Supporting Information

Harnessing the Reactivity of Poly(methylhydrosiloxane) for the Reduction and Cyclization of Biomass to High-Value Products

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Methods and Materials

All catalytic reactions were performed using oven-dried glassware (130 °C) and were setup in a nitrogen-filled glovebox. All reactions were performed at ambient temperature (23 °C). Dowex® Resin refers to Dowex® 50W-X8 purchased from Baker Chemical Company. All workup procedures were performed under air with reagent grade materials. Activated alumina refers to Brockmann activity I neutral alumina gel purchased from Sigma-Aldrich. Column chromatography was performed using SilaFlash P60 40-63 μm (230-400 mesh). Thin layer chromatography (TLC) was performed on SiliCycle silica gel 60 F254 plates and was visualized using potassium permanganate stain. All NMR spectra were recorded on a Bruker Avance 600 MHz spectrometer at standard pressure and temperature. d_2-dichloromethane and d_8-toluene were purchased from Cambridge Isotope Laboratories, Inc. and were degassed by three freeze-pump-thaw cycles before being dried over activated 3 Å molecular sieves. d_4-methanol, *d*-chloroform and deuterium oxide were purchased from Cambridge Isotope Laboratories, Inc. and were used as received. The residual solvent protons (^{1}H) or the solvent carbon (^{13}C) were used as internal references. The following abbreviations are used in reporting NMR data: d, doublet; t, triplet; m, multiplet; dd, doublet of doublets; dt, doublet of triplets. When necessary, 2D COSY, HSQC and HMBC data were used for peak assignment. High resolution mass spectra were obtained on a Q Exactive™ HF-X Hybrid Quadrupole-Orbitrap™ Mass spectrometer.

D-glucose, D-xylose, D-mannose, D-mannitol, D-galactose, copper sulfate, magnesium sulfate and trimethylsilyl chloride were purchased from Sigma-Aldrich and were used as received. Galactitol, β-maltose, and β-cellobiose were purchased from ChemImpex and were used as received. $EtMe_2SiCl$ was purchased from Gelest and was used as received. Poly(methylhydrosiloxane) (PMHS) average M_n 1,700-3,200 and average M_n ~390 were purchased from Sigma-Aldrich. PMHS of average M_n 1,700-3,200 was degassed by exposure to high-vacuum while stirring for 1 hour and PMHS of average M_n ~390 was degassed by three freeze-pump-thaw cycles. Tris(pentafluorophenyl)borane (BCF) was purchased from Strem and was used as received. Methanol, dichloromethane, ethyl acetate, and pyridine were purchased from Fisher.

In addition to the line list data that follows, our group has created a database of high-resolution ^{1}H and ^{13}C NMR spectra of biomass derived partial deoxygenation products. Raw FID files are also available for 75+ compounds at the latest count. These data can be obtained at http://gagnegroup.web.unc.edu/sugars-spectroscopy/sugars

General Procedure for the Silyl-Protection of Substrates[1]

A 100 mL round-bottom flask was charged with a magnetic stir-bar and sugar substrate (between 1-2 g). The sugar was dissolved in 25 mL of pyridine with vigorous stirring before being cooled in a 0 °C ice-water bath. To this cooled solution was added either Me_3SiCl or $EtMe_2SiCl$ (1.25 equivalents per OH) by syringe. After addition of silyl chloride, the reaction mixture is allowed to warm to room temperature. For reactions where Me_3SiCl is used as the protecting reagent, the reaction was allowed to proceed for 24 hours before workup. When $EtMe_2SiCl$ is used as the protecting reagent, the reaction is allowed 48 hours to reach completion. In all cases, the reaction mixture is quenched by the addition of deionized water (15 mL) and ethyl acetate (20 mL) before

being poured into a separatory funnel. The aqueous phase is removed and the organic phase is rinsed with an aqueous 10 w% $CuSO_4$ solution (to remove pyridine) until the rinses are light blue in appearance. The organic phase is then rinsed with deionized water and brine before being dried over $MgSO_4$. The $MgSO_4$ was removed by gravity filtration through a plug of cotton and the volatiles were removed on a rotary evaporator. The silyl-protected substrates were degassed by exposure to high vacuum for one hour while stirring and were stored for use in a N_2-filled glovebox.

1,2,3,4,6-Penta-*O*-trimethylsilyl-α-glucopyranose[2] (TMS-D-Glucose): Colorless oil (4.63 g, 82% yield). ^{1}H NMR (600 MHz, $CDCl_3$): δ 5.00 (d, J = 3.17 Hz, 1H, α-H_1), 3.77 (t, J = 8.9 Hz, 1H), 3.75-3.69 (m, 1H), 3.68-3.64 (m, 2H), 3.49-3.38 (m, 1H), 3.33 (dd, J = 9.1, 3.1 Hz, 1H), 0.17-0.10 (m, 45H). ^{13}C{^{1}H} NMR (121 MHz, $CDCl_3$): δ 94.0, 73.3, 74.2, 72.6, 72.4, 62.5.

1,2,3,4-Tetra-*O*-trimethylsilyl-xylopyranose[3] (TMS-D-Xylose): Colorless oil (2.34 g, 74% yield). Mixture of anomers (major: α, 78%, minor: β, 22%). ^{1}H NMR (600 MHz, CD_2Cl_2, α-anomer): δ 4.94 (d, J = 3.1 Hz, 1H, α-H_1), 3.66 (t, J = 8.6 Hz, 1H), 3.59 (t, J = 10.5 Hz, 1H), 3.51-3.47 (m, 1H), 3.43 (dd, J = 10.6, 5.5 Hz, 1H), 3.35 (dd, J = 9.0, 3.1 Hz, 1H), 0.16-0.12 (m, 36 H). ^{13}C{^{1}H} NMR (121 MHz, CD_2Cl_2, α-anomer): δ 94.8, 74.9, 74.7, 72.5, 62.8, 1.3, 0.7, 0.6, 0.5. (β-anomer): δ 99.2, 78.8, 77.6, 72.1, 66.8, 1.5, 1.4, 0.6.

1,2,3,4,6-Penta-*O*-trimethylsilyl-α-mannopyranose[4] (TMS-D-Mannose): Colorless oil (2.68 g, 64%). ^{1}H NMR (600 MHz, $CDCl_3$): δ 4.89 (d, J = 1.9 Hz, 1H, α-H_1), 3.81-3.80 (m, 2H), 3.74 (dd, J = 11.3, 2.2 Hz, 1H), 3.70 (dd, J = 11.3, 5.4 Hz, 1H), 3.63 (m, 1H), 3.58-3.56 (m, 1H), 0.15-0.10 (m, 45H). ^{13}C{^{1}H} NMR (121 MHz, $CDCl_3$): δ 95.7, 75.3, 74.7, 72.3, 68.6, 62.7, 0.9, 0.8, 0.5, 0.1, 0.0.

1,2,3,4,6-Penta-*O*-trimethylsilyl-α-galactopyranose[3] (TMS-D-Galactose): Colorless oil (2.13 g, 71% yield). ^{1}H NMR (600 MHz, CD_2Cl_2): δ 5.01 (d, J = 2.4 Hz, 1H, α-H_1), 3.88-3.86 (m, 2H), 3.81 (t, J = 2.3 Hz, 2H), 3.56 (dd, J = 9.7, 7.5 Hz, 1H), 3.50 (dd, J = 9.7, 5.9 Hz, 1H), 0.15-0.10 (m, 45H). ^{13}C{^{1}H} NMR (121 MHz, CD_2Cl_2): δ 95.2, 73.0, 71.7, 71.1, 70.6, 61.9, 0.9, 0.7, 0.6, 0.5, -0.3.

1,2,3,4,5,6-Hexa-*O*-trimethylsilyl-mannitol[5] (TMS-mannitol): Substrate used in this study was left over material from our previously published work. Colorless oil (1.62 g, 48%); ^{1}H NMR (600 MHz, $CDCl_3$) δ 3.78-3.73 (m, 2H), 3.67-3.66 (m, 2H), 3.64 (dd, J = 10.5, 3.4 Hz, 2H), 3.48 (dd, J = 10.5, 7.5 Hz, 2H), 0.17-0.04 (m, 54H); ^{13}C NMR (151 MHz, $CDCl_3$) δ 77.45, 75.17, 63.88, 1.02, 0.86, -0.34.

1,2,3,4,5,6-Hexa-*O*-ethyldimethylsilyl-mannitol[6] (EtMe$_2$Si-mannitol): Substrate used in this study was left over material from our previously published work. Colorless oil (2.65 g, 48% yield). ^{1} H NMR ($CDCl_3$, 600 MHz): δ 3.74 (dd, J = 7.7, 3.3 Hz, 2H), 3.65 (s, 2H), 3.64–3.61 (m, 2H), 3.47 (dd, J = 10.5, 7.7 Hz, 2H), 0.98–0.86 (m, 18H), 0.62–0.49 (m, 12H), 0.13–0.03 (m, 36H). ^{13}C{^{1}H} NMR ($CDCl_3$, 151 MHz): δ 77.5, 75.6, 64.2, 9.0, 8.9, 8.1, 7.11, 7.09, 6.9, -1.46, -1.52, -1.6, -2.59, -2.64.

1,2,3,6,2′,3′,4′,6′-Octa-*O*-trimethylsilyl-β-cellobiose[5] (TMS-cellobiose): Substrate used in this study was left over material from our previously published work. White solid (1.79 g, 67%); ^{1}H NMR (600 MHz, $CDCl_3$): δ 4.46 (d, *J* = 7.4 Hz, 1H), 4.36 (d, *J* = 7.6 Hz, 1H), 3.85 (dd, *J* = 11.0, 3.8 Hz, 1H), 3.82-3.72 (m, 3H), 3.57 (dd, *J* = 10.9, 6.0 Hz, 1H), 3.43 (t, *J* = 8.9 Hz, 1H), 3.35-3.26 (m, 2H), 3.26-3.18 (m, 3H), 3.12-3.10 (m, 1H), 0.27 – -0.01 (m, 72H); ^{13}C{^{1}H} NMR (151 MHz, $CDCl_3$): δ 101.4, 98.4, 78.5, 78.0, 77.7, 76.6, 76.1, 75.3, 74.3, 72.2, 62.6, 61.0, 1.6, 1.49, 1.46, 1.17, 1.18, 0.6, 0.0, -0.3.

1,2,3,6,2',3',4',6'-Octa-*O*-trimethylsilyl-β-maltose[5] (TMS-maltose): Substrate used in this study was left over material from our previously published work. Colorless oil (3.64 g, 68%); ^{1}H NMR (600 MHz, $CDCl_3$): δ 5.19 (d, *J* = 3.4 Hz, 1H), 4.59 (d, *J* = 7.4 Hz, 1H), 3.83 (dd, *J* = 10.7, 4.9 Hz, 1H), 3.81-3.74 (m, 3H), 3.74-3.68 (m, 3H), 3.56-3.54 (m, 1H), 3.53-3.48 (m, 2H), 3.42 (dd, *J* = 8.7, 3.4 Hz, 1H), 3.38 (d, *J* = 7.1 Hz, 1H), 0.23-0.08 (m, 72H); ^{13}C{^{1}H} NMR (151 MHz, $CDCl_3$): δ 97.3, 96.4, 79.14, 79.10, 76.4, 75.0, 73.8, 73.1, 71.8, 62.7, 61.9, 1.6, 1.5, 1.4, 1.0, 0.8, 0.7, 0.0, -0.4.

General Procedure for Comparing Reactivity of Polymeric and Oligomeric PMHS

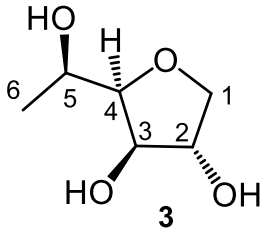
TMS-D-Glucose (between 80-90 mg) was dissolved in 0.6 mL of d_2-DCM. The desired stoichiometry of PMHS was then added using a 50 μL syringe. The resulting solution was added to a separate vial charged with pre-weighed BCF corresponding to 10 mol% relative to the TMS-D-glucose. The resulting solution was transferred to a J-Young NMR tube and the reaction progress was monitored by ^{13}C{^{1}H} NMR spectroscopy.

Isolation of Compound 2 from 3

TMS-D-Glucose (91.9 mg, 0.170 mmol) was dissolved in 0.6 mL of d_2-DCM, followed by the addition of polymeric PMHS (33.5 μL, 0.560 mmol, 3.3 equiv). The resulting mixture was added to BCF (8.7 mg, 0.017 mmol) before being transferred to a J-Young NMR tube. The reaction was monitored periodically by NMR spectroscopy before being quenched after 24 hours. The contents of the J-Young tube were poured into a 20 mL scintillation vial and the tube was rinsed with 1 mL of methanol. Dowex® resin (~30 beads) was added to the vial and the resulting suspension was stirred for 2 hours. The suspension was then filtered through a plug of sand to remove the Dowex® and the filtrate was concentrated under vacuum. The material was purified by column chromatography (silica gel) using gradient elution (8:1 to 5:1 to1:1 DCM/MeOH).

1,4-anhydrosorbitol (2)[5]: Colorless film (5.0 mg, 0.03 mmol, 18% yield). ^{1}H NMR (600 MHz, CD_3OD): δ 4.14-4.13 (m, 2H), 4.11 (dd, *J* = 9.4, 3.7 Hz, 1H), 3.88-3.87 (m, 2H), 3.78-3.76 (m, 1H), 3.64 (d, *J* = 9.8 Hz, 1H), 3.62-3.59 (m, 1H). ^{13}C{^{1}H} NMR (121 MHz, CD_3OD): δ 81.6, 78.3, 77.8, 74.4, 71.1, 65.6.

6-deoxy-1,4-anhydrosorbitol (3): Colorless film (5.5 mg, 0.04 mmol, 22% yield). ^{1}H NMR (600 MHz, CD_3OD): δ 3.93 (t, J = 6.0 Hz, 1H, H_3), 3.84 (m, 1H, H_5), 3.79 (m, 1H, H_2), 3.67 (dd, J = 11.8, 3.3 Hz, 1H, H_1), 3.64 (t, J = 6.4 Hz, 1H, H_4), 3.60 (dd, J = 11.9, 5.3 Hz, 1H, H_1), 1.27 (d, J = 6.3 Hz, 3H, H_6). $^{13}C\{^{1}H\}$ NMR (121 MHz, CD_3OD): δ 84.5 (C_2), 84.0 (C_4), 79.9 (C_5), 78.9 (C_3), 63.4 (C_1), 19.2 (C_6). HRMS (ESI^+): Calcd for $C_6H_{12}O_4Na$ $[M+Na]^+$: 171.06333. Found: 171.06297.



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General Procedure for Optimized Reactions

TMS-protected sugar was dissolved in 0.6 mL of DCM. The desired stoichiometry of polymeric PMHS was added by a 50 μL syringe and the resulting solution was transferred to a vial containing pre-weighed BCF corresponding to 10 mol% relative to TMS-protected sugar. The resulting solution was transferred to a J-Young tube and the progress of reactivity was monitored by $^{13}C\{^{1}H\}$ NMR spectroscopy. When the reaction was deemed complete, the contents of the J-Young tube were transferred to a 20 mL scintillation vial and the J-Young tube was rinsed with 1 mL of methanol. Dowex® resin (~30 beads) was added and the resulting mixture was stirred for 2 hours. The suspension was filtered through a plug of sand to remove the Dowex® and the filtrate was dried under vacuum, yielding a resinous material. Deionized water (~5 mL) was added to the siloxane resin and the suspension was heated to 50 °C for 30 minutes. The aqueous suspension was filtered through a plug of activated neutral alumina and the filtrate was dried under high vacuum, affording deprotected product free of oxidized PMHS by-product.

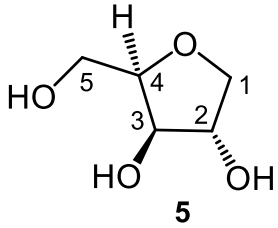
To document the purities obtainable without chromatography, the spectra provided below are of crude products after workup and the major product (>75%) is indicated. Percent purity was determined by the ratio of product integration (using a resonance with no overlap) over the sum of the product and impurity integrals (integration of a known impurity resonance normalized by number of protons corresponding to said resonance). Each compound can be purified by chromatography if desired. Compound **5**, while known, is under characterized and so we report a full spectroscopic dataset to supplement literature data.[7-8] Compounds previously reported in the literature are referenced and are in good agreement with reported spectra.

Sorbitol (1)[9]**:** Starting materials: TMS-D-glucose (88.7 mg, 0.164 mmol), BCF (8.4 mg, 0.016 mmol), polymeric PMHS (18 μL, 0.29 mmol, 1.8 equiv). Product: white solid (29.8 mg, 89% purity, 68% yield). ^{1}H NMR (600 MHz, D_2O): δ 3.79-3.76 (m, 3H), 3.74-3.68 (m, 2H), 3.61-3.55 (m, 3H). $^{13}C\{^1H\}$ NMR (121 MHz, D_2O): δ 72.8, 70.9, 70.8, 69.5, 62.7, 62.3.

1,4-anhydrosorbitol (2)[5]**:** Starting materials: TMS-D-glucose (86.7 mg, 0.160 mmol), BCF (8.2 mg, 0.016 mmol), polymeric PMHS (22 μL, 0.37 mmol, 2.3 equiv). Product: Colorless film (18.9 mg, 81% purity, 58% yield). ^{1}H NMR (600 MHz, CD_3OD): δ 4.14 (m, 2H), 4.11 (dd, J = 9.4, 3.7 Hz, 1H), 3.88-3.87 (m, 2H), 3.78-3.76 (m, 1H), 3.64 (d, J = 9.8 Hz, 1H), 3.62-3.59 (m, 1H). $^{13}C\{^1H\}$ NMR (121 MHz, CD_3OD): δ 81.6, 78.3, 77.8, 74.7, 71.0, 65.5.

Xylitol (4)[9]**:** Starting materials: TMS-D-xylose (81.9 mg, 0.187 mmol), BCF (9.6 mg, 0.019 mmol), polymeric PMHS (14.5 μL, 0.243 mmol, 1.3 equiv.). Product: white solid (17.9 mg, 76% purity, 48% yield). 24% impurity is 1,4-anhydroxylitol. ^{1}H NMR (600 MHz, CD_3OD): δ 3.76-3.72 (m, 2H), 3.68-3.60 (m, 5H). $^{13}C\{^1H\}$ NMR (121 MHz, CD_3OD): δ 73.9, 72.0, 64.2.

1,4-anhydroxylitol (5): Starting materials: TMS-D-xylose (74.8 mg, 0.170 mmol), BCF (8.7 mg, 0.017 mmol), polymeric PMHS (15 μL, 0.25 mmol, 1.5 equiv.). Product: colorless crystals (14.1 mg, 79% purity, 49% yield). ^{1}H NMR (600 MHz, CD_3OD): δ 4.14-4.13 (m, 1H, H_4), 4.11 (dd, J = 9.3, 4.2 Hz, 1H, H_5), 4.06-4.05 (m, 1H, H_3), 4.04-4.02 (m, 1H, H_2), 3.79 (dd, J = 11.5, 5.0 Hz, 1H, H_1), 3.72 (dd, J = 11.4, 6.4 Hz, 1H, H_1), 3.65 (d, J = 8.4 Hz, 1H, H_5). $^{13}C\{^1H\}$ NMR (121 MHz, CD_3OD): δ 82.3 (C_2), 78.6 (C_4), 78.1 (C_3), 74.3 (C_5), 61.6 (C_1). HRMS (ESI^+): Calcd for $C_5H_{10}O_4Na$ $[M+Na]^+$: 157.04768. Found: 157.04644.



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Mannitol (6)[9]**:** Starting materials: TMS-D-mannose (84.5 mg, 0.156 mmol), BCF (8.0 mg, 0.016 mmol), polymeric PMHS (14 μL, 0.23 mmol, 1.5 equiv.). Product: white solid (17.6 mg, 87% purity, 54% yield). ^{1}H NMR (600 MHz, D_2O): δ 3.81 (dd, J = 11.8, 2.7 Hz, 2H), 3.75-3.71 (m, 2H), 3.71-3.69 (m, 2H), 3.62 (dd, J = 11.8, 6.2 Hz, 2H). $^{13}C\{^1H\}$ NMR (121 MHz, D_2O): δ 70.6, 69.1, 63.1.

2,5-anhydro-D-glucitol (7)[10]**:** Starting materials: TMS-D-mannose (73.8 mg, 0.136 mmol), BCF (7.0 mg, 0.014 mmol), polymeric PMHS (16 μL, 0.27 mmol, 2.0 equiv.). Product: colorless film (17.7 mg, 85% purity, 67% yield). ^{1}H NMR (600 MHz, CD_3OD): δ 4.04 (dt, J = 6.3, 4.4 Hz, 1H), 4.00 (dd, J = 4.0, 2.1 Hz, 1H), 3.97 (dd, J = 3.2, 2.2 Hz, 1H), 3.81-3.77 (m, 2H), 3.74-3.69 (m, 2H), 3.67-3.64 (m, 1H). $^{13}C\{^1H\}$ NMR (121 MHz, CD_3OD): δ 87.1, 82.8, 79.9, 78.7, 63.5, 61.8.

Mixture of 1,6-anhydrogalactofuranose (8) and 1,4-anhydrogalactitol (9): Order of addition varied so that PMHS and BCF are premixed before addition to TMS-D-galactose. Starting materials: TMS-D-galactose (79.1 mg, 0.146 mmol), BCF (7.5 mg, 0.015 mmol), polymeric PMHS (17.5 μL, 0.29 mmol, 2.0 equiv.). Product: colorless film (18.3 mg, 76% combined purity, 58% combined yield). Mixture can be separated at the expense of yield to obtain pure **8** and **9** by column chromatography using gradient elution 5:1 to 4:1 DCM/MeOH.

1,6-anhydrogalactofuranose (8)[5]: Yield: (4.2 mg, 0.026 mmol, 17% yield). ^{1}H NMR (600 MHz, CD_3OD): δ 5.10 (d, J = 4.6 Hz, 1H), 4.17 (d, J = 2.2 Hz, 1H), 4.10-4.09 (m, 1H), 3.99 (d, J = 4.2 Hz, 1H), 3.90-3.83 (m, 2H), 3.59 (t, J = 10.4 Hz, 1H). ^{13}C{^{1}H} NMR (121 MHz, CD_3OD): δ 99.8, 86.7, 82.6, 76.5, 66.5, 63.8.

1,4-anhydrogalactitol (9)[5]: Yield: (6.1 mg, 0.037 mmol, 25%). ^{1}H NMR (600 MHz, CD_3OD): δ 4.08 (m, 1H), 4.03 (dt, J = 4.3, 2.2 Hz, 1H), 3.93 (dd, J = 9.5, 4.2 Hz, 1H), 3.79-3.76 (m, 2H), 3.74-3.72 (m, 1H), 3.64-3.57 (m, 2H). ^{13}C{^{1}H} NMR (121 MHz, CD_3OD): δ 86.7, 80.1, 78.6, 74.6, 73.1, 64.4.

1-deoxyglucose (10)[9]: *From TMS-cellobiose*: TMS-cellobiose (70.3 mg, 0.076 mmol), polymeric PMHS (23 μL, 0.38 mmol, 5.0 equiv.). Product: white residue (11.0 mg, 82% purity, 36% yield). ^{1}H NMR (600 MHz, D_2O): δ 3.93 (dd, J = 11.2, 5.4 Hz, 1H), 3.83 (d, J = 12.3 Hz, 1H), 3.64-3.61 (m, 1H), 3.56-3.51 (m, 1H), 3.39-3.37 (m, 1H), 3.30-3.29 (m, 2H), 3.22 (t, J = 11.0 Hz, 1H). ^{13}C{^{1}H} NMR (121 MHz, D_2O): δ 80.2, 77.4, 69.6, 69.3, 68.7, 60.8. Product **10** can also be obtained from TMS-maltose: TMS-maltose (65.5 mg, 0.071 mmol), polymeric PMHS (21 μL, 0.35 mmol, 5.0 equiv.). Product: white residue (13.1 mg, 91% purity, 51% yield).

Procedures for Monitoring Silyl Exchange

Step-wise: TMS-D-mannose (70.9 mg, 0.131 mmol) was dissolved in 0.6 mL of d_2-DCM and polymeric PMHS (12 μL, 0.20 mmol, 1.5 equiv.) was added to the resulting solution. The mixture was then transferred to a vial containing BCF (6.7 mg, 0.013 mmol) before being transferred to a J-Young NMR tube. The reaction was monitored by ^{13}C{^{1}H} NMR spectroscopy after 1 hour and was determined to reach full conversion to TMS-mannitol. The J-Young tube was transferred into an N_2 -filled glovebox and the solution was transferred to a vial containing 1 equivalent of $EtMe_2Si$-mannitol (91.6 mg, 0.131 mmol). The resulting mixture was transferred back into the J-Young tube and was monitored by ^{13}C{^{1}H} and ^{1}H NMR spectroscopy after 24 hours.

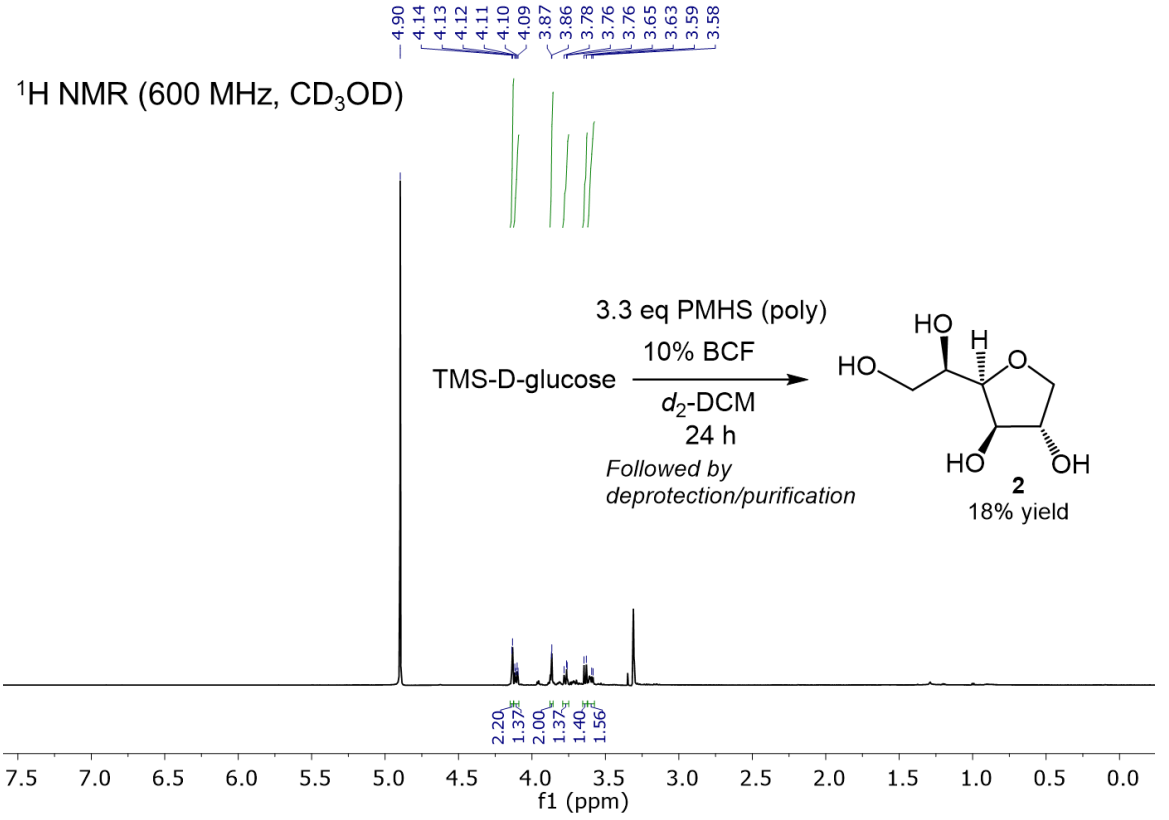
Premixed TMS-Mannose and $EtMe_2Si$-Mannose: An equimolar amount of TMS-D-mannose (53.8 mg, 0.099 mmol) and $EtMe_2Si$-D-mannose (60.8 mg, 0.099 mmol) were dissolved in 0.6 mL d_2-DCM. To this mixture was added polymeric PMHS (18 μL, 0.199 mmol, 1.5 equiv. to total substrate amount). The resulting solution was transferred to a vial containing BCF (10.2 mg, 0.020 mmol) before being transferred to a J-Young tube. The extent of silyl exchange was monitored after 24 hours by ^{13}C{^{1}H} and ^{1}H NMR spectroscopy.

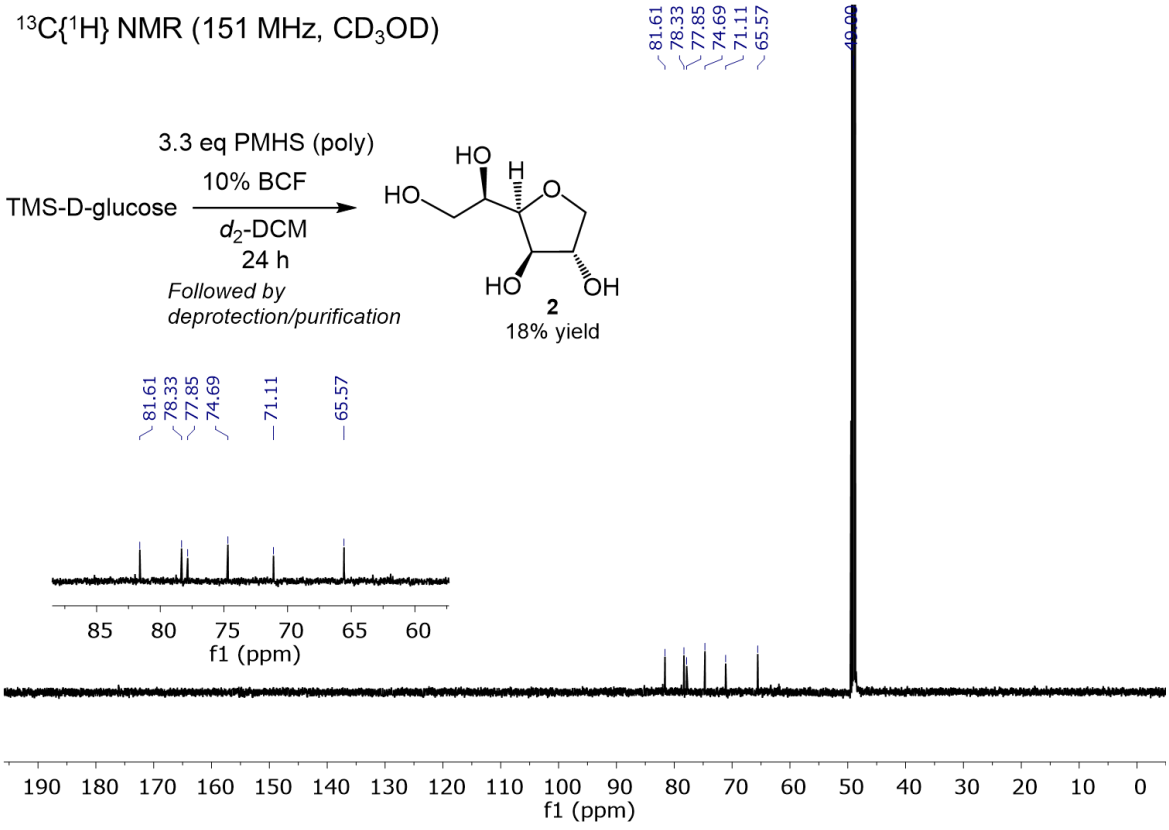
Control Reaction: An equimolar amount of TMS-mannitol (39.4 mg, 0.064 mmol) and $EtMe_2Si$-mannitol (44.8 mg, 0.064 mmol) were dissolved in 0.6 mL d_2-DCM before being transferred to a vial containing BCF (6.6 mg, 0.013 mmol). The resulting solution was transferred to a J-Young tube and was monitored by $^{13}C\{^1H\}$ and ^1H NMR spectroscopy after 24 hours.

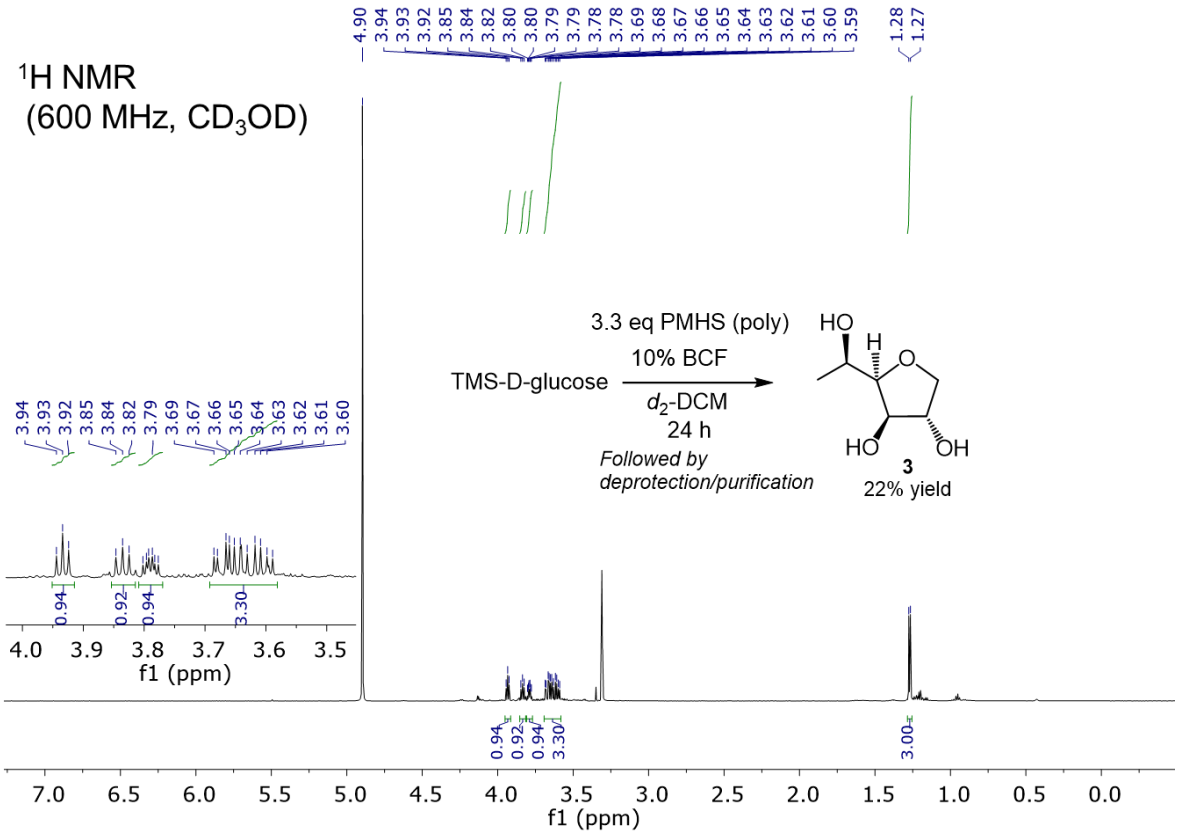
Representative Procedure for the Reduction of TMS-D-Glucose in Toluene

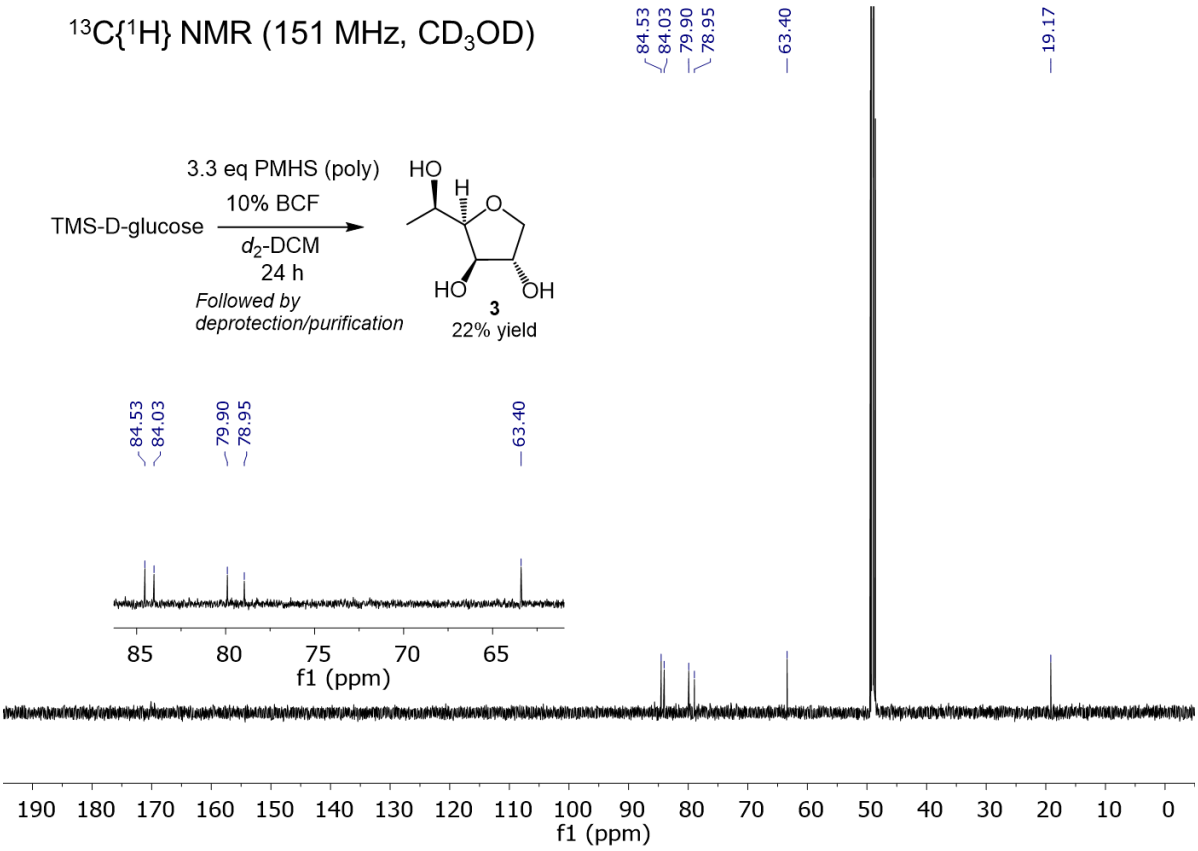
TMS-D-glucose (74.1 mg, 0.137 mmol) was dissolved in d_8-toluene (0.6 mL) and polymeric PMHS (19 μL, 0.318 mmol, 2.3 equiv.) was added by microliter syringe. This solution was transferred to a vial containing BCF (7.0 mg, 0.014 mmol) and the resulting mixture was transferred to a J-Young tube. The progress of the reaction was monitored by $^{13}C\{^1H\}$ NMR spectroscopy over 24 hours.

Spectra Corresponding to Isolation of 2 and 3 (From Scheme 3)

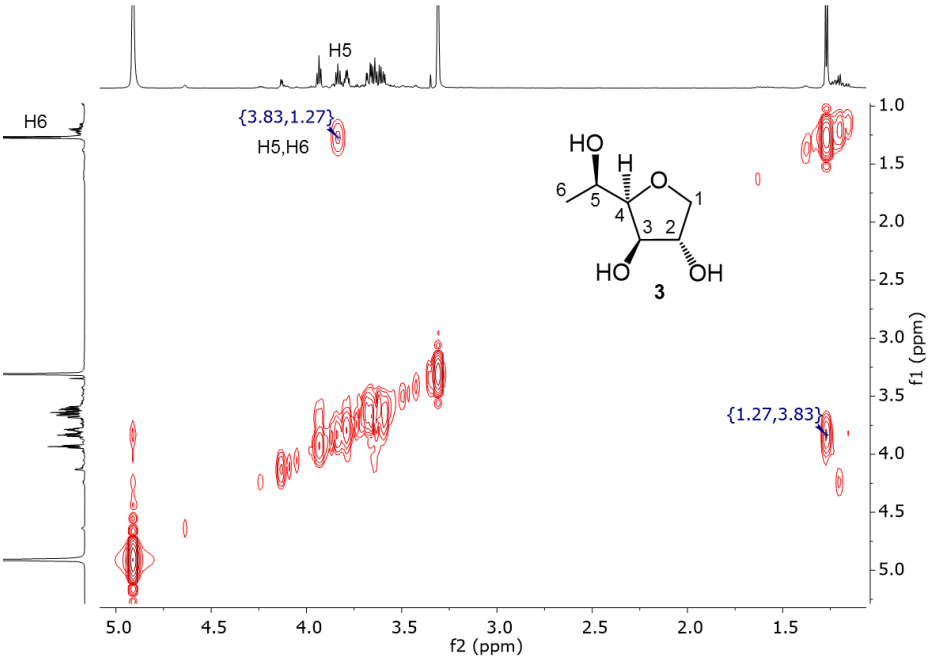




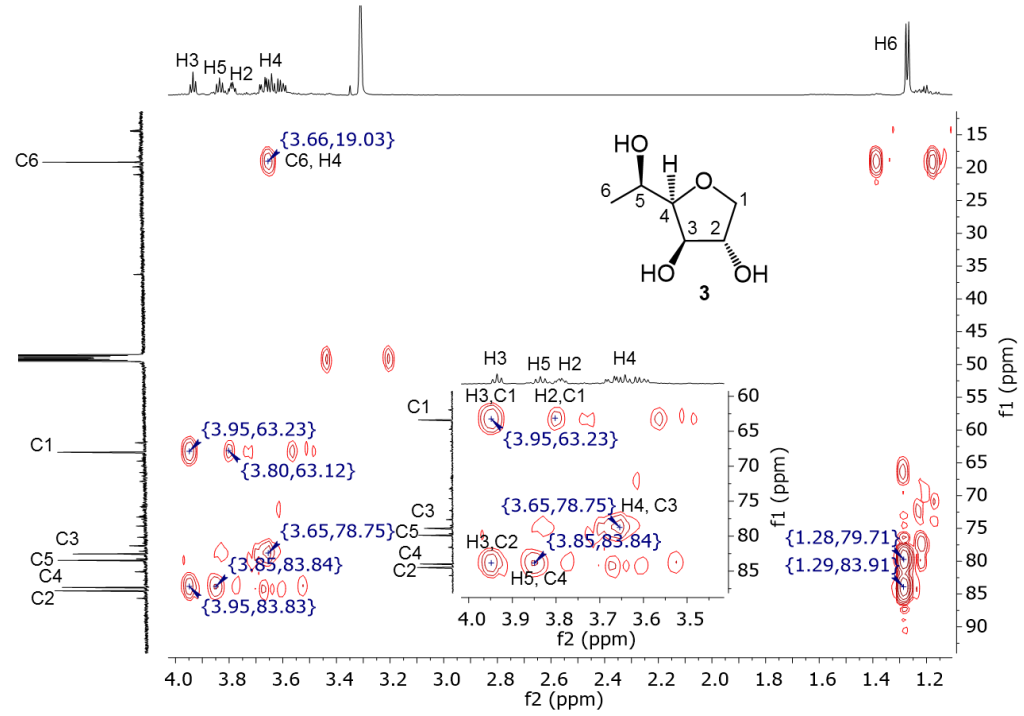

^{1}H NMR
(600 MHz, CD_3OD)
3.3 eq PMHS (poly)
10% BCF
TMS-D-glucose
d_2-DCM
24 h
Followed by
deprotection/purification
HO
H
O
HO
OH
3
22% yield
f1 (ppm)

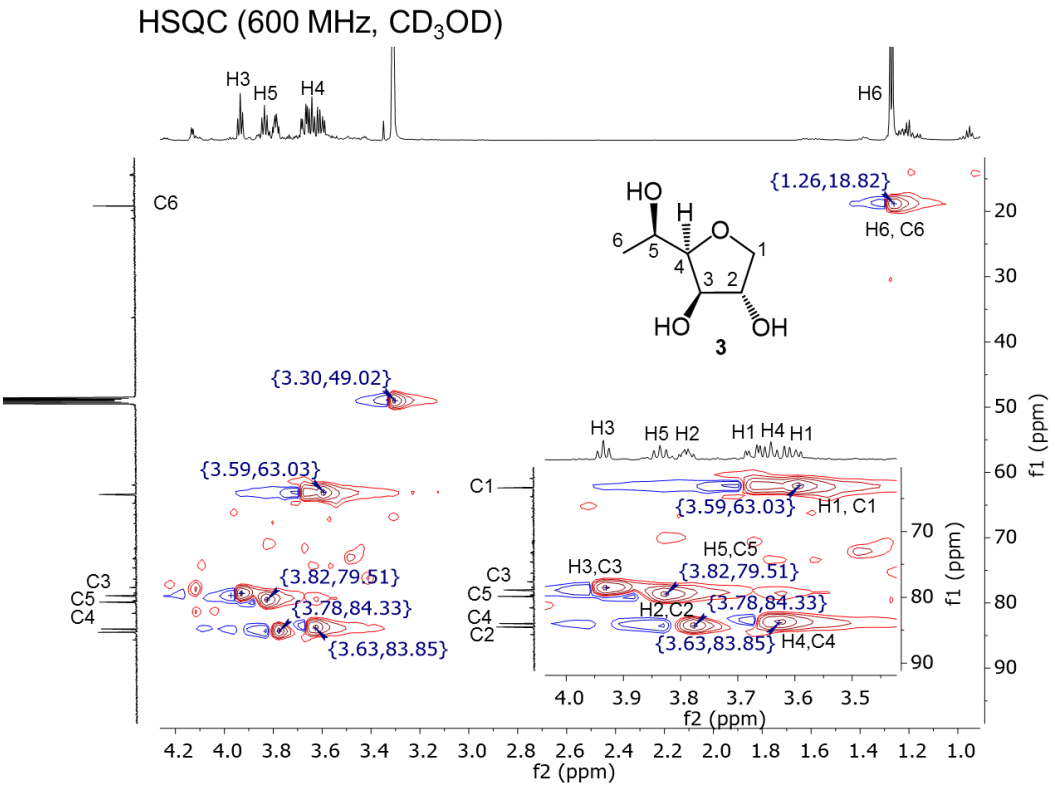

^{13}C{^{1}H} NMR (151 MHz, CD_3OD)
3.3 eq PMHS (poly)
10% BCF
TMS-D-glucose
d_2-DCM
24 h
Followed by
deprotection/purification
HO
H
O
HO
OH
3
22% yield
f1 (ppm)

COSY (600 MHz, CD_3OD)

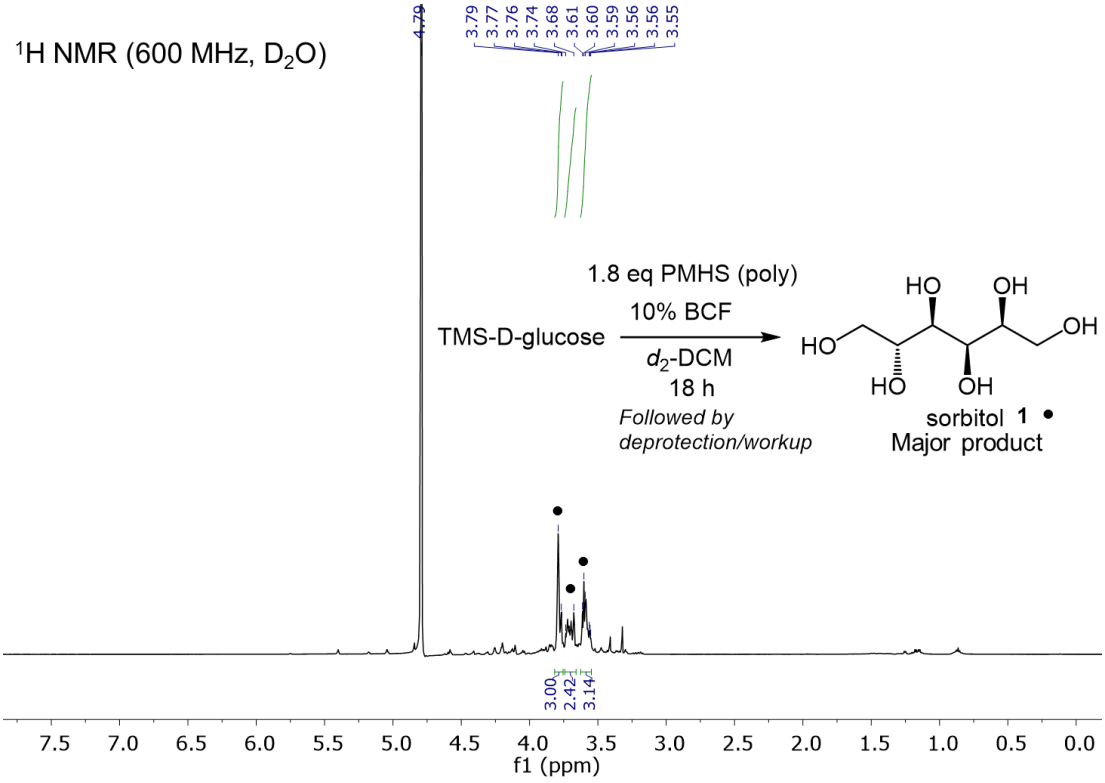


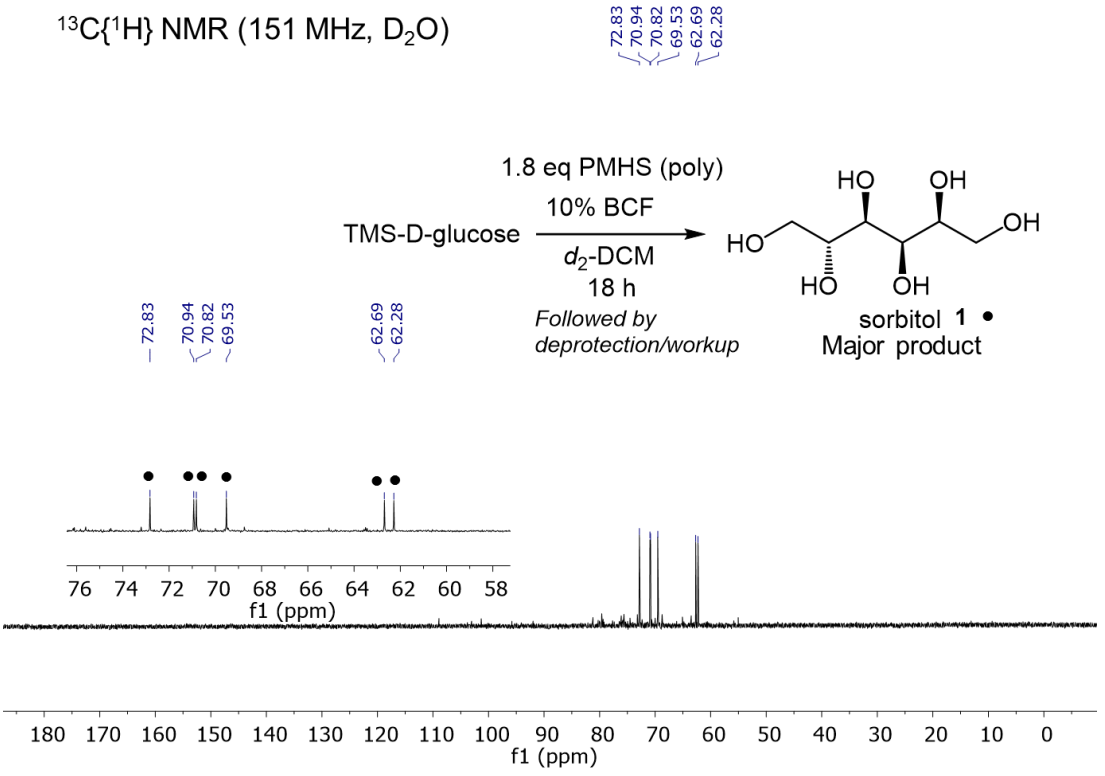
HMBC (600 MHz, CD_3OD)

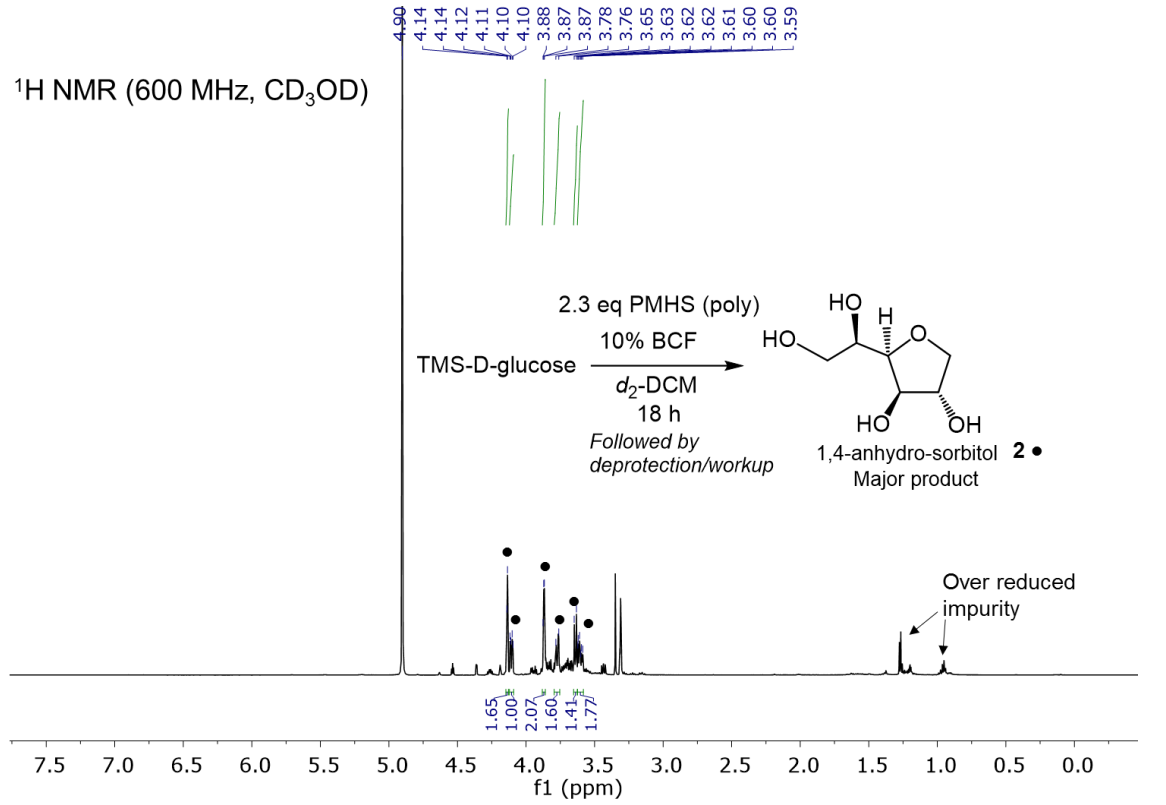


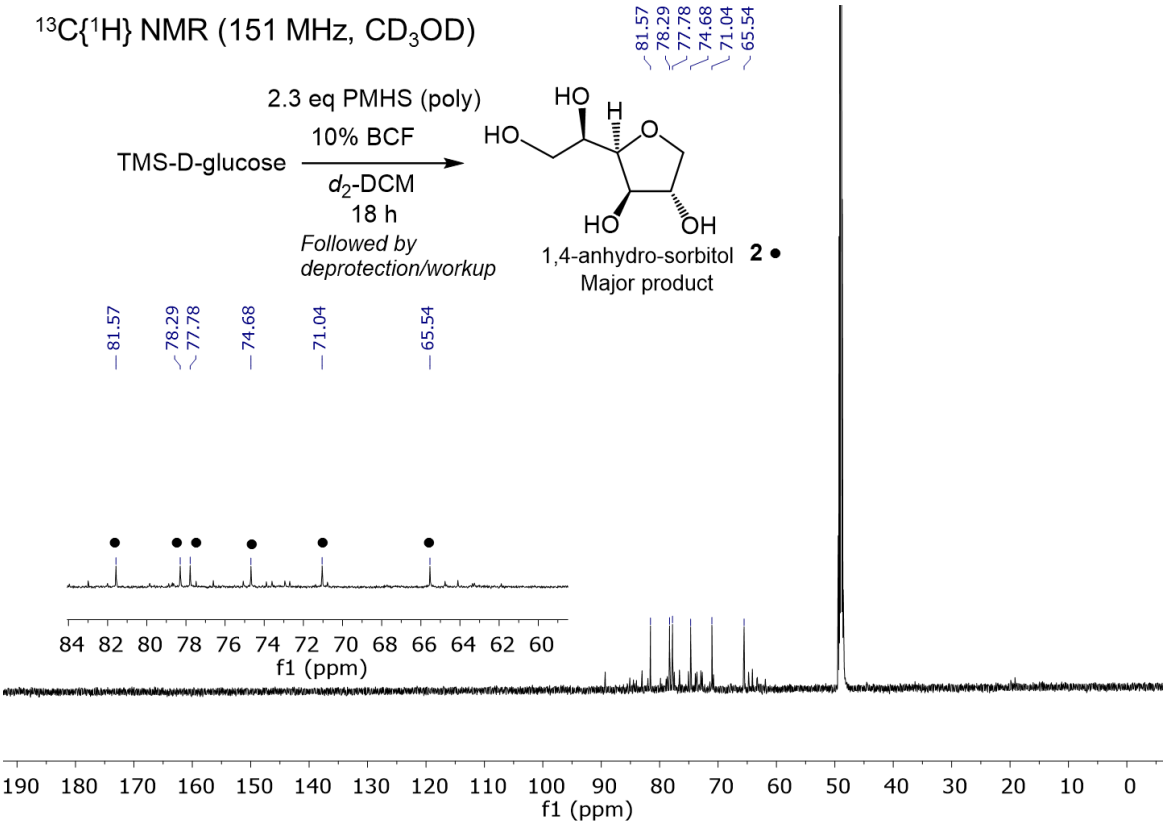

HSQC (600 MHz, CD3OD)
H3
H5
H4
H6
C6
{1.26,18.82}
H6, C6
HO
H
O
6
5
4
3
2
1
HO
OH
3
{3.30,49.02}
{3.59,63.03}
{3.82,79.51}
{3.78,84.33}
{3.63,83.85}
C3
C5
C4
H3
H5 H2
H1 H4 H1
C1
{3.59,63.03}
H1, C1
H5,C5
H3,C3
{3.82,79.51}
C3
C5
C4
C2
H2,C2
{3.78,84.33}
{3.63,83.85}
H4,C4
4.0 3.9 3.8 3.7 3.6 3.5
f2 (ppm)
f1 (ppm)
4.2 4.0 3.8 3.6 3.4 3.2 3.0 2.8 2.6 2.4 2.2 2.0 1.8 1.6 1.4 1.2 1.0
f2 (ppm)
20 30 40 50 60 70 80 90
f1 (ppm)

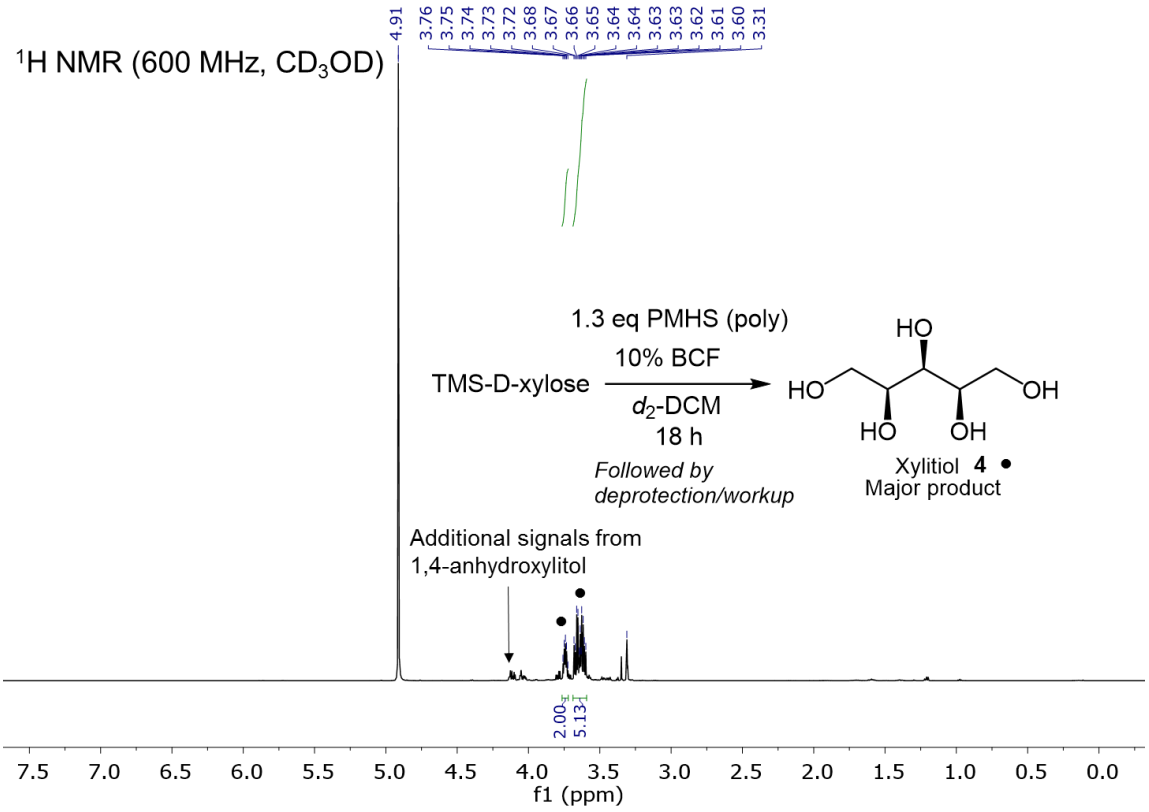
Crude ^{1}H and $^{13}C\{^{1}H\}$ NMR Spectra for Products Obtained with Optimized Reaction Conditions (Product marked with ●)

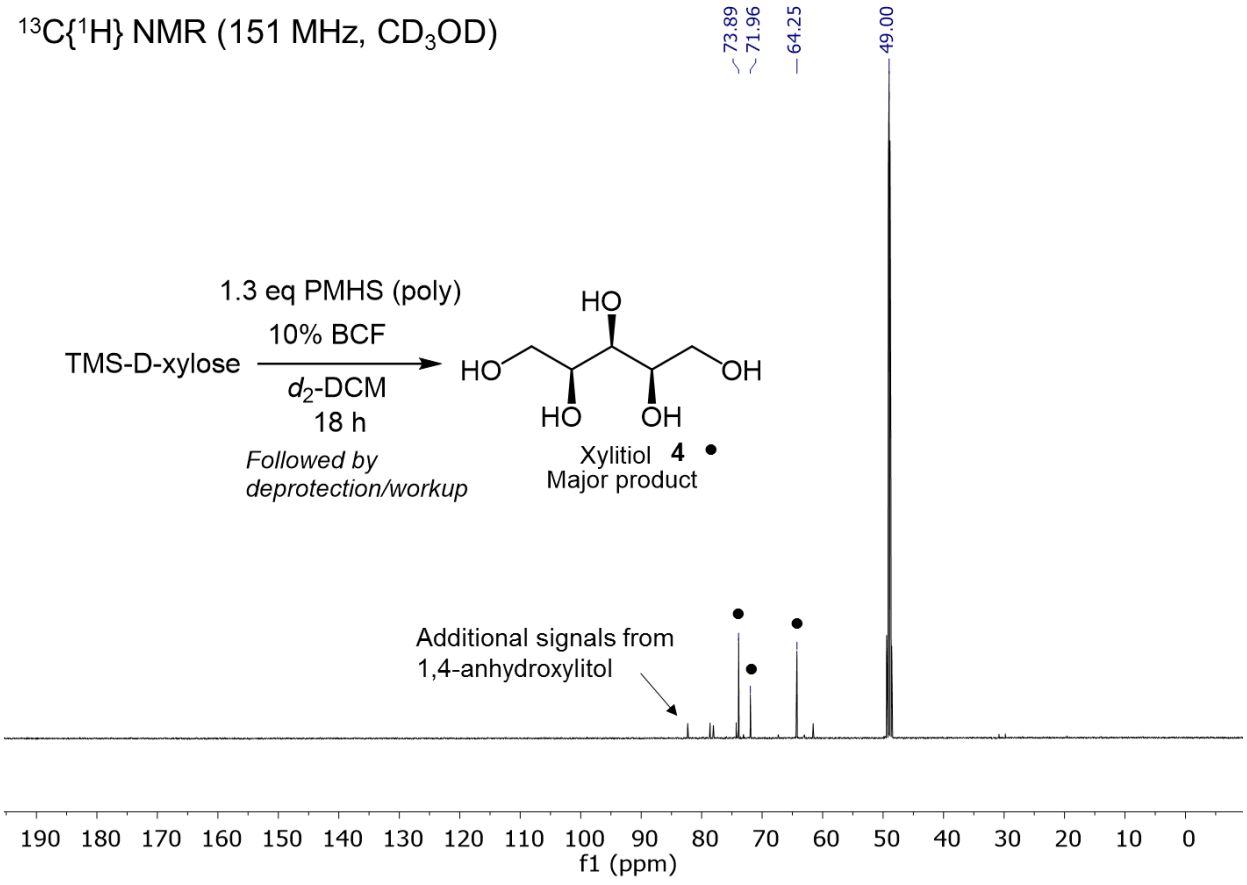


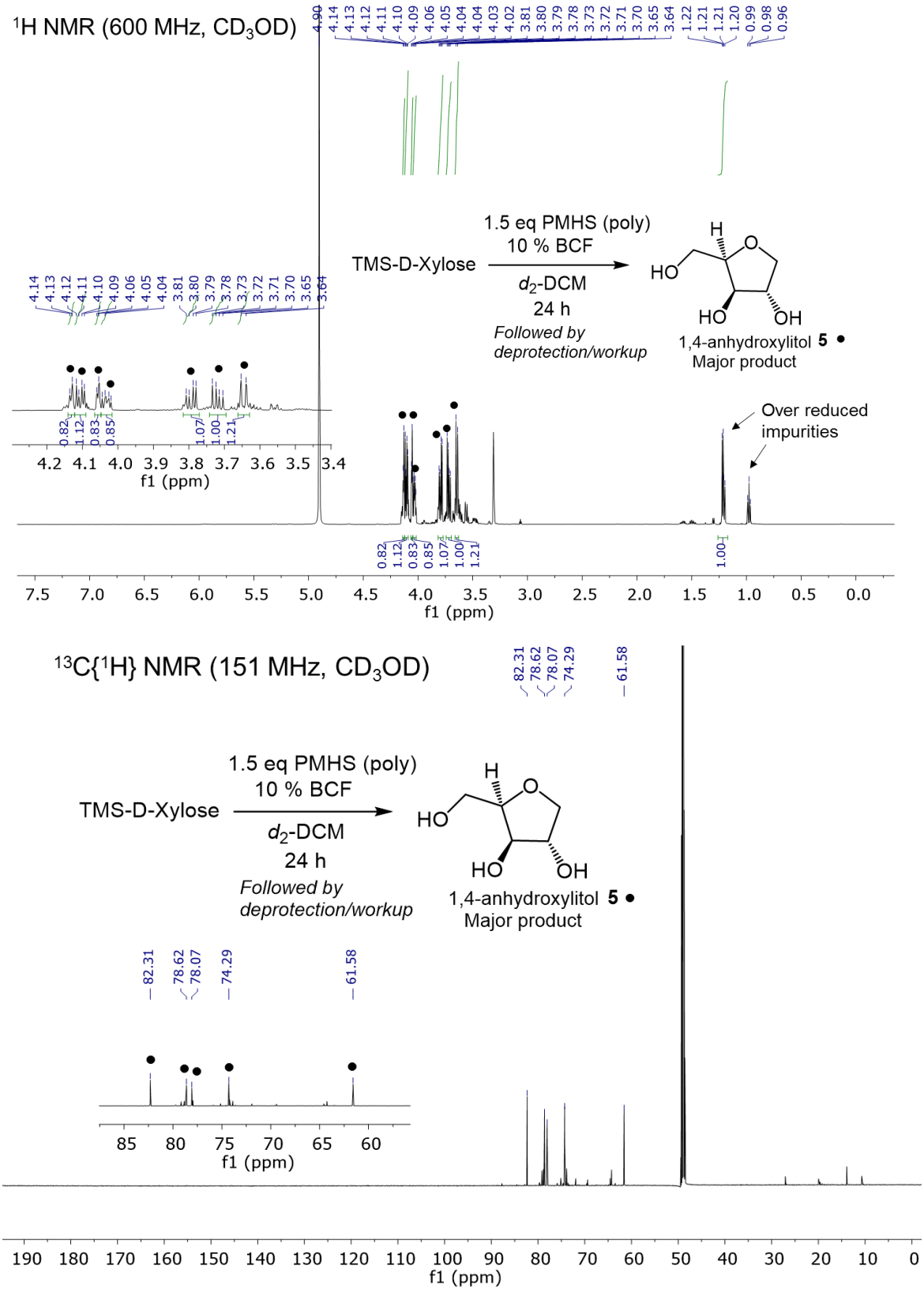



^{1}H NMR (600 MHz, CD_3OD)
4.90
4.14
4.14
4.12
4.11
4.10
4.10
3.88
3.87
3.87
3.78
3.76
3.65
3.63
3.62
3.62
3.61
3.60
3.60
3.59
2.3 eq PMHS (poly)
10% BCF
TMS-D-glucose
d_2-DCM
18 h
Followed by
deprotection/workup
HO
H
O
HO
HO
OH
1,4-anhydro-sorbitol 2 •
Major product
Over reduced
impurity
1.65
1.00
2.07
1.60
1.41
1.77
7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
f1 (ppm)

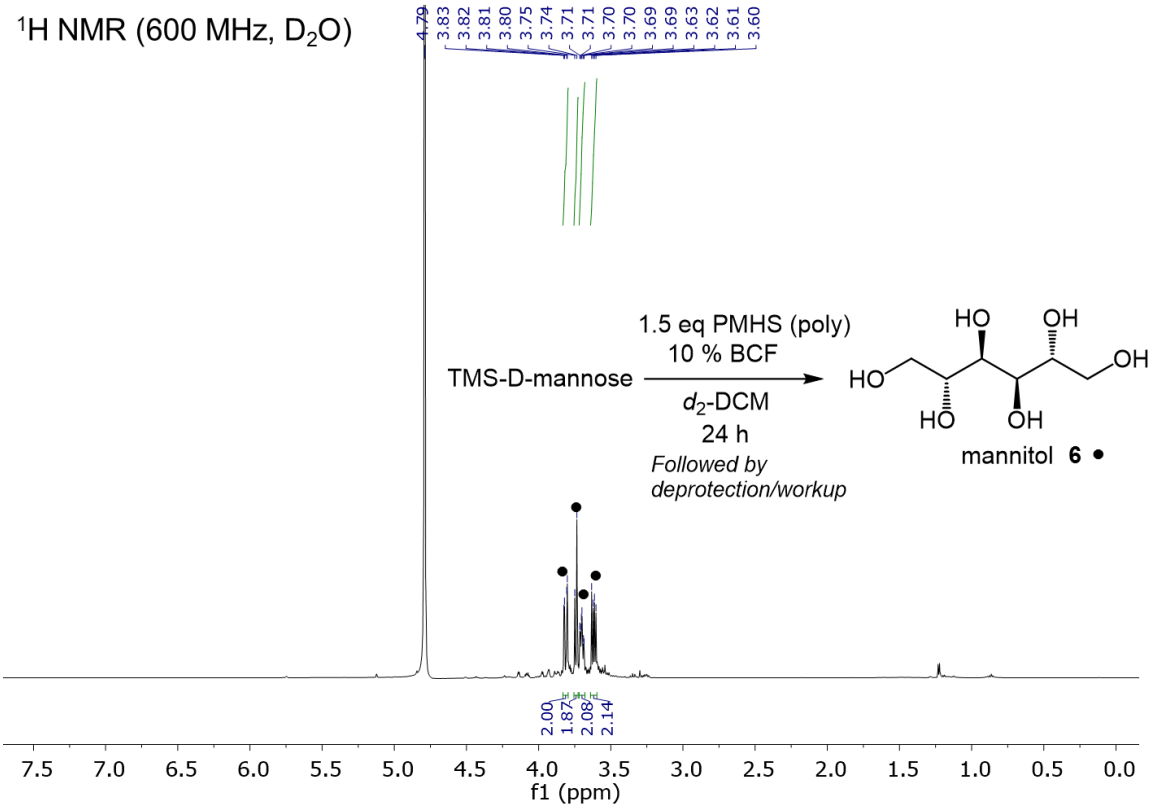

^{13}C{^{1}H} NMR (151 MHz, CD_3OD)
81.57
78.29
77.78
74.68
71.04
65.54
2.3 eq PMHS (poly)
10% BCF
TMS-D-glucose
d_2-DCM
18 h
Followed by
deprotection/workup
HO
H
O
HO
HO
OH
1,4-anhydro-sorbitol 2 •
Major product
84 82 80 78 76 74 72 70 68 66 64 62 60
f1 (ppm)
190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0
f1 (ppm)


^{1}H NMR (600 MHz, CD_3OD)
4.91
3.76
3.75
3.74
3.73
3.72
3.68
3.67
3.66
3.65
3.64
3.64
3.63
3.63
3.62
3.61
3.60
3.31
1.3 eq PMHS (poly)
10% BCF
TMS-D-xylose
d_2-DCM
18 h
Followed by
deprotection/workup
HO
HO
OH
HO
OH
Xylitiol 4
Major product
Additional signals from
1,4-anhydroxylitol
2.00
5.13
7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
f1 (ppm)

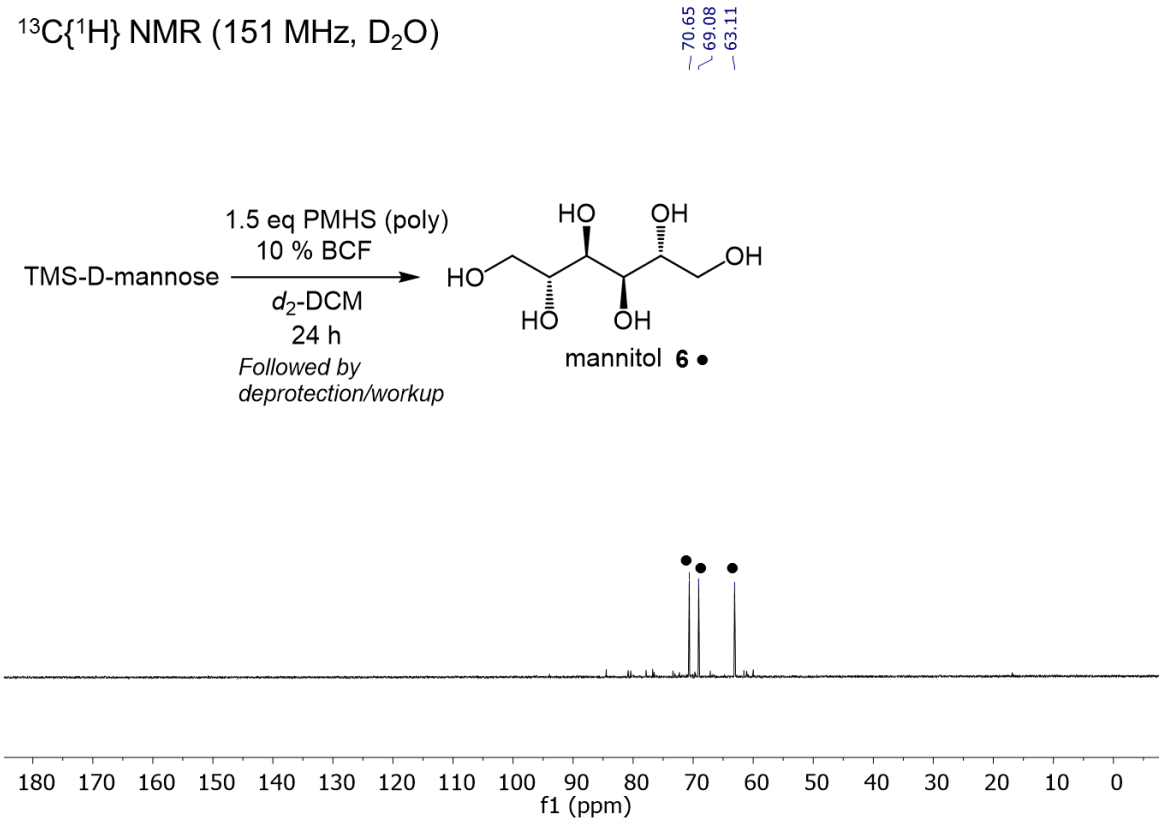

^{13}C{^{1}H} NMR (151 MHz, CD_3OD)
73.89
71.96
64.25
49.00
1.3 eq PMHS (poly)
10% BCF
TMS-D-xylose
d_2-DCM
18 h
Followed by
deprotection/workup
HO
HO
OH
HO
OH
Xylitiol 4
Major product
Additional signals from
1,4-anhydroxylitol
190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0
f1 (ppm)

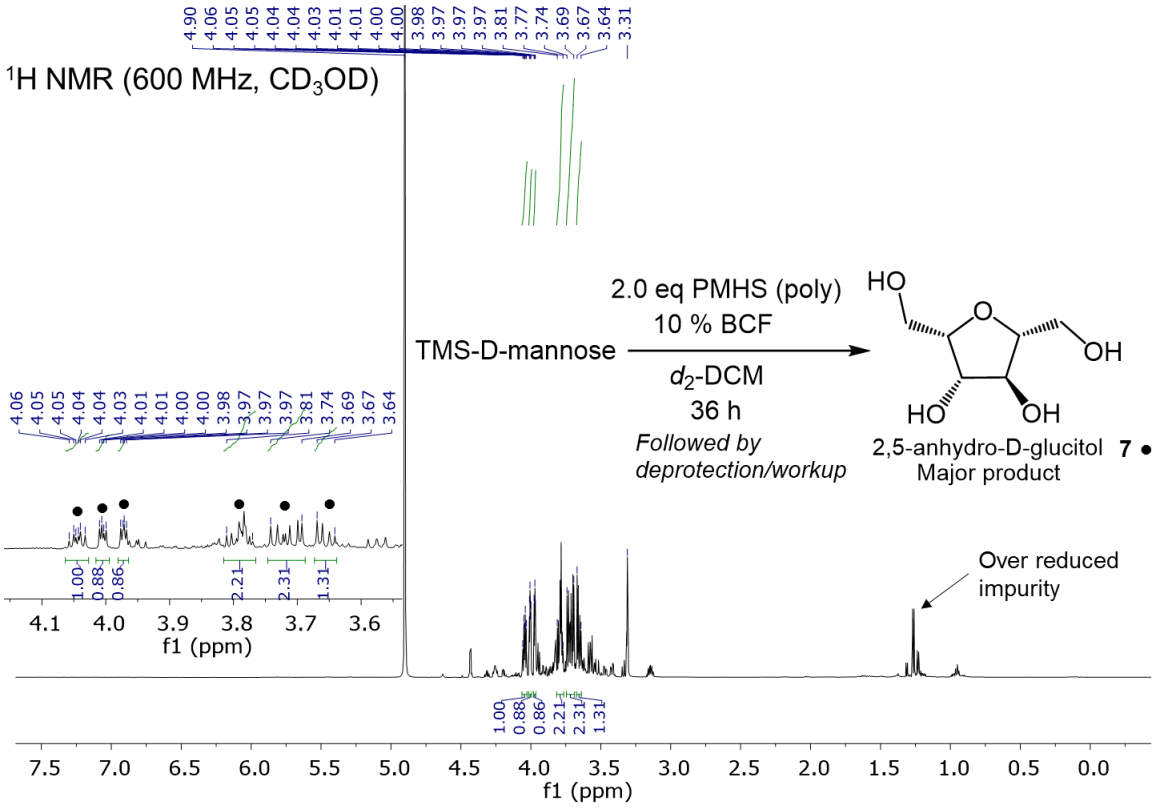

1H NMR (600 MHz, CD3OD)
TMS-D-Xylose
1.5 eq PMHS (poly)
10 % BCF
d2-DCM
24 h
Followed by deprotection/workup
1,4-anhydroxylitol 5 •
Major product
Over reduced impurities
f1 (ppm)
13C{1H} NMR (151 MHz, CD3OD)
82.31
78.62
78.07
74.29
61.58

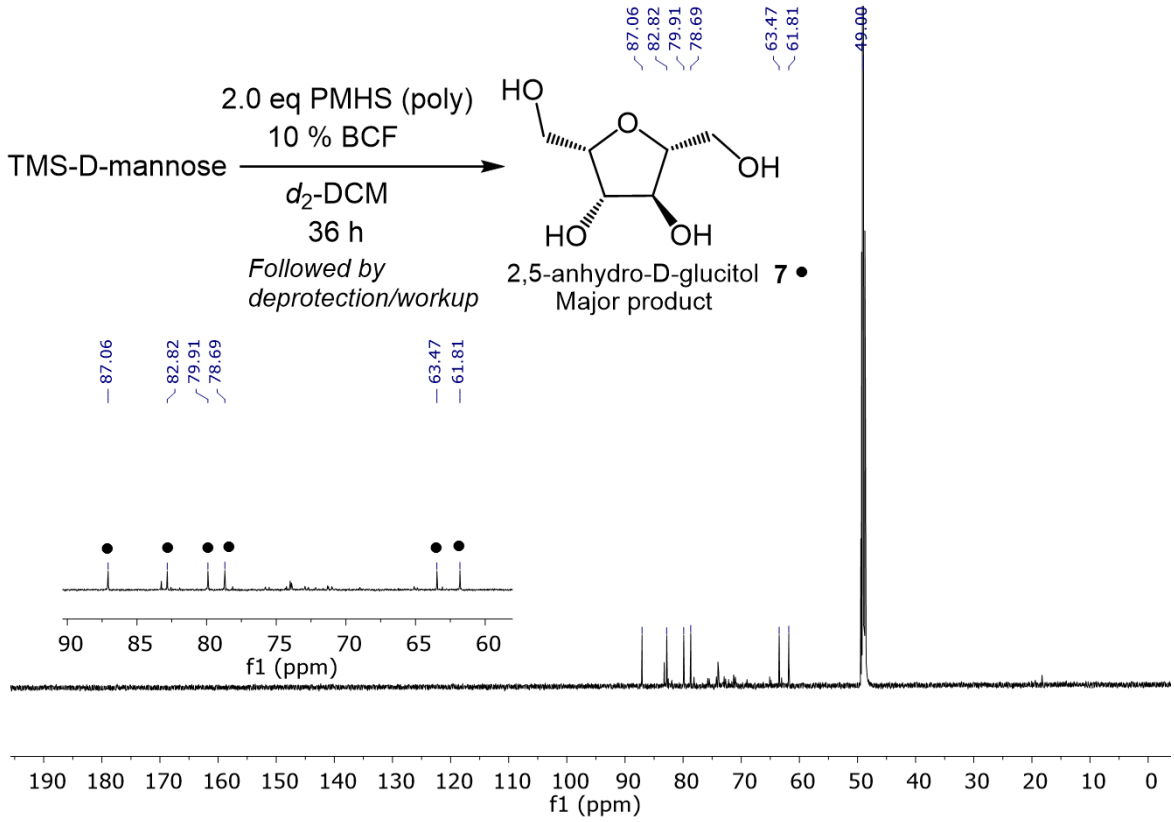
^{1}H NMR (600 MHz, D_2O)

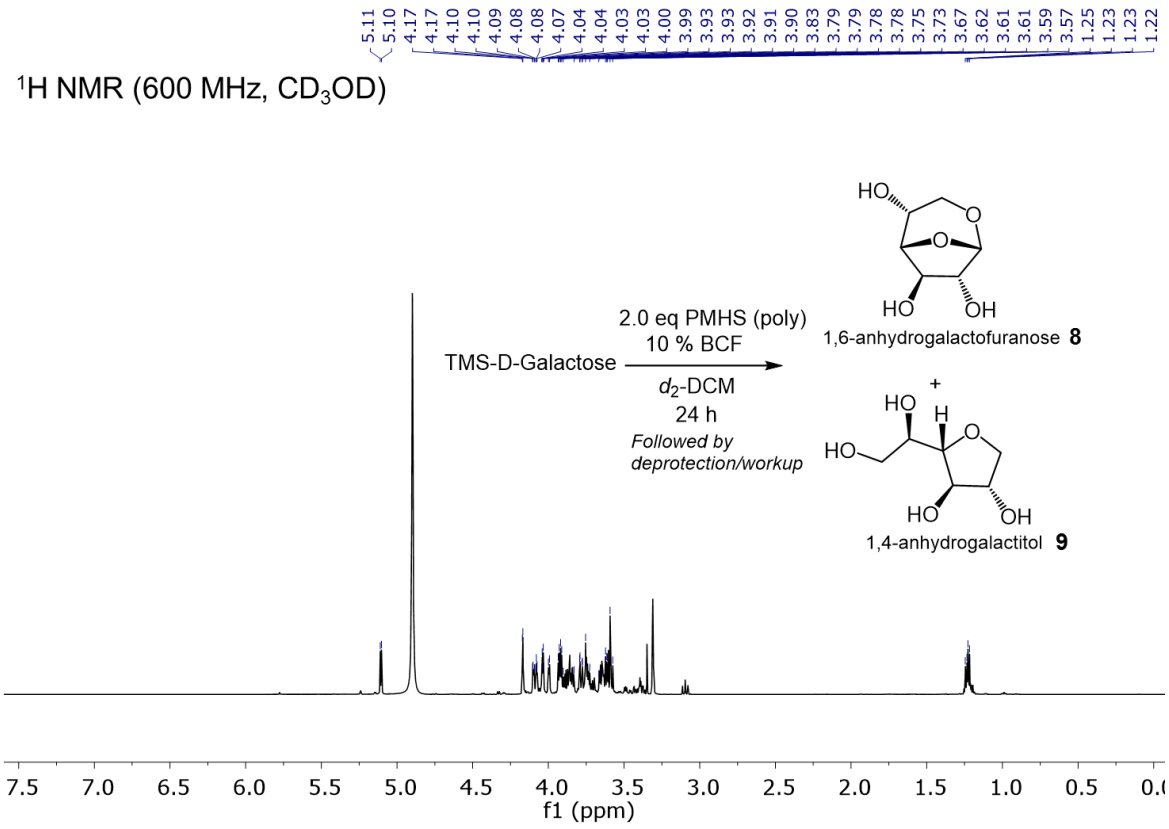


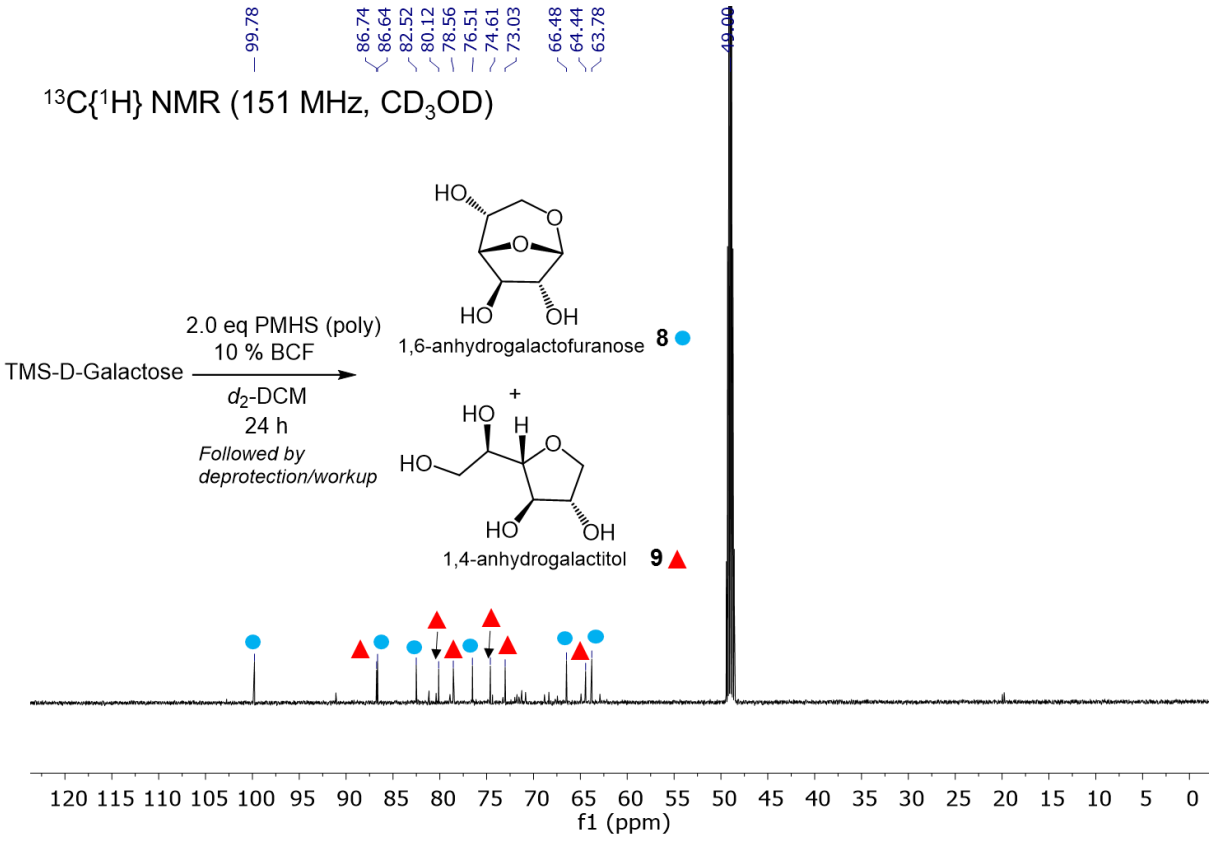
^{13}C{^{1}H} NMR (151 MHz, D_2O)

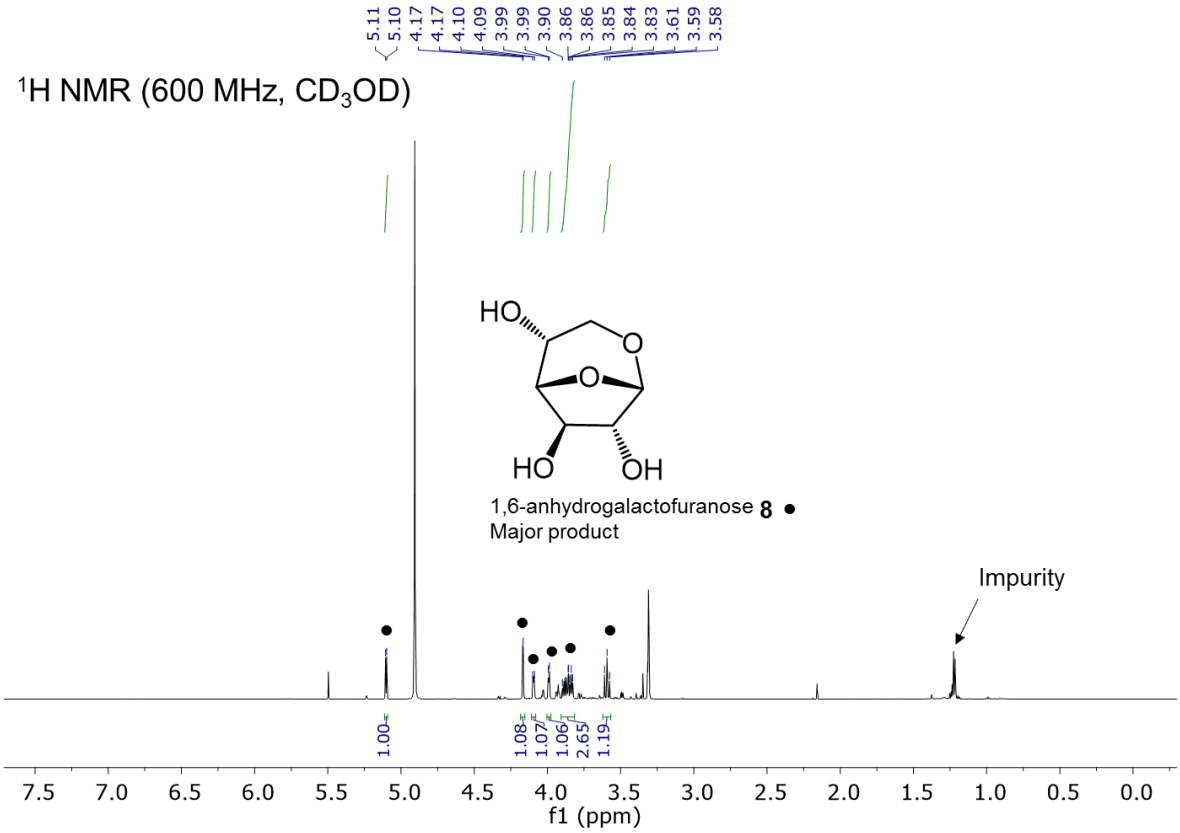


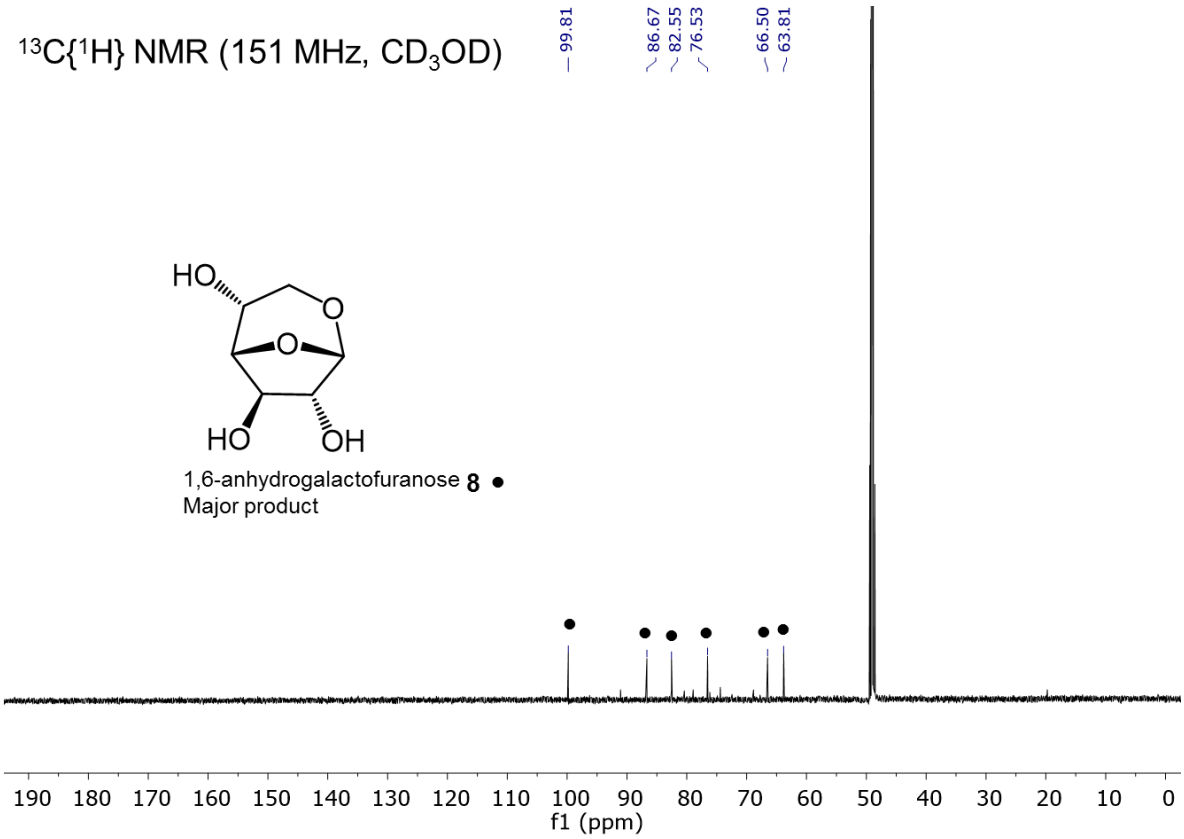

1H NMR (600 MHz, CD3OD)
TMS-D-mannose
2.0 eq PMHS (poly)
10 % BCF
d2-DCM
36 h
Followed by deprotection/workup
2,5-anhydro-D-glucitol 7 •
Major product
Over reduced impurity
f1 (ppm)

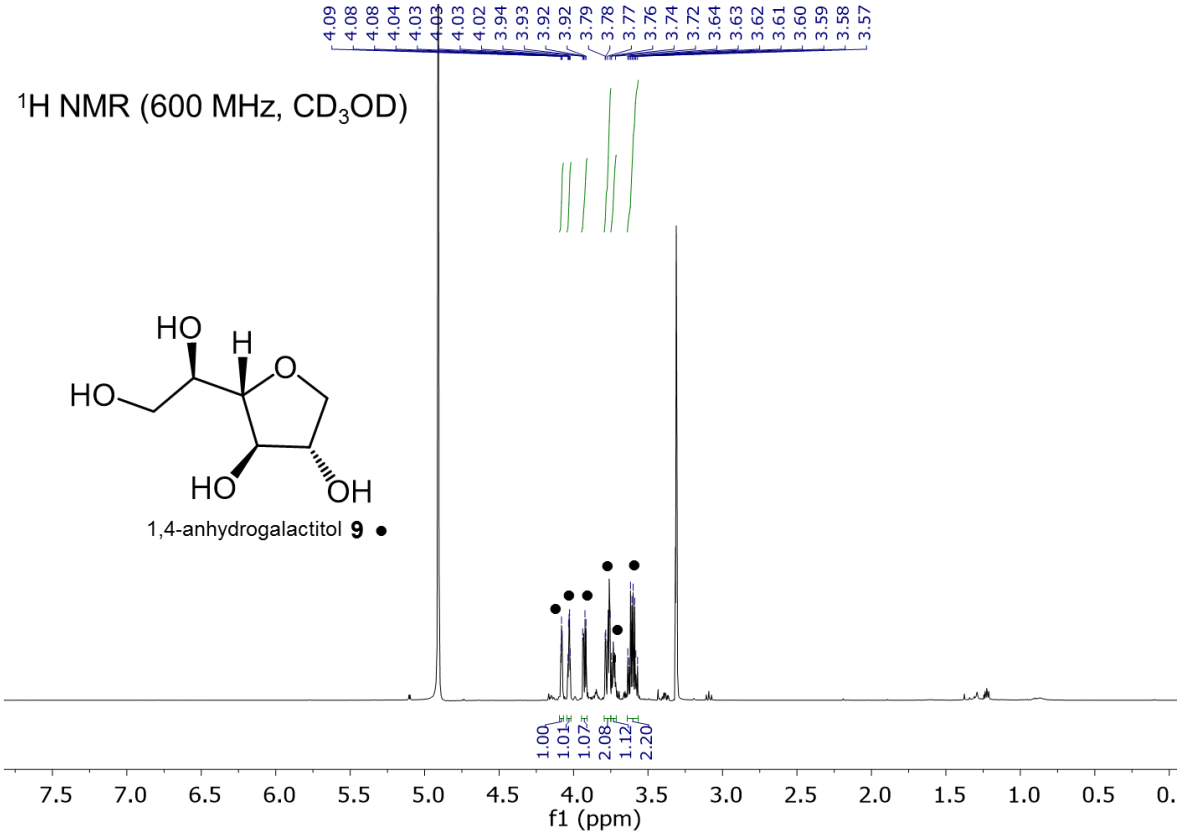

13C{1H} NMR (151 MHz, CD3OD)
TMS-D-mannose
2.0 eq PMHS (poly)
10 % BCF
d2-DCM
36 h
Followed by deprotection/workup
2,5-anhydro-D-glucitol 7 •
Major product
f1 (ppm)

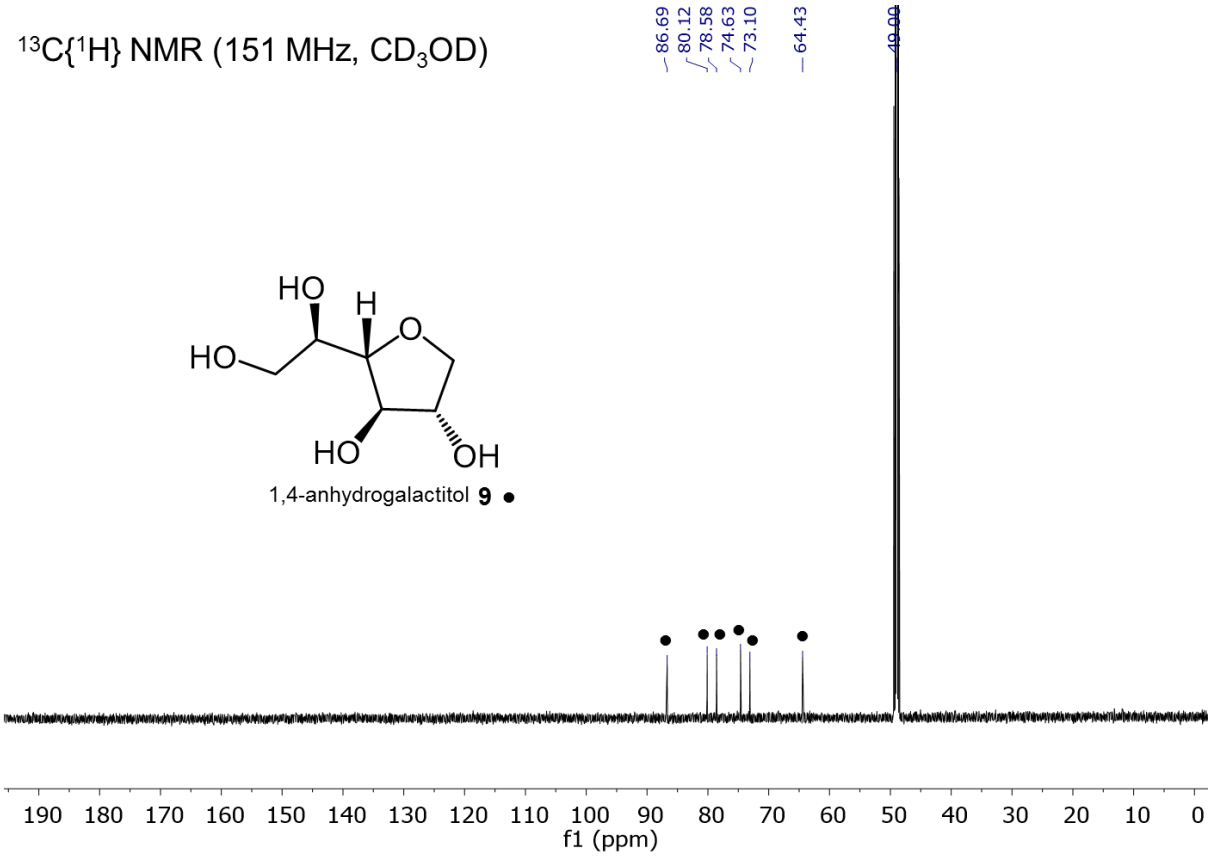

5.11 5.10 4.17 4.17 4.10 4.10 4.09 4.08 4.08 4.07 4.04 4.04 4.03 4.03 4.00 3.99 3.93 3.93 3.92 3.91 3.90 3.83 3.79 3.79 3.78 3.78 3.75 3.73 3.67 3.62 3.61 3.61 3.59 3.57 1.25 1.23 1.22
^{1}H NMR (600 MHz, CD_3OD)
TMS-D-Galactose
2.0 eq PMHS (poly)
10 % BCF
d_2-DCM
24 h
Followed by deprotection/workup
1,6-anhydrogalactofuranose 8
1,4-anhydrogalactitol 9
7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5
f1 (ppm)

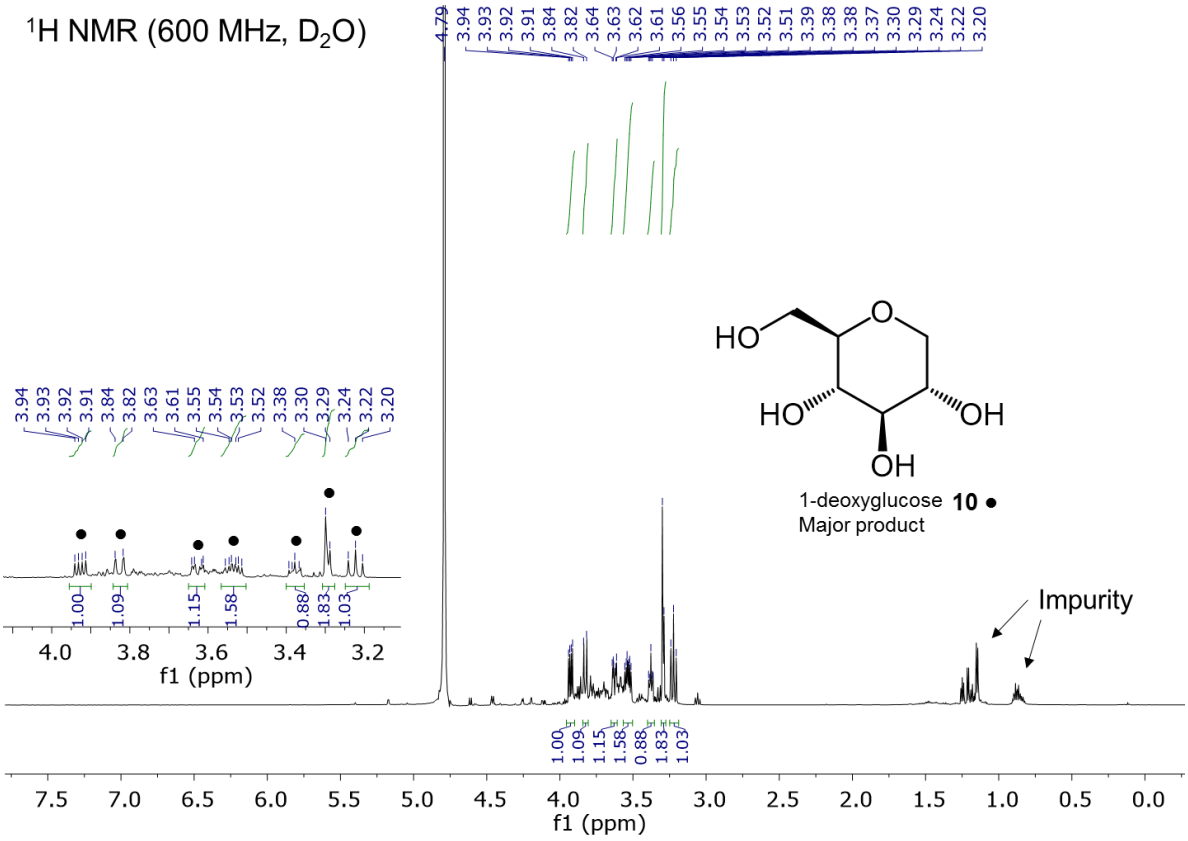

99.78 86.74 86.64 82.52 80.12 78.56 76.51 74.61 73.03 66.48 64.44 63.78 49.00
^{13}C{^{1}H} NMR (151 MHz, CD_3OD)
TMS-D-Galactose
2.0 eq PMHS (poly)
10 % BCF
d_2-DCM
24 h
Followed by deprotection/workup
1,6-anhydrogalactofuranose 8
1,4-anhydrogalactitol 9
120 115 110 105 100 95 90 85 80 75 70 65 60 55 50 45 40 35 30 25 20 15 10 5 0
f1 (ppm)

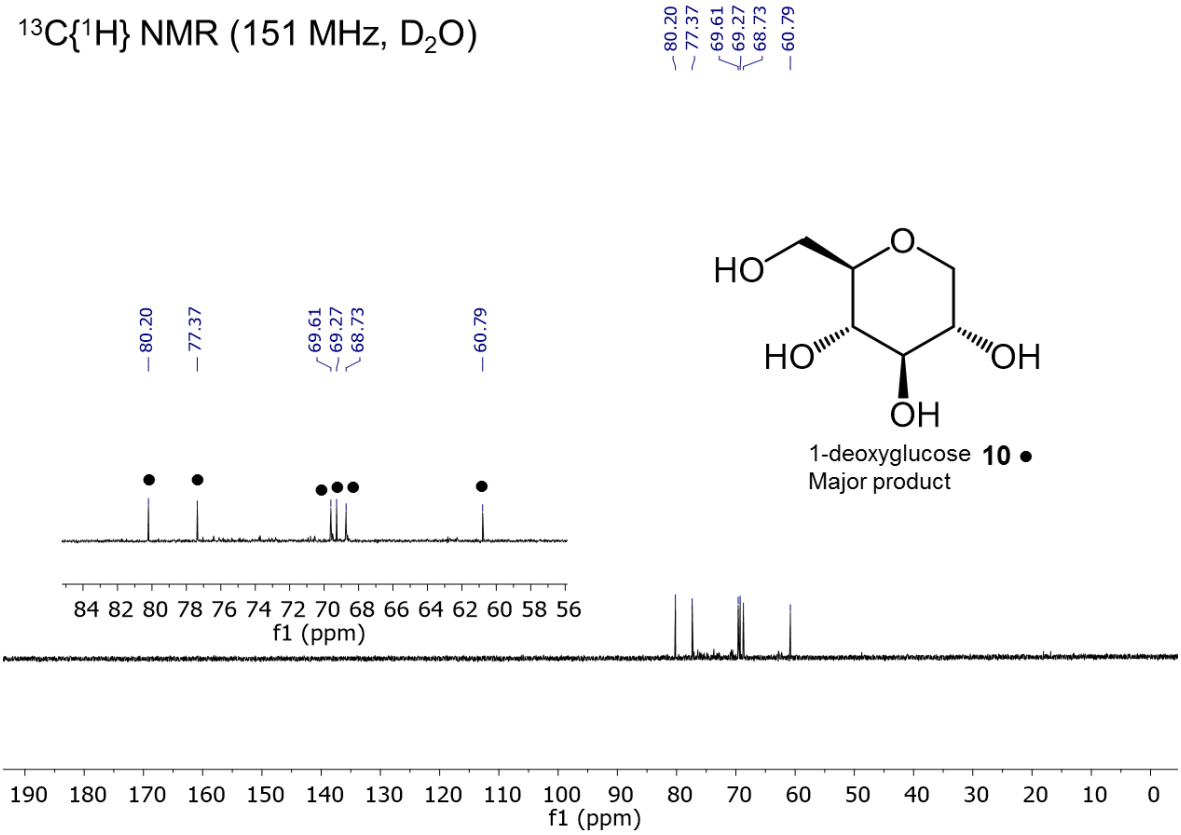

5.11
5.10
4.17
4.17
4.10
4.09
3.99
3.99
3.90
3.86
3.86
3.85
3.84
3.83
3.61
3.59
3.58
1H NMR (600 MHz, CD3OD)
HO
O
O
HO
OH
1,6-anhydrogalactofuranose 8 ●
Major product
Impurity
1.00
1.08
1.07
1.06
2.65
1.19
7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
f1 (ppm)


13C{1H} NMR (151 MHz, CD3OD)
99.81
86.67
82.55
76.53
66.50
63.81
HO
O
O
HO
OH
1,6-anhydrogalactofuranose 8 ●
Major product
190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0
f1 (ppm)

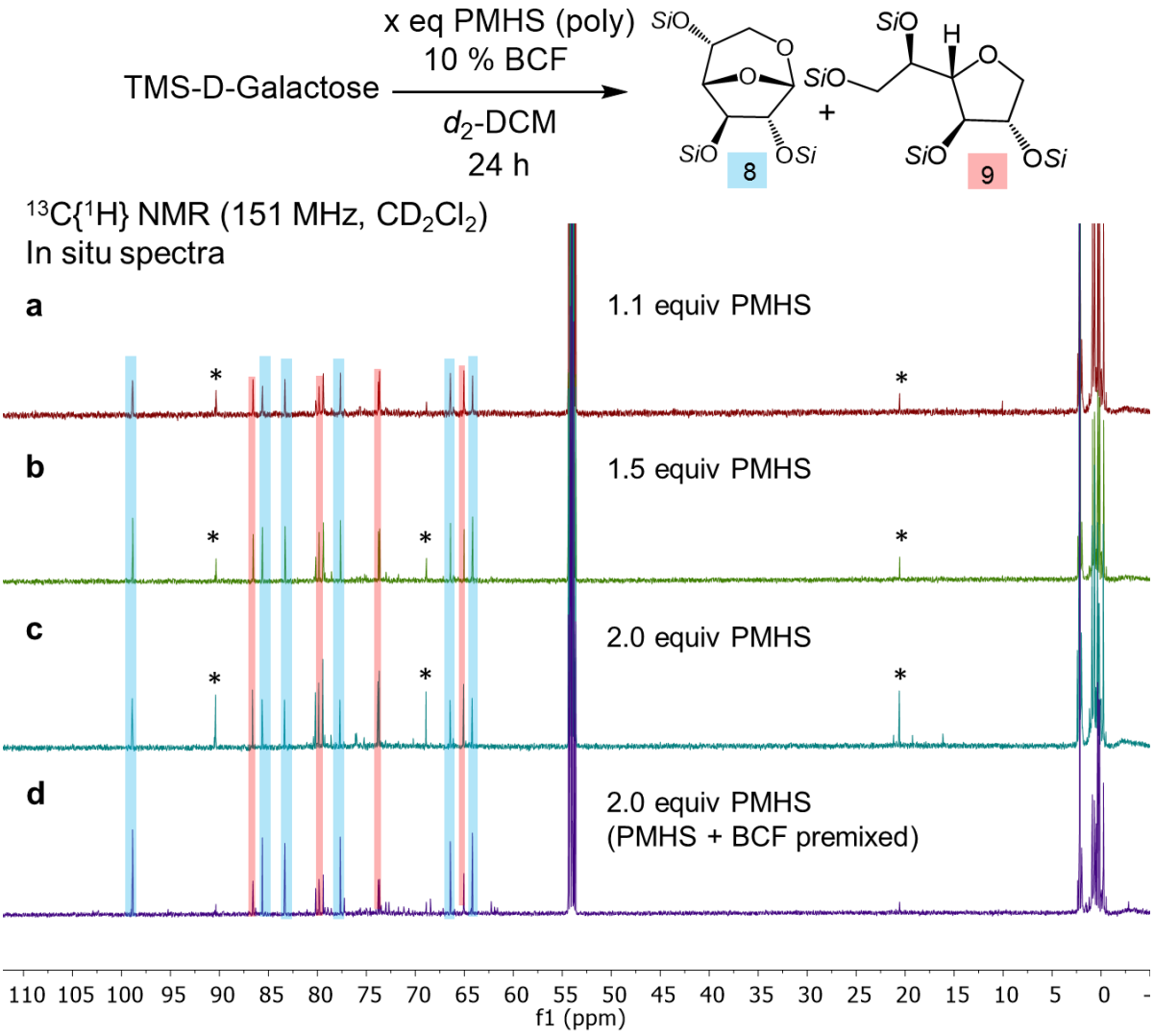

^{1}H NMR (600 MHz, CD_3OD)
4.09 4.08 4.08 4.04 4.03 4.03 4.03 4.02 3.94 3.93 3.92 3.92 3.79 3.78 3.77 3.76 3.74 3.72 3.64 3.63 3.62 3.61 3.60 3.59 3.58 3.57
HO H O HO HO OH
1,4-anhydrogalactitol 9 ●
1.00 1.01 1.07 2.08 1.12 2.20
7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.
f1 (ppm)


^{13}C{^{1}H} NMR (151 MHz, CD_3OD)
86.69 80.12 78.58 74.63 73.10 64.43 49.00
HO H O HO HO OH
1,4-anhydrogalactitol 9 ●
190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0
f1 (ppm)


^{1}H NMR (600 MHz, D_2O)
HO
HO
OH
OH
O
1-deoxyglucose **10** ●
Major product
Impurity
f1 (ppm)

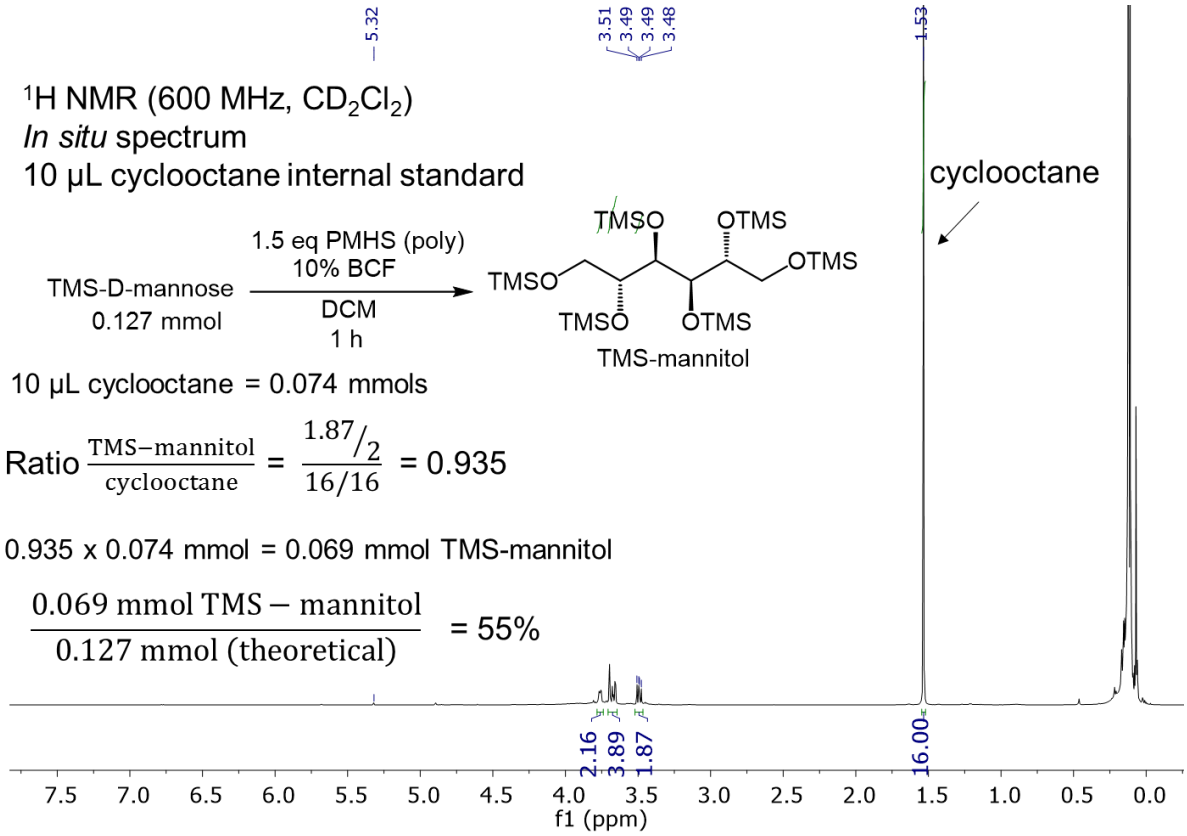

^{13}C{^{1}H} NMR (151 MHz, D_2O)
80.20
77.37
69.61
69.27
68.73
60.79
HO
HO
OH
OH
O
1-deoxyglucose **10** ●
Major product
f1 (ppm)

NMR Spectra for TMS-D-Galactose Reactivity Based on Equivalents of PMHS

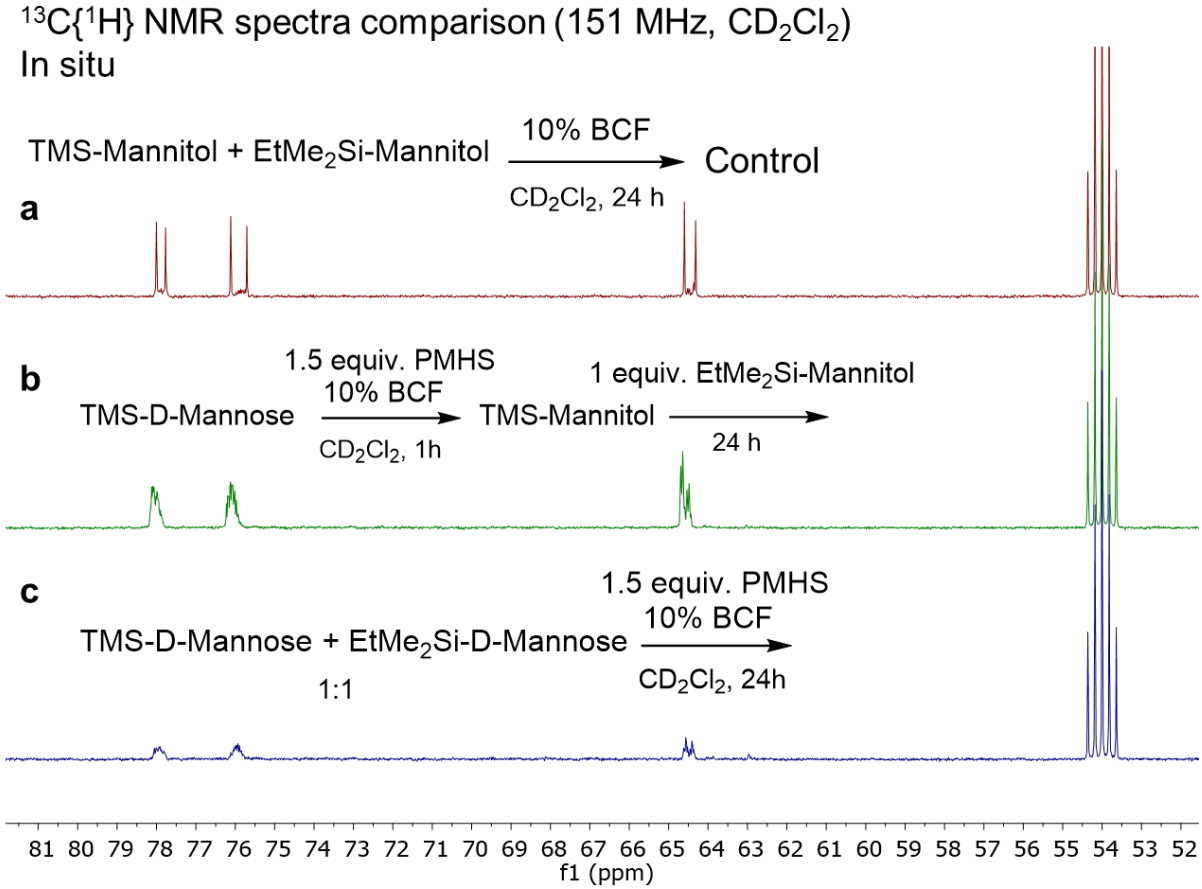


Reactions **a-c** were performed by premixing TMS-D-galactose with PMHS in 0.6 mL of CD_2Cl_2 before addition to BCF. Reaction **d** was performed by premixing PMHS with BCF in 0.6 mL of CD_2Cl_2 before addition to TMS-D-galactose. Signals denoted with * likely belong to the product resulting from the reduction of **9** at C6.

Integration of TMS-Mannitol from TMS-D-Mannose Reduction Relative to Cyclooctane Internal Standard

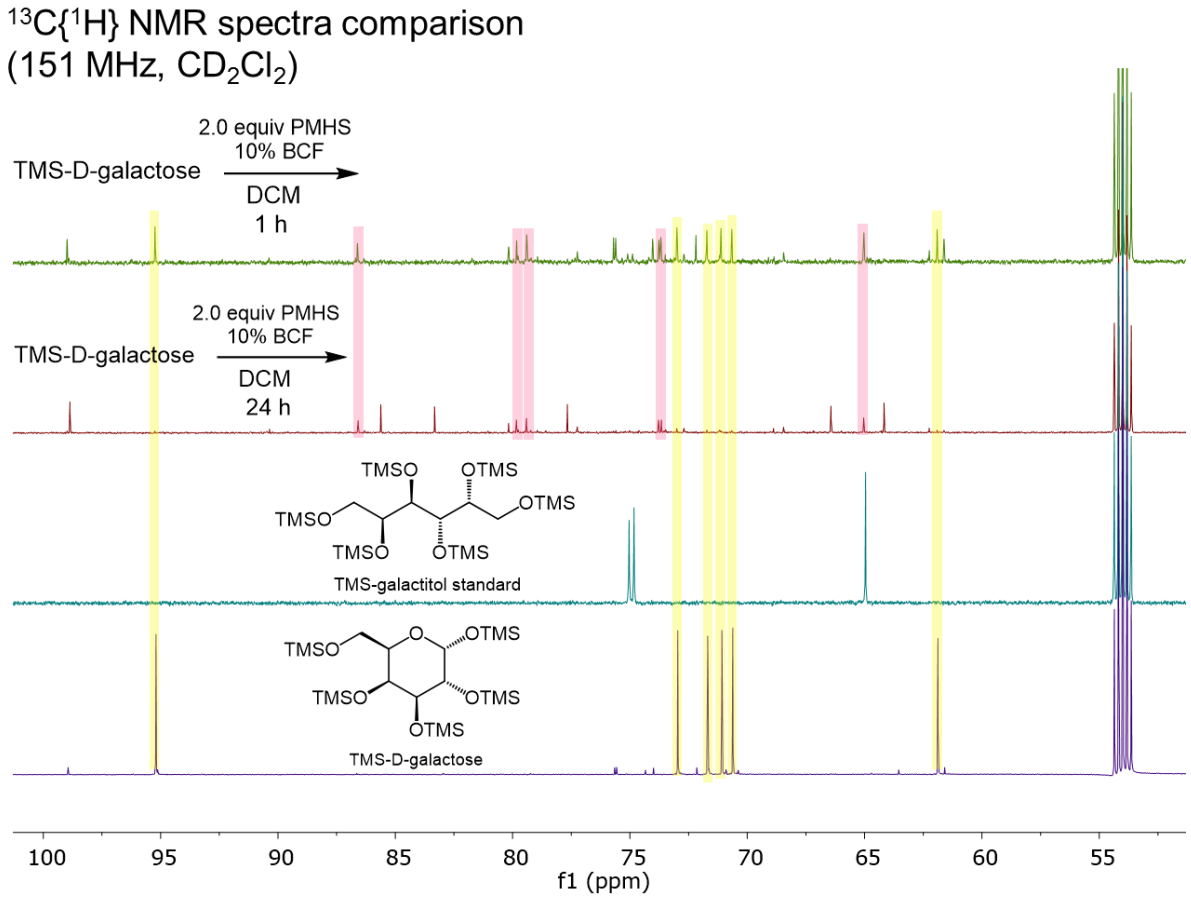


NMR Spectra for Silyl Exchange Between TMS and $EtMe_2Si$-Protected Substrates



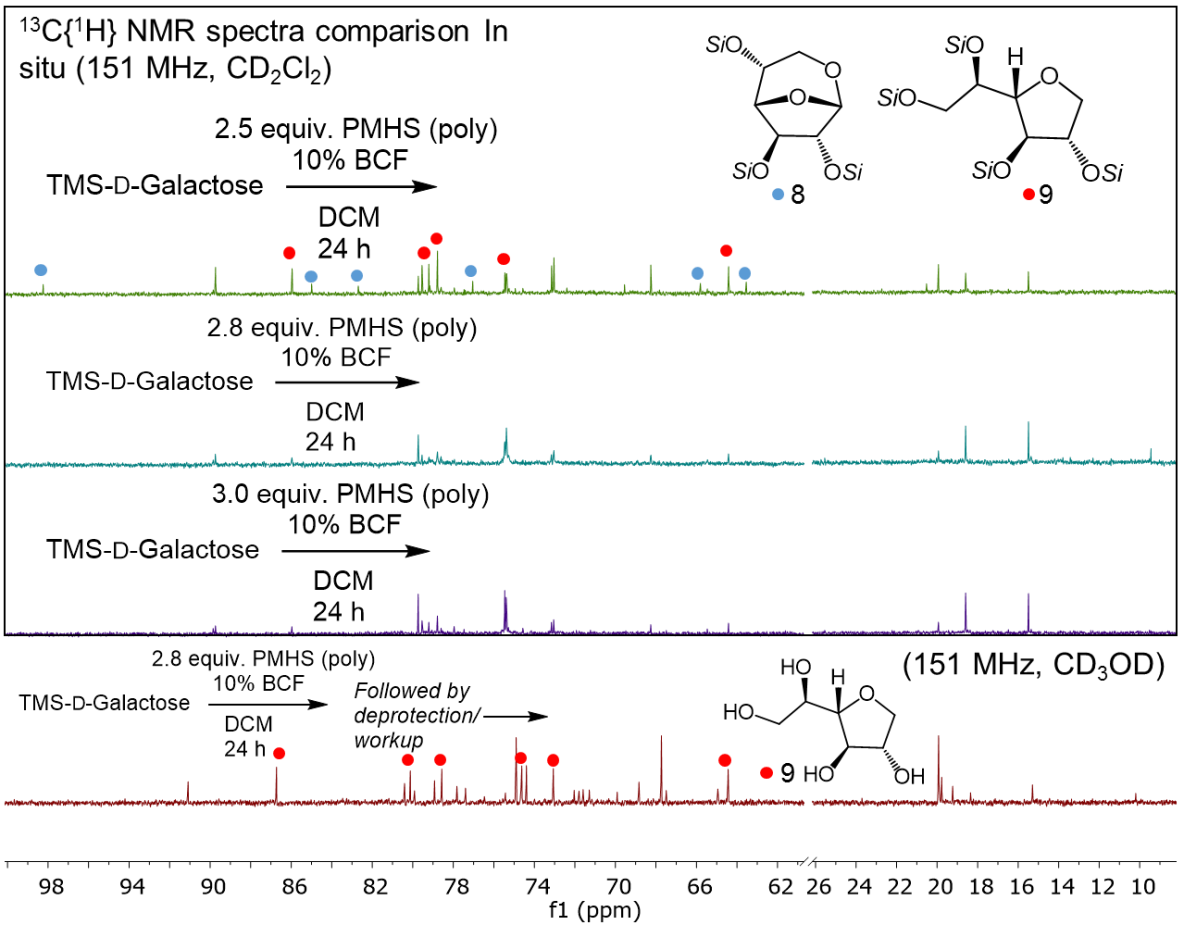
The control experiment shown in **a** indicates silyl exchange is slow when TMS-mannitol and $EtMe_2Si$-mannitol are mixed in the presence of catalytic BCF, as unique carbon resonances for the two protected forms of mannitol are observed, but baseline broadening is apparent. When TMS-D-mannose is reduced to TMS-mannitol with 1.5 equivalents of PMHS with catalytic BCF and the resulting solution is subsequently treated with a stoichiometric standard of $EtMe_2Si$-mannitol, broadening of the mannitol resonances occurs, indicating silyl exchange (shown in **b**). A 1:1 mixture of TMS-D-mannose and $EtMe_2Si$-mannose is reduced with 1.5 equivalents of PMHS (relative to combined mole total) under BCF catalysis, giving a set of broadened resonances corresponding to mannitol that has experienced silyl exchange (shown in **c**).

Comparison of NMR Spectra for TMS-D-Galactose Reduction to Reference Compounds



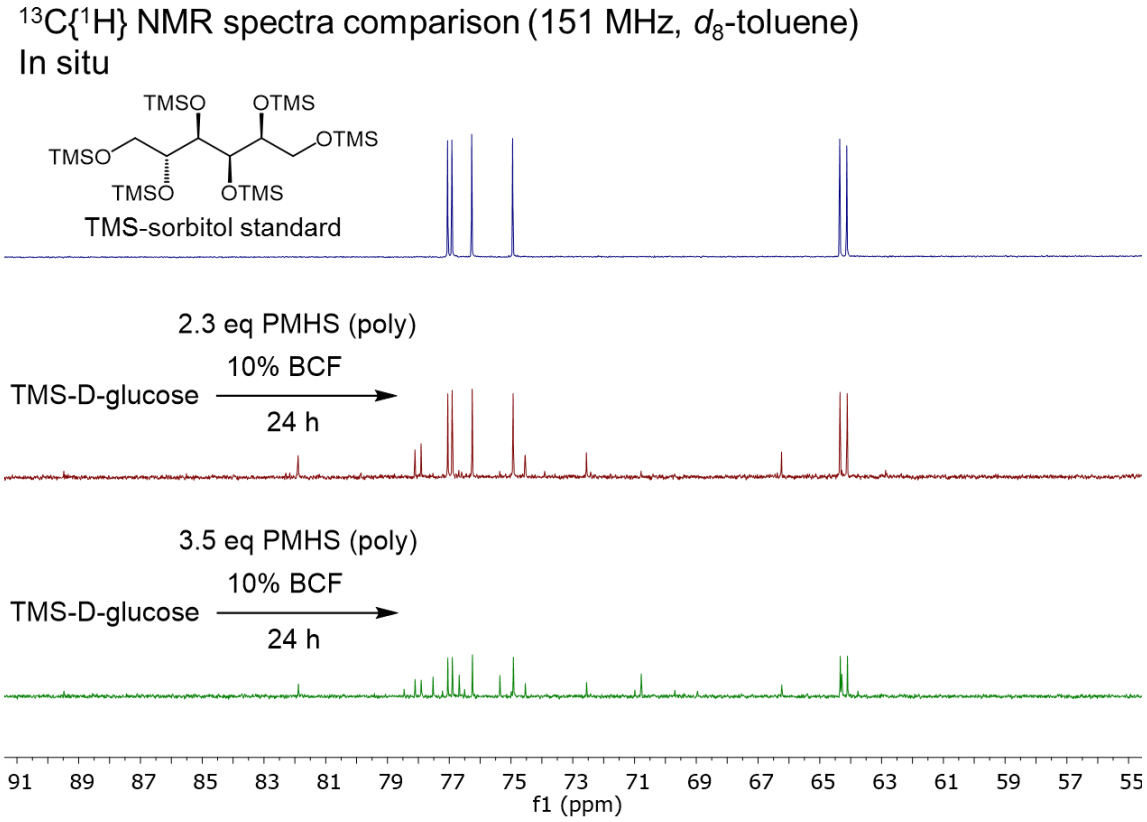
Resonances highlighted in yellow belong to TMS-D-galactose. Peaks highlighted in pink belong to 1,4-anhydrogalactitol **9**. TMS-galactitol is not observed in reaction mixture, even early in the reaction (1 hour). The full set of resonances belonging to 1,6-anhydrogalactofuranose **8** are not observed until after 24 hours.

NMR Spectra for the Reduction of TMS-D-Galactose at Higher Equivalents of PMHS



Peaks denoted with the blue circle belong to **8** and peaks marked with the red circle belong to **9**. When 2.5 equivalents of PMHS are used in the reaction, the consumption of **8** has started to become apparent, while **9** is still present. In addition, three major resonances are observed in the alkyl region. With both 2.8 and 3.0 equivalents of PMHS, **8** and **9** are no longer observed, and it appears as though one major species is present. However, after deprotection and workup (example shown of reaction using 2.8 equivalents of PMHS), a complex product mixture results. Compound **9** is still observed in this mixture.

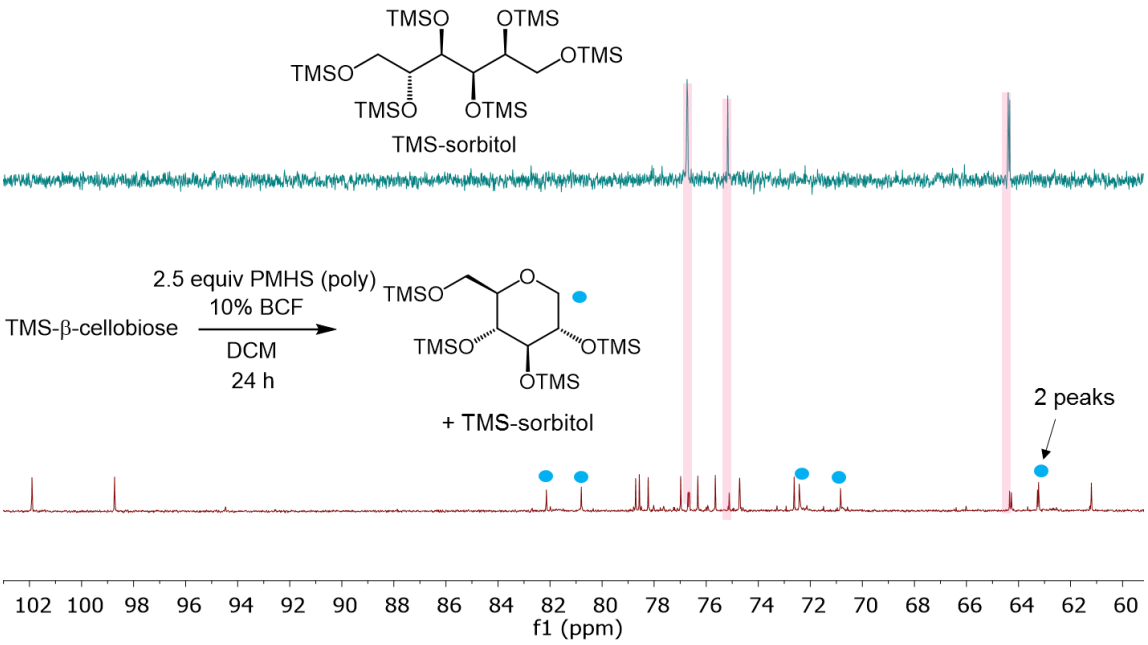
NMR Spectra for Reduction of TMS-D-glucose in Toluene



TMS-D-glucose is reduced to TMS-sorbitol **1** after 24 hours in d_8-toluene. When 2.3 equivalents of PMHS were used in the reaction, minor amounts of 1,4-anhydrosorbitol **2** were produced. When 3.5 equivalents of PMHS were used, increasing amounts of by-product are formed from over-reduction.

Reduction of TMS-cellobiose with 2.5 Equivalents of PMHS

$^{13}C\{^{1}H\}$ NMR spectra comparison (151 MHz, CD_2Cl_2)
In situ



Comparison between the $^{13}C\{^{1}H\}$ NMR spectrum of a TMS-sorbitol standard in d_2-DCM to the spectrum obtained from the reduction of TMS-cellobiose with 2.5 equivalents of polymeric PMHS under BCF catalysis. Peaks belonging to TMS-sorbitol are highlighted in pink (minor contribution). Resonances denoted with a blue circle belong to **10** and unlabeled peaks belong to TMS-cellobiose starting material.

References

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