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Reactions of cyrene with formaldehyde

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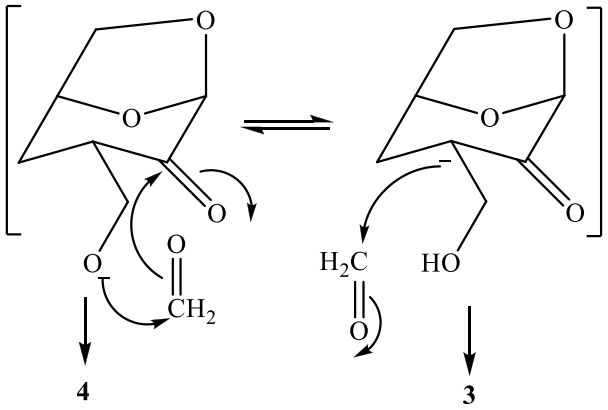
The spectral and analytical data were obtained using the equipment of the *Khimiya* Joint Center at the Institute of Organic Chemistry, Ufa Research Center, Russian Academy of Sciences. ^{1}H and ^{13}C NMR spectra were registered on a spectrometer Bruker Avance III, (500.13 MHz for ^{1}H and 125.47 MHz for ^{13}C). IR spectra were recorded on spectrophotometers Shimadzu IRPrestige-21 or Bruker Tensor 27 (from films or mulls in mineral oil). Mass spectra were recorded on a Shimadzu LCMS-2010 EV LC-MS system with one quadrupole in the positive and negative ion detection mode at a capillary potential of 4.5 and –3.5 kV, respectively, electrospray ionization, eluent MeCN–H_2O. Optical rotation was determined on a polarimeter Perkin Elmer-341. Analytic TLC was carried out on Sorbfil plates of the grade PTSKh-AF-A ('Sorbpolymer' Co., Krasnodar). The melting points were measured on a Boëtius 05 heating block.

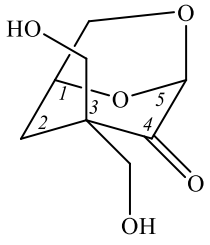
6,8-Dioxabicyclo[3.2.1]octan-4-one (cyrene) **1** was obtained from Circa, Melbourne, Australia. The authors are grateful to Circa Group for providing industrial grade cyrene.



Scheme S1 Probable mechanism of the formation of keto diol **3** and dioxane **4**

1,6-Anhydro-3,4-dideoxy-β-D-hexopyranose (2a,b). To a solution of LDA obtained for 30 min in an argon atmosphere at –10 °C from diisopropylamine (0.3 ml, 2.00 mmol), *n*-BuLi (1.9 M in hexane, 1.0 ml, 1.9 mmol) in THF (3.0 ml), a solution of cyrene **1** (0.20 g, 1.6 mmol) in THF (2.0 ml) was added at –40 °C, and stirring was continued for another 30 min at this temperature. Then the temperature was reduced to – 78 °C and formaldehyde was added to the solution for 2-3 minutes at this temperature (TLC control). Then the reaction mixture was treated with 3% HCl solution, the reaction products were extracted with ethyl acetate (3×5.0 ml), the combined organic layers were dried over $MgSO_4$, the solvent was distilled off, the residue was chromatographed on SiO_2. Yield 0.087 g (42%) in ratio β:α =15:1. $[\alpha]_D^{25}$ = – 118° (*c* 0.5, $CHCl_3$) {lit.[S6] $[\alpha]_D^{25}$ = – 134.2° (*c* 1.0, $CHCl_3$)}.

(1*S*,5*R*)-3,3-Bis(hydroxymethyl)-6,8-dioxabicyclo[3.2.1]octan-4-one (3), (1*R*,2*R*,9*S*)-3,5,11,12-tetraoxatricyclo[7.2.1.0^{2,7}]dodecan-2-ol (4), ((1*S*,4*R*,5*R*)-4-hydroxy-6,8-dioxabicyclo[3.2.1]octane-3,3-diyl)dimethanol (5).



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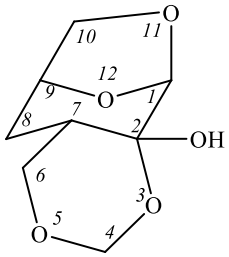

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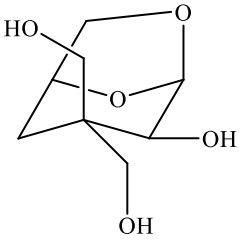

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Method a. Cyrene **1** (2.0 g, 0.0078 mol) was dissolved in formalin (35% aq, 12.0 ml, 0.032 mol), and catalytic amounts of K_2CO_3 (10% of the cyrene weight) was added. This was stirred at room temperature until the initial mixture disappeared (TLC control ~ 1 h). Then the reaction mixture was treated with 3% HCl solution, the products were extracted with ethyl acetate (3×10 ml), the combined organic layers were dried over $MgSO_4$, the solvent was distilled off, the residue was chromatographed on SiO_2, eluent petroleum ether–EtOAc, 3:1. Yield 1.28 g (44%) **3**, 0.72 g (25%) **4**, 0.69 g (23%) **5**.

Method b. Cyrene **1** (0.25 g, 0.002 mol) was dissolved in isopropyl alcohol (10 ml), and formalin (35 % aq., 2.3 ml) and Et_3N (2.8 ml) were added. This was stirred at room temperature until the initial mixture disappeared (TLC control, ~ 15 min). Then H_2O was added, the reaction products were extracted with ethyl acetate (3×10 ml), the combined organic layers were dried over $MgSO_4$, the solvent was distilled off, the residue was chromatographed on SiO_2, eluent petroleum ether–EtOAc, 3:1. Yield 0.14 g (36%) **3**, 0.086 g (23%) **4**.

Method c. Cyrene **1** (0.2 g, 0.002 mol) was dissolved in MeCN (2 ml), formalin (35% aq., 2.0 ml) and catalytic amounts of TMG (10% of the cyrene weight) were added. This was stirred at room temperature until the initial mixture disappeared (TLC control, ~ 20 min). Then water (3 ml) was added, the reaction products were extracted with ethyl acetate (3×4.0 ml), the combined organic layers were dried over $MgSO_4$, the solvent was distilled off, the residue was chromatographed on SiO_2, eluent petroleum ether–EtOAc, 3:1. Yield 0.13 g (45%) **3**, 0.036 g (12%) **4**, 0.043 g (15%) **5**.

Compound **3**: White crystals, m.p. 95 °C, $[\alpha]_D^{20}$ -75° (*c* 1.0, DMSO). R_f 0.24 (petroleum ether–EtOAc, 1:1). ^{1}H NMR (DMSO-d6), δ: 1.86 (d, 1H, $^2J_{2A,2B}$ 14.3, H^{2A}), 2.27 (dd, 1H, $^2J_{2B,2A}$ 14.3, $^3J_{2B,1}$ 5.5, H^{2B}), 3.21 (d, 1H, $^2J_{1'',1''A}$ 10.8, H$^{1''B}$), 3.24 (d, 1H, $^2J_{1'B,1'A}$ 10.4, H$^{1'B}$), 3.50 (d, 1H, $^2J_{1''A,1''B}$ 10.8, H$^{1''A}$), 3.54 (d, 1H, $^2J_{1'A,1'B}$ 10.4, H$^{1'A}$), 3.65 (dd, 1H, $^2J_{7B,7A}$ 7.2, $^3J_{7B,1}$ 5.5, H^{7B}), 3.92 (d, 1H, $^2J_{7A,7B}$ 7.2, H^{7A}), 4.75 (br.s., 1H, OH), 4.81 (t, 1H, $^3J_{1,7B}$ 5.5, $^3J_{1,2B}$ 5.5, H^1), 4.94 (br.s., 1H, OH), 4.97 (s, 1H, H^5). ^{13}C NMR (DMSO-d6), δ: 30.32 (C^2), 52.72 (C^3), 65.18 (C$^{1'}$), 65.35 (C$^{1''}$), 68.30 (C^7), 73.05 (C^1), 99.91 (C^5), 203.51 (C=O).

Mass spectrum, *m/z*: 187.1 [*M*-H]$^-$. Calcd for $C_8H_{12}O_5$. 188.18.

IR: 3431, 2959, 1722, 1173, 1119, 1028, 972, 754 cm^{-1}.

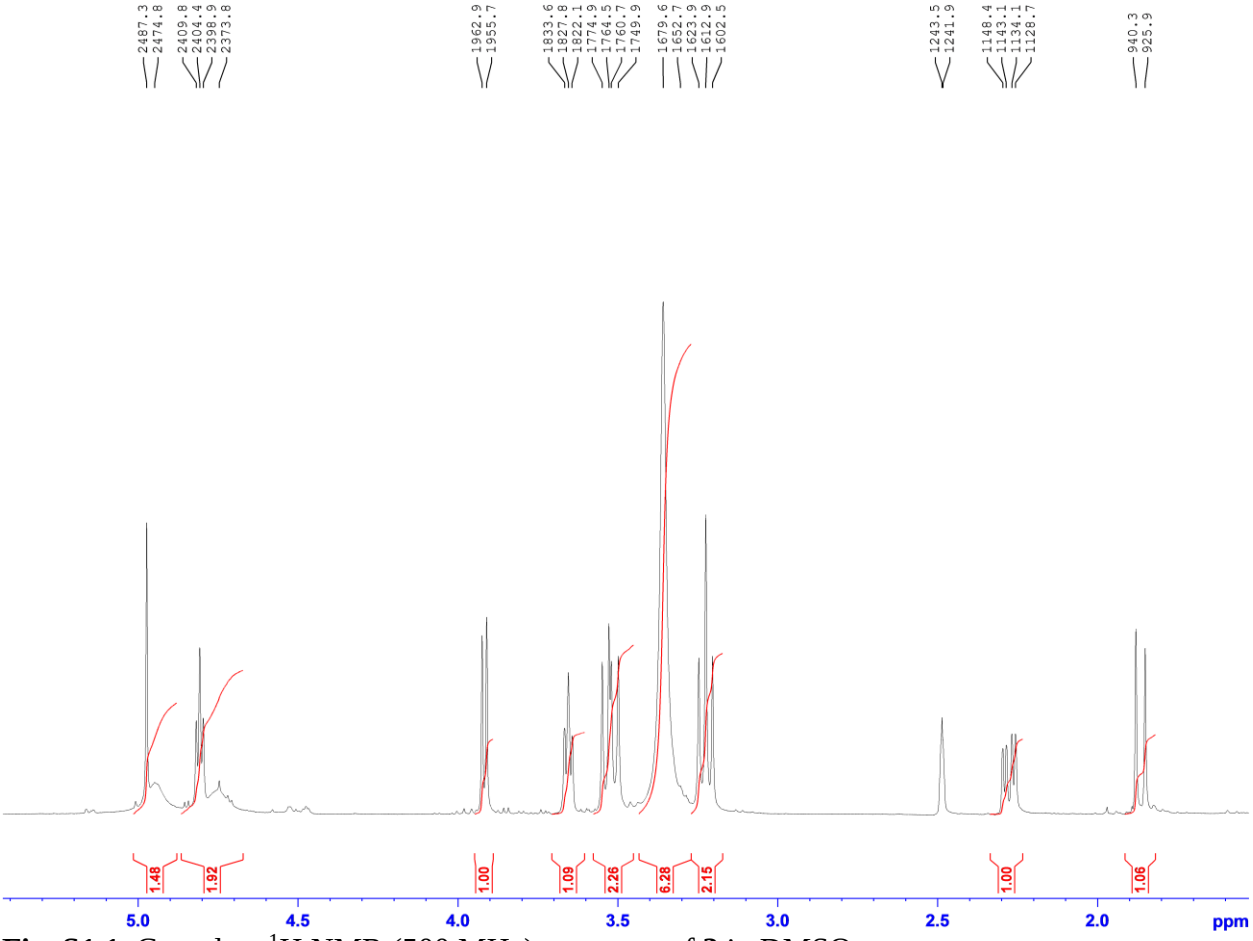


Fig. S1.1. Complete ^{1}H NMR (500 MHz) spectrum of **3** in DMSO

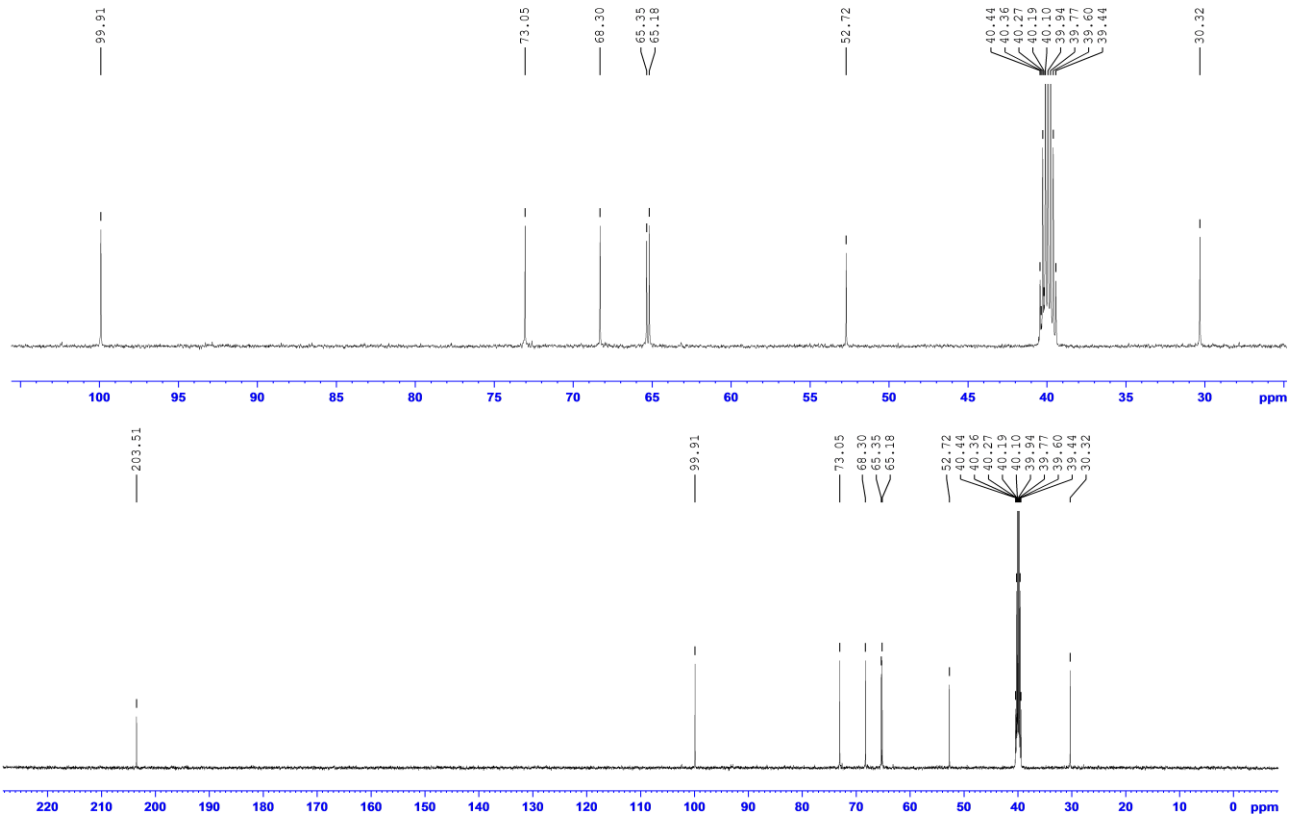


Fig. S1.2. Complete ^{13}C{^{1}H} NMR spectrum of **3** in DMSO

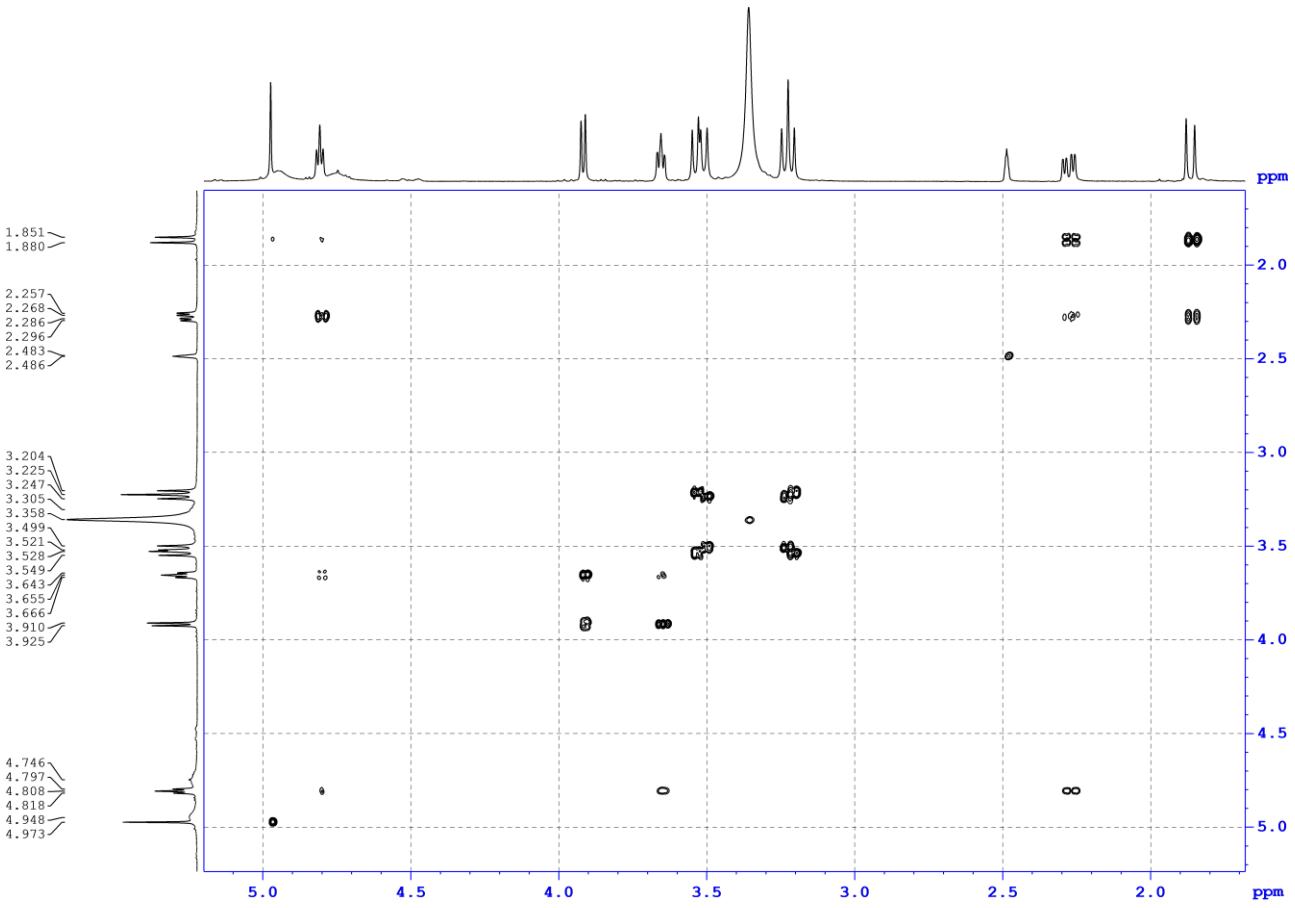


Fig. S1.3. Complete {^{1}H,^{1}H} COSY NMR spectrum of **3** in DMSO

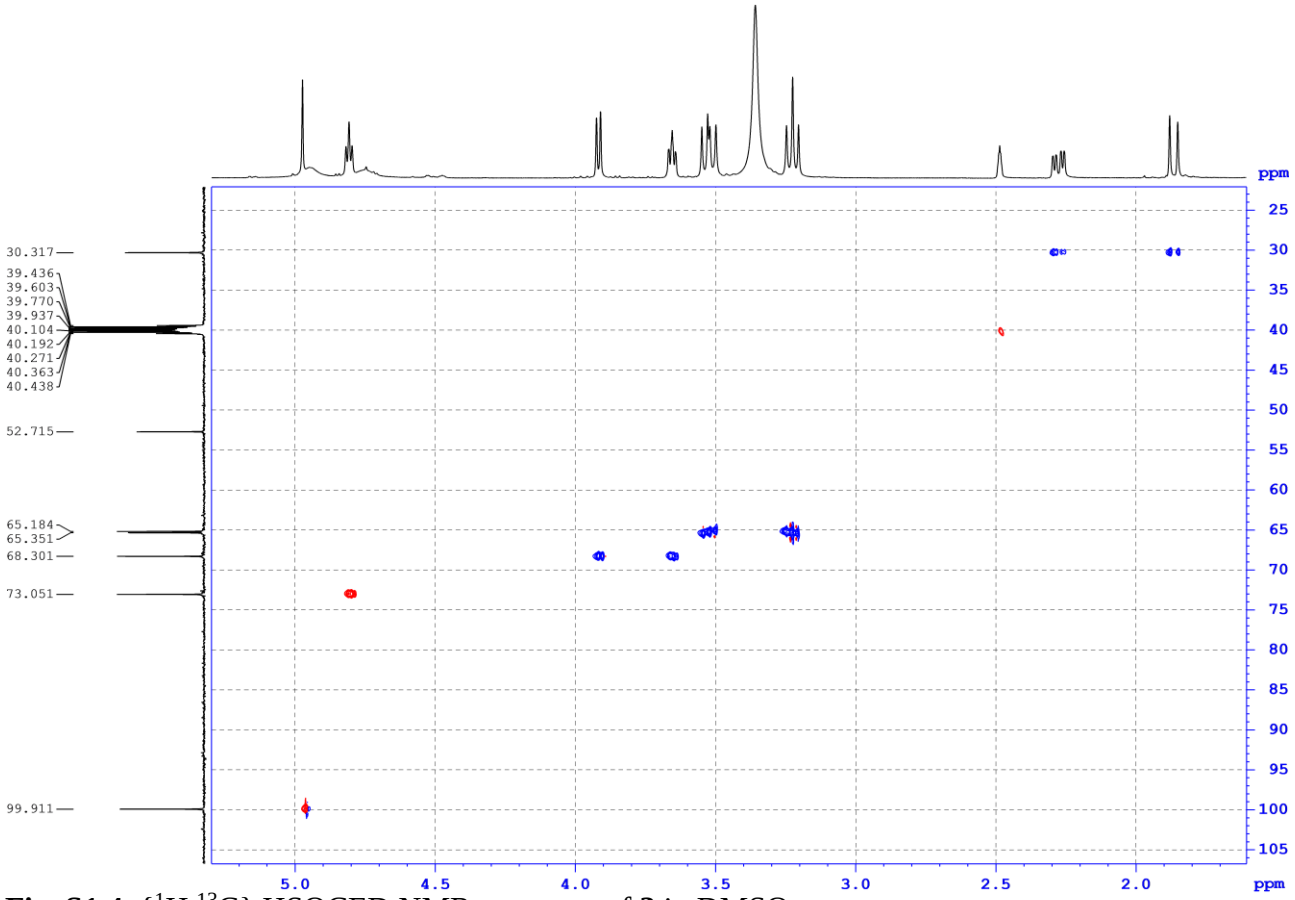


Fig. S1.4. {^{1}H,^{13}C} HSQCED NMR spectrum of **3** in DMSO

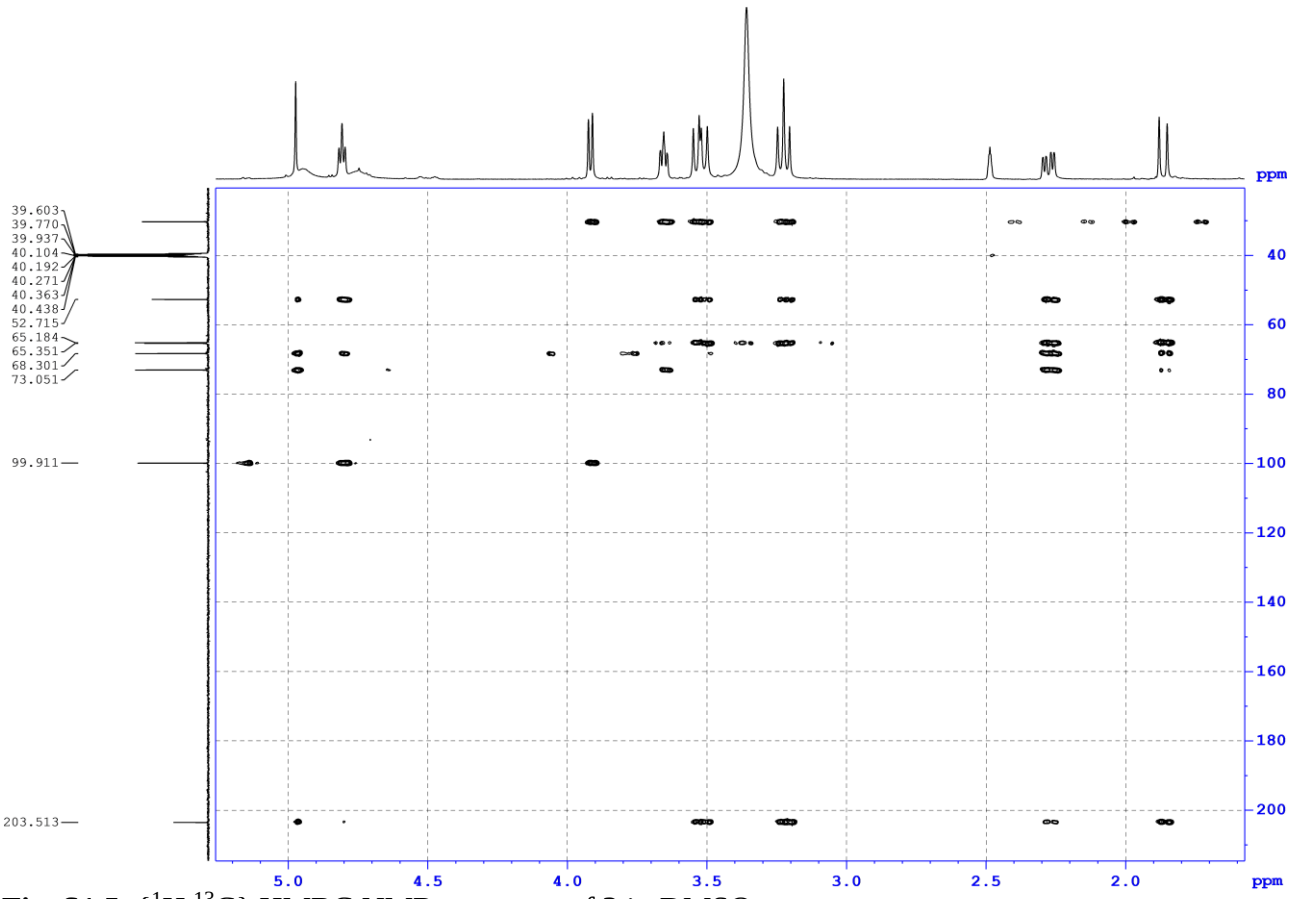


Fig. S1.5. {^{1}H,^{13}C} HMBC NMR spectrum of **3** in DMSO

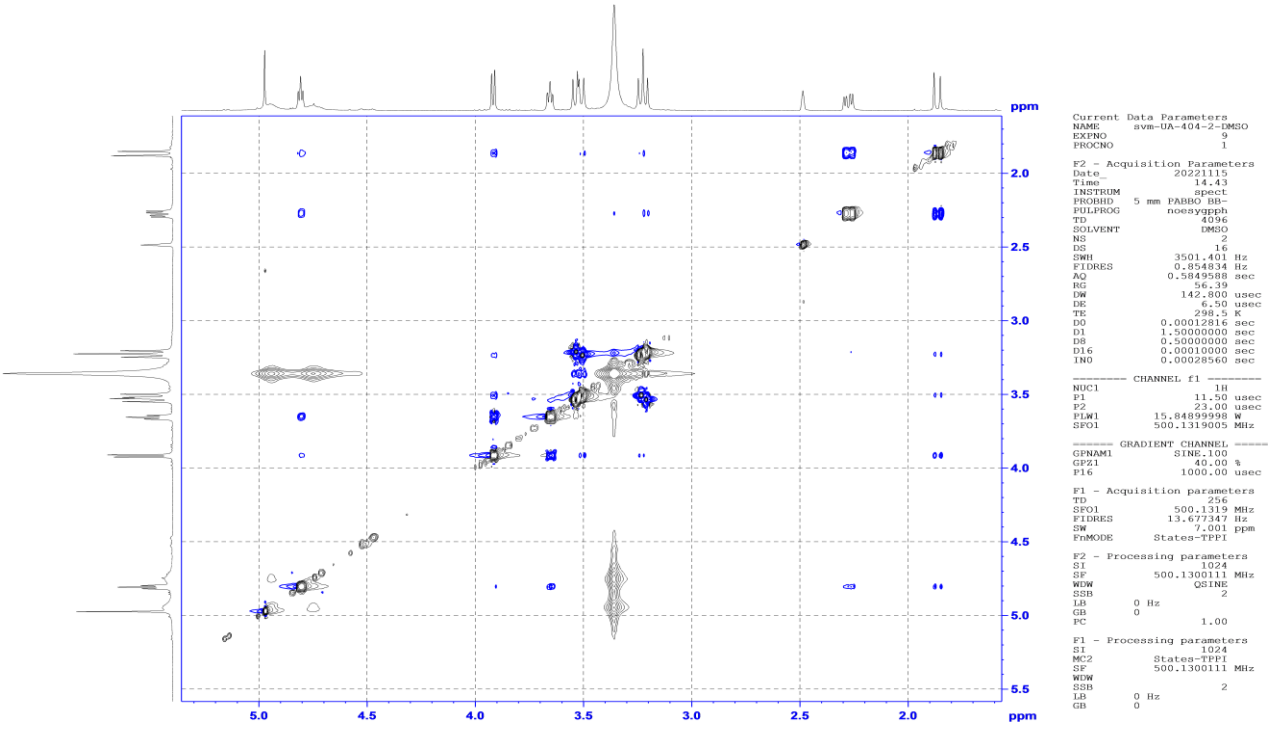


Fig. S1.6. Complete {^{1}H,^{1}H} NOESY NMR spectrum of **3** in DMSO

Compound **4**: White crystals, m.p. 91 °C, $[\alpha]_D^{20}$ -32.3° (*c* 1.0, $CHCl_3$). R_f 0.3 (petroleum ether–EtOAc, 1:1). ^{1}H NMR ($CDCl_3$), δ: 1.51 (ddd, 1H, $^2J_{8B,8A}$ 13.6, $^3J_{8B,9}$ 1.5, $^3J_{8B,7}$ 6.0, H^{8B}), 1.79-1.85 (m, 1H, H^7), 2.41 (dt, 1H, $^2J_{8A,8B}$ 13.6, $^3J_{8A,1}$ 13.6, $^3J_{8A,7}$ 1.8, H^{8A}), 3.21 (br.s, 1H, OH), 3.59 (d, 1H, $^2J_{6B,6A}$ 11.6, H^{6B}), 3.79 (dd, 1H, $^2J_{10B,10A}$ 7.6, $^3J_{10B,9}$ 5.1, H^{10B}), 3.86 (d, 1H, $^2J_{10A,10B}$ 7.6, H^{10A}), 4.19 (dd, 1H, $^2J_{6A,6B}$ 11.6, $^3J_{6A,7}$ 3.0, H^{6A}), 4.58-4.62 (m, 1H, H^9), 4.84 (d, 1H, $^2J_{4B,4A}$ 5.8, H^{4B}), 4.98 (s, 1H, H^1), 5.11 (d, 1H, $^2J_{4A,4B}$ 5.8, H^{4A}). ^{13}C NMR ($CDCl_3$), δ: 29.49 (C^8), 31.90 (C^7), 66.57 (C^6), 67.89 (C^{10}), 72.91 (C^9), 87.42 (C^4), 91.76 (C^2), 102.18 (C^1).

Mass spectrum, *m/z*: 187.1 $[M\text{-H}]^-$. Calcd for $C_8H_{12}O_5$. 188.18.

IR: 3422, 2959, 1730, 1281, 1115, 1015, 966, 494 cm^{-1}.

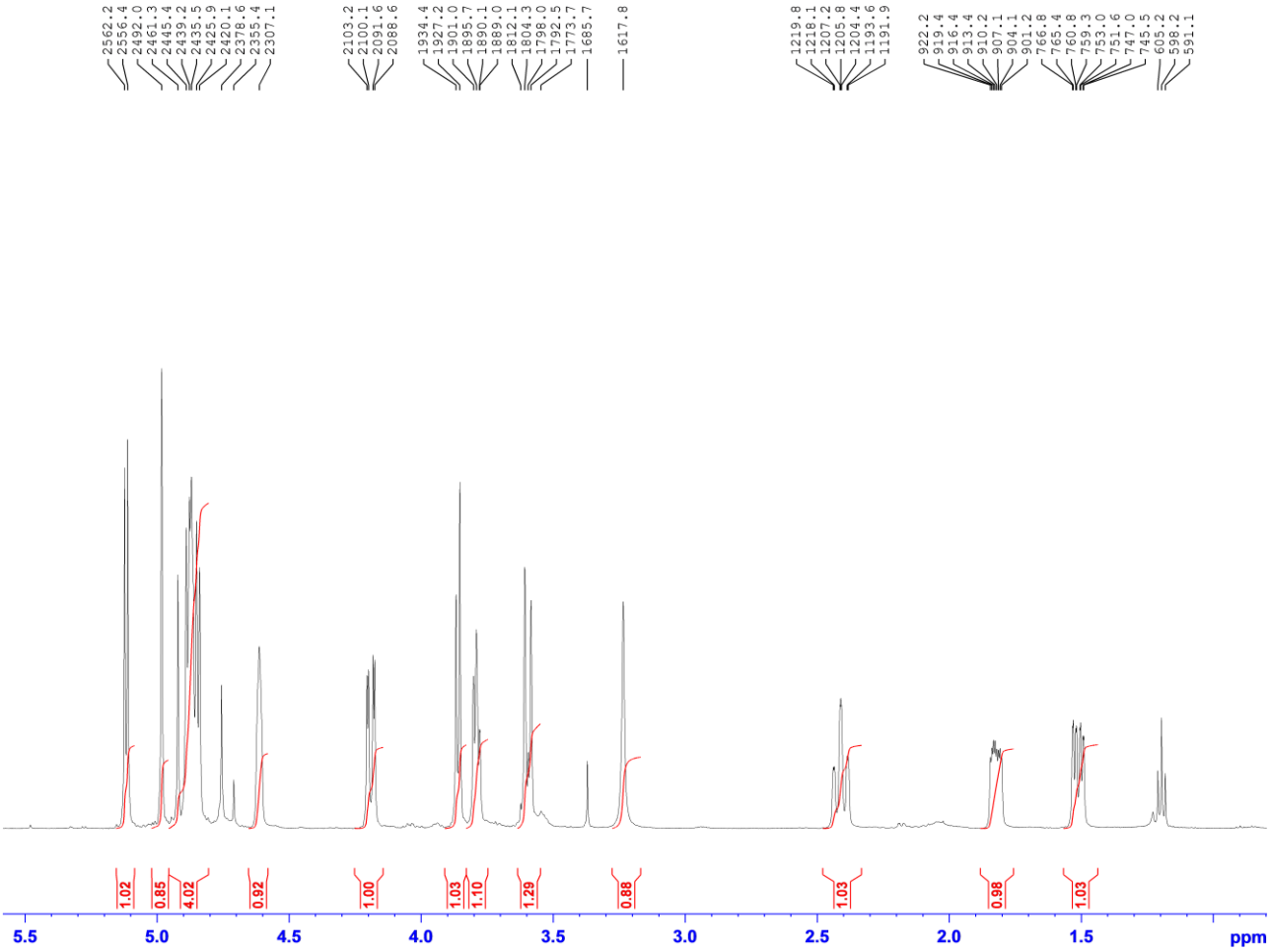


Fig. S2.1. Complete ^{1}H NMR (500 MHz) spectrum of **4** in $CDCl_3$

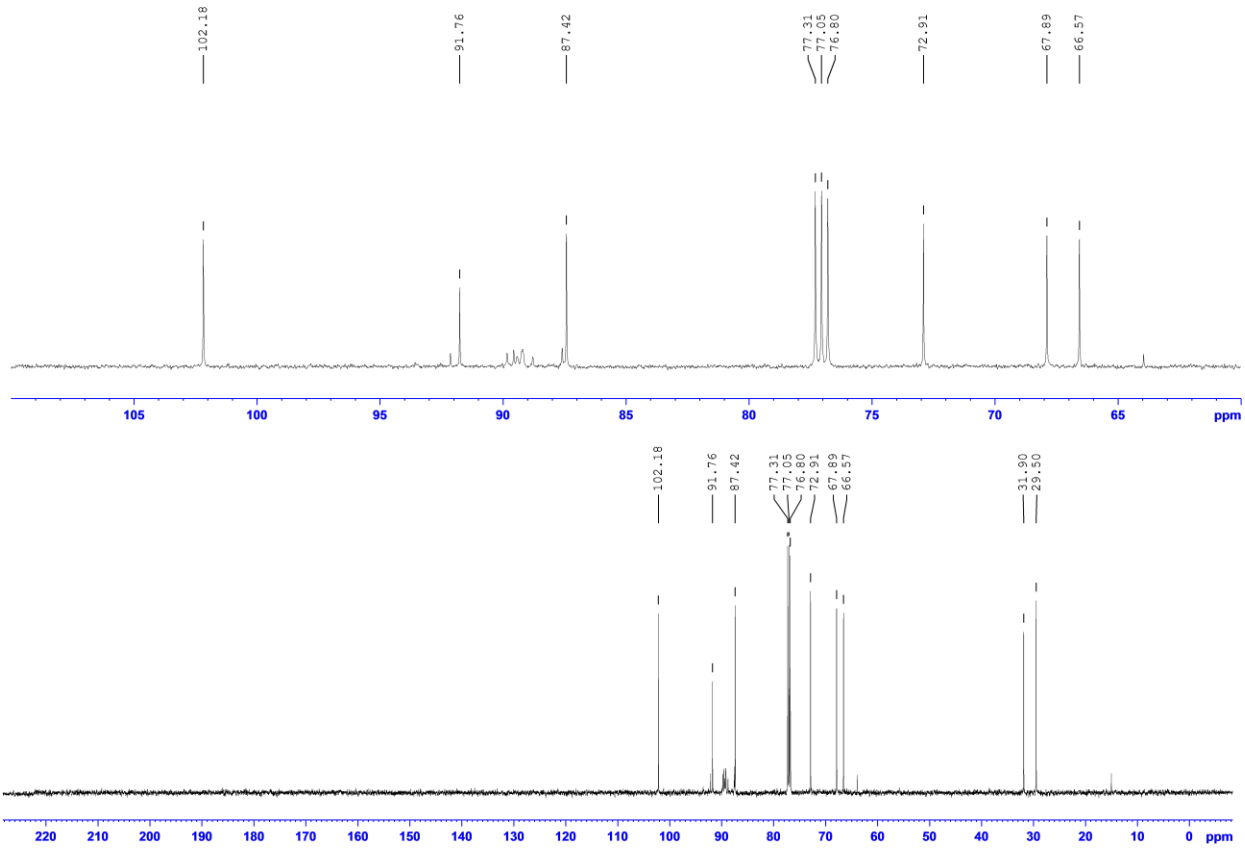


Fig. S2.2. Complete $^{13}C\{^{1}H\}$ NMR spectrum of **4** in $CDCl_3$

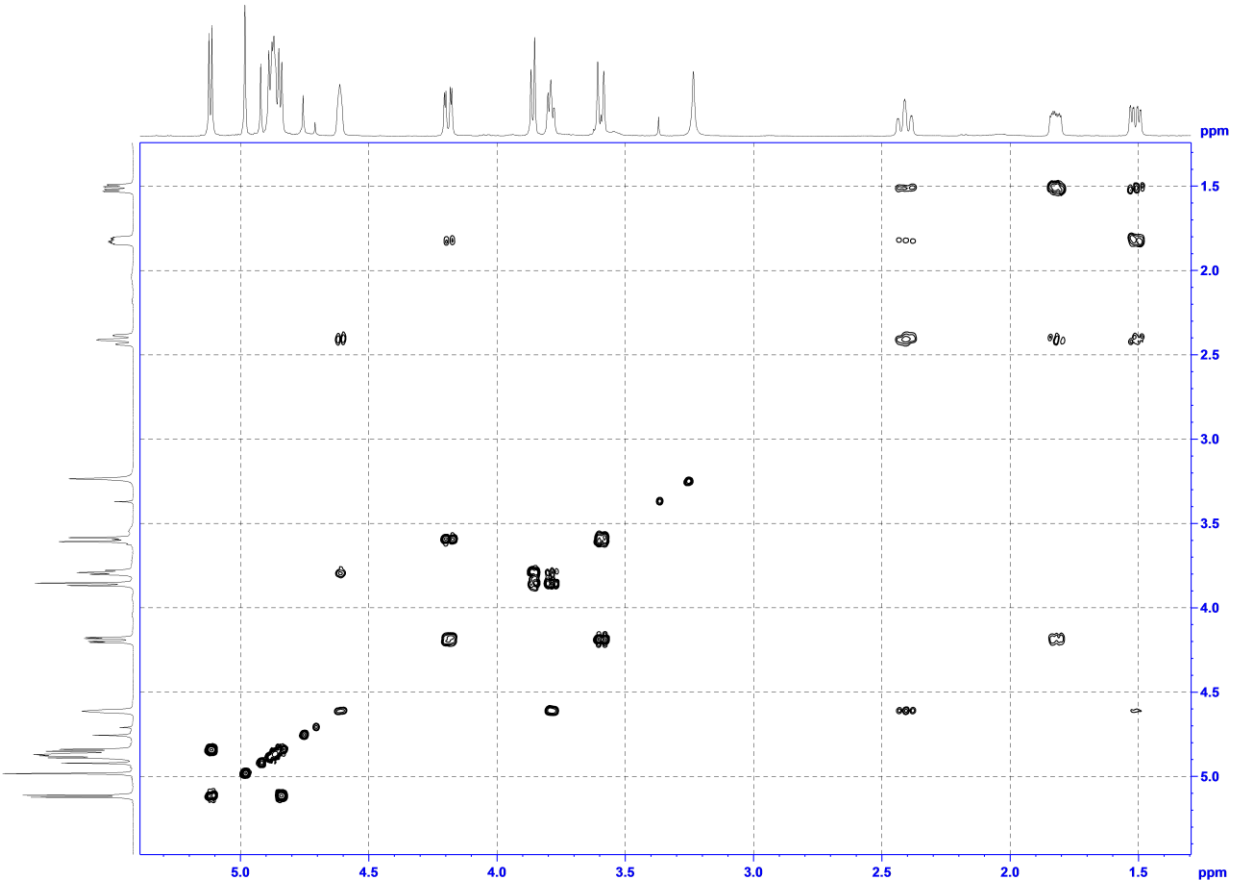


Fig. S2.3. Complete $\{^{1}H,^{1}H\}$ COSY NMR spectrum of **4** in $CDCl_3$

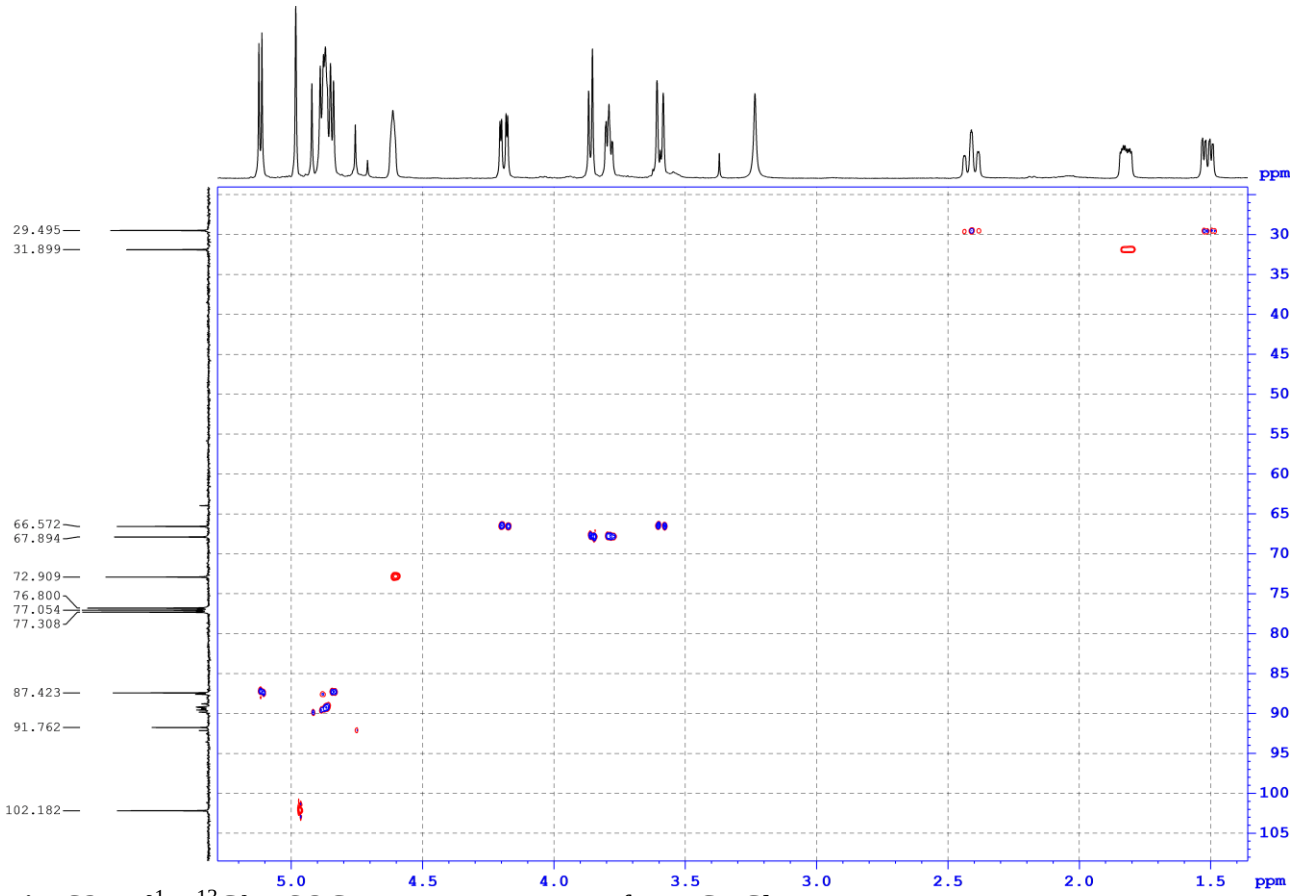


Fig. S2.4. {^{1}H,^{13}C} HSQCED NMR spectrum of **4** in $CDCl_3$

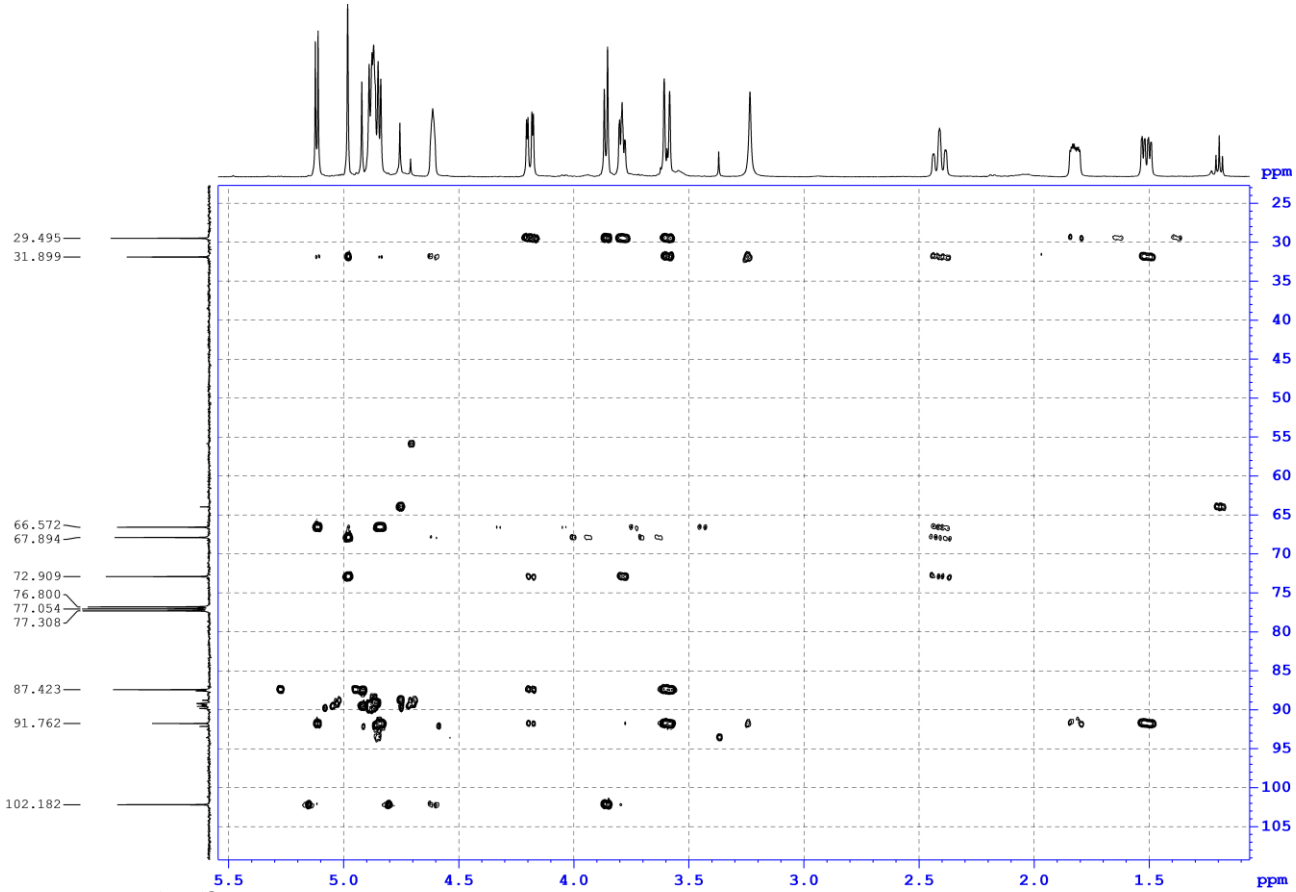


Fig. S2.5. {^{1}H,^{13}C} HMBC NMR spectrum in of **4** $CDCl_3$

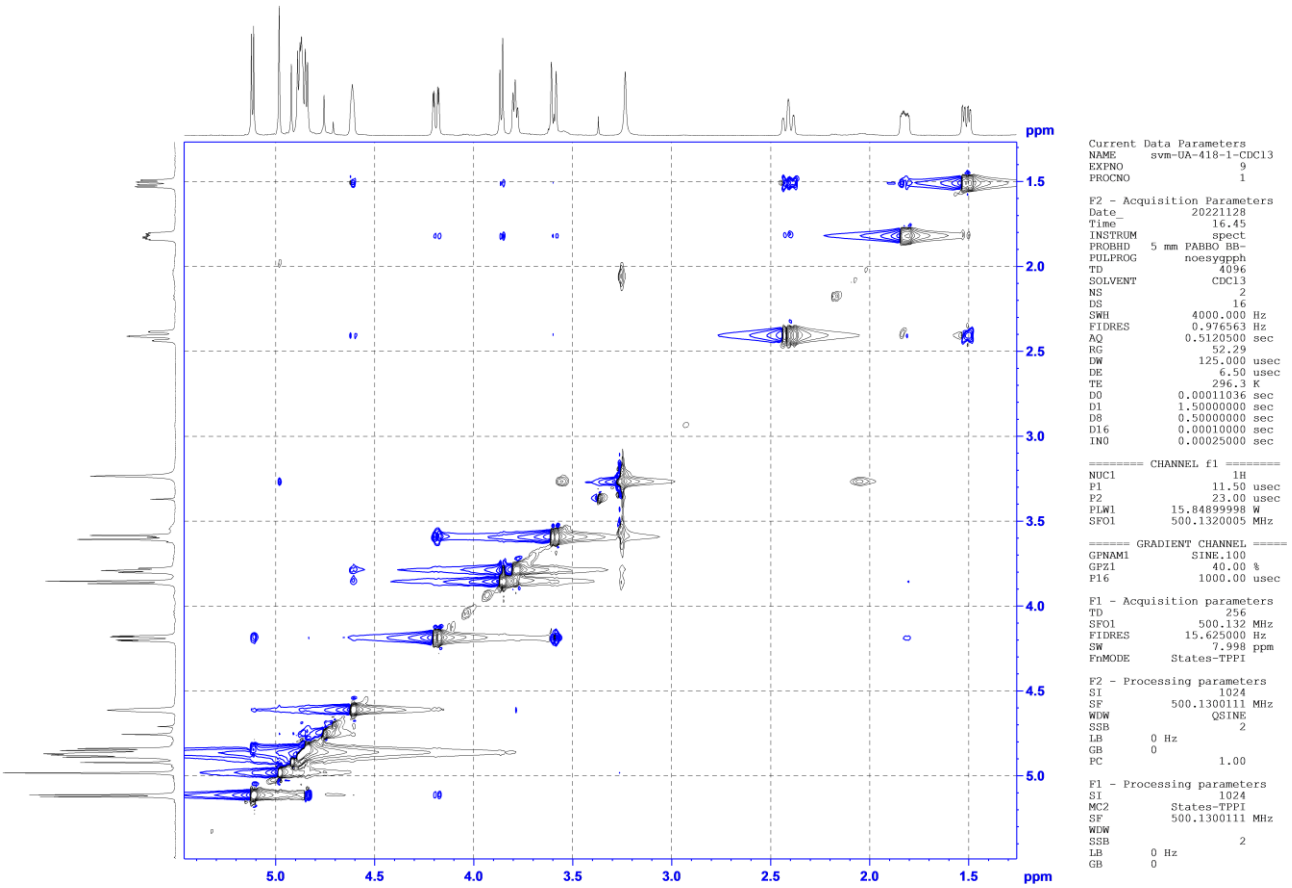


Fig. S2.6. Complete {^{1}H,^{1}H} NOESY NMR spectrum of **4** in $CDCl_3$

Compound **5**: White crystals, m.p. 128-130 °C, $[\alpha]_D^{20}$ -61.5° (*c* 1.0, DMSO). R_f 0.1 (petroleum ether–EtOAc, 1:1). ^{1}H NMR (DMSO-d6), δ: 1.65 (dd, 1H, $^2J_{2B,2A}$ 14.3, $^3J_{2B,1}$ 3.8, H^{2B}), 1.70 (d, 1H, $^2J_{2A,2B}$ 14.3, H^{2A}), 3.19 (d, 1H, $^2J_{1''B,1''A}$ 10.4, H$^{1''B}$), 3.26 (d, 1H, $^2J_{1''A,1''B}$ 10.4, H$^{1''A}$), 3.38 (d, 1H, $^2J_{1'B,1'A}$ 11.7, H$^{1'B}$), 3.50 (dd, 1H, $^2J_{7B,7A}$ 7.0, $^3J_{7B,1}$ 3.8, H^{7B}), 3.56 (d, 1H, $^3J_{4,5}$ 1.6, H^4), 3.65 (d, 1H, $^2J_{1'A,1'B}$ 11.7, H$^{1'A}$), 3.78 (d, 1H, $^2J_{7A,7B}$ 7.0, H^{7A}), 4.42 (t, 1H, $^3J_{1,7B}$ 3.8, $^3J_{1,2B}$ 3.8, H^1), 5.11 (d, 1H, $^3J_{5,4}$ 1.6, H^5). ^{13}C NMR (DMSO-d6), δ: 28.80 (C^2), 43.17 (C^3), 62.03 (C$^{1'}$), 65.33 (C$^{1''}$), 67.97 (C^7), 70.35 (C^4), 73.18 (C^1), 102.85 (C^5).

Mass spectrum, *m/z*: 189.2 [*M*-H]$^-$. Calcd for $C_8H_{14}O_5$. 190.19

IR: 3347, 1589, 1462, 1119, 1042, 964, 827 cm^{-1}.

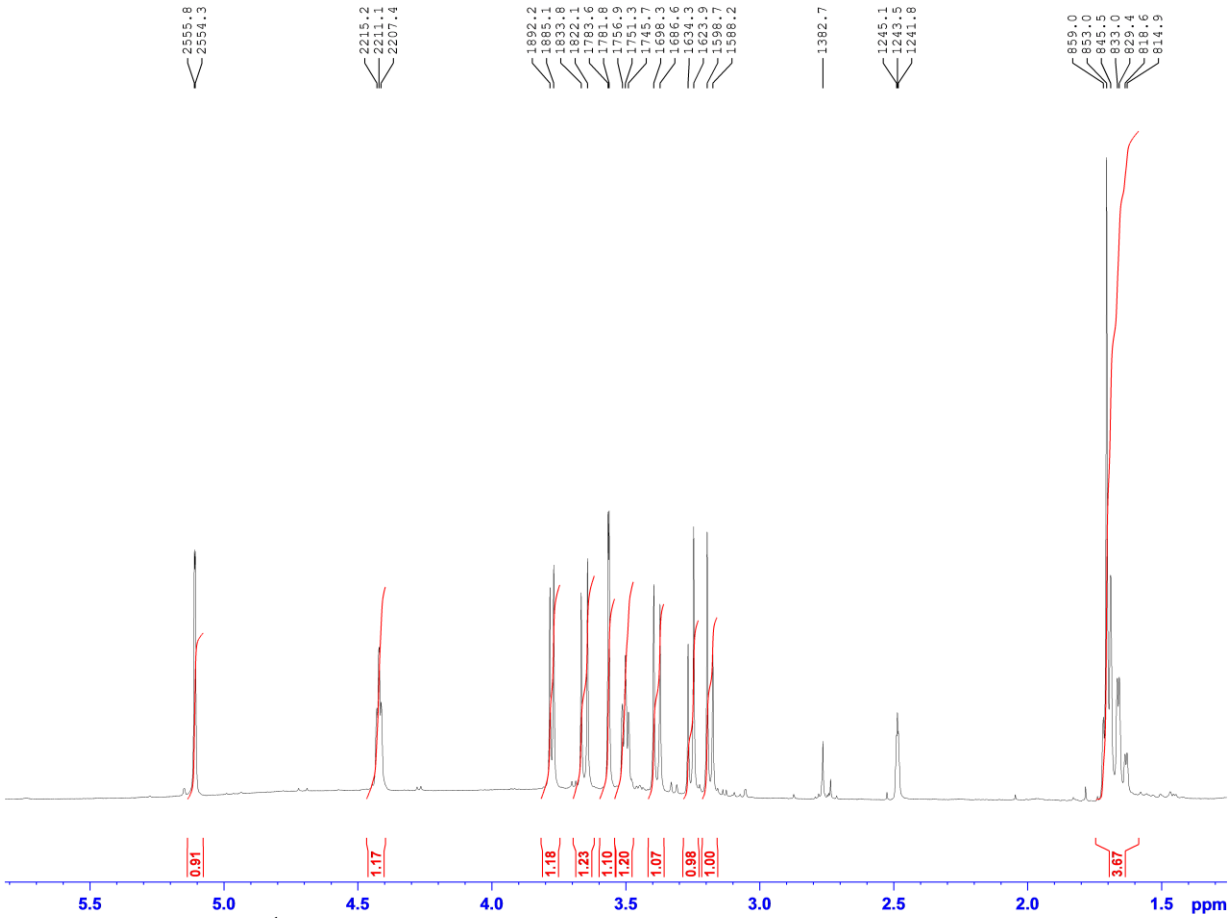


Fig. S3.1. Complete ^{1}H NMR (500 MHz) spectrum of **5** in DMSO

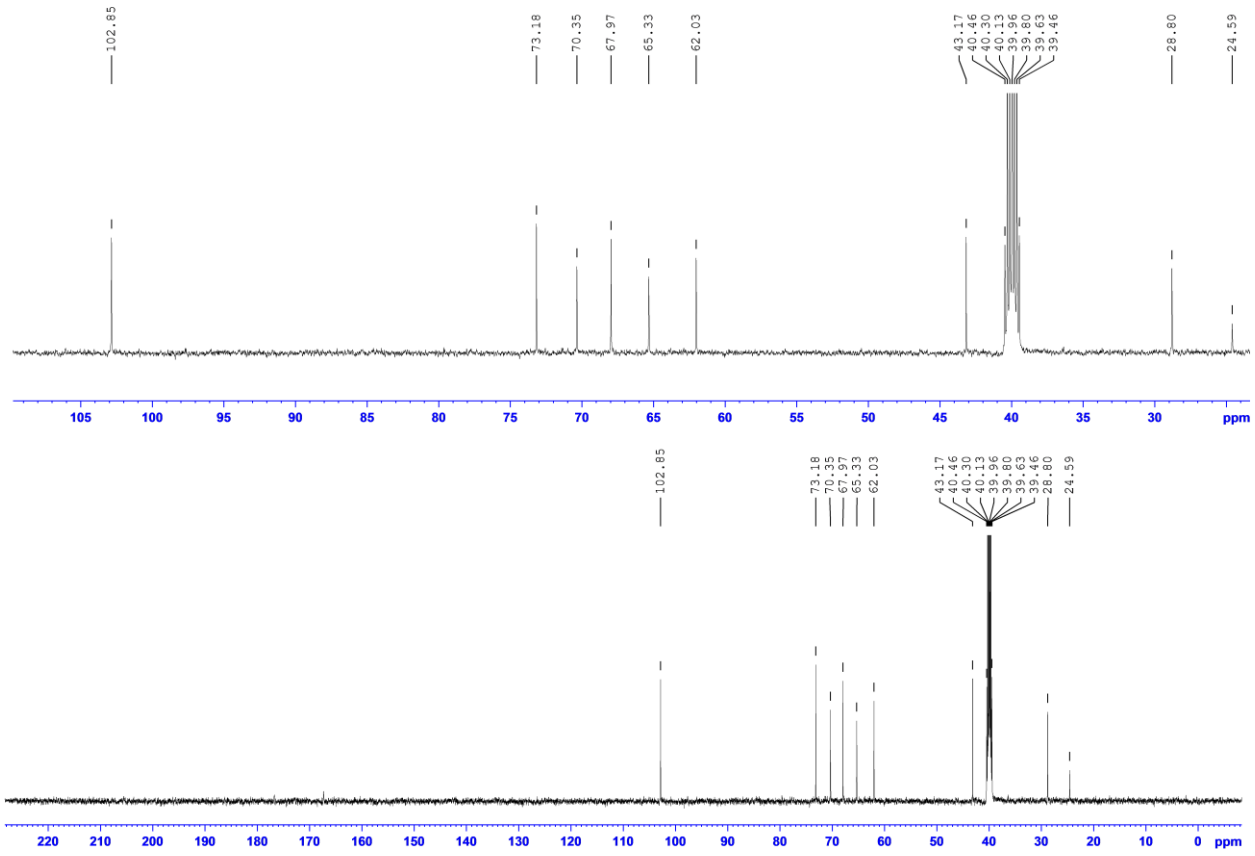


Fig. S3.2. Complete ^{13}C{^{1}H} NMR spectrum of **5** in DMSO

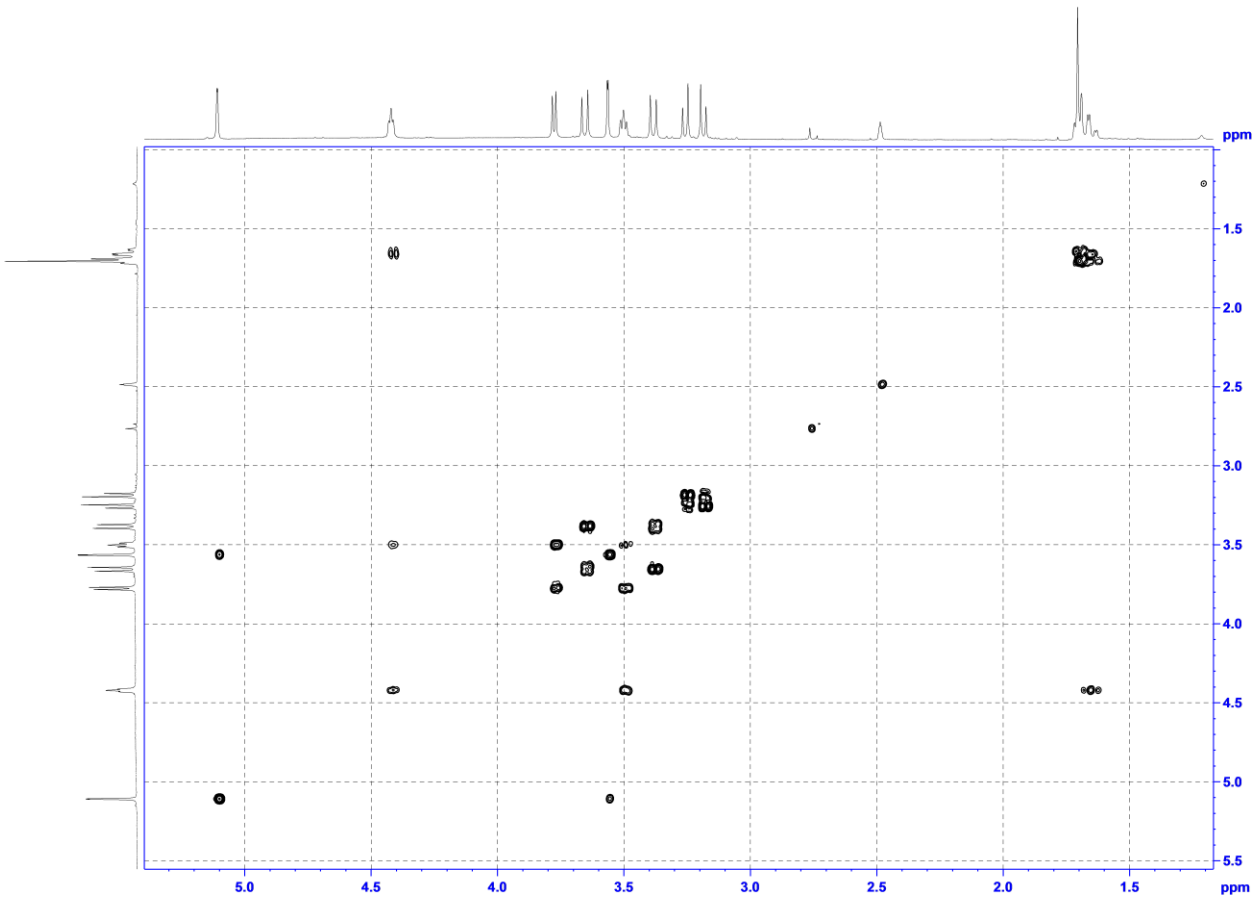


Fig. S3.3. Complete {^{1}H,^{1}H} COSY NMR spectrum of **5** in DMSO

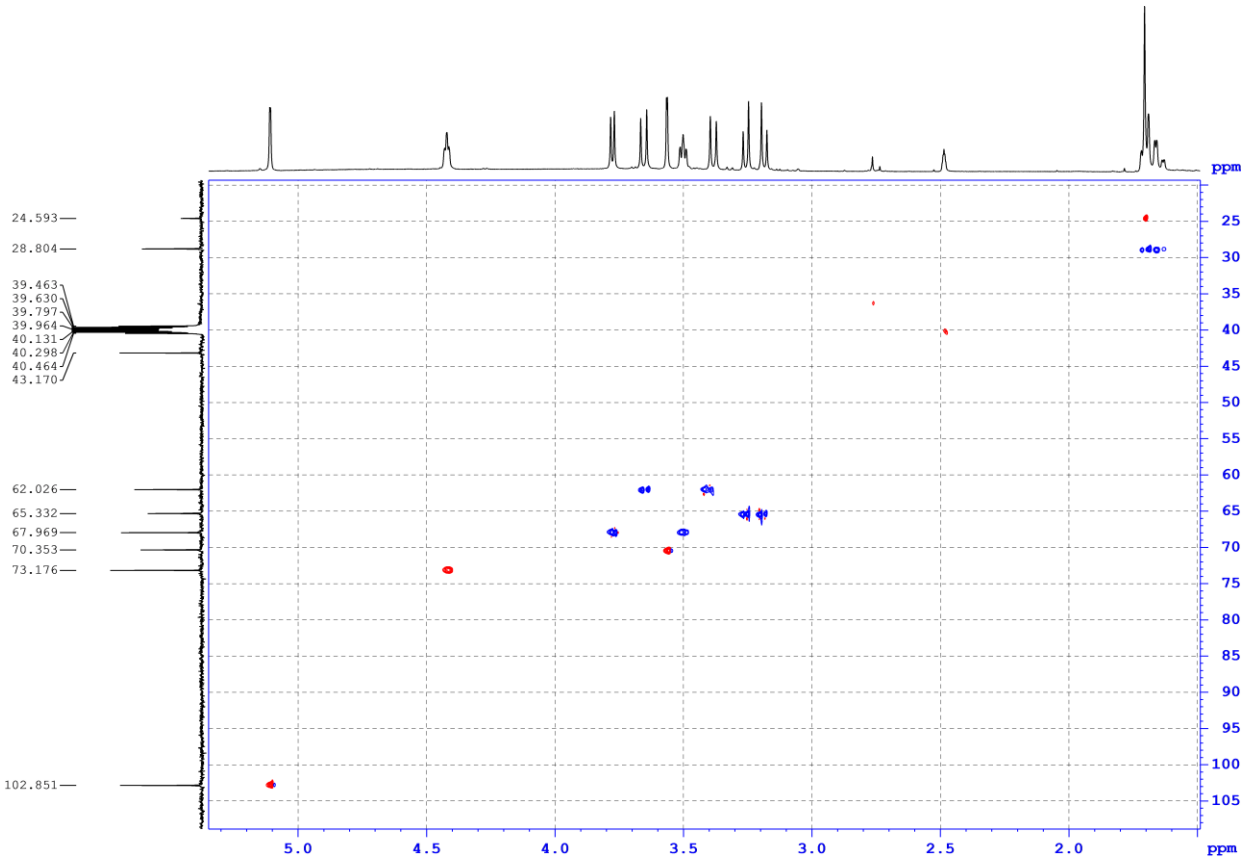


Fig. S3.4. {^{1}H,^{13}C} HSQCED NMR spectrum of **5** in DMSO

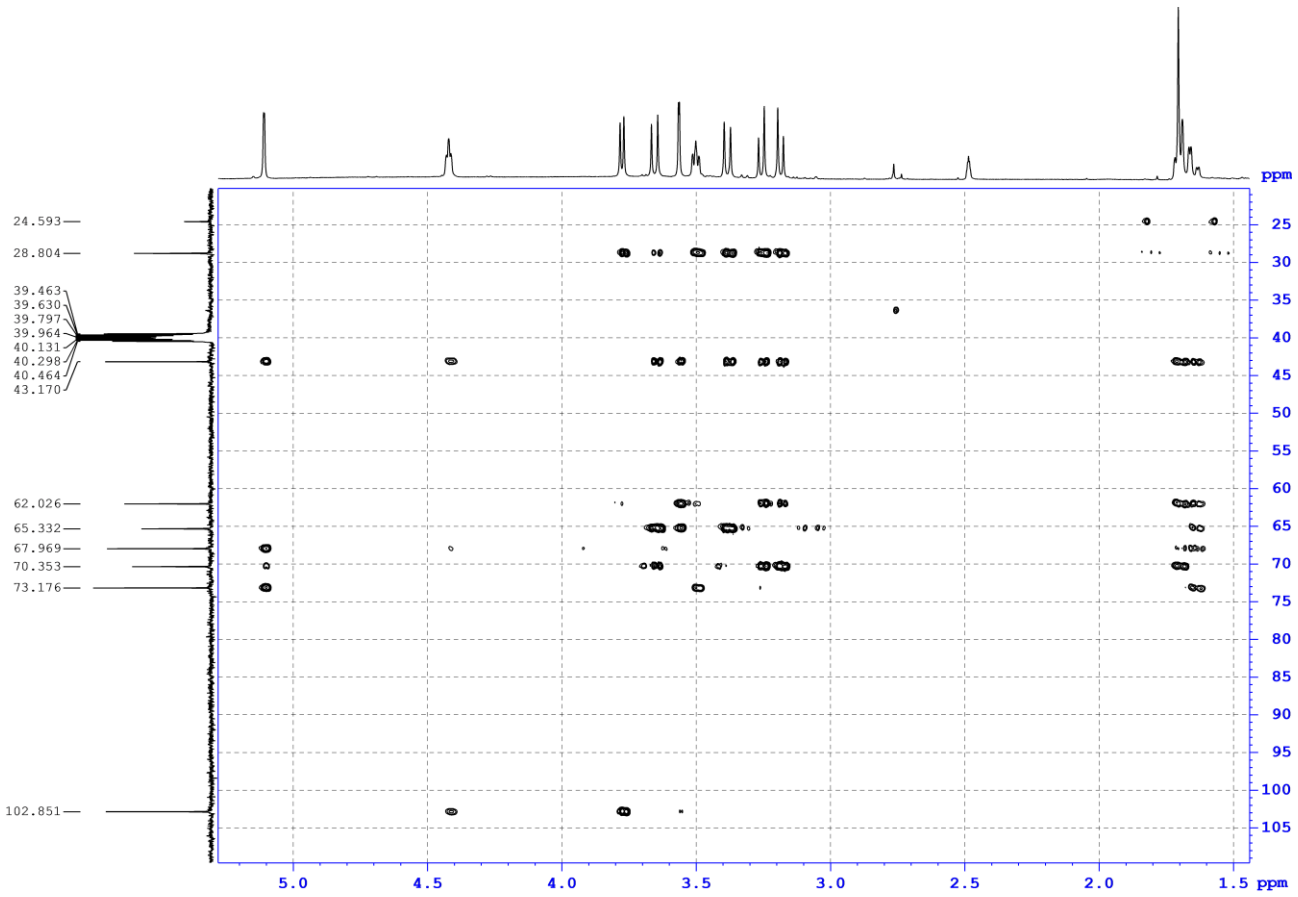


Fig. S3.5. {^{1}H,^{13}C} HMBC NMR spectrum of **5** in DMSO

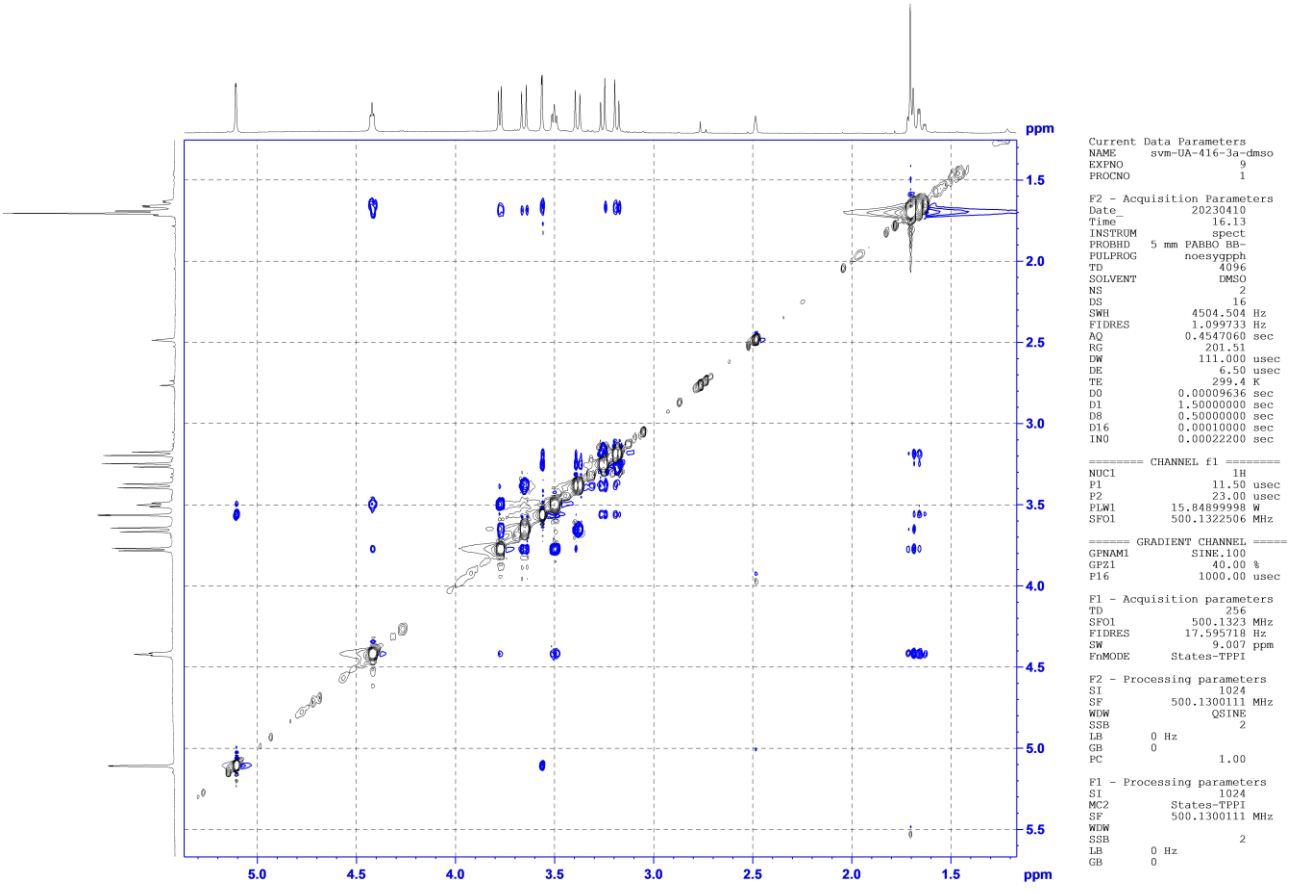


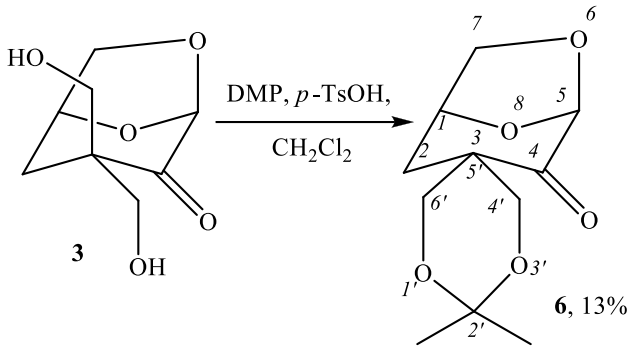
Fig. S3.6. Complete {^{1}H,^{1}H} NOESY NMR spectrum of **5** in DMSO

Transformation of keto diol 3 into triol 5

Method a. Keto diol **3** (0.024 g, 0.00013 mol) was dissolved in MeCN (1.0 ml), formalin (35% aq, 0.13 ml) and catalytic amounts of TMG (10% of the diol weight) were added. This was stirred at room temperature until the initial mixture disappeared (TLC control, ~ 30 min). Water (2 ml) was added, the reaction products were extracted with ethyl acetate (3×2.0 ml), the combined organic layers were dried over $MgSO_4$, the solvent was distilled off, the residue was chromatographed on SiO_2, eluent petroleum ether–EtOAc, 1:1. Yield 0.018 g (75%).

Method b. Keto diol **3** (0.04 g, 0.00021 mol) was dissolved in MeCN (1.0 ml), and catalytic amounts of TMG (10% of the diol weight) was added. This was stirred at room temperature until the initial mixture disappeared (TLC control, ~ 30 min). Water (2 ml) was added, the reaction products were extracted with ethyl acetate (3×2.0 ml), the combined organic layers were dried over $MgSO_4$, the solvent was distilled off, the residue was chromatographed on SiO_2, eluent petroleum ether–EtOAc, 1:1. Yield 0.010 g (24%).

(1*S*,5*R*)-2',2'-Dimethyl-6,8-dioxaspiro[bicyclo[3.2.1]octane-3,5'-[1,3]dioxan]-4-one (6).



To a solution of keto diol **3** (0.1 g, 0.5 mmol) in CH_2Cl_2 (2.0 ml) at room temperature, 2,2-dimethoxypropane (DMP, 0.2 g, 1.9 mmol) and catalytic amounts of *p*-TsOH (10% of the **3** weight) were added. This was stirred at room temperature until the initial mixture disappeared (TLC control, ~ 6 h). Then the reaction mixture was treated with H_2O (2 ml), the products were extracted with ethyl acetate (3×5.0 ml), the combined organic layers were dried over $MgSO_4$, the solvent was distilled off, the residue was chromatographed on SiO_2, eluent petroleum ether–EtOAc, 5:1. Yield 0.016 g (13%). White crystals, m.p. 133 °C, $[\alpha]_D^{20}$ -111° (*c* 1.0, $CHCl_3$). R_f 0.3 (petroleum ether–EtOAc, 1:1). ^{1}H NMR ($CDCl_3$), δ: 1.39 (s, 3H, CH_3), 1.48 (s, 3H, CH_3), 2.29 (ddt, 1H, $^2J_{2B,2A}$ 15.0, $^3J_{2B,1}$ 5.2, $^4J_{2B,7B}$ 1.4, $^4J_{2B,4'B}$ 1.4, H^{2B}), 2.56 (d, 1H, $^2J_{2A,2B}$ 15.0, H^{2A}), 3.48 (d, 1H, $^2J_{6'B,6'A}$ 11.5, $^3J_{6'B,4'B}$ 2.8, $H^{6'B}$), 3.71 (dd, 1H, $^2J_{4'B,4'A}$ 11.5, $^3J_{4'B,6'B}$ 2.8, $H^{4'B}$), 3.85 (ddd, 1H, $^2J_{7B,7A}$ 7.0, $^3J_{7B,1}$ 5.2, $^3J_{7B,2}$ 1.4, H^{7B}), 4.00 (dd, 1H, $^2J_{7A,7B}$ 7.0, $^4J_{7A,2B}$ 1.4, H^{7A}), 4.02 (d, 1H, $^2J_{4'A,4'B}$ 11.5, $H^{4'A}$), 4.38 (d, 1H, $^2J_{6'A,6'B}$ 11.5, $H^{6'A}$), 4.82 (t, 1H, $^3J_{1,7B}$ 5.2, $^3J_{1,2A}$ 5.2, H^1), 5.08 (s, 1H, H^5). ^{13}C NMR ($CDCl_3$), δ: 18.39 (CH_3), 28.80 (CH_3), 34.71 (C^2), 44.83 (C^3), 67.67 ($C^{4'}$), 68.10 (C^7), 68.36 (C^1), 98.30 ($C^{2'}$), 100.02 (C^5), 200.79 (C=O).

Mass spectrum, *m/z*: 227 $[M\text{-H}]^-$. Calcd for $C_{11}H_{16}O_5$. 228.10.

IR: 2999, 3009, 1715, 1099, 1043, 927, 881, 644 cm^{-1}.

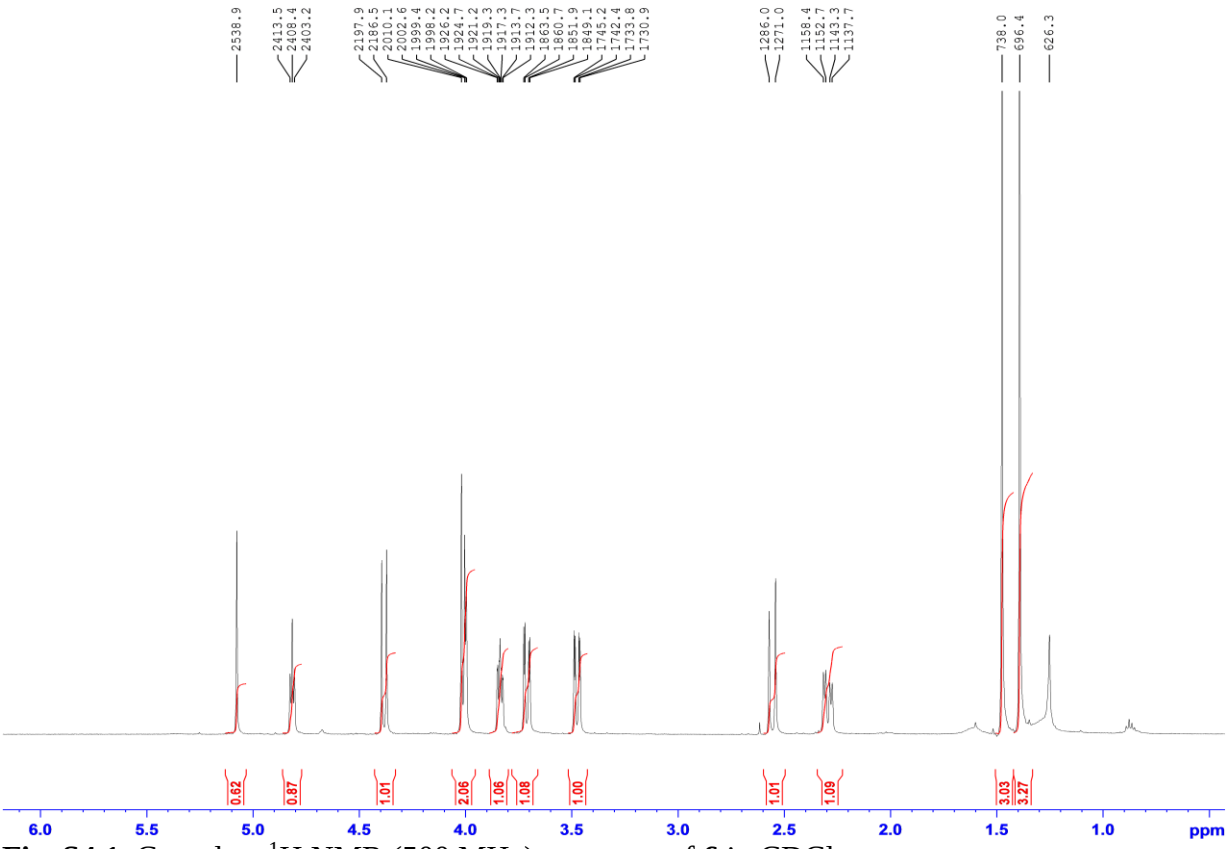


Fig. S4.1. Complete ^{1}H NMR (500 MHz) spectrum of **6** in $CDCl_3$

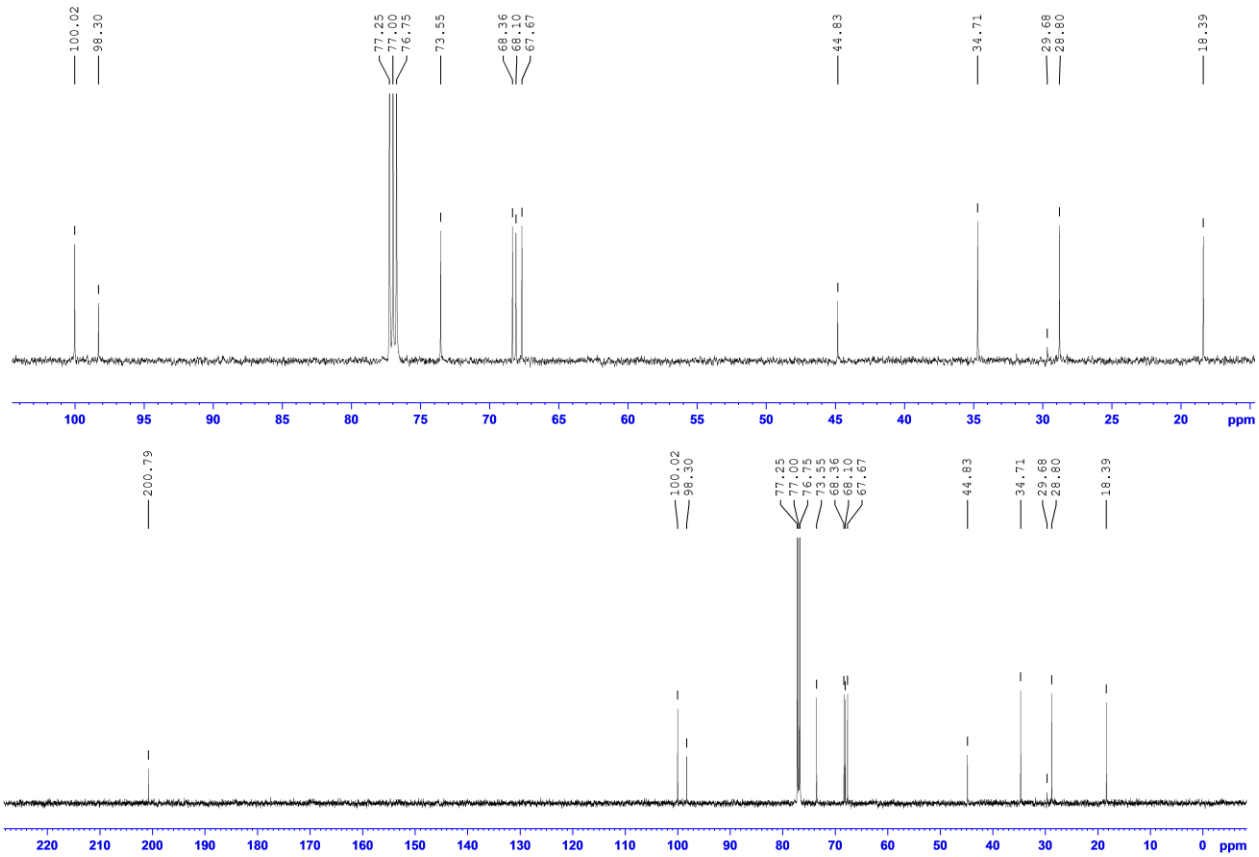


Fig. S4.2. Complete $^{13}C\{^{1}H\}$ NMR spectrum of **6** in $CDCl_3$

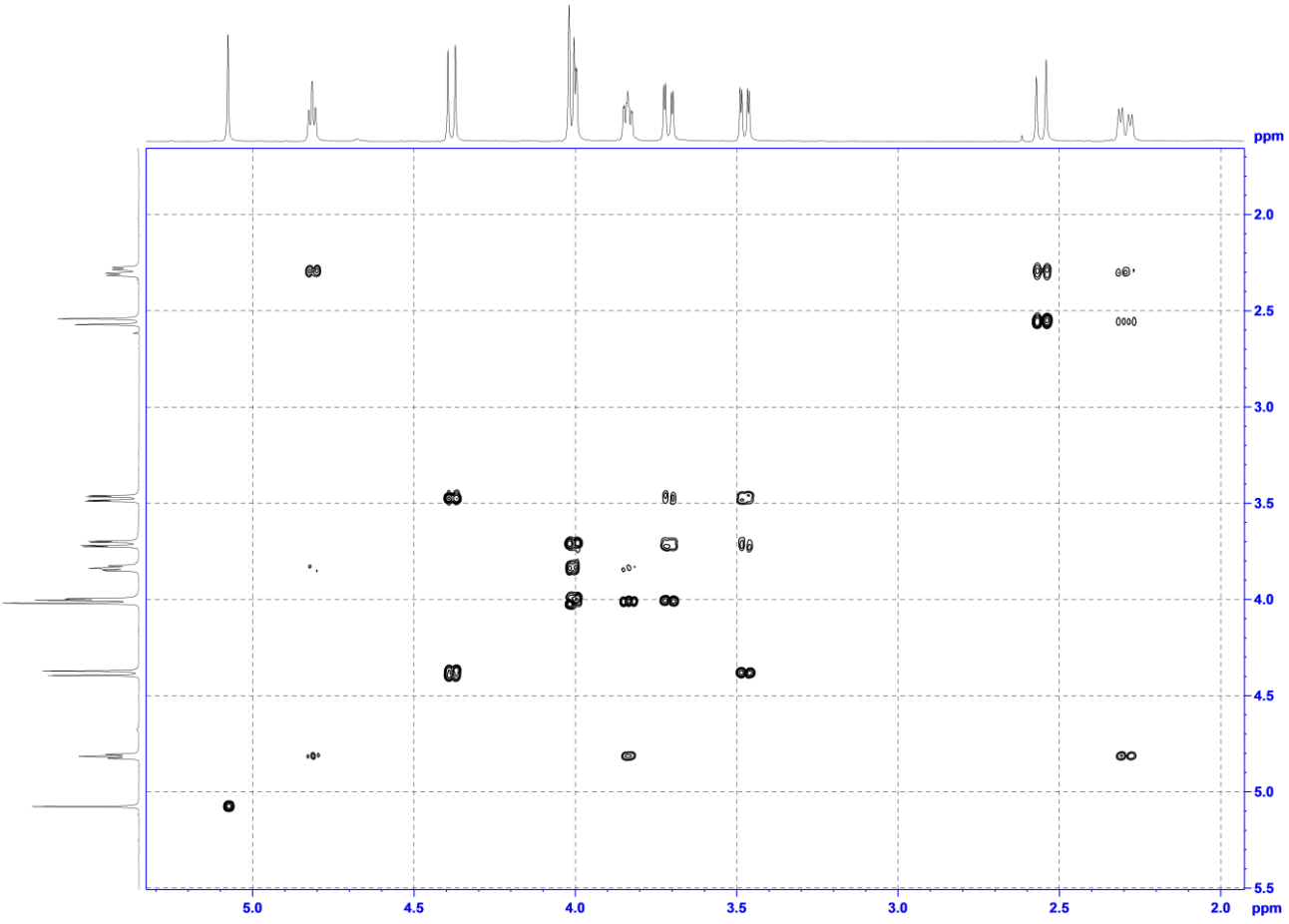


Fig. S4.3. Complete $\{^{1}H,^{1}H\}$ COSY NMR spectrum of **6** in $CDCl_3$

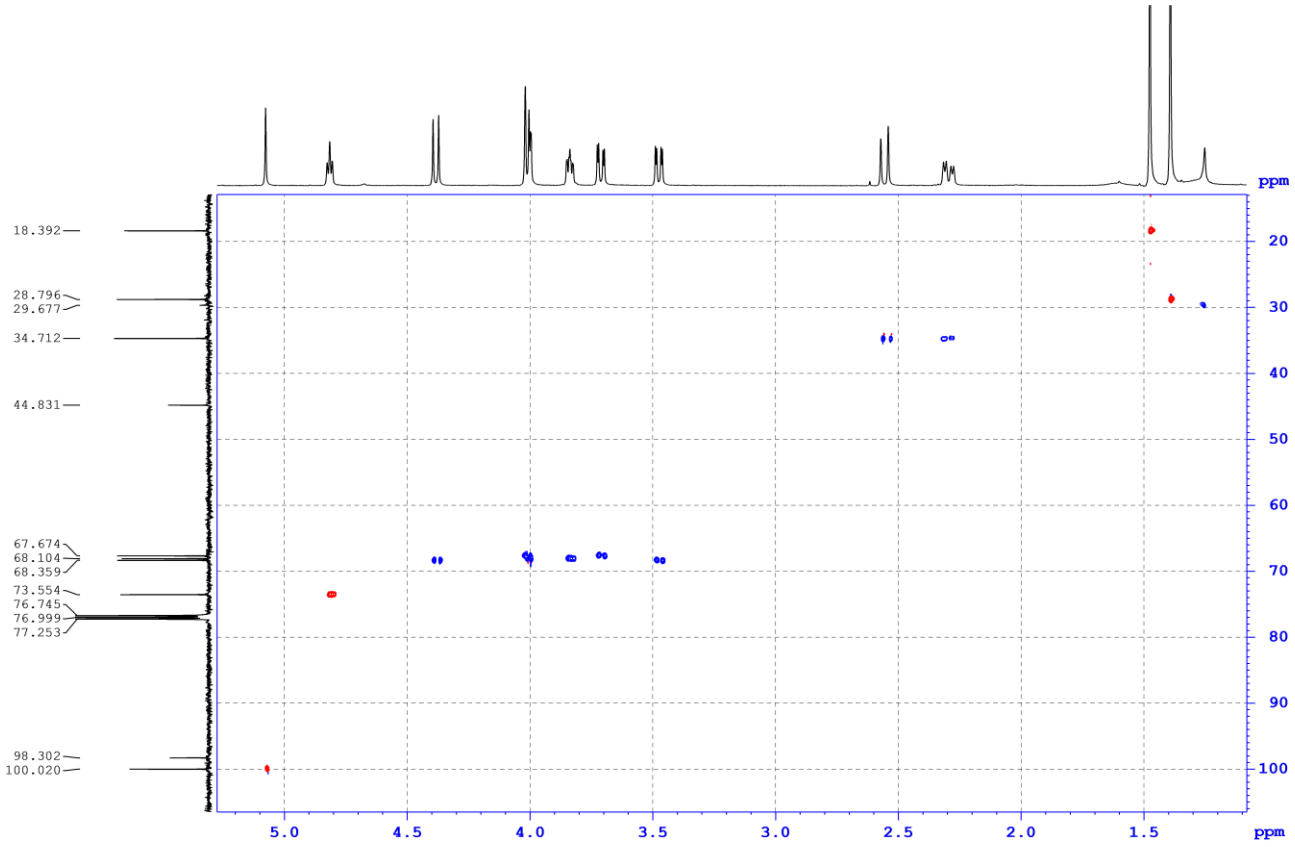


Fig. S4.4. {^{1}H,^{13}C} HSQCED NMR spectrum of **6** in $CDCl_3$

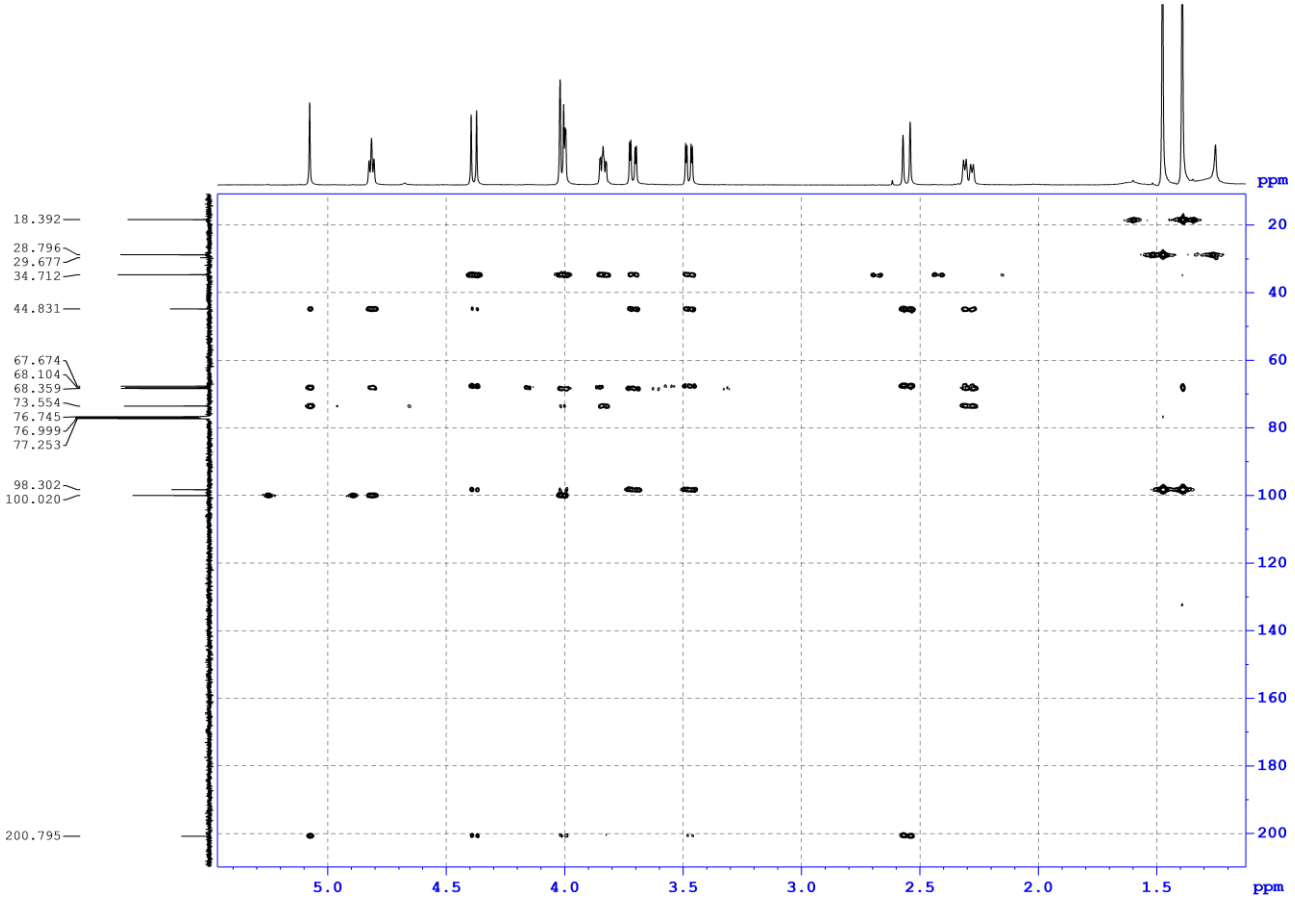


Fig. S4.5. {^{1}H,^{13}C} HMBC NMR spectrum of **6** in $CDCl_3$

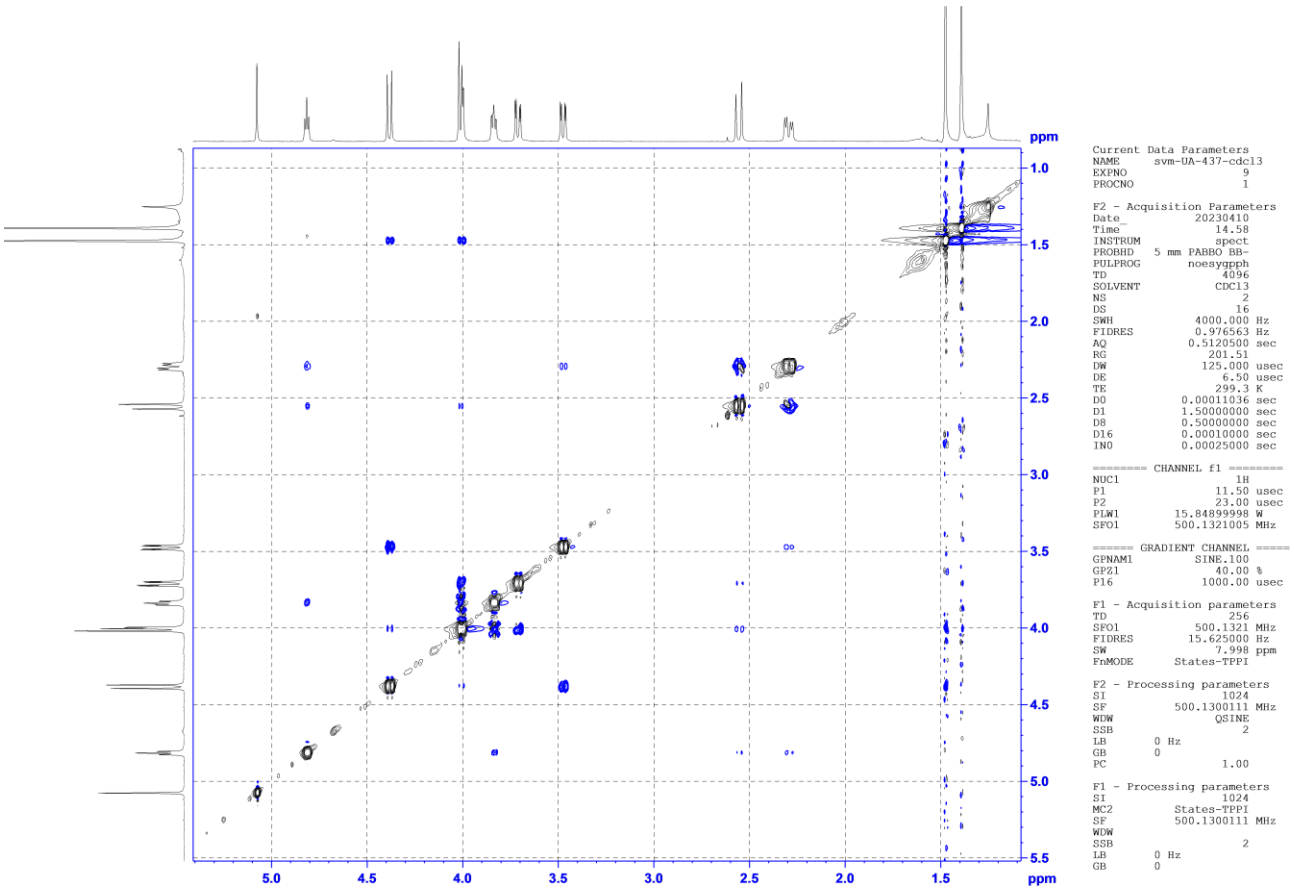
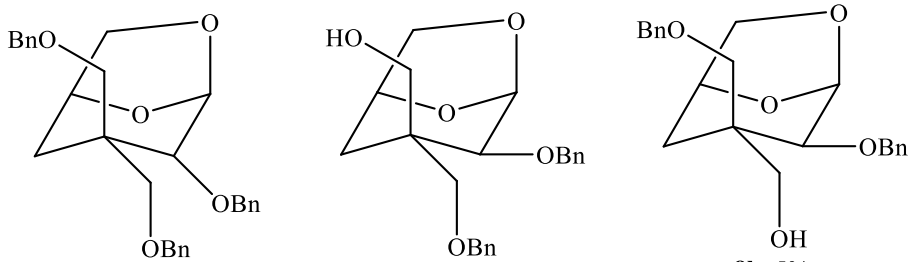


Fig. S4.6. Complete {^{1}H,^{1}H} NOESY NMR spectrum of **6** in $CDCl_3$

(1*S*,4*R*,5*R*)-4-Benzyloxy-3,3-bis(benzyloxymethyl)-6,8-dioxabicyclo[3.2.1]octane (7),
((1*S*,3*R*,4*R*,5*R*)-4-Benzyloxy-3-benzyloxymethyl-6,8-dioxabicyclo[3.2.1]octan-3-yl)methanol (8a),
((1*S*,3*R*,4*R*,5*R*)-4-Benzyloxy-3-benzyloxymethyl-6,8-dioxabicyclo[3.2.1]octan-3-yl)methanol (8b).



7, 8% **8a**, 5% **8b**, 5%

A solution of sodium hydride (0.14 g, 6.0 mmol) in DMSO (5.2 ml) was stirred for 30 min under argon, then a solution of keto diol **3** (0.30 g, 2.0 mmol) in DMSO (6.6 ml) was added. The mixture was stirred for 5 min, benzyl chloride (0.30 g, 2.0 mmol) was added dropwise, and the mixture was stirred at room temperature until the initial compound disappeared (TLC). The mixture was treated with water (5.0 ml) and extracted with ethyl acetate (3×5.0 ml), the extract was dried over $MgSO_4$, the solvent was distilled off, and the residue was chromatographed on SiO_2, eluent petroleum ether–EtOAc, 5:1.

Compound **7**: Yield 0.052 g (8%). Oil. $[\alpha]_D^{20}$ -51° (*c* 1.0, $CHCl_3$). R_f 0.7 (petroleum ether–EtOAc, 2:1). ^{1}H NMR ($CDCl_3$), δ: 1.99 (dd, 1H, $^2J_{2B,2A}$ 14.4, $^3J_{2B,1}$ 4.0, H^{2B}), 2.13 (d, 1H, $^2J_{2A,2B}$

14.4, H^{2A}), 3.31 (d, 1H, $^{2}J_{1'B,1'A}$ 9.0, $H^{1'B}$), 2.35 (d, 1H, $^{2}J_{1'A,1'B}$ 9.0, $H^{1'A}$), 2.52 (d, 1H, $^{2}J_{1''B,1''A}$ 10.3, $H^{1''B}$), 3.68 (dd, 1H, $^{2}J_{7B,7A}$ 7.2, $^{3}J_{7B,1}$ 5.4, H^{7B}), 3.72 (d, 1H, $^{2}J_{7A,7B}$ 7.2, H^{7A}), 3.77 (d, 1H, $^{3}J_{4,5}$ 1.5, H^{4}), 4.01 (d, 1H, $^{2}J_{1''A,1''B}$ 10.3, $H^{1''A}$), 4.35 (d, 1H, $^{2}J_{3'B,3'A}$ 12.0, $H^{3'B}$), 4.43-4.49 (m, 4H, H^{1}, $H^{1'''B}$, $H^{3'A}$, $H^{3''B}$), 4.53 (d, 1H, $^{2}J_{3''A,3''B}$ 12.0, $H^{3''A}$), 4.61 (d, 1H, $^{2}J_{1'''A,1'''B}$ 12.0, $H^{1'''A}$), 5.42 (d, 1H, $^{3}J_{5,4}$ 1.5, H^{5}), 7.26-7.40 (m, 15H, Ph). ^{13}C NMR ($CDCl_3$), δ: 29.25 (C^{2}), 42.76 (C^{3}), 68.22 (C^{7}), 70.20 ($C^{1''}$), 72.89 ($C^{1'''}$), 73.03 ($C^{3'}$), 73.07 ($C^{3''}$), 73.41 (C^{1}), 73.69 ($C^{1'}$), 77.98 (C^{4}), 100.01 (C^{5}), 127.47-128.32 (C^{Ph}), 138.43 (C^{Ph}), 138.53 (C^{Ph}), 138.73 (C^{Ph}).

Mass spectrum, *m/z*: 459.1 $[M\text{-H}]^-$. Calcd for $C_{29}H_{32}O_5$. 460.23.

IR: 3429, 2941, 1720, 1454, 1096, 1028, 737, 698 cm^{-1}.

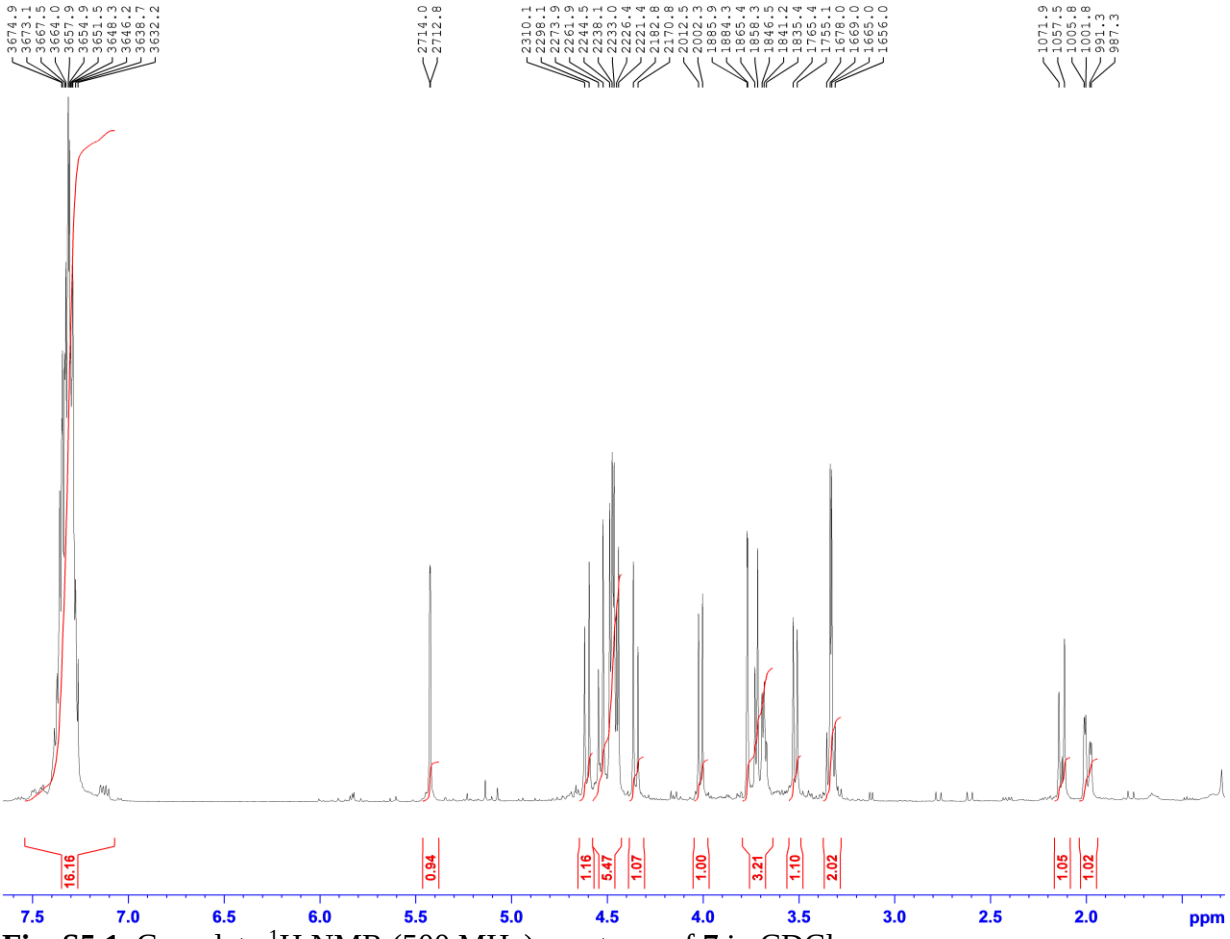


Fig. S5.1. Complete ^{1}H NMR (500 MHz) spectrum of **7** in $CDCl_3$

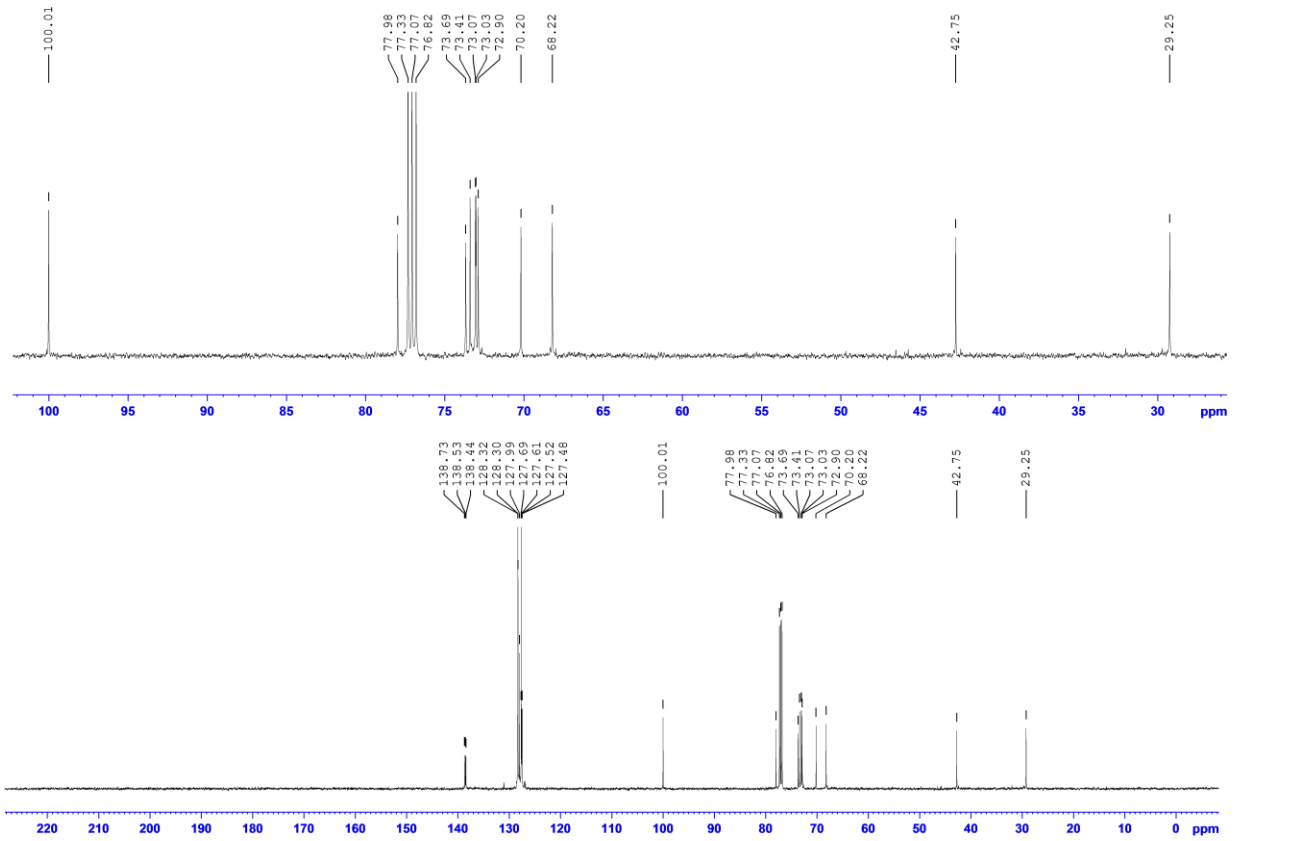


Fig. S5.2. Complete $^{13}C\{^{1}H\}$ NMR spectrum of **7** in $CDCl_3$

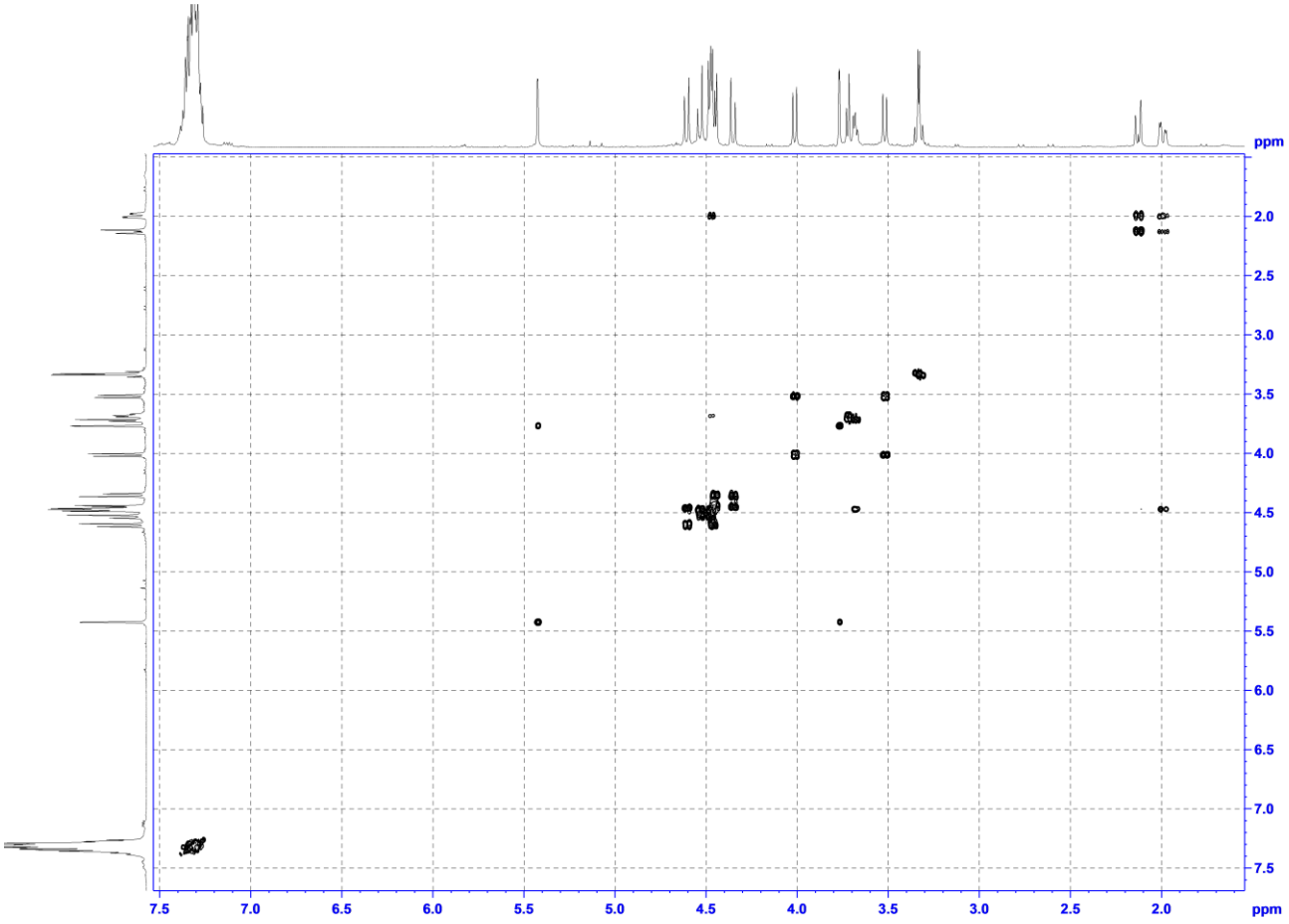


Fig. S5.3. Complete $\{^{1}H,^{1}H\}$ COSY NMR spectrum of **7** in $CDCl_3$

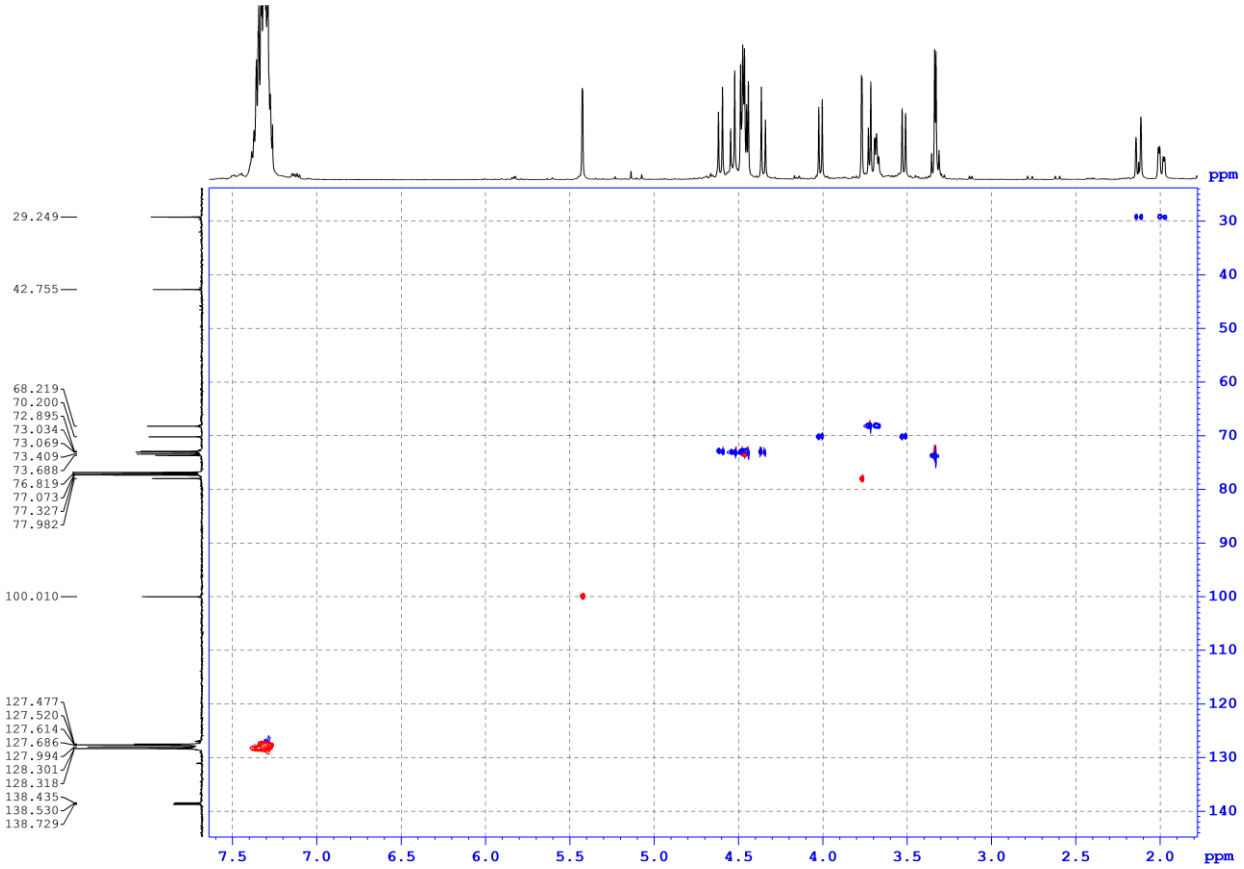


Fig. S5.4. {^{1}H,^{13}C} HSQCED NMR spectrum of **7** in $CDCl_3$

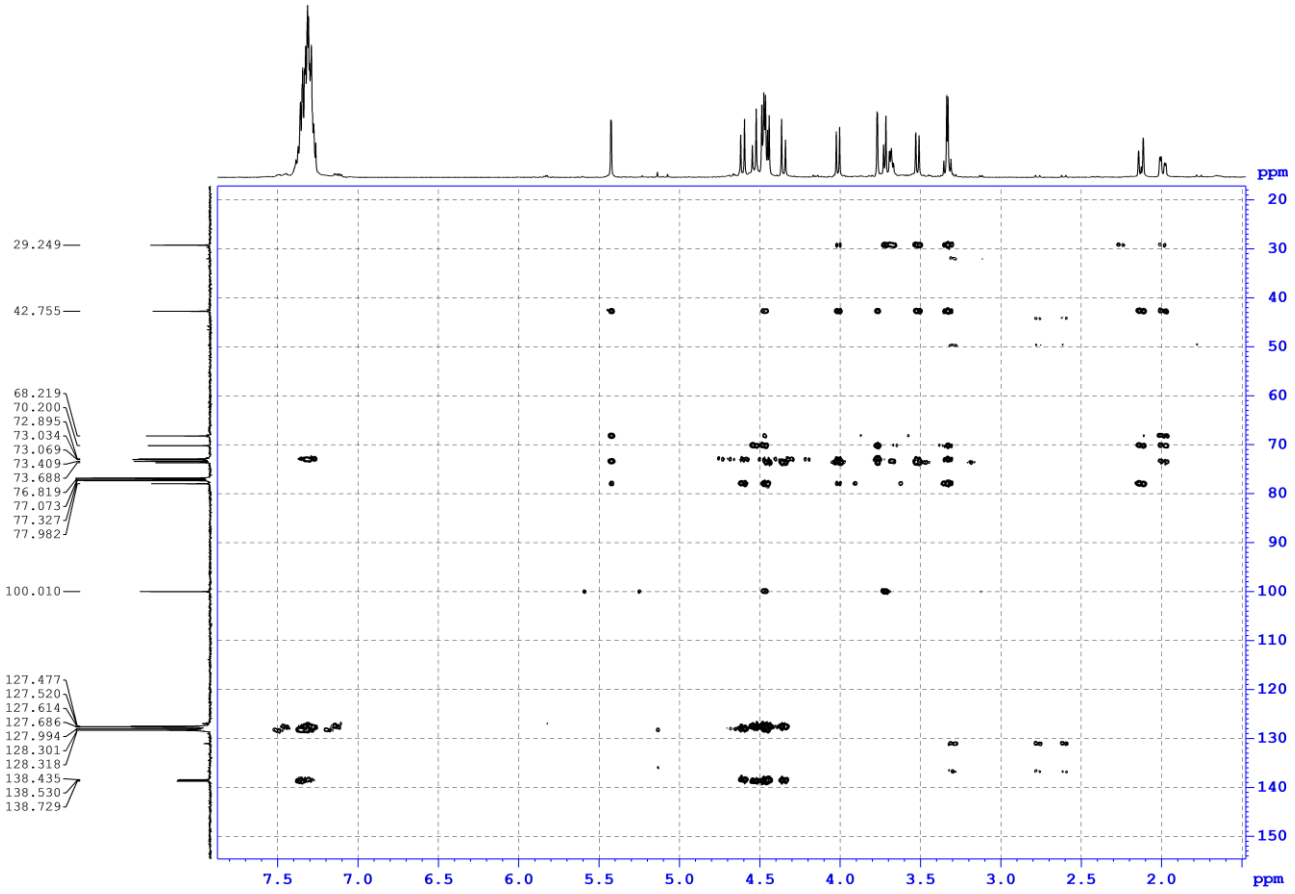


Fig. S5.5. {^{1}H,^{13}C} HMBC NMR spectrum of **7** in $CDCl_3$

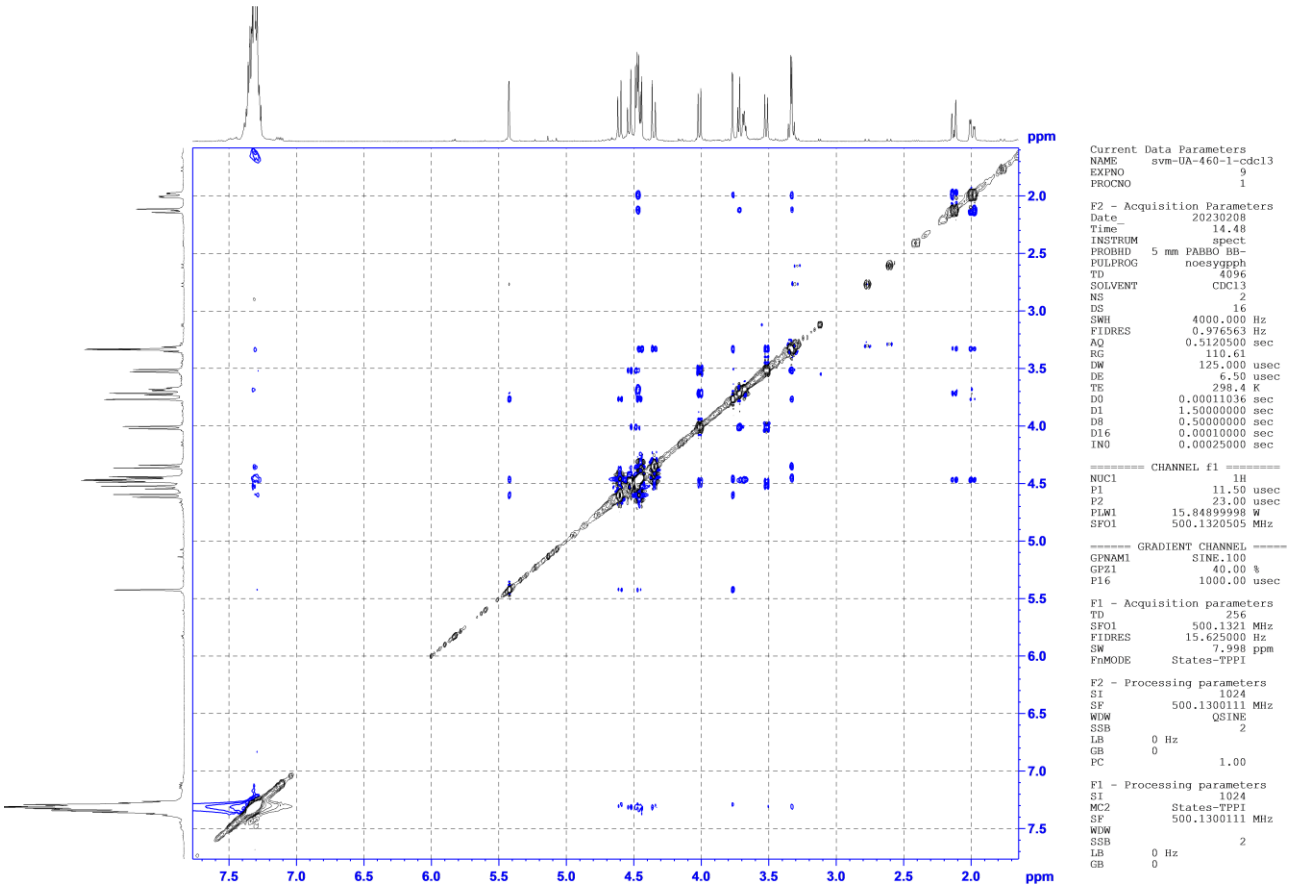


Fig. S5.6. Complete {^{1}H,^{1}H} NOESY NMR spectrum of **7** in $CDCl_3$

Compound **8a**: Yield 0.027 g (5%). Oil. $[\alpha]_D^{20}$ -47° (*c* 1.0, $CHCl_3$). R_f 0.4 (petroleum ether–EtOAc, 2:1). ^{1}H NMR ($CDCl_3$), δ: 1.72 (dd, 1H, $^{2}J_{2B,2A}$ 14.7, $^{3}J_{2B,1}$ 4.1, H^{2B}), 2.23 (d, 1H, $^{2}J_{2A,2B}$ 14.7, H^{2A}), 3.34 (d, 1H, $^{2}J_{1''B,1''A}$ 10.4, $H^{1''B}$), 3.38 (d, 1H, $^{3}J_{4,5}$ 1.4, H^{4}), 3.63-3.67 (m, 2H, H^{7A}, $H^{7'B}$), 3.69 (d, 1H, $^{2}J_{1''A,1''B}$ 10.4, $H^{1''A}$), 3.78 (d, 1H, $^{2}J_{1'B,1'A}$ 10.2, $H^{1'B}$), 4.02 (d, 1H, $^{2}J_{1'A,1'B}$ 10.2, $H^{1'A}$), 4.45-4.50 (m, 2H, H^{1}, $H^{3''B}$), 4.52 (d, 1H, $^{2}J_{1'''B,1'''A}$ 11.8, $H^{1''B}$), 4.59 (d, 1H, $^{2}J_{3''A,3''B}$ 11.9, $H^{3''A}$), 4.67 (d, 1H, $^{2}J_{1'''A,1'''B}$ 11.8, $H^{1'''A}$), 5.42 (d, 1H, $^{3}J_{5,4}$ 1.4, H^{5}), 7.27-7.38 (m, 10H, Ph). ^{13}C NMR ($CDCl_3$), δ: 30.31 (C^{2}), 42.48 (C^{3}), 68.12 (C^{7}), 71.68 ($C^{1''}$), 71.75 ($C^{1'}$), 72.56 ($C^{1'''}$), 73.22 (C^{1}), 73.33 ($C^{3''}$), 79.56 (C^{4}), 99.15 (C^{5}), 127.78-128.50 (C^{Ph}), 137.82 (C^{Ph}), 138.07 (C^{Ph}).

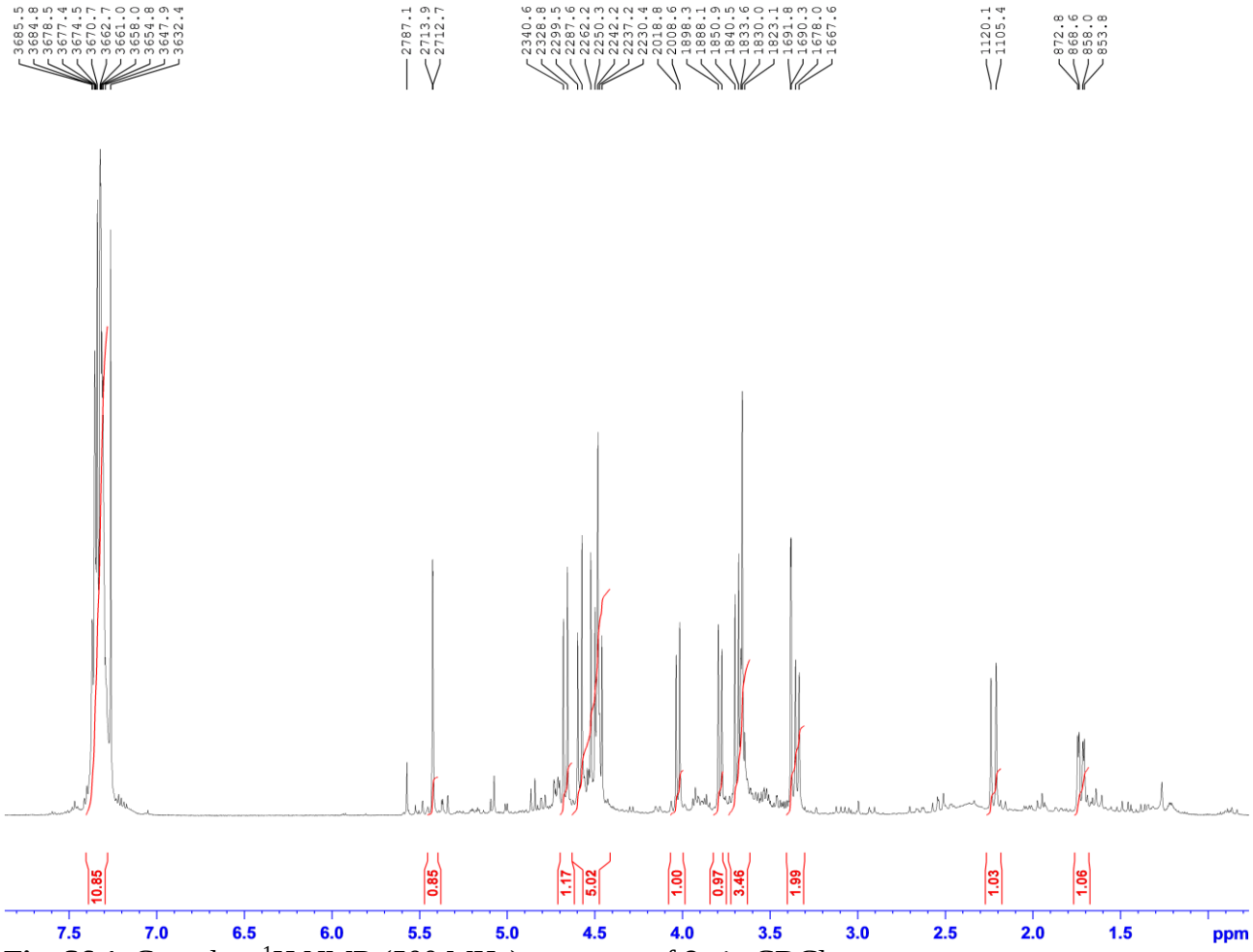


Fig. S6.1. Complete ^{1}H NMR (500 MHz) spectrum of **8a** in $CDCl_3$

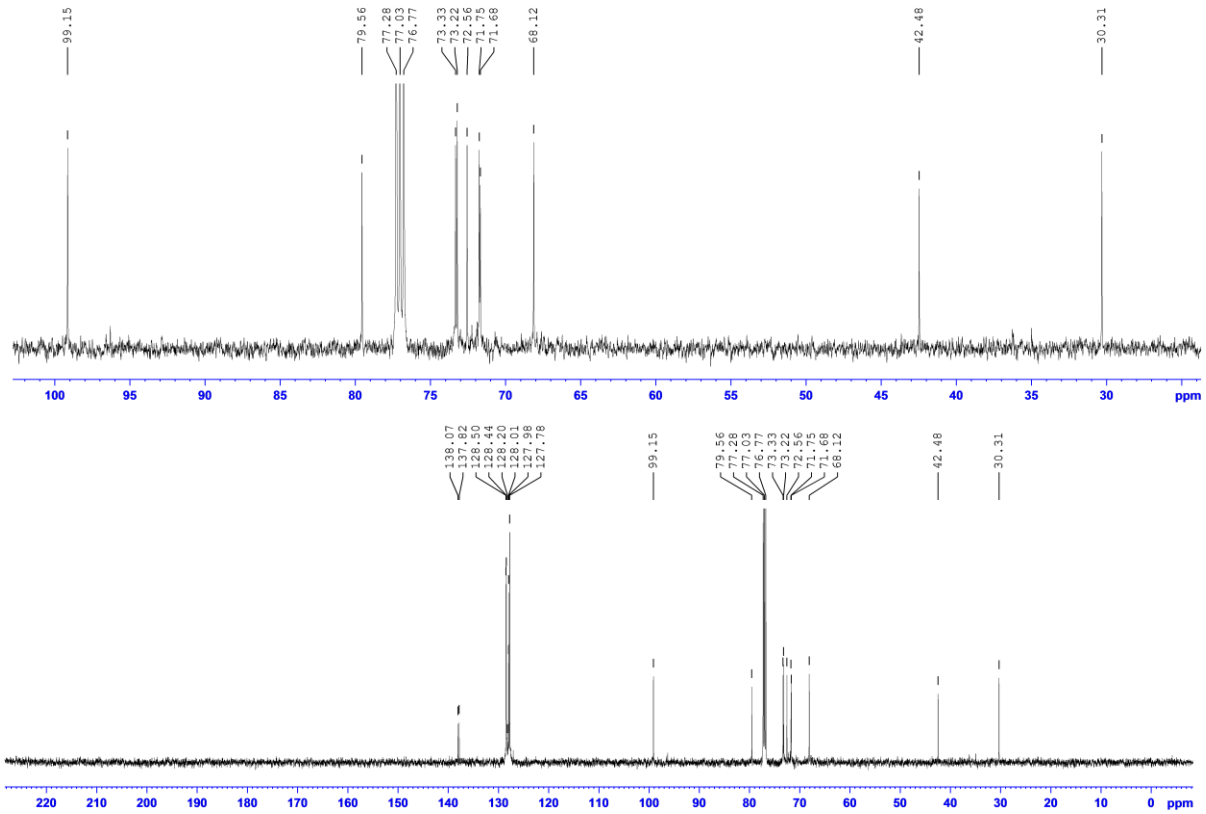


Fig. S6.2. Complete $^{13}C\{^{1}H\}$ NMR spectrum of **8a** in $CDCl_3$

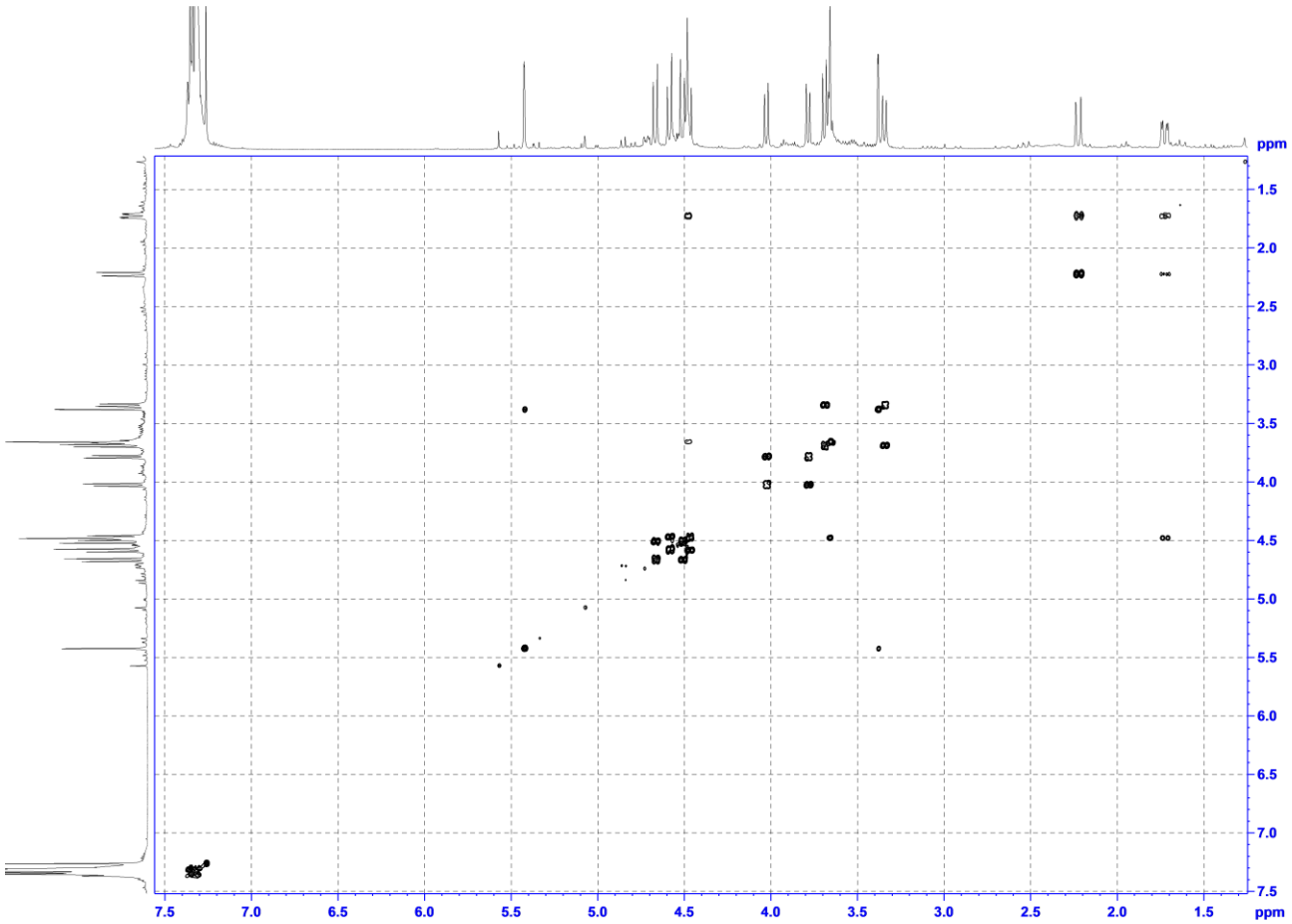


Fig. S6.3. Complete {^{1}H,^{1}H} COSY NMR spectrum of **8a** in $CDCl_3$

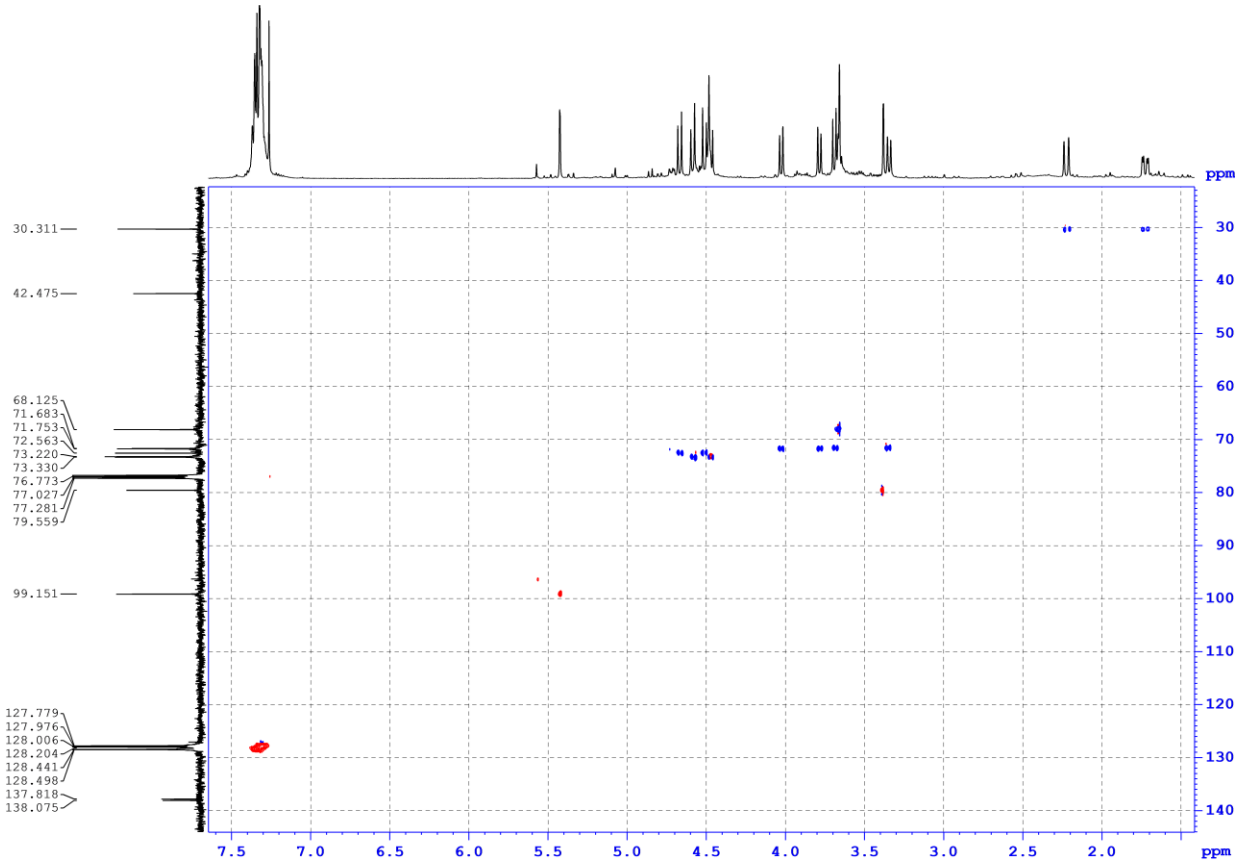


Fig. S6.4. {^{1}H,^{13}C} HSQCED NMR spectrum of **8a** in $CDCl_3$

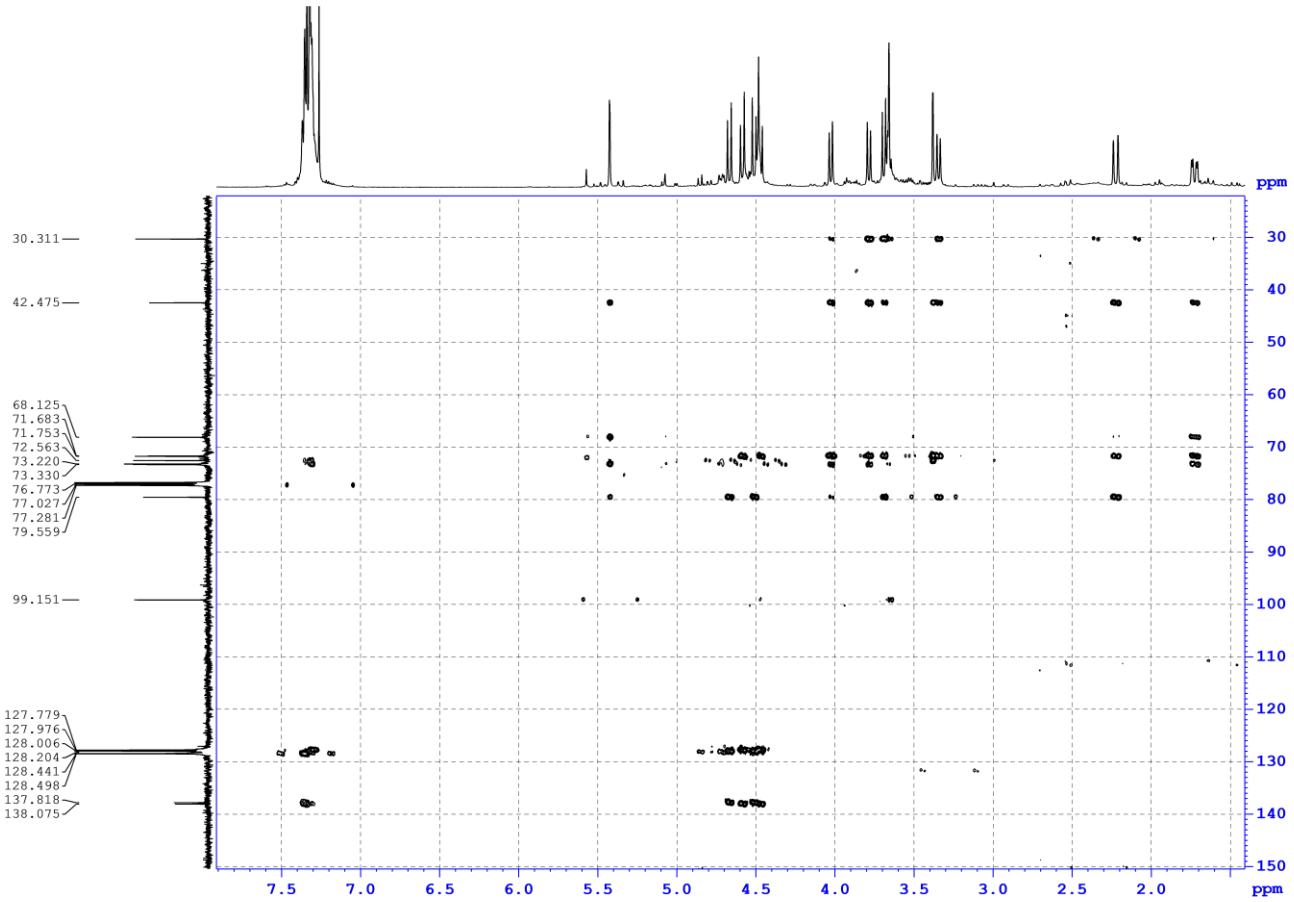


Fig. S6.5. {^{1}H,^{13}C} HMBC NMR spectrum of **8a** in $CDCl_3$

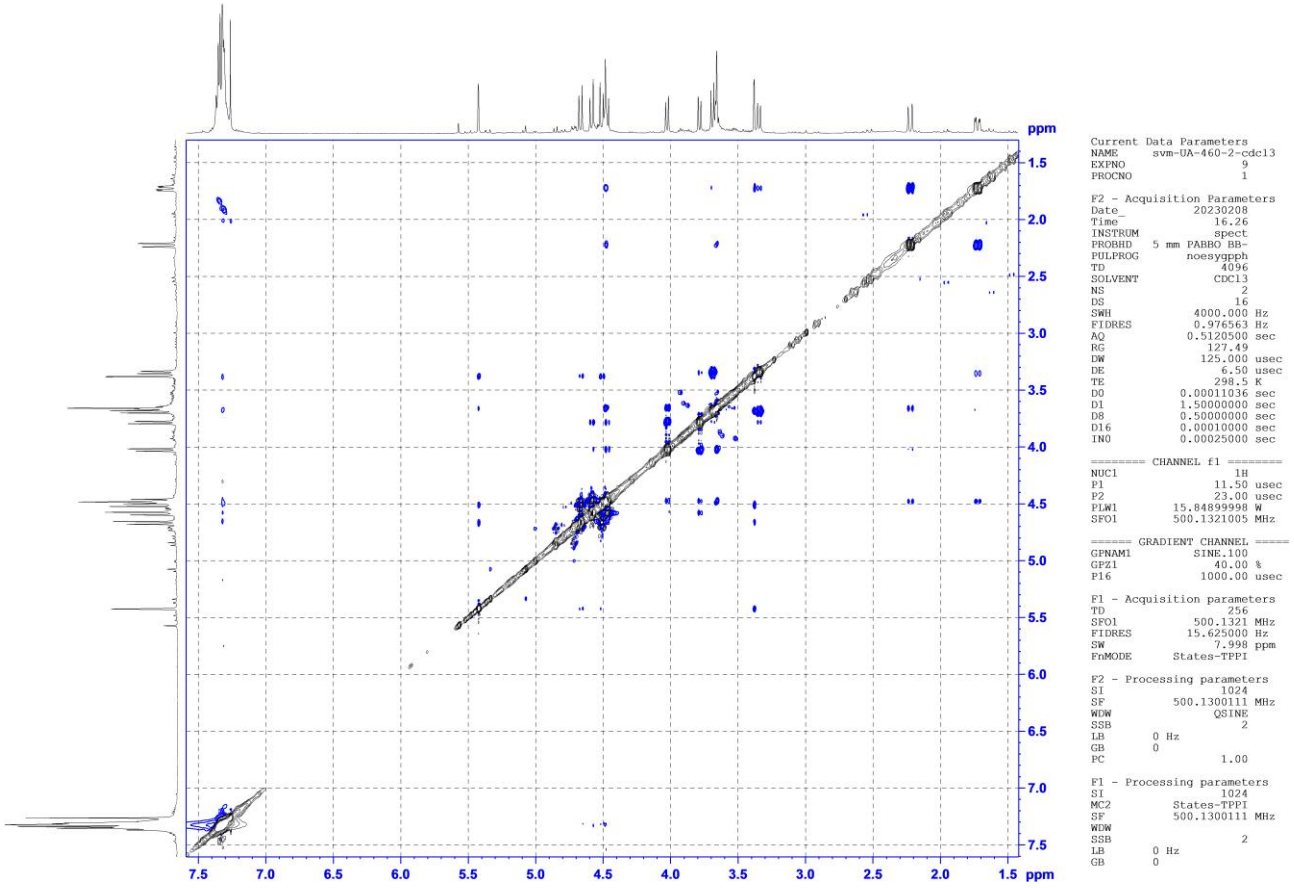


Fig. S6.6. Complete {^{1}H,^{1}H} NOESY NMR spectrum of **8a** in $CDCl_3$

Compound **8b**: Yield 0.030 g (5%). Oil. $[\alpha]_D^{20}$ -78° (*c* 1.0, $CHCl_3$). R_f 0.2 (petroleum ether–EtOAc, 2:1). ^{1}H NMR ($CDCl_3$), δ: 1.77 (d, 1H, $^2J_{2A,2B}$ 14.6, H^{2A}), 2.05 (dd, 1H, $^2J_{2B,2A}$ 14.6, $^3J_{2B,1}$ 3.4, H^{2B}), 3.32 (d, 1H, $^2J_{1'B,1'A}$ 8.7, $H^{1'B}$), 3.37 (d, 1H, $^2J_{1'A,1'B}$ 8.7, $H^{1'A}$), 3.53 (d, 1H, $^3J_{4,5}$ 1.3, H^4), 3.69 (d, 1H, $^2J_{1''B,1''A}$ 11.0, $H^{1''B}$), 3.74 (dd, 1H, $^2J_{7B,7A}$ 7.4, $^3J_{7B,1}$ 5.6, H^{7B}), 3.89 (d, 1H, $^2J_{7A,7B}$ 7.4, H^{7A}), 4.13 (d, 1H, $^2J_{1''A,1''B}$ 11.0, $H^{1''A}$), 4.37 (d, 1H, $^2J_{3'B,3'A}$ 12.0, $H^{3'B}$), 4.42 (d, 1H, $^2J_{1'''B,1'''A}$ 11.6, $H^{1''B}$), 4.44 (d, 1H, $^2J_{3'A,3'B}$ 12.0, $H^{3'A}$), 4.48 (dd, 1H, $^3J_{1,7B}$ 5.6, $^3J_{1,2B}$ 3.4, H^1), 4.67 (d, 1H, $^2J_{1'''A,1'''B}$ 11.6, $H^{1'''A}$), 5.49 (d, 1H, $^3J_{5,4}$ 1.3, H^5), 7.25-7.38 (m, 10H, Ph). ^{13}C NMR ($CDCl_3$), δ: 33.31 (C^2), 42.48 (C^3), 66.50 ($C^{1''}$), 68.62 (C^7), 72.79 ($C^{1'''}$), 72.99 (C^1), 73.32 ($C^{3'}$), 76.14 ($C^{1'}$), 79.45 (C^4), 99.00 (C^5), 127.66-128.52 (C^{Ph}), 137.58 (C^{Ph}), 138.08 (C^{Ph}).

Mass spectrum, *m/z*: 369 $[MH]^-$. Calcd for $C_{22}H_{26}O_5$. 370.18.

IR: 3535, 2961, 1720, 1454, 1161, 1103, 928, 638 cm^{-1}.

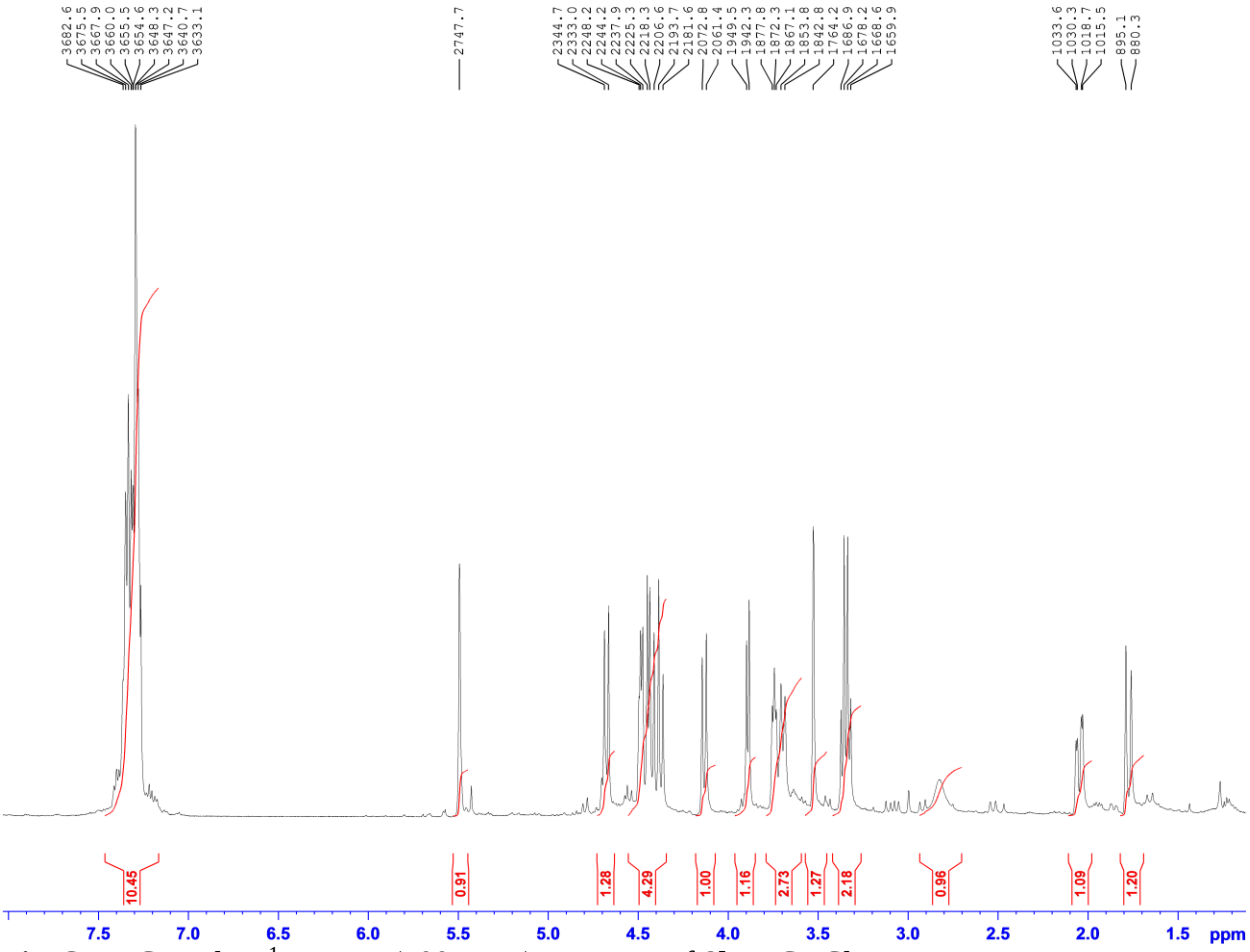


Fig. S7.1. Complete ^{1}H NMR (500 MHz) spectrum of **8b** in $CDCl_3$

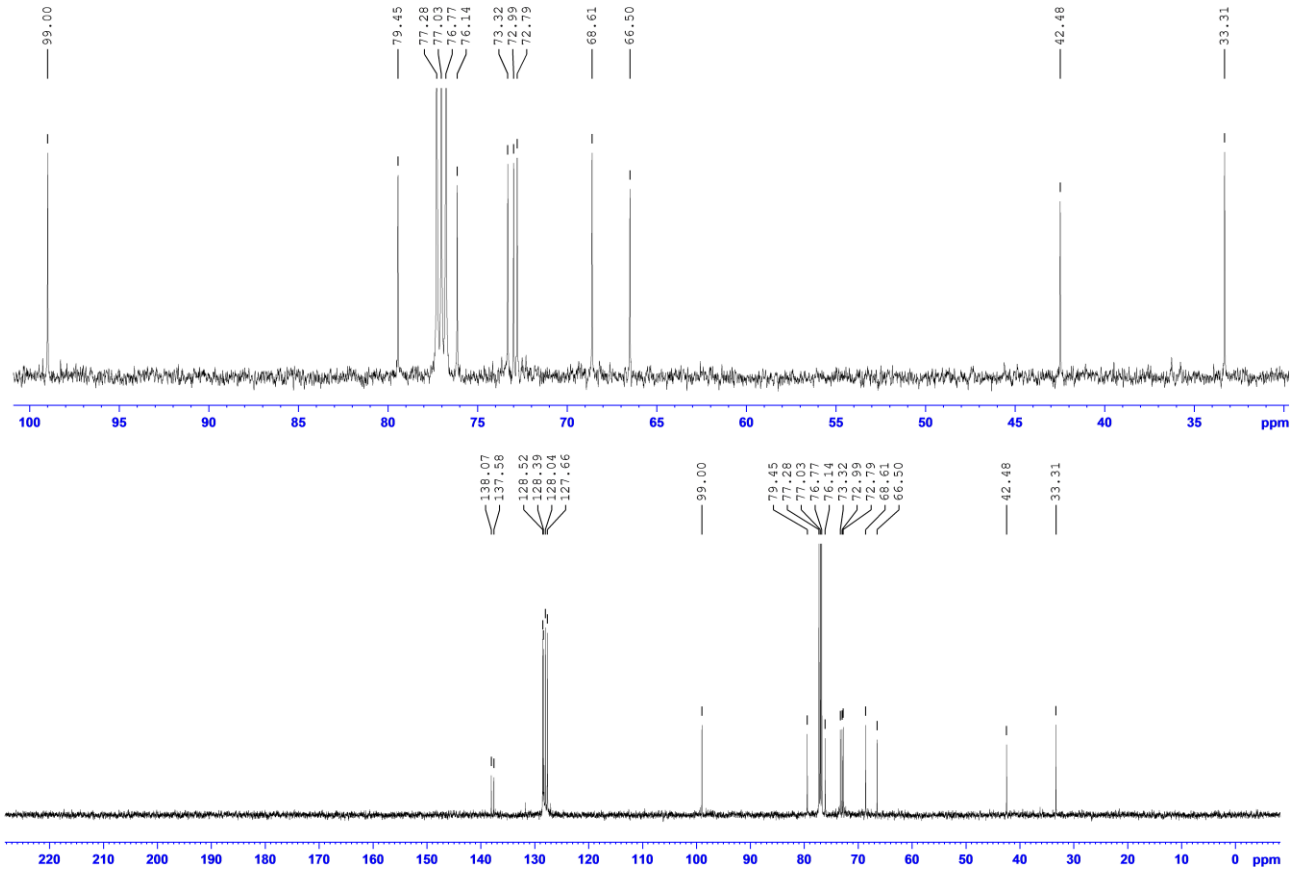


Fig. S7.2. Complete $^{13}C\{^{1}H\}$ NMR spectrum of **8b** in $CDCl_3$

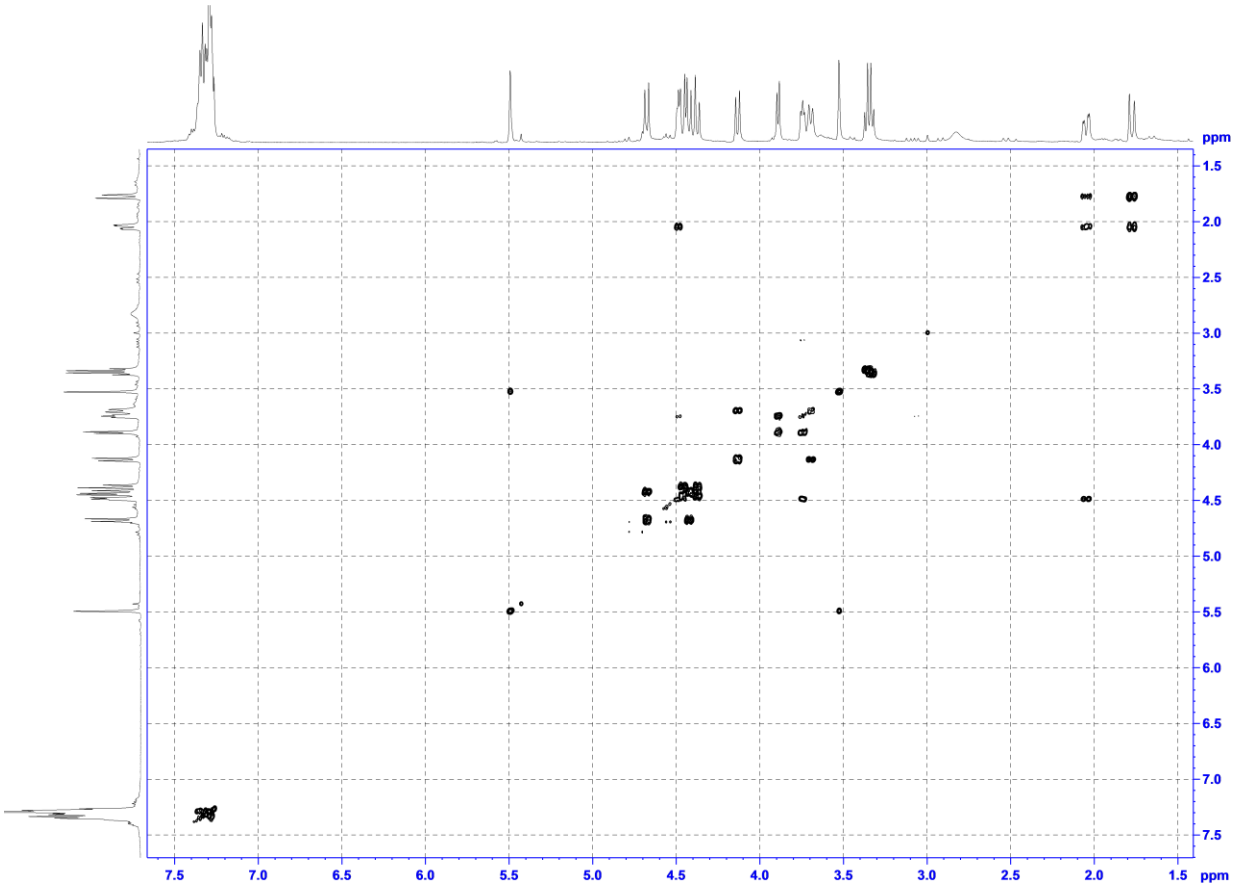


Fig. S7.3. Complete $\{^{1}H,^{1}H\}$ COSY NMR spectrum of **8b** in $CDCl_3$

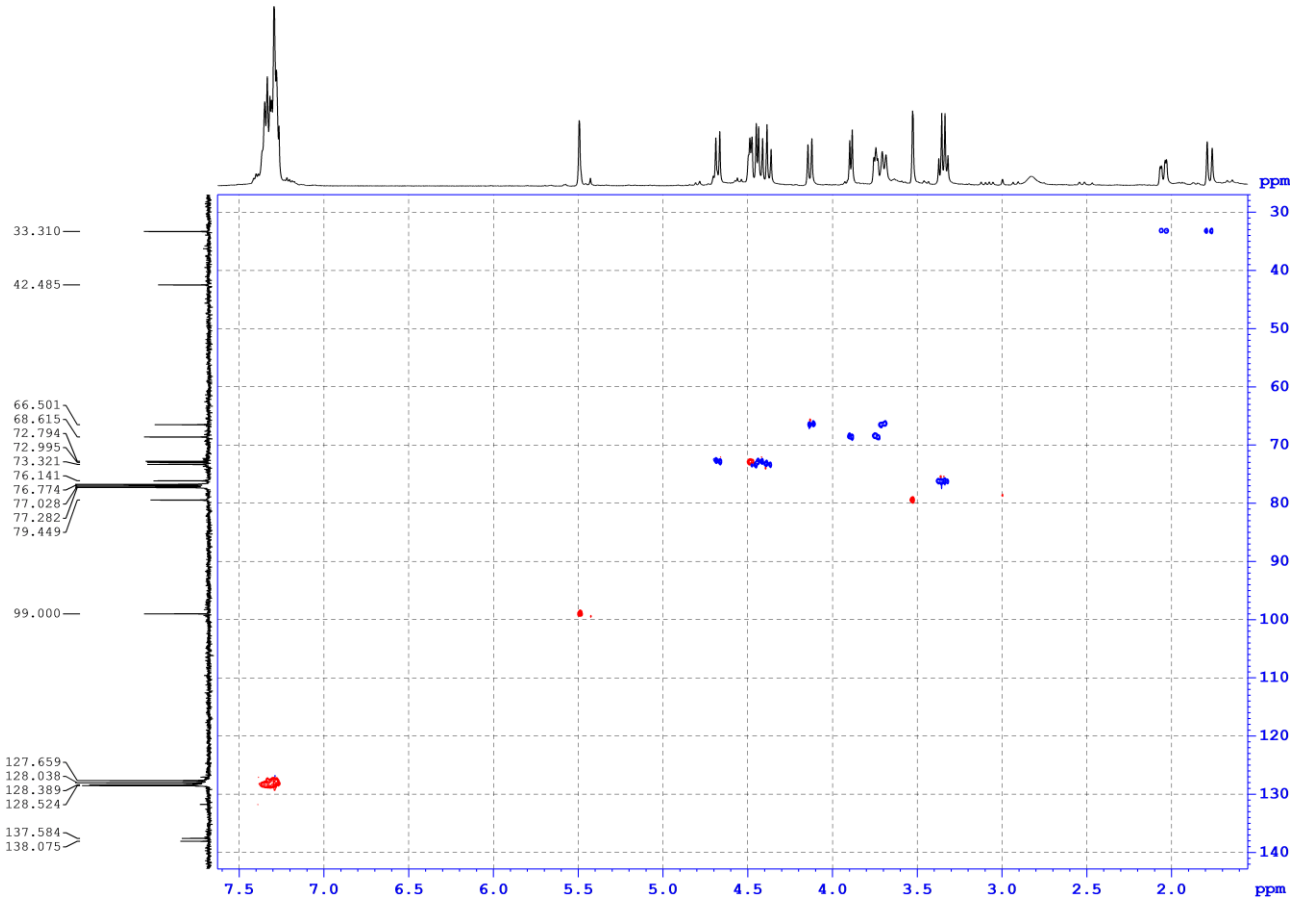


Fig. S7.4. {^{1}H,^{13}C} HSQCED NMR spectrum of **8b** in $CDCl_3$

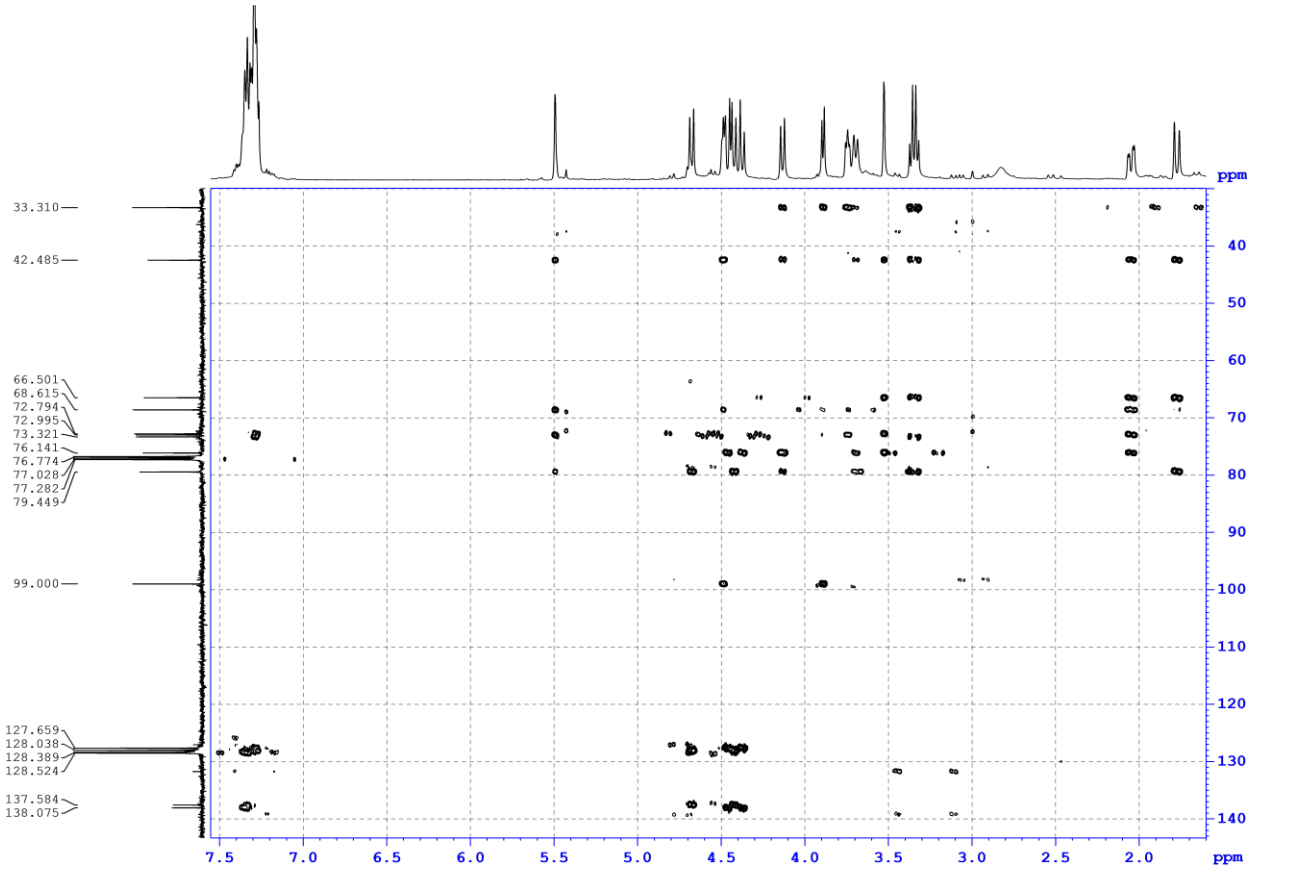


Fig. S7.5. {^{1}H,^{13}C} HMBC NMR spectrum of **8b** in $CDCl_3$

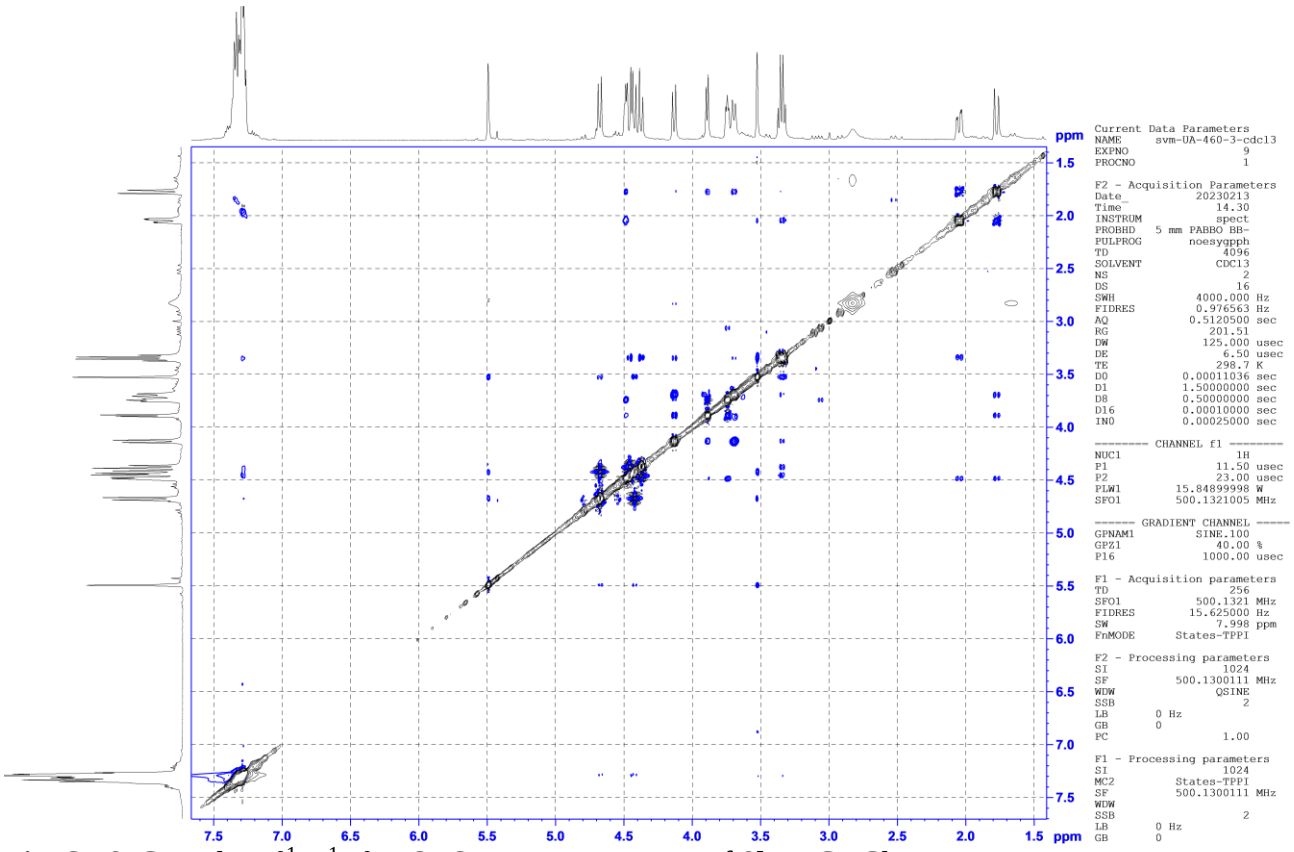
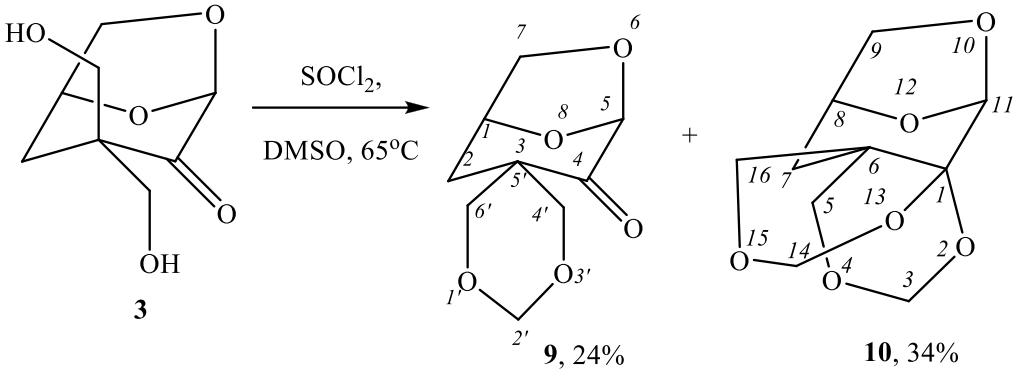


Fig. S7.6. Complete {^{1}H,^{1}H} NOESY NMR spectrum of **8b** in $CDCl_3$

(1*S*,5*R*)-6,8-Dioxaspiro[bicyclo[3.2.1]octane-3,5'-[1,3]dioxan]-4-one (9) and 2,4,10,12,14,15-hexaoxatetracyclo[5.4.4^{1,7}.1^{8,11}.0^{1,6}]hexadecane (10)



To a solution of keto diol **3** (0.1 g, 0.5 mmol) in DMSO (0.4 ml) at room temperature $SOCl_2$ (0.06 ml, 0.8 mmol) was added. This was stirred at 65 °C until the initial mixture disappeared (TLC control,) ~ 1 h). Then the mixture was treated with water (1.0 ml), the reaction products were extracted with $CHCl_3$ (3×2.0 ml), the combined organic layers were dried over $MgSO_4$, the solvent was distilled off, the residue was chromatographed on SiO_2, eluent petroleum ether–EtOAc, 6:1.

Dioxane **9**: Yield 0.025 g (24%). White crystals, m.p. 85 °C, $[\alpha]_D^{20}$ -163° (*c* 1.0, $CHCl_3$). R_f 0.7 (petroleum ether–EtOAc, 1:1). ^{1}H NMR ($CDCl_3$), δ: 2.33 (ddt, 1H, $^2J_{2B,2A}$ 15.0, $^3J_{2B,1}$ 5.2, $^4J_{2B,7B}$ 1.4, $^4J_{2B,4'B}$ 1.4, H^{2B}), 2.55 (d, 1H, $^2J_{2A,2B}$ 15.0, H^{2A}), 3.72 (d, 1H, $^2J_{6'B,6'A}$ 11.1, H$^{6'B}$), 3.75 (dd, 1H, $^2J_{4'B,4'A}$ 11.3, $^3J_{4'B,2}$ 1.4, H$^{4'B}$), 3.85 (ddd, 1H, $^2J_{7B,7A}$ 7.6, $^3J_{7B,1}$ 5.2, $^3J_{7B,2}$ 1.4, H^{7B}), 3.94 (dd, 1H, $^2J_{4'A,4'B}$ 11.3, $^4J_{4'A,6'B}$ 2.7, H$^{4'A}$), 4.01 (d, 1H, $^2J_{7A,7B}$ 7.6, H^{7A}), 4.10 (d, 1H, $^2J_{6'A,6'B}$ 11.1, H$^{6'A}$), 4.65 (d, 1H, $^2J_{2'B,2'A}$ 6.1, H$^{2'B}$), 4.83 (t, 1H, $^3J_{1,7B}$ 5.2, $^3J_{1,2A}$ 5.2, H^1), 4.99 (d, 1H, $^2J_{2'A,2'B}$ 6.1, H$^{2'A}$), 5.08 (s, 1H, H^5). ^{13}C NMR ($CDCl_3$), δ: 34.94 (C^2), 44.99 (C^3), 68.18 (C^7), 73.46 (C^1), 73.84 (C$^{4'}$), 74.74 (C$^{6'}$), 94.00 (C$^{2'}$), 99.95 (C^5), 199.74 (C=O).

Mass spectrum, *m/z*: 199.3 [*M*-H]$^-$. Calcd for $C_9H_{12}O_5$. 200.07.

IR: 3342, 3009, 1727, 1482, 1048, 956, 818, 714 cm^{-1}.

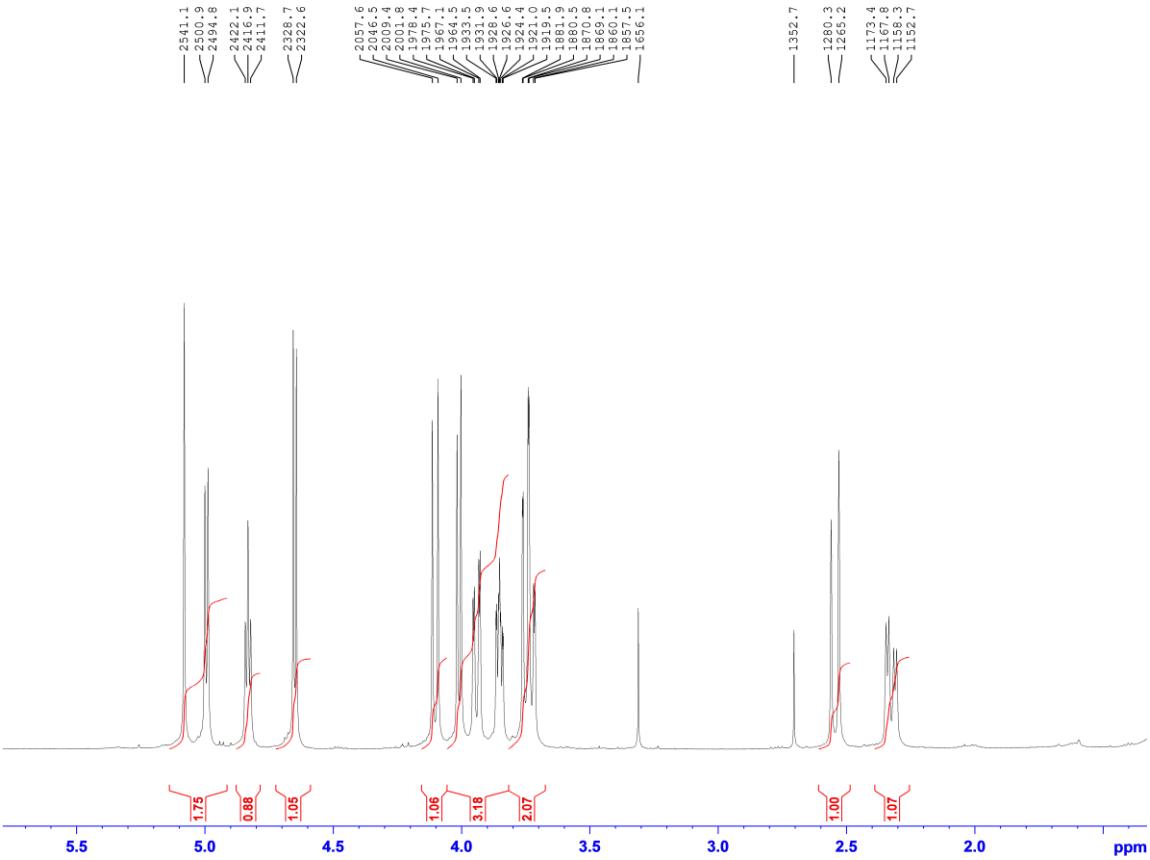


Fig. S8.1. Complete ^{1}H NMR (500 MHz) spectrum of **9** in $CDCl_3$

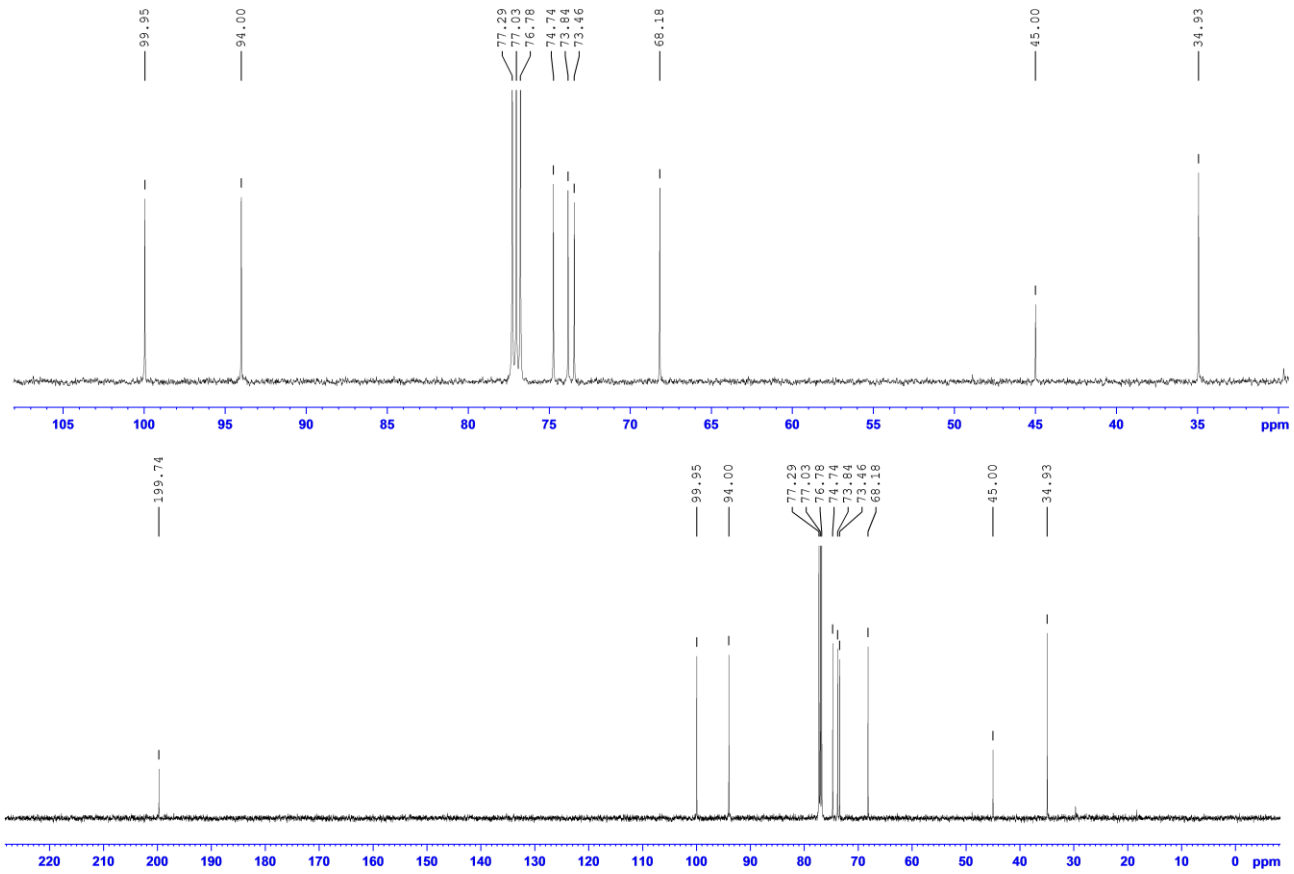


Fig. S8.2. Complete $^{13}C\{^{1}H\}$ NMR spectrum of **9** in $CDCl_3$

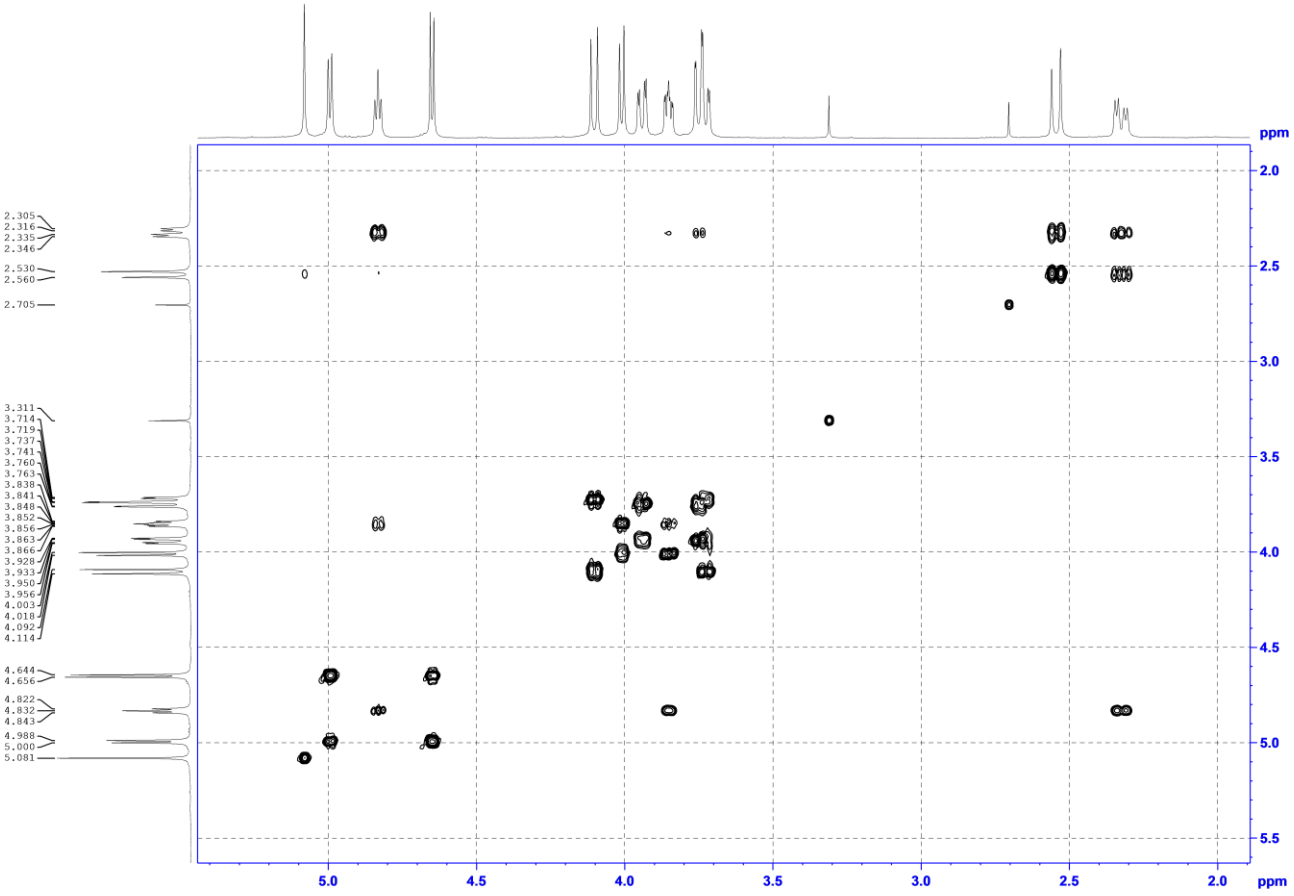


Fig. S8.3. Complete $\{^{1}H,^{1}H\}$ COSY NMR spectrum of **9** in $CDCl_3$

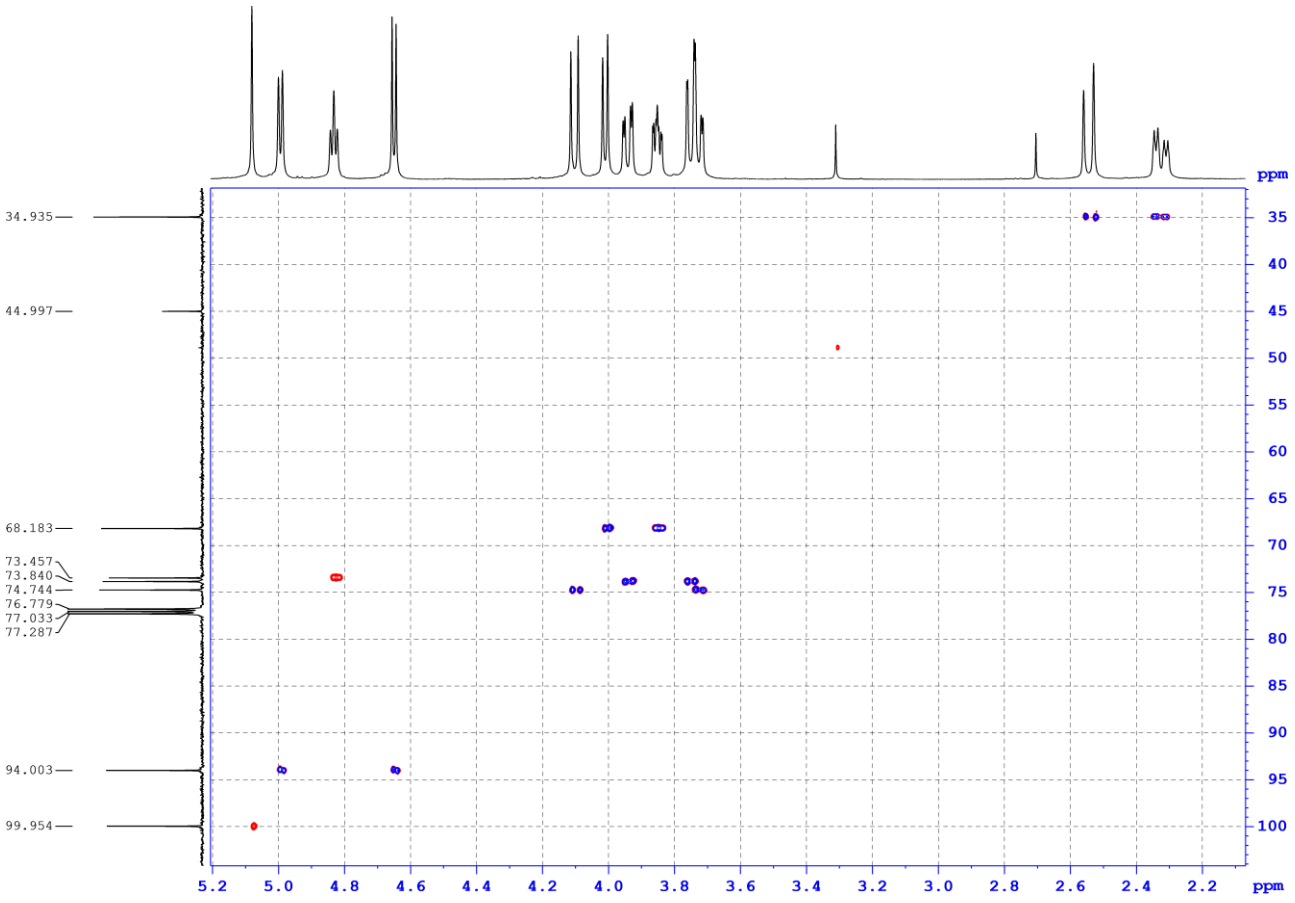


Fig. S8.4. {^{1}H,^{13}C} HSQCED NMR spectrum of **9** in $CDCl_3$

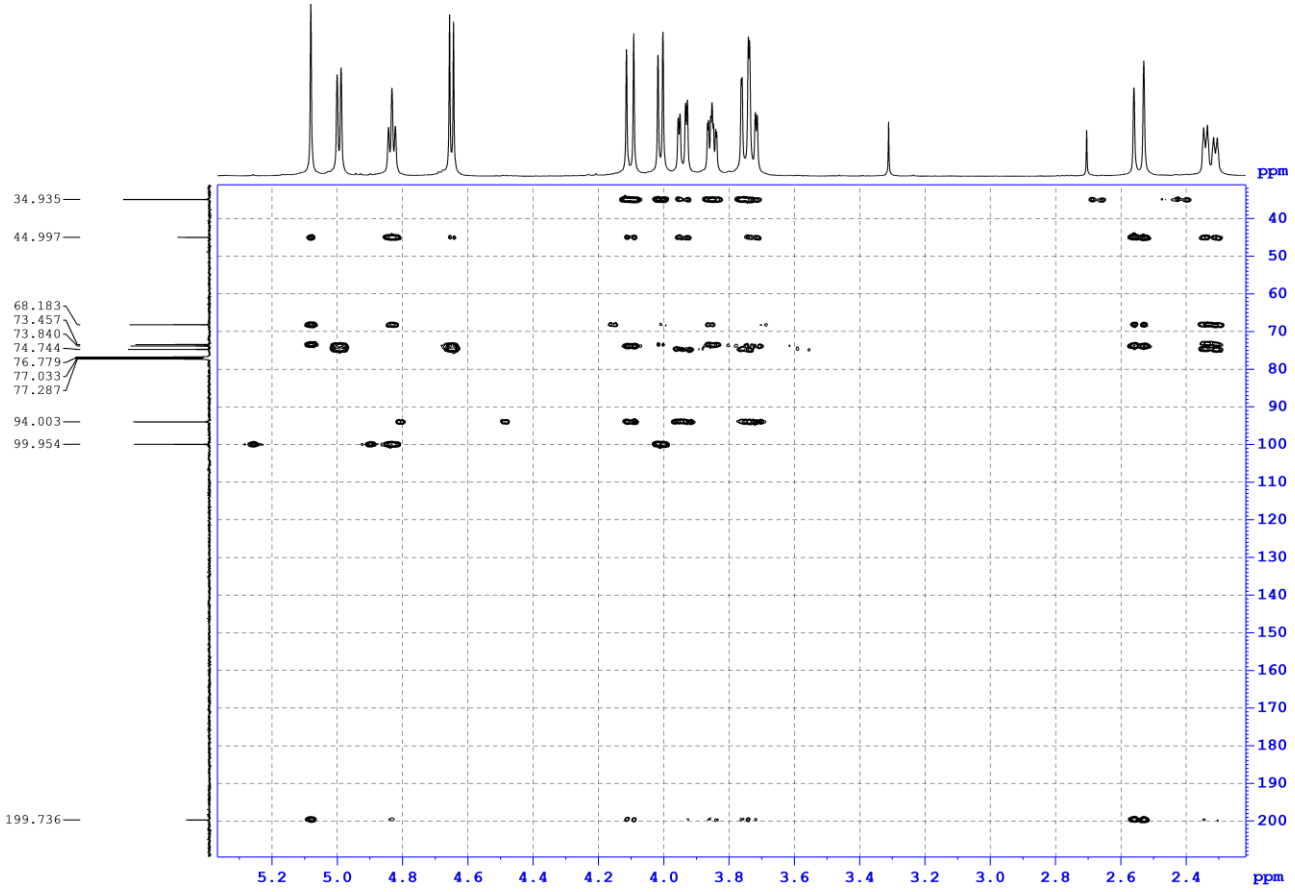


Fig. S8.5. {^{1}H,^{13}C} HMBC NMR spectrum of **9** in $CDCl_3$

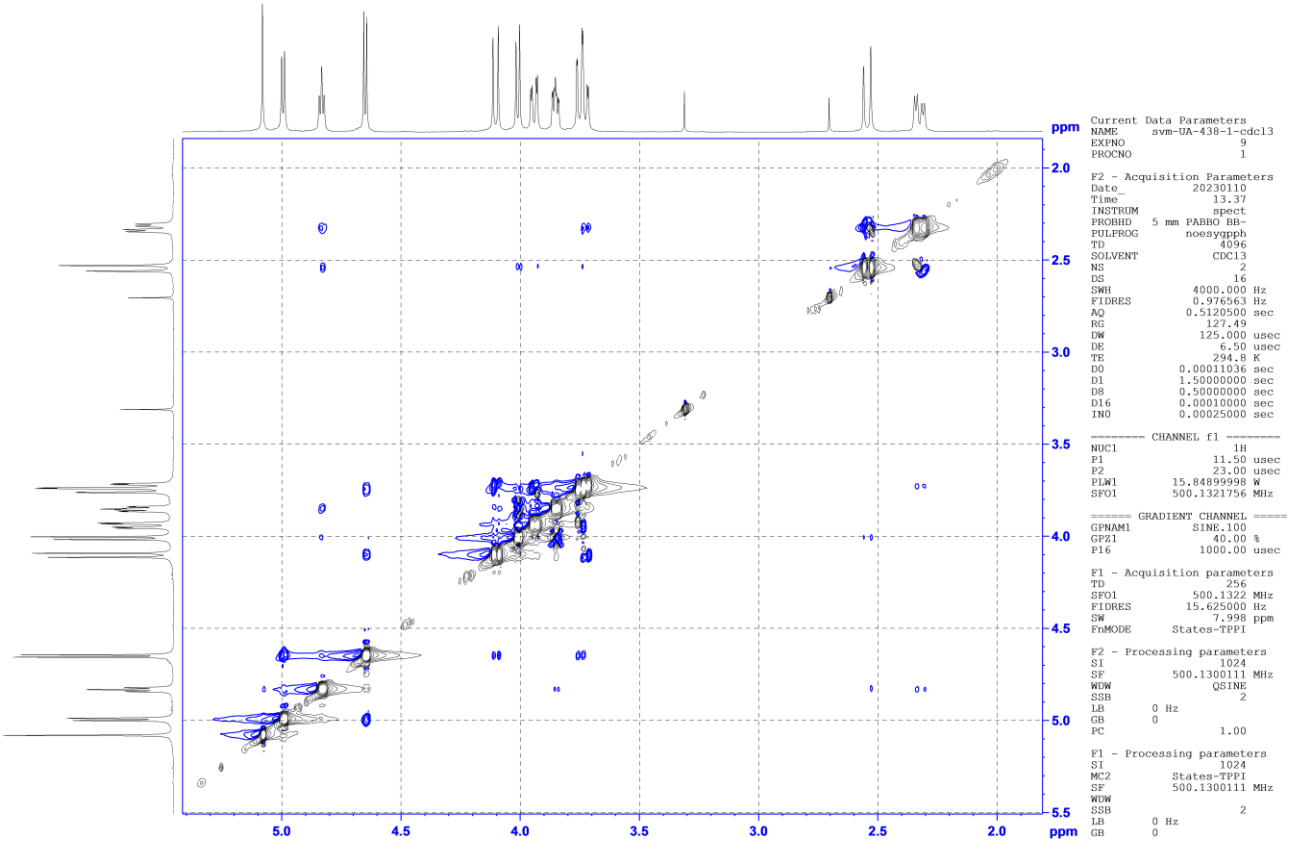


Fig. S8.6. Complete {^{1}H,^{1}H} NOESY NMR spectrum of **9** in $CDCl_3$

Compound **10**: Yield 0.042 g (24%). White crystals, m.p. 219 °C, $[\alpha]_D^{20}$ +5.5 ° (*c* 1.0, $CHCl_3$). R_f 0.5 (petroleum ether–EtOAc, 1:1). ^{1}H NMR ($CDCl_3$), δ: 1.08 (d, 1H, $^2J_{7B,7A}$ 14.7, H^{7B}), 2.53 (dd, 1H, $^2J_{7A,7B}$ 14.7, $^3J_{7A,8}$ 4.4, H^{7A}), 3.23 (d, 1H, $^2J_{5B,6A}$ 11.5, H^{5B}), 3.28 (d, 1H, $^2J_{15B,15A}$ 11.5, H^{15B}), 3.76 (dd, 1H, $^2J_{9B,9A}$ 8.0, $^3J_{9B,8}$ 4.4, H^{9B}), 3.90 (d, 1H, $^2J_{9A,9B}$ 8.0, H^{9A}), 3.93 (d, 1H, $^2J_{5A,5B}$ 11.5, H^{5A}), 4.19 (d, 1H, $^2J_{15A,15B}$ 11.5, H^{15A}), 4.55 (t, 1H, $^3J_{8,9B}$ 4.4, $^3J_{8,7A}$ 4.4, H^8), 4.86 (d, 1H, $^2J_{13B,13A}$ 5.5, H^{13B}), 5.01 (d, 1H, $^2J_{3B,3A}$ 5.5, H^{3B}), 5.05 (d, 1H, $^2J_{13A,13B}$ 5.5, H^{13A}), 5.10 (s, 1H, H^{11}), 5.46 (d, 1H, $^2J_{3A,3B}$ 5.5, H^{3A}). ^{13}C NMR ($CDCl_3$), δ: 31.94 (C^7), 33.38 (C^6), 68.27 (C^9), 69.83 (C^5), 70.85 (C^{15}), 72.39 (C^8), 87.54 (C^{13}), 91.05 (C^3), 92.19 (C^1), 103.50 (C^{11}).

Mass spectrum, *m/z*: 229.1 $[M\text{-H}]^-$. Calcd for $C_{10}H_{14}O_6$. 230.21.

IR: 3509, 2963, 1720, 1161, 1101, 928, 638 cm^{-1}.

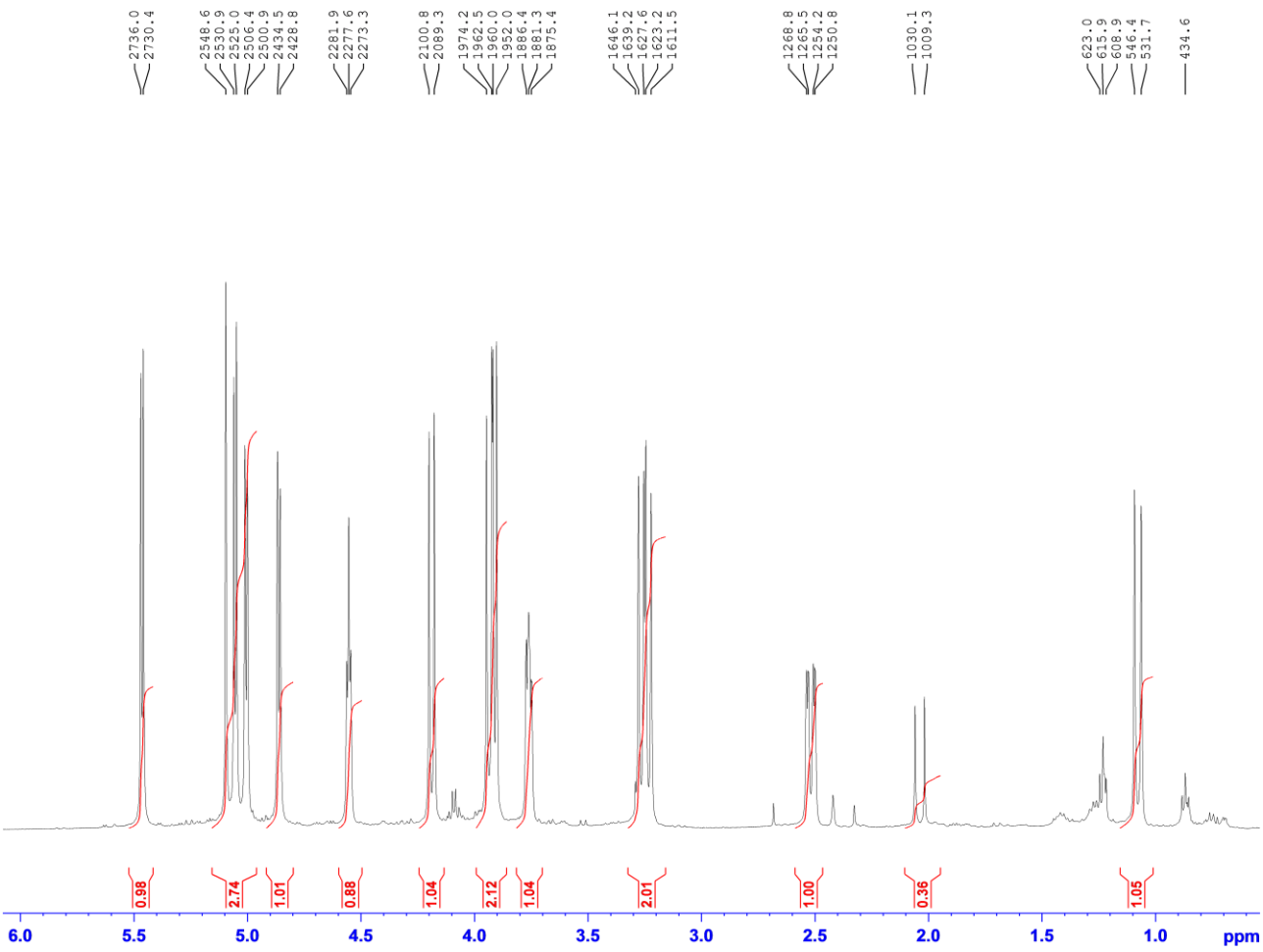


Fig. S9.1. Complete ^{1}H NMR (500 MHz) spectrum of **10** in $CDCl_3$

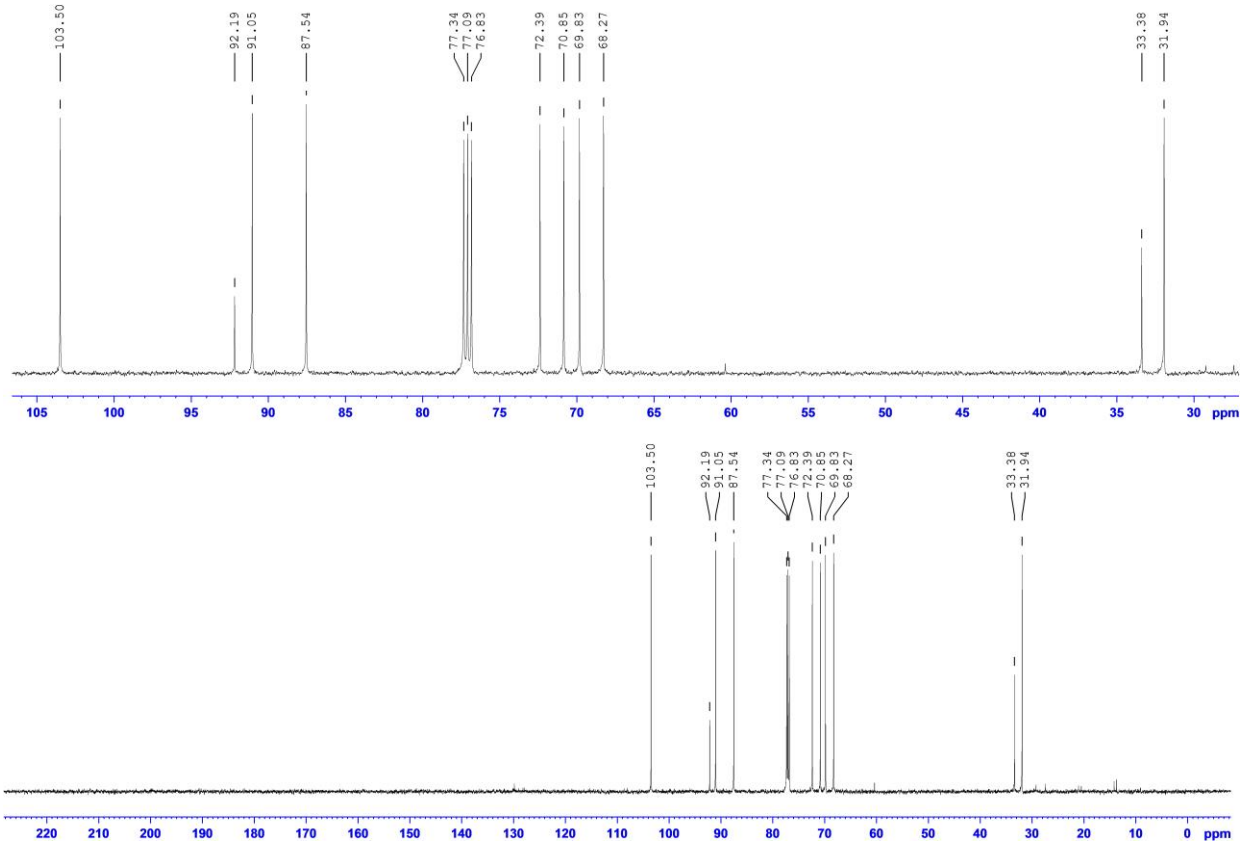


Fig. S9.2. Complete $^{13}C\{^{1}H\}$ NMR spectrum of **10** in $CDCl_3$

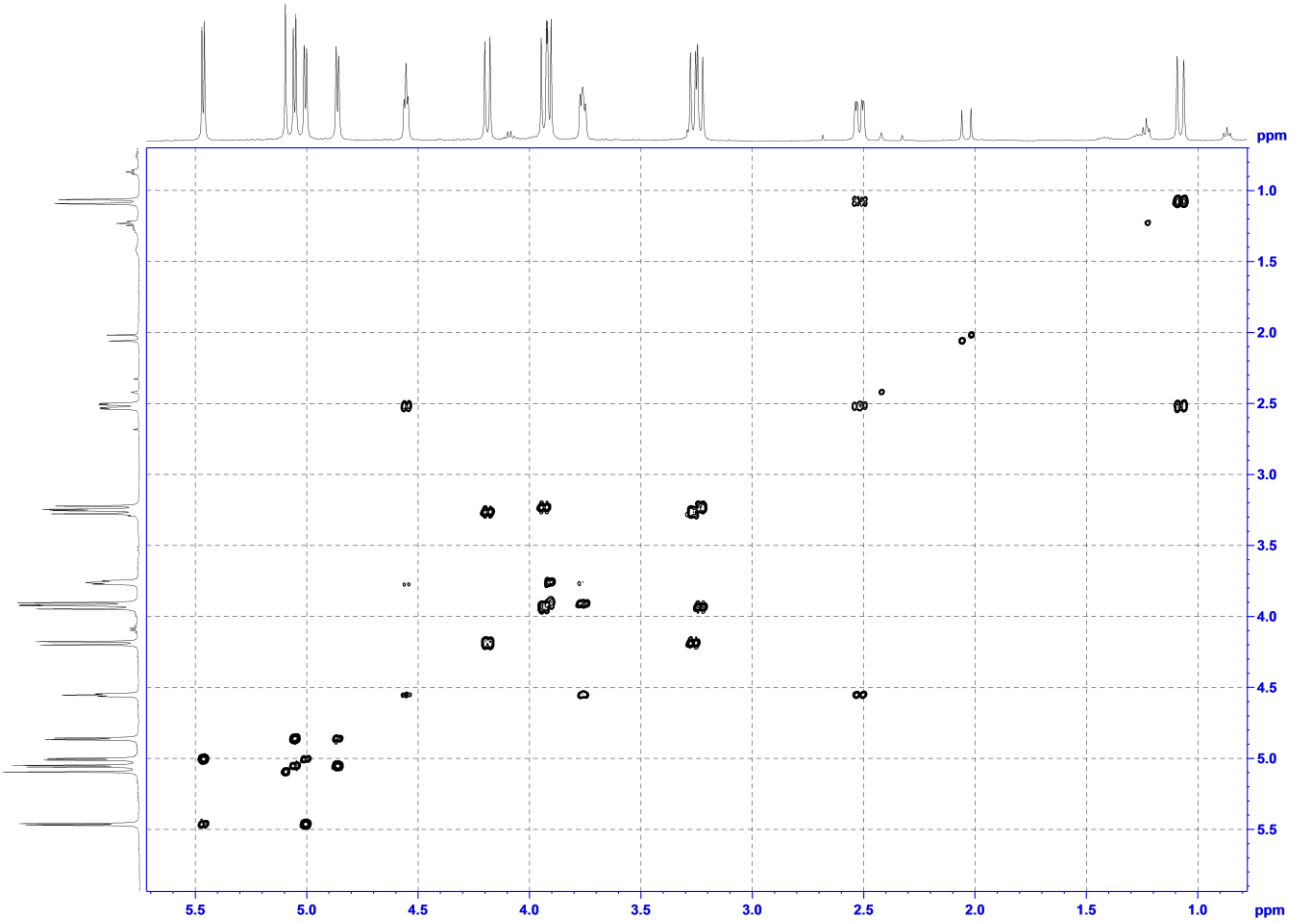


Fig. S9.3. Complete {^{1}H,^{1}H} COSY NMR spectrum of **10** in $CDCl_3$

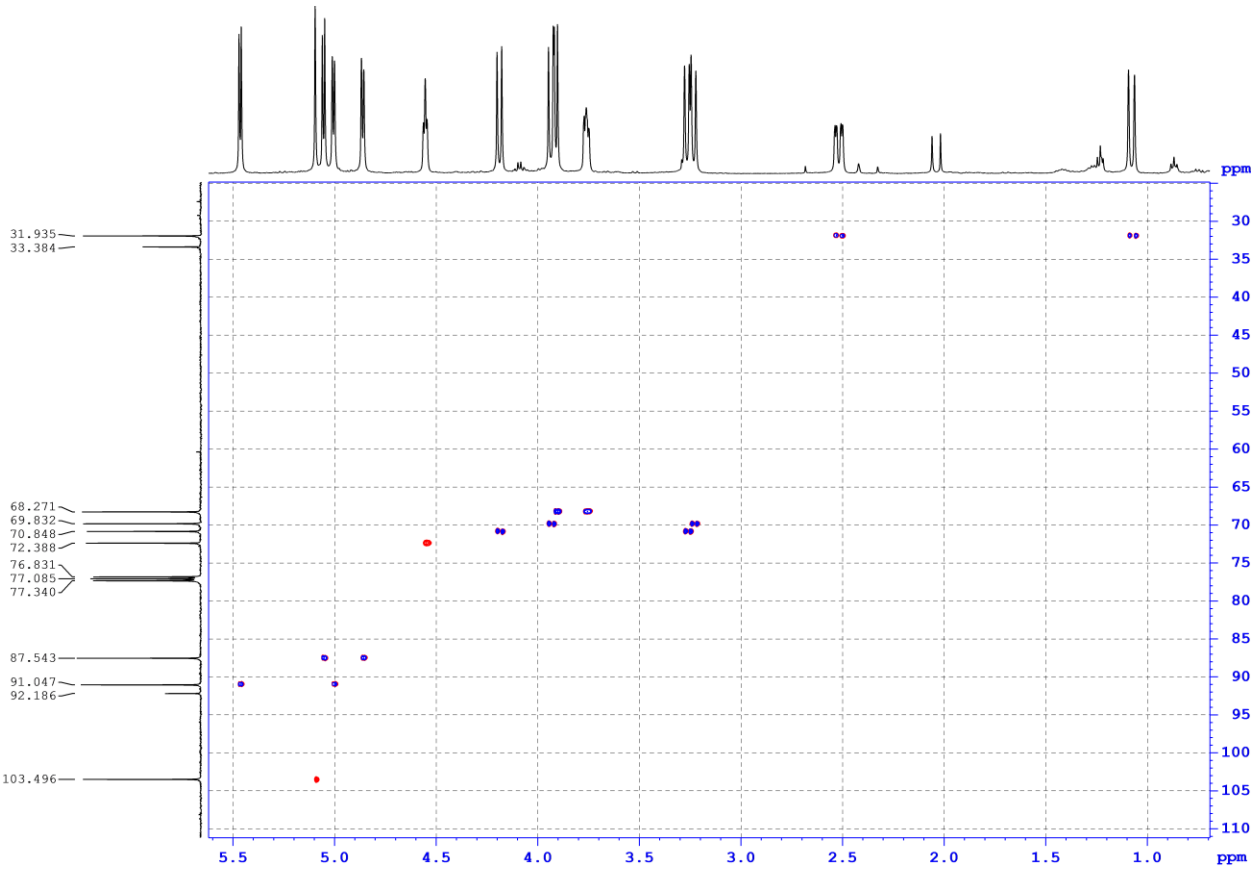


Fig. S9.4. {^{1}H,^{13}C} HSQCED NMR spectrum of **10** in $CDCl_3$

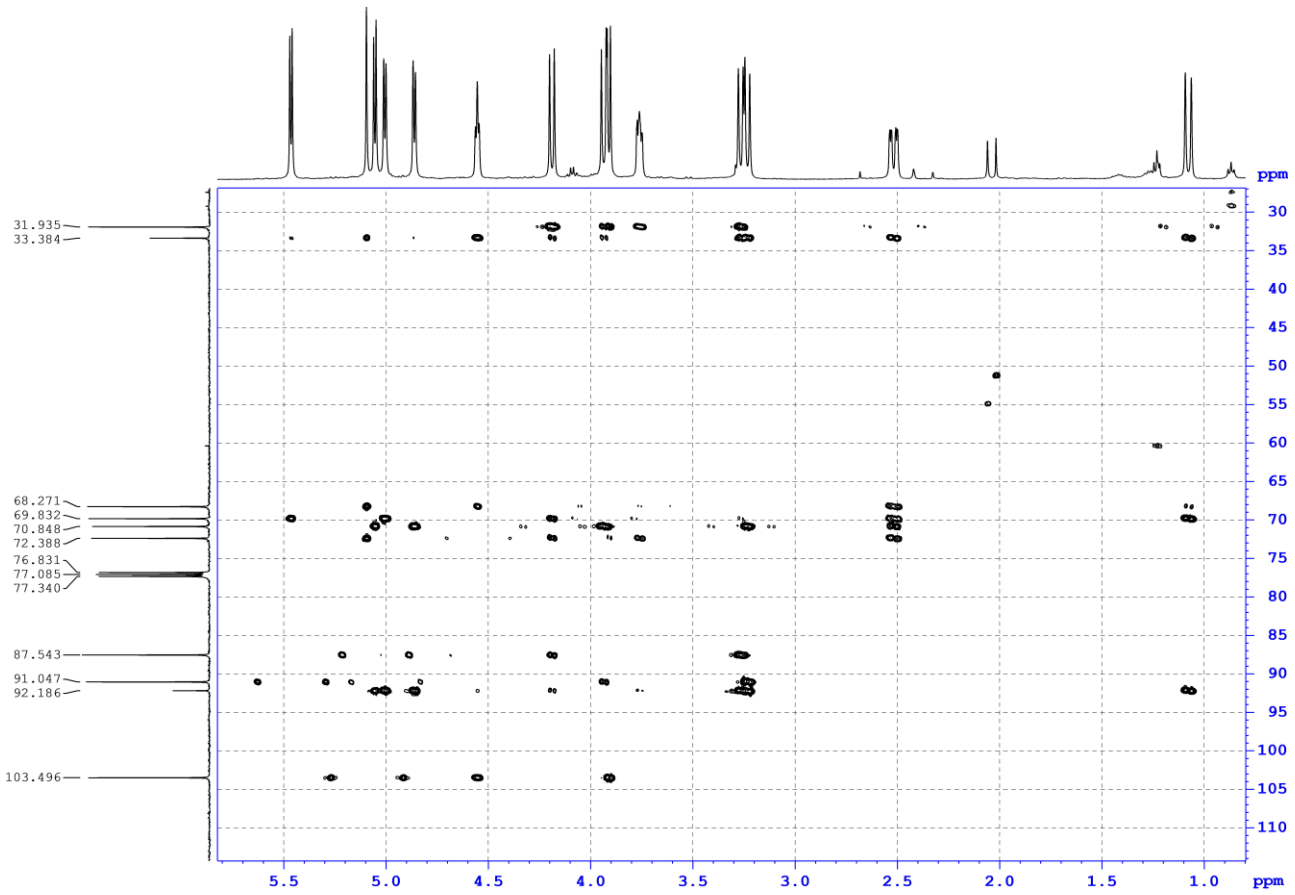


Fig. S9.5. {^{1}H,^{13}C} HMBC NMR spectrum of **10** in $CDCl_3$

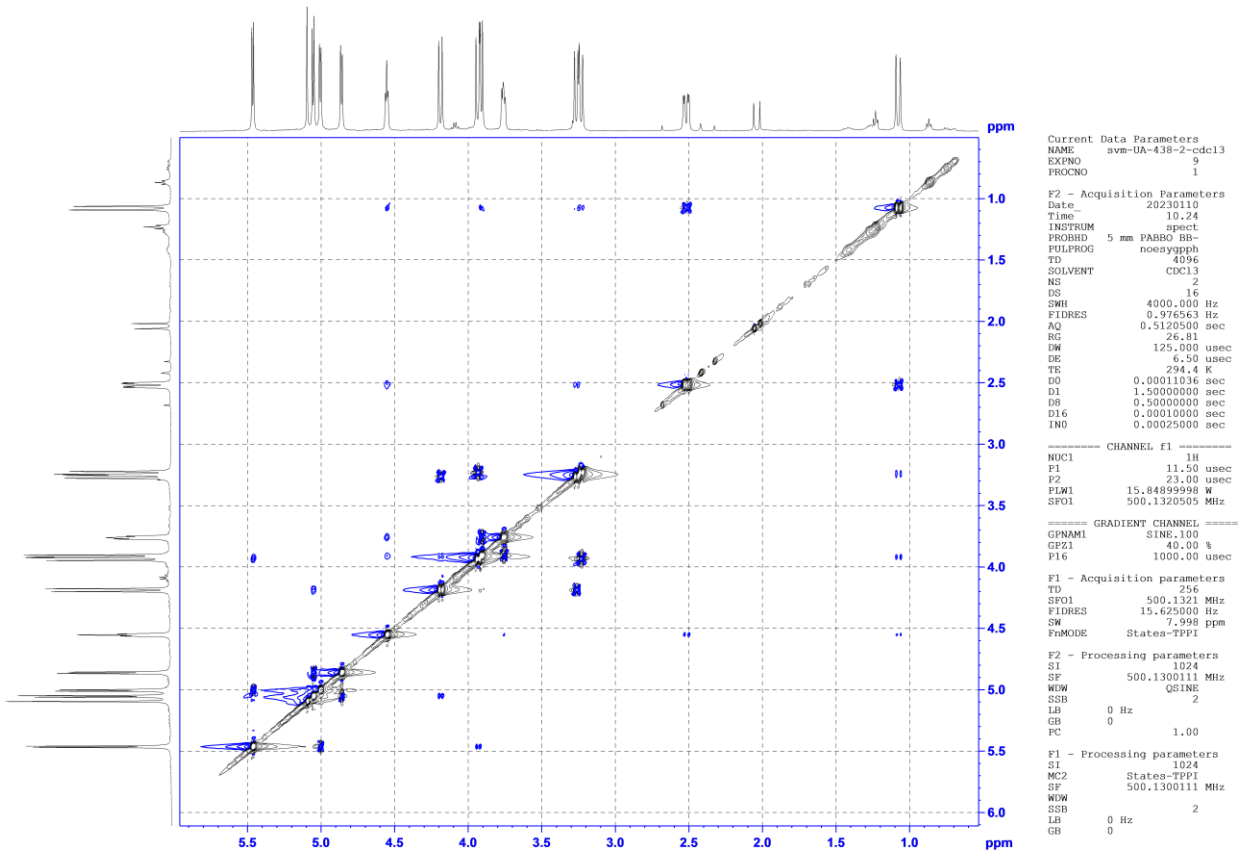


Fig. S9.6. Complete {^{1}H,^{1}H} NOESY NMR spectrum of **10** in $CDCl_3$

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