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Asymmetric Total Synthesis of Penicilfuranone A through NHC-Catalyzed Umpolung

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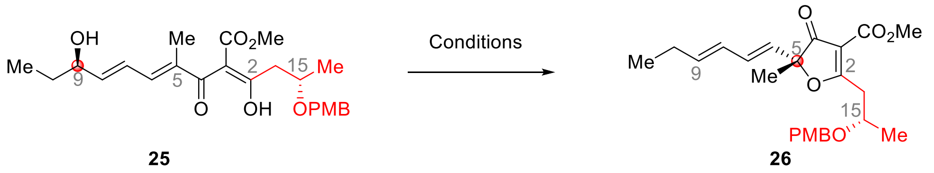
1. General Procedure

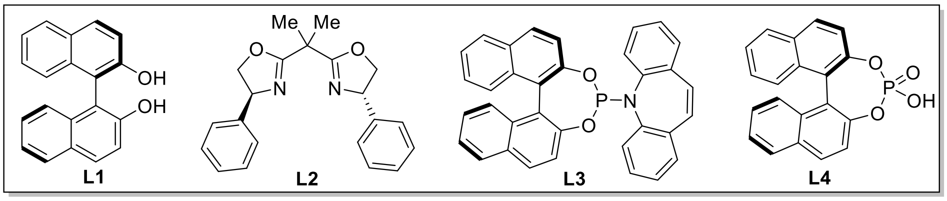
All reactions were carried out under a nitrogen atmosphere with dry solvents under anhydrous conditions, unless otherwise noted. Tetrahydrofuran (THF), 1,4-dioxane and diethyl ether (Et_2O) were distilled immediately before use from sodium-benzophenoneketyl. Methylene chloride (DCM), *N*,*N*-Dimethylformamide (DMF), triethylamine (Et_3N), 2,6-lutidine and pyridine were distilled from calcium hydride and stored under an argon atmosphere. Reagents were purchased at the highest commercial quality and used without further purification, unless otherwise stated. Solvents for chromatography were used as supplied by Titan chemical. Reactions were monitored by thin layer chromatography (TLC) carried out on 0.2 mm Huanghai gel plates (60F-254) using UV light as visualizing agent and aqueous ammonium cerium nitrate/ammonium molybdate or basic aqueous potassium permanganate as developing agent. Huanghai silica gel (60, particle size 0.040-0.063 mm) was used for flash column chromatography.

NMR spectra were recorded on Bruker AV III 400. The spectra were calibrated by using residual undeuterated solvents (for ^{1}H NMR) and deuterated solvents (for ^{13}C NMR) as internal references: chloroform (δ_H = 7.26 ppm) and $CDCl_3$ (δ_C = 77.16 ppm); methanol (δ_H = 3.31 ppm) and methanol–d_4 (δ_C = 49.00 ppm); Acetone (δ_H = 2.05 ppm) and acetone–d_6 (δ_C = 29.84 ppm, 206.26 ppm). The following abbreviations are used to designate multiplicities: s = singlet, d = doublet, t = triplet, q = quartet, m = multiplet, quint = quintet, br = broad. IR spectra were recorded on a BRUKER Tensor-27 FT-IR spectrometer. Specific Rotation were recorded on Rudolph Autopol V. High-resolution mass spectra (HRMS) were recorded on Agilent G6230 ESI-FT.

2. Tables of optimization of the reaction conditions

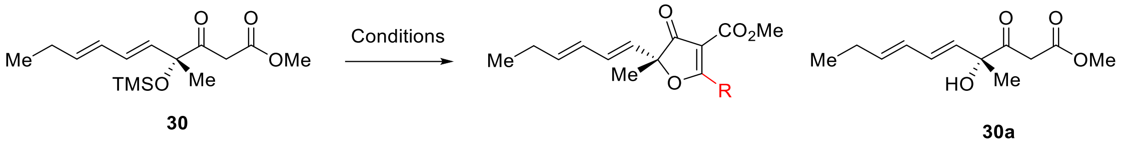
Table S1. Investigation of the reaction conditions for synthesis of compound 26.

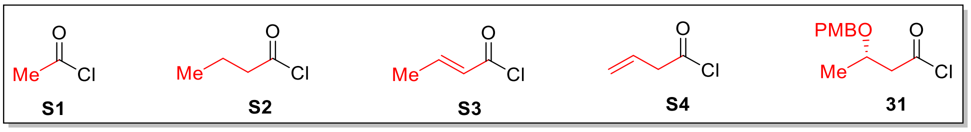




Entry	Diastereomeric ratio of 25	Conditions	Yield	Diastereomeric ratio of 26
1	19:1	5.0 eq. MsCl, 5.0 eq. Et_3N, DCM, 25 °C	41%	2:1
2	19:1	20 mol% $Pd(Ph_3P)_4$, 2.0 equiv Et_3N, MeCN, 60 °C	9%	2:1
3	19:1	20 mol% $Pd(Ph_3P)_2Cl_2$, 2.0 equiv Et_3N, toluene, 60 °C	17%	2:1
4	19:1	20 mol% Ph_3PAuCl, 2.0 equiv Et_3N, toluene, 25 °C	49%	1:1
5	1:1	20 mol% $PdCl_2$, 30 mol% **L1**, 2.0 equiv Et_3N, toluene, 60 °C	25%	1:1
6	1:1	20 mol% $PdCl_2$, 30 mol% **L2**, 2.0 equiv Et_3N, toluene, 60 °C	8%	1:1
7	1:1	10 mol% $[Ir(cod)Cl]_2$, 16 mol% **L3**, 1.0 equiv LiCl, DCE, 25 °C	trace	–
8	1:1	10 mol% $[Ir(cod)Cl]_2$, 16 mol% **L3**, 1.0 equiv $Zn(OTf)_2$, DCE, 25 °C	16%	5.5:1
9	1:1	10 mol% $[Ir(cod)Cl]_2$, 16 mol% **L3**, 1.0 equiv $MgBr_2$, DCE, 25 °C	11%	2:1
10	1:1	10 mol% $[Ir(cod)Cl]_2$, 16 mol% **L3**, 1.0 equiv $ZnBr_2$, toluene, 25 °C	32%	3:1
11	1:1	10 mol% $[Ir(cod)Cl]_2$, 16 mol% **L3**, 25 mol% **L4**, DCE, 25 °C	5%	3:1

Table S2. Evaluation of condensation reaction conditions.

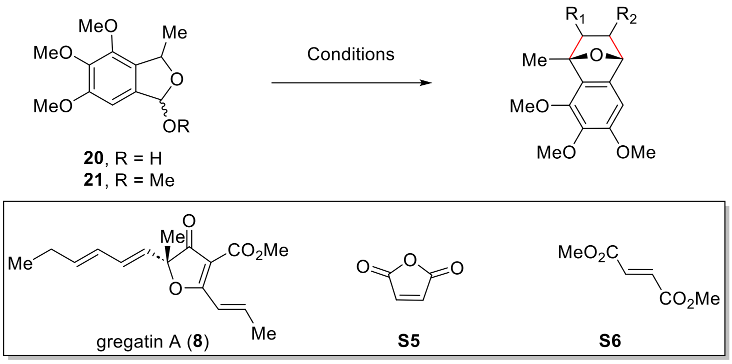




Entry	Conditions	Yield
1	NaH, **S3** *then* HF, 25 °C	No Desired
2	NaH, **S3** *then* HF·Et_3N, 25 °C	No Desired
3	NaH, **S3**, *then* TBAF, 25 °C	5%[a]
4	NaH, **S2**, *then* TBAF, 25 °C	77%
5	NaH, **S1**, *then* TBAF, 25 °C	85%
6	NaH, **S4**, *then* TBAF, 25 °C	30%[b]
7	NaH, **31**, *then* TBAF, 25 °C	47%
8	NaH, **31**, *then* TBAF, 0 °C	60%

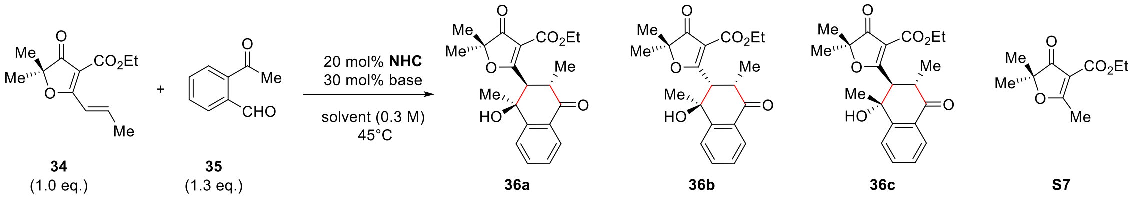
[a] the yield of by-product **30a** = 88% [b] the yield of by-product **30a** = 45%

Table S3. Investigating conditions of the intermolecular Diels-Alder reaction.

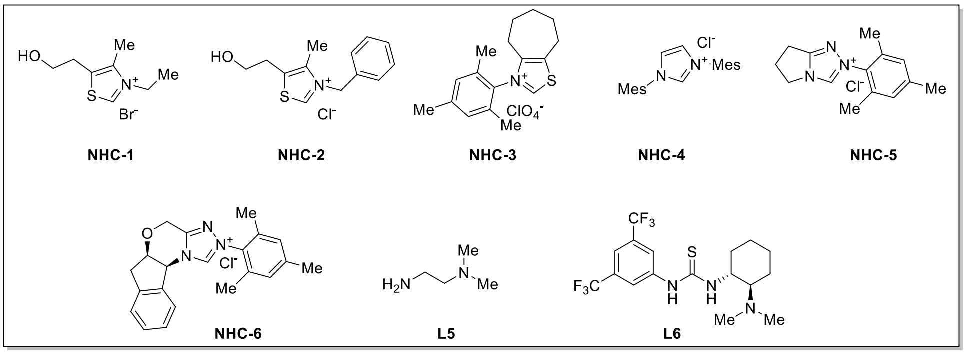


Entry	Conditions	Results
1, R = H	**8**, AcOH, 65 °C	Decomposed
2, R = H	**8**, PTSA, toluene, 100 °C	Decomposed
3, R = H	**8**, $Cu(OTf)_2$, toluene, 80 °C	Decomposed
4, R = H	**8**, $Eu(fod)_3$, toluene, 100 °C	Decomposed
5, R = Me	**8**, $Cu(OTf)_2$, toluene, 80 °C	Decomposed
6, R = Me	**8**, LDA, THF, –78 °C	No Desired
7, R = H	**S5**, AcOH, 65 °C	No Desired
8, R = H	**S6**, AcOH, 65 °C	No Desired

Table S4 Screening of conditions for intermolecular Stetter-Aldol cascade reaction.



34 (1.0 eq.) **35** (1.3 eq.) **36a** **36b** **36c** **S7**



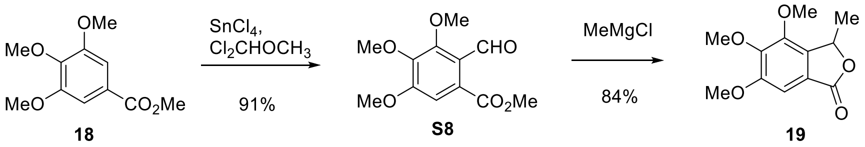
NHC-1 **NHC-2** **NHC-3** **NHC-4** **NHC-5** **NHC-6** **L5** **L6**

Entry	Conditions	Yield
1	**NHC-1**, Cs_2CO_3, DCM,	**36a**, 36%; **36b**, 12%; **36c**, 38%
2	**NHC-1**, K_2CO_3, DCM	No Reaction
3	**NHC-1**, Li_2CO_3, DCM	No Reaction
4	**NHC-1**, Cs_2CO_3, DMF	Decomposed
5	**NHC-1**, Cs_2CO_3, DMSO	Decomposed
6	**NHC-1**, Cs_2CO_3, DCE	No Reaction
7	**NHC-1,** DBU, LiBr, DCM	**36c**, 8%
8	**NHC-1,** DBU, THF	No Desired product
9	**NHC-1**, DIPEA, LiBr, DCM	No Reaction
10[a]	**NHC-1**, 1.0 equiv **L5**, DCM	**S7**, 23%
11	**NHC-2**, Cs_2CO_3, DCM	**36a**, 18%; **36b**, 12%; **36c**, 19%
12	**NHC-3**, Cs_2CO_3, DCM	No Desired product
13	**NHC-4**, Cs_2CO_3, DCM	No Reaction
14	**NHC-5**, Cs_2CO_3, DCM	No Desired product
15	**NHC-6**, Cs_2CO_3, DCM	No Reaction
16[b]	**NHC-1**, 30% mol **L6**, DCM	No Reaction

[a] the base was changed to **L5**; [b] the base was changed to **L6**.

3. Preparation of the hemiacetal (20) and methyl acetal (21)

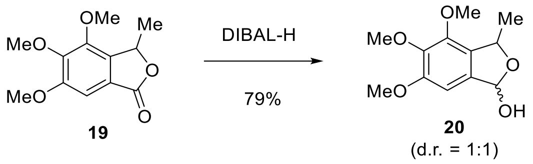
Compound **19**



According to the reported literature [1]: To a stirred solution of methyl 3,4,5-trimethoxybenzoate **18** (1.5 g, 6.6 mmol) in DCM (13.0 mL) was added 1,1-dichlorodimethyl ether (0.9 mL, 9.9 mmol) and $SnCl_4$ (7.9 mL, 7.9 mmol, 1.0 M in DCM) at 0 °C. The reaction mixture was then allowed to stir at room temperature for 3 h before it was quenched with saturated aq. $NaHCO_3$ (40 mL). The mixture so obtained was extracted with EtOAc (3 × 30 mL). The combined organic phases were washed with brine (2 × 20 mL), dried over anhydrous Na_2SO_4, filtered, and concentrated under vacuum. The residue was purified by flash column chromatography (silica gel, petroleum ether: EtOAc = 5:1) to give **S8** (1.5 g, 91%) as a colorless oil.

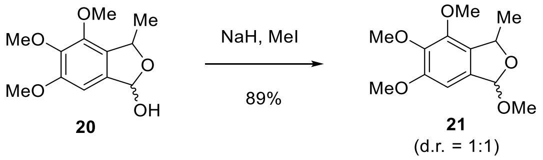
To a stirred solution of **S8** (1.2 g, 4.7 mmol) in THF (16.0 mL) was added methylmagnesium chloride (5.7 mL, 5.7 mmol, 1.0 M in THF) at 0 °C. The reaction mixture was then allowed to stir at 0 °C for 30 min before it was quenched with saturated aq. $NaHCO_3$ (20 mL). The mixture so obtained was extracted with EtOAc (3 × 30 mL). The combined organic phases were washed with brine (2 × 20 mL), dried over anhydrous Na_2SO_4, filtered, and concentrated under vacuum. The residue was purified by flash column chromatography (silica gel, petroleum ether: EtOAc = 6:1) to give **19** (950.0 mg, 84%) as a pink oil. **19**: $R_f = 0.55$ (silica, petroleum ether: EtOAc = 6:1); IR (film): ν_{max} = 2982, 2935, 1760, 1478, 1419, 1339, 1118, 1073, 852 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) : δ = 7.00 (s, 1H), 5.41 (q, J = 6.6 Hz, 1H), 3.90 (s, 3H), 3.85 (s, 3H), 3.82 (s, 3H), 1.53 (d, J = 6.6 Hz, 3H) ppm; ^{13}C NMR (101 MHz, $CDCl_3$) : δ = 170.13, 155.49, 147.48, 146.71, 136.54, 120.87, 102.36, 76.28, 60.97, 60.75, 56.29, 19.59 ppm; HRMS (m/z): $[M + Na]^+$ calcd for $C_{12}H_{14}O_5Na^+$ 261.0733, found 261.0741.

Compound **20**



To a stirred solution of **19** (800.0 mg, 3.4 mmol) in DCM (14.0 mL) was added diisobutylaluminium hydride (3.4 mL, 3.4 mmol, 1.0 M in hexanes) at −78 °C. The reaction mixture was then allowed to stir at −78 °C for 30 min before it was quenched with saturated aq. potassium sodium tartrate (30 mL). The mixture so obtained was extracted with EtOAc (3 × 30 mL). The combined organic phases were washed with brine (2 × 20 mL), dried over anhydrous Na_2SO_4, filtered, and concentrated under vacuum. The residue was purified by flash column chromatography (silica gel, petroleum ether: EtOAc = 3:1) to give **20** (640 mg, 79%) as a colorless oil. **20**: $R_f = 0.3$ (silica, petroleum ether: EtOAc = 3:1); IR (film): ν_{max} = 3379, 2975, 2937, 1610, 1474, 1415, 1349, 1127, 831 cm^{-1}; ^{1}H NMR (400 MHz, Acetone-d_6) : δ = 6.75 (s, 1H), 6.73 (s, 1H), 6.30 (dd, *J* = 7.9, 2.1 Hz, 1H), 6.19 (d, *J* = 8.0 Hz, 1H), 5.51 (d, *J* = 8.0 Hz, 1H), 5.43 (d, *J* = 8.0 Hz, 1H), 5.37 (qd, *J* = 6.3, 2.2 Hz, 1H), 5.15 (q, *J* = 6.4 Hz, 1H), 3.89 (s, 3H), 3.87 (s, 3H), 3.85 (s, 6H), 3.79 (s, 6H), 1.48 (d, *J* = 6.4 Hz, 3H), 1.40 (d, *J* = 6.4 Hz, 3H) ppm; ^{13}C NMR (101 MHz, Acetone-d_6) : δ = 155.46, 155.40, 148.40, 148.27, 143.15, 143.12, 136.88, 136.51, 129.25, 129.15, 102.50, 102.47, 101.73, 101.27, 78.55, 77.97, 60.92, 60.87, 60.86, 56.50, 23.58, 21.74 ppm; HRMS (m/z): [M + Na]$^+$ calcd for $C_{12}H_{16}O_5Na^+$ 263.0890, found 263.0886.

Compound **21**

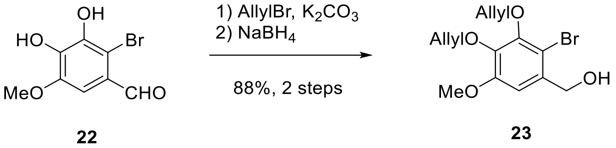


To a stirred solution of **20** (460.0 mg, 1.9 mmol) in THF (9.6 mL) was added NaH (191.0 mg, 4.8 mmol, 60% dispersion in mineral oil) and CH_3I (360.0 μL, 5.7 mmol) at 0 °C. The reaction mixture was then allowed to stir at 30 °C for 1 h before it was quenched with saturated aq. $NaHCO_3$ (10 mL). The mixture so obtained was extracted with EtOAc (3 × 30 mL). The combined organic phases were washed with brine (2 ×

20 mL), dried over anhydrous Na_2SO_4, filtered, and concentrated under vacuum. The residue was purified by flash column chromatography (silica gel, petroleum ether: EtOAc = 8:1) to give **21** (435.0 mg, 89%) as a colorless oil. **21**: R_f = 0.6 (silica, petroleum ether: EtOAc = 7:1); IR (film): ν_{max} = 3425, 2974, 2935, 1610, 1473, 1370, 1348, 1128, 835 cm^{-1}; ^{1}H NMR (400 MHz, Acetone-d_6) : δ = 6.73 (s, 1H), 6.72 (s, 1H), 6.02 (d, J = 2.2 Hz, 1H), 5.91 (s, 1H), 5.37 (qd, J = 6.3, 2.2 Hz, 1H), 5.22 (q, J = 6.4 Hz, 1H), 3.90 (s, 3H), 3.89 (s, 3H), 3.85 (s, 6H), 3.80 (s, 6H), 3.35 (s, 3H), 3.29 (s, 3H), 1.47 (d, J = 6.4 Hz, 3H), 1.44 (d, J = 6.4 Hz, 3H) ppm; ^{13}C NMR (101 MHz, Acetone-d_6) : δ = 155.56, 155.53, 148.53, 148.34, 143.49, 143.37, 134.29, 134.08, 129.71, 129.65, 107.87, 107.28, 102.60, 102.54, 79.13, 79.08, 60.98, 60.90, 56.52, 54.06, 53.79, 23.12, 21.68 ppm; HRMS (m/z): [M + Na]$^+$ calcd for $C_{13}H_{18}O_5Na^+$ 277.1046, found 277.1044.

4. Preparation of the benzaldehyde (14a)

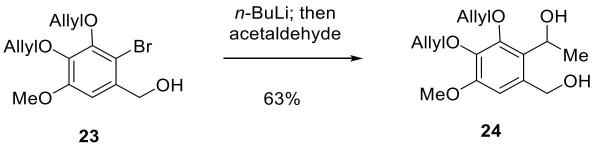
Compound **23**



To a stirred suspension of **22**[2] (4.5 g, 18.2 mmol) and K_2CO_3 (8.8 g, 63.8 mmol) in DMF (60.0 mL) was added allyl bromide (4.7 mL, 54.7 mmol) at 0 °C. The resultant mixture was allowed to stir at 25 °C for 40 min before it was quenched with saturated aq. $NaHCO_3$ (100 mL). The mixture so obtained was extracted with EtOAc (3 × 100 mL). The combined organic phases were washed with brine (3 × 80 mL), dried over anhydrous Na_2SO_4, filtered, and concentrated under vacuum. The residue was used directly in the next step without further purification.

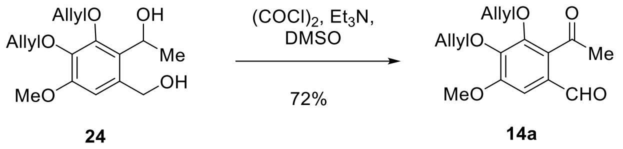
To a stirred solution of the residue in MeOH/THF (60.0 mL, 1:1) was added $NaBH_4$ (1.3 g, 34.6 mmol) at 0 °C. The resultant mixture was allowed to stirred at 0 °C for 15 minutes before it quenched with saturated aq. $NaHCO_3$ (100 mL). The mixture so obtained was extracted with EtOAc (3 × 100 mL). The combined organic phases were washed with brine (100 mL), dried over anhydrous Na_2SO_4, filtered, and concentrated under vacuum. The residue was purified by flash column chromatography (silica gel, petroleum ether: EtOAc = 4:1) to give **23** (5.3 g, 88% over 2 steps) as a colorless oil. **23**: $R_f = 0.25$ (silica, petroleum ether: EtOAc = 4:1); IR (film): $\nu_{max} = 3428$, 2952, 2934, 1568, 1474, 1326, 1226, 1109, 924 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) : δ = 6.87 (s, 1H), 6.18 – 5.98 (m, 2H), 5.44 – 5.27 (m, 2H), 5.22 (ddd, *J* = 11.9, 10.3, 1.4 Hz, 2H), 4.68 (s, 2H), 4.57 (d, *J* = 6.0 Hz, 2H), 4.51 (d, *J* = 6.0 Hz, 2H), 3.84 (s, 3H) ppm; ^{13}C NMR (101 MHz, $CDCl_3$) : δ = 153.18, 149.91, 141.12, 135.59, 134.00, 133.77, 118.38, 118.10, 108.72, 107.67, 74.60, 74.49, 65.18, 56.23 ppm; HRMS (m/z): $[M + Na]^+$ calcd for $C_{14}H_{17}BrO_4Na^+$ 351.0202, found 351.0204.

Compound **24**



To a stirred solution of **23** (4.0 g, 12.2 mmol) in Et_2O (60.0 mL) was added *n*-BuLi (10.6 mL, 2.4 M in hexane, 25.4 mmol) at −78 °C. The reaction mixture was allowed to stir at −78 °C for 30 min before acetaldehyde (12.2 mL, 3.0 M in THF, 36.6 mmol) was added. The resultant mixture was further stirred for 30 min at −78 °C before it was quenched with saturated aq. $NaHCO_3$ (80 mL). The mixture so obtained was extracted with EtOAc (3 × 90 mL). The combined organic phases were washed with brine (80 mL), dried over anhydrous Na_2SO_4, and filtered. The solvent was evaporated under vacuum, and the residue was purified by flash column chromatography (silica gel, petroleum ether: EtOAc = 3:1) to give **24** (2.3 g, 63%) as a colorless oil. **24**: $R_f = 0.25$ (silica, petroleum ether: EtOAc = 3:1); IR (film): $\nu_{max} = 3385$, 3081, 2968, 2933, 1598, 1492, 1319, 1223, 1130, 995 cm^{-1}; ^1H NMR (400 MHz, Acetone-d_6) : δ = 6.88 (s, 1H), 6.19 – 6.02 (m, 2H), 5.45 – 5.30 (m, 3H), 5.19 (ddd, *J* = 20.3, 10.5, 1.6 Hz, 2H), 4.87 (dd, *J* = 12.8, 5.1 Hz, 1H), 4.65 – 4.53 (m, 3H), 4.51 (d, *J* = 5.6 Hz, 1H), 4.49 (dt, *J* = 5.6, 1.5 Hz, 2H), 4.40 (dd, *J* = 6.9, 5.1 Hz, 1H), 3.82 (s, 3H), 1.48 (d, *J* = 6.7 Hz, 3H) ppm; ^{13}C NMR (101 MHz, Acetone-d_6) : δ = 152.82, 150.89, 140.77, 136.42, 135.78, 135.54, 130.39, 117.10, 116.92, 110.05, 74.96, 74.24, 65.26, 63.37, 56.17, 24.68 ppm; HRMS (m/z): $[M+Na]^+$ calcd for $C_{16}H_{22}O_5Na^+$ 317.1359, found 317.1359.

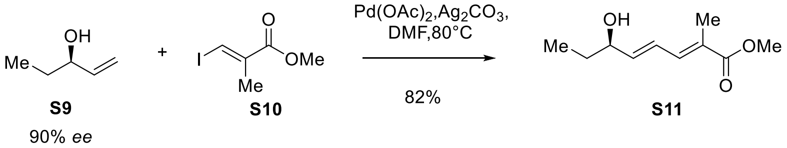
Compound **14a**



To a stirred solution of oxalyl chloride (2.7 g, 21.3 mmol) in DCM (43.0 mL) was added DMSO (3.0 mL, 42.8 mmol) at − 78 °C. The reaction mixture was allowed to stir at − 78 °C for 30 min before a solution of **24** (6.8 mL, 0.9 M in DCM, 1.8 g, 6.1 mmol) was added. The reaction mixture was allowed to stir at − 78 °C for another 30 min before Et$_3$N (6.8 mL, 48.9 mmol) was added. The reaction mixture was allowed to stir at − 40 °C for 30 min before it was quenched with saturated aq. NaHCO$_3$ (80 mL). The mixture so obtained was extracted with DCM (3 × 90 mL). The combined organic phases were washed with brine (100 mL), dried over anhydrous Na$_2$SO$_4$, and filtered. The solvent was evaporated under vacuum, and the residue was purified by flash column chromatography (silica gel, petroleum ether: EtOAc = 5:1) to give **14a** (1.3 g, 72%) as a yellow oil. **14a**: R_f = 0.45 (silica, petroleum ether: EtOAc = 4:1); IR (film): ν_{max} = 3084, 2942, 1693, 1585, 1462, 1324, 1264, 1154, 992 cm^{-1}; ^{1}H NMR (400 MHz, Acetone-d_6) : δ = 9.82 (s, 1H), 7.40 (s, 1H), 6.19 – 5.91 (m, 2H), 5.44 – 5.32 (m, 2H), 5.25 – 5.19 (m, 2H), 4.68 (dt, J = 5.7, 1.4 Hz, 2H), 4.60 (dt, J = 5.7, 1.4 Hz, 2H), 3.98 (s, 3H), 2.48 (s, 3H) ppm; ^{13}C NMR (101 MHz, Acetone-d_6) : δ = 201.55, 190.95, 155.24, 150.08, 146.47, 134.90, 134.66, 132.40, 130.02, 118.09, 118.01, 111.31, 75.69, 74.66, 56.72, 32.29 ppm; HRMS (m/z): [M + Na]$^+$ calcd for C$_{16}$H$_{18}$O$_5$Na$^+$ 313.1046, found 313.1048.

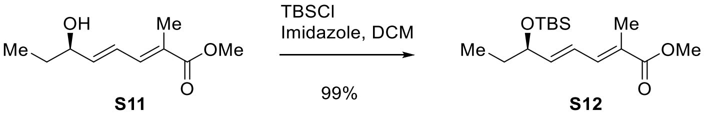
5. Bioinspired synthesis of gregatin A (8)

Compound **S11**



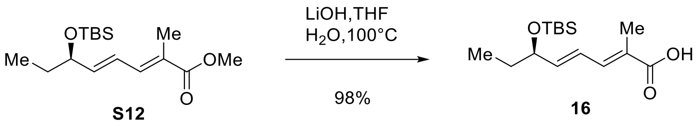
To a solution of **S10**[3] (20.0 g, 88.5 mmol) in anhydrous DMF (176.0 mL) was added **S9**[4] (8.4 g, 97.3 mmol), Pd(OAc)$_2$ (397.3 mg, 1.8 mmol) and Ag$_2$CO$_3$ (36.6 g, 132.7 mmol). The reaction mixture was stirred vigorously at 80 ℃. Upon full conversion of the **S10** (monitored by TLC), the reaction mixture was quenched with saturated aq. NH_4Cl (90 mL) and extracted with EtOAc (3 × 100 mL). The combined extracts were washed with brine (150 mL), and dried over anhydrous Na_2SO_4. The solvent was evaporated under vacuum, and the residue was purified by flash column chromatography (silica gel, petroleum ether: EtOAc = 5:1) to give **S11** (13.4 g, 82%) as colorless oil. **S11**: R_f = 0.2 (silica, petroleum ether: EtOAc = 5:1), $[\alpha]_D^{20}$ = + 31.0 (c = 1.0, $CHCl_3$); IR (film): ν_{max} = 3431, 2957, 2933, 1720, 1632, 1423, 1261, 1046, 979 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) : δ = 7.16 (d, *J* = 11.4 Hz, 1H), 6.52 (ddd, *J* = 15.2, 11.4, 1.4 Hz, 1H), 6.04 (dd, *J* = 15.2, 6.1 Hz, 1H), 4.17 (q, *J* = 6.2 Hz, 1H), 3.73 (s, 3H), 1.93 (d, *J* = 1.6 Hz, 3H), 1.59 (p, *J* = 7.4 Hz, 2H), 0.93 (t, *J* = 7.4 Hz, 3H) ppm; ^{13}C NMR (101 MHz, $CDCl_3$) : δ = 169.03 , 143.59 , 137.87 , 127.14 , 125.21 , 73.61 , 51.97 , 30.14 , 12.77 , 9.69 ppm; HRMS (m/z): $[M+Na]^+$ calcd for $C_{10}H_{16}O_3Na^+$ 207.0992; found: 207.0990.

Compound **S12**



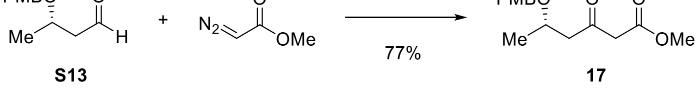
To a solution of **S11** (3.0 g, 16.3 mmol) in anhydrous DCM (32.0 mL) was added imidazole (2.2 g, 32.6 mmol) and TBSCl (4.9 g, 32.6 mmol) at 0 ℃. The reaction mixture was stirred vigorously at room temperature. Upon completion of the reaction (monitored by TLC), the reaction mixture was quenched with saturated aq. $NaHCO_3$ (60 mL) and extracted with EtOAc (3 × 70 mL). The combined extracts were washed with brine (100 mL), and dried over anhydrous Na_2SO_4. The solvent was evaporated under vacuum, and the residue was purified by flash column chromatography (silica gel, petroleum ether: EtOAc = 20:1) to give **S12** (4.8 g, 99%) as colorless oil. **S12**: R_f = 0.4 (silica, petroleum ether: EtOAc = 20:1), $[\alpha]_D^{20}$ = + 48.0 (c = 1.0, $CHCl_3$); IR (film): ν_{max} = 3426, 2956, 2931, 1714, 1641, 1436, 1256, 1108, 836, cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) : δ = 7.18 (d, *J* = 11.5 Hz, 1H), 6.50 (ddd, *J* = 15.1, 11.5, 1.5 Hz, 1H), 6.04 (dd, *J* = 15.0, 5.3 Hz, 1H), 4.19 (q, *J* = 5.4 Hz, 1H), 3.75 (s, 3H), 1.94 (d, *J* = 1.4 Hz, 3H), 1.58 – 1.48 (m, 2H),, 0.91 (s, 9H), 0.88 (t, *J* = 7.4 Hz, 3H), 0.06 (s, 3H), 0.03 (s, 3H) ppm; ^{13}C NMR (101 MHz, $CDCl_3$) : δ = 169.13, 144.78, 138.19, 126.43, 124.35, 73.90, 51.94, 30.98, 25.99, 18.40, 12.74, 9.63, -4.35, -4.66 ppm; HRMS (m/z): $[M+Na]^+$ calcd for $C_{16}H_{30}O_3SiNa^+$ 321.1856; found: 321.1857.

Compound **16**



To a stirred solution of **S12** (4.8 g, 16.0 mmol) in THF/H_2O (32.0 mL, 1:1) was added LiOH (2.3 g, 96.5 mmol). The reaction mixture was stirred vigorously at 100 °C. Upon completion of the reaction (monitored by TLC), the reaction mixture was cooled to room temperature and quenched with 1.0 M aq. HCl (50 mL). The mixture was then extracted with EtOAc (3 × 100 mL). The combined extracts were washed with brine (80 mL), and dried over anhydrous Na_2SO_4. The solvent was evaporated under vacuum, and the residue was purified by flash column chromatography (silica gel, petroleum ether: EtOAc = 10:1) to give **16** (4.5 g, 98%) as a white solid. **16**: R_f = 0.3 (silica, petroleum ether: EtOAc = 5:1), $[\alpha]_D^{20}$ = + 15.0 (c = 1.0, $CHCl_3$); IR (film): ν_{max} = 3424, 2958, 2931, 1683, 1463, 1421, 1256, 1113, 836 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$) : δ = 7.31 (d, *J* = 11.5 Hz, 1H), 6.54 (ddd, *J* = 15.1, 11.5, 1.5 Hz, 1H), 6.11 (dd, *J* = 15.1, 5.2 Hz, 1H), 4.21 (q, *J* = 5.8 Hz, 1H), 1.95 (s, 3H), 1.55 (p, *J* = 7.2 Hz, 2H), 0.92 (s, 9H), 0.94 – 0.86 (m, 3H), 0.07 (s, 3H), 0.04 (s, 3H) ppm; ^{13}C NMR (101 MHz, $CDCl_3$) : δ = 174.11, 146.00, 140.31, 125.75, 124.29, 73.80, 30.92, 25.99, 25.78, 18.41, 12.35, 9.61, -3.46, -4.36, -4.66 ppm; HRMS (m/z): $[M+Na]^+$ calcd for $C_{15}H_{28}O_3SiNa^+$ 307.1700; found: 307.1702.

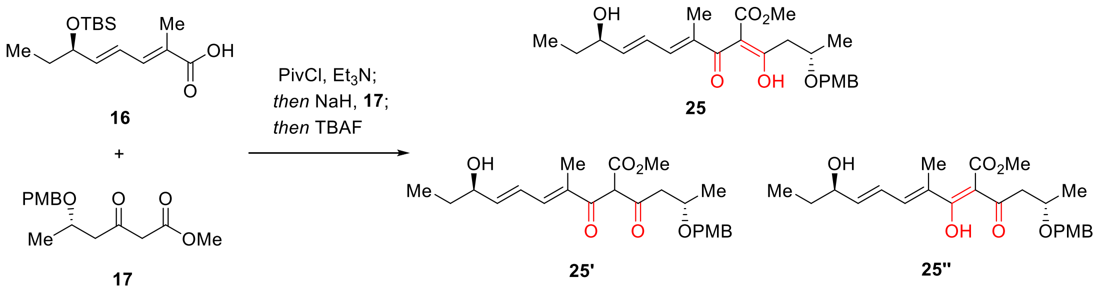
Compound **17**



To a stirred solution of methyl diazoacetate[5] (1.9 g, 19.2 mmol) in DCM (10.0 mL) was added $SnCl_2$ (182.0 mg, 960.0 μmol) at 0°C. After the mixture no longer generated gas, **S13**[6] (2.0 g, 9.6 mmol) in DCM (10.0 mL) was added at 0 °C and the mixture was allowed to stir at room temperature for 6 h before it was quenched with

H_2O (10 mL). The mixture was then extracted with EtOAc (3 × 30 mL). The combined extracts were washed with brine (40 mL), and dried over anhydrous Na_2SO_4. The solvent was evaporated under vacuum, and the residue was purified by flash column chromatography (silica gel, petroleum ether: EtOAc = 5:1) to give **17** (2.1 g, 77%) as a colorless oil. **17**: $R_f = 0.4$ (silica, petroleum ether: EtOAc = 5:1); $[\alpha]_D^{20} = +61.4$ ($c = 0.4$ in $CHCl_3$); IR (film): ν_{max} = 2969, 2934, 1749, 1717, 1613, 1514, 1438, 1248, 1033, 822 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) : δ = 7.23 (d, J = 8.6 Hz, 2H), 6.86 (d, J = 8.7 Hz, 2H), 4.49 (d, J = 11.0 Hz, 1H), 4.37 (d, J = 11.0 Hz, 1H), 4.08 – 3.95 (m, 1H), 3.80 (s, 3H), 3.72 (s, 3H), 3.48 (s, 2H), 2.84 (dd, J = 15.9, 7.6 Hz, 1H), 2.59 (dd, J = 15.8, 4.9 Hz, 1H), 1.23 (d, J = 6.2 Hz, 3H) ppm; ^{13}C NMR (101 MHz, $CDCl_3$) : δ = 201.68, 167.69, 159.33, 130.49, 129.49, 113.93, 71.32, 70.71, 55.42, 52.44, 50.19, 19.88 ppm; HRMS (m/z): $[M+Na]^+$ calcd for $C_{15}H_{20}O_5Na^+$ 303.1203 found 303.1206.

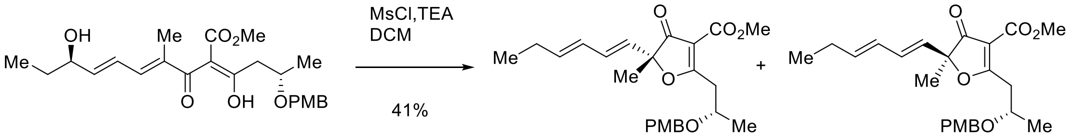
Compound **25**



To a stirred solution of **16** (200.0 mg, 0.7 mmol) in DCM (3.5 mL) was added Et_3N (195.0 μL, 1.4 mmol) and pivaloyl chloride (173.0 μL, 1.4 mmol) at 0 °C. the mixture was allowed to stir at room temperature for 1 h before it was quenched with saturated aq. NaCl (10 mL). The combined extracts were washed with brine (3 mL), and dried over anhydrous Na_2SO_4. The solvent was evaporated under vacuum, and the residue was used directly for the next step.

To a stirred solution of **17** (310 mg, 1.1 mmol) in THF (3.7 mL) was added NaH (56.2 mg, 1.4 mmol, 60% dispersion in mineral oil), and then the residue in THF (2.0 mL) was added slowly. The reaction mixture was stirred vigorously at room temperature for 2 h. And then TBAF (7.0 mL, 7.0 mmol, 1.0 M in THF) was added. The reaction mixture was further stirred at 40 °C for 50 min before it was quenched with saturated aq. NH_4Cl (10 mL). The mixture was then extracted with EtOAc (3 × 15 mL). The combined extracts were washed with brine (20 mL), and dried over anhydrous Na_2SO_4. The solvent was evaporated under vacuum, and the residue was purified by flash column chromatography (silica gel, petroleum ether: EtOAc = 5:1 → 3:1) to give **25** (a mixture of three isomer) (168.0 mg, 55%) as colorless oil. **25**: $R_f = 0.3$ (silica, petroleum ether: EtOAc = 4:1). ^{1}H NMR (400 MHz, $CDCl_3$) : δ = 7.33 – 7.14 (m, 2H), 6.97 – 6.78 (m, 3H), 6.65 – 6.41 (m, 1H), 6.12 – 5.77 (m, 1H), 4.54 – 4.30 (m, 2H), 4.24 – 4.10 (m, 1H), 4.06 – 3.91 (m, 1H), 3.85 – 3.60 (m, 6H), 3.10 – 2.65 (m, 1H), 2.60 – 2.20 (m, 1H), 1.99 – 1.86 (m, 3H), 1.69 – 1.49 (m, 2H), 1.30 – 1.13 (m, 3H), 1.03 – 0.87 (m, 3H) ppm; ^{13}C NMR (101 MHz, $CDCl_3$) : δ = 200.17, 199.85, 195.27, 193.43, 193.15, 191.83, 175.88, 175.84, 171.41, 168.49, 166.28, 166.24, 159.03, 146.41, 144.81, 144.74, 142.56, 141.17, 141.08, 140.69, 140.35, 137.79, 137.71, 135.55, 134.23, 133.60, 130.74, 130.61, 130.44, 129.41, 129.25, 129.17, 129.15, 125.62, 125.46, 125.07, 124.84, 113.80, 113.75, 113.70, 108.38, 105.30, 73.46, 73.39, 72.23, 72.13, 71.92, 71.04, 70.48, 70.44, 70.39, 70.31, 55.26, 52.89, 52.03, 49.09, 43.45, 40.42, 40.38, 30.11, 29.99, 29.97, 20.12, 19.93, 19.92, 19.62, 13.48, 11.77, 11.66, 9.63, 9.60 ppm; HRMS (m/z): $[M+Na]^+$ calcd for $C_{24}H_{32}O_7Na^+$ 455.2040 found 455.2042.

Compound **26** and *epi*-**26**



25 **26** *epi*-**26**

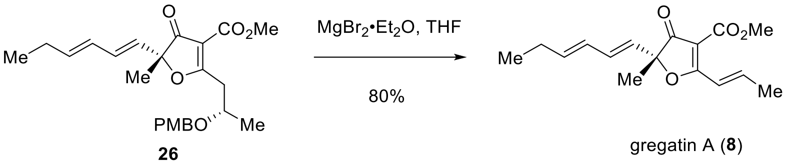
To a stirred solution of **25** (87.0 mg, 0.2 mmol) in DCM (1.7 mL) was added Et_3N (140.0 μL, 1.0 mmol) and MsCl (78.0 μL, 1.0 mmol) at 0 °C. The mixture was allowed to stir at room temperature for 40 min before it was quenched with saturated aq. $NaHCO_3$ (10 mL). The mixture was extracted with EtOAc (3 × 15 mL). The combined extracts were washed with brine (6 mL), and dried over anhydrous Na_2SO_4. The solvent was evaporated under vacuum, and the residue was purified by flash column chromatography (silica gel, petroleum ether: EtOAc = 5:1) to give **26** and *epi*-**26** (d.r. = 2:1) (34.0 mg, 41%) as colorless oil. $R_f = 0.4$ (silica, petroleum ether: EtOAc = 5:1);

26: ^{1}H NMR (400 MHz, $CDCl_3$) : δ = 7.19 (d, $J = 8.6$ Hz, 2H), 6.83 (d, $J = 8.7$ Hz, 2H), 6.27 (dd, *J* = 15.5, 3.5 Hz, 1H), 5.93 (dd, *J* = 15.1, 10.7 Hz, 1H), 5.76 – 5.67 (m, 1H), 5.49 (d, *J* = 15.5 Hz, 1H), 4.51 (d, *J* = 11.3 Hz, 1H), 4.43 (d, *J* = 10.8 Hz, 1H), 4.07 (dt, *J* = 13.5, 7.3 Hz, 1H), 3.79 (s, 6H), 3.32 (d, *J* = 7.5 Hz, 1H), 3.15 – 3.08 (m, 1H), 2.07 (p, *J* = 7.1 Hz, 2H), 1.49 (s, 3H), 1.30 (d, *J* = 6.1 Hz, 3H), 0.97 (t, *J* = 7.4 Hz, 3H) ppm; ^{13}C NMR (101 MHz, $CDCl_3$) : δ = 198.24, 196.21, 163.37, 159.31, 139.60, 132.13, 130.34, 129.36, 127.78, 125.48, 113.89, 107.18, 91.60, 72.15, 70.43, 55.39, 51.69, 38.66, 25.81, 22.57, 20.29, 13.38 ppm;

epi-**26**: ^{1}H NMR (400 MHz, $CDCl_3$) : δ = 7.21 (d, *J* = 3.9 Hz, 2H), 6.84 (d, *J* = 8.6 Hz, 2H), 6.30 (dd, *J* = 10.5, 3.6 Hz, 1H), 5.93 (dd, *J* = 15.1, 10.5 Hz, 1H), 5.80 – 5.72 (m, 1H), 5.50 (d, *J* = 15.5 Hz, 1H), 4.51 (d, *J* = 11.1 Hz, 1H), 4.43 (d, *J* = 10.8 Hz, 1H), 4.07 (dt, *J* = 13.5, 7.3 Hz, 1H), 3.81 (s, 3H), 3.80 (s, 3H), 3.37 (dd, *J* = 13.8, 7.5 Hz, 1H), 3.18 – 3.10 (m, 1H), 2.07 (p, *J* = 7.1 Hz, 2H), 1.49 (s, 3H), 1.31 (d, *J* = 6.1 Hz, 3H), 0.97 (t, *J* = 7.4 Hz, 3H) ppm; ^{13}C NMR (101 MHz, $CDCl_3$) : δ = 198.27, 196.14, 163.40, 159.31, 139.65, 132.20, 130.38, 129.30, 127.83, 125.48, 113.89, 107.28, 91.64, 72.46, 70.53, 55.39, 51.71, 38.49, 25.81, 22.57, 20.35, 13.39 ppm;

HRMS (m/z): $[M+Na]^+$ calcd for $C_{24}H_{30}O_6Na^+$ 437.1935 found 437.1939.

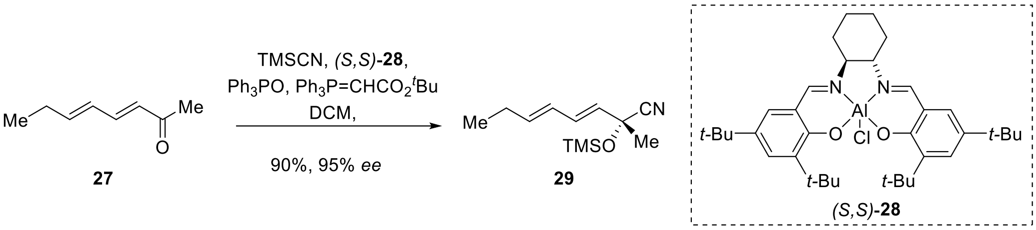
Gregatin (**8**)



To a stirred solution of **26** (30.0 mg, 72.4 μmol) in THF (360.0 μL) was added $MgBr_2·Et_2O$ (16.8 mg, 65.1 μmol) at 0 °C. The mixture was allowed to stir at 0 °C for 1 h before it was quenched with saturated aq. $NaHCO_3$ (2 mL). The mixture was extracted with EtOAc (3 × 2 mL). The combined extracts were washed with brine (3 mL), and dried over anhydrous Na_2SO_4. The solvent was evaporated under vacuum, and the residue was purified by flash column chromatography (silica gel, petroleum ether: EtOAc = 5:1) to give gregatin A (**8**) (15.9 mg, 80%) as a colorless oil.

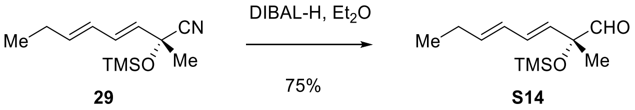
6. Asymmetric synthesis of gregatin A (8)

Compound **29**



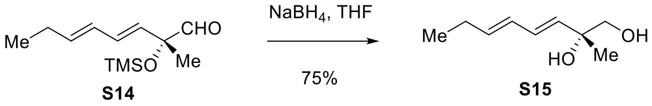
To a 100 mL round-bottomed flask was added ketone **27**[7] (2.0 g, 16.1 mmol), anhydrous DCM (16.0 mL), (salen)AlCl (*S*,*S*)-**28**[8] (0.5 g, 0.8 mmol), tert-butyl(triphenylphosphoranylidene)acetate (1.0 g, 2.6 mmol) and Ph_3PO (2.2 g, 8.1 mmol). The resultant solution was stirred at –30 °C for 30 min before TMSCN (4.0 mL, 32.2 mmol) was added. Upon full consumption of the **27** (monitored by NMR), the mixture was directly purified by flash column chromatograph (silica gel, from petroleum ether to petroleum ether: diethyl ether = 30:1) to give product **29** (3.2 g, 90%, 95% ee as measured by **S15**) as colorless oil **29**: $R_f = 0.7$ (silica, petroleum ether: EtOAc = 50:1) ; $[\alpha]_D^{20} = +3.17$ ($c = 0.5$ in $CHCl_3$); IR (film): ν_{max} = 2960, 2924, 1632, 1541, 1457, 1383, 1256, 1111, 849 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) : δ = 6.47 (dd, J = 15.3, 10.1 Hz, 1H), 6.01 (dd, J = 15.2, 10.2 Hz, 1H), 5.90 (dt, J = 15.2, 6.3 Hz, 1H), 5.51 (d, J = 15.3 Hz, 1H), 2.13 (q, J = 7.1 Hz, 2H), 1.65 (s, 3H), 1.02 (t, J = 7.5 Hz, 3H), 0.20 (s, 9H) ppm; ^{13}C NMR (101 MHz, $CDCl_3$) : δ = 140.29, 131.67, 130.35, 127.09, 120.95, 69.82, 30.95, 25.85, 13.34, 1.50 ppm; HRMS (m/z): $[M+H]^+$ calcd for $C_{12}H_{22}NOSi^+$ 224.1465 found 224.1470.

Compound **S14**

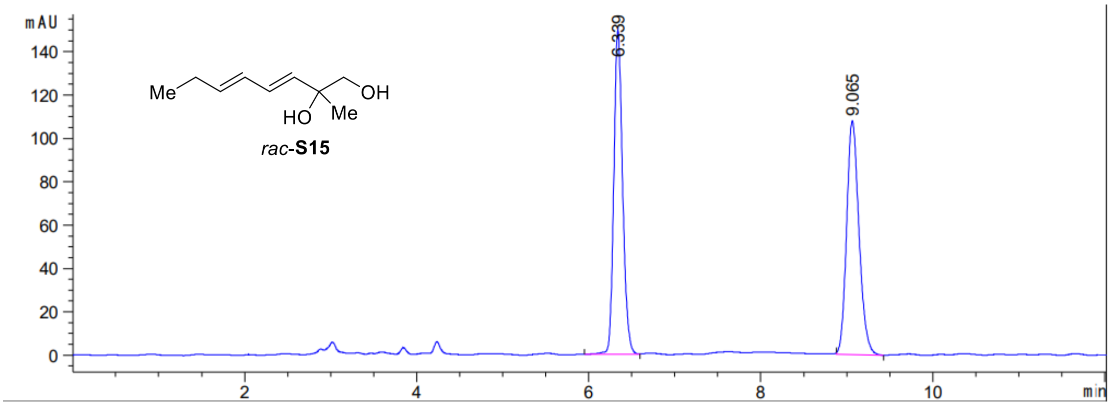


To a stirred solution of **29** (3.0 g, 13.4 mmol) in anhydrous Et_2O (45.0 mL) was added DIBAL-H (26.8 mL, 26.8 mmol, 1.0 mol/L in hexanes) at – 30 °C. The mixture was allowed to stir at –30 °C for 30 min before it was quenched with saturated aq. potassium sodium tartrate (80 mL). The resultant mixture was further stirred at room temperature for 2 h. And then the mixture was extracted with EtOAc (3 × 100 mL). The combined extracts were washed with 1.0 M aq. HCl (100 mL) and brine (150 mL), and dried over anhydrous Na_2SO_4. The solvent was evaporated under vacuum, and the residue was purified by flash column chromatography quickly (silica gel, petroleum ether: EtOAc = 25:1) to give **S14** (2.3 g, 75%) as colorless oil. **S14**: R_f = 0.9 (silica, petroleum ether: EtOAc = 20:1); $[\alpha]_D^{20}$ = + 5.32 (c = 0.5 in $CHCl_3$); IR (film): ν_{max} = 2970, 2936, 1714, 1677, 1460, 1363, 1258, 1096, 979 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$) : δ = 9.33 (s, 1H), 6.29 (dd, J = 15.3, 10.5 Hz, 1H), 6.03 (dd, J = 15.1, 10.6 Hz, 1H), 5.81 (dt, J = 15.1, 6.5 Hz, 1H), 5.42 (d, J = 15.3 Hz, 1H), 2.11 (p, J = 6.9, 6.5 Hz, 2H), 1.42 (s, 3H), 1.01 (t, J = 7.5 Hz, 3H), 0.16 (s, 9H) ppm; ^{13}C NMR (101 MHz, $CDCl_3$) : δ = 200.25, 138.60, 132.84, 129.99, 128.28, 80.93, 25.82, 22.87, 13.46, 2.36 ppm; HRMS (m/z): $[M+Na]^+$ calcd for $C_{12}H_{22}O_2SiNa^+$ 249.1281 found 249.1283.

Compound **S15**



To a solution of **S14** (115.0 mg, 0.5 mmol) in anhydrous THF (2.5 mL) was added $NaBH_4$ (38.0 mg, 1.0 mmol) and tetrabutylammonium fluoride trihydrate (284.0 mg, 1.0 mmol). The reaction mixture was stirred vigorously at room temperature. Upon completion of the reaction (monitored by TLC), the reaction mixture was quenched with saturated aq. NH_4Cl (5 mL). The mixture was then extracted with EtOAc (3 × 10 mL). The combined extracts were washed with brine (15 mL), and dried over anhydrous Na_2SO_4. The solvent was evaporated under vacuum, and the residue was purified by flash column chromatography (silica gel, petroleum ether: EtOAc = 2:1) to give diol **S15** (59.6 mg, 75%) as a colorless oil; HPLC analysis (Chiralcel AD, *i*PrOH/hexane = 3.5/96.5, 1.0 mL/min, 210 nm; t_R (major) = 9.17 min, t_R (minor) = 6.38 min) gave the isomeric composition of the product: 95% ee, $[\alpha]_D^{20}$ = + 2.6 (c = 1.0, $CHCl_3$); IR (film): ν_{max} = 3398, 2966, 2931, 1659, 1458, 1376, 1260, 1046, 990 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$) : δ = 6.24 (dd, J = 15.5, 10.4 Hz, 1H), 6.00 (dd, J = 15.0, 10.5 Hz, 1H), 5.73 (dt, J = 15.1, 6.5 Hz, 1H), 5.57 (d, J = 15.5 Hz, 1H), 3.45 (d, J = 11.1 Hz, 1H), 3.38 (d, J = 11.1 Hz, 1H), 3.08 (brs, 2H), 2.07 (p, J = 7.4 Hz, 2H), 1.24 (s, 3H), 0.98 (t, J = 7.5 Hz, 3H) ppm; ^{13}C NMR (101 MHz, $CDCl_3$) : δ = 137.07, 134.36, 129.90, 128.60, 73.42, 69.91, 25.70, 24.24, 13.50 ppm; HRMS (m/z): $[M+Na]^+$ calcd for $C_9H_{16}O_2Na^+$ 179.1043; found: 179.1044.



信号 1: VWD1 A, Wavelength=210 nm

峰 #	保留时间 [min]	类型	峰宽 [min]	峰面积 [mAU*s]	峰高 [mAU]	峰面积 %
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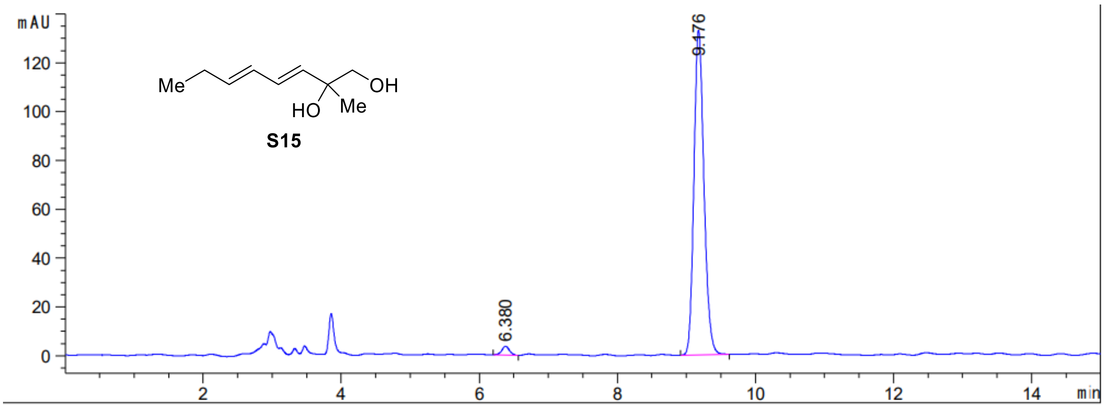
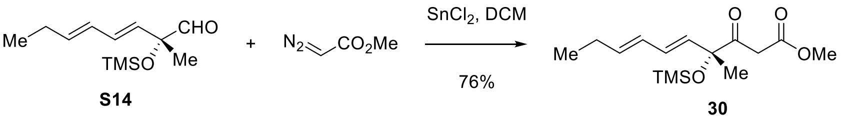
2	9.065	HB	0.1543	1076.26758	107.91991	50.2458



信号 1: VWD1 A, Wavelength=210 nm

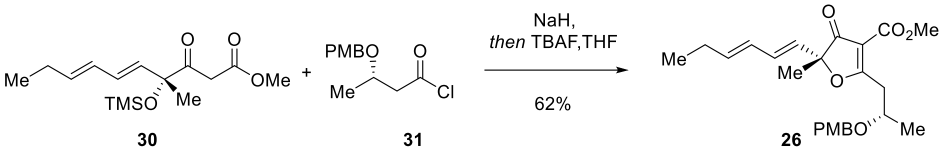
峰 #	保留时间 [min]	类型	峰宽 [min]	峰面积 [mAU*s]	峰高 [mAU]	峰面积 %
1	6.380	HB	0.1183	28.35985	3.66539	2.0701
2	9.176	HBA	0.1557	1341.63293	133.03761	97.9299

Compound **30**



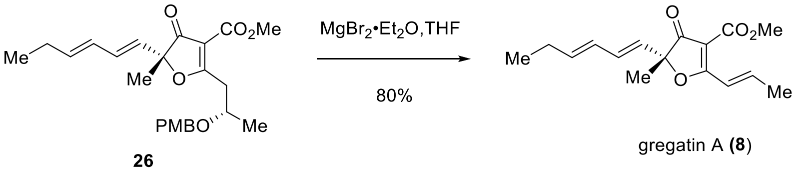
To a stirred solution of methyl diazoacetate (1.77 g, 17.7 mmol) in DCM (10.0 mL) was added $SnCl_2$ (167.5 mg, 0.9 mmol) at 0 °C. After the mixture no longer generated gas, **S14** (2.0 g, 8.8 mmol) in DCM (10.0 mL) was added at 0 °C and the mixture was allowed to stir at room temperature for 8 h before it was quenched with H_2O (15 mL). The mixture was then extracted with EtOAc (3 × 70 mL). The combined extracts were washed with brine (50 mL), and dried over anhydrous Na_2SO_4. The solvent was evaporated under vacuum, and the residue was purified by flash column chromatography (silica gel, petroleum ether: EtOAc = 20:1) to give **30** (2.0 g, 76%) as colorless oil. **30**: $R_f = 0.6$ (silica, petroleum ether: EtOAc = 20:1); $[\alpha]_D^{20} = +59.97$ (c = 0.4 in $CHCl_3$); IR (film): ν_{max} = 2962, 1753, 1723, 1654, 1436, 1318, 1253, 992, 843 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) : δ = 6.24 (dd, J = 15.3, 10.4 Hz, 1H), 5.98 (dd, J = 15.1, 10.5 Hz, 1H), 5.77 (dt, J = 15.1, 6.5 Hz, 1H), 5.47 (d, J = 15.3 Hz, 1H), 3.69 (d, J = 15.9 Hz, 1H), 3.69 (s, 3H), 3.49 (d, J = 15.9 Hz, 1H), 2.09 (p, J = 6.4 Hz, 2H), 1.48 (s, 3H), 0.99 (t, J = 7.5 Hz, 3H), 0.14 (s, 9H) ppm; ^{13}C NMR (101 MHz, $CDCl_3$) : δ = 205.05, 168.33, 138.41, 131.82, 131.67, 128.12, 82.70, 52.17, 43.80, 25.78, 24.39, 13.42, 2.22 ppm; HRMS (m/z): $[M+Na]^+$ calcd for $C_{15}H_{26}SiO_4Na^+$ 321.1493 found 321.1495.

Compound **26**



To a stirred solution of **30** (600.0 mg, 2.0 mmol) in THF (10.0 mL) was added NaH (112.6 mg, 2.8 mmol, 60% dispersion in mineral oil) at 0 °C. After the mixture no longer generated gas, **31**[9] (683.0 mg, 1.3 mmol) in THF (1.4 mL) was added slowly at 0 °C and the mixture was allowed to stir at room temperature for 2 h and then TBAF (6.0 mL, 6.0 mmol, 1.0 M in THF) was added. The mixture was further stirred at room temperature for 15 min, before it was quenched with 1.0 M aq. HCl (10 mL). The resultant mixture was extracted with EtOAc (3 × 15 mL). The combined extracts were washed with brine (30 mL), and dried over anhydrous Na_2SO_4. The solvent was evaporated under vacuum, and the residue was purified by flash column chromatography (silica gel, petroleum ether: EtOAc = 5:1) to give **26** (518.0 mg, 62%) as a colorless oil. **26**: R_f = 0.6 (silica, petroleum ether: EtOAc = 5:1); $[\alpha]_D^{20}$ = + 9.33 (c = 0.4 in $CHCl_3$); IR (film): ν_{max} = 2966, 2933, 1708, 1585, 1513, 1386, 1247, 1039, 992; ^{1}H NMR (400 MHz, $CDCl_3$) : δ = 7.19 (d, *J* = 8.6 Hz, 2H), 6.83 (d, *J* = 8.7 Hz, 2H), 6.28 (dd, *J* = 15.5, 10.4 Hz, 1H), 5.93 (dd, *J* = 15.1, 10.7 Hz, 1H), 5.74 (dt, *J* = 15.2, 6.5 Hz, 1H), 5.49 (d, *J* = 15.5 Hz, 1H), 4.50 (d, *J* = 11.4 Hz, 1H), 4.42 (d, *J* = 11.4 Hz, 1H), 4.15 – 3.98 (m, 1H), 3.79 (s, 3H), 3.78 (s, 3H), 3.33 (dd, *J* = 13.5, 7.7 Hz, 1H), 3.13 (dd, *J* = 13.5, 5.3 Hz, 1H), 2.07 (p, *J* = 6.4 Hz, 2H), 1.49 (s, 3H), 1.30 (d, *J* = 6.1 Hz, 3H), 0.97 (t, *J* = 7.4 Hz, 3H) ppm; ^{13}C NMR (101 MHz, $CDCl_3$) : δ = 198.25, 196.24, 163.34, 159.25, 139.58, 132.09, 130.27, 129.34, 127.78, 125.42, 113.84, 107.12, 91.60, 72.09, 70.39, 55.35, 51.68, 38.63, 25.78, 22.52, 20.29, 13.37 ppm; HRMS (m/z): $[M+Na]^+$ calcd for $C_{24}H_{30}O_6Na^+$ 437.1935 found 437.1939.

Gregatin A (**8**)



26

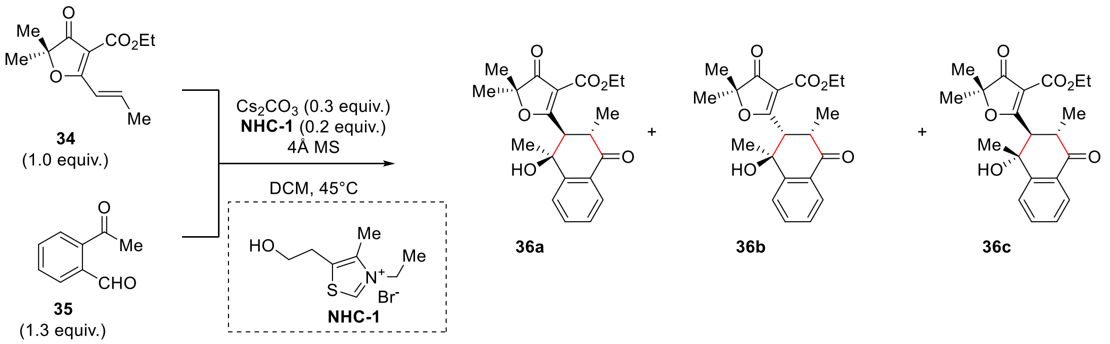
gregatin A (**8**)

To a stirred solution of **26** (330.0 mg, 0.8 mmol) in THF (4.0 mL) was added $MgBr_2 \cdot Et_2O$ (185.0 mg, 0.7 mmol) at 0 °C. The mixture was allowed to stir at room temperature for 1 h before it was quenched with saturated aq. $NaHCO_3$ (3 mL). The resultant mixture was extracted with EtOAc (3 × 4 mL). The combined extracts were washed with brine (3 mL), and dried over anhydrous Na_2SO_4. The solvent was evaporated under vacuum, and the residue was purified by flash column chromatography (silica gel, petroleum ether: EtOAc = 5:1) to give gregatin A (**8**) (175.0 mg, 80%) as a colorless oil. Gregatin A (**8**): R_f = 0.6 (silica, petroleum ether: EtOAc = 5:1); $[\alpha]_D^{20}$ = – 163.06 (c = 0.4 in $CHCl_3$); IR (film) : vmax = 2963, 2931, 1710, 1644, 1557, 1441, 1398, 1204, 1053 cm^{-1}; ^{1}H NMR (400 MHz, Acetone-*d*$_6$) : δ =7.33 – 7.20 (m, 2H), 6.30 (dd, *J* = 15.5, 10.4 Hz, 1H), 6.05 (dd, *J* = 15.0, 10.6 Hz, 1H), 5.83 (dt, *J* = 15.1, 6.6 Hz, 1H), 5.59 (d, *J* = 15.4 Hz, 1H), 3.73 (s, 3H), 2.13 – 2.02 (m, 2H), 2.05 (dd, *J* = 6.3, 1.0 Hz, 3H), 1.49 (s, 3H), 0.97 (t, *J* = 7.5 Hz, 3H) ppm; ^{13}C NMR (101

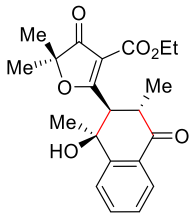
MHz, Acetone-d_6) : δ = 197.58, 185.32, 163.66, 145.38, 139.53, 132.07, 128.96, 127.66, 121.19, 104.31, 90.66, 51.37, 26.24, 22.38, 19.38, 13.64 ppm; HRMS (m/z) : $[M+H]^+$ calcd for $C_{16}H_{21}O_4^+$ 277.1434, found 277.1435.

7. Asymmetric total synthesis of penicilfuranone A (1)

Compound **36a**, **36b** and **36c**

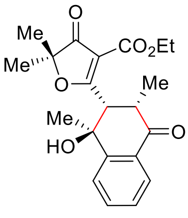


To a stirred suspension of **34**[10] (55.0 mg, 245.3 μmol), **35**[11] (47.3 mg, 318.8 μmol) and 4Å molecular sieves (55.0 mg) in DCM (820.0 μL) was added **NHC-1** (12.4 mg, 49.0 μmol) and Cs_2CO_3 (24.0 mg, 73.6 μmol) at room temperature. The resultant mixture was allowed to stir at 45 °C for 6 h. Then the reaction mixture was cooled to room temperature and filtered through a pad of celite. The solvent was evaporated under vacuum, and the residue was purified by flash column chromatography (silica gel, petroleum ether: EtOAc = 4:1 → 2:1) to give **36a**, **36b** and **36c**.



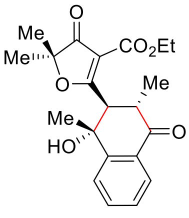
36a

36a as a yellow oil: 33.0 mg, 36%, R_f = 0.53 (silica, petroleum ether: EtOAc = 3:1); IR (film): ν_{max} = 3465, 2965, 2930, 1716, 1598, 1402, 1307, 1161, 810 cm^{-1}; ^1H NMR (400 MHz, Acetone-d_6) : δ = 8.02 – 7.95 (m, 1H), 7.74 (d, J = 7.8 Hz, 1H), 7.68 (t, J = 7.6 Hz, 1H), 7.50 (t, J = 7.4 Hz, 1H), 4.61 (s, 1H), 4.56 (d, J = 11.8 Hz, 1H), 4.19 (q, J = 7.1 Hz, 2H), 3.52 (dq, J = 12.1, 6.9 Hz, 1H), 1.75 (s, 3H), 1.44 (s, 6H), 1.26 – 1.19 (m, 6H) ppm; ^{13}C NMR (101 MHz, Acetone-d_6) : δ = 200.04, 198.76, 194.59, 163.70, 147.45, 134.77, 131.42, 129.23, 127.98, 125.75, 110.86, 90.30, 70.80, 60.80, 51.99, 39.93, 26.46, 23.23, 22.66, 14.50, 13.97 ppm; HRMS (m/z): $[M+Na]^+$ calcd for $C_{21}H_{24}O_6Na^+$ 395.1465 found 395.1461.



36b

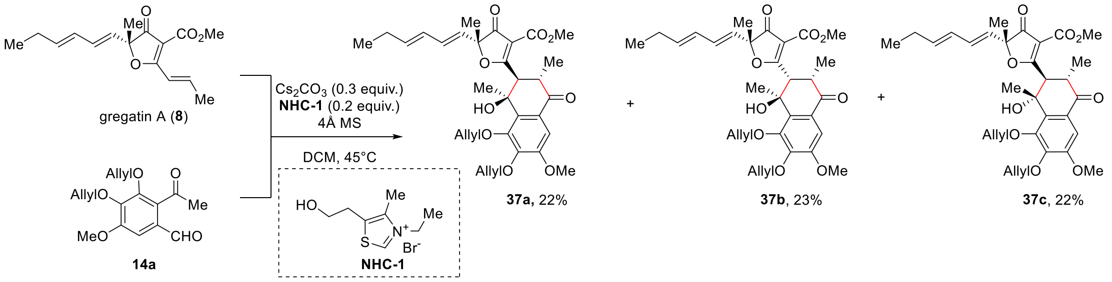
36b as a yellow oil: 11.0 mg, 12%, R_f = 0.55 (silica, petroleum ether: EtOAc = 3:1); IR (film): ν_{max} = 3421, 2953, 2922, 1705, 1677, 1520, 1381, 1214, 1048 cm^{-1}; ^1H NMR (400 MHz, Acetone-d_6) : δ = 7.97 (dd, J = 7.8, 0.9 Hz, 1H), 7.67 – 7.58 (m, 2H), 7.45 (ddd, J = 7.8, 6.8, 1.7 Hz, 1H), 5.09 (s, 1H), 4.88 (d, J = 5.3 Hz, 1H), 4.28 (q, J = 7.1 Hz, 2H), 3.72 (qd, J = 7.0, 5.3 Hz, 1H), 1.76 (s, 3H), 1.32 (t, J = 7.1 Hz, 3H), 1.18 (d, J = 7.0 Hz, 3H), 1.11 (s, 3H), 0.89 (s, 3H) ppm; ^{13}C NMR (101 MHz, Acetone-d_6) : δ = 199.48, 197.84, 194.28, 163.44, 145.57, 134.10, 133.10, 128.75, 126.71, 126.46, 110.92, 89.76, 70.81, 60.91, 54.91, 40.26, 26.76, 22.78, 22.05, 14.56, 12.72 ppm; HRMS (m/z): $[M+Na]^+$ calcd for $C_{21}H_{24}O_6Na^+$ 395.1465 found 395.1477.



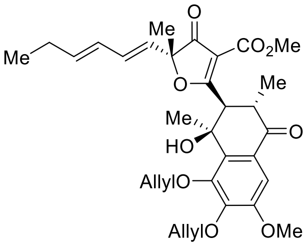
36c

36c as a yellow oil: 35.0 mg, 38%, R_f = 0.35 (silica, petroleum ether: EtOAc = 4:1); IR (film): ν_{max} = 3434, 2979, 2934, 1720, 1686, 1588, 1455, 1186, 769 cm^{-1}; ^1H NMR (400 MHz, Acetone-d_6) : δ = 7.94 (dd, J = 7.8, 1.4 Hz, 1H), 7.84 (dd, J = 7.9, 1.2 Hz, 1H), 7.70 (td, J = 7.6, 1.5 Hz, 1H), 7.46 (td, J = 7.5, 1.2 Hz, 1H), 4.86 (s, 1H), 4.59 (d, J = 12.8 Hz, 1H), 4.18 (qd, J = 7.1, 2.8 Hz, 2H), 3.21 (dq, J = 13.4, 6.7 Hz, 1H), 1.61 (s, 3H), 1.51 (s, 3H), 1.48 (s, 3H), 1.27 (d, J = 6.7 Hz, 3H), 1.23 (t, J = 7.1 Hz, 3H) ppm; ^{13}C NMR (101 MHz, Acetone-d_6) : δ = 199.82, 197.42, 193.39, 164.66, 152.48, 135.03, 130.15, 128.55, 127.53, 125.91, 112.04, 90.62, 73.55, 61.20, 53.15, 41.83, 27.57, 23.20, 22.73, 14.43, 14.37 ppm; HRMS (m/z): $[M+Na]^+$ calcd for $C_{21}H_{24}O_6Na^+$ 395.1465 found 395.1471.

Compound **37a**, **37b** and **37c**

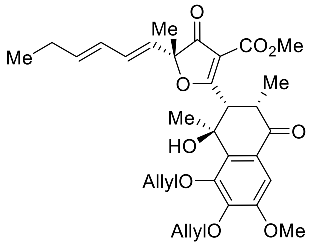


To a stirred suspension of gregatin (**8**) (40.0 mg, 144.8 μmol), **14a** (54.6 mg, 188.2 μmol) and 4Å molecular sieves (40 mg) in DCM (480.0 μL) was added **NHC-1** (7.3 mg, 28.9 μmol) and Cs_2CO_3 (14.2 mg, 43.4 μmol) at room temperature. The resultant mixture was allowed to stir at 45 °C for 6 h. Then the reaction mixture was cooled to room temperature and filtered through a pad of celite. The solvent was evaporated under vacuum, and the residue was purified by flash column chromatography (silica gel, petroleum ether: EtOAc = 5:1 → 3:1) to give **37a**, **37b** and **37c**.



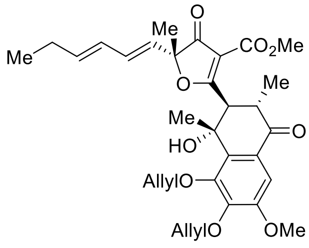
37a

37a: 18.0 mg, 22%, R_f = 0.55 (silica, petroleum ether: EtOAc = 4:1); $[\alpha]_D^{20}$ = + 44.35 (c = 0.32 in MeOH); IR (film): ν_{max} = 3477, 2965, 2933, 1710, 1586, 1411, 1334, 1200, 1121, 993 cm^{-1}; ^1H NMR (400 MHz, Acetone-d_6) : δ = 7.40 (s, 1H), 6.30 (dd, J = 15.5, 10.4 Hz, 1H), 6.25 – 6.02 (m, 3H), 5.88 (dt, J = 15.2, 6.6 Hz, 1H), 5.60 (d, J = 15.5 Hz, 1H), 5.45 – 5.33 (m, 2H), 5.28 – 5.16 (m, 2H), 4.77 – 4.67 (m, 1H), 4.67 – 4.55 (m, 4H), 4.54 (brs, 1H), 3.93 (s, 3H), 3.73 (s, 3H), 3.33 (dq, J = 10.1, 6.9 Hz, 1H), 2.12 (q, J = 7.2 Hz, 2H), 1.92 (s, 3H), 1.47 (s, 3H), 1.24 (d, J = 7.1 Hz, 3H), 0.99 (t, J = 7.5 Hz, 3H) ppm; ^{13}C NMR (101 MHz, Acetone-d_6) : δ = 197.58, 197.26, 195.74, 164.01, 154.34, 152.10, 147.83, 139.89, 135.31, 135.22, 133.86, 132.96, 128.93, 127.55, 126.61, 117.80, 117.62, 110.63, 106.35, 91.69, 75.40, 74.62, 71.94, 56.33, 52.73, 51.59, 40.10, 29.62, 26.24, 22.75, 14.64, 13.59 ppm; HRMS (m/z): $[M+Na]^+$ calcd for $C_{32}H_{38}O_9Na^+$ 589.2408 found 589.2414.



37b

37b: 19.0 mg, 23%, R_f = 0.25 (silica, petroleum ether: EtOAc = 4:1); $[\alpha]_D^{20}$ = + 16.66 (c = 0.30 in MeOH); IR (film): ν_{max} = 3465, 2965, 2933, 1716, 1585, 1473, 1377, 1286, 1201, 993 cm^{-1}; ^{1}H NMR (400 MHz, Acetone-d_6) : δ = 7.48 (s, 1H), 6.30 – 6.03 (m, 2H), 5.92 – 5.82 (m, 1H), 5.49 (t, *J* = 6.7 Hz, 1H), 5.46 – 5.38 (m, 2H), 5.34 (s, 1H), 5.33 (d, *J* = 2.0 Hz, 1H), 5.22 (ddd, *J* = 10.5, 3.4, 1.7 Hz, 2H), 5.00 (brs, 1H), 4.82 – 4.74 (m, 2H), 4.62 (qdt, *J* = 12.4, 5.6, 1.5 Hz, 2H), 4.48 (ddt, *J* = 11.9, 5.7, 1.5 Hz, 1H), 3.93 (s, 3H), 3.79 (s, 3H), 3.64 (qd, *J* = 6.9, 5.1 Hz, 1H), 2.05 – 1.96 (m, 2H), 1.90 (s, 3H), 1.26 (s, 3H), 1.17 (d, *J* = 6.9 Hz, 3H), 0.92 (t, *J* = 7.5 Hz, 3H) ppm; ^{13}C NMR (101 MHz, Acetone-d_6) : δ = 197.23, 196.63, 195.21, 163.88, 154.26, 152.87, 147.45, 139.54, 135.45, 135.33, 131.81, 131.53, 130.00, 128.62, 126.41, 117.41, 117.33, 110.90, 105.60, 91.46, 75.18, 74.65, 71.70, 56.79, 56.39, 51.72, 39.66, 28.05, 26.10, 23.18, 13.58, 12.69 ppm; HRMS (m/z): $[M+Na]^+$ calcd for $C_{32}H_{38}O_9Na^+$ 589.2408 found 589.2412.

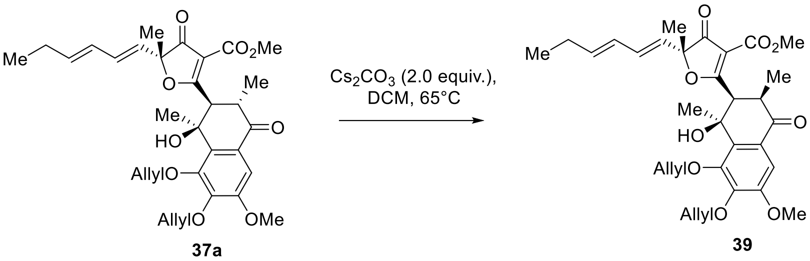


37c

37c: 18.0 mg, 22%, R_f = 0.55 (silica, petroleum ether: EtOAc = 4:1); $[\alpha]_D^{20}$ = + 31.35 (c = 0.44 in MeOH); IR (film): ν_{max} = 3504, 2959, 2929, 1719, 1684, 1590, 1460, 1377, 1124, 917 cm^{-1}; ^{1}H NMR (400 MHz, Acetone-d_6) : δ = 7.40 (s, 1H), 6.44 (dd, *J* = 15.5, 10.3 Hz, 1H), 6.27 – 6.04 (m, 3H), 5.91 (dt, *J* = 15.1, 6.7 Hz, 1H), 5.67 (d, *J* = 15.5 Hz, 1H), 5.54 – 5.34 (m, 2H), 5.25 (ddd, *J* = 21.6, 10.5, 1.5 Hz, 2H), 4.94 – 4.80

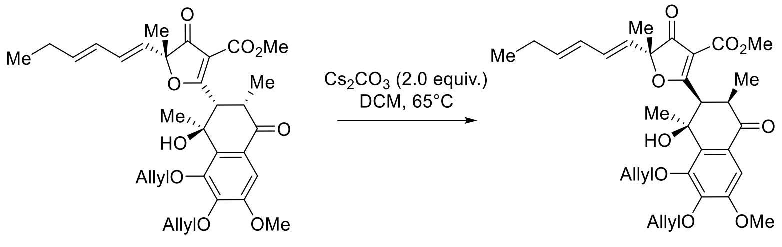
(m, 2H), 4.77 – 4.60 (m, 4H), 3.94 (s, 3H), 3.69 (s, 3H), 3.12 (dp, *J* = 13.9, 6.8 Hz, 1H), 2.12 (p, *J* = 7.3 Hz, 2H), 1.78 (s, 3H), 1.59 (s, 3H), 1.23 (d, *J* = 6.6 Hz, 3H), 1.00 (t, *J* = 7.5 Hz, 3H) ppm; ^{13}C NMR (101 MHz, Acetone-d_6) : δ = 197.63, 196.33, 193.57, 163.92, 154.22, 150.60, 147.37, 140.08, 136.68, 135.05, 134.86, 133.42, 128.89, 126.59, 126.22, 118.53, 118.06, 112.48, 106.42, 91.63, 75.50, 74.65, 74.18, 56.37, 52.28, 51.56, 40.80, 26.26, 26.15, 22.60, 13.78, 13.59 ppm; HRMS (m/z): [M+Na]$^+$ calcd for $C_{32}H_{38}O_9Na^+$ 589.2408 found 589.2415.

Compound **39**



To a 4 mL sealed-tube was charged with **37a** (15.0 mg, 26.5 μmol), DCM (260.0 μL), and Cs_2CO_3 (17.3 mg, 52.9 μmol) at room temperature. The tube was sealed with a PTFE-lined cap and the reaction mixture was allowed to stir at 65 °C for 1 hour. Then the reaction mixture was cooled to room temperature and filtered through a pad of celite. The solvent was evaporated under vacuum, and the residue was purified by flash column chromatography (silica gel, petroleum ether: EtOAc = 5:1 → 4:1) to give **39** (7.7 mg, 51%) as a colorless oil. R_f = 0.55 (silica, petroleum ether: EtOAc = 4:1); $[\alpha]_D^{20}$ = + 1.19 (c = 0.50 in MeOH); IR (film): ν_{max} = 3495, 2964, 2931, 1715, 1590, 1439, 1287, 1111, 791 cm^{-1}; ^{1}H NMR (400 MHz, Acetone-d_6) : δ = 7.43 (s, 1H), 6.27 – 6.04 (m, 2H), 5.84 (ddt, *J* = 15.1, 10.1, 1.6 Hz, 1H), 5.53 – 5.35 (m, 5H), 5.33 – 5.18 (m, 3H), 4.91 (d, *J* = 5.3 Hz, 1H), 4.80 – 4.73 (m, 2H), 4.67 – 4.60 (m, 2H), 3.93 (s, 3H), 3.74 (s, 3H), 3.37 – 3.25 (m, 1H), 2.03 – 1.97 (m, 2H), 1.96 (s, 3H), 1.25 (s, 3H), 1.22 (d, *J* = 6.8 Hz, 3H), 0.93 (t, *J* = 7.4 Hz, 3H) ppm; ^{13}C NMR (101 MHz, Acetone-d_6): δ: = 197.36, 196.10, 195.79, 164.10, 154.01, 151.11, 146.67, 139.06, 135.08, 134.84, 133.58, 131.17, 128.89, 128.52, 126.56, 118.39, 117.83, 111.05, 105.42, 91.27, 75.45, 74.59, 73.52, 56.42, 54.48, 51.44, 41.43, 31.62, 26.19, 22.96, 13.72, 13.25 ppm; HRMS (m/z): [M+Na]$^+$ calcd for $C_{32}H_{38}O_9Na^+$ 589.2408 found 589.2416.

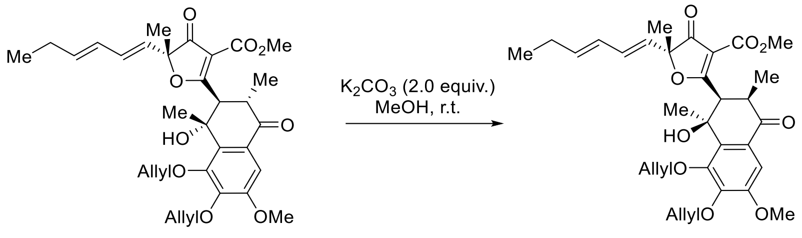
Compound **39**



37b **39**

To a 4 mL sealed-tube was charged with **37b** (15.0 mg, 26.5 μmol), DCM (260.0 μL), and Cs$_2$CO$_3$ (17.3 mg, 52.9 μmol) at room temperature. The tube was sealed with a PTFE-lined cap and the reaction mixture was allowed to stir at 65 °C for 1 hour. Then the reaction mixture was cooled to room temperature and filtered through a pad of celite. The solvent was evaporated under vacuum, and the residue was purified by flash column chromatography (silica gel, petroleum ether: EtOAc = 5:1 → 4:1) to give **39** (8.3 mg, 55%) as a colorless oil.

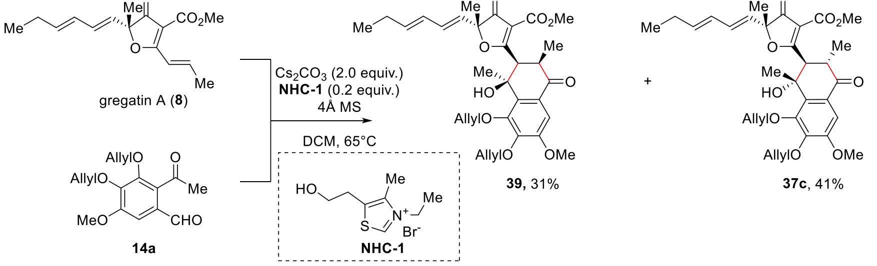
Compound **39**



37c **39**

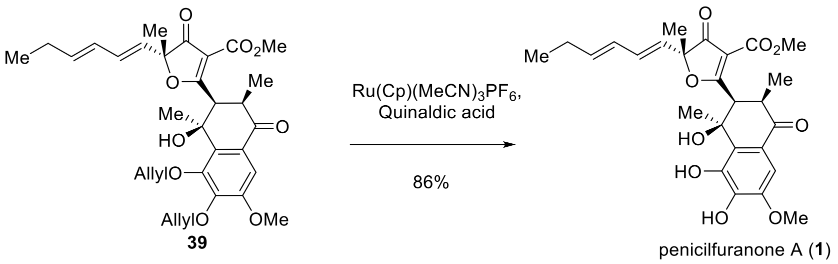
To a stirred solution of **37c** (15.0 mg, 26.5 μmol) in MeOH (260.0 μL) was added K$_2$CO$_3$ (7.3 mg, 52.9 μmol) at room temperature. The resultant mixture was allowed to stir at room temperature for 30 min. Then the reaction mixture was filtered through a pad of celite. The solvent was evaporated under vacuum, and the residue was purified by flash column chromatography (silica gel, petroleum ether: EtOAc = 5:1 → 4:1) to give **39** (6.1 mg, 41%) as a colorless oil.

One step to Compound **39**



To a 15 mL sealed-tube was charged with gregatin (**8**) (26.0 mg, 94.1 μmol), **14a** (35.5 mg, 122.3 μmol), 4Å molecular sieves (30 mg), DCM (360.0 μL), **NHC-1** (4.8 mg, 18.8 μmol) and Cs_2CO_3 (61.3 mg, 188.2 μmol) at room temperature. The tube was sealed with a PTFE-lined cap and the resultant mixture was allowed to stir at 65 °C for 2 h. Then the reaction mixture was cooled to room temperature and filtered through a pad of celite. The solvent was evaporated under vacuum, and the residue was purified by flash column chromatography (silica gel, petroleum ether: EtOAc = 5:1 → 3:1) to give **39** (16.4 mg, 31%) and **37c** (22.0 mg, 41%).

Penicilfuranone A (**1**)

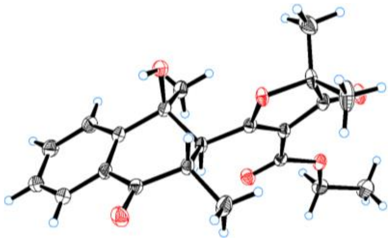


To a stirred solution of **39** (12.0 mg, 21.2 μmol) and quinaldic acid (0.8 mg, 4.7 μmol) in MeOH (420.0 μL) was added Ru(Cp)$(MeCN)_3PF_6$ (1.8 mg, 4.92 μmol) at room temperature. The resultant mixture was allowed to stir at room temperature for 20 min. Then the solvent was evaporated under vacuum, and the residue was purified by flash column chromatography (silica gel, DCM: acetone = 1:1) to give penicilfuranone A (**1**) (8.9 mg, 86%) as a white foam. R_f = 0.40 (silica, DCM: MeOH = 20:1); $[\alpha]_D^{20}$ = − 9.32 (c = 0.30 in MeOH); IR (film): ν_{max} = 3383, 2964, 1716, 1703, 1609, 1591, 1439, 1367, 1204, 1106, 823 cm^{-1}; ^{1}H NMR (400 MHz, Acetone-d_6) : δ = 9.05 (brs, 1H), 8.25 (brs, 1H), 7.23 (s, 1H), 5.91 – 5.71 (m, 2H), 5.47 (dt, *J* = 15.2, 6.6 Hz, 1H), 5.32 – 5.21 (m, 2H), 4.86 (d, *J* = 5.2 Hz, 1H), 3.88 (s, 3H), 3.77 (s, 3H), 3.31 – 3.23 (m, 1H), 2.01 (s, 3H), 2.00 – 1.94 (m, 2H), 1.27 (s, 3H), 1.24 (d, *J* = 6.8 Hz, 3H), 0.93 (t, *J* = 7.5 Hz, 3H) ppm; ^{13}C NMR (101 MHz, Acetone-d_6) : δ = 197.31, 195.82, 195.18, 164.88, 148.41, 143.56, 140.85, 139.42, 131.18, 128.61, 126.02, 125.87, 123.92, 111.12, 102.01, 91.65, 75.22, 56.36, 54.92, 51.80, 41.42, 30.26, 26.28, 22.87, 13.58, 13.51 ppm; HRMS (m/z): $[M+Na]^+$ calcd for $C_{26}H_{30}O_9Na^+$ 509.1782 found 509.1789.

8. Single crystal x-ray diffraction analysis

X-ray crystallographic data for (±)-36a:

Crystal sample preparation: a solution of (+)-**36a** (20 mg) in DCM/n-hexane (0.4 mL, 1:1) was loaded in a 5.0 mL glass vial and maintained still and undisturbed. After slow evaporation for 3 days at room temperature, a colorless crystal of (+)-**36a** was obtained for x-ray analysis.



ORTEP of **36a**

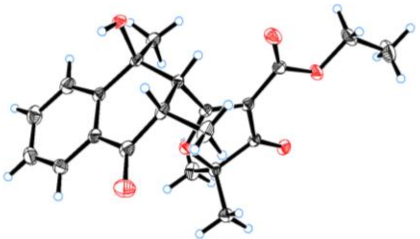
Table S5. Crystal data and structure refinement for (±)-**36a**

CCDC number	2424508
Empirical formula	$C_{21}H_{24}O_6$
Formula weight	372.40
Temperature [K]	100.00(10)
Crystal system	monoclinic
Space group (number)	$P2_1/n$ (14)
a [Å]	8.75710(10)
b [Å]	19.7605(2)
c [Å]	11.26570(10)
α [°]	90
β [°]	105.4910(10)
γ [°]	90
Volume [Å^3]	1878.65(3)
Z	4
ρ_{calc} [gcm^{-3}]	1.317
μ [mm^{-1}]	0.794
F(000)	792
Crystal size [mm^3]	0.2×0.3×0.3
Crystal colour	dull light colourless
Crystal shape	needle
Radiation	Cu K_α (λ=1.54184 Å)
2θ range [°]	8.95 to 151.85 (0.79 Å)
Index ranges	$-10 \le h \le 10$, $-24 \le k \le 24$, $-14 \le l \le 13$
Reflections collected	31260
Independent reflections	3830 R_{int} = 0.0311, R_{sigma} = 0.0136
Completeness to θ = 67.684°	100.0 %
Data / Restraints / Parameters	3830 / 0 / 251
Absorption correction T_{min}/T_{max} (method)	0.7966 / 1.0000 (psi-scan)

Goodness-of-fit on F^2	1.060
Final R indexes [$I \geq 2\sigma(I)$]	$R_1 = 0.0442$, w$R_2 = 0.1075$
Final R indexes [all data]	$R_1 = 0.0446$, w$R_2 = 0.1078$
Largest peak/hole [eÅ^{-3}]	0.58/−0.24
Extinction coefficient	0.0035(3)

X-ray crystallographic data for (±)-36b:

Crystal sample preparation: a solution of (+)-**36b** (10 mg) in DCM/n-hexane (0.4 mL, 1:1) was loaded in a 5.0 mL glass vial and maintained still and undisturbed. After slow evaporation for 5 days at room temperature, a colorless crystal of (+)-**36b** was obtained for x-ray analysis.



ORTEP of **36b**

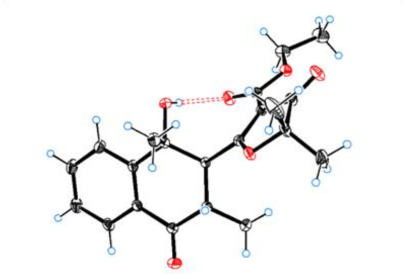
Table S6. Crystal data and structure refinement for (±)-**36b**

CCDC number	2425647
Empirical formula	$C_{21}H_{24}O_6$
Formula weight	372.40
Temperature [K]	100.00(10)
Crystal system	monoclinic
Space group (number)	$P2_1/n$ (14)
a [Å]	8.70700(10)
b [Å]	19.1093(2)
c [Å]	11.79410(10)
α [°]	90
β [°]	92.1030(10)
γ [°]	90
Volume [Å^3]	1961.04(3)
Z	4
ρ_{calc} [gcm^{-3}]	1.261
μ [mm^{-1}]	0.760
F(000)	792
Crystal size [mm^3]	0.1×0.2×0.3
Crystal colour	clear light colourless
Crystal shape	needle
Radiation	Cu K_α (λ=1.54184 Å)
2θ range [°]	8.82 to 152.37 (0.79 Å)
Index ranges	$-10 \leq h \leq 10$, $-23 \leq k \leq 23$, $-14 \leq l \leq 14$
Reflections collected	35739

Independent reflections	4002 R_{int} = 0.0343, R_{sigma} = 0.0171
Completeness to θ = 67.684°	100.0 %
Data / Restraints / Parameters	4002 / 0 / 250
Absorption correction $T_{\text{min}}/T_{\text{max}}$ (method)	0.7003 / 1.0000 (multi-scan)
Goodness-of-fit on F^2	1.064
Final R indexes [$I \geq 2\sigma(I)$]	R_1 = 0.0359, wR_2 = 0.0934
Final R indexes [all data]	R_1 = 0.0374, wR_2 = 0.0947
Largest peak/hole [eÅ^{-3}]	0.24/−0.31

X-ray crystallographic data for (±)-36c:

Crystal sample preparation: a solution of (+)-**36c** (12 mg) in DCM/n-hexane (0.4 mL, 1:1) was loaded in a 5.0 mL glass vial and maintained still and undisturbed. After slow evaporation for 7 days at room temperature, a colorless crystal of (+)-**36c** was obtained for x-ray analysis.



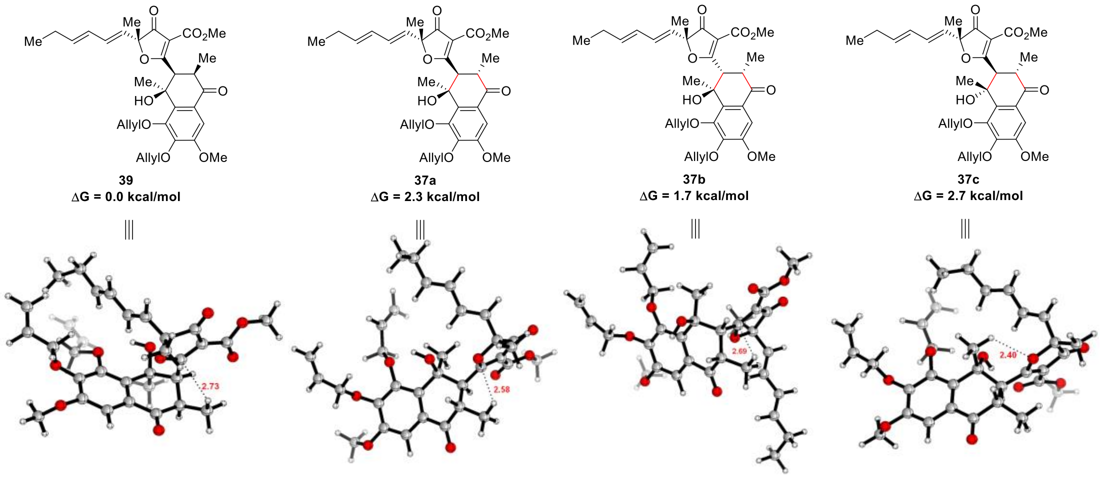
ORTEP of **36c**

Table S7. Crystal data and structure refinement for (±)-**36c**

CCDC number	2440564
Empirical formula	$C_{21}H_{24}O_6$
Formula weight	372.40
Temperature [K]	104(7)
Crystal system	monoclinic
Space group (number)	$P2_1/n$ (14)
a [Å]	8.9343(2)
b [Å]	19.9249(5)
c [Å]	11.1682(4)
α [°]	90
β [°]	106.262(3)
γ [°]	90
Volume [Å^3]	1908.57(10)
Z	4
ρ_{calc} [gcm^{-3}]	1.296
μ [mm^{-1}]	0.095
F(000)	792
Crystal size [mm^3]	0.2×0.3×0.3
Crystal colour	clear light colourless
Crystal shape	needle
Radiation	Mo K_α (λ=0.71073 Å)

2θ range [°]	5.17 to 71.81 (0.61 Å)
Index ranges	$-13 \leq h \leq 14$, $-29 \leq k \leq 31$, $-14 \leq l \leq 16$
Reflections collected	25650
Independent reflections	7654, R_{int} = 0.0390, R_{sigma} = 0.0462
Completeness to θ = 25.242°	99.9 %
Data / Restraints / Parameters	7654 / 0 / 250
Absorption correction $T_{\mathrm{min}}/T_{\mathrm{max}}$ (method)	0.6344 / 1.0000 (multi-scan)
Goodness-of-fit on F^2	1.014
Final R indexes [$I \geq 2\sigma(I)$]	R_1 = 0.0501, wR_2 = 0.1454
Final R indexes [all data]	R_1 = 0.0728, wR_2 = 0.1602
Largest peak/hole [eÅ^{-3}]	0.46/−0.26

9. DFT calculation



39 ΔG = 0.0 kcal/mol

37a ΔG = 2.3 kcal/mol

37b ΔG = 1.7 kcal/mol

37c ΔG = 2.7 kcal/mol

All density functional theory (DFT) calculations were carried out using the Gaussian 16 software package.[12] Geometry optimizations were performed with the M062X functional and Grimme's third generation empirical dispersion correction. The 6-31G(d,p) basis set was used for all geometry optimizations performed.[13,14,15] Vibrational frequencies were computed at the same level of theory as the geometry optimizations to validate each optimized structure being a minimum (no imaginary frequency). Single-point energies were computed based on the optimized structures under M062X-D3/def2-TZVPP level of theory.[16]

37a

Thermal correction to Gibbs Free Energy (Hartree): 0.576509
Single point energy (Hartree): -1919.177321
Gibbs free energy (Hartree): -1918.600812

C	-3.79788900	0.89682100	0.10418400
C	-3.96995200	2.25754400	-0.19035600
C	-2.85487600	3.01499900	-0.52299300
C	-1.58419500	2.44285900	-0.51800000
C	-1.37517600	1.11817900	-0.11009100
C	-2.51312700	0.34261600	0.14237800
C	-0.46618000	3.25133100	-1.09687800
C	0.79373700	2.47717000	-1.44814200
C	1.10119700	1.57602400	-0.23697700
C	0.01801700	0.48798000	-0.00921800
C	2.47092700	0.97979700	-0.34241400
H	0.55209100	1.82214400	-2.29693700

O	-0.58762400	4.43659700	-1.32009600
O	-5.19121500	2.84428900	-0.27343100
O	-4.88735600	0.09212400	0.31286100
O	-2.36652400	-1.01763200	0.29042700
C	3.49600100	1.00164100	0.56115200
C	4.64202700	0.34423700	-0.07890900
C	4.09562600	-0.16913300	-1.42648100
O	2.76765900	0.38951000	-1.50215300
O	5.77977200	0.16981900	0.28841000
C	4.00827600	-1.66910500	-1.33889100
C	2.85775700	-2.34380800	-1.26272800
C	2.76480900	-3.78877500	-1.09606600
C	1.59308800	-4.42396900	-0.98477300
C	1.41653500	-5.89740100	-0.77821400
O	0.14878600	-0.48379400	-1.03990200
H	1.11430300	2.19237200	0.66744400
C	-2.83801300	-1.60398600	1.52013400
C	-2.32046600	-3.00679000	1.56532500
C	-1.56742600	-3.47958000	2.55278500
C	-5.24763900	-0.67573800	-0.84700000
C	-6.30098900	-1.65221200	-0.43090300
C	-6.17933200	-2.96508000	-0.59318500
C	-6.15566800	2.54252000	0.72908500
C	0.26798600	-0.15320300	1.36231700
C	3.43283500	1.59337600	1.90421400
O	2.42442600	1.99234000	2.45313000
O	4.63942800	1.64076400	2.47621500
C	4.65842300	2.18730500	3.79280000
C	4.92584800	0.33181000	-2.59514400
C	0.59617100	-6.20178700	0.47963700
C	1.92830000	3.42753700	-1.81061200
H	-2.97474800	4.04713900	-0.83267100
H	4.97399600	-2.16749400	-1.27131100
H	1.92142300	-1.79083000	-1.31144200
H	3.69462500	-4.35621200	-1.04981400
H	0.67784100	-3.82882300	-1.02236000
H	0.90549400	-6.33030900	-1.64811600
H	2.39773000	-6.37979600	-0.71626600
H	-0.55754500	-1.12750500	-0.88198300
H	-2.46168800	-1.01922000	2.36844400
H	-3.93175800	-1.58190200	1.53034000
H	-2.61059000	-3.64640400	0.73309100
H	-1.22918400	-4.50999300	2.57050400
H	-1.26697800	-2.84645900	3.38377200

H	-5.61875100	0.01393000	-1.61802700
H	-4.36438300	-1.19815200	-1.23274800
H	-7.19602200	-1.22877300	0.02082500
H	-6.96477800	-3.65247800	-0.29868000
H	-5.28660400	-3.39632200	-1.03924600
H	-6.76780900	1.68290200	0.44843400
H	-5.67209100	2.33322400	1.68792600
H	0.10972400	0.56849000	2.16717400
H	-0.37280500	-1.02193000	1.50644400
H	1.30511400	-0.49576000	1.41513700
H	5.69718500	2.14344800	4.11355900
H	4.29903900	3.21842800	3.78372200
H	4.02251400	1.60040900	4.45891400
H	5.95080700	-0.02271400	-2.46504500
H	4.52345200	-0.04464100	-3.53734700
H	4.93684200	1.42479300	-2.61232200
H	0.45580200	-7.27740700	0.61242000
H	1.09301800	-5.80473500	1.36905100
H	-0.39308100	-5.73702200	0.41416300
H	1.59333300	4.13592500	-2.56902900
H	2.24016400	4.00456100	-0.93450000
H	2.78834300	2.87541000	-2.19474000
H	-6.78264800	3.43048400	0.82133100

37b

Thermal correction to Gibbs Free Energy (Hartree): 0.574269
Single point energy (Hartree): -1919.175919
Gibbs free energy (Hartree): -1918.60165

C	-3.07179400	1.55206600	0.04155800
C	-2.25861900	2.67986500	-0.10801000
C	-0.99403200	2.52774100	-0.65192000
C	-0.54280300	1.26933900	-1.04969600
C	-1.32175700	0.10889900	-0.86861000
C	-2.60956900	0.28257000	-0.33681500
C	0.81485500	1.22627200	-1.67990600
C	1.24044400	-0.07673000	-2.32579200
C	0.71950900	-1.28279400	-1.53005000
C	-0.83125000	-1.25936700	-1.35759400
C	1.44523600	-1.40183800	-0.22802600
H	0.71120500	-0.11632500	-3.28976100
O	1.52199800	2.21503200	-1.71449100
O	-2.72868900	3.92109700	0.20692200
O	-4.33064200	1.69070200	0.55515000

O	-3.48330600	-0.76592300	-0.24856900
C	2.13818400	-2.44601900	0.31221000
C	2.67456900	-1.98420600	1.59832600
C	2.21830900	-0.51819800	1.72016700
O	1.43883600	-0.29466900	0.52481300
O	3.32701900	-2.54523300	2.44689100
C	3.41742300	0.38605000	1.72583000
C	3.58559500	1.41352900	0.88808400
C	4.75551800	2.28195500	0.86868200
C	4.89515400	3.26602600	-0.02668500
C	6.06111400	4.20376900	-0.10152700
O	-1.39448600	-1.52155200	-2.64102700
H	0.92359500	-2.19652700	-2.09100400
C	-3.81756500	-1.17924400	1.08749000
C	-4.78362400	-2.31392700	0.97331400
C	-4.55142200	-3.52387100	1.46946000
C	-5.37052500	1.61498500	-0.43456200
C	-6.66659700	1.42152200	0.28544800
C	-7.53224700	0.46054600	-0.01842800
C	-2.90593100	4.14085700	1.60302400
C	-1.21364400	-2.45090600	-0.47531800
C	2.29364700	-3.77236300	-0.30276900
O	1.73275000	-4.15219500	-1.31113300
O	3.14135500	-4.53616900	0.39136600
C	3.33721800	-5.84691200	-0.13547200
C	1.31512400	-0.33537000	2.93188300
C	5.63270300	5.66334200	0.08611600
C	2.74391400	-0.11995100	-2.57415600
H	-0.35615900	3.39181100	-0.79897400
H	4.16374200	0.12564000	2.47466000
H	2.81520400	1.63620500	0.15287400
H	5.53518800	2.10119400	1.60878000
H	4.09610100	3.41617900	-0.75578200
H	6.80400600	3.92825500	0.65475500
H	6.54878000	4.09871400	-1.07912900
H	-1.60283500	-0.68110300	-3.06333100
H	-2.90633900	-1.49610800	1.61019600
H	-4.26433000	-0.33508200	1.62345600
H	-5.71626500	-2.08875300	0.45973800
H	-5.28080200	-4.32278500	1.39182800
H	-3.61720400	-3.75502100	1.97499100
H	-5.36440900	2.55250000	-1.00667700
H	-5.17807300	0.77643100	-1.11215400
H	-6.87884200	2.13138300	1.08241700

H	-8.47784700	0.35885500	0.50287000
H	-7.32648500	-0.25176600	-0.81358300
H	-3.63677100	3.44310600	2.02028600
H	-1.95055500	4.03777600	2.12991800
H	-0.97708100	-2.24867800	0.57425000
H	-2.27339900	-2.67133500	-0.57586100
H	-0.63146900	-3.31967200	-0.79608700
H	4.03207900	-6.33518500	0.54461900
H	2.38926600	-6.38739600	-0.17559100
H	3.75389600	-5.79465500	-1.14342600
H	1.88279000	-0.59051000	3.82935200
H	0.97695300	0.70082600	2.99187100
H	0.44909500	-1.00027500	2.86282000
H	6.48663600	6.33973600	-0.00164700
H	4.89432100	5.95099600	-0.66801900
H	5.17832800	5.80770700	1.06966500
H	3.05178800	0.71883500	-3.19935800
H	3.29321400	-0.04583600	-1.62984800
H	3.02017300	-1.05692400	-3.06429400
H	-3.26900400	5.16325000	1.70826900

37c
Thermal correction to Gibbs Free Energy (Hartree): 0.579812
Single point energy (Hartree): -1919.179866
Gibbs free energy (Hartree): -1918.600054

C	3.51185900	-1.01559800	0.11133000
C	3.65162000	-2.37422900	-0.20455100
C	2.54452700	-3.08811400	-0.63405900
C	1.29857300	-2.46201300	-0.73502000
C	1.13217000	-1.11693000	-0.36989800
C	2.26646700	-0.38742000	0.00623900
C	0.16852700	-3.26654000	-1.30086000
C	-1.17082100	-2.56074000	-1.51683200
C	-1.32671100	-1.51653300	-0.40566900
C	-0.22087100	-0.42019600	-0.46088400
C	-2.67498700	-0.87465000	-0.34128500
H	-1.10932200	-2.04303400	-2.48404300
O	0.31470200	-4.43402400	-1.59606800
O	4.88314000	-2.96415400	-0.17341900
O	4.59901500	-0.28294200	0.49989000
O	2.21693800	0.96936500	0.16908600
C	-3.46068700	-0.64482700	0.75145100
C	-4.66364600	0.05396700	0.27745800

C	-4.36604100	0.38267500	-1.20134400
O	-3.18242700	-0.42760000	-1.48963800
O	-5.67637100	0.36947300	0.85252400
C	-3.97413400	1.84209400	-1.33988800
C	-2.87639100	2.32237400	-0.74351700
C	-2.27841600	3.63846800	-0.91213200
C	-1.04887000	3.88135600	-0.43678200
C	-0.26219900	5.13735200	-0.64213300
O	-0.43242100	0.45815500	0.63332500
H	-1.19302200	-2.02792000	0.55508300
C	2.30466500	1.43850400	1.52158500
C	2.69033700	2.88226100	1.47125200
C	1.93538200	3.85889200	1.96474400
C	5.16848900	0.48026700	-0.57564200
C	6.23185200	1.36014300	-0.00123400
C	6.32008700	2.66091800	-0.25758400
C	5.41275400	-3.13455500	1.13746100
C	-0.22621800	0.43571400	-1.73142800
C	-3.08913700	-0.93807400	2.13581500
O	-1.94127800	-1.06680300	2.53931900
O	-4.14583200	-1.03009800	2.93552700
C	-3.85118900	-1.24084600	4.31735000
C	-5.49620700	-0.03256700	-2.11643800
C	0.99040900	4.86120100	-1.48356900
C	-2.31306800	-3.57069400	-1.56092600
H	2.64571600	-4.12772400	-0.92501200
H	-4.60371800	2.46107300	-1.97499400
H	-2.28557100	1.65793100	-0.11263400
H	-2.81884600	4.39673900	-1.47779800
H	-0.53559900	3.07646500	0.09744900
H	-0.88532800	5.89993600	-1.12152500
H	0.04565100	5.53657400	0.33312800
H	-0.72325800	-0.06554400	1.40198700
H	1.33129600	1.30448200	2.00355900
H	3.06869800	0.85750700	2.05170800
H	3.65236100	3.09639100	1.00694600
H	2.25171800	4.89668400	1.93201500
H	0.97283200	3.64806200	2.42464300
H	5.58889900	-0.22194100	-1.30864900
H	4.38600800	1.07855700	-1.05654600
H	6.96305900	0.86646100	0.63576000
H	7.12372900	3.26841400	0.14410100
H	5.59166300	3.16038400	-0.89181000
H	5.53937900	-2.17056100	1.63759600

H	4.75693500	-3.77866600	1.73409000
H	0.09447600	-0.15221900	-2.59479100
H	-1.20771700	0.86082100	-1.93758600
H	0.49291700	1.24427800	-1.58021600
H	-4.81440500	-1.25085000	4.82241200
H	-3.33109500	-2.19087400	4.45363700
H	-3.22170200	-0.43425200	4.69771200
H	-6.40099400	0.48830300	-1.79398200
H	-5.27137000	0.23114700	-3.15218700
H	-5.67002900	-1.10852600	-2.04656800
H	1.59822100	5.76306800	-1.59538400
H	1.60362500	4.08902500	-1.00871900
H	0.71113400	4.50696700	-2.47949500
H	-2.09069500	-4.35338700	-2.28631900
H	-2.44171300	-4.04726900	-0.58409800
H	-3.24866000	-3.07931000	-1.83791300
H	6.38222700	-3.61813700	1.01600300

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Thermal correction to Gibbs Free Energy (Hartree): 0.579516
Single point energy (Hartree): -1919.183955
Gibbs free energy (Hartree): -1918.604439

C	-2.40989000	1.59839200	0.00689100
C	-2.04369500	2.77183800	-0.66578500
C	-0.74435100	3.23918100	-0.55060200
C	0.18471400	2.54517800	0.22114000
C	-0.16690200	1.39181100	0.93866300
C	-1.49317000	0.95391000	0.84660400
C	1.59458000	3.05057100	0.18842800
C	2.63048400	2.34686800	1.05265500
C	2.29450400	0.85767000	1.25129000
C	0.86199300	0.63054000	1.78196000
C	2.50202600	0.08537500	-0.01971600
H	2.54759700	2.81500900	2.04440500
O	1.89955000	4.00509100	-0.49609200
O	-2.89801000	3.41904300	-1.50581600
O	-3.63489300	1.02513800	-0.21002000
O	-1.86002200	-0.19091600	1.51418500
C	3.48573500	-0.79008400	-0.37157300
C	3.18799500	-1.24329200	-1.73683100
C	1.86979300	-0.53039100	-2.11438900
O	1.59151000	0.30359700	-0.97399500
O	3.78042500	-1.98431700	-2.48468000

C	0.76979700	-1.54414000	-2.27275900
C	-0.19831300	-1.74481400	-1.37330600
C	-1.21621300	-2.78510100	-1.47354600
C	-2.04764600	-3.07108800	-0.46235800
C	-3.04099800	-4.19929800	-0.44127600
O	0.71195900	-0.77627500	1.70753000
H	2.99126600	0.43643500	1.97913500
C	-3.12848500	-0.22395500	2.18847000
C	-2.97065000	-1.06267300	3.41822000
C	-3.83989200	-2.00210400	3.77502400
C	-3.66592300	0.34141800	-1.47753600
C	-4.99082900	-0.33430000	-1.61805700
C	-5.11330600	-1.59195200	-2.03003500
C	-4.22061300	3.66476700	-1.04018300
C	0.73864700	1.07886600	3.24298000
C	4.62667300	-1.15949900	0.47572500
O	4.93538500	-0.61447800	1.51739700
O	5.31372800	-2.18166900	-0.04236700
C	6.45296500	-2.58343500	0.71413400
C	2.06313200	0.35176100	-3.33771600
C	-4.23004500	-3.91313500	0.47546700
C	4.04403800	2.57582600	0.52430200
H	-0.43409000	4.12450200	-1.09341800
H	0.85377600	-2.16158700	-3.16534300
H	-0.21255000	-1.13870600	-0.46990100
H	-1.25280300	-3.37279300	-2.39190500
H	-1.97468700	-2.46995100	0.44758700
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H	-2.53495200	-5.10668000	-0.08516400
H	-0.20600400	-0.99012200	1.92507200
H	-3.41253100	0.80486800	2.44443500
H	-3.89298300	-0.63283800	1.52195600
H	-2.10818900	-0.84021900	4.04509400
H	-3.72565600	-2.56456500	4.69512000
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H	-3.51574700	1.08527900	-2.27332600
H	-2.84910500	-0.39059900	-1.51892200
H	-5.86802300	0.27364100	-1.40265300
H	-6.08365000	-2.05473900	-2.17611800
H	-4.23306000	-2.19697100	-2.23648200
H	-4.89246700	2.83789000	-1.28455600
H	-4.23031600	3.81963300	0.04308700
H	0.88367700	2.15588600	3.35860000
H	-0.26775300	0.84093600	3.60190800

H	1.46734100	0.54261400	3.85627800
H	6.90422300	-3.39993000	0.15409100
H	7.15390800	-1.75272000	0.81962200
H	6.15203600	-2.91676600	1.70955600
H	2.38162700	-0.27691100	-4.17232100
H	1.13013100	0.85924200	-3.59063400
H	2.83826400	1.09787500	-3.14391300
H	-4.94087300	-4.74307700	0.47895100
H	-3.88101300	-3.76137100	1.50162400
H	-4.75880500	-3.00729500	0.16319500
H	4.76622900	2.02460000	1.13072800
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H	4.28266000	3.63946800	0.53253100
H	-4.55606900	4.57267500	-1.54302900

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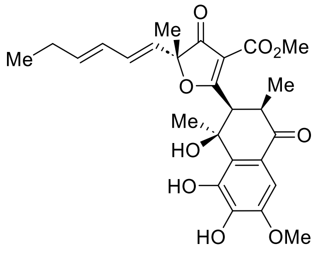
11. Comparison of the data of natural and synthetic penicilfuranone A.

Table S8. Comparison of the ^{1}H NMR spectroscopic data (Acetone-d_6) of natural and synthetic penicilfuranone A (**1**)

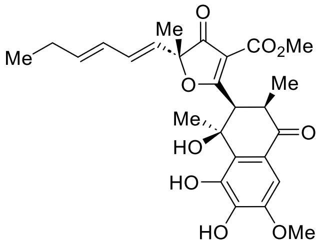


penicilfuranone A (**1**)

Natural δ$_H$ [ppm, mult, *J* (Hz)] 600 MHz		**Synthetic** δ$_H$ [ppm, mult, *J* (Hz)] 400 MHz		**Err** (Natural–Synthetic) Δδ$_H$ (ppm)
		9.05	1 H, brs	–
		8.25	1 H, brs	–
7.21	1 H, s	7.23	1 H, s	−0.02
5.78	1 H, ddd, 15.1, 8.2, 1.3	5.91 – 5.71	2 H, m	–
5.46	1 H, dt, 15.1, 6.6	5.47	1 H, dt, 15.2, 6.6	−0.01
5.26	1 H, t, 15.1	5.32 – 5.21	2 H, m	–
5.25	1 H, dd, 15.1, 8.2			–
4.85	1 H, d, 5.2	4.86	1 H, d, 5.2	−0.01
3.87	3 H, s	3.88	3 H, s	−0.01
3.75	3 H, s	3.77	3 H, s	−0.02
3.26	1 H, dq, 6.8, 5.2	3.31 – 3.23	1 H, m	–
2.00	3H, s	2.01	3 H, s	−0.01
1.93	2 H, m	2.00 – 1.94	2 H, m	–
1.26	3 H, s	1.27	3 H, s	−0.01
1.23	3 H, d, 6.8	1.24	3 H, d, 6.8	−0.01
0.92	3 H, t, 7.5	0.93	3H, t, 7.5	−0.01

Calibrated by using Acetone-d_6 (δ$_H$ = 2.05 ppm) as internal reference.

Table S9. Comparison of the ^{13}C NMR spectroscopic data (Acetone-d_6) of natural and synthetic penicilfuranone A (**1**)



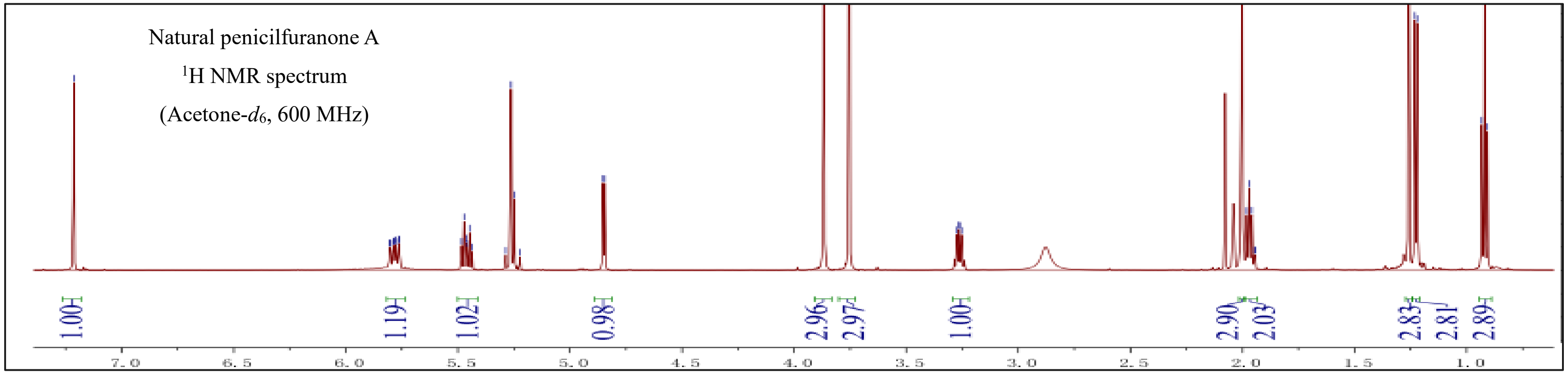
penicilfuranone A (**1**)

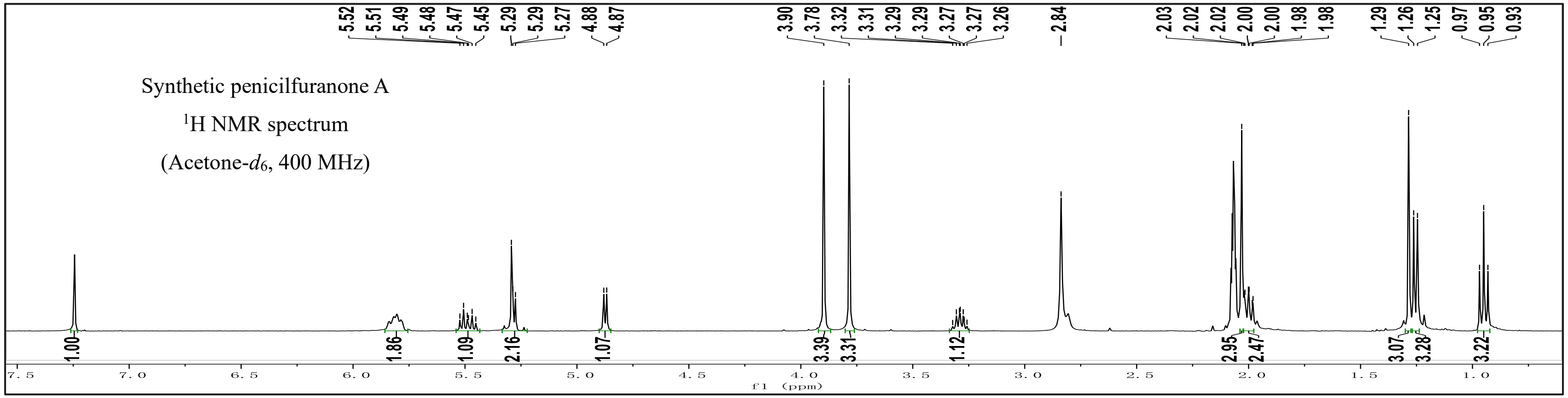
Natural δ_C (ppm) 151 MHz	**Synthetic** δ_C (ppm) 101 MHz	**Err** (Natural–Synthetic) $\Delta\delta_C$ (ppm)
197.3	197.3	0
195.8	195.8	0
195.2	195.2	0
164.8	164.9	–0.1
148.3	148.4	–0.1
143.5	143.6	–0.1
140.8	140.9	–0.1
139.4	139.4	0
131.1	131.2	–0.1
128.5	128.6	–0.1
126.0	126.0	0
125.8	125.9	–0.1
123.9	123.9	0
111.1	111.1	0
101.9	102.0	–0.1
91.6	91.7	–0.1
75.1	75.2	–0.1
56.3	56.4	–0.1
54.8	54.9	–0.1
51.8	51.8	0
41.4	41.4	0

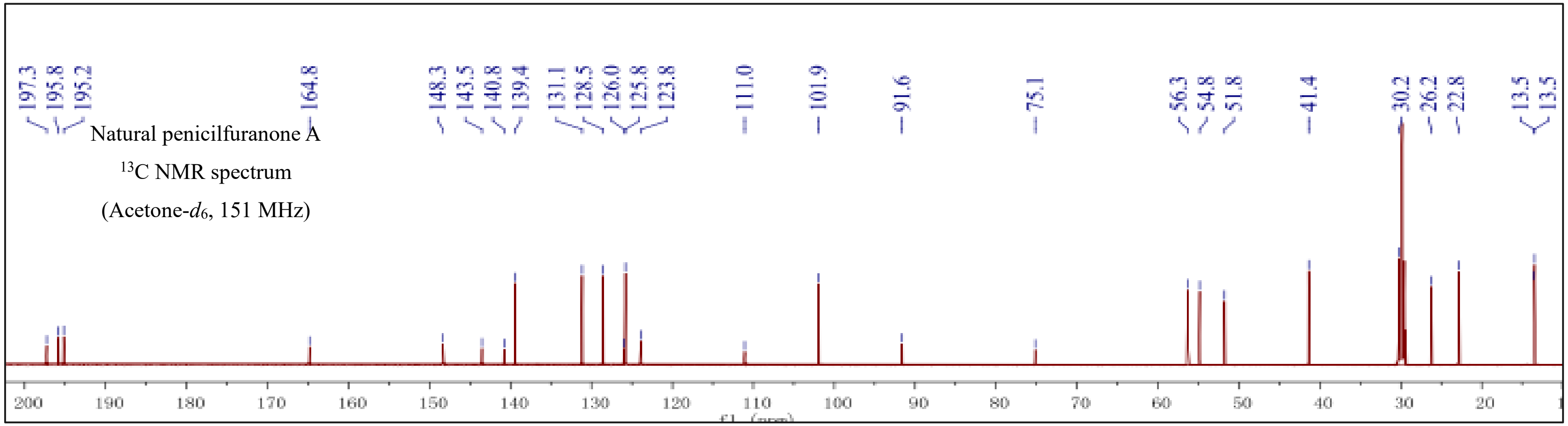
30.2	30.3	−0.1
26.2	26.3	−0.1
22.8	22.9	−0.1
13.5	13.6	−0.1
13.5	13.5	0

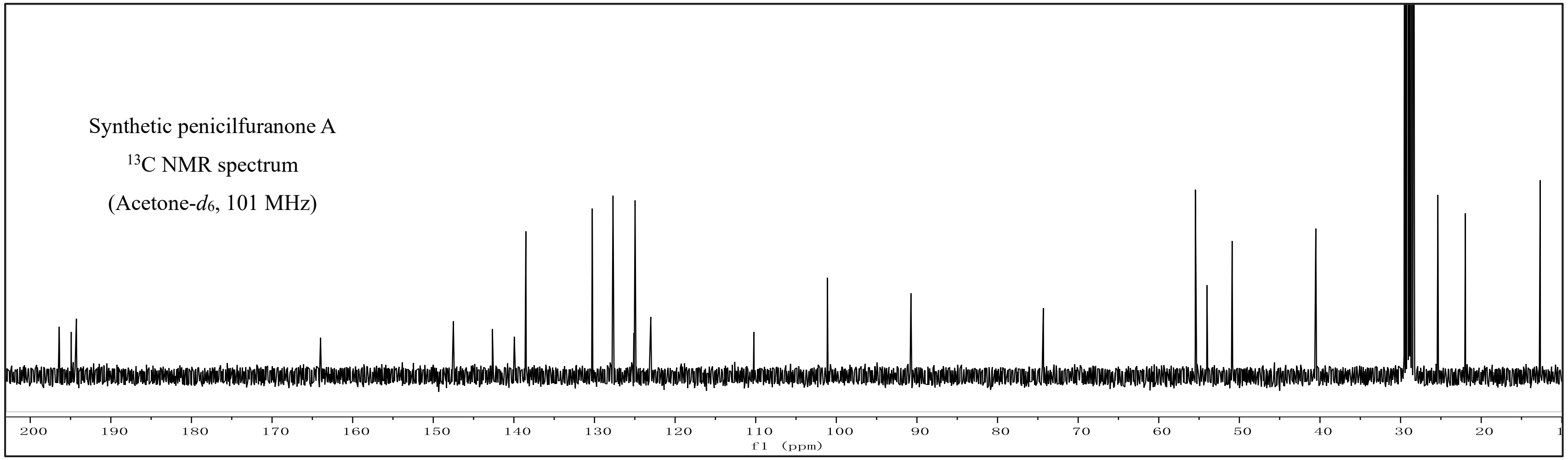
Calibrated by using Acetone-d_6 (δ_C= 29.84 ppm) as internal reference.

12. Comparison of the spectra of natural and synthetic penicilfuranone A.



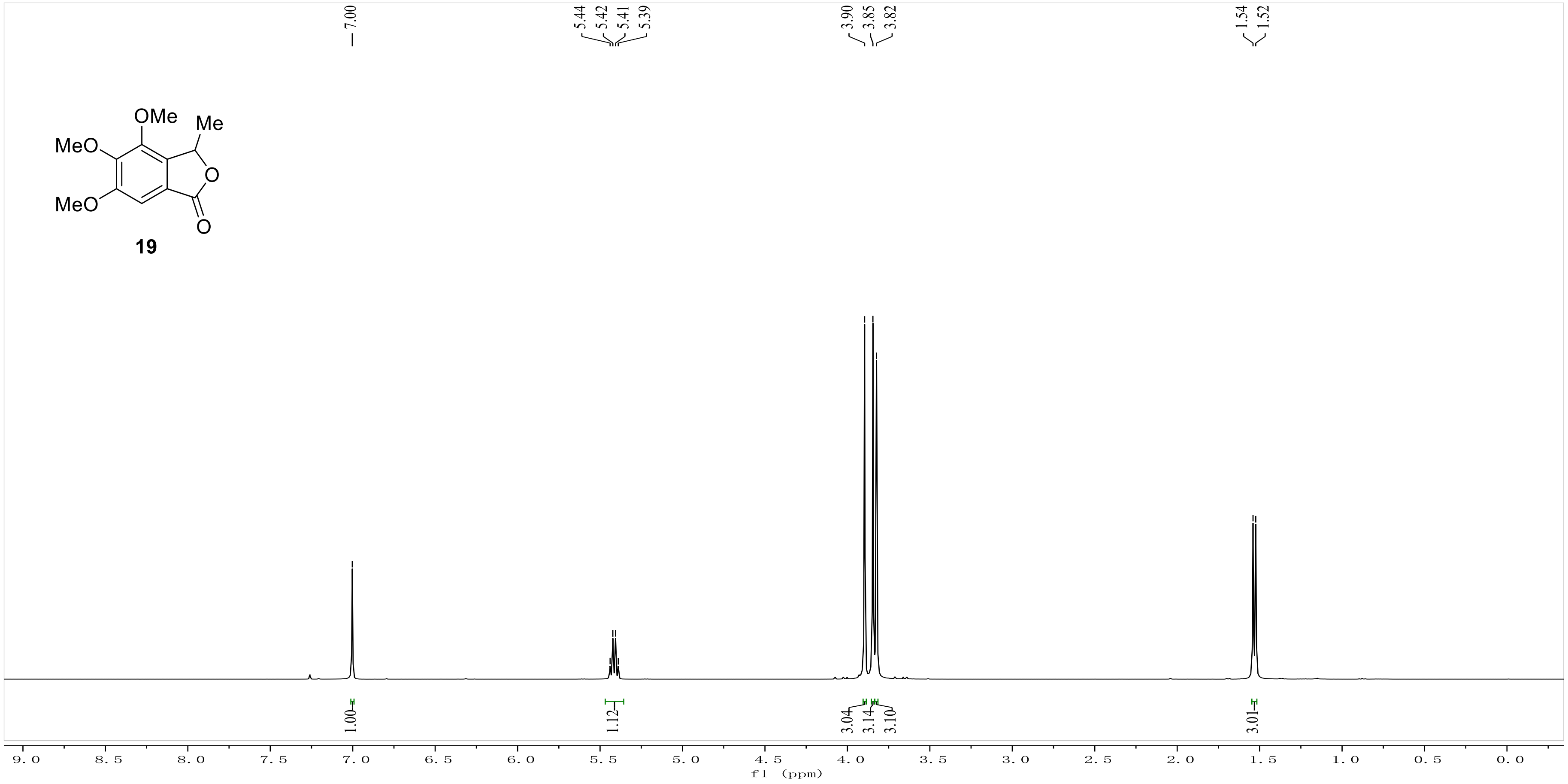



197.3
195.8
195.2
164.8
148.3
143.5
140.8
139.4
131.1
128.5
126.0
125.8
123.8
111.0
101.9
91.6
75.1
56.3
54.8
51.8
41.4
30.2
26.2
22.8
13.5
13.5
Natural penicilfuranone A
^{13}C NMR spectrum
(Acetone-d_6, 151 MHz)
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
f1 (ppm)

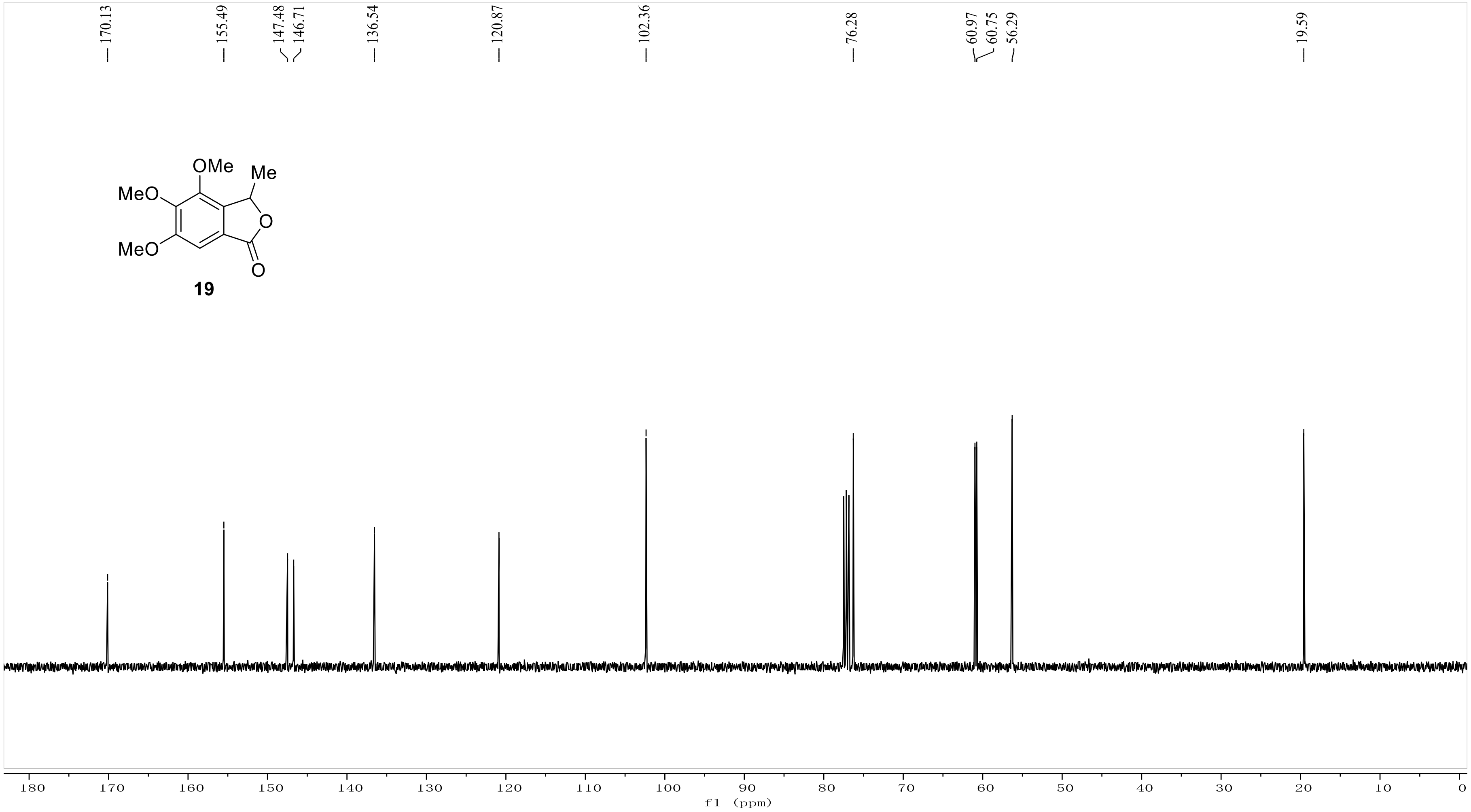

Synthetic penicilfuranone A
^{13}C NMR spectrum
(Acetone-d_6, 101 MHz)
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
f1 (ppm)

13. ^{1}H and ^{13}C NMR spectra of compounds.

^{1}H NMR Spectrum of 19 (400 MHz, $CDCl_3$)

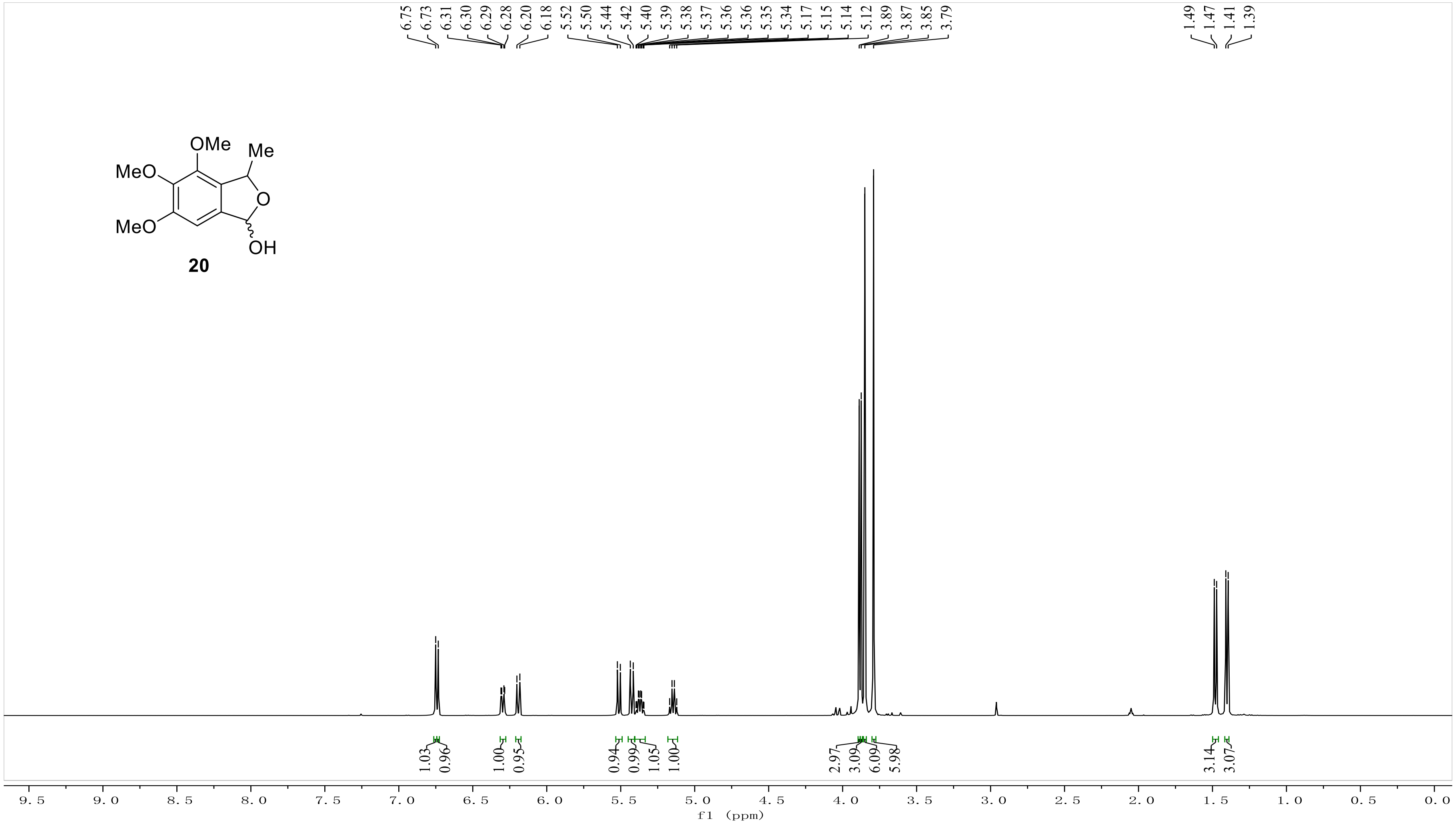


^{13}C NMR Spectrum of 19 (101 MHz, CDCl$_3$)

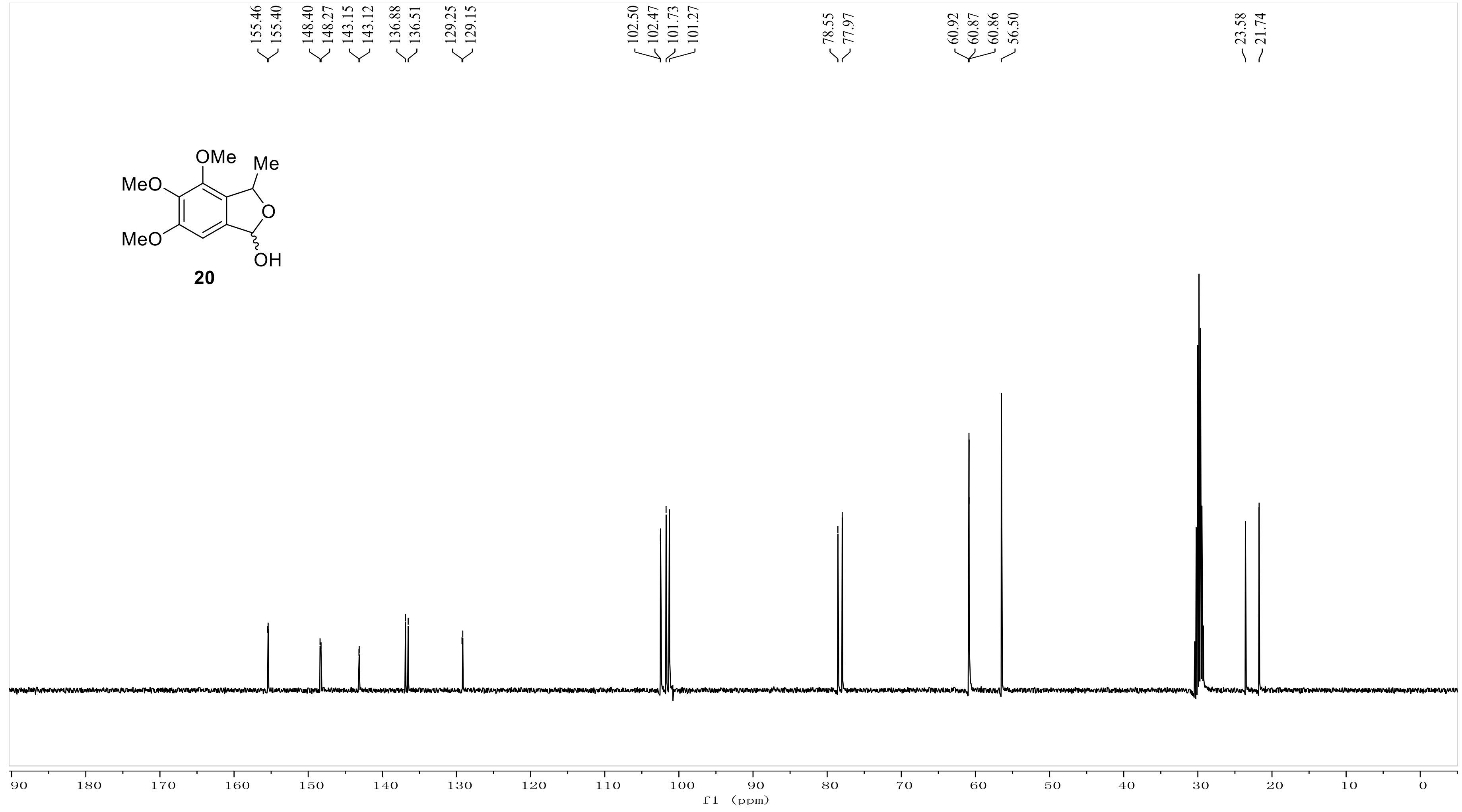


19

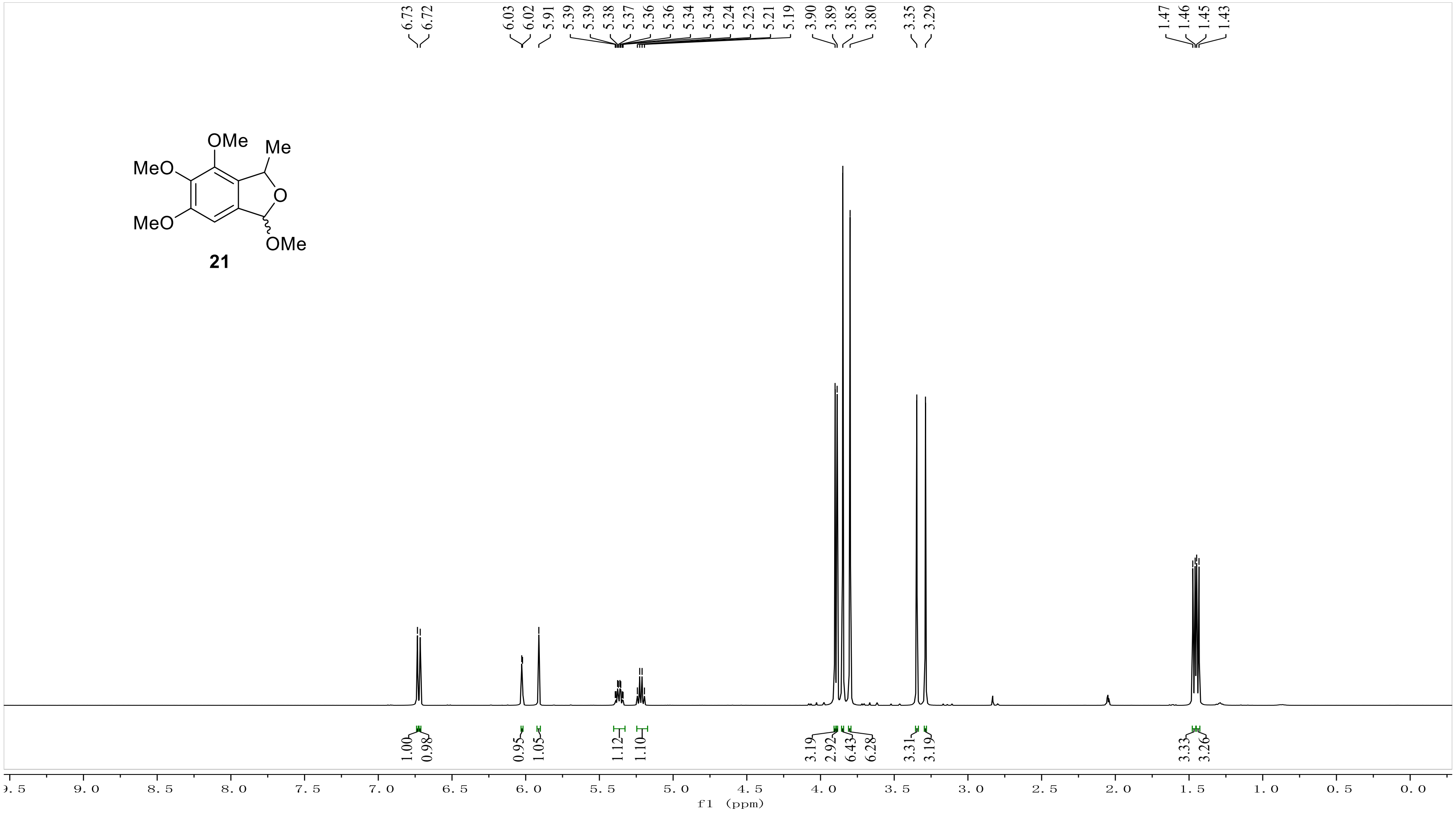
^{1}H NMR Spectrum of 20 (400 MHz, Acetone-d_6)



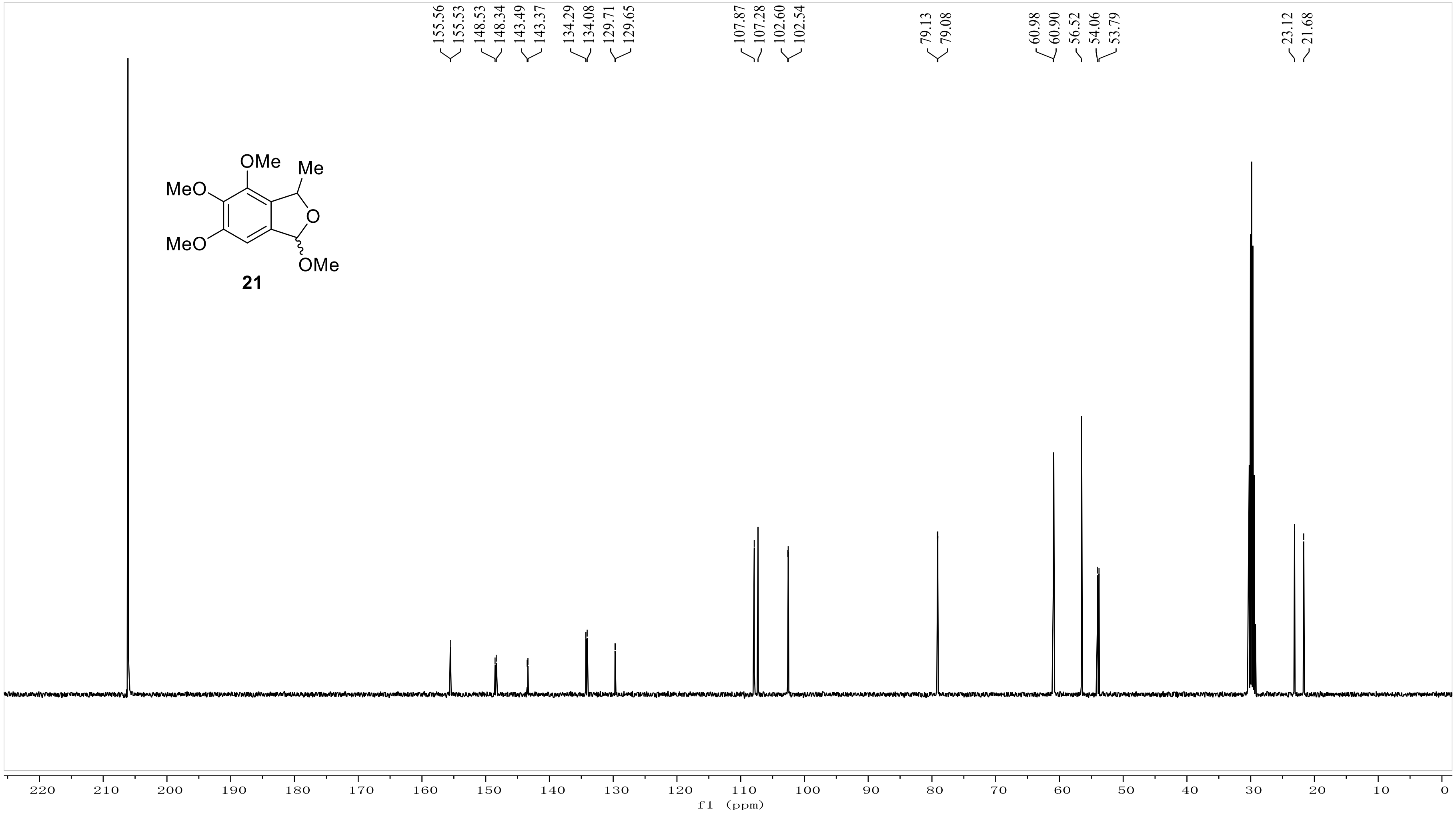
^{13}C NMR Spectrum of 20 (101 MHz, Acetone-d_6)



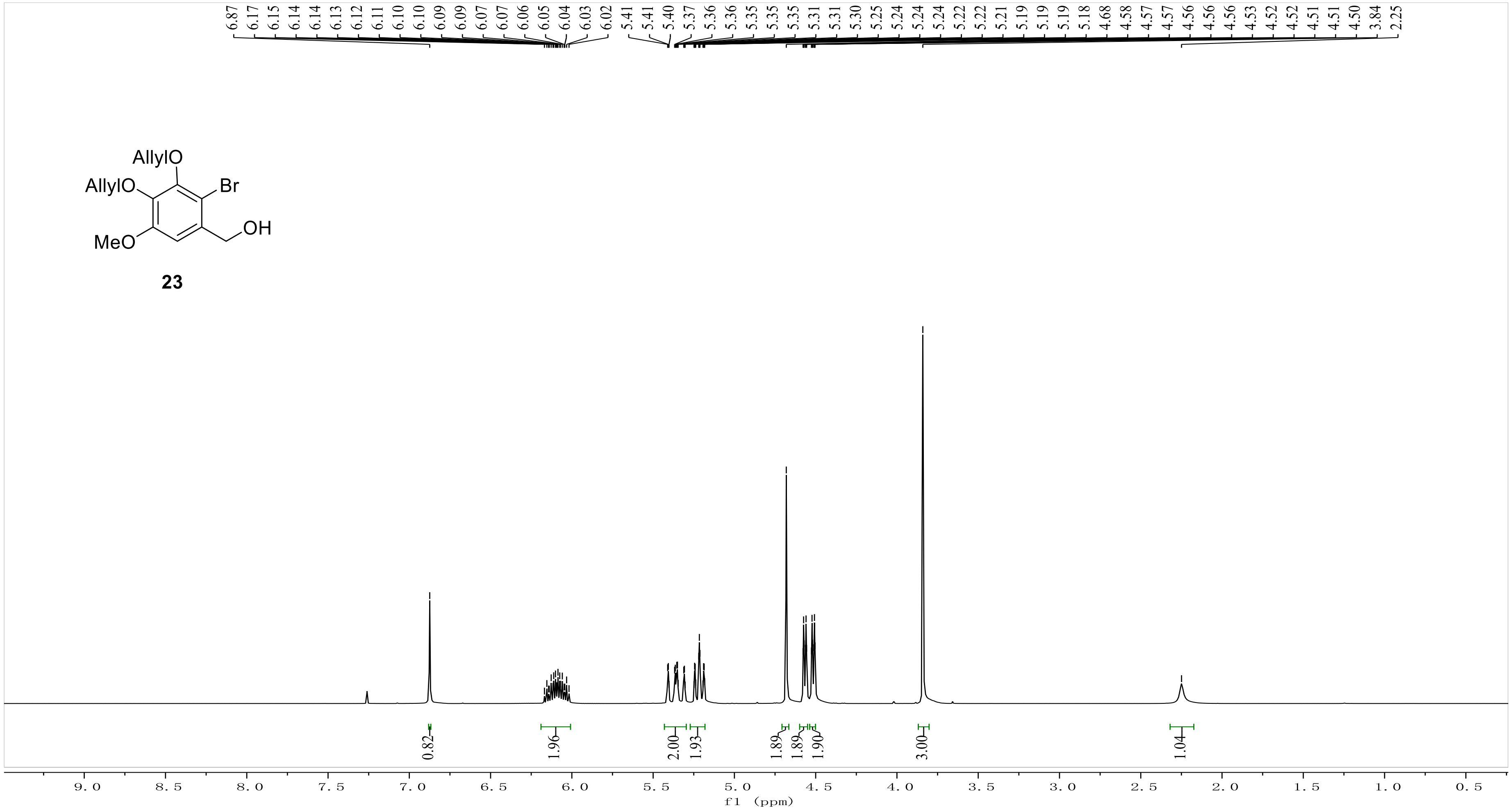
^{1}H NMR Spectrum of 21 (400 MHz, Acetone-d_6)



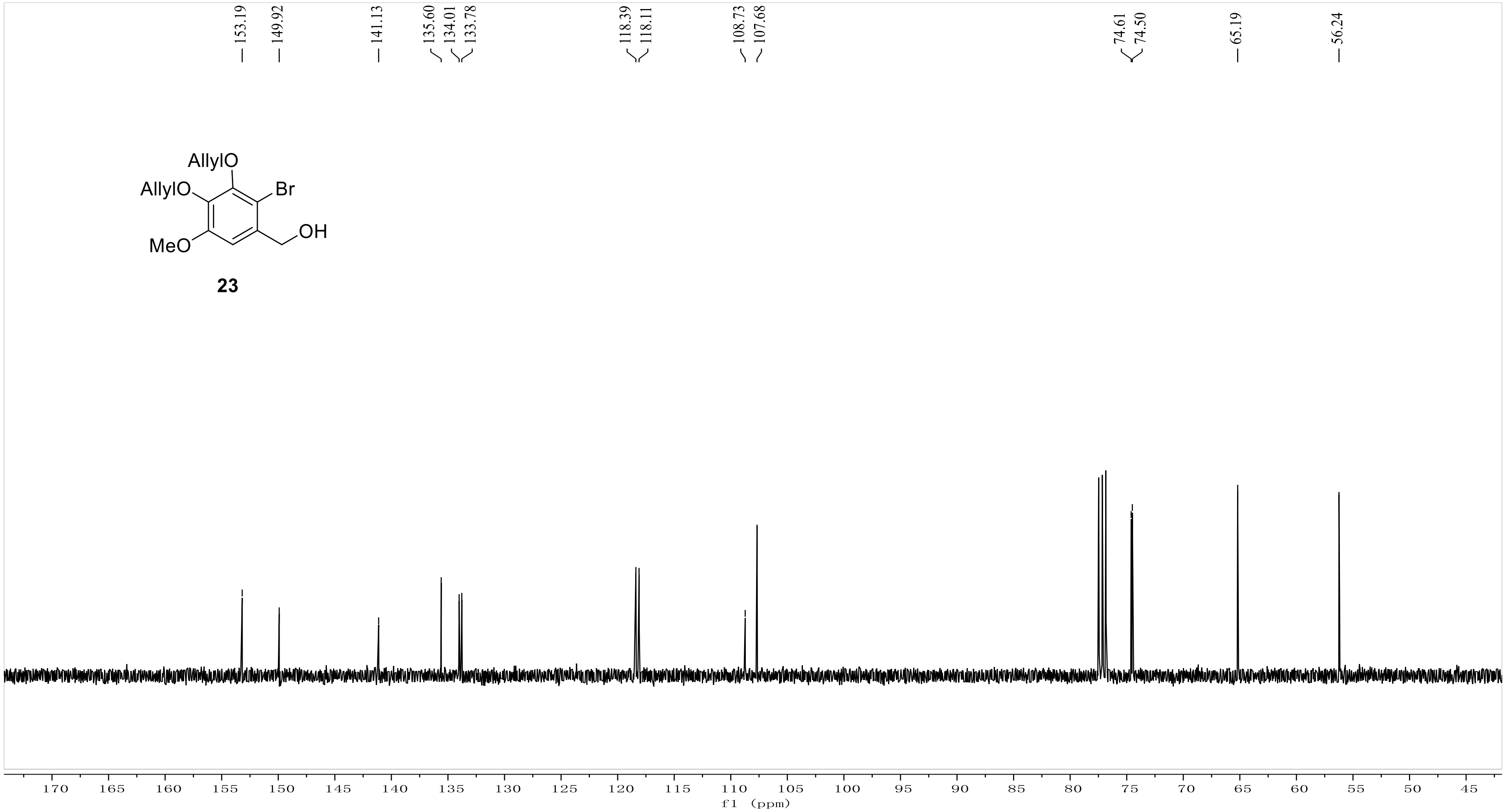
^{13}C NMR Spectrum of 21 (101 MHz, Acetone-*d*$_6$)



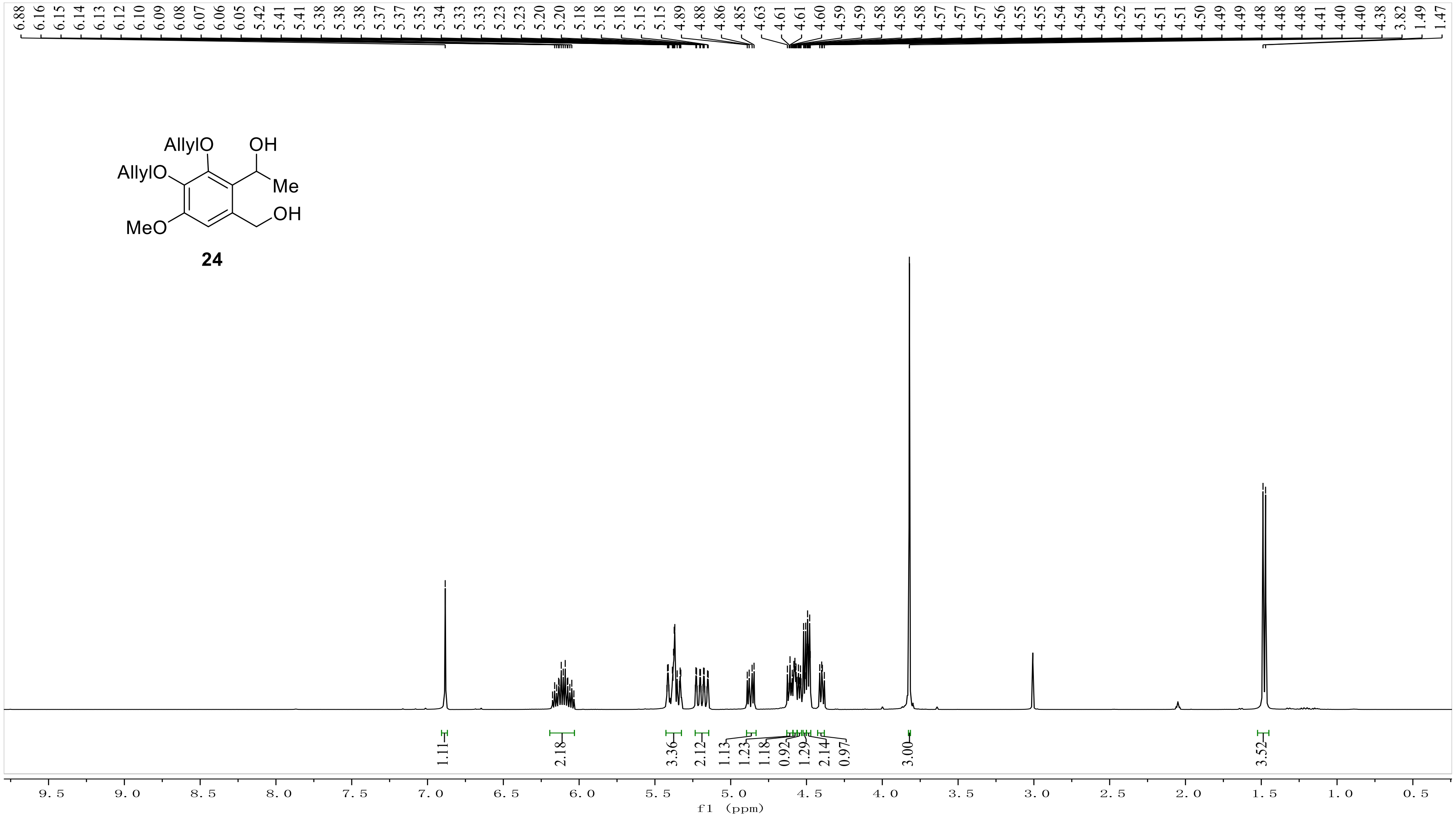
^{1}H NMR Spectrum of 23 (400 MHz, $CDCl_3$)



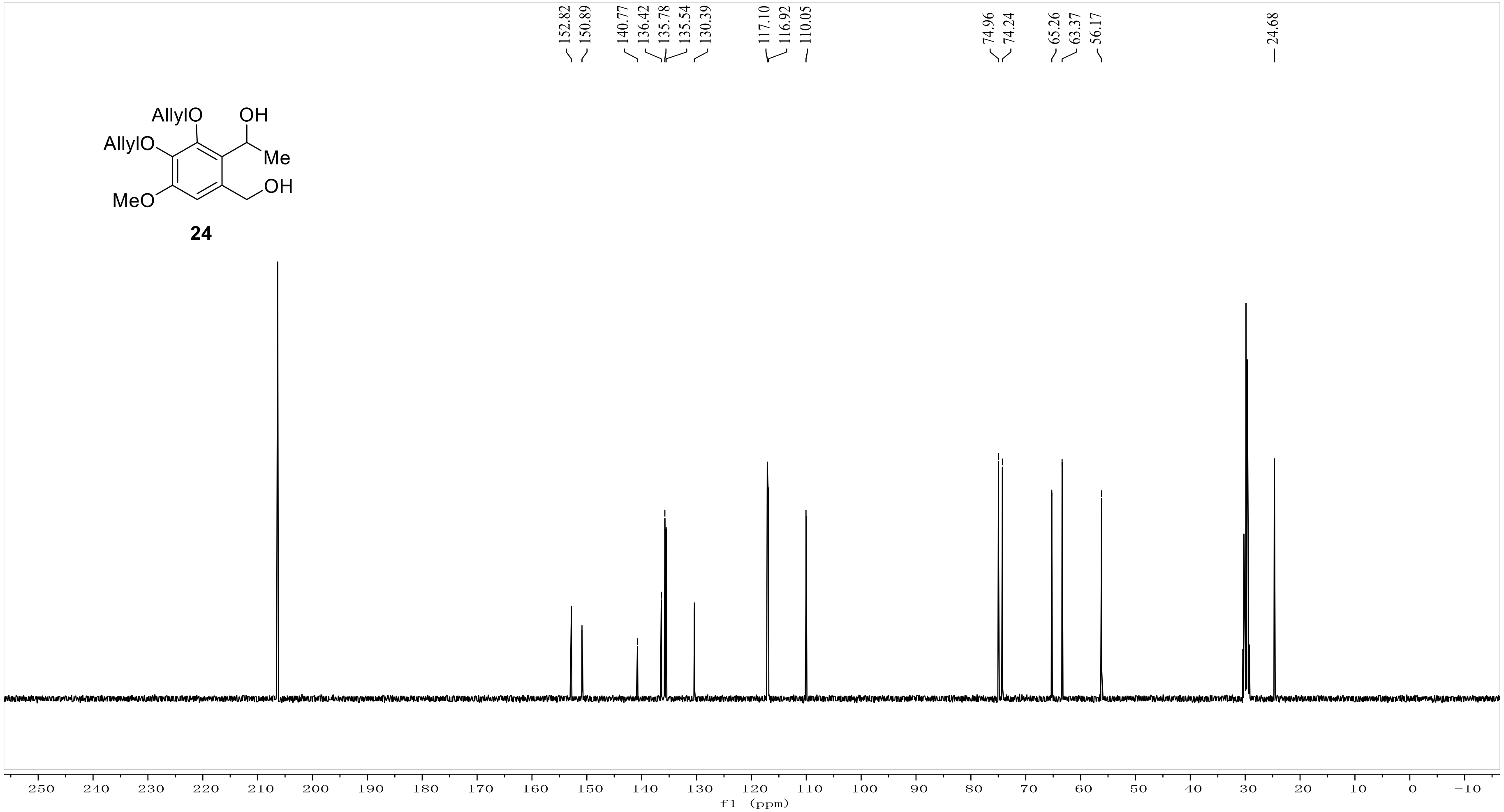
^{13}C NMR Spectrum of 23 (101 MHz, $CDCl_3$)



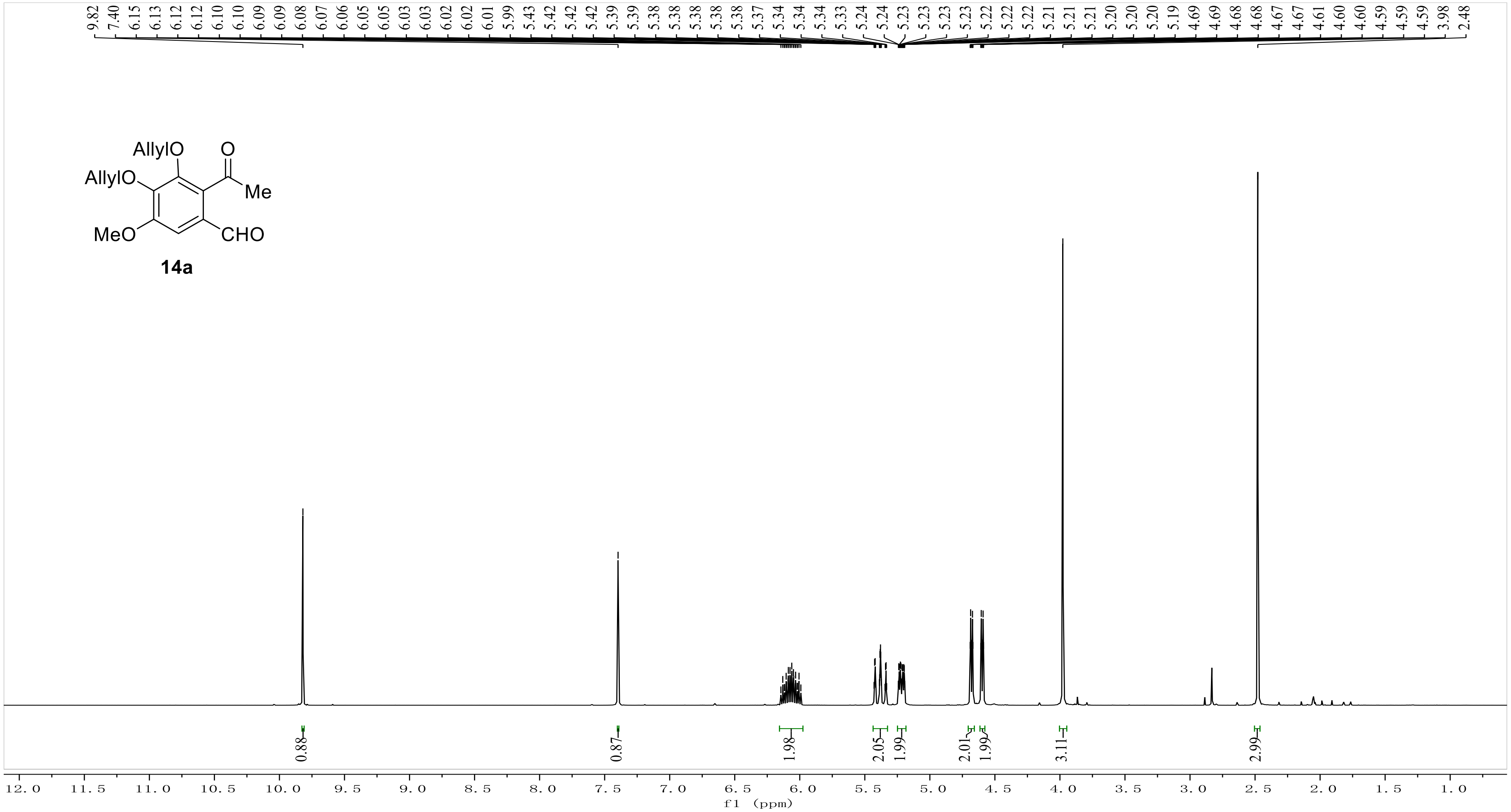
^{1}H NMR Spectrum of 24 (400 MHz, Acetone-d_6)



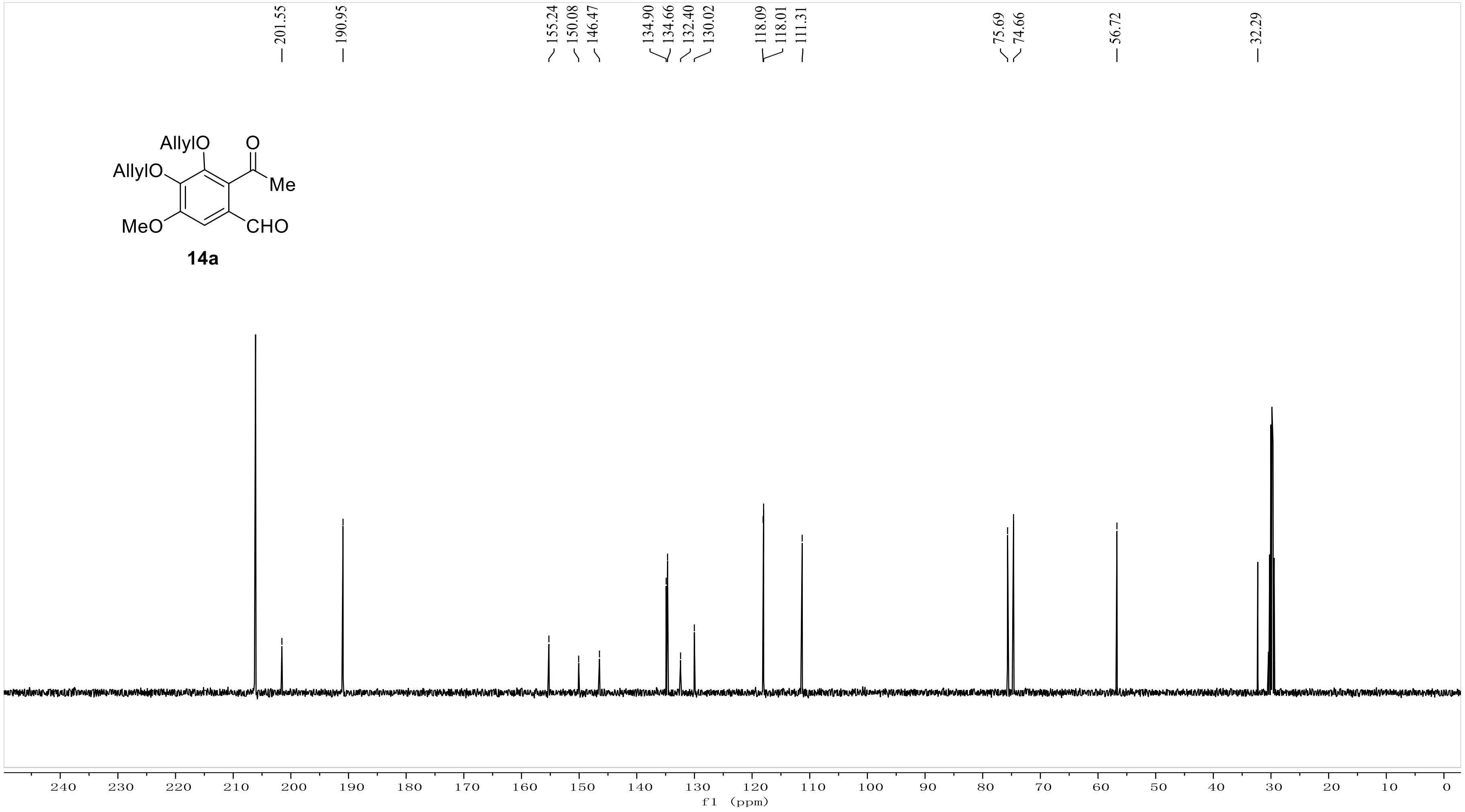
^{13}C NMR Spectrum of 24 (101 MHz, Acetone-d_6)



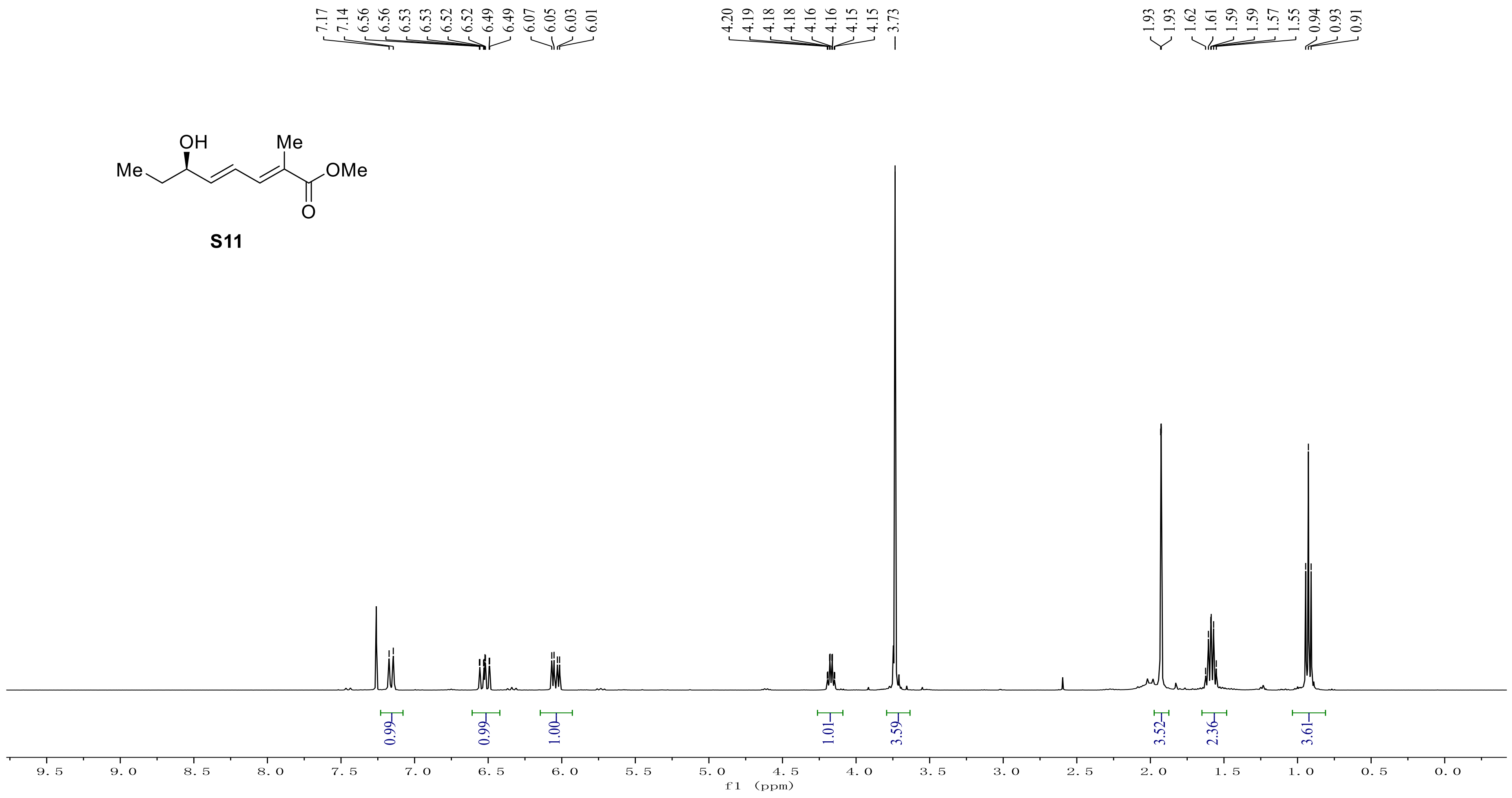
^{1}H NMR Spectrum of 14a (400 MHz, Acetone-d_6)



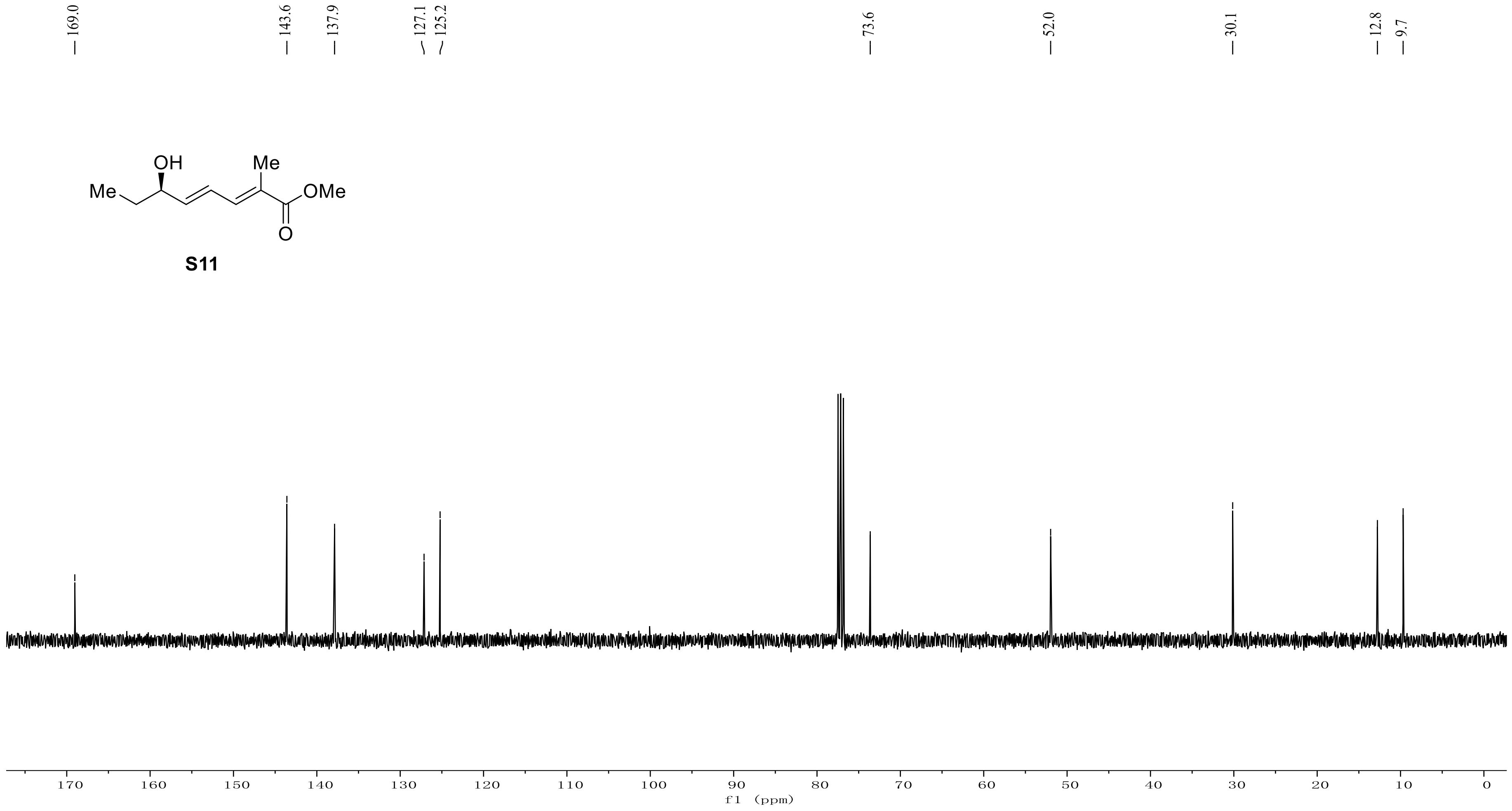
^{13}C NMR Spectrum of 14a (101 MHz, Acetone-d_6)



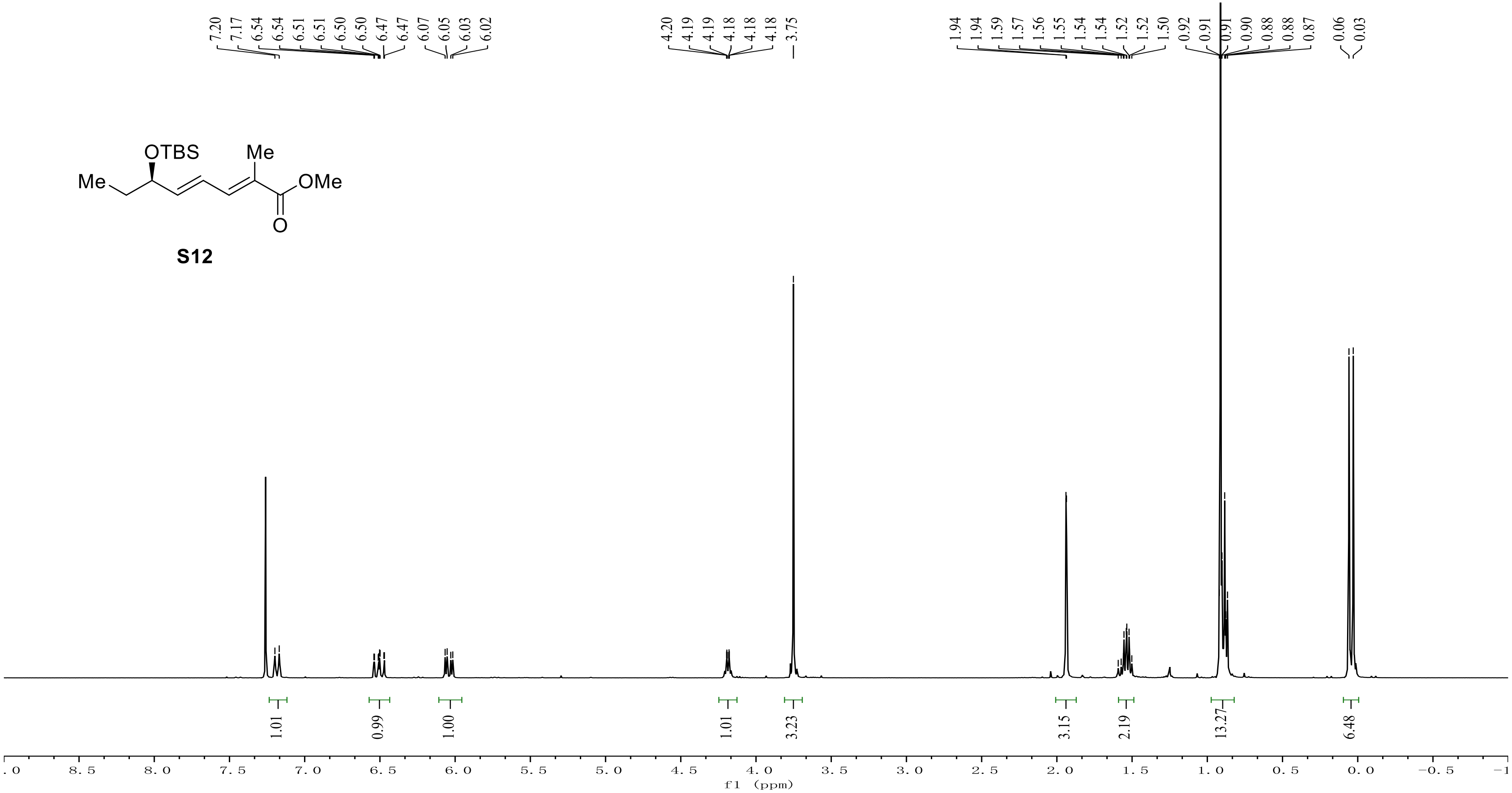
^{1}H NMR Spectrum of S11 (400 MHz, $CDCl_3$)



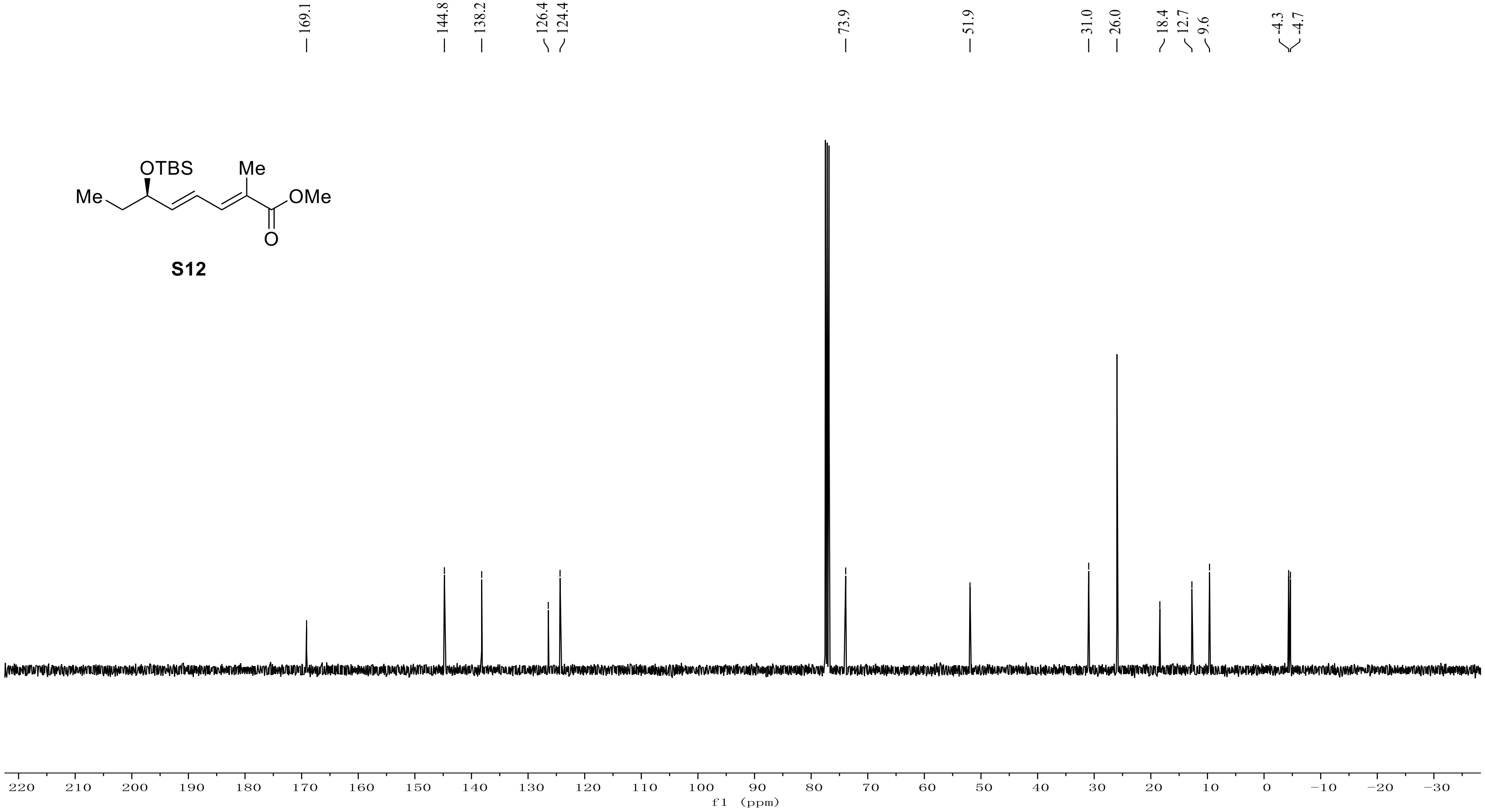
^{13}C NMR Spectrum of S11 (101 MHz, CDCl$_3$)



^{1}H NMR Spectrum of S12 (400 MHz, CDCl$_3$)

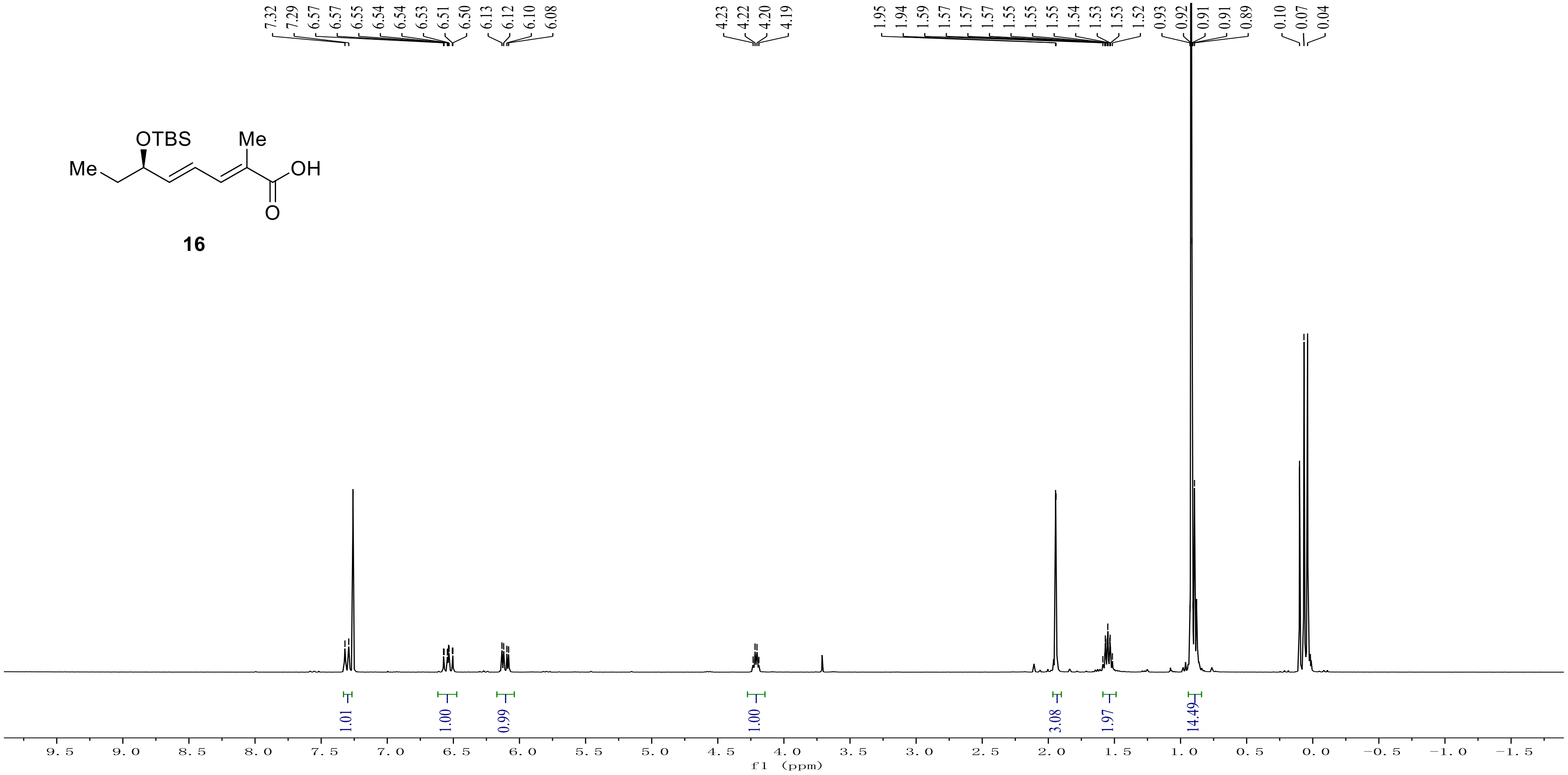


^{13}C NMR Spectrum of S12 (101 MHz, CDCl$_3$)

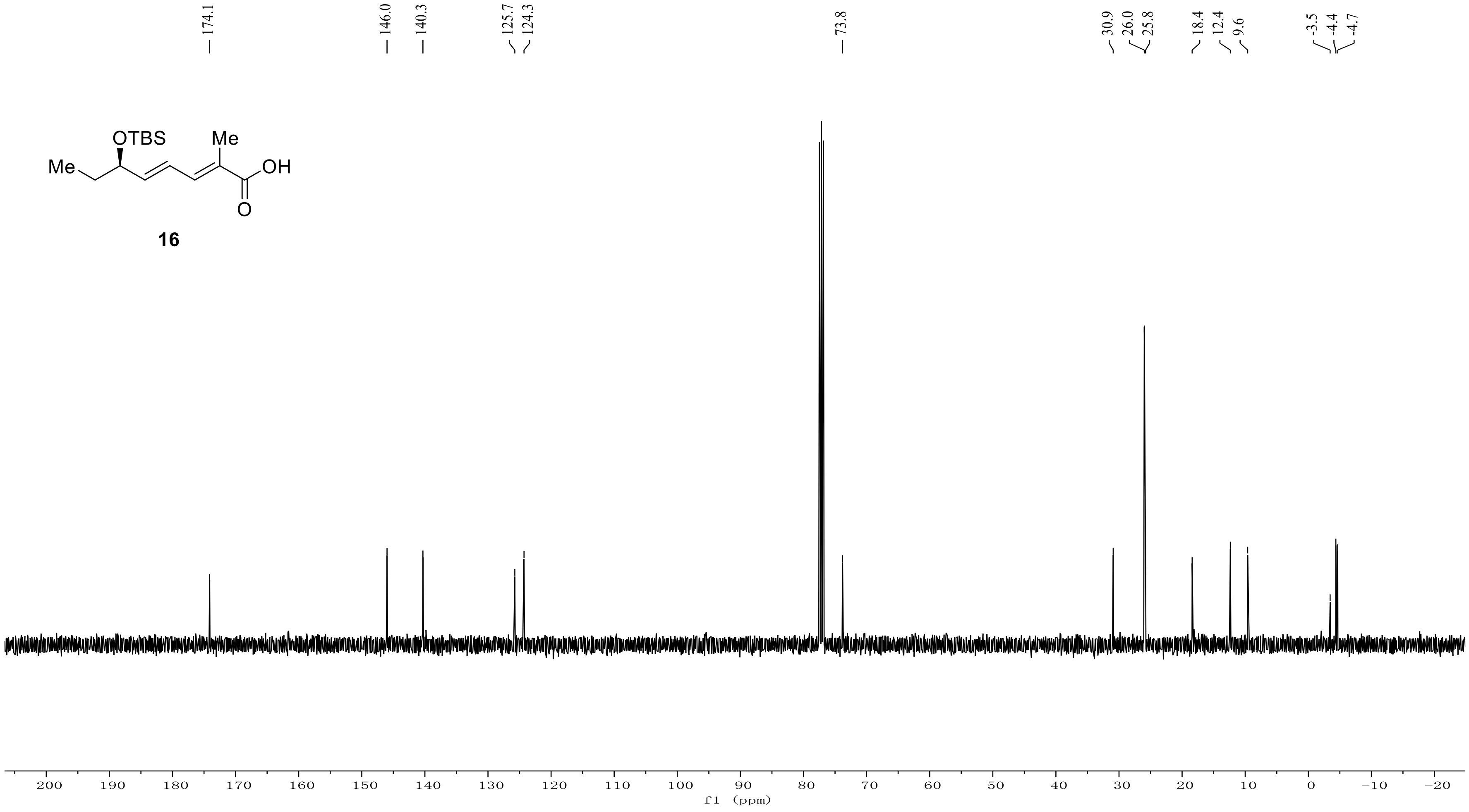


^{1}H NMR Spectrum of 16 (400 MHz, CDCl$_3$)

16

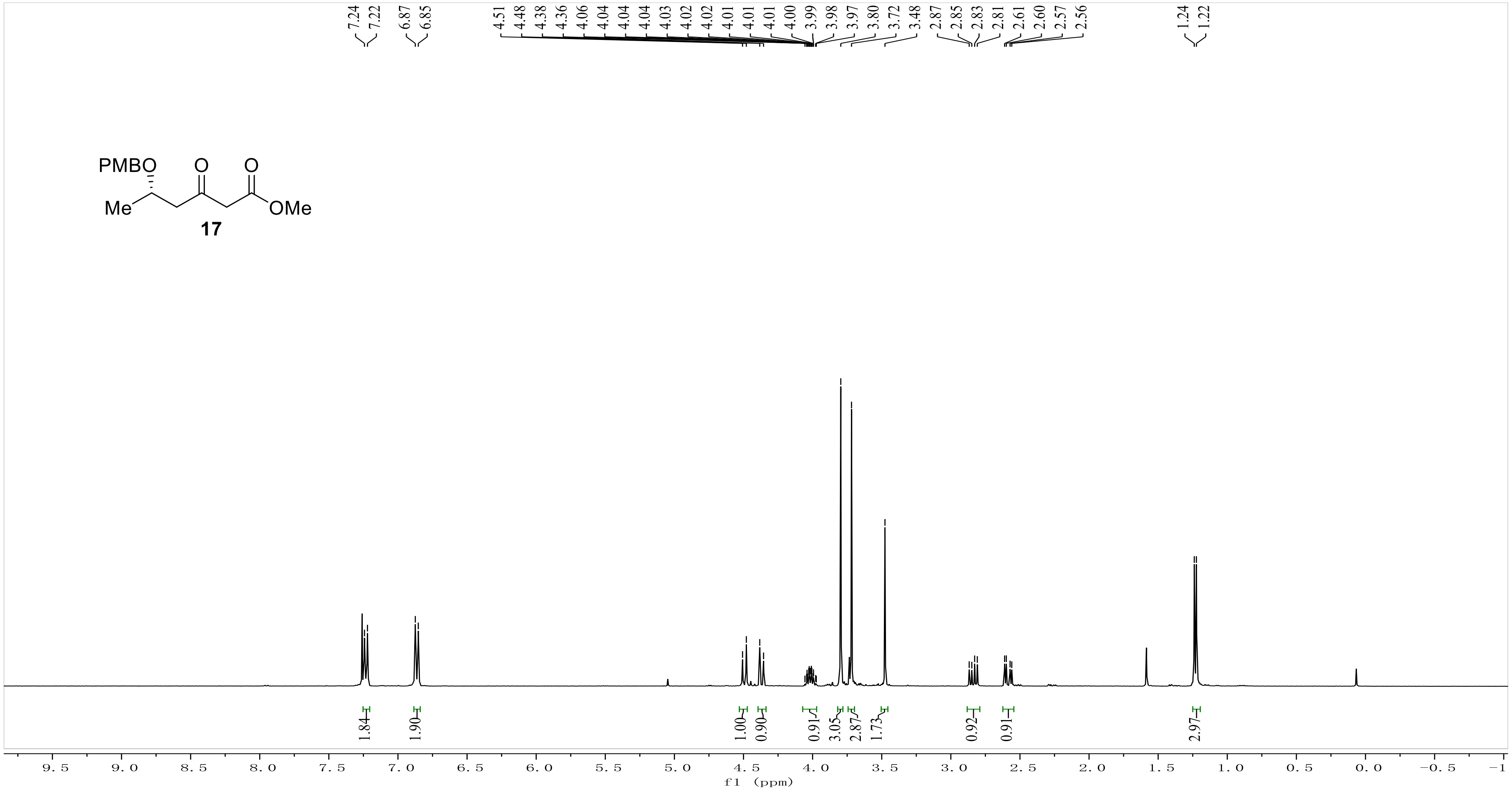


^{13}C NMR Spectrum of 16 (101 MHz, CDCl$_3$)

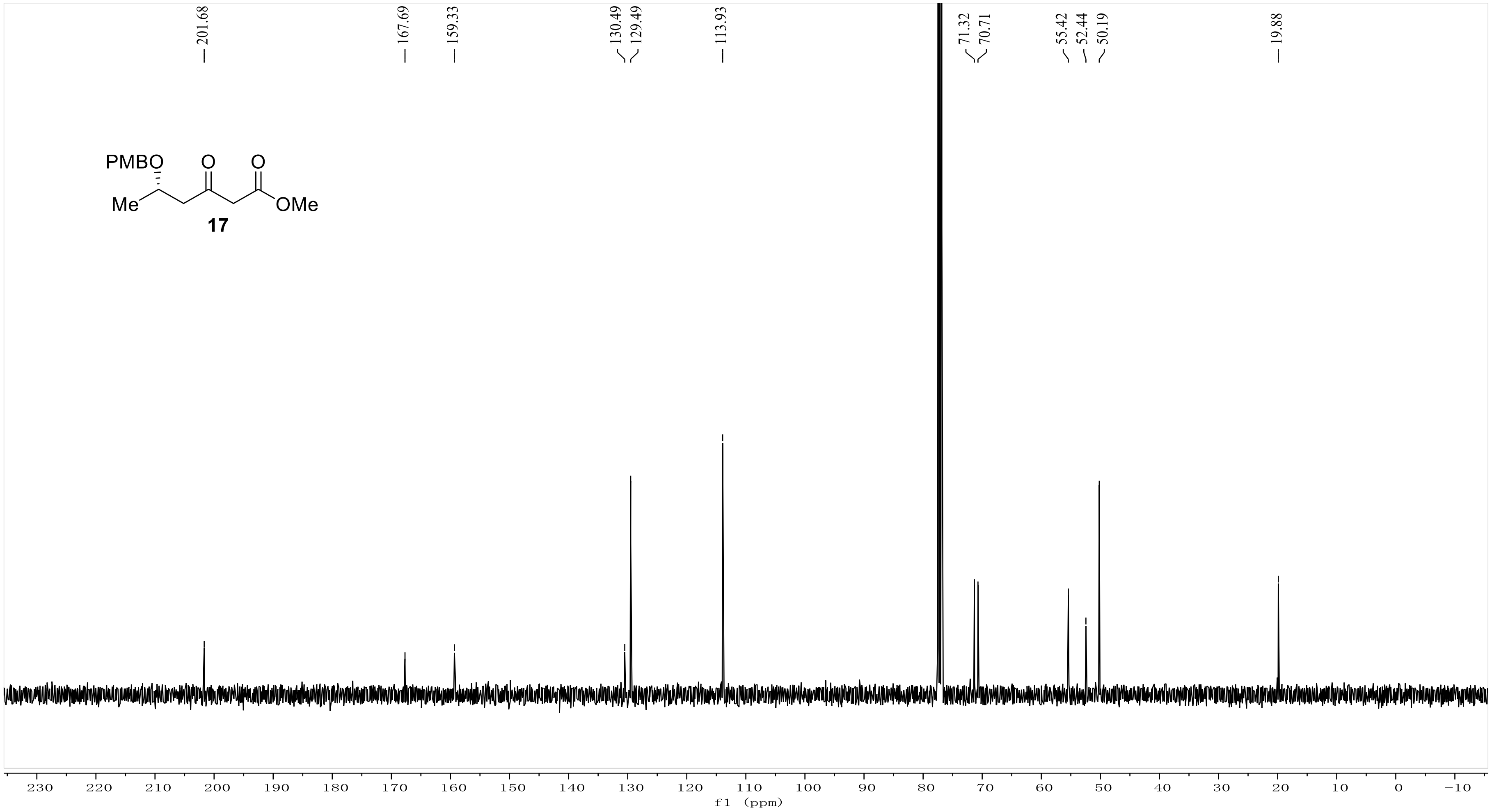


^{1}H NMR Spectrum of 17 (400 MHz, CDCl$_3$)

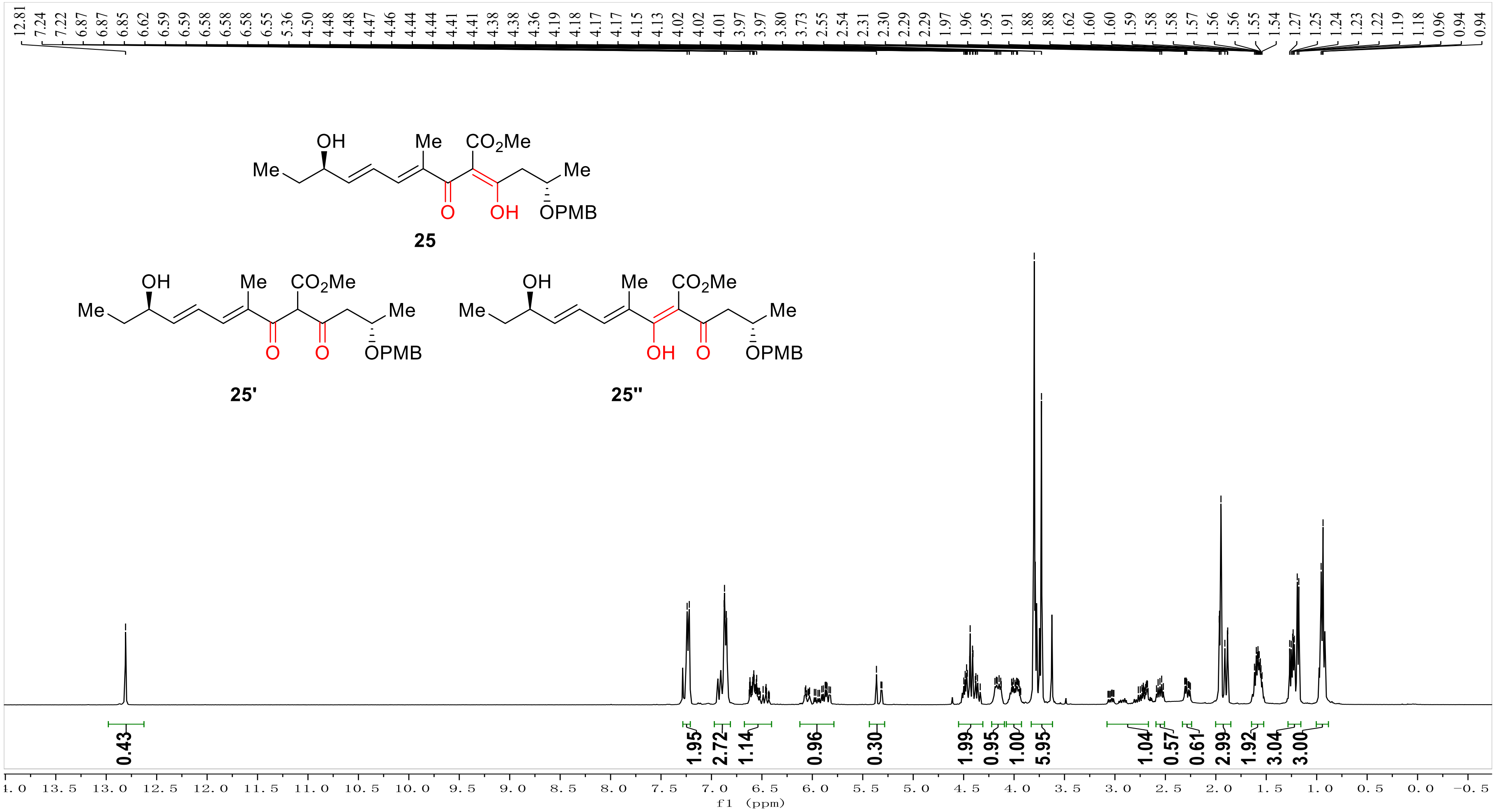
17



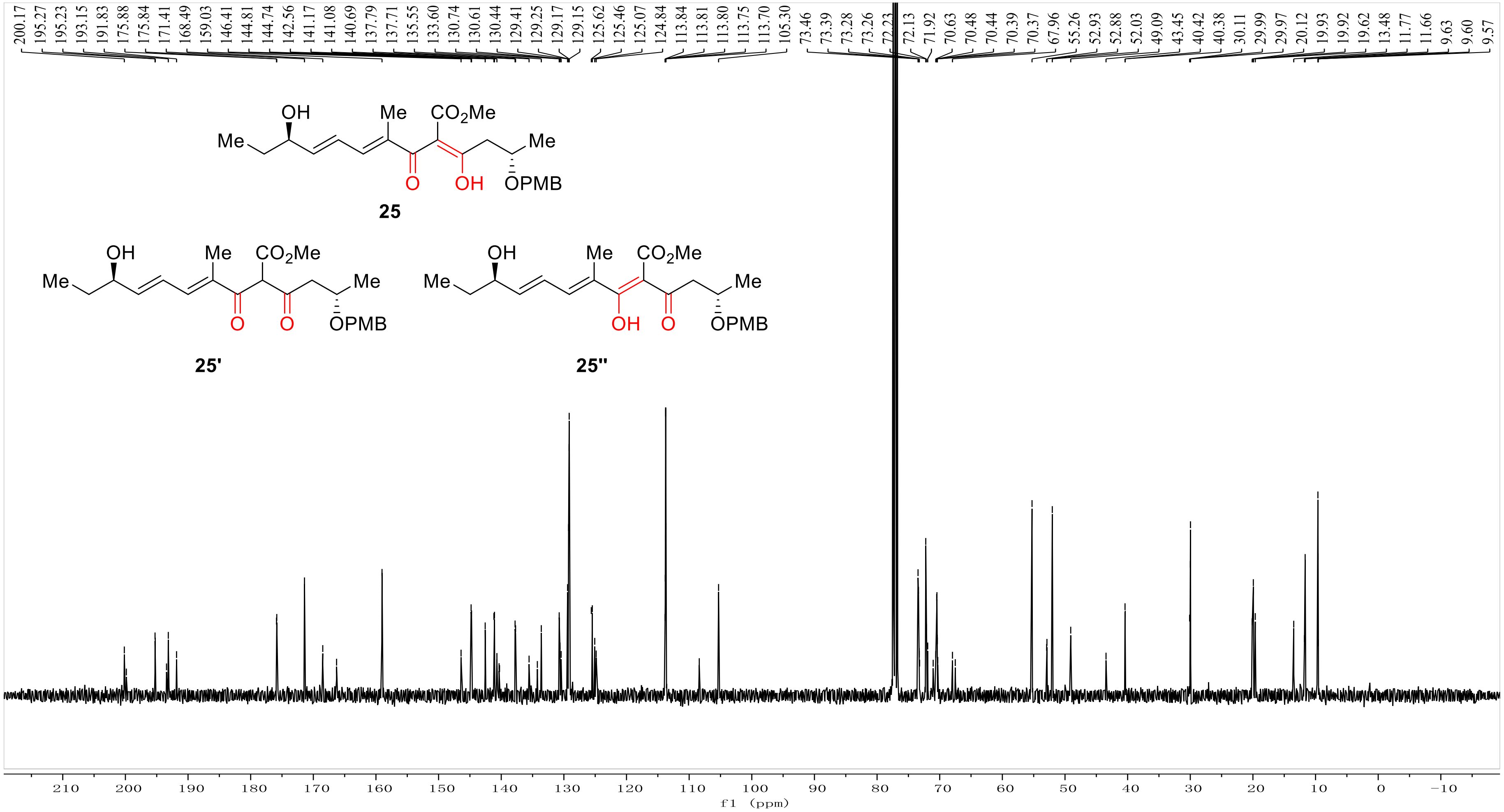
^{13}C NMR Spectrum of 17 (101 MHz, CDCl$_3$)



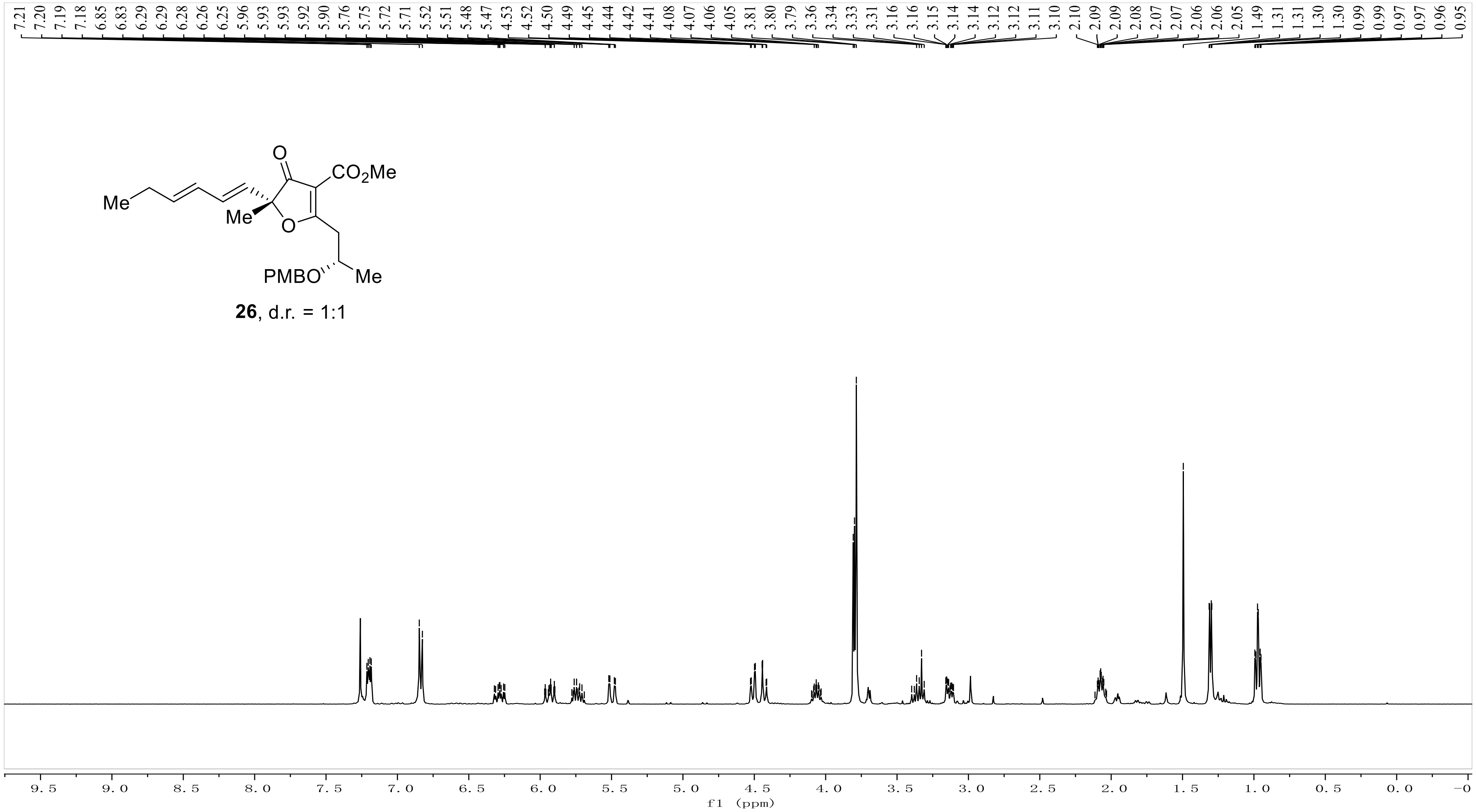
^1H NMR Spectrum of 25 (400 MHz, $CDCl_3$)



^{13}C NMR Spectrum of 25 (101 MHz, CDCl$_3$)

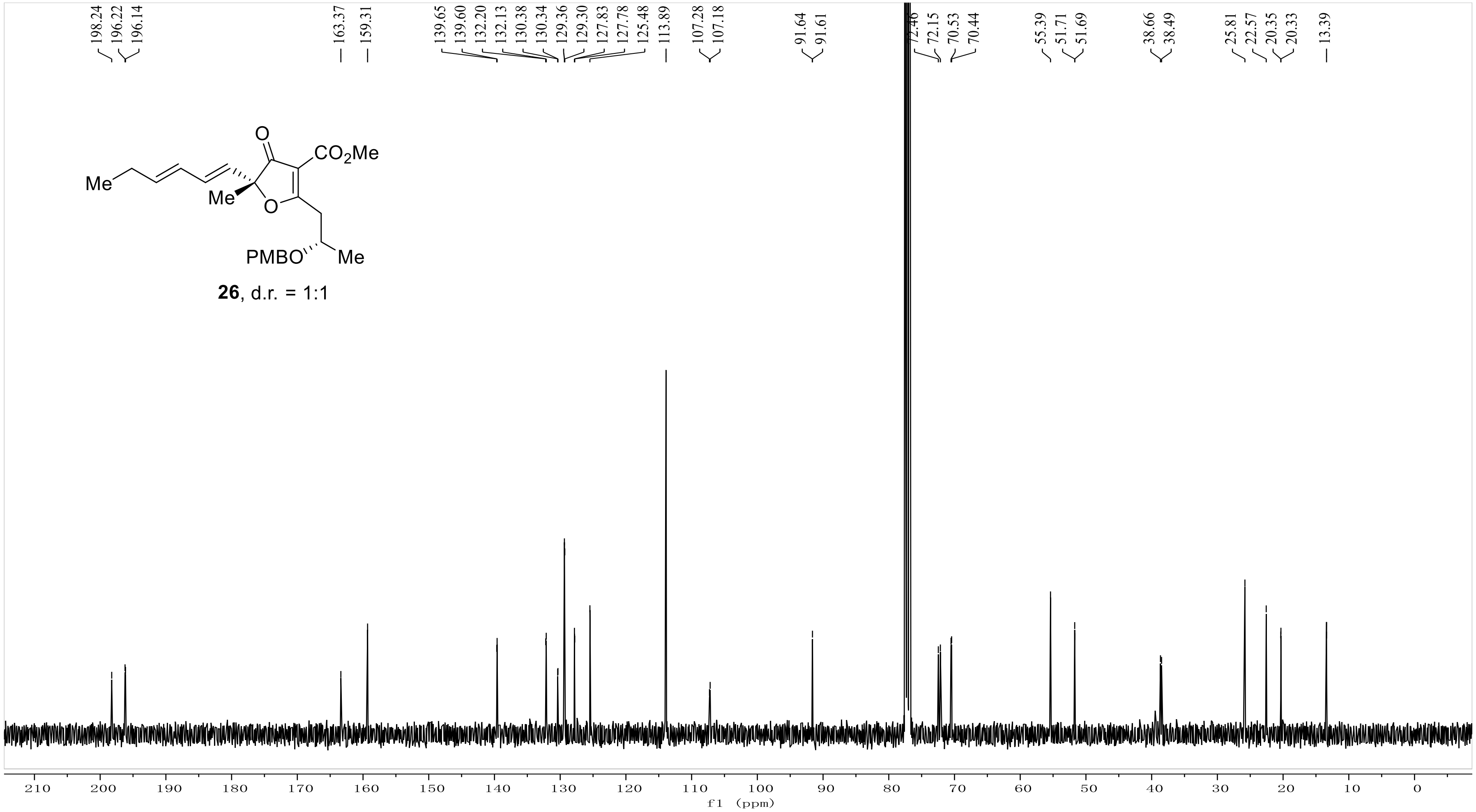


^{1}H NMR Spectrum of 26 (400 MHz, CDCl$_3$)

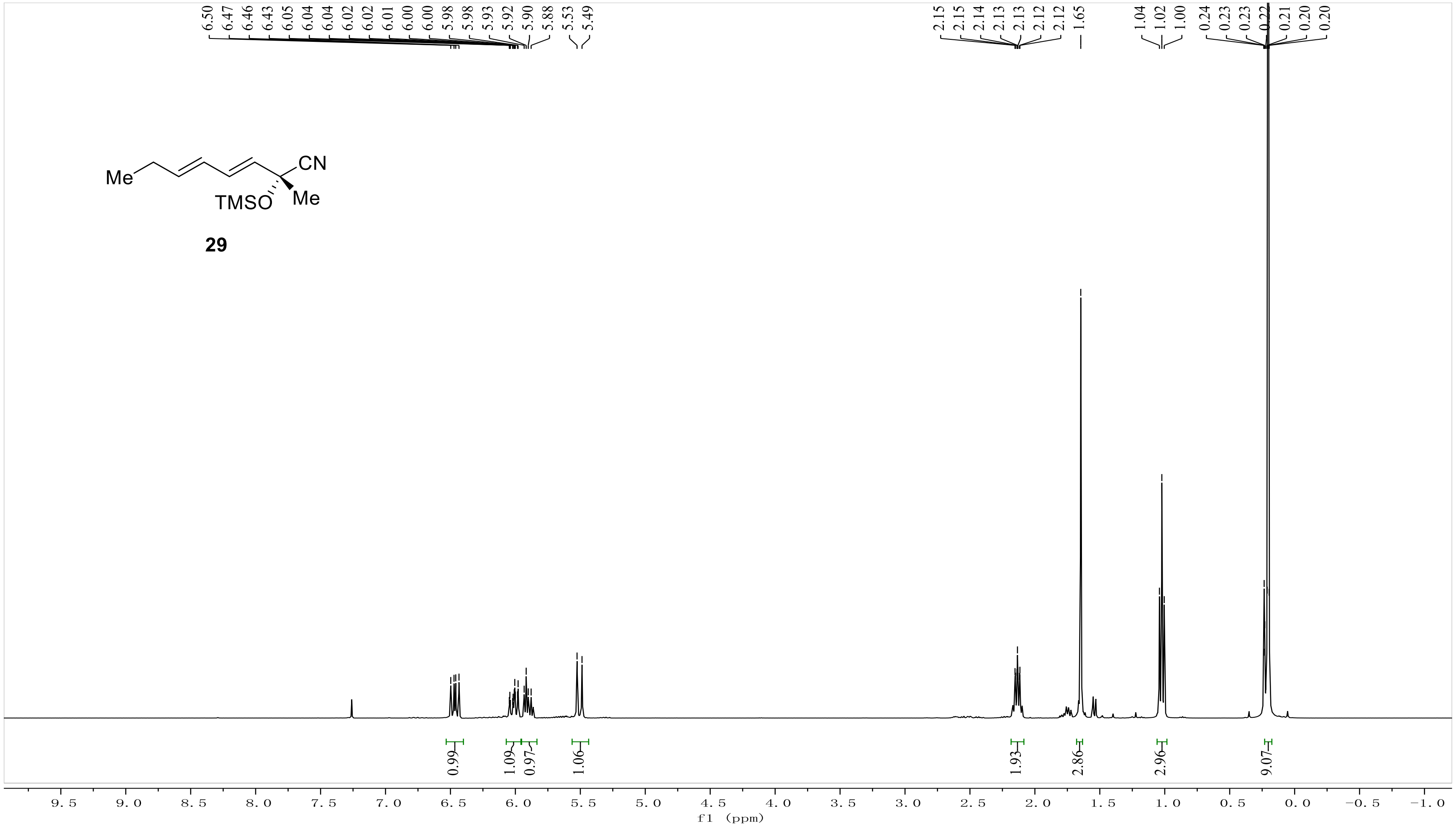


26, d.r. = 1:1

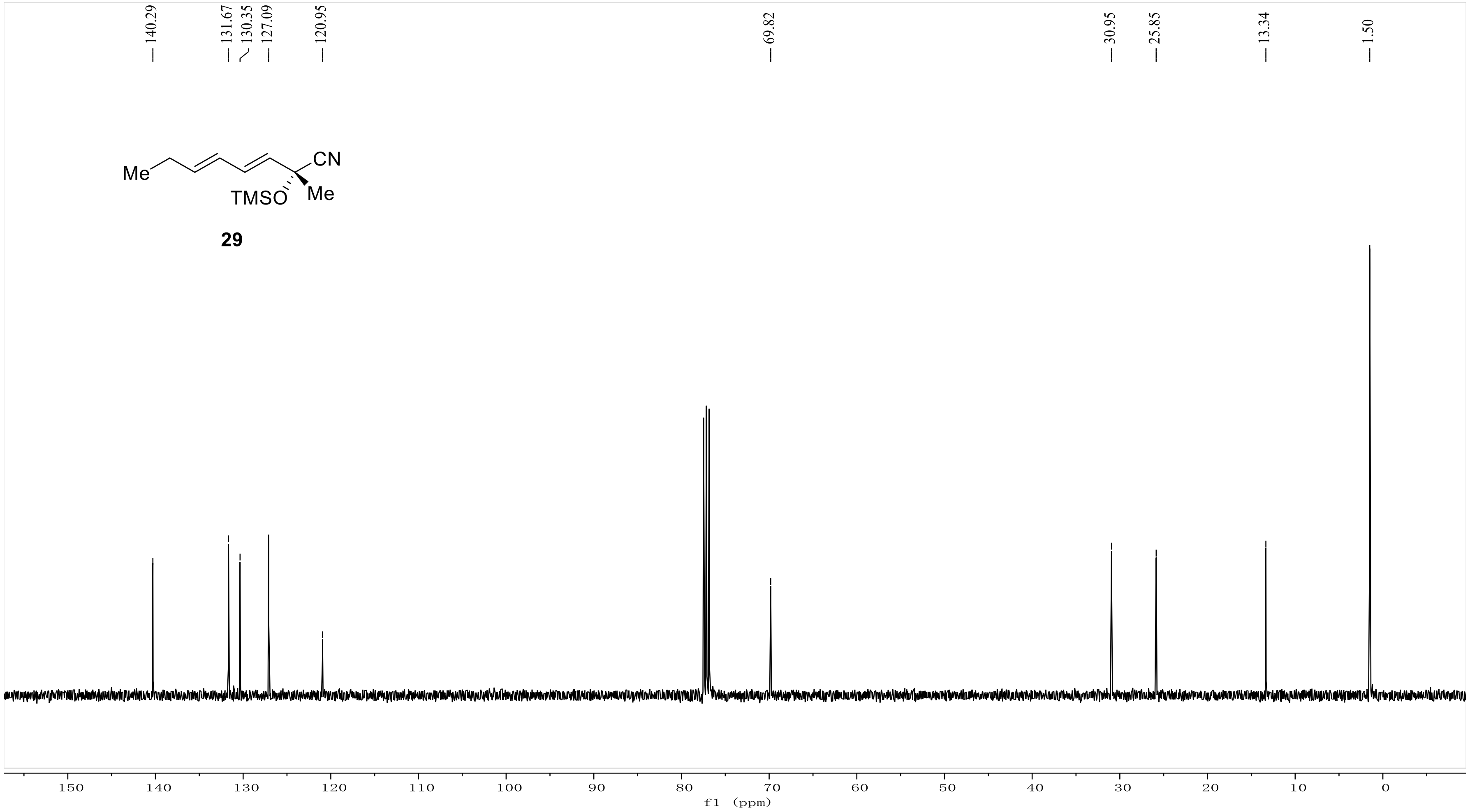
^{13}C NMR Spectrum of 26 (101 MHz, CDCl$_3$)



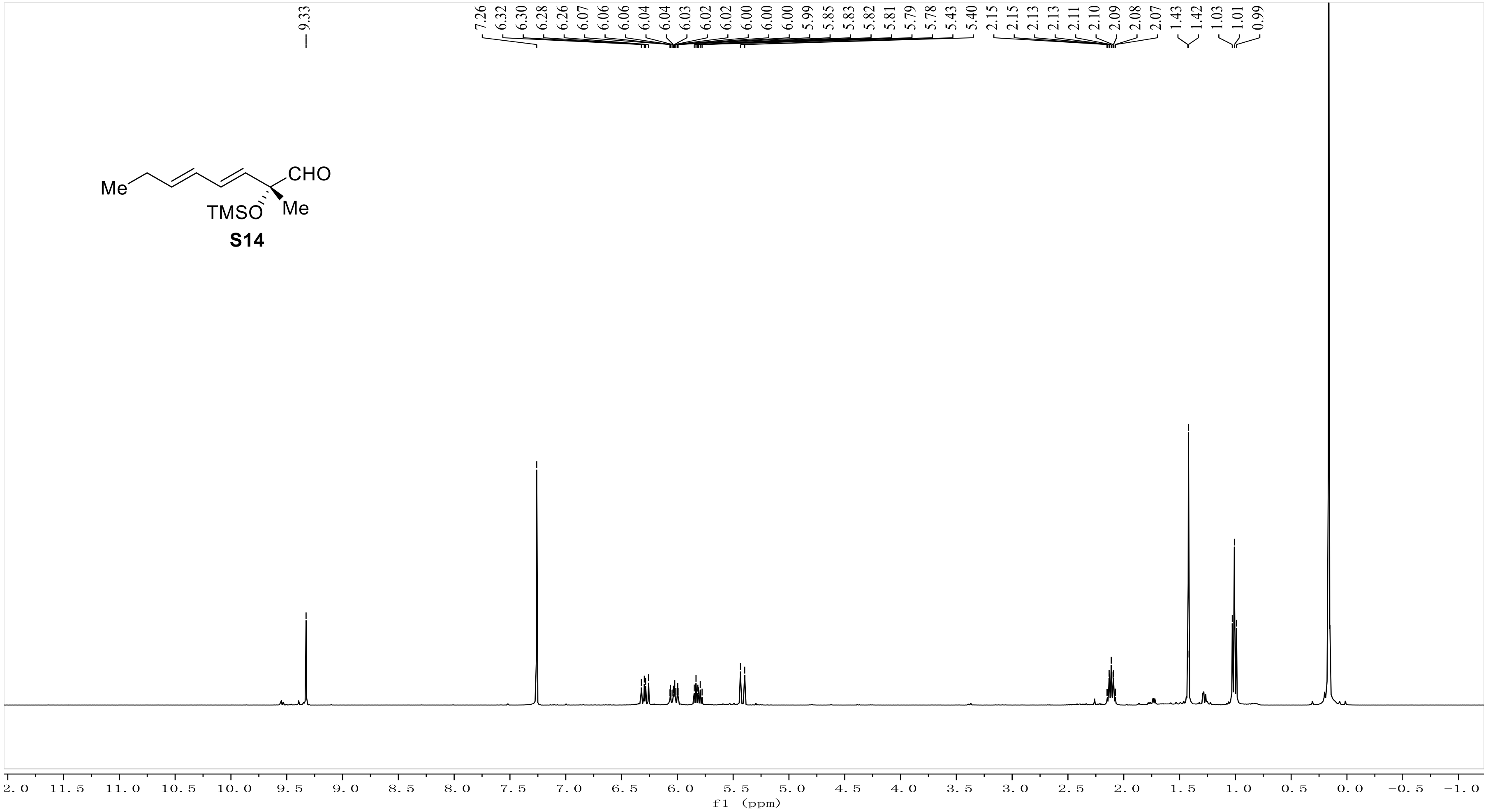
^{1}H NMR Spectrum of 29 (400 MHz, $CDCl_3$)



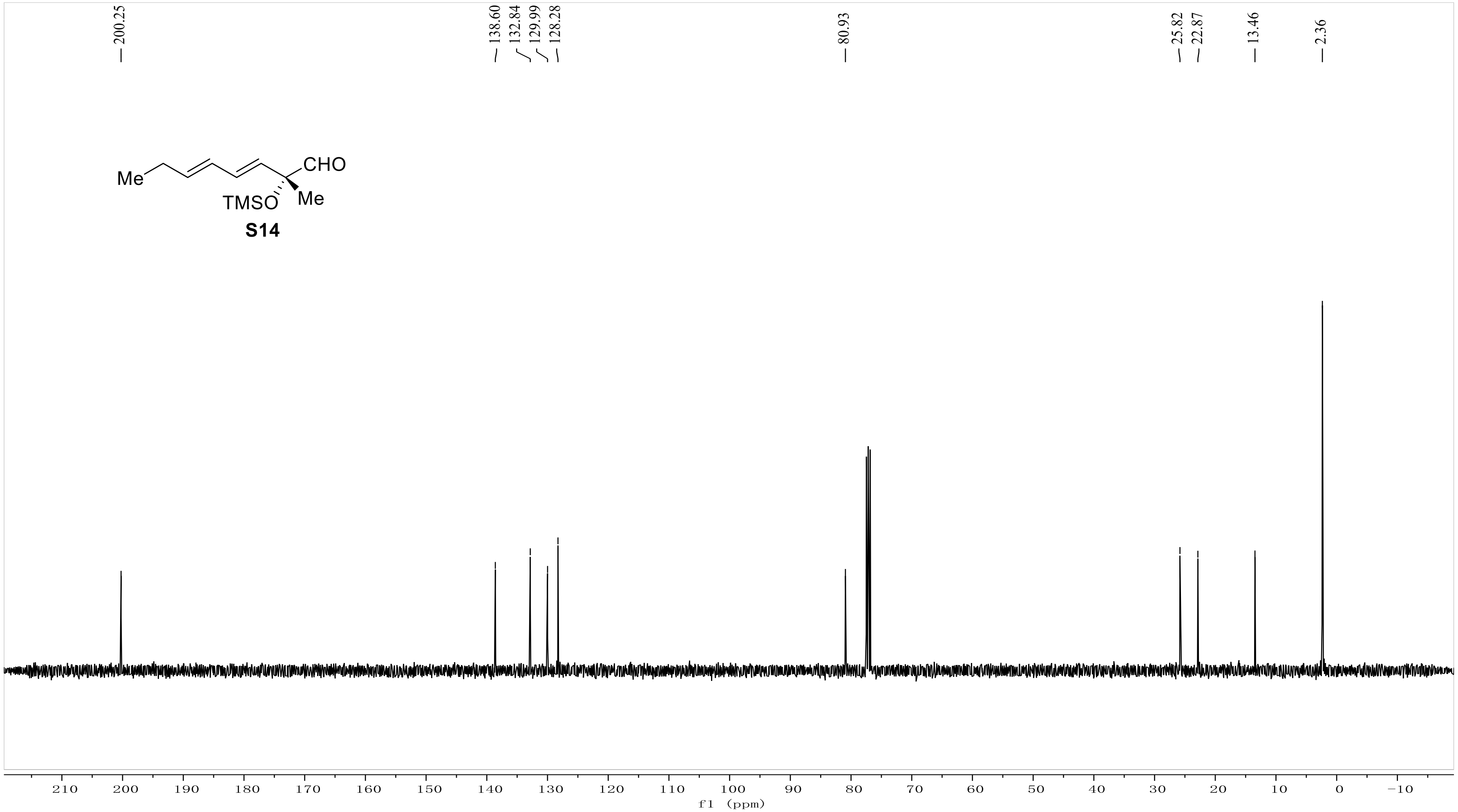
^{13}C NMR Spectrum of 29 (101 MHz, CDCl$_3$)



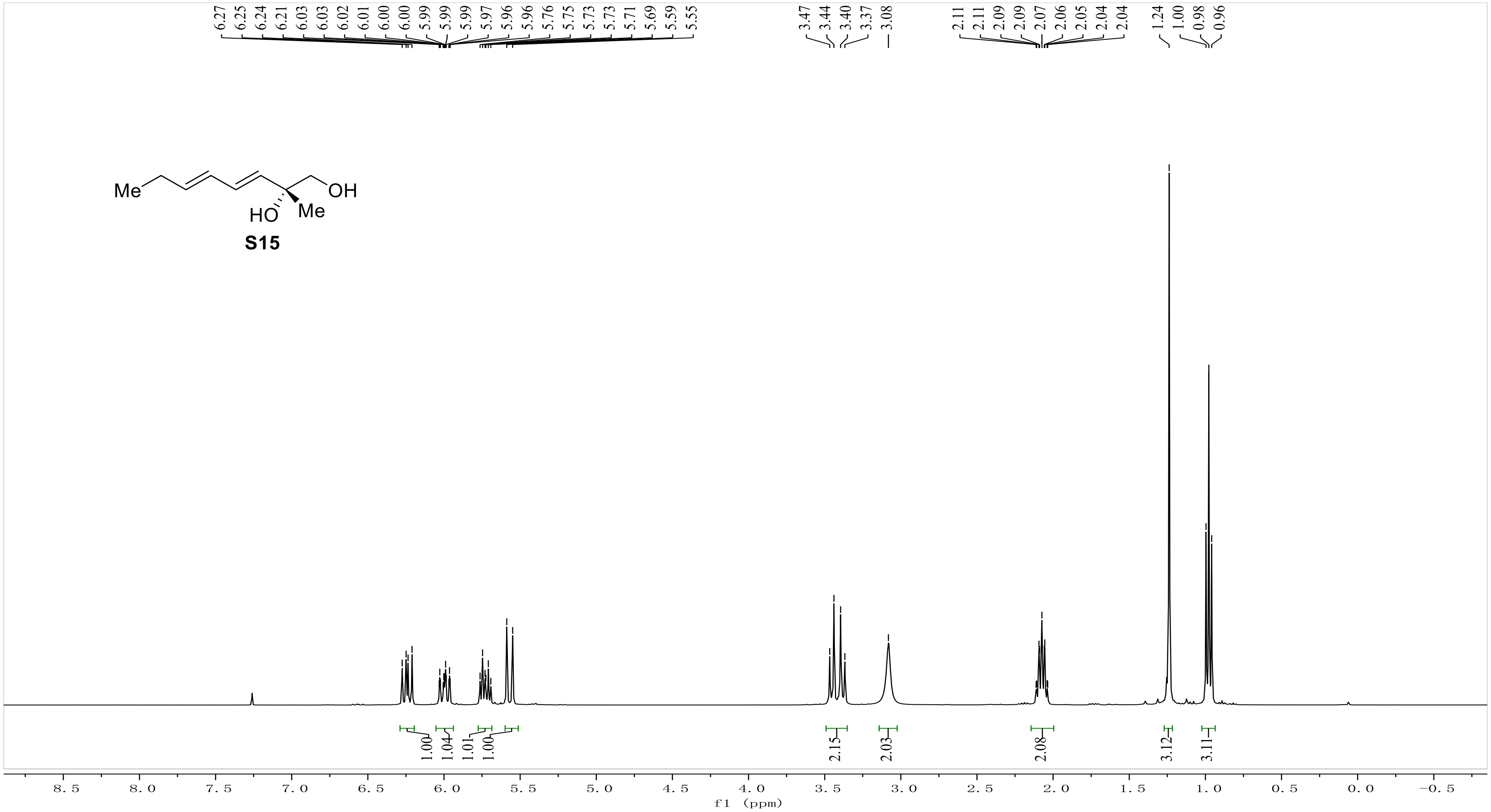
^{1}H NMR Spectrum of S14 (400 MHz, $CDCl_3$)



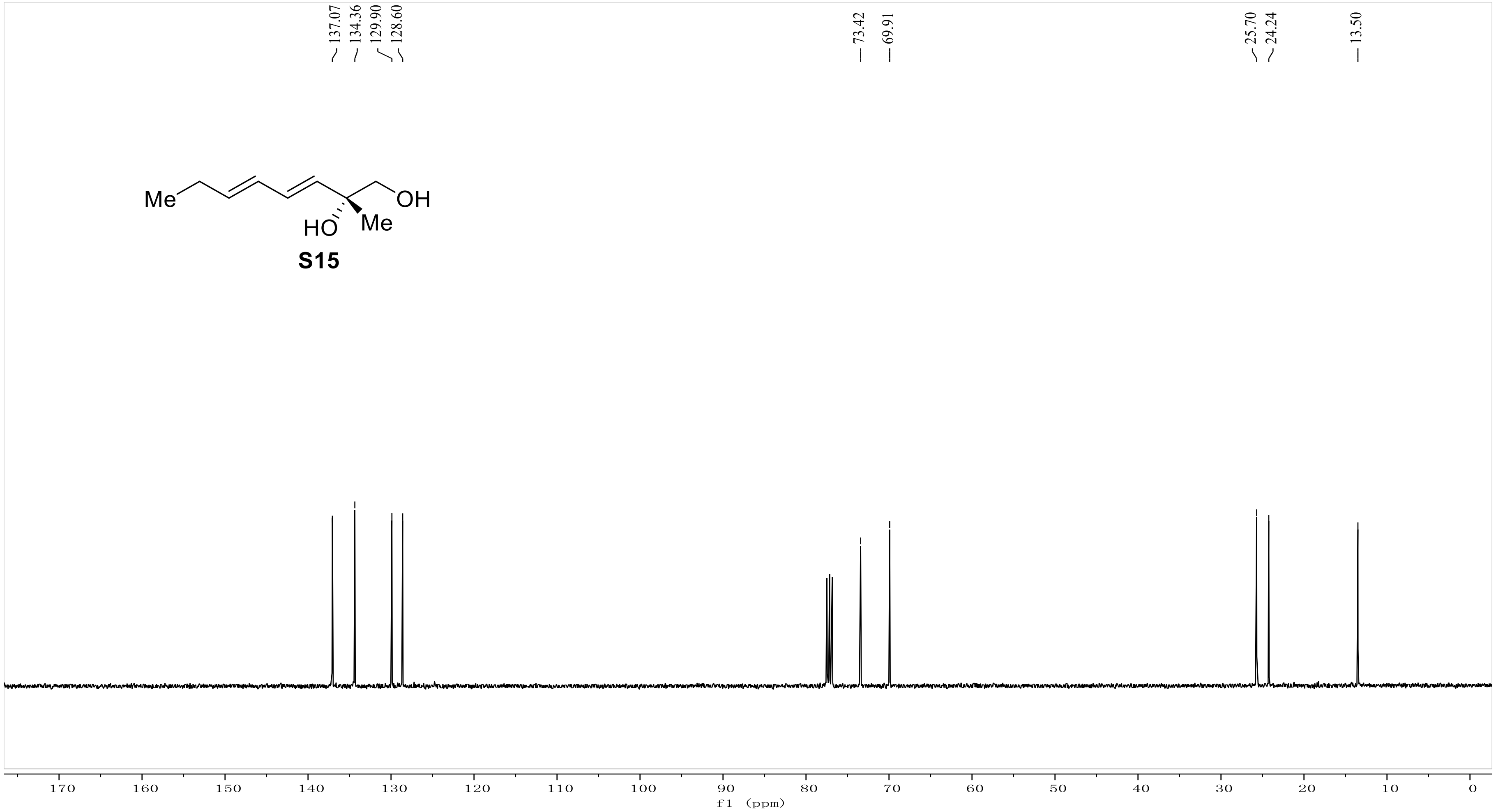
^{13}C NMR Spectrum of S14 (101 MHz, CDCl$_3$)



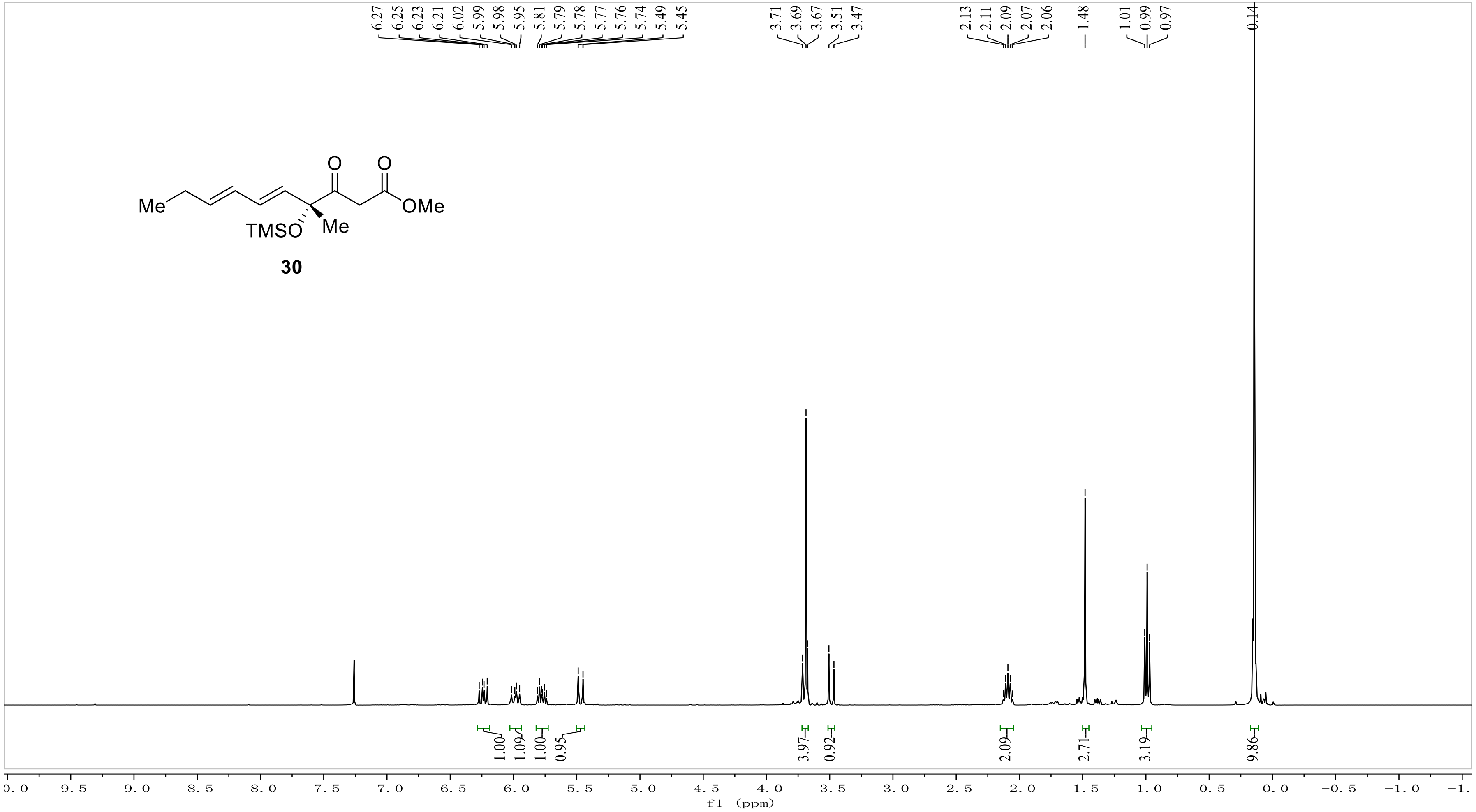
^{1}H NMR Spectrum of S15 (400 MHz, $CDCl_3$)



^{13}C NMR Spectrum of S15 (101 MHz, CDCl$_3$)

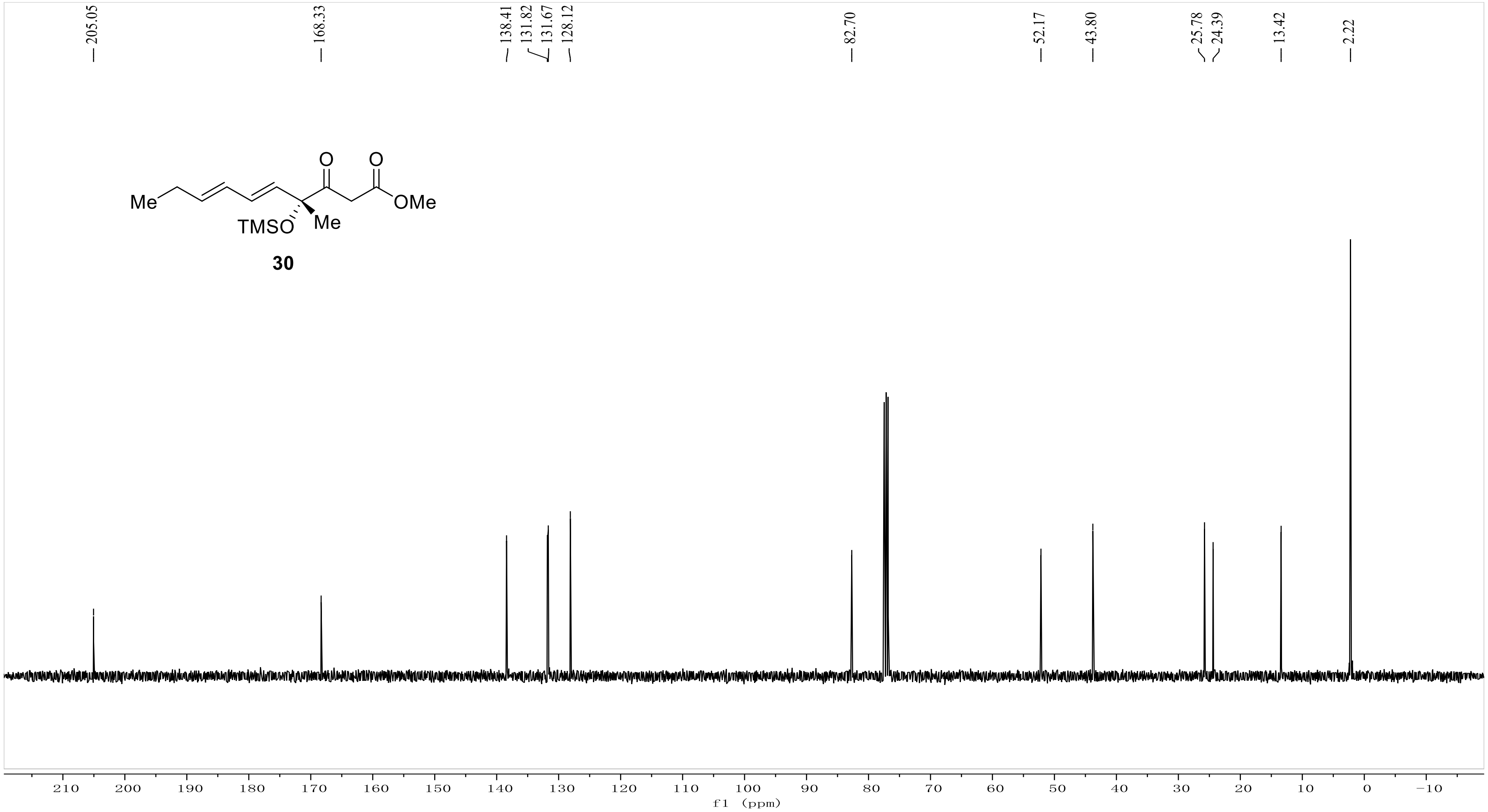


^{1}H NMR Spectrum of 30 (400 MHz, CDCl$_3$)

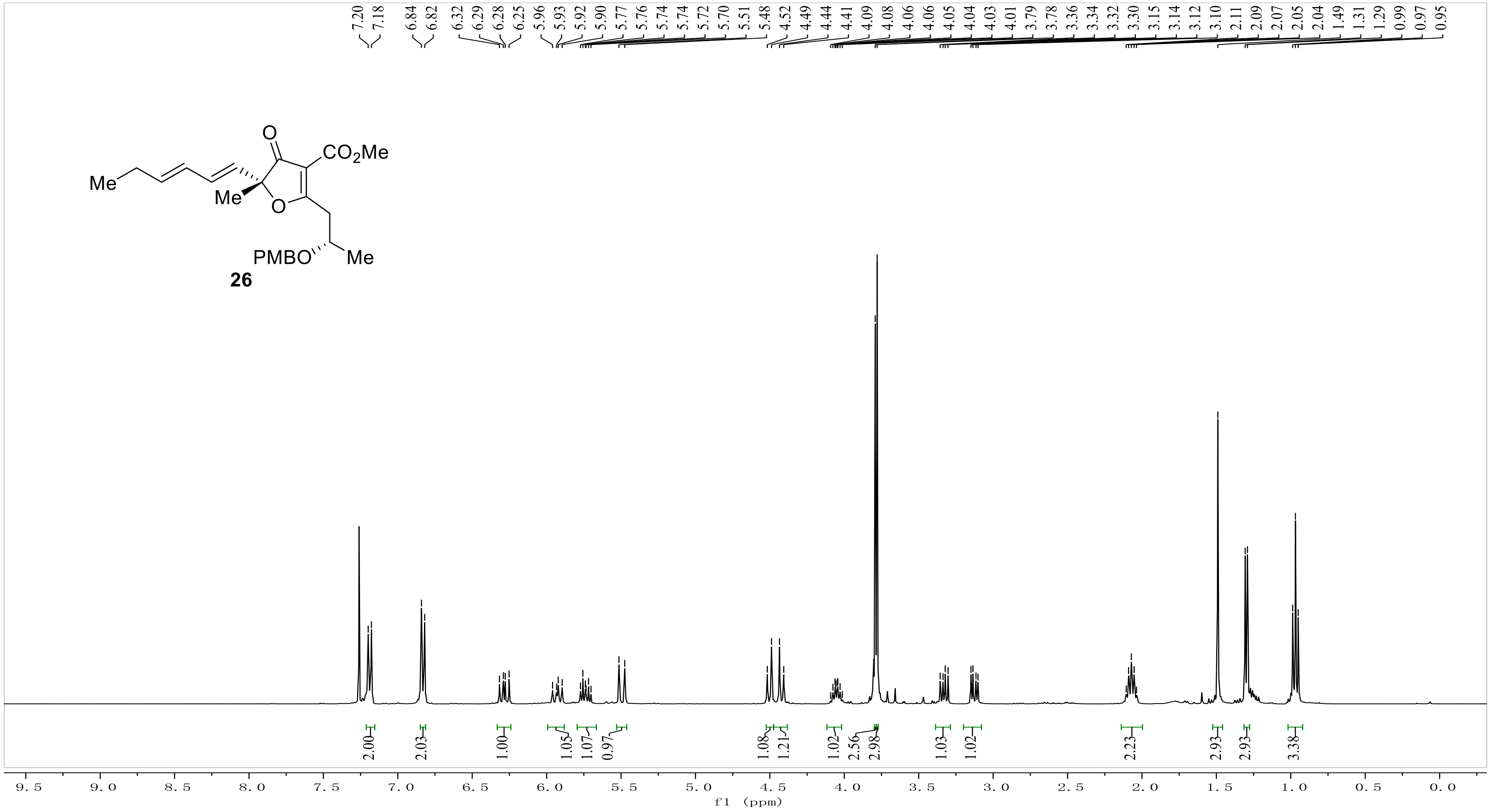


30

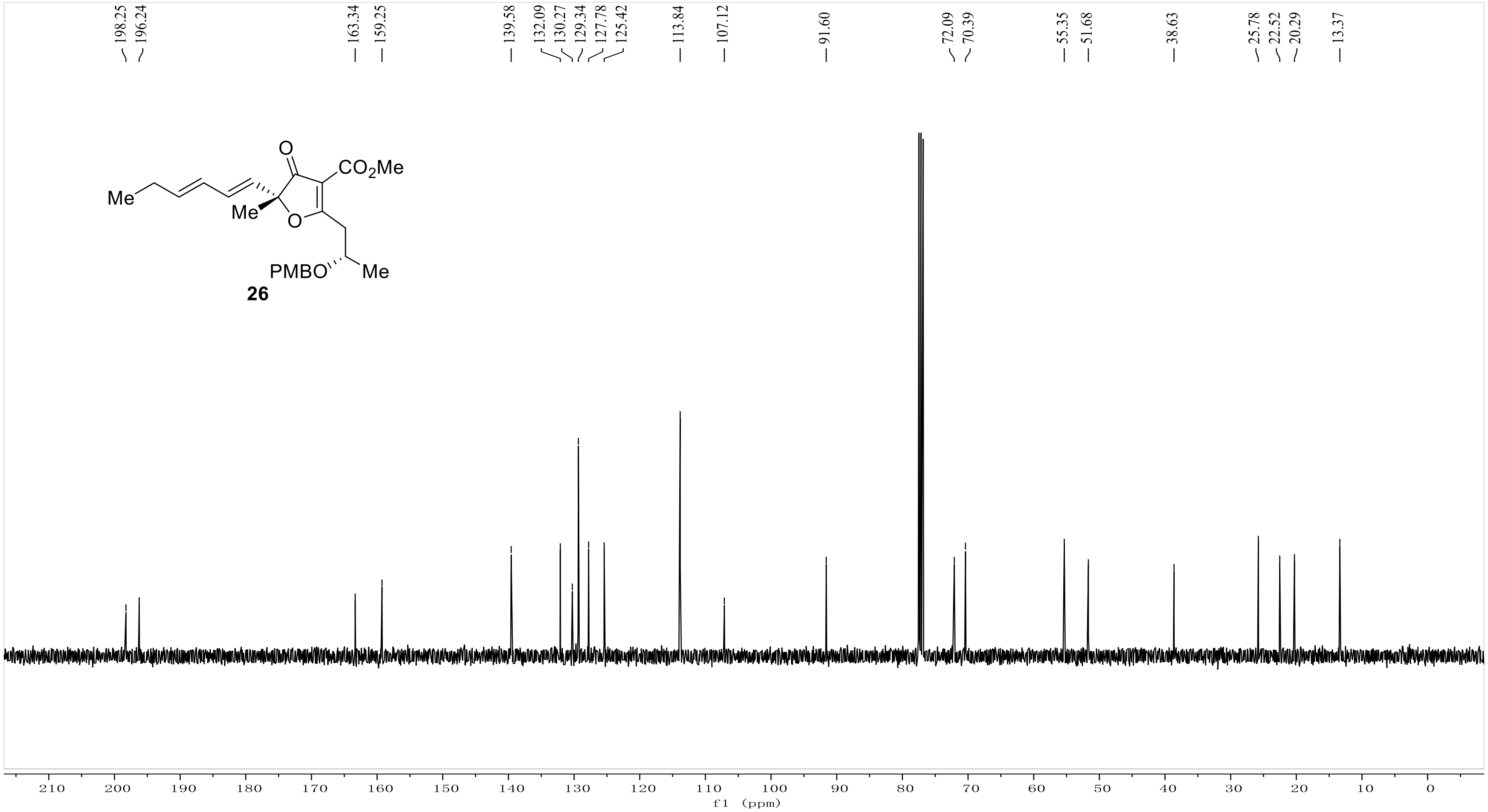
^{13}C NMR Spectrum of 30 (101 MHz, CDCl$_3$)



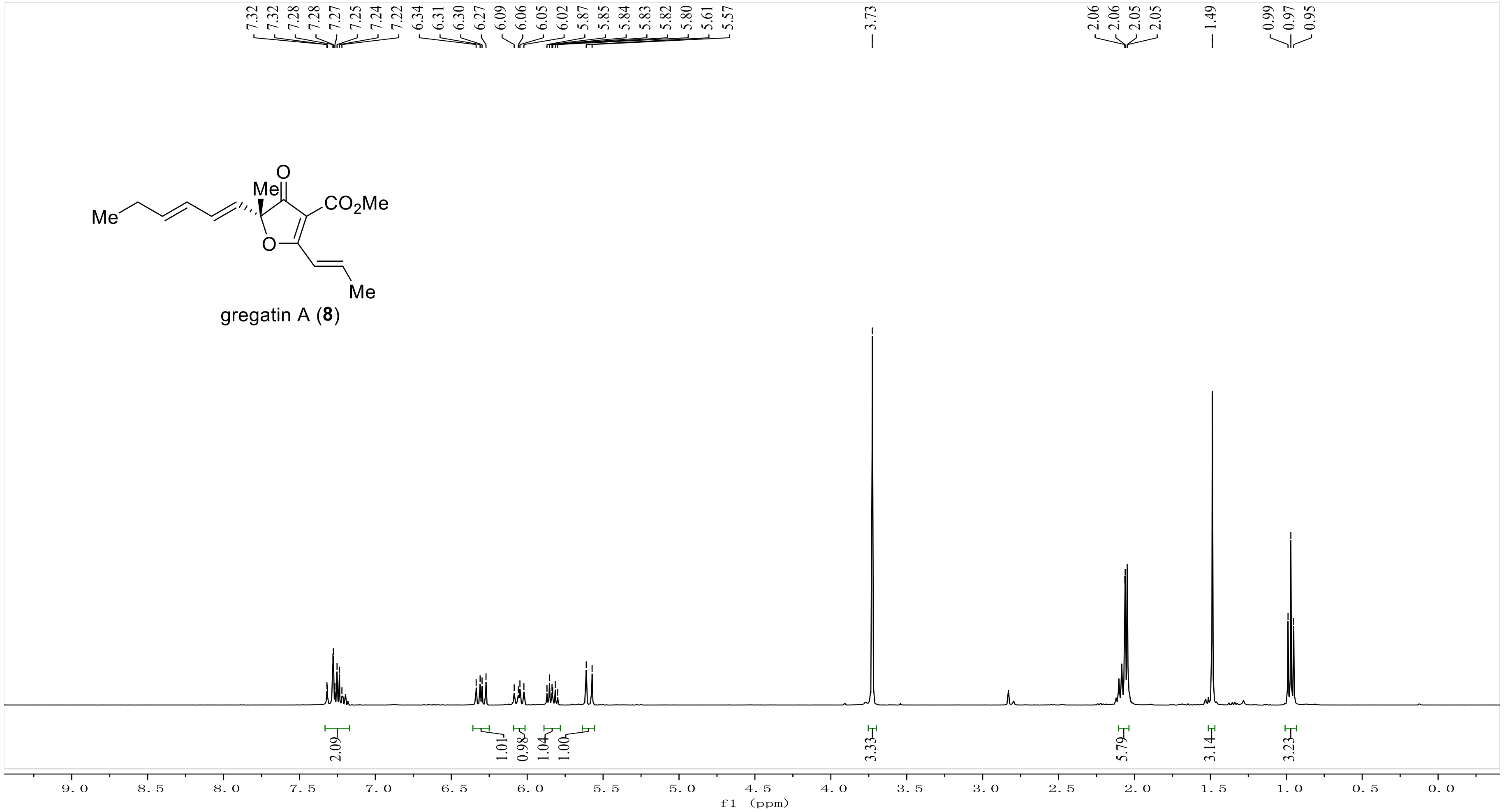
^{1}H NMR Spectrum of 26 (400 MHz, $CDCl_3$)



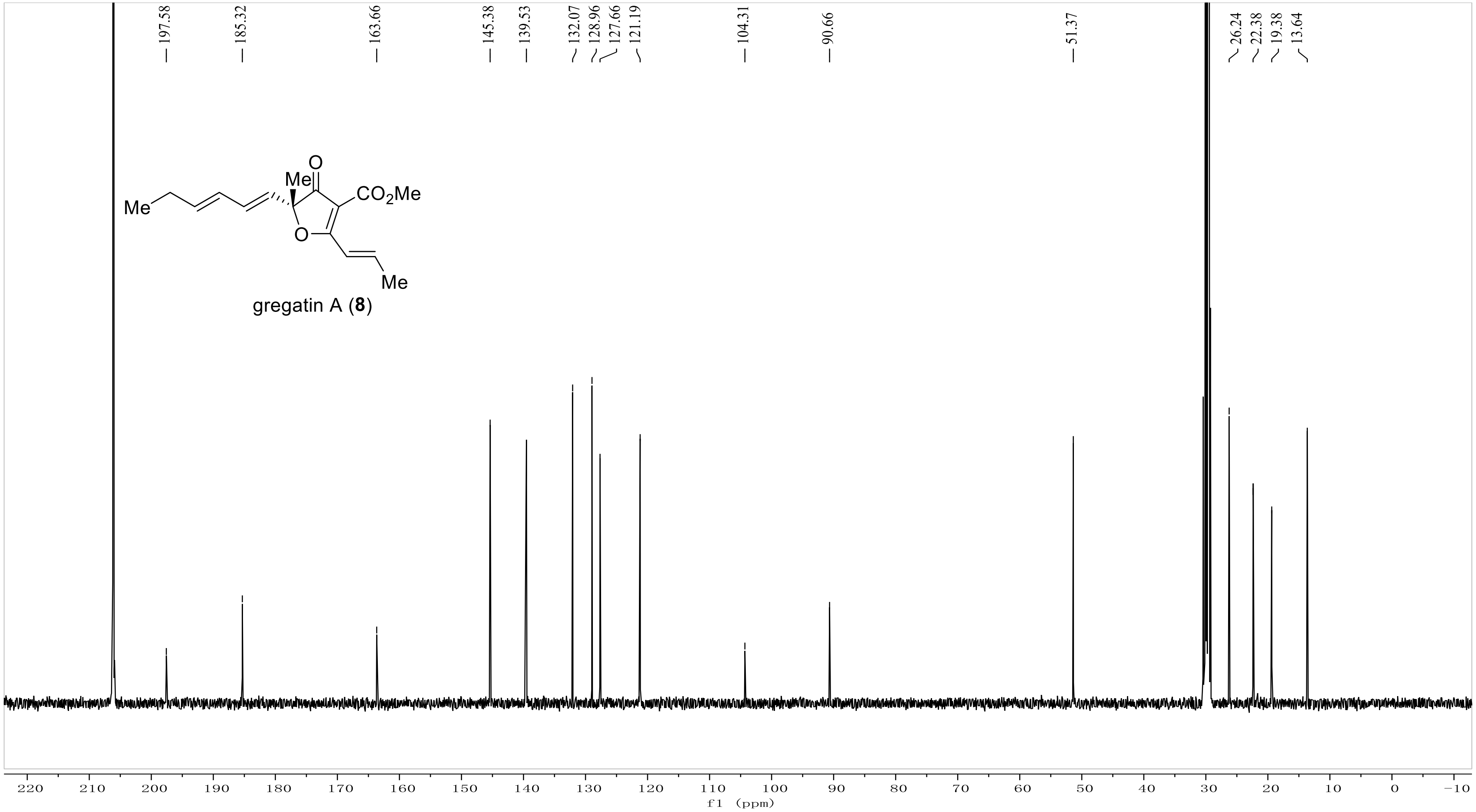
^{13}C NMR Spectrum of 26 (101 MHz, CDCl$_3$)



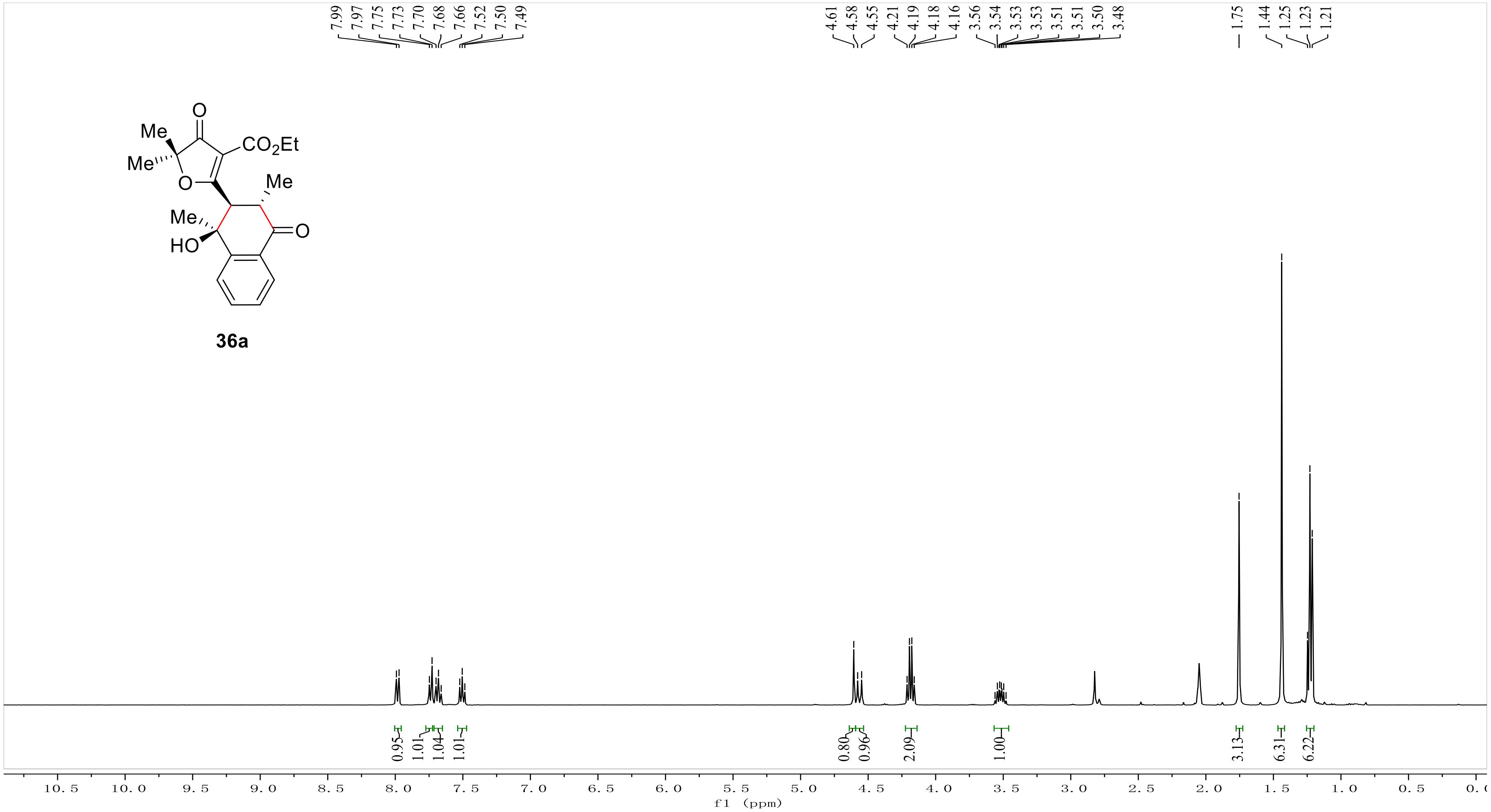
^{1}H NMR Spectrum of gregatin A (8) (400 MHz, Acetone-d_6)



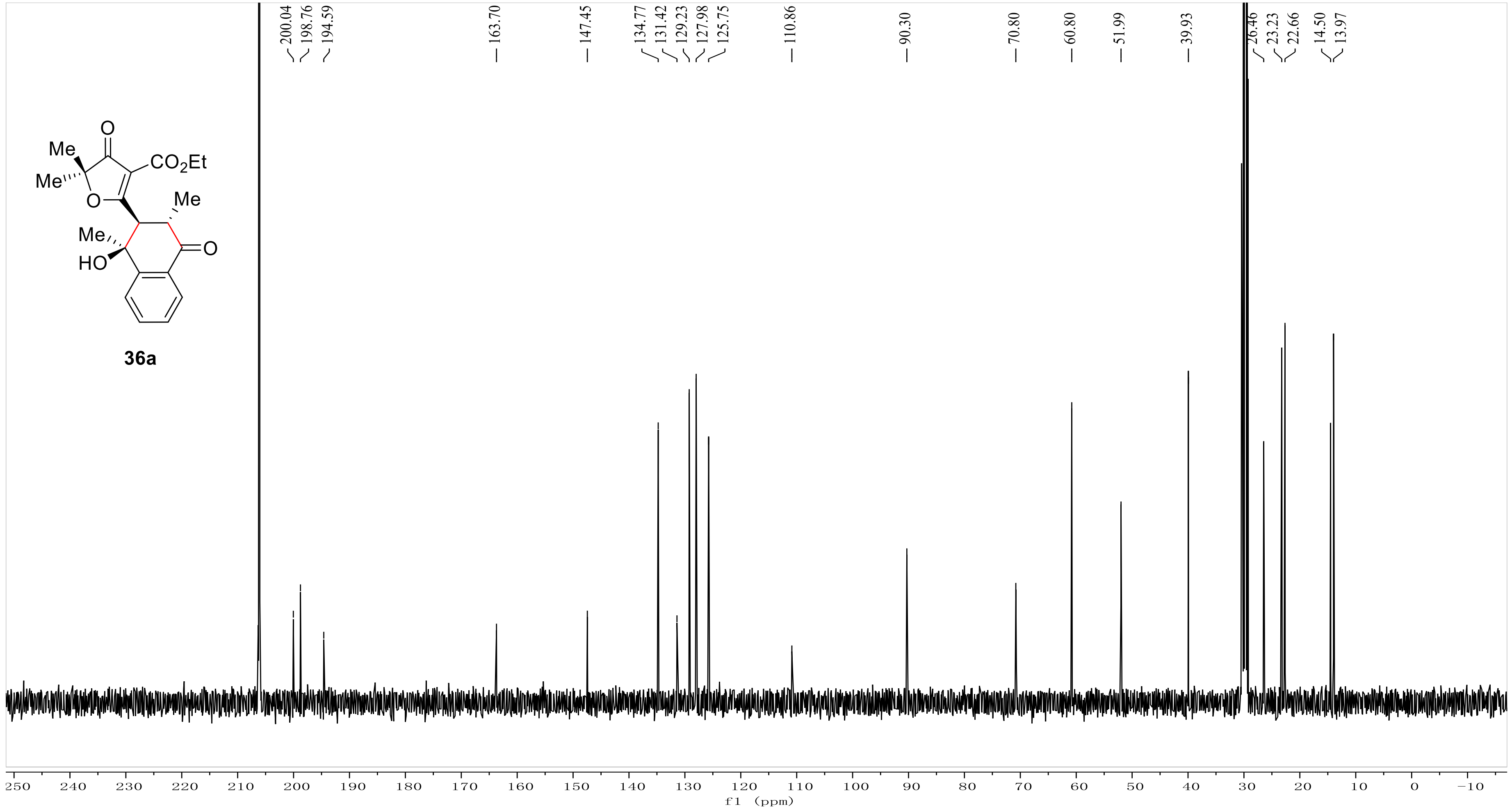
^{13}C NMR Spectrum of gregatin A (8) (101 MHz, Acetone-d_6)



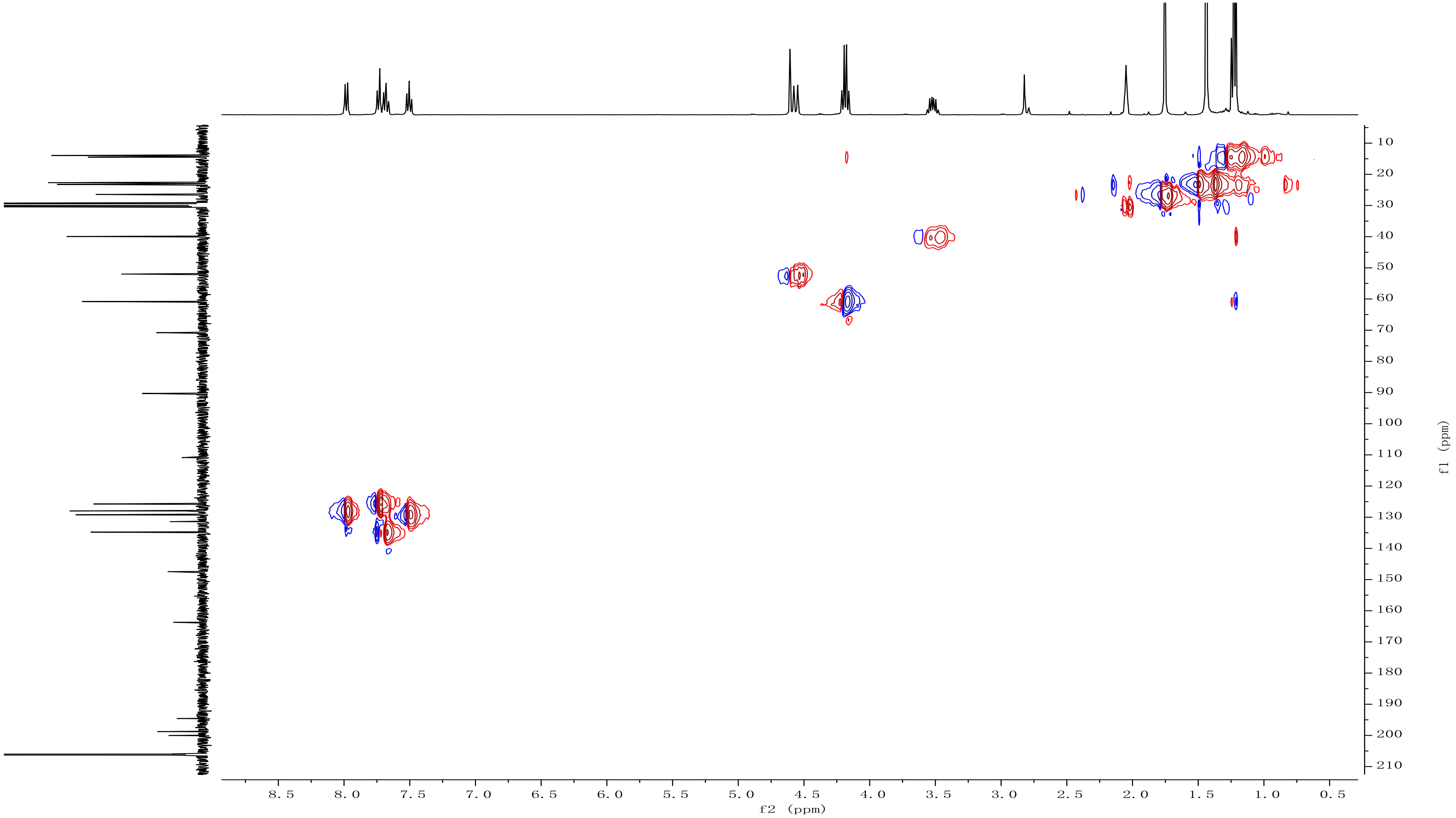
^{1}H NMR Spectrum of 36a (400 MHz, Acetone-d_6)



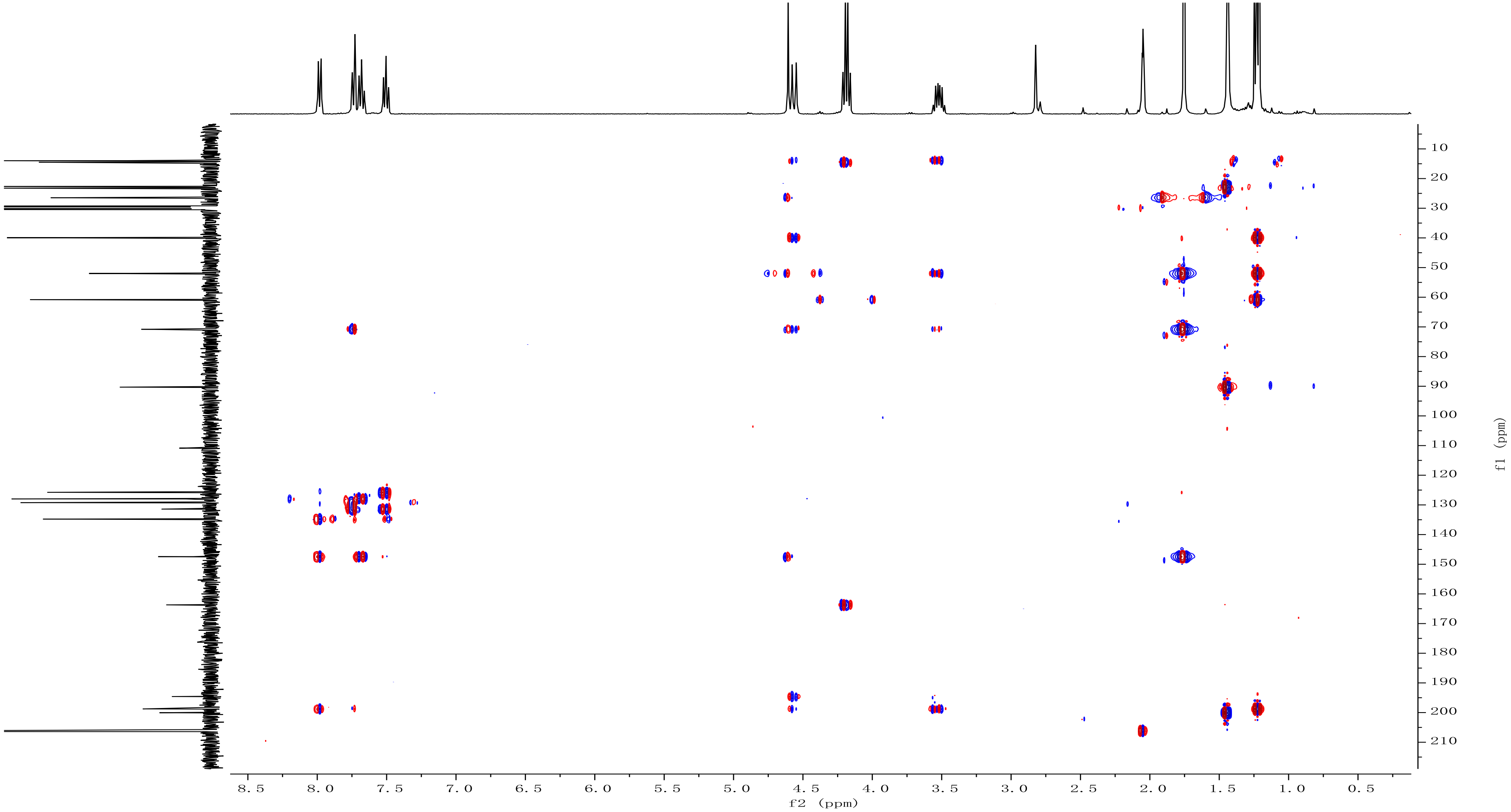
^{13}C NMR Spectrum of 36a (101 MHz, Acetone-d_6)



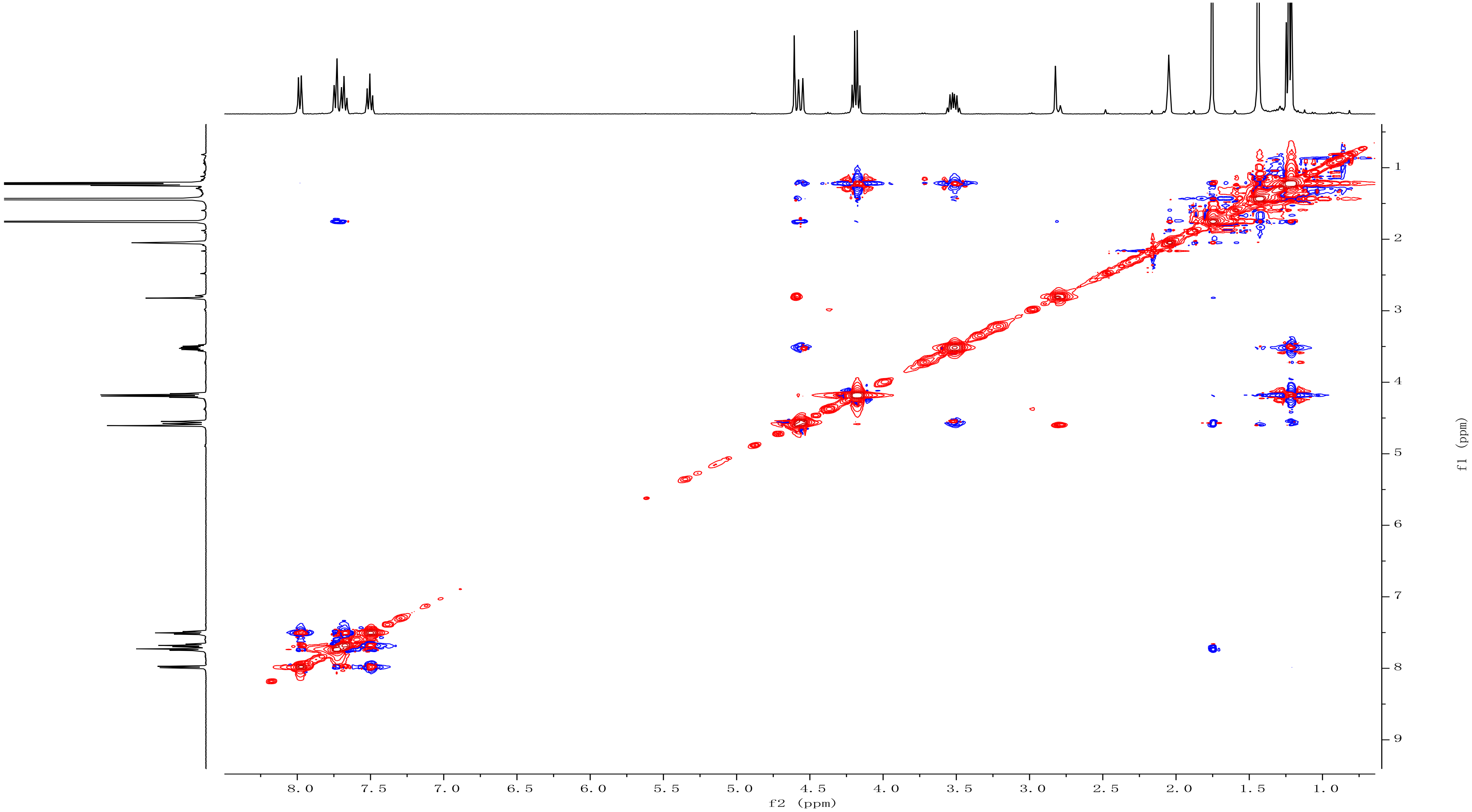
HSQC Spectrum of 36a (Acetone-d_6)



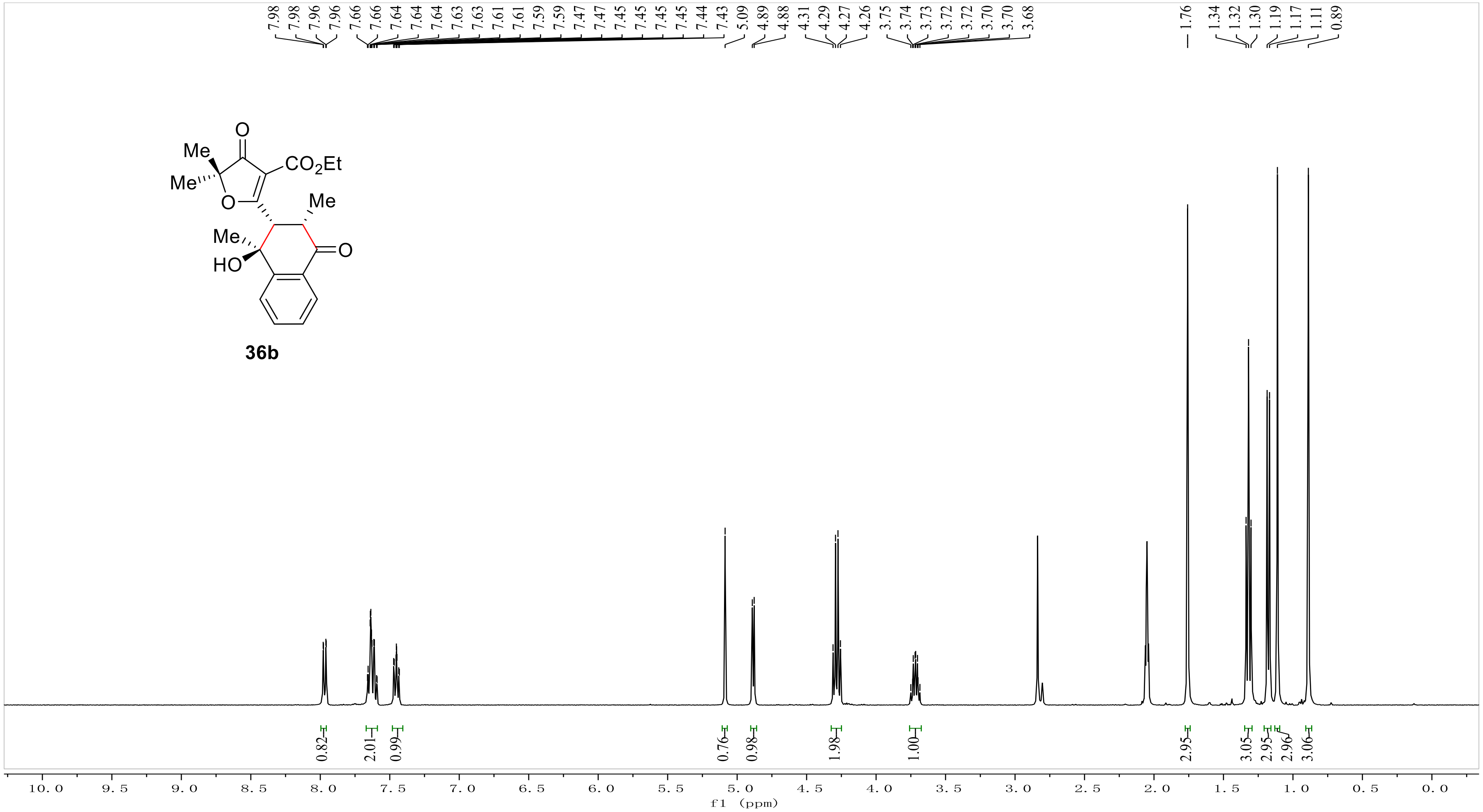
HMBC Spectrum of 36a (Acetone-d_6)



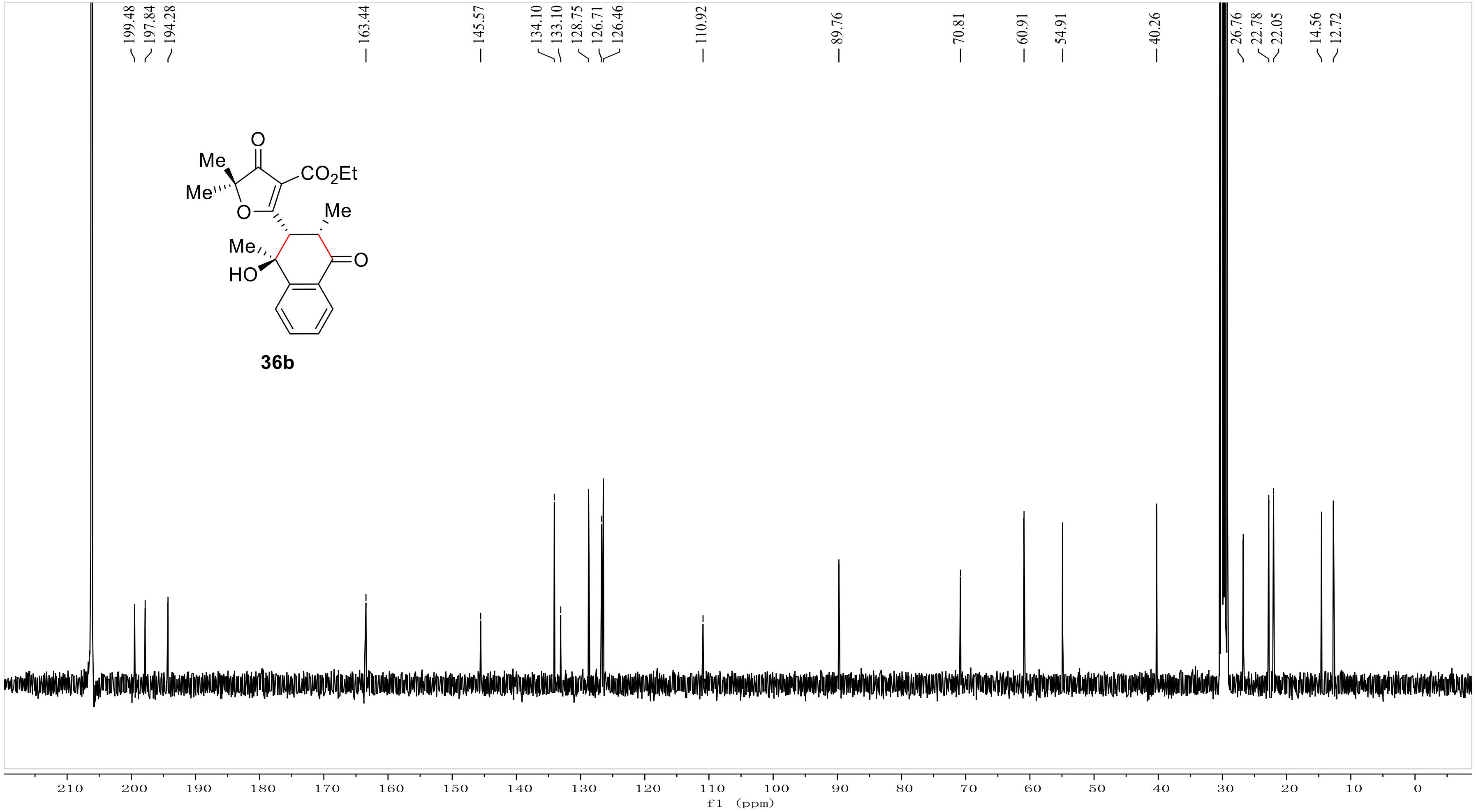
NOESY Spectrum of 36a (Acetone-d_6)



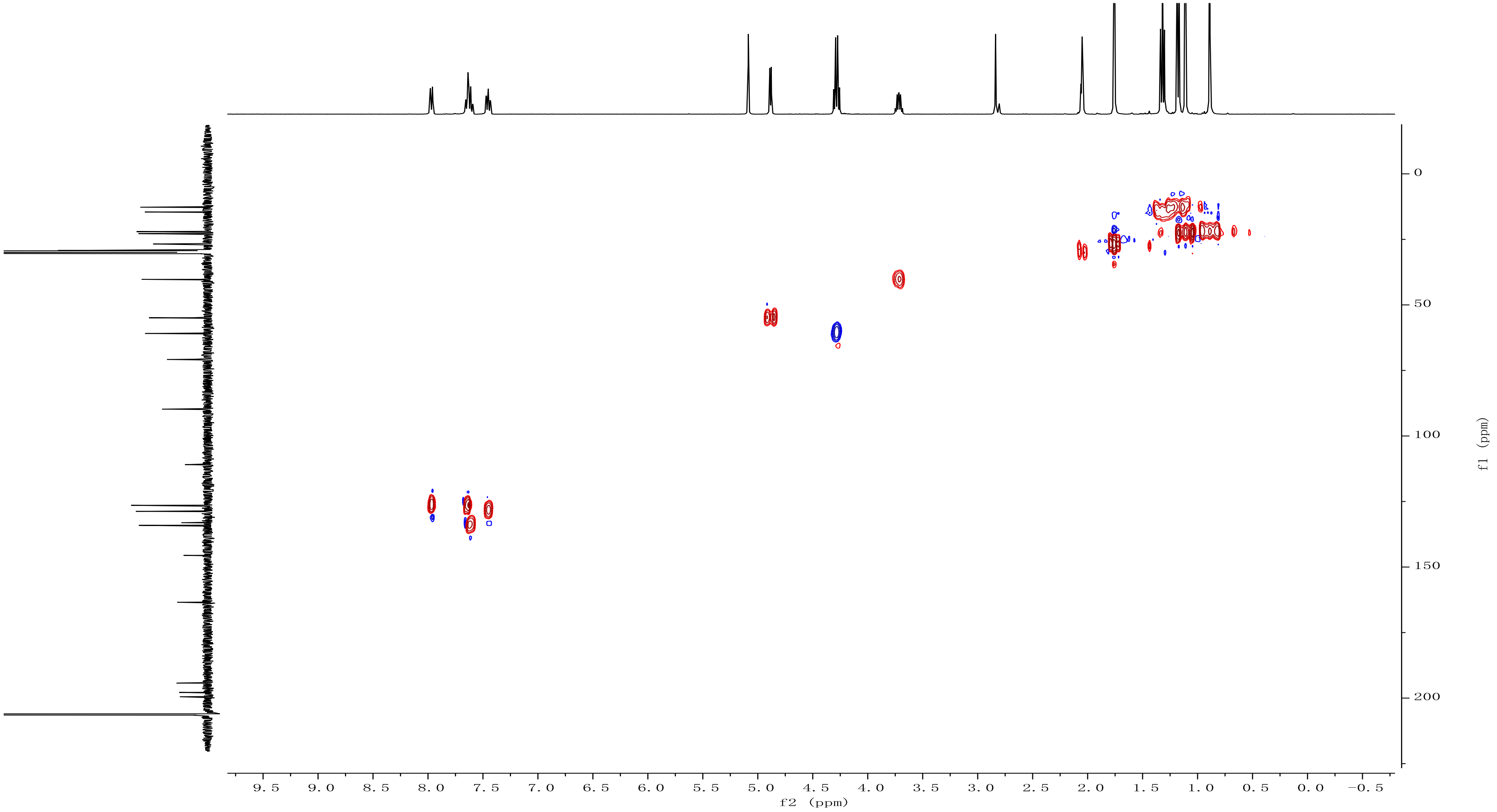
^{1}H NMR Spectrum of 36b (400 MHz, Acetone-d_6)



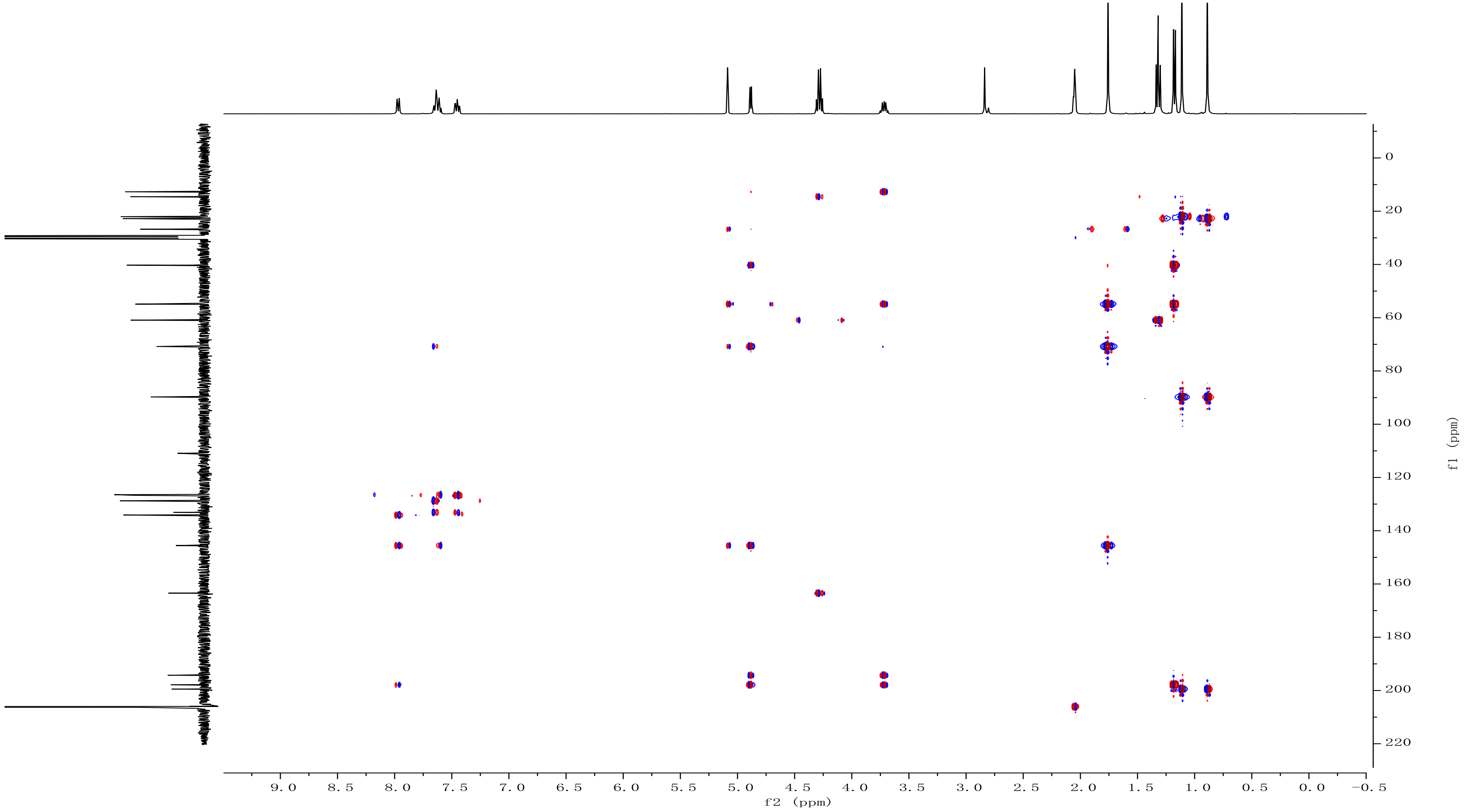
^{13}C NMR Spectrum of 36b (101 MHz, Acetone-d_6)



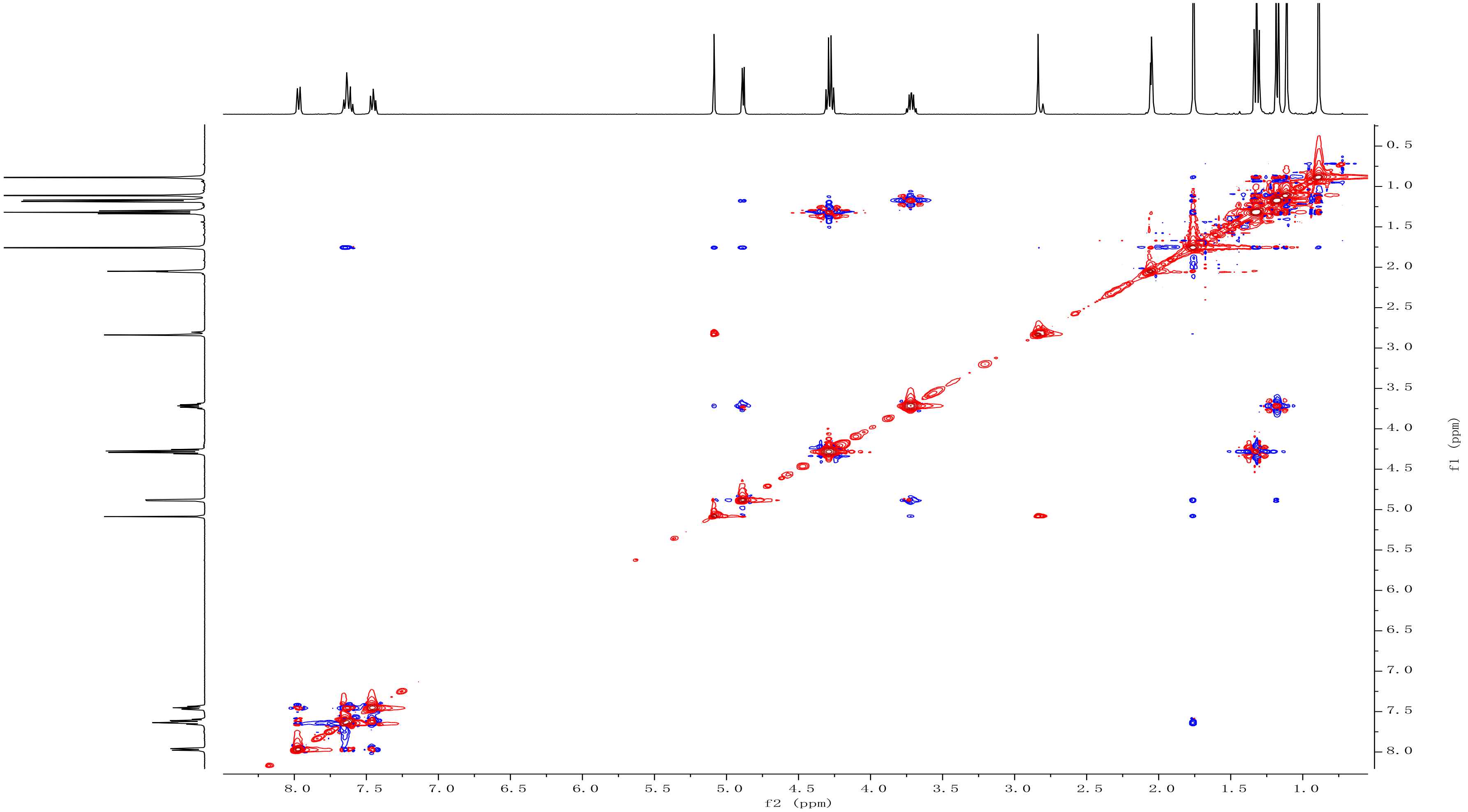
HSQC Spectrum of 36b (Acetone-d_6)



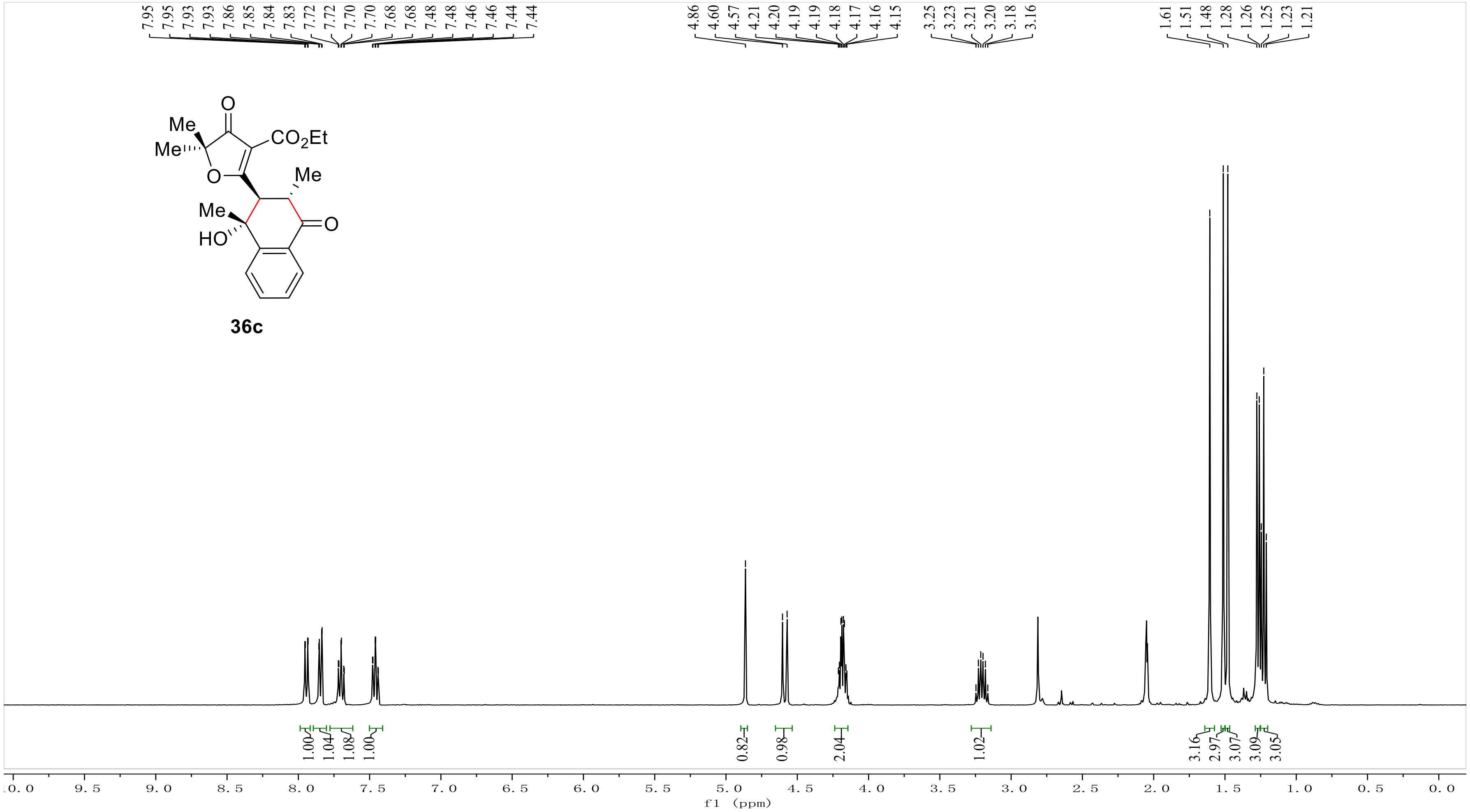
HMBC Spectrum of 36b (Acetone-d_6)



NOESY Spectrum of 36b (Acetone-d_6)

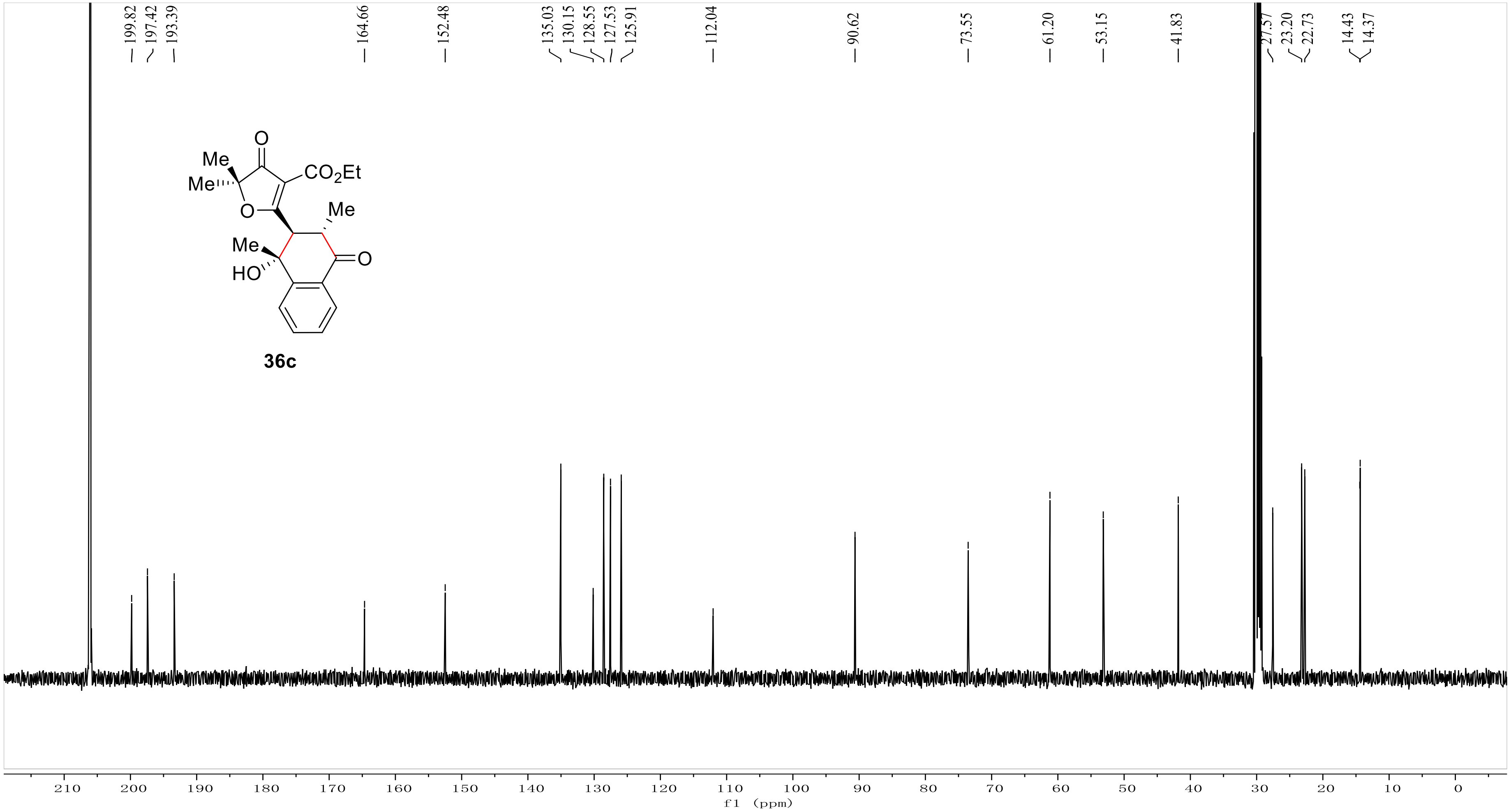


^{1}H NMR Spectrum of 36c (400 MHz, Acetone-d_6)

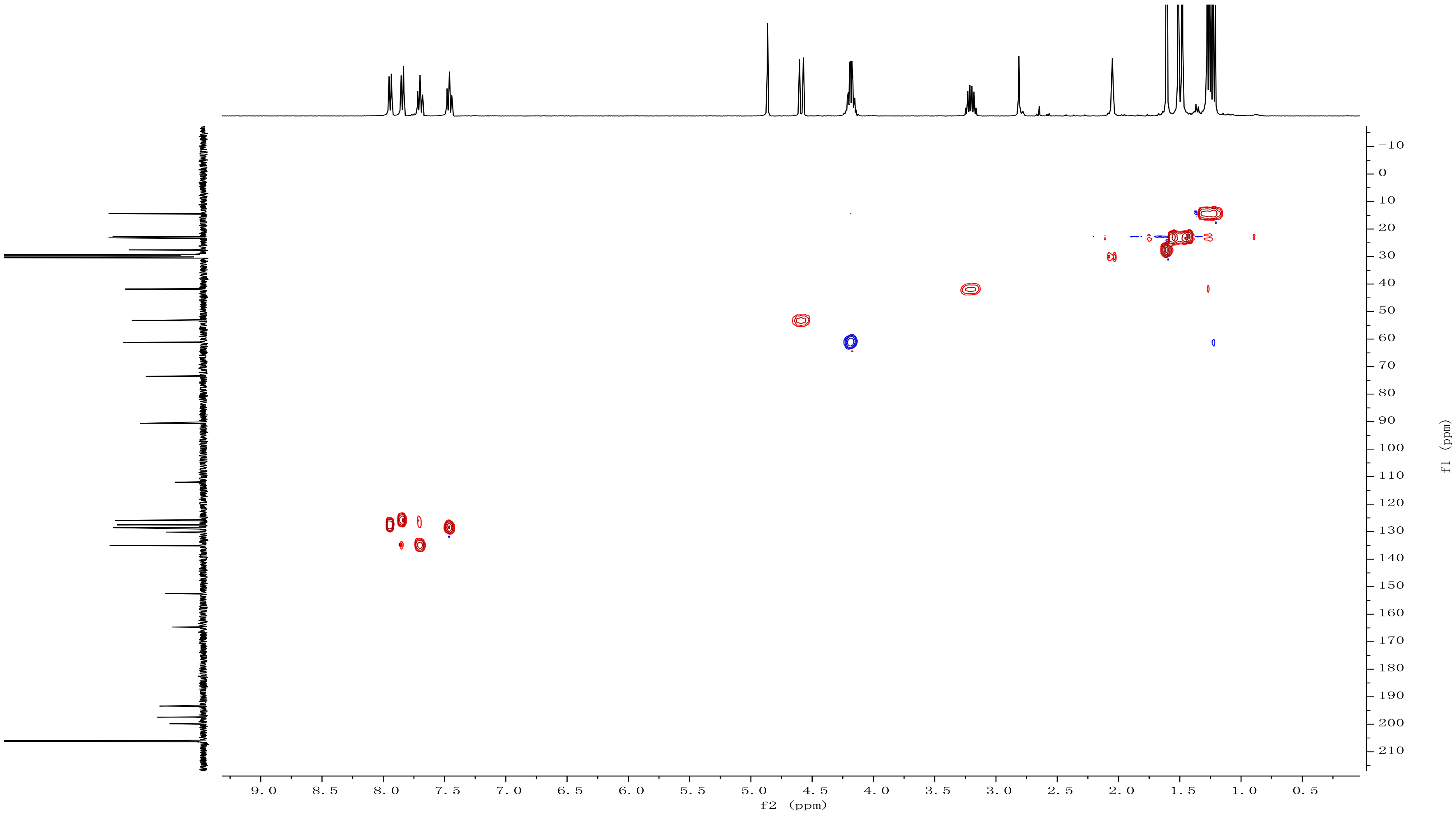


36c

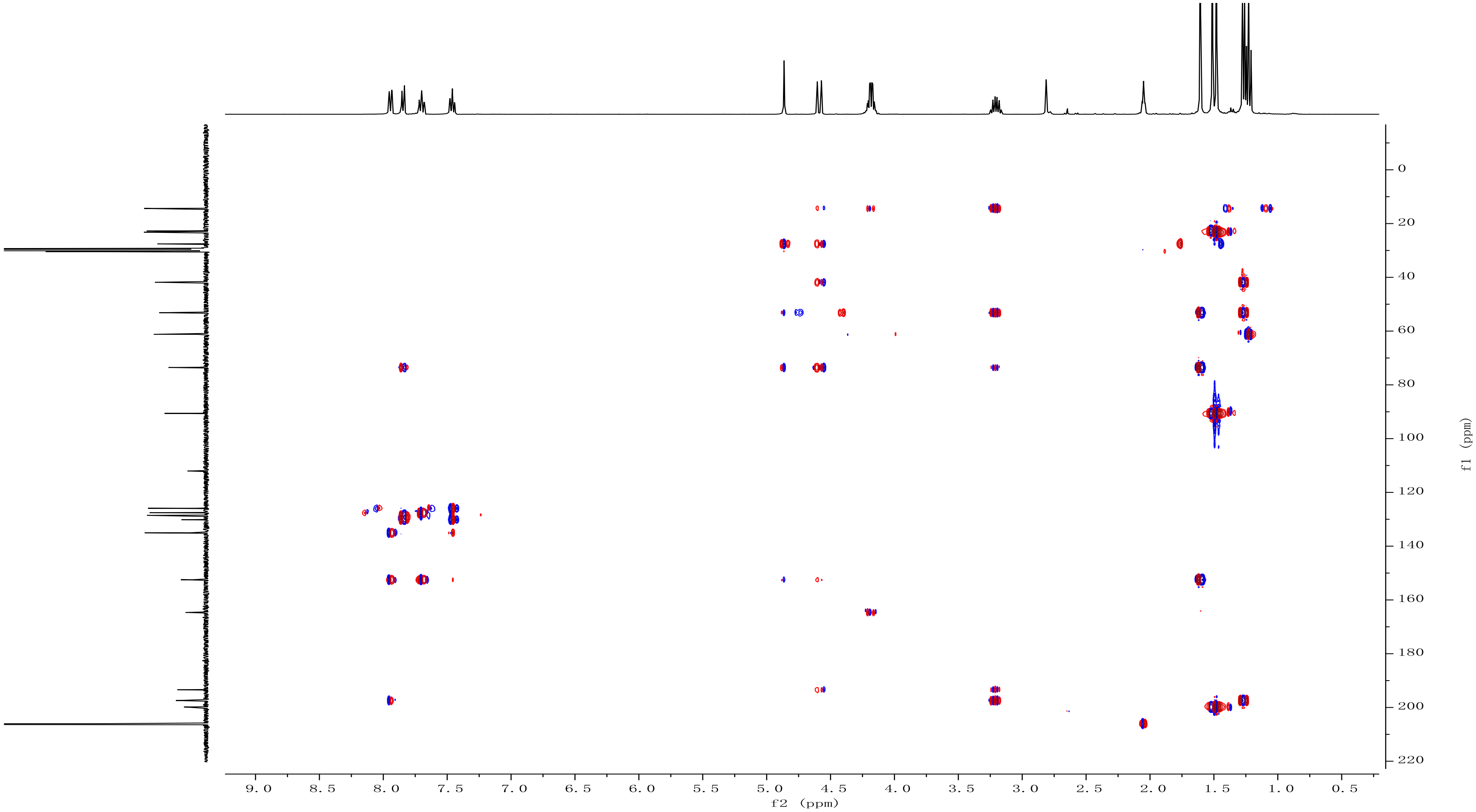
^{13}C NMR Spectrum of 36c (101 MHz, Acetone-d_6)



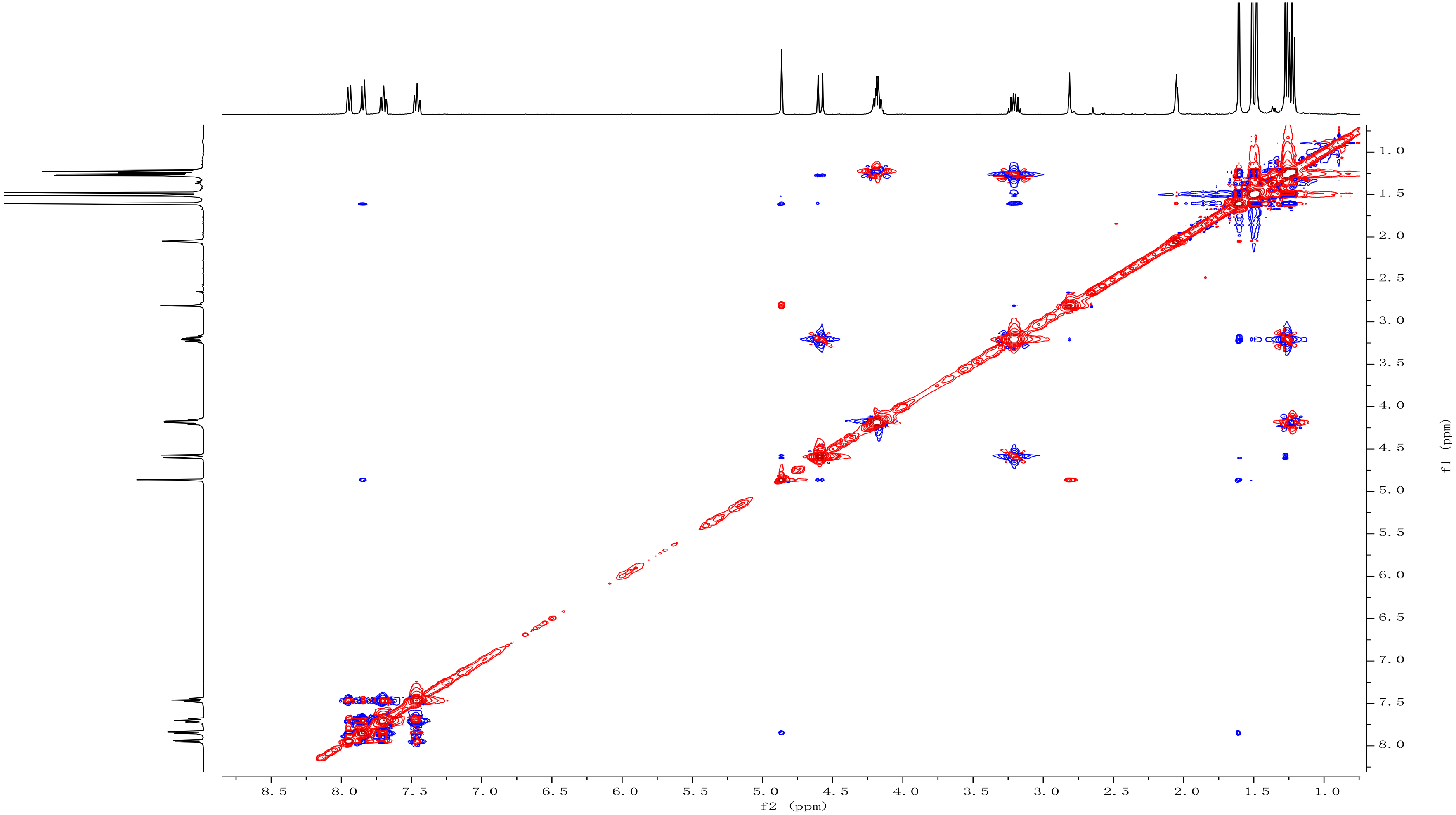
HSQC Spectrum of 36c (Acetone-d_6)



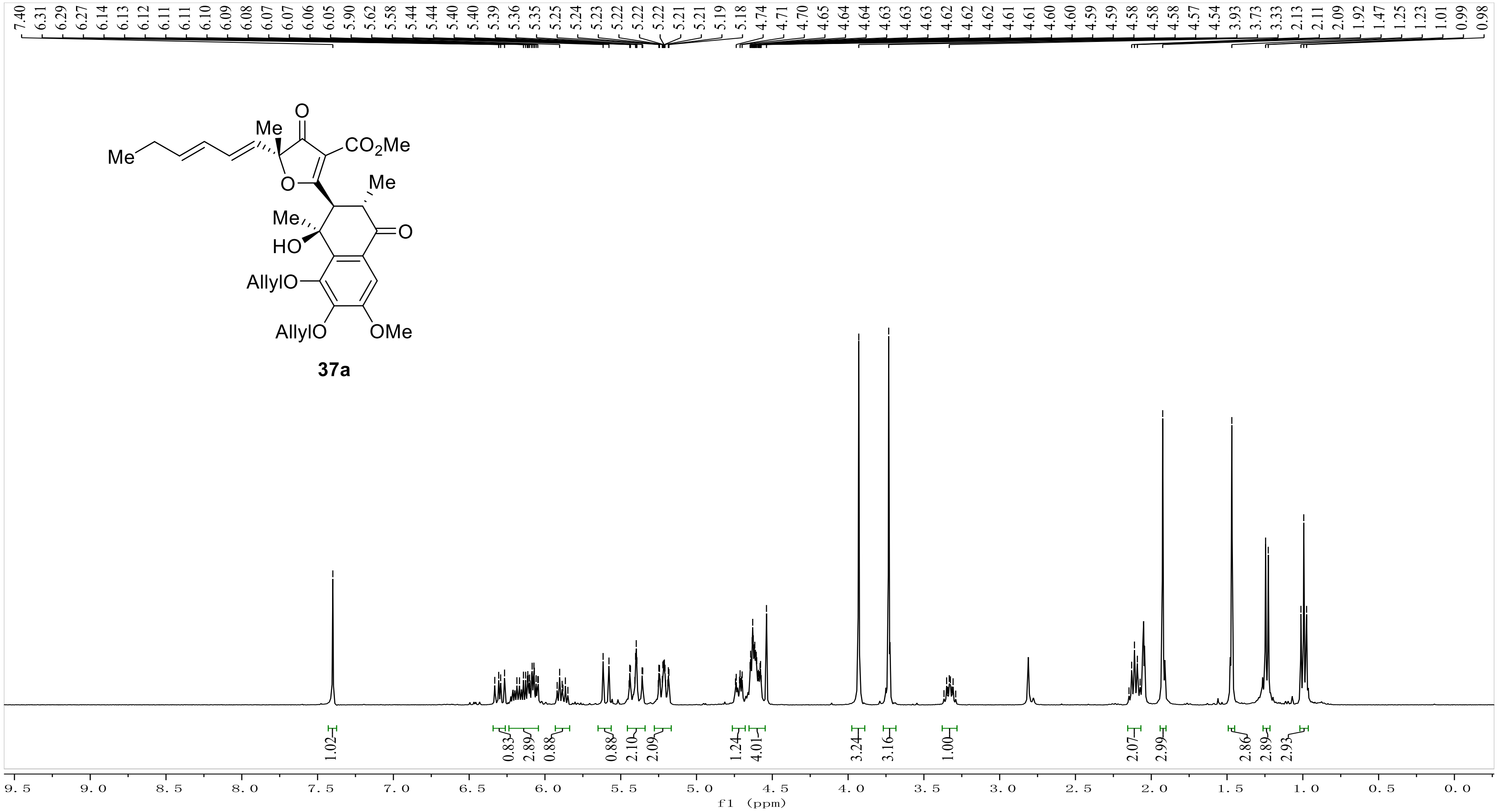
HMBC Spectrum of 36c (Acetone-*d*$_6$)



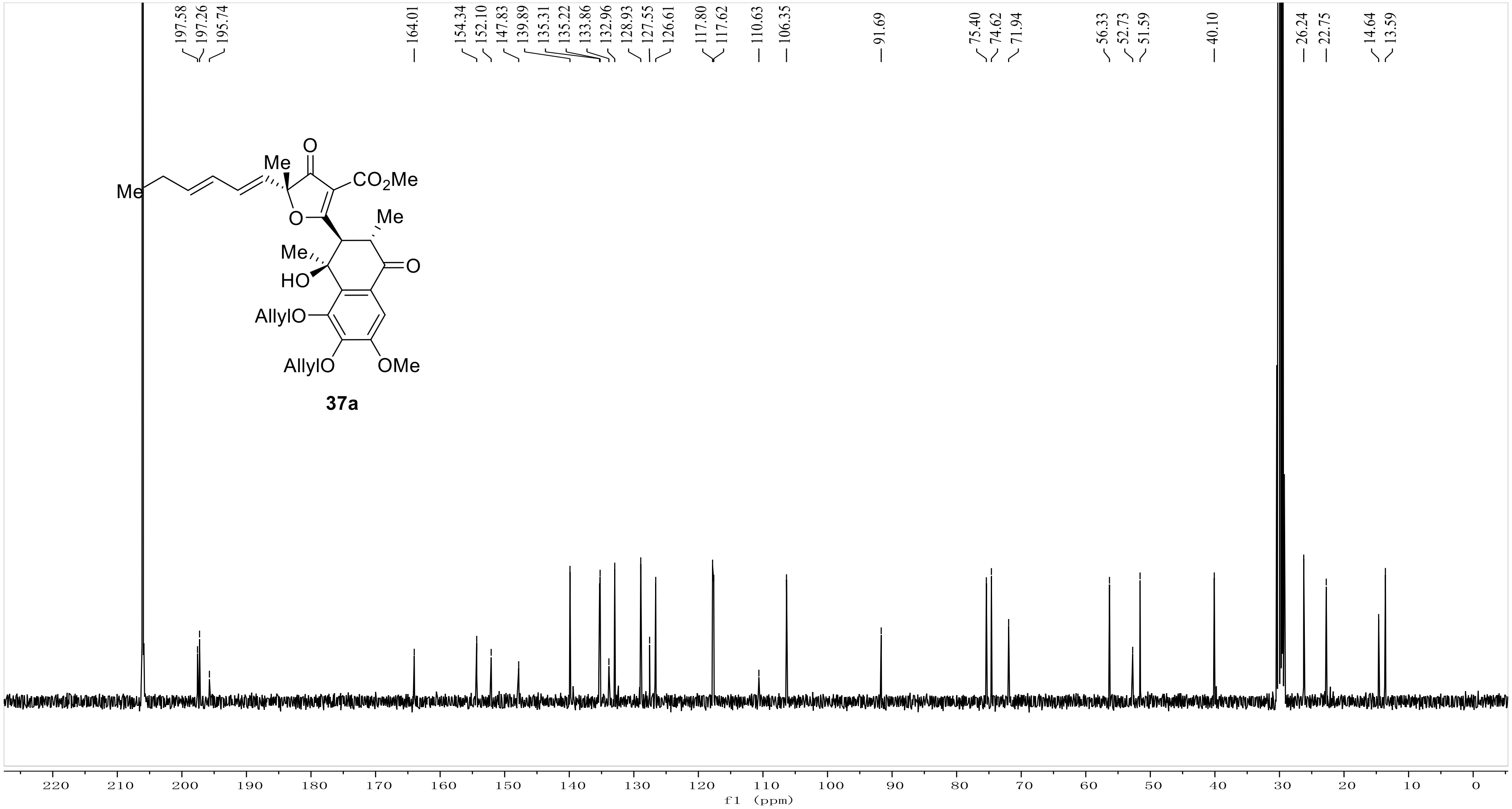
NOESY Spectrum of 36c (Acetone-*d*₆)



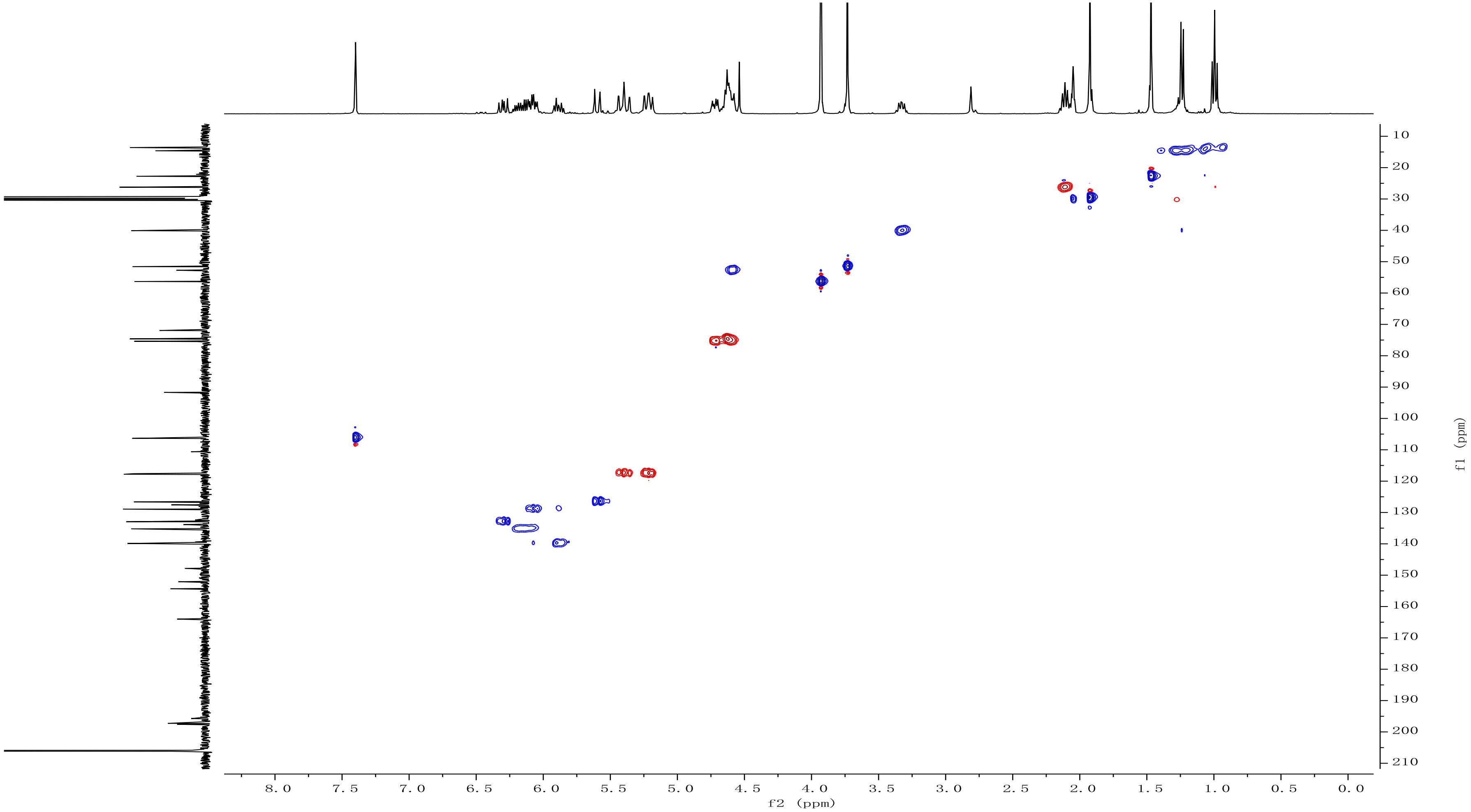
^{1}H NMR Spectrum of 37a (400 MHz, Acetone-d_6)



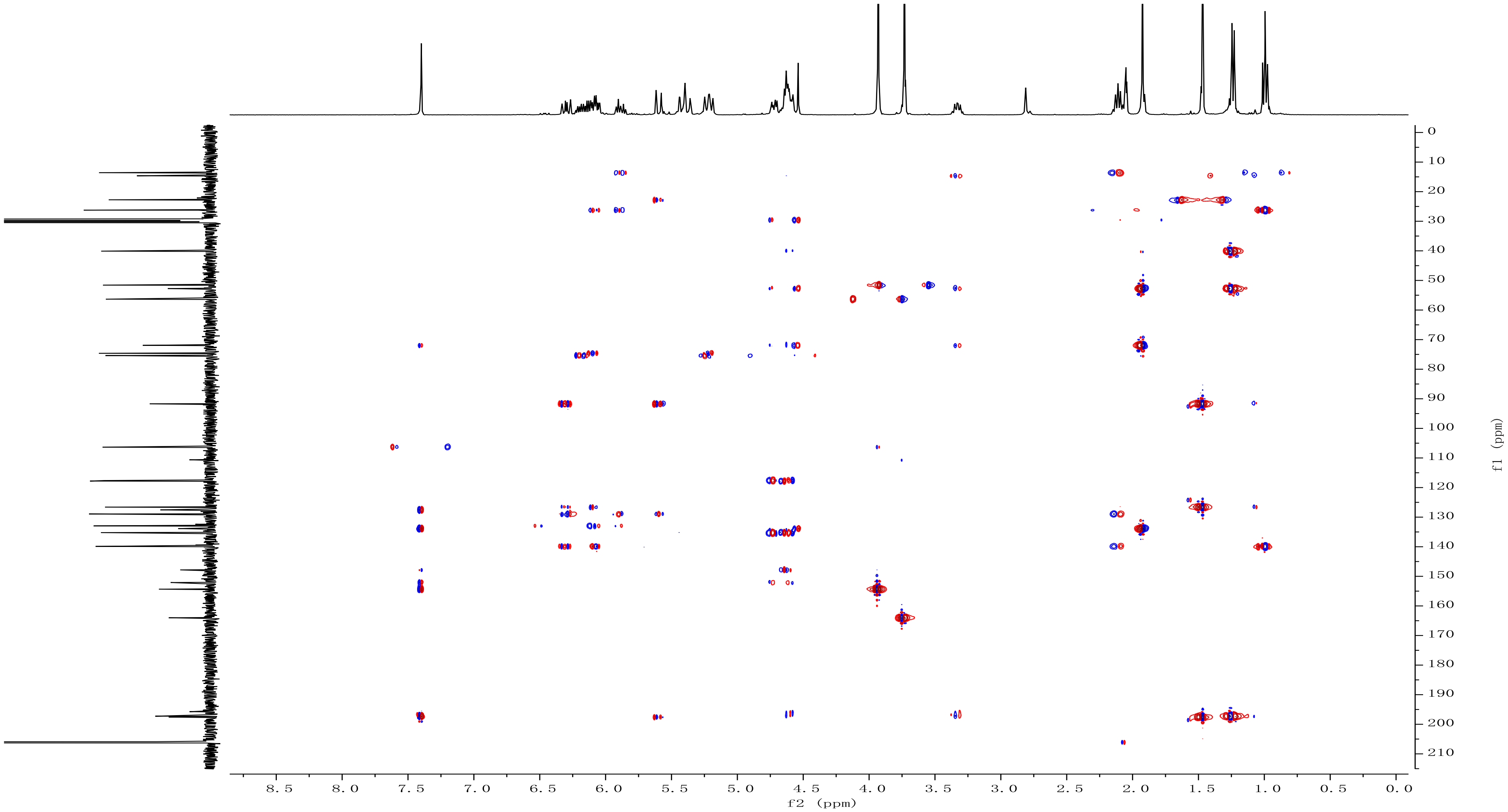
^{13}C NMR Spectrum of 37a (101 MHz, Acetone-d_6)



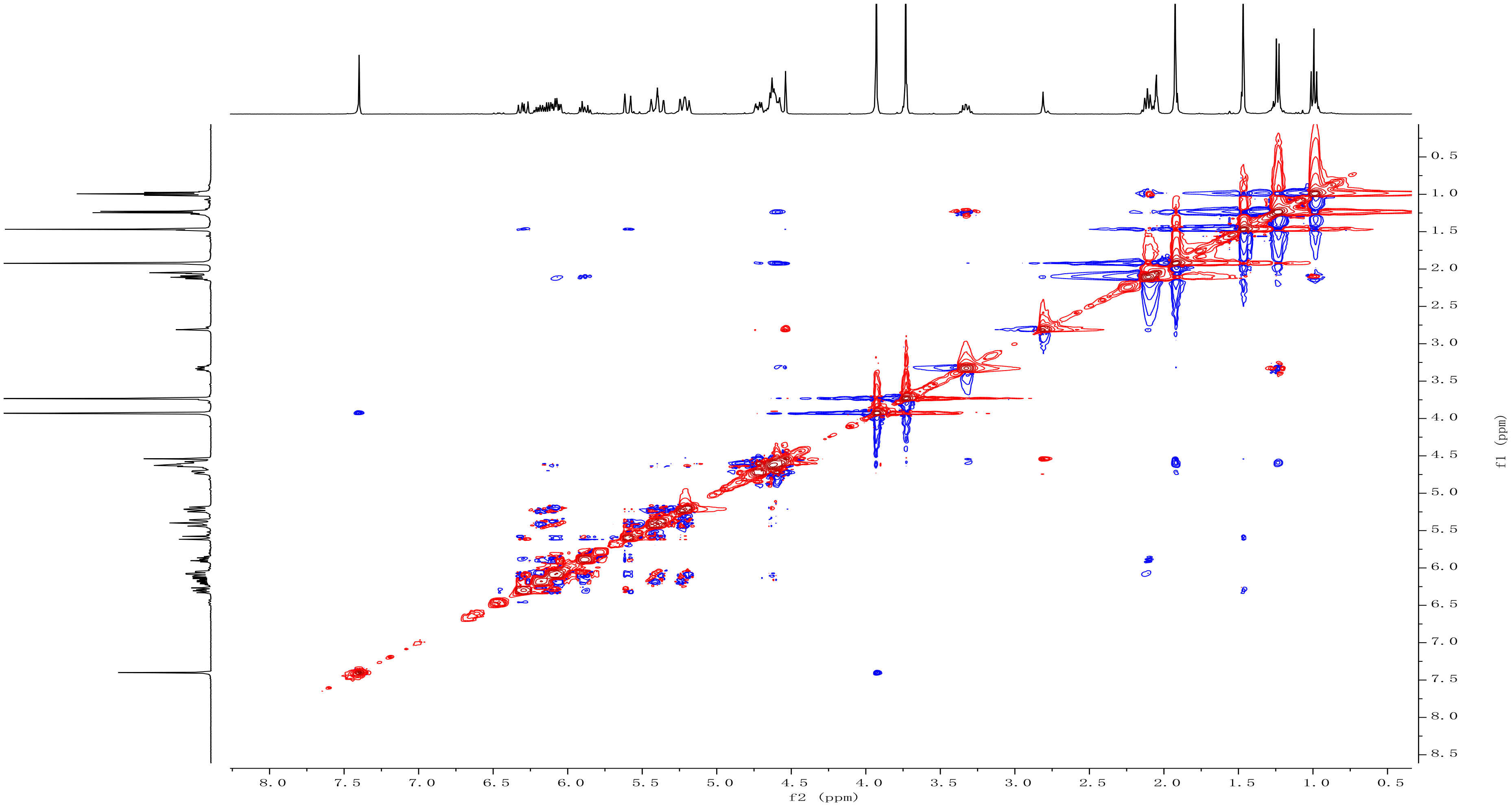
HSQC Spectrum of 37a (Acetone-d_6)



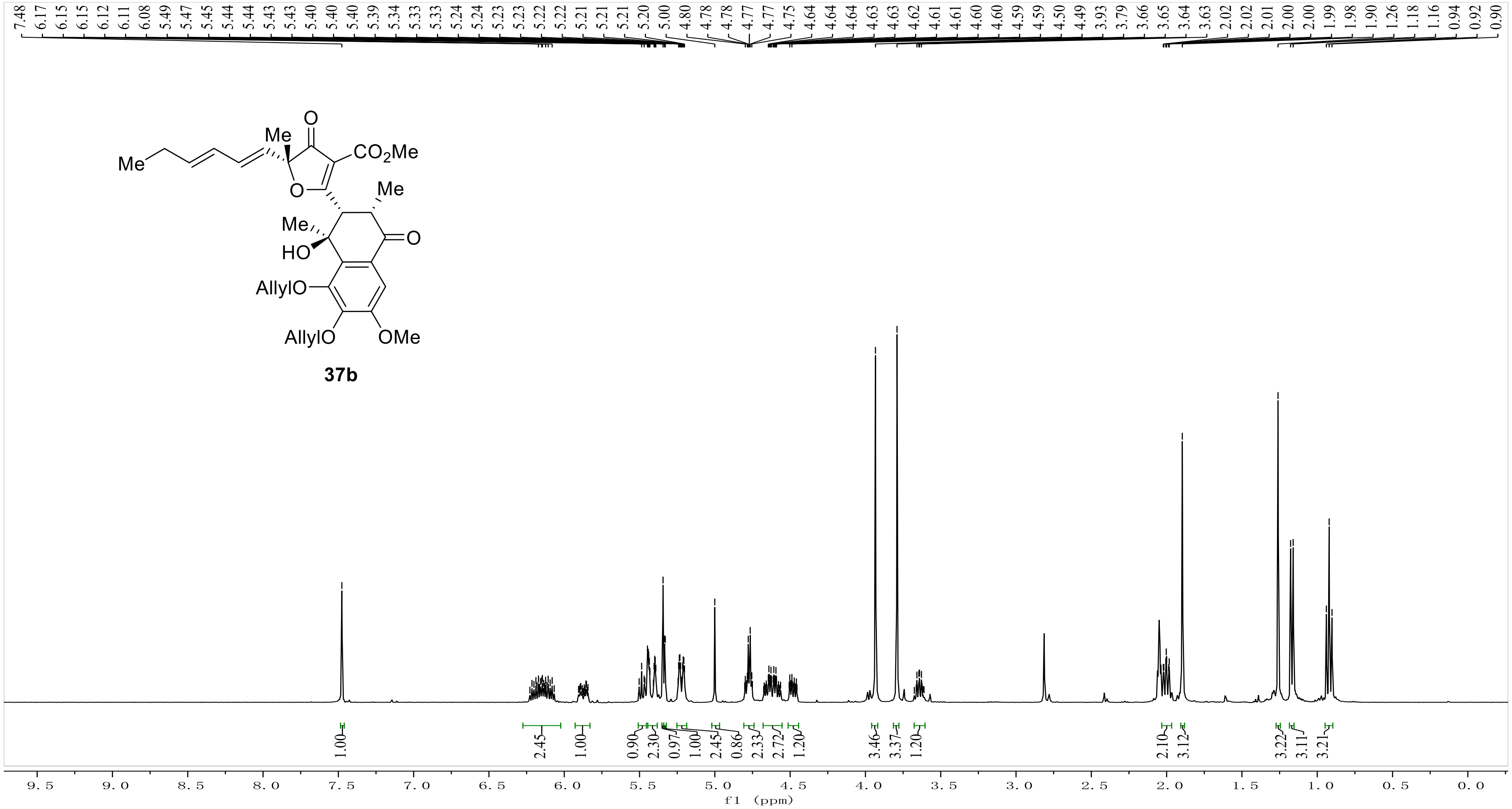
HMBC Spectrum of 37a (Acetone-d_6)



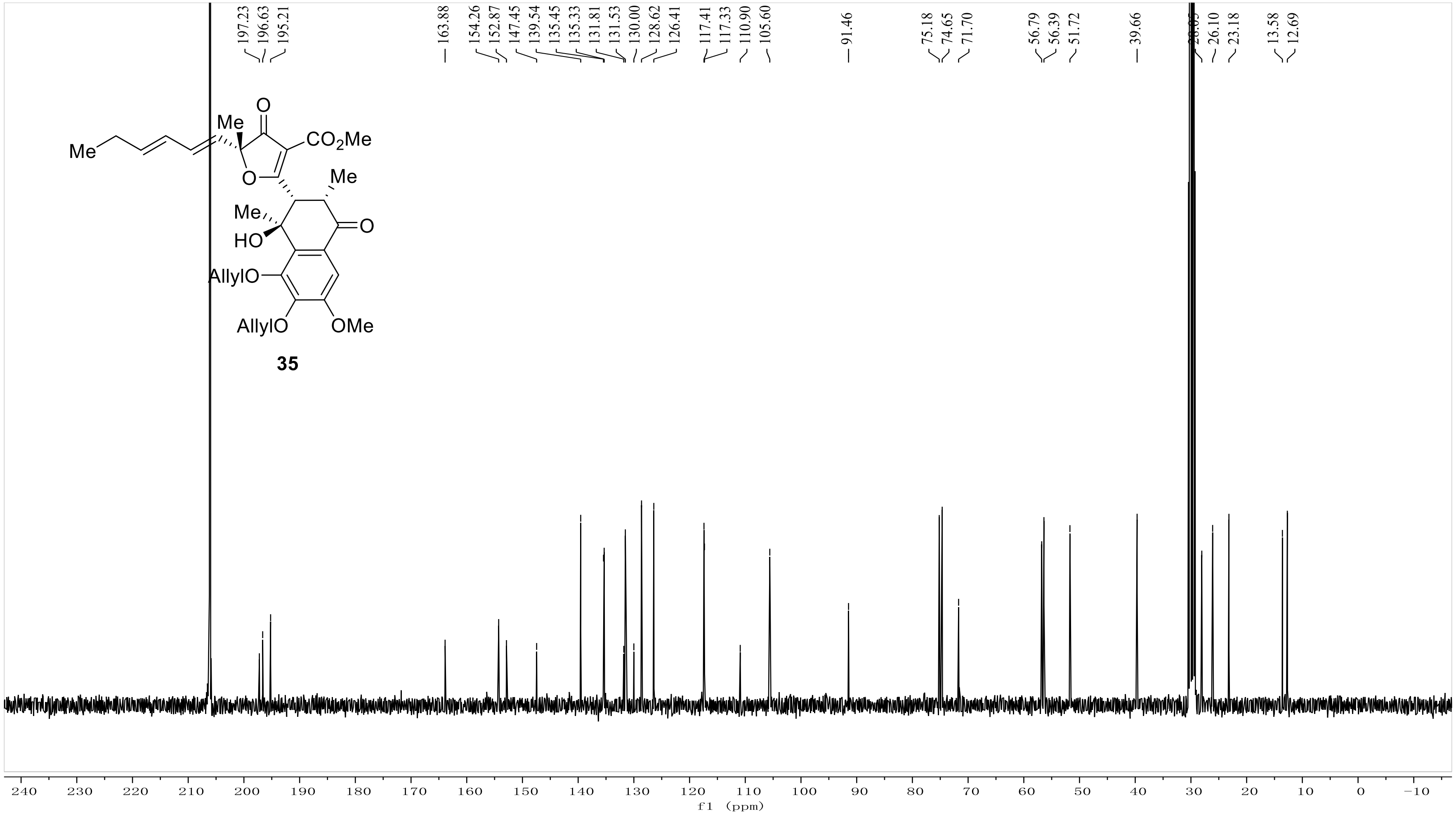
NOESY Spectrum of 37a (Acetone-d_6)



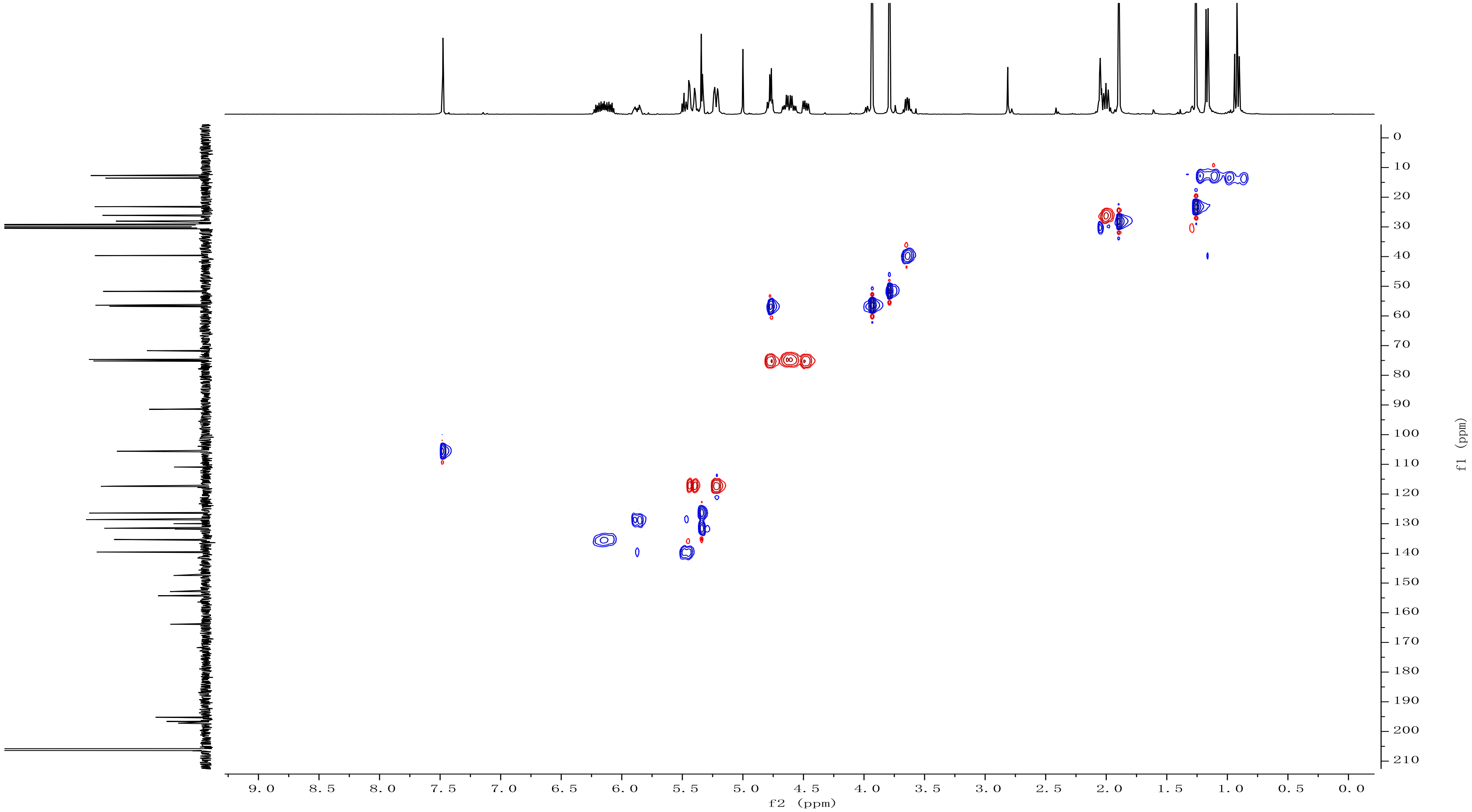
^{1}H NMR Spectrum of 37b (400 MHz, Acetone-d_6)



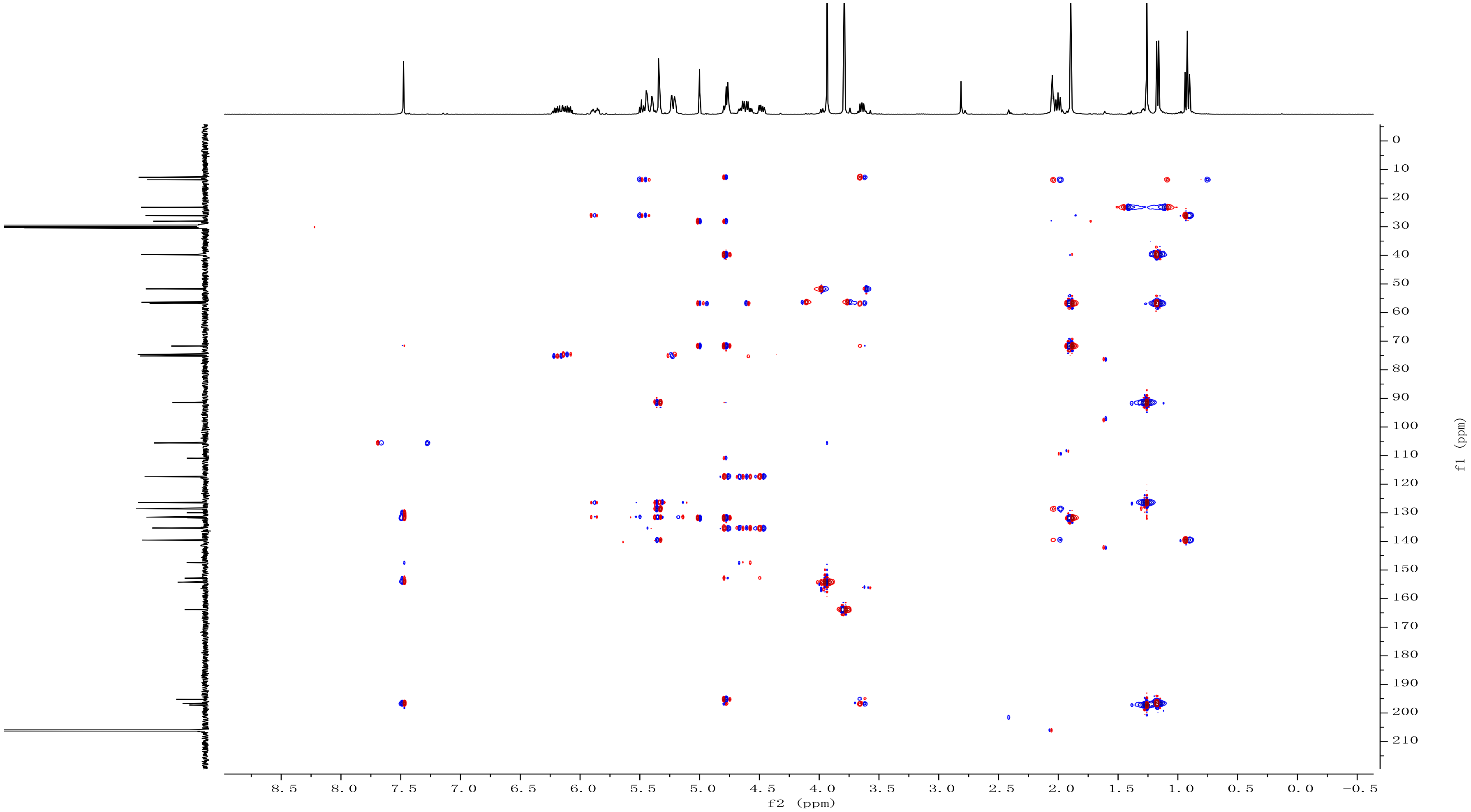
^{13}C NMR Spectrum of 37b (101 MHz, Acetone-*d*$_6$)


35

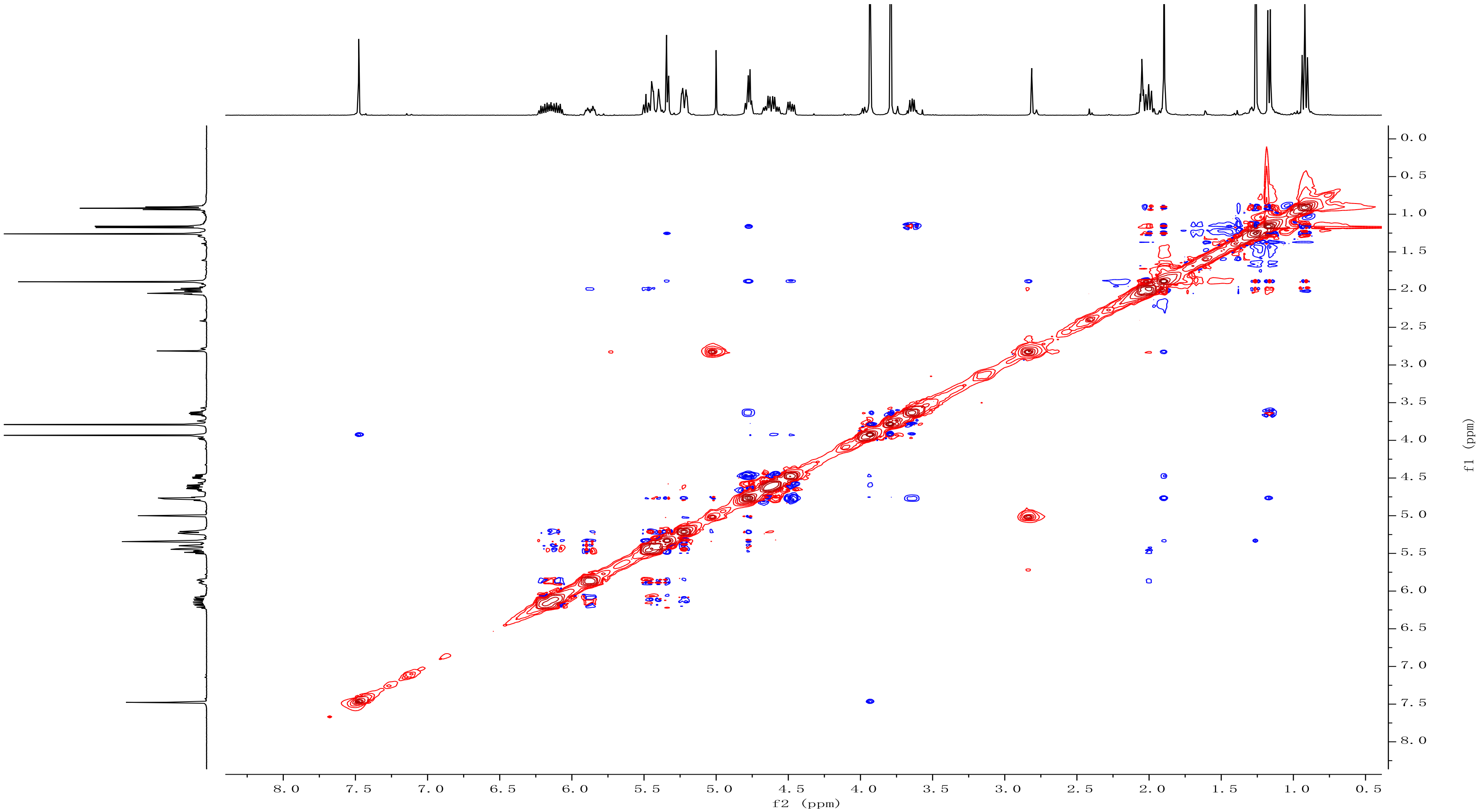
HSQC Spectrum of 37b (Acetone-*d*₆)



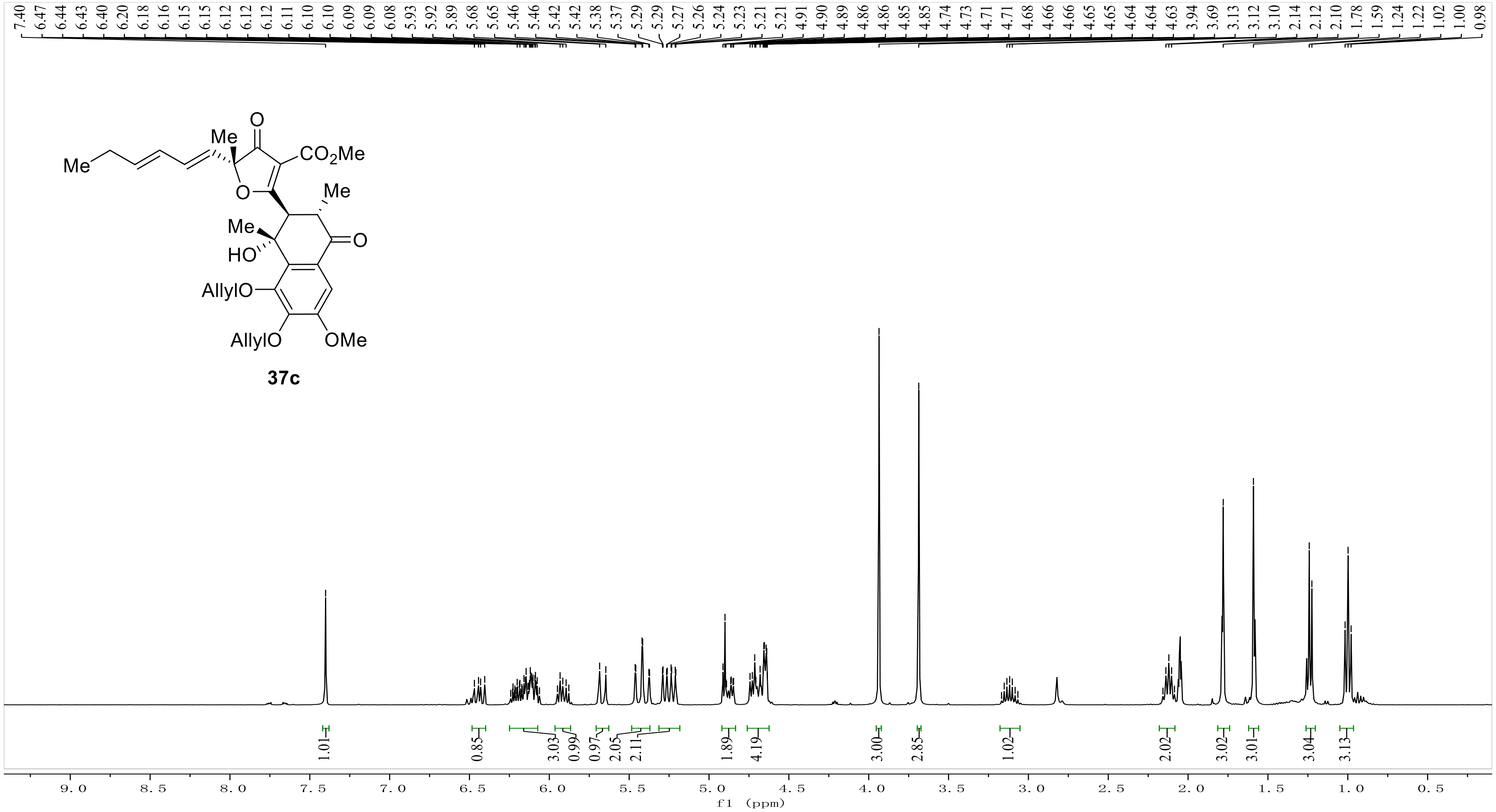
HMBC Spectrum of 37b (Acetone-d_6)



NOESY Spectrum of 37b (Acetone-d_6)

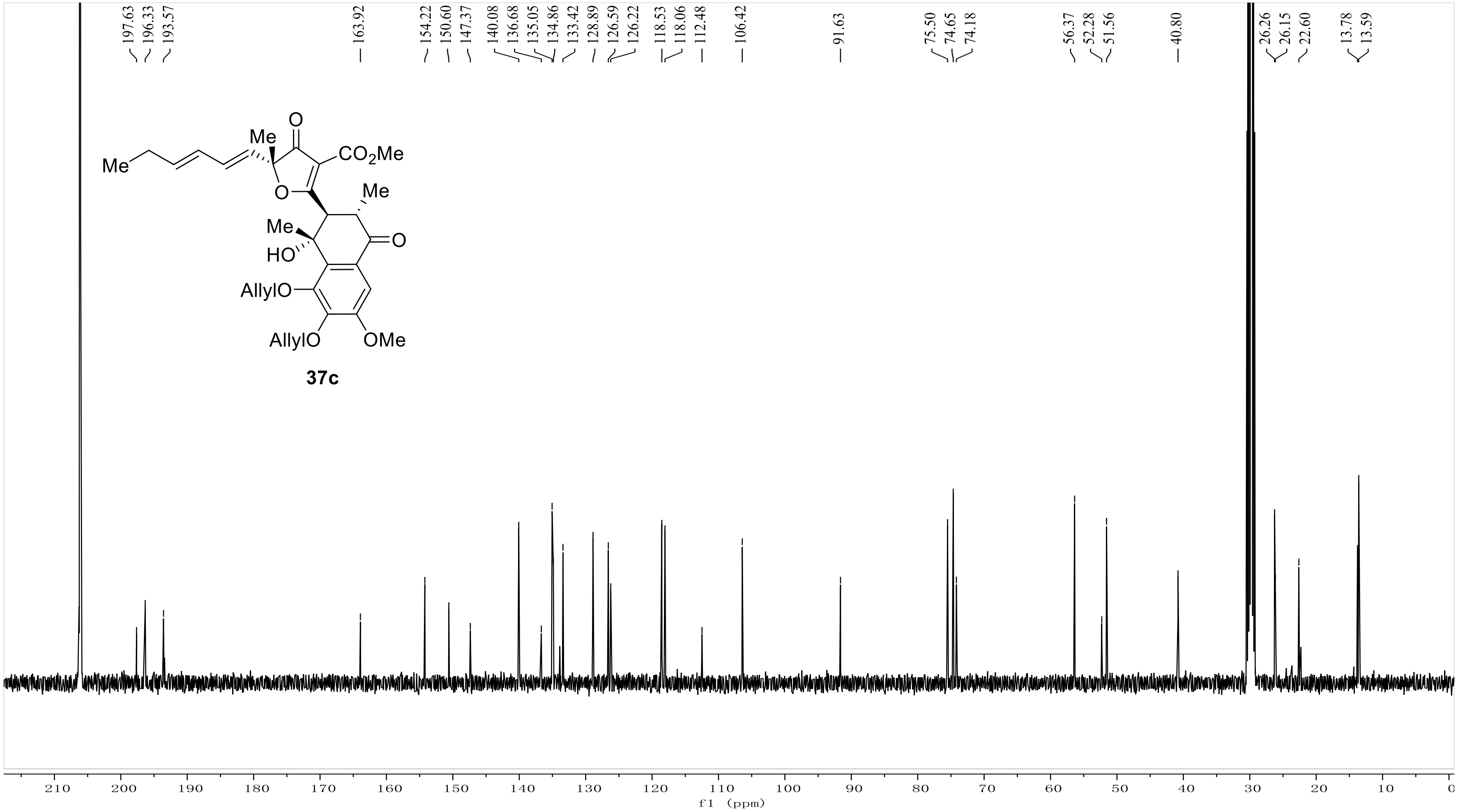


^{1}H NMR Spectrum of 37c (400 MHz, Acetone-d_6)

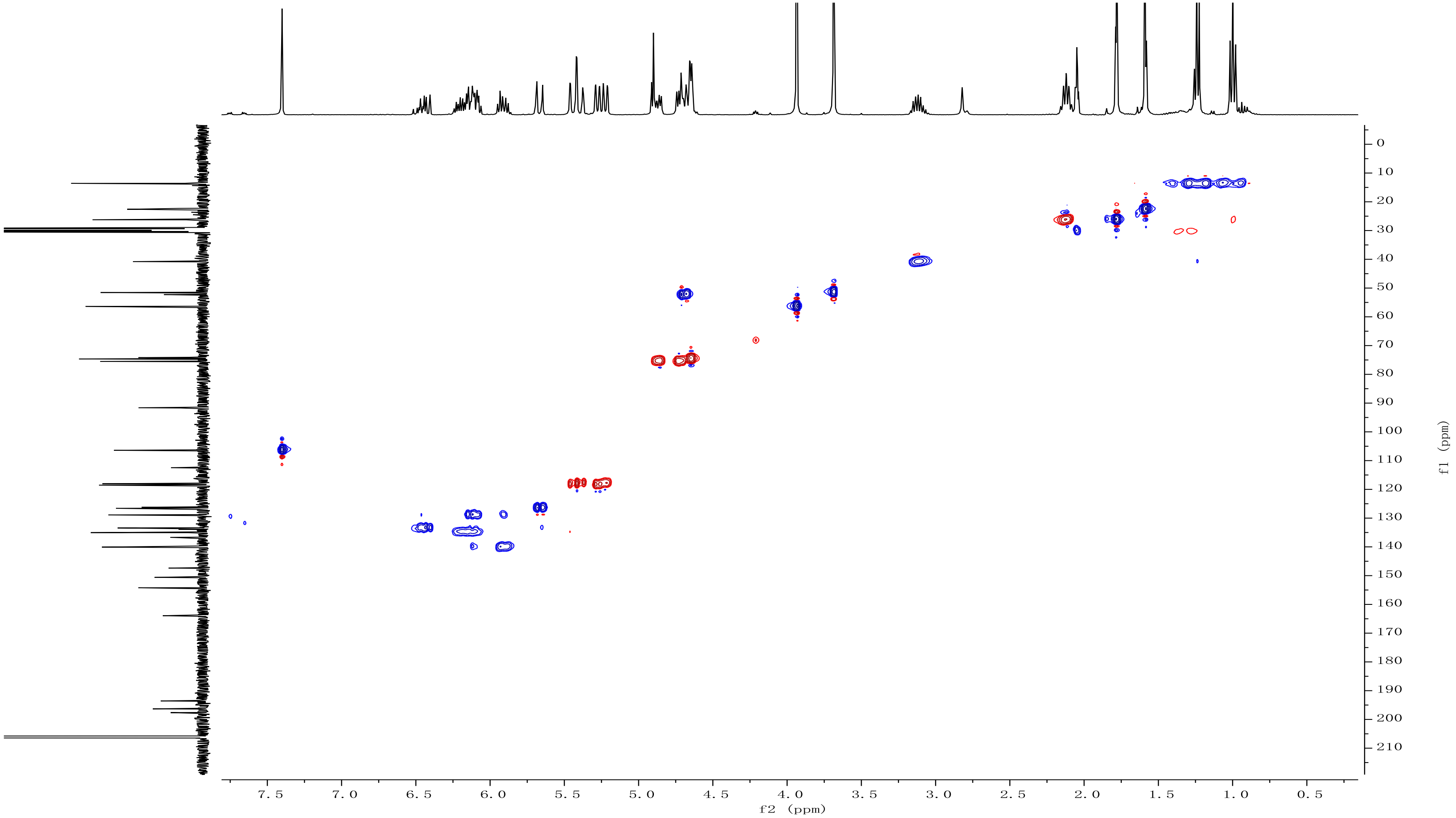


37c

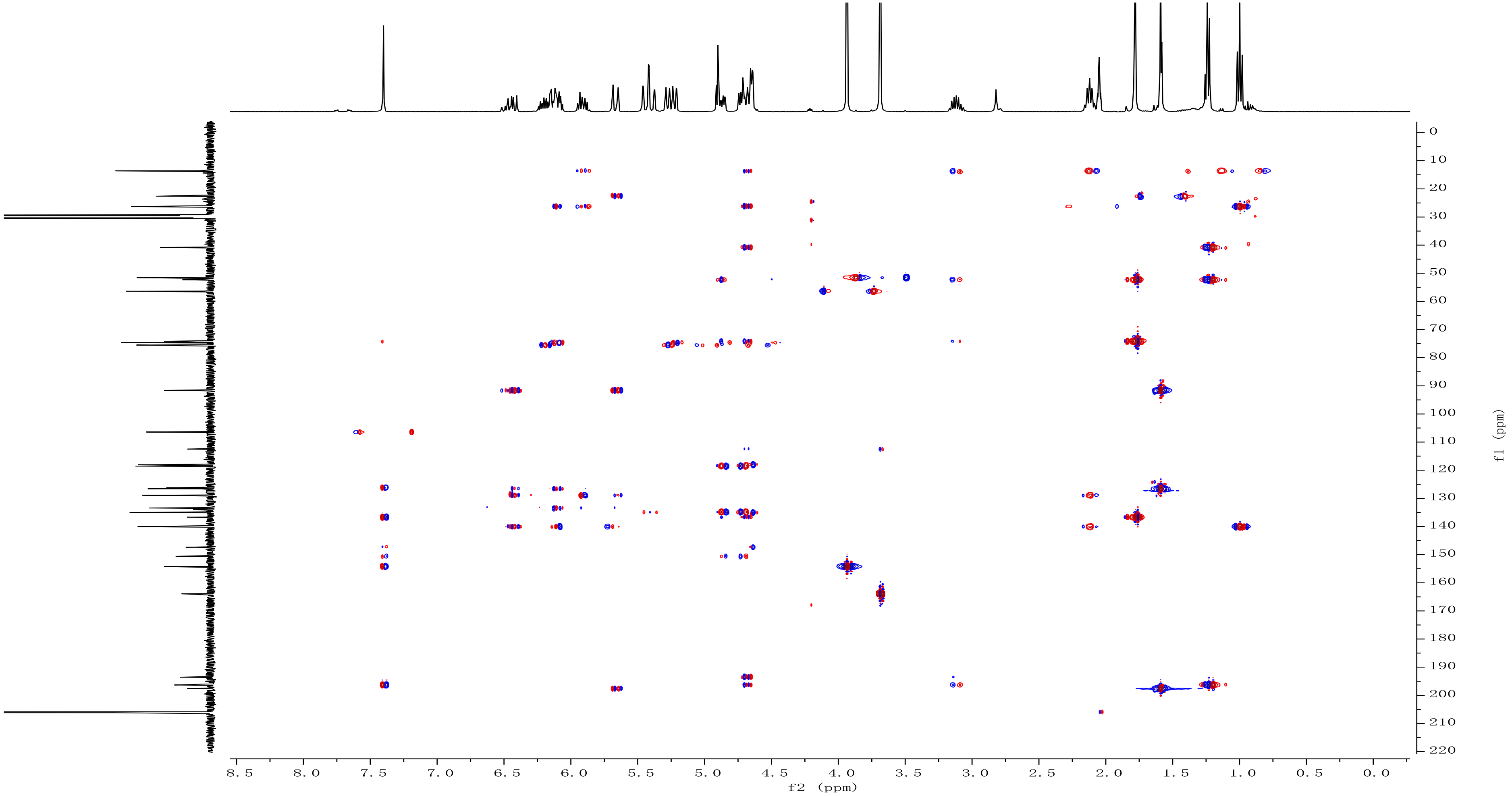
^{13}C NMR Spectrum of 37c (101 MHz, Acetone-d_6)



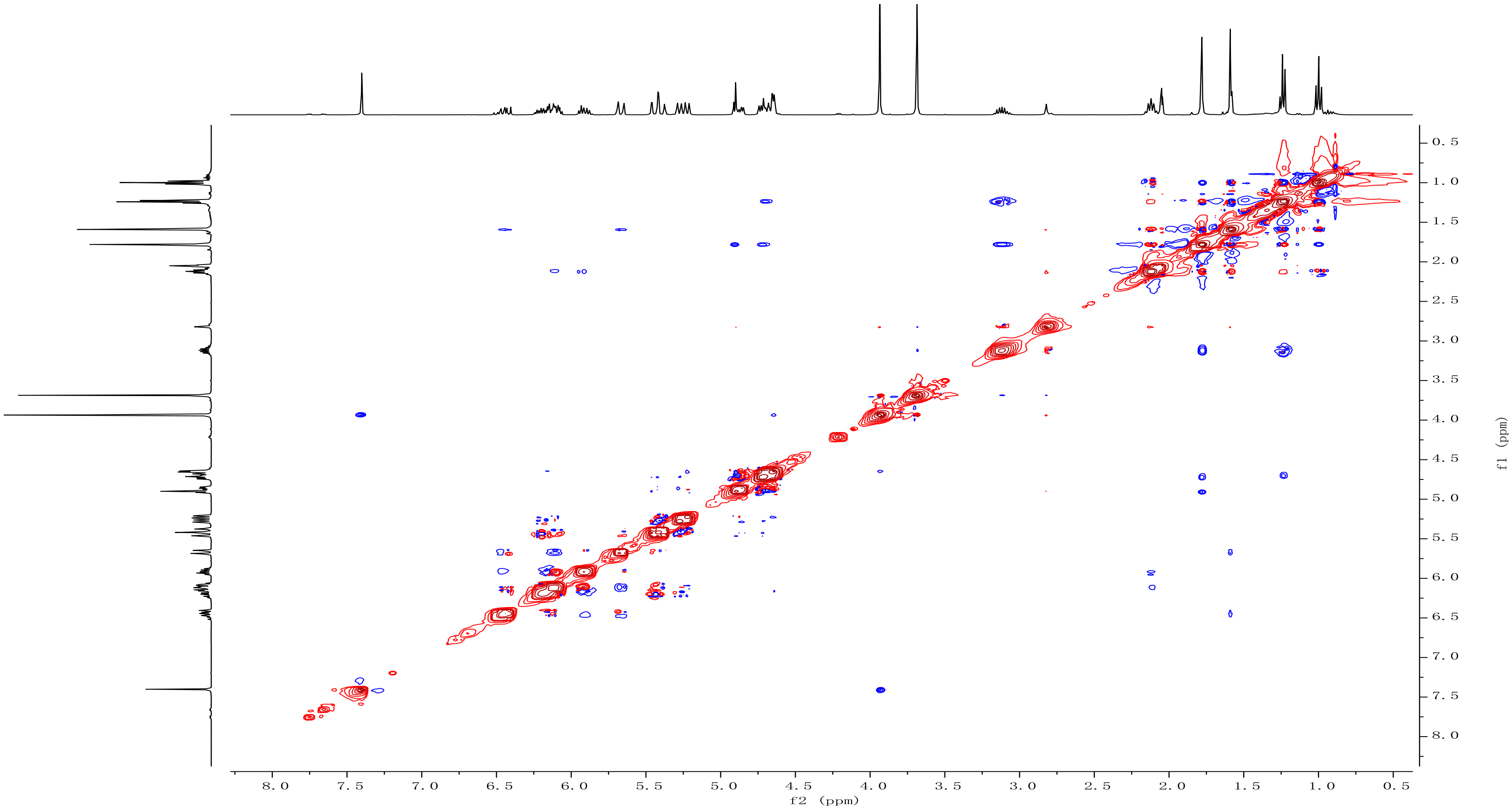
HSQC Spectrum of 37c (Acetone-*d*$_6$)



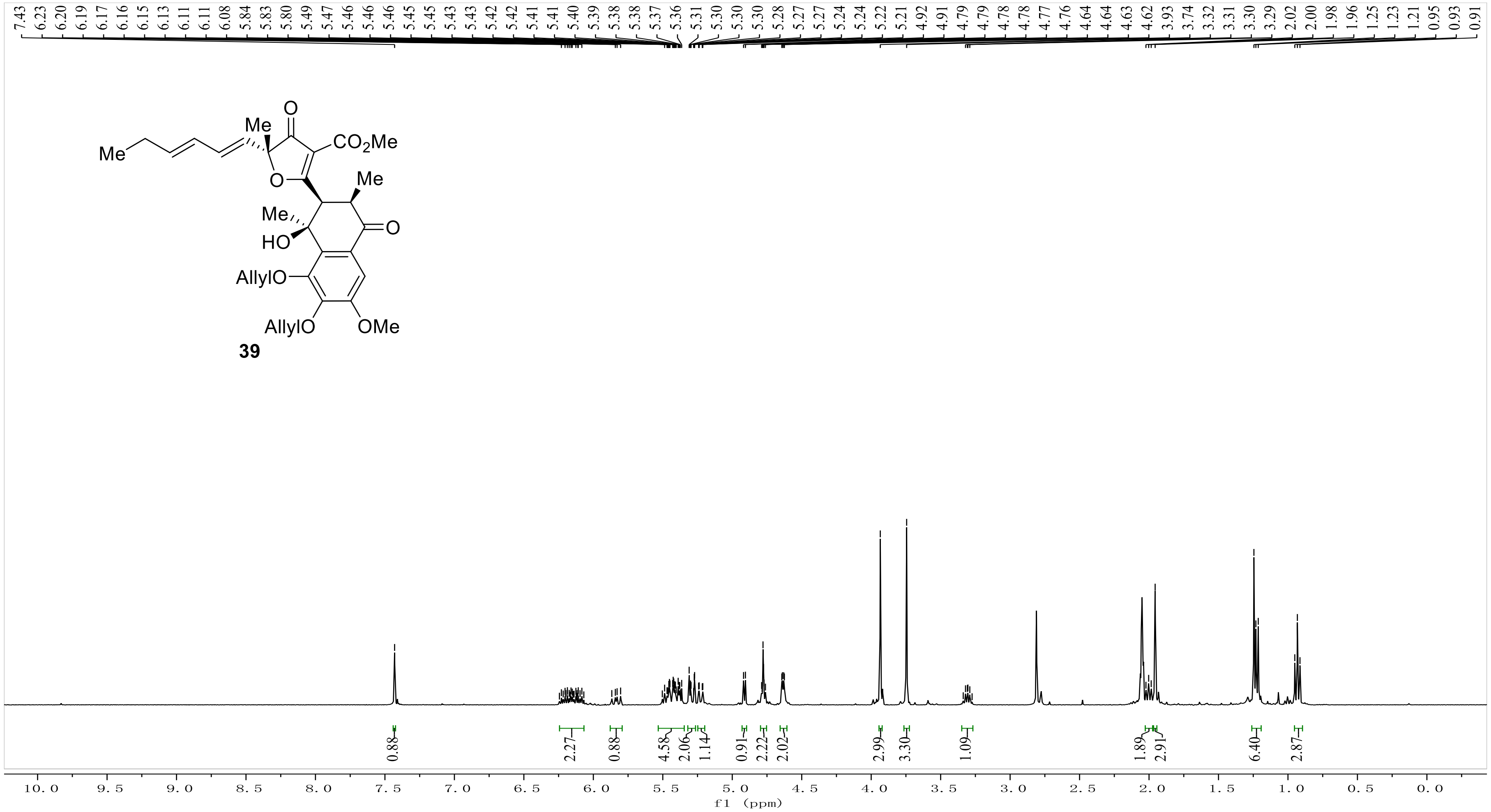
HMBC Spectrum of 37c (Acetone-d_6)



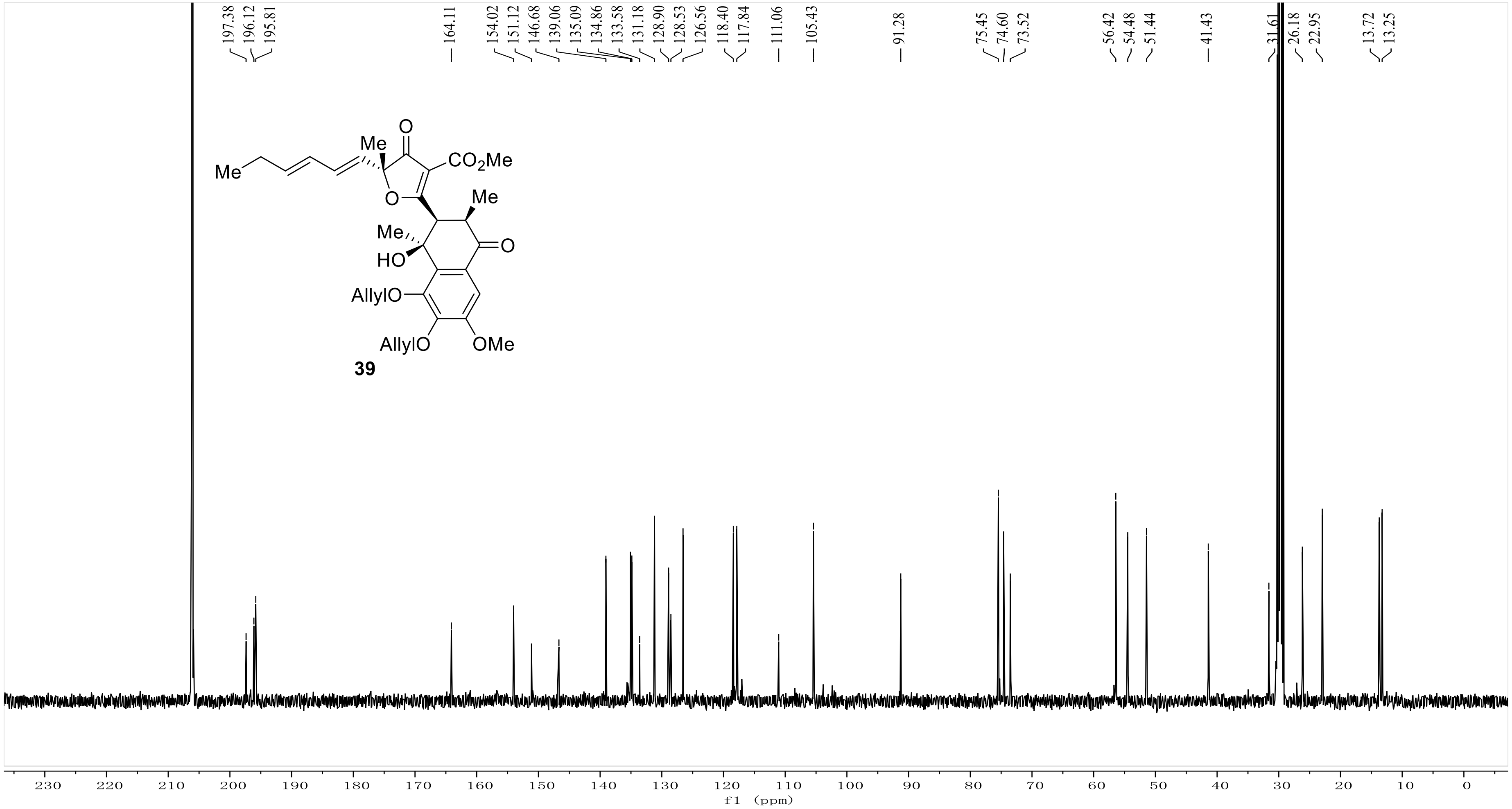
NOESY Spectrum of 37c (Acetone-*d*$_6$)



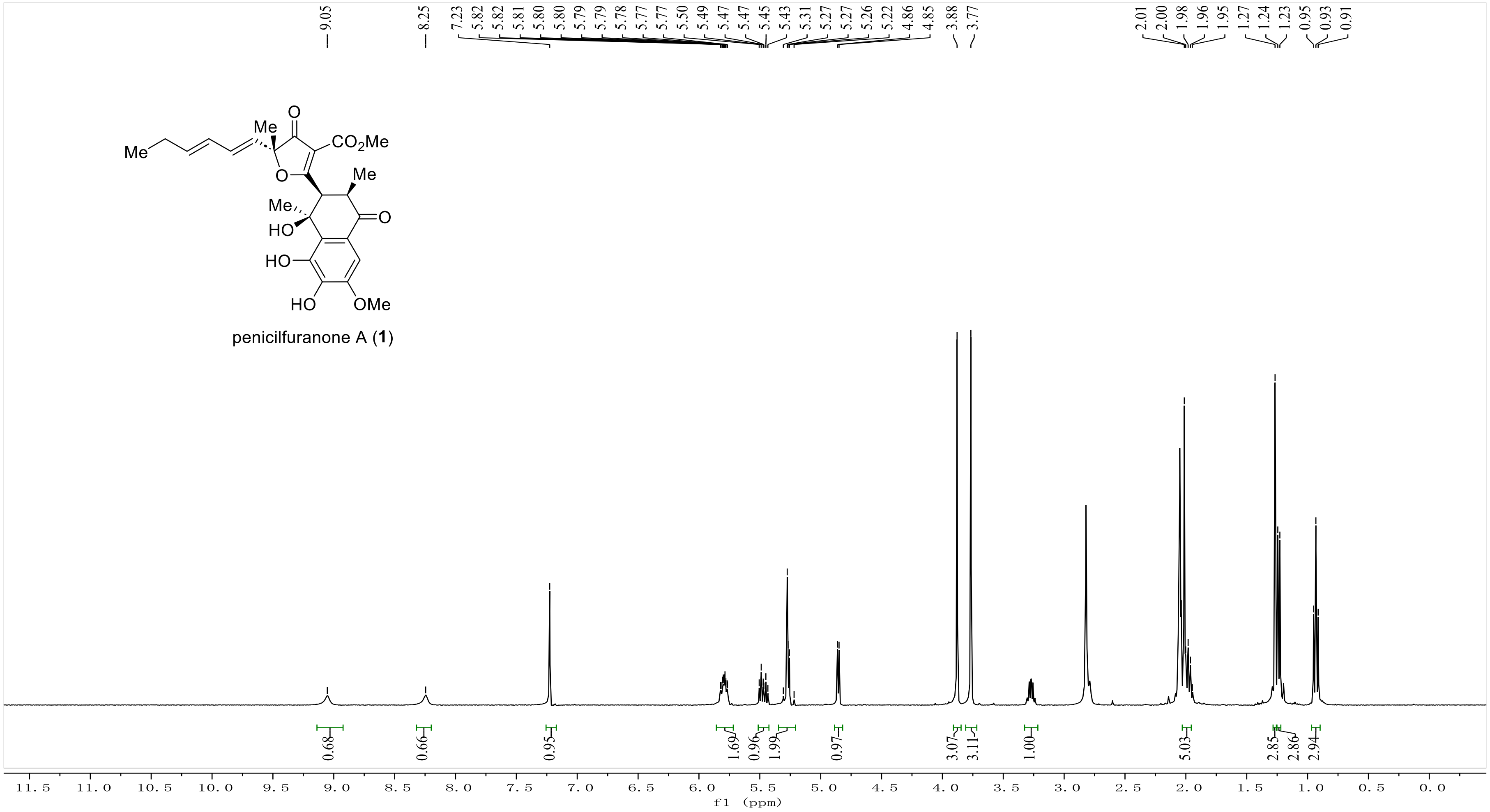
^{1}H NMR Spectrum of 39 (400 MHz, Acetone-d_6)



^{13}C NMR Spectrum of 39 (101 MHz, Acetone-d_6)



^{1}H NMR Spectrum of penicilfuranone A (1) (400 MHz, Acetone-d_6)



^{13}C NMR Spectrum of penicilfuranone A (1) (101 MHz, Acetone-d_6)