Supplementary Information

Regioselective C(sp^3)–H Alkylation of Fructopyranose Derivative by 1,6-HAT

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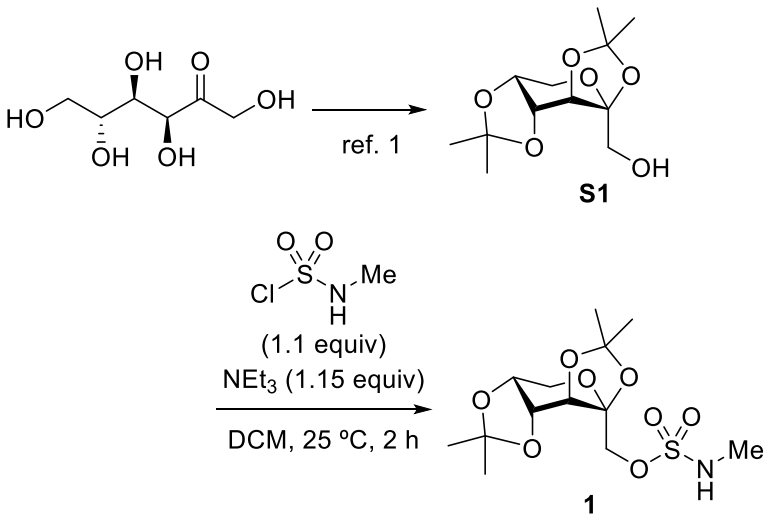
1. General

All reactions were carried out under nitrogen atmosphere unless otherwise noted. Fructopyranose derivative **S1** was prepared from D-fructose according to the literature procedure.[1] 1,2-Dichloroethane (1,2-DCE, Wako) was distilled over CaH_2 prior to use. H_2O (deionized, Takasugi Seiyaku), tetrahydrofuran (THF, anhydrous, Wako), *N*,*N*-dimethylformamide (DMF, anhydrous, Wako), and dichloromethane (DCM, anhydrous, Wako) were used as received from commercial sources. Other reagents were purchased from commercial sources and used without further purification.

^1H (400 MHz) and ^{13}C (100 MHz) NMR spectra were recorded using a JEOL ECZ400 spectrometer. Proton chemical shifts are reported relative to residual solvent peak ($CDCl_3$ at δ 7.26 ppm). Carbon chemical shifts are reported relative to $CDCl_3$ at δ 77.0 ppm. IR spectra were recorded on a JASCO FT/IR-4200. High resolution mass spectra were recorded on JEOL JMS-700 (EI, FAB) spectrometer. Gel Permeation Chromatography (GPC) was performed by Japan Analytical Industry LC-5060 with series-connected JAIGEL-1H (ϕ20 mm x 600 mm) and JAIGEL-2H (ϕ20 mm x 600 mm). Photo reactions were carried out using PhotoRedOx TC (HepatoChem) with 18W Blue LED (450 nm).

2. Preparation of Substrate 1[2]



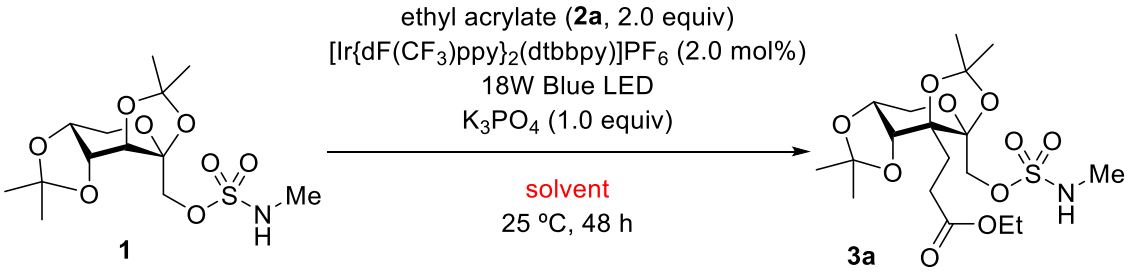
To a dichloromethane (18 mL) solution of methylsulfamoyl chloride, which was prepared by the reaction of methylsulfamic acid (0.940 g, 8.50 mmol) with PCl_5 (1.94 g, 9.30 mmol) in toluene (16 mL) at 80 ºC for 5 h, was added **S1** (2.00 g, 7.70 mmol). Et_3N (0.896 g, 8.85 mmol) was added dropwise to the mixture, and stirred at 25 ºC. After 2 h, the reaction was quenched by slow addition of 1.0 M aq. HCl (9.2 mL). The organic layer was collected and the aqueous layer was extracted with dichloromethane (1 x 18 mL) and ethyl acetate (1 x 18 mL). The combined organic fractions were dried over Na_2SO_4, filtered, and concentrated under reduced pressure. The crude product was purified by column chromatography on silica gel to give compound **1** (2.72 g, 98%). ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.33 (s, 3H), 1.41 (s, 3H), 1.47 (s, 3H), 1.54 (s, 3H), 2.83 (d, J = 5.2 Hz, 3H), 3.74 (d, J = 12.8 Hz, 1H), 3.89 (d, J = 13.2 Hz, 1H), 4.07-4.12 (m, 2H), 4.18 (d, J = 10.4 Hz, 1H), 4.23 (d, J = 8.0 Hz, 1H), 4.32 (d, J = 2.0 Hz, 1H), 4.57-4.61 (m, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 24.0, 25.1, 25.8, 26.5, 29.8, 61.3, 69.9, 70.1, 70.2, 70.6, 100.8, 109.18, 109.24.

3. Optimization of Reaction Conditions

3.1 Screening of Solvents and Bases (Tables S1 and S2)

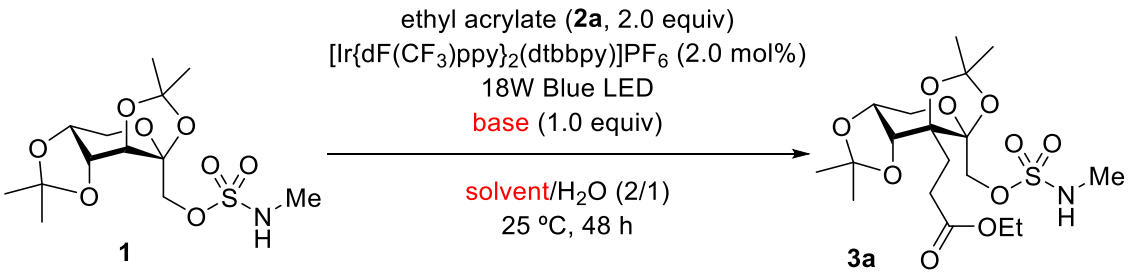
To a test tube, $[Ir\{dF(CF_3)ppy\}_2(dtbbpy)]PF_6]_2$ (2.20 mg, 2.00 μmol, 2.0 mol%), base (0.100 mmol, 1.0 equiv), **1** (35.3 mg, 0.100 mmol), and solvent (2.0 mL) were added, and the mixture was frozen-thaw two times to remove air from the system. To the mixture, ethyl acrylate (**2a**, 20.0 mg, 0.200 mmol, 2.0 equiv) was added via syringe, and the tube was sealed with a Teflon lined screw cap. The mixture was stirred under the irradiation of 18W Blue LED at 25 °C for 48 h. After cooling to room temperature, the mixture was diluted with dichloromethane, washed with water, brine, dried over Na_2SO_4 and concentrated in vacuo. The crude product was purified by GPC.

Table S1 Screening of solvents



entry	solvent	conv. (%)	yield (%)	isomer C-H/N-H
1	DCE	97	20	96:4
2	$PhCF_3$	86	8	27:73
3	DMF	98	<1	<1:>99
4	PhCl	89	15	59:41
5	DCM	83	20	83:17
6	MeCN	99	<1	<1:>99

Table S2 Screening of solvents and bases



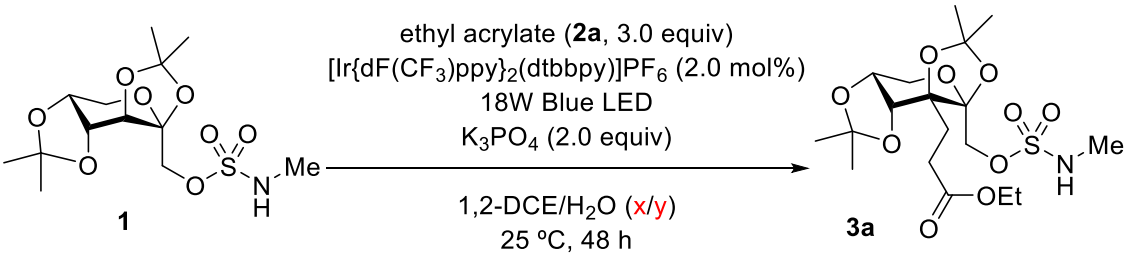
entry	organic solvent:H_2O^a	base	conv. (%)	yield (%)	isomer C-H/N-H
1	DCE	K_3PO_4	94	29	98:2
2	DCE	Cs_2CO_3	87	20	>99:<1
3	DMF	K_3PO_4	68	<1	<1:>99
4	DMF	Cs_2CO_3	84	<1	<1:>99
5	DCM	Cs_2CO_3	68	14	97:3
6	MeCN	Cs_2CO_3	91	1	4:96

[a]Organic solvent:H_2O (2:1, 0.05 M).

3.2 Screening of Amount of H_2O (Table S3)

To a test tube, $[Ir\{dF(CF_3)ppy\}_2(dtbbpy)]PF_6]_2$ (2.20 mg, 2.0 μmol, 2.0 mol%), K_3PO_4 (42.4 mg, 0.200 mmol, 2.0 equiv), **1** (35.3 mg, 0.100 mmol), 1,2-dichloroethane and H_2O were added, and the mixture was frozen-thaw two times to remove air from the system. To the mixture, ethyl acrylate (**2a**, 30.0 mg, 0.300 mmol, 3.0 equiv) was added via syringe, and the tube was sealed with a Teflon lined screw cap. The mixture was stirred under the irradiation of 18W Blue LED at 25 °C for 48 h. After cooling to room temperature, the mixture was diluted with dichloromethane, washed with water, brine, dried over Na_2SO_4 and concentrated in vacuo. The crude product was purified by GPC.

Table S3 Screening of the amount of H_2O



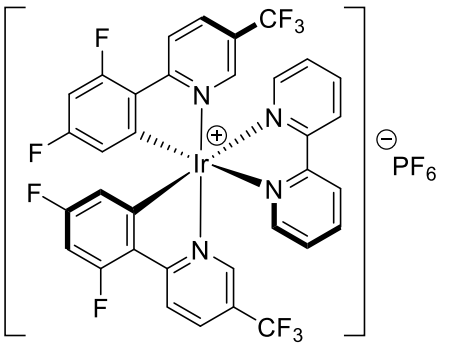
entry	1,2-DCE : H_2O	conc. (M)	conv. (%)	yield (%)
1	3:1	0.05	98	31
2	1:1	0.05	97	37
3	1:2	0.05	84	38
4	2:1	0.2	81	23
5	2:1	0.1	99	21
6	2:1	0.07	99	19
7	2:1	0.04	98	30
8	2:1	0.03	92	40

3.3 Screening of Photocatalysts (Tables S4 and S5)

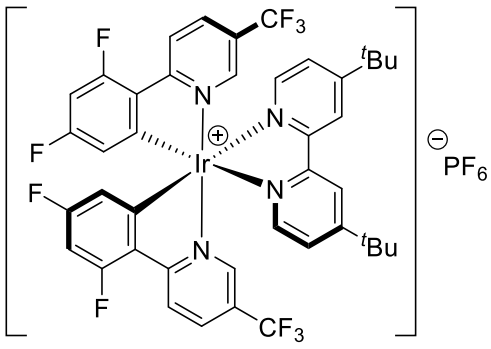
To a test tube, photocatalyst, K_3PO_4 (42.4 mg, 0.200 mmol, 2.0 equiv), **1** (35.3 mg, 0.100 mmol), 1,2-dichloroethane (1.33 mL) and H_2O (0.67 mL) were added, and the mixture was frozen-thaw two times to remove air from the system. To the mixture, ethyl acrylate (**2a**, 30.0 mg, 0.300 mmol, 3.0 equiv) was added via syringe, and the tube was sealed with a Teflon lined screw cap. The mixture was stirred under the irradiation of 18W Blue LED at 25 ℃ for 48 h. After cooling to room temperature, the mixture was diluted with dichloromethane, washed with water, brine, dried over Na_2SO_4 and concentrated in vacuo. The crude product was purified by GPC.

Table S4 Screening of photocatalysts

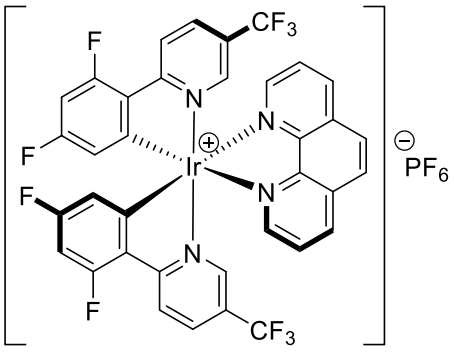
entry	photocatalyst	conv. (%)	yield (%)
1	$[Ir\{dF(CF_3)ppy\}_2(bpy)]PF_6$	85	32
2	$[Ir\{dF(CF_3)ppy\}_2(dtbpy)]PF_6$	99	31
3	$[Ir\{dF(CF_3)ppy\}_2(phen)]PF_6$	84	31
4	$[Ir\{dF(CH_3)ppy\}_2(bpy)]PF_6$	96	34
5	$[Ir\{dF(CH_3)ppy\}_2(dtbpy)]PF_6$	85	29
6	$[Ir\{dF(CF_3)ppy\}_2(5,5'\text{-}dCF_3bpy)]PF_6$	16	3
7	$[Ir\{dF(CH_3)ppy\}_2(5,5'\text{-}dCF_3bpy)]PF_6$	36	11
8	$RuCl_2(phen)_3$	29	<1



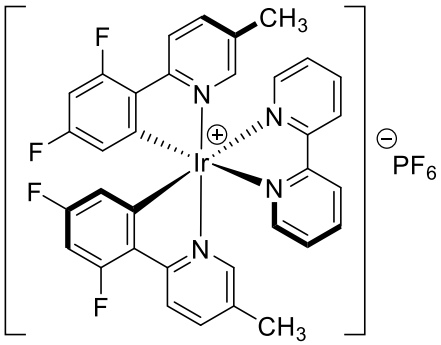
$[Ir\{dF(CF_3)ppy\}_2(bpy)]PF_6$
(entry 1)



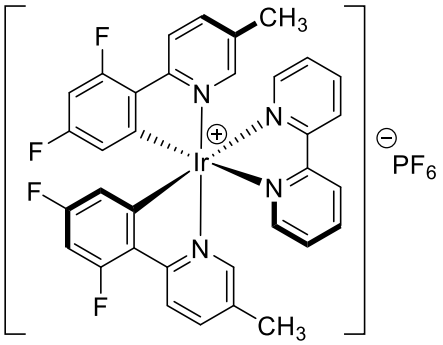
$[Ir\{dF(CF_3)ppy\}_2(dtbpy)]PF_6$
(entry 2)



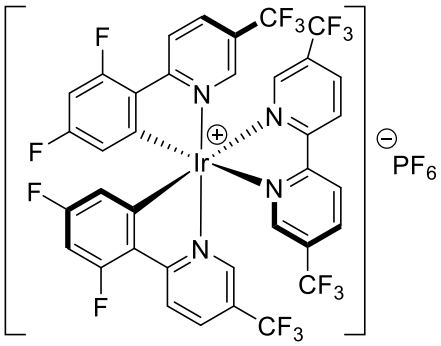
$[Ir\{dF(CF_3)ppy\}_2(phen)]PF_6$
(entry 3)



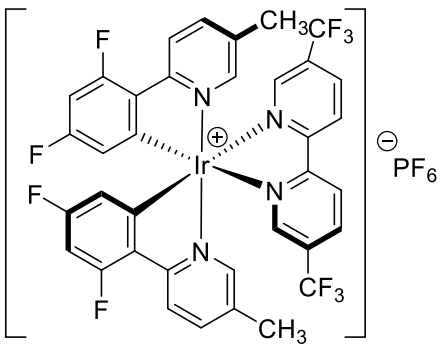
$[Ir\{dF(CH_3)ppy\}_2(bpy)]PF_6$
(entry 4)



$[Ir\{dF(CH_3)ppy\}_2(dtbpy)]PF_6$
(entry 5)

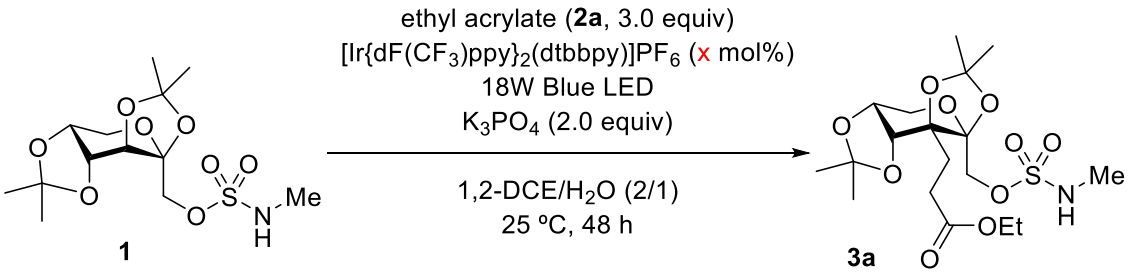


$[Ir\{dF(CF_3)ppy\}_2(5,5'\text{-}dCF_3bpy)]PF_6$
(entry 6)



$[Ir\{dF(CH_3)ppy\}_2(5,5'\text{-}dCF_3bpy)]PF_6$
(entry 7)

Table S5 Screening of the amount of $[Ir\{dF(CF_3)ppy\}_2(dtbbpy)]PF_6]_2$[a]



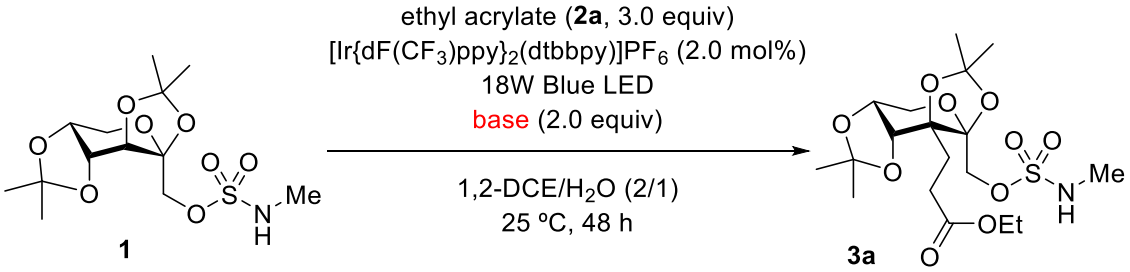
entry	catalyst (mol %)	conv. (%)	yield (%)
1	1.0	93	35
2	2.0	99	40
3	3.0	99	35
4	4.0	96	38
5	5.0	92	37

[a]Reaction time = 36 h.

3.4 Screening of Bases (Tables S6 and S7)

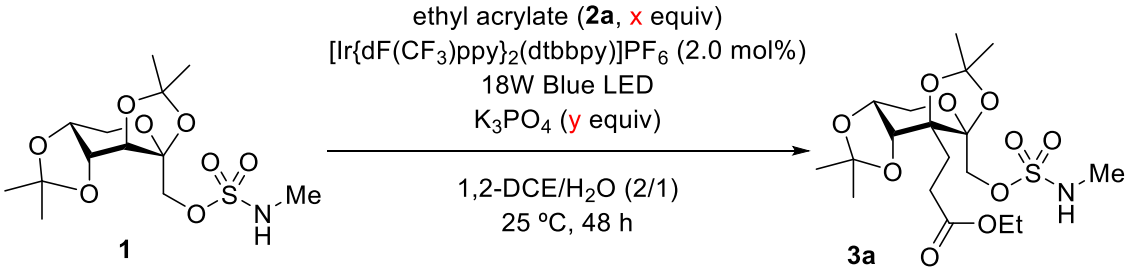
To a test tube, $[Ir\{dF(CF_3)ppy\}_2(dtbbpy)]PF_6]_2$ (2.20 mg, 2.0 μmol, 2.0 mol%), base, **1** (35.3 mg, 0.100 mmol), 1,2-dichloroethane (1.33 mL) and H_2O (0.67 mL) were added, and the mixture was frozen-thaw two times to remove air of the system. To the mixture, ethyl acrylate (**2a**) was added via syringe, and the tube was sealed with a Teflon lined screw cap. The mixture was stirred under the irradiation of 18W Blue LED at 25 ℃ for 48 h. After cooling to room temperature, the mixture was diluted with dichloromethane, washed with water, brine, dried over Na_2SO_4 and concentrated in vacuo. The crude product was purified by GPC.

Table S6 Screening of bases



entry	base	conv. (%)	yield (%)
1	K_3PO_4	95	35
2	K_2CO_3	85	27
3	Na_2CO_3	94	31
4	K_2HPO_4	<1	<1
5	Na_2HPO_4	<1	<1
6	AcONa	<1	<1
7	$Na_2HPO_4•2H_2O$	<1	<1
8	KH_2PO_4	<1	<1
9	AcOK	<1	<1
10	Cs_2CO_3	96	28
11	NaH_2PO_4	<1	<1
12	NEt_3	<1	<1

Table S7 Screening of the amount of ethyl acrylate and K_3PO_4

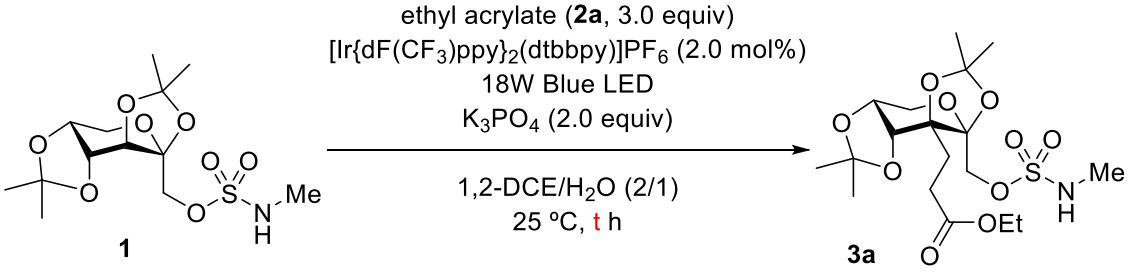


entry	ethyl acrylate (equiv)	K_3PO_4 (equiv)	conv. (%)	yield (%)
1	1.0	1.0	85	29
2	2.0	1.0	98	37
3	3.0	1.0	99	29
4	2.0	2.0	95	42
5	3.0	2.0	83	44
6	3.0	3.0	97	33

3.5 Screening of Reaction Time (Table S8)

To a test tube, $[Ir\{dF(CF_3)ppy\}_2(dtbbpy)]PF_6]_2$ (2.20 mg, 2.0 μmol, 2.0 mol%), K_3PO_4 (42.4 mg, 0.200 mmol, 2.0 equiv), **1** (35.3 mg, 0.100 mmol), 1,2-dichloroethane (1.33 mL) and H_2O (0.67 mL) were added, and the mixture was frozen-thaw two times to remove air of the system. To the mixture, ethyl acrylate (**2a,** 30.0 mg, 0.300 mmol, 3.0 equiv) was added via syringe, and the tube was sealed with a Teflon lined screw cap. The mixture was stirred under the irradiation of 18W Blue LED at 25 ℃ for different reaction times. After cooling to room temperature, the mixture was diluted with dichloromethane, washed with water, brine, dried over Na_2SO_4 and concentrated in vacuo. Purification of the crude product by GPC.

Table S8 Screening of reaction time

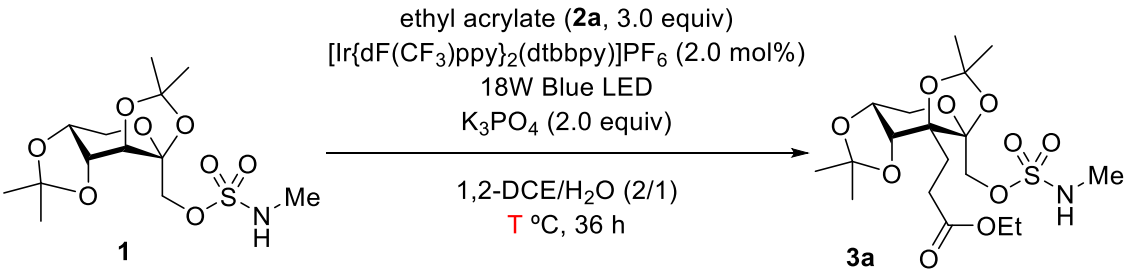


entry	time (h)	conv. (%)	yield (%)
1	24	99	29
2	36	99	31
3	48	94	27

3.6 Screening of Reaction Temperature (Table S9)

To a test tube, $[Ir\{dF(CF_3)ppy\}_2(dtbbpy)]PF_6]_2$ (2.20 mg, 2.0 μmol, 2.0 mol%), K_3PO_4 (42.4 mg, 0.200 mmol, 2.0 equiv), **1** (35.3 mg, 0.100 mmol), 1,2-dichloroethane (1.33 mL) and H_2O (0.67 mL) were added, and the mixture was frozen-thaw two times to remove air of the system. To the mixture, ethyl acrylate (**2a,** 30.0 mg, 0.300 mmol, 3.0 equiv) was added via syringe, and the tube was sealed with a Teflon lined screw cap. The mixture was stirred under the irradiation of 18W Blue LED at different temperatures for 36 h. After cooling to room temperature, the mixture was diluted with dichloromethane, washed with water, brine, dried over Na_2SO_4 and concentrated in vacuo. The crude product was purified by GPC.

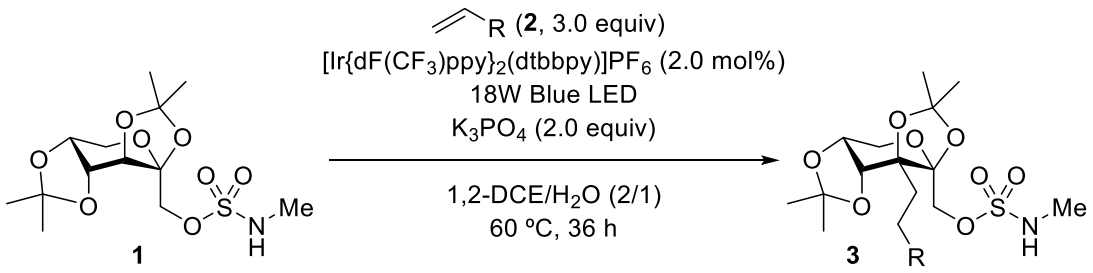
Table S9 Screening of reaction temperature



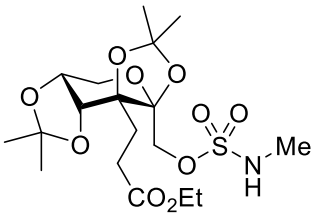
entry	T (°C)	conv. (%)	yield (%)
1	15	97	30
2	25	99	31
3	40	92	45
4	50	91	45
5	60	86	46
6	75	95	38

4. Substrate Scope of Alkenes

General procedure: To a test tube, $[Ir\{dF(CF_3)ppy\}_2(dtbbpy)]PF_6]_2$ (2.20 mg, 2.0 μmol, 2.0 mol%), K_3PO_4 (42.4 mg, 0.200 mmol, 2.0 equiv), **1** (35.3 mg, 0.100 mmol), 1,2-dichloroethane (1.33 mL) and H_2O (0.67 mL) were added, and the mixture was frozen-thaw two times to remove air of the system. To the mixture, ethyl acrylate (**2a,** 30.0 mg, 0.300 mmol, 3.0 equiv) was added via syringe, and the tube was sealed with a Teflon lined screw cap. The mixture was stirred under the irradiation of 18W Blue LED at 60°C for 36 h. After cooling to room temperature, the mixture was diluted with dichloromethane, washed with water, brine, dried over Na_2SO_4 and concentrated in vacuo. The crude product was purified by GPC.



Synthesis of compound 3a



Following General Procedure (ethyl acrylate (**2a**, 0.300 mmol), 60 °C, 36 h). Compound **3a** was obtained as a colorless oil (18.1 mg, 40%) by GPC.

^{1}H NMR (400 MHz, $CDCl_3$) δ 1.26 (t, J = 7.0 Hz, 3H), 1.30 (s, 3H), 1.45 (s, 3H), 1.49 (s, 3H), 1.52 (s, 3H), 2.20-2.26 (m, 2H), 2.43-2.58 (m, 2H), 2.82 (d, J = 6.8 Hz, 3H), 3.73 (d, J = 14.4 Hz, 1H), 3.95 (dd, J = 12.8, 2.8 Hz, 1H), 4.13 (dd, J = 14.4, 7.6 Hz, 2H), 4.21-4.24 (m, 3H), 4.30 (d, J = 7.6 Hz, 1H), 4.65 (d, J = 15.2 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 14.2, 24.4, 26.2, 27.4, 27.9, 29.2, 29.7, 30.1, 60.6, 61.5, 69.8, 70.4, 71.1, 80.5, 104.0, 108.6, 110.0, 173.4; HRMS (EI) exact mass calculated for $C_{18}H_{31}NO_{10}S$ $[M+H]^+$ 453.1669, found 453.1670; IR (ν/cm^{-1}) 2981, 1734.

In DEPT-135 spectrum of **3a**, eight and five signals were observed, and these signals can be assigned as CH_3 and CH signals and CH_2 signals, respectively (Figure S1). The result is suitable for **3a**. DEPT-135 spectrum of **3b**-**3i** were also measured and the results were consistent with C–H alkylated products.

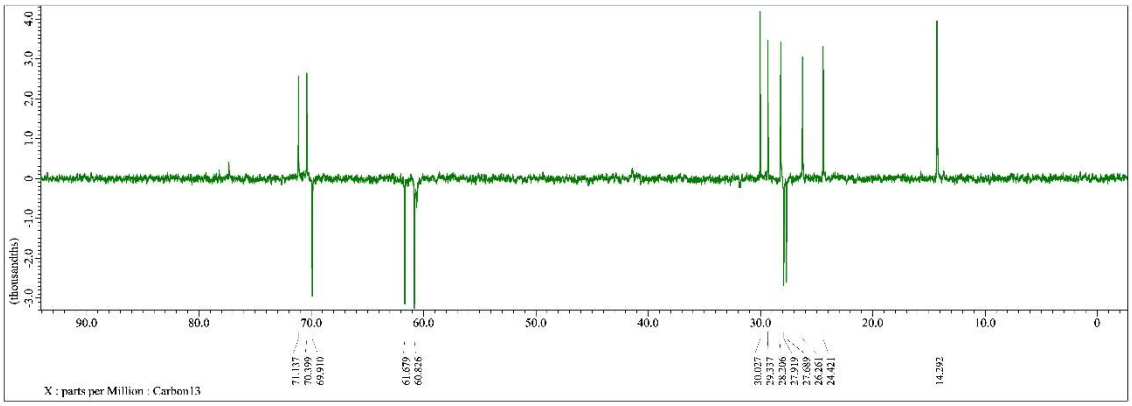


Fig. S1 DEPT-135 spectrum of **3a**.

In NOESY spectrum of **3a**, the correlation between hydrogen atoms on carbons 1 and 2 was observed, and the result showed that the hydrogen atoms exist close to each other in space (Figure S2). These results support the structure of **3a**.

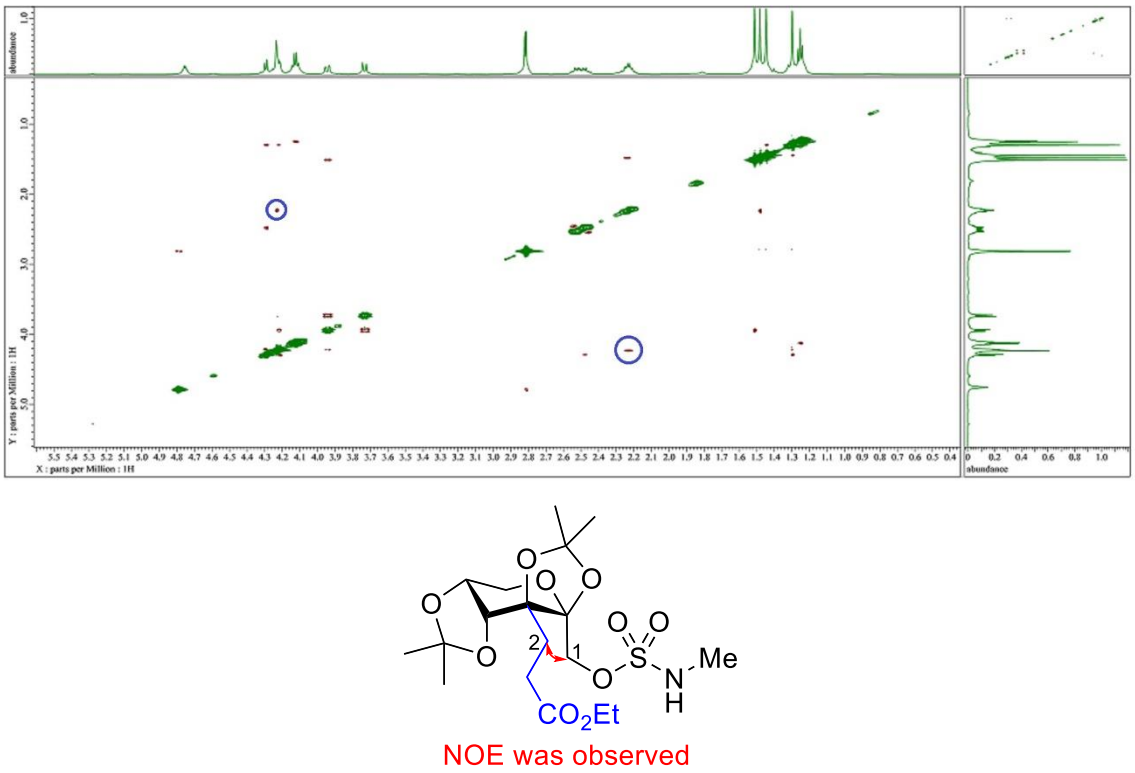
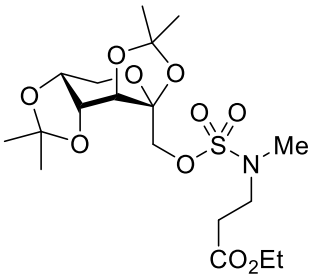


Fig. S2 NOESY spectrum of **3a** (600 MHz, $CDCl_3$).

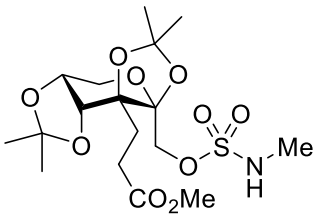
Synthesis of compound 3a′



Following Procedure in Table S2, Entry 3 (ethyl acrylate (**2a**, 0.200 mmol), 25 °C, 48 h). Compound **3a′** was obtained as a colorless oil (19.8 mg, 44%) by GPC.

^{1}H NMR (400 MHz, $CDCl_3$) δ 1.28 (t, J = 7.6 Hz, 3H), 1.35 (s, 3H), 1.43 (s, 3H), 1.49 (s, 3H), 1.56 (s, 3H), 2.67 (t, J = 6.9 Hz, 2H), 2.96 (s, 3H), 3.56 (t, J = 6.9 Hz, 2H), 3.77 (d, J = 12.8, 1H), 3.92 (d, J = 12.8, 1H), 4.10-4.19 (m, 4H), 4.25 (d, J = 7.8 Hz, 1H), 4.36 (d, J = 2.4 Hz, 1H) 4.62 (dd, J = 7.8, 2.4 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 14.1, 23.9, 25.2, 25.8, 26.5, 33.2, 36.4, 47.0, 60.9, 61.3, 69.3, 69.8, 70.0, 70.6, 100.7, 109.13, 109.18, 171.1; HRMS (FAB$^+$) exact mass calculated for $C_{18}H_{31}NO_{10}S$ $[M+H]^+$ 454.1747, found 454.1747; IR (ν/cm^{-1}) 2986, 2936, 1734.

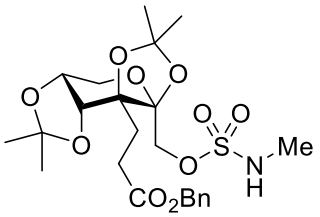
Synthesis of compound 3b



Following General Procedure (methyl acrylate (**2b**, 0.300 mmol), 60 °C, 36 h). Compound **3b** was obtained as a colorless oil (17.6 mg, 40%) by GPC.

^{1}H NMR (400 MHz, $CDCl_3$) δ 1.30 (s, 3H), 1.45 (s, 3H), 1.48 (s, 3H), 1.52 (s, 3H), 2.20-2.28 (m, 2H), 2.45-2.59 (m, 2H), 2.83 (d, *J* = 5.2 Hz, 3H), 3.68 (s, 3H), 3.73 (d, *J* = 13.6 Hz, 1H), 3.95 (d, *J* = 16.0 Hz, 1H), 4.21-4.24 (m, 3H), 4.30 (d, *J* = 8.0 Hz, 1H), 4.48 (s, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 24.4, 26.2, 27.74, 27.76, 28.1, 29.3, 30.0, 51.9, 61.6, 69.8, 70.3, 71.2, 80.6, 103.7, 108.7, 109.9, 173.7; HRMS (EI) exact mass calculated for $C_{17}H_{29}NO_{10}S$ $[M+H]^+$ 439.1512, found 439.1512; IR (ν/cm^{-1}) 2981, 1739.

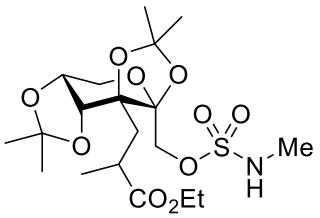
Synthesis of compound 3c



Following General Procedure (benzyl acrylate (**2c**, 0.300 mmol), 60 °C, 36 h). Compound **3c** was obtained as a colorless oil (24.7 mg, 48%) by GPC.

^{1}H NMR (400 MHz, $CDCl_3$) δ 1.29 (s, 3H), 1.45 (s, 3H), 1.48 (s, 3H), 1.51 (s, 3H), 2.24-2.30 (m, 2H), 2.54-2.61 (m, 2H), 2.80 (d, *J* = 5.2 Hz, 3H), 3.73 (d, *J* = 12.8 Hz, 1H), 3.96 (d, *J* = 12.8 Hz, 1H), 4.20-4.30 (m, 6H), 4.50 (d, *J* = 5.6 Hz, 1H), 7.32-7.39 (m, 5H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 24.4, 26.2, 27.7, 27.9, 28.1, 29.3, 30.0, 61.6, 66.6, 69.8, 70.4, 71.1, 80.4, 103.5, 108.9, 109.7, 128.3 (2C), 128.4, 128.7 (2C), 135.8, 173.0; HRMS (EI) exact mass calculated for $C_{23}H_{33}NO_{10}S$ $[M+H]^+$ 515.1825, found 515.1824; IR (ν/cm^{-1}) 2956, 1734.

Synthesis of compound 3d

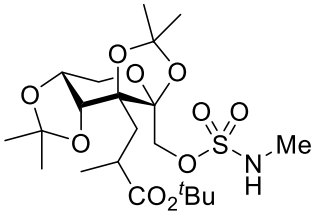


Following General Procedure (ethyl methacrylate (**2d**, 0.300 mmol), 60 °C, 36 h). Compound **3d** was obtained as a colorless oil (24.3 mg, 52%) by GPC.

^{1}H NMR (400 MHz, $CDCl_3$) δ 1.20-1.26 (m, 6H), 1.33 (s, 3H), 1.42-1.49 (m, 6H), 1.61 (s, 3H), 1.87-1.98 (m, 1H), 2.28-2.47 (m, 1H), 2.76-2.86 (m, 4H), 3.70 (d, *J* = 14.4 Hz, 1H), 3.93 (dd, *J* = 13.4, 13.4 Hz, 1H), 4.01-4.16 (m, 1H), 3.96-4.38 (m, 5H), 4.61 (d, *J* = 8.4 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 14.2, 19.3, 24.6, 26.3, 28.1, 29.1, 29.9, 34.9, 37.4, 60.4, 61.8, 69.8, 70.4,

71.6, 81.0, 103.7, 108.6, 110.0, 176.6; HRMS (EI) exact mass calculated for $C_{19}H_{33}NO_{10}S$ $[M+H]^+$ 467.1825, found 467.1826; IR (ν/cm^{-1}) 2961, 1724.

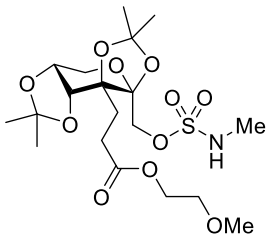
Synthesis of compound 3e



Following General Procedure (*tert*-butyl methacrylate (**2e**, 0.300 mmol), 25 °C, 48 h). Compound **3e** was obtained as a colorless oil (19.8 mg, 40%) by GPC.

^{1}H NMR (400 MHz, $CDCl_3$) δ 1.34 (s, 3H), 1.44-1.48 (m, 21H), 1.89 (dd, *J* = 14.0, 4.0 Hz, 1H), 2.30 (*J* = 14.0, 9.6 Hz, 1H), 2.65-2.75 (m, 1H), 2.83 (d, *J* = 5.2 Hz, 3H), 3.72 (dd, *J* = 14.4, 5.2 Hz, 1H), 3.94 (dd, *J* = 12.8, 2.8 Hz, 1H), 4.23-4.25 (m, 3H), 4.55-4.65 (m, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 19.5, 24.5, 26.3, 28.0, 28.2, 29.3, 30.0, 35.6, 36.9, 61.8, 70.0, 70.7, 71.6, 80.1, 81.1, 103.8, 108.7, 110.1, 175.9; HRMS (EI) exact mass calculated for $C_{21}H_{37}NO_{10}S$ $[M+H]^+$ 496.2216, found 496.2216; IR (ν/cm^{-1}) 2981, 1729.

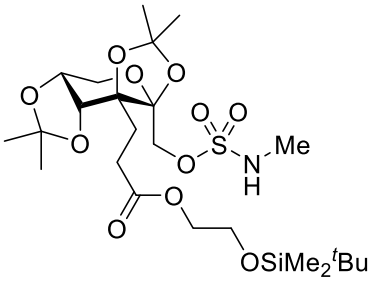
Synthesis of compound 3f



Following General Procedure (2-methoxyethyl acrylate (**2f**, 0.300 mmol), 60 °C, 36 h). Compound **3f** was obtained as a colorless oil (22.2 mg, 46%) by GPC.

^{1}H NMR (400 MHz, $CDCl_3$) δ 1.29 (s, 3H), 1.45 (s, 3H), 1.48 (s, 3H), 1.51 (s, 3H), 2.21-2.28 (m, 2H), 2.54-2.60 (m, 2H), 2.82 (d, *J* = 5.2 Hz, 3H), 3.35-3.38 (m, 3H), 3.59-3.61 (m, 2H), 3.73 (d, *J* = 13.2 Hz, 1H), 3.95 (d, *J* = 12.8 Hz, 1H), 4.24-4.29 (m, 6H), 4.70 (d, *J* = 4.8 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 24.4, 26.2, 27.6, 27.8, 28.2, 29.3, 30.0, 59.0, 61.6, 63.8, 69,6, 70.3, 70.4, 71.1, 81.3, 103.5, 108.8, 109.7, 173.2; HRMS (EI) exact mass calculated for $C_{19}H_{33}NO_{11}S$ $[M+H]^+$ 483.1774, found 483.1773; IR (ν/cm^{-1}) 2956, 1729.

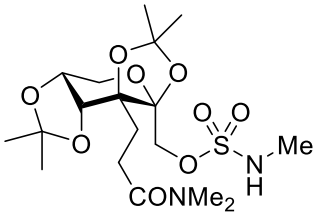
Synthesis of compound 3g



Following General Procedure (2-((*tert*-butyldimethylsilyl)oxy)ethyl acrylate (**2g**, 0.300 mmol), 60 °C, 36 h). Compound **3g** was obtained as a colorless oil (30.4 mg, 52%) by GPC.

^{1}H NMR (400 MHz, $CDCl_3$) δ 0.06 (s, 6H), 0.89 (s, 9H), 1.31 (s, 3H), 1.46 (s, 3H), 1.49 (s, 3H), 1.53 (s, 3H), 2.20-2.28 (m, 2H), 2.48-2.62 (m, 2H), 2.84 (d, J = 5.2 Hz, 3H), 3.74 (dd, J = 12.8, 1.6 Hz 1H), 3.80-3.82 (m, 2H), 3.96 (dd, J = 13.2, 2.8 Hz, 1H), 4.14-4.17 (m, 2H), 4.22-4.17 (m, 3H), 4.31 (d, J = 7.2 Hz, 1H) 4.56-4.60 (m, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ -5.2, 18.4, 24.4, 25.9, 26.3, 27.7, 27.8, 28.2, 29.4, 30.0, 61.3, 61.7, 66.0, 69.9, 70.4, 71.2, 80.5, 103.6, 108.9, 109.8, 173.2; HRMS (EI) exact mass calculated for $C_{24}H_{45}NO_{11}SSi$ $[M+H]^+$ 583.2483, found 583.2482; IR (ν/cm^{-1}) 2941, 1734.

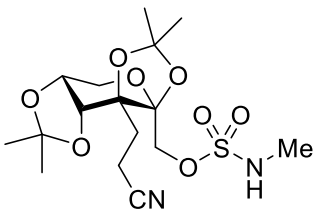
Synthesis of compound 3h



Following General Procedure (*N*,*N*-dimethylacrylamide (**2h**, 0.300 mmol), 25 °C, 48 h). Compound **3h** was obtained as a colorless oil (12.8 mg, 28%) by GPC.

^{1}H NMR (400 MHz, $CDCl_3$) δ 1.31 (s, 3H), 1.45 (s, 3H), 1.49 (s, 3H), 1.65 (s, 3H), 2.14-2.22 (m, 1H), 2.27-2.35 (m, 1H), 2.43-2.56 (m, 2H), 2.83 (d, J = 5.2 Hz, 3H), 2.94 (s, 3H), 3.03(s, 3H), 3.75 (d, J = 13.2 Hz, 1H), 3.97 (d, J = 13.2 Hz, 1H), 4.22-4.36 (m, 4H), 5.12 (d, J = 5.2 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ24.6, 26.2, 26.7, 28.0, 28.2, 29.4, 30.0, 35.6, 37.2, 61.6, 69.7, 70.5, 71.5, 80.7, 103.7, 108.9, 109.6, 172.4; HRMS (EI) exact mass calculated for $C_{18}H_{32}N_2O_9S$ $[M+H]^+$ 452.1829, found 452.1831; IR (ν/cm^{-1}) 2940, 1624.

Synthesis of compound 3i



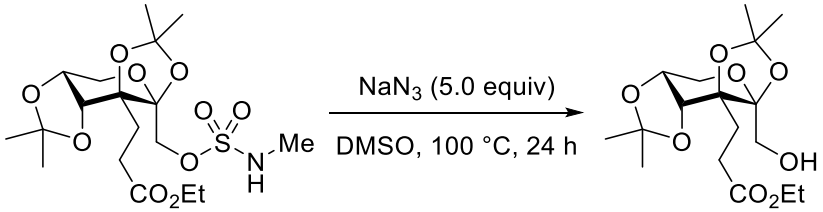
Following General Procedure (acrylonitrile (**2i**, 0.300 mmol), 25 °C, 48 h). Compound **3i** was obtained as a colorless oil (9.2 mg, 23%) by GPC.

^{1}H NMR (400 MHz, $CDCl_3$) δ 1.32 (s, 3H), 1.46 (s, 3H), 1.51 (s, 3H), 1.54 (s, 3H), 2.22-2.29 (m, 1H), 2.38-2.45 (m, 1H), 2.54-2.58 (m, 2H), 2.82 (d, J = 5.6 Hz, 3H), 3.76 (d, J = 12.8 Hz, 1H), 3.94 (d, J =

15.6 Hz, 1H), 4.14-4.19 (m, 2H), 4.22-4.26 (m, 1H), 4.32 (d, *J* = 7.6 Hz, 1H), 4.49 (d, *J* = 4.8 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 11.3, 24.3, 26.1, 28.0, 28.5, 29.5, 29.9, 61.4, 69.4, 70.2, 70.6, 80.0, 103.4, 109.1, 110.0, 119.3; HRMS (EI) exact mass calculated for $C_{16}H_{26}N_2O_8S$ $[M+H]^+$ 406.1410, found 406.1411; IR (ν/cm^{-1}) 2930.

5. Conversion of *N*-methyl sulfamate group in alkylated fructo-pyranose derivative 3a to a hydroxy group (Scheme S1)

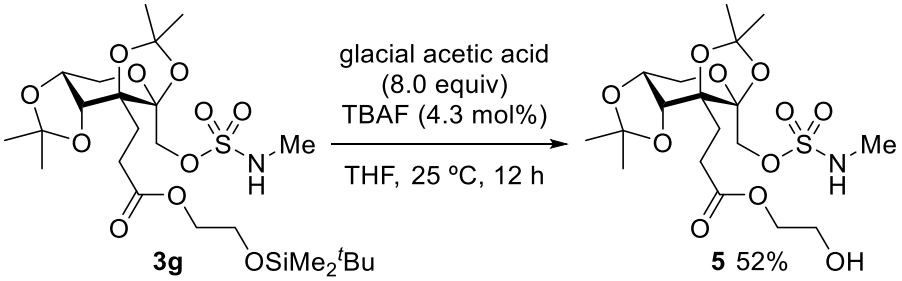
Scheme S1. Conversion of *N*-methyl sulfamate group in alkylated fructopyranose derivative 3a to a hydroxy group



3a **4**

To a test tube charged with a stir bar was added **3a** (31.7 mg, 0.0700 mmol), NaN_3 (22.7 mg, 0.350 mmol) and DMSO (0.10 M, 0.70 mL). The mixture was then heated to 100 ℃ and stirred for 24 h. The mixture was diluted with water (7.0 mL) and extracted with dichloromethane (2 x 7.0 mL). The combined organic phase was washed with water and brine. The solvent was removed under vacuum. The residue was further purified by column chromatography on silica gel (eluted by hexane:ethyl acetate= 3:1) to give compound **4** as colorless oil (17.9 mg, 71% yield). ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.26 (t, *J* = 7.2 Hz, 3H), 1.32 (s, 3H), 1.45 (s, 3H), 1.48 (s, 3H), 1.52 (s, 3H), 2.14 (t, *J* = 6.0 Hz, 1H), 2.28-2.38 (m, 2H), 2.43-2.58 (m, 2H), 3.74 (d, *J* = 6.4 Hz, 2H), 3.77 (dd, *J* = 12.8, 0.8 Hz, 1H), 4.01 (dd, *J* = 12.8, 2.0 Hz, 1H), 4.13 (q, *J* = 14.4, 6.8 Hz, 2H), 4.21-4.24 (m, 1H), 4.31 (d, *J* = 8.0 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 14.3, 24.4, 26.2, 27.6, 28.0, 28.2, 29.5, 60.7, 61.7, 64.5, 70.9, 71.0, 80.4, 105.5, 108.6, 109.1, 173.4. HRMS (EI) exact mass calculated for $C_{17}H_{28}O_8$ $[M+H]^+$ 360.1784, found 360.1784; IR (ν/cm^{-1}) 2986, 1729.

Scheme S2. Deprotection of silyl group pf 3g.

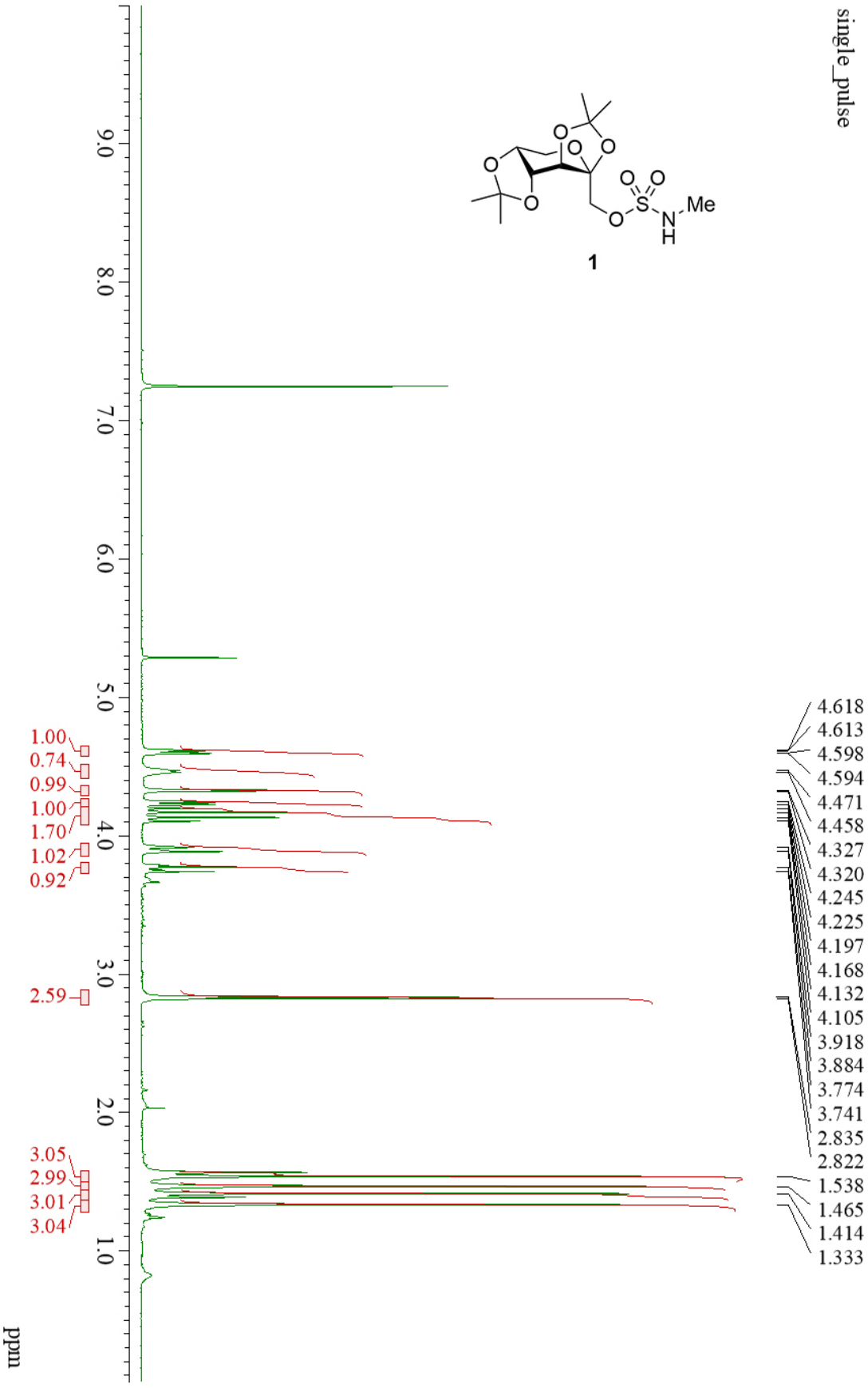


Synthesis of compound 5

Alkylated fructopyranose derivative **3g** (68.2 mg, 0.117 mmol, 1.0 equiv) was dissolved in anhydrous THF (0.50 mL, 0.23 M) at 0 °C under nitrogen. To the solution, glacial acetic acid (53.0 μL, 0.936 mmol, 8.0 equiv) and tetrabutylammonium fluoride (0.10 M TBAF in THF, 50.9 μL, 4.3 mol%) were added dropwise. The mixture was warmed to room temperature and stirred for 18 h. The reaction mixture was diluted with EtOAc (2 x 2.0 mL) and was washed with sat. $NaHCO_3$ (2.0 mL) and brine (2.0 mL). The organic layer was dried over Na_2SO_4, filtered and concentrated under reduced pressure. The residue was further purified by column chromatography on silica gel (eluted by hexane:ethyl acetate = 1:5) to give compound **5** as colorless oil (28.3 mg, 52% yield). ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.31 (s, 3H), 1.45 (s, 3H), 1.49 (s, 3H), 1.52 (s, 3H), 2.23-2.37 (m, 2H), 2.50-2.64 (m, 2H), 3.81 (d, J = 5.2 Hz, 3H), 3.74 (dd, J = 13.2, 1.6 Hz, 1H), 3.82 (q, 2H), 3.95 (dd, J = 13.6, 2.8 Hz, 1H), 4.15-4.27 (m, 5H), 4.31 (d, J = 7.2 Hz, 1H), 4.93-4.97 (m, 1H) [A proton signal of OH group was not observed.]; ^{13}C NMR (100 MHz, $CDCl_3$) δ 24.4, 26.2, 27.8, 28.0, 28.1, 29.3, 29.9, 61.0, 61.6, 66.3, 69.5, 70.4, 80.5, 103.6, 108.9, 109.7, 173.5; HRMS (EI) exact mass calculated for $C_{18}H_{31}NO_{11}S$ $[M+H]^+$ 469.1618, found 469.1617; IR (ν/cm^{-1}) 2925, 1729.

References

1. M. Callari, P. L. De Souza, A. Rawal and M. H. Stenzel, *Angew. Chem. Int. Ed*., 2017, **56**, 8441-8445.
2. H. Saeidian, and M. Abdoli, *J. Sulfur Chem*., 2015, **36**, 463-470.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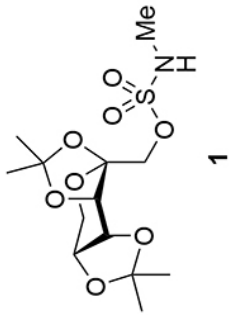
single pulse decoupled gated NOE



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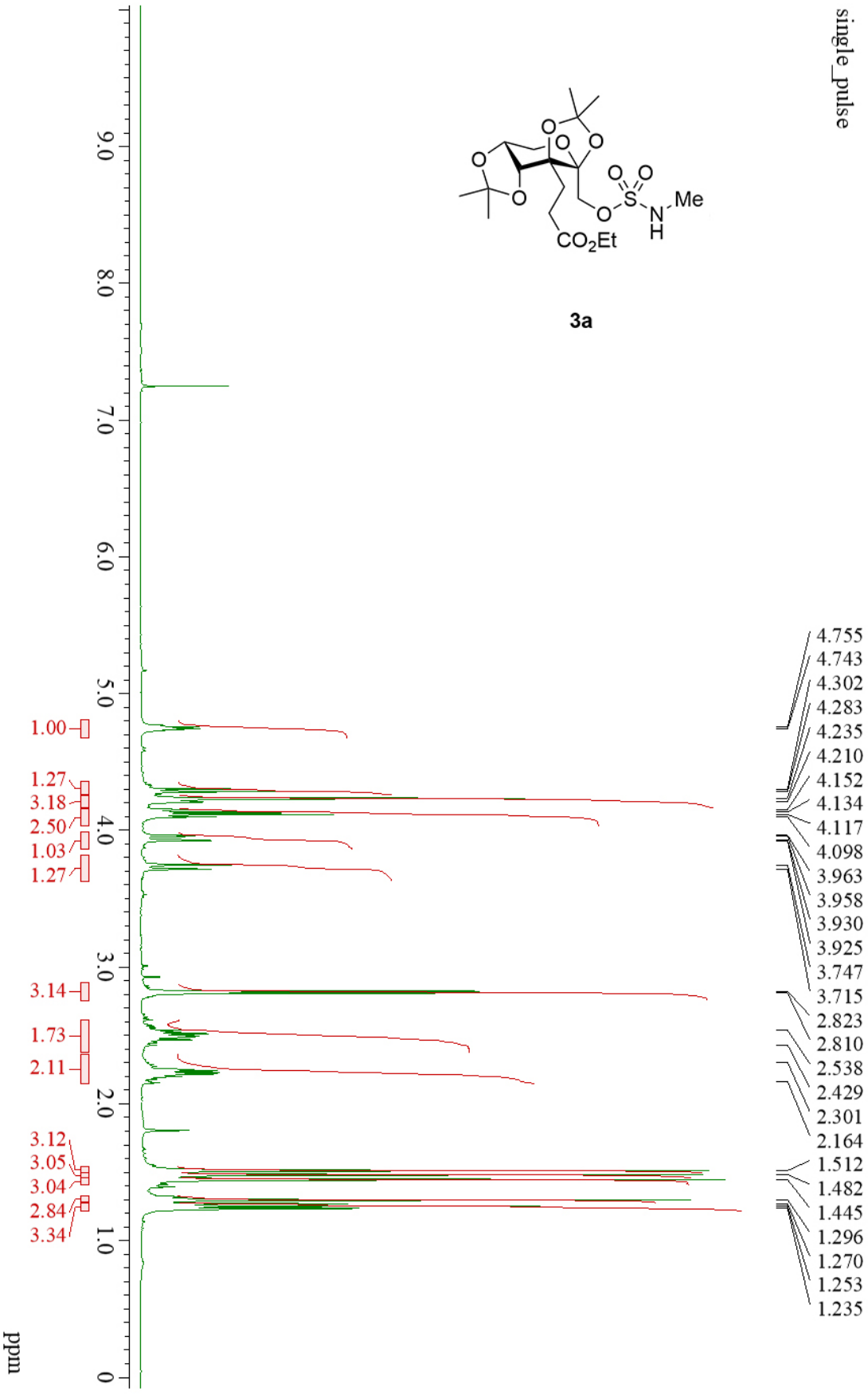
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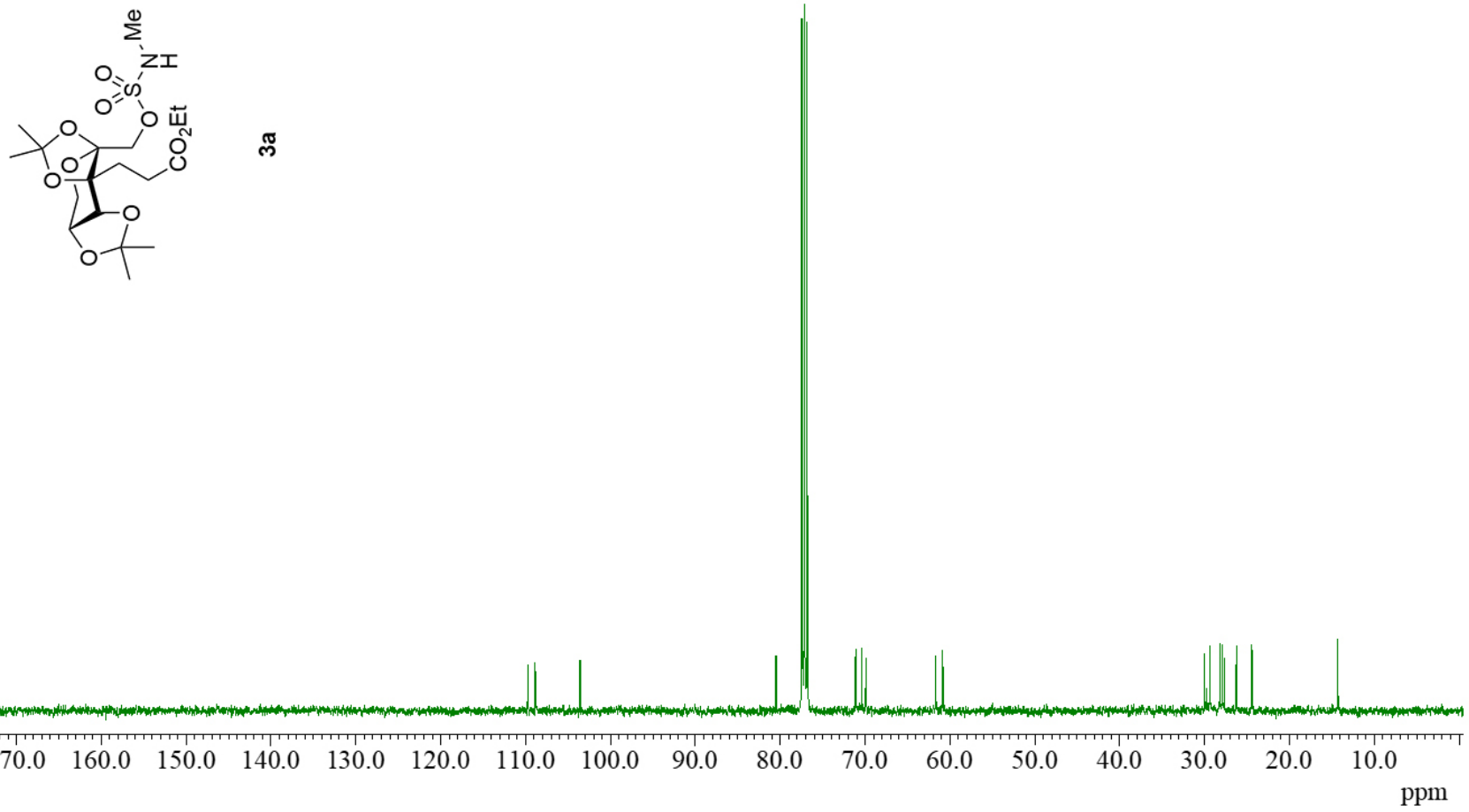

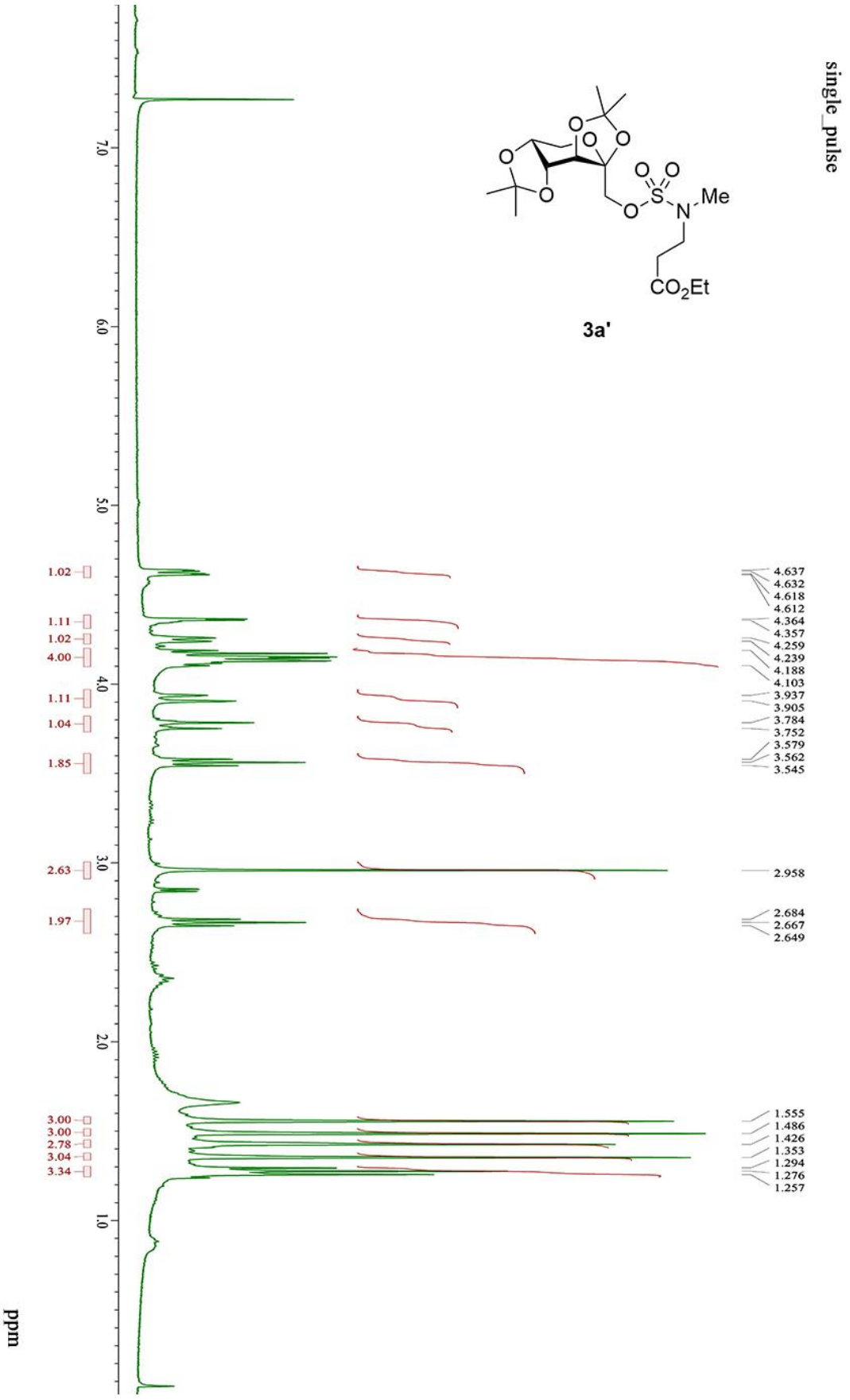
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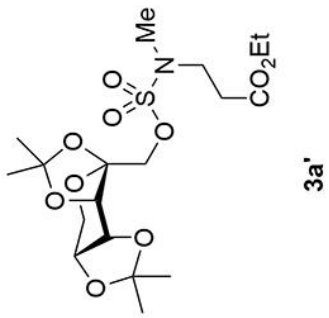
single pulse decoupled gated NOE



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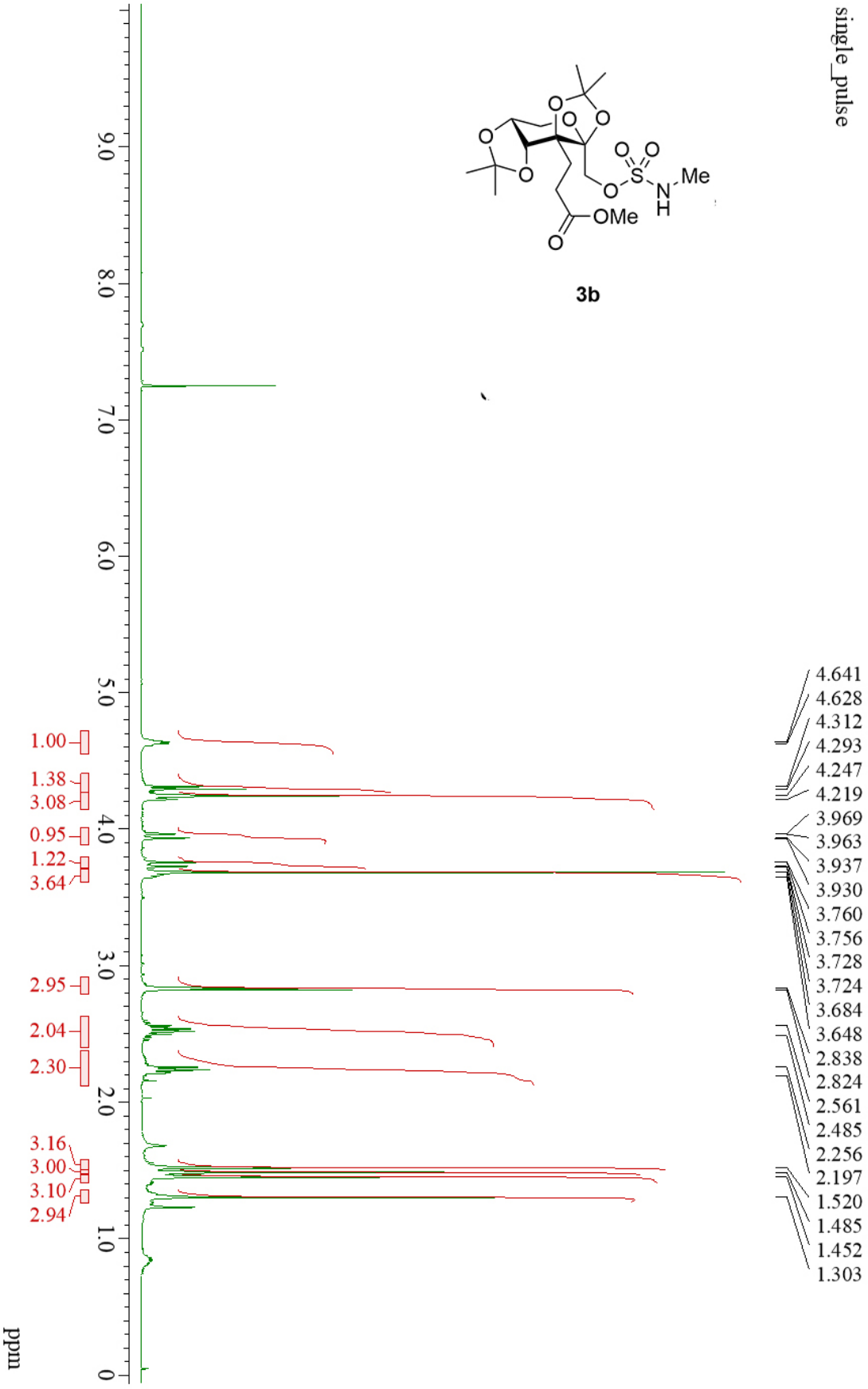
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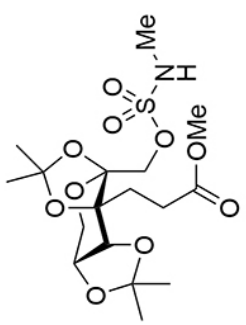
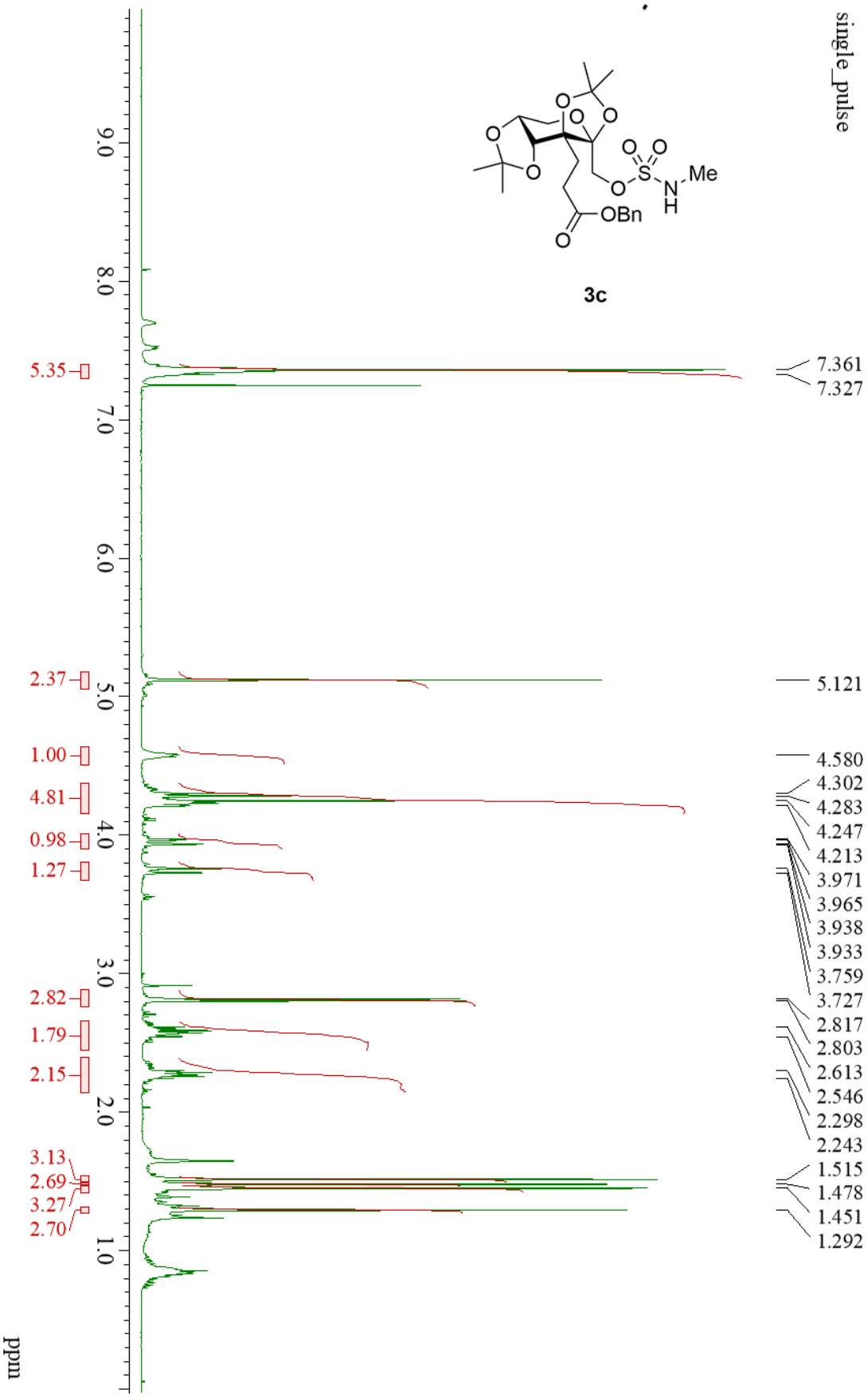
0

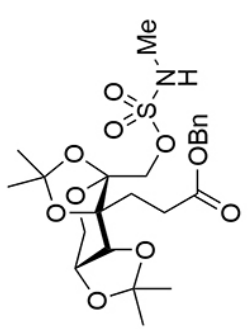
single pulse decoupled gated NOE



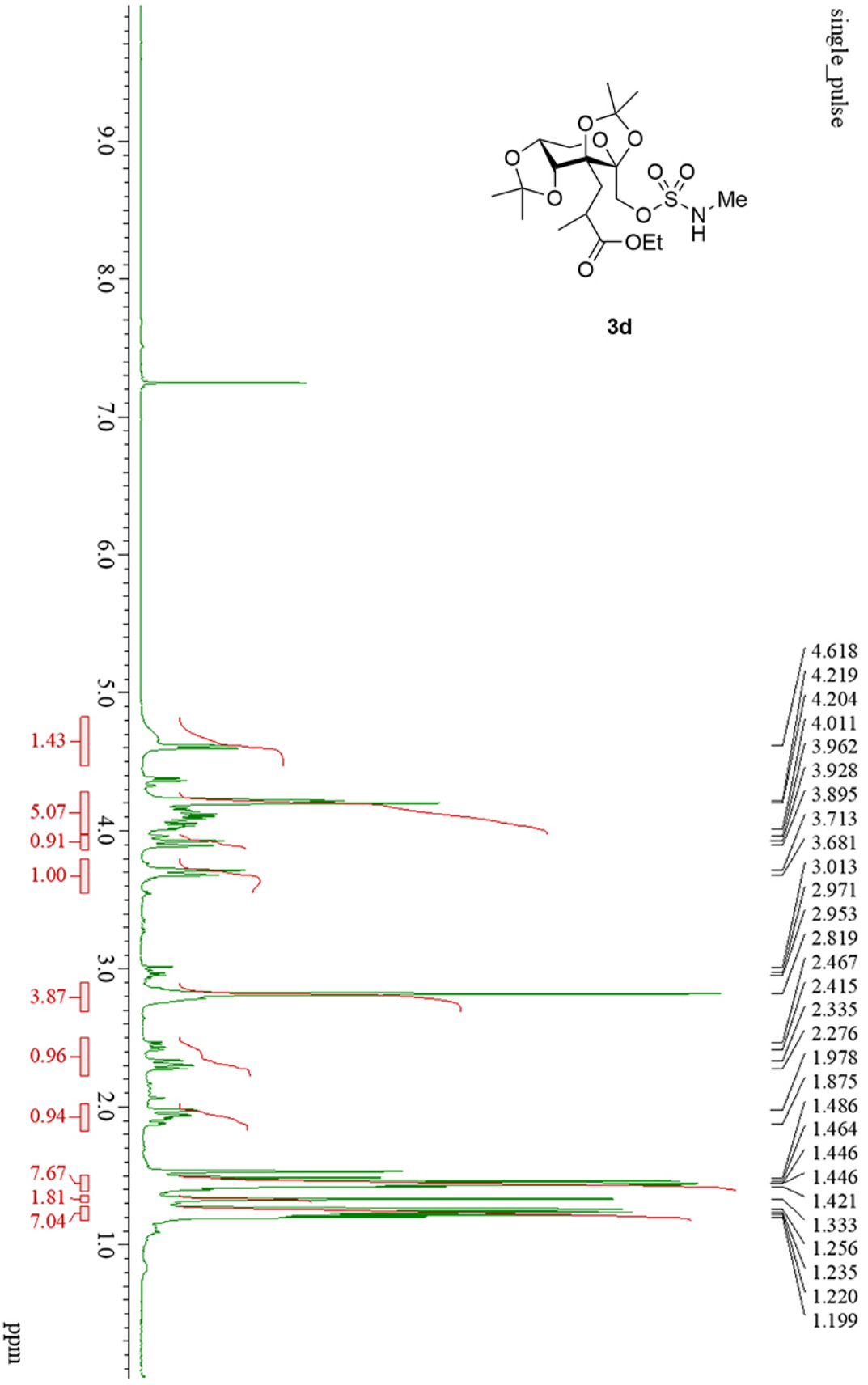
3b


single_pulse
3c
Me
OBn
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
ppm
5.35
2.37
1.00
4.81
0.98
1.27
2.82
1.79
2.15
3.13
2.69
3.27
2.70
7.361
7.327
5.121
4.580
4.302
4.283
4.247
4.213
3.971
3.965
3.938
3.933
3.759
3.727
2.817
2.803
2.613
2.546
2.298
2.243
1.515
1.478
1.451
1.292

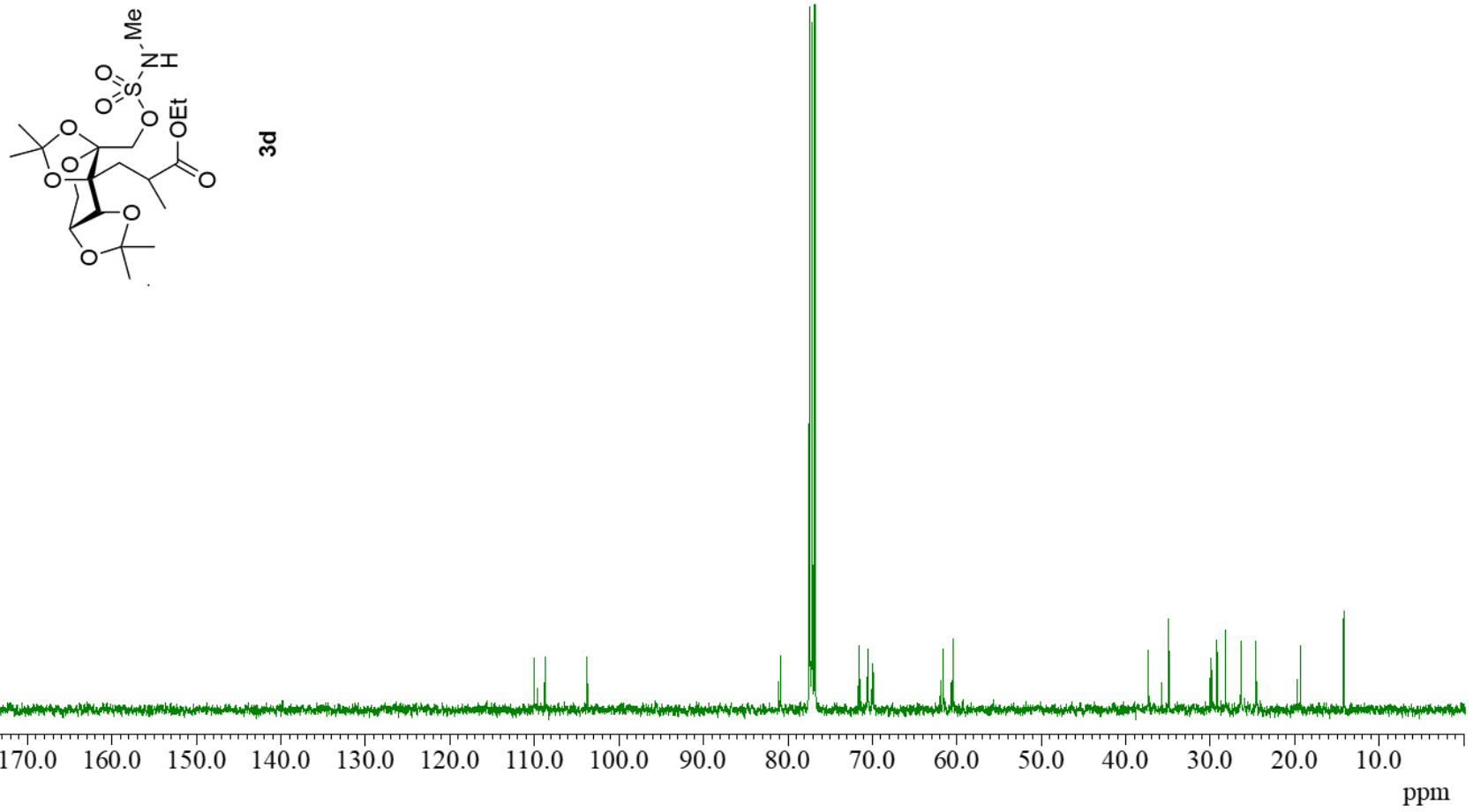
single pulse decoupled gated NOE

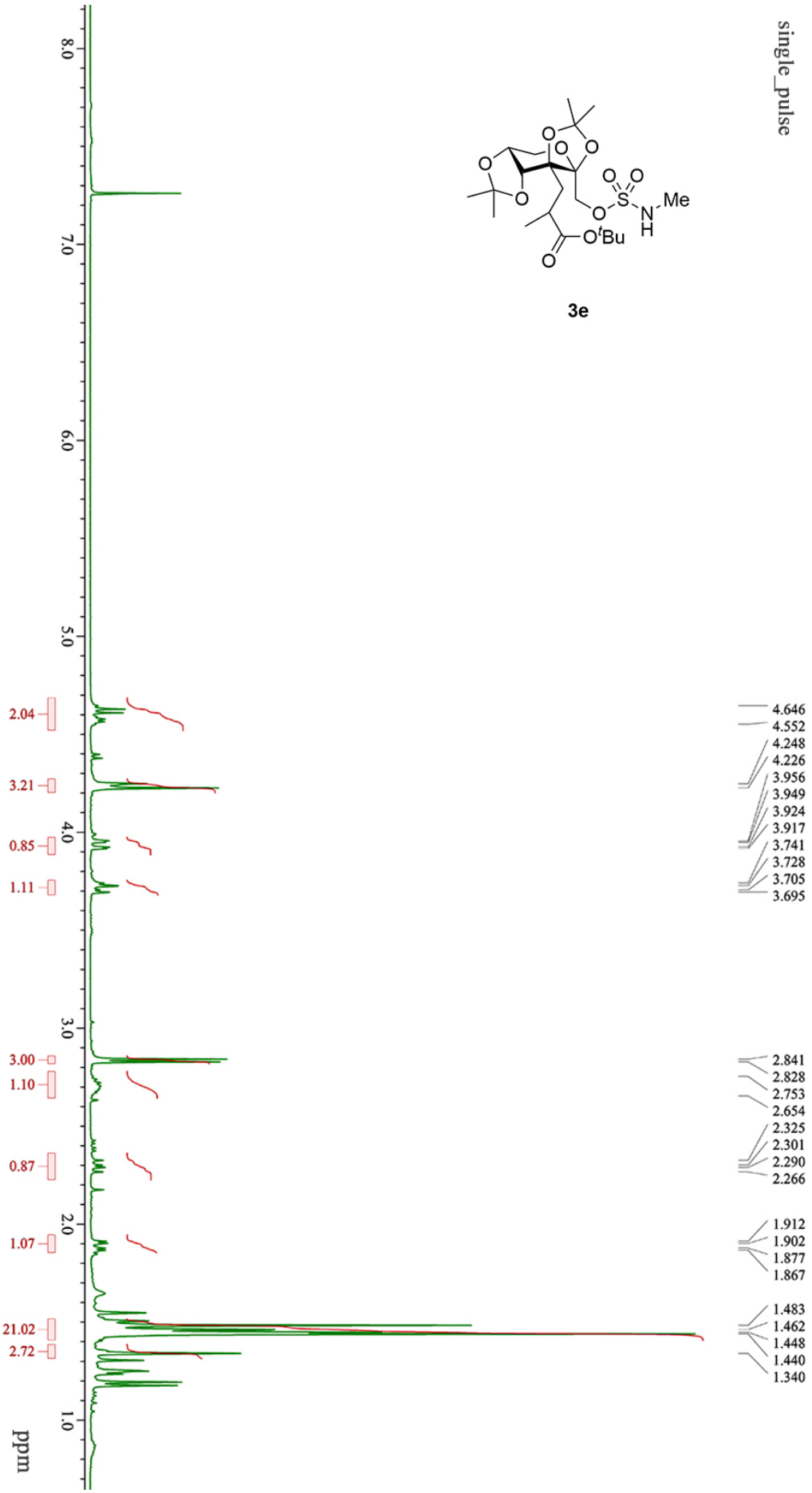


3c

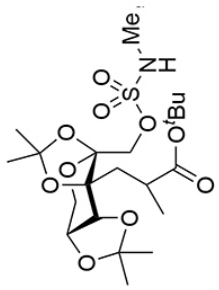

single_pulse
3d
ppm
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
1.43
5.07
0.91
1.00
3.87
0.96
0.94
7.67
1.81
7.04
4.618
4.219
4.204
4.011
3.962
3.928
3.895
3.713
3.681
3.013
2.971
2.953
2.819
2.467
2.415
2.335
2.276
1.978
1.875
1.486
1.464
1.446
1.446
1.421
1.333
1.256
1.235
1.220
1.199

single pulse decoupled gated NOE

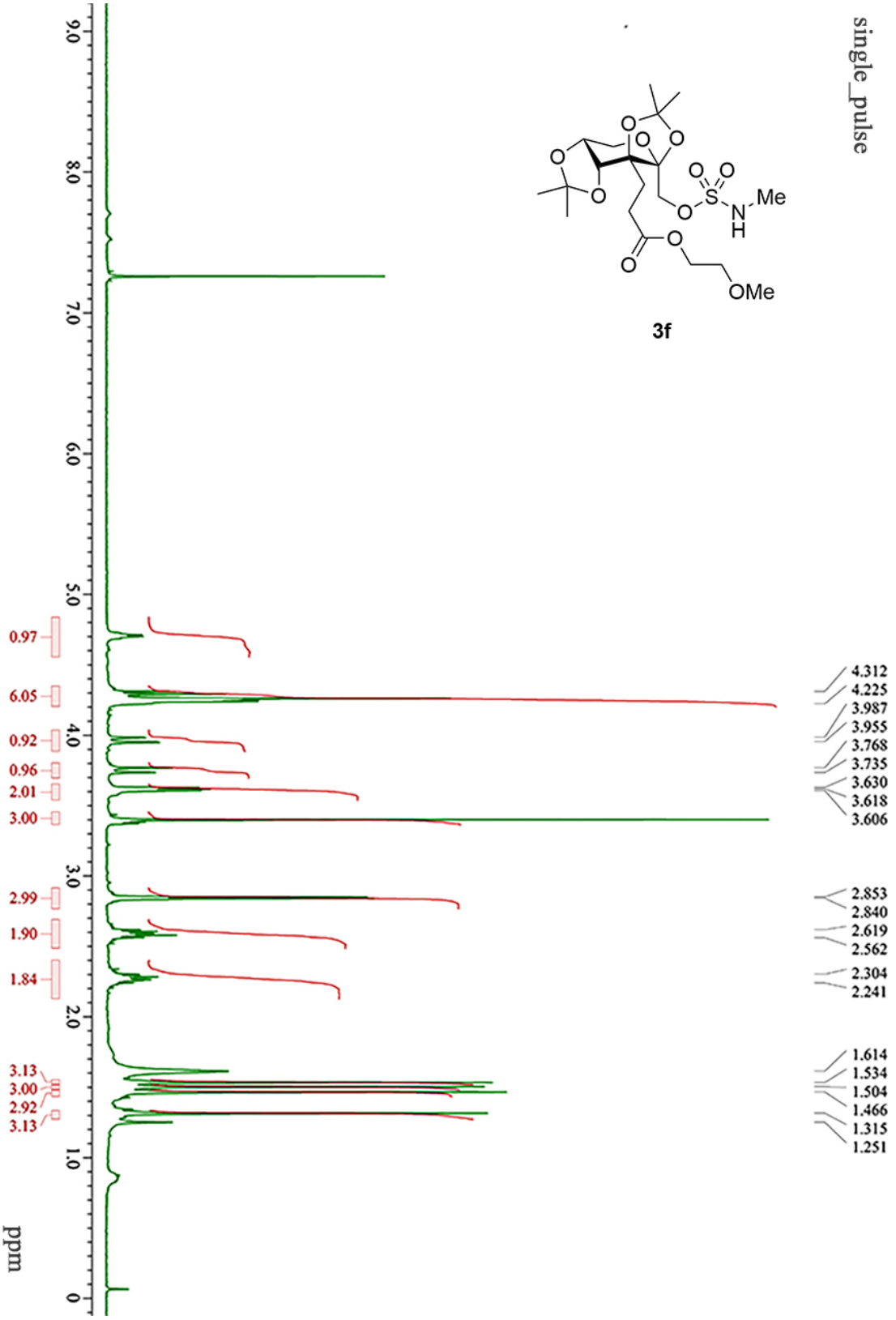



single_pulse
3e
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
ppm
2.04
3.21
0.85
1.11
3.00
1.10
0.87
1.07
21.02
2.72
4.646
4.552
4.248
4.226
3.956
3.949
3.924
3.917
3.741
3.728
3.705
3.695
2.841
2.828
2.753
2.654
2.325
2.301
2.290
2.266
1.912
1.902
1.877
1.867
1.483
1.462
1.448
1.440
1.340

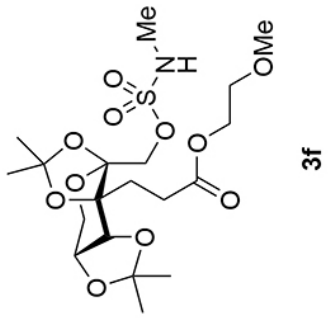
single pulse decoupled gated NOE



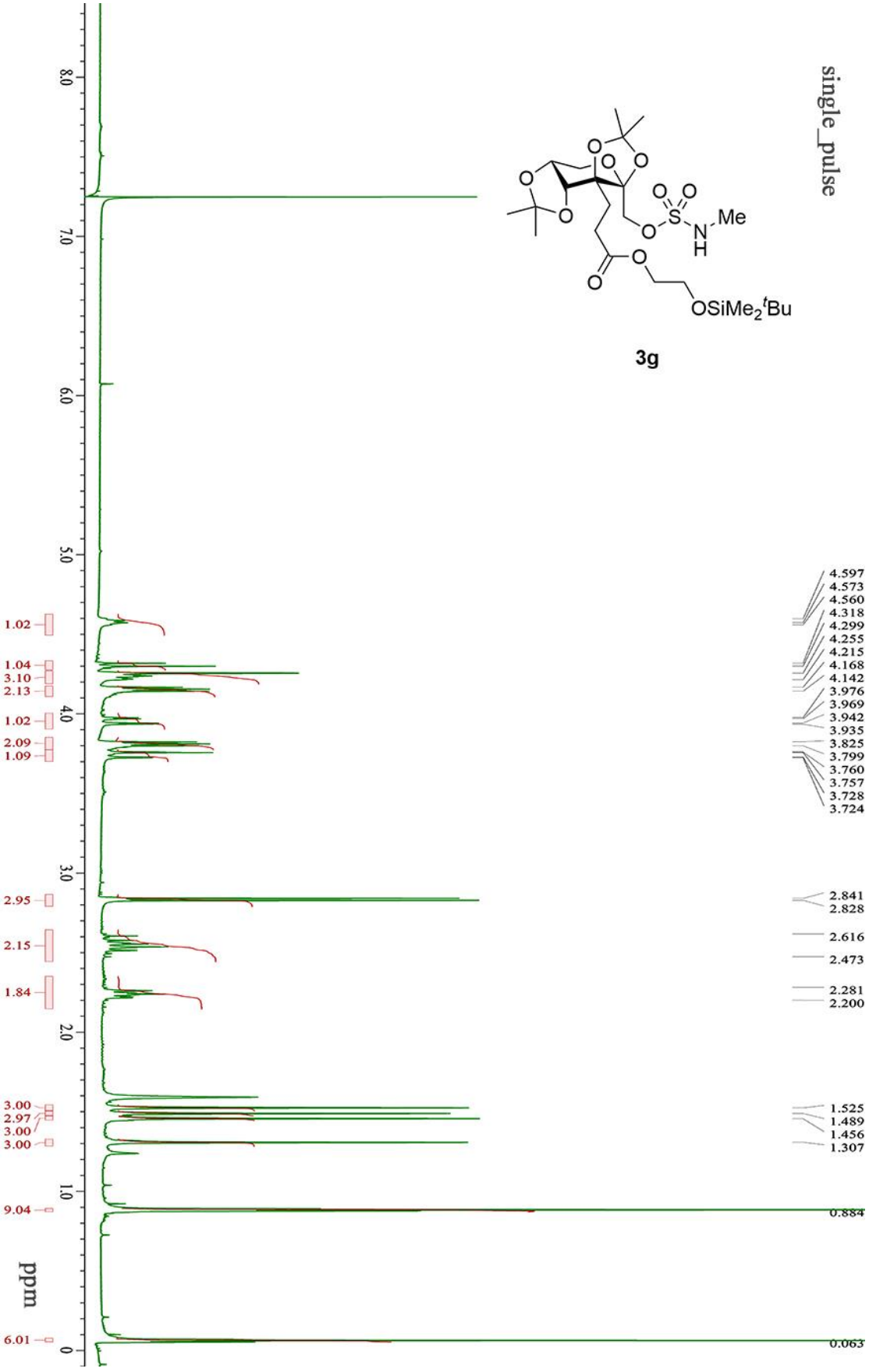
3e

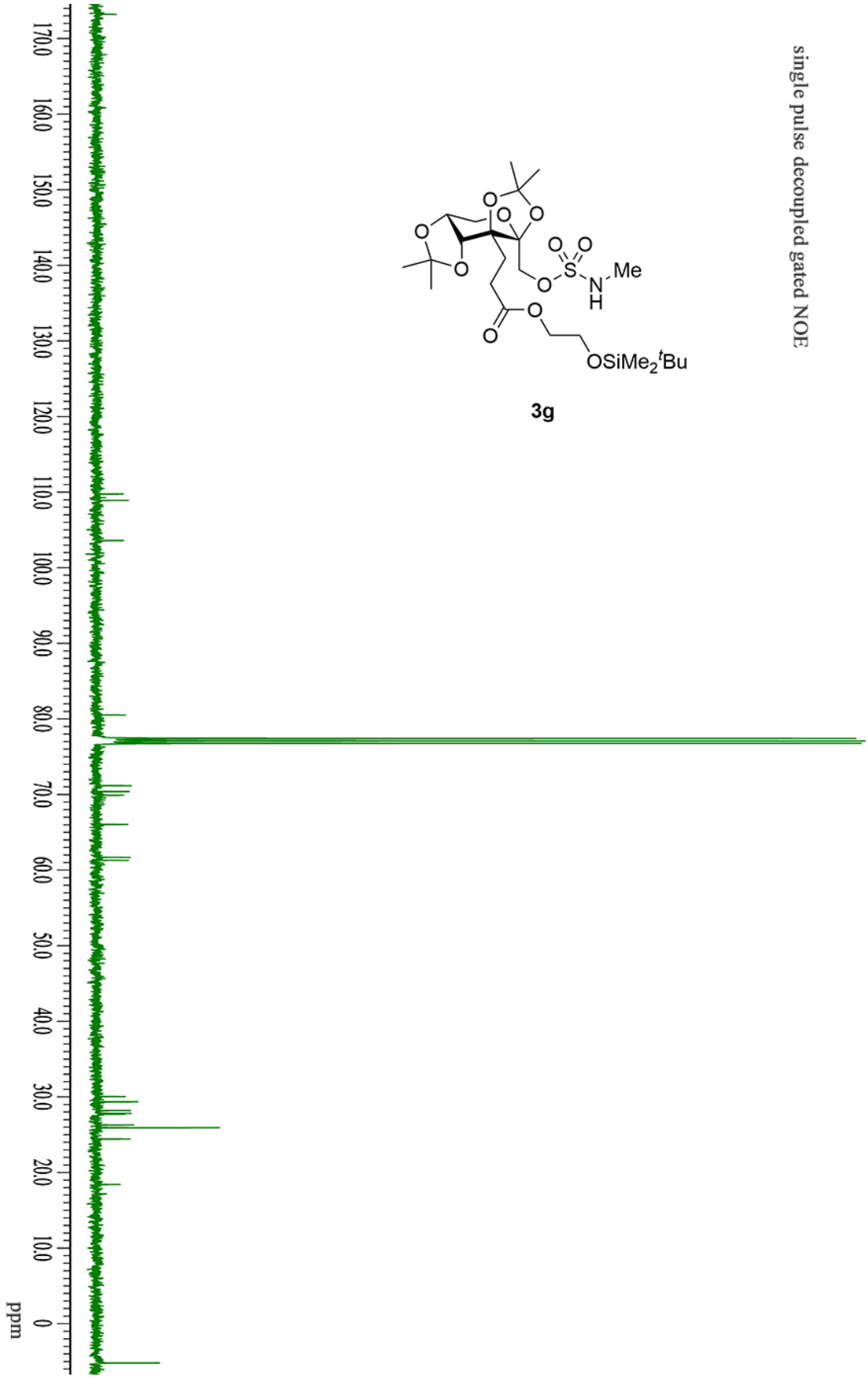

single_pulse
3f
ppm
0.97
6.05
0.92
0.96
2.01
3.00
2.99
1.90
1.84
3.13
3.00
2.92
3.13
4.312
4.225
3.987
3.955
3.768
3.735
3.630
3.618
3.606
2.853
2.840
2.619
2.562
2.304
2.241
1.614
1.534
1.504
1.466
1.315
1.251

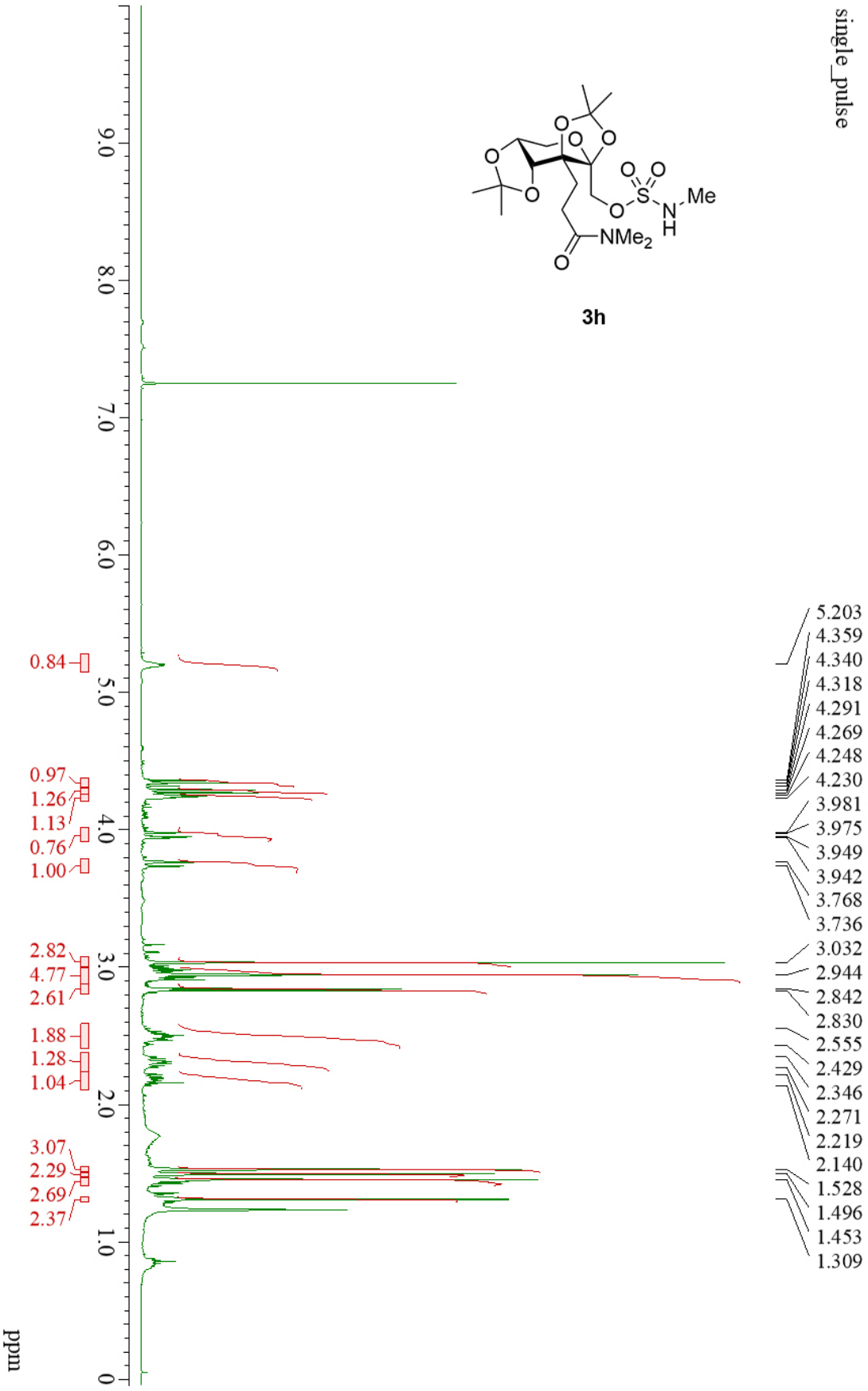
single pulse decoupled gated NOE



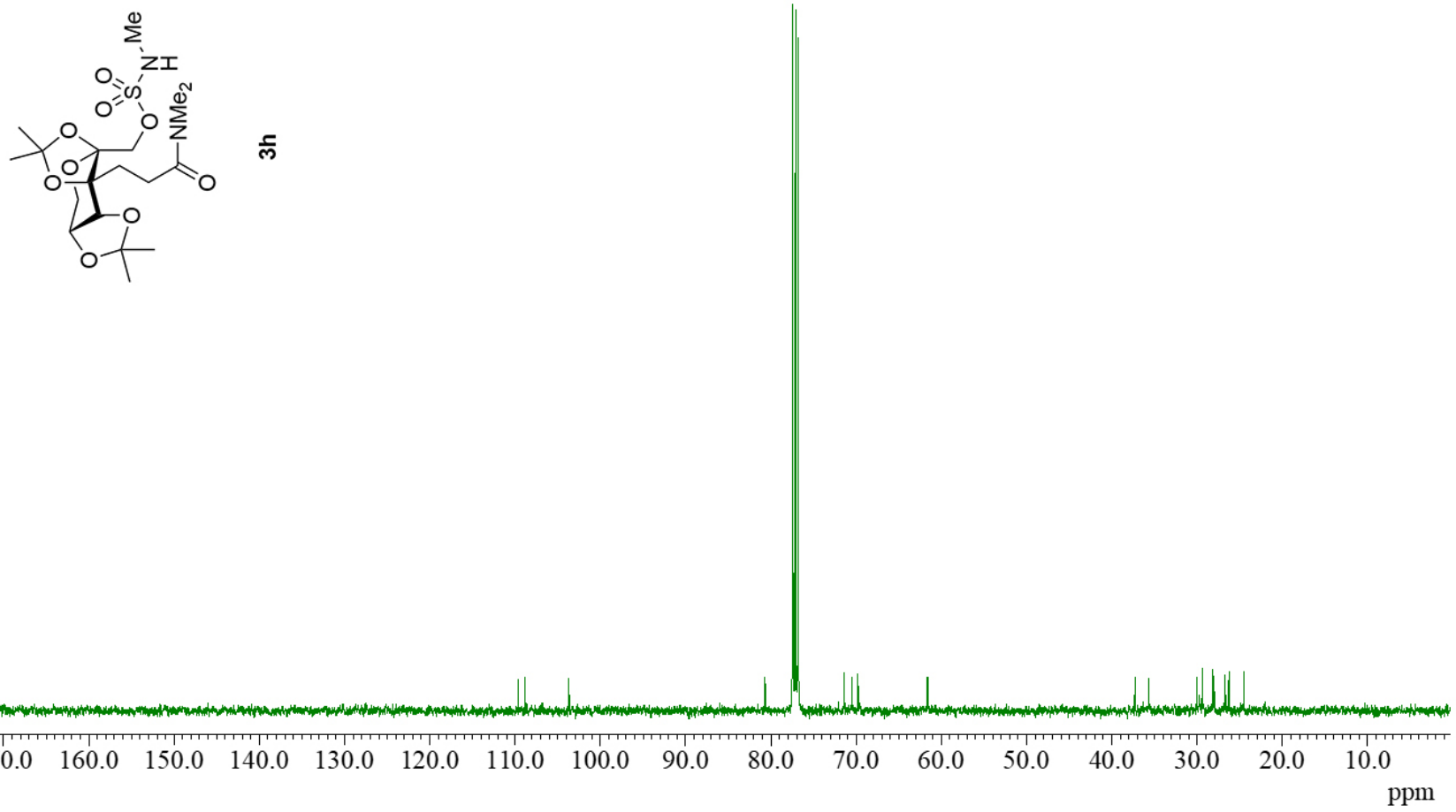
3f

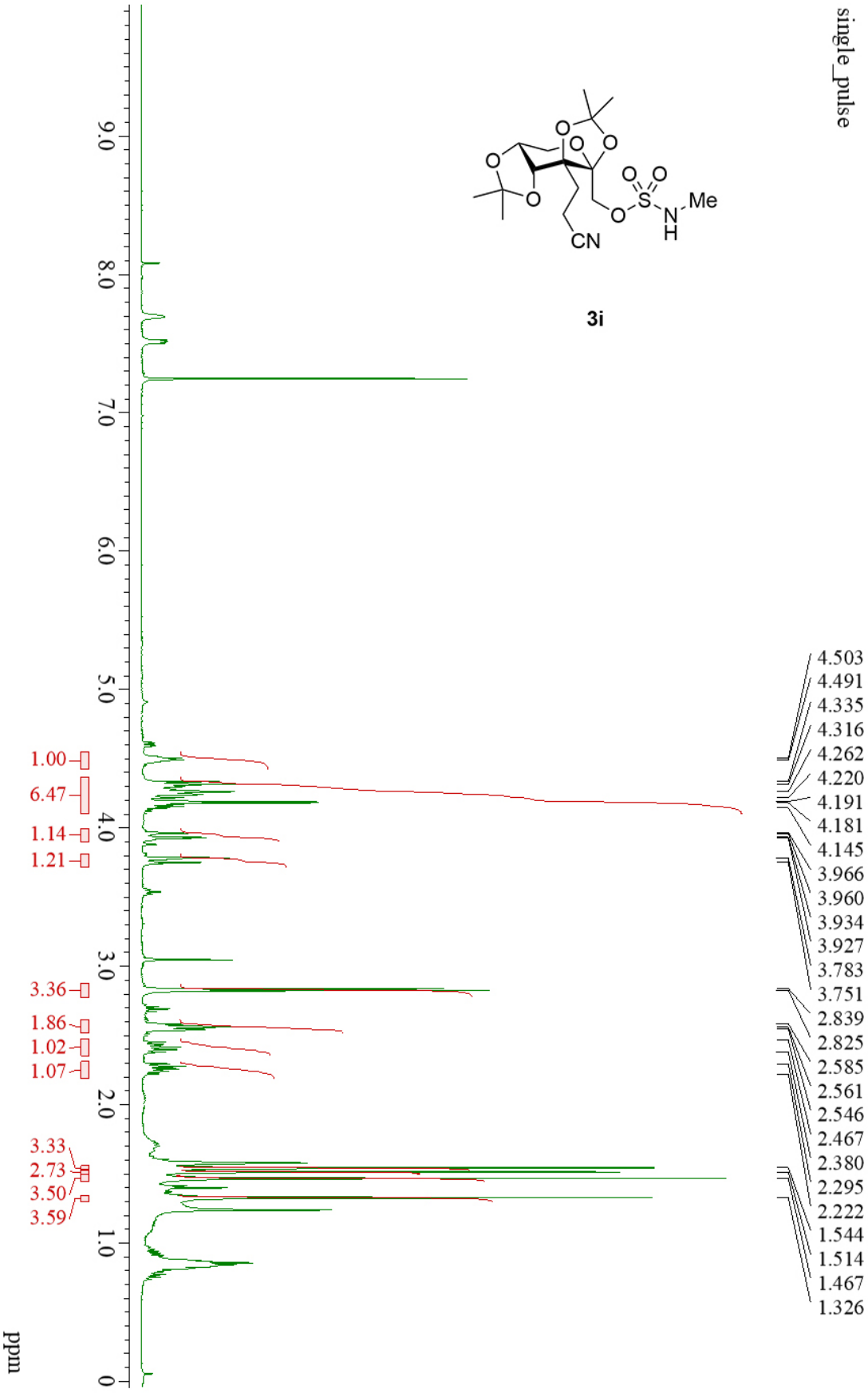

single_pulse
3g
OSiMe2tBu
Me
N
H
S
O
ppm
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0
1.02
1.04
3.10
2.13
1.02
2.09
1.09
2.95
2.15
1.84
3.00
2.97
3.00
3.00
9.04
6.01
4.597
4.573
4.560
4.318
4.299
4.255
4.215
4.168
4.142
3.976
3.969
3.942
3.935
3.825
3.799
3.760
3.757
3.728
3.724
2.841
2.828
2.616
2.473
2.281
2.200
1.525
1.489
1.456
1.307
0.884
0.063


single pulse decoupled gated NOE
Me
H
OSiMe2tBu
3g
170.0
160.0
150.0
140.0
130.0
120.0
110.0
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0
ppm

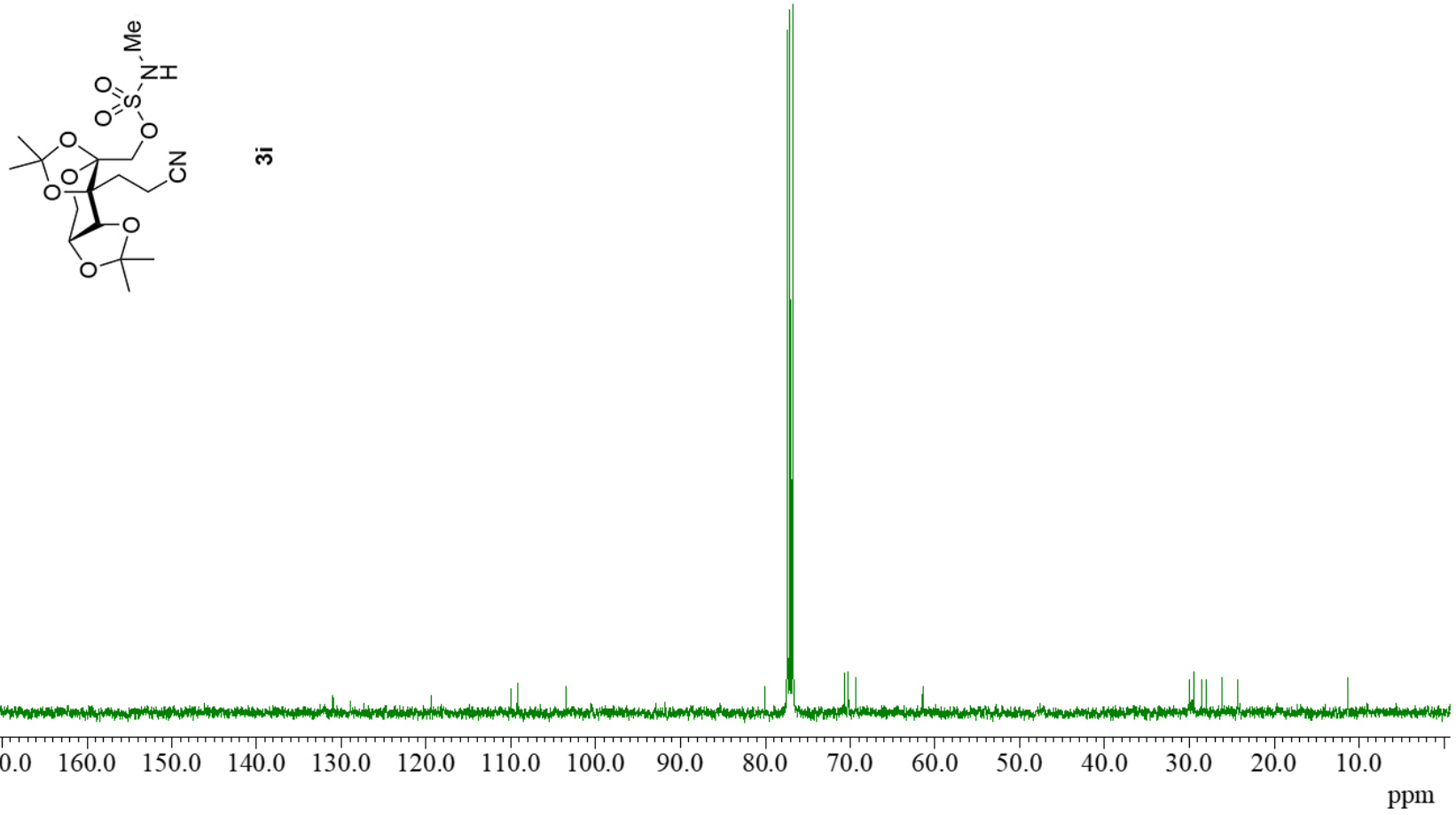

single_pulse
3h
ppm
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0
0.84
0.97
1.26
1.13
0.76
1.00
2.82
4.77
2.61
1.88
1.28
1.04
3.07
2.29
2.69
2.37
5.203
4.359
4.340
4.318
4.291
4.269
4.248
4.230
3.981
3.975
3.949
3.942
3.768
3.736
3.032
2.944
2.842
2.830
2.555
2.429
2.346
2.271
2.219
2.140
1.528
1.496
1.453
1.309

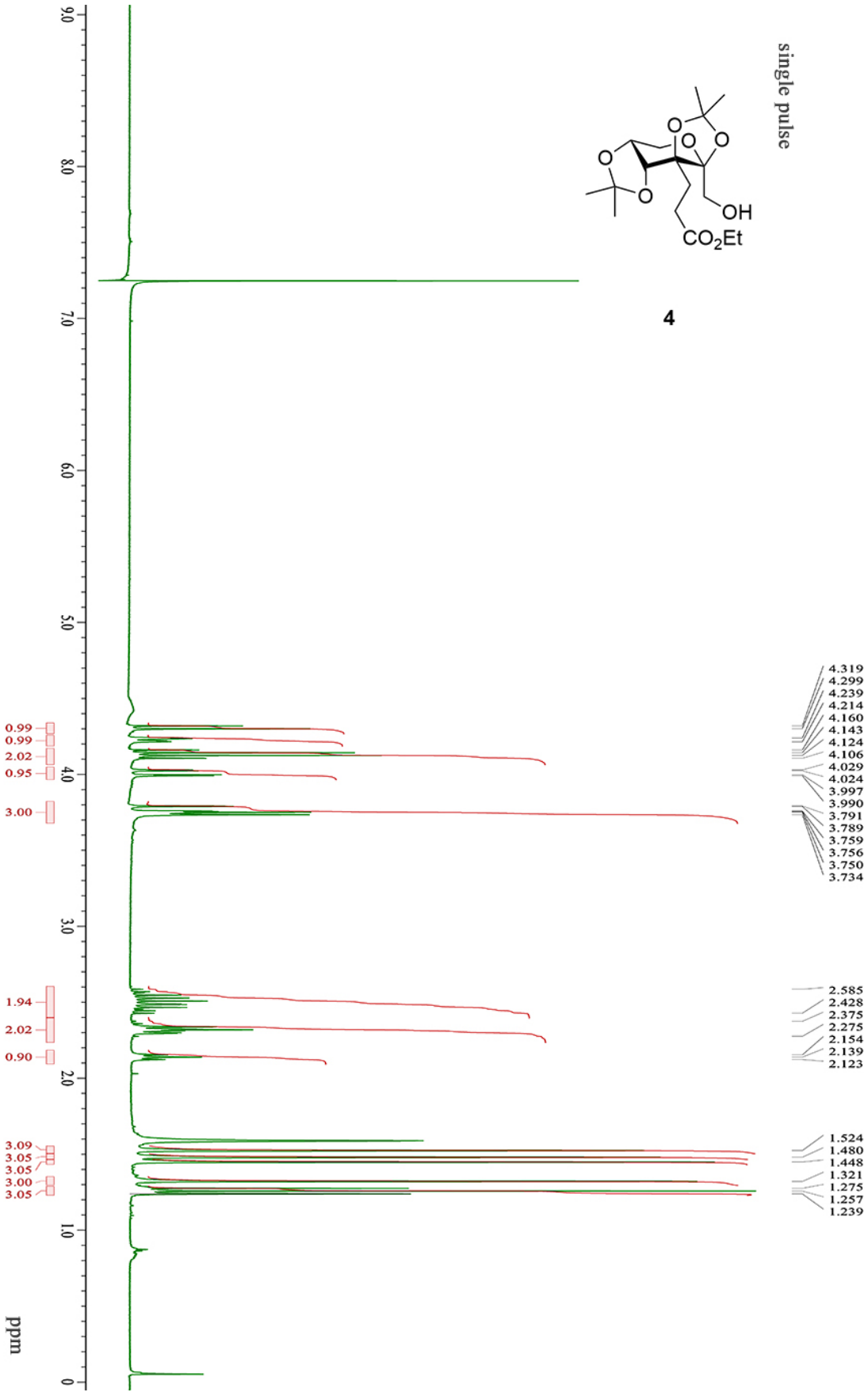
single pulse decoupled gated NOE



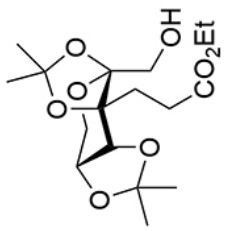

single_pulse
3i
Me
N
H
CN
4.503
4.491
4.335
4.316
4.262
4.220
4.191
4.181
4.145
3.966
3.960
3.934
3.927
3.783
3.751
2.839
2.825
2.585
2.561
2.546
2.467
2.380
2.295
2.222
1.544
1.514
1.467
1.326
1.00
6.47
1.14
1.21
3.36
1.86
1.02
1.07
3.33
2.73
3.50
3.59
ppm
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0

single pulse decoupled gated NOE

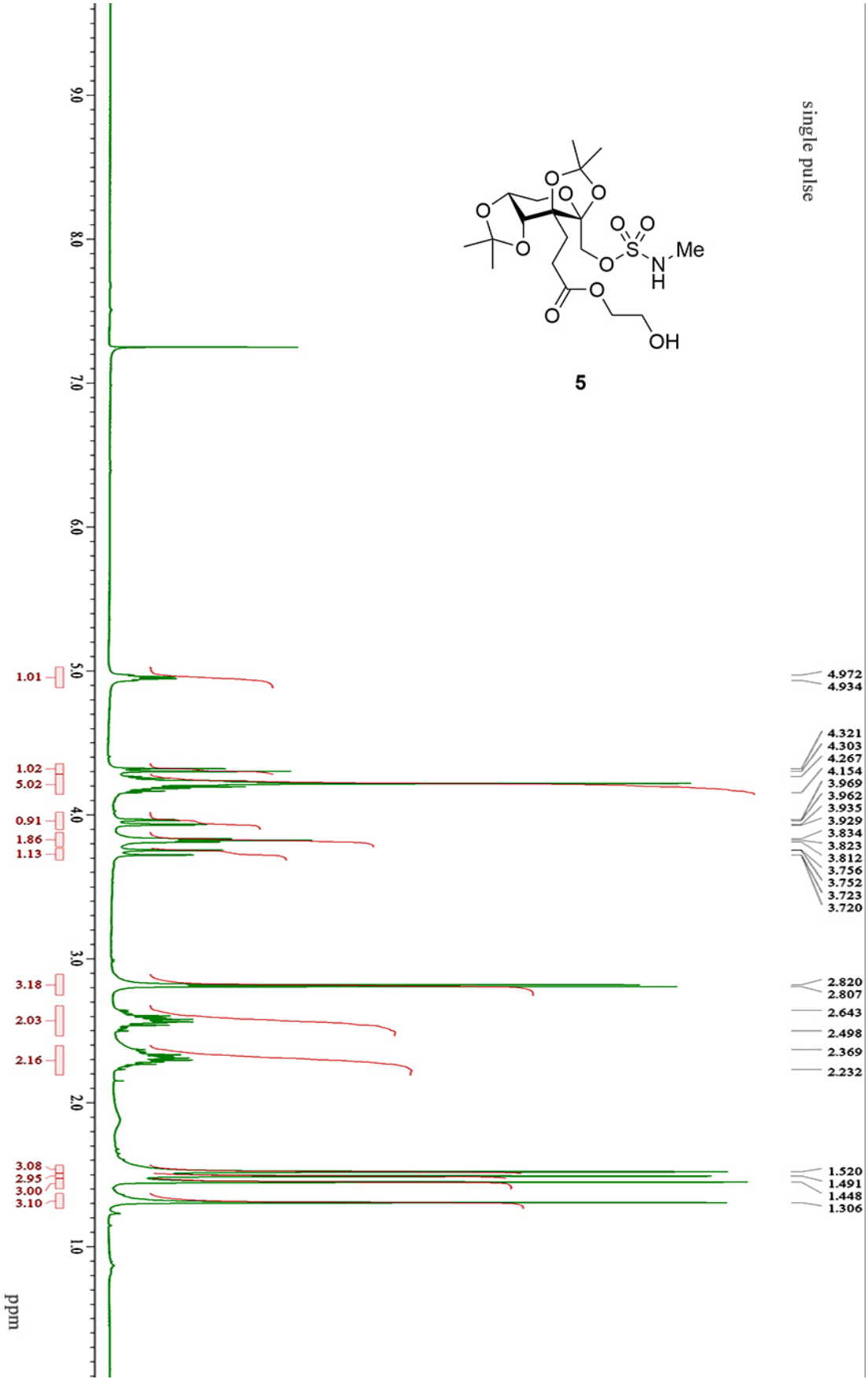



single pulse
OH
CO2Et
4
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0
ppm
0.99
0.99
2.02
0.95
3.00
1.94
2.02
0.90
3.09
3.05
3.05
3.00
3.05
4.319
4.299
4.239
4.214
4.160
4.143
4.124
4.106
4.029
4.024
3.997
3.990
3.791
3.789
3.759
3.756
3.750
3.734
2.585
2.428
2.375
2.275
2.154
2.139
2.123
1.524
1.480
1.448
1.321
1.275
1.257
1.239

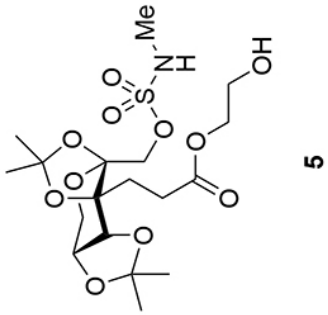
single pulse decoupled gated NOE



4


single pulse
5
ppm
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
1.01
1.02
5.02
0.91
1.86
1.13
3.18
2.03
2.16
3.08
2.95
3.00
3.10
4.972
4.934
4.321
4.303
4.267
4.154
3.969
3.962
3.935
3.929
3.834
3.823
3.812
3.756
3.752
3.723
3.720
2.820
2.807
2.643
2.498
2.369
2.232
1.520
1.491
1.448
1.306

single pulse decoupled gated NOE



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