Supporting Information

C−H Alkenylation of Heteroarenes: Mechanism, Rate, and Selectivity Changes Enabled by Thioether Ligands

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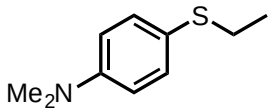
General Methods. All reagents were purchased from commercial sources and used as received unless otherwise indicated. 2-methyl furan, butyl acrylate, and *tert*-butyl acrylate were distilled prior to use. Benzoquinone was sublimed under vacuum prior to use. ^{1}H, $^{13}C\{^{1}H\}$, $^{11}B\{^{1}H\}$ nuclear magnetic resonance spectra (NMR) were obtained on a Bruker 300 MHz or 500 MHz or Varian 400 MHz spectrometers and chemical shifts reported in ppm (δ) referenced against residual $CHCl_3$, CD_2HOD, etc. Spin-spin coupling constants are described as singlet (s), doublet (d), triplet (t), quartet (q), quintet (quint), broad (br) or multiplet (m), with coupling constants (*J*) in Hz. Flash column chromatography was performed on Teledyne Isco*RediSep*® prepacked silica gel columns. GC analysis was performed on an Agilent 6890 GC equipped with an HP-1 column (30m x 0.32 mm ID x 0.25 μm film) and an FID detector. High resolution mass spectrometry (HR-MS) data were obtained using an Agilent 6210 High Resolution Electrospray TOF-MS. Preparative TLC was performed on Merck 60 F254 silica gel plates (20 cm x 20 cm x 1 mm).



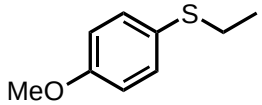
L7

4-(ethylthio)-*N*,*N*-dimethylaniline (L7). 4-(*N*,*N*-dimethylamino)benzenethiol (415 mg, 2.71 mmol), sodium hydroxide (108 mg, 2.71 mmol), and bromoethane (0.20 mL, 2.7 mmol) were added to a 20 mL scintillation vial. Methanol (10 mL) was added and the mixture was stirred at room temperature for 4 h. Solvent was then removed under reduced pressure to give a moist solid. The crude residue was purified by silica gel chromatography using a gradient of hexanes and ethyl acetate from 100:0 to 70:30 to afford 415 mg (85%) of **L7** as pale yellow liquid. NMR spectroscopic data agree with literature values.[1]

^{1}H NMR (500 MHz, $CDCl_3$) δ 7.33 (d, *J* = 8.8 Hz, 2H), 6.66 (d, *J* = 8.8 Hz, 2H), 2.95 (s, 6H), 2.78 (q, *J* = 7.3 Hz, 2H), 1.23 (t, *J* = 7.3 Hz, 3H).

^{13}C NMR (126 MHz, $CDCl_3$) δ 149.88, 134.10, 120.78, 112.82, 40.50, 30.64, 14.81.

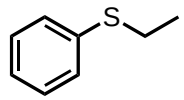
HRMS calc'd for [$C_{10}H_{16}NS^+$] (M+H): 182.0998, found: 182.0997.



L8

ethyl(4-methoxyphenyl)sulfane (L8). 4-methoxybenzenethiol (2.00 g, 14.3 mmol), potassium hydroxide (800 mg, 14.3 mmol), and bromoethane (1.06 mL, 14.3 mmol) were mixed in 50 mL methanol. The reaction was stirred at room temperature for 4 h. The methanol was then removed under reduced pressure to give a moist solid. The solid was washed with water and extracted with ether. The organic layer was collected and dried over magnesium sulfate. Then the ether was removed under reduced pressure to give the crude product as a slightly yellow liquid. The product was purified via distillation under vacuum at 130 °C to give 1.10 g (46%) **L8** as clear liquid. NMR spectroscopic data agree with literature values.[2]

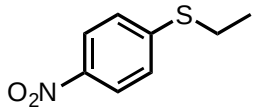
^{1}H NMR (500 MHz, $CDCl_3$) δ 7.48-7.27 (m, 2H), 6.94-6.74 (m, 2H), 3.80 (s, 3H), 2.84 (q, *J* = 7.3 Hz, 2H), 1.25 (t, *J* = 7.3, 3H).



L10

ethyl(phenyl)sulfane (L10). benzenethiol (2.00 g, 18.2 mmol), potassium hydroxide (1.02 g, 18.2 mmol), and bromoethane (1.36 mL, 18.2 mmol) were mixed in 60 mL methanol. The reaction was stirred at room temperature for 4 h. The methanol was then removed under reduced pressure to give a moist solid. The solid was washed with water and extracted with ether. Then the organic layer was collected and dried over magnesium sulfate. The ether was removed under reduced pressure to give the crude product as a slightly yellow liquid. The product was purified via distillation under vacuum at 120 °C to give 1.10 g (44%) **L10** as clear liquid. NMR spectroscopic data agree with literature values.[3]

^{1}H NMR (500 MHz, $CDCl_3$) δ 7.36-7.26 (m, 4H), 7.20-7.14 (m, 1H), 2.95 (q, *J* = 7.4 Hz, 2H), 1.32 (t, *J* = 7.4 Hz, 3H).

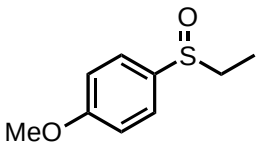


L12

ethyl(4-nitrophenyl)sulfane (L12). 4-nitrobenzenethiol (2.00 g, 12.9 mmol), potassium hydroxide (723 mg, 12.9 mmol), and bromoethane (0.96 mL, 13 mmol) were mixed in 40 mL methanol. The reaction was stirred for 24 h at 55 °C upon which the heterogeneous reaction mixture turns from red to yellow. The reaction vessel was allowed to cool and the methanol was removed under reduced pressure to give a moist solid. The solid was washed with water and extracted with ether. The organic layer was collected and dried over magnesium sulfate. The ether was then removed under reduced pressure to give the crude product as a yellow-orange solid. The product was recrystallized from refluxing

acetone to give 213 mg (9%) **L12** as orange-red feathery crystals. NMR spectroscopic data agree with literature values.[3]

^{1}H NMR (500 MHz, $CDCl_3$) δ 8.15-8.10 (m, 2H), 7.36-7.28 (m, 2H), 3.06 (q, *J* = 7.4 Hz, 2H), 1.40 (t, *J* = 7.4 Hz, 3H).



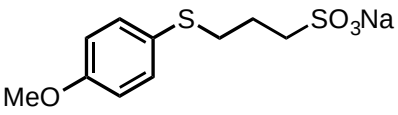
L13

1-(ethylsulfinyl)-4-methoxybenzene (L13). To a 100 mL flask ethyl(4-methoxyphenyl)sulfane (**L8**) (500 mg, 2.97 mmol) was dissolved in 50 mL of acetonitrile and sealed. To the flask hydrogen peroxide (0.34 g, 30 wt%, 3 mmol) and chlorotrimethylsilane (0.38 mL, 3.0 mmol) were added. The reaction was stirred at room temperature for 4 h. The solvent was removed under vacuum to give a white solid that was washed with hexanes to give the 399 mg (73%) **L13** as white solid.

^{1}H NMR (500 MHz, $CDCl_3$) δ 7.55 (d, *J* = 8.7 Hz, 2H), 7.06-7.00 (m, 2H), 3.86 (s, 3H), 2.95-2.66 (m, 2H), 1.18 (t, *J* = 7.4 Hz, 3H).

^{13}C NMR (126 MHz, $CDCl_3$) δ 161.90, 130.38, 126.08, 114.68, 55.53, 50.50, 6.20.

HRMS calc'd for [$C_9H_{13}O_2S^+$] (M+H): 185.0631, found: 185.0630.



L14

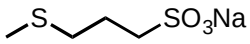
sodium 3-{(4-methoxyphenyl)thio}propane-1-sulfonate (L14). To a 100 mL round bottom flask 4-methoxybenzenethiol (0.62 mL, 5.0 mmol) and sodium hydroxide (0.20 g, 5.0 mmol) were mixed in 10 mL methanol. Under rigorous stirring, 1,2-oxathiolane 2,2-dioxide (0.44 mL, 5.0 mmol) was added and white precipitate generated immediately. The reaction was stirred for 30 min at room temperature to allow full conversion, and 20

mL ether was added to fully precipitate out the product. The afforded suspension was filtered, and the solid was rinsed with ether (20 mL × 2). After air drying for 20 min, 1.39 g (98%) **L14** was obtained as white solid.

^{1}H NMR (500 MHz, CD_3OD) δ 7.36 (d, *J* = 8.7 Hz, 2H), 6.87 (d, *J* = 8.7 Hz, 2H), 3.77 (s, 4H), 2.98 – 2.87 (m, 5H), 2.06 – 1.97 (m, 2H).

^{13}C NMR (126 MHz, CD_3OD) δ 160.58, 134.55, 127.29, 115.63, 55.74, 51.23, 35.55, 26.01.

HRMS calc'd for [$C_{10}H_{15}O_4S_2^+$] ($RSO_3H_2^+$): 263.0406, found: 263.0405.



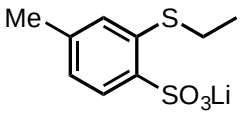
L15

sodium 3-(methylthio)propane-1-sulfonate (L15). To a 100 mL round bottom flask sodium methanethiolate (350 mg, 5.00 mmol) was dissolved in 10 methanol under nitrogen. The reaction system was cooled to 0 ^{o}C, and 1,2-oxathiolane 2,2-dioxide (0.44 mL, 5.0 mmol) was added dropwise *via* syringe. After stirring at room temperature for 3 h, the suspension was concentrated under reduced pressure at 30 ^{o}C then the remaining suspension was filtered and rinsed with ether (20 mL ×2). After air drying for 20 min, 831 mg (86%) **L15** was obtained as white solid.

^{1}H NMR (500 MHz, CD_3OD) δ 2.95 – 2.86 (m, 1H), 2.62 (t, *J* = 7.2 Hz, 3H), 2.10 – 2.02 (m, 5H).

^{13}C NMR (126 MHz, CD_3OD) δ 51.28, 33.76, 25.49, 14.97.

HRMS calc'd for [$C_4H_{11}O_3S_2^+$] ($RSO_3H_2^+$): 171.0144, found: 171.0143.



L16

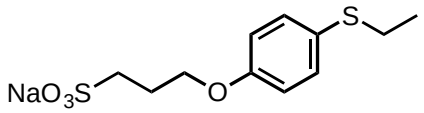
lithium 2-(ethylthio)-4-methylbenzenesulfonate (L16). Lithium 4-methylbenzenesulfonate (1.78 g, 10.0 mmol) was dissolved in THF (100 mL) in a 500 mL round bottom flask in glove box. The flask was sealed with a septum then taken out of the glove box. After cooling down to 0 ^{o}C, *n*-butyllithium (2.5 M in hexanes, 6.9 mL,

11 mmol) was injected dropwise and the colorless solution gradually became a yellow suspension. Diethyl disulfide (1.23 mL, 10.0 mmol) was injected slowly and the solution became light yellow. The reaction was then warmed to room temperature and stirred for 18 h. An aqueous solution of HCl (100 mL, 2 M) was added to quench the reaction. The aqueous phase was separated and extracted with ether (50 mL × 3). The organic layers were combined and solvent was removed under vacuum to afford 6.1 g of a light yellow oil. The crude product was then dissolved in water and neutralized with LiOH. Recrystallization using THF/ether gave 2.04 g (86%) **L16** as a white solid.

^{1}H NMR (501 MHz, CD_3OD) δ 7.82 (d, *J* = 7.9 Hz, 1H), 7.21 (d, *J* = 1.5 Hz, 1H), 6.97 (dd, *J* = 8.0, 1.6 Hz, 1H), 3.01 (q, *J* = 7.4 Hz, 2H), 2.35 (s, 3H), 1.35 (t, *J* = 7.4 Hz, 3H).

^{13}C NMR (126 MHz, CD_3OD) δ 141.86, 141.17, 137.68, 129.34, 129.06, 125.81, 27.64, 21.23, 13.94.

HRMS calc'd for [$C_9H_{13}O_3S_2^+$] ($RSO_3H_2^+$): 233.0301, found: 233.0291.



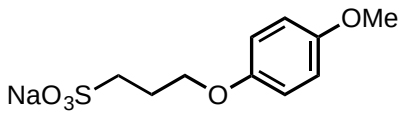
L17

sodium 3-(4-(ethylthio)phenoxy)propane-1-sulfonate (L17). 4-(Ethylthio)phenol (771 mg, 5.00 mmol) and sodium hydroxide (0.210 g, 5.25 mmol) were mixed with 10 mL methanol in a 25 mL round bottom flask. With rigorous stirring, sodium 3-bromopropane-1-sulfonate (1.18 g, 5.25 mmol) was added and a white precipitate gradually formed. The reaction was stirred overnight at 60 ^{o}C. The resulting suspension was then filtered and the solid was rinsed with ether (20 mL × 3) and hexane (20 mL × 3). After air drying for 20 min, 0.88 g (59%) **L17** was obtained as a white solid.

^{1}H NMR (501 MHz, CD_3OD) δ 7.31 (d, *J* = 8.7 Hz, 2H), 6.88 (d, *J* = 8.7 Hz, 2H), 4.10 (t, *J* = 6.3 Hz, 2H), 3.00 – 2.94 (m, 2H), 2.81 (q, *J* = 7.3 Hz, 2H), 2.27 – 2.19 (m, 2H), 1.21 (t, *J* = 7.3 Hz, 3H).

^{13}C NMR (126 MHz, CD_3OD) δ 159.65, 134.19, 127.81, 116.18, 67.75, 49.36, 30.42, 26.29, 15.03.

HRMS calc'd for [$C_{11}H_{17}O_4S_2^+$] ($RSO_3H_2^+$): 277.0563, found: 277.0565.



L18

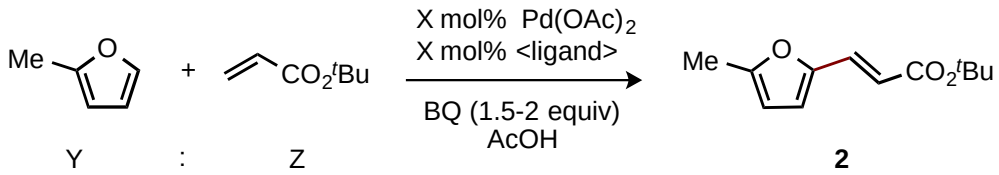
sodium 3-(4-methoxyphenoxy)propane-1-sulfonate (L18). 4-Methoxyphenol (0.62 g, 5.0 mmol) and sodium hydroxide (0.20 g, 5.0 mmol) were mixed with 10 mL methanol in a 100 mL round bottom flask. Under rigorous stirring, 1,2-oxathiolane 2,2-dioxide (0.44 mL, 5.0 mmol) was added and white precipitate generated gradually. The reaction was stirred overnight at room temperature to allow full conversion, and 20 mL ether was added to fully precipitate out the product. The afforded suspension was filtered, and the solid was rinsed with ether (20 mL × 2). After air dry for 20 min, 0.90 g (67%) **L18** was obtained as white solid.

^{1}H NMR (500 MHz, CD_3OD) δ 6.89 – 6.78 (m, 4H), 4.04 (t, *J* = 6.3 Hz, 2H), 3.73 (s, 3H), 3.02 – 2.93 (m, 2H), 2.26 – 2.16 (m, 2H).

^{13}C NMR (126 MHz, CD_3OD) δ 155.36, 154.47, 116.55, 115.62, 68.30, 56.08, 49.85, 26.43.

HRMS calc'd for [$C_{10}H_{15}O_5S^+$] ($RSO_3H_2^+$): 247.0635, found: 247.0636.

Table S1. Screening of sulfur ligand effects on C-H alkenylation of **1**.[a]



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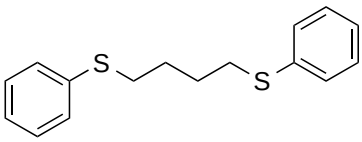
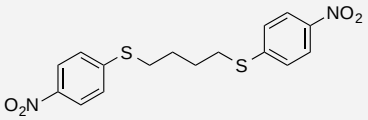
2		1%	60	30	1.5:1	2.0%
3		1%	60	180	1:2	35.4%
4		1%	70	60	1.5:1	23.7%
5		1%	80	60	1.5:1	13.4%
6		1%	90	60	1.5:1	31.6%
7		1%	120	60	1.5:1	13.7%
8	1:1 AcOH:DMSO solvent	1%	50	60	1.5:1	54.5%
9		1%	50	60	1.5:1	28.1%
10		5%	50	60	1.5:1	94.8%
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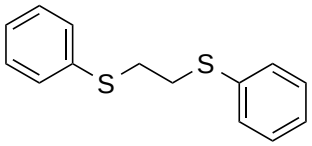
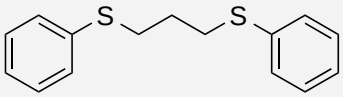
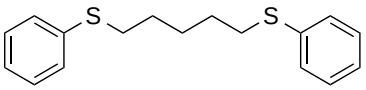
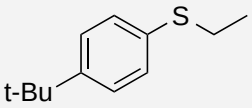
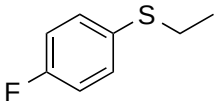
12		5%	50	60	1.5:1	2.8%
13		5%	50	60	1.5:1	5.0%
14		5%	50	60	1.5:1	41.7%
15		1%	50	60	1.5:1	59.9%
16		1%	50	60	1.5:1	53.9%
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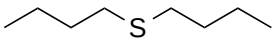
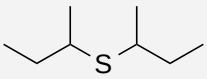
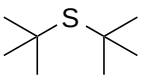
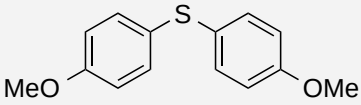
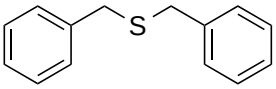
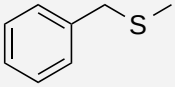
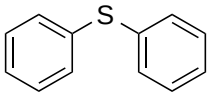
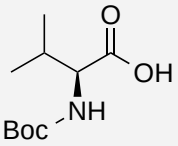
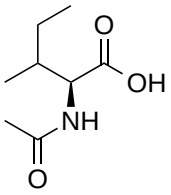
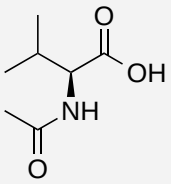
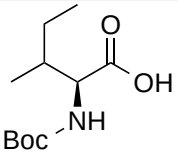
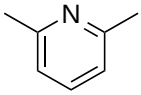
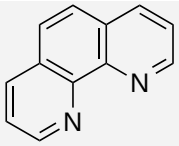
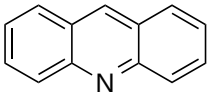
19		1%	45	60	1.5:1	44.7%
20		1%	45	60	1.5:1	41.2%
20		1%	60	30	1:2	6.1 %
21		1%	50	60	1.5:1	27.8%

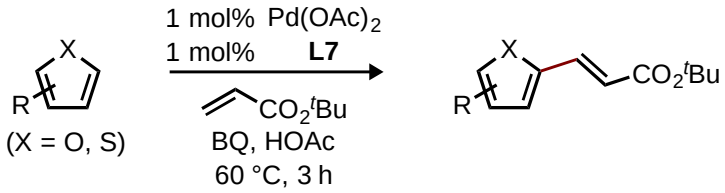
22		1%	45	60	1.5:1	5.7%
23		1%	45	60	1.5:1	15.7%
24		1%	45	60	1.5:1	11.8%

[a]Reactions conditions of Figure 1. [b]Yield was determined by GC analysis versus internal standard.

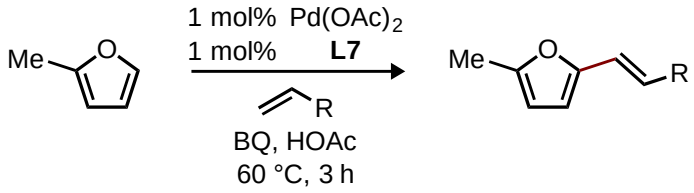
Table S2. Screening of other ligands.[a]

Entry	Ligand	X (mol%)	T (°C)	Time	Y:Z	%Yield[b]
1	none	1%	60	30 min	1:2	4.6%
2		1%	60	30 min	1.5:1	2.2%
3		1%	60	30 min	1.5:1	2.6%
4		1%	60	30 min	1.5:1	2.3%
5		1%	60	30 min	1.5:1	1.9%
6		0.5%	60	1 h	1:2	17.0%
7		0.5%	60	1 h	1:2	9.0%
8		0.5%	60	1 h	1:2	0%
9		0.5%	60	1 h	1:2	6.9%
10	PPh_3	1%	60	30 min	1:2	8.0%

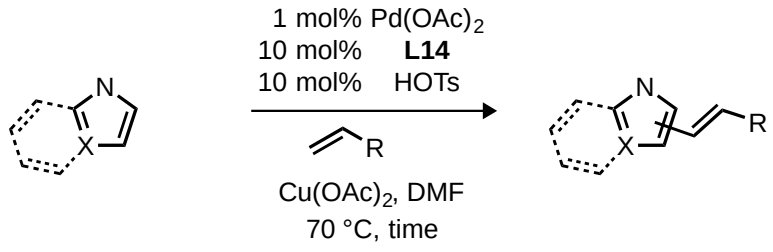
[a]Reactions conditions of Figure 1. [b]Yield was determined by GC analysis versus internal standard.



C-H Alkenylation of Furans and Thiophenes; General Procedure A. A stock solution (0.17 M) was prepared by dissolving palladium acetate (2.2 mg, 10 μmol), benzoquinone (162 mg, 1.50 mmol), *tert*-butyl acrylate (0.29 mL, 2.0 mmol), and **L7** (1.8 μl, 10 μmol) in AcOH (6.0 mL). To a 4 mL vial equipped with a magnetic stir bar was added heteroarene (0.25 mmol) then 1.5 mL of the stock solution. The mixture was stirred at 60 °C for 3 h. Solvent was then evaporated under vacuum at 45 °C. The solid residue was purified by silica gel chromatography.



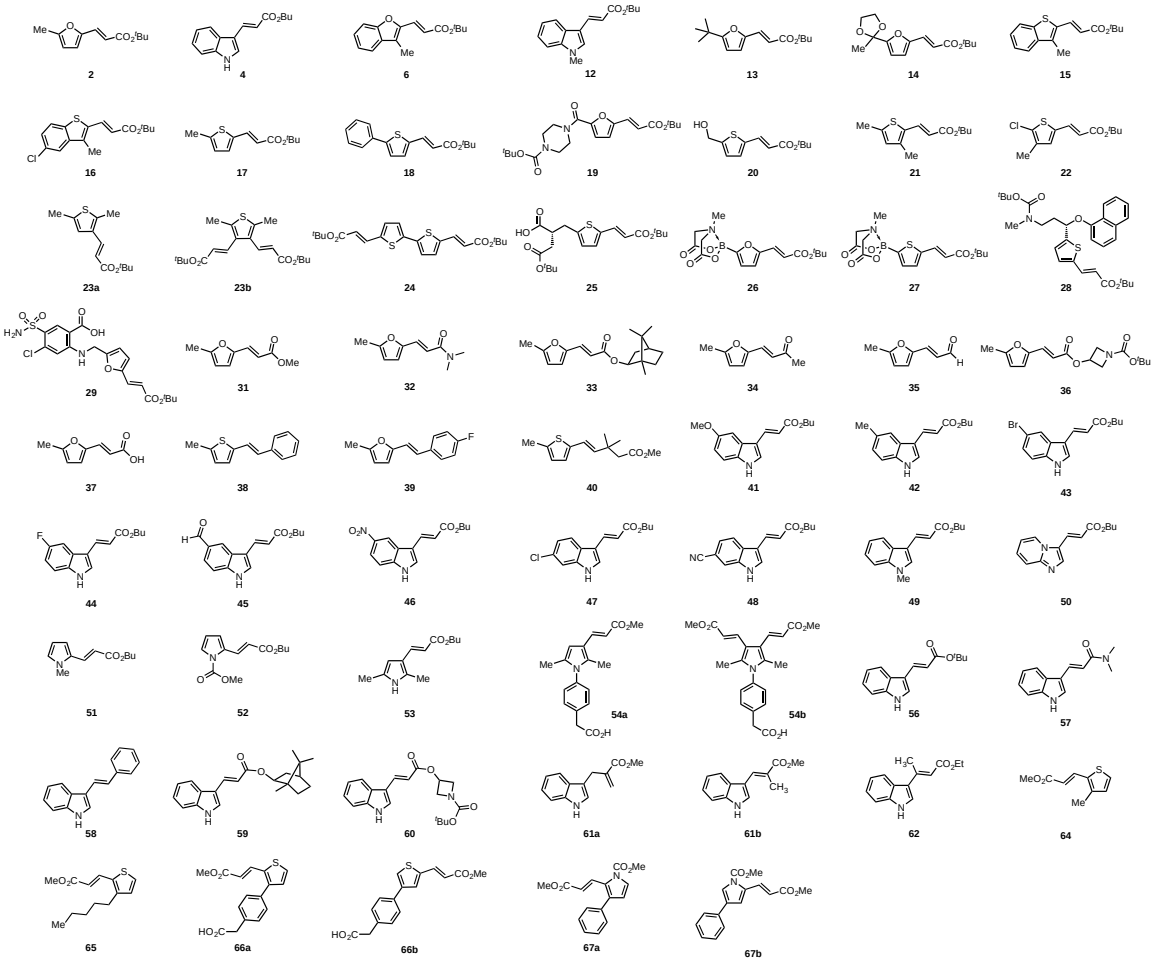
C-H Alkenylation of Furans and Thiophenes; General Procedure B. A stock solution (0.17 M) was prepared by dissolving palladium acetate (2.2 mg, 10 μmol), benzoquinone (162 mg, 1.50 mmol), 2-methylfuran (82 mg, 1.0 mmol), and **L7** (1.8 μl, 10 μmol) in AcOH (6.0 mL). To a 4 mL vial equipped with a magnetic stir bar was added olefin (0.50 mmol) then 1.5 mL of the stock solution. The mixture was stirred at 60 °C for 3 h. Solvent was then evaporated under vacuum at 45 °C. The solid residue was purified by silica gel chromatography.

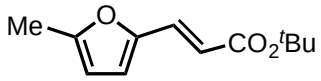


C-H Alkenylation of *N*-heteroarenes: General Procedure C. *N*-heteroarene (0.50 mmol), olefin (1.00 mmol), palladium acetate (1.1 mg, 5.0 μmol), copper(II) acetate (182

mg, 1.00 mmol), *p*-toluenesulfonic acid monohydrate (9.5 mg, 0.050 mmol), and **L14** (14 mg, 50 μmol) were combined in DMF (1.0 mL) under air in a 4 mL vial equipped with a magnetic stir bar. The reaction was then capped and stirred at 70 ^{o}C until the initial dark green suspension became yellow-brown (Cu(II) → Cu(I)). After cooling to room temperature, water (20 mL) and ethyl acetate (20 mL) were added and the mixture was then filtered through a plug of Celite. The organic layer was separated, washed with brine (20 mL × 2), and then dried over Na_2SO_4. Solvent was evaporated under reduced pressure at 45 ^{o}C then the crude residue was purified by silica gel chromatography.

Table S3. Products from DHR reactions.

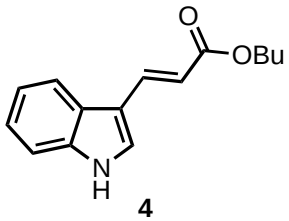




2

***tert*-butyl (*E*)-3-(5-methylfuran-2-yl)acrylate (2).** The general procedure **B** was followed using *tert*-butyl acrylate. The solid residue was purified by silica gel chromatography (20:1 hexanes:ethyl acetate) to give 45 mg (85%) of **2** as a clear liquid. NMR spectroscopic data agree with literature values.[4]

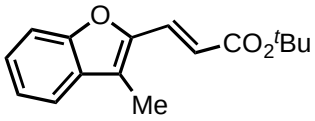
^{1}H NMR (500 MHz, $CDCl_3$) δ 7.25 (d, *J* = 13.7 Hz, 1H), 6.48-6.42 (m, 1H), 6.16 (dd, *J* = 15.6, 2.0 Hz, 1H), 6.08-6.02 (m, 1H), 2.32 (d, *J* = 3.4 Hz, 3H), 1.51 (s, 9H).



4

butyl (*E*)-3-(1*H*-indol-3-yl)acrylate (4). The general procedure **C** was followed with 1*H*-indole and butyl acrylate. The reaction time was 1 h. The crude residue was purified by silica gel chromatography using a gradient of hexanes and ethyl acetate from 100:0 to 70:30 to afford 106 mg (87%) of **4** as yellow solid. NMR spectroscopic data agree with literature values.[5]

^{1}H NMR (500 MHz, $CDCl_3$) δ 8.69 (br, 1H), 7.97 – 7.89 (m, 2H), 7.47 (d, *J* = 2.7 Hz, 1H), 7.44 – 7.40 (m, 1H), 7.33 – 7.22 (m, 2H), 6.48 (d, *J* = 16.0 Hz, 1H), 4.23 (t, *J* = 6.7 Hz, 2H), 1.80 – 1.67 (m, 2H), 1.54 – 1.42 (m, 2H), 0.98 (t, *J* = 7.4 Hz, 3H).



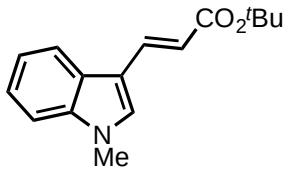
6

***tert*-butyl (*E*)-3-(3-methylbenzofuran-2-yl)acrylate (6)**: The general procedure **A** was followed with 3-methylbenzofuran. The crude product was purified by silica gel chromatography (20:1 hexanes:ethyl acetate) to give 54 mg (83%) of **6** as a clear liquid.

^{1}H NMR (500 MHz, $CDCl_3$) δ 7.46 (d, *J* = 15.5 Hz, 1H), 7.41 (d, *J* = 7.8 Hz, 1H), 7.31 (d, *J* = 8.2 Hz, 1H), 7.26 (d, *J* = 8.8 Hz, 1H), 7.17-7.10 (m, 1H), 6.37 (d, *J* = 15.5 Hz, 1H), 2.25 (s, 3H), 1.45 (s, 9H).

^{13}C NMR (126 MHz, $CDCl_3$) δ 166.62, 154.86, 148.71, 129.98, 128.47, 126.56, 122.86, 120.17, 119.43, 111.30 (overlapping), 80.69, 28.36, 8.48.

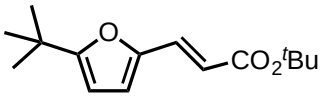
HRMS calc'd for [$C_{12}H_9O_2$•] (M-O^{t}Bu): 185.0597, found: 185.0600.



12

(from aerobic reaction in Scheme 4)

***tert*-butyl (*E*)-3-(1-methyl-1*H*-indol-3-yl)acrylate (12).** 1-methyl-1*H*-indole (131 mg, 1.00 mmol), palladium acetate (11 mg, 50 µmol), *p*-toluenesulfonic acid monohydrate (9.5 mg, 50 µmol) and **L14** (14 mg, 50 µmol) were weighed into a 50 mL round bottom flask that was equipped with a magnetic stir bar. The container was sealed, evacuated then refilled three times with an O_2 balloon then filled with a solution of *tert*-butyl acrylate (0.29 mL, 2.0 mmol) and mesitylene (0.14 mL, 1.0 mmol, as *internal standard*) in DMF (4 mL). After heating at 80 ^{o}C for 4 h, a NMR sample was prepared by diluting 15 µL solution in 0.5 mL $CDCl_3$. The yield was determined by ^{1}H-NMR. NMR spectroscopic data agree with literature values.[5]



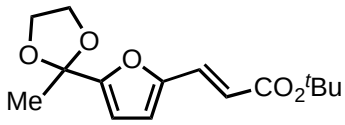
13

***tert*-butyl (*E*)-3-(5-(*tert*-butyl)furan-2-yl)acrylate (13).** The general procedure **A** was followed with 2-*tert*-butylfuran. The crude product was purified by silica gel chromatography (20:1 hexanes:ethyl acetate) to give 54 mg (86%) of **13** as a slightly red liquid.

^{1}H NMR (500 MHz, CDCl3) δ 7.26 (d, *J* = 16.0 Hz, 1H), 6.45 (d, *J* = 3.3 Hz, 1H), 6.18 (d, *J* = 15.6 Hz, 1H), 6.04 (d, *J* = 3.3 Hz, 1H), 1.52 (s, 9H), 1.29 (s, 9H).

^{13}C NMR (126 MHz, CDCl3) δ 167.21, 166.92, 149.57, 130.63, 116.20, 115.62, 105.19, 80.36, 33.19, 29.15, 28.44.

HRMS calc'd for [$C_{11}H_{13}O_2$•] (M-O^{t}Bu): 177.0910, found: 177.0914.



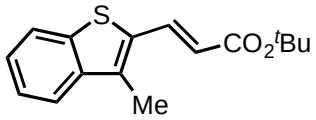
14

***tert*-butyl (*E*)-3-(5-(2-methyl-1,3-dioxolan-2-yl)furan-2-yl)acrylate (14).** The general procedure **A** was followed with 2-(furan-2-yl)-2-methyl-[1,3]dioxolane that was prepared by literature method.[6] The crude residue was purified by silica gel chromatography using a gradient of hexanes (with 3% NEt_3) and ethyl acetate from 100:0 to 70:30 to afford 40 mg (57%) of **14** as colorless liquid.

^{1}H NMR (500 MHz, $CDCl_3$) δ 7.28 (d, *J* = 16.0 Hz, 1H), 6.47 (d, *J* = 3.5 Hz, 1H), 6.36 (d, *J* = 3.5 Hz, 1H), 6.25 (d, *J* = 16.0 Hz, 1H), 3.98-4.08 (m, 4H), 1.73 (s, 3H), 1.50 (s, 9H).

^{13}C NMR (125 MHz, $CDCl_3$) δ 166.24, 156.48, 150.85, 129.89, 118.18, 114.30, 108.86, 104.45, 80.37, 65.21, 28.15, 24.24.

HRMS calc'd for [$C_{15}H_{21}O_5^+$] (M+H) 281.1384; found 281.1384.



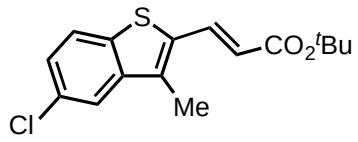
15

***tert*-butyl (*E*)-3-(3-methylbenzo[b]thiophen-2-yl)acrylate (15).** The general procedure **A** was followed with 3-methylbenzothiophene. The crude product was purified by silica gel chromatography (20:1 hexanes:ethyl acetate) to give 54 mg (79%) of **15** as a clear liquid.

^{1}H NMR (500 MHz, $CDCl_3$) δ 7.96 (d, *J* = 15.4 Hz, 1H), 7.82-7.66 (m, 2H), 7.42-7.35 (m, 2H), 6.22 (d, *J* = 15.5 Hz, 1H), 2.51 (s, 3H), 1.55 (s, 9H).

^{13}C NMR (126 MHz, $CDCl_3$) δ 166.37, 140.74, 139.22, 135.86, 134.88, 133.98, 126.46, 124.57, 122.75, 122.55, 120.71, 80.86, 28.35, 12.22.

HRMS calc'd for [$C_{12}H_9OS\bullet$] (M-O^{t}Bu): 201.0369, found: 201.0369.



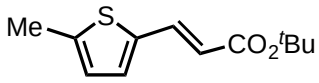
16

***tert*-butyl (*E*)-3-(5-chloro-3-methylbenzo[*b*]thiophen-2-yl)acrylate (16).** The general procedure **A** was followed with 5-chloro-3-methylbenzo[*b*]thiophene and 3 mol% of $Pd(OAc)_2$/**L7** was employed. Two parallel reactions (0.25 mmol each) were conducted and combined for isolation. The crude product was purified by silica gel chromatography using a gradient of hexanes and ethyl acetate from 100:0 to 90:10 to afford 115 mg (75%) of **16** as a white solid.

^{1}H NMR (500 MHz, $CDCl_3$) δ 7.92 (d, *J* = 15.4, 1H), 7.72-7.62 (m, 2H), 7.33 (m, 1H), 6.22 (d, *J* = 15.5 Hz, 1H), 2.46 (s, 3H), 1.54 (s, 9H).

^{13}C NMR (126 MHz, $CDCl_3$) δ 165.96, 141.85, 137.07, 135.70, 134.73, 134.29, 130.82, 126.59, 123.41, 122.24, 121.44, 80.91, 28.20, 12.05.

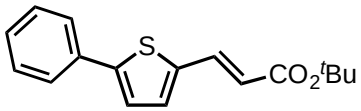
HRMS calc'd for [$C_{16}H_{18}ClO_2S^+$] (M+H): 309.0711, found: 309.0715.



17

***tert*-butyl (E)-3-(5-methylthiophen-2-yl)acrylate (17).** The general procedure **A** was followed with 2-methylthiophene. The crude product was purified by silica gel chromatography (20:1 hexanes:ethyl acetate) to give 48 mg (85%) of **17** as a clear liquid. NMR spectroscopic data agree with literature values.[7]

^{1}H NMR (500 MHz, CDCl3) δ 7.59 (d, *J* = 15.6 Hz, 1H), 7.01 (d, *J* = 3.5 Hz, 1H), 6.68 (d, *J* = 3.5 Hz, 1H), 6.03 (d, *J* = 15.6 Hz, 1H), 2.48 (s, 3H), 1.51 (s, 9H).



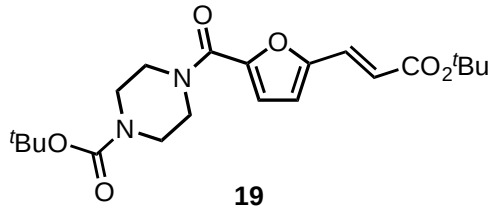
18

***tert*-butyl (*E*)-3-(5-phenylthiophen-2-yl)acrylate (18).** The general procedure **A** was followed with 2-phenylthiophene. The crude product was purified by silica gel chromatography (20:1 hexanes:ethyl acetate) to give 67 mg (94%) of **18** as a white solid.

^{1}H NMR (500 MHz, $CDCl_3$) δ 7.65 (d, *J* = 15.6 Hz, 1H), 7.63-7.56 (m, 2H), 7.43-7.36 (m, 2H), 7.35-7.29 (m, 1H), 7.25 (d, *J* = 3.8 Hz, 1H), 7.19 (d, *J* = 3.8 Hz, 1H), 6.17 (d, *J* = 15.6 Hz, 1H), 1.53 (s, 9H).

^{13}C NMR (126 MHz, $CDCl_3$) δ 166.35, 146.98, 139.12, 136.24, 133.81, 131.96, 129.16, 128.43, 126.07, 124.01, 118.78, 80.67, 28.37.

HRMS calc'd for [$C_{17}H_{19}O_2S^+$] (M+H): 287.1100, found: 287.1106.



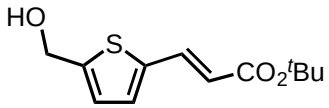
19

***tert*-butyl (*E*)-4-(5-(3-(tert-butoxy)-3-oxoprop-1-en-1-yl)furan-2-carbonyl)piperazine -1-carboxylate (19).** *tert*-butyl 4-(furan-2-carbonyl)piperazine-1-carboxylate (140 mg, 0.500 mmol), *tert*-butyl acrylate (0.15 mL, 1.0 mmol), palladium acetate (5.6 mg, 25 μmol), **L7** (4.4 μl, 25 μmol), and benzoquinone (81 mg, 0.75 mmol) were mixed in AcOH (3 mL) in a 4 mL vial equipped with a magnetic stir bar. The reaction was capped and stirred at 60 °C for 6 h. Solvent was then evaporated under vacuum at 45 °C. The crude residue was purified by silica gel chromatography using a gradient of hexanes and ethyl acetate from 100:0 to 0:100 to afford 116 mg (57%) of **19** as a yellow solid.

^{1}H NMR (501 MHz, $CDCl_3$) δ 7.34 (d, *J* = 15.8 Hz, 1H), 7.08 (d, *J* = 3.6 Hz, 1H), 6.65 (d, *J* = 3.5 Hz, 1H), 6.29 (d, *J* = 15.8 Hz, 1H), 3.80 (br, 4H), 3.58 – 3.52 (m, 4H), 1.53 (s, 9H), 1.50 (s, 9H).

^{13}C NMR (126 MHz, $CDCl_3$) δ 165.74, 158.78, 154.66, 152.01, 148.72, 129.47, 120.61, 118.90, 114.82, 81.13, 80.54, 46.63, 43.36, 28.50, 28.26.

HRMS calc'd for [$C_{21}H_{31}N_2O_6^+$] (M+Na^+): 407.2177, found: 407.2176.



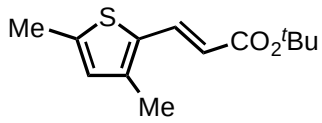
20

***tert*-butyl (*E*)-3-(5-(hydroxymethyl)thiophen-2-yl)acrylate (20).** The general procedure **A** was followed with 2-thiophenemethanol. The crude product was purified by silica gel chromatography (20:1 hexanes:ethyl acetate) to give 52 mg (86%) of **20** as a clear liquid.

^{1}H NMR (500 MHz, $CDCl_3$) δ 7.59 (d, *J* = 15.6 Hz, 1H), 7.06 (d, *J* = 3.7 Hz, 1H), 6.90 (d, *J* = 3.6 Hz, 1H), 6.08 (d, *J* = 15.7 Hz, 1H), 4.79 (s, 2H), 1.51 (s, 9H).

^{13}C NMR (126 MHz, $CDCl_3$) δ 166.42, 147.29, 139.76, 136.35, 130.70, 126.01, 118.81, 80.79, 60.34, 28.31.

HRMS calc'd for [$C_8H_7O_2S$•] (M-O^{t}Bu): 167.0161, found: 167.0161.



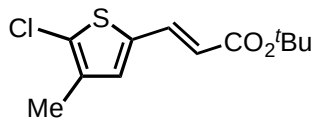
21

***tert*-butyl (*E*)-3-(3,5-dimethylthiophen-2-yl)acrylate (21).** The general procedure **A** was followed with 2,4-dimethylthiophene. The crude product was purified by silica gel chromatography (20:1 hexanes:ethyl acetate) to give 39 mg (65%) of **21** as a clear liquid.

^{1}H NMR (500 MHz, $CDCl_3$) δ 7.70 (d, *J* = 15.5 Hz, 1H), 6.52 (s, 1H), 5.96 (d, *J* = 15.5 Hz, 1H), 2.43 (s, 3H), 2.24 (s, 3H), 1.51 (s, 9H).

^{13}C NMR (126 MHz, $CDCl_3$) δ 167.05, 141.99, 141.57, 134.93, 131.96, 129.93, 116.52, 80.42, 28.47, 15.91, 14.27.

HRMS calc'd for [$C_{13}H_{19}O_2S^+$] (M+H): 239.1100, found: 239.1100.



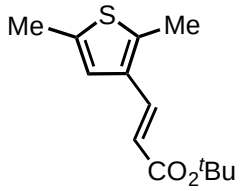
22

***tert*-butyl (*E*)-3-(5-chloro-4-methylthiophen-2-yl)acrylate (22).** The general procedure **A** was followed with 2-chloro-3-methylthiophene and 3 mol% of $Pd(OAc)_2$/**L7** was employed. Two parallel reactions (0.25 mmol each) were conducted and combined for isolation. The crude product was purified by silica gel chromatography using a gradient of hexanes and ethyl acetate from 100:0 to 90:10 to afford 100 mg (78%) of **22** as a white solid.

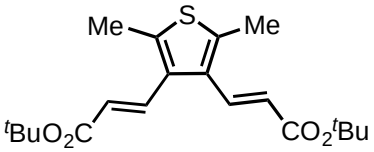
^{1}H NMR (500 MHz, $CDCl_3$) δ 7.49 (d, *J* = 15.6 Hz, 1H), 6.89 (s, 1H), 6.01 (d, *J* = 15.6 Hz, 1H), 2.15 (s, 3H), 1.51 (s, 9H).

^{13}C NMR (126 MHz, $CDCl_3$) δ 165.97, 135.95, 135.57, 135.53, 132.23, 127.74, 118.68, 80.67, 28.19, 13.50.

HRMS calc'd for [$C_8H_8ClO_2S^+$] (M-^{t}Bu+H): 202.9928, found: 202.9931.



23a



23b

The general procedure **A** was followed with 2,5-dimethylthiophene and 3 mol% of $Pd(OAc)_2$/**L7** was employed. Two parallel reactions (0.25 mmol each) were conducted and combined for isolation. The crude product was purified by silica gel chromatography using a gradient of hexanes and ethyl acetate from 100:0 to 90:10 to give 78 mg (65%) of **23a** as a colorless oil and also 19 mg (10%) of **23b** as a yellow solid. The reaction was not further optimized to increase the selectivity for either product.

***tert*-butyl (*E*)-3-(2,5-dimethylthiophen-3-yl)acrylate (23a).**

^{1}H NMR (500 MHz, $CDCl_3$) δ 7.53 (d, *J* = 15.7 Hz, 1H), 6.79 (s, 1H), 6.04 (d, *J* = 15.7 Hz, 1H), 2.45 (s, 3H), 2.38 (s, 3H), 1.52 (s, 9H).

^{13}C NMR (126 MHz, $CDCl_3$) δ 167.18, 140.26, 136.65, 135.40, 132.92, 123.00, 118.24, 80.22, 28.24, 15.19, 13.14.

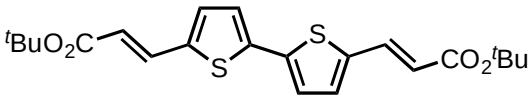
HRMS calc'd for [$C_{13}H_{19}O_2S^+$] (M+H): 239.1100, found: 239.1098.

di-*tert*-butyl 3,3'-(2,5-dimethylthiophene-3,4-diyl)(2*E*,2'*E*)-diacrylate (23b).

^{1}H NMR (500 MHz, $CDCl_3$) δ 7.55 (d, *J* = 16.1 Hz, 1H), 5.95 (d, *J* = 16.1 Hz, 1H), 2.44 (s, 3H), 1.52 (s, 9H).

^{13}C NMR (126 MHz, $CDCl_3$) δ 166.46, 136.83, 136.81, 132.46, 123.02, 80.60, 77.41, 77.16, 76.91, 28.34, 14.59.

HRMS calc'd for [$C_{20}H_{29}O_4S^+$] (M+H): 365.1781, found: 365.1775.



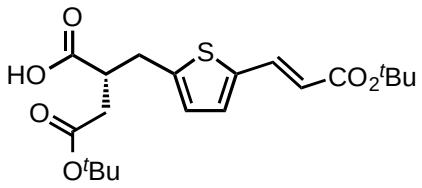
24

di-*tert*-butyl 3,3'-([2,2'-bithiophene]-5,5'-diyl)(2*E*,2'*E*)-diacrylate (24). 2,2'-bithiophene (42 mg, 0.25 mmol), *tert*-butyl acrylate (0.11 mL, 0.75 mmol), palladium acetate (1.7 mg, 7.5 μmol), **L7** (1.3 μl, 7.5 μmol), and benzoquinone (81 mg, 0.75 mmol) were mixed in AcOH (1.5 mL) in a 4 mL vial equipped with a magnetic stir bar. The reaction was capped and stirred at 60 °C for 3 h. Solvent was then evaporated under vacuum at 45 °C. The solid residue was purified by silica gel chromatography using a gradient of hexanes and ethyl acetate from 100:0 to 70:30 to afford 100 mg (96%) of **24** as an orange solid.

^{1}H NMR (500 MHz, $CDCl_3$) δ 7.61 (d, *J* = 15.6 Hz, 2H), 7.13 (s, 4H), 6.14 (d, *J* = 15.6 Hz, 2H), 1.52 (s, 18H).

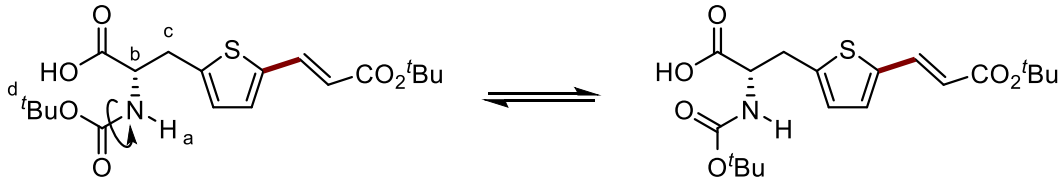
^{13}C NMR (126 MHz, $CDCl_3$) δ 166.11, 139.57, 139.09, 135.67, 131.80, 125.29, 119.47, 80.82, 28.34.

HRMS calc'd for [$C_{22}H_{27}O_4S_2^+$] (M+H): 419.1345, found: 419.1354.



25

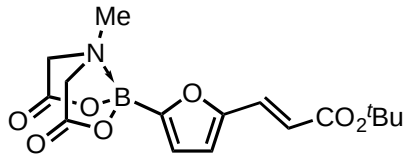
(*S*,*E*)-3-(5-(3-(tert-butoxy)-3-oxoprop-1-en-1-yl)thiophen-2-yl)-2-((tert-butoxycarbonyl)amino)propanoic acid (25). BOC-3-(2-thienyl)-L-alanine (136 mg, 0.500 mmol), *tert*-butyl acrylate (0.15 mL, 1.0 mmol), palladium acetate (3.4 mg, 15 µmol), **L7** (2.7 µl, 15 µmol), and benzoquinone (81 mg, 0.75 mmol) were mixed in AcOH (3.0 mL) in a 4 mL vial equipped with a magnetic stir bar. The reaction was capped and stirred at 60 °C for 3 h. Solvent was then evaporated under vacuum at 45 °C. The solid residue was purified by silica gel chromatography using a gradient of hexanes (with 2% AcOH) and ethyl acetate from 100:0 to 50:50 to afford 190 mg (95%) of **25** as a white solid. Amide rotamers (below), identified by a NOESY experiment, account for the complicated ^{1}H NMR spectrum of **25**. ^{13}C NMR data are reported for the major isomer.



^{1}H NMR (500 MHz, $CDCl_3$) δ 10.68 (br, 1H), 7.57 (d, *J* = 15.6 Hz, 1H), 7.02 (d, *J* = 3.5 Hz, 1H), 6.76 (d, *J* = 3.0 Hz, 1H), 6.79 – 6.75 (m, 0.4H, $\mathbf{H_a}$), 6.05 (d, *J* = 15.6 Hz, 1H), 5.27 (d, *J* = 7.9 Hz, 0.6H, $\mathbf{H_a}$), 4.64 – 4.56 (m, 0.6H, $\mathbf{H_b}$), 4.43 – 4.34 (m, 0.4H, $\mathbf{H_b}$), 3.44 – 3.26 (m, 1.6H, $\mathbf{H_c}$), 3.19 – 3.10 (m, 0.4H, $\mathbf{H_c}$), 1.50 (s, 9H), 1.43 (s, 6H, $\mathbf{H_d}$), 1.34 (s, 3H, $\mathbf{H_d}$).

^{13}C NMR (126 MHz, $CDCl_3$) δ 174.71, 166.68, 155.41, 141.12, 139.26, 136.44, 131.00, 127.98, 118.33, 80.86, 80.65, 54.05, 32.76, 28.42, 28.29.

HRMS calc'd for [$C_{19}H_{28}NO_6S^+$] (M+H): 398.1632, found: 398.1630.



26

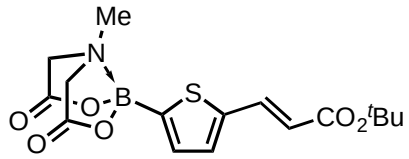
***tert*-butyl (*E*)-3-(5-MIDA-furan-2-yl)acrylate (26).** The general procedure **A** was followed with 2-furyl MIDA boronate (prepared by literature method)[8] and 3 mol% of $Pd(OAc)_2$/**L7** was employed. The crude product was purified by silica gel chromatography using a gradient of hexanes and ethyl acetate from 100:0 to 50:50 followed by a gradient of dichloromethane and methanol from 100:0 to 95:5 to give 80 mg (91%) of **26** as a yellow solid.

^{1}H NMR (500 MHz, CD_3CN) δ 7.37 (d, *J* = 15.8 Hz, 1H), 6.78 (d, *J* = 3.3 Hz, 1H), 6.71 (d, *J* = 3.3 Hz, 1H), 6.24 (d, *J* = 15.8 Hz, 1H), 4.08 (d, *J* = 17.1 Hz, 2H), 3.94 (d, *J* = 17.1 Hz, 2H), 2.68 (s, 3H), 1.48 (s, 9H).

^{13}C NMR (126 MHz, CD_3CN) δ 169.00, 166.79, 154.86, 130.95, 130.93, 121.45, 118.73, 115.79, 80.96, 62.53, 48.11, 28.23.

^{11}B NMR (96 MHz, CD_3CN) δ 8.71.

HRMS calc'd for [$C_{16}H_{20}BNNaO_7^+$] ($M+Na^+$) 372.1225; found 372.1228.



27

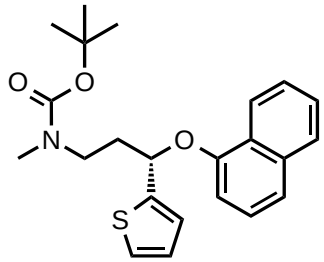
tert-butyl (*E*)-3-(5-MIDA-thiophen-2-yl)acrylate (**27**). The general procedure **A** was followed with 2-thiophenyl MIDA boronate (prepared by literature method)[8] and 3 mol% of $Pd(OAc)_2$/**L7** was employed. The crude product was purified by silica gel chromatography using a gradient of hexanes and ethyl acetate from 100:0 to 50:50 followed by a gradient of dichloromethane and methanol from 100:0 to 95:5 to give 87.8 mg (96%) of **27** as a light yellow solid.

^{1}H NMR (500 MHz, CD_3CN) δ 7.71 (d, *J* = 15.8 Hz, 1H), 7.38 (d, *J* = 3.7 Hz, 1H), 7.23 (d, *J* = 3.7 Hz, 1H), 6.18 (d, *J* = 15.7 Hz, 1H), 4.10 (d, *J* = 17.3 Hz, 2H), 3.93 (d, *J* = 17.2 Hz, 2H), 2.64 (s, 3H), 1.48 (s, 9H).

^{13}C NMR (126 MHz, CD_3CN) δ 168.86, 166.55, 144.25 (possible overlap), 136.57, 135.18, 133.10, 120.05, 81.03, 62.46, 48.35, 28.24.

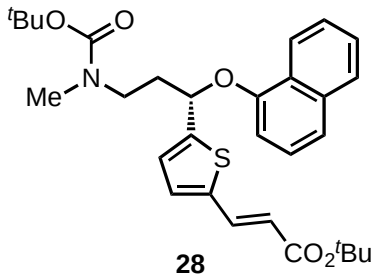
^{11}B NMR (96 MHz, CD_3CN) δ 10.31.

HRMS calc'd for [$C_{16}H_{20}BNNaO_6S^+$] ($M+Na^+$) 388.0997; found 388.0998.



(*S*)-*N*-BOC-duloxetine.[9] (S)-duloxetine HCl (0.25 g, 0.84 mmol), triethylamine (0.32 mL, 2.3 mmol), and di-*tert*-buytyl dicarbonate (0.20 g, 0.92 mmol) were added to a 50 mL round bottom flask. DCM (25 mL) was added and the mixture stirred at room temperature for 2 h. The reaction was washed with water then the organics were extracted with ethyl acetate. The organic layer was dried over magnesium sufonate and the solvent was removed under vacuum to give 0.30 g (90%) of the desired product as a brown liquid.

^{1}H NMR (500 MHz, $CDCl_3$) δ 8.46 – 8.23 (m, 1H), 7.88 – 7.69 (m, 1H), 7.49 (dd, *J* = 6.1, 3.2 Hz, 2H), 7.39 (d, *J* = 8.1 Hz, 1H), 7.26 (t, 1H), 7.21 (d, *J* = 5.1 Hz, 1H), 7.10 – 7.02 (m, 1H), 6.98 – 6.89 (m, 1H), 6.81 (d, *J* = 7.5 Hz, 1H), 3.48 (s, 2H), 2.86 (s, 4H), 2.53 (d, *J* = 7.3 Hz, 1H), 2.45 (d, *J* = 19.6 Hz, 1H), 2.31 (ddt, *J* = 14.2, 9.0, 3.9 Hz, 1H), 1.53 (s, 9H).



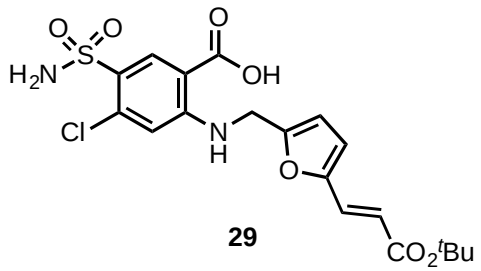
28

***tert*-butyl (*S*,*E*)-3-(5-(3-((*tert*-butoxycarbonyl)(methyl)amino)-1-(naphthalen-1-yloxy)propyl)thiophen-2-yl)acrylate (28).** The general procedure **A** was followed with (S)-*N*-BOC-duloxetine. The crude product was purified by silica gel chromatography (20:1 hexanes:ethyl acetate) to give 73 mg (56%) of **28** as a yellow viscous liquid.

^{1}H NMR (500 MHz, $CDCl_3$) δ 8.37-8.30 (m, 1H), 7.79 (dd, *J* = 6.4, 3.1 Hz, 1H), 7.56 (d, *J* = 15.7 Hz, 1H), 7.50 (dd, *J* = 6.4, 3.3 Hz, 2H), 7.41 (d, *J* = 8.2 Hz, 1H), 7.26 (d, *J* = 15.7 Hz, 1H), 7.04 (d, *J* = 3.6 Hz, 1H), 7.02-6.93 (m, 1H), 6.77 (d, *J* = 7.6 Hz, 1H), 6.05 (d, *J* = 15.6 Hz, 1H), 5.60 (s, 1H), 3.49 (d, *J* = 29.8 Hz, 2H), 2.85 (s, 3H), 2.42 (s, 1H), 2.30 (ddt, *J* = 14.3, 7.6, 3.7 Hz, 1H), 1.48 (s, 9H), 1.38 (s, 9H).

^{13}C NMR (126 MHz, $CDCl_3$) δ 166.03, 155.76, 152.85, 147.77, 139.17, 135.90, 134.61, 130.35, 130.15, 127.57, 126.46, 125.90, 125.61, 125.41, 121.89, 120.96, 119.00, 106.59, 80.51, 79.63, 73.50, 45.68, 28.43, 28.36, 28.18, 21.14.

HRMS calc'd for [$C_{30}H_{38}NO_5S^+$] (M+H): 524.2465, found: 524.2459.



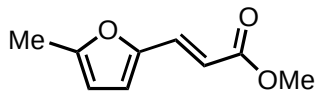
29

(*E*)-2-(((5-(3-(*tert*-butoxy)-3-oxoprop-1-en-1-yl)furan-2-yl)methyl)amino)-4-chloro-5-sulfamoylbenzoic acid (29). furosemide (165 mg, 0.50 mmol), *tert*-butyl acrylate (0.15 mL, 1.0 mmol), palladium acetate (3.4 mg, 15 μmol), **L7** (2.7 μl, 15 μmol), and benzoquinone (81 mg, 0.75 mmol) were mixed in AcOH (3 mL) in a 4 mL vial equipped with a magnetic stir bar. The reaction was capped and stirred at 60 °C for 3 h. Solvent was then evaporated under vacuum at 45 °C. The crude residue was purified by silica gel chromatography using a gradient of hexanes (with 2% AcOH) and acetone from 100:0 to 80:20 to afford 196 mg (86%) of **29** as a light yellow solid.

^{1}H NMR (500 MHz, CD_3OD) δ 8.59 (s, 1H), 7.30 (d, *J* = 15.8 Hz, 1H), 7.02 (s, 1H), 6.67 (d, *J* = 3.3 Hz, 1H), 6.42 (d, *J* = 3.3 Hz, 1H), 6.17 (d, *J* = 15.7 Hz, 1H), 4.57 (s, 2H), 1.50 (s, 9H).

^{13}C NMR (126 MHz, CD_3OD) δ 170.28, 168.01, 155.61, 154.26, 152.03, 138.33, 135.32, 131.35, 127.84, 118.06, 116.91, 114.70, 111.16, 109.92, 81.74, 40.68, 28.41.

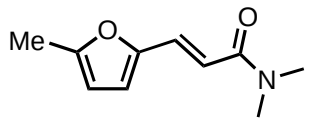
HRMS calc'd for [$C_{19}H_{22}ClN_2O_7S^+$] (M+H) 457.0831; found 457.0825.



31

methyl (*E*)-3-(5-methylfuran-2-yl)acrylate (31). The general procedure **B** was followed with methyl acrylate. The crude product was purified by silica gel chromatography (20:1 hexanes:ethyl acetate) to give 40 mg (96%) of **31** as a clear liquid. NMR spectroscopic data agree with literature values.[10]

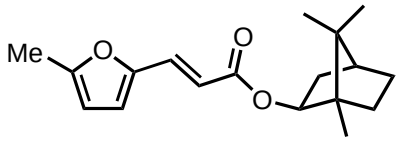
^{1}H NMR (500 MHz, $CDCl_3$) δ 7.36 (d, *J* = 15.7 Hz, 1H), 6.50 (d, *J* = 3.2 Hz, 1H), 6.23 (d, *J* = 15.6 Hz, 1H), 6.10- 6.05 (m, 1H), 3.77 (s, 3H), 2.35 (s, 3H).



32

(*E*)-*N*,*N*-dimethyl-3-(5-methylfuran-2-yl)acrylamide (32). The general procedure **B** was followed with *N*,*N*-dimethylacrylamide. The crude product was purified by silica gel chromatography (2:3 hexanes:ethyl acetate) to give 34 mg (75%) of **32** as a white solid. NMR spectroscopic data agree with literature values.[11]

^{1}H NMR (500 MHz, $CDCl_3$) δ 7.38 (d, *J* = 15.0 Hz, 1H), 6.71 (d, *J* = 15.3 Hz, 1H), 6.43 (d, *J* = 3.2 Hz, 1H), 6.07-6.01 (m, 1H), 3.16 (s, 3H), 3.06 (s, 3H), 2.35 (s, 3H).



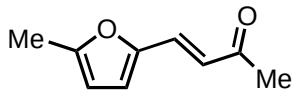
33

isobornyl (*E*)-3-(5-methylfuran-2-yl)acrylate (33). The general procedure **B** was followed with isobornyl acrylate that was distilled from technical grade commercial reagent. Two parallel reactions (0.25 mmol each) were combined for isolation. The crude product was purified by silica gel chromatography (20:1 hexanes:ethyl acetate) to give 65.5 mg (46%) of **33** as a colorless oil.

^{1}H NMR (500 MHz, $CDCl_3$) δ 7.30 (d, *J* = 15.6 Hz, 1H), 6.49 (d, *J* = 3.3 Hz, 1H), 6.21 (d, *J* = 15.6 Hz, 1H), 6.07 (dd, *J* = 3.2, 1.2 Hz, 1H), 4.77 (dd, *J* = 7.7, 4.0 Hz, 1H), 2.34 (s, 3H), 1.92-1.51 (m, 6H), 1.22-1.07 (m, 2H), 1.04 (s, 3H), 0.87 (s, 3H), 0.85 (s, 3H).

^{13}C NMR (126 MHz, $CDCl_3$) δ 166.91, 155.29, 149.61, 130.70, 116.23, 114.65, 108.76, 80.85, 48.86, 46.98, 45.08, 38.90, 33.76, 27.09, 20.17, 20.02, 13.91, 11.49.

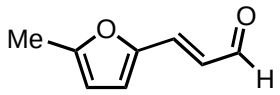
HRMS calc'd for [$C_{18}H_{25}O_3^+$] (M+H): 289.1798, found: 289.1801.



34

(*E*)-4-(5-methylfuran-2-yl)but-3-en-2-one (34). The general procedure **B** was followed with methyl vinyl ketone that was distilled from 90% (technical grade) methyl vinyl ketone. The crude product was purified by silica gel chromatography (20:1 hexanes:ethyl acetate) to give 35 mg (92%) of **34** as a slightly red liquid. NMR spectroscopic data agree with literature values.[12]

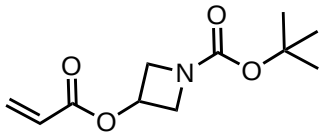
^{1}H NMR (500 MHz, $CDCl_3$) δ 7.21 (d, *J* = 15.8 Hz, 1H), 6.56 (d, *J* = 2.3 Hz, 1H), 6.55 (d, *J* = 21.7 Hz, 0H), 6.10 (dt, *J* = 3.4, 0.9 Hz, 1H), 2.36 (s, 3H), 2.31 (s, 3H).



35

(*E*)-3-(5-methylfuran-2-yl)acrylaldehyde (35). The general procedure **B** was followed with acrolein that was distilled from 90% (technical grade) acrolein. The crude product was purified by silica gel chromatography (20:1 hexanes:ethyl acetate) to give 25 mg (74%) of **35** as a slightly red liquid. NMR spectroscopic data agree with literature values.[12]

^{1}H NMR (500 MHz, $CDCl_3$) δ 9.58 (d, *J* = 8.0 Hz, 1H), 7.13 (d, *J* = 15.5 Hz, 1H), 6.67 (d, *J* = 3.3 Hz, 1H), 6.51 (dd, *J* = 15.5, 8.0 Hz, 1H), 6.19- 6.08 (m, 1H), 2.38 (s, 3H).

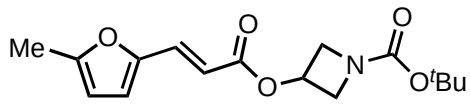


***tert*-butyl 3-{(acryloyloxy)methyl}azetidine-1-carboxylate.** To a stirred solution of 1-BOC-3-azetidinemethanol (4.7 g, 25 mmol) and triethylamine (3.9 mL, 28 mmol) in dichloromethane (20 mL) was slowly added acryloyl chloride (2.3 mL, 28 mmol) at 0 ^{o}C. The reaction was stirred at 0 ^{o}C for 0.5 h, then removed from the ice bath and stirred for another 8 h at room temperature. Brine (100 mL) was added and extracted with dichloromethane (100 mL ×3). The combined organic layers were dried with $MgSO_4$ then solvent was removed under vacuum. The crude product was then purified by column chromatography (hexane:ethyl acetate from 100:0 to 0:100 with gradient method) to give 4.82 g (71%) of the desired product as a light yellow oil .

^{1}H NMR (500 MHz, $CDCl_3$) δ 6.41 (dd, *J* = 17.5 Hz 1.5 Hz, 1H), 6.11 (dd, *J* = 17.5 Hz, 10.5 Hz, 1H), 5.84 (dd, *J* = 10.5 Hz, 1.0 Hz, 1H), 4.28 (d, *J* = 6.5 Hz, 2H), 4.01 (t, *J* = 8.5 Hz, 2H), 3.70 (dd, *J* = 8.5 Hz, 5.0 Hz, 2H), 2.81-2.90 (m, 1H), 1.42 (s, 10H).

^{13}C NMR (125 MHz, $CDCl_3$) δ 166.01, 156.25, 131.29, 127.96, 79.48, 65.60, 51.93, 50.91, 28.34, 27.64.

HRMS calc'd for [$C_8H_{12}NO_4^+$] (M-^{t}Bu+H) 186.0761; found 186.0758.



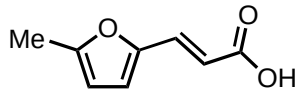
36

***tert*-butyl (*E*)-3-[{(3-(5-methylfuran-2-yl)acryloyl)oxy}methyl]azetidine-1-carboxylate** (**36**). The general procedure **B** was followed with 1-BOC-3-((acryloyloxy)methyl)azetidine (1.2 equiv). The crude residue was purified by silica gel chromatography using a gradient of hexanes/NEt_3 (97:3) and ethyl acetate from 100:0 to 0:100 to afford 45 mg (56%) of **36** as colorless liquid.

^{1}H NMR (500 MHz, $CDCl_3$) δ 7.35 (d, *J* = 16.0 Hz, 1H), 6.51 (d, *J* = 3.5 Hz, 1H), 6.22 (d, *J* = 16.0 Hz, 1H), 6.07 (d, *J* = 3.5 Hz, 1H), 4.29 (d, *J* = 7.0 Hz, 2H), 4.02 (t, *J* = 8.5 Hz, 2H), 3.73 (dd, *J* = 8.5, 5.0 Hz, 2H), 2.82-2.93 (m, 1H), 2.33 (s, 3H), 1.43 (s, 9H).

^{13}C NMR (125 MHz, $CDCl_3$) δ 167.18, 156.28, 155.66, 149.34, 131.60, 116.87, 113.13, 108.87, 79.44, 65.37, 51.94, 50.97, 28.35, 27.77, 13.88.

HRMS calc'd for [$C_{13}H_{16}NO_5^+$] (M-O^{t}Bu+H) 266.1023; found 266.1017.



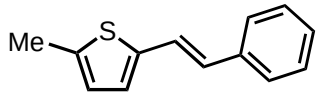
37

(*E*)-3-(5-methylfuran-2-yl)acrylaldehyde (37). The general procedure **B** was followed with acrylic acid and 3 mol% of $Pd(OAc)_2$/**L7**. Two parallel reactions (0.25 mmol scale) were combined for isolation. The crude product was purified by silica gel chromatography using a gradient of hexanes and ethyl acetate from 100:0 to 90:10 to afford 64.5 mg (85%) of **37** as a light yellow solid.

^{1}H NMR (500 MHz, $CDCl_3$) δ 7.45 (d, *J* = 15.5 Hz, 1H), 6.57 (d, *J* = 3.3 Hz, 1H), 6.22 (d, *J* = 15.5 Hz, 1H), 6.10 (dd, *J* = 3.3, 1.0 Hz, 1H), 2.36 (s, 3H).

^{13}C NMR (126 MHz, $CDCl_3$) δ 172.86, 156.35, 149.42, 133.22, 117.79, 112.99, 109.23, 14.11.

HRMS calc'd for [$C_8H_9O_3^+$] (M+H): 153.0546, found: 153.0547.



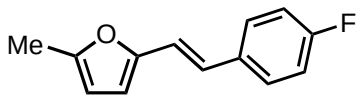
38

(*E*)-2-methyl-5-styrylthiophene (38). Catalyst stock solution was prepared by mixing $Pd(OAc)_2$ (0.025 mmol, 5.6 mg), **L15** (0.025 mmol, 4.8 mg) and HBF_4•Et_2O (0.050 mmol, 6.8 μL) in 15 mL AcOH. In a 20 mL vial, 2-methylthiophene (48.4 μl, 0.50 mmol), styrene (115 μl, 1.00 mmol), benzoquinone (81 mg, 0.75 mmol), 1,3,5-tris(trifluoromethyl)benzene (31.0 μl, 0.167 mmol) were mixed with 3.0 mL THF, and 3.0 mL of the catalyst stock solution was then added. The vial was capped and heated to 40 ^oC for 18 h. After completion of reaction, the crude was transferred to a separatory funnel that contained 100 mL saturated Na_2CO_3 aqueous solution and 100 mL EtOAc. The organic layer was retained and washed with saturated Na_2CO_3 aqueous solution (50 mL × 2). The combined aqueous phase was back extracted with EtOAc (50 mL × 2). Then, the organic layer was combined and dried over anhydrous Na_2SO_4 for 30 min. The solvent was removed by evaporating under vacuum at 45 ^oC. The crude was purified by flash chromatography (EtOAc/Hexane (contains 1% Et_3N) from 0% to 5% with gradient method) to give 88 mg (88%) of **38** as a white solid.

^1H NMR (500 MHz, $CDCl_3$) δ 7.47 (d, J = 7.3 Hz, 2H), 7.36 (t, J = 7.6 Hz, 2H), 7.28 – 7.23 (m, 1H), 7.18 (d, J = 16.0 Hz, 1H), 6.88 (d, J = 3.5 Hz, 1H), 6.82 (d, J = 16.0 Hz, 1H), 6.67 (dd, J = 3.3, 1.3 Hz, 1H), 2.51 (s, 3H).

^{13}C NMR (126 MHz, $CDCl_3$) δ 140.95, 139.39, 137.30, 128.77, 127.42, 127.15, 126.53, 126.26, 125.88, 122.28, 15.77.

HRMS calc'd for [$C_{13}H_{13}S^+$] ($M+H^+$): 201.0732, found: 201.0731.

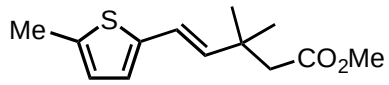


39

(*E*)-2-(4-fluorostyryl)-5-methylfuran (39). The general procedure **B** was followed with 4-fluorostyrene. The crude product was purified by silica gel chromatography (20:1 hexanes:ethyl acetate) to give 24 mg (48%) of **39** as a white solid. NMR spectroscopic data agree with literature values.[13]

^{1}H NMR (500 MHz, $CDCl_3$) δ 7.44-7.38 (m, 2H), 7.02 (t, *J* = 8.7 Hz, 2H), 6.91 (d, *J* = 16.2 Hz, 1H), 6.74 (d, *J* = 16.2 Hz, 1H), 6.22 (d, *J* = 3.1 Hz, 1H), 6.01 (dt, *J* = 3.3, 1.0 Hz, 1H), 2.35 (s, 3H).

^{19}F NMR (376 MHz, $CDCl_3$) δ -115.22.



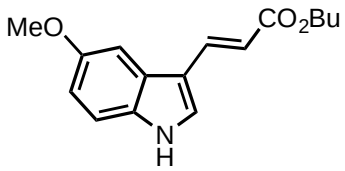
40

methyl (*E*)-3,3-dimethyl-5-(5-methylthiophen-2-yl)pent-4-enoate (40). Catalyst stock solution was prepared by mixing $Pd(OAc)_2$ (0.025 mmol, 5.6 mg) and **L15** (0.025 mmol, 4.8 mg) in 15 mL AcOH. In a 20 mL vial, 2-methylthiophene (48.4 μl, 0.50 mmol), methyl 3,3-dimethylpent-4-enoate (158 μl, 1.00 mmol), benzoquinone (81 mg, 0.75 mmol), 1,3,5-tris(trifluoromethyl)benzene (31.0 μl, 0.167 mmol) were mixed with 3.0 mL AcOH, and 3.0 mL of the catalyst stock solution was then added. The vial was capped and heated to 40 ^{o}C for 18 h. After completion of reaction, the crude was transferred to a separatory funnel that contained 100 mL saturated Na_2CO_3 aqueous solution and 100 mL EtOAc. The organic layer was retained and washed with saturated Na_2CO_3 aqueous solution (50 mL × 2). The combined aqueous phase was back extracted with EtOAc (50 mL × 2). Then, the organic layer was combined and dried over anhydrous Na_2SO_4 for 30 min. The solvent was removed by evaporating under vacuum at 45 ^{o}C. The crude was purified by flash chromatography (EtOAc/Hexane (contains 1% Et_3N) from 0% to 5% with gradient method) to give 94 mg (79%) of **40** as a colorless oil.

^{1}H NMR (500 MHz, $CDCl_3$) δ 6.67 (d, J = 3.4 Hz, 1H), 6.60 – 6.54 (m, 1H), 6.38 (d, J = 16.0 Hz, 1H), 6.00 (d, J = 16.0 Hz, 1H), 3.63 (s, 3H), 2.43 (d, J = 1.1 Hz, 3H), 2.36 (s, 2H), 1.21 (s, 6H).

^{13}C NMR (126 MHz, $CDCl_3$) 172.14, 140.93, 138.26, 137.37, 125.42, 125.07, 120.18, 51.40, 47.09, 35.91, 27.41, 15.64.

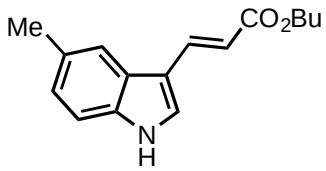
HRMS calc'd for [$C_{13}H_{19}O_2S^+$] ($M+H^+$): 239.1100, found: 239.1100.



41

butyl (*E*)-3-(5-methoxy-1*H*-indol-3-yl)acrylate (41). The general procedure **C** was followed with 5-methoxy-1*H*-indole and butyl acrylate. The reaction time was 2 h. The crude residue was purified by silica gel chromatography using a gradient of hexanes and ethyl acetate from 100:0 to 70:30 to afford 120 mg (88%) of **41** as yellow oil. NMR spectroscopic data agree with literature values.[14]

^{1}H NMR (500 MHz, $CDCl_3$) δ 8.49 (br, 1H), 7.91 (d, *J* = 15.9 Hz, 1H), 7.46 (d, *J* = 2.8 Hz, 1H), 7.33 (d, *J* = 2.4 Hz, 1H), 7.30 (d, *J* = 8.9 Hz, 1H), 6.93 (dd, *J* = 8.8, 2.4 Hz, 1H), 6.38 (d, *J* = 16.0 Hz, 1H), 4.23 (t, *J* = 6.7 Hz, 2H), 3.90 (s, 3H), 1.79 – 1.67 (m, 2H), 1.51 – 1.40 (m, 2H), 0.98 (t, *J* = 7.4 Hz, 3H).



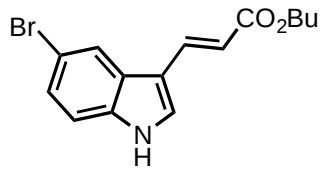
42

butyl (*E*)-3-(5-methyl-1*H*-indol-3-yl)acrylate (42). The general procedure **C** was followed with 5-methyl-1*H*-indole and butyl acrylate. The reaction time was 2 h. The crude residue was purified by silica gel chromatography using a gradient of hexanes and ethyl acetate from 100:0 to 70:30 to afford 115 mg (89%) of **42** as yellow solid.

^{1}H NMR (500 MHz, $CDCl_3$) δ 8.59 (br, 1H), 7.91 (d, *J* = 16.0 Hz, 1H), 7.72 (d, *J* = 1.5 Hz, 1H), 7.43 (d, *J* = 2.8 Hz, 1H), 7.30 (d, *J* = 8.2 Hz, 1H), 7.10 (dd, *J* = 8.3, 1.5 Hz, 1H), 6.46 (d, *J* = 15.9 Hz, 1H), 4.24 (t, *J* = 6.7 Hz, 2H), 2.50 (s, 3H), 1.79 – 1.67 (m, 2H), 1.52 – 1.41 (m, 2H), 0.98 (t, *J* = 7.4 Hz, 3H).

^{13}C NMR (126 MHz, $CDCl_3$) δ 168.73, 138.65, 135.52, 131.14, 129.25, 125.63, 125.00, 120.44, 113.29, 113.10, 111.53, 64.25, 31.06, 21.76, 19.40, 13.95.

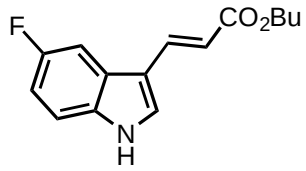
HRMS calc'd for [$C_{16}H_{20}NO_2^+$] (M+H) 258.1489; found 258.1488.



43

butyl (*E*)-3-(5-bromo-1*H*-indol-3-yl)acrylate (43). The general procedure **C** was followed with 5-bromo-1*H*-indole and butyl acrylate. The reaction time was 18 h. The crude residue was purified by silica gel chromatography using a gradient of hexanes and ethyl acetate from 100:0 to 70:30 to afford 117 mg (73%) of **43** as yellow oil. NMR spectroscopic data agree with literature values.[14]

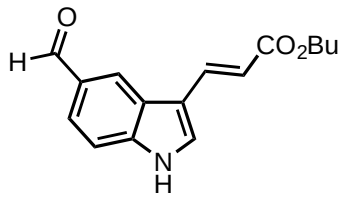
^{1}H NMR (500 MHz, $CDCl_3$) δ 8.83 (br, 1H), 8.00 (d, *J* = 1.8 Hz, 1H), 7.81 (d, *J* = 16.0 Hz, 1H), 7.42 (d, *J* = 2.8 Hz, 1H), 7.32 (dd, *J* = 8.6, 1.8 Hz, 1H), 7.24 (d, *J* = 5.5 Hz, 1H), 6.37 (d, *J* = 16.1 Hz, 1H), 4.20 (t, *J* = 6.7 Hz, 2H), 1.76 – 1.61 (m, 2H), 1.57 – 1.38 (m, 2H), 0.95 (t, *J* = 7.4 Hz, 3H).



44

butyl (*E*)-3-(5-fluoro-1*H*-indol-3-yl)acrylate (44). The general procedure **C** was followed with 5-fluoro-1*H*-indole and butyl acrylate. The reaction time was 3 h. The crude residue was purified by silica gel chromatography using a gradient of hexanes and ethyl acetate from 100:0 to 70:30 to afford 109 mg (83%) of **44** as light yellow solid. NMR spectroscopic data agree with literature values.[14]

^{1}H NMR (500 MHz, $CDCl_3$) δ 8.79 (br, 1H), 7.86 (d, *J* = 16.0 Hz, 1H), 7.55 (dd, *J* = 9.7, 2.5 Hz, 1H), 7.50 (d, *J* = 2.8 Hz, 1H), 7.34 (dd, *J* = 8.8, 4.4 Hz, 1H), 7.02 (td, *J* = 8.9, 2.5 Hz, 1H), 6.38 (d, *J* = 16.1 Hz, 1H), 4.23 (t, *J* = 6.7 Hz, 2H), 1.80 – 1.65 (m, 2H), 1.55 – 1.39 (m, 2H), 0.98 (t, *J* = 7.4 Hz, 3H).



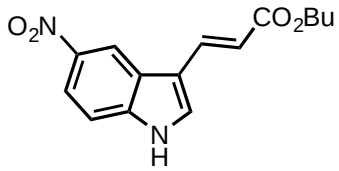
45

butyl (*E*)-3-(5-formyl-1*H*-indol-3-yl)acrylate (45). The general procedure **C** was followed with 5-formyl-1*H*-indole and butyl acrylate. The reaction time was 18 h. The crude residue was purified by silica gel chromatography using a gradient of hexanes and ethyl acetate from 100:0 to 70:30 to afford 84 mg (62%) of **45** as yellow solid.

^{1}H NMR (500 MHz, $CDCl_3$) δ 10.05 (s, 1H), 9.99 (br, 1H), 8.39 (d, *J* = 1.3 Hz, 1H), 7.91 (d, *J* = 16.0 Hz, 1H), 7.80 (dd, *J* = 8.4, 1.4 Hz, 1H), 7.60 (d, *J* = 2.7 Hz, 1H), 7.54 (d, *J* = 8.4 Hz, 1H), 6.52 (d, *J* = 16.0 Hz, 1H), 4.24 (t, *J* = 6.7 Hz, 2H), 1.77 – 1.66 (m, 2H), 1.50 – 1.40 (m, 2H), 0.96 (t, *J* = 7.4 Hz, 3H).

^{13}C NMR (126 MHz, $CDCl_3$) δ 192.84, 168.45, 140.97, 137.43, 130.74, 130.59, 127.79, 125.40, 123.61, 114.75, 114.73, 112.86, 64.55, 30.91, 19.31, 13.86.

HRMS calc'd for [$C_{16}H_{18}NO_3^+$] (M+H) 272.1281; found 272.1275.

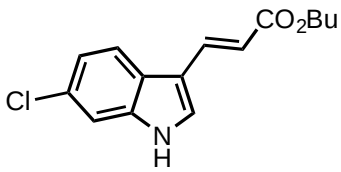


46

butyl (*E*)-3-(5-nitro-1*H*-indol-3-yl)acrylate (46). The general procedure **C** was followed with 5-nitro-1*H*-indole and butyl acrylate. The reaction time was 18 h. The crude residue was purified by silica gel chromatography using a gradient of hexanes and ethyl acetate from 100:0 to 0:100 to afford 114 mg (79%) of **46** as yellow solid. NMR spectroscopic data agree with literature values.[5]

^{1}H NMR (500 MHz, $CDCl_3$) δ 8.95 (br, 1H), 8.86 (d, *J* = 2.1 Hz, 1H), 8.20 (dd, *J* = 9.0, 2.1 Hz, 1H), 7.88 (d, *J* = 16.1 Hz, 1H), 7.65 (d, *J* = 2.7 Hz, 1H), 7.49 (d, *J* = 9.0 Hz, 1H),

6.53 (d, *J* = 16.1 Hz, 1H), 4.25 (t, *J* = 6.7 Hz, 2H), 1.80 – 1.68 (m, 2H), 1.54 – 1.40 (m, 2H), 0.99 (t, *J* = 7.4 Hz, 3H).



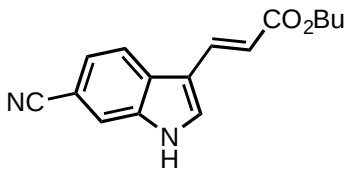
47

butyl (*E*)-3-(6-chloro-1*H*-indol-3-yl)acrylate (47). The general procedure **C** was followed with 6-chloro-1*H*-indole and butyl acrylate. The reaction time was 18 h. The crude residue was purified by silica gel chromatography using a gradient of hexanes and ethyl acetate from 100:0 to 70:30 to afford 119 mg (86%) of **47** as light yellow solid.

^{1}H NMR (500 MHz, $CDCl_3$) δ 8.72 (br, 1H), 7.86 (d, *J* = 16.1 Hz, 1H), 7.81 (d, *J* = 8.5 Hz, 1H), 7.47 (d, *J* = 2.8 Hz, 1H), 7.41 (d, *J* = 1.8 Hz, 1H), 7.21 (dd, *J* = 8.6, 1.9 Hz, 1H), 6.42 (d, *J* = 16.1 Hz, 1H), 4.23 (t, *J* = 6.7 Hz, 2H), 1.79 – 1.63 (m, 2H), 1.58 – 1.39 (m, 2H), 0.97 (t, *J* = 7.4 Hz, 3H).

^{13}C NMR (126 MHz, $CDCl_3$) δ 168.43, 137.72, 137.59, 129.32, 129.27, 124.00, 122.25, 121.41, 114.23, 113.75, 111.91, 64.40, 31.01, 19.38, 13.93.

HRMS calc'd for [$C_{15}H_{17}ClNO_2^+$] (M+H) 278.0942; found 278.0944.



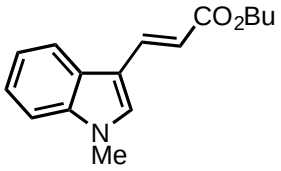
48

butyl (*E*)-3-(6-cyano-1*H*-indol-3-yl)acrylate (48). The general procedure **C** was followed with 1*H*-indole-6-carbonitrile and butyl acrylate. The reaction time was 24 h. The crude residue was purified by silica gel chromatography using a gradient of hexanes and ethyl acetate from 100:0 to 70:30 to afford 71 mg (53%) of **48** as light yellow solid.

^{1}H NMR (500 MHz, $CDCl_3$) δ 9.06 (br, 1H), 7.97 (d, *J* = 8.3 Hz, 1H), 7.88 (d, *J* = 16.0 Hz, 1H), 7.79 (d, *J* = 0.7 Hz, 1H), 7.70 (d, *J* = 2.8 Hz, 1H), 7.48 (dd, *J* = 8.3, 1.4 Hz, 1H), 6.46 (d, *J* = 16.1 Hz, 1H), 4.23 (t, *J* = 6.7 Hz, 2H), 1.77 – 1.64 (m, 2H), 1.52 – 1.39 (m, 2H), 0.97 (t, *J* = 7.4 Hz, 3H).

^{13}C NMR (126 MHz, $CDCl_3$) δ 168.04, 136.68, 136.00, 131.23, 128.66, 124.41, 121.28, 120.09, 116.72, 115.49, 114.14, 106.00, 64.54, 30.98, 19.38, 13.93.

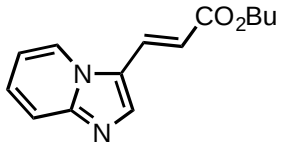
HRMS calc'd for [$C_{16}H_{17}N_2O_2^+$] (M+H) 269.1285; found 269.1266.



49

butyl (*E*)-3-(1-methyl-1*H*-indol-3-yl)acrylate (49). The general procedure **C** was followed with 1-methyl-1*H*-indole and butyl acrylate. The reaction time was 6 h. The crude residue was purified by silica gel chromatography using a gradient of hexanes and ethyl acetate from 100:0 to 70:30 to afford 113 mg (88%) of **49** as yellow solid. NMR spectroscopic data agree with literature values.[5]

^{1}H NMR (500 MHz, $CDCl_3$) δ 7.85 (d, *J* = 7.9 Hz, 1H), 7.82 (d, *J* = 15.9 Hz, 1H), 7.33 – 7.13 (m, 4H), 6.35 (d, *J* = 16.0 Hz, 1H), 4.14 (t, *J* = 6.7 Hz, 2H), 3.73 (s, 3H), 1.76 – 1.59 (m, 2H), 1.49 – 1.31 (m, 2H), 0.91 (t, *J* = 7.4 Hz, 3H).



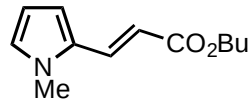
50

butyl (*E*)-3-(imidazo[1,2-*a*]pyridin-3-yl)acrylate (50). The general procedure **C** was followed with imidazo[1,2-*a*]pyridine and butyl acrylate. The reaction time was 24 h. The crude residue was purified by silica gel chromatography using a gradient of dichloromethane and methanol from 100:0 to 90:10 to afford 49 mg (40%) **50** as yellow solid.

^{1}H NMR (500 MHz, $CDCl_3$) δ 8.30 (d, *J* = 6.9, 1H), 8.03 (s, 1H), 7.86 (d, *J* = 15.9 Hz, 1H), 7.68 (d, *J* = 9.0, 1H), 7.30 (ddd, *J* = 9.0, 6.8, 1.2 Hz, 1H), 6.98 (td, *J* = 6.8, 1.0 Hz, 1H), 6.40 (d, *J* = 15.9 Hz, 1H), 4.22 (t, *J* = 6.7 Hz, 2H), 1.83 – 1.60 (m, 2H), 1.50 – 1.28 (m, 2H), 0.96 (t, *J* = 7.4 Hz, 3H).

^{13}C NMR (126 MHz, $CDCl_3$) δ 167.42, 148.08, 137.18, 128.54, 126.15, 124.23, 121.82, 118.67, 114.27, 114.03, 64.66, 30.92, 19.32, 13.89.

HRMS calc'd for [$C_{14}H_{17}N_2O_2^+$] (M+H) 245.1285; found 245.1281.



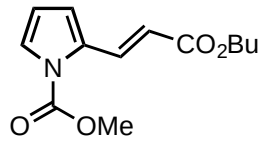
51

butyl (*E*)-3-(1-methyl-1*H*-pyrrol-2-yl)acrylate (51). The general procedure **C** was followed with methyl 1-methyl-1*H*-pyrrole and butyl acrylate. The reaction time was 18 h. The crude residue was purified by silica gel chromatography using a gradient of hexanes and ethyl acetate from 100:0 to 70:30 to afford 65 mg (62%) **51** as yellow oil.

^{1}H NMR (500 MHz, $CDCl_3$) δ 7.59 (d, *J* = 15.7 Hz, 1H), 6.77 – 6.70 (m, 1H), 6.66 (dd, *J* = 4.0, 1.6 Hz, 1H), 6.19 – 6.12 (m, 2H), 4.18 (t, *J* = 6.7 Hz, 2H), 3.71 (s, 3H), 1.74 – 1.60 (m, 2H), 1.51 – 1.40 (m, 2H), 0.96 (t, *J* = 7.4 Hz, 3H).

^{13}C NMR (126 MHz, $CDCl_3$) δ 168.08, 132.35, 129.41, 126.98, 112.82, 111.99, 109.42, 64.25, 34.54, 30.97, 19.33, 13.90.

HRMS calc'd for [$C_{12}H_{18}NO_2^+$] (M+H) 208.1332; found 208.1338.



52

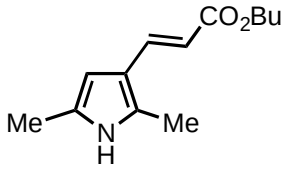
methyl (*E*)-2-(3-butoxy-3-oxoprop-1-en-1-yl)-1*H*-pyrrole-1-carboxylate (52). The general procedure **C** was followed with methyl 1*H*-pyrrole-1-carboxylate and butyl acrylate. The reaction time was 18 h. The crude residue was purified by silica gel

chromatography using a gradient of hexanes and ethyl acetate from 100:0 to 70:30 to afford 74 mg (59%) **52** as yellow oil.

^{1}H NMR (500 MHz, $CDCl_3$) δ 8.28 (d, *J* = 15.9 Hz, 1H), 7.40 (dd, *J* = 3.3, 1.6 Hz, 1H), 6.72 (ddd, *J* = 3.6, 1.6, 0.8 Hz, 1H), 6.33 – 6.19 (m, 2H), 4.18 (t, *J* = 6.7 Hz, 2H), 3.99 (s, 3H), 1.72 – 1.63 (m, 2H), 1.54 – 1.34 (m, 2H), 0.95 (t, *J* = 7.4 Hz, 3H).

^{13}C NMR (126 MHz, $CDCl_3$) δ 167.22, 151.08, 134.27, 131.61, 124.71, 117.30, 115.16, 112.29, 64.40, 54.44, 30.91, 19.32, 13.89.

HRMS calc'd for [$C_{13}H_{18}NO_4^+$] (M+H) 252.1230; found 252.1222.



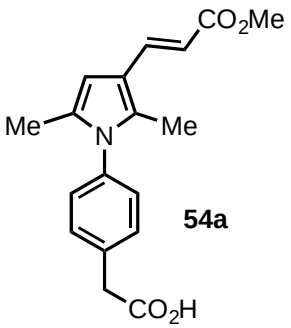
53

butyl (*E*)-3-(2,5-dimethyl-1*H*-pyrrol-3-yl)acrylate (53). The general procedure **C** was followed with 2,5-dimethyl-1*H*-pyrrole and butyl acrylate. The reaction time was 2 h. The crude residue was purified by silica gel chromatography using a gradient of hexanes and ethyl acetate from 100:0 to 70:30 to afford 65 mg (59%) **53** as light yellow solid.

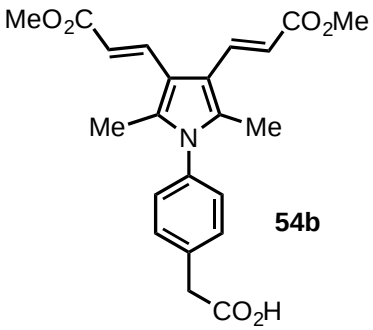
^{1}H NMR (500 MHz, $CDCl_3$) δ 8.02 (br, 1H), 7.63 (d, *J* = 15.5 Hz, 1H), 6.02 (d, *J* = 1.2 Hz, 1H), 5.96 (d, *J* = 15.5 Hz, 1H), 4.16 (t, *J* = 6.7 Hz, 2H), 2.29 (s, 3H), 2.20 (d, *J* = 1.0 Hz, 3H), 1.74 – 1.61 (m, 2H), 1.53 – 1.32 (m, 2H), 0.95 (t, *J* = 7.4 Hz, 3H).

^{13}C NMR (126 MHz, $CDCl_3$) δ 168.87, 138.14, 130.95, 128.02, 117.09, 111.13, 103.77, 63.94, 31.03, 19.35, 13.91, 12.93, 11.25.

HRMS calc'd for [$C_{13}H_{20}NO_2^+$] (M+H) 222.1489; found 222.1497.



54a



54b

2-(4-(2,5-dimethyl-1*H*-pyrrol-1-yl)phenyl)acetic acid (183 mg, 0.800 mmol), methyl acrylate (0.14 mL, 1.6 mmol), palladium acetate (5.4 mg, 24 μmol), **L14** (23 mg, 80 μmol), *p*-toluenesulfonic acid monohydrate (15 mg, 80 μmol), and copper(II) acetate (291 mg, 1.60 mmol) were mixed in DMF (5.0 mL) under air in a 50 mL round bottom flask equipped with a magnetic stir bar. The reaction was then sealed and stirred at 70 ^{o}C for 2 h. After cooling to room temperature, the crude was partitioned between water (30 mL) and ethyl acetate (30 mL) then filtered through a plug of Celite. The layers were separated and the organic layer was washed with brine (30 mL × 2) then dried over Na_2SO_4. Solvent was removed by evaporating under reduced pressure at 45 ^{o}C, and the crude residue was purified by silica gel chromatography using a gradient of hexanes (with 2% AcOH) and ethyl acetate from 100:0 to 50:50 to afford 165 mg (66%) of **54a** as light yellow solid and separately 49 mg (15%) of **54b** as yellow solid.

(*E*)-2-(4-(3-(3-(tert-butoxy)-3-oxoprop-1-en-1-yl)-2,5-dimethyl-1*H*-pyrrol-1-yl)phenyl)acetic acid (54a).

^{1}H NMR (500 MHz, $CDCl_3$) δ 7.71 (d, *J* = 15.5 Hz, 1H), 7.42 (d, *J* = 8.2 Hz, 2H), 7.15 (d, *J* = 8.3 Hz, 2H), 6.19 (s, 1H), 6.04 (d, *J* = 15.5 Hz, 1H), 3.77 (s, 3H), 3.74 (s, 2H), 2.08 (s, 3H), 1.99 (s, 3H).

^{13}C NMR (126 MHz, $CDCl_3$) δ 176.46, 169.11, 138.42, 137.16, 133.72, 133.29, 131.04, 130.55, 128.37, 116.89, 111.06, 104.07, 51.46, 40.59, 12.97, 11.06.

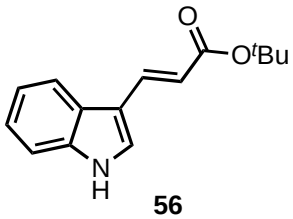
HRMS calc'd for [$C_{18}H_{20}NO_4^+$] (M+H) 314.1387; found 314.1388.

2-(4-(3,4-bis((*E*)-3-(tert-butoxy)-3-oxoprop-1-en-1-yl)-2,5-dimethyl-1*H*-pyrrol-1-yl)phenyl)acetic acid (54b).

^{1}H NMR (500 MHz, $CDCl_3$) δ 7.83 (d, *J* = 16.0 Hz, 2H), 7.45 (d, *J* = 8.2 Hz, 2H), 7.15 (d, *J* = 8.3 Hz, 2H), 6.03 (d, *J* = 16.0 Hz, 2H), 3.79 (s, 6H), 3.75 (s, 2H), 2.09 (s, 6H).

^{13}C NMR (126 MHz, $CDCl_3$) δ 176.32, 168.44, 138.25, 136.39, 134.47, 132.35, 130.82, 128.39, 116.17, 115.89, 51.67, 40.61, 12.24.

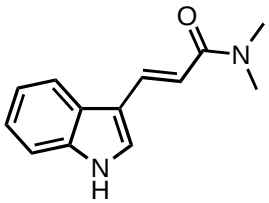
HRMS calc'd for [$C_{22}H_{24}NO_6^+$] (M+H) 398.1598; found 398.1600.



56

***tert*-butyl (*E*)-3-(1*H*-indol-3-yl)acrylate (56).** The general procedure **C** was followed with 1*H*-indole and *tert*-butyl acrylate. The reaction time was 2 h. The crude residue was purified by silica gel chromatography using a gradient of hexanes and ethyl acetate from 100:0 to 70:30 to afford 106 mg (87%) of **56** as yellow solid. NMR spectroscopic data agree with literature values.[5]

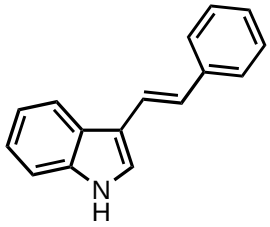
^{1}H NMR (500 MHz, $CDCl_3$) δ 8.63 (br, 1H), 7.92 (d, *J* = 7.1 Hz, 1H), 7.84 (d, *J* = 15.9 Hz, 1H), 7.45 (d, *J* = 2.8 Hz, 1H), 7.41 (d, *J* = 7.1 Hz, 1H), 7.31 – 7.21 (m, 2H), 6.41 (d, *J* = 16.0 Hz, 1H), 1.57 (s, 9H).



57

(*E*)-3-(1*H*-indol-3-yl)-*N*,*N*-dimethylacrylamide (57). The general procedure **C** was followed with 1*H*-indole and *N*,*N*-dimethylacrylamide. The reaction was run for 2 h. The crude residue was purified by silica gel chromatography using a gradient of dichloromethane and methanol from 100:0 to 90:10 to afford 95 mg (89%) of **57** as light brown solid. NMR spectroscopic data agree with literature values.[5]

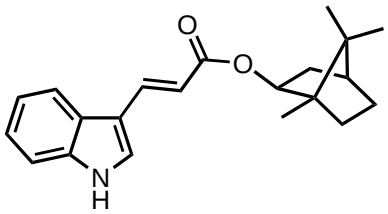
^{1}H NMR (500 MHz, $CDCl_3$) δ 9.81 (s, 1H), 7.93 (d, *J* = 15.2 Hz, 1H), 7.88 – 7.84 (m, 1H), 7.46 – 7.41 (m, 1H), 7.39 (d, *J* = 2.4 Hz, 1H), 7.25 – 7.19 (m, 2H), 6.91 (d, *J* = 15.3 Hz, 1H), 3.22 (s, 3H), 3.12 (s, 3H).



58

(*E*)-3-styryl-1*H*-indole (58). The general procedure **C** was followed with 1*H*-indole and styrene. The reaction was run for 2 h. The crude residue was purified by silica gel chromatography using a gradient of hexanes and ethyl acetate from 100:0 to 70:30 to afford 66 mg (60%) of **58** as light yellow solid. NMR spectroscopic data agree with literature values.[5]

^{1}H NMR (500 MHz, $CDCl_3$) δ 8.18 (br, 1H), 8.01 (d, *J* = 6.9 Hz, 1H), 7.53 (d, *J* = 7.1 Hz, 2H), 7.44 – 7.30 (m, 6H), 7.26 – 7.19 (m, 2H), 7.15 (d, *J* = 16.4 Hz, 1H).



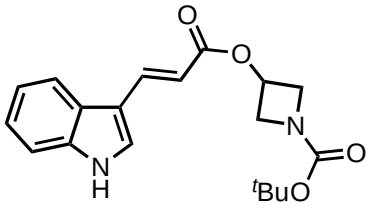
59

isobornyl (*E*)-3-(1*H*-indol-3-yl)acrylate (59). The general procedure **C** was followed with 1*H*-indole and isobornyl acrylate. The reaction time was 2 h. The crude residue was purified by silica gel chromatography using a gradient of hexanes and ethyl acetate from 100:0 to 0:100 to afford 135 mg (83%) **59** as light yellow sticky oil.

^{1}H NMR (500 MHz, $CDCl_3$) δ 8.78 (br, 1H), 7.94 – 7.85 (m, 2H), 7.47 (d, *J* = 2.8 Hz, 1H), 7.42 (dd, *J* = 7.9, 1.5 Hz, 1H), 7.34 – 7.20 (m, 2H), 6.44 (d, *J* = 15.9 Hz, 1H), 4.85 (t, *J* = 5.8 Hz, 1H), 1.94 – 1.84 (m, 2H), 1.81 – 1.68 (m, 2H), 1.59 (td, *J* = 12.2, 4.1 Hz, 1H), 1.22 (ddd, *J* = 13.0, 9.4, 4.0 Hz, 1H), 1.17 – 1.07 (m, 4H), 0.94 (s, 3H), 0.88 (s, 3H).

^{13}C NMR (126 MHz, $CDCl_3$) δ 168.11, 137.98, 137.20, 128.79, 125.44, 123.40, 121.55, 120.50, 114.10, 113.64, 111.94, 80.85, 49.03, 47.13, 45.23, 39.08, 33.93, 27.24, 20.32, 20.23, 11.71.

HRMS calc'd for [$C_{21}H_{26}NO_2^+$] (M+H) 324.1958; found 324.1951.



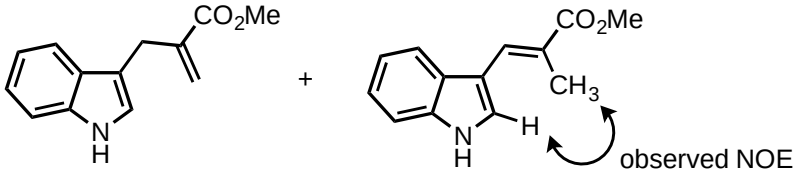
60

***tert*-butyl (*E*)-3-[{(3-(1*H*-indol-3-yl)acryloyl)oxy}methyl]azetidine-1-carboxylate (60).** The general procedure **C** was followed with 1*H*-indole and 1.5 equiv of *tert*-butyl 3-((acryloyloxy)methyl)azetidine-1-carboxylate. The reaction was run for 2 h. The crude residue was purified by silica gel chromatography using a gradient of hexanes and ethyl acetate from 100:0 to 0:100 to afford 147 mg (83%) **60** as yellow oil.

^{1}H NMR (500 MHz, $CDCl_3$) δ 8.91 (br, 1H), 8.02 – 7.86 (m, 2H), 7.48 (d, *J* = 2.8 Hz, 1H), 7.46 – 7.39 (m, 1H), 7.31 – 7.23 (m, 2H), 6.45 (d, *J* = 15.9 Hz, 1H), 4.34 (d, *J* = 6.6 Hz, 2H), 4.07 (t, *J* = 8.6 Hz, 2H), 3.78 (dd, *J* = 8.8, 5.3 Hz, 2H), 2.97 – 2.83 (m, 1H), 1.46 (s, 9H).

^{13}C NMR (126 MHz, $CDCl_3$) δ 168.30, 156.58, 139.20, 137.28, 129.44, 125.36, 123.49, 121.69, 120.61, 113.57, 112.54, 112.00, 79.74, 65.42, 52.09, 51.17, 28.55, 28.03.

HRMS calc'd for [$C_{20}H_{25}N_2O_4^+$] (M+H) 357.1809; found 357.1800.



61a **61b**

The general procedure **C** was followed with 1*H*-indole and methyl methacrylate. The reaction was run for 2 h. The crude residue was purified by silica gel chromatography

using a gradient of hexanes and ethyl acetate from 100:0 to 70:30 to afford 31 mg (29%) **61a** as yellow oil and separately 41 mg (38%) of **61b** as light gray solid. The *Z*/*E* configuration was confirmed by NOESY NMR.

methyl 2-((1*H*-indol-3-yl)methyl)acrylate (61a).

^{1}H NMR (500 MHz, $CDCl_3$) δ 8.03 (br, 1H), 7.54 (d, *J* = 7.9 Hz, 1H), 7.37 (d, *J* = 8.1 Hz, 1H), 7.20 (ddd, *J* = 8.1, 6.9, 1.2 Hz, 1H), 7.11 (ddd, *J* = 8.0, 7.1, 1.0 Hz, 1H), 7.04 (d, *J* = 2.5 Hz, 1H), 6.21 (d, *J* = 1.2 Hz, 1H), 5.50 (d, *J* = 1.6 Hz, 1H), 3.79 (s, 2H), 3.77 (s, 3H).

^{13}C NMR (126 MHz, $CDCl_3$) δ 167.95, 139.57, 136.46, 127.42, 125.75, 122.93, 122.13, 119.51, 119.23, 112.99, 111.26, 52.02, 27.75.

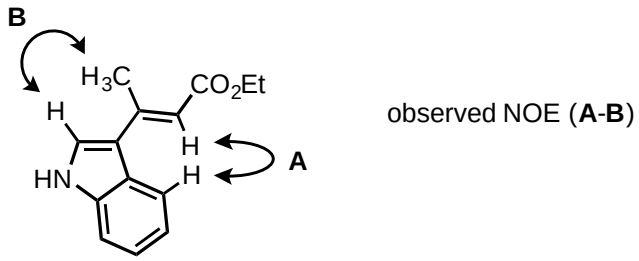
HRMS calc'd for [$C_{13}H_{14}NO_2^+$] (M+H) 216.1019; found 216.1019.

methyl (*E*)-3-(1*H*-indol-3-yl)-2-methylacrylate (61b).

^{1}H NMR (500 MHz, $CDCl_3$) δ 8.60 (br, 1H), 8.06 (s, 1H), 7.83 (d, *J* = 7.8 Hz, 1H), 7.51 (d, *J* = 2.7 Hz, 1H), 7.42 (d, *J* = 8.1 Hz, 1H), 7.32 – 7.18 (m, 2H), 3.85 (s, 3H), 2.20 (d, *J* = 1.3 Hz, 3H).

^{13}C NMR (126 MHz, $CDCl_3$) δ 169.70, 135.55, 130.37, 127.76, 125.74, 123.27, 123.00, 120.90, 119.07, 113.36, 111.39, 52.08, 15.23.

HRMS calc'd for [$C_{13}H_{14}NO_2^+$] (M+H) 216.1019; found 216.1024.



observed NOE (**A**-**B**)

62

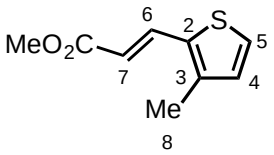
ethyl (*E*)-3-(1*H*-indol-3-yl)but-2-enoate (62). The general procedure **C** was followed with 1*H*-indole and *trans*-ethyl crotonate. The reaction was run for 18 h. The crude residue was purified by silica gel chromatography using a gradient of hexanes and ethyl acetate from 100:0 to 70:30 to afford 74 mg (65%) of **62** as white solid. The *Z*/*E* configuration was confirmed by NOESY experiment.

^{1}H NMR (500 MHz, $CDCl_3$) δ 8.65 (br, 1H), 7.99 (d, *J* = 8.9 Hz, 1H), 7.45 (d, *J* = 2.8 Hz, 1H), 7.40 (dd, *J* = 6.8, 1.4 Hz, 1H), 7.30 – 7.20 (m, 2H), 6.47 (s, 1H), 4.26 (q, *J* = 7.1 Hz, 2H), 2.68 (s, 3H), 1.36 (t, *J* = 7.2 Hz, 3H).

^{13}C NMR (126 MHz, $CDCl_3$) δ 168.12, 150.60, 137.14, 125.83, 125.83, 124.78, 121.23, 121.00, 119.21, 112.97, 111.85, 59.73, 18.41, 14.59.

HRMS calc'd for [$C_{14}H_{16}NO_2^+$] (M+H) 230.1176; found 230.1181.

$J_{4,5}$ = 5.0 Hz



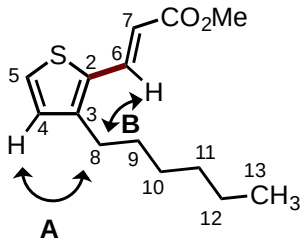
64

methyl (E)-3-(3-methylthiophen-2-yl)acrylate (64). Catalyst stock solution was prepared by mixing $Pd(OAc)_2$ (0.025 mmol, 5.6 mg), **L15** (0.025 mmol, 4.8 mg) and HBF_4•Et_2O (0.050 mmol, 6.8 μL) in 15 mL AcOH. In a 20 mL vial, 3-methylthiophene (1.00 mmol, 97 μL), methyl acrylate (0.50 mmol, 45 μL), 1,3,5-tris(trifluoromethyl)benzene (0.167 mmol, 31 μL), benzoquinone (0.75 mmol, 81 mg) were mixed with 3.0 mL THF, and 3.0 mL of the catalyst stock solution was then added. The vial was capped and heated to 40 ^{o}C for 18 h. After completion of reaction, solvent was removed by evaporating under vacuum at 45 ^{o}C. The crude was purified by flash chromatography (EtOAc/Hexane from 0% to 3% with gradient method) to give 73 mg (80% yield) of **64** as a yellow oil. The NMR data agree with literature values.[15]

^{1}H NMR (500 MHz, $CDCl_3$) δ 7.84 (d, $J_{6,7}$ = 15.6 Hz, 1H, **H_6**), 7.24 (d, $J_{4,5}$ = 5.0 Hz, 1H, **H_5**), 6.85 (d, $J_{4,5}$ = 5.0 Hz, 1H, **H_4**), 6.16 (d, $J_{6,7}$ = 15.6 Hz, 1H, **H_7**), 3.78 (s, 3H, **OMe**), 2.33 (s, 3H, **Me**).

^{13}C NMR (126 MHz, $CDCl_3$) δ 167.64, 141.42, 135.80, 133.65, 131.23, 127.05, 115.57, 51.72, 14.25.

$J_{4,5}$ = 4.9-5.1 Hz



observed NOE (**A**-**B**)

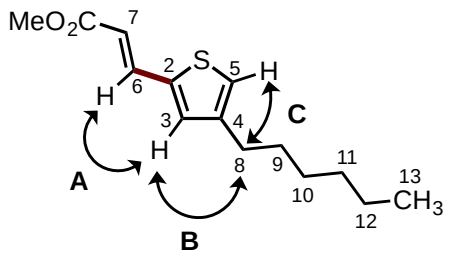
65

methyl (*E*)-3-(3-hexylthiophen-2-yl)acrylate (65). Catalyst stock solution was prepared by mixing $Pd(OAc)_2$ (0.025 mmol, 5.6 mg), **L15** (0.025 mmol, 4.8 mg) and HBF_4•Et_2O (0.050 mmol, 6.8 μL) in 15 mL AcOH. In a 20 mL vial, 3-hexylthiophene (1.00 mmol, 180 μL), methylacrylate (0.50 mmol, 45 μL), 1,3,5-tris(trifluoromethyl)benzene (0.167 mmol, 31 μL), benzoquinone (0.75 mmol, 81 mg) were mixed with 3.0 mL THF, and 3.0 mL of the catalyst stock solution was then added. The vial was capped and heated to 40 ^{o}C for 18 h. After completion of reaction, solvent was removed by evaporating under vacuum at 45 ^{o}C. The crude was purified by flash chromatography (EtOAc/Hexane from 0% to 3% with gradient method) to give 102 mg (80% yield) of **65** as a brown oil.

^{1}H NMR (500 MHz, $CDCl_3$) δ 7.86 (d, $J_{6,7}$ = 15.8 Hz, 1H, **H_6**), 7.26 (d, $J_{4,5}$ = 4.9 Hz, 1H, **H_5**), 6.90 (d, $J_{4,5}$ = 5.1 Hz, 1H, **H_4**), 6.19 (d, $J_{6,7}$ = 15.6 Hz, 1H, **H_7**), 3.79 (s, 3H, **OMe**), 2.70 (t, $J_{8,9}$ = 8.0 Hz, 2H, **H_8**), 1.62 – 1.54 (m, 2H, **H_9**), 1.36 – 1.25 (m, 6H, **H_{10}-H_{12}**), 1.04 – 0.81 (m, 3H, **H_{13}**).

^{13}C NMR (126 MHz, $CDCl_3$) δ 167.75, 146.98, 135.80, 133.46, 130.25, 127.17, 115.61, 51.78, 31.76, 31.22, 29.13, 28.68, 22.72, 14.22.

HRMS calc'd for [$C_{14}H_{21}O_2S^+$] (M+H): 253.1257, found: 253.1256.



observed NOE (**A**-**C**)

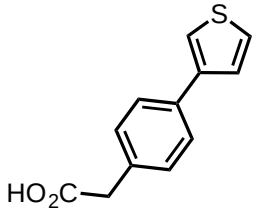
S1

methyl (*E*)-3-(4-hexylthiophen-2-yl)acrylate (S1). Palladium acetate (5.6 mg, 25 μmol) and benzoquinone (81 mg, 0.75 mmol) were dissolved in 6 mL AcOH in a 20 mL vial that was equipped with a magnetic stir bar. Methyl acrylate (45 μL, 0.50 mmol), 3-hexylthiophene (0.45 mL, 2.5 mmol), 1,3,5-tris(trifluoromethyl)benzene (31 μL, 0.167 mmol, as *internal standard*), and pyridine (4.0 μL, 50 μmol) were then added. The vial was capped and heated to 60 ^{o}C for 3 h. After completion of reaction, solvent was removed by evaporating under vacuum at 45 ^{o}C. The crude was purified by flash chromatography (EtOAc/Hexane from 0% to 10% with gradient method) to give 112 mg (89% combined yield) of **S1** as a brown oil. Removal of minor amounts of **65** was not successful by simple flash chromatography.

^{1}H NMR (500 MHz, $CDCl_3$) δ 7.73 (d, $J_{6,7}$ = 15.7 Hz, 1H, **H$_6$**), 7.08 (s, 1H, **H$_3$**), 6.96 (s, 1H, **H$_5$**), 6.20 (d, $J_{6,7}$ = 15.7 Hz, 1H, **H$_7$**), 3.78 (s, 3H, **OMe**), 2.56 (t, $J_{8,9}$ = 7.7 Hz, 2H, **H$_8$**), 1.65 – 1.55 (m, 2H, **H$_9$**), 1.35 – 1.28 (m, 6H, **H$_{10}$-H$_{12}$**), 0.94 – 0.83 (m, 3H, **H$_{13}$**).

^{13}C NMR (126 MHz, $CDCl_3$) δ 167.56, 144.52, 139.24, 137.76, 132.37, 123.54, 116.07, 51.81, 31.77, 30.46, 30.38, 29.04, 22.73, 14.23.

HRMS calc'd for [$C_{14}H_{21}O_2S^+$] (M+H): 253.1257, found: 253.1259.



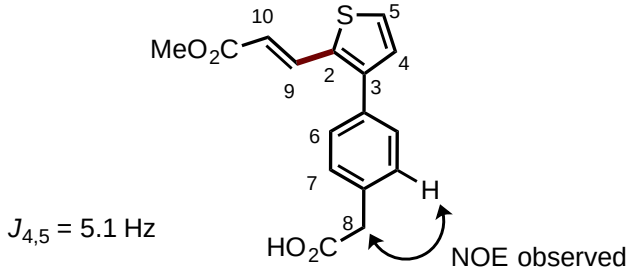
S2

2-(4-(thiophen-3-yl)phenyl)acetic acid (S2). methyl 2-(4-(thiophen-3-yl)phenyl)acetate (500 mg, 2.15 mmol) was dissolved in 30 mL MeOH in a 100 mL round bottom flask. A solution of lithium hydroxide (0.26 g, 11 mmol) in 10 mL water was then added in portions. Reaction was stirred at room temperature for 3 h after which TLC indicated full conversion. The solution was then quenched with 20 mL HCl (1 M) followed by extraction with ether (20 mL × 3). The organic layers were combined and dried over anhydrous magnesium sulfate. Solvent was then evaporated to afford 398 mg (85%) **S2** as white solid.

^{1}H NMR (500 MHz, CD_3OD) δ 7.65 – 7.56 (m, 3H), 7.49 – 7.41 (m, 2H), 7.31 (d, *J* = 8.0 Hz, 2H), 3.65 (s, 2H).

^{13}C NMR (126 MHz, CD_3OD) δ 174.81, 143.22, 135.92, 134.90, 130.87, 127.34, 127.24, 127.09, 121.11, 66.92.

HRMS calc'd for [$C_{12}H_{11}O_2S^+$] (M+H): 219.0474, found: 219.0472.



66a

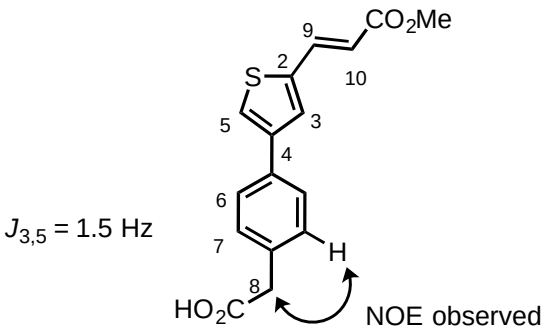
(*E*)-2-(4-(2-(3-methoxy-3-oxoprop-1-en-1-yl)thiophen-3-yl)phenyl)acetic acid (66a). Catalyst stock solution was prepared by mixing $Pd(OAc)_2$ (0.025 mmol, 5.6 mg), **L15** (0.025 mmol, 4.8 mg) and HBF_4•Et_2O (0.050 mmol, 6.8 μL) in 15 mL AcOH. In a 4 mL vial, **S2** (0.40 mmol, 87 mg), methyl acrylate (0.20 mmol, 18 μL), 1,3,5-tris(trifluoromethyl)benzene (0.067 mmol, 12 μL), benzoquinone (0.30 mmol, 32 mg) were mixed with 1.2 mL THF, and 1.2 mL of the catalyst stock solution was then added. The vial was capped and heated to 40 ^{o}C for 18 h. After completion of reaction, solvent was removed by evaporating under vacuum at 45 ^{o}C. The crude was purified by flash chromatography (EtOAc/Hexane (contains 2% AcOH) from 0% to 20% with gradient

method) to give 58 mg (96% combined yield) of **66a**/**66b** (8:1) as a light brown oil. Removal of **66b** by simple flash chromatography was not successful.

^{1}H NMR (500 MHz, $CDCl_3$) δ 7.81 (d, $J_{9,10}$ = 15.6 Hz, 1H, **H_9**), 7.41 – 7.32 (m, 5H, **H_5-H_8**), 7.10 (d, $J_{4,5}$ = 5.1 Hz, 1H, **H_4**), 6.29 (d, $J_{9,10}$ = 15.7 Hz, 1H, **H_{10}**), 3.75 (s, 3H, **OMe**), 3.71 (s, 2H, **H_8**).

^{13}C NMR (126 MHz, $CDCl_3$) δ 177.34, 167.47, 145.30, 136.83, 134.46, 134.37, 133.17, 130.46, 129.93, 129.64, 127.23, 117.33, 51.85, 40.85.

HRMS calc'd for [$C_{16}H_{15}O_4S^+$] (M+H): 303.0686, found: 303.0682.



66b

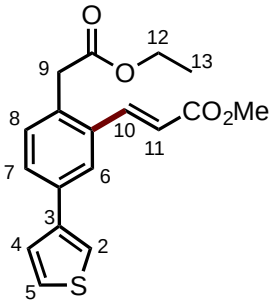
(*E*)-2-(4-(5-(3-methoxy-3-oxoprop-1-en-1-yl)thiophen-3-yl)phenyl)acetic acid (66b). A stock solution was prepared by mixing palladium acetate (2.8 mg, 13 μmol), benzoquinone (41 mg, 0.38 mol), methyl acrylate (23 μL, 0.25 mol), pyridine (2.0 μl, 25 μmol), and 1,3,5-tris(trifluoromethyl)benzene (16 μL, 0.083 mmol, as *internal standard*) in 1.5 mL AcOH. To a 4 mL vial equipped with a magnetic stir bar was added 2-(4-(thiophen-3-yl)phenyl)acetic acid (55 mg, 250 μmol), stock solution (0.30 mL), and additional 0.3 mL AcOH. The vial was capped and stirred at 60 ^{o}C for 3 h. After completion of reaction, 20 μL aliquot was taken from the crude system and mixed with 500 μL $CDCl_3$. NMR yield was determined for **66b** (78%) and **66a** (6%). Two parallel reactions (0.05 mmol scale) were combined for isolation. The solvent was removed by evaporating under vacuum at 45 ^{o}C. The crude residue was purified by flash chromatography (EtOAc and hexane (contains 2% AcOH)) from 0% to 30% with

gradient method to give 19 mg (63%) of **66b** as a white solid. The mass loss resulted from the difficulty in separating C(2)/C(5) isomers.

^{1}H NMR (500 MHz, $CDCl_3$) δ 7.80 (d, $J_{9,10}$ = 15.7 Hz, 1H, **H_9**), 7.53 (d, $J_{6,7}$ = 8.3 Hz, 2H, **H_6**), 7.49 (d, $J_{2,4}$ = 1.5 Hz, 1H, **H_3**), 7.46 (d, $J_{2,4}$ = 1.5 Hz, 1H, **H_5**), 7.33 (d, $J_{6,7}$ = 8.0 Hz, 2H, **H_7**), 6.27 (d, $J_{9,10}$ = 15.8 Hz, 1H, **H_{10}**), 3.80 (s, 3H, **OMe**), 3.69 (s, 2H, **H_8**).

^{13}C NMR (126 MHz, $CDCl_3$) δ 177.02, 167.39, 142.86, 140.23, 137.38, 134.26, 132.77, 130.11, 129.86, 126.68, 123.36, 117.01, 51.95, 40.69.

HRMS calc'd for [$C_{16}H_{15}O_4S^+$] (M+H): 303.0686, found: 303.0686.



S3

methyl (*E*)-3-(2-(2-ethoxy-2-oxoethyl)-5-(thiophen-3-yl)phenyl)acrylate (S3). The reaction was set up on 0.10 mmol scale using a reported protocol[16]. Upon completion, the reaction was diluted with EtOAc and let stand for 2 weeks during which the product underwent esterification. The mixture was filtered through Celite, and the filtrate partitioned by 20 mL HCl (1 M) and 20 mL EtOAc. The aqueous layer was extracted with EtOAc (20 mL × 2), and the organic layer was combined and backwashed with 20 mL brine, then dried over Na_2SO_4. Solvent was evaporated under vacuum at 45 ^{o}C, and the crude residue was purified by chromatography (EtOAc and hexane (contains 2% AcOH)) from 0% to 30% with gradient method to give 3 mg of the ethyl ester **S3** as white solid. This pure material was sufficient to confirm by NMR analysis the structure of the product formed from the dehydrogenative Heck reaction.

^{1}H NMR (500 MHz, $CDCl_3$) δ 7.99 (d, $J_{10,11}$ = 15.8 Hz, 1H, **H_{10}**), 7.80 (d, $J_{6,7}$ = 2.0 Hz, 1H, **H_6**), 7.57 (dd, $J_{7,8}$ = 8.0, $J_{6,7}$ = 1.9 Hz, 1H, **H_7**), 7.49 – 7.46 (m, 1H, **H_2**), 7.44 – 7.37 (m, 2H, **H_4&H_5**), 7.32 (d, $J_{7,8}$ = 8.1 Hz, 1H, **H_8**), 6.45 (d, $J_{10,11}$ = 15.8 Hz, 1H, **H_{11}**), 4.17

(q, $J_{12,13}$ = 7.1 Hz, 2H, **H_{12}**), 3.82 (s, 3H, **OMe**), 3.78 (s, 2H, **H_9**), 1.26 (t, $J_{12,13}$ = 7.1 Hz, 3H, **H_{13}**).

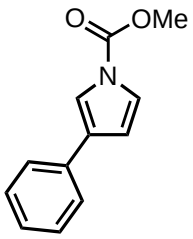
^{13}C NMR (126 MHz, $CDCl_3$) δ 171.02, 167.24, 142.13, 141.43, 135.66, 134.53, 132.61, 131.76, 128.32, 126.69, 126.31, 124.98, 120.93, 120.42, 61.34, 51.97, 38.83, 14.28.

HRMS calc'd for [$C_{18}H_{19}O_4S^+$] (M+H): 331.0999, found: 331.0996.

Table S4. Condition optimization for C(2) versus C(5) selectivity during the C-H alkenylation of S4.

Entry	Condition	**69a** (%)	**69b** (%)	ratio
1[17]	$Pd(OAc)_2$ (10 mol%), ^{t}BuOOBz (1 equiv) Dioxane/HOAc/DMSO 40 ^{o}C, 24 h	18	60	1:3
2	$Pd(OAc)_2$ (5 mol%), pyridine (10 mol%) BQ (1.5 equiv), AcOH 60 ^{o}C, 3 h	13	62	1:5
3	$Pd(OAc)_2$ (3 mol%), **L15** (3 mol%), TsOH•H_2O (3 mol%) BQ (1.5 equiv), AcOH r.t., 18 h	51	19	3:1
4	$Pd(OAc)_2$ (6 mol%), **L15** (6 mol%), HBF_4•H_2O (12 mol%) BQ (1.5 equiv), AcOH/Ac_2O 40 ^{o}C, 18 h	48	6	8:1

The yields were determined by ^{1}H NMR with 1,3,5-tris(trifluoromethyl)benzene as internal standard.



S4

methyl 3-phenyl-1*H*-pyrrole-1-carboxylate (S4).[18] To a stirred solution of 3-phenyl-1*H*-pyrrole (445 mg, 3.11 mmol) in 5 mL THF in a 20 mL scintillation vial was added sodium hydride (248 mg, 6.21 mmol, 60 % dispersion in mineral oil) at 0 ^{o}C. Stirring

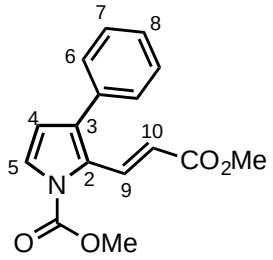
continued until bubbles were no longer visibly generated, then methyl chloroformate (0.48 mL, 6.2 mmol) was then added slowly. The resulting suspension was warmed to room temperature and stirred for additional 2 h. The mixture was then quenched with HCl (10 mL, 1 M) then extracted with EtOAc (10 mL × 3). The organic layers were combined and backwashed with 20 mL brine, then dried with Na_2SO_4. Solvent was evaporated under vacuum at 45 °C. The crude residue was purified by flash chromatography (EtOAc and hexane) from 0% to 20% with gradient method to give 298 mg (48%) of **S4** as a white solid.

^{1}H NMR (500 MHz, $CDCl_3$) δ 7.59 – 7.51 (m, 3H), 7.37 (t, *J* = 7.8 Hz, 2H), 7.34 – 7.30 (m, 1H), 7.27 – 7.22 (m, 1H), 6.59 (dd, *J* = 3.3, 1.7 Hz, 1H), 4.00 (s, 3H).

^{13}C NMR (126 MHz, $CDCl_3$) δ 150.98, 134.13, 128.89, 128.50, 126.91, 125.69, 121.16, 115.92, 111.27, 54.33.

HRMS calc'd for [$C_{12}H_{12}NO_2^+$] (M+H): 202.0863, found: 202.0858.

$J_{4,5}$ = 3.3 Hz



67a

no clear NOE observed

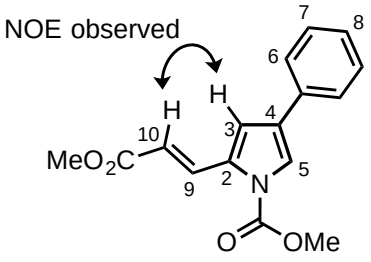
methyl (*E*)-2-(3-methoxy-3-oxoprop-1-en-1-yl)-3-phenyl-1*H*-pyrrole-1-carboxylate (67a). Stock solution (**A**) was prepared by mixing palladium acetate (6.7 mg, 30 μmol), **L15** (5.8 mg, 30 μmol), *p*-toluenesulfonic acid (5.7 mg, 30 μmol), and methyl acrylate (90 μL, 1.0 mmol) in 12 mL AcOH. A stock solution (**B**) was prepared by mixing benzoquinone (41 mg, 0.38 mmol), 1,3,5-tris(trifluoromethyl)benzene (16 μL, 83 μmol, as *internal standard*), and 3 mL of stock solution **A**. To a 4 mL vial equipped with a magnetic stir bar was added 0.6 mL of stock solution **B** and methyl 3-phenyl-1*H*-pyrrole-1-carboxylate (20 mg, 0.10 mmol). The vial was capped and the mixture stirred at room temperature for 18 h. After completion of reaction, the solvent was evaporated under vacuum at 45 ^{o}C. The crude residue was purified by flash chromatography (EtOAc and

hexane from 0% to 10% with a gradient method to give 5 mg of **67a**/**67b** (3:1) as a white solid. Spectral data are reported for **67a** in this inseparable mixture of isomers.

^{1}H NMR (500 MHz, $CDCl_3$) δ 8.21 (d, $J_{9,10}$ = 16.2 Hz, 1H, **H_9**), 7.44 (d, $J_{4,5}$ = 3.3 Hz, 1H, **H_4**), 7.39 – 7.37 (m, 4H, **H_6** and **H_7**), 7.34 – 7.30 (m, 1H, **H_8**), 6.29 (d, $J_{4,5}$ = 3.3 Hz, 1H, **H_5**), 5.90 (d, $J_{9,10}$ = 16.2 Hz, 1H, **H_{10}**), 4.01 (s, 3H, **OMe**), 3.70 (s, 3H, **OMe**).

^{13}C NMR (126 MHz, $CDCl_3$) δ 167.65, 151.20, 135.21, 133.81, 132.96, 129.00, 128.92, 127.75, 125.70, 123.96, 119.46, 114.84, 54.54, 51.68.

HRMS calc'd for [$C_{16}H_{16}NO_4^+$] (M+H): 286.1074, found: 286.1075.



$J_{3,5}$ = 1.8-1.9 Hz

67b

methyl (*E*)-2-(3-methoxy-3-oxoprop-1-en-1-yl)-4-phenyl-1*H*-pyrrole-1-carboxylate (67b). A literature protocol was followed.[17] A stock solution was prepared by mixing methyl acrylate (23 µL, 0.25 mmol), *tert*-butyl benzoperoxoate (47 µL, 0.25 mmol), 1,3,5-tris(trifluoromethyl)benzene (16 µL, 83 µmol, as *internal standard*), AcOH (0.23 mL), dioxane (0.69 mL), and DMSO (80 µL). To a 4 mL vial equipped with a magnetic stir bar was added 0.2 mL of the stock solution, palladium acetate (1.1 mg, 5.0 µmol), and methyl 3-phenyl-1*H*-pyrrole-1-carboxylate (20 mg, 0.10 mmol). The vial was capped and the mixture stirred at 40 ^{o}C for 24 h. After completion of reaction, the solvent was evaporated under vacuum at 45 ^{o}C. The crude residue was purified by flash chromatography (EtOAc and hexane from 0% to 10% with a gradient method to give 5 mg of **67a**/**67b** (1:3) as a white solid. Spectral data are reported for **67b** in this inseparable mixture of isomers.

^{1}H NMR (500 MHz, $CDCl_3$) δ 8.32 (d, $J_{9,10}$ = 16.0 Hz, 1H, **H_9**), 7.69 (d, $J_{2,4}$ = 1.9 Hz, 1H, **H_5**), 7.52 (d, $J_{6,7}$ = 8.2, 2H, **H_6**), 7.41 – 7.36 (m, 3H, **H_7** and **H_8**), 7.04 (d, $J_{2,4}$ = 1.8 Hz, 1H, **H_3**), 6.32 (d, $J_{9,10}$ = 16.0 Hz, 1H, **H_{10}**), 4.03 (s, 3H, **OMe**), 3.80 (s, 3H, **OMe**).

^{13}C NMR (126 MHz, $CDCl_3$) δ 167.48, 151.02, 134.35, 133.81, 133.07, 129.01, 127.74, 127.43, 125.69, 120.44, 117.38, 113.26, 54.61, 51.83.

HRMS calc'd for [$C_{16}H_{16}NO_4^+$] (M+H): 286.1074, found: 286.1075.

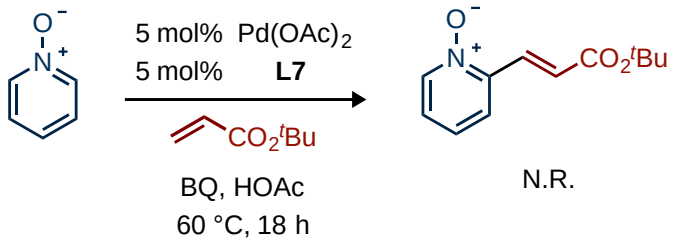


Figure S1. Attempted DHR using a prototypical electron-poor heteroarene.

H/D Exchange Experiment. $Pd(OAc)_2$ (1.3 mg, 6.0 μmol), **L14** (1.7 mg, 3.0 μmol), benzoquinone (32 mg, 0.30 mmol), HBF_4•Et_2O (1.6 μL, 6.0 μmol) and 1.0 mL AcOD-d_4 were mixed in a 4 mL vial to afford a yellow homogeneous solution. 500 μL of such solution was transferred to a NMR tube that contained 2-methylthiophene (9.7 μL, 0.10 mmol) and methyl acrylate (18 μL, 0.20 mmol). The NMR tube was capped and shaken, then the ^{1}H NMR spectrum collected immediately. After that, the NMR tube was warmed to 40 ^{o}C in a pre-heated oil bath for 20 min, and the second spectrum was collected.

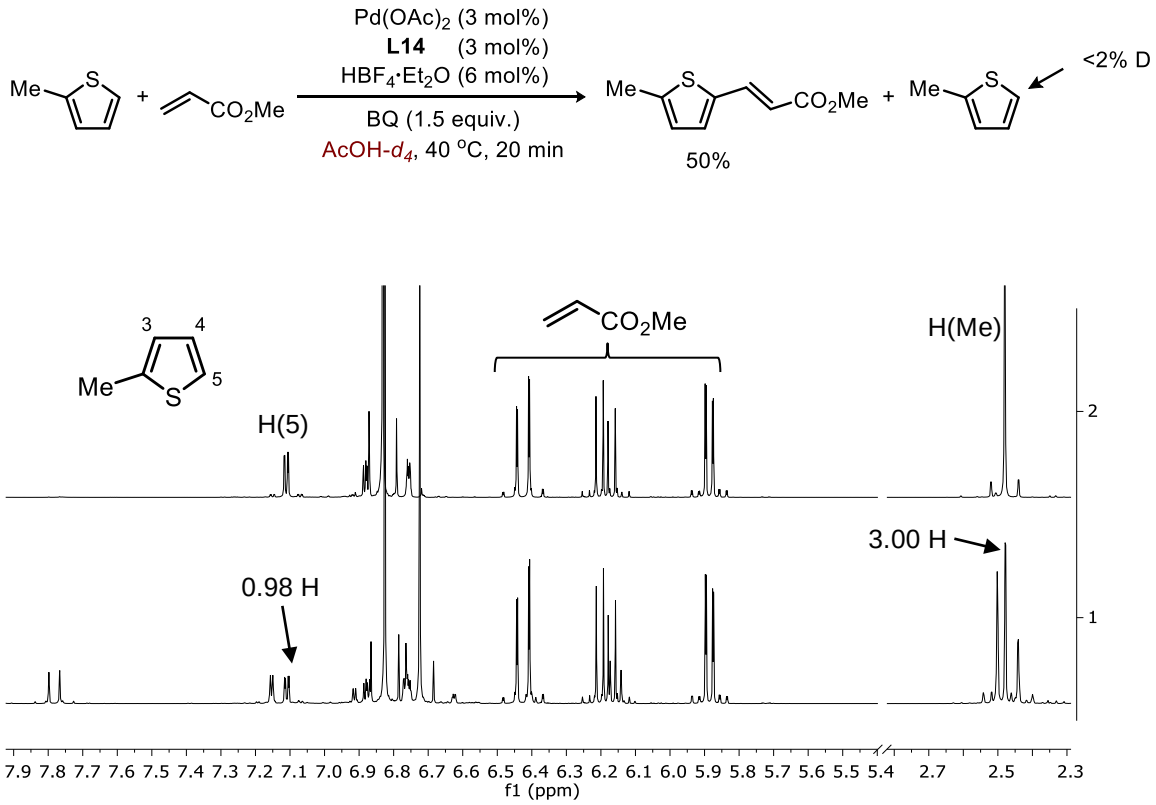


Figure S2. ^{1}H NMR collected before heating (top) and after heating at 40 ^{o}C for 20 min (bottom). The substrate methyl group resonance was used as internal standard.

H/D Exchange Experiment. $Pd(OAc)_2$ (1.3 mg, 6.0 μmol), **L14** (1.7 mg, 3.0 μmol), benzoquinone (32 mg, 0.30 mmol), HBF_4•Et_2O (1.6 μL, 6.0 μmol) and 1.0 mL AcOD-d_4 were mixed in a 4 mL vial to afford a yellow homogeneous solution. 500 μL of such solution was transferred to a NMR tube that contained 3-methylbenzofuran (13 μL, 0.10 mmol). The NMR tube was capped and shaken, then the ^{1}H NMR spectrum was collected immediately. After that, the NMR tube was warmed to 40 ^{o}C in a pre-heated oil bath, and additinoal spectra were collected at 20 min and 40 min.

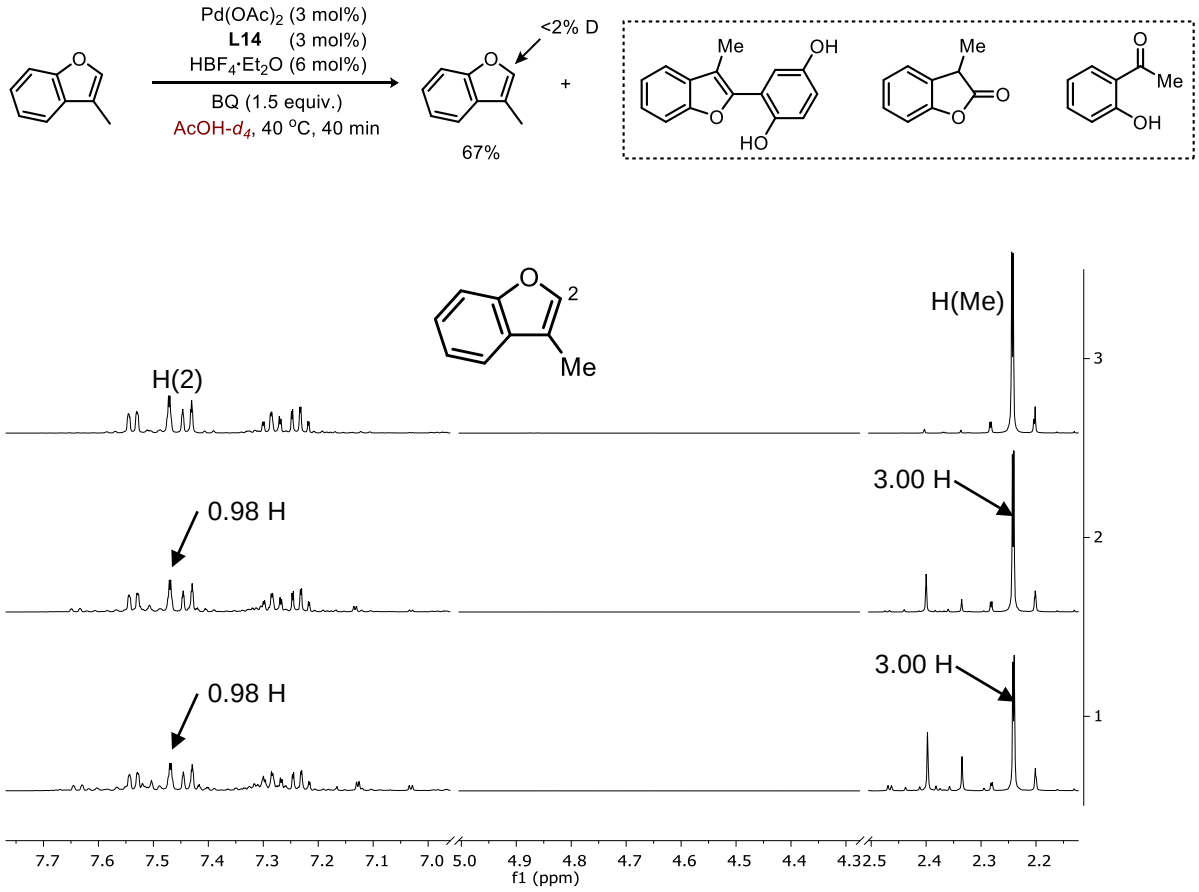
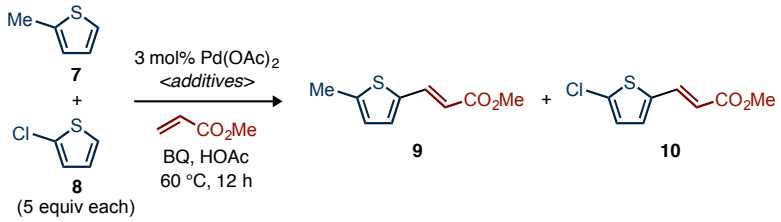


Figure S3. ^{1}H NMR collected before heating (top) and after heating at 40 ^{o}C for 20 min (middle) and 40 min (bottom). The substrate methyl group resonance was used as internal standard.

Intermolecular Competition Experiments. Stock solution (A) was prepared by dissolving $Pd(OAc)_2$ (5.6 mg, 25 μmol) and ligand in 5.0 mL AcOH. Stock solution (B) was prepared by mixing 2-methylthiophene (0.484 ml, 5.00 mmol), 2-chlorothiophene (0.461 ml, 5.00 mmol), methyl acrylate (0.090 ml, 1.0 mmol), benzoquinone (0.162 g, 1.50 mmol) and 1,3,5-tris(trifluoromethyl)benzene (0.062 ml, 0.33 mmol, *internal standard*) in 6.0 mL AcOH. 0.60 mL stock solution (A) and 0.60 mL stock solution (B) were mixed in a 4 mL vial that was equipped with a magetic stir bar, and the vial was capped and heated up to 60 °C for 12 hours. Upon completion of reaction, 20 μL of reaction mixture was diluted by 0.50 mL $CDCl_3$, and ^1H NMR was used to determine the product ratios.

Table S5. Intermolecular competition experiments with 2-substituted thiophenes.[a]



entry	ligand	yield (%)[b]	**9**/**10**
1[c]	**L14** (3 mol%)	39	>20:1
2[c]	**L15** (3 mol%)	38	>20:1
3	4,5-diazafluorenone (3 mol%)	90	5.0:1
4	4,5-diazafluorenone (1.5 mol%)	95	3.5:1
6	pyridine (6 mol%)	88	0.9:1
7	pyridine (3 mol%)	87	1.4:1
5	**L7** (3 mol%)	89	1.9:1
1	**L8** (3 mol%)	97	2.6:1
2	**L9** (3 mol%)	95	2.5:1
3[c]	**L9** (3 mol%)	71	4.5:1
4	**L10** (3 mol%)	96	2.6:1
5	**L11** (3 mol%)	99	2.6:1
6	**L12** (3 mol%)	94	3.1:1

[a]Determined by ^1H NMR versus 1,3,5-$(CF_3)_3C_6H_3$ as internal standard. [b]Combined yield of **9** and **10**. [c]HBF_4 (6 mol%) added.

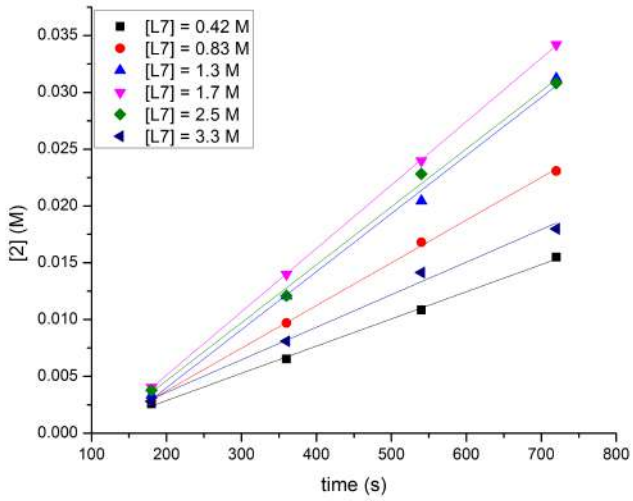


Figure S4. Reaction of **1** (0.17 M), *tert*-butyl acrylate (0.33 M), BQ (0.25 M), $Pd(OAc)_2$ (1.7 mM), and **L7** (0.42-3.3 mM) in AcOH at 50 °C.

Table S6. Tabular data for reactions in Figure S4.

[**L7**] (mM)	Time (s)			
	180	360	540	720
0.42	2.58E-03	6.54E-03	1.08E-02	1.55E-02
0.83	2.89E-03	9.70E-03	1.68E-02	2.31E-02
1.3	3.36E-03	1.21E-02	2.04E-02	3.12E-02
1.7	4.05E-03	1.40E-02	2.40E-02	3.42E-02
2.5	3.79E-03	1.21E-02	2.28E-02	3.08E-02
3.3	2.81E-03	8.11E-03	1.42E-02	1.80E-02

Table S7. Tabular data for data in Figure 4a.

[**L7**] (mM)	k_{obs} (M s^{-1})	Standard Error	R^2
0.42	2.39E-05	6.03E-07	0.998
0.83	3.76E-05	6.62E-07	0.999
1.3	5.11E-05	2.12E-06	0.995
1.7	5.58E-05	2.61E-07	1.000
2.5	5.10E-05	2.04E-06	0.995
3.3	2.87E-05	1.73E-06	0.989

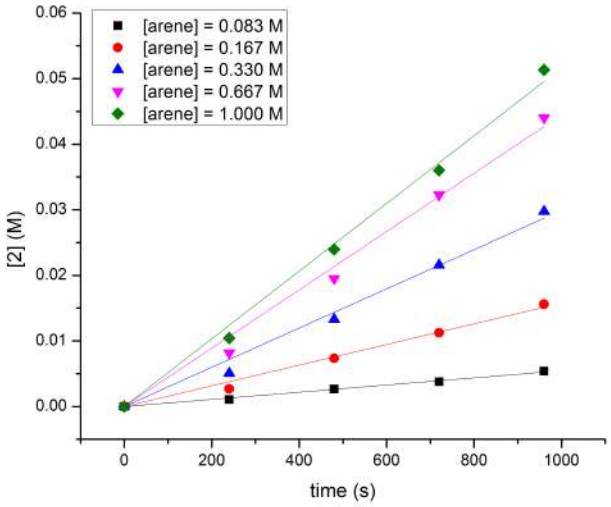


Figure S5. Reaction of **1** (0.083-1.0 M), *tert*-butyl acrylate (0.33 M), BQ (0.25 M), $Pd(OAc)_2$ (1.7 mM), and **L7** (1.7 mM) in AcOH at 50 °C,

Table S8. Tabular data for reactions in Figure S5.

[**1**] (M)	time (s)				
	0	240	480	720	960
0.083	0	1.07E-03	2.66E-03	3.77E-03	5.39E-03
0.17	0	2.69E-03	7.33E-03	1.13E-02	1.56E-02
0.33	0	5.04E-03	1.33E-02	2.16E-02	2.97E-02
0.67	0	8.18E-03	1.95E-02	3.23E-02	4.41E-02
1.0	0	1.04E-02	2.40E-02	3.60E-02	5.13E-02

Table S9. Tabular data for reactions in Figure 4b.

[**1**] (M)	k_{obs} (M s^{-1})	Standard Error	R^2
0.083	5.46E-06	1.24E-07	0.997
0.17	1.58E-05	4.62E-07	0.996
0.33	2.99E-05	9.88E-07	0.995
0.67	4.45E-05	1.29E-06	0.996
1.0	5.16E-05	1.14E-06	0.998

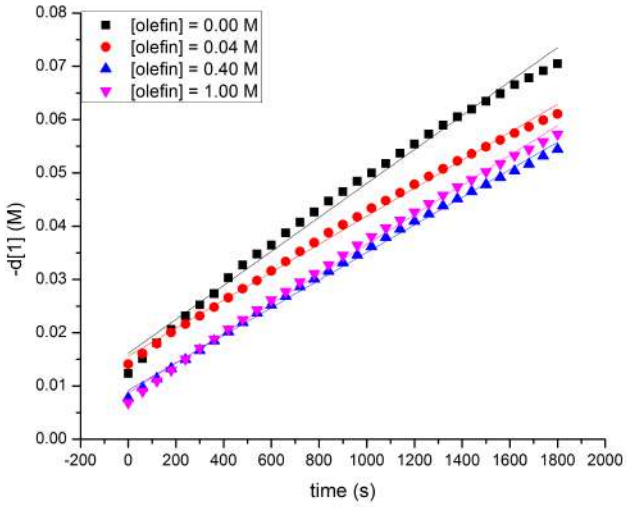


Figure S6. Reaction of **1** (0.17 M), *tert*-butyl acrylate (0.02–0.40 M), BQ (0.25 M), $Pd(OAc)_2$ (1.7 mM), and **L7** (1.7 mM) in AcOH at 50 °C as monitored by disappearance of **1** by ^{1}H NMR.

Table S10. Tabular data for reactions in Figure S6.

	[olefin] = 0.0 M		[olefin] = 0.04 M		[olefin] = 0.10 M		[olefin] = 0.40 M	
time (s)	*conv.* **1**	-Δ[**1**]*	*conv.* **1**	-Δ[**1**]*	*conv.* **1**	-Δ[**1**]*	*conv.* **1**	-Δ[**1**]*
0	7.3%	1.23	8.3%	1.41	4.6%	0.78	4.0%	0.69
60	8.9%	1.51	9.5%	1.61	5.7%	0.97	5.3%	0.90
120	10.6%	1.81	10.6%	1.80	6.7%	1.14	6.4%	1.09
180	12.1%	2.06	11.8%	2.01	7.8%	1.33	7.6%	1.30
240	13.6%	2.32	12.7%	2.16	8.8%	1.49	8.9%	1.51
300	14.8%	2.52	13.6%	2.31	9.8%	1.67	10.0%	1.71
360	16.1%	2.73	14.6%	2.48	10.9%	1.85	11.1%	1.88
420	17.8%	3.03	15.6%	2.66	11.9%	2.02	12.2%	2.07
480	19.2%	3.27	16.6%	2.83	12.9%	2.19	13.2%	2.25
540	20.4%	3.48	17.5%	2.98	14.0%	2.37	14.3%	2.43
600	21.4%	3.64	18.6%	3.16	14.8%	2.52	15.4%	2.62
660	22.8%	3.87	19.6%	3.34	15.8%	2.68	16.3%	2.77
720	23.9%	4.07	20.7%	3.53	16.8%	2.86	17.4%	2.95

780	25.1%	4.26	21.7%	3.69	17.7%	3.01	18.3%	3.11
840	26.3%	4.47	22.8%	3.88	18.6%	3.15	19.3%	3.28
900	27.3%	4.65	23.7%	4.03	19.5%	3.31	20.3%	3.46
960	28.5%	4.84	24.5%	4.17	20.4%	3.46	21.4%	3.65
1020	29.4%	5.00	25.5%	4.34	21.3%	3.62	22.4%	3.80
1080	30.4%	5.18	26.4%	4.48	22.3%	3.79	23.3%	3.97
1140	31.6%	5.37	27.2%	4.63	23.2%	3.94	24.2%	4.11
1200	32.6%	5.54	28.1%	4.78	24.1%	4.09	25.1%	4.27
1260	33.7%	5.73	29.0%	4.93	24.9%	4.23	26.0%	4.42
1320	34.7%	5.89	29.9%	5.08	25.8%	4.38	27.0%	4.58
1380	35.6%	6.05	30.7%	5.22	26.5%	4.51	27.9%	4.74
1440	36.5%	6.20	31.5%	5.36	27.4%	4.65	28.7%	4.87
1500	37.3%	6.35	32.3%	5.49	28.1%	4.78	29.5%	5.02
1560	38.2%	6.49	33.0%	5.62	28.9%	4.92	30.4%	5.17
1620	39.1%	6.65	33.8%	5.75	29.6%	5.04	31.4%	5.33
1680	39.9%	6.78	34.5%	5.86	30.4%	5.17	32.0%	5.45
1740	40.7%	6.92	35.2%	5.99	31.3%	5.32	32.9%	5.59
1800	41.5%	7.05	35.9%	6.11	32.0%	5.44	33.7%	5.73

Table S11. Kinetic data for reactions in Figure 4c.

[olefin] (M)	k_{obs} (M s^{-1})	Standard Error	R^2
0.00	3.19E-05	3.19E-06	0.991
0.04	2.87E-05	2.87E-06	0.997
0.10	2.59E-05	2.59E-06	0.997
0.40	2.79E-05	2.79E-06	0.997

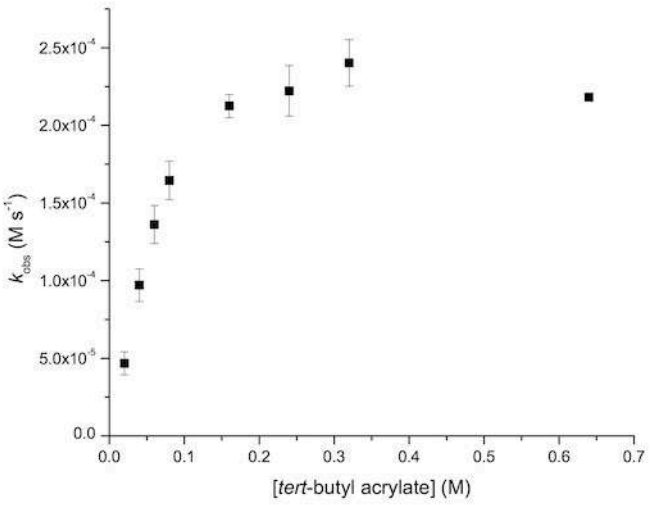


Figure S7. Dependence of the formation of **2** on the concentration of *tert*-butyl acrylate (0.02–0.64 M) during the reaction with **1** (0.17 M), benzoquinone (0.25 M), $Pd(OAc)_2$ (1.7 mM), and **L7** (1.7 mM) in AcOH (1.5 mL) at 50 °C.

Table S12. Tabular data for reactions in Figure S7.

[*tert*-butyl acrylate] (M)	k_{obs} (M s^{-1})	Error
0.020	4.68E-05	7.38E-06
0.040	9.71E-05	1.05E-05
0.060	1.36E-04	1.22E-05
0.080	1.65E-04	1.24E-05
0.160	2.12E-04	7.48E-06
0.240	2.22E-04	1.63E-05
0.320	2.40E-04	1.50E-05
0.640	2.18E-04	1.70E-06

Note: The yield of **2** is significantly diminished at low [alkene], presumably due to the instability of the arylpalladium intermediate that is diverted to side product(s). This must have a negative impact on the apparent observed rate constant calculated from the formation of **2** over time, which accounts for the observed curvature in Figure S4 as opposed to the zeroth order behavior apparent in Figure 4c calculated instead from rate of consumption of **1**.

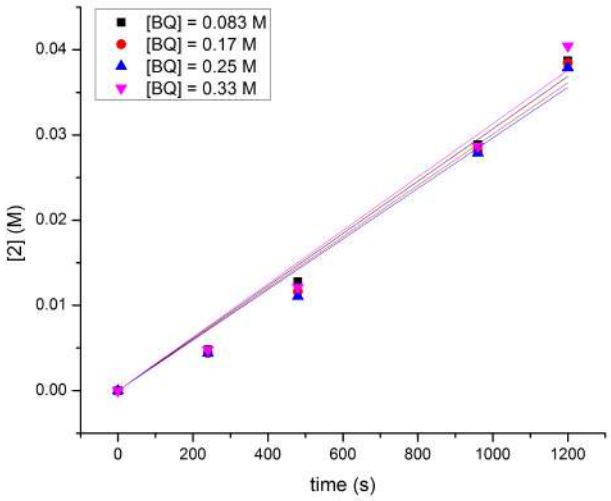


Figure S8. Reaction of **1** (0.17 M), *tert*-butyl acrylate (0.33 M), BQ (0.083-0.33 M), $Pd(OAc)_2$ (1.7 mM), and **L7** (1.7 mM) in AcOH at 50 °C.

Table S13. Tabular data for reactions in Figure S8.

[BQ] (M)	time (s)				
	0	240	480	960	1200
0.083	0	4.79E-03	1.28E-02	2.89E-02	3.87E-02
0.17	0	4.41E-03	1.16E-02	2.81E-02	3.84E-02
0.25	0	4.38E-03	1.11E-02	2.79E-02	3.79E-02
0.33	0	4.79E-03	1.21E-02	2.87E-02	4.04E-02

Table S14. Tabular data for reactions in Figure 4d.

[BQ] (M)	k_{obs} (M s^{-1})	Standard Error	R^2
0.083	3.07E-05	1.16E-06	0.993
0.17	3.01E-05	1.44E-06	0.989
0.25	2.97E-05	1.47E-06	0.988
0.33	3.13E-05	1.57E-06	0.988

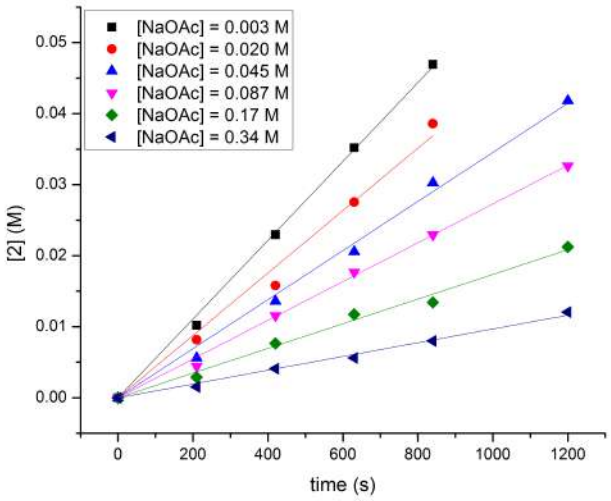


Figure S9. Reaction of **1** (0.17 M), *tert*-butyl acrylate (0.33 M), BQ (0.25 M), sodium acetate (0.0030-0.34 M), $Pd(OAc)_2$ (1.7 mM), and **L7** (1.7 mM) in AcOH at 50 °C.

Table S15. Tabular data for reactions in Figure S9.

[NaOAc] (M)	time (s)					
	0	210	420	630	840	1200
0.0030	0	1.02E-02	2.30E-02	3.52E-02	4.69E-02	-
0.020	0	8.16E-03	1.58E-02	2.75E-02	3.86E-02	-
0.045	0	5.61E-03	1.36E-02	2.06E-02	3.03E-02	4.18E-02
0.087	0	4.42E-03	1.16E-02	1.77E-02	2.30E-02	3.26E-02
0.17	0	2.89E-03	7.65E-03	1.17E-02	1.34E-02	2.13E-02
0.34	0	1.53E-03	4.08E-03	5.61E-03	7.99E-03	1.21E-02

Table S16. Tabular data for reactions in Figure 4e.

[NaOAc] (M)	k_{obs} (M s^{-1})	Standard Error	R^2
0.0030	5.55E-05	6.71E-07	0.999
0.020	4.39E-05	1.44E-06	0.995
0.045	3.45E-05	6.93E-07	0.998
0.087	2.73E-05	3.78E-07	0.999
0.17	1.74E-05	4.53E-07	0.996
0.34	9.69E-06	2.28E-07	0.997

General procedure for kinetic experiments to determine the dependence of the rate on [catalyst]. A stock solution (**A**) was prepared by mixing 2-methylfuran (0.18 ml, 2.0 mmol), *tert*-butyl acrylate (0.58 mL, 4.0 mmol), benzoquinone (324 mg, 3.00 mmol), nitrobenzene (0.21 mL, 2.0 mmol, as *internal standard*) in AcOH (8.0 mL). Another stock solution (**B**) was then prepared by mixing palladium acetate (11.2 mg, 50 μmol) and **L7** (8.9 μl, 50 μmol) in AcOH (2.0 mL). To one 4 mL vial was added 1.15 mL of stock solution (**A**). To another 4 mL vial was added stock solution (**B**) and then AcOH to give a total volume of 0.5 mL. These two vials were preheated at 45 ^{o}C for 2 min then combined. Yield was determined by GC at 2-6 min. Sample were prepared by quenching a 15 μl aliquot onto a silica pad followed by elution with EtOAc (1.0 mL).

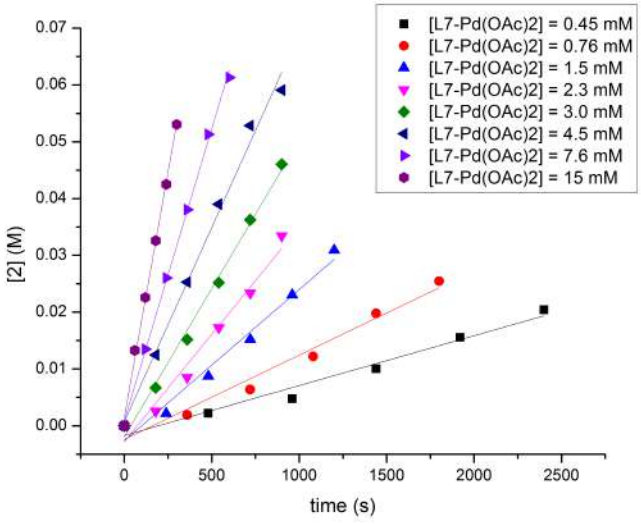


Figure S10. Reaction of **1** (0.17 M), *tert*-butyl acrylate (0.33 M), BQ (0.25 M), and **L7**-$Pd(OAc)_2$ (0.40-15 mM) in AcOH at 45 °C.

Table S17. Tabular data for reactions in Figure S10.

[catalyst]	time (s)	yield	[**2**] (M)	[catalyst]	time (s)	yield	[**2**] (M)
	0	0	0		0	0	0
	480	1.3%	2.24E-03		180	3.9%	6.69E-03
0.3% Pd/L	960	2.8%	4.77E-03	2.0% Pd/L	360	8.9%	1.52E-02
(0.45 mM)	1440	5.9%	1.00E-02	(3.0 mM)	540	14.8%	2.52E-02
	1920	9.2%	1.56E-02		720	21.3%	3.62E-02
	2400	12.0%	2.04E-02		900	27.1%	4.60E-02
	0	0	0		0	0	0
	360	1.1%	1.92E-03		180	7.3%	1.25E-02
0.5% Pd/L	720	3.8%	6.39E-03	3.0% Pd/L	360	14.9%	2.53E-02
(0.76 mM)	1080	7.2%	1.22E-02	(4.5 mM)	540	22.9%	3.90E-02
	1440	11.6%	1.98E-02		720	31.1%	5.29E-02
	1800	15.0%	2.55E-02		900	34.8%	5.91E-02
	0	0	0		0	0	0
	240	1.3%	2.19E-03		120	7.9%	1.35E-02
1.0% Pd/L	480	5.1%	8.72E-03	5.0% Pd/L	240	15.3%	2.60E-02
(1.5 mM)	720	8.9%	1.52E-02	(7.6 mM)	360	22.4%	3.81E-02
	960	13.6%	2.31E-02		480	30.2%	5.13E-02
	1200	18.2%	3.09E-02		600	36.0%	6.13E-02
	0	0	0		0	0	0
	180	1.5%	2.60E-03		60	7.8%	1.33E-02
1.5% Pd/L	360	5.0%	8.52E-03	10.0% Pd/L	120	13.3%	2.26E-02
(2.3 mM)	540	10.2%	1.73E-02	(15 mM)	180	19.2%	3.26E-02
	720	13.8%	2.34E-02		240	25.0%	4.25E-02
	900	19.7%	3.34E-02		300	31.2%	5.30E-02

Table S18. Tabular data for reactions in Figure 4f.

[**L7**-Pd(OAc)$_2$] (mM)	k_{obs} (M s^{-1})	Standard Error	R^2
0.45	8.78E-06	7.43E-07	0.965
0.76	1.48E-05	1.26E-06	0.965
1.5	2.66E-05	1.97E-06	0.973
2.3	3.78E-05	3.05E-06	0.968
3.0	5.22E-05	2.05E-06	0.992
4.5	6.83E-05	3.06E-06	0.990
7.6	1.03E-04	1.97E-06	0.998
15	1.73E-04	4.28E-06	0.997

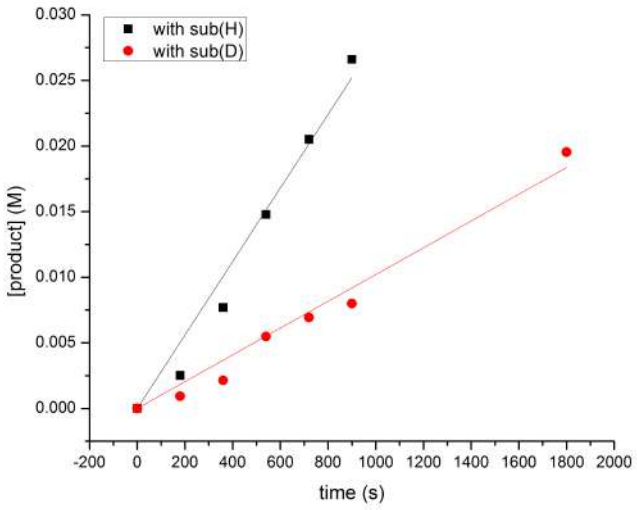


Figure S11. Yield of **10** during the reaction of **9** (black) or **9**-2-*d* (red) (0.17 M), *tert*-butyl acrylate (0.33 M), benzoquinone (0.25 M), Pd(OAc)$_2$ (1.7 mM), and **L7** (1.7 mM) in AcOH at 50 °C.

Table S19. Tabular data for reactions in Figure S11.

time (s)	with **9**		with **9**-2-*d*	
	yield	[product] (M)	yield	[product] (M)
0	0	0	0	0
180	1.5%	2.51E-03	0.5%	9.35E-04
360	4.5%	7.68E-03	1.3%	2.15E-03
540	8.7%	1.48E-02	3.2%	5.48E-03
720	12.1%	2.05E-02	4.1%	6.93E-03
900	15.7%	2.66E-02	4.7%	8.00E-03
1800	-	-	11.5%	1.95E-02

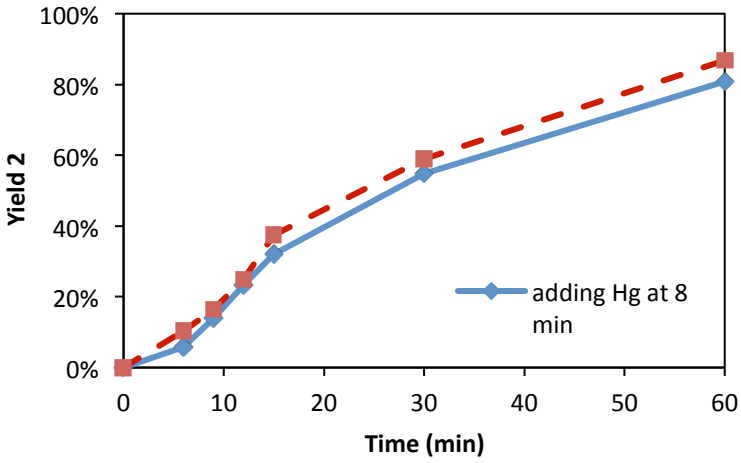


Figure S12. Yield of **2** during reactions of **1** (0.17 M), *tert*-butyl acrylate (0.33 M), benzoquinone (0.25 M), $Pd(OAc)_2$ (1.7 mM), nitrobenzene (0.25 mmol, internal standard) and **L7** (1.7 mM) in AcOH at 60 °C in the presence or absence of an added Hg drop.

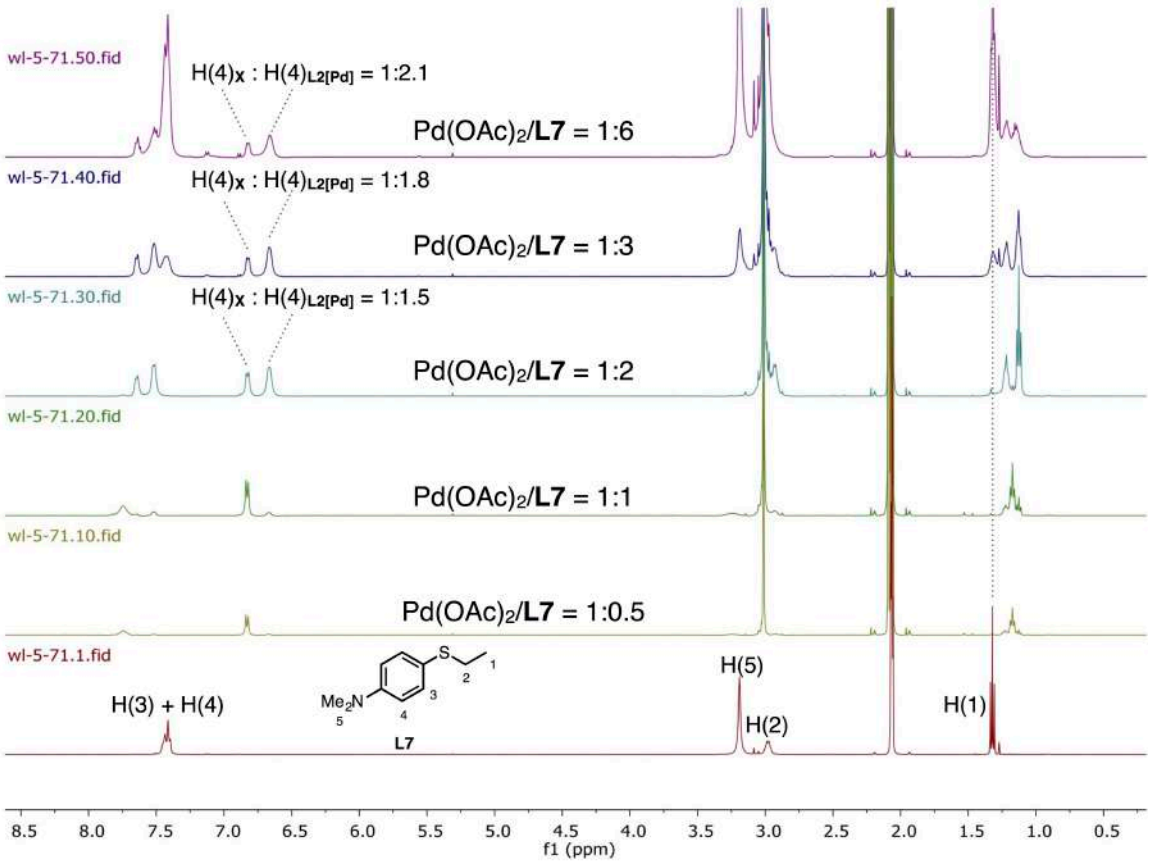
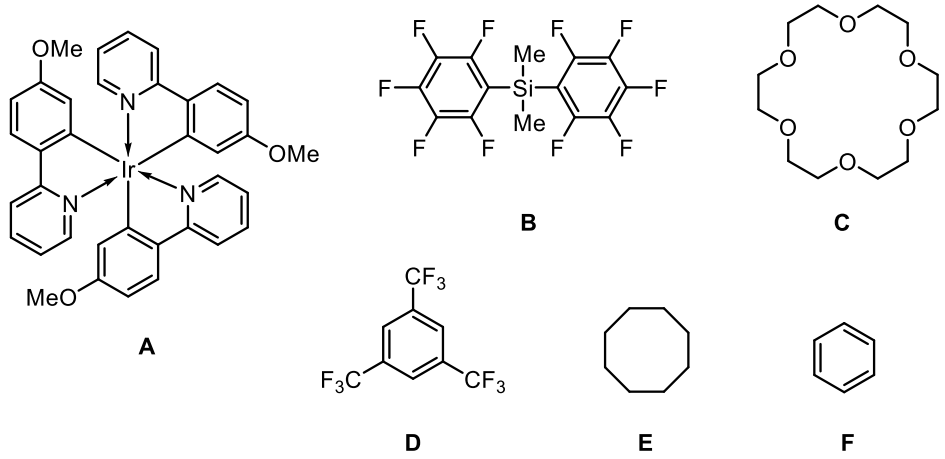


Figure S13. ^{1}H NMR titration of L7 with $Pd(OAc)_2$. [$Pd(OAc)_2$] = 8.4 mM, [**L7**] = 4.2–50.4 mM. *T* = room temperature. Solvent = AcOD-d_4.

a)



b)

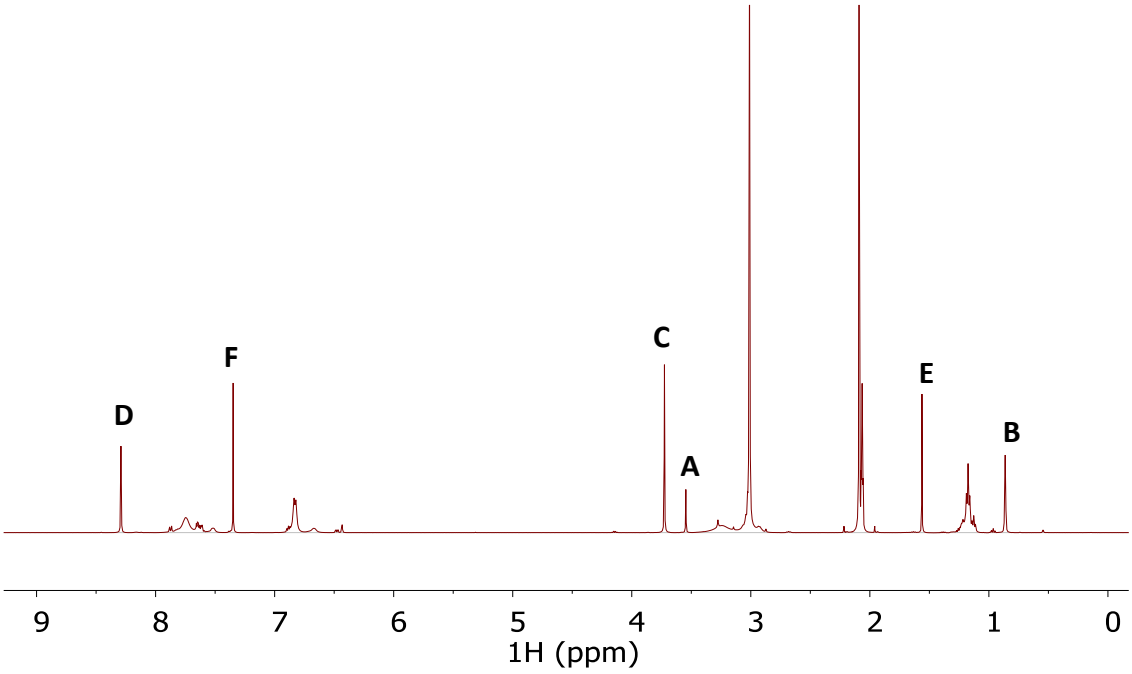


Figure S14. (a) Selected internal standards for MW determination by DOSY NMR; (b) 1H NMR spectrum of $Pd(OAc)_2$/**L7** (1:1) combined with all standards.

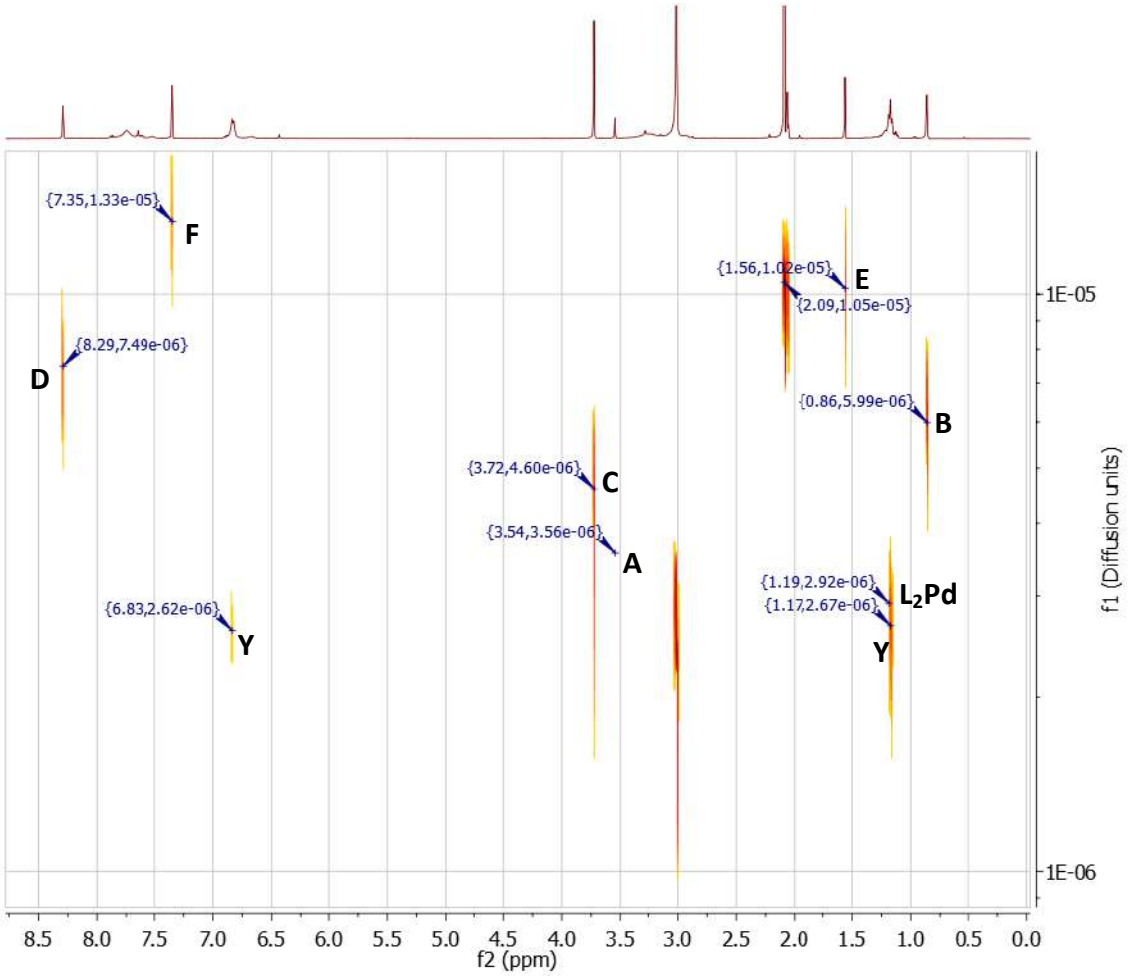


Figure S15. DOSY spectrum of $Pd(OAc)_2$/**L7** (1:1) recorded at 25 °C on Bruker 500 MHz.

Table S20. Results from DOSY NMR (Pd/L7 = 1:1) for all internal standards. The molecular weight of species Y was calculated by linear regression.

Standards	MW	log(MW)	D	log(D)
A	744.9	2.87	3.56E-06	-5.45
B	392.3	2.59	5.99E-06	-5.22
C	264.3	2.42	4.60E-06	-5.34
D	281.1	2.45	7.49E-06	-5.13
E	112.2	2.05	1.02E-05	-4.99
F	78.1	1.89	1.33E-05	-4.88
$Pd(\mathbf{L7})_2(OAc)_2$	587.1	2.77	2.92E-06	-5.53

Species	MW	log(MW)	D	log(D)
Y			2.62E-06 2.67E-06	
	1036	3.02	2.64E-06	-5.55

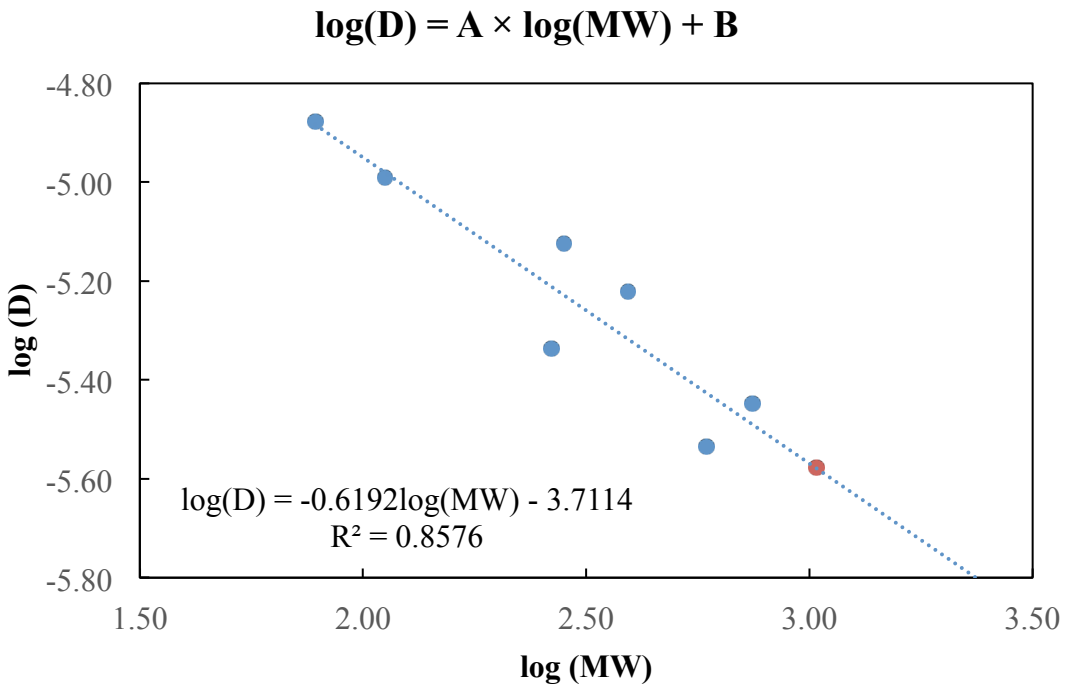


Figure S16. Plot of log(MW) versus log(D). Blue dots for standards and red dot for species **Y**.

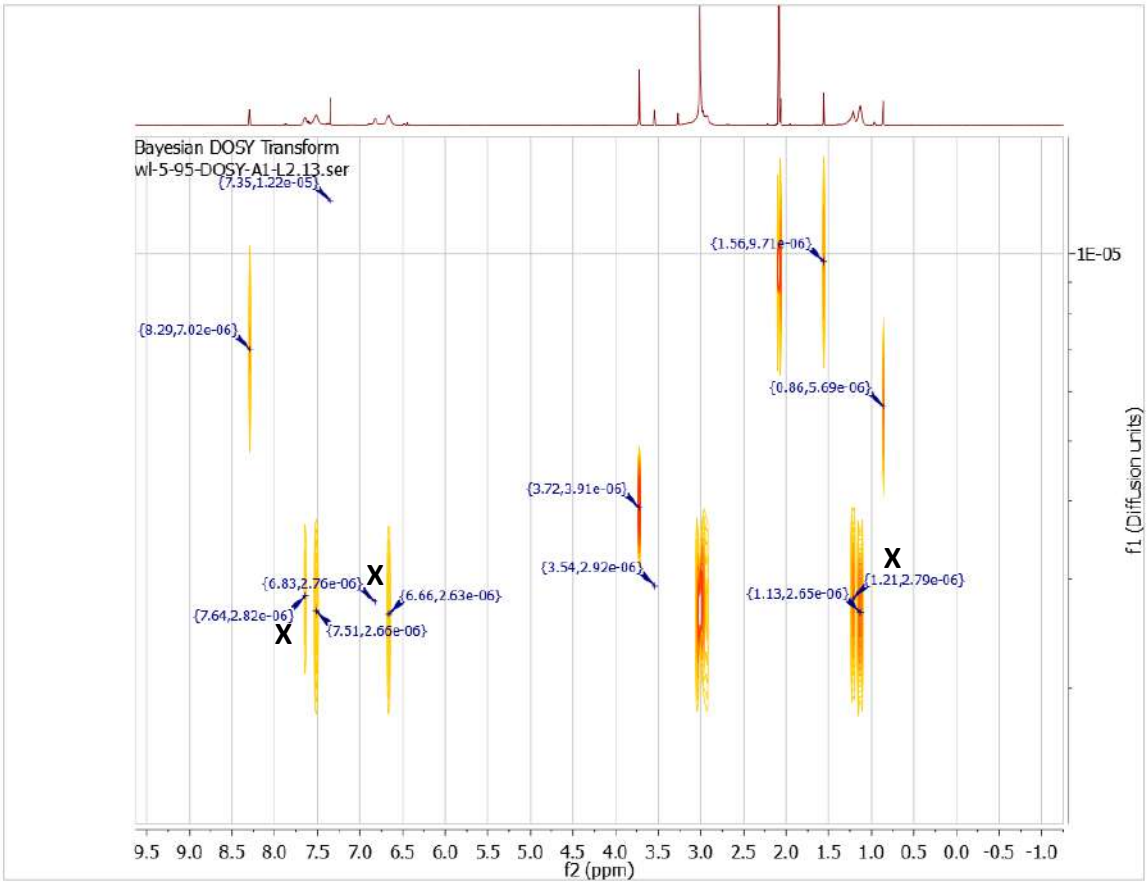


Figure S17. DOSY spectrum of $Pd(OAc)_2$/**L7** (1:2) recorded at 25 ^{o}C on Bruker 500 MHz.

Table S21. Results from DOSY NMR (Pd/L7 = 1:2) for all internal standards. The molecular weight of species X was calculated by linear regression.

Standards	MW	log(MW)	D	log(D)
A	744.9	2.87	2.92E-06	-5.53
B	392.3	2.59	5.69E-06	-5.24
C	264.3	2.42	3.91E-06	-5.41
D	281.1	2.45	7.02E-06	-5.15
E	112.2	2.05	9.71E-06	-5.01
F	78.1	1.89	1.22E-05	-4.91
Pd(**L7**)$_2$(OAc)$_2$	587.1	2.77	2.65E-06	-5.58

Species	MW	log(MW)	D	log(D)
X			2.79E-06 2.76E-06 2.82E-06	
	834	2.92	2.79E-06	-5.55

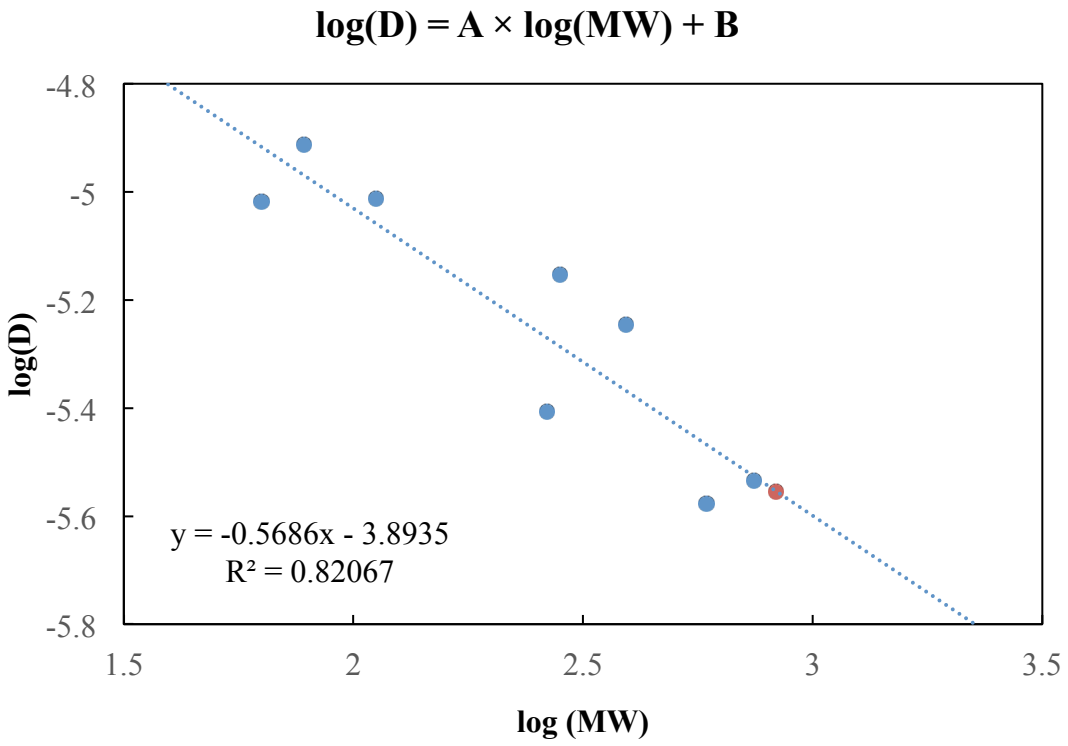


Figure S18. Plot of log(MW) versus log(D). Blue dots for standards, red dot for species **X**.

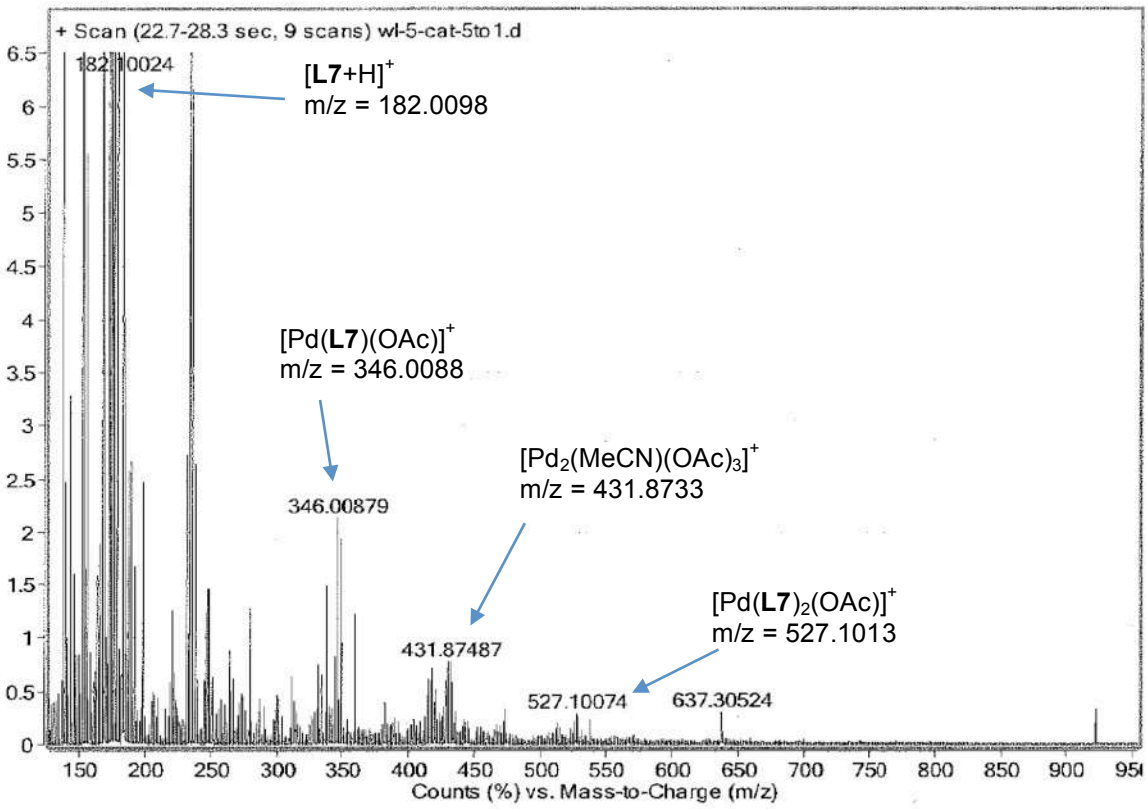


Figure S19. High-resolution mass spectrometry (HRMS) of $Pd(OAc)_2$/**L7** mixture. Sample was prepared by mixing $Pd(OAc)_2$/**L7** (5:1) in acetic acid. Direct injection method with H_2O/MeCN/HCOOH (90:10:0.1) as carrying solvent. We obtained similar spectra with varied $Pd(OAc)_2$/**L7** ratios.

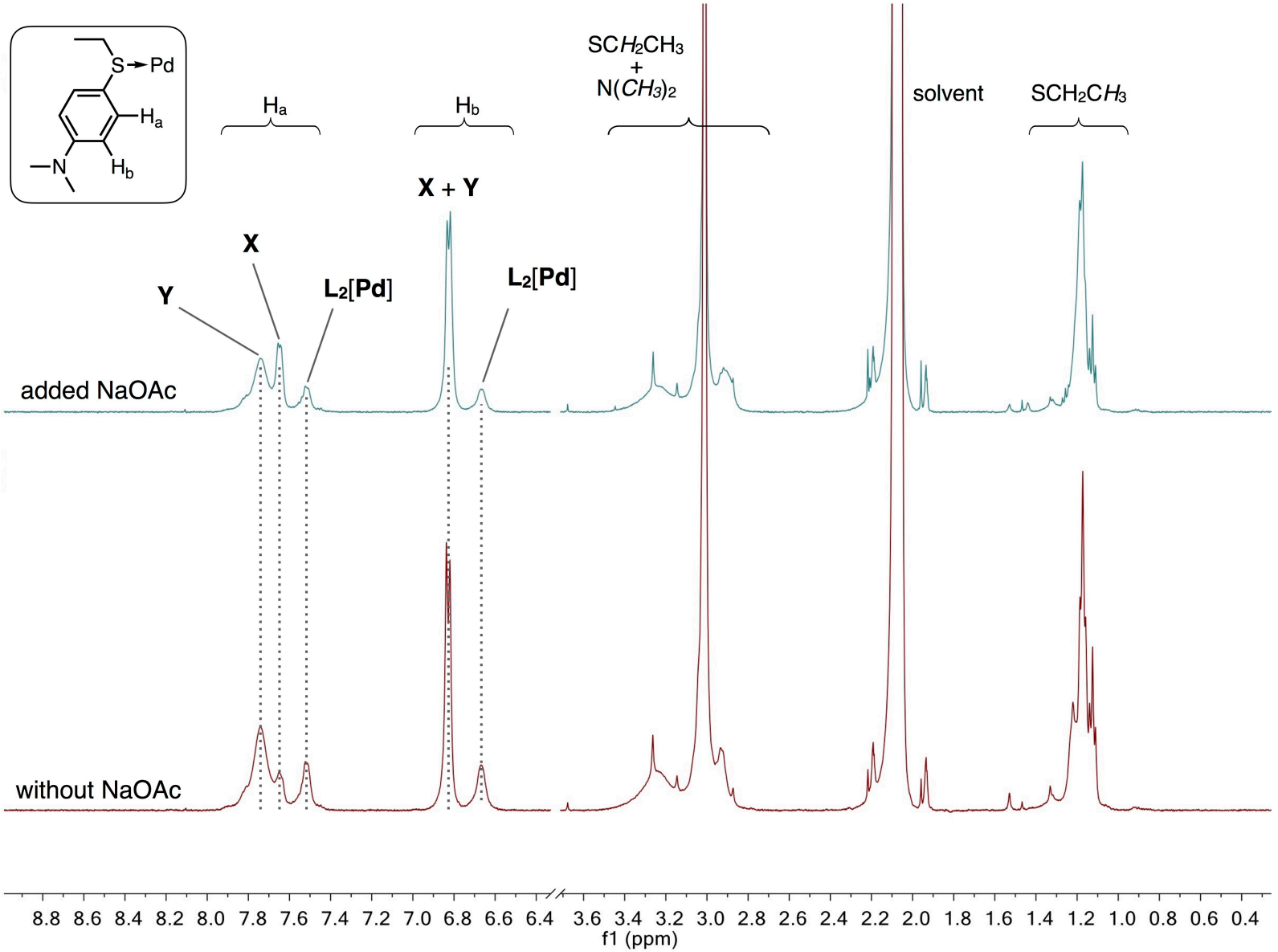


Figure S20. ^{1}H NMR (500 MHz, CD_3CO_2D) of $Pd(OAc)_2$ (8.4 mM) and **L7** (8.4 mM) before (bottom) and after (top) addition of NaOAc (0.17 M).

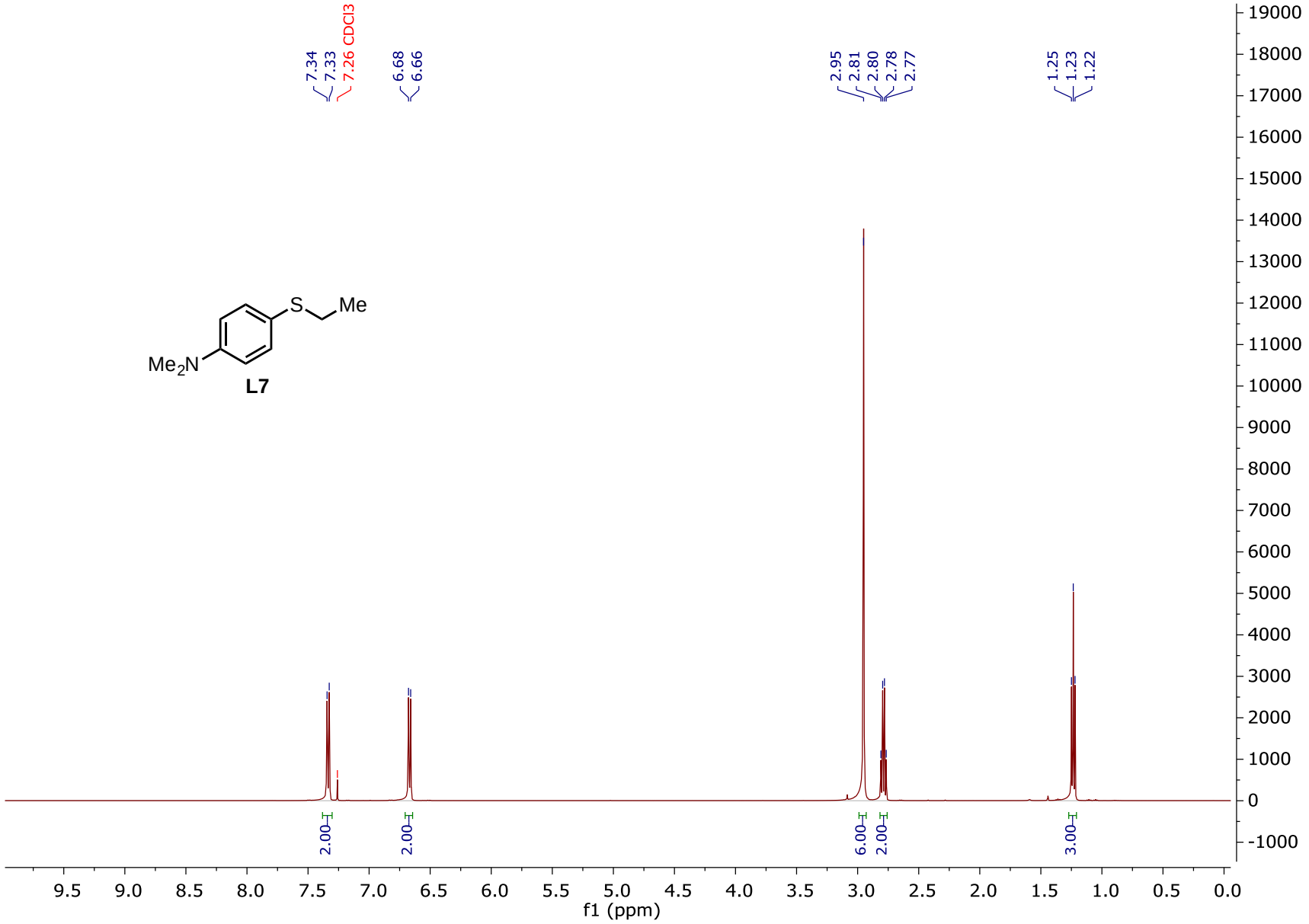


Figure S21. ^{1}H NMR (500 MHz, $CDCl_3$) of **L7**.

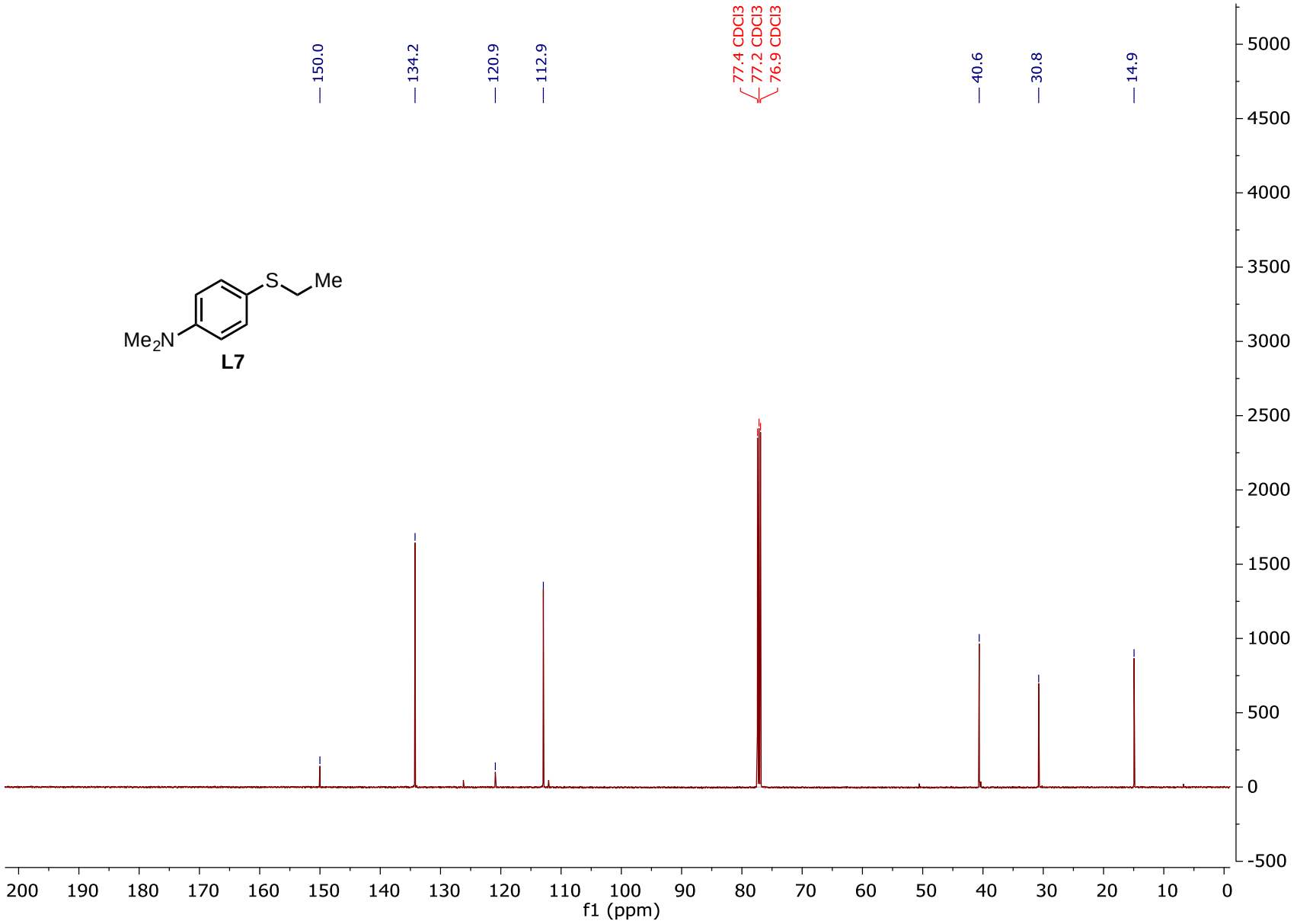


Figure S22. $^{13}C\{^{1}H\}$ NMR (126 MHz, $CDCl_3$) of **L7**.

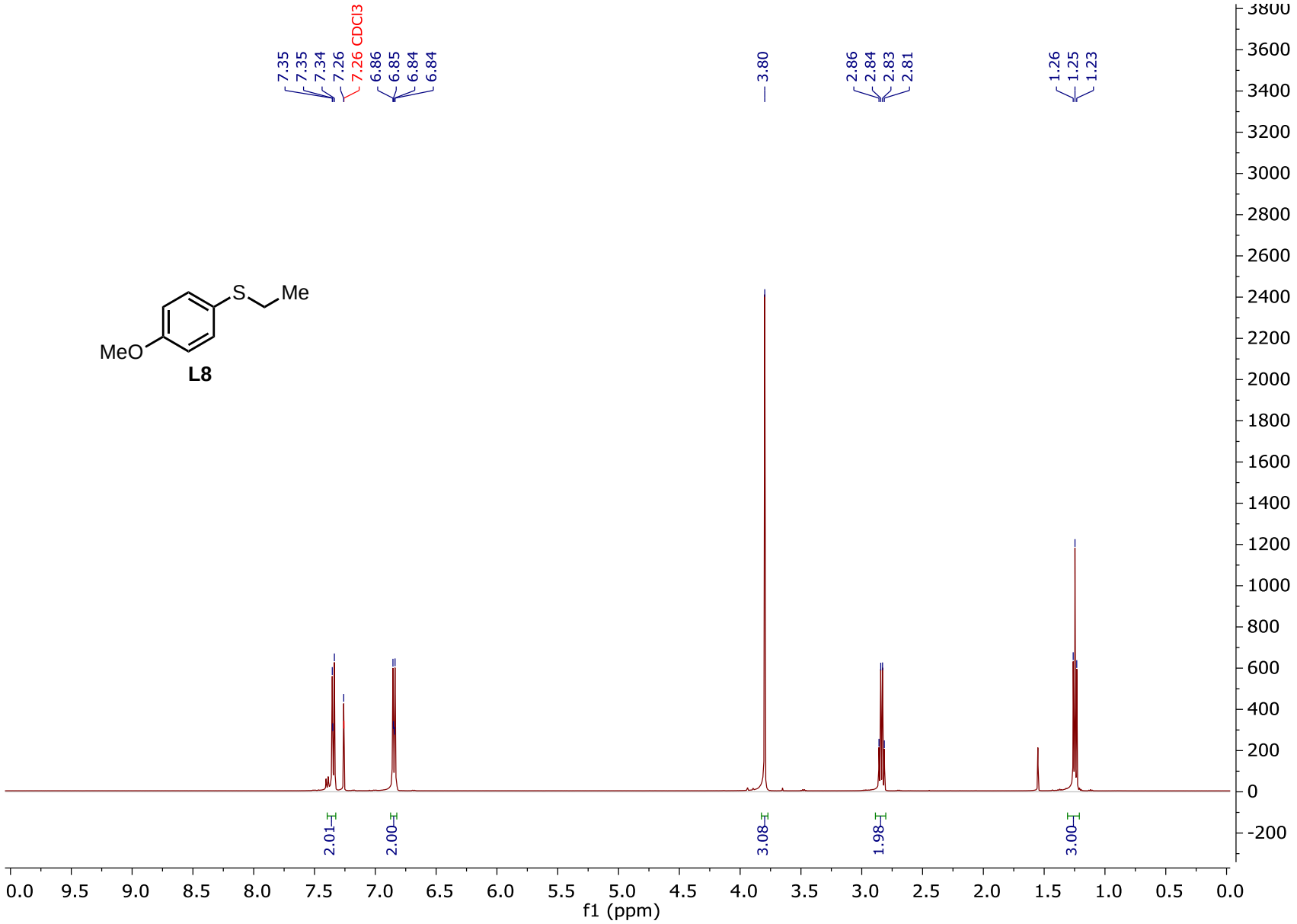


Figure S23. ^{1}H NMR (500 MHz, $CDCl_3$) of **L8**.

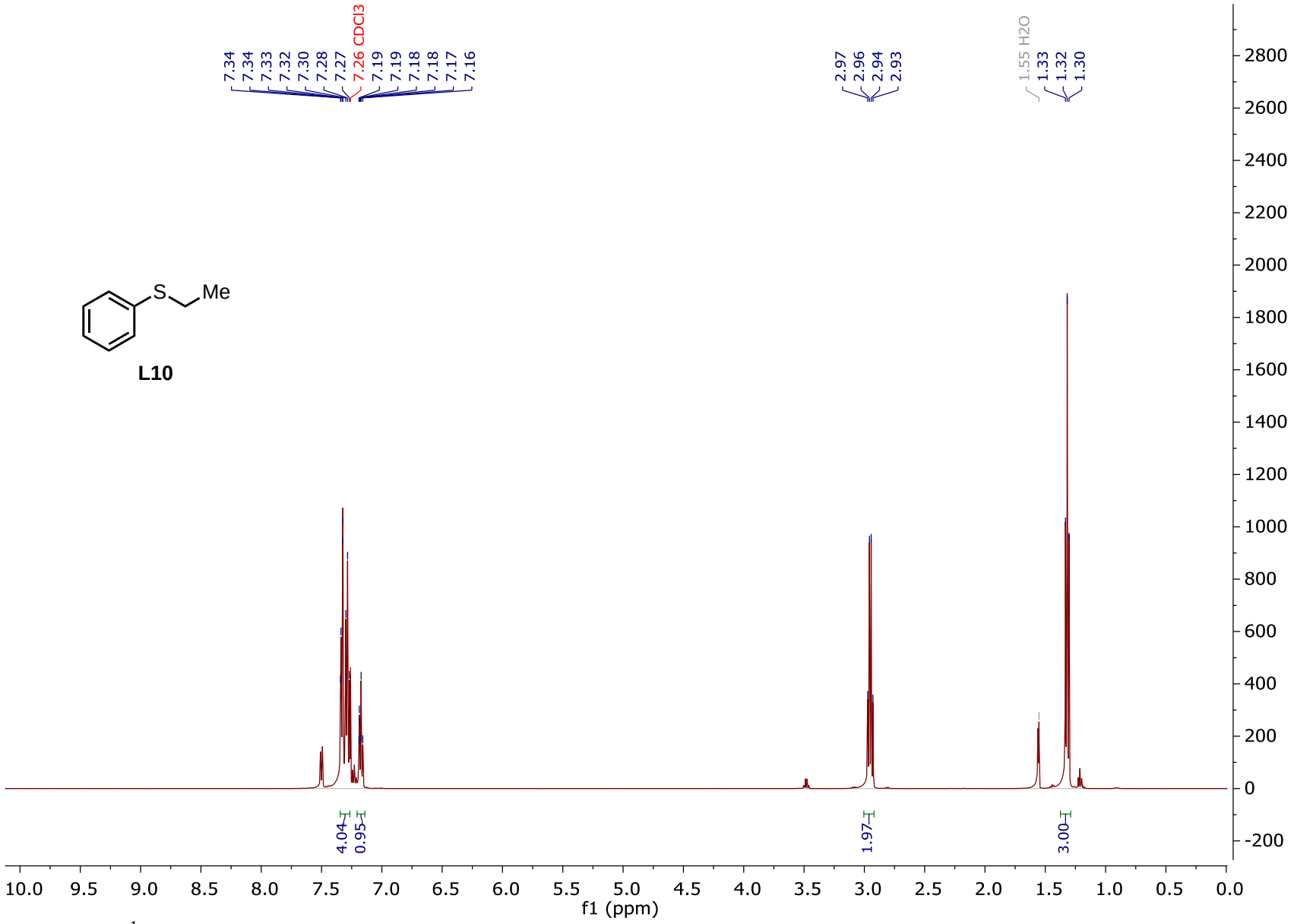


Figure S24. ^{1}H NMR (500 MHz, $CDCl_3$) of **L10**.

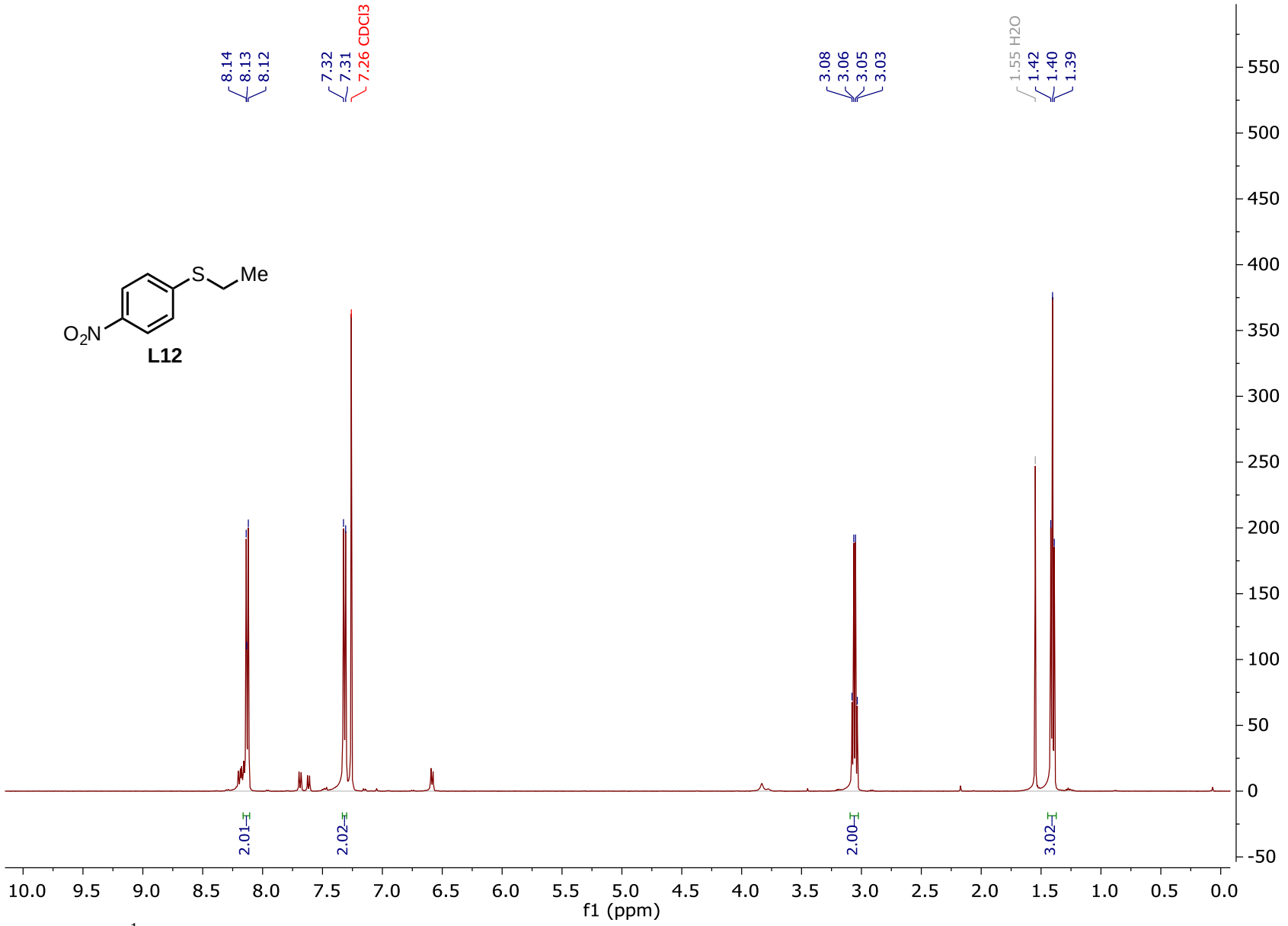


Figure S25. ^{1}H NMR (500 MHz, $CDCl_3$) of **L12**.

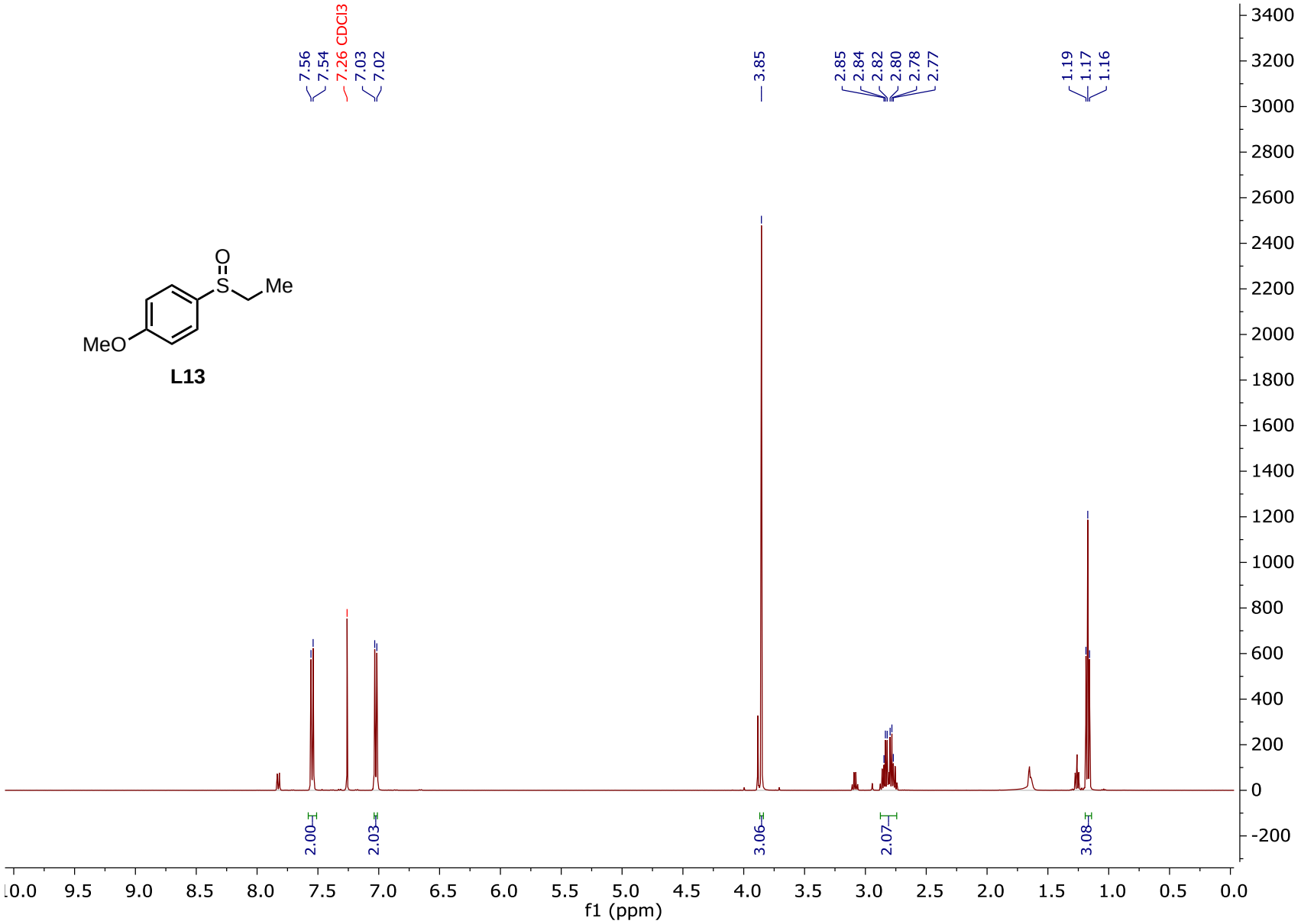


Figure S26. ^{1}H NMR (500 MHz, $CDCl_3$) of **L13**.

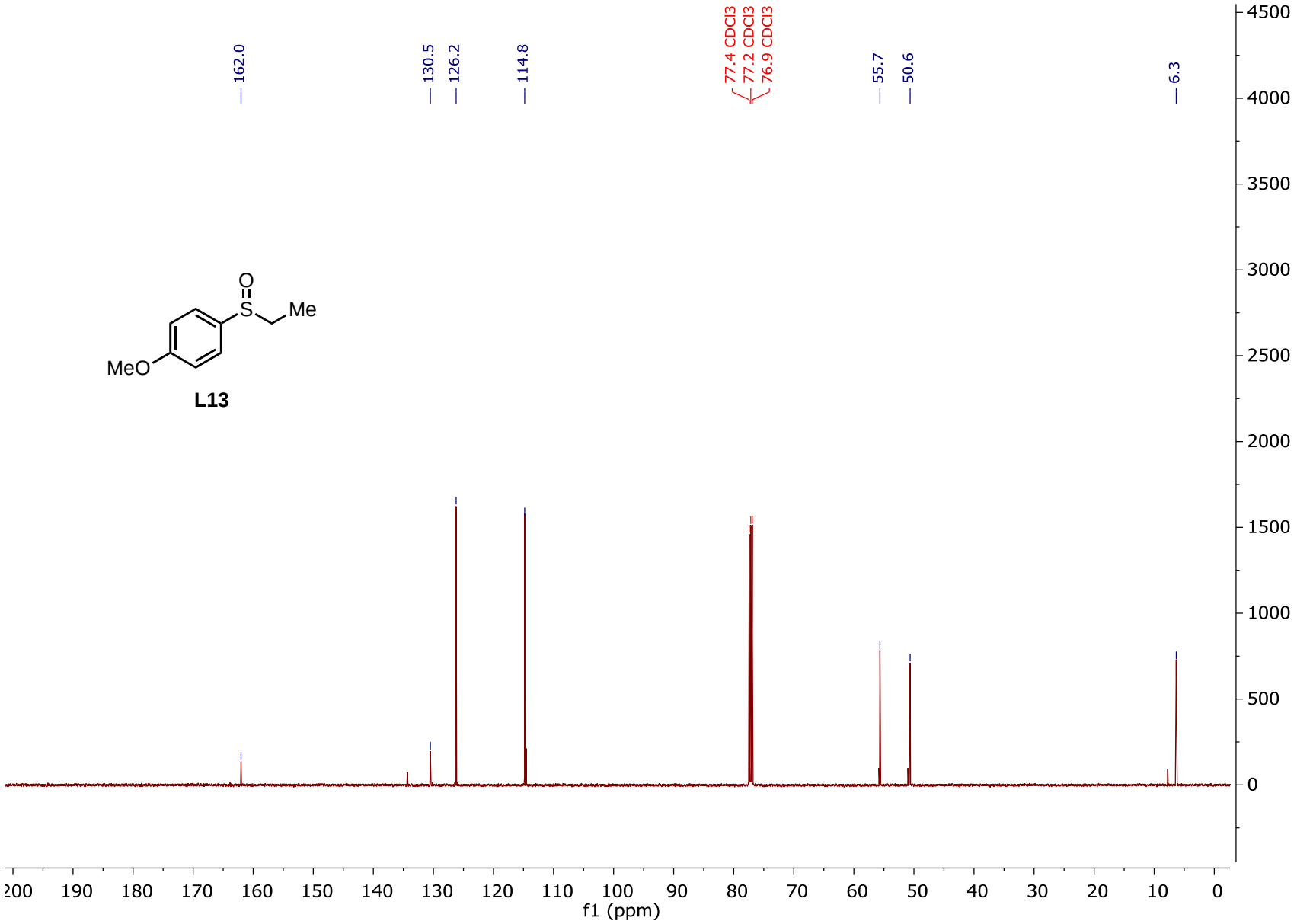


Figure S27. $^{13}C\{^{1}H\}$ NMR (126 MHz, $CDCl_3$) of **L13**.

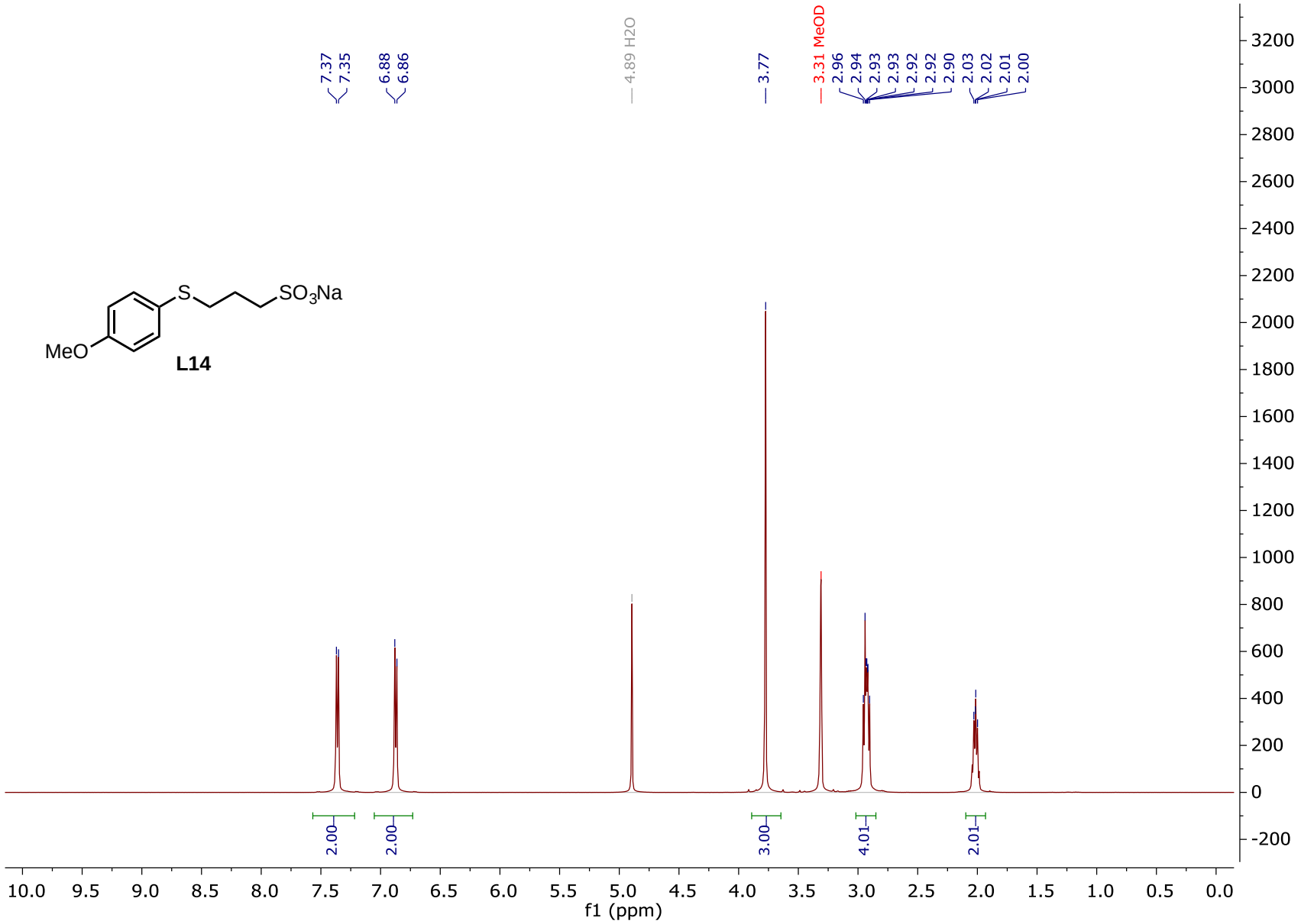


Figure S28. ^{1}H NMR (500 MHz, CD3OD) of **L14**.

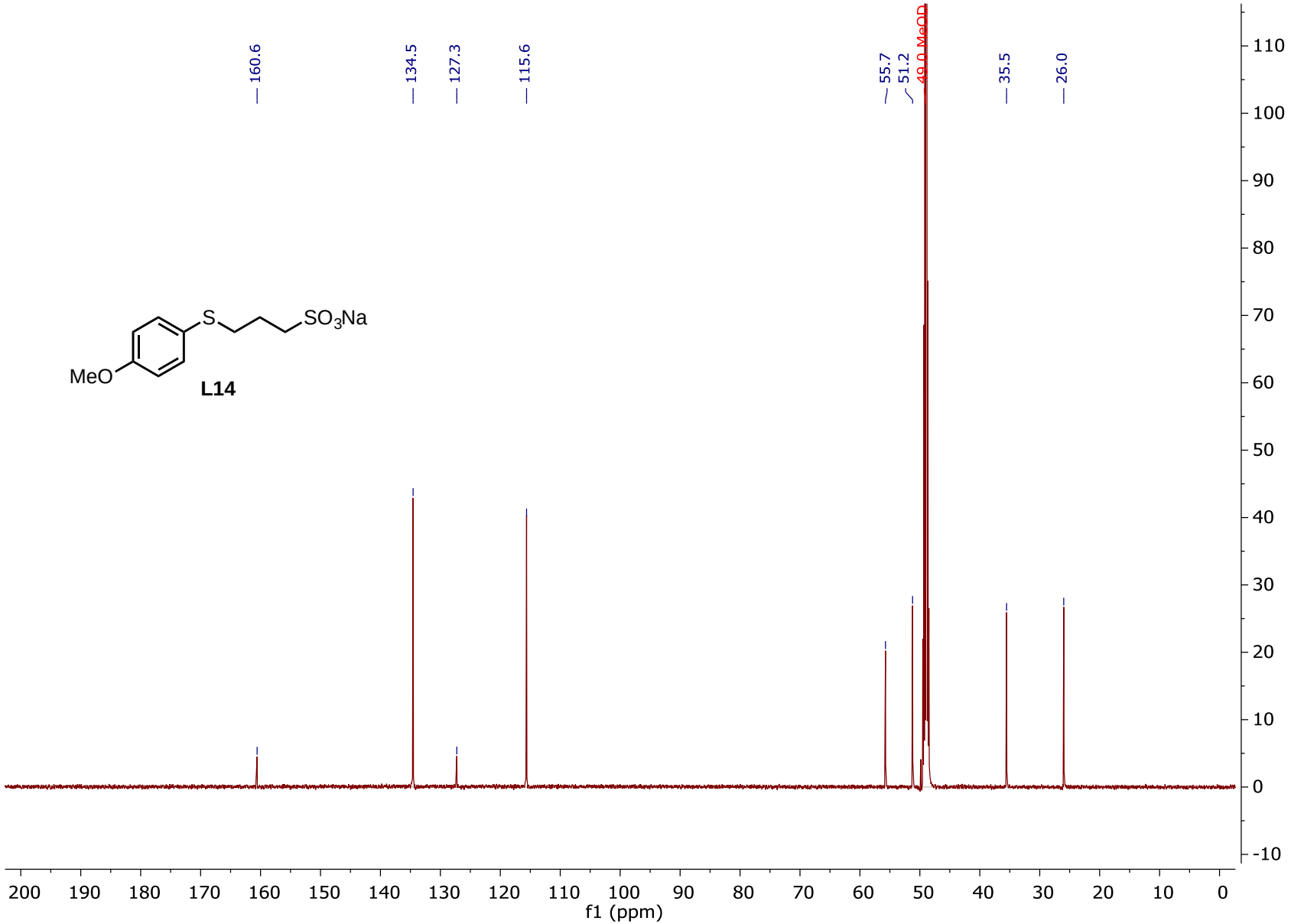


Figure S29. $^{13}C\{^{1}H\}$ NMR (126 MHz, CD3OD) of **L14**.

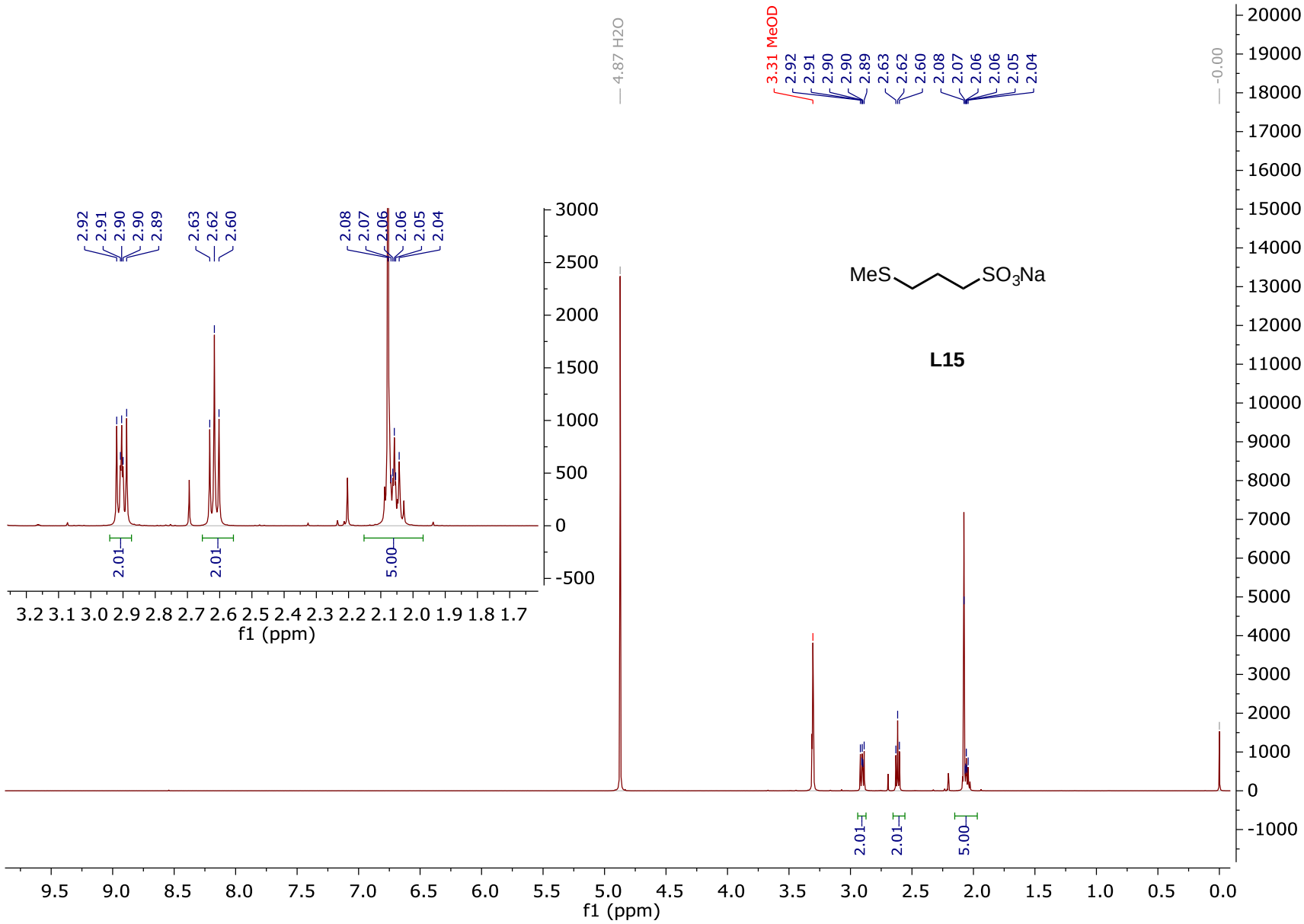


Figure S30. ^{1}H NMR (500 MHz, CD3OD) of **L15**.

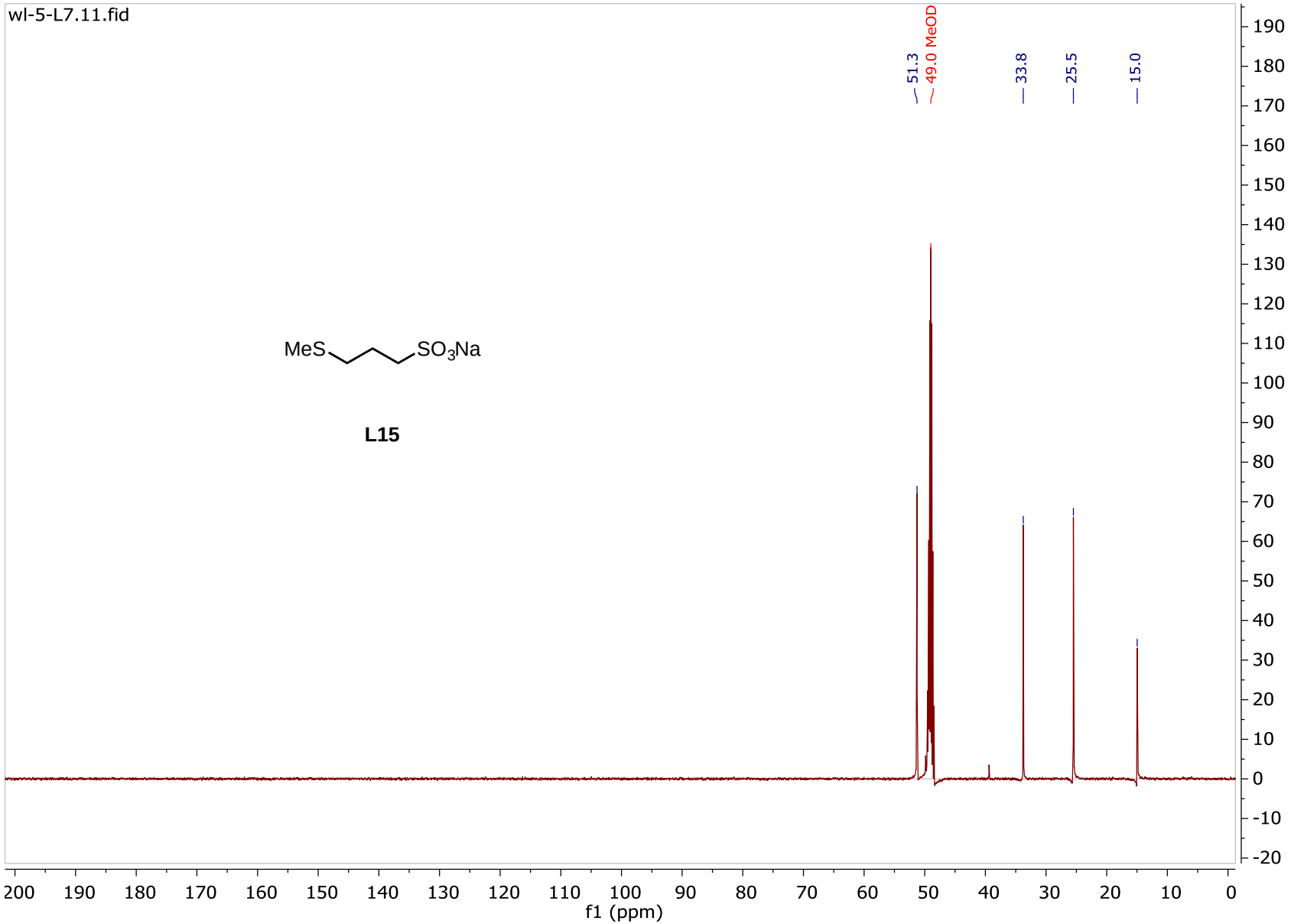


Figure S31. $^{13}C\{^{1}H\}$ NMR (126 MHz, CD3OD) of **L15**.

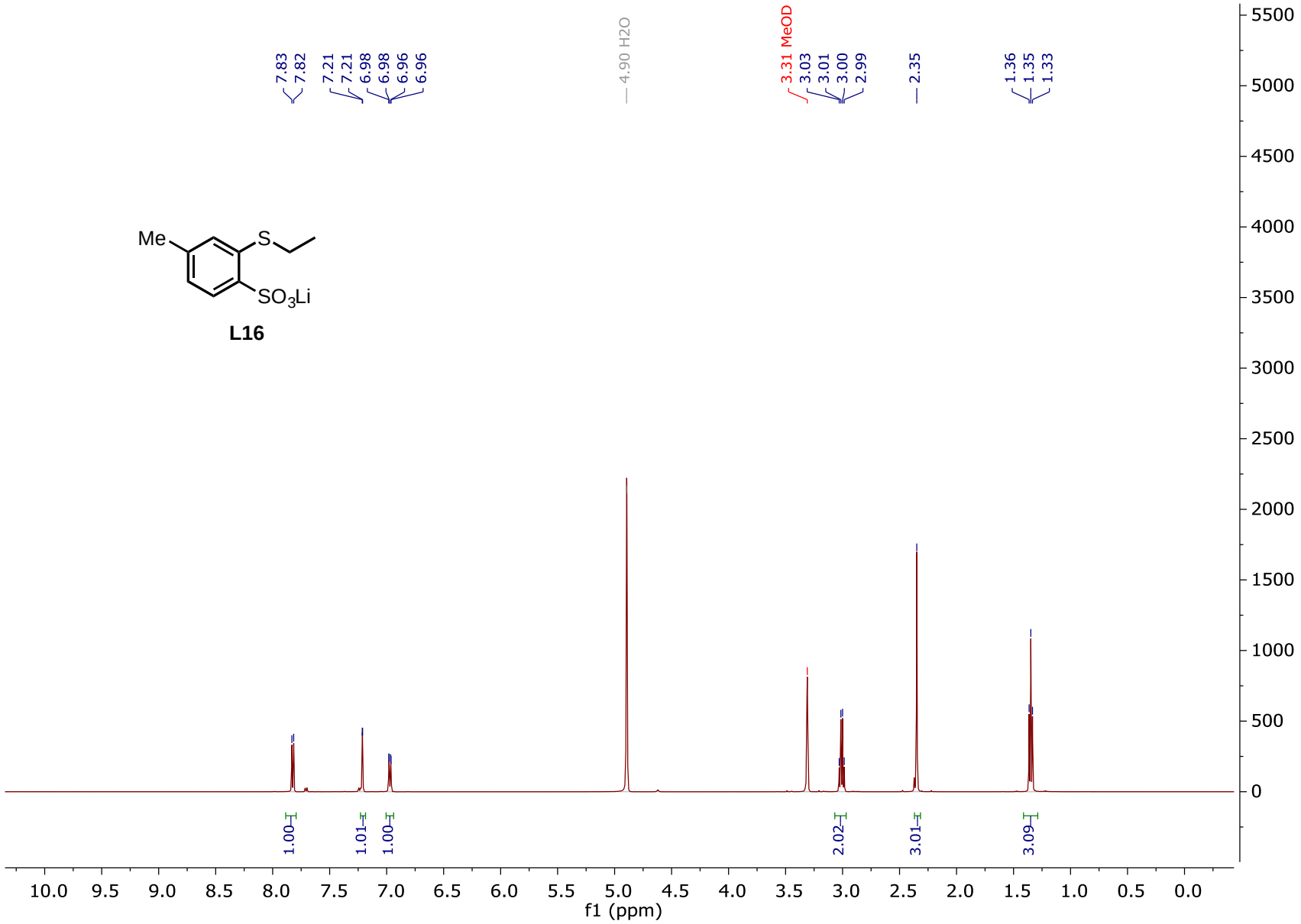


Figure S32. ^{1}H NMR (500 MHz, CD3OD) of **L16**.

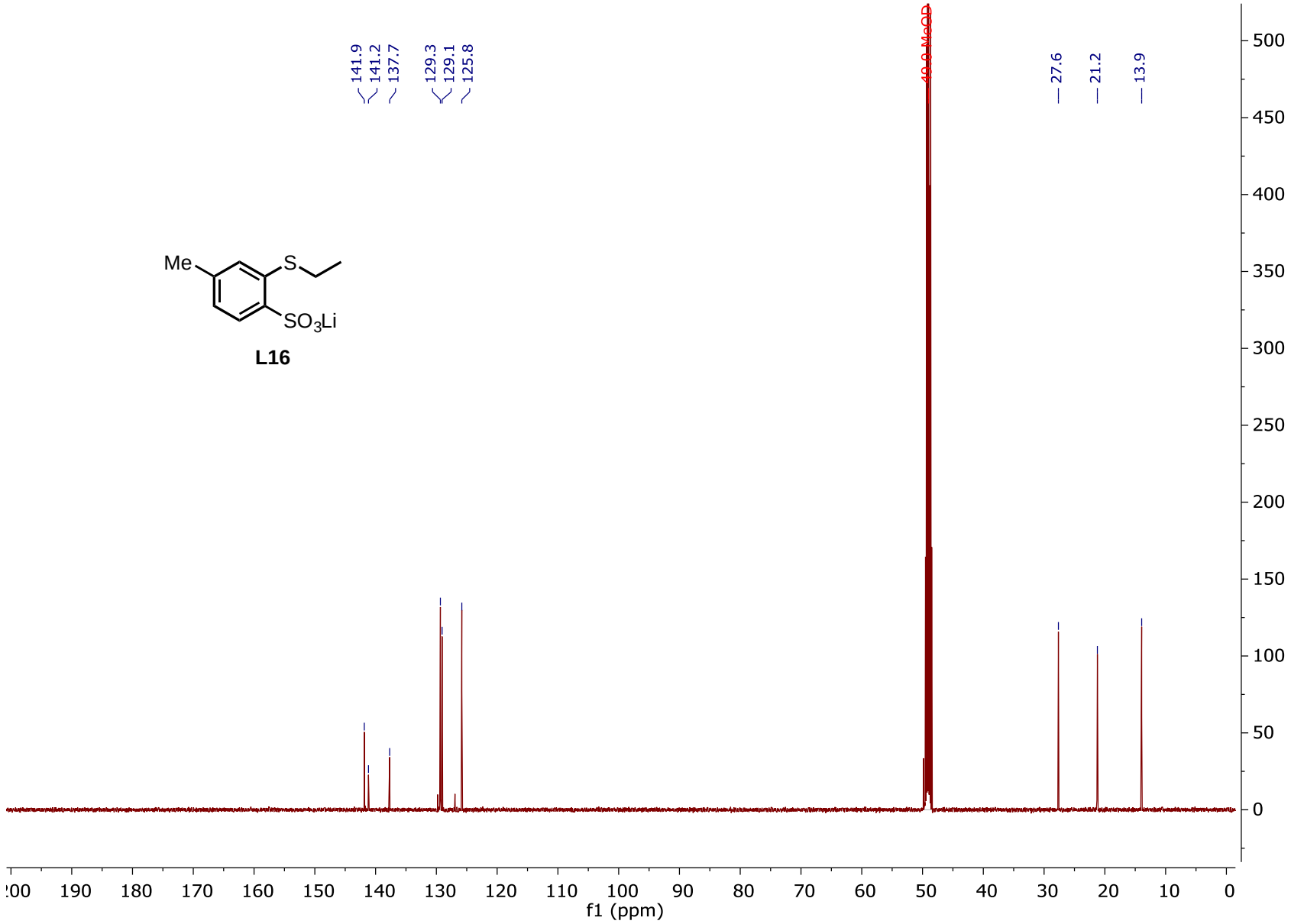


Figure S33. $^{13}C\{^{1}H\}$ NMR (126 MHz, CD3OD) of **L16**.

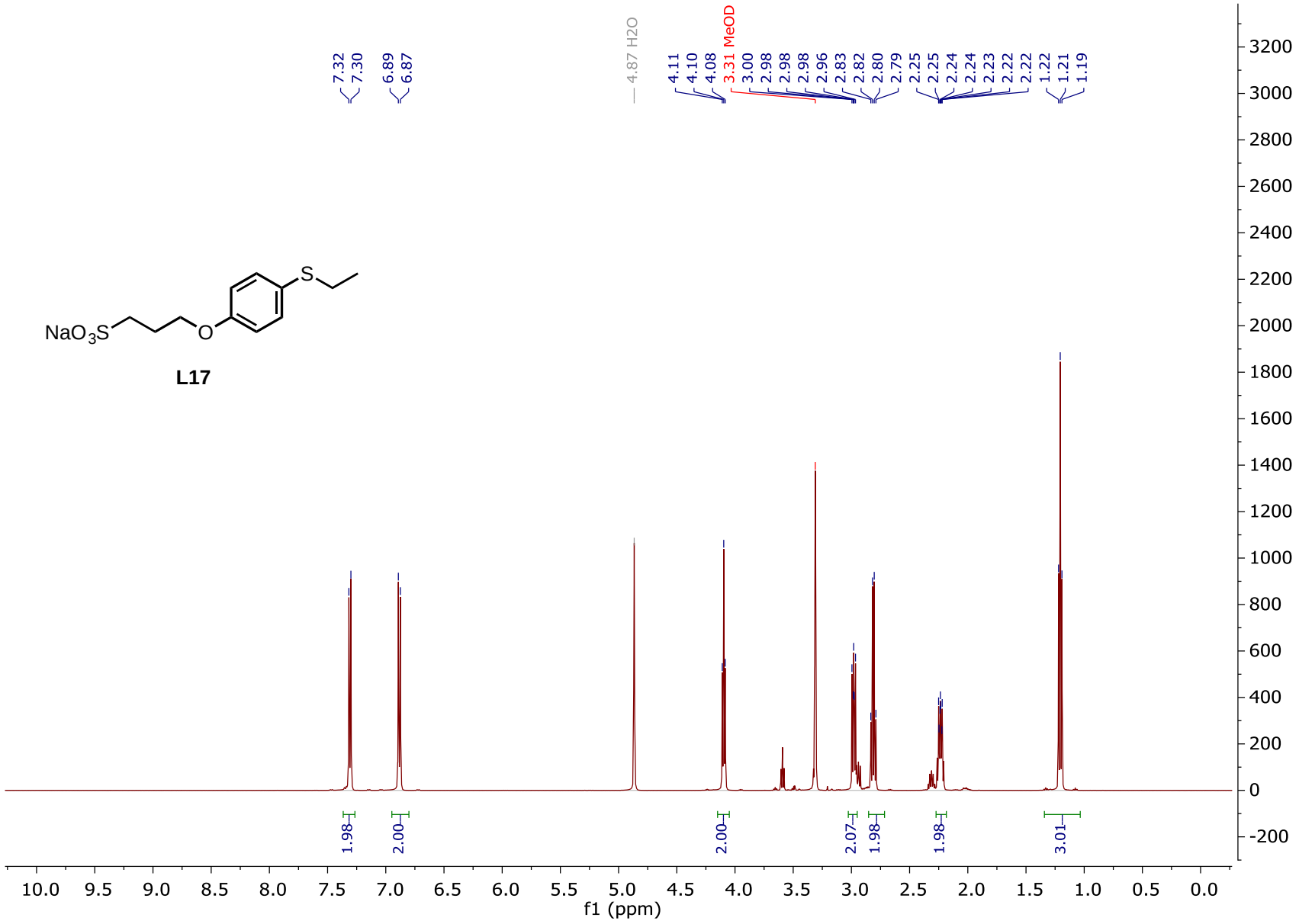


Figure S34. ^{1}H NMR (500 MHz, CD3OD) of **L17**.

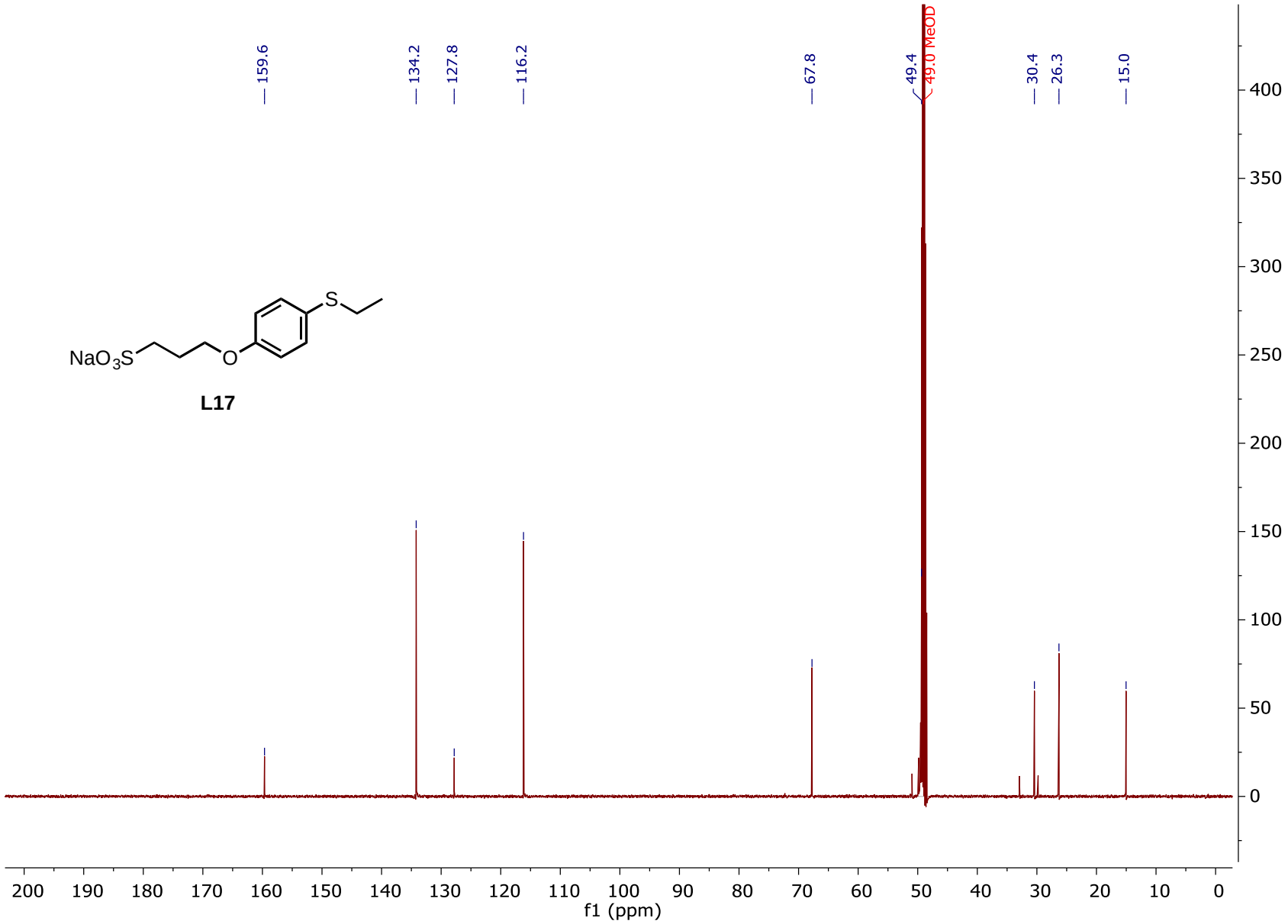


Figure S35. $^{13}C\{^{1}H\}$ NMR (126 MHz, CD3OD) of **L17**.

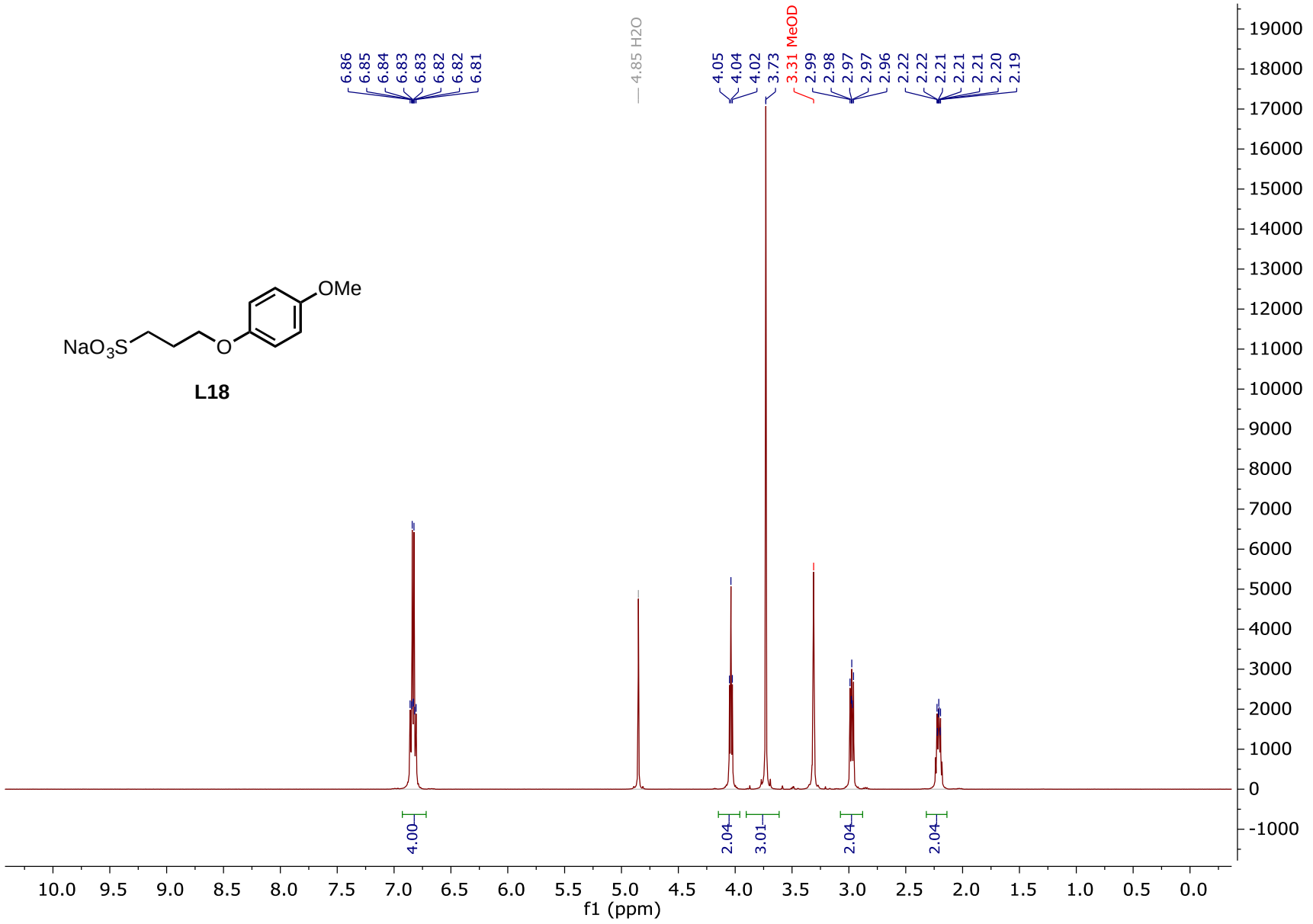


Figure S36. ^{1}H NMR (500 MHz, CD3OD) of **L18**.

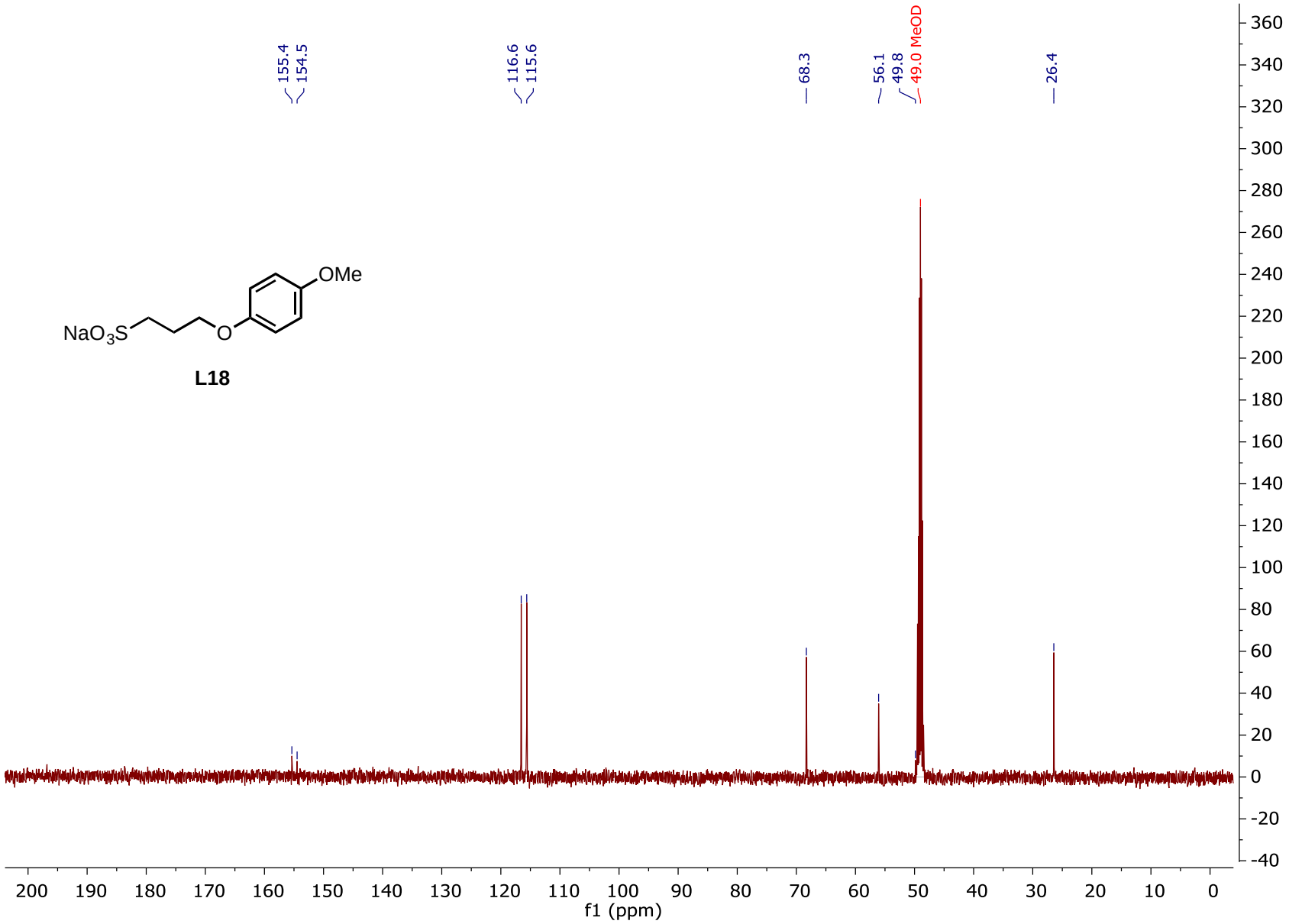


Figure S37. $^{13}C\{^{1}H\}$ NMR (126 MHz, CD3OD) of **L18**.

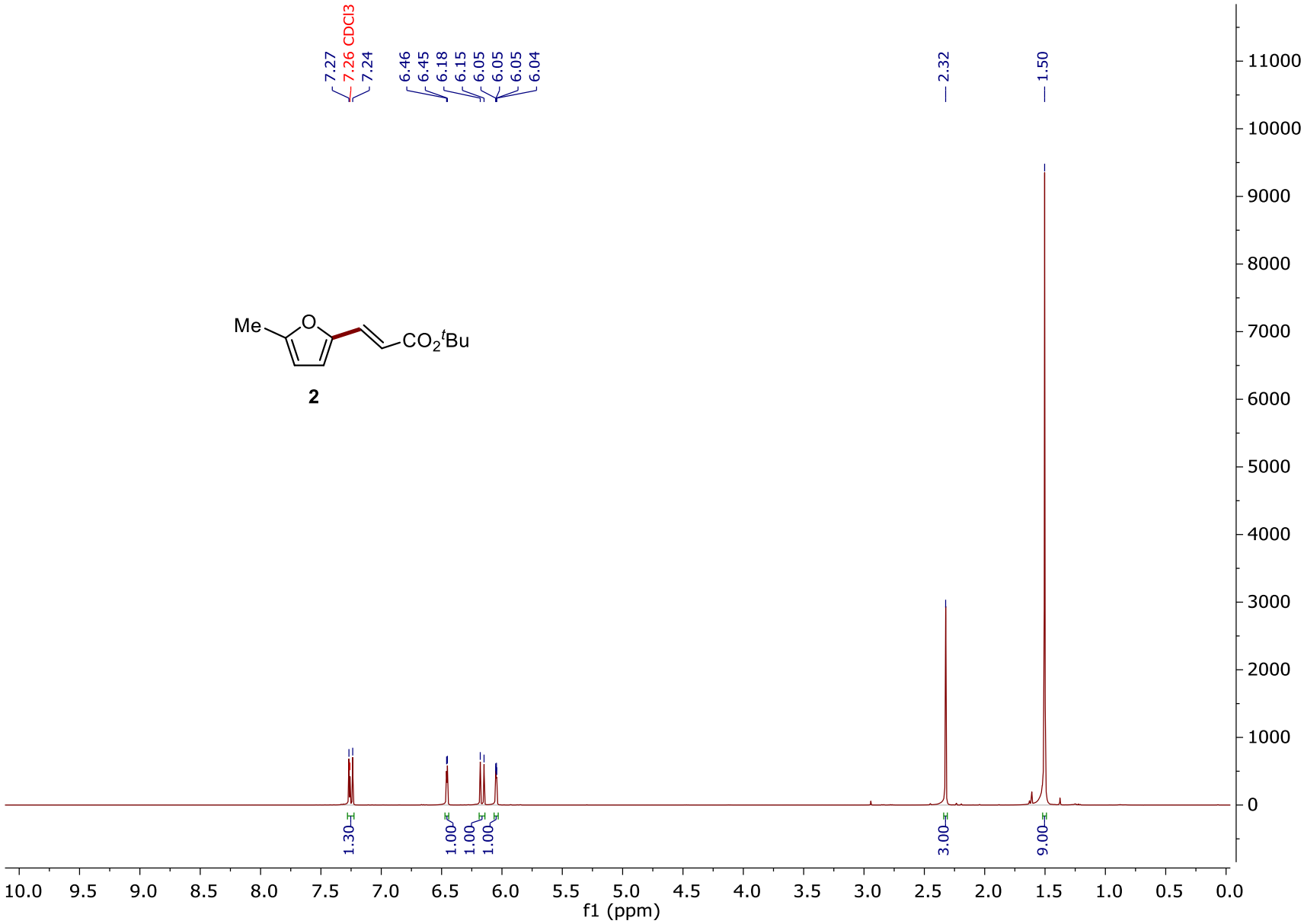


Figure S38. ^{1}H NMR (500 MHz, $CDCl_3$) of **2**.

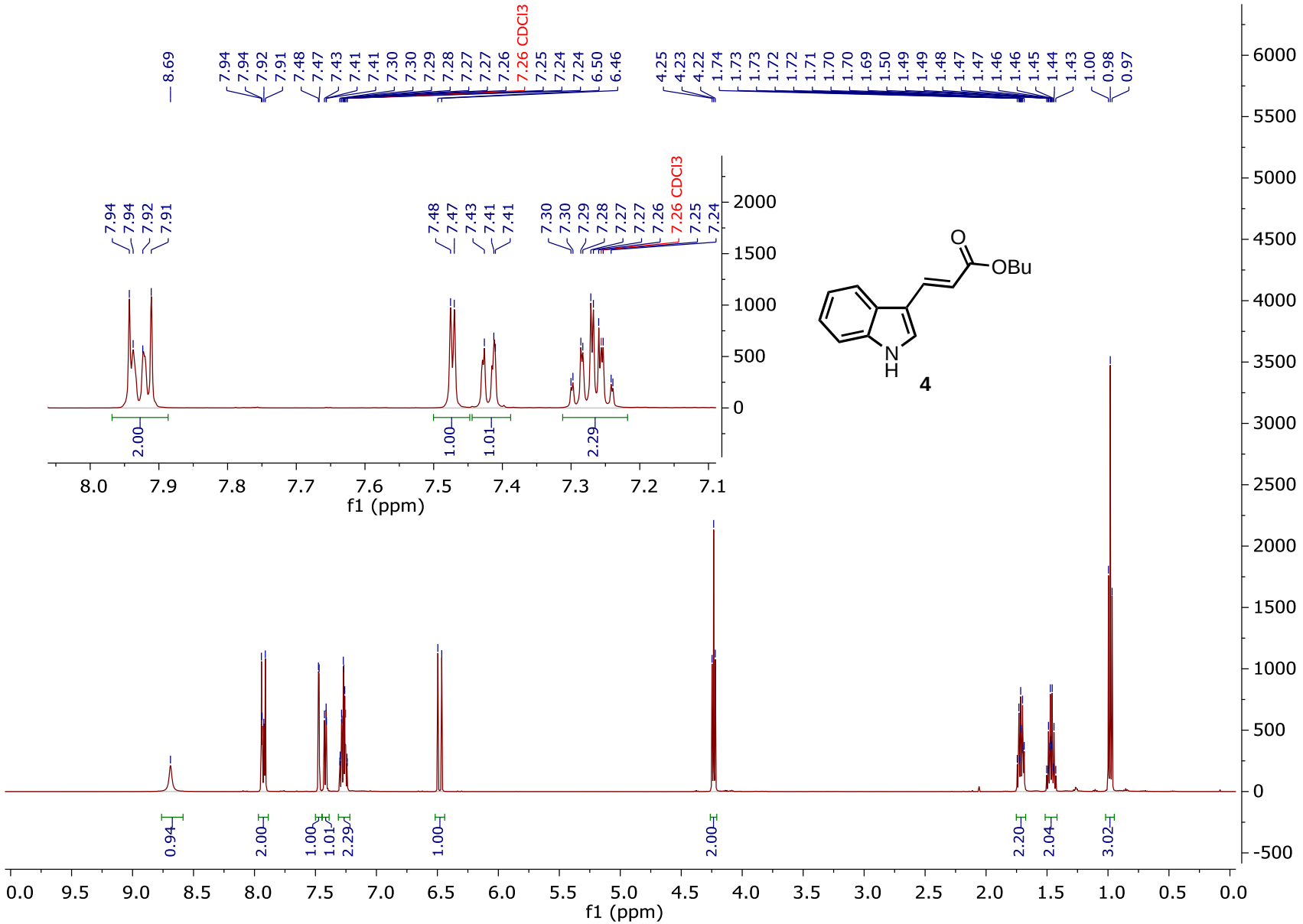


Figure S39. ^{1}H NMR (500 MHz, $CDCl_3$) of **4**.

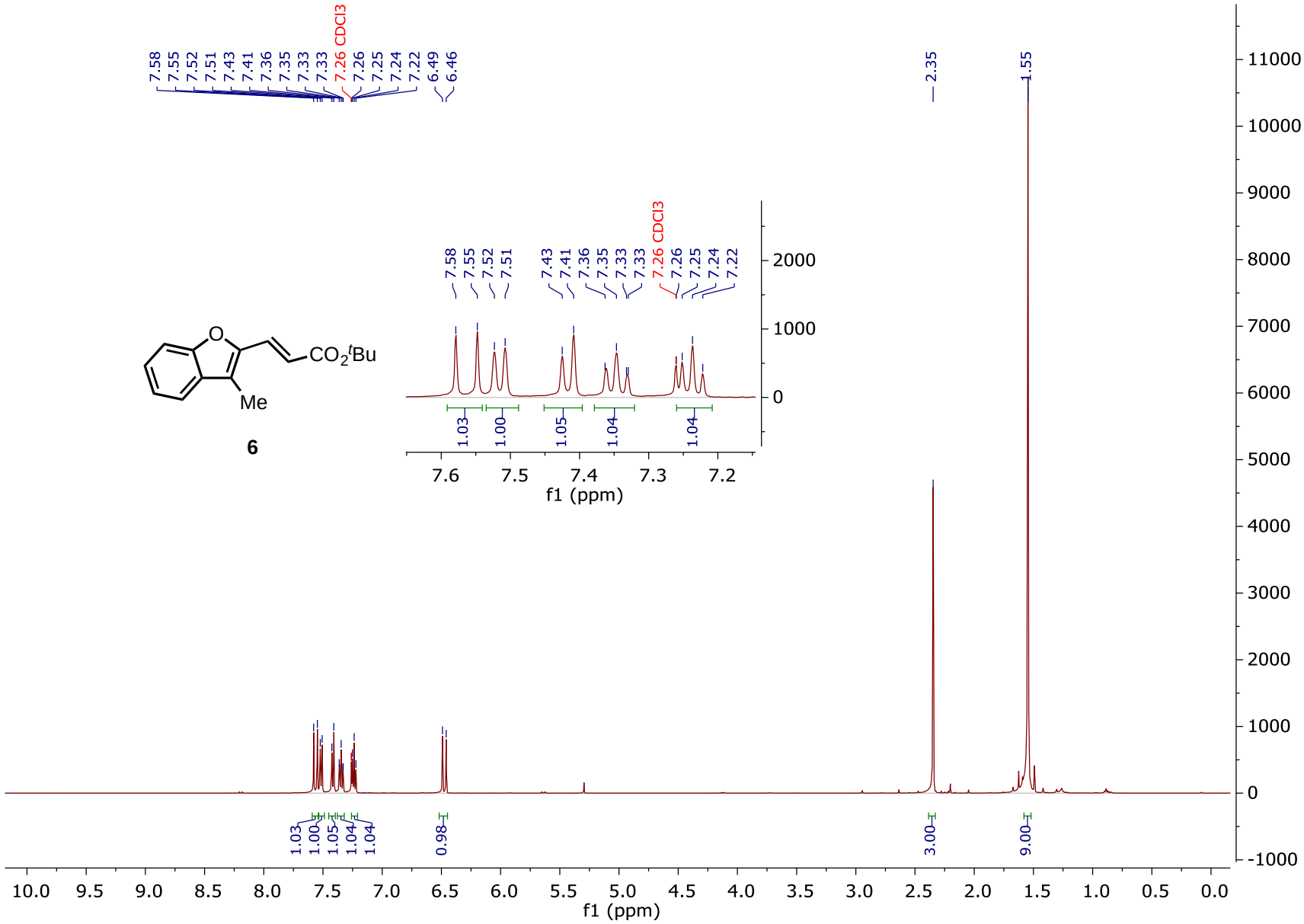


Figure S40. ^{1}H NMR (500 MHz, $CDCl_3$) of **6**.

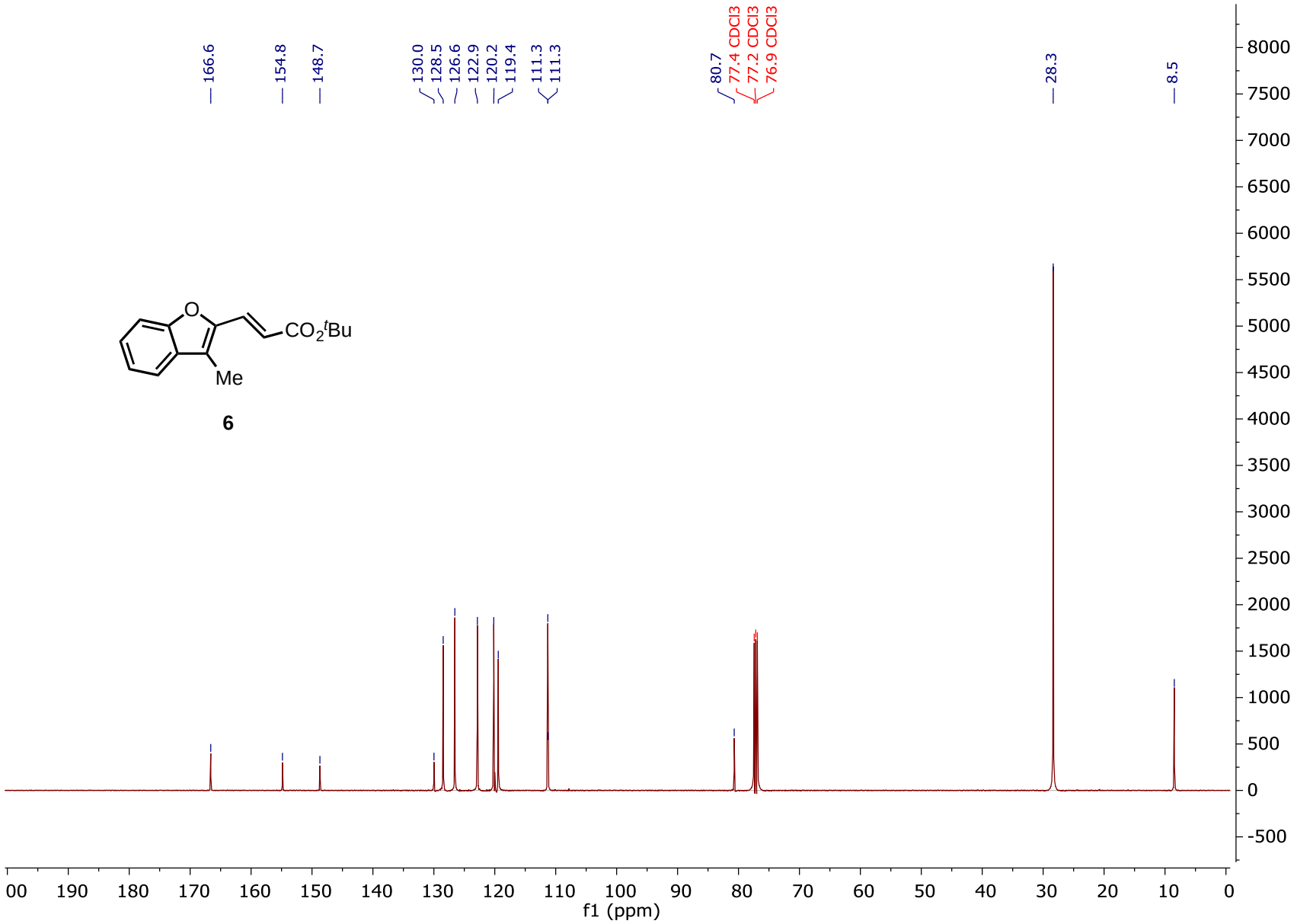


Figure S41. $^{13}C\{^{1}H\}$ NMR (126 MHz, $CDCl_3$) of **6**.

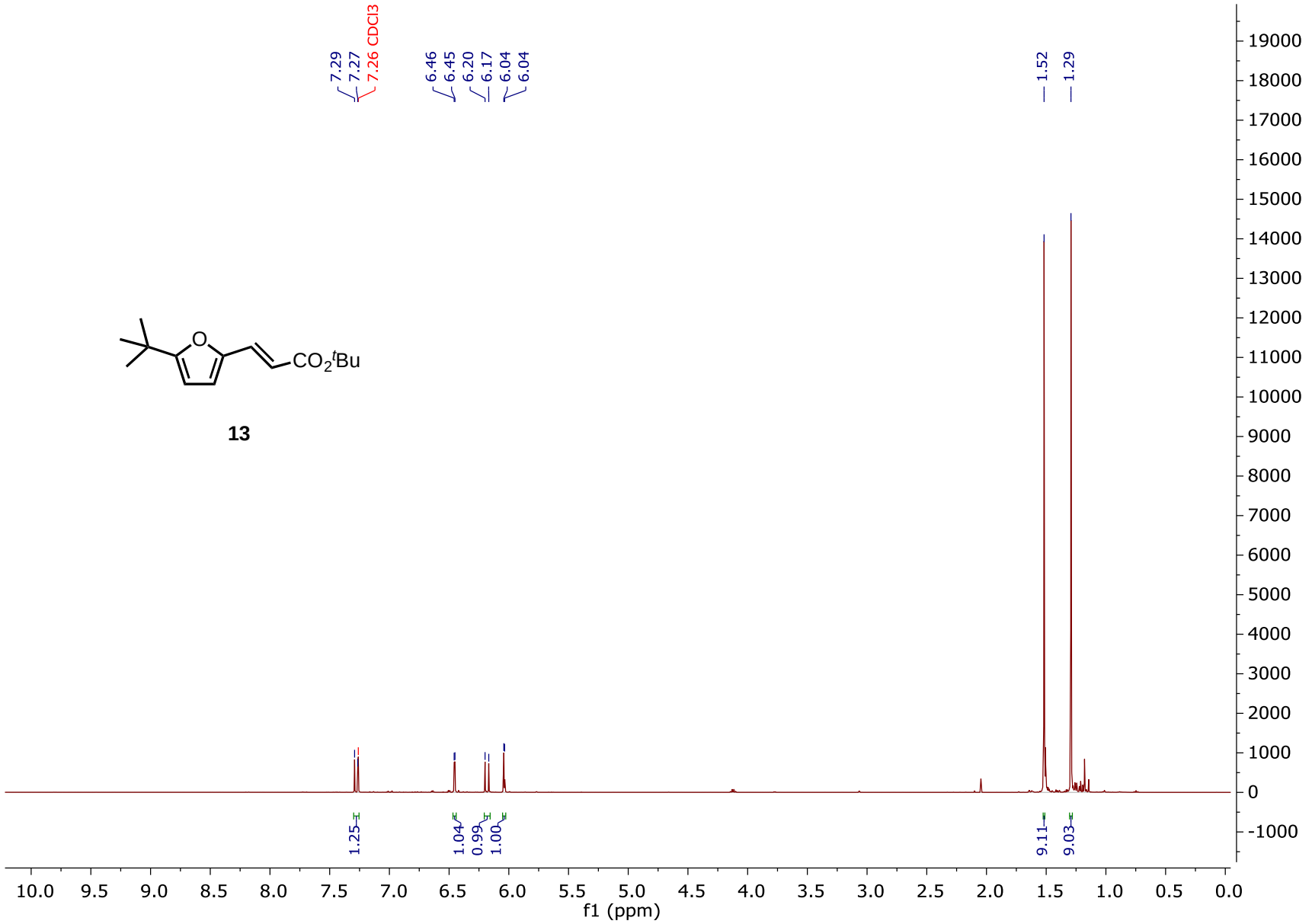


Figure S42. ^{1}H NMR (500 MHz, $CDCl_3$) of **13**.

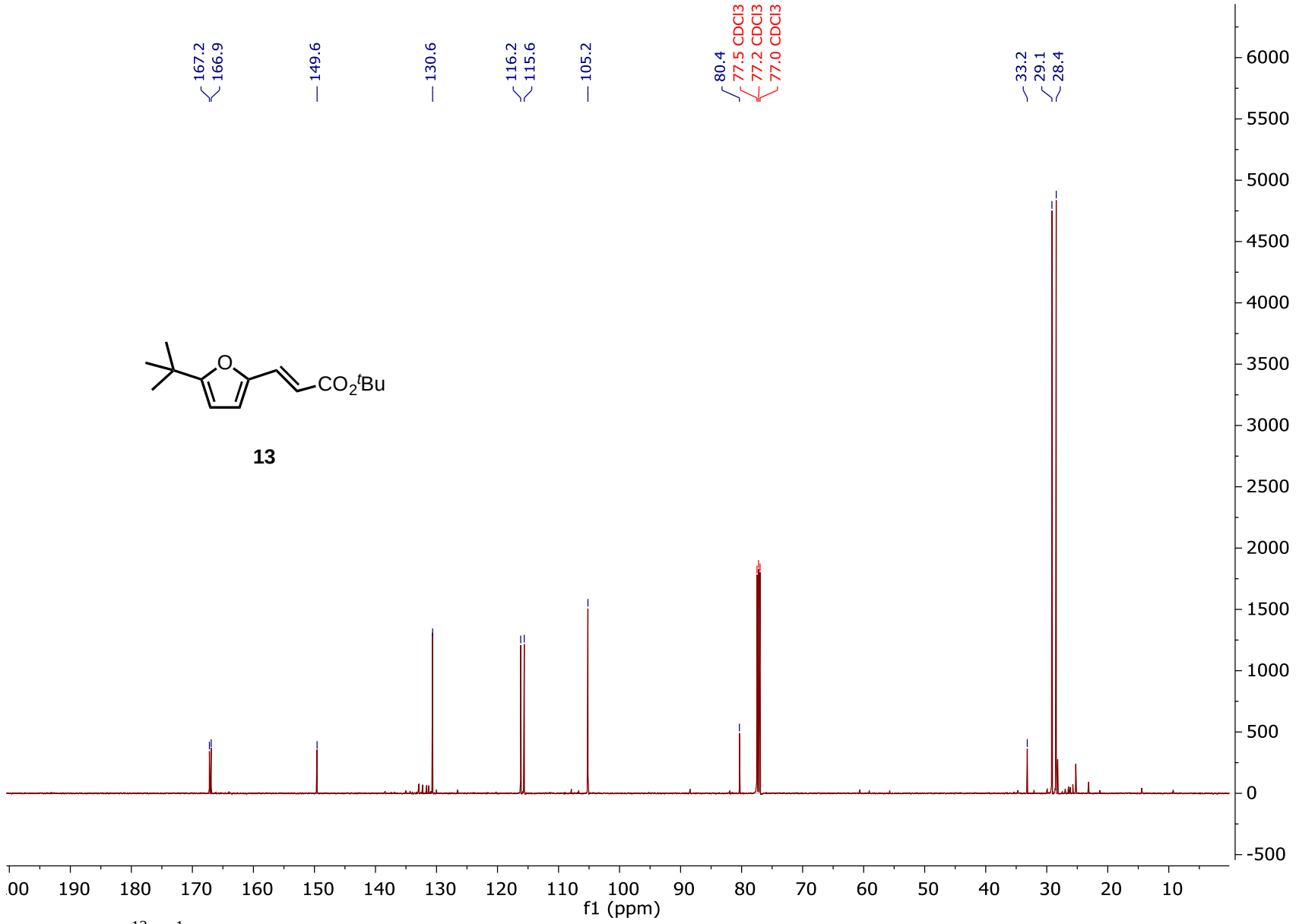


Figure S43. $^{13}C\{^{1}H\}$ NMR (126 MHz, $CDCl_3$) of **13**.

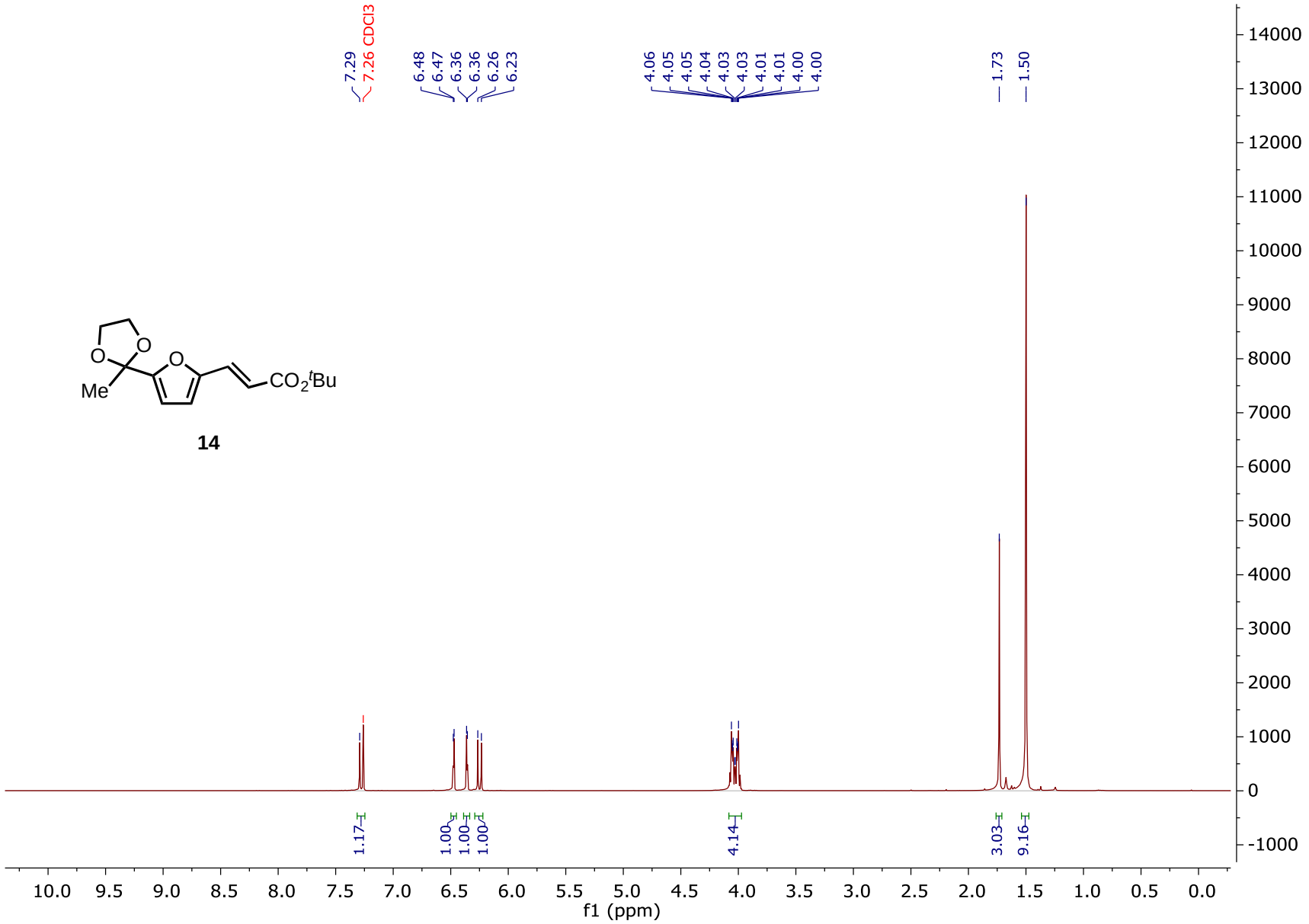


Figure S44. ^{1}H NMR (500 MHz, $CDCl_3$) of **14**.

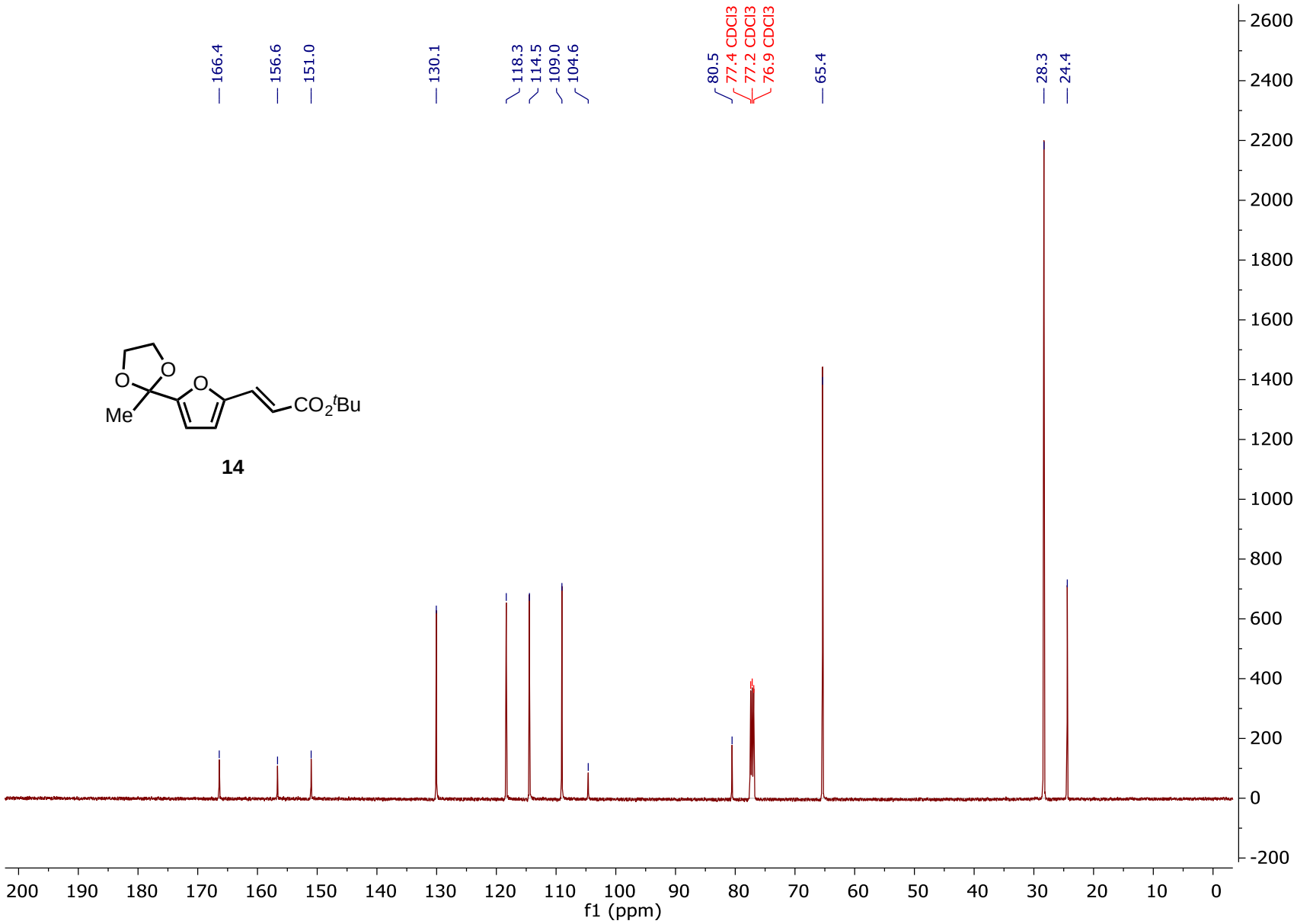


Figure S45. $^{13}C\{^{1}H\}$ NMR (126 MHz, $CDCl_3$) of **14**.

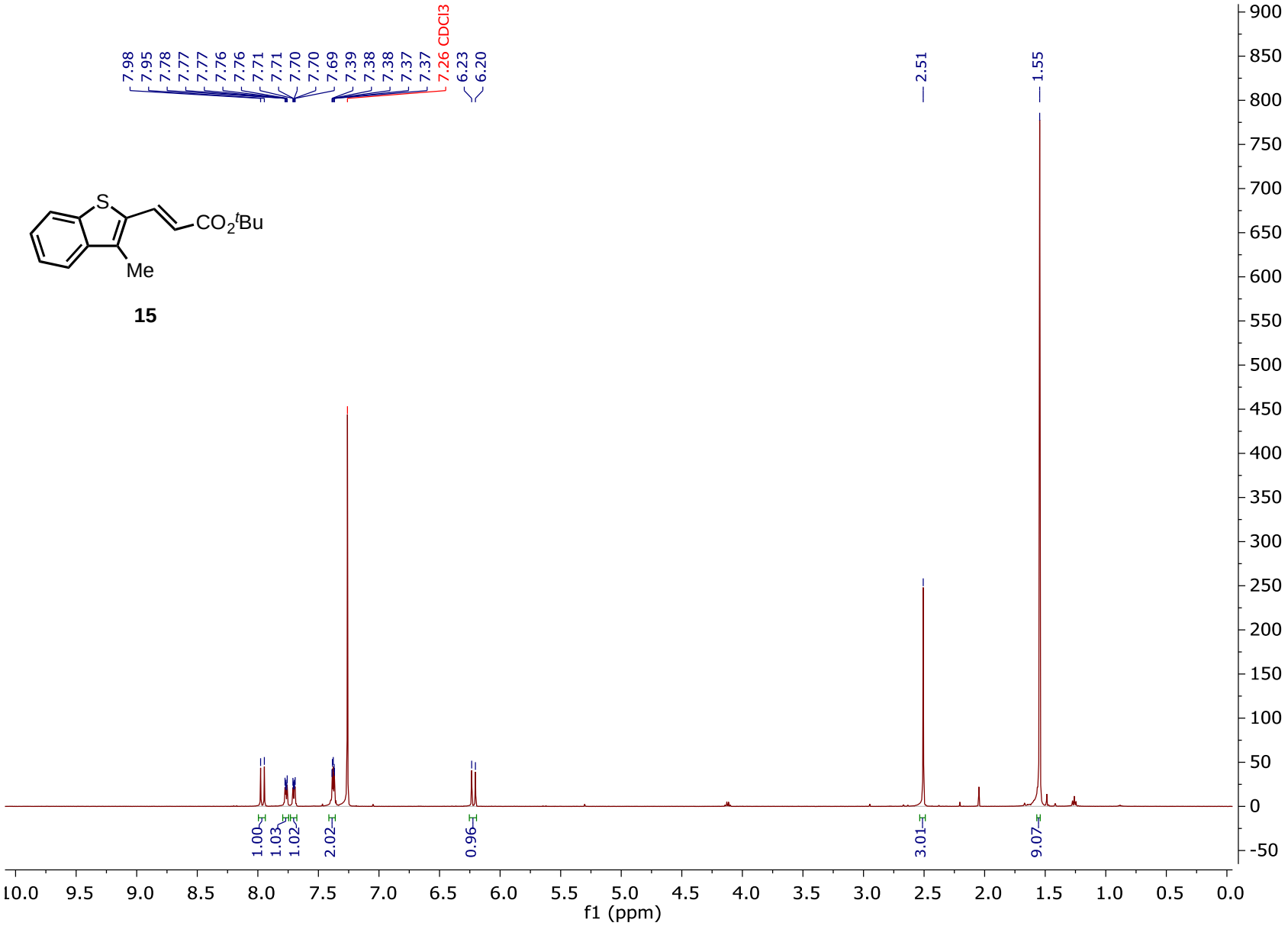


Figure S46. ^{1}H NMR (500 MHz, $CDCl_3$) of **15**.

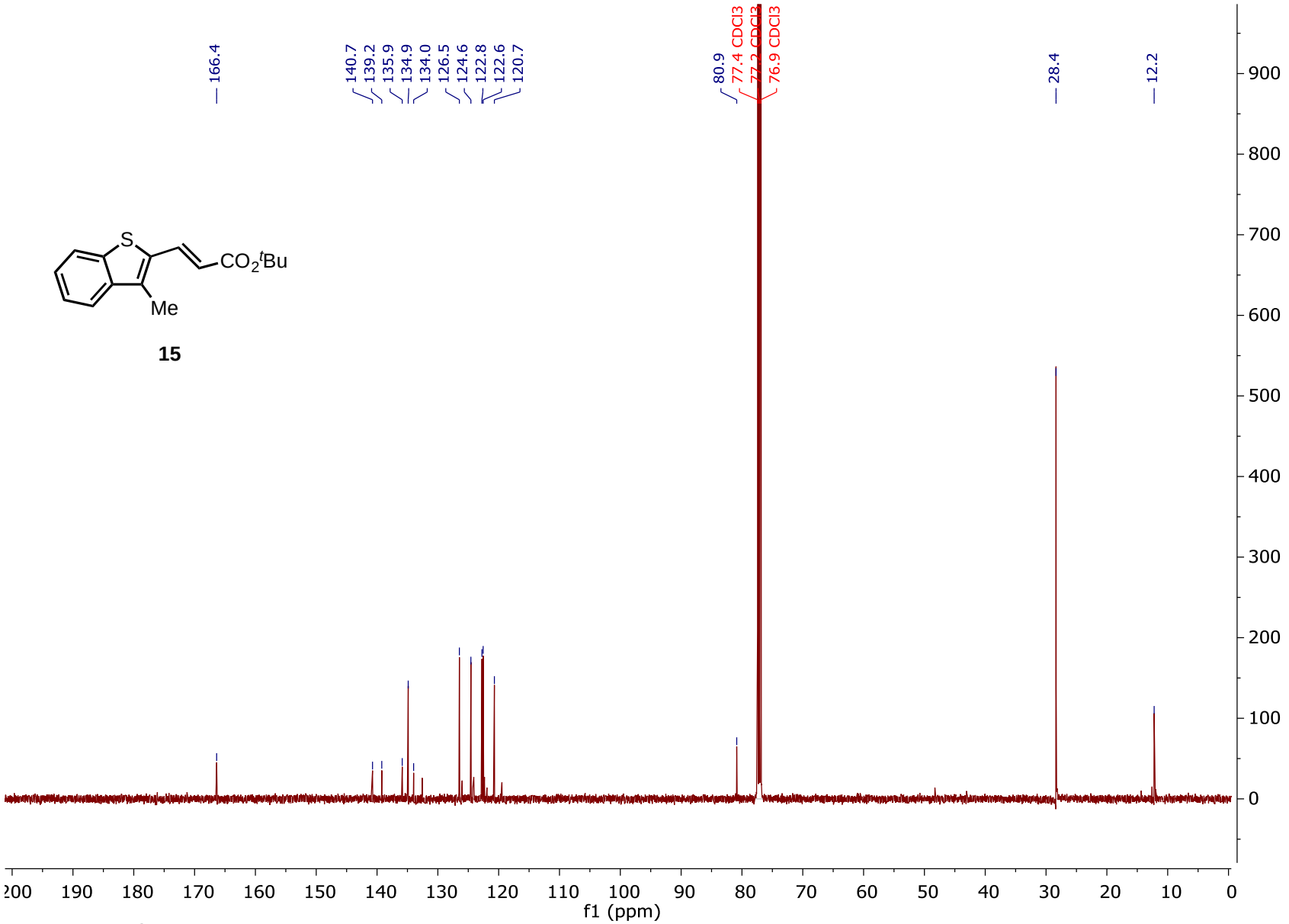


Figure S47. $^{13}C\{^{1}H\}$ NMR (126 MHz, $CDCl_3$) of **15**.

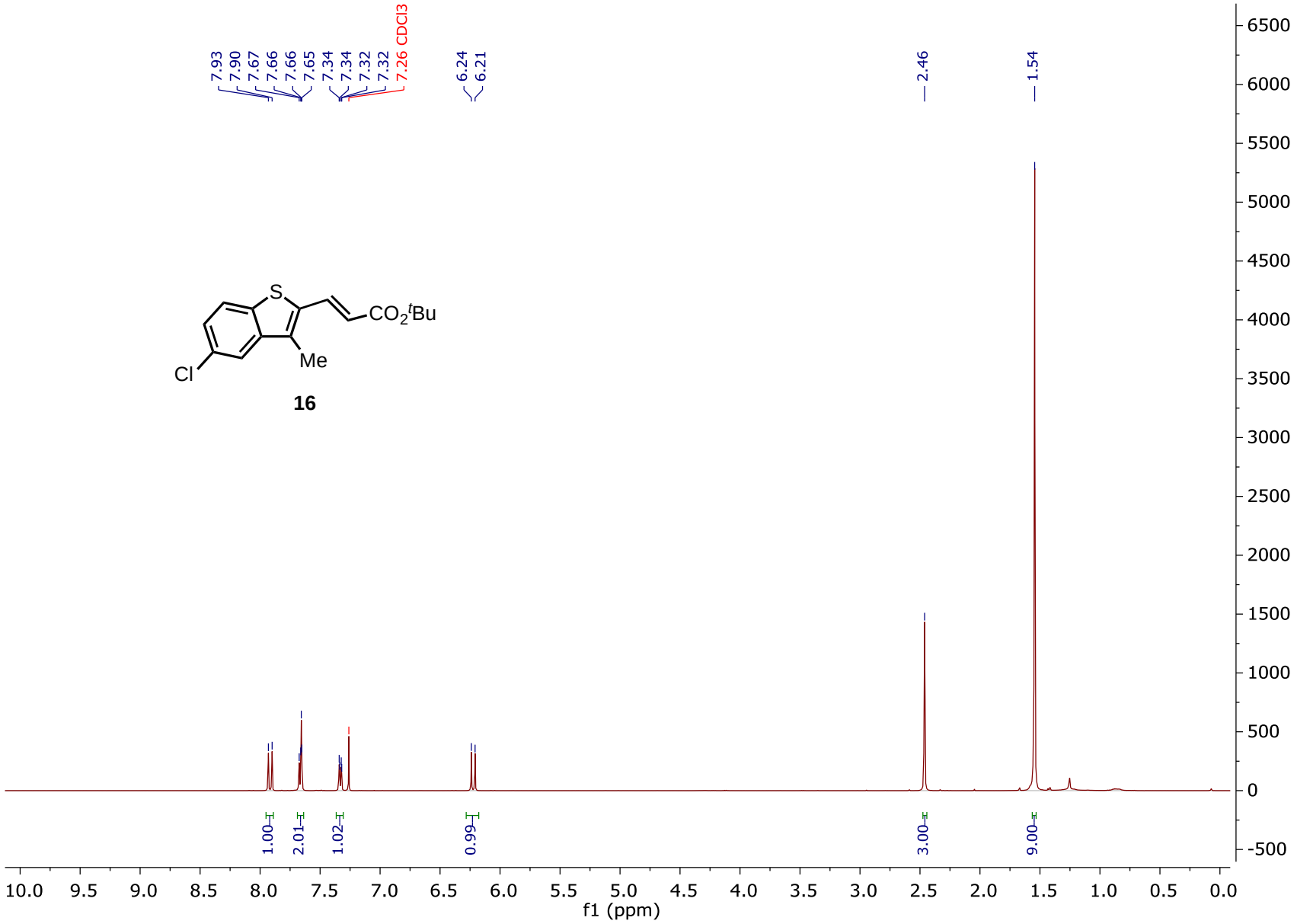


Figure S48. ^{1}H NMR (500 MHz, $CDCl_3$) of **16**.

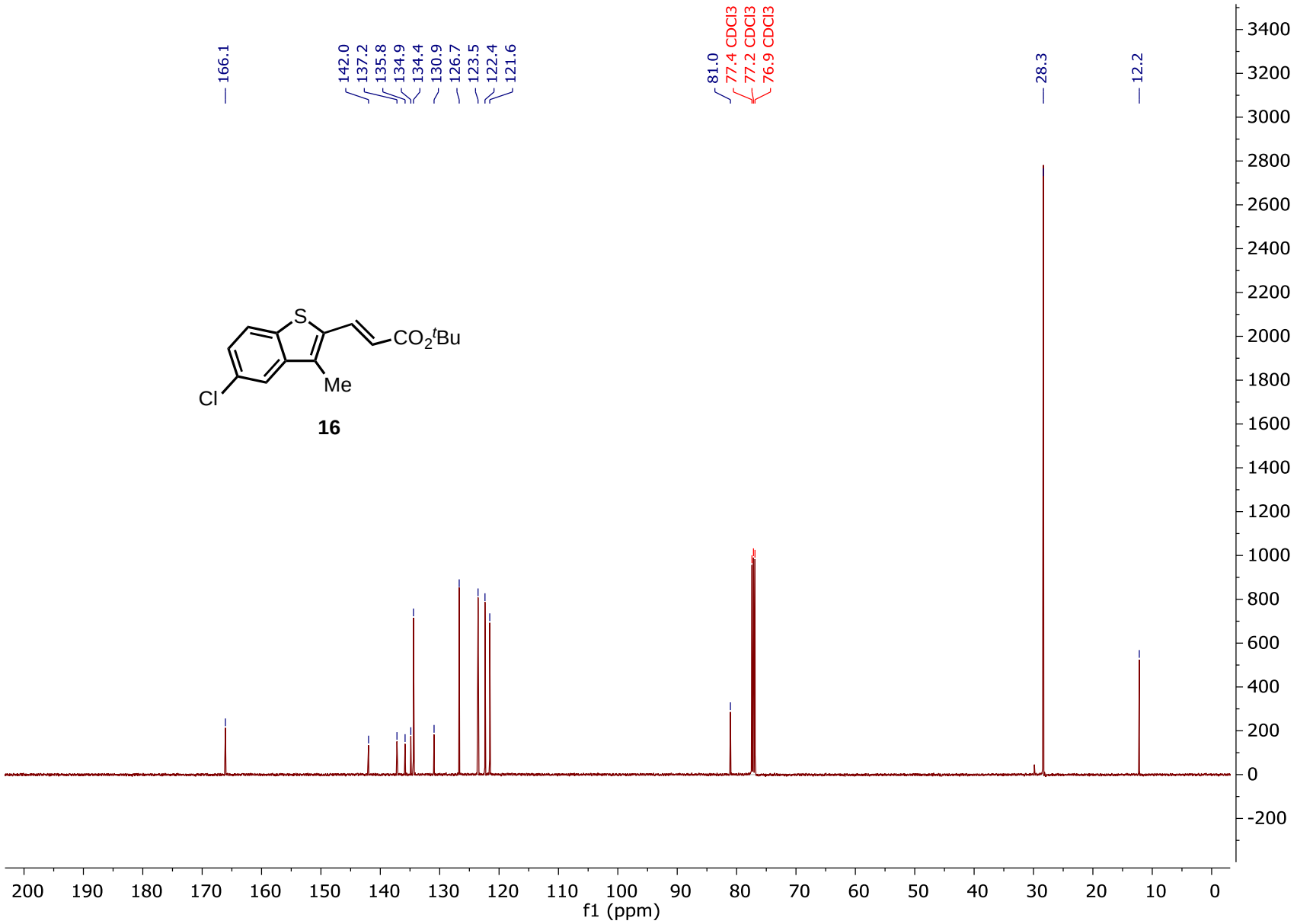


Figure S49. $^{13}C\{^{1}H\}$ NMR (126 MHz, $CDCl_3$) of **16**.

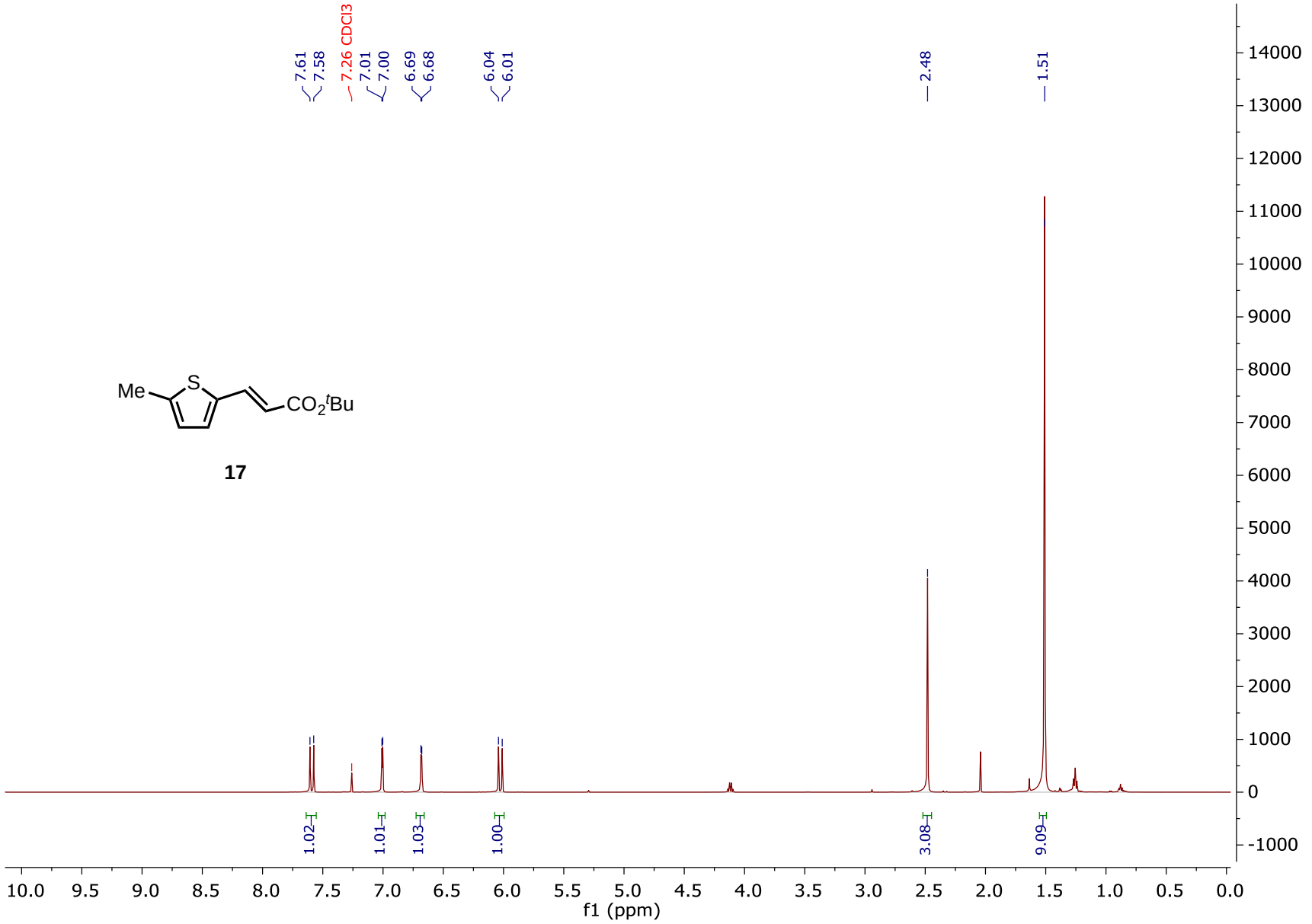


Figure S50. ^{1}H NMR (500 MHz, $CDCl_3$) of **17**.

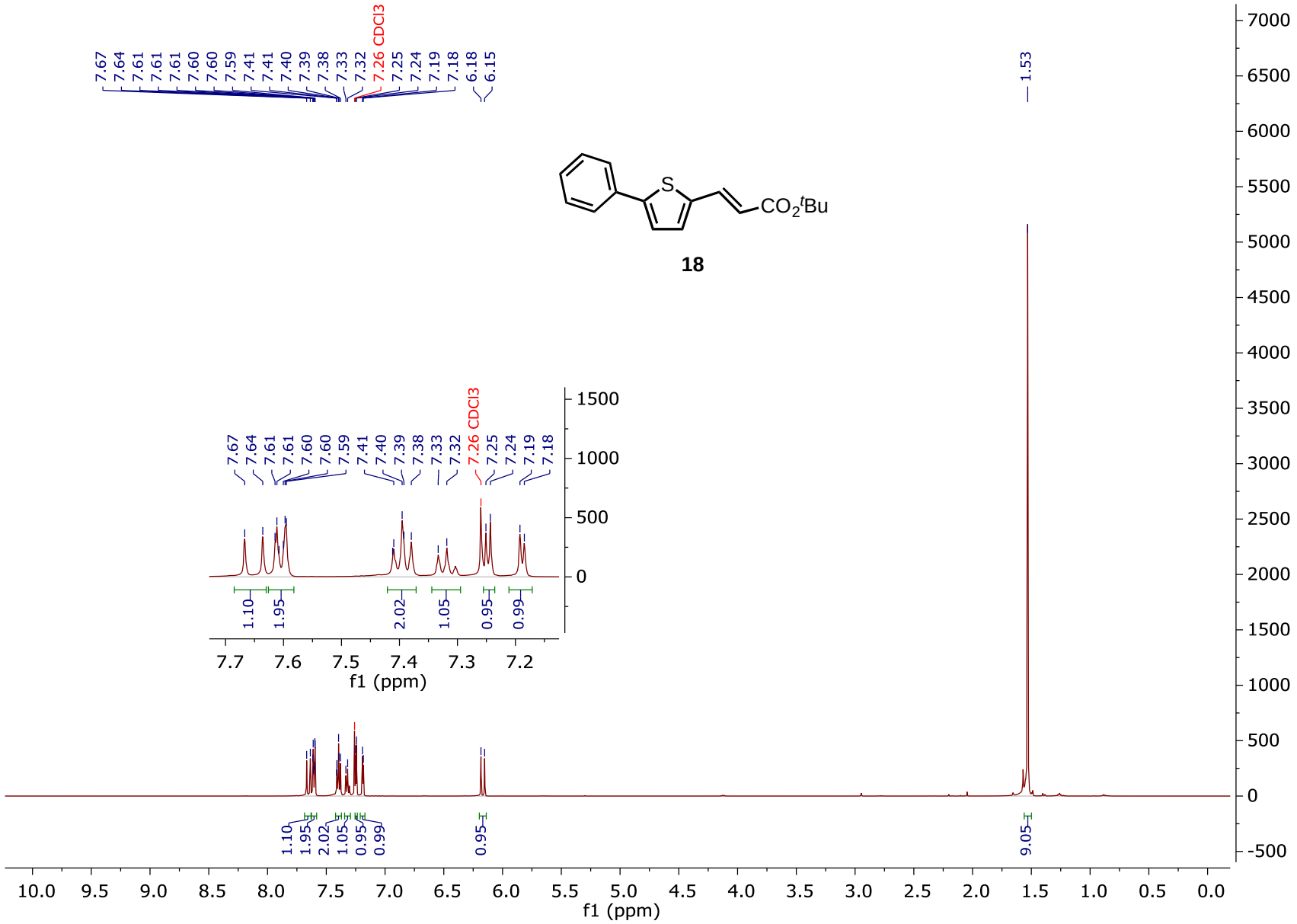


Figure S51. ^{1}H NMR (500 MHz, $CDCl_3$) of **18**.

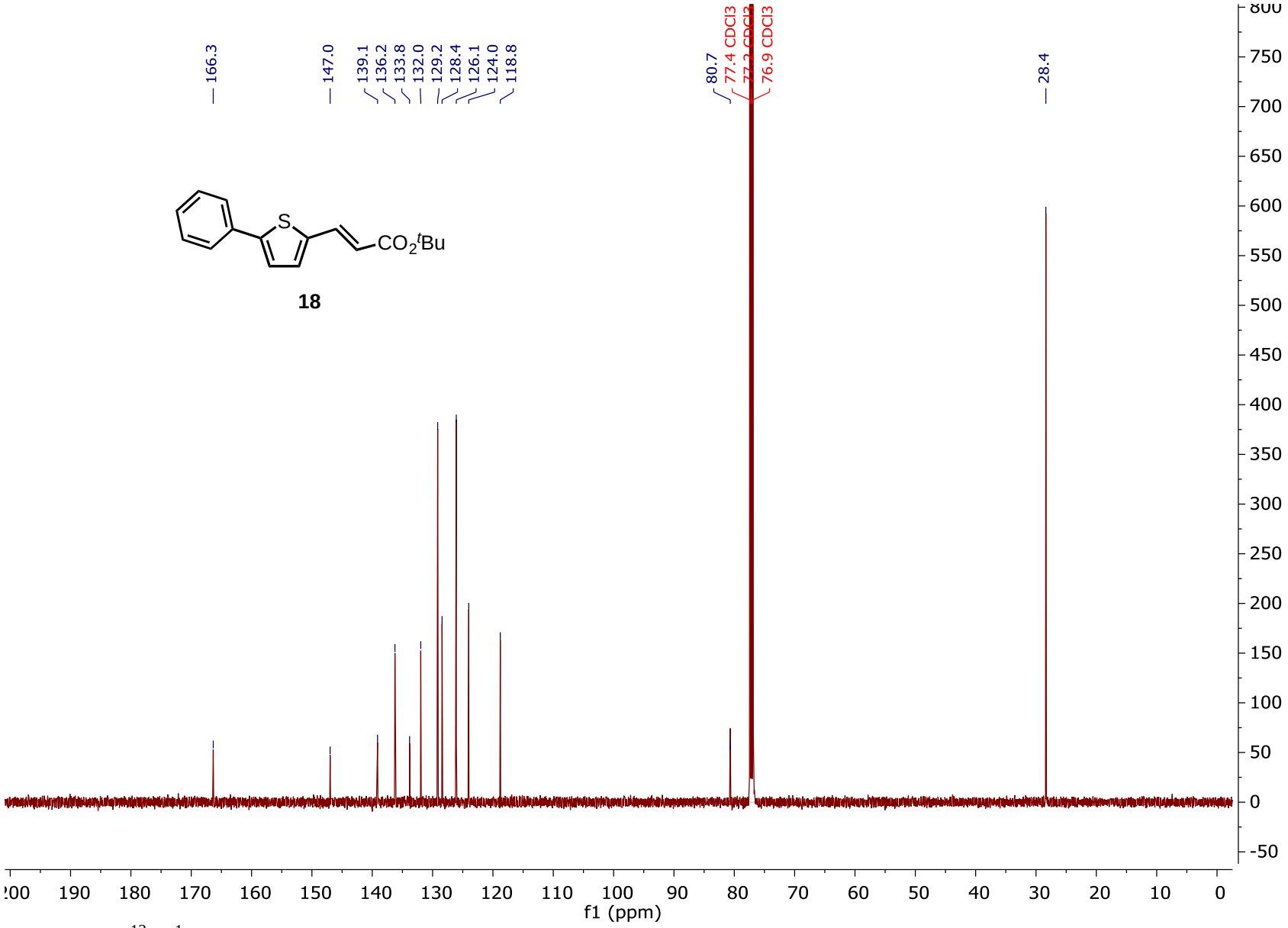


Figure S52. $^{13}C\{^{1}H\}$ NMR (126 MHz, $CDCl_3$) of **18**.

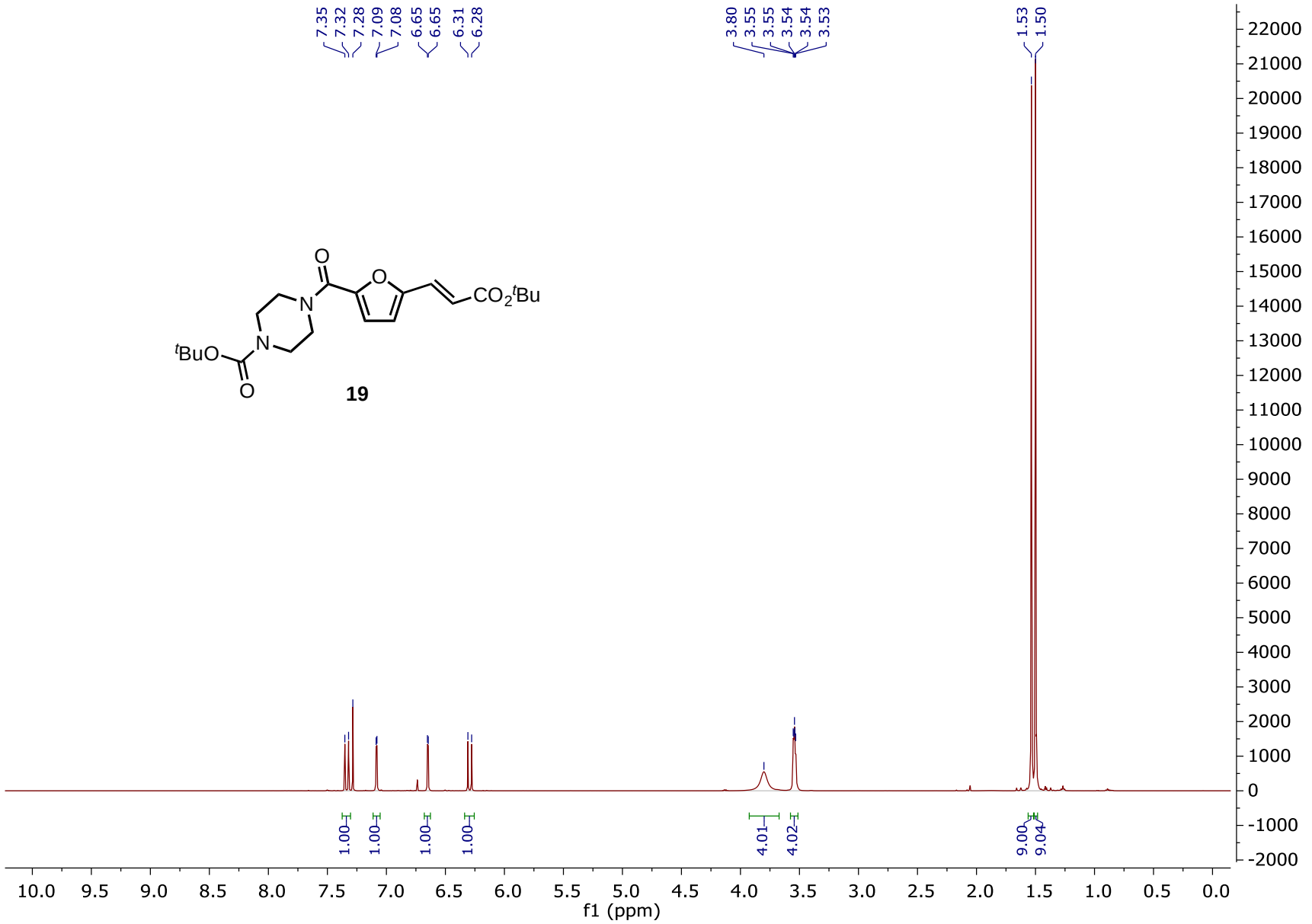


Figure S53. ^{1}H NMR (500 MHz, $CDCl_3$) of **19**.

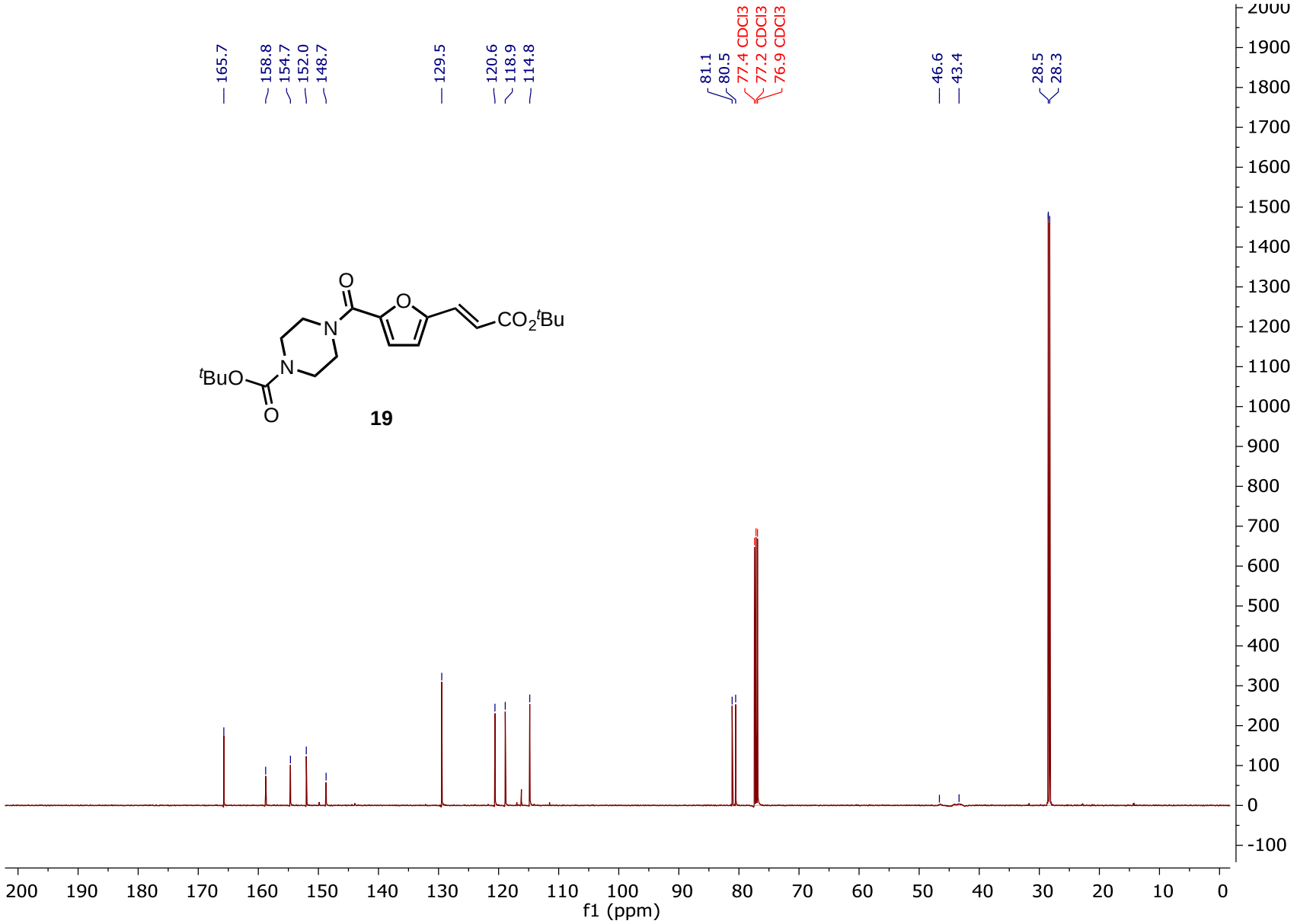


Figure S54. $^{13}C\{^{1}H\}$ NMR (126 MHz, $CDCl_3$) of **19**.

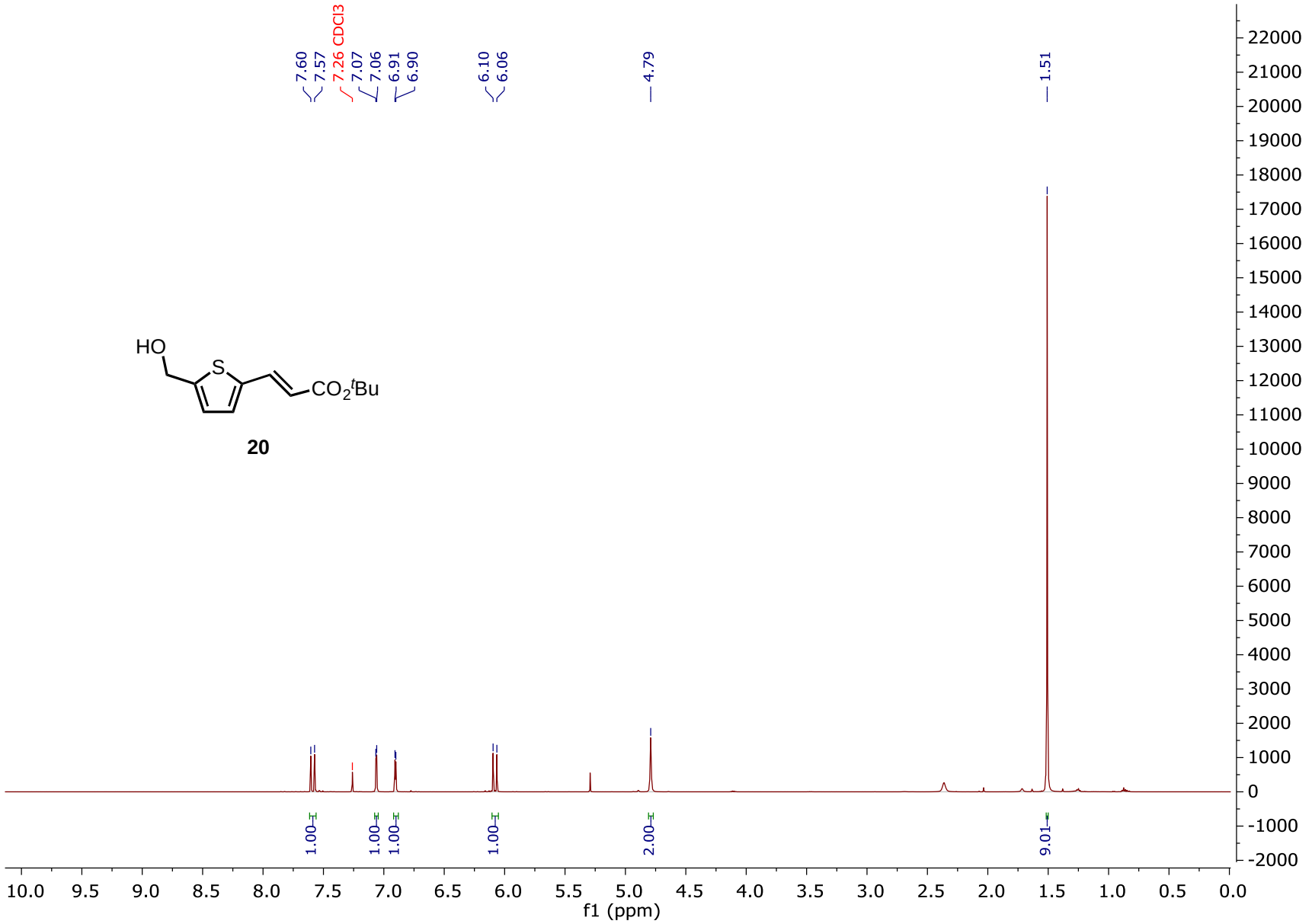


Figure S55. ^{1}H NMR (500 MHz, $CDCl_3$) of **20**.

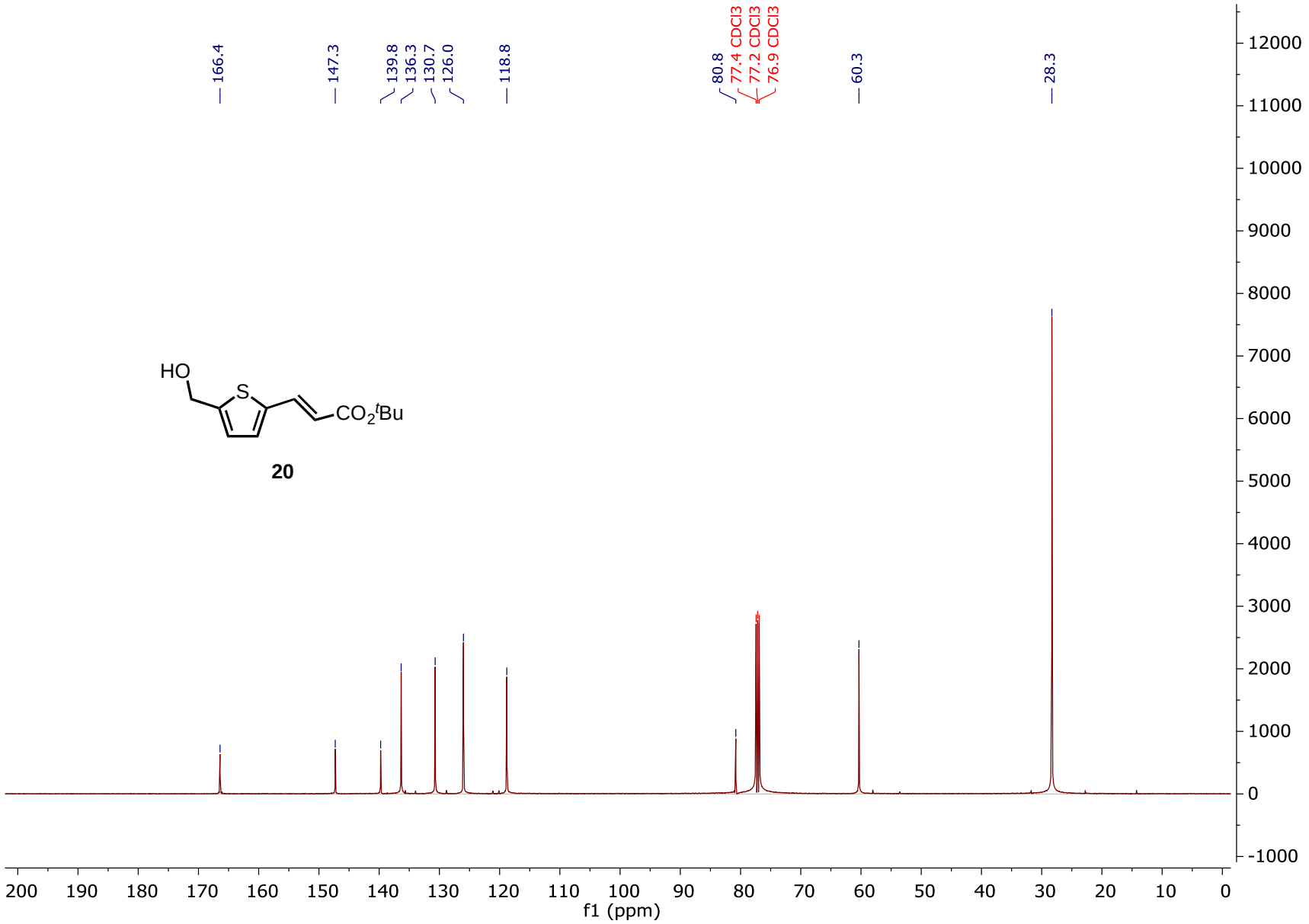


Figure S56. $^{13}C\{^{1}H\}$ NMR (126 MHz, $CDCl_3$) of **20**.

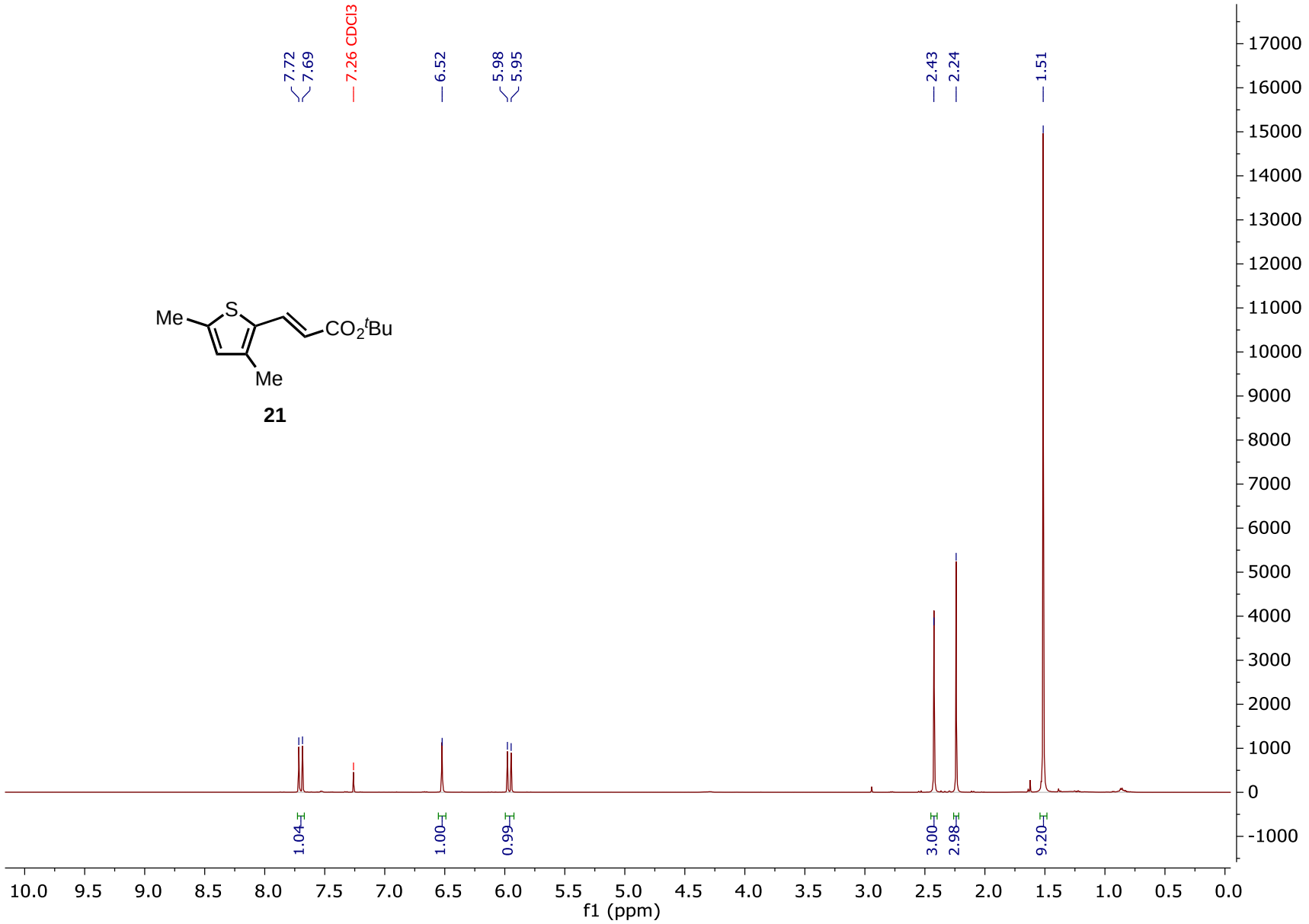


Figure S57. ^{1}H NMR (500 MHz, $CDCl_3$) of **21**.

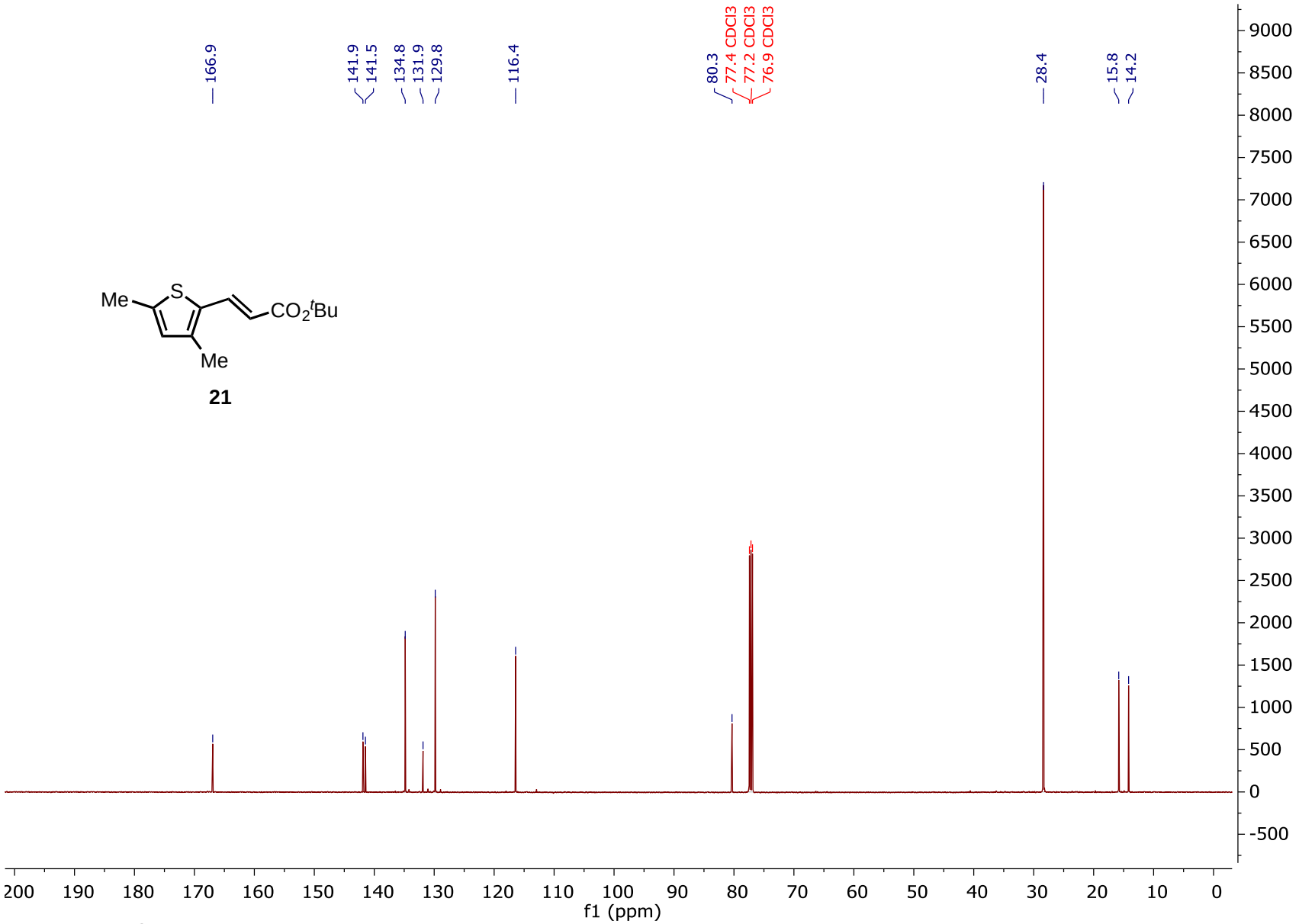


Figure S58. $^{13}C\{^{1}H\}$ NMR (126 MHz, $CDCl_3$) of **21**.

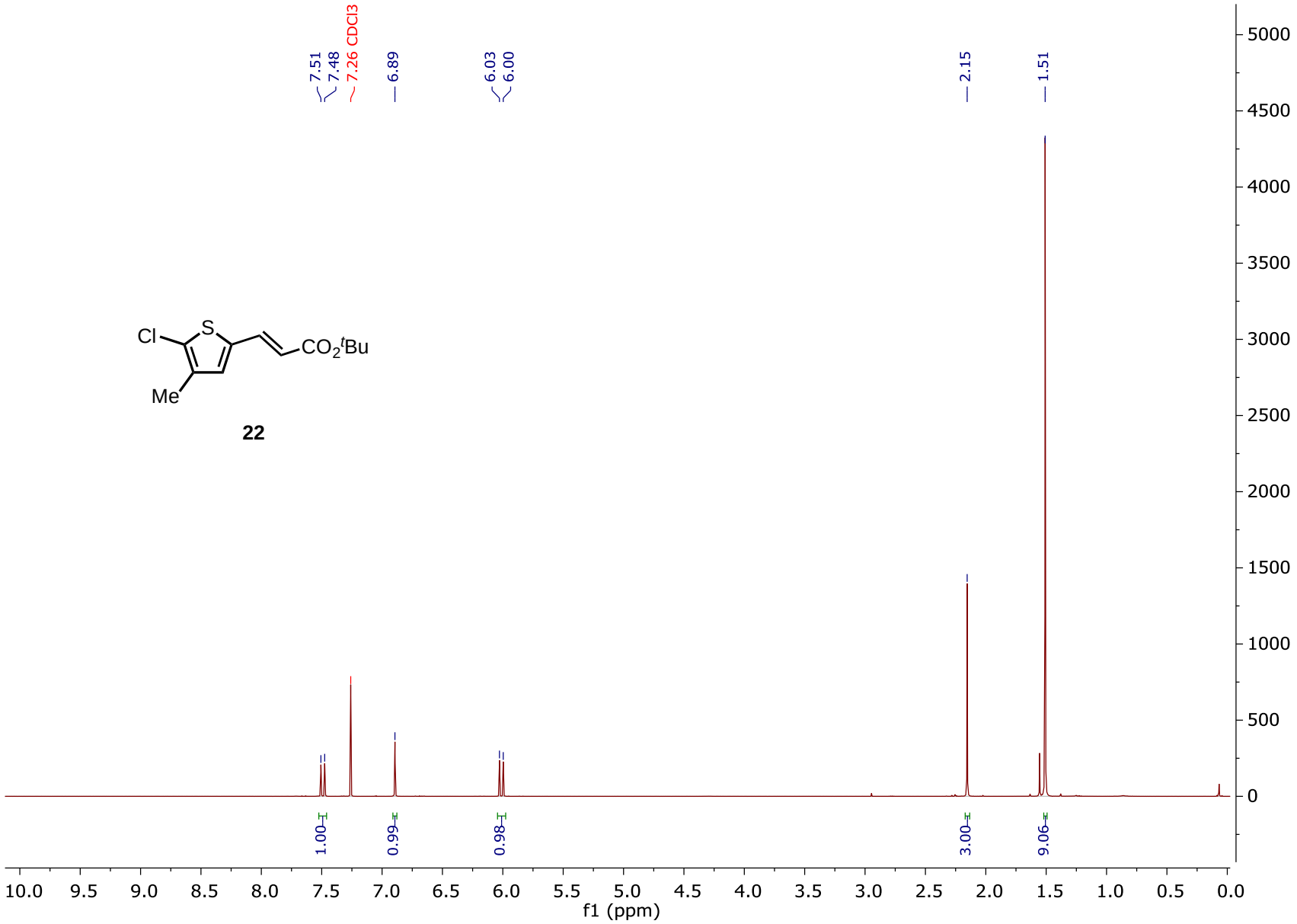


Figure S59. ^{1}H NMR (500 MHz, $CDCl_3$) of **22**.

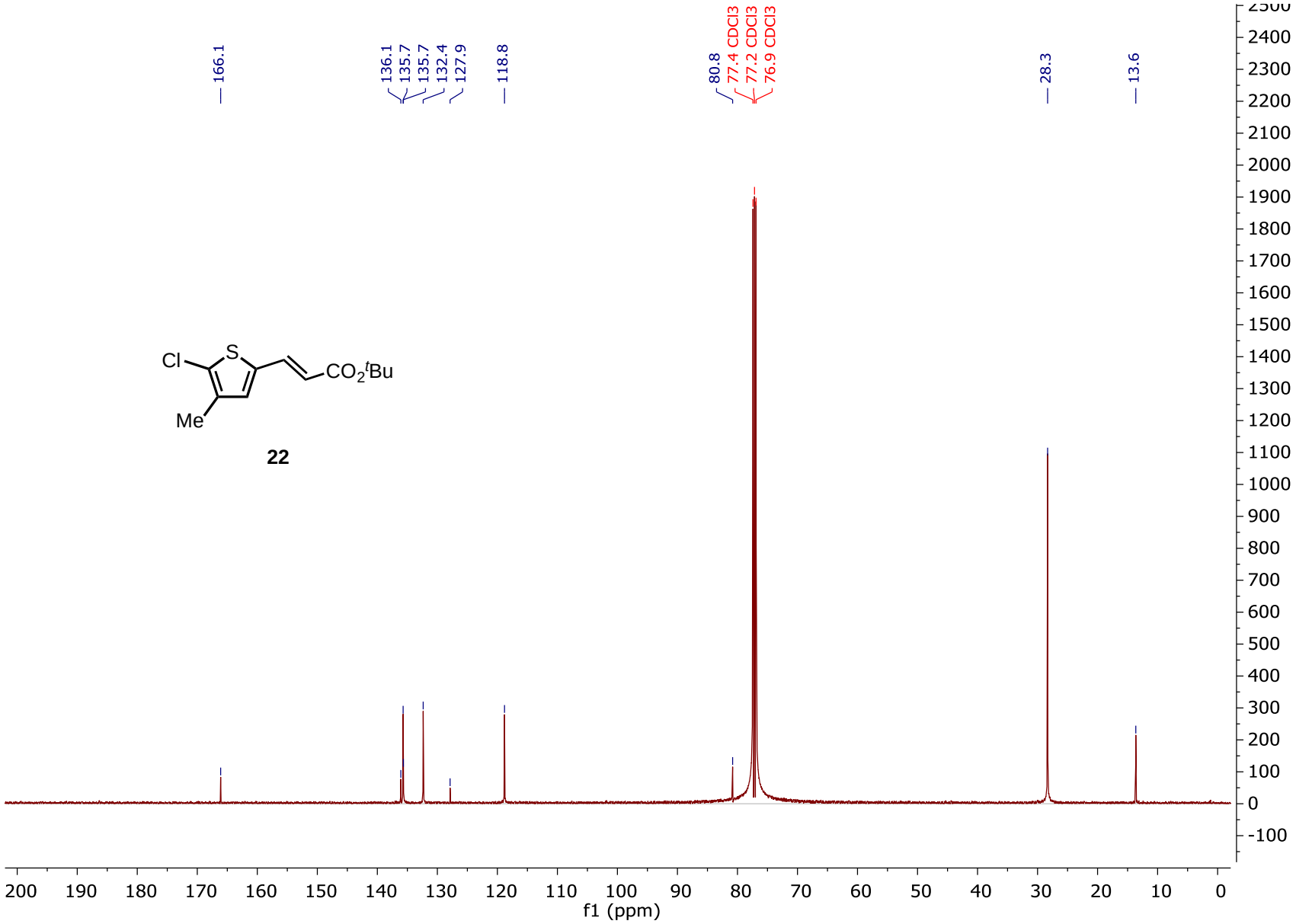


Figure S60. $^{13}C\{^{1}H\}$ NMR (126 MHz, $CDCl_3$) of **22.**

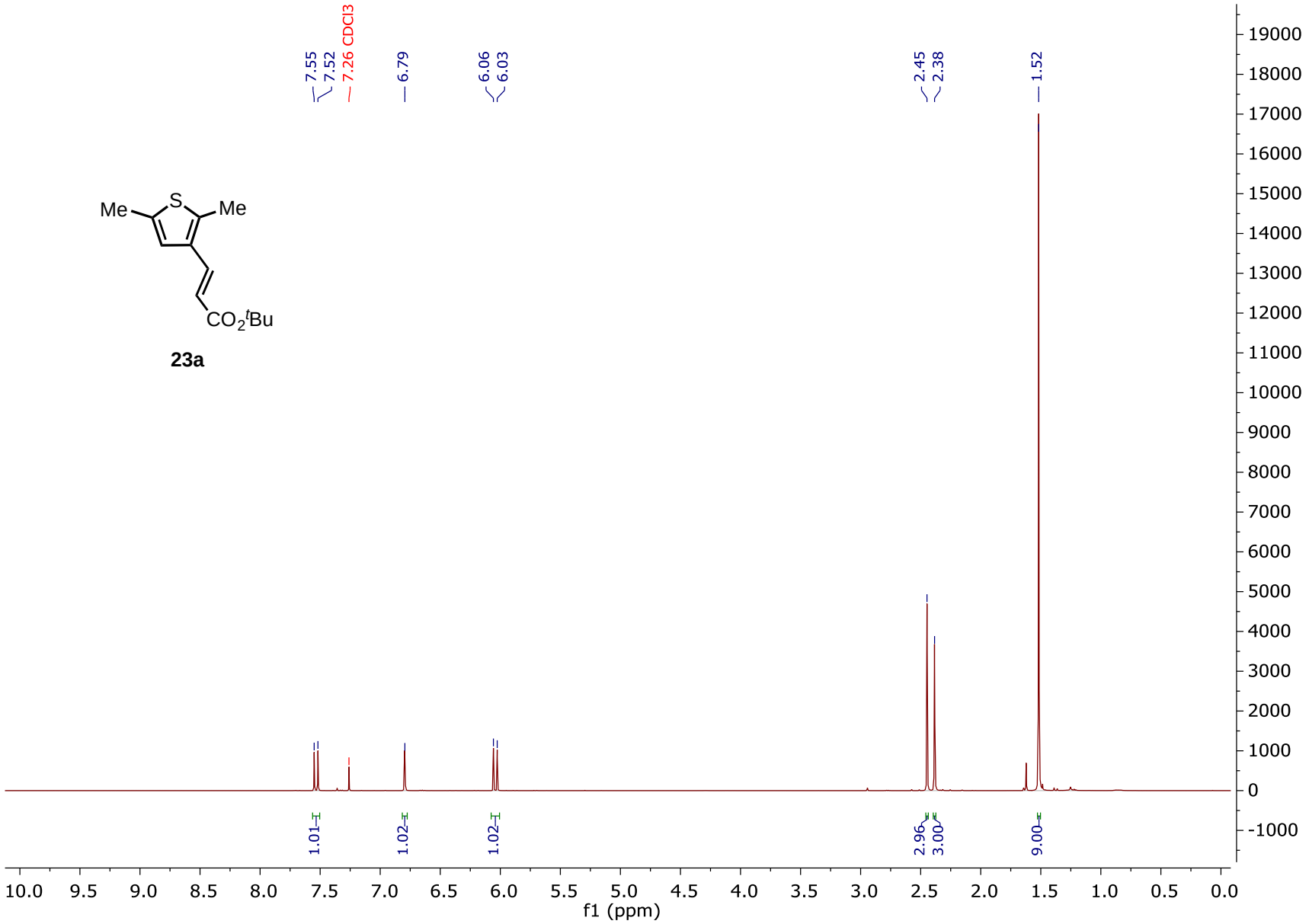


Figure S61. ^{1}H NMR (500 MHz, $CDCl_3$) of **23a**.

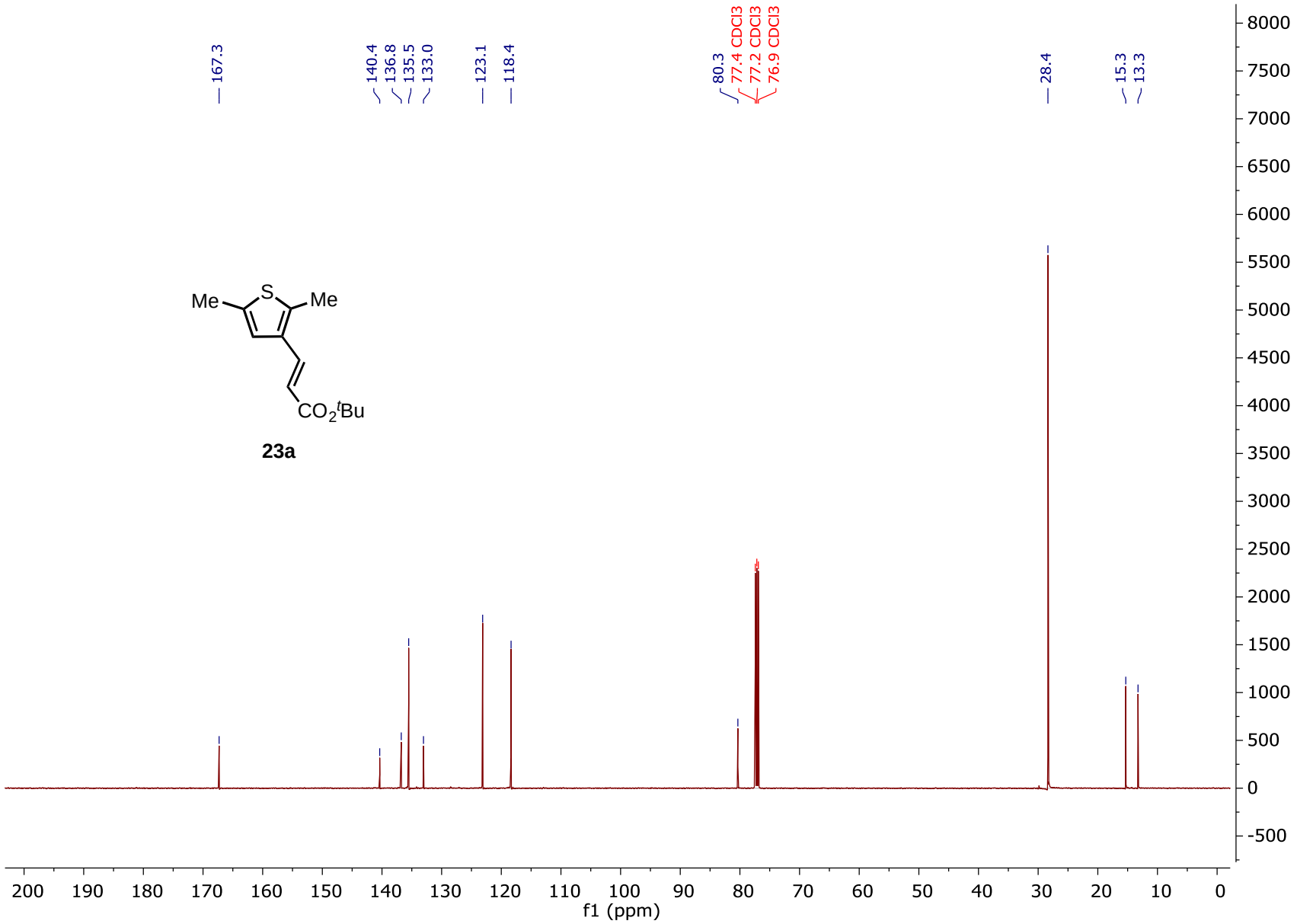


Figure S62. $^{13}C\{^{1}H\}$ NMR (126 MHz, $CDCl_3$) of **23a**.

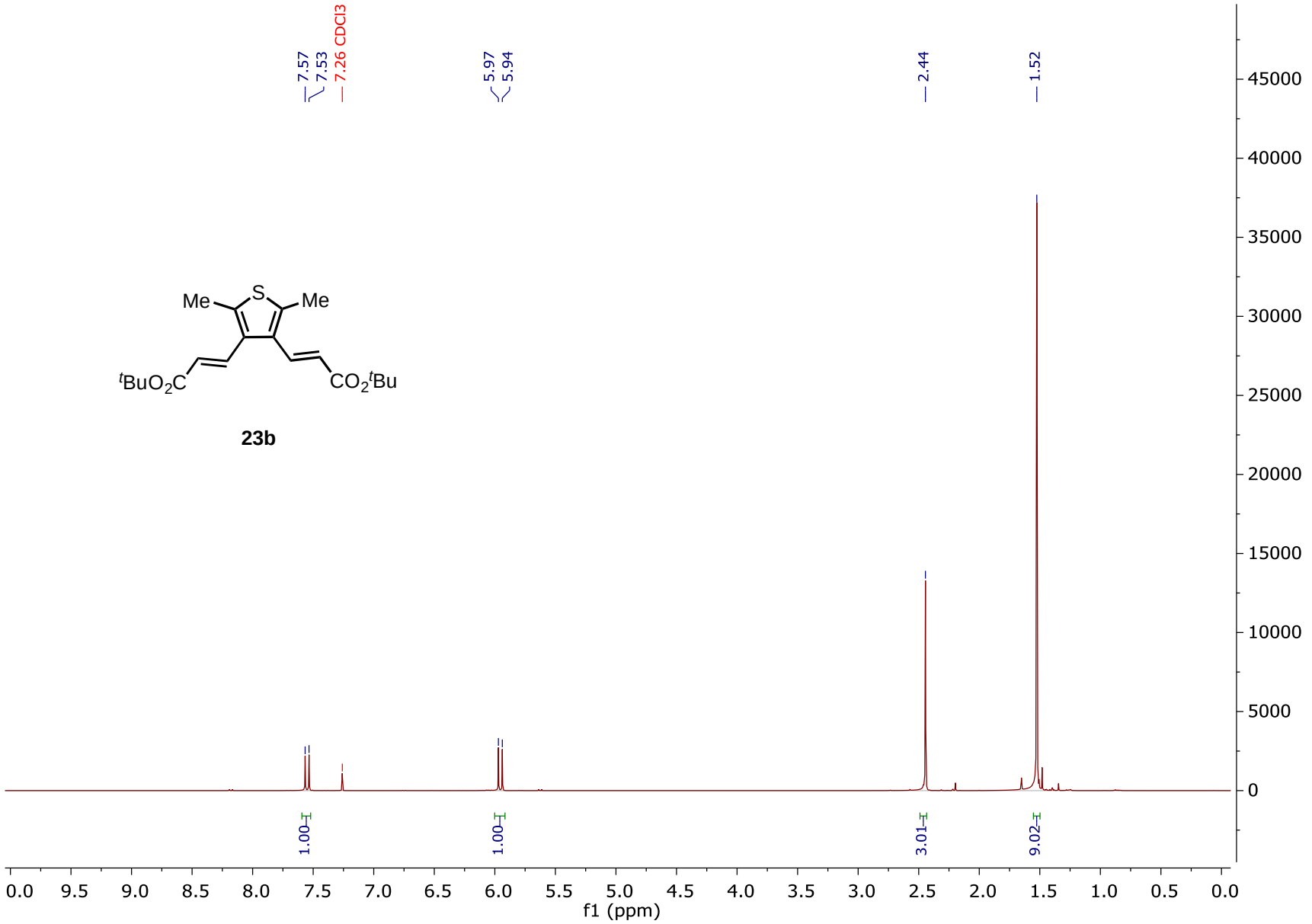


Figure S63. ^{1}H NMR (500 MHz, $CDCl_3$) of **23b**.

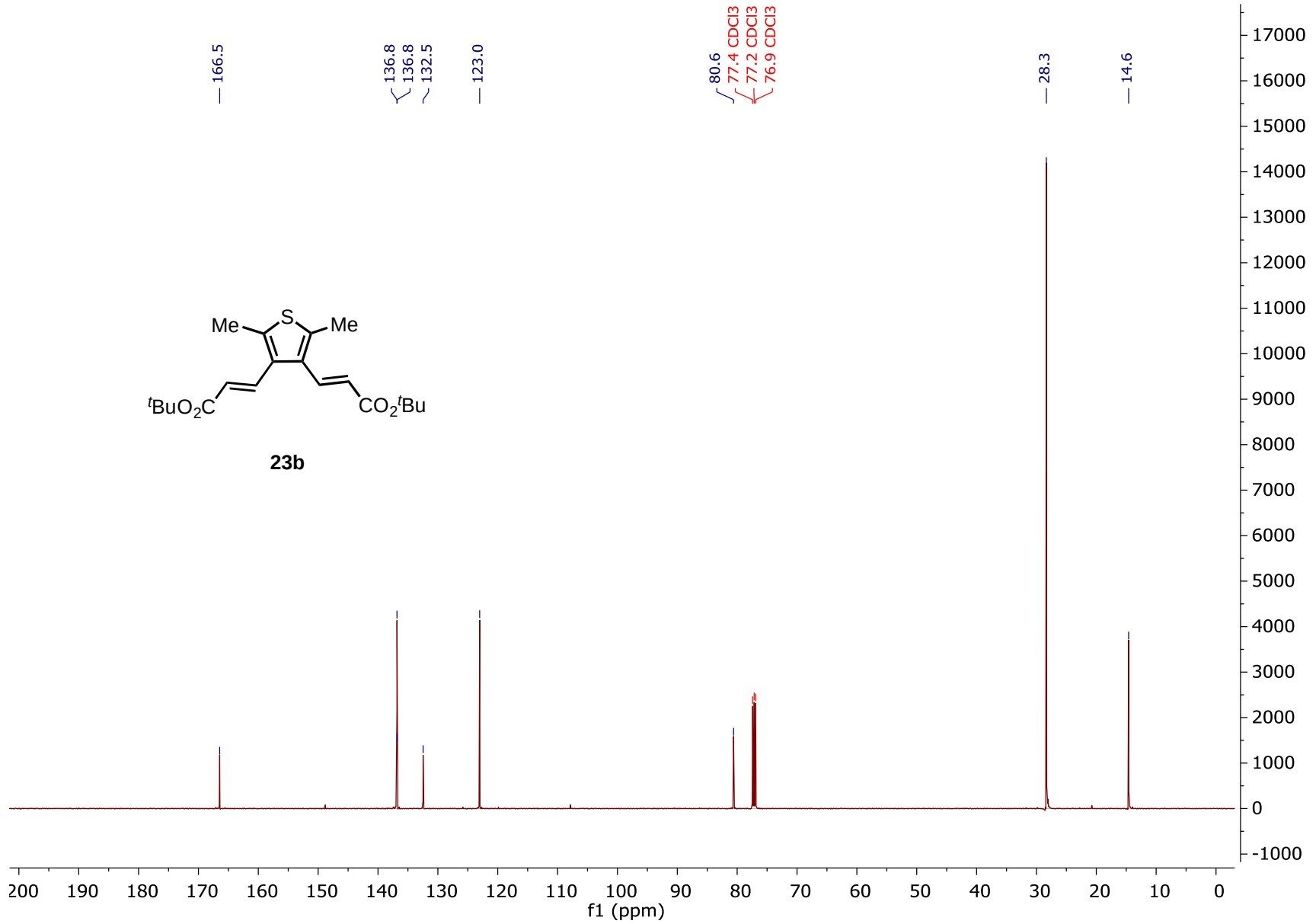


Figure S64. $^{13}C\{^{1}H\}$ NMR (126 MHz, $CDCl_3$) of **23b**.

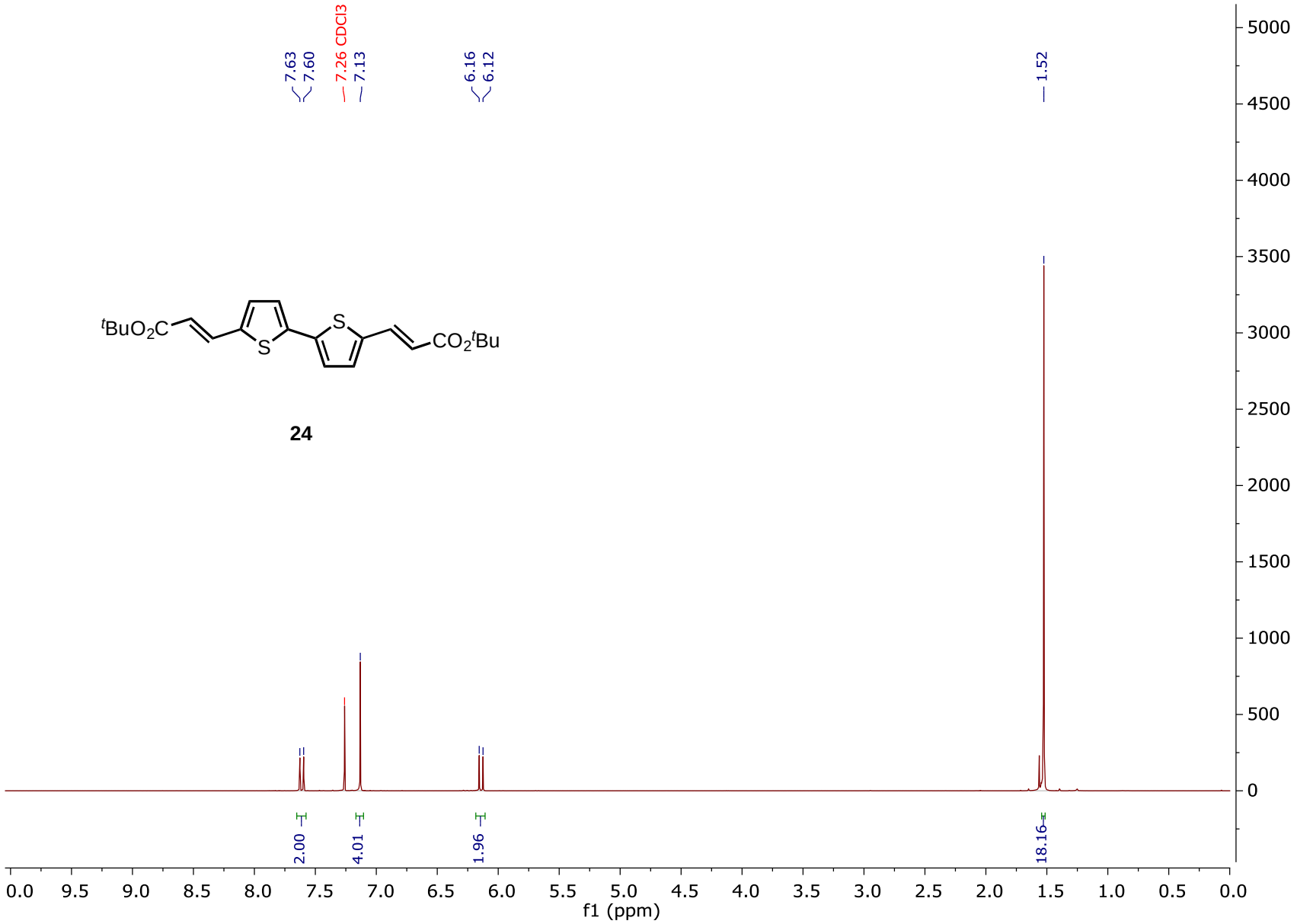


Figure S65. ^{1}H NMR (500 MHz, $CDCl_3$) of **24**.

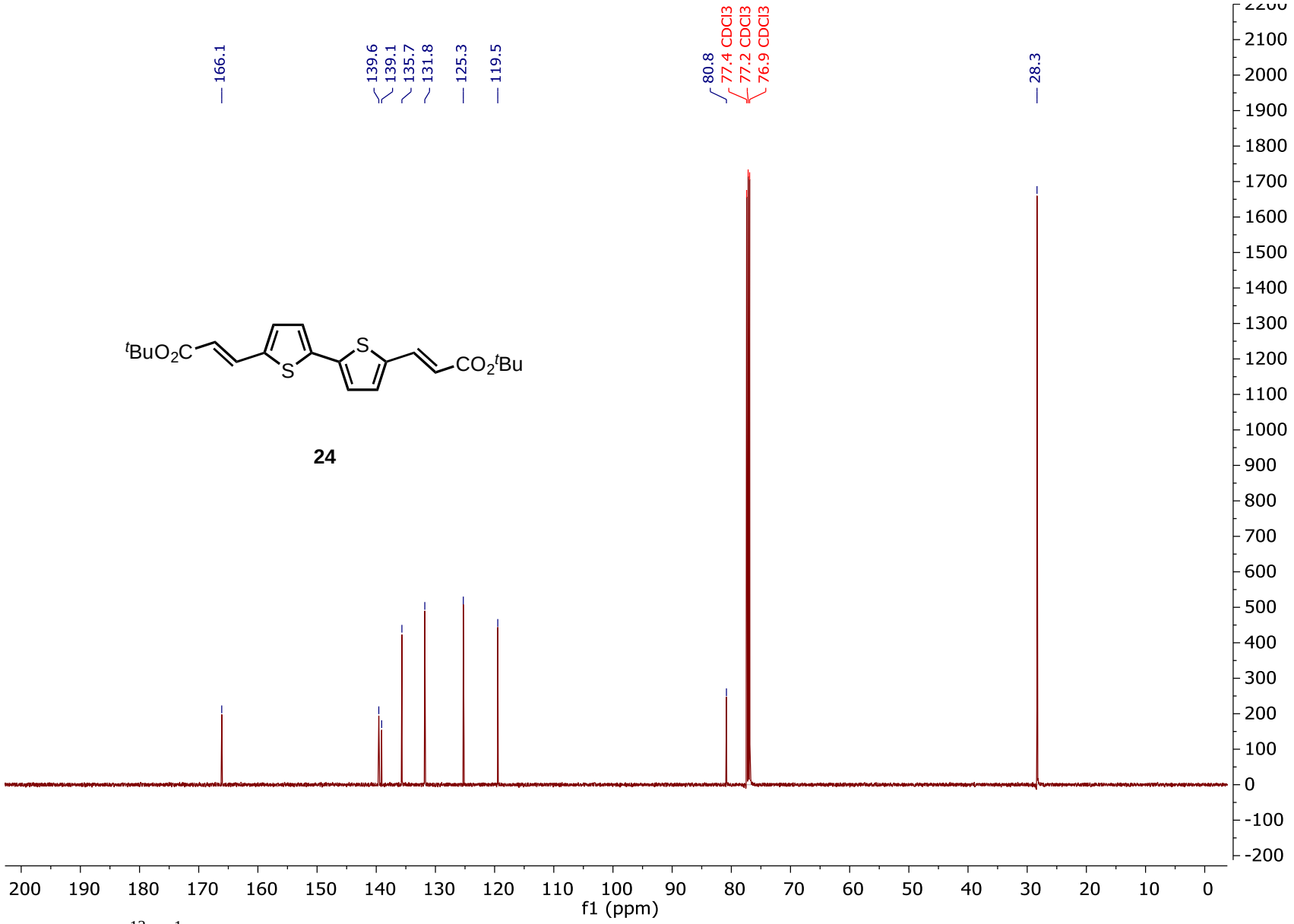


Figure S66. $^{13}C\{^{1}H\}$ NMR (126 MHz, $CDCl_3$) of **24**.

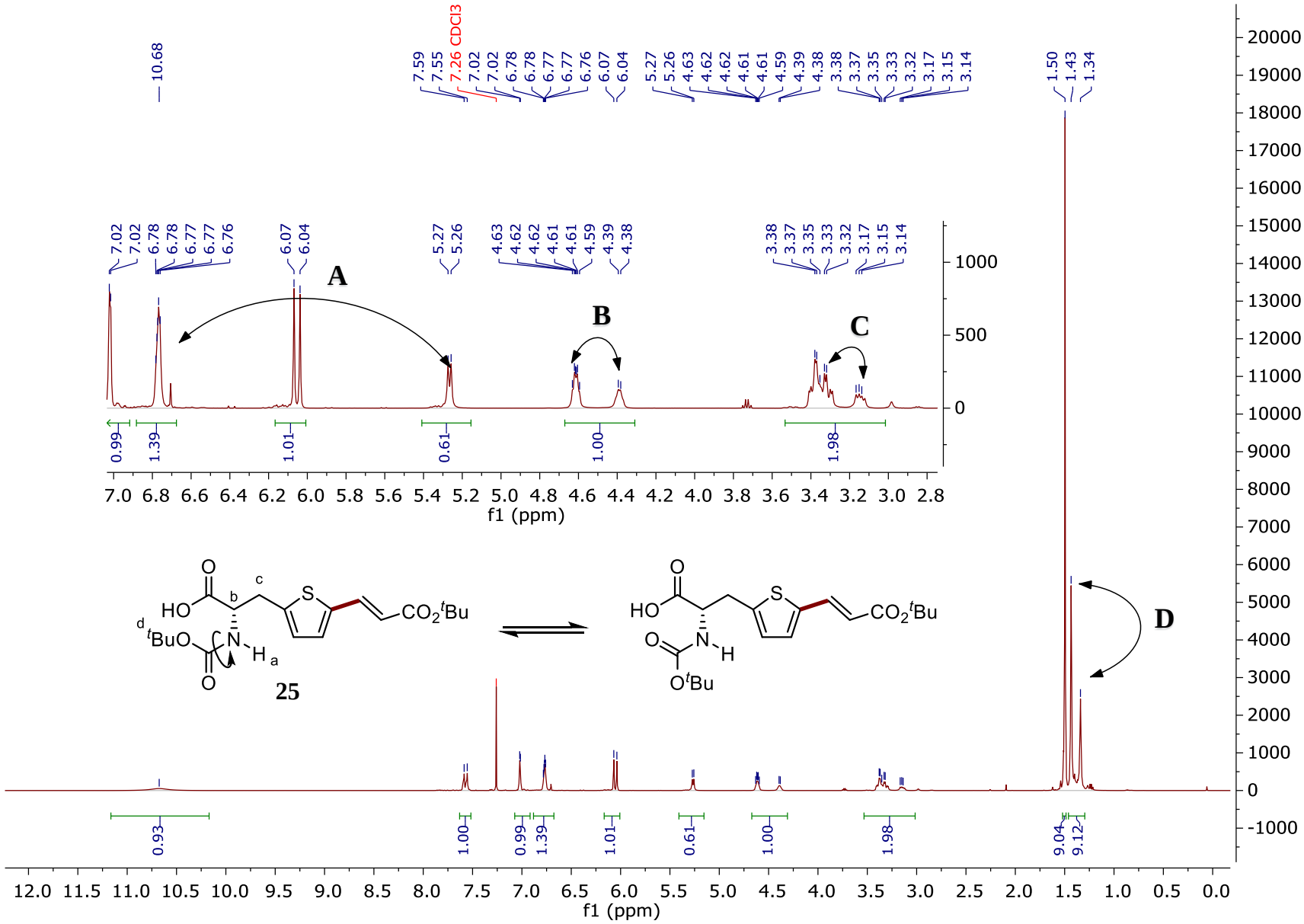


Figure S67. ^{1}H NMR (500 MHz, $CDCl_3$) of **25**.

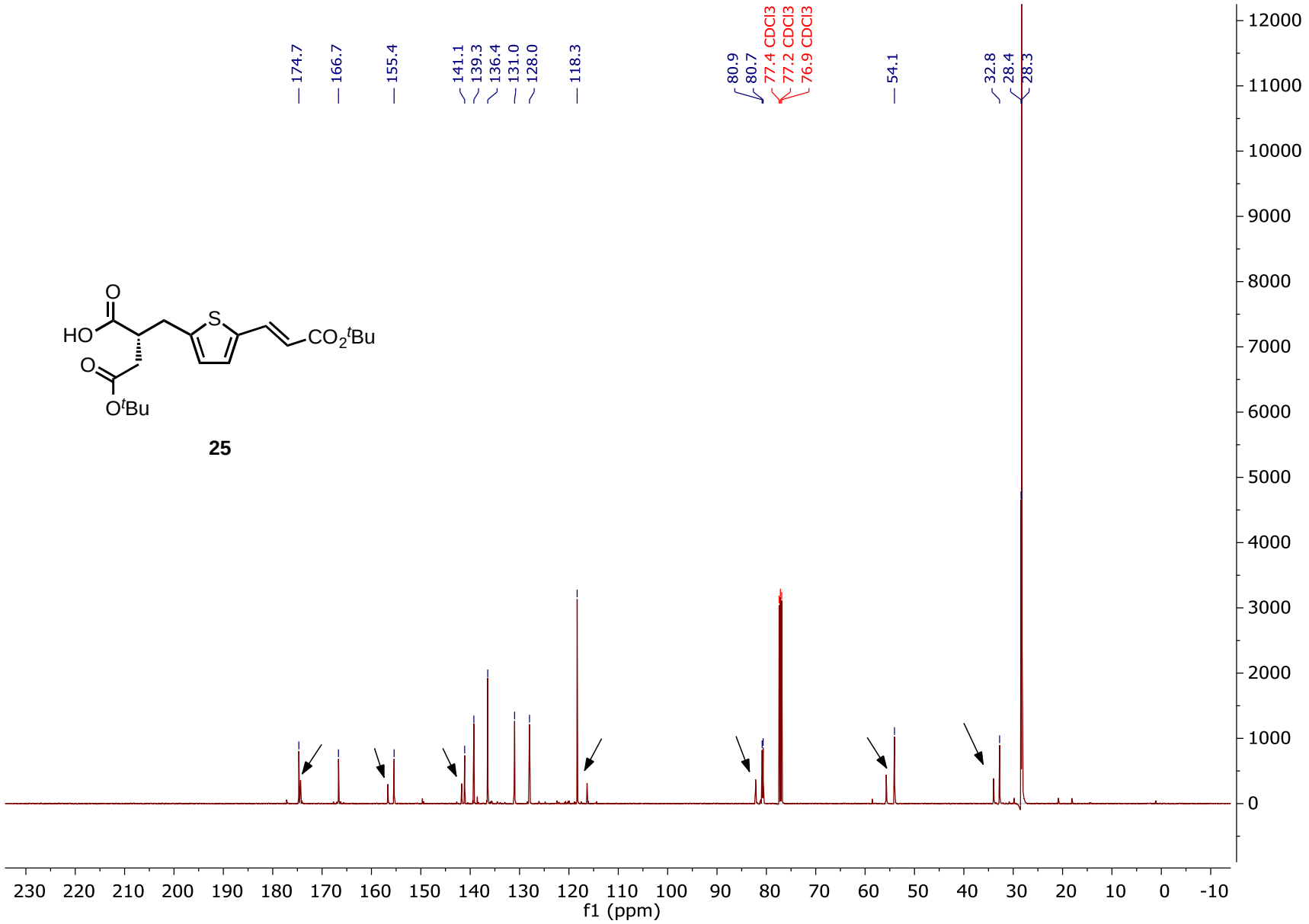


Figure S68. $^{13}C\{^{1}H\}$ NMR (126 MHz, $CDCl_3$) of **25**. (Arrows indicate minor rotamer peaks)

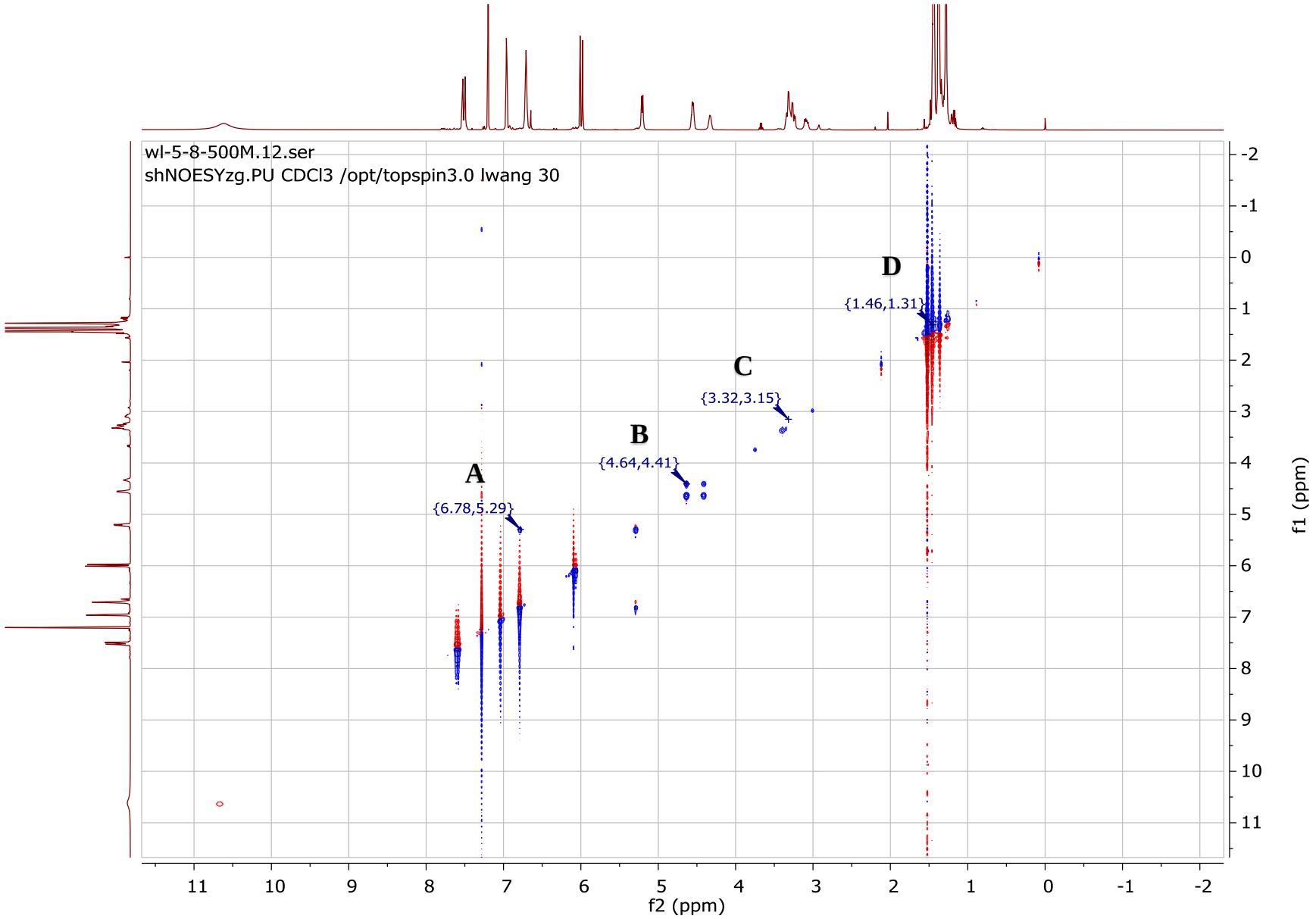


Figure S69. NOESY {^{1}H} (500 MHz, $CDCl_3$) of **25**.

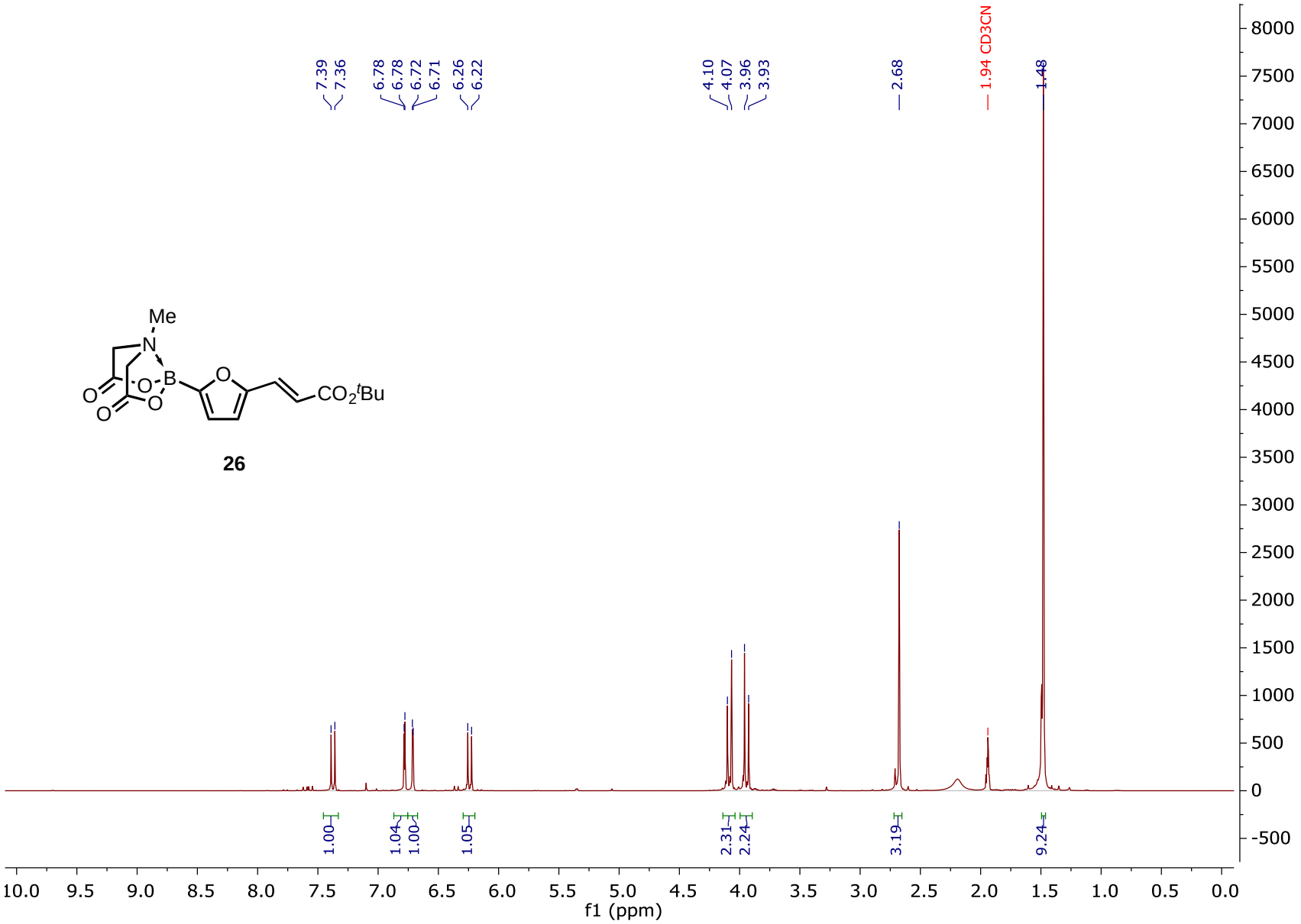


Figure S70. ^{1}H NMR (500 MHz, CD_3CN) of **26**.

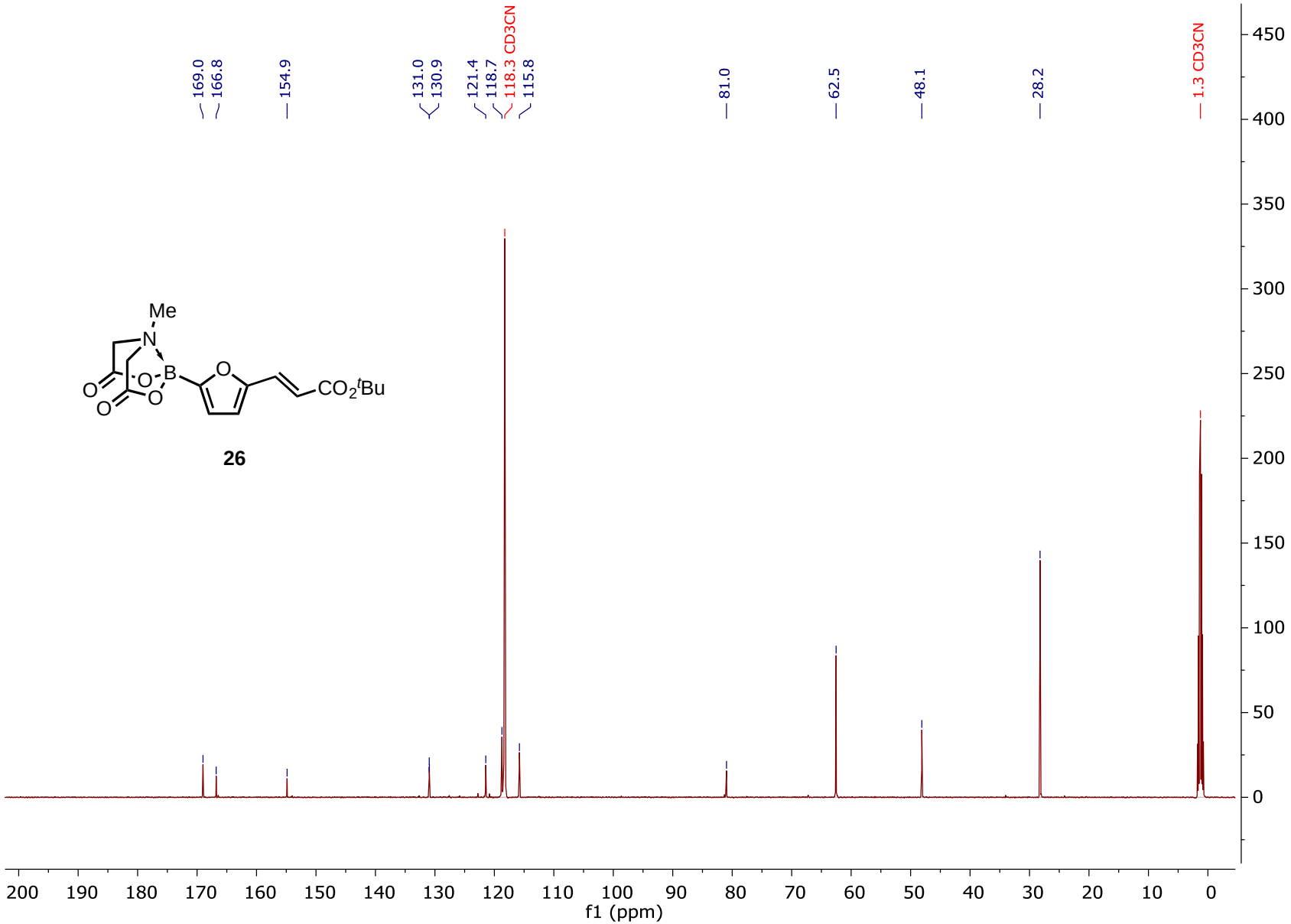


Figure S71. $^{13}C\{^{1}H\}$ NMR (126 MHz, CD_3CN) of **26**.

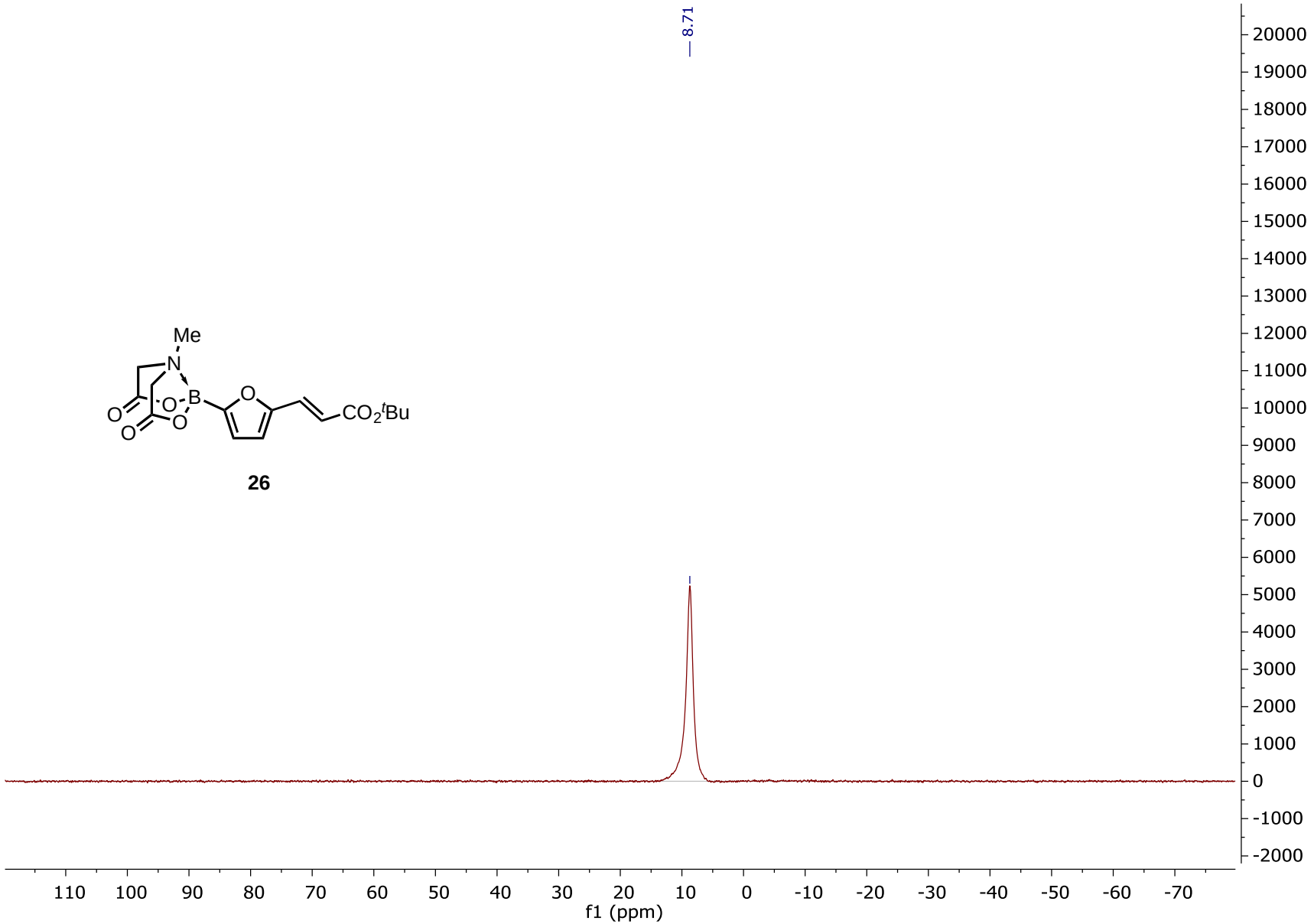


Figure S72. ^{11}B NMR (96 MHz, CD_3CN) of **26**.

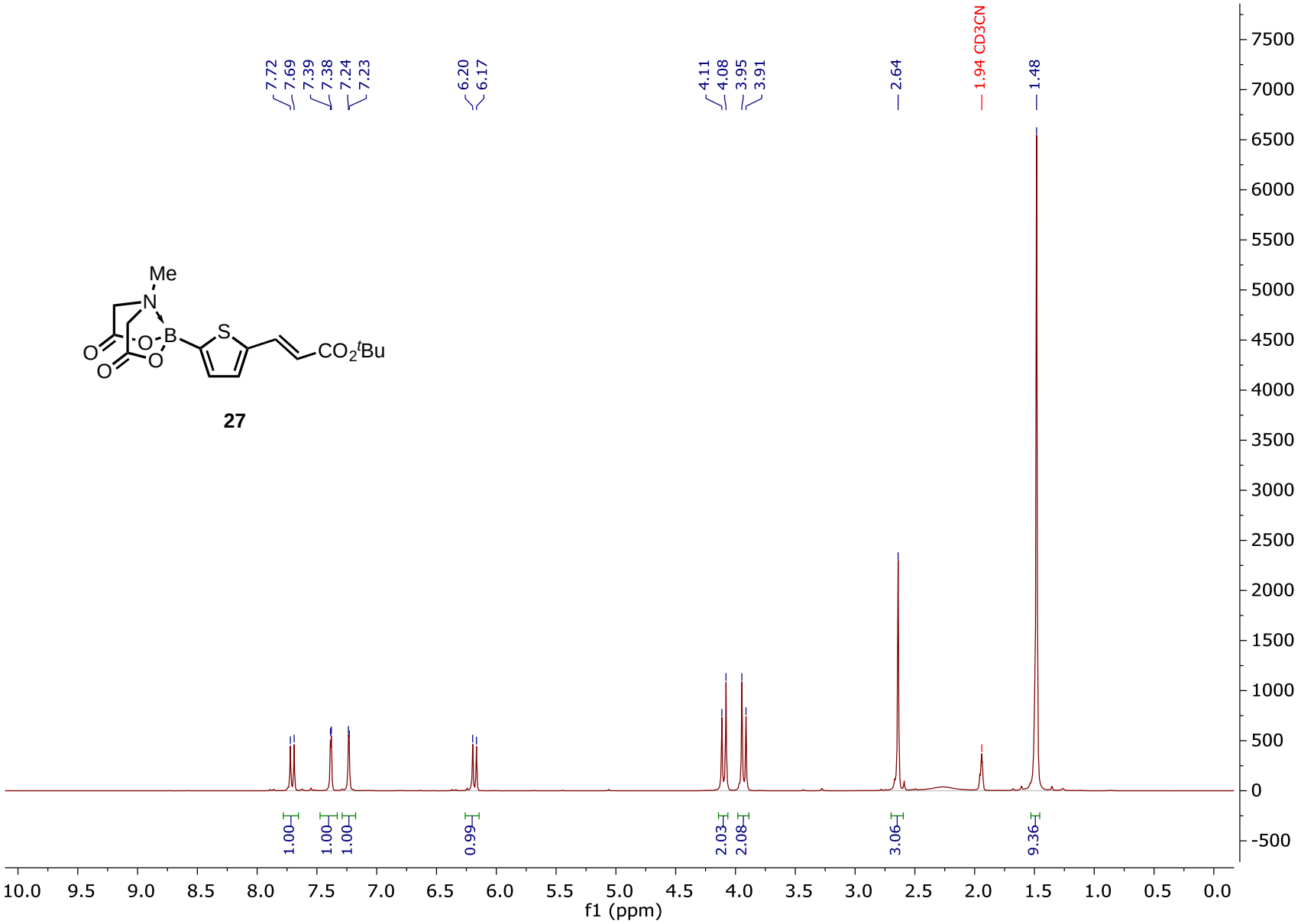


Figure S73. ^{1}H NMR (500 MHz, CD_3CN) of **27**.

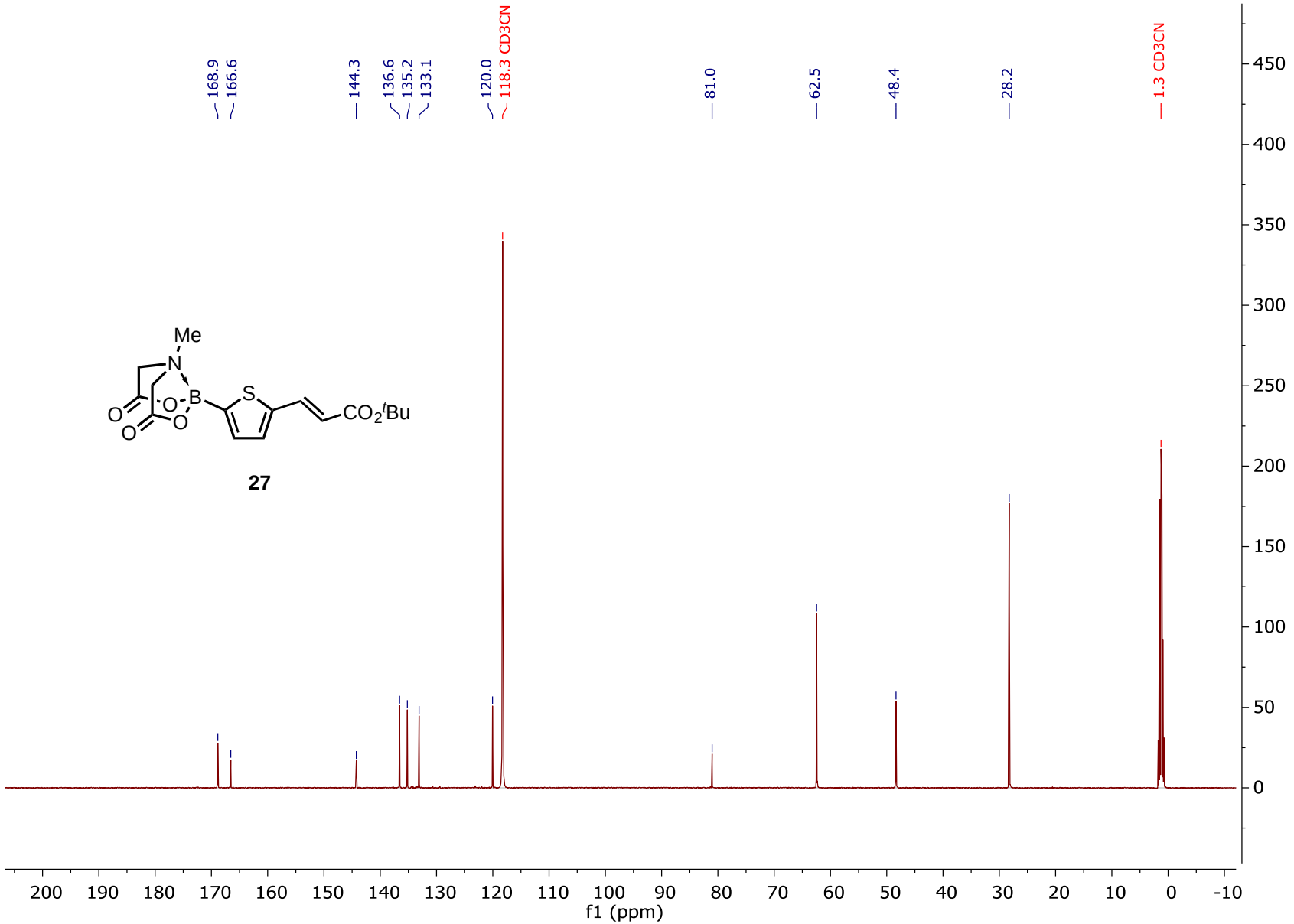


Figure S74. $^{13}C\{^{1}H\}$ NMR (126 MHz, CD_3CN) of **27**.

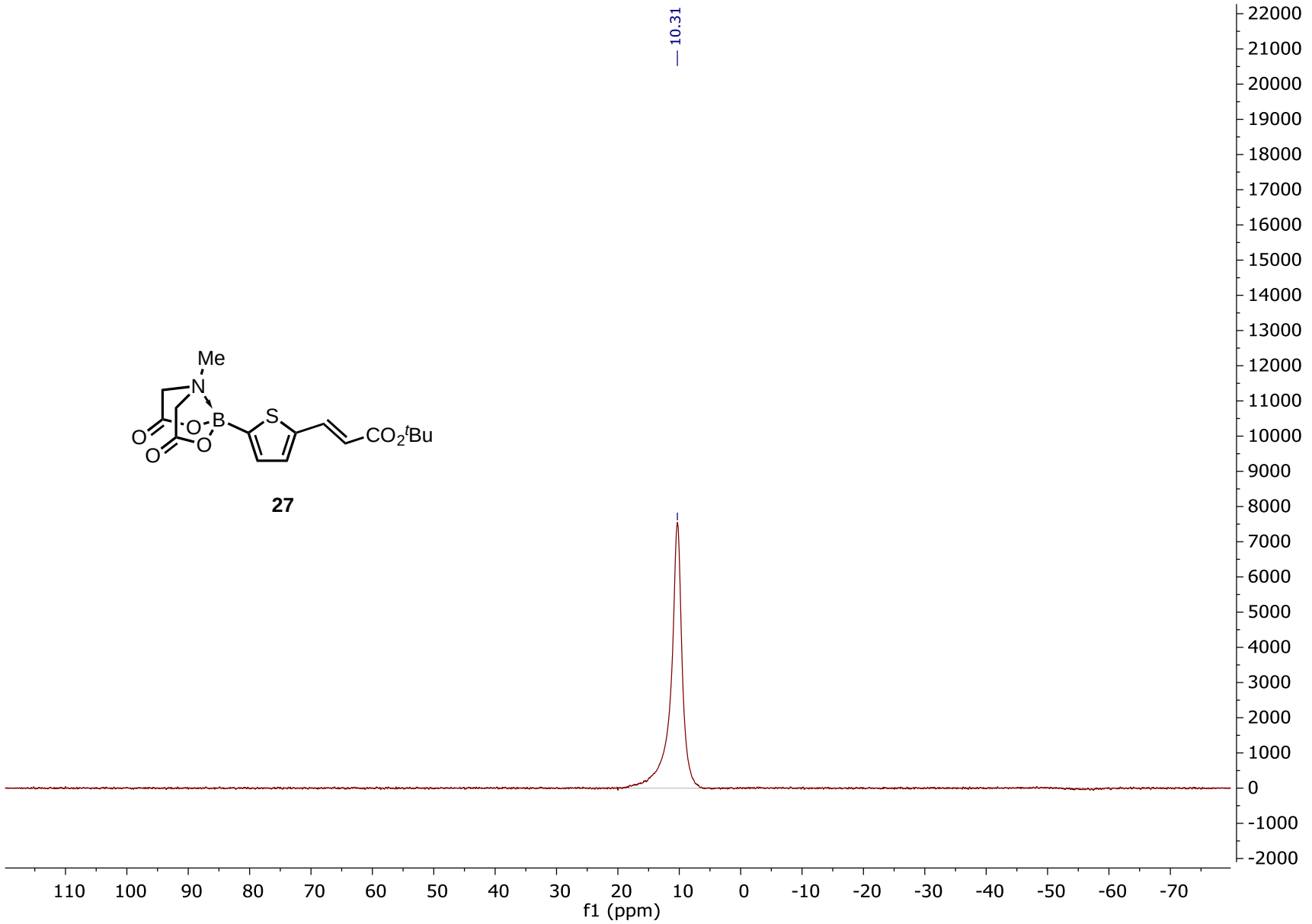


Figure S75. ^{11}B NMR (96 MHz, CD_3CN) of **27**.

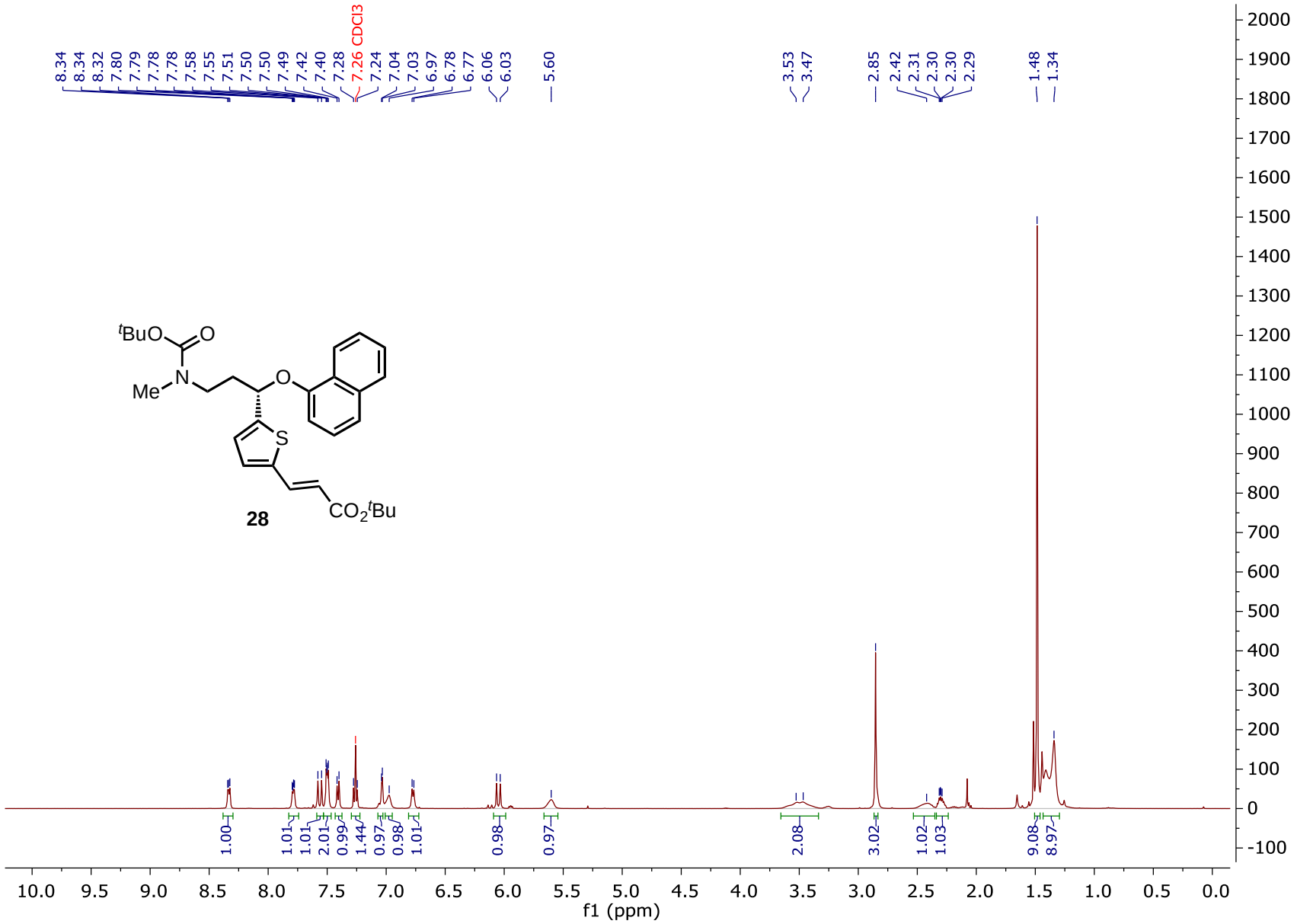


Figure S76. ^{1}H NMR (500 MHz, $CDCl_3$) of **28**.

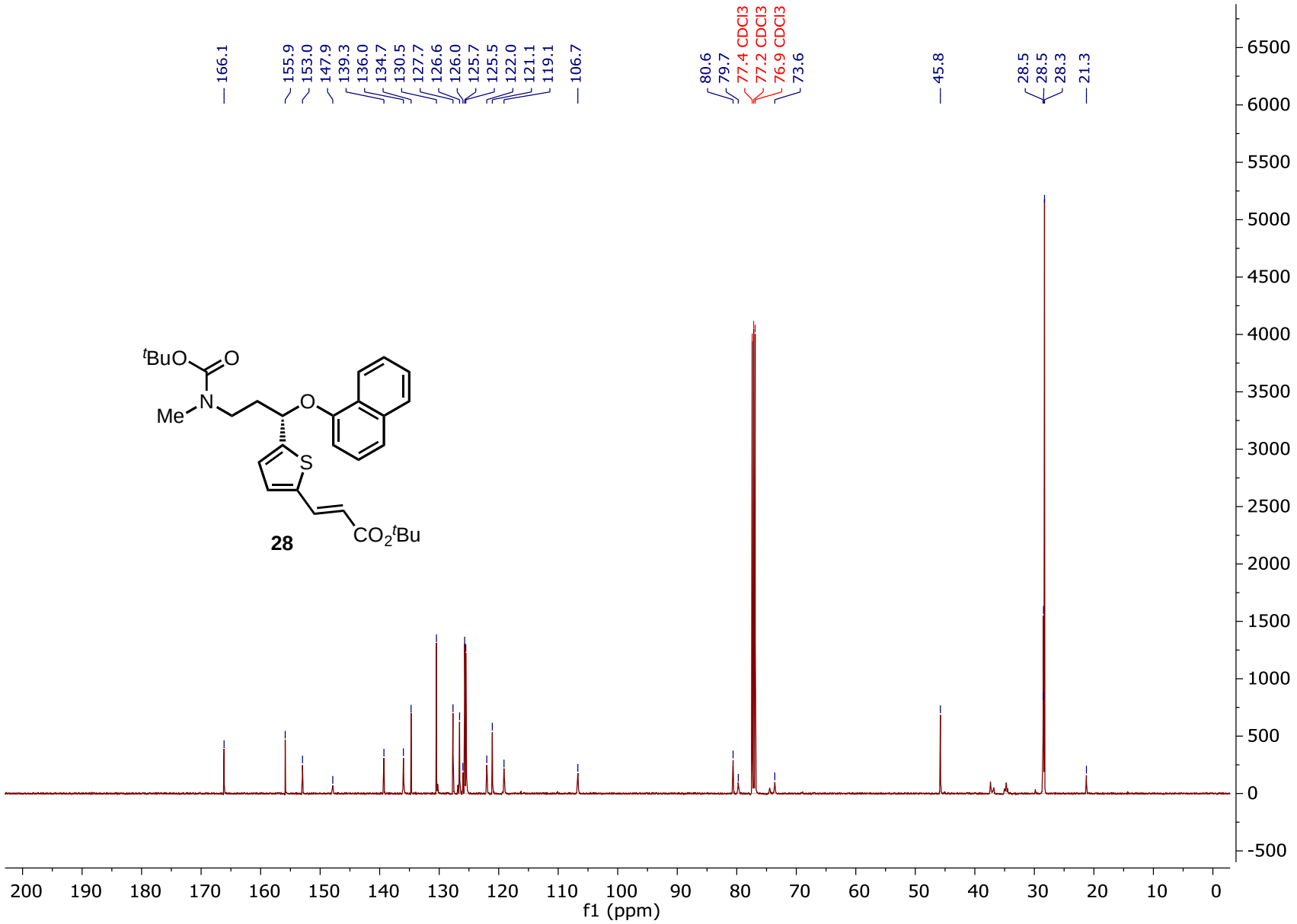


Figure S77. $^{13}C\{^{1}H\}$ NMR (126 MHz, $CDCl_3$) of **28**.

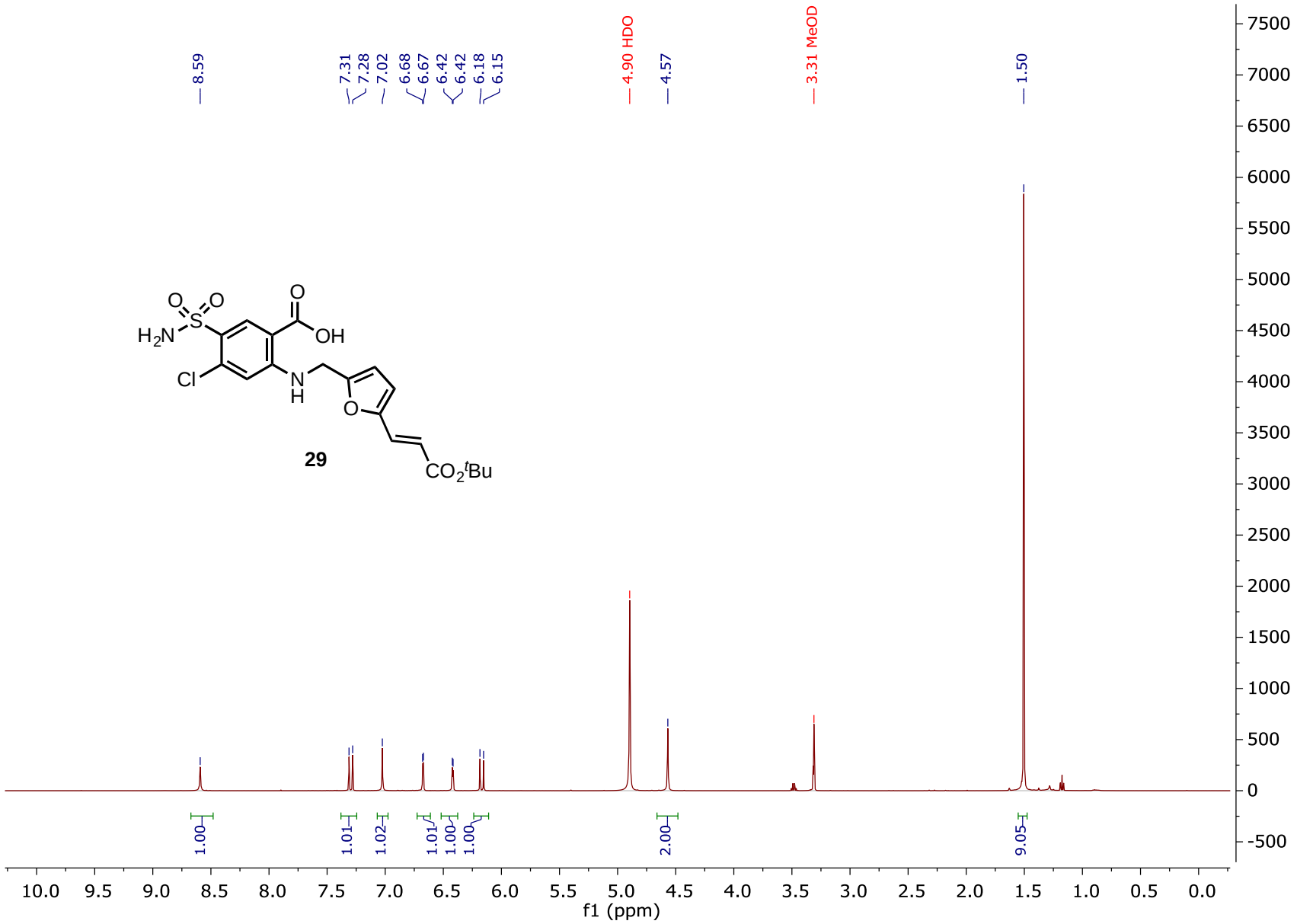


Figure S78. ^{1}H NMR (500 MHz, $CDCl_3$) of **29**.

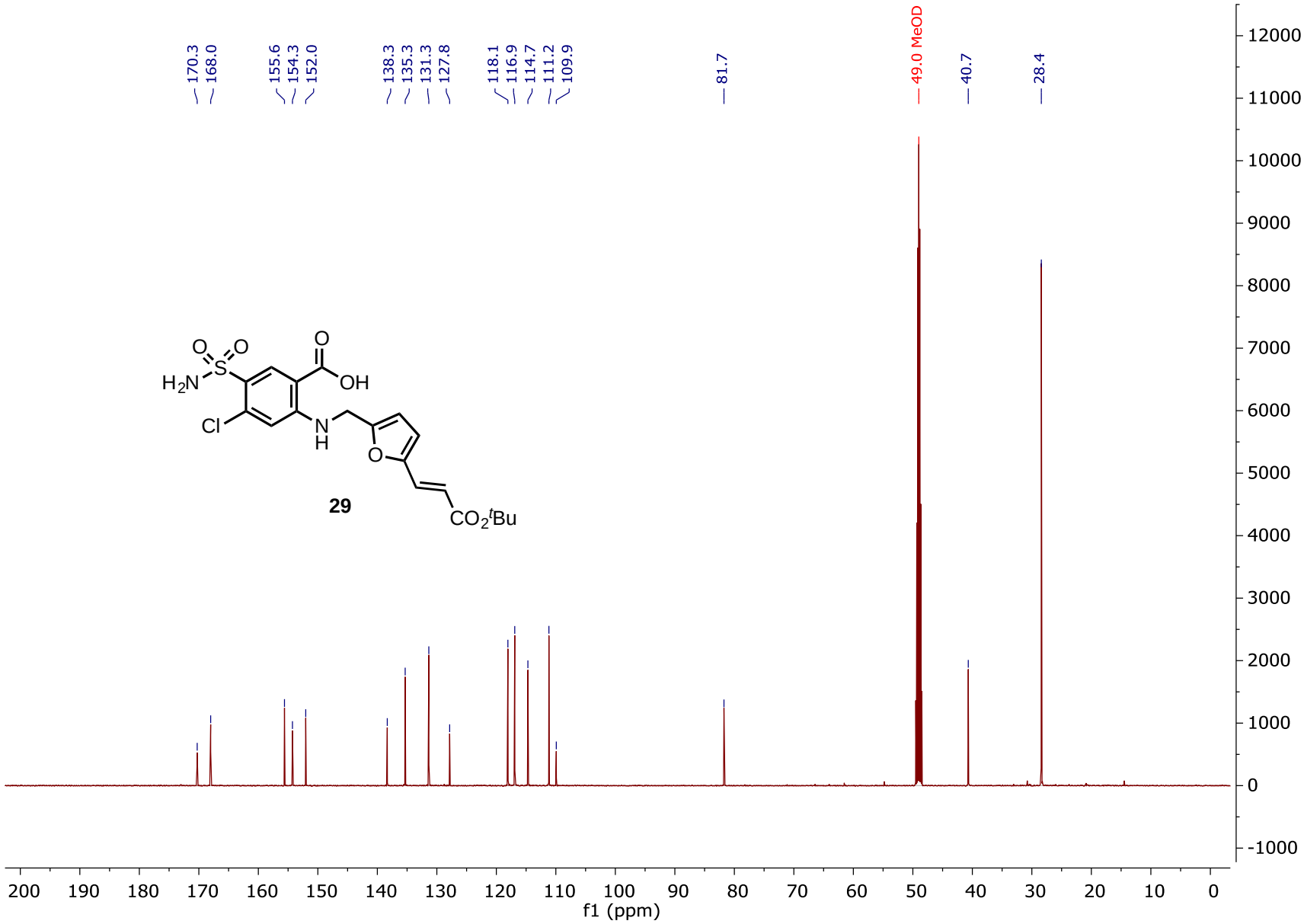


Figure S79. $^{13}C\{^{1}H\}$ NMR (126 MHz, $CDCl_3$) of **29**.

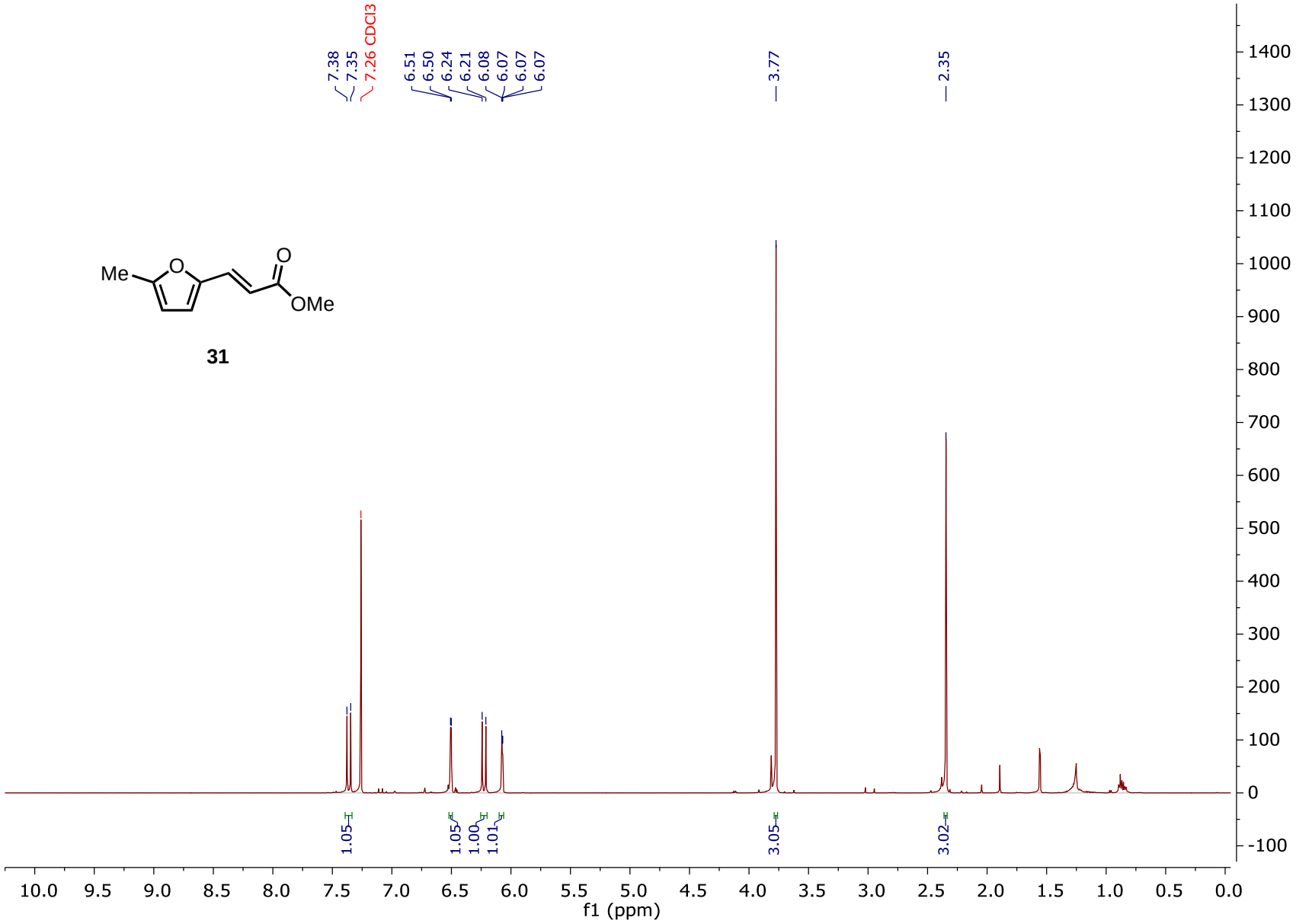


Figure S80. ^{1}H NMR (500 MHz, $CDCl_3$) of **31**.

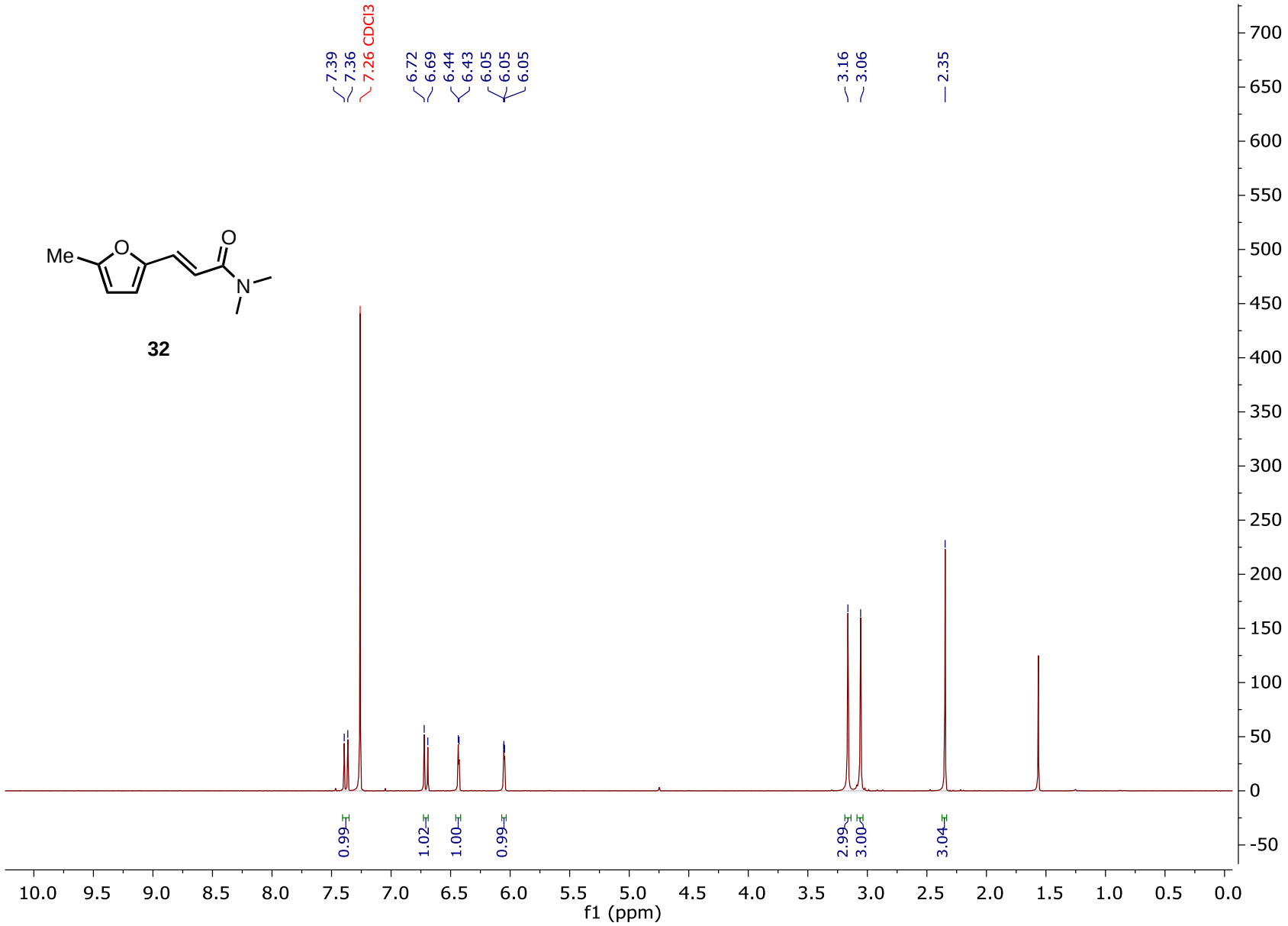


Figure S81. ^{1}H NMR (500 MHz, $CDCl_3$) of **32**.

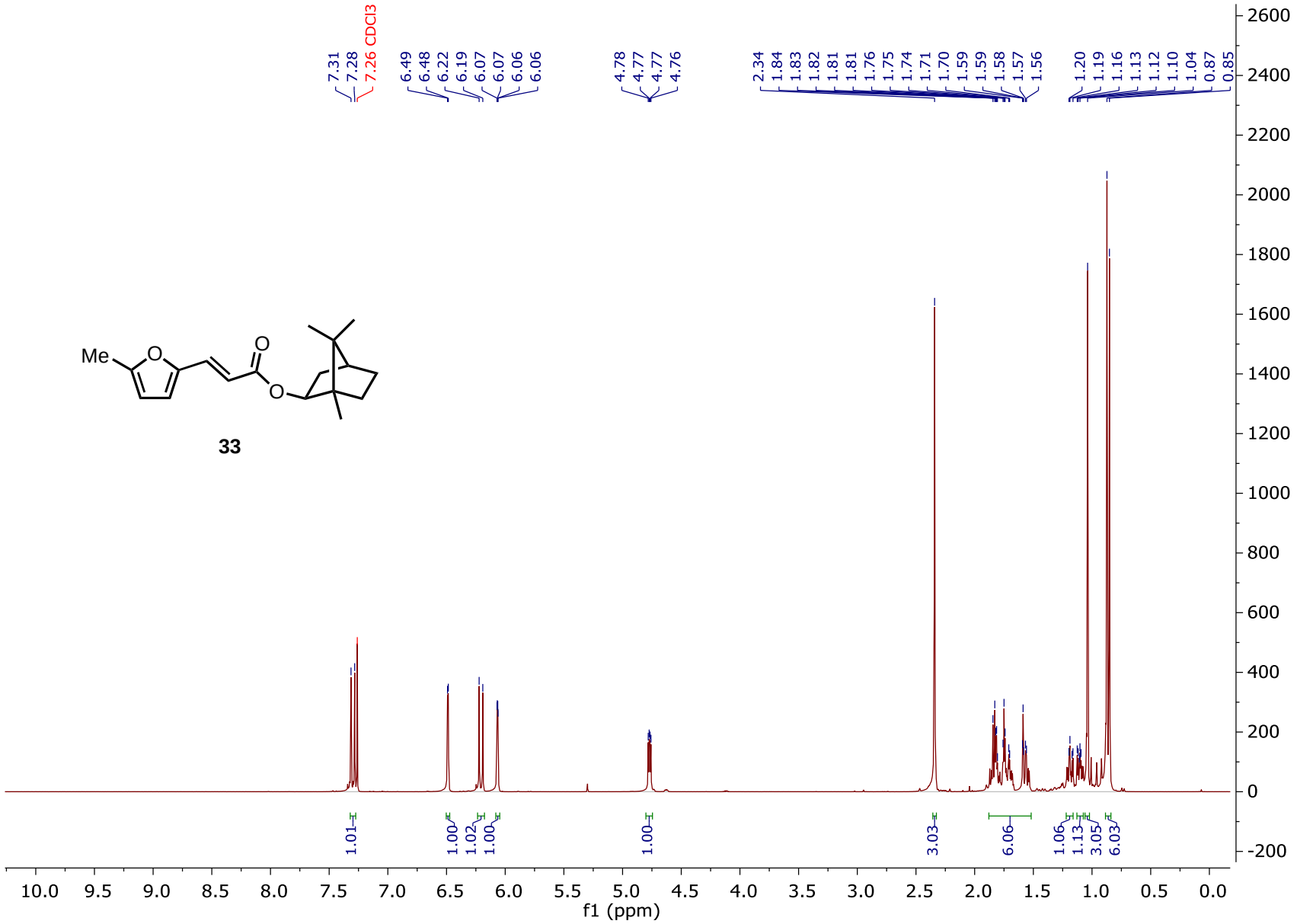


Figure S82. ^{1}H NMR (500 MHz, $CDCl_3$) of **33**.

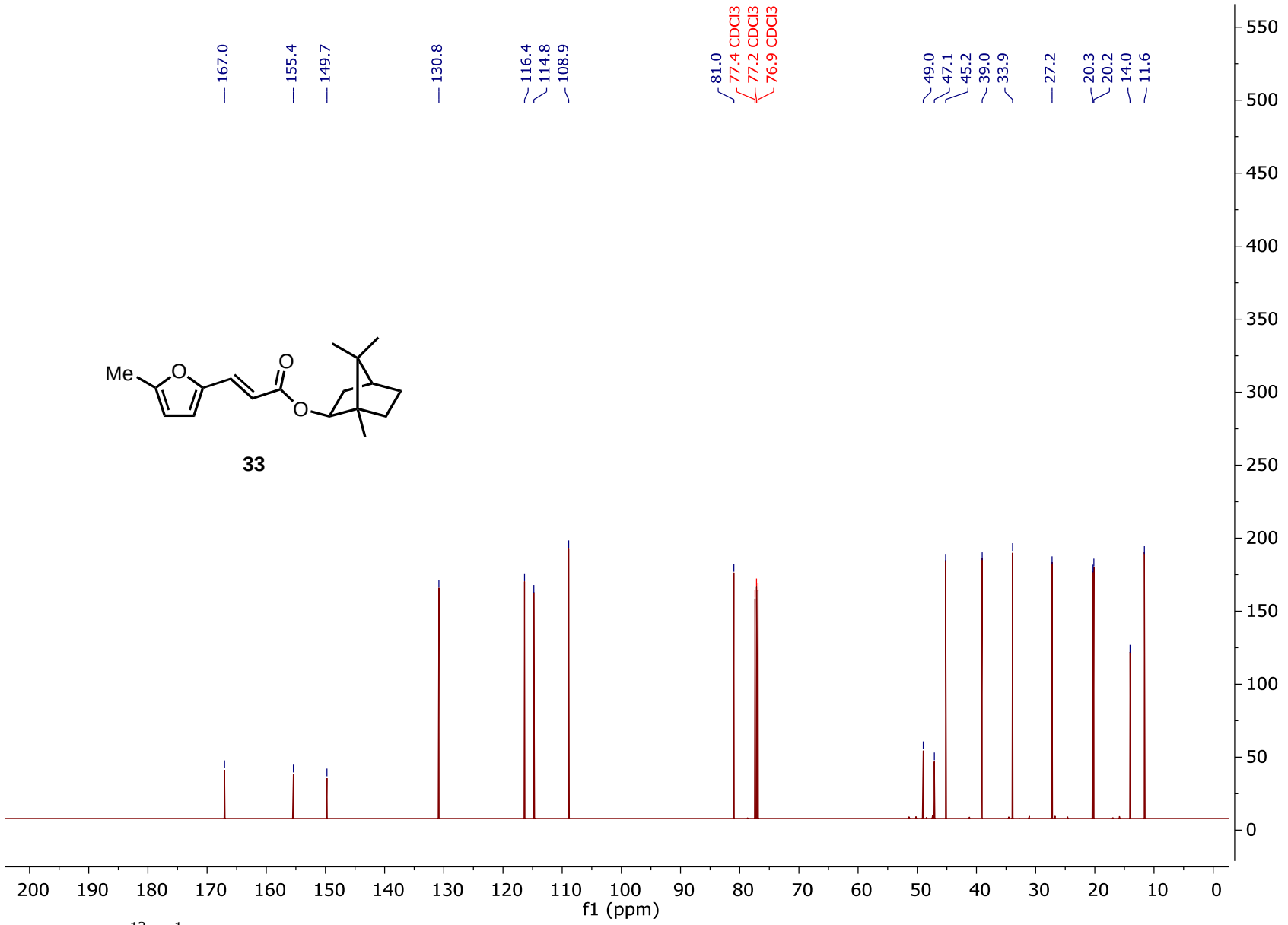


Figure S83. $^{13}C\{^{1}H\}$ NMR (126 MHz, $CDCl_3$) of **33**.

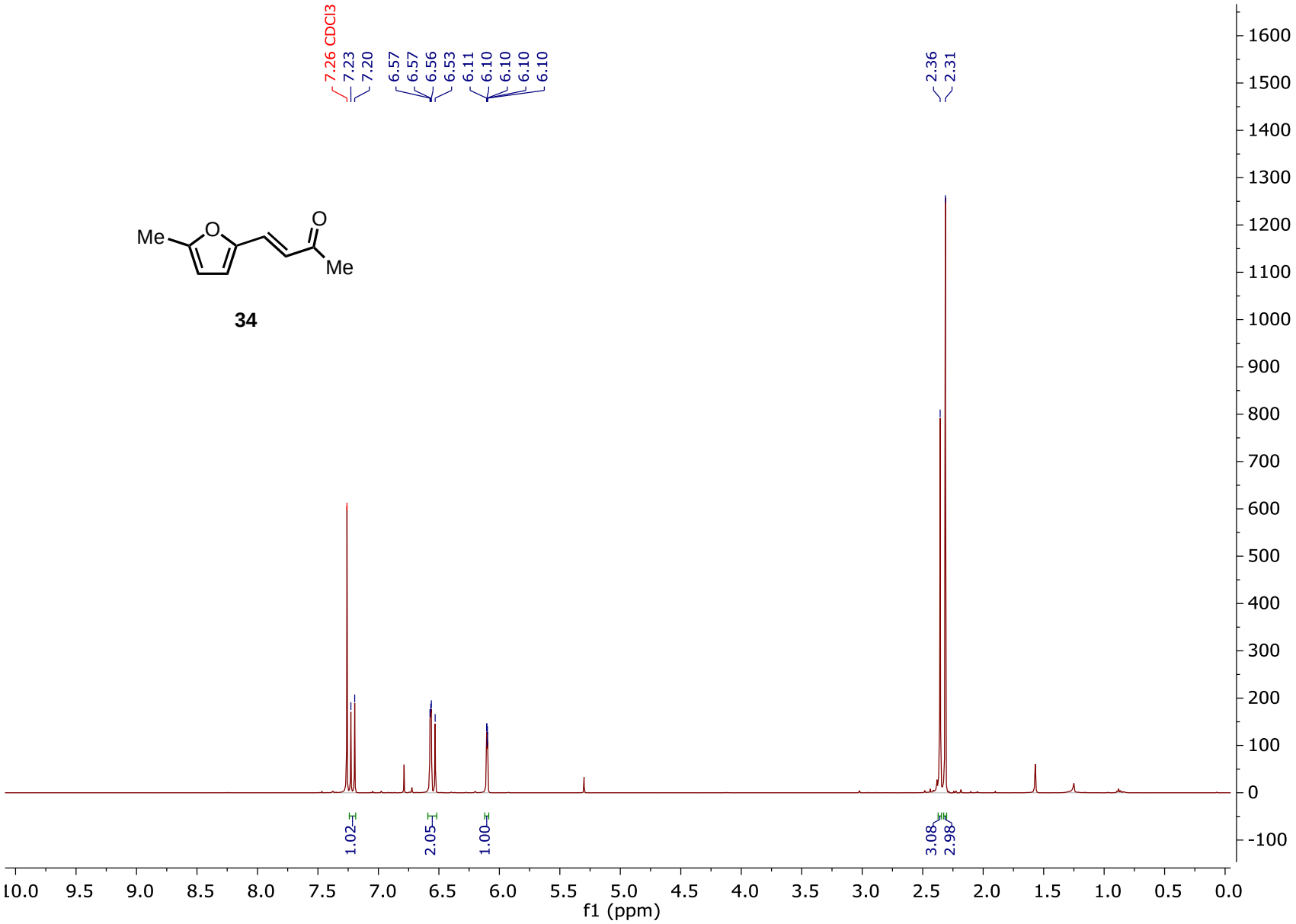


Figure S84. ^{1}H NMR (500 MHz, $CDCl_3$) of **34**.

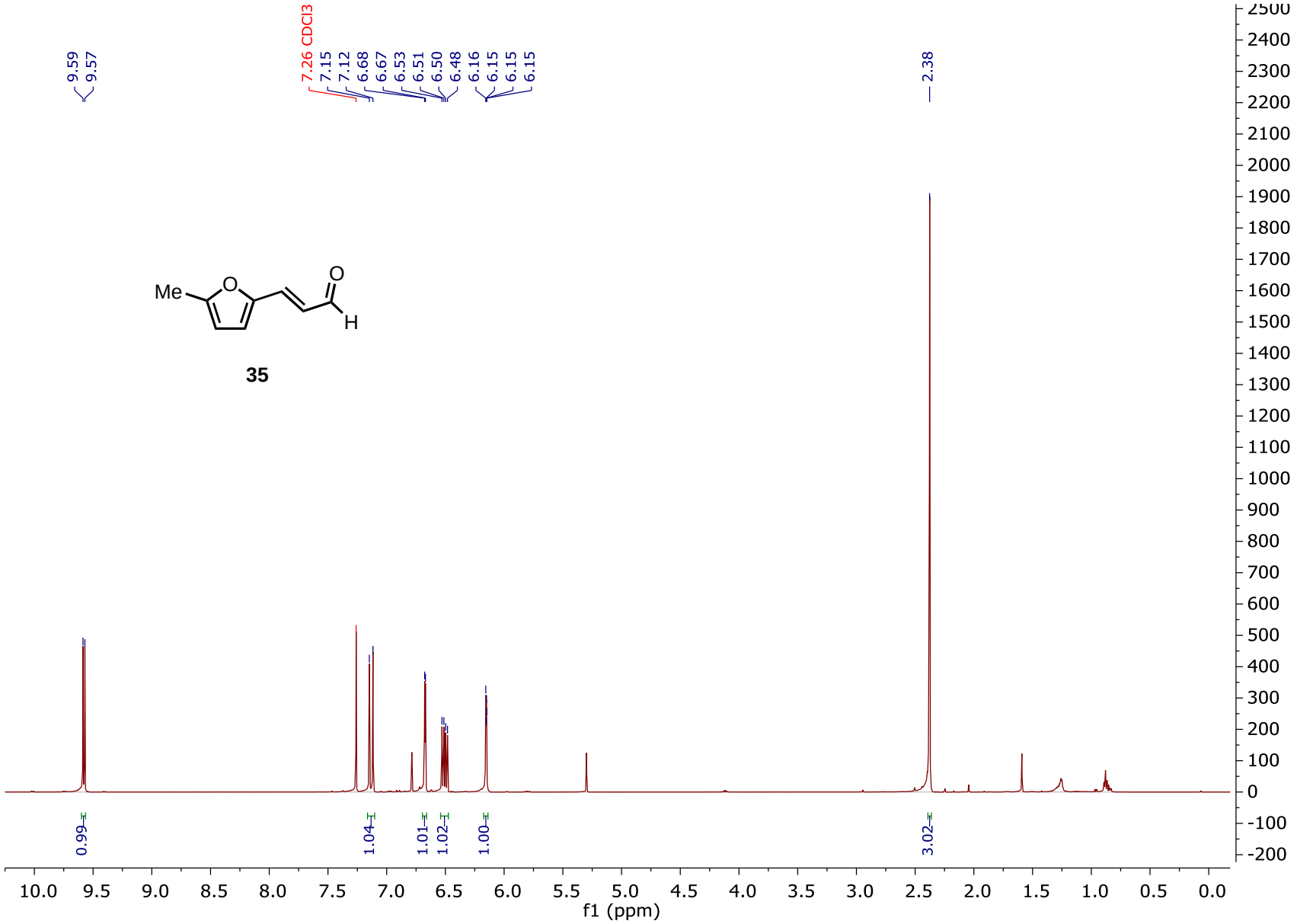


Figure S85. ^{1}H NMR (500 MHz, $CDCl_3$) of **35**.

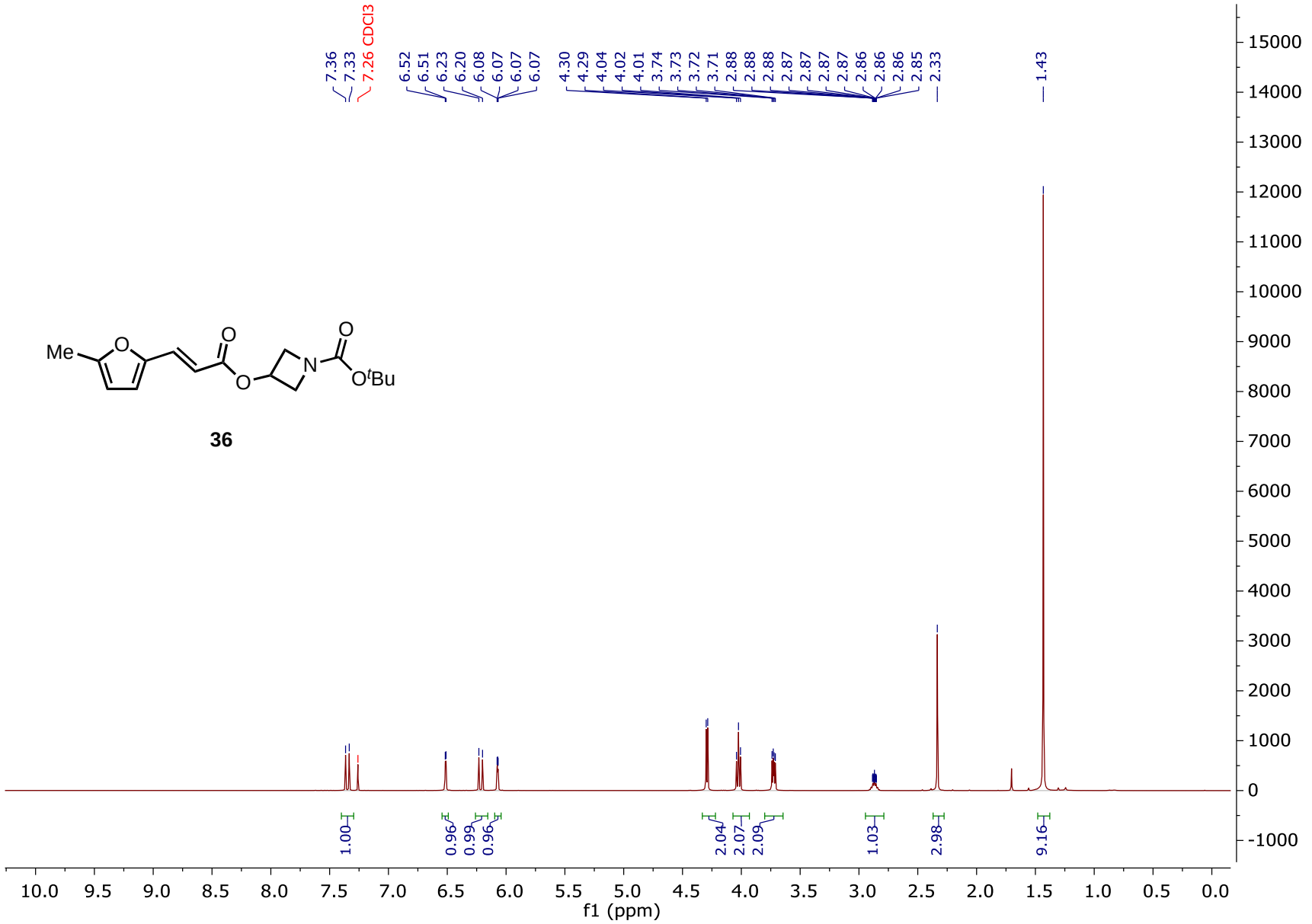


Figure S86. ^{1}H NMR (500 MHz, $CDCl_3$) of **36**.

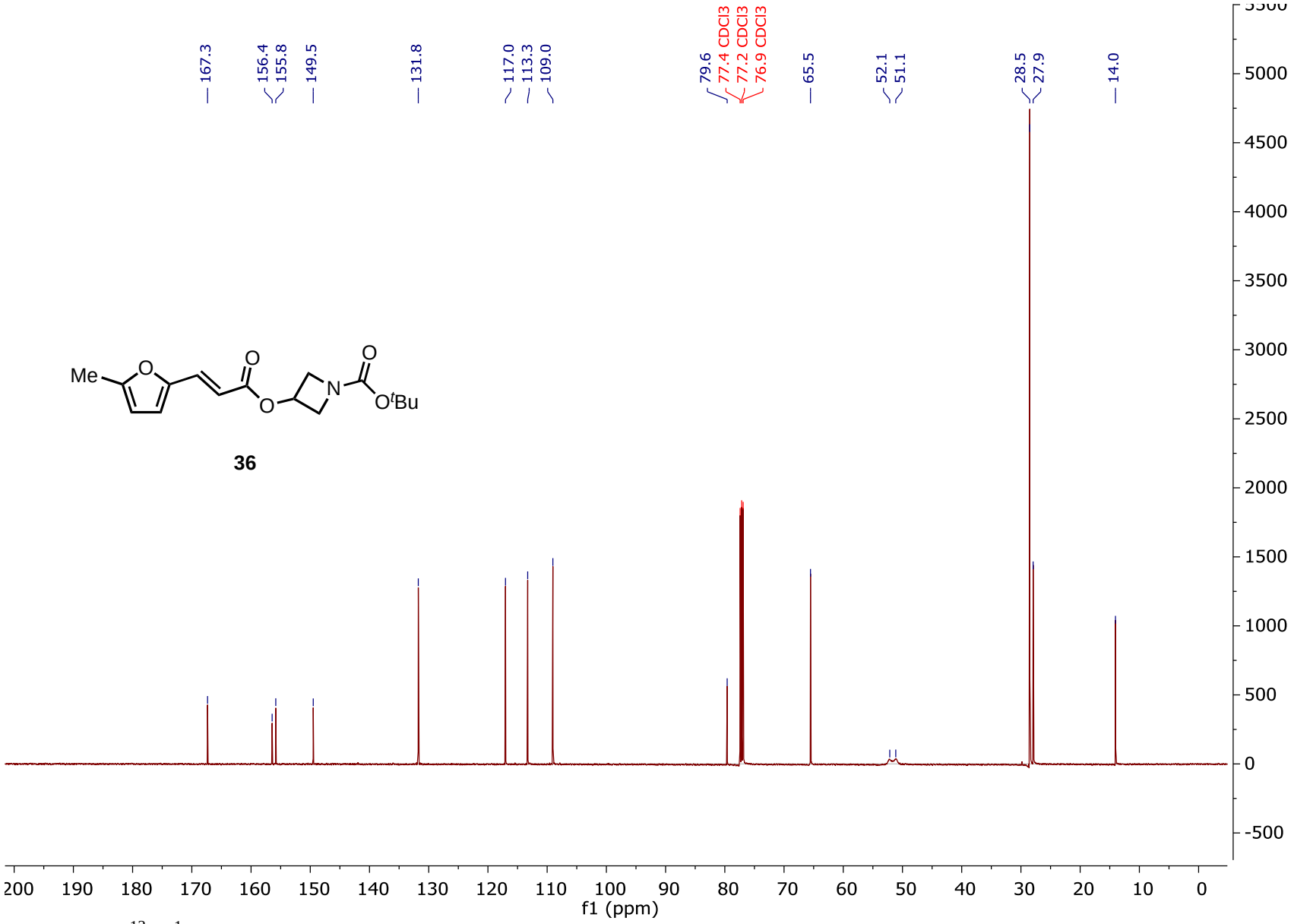


Figure S87. $^{13}C\{^1H\}$ NMR (126 MHz, $CDCl_3$) of **36**.

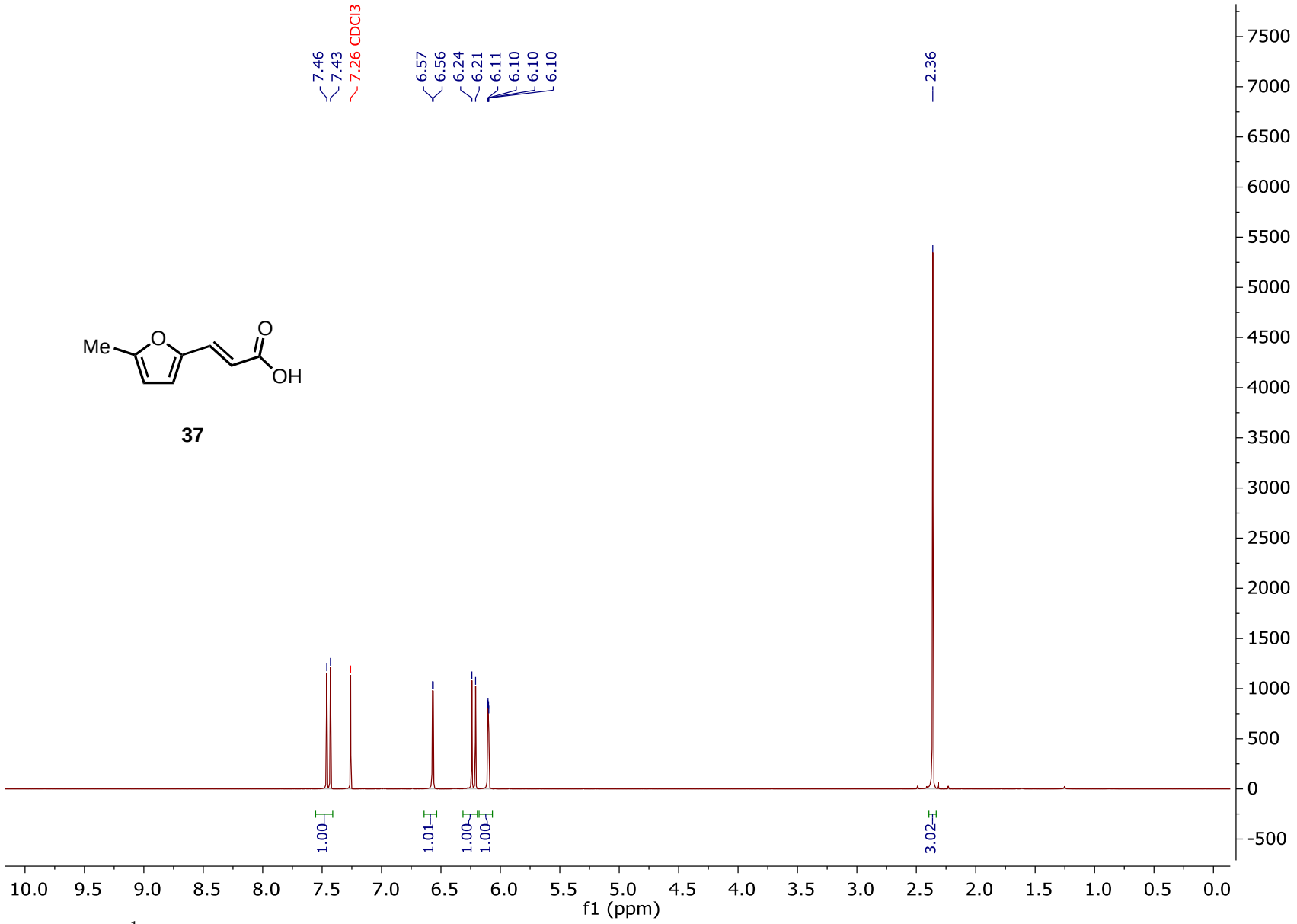


Figure S88. ^{1}H NMR (500 MHz, $CDCl_3$) of **37**.

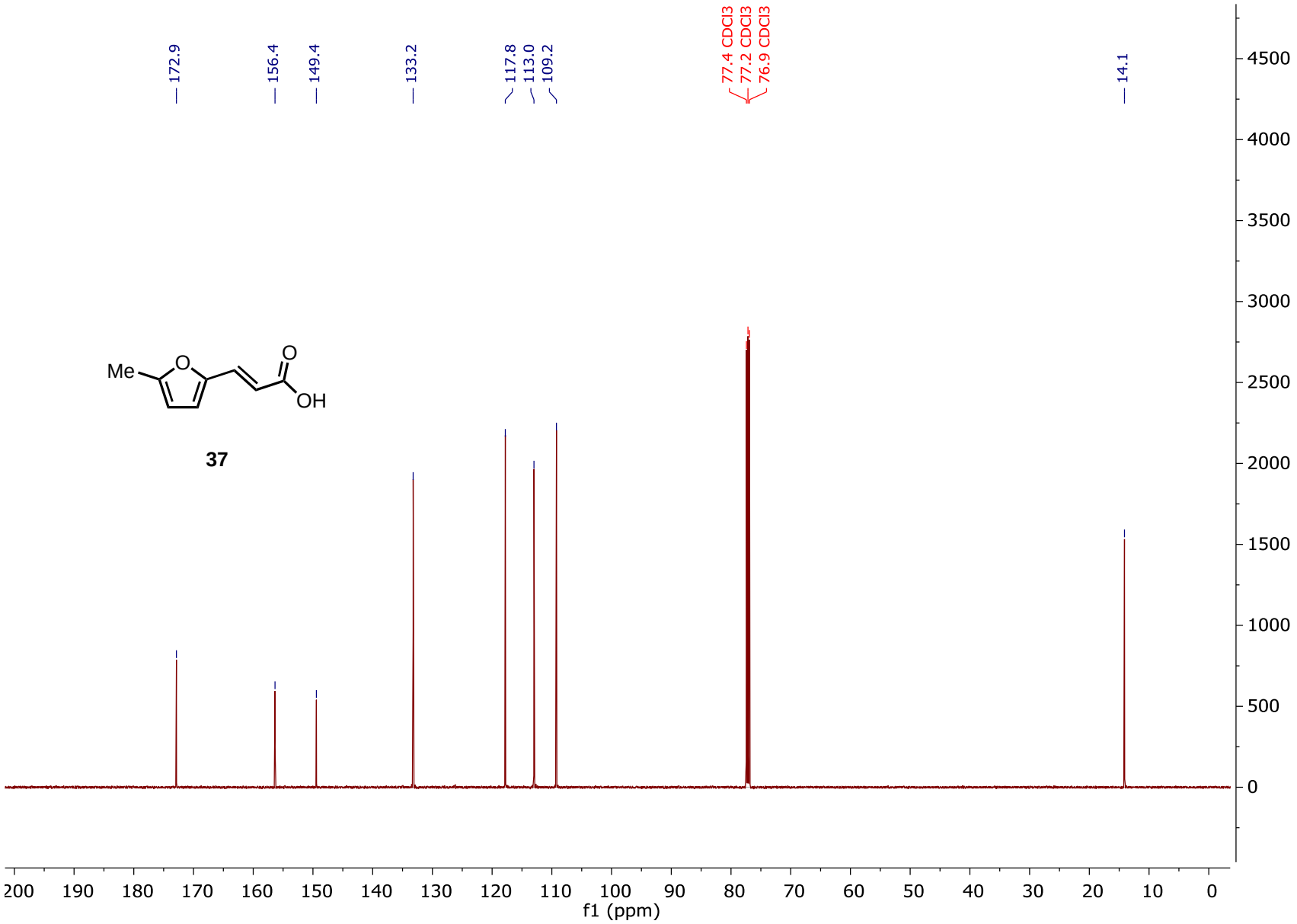


Figure S89. $^{13}C\{^{1}H\}$ NMR (126 MHz, $CDCl_3$) of **37**.

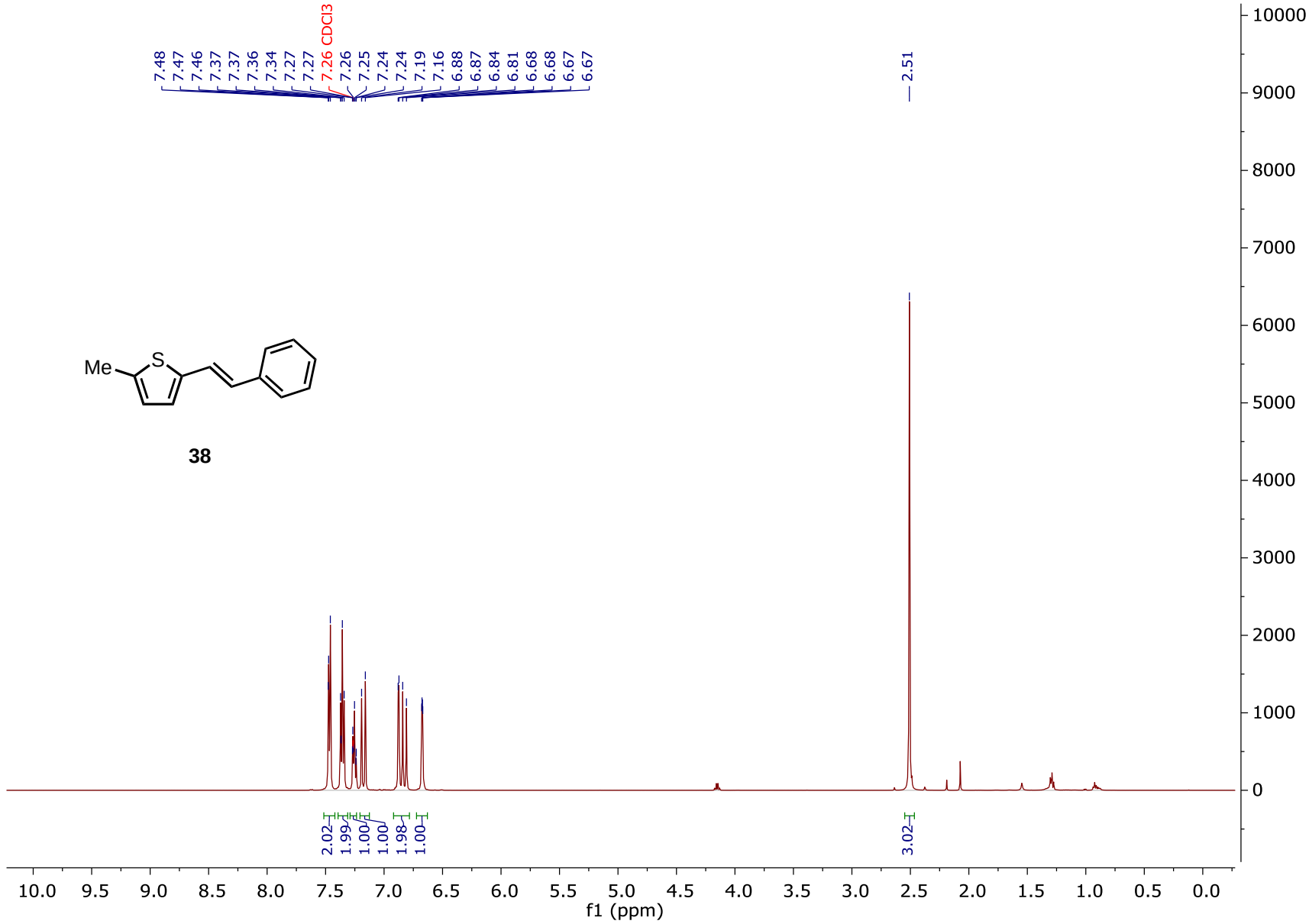


Figure S90. ^{1}H NMR (500 MHz, $CDCl_3$) of **38**.

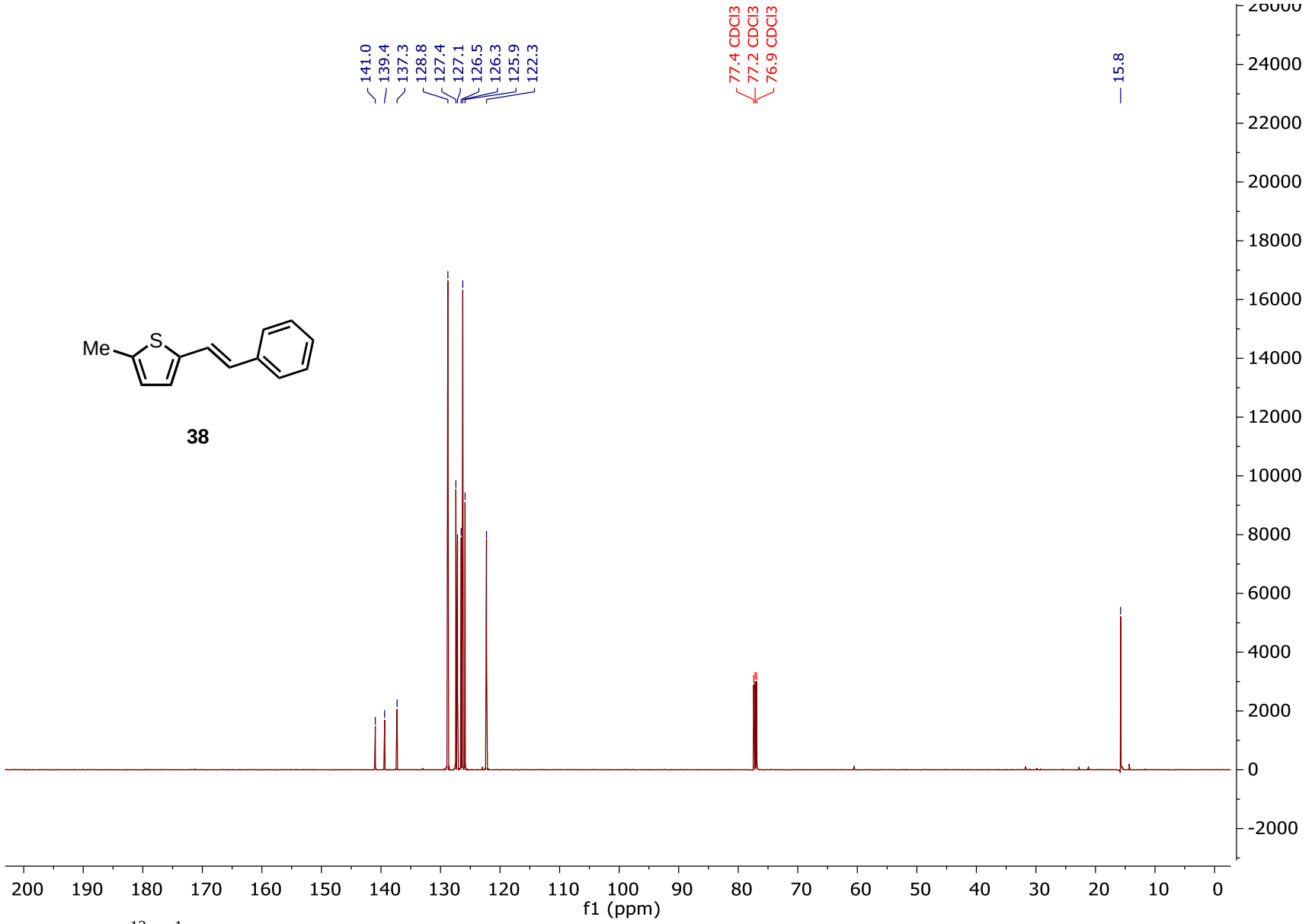


Figure S91. $^{13}C\{^{1}H\}$ NMR (126 MHz, $CDCl_3$) of **38**.

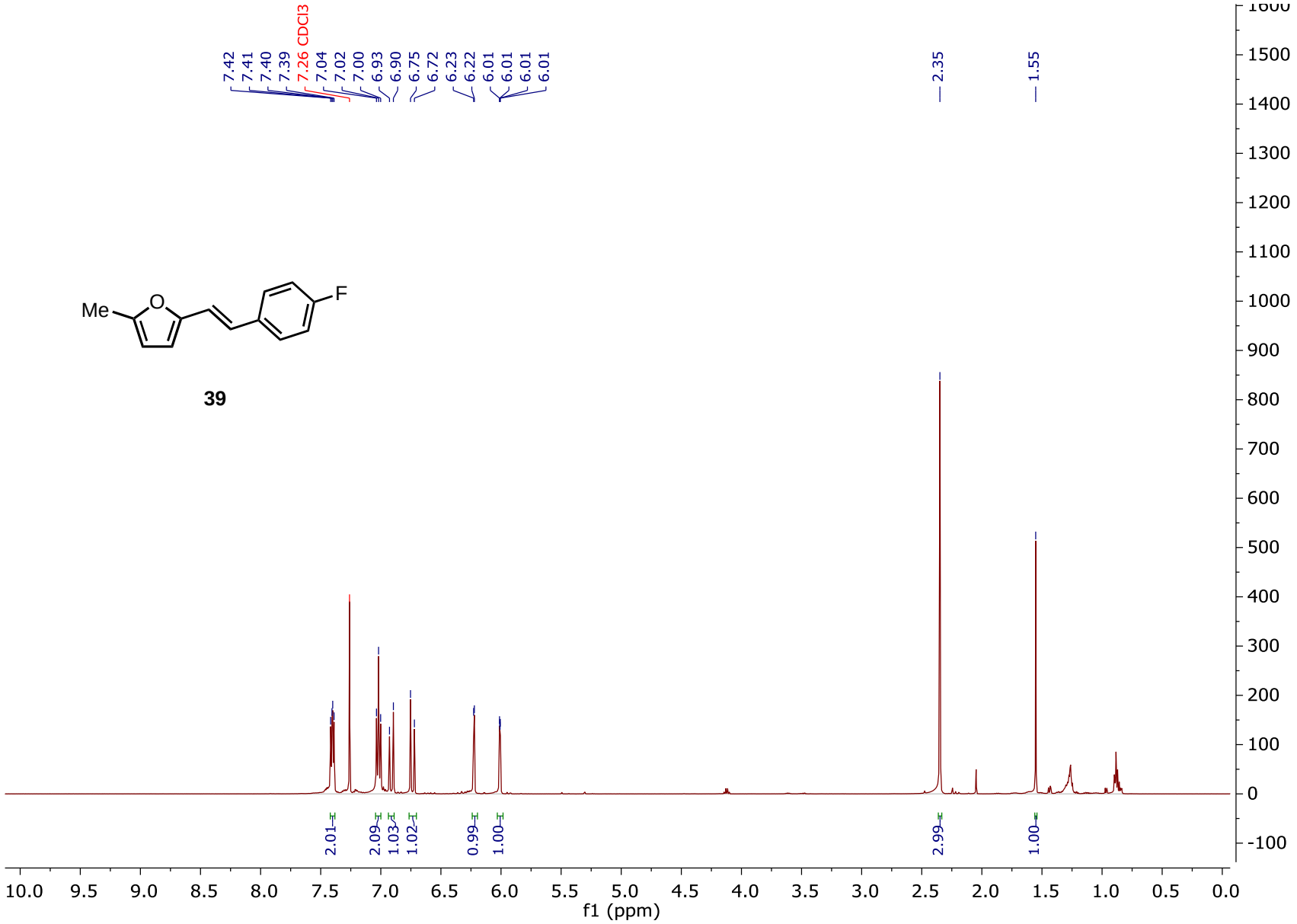


Figure S92. ^{1}H NMR (500 MHz, $CDCl_3$) of **39**.

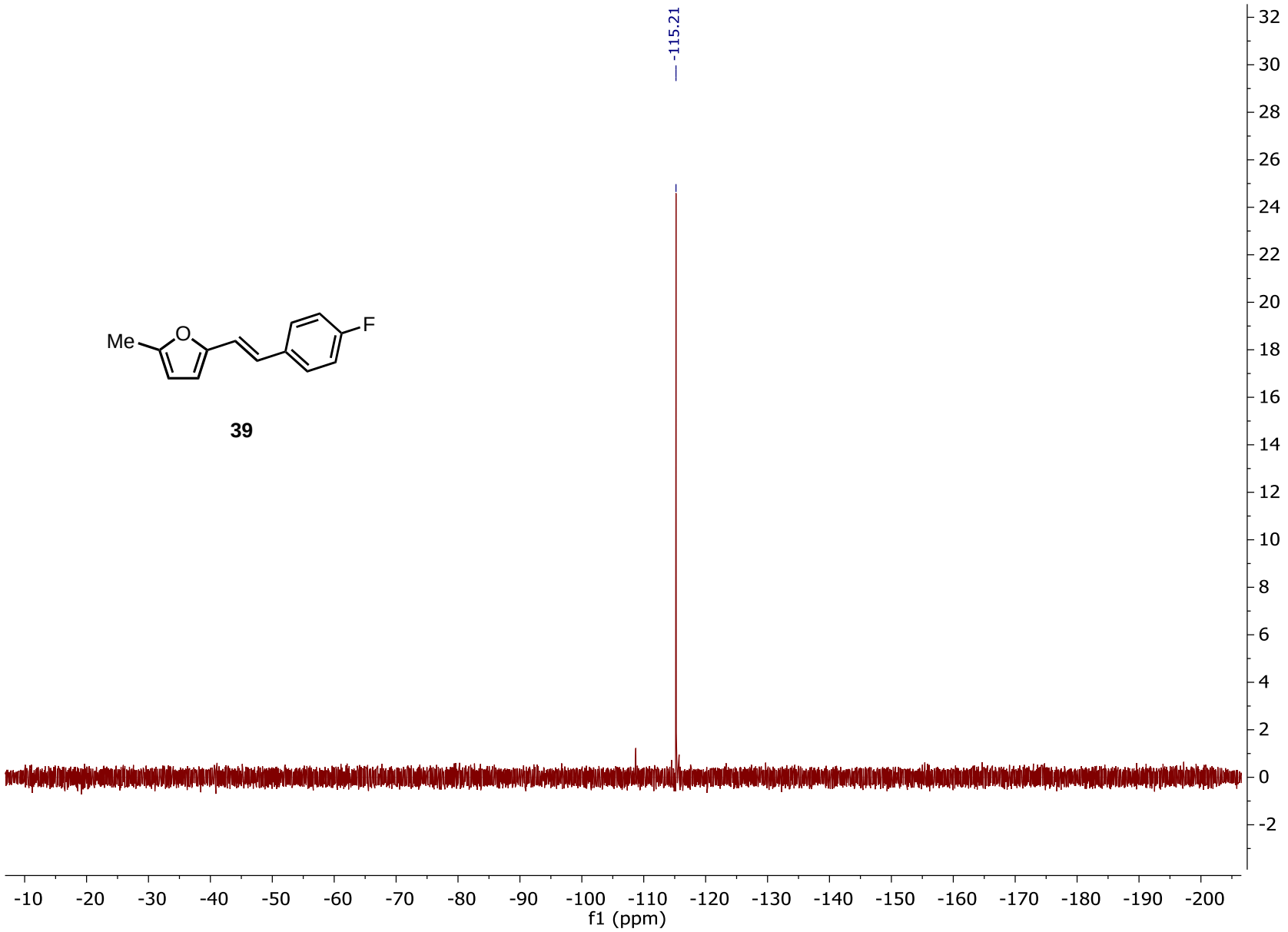


Figure S93. $^{19}F\{^{1}H\}$ NMR (376 MHz, $CDCl_3$) of **39**.

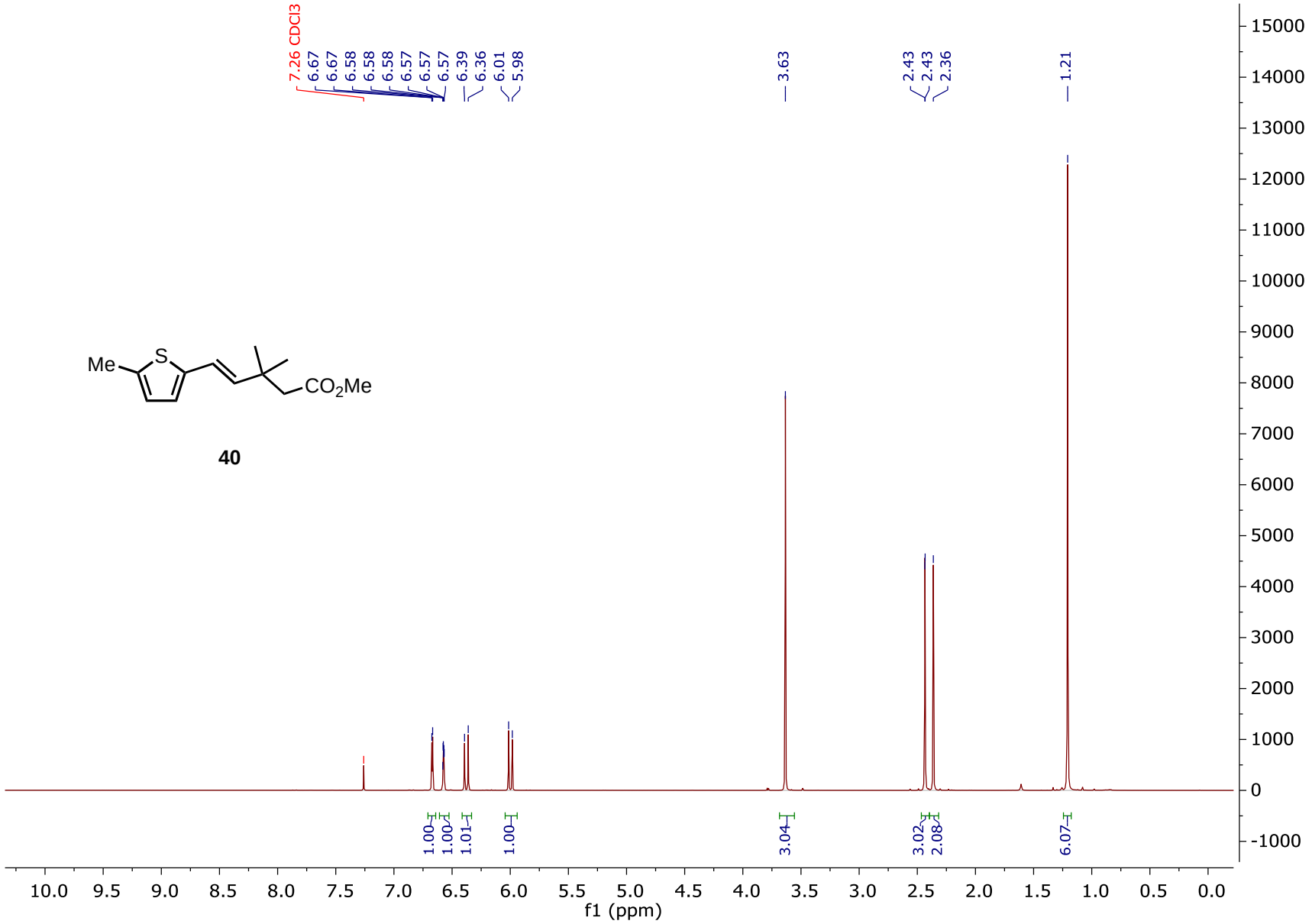


Figure S94. ^{1}H NMR (500 MHz, $CDCl_3$) of **40**.

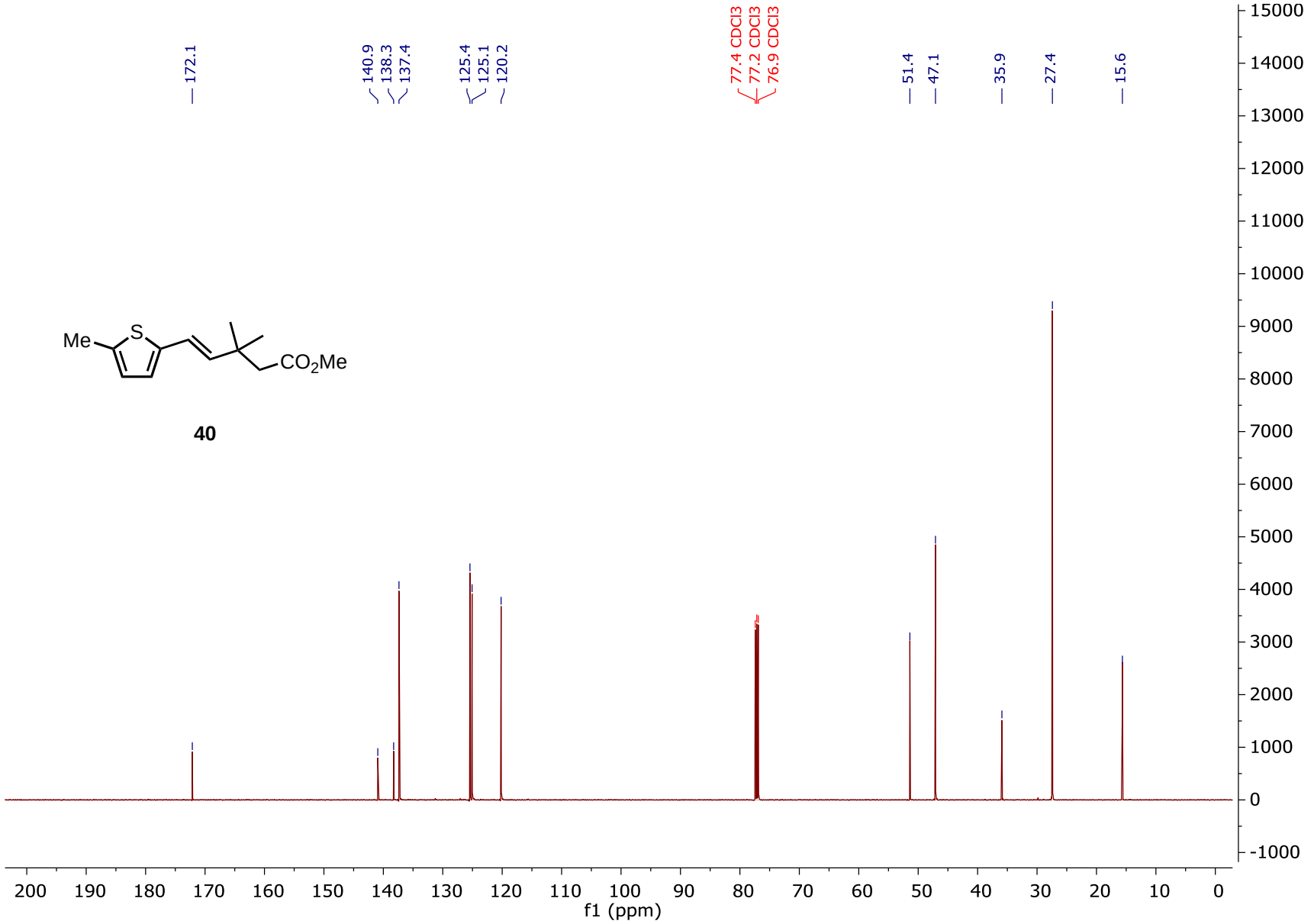


Figure S95. $^{13}C\{^{1}H\}$ NMR (126 MHz, $CDCl_3$) of **40**.

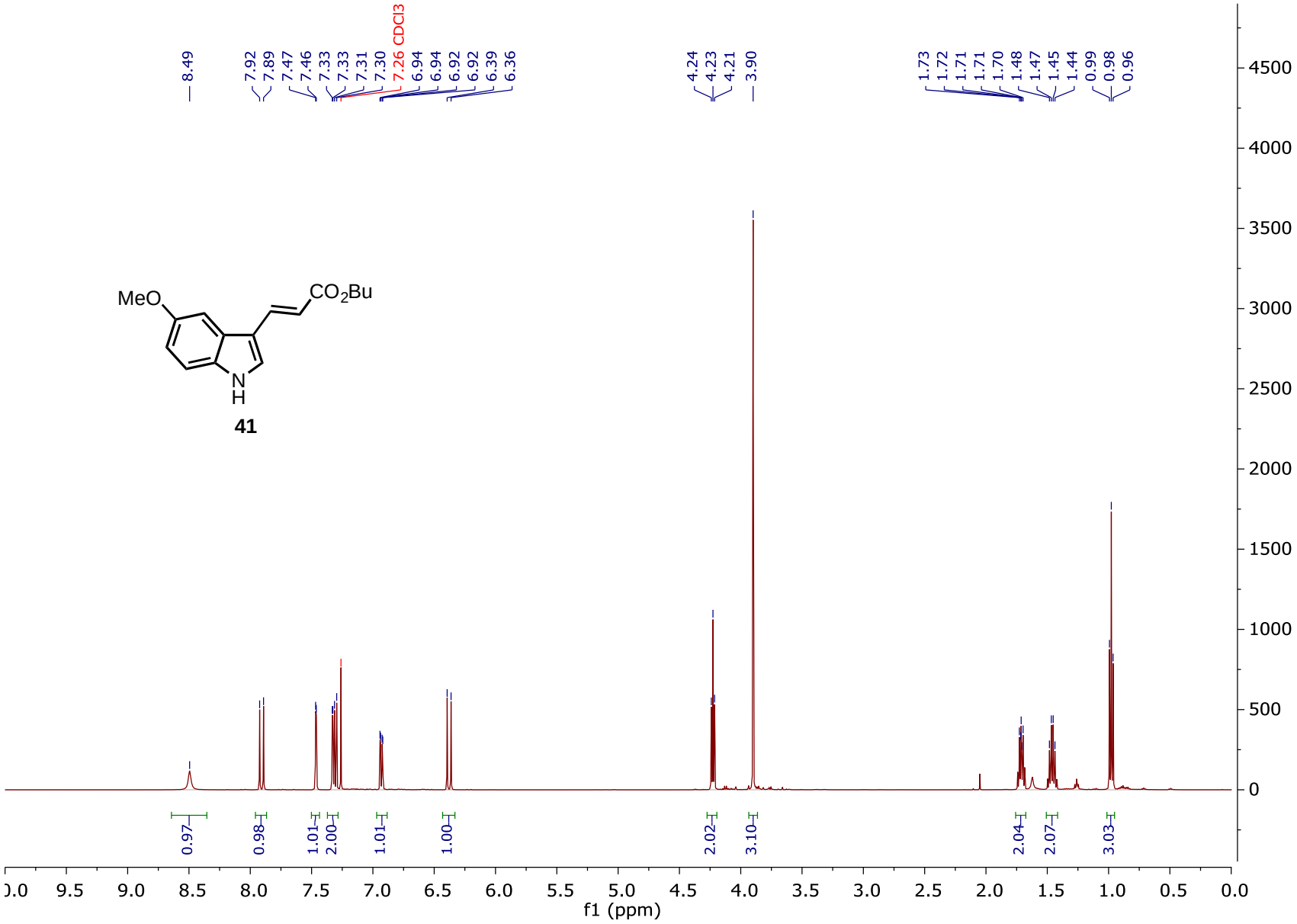


Figure S96. ^{1}H NMR (500 MHz, $CDCl_3$) of **41**.

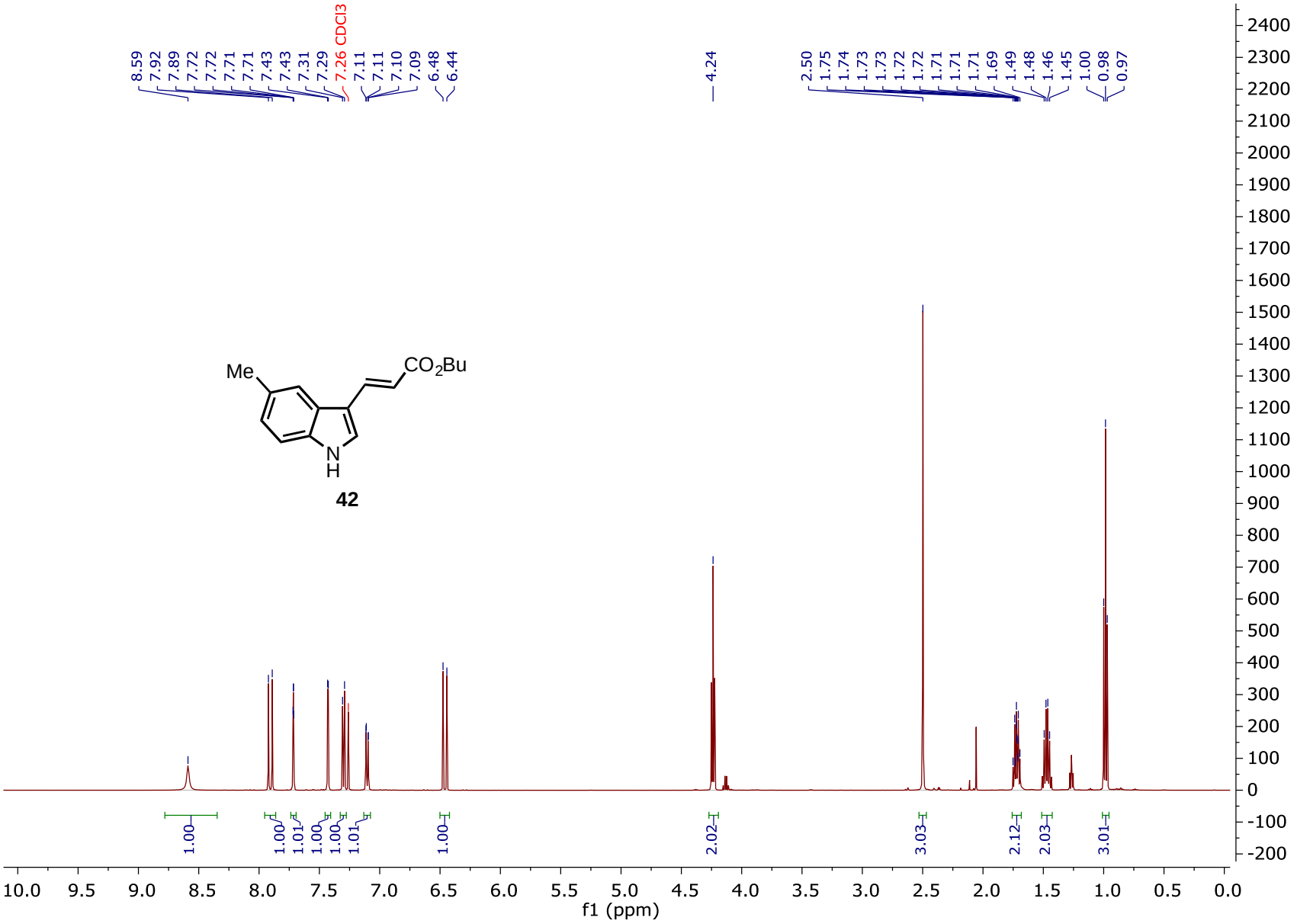


Figure S97. ^{1}H NMR (500 MHz, $CDCl_3$) of **42**.

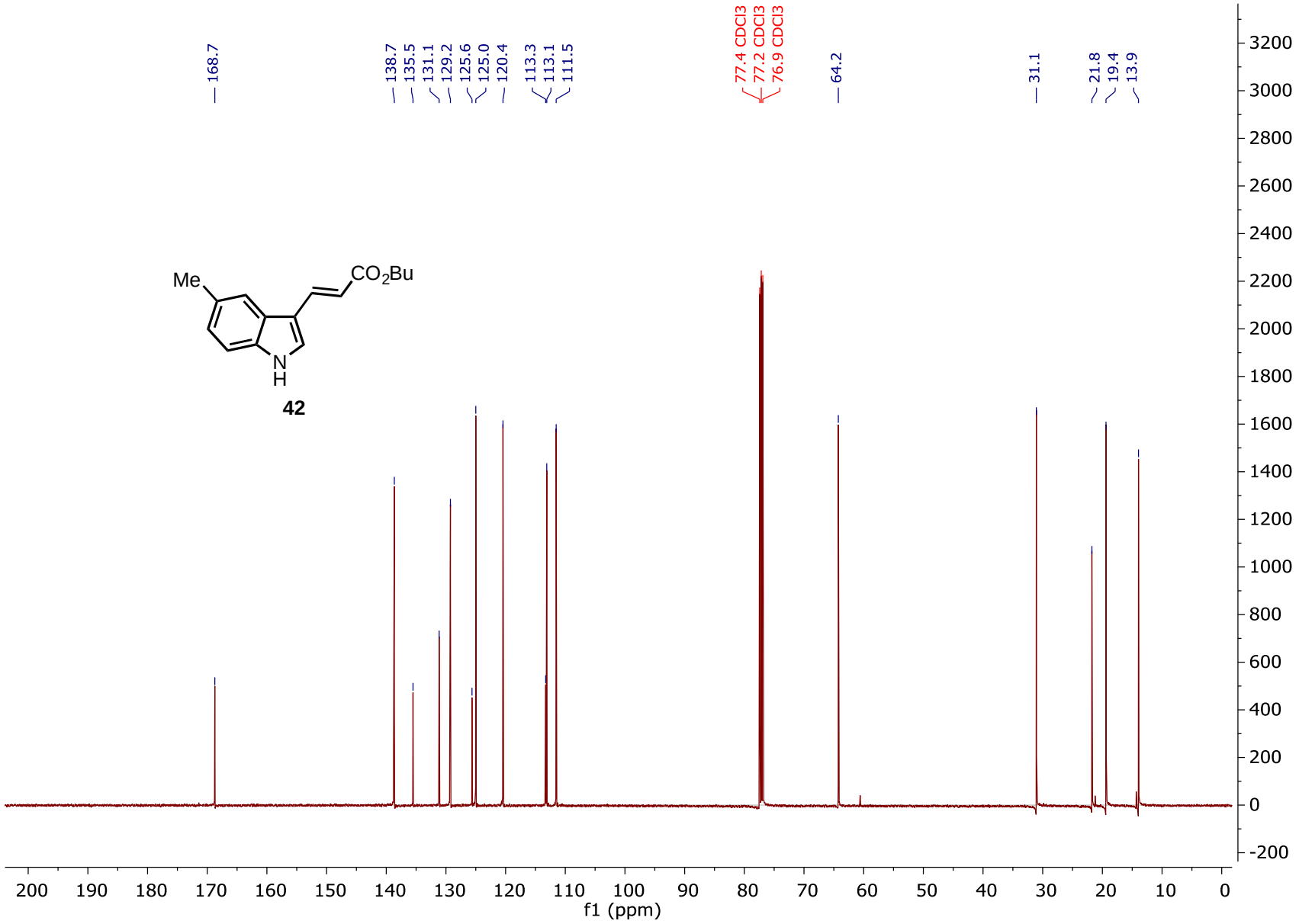


Figure S98. $^{13}C\{^{1}H\}$ NMR (126 MHz, $CDCl_3$) of **42**.

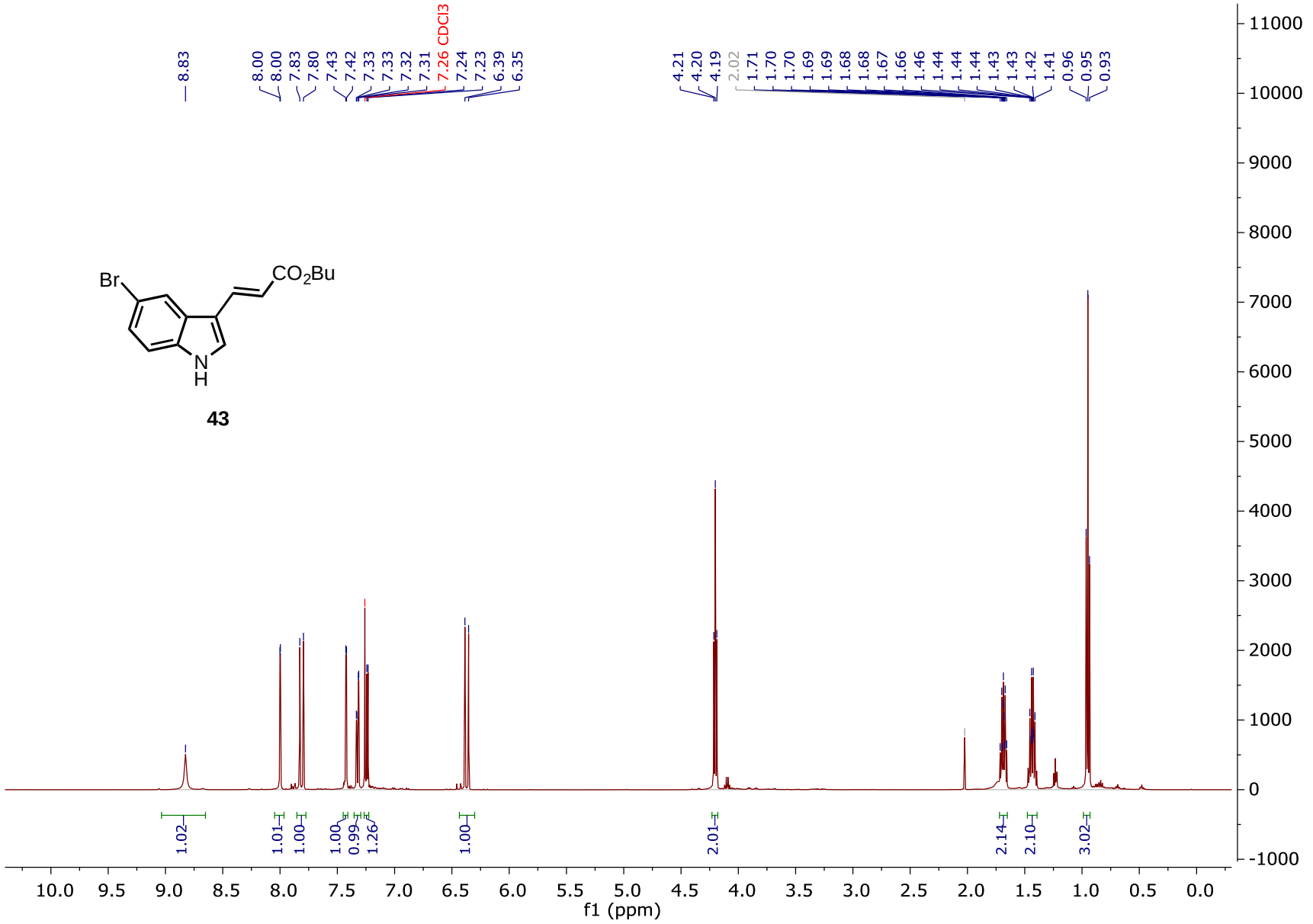


Figure S99. ^{1}H NMR (500 MHz, $CDCl_3$) of **43**.

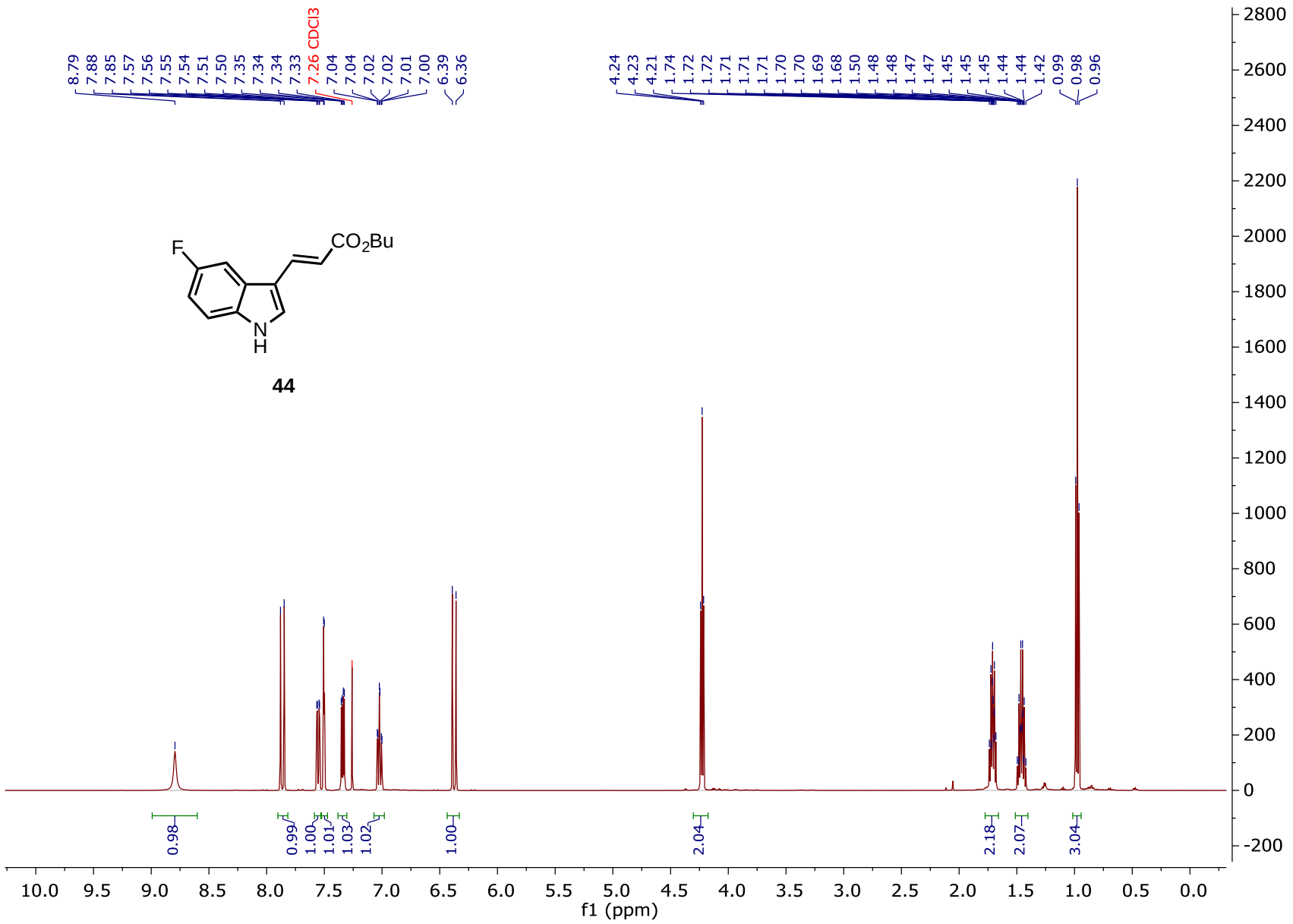


Figure S100. ^{1}H NMR (500 MHz, $CDCl_3$) of **44**.

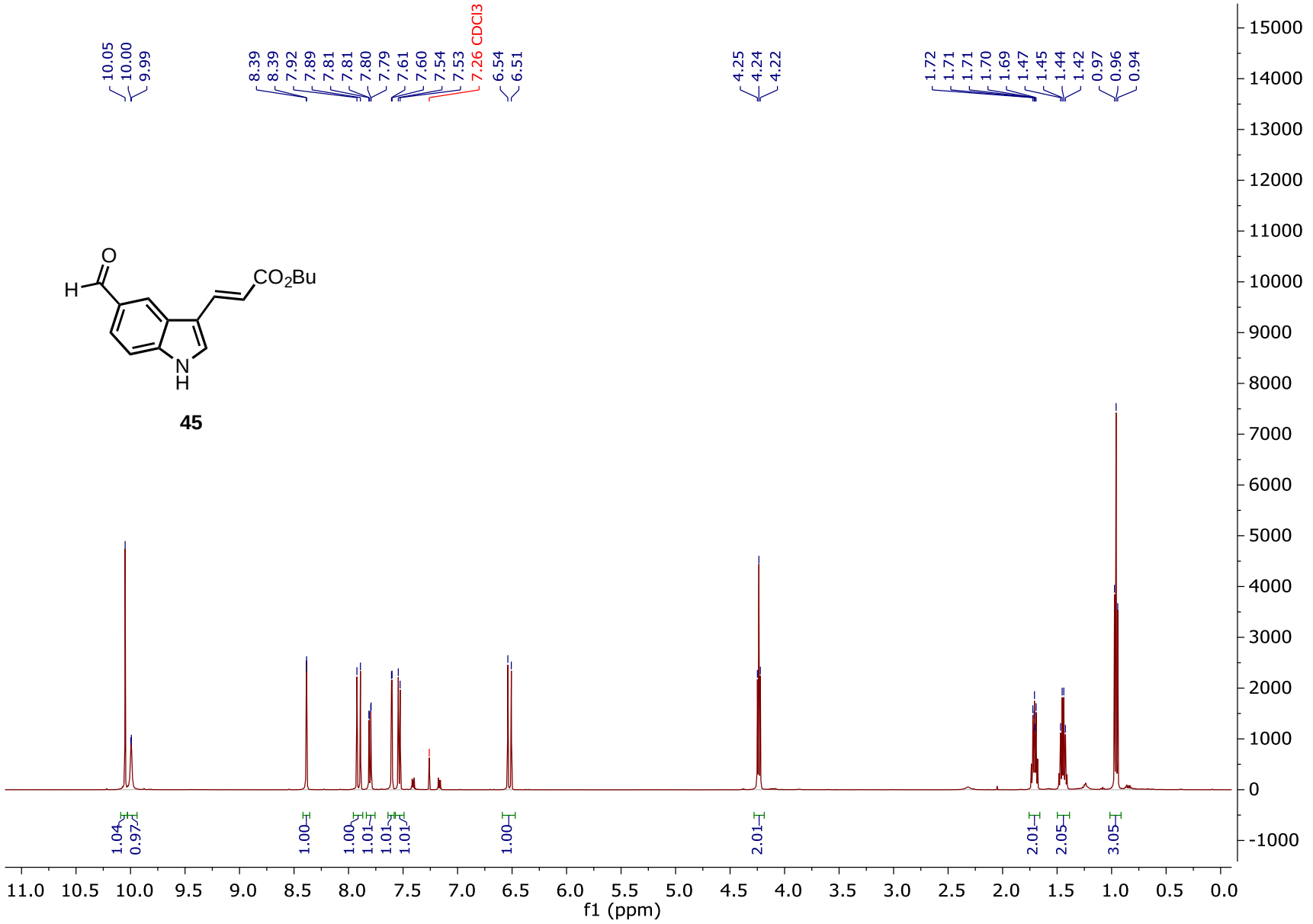


Figure S101. ^{1}H NMR (500 MHz, $CDCl_3$) of **45**.

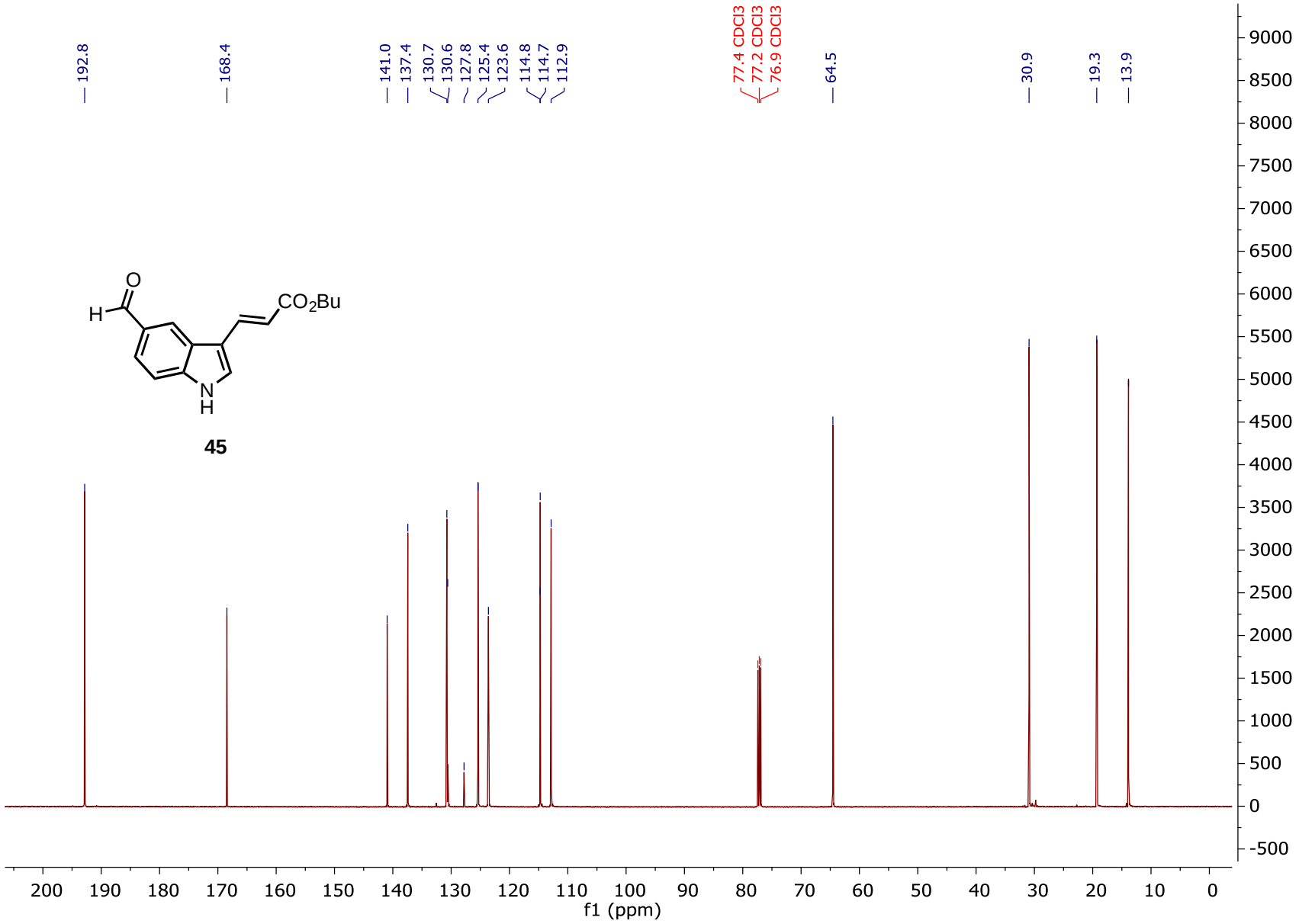


Figure S102. $^{13}C\{^{1}H\}$ NMR (126 MHz, $CDCl_3$) of **45**.

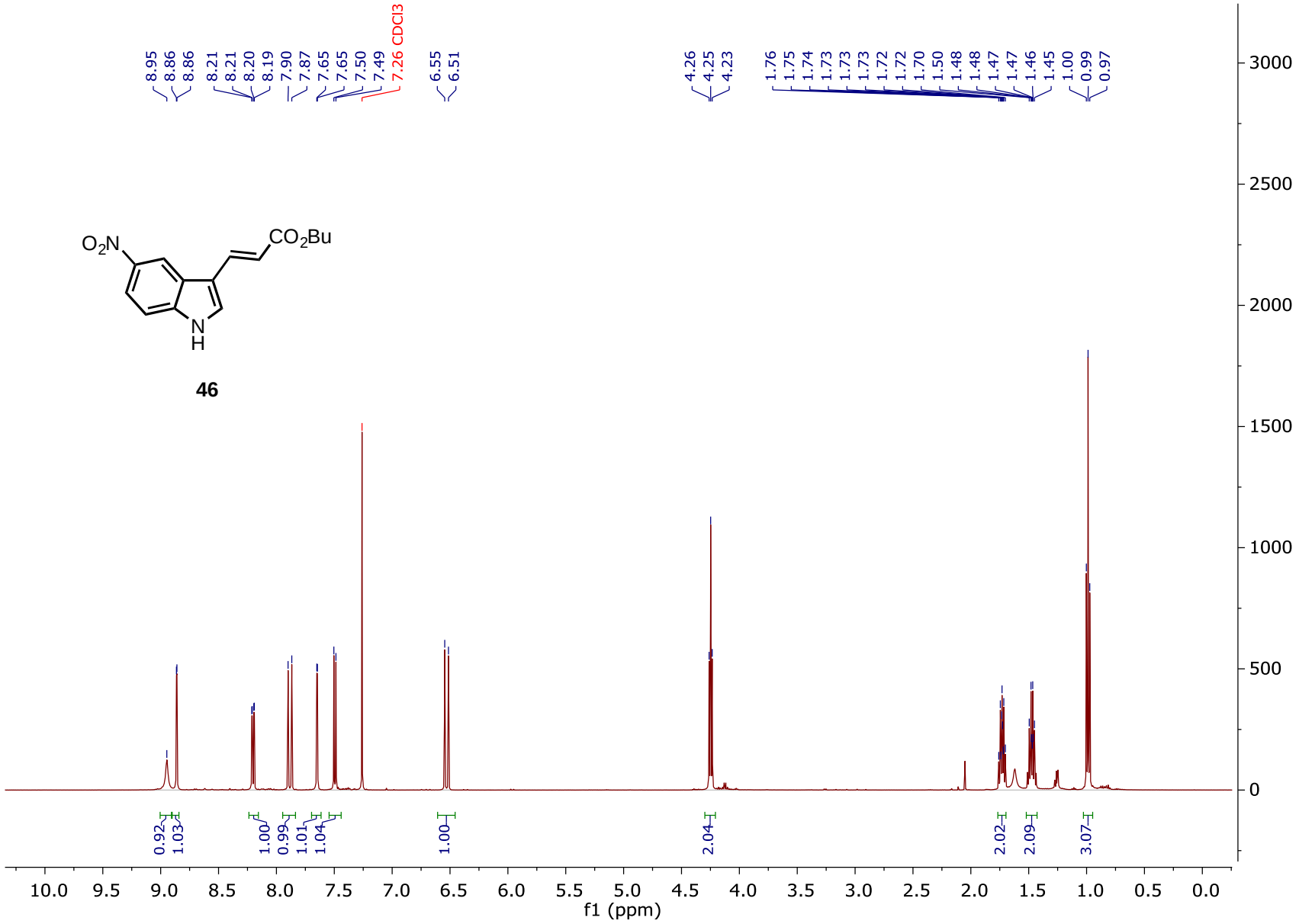


Figure S103. ^{1}H NMR (500 MHz, $CDCl_3$) of **46**.

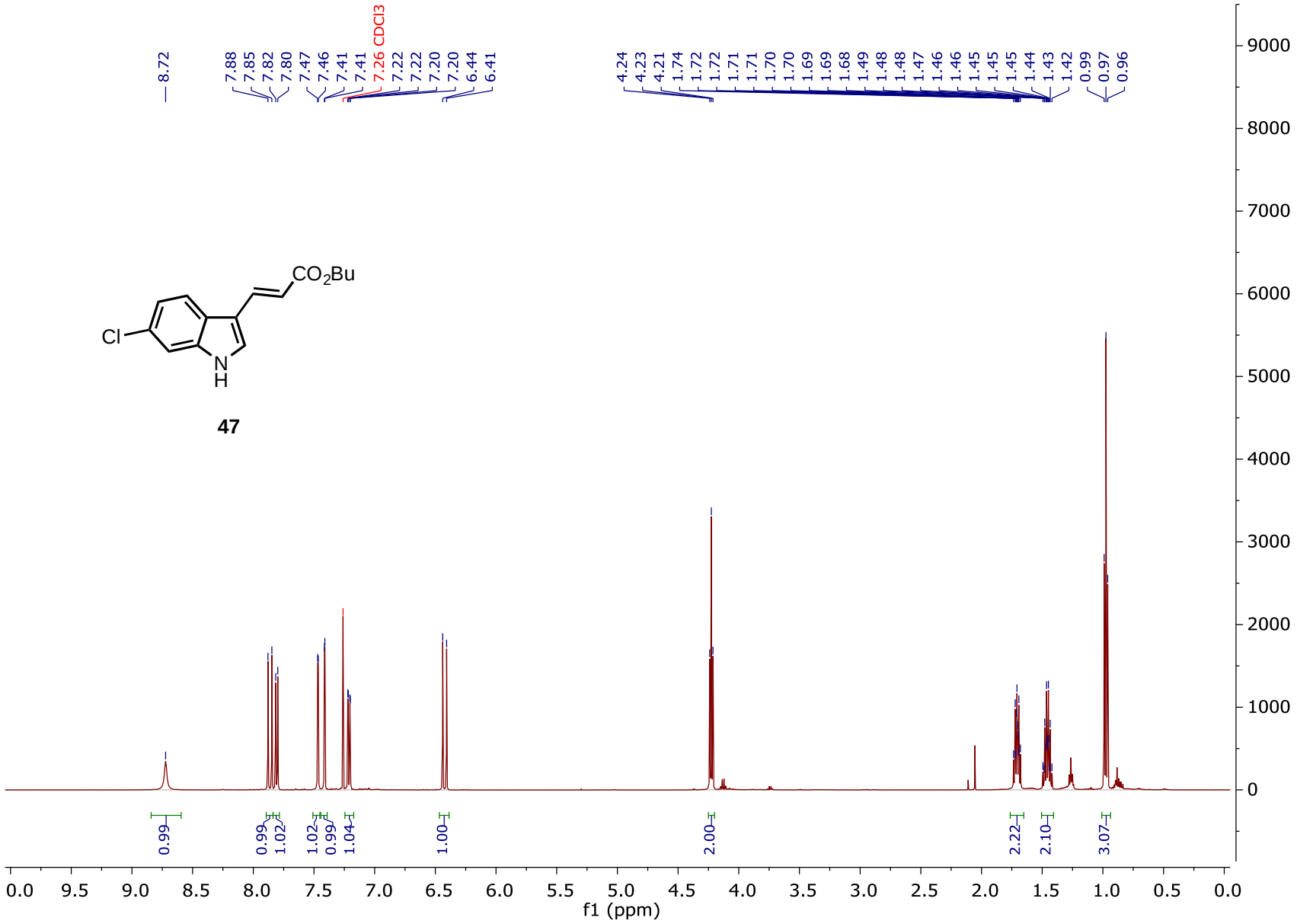


Figure S104. ^{1}H NMR (500 MHz, $CDCl_3$) of **47**.

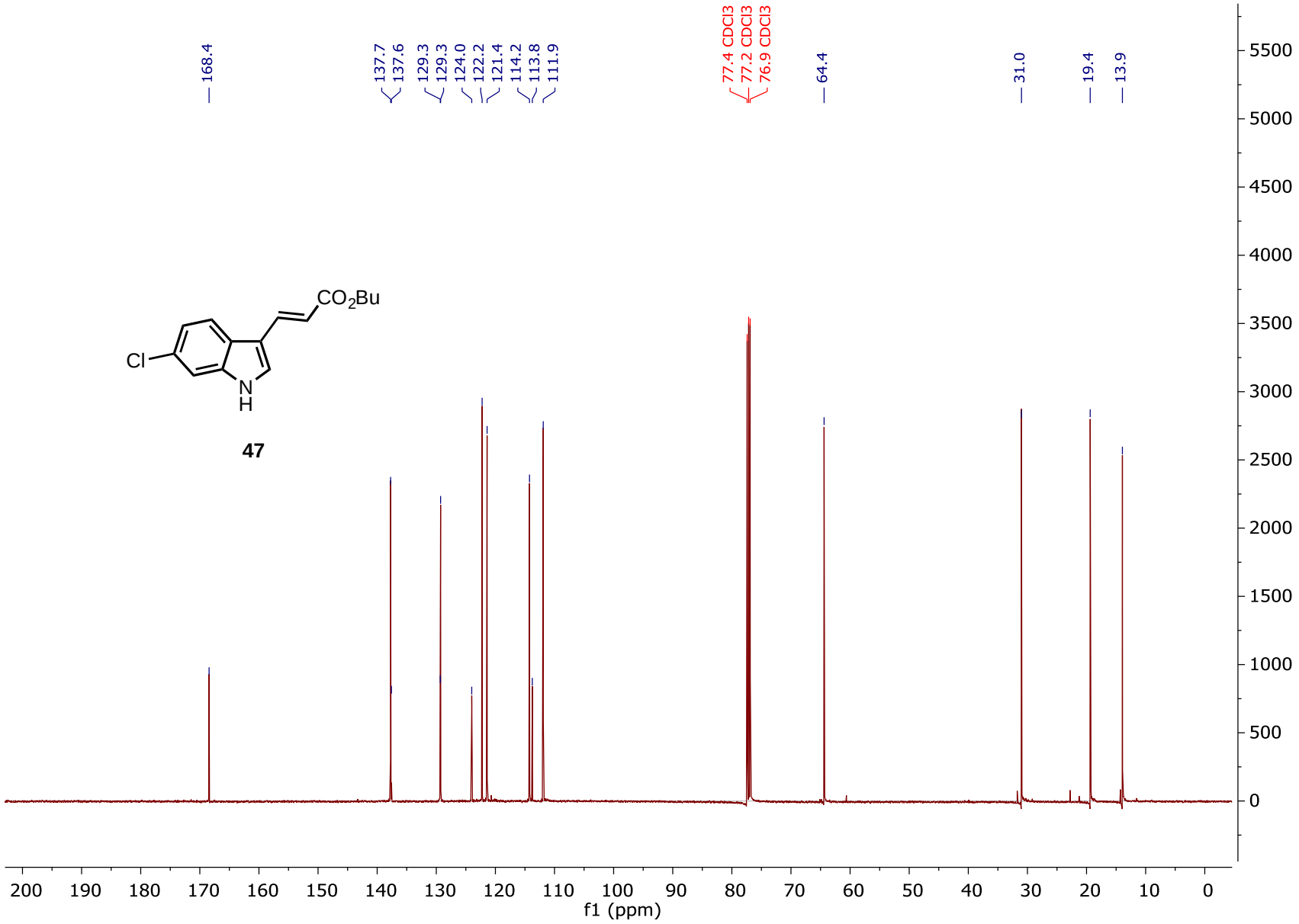


Figure S105. $^{13}C\{^{1}H\}$ NMR (126 MHz, $CDCl_3$) of **47**.

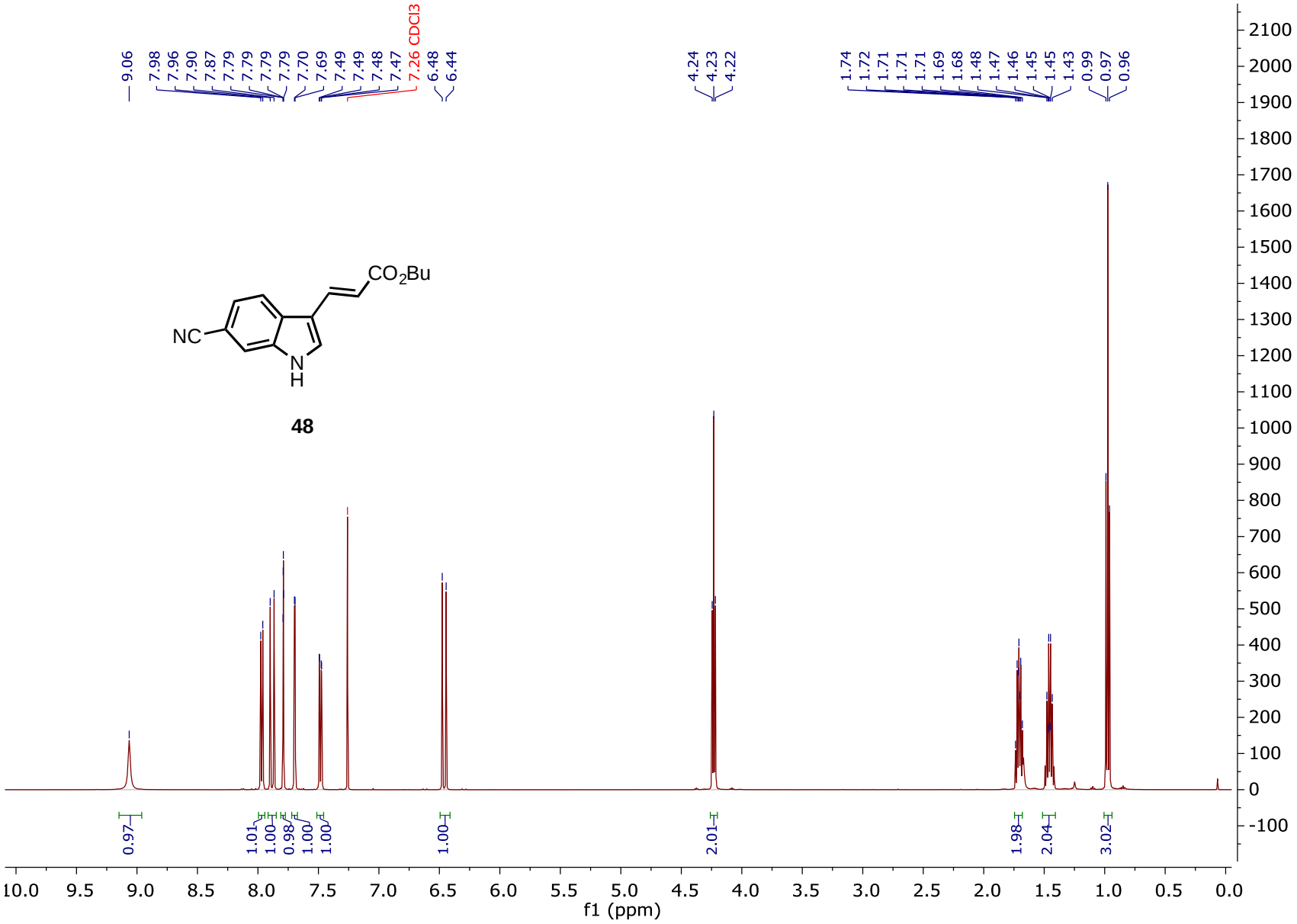


Figure S106. ^{1}H NMR (500 MHz, $CDCl_3$) of **48**.

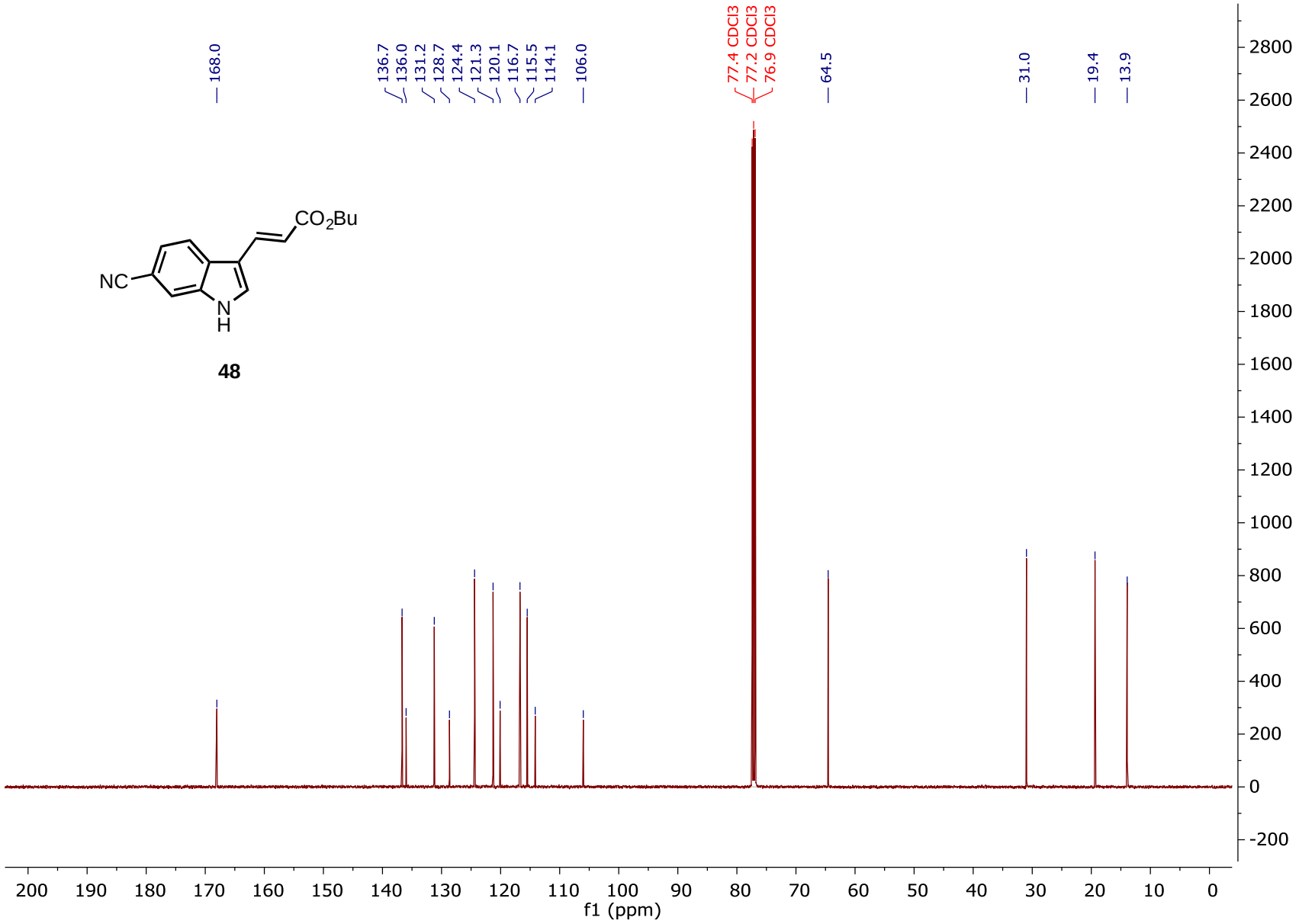


Figure S107. $^{13}C\{^{1}H\}$ NMR (126 MHz, $CDCl_3$) of **48**.

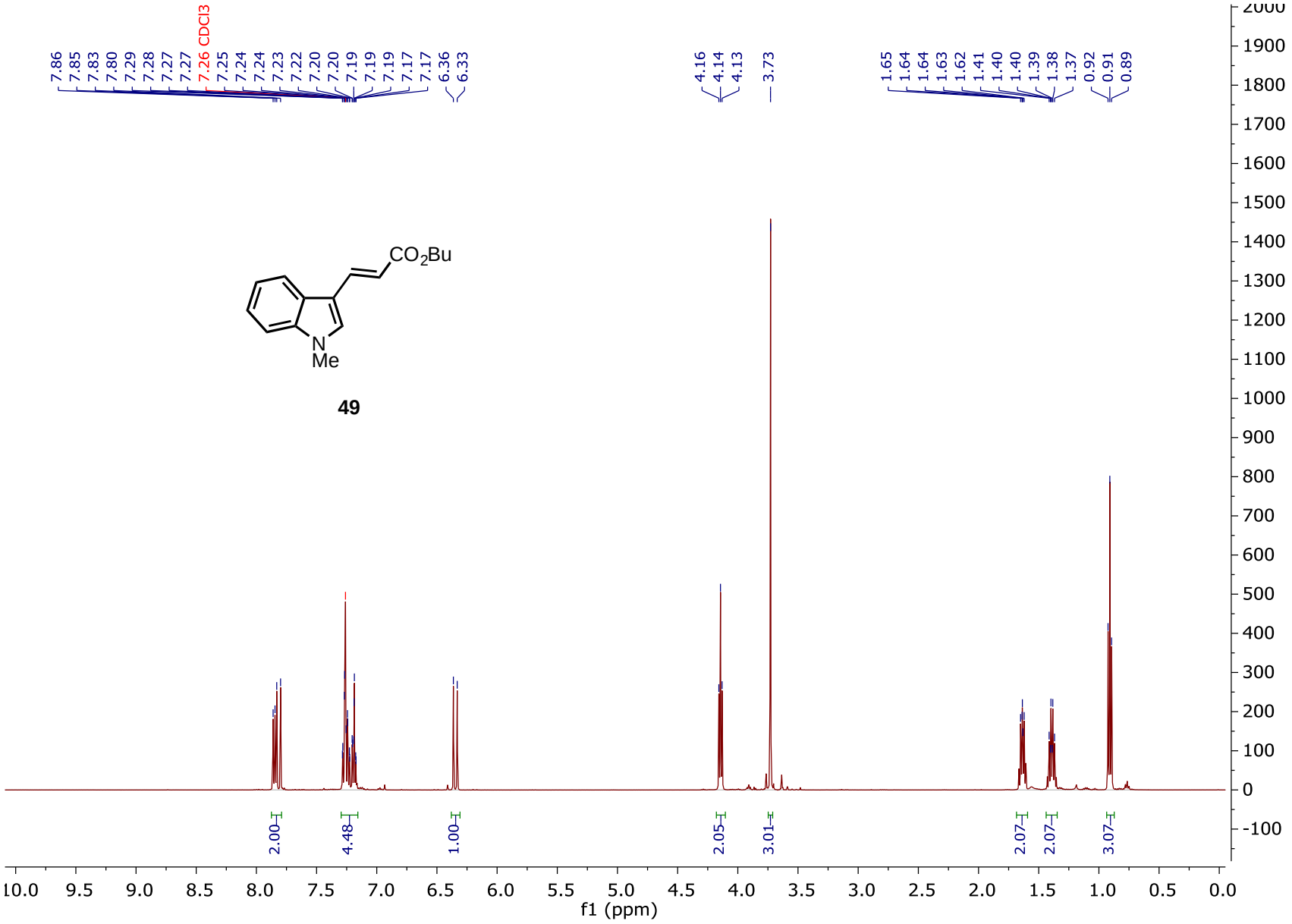


Figure S108. ^{1}H NMR (500 MHz, $CDCl_3$) of **49**.

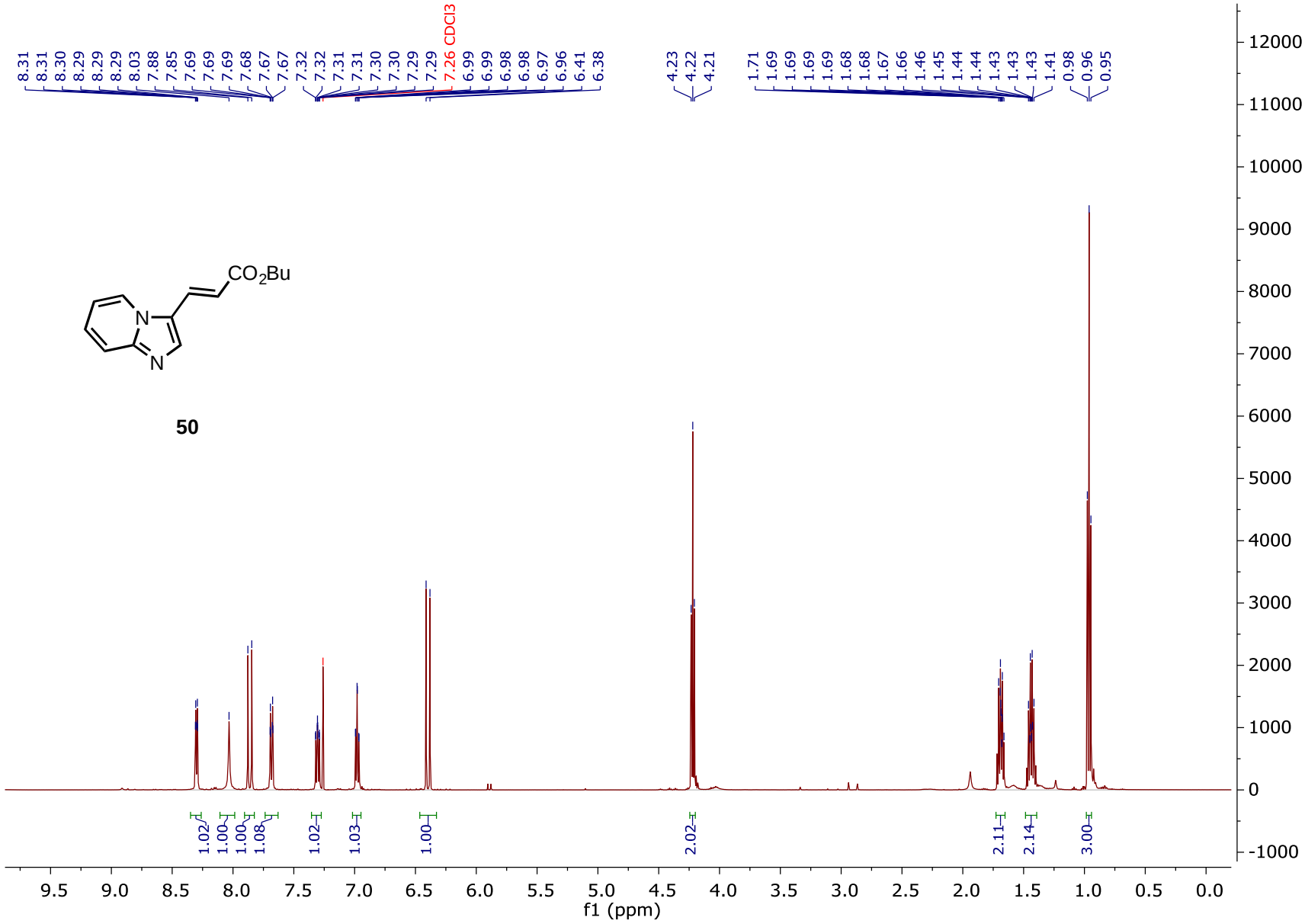


Figure S109. ^{1}H NMR (500 MHz, $CDCl_3$) of **50**.

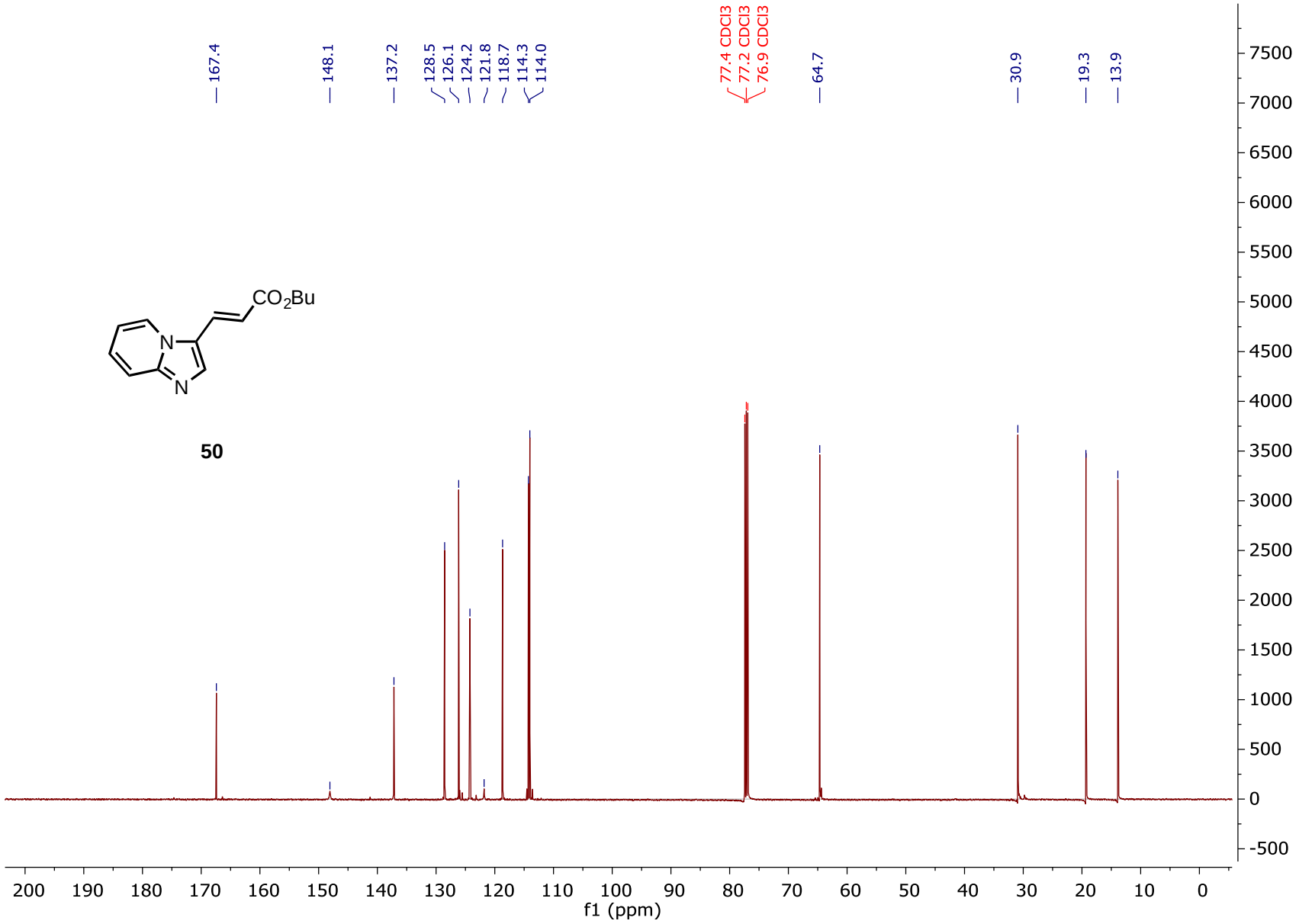


Figure S110. $^{13}C\{^{1}H\}$ NMR (126 MHz, $CDCl_3$) of **50**.

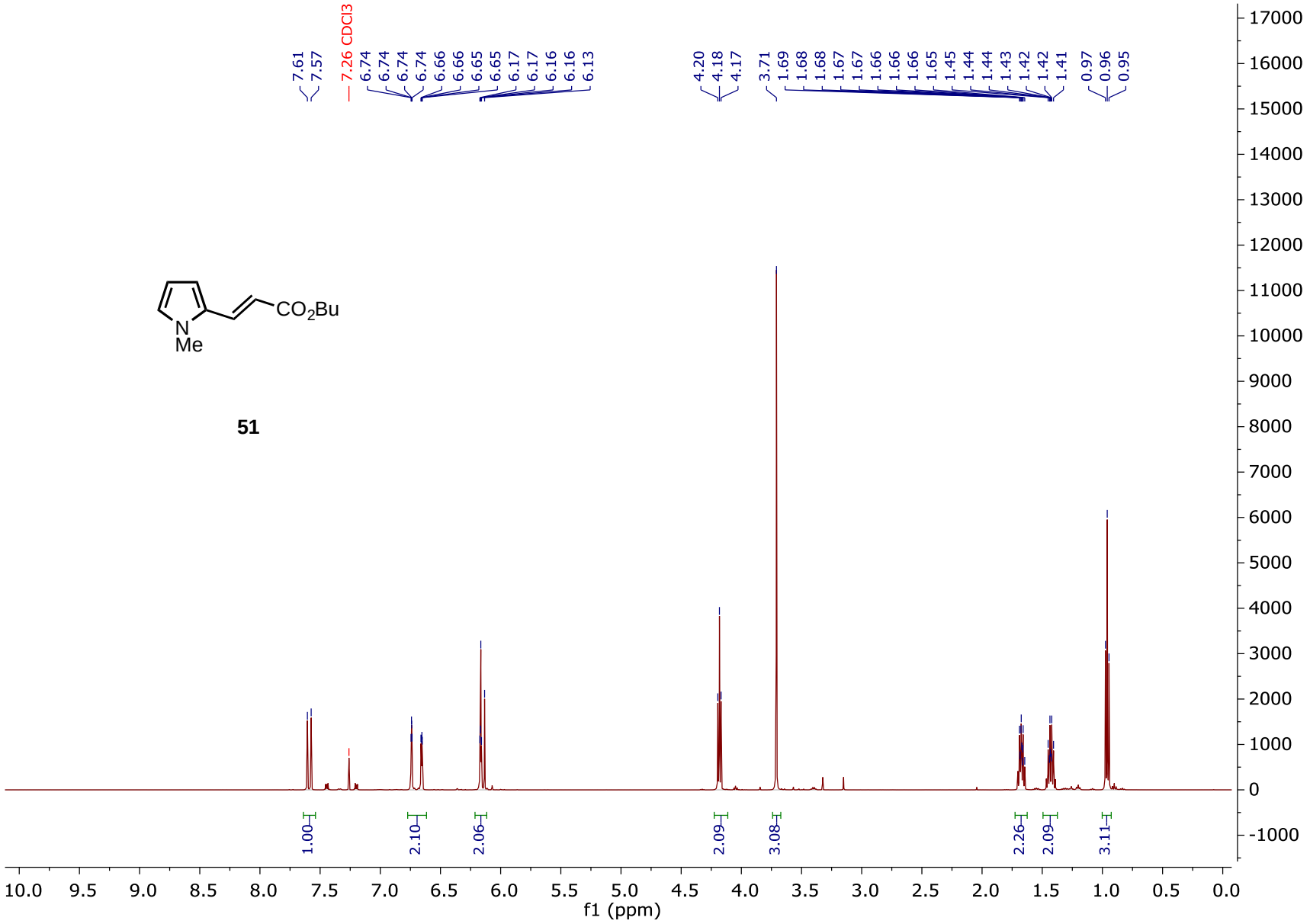


Figure S111. ^{1}H NMR (500 MHz, $CDCl_3$) of **51**.

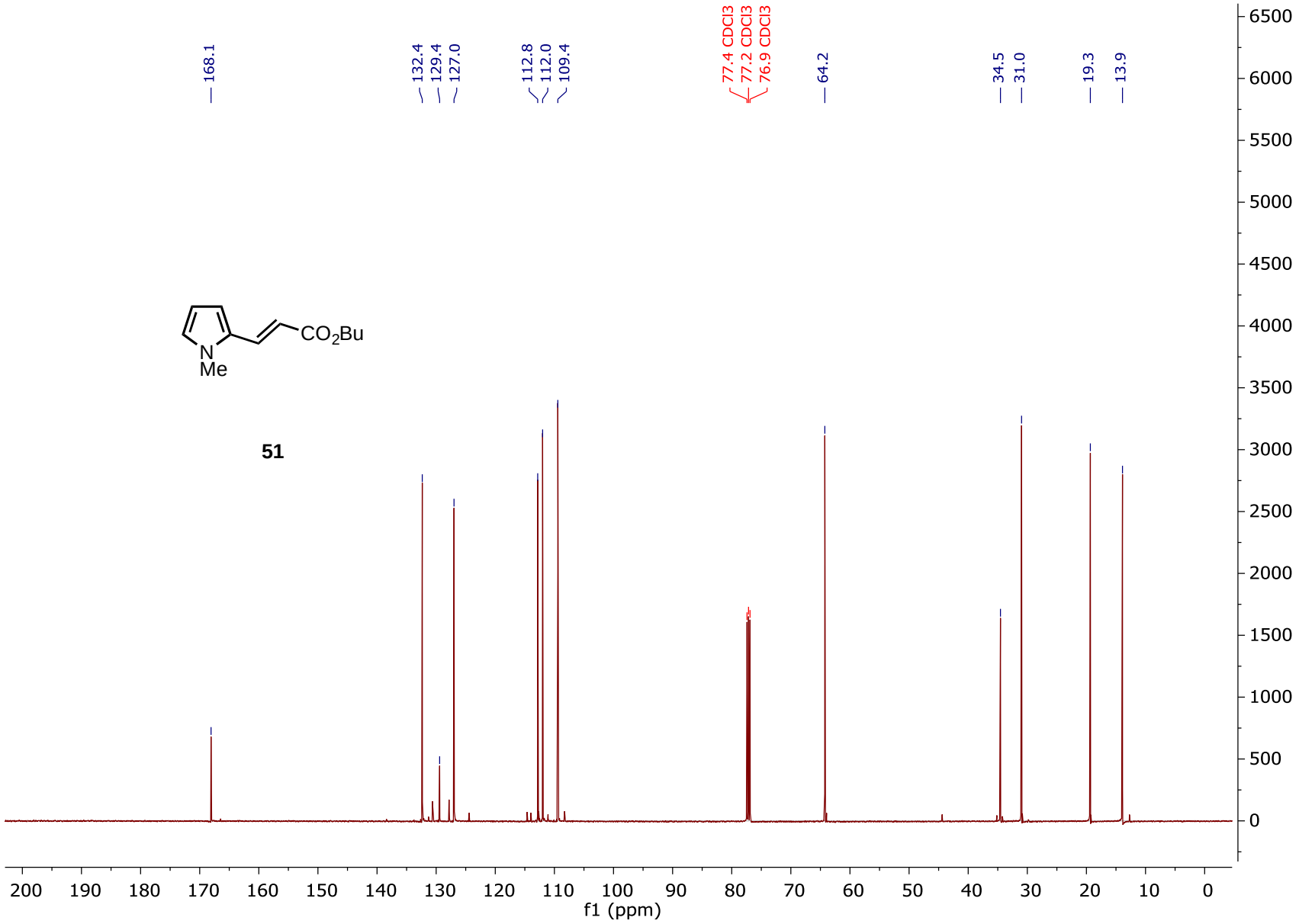


Figure S112. $^{13}C\{^{1}H\}$ NMR (126 MHz, $CDCl_3$) of **51**.

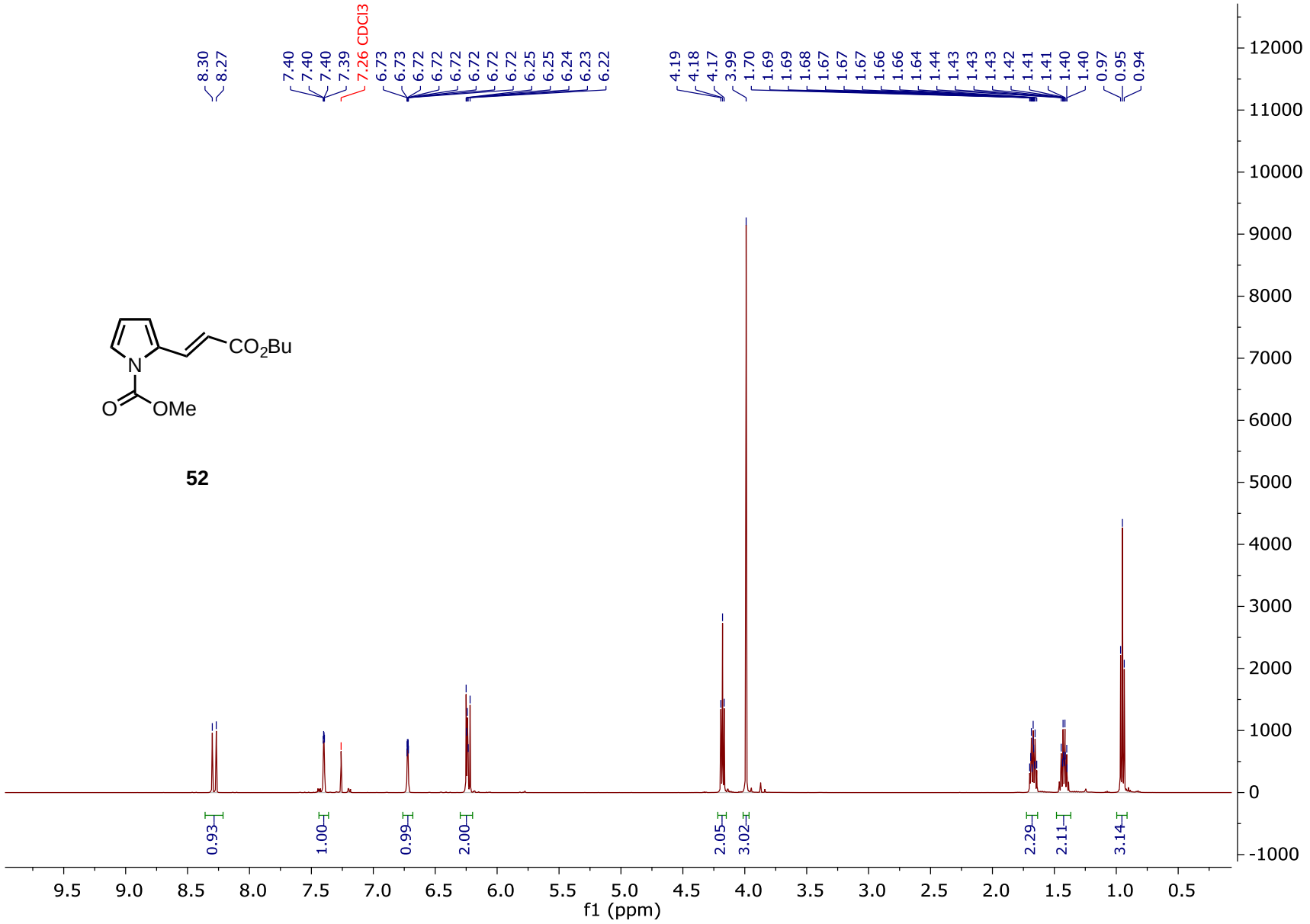


Figure S113. ^{1}H NMR (500 MHz, $CDCl_3$) of **52**.

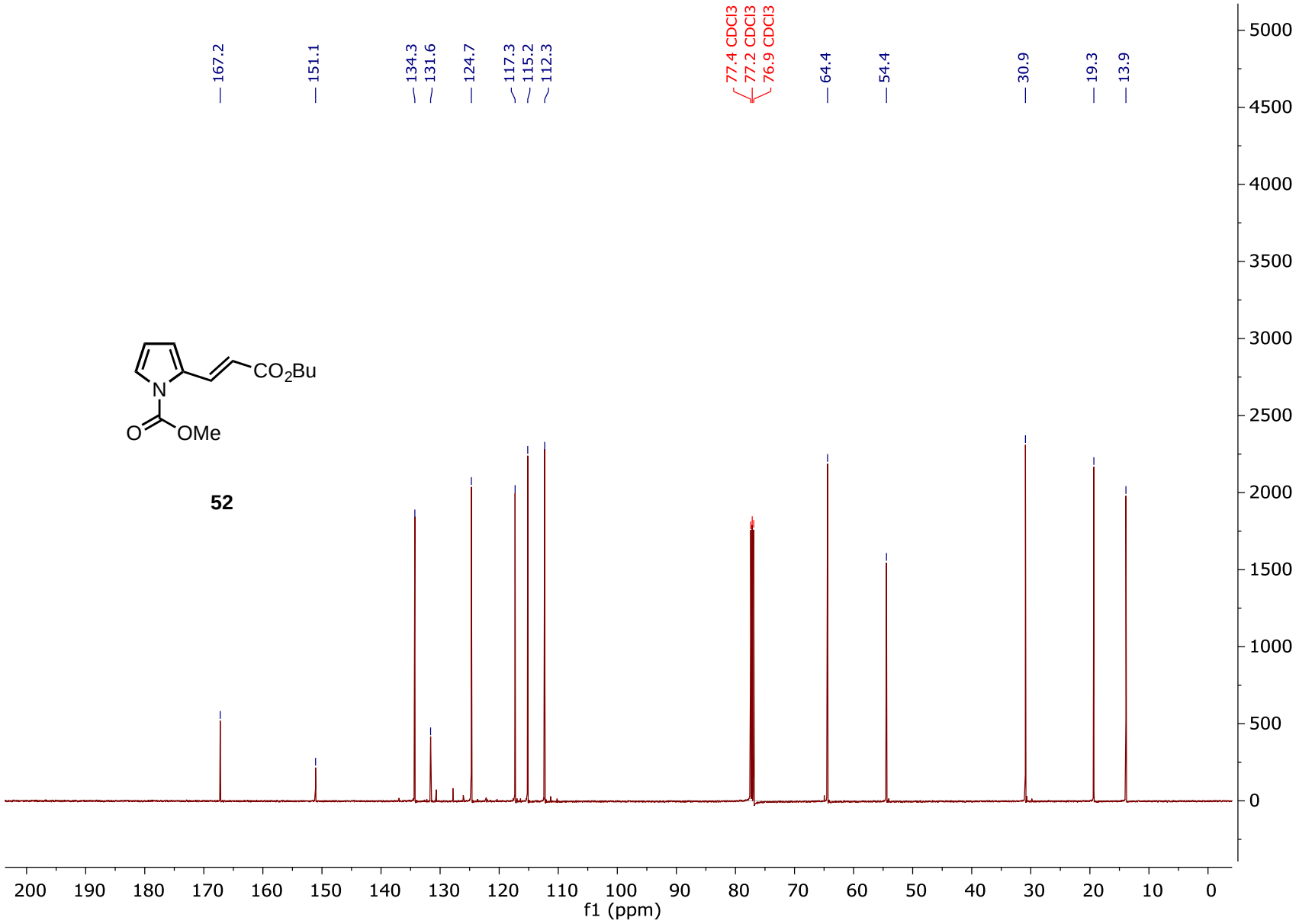


Figure S114. $^{13}C\{^{1}H\}$ NMR (126 MHz, $CDCl_3$) of **52**.

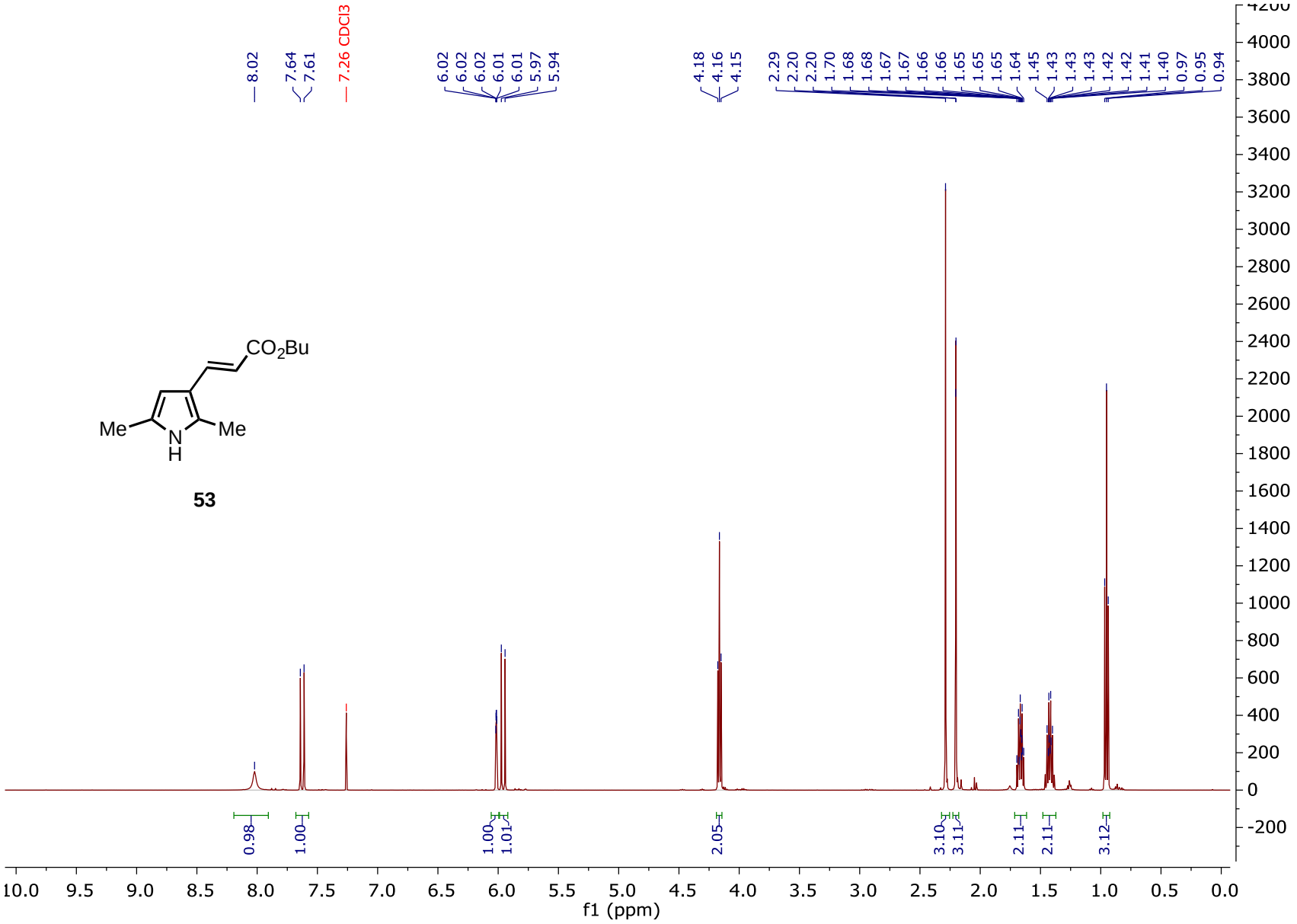


Figure S115. ^{1}H NMR (500 MHz, $CDCl_3$) of **53**.

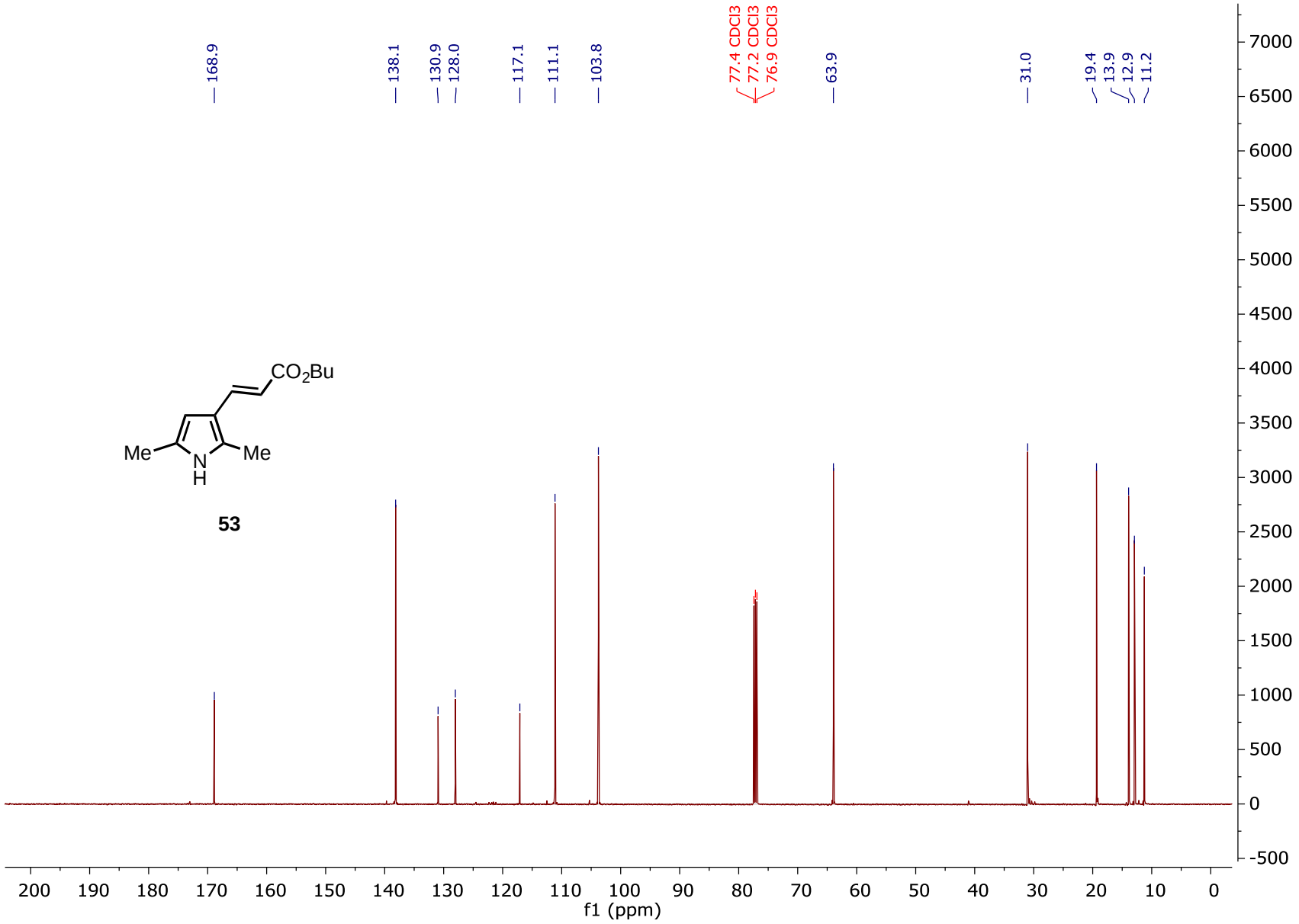


Figure S116. $^{13}C\{^{1}H\}$ NMR (126 MHz, $CDCl_3$) of **53**.

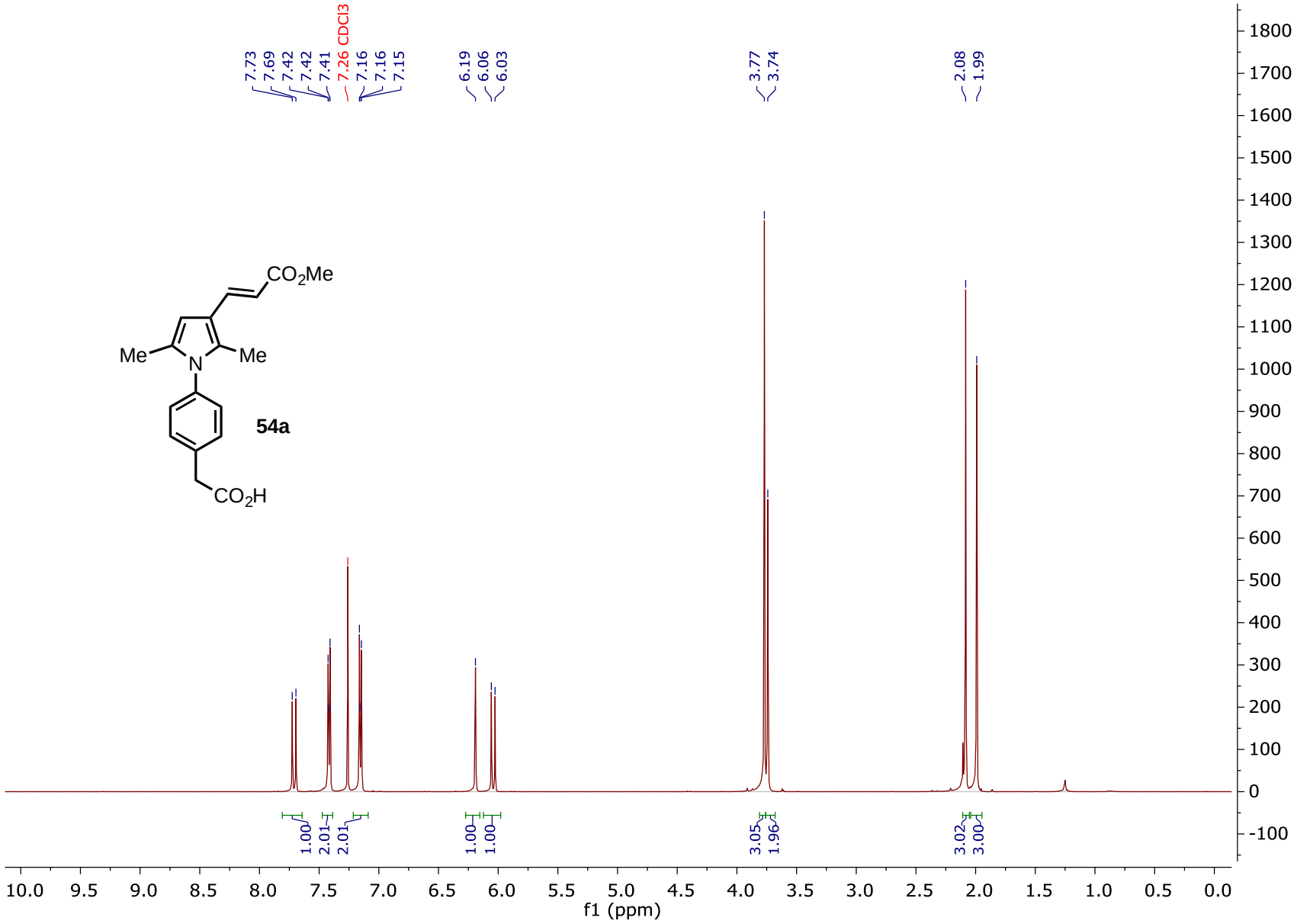


Figure S117. ^{1}H NMR (500 MHz, $CDCl_3$) of **54a**.

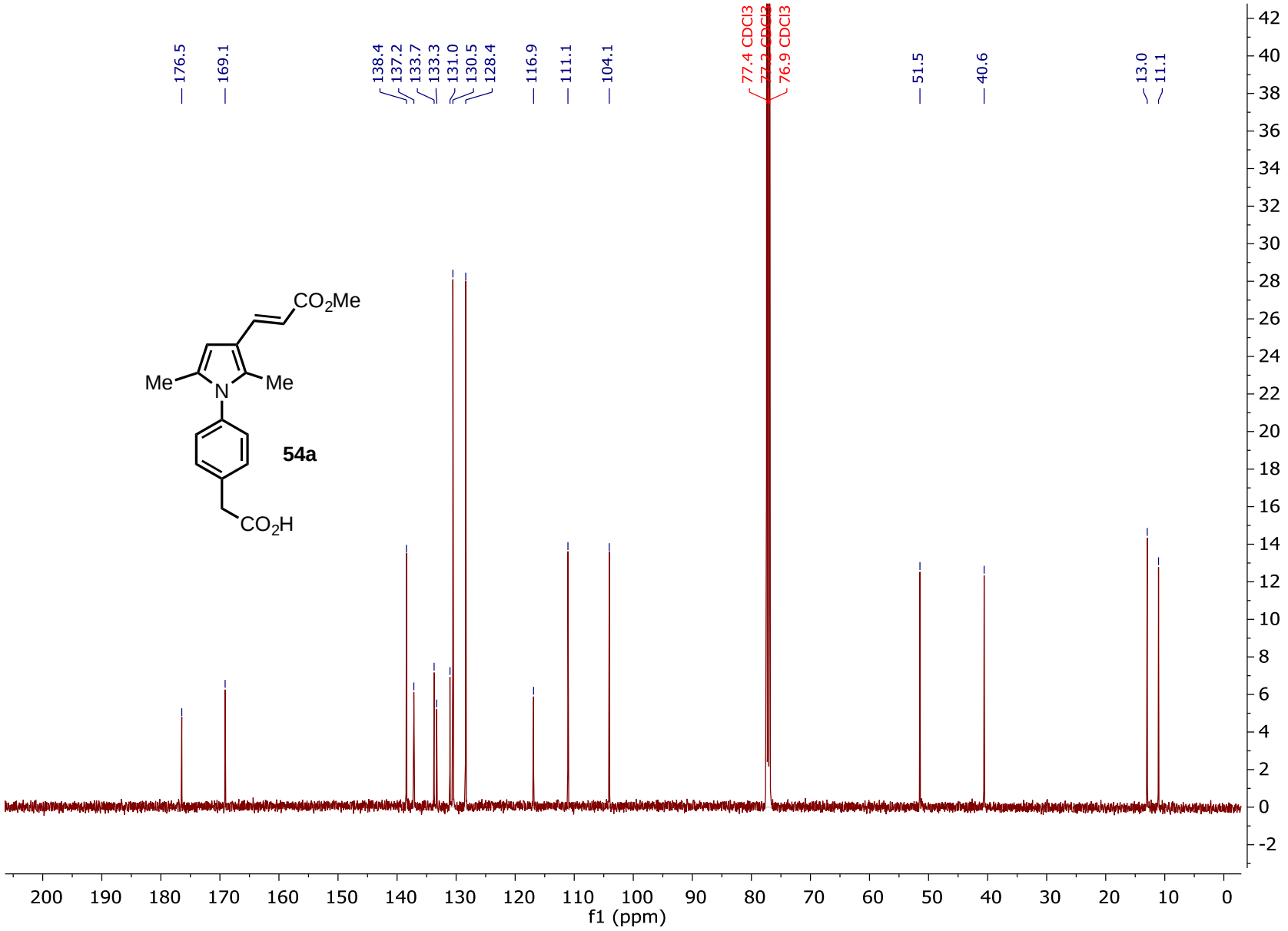


Figure S*118.* $^{13}C\{^{1}H\}$ NMR *(126 MHz, $CDCl_3$) of **54a**.*

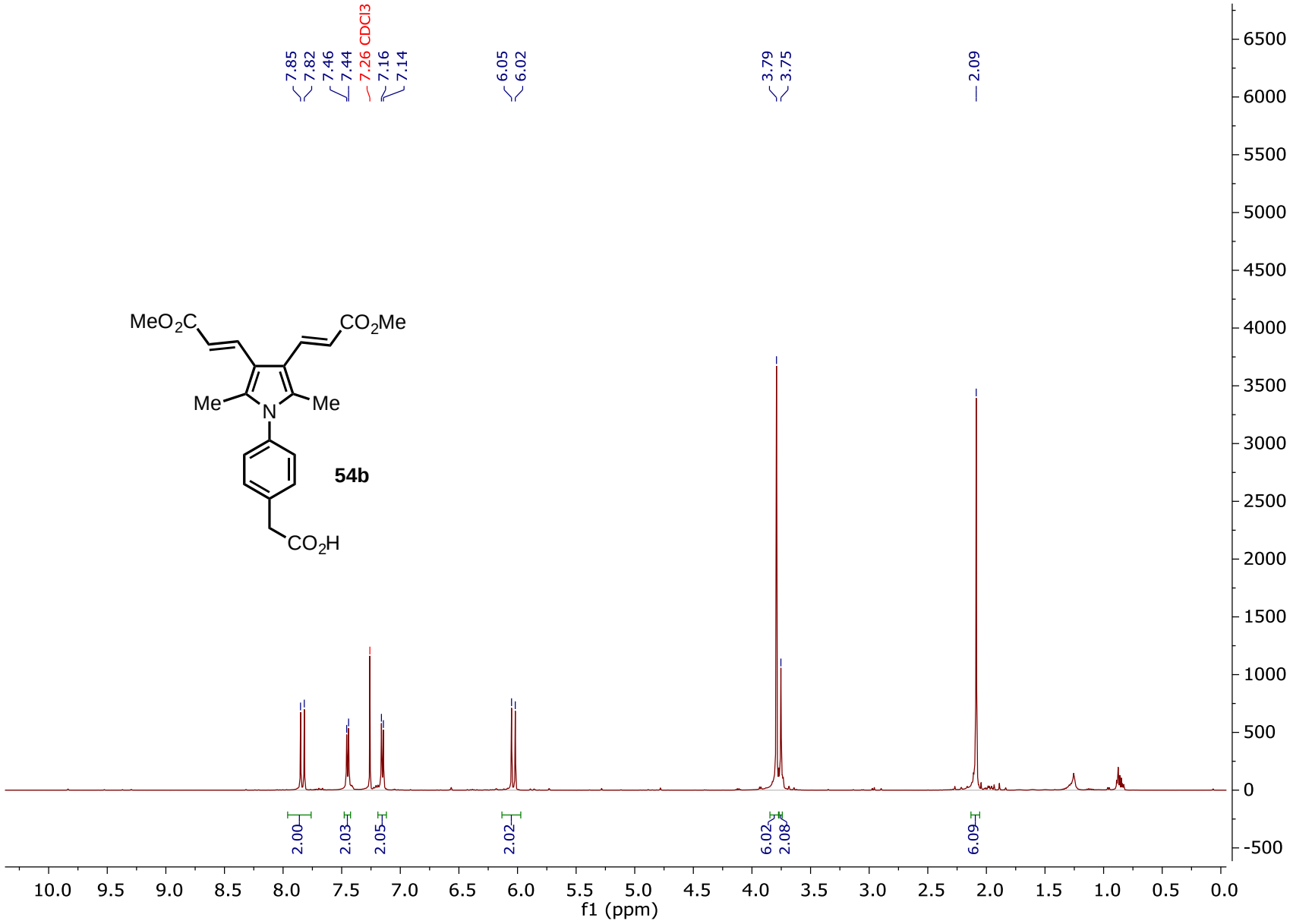


Figure S119. ^{1}H NMR (500 MHz, $CDCl_3$) of **54b**.

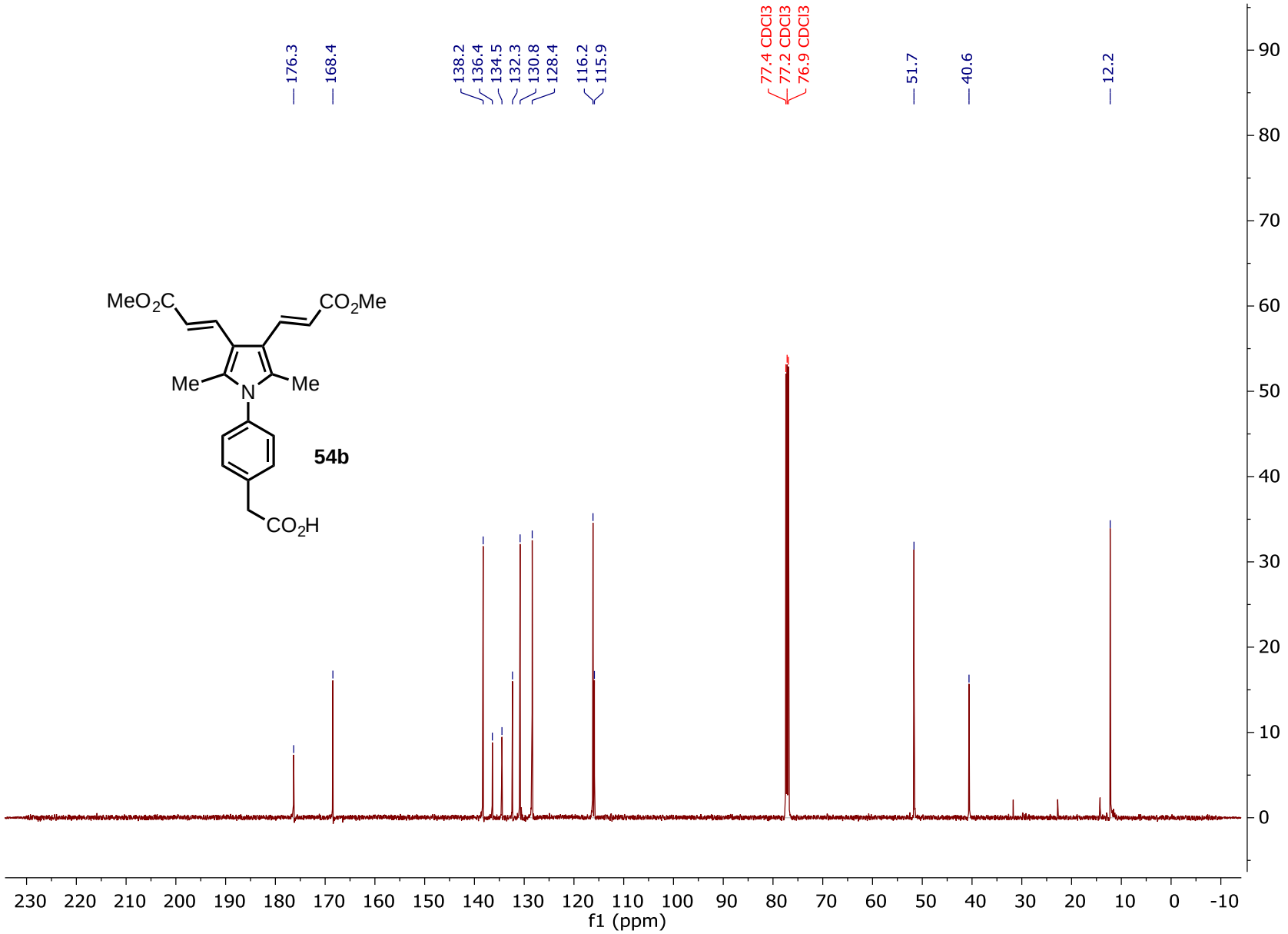


Figure S120. $^{13}C\{^{1}H\}$ NMR (126 MHz, $CDCl_3$) of **54b**.

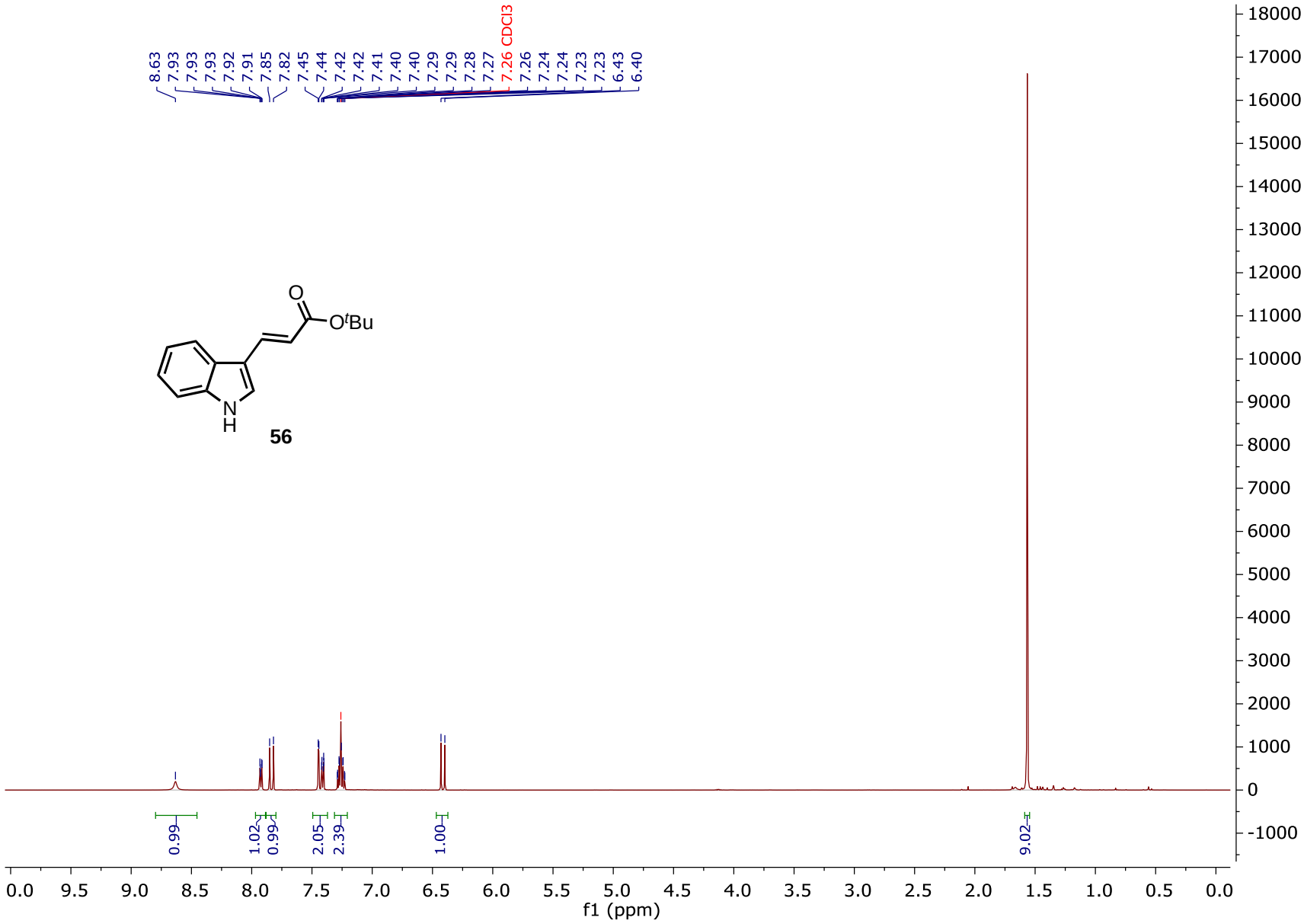


Figure S121. ^{1}H NMR (500 MHz, $CDCl_3$) of **56**.

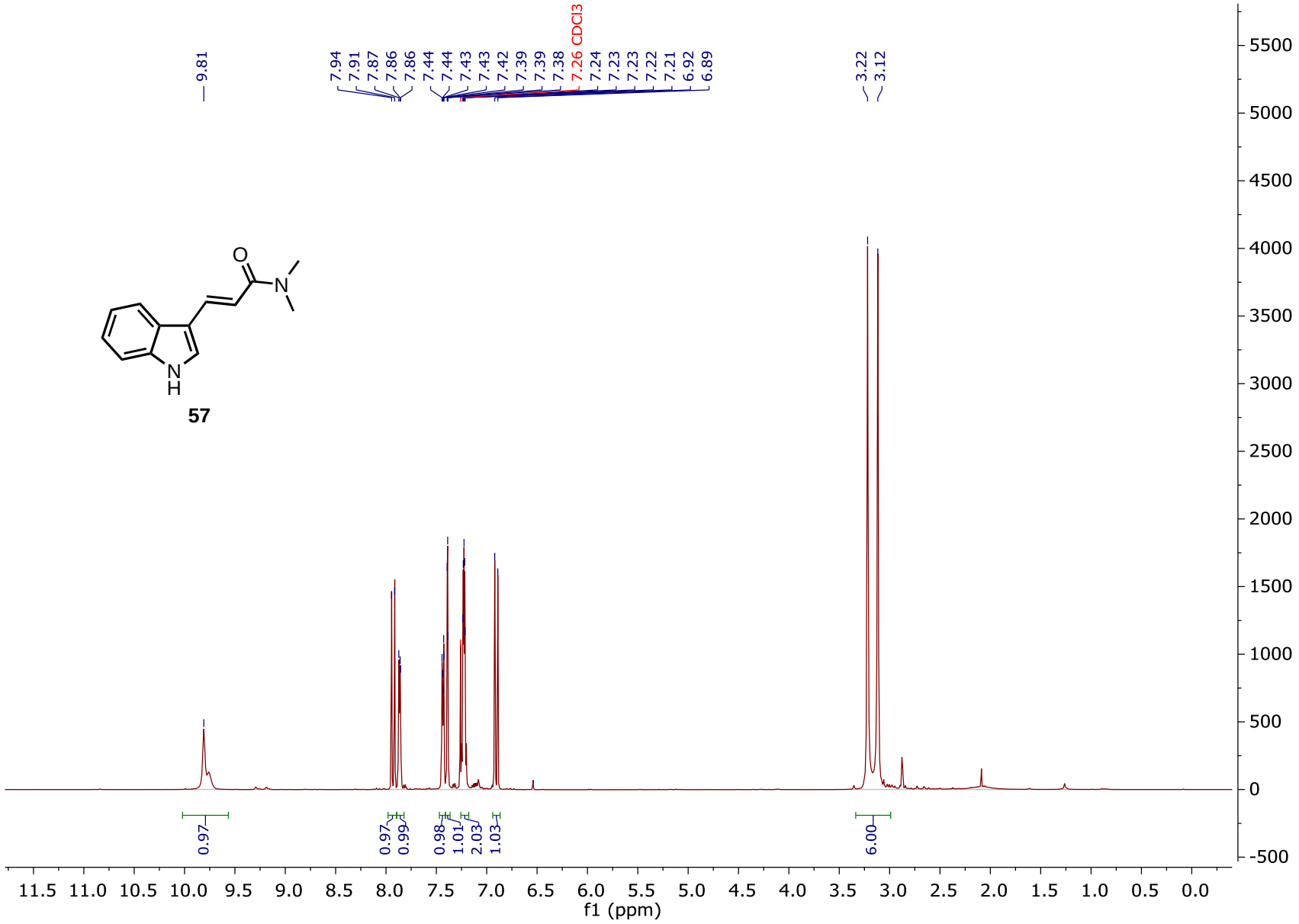


Figure S122. ^{1}H NMR (500 MHz, $CDCl_3$) of **57**.

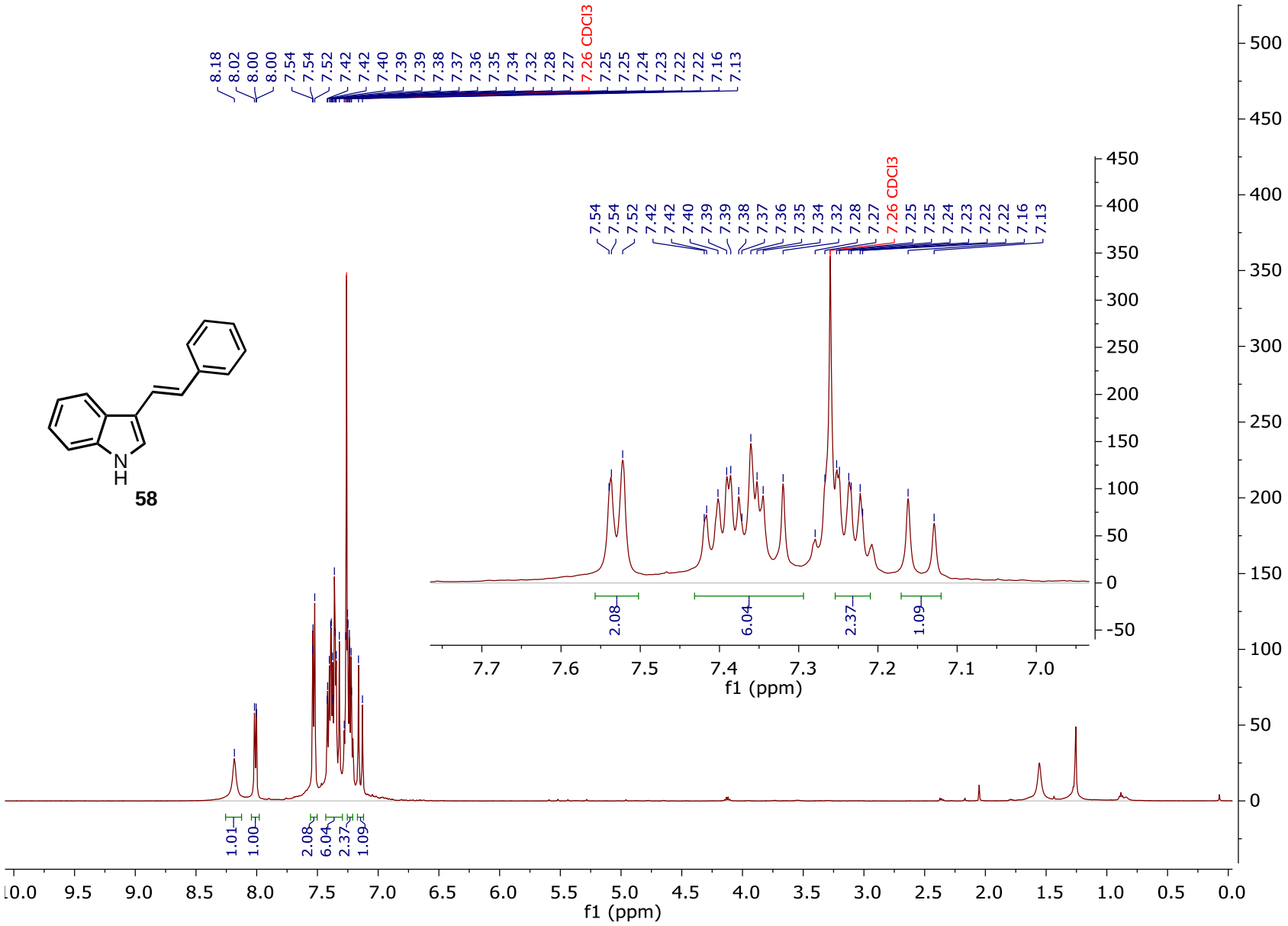


Figure S123. ^{1}H NMR (500 MHz, $CDCl_3$) of **58**.

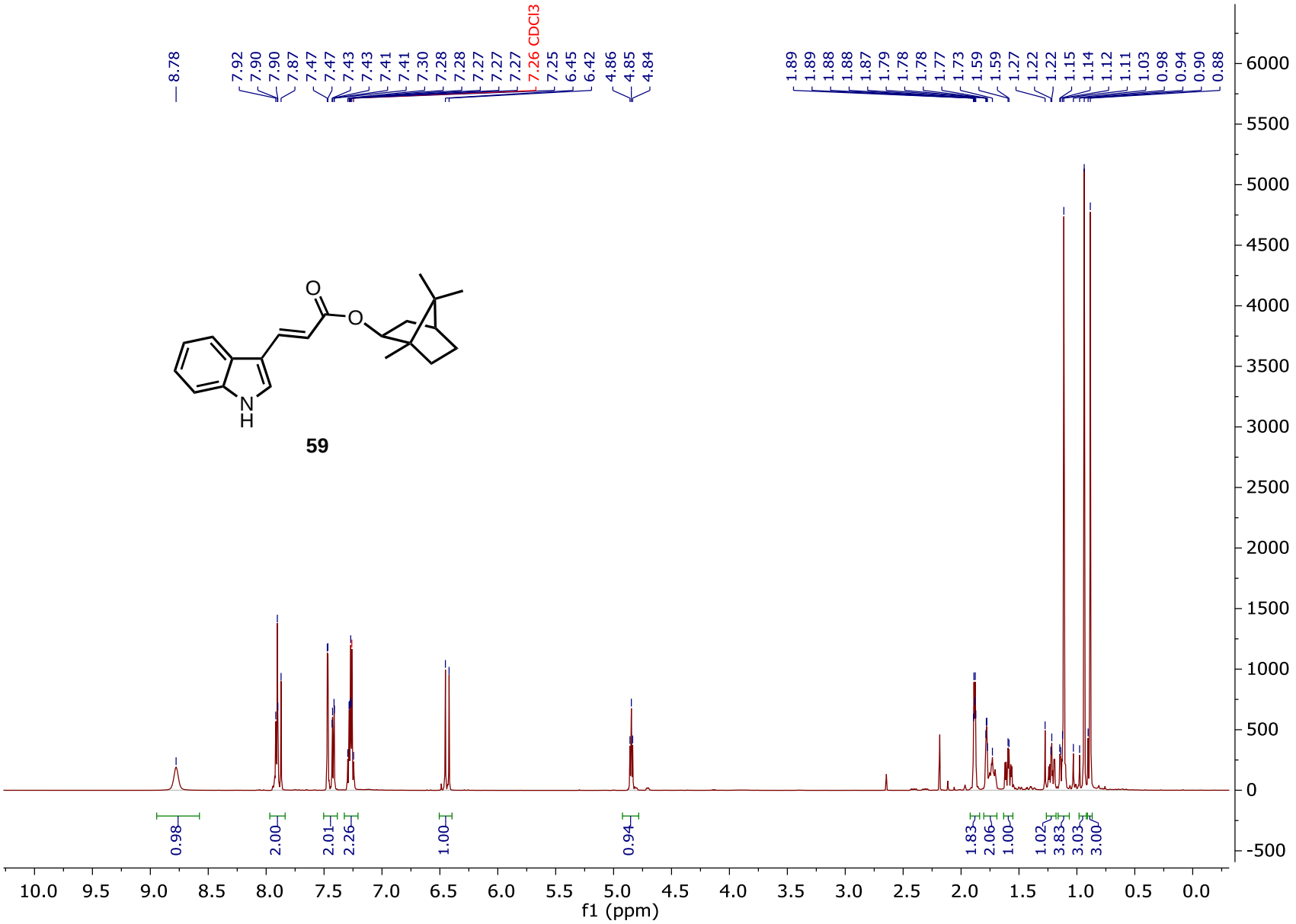


Figure S124. ^{1}H NMR (500 MHz, $CDCl_3$) of **59**.

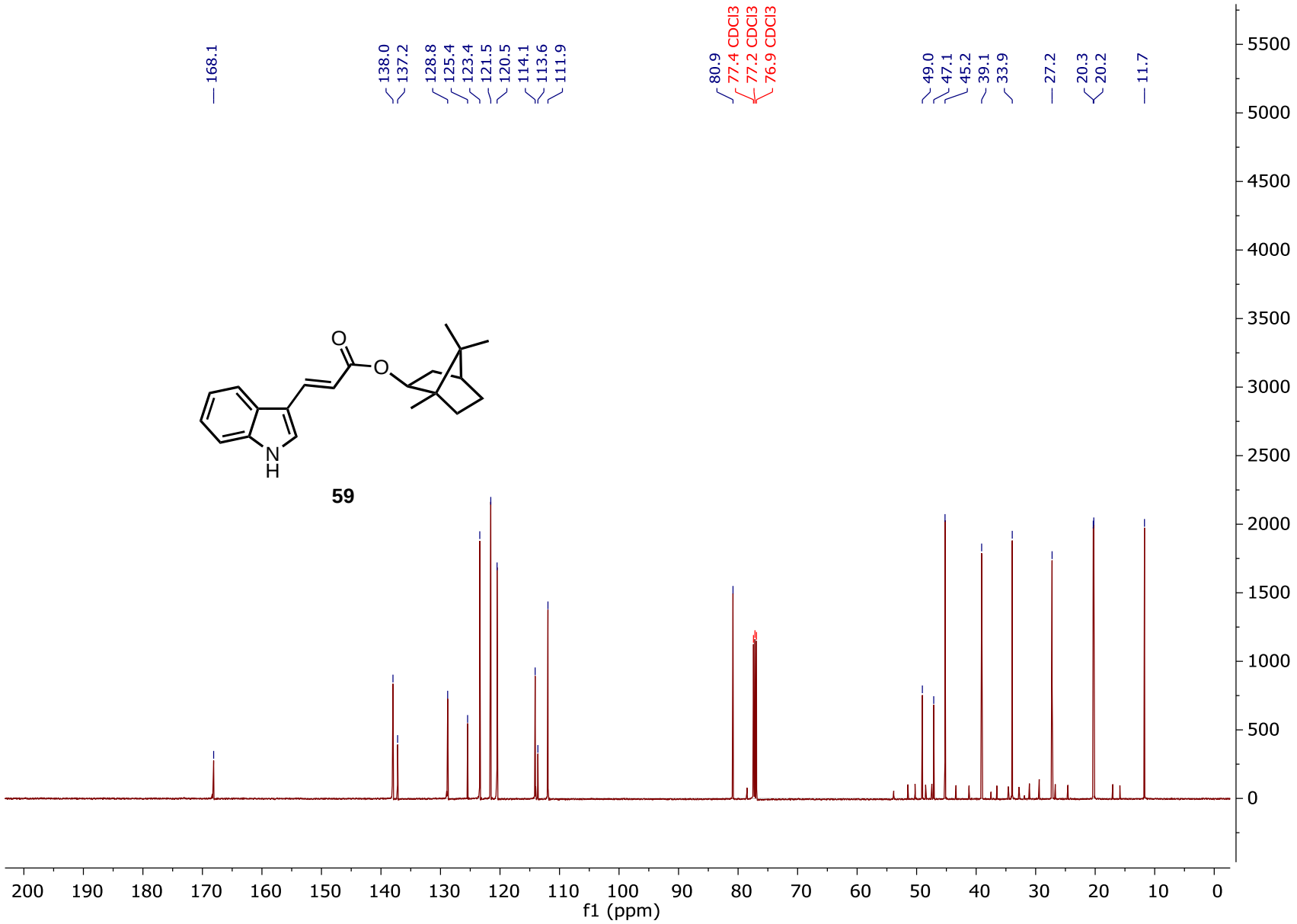


Figure S125. $^{13}C\{^{1}H\}$ NMR (126 MHz, $CDCl_3$) of **59**.

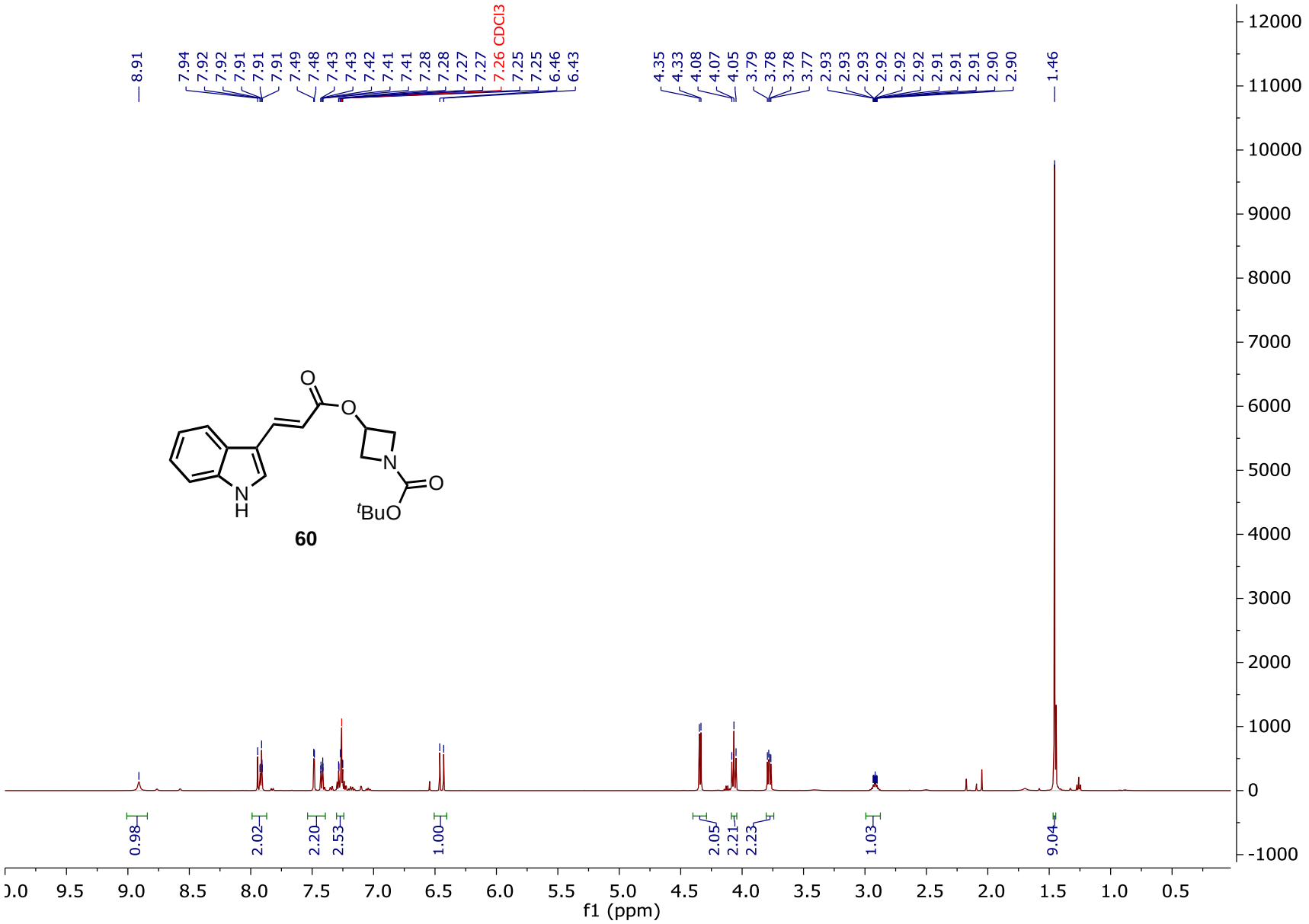


Figure S126. ^{1}H NMR (500 MHz, $CDCl_3$) of **60**.

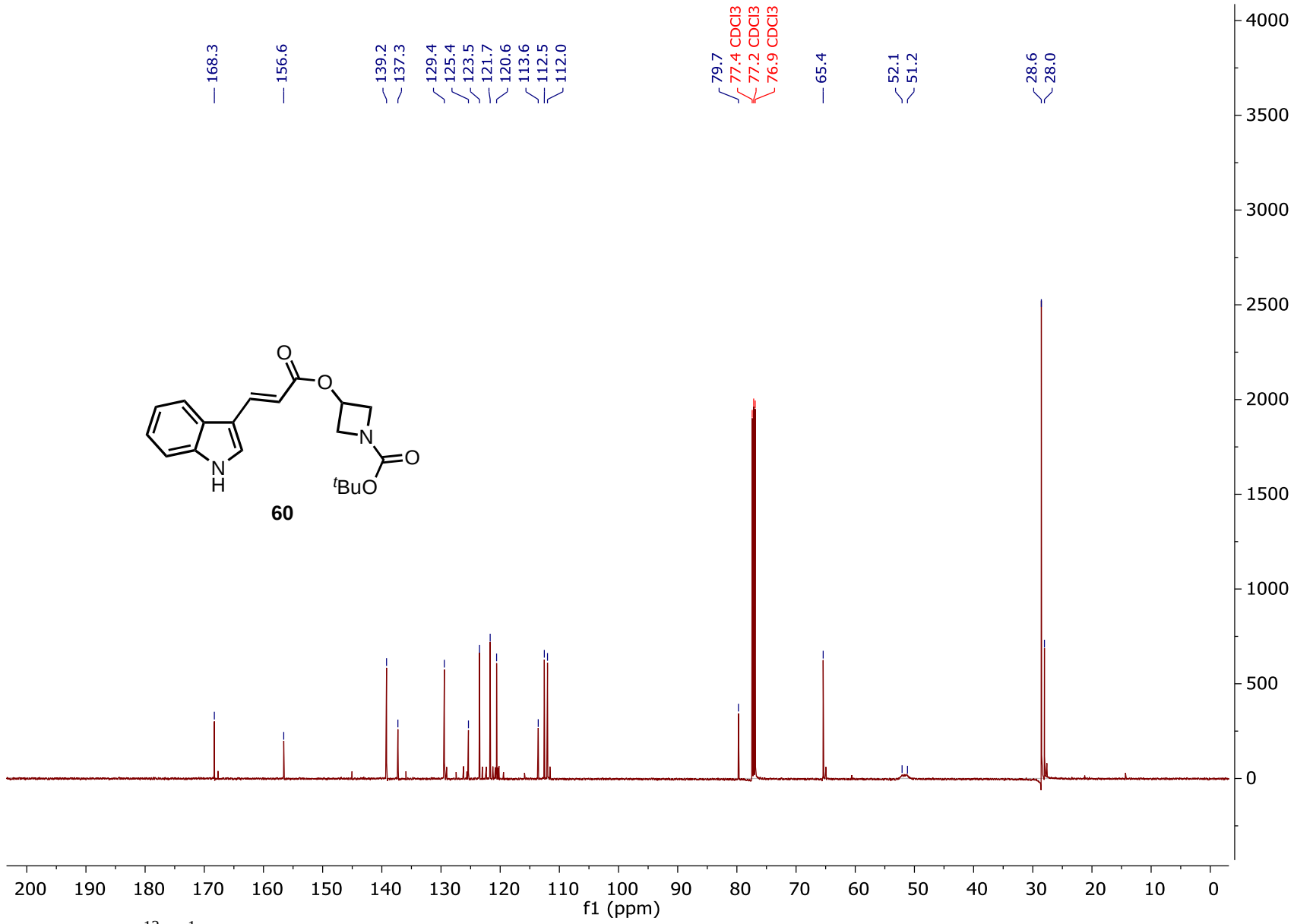


Figure S127. $^{13}C\{^{1}H\}$ NMR (126 MHz, $CDCl_3$) of **60**.

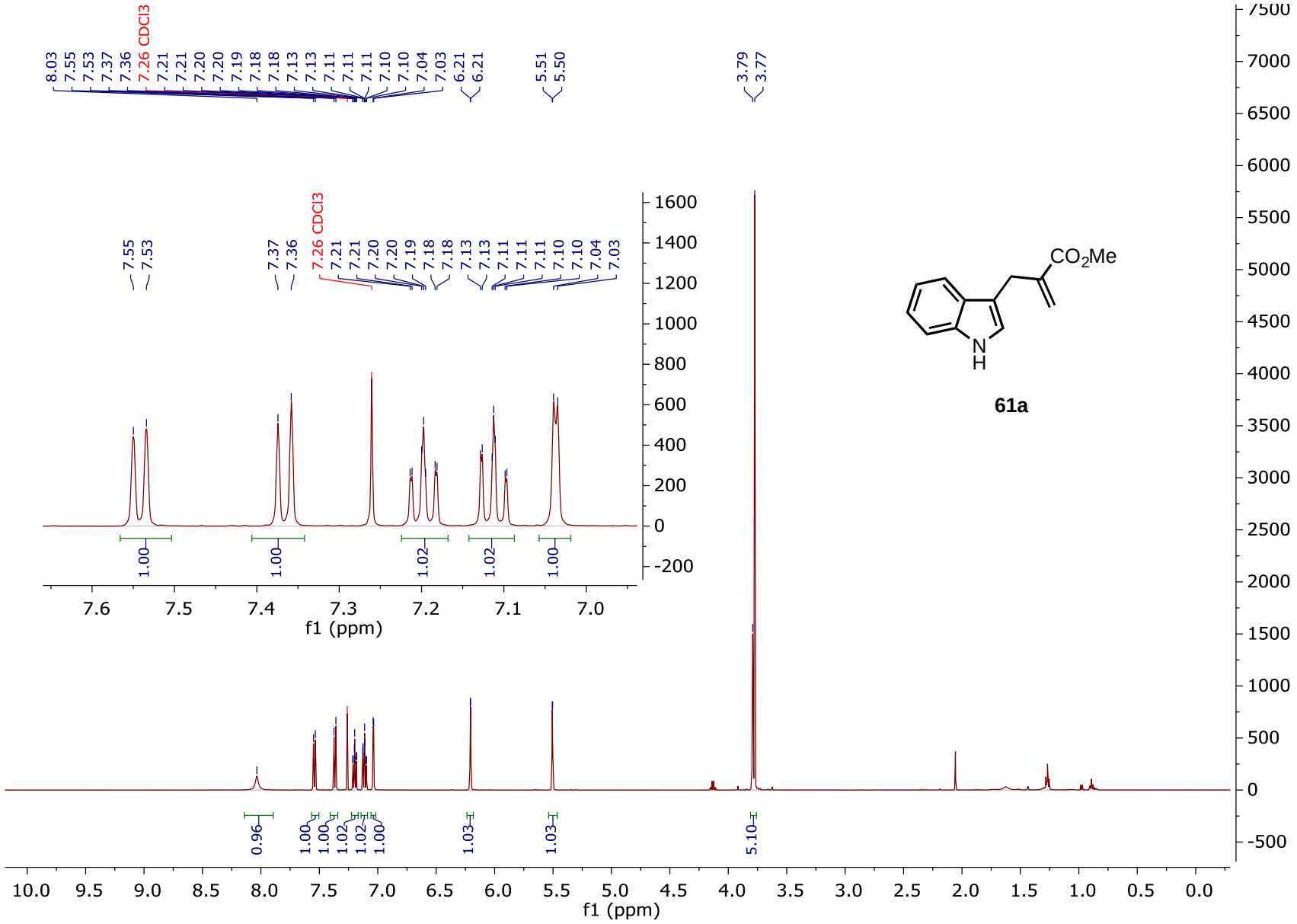


Figure S128. ^{1}H NMR (500 MHz, $CDCl_3$) of **61a**.

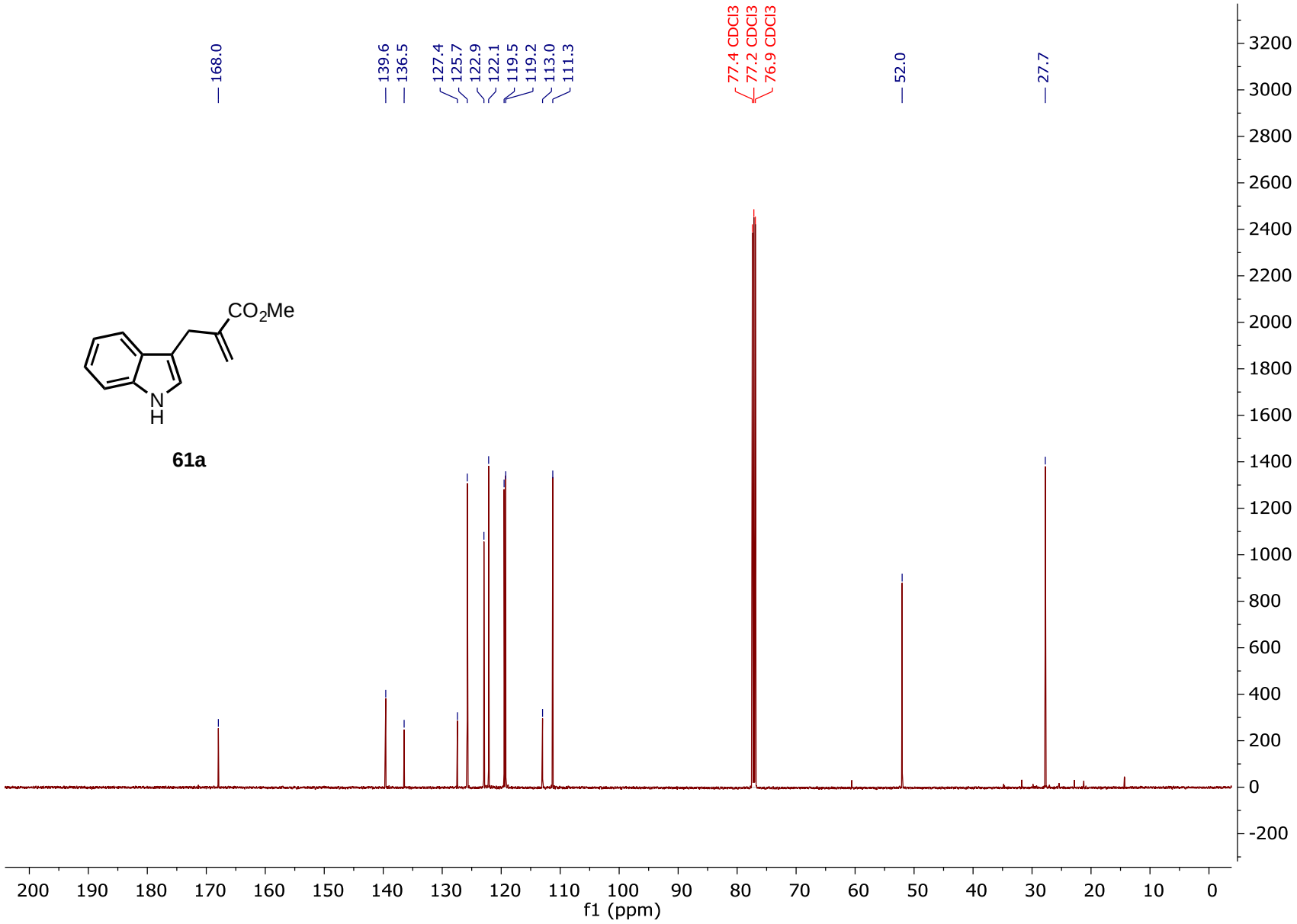


Figure S129. $^{13}C\{^{1}H\}$ NMR (126 MHz, $CDCl_3$) of **61a**.

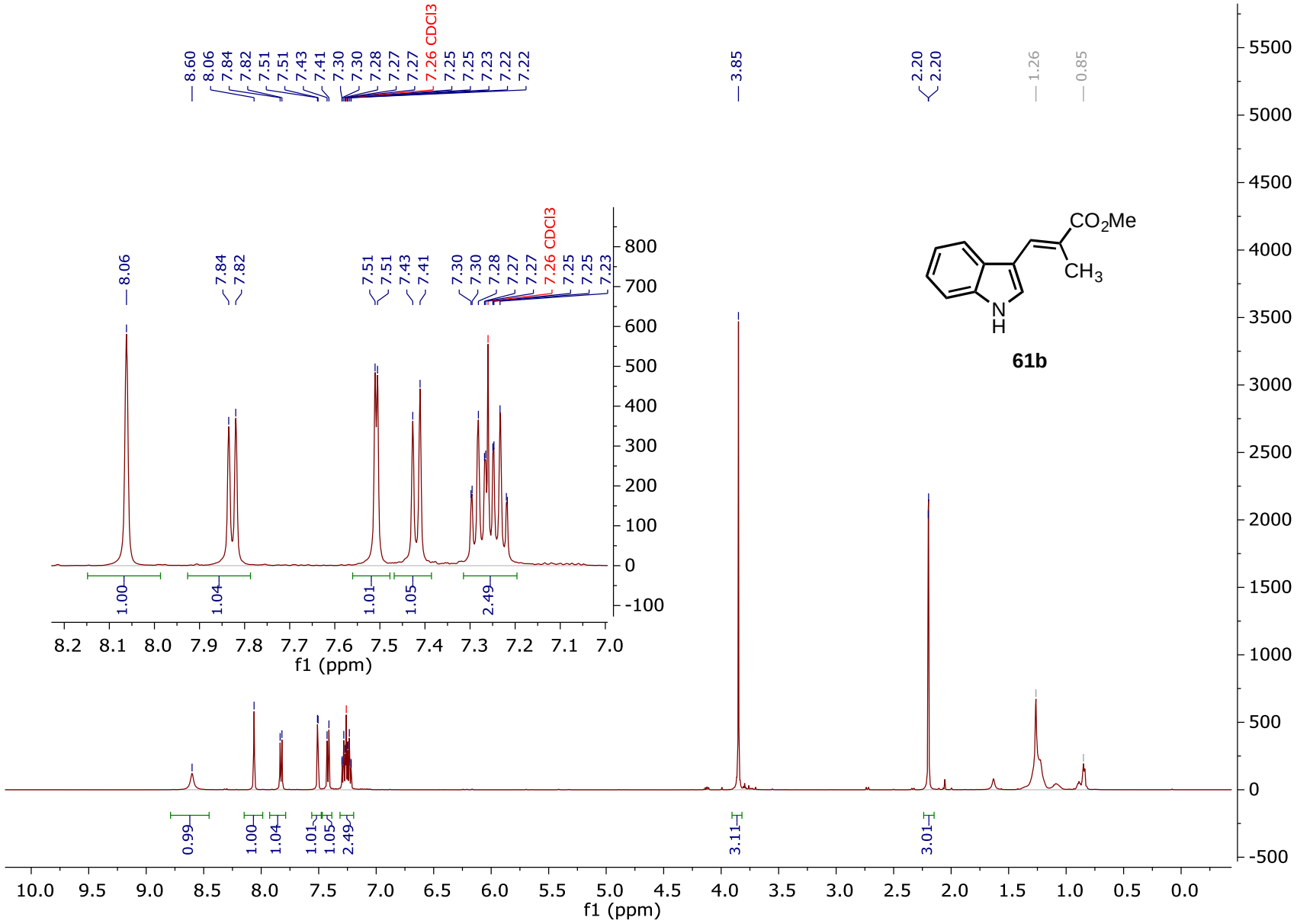


Figure S130. ^{1}H NMR (500 MHz, $CDCl_3$) of **61b**.

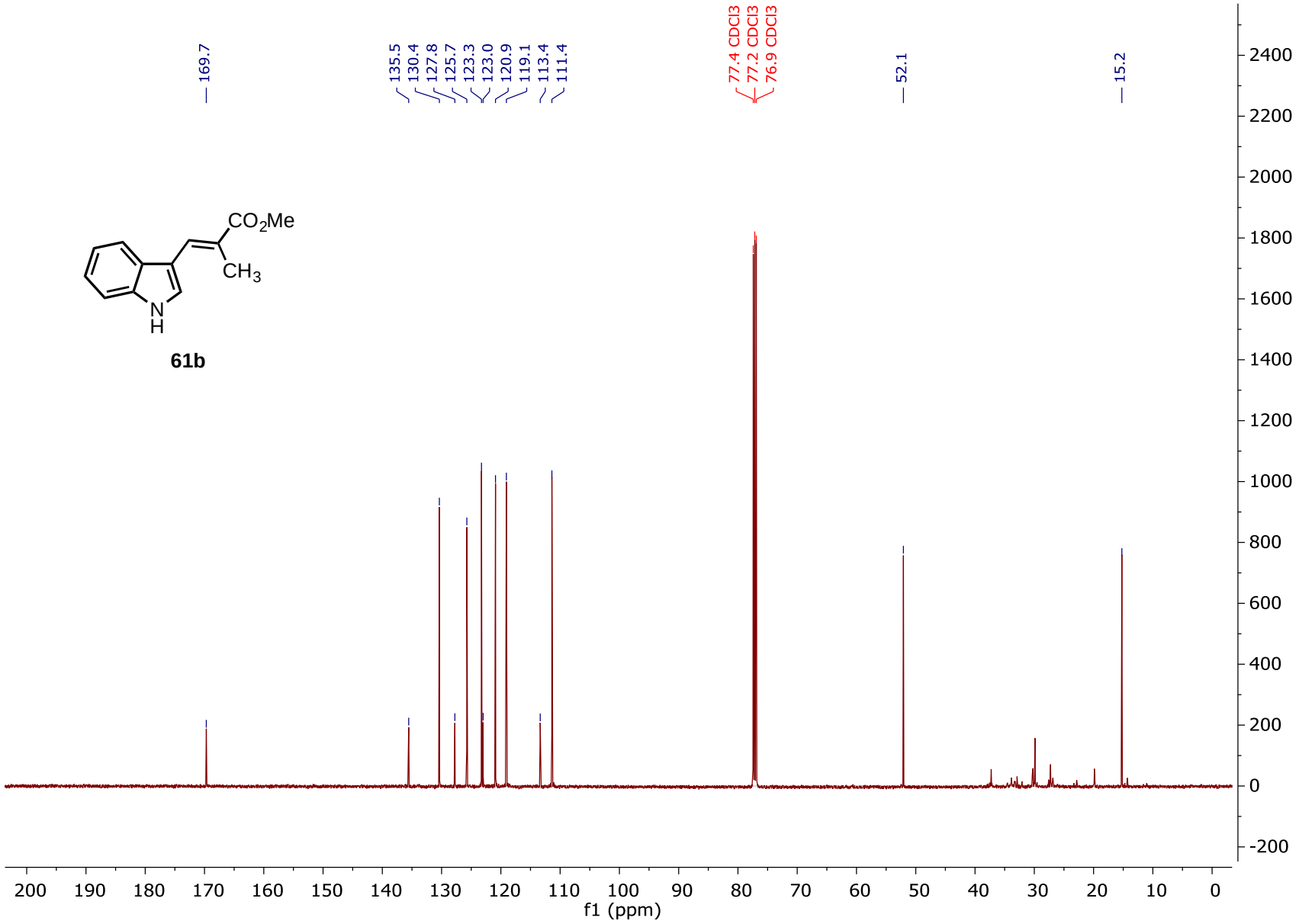


Figure S131. $^{13}C\{^{1}H\}$ NMR (126 MHz, $CDCl_3$) of **61b**.

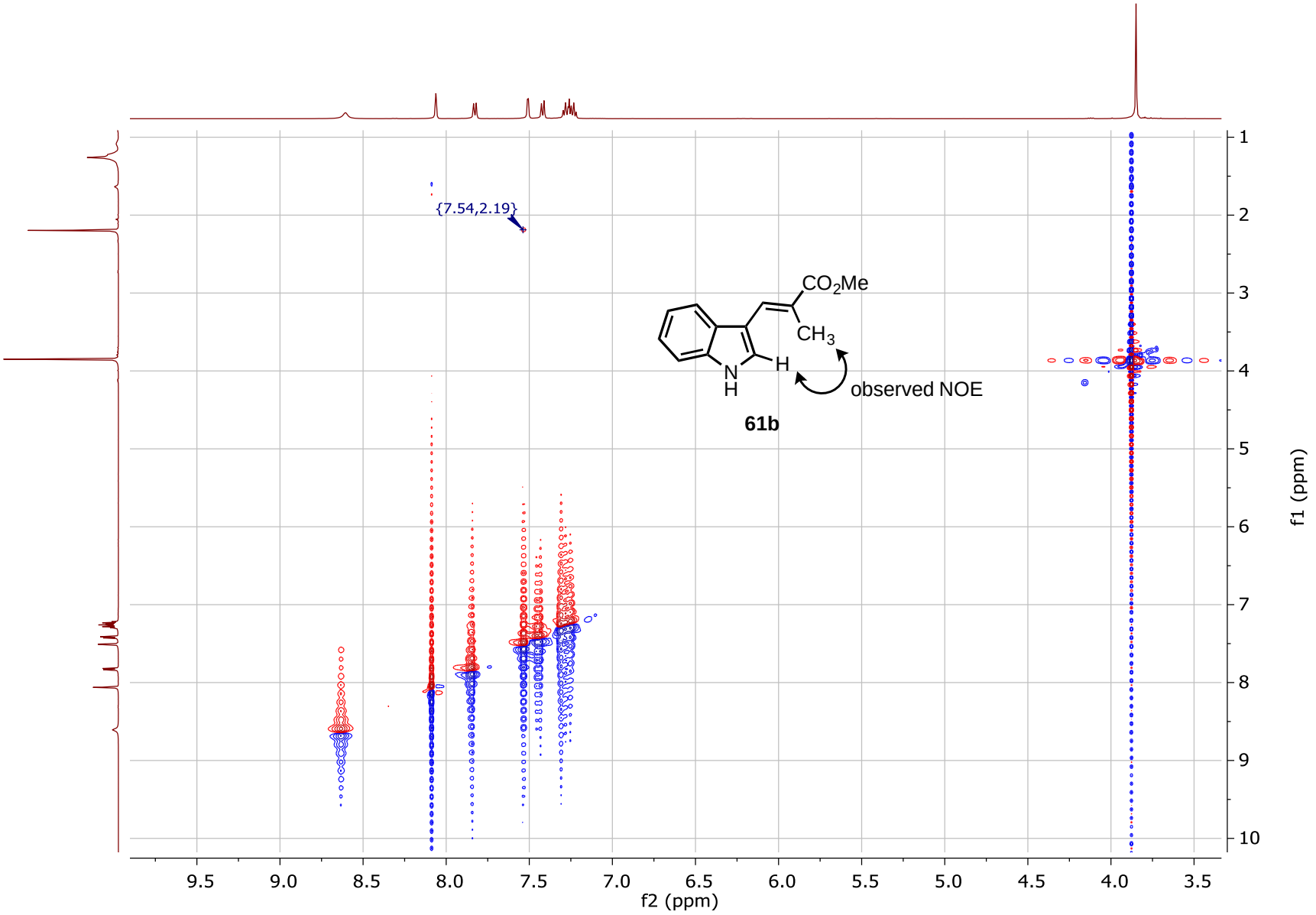


Figure S132. NOESY {^{1}H} (500 MHz, $CDCl_3$) of **61b**.

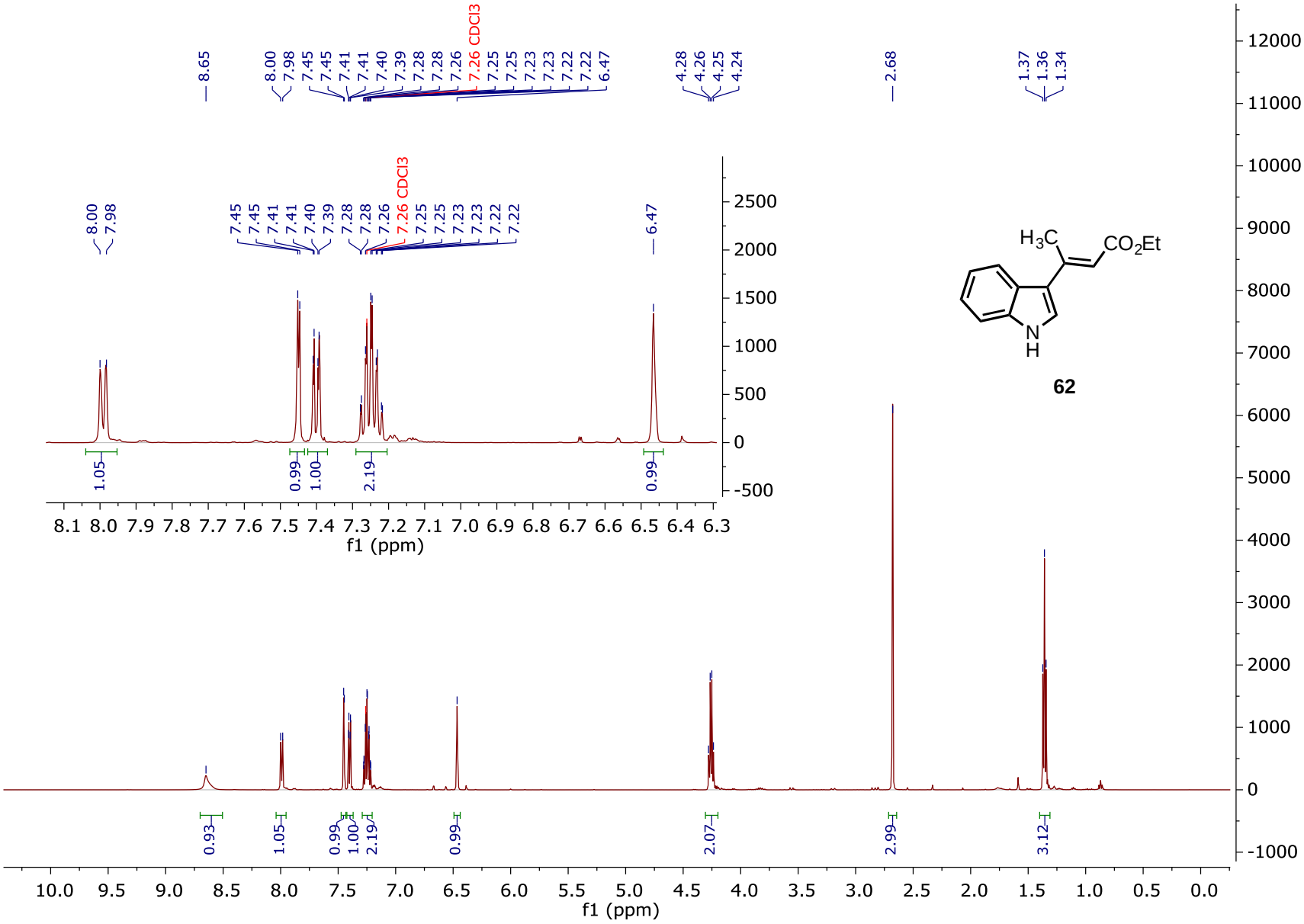


Figure S133. ^{1}H NMR (500 MHz, $CDCl_3$) of **62**.

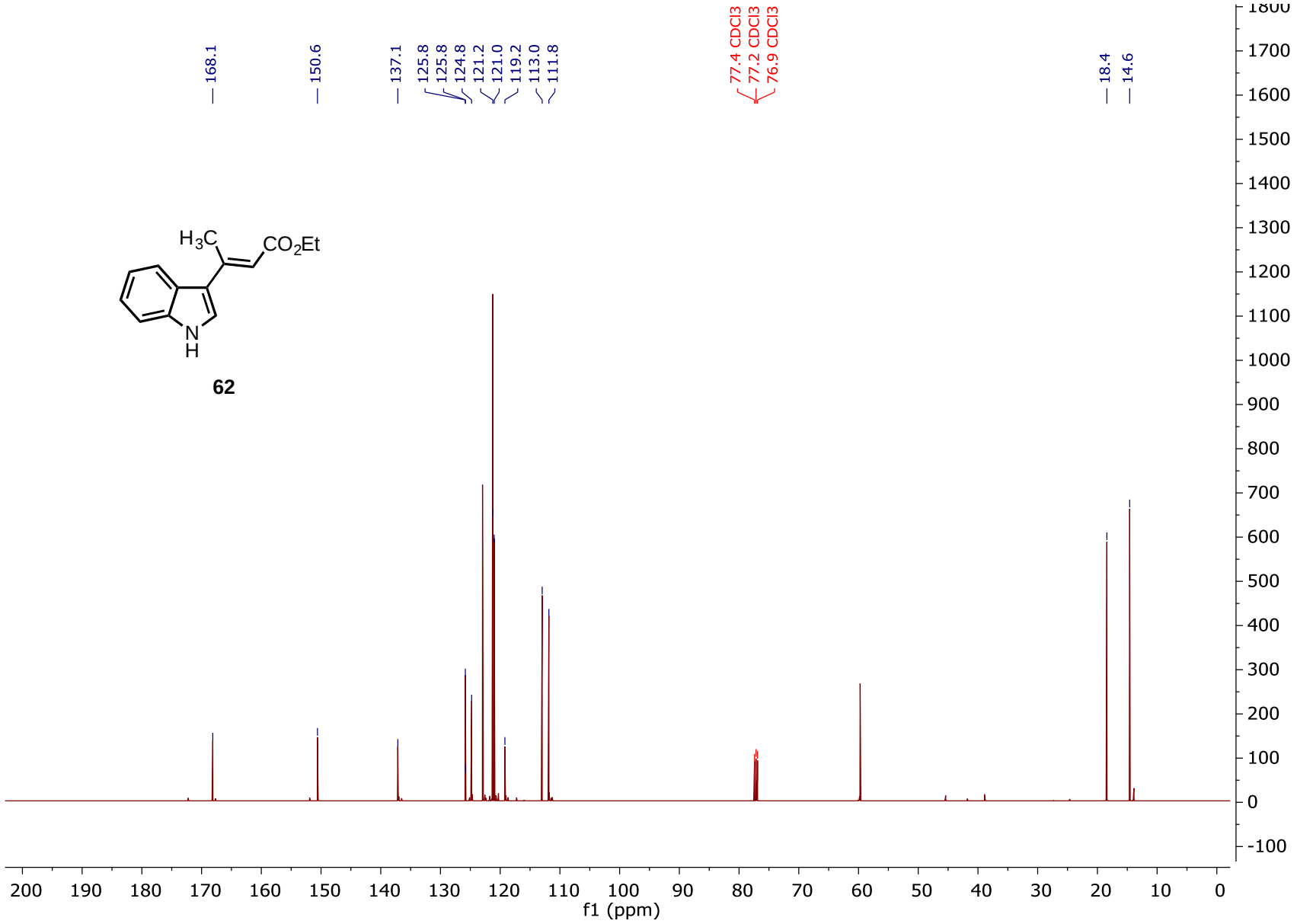


Figure S134. $^{13}C\{^{1}H\}$ NMR (126 MHz, $CDCl_3$) of **62**.

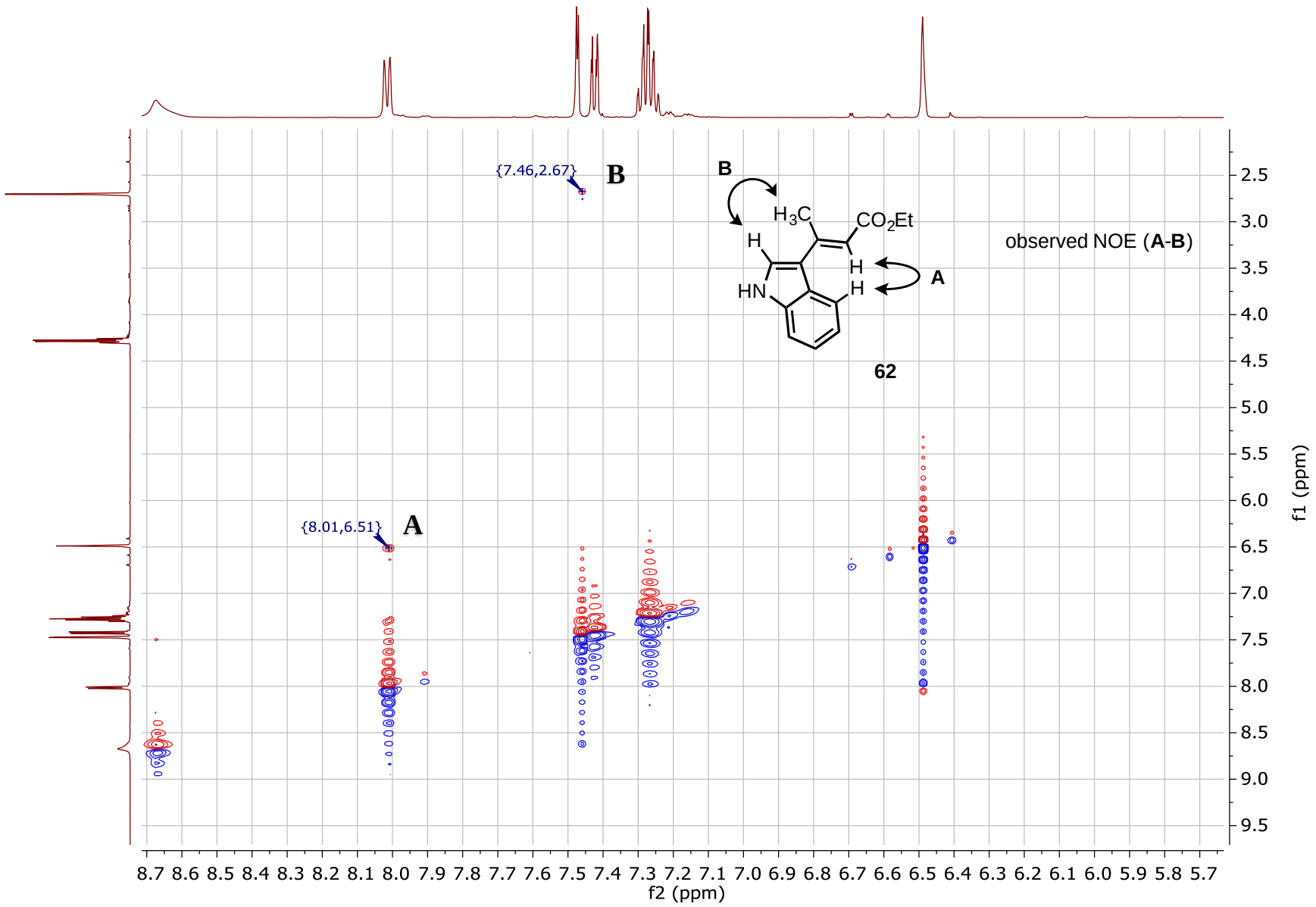


Figure S135. NOESY NMR (500 MHz, $CDCl_3$) of **62**.

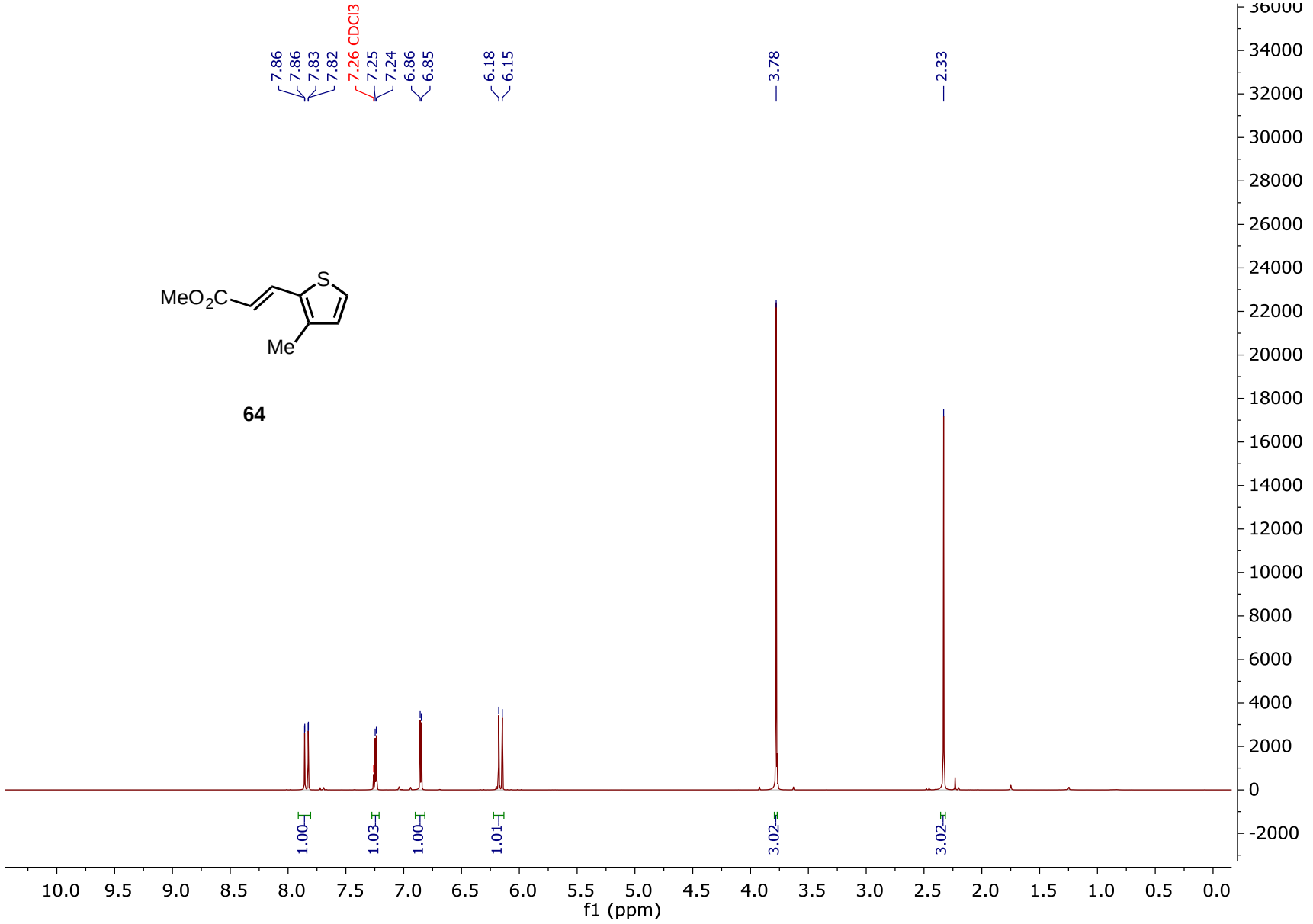


Figure S136. ^{1}H NMR (500 MHz, $CDCl_3$) of **64**.

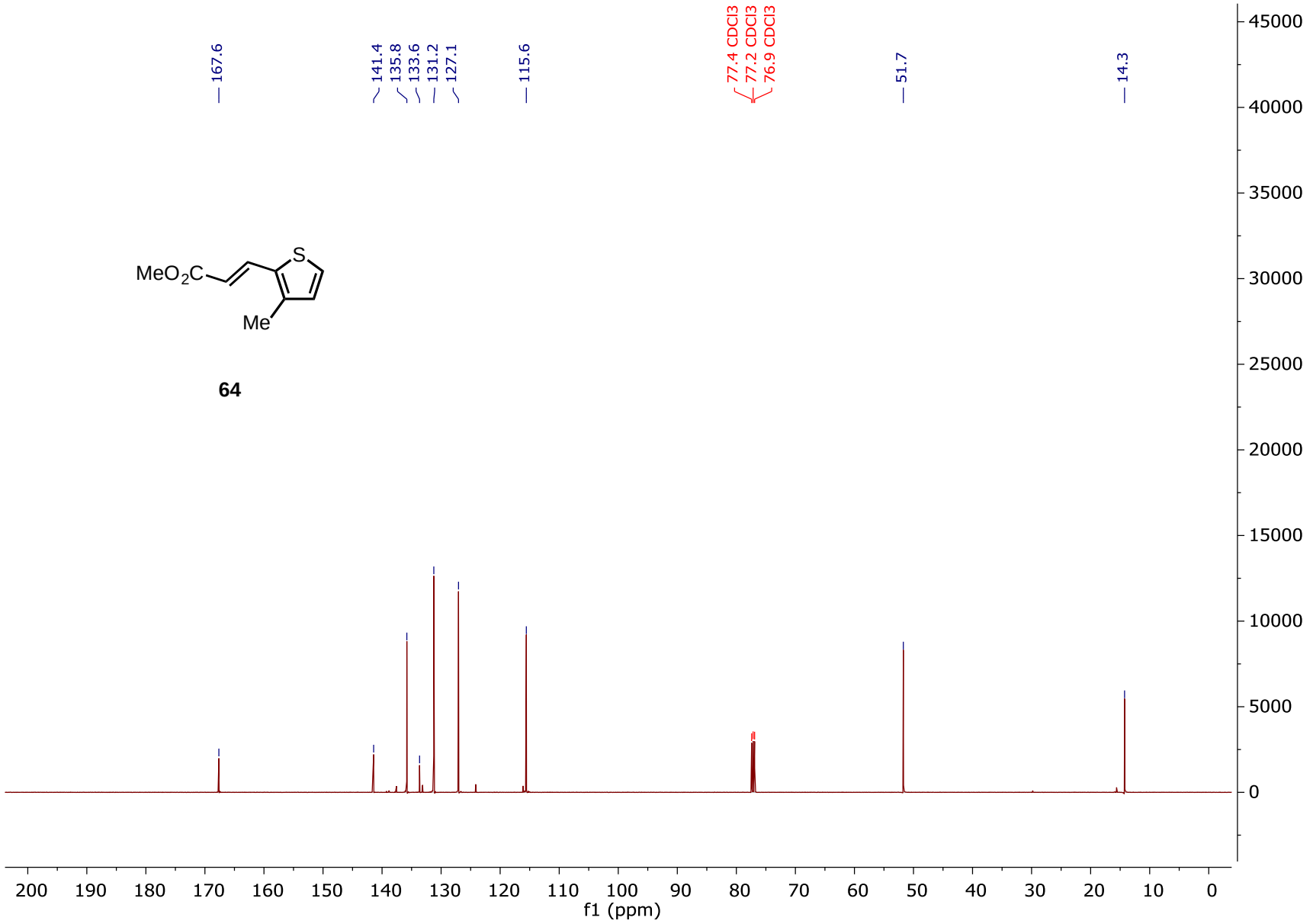


Figure S137. $^{13}C\{^{1}H\}$ NMR (126 MHz, $CDCl_3$) of **64**.

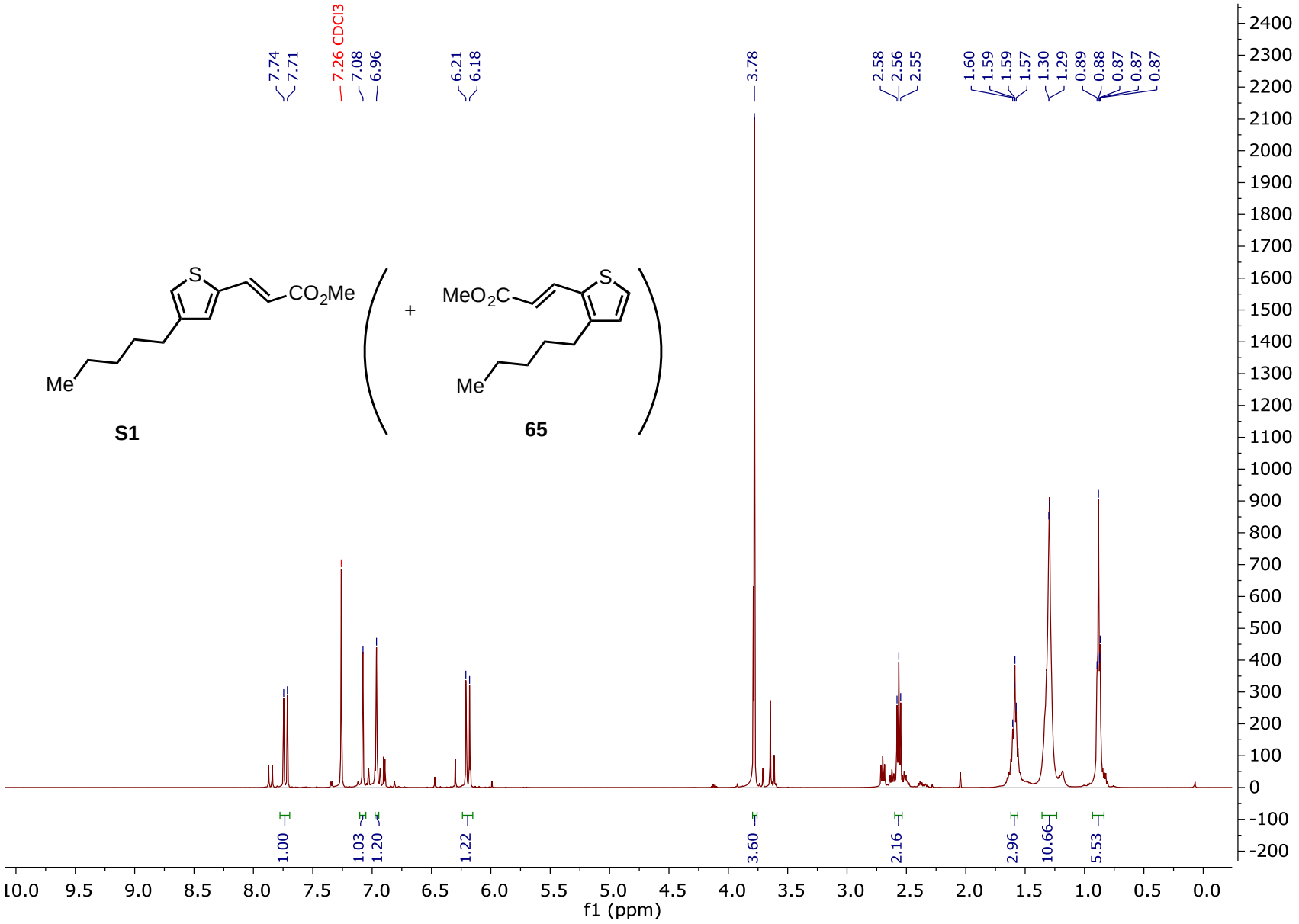


Figure S138. ^{1}H NMR (500 MHz, $CDCl_3$) of **S1**. Minor amount of **65** could not be completely removed.

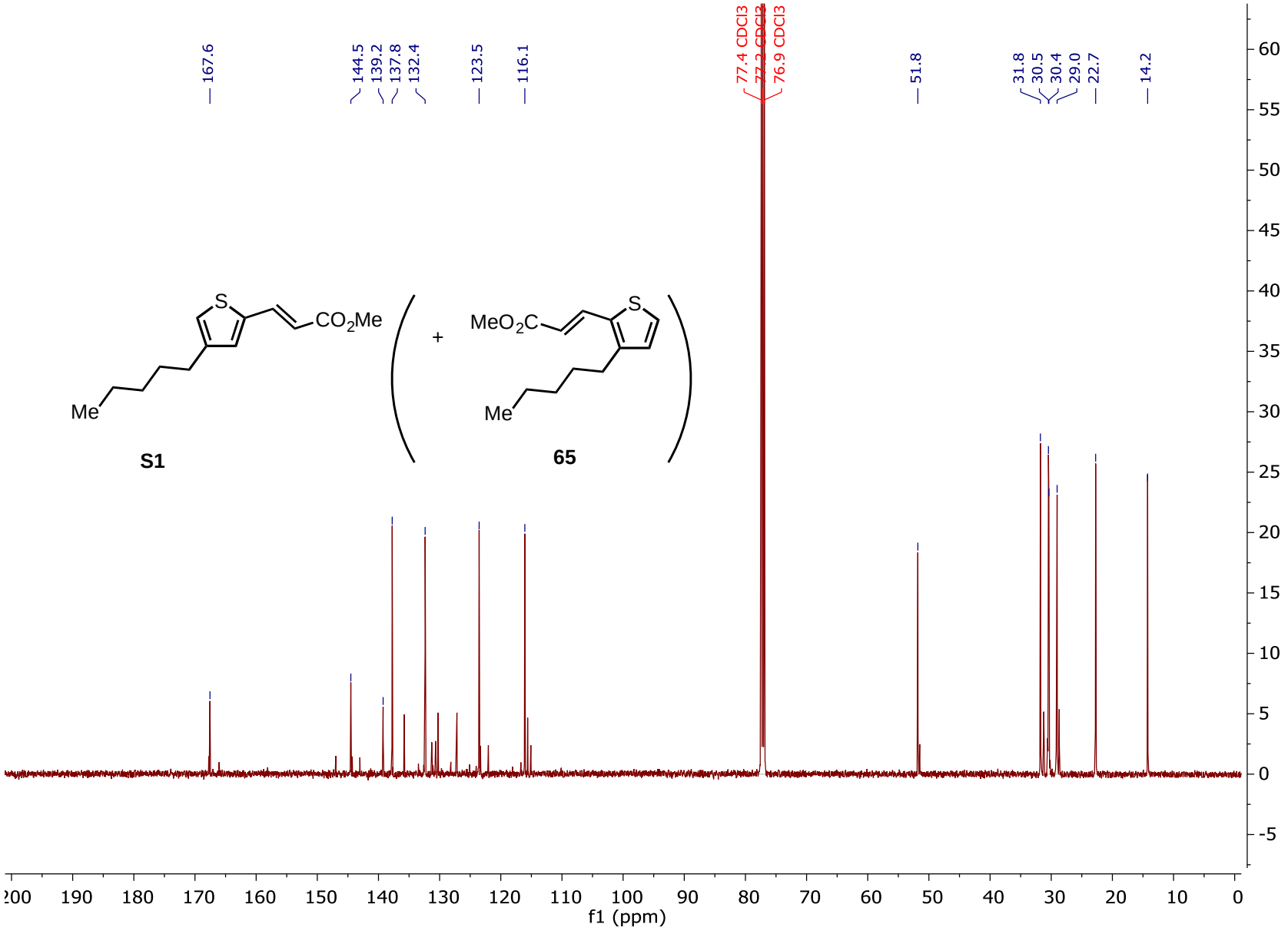


Figure S139. $^{13}C\{^{1}H\}$ NMR (126 MHz, $CDCl_3$) of **S1**. Minor amount of **65** could not be completely removed

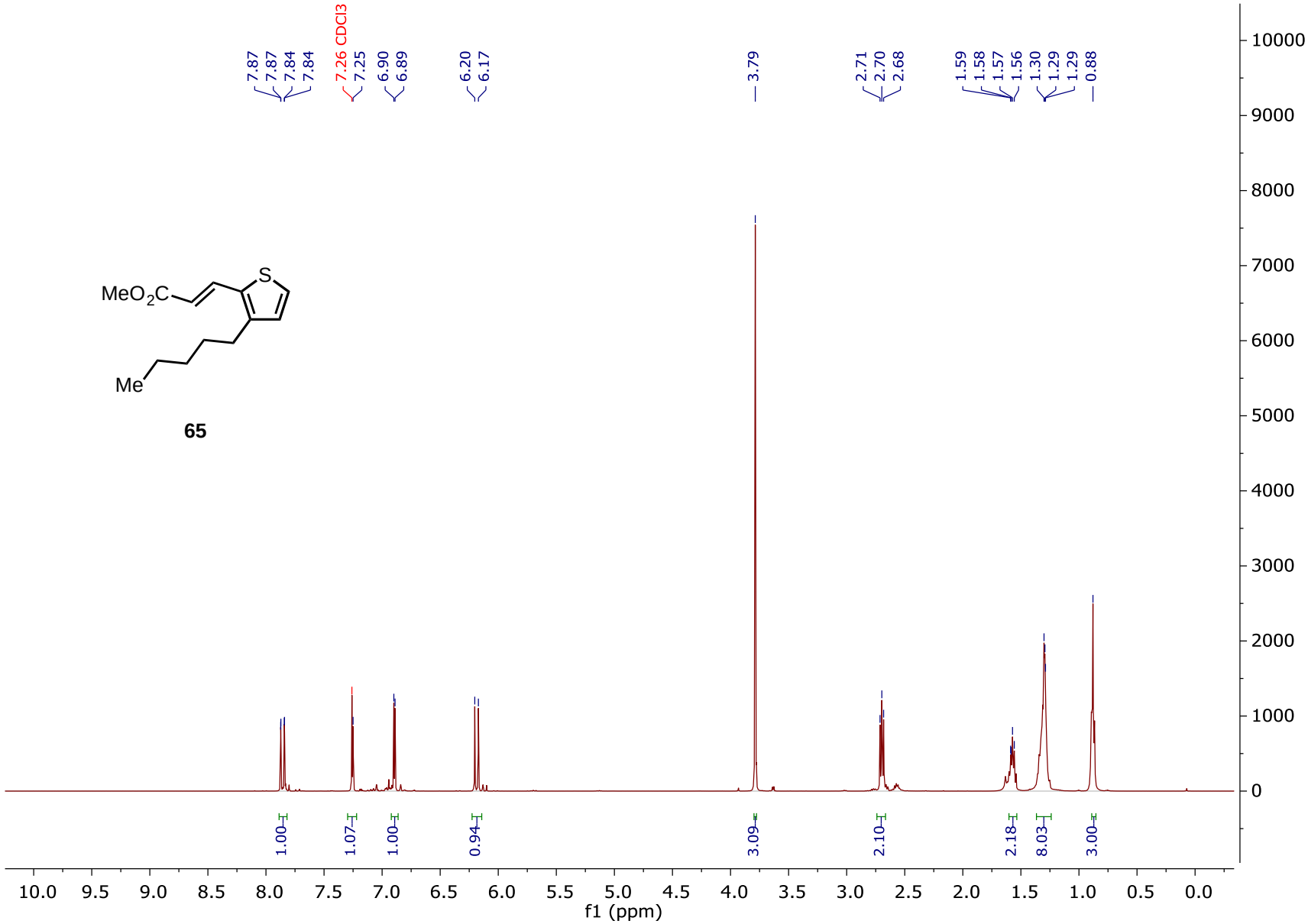


Figure S140. ^{1}H NMR (500 MHz, $CDCl_3$) of **65**. Minor amount of **S1** could not be completely removed.

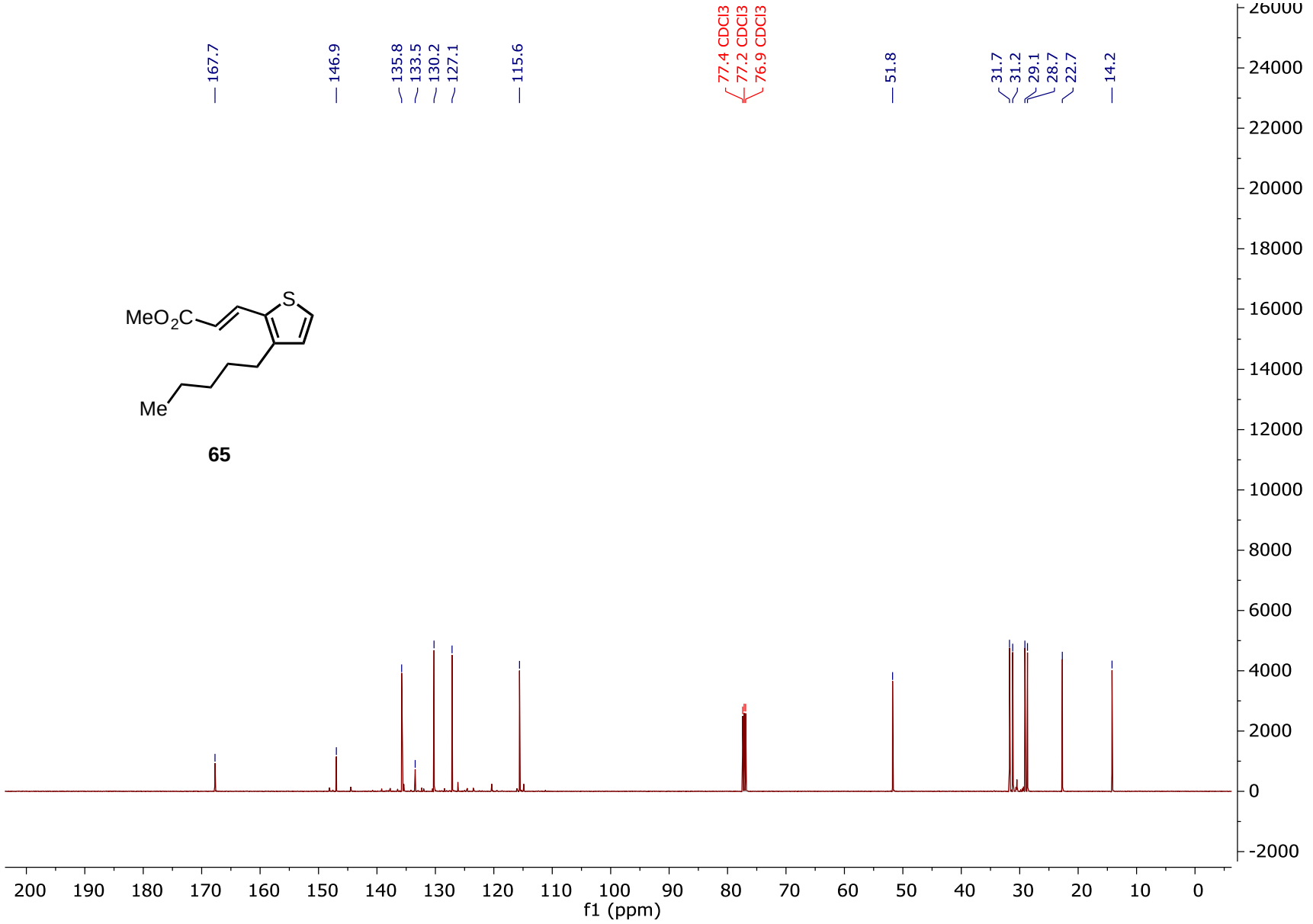


Figure S141. $^{13}C\{^{1}H\}$ NMR (126 MHz, $CDCl_3$) of **65**. Minor amount of **S1** could not be completely removed.

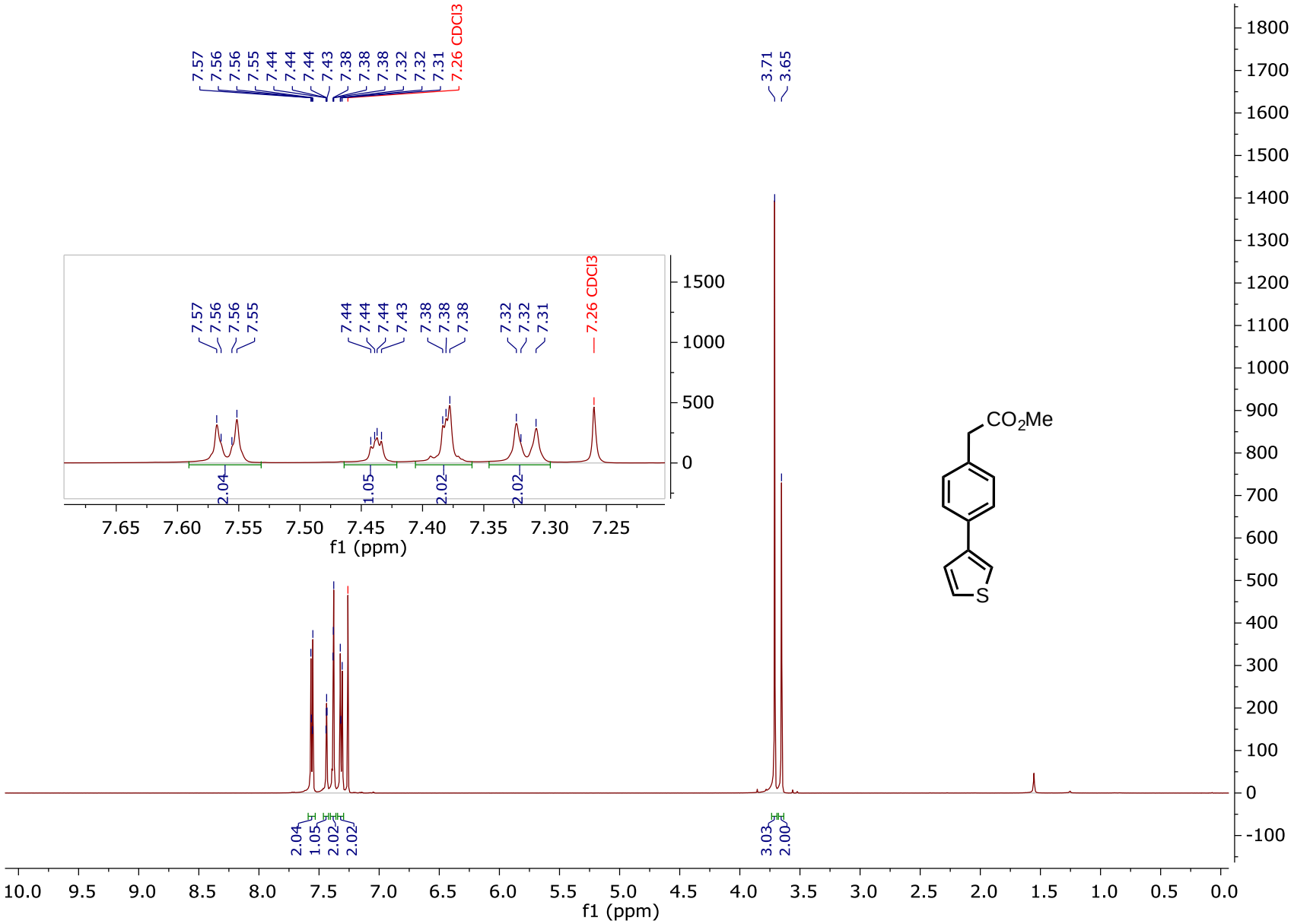


Figure S142. ^{1}H NMR (500 MHz, $CDCl_3$) of methyl 2-(4-(thiophen-3-yl)phenyl)acetate.

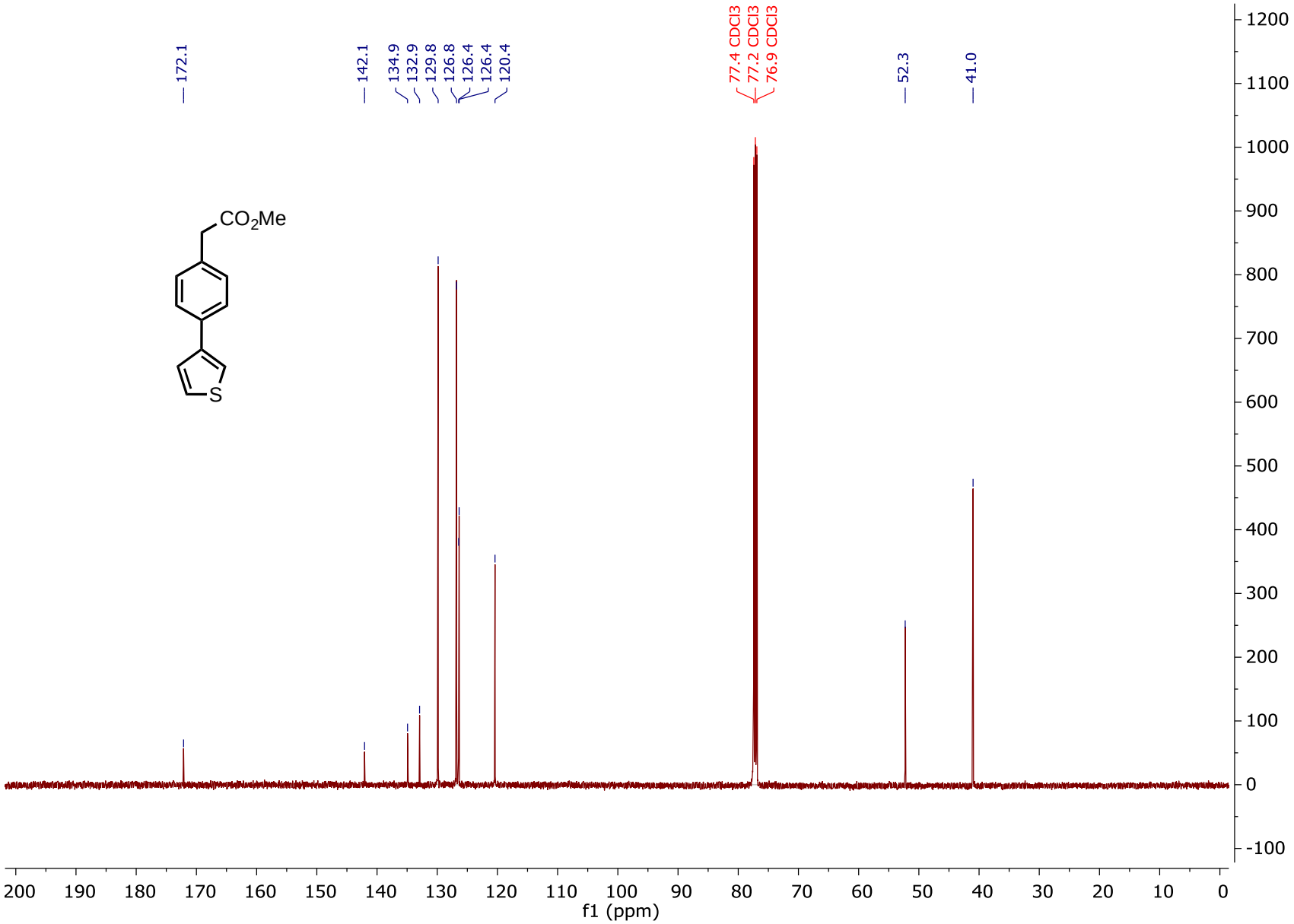


Figure S143. $^{13}C\{^{1}H\}$ NMR (126 MHz, $CDCl_3$) of methyl 2-(4-(thiophen-3-yl)phenyl)acetate.

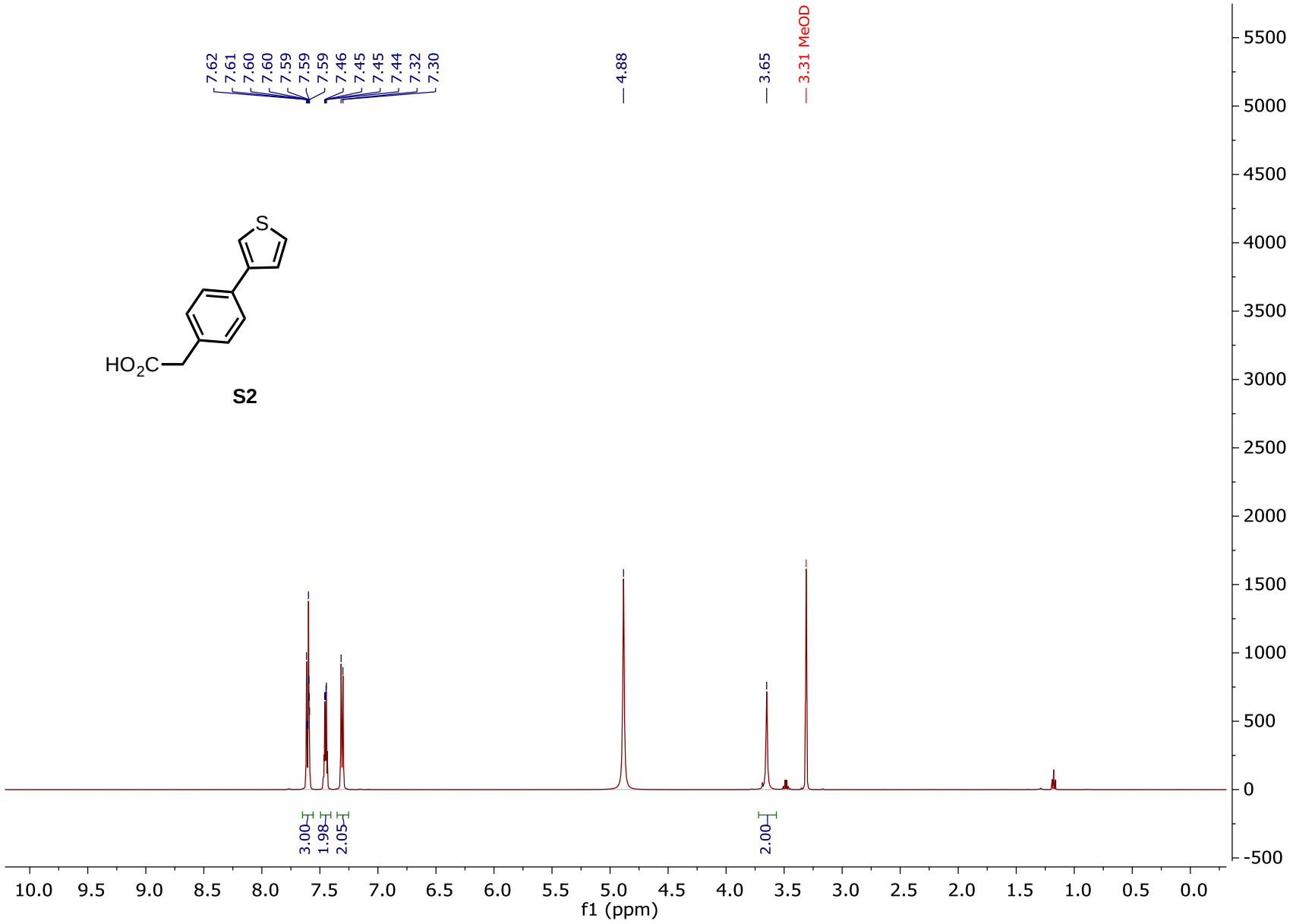


Figure S144. [1]H NMR (500 MHz, CD3OD) of **S2**.

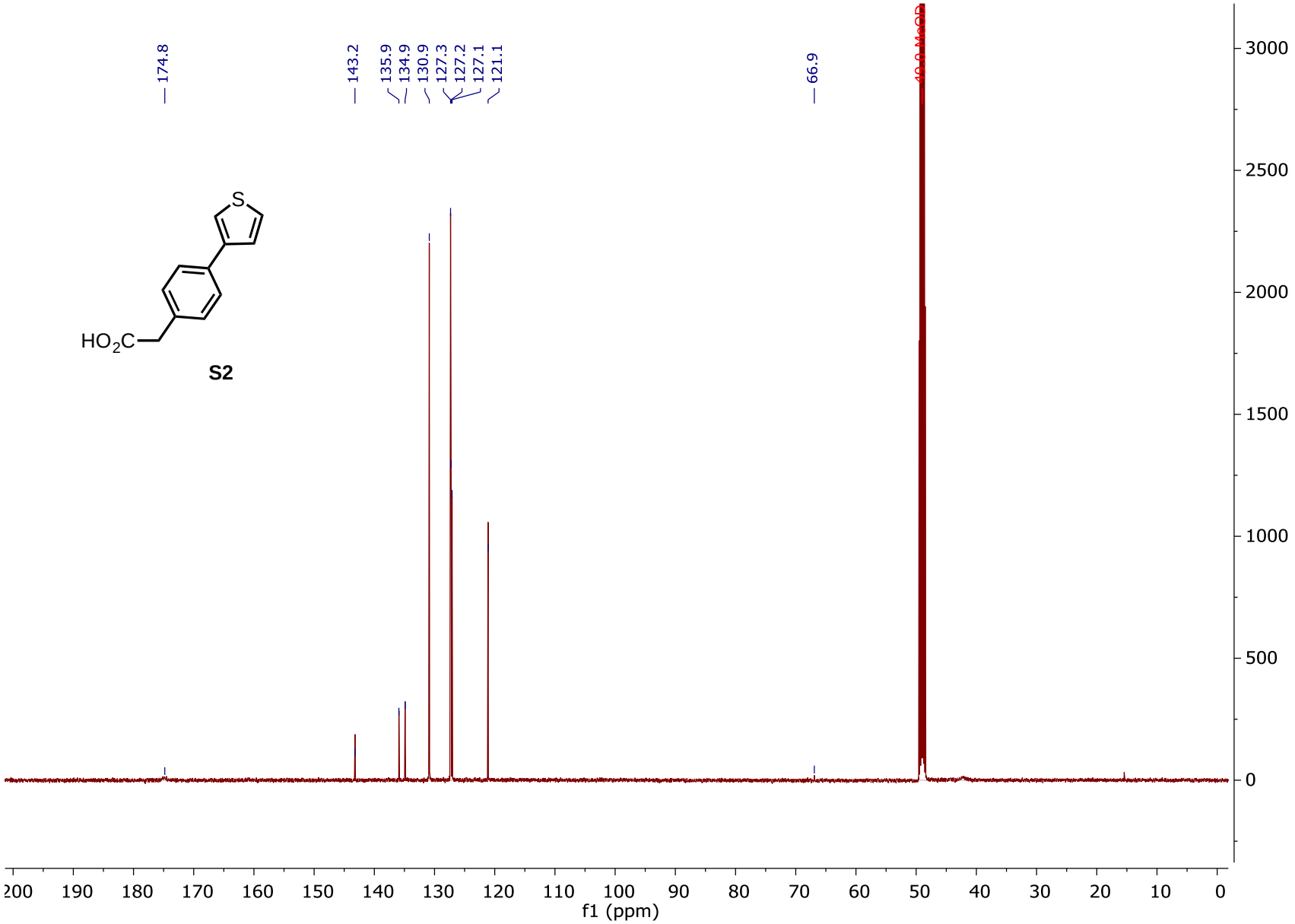


Figure S145. $^{13}C\{^{1}H\}$ NMR (126 MHz, CD3OD) of **S2**.

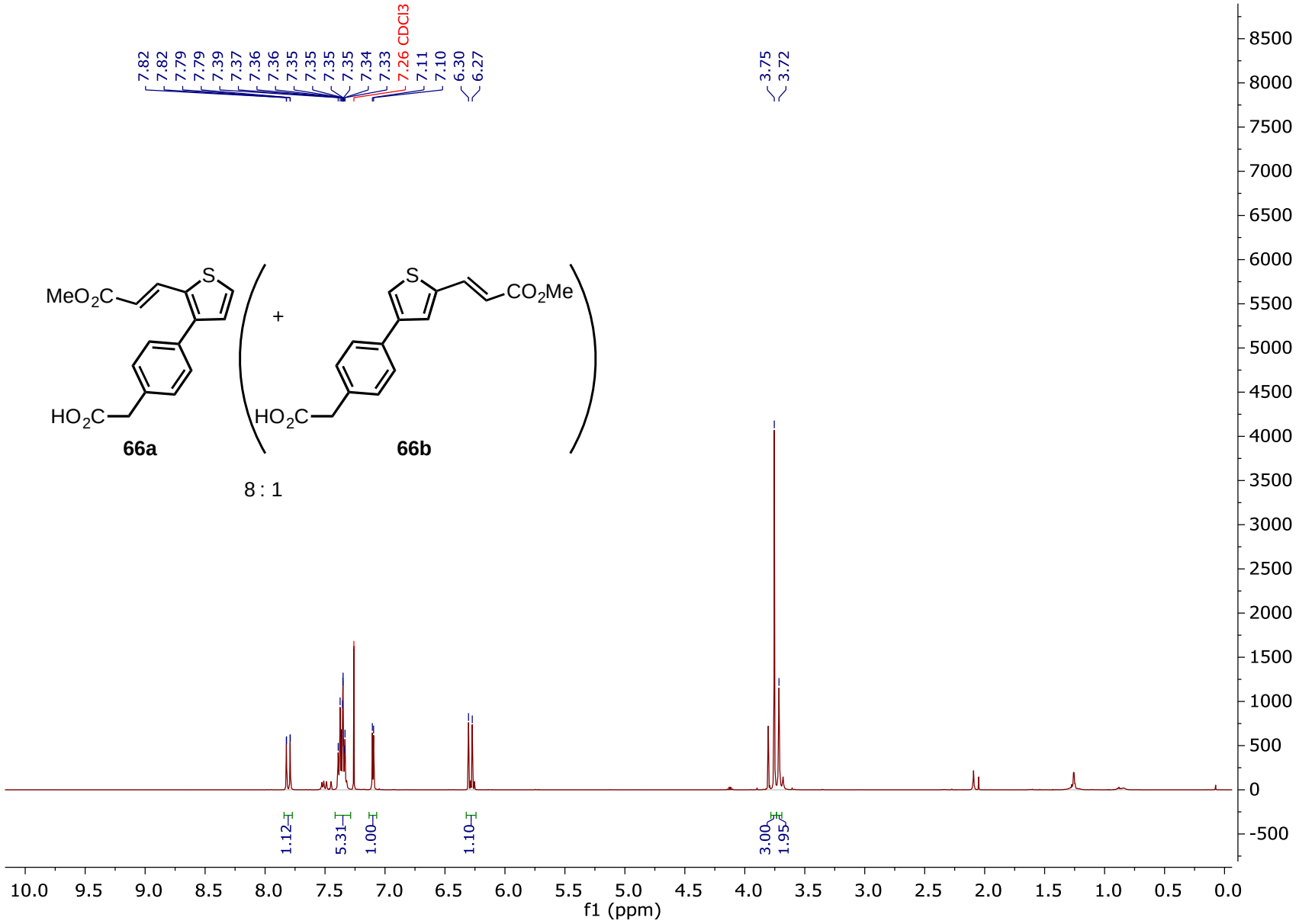


Figure S146. ^{1}H NMR (500 MHz, $CDCl_3$) of **66a**.

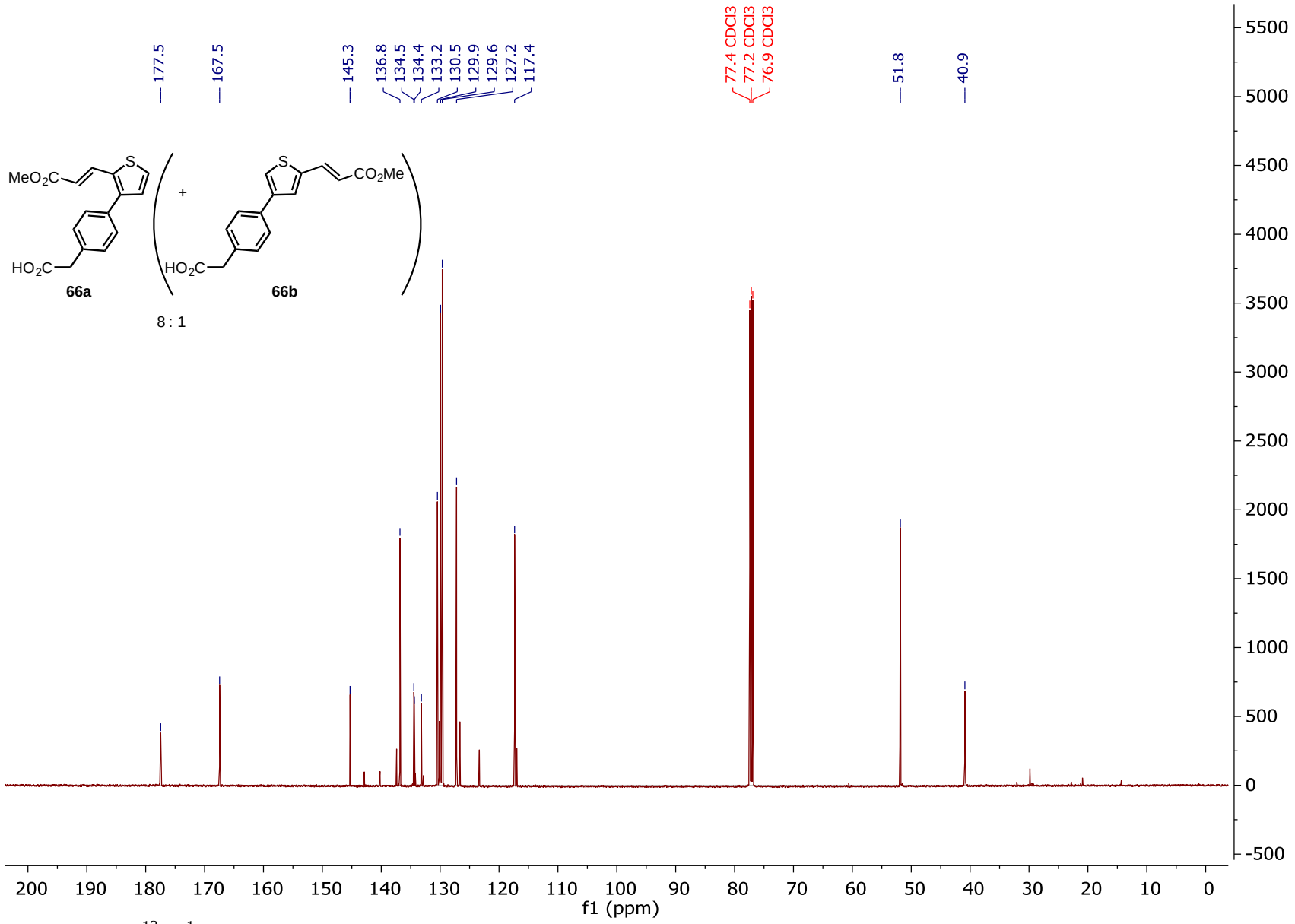


Figure S147. $^{13}C\{^{1}H\}$ NMR (126 MHz, $CDCl_3$) of **66a**.

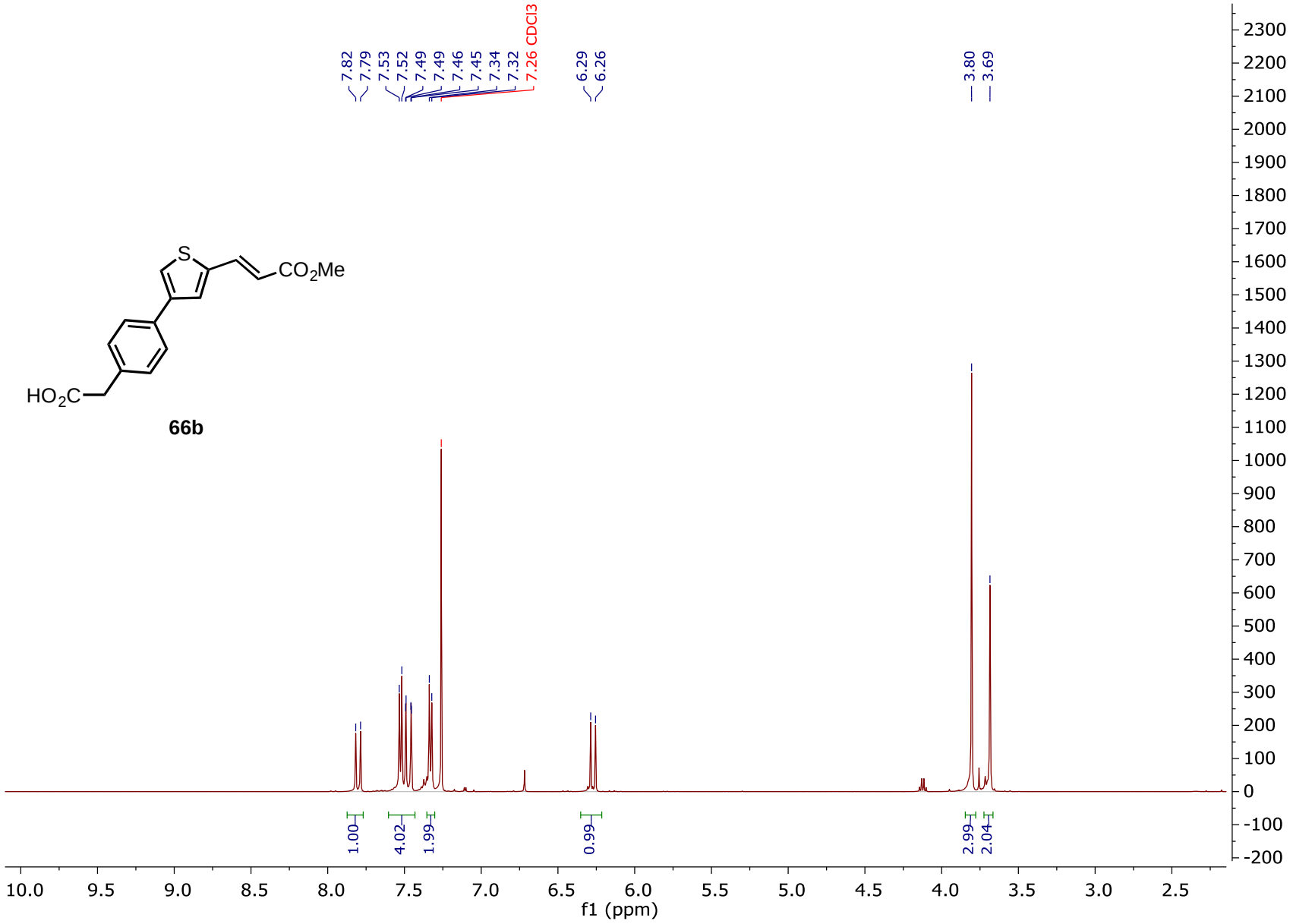


Figure S148. ^{1}H NMR (500 MHz, $CDCl_3$) of **66b**.

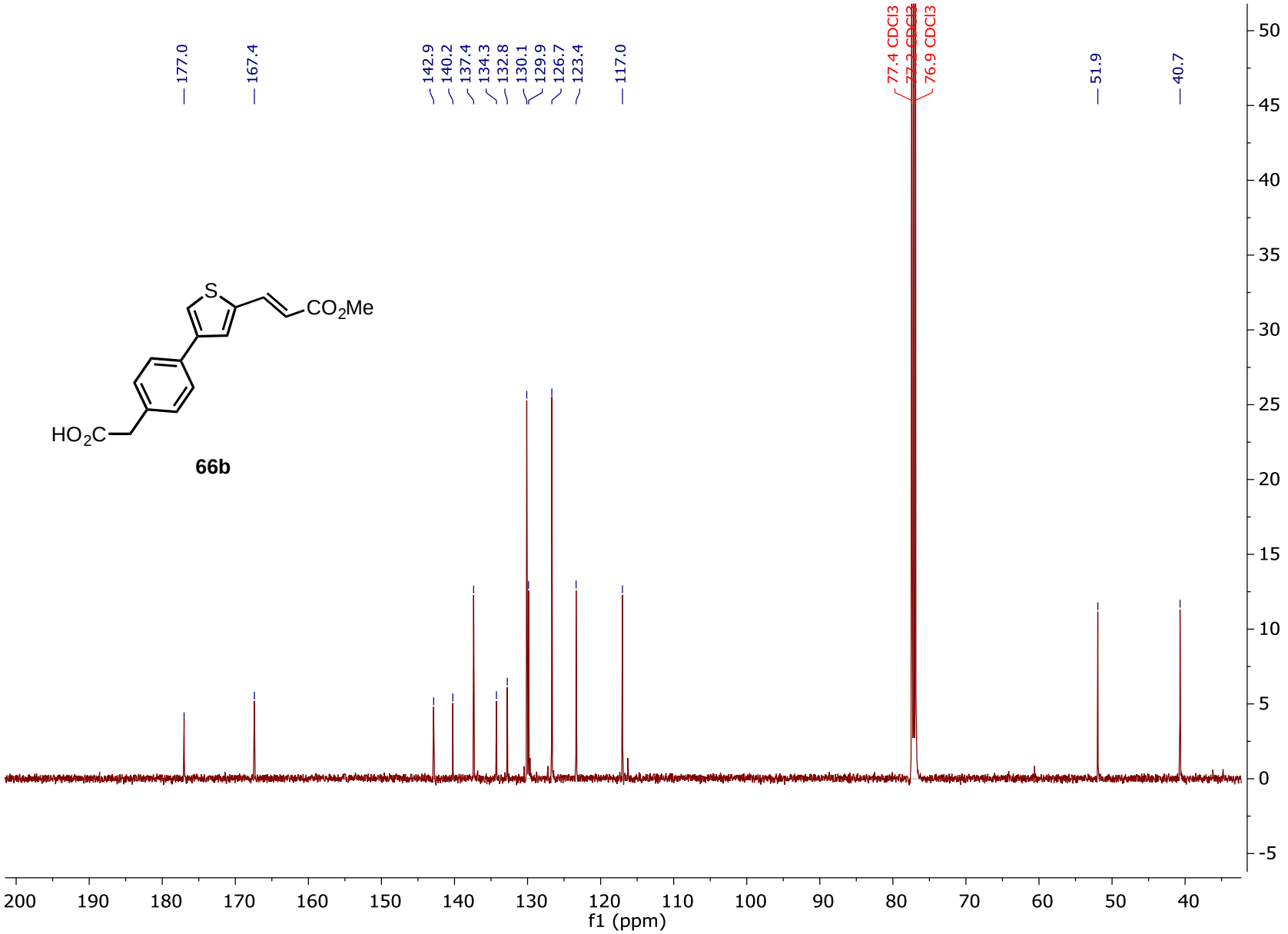


Figure S149. $^{13}C\{^{1}H\}$ NMR (126 MHz, $CDCl_3$) of **66b**.

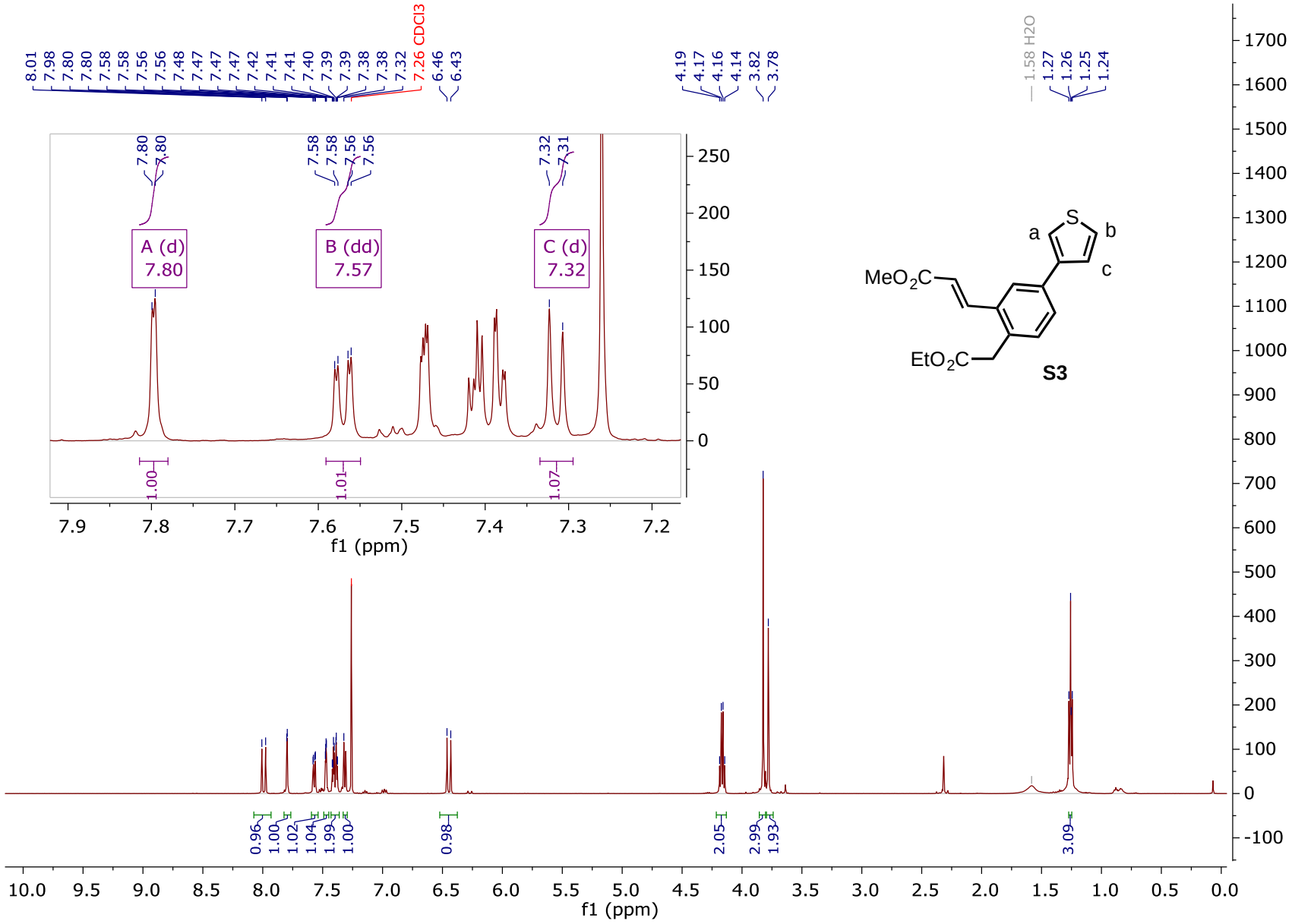


Figure S150. ^{1}H NMR (500 MHz, $CDCl_3$) of **S3**.

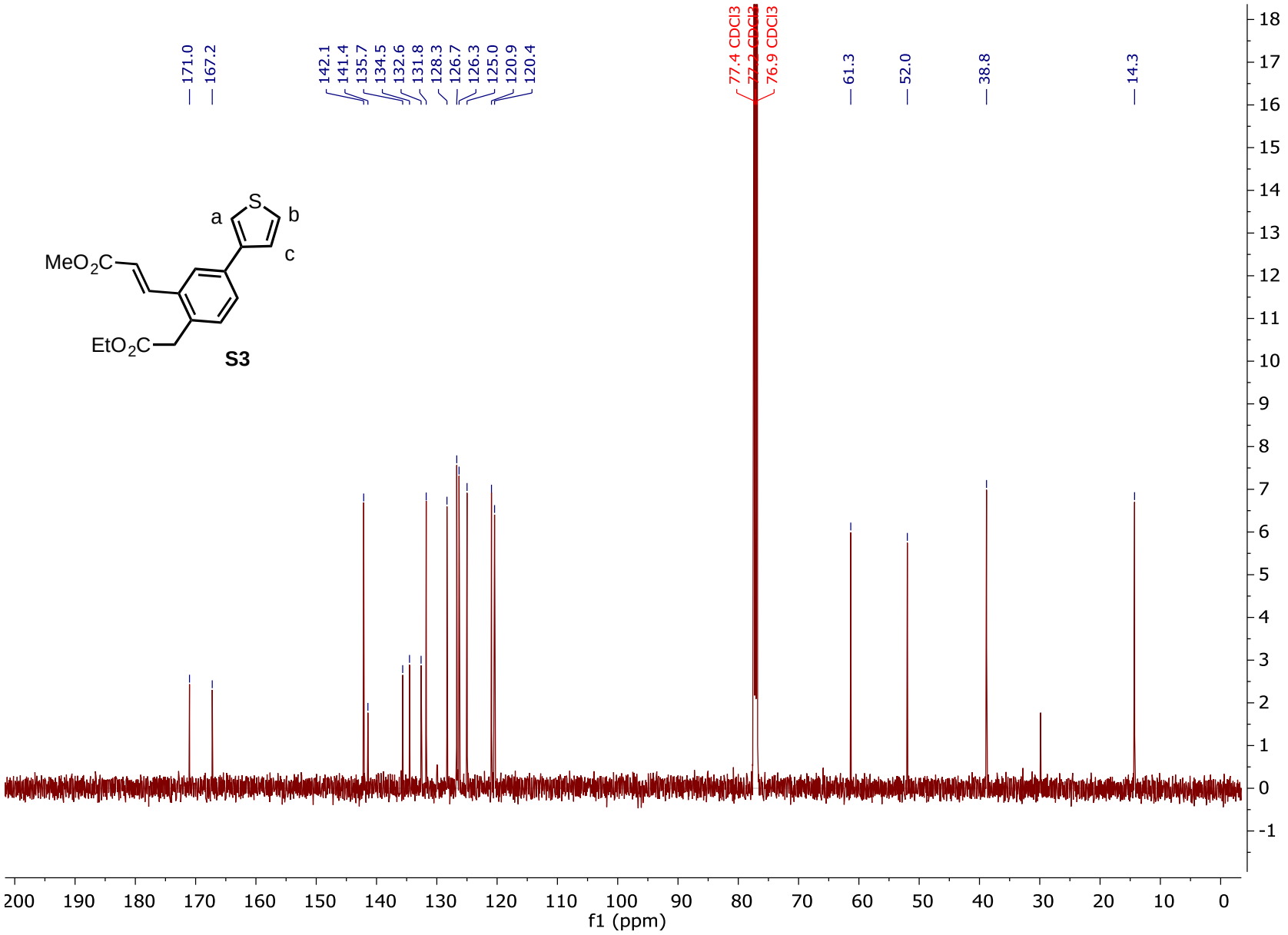


Figure S151. ^{13}C NMR (126 MHz, $CDCl_3$) of **S3**.

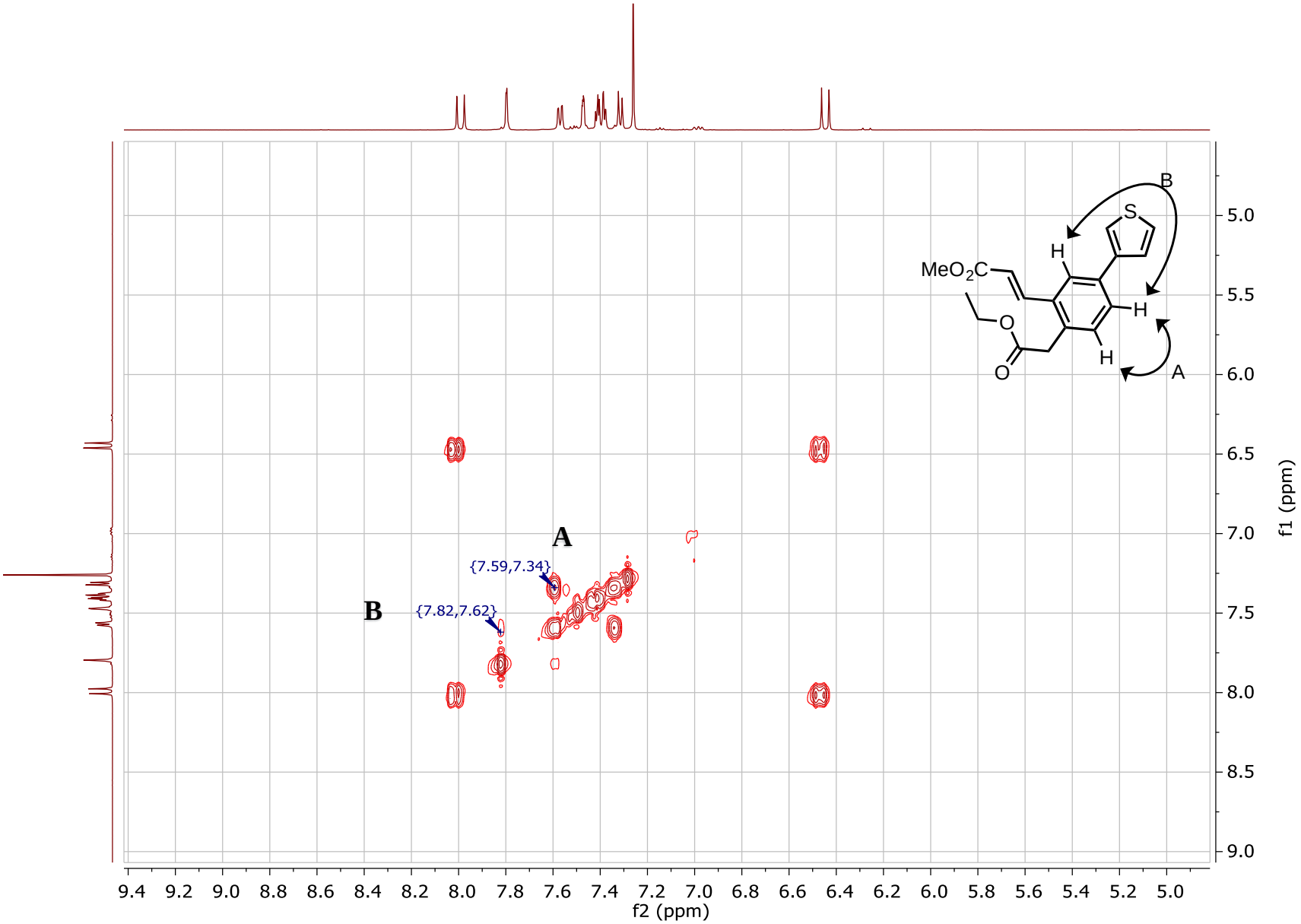


Figure S152. ^{1}H-^{1}H COSY NMR (500 MHz, $CDCl_3$) of **S3**.

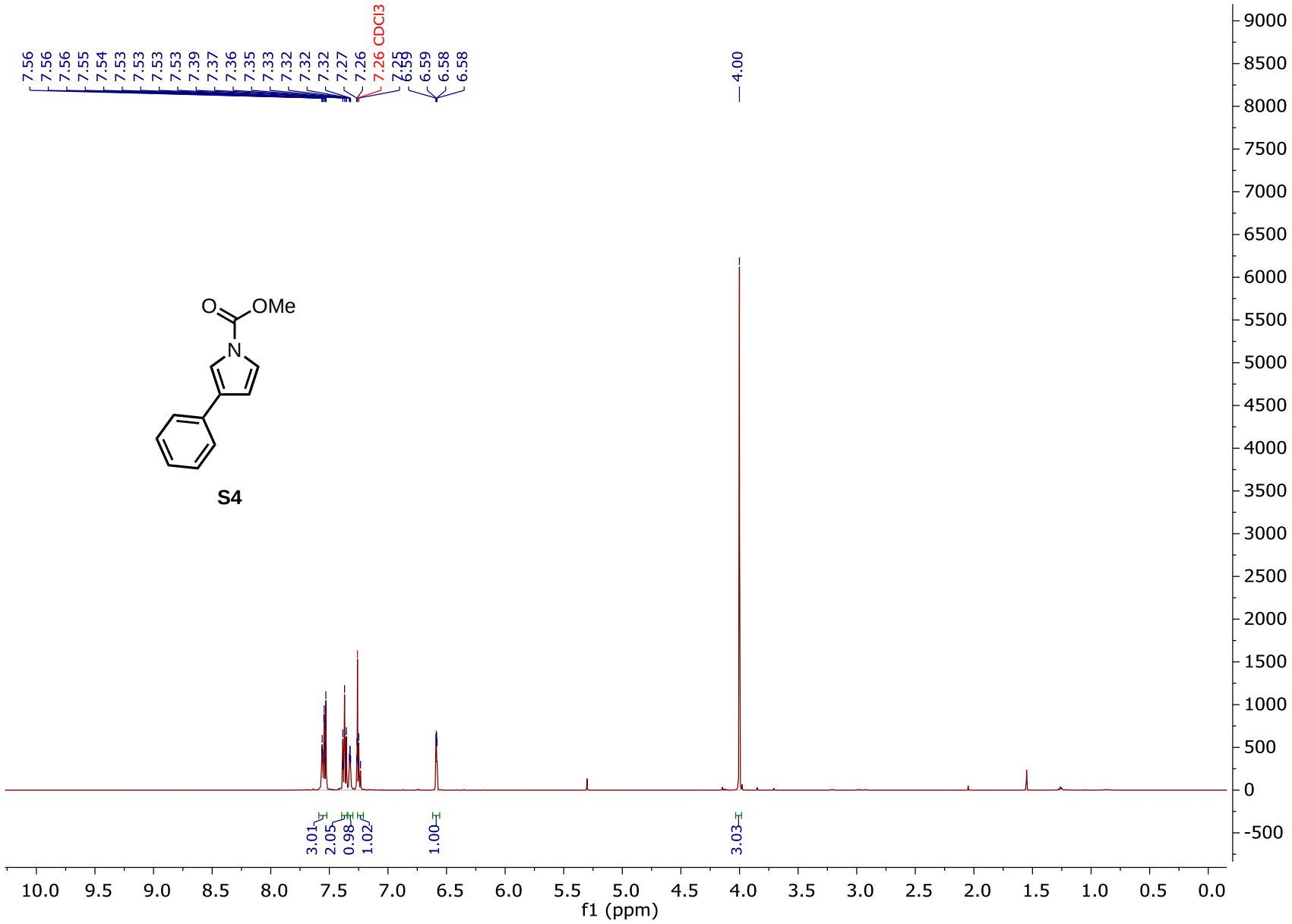


Figure S153. ^{1}H NMR (500 MHz, $CDCl_3$) of **S4**.

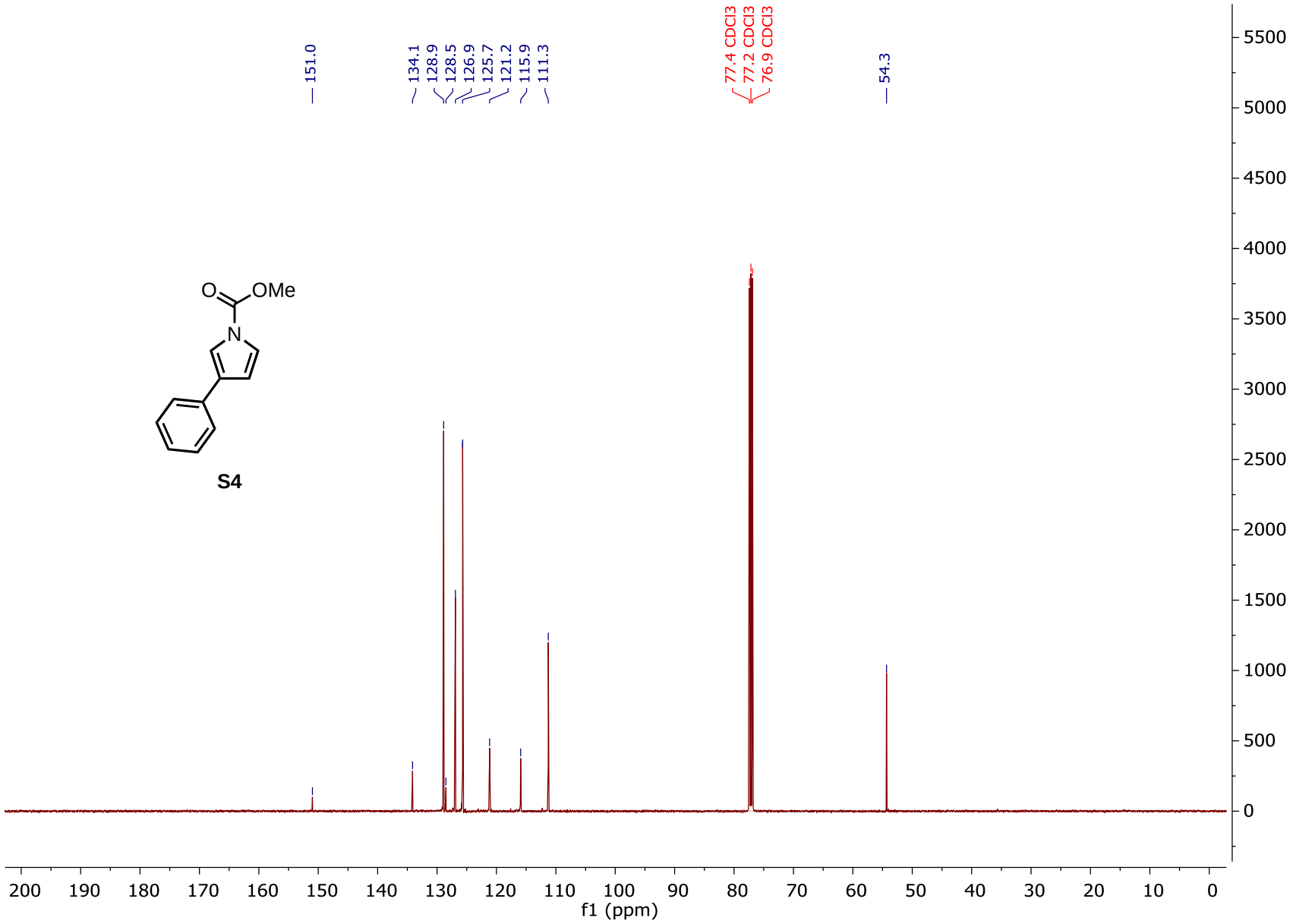


Figure S154. ^{13}C NMR (126 MHz, $CDCl_3$) of **S4**.

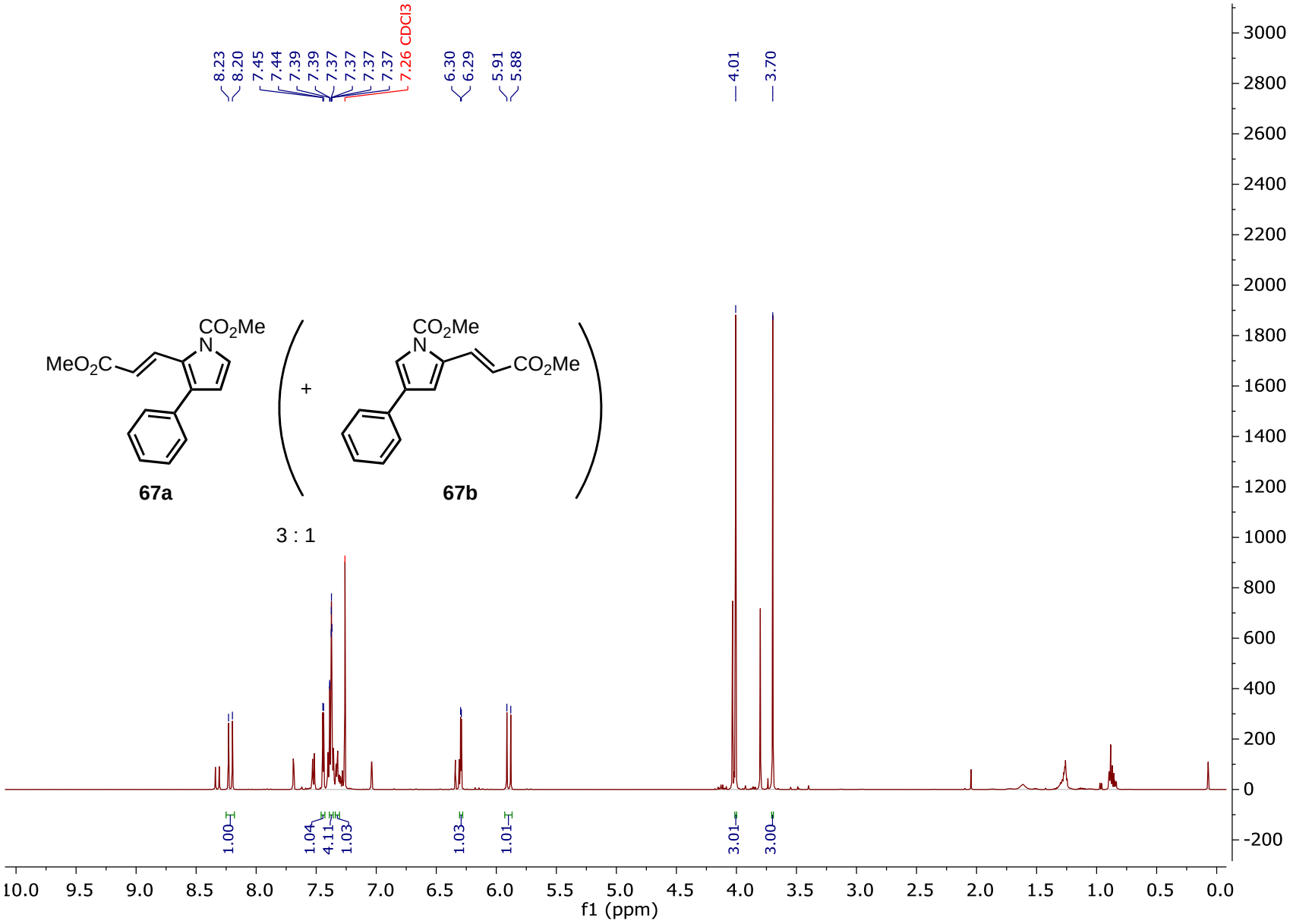


Figure S155. ^{1}H NMR (500 MHz, $CDCl_3$) of **67a** (major). Minor amount of **67b** could not be completely removed.

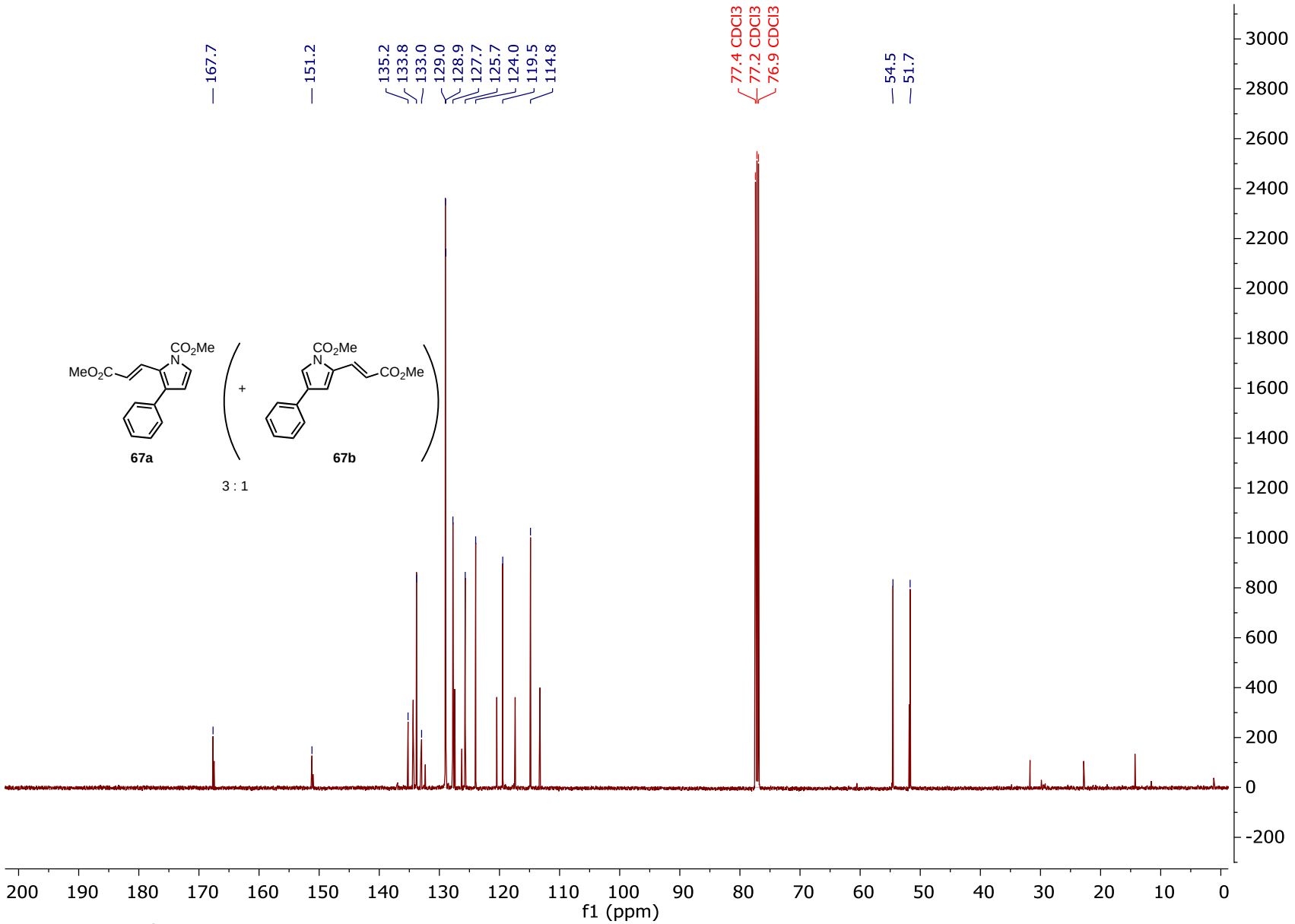


Figure S156. ^{13}C NMR (126 MHz, $CDCl_3$) of **67a** (major). Minor amount of **67b** could not be completely removed.

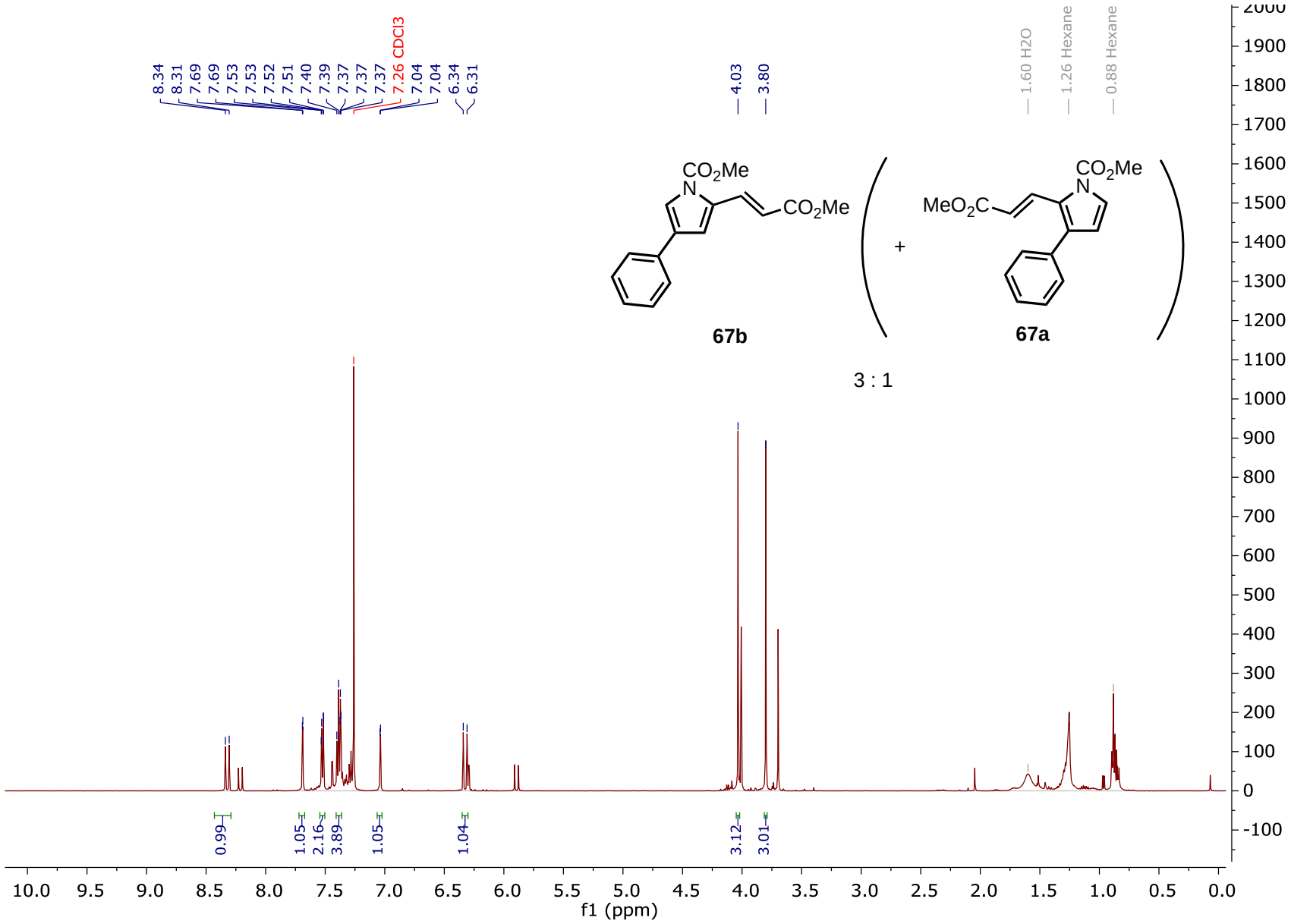


Figure S157. ^{1}H NMR (500 MHz, $CDCl_3$) of **67b** (major). Minor amount of **67a** could not be completely removed.

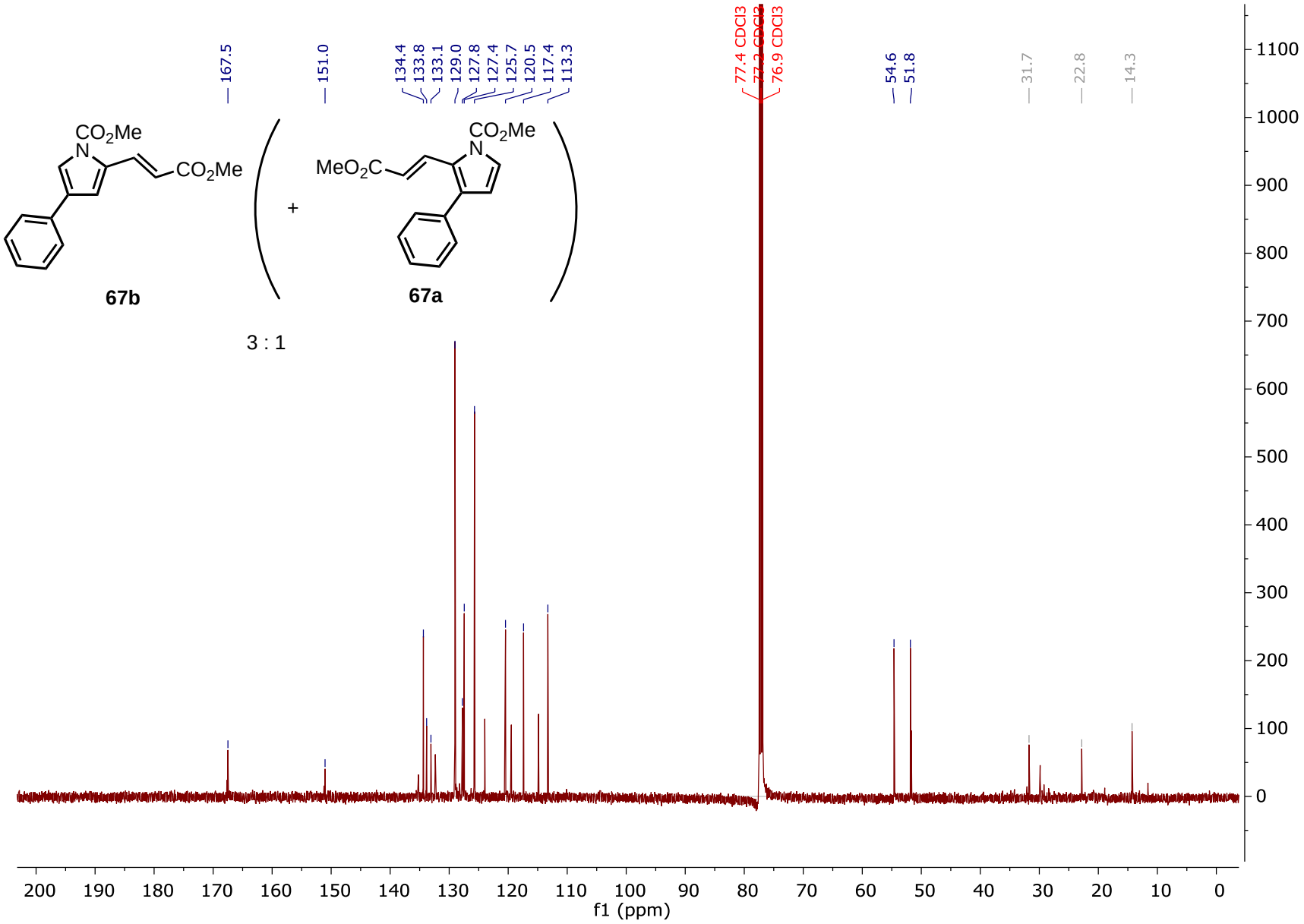


Figure S158. ^{13}C NMR (126 MHz, $CDCl_3$) of **67b** (major). Minor amount of **67a** could not be completely removed.

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