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SUPPORTING INFORMATION

Iridium-Catalysed Asymmetric Allylic Alkylation of Benzofuran γ-Lactone Followed by Heteroaromatic Cope Rearrangement: Study of an Unusual Reaction Sequence

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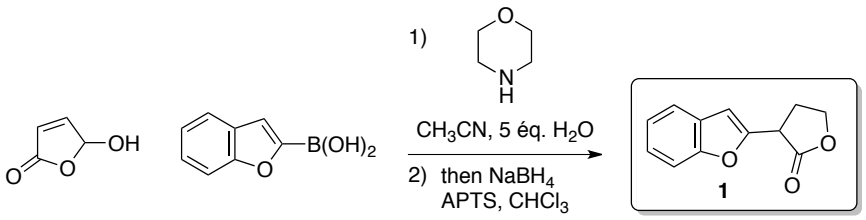
General considerations

Solvents and commercially available reagents were purchased from standard chemical suppliers (Fisher, Sigma-Aldrich, ABCR, Borochem) and used as received without further purification or drying. Exceptions were made for LiO^tBu and KO^tBu that were purified by sublimation prior to use and 1,5,7-Triazabicyclo[4.4.0]dec-5-ene that was purified by recrystallization. All glassware was stored in the oven and/or was flame-dried prior to use under an inert atmosphere of gas. Anhydrous solvents were obtained by filtration through drying columns (THF, Et_2O, CH_2Cl_2, DMF, CH_3CN, toluene). Reactions were performed under an atmosphere of dry nitrogen argon. Thin-layer chromatography (TLC) analyses were done using aluminum sheets coated with silica gel 60 F_{254}. Flash column chromatography (FC) was carried out using silica gel 60 Å (0.04−0.06 mm). Preparative centrifugal thin-layer chromatography carried out on a Chromatotron, Model 7924T (Harrison Research, Palo Alto, CA, U.S.A.); the rotors were coated with silica gel 60 PF254 containing gypsum. NMR spectra were recorded with 250 MHz (BBFO + Z-GRD Probe) (^{1}H: 250 and ^{13}C: 63 MHz), 500 MHz (BBFO + Z-GRD Probe) (^{1}H: 500 and ^{13}C: 126 MHz) and 600 MHz (CPTCI Z-GRD CryoProbe) (^{1}H: 600 and ^{13}C: 151 MHz) spectrometers in $CDCl_3$. Chemical shifts are given in ppm, calibrated to the residual solvent peak, and coupling constants "J" are expressed in hertz (multiplicity: s = singlet, bs = broad singlet, d = doublet, dd = double doublet, dt = double triplet, t = triplet, m = multiplet). Optical rotations were determined at 20 °C in the specified solvents. High-resolution mass spectra (HRMS) were performed on Q-TOF Micro micromass positive ESI (EV = 30 V). Enantiomeric ratios were determined by high-performance liquid chromatography (HPLC) with a chiral column.

I Synthesis of 3-(benzofuran-2-yl)dihydrofuran-2(3*H*)-one 1.



The 5-hydroxyfuran-2(*5H*)-one (6.7 g, 67.4 mmol) and the 2-Benzofuranylboronic acid (10 g, 61.3 mmol) were dissolved in acetonitrile (100 mL), H_2O (2.5 equiv) was then added. The reaction was stirred until total consumption of the 2-Benzofuranylboronic acid (TLC analysis). The reaction mixture was then diluted with CH_3CN, and $NaBH_4$ (2.318 g, 61.3 mmol) was added. When the reduction was completed, 1 M HCl solution was carefully added. The reaction mixture was extracted with CH_2Cl_2. The organic phase was dried over $MgSO_4$, filtered, and concentrated under reduced pressure. The crude mixture was dissolved in $CHCl_3$ (100 mL), and *p*-toluenesulfonic acid was added (0.583 mg, 3 mmol). The reaction mixture was then stirred overnight. The crude material was purified by silica gel column chromatography to yield the desired product as a white solid (11.282, 55.8 mmol, 91%,), (Rf CH_2Cl_2 = 0.65) mp 82-84°C . **^{1}H NMR (500 MHz, CDCl3):** δ 7.54 (d, *J* = 7.5 Hz, 1H), 7.45 (d, *J* = 8.0 Hz, 1H), 7.33 – 7.17 (m, 2H), 6.73 (s,1H), 4.56 (td, *J* = 8.5, 4.4 Hz, 1H), 4.48 – 4.34 (m, 1H), 4.05 (t, *J* = 9.0 Hz, 1H), 3.05 – 2.34 (m, 3H). **^{13}C NMR (126 MHz, CDCl3):** δ 178.4, 137.5, 134.6, 129.8, 129.1, 127.6, 125.1, 122.1, 116.5, 67.8, 43.9, 30.3. **ESI-HRMS:** m/z: calcd for $C_{12}H_{10}NaO_3^+$ ($[M + Na]^+$) 225.0528, found 225.0527.

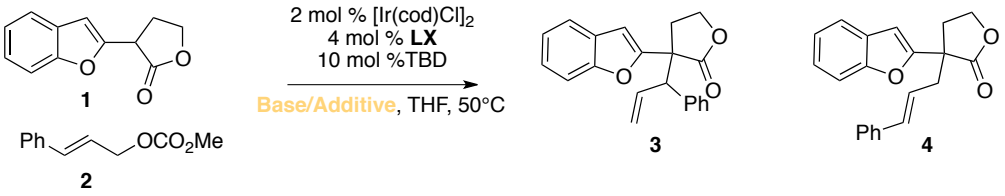
II Asymmetric Allylic alkylation of Lactone 1

II-a Optimization of Ir-Catalyzed Allylic Alkylation

General procedure A for Ligand solvent base and additive screening:

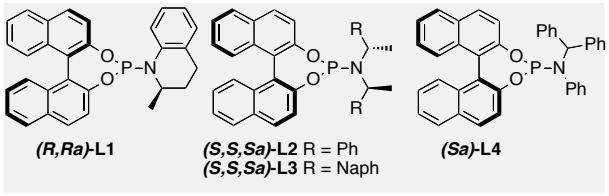
$[Ir(cod)Cl]_2$ (3.4 mg, 0.005 mmol, 2 mol%), **LX** (0.01 mmol, 4 mol%), and TBD (3.5 mg, 0.025 mmol, 10 mol%) were charged to a vial (**vial 1**) equipped with a magnetic stirring bar. The **vial 1** was sealed with a septum-lined cap and evacuated and backfilled with argon three times. The **vial 1** was then charged with solvent (1 mL) and stirred at 50°C for 20 min, generating a yellow solution. In a separated vial (**vial 2**), was charged the lactone (50 mg, 0.25 mmol, 1 equiv) and a magnetic stiring bar. The **vial 2** was sealed with a septum-lined cap and evacuated and backfilled with argon three times. The **vial 2** was then charged with solvent (1 mL) and base/additive (1 equiv) was added and stirred for 10 min. Cinnamyl carbonate (53 mg, 0.275 mmol, 1.1 equiv) was then added to the **vial 1** containing iridium complex followed by the content of **vial 2**. The reaction was stirred at 50°C until total consumption of the lactone (TLC analysis). The reaction mixture was filtered through a silica pad, rinsed with ethyl acetate. After concentration under reduced pressure, the crude residue was purified by silica gel column chromatography to yield the desired products.

Table of optimization

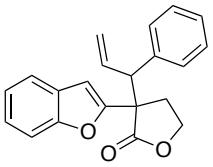


Entry	LX	Base/Additive	Time (h)	Yield[a] (%)	b/l[b]	d.r.[b]	e.r.[c,d]
1	L1	LiO^tBu	1.5	98	85:15	1.5:1	9:91(12:88)
2	L2	LiO^tBu	1.5	90	>20:1	1.5:1	3:97(6:94)
3	L2	Cs_2CO_3	1.5	98	>20:1	1.5:1	3:97(3:97)
4	L2	LiHMDS	1	93	>20:1	1.5:1	2:98(4:96)
5	L2	KHMDS	48	-	-	-	-
6	L2	KHMDS/18C6	0.5	95	>20:1	1.5:1	2:98(4:96)
7	L2	NaH	2	95	>20:1	1.5:1	4:96 (2:98)
8	L2	$ZnEt_2$	1	98	>20:1	1.2:1	2:98 (9:91)
9	L3	LiO^tBu	1.5	95	>20:1	1.5:1	3:97 (6:94)
10	L4	LiO^tBu	1.5	80	>20:1	4:1	94:6(94:6)
11	L4	-	96	-	-	-	-
12	L4	LDA	1	93	>20:1	4:1	98:2(95:5)
13	L4	LiHMDS	1	93	>20:1	4:1	98:2(94:6)
14	L4	LiHMDS/CuBr	2	50	>20:1	1.5:1	60:40(55:50)
15	L4	Cs_2CO_3	12	70	4 :1	1.5:1	83:27(72:28)
16	L4	KHMDS	96	-	-	-	-
17	L4	KHMDS/18C6	16	32	1,5:1	1.3:1	72:28(63:37)
18	L4	$ZnEt_2$	24	51	3:1	1.9:1	73:27(80:20)

[a] Yields of isolated diastereoisomeric mixture [a] Regioselectivity (b:l) and dr was determined by ^{1}H NMR analysis of the crude mixture.. [c] er determined by chiral HPLC analysis. [d] er of the major diastereoisomer and minor diastereoisomer given in parentheses.



*Gram scale synthesis of compound **3:***



3

According to the general procedure A.

Vial 1 $[Ir(cod)Cl]_2$ (68 mg, 0.1 mmol, 2 mol%); ***(S)*-L4** (114 mg, 0.2 mmol, 4 mol%); TBD (80 mg, 0.5 mmol, 10 mol%); carbonate (1.056 g, 5.5 mmol); THF (10 mL)

Vial 2 Lactone **1** (1.010 g, 5 mmol); LiHMDS 1 M in THF (5 mL); THF (10 mL)

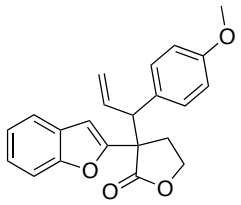
Diastereoisomeric mixture **3** (1.3 g, 4.08 mmol, 82 %) was obtained as a yellowish amorphous solid after silica gel column chromatography (Hexane/EtOAc) (98:2). The diastereoisomeric ratio (80:20) and regio selectivity (>20:1) were determined by ^{1}H NMR of the crude mixture. **^{1}H NMR (500 MHz, $CDCl_3$):** δ 7.55 (d, *J* = 7.5 Hz, 1H, major dia.), 7.53 – 7.47 (m, 2H), 7.45 (d, *J* = 8.0 Hz, 1H, minor dia.), 7.38 – 7.12 (m, 14H), 6.82 (s, 1H, major dia.), 6.67 (s, 1H,minor dia.), 6.38 (ddd, *J* = 16.5, 10.0, 8.0 Hz, 1H, minor dia.), 6.22 (dt, *J* = 16.5, 9.0 Hz, 1H, major dia.), 5.26 – 4.85 (m, 4H), 4.38 (d, *J* = 9.0 Hz, 1H, major dia.), 4.28 (d, *J* = 8.0 Hz, 1H, minor dia.), 4.24 – 4.13 (m, 2H), 3.99 – 3.87 (m, 2H), 2.91 (ddd, *J* = 12.5, 7.5, 4.5 Hz, 1H, major dia.), 2.83 – 2.66 (m, 3H). **^{13}C NMR (126 MHz, $CDCl_3$):** δ 175.42 (minor dia.), 175.39 (major dia.), 154.9 (minor dia.), 154.8 (major dia), 154.0 (major dia.), 138.8 (minor dia.), 138.7 (major dia.), 135.9 (minor dia.), 135.3 (major dia.), 129.5 (major dia.), 128.8 (minor dia.), 128.6 (minor dia.), 128.5 (major dia.), 128.1 (major dia.), 127.5 (major dia.), 127.4 (minor dia.), 124.4 (major dia.), 124.3 (minor dia.), 123.0 (major dia.), 122.9 minor dia.), 121.11 (minor dia.) 121.11 (major dia.), 119.0 (minor dia.), 118.9 (major dia.), 111.2 (major dia.), 111.1 (minor dia.), 105.4 (major dia.), 105.2 (minor dia.), 65.8 (major dia.), 65.7 (minor dia.), 55.2 (minor dia.), 54.5 (major dia.), 53.5 (minor dia.), 53.2 (major dia.), 30.9 (minor dia.), 29.0 (major dia.). **ESI-HRMS:** m/z: calcd for $C_{21}H_{18}NaO_3^+$ ($[M + Na]^+$) 341.1154, found 341.1143. **Enantiomeric Ratio:** 99:1 major; 97:3 minor. The enantiomeric ratio was determined by HPLC with a CHIRALCEL IC column (hexane/iPrOH = 90:10, 254 nm, 1 mL/min), t_R (minor, major) = 7.9 min, t_R (minor, minor) = 8.7 min, t_R (major, minor) = 9.9 min, t_R (major, major) = 10.8 min.

II-b Substrate scope of Allyl Carbonate Electrophiles

General procedure B for Ir-AAA:

$[Ir(cod)Cl]_2$ (27 mg, 0.04 mmol, 2 mol%), **(*Sa*)-L4** (45 mg, 0.08 mmol, 4 mol%), and TBD (28 mg, 0.2 mmol, 10 mol%) were charged to a vial (**vial 1**) equipped with a magnetic stirring bar. The vial was sealed with a septum-lined cap and evacuated and backfilled with argon three times. The **vial 1** was then charged with solvent (1 mL) and stirred at 50°C for 20 min, generating a yellow solution. In a separated vial **(vial 2)**, was charged the lactone **3** (404 mg, 2 mmol, 1 equiv) and a magnetic stiring bar. The **vial 2** was sealed with a septum-lined cap and evacuated and backfilled with argon three times. The **vial 2** was then charged with solvent (1 mL) and LiHMDS 1M in THF (2 mL, 2 mmoL) was added and stirred for 10 min. Cinnamyl carbonate (2.2 mmol) was then added to the **vial 1** containing iridium complex followed by the content of the **vial 2**. The reaction was stirred at 50°C until total consumption of the lactone (TLC analysis). The reaction mixture was filtered through a silica pad, rinsed with ethyl acetate. After concentration under reduced pressure, the crude residue was purified by silica gel column chromatography to yield the desired products.

Compound **4**

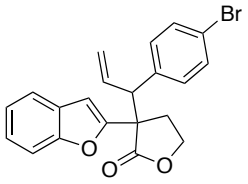


4

Compound **4** (545 mg, 1.56 mmol, 78 %), was obtained as pale brown oil after silica gel column chromatography (Hexane/EtOAc) (90:10). The diastereoisomeric ratio (70:30) and regio selectivity (10:1) were determined by ^{1}H NMR of the crude mixture (isolated with traces <5% of linear product). **^{1}H NMR (600 MHz, $CDCl_3$):** δ 7.53 (d, *J* = 7.5 Hz, 1H, major dia.), 7.51 – 7.46 (m, 2H), 7.43 (d, *J* = 8.0 Hz, 1H, minor dia.), 7.32-7.17 (m, 6H), 7.12 (d, J = 8.5 Hz, 2H, major dia.), 6.83 (d, J = 8.5 Hz, 2H, major dia.), 6.81-6.76 (m, 2H), 6.65 (s, 1H, minor dia.), 6.33 (ddd, J = 18.0, 10.0, 8.0 Hz, 1H, minor dia.), 6.15 (m, 1H, major dia), 5.14-4.98 (m, 4H), 4.33 (d, J = 9.0 Hz, 1H, major dia.), 4.23-4.09 (m, 3H), 3.96-3.89 (m, 2H), 3.80 (m, 1H, minor dia.), 3.78 (s, 3H, major dia.), 3.75 (s, 3H, minor dia.), 2.87 (ddd, J = 12.5, 7.5, 4.5 Hz, 1H, major dia.), 2.81-2.62 (m, 3H). **^{13}C NMR (151 MHz, $CDCl_3$):** δ 175.7 (major dia.), 175.6 (minor dia.), 158.94 (major dia.), 158.90 (minor dia.), 155.0 (minor dia.), 154.9 (major dia.), 154.3 (major dia.), 136.3 (minor dia.), 135.6 (major dia.), 130.74 (minor dia.), 130.66 (major dia.), 130.0 (major dia.), 128.2 (major dia.), 128.0 (minor dia.), 124.44 (major dia.), 124.39 (minor dia.), 123.1 (major dia.), 123.0 (minor dia.), 121.22 (minor dia.), 121.19 (major dia.), 118.8 (major dia.), 118.7 (minor dia.), 114.1 (minor dia.), 113.9 (major dia.), 111.3

(major dia.), 111.2 (minor dia.), 105.4 (major dia.), 105.3 (minor dia.), 65.9 (major dia.), 65.8 (minor dia.), 55.3 (major dia.), 54.5 (minor dia.), 53.8 (major dia.), 53.4 (minor dia.), 31.1 (minor dia.), 28.9 (major dia.). **ESI-HRMS:** m/z: calcd for $C_{22}H_{20}NaO_4^+$ ([M + Na]$^+$) 371.1259, found 371.1254. **Enantiomeric Ratio:** 88:12 major; 75:25 minor. The enantiomeric ratio was determined by HPLC with a CHIRALCEL IC column (hexane/iPrOH = 95:5, 254 nm, 1 mL/min), t_R (minor, major) = 14.1 min, t_R (minor, minor) = 16.1 min, t_R (major, minor) = 20.9 min, t_R (major, major) = 22.2 min.

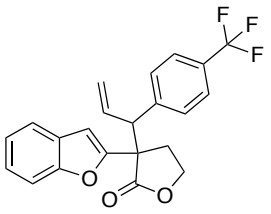
Compound **5**



5

Compound **5** (660 mg, 1.66 mmol, 83%) was obtained as colorless oil after silica gel column chromatography (Hexane/EtOAc) (95:5). The diastereoisomeric ratio (75:25) and regio selectivity (>20:1) were determined by ^{1}H NMR of the crude mixture. **1H NMR (600 MHz, $CDCl_3$):** 7.54 (d, J = 7.5 Hz, 1H, major dia.), 7.50 (d, J = 8.2 Hz, 1H, major dia.), 7.45 (d, J = 8.0 Hz, 1H, minor dia.), 7.42 (d, J = 8.5 Hz, 2H, major dia.), 7.38 (d, J = 8.5 Hz, 2H, minor dia.), 7.33-7.27 (m, 3H), 7.27-7.22 (m, 2H), 7.20 (d, J = 8.4 Hz, 2H, major dia.), 7.07 (d, J = 8.4 Hz, 2H, minor dia.), 6.76 (s, 1H, major dia.), 6.65 (s, 1H, minor dia.), 6.30 (ddd, J = 17.0, 10.5, 8.0 Hz, 1H, minor dia.), 6.17 (ddd, J = 17.0, 10.5, 9.0 Hz, 1H, major dia.), 5.20 (d, J = 10.5 Hz, 1H, minor dia.), 5.17-5.10 (m, 2H, major dia.), 5.08 (d, J = 17.0 Hz, 1H, minor dia.), 4.31 (d, J = 9.0 Hz, 1H, major dia.), 4.27 (d, J = 8.0 Hz, 1H, minor dia.), 4.25-4.16 (m, 2H), 4.11 (m, 1H, minor dia.), 4.08 (td, J = 8.5, 4.0 Hz, 1H, major dia.), 2.89 (ddd, J = 13.5, 7.5, 4.0 Hz, 1H, major dia.), 2.78-2.74 (m, 2H, minor dia.), 2.69 (dt, J = 13.5, 8.5 Hz, 1H, major dia.). **^{13}C NMR (151 MHz, $CDCl_3$):** δ 175.2 (minor dia.), 175.1 (major dia.), 155.0 (major dia.), 154.9 (minor dia.), 153.5 (minor dia.), 153.3 (major dia.), 138.0 (minor dia.), 137.9 (major dia.), 135.5 (minor dia.), 135.0 (major dia.), 131.8 (minor dia.), 131.6 (major dia.), 131.4 (major dia.), 130.7 (major dia.), 128.0 (major dia), 127.8 (minor dia.), 124.6 (major dia.), 123.19 (major dia.), 123.17 (minor dia.), 121.6 (major dia.), 121.5 (minor dia.), 121.3 (major dia.), 119.64 (minor dia.), 119.59 (major dia.), 111.3 (major dia.), 111.2 (minor dia.), 105.7 (major dia.), 105.6 (minor dia.), 65.9 (major dia.), 65.8 (minor dia.), 54.4 (minor dia.), 54.1 (major dia.), 53.4 (minor dia.), 53.0 (major dia.), 30.5 (minor dia.), 29.5 (major dia.). **ESI-HRMS:** m/z: calcd for $C_{21}H_{17}BrNaO_3^+$ ([M + Na]$^+$) 419.0259, found 419.0256. **Enantiomeric Ratio:** 97:3 major; 90:10 minor. The enantiomeric ratio was determined by HPLC with a Whelk (R,R)-01 column (hexane/CH_2Cl_2 = 70:30, 254 nm, 1 mL/min), t_R (minor, minor) = 7.7 min, t_R (major, major) = 10.5 min, t_R (minor, major) = 13.0 min, t_R (major, minor) = 14.9 min.

Compound **6**

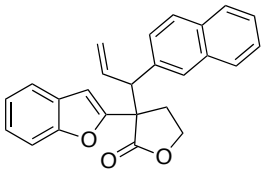


6

Compound **6** (570 mg, 1.48 mmol, 74%) was obtained as colorless oil after silica gel column chromatography (Hexane/EtOAc) (95:5). The diastereoisomeric ratio (75:25) and regio selectivity (>20:1) were determined by ^{1}H NMR of the crude mixture. **^{1}H NMR (600 MHz, $CDCl_3$):** δ 7.54 – 7.49 (m, 6H), 7.47 (d, *J* = 8.5 Hz, 2H, major dia.), 7.44 – 7.40 (m, 3H), 7.39 (d, *J* = 8.5 Hz, 1H, minor dia.), 7.31 – 7.17 (m, 4H), 6.73 (s, 1H, major dia.), 6.62 (s, 1H, minor dia.), 6.30 (ddd, *J* = 17.0, 10.5, 8.0 Hz, 1H, minor dia.), 6.19 (dt, *J* = 17.0, 9.5 Hz, 1H, major dia.), 5.20 (d, *J* = 10.3 Hz, 1H, minor dia.), 5.18 – 5.02 (m, 3H), 4.39 – 4.32 (m, 2H), 4.22 – 4.15 (m, 2H), 4.13 (dt, *J* = 9.0, 6.5 Hz, 1H, minor dia.), 4.08 (td, *J* = 9.0, 3.5 Hz, 1H, major dia.), 2.88 (ddd, *J* = 13.0, 7.0, 3.5 Hz, 1H, major dia.), 2.79 – 2.73 (m, 2H, minor dia.), 2.67 (dt, *J* = 13.5, 8.5 Hz, 1H, major dia.). **^{13}C NMR (151 MHz, $CDCl_3$):** δ 175.0 (minor dia.), 174.9 (major dia.), 154.90 (minor dia.), 154.85 (major dia.), 153.1 (major dia.), 152.9 (minor dia), 143.1 (minor dia.), 143.0 (major dia.), 135.1 (minor dia.), 134.6 (major dia.), 130.0 (major dia.), 129.7 (minor dia.), 129.4 (minor dia.), 129.2 (major dia.), 127.9 (major dia.), 127.7 (minor dia.), 125.46 (q, $J_{C\text{-}F}$ = 3.5 Hz), 125.23 (q, $J_{C\text{-}F}$ = 3.5 Hz).124.6, 123.2 (major dia.), 123.1 (minor dia.), 121.21 (major dia.), 121.19 (minor dia.), 120.0 (minor dia.), 119.9 (major dia.), 111.2 (major dia.), 111.1 (minor dia.), 105.7 (major dia.), 105.6 (minor dia.), 65.8 (major dia.), 65.7 (minor dia.), 54.7(minor dia.), 54.4 (major dia.), 53.4 (minor dia.), 53.0 (major dia.), 30.3 (minor dia.), 29.6 (major dia.). **^{19}F NMR (235 MHz, $CDCl_3$):** δ -62.5 (s, 3F). **ESI-HRMS:** m/z: calcd for $C_{22}H_{17}F_3NaO_3^+$ ($[M + Na]^+$) 409.1027, found 429.1036. **Enantiomeric Ratio** (determined after reduction of allylic double bond of an analytical simple)**:** 99:1 major; 90:10 minor. The enantiomeric ratio was determined by HPLC with a Whelk (R,R)-01 column (hexane/CH_2Cl_2 = 70:30, 254 nm, 1 mL/min), t_R (minor, minor) = 9.6 min, t_R (minor, major) = 14.7 min, t_R (major, major) = 18.7 min, t_R (major, minor) = 20.7 min.

Compounds ***(R,S)*-7 and *(R,S)*-7** (see Section I c)

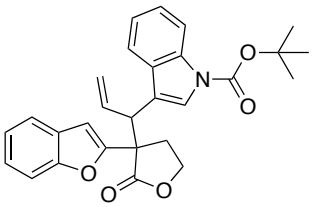
Compound **8**



8

Compound **8** (500 mg, 1.36 mmol, 68%) was obtained as colorless oil after silica gel column chromatography (Hexane/EtOAc) (95:5). The diastereoisomeric ratio (80:20) and regio selectivity (>20:1) were determined by ^{1}H NMR of the crude mixture. **^{1}H NMR (600 MHz, $CDCl_3$):** δ 7.82 – 7.65 (m, 10H), 7.54 – 7.51 (m, 1H, major dia.), 7.49 (d, *J* = 8.2 Hz, 1H, major dia.), 7.47 – 7.39 (m, 6H), 7.32 (dd, *J* = 8.5, 1.5 Hz, 1H, minor dia.), 7.30 – 7.26 (m, 1H, major dia.), 7.25 – 7.20 (m, 1H, major dia.), 7.19 – 7.15 (m, 1H, minor dia.), 6.81 (s, 1H, major dia.), 6.65 (s, 1H, minor dia.), 6.45 (ddd, *J* = 17.0, 10.5, 8.0 Hz, 1H, minor dia.), 6.29 (ddd, *J* = 16.7, 10.4, 9.0 Hz, 1H, major dia.), 5.15 (d, *J* = 10.5 Hz, 1H, minor dia.), 5.13 – 5.08 (m, 2H, major dia.), 5.05 (d, *J* = 17.0 Hz, 1H, minor dia.), 4.52 (d, *J* = 9.0 Hz, 1H, major dia.), 4.42 (d, *J* = 8.0 Hz, 1H, minor dia.), 4.20 – 4.07 (m, 2H), 3.96 – 3.86 (m, 2H), 2.89 (ddd, *J* = 13.2, 7.4, 4.3 Hz, 1H, major dia.), 2.85 – 2.70 (m, 3H). **^{13}C NMR (151 MHz, $CDCl_3$):** δ 175.6 (minor dia.), 175.5 (major dia.), 155.00 (minor dia.), 155.95 (major dia.), 154.0 (minor dia.), 153.9 (major dia.), 136.6 (minor dia.), 136.4 major dia.), 136.0 (minor dia.), 135.5 (major dia.), 133.5 (minor dia.), 133.3 (major dia.), 132.7 (major dia.), 128.9 (major dia.), 128.4 (minor dia.), 128.19 (minor dia), 128.16 (major dia.), 128.1 (major dia.), 128.0 (minor dia.), 127.7 (minor dia.), 127.6 (major dia.), 127.5 (major dia.), 126.8 (major dia.), 126.29 (minro dia.), 126.27 (major dia.), 126.2 (major dia.), 126.1 (minor dia.), 124.54 (major dia.), 124.48 (minor dia.), 123.13 (major dia.), 123.07 (minor dia.), 121.2 (major dia), 119.25 (minor dia., 119.22 (major dia.), 111.4 (major dia.), 111.2 (minor dia.), 105.6 (major dia.), 105.5 (minor dia.), 65.91 (major dia.), 65.88 (minor dia.), 55.3 (minor dia.), 54.6 (major dia.), 53.6 (minor dia.), 53.4 (major dia.), 31.1 (minor dia.), 29.2 (major dia.). **ESI-HRMS:** m/z: calcd for $C_{25}H_{20}NaO_3^+$ ($[M + Na]^+$) 391.1310, found 391.1303. **Enantiomeric Ratio:** 97:3 major; 91:9 minor. The enantiomeric ratio was determined by HPLC with a CHIRALCEL IC column (hexane/iPrOH = 90:10, 254 nm, 1 mL/min), t_R (minor, major) = 9.0 min, t_R (minor, minor) = 10.1 min, t_R (major, minor) = 12.1 min, t_R (major, major) = 17.8 min.

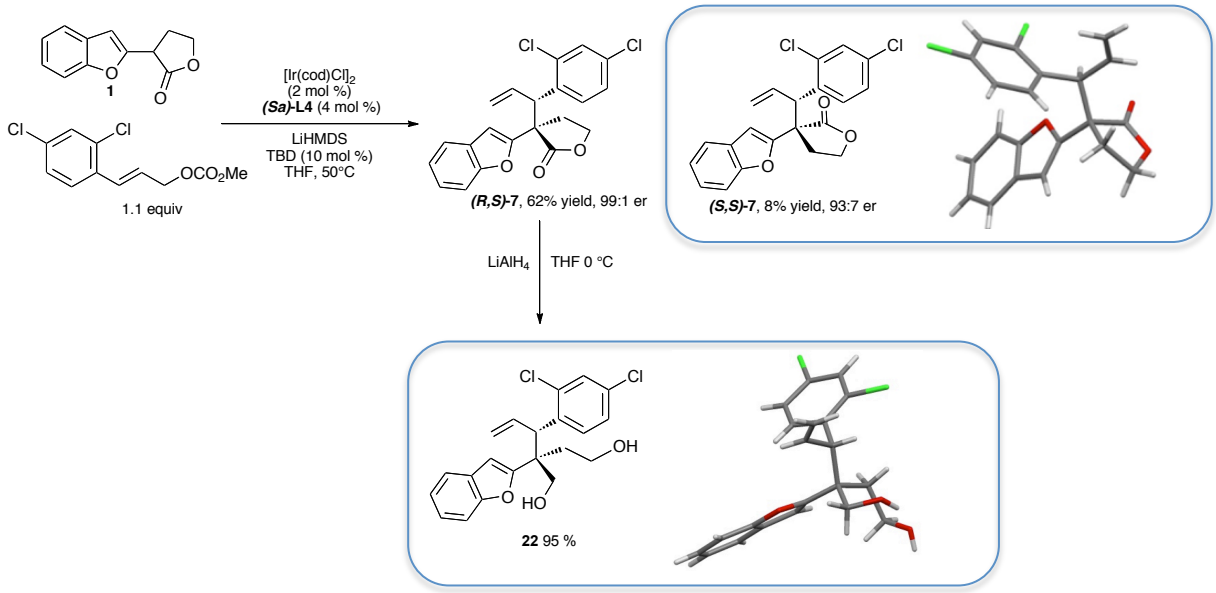
Compound **9**



9

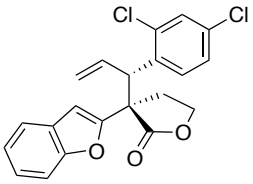
Compound **9** (585 mg, 1.28 mmol, 64%) was obtained as colorless oil after silica gel column chromatography (Hexane/EtOAc) (95:5). The diastereoisomeric ratio (68:32) and regio selectivity (>20:1) were determined by ^{1}H NMR of the crude mixture. **1H NMR (600 MHz, CDCl):** δ 8.20-8.05 (m, 2H), 7.63 (d, J = 8.0 Hz, 1H, major dia.), 7.61-7.52 (m, 3H), 7.48 (dd, J = 8.0, 0.5 Hz, 1H, major dia.), 7.47-7.37 (m, 2H), 7.33-7.27 (m, 4H), 7.25-7.13 (m, 4H), 6.84 (s, 1H, major dia.), 6.66 (s, 1H, minor dia.), 6.31 (ddd, J = 17.5, 10.0, 8.0 Hz, 1H, minor dia.), 6.24-6.13 (m, 1H, major ida.), 5.22- 4.98 (m, 4H), 4.64 (d, J = 8.0 Hz, 1H, minor dia.), 4.60 (d, J = 8.5 Hz, 1H, major dia.), 4.31-4.17 (m, 4H), 2.95 (ddd, J = 13.5, 7.0, 4.0 Hz, 1H, major dia.), 2.90-2.79 (m, 3H), 1.66 (s, 9H, major dia.), 1.64 (s, 9H, minor dia.). **^{13}C NMR (151 MHz, $CDCl_3$):** δ 175.7 (minor dia.), 175.3 (major dia.), 155.0 (minor dia.), 154.9 (major dia.), 153.9 (minor dia.), 153.6 (major dia.), 149.7 (major dia.), 135.2 (minor dia.), 135.1 (major dia.), 130.4 (minor dia.), 130.1 (major dia.), 128.1 (major dia.), 128.0 (minor dia.), 125.2 (major dia.), 124.7 (minor dia.), 124.6 (major dia.), 124.55 (major dia.), 124.49 (minor dia.), 123.9 (major dia.), 123.14 (major dia.), 123.05 (minor dia.), 122.7 (minor dia.), 122.6 (major dia.), 121.21 (major dia.), 121.19 (minor dia.), 120.2 (major dia.), 119.3 (major dia.), 119.2 (minor dia.), 118.7 (major dia.), 118.1 (minor dia.), 117.8 (major dia.), 115.3 (major dia.), 111.4 (major dia.), 111.2 (minor dia.), 105.6 (major dia.), 105.4 (minor dia.), 84.0 (major dia.), 66.1 (minor dia.), 65.9 (major dia.), 53.6 (minor dia.), 52.9 (major dia.), 46.6 (major dia.), 45.5 (minor dia.), 30.6 (minor dia.), 30.3 (major dia.), 28.29 (major dia.), 28.27 (minor dia.). **ESI-HRMS:** m/z: calcd for $C_{28}H_{27}NNaO_5^+$ ([M + Na]$^+$) 480.1787, found 480.1778. **Enantiomeric Ratio:** 98:2 major dia.; 91:9 minor dia. The enantiomeric ratio was determined by HPLC with a Whelk (R,R)-01 column (hexane/CH_2Cl_2 = 68:32, 254 nm, 1 mL/min), t_R (minor, minor) = 9.1 min, t_R (major, major) = 11.7 min, t_R (minor, major) = 13.7 min, t_R (major, minor) = 15.5 min.

II-c Determination of absolute configuration of compounds *(R,S)*-7 and *(R,S)*-7



According to the general procedure B. The diastereoisomeric ratio (83:17) and regio selectivity (>20:1) were determined by ^{1}H NMR of the crude mixture.

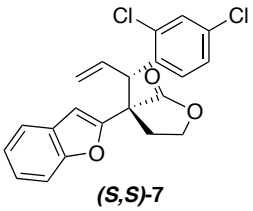
Compound **(R,S)-7**



(R,S)-7

Major diastereoisomer ***(R,S)-7***) (482 mg, 1.24 mmol, 62%) was obtained as a colourless gum after silica gel column chromatography (Hexane/EtOAc) (97:3). **^{1}H NMR (500 MHz, $CDCl_3$):** δ 7.50 (d, *J* = 7.5 Hz, 1H), 7.41 (d, *J* = 8.0 Hz, 1H), 7.33 – 7.24 (m, 3H), 7.22 (td, *J* = 7.5, 1.0 Hz, 1H), 7.07 (dd, *J* = 8.6, 2.0 Hz, 1H), 6.71 (s, 1H), 6.28 (ddd, *J* = 17.0, 10.0, 8.5 Hz, 1H), 5.26 (d, *J* = 10.0 Hz, 1H), 5.17 (d, *J* = 17.0 Hz, 1H), 4.59 (d, *J* = 8.5 Hz, 1H), 4.44 (ddd, *J* = 9.0, 8.0, 4.5 Hz, 1H), 4.23 (td, *J* = 9.0, 7.5 Hz, 1H), 2.86 (ddd, *J* = 13.0, 7.0, 4.5 Hz, 1H), 2.68 (dt, *J* = 13.0, 8.0 Hz, 1H). **^{13}C NMR (126 MHz, $CDCl_3$):** δ 174.9, 154.7, 152.1, 135.4, 135.4, 135.1, 133.5, 131.7, 129.2, 128.0, 127.1, 124.7, 123.2, 121.4, 119.9, 111.3, 106.6, 66.0, 52.1, 50.0, 33.0. **ESI-HRMS:** m/z: calcd for $C_{21}H_{16}Cl_2NaO_3^+$ ([M + Na]+) 409.0374, found 409.0366. **$[\alpha]^{20}_D$ =** -126 (*c* 1, $CHCl_3$). **Enantiomeric Ratio:** 99:1. The enantiomeric ratio was determined by HPLC with a Whelk (R,R)-01 column (hexane/CH_2Cl_2 = 70:30, 254 nm, 1 mL/min), t_R (major) = 23.8 min, t_R (minor) = 26.0 min.

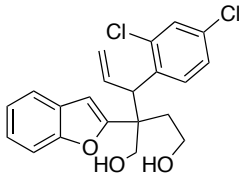
Compound **(S,S)-7**



***(S,S)*-7**

Minor diastereoisomer ***(S,S)*-7** (61 mg, 0.157 mmol, 8%) was obtained as a white solid after silica gel column chromatography (Hexane/EtOAc) (97:3). mp 129-131°C **^{1}H NMR (600 MHz, $CDCl_3$):** δ 7.53 – 7.47 (m, 1H), 7.46 – 7.41 (m, 1H), 7.37 (d, *J* = 2.0 Hz, 1H), 7.29 – 7.16 (m, 4H), 6.67 (d, *J* = 1.0 Hz, 1H), 6.28 (ddd, *J* = 17.0, 10.5, 8.0 Hz, 1H), 5.11 (dt, *J* = 10.5, 1.0 Hz, 1H), 4.96 (dt, *J* = 17.0, 1.0 Hz, 1H), 4.92 (d, *J* = 8.0 Hz, 1H), 4.16 (td, *J* = 9.0, 7.0 Hz, 1H), 4.09 (td, *J* = 9.0, 3.5 Hz, 1H), 2.83 (ddd, *J* = 13.0, 7.0, 3.5 Hz, 1H), 2.67 (dt, *J* = 13.0, 8.5 Hz, 1H). mp 129-131°C. **^{13}C NMR (151 MHz, $CDCl_3$):** δ 175.3, 155.0, 153.2, 135.7, 135.6, 135.2, 133.7, 130.6, 129.7, 127.9, 127.6, 124.7, 123.2, 121.4, 119.5, 111.3, 106.0, 66.0, 53.3, 49.2, 31.4. **ESI-HRMS:** m/z: calcd for $C_{21}H_{16}Cl_2NaO3+$ ([M + Na]+) 409.0374, found 409.0369. **$[\alpha]^{20}_D$ =** -14 (*c* 0.5, $CHCl_3$). **Enantiomeric Ratio:** 93:7. The enantiomeric ratio was determined by HPLC with a Whelk (R,R)-01 column (hexane/CH_2Cl_2 = 70:30, 254 nm, 1 mL/min), t_R (minor) = 17.9 min, t_R (major) = 21.6 min.

Compound **22:**



22

Compound ***(R,S)*-7** (200 mg, 0.516 mmol) was dissolved in THF 4 mL. $LiAlH_4$ 1 M in THF (500 µL) was added at 0°C. After stirring at 0°C for 30 min HCl 1M was added (10ml). The resulting solution was extracted twice with CH_2Cl_2 (15mL). The organic layer was dried over $MgSO_4$ filtered and concentrated under reduced pressure. The crude mixture was purified by silica gel column chromatography (Hexane/EtOAc) (85:15) to yield compound **22** (195 mg, 0.500 mmol, 97%) as a white solid. mp 117-119°C **^{1}H NMR (500 MHz, $CDCl_3$):** δ 7.54 (m, 1H), 7.44 (d, *J* = 8.0 Hz, 1H), 7.36 (d, *J* = 2.0 Hz, 1H), 7.33 – 7.14 (m, 2H), 6.94 (dd, *J* = 8.5, 2.0 Hz, 1H), 6.38 (d, *J* = 8.5 Hz, 1H), 6.35 (s, 1H), 6.02 (dt, *J* = 17.0, 10.0 Hz, 1H), 5.24 (dd, *J* = 17.0, 1.0 Hz, 1H), 5.17 (dd, *J* = 17.0, 1.0 Hz, 1H), 4.46 (d, *J* = 10.0 Hz, 1H), 4.10 (dd, *J* = 30.5, 12.0 Hz, 1H), 3.81 (ddd, *J* = 11.0, 6.0, 3.0 Hz, 1H), 3.65 (ddd, *J* = 11.0, 9.0, 2.0 Hz, 1H), 2.97 (s, 2H), 2.10 (ddd, *J* = 15.5, 9.0, 3.0 Hz, 1H), 1.99 (ddd, *J* = 15.5, 6.0, 2.0 Hz, 1H). **^{13}C NMR (126 MHz, $CDCl_3$):** δ 158.1, 154.3, 137.1, 137.1, 135.2, 132.7, 131.2, 129.3, 128.2, 126.7, 124.1, 123.0, 120.9, 118.6, 111.3, 105.7, 64.5, 59.3, 50.7, 49.0, 34.4. **ESI-HRMS:** m/z: calcd for $C_{21}H_{20}Cl_2NaO3+$ ([M + Na]+) 413.0687, found 413.0693. **$[\alpha]^{20}_D$ =** -162 (*c* 1, $CHCl_3$). **Enantiomeric Ratio:** 99:1.

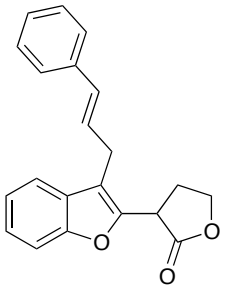
The enantiomeric ratio was determined by HPLC with a CHIRALCEL IC column (hexane/*i*-PrOH = 97:3, 254 nm, 1 mL/min), t_R (major) = 22.3 min, t_R (minor) = 25.0 min.

III Cope-Aromatization Reaction

III-a General Procedure C for the Cope-aromatization reaction:

The corresponding lactone, APTS (5-10 mol%) or Et_3N (10 mol%) and toluene (X ml, 0.2M) was charged to vial equipped with a magnetic stirring bar and a condenser. The vial heated at 110°C under stirring over a period of 12h. After concentration under reduced pressure, the crude residue was purified by silica gel column chromatography to yield the desired product.

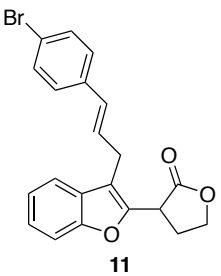
Compound **10**



10

According to the general procedure Compound **3** (639 mg, 2 mmol) and PTSA (19 mg, 0.1 mmol), Compound **10** (590 mg, 1.85 mmol, 92 %) was obtained as a white solid after silica gel column chromatography (Hexane/EtOAc) (90:10). mp 120-122°C. **^{1}H NMR (600 MHz, $CDCl_3$):** δ 7.54 (d, *J* = 7.5 Hz, 1H), 7.43 (d, *J* = 8.0 Hz, 1H), 7.35 (d, *J* = 7.5 Hz, 2H), 7.32 – 7.27 (m, 3H), 7.24 – 7.19 (m, 2H), 6.55 (d, *J* = 16.0 Hz, 1H), 6.38 (dt, *J* = 16.0, 6.5 Hz, 1H), 4.63 (td, *J* = 8.5, 4.0 Hz, 1H), 4.41 (td, *J* = 8.5, 7.5 Hz, 1H), 4.12 (t, *J* = 9.5 Hz, 1H), 3.65 (dd, *J* = 6.5, 1.5 Hz, 2H), 2.77 (ddt, *J* = 13.0, 8.5, 8.5 Hz, 1H), 2.63 (dddd, *J* = 13.0, 9.5, 7.5, 4.0 Hz, 1H). **^{13}C NMR (151 MHz, $CDCl_3$):** δ 174.8, 154.3, 148.0, 137.2, 131.5, 129.0, 128.7, 127.4, 127.1, 126.3, 124.6, 122.8, 119.9, 115.9, 111.3, 67.3, 38.5, 28.3, 27.1. **ESI-HRMS:** m/z: calcd for $C_{21}H_{18}NaO_3^+$ ([M + Na]$^+$) 341.1154, found 341.1148.

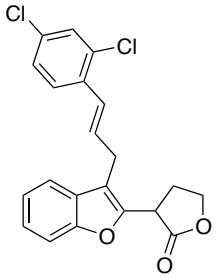
Compound **11**



11

According to the general procedure C. Compound **5** (595 mmol, 1.5 mmol) and PTSA (14 mg, 0.075 mmol) Compound **11** (545 mg, 1.38 mmol, 92 %) was obtained as a white solid after silica gel column chromatography (Hexane/EtOAc) (90:10). mp 156-158°C. **^{1}H NMR (600 MHz, $CDCl_3$):** δ 7.51 (d, *J* = 7.5 Hz, 1H), 7.46 – 7.36 (m, 2H), 7.29 (ddd, *J* = 8.5, 7.5, 1.0 Hz, 1H), 7.25 – 7.17 (m, 3H), 6.47 (d, *J* = 16.0 Hz, 1H), 6.37 (dt, *J* = 16.0, 6.0 Hz, 1H), 4.63 (td, *J* = 8.5, 4.0 Hz, 1H), 4.41 (td, *J* = 8.5, 7.5 Hz, 1H), 4.09 (t, *J* = 9.5 Hz, 1H), 3.62 (d, *J* = 6.0 Hz, 2H), 2.77 (dt, *J* = 13.0, 8.5 Hz, 1H), 2.64 (dddd, *J* = 13.0, 9.5, 7.0, 4.0 Hz, 1H). **^{13}C NMR (151 MHz, $CDCl_3$):** δ 174.7, 154.3, 148.1, 136.1, 131.7, 130.3, 128.9, 128.0, 127.8, 124.7, 122.8, 121.1, 119.8, 115.7, 111.3, 67.4, 38.5, 28.3, 27.0. **ESI-HRMS:** m/z: calcd for $C_{21}H_{17}BrNaO_3^+$ ([M + Na]$^+$) 419.0259, found 419.0263.

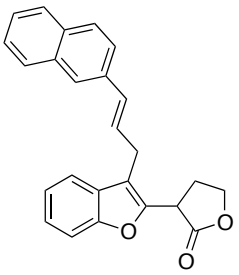
Compound **12**



12

According to the general procedure C. Compound **7** (135 mg, 0.35 mmol) and PTSA (7 mg, 0.035 mmol), Compound **12** (110 mg, 0.335 mmol, 96 %) was obtained as a white solid after silica gel column chromatography (Hexane/EtOAc) (90:10). mp 102-104°C. **^{1}H NMR (500 MHz, $CDCl_3$):** δ 7.54 (d, *J* = 7.0 Hz, 1H), 7.41 (dd, *J* = 12.0, 8.5 Hz, 2H), 7.34 (d, *J* = 2.0 Hz, 1H), 7.29 (t, *J* = 7.0 Hz, 1H), 7.23 (t, *J* = 7.0 Hz, 1H), 7.15 (dd, *J* = 8.5, 2.0 Hz, 1H), 6.87 (d, *J* = 15.5 Hz, 1H), 6.32 (dt, *J* = 15.5, 6.5 Hz, 1H), 4.64 (td, *J* = 8.5, 4.0 Hz, 1H), 4.43 (q, *J* = 8.5 Hz, 1H), 4.12 (t, *J* = 9.0 Hz, 1H), 3.67 (d, *J* = 6.5 Hz, 2H), 2.79 (dq, *J* = 13.0, 8.5 Hz, 1H), 2.66 (dddd, *J* = 13.0, 9.5, 7.5, 4.0 Hz, 1H). **^{13}C NMR (126 MHz, $CDCl_3$):** δ 174.7, 154.3, 148.1, 134.0, 133.4, 133.3, 131.0, 129.4, 128.9, 127.8, 127.4, 126.9, 124.7, 122.9, 119.8, 115.5, 111.3, 67.4, 38.5, 28.2, 27.5. **ESI-HRMS:** m/z: calcd for $C_{21}H_{16}Cl_2NaO_3^+$ ([M + Na]$^+$) 409.0374, found 409.0384.

Compound **13**

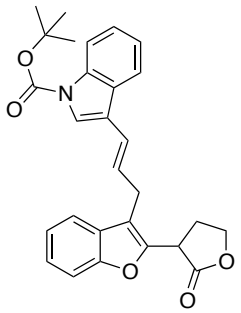


13

According to the general procedure C. Compound **8** (129 mg, 0.35 mmol) and PTSA (7 mg, 0.035 mmol), Compound **13** (124 mg, 0.33 mmol, 94 %) was obtained as a white solid after silica gel column

chromatography (Hexane/EtOAc) (90:10). mp 154-156°C **^{1}H NMR (500 MHz, $CDCl_3$):** δ 7.76 (t, *J* = 9.0 Hz, 3H), 7.69 (s, 1H), 7.57 (d, *J* = 8.5 Hz, 2H), 7.48 – 7.38 (m, 3H), 7.32 – 7.27 (m, 1H), 7.23 (t, *J* = 7.5 Hz, 1H), 6.70 (d, *J* = 16.0 Hz, 1H), 6.51 (dt, *J* = 16.0, 6.5 Hz, 1H), 4.63 (td, *J* = 8.5, 4.0 Hz, 1H), 4.41 (dt, *J* = 8.5, 7.5 Hz, 1H), 4.14 (t, *J* = 9.5 Hz, 1H), 3.70 (dd, *J* = 6.5, 1.5 Hz, 2H), 2.78 (dq, *J* = 13.0, 8.5 Hz, 1H), 2.64 (dddd, *J* = 13.0, 9.5, 7.0, 4.0 Hz, 1H). **^{13}C NMR (126 MHz, $CDCl_3$):** δ 174.8, 154.4, 148.1, 134.7, 133.7, 133.0, 131.6, 129.1, 128.3, 128.0, 127.8, 127.6, 126.4, 126.0, 125.9, 124.6, 123.6, 122.8, 119.9, 116.0, 111.3, 67.4, 38.5, 28.4, 27.2. **ESI-HRMS:** m/z: calcd for $C_{25}H_{20}NaO_3^+$ ($[M + Na]^+$) 391.1310, found 391.1308.

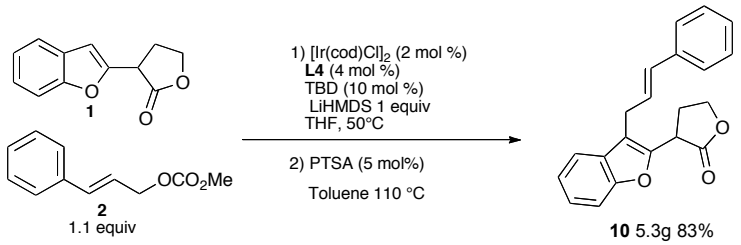
Compound **14**



14

According to the general procedure C. Compound **9** (228 mg, 0.5 mmol) and Et_3N (7 μL, 0.05 mmol), Compound **14** (200 mg, 0.437 mmol, 87%) was obtained as a pale brown gum after silica gel column chromatography (Hexane/EtOAc) (90:10). **^{1}H NMR (500 MHz, $CDCl_3$):** δ 8.17 (d, *J* = 7.5 Hz, 1H), 7.74 (d, *J* = 8.0 Hz, 1H), 7.64 – 7.51 (m, 3H), 7.44 (d, *J* = 8.0 Hz, 1H), 7.40 – 7.13 (m, 6H), 6.64 (d, *J* = 16.0 Hz, 1H), 6.46 (dt, *J* = 16.0, 6.0 Hz, 1H), 4.63 (td, *J* = 8.5, 4.0 Hz, 1H), 4.41 (dt, *J* = 8.5, 7.5 Hz, 1H), 4.15 (t, *J* = 9.5 Hz, 1H), 3.69 (dd, *J* = 6.0, 1.5 Hz, 3H), 2.78 (dq, *J* = 13.0, 8.5 Hz, 1H), 2.64 (dddd, *J* = 13.0, 9.5, 7.5, 4.0 Hz, 1H), 1.66 (s, 8H). **^{13}C NMR (126 MHz, $CDCl_3$):** δ 174.7, 154.2, 149.6, 148.0, 135.9, 129.0, 128.7, 127.3, 124.6, 124.5, 123.4, 122.9, 122.7, 122.7, 119.9, 119.8, 118.5, 115.9, 115.3, 115.0, 111.2, 83.8, 67.2, 38.4, 33.6, 28.3, 28.2, 27.5. **ESI-HRMS:** m/z: calcd for $C_{28}H_{27}NNaO_5^+$ ($[M + Na]^+$) 480.1787, found 480.1782

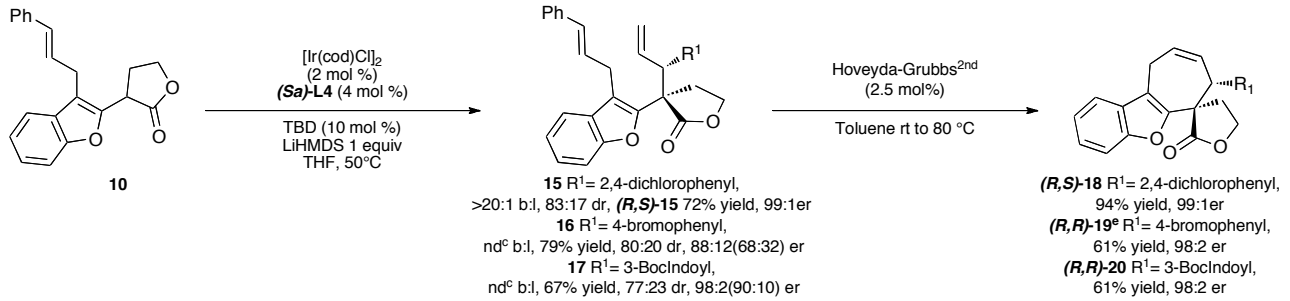
III-b Gram scale synthesis of compound **10** by sequential Ir-AAA/Cope/Aromatization sequence

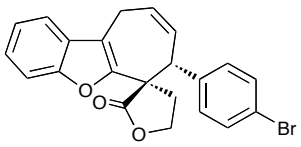


$[Ir(cod)Cl]_2$ (136 mg, 0.2 mmol, 1 mol%), **L4** (460 mg, 0.8 mmol, 4 mol%), and TBD (140 mg, 1 mmol, 5 mol%) were charged to a vial equipped with a magnetic stirring bar. The vial was sealed with a septum-lined cap and evacuated and backfilled with argon three times. The vial was then charged with THF (40 mL),

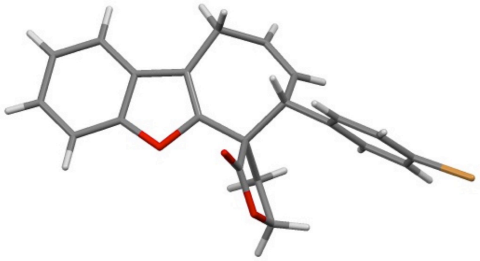
cinnamyl carbonate **2** (4 mL, 22 mmol, 1.1 equiv) and stirred at 50°C for 20 min. A separated vial was charged with the lactone **1** (4.044 g, 20 mmol) and a magnetic stiring bar. The vial was sealed with a septum-lined cap and evacuated and backfilled with argon three times. The vial was then charged with solvent (40 mL) and LiHMDS 1M in THF (20mL, 20 mmol, 1 equiv) was added. After stirring for 10 min the lactone base solution was transferred to the first vial containing iridium complex cinnamyl carbonate solution. After 4 hours Lactone **1** was fully consumed, as indicated by TLC analysis. The reaction mixture was filtered through a silica pad, dichloromethane 200 mL was added to the filtrate and the organic mixture was washed three time with 100 mL of HCl 1M. The organic layer was dried over $MgSO_4$. After concentration under reduced pressure 200 mL of toluene was added to the crude mixture. APTS (172 mg, 1 mmol, 5 mol%) was added and the mixture was stirred at reflux for 48 h. After concentration under reduced pressure, the crude residue was purified by silica gel column chromatography to yield compound **10** (5.3 g, 16.6 mmol, 83%) as a white solid.

IV Synthesis of spirocyclic compound (R,S)-18; (R,R)-19; (R,R)-20





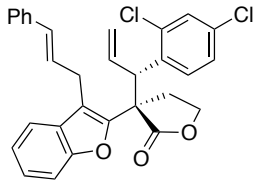
***(R,R)*-19**



IV-a Iterative Ir-AAA:

Compounds ***(R,S)*-15**, **16** and **17** were obtained according general procedure B:

Compound ***(R,S)*-15**:



(R,S)-15

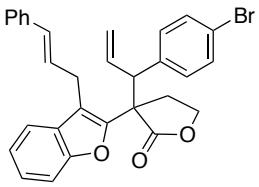
Vial 1 $[Ir(cod)Cl]_2$ (20 mg, 0.03 mmol, 2 mol%); **L4** (34 mg, 0.06 mmol, 4 mol%); TBD (20 mg, 0.15 mmol, 10 mol%); carbonate (443 mg, 1.7 mmol); THF (3mL)

Vial 2 Lactone **1** (477 mg, 1.5 mmol); LiHMDS 1 M in THF (1.5 mL); THF (3mL)

Major diastereoisomer ***(R,S)*-15** (545 mg, 1.08 mmol, 72%) was obtained as a white gum after silica gel column chromatography (Hexane/EtOAc) (98:2) (The minor diastereoisomer was not isolated).

^{1}H NMR (500 MHz, $CDCl_3$): δ 7.87 (d, *J* = 8.5 Hz, 1H), 7.46 (d, *J* = 7.5 Hz, 1H), 7.38 (d, *J* = 8.5 Hz, 1H), 7.31 – 7.24 (m, 6H), 7.24 – 7.11 (m, 3H), 7.01 (dd, *J* = 8.5, 2.0 Hz, 1H), 6.33 (d, *J* = 16.0 Hz, 1H), 6.23 – 6.01 (m, 2H), 5.34 – 5.16 (m, 2H), 4.68 (d, *J* = 9.0 Hz, 1H), 4.35 (ddd, *J* = 9.0, 8.0, 1.5 Hz, 1H), 4.11 (ddd, *J* = 11.0, 9.0, 5.5 Hz, 1H), 3.58 (ddd, *J* = 16.5, 6.0, 1.5 Hz, 1H), 3.48 (ddd, *J* = 16.5, 6.0, 1.5 Hz, 1H), 2.94 (ddd, *J* = 12.5, 5.5, 1.5 Hz, 1H), 2.83 (ddd, *J* = 12.5, 11.0, 8.0 Hz, 1H). **^{13}C NMR (126 MHz, $CDCl_3$):** δ 174.7, 153.4, 146.0, 137.3, 135.9, 135.5, 135.0, 133.1, 132.2, 131.2, 129.6, 129.2, 128.6, 127.3, 127.1, 126.8, 126.3, 124.9, 122.8, 120.4, 120.3, 116.9, 111.0, 66.2, 53.0, 50.8, 35.0, 26.6. **ESI-HRMS:** m/z: calcd for $C_{30}H_{24}Cl_2NaO_3^+$ ($[M + Na]^+$) 525.1000, found 525.0991. **$[\alpha]^{20}_D$ =** -127 (*c* 0.5, $CHCl_3$). **Enantiomeric Ratio:** 99:1. The enantiomeric ratio was determined by HPLC with a CHIRALCEL IC column (hexane/iPrOH = 95:5, 254 nm, 1 mL/min), t_R (minor) = 5.8 min, t_R (major) = 6.6 min.

Compound **16**:



16

Vial 1 $[Ir(cod)Cl]_2$ (47 mg, 0.07 mmol, 2 mol%); **L4** (80 mg, 0.14 mmol, 4 mol%); TBD (48 mg, 0.35 mmol, 10 mol%); carbonate (1.043 g, 3.85 mmol); THF (7mL)

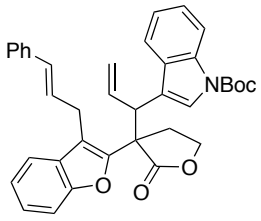
Vial 2 Lactone **1** (1.114 g, 3.5 mmol); LiHMDS 1 M in THF (3.5 mL); THF (7mL)

Diastereoisomeric mixture **16** (1.415 g, 2.75 mmol, 79%) was obtained as a yellowish amorphous solid after silica gel column chromatography (Hexane/EtOAc) (98:2)

The diastereoisomeric ratio (80:20) was determined by ^{1}H NMR of the crude mixture. **^{1}H NMR (600 MHz, $CDCl_3$):** δ 7.53 – 7.47 (m, 2H), 7.42 (d, *J* = 8.0 Hz, 1H, major dia.), 7.39 – 7.12 (m, 21H), 7.06 – 6.98 (m, 2H, minor dia.), 6.43 (dt, *J* = 16.0, 1.5 Hz, 1H, major dia.), 6.38 (t, *J* = 1.5 Hz, 1H, minor dia.), 6.30 (ddd, *J* = 17.0,

10.5, 7.5 Hz, 1H, minor dia.), 6.21 – 6.01 (m, 3H), 5.15 (dt, *J* = 10.5, 1.0 Hz, 1H, minor dia.), 5.13 – 5.05 (m, 2H, major dia.), 5.02 (dt, *J* = 17.0, 1.0 Hz, 1H, minor dia.), 4.32 (d, *J* = 7.5 Hz, 1H, minor dia.), 4.29 (d, *J* = 9.0 Hz, 1H, major dia.), 4.21 – 4.01 (m, 4H), 3.75 (dd, *J* = 6.5, 1.5 Hz, 1H, minor dia.), 3.70 – 3.62 (m, 3H), 3.09 (ddd, *J* = 13.0, 5.5, 1.5 Hz, 1H, major dia.), 2.96 (ddd, *J* = 13.0, 6.0, 2.0 Hz, 1H, minor dia.), 2.75 – 2.50 (m, 2H). **^{13}C NMR (151 MHz, $CDCl_3$):** δ 175.1 (minor dia.), 174.8 (major dia.), 153.4 (minor dia.), 153.2(major dia.), 146.8 (minor dia.), 146.6 (major dia.), 138.3 (major dia.), 138.0 (minor dia.), 137.4 (major dia.), 137.3 (minor dia.), 136.0 (minor dia.), 135.4 (major dia.), 131.75 (major dia.), 131.67 (minor dia.), 131.4 (major dia.), 131.34 (minor dia.), 131.29 (major dia.), 131.1 (minor dia.), 130.1 (major dia.), 129.9 (minor dia.), 128.6 (major dia.), 127.3 (major dia.), 127.2 (minor dia.), 127.1 (major dia.), 127.0 (minor dia.), 126.3 (major dia.), 124.80 (minor dia.), 124.78 (major dia.), 122.9 (major dia.), 122.8 (minor dia.), 121.41 (major dia.), 121.40 (minor dia.), 120.4 (major dia.), 120.2 (minor dia.), 119.8 (major dia.), 119.5 (minor dia.), 117.0 (major dia.), 116.7 (minor dia.), 111.99 (minor dia.), 111.95 (major dia.), 66.3 (major dia.), 66.1 (minor dia.), 54.2 (minor dia.), 54.1 (major dia.), 53.8 (minor dia.), 53.6 (major dia.), 31.4 (minor dia.), 30.9 (major dia.), 26.93 (major dia.), 26.87 (minor dia.). **ESI-HRMS:** m/z: calcd for $C_{30}H_{25}BrNaO_3^+$ ($[M + Na]^+$) 535.0885, found 535.0889. **Enantiomeric Ratio:** 88:12 major; 68:32 minor. The enantiomeric ratio was determined by HPLC with a CHIRALCEL IC column (hexane/iPrOH = 95:5, 254 nm, 1 mL/min), t_R (major, minor) = 8.3 min, t_R (minor, major) = 8.6 min, t_R (major, major) = 9.4 min, t_R (minor, minor) = 10.5 min.

Compound **17**:



17

Vial 1 $[Ir(cod)Cl]_2$ (20 mg, 0.03 mmol, 2 mol%); **L4** (34 mg, 0.06 mmol, 4 mol%); TBD (20 mg, 0.15 mmol, 10 mol%); carbonate (563 mg, 1.7 mmol); THF (4mL)

Vial 2 Lactone **1** (477 mg, 1.5 mmol); LiHMDS 1 M in THF (1.5 mL); THF (4mL)

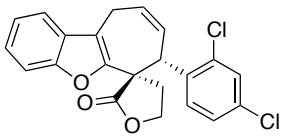
Diastereoisomeric mixture **17** (580 mg, 1.01 mmol, 67%) was obtained as a yellowish amorphous solid after silica gel column chromatography (Hexane/EtOAc) (95:5) The diastereoisomeric ratio (77:23) was determined by 1H NMR of the crude mixture. **1H NMR (600 MHz, $CDCl_3$):** δ 8.11 (s, 1H, major dia.), 7.70 (s, 2H, minor dia.), 7.63 (d, J = 8.0 Hz, 1H, amjor dia.), 7.54 (d, J = 7.5 Hz, 1H, major dia.), 7.51 – 7.46 (m, 2H, minor dia.), 7.44 (d, J = 8.0 Hz, 1H, major dia.), 7.34 – 7.25 (m, 12H), 7.24 – 7.13 (m, 6H), 7.09 (d, J = 7.0 Hz, 2H, minor dia.), 6.52 (d, J = 16.0 Hz, 1H, major dia.), 6.41 – 6.32 (m, 2H, minor dia.), 6.29 (dt, J = 16.0, 6.5 Hz, 1H, major dia.), 6.17 – 6.06 (m, 2H), 5.18 – 5.01 (m, 4H), 4.76 (d, J = 7.5 Hz, 1H, minor dia.), 4.65 (d, J = 8.5 Hz, 1H, major dia.), 4.32 – 4.16 (m, 4H), 3.91 (dd, J = 16.5, 6.5 Hz, 1H, major dia.), 3.87 – 3.78 (m, 2H), 3.67 (ddd, J = 16.5, 7.0, 1.5 Hz, 1H, minor dia.), 3.23 (ddd, J = 13.0, 5.5, 1.0 Hz, 1H, major dia.), 3.12 (dd, J =

13.0, 5.5 Hz, 1H, minor dia.), 2.84 (ddd, J = 13.0, 10.5, 8.5 Hz, 1H, major dia.), 2.75 (ddd, *J* = 13.0, 10.5, 9.0 Hz, 1H, minor dia.), 1.66 (s, 9H, major dia.), 1.63 (s, 9H, minor dia.). **^{13}C NMR (151 MHz, $CDCl_3$):** δ 175.7 (minor dia.), 175.1 (major dia.), 153.4 (minor dia.), 153.3 (major dia.), 149.7 (major dia.), 149.6 (minor dia.), 147.3 (minor dia.), 147.1 (major dia.), 137.4 (major dia.), 137.3 (minor dia.), 135.7 (minor dia.), 135.5 (major dia.), 131.3 (major dia.), 131.2 (minor dia.), 130.7 (minor dia.), 130.32 (major dia.), 130.27 (major dia.), 130.1 (minor dia.), 128.6 (major dia.), 128.5 (minor dia.), 127.3 (major dia.), 127.2 (major dia.), 127.12 (minor dia.), 127.10 (minor dia.), 126.3 (major dia.), 126.2 (minor dia.), 125.6 (major dia.), 124.67 (major dia.), 124.65 (minor dia.), 124.4 (major dia.), 124.1 (minor dia.), 122.80 (major dia.), 122.76 (minor dia.), 122.5 (major dia.), 120.3 (major dia.), 120.2 (major dia.), 119.3 (major dia.), 119.1 (minor dia.), 118.9 (major dia.), 118.0 (major dia.), 117.9 (minor dia.), 116.7 (major dia.), 116.5 (minor dia.), 115.33 (minor dia.), 115.27 (major dia.), 111.0 (major dia.), 110.9 (minor dia.), 83.9 (major dia.), 66.4 (minor dia.), 66.2 (major dia.), 53.8 (minor dia.), 53.5 (major dia.), 46.4 (major dia.), 45.4 (minor dia.), 31.3 (major dia.), 28.31 (major dia.), 28.27 (minro dia.), 27.1 (major dia.), 27.0 (minor dia.). **ESI-HRMS:** m/z: calcd for $C_{37}H_{35}NNaO_5^+$ ([M + Na]$^+$) 596.2413, found 596.2426. **Enantiomeric Ratio:** 98:2 major; 90:10 minor. The enantiomeric ratio was determined by HPLC with a Whelk (R,R)-01 column (hexane/CH_2Cl_2 = 77:23, 254 nm, 1 mL/min), t_R (minor, minor) = 17.0 min, t_R (major, major) = 19.0 min, t_R (major, minor) = 21.1 min, t_R (minor, major) = 24.7 min.

IV-b Ring closing metathesis step

General procedure D: To a solution of allylic lactone 0.1 M in toluene compound Hoveyda-Grubs catalyst 2nd (1 to 2.5 mol%) was added at room temperature. The solution was then heated at 80°C and stirring until the full consumption of the starting material, as indicated by TLC analysis. After concentration under reduced pressure, the crude residue was purified by silica gel column chromatography (Hexane/EtOAc) to yield the corresponding spirocyclic lactones.

Compound ***(R,S)*-18:**

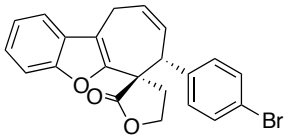


(R,S)-18

According to the general procedure D. ***(R,S)*-15** (163 mg, 0.32 mmol), Hoveyda-Grubs catalyst 2nd (5 mg, 2.5 mol%), Toluene (3mL). Compound ***(R,S)*-18** (120 mg, 0.3 mmol, 94 %) was obtained as colourless gum after silica gel column chromatography (Hexane/EtOAc) (90:10). **^{1}H NMR (600 MHz, $CDCl_3$):** δ 7.61 – 7.49 (m, 1H), 7.45 – 7.36 (m, 1H), 7.35 – 7.27 (m, 2H), 7.01 (d, *J* = 1.0 Hz, 2H), 6.24 – 5.99 (m, 1H), 5.98 – 5.70 (m, 1H), 4.65 (d, *J* = 7.0 Hz, 1H), 4.52 (dt, *J* = 9.0, 7.5 Hz, 1H), 4.42 (td, *J* = 8.5, 5.0 Hz, 1H), 3.80 (ddt, *J* = 20.5, 3.5, 2.5 Hz, 1H), 3.57 (dd, *J* = 20.5, 6.0 Hz, 1H), 2.88 (ddd, *J* = 13.0, 7.5, 5.0 Hz, 1H), 2.45 (dt, *J* = 14.0, 7.5 Hz, 1H). **^{13}C**

NMR (151 MHz, $CDCl_3$): δ 174.9, 153.3, 149.1, 136.5, 135.2, 133.8, 130.4, 129.7, 129.3, 128.1, 127.8, 127.3, 124.8, 123.0, 119.2, 116.2, 111.3, 66.3, 51.6, 43.5, 31.8, 24.0. **ESI-HRMS: m/z:** calcd for $C_{22}H_{16}Cl_2NaO_3^+$ ([M + Na]$^+$) 421.0374, found 421.0373. **$[\alpha]^{20}_D$ =** +28 (*c* 0.5, $CHCl_3$). **Enantiomeric Ratio:** 99:1. The enantiomeric ratio was determined by HPLC with a CHIRALCEL IC column (hexane/iPrOH = 90:10, 254 nm, 1 mL/min), t_R (major) = 16.9 min, t_R (minor) = 19.9 min.

Compound ***(R,R)*-19:**

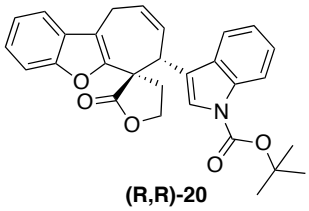


(R,R)-19

According to the general procedure D. Compound **16** (1.027 g, 2 mmol), Hoveyda-Grubs catalyst 2nd (12.5 mg, 1 mol%), Toluene (20mL). Compound ***(R,R)*-19** (500 mg, 1.22 mmol, 61 %) was obtained as white solid after silica gel column chromatography (Hexane/EtOAc) (95:5) and recrystallization (Hexane/EtOAc) (The minor diastereoisomer was not isolated). **^{1}H NMR (600 MHz, $CDCl_3$):** δ 7.55 – 7.43 (m, 3H), 7.40 – 7.34 (m, 1H), 7.31 (d, *J* = 8.5 Hz, 2H), 7.30 – 7.19 (m, 2H), 6.27 (dddd, *J* = 10.0, 7.5, 3.5, 2.0 Hz, 1H), 6.11 (ddd, *J* = 10.5, 6.5, 3.0 Hz, 1H), 4.44 (d, *J* = 6.5 Hz, 1H), 4.37 (td, *J* = 9.0, 6.0 Hz, 1H), 3.79 (dt, *J* = 8.5, 6.5 Hz, 1H), 3.65 (dtd, *J* = 18.5, 3.5, 1.5 Hz, 1H), 3.48 (dd, *J* = 18.5, 7.5 Hz, 1H), 2.69 (ddd, *J* = 14.0, 8.5, 6.0 Hz, 1H), 2.62 (ddd, *J* = 14.0, 9.0, 6.5 Hz, 1H). **^{13}C NMR (126 MHz, $CDCl_3$):** δ 175.8, 153.0, 151.8, 137.3, 132.0, 131.9, 131.4, 130.8, 128.8, 124.7, 122.8, 122.2, 119.0, 114.8, 111.3, 66.2, 53.4, 46.6, 30.5, 22.1. **ESI-HRMS:** m/z: calcd for $C_{22}H_{17}BrNaO_3^+$ ([M + Na]$^+$) 431.0259, found 431.0251. **$[\alpha]^{20}_D$ =** -97 (*c* 1, $CHCl_3$). **Enantiomeric Ratio:** 98:2. The enantiomeric ratio was determined by HPLC with a WHELK column (hexane/iPrOH = 70:30, 254 nm, 1 mL/min), t_R (major) = 8.1 min, t_R (minor) = 9.6 min.

Enantiomeric Ratio: 99:1 (after recrystallization). The enantiomeric ratio was determined by HPLC with a CHIRALCEL IC column (hexane/*i*-PrOH = 80:20, 254 nm, 1 mL/min), t_R (major) = 12.9 min, t_R (minor) = 16.3 min.

Compound ***(R,R)*-20:**



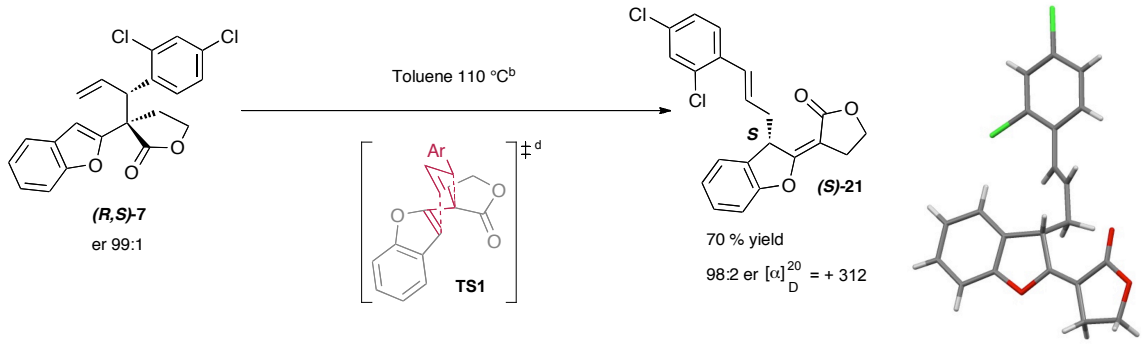
(R,R)-20

According to the general procedure D. Compound **17** (344 mg, 0.6 mmol) and Hoveyda-Grubs catalyst 2nd (9 mg, 2.5 mol%), Toluene (6 mL). Compound ***(R,R)*-20** (162 mg, 0.36 mmol, 61 %) was obtained as colourless gum after silica gel column chromatography (Hexane/EtOAc) (95:5), (The minor diastereoisomer was not isolated). **^{1}H NMR (500 MHz, $CDCl_3$):** δ 8.13 (d, *J* = 6.0 Hz, 1H), 7.73 (d, *J* = 8.0 Hz, 1H), 7.59 (s, 1H), 7.52 (m,

1H), 7.40 (dd, *J* = 7.0, 1.5 Hz, 1H), 7.33 (m, 1H), 7.33 – 7.20 (m, 4H), 6.26 (dddd, *J* = 10.5, 7.5, 3.5, 1.5 Hz, 1H), 6.19 (ddd, *J* = 10.5, 6.5, 2.5 Hz, 1H), 4.77 (d, *J* = 6.5 Hz, 1H), 4.49 (td, *J* = 9.0, 7.0 Hz, 1H), 4.07 (td, *J* = 9.0, 5.5 Hz, 1H), 3.70 (m, 1H), 3.50 (dd, *J* = 18.5, 7.5 Hz, 1H), 2.94 (ddd, *J* = 13.5, 8.5, 7.0 Hz, 1H), 2.68 (ddd, *J* = 13.5, 8.5, 5.5 Hz, 1H), 1.66 (s, 9H). **^{13}C NMR (126 MHz, $CDCl_3$):** δ 176.0, 153.1, 152.5, 149.7, 135.3, 132.0, 131.6, 129.9, 128.8, 124.9, 124.7, 124.6, 122.9, 122.8, 120.1, 119.0, 118.7, 115.4, 114.5, 111.3, 84.2, 66.4, 52.9, 39.2, 31.5, 28.3, 28.3, 22.0. **ESI-HRMS**: m/z: calcd for $C_{29}H_{27}NNaO_5^+$ ([M + Na]$^+$) 492.1787, found 492.1777. **$[\alpha]^{20}_D$ =** -101 (*c* 0.5, $CHCl_3$). **Enantiomeric Ratio: 99:1.** The enantiomeric ratio was determined by HPLC with a CHIRALCEL IC column (hexane/*i*-PrOH = 75:25, 254 nm, 1 mL/min), t_R (major) = 10.1 min, t_R (minor) = 15.7 min.

V Stereo specific [3,3] sigmatropic reaction: Synthesis of compound *(S)*-21 and *(R)*-21

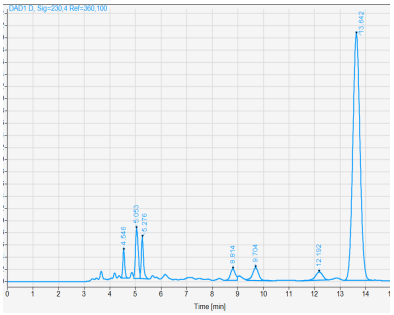
Compound **(S)-21**



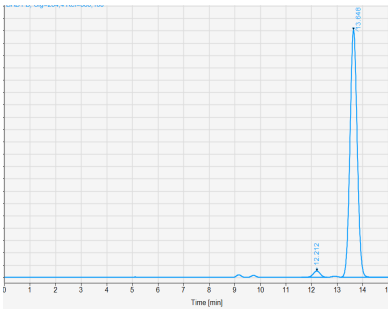
A solution containing 290 mg (0.75 mmol) of compound ***(R,S)-7*** in 6 mL of toluene was heated at 110°C for 12h. After concentration under reduced pressure, the crude residue was purified by preparative centrifugal thin-layer chromatography (Hexane/EtOAc; 90/10), the layer thickness was 1 mm. Compounds ***(S)*-21** is obtained as a white solid (203 mg, 0.52 mmol, 70%), mp 122-124°C **^{1}H NMR (600 MHz, $CDCl_3$):** δ 7.32 – 7.24 (m, 4H), 7.17 – 7.12 (m, 1H), 7.08 (t, J = 7.5 Hz, 1H), 7.03 (d, J = 8.0 Hz, 1H), 6.58 (d, J = 15.5 Hz, 1H), 5.96 (ddd, J = 15.5, 9.0, 6.5 Hz, 1H), 4.77 (dd, J = 6.5, 3.0 Hz, 1H), 4.43 (t, J = 7.5 Hz, 2H), 3.10 (td, J = 7.5, 2.5 Hz, 2H), 3.01 (dddd, J = 13.5, 6.0, 4.0, 1.5 Hz, 1H), 2.90 (dt, J = 13.5, 8.0 Hz, 1H). **^{13}C NMR (151 MHz, $CDCl_3$):** δ 171.7, 169.4, 156.4, 134.2, 133.4, 133.3, 129.4, 129.3, 129.1, 128.9, 128.8, 127.8, 127.3, 124.9, 123.6, 110.1, 99.0, 65.9, 44.9, 37.8, 25.6. **ESI-HRMS**: m/z: calcd for $C_{21}H_{16}Cl_2NaO_3^+$ ([M + Na]$^+$) 409.0374, found 409.0365. **$[\alpha]^{20}_{D}$ =** +312 (*c* 0.5, CH_2Cl_2) **Enantiomeric Ratio: 99:1.** The enantiomeric ratio was determined by HPLC with a CHIRALCEL IC column (hexane/*i*-PrOH = 70:30, 254 nm, 1 mL/min), t_R (minor) = 12.2 min, t_R (major) = 13.6 min.

HPLC chromatograms of

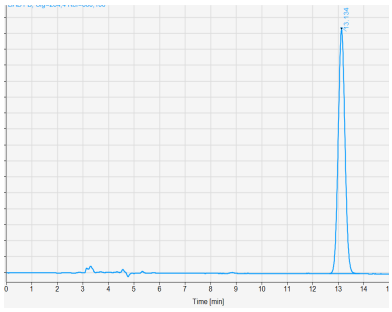
Crude Mixture



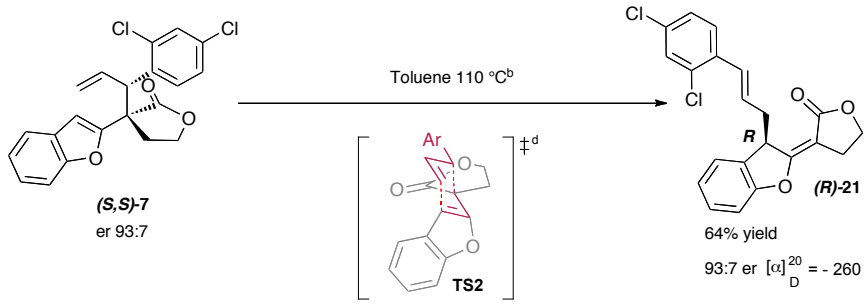
Purified product



Crystal



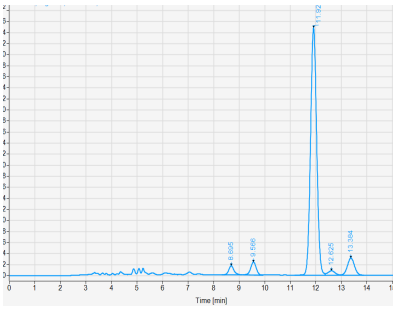
Compound **(R)-21**



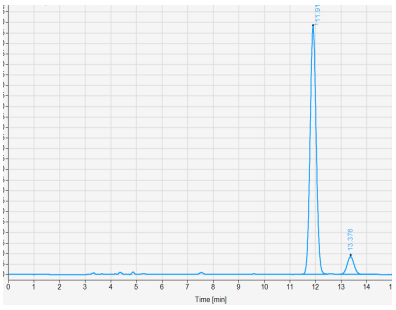
A solution containing 135 mg (0.35 mmol) of compound ***(S,S)*-7** in 4 mL of toluene was heated at 110°C for 12h. After concentration under reduced pressure, the crude residue was purified by preparative centrifugal thin-layer chromatography (Hexane/EtOAc; 90/10), the layer thickness was 1 mm. Compounds ***(R)*-21** (87 mg, 0.22 mmol, 64%) was obtained as a white solid. **^{1}H NMR (600 MHz, $CDCl_3$):** δ 7.32 – 7.24 (m, 4H), 7.17 – 7.12 (m, 1H), 7.08 (t, J = 7.5 Hz, 1H), 7.03 (d, J = 8.0 Hz, 1H), 6.58 (d, J = 15.5 Hz, 1H), 5.96 (ddd, J = 15.5, 9.0, 6.5 Hz, 1H), 4.77 (dd, J = 6.5, 3.0 Hz, 1H), 4.43 (t, J = 7.5 Hz, 2H), 3.10 (td, J = 7.5, 2.5 Hz, 2H), 3.01 (dddd, J = 13.5, 6.0, 4.0, 1.5 Hz, 1H), 2.90 (dt, J = 13.5, 8.0 Hz, 1H). **^{13}C NMR (151 MHz, $CDCl_3$):** δ 171.7, 169.4, 156.4, 134.2, 133.4, 133.3, 129.4, 129.3, 129.1, 128.9, 128.8, 127.8, 127.3, 124.9, 123.6, 110.1, 99.0, 65.9, 44.9, 37.8, 25.6. **$[\alpha]^{20}_{D}$ =** -260 (*c* 1, CH_2Cl_2), **Enantiomeric Ratio: 97:3.** The enantiomeric ratio was determined by HPLC with a CHIRALCEL IC column (hexane/*i*-PrOH = 70:30, 254 nm, 1 mL/min), t_R (major) = 12.2 min, t_R (minor) = 13.6 min.

HPLC chromatograms of

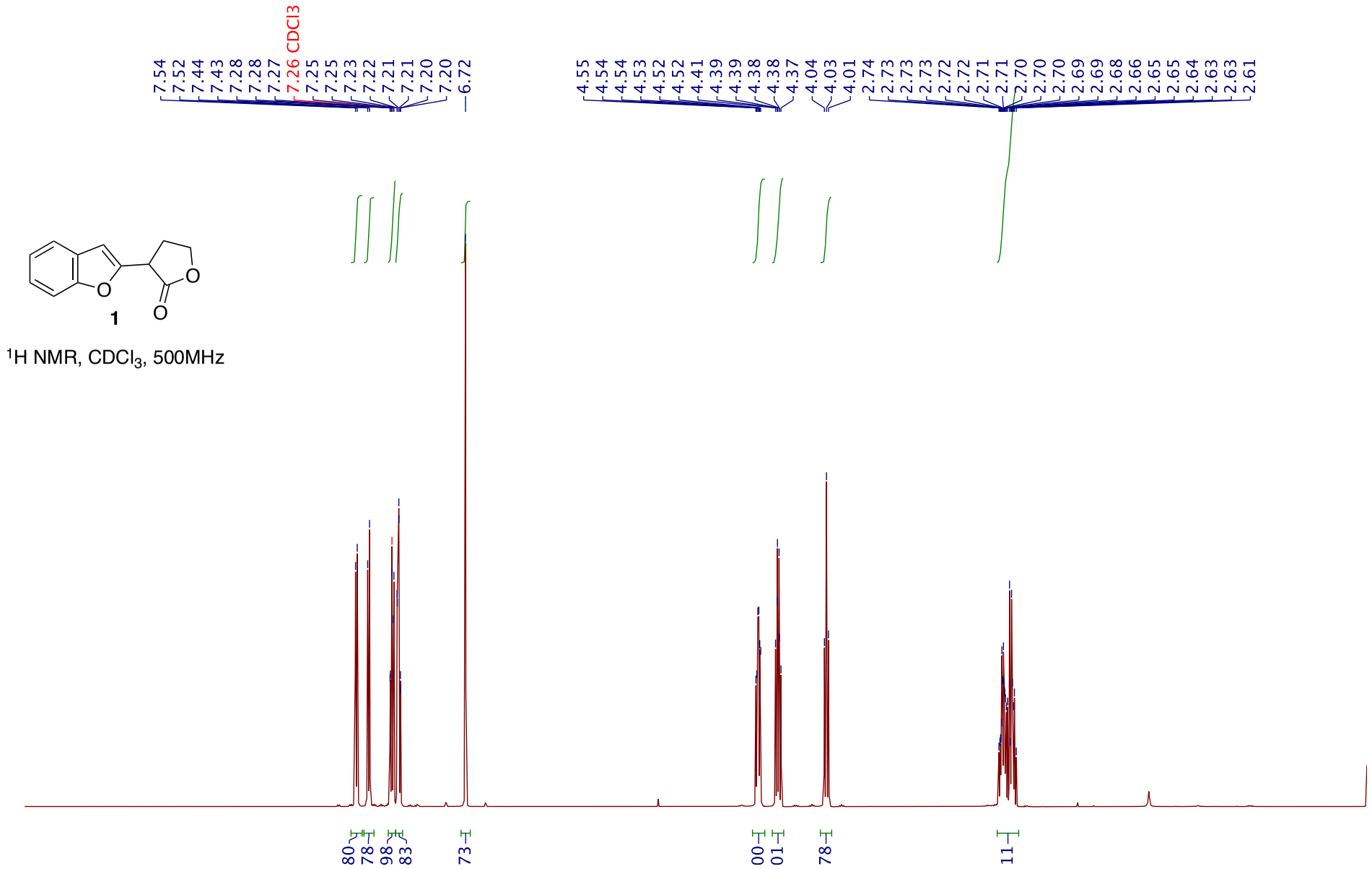
Crude Mixture



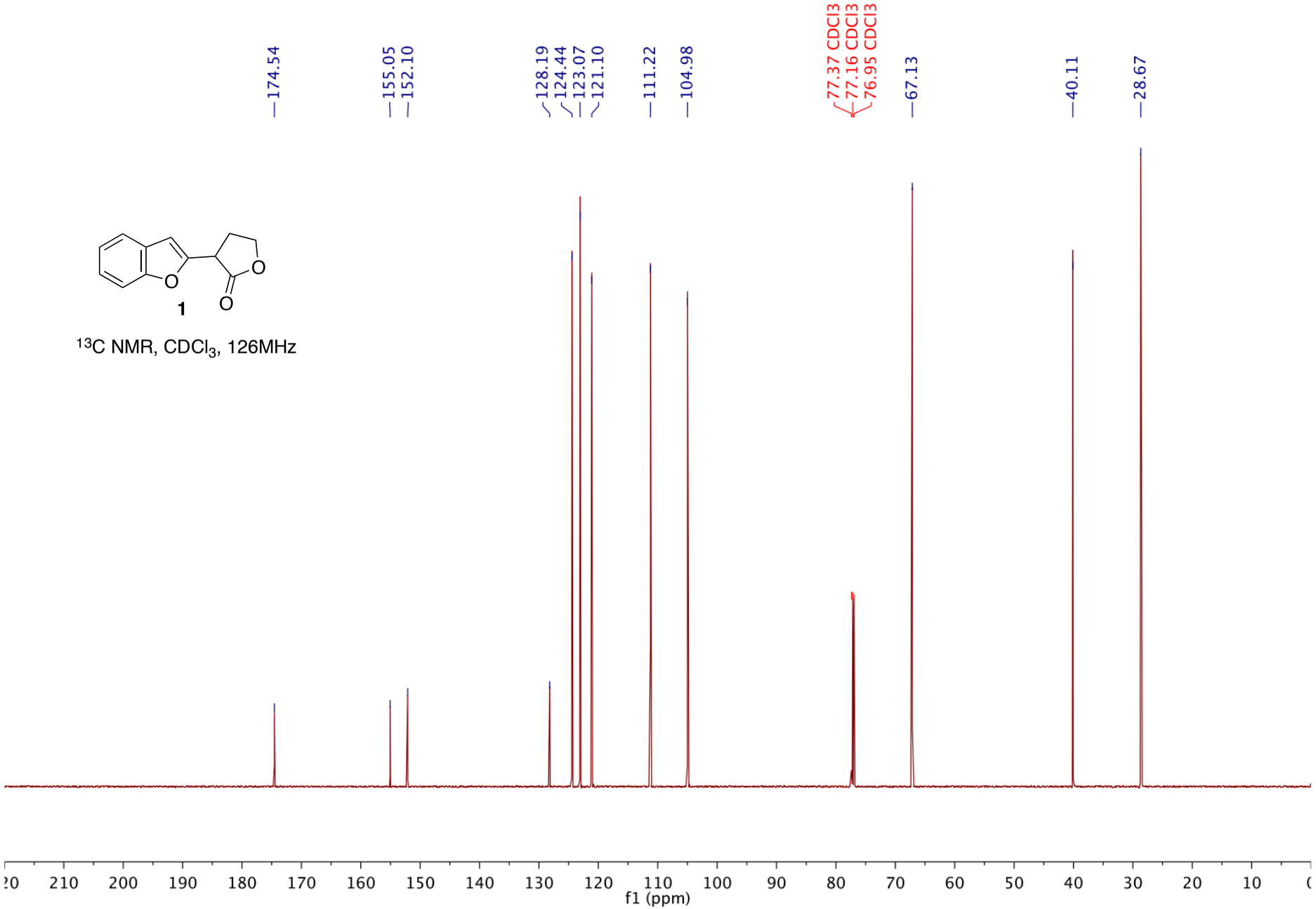
Purified product

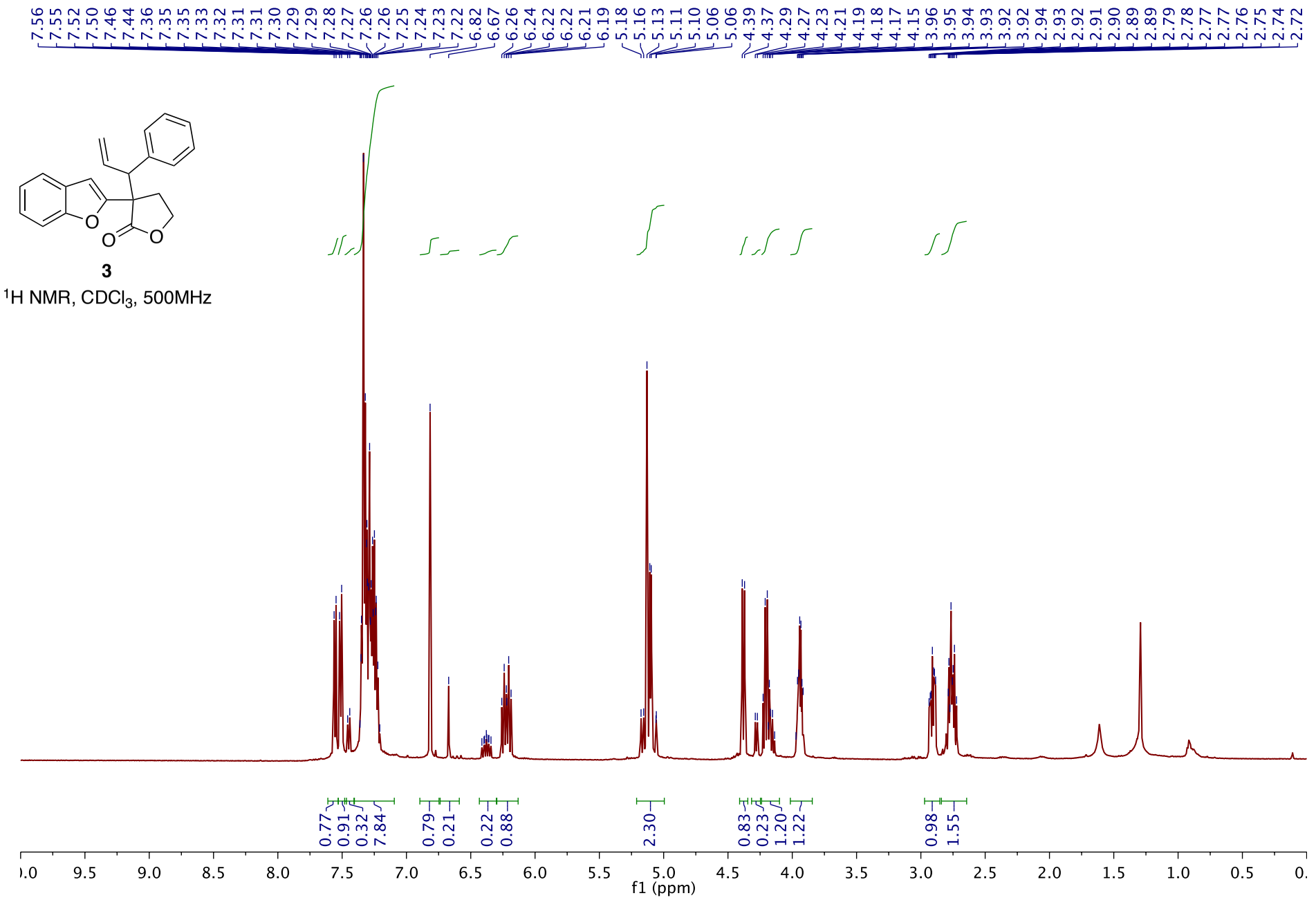


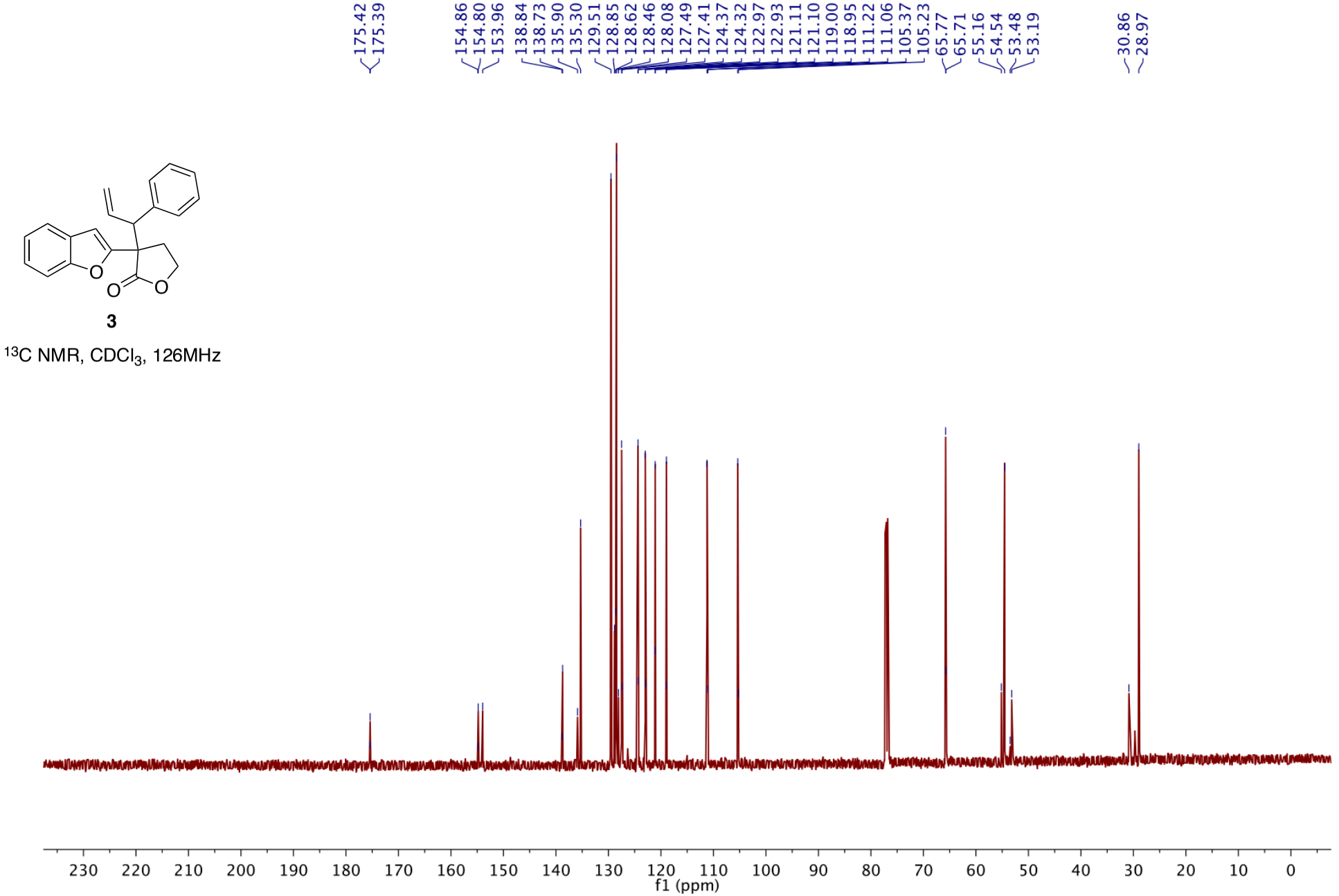
VI ^{1}H & ^{13}C NMR spectra and chiral HPLC analysis

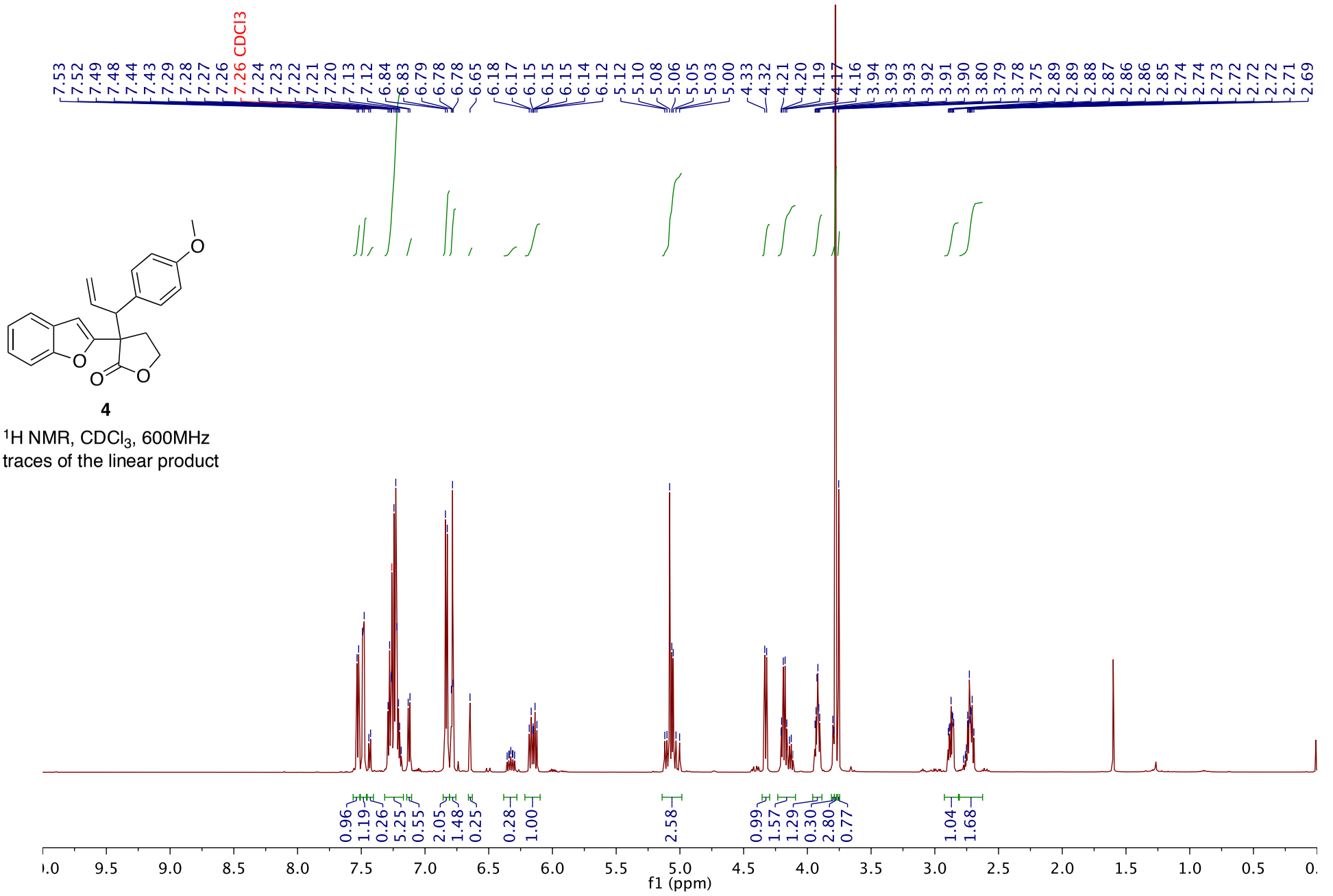


^{1}H NMR, $CDCl_3$, 500MHz


174.54
155.05
152.10
128.19
124.44
123.07
121.10
111.22
104.98
77.37 CDCl3
77.16 CDCl3
76.95 CDCl3
67.13
40.11
28.67
O
O
O
1
^{13}C NMR, $CDCl_3$, 126MHz
f1 (ppm)

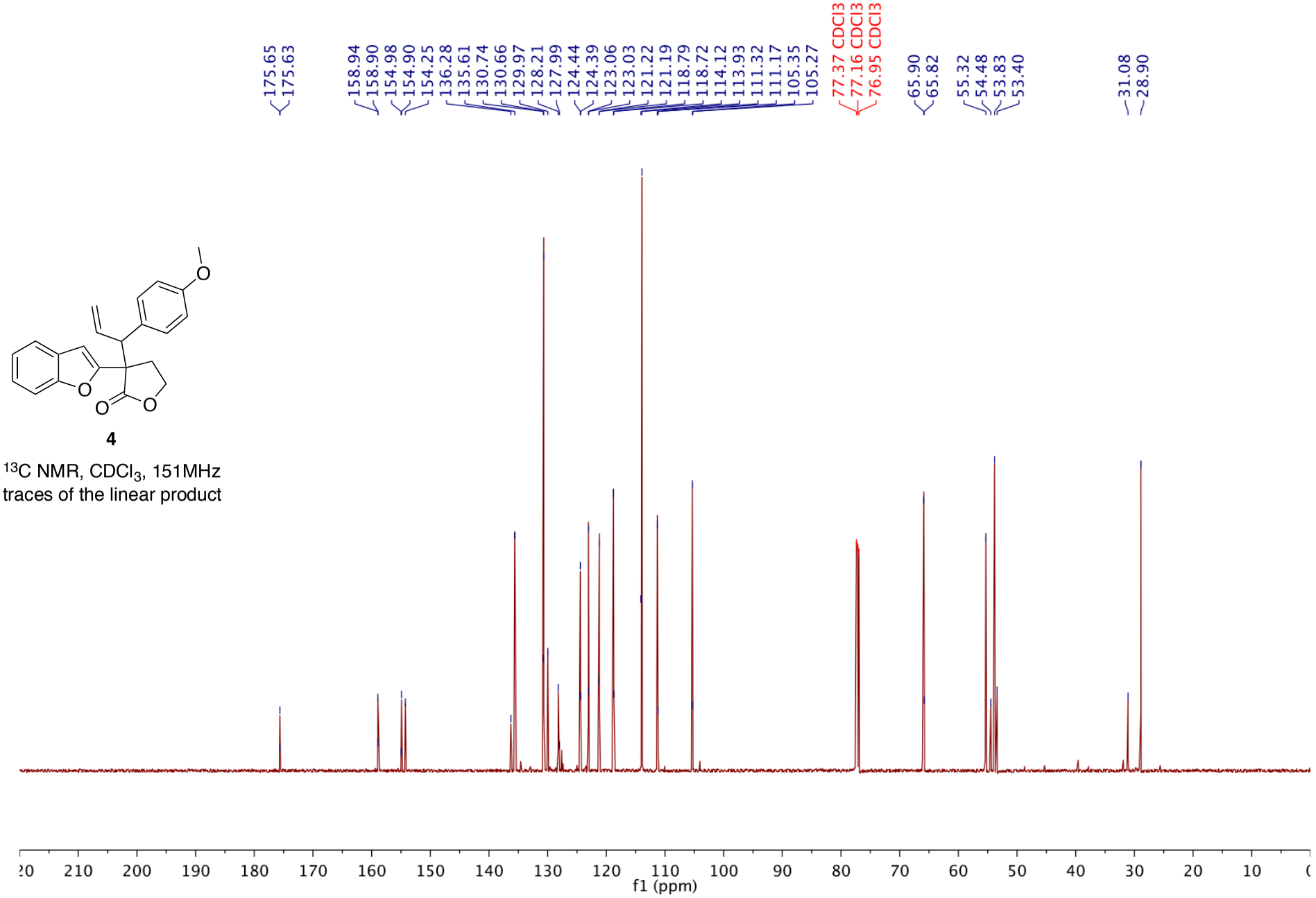

7.56 7.55 7.52 7.50 7.46 7.44 7.36 7.35 7.35 7.33 7.32 7.31 7.31 7.30 7.29 7.29 7.28 7.27 7.26 7.26 7.25 7.24 7.23 7.22 6.82 6.67 6.26 6.24 6.22 6.22 6.21 6.19 5.18 5.16 5.13 5.11 5.10 5.06 5.06 4.39 4.37 4.29 4.27 4.23 4.21 4.19 4.18 4.17 4.15 3.96 3.95 3.94 3.93 3.92 3.92 2.94 2.93 2.92 2.91 2.90 2.89 2.89 2.79 2.78 2.77 2.77 2.76 2.75 2.74 2.72
O
O
O
3
1H NMR, CDCl3, 500MHz
0.77 0.91 0.32 7.84 0.79 0.21 0.22 0.88 2.30 0.83 0.23 1.20 1.22 0.98 1.55
9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5
f1 (ppm)


175.42
175.39
154.86
154.80
153.96
138.84
138.73
135.90
135.30
129.51
128.85
128.62
128.46
128.08
127.49
127.41
124.37
124.32
122.97
122.93
121.11
121.10
119.00
118.95
111.22
111.06
105.37
105.23
65.77
65.71
55.16
54.54
53.48
53.19
30.86
28.97
O
O
O
3
13C NMR, CDCl3, 126MHz
230 220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0
f1 (ppm)



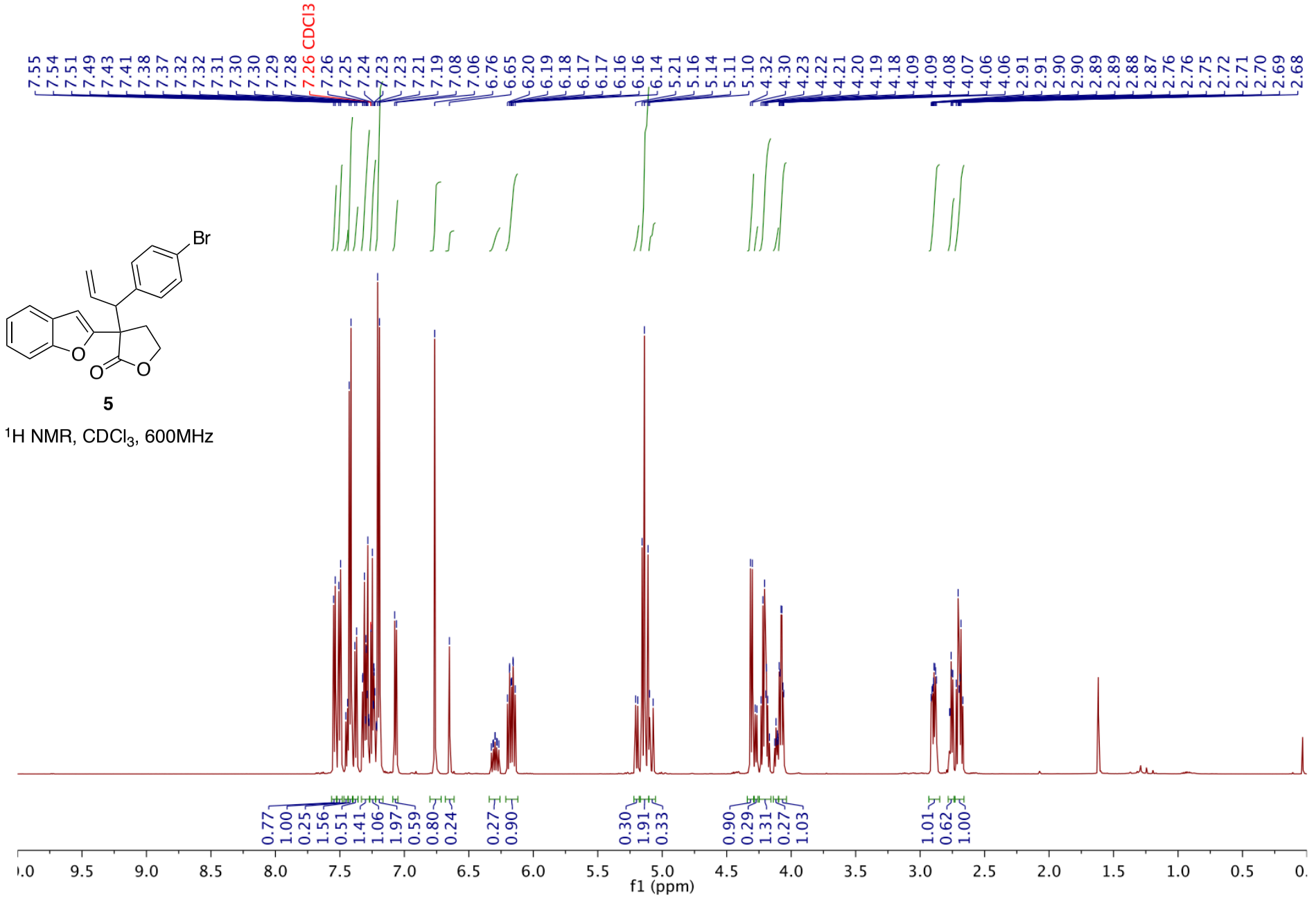
4

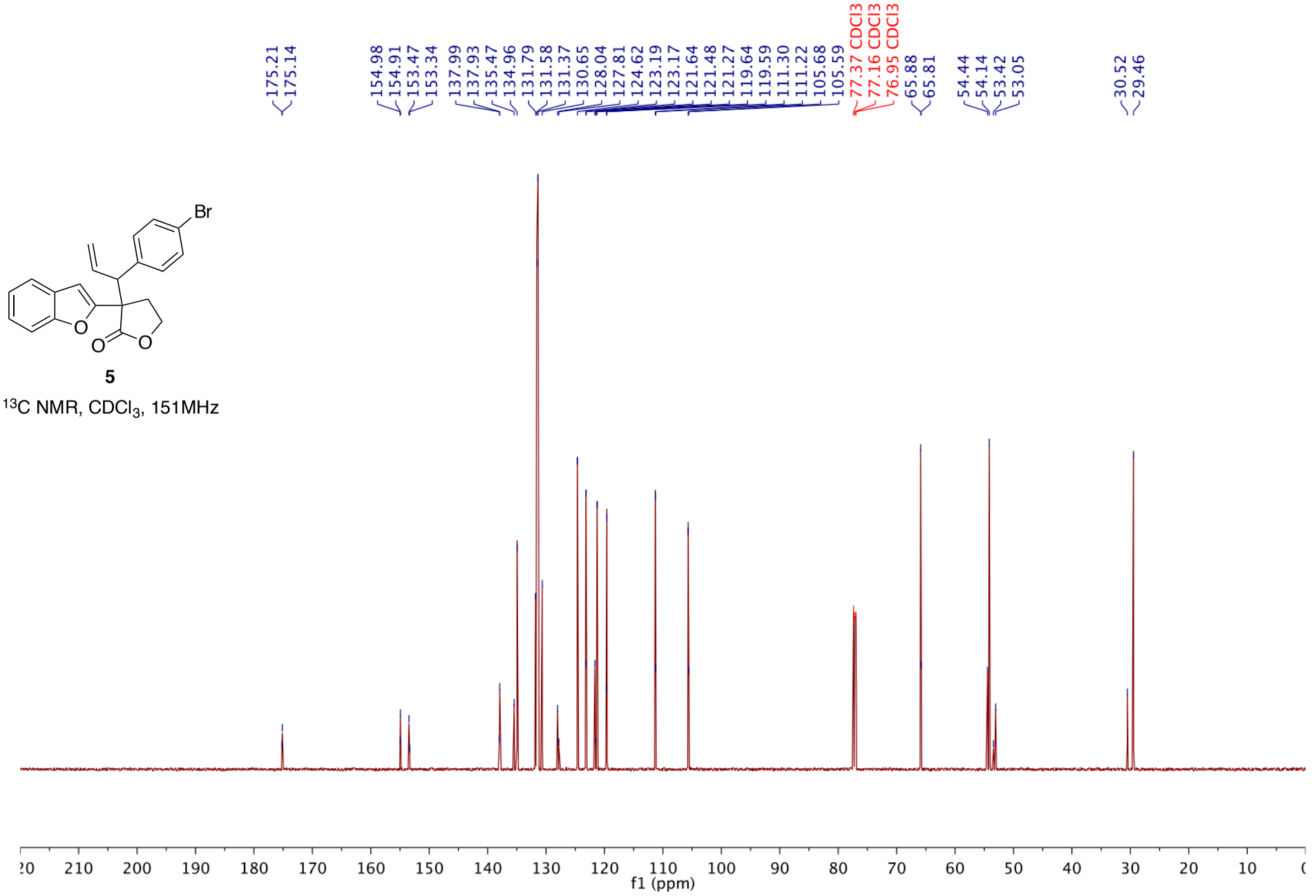
^{1}H NMR, $CDCl_3$, 600MHz
traces of the linear product

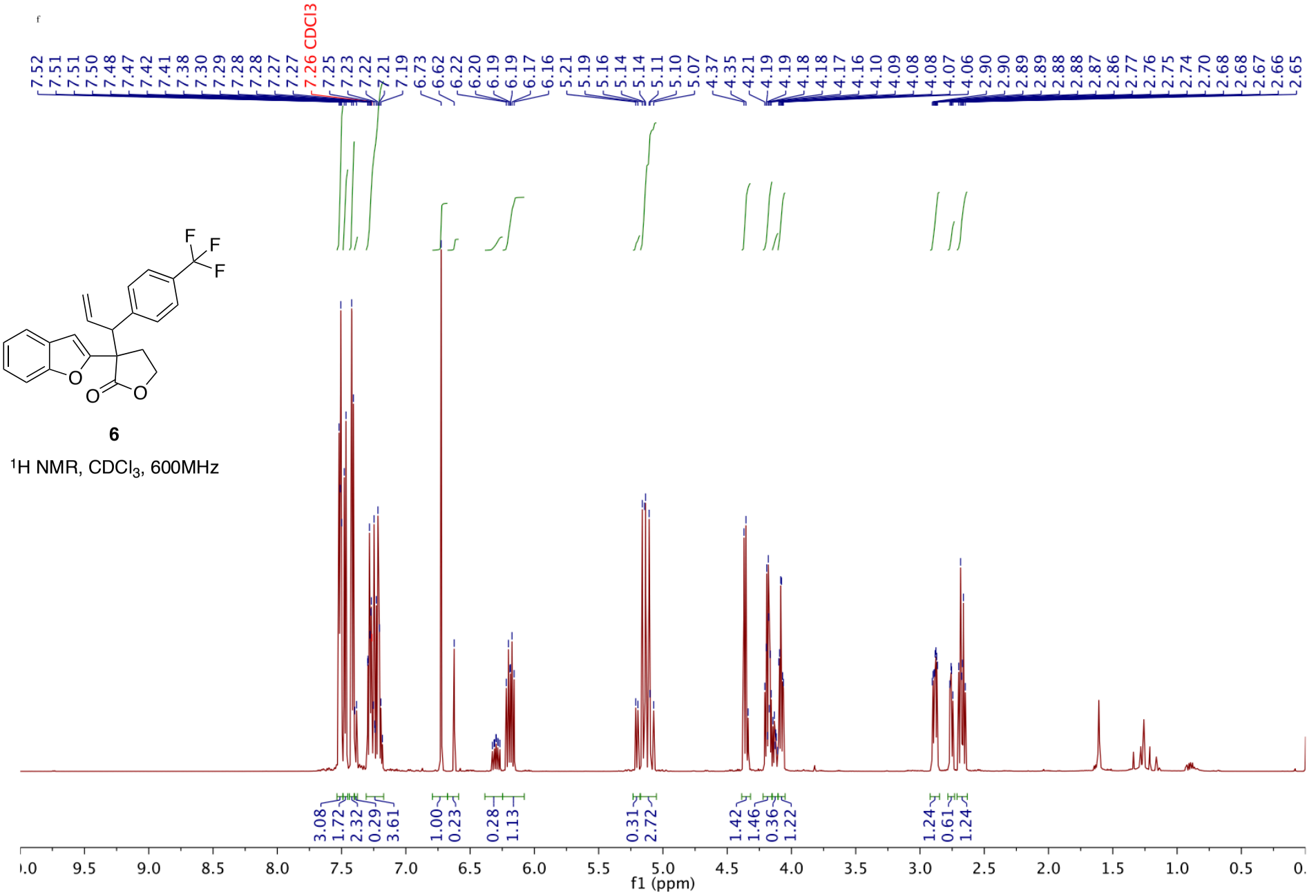


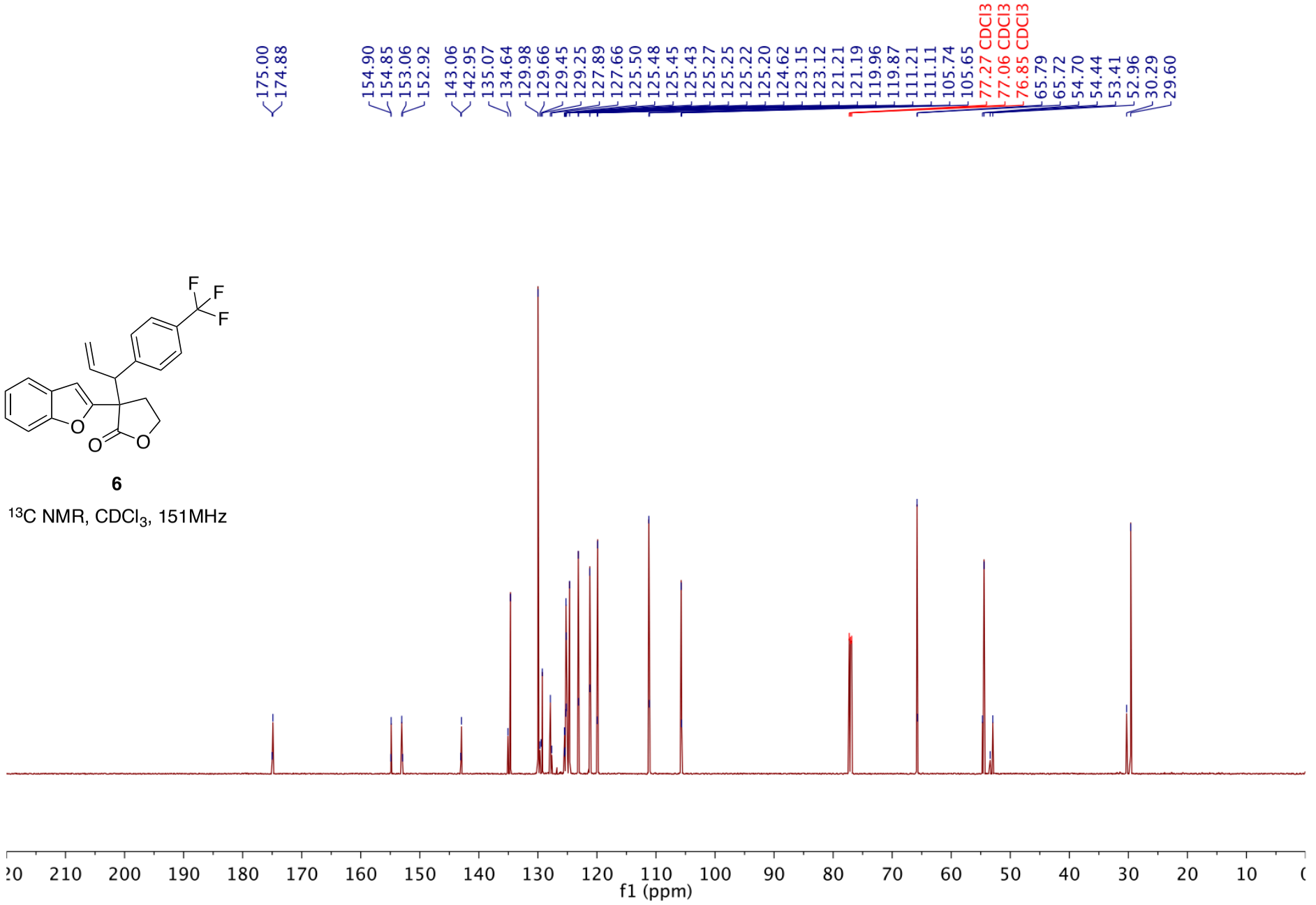
4

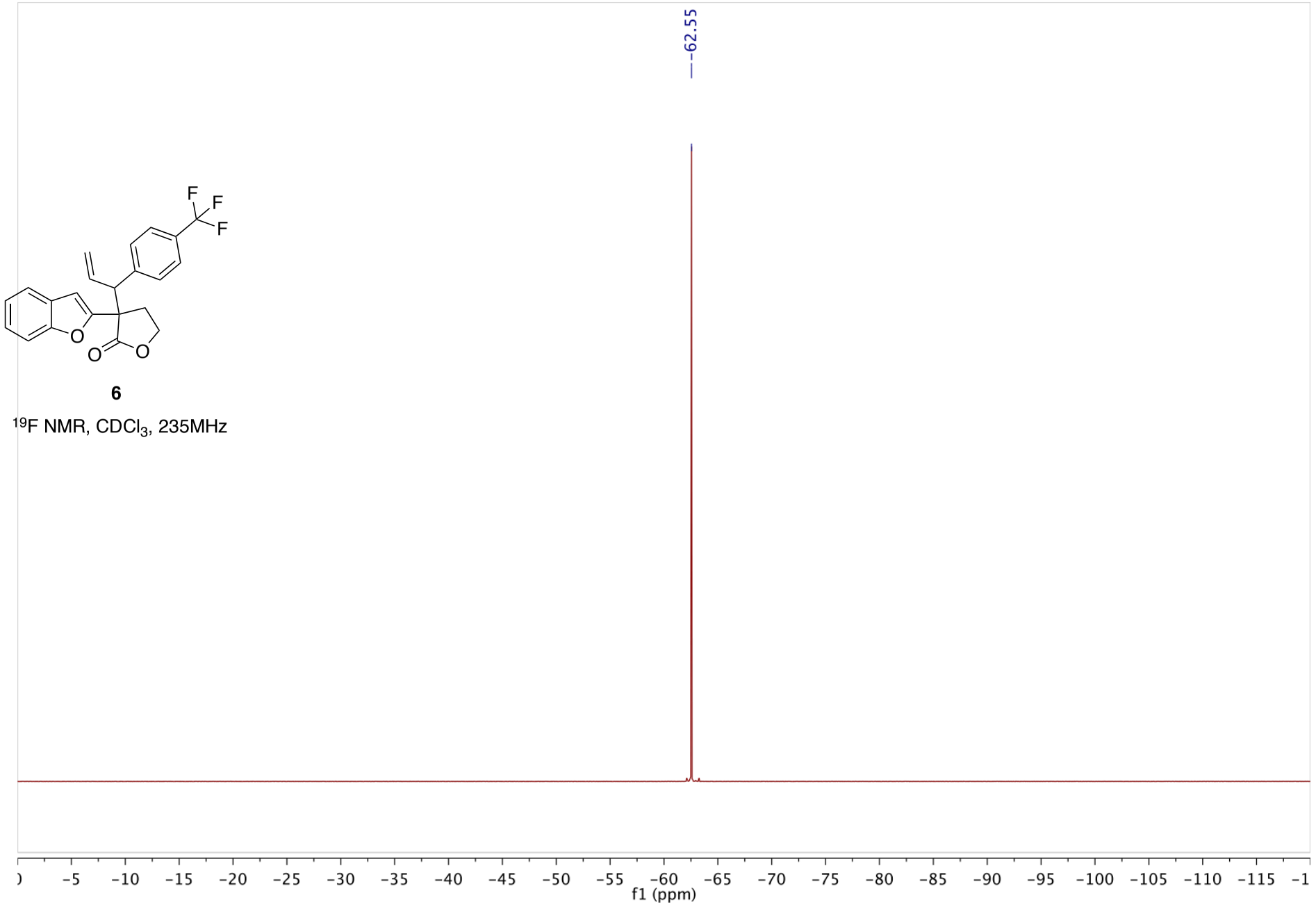
^{13}C NMR, $CDCl_3$, 151MHz
traces of the linear product


Br
O
O
O
5
1H NMR, CDCl3, 600MHz
CDCl3
f1 (ppm)


175.21
175.14
154.98
154.91
153.47
153.34
137.99
137.93
135.47
134.96
131.79
131.58
131.37
130.65
128.04
127.81
124.62
123.19
123.17
121.64
121.48
121.27
119.64
119.59
111.30
111.22
105.68
105.59
77.37 CDCl3
77.16 CDCl3
76.95 CDCl3
65.88
65.81
54.44
54.14
53.42
53.05
30.52
29.46
Br
O
O
O
5
13C NMR, CDCl3, 151MHz
f1 (ppm)

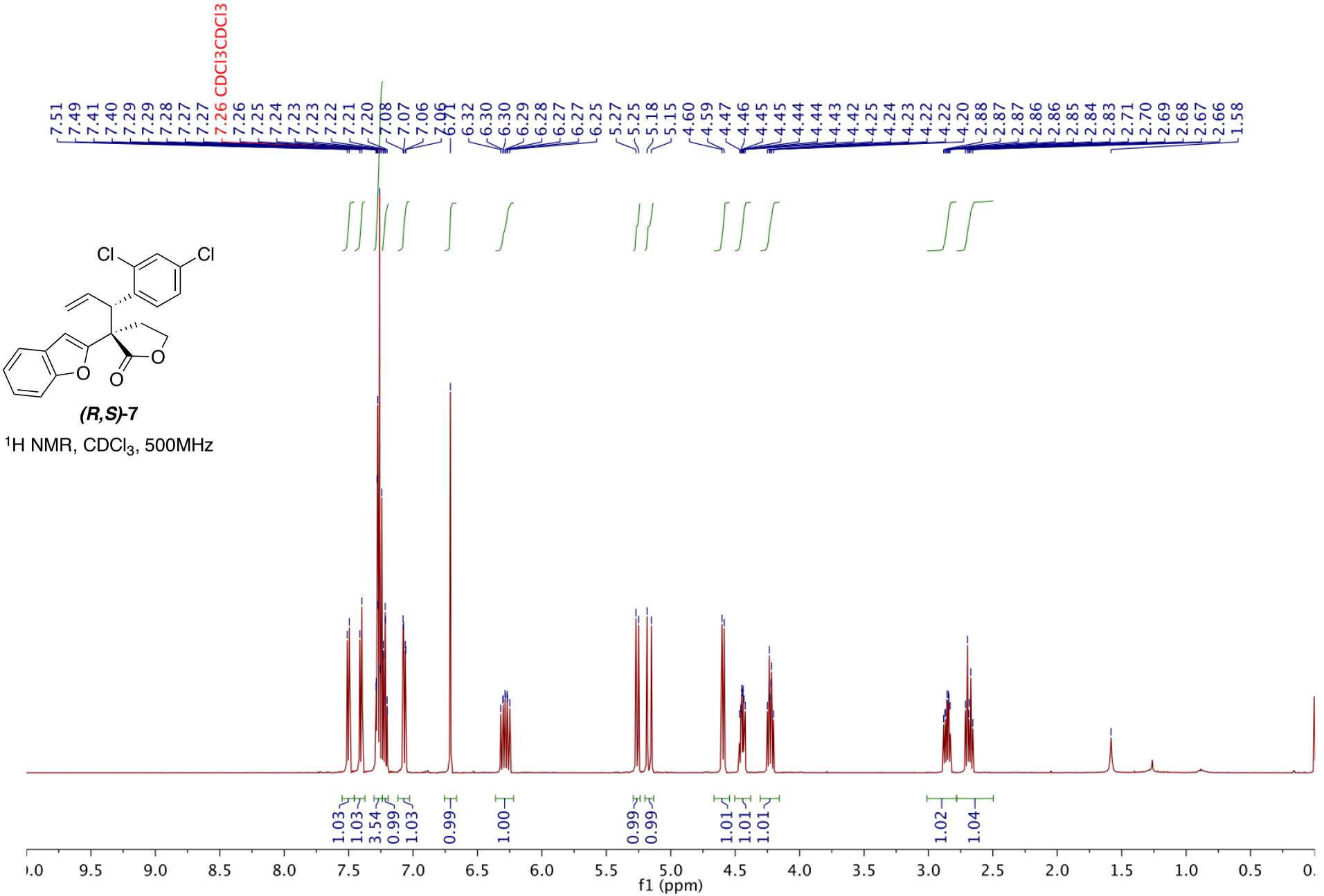

7.52 7.51 7.51 7.50 7.48 7.47 7.42 7.41 7.38 7.30 7.29 7.28 7.28 7.27 7.27 7.26 CDCl3 7.25 7.23 7.22 7.21 7.19 6.73 6.62 6.22 6.20 6.19 6.19 6.17 6.16 5.21 5.19 5.16 5.14 5.14 5.11 5.10 5.07 4.37 4.35 4.21 4.19 4.19 4.18 4.18 4.17 4.16 4.10 4.09 4.08 4.08 4.07 4.06 2.90 2.90 2.89 2.89 2.88 2.88 2.87 2.86 2.77 2.76 2.75 2.74 2.70 2.68 2.68 2.67 2.66 2.65
F F F
O O O
6
^{1}H NMR, $CDCl_3$, 600MHz
3.08 1.72 2.32 0.29 3.61 1.00 0.23 0.28 1.13 0.31 2.72 1.42 1.46 0.36 1.22 1.24 0.61 1.24
9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5
f1 (ppm)


175.00
174.88
154.90
154.85
153.06
152.92
143.06
142.95
135.07
134.64
129.98
129.66
129.45
129.25
127.89
127.66
125.50
125.48
125.45
125.43
125.27
125.25
125.22
125.20
124.62
123.15
123.12
121.21
121.19
119.96
119.87
111.21
111.11
105.74
105.65
77.27 CDCl3
77.06 CDCl3
76.85 CDCl3
65.79
65.72
54.70
54.44
53.41
52.96
30.29
29.60
F
F
F
O
O
O
6
13C NMR, CDCl3, 151MHz
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
f1 (ppm)



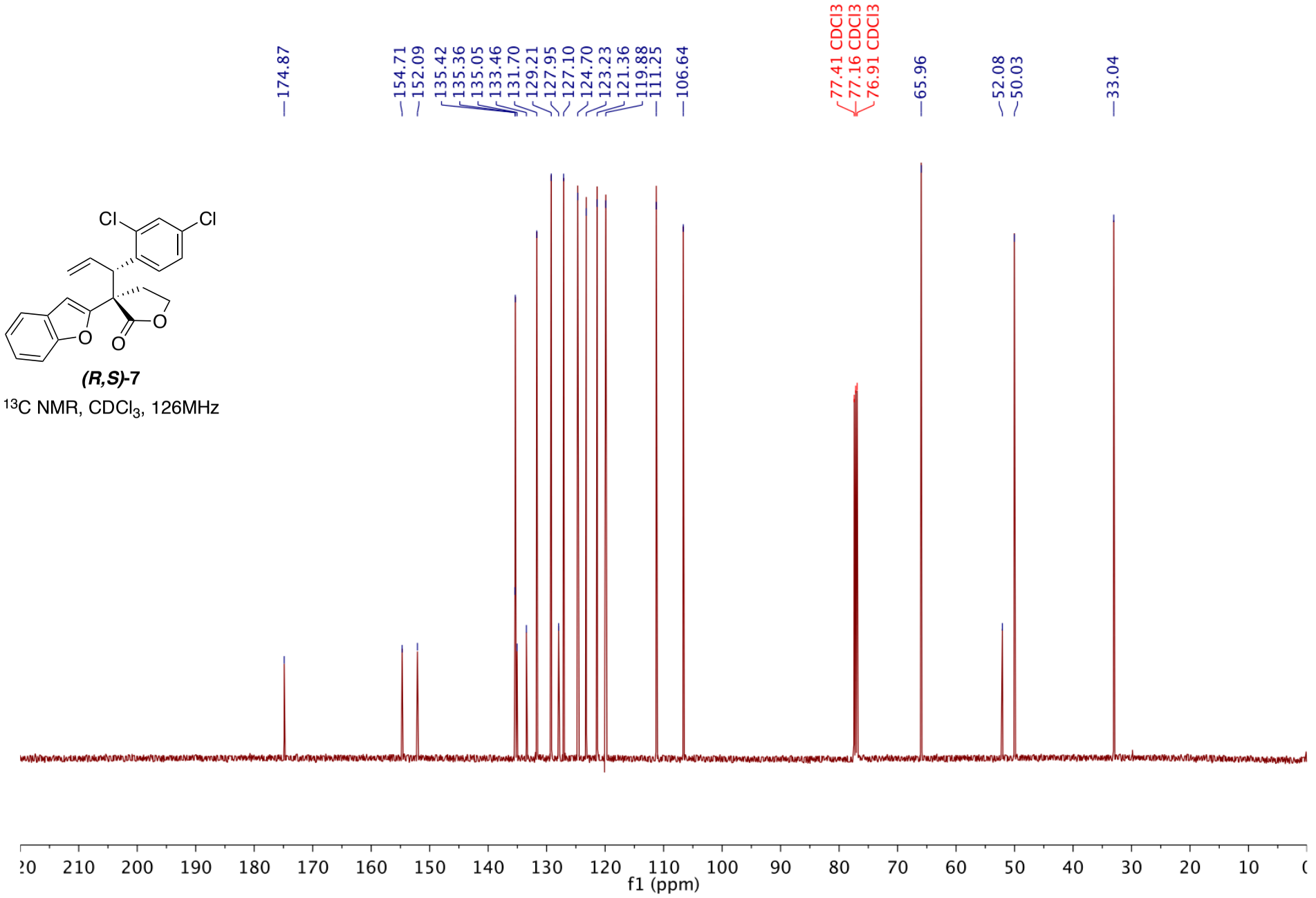
6

^{19}F NMR, $CDCl_3$, 235MHz



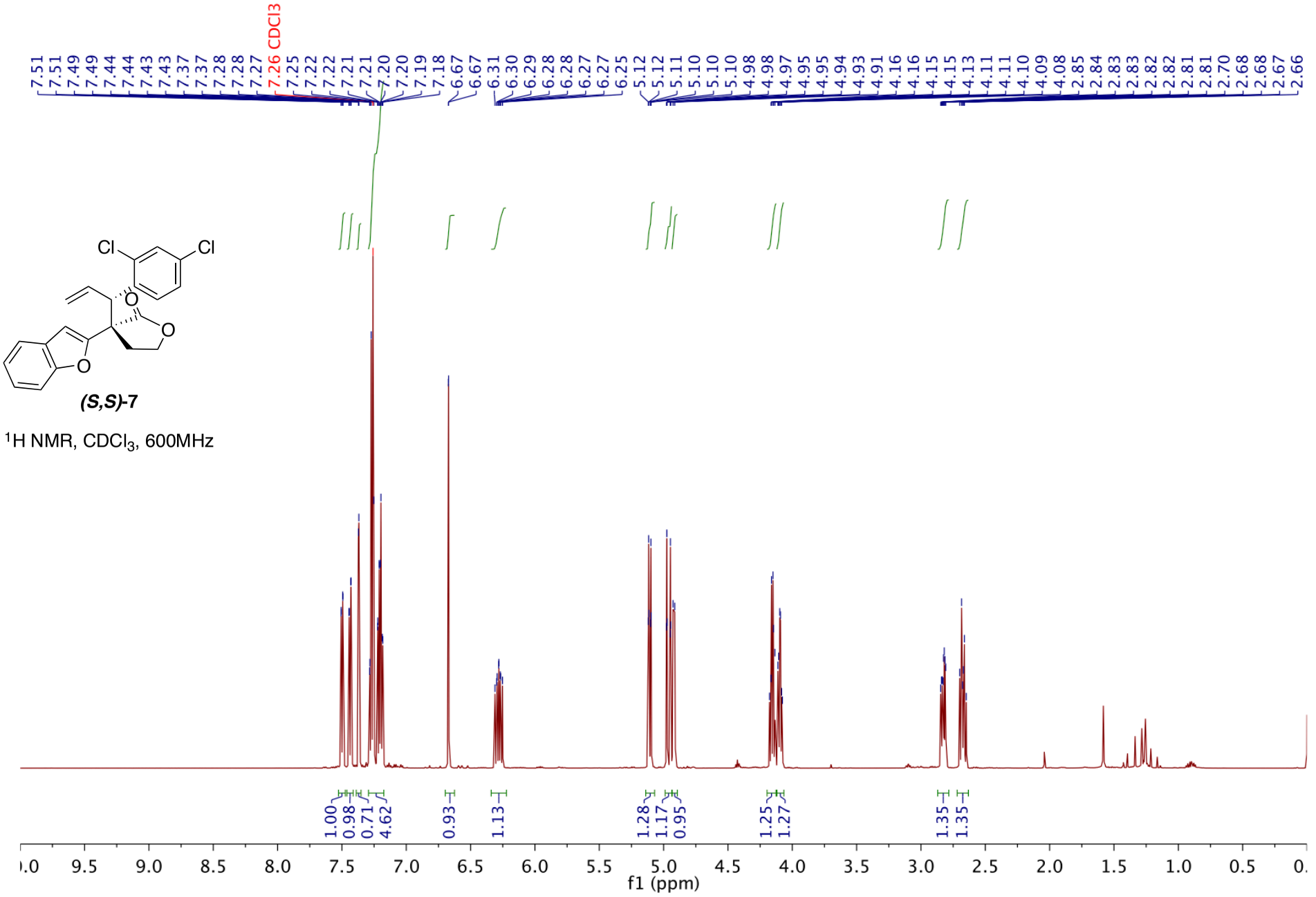
(R,S)-7

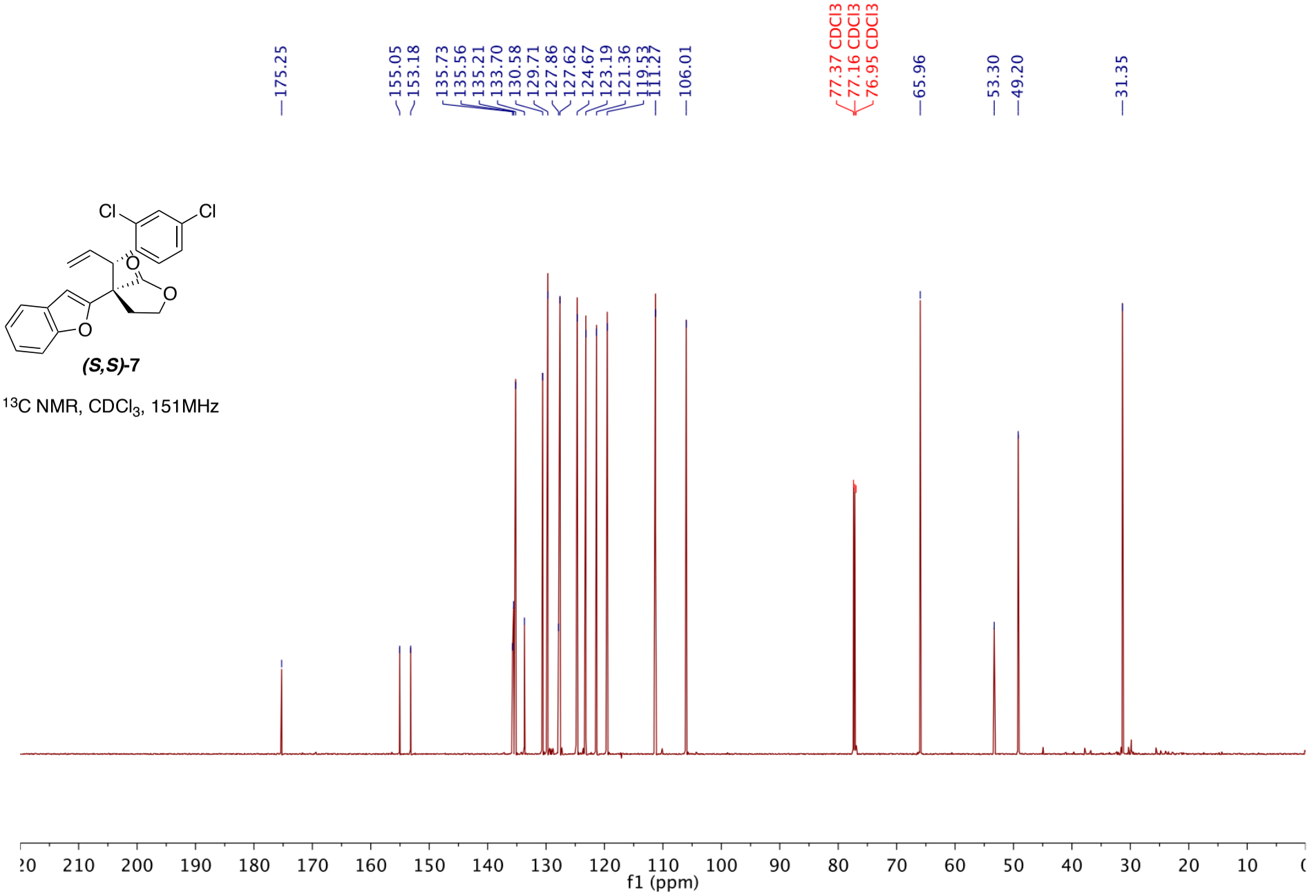
^{1}H NMR, $CDCl_3$, 500MHz



***(R,S)*-7**

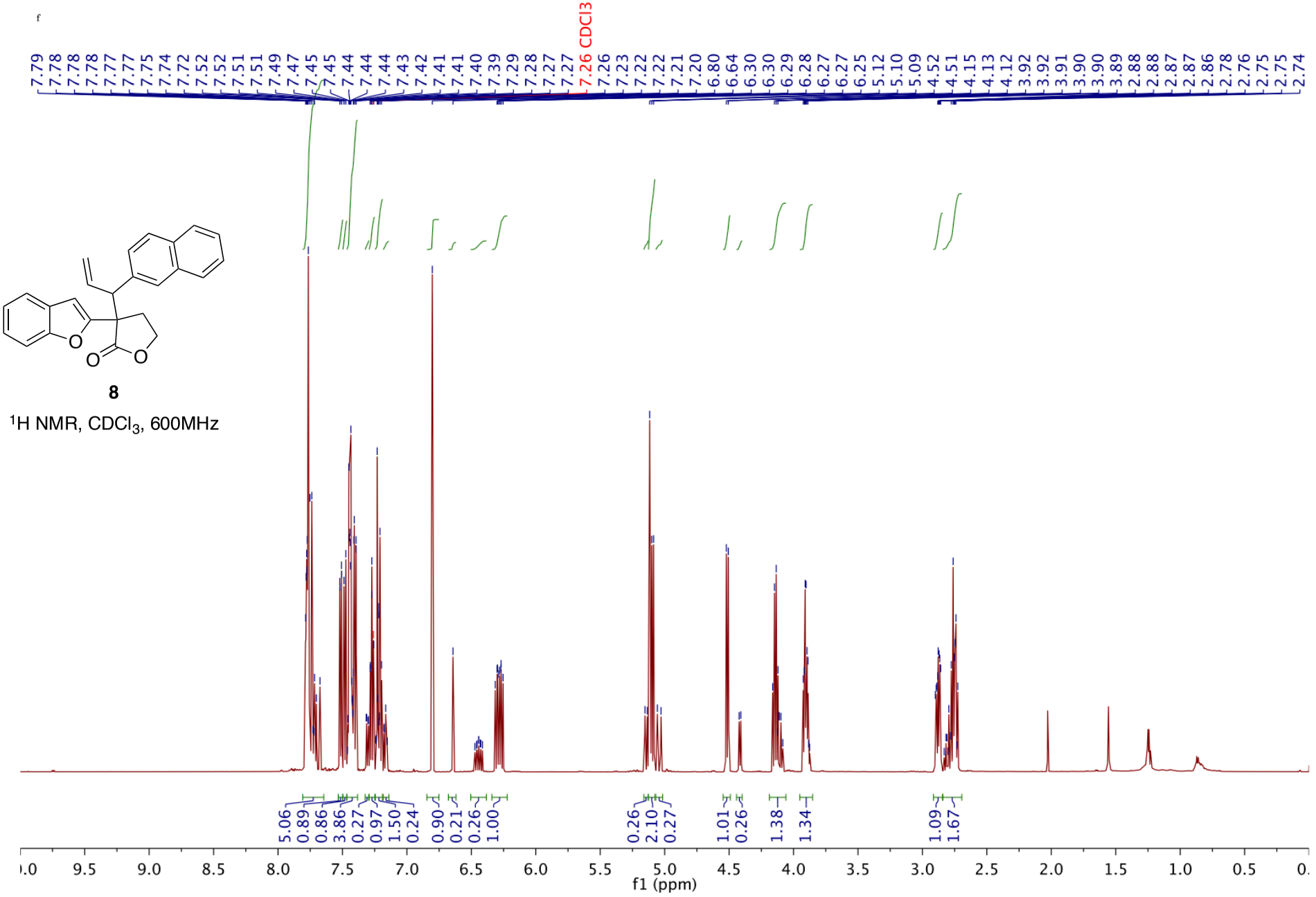
^{13}C NMR, $CDCl_3$, 126MHz

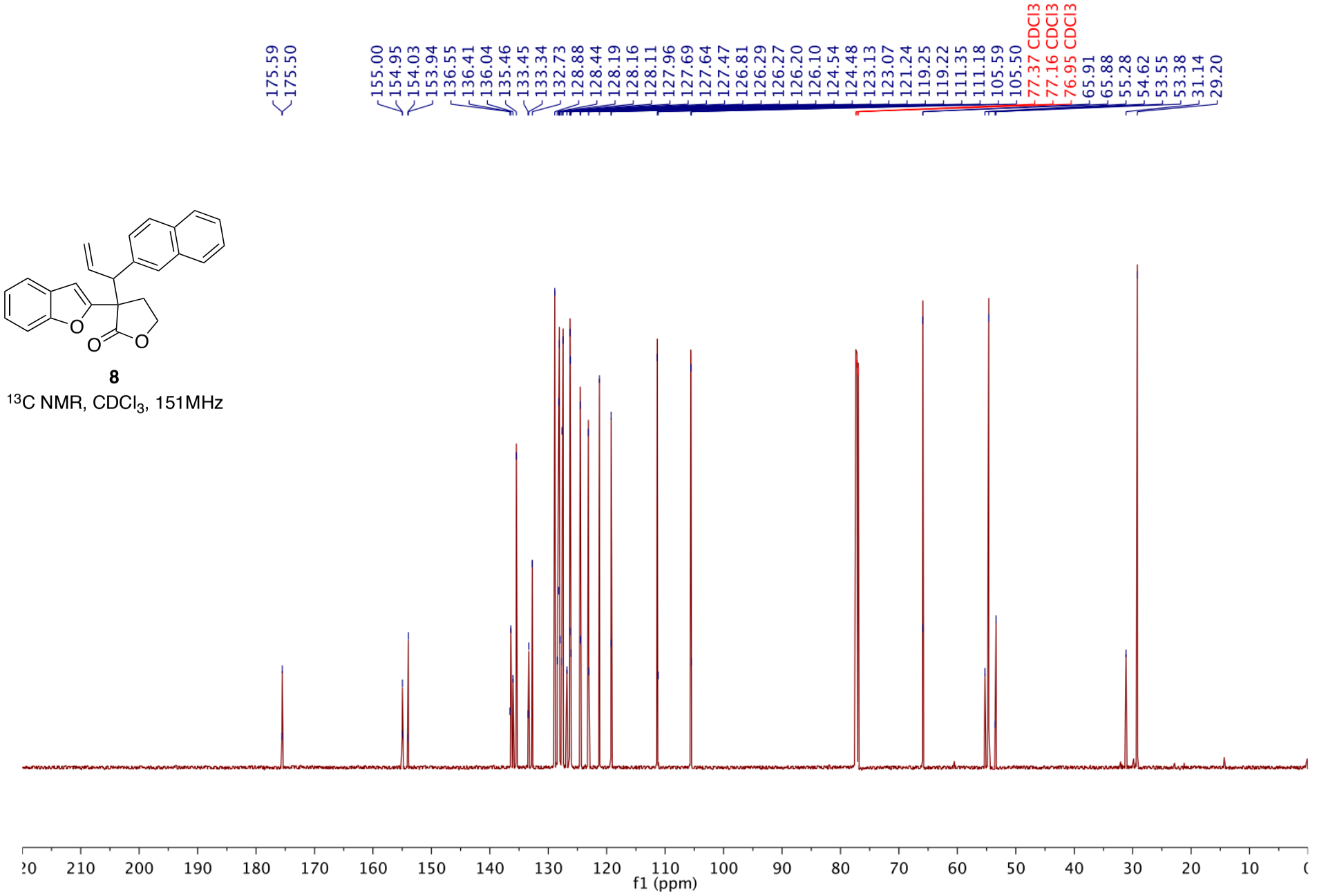

CDCl3
Cl
Cl
O
O
O
(S,S)-7
1H NMR, CDCl3, 600MHz
f1 (ppm)

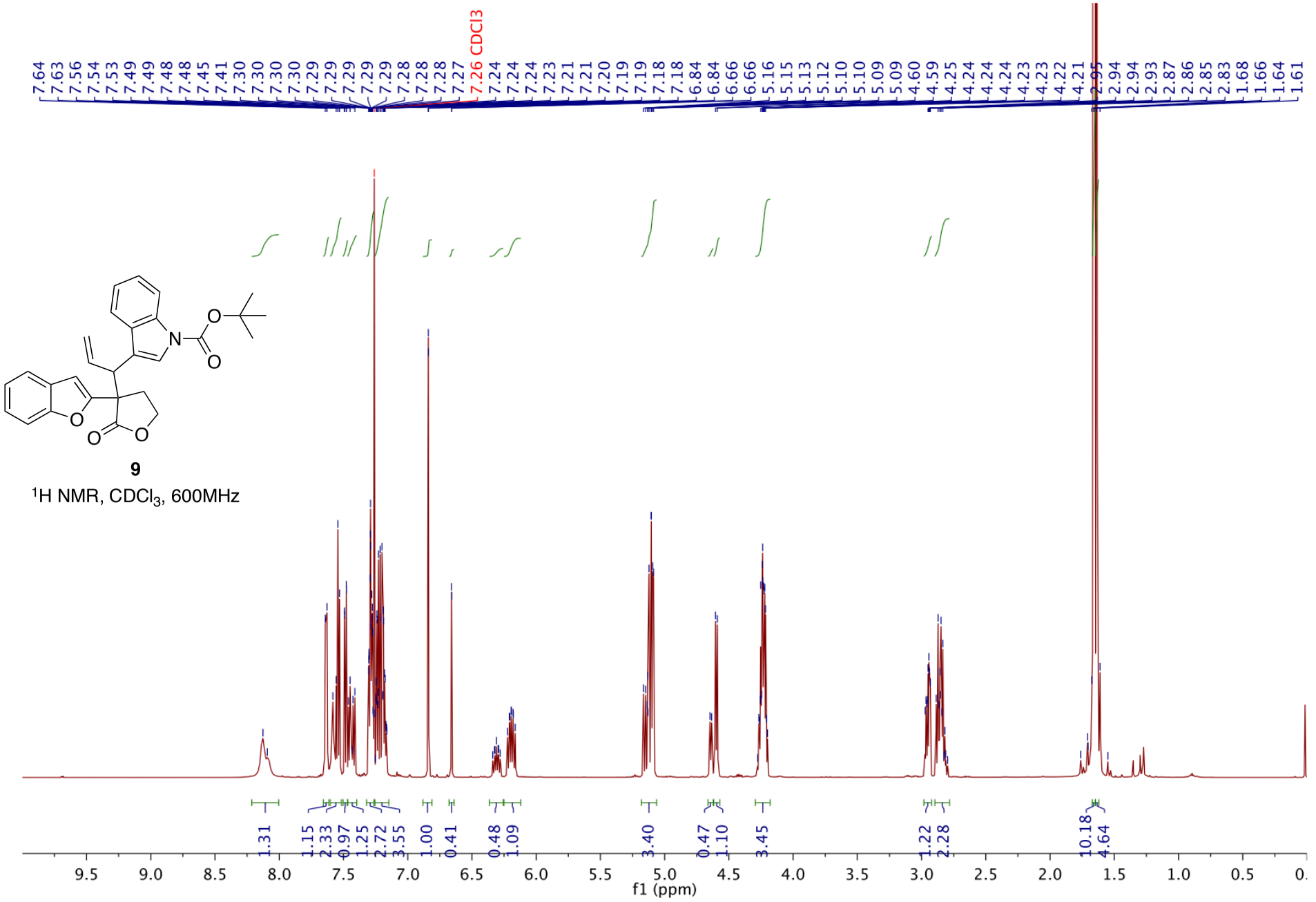


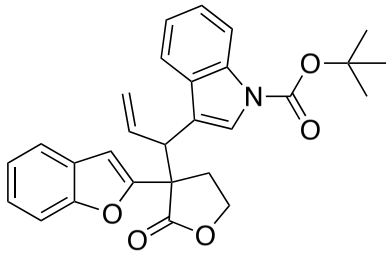
(S,S)-7

^{13}C NMR, $CDCl_3$, 151MHz


f
7.79 7.78 7.78 7.78 7.77 7.77 7.75 7.74 7.72 7.52 7.52 7.51 7.51 7.49 7.47 7.45 7.45 7.44 7.44 7.44 7.43 7.42 7.41 7.41 7.40 7.39 7.29 7.28 7.27 7.27 7.26 CDCl3 7.26 7.23 7.22 7.22 7.21 7.20 6.80 6.64 6.30 6.30 6.29 6.28 6.27 6.27 6.25 5.12 5.10 5.09 4.52 4.51 4.15 4.13 4.12 3.92 3.92 3.91 3.90 3.90 3.89 2.88 2.88 2.87 2.87 2.86 2.78 2.76 2.75 2.75 2.74
O
O
O
8
1H NMR, CDCl3, 600MHz
5.06 0.89 0.86 3.86 0.27 0.97 1.50 0.24 0.90 0.21 0.26 1.00 0.26 2.10 0.27 1.01 0.26 1.38 1.34 1.09 1.67
9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5
f1 (ppm)

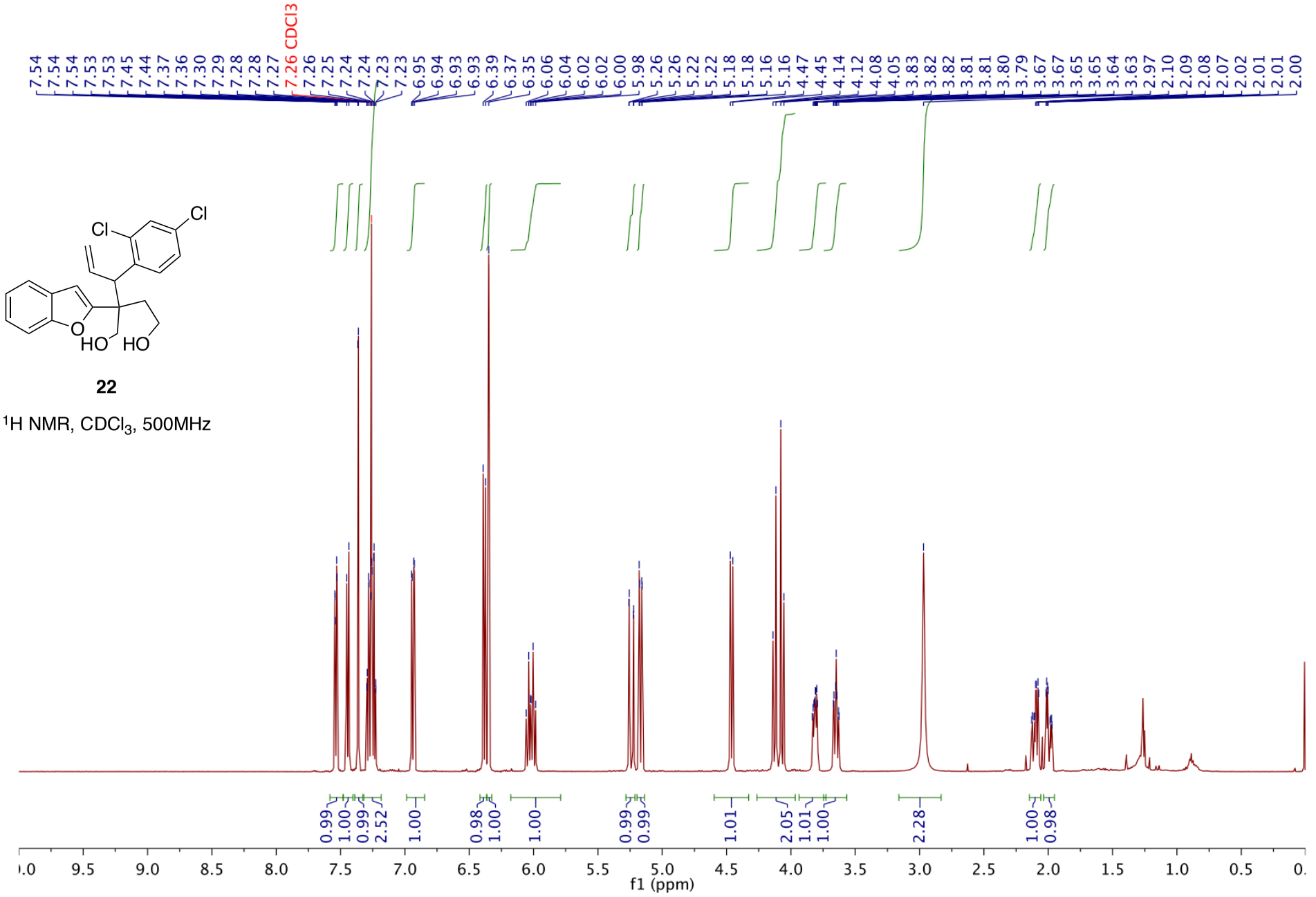

175.59
175.50
155.00
154.95
154.03
153.94
136.55
136.41
136.04
135.46
133.45
133.34
132.73
128.88
128.44
128.19
128.16
128.11
127.96
127.69
127.64
127.47
126.81
126.29
126.27
126.20
126.10
124.54
124.48
123.13
123.07
121.24
119.25
119.22
111.35
111.18
105.59
105.50
77.37 CDCl3
77.16 CDCl3
76.95 CDCl3
65.91
65.88
55.28
54.62
53.55
53.38
31.14
29.20
O
O
O
8
13C NMR, CDCl3, 151MHz
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
f1 (ppm)

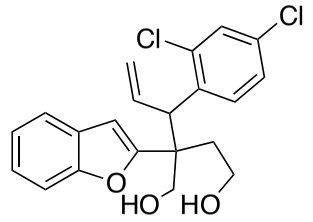

7.64 7.63 7.56 7.54 7.53 7.49 7.49 7.48 7.48 7.45 7.41 7.30 7.30 7.30 7.30 7.29 7.29 7.29 7.29 7.29 7.28 7.28 7.28 7.27 7.26 CDCl3 7.24 7.24 7.24 7.23 7.21 7.21 7.20 7.19 7.19 7.18 7.18 6.84 6.84 6.66 6.66 5.16 5.15 5.13 5.12 5.10 5.10 5.09 5.09 4.60 4.59 4.25 4.24 4.24 4.24 4.23 4.23 4.22 4.21 2.95 2.94 2.94 2.93 2.87 2.86 2.85 2.83 1.68 1.66 1.64 1.61
O
N
O
O
O
O
O
9
1H NMR, CDCl3, 600MHz
1.31 1.15 2.33 0.97 1.25 2.72 3.55 1.00 0.41 0.48 1.09 3.40 0.47 1.10 3.45 1.22 2.28 10.18 4.64
9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.
f1 (ppm)



9

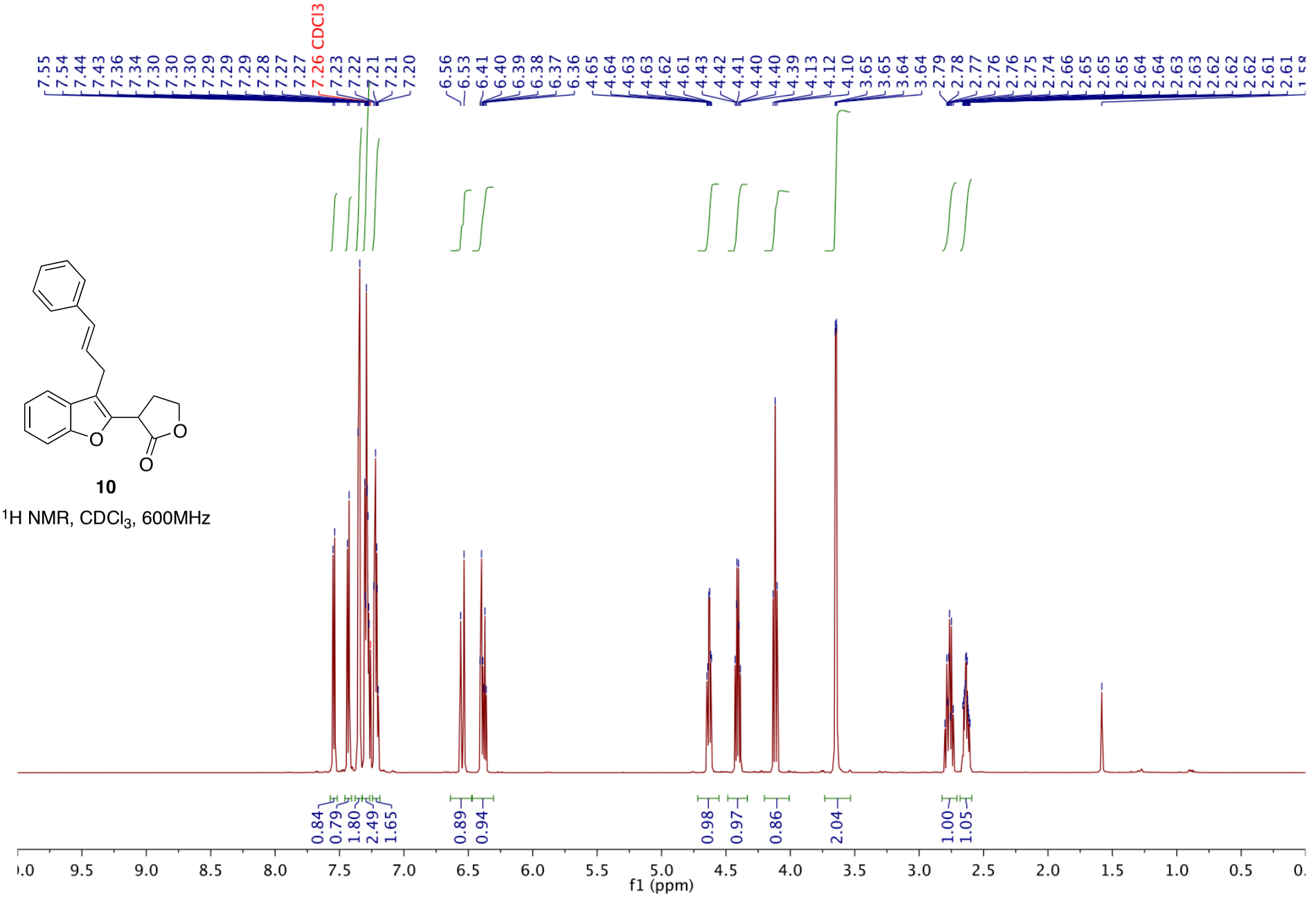
^{13}C NMR, $CDCl_3$, 151MHz


Cl
Cl
O
HO
HO
22
1H NMR, CDCl3, 500MHz
CDCl3
f1 (ppm)



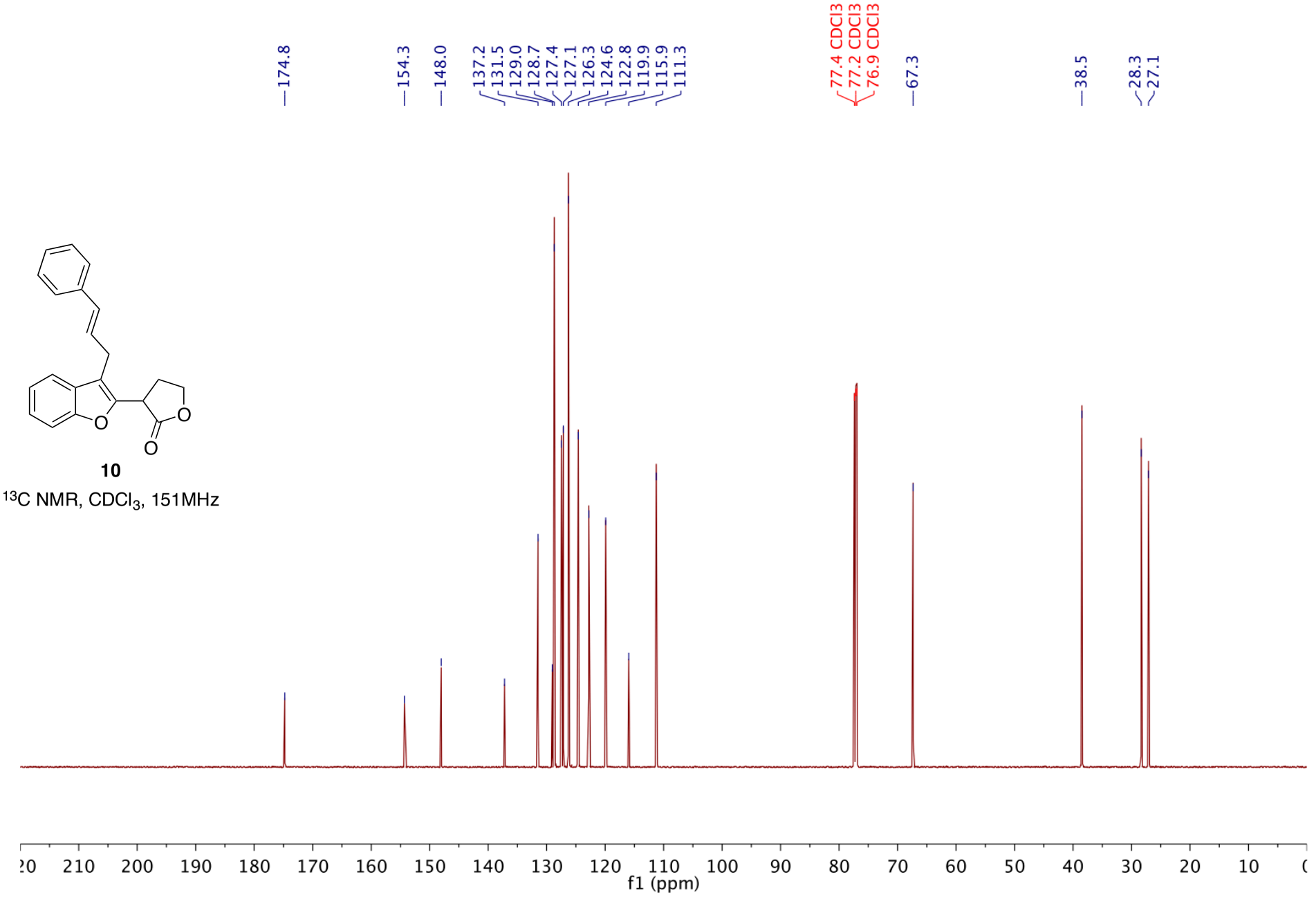
22

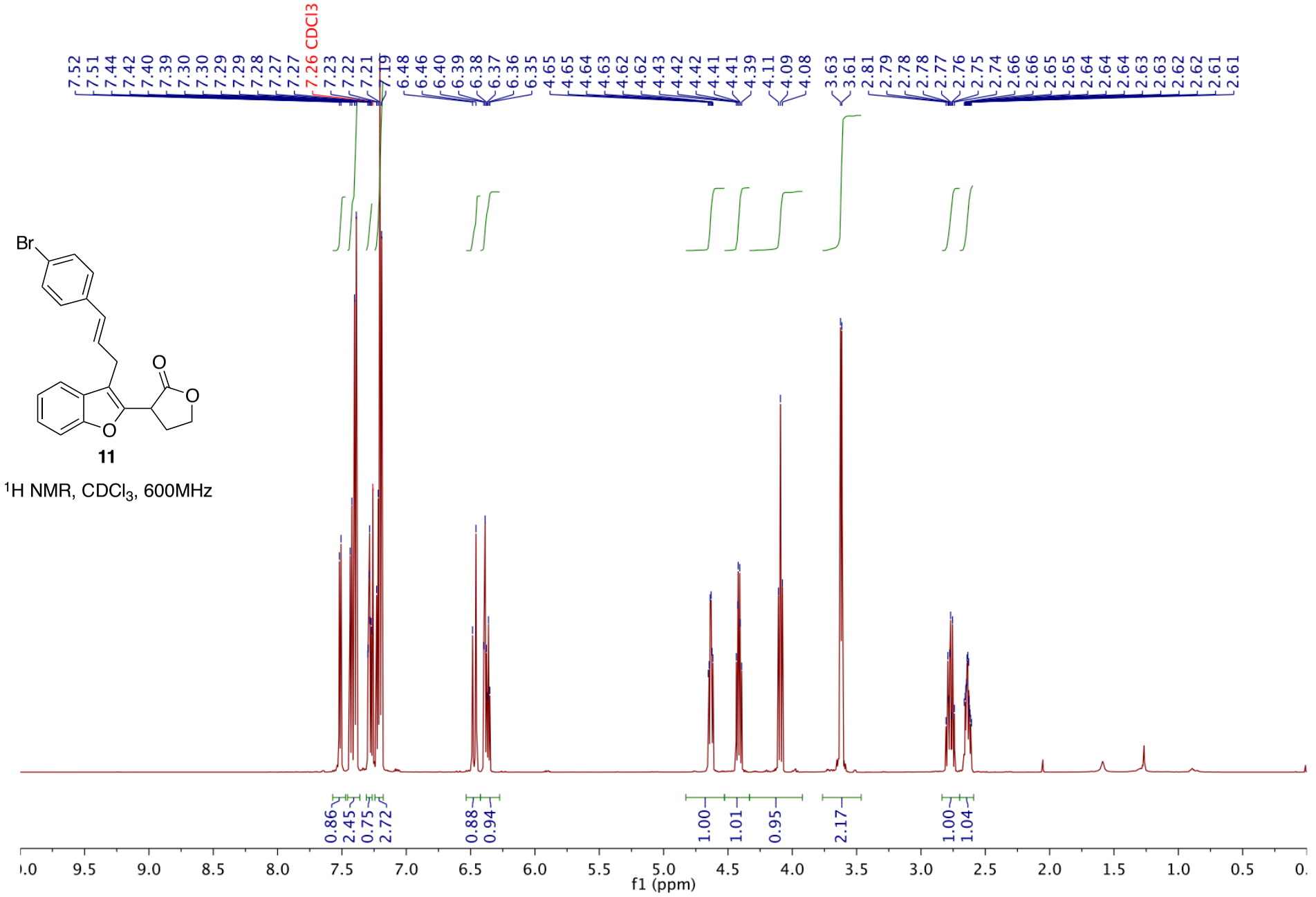
^{13}C NMR, $CDCl_3$, 126MHz

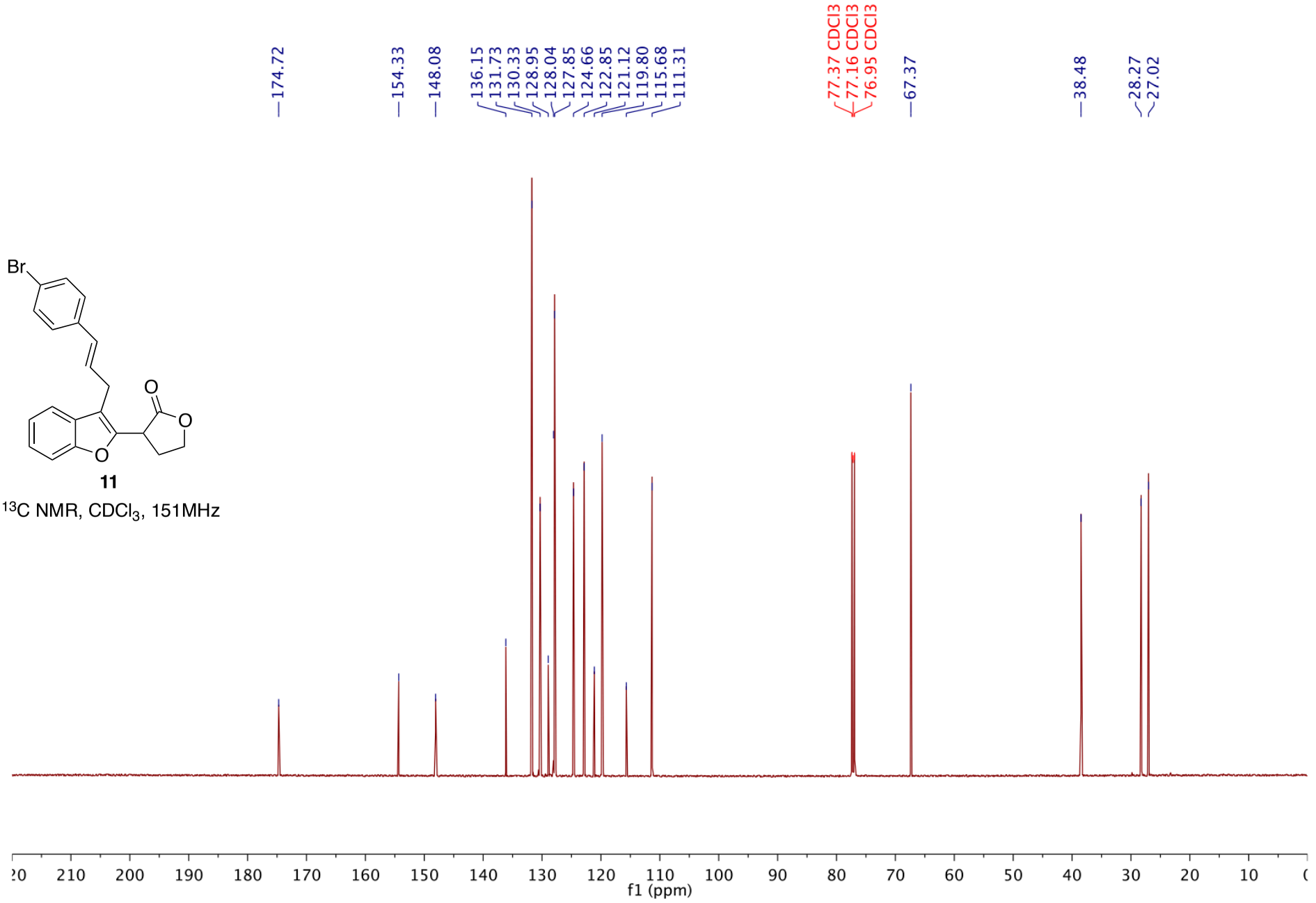


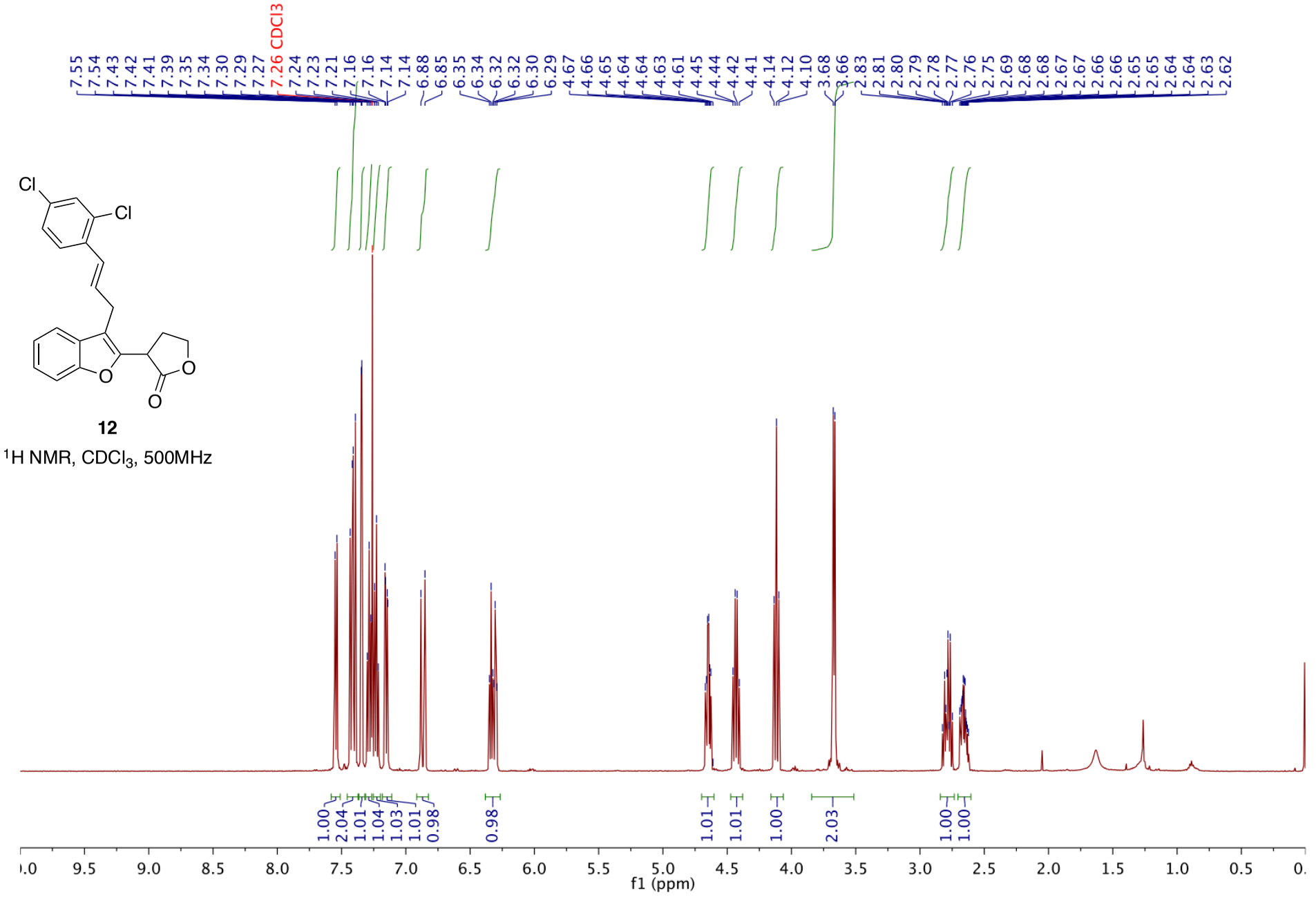
10

^{1}H NMR, $CDCl_3$, 600MHz


174.8
154.3
148.0
137.2
131.5
129.0
128.7
127.4
127.1
126.3
124.6
122.8
119.9
115.9
111.3
77.4 CDCl3
77.2 CDCl3
76.9 CDCl3
67.3
38.5
28.3
27.1
O
O
O
10
13C NMR, CDCl3, 151MHz
f1 (ppm)

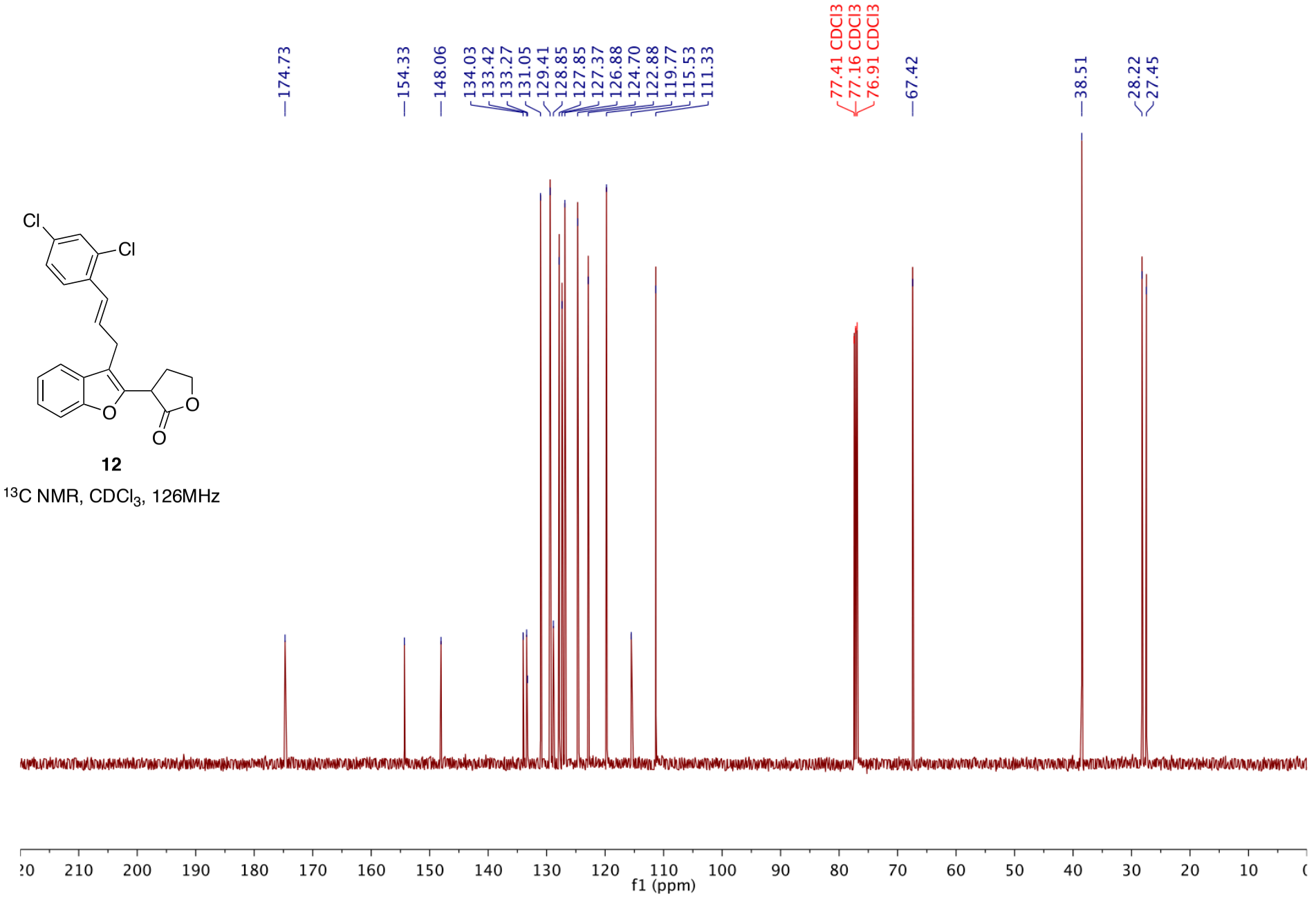

7.52 7.51 7.44 7.42 7.40 7.39 7.30 7.30 7.29 7.29 7.28 7.27 7.27 7.26 CDCl3 7.23 7.22 7.21 7.19 6.48 6.46 6.40 6.39 6.38 6.37 6.36 6.35 4.65 4.64 4.63 4.62 4.62 4.43 4.42 4.42 4.41 4.41 4.39 4.11 4.09 4.08 3.63 3.61 2.81 2.79 2.78 2.78 2.77 2.76 2.75 2.74 2.66 2.66 2.65 2.65 2.64 2.64 2.64 2.63 2.63 2.62 2.62 2.61 2.61
Br
O
O
O
11
^{1}H NMR, $CDCl_3$, 600MHz
0.86 2.45 0.75 2.72 0.88 0.94 1.00 1.01 0.95 2.17 1.00 1.04
9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5
f1 (ppm)

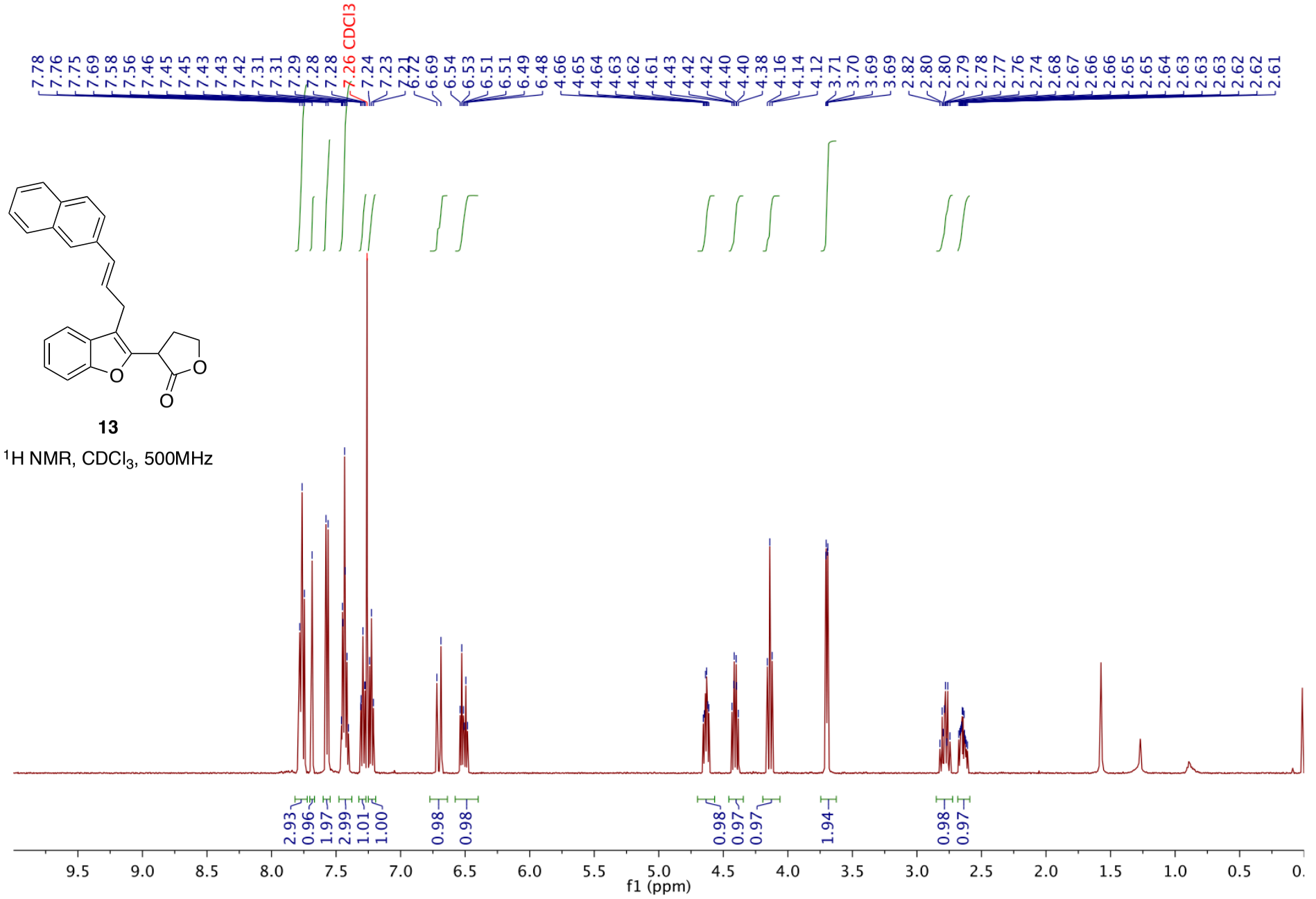

174.72
154.33
148.08
136.15
131.73
130.33
128.95
128.04
127.85
124.66
122.85
121.12
119.80
115.68
111.31
77.37 CDCl3
77.16 CDCl3
76.95 CDCl3
67.37
38.48
28.27
27.02
Br
O
O
O
11
13C NMR, CDCl3, 151MHz
f1 (ppm)

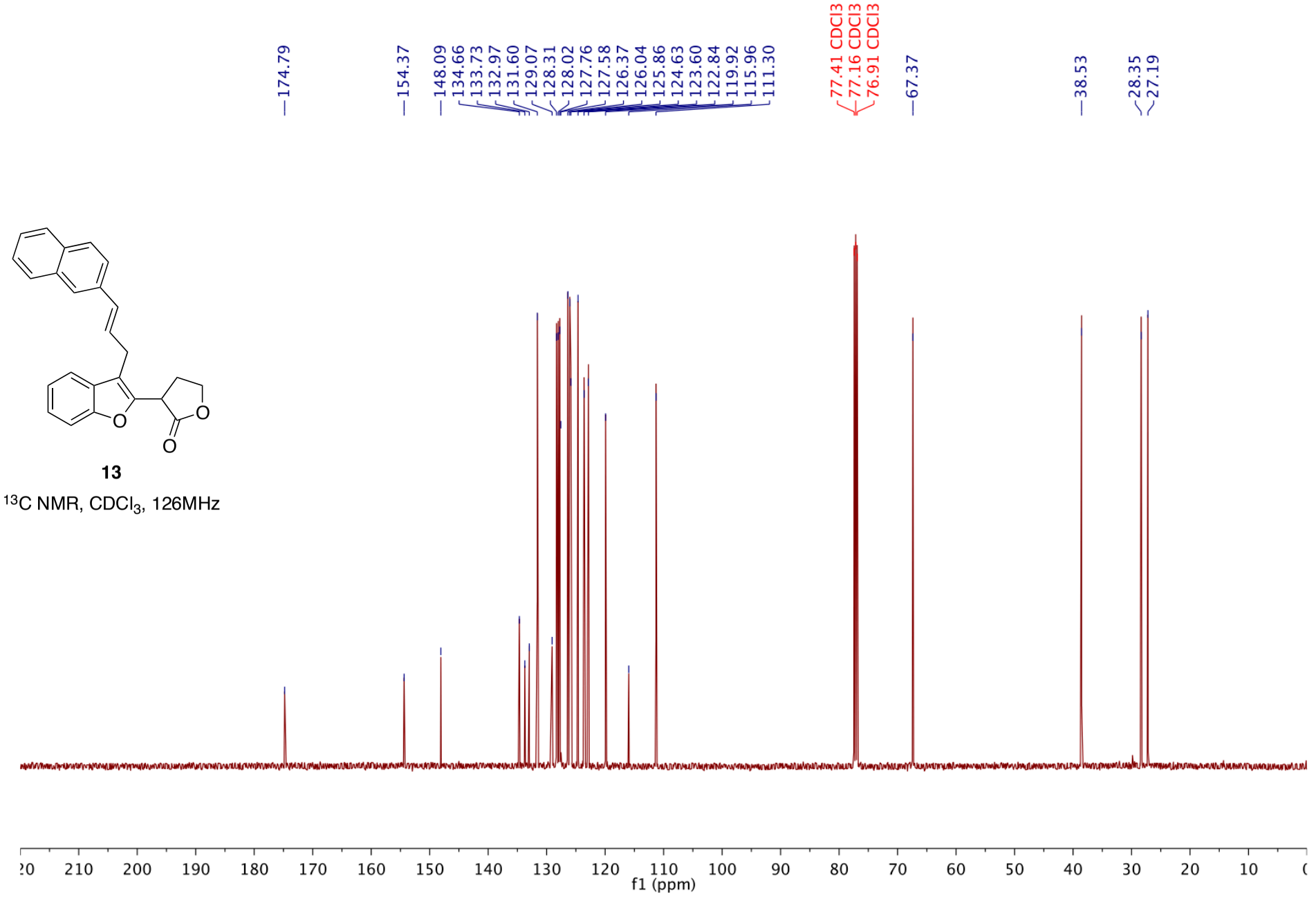


12

^{1}H NMR, $CDCl_3$, 500MHz

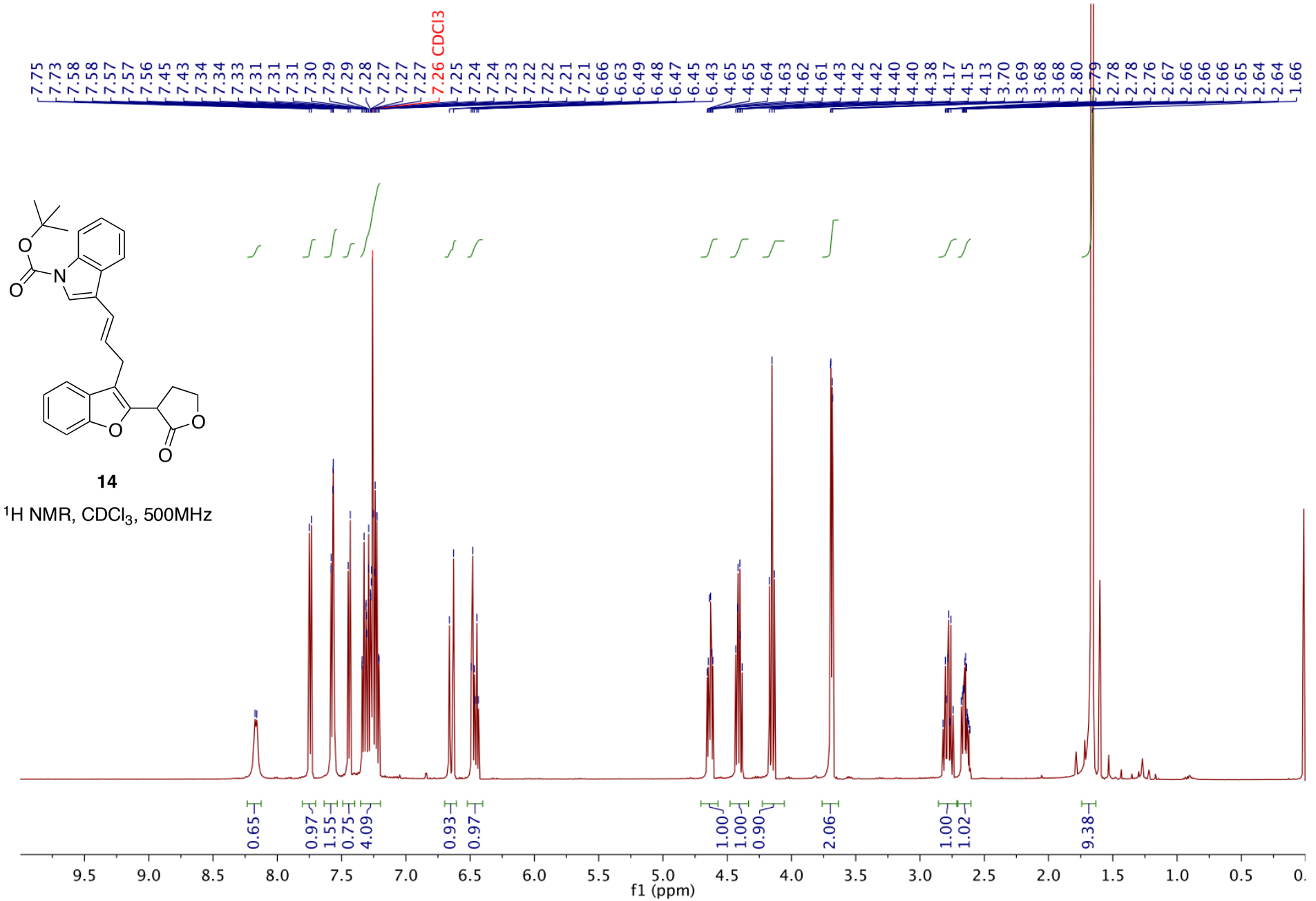

174.73
154.33
148.06
134.03
133.42
133.27
131.05
129.41
128.85
127.85
127.37
126.88
124.70
122.88
119.77
115.53
111.33
77.41 CDCl3
77.16 CDCl3
76.91 CDCl3
67.42
38.51
28.22
27.45
Cl
Cl
O
O
O
12
13C NMR, CDCl3, 126MHz
f1 (ppm)


7.78 7.76 7.75 7.69 7.58 7.56 7.46 7.45 7.45 7.43 7.43 7.42 7.31 7.31 7.29 7.28 7.28 7.26 CDCl3 7.24 7.23 7.21 6.72 6.69 6.54 6.53 6.51 6.51 6.49 6.48 4.66 4.65 4.64 4.63 4.62 4.61 4.43 4.42 4.42 4.40 4.40 4.38 4.16 4.14 4.12 3.71 3.70 3.69 3.69 2.82 2.80 2.80 2.79 2.78 2.77 2.76 2.74 2.68 2.67 2.66 2.66 2.65 2.65 2.64 2.63 2.63 2.63 2.62 2.62 2.61
O
O
O
13
1H NMR, CDCl3, 500MHz
2.93 0.96 1.97 2.99 1.01 1.00 0.98 0.98 0.98 0.97 0.97 1.94 0.98 0.97
9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.
f1 (ppm)



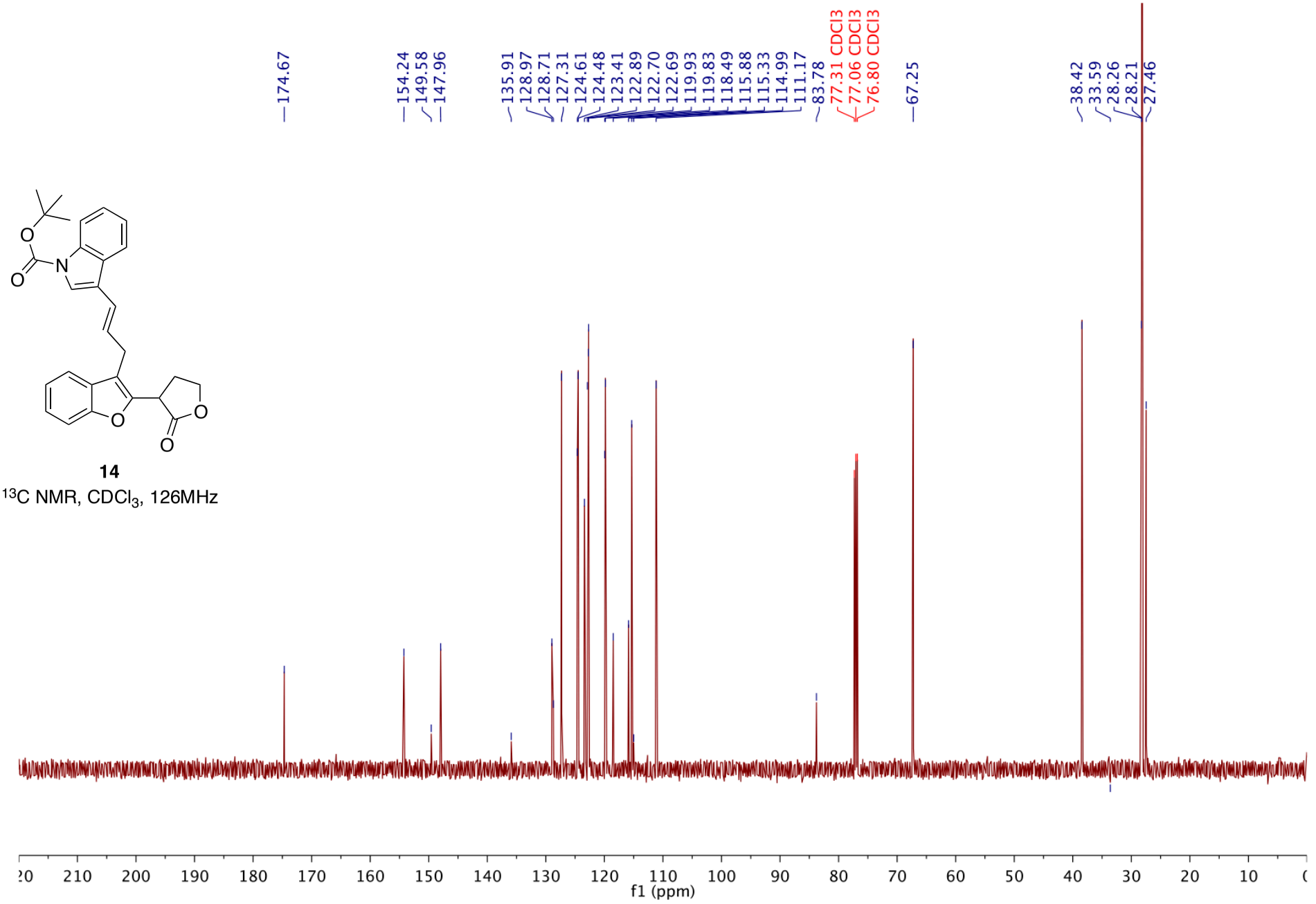
13

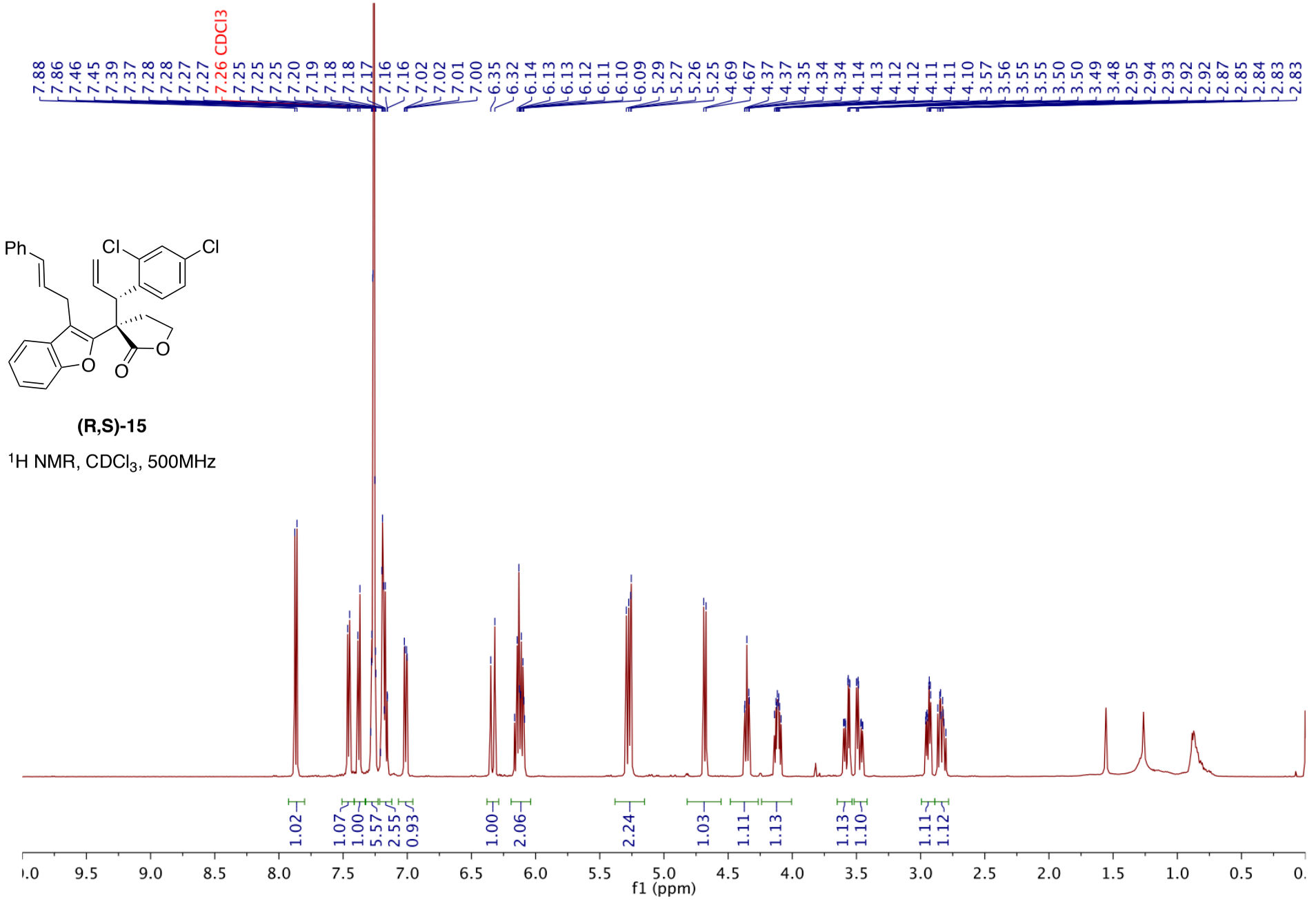
^{13}C NMR, $CDCl_3$, 126MHz



14

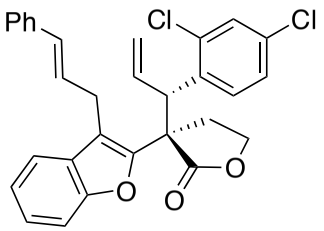
^{1}H NMR, $CDCl_3$, 500MHz


174.67
154.24
149.58
147.96
135.91
128.97
128.71
127.31
124.61
124.48
123.41
122.89
122.70
122.69
119.93
119.83
118.49
115.88
115.33
114.99
111.17
83.78
77.31 CDCl3
77.06 CDCl3
76.80 CDCl3
67.25
38.42
33.59
28.26
28.21
27.46
O
N
O
O
O
O
14
13C NMR, CDCl3, 126MHz
f1 (ppm)



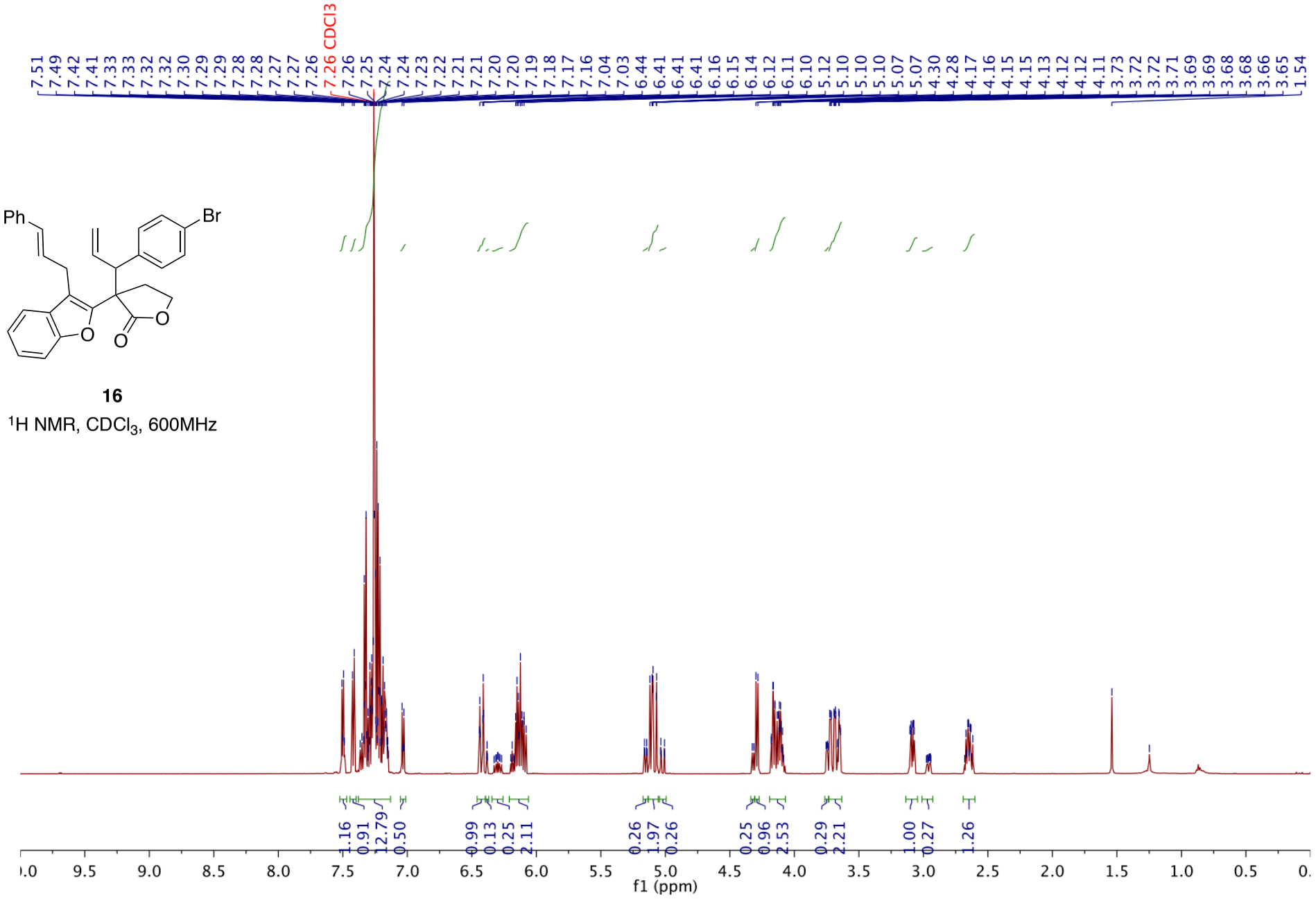
(R,S)-15

^{1}H NMR, $CDCl_3$, 500MHz



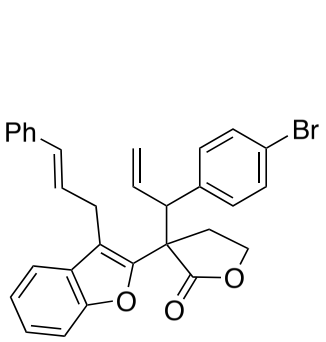
(R,S)-15

^{13}C NMR, $CDCl_3$, 126MHz



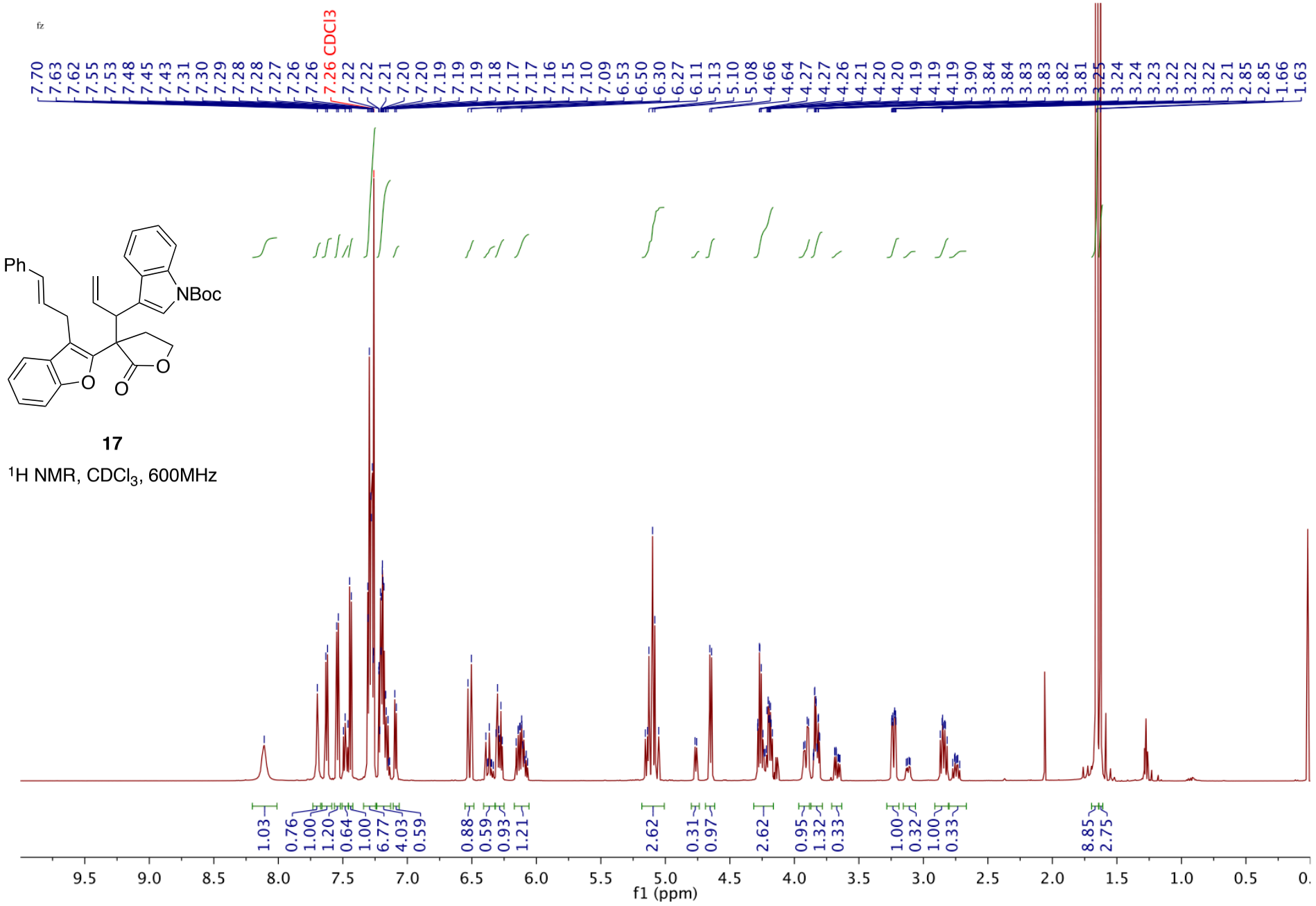
16

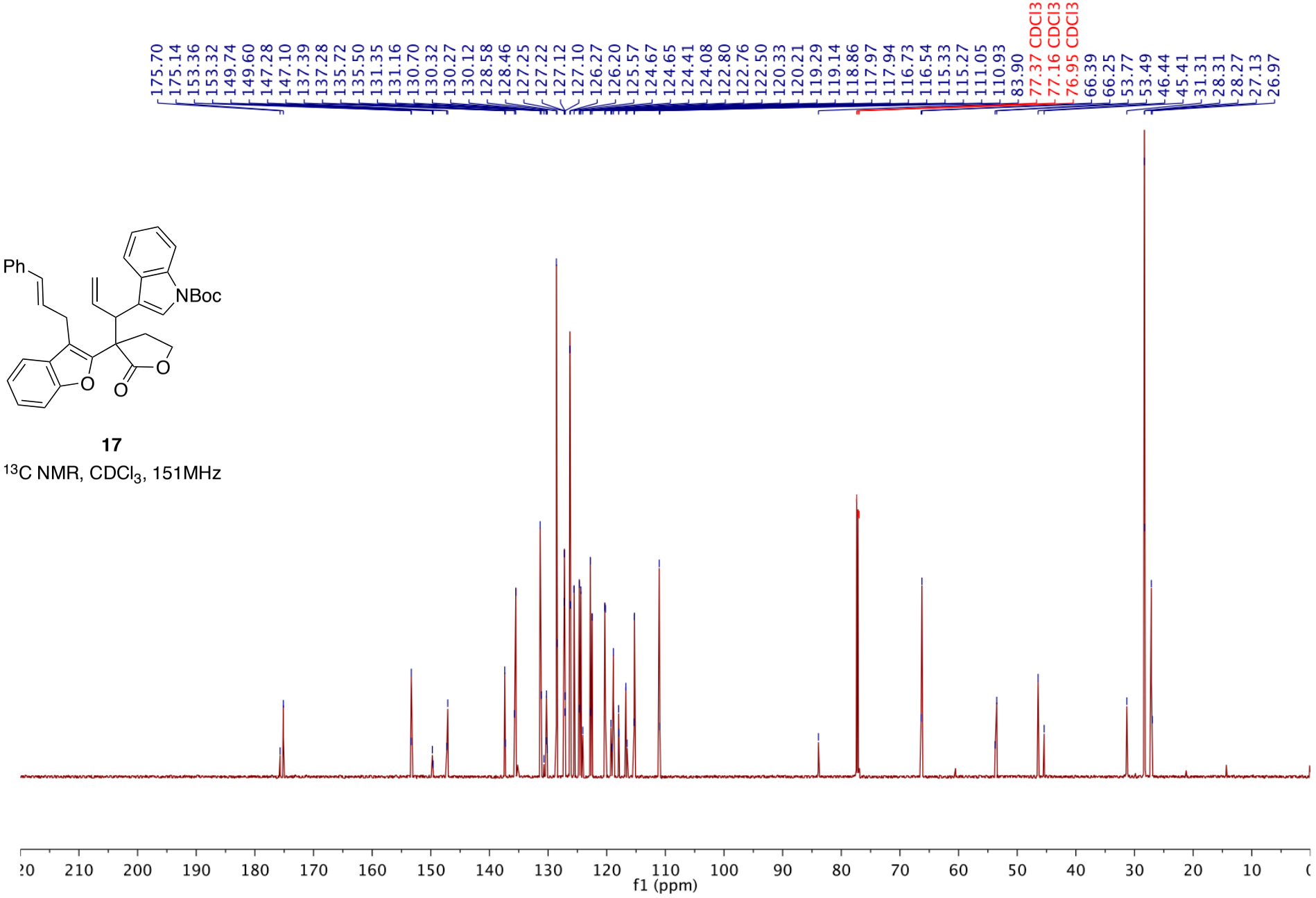
^{1}H NMR, $CDCl_3$, 600MHz

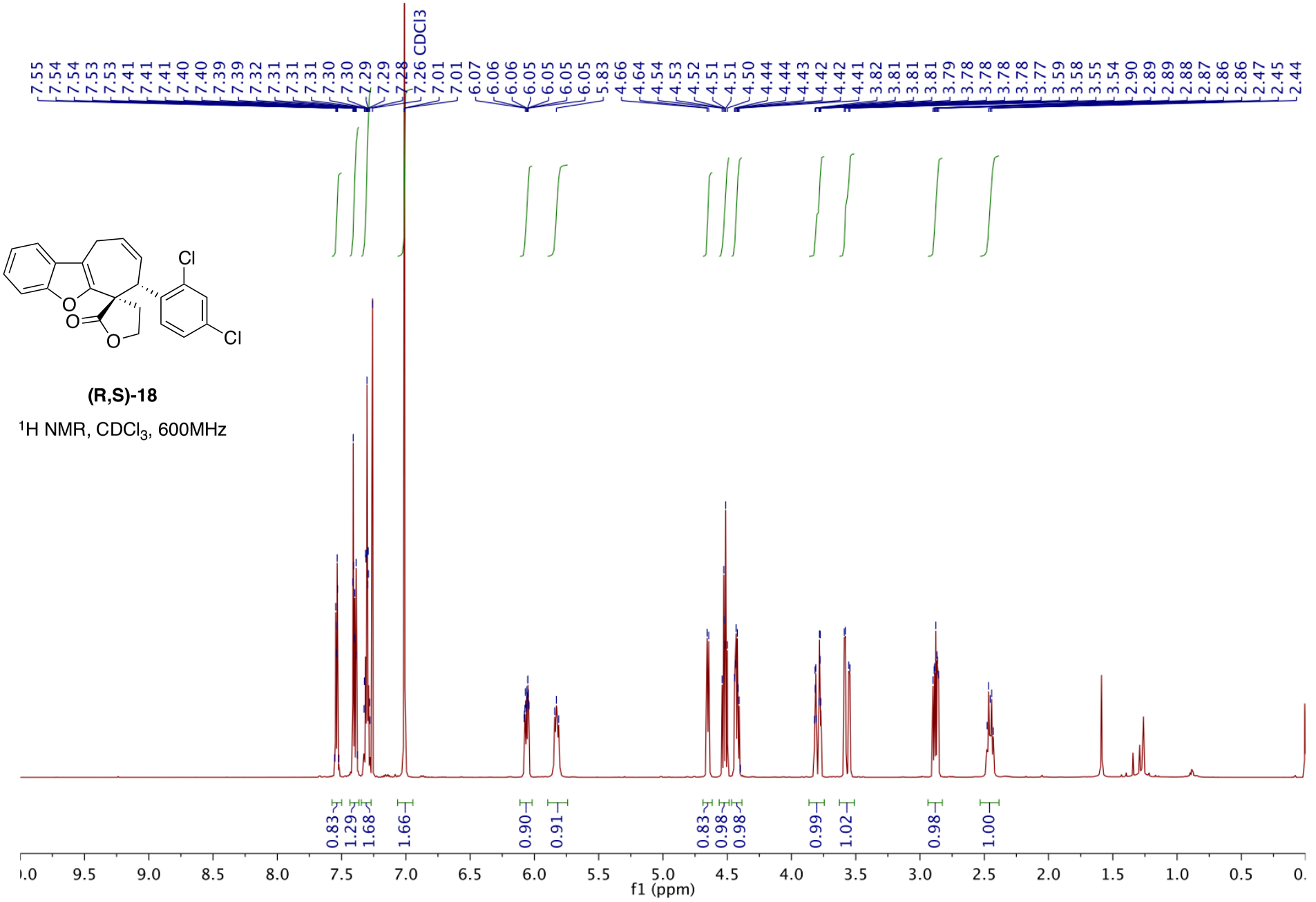


16

^{13}C NMR, $CDCl_3$, 151MHz

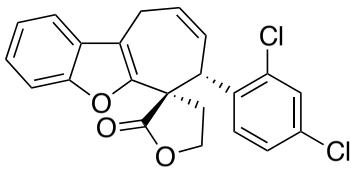

fz
7.26 CDCl3
Ph
NBoc
O
O
O
17
1H NMR, CDCl3, 600MHz
f1 (ppm)


175.70
175.14
153.36
153.32
149.74
149.60
147.28
147.10
137.39
137.28
135.72
135.50
131.35
131.16
130.70
130.32
130.27
130.12
128.58
128.46
127.25
127.22
127.12
127.10
126.27
126.20
125.57
124.67
124.65
124.41
124.08
122.80
122.76
122.50
120.33
120.21
119.29
119.14
118.86
117.97
117.94
116.73
116.54
115.33
115.27
111.05
110.93
83.90
77.37 CDCl3
77.16 CDCl3
76.95 CDCl3
66.39
66.25
53.77
53.49
46.44
45.41
31.31
28.31
28.27
27.13
26.97
Ph
NBoc
O
O
O
17
13C NMR, CDCl3, 151MHz
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
f1 (ppm)



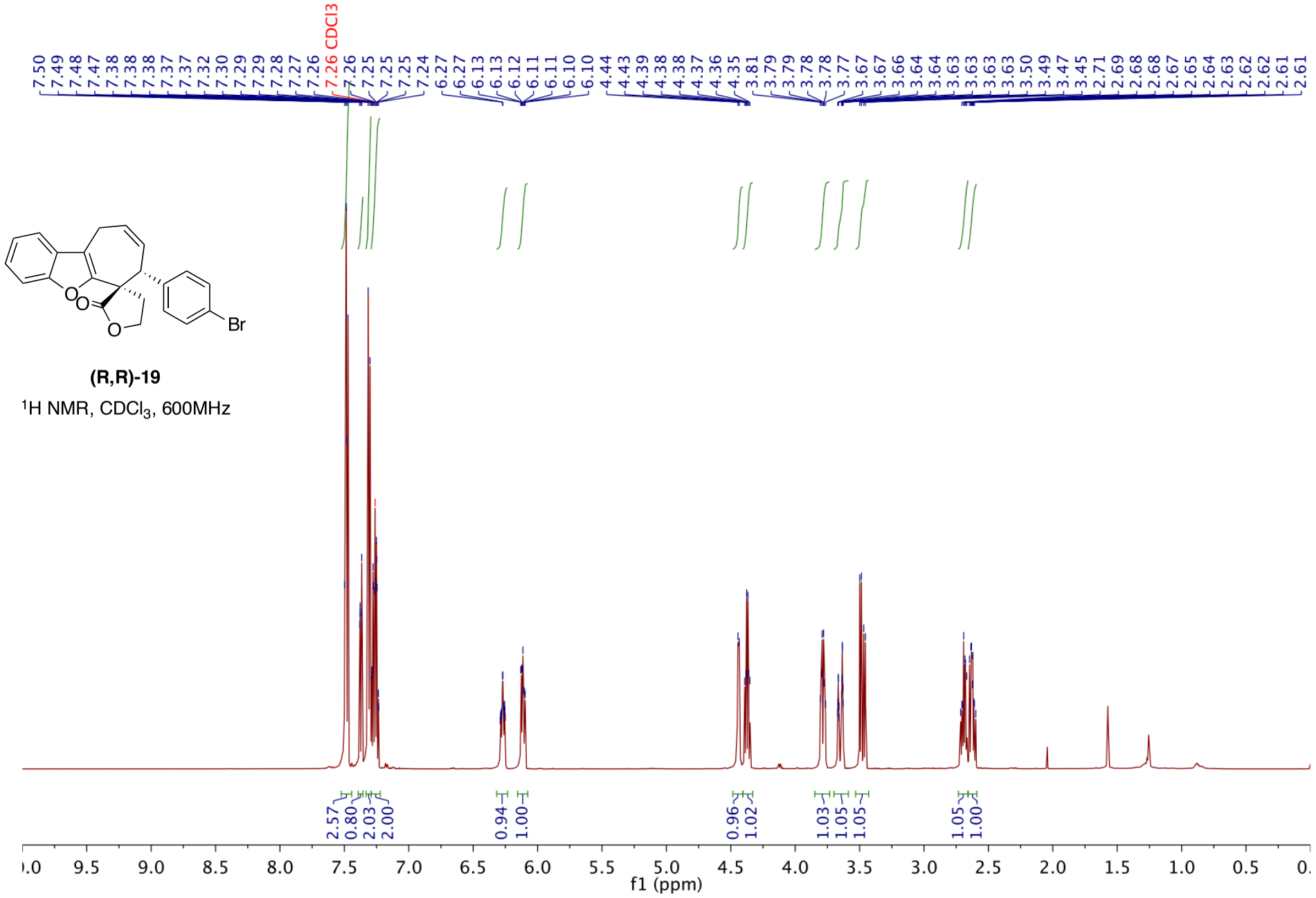
(R,S)-18

^{1}H NMR, $CDCl_3$, 600MHz



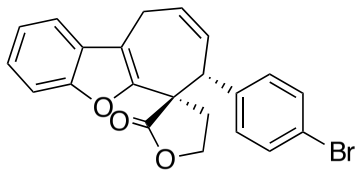
(R,S)-18

^{13}C NMR, $CDCl_3$, 151MHz



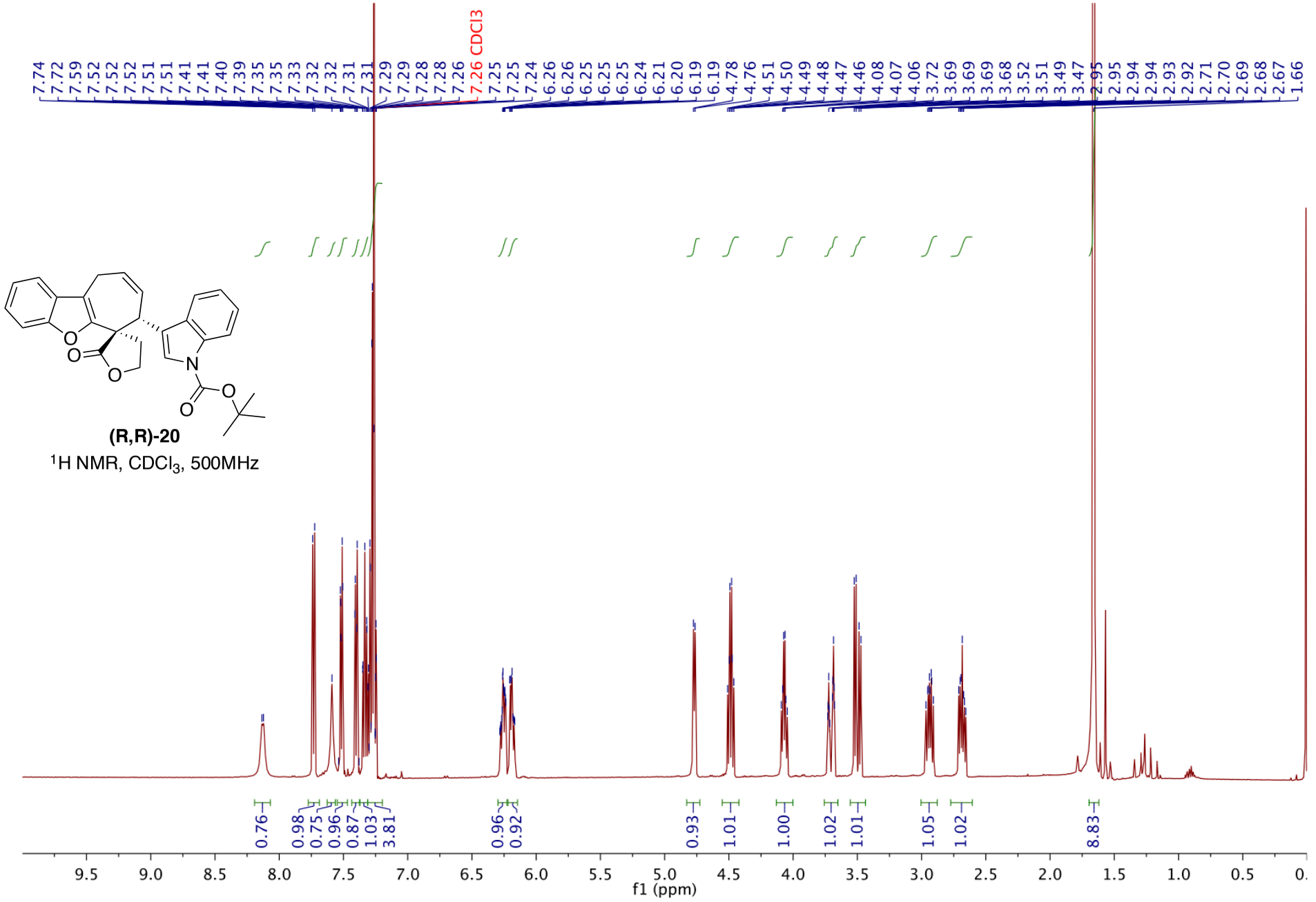
(R,R)-19

^{1}H NMR, $CDCl_3$, 600MHz



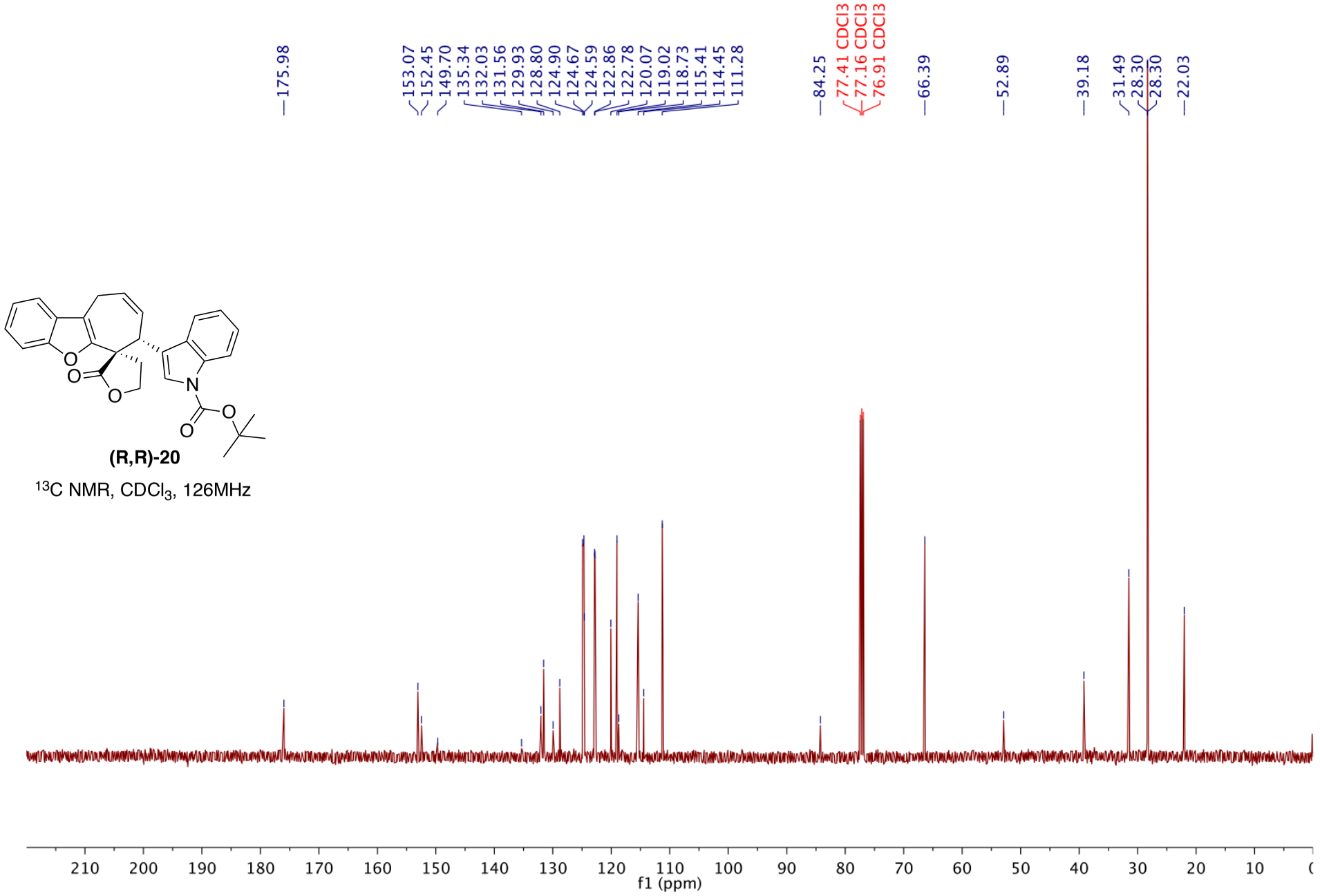
(R,R)-19

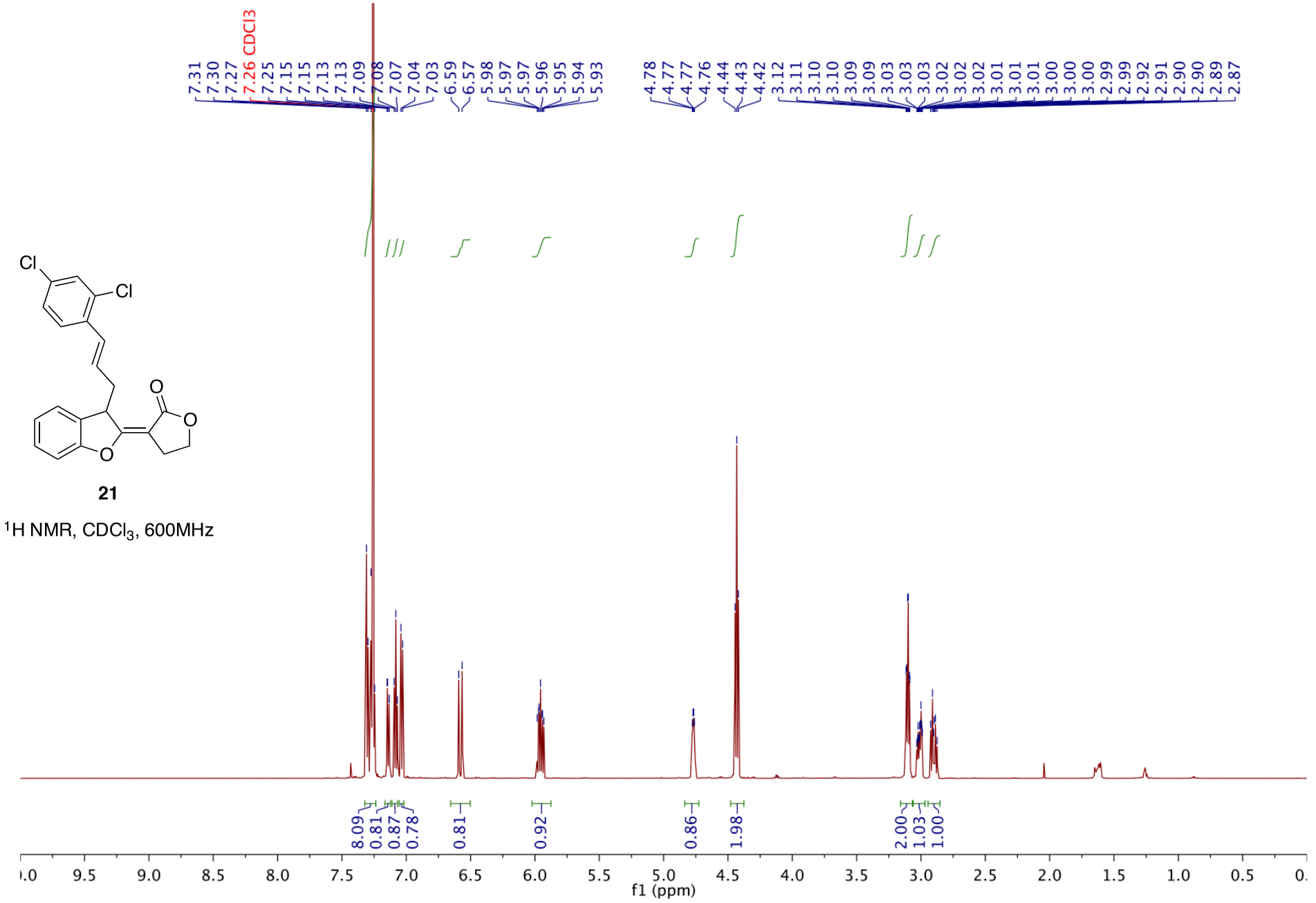
^{13}C NMR, $CDCl_3$, 151MHz



(R,R)-20

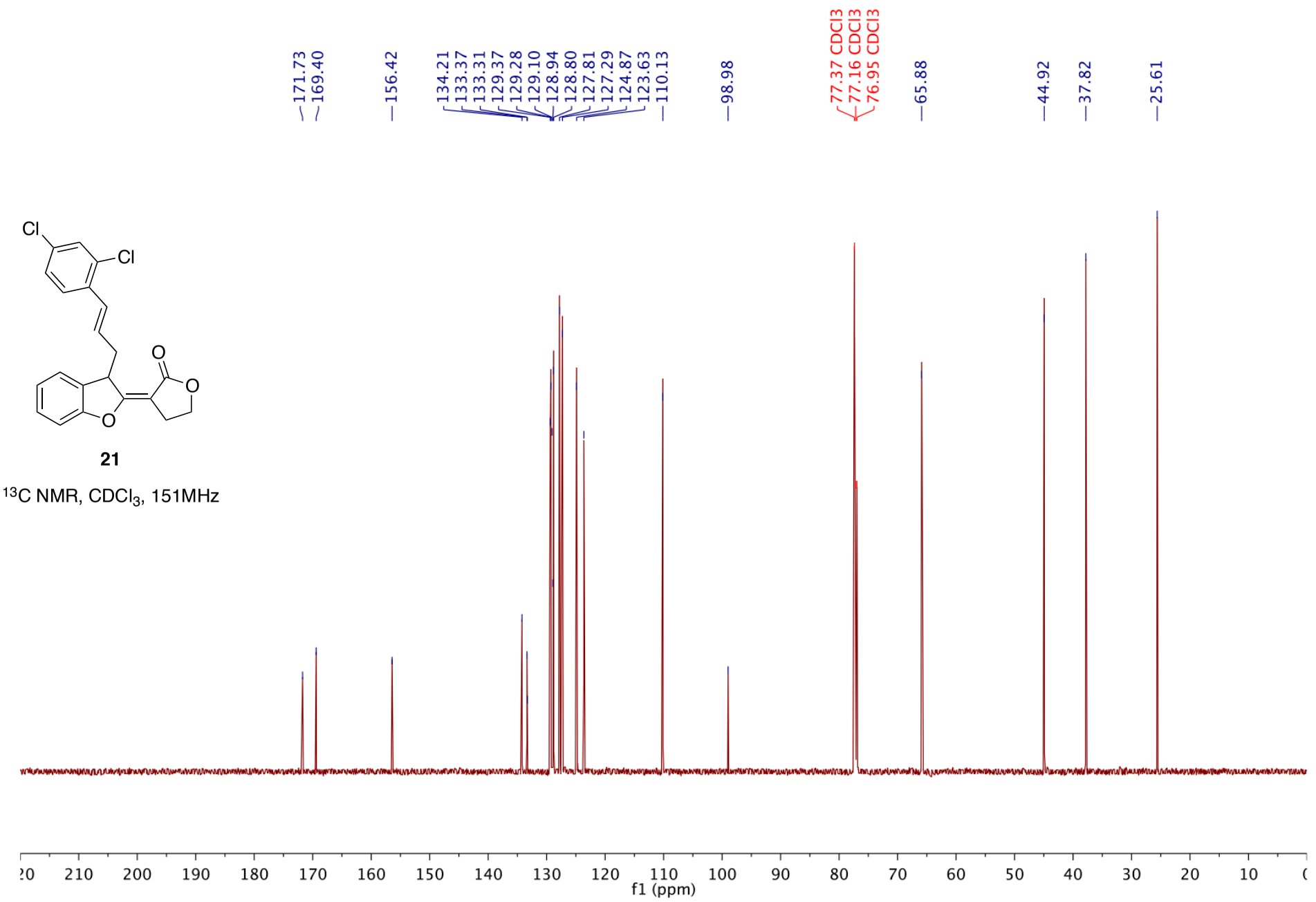
^{1}H NMR, $CDCl_3$, 500MHz


175.98
153.07
152.45
149.70
135.34
132.03
131.56
129.93
128.80
124.90
124.67
124.59
122.86
122.78
120.07
119.02
118.73
115.41
114.45
111.28
84.25
77.41 CDCl3
77.16 CDCl3
76.91 CDCl3
66.39
52.89
39.18
31.49
28.30
28.30
22.03
O
O
O
N
O
O
(R,R)-20
13C NMR, CDCl3, 126MHz
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
f1 (ppm)



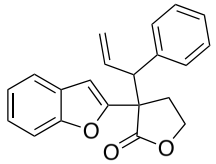
21

^{1}H NMR, $CDCl_3$, 600MHz

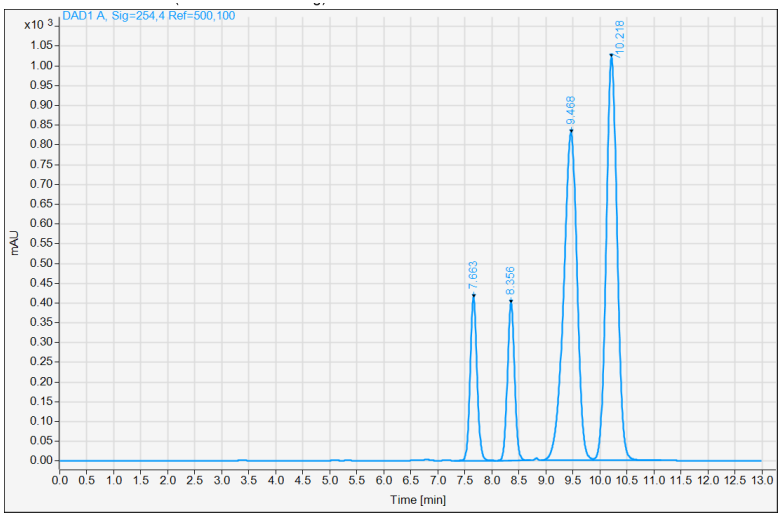


21

^{13}C NMR, $CDCl_3$, 151MHz

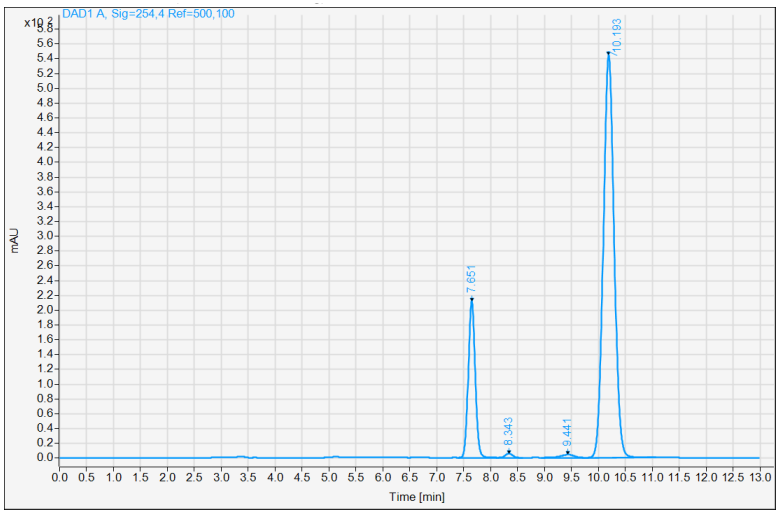


3



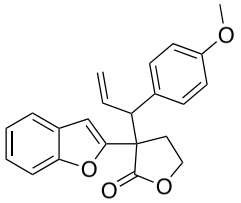
Signal: DAD1 A, Sig=254,4 Ref=500,100

RT [min]	Type	Width [min]	Area	Height	Area%	Peak_Symmetry	Peak_Plate5Sigma
7.663	BB	0.1408	3710.3875	413.2197	10.2655	0.91079	15678.75467
8.356	BB	0.1440	3698.1492	399.5082	10.2316	0.93836	17831.78101
9.468	VV	0.2659	14354.0029	829.5563	39.7129	1.20940	6053.28407
10.218	VB	0.2184	14381.8574	1020.7379	39.7900	0.93067	11466.31779
		Sum	36144.3970				

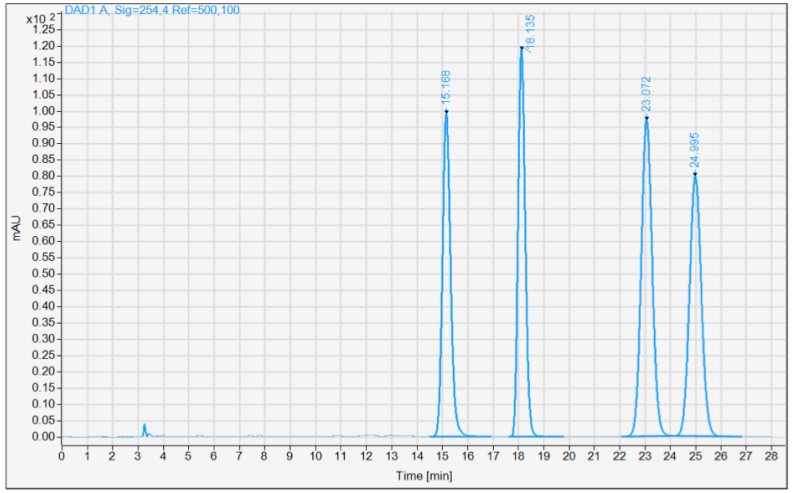


Signal: DAD1 A, Sig=254,4 Ref=500,100

RT [min]	Type	Width [min]	Area	Height	Area%	Peak_Symmetry	Peak_Plate5Sigma
7.651	BB	0.1383	1895.4955	211.9362	19.6977	0.90919	15741.61068
8.343	BB	0.1422	51.5797	5.6663	0.5360	0.95562	18672.43185
9.441	BB	0.2651	71.4393	4.1035	0.7424	1.27197	5801.25874
10.193	BB	0.2169	7604.4067	544.4658	79.0239	0.93869	11615.41095
		Sum	9622.9212				

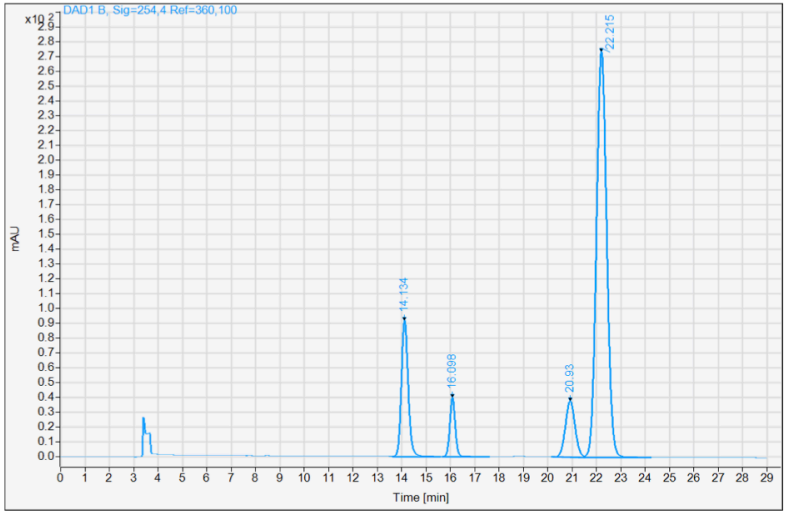


4



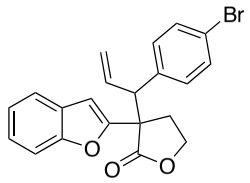
Signal: DAD1 A, Sig=254,4 Ref=500,100

RT [min]	Type	Width [min]	Area	Height	Area%	Peak_Symmetry	Peak_Plate5Sigma
15.168	BB	0.3435	2206.2698	99.2000	21.8302	0.83094	9561.47393
18.135	BB	0.3075	2336.2480	118.7567	23.1163	0.84411	19253.98322
23.072	BB	0.4708	2937.7051	97.1573	29.0675	0.92341	12719.05176
24.995	BB	0.5120	2626.2634	79.7823	25.9859	0.91954	12612.61242
		Sum	10106.4863				

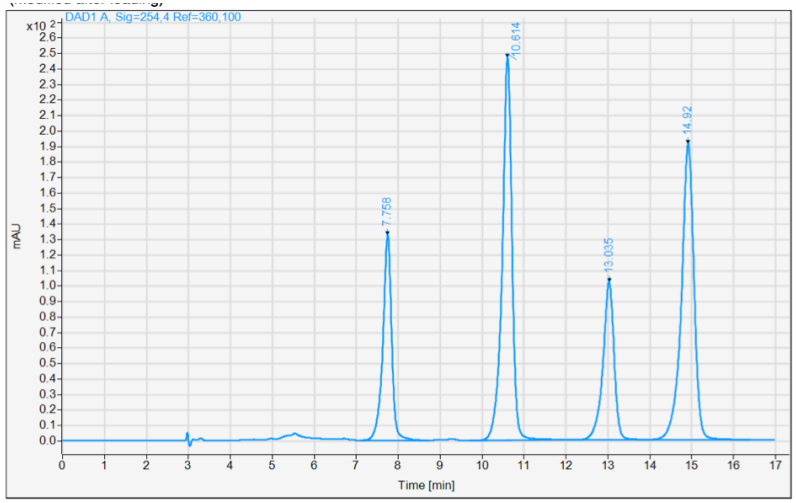


Signal: DAD1 B, Sig=254,4 Ref=360,100

RT [min]	Type	Width [min]	Area	Height	Area%	Peak_Symmetry	Peak_Plate5Sigma
14.134	BB	0.2969	1771.9258	91.9379	15.3977	0.84946	11011.61856
16.098	BB	0.2355	612.0980	39.7854	5.3190	0.92215	23062.43381
20.930	BV	0.4310	1046.5292	37.7980	9.0941	0.95595	12573.01676
22.215	VB	0.4603	8077.2124	273.6856	70.1892	0.91854	12792.90055
		Sum	11507.7654				

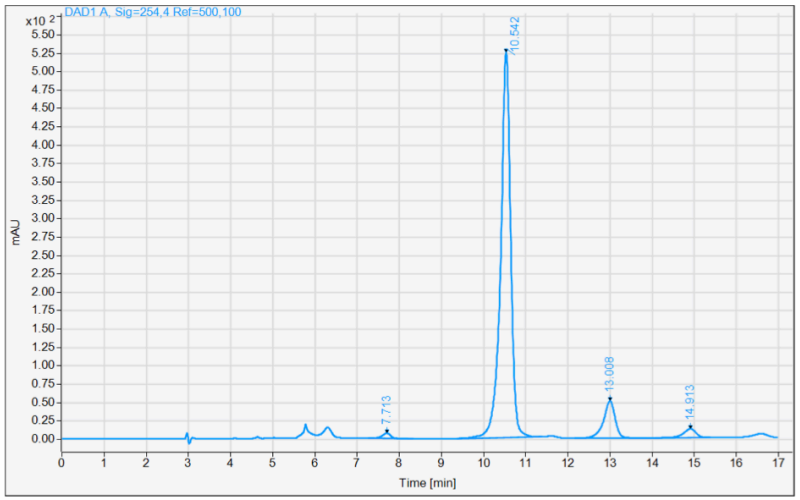


5



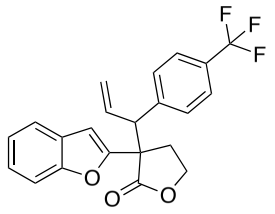
Signal: DAD1 A, Sig=254,4 Ref=360,100

RT [min]	Type	Width [min]	Area	Height	Area%	Peak_Symmetry	Peak_Plate5Sigma
7.758	BB	0.2176	1929.5001	132.7104	16.3485	1.18705	4797.14961
10.614	BB	0.2406	3999.2288	247.3951	33.8852	1.18243	7364.67113
13.035	BB	0.2755	1884.8521	102.0634	15.9702	1.22793	8589.97333
14.920	BB	0.3116	3988.7031	191.0582	33.7960	1.17367	8839.10069
		Sum	11802.2841				

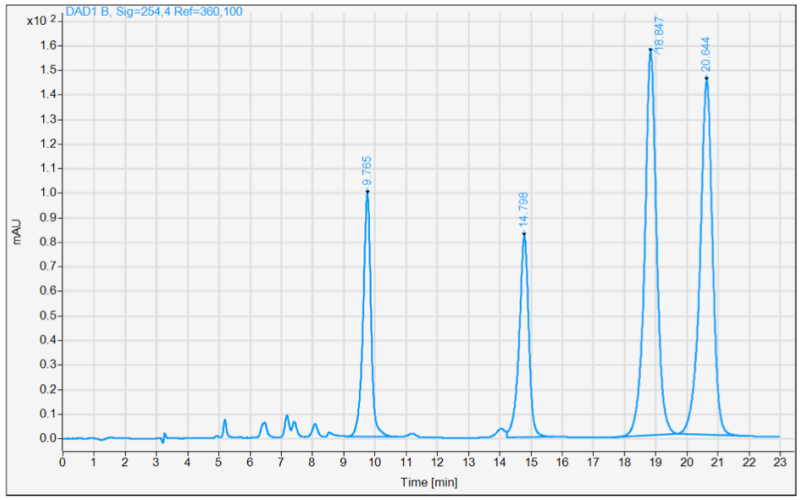


Signal: DAD1 A, Sig=254,4 Ref=500,100

RT [min]	Type	Width [min]	Area	Height	Area%	Peak_Symmetry	Peak_Plate5Sigma
7.713	MM	0.2669	121.1922	7.5676	1.2096	1.07373	3248.70468
10.542	BB	0.2455	8690.6240	523.8643	86.7394	1.20133	6713.06404
13.008	BB	0.2810	953.8932	50.3555	9.5206	1.27324	8086.00835
14.913	BB	0.3131	253.5206	12.1649	2.5303	1.32043	9545.14068
		Sum	10019.2301				

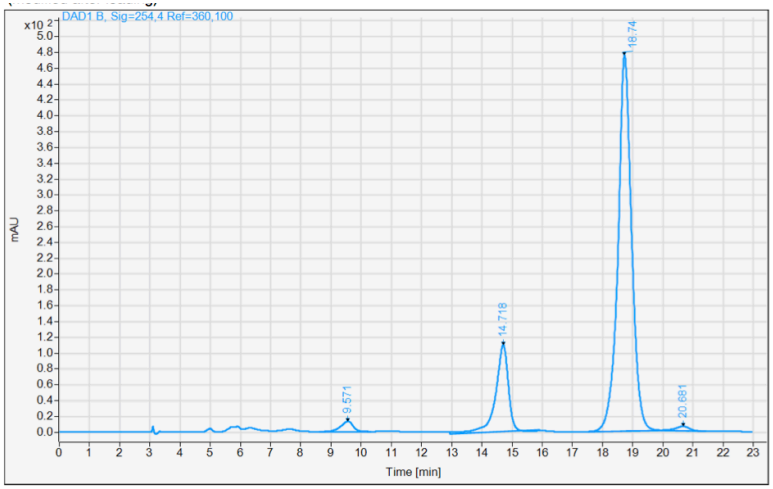


6



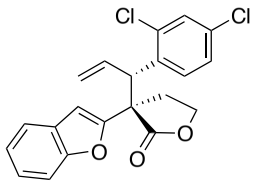
Signal: DAD1 B, Sig=254,4 Ref=360,100

RT [min]	Type	Width [min]	Area	Height	Area%	Peak_Symmetry	Peak_Plate5Sigma
9.765	BB	0.2639	1747.9900	99.0558	14.8979	1.10913	5102.43654
14.798	VB	0.3196	1754.5504	82.0066	14.9538	1.15777	8073.36808
18.847	BB	0.3974	4139.0967	156.0990	35.2770	0.99219	8426.65881
20.644	BB	0.4270	4091.4866	144.2069	34.8712	1.10495	9362.63367
		Sum	11733.1237				

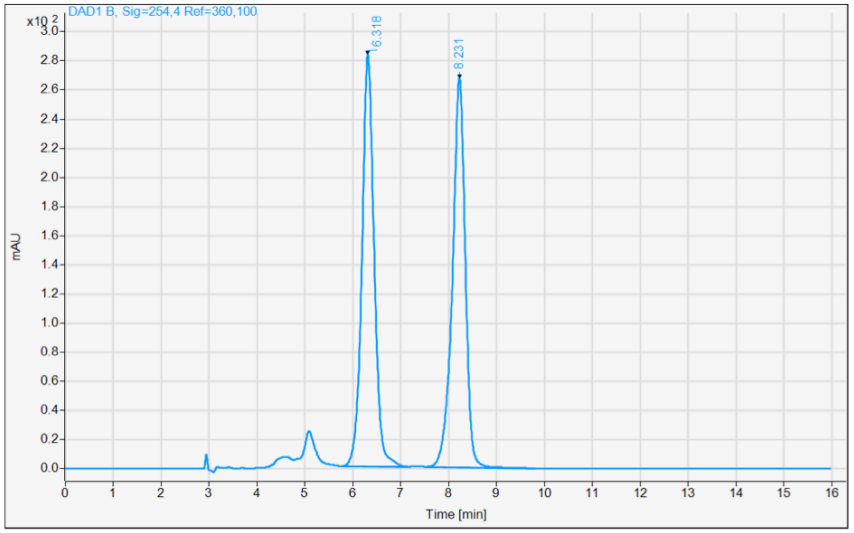


Signal: DAD1 B, Sig=254,4 Ref=360,100

RT [min]	Type	Width [min]	Area	Height	Area%	Peak_Symmetry	Peak_Plate5Sigma
9.571	BB	0.4267	372.4677	12.9813	1.9909	1.36486	2076.84191
14.718	MM	0.4962	3268.8755	109.8012	17.4730	1.51191	3760.17647
18.740	BB	0.4642	14894.5850	474.5736	79.6155	0.92019	6027.80660
20.681	BB	0.4765	172.2272	5.4534	0.9206	1.14213	8277.96608
		Sum	18708.1553				

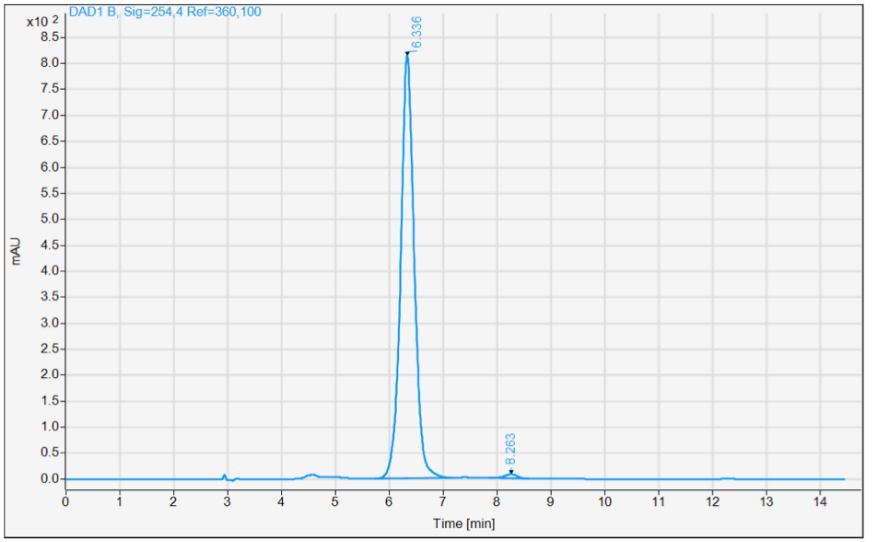


***(R,S)*-7**



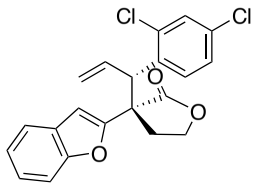
Signal: DAD1 B, Sig=254,4 Ref=360,100

RT [min]	Type	Width [min]	Area	Height	Area%	Peak_Symmetry	Peak_Plate5Sigma
6.318	BB	0.2616	4982.7554	282.7007	50.0121	0.89519	2385.83151
8.231	BB	0.2775	4980.3398	267.1848	49.9879	1.16108	3557.18603
		Sum	9963.0952				

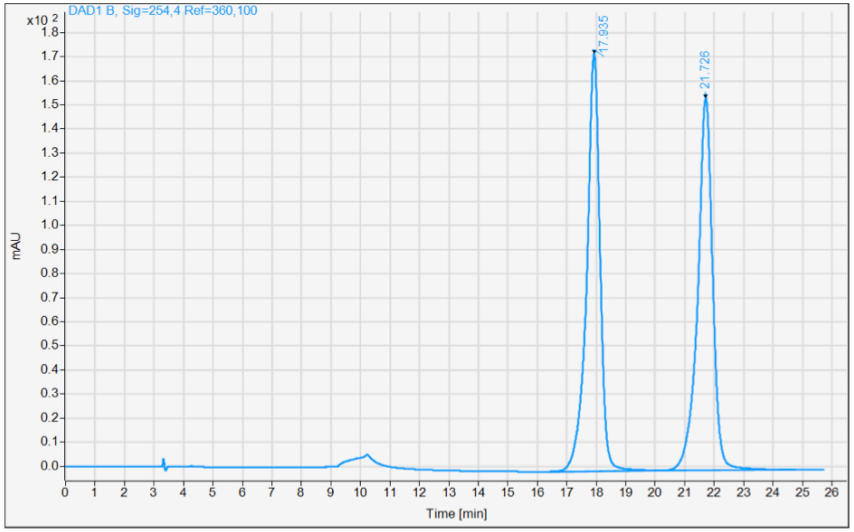


Signal: DAD1 B, Sig=254,4 Ref=360,100

RT [min]	Type	Width [min]	Area	Height	Area%	Peak_Symmetry	Peak_Plate5Sigma
6.336	BB	0.2611	14294.2451	813.1917	99.0297	0.90573	2399.38378
8.263	BB	0.2536	140.0581	8.3524	0.9703	1.14961	4166.16226
		Sum	14434.3033				

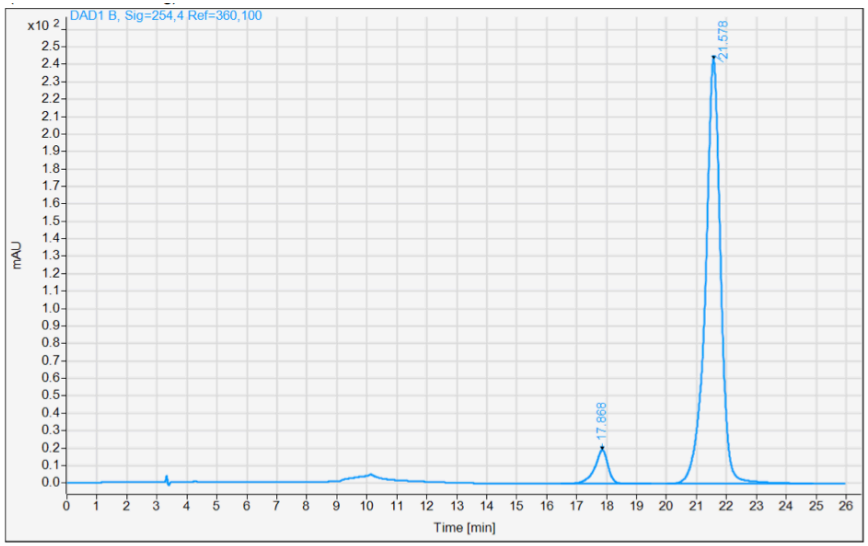


***(S,S)*-7**



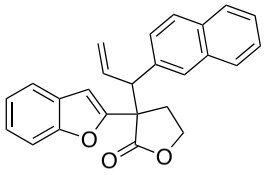
Signal: DAD1 B, Sig=254,4 Ref=360,100

RT [min]	Type	Width [min]	Area	Height	Area%	Peak_Symmetry	Peak_Plate5Sigma
17.935	BB	0.4648	5448.5649	173.3031	49.8998	1.20751	5460.86487
21.726	BB	0.5227	5470.4531	154.6480	50.1002	1.13515	6506.87816
		Sum	10919.0181				



Signal: DAD1 B, Sig=254,4 Ref=360,100

RT [min]	Type	Width [min]	Area	Height	Area%	Peak_Symmetry	Peak_Plate5Sigma
17.868	BB	0.4640	608.3607	19.2890	6.6232	1.32826	5361.13039
21.578	BB	0.5194	8576.9082	243.2573	93.3768	1.09638	6419.19259
		Sum	9185.2689				



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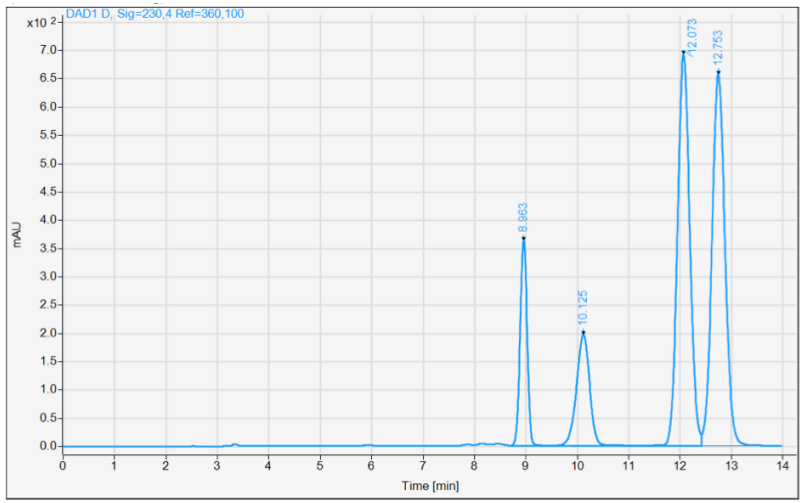
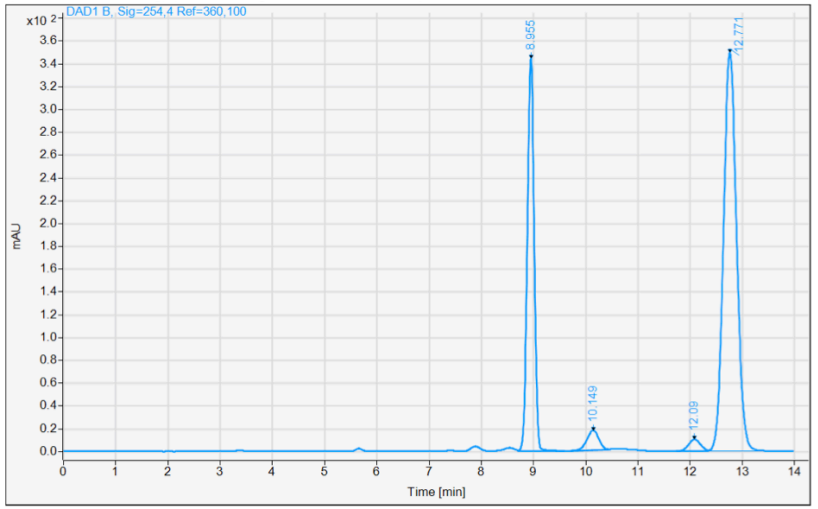


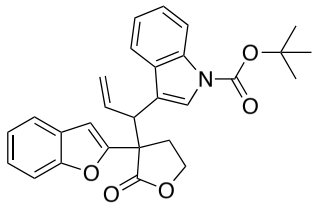
Signal: DAD1 D, Sig=230,4 Ref=360,100

RT [min]	Type	Width [min]	Area	Height	Area%	Peak_Symmetry	Peak_Plate5Sigma
8.963	BB	0.1488	3448.8979	363.1357	11.4205	1.00620	20463.83514
10.125	BB	0.2743	3514.7322	196.8604	11.6384	1.08203	6812.41648
12.073	BV	0.2604	11540.4414	692.4143	38.2142	0.92951	11296.48046
12.753	VB	0.2775	11695.2441	657.7061	38.7269	0.91544	10951.03563
		Sum	30199.3157				



Signal: DAD1 B, Sig=254,4 Ref=360,100

RT [min]	Type	Width [min]	Area	Height	Area%	Peak_Symmetry	Peak_Plate5Sigma
8.955	VB	0.1417	3120.1702	344.3058	32.1970	1.01318	22493.21702
10.149	BB	0.2446	268.0965	17.1320	2.7665	1.12080	9525.00925
12.090	BV	0.2533	165.1967	10.2899	1.7047	0.95479	13136.57137
12.771	VB	0.2728	6137.3989	349.6302	63.3318	0.91145	11639.08128
		Sum	9690.8623				



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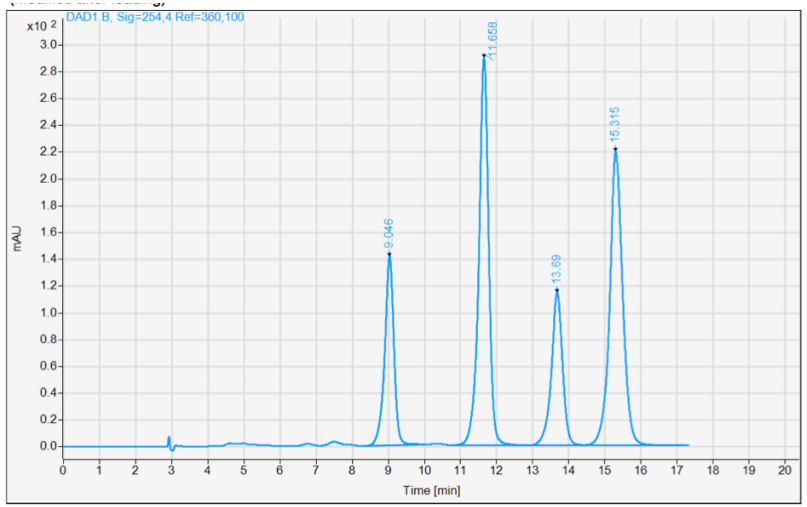
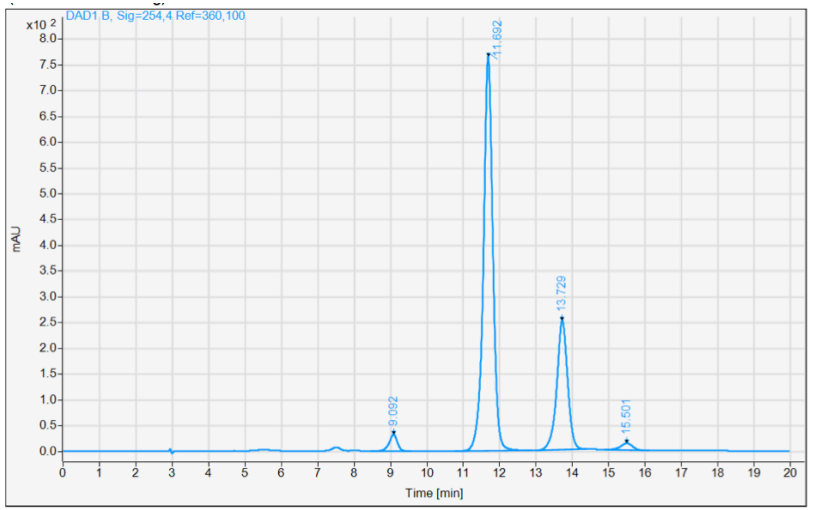


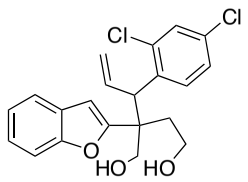
Signal: DAD1 B, Sig=254,4 Ref=360,100

RT [min]	Type	Width [min]	Area	Height	Area%	Peak_Symmetry	Peak_Plate5Sigma
9.046	BB	0.2674	2508.9856	141.1575	15.7365	1.12653	4557.92926
11.658	BB	0.2856	5495.4990	289.3707	34.4682	1.09316	6496.21143
13.690	BB	0.3281	2479.7439	113.8559	15.5531	1.10095	6908.50366
15.315	BB	0.3726	5459.4604	219.1934	34.2421	0.87510	6450.44868
		Sum	15943.6890				



Signal: DAD1 B, Sig=254,4 Ref=360,100

RT [min]	Type	Width [min]	Area	Height	Area%	Peak_Symmetry	Peak_Plate5Sigma
9.092	BB	0.2417	524.1783	32.5894	2.6348	1.16411	5809.52672
11.692	BB	0.2709	13837.8828	765.6717	69.5570	0.97405	7311.80373
13.729	BB	0.3121	5218.0059	251.4063	26.2287	1.01366	7811.69580
15.501	BB	0.3558	314.2298	13.3882	1.5795	1.08598	6429.50817
		Sum	19894.2968				



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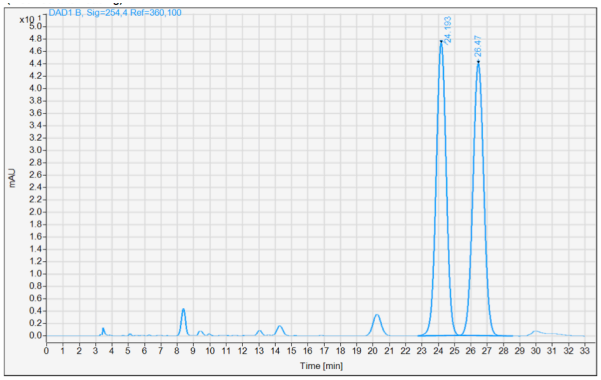
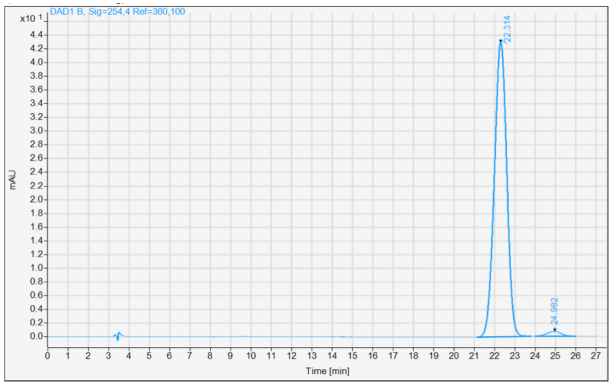
Crystal



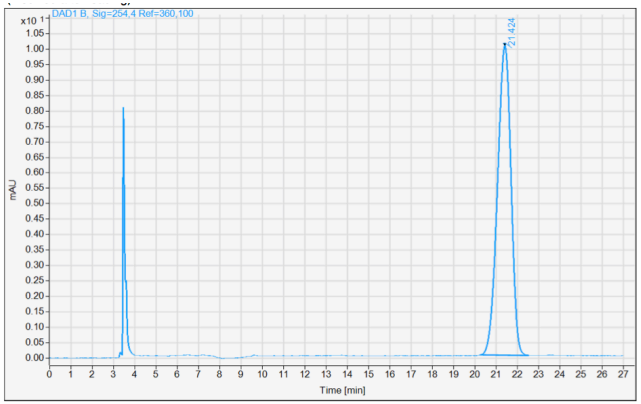
Signal: DAD1 B, Sig=254,4 Ref=360,100

RT [min]	Type	Width [min]	Area	Height	Area%	Peak_Symmetry	Peak_Plate5Sigma
24.193	BB	0.6712	2032.5682	47.3167	49.9207	0.98923	6991.40657
26.470	BB	0.7248	2039.0228	43.9912	50.0793	0.95951	7266.38754
		Sum	4071.5911				



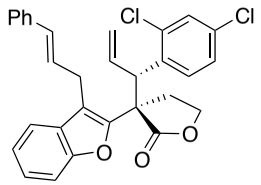
Signal: DAD1 B, Sig=254,4 Ref=360,100

RT [min]	Type	Width [min]	Area	Height	Area%	Peak_Symmetry	Peak_Plate5Sigma
22.314	BB	0.6643	1825.8617	42.9178	98.2160	1.03875	6322.49159
24.982	MM	0.8018	33.1645	0.6893	1.7840	1.26005	5528.04052
		Sum	1859.0262				



Signal: DAD1 B, Sig=254,4 Ref=360,100

RT [min]	Type	Width [min]	Area	Height	Area%	Peak_Symmetry	Peak_Plate5Sigma
21.424	BB	0.6709	443.1680	10.0026	100.0000	1.17032	5335.11550
		Sum	443.1680				



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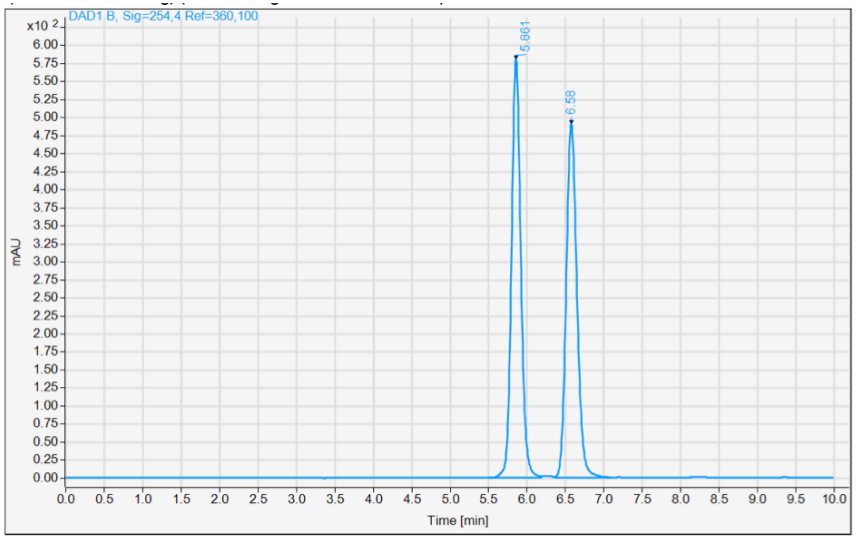
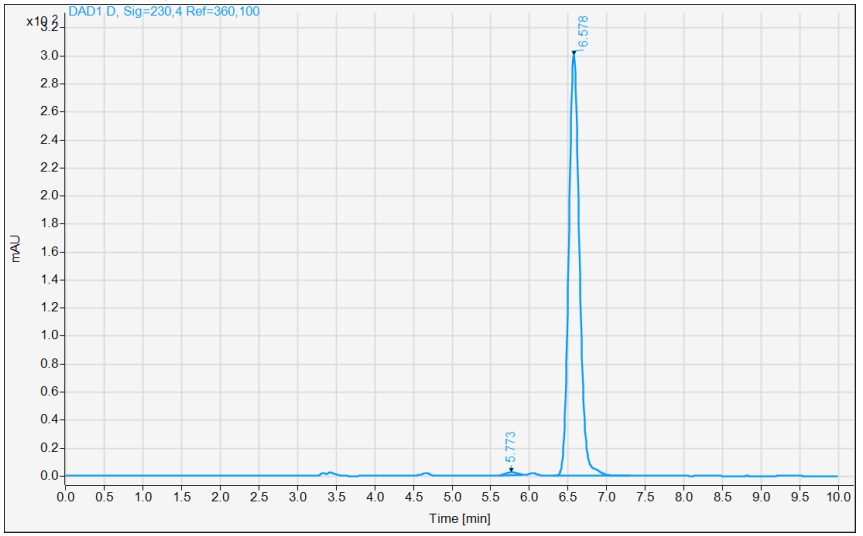


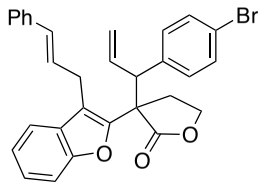


Signal: DAD1 B, Sig=254,4 Ref=360,100

RT [min]	Type	Width [min]	Area	Height	Area%	Peak_Symmetry	Peak_Plate5Sigma
5.861	BV	0.1307	4908.6587	580.4289	50.8417	0.88882	9723.98395
6.580	VB	0.1487	4746.1304	491.1398	49.1583	0.84042	9678.08777
		Sum	9654.7891				

Signal: DAD1 D, Sig=230,4 Ref=360,100

RT [min]	Type	Width [min]	Area	Height	Area%	Peak_Symmetry	Peak_Plate5Sigma
5.773	MM	0.1727	24.3159	2.3462	0.8349	1.10557	9800.46685
6.578	BB	0.1481	2888.0630	300.6688	99.1651	0.83169	10038.41216
		Sum	2912.3789				



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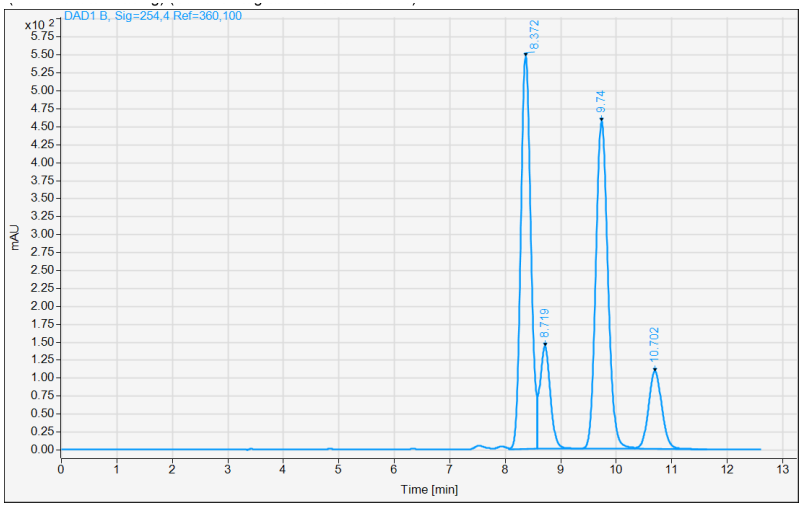
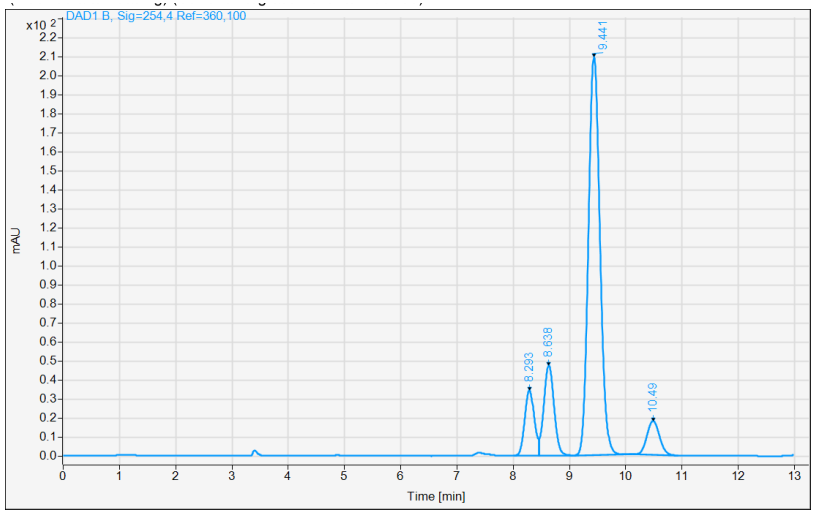


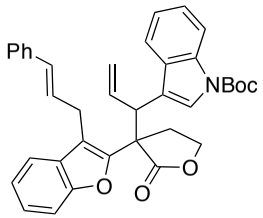
Signal: DAD1 B, Sig=254,4 Ref=360,100

RT [min]	Type	Width [min]	Area	Height	Area%	Peak_Symmetry	Peak_Plate5Sigma
8.372	VV	0.1934	6815.6699	546.9485	39.1899	0.87952	10567.21692
8.719	VB	0.1984	1865.0098	142.8167	10.7238	0.82634	12781.81016
9.740	BV	0.2342	6885.0020	455.8506	39.5886	0.85079	8772.54383
10.702	VB	0.2603	1825.7057	108.5134	10.4978	0.88536	8509.79742
		Sum	17391.3873				



Signal: DAD1 B, Sig=254,4 Ref=360,100

RT [min]	Type	Width [min]	Area	Height	Area%	Peak_Symmetry	Peak_Plate5Sigma
8.293	BV	0.1861	406.6057	34.3454	9.5431	0.93914	13749.95806
8.638	VB	0.1959	600.7176	47.3750	14.0989	0.92094	11086.95502
9.441	BB	0.2198	2975.4897	209.4287	69.8349	0.88191	9408.40206
10.490	BB	0.2440	277.9348	17.8209	6.5231	0.90856	9997.73318
		Sum	4260.7479				



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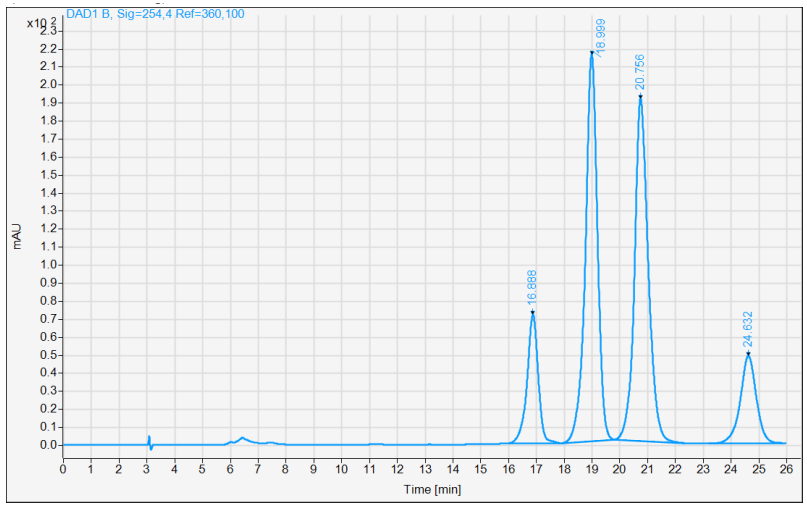
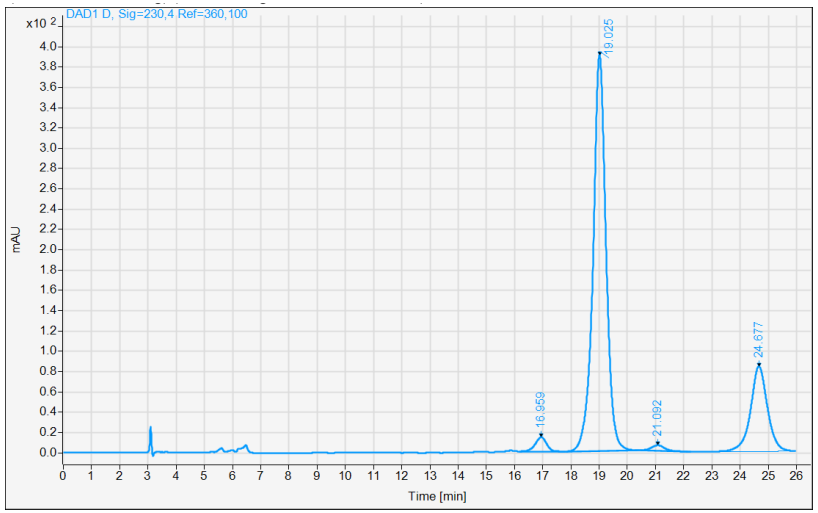


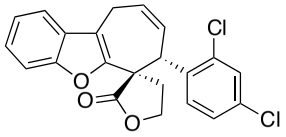
Signal: DAD1 B, Sig=254,4 Ref=360,100

RT [min]	Type	Width [min]	Area	Height	Area%	Peak_Symmetry	Peak_Plate5Sigma
16.888	BB	0.4157	1978.4585	71.2998	11.7132	1.09217	6548.13172
18.999	BB	0.4563	6478.8706	214.5293	38.3574	1.08560	7025.45959
20.756	BB	0.5083	6489.9873	190.0895	38.4233	0.76932	6374.64056
24.632	BB	0.6015	1943.4614	48.4953	11.5061	1.01341	6682.02258
		Sum	16890.7778				



Signal: DAD1 D, Sig=230,4 Ref=360,100

RT [min]	Type	Width [min]	Area	Height	Area%	Peak_Symmetry	Peak_Plate5Sigma
16.959	BB	0.4180	394.4431	14.2021	2.3832	1.11461	7237.61336
19.025	BB	0.4770	12462.8350	389.8425	75.3009	0.97691	6013.48621
21.092	BB	0.4880	192.2878	5.5806	1.1618	0.85236	8264.89857
24.677	BB	0.6214	3501.1370	83.8002	21.1540	0.96575	5801.41596
		Sum	16550.7029				



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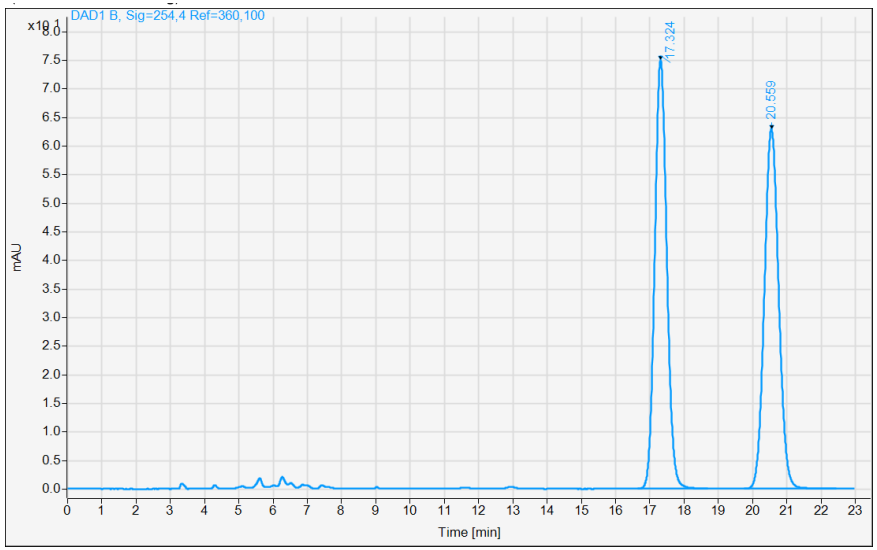
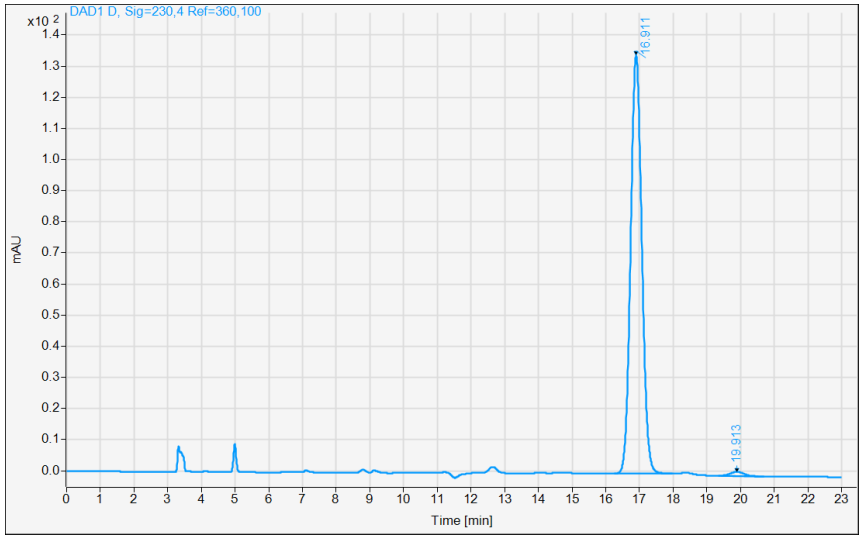


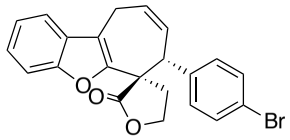


Signal: DAD1 B, Sig=254,4 Ref=360,100

RT [min]	Type	Width [min]	Area	Height	Area%	Peak_Symmetry	Peak_Plate5Sigma
17.324	BB	0.3810	1833.1206	75.0473	50.0715	0.89281	10937.24755
20.559	BB	0.4507	1827.8831	62.9684	49.9285	0.91310	11040.07647
		Sum	3661.0037				

Signal: DAD1 D, Sig=230,4 Ref=360,100

RT [min]	Type	Width [min]	Area	Height	Area%	Peak_Symmetry	Peak_Plate5Sigma
16.911	BB	0.3581	3090.9683	134.5217	98.6413	0.91077	12061.62571
19.913	MM	0.5031	42.5745	1.4104	1.3587	1.03587	9286.71981
		Sum	3133.5427				



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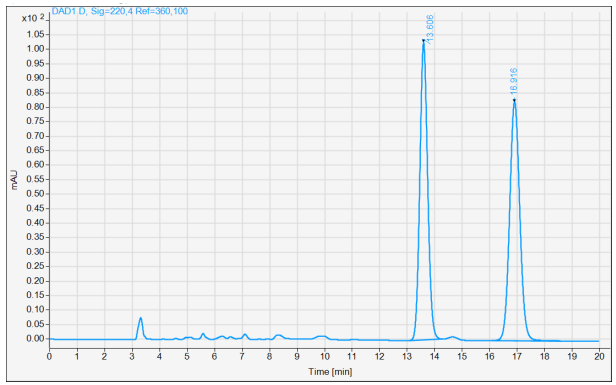
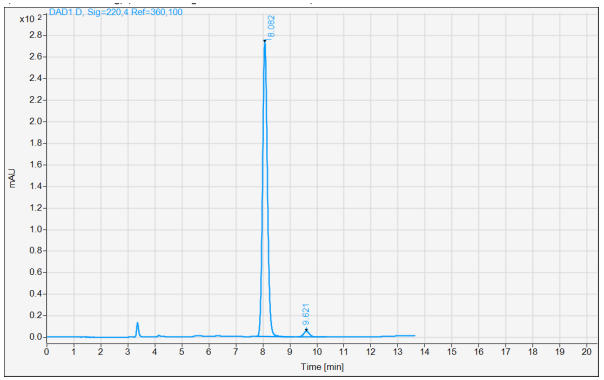


Signal: DAD1 D, Sig=220,4 Ref=360,100

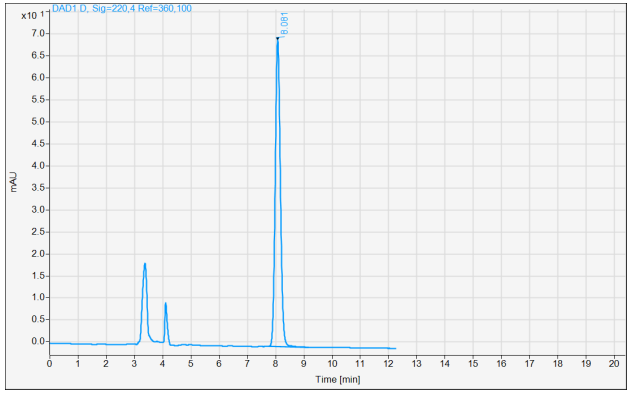
RT [min]	Type	Width [min]	Area	Height	Area%	Peak_Symmetry	Peak_Plate5Sigma
13.606	BB	0.3133	2073.9260	102.8468	49.5052	0.89141	9912.38786
16.916	BB	0.3989	2115.3875	82.5802	50.4948	0.91893	9448.43587
		Sum	4189.3135				

Crystal



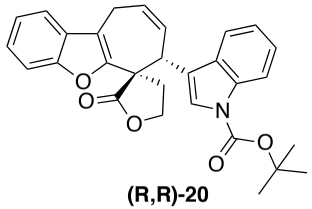
Signal: DAD1 D, Sig=220,4 Ref=360,100

RT [min]	Type	Width [min]	Area	Height	Area%	Peak_Symmetry	Peak_Plate5Sigma
8.082	BB	0.1929	3393.1946	273.2119	97.6935	0.85794	8977.26641
9.621	BB	0.2394	80.1115	5.2084	2.3065	0.90006	8338.46390
		Sum	3473.3061				

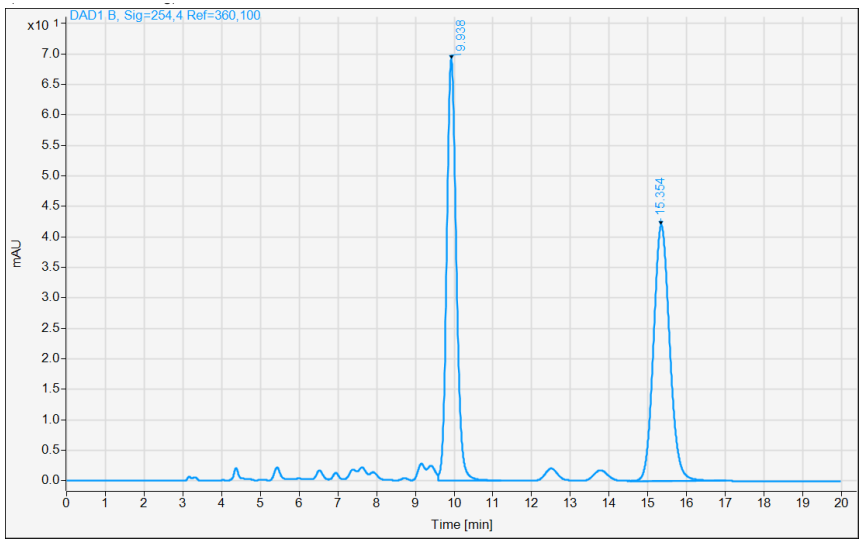


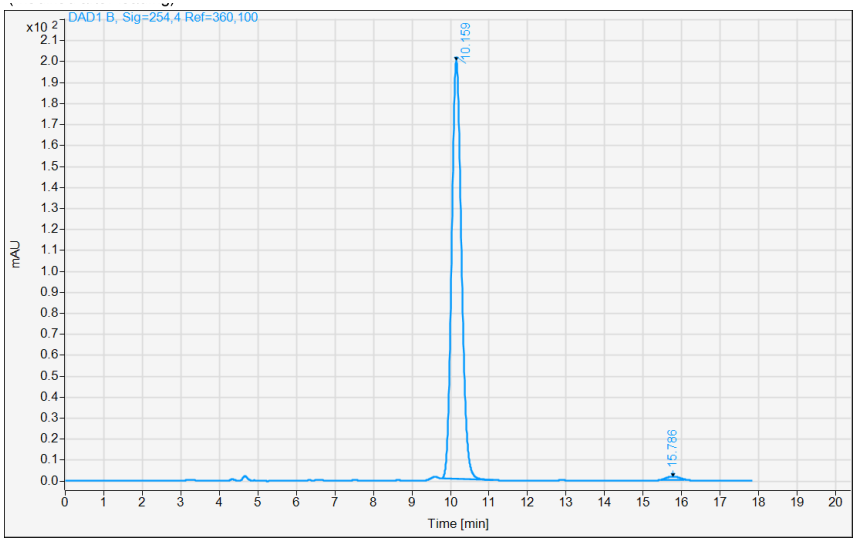
Signal: DAD1 D, Sig=220,4 Ref=360,100

RT [min]	Type	Width [min]	Area	Height	Area%	Peak_Symmetry	Peak_Plate5Sigma
8.081	BB	0.1962	885.1520	69.6876	100.0000	0.87651	8960.17542
		Sum	885.1520				



(R,R)-20



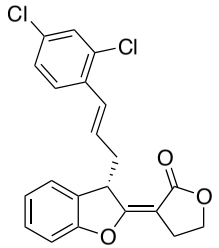


Signal: DAD1 B, Sig=254,4 Ref=360,100

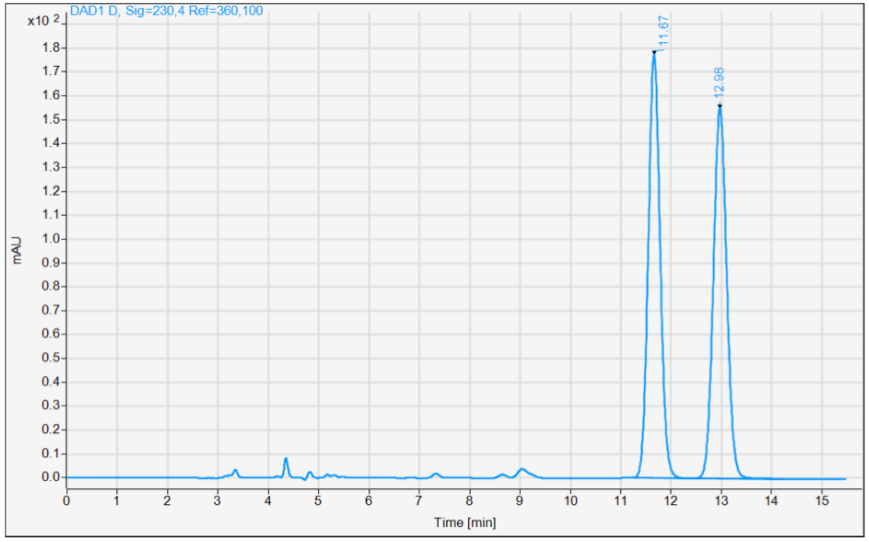
RT [min]	Type	Width [min]	Area	Height	Area%	Peak_Symmetry	Peak_Plate5Sigma
9.938	VB	0.2667	1188.9773	69.1316	49.5581	0.86241	7008.94265
15.354	BB	0.4445	1210.1824	41.9630	50.4419	0.87234	6055.77100
		Sum	2399.1597				

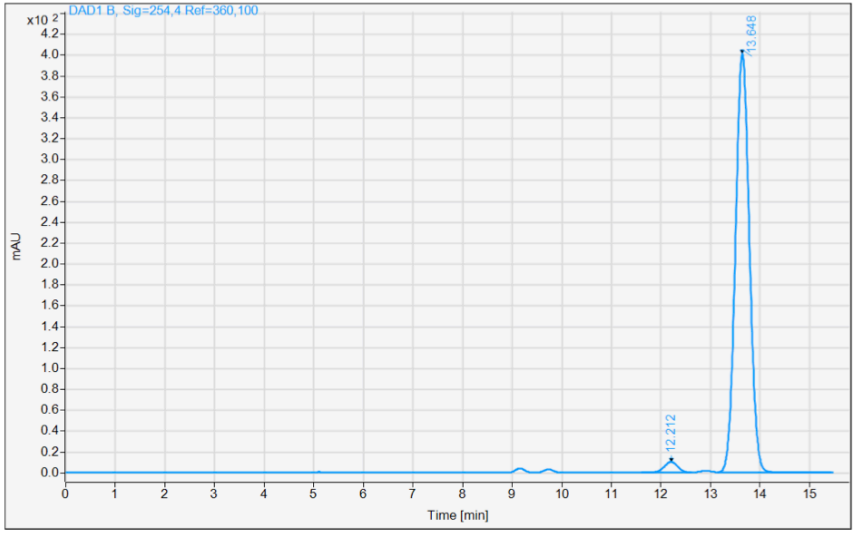
Signal: DAD1 B, Sig=254,4 Ref=360,100

RT [min]	Type	Width [min]	Area	Height	Area%	Peak_Symmetry	Peak_Plate5Sigma
10.159	BB	0.2760	3519.9753	199.3243	99.0443	0.84545	7087.40725
15.786	MM	0.3661	33.9648	1.5461	0.9557	0.96433	19203.24899
		Sum	3553.9401				



***(S)*-21**



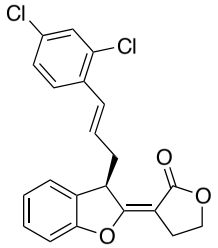


Signal: DAD1 D, Sig=230,4 Ref=360,100

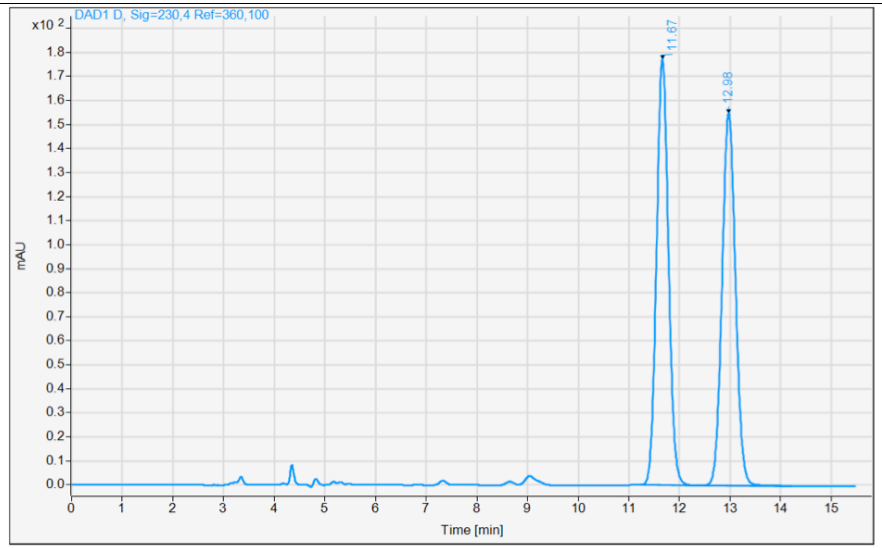
RT [min]	Type	Width [min]	Area	Height	Area%	Peak_Symmetry	Peak_Plate5Sigma
11.670	BB	0.2555	2911.2471	177.3920	50.4174	0.92228	11115.70084
12.980	BB	0.2874	2863.0466	155.0471	49.5826	0.93524	11194.42529
		Sum	5774.2937				

Signal: DAD1 B, Sig=254,4 Ref=360,100

RT [min]	Type	Width [min]	Area	Height	Area%	Peak_Symmetry	Peak_Plate5Sigma
12.212	BB	0.3003	197.9469	10.2956	2.4537	1.04859	9008.07530
13.648	VB	0.3047	7869.1978	401.3771	97.5463	0.93785	10795.45884
		Sum	8067.1446				

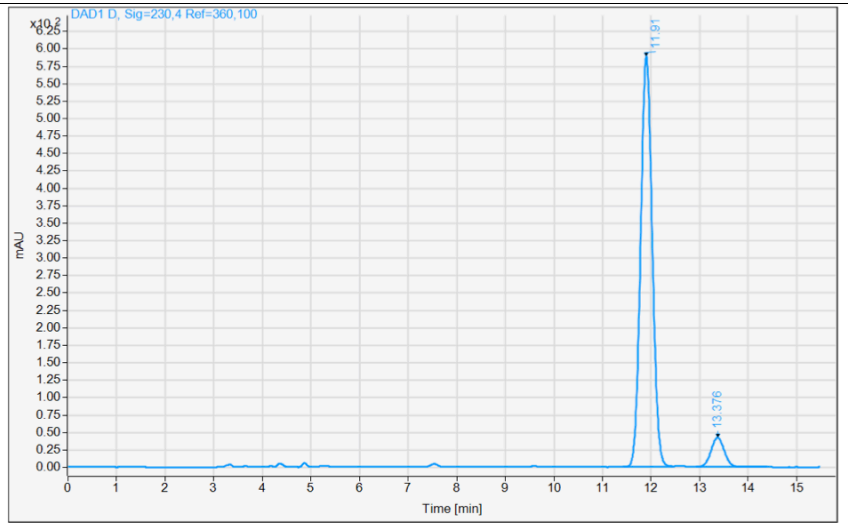


***(R)*-21**



Signal: DAD1 D, Sig=230,4 Ref=360,100

RT [min]	Type	Width [min]	Area	Height	Area%	Peak_Symmetry	Peak_Plate5Sigma
11.670	BB	0.2555	2911.2471	177.3920	50.4174	0.92228	11115.70084
12.980	BB	0.2874	2863.0466	155.0471	49.5826	0.93524	11194.42529
		Sum	5774.2937				

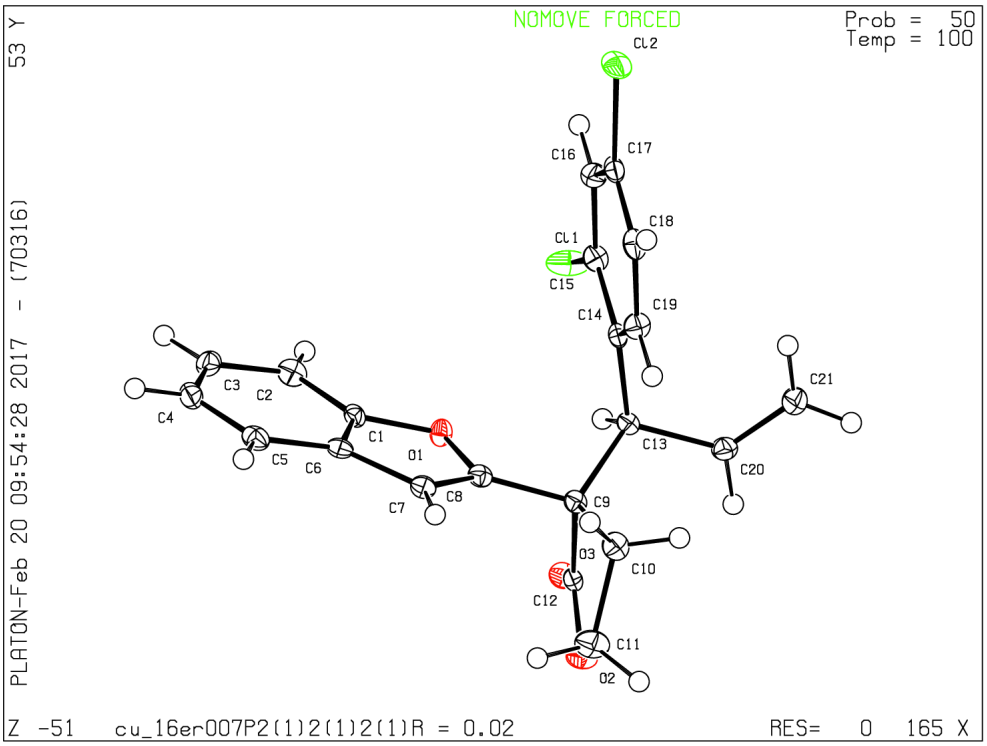


Signal: DAD1 D, Sig=230,4 Ref=360,100

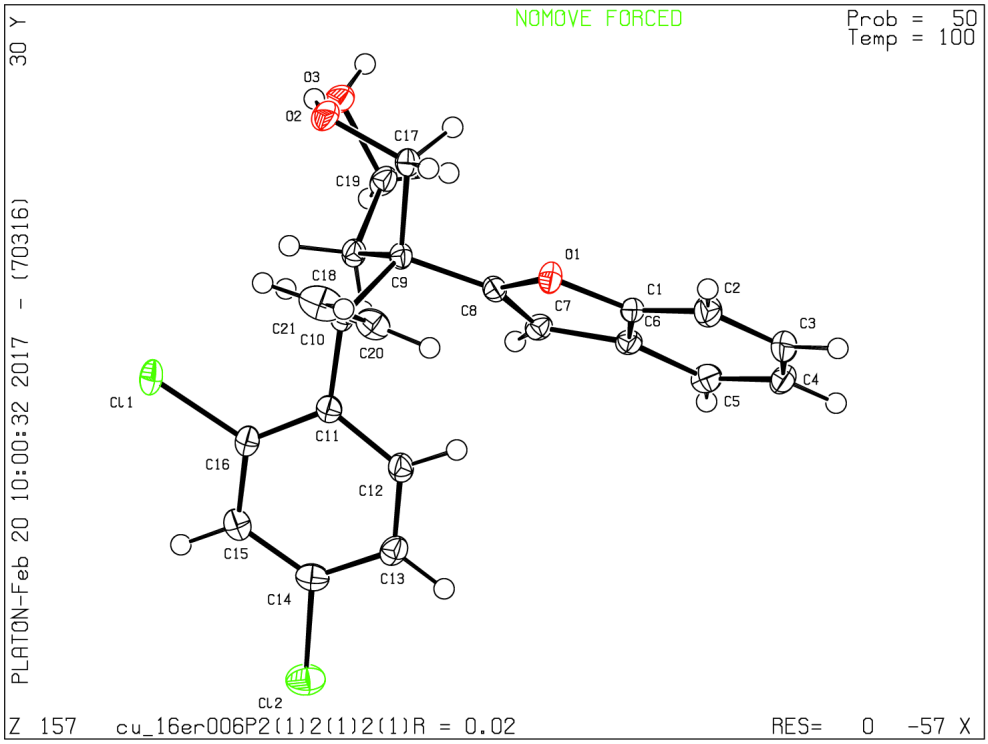
RT [min]	Type	Width [min]	Area	Height	Area%	Peak_Symmetry	Peak_Plate5Sigma
11.910	BB	0.2598	9775.9805	588.5177	91.4865	0.93054	11411.36233
13.376	BB	0.2945	796.2402	42.1381	7.4515	0.93604	11152.80510
18.259	BB	0.4125	113.4873	4.1310	1.0620	0.95141	9989.27295
		Sum	10685.7080				

VII ORTEP of compounds *(S,S)*-7, 22, *(R,R)*-19, and *(S)*-21

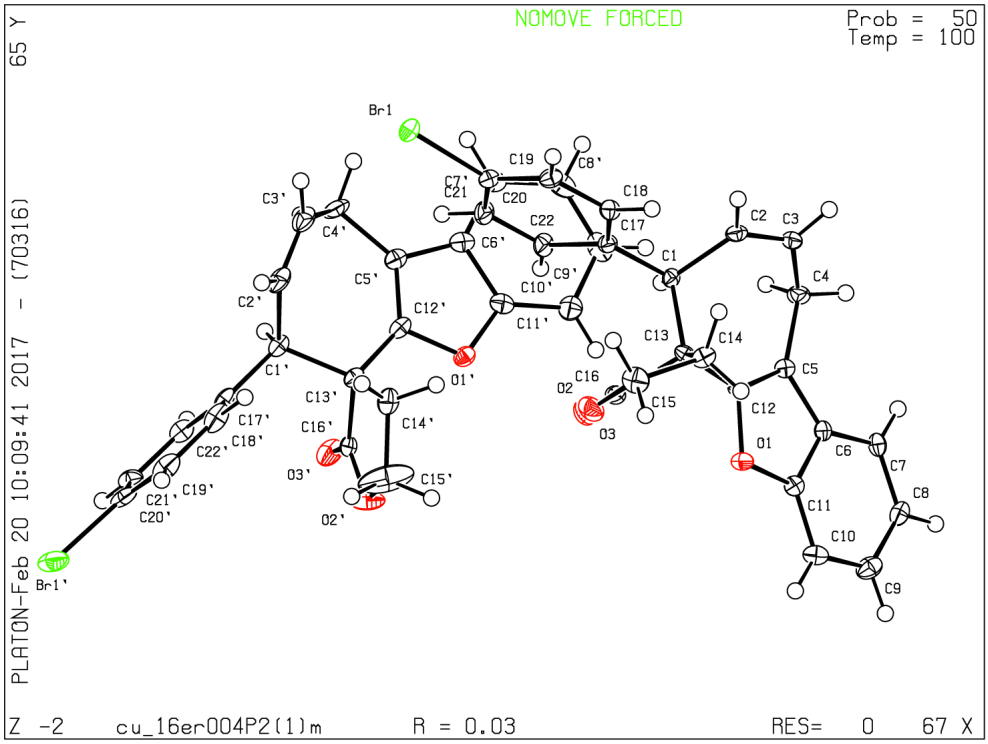
ORTEP for compound ***(S,S)*-7** (CCDC 1533672)



ORTEP for compound **22** (CCDC 1533735)



ORTEP for compound ***(R,R)*-19** (CCDC 1533736)



ORTEP for compound ***(S)*-21** (CCDC 1533751)