Electronic Supplementary Material (ESI) for Green Chemistry.

Organic solvent- and catalyst-free Baeyer Villiger oxidation of levoglucosenone and dihydrolevoglucosenone (Cyrene®): a sustainable route to (*S*)-γ-hydroxymethyl-α,β-butenolide and (*S*)-γ-hydroxymethyl-γ-butyrolactone

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Electronic Supplementary Information (ESI)

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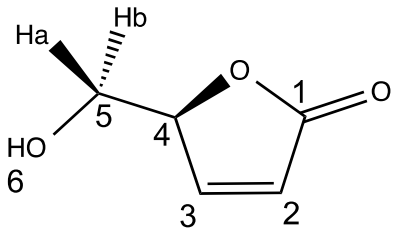
General organic solvent- and catalyst-free Baeyer Villiger oxidation procedure for HBO

An 30% aq. H_2O_2 solution (9.78 M, 0.81 L, 7.92 mol, 1 eq./**LGO**) was added dropwise over 3.5 hours under nitrogen to **LGO** (1 kg, 7.93 mol) cooled down with an ice bath. After completion of the addition, the reaction was warmed to 50 °C and stirred for an extra 20 hours. Presence of H_2O_2 was evaluated with peroxide strips and, if any, the residual H_2O_2 was quenched using the methods described in the manuscript. The reaction mixture was then concentrated in vacuo and the residue was distilled of (150 °C/0.7-0.9 mbar) to provide **HBO** as a clear oil that readily cristallyzes (71% yield).

Optimized kilo-scale organic solvent- and catalyst-free Baeyer Villiger oxidation procedure for HBO

An 30% aq. H_2O_2 solution (9.78 M, 0.81 L, 7.93 mol, 1 eq./**LGO**) was added dropwise over 4 hours under nitrogen to a solution of **LGO** (1 kg, 7.93 mol) in water (1 L) cooled down with an ice bath. After completion of the addition, the reaction was warmed to 50 °C and stirred for an extra 6 hours. Presence of H_2O_2 was evaluated with peroxide strips and, if any, the residual H_2O_2 was quenched using the methods described in the manuscript. The reaction mixture was then concentrated in vacuo and the residue was distilled of (150 °C/0.7-0.9 mbar) to provide **HBO** as a clear oil that readily cristallyzes (71% yield).

Analytical data for HBO



R_f = 0.24 (20/80 cyclohexane/ethyl acetate), light brown spot

FT-IR (neat, cm^{-1}): 3423 (OH), 1728 (C=O), 1329, 1162, 1050

UV (EtOH, nm): 221

$[\alpha]_D^{20}$ -112.0 (*c* 0.01, $CHCl_3$). [(Lit. -114.5 (*c* 0.1, $CHCl_3$)]

^{1}H NMR ($CDCl_3$, 300 MHz): δ_H 3.25 (s, 1H, H_6), 3.79 (dd, 1H, *J* = 12 and 3.6 Hz, H_{5a}), 3.99 (d, 1H, *J* = 12 Hz, H_{5b}), 5.17 (m, 1H, H_4), 6.20 (dd, 1H, *J* = 5.7 and 1.8 Hz, H_2), 7.53 (dd, 1H, *J* = 5.7 and 1.5 Hz, H_3).

^{13}C NMR ($CDCl_3$, 75 MHz): δ_C 62.2 (t, C_1), 84.3 (d, C_4), 122.8 (d, C_2), 154.0 (d, C_3), 173.5 (s, C_1)

HRMS: *m/z* [M+H]+ calcd for $C_5H_6O_3$: 115.0395, found: 115.0396

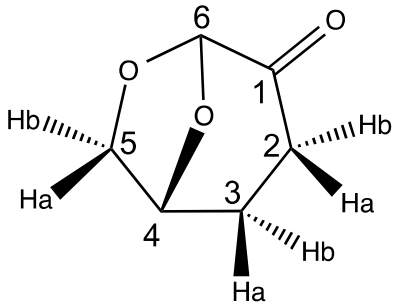
HPLC method for HBO production monitoring

HPLC analyses were performed on a Thermofisher Ultimate 3000 equipped with a DAD detector (220 nm) and a Thermoscientific Syncronis aQ (250 x 4.6 mm, 5µm) column. Samples were prepared by diluting 10 µL of reaction mixture in 1.5 mL of acetonitrile. Following conditions were applied: injection 10 µL, oven temperature 30 °C, flow 0.8 mL/min, elution method (water/acetonitrile): 0-5 min isocratic 85/15, 5-10 min from 85/15 to 90/10, 10-15 min isocratic 90/10, 15-20 min 90/10 to 85/15. Retention times: t_r(LGO) = 7.91 min, t_r(HBO) = 3.66 min, t_r(FBO) = 6.23 min.

Palladium-catalyzed hydrogenation of LGO into 2H-LGO

10% Pd/C (10% w/w, 500 mg) was added to a solution of (-)-Levoglucosenone **LGO** (5 g, 39.7 mmol) in ethyl acetate (50 mL, C = 0.8 M) at rt. The stirred suspension was degassed 3 times and put under nitrogen. The suspension was then hydrogenated under hydrogen atmosphere at rt until TLC showed complete consumption of starting material. The crude mixture was filtered over a pad of Celite® and the filtrate was

concentrated to dryness with silica gel. The crude product was purified by silica gel chromatography (elution with 10 to 60% ethyl acetate in cyclohexane) to yield pure **2H-LGO** (colorless oil, 4.4 g, 87%)



R_f = 0.64 (20/80 cyclohexane/ethyl acetate), violet spot

FT-IR (neat, cm^{-1}): 2965, 1739 (C=O), 1418, 1285, 1108

UV (EtOH, nm): 308, 211

$[\alpha]_D^{20}$ -253.6 (*c* 0.01, $CHCl_3$)

^1H NMR ($CDCl_3$, 300 MHz): δ_H 2.02 (m, 1H, H_{3b}), 2.34 (m, 2H, $H_{2b,3a}$), 2.62 (m, 1H, H_{2a}), 4.00 (m, 2H, $H_{5a,4}$), 4.70 (m, 1H, H_{5b}), 5.10 (s, 1H, H_6).

^{13}C NMR ($CDCl_3$, 75 MHz): δ_C 29.9 (t, C_3), 31.1 (t, C_2), 67.5 (t, C_5), 73.1 (d, C_4), 101.5 (d, C_6), 200.3 (s, C_1).

HRMS: *m/z* [M+H]+ calcd for $C_6H_9O_3$: 129.0552, found: 129.0553

Palladium-catalyzed hydrogenation of HBO into 2H-HBO

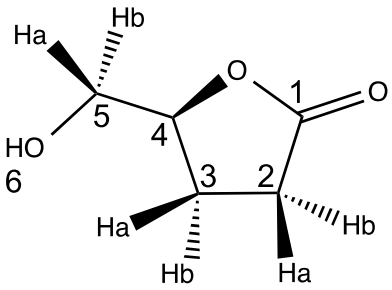
10% Pd/C (10% w/w, 250 mg) was added to a solution of **HBO** (1.4 g, 12.3 mmol) in ethyl acetate (15 mL, C = 0.8 M) at rt. The stirred suspension was degassed 3 times and put under nitrogen. The suspension was then hydrogenated under hydrogen atmosphere at rt until TLC showed complete consumption of starting material. The crude mixture was filtered over a pad of Celite® and the filtrate was concentrated to

dryness with silica gel. The crude product was purified by silica gel chromatography (elution with 100% ethyl acetate) to yield pure **2H-HBO** (1.26 g, 87%).

Optimized kilo-scale organic solvent- and catalyst-free Baeyer Villiger oxidation procedure for 2H-HBO

An 30% aq. H_2O_2 solution (9.78 M, 0.81 L, 7.92 mol, 1 eq./**2H-LGO**) was added dropwise over 4 hours under nitrogen to a solution of **2H-LGO** (844 g, 7.93 mol) in water (1L) cooled down with an ice bath. After completion of the addition, the reaction was warmed to 50 °C and stirred for an extra 6 hours. Presence of H_2O_2 was evaluated with peroxide strips and, if any, the residual H_2O_2 was quenched using the methods described in the manuscript. The reaction mixture was then concentrated in vacuo and the residue was distilled of (150 °C/0.7-0.9 mbar) to provide **2H-HBO** as a clear oil that readily cristallyzes (72% yield).

Analytical data for 2H-HBO



R_f = 0.27 (20/80 cyclohexane/ethyl acetate), black spot

FT-IR (neat, cm^{-1}): 3420 (OH), 2938, 1752 (C=O), 1353, 1181

UV (EtOH, nm): 207

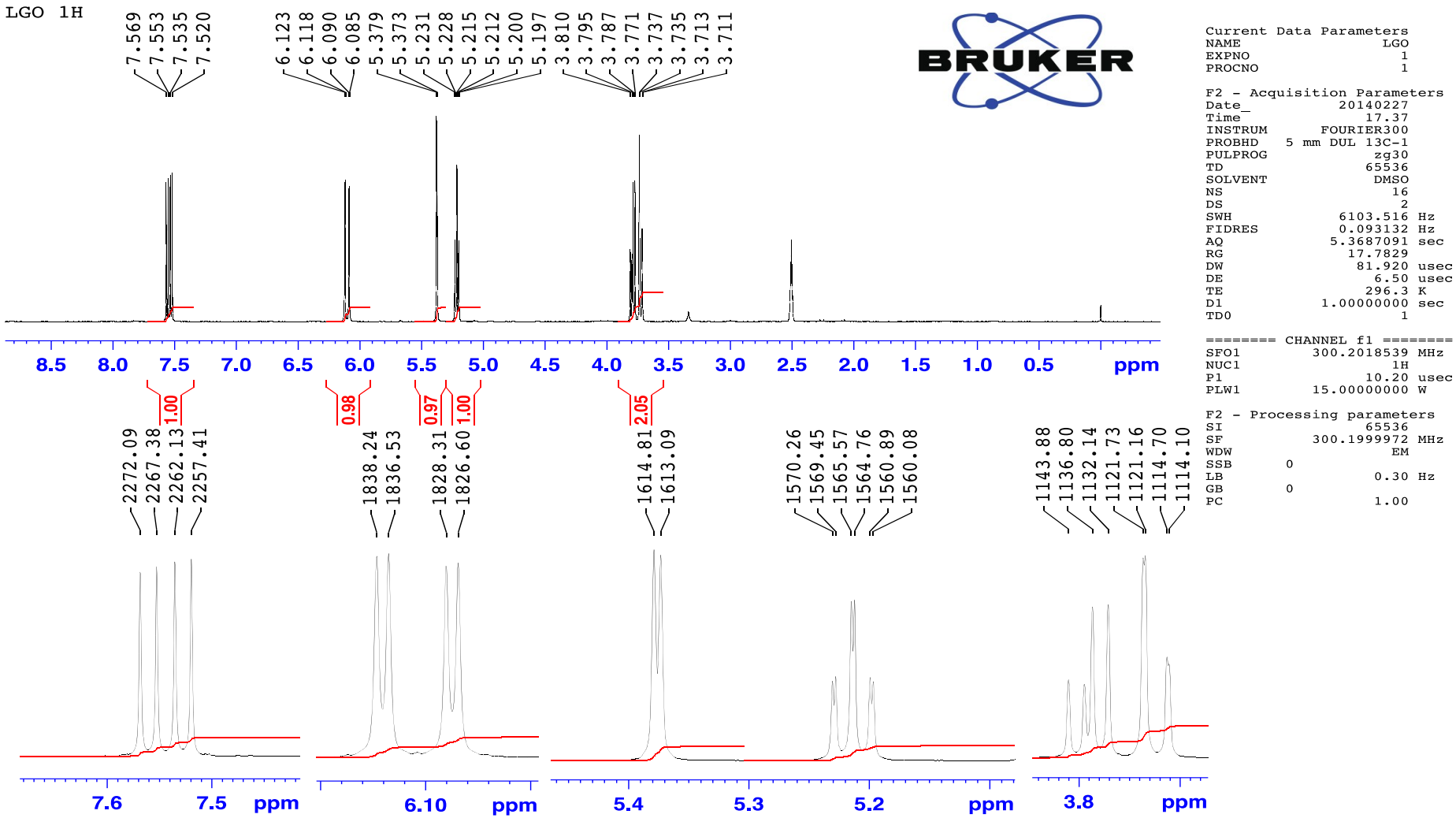
$[\alpha]_D^{20}$ +52.9 (*c* 0.01, $CHCl_3$). [(Lit.[24] +55.2 (*c* 0.1, $CHCl_3$)]

^{1}H NMR ($CDCl_3$, 300 MHz): δ_H 2.20 (m, 2H, H_3), 2.61 (m, 3H, $H_{2,6}$), 3.66 (dd, 1H, *J* = 12.6 and 4.5 Hz, H_{5a}), 3.92 (dd, 1H, *J* = 12.6 and 2.7 Hz, H_{5b}), 4.64 (m, 1H, H_4)

^{13}C NMR ($CDCl_3$, 75 MHz): δ_C 23.1 (t, C_2), 28.7 (t, C_3), 64.1 (t, C_5), 80.8 (d, C_4), 177.7 (s, C_1)

HRMS: *m/z* [M+Na]+ calcd for $C_5H_8NaO_3$: 139.0371, found: 139.0379

^{1}H NMR spectrum of industrial grade levoglucosenone (LGO)

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FIDRES          0.093132 Hz
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TE                 296.3 K
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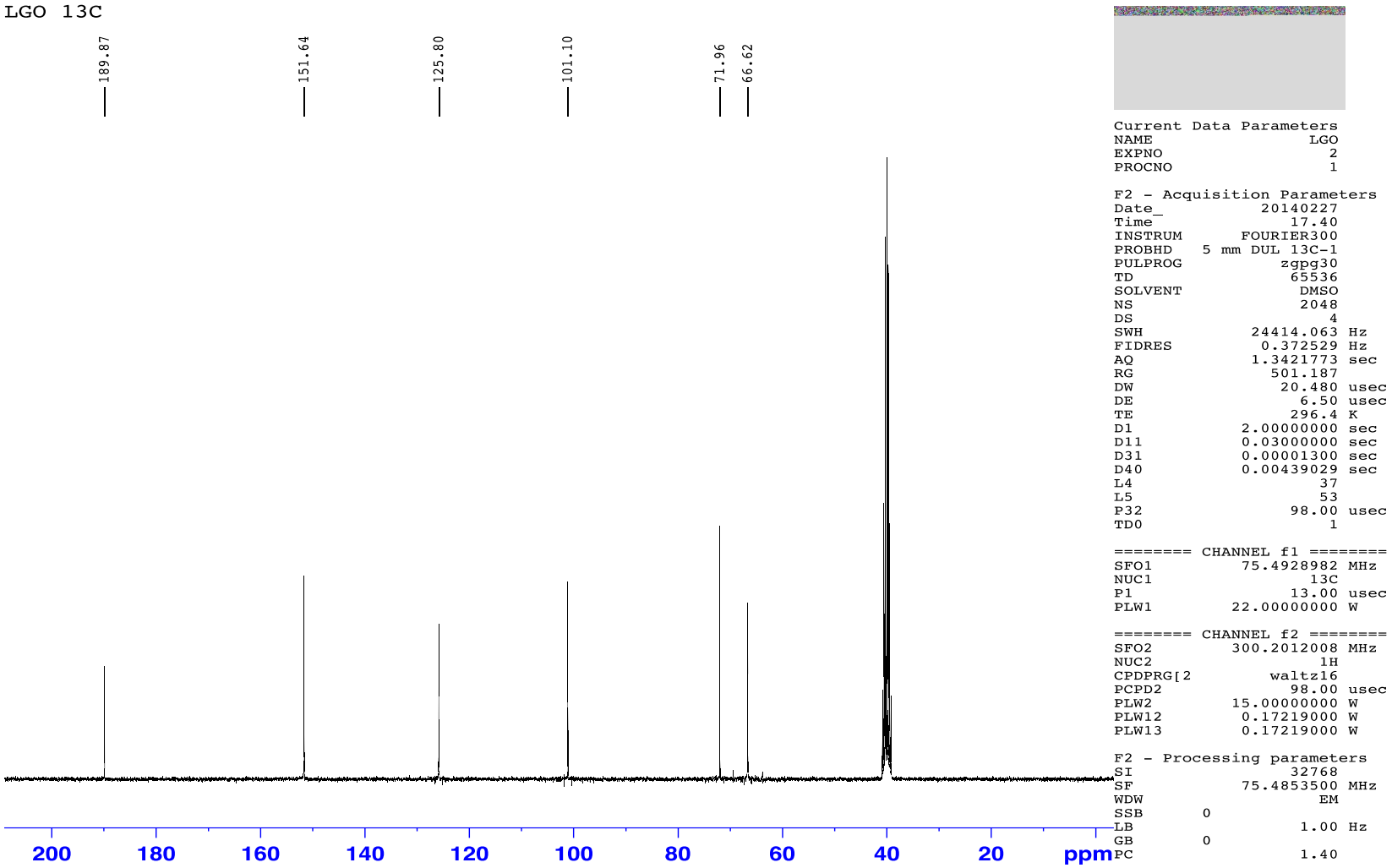
^{13}C NMR spectrum of industrial grade levoglucosenone (LGO)

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PLW13         0.17219000 W

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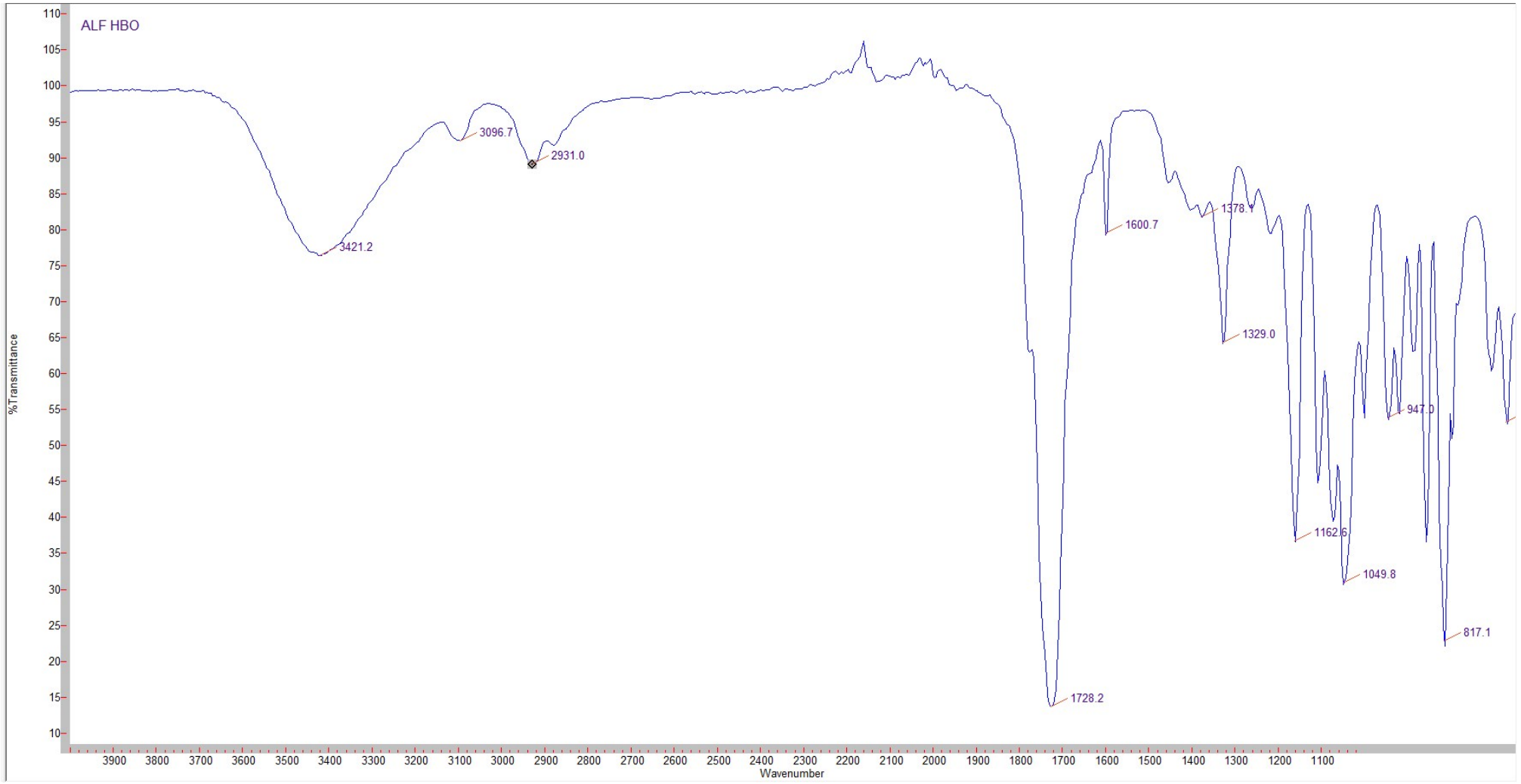
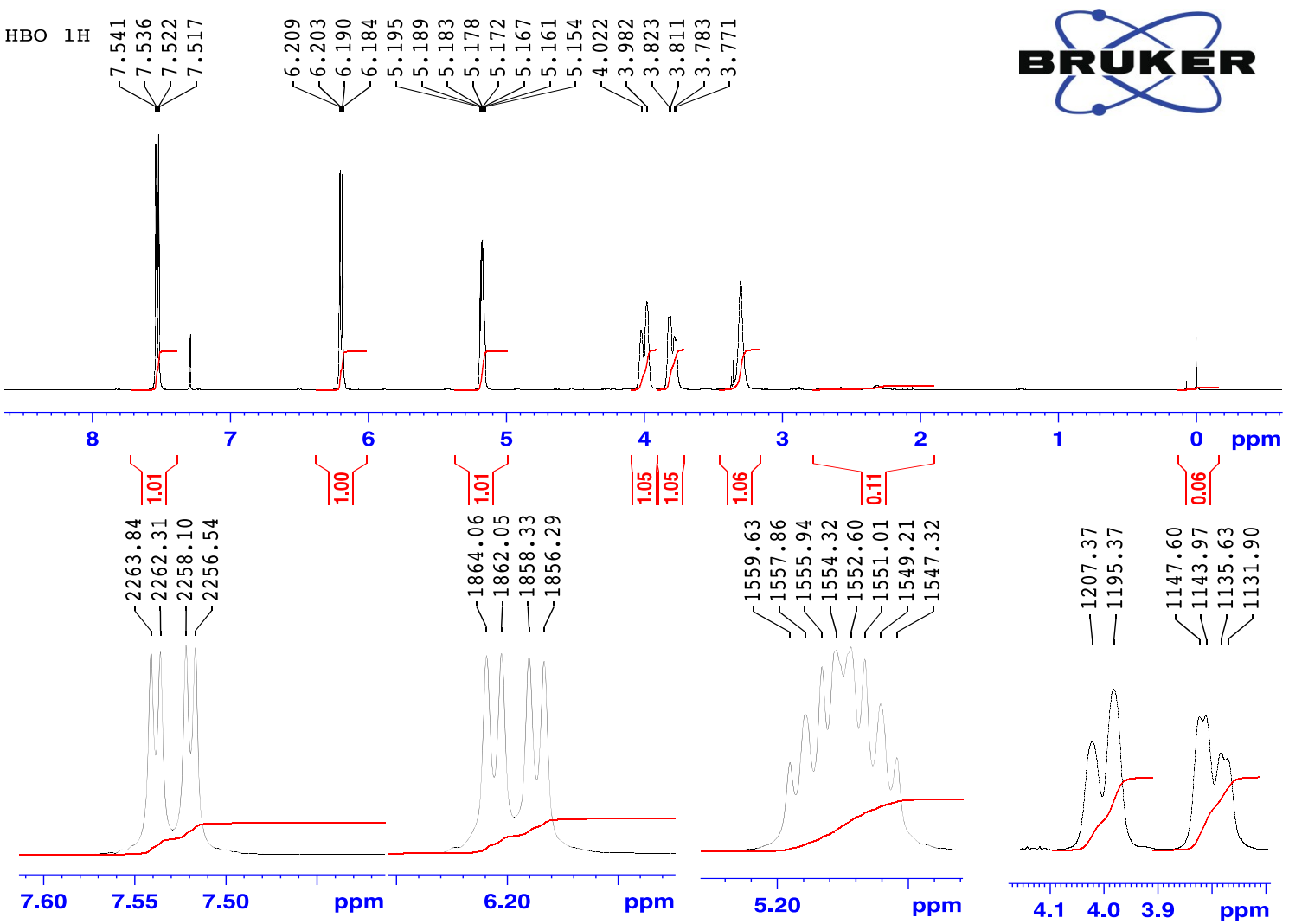
FT-IR spectrum of (*S*)-γ-hydroxymethyl-α,β-butenolide (HBO)



^{1}H NMR spectrum of (*S*)-γ-hydroxymethyl-α,β-butenolide (HBO)

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NS                    16
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FIDRES             0.093132 Hz
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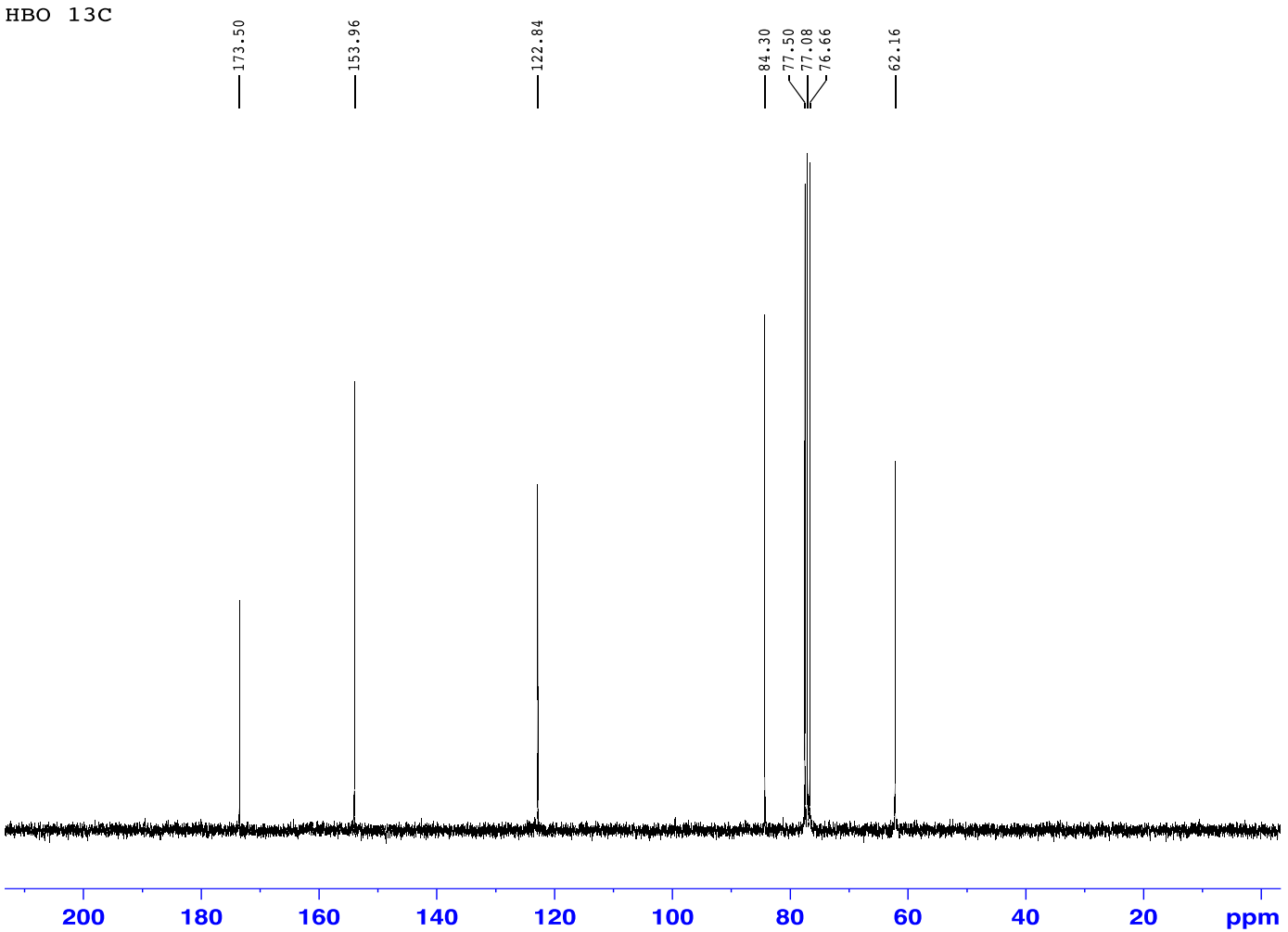
^{13}C NMR spectrum of (*S*)-γ-hydroxymethyl-α,β-butenolide (HBO)

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NS                  512
DS                    4
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RG               501.187
DW                20.480 usec
DE                 6.50 usec
TE                297.3 K
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D11           0.03000000 sec
D31           0.00001300 sec
D40           0.00439029 sec
L4                   37
L5                   53
P32               98.00 usec
TD0                   1

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PLW1        22.00000000 W

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WDW                   EM
SSB       0
LB                 1.00 Hz
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PC                 1.40
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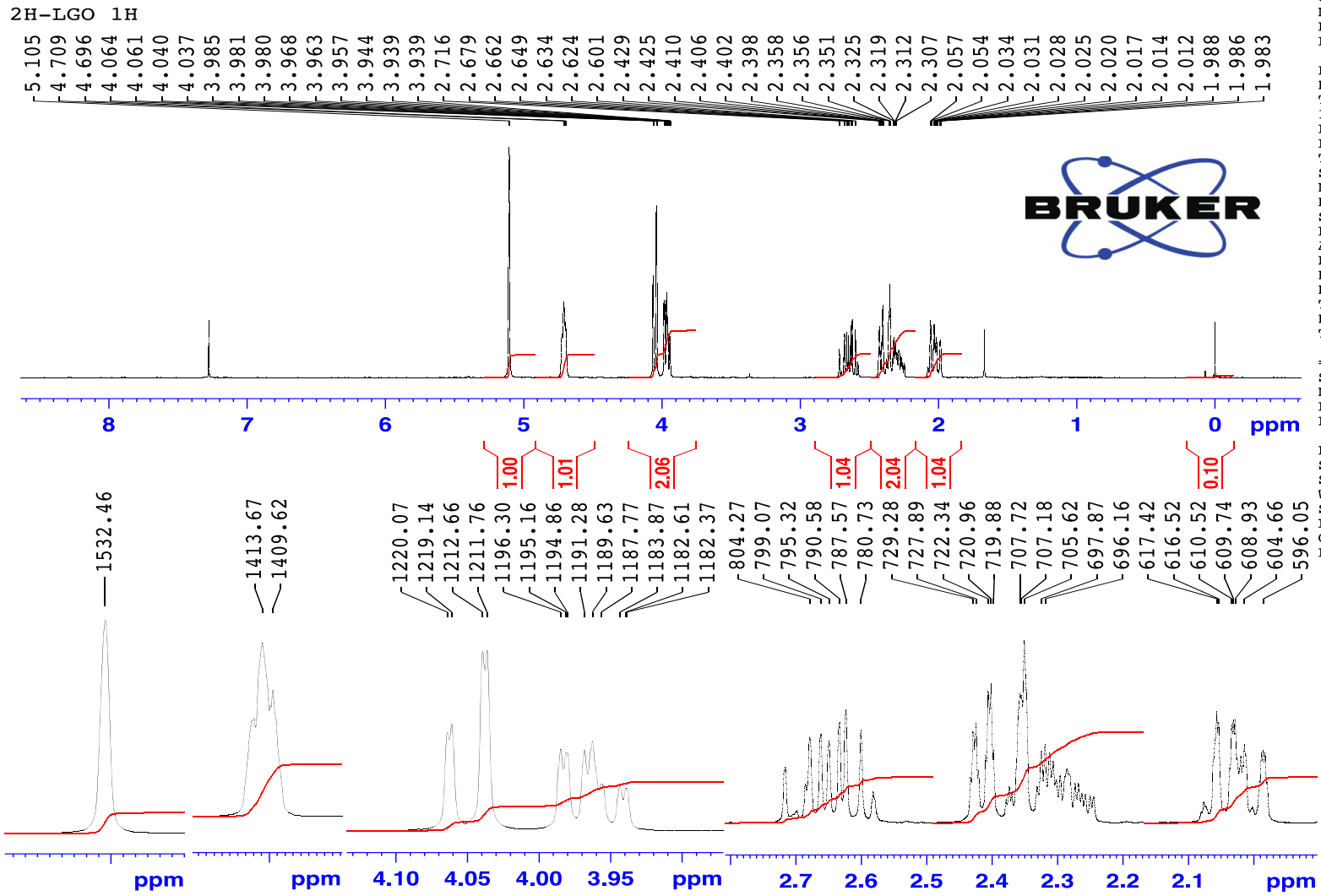
FT-IR spectrum of 2,3-dehydro levoglucosenone (2H-LGO)

^{1}H NMR spectrum of 2,3-dehydro levoglucosenone (2H-LGO)

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PROCNO                 1

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TE               297.1 K
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NUC1                   1H
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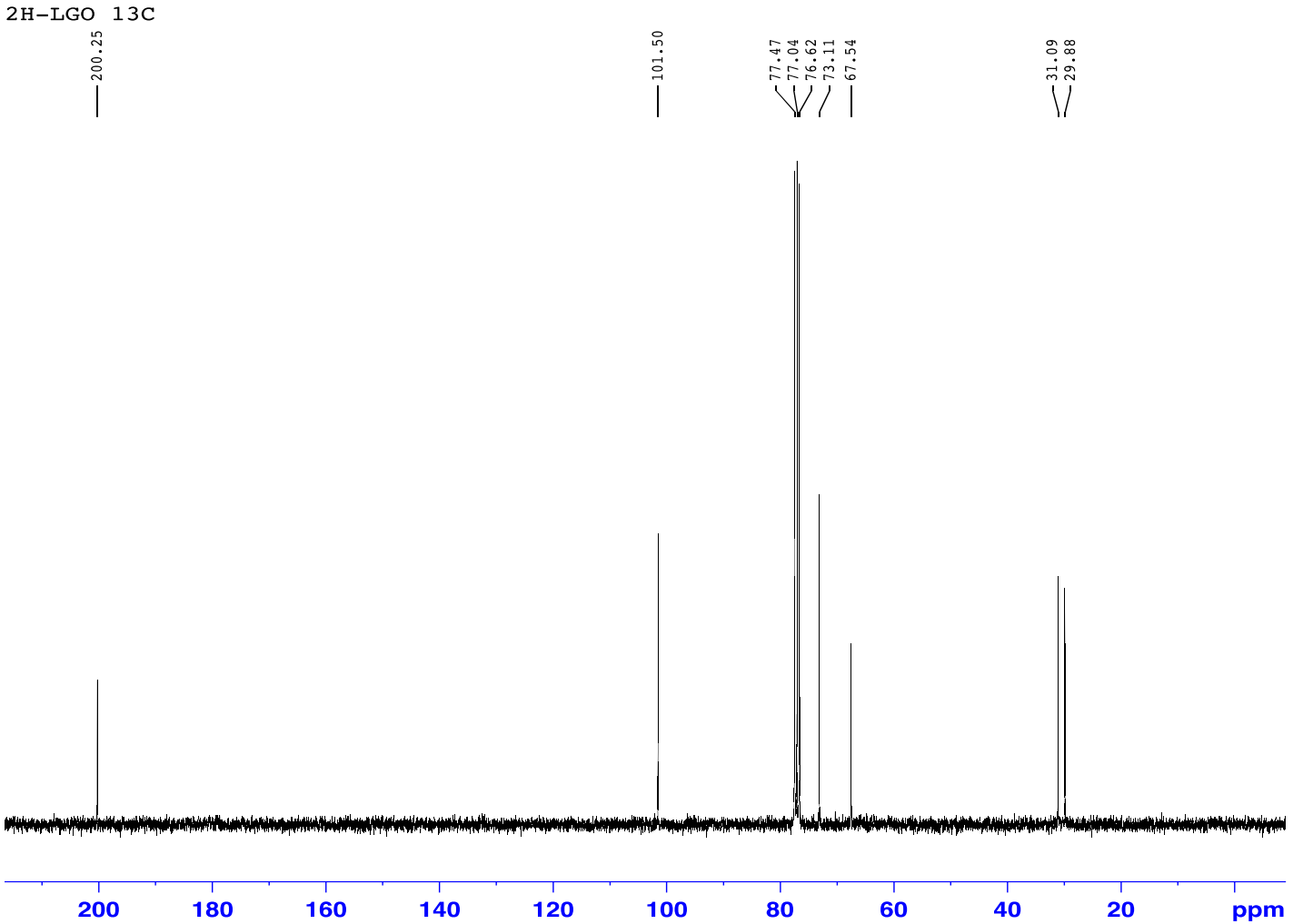
^{13}C NMR spectrum of 2,3-dehydro levoglucosenone (2H-LGO)

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NUC1                  13C
P1                  13.00 usec
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PLW12         0.17219000 W
PLW13         0.17219000 W

F2 - Processing parameters
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WDW                    EM
SSB       0
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GB        0
PC                  1.40
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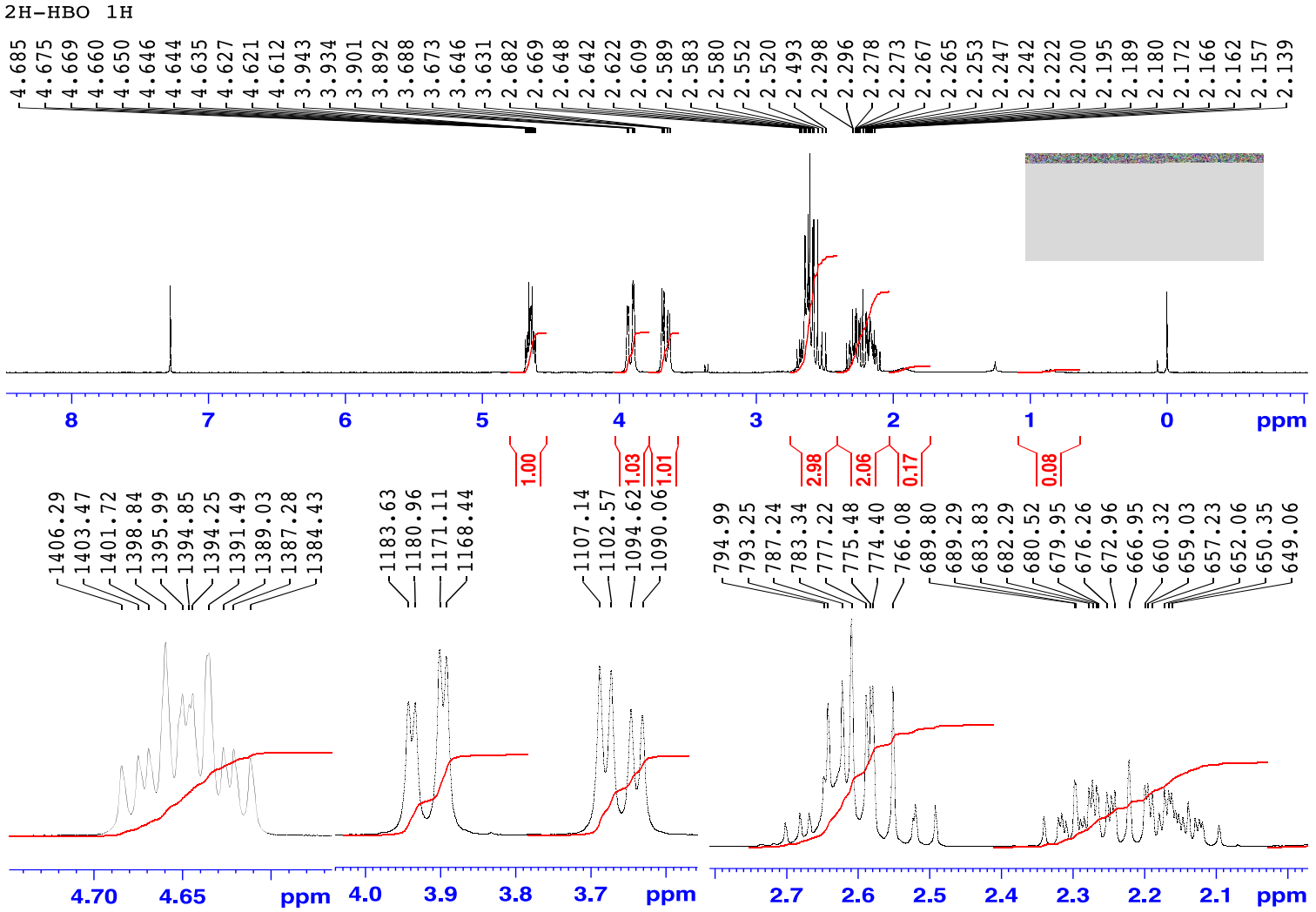
FT-IR spectrum of (*S*)-γ-hydroxymethyl-γ-butyrolactone (2H-HBO)

^{1}H NMR spectrum of (*S*)-γ-hydroxymethyl-γ-butyrolactone (2H-HBO)

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RG               25.1803
DW                81.920 usec
DE                 6.50 usec
TE                294.6 K
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TD0                   1

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NUC1                 1H
P1                10.20 usec
PLW1         15.00000000 W

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WDW                  EM
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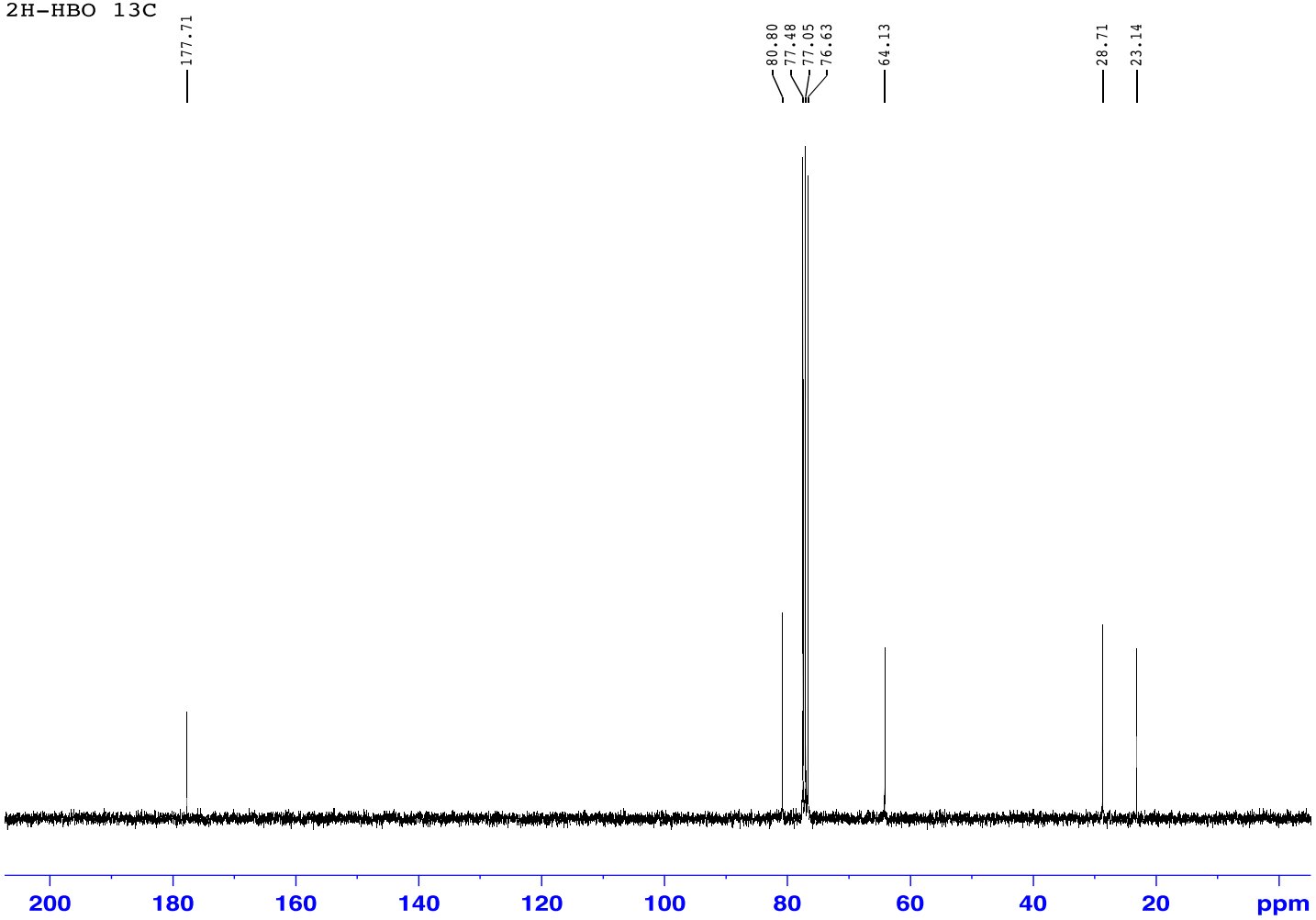
^{13}C NMR spectrum of (*S*)-γ-hydroxymethyl-γ-butyrolactone (2H-HBO)

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PROCNO                  1

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RG               501.187
DW                20.480 usec
DE                 6.50 usec
TE                294.6 K
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D31            0.00001300 sec
D40            0.00439029 sec
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L5                    53
P32                98.00 usec
TD0                    1

======== CHANNEL f1 ========
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NUC1                 13C
P1                13.00 usec
PLW1         22.00000000 W

======== CHANNEL f2 ========
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NUC2                 1H
CPDPRG[2          waltz16
PCPD2             98.00 usec
PLW2         15.00000000 W
PLW12         0.17219000 W
PLW13         0.17219000 W

F2 - Processing parameters
SI                 32768
SF            75.4853500 MHz
WDW                  EM
SSB       0
LB                1.00 Hz
GB        0
PC                1.40
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