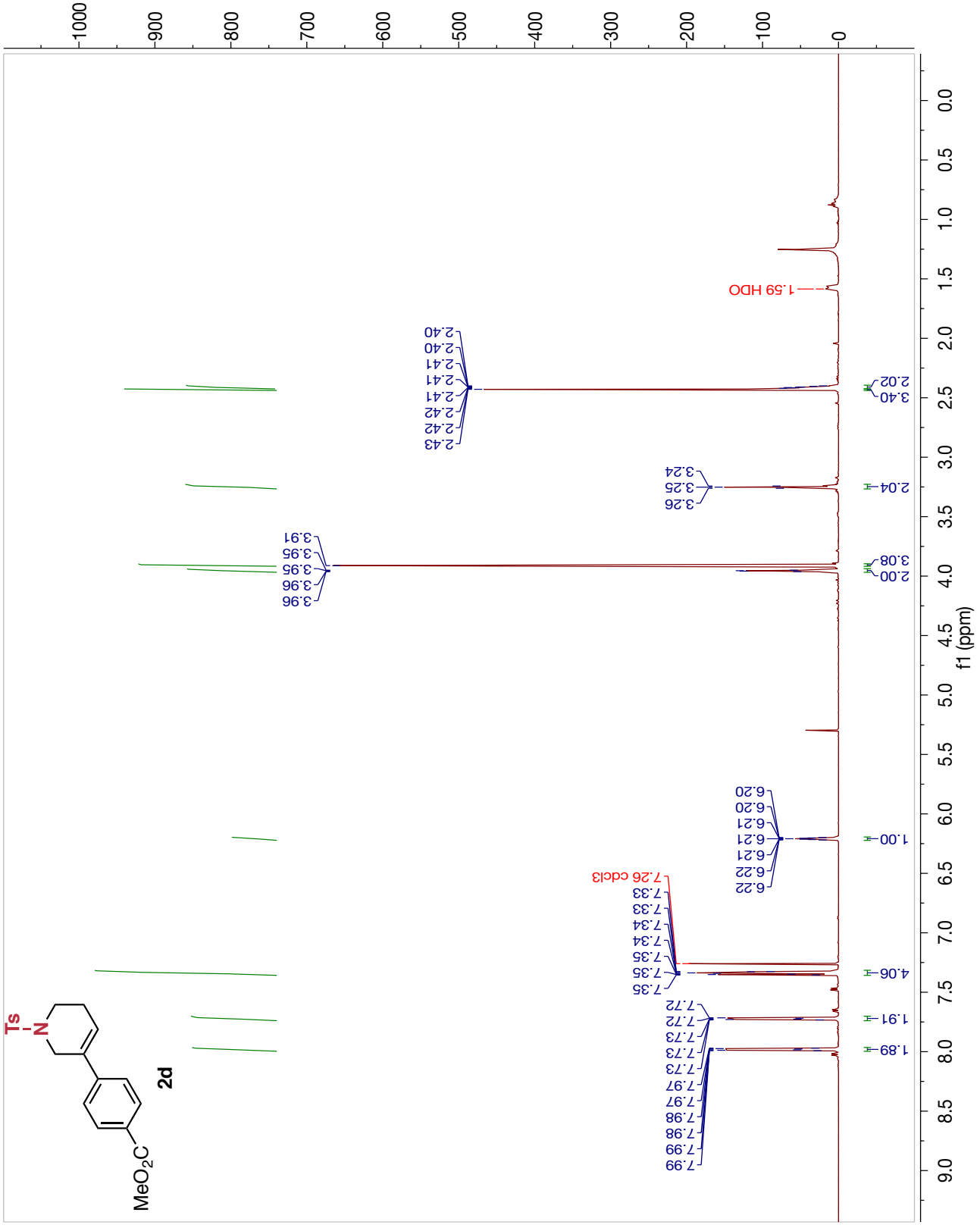


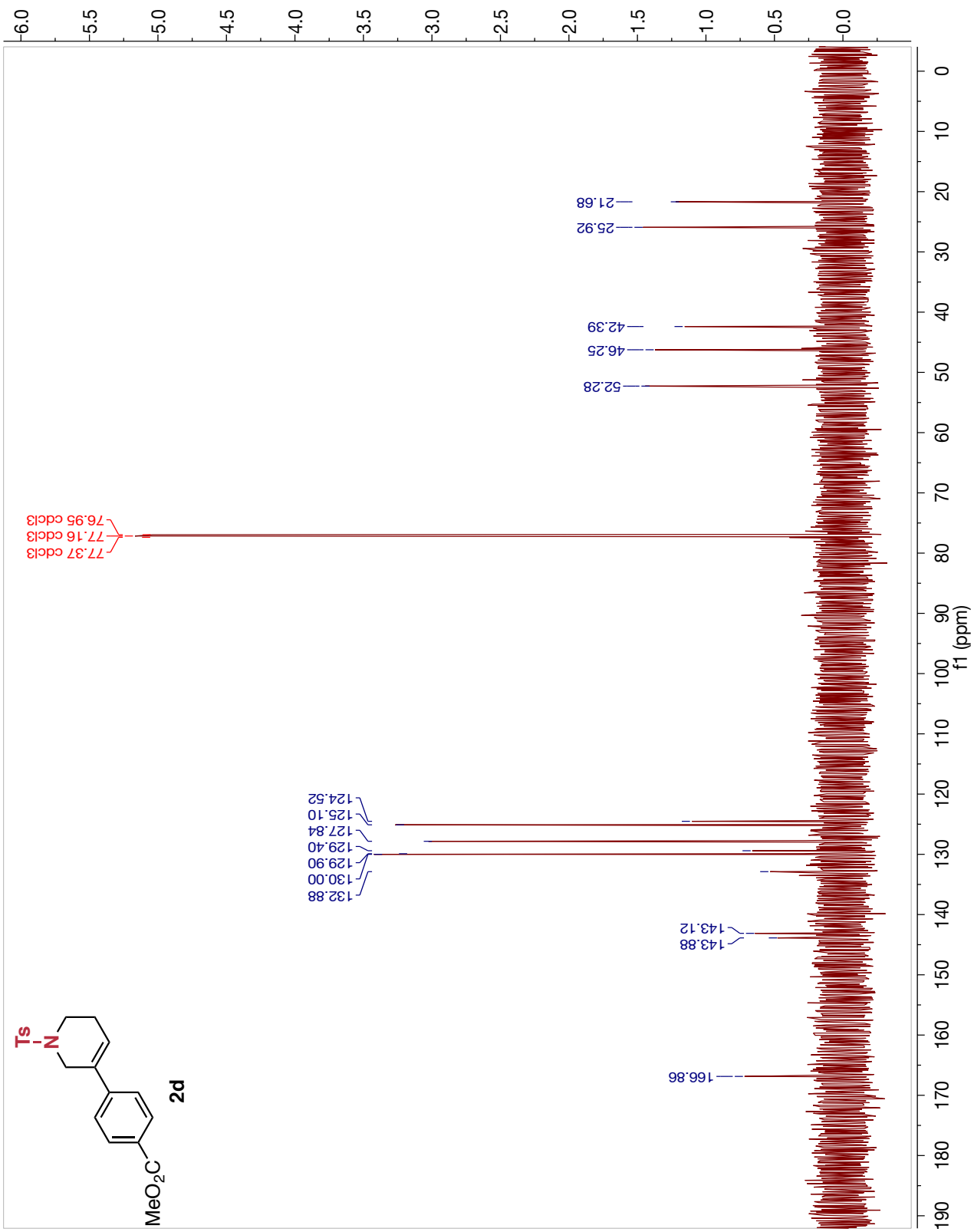

Ts
N
Cl
2b
1.56 HDO
7.26 cdcl3
f1 (ppm)

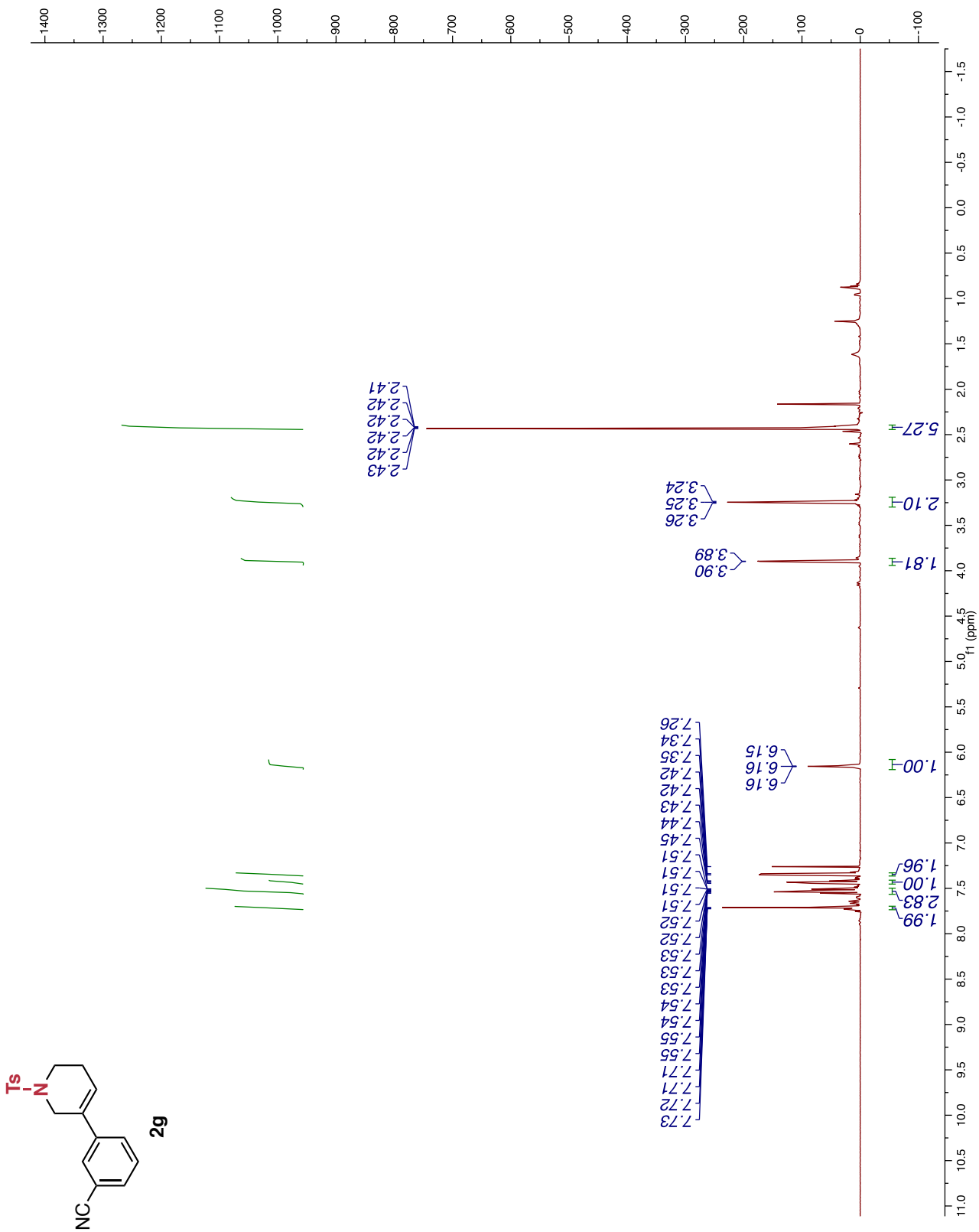

Ts
N
F3C
2c
f1 (ppm)

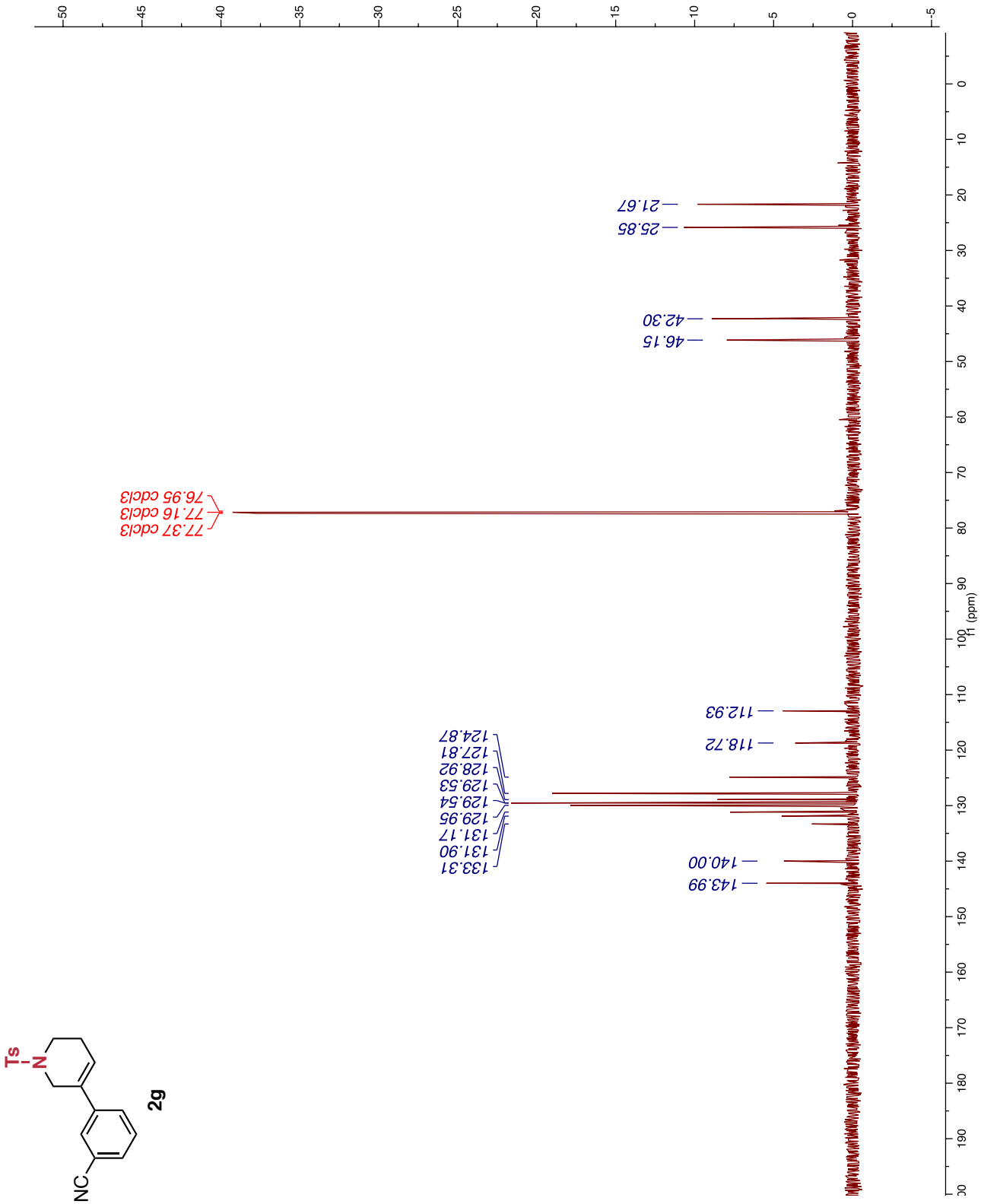

Ts
N
Br
2f
f1 (ppm)

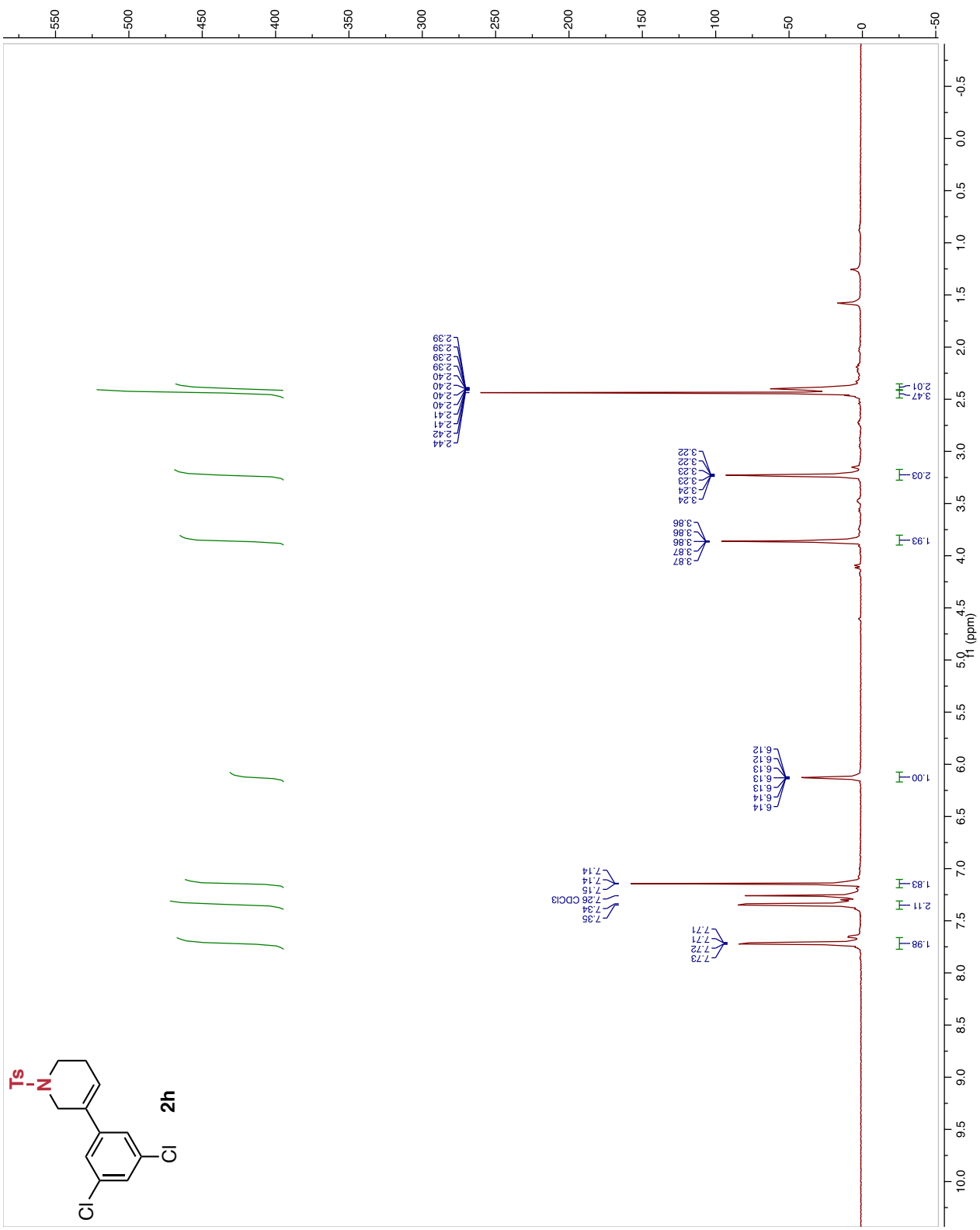
NMR spectra of new compounds:

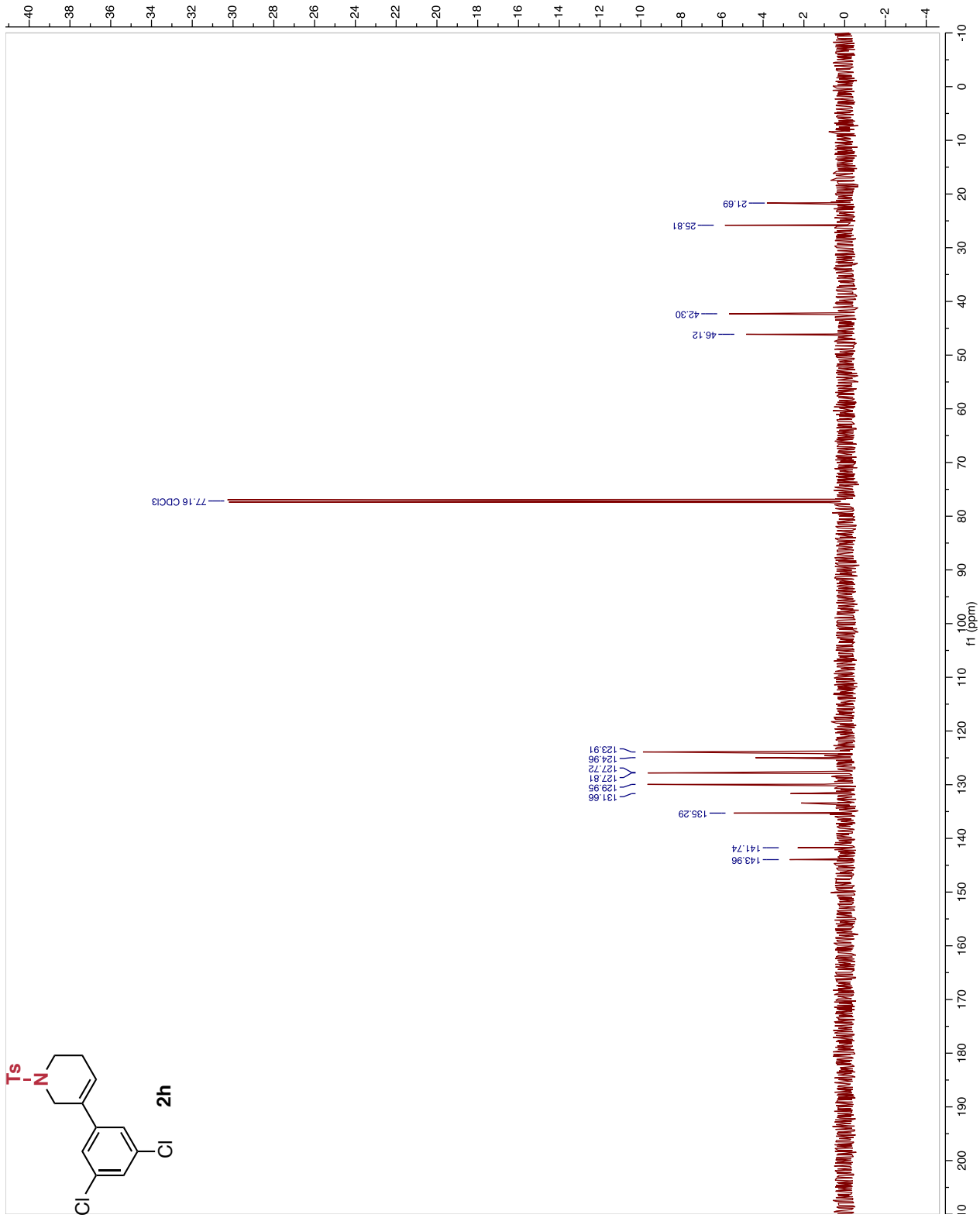


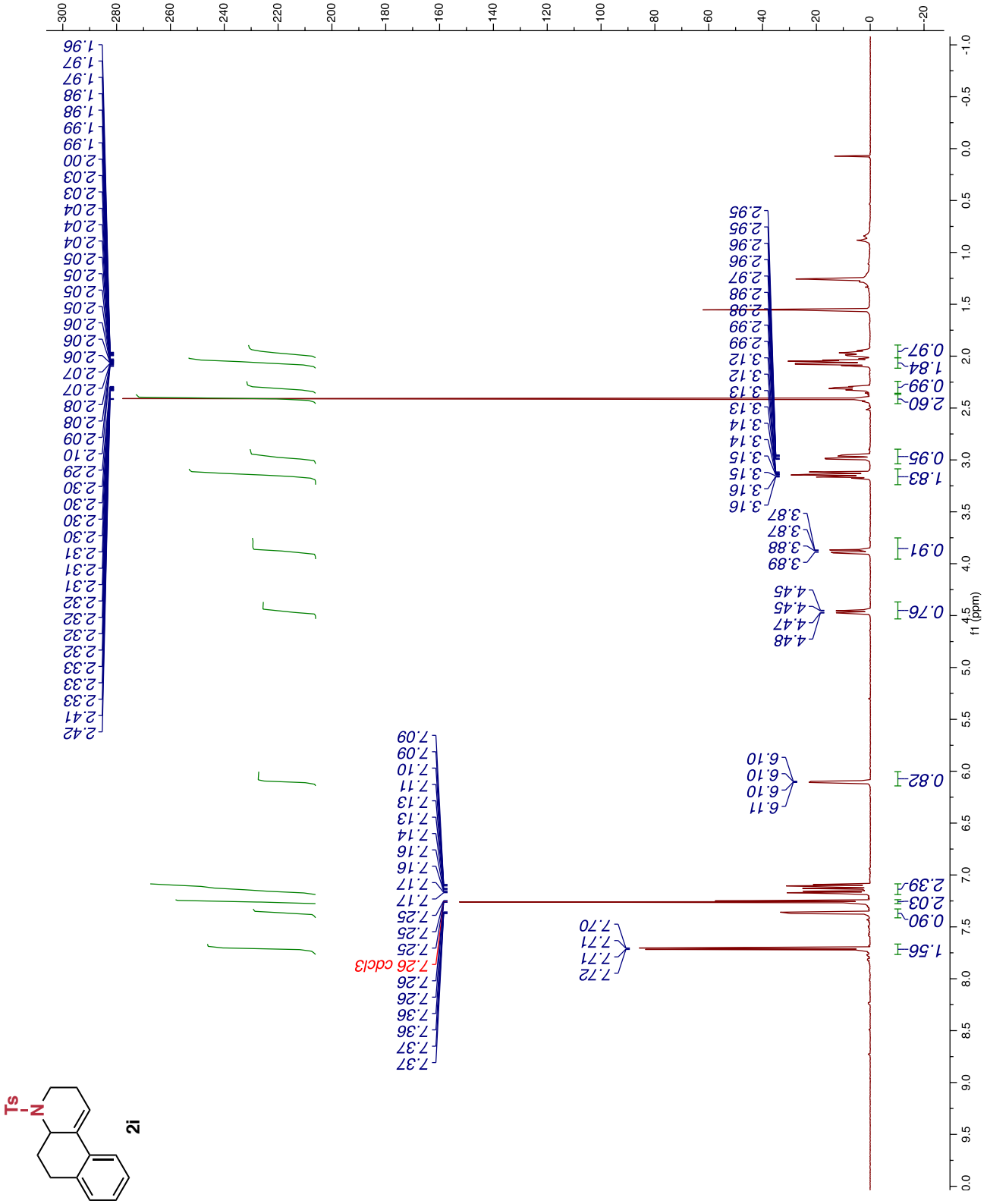

Ts
N
MeO2C
2d
166.86
143.88
143.12
132.88
130.00
129.90
129.40
127.84
125.10
124.52
77.37 cdcl3
77.16 cdcl3
76.95 cdcl3
52.28
46.25
42.39
25.92
21.68
f1 (ppm)

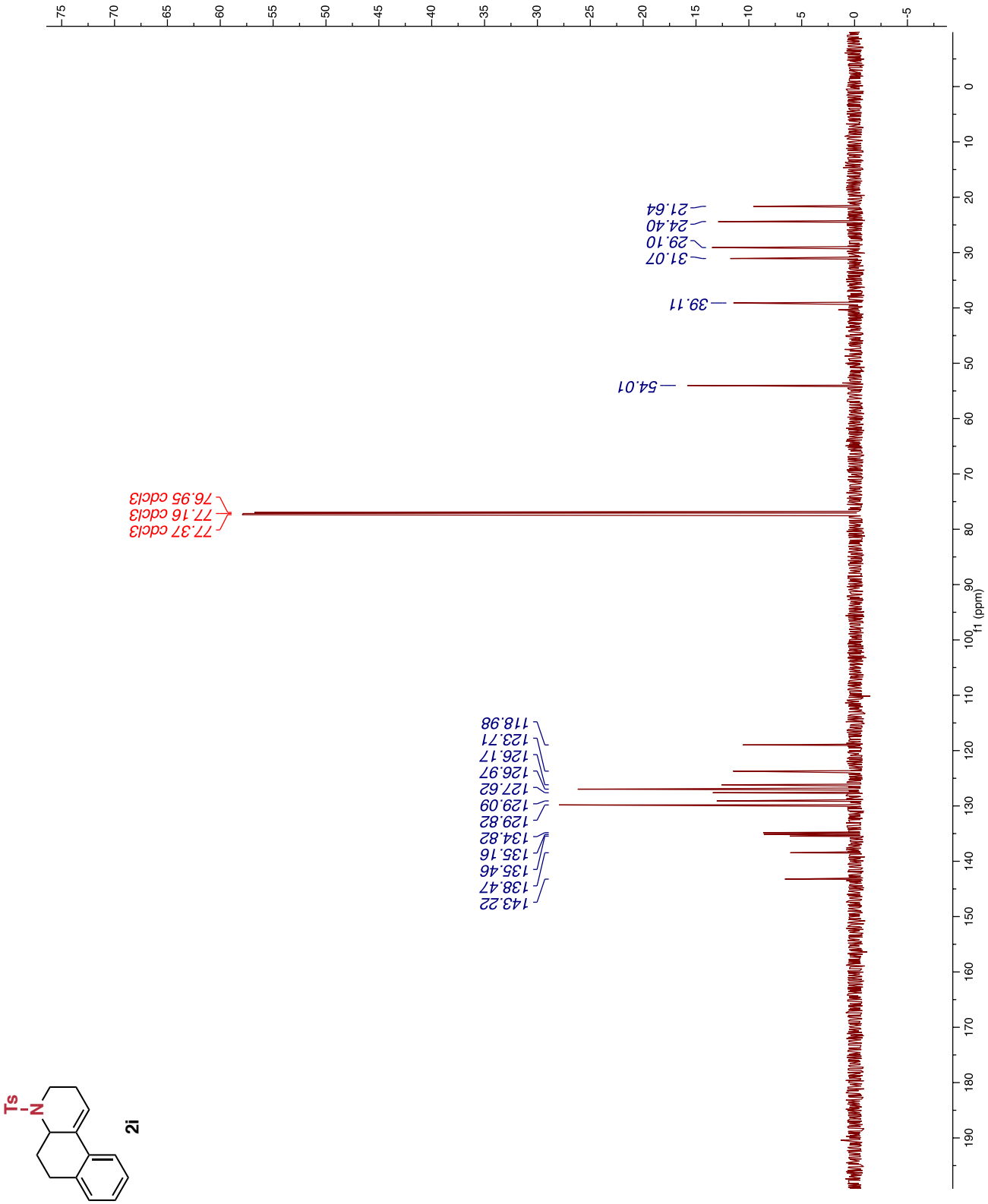

Ts
N
NC
2g
f1 (ppm)
7.73
7.72
7.71
7.71
7.55
7.55
7.54
7.54
7.53
7.53
7.53
7.52
7.52
7.51
7.51
7.51
7.45
7.44
7.43
7.42
7.42
7.35
7.34
7.26
6.16
6.16
6.15
3.90
3.89
3.26
3.25
3.24
2.43
2.42
2.42
2.42
2.42
2.41
1.99
2.83
1.00
1.96
1.00
1.81
2.10
5.27

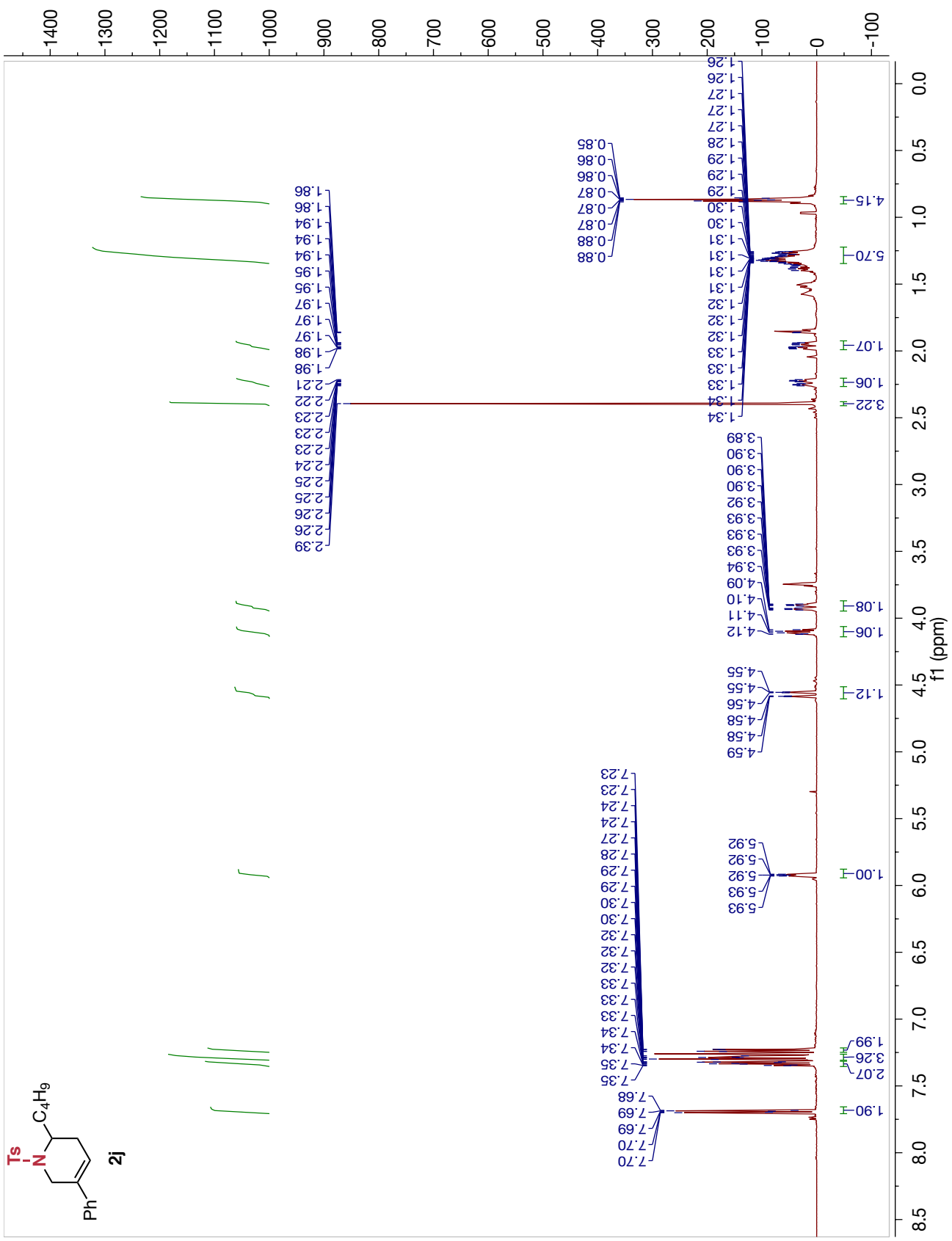

Ts
N
NC
2g
143.99
140.00
133.31
131.90
131.17
129.95
129.54
129.53
128.92
127.81
124.87
118.72
112.93
77.37 cdcl3
77.16 cdcl3
76.95 cdcl3
46.15
42.30
25.85
21.67
f1 (ppm)

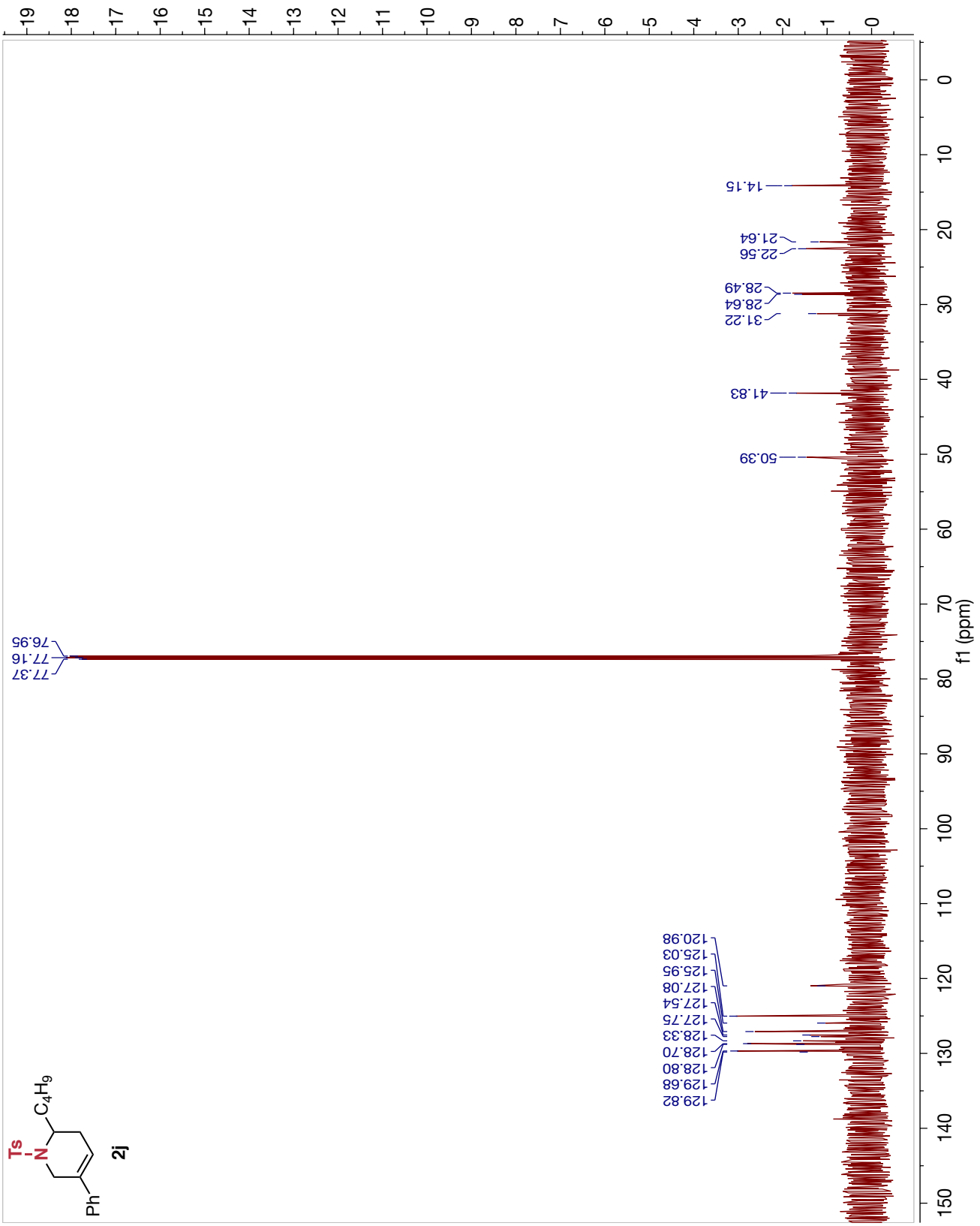

Ts
N
Cl
Cl
2h
f1 (ppm)
CDCl3

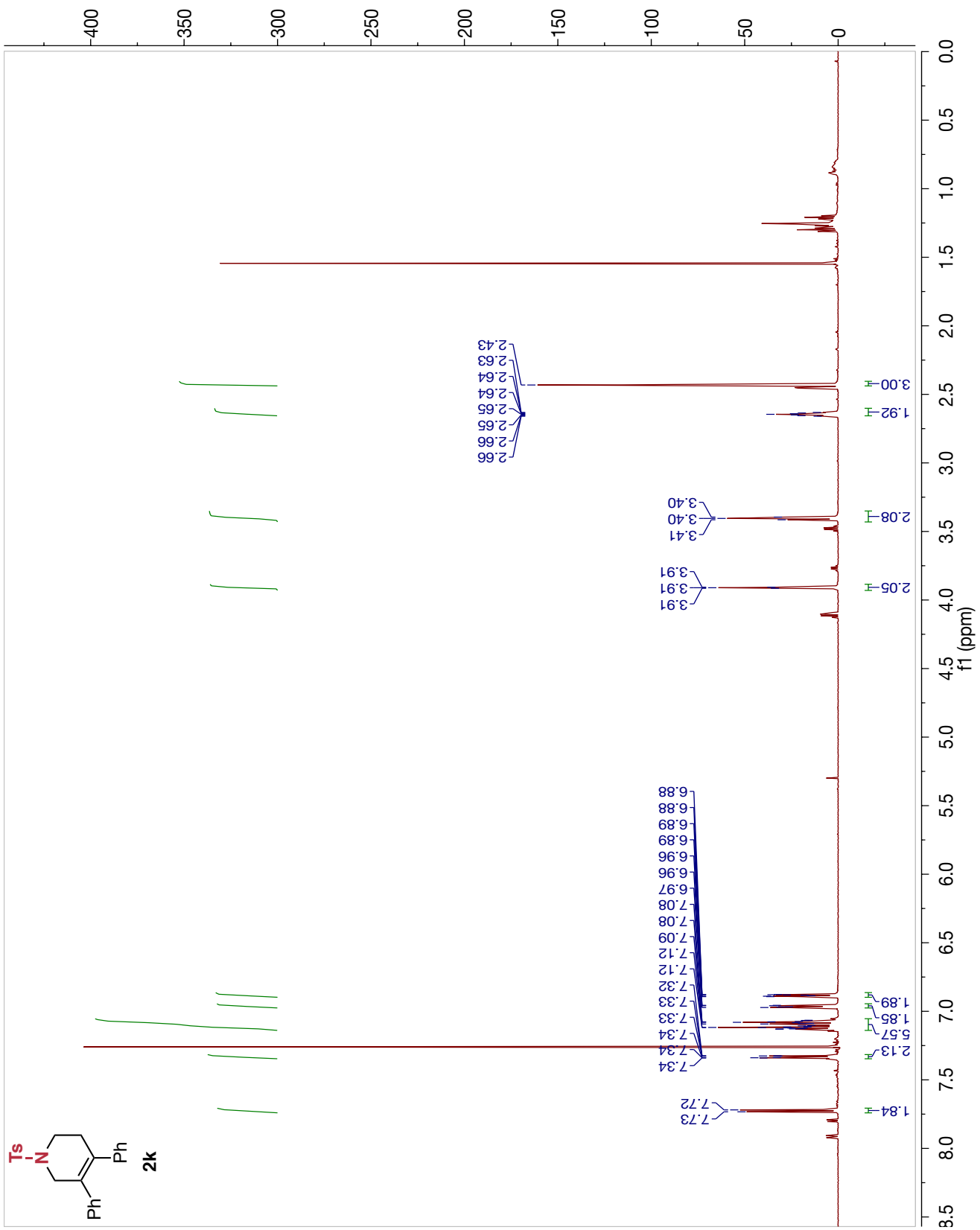

Ts
N
Cl
Cl
2h
143.96
141.74
135.29
131.66
129.95
127.81
127.72
124.96
123.91
77.16 CDCl3
46.12
42.30
25.81
21.69
f1 (ppm)

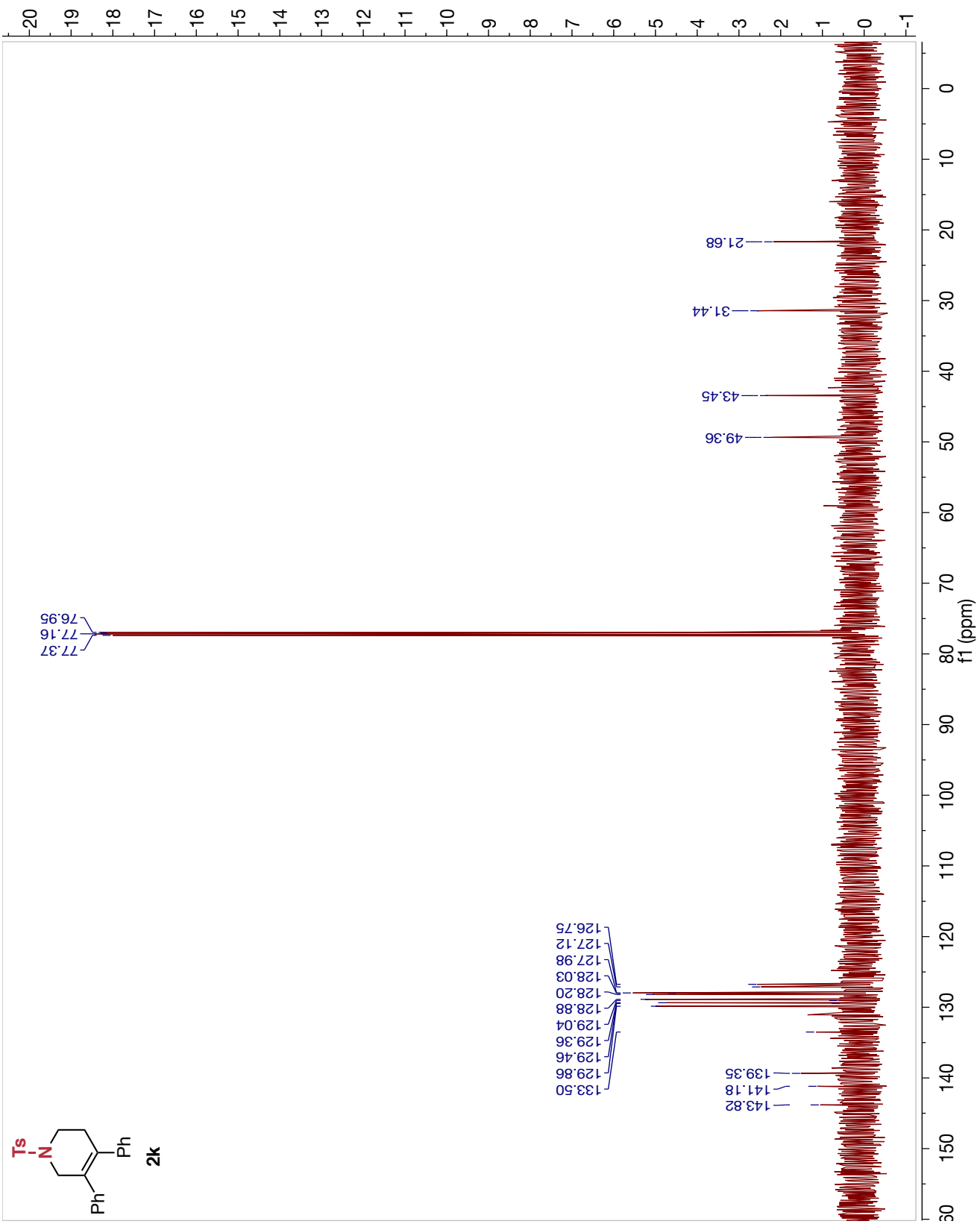

Ts
N
2i
f1 (ppm)


Ts
N
2i
143.22
138.47
135.46
135.16
134.82
129.82
129.09
127.62
126.97
126.17
123.71
118.98
77.37 cdcl3
77.16 cdcl3
76.95 cdcl3
54.01
39.11
31.07
29.10
24.40
21.64
f1 (ppm)

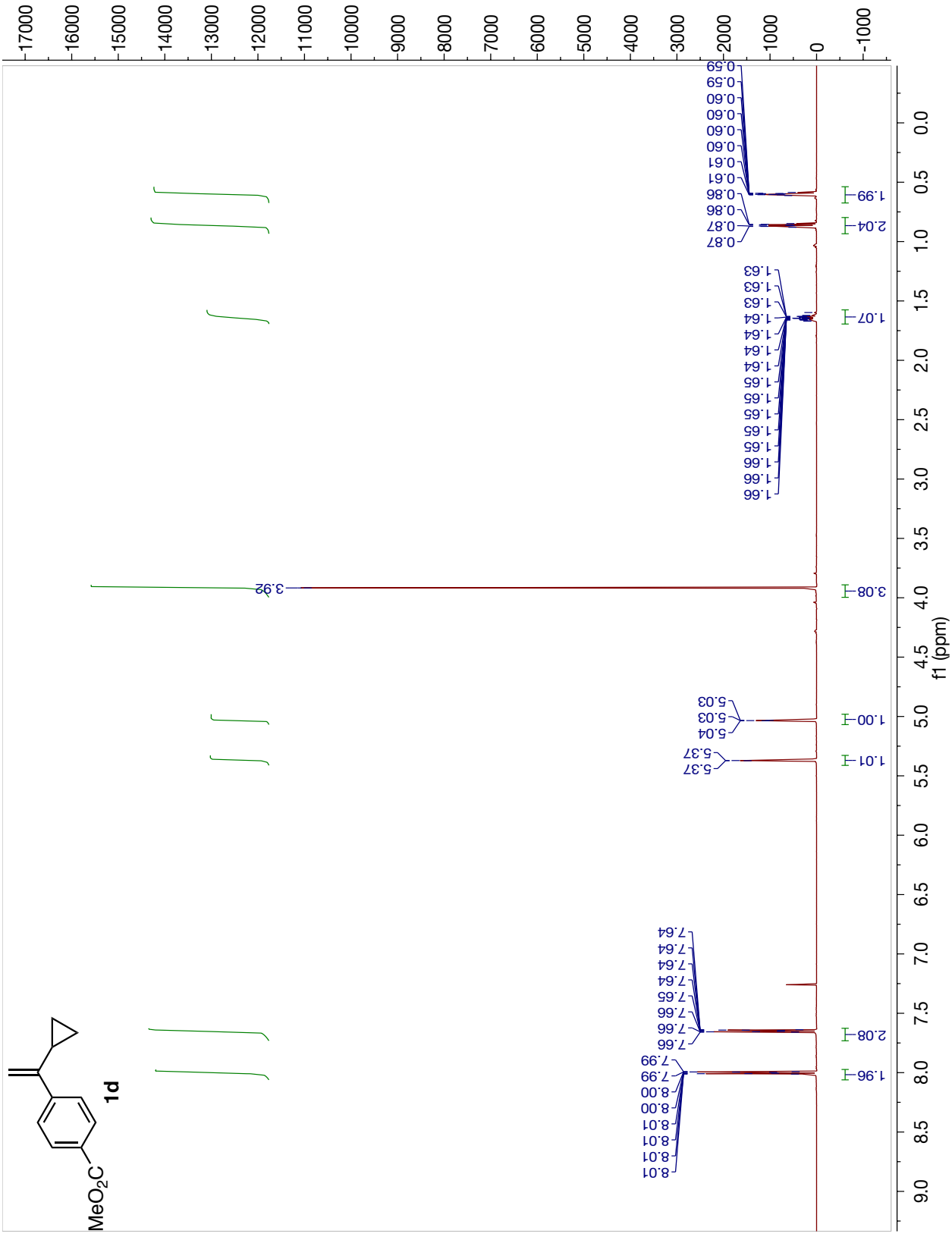

Ts
N
C4H9
Ph
2j
f1 (ppm)

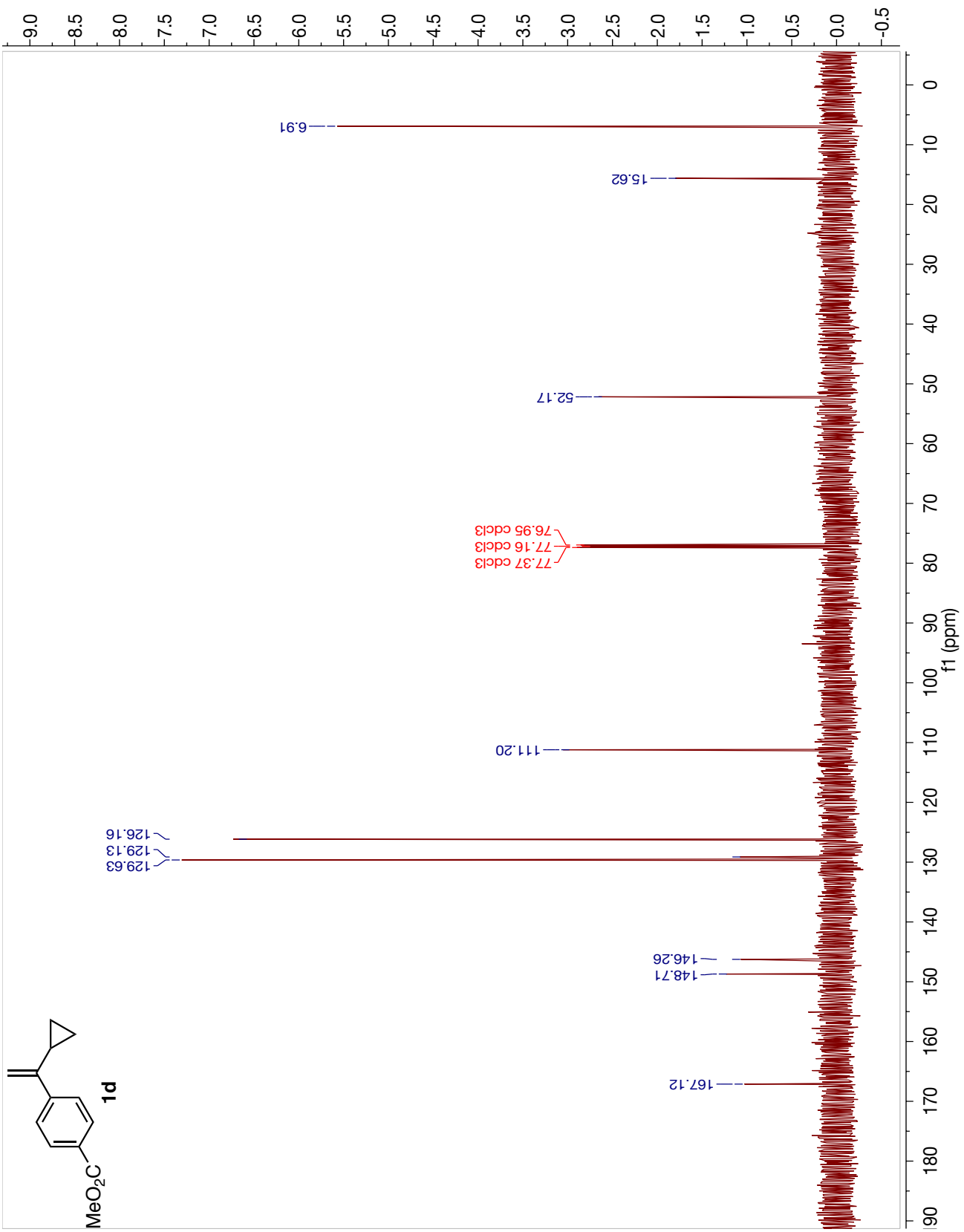

Ts
N
C4H9
Ph
2j
14.15
21.64
22.56
28.49
28.64
31.22
41.83
50.39
76.95
77.16
77.37
120.98
125.03
125.95
127.08
127.54
127.75
128.33
128.70
128.80
129.68
129.82
f1 (ppm)

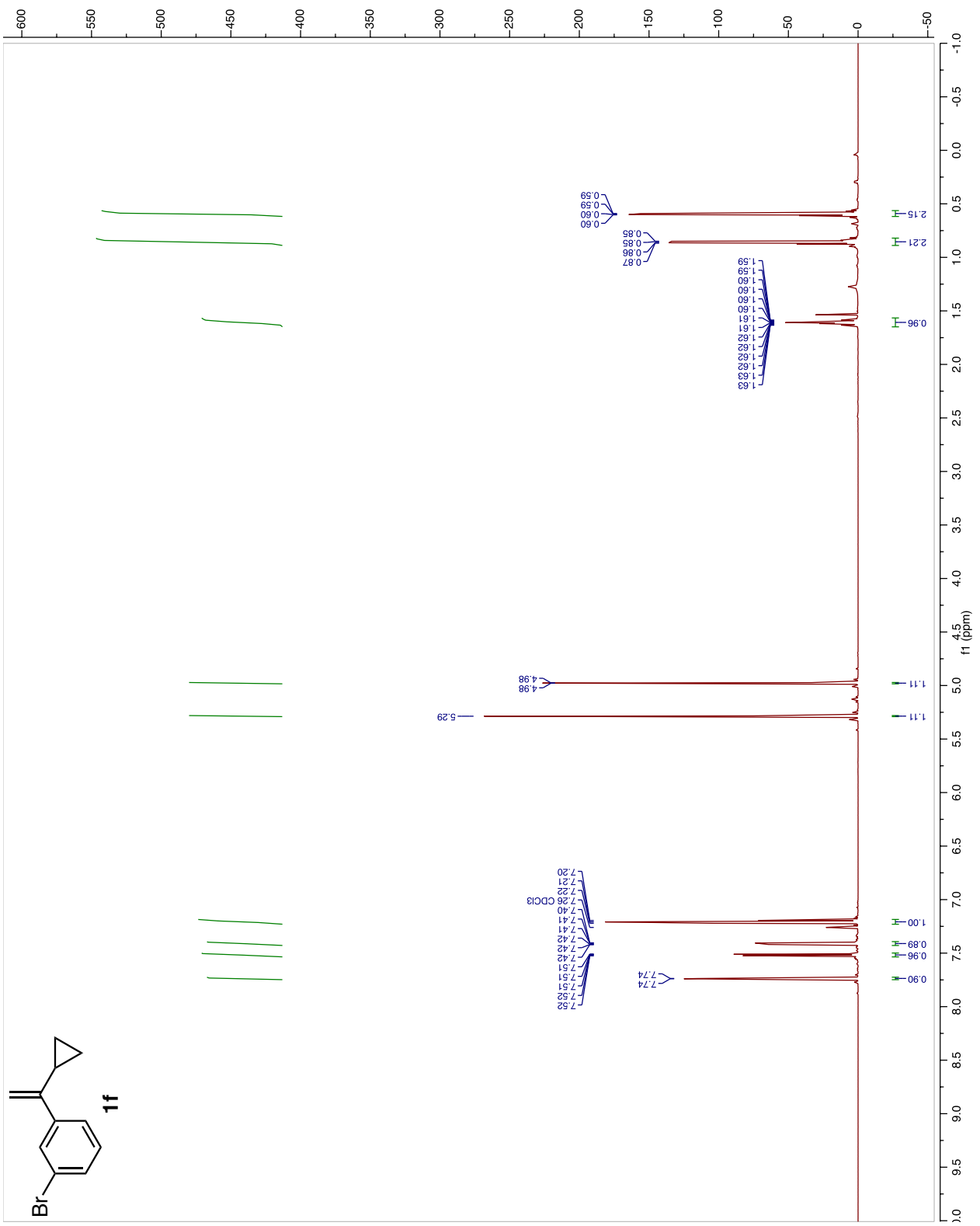

Ts
N
Ph
Ph
2k
f1 (ppm)

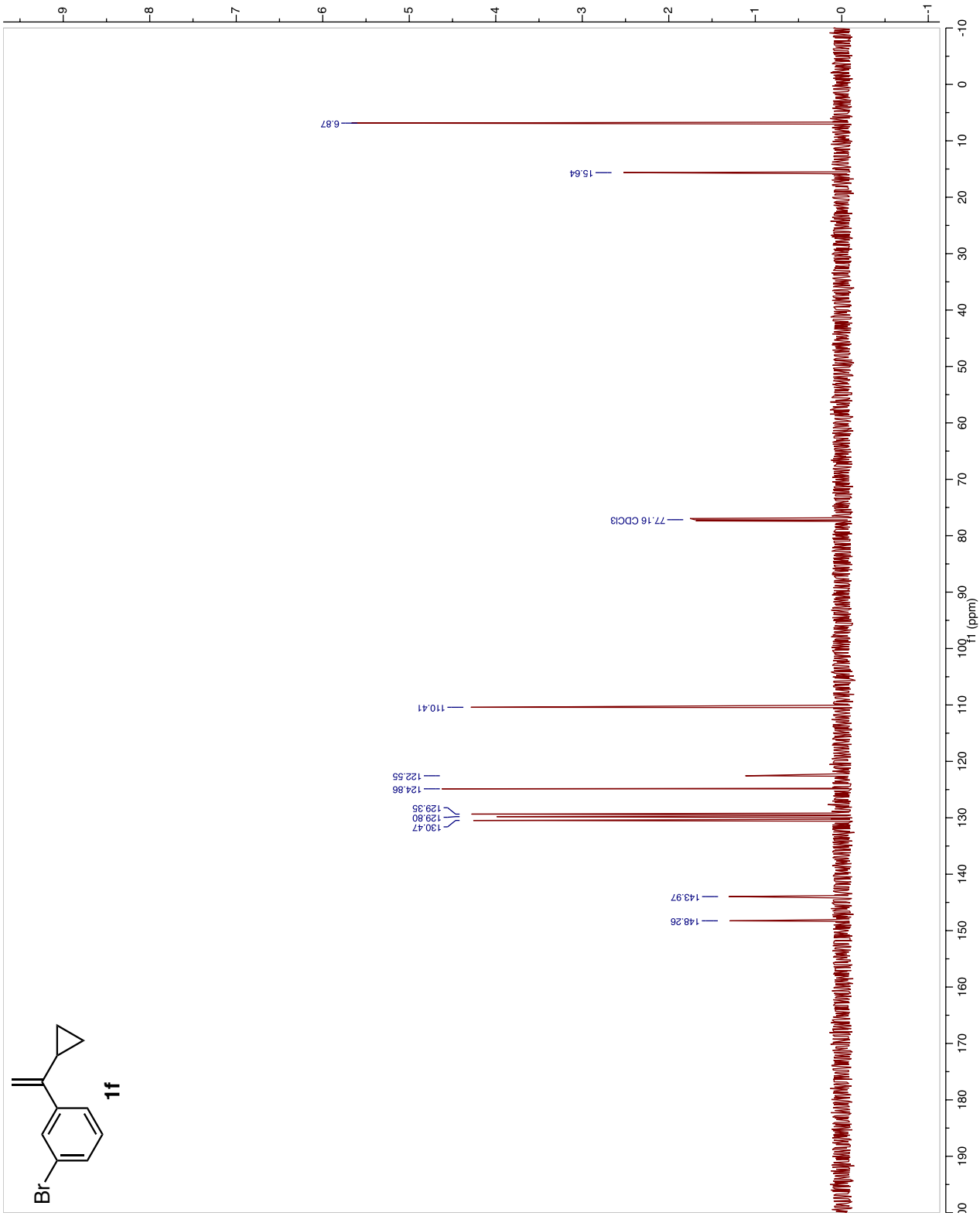

Ts
N
Ph
Ph
2k
143.82
141.18
139.35
133.50
129.86
129.46
129.36
129.04
128.88
128.20
128.03
127.98
127.12
126.75
77.37
77.16
76.95
49.36
43.45
31.44
21.68
f1 (ppm)

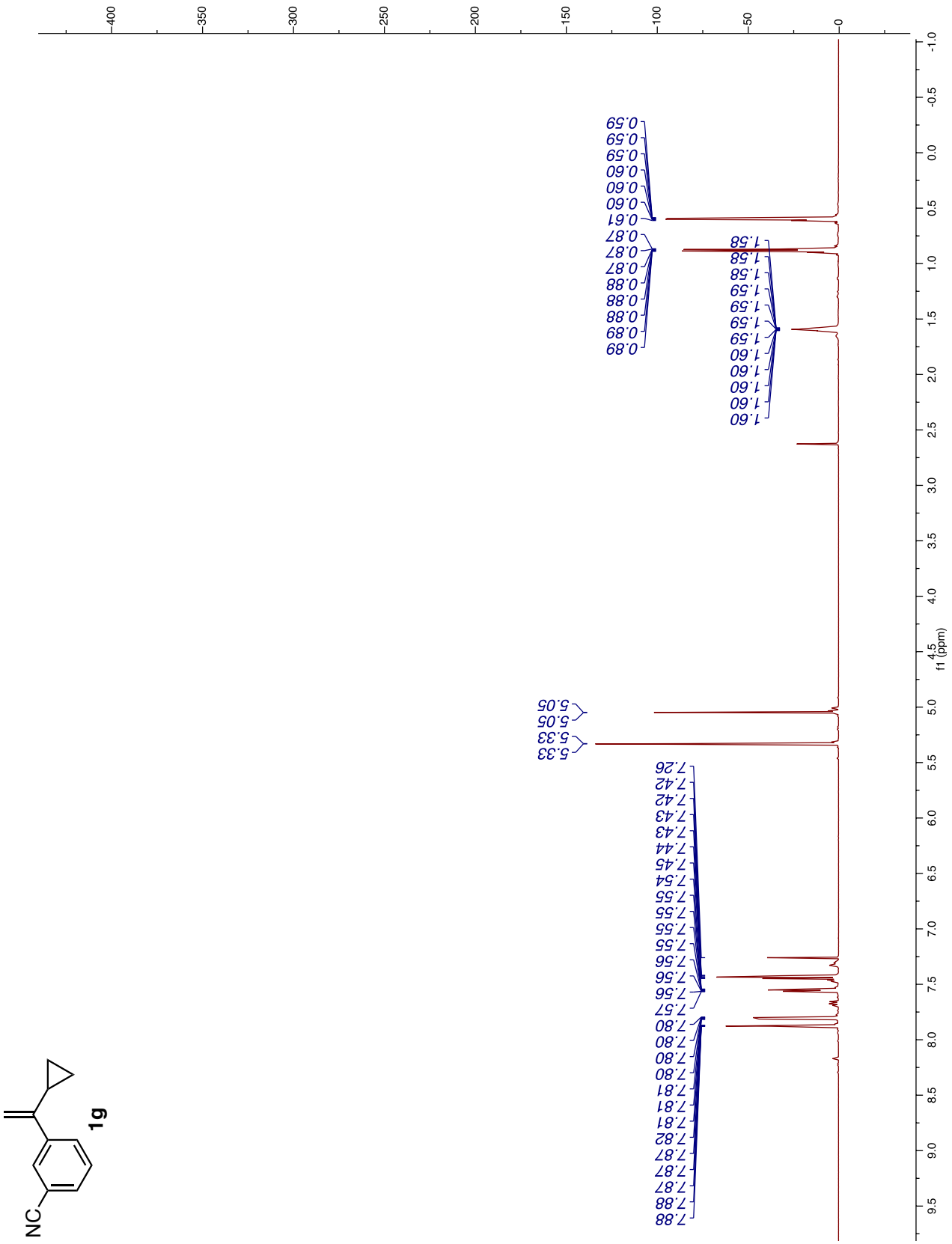
NMR spectra of vinylcyclopropanes:

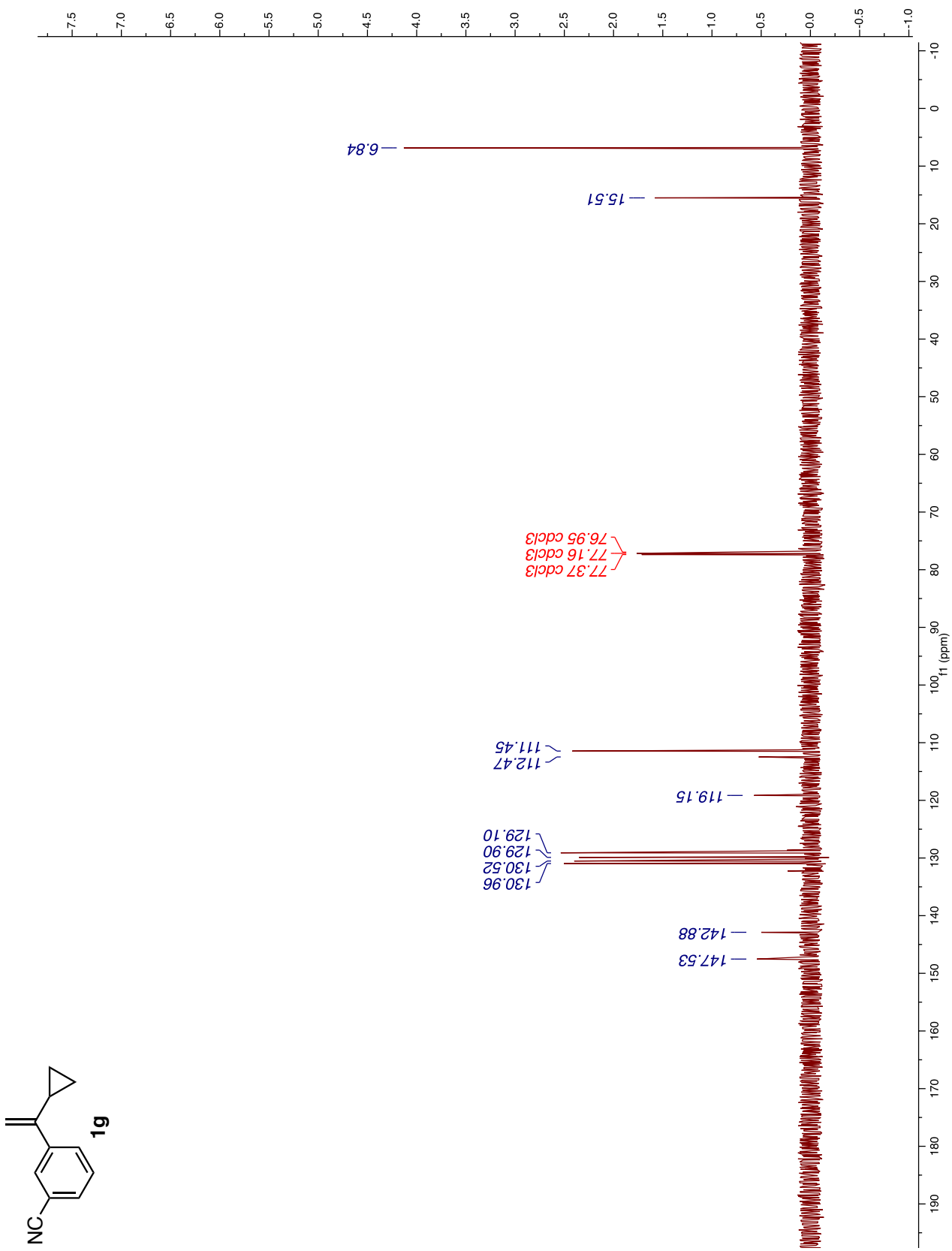


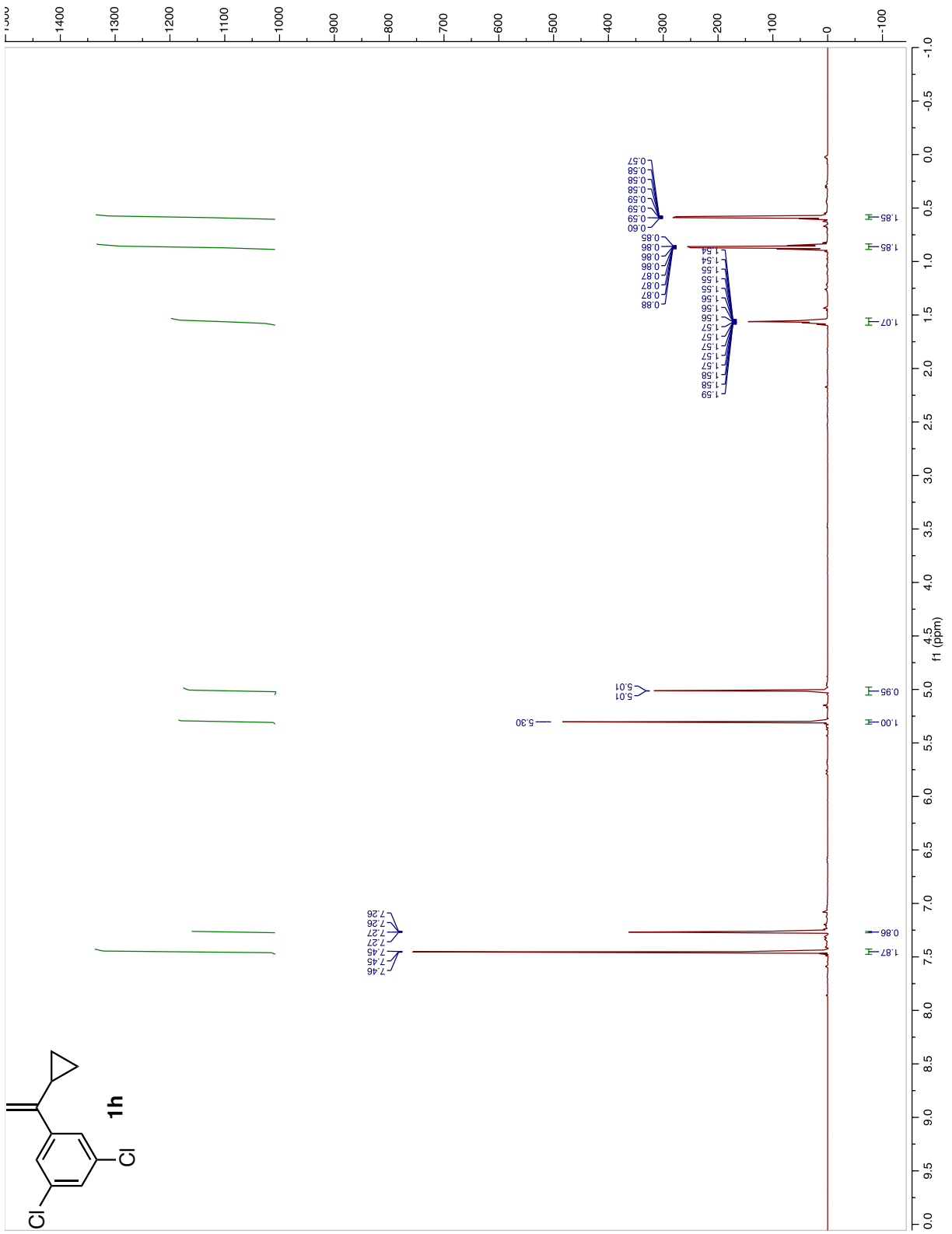

6.91
15.62
52.17
77.37 cdcl3
77.16 cdcl3
76.95 cdcl3
111.20
126.16
129.13
129.63
146.26
148.71
167.12
MeO2C
1d
f1 (ppm)

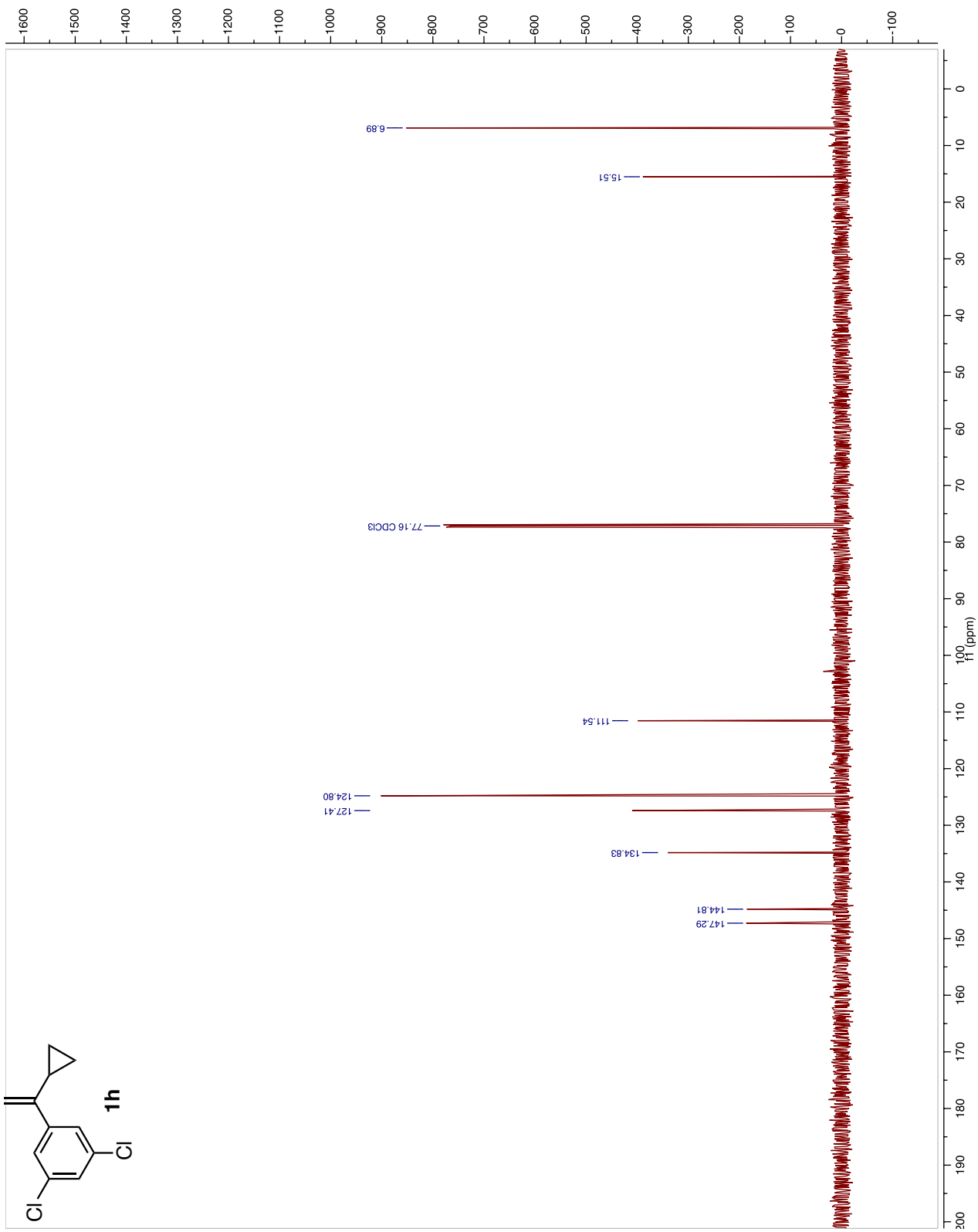

1f
Br
f1 (ppm)
CDCl3

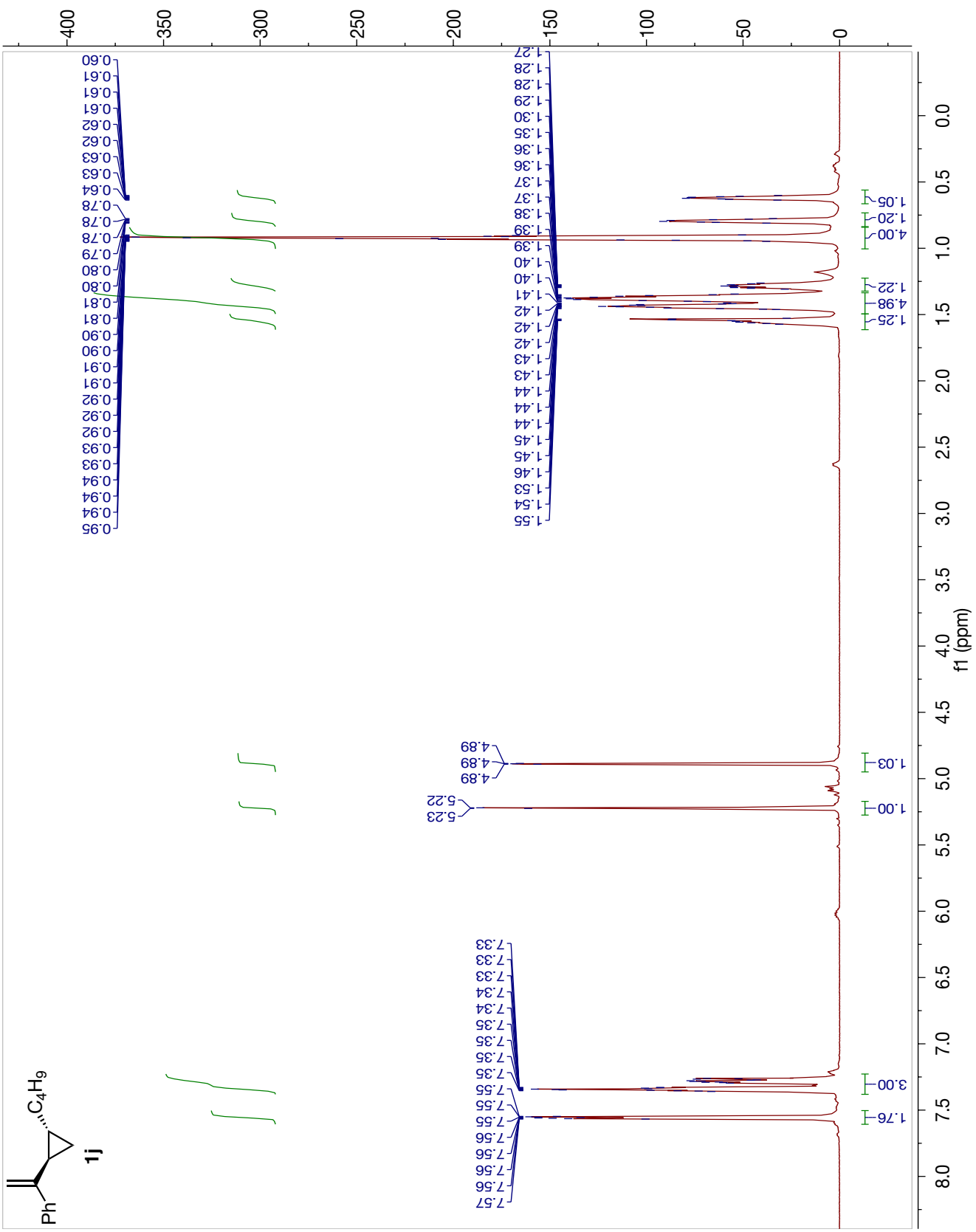

148.26
143.97
130.47
129.80
129.35
124.86
122.55
110.41
77.16 CDCl3
15.64
6.87
f1 (ppm)
1f
Br

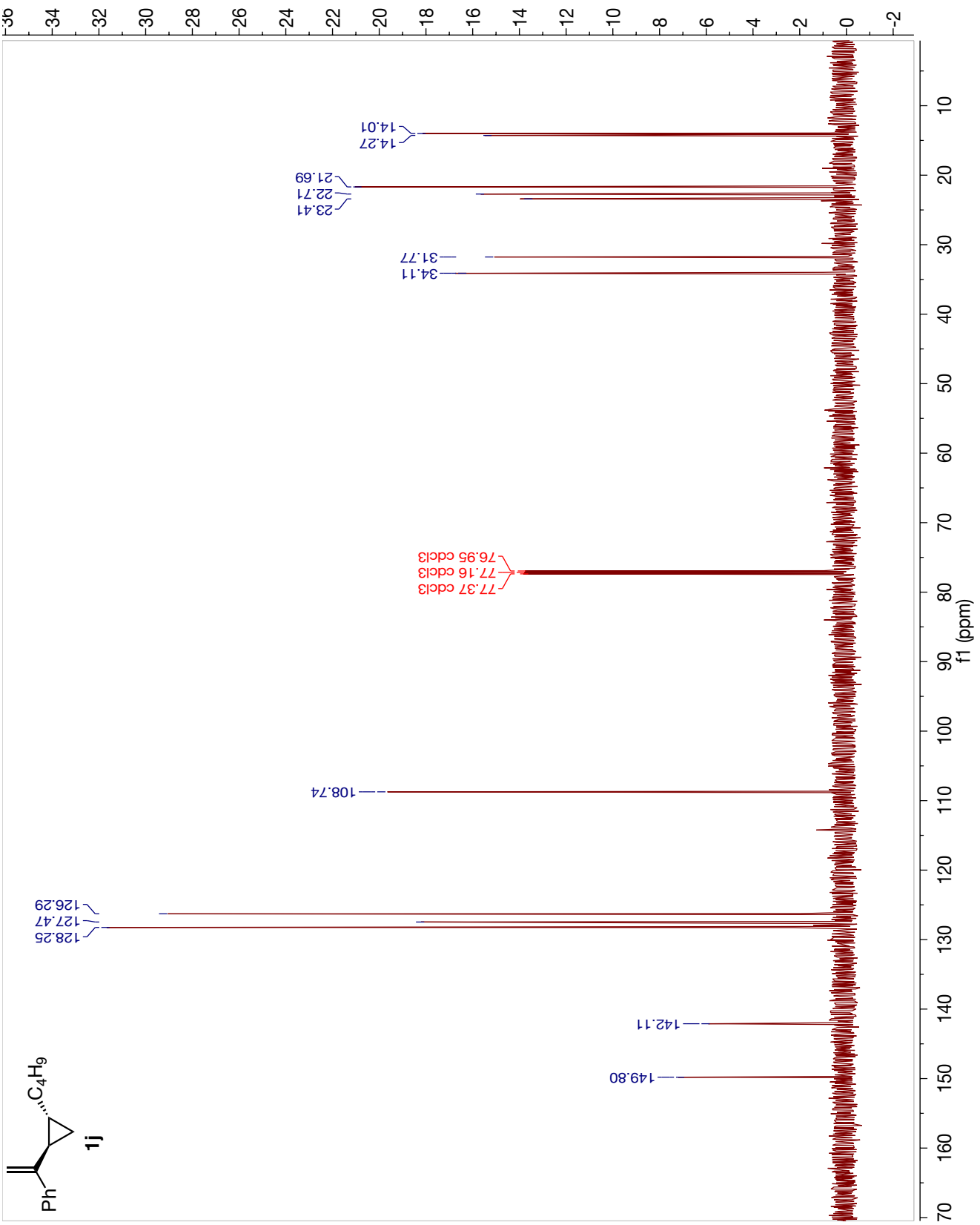

1g
NC
f1 (ppm)

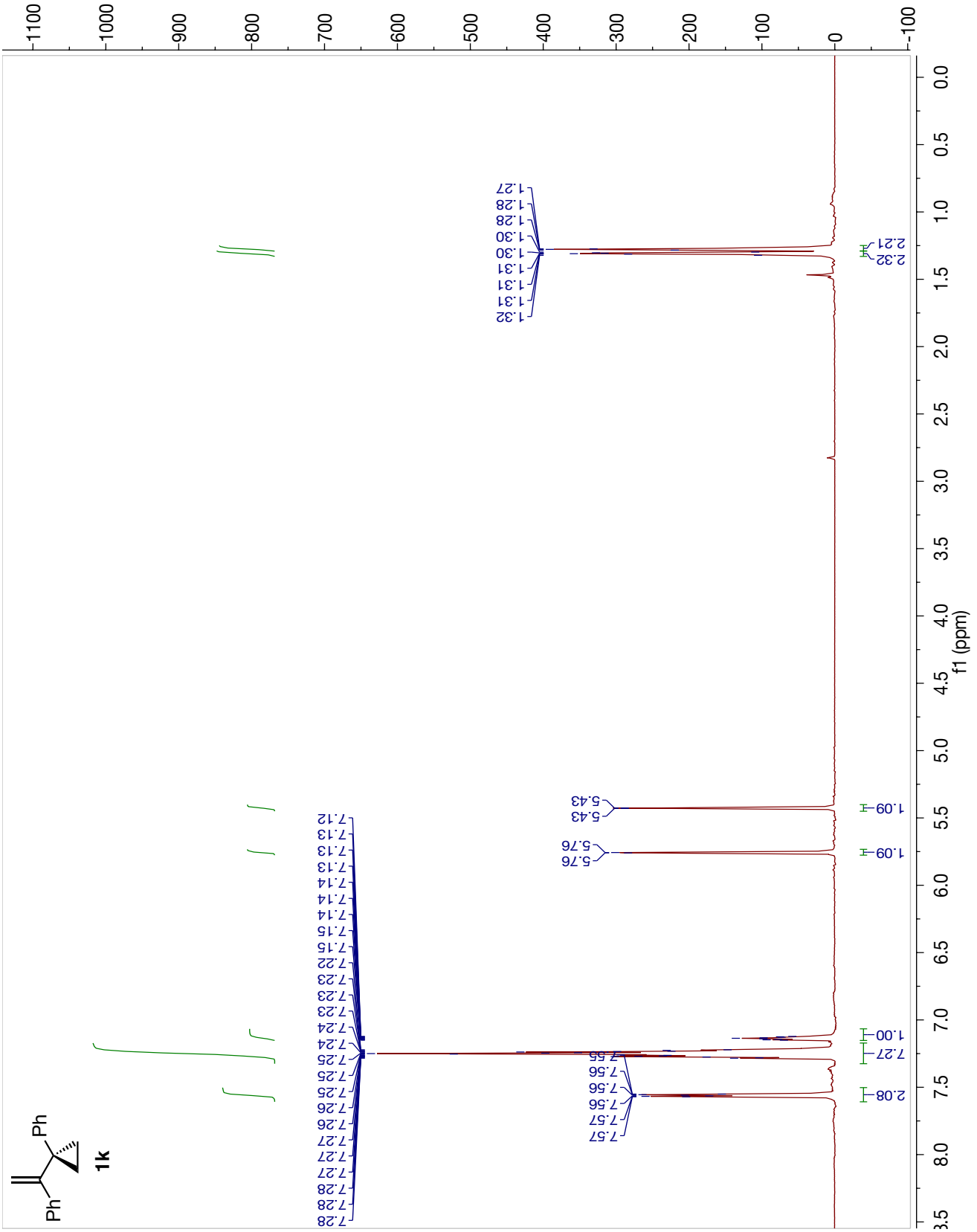

6.84
15.51
77.37 cdcl3
77.16 cdcl3
76.95 cdcl3
112.47
111.45
119.15
130.96
130.52
129.90
129.10
142.88
147.53
f1 (ppm)
NC
1g

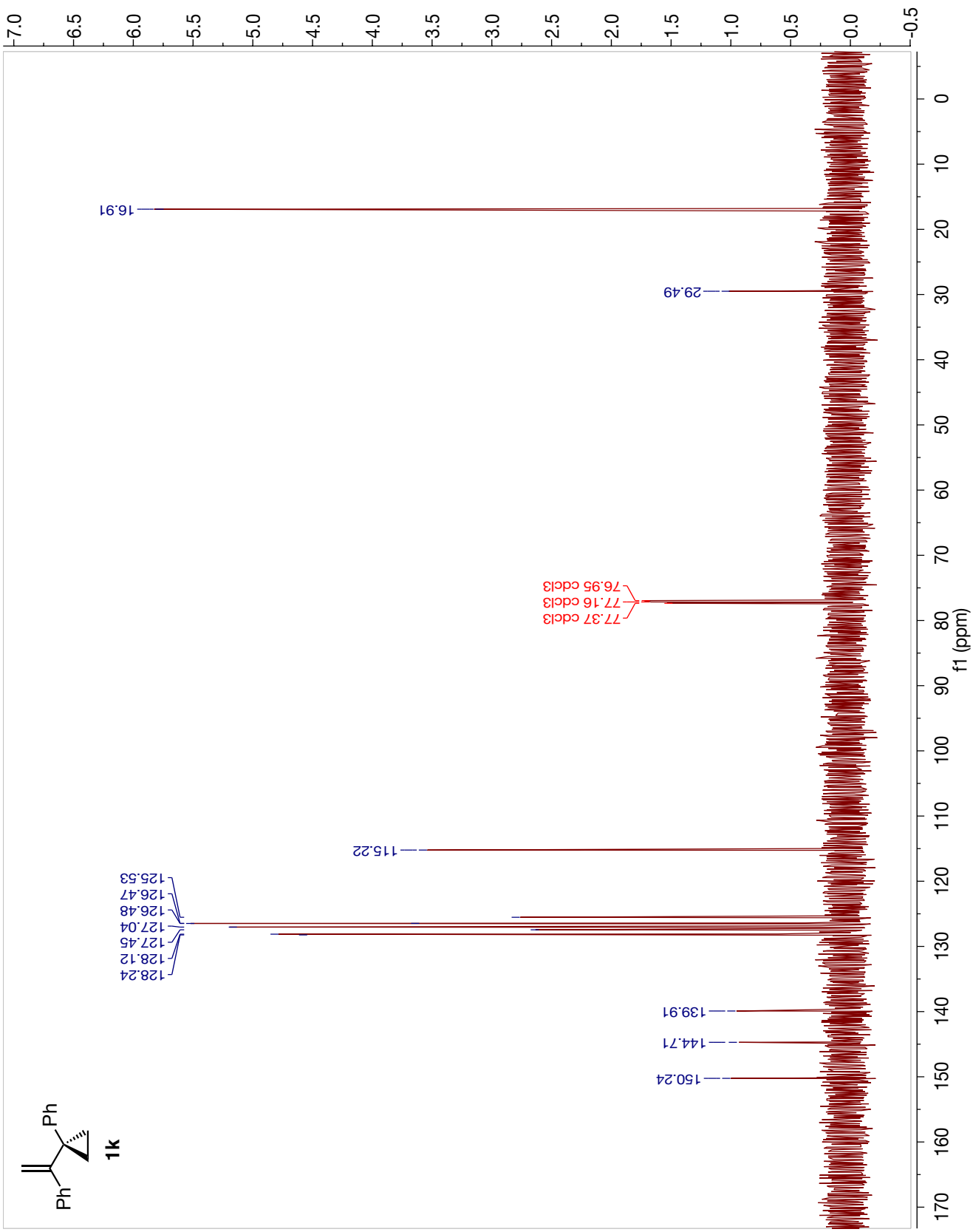

1h
Cl
Cl
f1 (ppm)


1h
Cl
Cl
6.89
15.51
77.16 CDCl3
111.54
124.80
127.41
134.83
144.81
147.29
f1 (ppm)


Ph
C4H9
1j
f1 (ppm)


Ph
C4H9
1j
149.80
142.11
128.25
127.47
126.29
108.74
77.37 cdcl3
77.16 cdcl3
76.95 cdcl3
34.11
31.77
23.41
22.71
21.69
14.27
14.01
f1 (ppm)


Ph
Ph
1k
f1 (ppm)


Ph
Ph
1k
150.24
144.71
139.91
128.24
128.12
127.45
127.04
126.48
126.47
125.53
115.22
77.37 cdcl3
77.16 cdcl3
76.95 cdcl3
29.49
16.91
f1 (ppm)

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