SUPPLEMENTARY INFORMATION

Palladium-catalysed regio- and stereoselective arylative substitution of γ,δ-epoxy-α,β-unsaturated esters and amides by sodium tetraaryl borates.

Yasemin Bilgi, Melih Kuş, and Levent Artok*

[a]*Department of Chemistry, Faculty of Science, Izmir Institute of Technology, Urla, Izmir 35430, Turkey.*

E-mail: leventartok@iyte.edu.tr

CONTENTS

Experimental

General

Diethyl ether (Et_2O) and 1,4-dioxane solvents were distilled from benzophenone-ketyl under nitrogen prior to use. Tetrahydrofuran (THF) solvent was purified by a solvent purification system or distilled from benzophenone-ketyl under nitrogen prior to use. DMF was purified by a solvent purification system. 1,4-Dioxane was distilled from benzophenone-ketyl under nitrogen and stored over 4Å molecular sieves under nitrogen and in dark. Dichloromethane (DCM) and Methanol were dried using molecular sieve 3Å under nitrogen atmosphere. Dimethyl sulfoxide (DMSO) was distilled over calcium hydride (5% w/v) under reduced pressure (12 mm-Hg) and stored over molecular sieve 4Å.

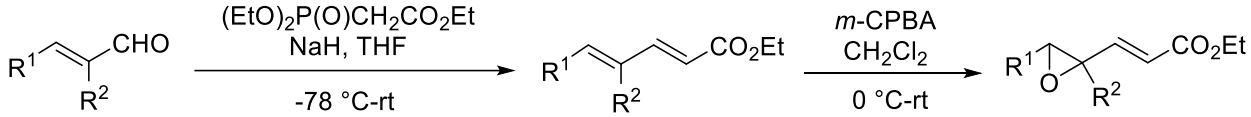
Sodium tetraphenylborate was provided from a commercial source and used as received. The $Pd_2(dba)_3{-}CHCl_3$[1] complex and substituted-sodium tetraarylborate reagents[2] were synthesized following the literature procedures. NMR analyses of the samples were performed in $CDCl_3$ unless otherwise indicated, and spectra were recorded on a 400 MHz instrument. Chemical shifts are reported in ppm downfield from Me_4Si. Infrared spectra were obtained by ATR method with neat samples. High-resolution mass spectral analyses (HRMS) of new compounds were performed using an ESI-LTQ Orbitrap and QTOF techniques.

Synthesis of γ,δ-epoxy-α,β-unsaturated esters

The syntheses of all compounds were performed under nitrogen gas and all reactions were monitored by TLC analysis. Purification of compounds synthesized were performed on a silica gel (60-200 mesh) column chromatography. Vinyl epoxide **1d** was synthesized by epoxidation of ethyl sorbate as described elsewhere.[3]

Syntheses of 1a, 1b, and 1f:

These compounds were prepared from corresponding 2-alkenals by Horner–Wadsworth–Emmons reaction with triethyl phosphonoacetate followed by epoxidation.



R^1 = Pr; R^2 = H: **S1a**
R^1 = Bu; R^2 = H: **S1b**
R^1 = R^2 = Me: **S1f**

R^1 = Pr; R^2 = H: **1a**
R^1 = Bu; R^2 = H **1b**
R^1 = R^2 = Me **1f**

Triethyl phosphonoacetate (1.5 equiv) was added dropwise to the suspension of NaH (60% dispersion in mineral oil, 1.7 equiv) in dry THF (~0.6 mmol/mL) at 0 °C, and the mixture was stirred for 1 h at rt. A commercially available alkenal, *trans*-2-hexenal (50 mmol, 5.8 mL), *trans*-2-heptenal (10 mmol, 1.31 ml), or (*E*)-2-methyl-2-butenal (5 mmol, 0.5 mL) was then added dropwise to the mixture precooled at -78 °C and stirred further at rt until the reaction was complete (2 h, 1 h, and 15 min, respectively). The reactions were quenched cautiously with saturated NH_4Cl(aq) and the aqueous phase was extracted with diethyl ether. The organic layer was washed with brine, dried over Na_2SO_4, filtered, and concentrated under reduced pressure. The crude mixture was purified by column chromatography on silica gel to provide ethyl (2*E*,4*E*)-octa-2,4-dienoate, **S1a** (hexane; light yellow oil; yield: 5.9 g, 35.1 mmol, 70.2%), (2*E*,4*E*)-octa-2,4-dienoate, **S1b** (hexane; light yellow oil; 839 mg, 4.6 mmol, 46%), or ethyl (2*E*,4*E*)-4-methylhexa-2,4-dienoate, **S1f,** (hexane; light yellow oil; yield: 650 mg, 4.22 mmol, 85%).[4]

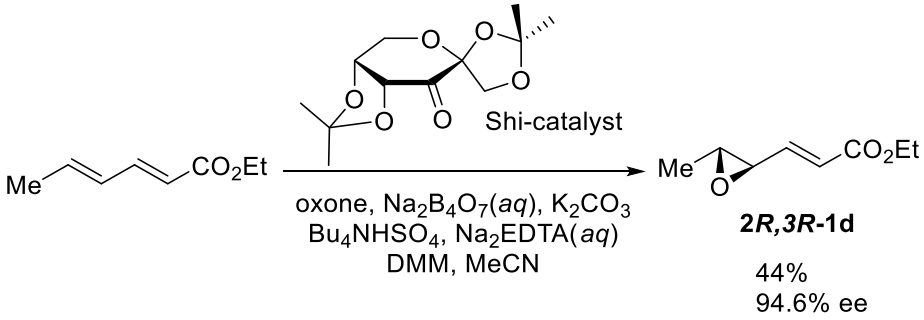
To a solution of dienoate (10 mmol, 1.68 g for **S1a**; 4.6 mmol, 830 mg for **S1b**; 4 mmol, 616 mg for **S1f**) in CH_2Cl_2 (30 mL for **S1a**; 15 mL for **S1b**; 25 mL for **S1f**) was added *m*-CPBA (1.3 equiv) at 0 °C. The epoxidation mixture of **S1a** or **S1b** was stirred at 0° C, while that of **S1f** was stirred at room temperature until the reaction is complete. The reactions were quenched with saturated Na_2CO_3(aq) and extracted with DCM. The organic layer was dried over Na_2SO_4, filtered, and concentrated under a reduced pressure. The crude mixture was purified by column chromatography on silica gel to provide the epoxide **1a** (hexane/EtOAc, 100:1-50:1; light yellow oil; yield: 6.68 mmol, 1.23 g, 66%), **1b** (hexane; light yellow oil; yield: 2.5 mmol, 496 mg, 54 %), or **1f** (hexane/EtOAc, 100:1; light yellow oil; yield: 2.7 mmol, 460 mg, 68 %).[5]

1a: ^{1}H NMR (400 MHz, $CDCl_3$) δ: 6.67 (dd, *J* = 15.7, 7.1 Hz, 1H), 6.11 (dd, *J* = 15.7, 0.7 Hz, 1H), 4.19 (q, *J* = 7.1 Hz, 2H), 3.20 (ddd, *J* = 7.1, 2.0, 0.7 Hz, 1H), 2.90 (td, *J* = 5.6, 2.0 Hz, 1H), 1.62–1.44 (m, 4H), 1.28 (t, *J* = 7.1 Hz, 3H), 0.96 (t, *J* = 7.3 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ: 165.7, 144.8, 123.5, 61.3, 60.6, 56.3, 33.9, 19.1, 14.2, 13.8; MS (EI, m/z): 139(2), 112(25), 101(63), 84(100), 73(1), 55(38).

1b: ^{1}H NMR (400 MHz, $CDCl_3$) δ: 6.66 (dd, *J* = 15.7, 7.2 Hz, 1H), 6.10 (dd, *J* = 15.7, 0.7 Hz, 1H), 4.18 (q, *J* = 7.1 Hz, 2H), 3.19 (dd, *J* = 7.2, 2.0 Hz, 1H), 2.87 (td, *J* = 5.7, 2.0 Hz, 1H), 1.64–1.56 (m, 2H), 1.47–1.31 (m, 4H), 1.27 (t, *J* = 7.1 Hz, 3H), 0.90 (t, *J* = 7.1 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ: 165.7, 144.8, 123.5, 61.4, 60.5, 56.3, 31.6, 27.8, 22.4, 14.2, 13.9; MS (EI, *m/z*): 125(10), 112(22), 95(3), 84(100), 69(17), 55(30).

1f: ^{1}H NMR (400 MHz, $CDCl_3$) δ: 6.72 (d, *J* = 15.7 Hz, 1H), 5.98 (d, *J* = 15.7 Hz, 1H), 4.16 (q, *J* = 7.2 Hz, 2H), 2.94 (q, *J* = 5.5 Hz, 1H), 1.39 (s, 3H), 1.32 (d, *J* = 5.5 Hz, 3H), 1.25 (t, *J* = 7.2 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ: 166.1, 149.8, 121.5, 61.5, 60.5, 58.4, 14.9, 14.2, 13.9; MS (EI, *m/z*): 126(10), 97(100), 79(10), 69(22), 53(70), 43(74).

The Synthesis of (2*R*,3*R*)-1d:

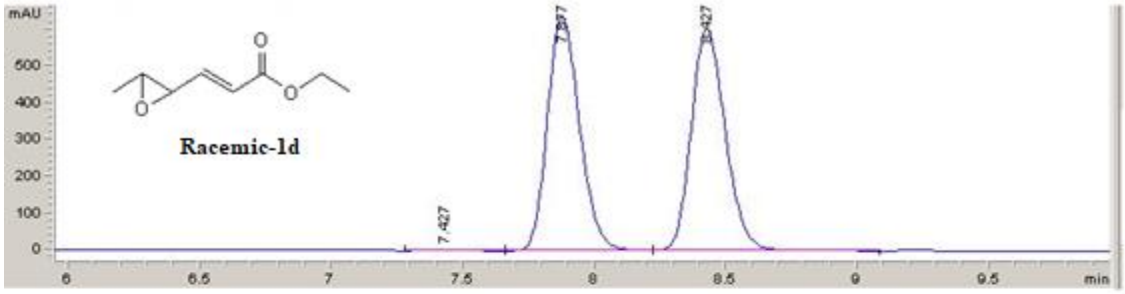


Optically active **1d** was prepared according to Shi's method.[6,7] To a mixture of dimethoxymethane (DMM) (50 mL) and acetonitrile (25 mL) was added a 50 mL aqueous solution of $Na_2B_4O_7$ (950 mg, 2.49 mmol) and Na_2EDTA (50 mL, $4x10^{-4}$ M) mixture and ethyl sorbate (5 mmol, 700 mg, 0.74 mL). The mixture was cooled to 0 °C and then, tetrabutylammonium hydrogensulfate (0.454 mmol, 150 mg) and Shi-catalyst (2.5 mmol, 630 mg) were added successively to the mixture. After stirring the mixture for 5 min, a solution of oxone (5.6 mmol, 3.45 g) in 30 mL of aqueous solution of Na_2EDTA ($4x10^{-4}$ M) and a solution of K_2CO_3 (25 mmol, 3.45 g) in 30 mL of ultrapure water were added simultaneously at the same rate using peristaltic syringe pump for 4.5 h. When the addition was complete, 50 mL of Et_2O was added to the solution and extracted with water. The combined organic layer was washed with brine, dried over Na_2SO_4, and concentrated under vacuum. The crude mixture was purified by silica gel column chromatography (hexane:CH_2Cl_2 (100:2-100:8) mixture containing 1% NEt_3; yield: 44%).

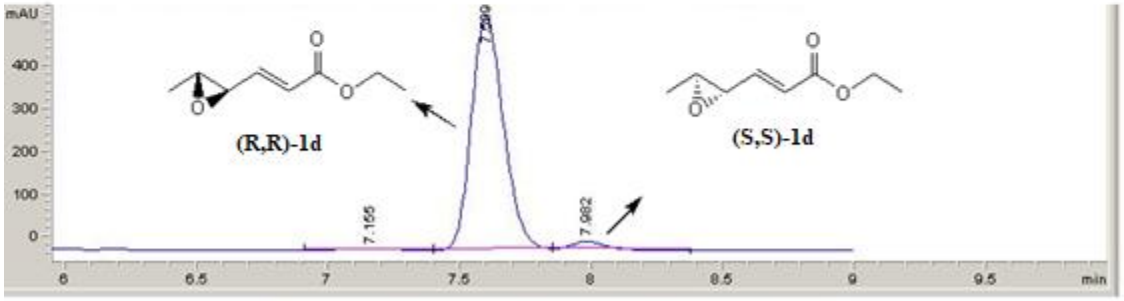
1d: ^{1}H NMR (400 MHz, $CDCl_3$) δ: 6.65 (dd, *J* = 15.7, 7.1 Hz, 1H), 6.11 (dd, *J* = 15.7, 0.6 Hz, 1H), 4.19 (q, *J* = 7.1 Hz, 2H), 3.16 (dd, *J* = 7.1, 2.0 Hz, 1H), 2.96 (qd, *J* = 5.2, 2.0 Hz, 1H), 1.37 (d, *J* = 5.2 Hz, 3H), 1.27 (t, *J* =

7.1 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ: 165.7, 144.6, 123.7, 60.6, 57.4, 57.2, 17.5, 14.2; MS (EI, *m/z*): 112(30), 99(2), 84(100), 55(70).

The enantiomeric purity was determined to be 94.7 ee% by HPLC analysis (λ: 210 nm; Chiralcel OD-3; hexane:IPA (98:2); 1.0 ml/min). $[\alpha]_D^{20}$ = 14.3 (c = 4.6, CH_2Cl_2); 10.4 (c = 4.6, $CHCl_3$).

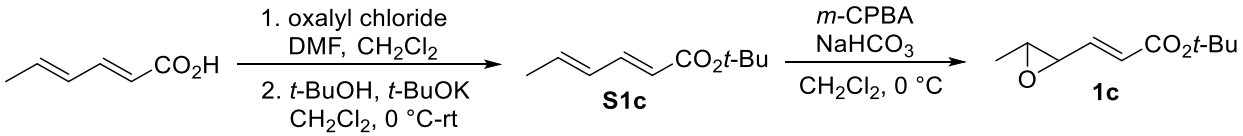


#	Time	Area	Height	Width	Area%
1	7.877	5412.2	639.2	0.1308	48.395
2	8.427	5407.1	604.7	0.1383	48.349



#	Time	Area	Height	Width	Area%
1	7.599	4611.6	545	0.1307	92.737
2	7.982	126.5	17	0.1207	2.545

Synthesis of 1c:



To a stirred solution of sorbic acid (10 mmol, 1.12 g) in CH_2Cl_2 (20 mL) was added 0.1 equiv of DMF and 3 equivalents of oxalyl chloride (30 mmol, 2.6 mL) dropwise at 0 °C, successively, and stirred for 30 min. Subsequently, the mixture was allowed to attain rt and stirred for additional 2 h. The crude sorbic chloride solution was directly used in the next reaction.

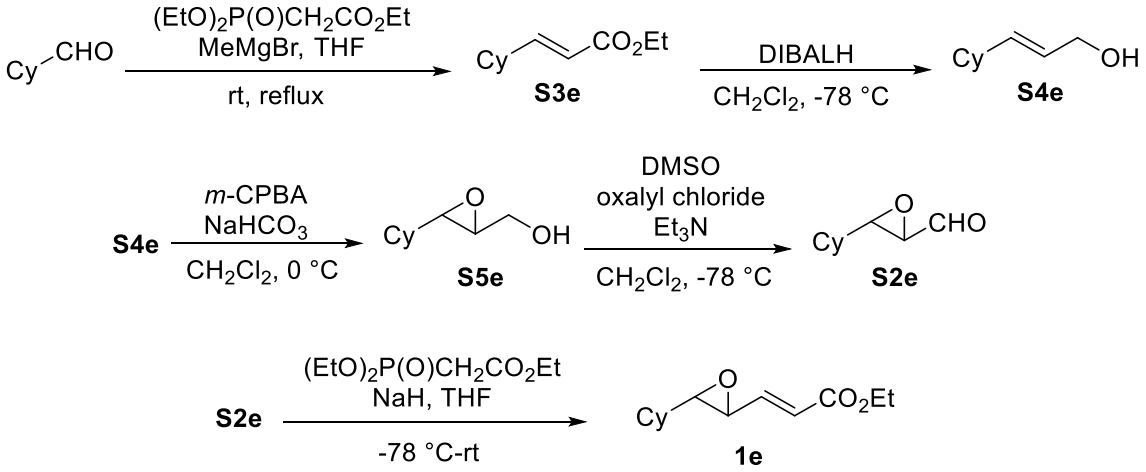
To a solution of *tert*-BuOK (25 mmol, 2.8 g) and *t*-BuOH (25 mmol, 2.4 mL) in CH_2Cl_2 (30 mL) was added the prepared sorbic chloride solution dropwise at 0°C and stirred further for 3 days at rt. The reaction mixture was quenched with saturated aqueous $NaHCO_3$ and extracted with Et_2O. The combined organic

layers were washed with brine, dried over anhydrous $MgSO_4$, and filtered to afford the *tert*-butyl (2*E*,4*E*)-hexa-2,4-dienoate **(S1c)** as a light yellow oil (hexane/EtOAc, 100:1; yield: 7.43 mmol, 1.25 g, 74%).[8]

From **S1c** (2.6 mmol, 450 mg) and *m*-CPBA (1.3 equiv, 3.38 mmol, 757 mg), following the general procedure for the epoxidation of **S1a**, the epoxide **1c** was obtained as a colourless oil (hexane/EtOAc, 50:1; yield: 1.76 mmol, 325 mg, 68%).

1c: ^{1}H NMR (400 MHz, $CDCl_3$) δ: 6.53 (dd, *J* = 15.7, 7.2 Hz, 1H), 6.03 (dd, *J* = 15.7, 0.7 Hz, 1H), 3.14 (dd, *J* = 7.2, 2.0 Hz, 1H), 2.95 (qd, *J* = 5.2, 2.0 Hz, 1H), 1.46 (s, 9H), 1.36 (d, *J* = 5.2 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ: 164.91, 143.34, 125.61, 80.68, 57.28, 57.21, 28.04, 17.47; MS (EI, *m/z*): 128(5), 111(15), 84(100), 57(70), 42(20), 33(40), 29(20).

Synthesis of 1e:



To a solution of triethyl phosphonoacetate (0.9 equiv, 22.5 mmol, 4.95 mL) in dry THF (200 mL) was added MeMgBr (3.0 M in Et_2O, 0.9 equiv, 22.5 mmol, 9 mL) solution dropwise and stirred for 15 min at rt. To this solution was added commercially available cyclohexanecarbaldehyde (25 mmol, 3.04 mL) in THF (100 mL) dropwise and the mixture was heated at reflux for 18 h. The reaction was quenched with saturated $NH_4Cl_{(aq)}$ solution and extracted with Et_2O. The organic layer was dried over $MgSO_4$, filtered, and concentrated under reduced pressure. The crude mixture was purified by column chromatography on silica gel to afford the ethyl (*E*)-3-cyclohexylacrylate **S3e** as a colourless oil (hexane/EtOAc, 15:1; yield: 20 mmol, 3.65 g, 80%).[9]

To a stirred solution of **S3e** (20 mmol, 3.65 g) in DCM (100 mL) was added DIBALH (3 equiv, 1 M in CH_2Cl_2, 70 mL) solution dropwise at -78 °C and stirred for 1 h. A saturated aqueous solution of sodium potassium tartarate tetrahydrate (200 mL) was added to the reaction mixture and stirred for 3 h at rt, and, then, the aqueous solution was extracted with DCM. The organic layer was dried over $MgSO_4$, filtered, and concentrated under reduced pressure. The crude mixture was purified by column chromatography on silica gel to provide the (*E*)-3-cyclohexylprop-2-en-1-ol (**S4e**) as a colourless oil (hexane/EtOAc, 16:1; yield: 17.1 mmol, 2.4 g, 85%).[10]

To a solution of **S4e** (17.1 mmol) in DCM (300 mL) was added *m*-CPBA (1.3 equiv, 22.1 mmol, 4.95 g) and $NaHCO_3$ (2.4 equiv, 40.8 mmol, 3.4 g) at 0 ℃, and stirred for 2.5 h at the same temperature. The reaction was quenched with saturated $NaHCO_3$(aq) solution and extracted with DCM. The organic layer was dried over $MgSO_4$, filtered, and concentrated under reduced pressure. The crude mixture was purified

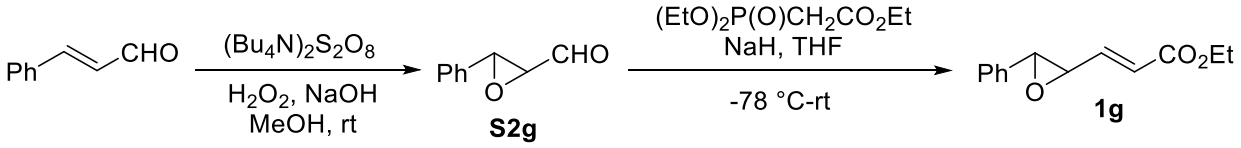
by column chromatography on an Et_3N-treated silica gel to afford (3-cyclohexyloxiran-2-yl)methanol (**S5e**) as a yellow oil (hexane/EtOAc, 7:1; yield: 10.3 mmol, 1.6 g, 60%).

To a stirred solution of DMSO (27 mmol, 1.9 mL) in dry DCM (20 mL) was added oxalyl chloride (13.5 mmol, 1.15 mL) at -78 °C, and stirred for 20 min. The epoxy alcohol **S5e** (9 mmol, 1.4 g) in DCM (7.5 mL) was added to the reaction mixture, and stirred further for 105 min. Then, following the addition of 5 mL of Et_3N (36 mmol) at -78 °C, the mixture was allowed to attain rt, and stirred for additional 30 min. The reaction was quenched with distilled water and extracted with Et_2O. The organic layer was washed with distilled water and brine, dried over $MgSO_4$, filtered, and concentrated under reduced pressure to afford the 3-cyclohexyloxirane-2-carbaldehyde (**S2e**), which was used directly in the next step.[11]

The HWE reaction of **S2e** (9 mmol, 1.38 g) and isolation of the product, **1e**, was performed as specified for **1a** (yellow oil; hexane; combined yield: 3.71 mmol, 832 mg, 60%).

1e: ^{1}H NMR (400 MHz, $CDCl_3$) δ: 6.67 (dd, *J* = 15.7, 7.1 Hz, 1H), 6.10 (dd, *J* = 15.7, 0.7 Hz, 1H), 4.19 (q, *J* = 7.1 Hz, 2H), 3.26 (ddd, *J* = 7.1, 2.1, 0.7 Hz, 1H), 2.69 (dd, *J* = 6.8, 2.1 Hz, 1H), 1.88–1.64 (m, 6H), 1.28 (t, *J* = 7.1 Hz, 3H), 1.25–1.06 (m, 5H); ^{13}C NMR (100 MHz, $CDCl_3$) δ: 165.7, 145.1, 123.3, 65.7, 60.5, 55.1, 40.0, 29.5, 28.8, 26.2, 25.3, 25.4, 14.2; MS (EI, *m/z*): 225(8), 189(20), 179(6), 161(8), 143(50), 96(100), 85(28), 67(20), 55(24), 41(22), 32(24).

Synthesis of 1g:



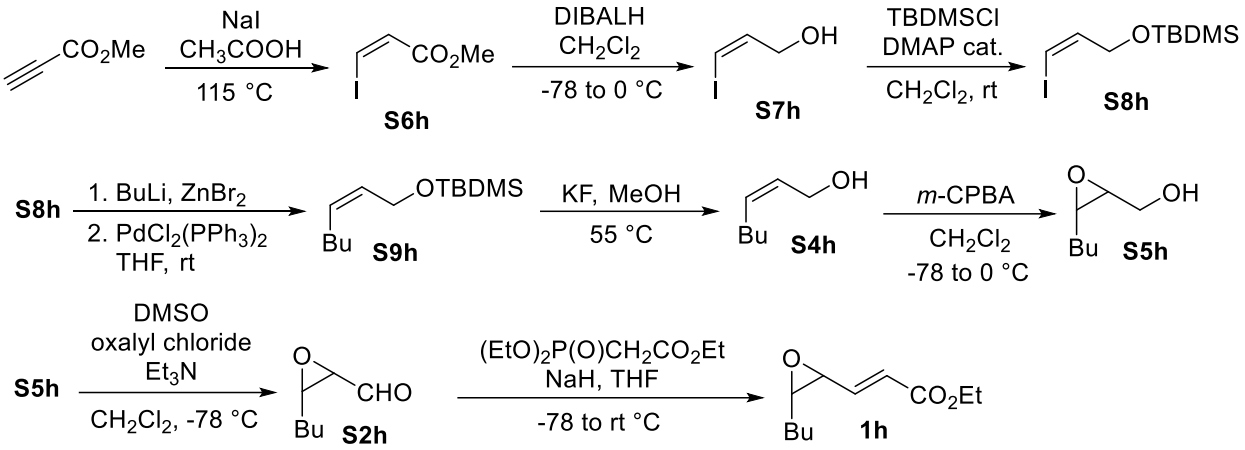
$(Bu_4N)HSO_4$ (64 mmol, 21.2 g) and potassium persulfate (32.0 mmol, 8.70 g) compounds were dissolved in distilled water (140 mL), and the reaction mixture was stirred for 30 min at rt. The solution was extracted with DCM, and the combined organic layers were washed with distilled water, dried over $MgSO_4$, filtered, and concentrated under reduced pressure to afford $(Bu_4N)_2S_2O_8$ salt as a white solid, and the compound was used directly without further purification.[12]

To a solution of commercially available *trans*-cinnamaldehyde (5 mmol, 0.58 mL) in MeOH (20 mL) was added $(Bu_4N)_2S_2O_8$ (5 mmol, 3.34 g), H_2O_2 (30% in H_2O, 5 mmol, 0.5 mL), and NaOH (5 mmol, 200 mg) at rt, and stirred for 2 h. The reaction was quenched with saturated NH_4Cl(aq), and extracted with Et_2O. The organic layer was washed with brine, dried over $MgSO_4$, filtered, and concentrated under reduced pressure. The crude mixture was purified by column chromatography on an Et_3N-treated silica gel to provide the 3-phenyloxirane-2-carbaldehyde **S2g** as a yellow oil (hexane/EtOAc, 15:1; yield: 3.63 mmol, 538 mg, 73%).[12]

From triethyl phosphonoacetate (1.5 mmol, 0.3 mL), NaH (60% dispersion in mineral oil, 1.7 mmol, 65.5 mg), and aldehyde **S2g** (1 mmol, 148 mg), following the procedure used for **1a**, the epoxide **1g** was obtained as a light yellow oil (hexane/EtOAc, 100:1; yield: 0.6 mmol, 131 mg, 60%).

1g: ^{1}H NMR (400 MHz, $CDCl_3$) δ: 7.39–7.27 (m, 5H), 6.81 (dd, *J* = 15.7, 6.9 Hz, 1H), 6.19 (dd, *J* = 15.7, 0.8 Hz, 1H), 4.22 (q, *J* = 7.1 Hz, 2H), 3.83 (d, *J* = 1.8 Hz, 1H), 3.47 (dd, *J* = 6.9, 1.8 Hz, 1H), 1.30 (t, *J* = 7.1 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ: 165.6, 143.5, 136.0, 128.6, 125.5, 124.1, 61.0, 60.7, 60.6, 14.2.

Synthesis of 1h:



To a solution of methyl propiolate (40 mmol) in acetic acid (256 mmol, 15 mL) was added sodium iodide (1.6 equiv, 64 mmol, 9.6 g), and stirred for 3 h at 115 °C. After completion of the reaction, the mixture was extracted with Et_2O, washed cautiously with saturated $NaHCO_3$(aq), $Na_2S_2O_3$(aq), and brine. The organic phase was dried over Na_2SO_4, filtered, and the volatile compound was cautiously concentrated under reduced pressure**.** The crude mixture was purified by column chromatography on silica gel to afford the methyl (*Z*)-3-iodoacrylate **S6h** as a colourless oil (pentane; yield: 30 mmol, 6.35 g, 75%).[13]

To a solution of **S6h** (30 mmol, 6.35 g) in dry DCM (100 mL) was added DIBALH (3 equiv, 90 mmol, 104 mL, 1 M in DCM solution) dropwise, and stirred for 2.5 h at -78 °C and 30 min at 0 °C, successively. The reaction was quenched with saturated sodium potassium tartarate tetrahydrate solution, stirred for 2 h (until the cloudy appearance disappeared and became a clear solution), and extracted with DCM. The organic layer was dried over Na_2SO_4, filtered, and concentrated under reduced pressure to afford **S7h**, which was used directly in the next step.[14]

To a stirred solution of **S7h** (~30 mmol) in dry DCM (100 mL) was added Et_3N (48 mmol, 6.6 mL), *tert*-butyldimethylsilyl chloride (TBDMSCl) (90 mmol, 5.85 g), and catalytic amount of 4-dimethylaminopyridine (DMAP) (2%, 0.6 mmol, 75 mg), successively, and stirred overnight. After the completion of the reaction, to the mixture was added water, and extracted with DCM. The organic layer was dried over Na_2SO_4, filtered, concentrated under reduced pressure, and purified by column chromatography on silica gel to afford **S8h** as a colourless oil (pentane; yield: 26 mmol, 7.7 g, 87%).[15]

$ZnBr_2$ (1.2 eq, 31 mmol, 7g), which was predried at 300 ℃ under vacuum for 1 h, was dissolved in dry THF, and BuLi (1.2 equiv, 22 mL, 1.7 M in hexane solution) was added to this solution at 0 °C. The mixture was stirred for 40 min at the same temperature to afford butylzinc bromide as a colorless oil. To a stirred solution of **S8h** (26 mmol, 7.7 g) and $PdCl_2(PPh_3)_2$ (1 mol%, 0.26 mmol, 182.5 mg) in dry THF (60 mL) was added the solution of butylzinc bromide, and stirred for overnight. After complete consumption of the starting material, as judged by TLC, the reaction was quenched by 0.25 M HCl(aq), and extracted with Et_2O. The organic layer was washed with saturated $NaHCO_3$(aq) and brine, dried over Na_2SO_4, filtered, and concentrated under reduced pressure to afford **S9h** as a light yellow oil (pentane; yield: 22 mmol, 5 g, 85%).[16]

To a stirred solution of **S9h** (20 mmol, 4.5 g) in 20 mL methanol was added KF (60 mmol, 3.5 g), and stirred for 3 days at 55 °C. The reaction was quenched with water and extracted with EtOAc. The organic

layer was dried over Na_2SO_4, filtered, concentrated under reduced pressure, and purified by column chromatography to afford **S4h** as a colourless oil (hexane/EtOAc, 20:1; yield: 18 mmol, 2 g, 90%).

From **S4h** (5 mmol, 570 mg) and *m*-CPBA (6.5 mmol, 2 g), following the general procedure for the epoxidation of **S1a**, the epoxide **S5h** was obtained as a light yellow oil (hexane/EtOAc, 10:1; yield: 3.4 mmol, 342 mg, 68%).

The oxidation of **S5h** was applied by a modification of a reported procedure:[17] To a DCM (30 mL) solution of oxalyl chloride (4.1 mmol, 0.35 mL) was added DMSO (2.5 equiv, 8.5 mmol, 0.6 mL) at -78 °C, and stirred for 15 min. Subsequently, **S5h** (3.4 mmol, 450 mg) was added to the mixture at the same temperature, and stirred for 15 min. Et_3N (20.4 mmol, 2.85 mL) was added next, and stirred for 20 min at -78 °C, allowed to attain rt, and stirred further for 15 min. The reaction was quenched by saturated $NaHCO_3$(aq), stirred further for 30 min, extracted with DCM, dried over Na_2SO_4, and concentrated under reduced pressure to afford the 3-butyloxirane-2-carbaldehyde (**S2h**), which was used directly in the next step.

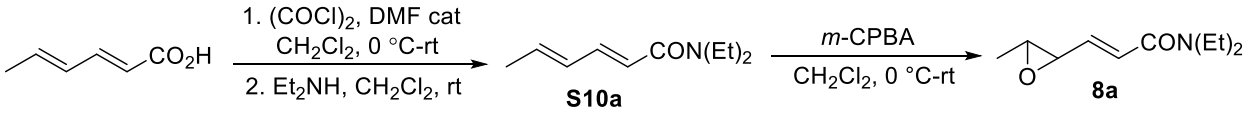
From triethyl phosphonoacetate (4.5 mmol, 0.9 mL), NaH (60% dispersion in mineral oil, 5.1 mmol, 200 mg) and the crude aldehyde **S2h** (4.86 mmol, 933 mg) following the procedure for **1a**, epoxide **1h** was obtained as a colorless oil (hexane/EtOAc, 100:1; yield: 2 mmol, 396 mg, 66%).

1h: ^{1}H NMR (400 MHz, $CDCl_3$) δ: 6.78 (dd, *J* = 15.7, 6.6 Hz, 1H), 6.10 (dd, *J* = 15.7, 0.9 Hz, 1H), 4.19 (q, *J* = 7.1 Hz, 2H), 3.49 (ddd, *J* = 6.7, 5.0, 0.9 Hz, 1H), 3.16 (dt, *J* = 6.4, 5.5 Hz, 1H), 1.63–1.31 (m, 6H), 1.28 (t, *J* = 7.1 Hz, 3H), 0.88 (t, *J* = 7.1 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ: 165.6, 142.0, 125.2, 60.6, 59.7, 55.2, 28.4, 27.3, 22.4, 14.2, 13.9; MS (EI, *m/z*): 125(16), 112(22), 84(100), 69(17), 55(17).

Synthesis of *γ,δ*-epoxy-*α,β*-unsaturated amides

The amidation and subsequent epoxidation of dienoic acids has been the general method in the synthesis of amides in this study, as has been prescribed elsewhere.[18]

Synthesis of 8a:



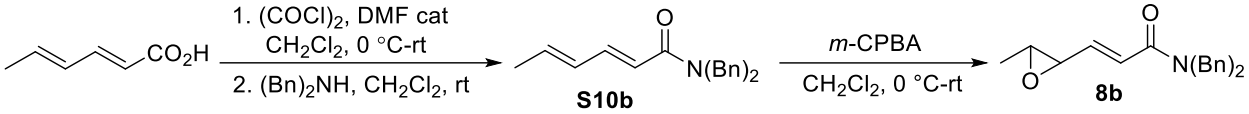
To a solution of sorbic acid (30 mmol, 3.36 g) and DMF (45 mmol, 3.48 mL) in dry DCM (60 mL) was added oxalyl chloride (29.4 mmol, 2.56 mL) dropwise at 0 °C. After the mixture was stirred for 4 hours at rt, Et_2NH (67.5 mmol, 7 mL) was added, and stirred for a further 2 hours. The mixture, then, was filtered through a short plug of silica, the organic phase was washed successively with NaOH(aq) (2 M, 100 mL), HCl(aq) (1 M, 100 mL), and saturated NaCl(aq) solutions, dried over Na_2SO_4, filtered, and concentrated under a reduced pressure to afford **S10a** as a light yellow oil (hexane/EtOAc, 5:1; yield: 25 mmol, 4.2 g, 83%).

To a solution of **S10a** (3 mmol, 501 mg) in DCM (20 mL) was added *m*-CPBA (6 mmol, 1.35 g) at 0 °C, and stirred for 53 h at rt. The reaction was quenched with water, and extracted with DCM. The organic layer was washed with saturated Na_2CO_3(aq), dried over Na_2SO_4, filtered, and concentrated under reduced pressure. The crude mixture was purified by column chromatography on silica gel to provide the epoxide **8a** as a light yellow oil (hexane/EtOAc, 1:1; yield: 2.5 mmol, 83%).

8a: ^{1}H NMR (400 MHz, $CDCl_3$) δ: 6.66 (dd, *J* = 15.0, 6.5 Hz, 1H), 6.48 (dd, *J* = 15.0, 0.7 Hz, 1H), 3.39 (q, J = 7.1 Hz, 2H), 3.34 (q, *J* = 7.2 Hz, 2H), 3.17 (dd, *J* = 6.5, 20 Hz, 1H), 2.91 (qd, *J* = 5.2, 2.0 Hz, 1H), 1.34 (d, *J*

= 5.2 Hz, 3H), 1.16 (t, *J* = 7.2 Hz, 3H), 1.10 (t, *J* = 7.1 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ: 164.7, 141.4, 122.6, 57.8, 57.7, 42.2, 40.8, 17.6, 14.9, 13.1; MS (EI, *m/z*): 183(2), 154(5), 139(30), 124(98), 100(16), 96(22), 83(60), 72(100), 55(60).

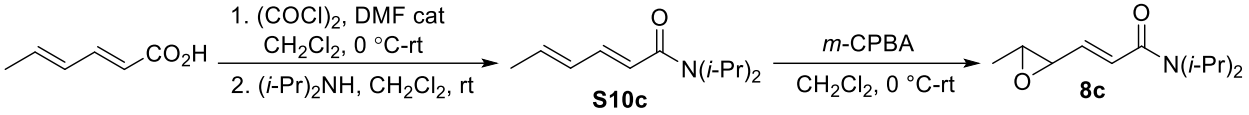
Synthesis of 8b:



Following the general procedures used for the synthesis of epoxy amide **8a**; amidation of sorbic acid (10 mmol) with dibenzylamine (yield of **S10b**: 5.5 mmol, 1.60 g, 55%), followed by epoxidation of the resulting diene amide **S10b** (5.5 mmol) produced epoxy amide **8b** as a white solid (hexane/EtOAc, 10:1; yield: 3.9 mmol, 1.20 g, 71%).

8b: M.P.: 97-99 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ: 7.40–7.10 (m, 10H), 6.81 (dd, *J* = 15.0, 6.8 Hz, 1H), 6.58 (dd, *J* = 15.0, 0.6 Hz, 1H), 4.65 (d, J_{AB} = 14.8 Hz, 1H), 4.59 (d, J_{AB} = 14.8 Hz, 1H), 4.49 (s, 2H), 3.15 (dd, *J* = 6.8, 2.0 Hz, 1H), 2.92 (qd, *J* = 5.2, 2.0 Hz, 1H), 1.33 (d, *J* = 5.2 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ: 166.2, 143.3, 137.0, 136.3, 129.0, 128.6, 128.3, 127.7, 127.5, 126.5, 122.4, 57.73, 57.69, 49.9, 48.5, 17.6; MS (EI, *m/z*): 263(2), 250(5), 216(6), 196(28), 172(7), 144(2), 132(14), 117(5), 106(30), 90(100), 83(26), 77(5), 65(20), 55(11).

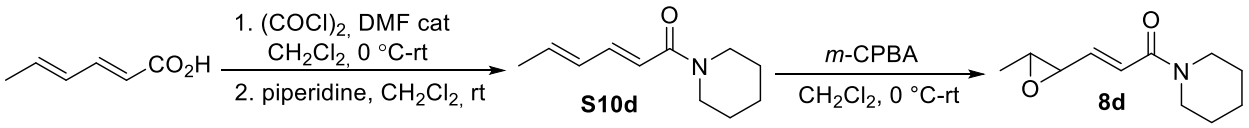
Synthesis of 8c:



Following the general procedures used for the synthesis of epoxy amide **8a**; amidation of sorbic acid (30 mmol) with diisopropyl amine (yield of **S10c**: 7.7 mmol, 77%), followed by epoxidation of the resulting diene amide **S10c** (5 mmol, 976 mg) produced the epoxy amide **8c** as a pale yellow oil (hexane/EtOAc, 10:1; yield: 2.5 mmol, 50%).

8c: ^{1}H NMR (400 MHz, $CDCl_3$) δ: 6.57–6.47 (m, 2H), 4.05–3.95 (m, 1H), 3.76–3.66 (m, 1H), 3.18–3.15 (m, 1H), 2.93 (qd, *J* = 5.2, 2.0 Hz, 1H), 1.35 (d, *J* = 5.2 Hz, 9H), 1.22 (d, *J* = 6.5 Hz, 6H); ^{13}C NMR (101 MHz, $CDCl_3$) δ: 165.2, 139.7, 125.5, 58.0, 57.6, 48.3, 45.8, 21.4, 20.5, 17.6; MS (EI, *m/z*): 196(2), 151(5), 110(10), 100(90), 86(100), 83(65), 70(20), 58(25), 55(40), 43(58).

Synthesis of 8d:

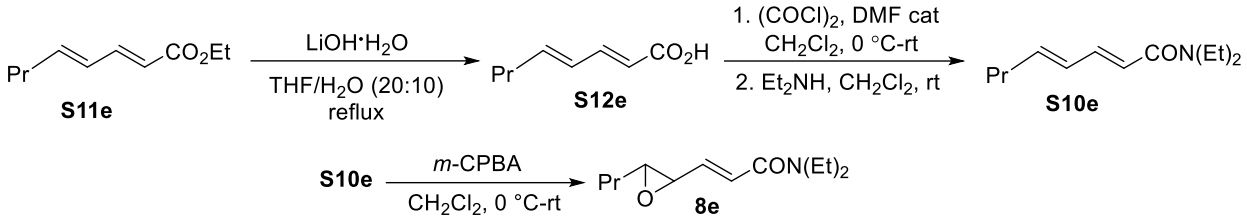


Following the general procedures used for the synthesis of epoxy amide **8a**, amidation of sorbic acid (30 mmol) with piperidine (yield of **S10d**: 21 mmol, 3.77 mg, 70%) followed by epoxidation of the resulting diene amide **S10d** (4 mmol, 716 mg) produced the epoxy amide **8d** as a pale yellow solid (hexane/EtOAc, 1:1; yield: 2.5 mmol, 488 mg, 83%).

8d: M.P.: 49-51 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ: 6.63–6.52 (m, 2H), 3.58 (br(t), *J* = 5.4 Hz, 2H), 3.46 (br(t), *J* = 5.3 Hz, 2H), 3.17 (dd, *J* = 5.2, 2.0 Hz, 1H), 2.92 (qd, *J* = 5.2, 2.0 Hz, 1H), 1.68–1.60 (m, 2H), 1.58–

1.51 (m, 4H), 1.35 (d, *J* = 5.2 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ: 164.3, 141.0, 122.7, 57.9, 57.7, 47.0, 43.1, 26.6, 25.5, 24.5, 17.6; MS (EI, *m/z*): 166(8), 151(42), 138(6), 122(22), 112(14), 84(100), 69(20), 55(50).

Synthesis of 8e:

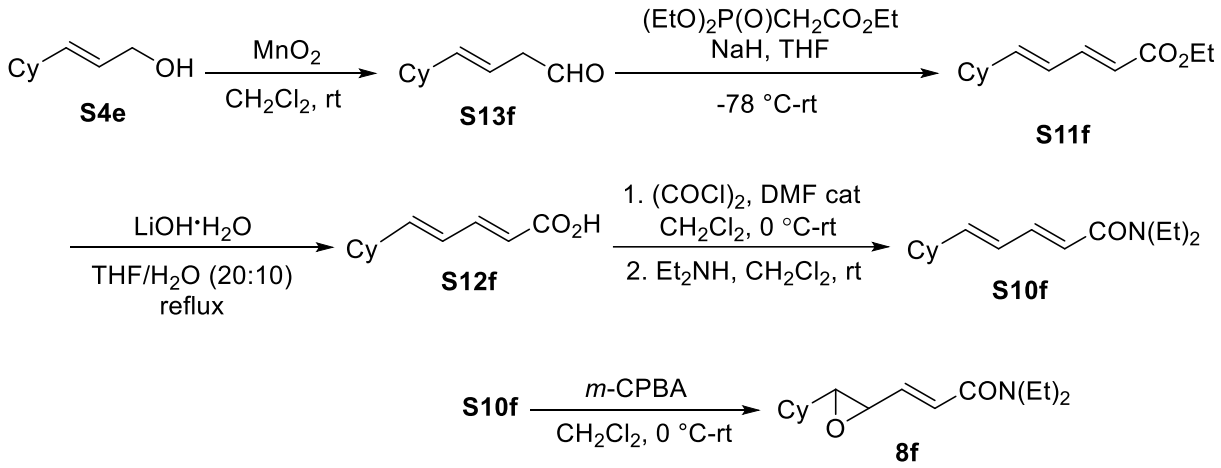


To a stirred solution of the diene ester **S11e** (13 mmol, 2.2 g) in THF/H_2O (20:10 mL) was added lithium hydroxide monohydrate (247 mmol, 10.4 g) at rt, heated to reflux, and stirred for 72 h. The reaction was quenched with 4 M HCl(aq) (pH should be 2-3), and extracted with CH_2Cl_2. The organic layer was dried over Na_2SO_4, filtered, and concentrated under reduced pressure to afford **S12e**, which was used directly in the next step.[19]

Following the general procedures used for the synthesis of epoxy amide **8a**; amidation of **S12e** (9 mmol) with diethylamine (yield of **S10e**: 7.7 mmol, 1.5 g, 85%), followed by epoxidation of the resulting diene amide **10e** (5 mmol) produced the epoxy amide **8e** as a pale yellow oil (hexane/EtOAc, 4:1; yield: 4.35 mmol, 919 mg, 87%).

8e: ^{1}H NMR (400 MHz, $CDCl_3$) δ: 6.68 (dd, *J* = 15.0, 6.5 Hz, 1H), 6.48 (dd, *J* = 15.0, 0.7 Hz, 1H), 3.40 (q, *J* = 7.1 Hz, 2H), 3.35 (q, *J* = 7.1 Hz, 2H), 3.21 (dd, *J* = 6.5, 2.1 Hz, 1H), 2.83 (td, J = 5.6, 2.1 Hz, 1H), 1.59–1.39 (m, 4H), 1.17 (t, *J* = 7.1 Hz, 3H), 1.11 (t, *J* = 7.1 Hz, 3H), 0.93 (t, *J* = 7.3 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ: 164.7, 141.6, 122.4, 61.6, 56.8, 42.2, 40.8, 34.0, 19.1, 14.9, 13.8, 13.0; MS (EI, *m/z*): 182(4), 139(46), 124(100), 111(12), 96(14), 82(14), 72(36), 58(12), 55(22). MS (EI, *m/z*): 182(4), 168(1), 139(44), 124(100), 111(12), 96(14), 82(14), 72(35), 58(12), 55(22).

Synthesis of 8f:



Activated MnO_2 (190 mmol, 13.1 g) was added to a stirred solution of **S4e** (9.5 mmol, 1.3 g) in DCM (100 mL) at rt, and stirred for 1 h. After completion of the reaction, the reaction mixture was filtered through silica gel, and concentrated under a reduced pressure to afford the alkenyl aldehyde **S13f**, which was used in next step without further purification.[20]

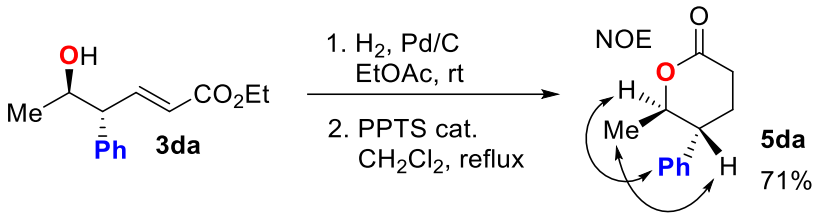
From triethyl phosphonoacetate (1.5 eq., 12.75 mmol, 2.5 mL), NaH (60% dispersion in mineral oil, 14.45 mmol, 580 mg), and **S13f** (8.5 mmol, 1.2 g), following the procedure used for the synthesis of **S1a**, the diene ester **S11f** was obtained as a light yellow oil (hexane:EtOAc, 50:1; yield: 7.2 mmol, 1.5 g, 85%).

To a stirred solution of **S11f** in THF:H_2O (20:10 mL) was added lithium hydroxide monohydrate (137 mmol, 6 g) at rt, heated to reflux, and stirred for 72 h. The reaction was quenched with 4 M HCl(aq) (pH should be 2-3), and extracted with DCM. The organic layer was dried over Na_2SO_4, filtered, and concentrated under reduced pressure to afford **S12f**, which was used directly in the next step.[17]

Following the general procedures used for the synthesis of epoxy amide **1a**, amidation of **S12f** (7 mmol) with diethylamine (yield of **S10f:** 823 mg, 3.5 mmol, 50%), followed by epoxidation of the resulting diene amide **S10f** (5 mmol) produced the epoxy amide **8f** as a light yellow oil (hexane/EtOAc, 1:1; yield: 1.92 mmol, 481 mg, 54%).

8f: ^{1}H NMR (400 MHz, $CDCl_3$) δ: 6.70 (dd, *J* = 15.0, 6.4 Hz, 1H), 6.47 (dd, *J* = 15.0, 0.7 Hz, 1H), 3.44–3.31 (m, 4H), 3.27 (ddd, *J* = 6.4, 2.1, 0.7 Hz, 1H), 2.64 (dd, *J* = 6.8, 2.1 Hz, 1H), 1.86–1.60 (m, 6H), 1.17 (t, *J* = 7.2 Hz, 3H), 1.29–1.04 (m, 5H), 1.12 (t, *J* = 7.1 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ: 164.80, 141.9, 122.1, 66.1, 55.7, 42.2, 40.9, 40.1, 29.5, 28.8, 26.2, 25.6, 25.5, 14.9, 13.1; MS (EI, *m/z*): 251(2), 222(4), 168(1), 156(5), 139(92), 124(100), 110(3), 96(12), 83(20), 72(28), 67(11), 55(32).

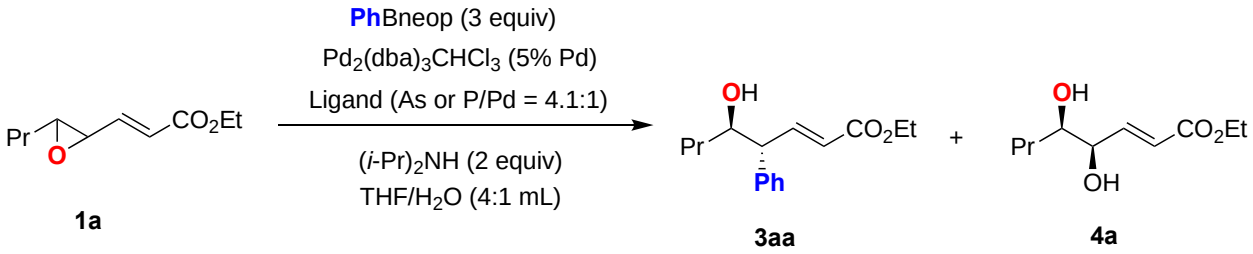
Synthesis of δ-lactones



To a suspension of 10% Pd/C (10 mg) in EtOAc (2.0 mL) was added **3da** (47 mg, 0.2 mmol) in EtOAc (2 mL), and stirred at rt under H_2 gas overnight. Then, the reaction mixture was filtered from a short silica gel column, and concentrated under reduced pressure. The crude mixture and a catalytic amount of pyridinium *p*-toluenenesulfonate (5 mg, 0.02 mmol) in DCM (15.0 mL) were heated at reflux for 6 h. Then, the solvent was evaporated, and aqueous saturated $NaHCO_3$ solution and EtOAc were added to the mixture. The organic layer was separated, and the aqueous layer was extracted with ethyl acetate. The combined organic layers were washed with water and brine, dried over Na_2SO_4, filtered, and concentrated under reduced pressure. The crude mixture was purified by column chromatography on silica gel to afford the corresponding lactone **5da** as a colourless oil (hexane/EtOAc, 10:1; yield: 0.142 mmol, 27 mg, 71%).[21]

Optimization studies

Ligand effect

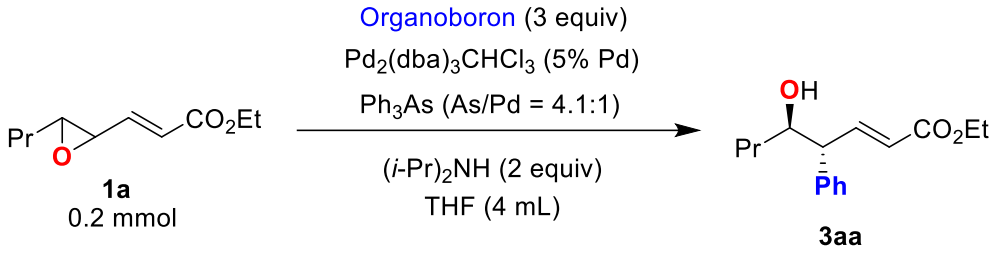


1a **3aa** **4a**

entry	ligand	T (°C)	time	3aa/4a	yield (%)[b]
1	PPh_3	rt	45 min	0:100	34
2	$P(4\text{-}OMeC_6H_4)_3$	rt	3 min	0:100	40 (38)[c]
3	Xantphos	rt	15 min	0:100	54
4	Dppe	rt	O.N.	0:100	77 (69)[c]
5	Dppb	rt	O.N.	0:100	43
6	$P(4\text{-}CF_3C_6H_4)_3$	rt	O.N.	29:71	45
7	Dppf	rt	O.N.	59:41	78
8	$HP(Cy)_3BF_4$	50	1 h	-	C.M.
9	$P(2\text{-furyl})_3$	rt	O.N.	-	C.M.
10	Xphos	rt	O.N.	100:0	30
11	DPEPhos	rt	O.N.	100:0	36 (32)[b]
12	**$AsPh_3$**	**rt**	**48 h**	**100:0**	**54**
13	$SbPh_3$	50	5 h	-	C.M.
14	ImesHCl	50	3 h	-	C.M.
15	2,2'-bipyridyl	50	3 h	-	N.C.
16	-	rt	48 h	-	N.C

[a]N.D.: not determined; N.C.: no conversion; C.M.: complex mixture; Dppe: 1,2-bis(diphenylphosphino)ethane; Dppb: 1,4-bis(diphenylphosphino)butane; Dppf: 1,1'-bis(diphenylphosphino)ferrocene; Xantphos: 4,5-bis(diphenylphosphino)-9,9-dimethylxanthene; DPEPhos: bis[(2-diphenylphosphino)phenyl] ether; ImesHCl: 1,3-Bis-(2,4,6-trimethylphenyl)imidazolium chloride. [b]Determined by ^{1}H-NMR using benzaldehyde as the internal standard. [c]Isolated yield.

Effect of organoboron and co-solvent



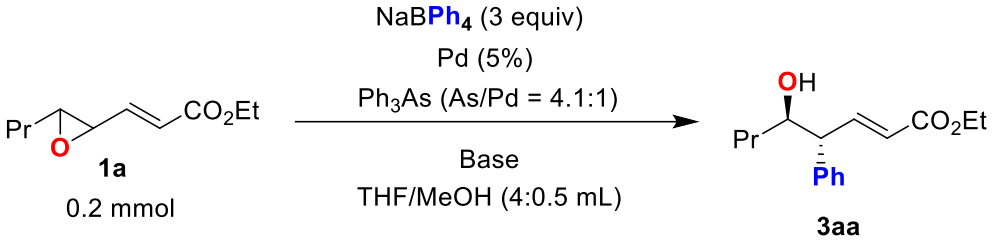
1a
0.2 mmol

3aa

entry	organoboron (equiv)	co-solvent (mL)	T (°C)	time (h)	yield (%)[a]
1	PhBneop (3)	-	OS	48	kompleks
2	PhBneop (3)	H_2O (1)	OS	48	54
3	PhBneop (1.1)	H_2O (1)	OS	48	33
4	PhBneop (1.5)	H_2O (1)	OS	48	43
5	PhBneop (3)	H_2O (0.5)	OS	48	55
6	PhBneop (3)	H_2O (0.5)	50	O.N.	55
7	PhBneop (3)	MeOH (1)	50	2.5	53
8	PhBneop (3)	MeOH (0.5)	50	3.0	55
9	$PhB(OH)_2$ (3)	H_2O (1)	rt	O.N.	41
10	$NaBPh_4$ (3)	H_2O (1)	rt	O.N.	30
11	$NaBPh_4$ (3)	MeOH (0.5)	rt	48	62
12	$NaBPh_4$ (3)	MeOH (0.5)	50	3.5	76
13	$NaBPh_4$ (3)	H_2O (0.5)	50	5.0	65
14	$NaBPh_4$ (3)	MeOH (0.25)	50	3.5	60
15	$NaBPh_4$ (3)	EtOH (0.5)	50	72	C.M.
16	$NaBPh_4$ (3)	*i*-PrOH (0.5)	50	72	C.M.
17	$KPhBF_3$ (3)	MeOH (0.5)	50	1,0	38
18[b]	$NaBPh_4$ (3)	MeOH (0.5)	50	4,0	78
19[c]	$NaBPh_4$ (3)	MeOH (0.5)	50	3.5	64
20[d]	$NaBPh_4$ (3)	MeOH (0,5)	50	2.5	62
21[b]	**$NaBPh_4$ (3)**	**MeOH (0.5)**	**70**	**1.0**	**82**
22[e]	$NaBPh_4$ (3)	MeOH (0,5)	rt	48 h	N.C.

[a]Determined by ^{1}H-NMR using benzaldehyde as the internal standard. [b] 5 mol% $Pd(OAc)_2$ was used as the Pd source. [c]As/Pd = 3:1. [d]As/Pd = 5:1. [e]Peformed without added Pd.

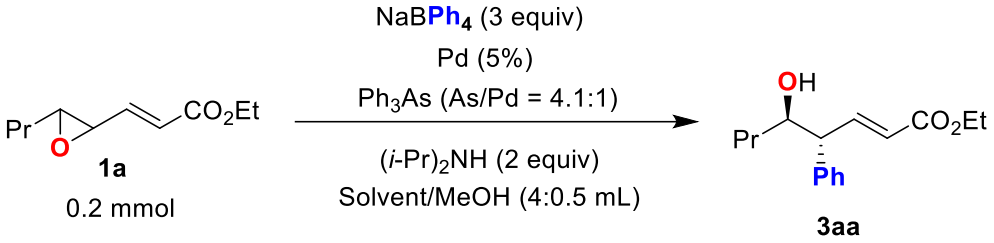
Base effect



entry	base (equiv)	Pd (mol%)	T (°C)	time	yield (%)[a]
1	-	$Pd_2(dba)_3CHCl_3$ (2.5)	50	48 h	48
2	(*i*-Pr)$_2$NH (1)	$Pd_2(dba)_3CHCl_3$ (2.5)	50	3.5 h	72
3	**(*i*-Pr)$_2$NH (1.5)**	**$Pd_2(dba)_3CHCl_3$ (2.5)**	**50**	**3.5 h**	**75**
4	**(*i*-Pr)$_2$NH (2)**	**$Pd_2(dba)_3CHCl_3$ (2.5)**	**50**	**3.5 h**	**76**
5	(*i*-Pr)$_2$NH (2.5)	$Pd_2(dba)_3CHCl_3$ (2.5)	50	3.5 h	60
6	(*i*-Pr)$_2$NH (4)	$Pd_2(dba)_3CHCl_3$ (2.5)	50	3.5 h	58
7	Cs_2CO_3 (2)	$Pd(OAc)_2$ (5)	70	40 min	13
8	Et_3N (2)	$Pd(OAc)_2$ (5)	70	30 min	55
9	NaOAc (2)	$Pd(OAc)_2$ (5)	70	37 min	65
10	AgOTf (2)	$Pd_2(dba)_3CHCl_3$ (2.5)	50	3.5 h	66
11	Na_2HPO_4 (2)	$Pd(OAc)_2$ (5)	70	35 min	71
12	DBU (2)	$Pd(OAc)_2$ (5)	70	2 h	C.M.
13	LiOH (2)	$Pd(OAc)_2$ (5)	70	15 min	C.M.
14	CsF[b] (1.75)	$Pd(OAc)_2$ (5)	70	4 min	C.M.
15	(*i*-Pr)$_2$NH (2)	$Pd(PPh_3)_2Cl_2$	70	1 h	C.M.

[a]Determined by ^{1}H-NMR using benzaldehyde as the internal standard. [b]PhBneop was used as the organoboron reagent, performed in the presence of 1 mL of H_2O.

Solvent effect



entry	Pd (% mol)	solvent	T (°C)	time	yield (%)[a]
1	$Pd_2(dba)_3CHCl_3$ (2.5)	THF	50	3.5 h	76
2	$Pd_2(dba)_3CHCl_3$ (2.5)	DME	50	O.N.	58
3	$Pd_2(dba)_3CHCl_3$ (2.5)	*tert*-BuOMe	50	O.N.	38
4	$Pd_2(dba)_3CHCl_3$ (2.5)	DMF	50	O.N.	C.M.
5	$Pd_2(dba)_3CHCl_3$ (2.5)	Toluene	50	O.N.	C.M.
6	$Pd(OAc)_2$ (5)	THF	50	4 h	78
7	$Pd(OAc)_2$ (5)	THF	70	1 h	82
8	$Pd(OAc)_2$ (5)	1,4-dioxane	70	40 min	85
9	$Pd(OAc)_2$ (5)	1,4-dioxane	100	5 min	82
10	**$Pd(OAc)_2$ (5)**	**1,4-dioxane**	**110**	**2 min**	**90 (87)[b]**
11[c]	$Pd(OAc)_2$ (5)	1,4-dioxane	110	2 min	55
12[d]	$Pd(OAc)_2$ (1)	1,4-dioxane	110	4 min	50
13[d]	**$Pd(OAc)_2$ (5)**	**1,4-dioxane**	**110**	**4 min**	**90**

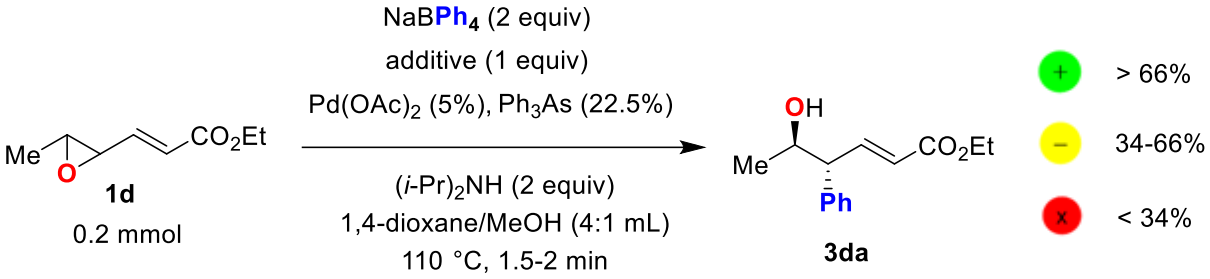
[a]Determined by ^{1}H-NMR using benzaldehyde as the internal standard. [b]Isolated yield. [c]PhBneop instead. [d]2 equiv of $NaBPh_4$.

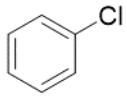
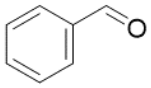
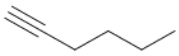
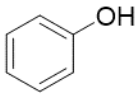
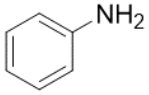
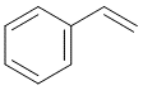
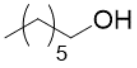
Robustness screening

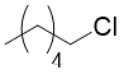
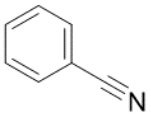
The reactions of **1d** and **2a** were carried out under standard conditions in the presence of 1 equivalent of an additive. Upon completion of the reaction, the crude mixture was diluted with ethyl acetate and passed through a silica plug. To the mixture, decane or dodecane was added as an internal standard and analysed by GC to determine the amount of additive remaining after the reaction. The yield of homoallyl product **3da** was determined by ^{1}H-NMR. For this purpose, the mixture was concentrated under reduced pressure, *p*-xylene was added as the internal standard, and dissolved in $CDCl_3$.

The product yields and additive recovery levels were categorized as specified by Collins and Glorius (see the Chart below).[21] Accordingly, the product formation was always within the tolerable range, despite the decrease in the yield (entries 1-8), with the exception of reactions using pentyl chloride and benzonitrile additives (entries 9 and 10). The most dramatic effect was observed for the reaction performed in the presence of chlorobenzene additive (entry 2). The Suzuki-Miyaura coupling reaction was the competing side reaction that led to the formation of biphenyl by-product in this process. On the

other hand, partial consumption of additive was generally observed during the reaction; among them, the recovery of 1-hexyne and 1-heptanol was intolerably low (entries 3 and 7).

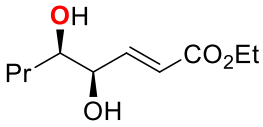


entry	additive	yield of 3a (%)[a]	additive remaining (%)[b]
1	None	90	–
2		67 +	40 –
3		82 +	64 –
4		74 +	11 x
5		75 +	40 –
6		79 +	71 +
7		83 +	75 +
8		79 +	5 x

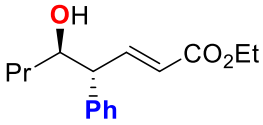
9		92	55
10		91	62

[a]Determined by ^{1}H-NMR using *p*-xylene as the internal standard. Determined by GC yield using decane or dodecane as the internal standard.

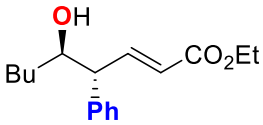
Characterization data of the products



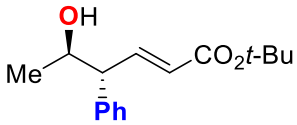
4a: ^{1}H NMR (400 MHz, $CDCl_3$) δ: 6.91 (dd, *J* = 15.6, 5.0 Hz, 1H), 6.12 (d, *J* = 15.6 Hz, 1H), 4.19 (q, *J* = 7.1 Hz, 2H), 4.14–4.07 (m, 1H), 3.72–3.53 (m, 1H), 3.59–3.52 (m, 1H), 2.31 (br(s), 2H), 1.57–1.33 (m, 4H), 1.28 (t, *J* = 7.1 Hz, 3H), 0.92 (t, *J* = 6.7 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ: 166.3, 146.7, 122.5, 74.1, 73.7, 60.6, 35.1, 18.8, 14.2, 13.92; MS (EI, *m/z*): 130(90), 102(50), 84(100), 73(62), 55(73); FTIR (ν_{max}/cm^{-1}): 3430, 2959, 2926, 2855, 1717 (C=O), 1658, 1465, 1369, 1270, 1179, 1080, 1037, 985, 871, 745, 584, 568; HRMS (ESI) $C_{10}H_{18}O_4$ $(M + H)^+$: 203,1278 (calculated), 203.1280 (measured).



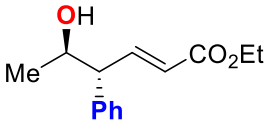
3aa: ^{1}H NMR (400 MHz, $CDCl_3$) δ: 7.36–7.17 (m, 6H), 5.89 (dd, *J* = 15.7, 1.0 Hz, 1H), 4.17 (q, *J* = 7.1 Hz, 2H), 3.90 (dd, *J* = 12.0, 6.5 Hz, 1H), 3.42 (dd, *J* = 8.9, 6.5 Hz, 1H), 1.70 (br(s), 1H), 1.54–1.31 (m, 4H), 1.27 (t, *J* = 7.1 Hz, 3H), 0.86 (t, *J* = 7.2 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ: 166.3, 147.9, 140.1, 128.8, 128.2, 127.1, 123.6, 74.1, 60.4, 55.4, 36.9, 18.9, 14.2, 13.9; ^{1}H NMR (400 MHz, C_6D_6) δ: 7.53 (dd, *J* = 15.7, 8.8 Hz, 1H), 7.09–6.93 (m, 5H), 5.93 (d, *J* = 15.7 Hz, 1H), 3.97 (q, *J* = 7.1 Hz, 2H), 3.62–3.56 (m, 1H), 3.19–3.12 (m, 1H), 1.46–1.30 (m, 2H), 1.21–1.13 (m, 2H), 0.92 (t, *J* = 7.1 Hz, 3H), 0.70 (t, *J* = 6.9 Hz, 3H); ^{13}C NMR (101 MHz, C_6D_6) δ: 166.0, 148.7, 140.7, 128.6, 128.2, 126.7, 123.3, 73.7, 59.9, 55.7, 37.2, 18.8, 13.9, 13.7; MS (EI, *m/z*): 190(90), 162(25), 144(100), 133(28), 117(88), 105(5), 91(18), 65(5), 55(30); FTIR (ν_{max}/cm^{-1}): 3420, 2959, 2924, 1715 (C=O), 1649, 1601, 1453, 1369, 1260, 1171, 1091, 1028, 982, 849, 799, 699, 553; HRMS (ESI) $C_{16}H_{23}O_3$ $(M + H)^+$: 263.1642 (calculated), 263.1641 (measured).



3ba: ^{1}H NMR (400 MHz, $CDCl_3$) δ: 7.34–7.17 (m, 6H), 5.87 (dd, *J* = 15.7, 1.0 Hz, 1H), 4.16 (q, *J* = 7.1 Hz, 2H), 3.92–3.82 (m, 1H), 3.41 (dd, *J* = 8.9, 6.7 Hz, 1H), 1.76 (br(s), 1H), 1.46–1.19 (m, 6H), 1.26 (t, *J* = 7.1 Hz, 3H), 0.83 (t, *J* = 7.2 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ: 166.31, 147.9, 140.1, 128.9, 128.2, 127.1, 123.6, 74.3, 60.4, 55.3, 34.5, 27.8, 22.5, 14.2, 14.0; MS (EI, *m/z*): 231(1), 190(100), 162(17), 144(94), 133(30), 115(80), 105(7), 91(15), 77(6), 69(17), 57(7); FTIR (ν_{max}/cm^{-1}): 3461, 2984, 1739(C=O), 1650, 1447, 1373, 1238, 1165, 1096, 1045, 938, 918, 787, 734, 702, 634, 608, 508; HRMS (ESI): $C_{17}H_{24}O_3$ $(M + H)^+$: 277,1798 (calculated), 277.1790 (found).

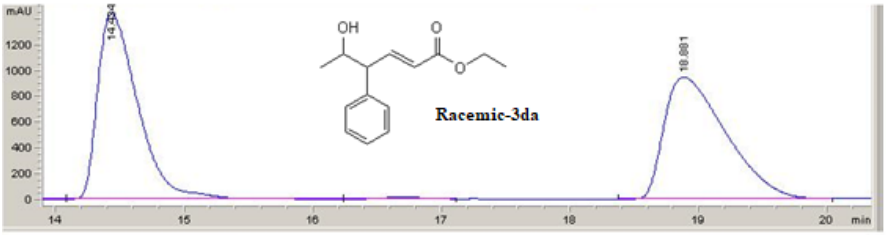


3ca: ^{1}H NMR (400 MHz, $CDCl_3$) δ: 7.36–7.18 (m, 5H), 7.15 (dd, *J* = 15.6, 9.0 Hz, 1H), 5.85 (dd, *J* = 15.6, 1.0 Hz, 1H), 4.08 (dq, *J* = 12.5, 6.2 Hz, 1H), 3.36–3.29 (m, 1H), 1.83 (br(s), 1.46 (s, 9H), 1.10 (d, *J* = 6.2 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ: 165.6, 146.7, 140.1,128.9, 128.2, 127.1, 125.4, 80.5, 70.5, 57, 28.1, 21.2; MS (EI, *m/z*): 162(100), 144(55), 117(50), 57(44), 45(10), 41(10), 29(5); FTIR (ν_{max}/cm^{-1}): 3430, 3084, 3062, 3029, 2981, 2979, 2871, 2248, 1951, 1709(C=O), 1650, 1601, 1584, 1493, 1477, 1454, 1392, 1368, 1318, 1249, 1152, 1132, 1084, 1056, 1032, 981, 934, 911, 882, 850, 811, 757, 735, 701; HRMS (ESI): $C_{16}H_{23}O_3$ $(M + H)^+$: 263.1642 (calculated), 263.1639 (found).

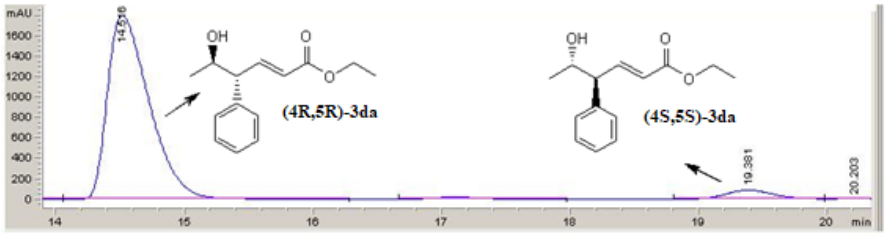


3da: ^{1}H NMR (400 MHz, $CDCl_3$) δ: 7.37–7.18 (m, 6H), 5.91 (dd, *J* = 15.7, 1.0 Hz, 1H), 4.18 (q, *J* = 7.1 Hz, 2H), 4.13–4.04 (m, 1H), 3.38–3.33 (m, 1H), 1.80 (br(s), 1H), 1.27 (t, *J* = 7.1 Hz, 3H), 1.11 (d, *J* = 6.2 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ: 166.3, 147.9, 139.9, 128.9, 128.2, 127.2, 123.7, 70.5, 60.4, 57.0, 21.3, 14.2; MS (EI, *m/z*): 235(1, M^+), 190(90), 162(20), 144(90), 133(20), 115(100), 105(8), 91(18), 45(45); FTIR (ν_{max}/cm^{-1}): 3425, 2976, 2927, 1714 (C=O), 1699, 1650, 1601, 1493, 1453, 1391, 1369, 1315, 1261, 1240, 1173, 1095, 1031, 982, 933, 862, 802, 759, 700, 537; HRMS (ESI) $C_{14}H_{19}O_3$ $(M + H)^+$: 235.1329 (calculated), 235.1325 (measured).

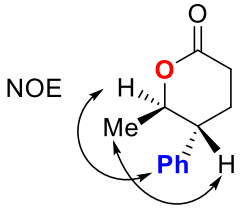
(4*R*,5*R*)-3da: The enantiomeric purity was measured to be 90 ee% by HPLC analysis. Chiralcel OD-3; λ: 220 nm; hexane/IPA = 98:2, 1.0 ml/min; t_R = 14.5 min (major), 19.4 min (minor); $[\alpha]_D^{20}$ = -9.3 (c = 1.5, CH_2Cl_2); -16.0 (c = 1.5, $CHCl_3$).



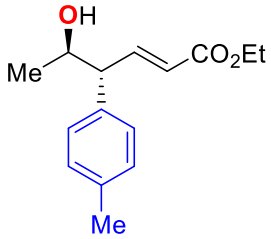
#	Time	Area	Height	Width	Area%
1	14.434	31067.4	1433.9	0.3328	41.384
2	18.881	31109.2	938.7	0.5146	41.440



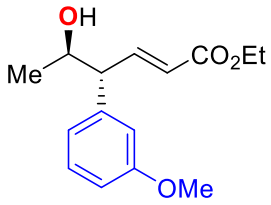
#	Time	Area	Height	Width	Area%
1	14.516	40435.9	1798.8	0.3483	87.066
2	19.381	2137.5	86.1	0.3877	4.602



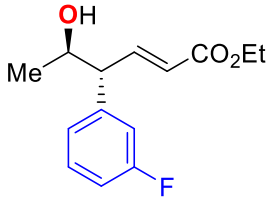
5da: ^{1}H NMR (400 MHz, $CDCl_3$) δ: 7.37–7.11 (m, 5H), 4.52 (dq, *J* = 10.4, 6.3 Hz, 1H), 2.82–2.55 (m, 3H), 2.15–2.06 (m, 2H), 1.84 (br(s), 1H), 1.17 (d, *J* = 6.3 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 171.2, 140.7, 129.0, 127.5, 127.5, 81.3, 47.1, 30.0, 27.6, 20.2; MS (EI, *m/z*): 191(1), 146(24), 128(2), 115(30), 104(100), 91(40), 78(35), 63(20), 51(28); FTIR (ν_{max}/cm^{-1}): 3452, 3063, 3031, 2980, 2934, 2251, 1732(C=O), 1603, 1495, 1455, 1382, 1380, 1348, 1295, 1271, 1242, 1225, 1200, 1178, 1135, 1089, 1077, 1044, 1022, 983, 943, 911, 823, 763, 733, 701, 647, 618, 590, 564.



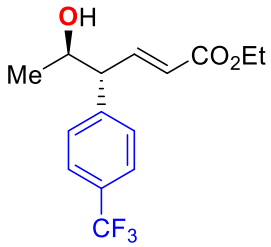
3db: ^{1}H NMR (400 MHz, $CDCl_3$) δ: 7.25 (dd, *J* = 15.7, 8.9 Hz, 1H), 7.15–7.06 (m, 4H), 5.90 (dd, *J* = 15.7, 1.0 Hz, 1H), 4.17 (q, *J* = 7.1 Hz, 2H), 4.07 (dt, *J* = 12.9, 6.3 Hz, 1H), 3.35–3.29 (m, 1H), 2.32 (s, 3H), 1.27 (t, *J* = 7.1 Hz, 3H), 1.10 (d, *J* = 6.3 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ: 166.3, 148.2, 136.8, 129.6, 128.0, 123.5, 70.5, 60.4, 56.6, 21.2, 21.0, 14.2; MS (EI, *m/z*): 204(80), 175(10), 158(90), 147(44), 131(100), 115(38), 91(30), 77(10), 68(8), 45(16); FTIR (ν_{max}/cm^{-1}): 3224, 2978, 2928, 1898, 1715 (C=O), 1649, 1513, 1447, 1369, 1315, 1238, 1167, 1131, 1039, 982, 930, 878, 812, 779, 723, 599, 547; HRMS (ESI) $C_{15}H_{21}O_3$ $(M + H)^+$: 249.1485 (calculated), 249.1484 (measured).



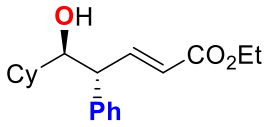
3dc: ^{1}H NMR (400 MHz, $CDCl_3$) δ: 7.23 (m, 1H), 7.23 (dd, *J* = 15.7, 9.0 Hz, 1H), 6.79–6.75 (m, 2H), 6.74–6.70 (m, 1H), 5.89 (dd, *J* = 15.7, 1.0 Hz, 1H), 4.15 (q, *J* = 7.1 Hz, 2H), 4.06 (dq, *J* = 12.5, 6.2 Hz, 1H), 3.78 (s, 3H), 3.33–3.25 (m, 1H), 1.98 br(s), 1H), 1.25 (t, *J* = 7.1 Hz, 3H), 1.09 (d, *J* = 6.2 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ: 166.30, 159.9, 147.8, 141.5, 129.9, 123.7, 120.5, 114.2, 112.1, 70.4, 60.4, 57.0, 55.2, 21.3, 14.2; MS (EI, *m/z*): 220(64), 174(70), 163(15), 147(100), 131(36), 115(40), 103(28), 91(24), 77(18); FTIR (ν_{max}/cm^{-1}): 3439, 3052, 2978, 2983, 2904, 2887, 2872, 2249, 1925, 1712 (C=O), 1649, 1600, 1584, 1487, 1465, 1453, 1437, 1392, 1369, 1264, 1238, 1177, 1152, 1130, 1096, 1042, 983, 943, 910, 876, 864, 779, 735, 700; HRMS (ESI) $C_{15}H_{21}O_4$ $(M + H)^+$: 265.1434 (calculated), 265.1433 (measured).



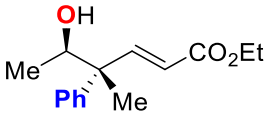
3dd: ^{1}H NMR (400 MHz, $CDCl_3$) δ: 7.30–7.24 (m, 1H), 7.20 (dd, *J* = 15.7, 8.7 Hz, 1H), 6.98–6.88 (m, 3H), 5.88 (dd, *J* = 15.7, 1.1 Hz, 1H), 4.16 (q, *J* = 7.1 Hz, 2H), 4.06 (dq, *J* = 7.1, 6.2 Hz, 1H), 3.33 (dd, *J* = 8.7, 7.1 Hz, 1H), 1.93 (br(s), 1H), 1.25 (t, *J* = 7.1 Hz, 3H), 1.10 (d, *J* = 6.2 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ: 166.2, 164.2, 161.7, 147.1, 142.4 (d, *J* = 7.0 Hz), 130.3 (d, *J* = 8.4 Hz), 124.0, 123.9 (d, *J* = 2.9 Hz), 115.1 (d, *J* = 21.6 Hz), 114.6 (dd, *J* = 104.3, 21.3 Hz), 114.1 (d, *J* = 21.0 Hz), 70.3, 60.5, 56.5, 21.4, 14.19; ^{19}F NMR (376 MHz, $CDCl_3$) δ: -112.3; MS (EI, *m/z*): 208(56), 180(26), 162(70), 151(20), 135(100), 123(3), 115(20), 109(16), 103(3), 83(10), 75)2), 57(4); FTIR (ν_{max}/cm^{-1}): 3439, 3052, 2978, 2983, 2904, 2887, 2872, 2249, 1925, 1712 (C=O), 1649, 1600, 1584, 1487, 1465, 1453, 1437, 1392, 1369, 1264, 1238, 1177, 1152, 1130, 1096, 1042, 983, 943, 910, 876, 864, 779, 735, 700; HRMS (ESI) $C_{14}H_{18}FO_3$ $(M + H)^+$: 253.1235 (calculated), 253.1233 (measured).



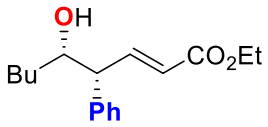
3de: ^{1}H NMR (400 MHz, $CDCl_3$) δ: 7.58 (d, *J* = 8.1 Hz, 2H), 7.33 (d, *J* = 8.1 Hz, 2H), 7.23 (dd, *J* = 15.7, 8.8 Hz, 1H), 5.90 (dd, *J* = 15.7, 1.0 Hz, 1H), 4.14–4.08 (m, 2H), 3.45–3.39 (m, 1H), 1.27 (t, *J* = 7.1 Hz, 3H), 1.12 (d, *J* = 6.2 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ: 166.0, 146.6, 144.0 (d, *J* = 1.2 Hz), 128.6, 125.8 (dd, *J* = 7.5, 3.7 Hz), 124.4, 70.3, 60.6, 56.5, 21.5, 14.2; ^{19}F NMR (376 MHz, $CDCl_3$) δ: -62.6 (s); MS (EI, *m/z*): 248(100), 239(10), 230(38), 212(70), 201(12), 193(10), 185(55), 165(20), 145(8), 133(10), 115(40), 45(35), 29(10); FTIR (ν_{max}/cm^{-1}): 3452, 2987, 2929, 2870, 2249, 1716 (C=O), 1653, 1619, 1457, 1420, 1393, 1371, 1327, 1271, 1243, 1167, 1130, 1069, 1040, 1018, 984, 910, 837, 768, 736; HRMS (ESI) $C_{15}H_{18}F_3O_3$ $(M + H)^+$: 303.1203 (calculated), 303.1201 (measured).



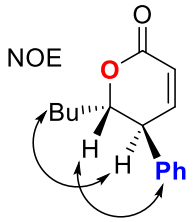
3ea: ^{1}H NMR (400 MHz, $CDCl_3$) δ: 7.41–7.15 (m, 6H), 5.87 (dd, *J* = 15.8, 0.6 Hz, 1H), 4.17 (q, *J* = 7.1 Hz, 2H), 3.68–3.60 (m, 2H), 1.87–1.56 (m, 6H), 1.27 (t, *J* = 7.1 Hz, 3H), 1.22–1.06 (m, 5H); ^{13}C NMR (100 MHz, $CDCl_3$) δ: 166.3, 148.1, 140.5, 128.9, 128.1, 127.0, 123.5, 60.4, 51.7, 39.9, 30.0, 26.7, 26.3, 26.2, 25.8, 14.2; MS (EI, *m/z*): 190(100), 162(10), 144(46), 133(15), 115(40), 95(10), 91(8), 55(12), 41(10), 29(6); FTIR (ν_{max}/cm^{-1}): 3458, 3085, 3061, 3028, 2980, 2926, 2853, 2669, 2249, 1946, 1880, 1715(C=O), 1649, 1600, 1583, 1494, 1450, 1392, 1369, 1314, 1266, 1238, 1166, 1115, 1095, 1068, 1040, 982, 943, 910, 892, 867, 842, 807, 764, 735, 701; HRMS (ESI): $C_{19}H_{26}O_3Na$ $(M + Na)^+$: 325.1774 (calculated); 325.1775 (found).



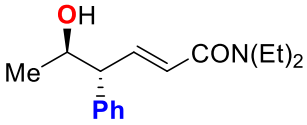
3fa : ^{1}H NMR (400 MHz, C_6D_6) δ: 7.68 (d, *J* = 16.2 Hz, 1H,Major) / 7.47 (d, *J* = 16.0 Hz, 1H, Minor), 7.08–6.91 (m, 6H), 5.95 (d, *J* = 16.2 Hz, 1H, Major) / 5.92 (d, *J* = 16.0 Hz, 1H, Minor), 4.00 (q, *J* = 7.1 Hz, 2H, Major) / 3.79 (q, *J* = 6.3 Hz, 2H, Minor), 1.17 (s, 3H, Minor) / 1.09 (s, 3H, Major), 0.93 (t, *J* = 7.1 Hz, 3H, Major) / 0.92 (t, *J* = 7.1 Hz, 3H, Minor), 0.83 (d, *J* = 6.4 Hz, 3H, Minor) / 0.77 (d, *J* = 6.3 Hz, 3H, Major); ^{13}C NMR (101 MHz, C_6D_6) δ: 166.1, 153.6 (Major) / 153.5 (Minor), 144.2 (Major) / 143.7 (Minor), 128.4 (Major) / 128.3 (Minor), 127.2 (Minor) / 126.8 (Major), 126.41 (Minor) / 126.37 (Major), 121.3 (Major) / 121.1 (Minor), 73.1 (Minor) / 72.7 (Major), 59.9, 49.45 (Major) / 49.31 (Minor), 19.35 (Minor) / 19.28 (s), 17.9 (Minor) / 17.6 (Major), 13.9; ^{1}H NMR (400 MHz, $CDCl_3$) δ: 7.44 (d, *J* = 16.2 Hz, 1H), 7.36–7.20 (m, 6H), 5.91 (d, *J* = 16.2 Hz, 1H, Major) / 5.85 (d, *J* = 16.0 Hz, 1H, Minor), 4.20 (q, *J* = 7.1 Hz, 3H), 1.68 (s, 1H), 1.47 (s, 3H, Minor) / 1.40 (s, 3H, Major), 1.29 (t, *J* = 7.1 Hz, 3H), 1.12 (d, *J* = 6.4 Hz, 3H, Minor) / 1.05 (d, *J* = 6.4 Hz, 3H, Major). ^{13}C NMR (101 MHz, $CDCl_3$) δ 166.7, 153.3 (Minor) / 152.9, 143.9 (Major) / 143.2 (Minor), 128.7 (Major) / (128.6 Minor), 127.2 (Minor) / 126.8 (Major), 121.6 (Major) / 121.1 (Minor), 73.4 (Minor) / 73.2 (Major), 60.6 Minor) / 60.4 (Major), 49.7 (Major) / (49.5, Minor), 20.3, 18.0 (Minor) / 17.72 (Major), 14.3; MS (EI, *m/z*): 203(32), 174(10), 157(45), 146(12), 129(100), 115(30), 105(4), 91(25), 77(12), 51(8), 44(34); FTIR (ν_{max}/cm^{-1}): 3458, 3058, 2978, 2926, 1715(C=O), 1646, 1599, 1495, 1445, 1368, 1293, 1177, 1097, 1063, 1029, 936, 905, 877, 805, 764, 699, 617, 582, 567; HRMS (ESI): $C_{15}H_{21}O_3$ $(M + H)^+$: 249.1485 (calculated); 249.1482 (found).



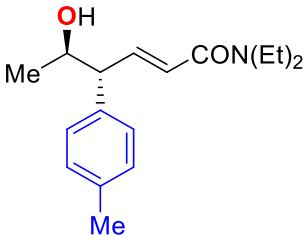
3ha: ^{1}H NMR (400 MHz, $CDCl_3$) δ: 7.36–7.22 (m, 5H), 7.13 (dd, *J* = 15.6, 8.7 Hz, 1H), 5.85 (dd, *J* = 15.6, 1.1 Hz, 1H), 4.15 (q, *J* = 7.1 Hz, 2H), 3.91 (td, *J* = 7.8, 3.8 Hz, 1H), 3.41 (dd, *J* = 8.7, 7.8 Hz, 1H), 1.60–1.28 (m, 6H), 1.25 (t, *J* = 7.1 Hz, 3H), 0.88 (t, *J* = 7.2 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ: 166.4, 148.1, 139.0, 129.0, 128.7, 127.4, 122.8, 73.9, 60.4, 55.7, 34.6, 27.8, 22.6, 14.2, 14.1; MS (EI, *m/z*): 219(1), 190(100), 162(15), 144(82), 115(63), 105(6), 91(11), 77(4), 69(14), 57(6); FTIR (ν_{max}/cm^{-1}): 3454, 3028, 2957, 2934, 2872, 1717(C=O), 1649, 1501, 1495, 1454, 1392, 1369, 1354, 1273, 1170, 1140, 910, 763, 734, 731, 549; HRMS (ESI): $C_{17}H_{24}O_3$ $(M + H)^+$: 277.1798 (calculated); 277.1795 (found).



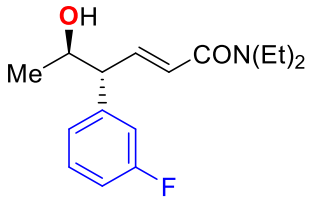
7ha: ^{1}H NMR (400 MHz, $CDCl_3$) δ: 7.39–7.30 (m, 3H), 7.18–7.14 (m, 2H), 6.78 (dd, *J* = 9.7, 2.3 Hz, 1H), 6.11 (dd, *J* = 9.7, 2.7 Hz, 1H), 4.41–4.34 (m, 1H), 3.58 (dt, *J* = 10.6, 2.5 Hz, 1H), 1.65–1.45 (m, 4H), 1.34–1.15 (m, 2H), 0.81 (t, *J* = 7.3 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ: 164.2, 149.7, 138.5, 129.1, 128.3, 127.9, 120.7, 83.6, 45.7, 32.4, 26.8, 22.3, 13.8; MS (EI, *m/z*): 144(100), 116(70); FTIR (ν_{max}/cm^{-1}): 2958, 2871, 1724(C=O), 1603, 1494, 1455, 1380, 1270, 1165, 1049, 1015, 911, 848, 816, 762, 735, 704, 647, 595, 574, 533, 526; HRMS (ESI): $C_{15}H_{18}O_2$ (M + H)$^{+}$: 231.1380 (calculated); 231.1369 (found).



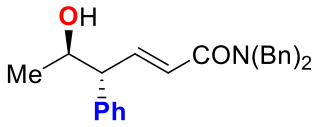
9aa: ^{1}H NMR (400 MHz, $CDCl_3$) δ: 7.33–7.18 (m, 5H), 7.15 (dd, *J* = 15.0, 9.4 Hz, 1H), 6.28 (d, *J* = 15.0 Hz, 1H), 4.05 (dq, *J* = 7.9, 6.2 Hz, 1H), 3.48–3.26 (m, 5H), 2.47 (br(s), 1H), 1.13 (t, *J* = 6.3 Hz, 3H), 1.10 (t, *J* = 6.2 Hz, 3H), 1.06 (d, *J* = 6.2 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ: 165.6, 145.4, 140.5, 128.8, 128.1, 127.0, 123.1, 70.5, 57.9, 42.2, 40.9; MS (EI, *m/z*): 217(100), 188(5), 144(50), 126(70), 100(42), 90(24), 72(45), 58(12), 45(38); FTIR (ν_{max}/cm^{-1}): 3391, 3061, 3028, 2973, 2931, 1738, 1655 (C=O), 1599, 1483, 1450, 1432, 1379, 1362, 1242, 1219, 1182, 1150, 1118, 1097, 1081, 1047, 977, 935, 683, 831, 803, 759, 700, 616, 568; HRMS (ESI): $C_{16}H_{24}NO_2$ (M + H)$^{+}$: 262.1802 (calculated); 262.1799 (found).



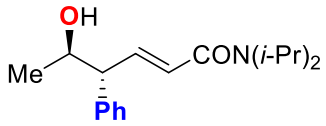
9ab: ^{1}H NMR (400 MHz, $CDCl_3$) δ: 7.13 (dd, *J* = 15.0, 9.4 Hz, 1H), 7.12–7.06 (m, 4H), 6.26 (dd, *J* = 15.0, 0.5 Hz, 1H), 4.02 (dq, *J* = 12.4, 6.2 Hz, 1H), 3.47–3.36 (m, 1H), 3.37–3.25 (m, 4H), 2.75 (br(s), 1H), 2.29 (s, 3H), 1.11 (dt, *J* = 14.1, 7.1 Hz, 6H), 1.05 (d, *J* = 6.2 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ: 165.7, 145.8, 137.5, 136.5, 129.4, 128.0, 122.7, 70.5, 57.6, 42.2, 40.8, 21.0, 20.8, 14.8, 13.1; MS (EI, *m/z*): 230(90), 202(3), 157(100), 145(12), 126(45), 114(32), 100(42), 91(18), 72(40),58(6), 45(26); FTIR (ν_{max}/cm^{-1}): 3391, 3061, 3028, 2973, 2931, 1738, 1655(C=O), 1599, 1483, 1450, 1432, 1379, 1362, 1242, 1219, 1182, 1150, 1118, 1097, 1081, 1047, 977, 935, 863, 831, 803, 759, 700, 616, 568; HRMS (ESI): $C_{17}H_{26}NO_2$ (M + H)$^{+}$: 276.1958 (calculated); 276.1955 (found).



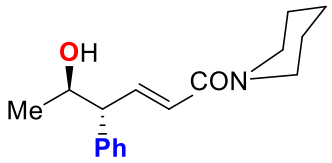
9ad: ^{1}H NMR (400 MHz, $CDCl_3$) δ: 7.24 (m, 1H), 7.10 (dd, *J* = 15.0, 9.2 Hz, 1H), 6.97 (d, *J* = 7.7 Hz, 1H), 6.94–6.86 (m, 2H), 6.25 (d, *J* = 15.0 Hz, 1H), 4.02 (dq, *J* = 12.5, 6.2 Hz, 1H), 3.46–3.25 (m, 5H), 3.05 (br(s), 1H), 1.12 (t, *J* = 5.9 Hz, 3H), 1.09 (t, *J* = 6.1 Hz, 3H), 1.06 (d, *J* = 6.2 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ: ^{13}C NMR (101 MHz, $CDCl_3$) δ 165.5, 164.1, 161.6, 143.2 (d, *J* = 7.0 Hz), 143.2 (d, *J* = 7.0 Hz), 130.1 (d, J = 8.3 Hz), 123.81 (d, *J* = 2.8 Hz), 123.79 (d, *J* = 2.8 Hz), 123.2 (s), 114.4 (dd, *J* = 137.0, 21.2 Hz), 70.3, 57.4 (d, *J* = 1.5 Hz), 42.2, 40.9, 21.0, 14.8, 13.1.1; ^{19}F NMR (376 MHz, $CDCl_3$) δ: -114.00; MS (EI, m/z): 235(60), 162(26), 133(58), 126(100), 109(28), 100(54), 83(12), 72(68), 58(32); FTIR (ν_{max}/cm^{-1}): 3393, 3060, 2973, 2929, 1655(C=O), 1590, 1484, 1447, 1380, 1361, 1262, 1218, 1097, 1082, 980, 951, 916, 881, 783, 765, 708, 695, 607, 576, 558; HRMS (ESI): $C_{16}H_{23}FNO_2$ $(M + H)^+$: 280.1707 (calculated); 280.1705 (found).



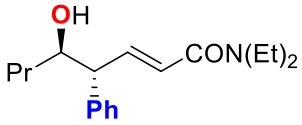
9ba: ^{1}H NMR (400 MHz, $CDCl_3$) δ: 7.37 – 7.08 (m, 16H), 6.37 (d, *J* = 15.0 Hz, 1H), 4.71 (d, *J* = 14.7 Hz, 1H), 4.52 (d, *J* = 14.7 Hz, 1H), 4.44 (d, *J* = 9.2 Hz, 2H), 4.04 (dq, *J* = 12.6, 6.2 Hz, 1H), 3.30 (t, *J* = 8.4 Hz, 1H), 2.79 (br(s), 1H), 1.04 (d, *J* = 6.2 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ: 167.1, 147.1, 140.4, 137.1, 136.5, 128.9, 128.8, 128.6, 128.4, 128.2, 127.7, 127.4, 126.9, 126.6, 122.6, 70.5, 57.7, 50.0, 48.6, 21.0; MS (EI, *m/z*): 341(10), 250(22), 117(22), 91(100), 77(3), 65(14); FTIR (ν_{max}/cm^{-1}): 3401, 3061, 3028, 2972, 2927, 1952, 1654(C=O), 1602, 1494, 1452, 1361, 1275, 1261, 1233, 1204, 1155, 1132, 1081, 1057, 1029, 1001, 979, 958, 936, 881, 820, 750, 699, 615, 577, 567; HRMS (ESI): $C_{26}H_{28}NO_2$ $(M + H)^+$: 386.2115 (calculated); 386.2112 (found).



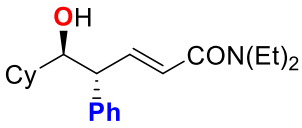
9ca: ^{1}H NMR (400 MHz, $CDCl_3$) δ: 7.31–7.17 (m, 5H), 7.02 (dd, *J* = 15.0, 9.3 Hz, 1H), 6.28 (d, *J* = 15.0 Hz, 1H), 4.03 (dq, *J* = 12.5, 6.2 Hz, 1H), 3.96–3.91 (m, 1H), 3.73–3.68 (m, 1H), 3.29 (br(t), *J* = 8.6 Hz, 1H), 2.64 (br(s), 1H), 1.32 (br(s), 6H), 1.17 (br(s), 6H), 1.05 (d, *J* = 6.2 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ: 166.0, 143.9, 140.6, 128.7, 128.2, 126.9, 125.6, 70.5, 58.0, 48.2, 45.8, 21.4, 20.8, 20.6; MS (EI, *m/z*): 245(100), 230(5), 201(22), 159(10), 144(65), 128(18), 117(86), 100(18), 91(24), 86(74), 58(80); FTIR (ν_{max}/cm^{-1}): 3384, 3061, 3027, 2969, 2929, 1737, 1651 (C=O), 1594, 1492, 1443, 1370, 1334, 1209, 1152, 1120, 1084, 1044, 979, 934, 897, 827, 757, 757, 701, 606, 570; HRMS (ESI): $C_{18}H_{28}NO_2$ $(M + H)^+$: 290.2115 (calculated); 290.2112 (found).



9da: ^{1}H NMR (400 MHz, $CDCl_3$) :δ 77.33–7.16 (m, 5H), 7.09 (dd, *J* = 15.0, 9.4 Hz, 1H), 6.35 (dd, *J* = 15.0, 0.4 Hz, 1H), 4.03 (dq, *J* = 12.4, 6.2 Hz, 1H), 3.56 (br(t), *J* = 4.1 Hz, 2H), 3.41 (br(t), *J* = 5.3 Hz, 2H), 3.33–3.27 (m, 1H), 2.51 (br(s), 1H), 1.67–1.46 (m, 6H), 1.05 (d, *J* = 6.2 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ: 165.1, 145.2, 140.5, 128.8, 128.1, 126.9, 122.8, 70.5, 58.0, 46.9, 43.11, 26.5, 25.5, 24.5, 20.9; MS (EI, *m/z*): 229(100), 143(65), 138(90), 114(60), 97(5), 91(20), 84(38), 56(18), 45(38); FTIR (ν_{max}/cm^{-1}): 3389, 3060, 3027, 2973, 2932, 2856, 1738, 1653 (C=O), 1595, 1492, 1442, 1370, 1350, 1253, 1230, 1183, 1119, 1083, 1051, 1019, 975, 958, 934, 913, 852, 790, 758, 701, 635, 564; HRMS (ESI): $C_{17}H_{24}NO_2$ $(M + H)^+$: 274.1802 (calculated); 274.1798 (found).



9ea: ^{1}H NMR (400 MHz, $CDCl_3$) δ: 7.33–7.12 (m, 6H), 6.27 (dd, *J* = 15.0, 0.5 Hz, 1H), 3.87 (td, *J* = 7.3, 4.5 Hz, 1H), 3.49–3.25 (m, 5H), 1.55–1.28 (m, 4H), 1.92 (br(s), 1H), 1.14 (t, *J* = 5.8 Hz, 3H), 1.10 (t, *J* = 5.8 Hz, 3H), 0.82 (t, *J* = 7.1 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ: 165.5, 145.4, 140.6, 128.7, 128.2, 126.85, 122.9, 74.0, 56.3, 42.2, 40.9, 36.6, 29.7, 18.9, 14.8, 13.9, 13.1; MS (EI, *m/z*): 217(100), 202(2), 188(3), 144(60), 126(70), 115(40), 100(30), 91(15), 85(4), 72(25), 58(7), 55(20); FTIR (ν_{max}/cm^{-1}): 3387, 3027, 2959, 2929, 2872, 1655(C=O), 1602, 1484, 1453, 1380, 1361, 1266, 1219, 1266, 1219, 1129, 1086, 979, 850, 762, 702, 615, 596; HRMS (ESI): $C_{18}H_{28}NO_2$ $(M + H)^+$: 290.2115 (calculated); 290.2111 (found).



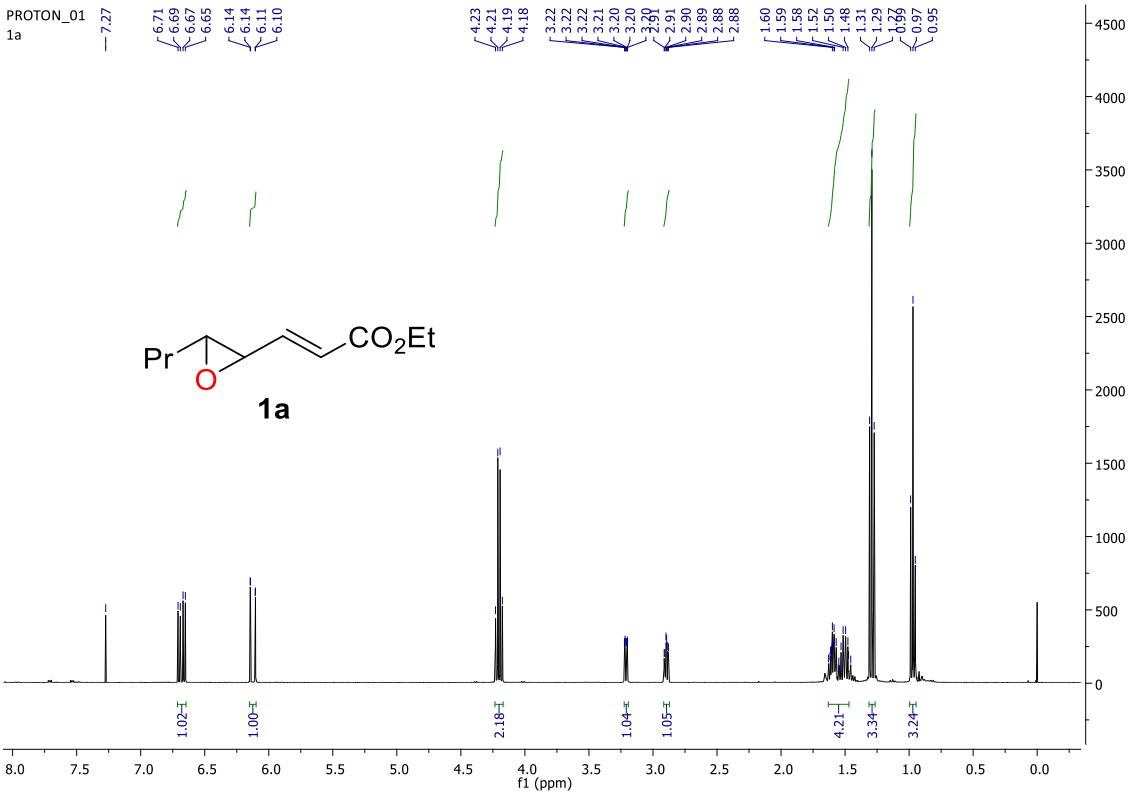
9fa: ^{1}H NMR (400 MHz, $CDCL_3$) δ: 7.33–7.20 (m, 5H), 7.17 (dd, *J* = 15.0, 8.7 Hz, 1H), 6.26 (dd, *J* = 15.0, 0.6 Hz, 1H), 3.67–3.57 (m, 2H), 3.50–3.24 (m, 4H), 1.84–1.50 (m, 9H), 1.13 (t, *J* = 5.1 Hz, 3H), 1.10 (t, *J* = 5.1 Hz, 3H), 1.16–1.04 (m, 2H); ^{13}C NMR (101 MHz, $CDCl_3$) δ: 165.7, 145.7, 141.1, 128.7, 128.1, 126.7, 122.7, 78.2, 52.4, 42.2, 140.8, 39.6, 30.3, 26.4, 26.3, 26.2, 25.9, 14.8, 13.1; MS (EI, *m/z*): 229(86), 214(14), 160(13), 130(20), 117(70), 104(100), 77(48), 69(38), 51(21); FTIR (ν_{max}/cm^{-1}): 3464, 2984, 2935, 1747(C=O), 1656, 1607, 1448, 1373, 1245, 1097, 1047, 938, 847, 787, 703, 633, 622, 611, 575; HRMS (ESI): $C_{21}H_{32}NO_2$ $(M + H)^+$: 330.2428 (calculated); 330.2424 (found).

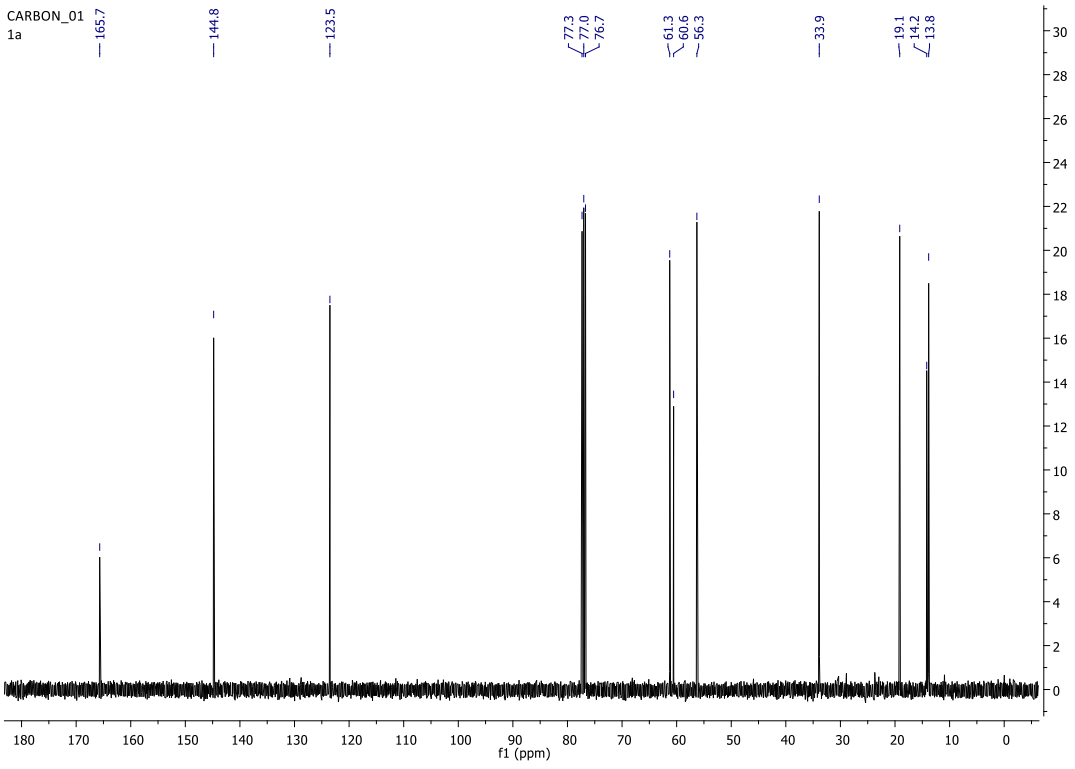
References

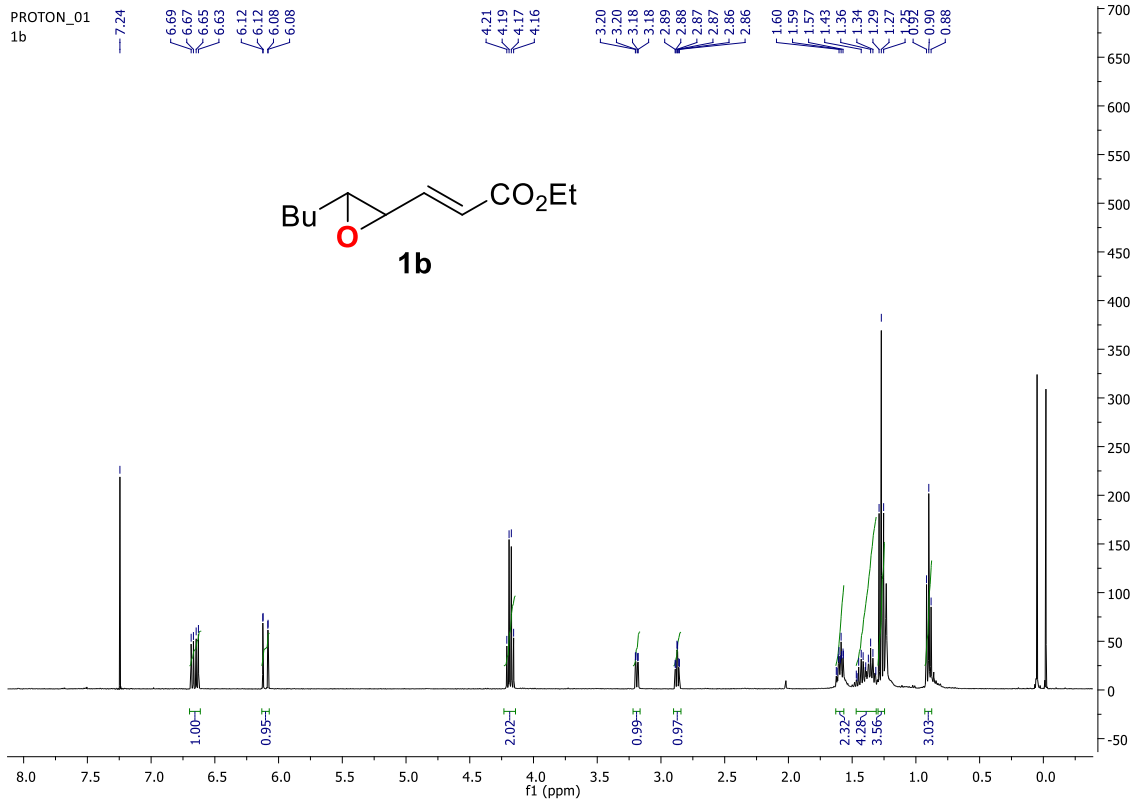
1. T. Ukai, H. Kawazura, Y. Ishii, J. J. Bonnet, J. A. Ibers, J. Organomet. Chem., 1974, **65**, 253.
2. (a) R. Shintani, Y. Tsutsumi, M. Nagaosa, T. Nishimura, T. Hayashi, J. Am. Chem. Soc. 2009, **131**, 13588; (b) J. Vandeberg, C. Moore, F.P. Cassaretto, H. Posvic, Anal. Chim. Acta, 1969, **44**, 175; (c) M. Marts Meisters, J. Vandeberg, F. P. Cassaretto, H. Posvic, C. E. Moore, Anal. Chim. Acta, 1970, **49**, 481.

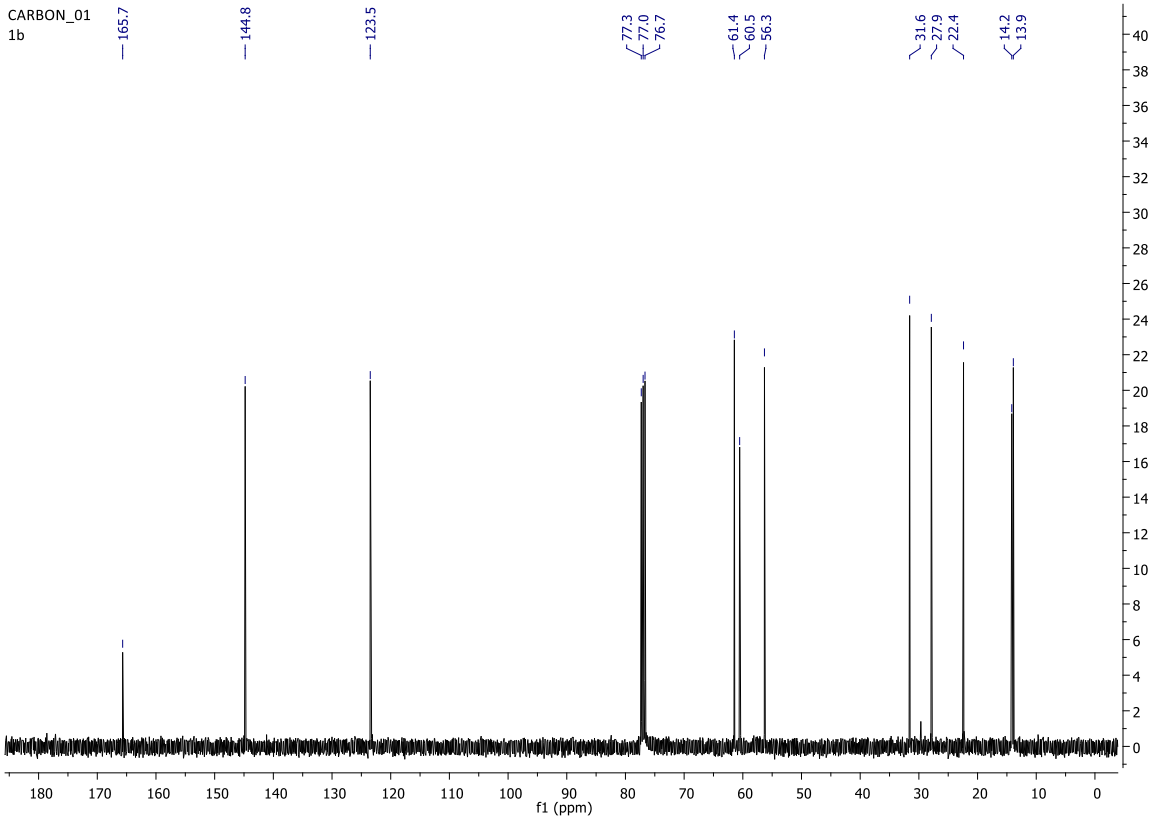
3. H. Akita, I. Umezawa, M. Takano, C. Ohyama, H. Matsukura, T. Oishi, Chem. Pharm. Bull., 1993, **41**, 55.
4. H. Urabe, K. Suzuki, F. Sato, J. Am. Chem., 1997, **119**, 10014.
5. M. Kuş, L. Artok, M. Aygün, J. Org. Chem., 2015, **80**, 5494.
6. Z.-X. Wang, Y. Tu, M.Frohn, J.-R. Zhang, Y. Shi, J. Am. Chem. Soc., 1997, **119**, 11224.
7. K. Uchida, K. Ishigami, H. Watanabea, T. Kitahara, Tetrahedron, 2007, **63**, 1281.
8. K. Oe, Y. Ohfune, T. Shinada, Org. Lett. 2014, **16**, 2550.
9. T. D. W. Claridge, S.G. Davies, J. A. Lee, R. L. Nicholson, P. M. Roberts, A. J. Russell, A. D. Smith, S. M. Toms, Org. Lett., 2008, **10**, 5437.
10. D. J. Pippel, G. A. Weisenburger, N. C. Faibish, P. Beak, J. Am. Chem. 2001, **123**, 4919.
11. U. M. Lindström, P. Somfai, Synthesis, 1998, 109.
12. S. G. Yang, J. P. Hwang, M. Y. Park, K. Lee, Y. H. Kim, Tetrahedron 2007, **63**, 5184.
13. E. Piers, T. Wong, P. D. Coish, C. Rogers, Can. J. Chem., 1994, **72**, 1816.
14. T. Kajikawa, K. Aoki, R. S. Singh, T. Iwashita, T. Kusumoto, H. A. Frank, H. Hashimoto, S. Katsumura, Org. Biomol. Chem., 2009, **7**, 3723.
15. B. Schmidt, M. Pohler, B. Costisella, Tetrahedron, 2002, **58**, 7951.
16. C. Wang, T. Tobrman, Z. Xu, E.-i. Negishi, Org. Lett., 2009, **11**, 4092.
17. U. M. Lindström, P. Somfai, Synthesis, 1998, 109.
18. K. D. Collins, F. Lied, F. Glorius, Chem. Commun., 2014, **50**, 4459.
19. (a) J. D. Goodreid, K. Wong, E. Leung, S. E. McCaw, S. D. Gray-Owen, A. Lough, W. A. Houry, R. A. Batey, J. Nat. Prod., 2014, **77**, 2170; (b) S. Tsuboi, N. Ishii, T. Sakai, I. Tari, M. Utaka, Bull. Chem. Soc. Jpn., 1990, **63**, 1888.
20. T. Hata, R. Bannai, M. Otsuki, H. Urabe, Org. Lett., 2010, **12**, 1012.
21. K. D. Collins, F. Glorius, Nat. Chem., 2013, **5**, 597.

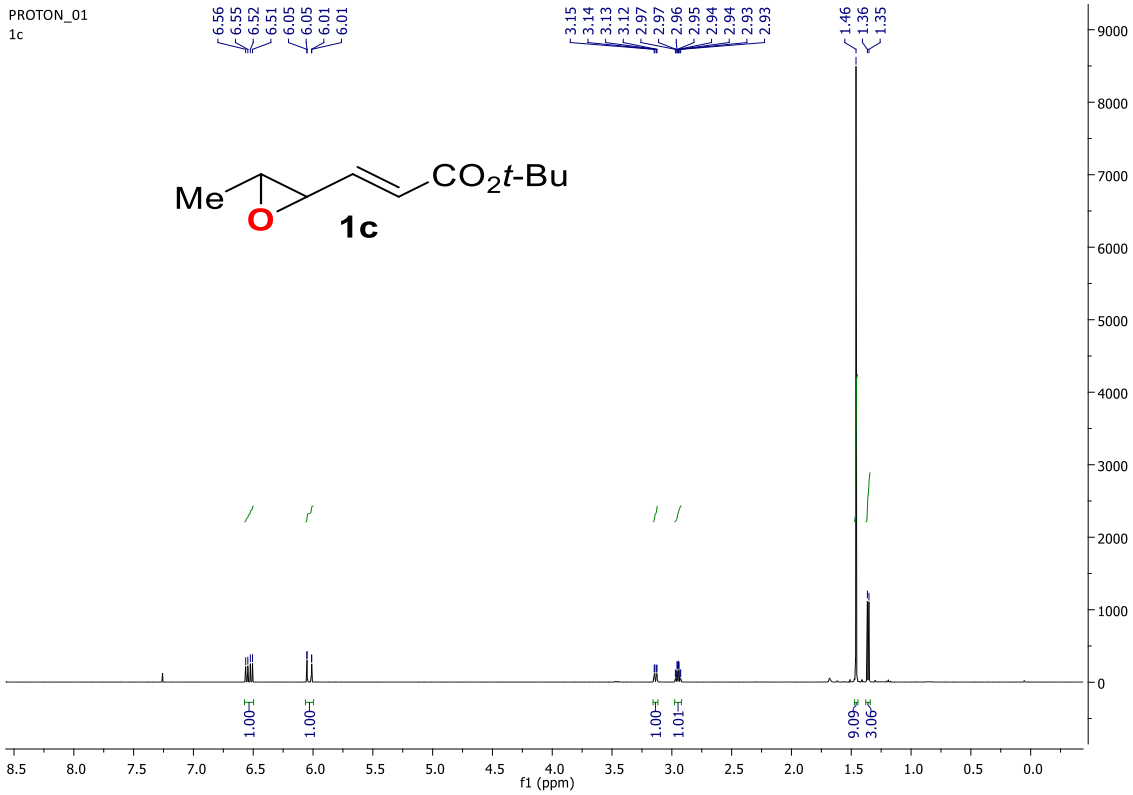
^{1}H-NMR and ^{13}C-NMR spectra of γ,δ-epoxy-α,β-unsaturated esters

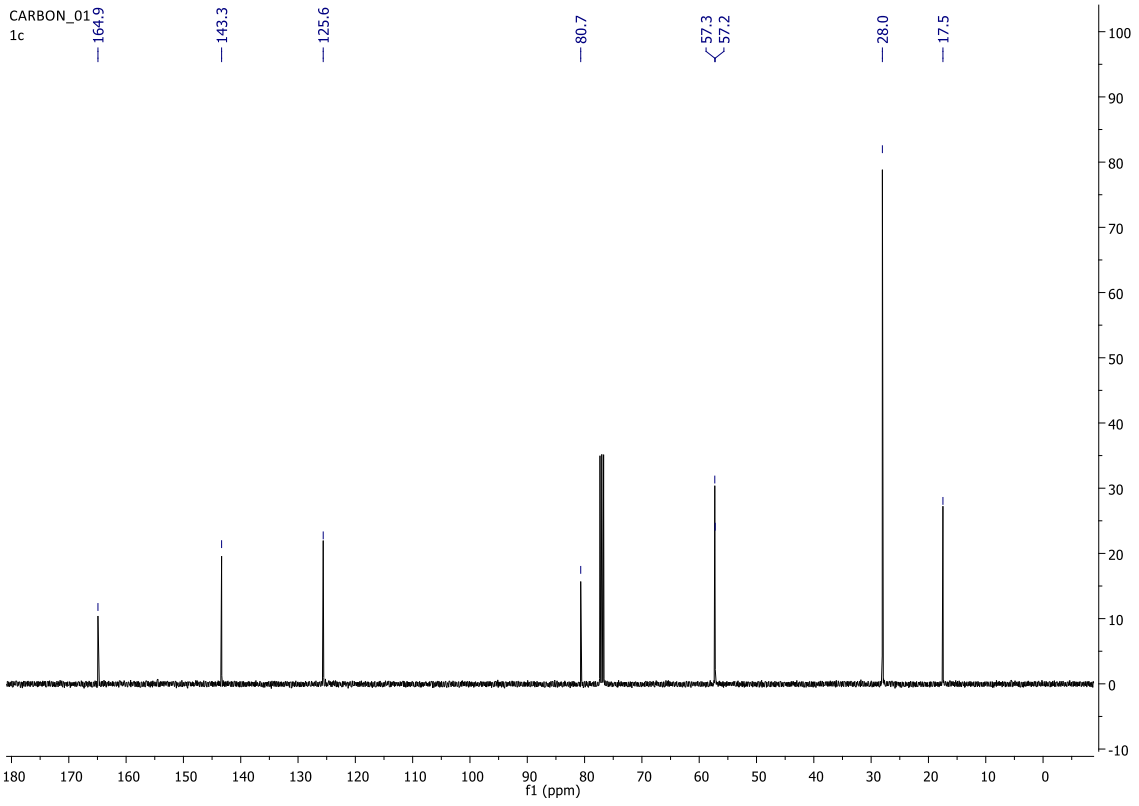


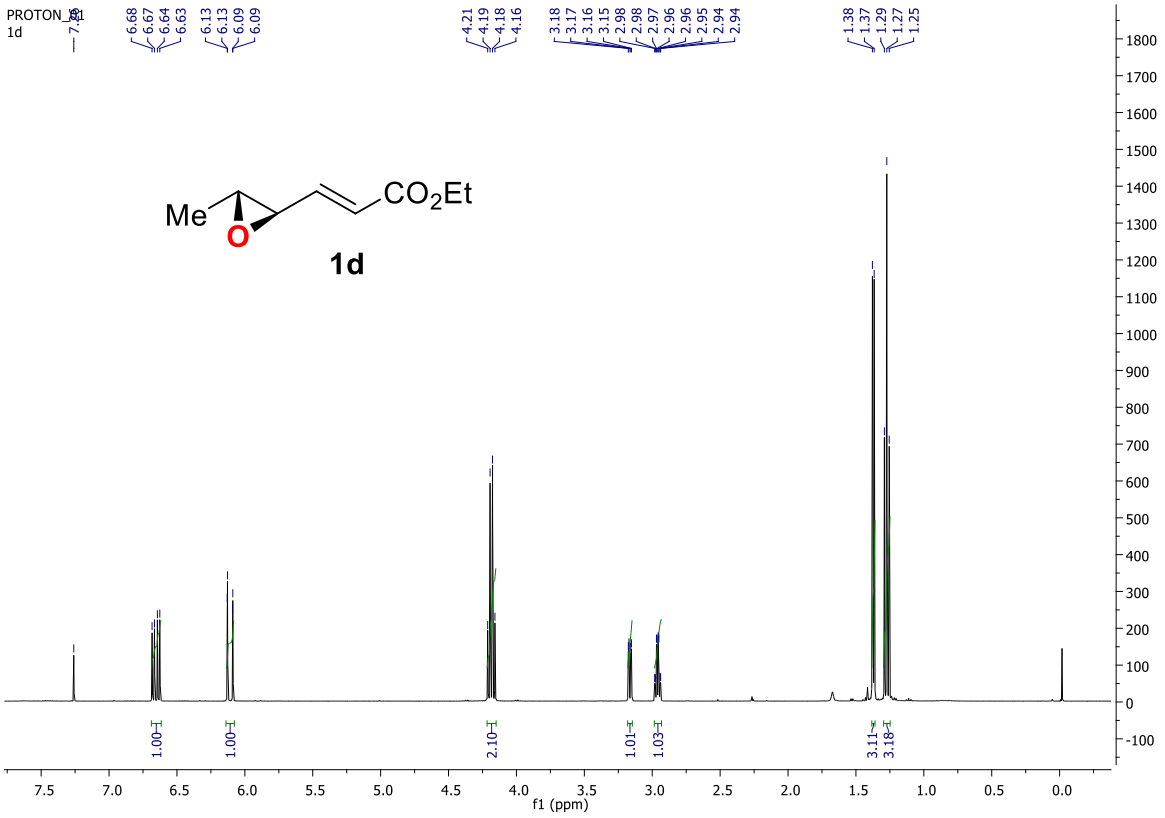


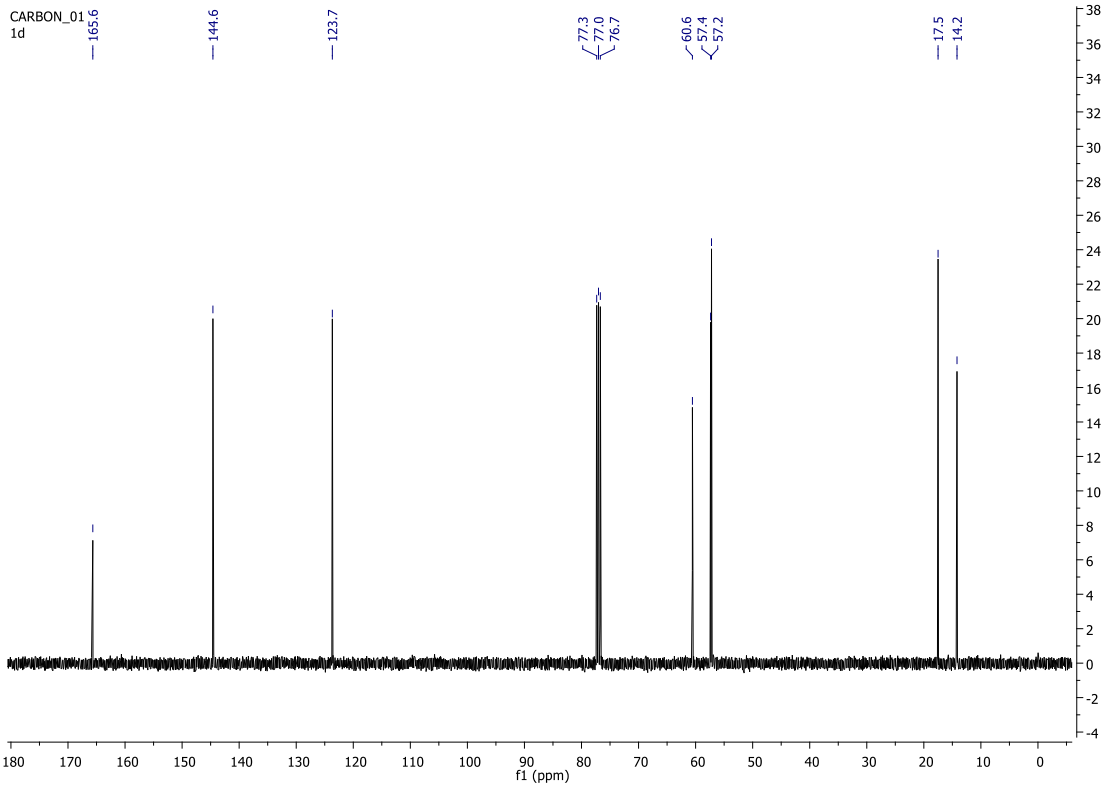

PROTON_01
1b
7.24
6.69
6.67
6.65
6.63
6.12
6.12
6.08
6.08
4.21
4.19
4.17
4.16
3.20
3.20
3.18
3.18
2.89
2.88
2.87
2.87
2.86
2.86
1.60
1.59
1.57
1.43
1.36
1.34
1.29
1.27
0.92
0.90
0.88
Bu
O
CO2Et
1b
1.00
0.95
2.02
0.99
0.97
2.32
4.28
3.56
3.03
f1 (ppm)

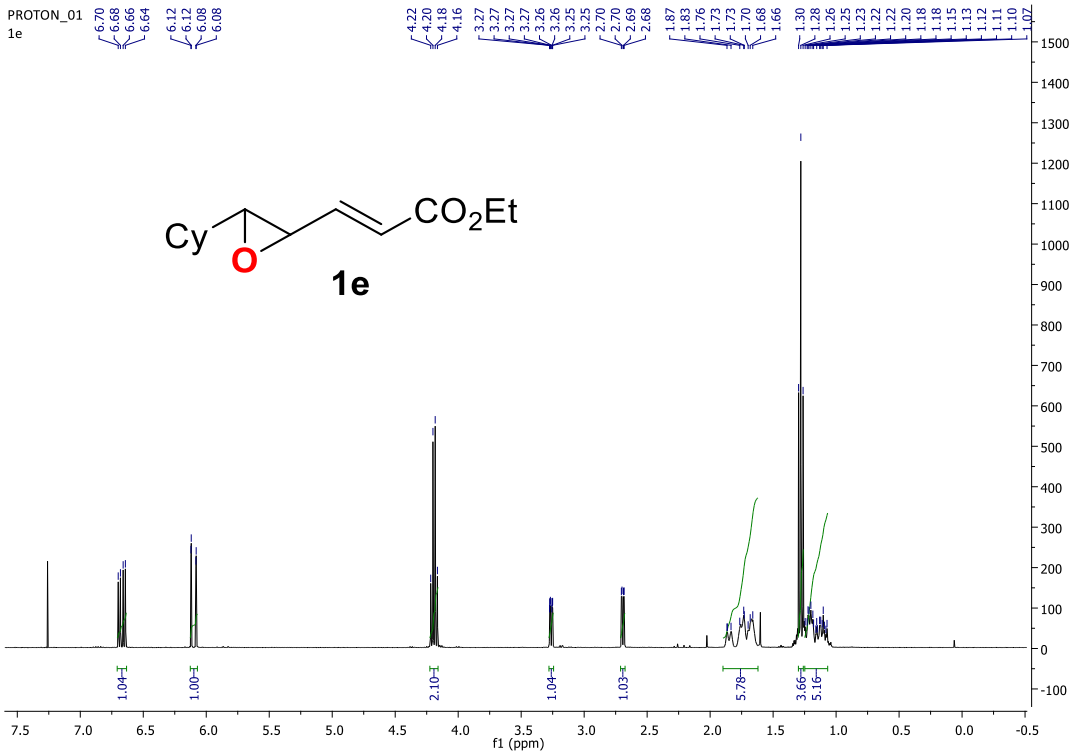

CARBON_01
1b
165.7
144.8
123.5
77.3
77.0
76.7
61.4
60.5
56.3
31.6
27.9
22.4
14.2
13.9
f1 (ppm)

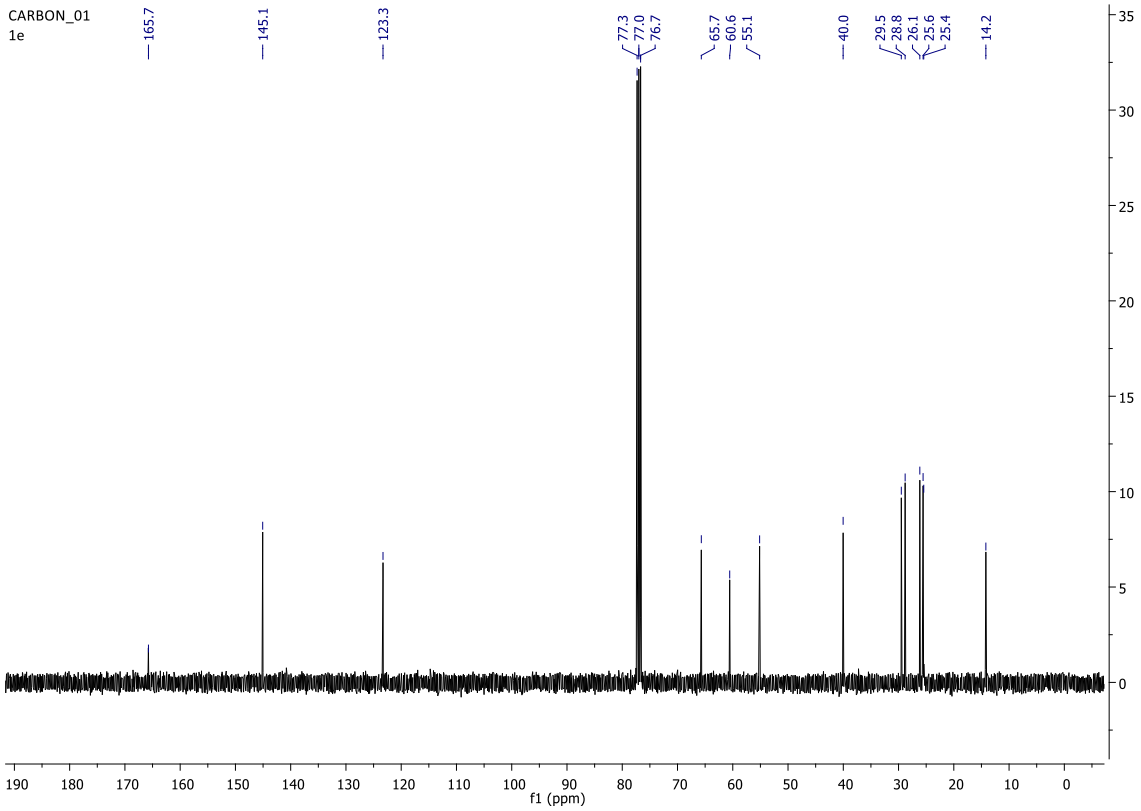

PROTON_01
1c
6.56
6.55
6.52
6.51
6.05
6.05
6.01
6.01
3.15
3.14
3.13
3.12
2.97
2.97
2.96
2.95
2.94
2.94
2.93
2.93
1.46
1.36
1.35
Me
O
CO2t-Bu
1c
1.00
1.00
1.00
1.01
9.09
3.06
f1 (ppm)

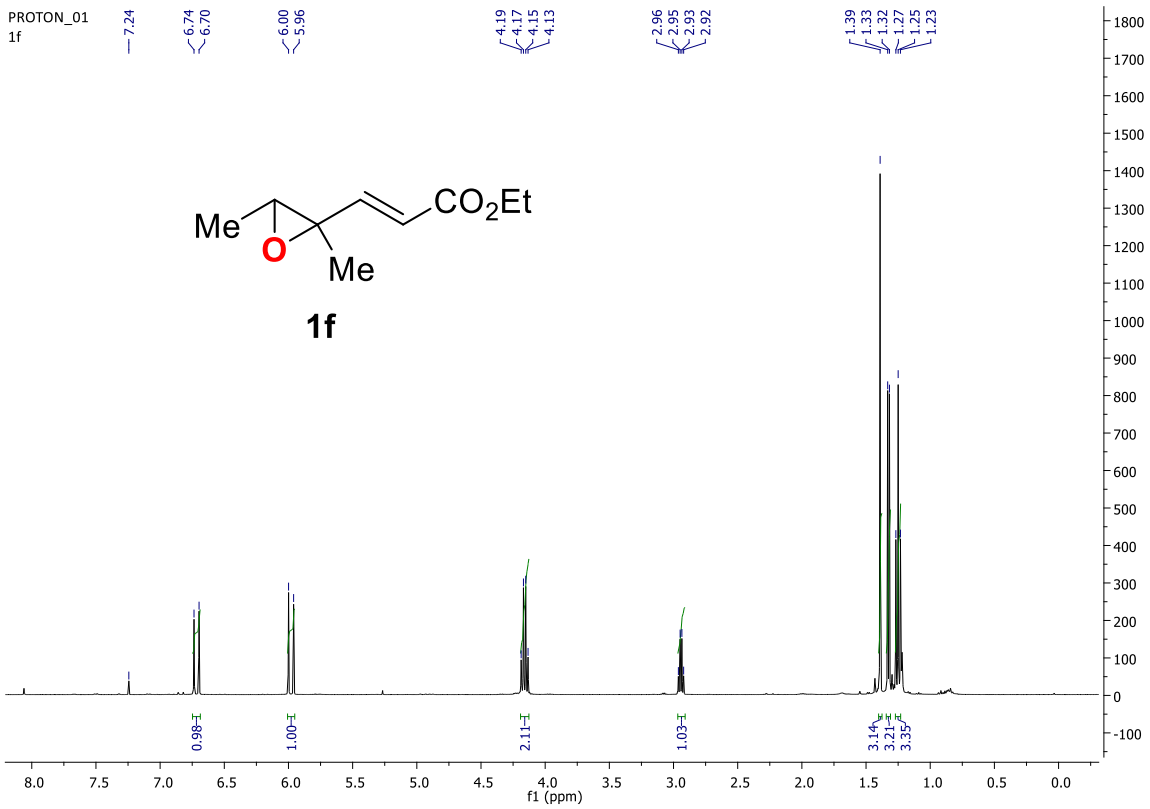

CARBON_01
1c
164.9
143.3
125.6
80.7
57.3
57.2
28.0
17.5
f1 (ppm)

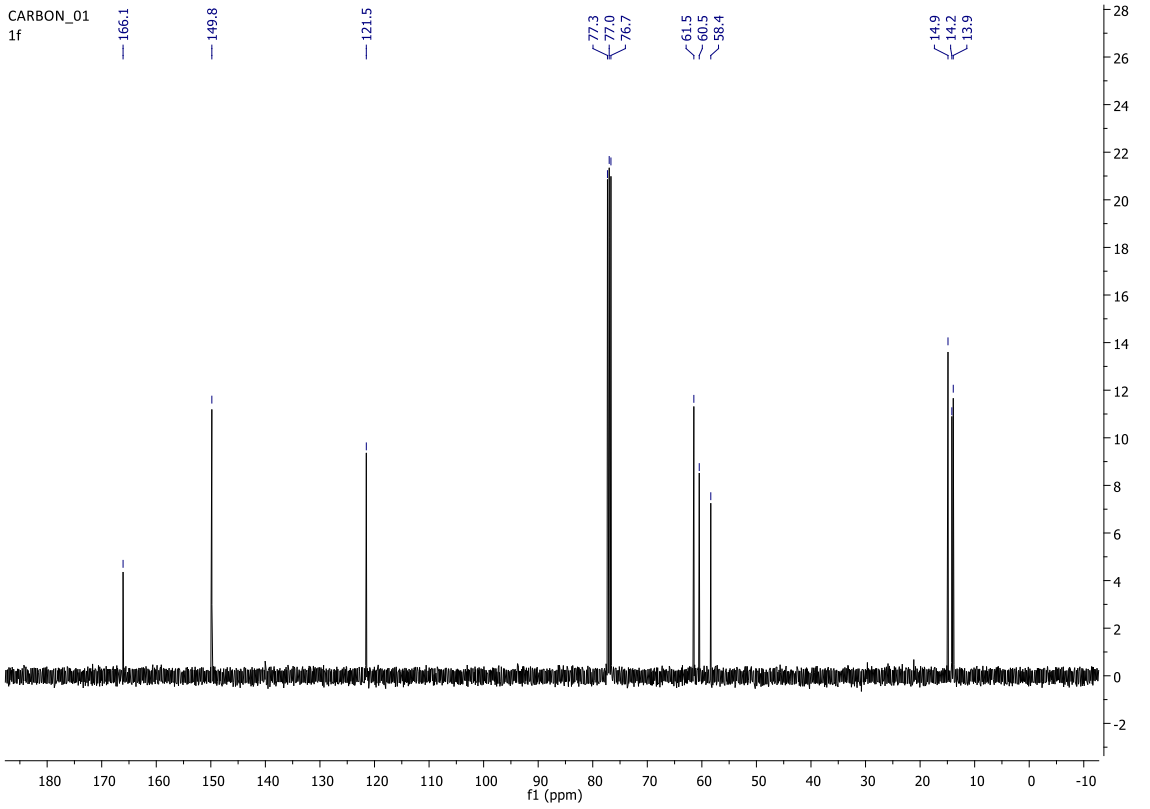

PROTON_01
1d
7.41
6.68
6.67
6.64
6.63
6.13
6.13
6.09
6.09
4.21
4.19
4.18
4.16
3.18
3.17
3.16
3.15
2.98
2.98
2.97
2.96
2.96
2.95
2.94
2.94
1.38
1.37
1.29
1.27
1.25
Me
O
CO2Et
1d
1.00
1.00
2.10
1.01
1.03
3.11
3.18
f1 (ppm)

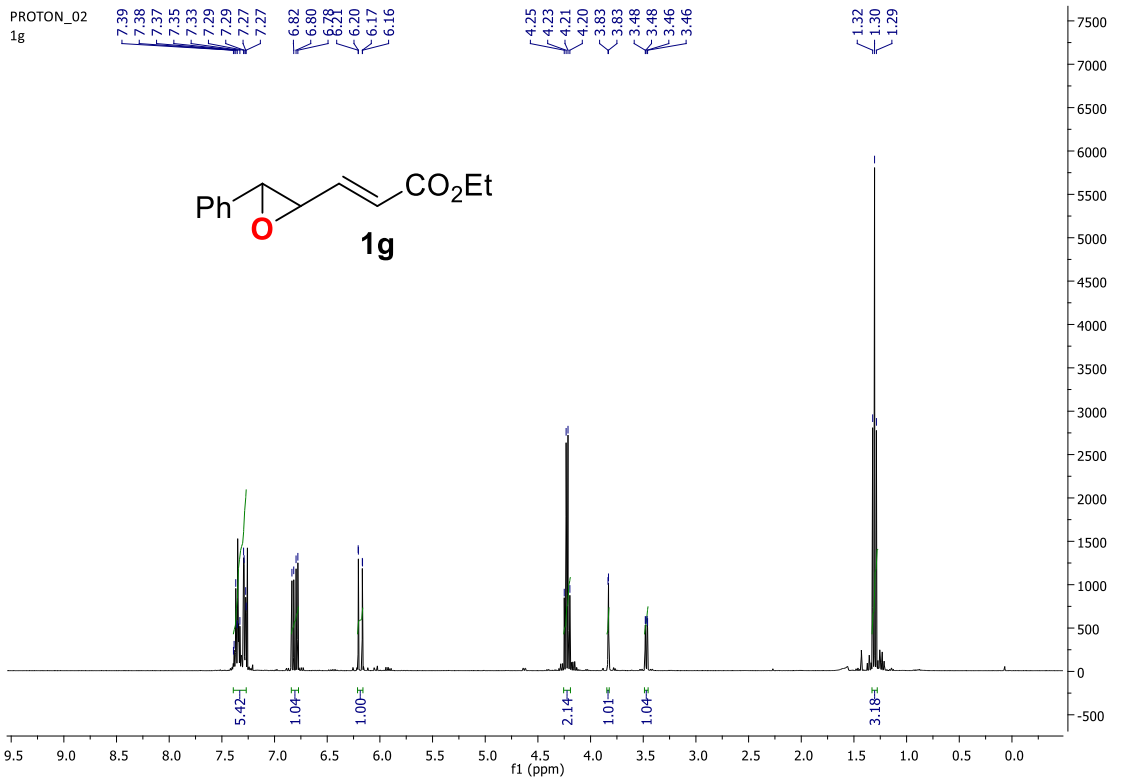

CARBON_01
1d
165.6
144.6
123.7
77.3
77.0
76.7
60.6
57.4
57.2
17.5
14.2
f1 (ppm)

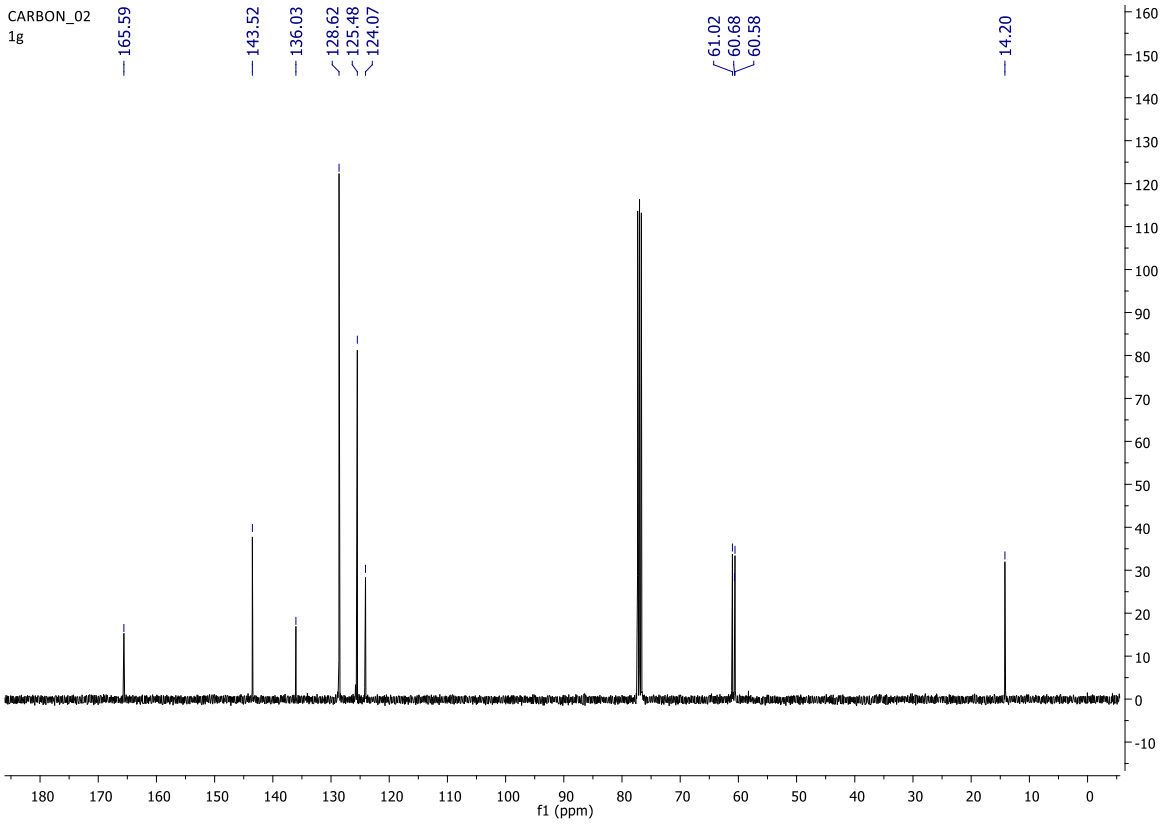

PROTON_01
1e
6.70
6.68
6.66
6.64
6.12
6.12
6.08
6.08
4.22
4.20
4.18
4.16
3.27
3.27
3.27
3.26
3.26
3.25
3.25
2.70
2.70
2.69
2.68
1.87
1.83
1.76
1.73
1.73
1.70
1.68
1.66
1.30
1.28
1.26
1.25
1.23
1.22
1.22
1.20
1.18
1.18
1.15
1.13
1.12
1.11
1.10
1.07
Cy
O
CO2Et
1e
1.04
1.00
2.10
1.04
1.03
5.78
3.66
5.16
f1 (ppm)

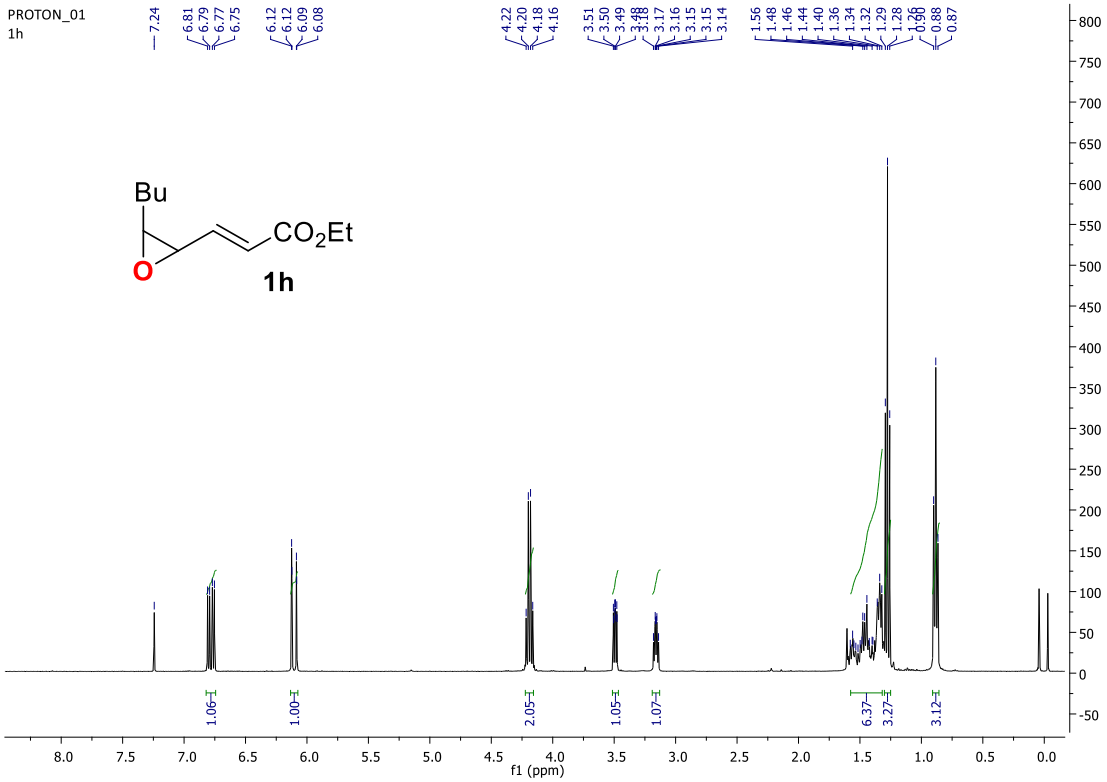

CARBON_01
1e
165.7
145.1
123.3
77.3
77.0
76.7
65.7
60.6
55.1
40.0
29.5
28.8
26.1
25.6
25.4
14.2
f1 (ppm)

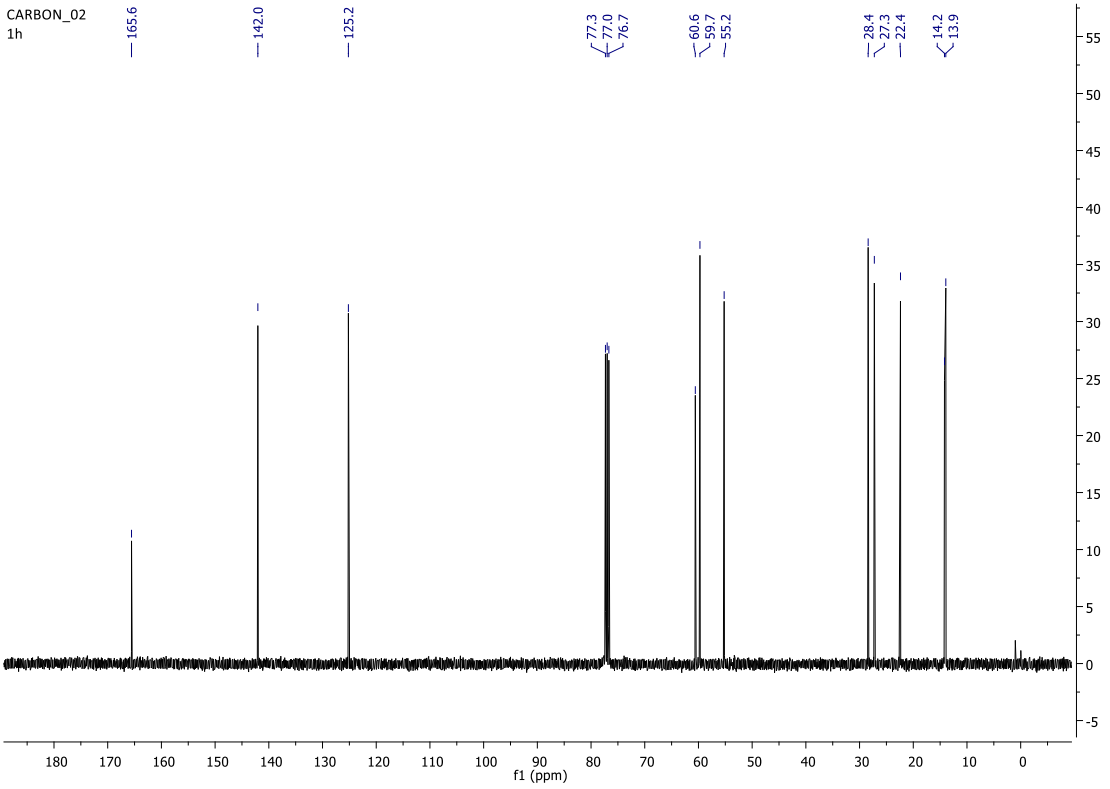

PROTON_01
1f
7.24
6.74
6.70
6.00
5.96
4.19
4.17
4.15
4.13
2.96
2.95
2.93
2.92
1.39
1.33
1.32
1.27
1.25
1.23
Me
O
Me
CO2Et
1f
0.98
1.00
2.11
1.03
3.14
3.21
3.35
f1 (ppm)


CARBON_01
1f
166.1
149.8
121.5
77.3
77.0
76.7
61.5
60.5
58.4
14.9
14.2
13.9
f1 (ppm)

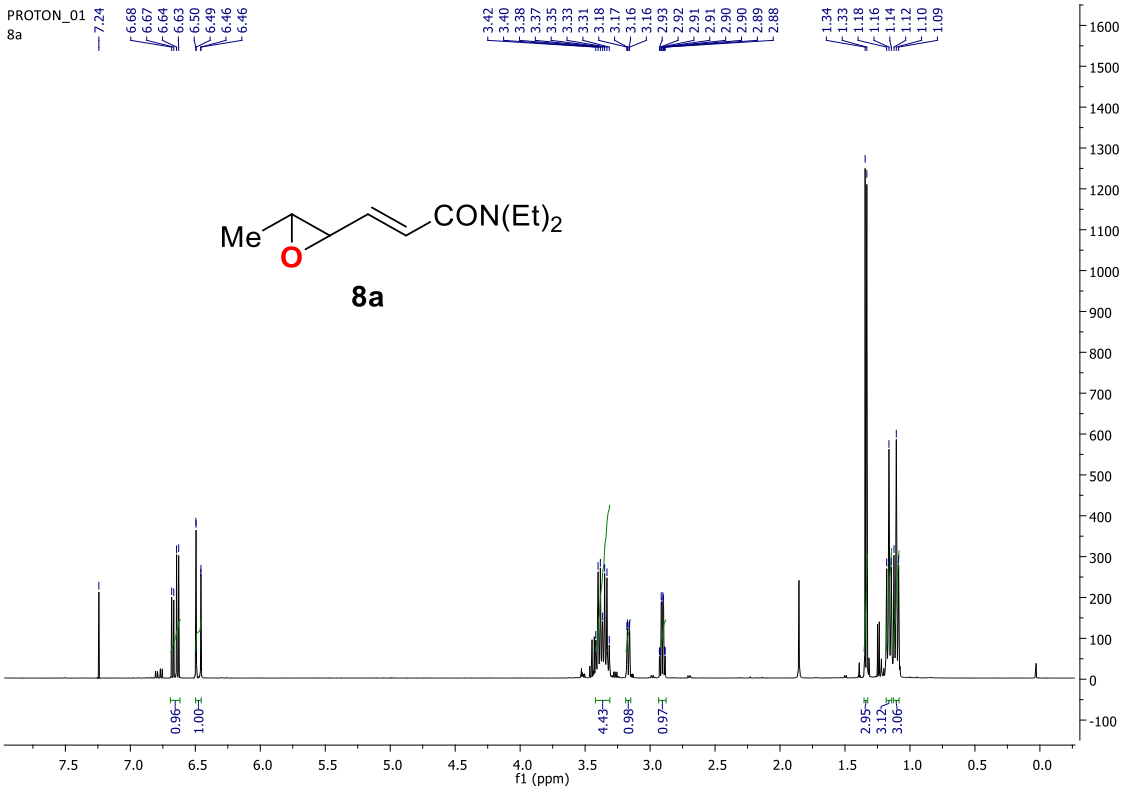

PROTON_02
1g
7.39
7.38
7.37
7.35
7.33
7.29
7.29
7.27
7.27
6.82
6.80
6.78
6.21
6.20
6.17
6.16
4.25
4.23
4.21
4.20
3.83
3.83
3.48
3.48
3.46
3.46
1.32
1.30
1.29
Ph
O
CO2Et
1g
5.42
1.04
1.00
2.14
1.01
1.04
3.18
f1 (ppm)

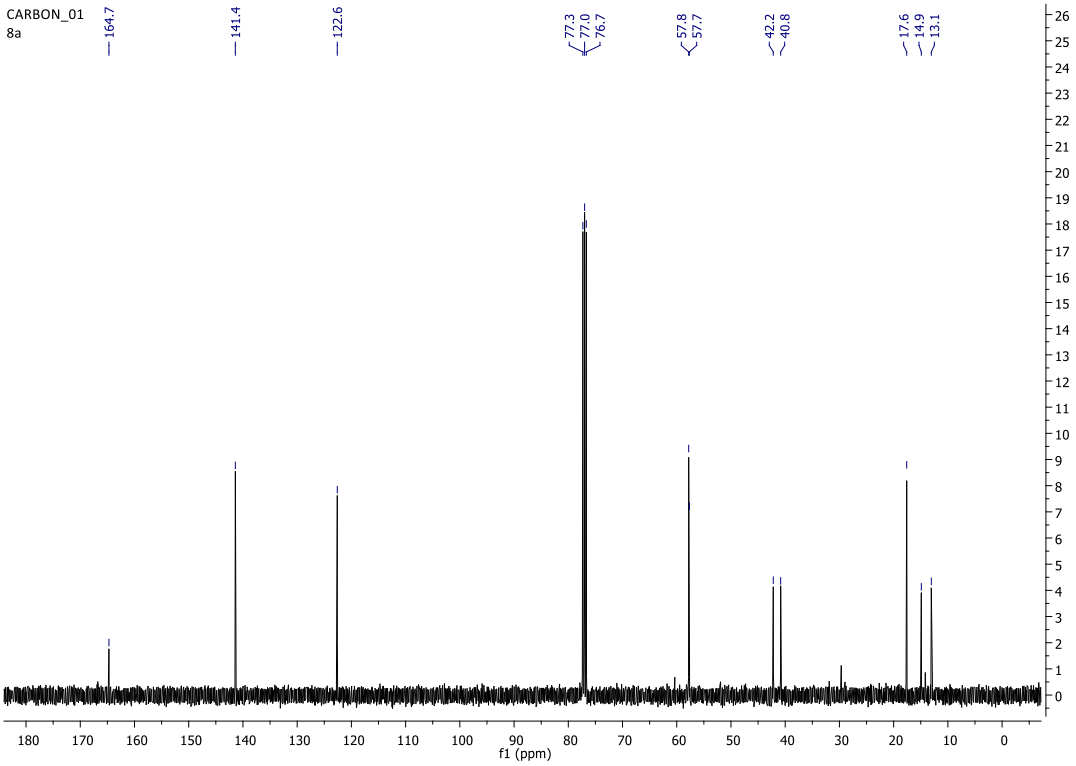

CARBON_02
1g
165.59
143.52
136.03
128.62
125.48
124.07
61.02
60.68
60.58
14.20
f1 (ppm)

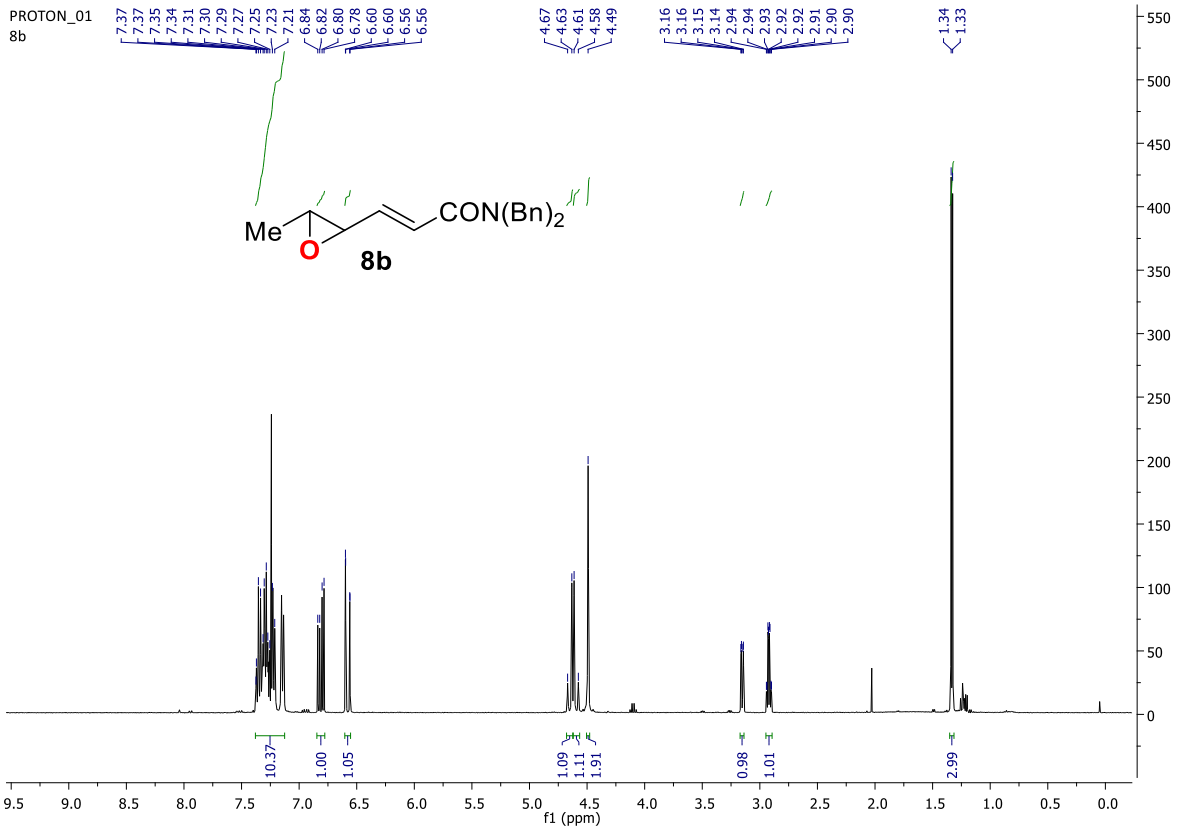

PROTON_01
1h
7.24
6.81
6.79
6.77
6.75
6.12
6.12
6.09
6.08
4.22
4.20
4.18
4.16
3.51
3.50
3.49
3.48
3.18
3.17
3.16
3.15
3.15
3.14
1.56
1.48
1.46
1.44
1.40
1.36
1.34
1.32
1.29
1.28
0.90
0.88
0.87
Bu
CO2Et
O
1h
1.06
1.00
2.05
1.05
1.07
6.37
3.27
3.12
f1 (ppm)

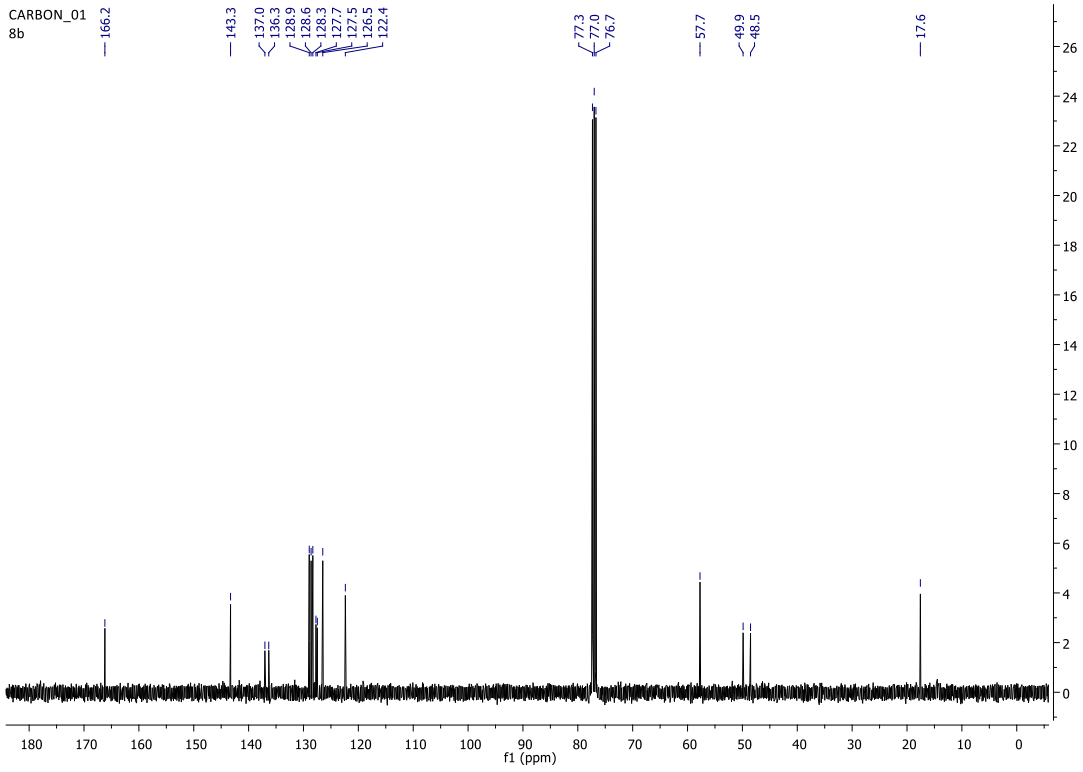

CARBON_02
1h
165.6
142.0
125.2
77.3
77.0
76.7
60.6
59.7
55.2
28.4
27.3
22.4
14.2
13.9
f1 (ppm)

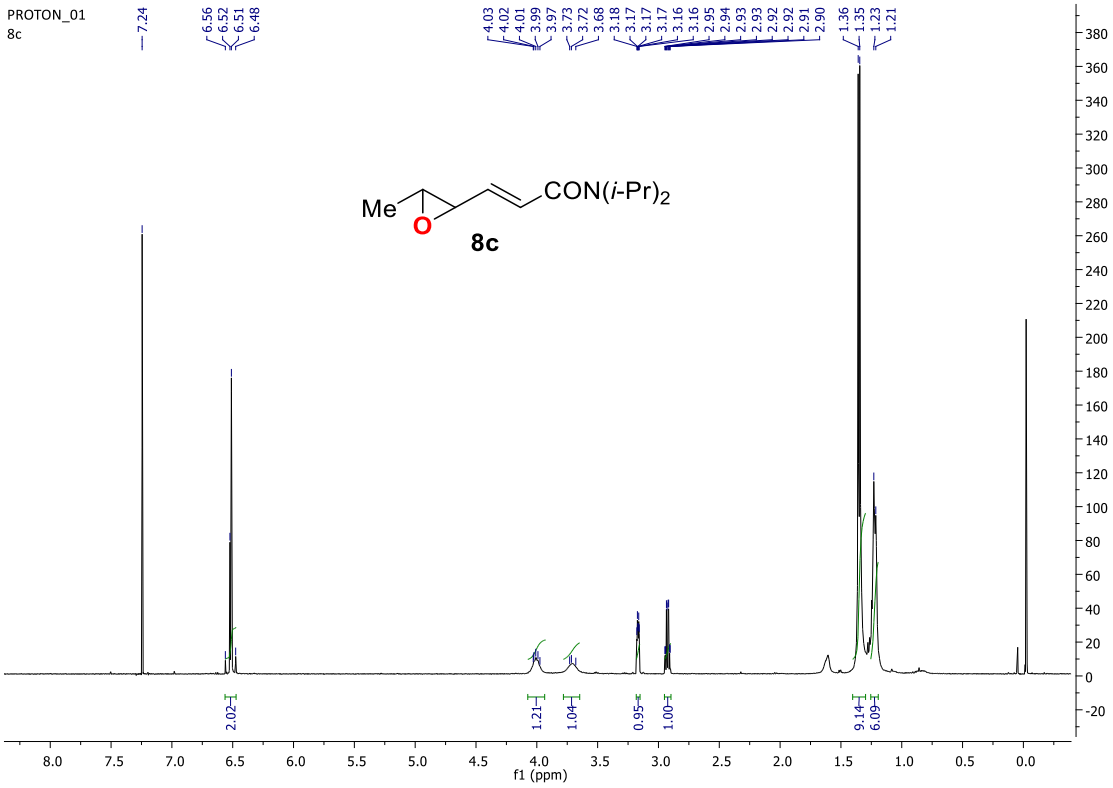
^{1}H-NMR and ^{13}C-NMR spectra of γ,δ-epoxy-α,β-unsaturated amides

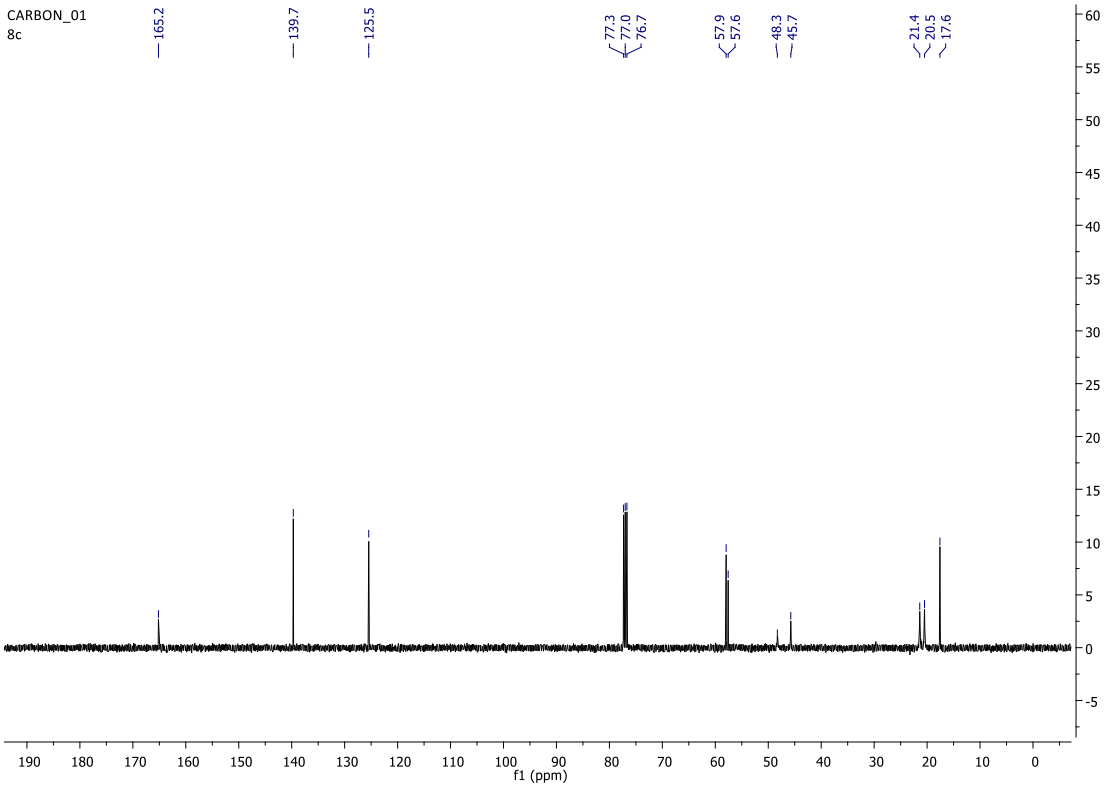


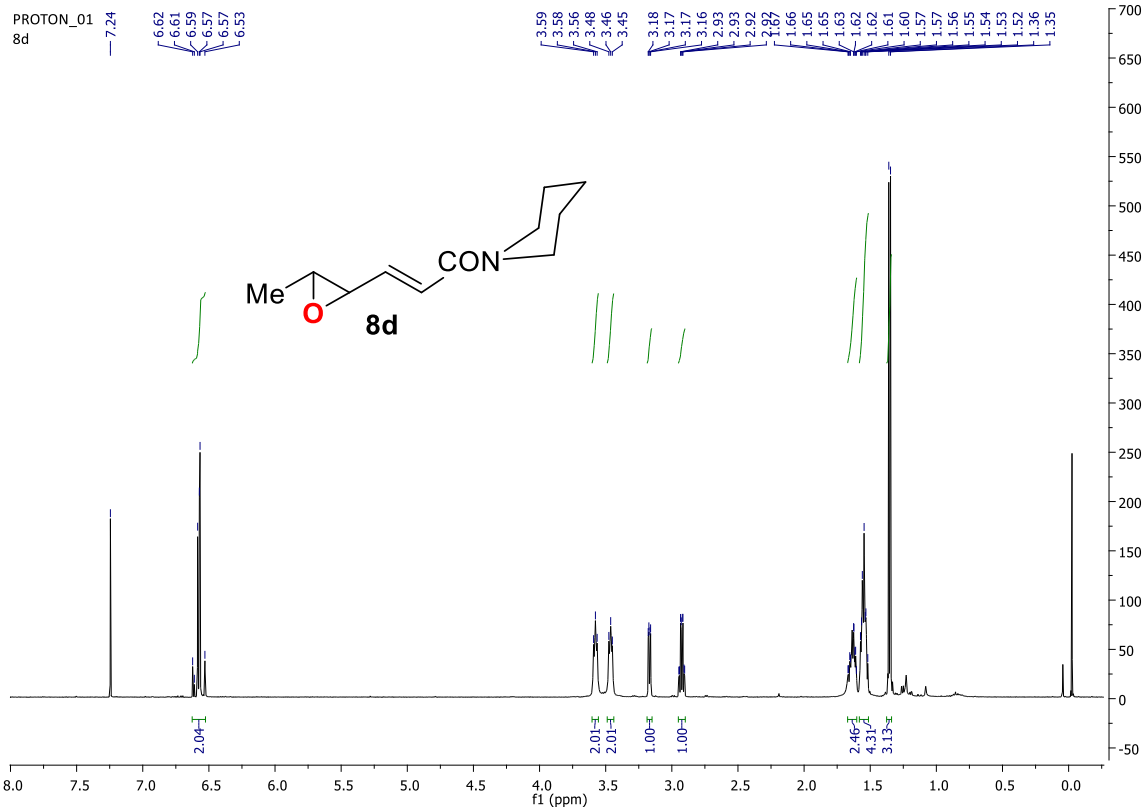


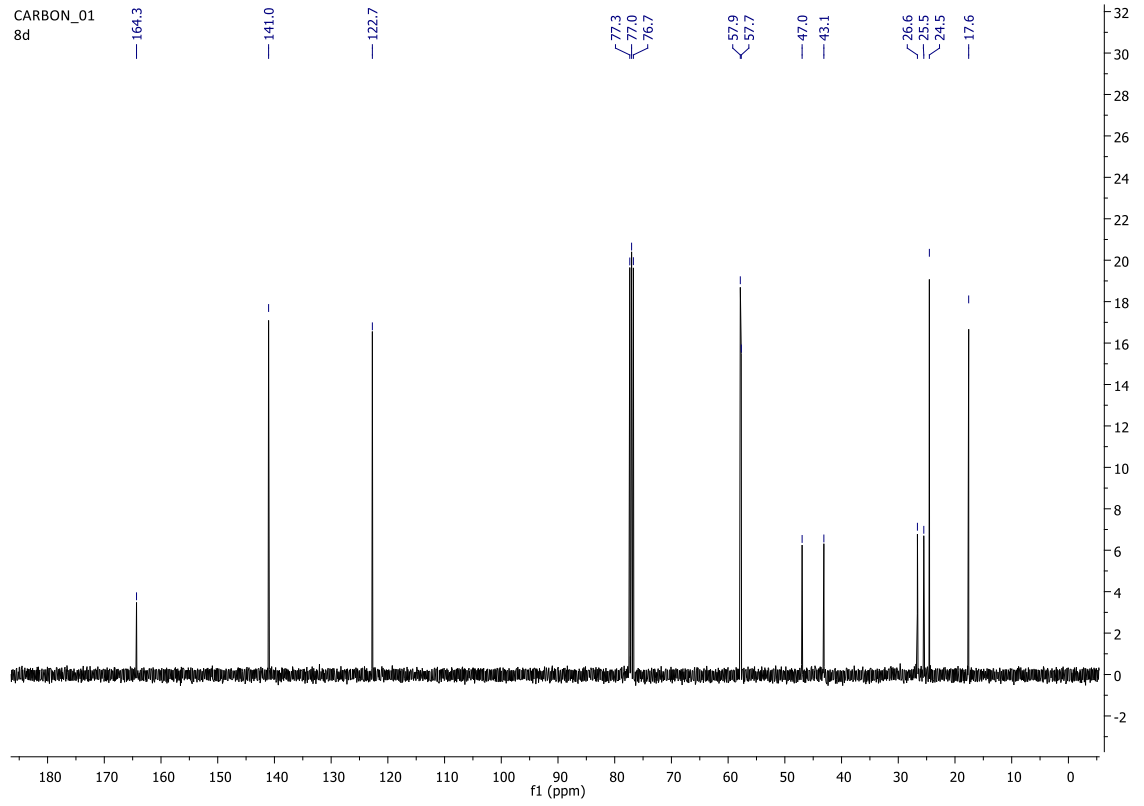

PROTON_01
8b
7.37
7.37
7.35
7.34
7.31
7.30
7.29
7.27
7.25
7.23
7.21
6.84
6.82
6.80
6.78
6.60
6.60
6.56
6.56
4.67
4.63
4.61
4.58
4.49
3.16
3.16
3.15
3.14
2.94
2.94
2.93
2.92
2.92
2.91
2.90
2.90
1.34
1.33
Me
O
CON(Bn)2
8b
10.37
1.00
1.05
1.09
1.11
1.91
0.98
1.01
2.99
f1 (ppm)

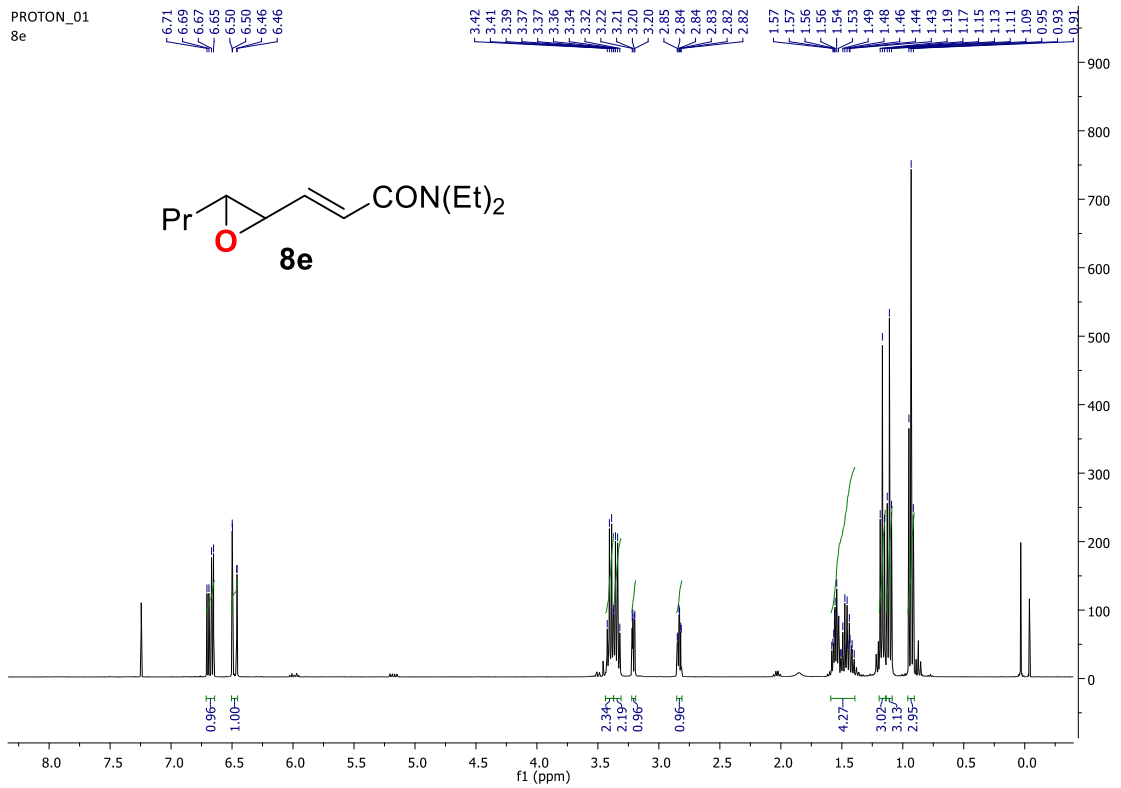

CARBON_01
8b
166.2
143.3
137.0
136.3
128.9
128.6
128.3
127.7
127.5
126.5
122.4
77.3
77.0
76.7
57.7
49.9
48.5
17.6
f1 (ppm)

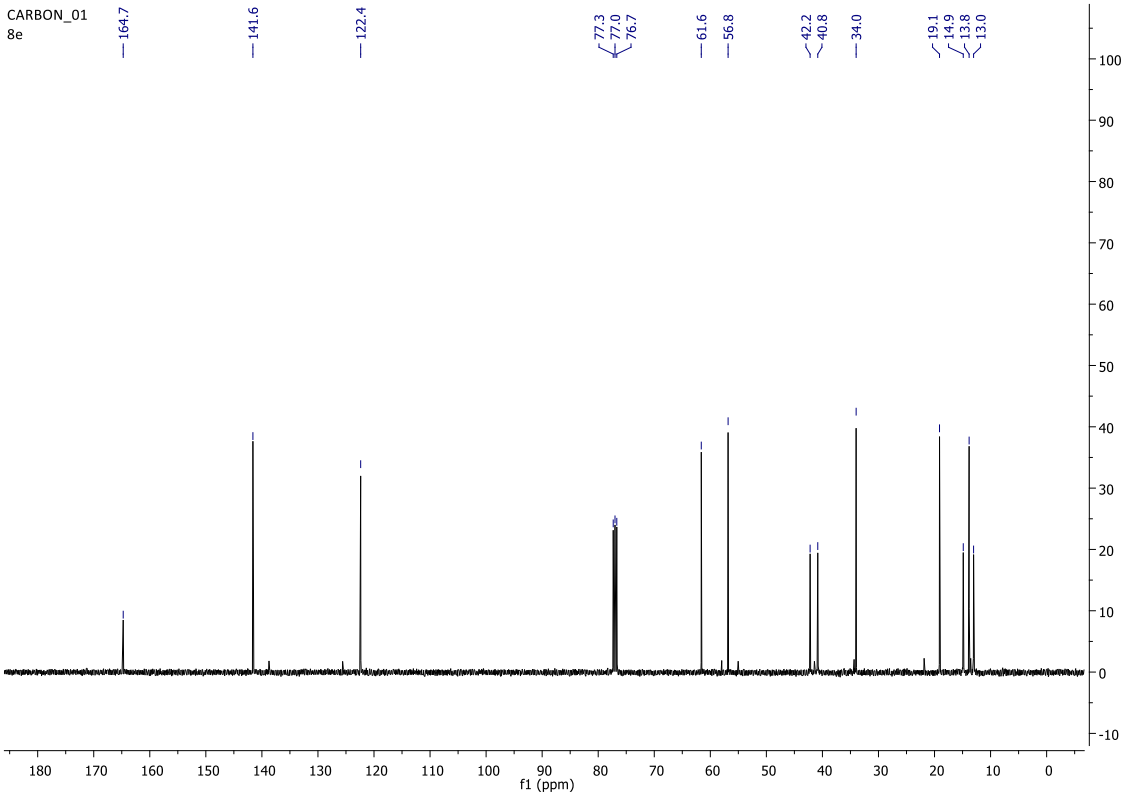

PROTON_01
8c
7.24
6.56
6.52
6.51
6.48
4.03
4.02
4.01
3.99
3.97
3.73
3.72
3.68
3.18
3.17
3.17
3.17
3.16
3.16
2.95
2.94
2.93
2.93
2.92
2.92
2.91
2.90
1.36
1.35
1.23
1.21
Me
O
CON(i-Pr)2
8c
2.02
1.21
1.04
0.95
1.00
9.14
6.09
f1 (ppm)

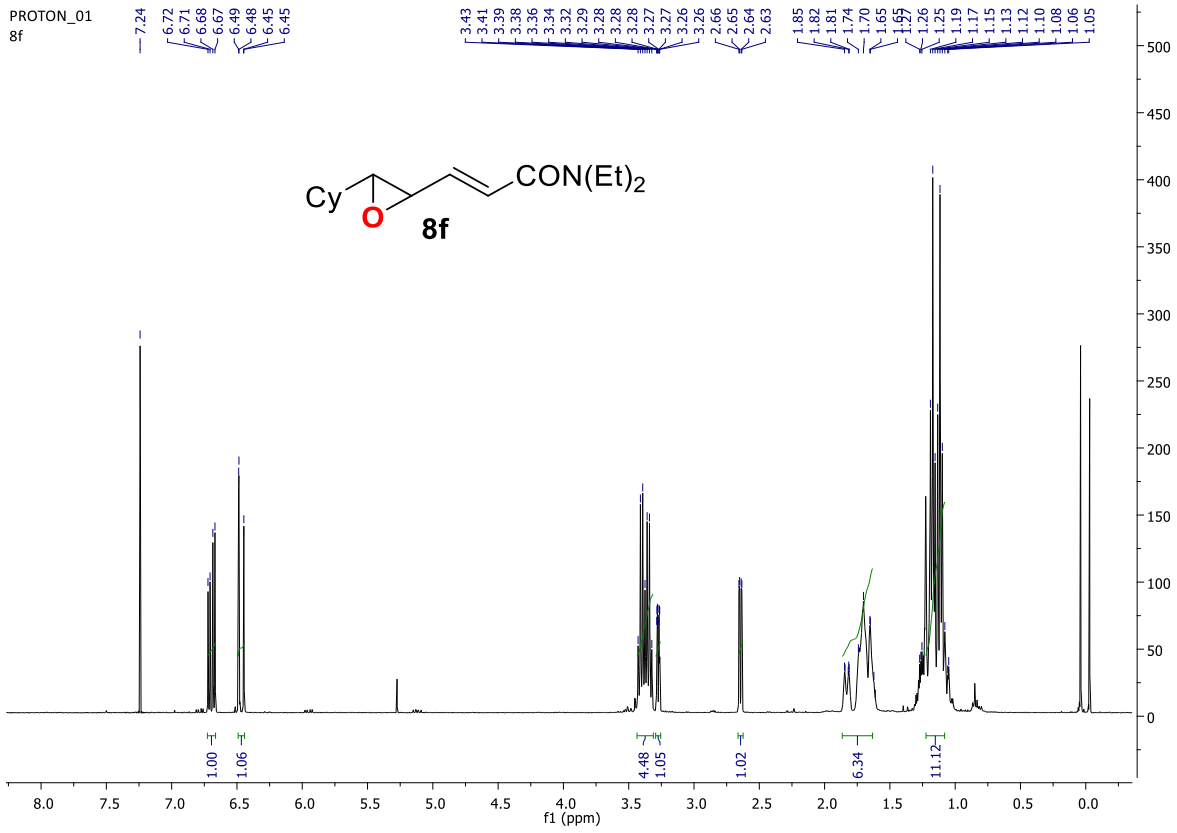

CARBON_01
8c
165.2
139.7
125.5
77.3
77.0
76.7
57.9
57.6
48.3
45.7
21.4
20.5
17.6
f1 (ppm)

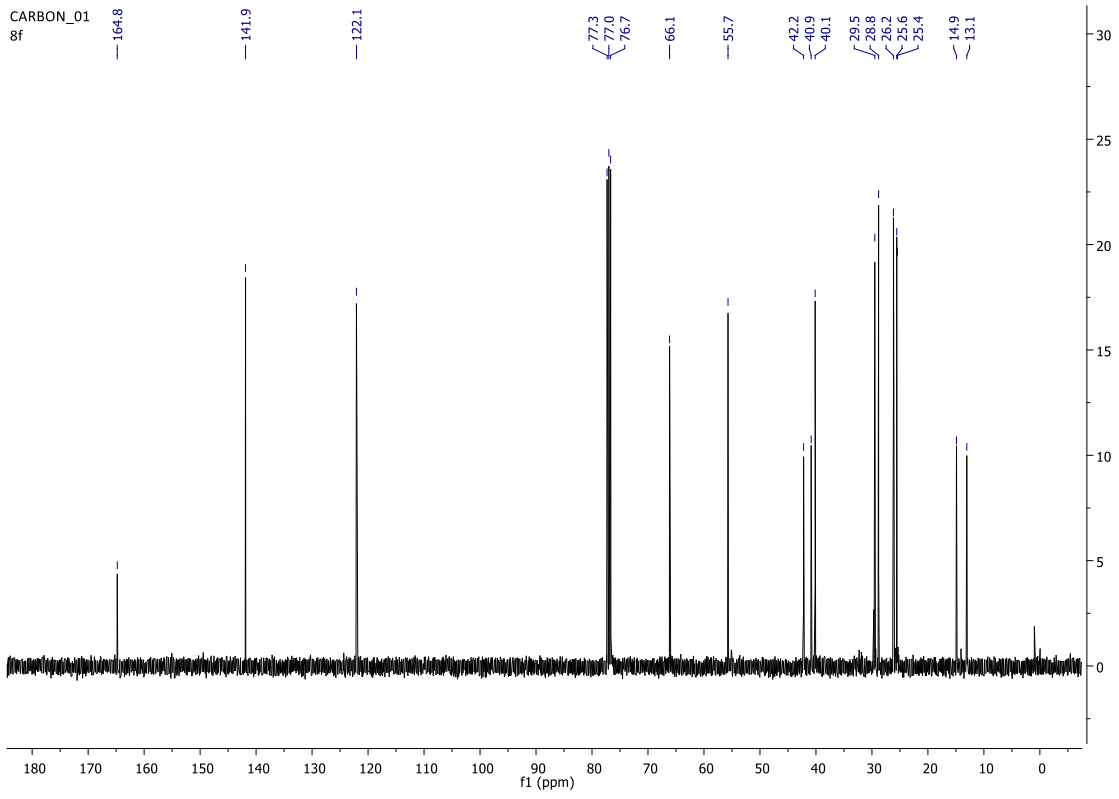

PROTON_01
8d
7.24
6.62
6.61
6.59
6.57
6.57
6.53
3.59
3.58
3.56
3.48
3.46
3.45
3.18
3.17
3.17
3.16
2.93
2.93
2.92
2.92
1.67
1.66
1.65
1.65
1.63
1.62
1.62
1.61
1.60
1.57
1.57
1.56
1.55
1.54
1.53
1.52
1.36
1.35
Me
O
CON
8d
2.04
2.01
2.01
1.00
1.00
2.46
4.31
3.13
f1 (ppm)


CARBON_01
8d
164.3
141.0
122.7
77.3
77.0
76.7
57.9
57.7
47.0
43.1
26.6
25.5
24.5
17.6
f1 (ppm)

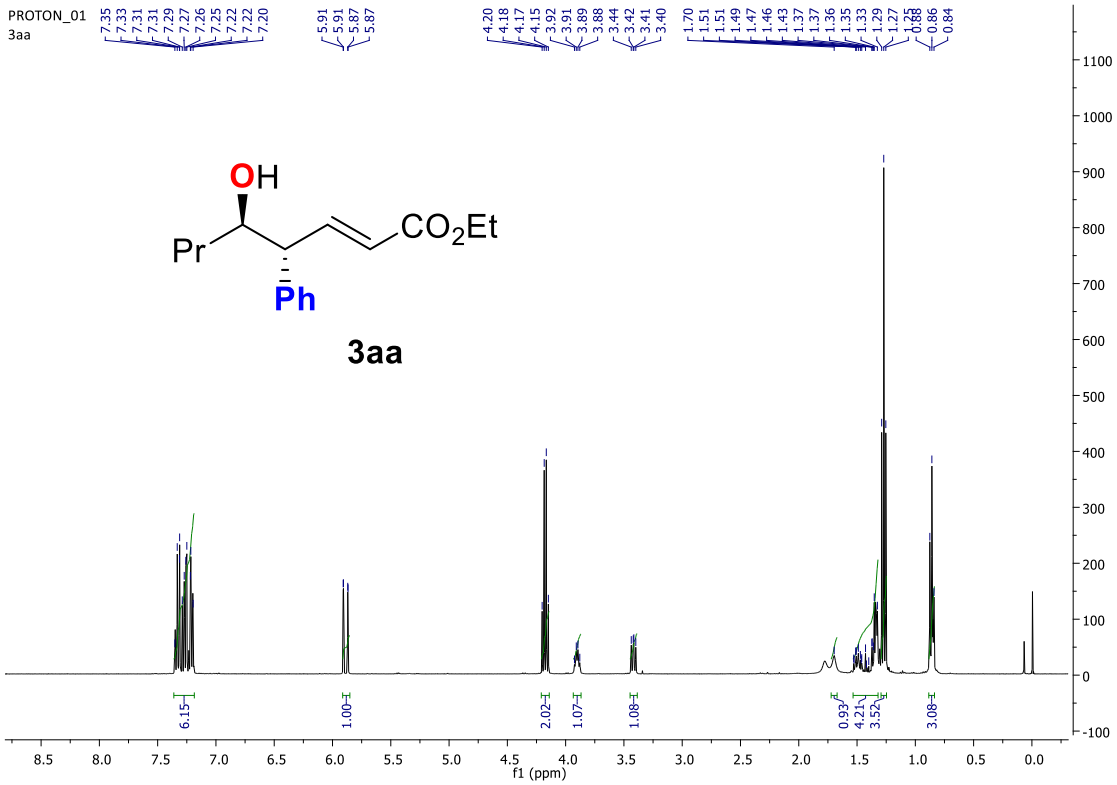

PROTON_01
8e
Pr
O
CON(Et)2
8e
f1 (ppm)

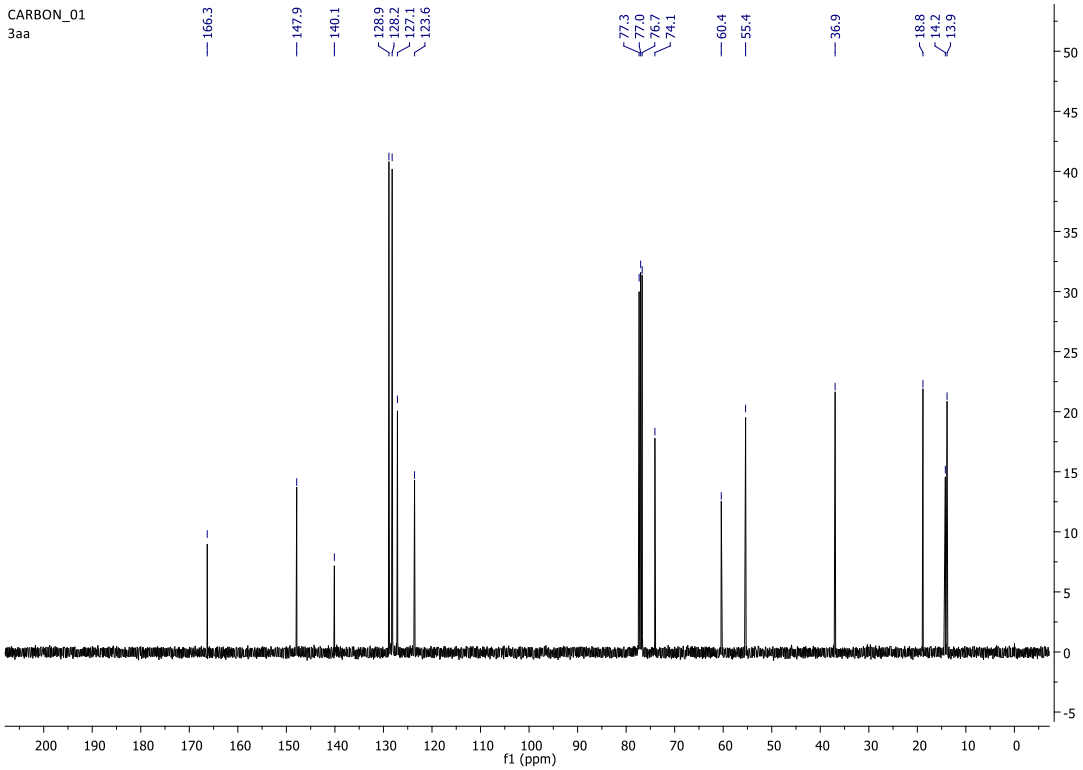

CARBON_01
8e
f1 (ppm)

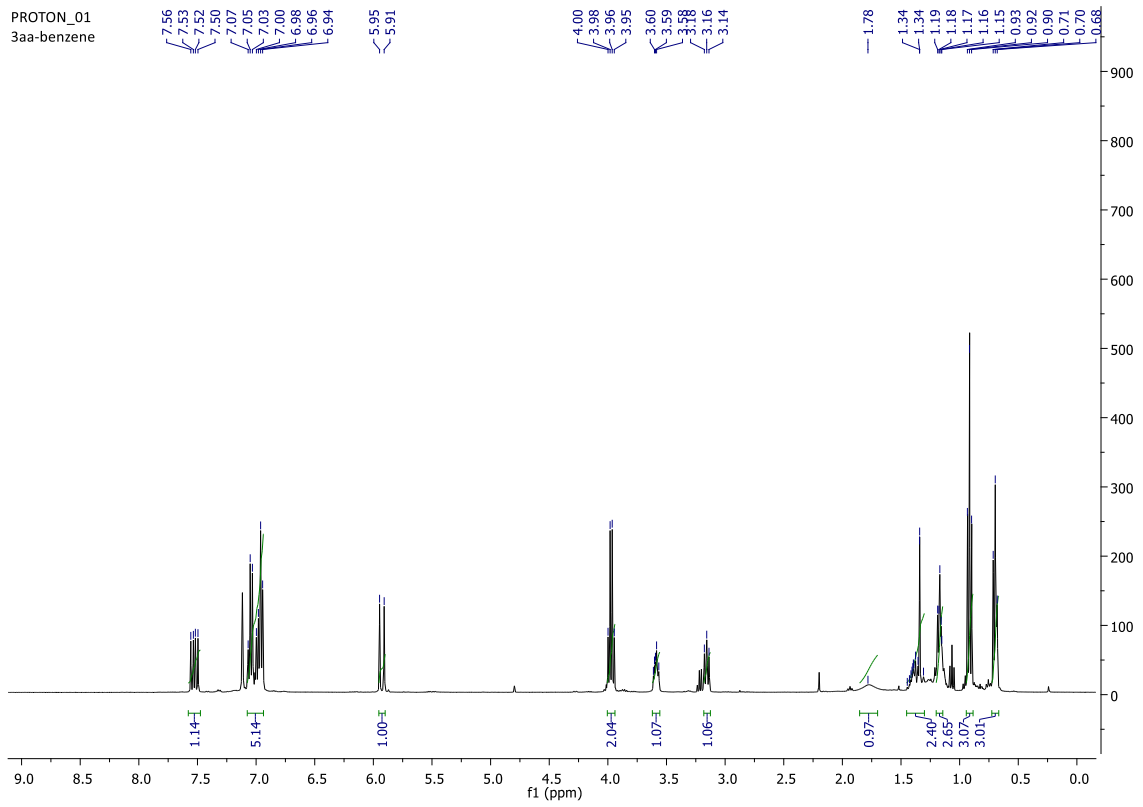

PROTON_01
8f
7.24
6.72
6.71
6.68
6.67
6.49
6.48
6.45
6.45
3.43
3.41
3.39
3.38
3.36
3.34
3.32
3.29
3.28
3.28
3.28
3.27
3.27
3.26
3.26
2.66
2.65
2.64
2.63
1.85
1.82
1.81
1.74
1.70
1.65
1.26
1.25
1.19
1.17
1.15
1.13
1.12
1.10
1.08
1.06
1.05
Cy
O
CON(Et)2
8f
1.00
1.06
4.48
1.05
1.02
6.34
11.12
f1 (ppm)

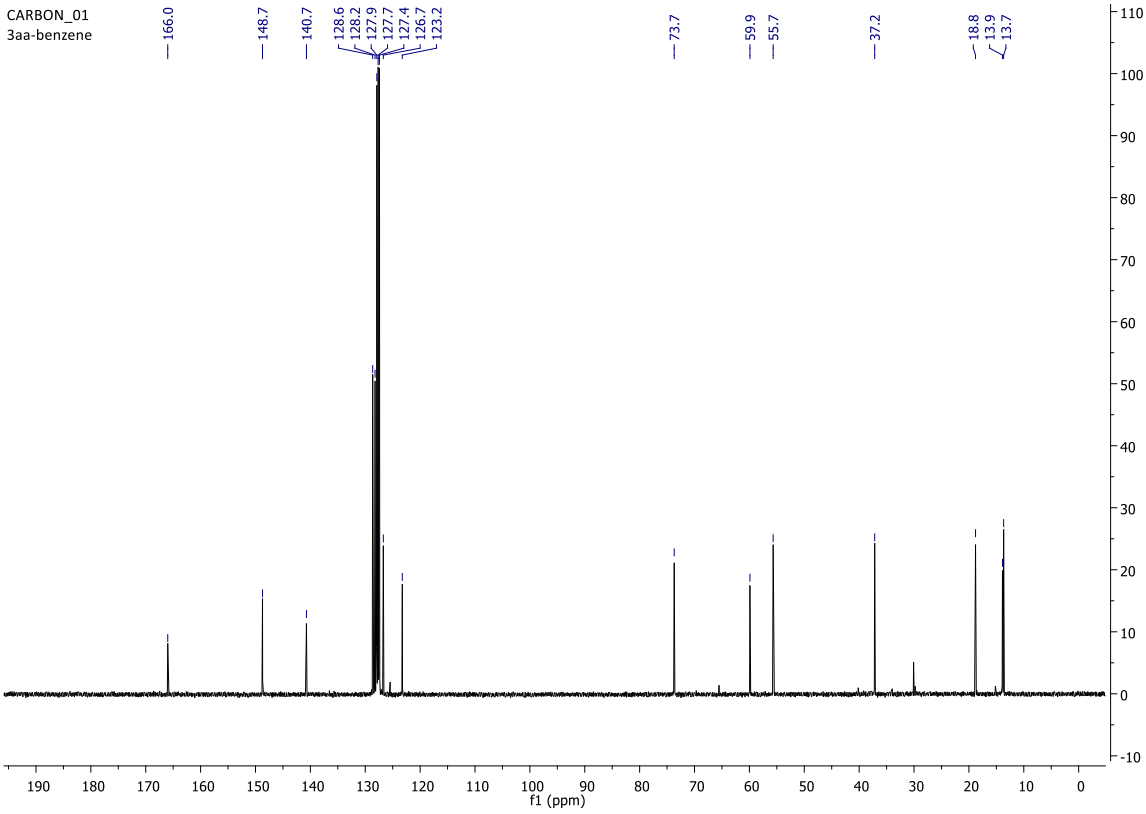

CARBON_01
8f
164.8
141.9
122.1
77.3
77.0
76.7
66.1
55.7
42.2
40.9
40.1
29.5
28.8
26.2
25.6
25.4
14.9
13.1
f1 (ppm)

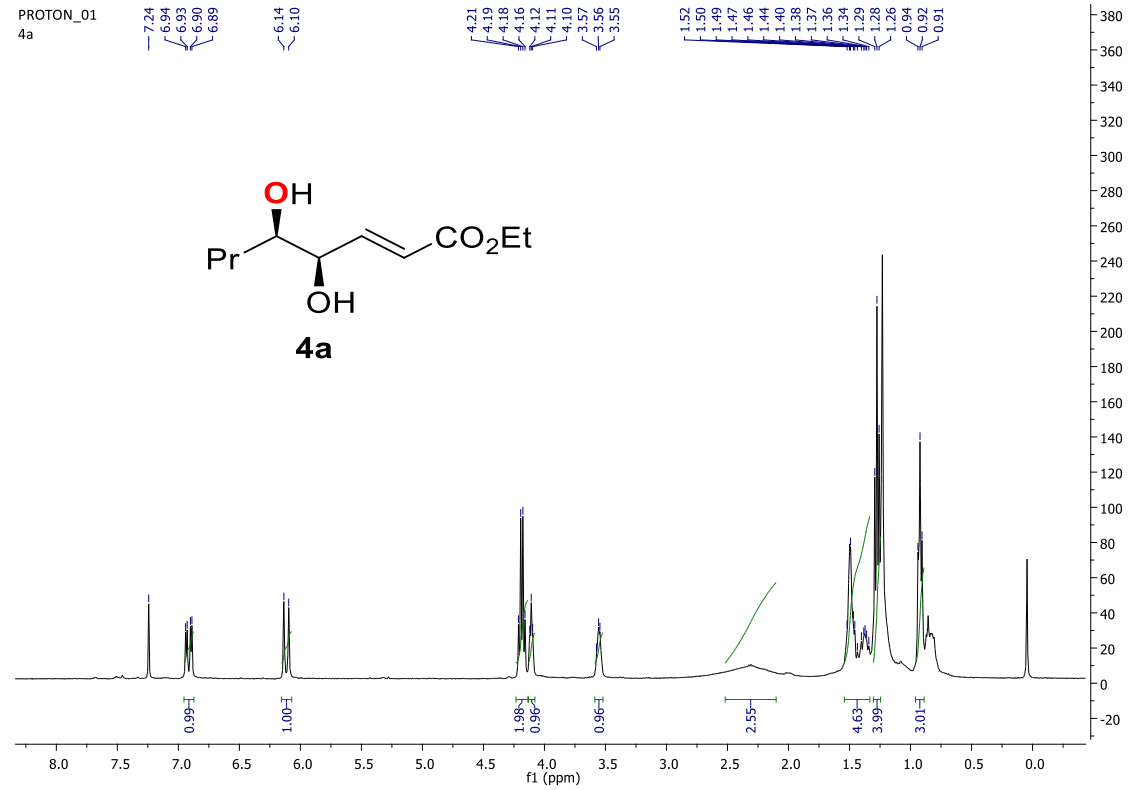
^{1}H-NMR, ^{13}C-NMR and ^{19}F-NMR spectra of the products

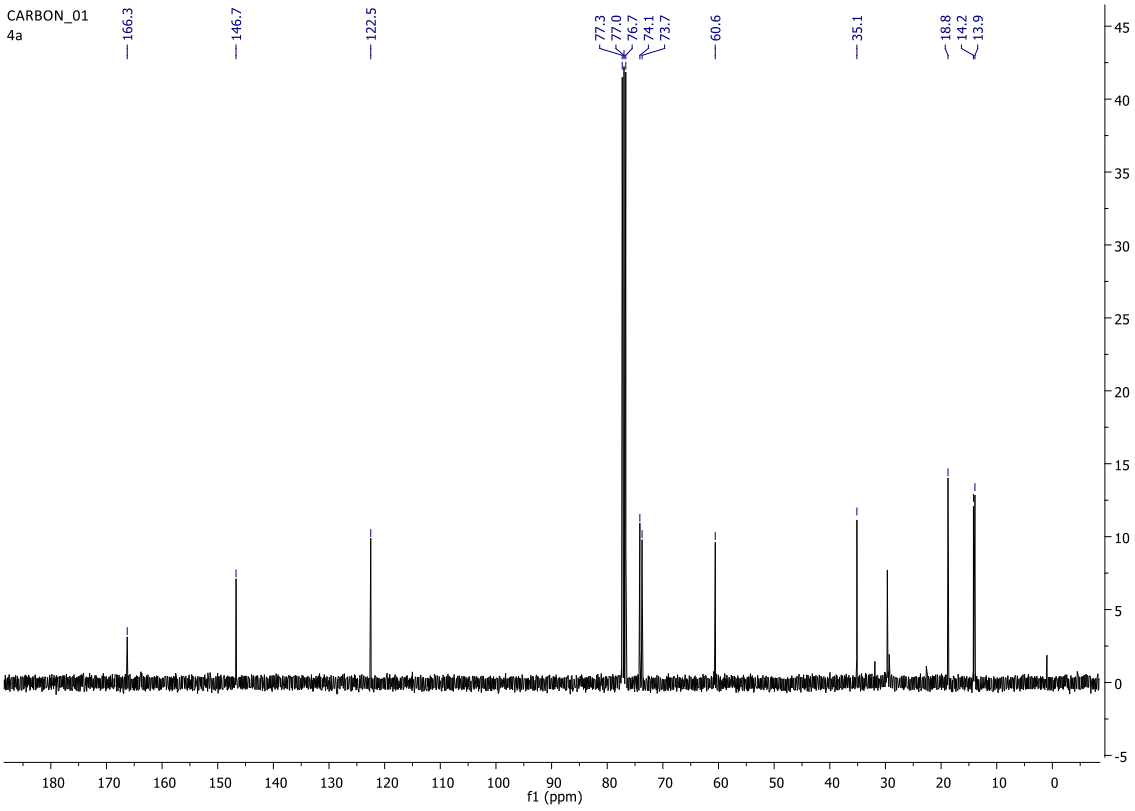


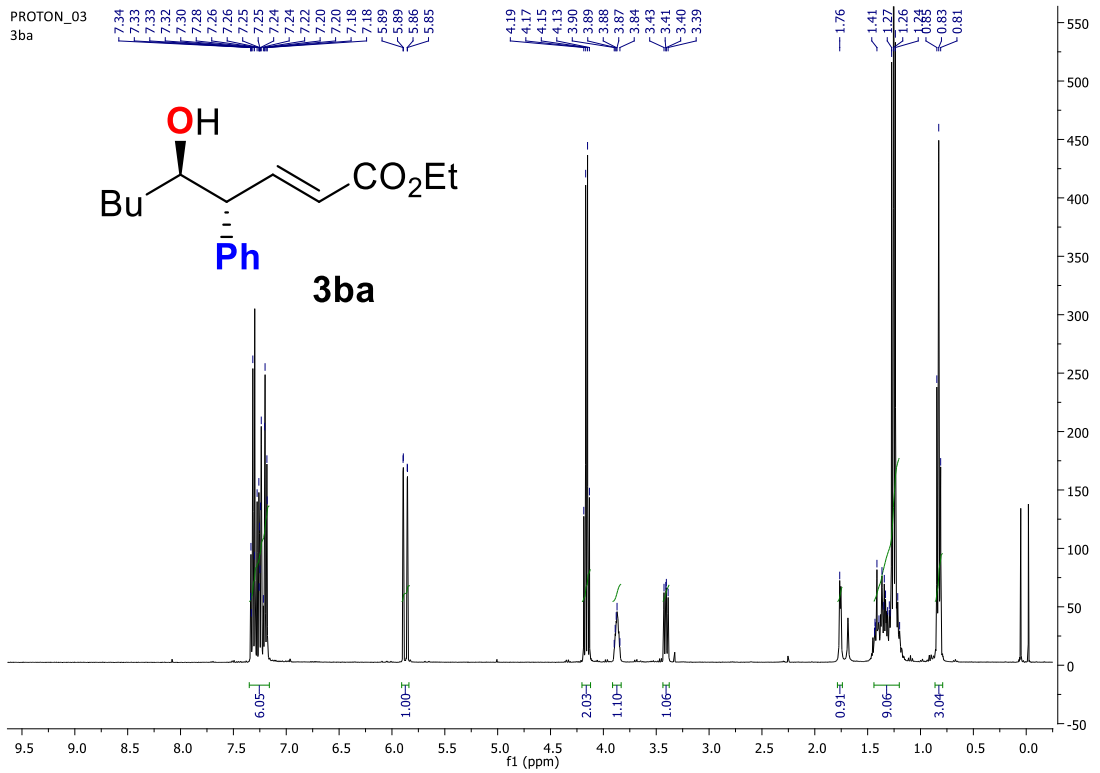


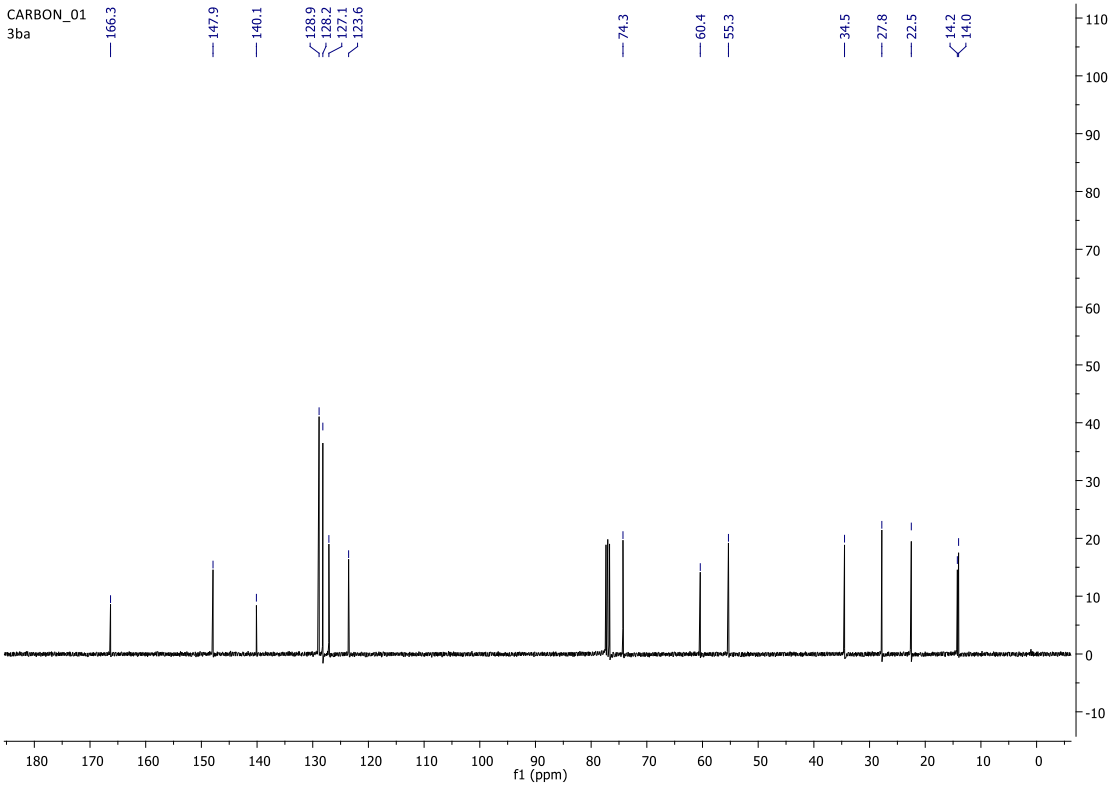

PROTON_01
3aa-benzene
7.56
7.53
7.52
7.50
7.07
7.05
7.03
7.00
6.98
6.96
6.94
5.95
5.91
4.00
3.98
3.96
3.95
3.60
3.59
3.58
3.18
3.16
3.14
1.78
1.34
1.34
1.19
1.18
1.17
1.16
1.15
0.93
0.92
0.90
0.71
0.70
0.68
1.14
5.14
1.00
2.04
1.07
1.06
0.97
2.40
2.65
3.07
3.01
f1 (ppm)

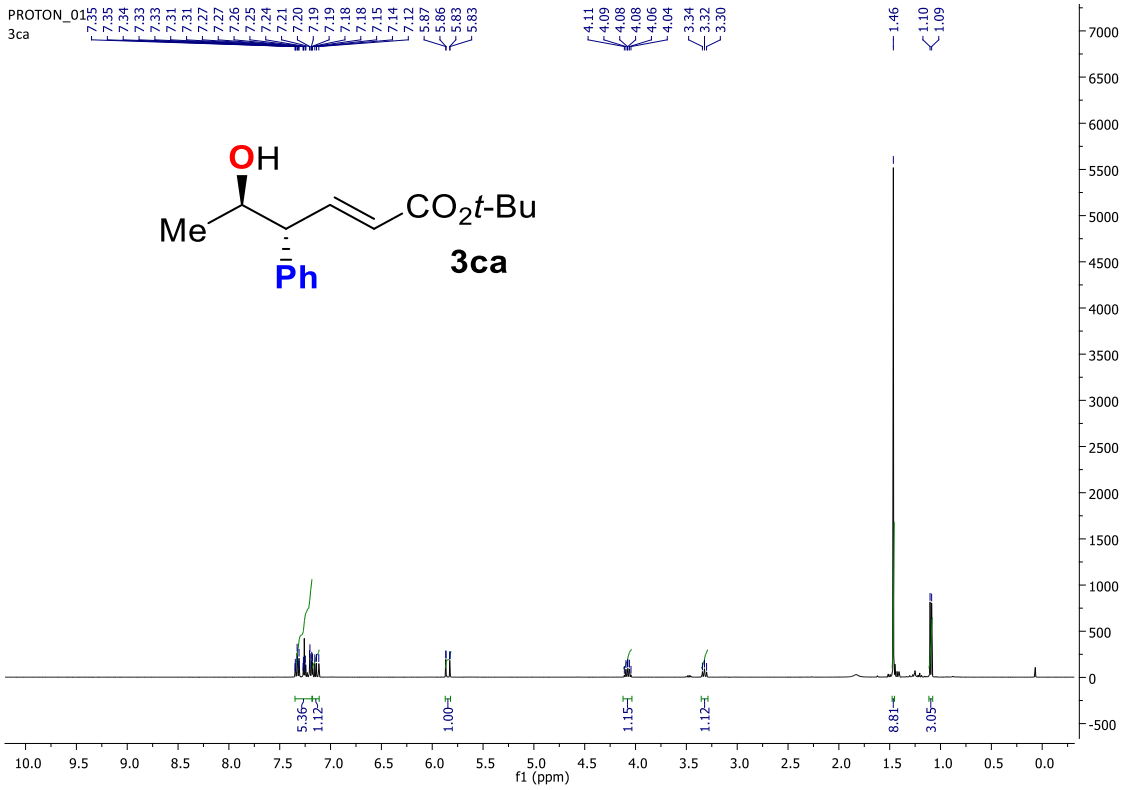

CARBON_01
3aa-benzene
166.0
148.7
140.7
128.6
128.2
127.9
127.7
127.4
126.7
123.2
73.7
59.9
55.7
37.2
18.8
13.9
13.7
f1 (ppm)

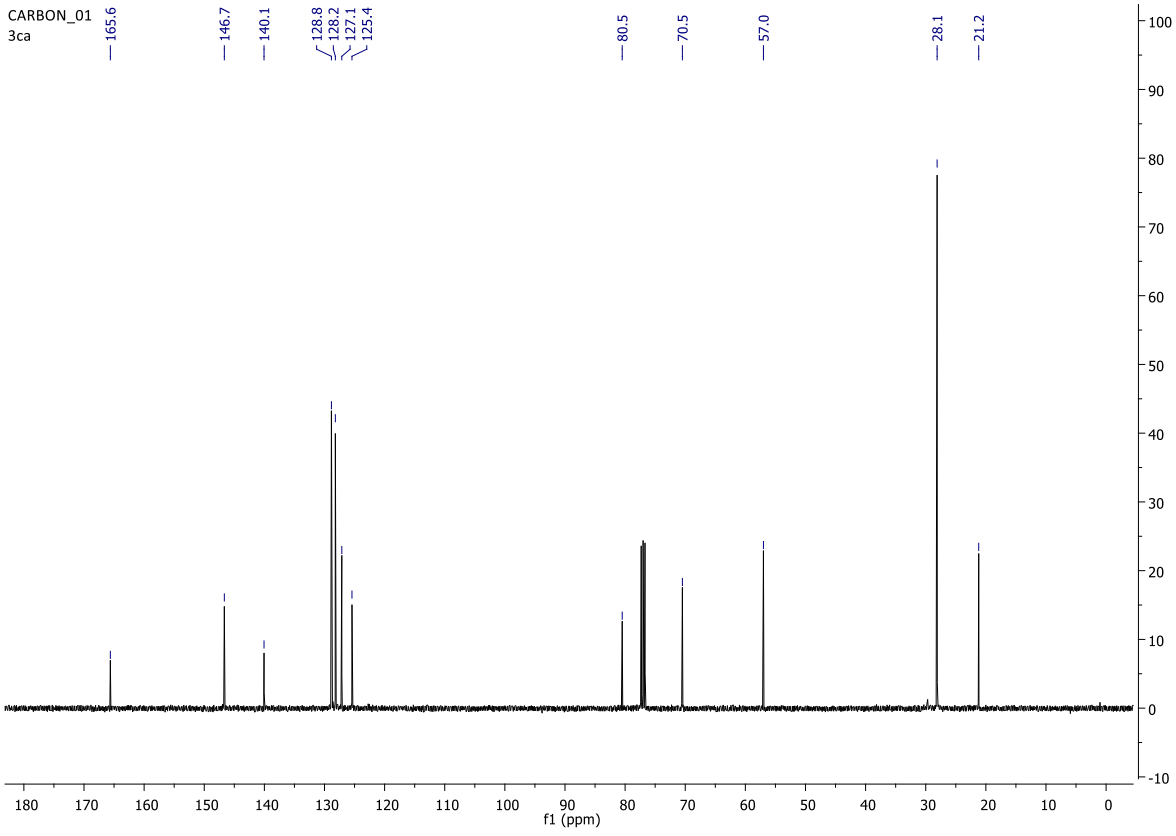

PROTON_01
4a
7.24
6.94
6.93
6.90
6.89
6.14
6.10
4.21
4.19
4.18
4.16
4.12
4.11
4.10
3.57
3.56
3.55
1.52
1.50
1.49
1.47
1.46
1.44
1.40
1.38
1.37
1.36
1.34
1.29
1.28
1.26
0.94
0.92
0.91
OH
Pr
CO2Et
OH
4a
0.99
1.00
1.98
0.96
0.96
2.55
4.63
3.99
3.01
f1 (ppm)

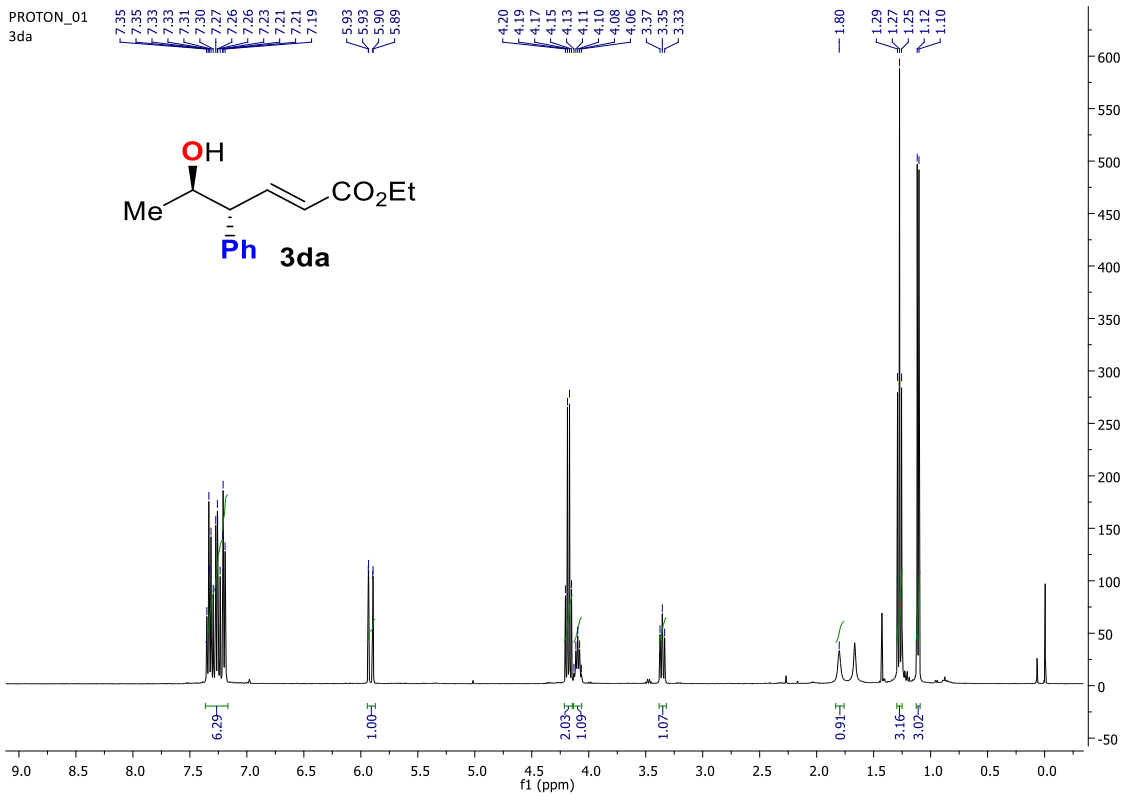

CARBON_01
4a
166.3
146.7
122.5
77.3
77.0
76.7
74.1
73.7
60.6
35.1
18.8
14.2
13.9
f1 (ppm)

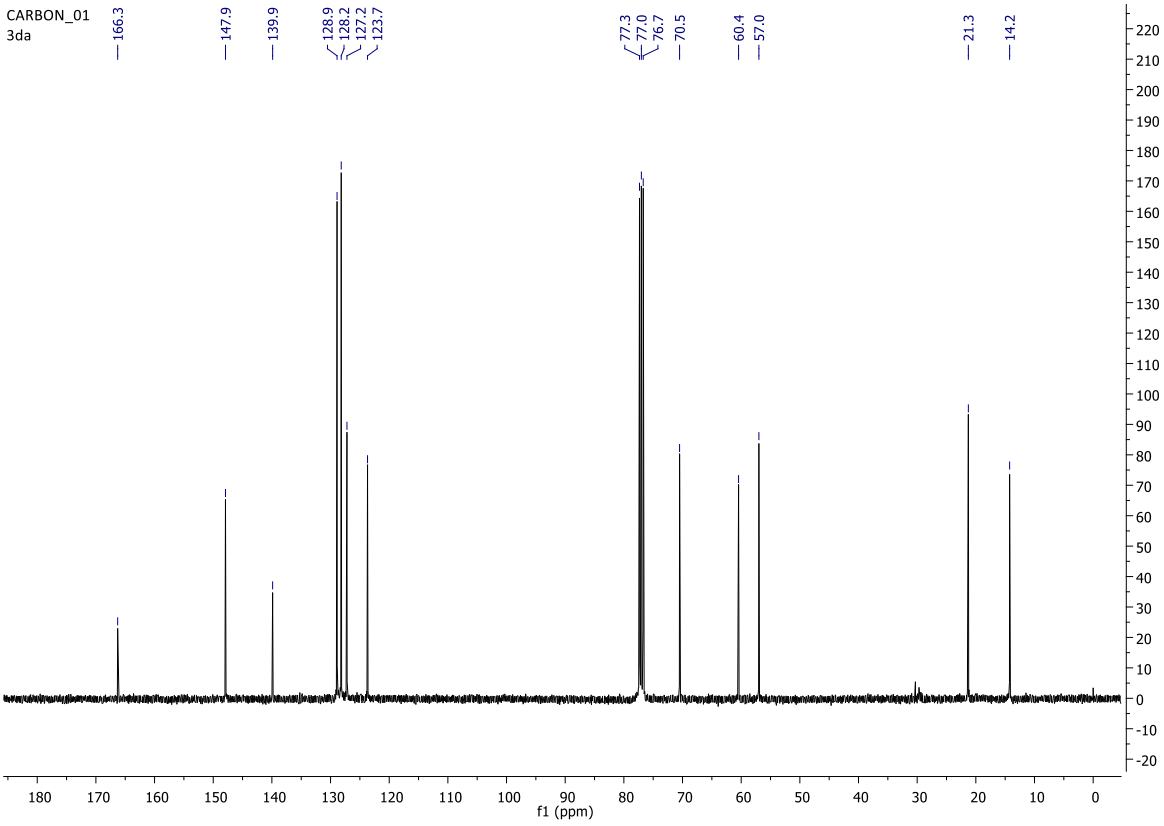

PROTON_03
3ba
OH
Bu
CO2Et
Ph
3ba
f1 (ppm)

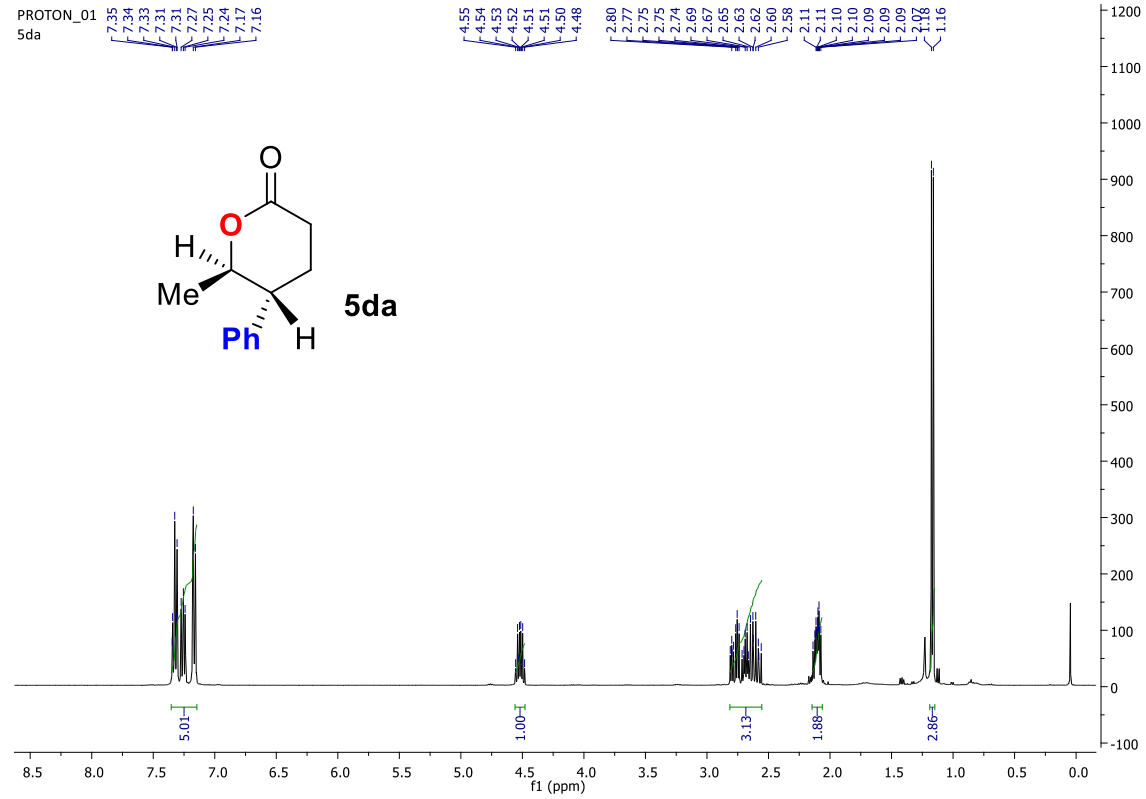

CARBON_01
3ba
f1 (ppm)

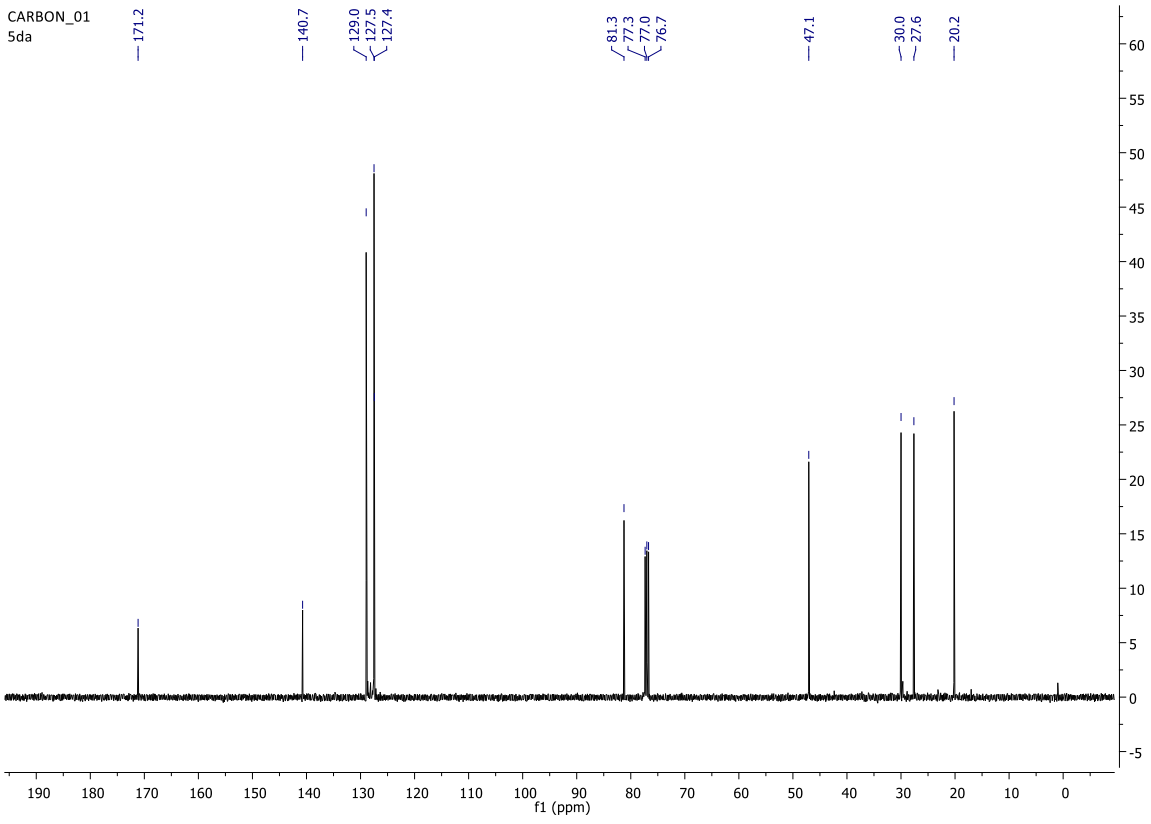

PROTON_01
3ca
7.35
7.35
7.34
7.33
7.33
7.31
7.31
7.27
7.27
7.26
7.25
7.24
7.21
7.20
7.19
7.19
7.18
7.18
7.15
7.14
7.12
5.87
5.86
5.83
5.83
4.11
4.09
4.08
4.08
4.06
4.04
3.34
3.32
3.30
1.46
1.10
1.09
OH
Me
CO2t-Bu
Ph
3ca
5.36
1.12
1.00
1.15
1.12
8.81
3.05
f1 (ppm)

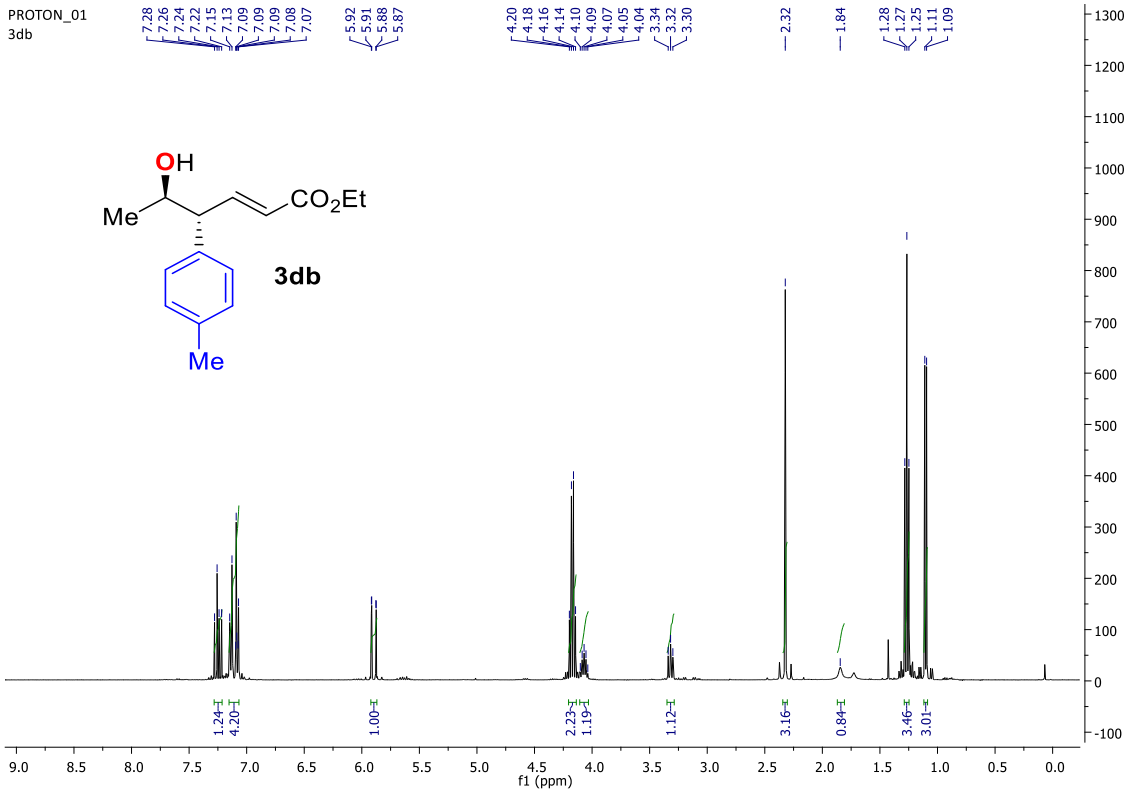

CARBON_01
3ca
165.6
146.7
140.1
128.8
128.2
127.1
125.4
80.5
70.5
57.0
28.1
21.2
f1 (ppm)

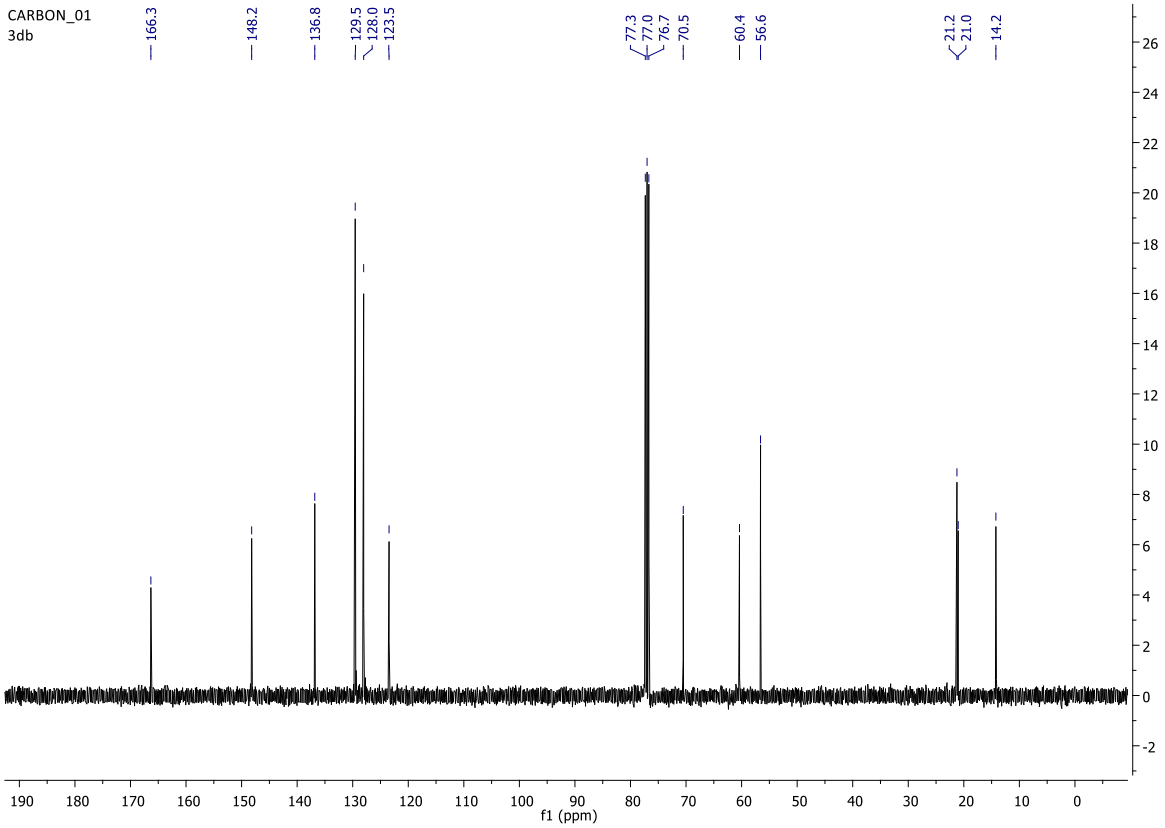

PROTON_01
3da
7.35
7.35
7.33
7.33
7.31
7.30
7.27
7.26
7.26
7.23
7.21
7.21
7.19
5.93
5.93
5.90
5.89
4.20
4.19
4.17
4.15
4.13
4.11
4.10
4.08
4.06
3.37
3.35
3.33
1.80
1.29
1.27
1.25
1.12
1.10
OH
Me
CO2Et
Ph
3da
6.29
1.00
2.03
1.09
1.07
0.91
3.16
3.02
f1 (ppm)

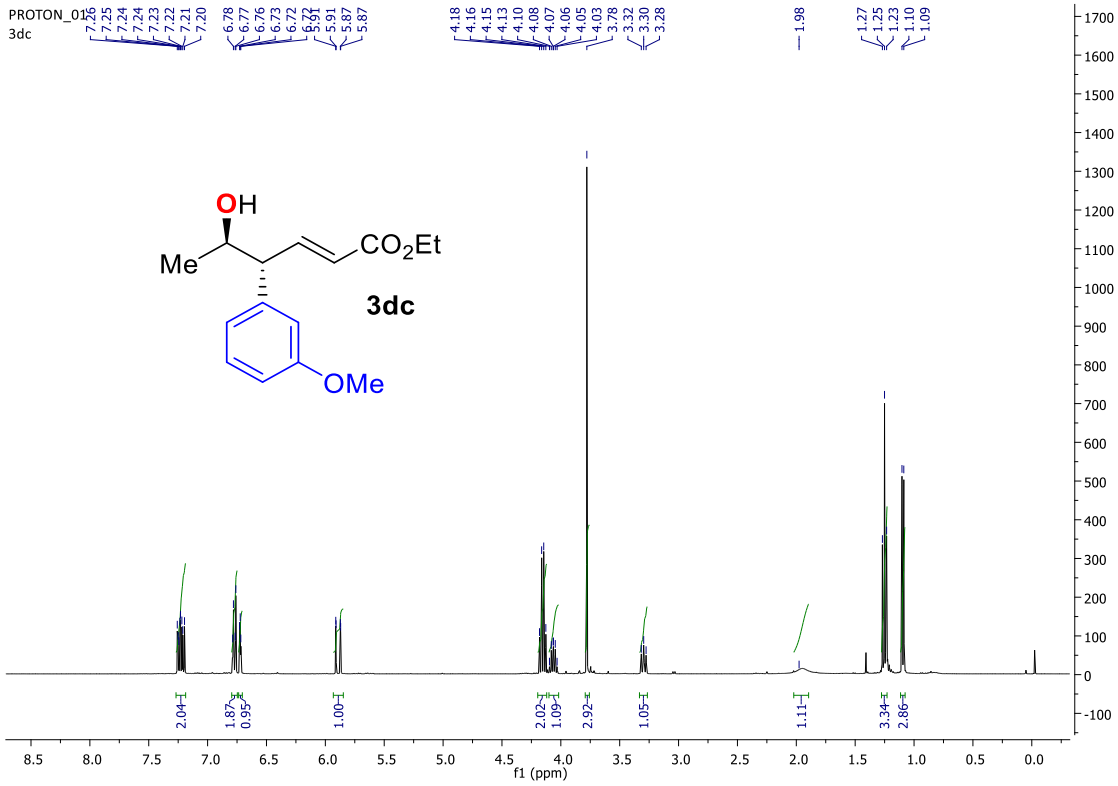

CARBON_01
3da
166.3
147.9
139.9
128.9
128.2
127.2
123.7
77.3
77.0
76.7
70.5
60.4
57.0
21.3
14.2
f1 (ppm)

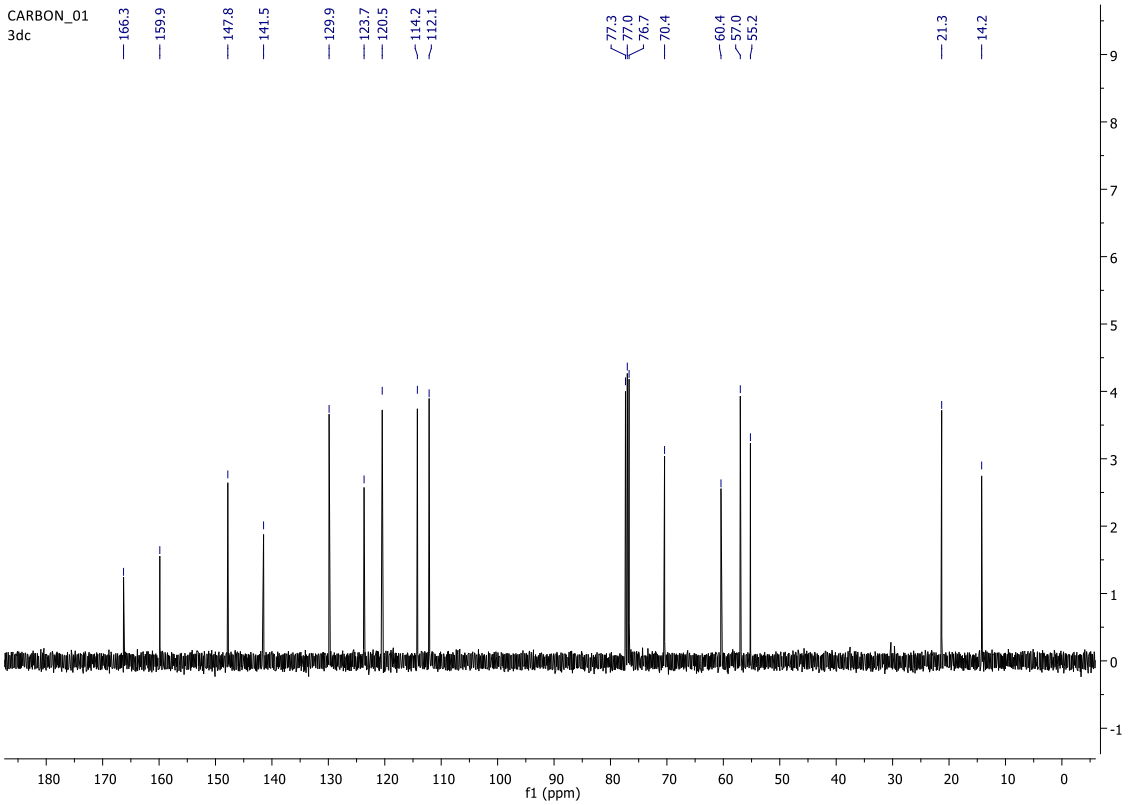

PROTON_01
5da
7.35
7.34
7.33
7.31
7.31
7.27
7.25
7.24
7.17
7.16
4.55
4.54
4.53
4.52
4.51
4.51
4.50
4.48
2.80
2.77
2.75
2.75
2.74
2.69
2.67
2.65
2.63
2.62
2.60
2.58
2.11
2.11
2.10
2.10
2.09
2.09
2.09
1.18
1.16
O
O
H
Me
Ph
H
5da
5.01
1.00
3.13
1.88
2.86
f1 (ppm)

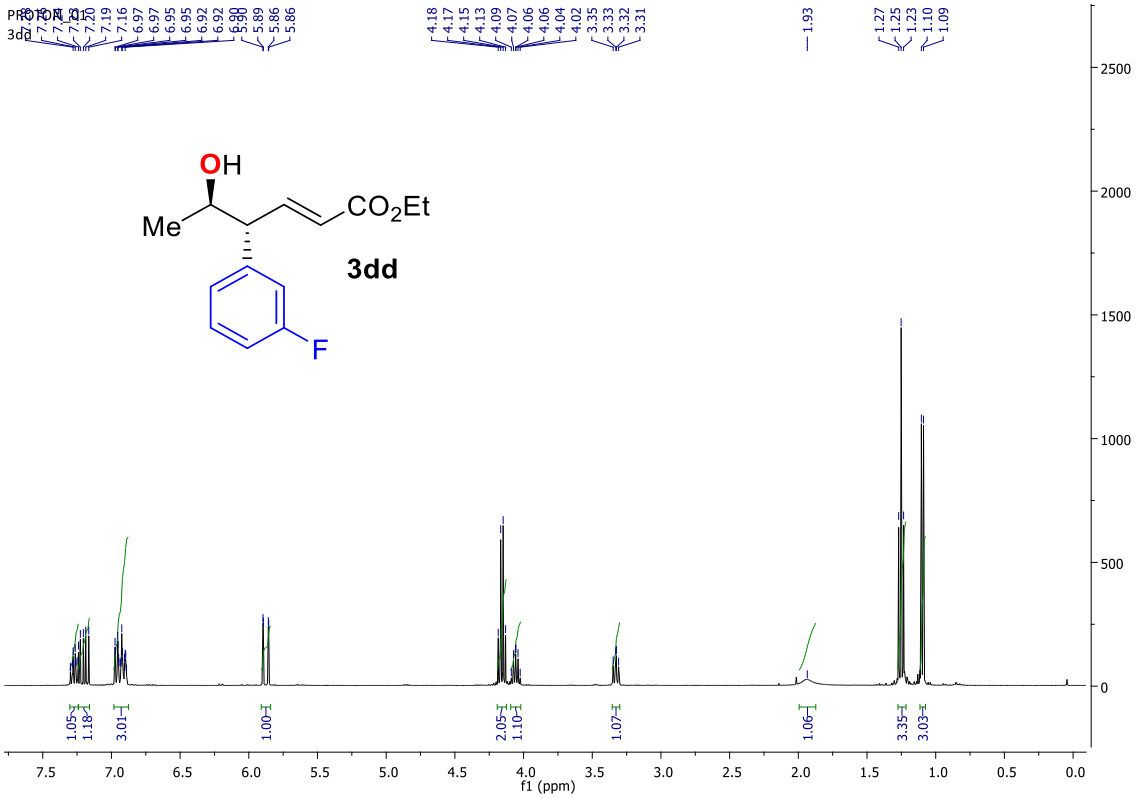

CARBON_01
5da
171.2
140.7
129.0
127.5
127.4
81.3
77.3
77.0
76.7
47.1
30.0
27.6
20.2
f1 (ppm)

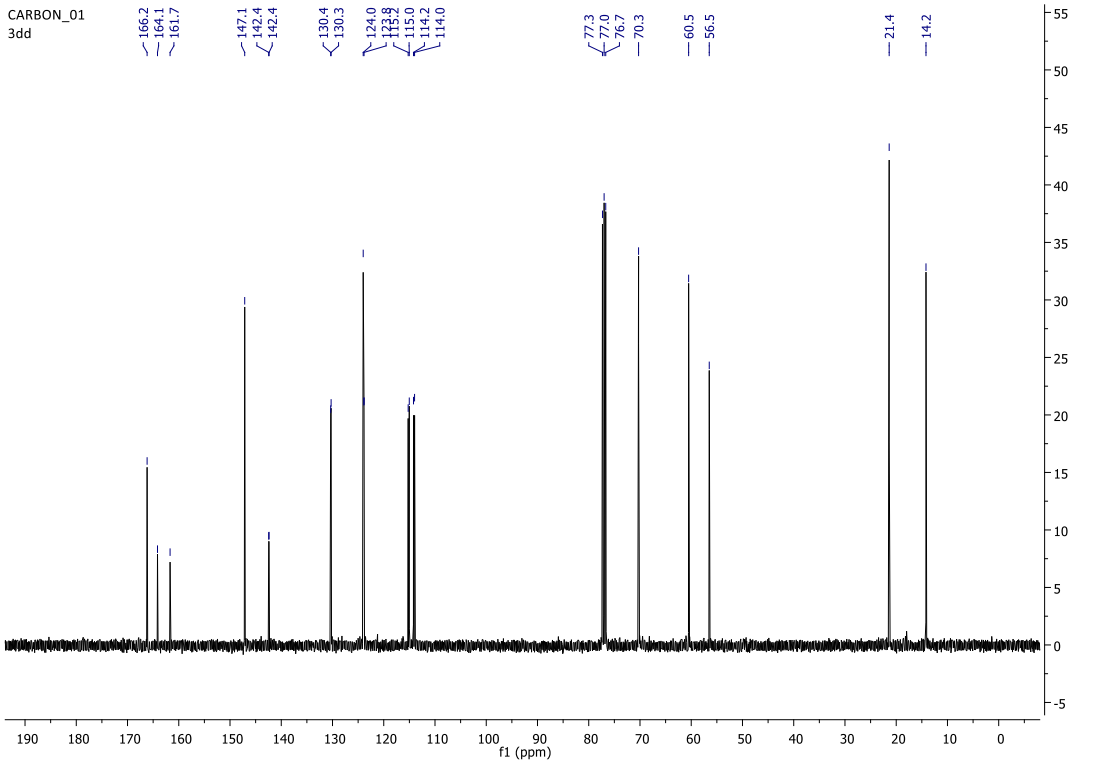

PROTON_01
3db
7.28
7.26
7.24
7.22
7.15
7.13
7.09
7.09
7.09
7.08
7.07
5.92
5.91
5.88
5.87
4.20
4.18
4.16
4.14
4.10
4.09
4.07
4.05
4.04
3.34
3.32
3.30
2.32
1.84
1.28
1.27
1.25
1.11
1.09
OH
Me
CO2Et
3db
Me
1.24
4.20
1.00
2.23
1.19
1.12
3.16
0.84
3.46
3.01
f1 (ppm)

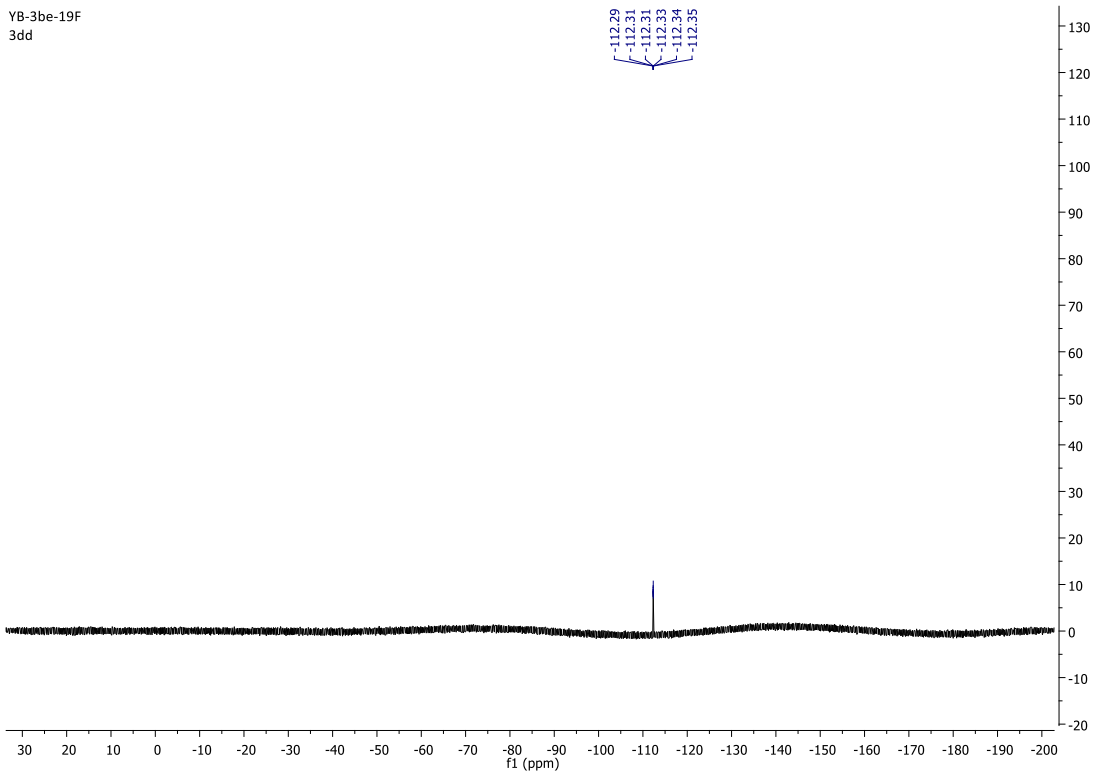

CARBON_01
3db
166.3
148.2
136.8
129.5
128.0
123.5
77.3
77.0
76.7
70.5
60.4
56.6
21.2
21.0
14.2
f1 (ppm)

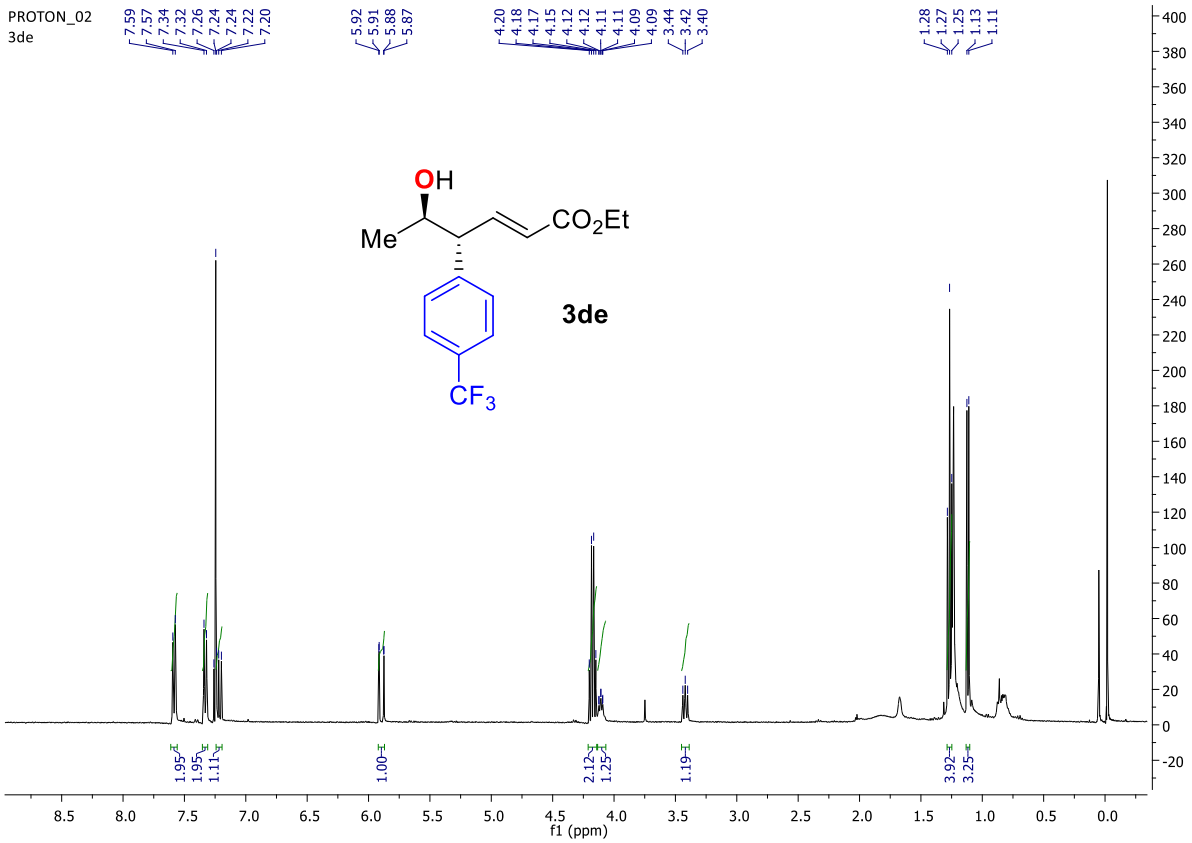

PROTON_01
3dc
7.26
7.25
7.24
7.24
7.23
7.22
7.21
7.20
6.78
6.77
6.76
6.73
6.72
6.72
5.91
5.91
5.87
5.87
4.18
4.16
4.15
4.13
4.10
4.08
4.07
4.06
4.05
4.03
3.78
3.32
3.30
3.28
1.98
1.27
1.25
1.23
1.10
1.09
OH
Me
CO2Et
3dc
OMe
2.04
1.87
0.95
1.00
2.02
1.09
2.92
1.05
1.11
3.34
2.86
f1 (ppm)

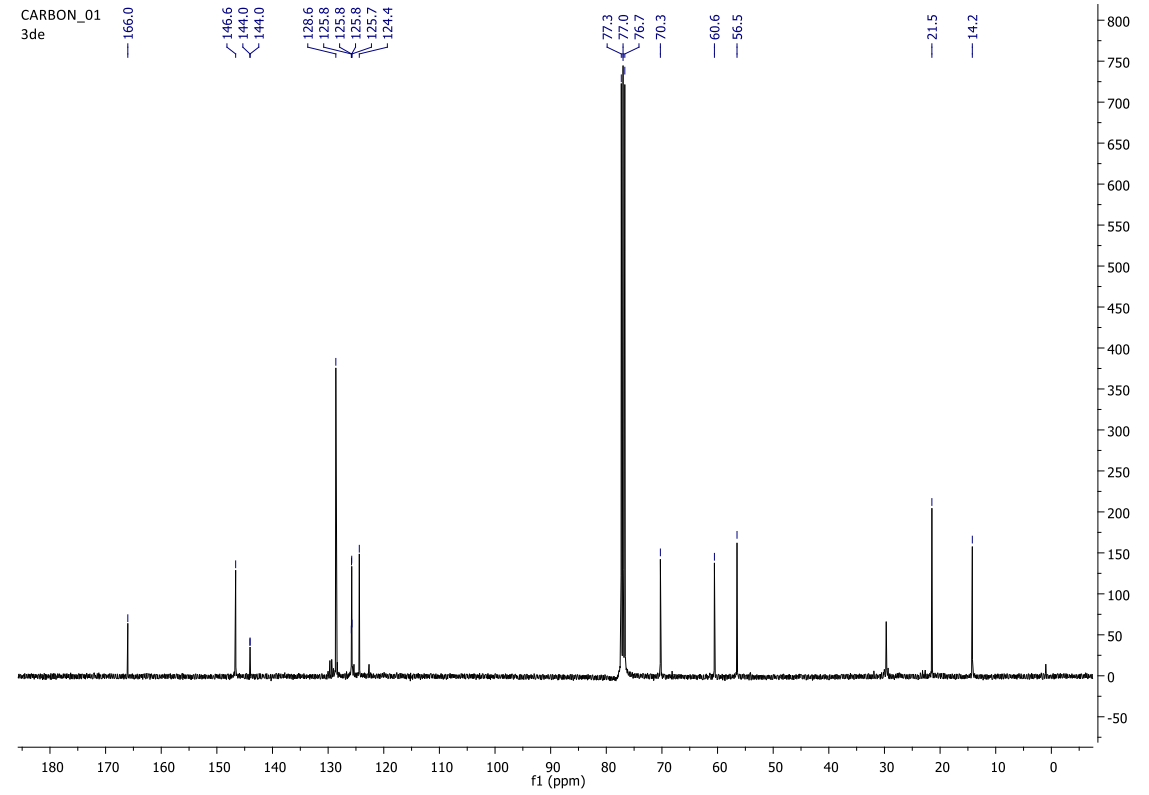

CARBON_01
3dc
166.3
159.9
147.8
141.5
129.9
123.7
120.5
114.2
112.1
77.3
77.0
76.7
70.4
60.4
57.0
55.2
21.3
14.2
f1 (ppm)

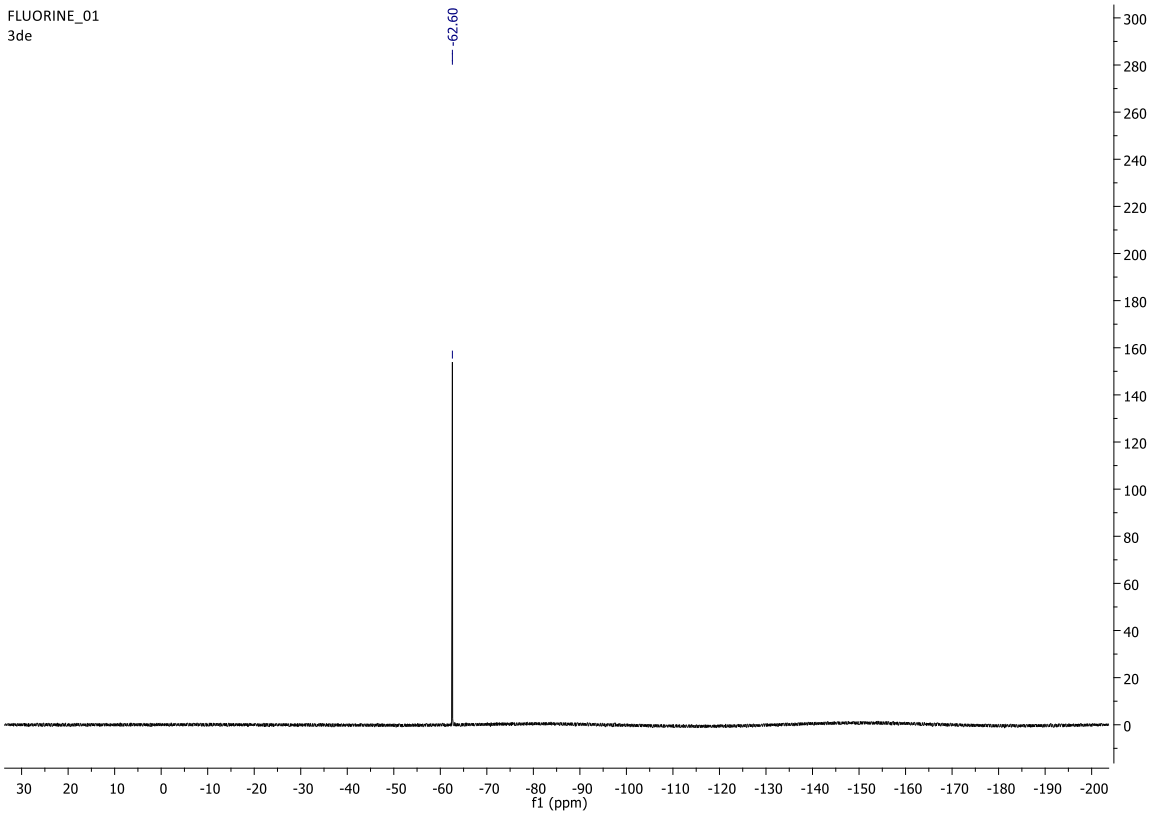

PROTON_01
3dd
7.21
7.20
7.19
7.16
6.97
6.97
6.95
6.95
6.92
6.92
5.90
5.89
5.86
5.86
4.18
4.17
4.15
4.13
4.09
4.07
4.06
4.06
4.04
4.02
3.35
3.33
3.32
3.31
1.93
1.27
1.25
1.23
1.10
1.09
OH
Me
CO2Et
3dd
F
1.05
1.18
3.01
1.00
2.05
1.10
1.07
1.06
3.35
3.03
f1 (ppm)

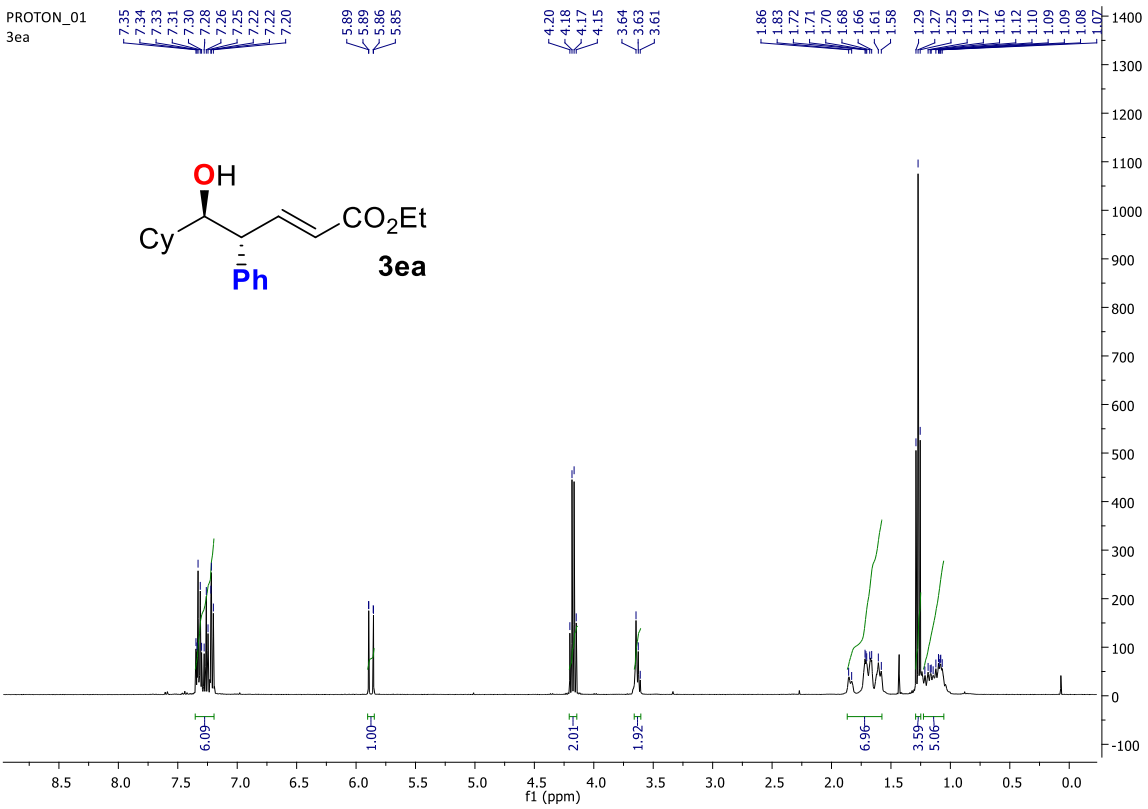

CARBON_01
3dd
166.2
164.1
161.7
147.1
142.4
142.4
130.4
130.3
124.0
123.8
115.2
115.0
114.2
114.0
77.3
77.0
76.7
70.3
60.5
56.5
21.4
14.2
f1 (ppm)

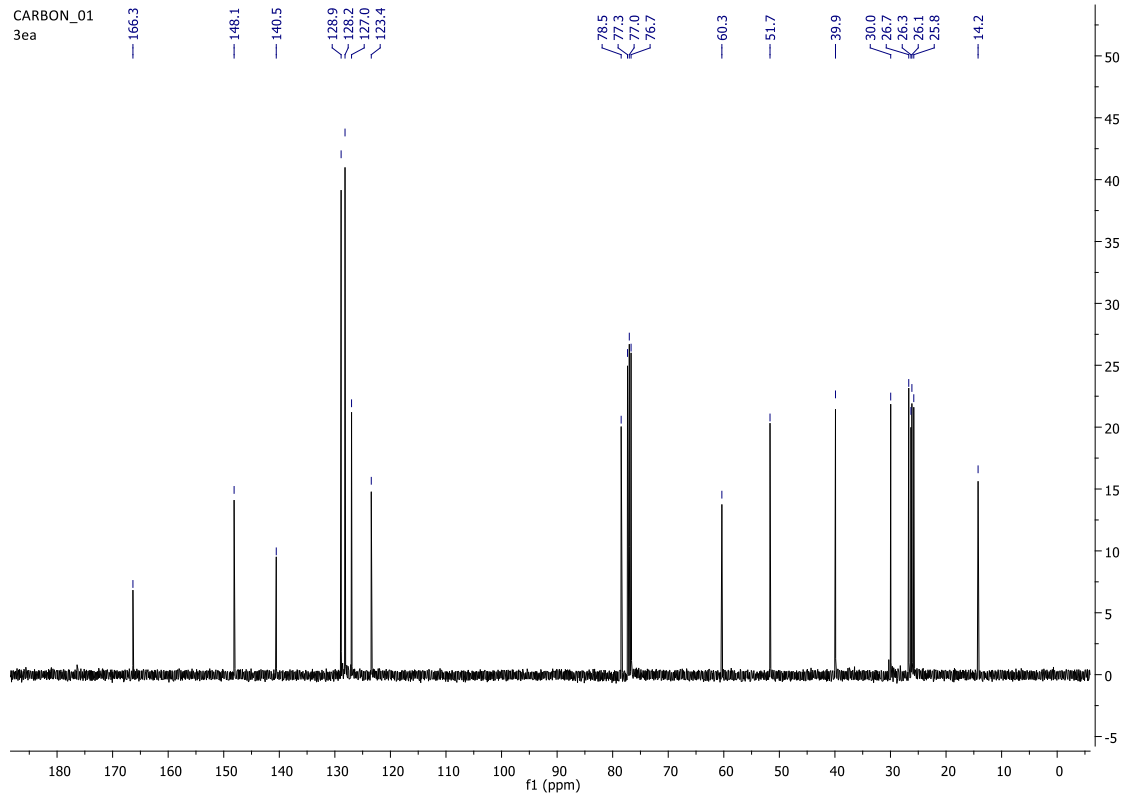

YB-3be-19F
3dd
-112.29
-112.31
-112.31
-112.33
-112.34
-112.35
f1 (ppm)

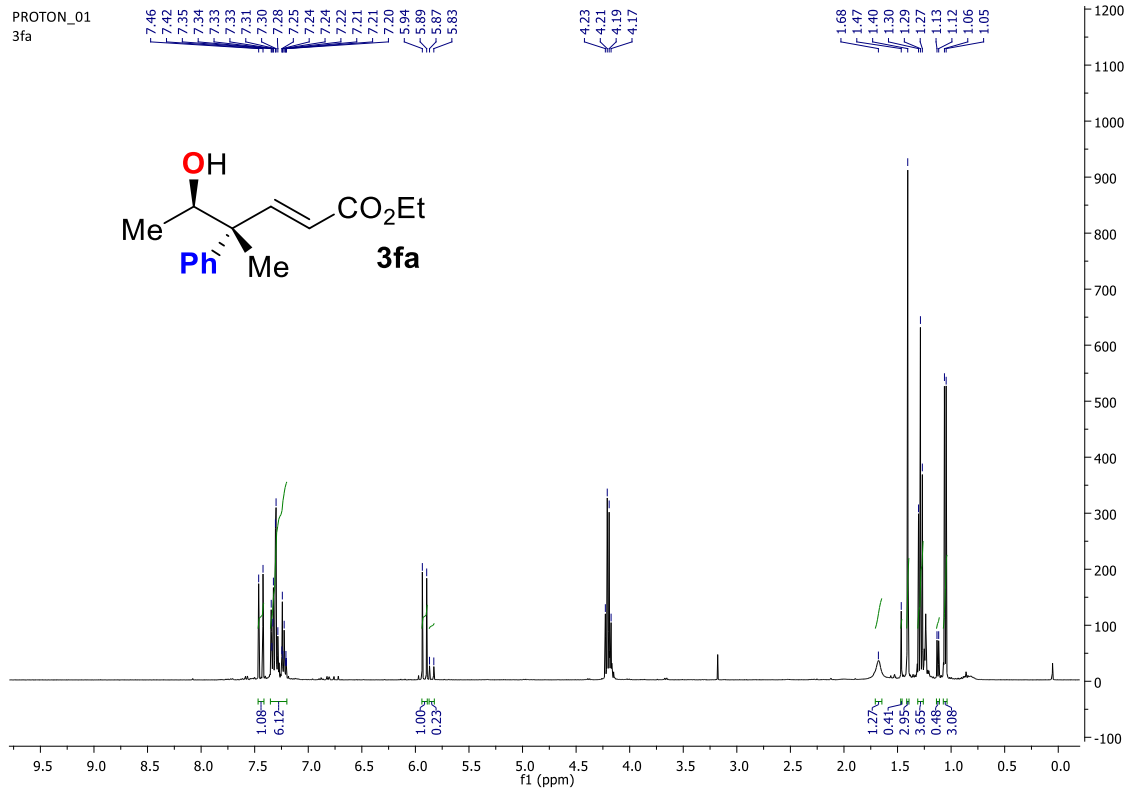

PROTON_02
3de
7.59
7.57
7.34
7.32
7.26
7.24
7.24
7.22
7.20
5.92
5.91
5.88
5.87
4.20
4.18
4.17
4.15
4.12
4.12
4.11
4.11
4.09
4.09
3.44
3.42
3.40
1.28
1.27
1.25
1.13
1.11
OH
Me
CO2Et
CF3
3de
1.95
1.95
1.11
1.00
2.12
1.25
1.19
3.92
3.25
f1 (ppm)

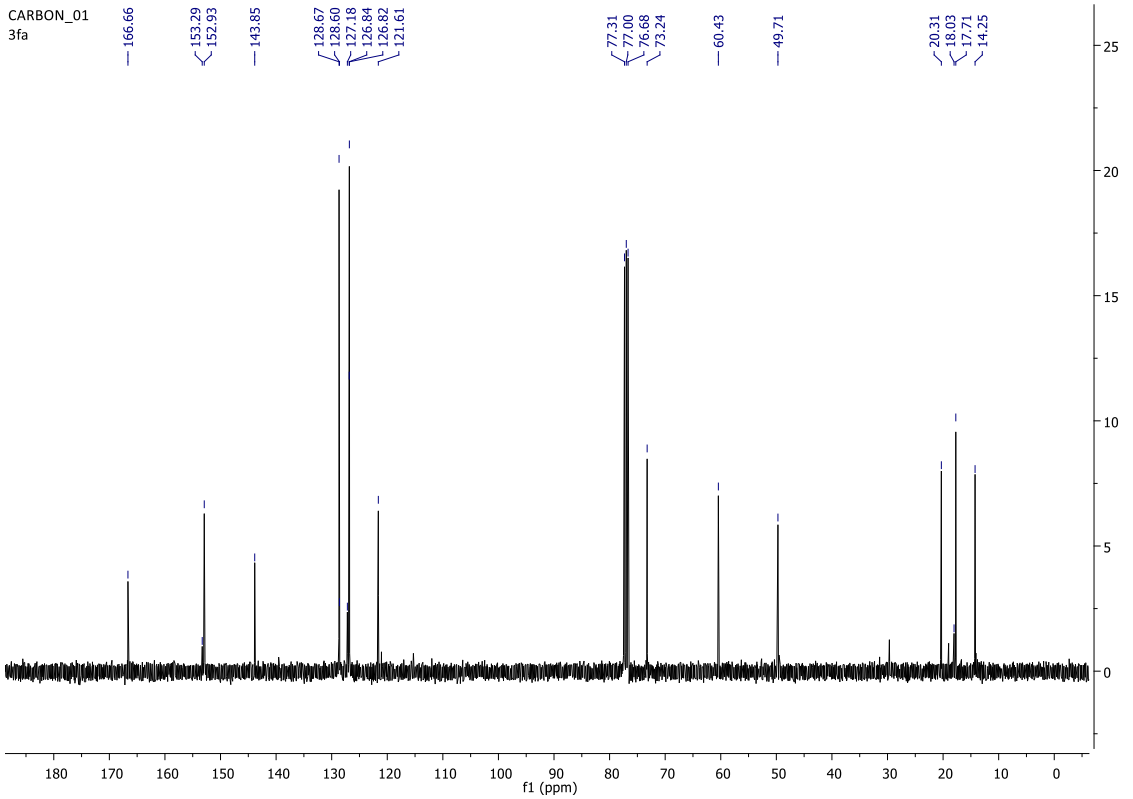

CARBON_01
3de
166.0
146.6
144.0
144.0
128.6
125.8
125.8
125.8
125.7
124.4
77.3
77.0
76.7
70.3
60.6
56.5
21.5
14.2
f1 (ppm)

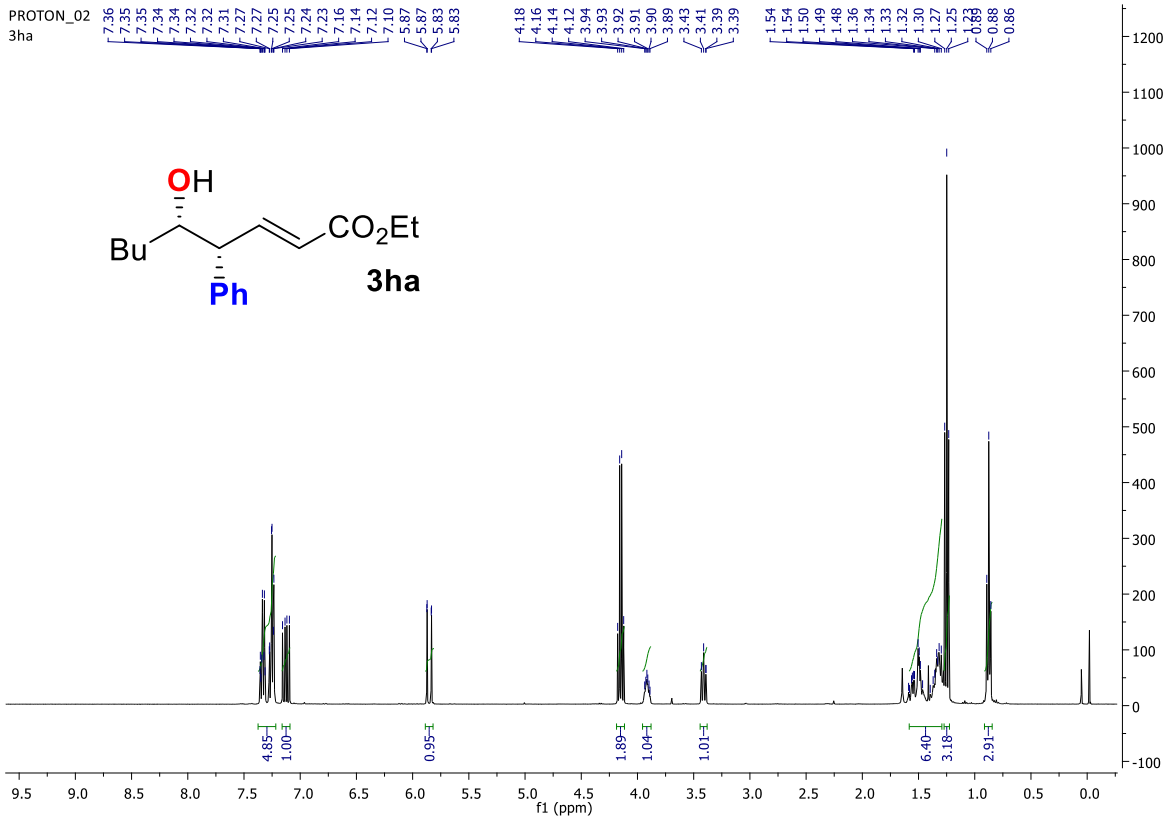

FLUORINE_01
3de
-62.60
f1 (ppm)

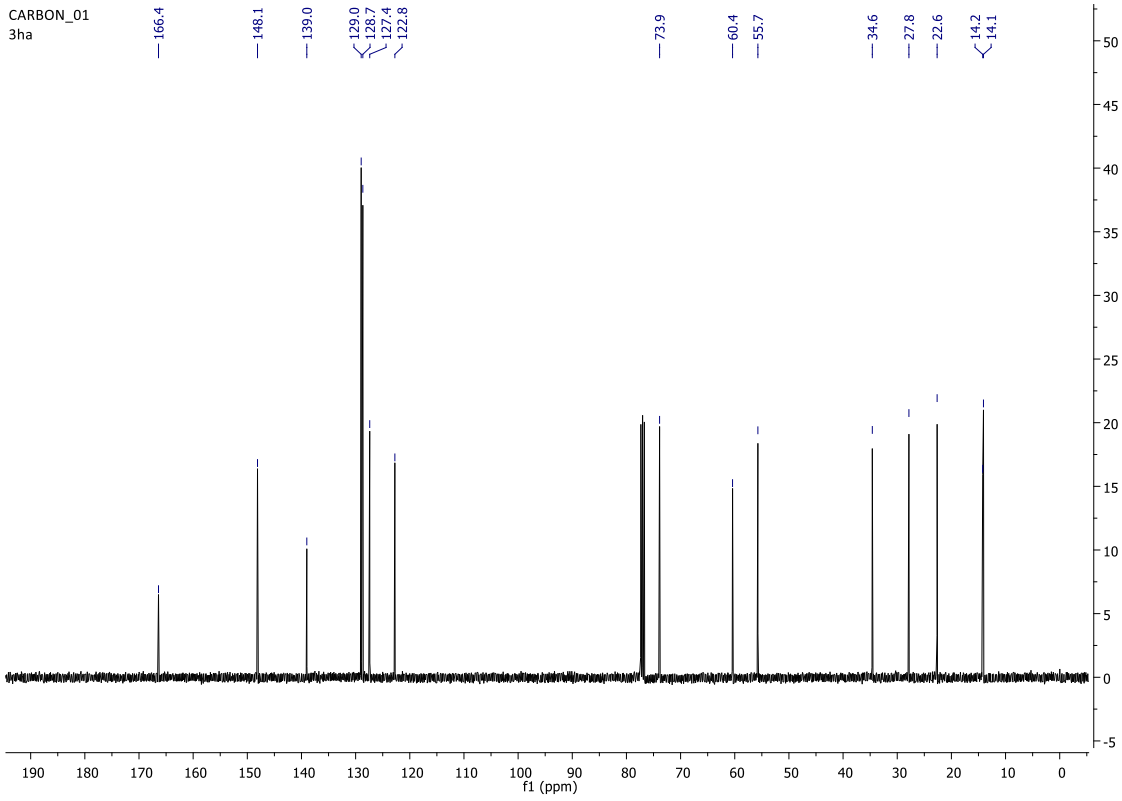

PROTON_01
3ea
7.35 7.34 7.33 7.31 7.30 7.28 7.26 7.25 7.22 7.22 7.20
5.89 5.89 5.86 5.85
4.20 4.18 4.17 4.15
3.64 3.63 3.61
1.86 1.83 1.72 1.71 1.70 1.68 1.66 1.61 1.58
1.29 1.27 1.25 1.19 1.17 1.16 1.12 1.10 1.09 1.09 1.08 1.07
OH
Cy
CO2Et
Ph
3ea
6.09
1.00
2.01
1.92
6.96
3.59
5.06
f1 (ppm)

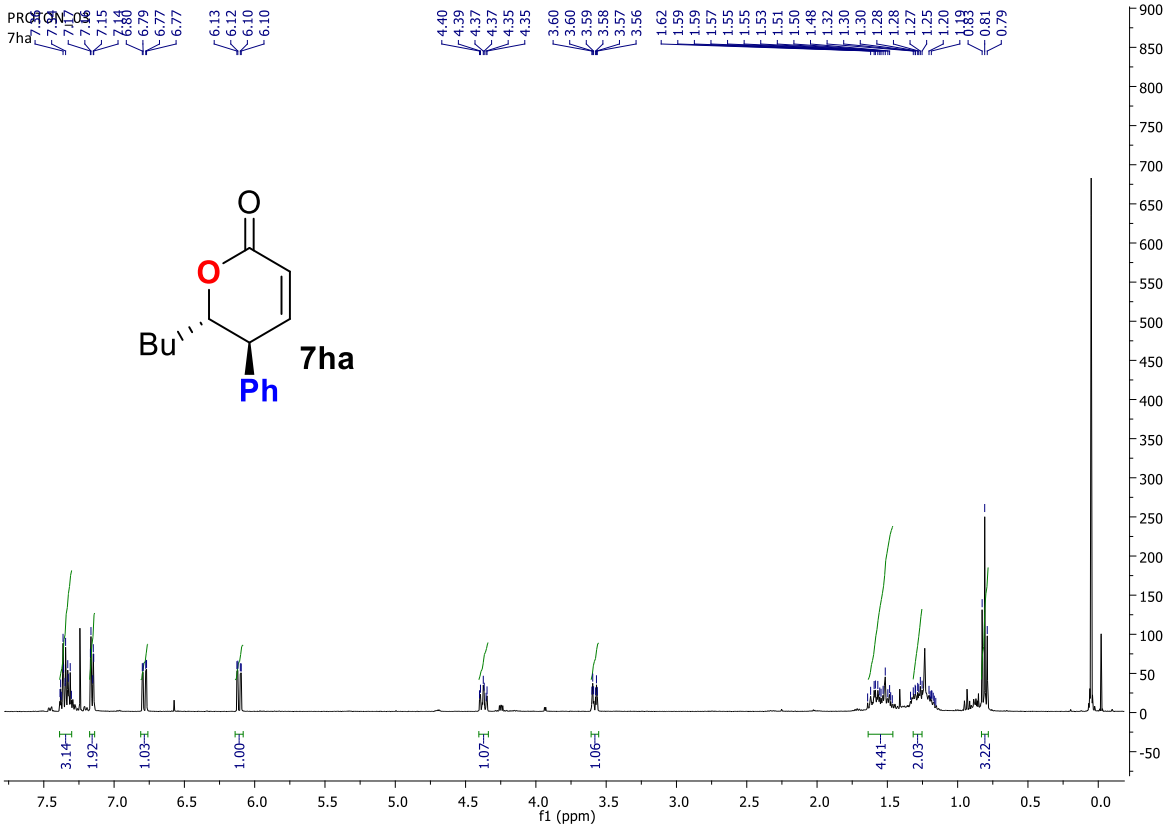

CARBON_01
3ea
166.3
148.1
140.5
128.9
128.2
127.0
123.4
78.5
77.3
77.0
76.7
60.3
51.7
39.9
30.0
26.7
26.3
26.1
25.8
14.2
f1 (ppm)

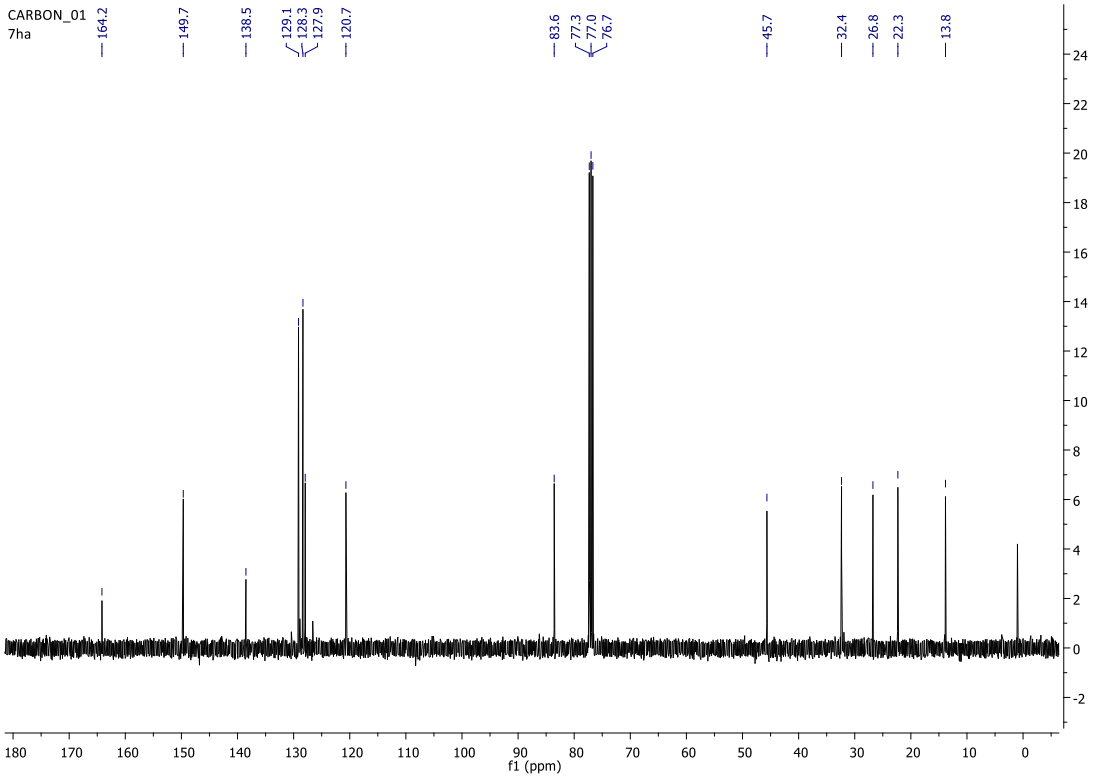

PROTON_01
3fa
7.46
7.42
7.35
7.34
7.33
7.33
7.31
7.30
7.28
7.25
7.24
7.24
7.22
7.21
7.21
7.20
5.94
5.89
5.87
5.83
4.23
4.21
4.19
4.17
1.68
1.47
1.40
1.30
1.29
1.27
1.13
1.12
1.06
1.05
OH
Me
Ph
Me
CO2Et
3fa
1.08
6.12
1.00
0.23
1.27
0.41
2.95
3.65
0.48
3.08
f1 (ppm)

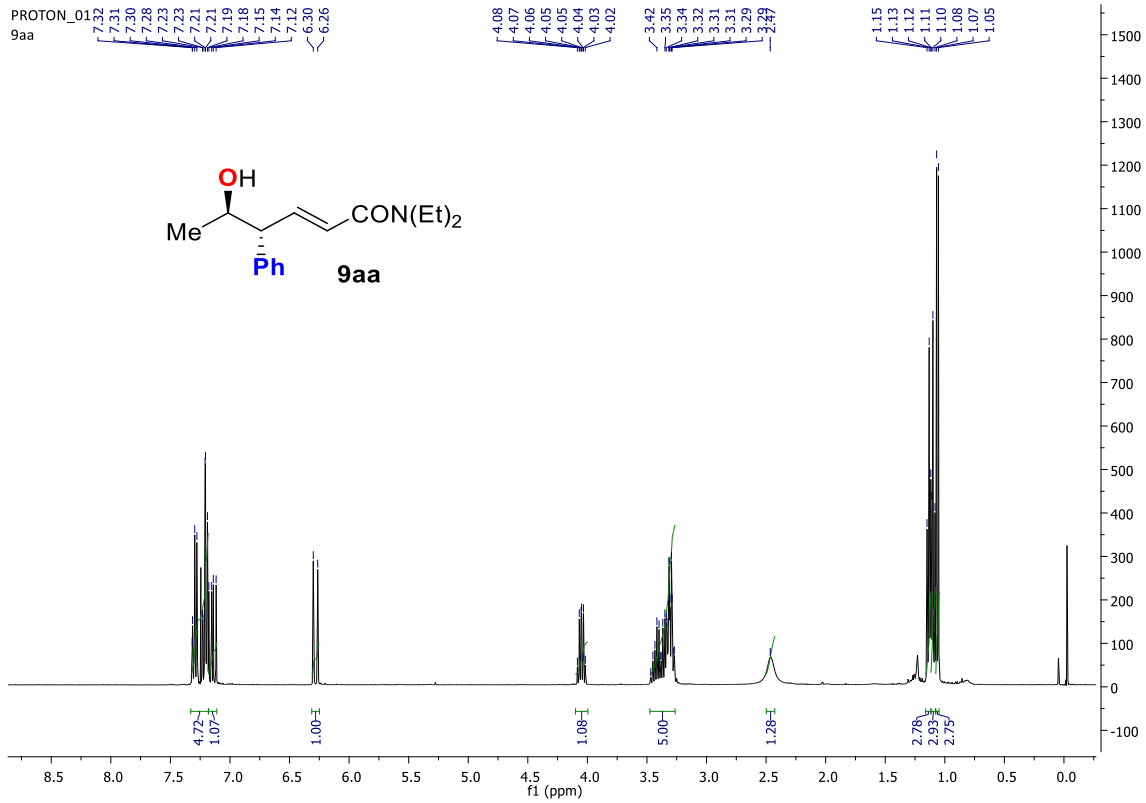

CARBON_01
3fa
166.66
153.29
152.93
143.85
128.67
128.60
127.18
126.84
126.82
121.61
77.31
77.00
76.68
73.24
60.43
49.71
20.31
18.03
17.71
14.25
f1 (ppm)

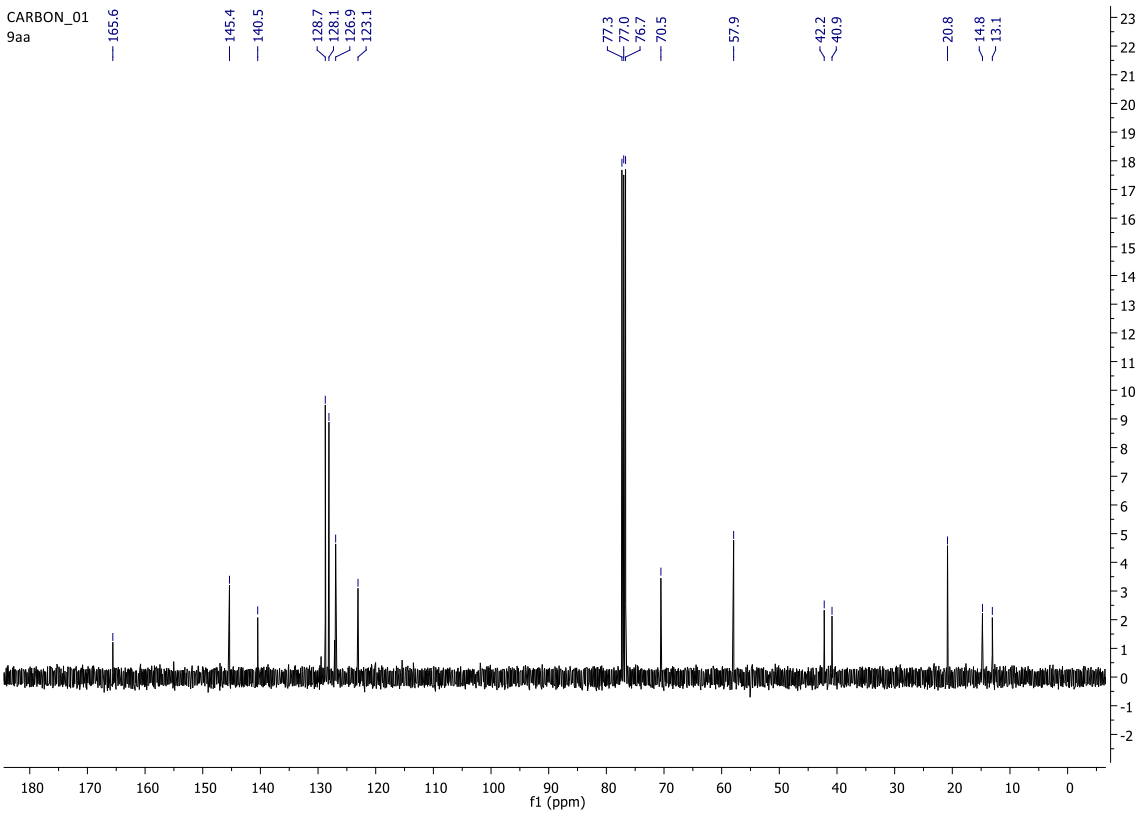

PROTON_02
3ha
OH
Bu
CO2Et
Ph
3ha
f1 (ppm)

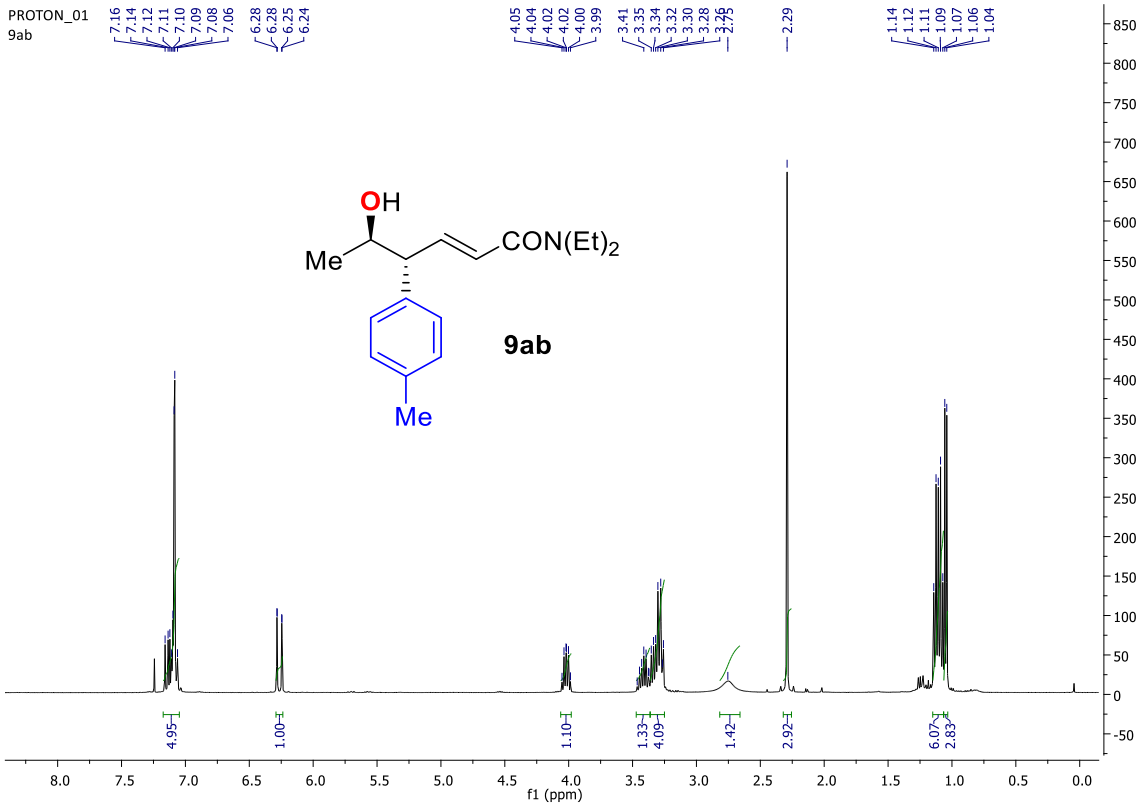

CARBON_01
3ha
166.4
148.1
139.0
129.0
128.7
127.4
122.8
73.9
60.4
55.7
34.6
27.8
22.6
14.2
14.1
f1 (ppm)

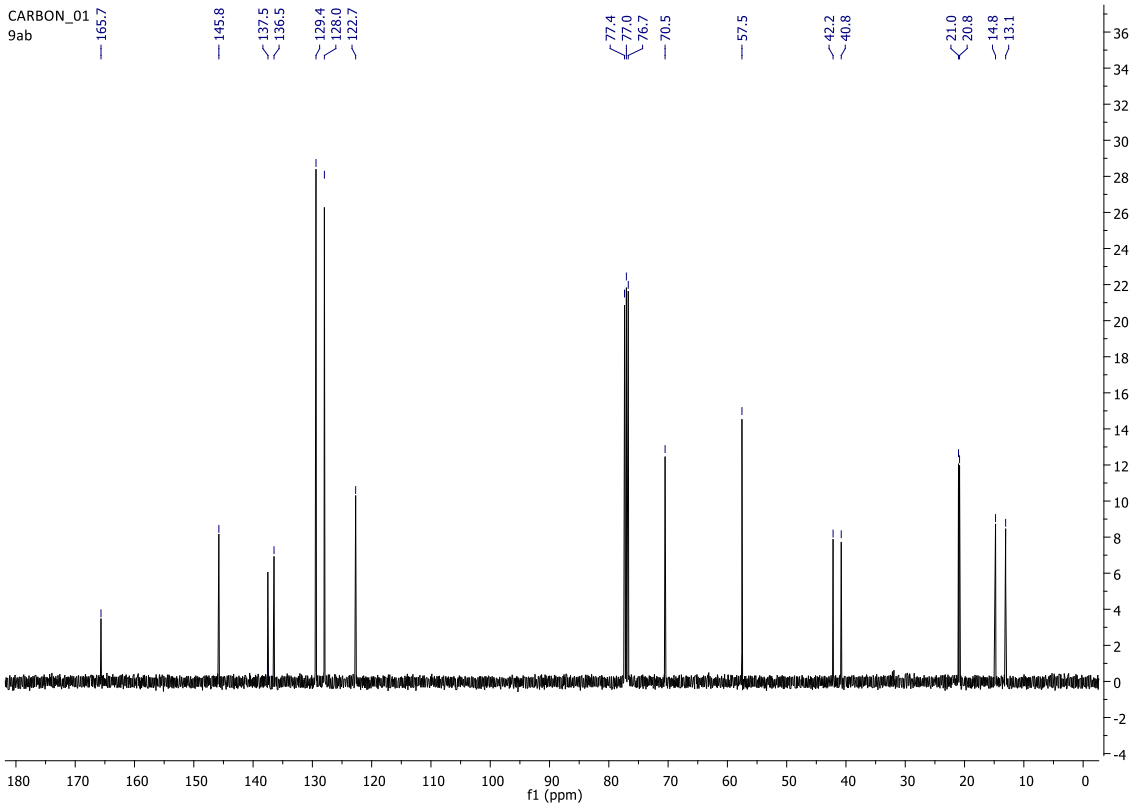

PROTON_03
7ha
O
O
Bu
Ph
7ha
f1 (ppm)

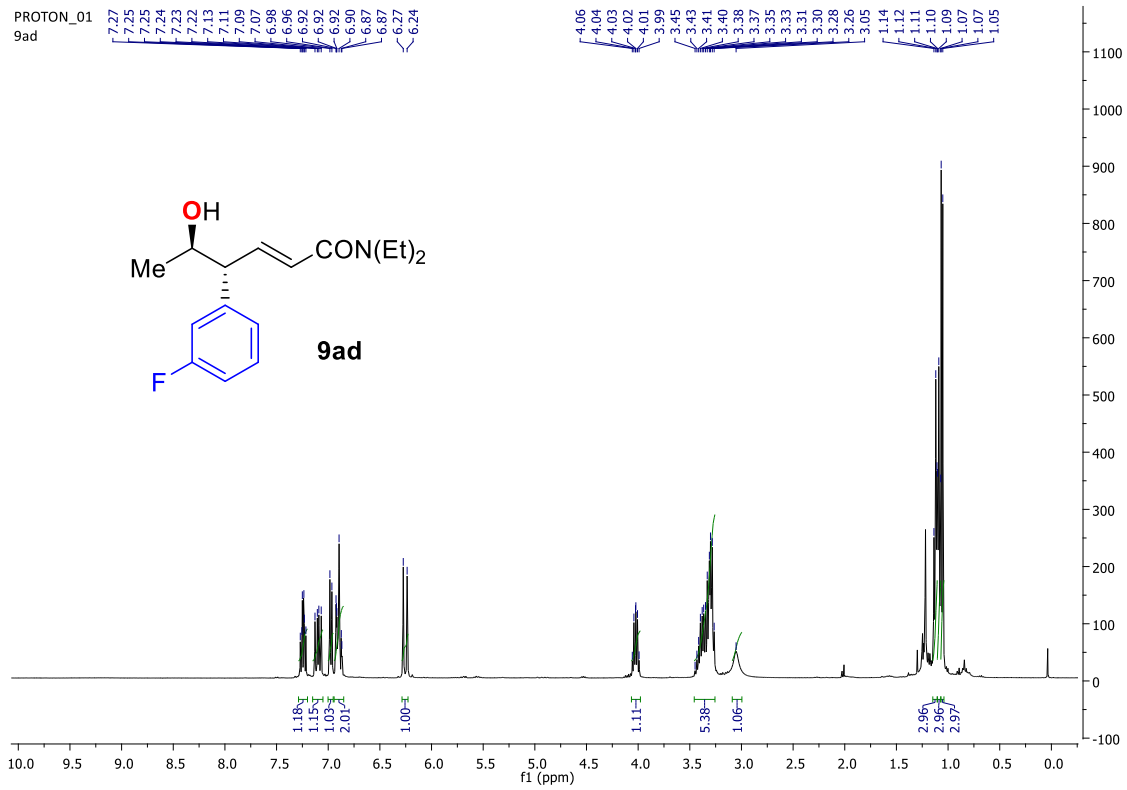

CARBON_01
7ha
f1 (ppm)

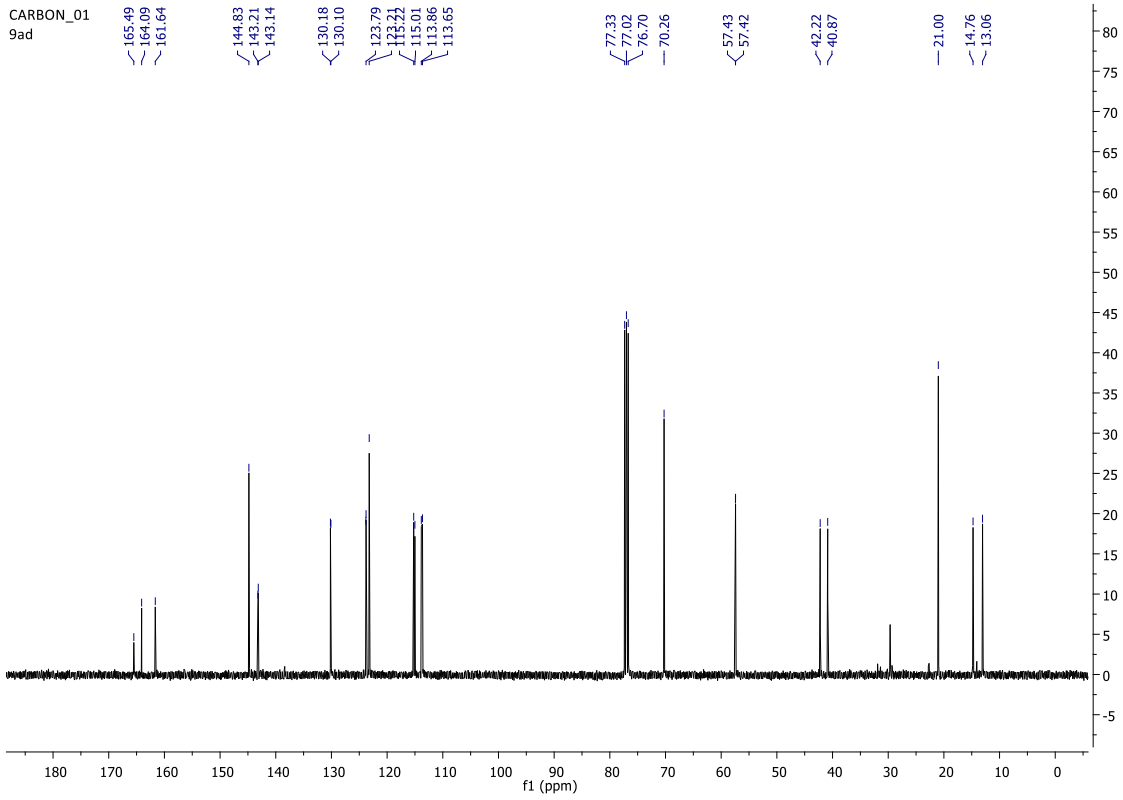

PROTON_01
9aa
OH
Me
CON(Et)2
Ph
9aa
f1 (ppm)

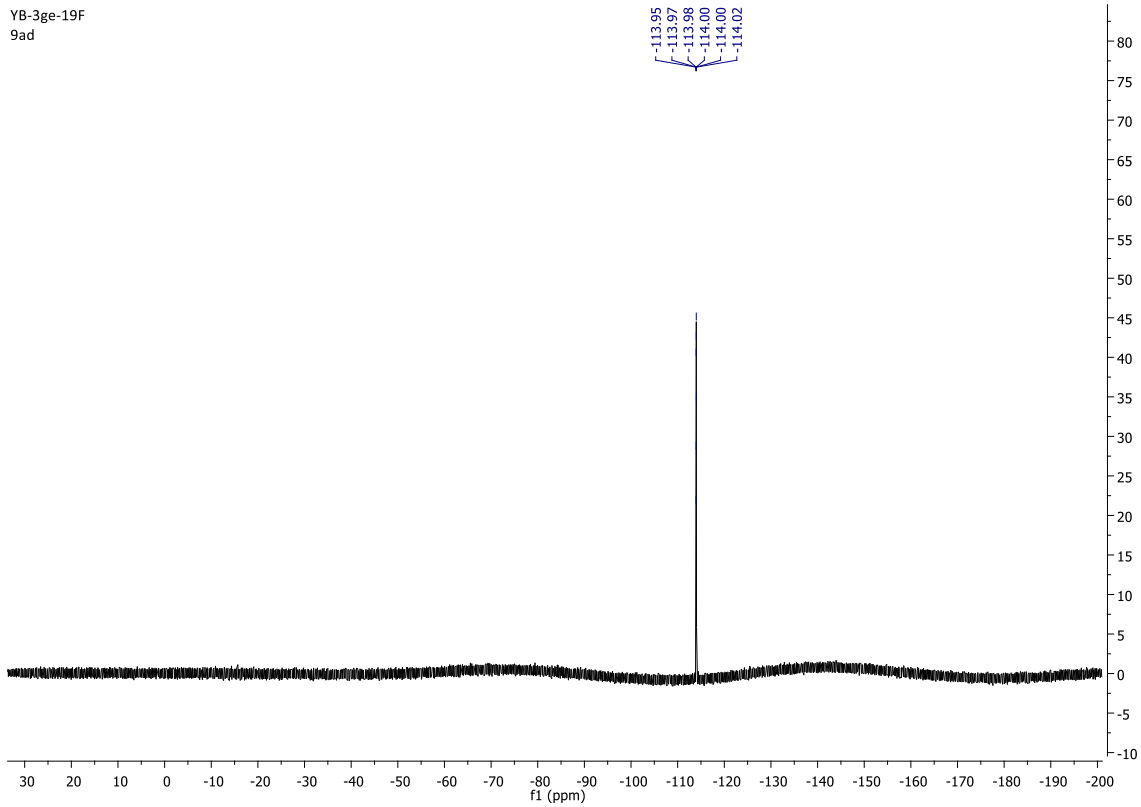

CARBON_01
9aa
f1 (ppm)

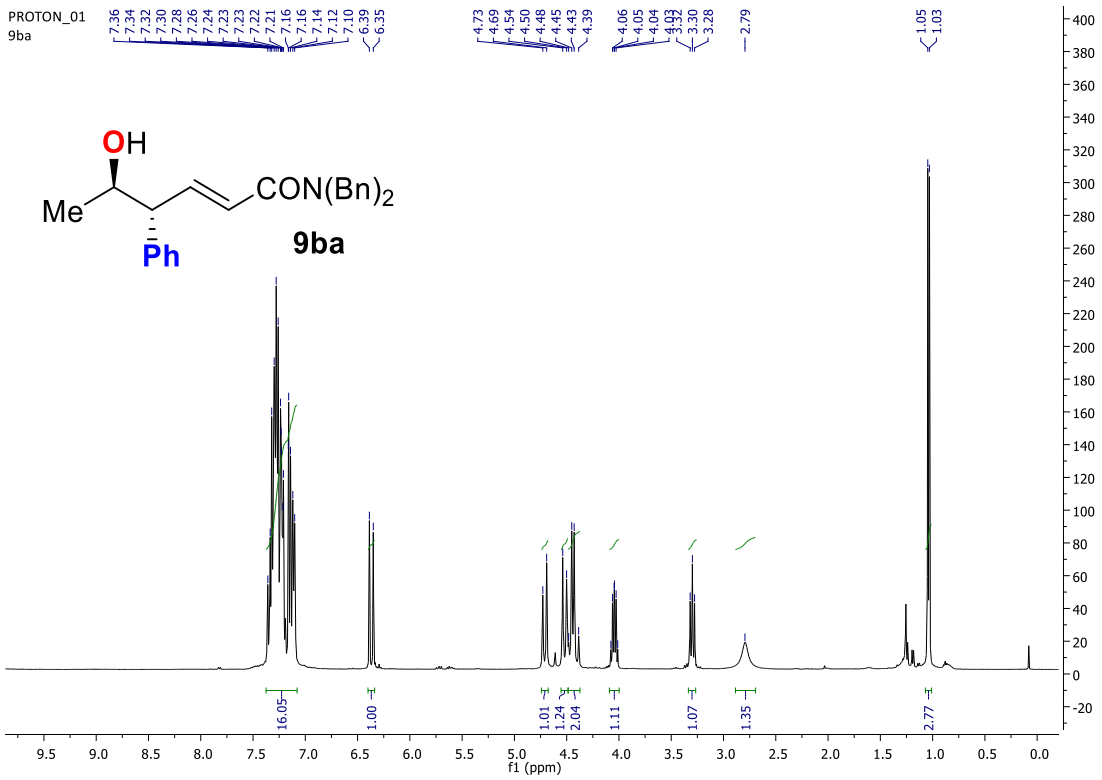

PROTON_01
9ab
7.16
7.14
7.12
7.11
7.10
7.09
7.08
7.06
6.28
6.28
6.25
6.24
4.05
4.04
4.02
4.02
4.00
3.99
3.41
3.35
3.34
3.32
3.30
3.28
3.26
2.75
2.29
1.14
1.12
1.11
1.09
1.07
1.06
1.04
OH
Me
CON(Et)2
9ab
Me
4.95
1.00
1.10
1.33
4.09
1.42
2.92
6.07
2.83
f1 (ppm)

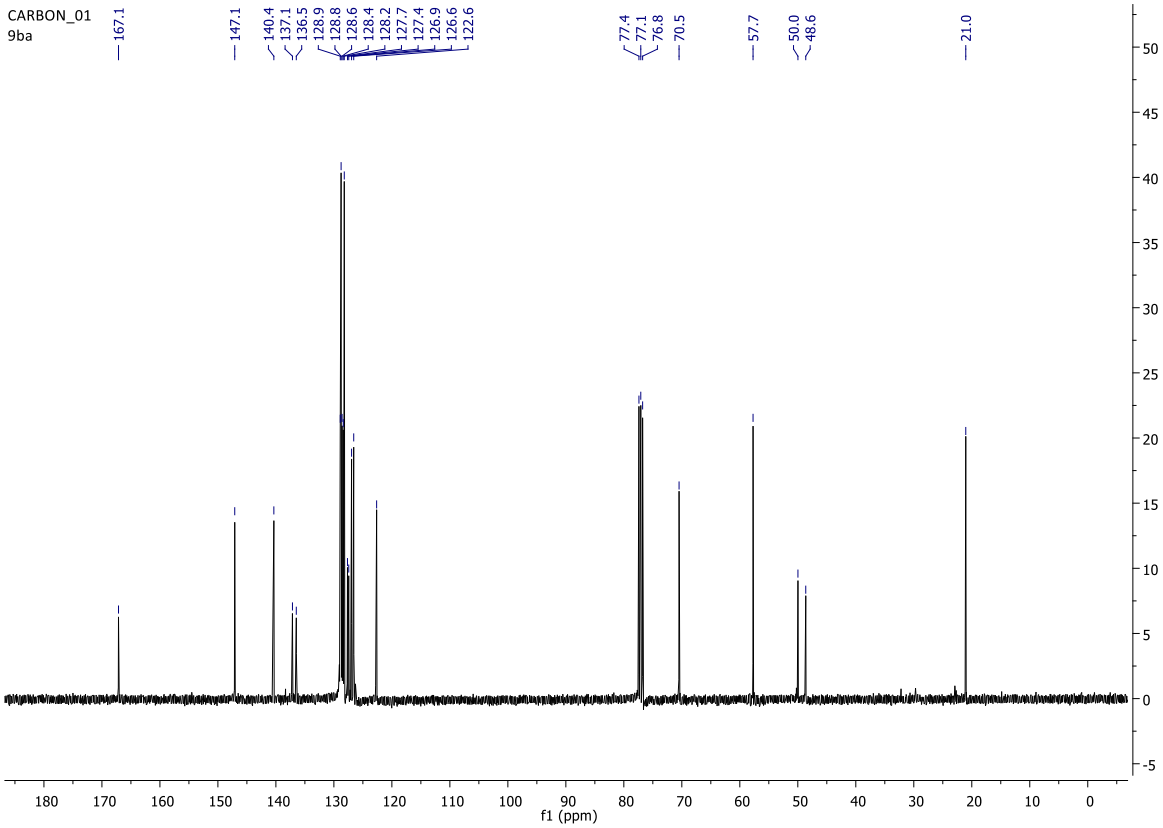

CARBON_01
9ab
165.7
145.8
137.5
136.5
129.4
128.0
122.7
77.4
77.0
76.7
70.5
57.5
42.2
40.8
21.0
20.8
14.8
13.1
f1 (ppm)

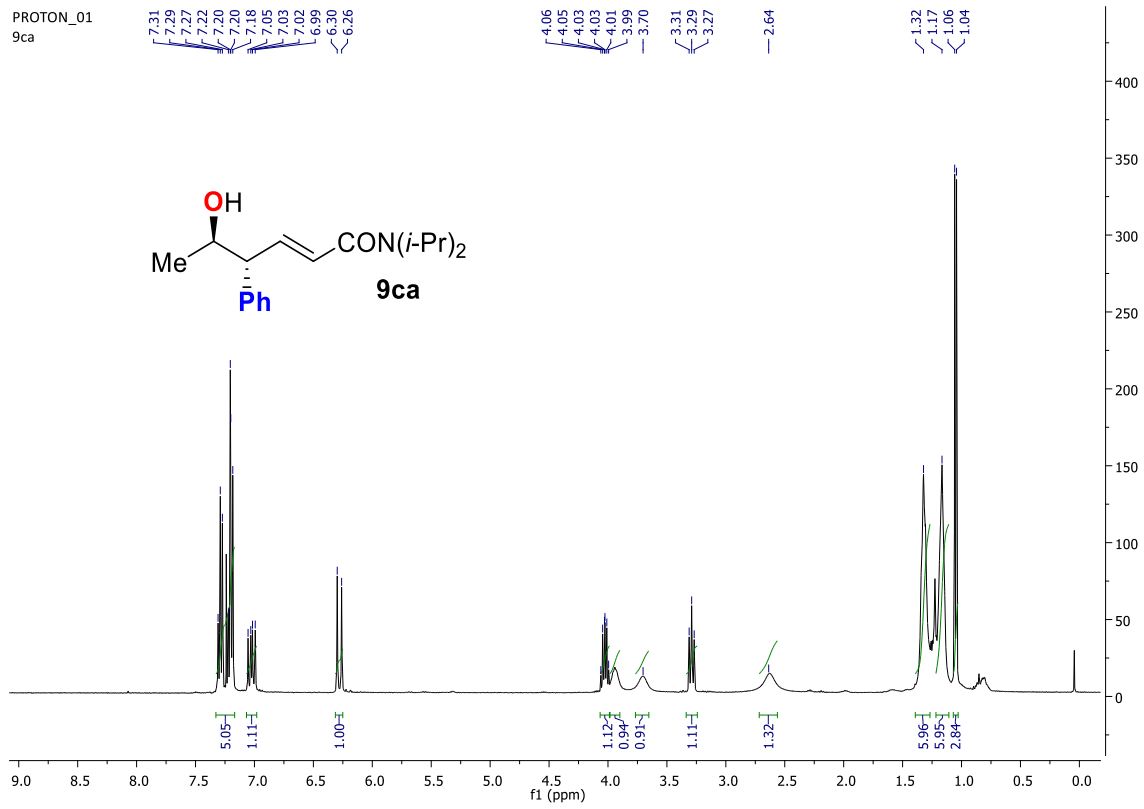

PROTON_01
9ad
OH
Me
CON(Et)2
F
9ad
f1 (ppm)

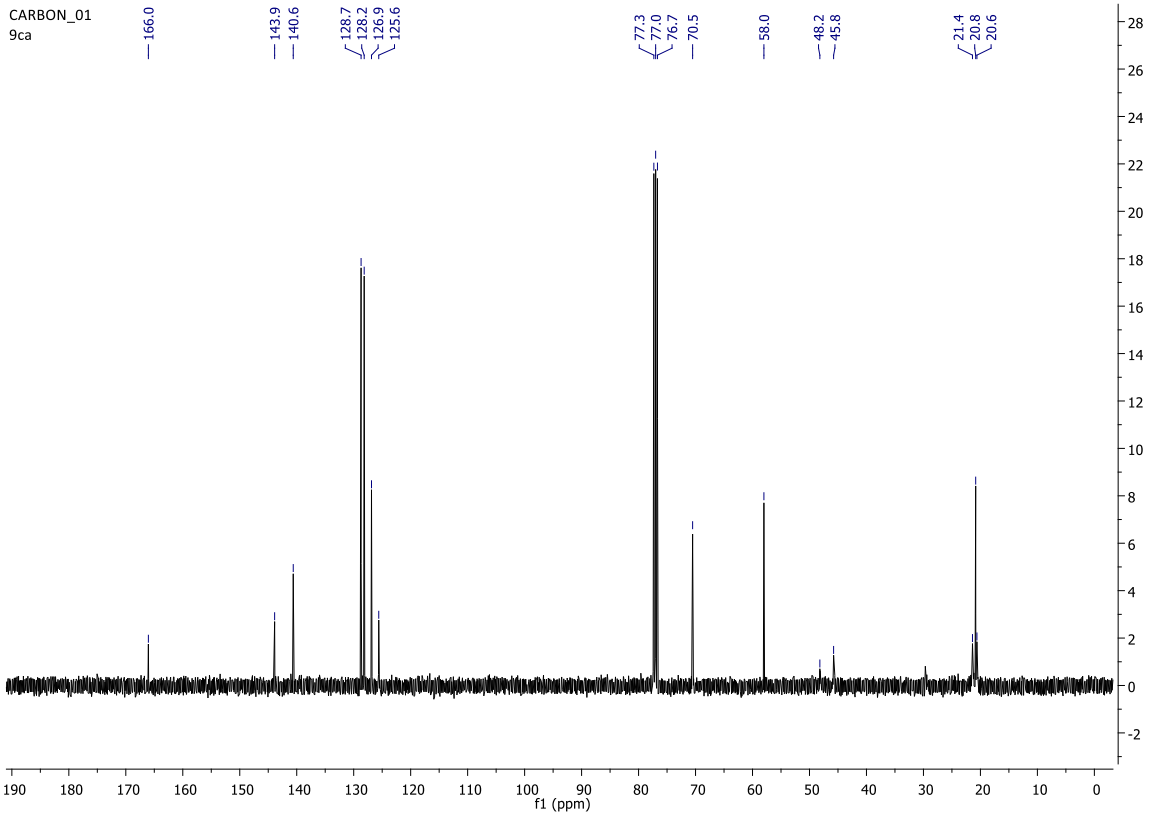

CARBON_01
9ad
f1 (ppm)

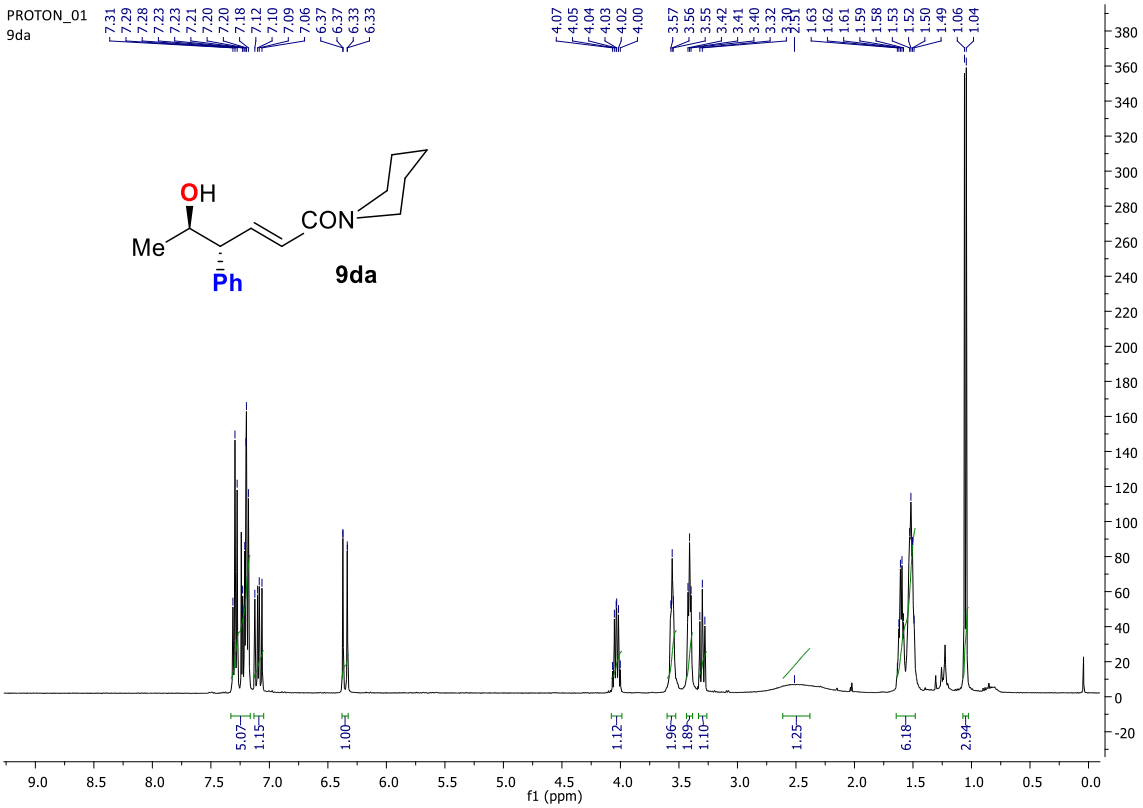

YB-3ge-19F
9ad
-113.95
-113.97
-113.98
-114.00
-114.00
-114.02
f1 (ppm)

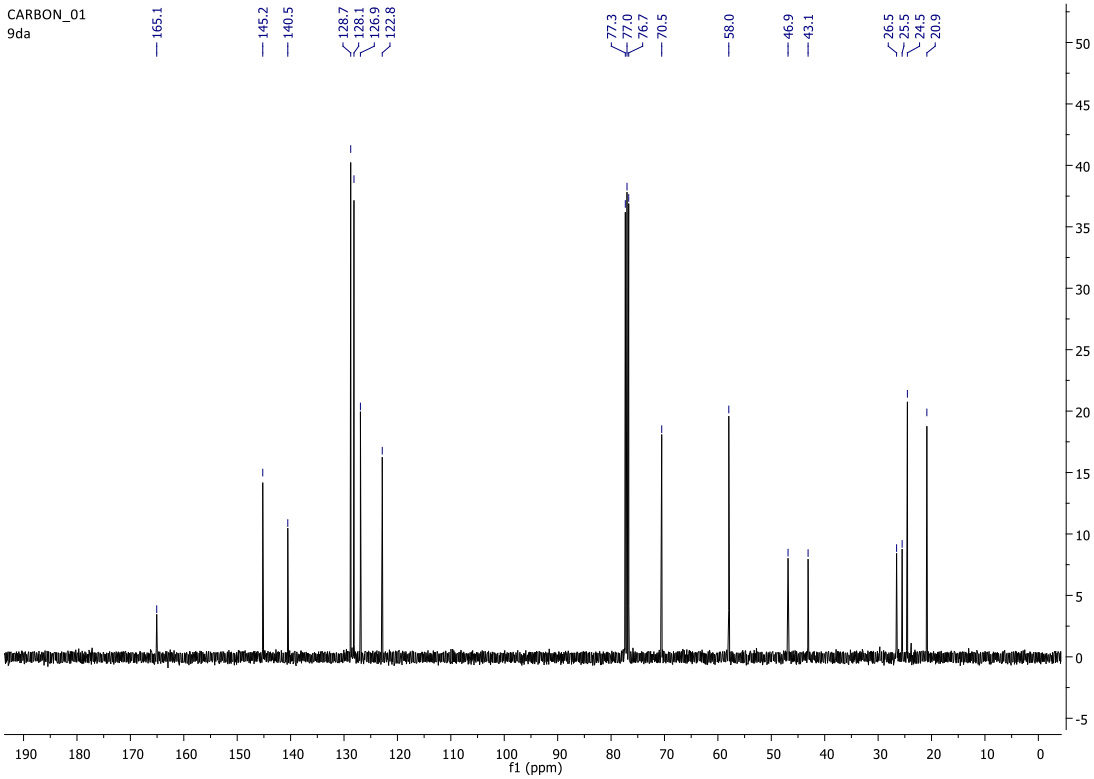

PROTON_01
9ba
7.36
7.34
7.32
7.30
7.28
7.26
7.24
7.23
7.23
7.22
7.21
7.16
7.16
7.14
7.12
7.10
6.39
6.35
4.73
4.69
4.54
4.50
4.48
4.45
4.43
4.39
4.06
4.05
4.04
4.03
3.32
3.30
3.28
2.79
1.05
1.03
OH
Me
CON(Bn)2
Ph
9ba
16.05
1.00
1.01
1.24
2.04
1.11
1.07
1.35
2.77
f1 (ppm)

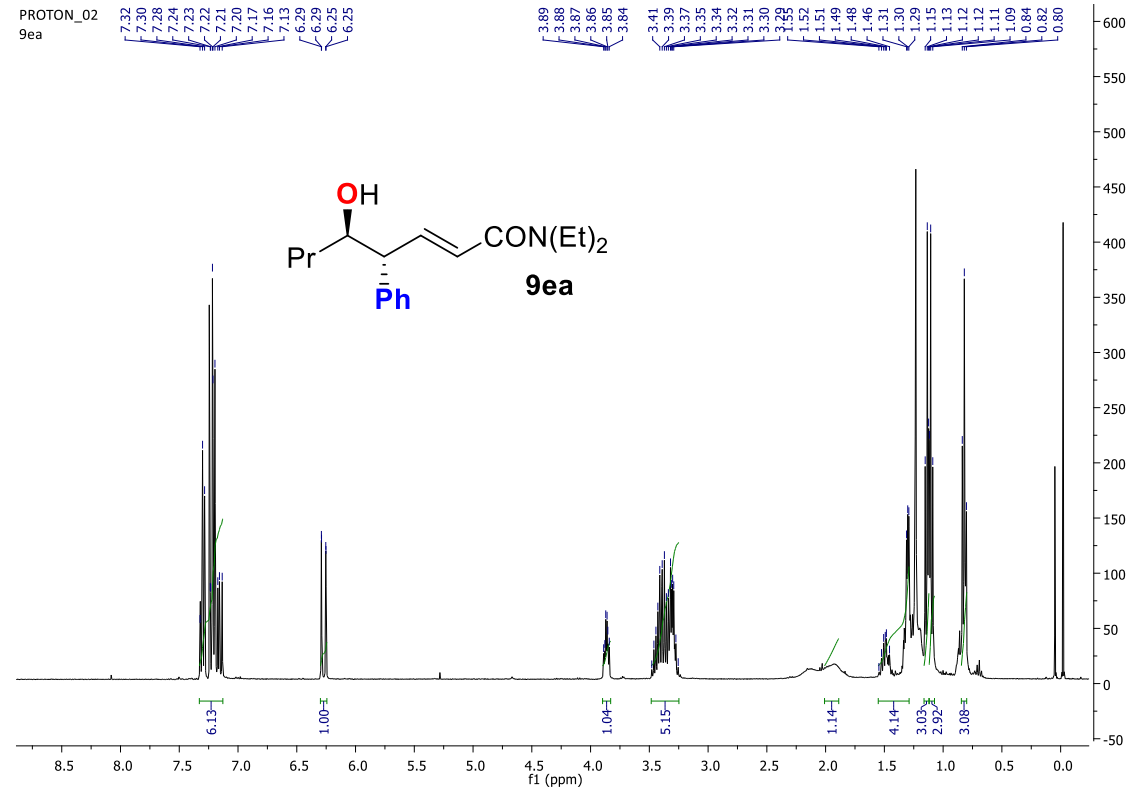

CARBON_01
9ba
167.1
147.1
140.4
137.1
136.5
128.9
128.8
128.6
128.4
128.2
127.7
127.4
126.9
126.6
122.6
77.4
77.1
76.8
70.5
57.7
50.0
48.6
21.0
f1 (ppm)

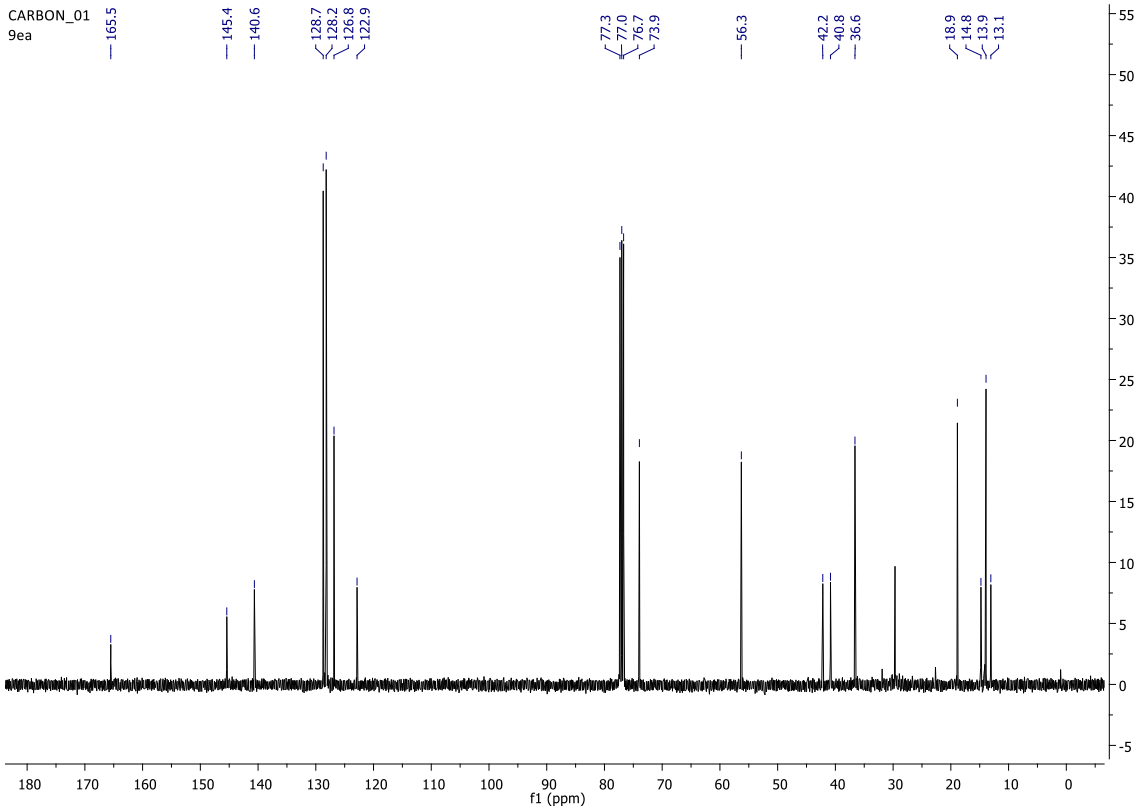

PROTON_01
9ca
7.31
7.29
7.27
7.22
7.20
7.20
7.18
7.05
7.03
7.02
6.99
6.30
6.26
4.06
4.05
4.03
4.03
4.01
3.99
3.70
3.31
3.29
3.27
2.64
1.32
1.17
1.06
1.04
OH
Me
Ph
CON(i-Pr)2
9ca
5.05
1.11
1.00
1.12
0.94
0.91
1.11
1.32
5.96
5.95
2.84
f1 (ppm)

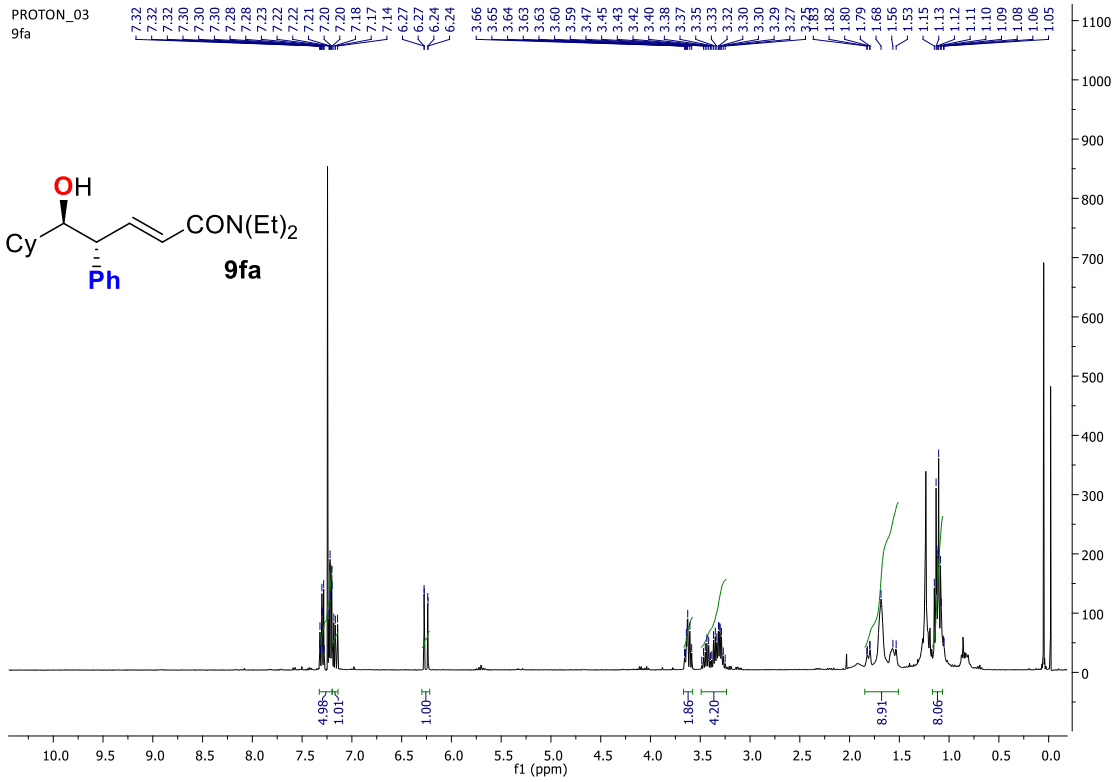

CARBON_01
9ca
166.0
143.9
140.6
128.7
128.2
126.9
125.6
77.3
77.0
76.7
70.5
58.0
48.2
45.8
21.4
20.8
20.6
f1 (ppm)

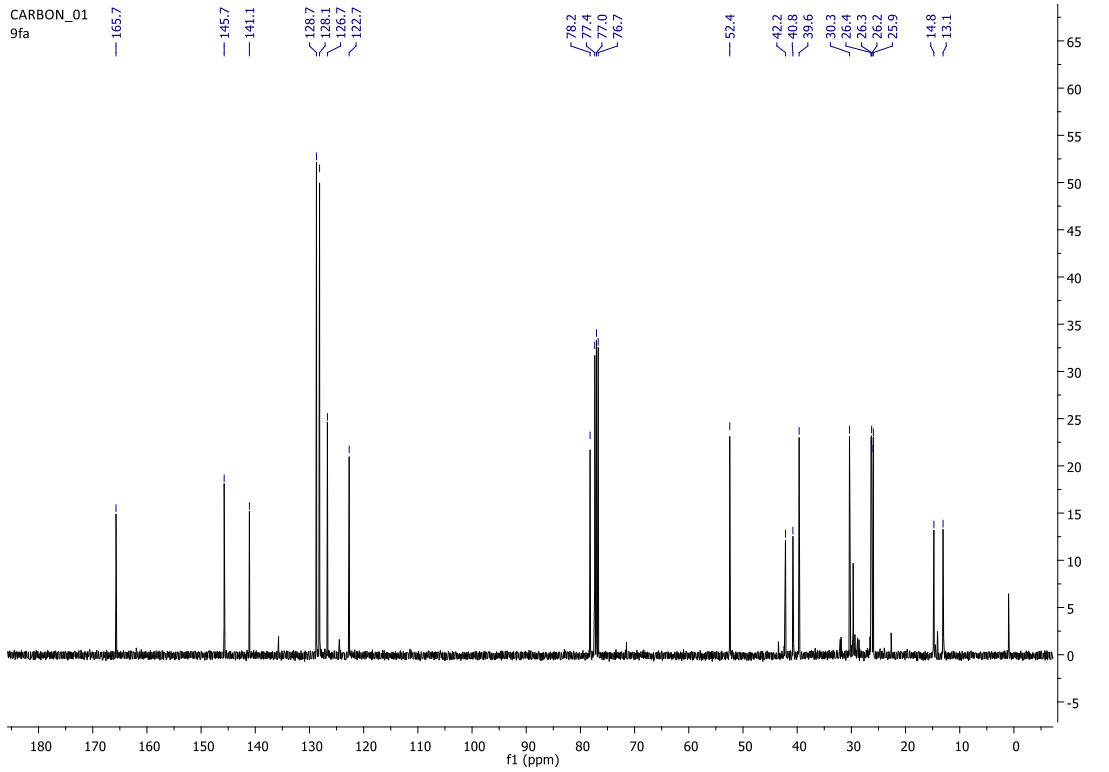

PROTON_01
9da
OH
Me
Ph
CON
9da
f1 (ppm)


CARBON_01
9da
f1 (ppm)


PROTON_02
9ea
OH
Pr
CON(Et)2
Ph
9ea
f1 (ppm)


CARBON_01
9ea
f1 (ppm)


PROTON_03
9fa
OH
Cy
CON(Et)2
Ph
9fa
f1 (ppm)


CARBON_01
9fa
f1 (ppm)