Electronic Supplementary Material (ESI) for Chemical Communications.

Supporting Information

Asymmetric Total Synthesis of (+)-Dihydroitomanallene B and Formal Synthesis of (–)-Kumausallene

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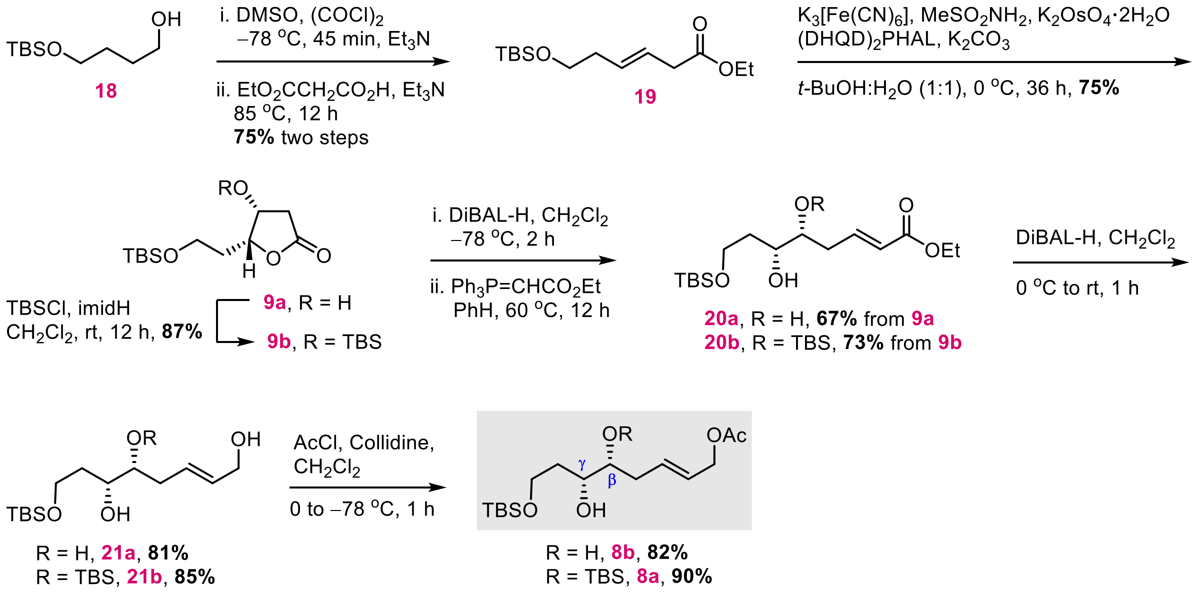
Experimental Data

General Information

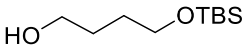
IR spectra were obtained on a Bruker Tensor 27 FT-IR spectrometer by evaporating compounds dissolved in $CHCl_3$ on CsCl pellets. ^{1}H NMR and ^{13}C NMR were recorded with the Bruker Avance III HD and Bruker Avance III 400 spectrometers operating at 500 or 400 and 125 or 100 MHz for proton and carbon nuclei, respectively. The chemical shifts are based on the $CDCl_3$ peaks at $\delta = 7.26$ ppm for proton NMR and $\delta = 77.00$ ppm (t) for carbon NMR. HRMS (ESI-TOF) spectra were recorded on Bruker Maxis Impact Sr no.282001.0008 spectrometer using positive electrospray ionization by the TOF method. Solvents were dried by using standard procedures. Tetrahydrofuran (THF) solvent was dried over sodium metal and CH_2Cl_2 by refluxing with CaH_2. Thin-layer chromatography was performed on EM 250 Kieselgel 60 F254 silica gel plates. The spots were visualized by staining with $KMnO_4$ or by using a UV lamp. For all reactions requiring heating, an oil bath was used.

Synthesis of β,γ-oxygenated allyl acetates 8a and 8b: The Sharpless asymmetric dihydroxylation[1] of (*E*)-β,γ-unsaturated ester **19** (prepared from **18**[2]) with $(DHQD)_2$PHAL provided the γ-lactone **9a**,[1c] which upon β-OH TBS protection delivered **9b** (Scheme S1). The DIBAL-H reduction of **9a** and **9b** to the lactols and subsequent Wittig olefination provided the esters **20a** and **20b**, respectively. These were next reduced to allyl alcohols (**21a** and **21b**) and then chemoselective acylation of primary OH furnished the β,γ-oxygenated allyl acetates **8b** and **8a**, respectively.



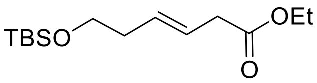
Scheme S1 Synthesis of β,γ-oxygenated allyl acetates **8a** and **8b** for Tsuji-Trost cyclization.

4-(*tert*-Butyldimethylsilyloxy)butan-1-ol (18):[2]



To a solution of 1,4-butanediol (4.0 g, 44.4 mmol) in THF (100 mL) at 0 °C was added NaH (1.78 g, 60% dispersion in mineral oil, 44.4 mmol, 1.0 equiv). The reaction mixture was stirred at 0 °C for 30 min, then warmed to room temperature and stirred for 2 h. *tert*-Butylchlorodimethylsilane (6.7 g, 44.4 mmol, 1.0equiv) was then added and the solution was stirred at room temperature for 14 h. The reaction mixture was poured into water (50 mL) and extracted with Et_2O (3 × 50 mL). The combined organic phases were dried (Na_2SO_4) and the solvent was removed by rotary evaporation. The resulting residue was purified by silica gel flash chromatography using petroleum ether/EtOAc (7:3) as eluent to give alcohol **18** (8.44 g, 93%) as colorless oil. IR ($CHCl_3$): ν_{max} = 3344, 2929, 2859, 1471, 1389, 1255, 1099, 1054, 940, 878, 838, 775, 709, 665 cm^{-1}. ^1H NMR (500 MHz, $CDCl_3$): δ = 3.66–3.61 (m, 4H), 2.63 (brs, 1H), 1.66–1.60 (m, 4H), 0.88 (s, 9H), 0.05 (s, 6H) ppm. $^{13}C\{^1H\}$ NMR (125 MHz, $CDCl_3$):δ = 63.3, 62.7, 30.1, 29.8, 25.9, 18.3, –5.5 ppm. HRMS (ESI-TOF) *m*/*z*: $[M + H]^+$ Calcd for $C_{10}H_{25}O_2Si$ 205.1619; Found 205.1626.

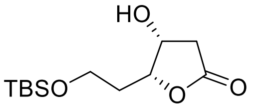
Ethyl (*E*)-6-(*tert*-butyldimethylsilyloxy)hex-3-enoate (19):



To a solution of DMSO (4.2 mL, 58.7 mmol, 3.0 equiv) in CH_2Cl_2 (100 mL) at −78 °C was added oxalyl chloride (2.5 mL, 29.35 mmol, 1.5 equiv). The resulting solution was stirred for 15 min and then the solution of alcohol **18** (4.0 g, 19.57 mmol) in CH_2Cl_2 (10 mL) was added and stirring continued for 45 min. It was then quenched with Et_3N (11 mL, 78.28 mmol, 4.0 equiv), stirred for 30 min and saturated aq. $NaHCO_3$ (50 mL) was added. The solution was extracted with CH_2Cl_2 (3 × 40 mL) and the combined organic layers were washed with water, brine, dried (Na_2SO_4) and concentrated. The crude aldehyde (4.0 g) was used without purification for next step.

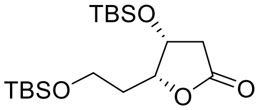
A mixture of aldehyde (4.0 g), Et_3N (2.7 mL, 19.57 mmol, 1.0 equiv) and monoethyl malonate (2.58 g, 19.57 mmol, 1.0 equiv) was heated at 85 °C under nitrogen atmosphere. After stirring for 12 h, the reaction mixture was cooled to room temperature and poured at 0 °C into aq. H_2SO_4 solution (20%, 100 mL). The organic phase was separated and the aqueous phase was extracted with EtOAc (3 × 100 mL). The combined organic layers were washed with water, brine, dried (Na_2SO_4) and concentrated under vacuum. Silica gel column chromatography of the crude product using petroleum ether/EtOAc (19:1) as eluent gave β,γ-unsaturated ester **19** (4.0 g, 75%) as colorless oil. IR ($CHCl_3$): ν_{max} = 2930, 2858, 1738, 1472, 1256, 1160, 1098, 1031, 970, 836, 776 cm^{-1}. ^1H NMR (400 MHz, $CDCl_3$): δ = 5.61–5.53 (m, 2H), 4.12 (q, *J* = 7.2 Hz, 2H), 3.62 (t, *J* = 6.8 Hz, 2H), 3.01 (d, *J* = 5.2 Hz, 2H), 2.24 (dd, *J* = 12.0, 6.0 Hz, 2H), 1.24 (t, *J* = 7.2 Hz, 3H), 0.87 (s, 9H), 0.03 (s, 6H) ppm. $^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$): δ = 172.0, 130.9, 123.7, 62.8, 60.5, 38.2, 36.1, 25.9, 18.3, 14.1, –5.3 ppm. HRMS (ESI-TOF) *m*/*z*: $[M + Na]^+$ Calcd for $C_{14}H_{28}O_3SiNa$ 295.1700; Found 295.1686.

(4*R*,5*R*)-5-(2-*tert*-Butyldimethylsilyloxyethyl)-4-hydroxydihydrofuran-2(3*H*)-one (9a):



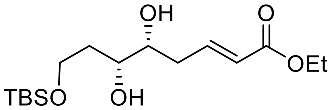
To a mixture of $K_3Fe(CN)_6$ (11.42 g, 35.23 mmol, 3.0 equiv), K_2CO_3 (4.87 g, 35.23 mmol, 3.0 equiv) and $(DHQD)_2PHAL$ (110 mg, 0.141 mmol, 1.2 mol%) in *t*–BuOH/H_2O (1:1, 40 mL) cooled at 0 °C was added $K_2OsO_4{\cdot}2H_2O$ (25.9 mg, 0.07 mmol, 0.6 mol%) followed by $MeSO_2NH_2$ (1.12 g 11.74 mmol, 1.0 equiv). After stirring for 5 min at 0 °C, the olefin **19** (3.2 g, 11.74 mmol) was added in one portion. The reaction mixture was stirred at 0 °C for 36 h and then quenched with solid Na_2SO_3 (0.6 g). The stirring was continued for an additional 45 min and then the solution was extracted with EtOAc (5 × 30 mL). The combined organic layers were washed with brine, dried (Na_2SO_4) and concentrated. Silica gel column chromatography of the crude product using petroleum ether/EtOAc (7:3) as eluent gave the lactone **9a** (2.29 g, 75%) as colorless oil. $[\alpha]_D^{25}$ +81.0 (*c* 1.0, $CHCl_3$). IR ($CHCl_3$): ν_{max} = 3433, 2955, 1767, 1475, 1359, 1257, 1168, 1087, 1017, 958, 837, 778, 692 cm^{-1}. ^{1}H NMR (400 MHz, $CDCl_3$): δ = 4.45 (d, *J* = 5.0 Hz, 2H), 3.89–3.85 (m, 1H), 3.67 (td, *J* = 11.0, 2.2 Hz, 1H), 2.77 (dd, *J* = 18.0, 5.3 Hz, 1H), 2.56 (d, *J* = 18.0 Hz, 1H), 2.25–2.09 (m, 2H), 0.90 (s, 9H), 0.10 (s, 3H), 0.10 (s, 3H) ppm. ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$): δ = 175.5, 84.0, 68.5, 59.4, 37.8, 30.7, 25.7, 18.1, –5.7, –5.72 ppm. HRMS (ESI-TOF) *m*/*z*: $[M + Na]^+$ Calcd for $C_{12}H_{24}O_4SiNa$ 283.1336; Found 283.1341.

4-(*tert*-Butyldimethylsilyloxy)-5-(2-*tert*-butyldimethylsilyloxyethyl)dihydrofuran-2(3*H*)-one (9b):



To a solution of alcohol **9a** (6.0 g, 2.3 mmol) in dry CH_2Cl_2 (60 mL) under argon was added imidazole (2.35 g, 3.45 mmol, 1.5 equiv) at 0 °C and the reaction mixture stirred for 30 min. *tert*-Butylchlorodimethylsilane (5.21 g, 3.45 mmol, 1.5 equiv) was then added and stirring continued for another 12 h at room temperature. The reaction mixture was diluted with CH_2Cl_2 (20 mL), H_2O (50 mL) and the organic layer separated. The aqueous layer was extracted with CH_2Cl_2 (2 × 30 mL) and the combined organic phases were washed with water, brine, dried (Na_2SO_4) and concentrated. The residue was purified by silica gel column chromatography using petroleum ether/EtOAc (9:1) as eluent to give **9b** (7.5 g, 87%) as colorless oil. $[\alpha]_D^{25}$ +35.6 (*c* 1.0, $CHCl_3$). IR ($CHCl_3$): ν_{max} = 2954, 2930, 2888, 2858, 1777, 1472, 1463, 1407, 1389, 1362, 1293, 1257, 1206, 1162, 1094, 1019, 1007, 957, 939, 912, 836, 809, 777, 735, 671, 664, 648 cm^{-1}. ^{1}H NMR (400 MHz, $CDCl_3$): δ = 4.62–4.58 (m, 1H), 4.42 (t, *J* = 4.0 Hz, 1H), 3.77 (dd, *J* = 7.2, 4.4 Hz, 2H), 2.74 (dd, *J* = 17.2, 5.2 Hz, 1H), 2.43 (d, *J* = 17.2 Hz, 1H), 2.04–1.96 (m, 1H), 1.83–1.75 (m, 1H), 0.89 (s, 8H), 0.88 (s, 9H), 0.05 (s, 12H) ppm. ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$): δ = 175.5, 81.7, 69.9, 59.2, 39.9, 32.4, 25.9, 25.6, 18.3, 18.0, –4.7, –5.4 ppm. HRMS (ESI-TOF) *m*/*z*: $[M + Na]^+$ Calcd for $C_{18}H_{38}O_4Si_2Na$ 397.2201; Found 397.2202.

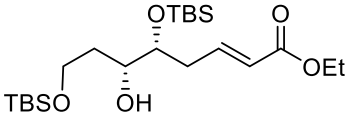
Ethyl (5*R*,6*R*,*E*)-8-((*tert*-butyldimethylsilyl)oxy)-5,6-dihydroxyoct-2-enoate (20a):



To a cooled solution of lactone **9a** (2.0 g, 7.68 mmol) in dry CH_2Cl_2 (40 mL) under argon atmosphere was added DIBAL-H (11 mL, 15.4 mmol, 1.4 M solution in toluene, 2.0 equiv) dropwise over a period of 15 min at –78 °C. The reaction mixture was stirred at –78 °C for 2 h until all starting material is consumed. The reaction was quenched with saturated aq. solution of Rochelle's salt (6 mL). Stirring was continued for 2 h at room temperature and then the aqueous layer was extracted with CH_2Cl_2 (3 × 20 mL). The combined organic layers were washed with water, brine, dried (Na_2SO_4) and concentrated to give the crude lactol (2.0 g), which was used for the next reaction without further purification.

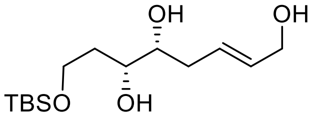
To a stirred solution of ethyl (triphenylphosphoranylidene)acetate (4.01 g, 11.52 mmol, 1.5 equiv) in benzene (20 mL) was added a solution of above lactol (2.0 g) in dry benzene (20 mL) and the mixture stirred for 12 h at 60 °C. It was then quenched with saturated aq. NH_4Cl (10 mL) and the solution extracted with EtOAc (3 × 20 mL). The combined organic layers were washed with water, brine, dried (Na_2SO_4) and concentrated. The residue was purified by silica gel column chromatography using petroleum ether/EtOAc (4:1) as eluent to give **20a** (1.71 g, 67%) as colorless oil. $[\alpha]_D^{25}$ –2.6 (*c* 1.0, $CHCl_3$). IR ($CHCl_3$): ν_{max} = 3447, 2959, 1715, 1439, 1283, 1056, 797, 593 cm^{-1}. ^1H NMR (400 MHz, $CDCl_3$): δ = 7.04–6.96 (m, 1H), 5.90 (d, *J* = 15.2 Hz, 1H), 4.17 (q, *J* =7.2 Hz, 2H), 3.91–3.81 (m, 2H), 3.74–3.70 (m, 1H), 3.60–3.56 (m, 1H), 2.75 (brs, 2H), 2.45–2.41 (m, 2H), 1.86–1.77 (m, 1H), 1.69–1.63 (m, 1H), 1.27 (t, *J* = 7.0 Hz, 3H), 0.89 (s, 9H), 0.07 (s, 6H) ppm. $^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$): δ = 166.4, 145.3, 123.6, 73.5, 73.0, 62.0, 60.3, 36.5, 35.0, 25.8, 18.1, 14.3, –5.55, –5.6 ppm. HRMS (ESI-TOF) *m*/*z*: $[M + Na]^+$ Calcd for $C_{16}H_{32}O_5SiNa$ 355.1911; Found 355.1914.

Ethyl (5*R*,6*R*,*E*)-5,8-bis(*tert*-butyldimethylsilyloxy)-6-hydroxyoct-2-enoate (20b):



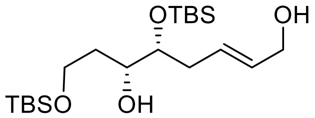
The titled compound was prepared from lactone **9b** (0.75 g, 2.0 mmol) by following a similar procedure as described for **20a** to give **20b** (0.653 g, 73%) as colorless oil. $[\alpha]_D^{25}$ +0.2 (*c* 1.0, $CHCl_3$). IR ($CHCl_3$): ν_{max} = 3407, 2954, 2930, 2888, 2857, 1742, 1472, 1463, 1386, 1363, 1255, 1093,1007, 971, 939, 913, 871, 2928, 2889, 2857, 1740, 1608, 1572, 1471, 1462, 1402, 1387, 1361, 1092, 1006, 972, 878, 836, 813, 776, 757, 726, 666 cm^{-1}. ^1H NMR (400 MHz, $CDCl_3$): δ = 6.98–6.90 (m, 1H), 5.85 (d, *J* = 15.6 Hz, 1H), 4.16 (q, *J* = 7.2 Hz, 2H), 3.88–3.77 (m, 1H), 3.76–3.74 (m, 1H), 3.73–3.68 (m, 2H), 2.59–2.53 (m, 1H), 2.36–2.25 (m, 2H), 1.69–1.62 (m, 2H), 1.26 (t, *J* = 8.0 Hz, 3H), 0.88 (s, 9H), 0.87 (s, 9H), 0.06 (s, 12H) ppm. $^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$): δ = 166.3, 145.8, 123.5, 73.8, 72.6, 61.8, 60.1, 35.8, 34.5, 25.84, 25.8, 18.1, 18.0, 14.2, –4.6, –5.5 ppm. HRMS (ESI-TOF) *m*/*z*: $[M + K]^+$ Calcd for $C_{22}H_{46}O_5Si_2K$ 485.2515; Found 485.2511.

(5*R*,6*R*,*E*)-8-(*tert*-Butyldimethylsilyloxy)oct-2-ene-1,5,6-triol (21a):



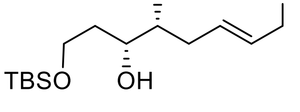
To a stirred solution of *α,β*-unsaturated ester **20a** (1.7 g, 5.11 mmol) in dry CH_2Cl_2 (25 mL) at 0 °C under argon atmosphere was added dropwise DiBAL-H (11 mL, 15.34 mmol, 1.4 M solution in toluene, 3.0 equiv). The reaction mixture was stirred for 30 min, warmed to room temperature and stirred for additional 30 min. It was then quenched with a saturated aq. solution of Rochelle's salt (20 mL), stirred for 2 h and then extracted with EtOAc (3 × 30 mL). The combined organic layers were washed with water, brine, dried (Na_2SO_4) and concentrated. The residue was purified by silica gel column chromatography using petroleum ether/EtOAc (1:1) as eluent to give **21a** (1.2 g, 81%) as colorless oil. $[\alpha]_D^{25}$ –2.9 (*c* 1.0, $CHCl_3$). IR ($CHCl_3$): ν_{max} = 3393, 2955, 2930, 2858, 1732, 1471, 1375, 1255, 1098, 1005, 972, 938, 837, 758, 666, 608 cm^{-1}. ^{1}H NMR (500 MHz, $CDCl_3$): δ = 5.75–5.67 (m, 2H), 5.32 (brs, 1H), 4.14–4.09 (m, 2H), 3.90–3.81 (m, 2H), 3.73–3.71 (m, 1H), 3.52–3.48 (m, 1H), 2.56 (brs, 2H), 2.37–2.20 (m, 2H), 1.82–1.66 (m, 2H), 0.90 (s, 9H), 0.08 (s, 6H) ppm. $^{13}C\{^1H\}$ NMR (125 MHz, $CDCl_3$): δ = 131.9, 128.9, 73.7, 73.5, 63.5, 62.0, 36.5, 35.1, 25.6, 18.1, 18.0, –3.6, –5.6 ppm. HRMS (ESI-TOF) *m*/*z*: $[M + Na]^+$ Calcd for $C_{14}H_{30}O_4SiNa$ 313.1806; Found 313.1799.

(5*R*,6*R*,*E*)-5,8-bis(*tert*-Butyldimethylsilyloxy)oct-2-ene-1,6-diol (21b):



The titled compound was prepared from *α,β*-unsaturated ester **20b** (2.5 g, 5.59 mmol) by following a similar procedure as described for **21a** to give **21b** (1.92 g, 85%) as colorless oil. $[\alpha]_D^{25}$ –49.4 (*c* 1.0, $CHCl_3$). IR ($CHCl_3$): ν_{max} = 3374, 2929, 2950, 2885, 2857, 1472, 1463, 1407, 1389, 1362, 1255, 1185, 1095, 1006, 973, 938, 836, 813, 776, 735, 668 cm^{-1}. ^{1}H NMR (400 MHz, $CDCl_3$): δ = 5.69–5.67 (m, 2H), 4.07 (d, *J* = 3.6 Hz, 2H), 4.08–3.73 (m, 2H), 3.69 (brs, 1H), 3.62–3.58 (m, 1H), 2.73 (brs, 1H), 2.46–2.40 (m, 1H), 2.19–2.12 (m, 1H), 1.66–1.64 (m, 2H), 0.88 (s, 18H), 0.06 (s, 12H) ppm. $^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$): δ = 131.7, 129.0, 74.6, 71.6, 63.6, 61.5, 36.1, 35.4, 25.9, 25.8, 18.2, 18.1, –4.2, –4.6, –5.4 ppm. HRMS (ESI-TOF) *m*/*z*: $[M + Na]^+$ Calcd for $C_{20}H_{44}O_4Si_2Na$ 427.2670; Found 427.2667.

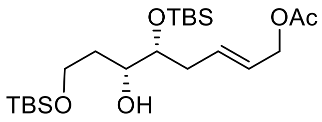
(5*R*,6*R*,*E*)-8-(*tert*-Butyldimethylsilyloxy)-5,6-dihydroxyoct-2-en-1-yl acetate (8b):



To a stirred solution of allyl alcohol **21a** (1.2 g, 4.13 mmol) in dry CH_2Cl_2 (25 mL) at 0 °C was added 2,3,5-collidine (1.1 mL, 8.26 mmol, 2.0 equiv) and the reaction mixture was stirred for 15 min. It was then cooled to –78 °C and acetyl chloride (0.35 mL, 4.96 mmol, 1.2 equiv) was added dropwise. The reaction mixture was stirred for 1 h and then warmed to room temperature. It was quenched with water (10 mL) and extracted with CH_2Cl_2 (3 × 20 mL). The combined organic layers were washed with water, brine, dried (Na_2SO_4) and concentrated. The residue was purified by silica gel column chromatography using petroleum ether/EtOAc (7:3) as eluent to give **8b** (1.12 g, 82%) as colorless oil. $[\alpha]_D^{25}$ +1.0 (*c* 1.0, $CHCl_3$). IR

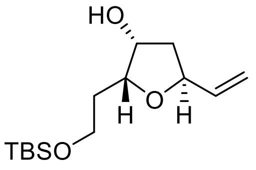
($CHCl_3$): $\nu_{\max}$ = 3451, 2931, 2858, 1739, 1613, 1572, 1471, 1383, 1362, 1249, 1104, 1027, 968, 939, 838, 757, 666, 608, 531 cm^{-1}. ^{1}H NMR (400 MHz, $CDCl_3$): δ = 5.86–5.79 (m, 1H), 5.69–5.62 (m, 1H), 4.51 (d, *J* = 6.4 Hz, 2H), 3.90–3.80 (m, 2H), 3.72–3.68 (m, 1H), 3.51–3.47 (m, 1H), 2.83 (brs, 2H), 2.38–2.20 (m, 2H), 2.04 (s, 3H), 1.82–1.73 (m, 1H), 1.69–1.63 (m, 1H), 0.88 (s, 9H), 0.07 (s, 6H) ppm. ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$): δ = 170.9, 132.1, 126.6, 73.5, 73.3, 65.0, 61.9, 36.5, 35.1, 25.8, 21.0, 18.1, −5.6, −5.61 ppm. HRMS (ESI-TOF) *m*/*z*: [M + K]$^+$ Calcd for $C_{16}H_{32}O_5SiK$ 371.1651; Found 371.1651.

(5*R*,6*R*,*E*)-5,8-*bis*(*tert*-Butyldimethylsilyloxy)-6-hydroxyoct-2-en-1-yl acetate (8a):



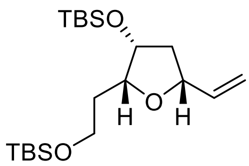
The titled compound was prepared from allyl alcohol **21b** (4.7 g, 11.61 mmol) by following a similar procedure as described for **8b** to give **8a** (4.67 g, 90%) as colorless oil. $[\alpha]_D^{25}$ +0.2 (*c* 1.0, $CHCl_3$). IR ($CHCl_3$): $\nu_{\max}$ = 3407, 2954, 2930, 2888, 2857, 1742, 1472, 1463, 1386, 1363, 1255, 1093, 1007, 971, 939, 913, 871, 836, 812, 776, 734, 668 cm^{-1}. ^{1}H NMR (400 MHz, $CDCl_3$): δ = 5.78–5.71 (m, 1H), 5.64–5.57 (m, 1H), 4.49 (d, *J* = 6.0 Hz, 2H), 3.86–3.81 (m, 1H), 3.78–3.72 (m, 1H), 3.70–3.67 (m, 1H), 3.61 (dd, *J* = 10.0, 5.2 Hz, 1H), 2.46–2.40 (m, 2H), 2.18–2.12 (m, 1H), 2.04 (s, 3H), 1.65–1.58 (m, 2H), 0.88 (s, 18H), 0.05 (s, 12H) ppm. ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$): δ = 170.8, 132.3, 126.4, 74.4, 71.9, 65.0, 61.6, 36.0, 35.0, 25.9, 25.8, 20.9, 18.2, 18.0, −4.3, −4.6, −5.5 ppm. HRMS (ESI-TOF) *m*/*z*: [M + Na]$^+$ Calcd for $C_{22}H_{46}O_5Si_2Na$ 469.2776; Found 469.2771.

(2*R*,3*R*,5*S*)-2-(2-*tert*-Butyldimethylsilyloxyethyl)-5-vinyltetrahydrofuran-3-ol (7b):



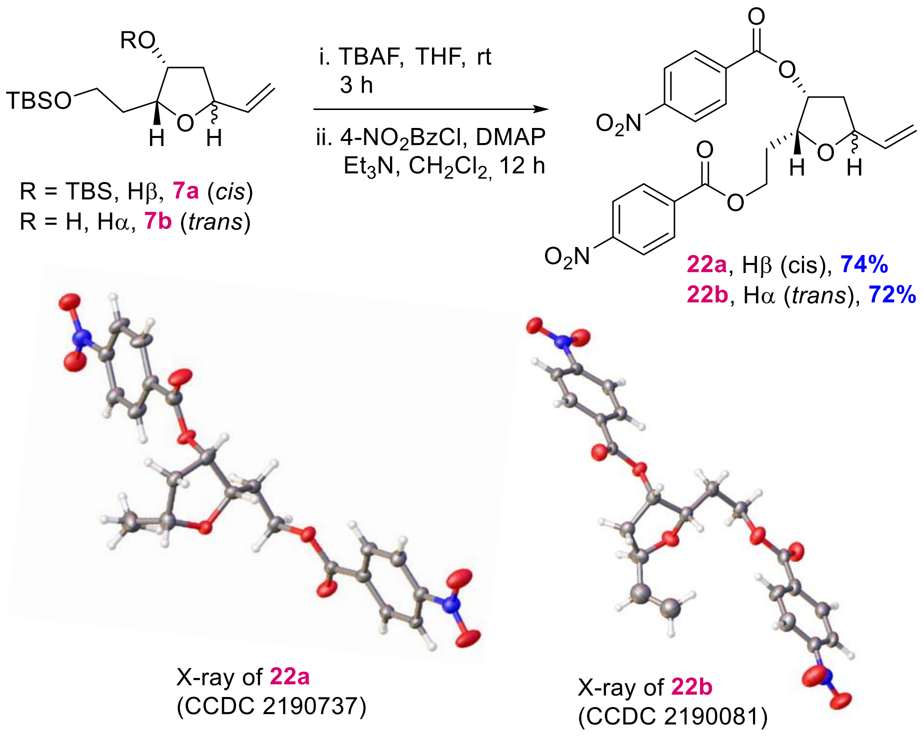
To a solution of allylacetate **8b** (66.7 mg, 0.2 mmol) in THF (4 mL) was added $Pd(OAc)_2$ (4.5 mg, 0.02 mmol, 0.1 equiv), PPh_3 (26.2 mg, 0.1 mmol, 0.5 equiv) and pyridine (12.7 mg, 0.16 mmol, 0.8 equiv). The reaction mixture was stirred at 50 °C for 1 h and then filtered through a pad of silica gel and the filtrate concentrated. The crude residue was purified by silica gel column chromatography using petroleum ether/EtOAc (3:1) as eluent to give **7b** (52.4 mg, 96%, *trans*:*cis* = 11:1 by ^{1}H NMR) as colorless oil. $[\alpha]_D^{25}$ −2.0 (*c* 1.0, $CHCl_3$). IR ($CHCl_3$): $\nu_{\max}$ = 3429, 2955, 2930, 2858, 1645, 1471, 1256, 1093, 835, 812, 777, 666 cm^{-1}. ^{1}H NMR (500 MHz, $CDCl_3$): δ = 5.87–5.78 (m, 1H), 5.25 (td, *J* = 17.1, 1.4 Hz, 1H), 5.10–5.08 (m, 1H), 4.65–4.61 (m, 1H), 4.31 (t, *J* = 4.3 Hz, 1H), 4.0–3.97 (m, 1H), 3.84–3.80 (m, 1H), 3.61 (td, *J* = 10.7, 2.0 Hz, 1H), 2.20–2.16 (m, 1H), 2.09–2.01 (m, 1H), 1.96–1.91 (m, 1H), 1.87–1.81 (m, 1H), 0.91 (s, 9H), 0.09 (s, 3H), 0.09 (s, 3H) ppm. ^{13}C{^{1}H} NMR (125 MHz, $CDCl_3$): δ = 139.0, 115.6, 82.9, 78.3, 72.9, 60.1, 41.1, 32.1, 25.8, 18.1, −5.66, −5.7 ppm. HRMS (ESI-TOF) *m*/*z*: [M + H]$^+$ Calcd for $C_{14}H_{28}O_3SiNa$ 295.1700; Found 295.1696.

tert-Butyl-(2-(2_R_,3_R_,5_R_)-3-(_tert_-butyldimethylsilyloxy)-5-vinyltetrahydrofuran-2-yl)ethoxydimethylsilane (7a):



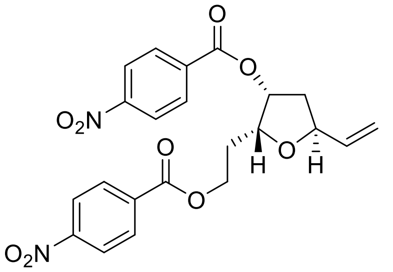
The titled compound was prepared from **8a** (89.7 mg, 0.2 mmol) by similar procedure as described for **8b** to give **7a** (71.2 mg, 92%, *trans*:*cis* = 1:9) as colorless oil. $[\alpha]_D^{25}$ –2.4 (*c* 1.0, $CHCl_3$). IR ($CHCl_3$): ν_{max} = 2955, 2929, 2894, 2857, 1472, 1463, 1388, 1362, 1255, 1158, 1088, 1006, 937, 922, 836, 812, 775, 735, 666 cm^{-1}. ^1H NMR, (500 MHz, $CDCl_3$): δ = 5.99–5.89 (m, 1H), 5.20–5.14 (m, 1H), 5.06–5.02 (m, 1H), 4.28–4.22 (m, 2H), 3.83 (q, *J* = 4.2 Hz, 1H), 3.75 (dd, *J* = 7.2, 5.6 Hz, 2H), 2.38–2.29 (m, 1H), 1.88–1.82 (m, 1H), 1.80–1.74 (m, 1H), 1.69–1.64 (m, 1H), 0.88 (s, 18H), 0.048 (s, 12H) ppm. $^{13}C\{^1H\}$ NMR (125 MHz, $CDCl_3$): δ = 140.2, 115.2, 79.9, 78.8, 73.5, 60.6, 42.3, 33.2, 25.9, 25.8, 18.3, 18.0, –4.6, –5.1, –5.3 ppm. HRMS (ESI-TOF) *m*/*z*: $[M + Na]^+$ Calcd for $C_{20}H_{42}O_3Si_2Na$ 409.2565; Found 409.2570.

Synthesis of esters 22a and 22b: To ascertain the stereochemical outcome of the Tsuji–Trost cyclization, we converted the cyclized products **7a** and **7b** to the esters by desilylation and then treatment with *p*-nitrobenzoyl chloride to provide crystalline diesters **22a** and **22b**, respectively (Scheme S2). The structures of these were unambiguously confirmed by X-ray analysis.



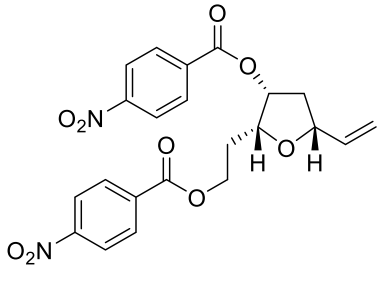
Scheme S2 Stereochemistry confirmation based on crystal structures of **22a** and **22b**.

2-((2*S*,3*R*,5*R*)-3-(4-Nitrobenzoyloxy)-5-vinyltetrahydrofuran-2-yl)ethyl 4-nitrobenzoate 22b):



To a stirred solution of **7b** (0.2 g, 0.734 mmol) in anhydrous THF (3 mL) was added 1M TBAF (0.74 mL, 0.734 mmol, 1.0 equiv) solution at 0 °C. The reaction mixture was then stirred at rt for 3 h. The solution was diluted with EtOAc (10 mL) and the separated organic layer was washed with brine, dried (Na_2SO_4) and concentrated. The crude product (0.115 g) was then dissolved in anhydrous CH_2Cl_2 (5 mL) followed by sequential addition of Et_3N (0.26 mL, 1.84 mmol, 2.5 equiv), 4-dimethylaminopyridine (9 mg, 0.0734 mmol, 0.1 equiv) and 4-nitrobenzoylchloride (0.273 g, 1.47 mmol, 2.0 equiv) at 0 °C. The mixture was then stirred at room temperature for 12 h. It was quenched with cold-water (10 mL) and extracted with CH_2Cl_2 (3 × 20 mL). The combined organic layers were washed with water, brine, dried (Na_2SO_4) and concentrated. The residue was purified by silica gel column chromatography using petroleum ether/EtOAc (7:3) as eluent to give **22b** (0.241 g, 72%) as white solid. M.P. 245–246°C. $[\alpha]_D^{25}$ –13.8 (*c* 1.0, $CHCl_3$). IR ($CHCl_3$): ν_{max} = 2932, 1725, 1529, 1349, 1274, 1104, 719 cm^{-1}. ^{1}H NMR, (500 MHz, $CDCl_3$): δ = 8.31 (d, *J* = 8.9 Hz, 2H), 8.25 (d, *J* = 8.8 Hz, 2H), 8.21 (d, *J* = 8.8 Hz, 2H), 8.16 (d, *J* = 8.7 Hz, 2H), 5.91–5.84 (m, 1H), 5.68 (t, *J* = 4.0 Hz, 1H), 5.31 (d, *J* = 17.3 Hz, 1H), 5.17 (d, *J* = 10.5 Hz, 1H), 4.73 (dd, *J* = 15.8, 6.7 Hz, 1H), 4.62–4.57 (m, 1H), 4.53–4.48 (m, 1H), 4.37–4.34 (m, 1H), 2.39 (dd, *J* = 14.2, 6.5 Hz, 1H), 2.20–2.12 (m, 3H) ppm. $^{13}C\{^1H\}$ NMR (125 MHz, $CDCl_3$): δ = 164.5, 163.9, 150.8, 150.5, 137.8, 135.4, 135.0, 130.8, 130.7, 123.7, 123.5, 116.3, 78.4, 77.9, 77.3, 63.2, 39.5, 29.1 ppm. HRMS (ESI-TOF) *m/z*: [M + Na]$^+$ Calcd for $C_{22}H_{20}N_2O_9Na$ 479.1061; Found 479.1062.

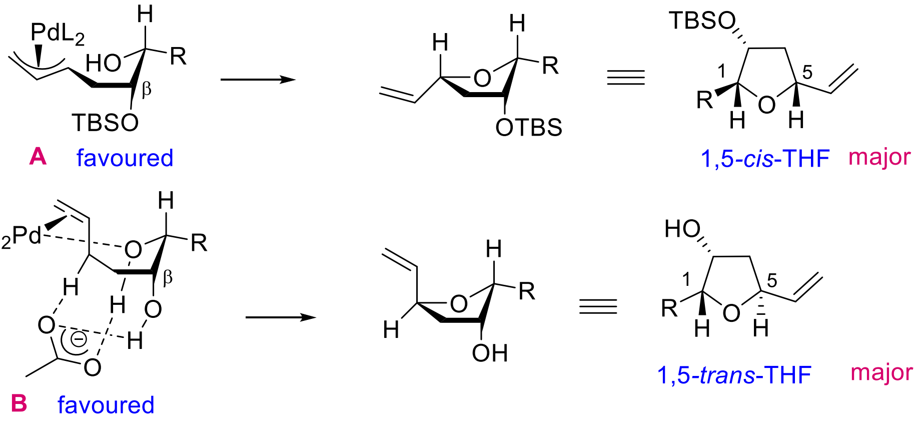
2-((2*R*,3*R*,5*R*)-3-(4-Nitrobenzoyloxy)-5-vinyltetrahydrofuran-2-yl)ethyl 4-nitrobenzoate 22a):



The titled compound was prepared from **7a** (0.1 g, 0.258 mmol) by a similar procedure as described for **22b** to give **22a** (87.3 mg, 74%) as white solid. M.P. 215–216 °C; $[\alpha]_D^{25}$ –0.6 (*c* 1.0, $CHCl_3$). IR ($CHCl_3$): ν_{max} = 2932, 1726, 1603, 1530, 1348, 1281, 1120, 1105, 1015, 907, 720 cm^{-1}. ^{1}H NMR, (500 MHz, $CDCl_3$): δ = 8.30 (d, *J* = 8.9 Hz, 2H), 8.26 (d, *J* = 8.8 Hz, 2H), 8.20–8.15 (m, 4H), 5.97–5.90 (m, 1H), 5.62–5.60 (m, 1H), 5.33 (d, *J* = 17.3 Hz, 1H), 5.18 (d, *J* = 10.4 Hz, 1H), 4.63–4.58 (m, 1H), 4.54–4.49 (m, 1H), 4.45 (dd,*J* = 13.8, 6.2 Hz, 1H), 4.15–4.12 (m, 1H), 2.75–2.69 (m, 1H), 2.22–2.17 (m, 2H), 1.93 (dd, *J* = 14.4, 2.2 Hz, 1H) ppm. $^{13}C\{^1H\}$ NMR (125 MHz, $CDCl_3$): δ = 164.5, 164.0, 150.7, 150.6, 138.2, 135.4, 135.0, 130.7, 130.7, 123.7, 123.5, 116.5, 78.6, 78.6, 76.8, 63.2, 39.5, 28.8 ppm. HRMS (ESI-TOF) *m/z*: [M + Na]$^+$ Calcd for $C_{22}H_{20}N_2O_9Na$ 479.1061; Found 479.1058.

Plausible Paths for Diastereoselectivity

Based on experimental results and literature,[3] it is evident that the *cis*-stereochemistry is favored in keeping the π-allyl-Pd moiety (in pseudo-equatorial site) away from the β-OTBS group, which is non-coordinating as in model **A** giving predominantly the 1,5-*cis*-THF unit (**8a**→**7a**) (Scheme S3). For the *trans*-ring closure as in model **B**, when the β-OH is free, the acetate co-ordination allows *trans*-ring closure (**8b**→**7b**). Thus, the β-*O*-silyl group leads predominantly to 1,5-*cis*-THF scaffold.

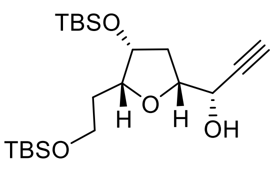


Scheme S3 Plausible models for diastereoselectivity.

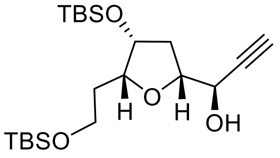
(*S*)-1-((2*R*,4*R*,5*R*)-4-(*tert*-Butyldimethylsilyloxy)-5-(2-*tert*-butyldimethylsilyloxyethyl) tetrahydrofuran-2-yl)prop-2-yn-1-ol (12a) and (*R*)-1-((2*R*,4*R*,5*R*)-4-(*tert*-Butyldimethylsilyloxy)-5-(2-*tert*-butyldimethylsilyloxyethyl) tetrahydrofuran-2-yl)prop-2-yn-1-ol (12b):

Ozone (O_3) was bubbled through a stirred solution of **7a** (2.1 g, 5.44 mmol) in CH_2Cl_2 (30 mL) at −78 °C for 10 min. Then dimethylsulfide (1.61 mL, 21.76 mmol, 4.0 equiv) was added and the mixture stirred at −78 °C for 2 h and room temperature for 1 h. The mixture was concentrated to give crude aldehyde (2.1 g) that was used directly for next reaction.

To the cooled solution of above aldehyde (2.1 g) at −20 °C in dry THF was added ethynylmagnesium bromide solution (27.2 mL, 0.5M solution hexane, 13.6 mmol, 2.5 equiv) dropwise under inert atmosphere. The reaction mixture was maintained at −20 °C for 2 h. It was then quenched with saturated aq. solution of NH_4Cl and extracted with EtOAc (2 × 20 mL). The combined organic phases were dried (Na_2SO_4) and the solvent was removed by rotary evaporation. The resulting residue (**12a**:**12b** = 1.1:1 by ^{1}H NMR) was purified by silica gel flash chromatography using petroleum ether/EtOAc (9.5:0.5) as eluent to give **12a** (1.04 g, 46%) as colorless oil. Further elution gave **12b** (0.901 g, 40%) as colorless oil.



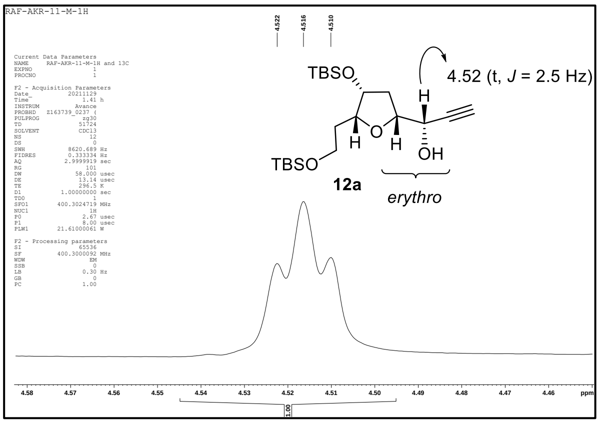
Data for 12a: $[\alpha]_D^{25}$ +26.3 (*c* 1.5, $CHCl_3$). IR ($CHCl_3$): ν_{max} = 3378, 3313, 3270, 2954, 2929, 2884, 2857, 1471, 1442, 1409, 1389, 1361, 1300, 1256, 1182, 1085, 1061, 1032, 1006, 959, 909, 865, 836, 780, 735, 663 cm^{-1}. ^1H NMR (400 MHz, $CDCl_3$): δ = 4.52 (t, *J* = 2.5 Hz, 1H), 4.26 (dt, *J* = 9.4, 3.3 Hz, 1H), 4.21–4.18 (m, 1H), 3.91 (dt, *J* = 8.9, 3.3 Hz, 1H), 3.76 (dd, *J* = 9.6, 3.2 Hz, 2H), 2.41 (d, *J* = 2.2 Hz, 1H), 2.32 (ddd, *J* = 14.3, 9.5, 5.0 Hz, 1H), 2.18 (dd, *J* = 14.1, 2.9 Hz, 1H), 1.87 (qd, *J* = 9.6, 5.0 Hz, 1H), 1.78–1.68 (m, 1H), 0.93 (s, 9H), 0.90 (s, 9H), 0.15 (s, 3H), 0.12 (s, 3H), 0.06 (s, 6H) ppm. $^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$): δ = 82.7, 80.6, 79.9, 73.3, 72.8, 63.2, 60.4, 35.8, 32.7, 26.0, 25.95, 25.8, 25.77, 18.4, 18.1, −4.7, −5.0, −5.3 ppm. HRMS (ESI-TOF) *m/z*: $[M + H]^+$ Calcd for $C_{21}H_{43}O_4Si_2$ 415.2694; Found 415.2692.

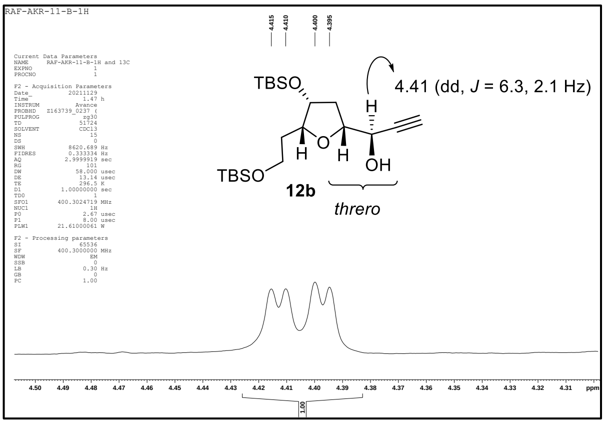


Data for 12b: $[\alpha]_D^{25}$ +0.2 (*c* 1.2, $CHCl_3$). IR ($CHCl_3$): ν_{max} = 3442, 3313, 2955, 2929, 2858, 2897, 1472, 1389, 1361, 1256, 1191, 1096, 1051, 1006, 955, 936, 836, 810, 776, 734, 665 cm^{-1}. ^1H NMR (400 MHz, $CDCl_3$): δ = 4.41 (dd, *J* = 6.3, 2.1 Hz, 1H), 4.21 (t, *J* = 3.4 Hz, 1H), 4.13–4.07 (m, 1H), 3.97 (dt, *J* = 8.0, 3.8 Hz, 1H), 3.77 (dd, *J* = 9.2, 3.9 Hz, 2H), 2.43 (d, *J* = 2.0 Hz, 1H), 2.30 (ddd, *J* = 14.0, 9.0, 5.1 Hz, 1H), 1.94 (dd, *J* = 14.4, 2.9 Hz, 1H), 1.86 (dt, *J* = 13.9, 7.0 Hz, 1H), 1.81–1.72 (m, 1H), 0.91 (s, 9H), 0.90 (s, 9H), 0.11 (s, 3H), 0.09 (s, 3H), 0.07 (s, 6H) ppm. $^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$): δ = 82.4, 81.0, 80.5, 73.1, 72.9, 65.5, 60.5, 38.0, 33.1, 26.0, 25.95, 25.8, 25.7, 18.4, 18.0, −4.7, −5.1, −5.3 ppm. HRMS (ESI-TOF) *m/z*: $[M + H]^+$ Calcd for $C_{21}H_{43}O_4Si_2$ 415.2694; Found 415.2694.

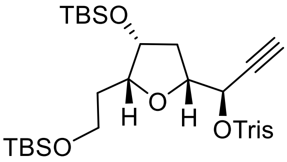
Assignment of absolute stereochemistry at propargylic alcohol center for 12a and 12b

In literature, the relative configurations of α-tetrahydrofurylpropargyl alcohols and their derivatives has been assigned on the basis of Felkin−Anh selectivity and their ^1H-NMR vicinal coupling constants.[4] The smaller vicinal coupling (*J* = 2-4 Hz) was assigned to *erythro* isomer than the larger value to the corresponding *threo* isomer (*J* = 6-8 Hz). In our study, the compounds **12a** and **12b** were appropriate for exact analysis as described in literature. The smaller, *J* = 2.5 Hz coupling constant for **12a** is consistent with the assignment of **12a** as the *erythro* isomer and **12b** (*J* = 6.3, 2.1 Hz) as *threo* isomer.



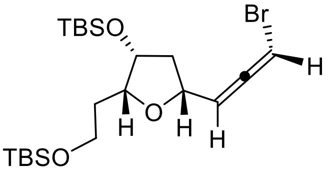


(*R*)-1-((2*R*,4*R*,5*R*)-4-(*tert*-Butyldimethylsilyloxy)-5-(2-*tert*-butyldimethylsilyloxyethyl) tetrahydrofuran-2-yl)prop-2-yn-1-yl 2,4,6-triisopropylbenzenesulfonate (6b):



To a stirred solution of **12b** (0.8 g, 1.93 mmol) in anhydrous CH_2Cl_2 (2.0 mL) were added DMAP (1.42 g, 11.59 mmol, 6.0 equiv) and 2,4,6-triisopropylbenzenesulfonyl chloride (1.75 g, 5.79 mmol, 3.0 equiv) at 0 °C under inert atmosphere. After being stirred at room temperature for 12 h, the reaction mixture was quenched with H_2O (10 mL) and extracted with CH_2Cl_2 (2 × 20 mL). The combined organic phases were dried (Na_2SO_4) and the solvent was removed by rotary evaporation. The resulting residue was purified by silica gel flash chromatography using petroleum ether/EtOAc (50:1) as eluent to give the trisylate **6b** (0.971 g, 74%) as a colorless oil. $[\alpha]_D^{25}$ −6.7 (*c* 0.75, $CHCl_3$). IR ($CHCl_3$): ν_{max} = 3311, 2956, 2929, 2858, 1600, 1566, 1471, 1463, 1426, 1380, 1362, 1350, 1299, 1256, 1196, 1179, 1157, 1137, 1083, 1062, 1006, 982, 928, 878, 835, 810, 776, 735, 668, 566 cm^{-1}. ^1H NMR (400 MHz, $CDCl_3$): δ = 7.14 (s, 2H), 5.38 (dd, J = 8.2, 2.1 Hz, 1H), 4.21–4.12 (m, 4H), 4.09–3.97 (m, 1H), 3.69–3.61 (m, 2H), 2.89 (dt, J = 13.8, 6.9 Hz, 1H), 2.29 (d, J = 2.1 Hz, 1H), 2.25 (td, J = 8.7, 4.3 Hz, 1H), 2.07 (d, J = 13.7 Hz, 1H), 1.81–1.72 (m, 1H), 1.70–1.60 (m, 1H), 1.27–1.23 (m, 18H), 0.91 (s, 9H), 0.87 (s, 9H), 0.07 (d, J = 3.7 Hz, 6H), 0.03 (s, 6H) ppm.$^{13}C\{^1H\}$ NMR (125 MHz, $CDCl_3$): δ = 153.2, 150.5, 131.5, 123.4, 81.1, 78.4, 77.8, 76.8, 73.4, 72.6, 60.2, 38.1, 34.2, 33.6, 29.6, 26.0, 25.8, 24.7, 23.7, 23.6, 18.3, 18.0, −4.7, −5.1, −5.3 ppm. HRMS (ESI-TOF) *m/z*: $[M + H]^+$ Calcd for $C_{36}H_{65}O_6SSi_2$ 681.4035; Found 681.4031.

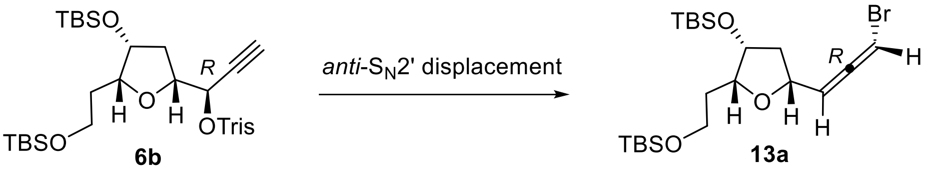
((2*R*,3*R*,5*R*)-5-((*R*)-3-Bromopropa-1,2-dien-1-yl)-2-(2-*tert*-butyldimethylsilyloxyethyl) tetrahydrofuran-3-yloxy)*tert*-butyldimethylsilane (13a):

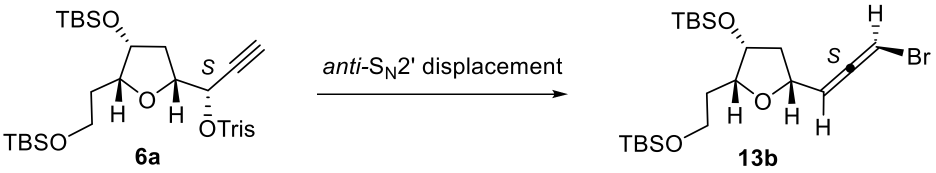


To a stirred suspension of LiBr (1.41 g, 16.2 mmol, 10.0 equiv) in dry THF was added CuBr (2.32 g, 16.2 mmol, 10.0 equiv) at room temperature and the mixture stirred for 30 min under inert atmosphere till $LiCuBr_2$ reagent was formed. The solution of **6b** (1.1 g, 1.62 mmol) in anhydrous THF (2 mL) was added dropwise to the above prepared $LiCuBr_2$ solution at room temperature and then heated at 70 °C for 4 h. The mixture was cooled to room temperature and quenched with saturated aq. NH_4Cl solution (20 mL) and extracted with EtOAc (2 × 20 mL). The combined organic phases were dried (Na_2SO_4) and the solvent was removed by rotary evaporation. The resulting residue was purified by silica gel flash chromatography using petroleum ether/EtOAc (100:1) as eluent giving bromoallene **13a** (0.71 g, 92%) as pale yellow oil. $[\alpha]_D^{25}$ −27.8 (*c* 1.0, $CHCl_3$). IR ($CHCl_3$): ν_{max} = 2959, 2928, 2857, 1471, 1461, 1362, 1256, 1190, 1077, 939, 836, 776, 660 cm^{-1}. ^1H NMR (400 MHz, $CDCl_3$): δ = 6.01 (dd, J = 5.7, 1.1 Hz, 1H), 5.54 (dd, J = 7.8, 5.7 Hz, 1H), 4.55–4.47 (m, 1H), 4.23 (ddd, J = 5.6, 3.7, 2.2 Hz, 1H), 3.88 (dt, J = 8.3, 4.0 Hz, 1H), 3.73 (dd, J = 7.2, 5.4 Hz, 2H), 2.38 (ddd, J = 13.6, 8.5, 5.3 Hz, 1H), 1.86–1.79 (m, 2H), 1.77–1.72 (m, 1H), 0.89 (s, 9H), 0.87 (s, 9H), 0.07 (s, 3H), 0.05 (s, 3H), 0.03 (s, 6H) ppm. $^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$): δ = 201.0, 103.5, 80.4, 74.7, 73.2, 72.9, 60.3, 42.2, 33.2, 25.9, 25.8, 18.3, 18.0, −4.6, −5.1, −5.3 ppm. HRMS (ESI-TOF) *m/z*: $[M + Na]^+$ Calcd for $C_{21}H_{41}BrNaO_3Si_2$ 499.1670; Found 499.1671.

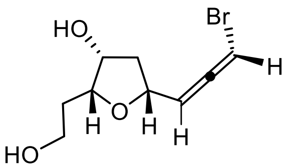
Assignment of allene stereochemistry for 13a and 13b

The reaction of **6b** or **6a** with bromocuprate reagent ($LiCuBr_2$) follow an *anti*-S_N2' bromination reaction giving rise to the corresponding bromoallenes **13a** or **13b**, respectively in a highly stereoselective manner. This is in accordance to literature reports.[5]





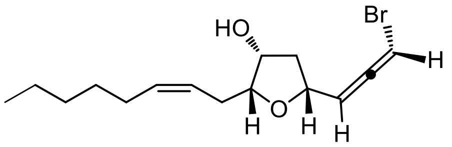
(2*R*,3*R*,5*R*)-5-((*R*)-3-Bromopropa-1,2-dien-1-yl)-2-(2-hydroxyethyl)tetrahydrofuran-3-ol (14a):



To a stirred solution of bromoallene **13a** (0.5 g, 1.05 mmol) in dry THF was added TBAF (3.16 mL, 1 M solution in THF, 3.0 equiv) at 0 °C dropwise. The mixture was stirred at room temperature for 3 h. The reaction mixture was quenched with H_2O (10 mL) and extracted with EtOAc (2 × 20 mL). The combined organic phases were dried (Na_2SO_4) and the solvent was removed by rotary evaporation. The resulting residue was purified by silica gel flash chromatography using petroleum ether/EtOAc (1:1) as eluent to give **14a** (0.226 g, 87%) as colorless oil. $[\alpha]_D^{25}$ −64.3 (*c* 0.75, $CHCl_3$). IR ($CHCl_3$): ν_{max}

= 3422, 3308, 3064, 2928, 2853, 2250, 1961, 1442, 1342, 1216, 1192, 1065, 1008, 909, 735, 650 cm^{-1}. ^{1}H NMR (400 MHz, $CDCl_3$): δ = 6.03 (dd, *J* = 5.7, 1.1 Hz, 1H), 5.52 (dd, *J* = 7.0, 5.8 Hz, 1H), 4.44 (dd, *J* = 13.2, 7.5 Hz, 1H), 4.26 (d, *J* = 2.6 Hz, 1H), 3.79 (d, *J* = 11.9 Hz, 2H), 3.78–3.72 (m, 2H), 3.63 (dd, *J* = 11.1, 5.3 Hz, 1H), 2.43 (ddd, *J* = 14.1, 8.2, 6.1 Hz, 1H), 1.89 (dd, *J* = 11.7, 6.0 Hz, 2H), 1.82 (ddd, *J* = 13.8, 5.3, 1.7 Hz, 1H) ppm. ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$): δ = 201.1, 102.3, 82.6, 74.5, 73.4, 72.2, 59.3, 40.7, 31.2 ppm. HRMS (ESI-TOF) *m/z*: [M + Na]$^+$ Calcd for $C_9H_{13}BrNaO_3$ 270.9940; Found 270.9940.

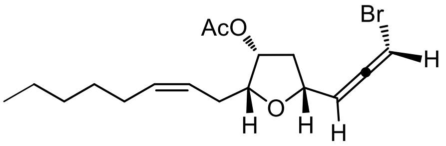
(2*R*,3*R*,5*R*)-5-((*R*)-3-Bromopropa-1,2-dien-1-yl)-2-((*Z*)-oct-2-en-1-yl)tetrahydrofuran-3-ol (15a):



To a stirred solution of **14a** (50 mg, 0.202 mmol) in anhydrous CH_2Cl_2(2 mL) under inert atmosphere was added Dess-Martin periodinane (94.2 mg, 0.22 mmol, 1.1 equiv) in single portion at 0 °C and the mixture was stirred at room temperature for 2 h. The reaction mixture was quenched by adding a mixture (1:1) of saturated aq. solution of $NaHCO_3$ and $Na_2S_2O_3$ (4 mL) and the aqueous phase was separated and extracted with CH_2Cl_2 (3 × 10 mL). The combined organic phases were dried (Na_2SO_4) and the solvent was removed by rotary evaporation giving the crude aldehyde (50 mg) that was directly subjected to the Wittig olefination.

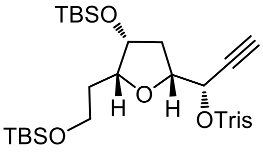
n-Hexyl triphenylphosphonium bromide (262 mg, 0.61 mmol, 3.0 equiv) was dissolved in anhydrous toluene under inert atmosphere. After cooling to −78 °C, NaHMDS (1.0 M solution, 0.61 mL, 3.0 equiv) was added dropwise. The mixture was stirred for 30 min and then a solution of above aldehyde (50 mg) in THF (1 mL) was added dropwise. The mixture was vigorously stirred for 4 h at −78 °C. The reaction was quenched with saturated aq. solution of NH_4Cl and diluted with EtOAc (3 × 20 mL). The aqueous phase was separated and then extracted with EtOAc (2 × 30 mL). The combined organic phases were dried (Na_2SO_4) and the solvent was removed by rotary evaporation. The resulting residue was purified by silica gel flash chromatography using petroleum ether/EtOAc (9.7:0.3) as eluent to give **15a** (48.2 mg, 76%) as colorless oil. $[\alpha]_D^{25}$ −53.6 (*c* 0.75, $CHCl_3$). IR ($CHCl_3$): ν_{max} = 3455, 3374, 2954, 2922, 2855, 1716, 1458, 1400, 1273, 1260, 1192, 1057, 969, 847, 719, 666, 660, 597, 518 cm^{-1}. ^{1}H NMR (400 MHz, $CDCl_3$): δ = 6.08 (dd, *J* = 5.7, 1.5 Hz, 1H), 5.60 (dd, *J* = 6.6, 5.7 Hz, 1H), 5.57–5.46 (m, 1H), 5.46–5.36 (m, 1H), 4.61–4.52 (m, 1H), 4.29–4.23 (m, 1H), 3.73 (td, *J* = 7.2, 3.2 Hz, 1H), 2.52–2.40 (m, 2H), 2.08 (dd, *J* = 14.2, 7.1 Hz, 1H), 1.94 (ddd, *J* = 14.0, 4.5, 1.5 Hz, 1H), 1.40–1.31 (m, 4H), 1.32–1.26 (m, 4H), 0.88 (t, *J* = 6.8 Hz, 3H) ppm. ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$): δ = 201.2, 132.9, 124.4, 103.0, 83.5, 74.3, 73.7, 72.4, 41.1, 31.5, 29.7, 29.2, 27.4, 27.2, 22.5, 14.0 ppm. HRMS (ESI-TOF) *m/z*: [M + Na]$^+$ Calcd for $C_{15}H_{23}BrNaO_2$ 337.0774; Found 337.0776.

1-*epi*-Dihydroitomanallene B (4′):



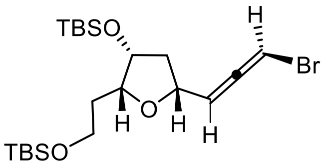
The alcohol **15a** (20 mg, 0.064 mmol) was dissolved in dry CH_2Cl_2 (2 mL) under inert atmosphere and pyridine (0.1 mL, 1.28 mmol, 20.0 equiv) was added in one portion at room temperature and then the reaction was cooled to 0 °C. Under vigorous stirring, acetic anhydride (0.037 mL, 0.384 mmol, 6.0 equiv) was added dropwise. The reaction was warmed to room temperature and stirred for 12 h. After completion, it was quenched with saturated aq. solution of $NaHCO_3$ (5 mL) and extracted with CH_2Cl_2 (2 × 10 mL). The combined organic phases were dried (Na_2SO_4) and the solvent was removed by rotary evaporation. The resulting residue was purified by silica gel flash chromatography using petroleum ether/EtOAc (9.5:0.5) as eluent to give 1-*epi*-dihydroitomanallene B **4′** (19.6 mg, 86%) as colorless oil. $[\alpha]_D^{25}$ −25.7 (*c* 0.7, $CHCl_3$). IR ($CHCl_3$): ν_{max} = 2954, 2928, 2885, 2856, 1741, 1447, 1374, 1080, 1059, 721, 712, 670, 661 cm^{-1}. ^1H NMR (400 MHz, C_6D_6): δ = 5.65 (dd, *J* = 5.6, 1.6 Hz, 1H), 5.50–5.46 (m, 2H), 5.32–5.29 (m, 1H), 5.07 (ddd, *J* = 5.8, 3.7, 1.9 Hz, 1H), 4.16 (dt, *J* = 8.2, 6.7, 1.5 Hz, 1H), 3.46 (td, *J* = 6.9, 3.7 Hz, 1H), 2.60–2.50 (m, 1H), 2.47–2.42 (m, 1H), 2.01 (dt, *J* = 13.6, 6.7 Hz, 2H), 1.91 (ddd, *J* = 14.4, 8.4, 6.0 Hz, 1H), 1.66 (s, 3H), 1.65–1.63 (m, 1H), 1.32–1.27 (m, 2H), 1.25–1.19 (m, 4H), 0.86 (t, *J* = 6.8 Hz, 3H) ppm. $^{13}C\{^1H\}$ NMR (100 MHz, C_6D_6): δ = 201.4, 169.5, 132.3, 125.2, 102.9, 82.0, 74.3, 74.2, 73.8, 39.2, 31.8, 29.6, 27.8, 27.7, 22.9, 20.6, 14.2 ppm. HRMS (ESI-TOF) *m/z*: $[M + Na]^+$ Calcd for $C_{17}H_{25}BrNaO_3$ 379.0879; Found 379.0879.

(*S*)-1-((2*R*,4*R*,5*R*)-4-(*tert*-Butyldimethylsilyloxy)-5-(2-*tert*-butyldimethylsilyloxyethyl) tetrahydrofuran-2-yl)prop-2-yn-1-yl 2,4,6-triisopropylbenzenesulfonate (6a):



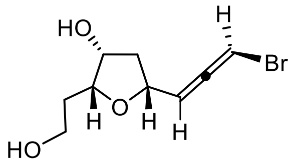
The titled compound was prepared from **12a** (1.1 g. 2.65 mmol) by a similar procedure as described for **6b** to give **6a** (1.35 g, 75%) as a colorless oil. $[\alpha]_D^{25}$ −19.2 (*c* 0.5, $CHCl_3$). IR ($CHCl_3$): ν_{max} = 3311, 2956, 2931, 2900, 2883, 2858, 2128, 1600, 1566, 1540, 1471, 1463, 1426, 1379, 1362, 1350, 1256, 1217, 1195, 1179, 1088, 1005, 950, 939, 913, 836, 813, 776, 735, 669, 650, 567 cm^{-1}. ^1H NMR (400 MHz, $CDCl_3$): δ = 7.14 (s, 2H), 5.19 (dd, *J* = 7.2, 2.1 Hz, 1H), 4.30–4.24 (m, 1H), 4.14 (dt, *J* = 13.5, 6.7 Hz, 2H), 4.06 (td, *J* = 7.6, 4.9 Hz, 1H), 3.95 (dt, *J* = 8.5, 4.2 Hz, 1H), 3.72 (dd, *J* = 7.1, 5.7 Hz, 2H), 2.90 (dt, *J* = 13.8, 6.9 Hz, 1H), 2.25 (ddd, *J* = 13.5, 7.8, 5.6 Hz, 1H), 2.13 (d, *J* = 2.1 Hz, 1H), 2.06 (ddd, *J* = 13.6, 4.9, 2.9 Hz, 1H), 1.88–1.70 (m, 2H), 1.28–1.22 (m, 18H), 0.91 (s, 9H), 0.87 (s, 9H), 0.12 (s, 3H), 0.07 (s, 3H), 0.03 (s, 6H) ppm. $^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$): δ = 153.6, 150.6, 131.2, 123.5, 80.6, 77.7, 77.4, 76.3, 72.5, 71.5, 60.3, 37.7, 34.2, 33.1, 29.6, 25.9, 25.8, 24.7, 24.5, 23.6, 18.3, 18.1, −4.5, −5.3, −5.4 ppm. HRMS (ESI-TOF) *m/z*: $[M + Na]^+$ Calcd for $C_{36}H_{64}NaO_6SSi_2$ 703.3854; Found 703.3851.

((2*R*,3*R*,5*R*)-5-((*S*)-3-Bromopropa-1,2-dien-1-yl)-2-(2-*tert*-butyldimethylsilyloxyethyl) tetrahydrofuran-3-yloxy)(*tert*-butyl)dimethylsilane (13b):



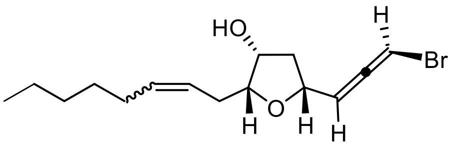
The titled compound was prepared from trisylate **6a** (0.5 g, 0.734 mmol) by a similar procedure as described for **13a** to give **13b** (0.325 g, 93%) as pale yellow oil. $[\alpha]_D^{25}$ +129.6 (*c* 0.5, $CHCl_3$). IR ($CHCl_3$): ν_{max} = 2956, 2931, 2883, 2858, 2252, 1471, 1388, 1361, 1256, 1218, 1192, 1088, 1005, 909, 836, 775, 735, 650 cm^{-1}. ^1H NMR (400 MHz, $CDCl_3$): δ = 5.97 (dd, *J* = 5.7, 1.3 Hz, 1H), 5.58 (dd, *J* = 6.8, 5.9 Hz, 1H), 4.57–4.49 (m, 1H), 4.24 (dd, *J* = 6.6, 4.7 Hz, 1H), 3.89 (dt, *J* = 8.3, 4.0 Hz, 1H), 3.75 (dd, *J* = 7.1, 5.5 Hz, 2H), 2.36 (ddd, *J* = 13.5, 8.4, 5.4 Hz, 1H), 1.87–1.72 (m, 3H), 0.89 (s, 9H), 0.88 (s, 9H), 0.06 (d, *J* = 0.9 Hz, 6H), 0.05 (s, 6H) ppm. $^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$): δ = 200.8, 103.8, 80.3, 74.2, 73.2, 72.9, 60.4, 41.9, 33.2, 26.0, 25.9, 25.8, 25.7, 18.3, 18.0, −4.6, −5.1, −5.3 ppm. HRMS (ESI-TOF) *m/z*: $[M + Na]^+$ Calcd for $C_{21}H_{41}BrNaO_3Si_2$ 499.1670; Found 499.1674.

(2*R*,3*R*,5*R*)-5-((*S*)-3-Bromopropa-1,2-dien-1-yl)-2-(2-hydroxyethyl)tetrahydrofuran-3-ol (14b):



The titled compound was prepared from **13b** (300 mg, 0.63 mmol) by a similar procedure as described for **14a** to give **14b** (139 mg, 89%) as colorless oil. $[\alpha]_D^{25}$ +201.6 (*c* 0.5, $CHCl_3$). IR ($CHCl_3$): ν_{max} = 3403, 2949, 2931, 2251, 1961, 1473, 1442, 1342, 1216, 1192, 1061, 1008, 909, 853, 735, 650, 624 cm^{-1}. ^1H NMR (400 MHz, $CDCl_3$): δ = 6.05 (dd, *J* = 5.7, 1.6 Hz, 1H), 5.58 (t, *J* = 6.0 Hz, 1H), 4.56–4.50 (m, 1H), 4.37–4.26 (m, 1H), 3.86 (td, *J* = 6.8, 3.5 Hz, 2H), 3.73 (d, *J* = 4.1 Hz, 1H), 3.11 (s, 2H), 2.45 (ddd, *J* = 14.1, 8.4, 6.0 Hz, 1H), 1.97 (dd, *J* = 10.9, 6.0 Hz, 2H), 1.90 (ddd, *J* = 13.8, 5.1, 1.8 Hz, 1H) ppm. $^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$): δ = 201.0, 102.9, 83.1, 74.1, 73.8, 72.6, 59.7, 40.7, 31.3 ppm. HRMS (ESI-TOF) *m/z*: $[M + Na]^+$ Calcd for $C_9H_{13}BrNaO_3$ 270.9940; Found 270.9929.

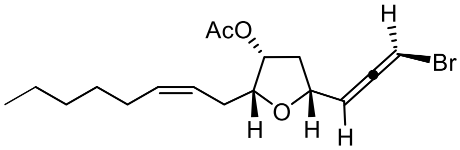
(2*R*,3*R*,5*R*)-5-((*S*)-3-Bromopropa-1,2-dien-1-yl)-2-(*Z*)-oct-2-en-1-yl)tetrahydrofuran-3-ol (15b):



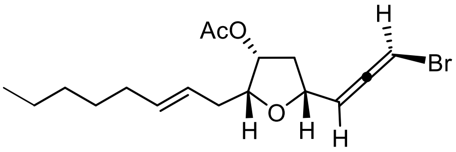
The titled compound was prepared from **14b** (60 mg, 0.242 mmol) by a similar procedure as described for **15a** to give inseparable mixture (*Z*:*E* = 76:24) of two isomers **15b** (59.2 mg, 78%) as colorless oil. ^1H NMR (400 MHz, $CDCl_3$): δ = 6.11 (d, *J* = 2.0 Hz, 1H), 5.62 (dd, *J* = 11.2, 5.6 Hz, 1H), 5.59–5.52 (m, 1H), 5.47–5.41 (m, 1H), 4.65–4.56 (m, 1H), 4.26 (s, 1H), 3.78 (td, *J* = 7.2, 3.2 Hz, 1H), 2.58–2.41 (m, 2H), 2.14–2.04 (m, 1H), 1.98 (dd, *J* = 13.1, 3.7 Hz, 1H), 1.40–1.31 (m, 4H), 1.35–1.25 (m, 4H), 0.90 (t, *J* = 6.7 Hz, 3H) ppm. $^{13}C\{^1H\}$ NMR (125 MHz, $CDCl_3$): δ = 200.8, 132.9, 124.3, 103.5, 83.6, 74.2, 73.6, 72.6, 41.0, 31.5, 29.7, 29.2, 27.4, 27.3, 22.5, 14.0 ppm.HRMS (ESI-TOF) *m/z*: $[M + Na]^+$ Calcd for $C_{15}H_{23}BrNaO_2$ 337.0774; Found 337.0776.

(+)-Dihydroitomanallene B (4) and 9*E*-(+)-dihydroitomanalleneB (4″):

The titled compounds were prepared from **15b** (20 mg, 0.064 mmol) by a similar procedure as described for **4′** to give easily separable two isomers, (+)-dihydroitomanallene B **4** (15 mg, 66%) and 9*E*-(+)-dihydroitomanallene B **4″** (4.8 mg, 21%) as colorless oils.

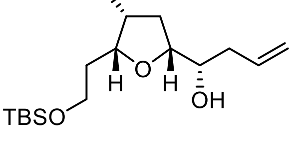


Data for **4:** $[\alpha]_D^{25}$ +73.6 (*c* 0.25, $CHCl_3$). lit.[6] $[\alpha]_D^{25}$ +64.01 (*c* 0.39, $CHCl_3$). IR ($CHCl_3$) ν_{max} = 2954, 2925, 2855, 1962, 1740, 1456, 1440, 1374, 1120, 1078, 1057, 966, 898, 845, 661, 605, 572 cm^{-1}. ^{1}H NMR (500 MHz, C_6D_6): δ = 5.68 (dd, J = 5.7, 1.8 Hz, 1H), 5.53–5.46 (m, 2H), 5.24 (t, J = 5.7 Hz, 1H), 5.07 (dd, J = 6.7, 2.9 Hz, 1H), 4.12–4.07 (m, 1H), 3.48 (td, J = 6.8, 3.8 Hz, 1H), 2.60–2.52 (m, 1H), 2.48 (dd, J = 13.6, 7.1 Hz, 1H), 2.07–2.00 (m, 2H), 1.91 (ddd, J = 14.4, 8.4, 6.1 Hz, 1H), 1.68 (s, 3H), 1.65–1.61 (m, 1H), 1.35–1.28 (m, 2H), 1.26–1.21 (m, 4H), 0.87 (t, J = 6.8 Hz, 3H) ppm. ^{13}C{^{1}H} NMR (125 MHz, C_6D_6): δ = 201.5, 169.7, 132.4, 125.3, 103.1, 82.1, 74.3, 74.0, 73.9, 39.3, 31.8, 29.7, 27.9, 27.8, 23.0, 20.6, 14.3 ppm. HRMS (ESI-TOF) *m/z*: [M + Na]$^+$ Calcd for $C_{17}H_{25}BrNaO_3$ 379.0879; Found 379.0874.



Data for **4″:** $[\alpha]_D^{25}$ +32.7 (*c* 0.3, $CHCl_3$). IR ($CHCl_3$): ν_{max} = 2959, 2929, 2893, 2885, 2857, 2336, 1740, 1464, 1394, 1378, 1081, 966, 822, 665, 603, 571 cm^{-1}. ^{1}H NMR (400 MHz, C_6D_6): δ = 5.70 (dd, J = 5.7, 2.1 Hz, 1H), 5.55–5.50 (m, 2H), 5.15 (t, J = 5.5 Hz, 1H), 4.91 (dt, J = 7.1, 3.0 Hz, 1H), 4.40–4.35 (m, 1H), 4.15–4.13 (m 1H), 2.32 (t, J = 5.8 Hz, 1H), 2.02 (ddd, J = 11.4, 7.4, 4.0 Hz, 3H), 1.62 (s, 3H), 1.29–1.21 (m, 8H), 0.88 (t, J = 6.8 Hz, 3H) ppm.^{13}C{^{1}H} NMR (125 MHz, C_6D_6): δ = 201.3, 169.9, 133.0, 124.6, 103.1, 84.0, 77.7, 77.66, 74.5, 74.3, 37.5, 31.8, 31.4, 29.7, 27.8, 23.0, 20.7, 14.3 ppm. HRMS (ESI-TOF) *m/z*: [M + Na]$^+$ Calcd for $C_{17}H_{25}BrNaO_3$ 379.0879; Found 379.0881.

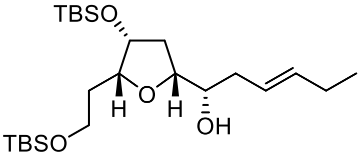
(*S*)-1-((2*R*,4*R*,5*R*)-4-(*tert*-Butyldimethylsilyloxy)-5-(2-*tert*butyldimethylsilyloxyethyl)tetrahydrofuran-2-yl)but-3-en-1-ol (16):



Ozone (O_3) was bubbled through a stirred solution of **7a** (200 mg, 0.517 mmol) in CH_2Cl_2 (30 mL) −78 °C for 10 min. Then dimethylsulfide (0.15 mL, 2.06 mmol, 4.0 equiv) was added and the mixture stirred at −78 °C for 2 h and then room temperature for 1 h. The mixture was concentrated to give crude aldehyde (200 mg) that was used directly for next reaction.

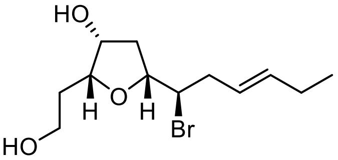
To the stirred solution of above aldehyde (200 mg) in anhydrous THF (5 mL) was added a solution of allyl magnesium chloride (2.0 M in THF, 0.65 mL, 1.294 mmol, 2.5 equiv). After stirring for 2 h at –78 °C, the reaction mixture was quenched with saturated aq. NH_4Cl solution (5 mL). The organic layer was separated and the aqueous layer was extracted with EtOAc (3 × 10 mL). The combined organic layers were washed with brine, dried (Na_2SO_4) and concentrated. The residue was purified by silica gel column chromatography using petroleum ether/EtOAc (9:1) as eluent to give alcohol **16** (122.5 mg, 55%) as colorless oil. $[\alpha]_D^{25}$ +2.9 (*c* 1.0, $CHCl_3$). IR ($CHCl_3$): ν_{max} = 3460, 3019, 3004, 2929, 2856, 1646, 1466, 1371, 1255, 1076, 1049, 836, 668, 541, 477, 460 cm^{-1}. ^1H NMR (500 MHz, $CDCl_3$): δ = 5.91–5.79 (m, 1H), 5.11–5.04 (m, 2H), 4.18-4.17 (m, 1H), 3.95–3.92 (m, 1H), 3.86–3.82 (m, 1H), 3.77–3.72 (m, 3H), 2.52 (brs, 1H), 2.30–2.06 (m, 3H), 1.93–1.69 (m, 3H), 0.89 (s, 9H), 0.88 (s, 9H), 0.09 (s, 6H), 0.07 (s, 6H) ppm. $^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$): δ = 134.7, 117.0, 79.8, 79.6, 73.1, 71.2, 60.5, 38.3, 34.7, 32.7, 25.9, 25.8 18.3, 18.1, –4.7, –5.1, –5.4 ppm. HRMS (ESI-TOF) *m/z*: $[M + K]^+$ Calcd for $C_{22}H_{46}O_4Si_2K$ 469.2566; Found 469.2559.

(*S*,*E*)-1-((2*R*,4*R*,5*R*)-4-(*tert*-butyldimethylsilyloxy)-5-(2-*tert*-butyldimethylsilyloxyethyl) tetrahydrofuran-2-yl)hex-3-en-1-ol (17):



To a solution of alcohol **16** (100 mg, 0.232 mmol) in CH_2Cl_2 (5 mL) was added *trans*–3–hexene (0.431 g, 2.32 mmol, 10.0 equiv) followed by Grubb's-II catalyst (5.0 mg, 0.0059 mmol, 2.5 mol%). The reaction was stirred at room temperature for 12 h and the solvent was removed under reduced pressure. Silica gel column chromatography of the crude product using petroleum ether/EtOAc (9 :1) as eluent gave the alcohol **17** (101 mg, 95%) as colorless oil. $[\alpha]_D^{25}$ +3.1 (*c* 1.0, $CHCl_3$). IR ($CHCl_3$): ν_{max} = 3431, 3018, 2952, 2929, 2856, 1645, 1470, 1363, 1256, 1084, 923, 837, 830, 810, 668 cm^{-1}. ^1H NMR (400 MHz, $CDCl_3$): δ = 5.58–5.45 (m, 1H), 5.45–5.32 (m, 1H), 4.21–4.14 (m, 1H), 3.99–3.87 (m, 1H), 3.84–3.69 (m, 4H), 2.24–2.14 (m, 1H), 2.13–1.96 (m, 4H), 1.94–1.66 (m, 3H), 0.95 (t, *J* = 7.4 Hz, 3H), 0.89 (s, 9H), 0.88 (s, 9H), 0.10–0.03 (m, 12H) ppm. $^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$): δ = 134.9, 124.7, 79.8, 79.6, 73.1, 71.7, 60.6, 37.0, 34.7, 32.7, 25.9, 25.8, 18.3, 18.1, 13.7, –4.7, –5.1, –5.3 ppm. HRMS (ESI-TOF) *m/z*: $[M + Na]^+$ Calcd for $C_{24}H_{50}O_4Si_2Na$ 481.3140; Found 481.3136.

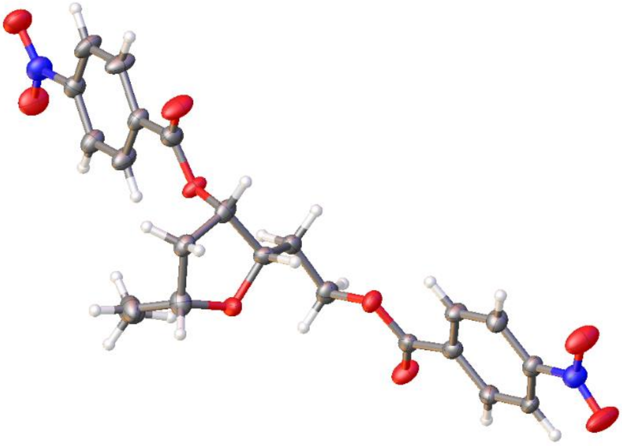
(2*R*,3*R*,5*R*)-5-((*R*,*E*)-1-Bromohex-3-en-1-yl)-2-(2-hydroxyethyl)tetrahydrofuran-3-ol (11):[5]

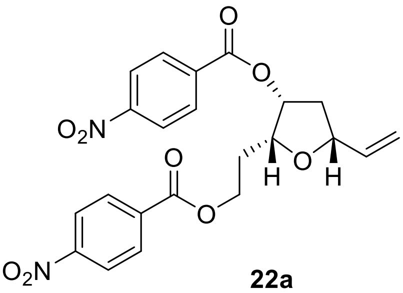


To a solution of **17** (0.15 g, 0.327 mmol) in benzene (10 mL) was added Ph_3P (0.343 g, 1.31 mmol, 4.0 equiv), 2,6-di-*tert*butylpyridine (0.251 g, 1.31 mmol, 4.0 equiv) and a solution of CBr_4 (0.434 g, 1.31 mmol, 4.0 equiv) in CH_2Cl_2 (5 mL) at 0 °C and the mixture then heated to 40 °C for 20 min. The reaction mixture was cooled to room temperature and diluted with petroleum ether/EtOAc (9:1) and the solution passed through a pad of silica gel. The filtrate was concentrated to afford bromo intermediate (172 mg) as colorless oil. This was used immediately for next step.

To a stirred solution of above bromo intermediate (172 mg) in THF (5 mL) was added 2 M solution of TBAF (0.33 mL, 2 M solution in THF, 0.654 mmol, 2.0 equiv) at 0 °C and the mixture stirred for 3 h at room temperature. The reaction mixture was quenched by few drops of Et_3N and the solvent evaporated under reduced pressure. Silica gel column chromatography of the crude product using petroleum ether/EtOAc (1 :1) as eluent gave **11** (39.3 mg, 41%) as colorless syrup. $[\alpha]_D^{25}$ –5.3 (*c* 0.25, $CHCl_3$). lit.[7] $[\alpha]_D^{25}$ –5.6 (*c* 0.2, $CHCl_3$). IR ($CHCl_3$): ν_{max} = 3646, 3393, 2929, 2864, 1679, 1458, 1264, 1107, 810, 715 cm^{-1}. ^1H NMR (400 MHz, $CDCl_3$): δ = 5.60 (dt, *J* = 15.2, 6.4 Hz, 1H), 5.45(dt, *J* = 15.2, 7.0 Hz, 1H), 4.27–4.25 (m, 1H), 4.08–3.98 (m, 2H), 3.91–3.76 (m, 3H), 2.71–2.59 (m, 2H), 2.40 (ddd,*J* = 15.0, 8.4, 6.4 Hz, 1H), 2.08–1.94 (m, 4H), 1.86 (ddd, *J* = 14.4, 6.0, 1.6 Hz, 1H), 0.98 (t, *J* = 7.5 Hz, 3H) ppm. $^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$): δ = 136.0, 124.8, 82.9, 79.2, 72.7, 60.4, 59.3, 39.0, 38.7, 30.9, 25.5, 13.6 ppm. HRMS (ESI-TOF) *m*/*z*: $[M + H]^+$ Calcd for $C_{12}H_{22}BrO_3$ 293.0747; Found 293.0746.

X-ray Data for compound 22a





22a

Compound 22a

Table S1 Crystal data and structure refinement for 22a

CCDC No	2190737
Identification code	RAF-RAM-061_Mo
Empirical formula	$C_{22}H_{21}N_2O_9$
Formula weight	457.41
Temperature/K	150
Crystal system	monoclinic
Space group	$P2_1/n$
a/Å	7.0311(7)
b/Å	41.153(3)
c/Å	7.9883(11)
α/°	90
β/°	112.911(14)
γ/°	90
Volume/Å^3	2129.1(4)
Z	4
ρ_{calc}g/cm^3	1.427
μ/mm^{-1}	0.112
F(000)	956.0
Crystal size/mm^3	0.19 × 0.12 × 0.09
Radiation	MoKα (λ = 0.71073)
2Θ range for data collection/°	3.958 to 49.998
Index ranges	$-7 \leq h \leq 8$, $-48 \leq k \leq 48$, $-9 \leq l \leq 9$
Reflections collected	8643
Independent reflections	3679 [R_{int} = 0.1019, R_{sigma} = 0.1479]
Data/restraints/parameters	3679/0/299
Goodness-of-fit on F^2	1.011
Final R indexes [I>=2σ (I)]	R_1 = 0.0849, wR_2 = 0.2095
Final R indexes [all data]	R_1 = 0.1676, wR_2 = 0.3167
Largest diff. peak/hole / e Å^{-3}	0.52/-0.49

Table S5 Bond Lengths for 22a

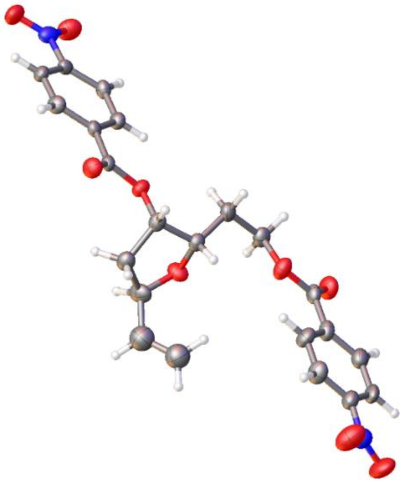
Atom	Atom	Length/Å	Atom	Atom	Length/Å
O001	C00D	1.343(6)	C00F	C00N	1.380(7)
O001	C00Q	1.451(6)	C00G	C00K	1.387(7)
O002	C00T	1.440(7)	C00G	C00N	1.383(7)
O002	C00U	1.440(6)	C00H	C00P	1.398(7)
O003	C00E	1.338(6)	C00H	C00W	1.408(8)
O003	C00L	1.462(6)	C00I	C00K	1.393(7)
O004	C00D	1.201(6)	C00J	C00M	1.388(8)
O005	C00E	1.202(7)	C00J	C00X	1.369(7)
O006	N00A	1.224(6)	C00L	C00R	1.523(8)
O007	N00A	1.228(6)	C00L	C00U	1.503(7)
O008	N009	1.226(6)	C00M	C00P	1.382(8)
N009	O00B	1.215(6)	C00O	C00T	1.472(8)

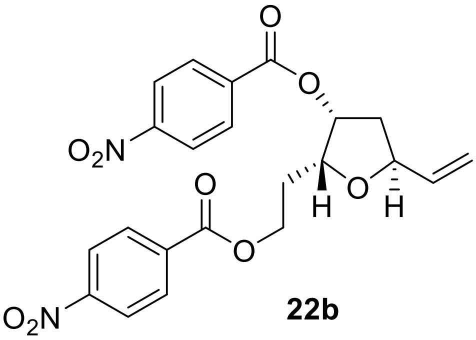
N009	C00F	1.461(7)	C00O	C00V	1.331(8)
N00A	C00J	1.472(7)	C00Q	C00S	1.511(7)
C00C	C00F	1.382(7)	C00R	C00T	1.560(8)
C00C	C00I	1.384(7)	C00S	C00U	1.501(8)
C00D	C00K	1.515(8)	C00W	C00X	1.376(8)
C00E	C00H	1.488(8)			

Table S6 Bond Angles for 22a

Atom	Atom	Atom	Angle/˚	Atom	Atom	Atom	Angle/˚
C00D	O001	C00Q	115.5(4)	C00M	C00J	N00A	117.5(5)
C00U	O002	C00T	111.0(4)	C00X	C00J	N00A	119.2(5)
C00E	O003	C00L	117.6(4)	C00X	C00J	C00M	123.2(5)
O008	N009	C00F	118.6(5)	C00G	C00K	C00D	122.2(5)
O00B	N009	O008	121.8(5)	C00G	C00K	C00I	121.0(5)
O00B	N009	C00F	119.6(5)	C00I	C00K	C00D	116.8(5)
O006	N00A	O007	123.5(5)	O003	C00L	C00R	108.4(4)
O006	N00A	C00J	118.1(5)	O003	C00L	C00U	107.5(4)
O007	N00A	C00J	118.4(5)	C00U	C00L	C00R	102.9(5)
C00F	C00C	C00I	117.9(5)	C00P	C00M	C00J	117.9(5)
O001	C00D	C00K	111.1(5)	C00F	C00N	C00G	118.6(5)
O004	C00D	O001	124.2(5)	C00V	C00O	C00T	125.1(6)
O004	C00D	C00K	124.6(5)	C00M	C00P	C00H	120.5(5)
O003	C00E	C00H	111.3(5)	O001	C00Q	C00S	106.6(4)
O005	C00E	O003	124.4(5)	C00L	C00R	C00T	103.7(4)
O005	C00E	C00H	124.3(5)	C00U	C00S	C00Q	113.9(4)
C00C	C00F	N009	118.3(5)	O002	C00T	C00O	111.8(5)
C00N	C00F	N009	118.6(5)	O002	C00T	C00R	104.9(4)
C00N	C00F	C00C	123.2(5)	C00O	C00T	C00R	114.0(5)
C00N	C00G	C00K	119.5(5)	O002	C00U	C00L	106.9(5)
C00P	C00H	C00E	118.8(5)	O002	C00U	C00S	108.2(4)
C00P	C00H	C00W	119.5(5)	C00S	C00U	C00L	117.6(5)
C00W	C00H	C00E	121.7(5)	C00X	C00W	C00H	120.1(5)
C00C	C00I	C00K	119.9(5)	C00J	C00X	C00W	118.8(5)

X-ray data for compound 22b





22b

Compound 22b

Table S1 Crystal data and structure refinement for 22b

CCDC No	2190081
Identification code	RAF-RAM-040_Mo
Empirical formula	$C_{22}H_{19.52}N_2O_9$
Formula weight	455.92
Temperature/K	150.0
Crystal system	monoclinic
Space group	$P2_1$
a/Å	14.892(2)
b/Å	4.6144(5)
c/Å	16.629(2)
α/°	90
β/°	114.720(18)
γ/°	90
Volume/Å^3	1038.0(3)
Z	2
ρ_{calc}g/cm^3	1.459
μ/mm^{-1}	0.115
F(000)	475.0
Crystal size/mm^3	0.2 × 0.18 × 0.02
Radiation	MoKα (λ = 0.71073)
2Θ range for data collection/°	4.81 to 49.988
Index ranges	$-17 \leq h \leq 16$, $-5 \leq k \leq 5$, $-19 \leq l \leq 19$
Reflections collected	9785
Independent reflections	3601 [R_{int} = 0.0819, R_{sigma} = 0.1167]
Data/restraints/parameters	3601/26/318
Goodness-of-fit on F^2	1.009
Final R indexes [I>=2σ (I)]	R_1 = 0.0645, wR_2 = 0.1046
Final R indexes [all data]	R_1 = 0.1155, wR_2 = 0.1347
Largest diff. peak/hole / e Å^{-3}	0.23/-0.26
Flack parameter	-0.9(10)

Table S2 Bond Lengths for 22b

Atom	Atom	Length/Å	Atom	Atom	Length/Å
O001	C00B	1.354(7)	N00E	C00U	1.482(9)
O001	C00S	1.455(7)	C00H	C00J	1.522(8)
O002	C00B	1.207(7)	C00H	C00K	1.504(8)
O003	C00K	1.431(7)	C00I	C00N	1.493(9)
O003	C00V	1.460(7)	C00K	C00S	1.524(8)
O004	C00I	1.342(7)	C00L	C00N	1.383(9)
O004	C00J	1.457(7)	C00L	C00R	1.379(9)
O005	N008	1.235(6)	C00M	C00P	1.370(8)
O006	C00I	1.202(7)	C00N	C00Q	1.388(8)
O007	N008	1.227(7)	C00O	C00Q	1.378(9)
N008	C00D	1.481(8)	C00O	C00U	1.376(9)
O009	N00E	1.217(7)	C00R	C00U	1.363(9)
C00A	C00D	1.375(8)	C00S	C00T	1.531(8)
C00A	C00F	1.394(8)	C00T	C00V	1.539(8)
C00B	C00C	1.490(8)	C00V	C00W	1.547(19)
C00C	C00F	1.401(8)	C00V	C1	1.414(18)
C00C	C00P	1.401(8)	C00W	C00X	1.419(19)
C00D	C00M	1.378(8)	C1	C00Y	1.25(4)
N00E	O00G	1.240(8)			

Table S3 Bond Angles for 22b

Atom	Atom	Atom	Angle/˚	Atom	Atom	Atom	Angle/˚
C00B	O001	C00S	115.9(4)	O003	C00K	C00S	104.1(5)
C00K	O003	C00V	107.9(5)	C00H	C00K	C00S	117.9(5)
C00I	O004	C00J	116.1(5)	C00R	C00L	C00N	120.6(7)
O005	N008	C00D	118.1(5)	C00P	C00M	C00D	118.6(6)
O007	N008	O005	124.5(6)	C00L	C00N	C00I	118.9(6)
O007	N008	C00D	117.4(6)	C00L	C00N	C00Q	119.9(7)
C00D	C00A	C00F	118.1(6)	C00Q	C00N	C00I	121.2(6)
O001	C00B	C00C	111.5(5)	C00U	C00O	C00Q	118.9(7)
O002	C00B	O001	123.6(6)	C00M	C00P	C00C	120.3(6)
O002	C00B	C00C	124.9(6)	C00O	C00Q	C00N	119.7(6)
C00F	C00C	C00B	117.8(5)	C00U	C00R	C00L	118.3(7)
C00F	C00C	C00P	119.8(6)	O001	C00S	C00K	106.2(5)
C00P	C00C	C00B	122.4(6)	O001	C00S	C00T	111.9(5)
C00A	C00D	N008	117.7(6)	C00K	C00S	C00T	101.9(5)
C00A	C00D	C00M	123.3(6)	C00S	C00T	C00V	105.8(5)
C00M	C00D	N008	119.0(6)	C00O	C00U	N00E	117.8(6)
O009	N00E	O00G	124.3(7)	C00R	C00U	N00E	119.5(6)
O009	N00E	C00U	117.7(6)	C00R	C00U	C00O	122.6(7)
O00G	N00E	C00U	118.0(6)	O003	C00V	C00T	104.9(5)
C00A	C00F	C00C	119.8(6)	O003	C00V	C00W	101.8(8)
C00K	C00H	C00J	111.8(5)	C00T	C00V	C00W	110.8(7)
O004	C00I	C00N	112.0(6)	C1	C00V	O003	120.2(13)
O006	C00I	O004	123.5(6)	C1	C00V	C00T	117.9(9)
O006	C00I	C00N	124.5(6)	C00X	C00W	C00V	118.7(16)
O004	C00J	C00H	107.5(5)	C00Y	C1	C00V	120(3)
O003	C00K	C00H	109.9(5)				

References:

1. (a) H. Becker and K. B. Sharpless, *Angew. Chem. Int. Ed.* 1996, **35**, 448; (b) H. C. Kolb, M. S. VanNieuwenhze, and K. B. Sharpless, *Chem. Rev*. 1994, **94**, 2483; (c) M. Neumeyer and R. Brückner, *Eur. J. Org. Chem.* 2016, 5060.
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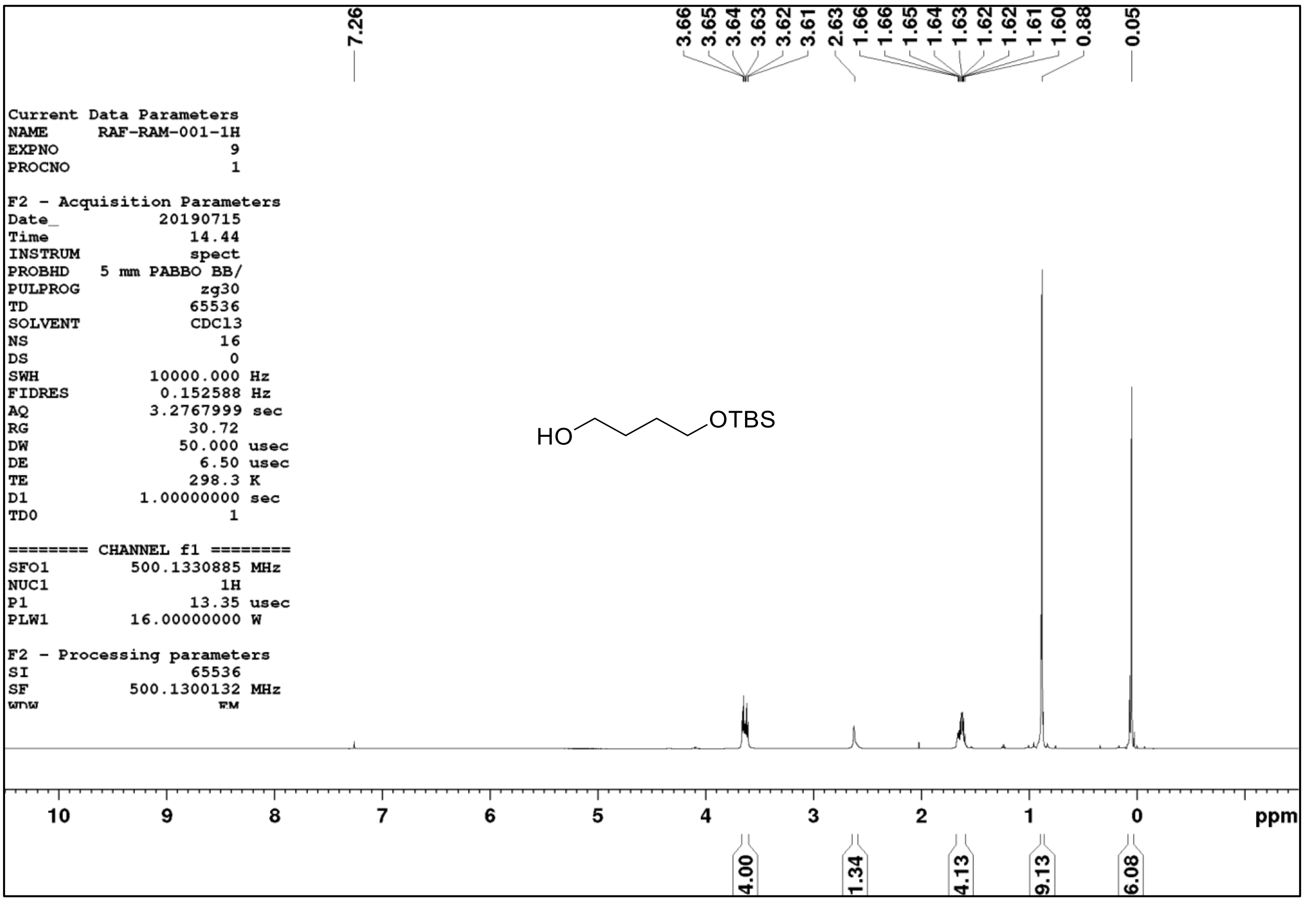
^{1}H NMR(500 MHz, CDCl$_3$) and ^{13}C{^{1}H} NMR(125 MHz, CDCl$_3$) of compound **18**



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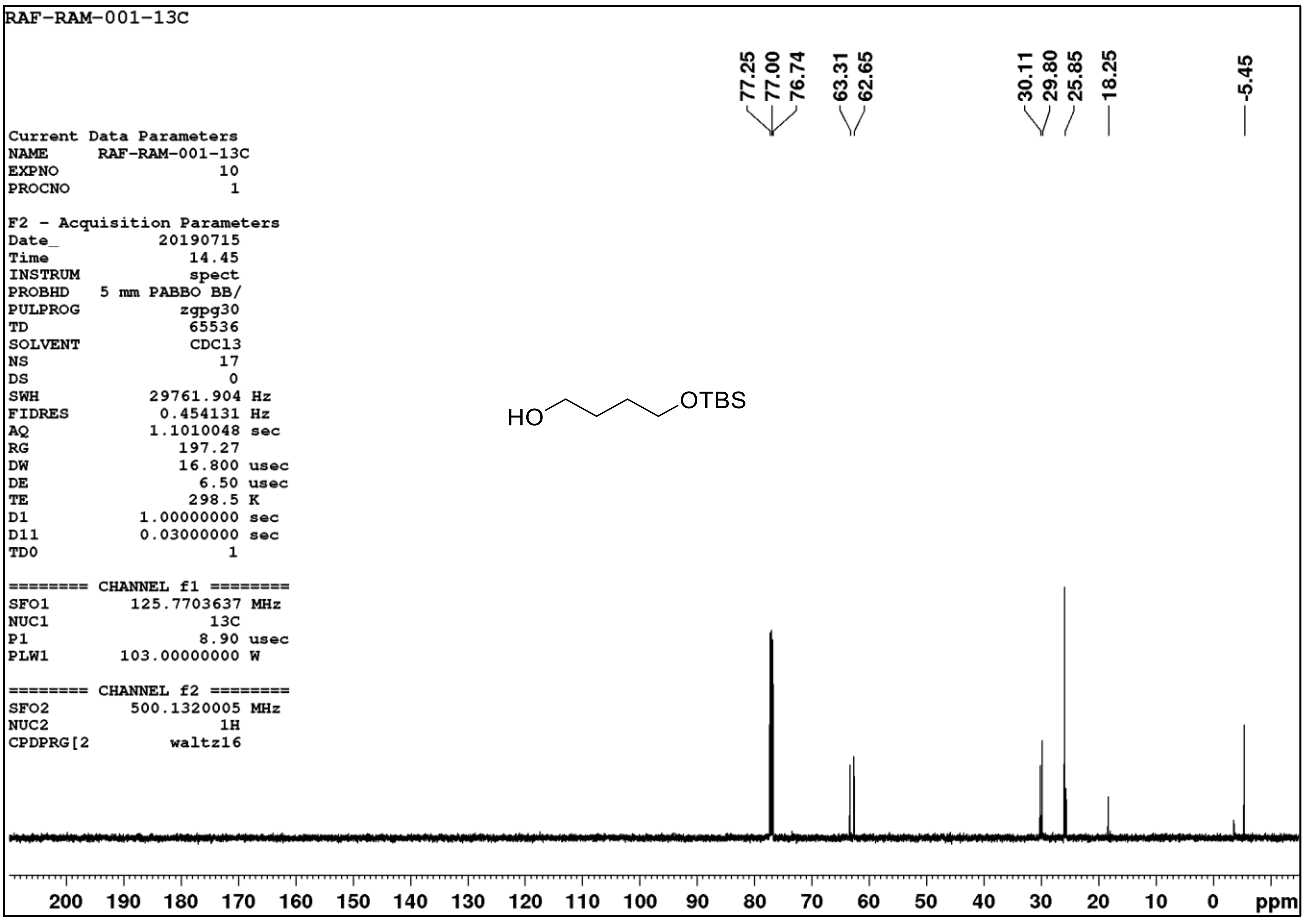

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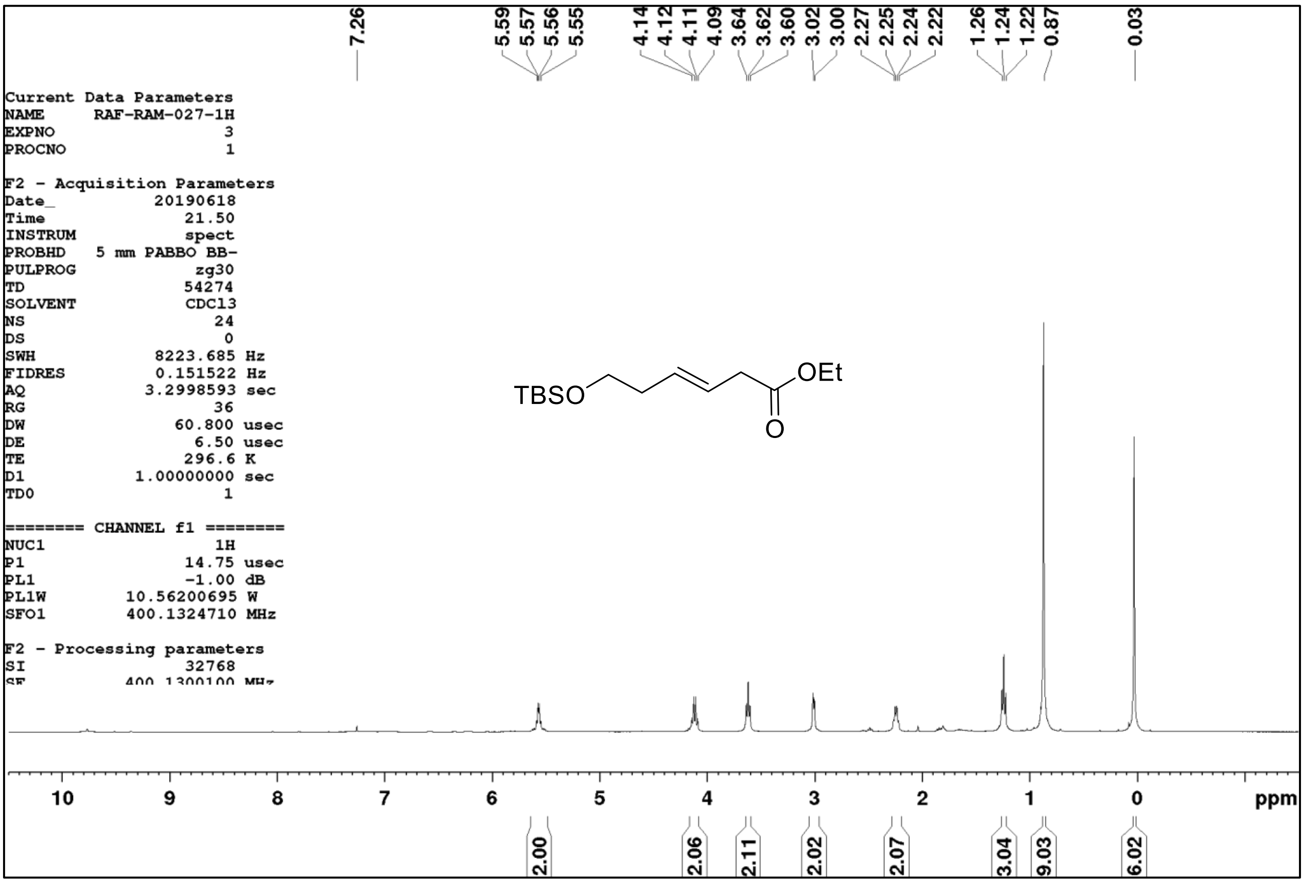
TD0                   1

======== CHANNEL f1 ========
SFO1        125.7703637 MHz
NUC1                13C
P1                 8.90 usec
PLW1       103.00000000 W

======== CHANNEL f2 ========
SFO2        500.1320005 MHz
NUC2                 1H
CPDPRG[2        waltz16
```

^1H NMR(400 MHz, $CDCl_3$) and $^{13}C\{^1H\}$ NMR(100 MHz, $CDCl_3$) of compound **19**

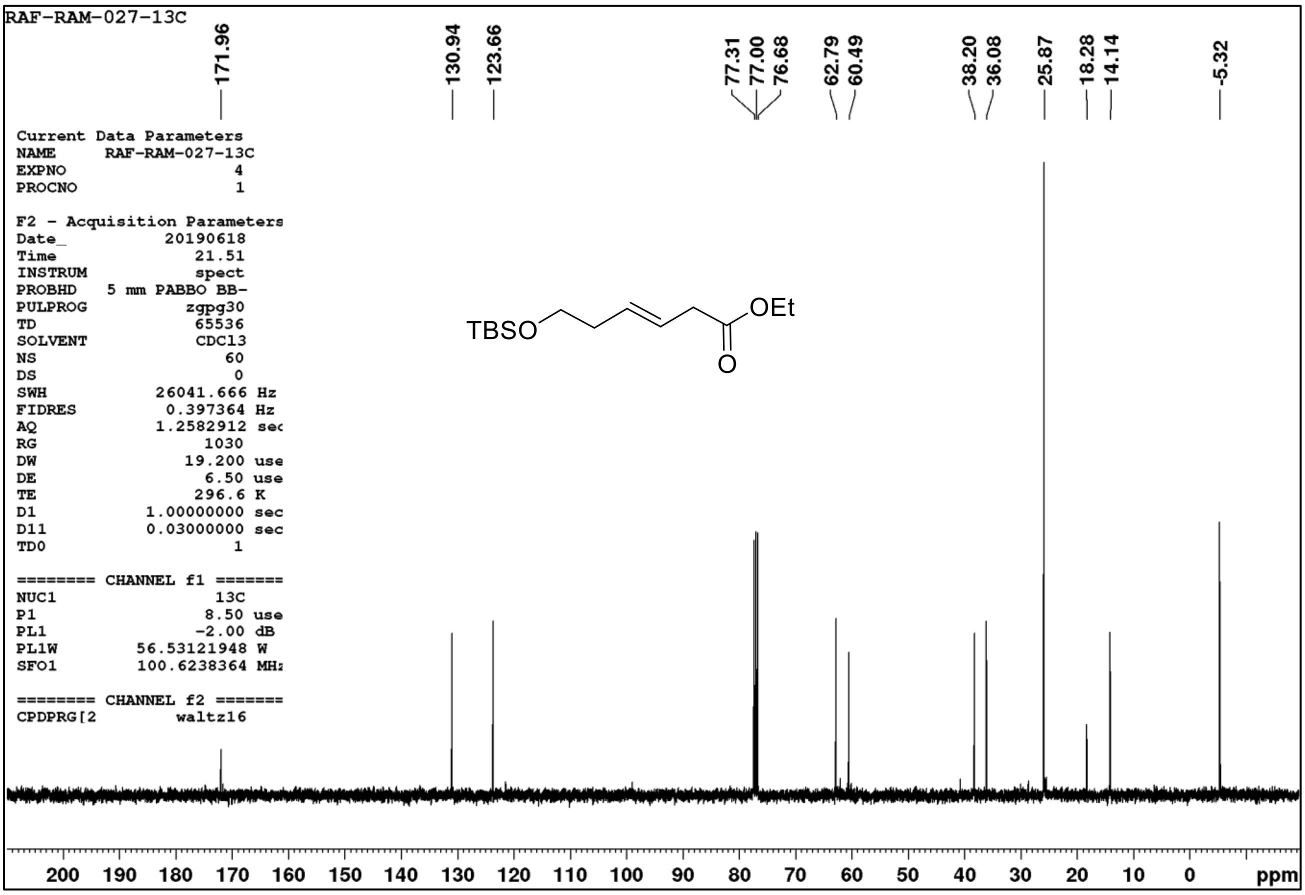


```
Current Data Parameters
NAME      RAF-RAM-027-1H
EXPNO                  3
PROCNO                 1

F2 - Acquisition Parameters
Date_           20190618
Time               21.50
INSTRUM            spect
PROBHD   5 mm PABBO BB-
PULPROG             zg30
TD                 54274
SOLVENT            CDCl3
NS                    24
DS                     0
SWH             8223.685 Hz
FIDRES          0.151522 Hz
AQ             3.2998593 sec
RG                    36
DW                60.800 usec
DE                  6.50 usec
TE                 296.6 K
D1            1.00000000 sec
TD0                    1

======== CHANNEL f1 ========
NUC1                  1H
P1                 14.75 usec
PL1                -1.00 dB
PL1W         10.56200695 W
SFO1         400.1324710 MHz

F2 - Processing parameters
SI                 32768
SF           400.1300100 MHz
```



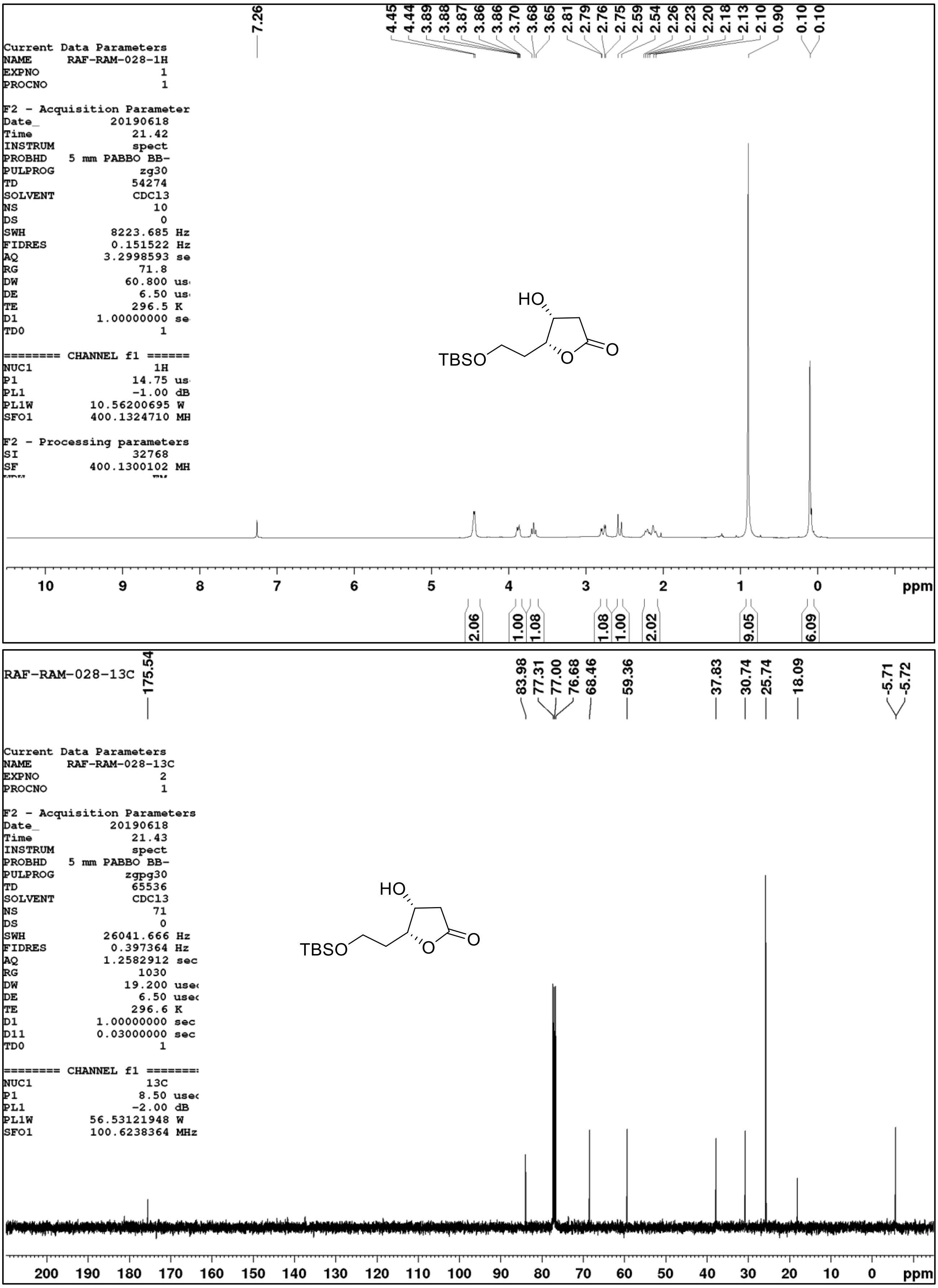
```
Current Data Parameters
NAME      RAF-RAM-027-13C
EXPNO                   4
PROCNO                  1

F2 - Acquisition Parameters
Date_            20190618
Time                21.51
INSTRUM             spect
PROBHD   5 mm PABBO BB-
PULPROG           zgpg30
TD                  65536
SOLVENT             CDCl3
NS                     60
DS                      0
SWH             26041.666 Hz
FIDRES           0.397364 Hz
AQ              1.2582912 se
RG                   1030
DW                 19.200 use
DE                   6.50 use
TE                  296.6 K
D1             1.00000000 sec
D11            0.03000000 sec
TD0                     1

======== CHANNEL f1 =======
NUC1                  13C
P1                   8.50 use
PL1                 -2.00 dB
PL1W          56.53121948 W
SFO1          100.6238364 MH

======== CHANNEL f2 =======
CPDPRG[2          waltz16
```

^{1}H NMR(400 MHz, $CDCl_3$) and $^{13}C\{^{1}H\}$ NMR(100 MHz, $CDCl_3$) of compound **9a**



```
Current Data Parameters
NAME     RAF-RAM-028-1H
EXPNO                 1
PROCNO                1

F2 - Acquisition Parameter
Date_          20190618
Time              21.42
INSTRUM           spect
PROBHD   5 mm PABBO BB-
PULPROG            zg30
TD                54274
SOLVENT           CDCl3
NS                   10
DS                    0
SWH            8223.685 Hz
FIDRES         0.151522 Hz
AQ            3.2998593 se
RG                 71.8
DW               60.800 us
DE                 6.50 us
TE                296.5 K
D1           1.00000000 se
TD0                   1

======== CHANNEL f1 ======
NUC1                 1H
P1                14.75 us
PL1               -1.00 dB
PL1W        10.56200695 W
SFO1        400.1324710 MH

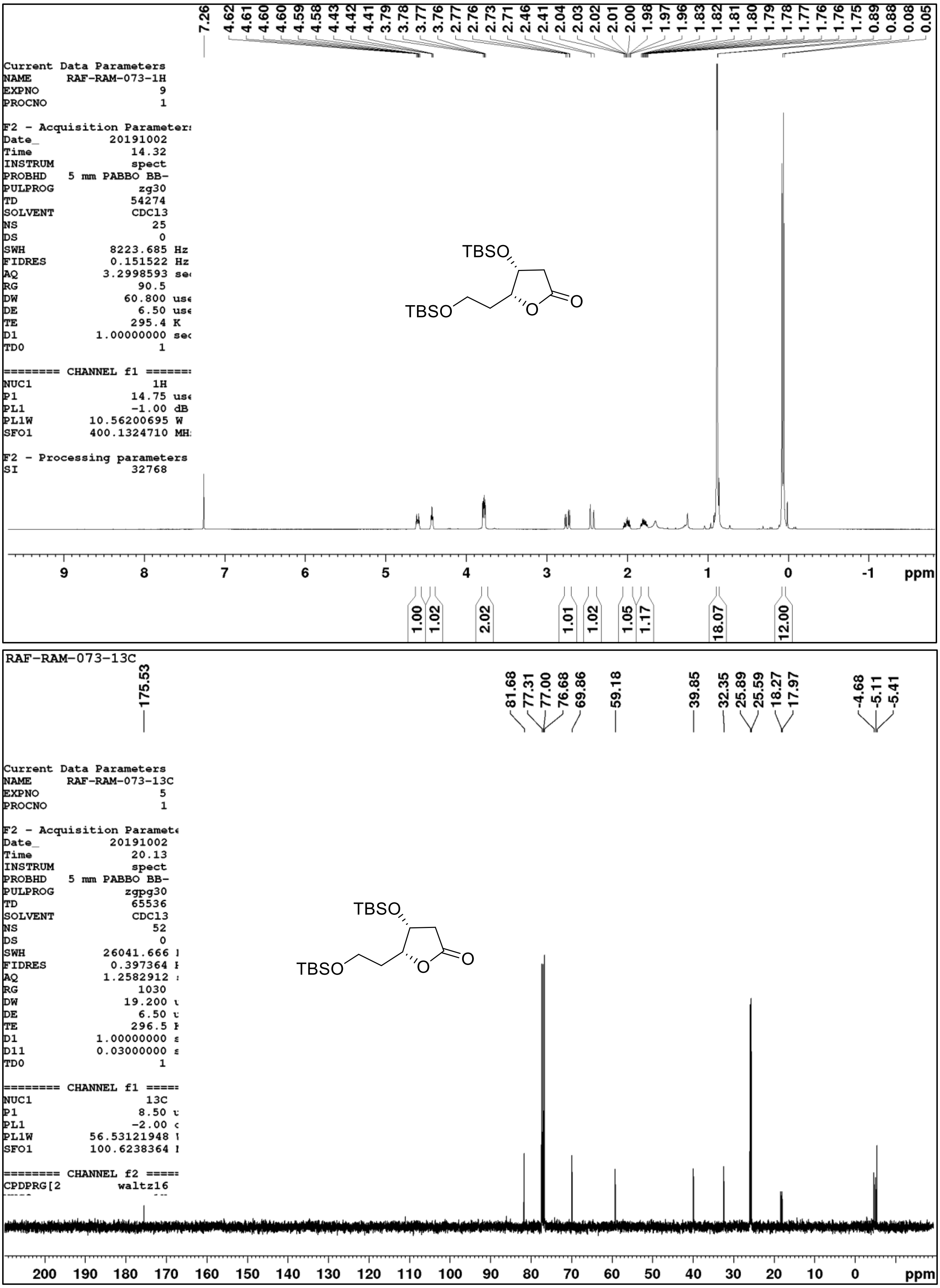
F2 - Processing parameters
SI                32768
SF          400.1300102 MH
```

```
Current Data Parameters
NAME     RAF-RAM-028-13C
EXPNO                 2
PROCNO                1

F2 - Acquisition Parameters
Date_          20190618
Time              21.43
INSTRUM           spect
PROBHD   5 mm PABBO BB-
PULPROG          zgpg30
TD                65536
SOLVENT           CDCl3
NS                   71
DS                    0
SWH           26041.666 Hz
FIDRES         0.397364 Hz
AQ            1.2582912 sec
RG                 1030
DW               19.200 usec
DE                 6.50 usec
TE                296.6 K
D1           1.00000000 sec
D11          0.03000000 sec
TD0                   1

======== CHANNEL f1 ========
NUC1                13C
P1                 8.50 usec
PL1               -2.00 dB
PL1W        56.53121948 W
SFO1        100.6238364 MHz
```

^{1}H NMR(400 MHz, CDCl$_3$) and ^{13}C{^{1}H} NMR(100 MHz, CDCl$_3$) of compound **9b**



```
Current Data Parameters
NAME     RAF-RAM-073-1H
EXPNO                 9
PROCNO                1

F2 - Acquisition Parameter
Date_          20191002
Time              14.32
INSTRUM           spect
PROBHD   5 mm PABBO BB-
PULPROG            zg30
TD                54274
SOLVENT           CDCl3
NS                   25
DS                    0
SWH           8223.685 Hz
FIDRES        0.151522 Hz
AQ           3.2998593 se
RG                 90.5
DW               60.800 us
DE                 6.50 us
TE                295.4 K
D1          1.00000000 se
TD0                   1

======== CHANNEL f1 ======
NUC1                 1H
P1                14.75 us
PL1               -1.00 dB
PL1W        10.56200695 W
SFO1        400.1324710 MH

F2 - Processing parameters
SI                32768
```

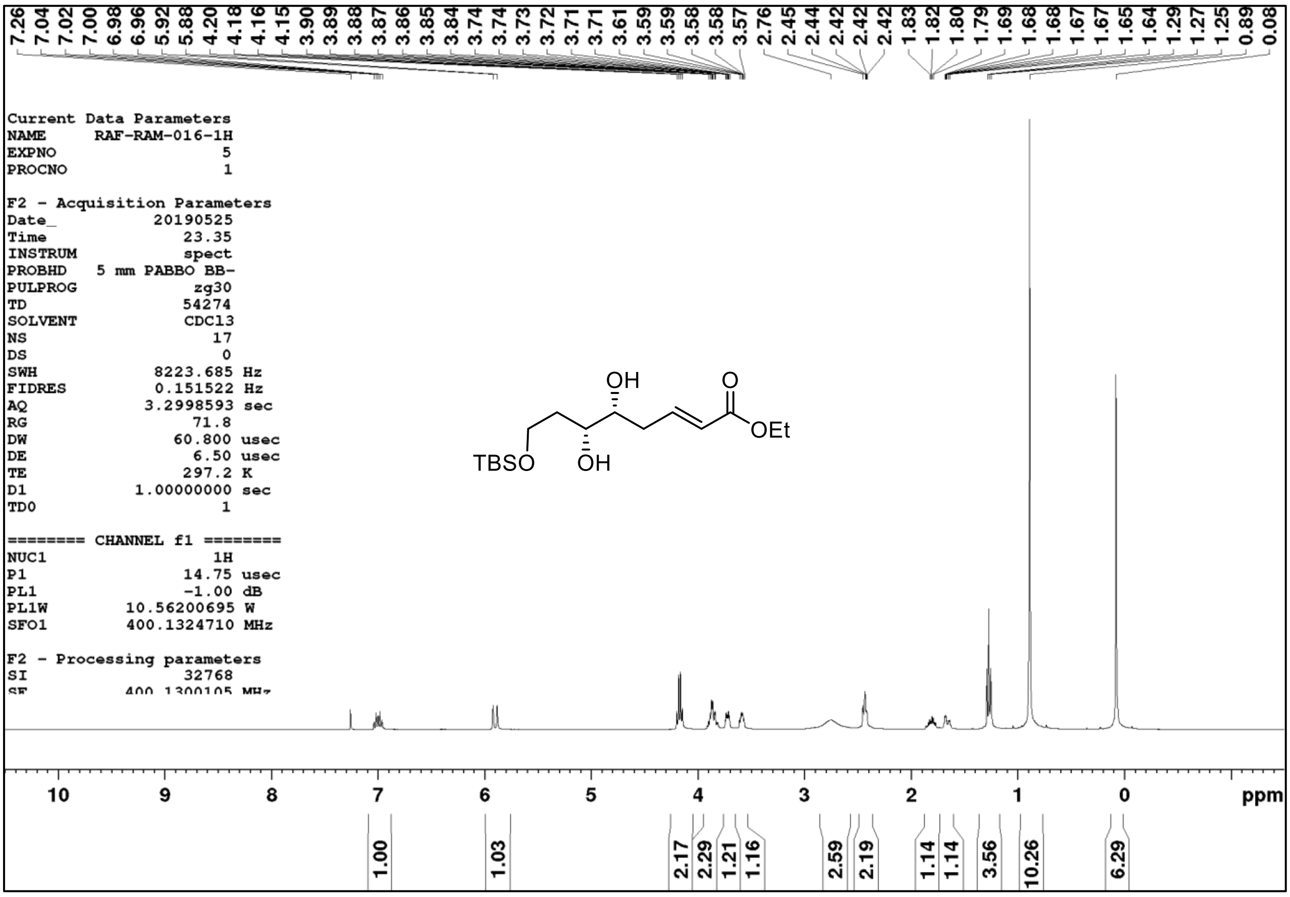
```
Current Data Parameters
NAME    RAF-RAM-073-13C
EXPNO                 5
PROCNO                1

F2 - Acquisition Paramete
Date_          20191002
Time              20.13
INSTRUM           spect
PROBHD   5 mm PABBO BB-
PULPROG          zgpg30
TD                65536
SOLVENT           CDCl3
NS                   52
DS                    0
SWH          26041.666 H
FIDRES        0.397364 H
AQ           1.2582912 s
RG                 1030
DW               19.200 u
DE                 6.50 u
TE                296.5 K
D1          1.00000000 s
D11         0.03000000 s
TD0                   1

======== CHANNEL f1 ====
NUC1                13C
P1                 8.50 u
PL1               -2.00 d
PL1W        56.53121948 W
SFO1        100.6238364 M

======== CHANNEL f2 ====
CPDPRG[2        waltz16
```

^{1}H NMR(400 MHz, $CDCl_3$) and $^{13}C\{^1H\}$ NMR(100 MHz, $CDCl_3$) of compound **20a**

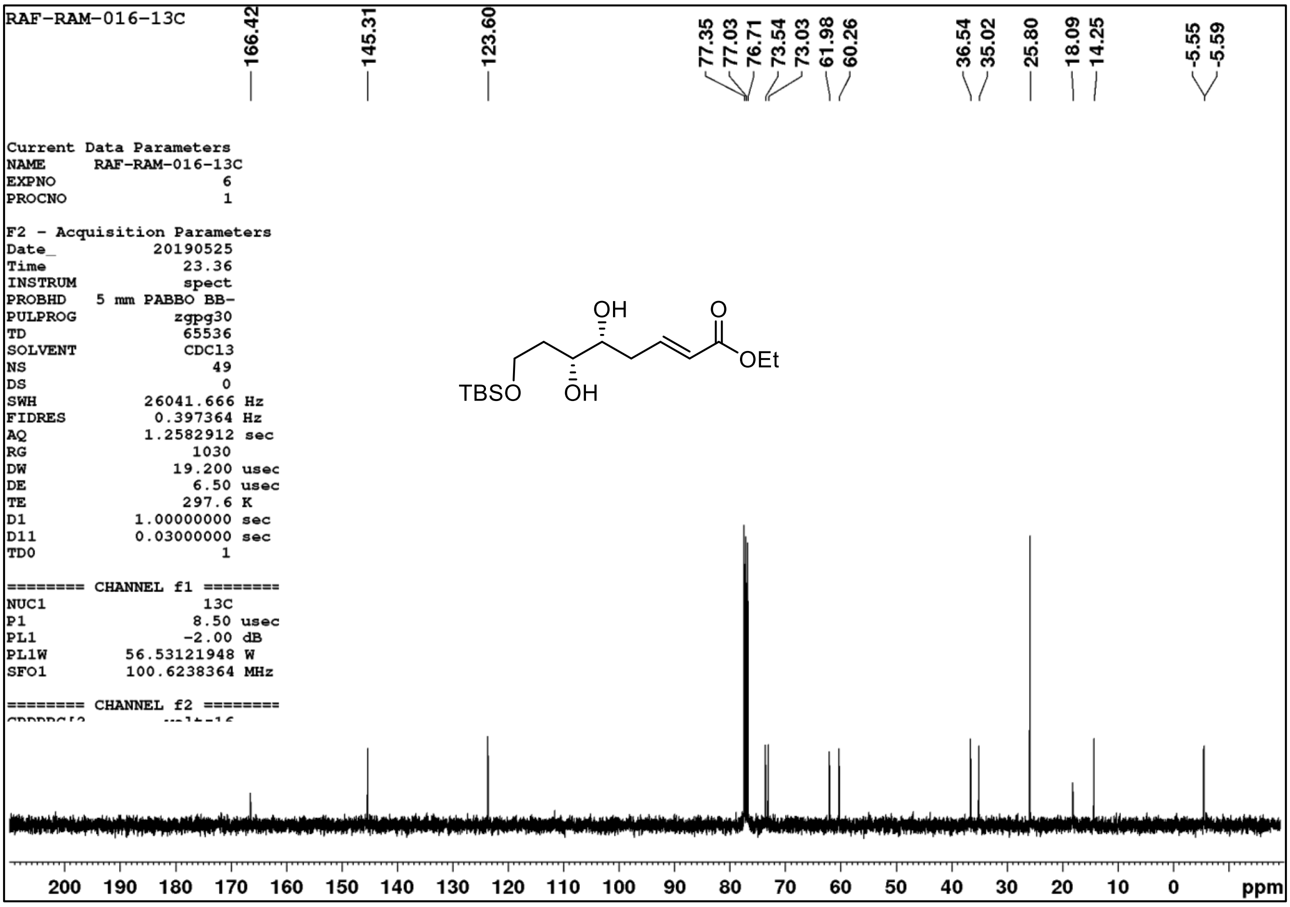


```
Current Data Parameters
NAME      RAF-RAM-016-1H
EXPNO                  5
PROCNO                 1

F2 - Acquisition Parameters
Date_           20190525
Time               23.35
INSTRUM            spect
PROBHD   5 mm PABBO BB-
PULPROG             zg30
TD                 54274
SOLVENT            CDCl3
NS                    17
DS                     0
SWH             8223.685 Hz
FIDRES          0.151522 Hz
AQ             3.2998593 sec
RG                  71.8
DW                60.800 usec
DE                  6.50 usec
TE                 297.2 K
D1            1.00000000 sec
TD0                    1

======== CHANNEL f1 ========
NUC1                  1H
P1                 14.75 usec
PL1                -1.00 dB
PL1W         10.56200695 W
SFO1         400.1324710 MHz

F2 - Processing parameters
SI                 32768
SF           400.1300105 MHz
```



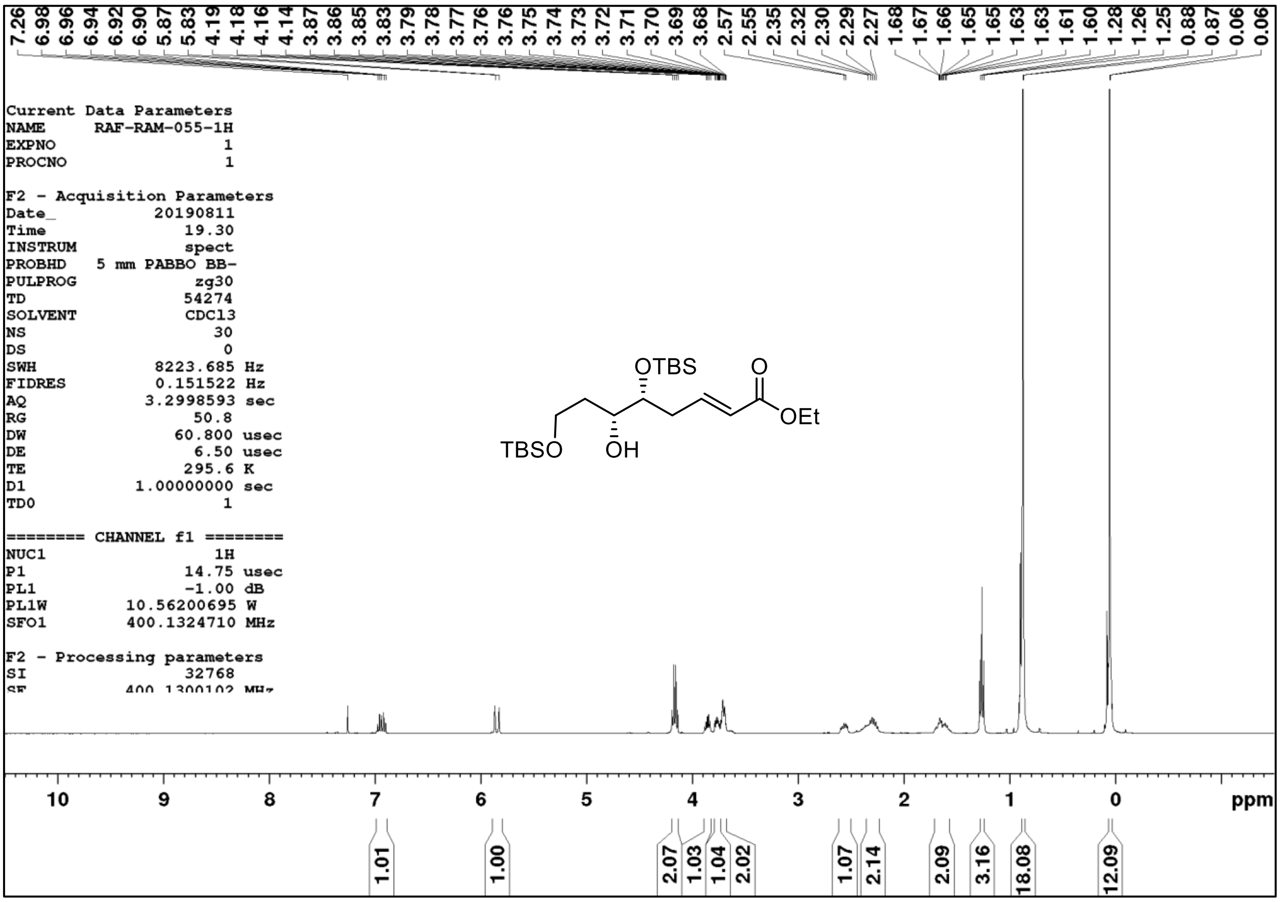
```
Current Data Parameters
NAME      RAF-RAM-016-13C
EXPNO                  6
PROCNO                 1

F2 - Acquisition Parameters
Date_           20190525
Time               23.36
INSTRUM            spect
PROBHD   5 mm PABBO BB-
PULPROG           zgpg30
TD                 65536
SOLVENT            CDCl3
NS                    49
DS                     0
SWH            26041.666 Hz
FIDRES          0.397364 Hz
AQ             1.2582912 sec
RG                  1030
DW                19.200 usec
DE                  6.50 usec
TE                 297.6 K
D1            1.00000000 sec
D11           0.03000000 sec
TD0                    1

======== CHANNEL f1 ========
NUC1                 13C
P1                  8.50 usec
PL1                -2.00 dB
PL1W         56.53121948 W
SFO1         100.6238364 MHz

======== CHANNEL f2 ========
```

^{1}H NMR(400 MHz, CDCl$_3$) and ^{13}C{^{1}H} NMR(100 MHz, CDCl$_3$) of compound **20b**

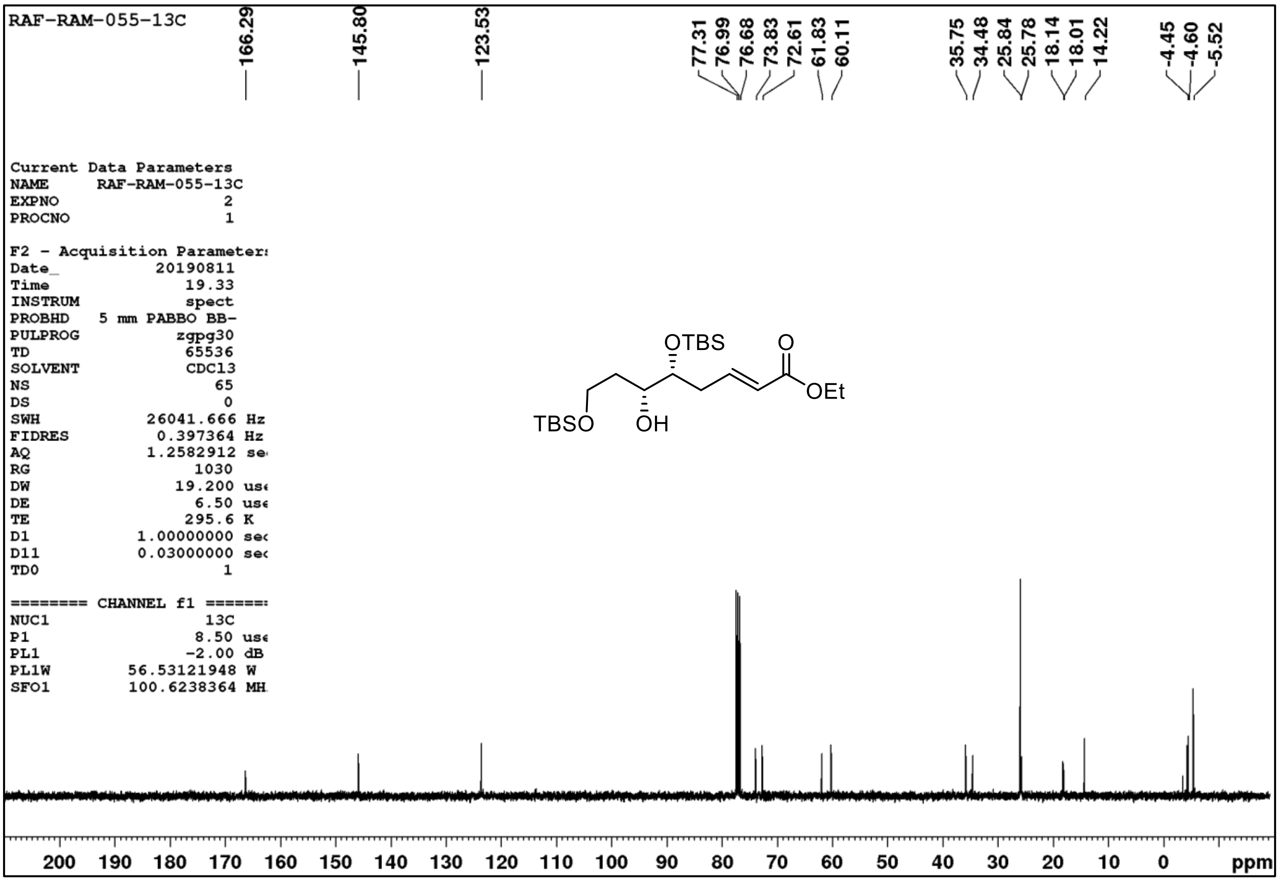


```
Current Data Parameters
NAME       RAF-RAM-055-1H
EXPNO                   1
PROCNO                  1

F2 - Acquisition Parameters
Date_            20190811
Time                19.30
INSTRUM             spect
PROBHD   5 mm PABBO BB-
PULPROG              zg30
TD                  54274
SOLVENT             CDCl3
NS                     30
DS                      0
SWH             8223.685 Hz
FIDRES          0.151522 Hz
AQ             3.2998593 sec
RG                   50.8
DW                 60.800 usec
DE                   6.50 usec
TE                  295.6 K
D1            1.00000000 sec
TD0                     1

======== CHANNEL f1 ========
NUC1                   1H
P1                  14.75 usec
PL1                 -1.00 dB
PL1W          10.56200695 W
SFO1          400.1324710 MHz

F2 - Processing parameters
SI                  32768
```



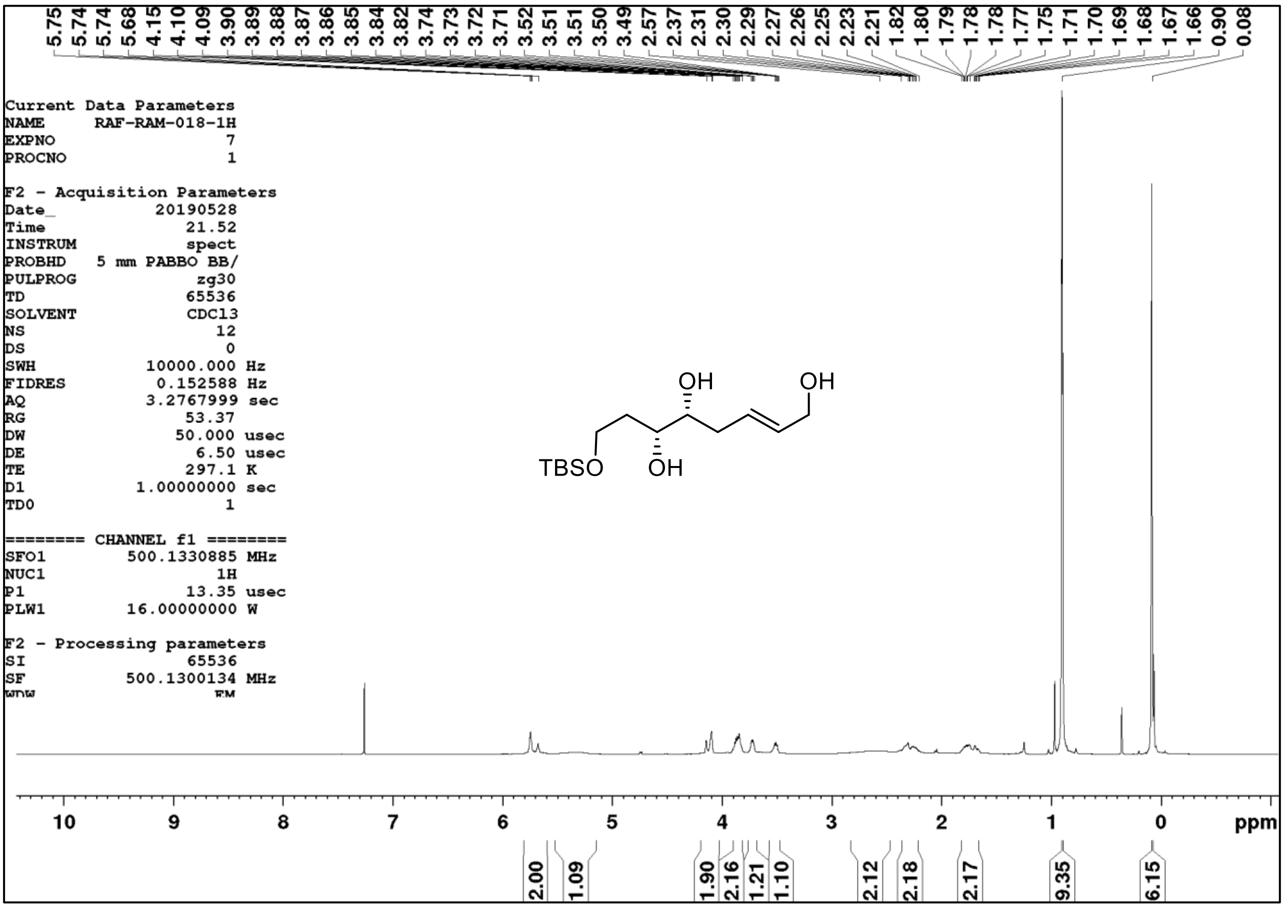
```
RAF-RAM-055-13C

Current Data Parameters
NAME       RAF-RAM-055-13C
EXPNO                   2
PROCNO                  1

F2 - Acquisition Parameter:
Date_            20190811
Time                19.33
INSTRUM             spect
PROBHD   5 mm PABBO BB-
PULPROG            zgpg30
TD                  65536
SOLVENT             CDCl3
NS                     65
DS                      0
SWH            26041.666 Hz
FIDRES          0.397364 Hz
AQ             1.2582912 se
RG                   1030
DW                 19.200 us
DE                   6.50 us
TE                  295.6 K
D1            1.00000000 se
D11           0.03000000 se
TD0                     1

======== CHANNEL f1 ======
NUC1                  13C
P1                   8.50 us
PL1                 -2.00 dB
PL1W          56.53121948 W
SFO1          100.6238364 MH
```

^{1}H NMR(500 MHz, $CDCl_3$) and $^{13}C\{^1H\}$ NMR(125 MHz, $CDCl_3$) of compound **21a**

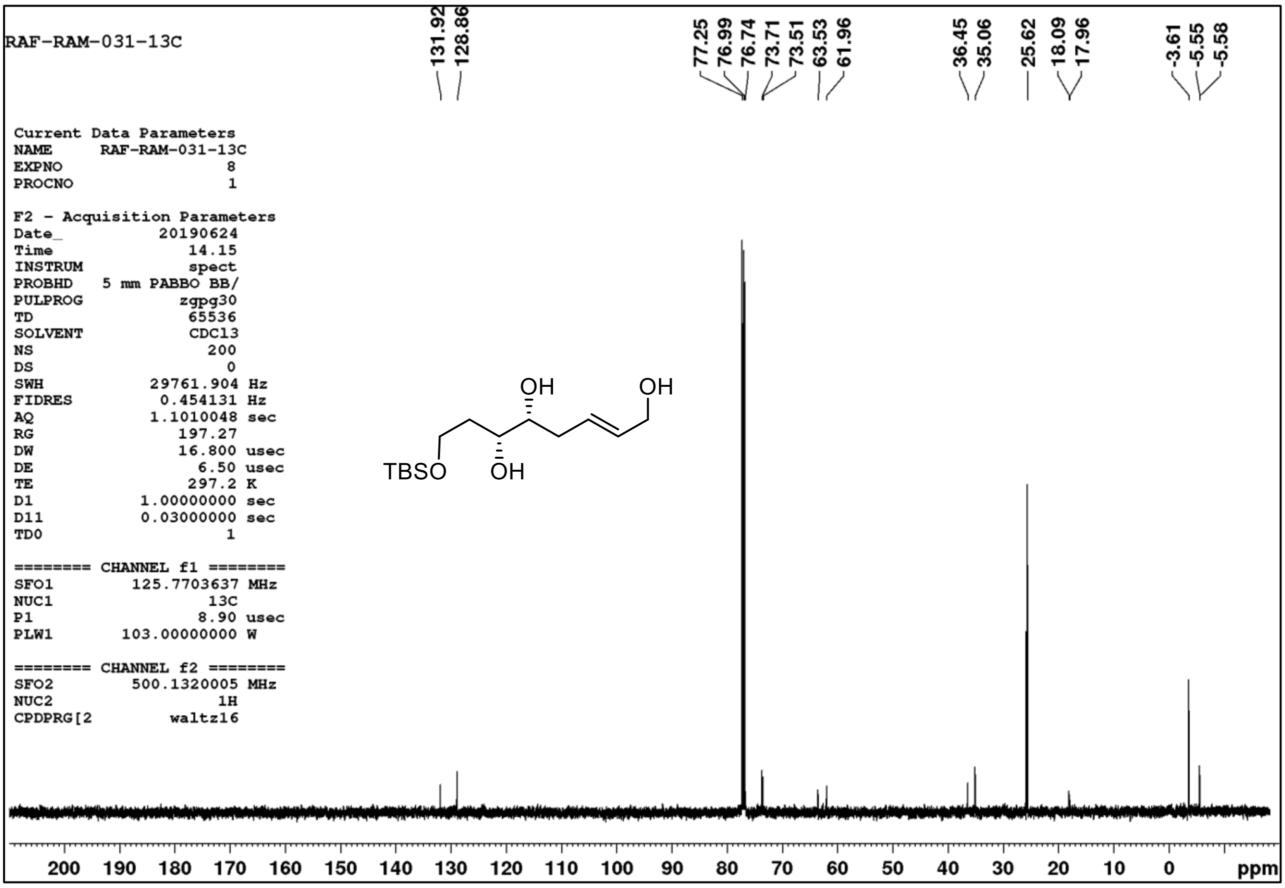


```
Current Data Parameters
NAME     RAF-RAM-018-1H
EXPNO                 7
PROCNO                1

F2 - Acquisition Parameters
Date_          20190528
Time              21.52
INSTRUM           spect
PROBHD   5 mm PABBO BB/
PULPROG            zg30
TD                65536
SOLVENT           CDCl3
NS                   12
DS                    0
SWH           10000.000 Hz
FIDRES         0.152588 Hz
AQ            3.2767999 sec
RG                53.37
DW               50.000 usec
DE                 6.50 usec
TE                297.1 K
D1           1.00000000 sec
TD0                   1

======== CHANNEL f1 ========
SFO1        500.1330885 MHz
NUC1                 1H
P1                13.35 usec
PLW1        16.00000000 W

F2 - Processing parameters
SI                65536
SF          500.1300134 MHz
```



```
RAF-RAM-031-13C

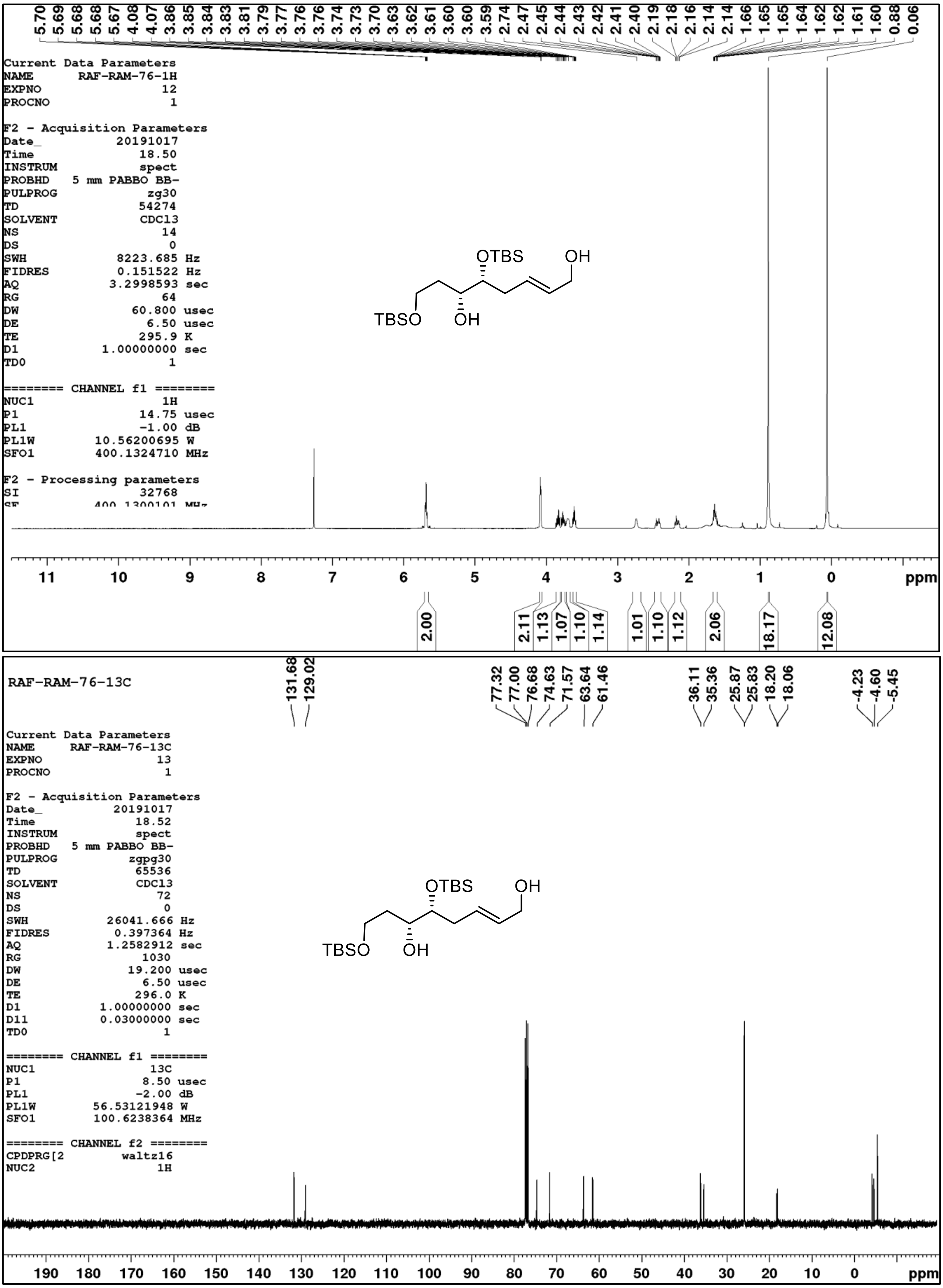
Current Data Parameters
NAME     RAF-RAM-031-13C
EXPNO                 8
PROCNO                1

F2 - Acquisition Parameters
Date_          20190624
Time              14.15
INSTRUM           spect
PROBHD   5 mm PABBO BB/
PULPROG          zgpg30
TD                65536
SOLVENT           CDCl3
NS                  200
DS                    0
SWH           29761.904 Hz
FIDRES         0.454131 Hz
AQ            1.1010048 sec
RG               197.27
DW               16.800 usec
DE                 6.50 usec
TE                297.2 K
D1           1.00000000 sec
D11          0.03000000 sec
TD0                   1

======== CHANNEL f1 ========
SFO1        125.7703637 MHz
NUC1                13C
P1                 8.90 usec
PLW1       103.00000000 W

======== CHANNEL f2 ========
SFO2        500.1320005 MHz
NUC2                 1H
CPDPRG[2        waltz16
```

^{1}H NMR(400 MHz, CDCl$_3$) and ^{13}C{^{1}H} NMR(100 MHz, CDCl$_3$) of compound **21b**



```
Current Data Parameters
NAME      RAF-RAM-76-1H
EXPNO                12
PROCNO                1

F2 - Acquisition Parameters
Date_          20191017
Time              18.50
INSTRUM           spect
PROBHD   5 mm PABBO BB-
PULPROG            zg30
TD                54274
SOLVENT           CDCl3
NS                   14
DS                    0
SWH            8223.685 Hz
FIDRES         0.151522 Hz
AQ            3.2998593 sec
RG                   64
DW               60.800 usec
DE                 6.50 usec
TE                295.9 K
D1           1.00000000 sec
TD0                   1

======== CHANNEL f1 ========
NUC1                 1H
P1                14.75 usec
PL1               -1.00 dB
PL1W        10.56200695 W
SFO1        400.1324710 MHz

F2 - Processing parameters
SI                32768
SF          400.1300101 MHz
```

```
RAF-RAM-76-13C

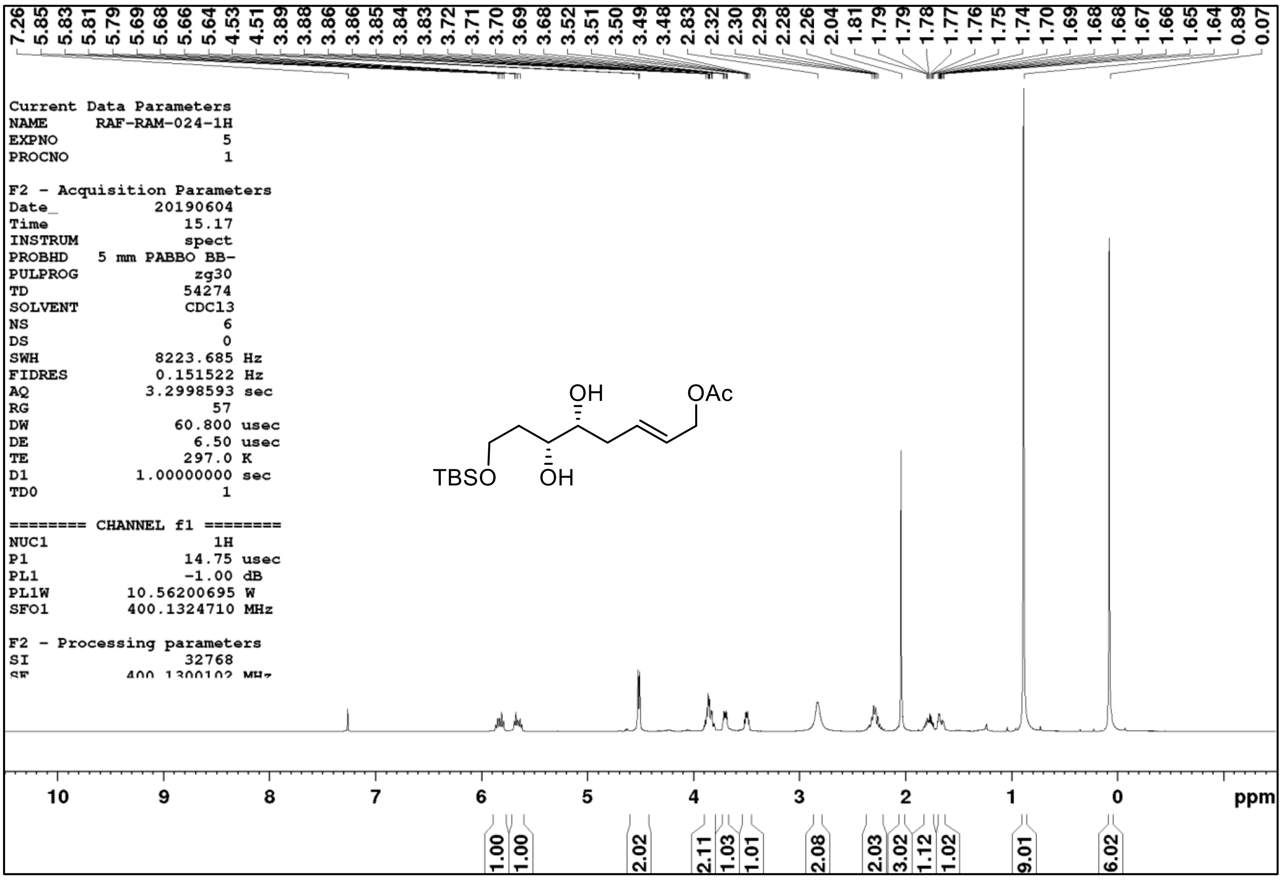
Current Data Parameters
NAME     RAF-RAM-76-13C
EXPNO                13
PROCNO                1

F2 - Acquisition Parameters
Date_          20191017
Time              18.52
INSTRUM           spect
PROBHD   5 mm PABBO BB-
PULPROG          zgpg30
TD                65536
SOLVENT           CDCl3
NS                   72
DS                    0
SWH           26041.666 Hz
FIDRES         0.397364 Hz
AQ            1.2582912 sec
RG                 1030
DW               19.200 usec
DE                 6.50 usec
TE                296.0 K
D1           1.00000000 sec
D11          0.03000000 sec
TD0                   1

======== CHANNEL f1 ========
NUC1                13C
P1                 8.50 usec
PL1               -2.00 dB
PL1W        56.53121948 W
SFO1        100.6238364 MHz

======== CHANNEL f2 ========
CPDPRG[2        waltz16
NUC2                 1H
```

^{1}H NMR(400 MHz, CDCl$_3$) and ^{13}C{^{1}H} NMR(100 MHz, CDCl$_3$) of compound **8b**

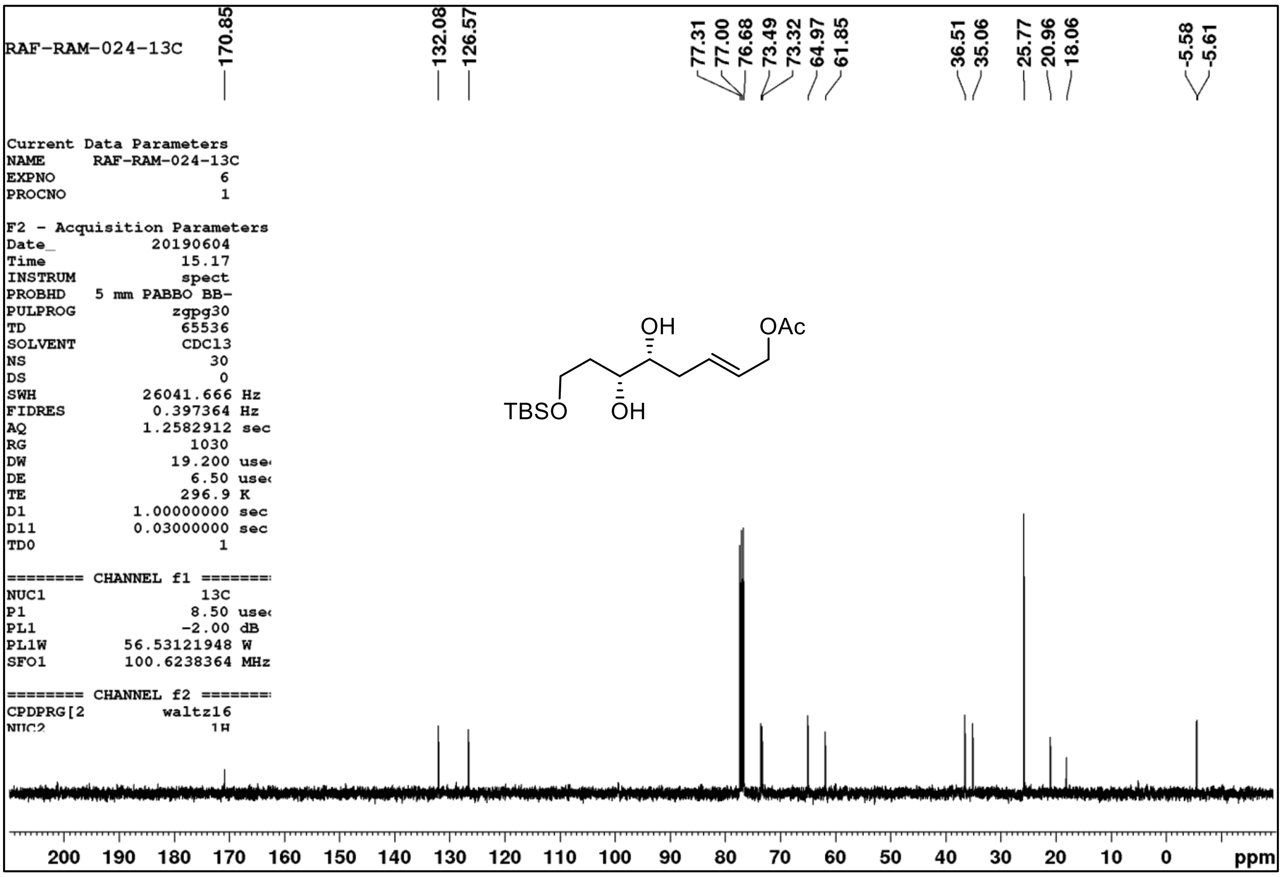


```
Current Data Parameters
NAME      RAF-RAM-024-1H
EXPNO                  5
PROCNO                 1

F2 - Acquisition Parameters
Date_           20190604
Time               15.17
INSTRUM            spect
PROBHD   5 mm PABBO BB-
PULPROG             zg30
TD                 54274
SOLVENT            CDCl3
NS                     6
DS                     0
SWH             8223.685 Hz
FIDRES          0.151522 Hz
AQ             3.2998593 sec
RG                    57
DW                60.800 usec
DE                  6.50 usec
TE                 297.0 K
D1            1.00000000 sec
TD0                    1

======== CHANNEL f1 ========
NUC1                  1H
P1                 14.75 usec
PL1                -1.00 dB
PL1W         10.56200695 W
SFO1         400.1324710 MHz

F2 - Processing parameters
SI                 32768
```



```
RAF-RAM-024-13C

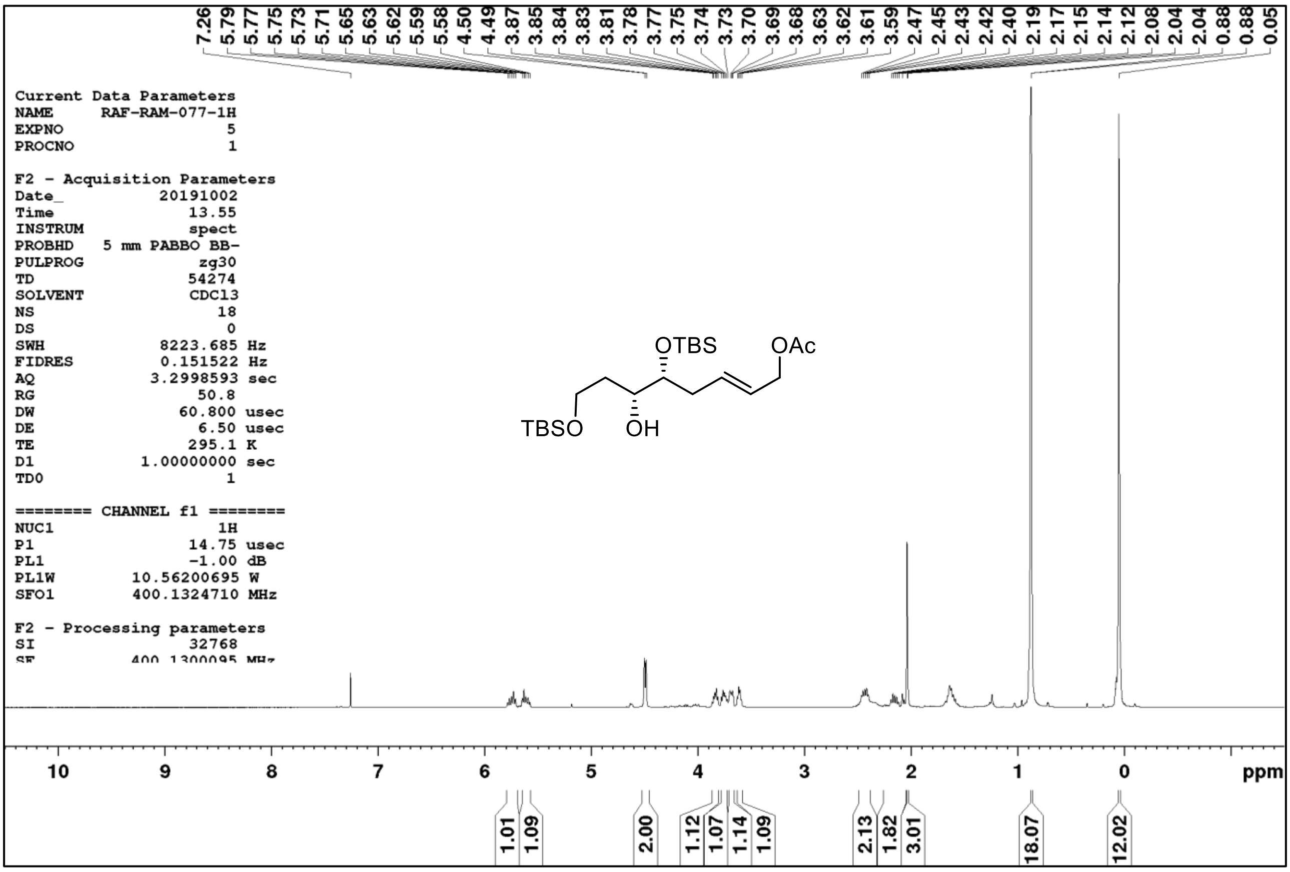
Current Data Parameters
NAME      RAF-RAM-024-13C
EXPNO                  6
PROCNO                 1

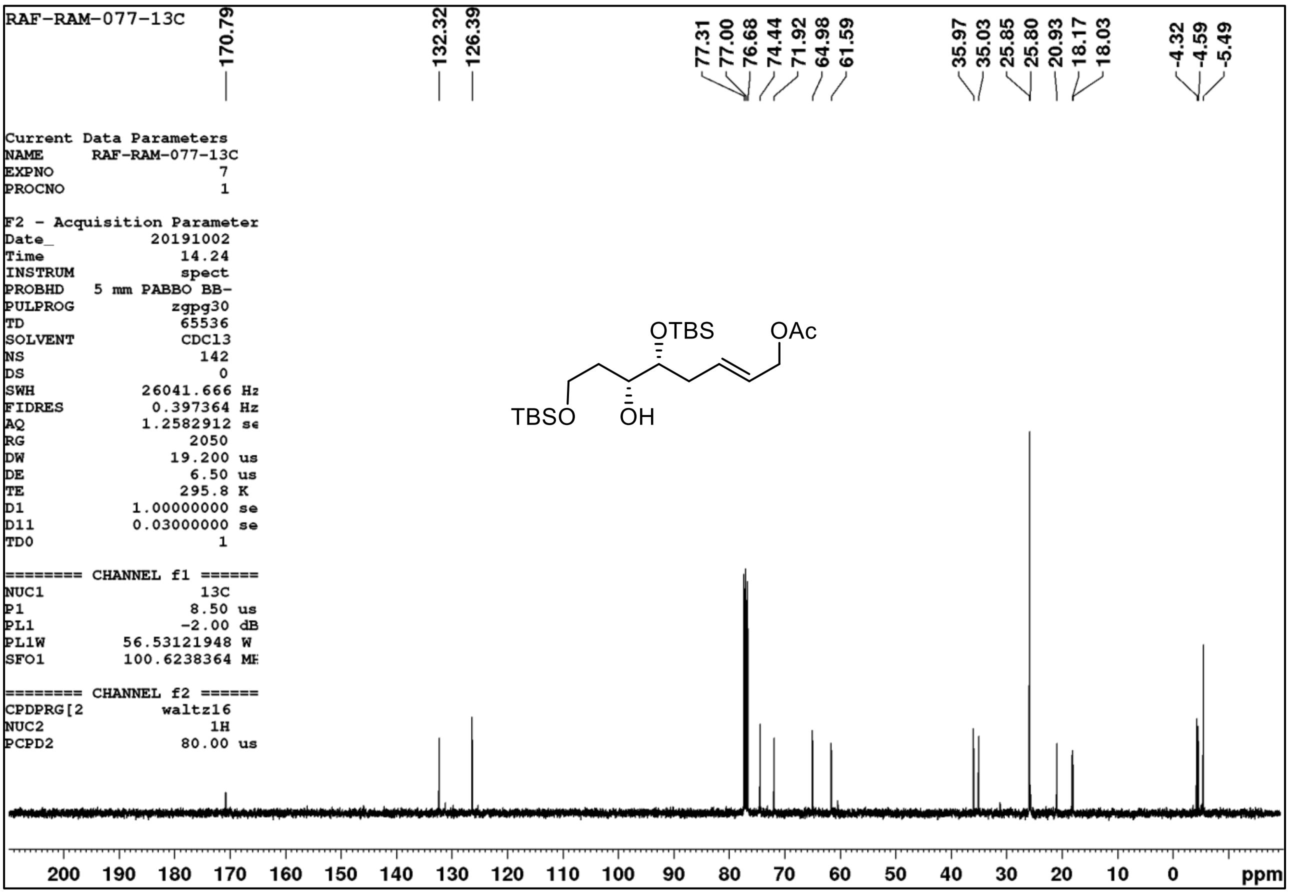
F2 - Acquisition Parameters
Date_           20190604
Time               15.17
INSTRUM            spect
PROBHD   5 mm PABBO BB-
PULPROG           zgpg30
TD                 65536
SOLVENT            CDCl3
NS                    30
DS                     0
SWH            26041.666 Hz
FIDRES          0.397364 Hz
AQ             1.2582912 sec
RG                  1030
DW                19.200 use
DE                  6.50 use
TE                 296.9 K
D1            1.00000000 sec
D11           0.03000000 sec
TD0                    1

======== CHANNEL f1 =======
NUC1                 13C
P1                  8.50 use
PL1                -2.00 dB
PL1W         56.53121948 W
SFO1         100.6238364 MHz

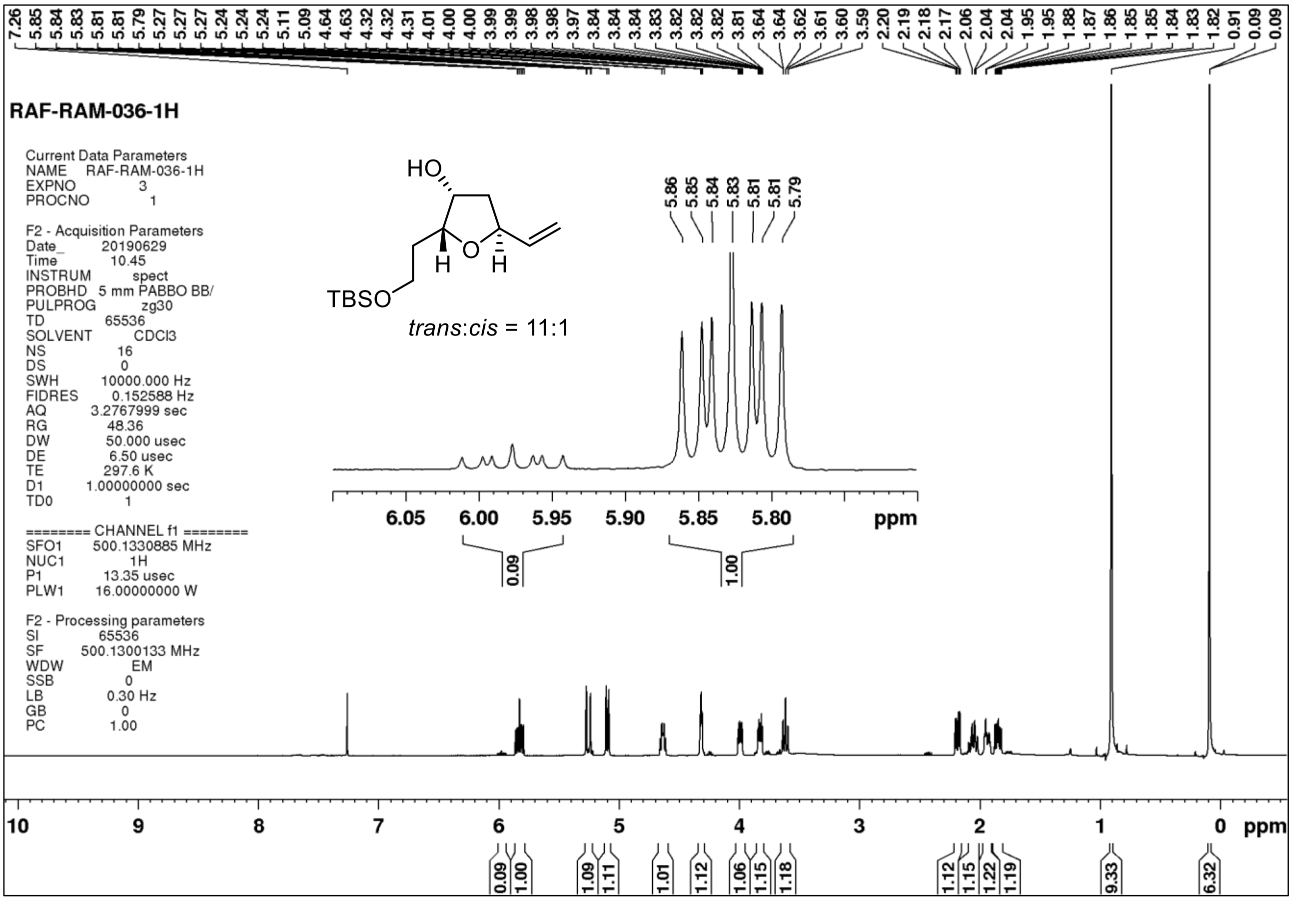
======== CHANNEL f2 =======
CPDPRG[2         waltz16
```

^{1}H NMR(400 MHz, CDCl$_3$) and ^{13}C{^{1}H} NMR(100 MHz, CDCl$_3$) of compound **8a**





^{1}H NMR(500 MHz, $CDCl_3$) and ^{13}C{^{1}H} NMR(125 MHz, $CDCl_3$) of compound **7b**



trans:*cis* = 11:1

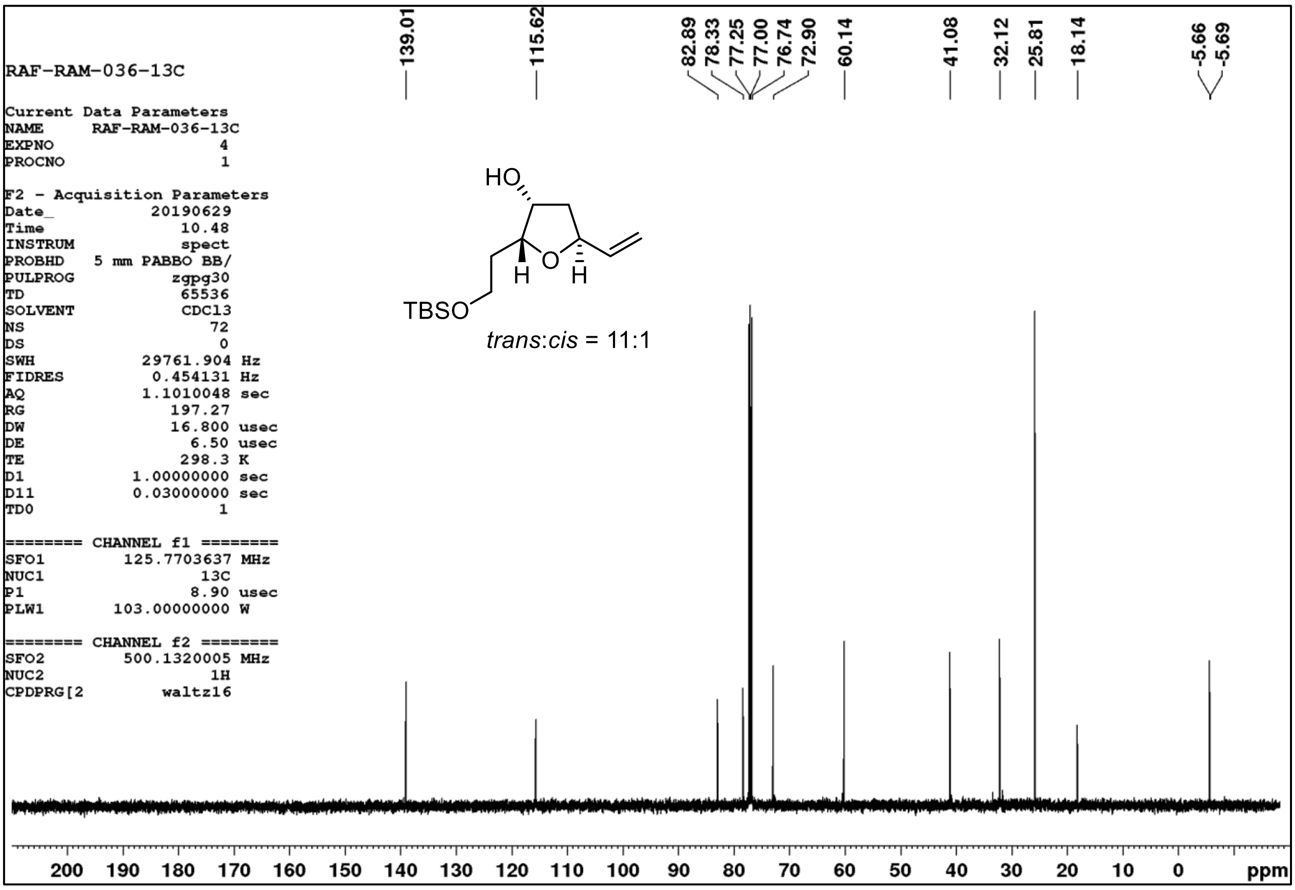
```
RAF-RAM-036-1H

Current Data Parameters
NAME     RAF-RAM-036-1H
EXPNO            3
PROCNO           1

F2 - Acquisition Parameters
Date_        20190629
Time            10.45
INSTRUM         spect
PROBHD   5 mm PABBO BB/
PULPROG          zg30
TD              65536
SOLVENT         CDCl3
NS                 16
DS                  0
SWH      10000.000 Hz
FIDRES    0.152588 Hz
AQ       3.2767999 sec
RG              48.36
DW         50.000 usec
DE           6.50 usec
TE            297.6 K
D1      1.00000000 sec
TD0                 1

======== CHANNEL f1 ========
SFO1     500.1330885 MHz
NUC1               1H
P1          13.35 usec
PLW1     16.00000000 W

F2 - Processing parameters
SI              65536
SF       500.1300133 MHz
WDW                EM
SSB                 0
LB            0.30 Hz
GB                  0
PC               1.00
```



trans:*cis* = 11:1

```
RAF-RAM-036-13C

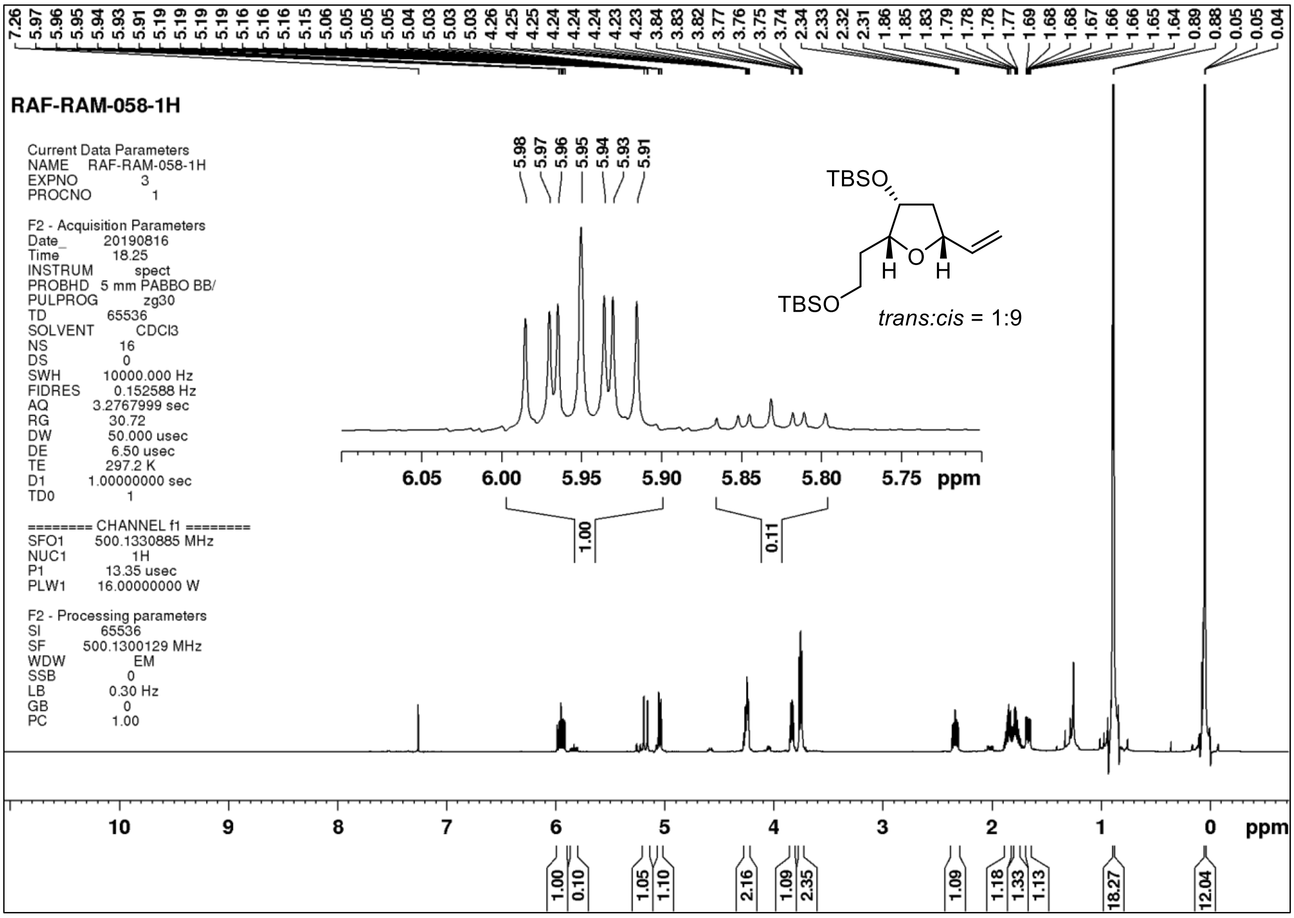
Current Data Parameters
NAME       RAF-RAM-036-13C
EXPNO                    4
PROCNO                   1

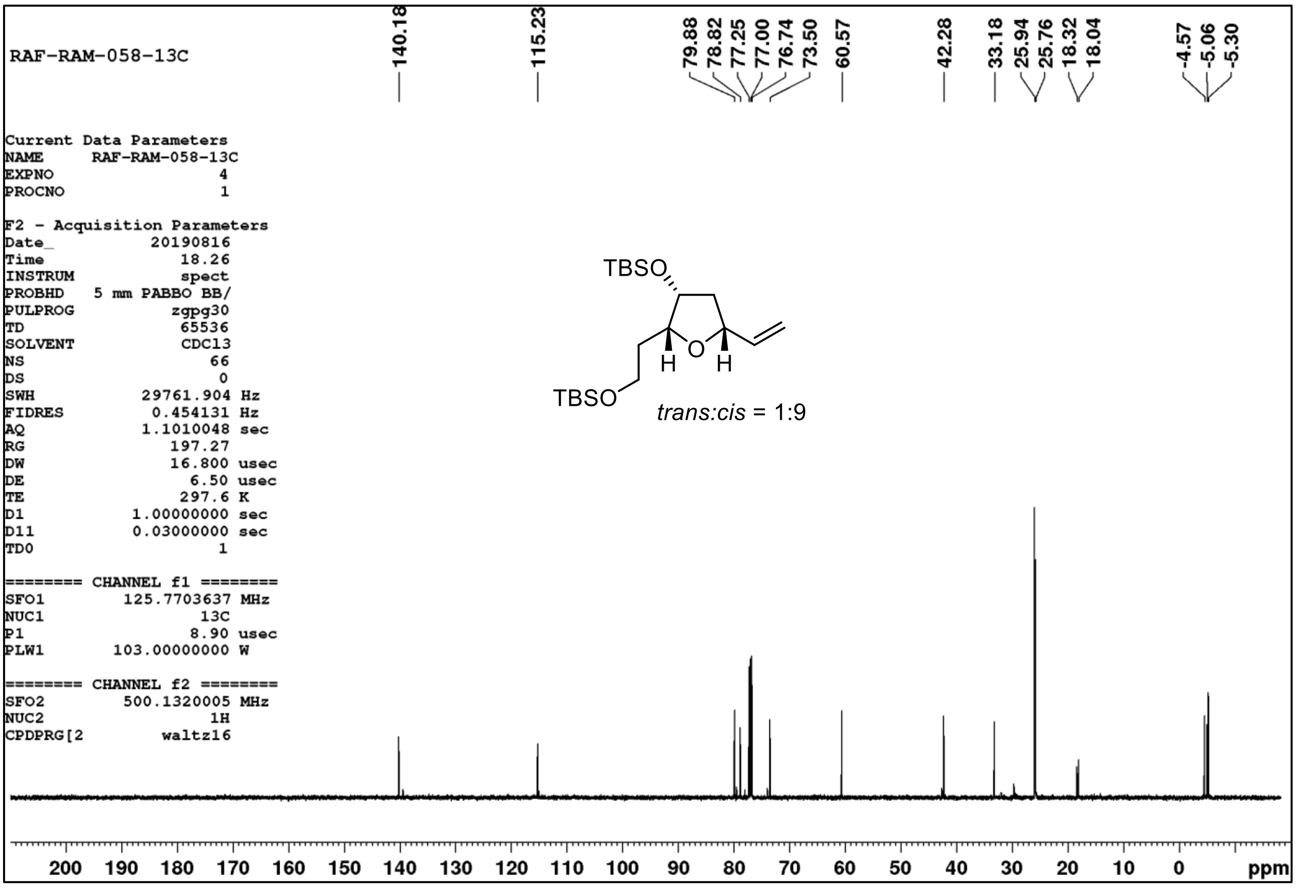
F2 - Acquisition Parameters
Date_             20190629
Time                 10.48
INSTRUM              spect
PROBHD    5 mm PABBO BB/
PULPROG            zgpg30
TD                   65536
SOLVENT              CDCl3
NS                      72
DS                       0
SWH              29761.904 Hz
FIDRES            0.454131 Hz
AQ               1.1010048 sec
RG                  197.27
DW                  16.800 usec
DE                    6.50 usec
TE                   298.3 K
D1              1.00000000 sec
D11             0.03000000 sec
TD0                      1

======== CHANNEL f1 ========
SFO1           125.7703637 MHz
NUC1                   13C
P1                    8.90 usec
PLW1          103.00000000 W

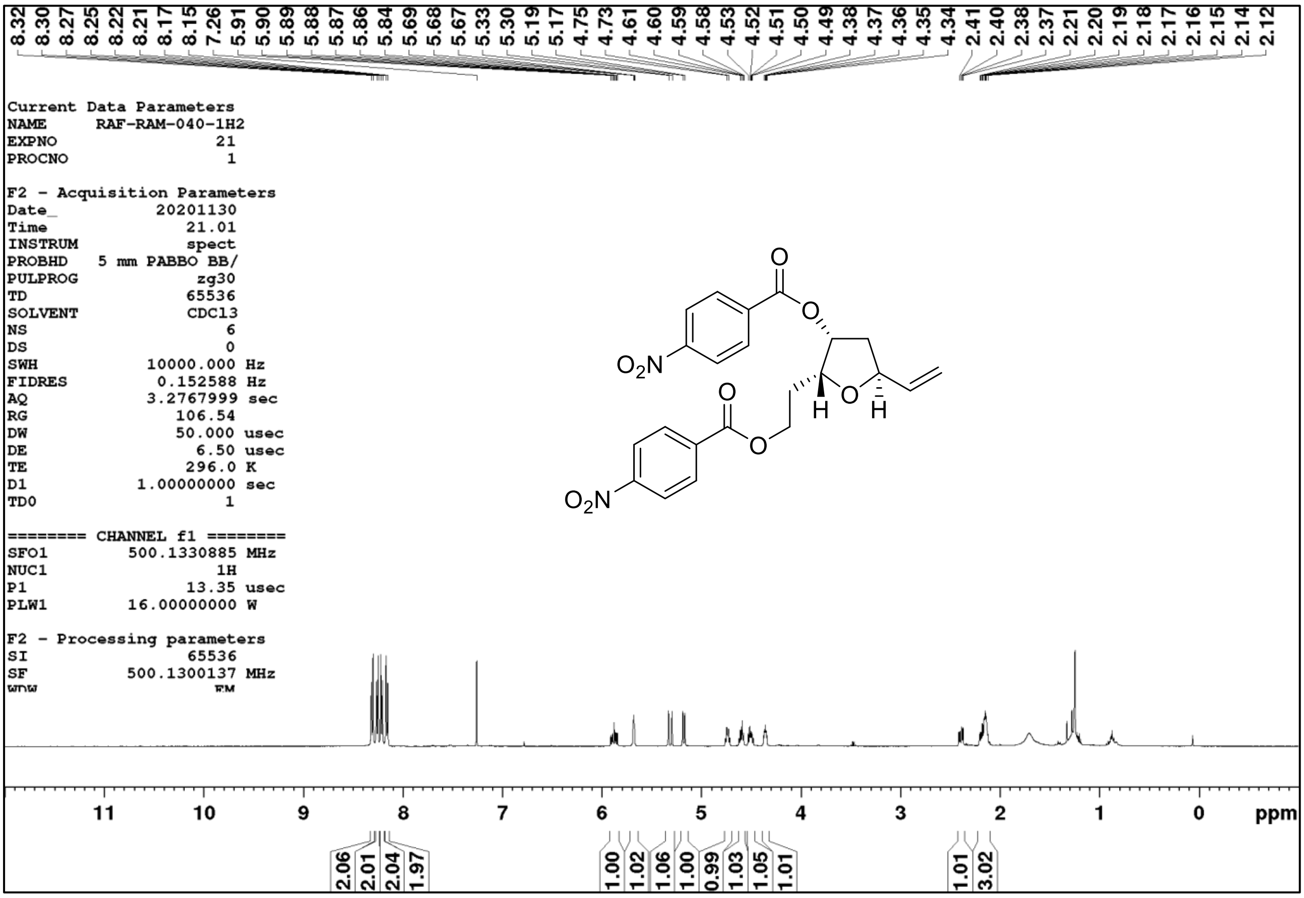
======== CHANNEL f2 ========
SFO2           500.1320005 MHz
NUC2                    1H
CPDPRG[2           waltz16
```

^{1}H NMR(500 MHz, CDCl$_3$) and ^{13}C{^{1}H} NMR(125 MHz, CDCl$_3$) of compound **7a**





^{1}H NMR(500 MHz, $CDCl_3$) and $^{13}C\{^{1}H\}$ NMR(125 MHz, $CDCl_3$) of compound **22b**

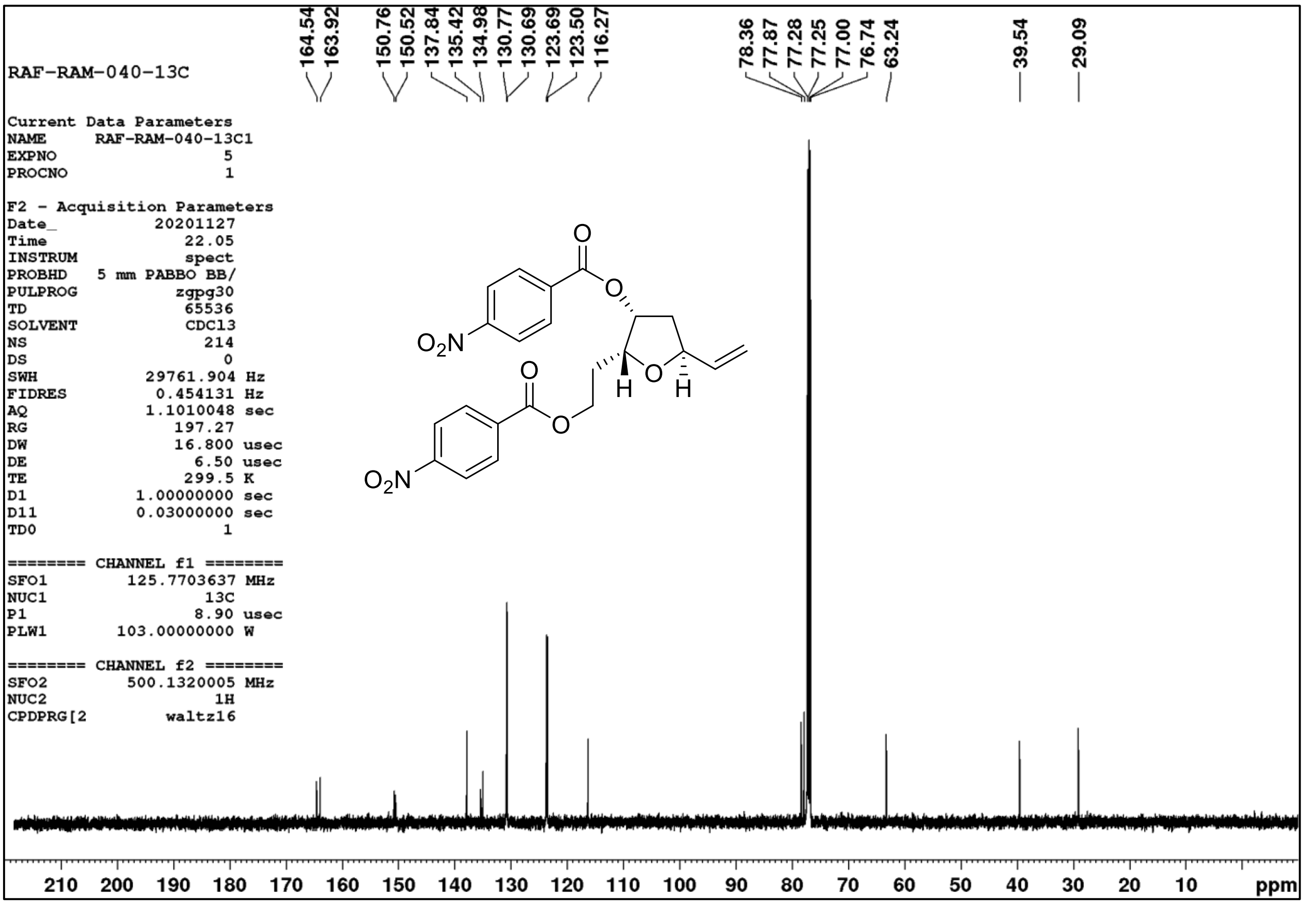


```
Current Data Parameters
NAME     RAF-RAM-040-1H2
EXPNO                 21
PROCNO                 1

F2 - Acquisition Parameters
Date_           20201130
Time               21.01
INSTRUM            spect
PROBHD   5 mm PABBO BB/
PULPROG             zg30
TD                 65536
SOLVENT            CDCl3
NS                     6
DS                     0
SWH           10000.000 Hz
FIDRES         0.152588 Hz
AQ            3.2767999 sec
RG                106.54
DW                50.000 usec
DE                  6.50 usec
TE                 296.0 K
D1           1.00000000 sec
TD0                    1

======== CHANNEL f1 ========
SFO1        500.1330885 MHz
NUC1                  1H
P1                 13.35 usec
PLW1       16.00000000 W

F2 - Processing parameters
SI                 65536
SF           500.1300137 MHz
WDW                   EM
```



```
RAF-RAM-040-13C

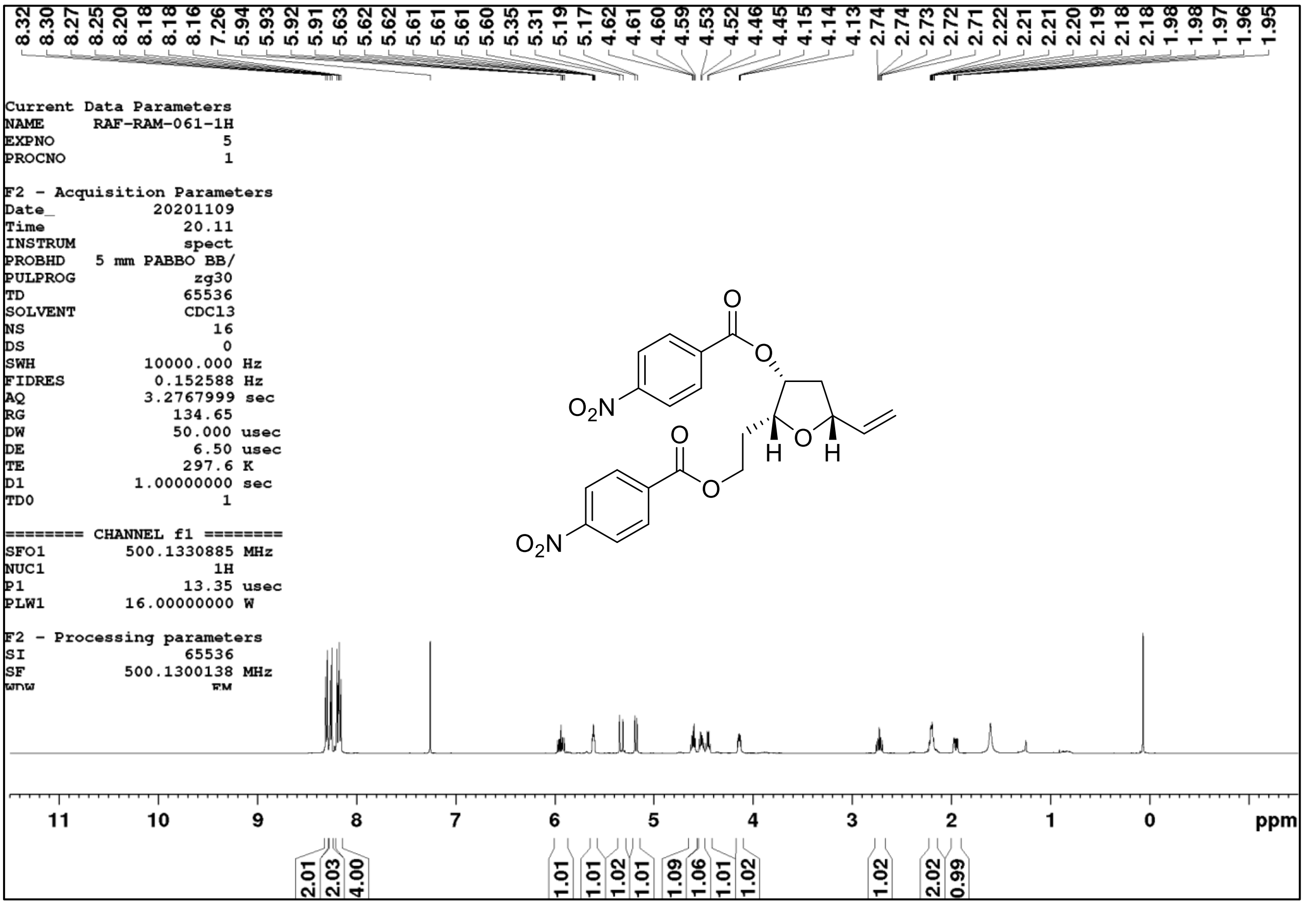
Current Data Parameters
NAME     RAF-RAM-040-13C1
EXPNO                  5
PROCNO                 1

F2 - Acquisition Parameters
Date_           20201127
Time               22.05
INSTRUM            spect
PROBHD   5 mm PABBO BB/
PULPROG           zgpg30
TD                 65536
SOLVENT            CDCl3
NS                   214
DS                     0
SWH           29761.904 Hz
FIDRES         0.454131 Hz
AQ            1.1010048 sec
RG                197.27
DW                16.800 usec
DE                  6.50 usec
TE                 299.5 K
D1           1.00000000 sec
D11          0.03000000 sec
TD0                    1

======== CHANNEL f1 ========
SFO1        125.7703637 MHz
NUC1                 13C
P1                  8.90 usec
PLW1      103.00000000 W

======== CHANNEL f2 ========
SFO2        500.1320005 MHz
NUC2                  1H
CPDPRG[2         waltz16
```

^{1}H NMR(500 MHz, $CDCl_3$) and $^{13}C\{^1H\}$ NMR(125 MHz, $CDCl_3$) of compound **22a**

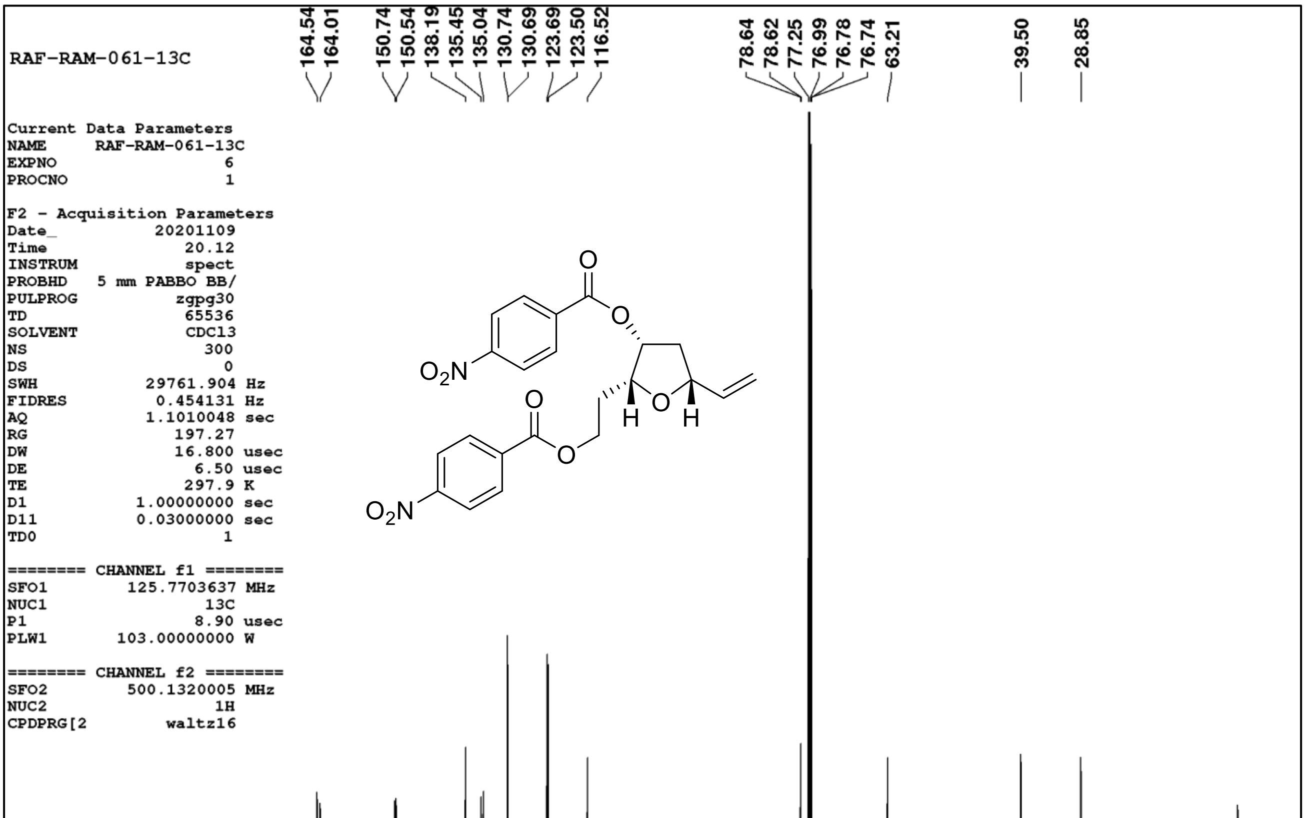


```
Current Data Parameters
NAME      RAF-RAM-061-1H
EXPNO                  5
PROCNO                 1

F2 - Acquisition Parameters
Date_           20201109
Time               20.11
INSTRUM            spect
PROBHD   5 mm PABBO BB/
PULPROG             zg30
TD                 65536
SOLVENT            CDCl3
NS                    16
DS                     0
SWH            10000.000 Hz
FIDRES          0.152588 Hz
AQ             3.2767999 sec
RG                134.65
DW                50.000 usec
DE                  6.50 usec
TE                 297.6 K
D1            1.00000000 sec
TD0                    1

======== CHANNEL f1 ========
SFO1         500.1330885 MHz
NUC1                  1H
P1                 13.35 usec
PLW1         16.00000000 W

F2 - Processing parameters
SI                 65536
SF           500.1300138 MHz
WDW                   EM
```



```
RAF-RAM-061-13C

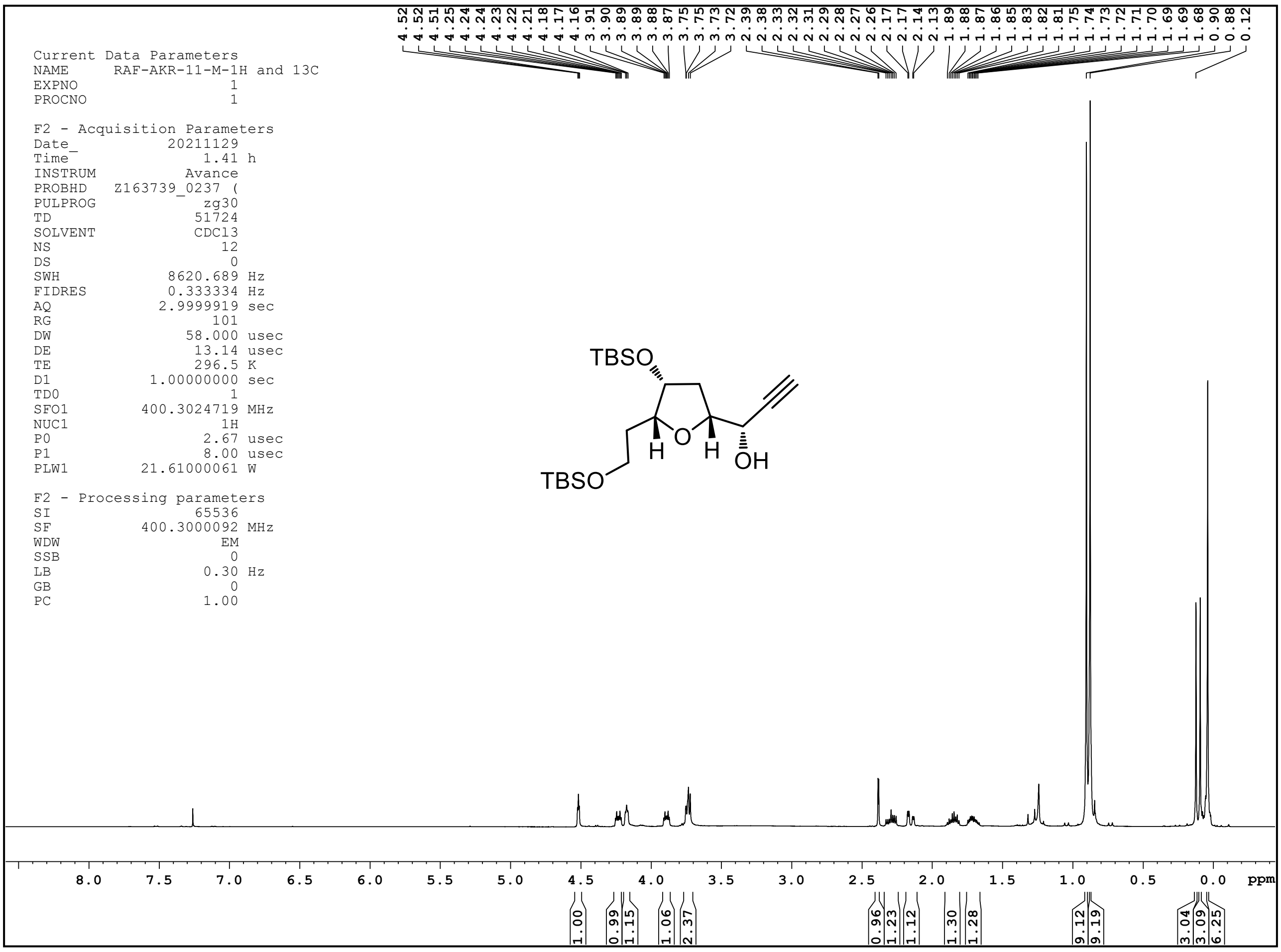
Current Data Parameters
NAME      RAF-RAM-061-13C
EXPNO                  6
PROCNO                 1

F2 - Acquisition Parameters
Date_           20201109
Time               20.12
INSTRUM            spect
PROBHD   5 mm PABBO BB/
PULPROG           zgpg30
TD                 65536
SOLVENT            CDCl3
NS                   300
DS                     0
SWH            29761.904 Hz
FIDRES          0.454131 Hz
AQ             1.1010048 sec
RG                197.27
DW                16.800 usec
DE                  6.50 usec
TE                 297.9 K
D1            1.00000000 sec
D11           0.03000000 sec
TD0                    1

======== CHANNEL f1 ========
SFO1         125.7703637 MHz
NUC1                 13C
P1                  8.90 usec
PLW1        103.00000000 W

======== CHANNEL f2 ========
SFO2         500.1320005 MHz
NUC2                  1H
CPDPRG[2         waltz16
```

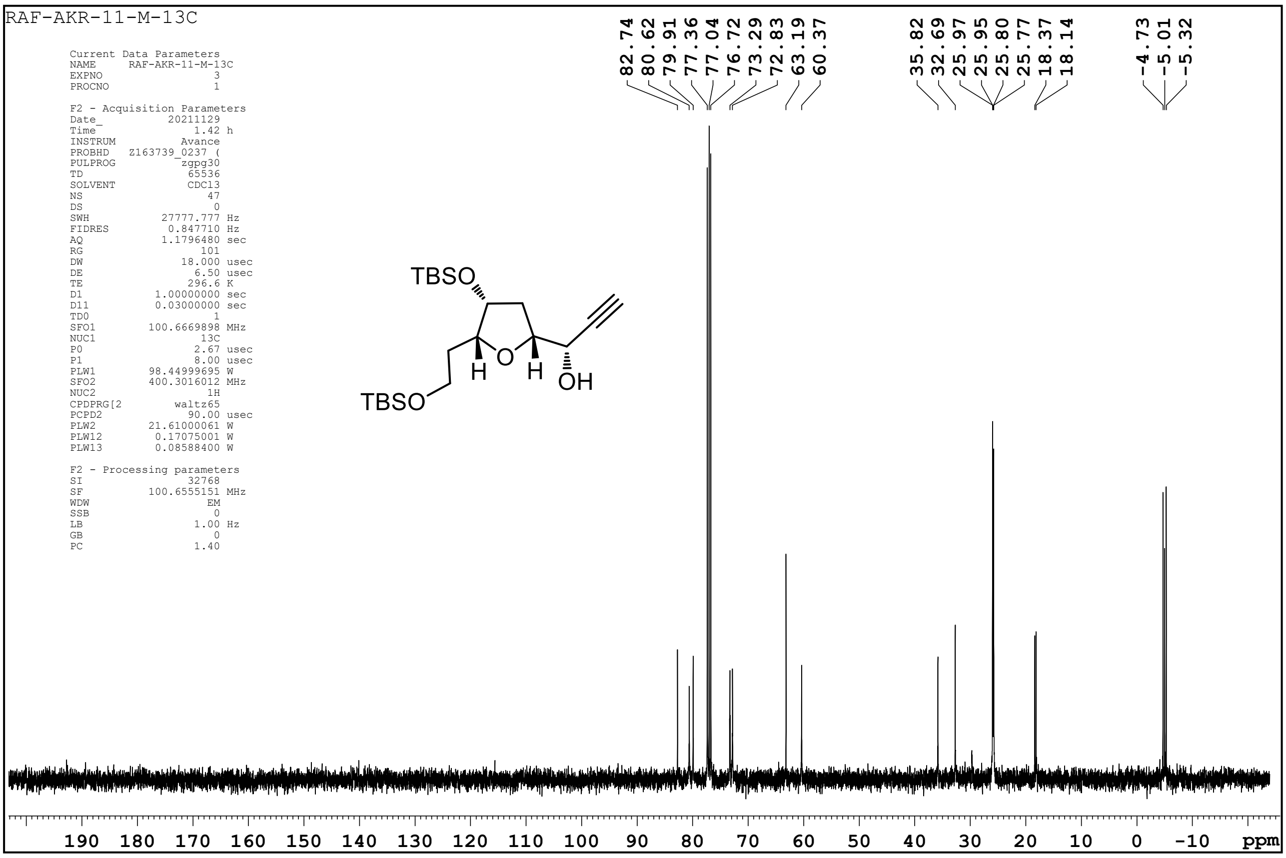
^{1}H NMR (400 MHz, CDCl$_3$) and ^{13}C{^{1}H} NMR (100 MHz, CDCl$_3$) of compound **12a**



```
Current Data Parameters
NAME     RAF-AKR-11-M-1H and 13C
EXPNO                 1
PROCNO                1

F2 - Acquisition Parameters
Date_          20211129
Time               1.41 h
INSTRUM          Avance
PROBHD   Z163739_0237 (
PULPROG            zg30
TD                51724
SOLVENT           CDCl3
NS                   12
DS                    0
SWH            8620.689 Hz
FIDRES         0.333334 Hz
AQ            2.9999919 sec
RG                  101
DW               58.000 usec
DE                13.14 usec
TE                296.5 K
D1           1.00000000 sec
TD0                   1
SFO1        400.3024719 MHz
NUC1                 1H
P0                 2.67 usec
P1                 8.00 usec
PLW1        21.61000061 W

F2 - Processing parameters
SI                65536
SF          400.3000092 MHz
WDW                  EM
SSB                   0
LB                 0.30 Hz
GB                    0
PC                 1.00
```



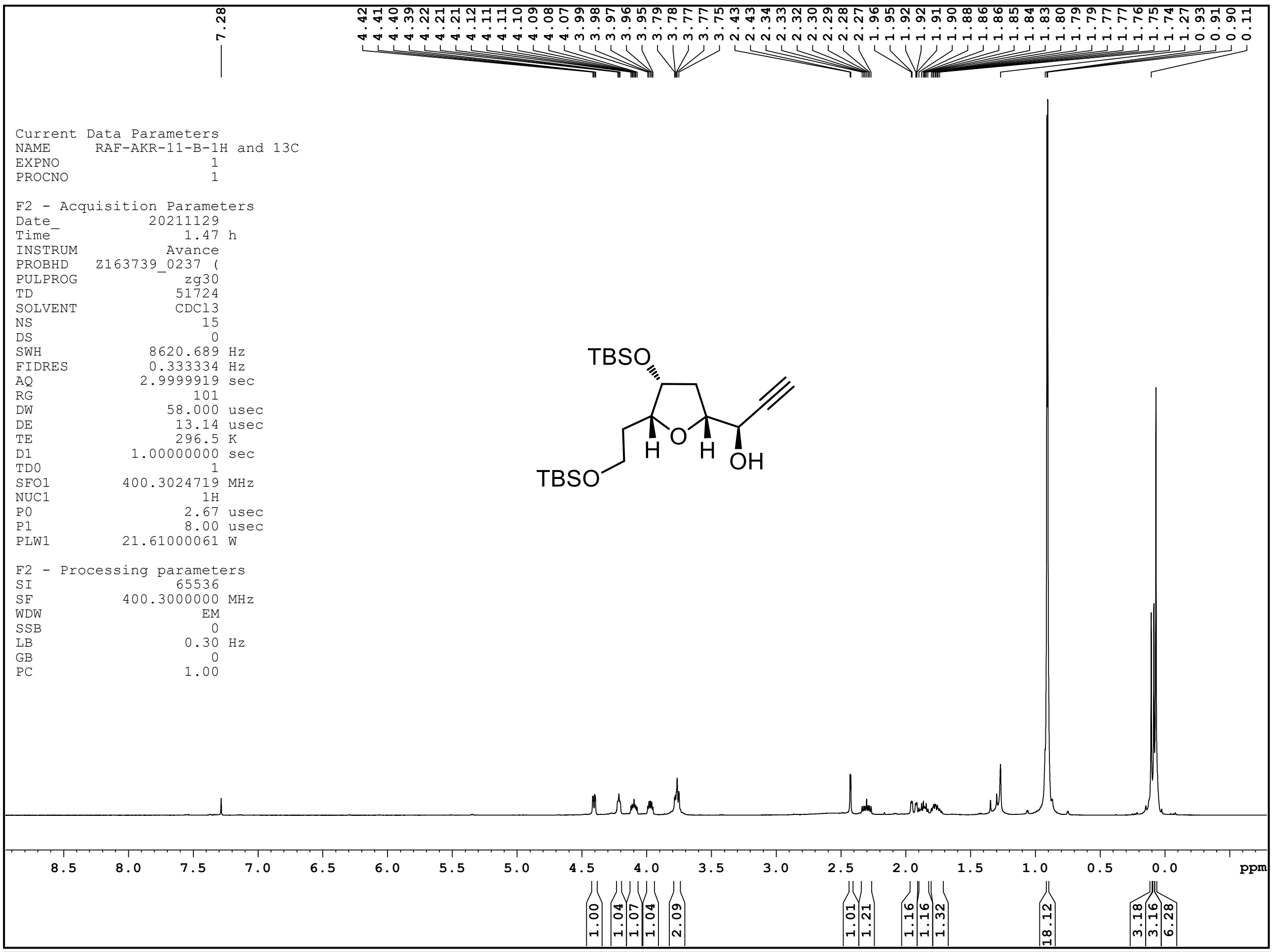
RAF-AKR-11-M-13C

```
Current Data Parameters
NAME     RAF-AKR-11-M-13C
EXPNO                 3
PROCNO                1

F2 - Acquisition Parameters
Date_          20211129
Time               1.42 h
INSTRUM          Avance
PROBHD   Z163739_0237 (
PULPROG          zgpg30
TD                65536
SOLVENT           CDCl3
NS                   47
DS                    0
SWH           27777.777 Hz
FIDRES         0.847710 Hz
AQ            1.1796480 sec
RG                  101
DW               18.000 usec
DE                 6.50 usec
TE                296.6 K
D1           1.00000000 sec
D11          0.03000000 sec
TD0                   1
SFO1        100.6669898 MHz
NUC1                13C
P0                 2.67 usec
P1                 8.00 usec
PLW1        98.44999695 W
SFO2        400.3016012 MHz
NUC2                 1H
CPDPRG[2        waltz65
PCPD2             90.00 usec
PLW2        21.61000061 W
PLW12        0.17075001 W
PLW13        0.08588400 W

F2 - Processing parameters
SI                32768
SF          100.6555151 MHz
WDW                  EM
SSB                   0
LB                 1.00 Hz
GB                    0
PC                 1.40
```

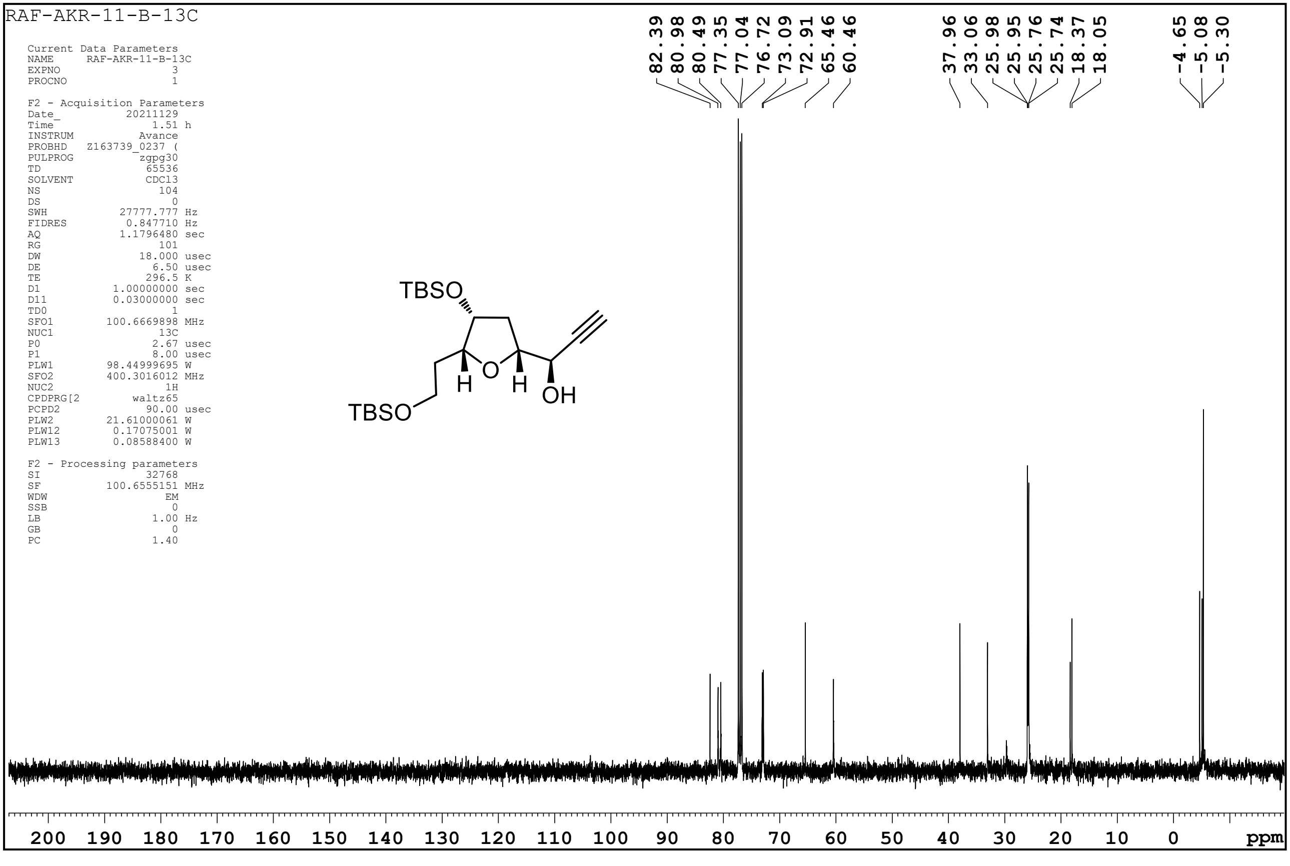
^{1}H NMR (400 MHz, $CDCl_3$) and $^{13}C\{^{1}H\}$ NMR (100 MHz, $CDCl_3$) of compound **12b**



```
Current Data Parameters
NAME     RAF-AKR-11-B-1H and 13C
EXPNO                  1
PROCNO                 1

F2 - Acquisition Parameters
Date_          20211129
Time               1.47 h
INSTRUM          Avance
PROBHD   Z163739_0237 (
PULPROG            zg30
TD                51724
SOLVENT           CDCl3
NS                   15
DS                    0
SWH            8620.689 Hz
FIDRES         0.333334 Hz
AQ            2.9999919 sec
RG                  101
DW               58.000 usec
DE                13.14 usec
TE                296.5 K
D1           1.00000000 sec
TD0                   1
SFO1        400.3024719 MHz
NUC1                 1H
P0                 2.67 usec
P1                 8.00 usec
PLW1        21.61000061 W

F2 - Processing parameters
SI                65536
SF          400.3000000 MHz
WDW                  EM
SSB                   0
LB                 0.30 Hz
GB                    0
PC                 1.00
```



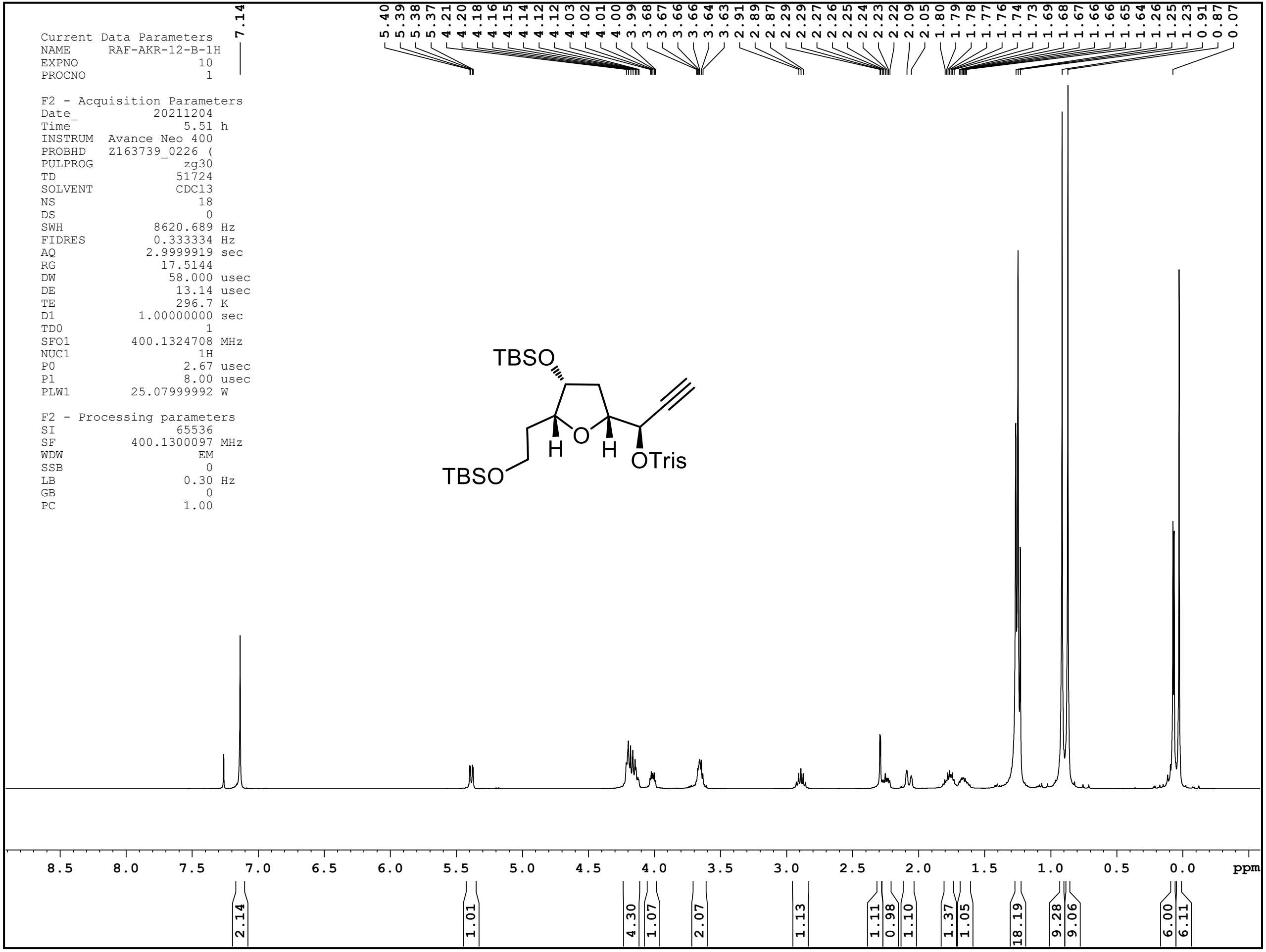
RAF-AKR-11-B-13C

```
Current Data Parameters
NAME     RAF-AKR-11-B-13C
EXPNO                  3
PROCNO                 1

F2 - Acquisition Parameters
Date_          20211129
Time               1.51 h
INSTRUM          Avance
PROBHD   Z163739_0237 (
PULPROG          zgpg30
TD                65536
SOLVENT           CDCl3
NS                  104
DS                    0
SWH           27777.777 Hz
FIDRES         0.847710 Hz
AQ            1.1796480 sec
RG                  101
DW               18.000 usec
DE                 6.50 usec
TE                296.5 K
D1           1.00000000 sec
D11          0.03000000 sec
TD0                   1
SFO1        100.6669898 MHz
NUC1                13C
P0                 2.67 usec
P1                 8.00 usec
PLW1        98.44999695 W
SFO2        400.3016012 MHz
NUC2                 1H
CPDPRG[2        waltz65
PCPD2             90.00 usec
PLW2        21.61000061 W
PLW12        0.17075001 W
PLW13        0.08588400 W

F2 - Processing parameters
SI                32768
SF          100.6555151 MHz
WDW                  EM
SSB                   0
LB                 1.00 Hz
GB                    0
PC                 1.40
```

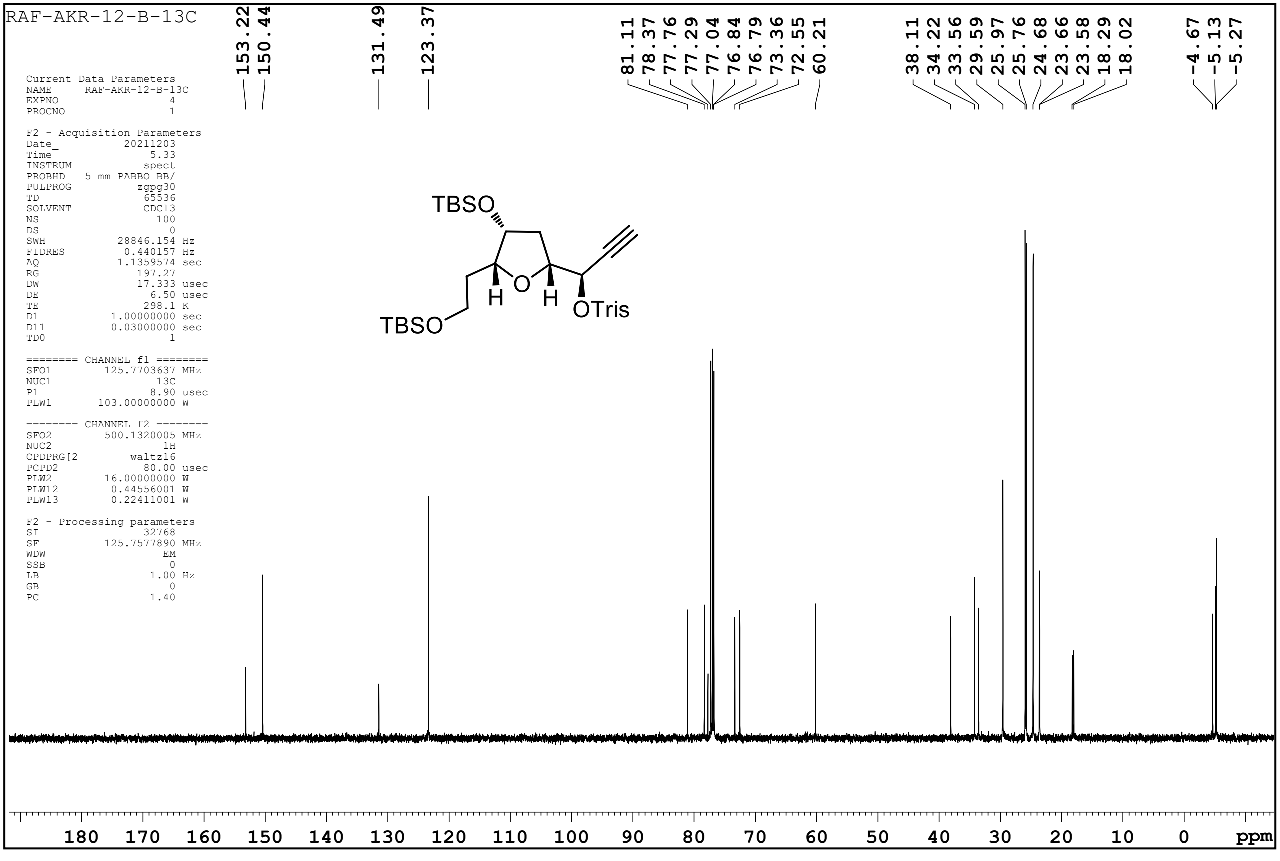
^{1}H NMR (400 MHz, CDCl$_3$) and ^{13}C{^{1}H} NMR (125 MHz, CDCl$_3$) of compound **6b**



```
Current Data Parameters
NAME     RAF-AKR-12-B-1H
EXPNO                 10
PROCNO                 1

F2 - Acquisition Parameters
Date_           20211204
Time                5.51 h
INSTRUM  Avance Neo 400
PROBHD   Z163739_0226 (
PULPROG             zg30
TD                 51724
SOLVENT            CDCl3
NS                    18
DS                     0
SWH             8620.689 Hz
FIDRES          0.333334 Hz
AQ             2.9999919 sec
RG               17.5144
DW                58.000 usec
DE                 13.14 usec
TE                 296.7 K
D1            1.00000000 sec
TD0                    1
SFO1         400.1324708 MHz
NUC1                  1H
P0                  2.67 usec
P1                  8.00 usec
PLW1         25.07999992 W

F2 - Processing parameters
SI                 65536
SF           400.1300097 MHz
WDW                   EM
SSB                    0
LB                  0.30 Hz
GB                     0
PC                  1.00
```



```
Current Data Parameters
NAME     RAF-AKR-12-B-13C
EXPNO                  4
PROCNO                 1

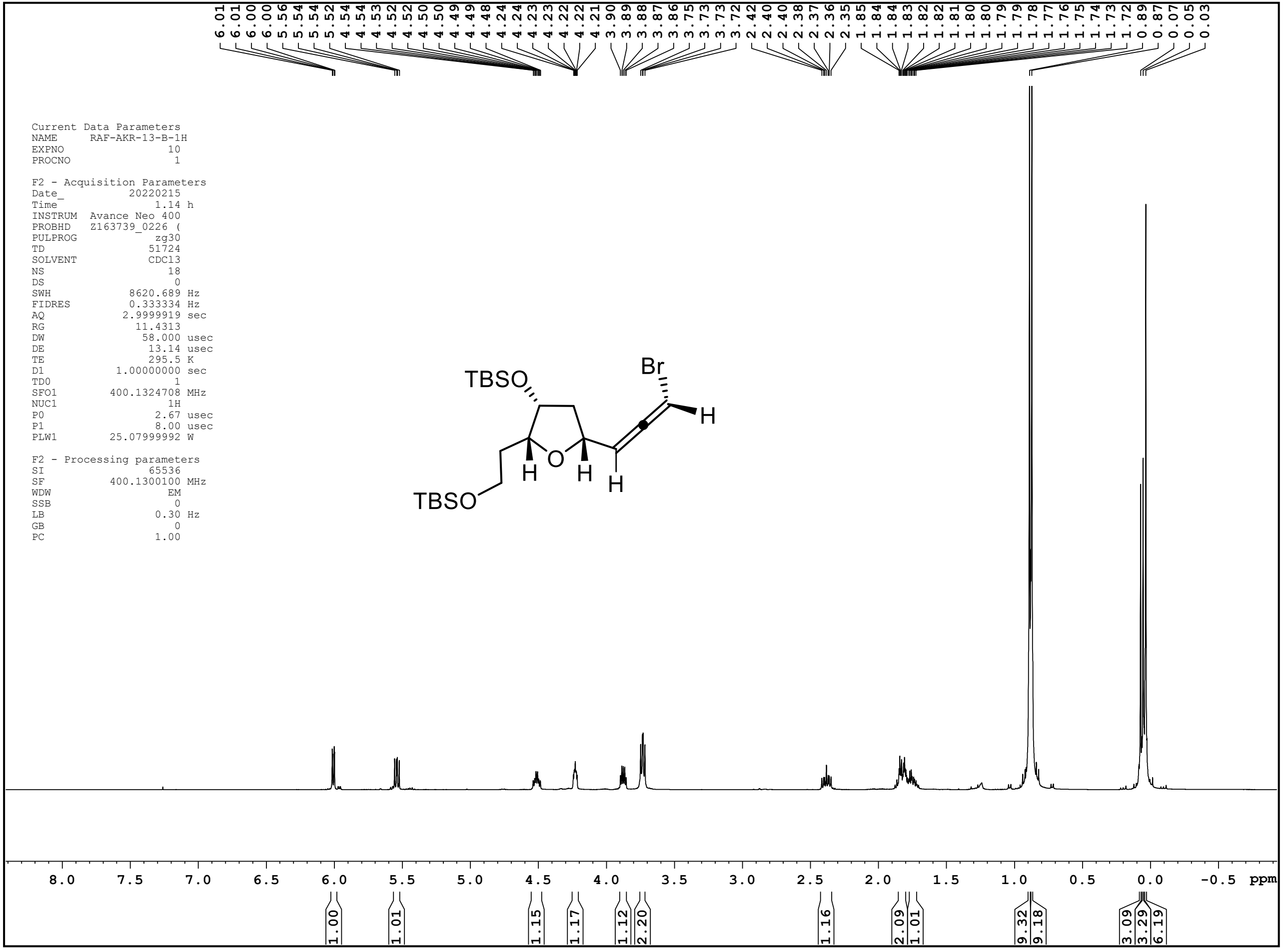
F2 - Acquisition Parameters
Date_           20211203
Time                5.33
INSTRUM            spect
PROBHD   5 mm PABBO BB/
PULPROG          zgpg30
TD                65536
SOLVENT           CDCl3
NS                  100
DS                    0
SWH           28846.154 Hz
FIDRES         0.440157 Hz
AQ            1.1359574 sec
RG               197.27
DW               17.333 usec
DE                 6.50 usec
TE                298.1 K
D1           1.00000000 sec
D11          0.03000000 sec
TD0                   1

======== CHANNEL f1 ========
SFO1        125.7703637 MHz
NUC1                13C
P1                 8.90 usec
PLW1       103.00000000 W

======== CHANNEL f2 ========
SFO2        500.1320005 MHz
NUC2                 1H
CPDPRG[2        waltz16
PCPD2             80.00 usec
PLW2        16.00000000 W
PLW12        0.44556001 W
PLW13        0.22411001 W

F2 - Processing parameters
SI                32768
SF          125.7577890 MHz
WDW                  EM
SSB                   0
LB                 1.00 Hz
GB                    0
PC                 1.40
```

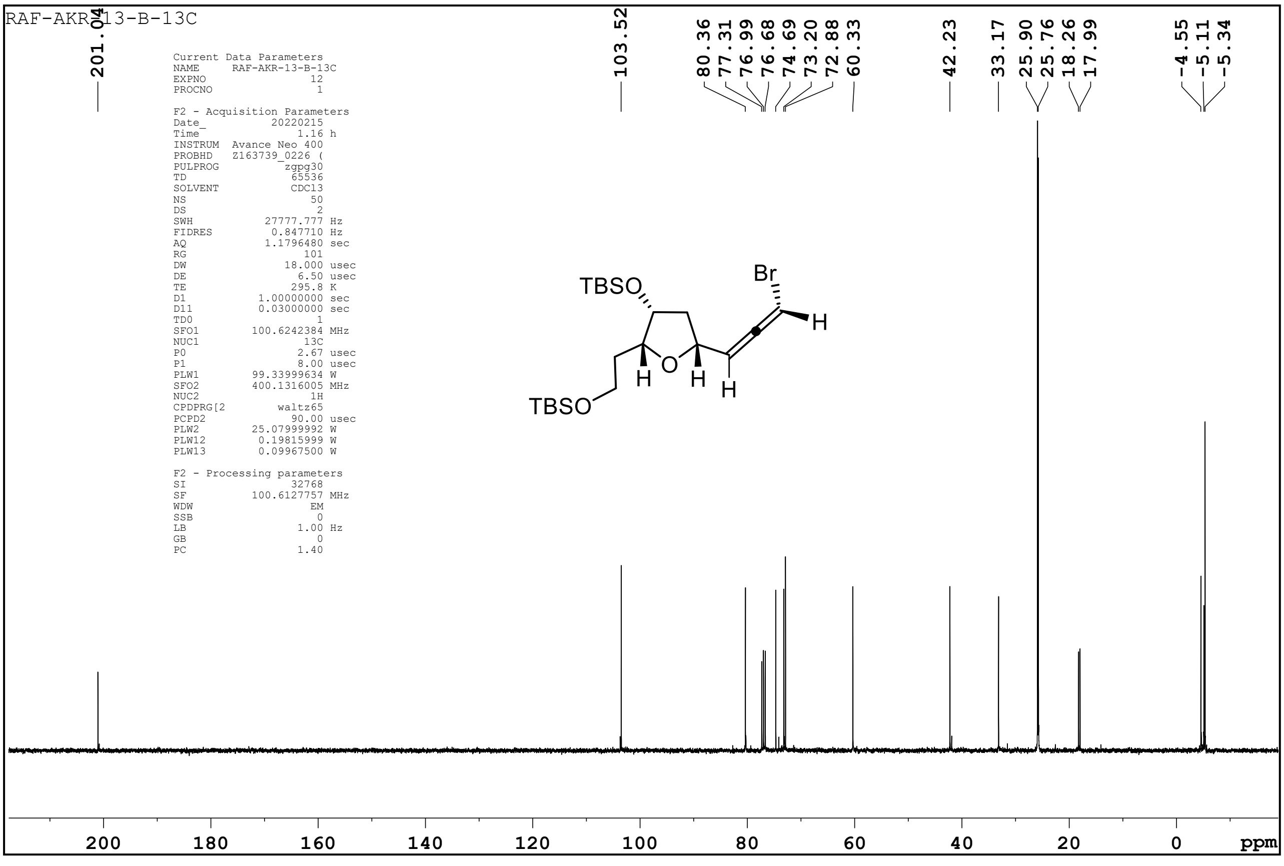
^{1}H NMR (400 MHz, CDCl$_3$) and ^{13}C{^{1}H} NMR (100 MHz, CDCl$_3$) of compound **13a**



```
Current Data Parameters
NAME      RAF-AKR-13-B-1H
EXPNO                  10
PROCNO                  1

F2 - Acquisition Parameters
Date_            20220215
Time                 1.14 h
INSTRUM   Avance Neo 400
PROBHD    Z163739_0226 (
PULPROG              zg30
TD                  51724
SOLVENT             CDCl3
NS                     18
DS                      0
SWH              8620.689 Hz
FIDRES           0.333334 Hz
AQ              2.9999919 sec
RG                11.4313
DW                 58.000 usec
DE                  13.14 usec
TE                  295.5 K
D1             1.00000000 sec
TD0                     1
SFO1          400.1324708 MHz
NUC1                   1H
P0                   2.67 usec
P1                   8.00 usec
PLW1          25.07999992 W

F2 - Processing parameters
SI                  65536
SF            400.1300100 MHz
WDW                    EM
SSB                     0
LB                   0.30 Hz
GB                      0
PC                   1.00
```

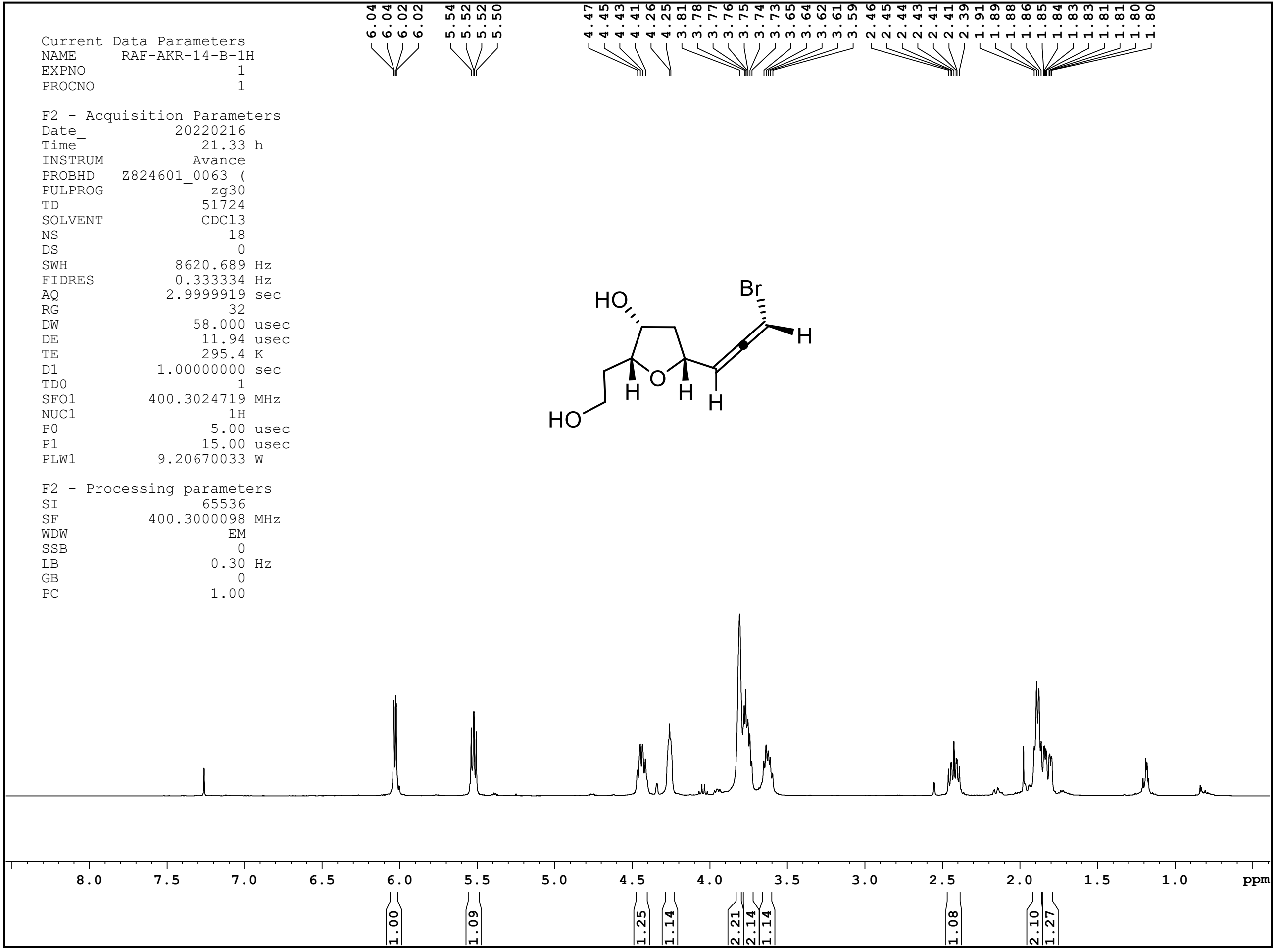


```
Current Data Parameters
NAME      RAF-AKR-13-B-13C
EXPNO                  12
PROCNO                  1

F2 - Acquisition Parameters
Date_            20220215
Time                 1.16 h
INSTRUM   Avance Neo 400
PROBHD    Z163739_0226 (
PULPROG            zgpg30
TD                  65536
SOLVENT             CDCl3
NS                     50
DS                      2
SWH             27777.777 Hz
FIDRES           0.847710 Hz
AQ              1.1796480 sec
RG                    101
DW                 18.000 usec
DE                   6.50 usec
TE                  295.8 K
D1             1.00000000 sec
D11            0.03000000 sec
TD0                     1
SFO1          100.6242384 MHz
NUC1                  13C
P0                   2.67 usec
P1                   8.00 usec
PLW1          99.33999634 W
SFO2          400.1316005 MHz
NUC2                   1H
CPDPRG[2          waltz65
PCPD2               90.00 usec
PLW2          25.07999992 W
PLW12          0.19815999 W
PLW13          0.09967500 W

F2 - Processing parameters
SI                  32768
SF            100.6127757 MHz
WDW                    EM
SSB                     0
LB                   1.00 Hz
GB                      0
PC                   1.40
```

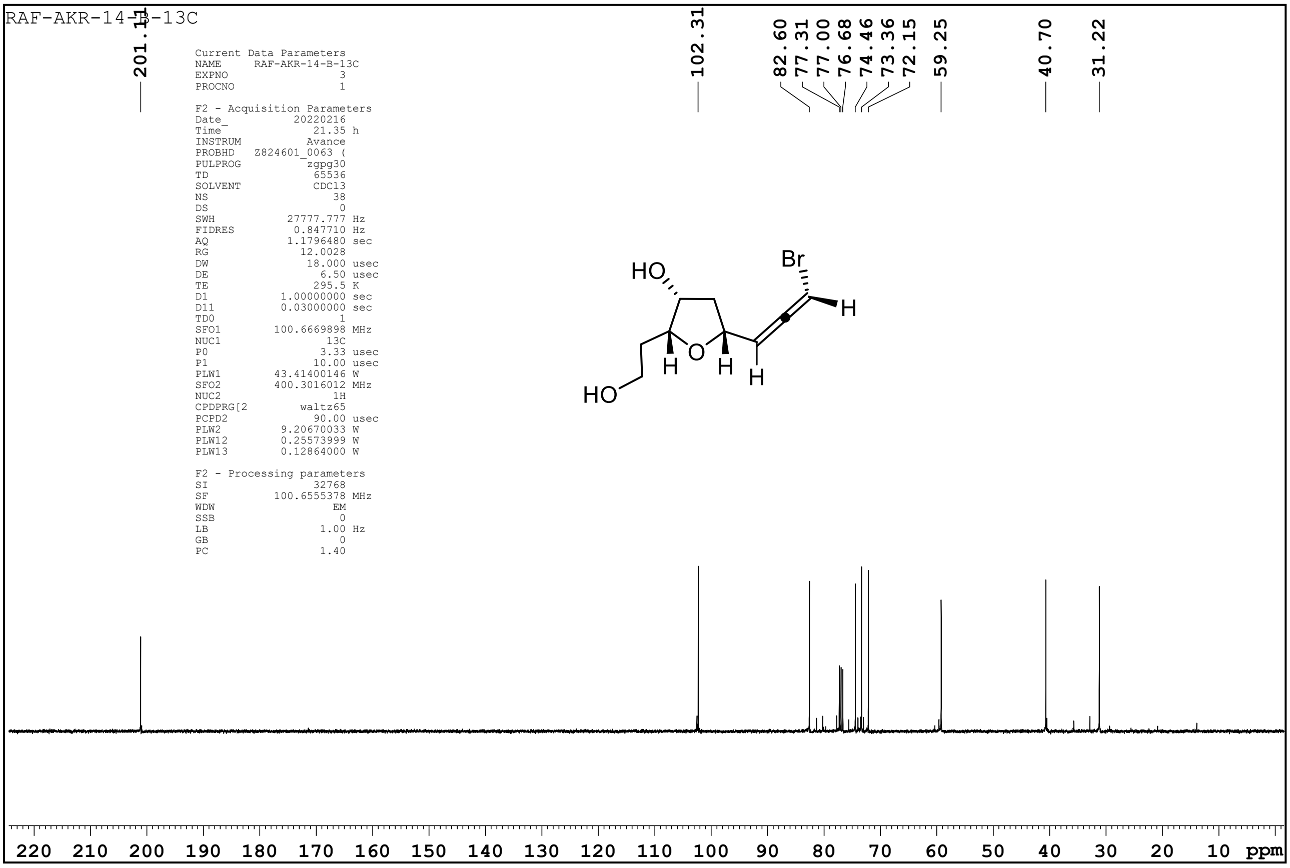
^{1}H NMR (400 MHz, $CDCl_3$) and $^{13}C\{^{1}H\}$ NMR (100 MHz, $CDCl_3$) of compound **14a**



```
Current Data Parameters
NAME     RAF-AKR-14-B-1H
EXPNO                  1
PROCNO                 1

F2 - Acquisition Parameters
Date_           20220216
Time               21.33 h
INSTRUM           Avance
PROBHD   Z824601_0063 (
PULPROG             zg30
TD                 51724
SOLVENT            CDCl3
NS                    18
DS                     0
SWH             8620.689 Hz
FIDRES          0.333334 Hz
AQ             2.9999919 sec
RG                    32
DW                58.000 usec
DE                 11.94 usec
TE                 295.4 K
D1            1.00000000 sec
TD0                    1
SFO1         400.3024719 MHz
NUC1                  1H
P0                  5.00 usec
P1                 15.00 usec
PLW1          9.20670033 W

F2 - Processing parameters
SI                 65536
SF           400.3000098 MHz
WDW                   EM
SSB                    0
LB                  0.30 Hz
GB                     0
PC                  1.00
```

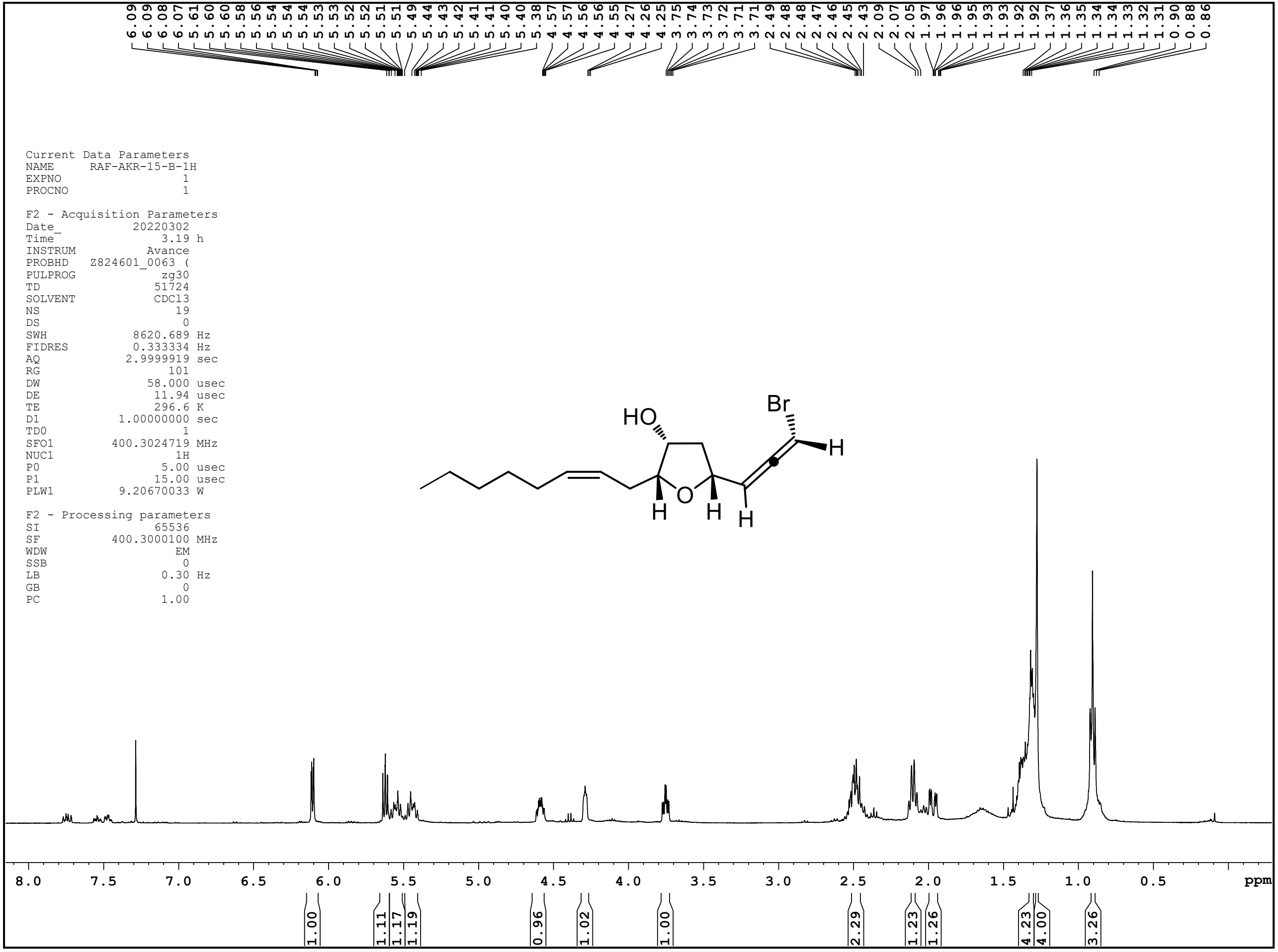


```
Current Data Parameters
NAME     RAF-AKR-14-B-13C
EXPNO                  3
PROCNO                 1

F2 - Acquisition Parameters
Date_           20220216
Time               21.35 h
INSTRUM           Avance
PROBHD   Z824601_0063 (
PULPROG           zgpg30
TD                 65536
SOLVENT            CDCl3
NS                    38
DS                     0
SWH            27777.777 Hz
FIDRES          0.847710 Hz
AQ             1.1796480 sec
RG               12.0028
DW                18.000 usec
DE                  6.50 usec
TE                 295.5 K
D1            1.00000000 sec
D11           0.03000000 sec
TD0                    1
SFO1         100.6669898 MHz
NUC1                 13C
P0                  3.33 usec
P1                 10.00 usec
PLW1         43.41400146 W
SFO2         400.3016012 MHz
NUC2                  1H
CPDPRG[2         waltz65
PCPD2              90.00 usec
PLW2          9.20670033 W
PLW12         0.25573999 W
PLW13         0.12864000 W

F2 - Processing parameters
SI                 32768
SF           100.6555378 MHz
WDW                   EM
SSB                    0
LB                  1.00 Hz
GB                     0
PC                  1.40
```

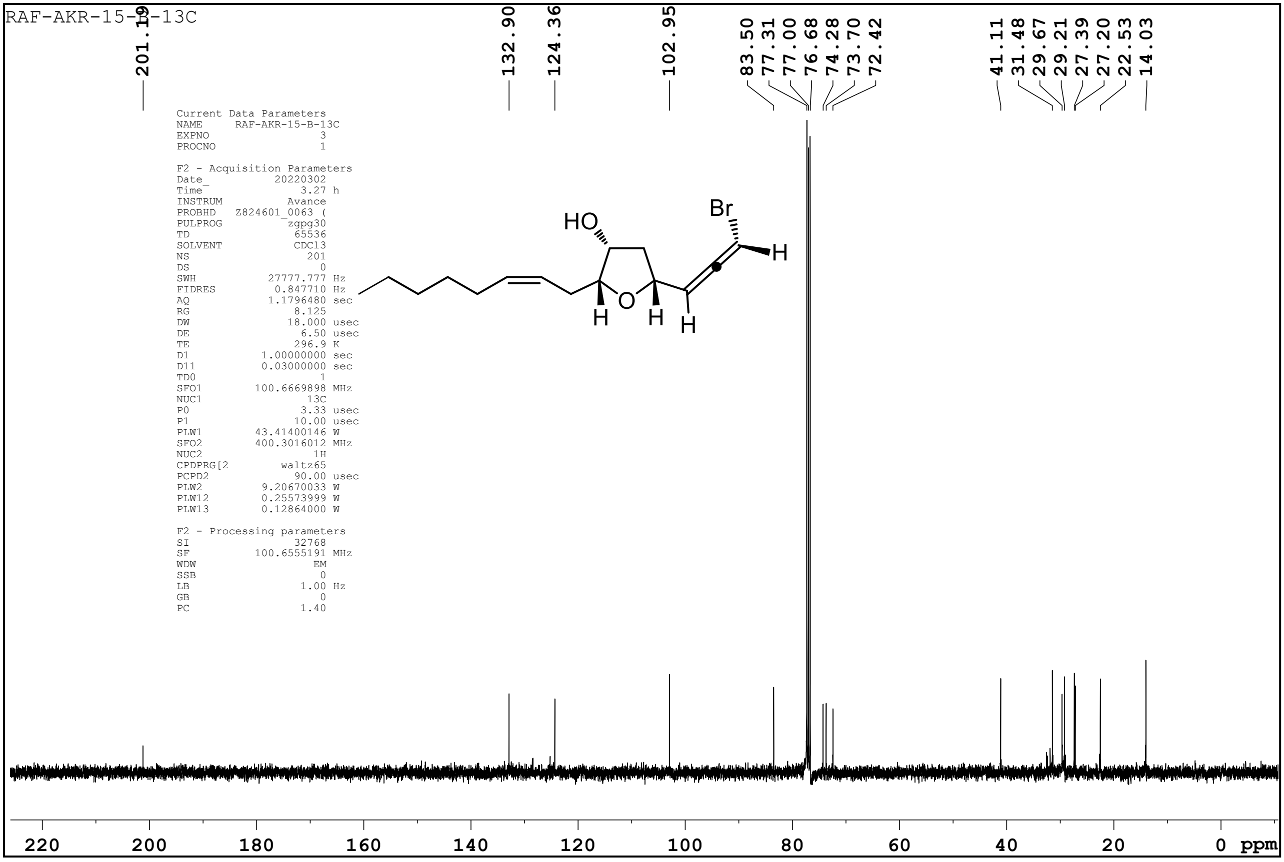
^{1}H NMR (400 MHz, $CDCl_3$) and $^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$) of compound **15a**



```
Current Data Parameters
NAME     RAF-AKR-15-B-1H
EXPNO                  1
PROCNO                 1

F2 - Acquisition Parameters
Date_           20220302
Time                3.19 h
INSTRUM           Avance
PROBHD   Z824601_0063 (
PULPROG             zg30
TD                 51724
SOLVENT            CDCl3
NS                    19
DS                     0
SWH             8620.689 Hz
FIDRES          0.333334 Hz
AQ             2.9999919 sec
RG                   101
DW                58.000 usec
DE                 11.94 usec
TE                 296.6 K
D1            1.00000000 sec
TD0                    1
SFO1         400.3024719 MHz
NUC1                  1H
P0                  5.00 usec
P1                 15.00 usec
PLW1          9.20670033 W

F2 - Processing parameters
SI                 65536
SF           400.3000100 MHz
WDW                   EM
SSB                    0
LB                  0.30 Hz
GB                     0
PC                  1.00
```

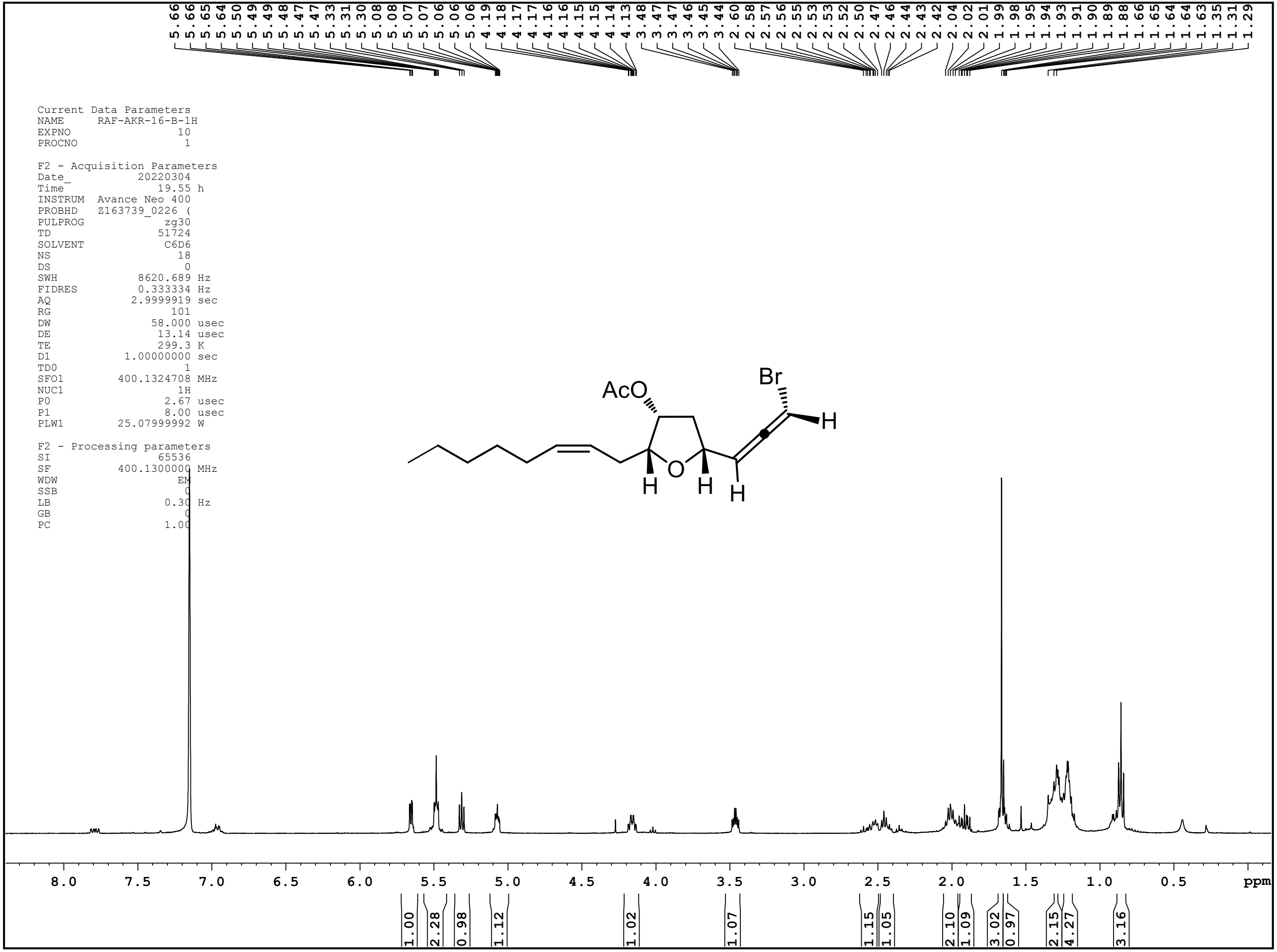


```
Current Data Parameters
NAME     RAF-AKR-15-B-13C
EXPNO                  3
PROCNO                 1

F2 - Acquisition Parameters
Date_           20220302
Time                3.27 h
INSTRUM           Avance
PROBHD   Z824601_0063 (
PULPROG           zgpg30
TD                 65536
SOLVENT            CDCl3
NS                   201
DS                     0
SWH            27777.777 Hz
FIDRES          0.847710 Hz
AQ             1.1796480 sec
RG                 8.125
DW                18.000 usec
DE                  6.50 usec
TE                 296.9 K
D1            1.00000000 sec
D11           0.03000000 sec
TD0                    1
SFO1         100.6669898 MHz
NUC1                 13C
P0                  3.33 usec
P1                 10.00 usec
PLW1         43.41400146 W
SFO2         400.3016012 MHz
NUC2                  1H
CPDPRG[2         waltz65
PCPD2              90.00 usec
PLW2          9.20670033 W
PLW12         0.25573999 W
PLW13         0.12864000 W

F2 - Processing parameters
SI                 32768
SF           100.6555191 MHz
WDW                   EM
SSB                    0
LB                  1.00 Hz
GB                     0
PC                  1.40
```

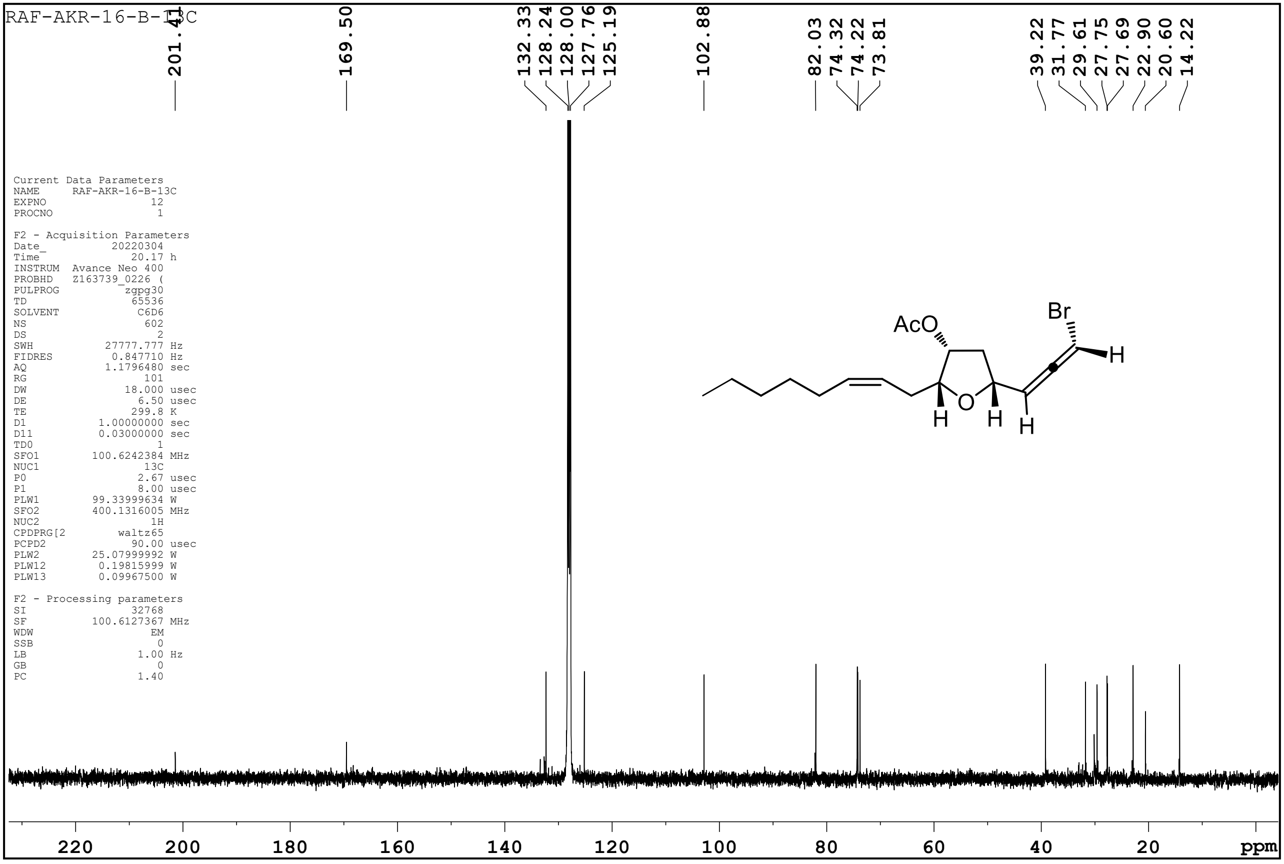
^{1}H NMR (400 MHz, C_6D_6) and $^{13}C\{^1H\}$ NMR (100 MHz, C_6D_6) of compound **4′**



```
Current Data Parameters
NAME     RAF-AKR-16-B-1H
EXPNO              10
PROCNO              1

F2 - Acquisition Parameters
Date_          20220304
Time              19.55 h
INSTRUM  Avance Neo 400
PROBHD   Z163739_0226 (
PULPROG            zg30
TD                51724
SOLVENT            C6D6
NS                   18
DS                    0
SWH            8620.689 Hz
FIDRES         0.333334 Hz
AQ            2.9999919 sec
RG                  101
DW               58.000 usec
DE                13.14 usec
TE                299.3 K
D1           1.00000000 sec
TD0                   1
SFO1        400.1324708 MHz
NUC1                 1H
P0                 2.67 usec
P1                 8.00 usec
PLW1        25.07999992 W

F2 - Processing parameters
SI                65536
SF          400.1300000 MHz
WDW                  EM
SSB                   0
LB                 0.30 Hz
GB                    0
PC                 1.00
```

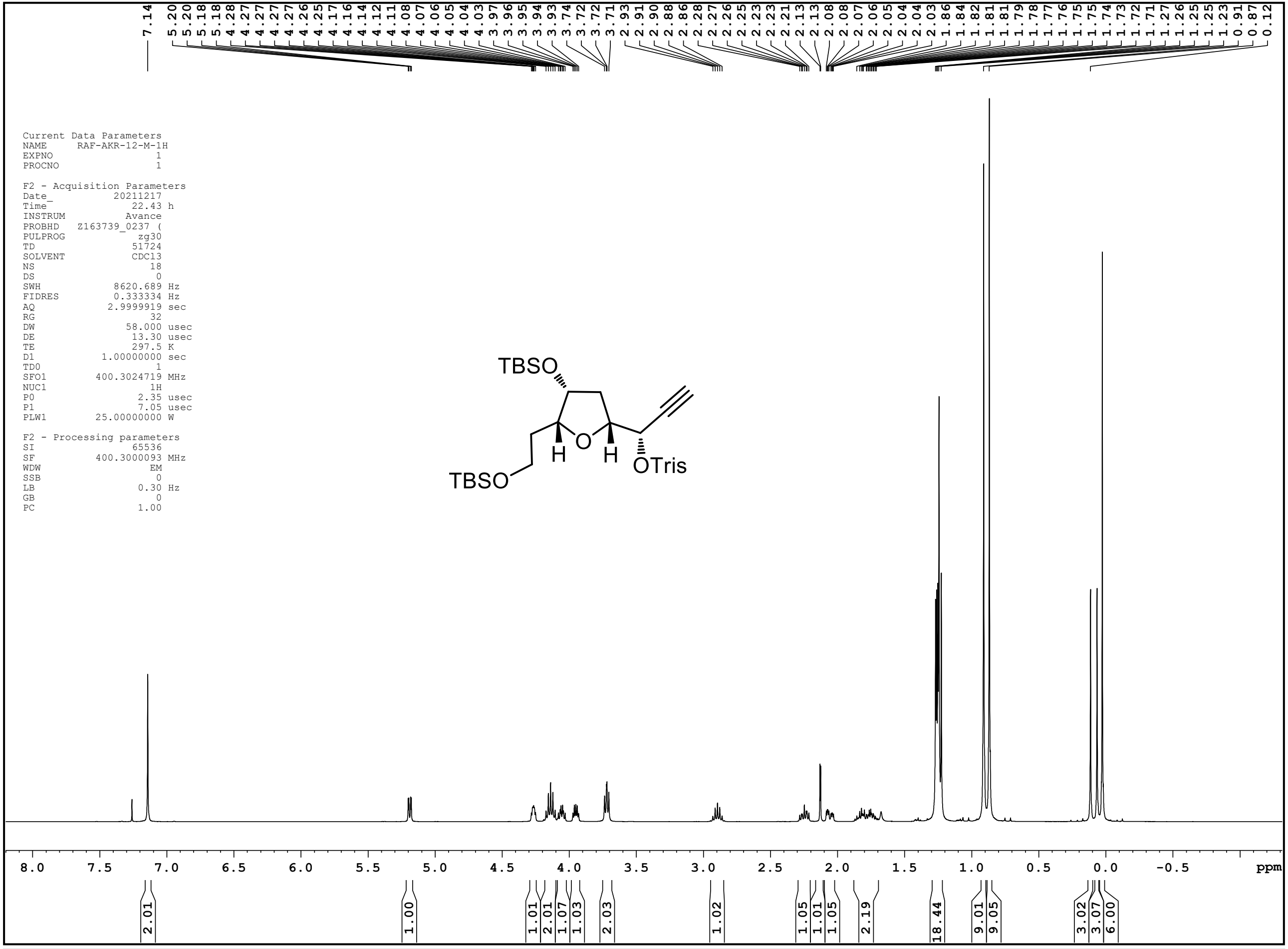


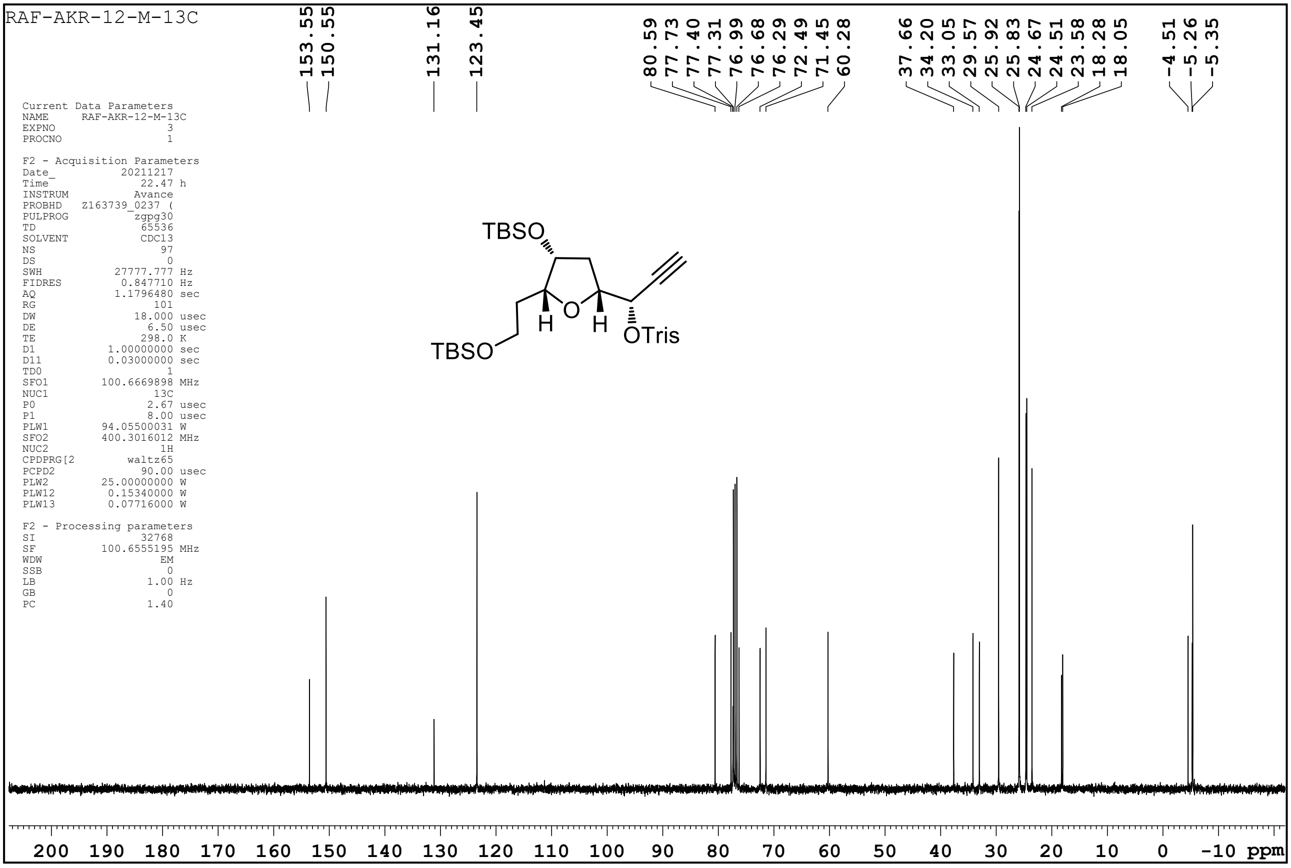
```
Current Data Parameters
NAME     RAF-AKR-16-B-13C
EXPNO              12
PROCNO              1

F2 - Acquisition Parameters
Date_          20220304
Time              20.17 h
INSTRUM  Avance Neo 400
PROBHD   Z163739_0226 (
PULPROG          zgpg30
TD                65536
SOLVENT            C6D6
NS                  602
DS                    2
SWH           27777.777 Hz
FIDRES         0.847710 Hz
AQ            1.1796480 sec
RG                  101
DW               18.000 usec
DE                 6.50 usec
TE                299.8 K
D1           1.00000000 sec
D11          0.03000000 sec
TD0                   1
SFO1        100.6242384 MHz
NUC1                13C
P0                 2.67 usec
P1                 8.00 usec
PLW1        99.33999634 W
SFO2        400.1316005 MHz
NUC2                 1H
CPDPRG[2        waltz65
PCPD2             90.00 usec
PLW2        25.07999992 W
PLW12        0.19815999 W
PLW13        0.09967500 W

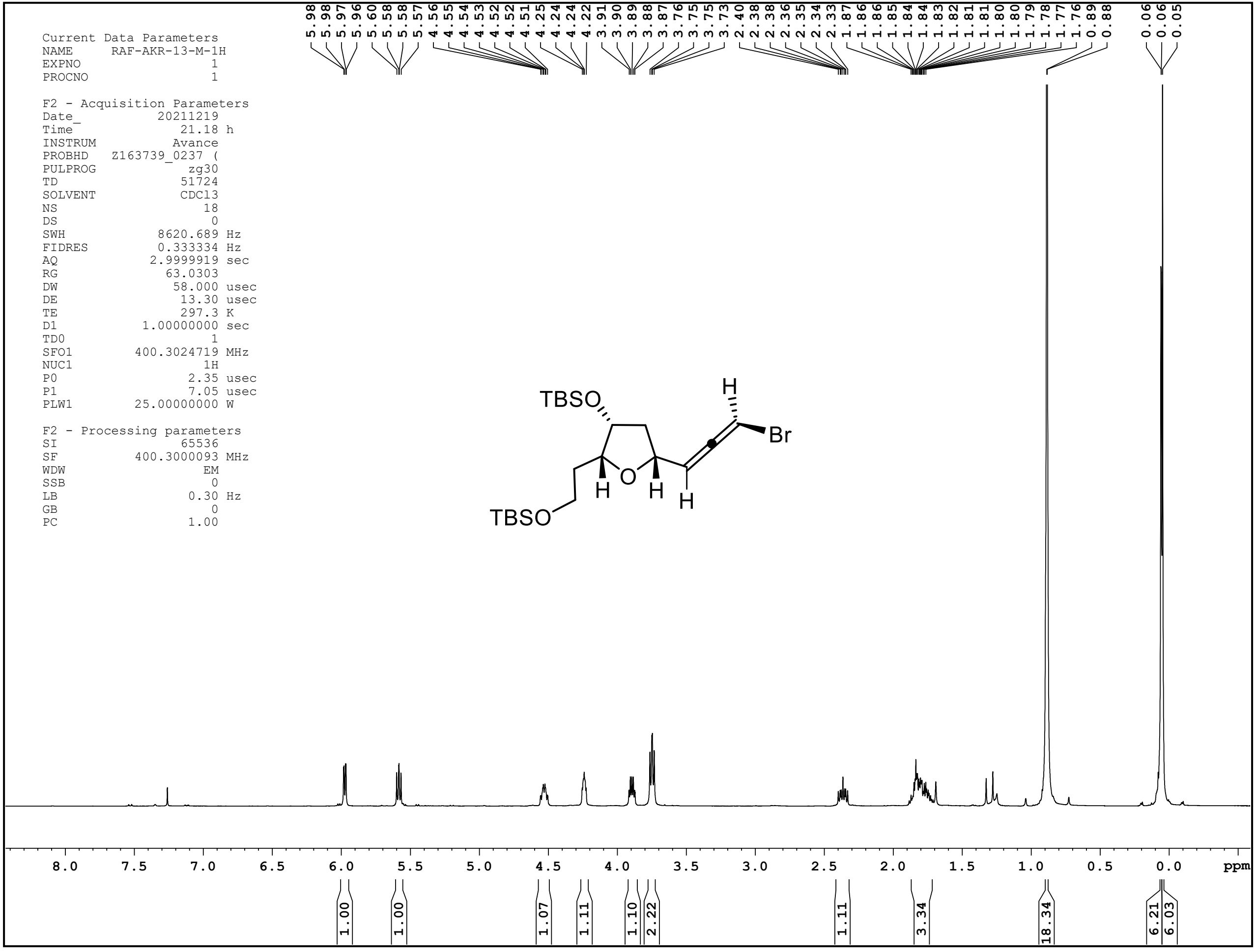
F2 - Processing parameters
SI                32768
SF          100.6127367 MHz
WDW                  EM
SSB                   0
LB                 1.00 Hz
GB                    0
PC                 1.40
```

^{1}H NMR (400 MHz, CDCl$_3$) and ^{13}C{^{1}H} NMR (100 MHz, CDCl$_3$) of compound **6a**





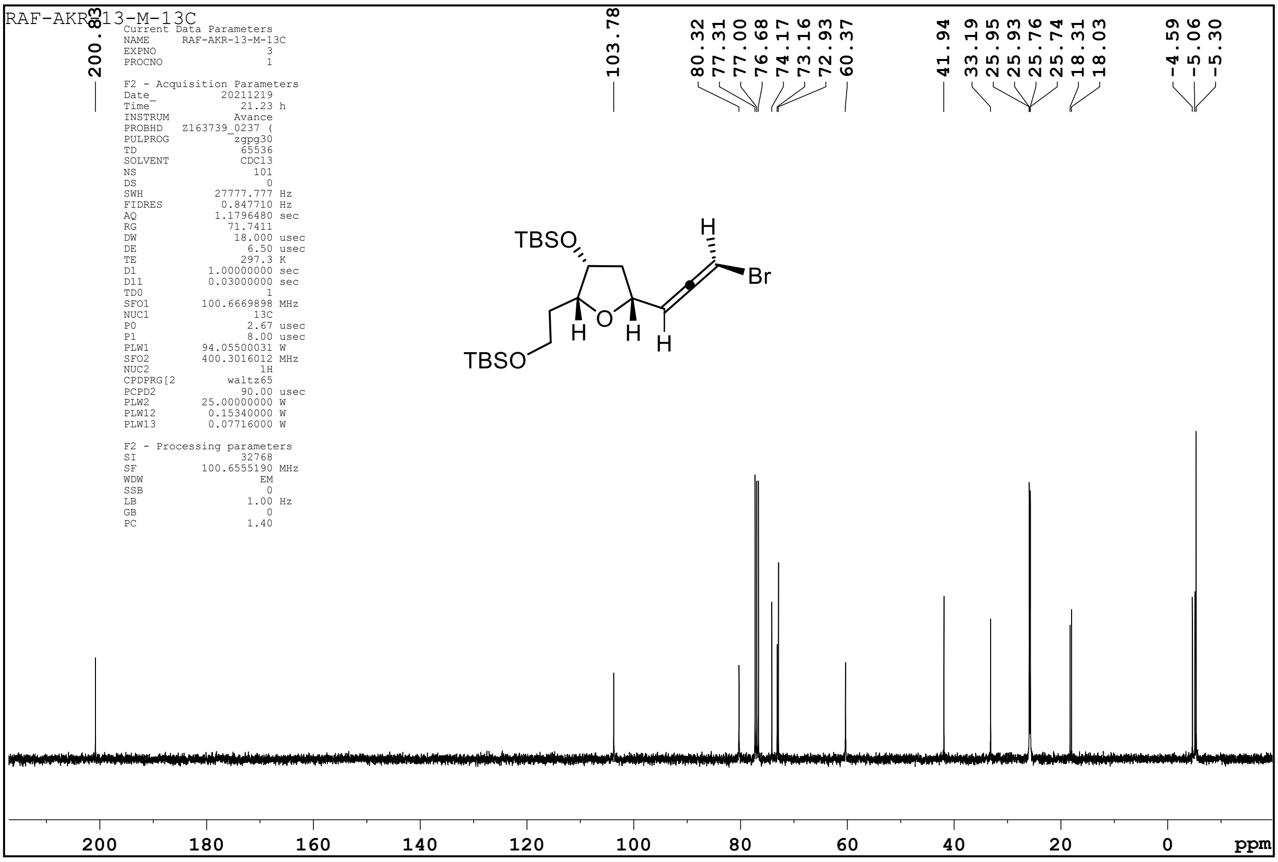
^{1}H NMR (400 MHz, $CDCl_3$) and $^{13}C\{^{1}H\}$ NMR (100 MHz, $CDCl_3$) of compound **13b**



```
Current Data Parameters
NAME     RAF-AKR-13-M-1H
EXPNO                  1
PROCNO                 1

F2 - Acquisition Parameters
Date_           20211219
Time               21.18 h
INSTRUM           Avance
PROBHD   Z163739_0237 (
PULPROG             zg30
TD                 51724
SOLVENT            CDCl3
NS                    18
DS                     0
SWH             8620.689 Hz
FIDRES          0.333334 Hz
AQ             2.9999919 sec
RG               63.0303
DW                58.000 usec
DE                 13.30 usec
TE                 297.3 K
D1            1.00000000 sec
TD0                    1
SFO1         400.3024719 MHz
NUC1                  1H
P0                  2.35 usec
P1                  7.05 usec
PLW1         25.00000000 W

F2 - Processing parameters
SI                 65536
SF           400.3000093 MHz
WDW                   EM
SSB                    0
LB                  0.30 Hz
GB                     0
PC                  1.00
```

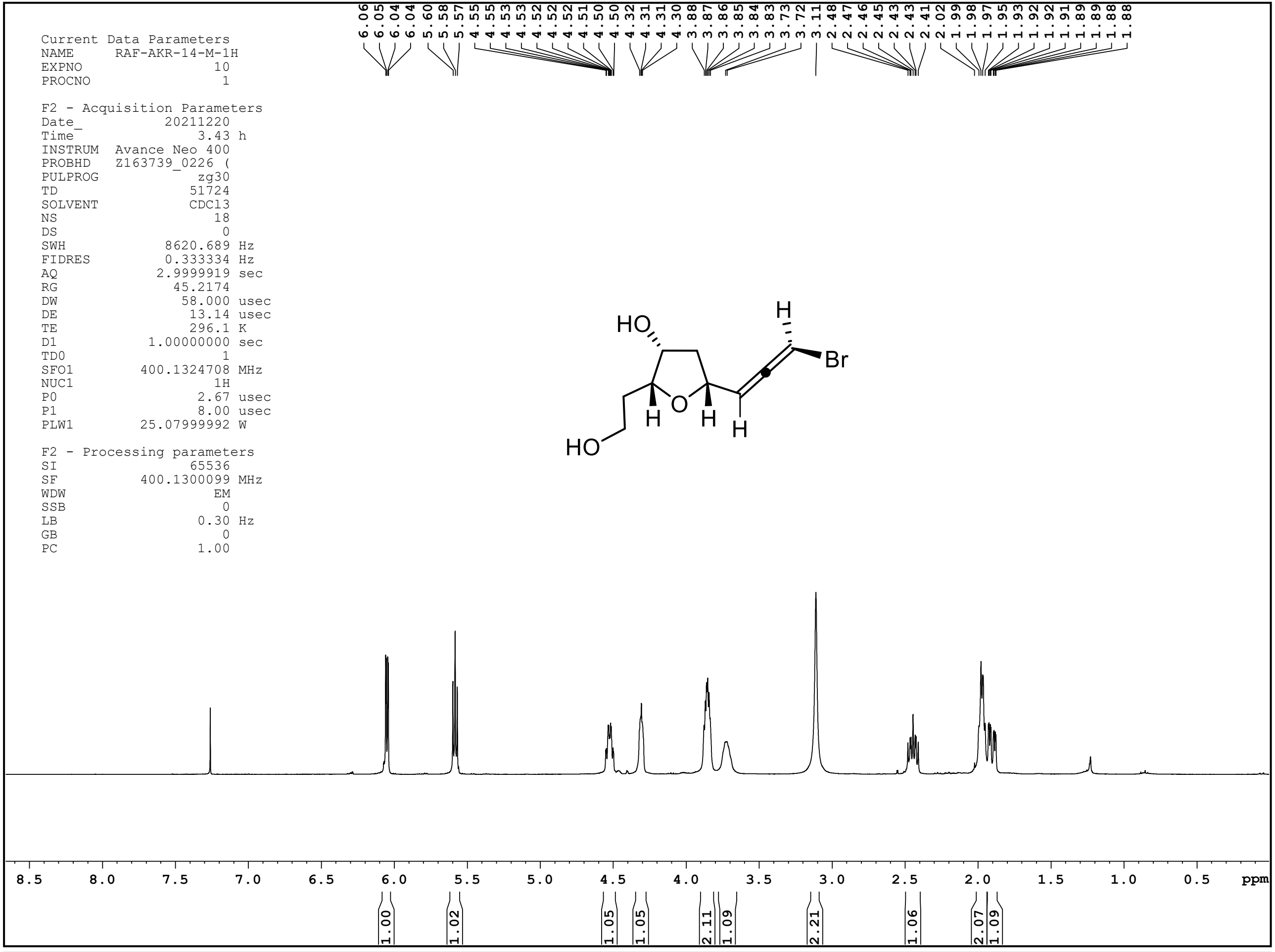


```
RAF-AKR-13-M-13C
Current Data Parameters
NAME     RAF-AKR-13-M-13C
EXPNO                   3
PROCNO                  1

F2 - Acquisition Parameters
Date_           20211219
Time               21.23 h
INSTRUM           Avance
PROBHD   Z163739_0237 (
PULPROG           zgpg30
TD                 65536
SOLVENT            CDCl3
NS                   101
DS                     0
SWH            27777.777 Hz
FIDRES          0.847710 Hz
AQ             1.1796480 sec
RG               71.7411
DW                18.000 usec
DE                  6.50 usec
TE                 297.3 K
D1            1.00000000 sec
D11           0.03000000 sec
TD0                    1
SFO1         100.6669898 MHz
NUC1                 13C
P0                  2.67 usec
P1                  8.00 usec
PLW1         94.05500031 W
SFO2         400.3016012 MHz
NUC2                  1H
CPDPRG[2         waltz65
PCPD2              90.00 usec
PLW2         25.00000000 W
PLW12         0.15340000 W
PLW13         0.07716000 W

F2 - Processing parameters
SI                 32768
SF           100.6555190 MHz
WDW                   EM
SSB                    0
LB                  1.00 Hz
GB                     0
PC                  1.40
```

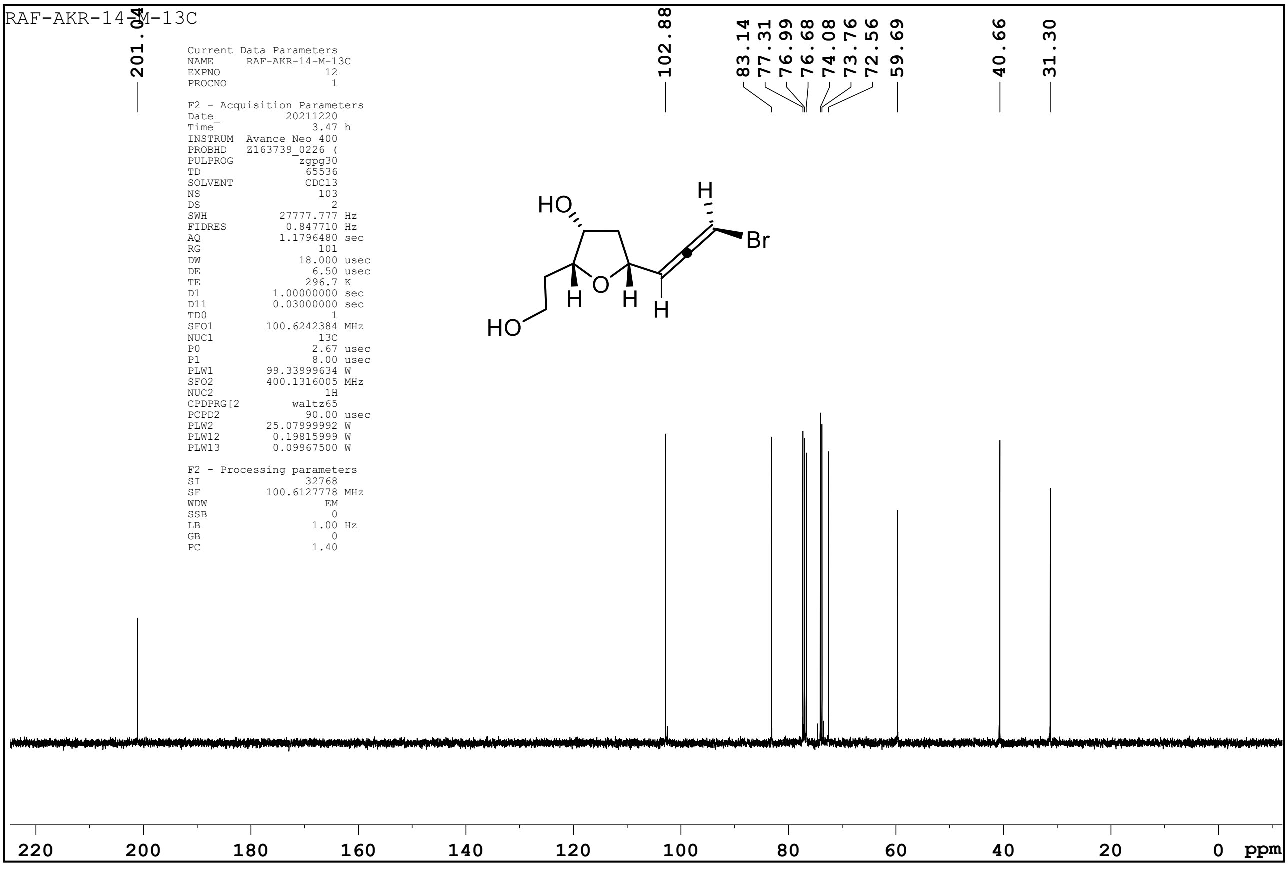
^{1}H NMR (400 MHz, $CDCl_3$) and $^{13}C\{^{1}H\}$ NMR (100 MHz, $CDCl_3$) of compound **14b**



```
Current Data Parameters
NAME      RAF-AKR-14-M-1H
EXPNO                  10
PROCNO                  1

F2 - Acquisition Parameters
Date_            20211220
Time                 3.43 h
INSTRUM   Avance Neo 400
PROBHD    Z163739_0226 (
PULPROG              zg30
TD                  51724
SOLVENT             CDCl3
NS                     18
DS                      0
SWH              8620.689 Hz
FIDRES           0.333334 Hz
AQ              2.9999919 sec
RG                45.2174
DW                 58.000 usec
DE                  13.14 usec
TE                  296.1 K
D1             1.00000000 sec
TD0                     1
SFO1          400.1324708 MHz
NUC1                   1H
P0                   2.67 usec
P1                   8.00 usec
PLW1          25.07999992 W

F2 - Processing parameters
SI                  65536
SF            400.1300099 MHz
WDW                    EM
SSB                     0
LB                   0.30 Hz
GB                      0
PC                   1.00
```

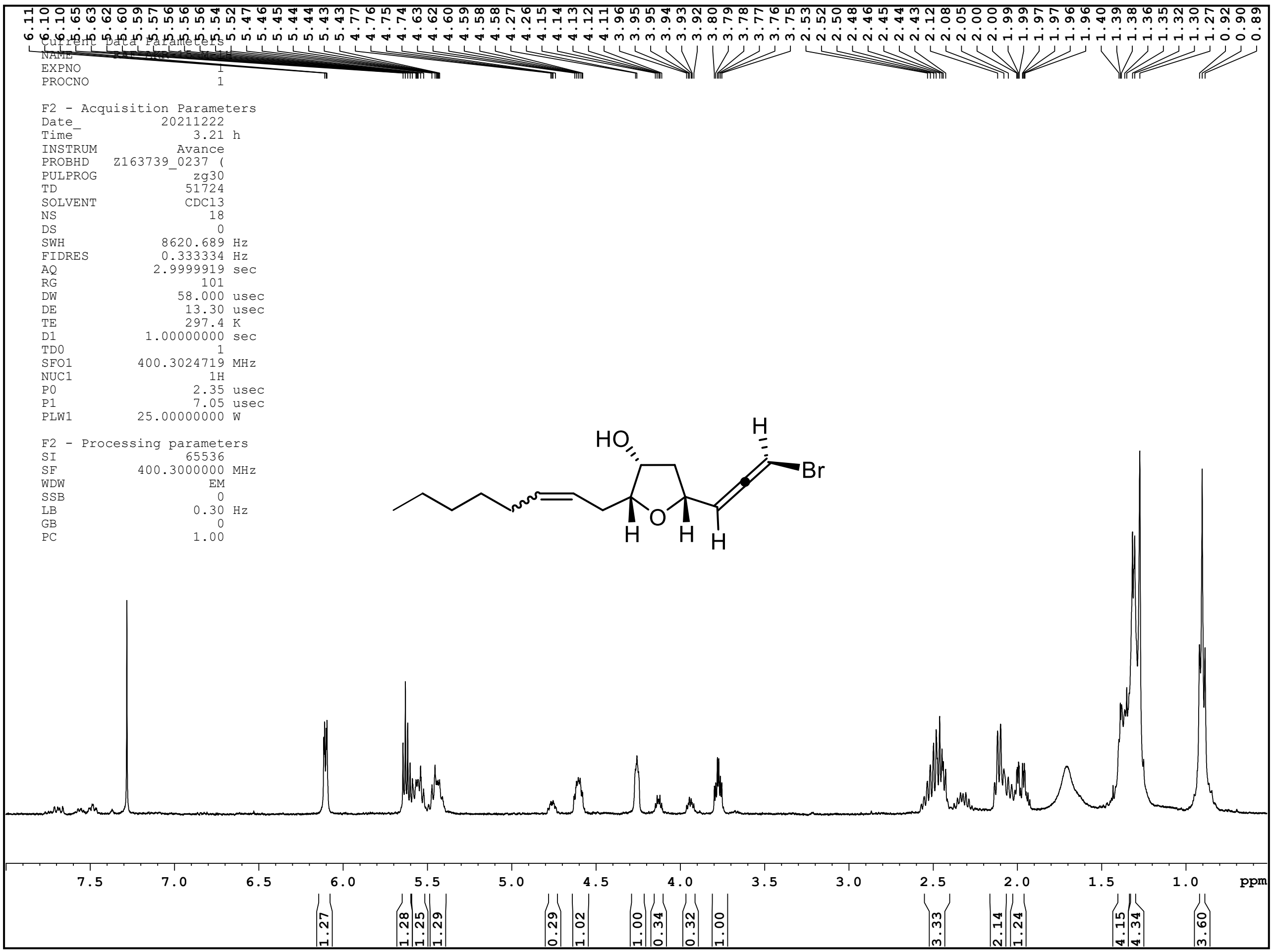


```
Current Data Parameters
NAME      RAF-AKR-14-M-13C
EXPNO                  12
PROCNO                  1

F2 - Acquisition Parameters
Date_            20211220
Time                 3.47 h
INSTRUM   Avance Neo 400
PROBHD    Z163739_0226 (
PULPROG            zgpg30
TD                  65536
SOLVENT             CDCl3
NS                    103
DS                      2
SWH             27777.777 Hz
FIDRES           0.847710 Hz
AQ              1.1796480 sec
RG                    101
DW                 18.000 usec
DE                   6.50 usec
TE                  296.7 K
D1             1.00000000 sec
D11            0.03000000 sec
TD0                     1
SFO1          100.6242384 MHz
NUC1                  13C
P0                   2.67 usec
P1                   8.00 usec
PLW1          99.33999634 W
SFO2          400.1316005 MHz
NUC2                   1H
CPDPRG[2          waltz65
PCPD2               90.00 usec
PLW2          25.07999992 W
PLW12          0.19815999 W
PLW13          0.09967500 W

F2 - Processing parameters
SI                  32768
SF            100.6127778 MHz
WDW                    EM
SSB                     0
LB                   1.00 Hz
GB                      0
PC                   1.40
```

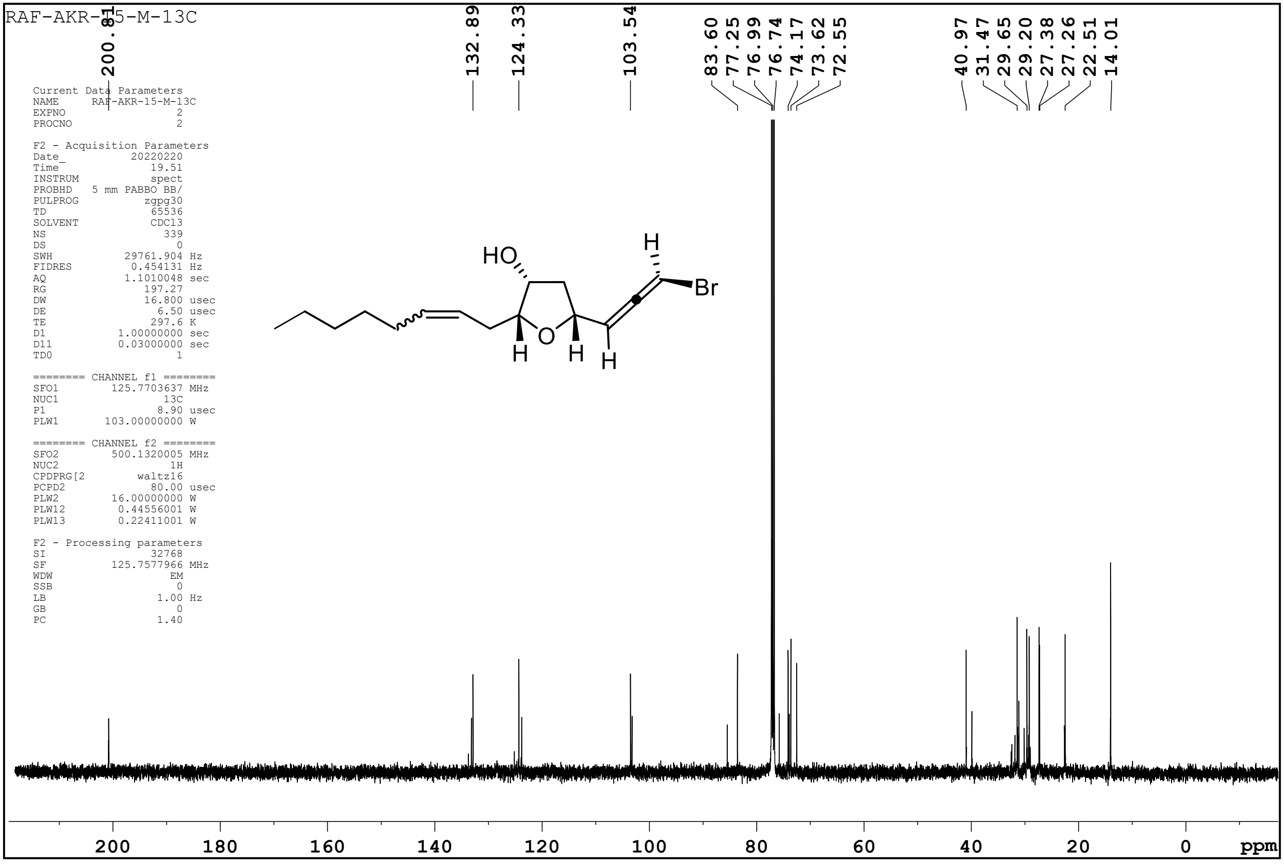
^{1}H NMR (400 MHz, $CDCl_3$) and ^{13}C{^{1}H} NMR (125 MHz, $CDCl_3$) of compound **15b**



```
Current Data Parameters
NAME         RAF-AKR-15-M-1H
EXPNO                     1
PROCNO                    1

F2 - Acquisition Parameters
Date_              20211222
Time                   3.21 h
INSTRUM              Avance
PROBHD   Z163739_0237 (
PULPROG                zg30
TD                    51724
SOLVENT               CDCl3
NS                       18
DS                        0
SWH                8620.689 Hz
FIDRES             0.333334 Hz
AQ                2.9999919 sec
RG                      101
DW                   58.000 usec
DE                    13.30 usec
TE                    297.4 K
D1               1.00000000 sec
TD0                       1
SFO1            400.3024719 MHz
NUC1                     1H
P0                     2.35 usec
P1                     7.05 usec
PLW1            25.00000000 W

F2 - Processing parameters
SI                    65536
SF              400.3000000 MHz
WDW                      EM
SSB                       0
LB                     0.30 Hz
GB                        0
PC                     1.00
```



```
RAF-AKR-15-M-13C

Current Data Parameters
NAME     RAF-AKR-15-M-13C
EXPNO                   2
PROCNO                  2

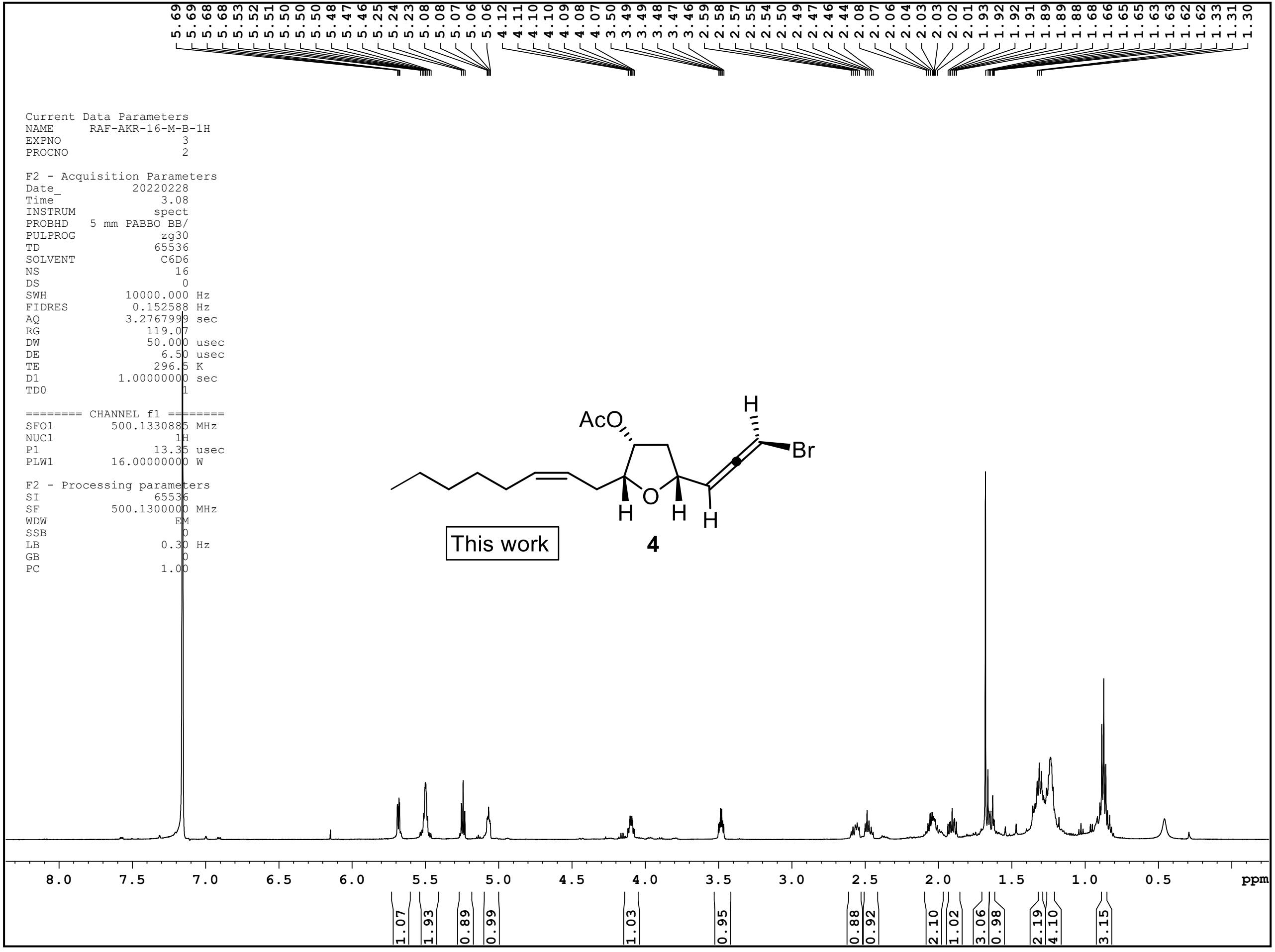
F2 - Acquisition Parameters
Date_            20220220
Time                19.51
INSTRUM             spect
PROBHD   5 mm PABBO BB/
PULPROG            zgpg30
TD                  65536
SOLVENT             CDCl3
NS                    339
DS                      0
SWH             29761.904 Hz
FIDRES           0.454131 Hz
AQ              1.1010048 sec
RG                 197.27
DW                 16.800 usec
DE                   6.50 usec
TE                  297.6 K
D1             1.00000000 sec
D11            0.03000000 sec
TD0                     1

======== CHANNEL f1 ========
SFO1         125.7703637 MHz
NUC1                  13C
P1                   8.90 usec
PLW1         103.00000000 W

======== CHANNEL f2 ========
SFO2         500.1320005 MHz
NUC2                   1H
CPDPRG[2          waltz16
PCPD2               80.00 usec
PLW2          16.00000000 W
PLW12          0.44556001 W
PLW13          0.22411001 W

F2 - Processing parameters
SI                  32768
SF            125.7577966 MHz
WDW                    EM
SSB                     0
LB                   1.00 Hz
GB                      0
PC                   1.40
```

^{1}H NMR (500 MHz, C_6D_6) of compound **4** and literature isolated compound **4** spectra

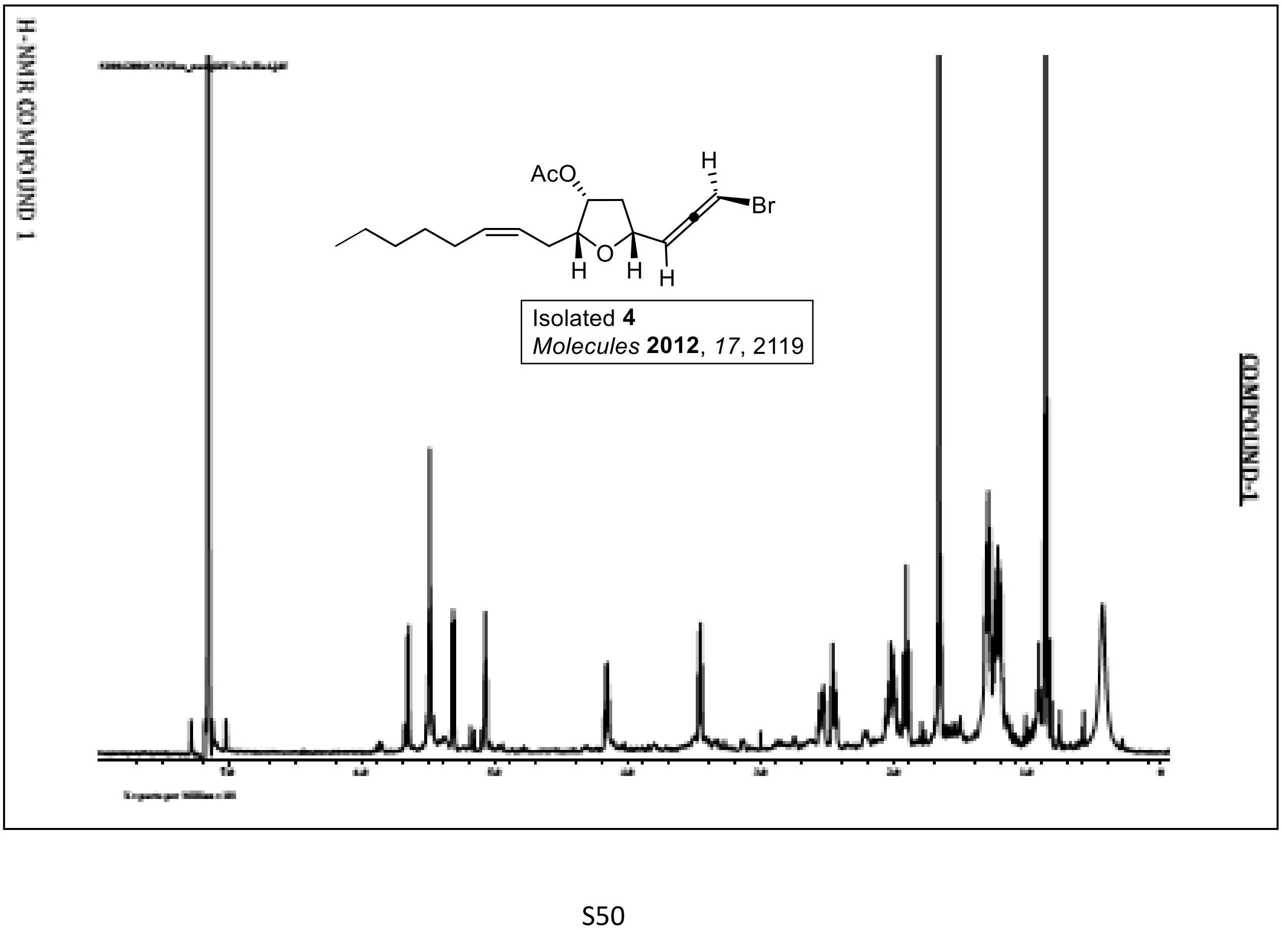


```
Current Data Parameters
NAME      RAF-AKR-16-M-B-1H
EXPNO                  3
PROCNO                 2

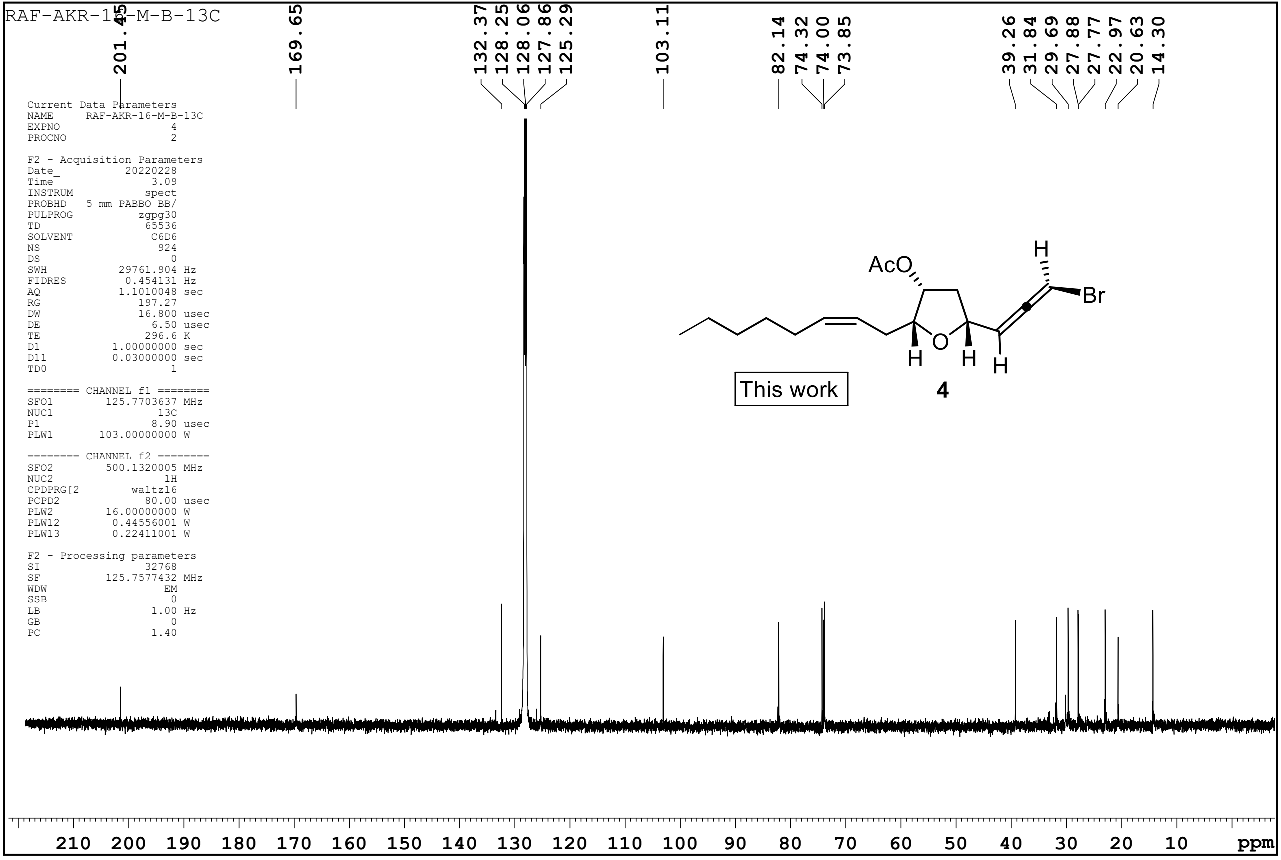
F2 - Acquisition Parameters
Date_           20220228
Time                3.08
INSTRUM            spect
PROBHD   5 mm PABBO BB/
PULPROG             zg30
TD                 65536
SOLVENT             C6D6
NS                    16
DS                     0
SWH            10000.000 Hz
FIDRES          0.152588 Hz
AQ             3.2767999 sec
RG                119.07
DW                50.000 usec
DE                  6.50 usec
TE                 296.5 K
D1            1.00000000 sec
TD0                    1

======== CHANNEL f1 ========
SFO1         500.1330885 MHz
NUC1                  1H
P1                 13.35 usec
PLW1         16.00000000 W

F2 - Processing parameters
SI                 65536
SF           500.1300000 MHz
WDW                   EM
SSB                    0
LB                  0.30 Hz
GB                     0
PC                  1.00
```



$^{13}C\{^{1}H\}$ NMR (125 MHz, C_6D_6) of compound **4**



```
Current Data Parameters
NAME     RAF-AKR-16-M-B-13C
EXPNO                     4
PROCNO                    2

F2 - Acquisition Parameters
Date_              20220228
Time                   3.09
INSTRUM               spect
PROBHD   5 mm PABBO BB/
PULPROG             zgpg30
TD                   65536
SOLVENT               C6D6
NS                     924
DS                       0
SWH              29761.904 Hz
FIDRES            0.454131 Hz
AQ               1.1010048 sec
RG                  197.27
DW                  16.800 usec
DE                    6.50 usec
TE                   296.6 K
D1              1.00000000 sec
D11             0.03000000 sec
TD0                      1

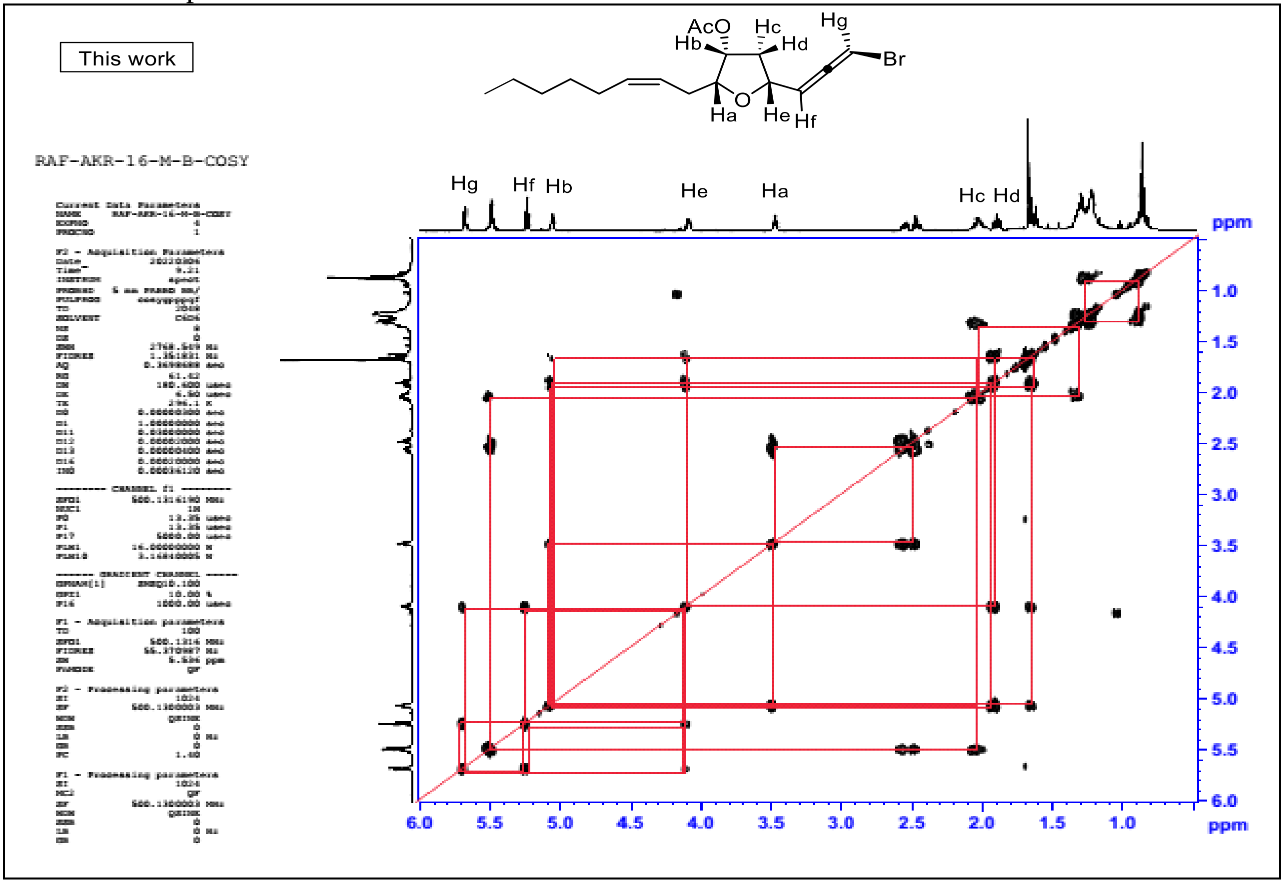
======== CHANNEL f1 ========
SFO1           125.7703637 MHz
NUC1                   13C
P1                    8.90 usec
PLW1          103.00000000 W

======== CHANNEL f2 ========
SFO2           500.1320005 MHz
NUC2                    1H
CPDPRG[2           waltz16
PCPD2                80.00 usec
PLW2           16.00000000 W
PLW12           0.44556001 W
PLW13           0.22411001 W

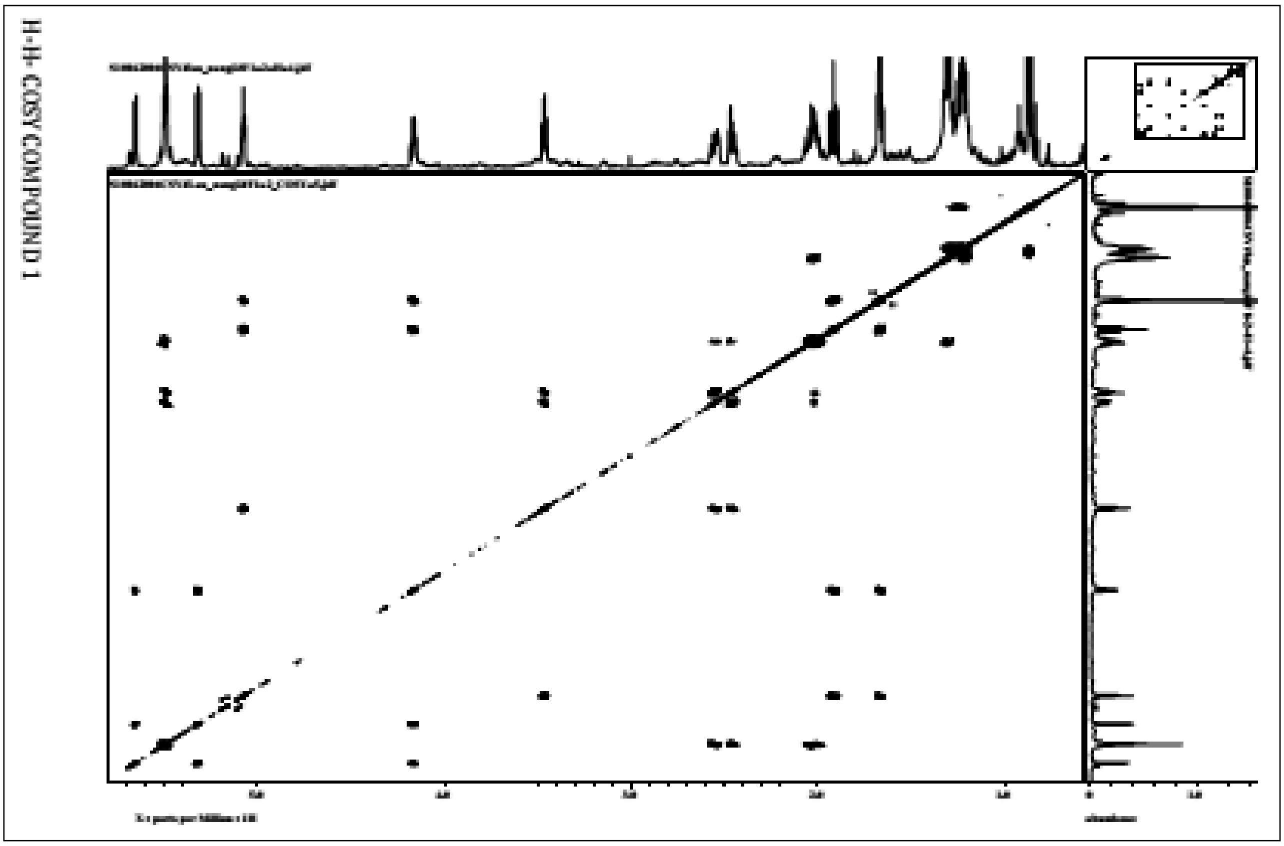
F2 - Processing parameters
SI                   32768
SF             125.7577432 MHz
WDW                     EM
SSB                      0
LB                    1.00 Hz
GB                       0
PC                    1.40
```

NOTE: ^{13}C NMR spectra copy of isolated natural product is not available for spectra comparison.

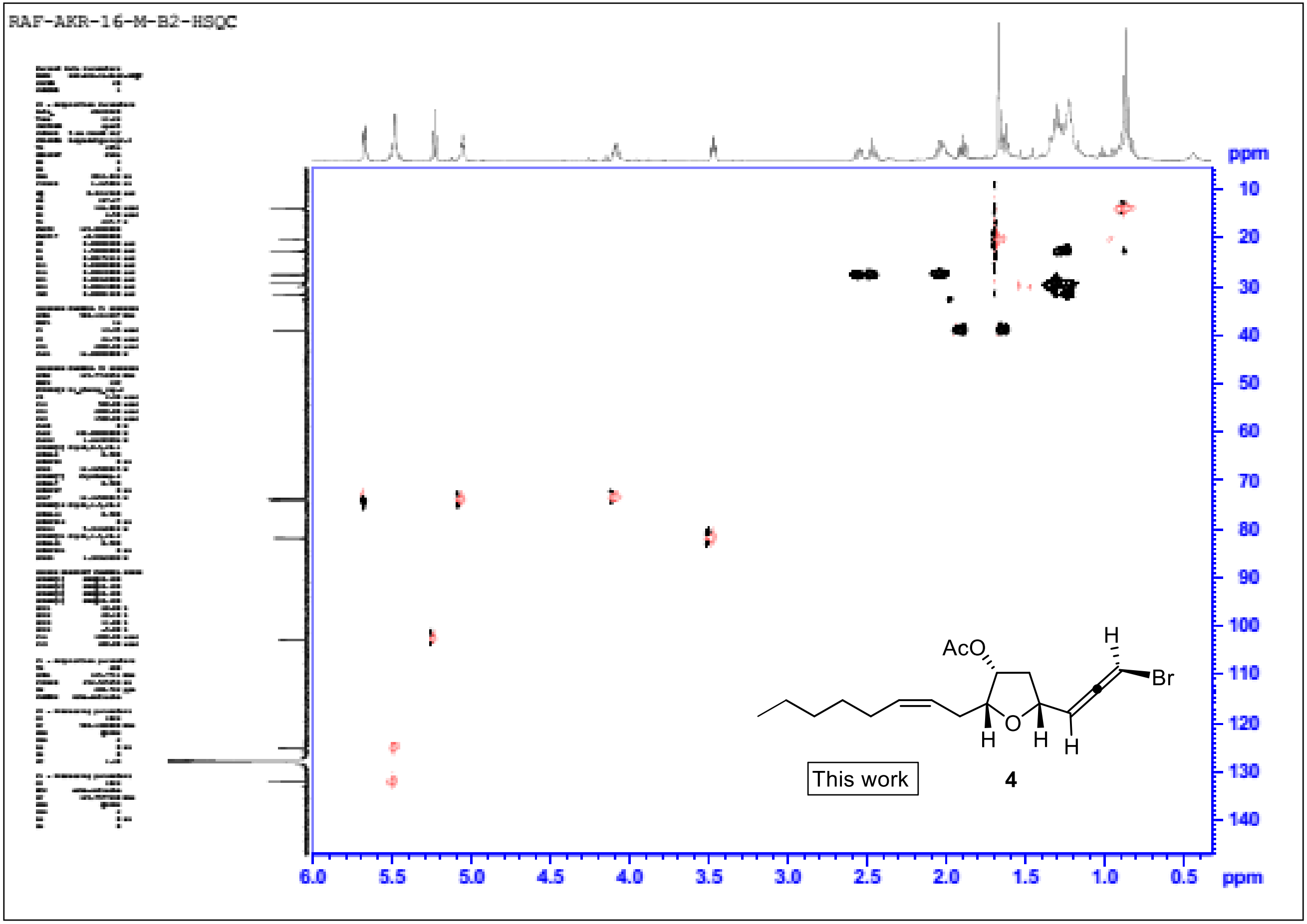
COSY of compound **4**

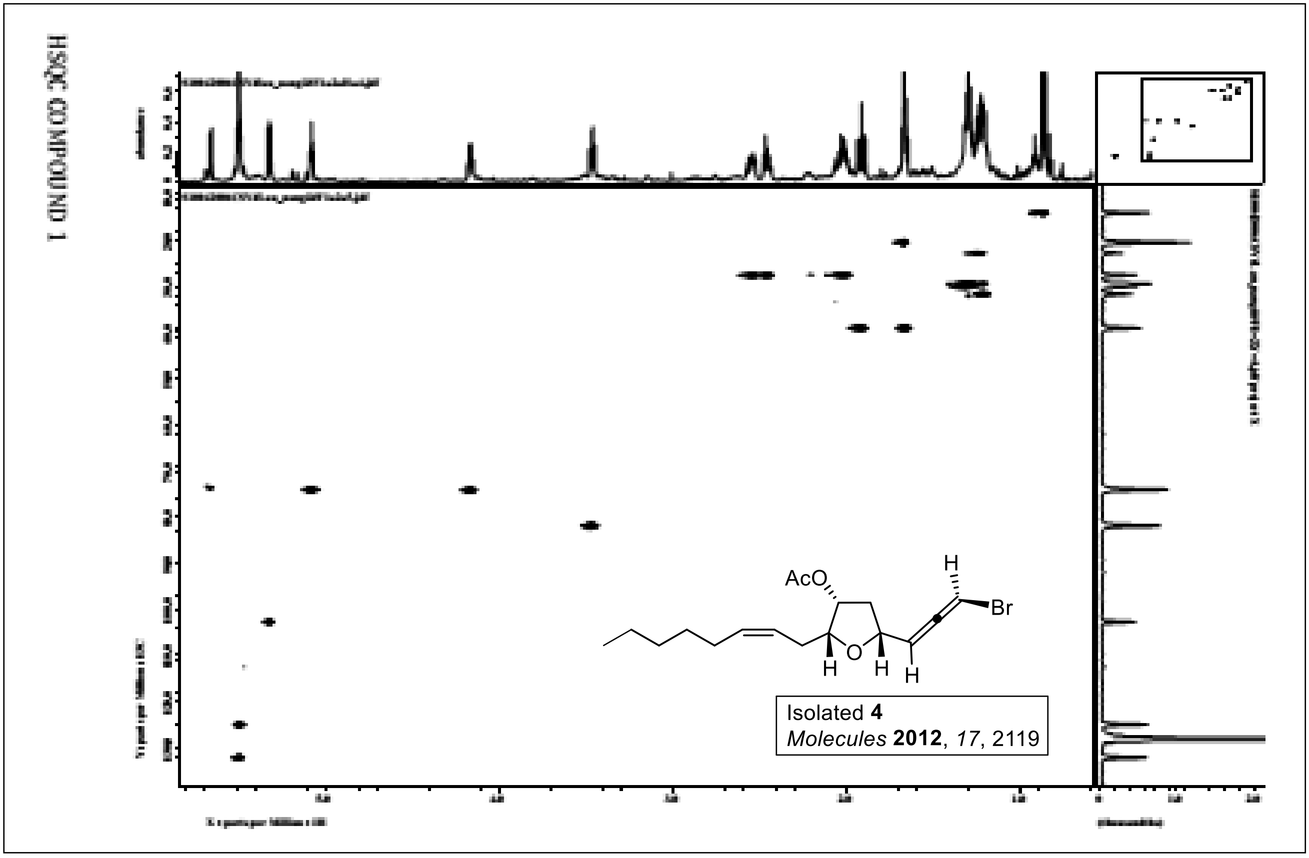


COSY of compound **4** reported [*Molecules* **2012**, *17*, 2119]



HSQC of compound **4** and reported spectra

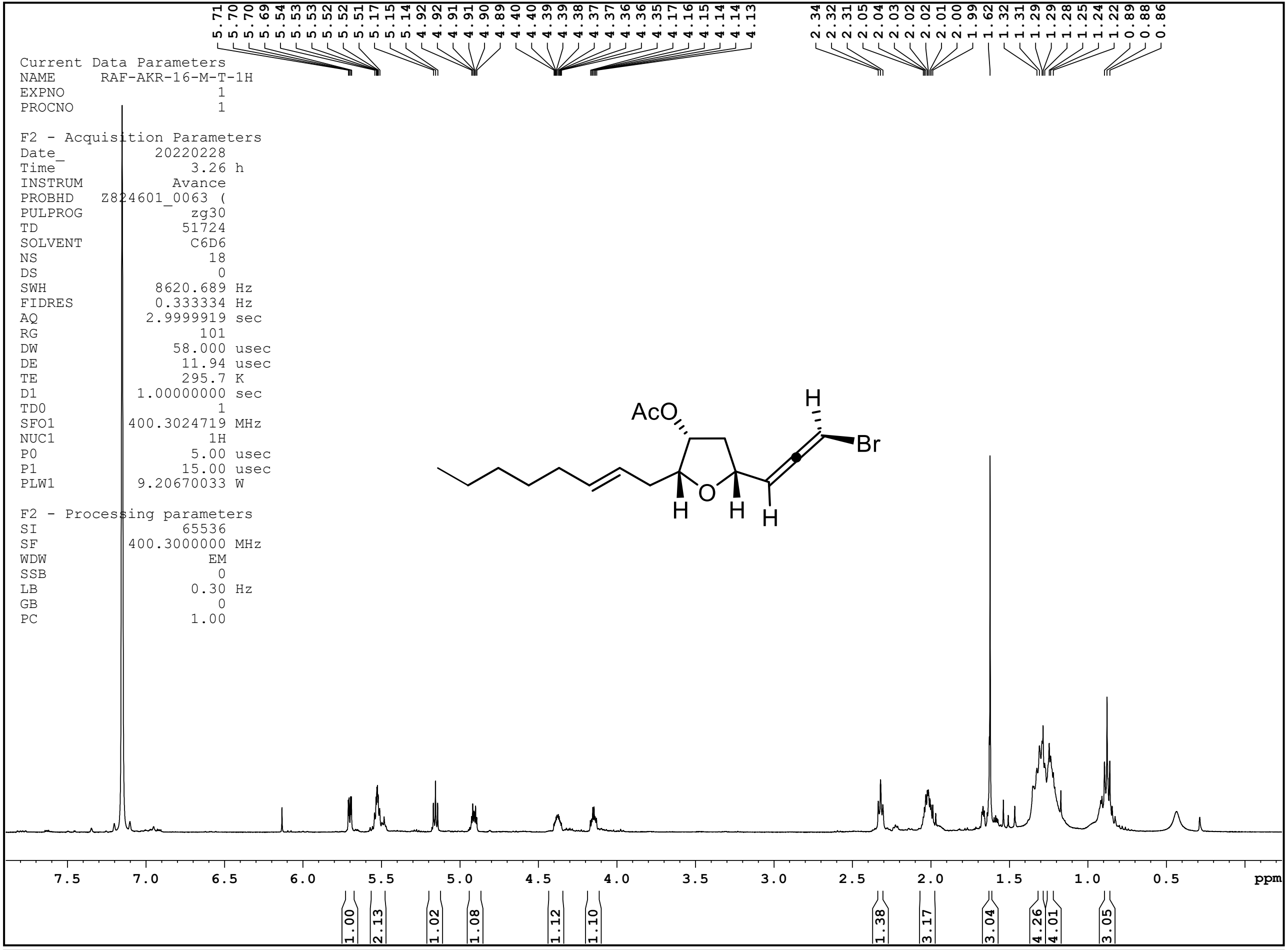




Comparison data of (+)-dihydroitomanallene B (**4**): Isolation and our data

Isolated Compound Data ***Molecules* 2012, *17*, 2119**		**Our Work Data**	
^{1}H-NMR	^{13}C-NMR	^{1}H-NMR	^{13}C-NMR
5.66 (dd, *J* = 5.8, 2.0 Hz, 1H)	73.5 201.5	5.68 (dd, *J* = 5.7, 1.8 Hz, 1H)	73.3 201.5
5.32 (dd, *J* = 5.8, 5.8 Hz, 1H)	102.6	5.24 (t, *J* = 5.7 Hz, 1H)	103.1
4.16 (dddd, *J* = 7.3, 5.8, 5.4, 2.0 Hz, 1H)	74.0	4.12–4.07 (m, 1H)	74.0
1.92 (ddd, *J* = 13.7, 5.4, 1.5 Hz, 1H) 1.67 (m, 1H)	38.9	1.91 (ddd, *J* = 14.4, 8.4, 6.1 Hz, 1H) 1.65–1.61 (m, 1H)	39.3
5.08 (m, IH)	73.9	5.07 (dd, *J* = 6.7, 2.9 Hz, 1H)	73.9
3.47 (ddd, *J* = 7.3, 7.3, 3.4 Hz, 1H)	81.8	3.48 (td, *J* = 6.8, 3.8 Hz, 1H)	82.1
2.54 (ddd, *J* = 13.7, 7.3, 3.4 Hz, 1H) 2.46 (ddd, *J* = 13.7, 7.3, 3.4 Hz, 1H)	27.5	2.60–2.52 (m, 1H) 2.48 (dd, *J* = 13.6, 7.1 Hz, 1H)	27.9
5.49 (m, 1H)	124.9	5.53–5.46 (m, 2H)	125.3
5.49 (m, 1H)	132.1		132.4
2.02 (m, 2H)	27.4	2.07–2.00 (m, 2H)	27.8
1.30 (m, 2H)	29.4	1.35–1.28 (m, 2H)	29.7
1.22 (m, 2H)	31.5	1.26–1.21 (m, 4H)	31.8
1.24 (m, 2H)	22.7		23.0
0.87 (t, *J* = 7.3 Hz, 3H)	13.9	0.87 (t, *J* = 6.8 Hz, 3H	14.3
-	169.5		169.7
1.67 (s, 1H)	20.4	1.68 (s, 3H)	20.6

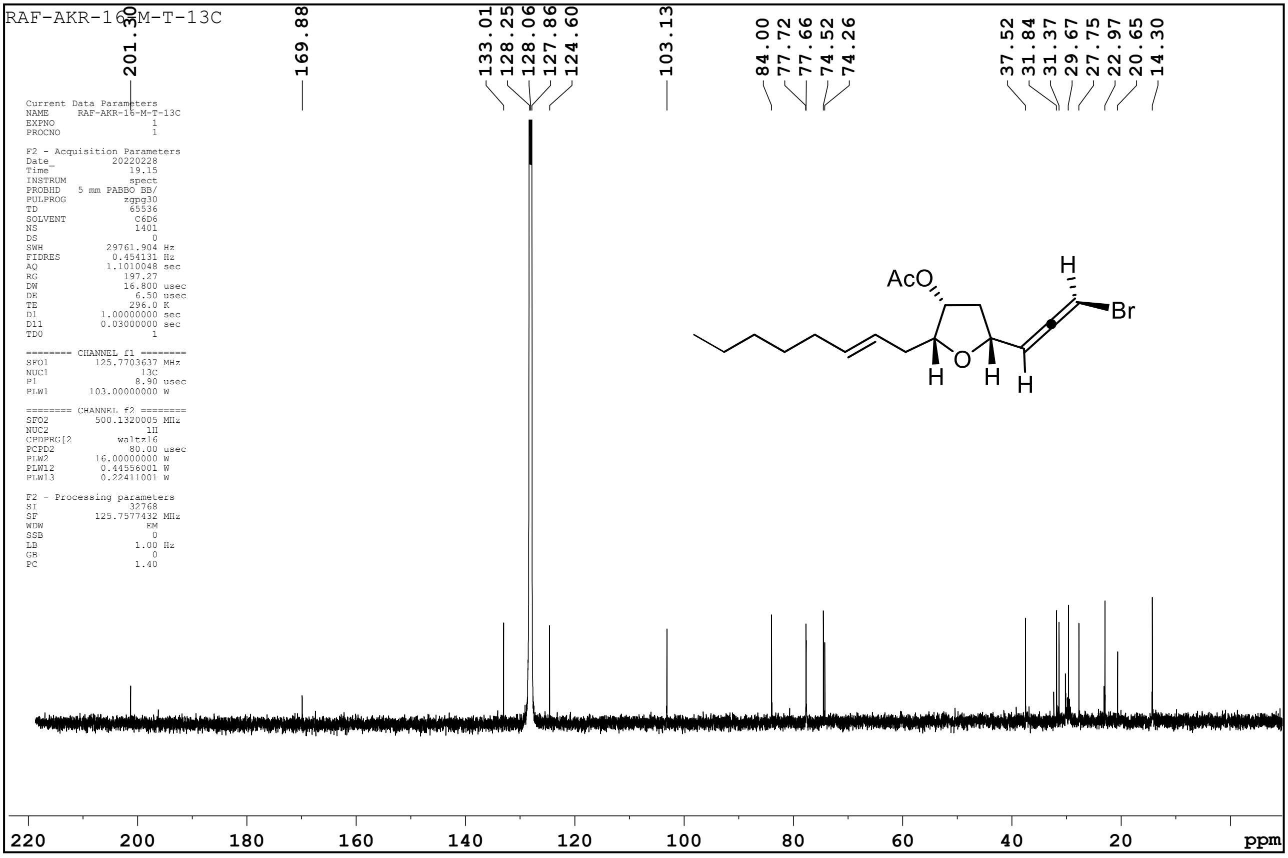
^{1}H NMR (400 MHz, C_6D_6) and $^{13}C\{^{1}H\}$ NMR (125 MHz, C_6D_6) of compound **4″**



```
Current Data Parameters
NAME      RAF-AKR-16-M-T-1H
EXPNO                  1
PROCNO                 1

F2 - Acquisition Parameters
Date_           20220228
Time                3.26 h
INSTRUM           Avance
PROBHD   Z824601_0063 (
PULPROG             zg30
TD                 51724
SOLVENT             C6D6
NS                    18
DS                     0
SWH             8620.689 Hz
FIDRES          0.333334 Hz
AQ             2.9999919 sec
RG                   101
DW                58.000 usec
DE                 11.94 usec
TE                 295.7 K
D1          1.00000000 sec
TD0                    1
SFO1         400.3024719 MHz
NUC1                  1H
P0                  5.00 usec
P1                 15.00 usec
PLW1          9.20670033 W

F2 - Processing parameters
SI                 65536
SF           400.3000000 MHz
WDW                   EM
SSB                    0
LB                  0.30 Hz
GB                     0
PC                  1.00
```



```
Current Data Parameters
NAME      RAF-AKR-16-M-T-13C
EXPNO                  1
PROCNO                 1

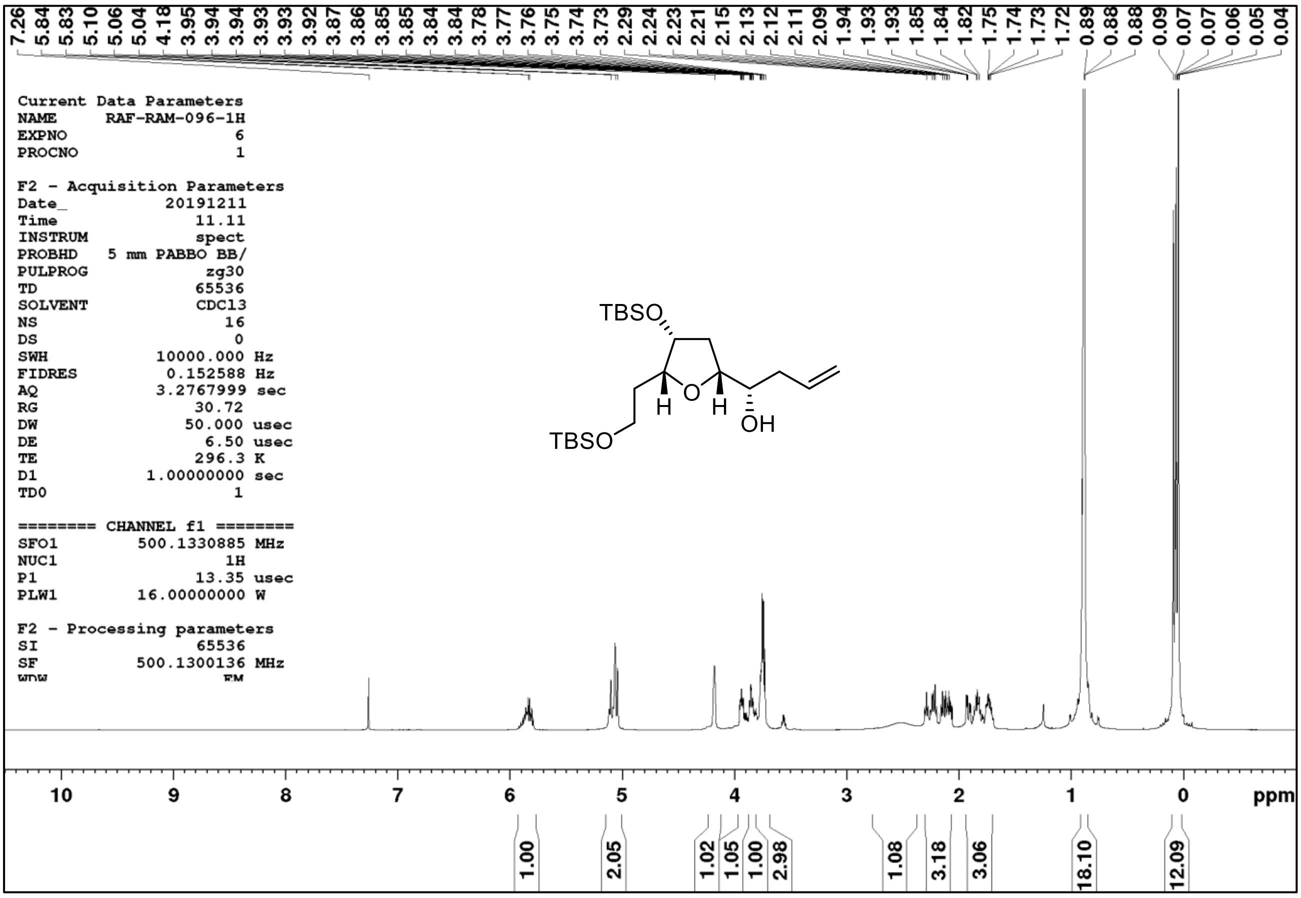
F2 - Acquisition Parameters
Date_           20220228
Time               19.15
INSTRUM            spect
PROBHD   5 mm PABBO BB/
PULPROG          zgpg30
TD                 65536
SOLVENT             C6D6
NS                  1401
DS                     0
SWH            29761.904 Hz
FIDRES          0.454131 Hz
AQ             1.1010048 sec
RG                197.27
DW                16.800 usec
DE                  6.50 usec
TE                 296.0 K
D1          1.00000000 sec
D11         0.03000000 sec
TD0                    1

======== CHANNEL f1 ========
SFO1         125.7703637 MHz
NUC1                 13C
P1                  8.90 usec
PLW1        103.00000000 W

======== CHANNEL f2 ========
SFO2         500.1320005 MHz
NUC2                  1H
CPDPRG[2         waltz16
PCPD2              80.00 usec
PLW2         16.00000000 W
PLW12         0.44556001 W
PLW13         0.22411001 W

F2 - Processing parameters
SI                 32768
SF           125.7577432 MHz
WDW                   EM
SSB                    0
LB                  1.00 Hz
GB                     0
PC                  1.40
```

^{1}H NMR(500 MHz, CDCl$_3$) and ^{13}C{^{1}H} NMR(100 MHz, CDCl$_3$) of compound **16**

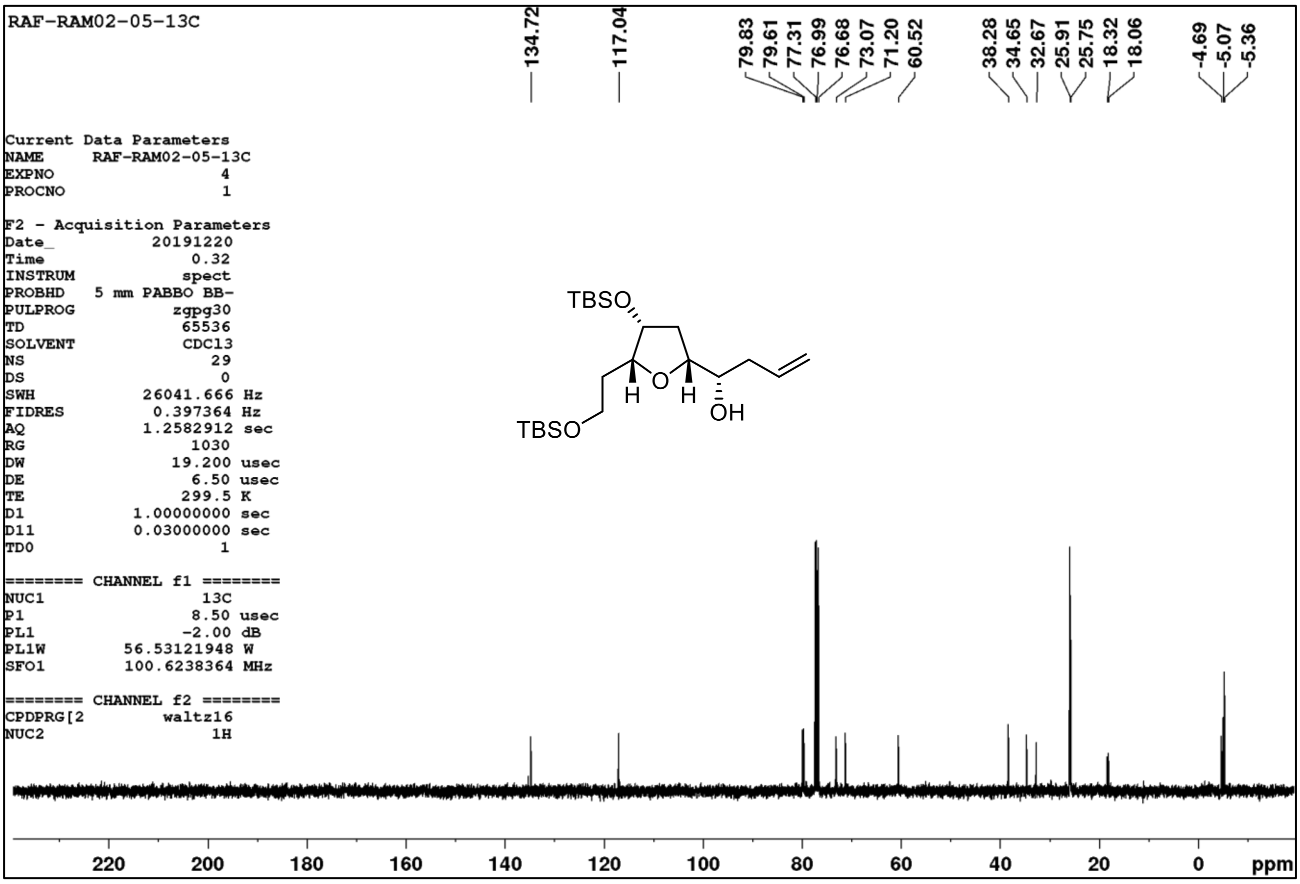


```
Current Data Parameters
NAME      RAF-RAM-096-1H
EXPNO                  6
PROCNO                 1

F2 - Acquisition Parameters
Date_           20191211
Time               11.11
INSTRUM            spect
PROBHD   5 mm PABBO BB/
PULPROG             zg30
TD                 65536
SOLVENT            CDCl3
NS                    16
DS                     0
SWH            10000.000 Hz
FIDRES          0.152588 Hz
AQ             3.2767999 sec
RG                 30.72
DW                50.000 usec
DE                  6.50 usec
TE                 296.3 K
D1            1.00000000 sec
TD0                    1

======== CHANNEL f1 ========
SFO1         500.1330885 MHz
NUC1                  1H
P1                 13.35 usec
PLW1         16.00000000 W

F2 - Processing parameters
SI                 65536
SF           500.1300136 MHz
WDW                   EM
```



RAF-RAM02-05-13C

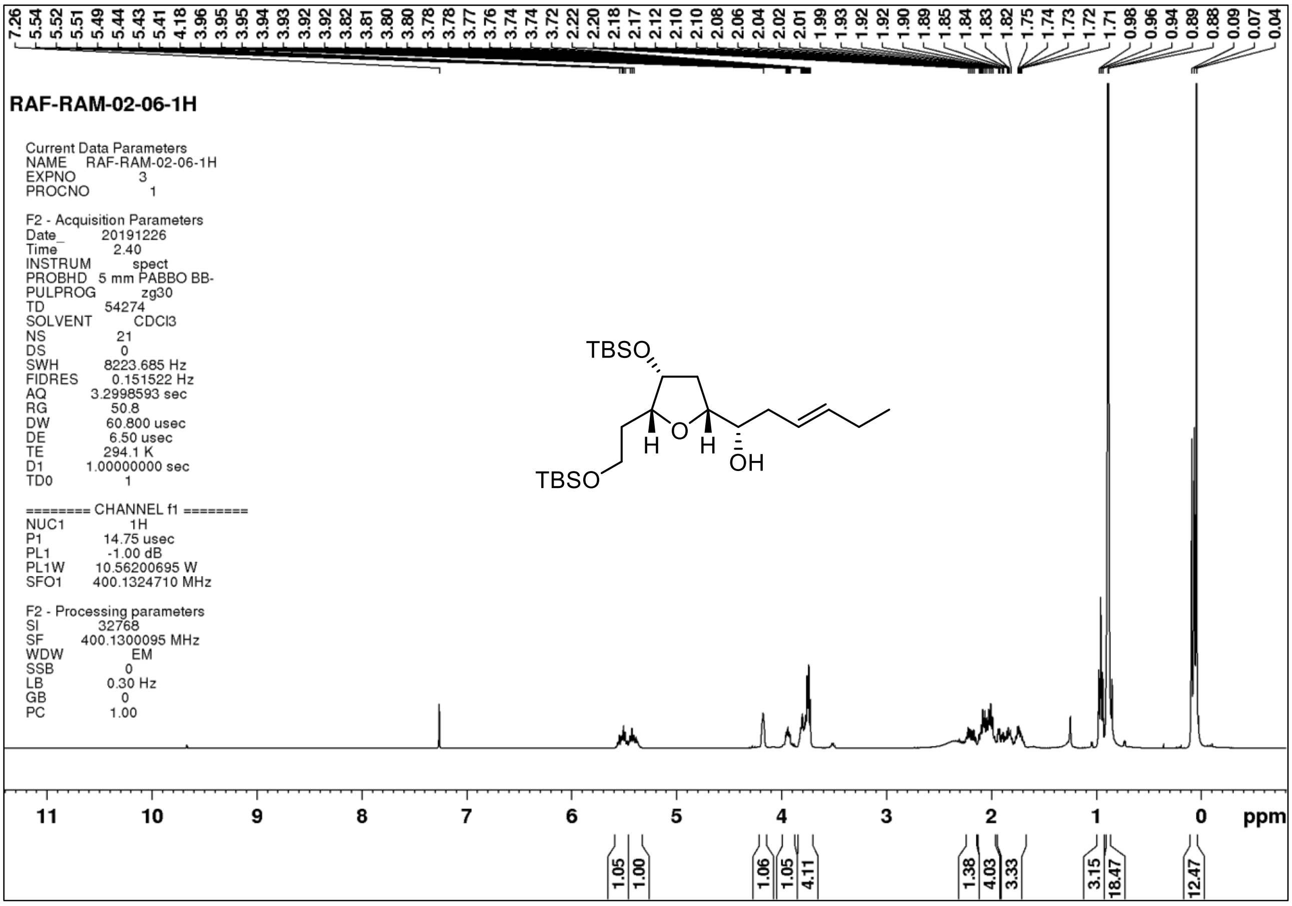
```
Current Data Parameters
NAME      RAF-RAM02-05-13C
EXPNO                  4
PROCNO                 1

F2 - Acquisition Parameters
Date_           20191220
Time                0.32
INSTRUM            spect
PROBHD   5 mm PABBO BB-
PULPROG           zgpg30
TD                 65536
SOLVENT            CDCl3
NS                    29
DS                     0
SWH            26041.666 Hz
FIDRES          0.397364 Hz
AQ             1.2582912 sec
RG                  1030
DW                19.200 usec
DE                  6.50 usec
TE                 299.5 K
D1            1.00000000 sec
D11           0.03000000 sec
TD0                    1

======== CHANNEL f1 ========
NUC1                 13C
P1                  8.50 usec
PL1                -2.00 dB
PL1W         56.53121948 W
SFO1         100.6238364 MHz

======== CHANNEL f2 ========
CPDPRG[2         waltz16
NUC2                  1H
```

^{1}H NMR(400 MHz, $CDCl_3$) and $^{13}C\{^{1}H\}$ NMR(100 MHz, $CDCl_3$) of compound **17**

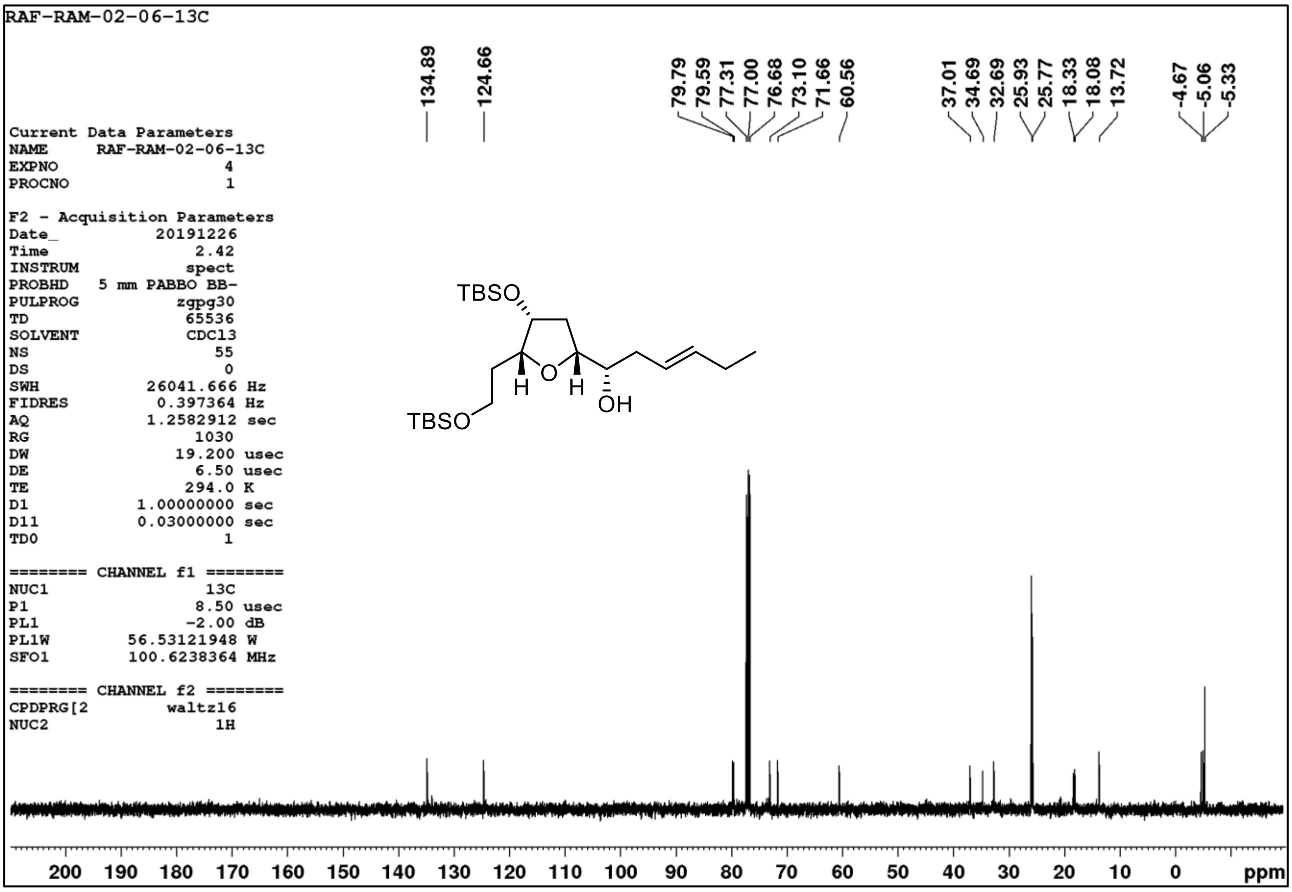


```
Current Data Parameters
NAME     RAF-RAM-02-06-1H
EXPNO              3
PROCNO             1

F2 - Acquisition Parameters
Date_        20191226
Time             2.40
INSTRUM         spect
PROBHD   5 mm PABBO BB-
PULPROG          zg30
TD              54274
SOLVENT         CDCl3
NS                 21
DS                  0
SWH       8223.685 Hz
FIDRES     0.151522 Hz
AQ       3.2998593 sec
RG               50.8
DW         60.800 usec
DE           6.50 usec
TE            294.1 K
D1      1.00000000 sec
TD0                 1

======== CHANNEL f1 ========
NUC1               1H
P1         14.75 usec
PL1          -1.00 dB
PL1W    10.56200695 W
SFO1   400.1324710 MHz

F2 - Processing parameters
SI              32768
SF     400.1300095 MHz
WDW                EM
SSB                 0
LB            0.30 Hz
GB                  0
PC               1.00
```



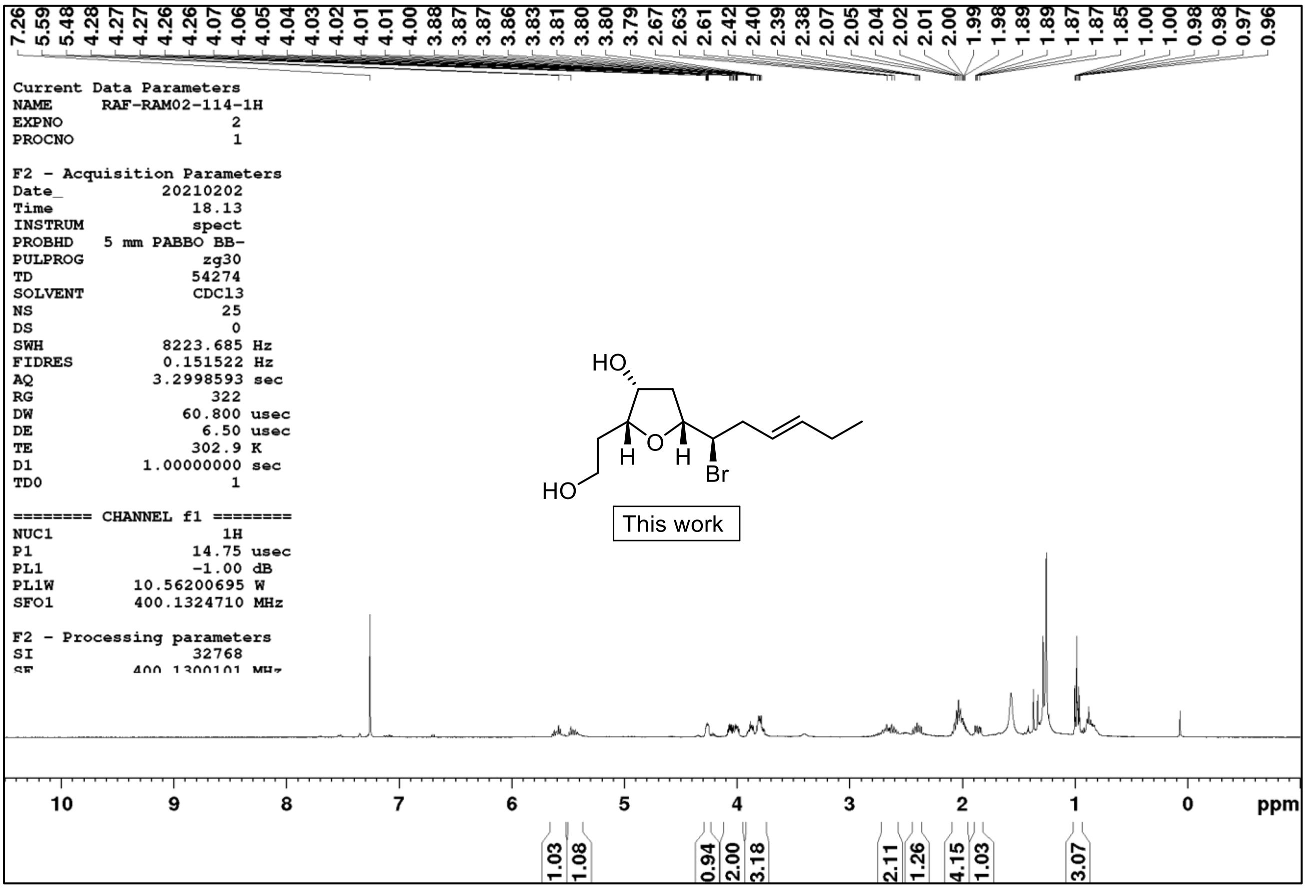
```
Current Data Parameters
NAME     RAF-RAM-02-06-13C
EXPNO                   4
PROCNO                  1

F2 - Acquisition Parameters
Date_           20191226
Time                2.42
INSTRUM            spect
PROBHD   5 mm PABBO BB-
PULPROG          zgpg30
TD                 65536
SOLVENT            CDCl3
NS                    55
DS                     0
SWH          26041.666 Hz
FIDRES        0.397364 Hz
AQ           1.2582912 sec
RG                  1030
DW              19.200 usec
DE                6.50 usec
TE                 294.0 K
D1          1.00000000 sec
D11         0.03000000 sec
TD0                    1

======== CHANNEL f1 ========
NUC1                 13C
P1                8.50 usec
PL1              -2.00 dB
PL1W         56.53121948 W
SFO1        100.6238364 MHz

======== CHANNEL f2 ========
CPDPRG[2         waltz16
NUC2                  1H
```

^{1}H NMR(400 MHz, $CDCl_3$) of **11** and reported compound **11** spectra



```
Current Data Parameters
NAME      RAF-RAM02-114-1H
EXPNO                    2
PROCNO                   1

F2 - Acquisition Parameters
Date_           20210202
Time               18.13
INSTRUM            spect
PROBHD   5 mm PABBO BB-
PULPROG             zg30
TD                 54274
SOLVENT            CDCl3
NS                    25
DS                     0
SWH             8223.685 Hz
FIDRES          0.151522 Hz
AQ             3.2998593 sec
RG                   322
DW                60.800 usec
DE                  6.50 usec
TE                 302.9 K
D1            1.00000000 sec
TD0                    1

======== CHANNEL f1 ========
NUC1                  1H
P1                 14.75 usec
PL1                -1.00 dB
PL1W         10.56200695 W
SFO1         400.1324710 MHz

F2 - Processing parameters
SI                 32768
SF           400.1300101 MHz
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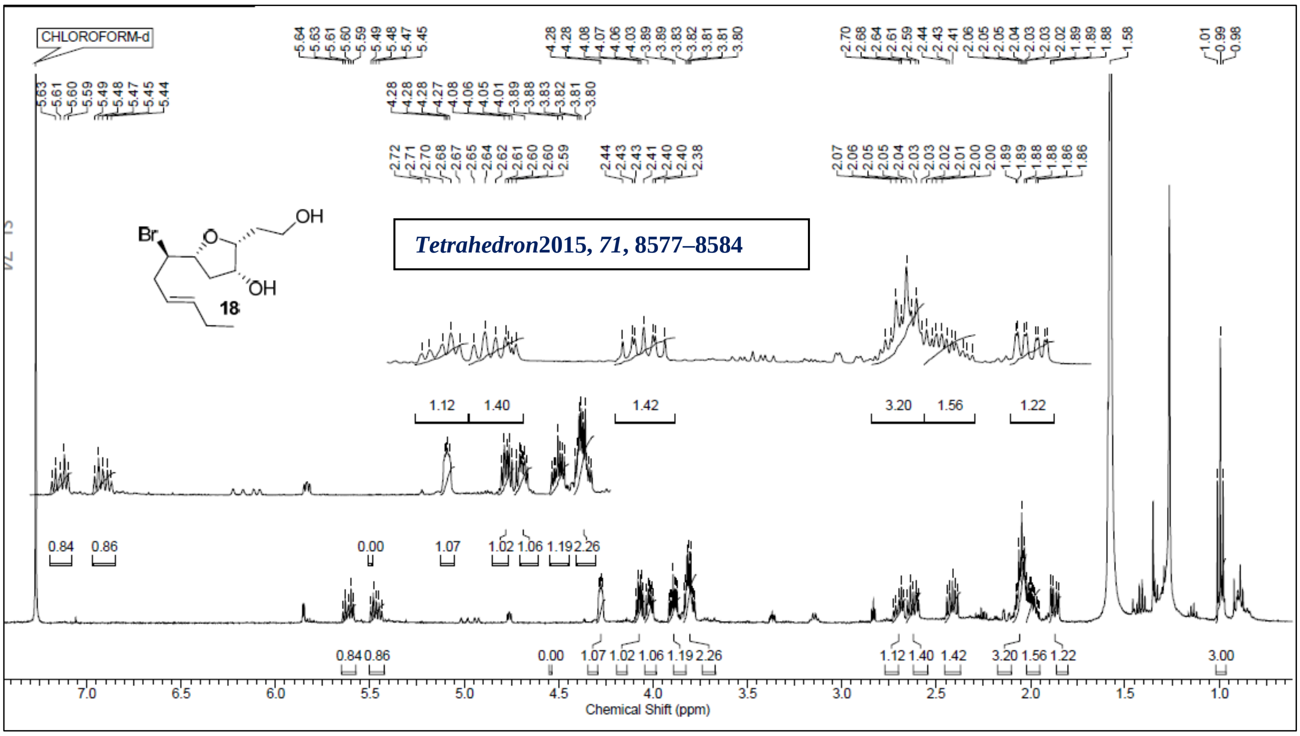
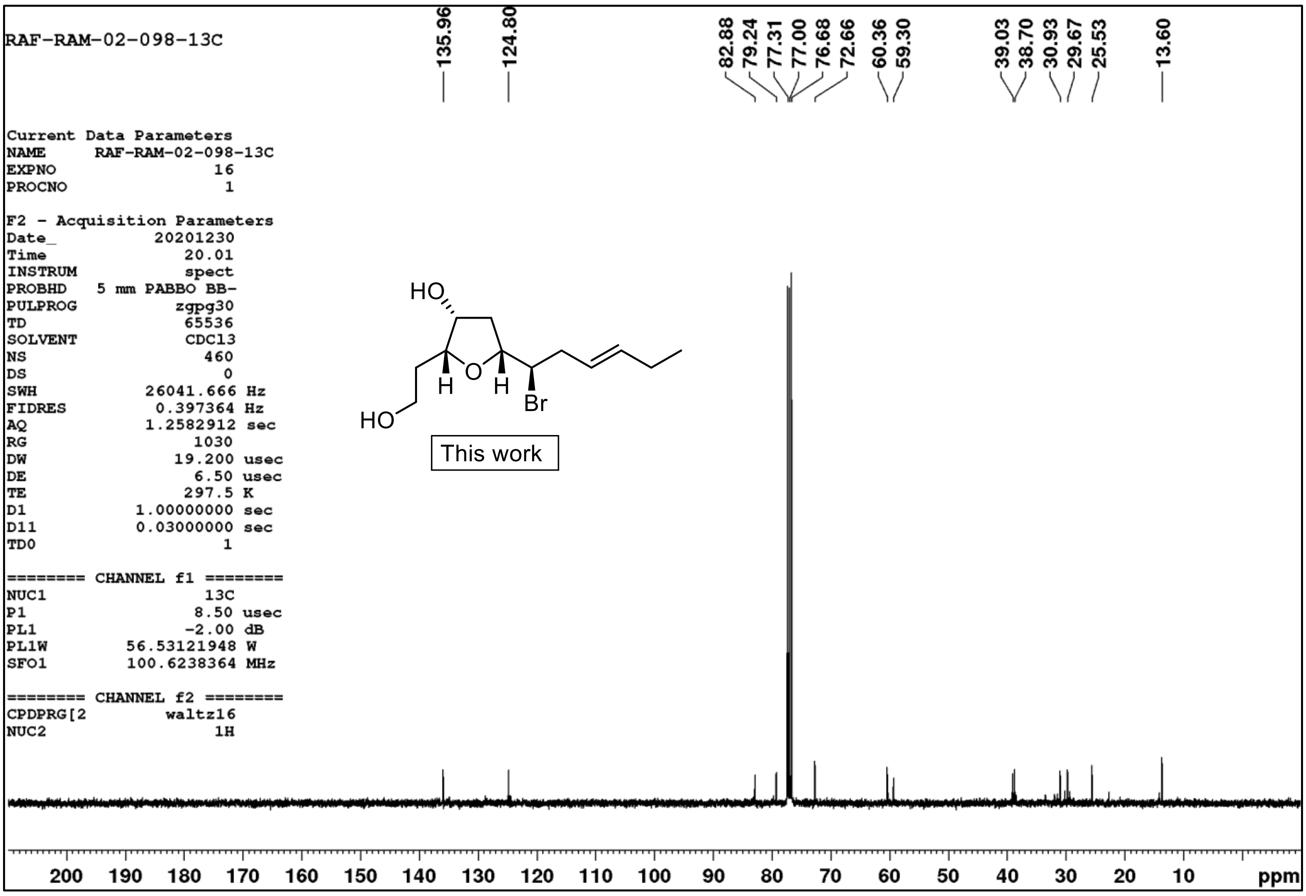


$^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$) of compound **11** and reported compound **11** spectra



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RAF-RAM-02-098-13C

Current Data Parameters
NAME      RAF-RAM-02-098-13C
EXPNO                   16
PROCNO                   1

F2 - Acquisition Parameters
Date_             20201230
Time                 20.01
INSTRUM              spect
PROBHD    5 mm PABBO BB-
PULPROG            zgpg30
TD                   65536
SOLVENT              CDCl3
NS                     460
DS                       0
SWH              26041.666 Hz
FIDRES            0.397364 Hz
AQ               1.2582912 sec
RG                    1030
DW                  19.200 usec
DE                    6.50 usec
TE                   297.5 K
D1              1.00000000 sec
D11             0.03000000 sec
TD0                      1

======== CHANNEL f1 ========
NUC1                   13C
P1                    8.50 usec
PL1                  -2.00 dB
PL1W           56.53121948 W
SFO1           100.6238364 MHz

======== CHANNEL f2 ========
CPDPRG[2           waltz16
NUC2                    1H
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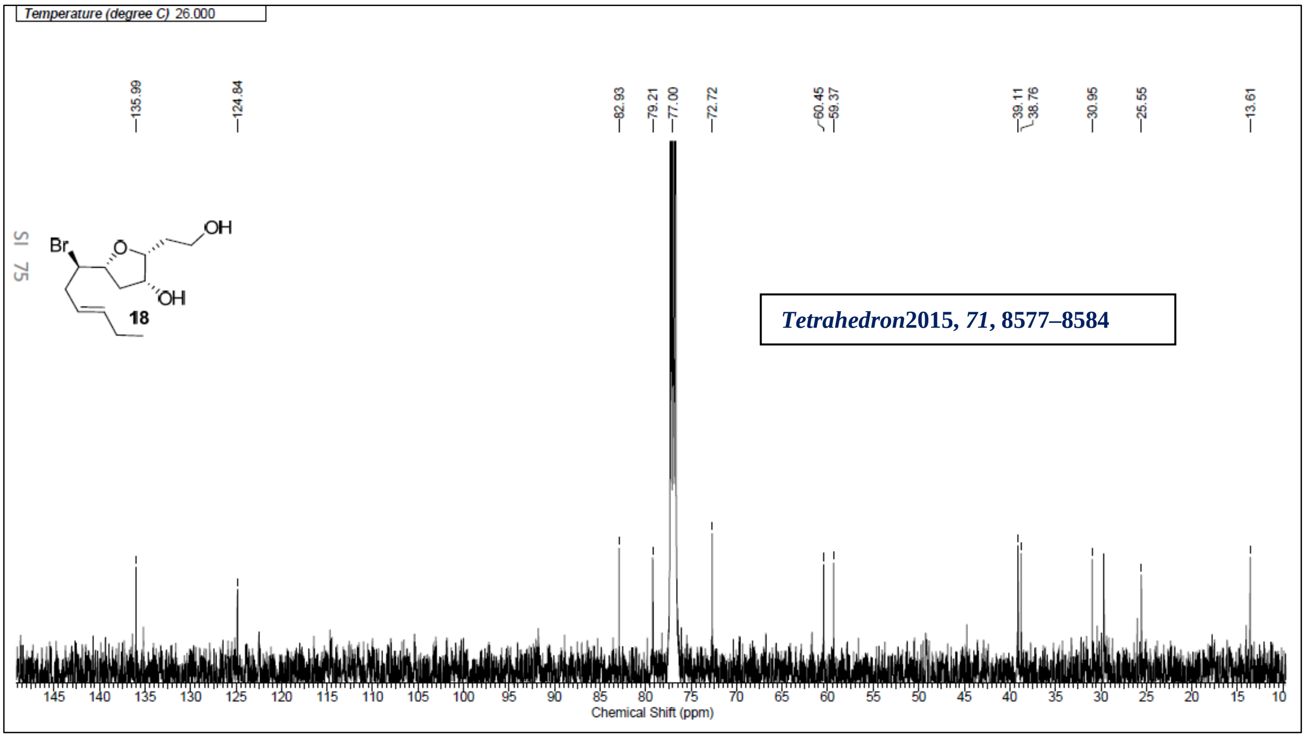

Tetrahedron 2015, *71*, 8577–8584

Comparison data of Compound **11**: Reported and our work

^{1}H NMR **Ramana (*Tetrahedron* 2015, *17*, 8577)**	**^{1}H NMR our work**
5.61 (dt, *J* = 6.3, 15.4 Hz, 1H)	5.60 (dt, *J* = 15.2, 6.4 Hz, 1H)
5.47 (dt, *J* = 7.1, 15.4 Hz, 1H)	5.45 (dt, *J* = 15.2, 7.0 Hz, 1H)
4.28–4.27 (m, 1H)	4.27–4.25 (m, 1H)
4.07 (dt, *J* = 4.6, 8.2 Hz, 1H), 4.02 (ddd, *J* = 4.3, 6.1, 10.4 Hz, 1H)	4.08–3.98 (m, 2H)
3.89 (ddd, *J* =3.7, 7.0, 10.7 Hz, 1H), 3.83–3.78 (m, 2H)	3.91–3.76 (m, 3H)
2.72–2.67 (m, 1H), 2.65–2.59 (m, 1H)	2.71–2.59 (m, 2H)
2.41 (ddd, *J* = 6.7, 8.5, 14.9 Hz, 1H)	2.40 (ddd, *J* = 15.0, 8.4, 6.4, 1H) (m, 1H)
2.02–1.95 (m, 1H), 2.09–2.03 (m, 3H)	2.08–1.94 (m, 4H)
1.87 (ddd, *J* = 1.5, 6.1, 14.3 Hz, 1H)	1.86 (ddd, *J* = 14.4, 6.0, 1.6 Hz, 1H)
0.99 (t, *J* = 7.5 Hz, 3H)	0.98 (t, *J* = 7.5 Hz, 3H)

^{13}C NMR **Ramana (*Tetrahedron* 2015, *17*, 8577)**	**^{13}C NMR our work**
136.0	136.0
124.8	124.8
82.9	82.9
79.2	79.2
72.7	72.7
60.4	60.4
59.4	59.3
39.1	39.0
38.8	38.7
30.9	30.9
25.5	25.5
13.6	13.6