Electronic Supplementary Material (ESI) for Organic & Biomolecular Chemistry.

Synthesis of β-lactams *via* diastereoselective, intramolecular Kinugasa reactions

Oskar Popik, Barbara Grzeszczyk, Olga Staszewska-Krajewska, Bartłomiej Furman and Marek Chmielewski*

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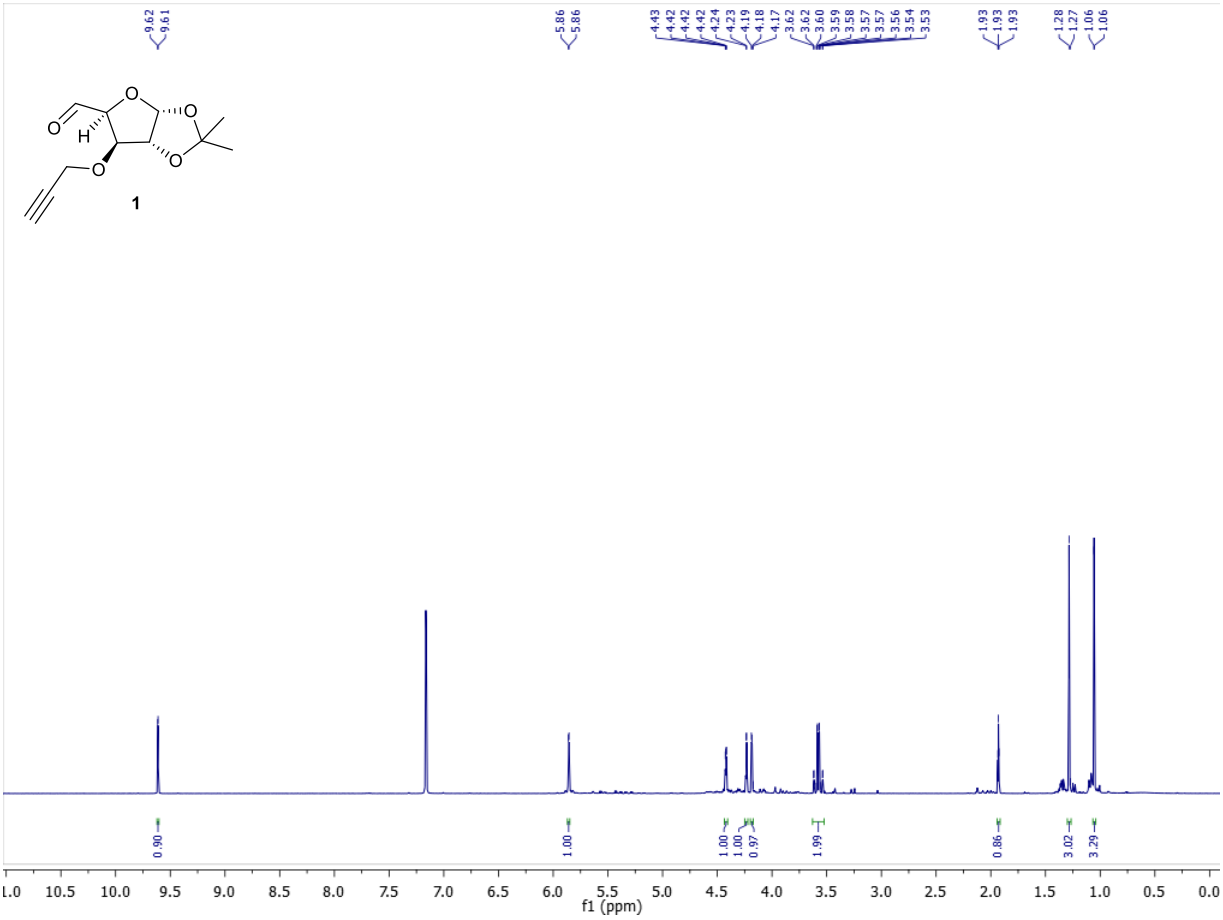
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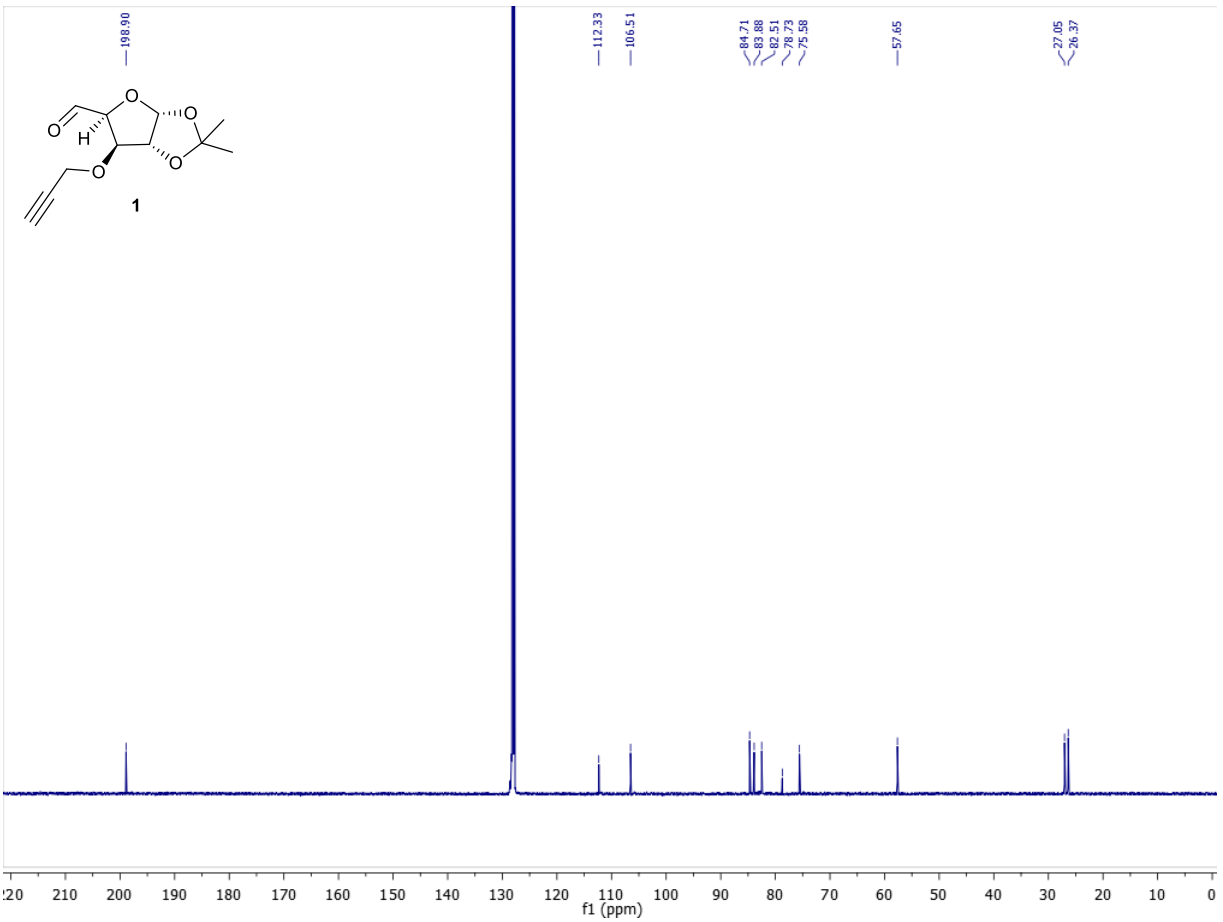
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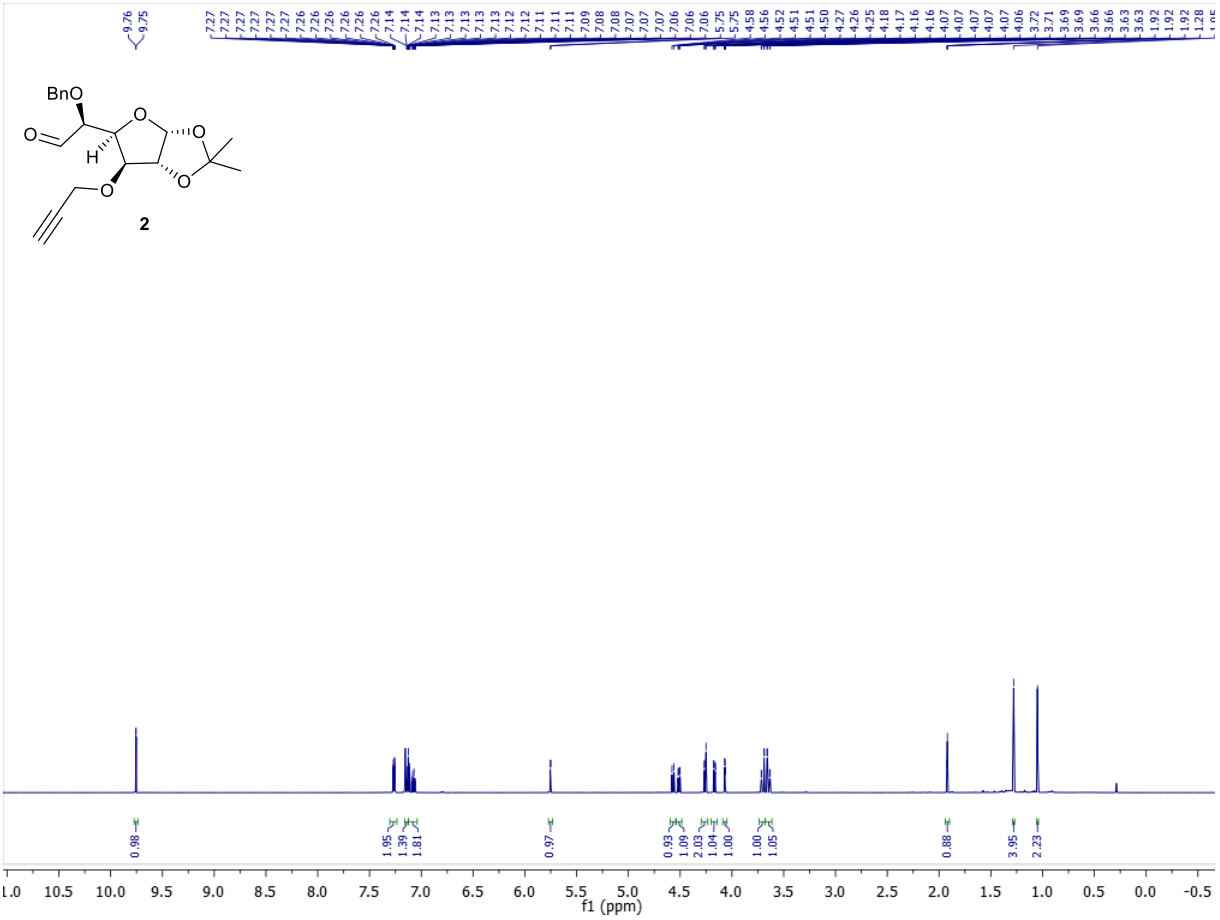
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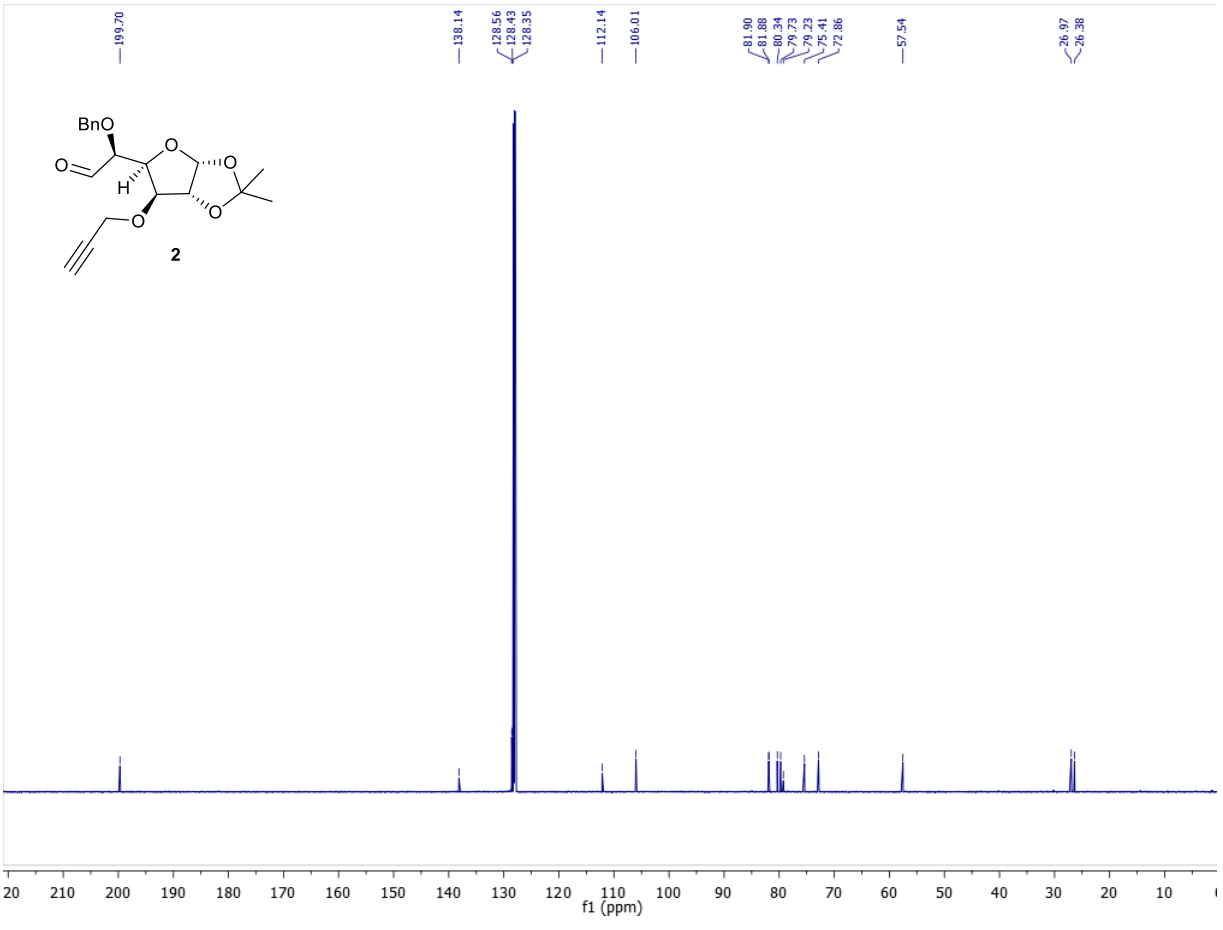
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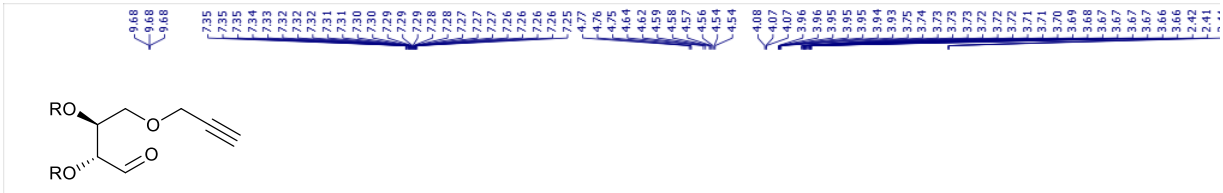

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RO
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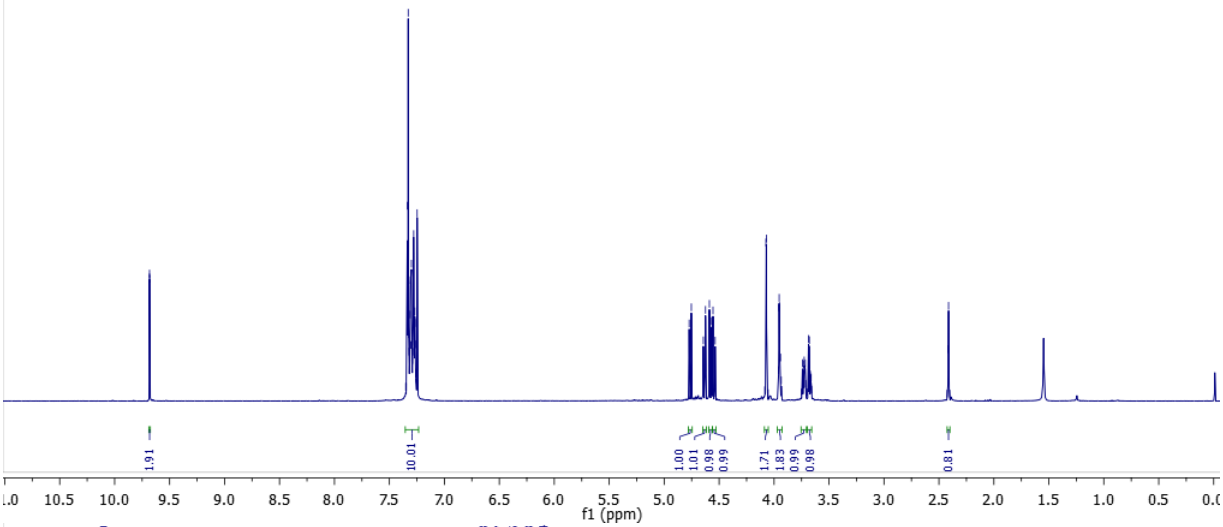
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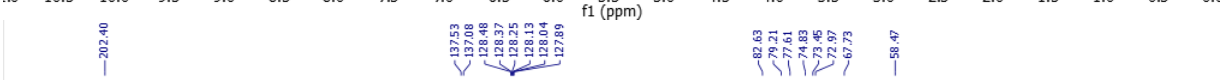
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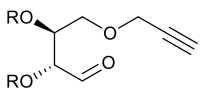
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RO
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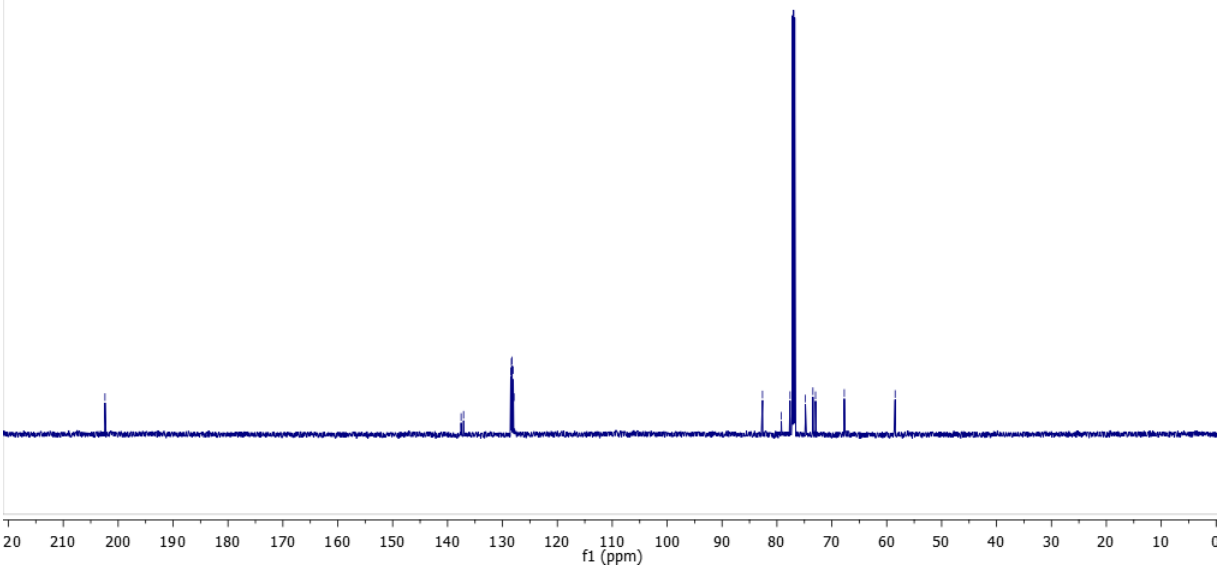
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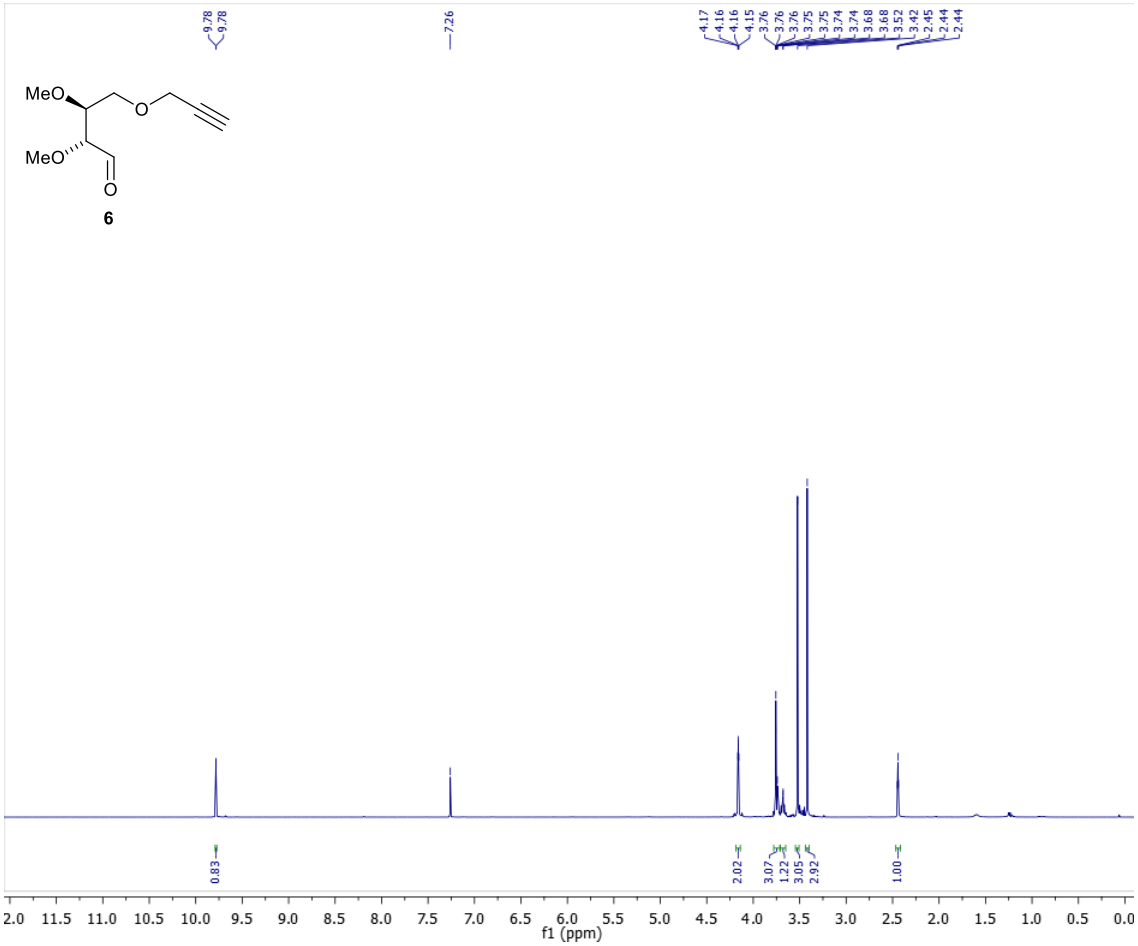
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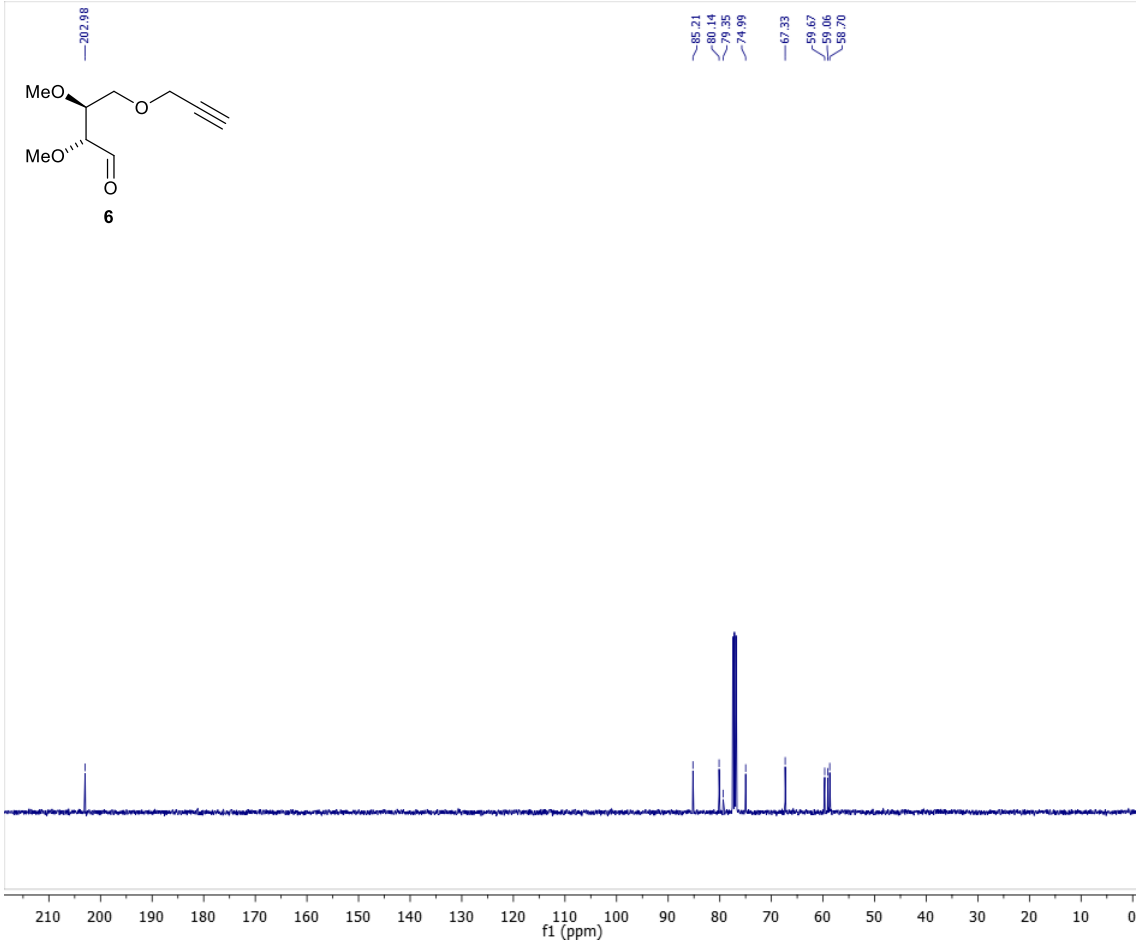
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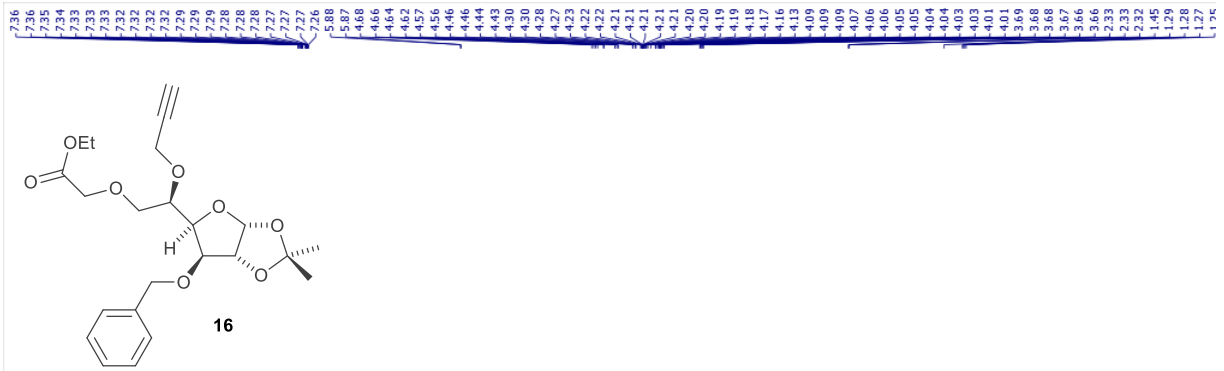
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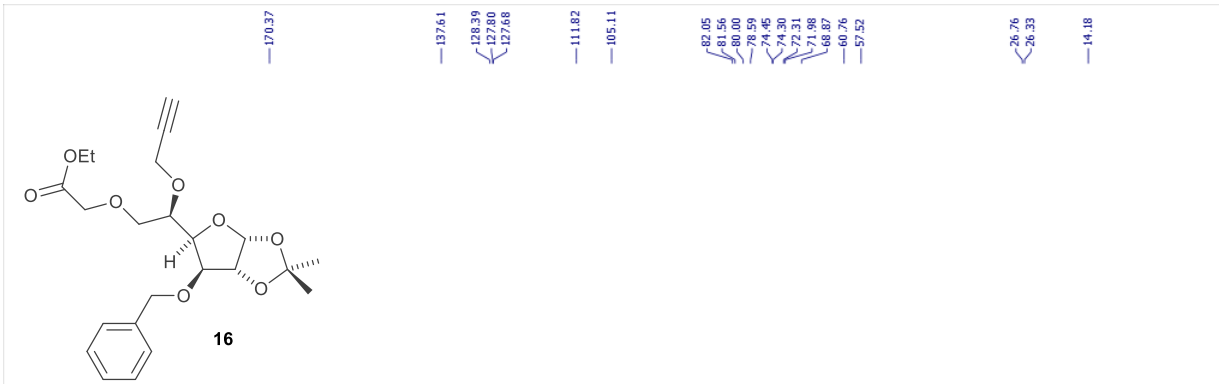
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O
O
O
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H
O
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82.05
81.56
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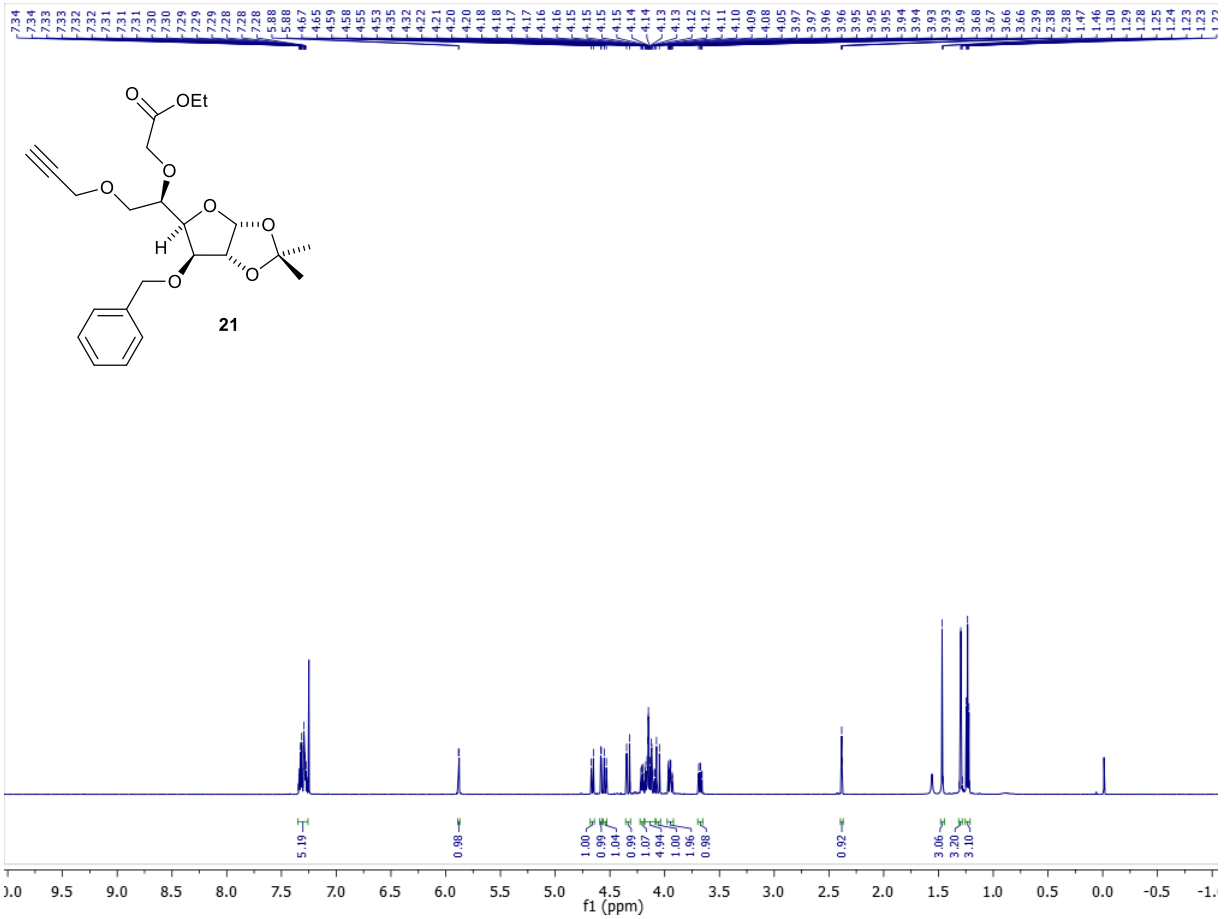
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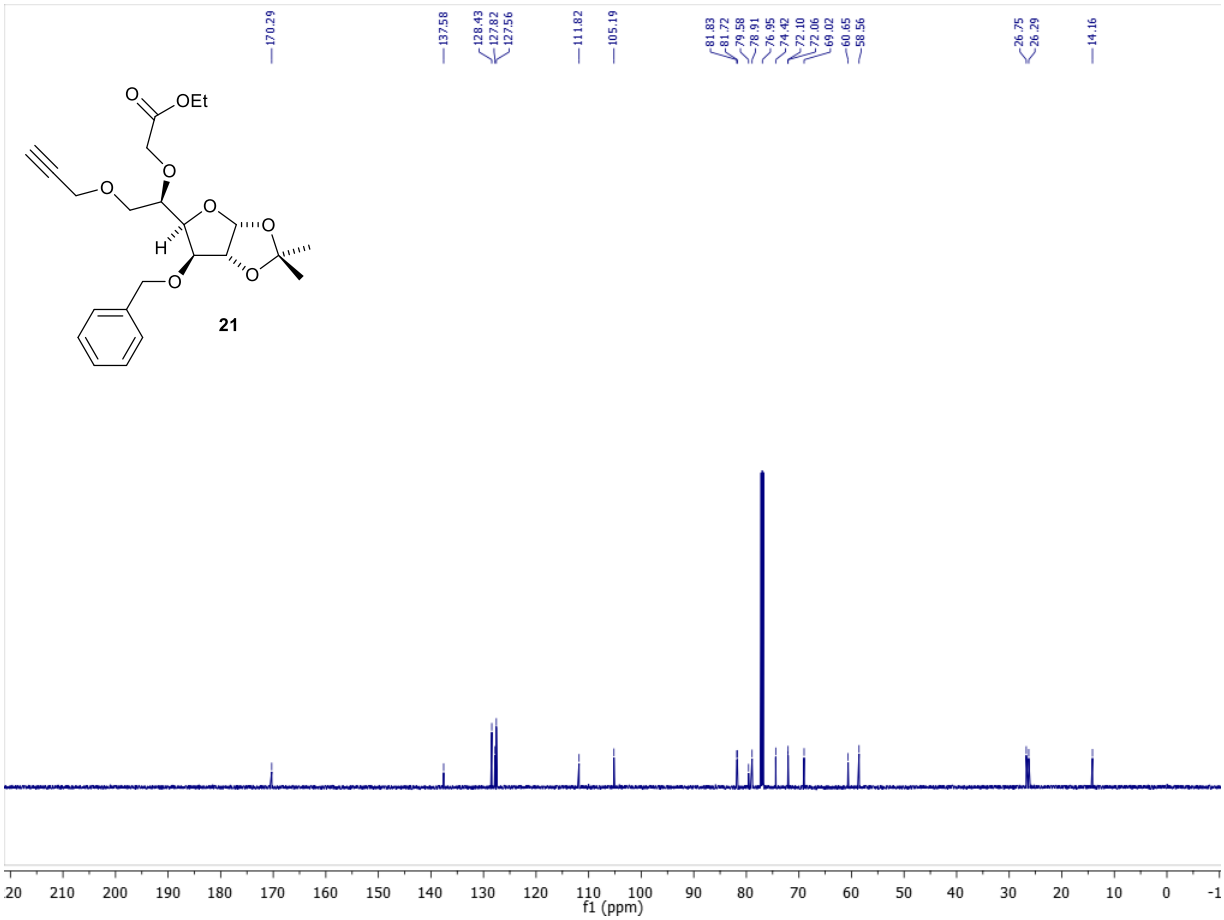
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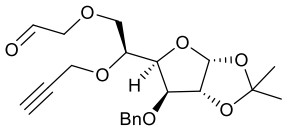
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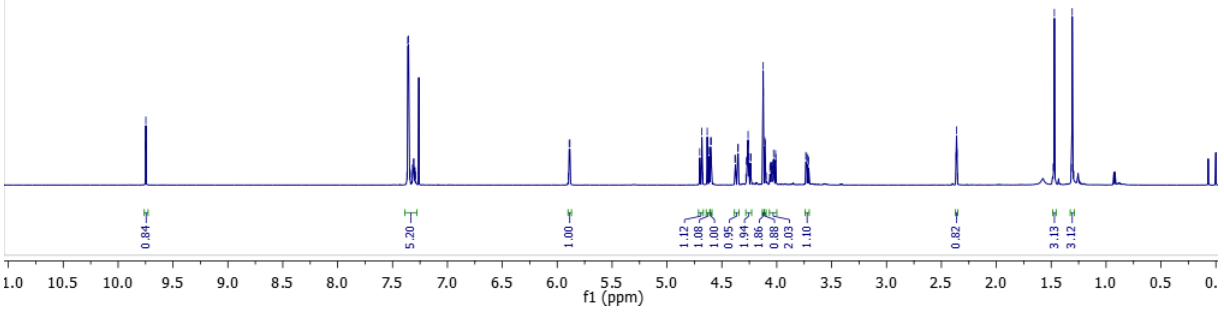
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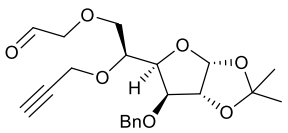
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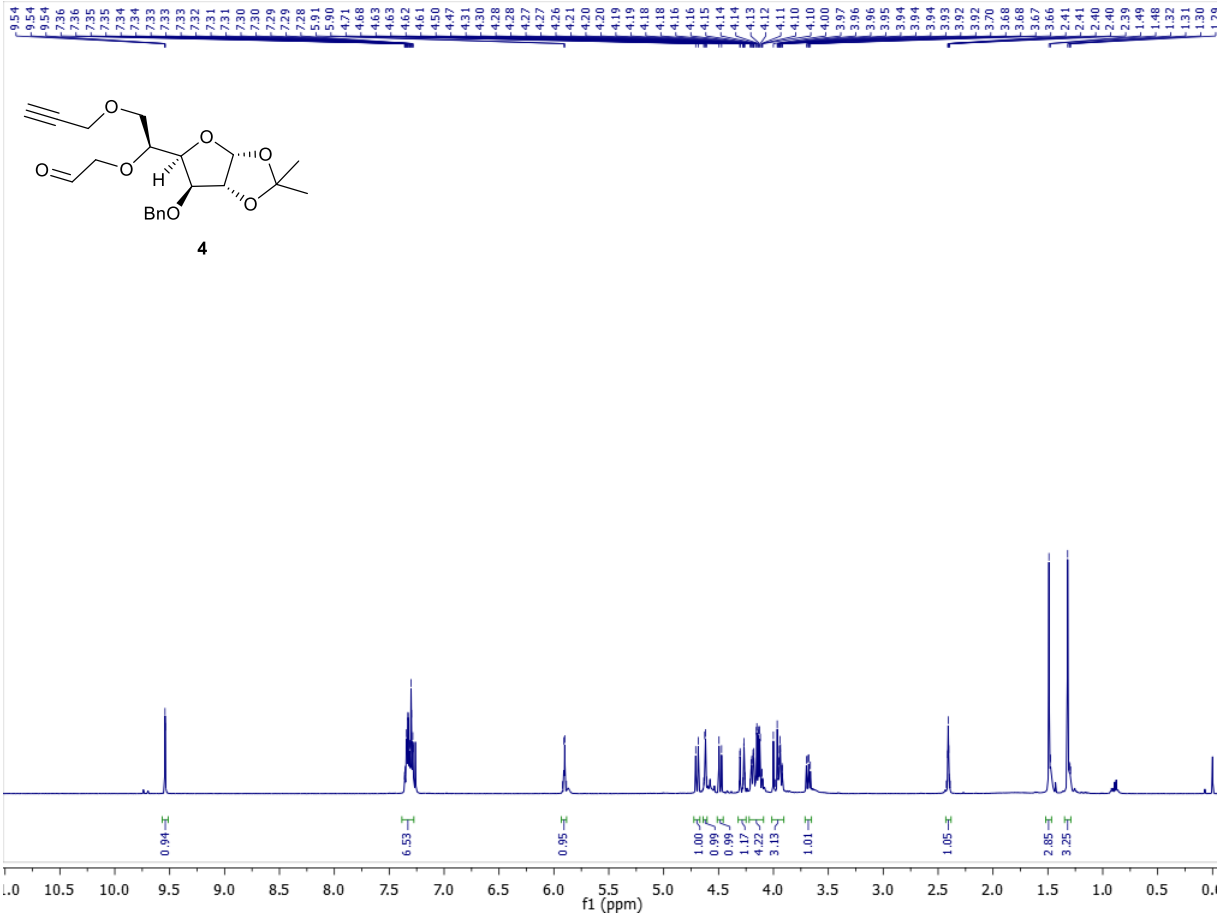
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O
O
O
O
O
H
BnO
O
O
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4.22
3.13
1.01
1.05
2.85
3.25
f1 (ppm)
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127.76
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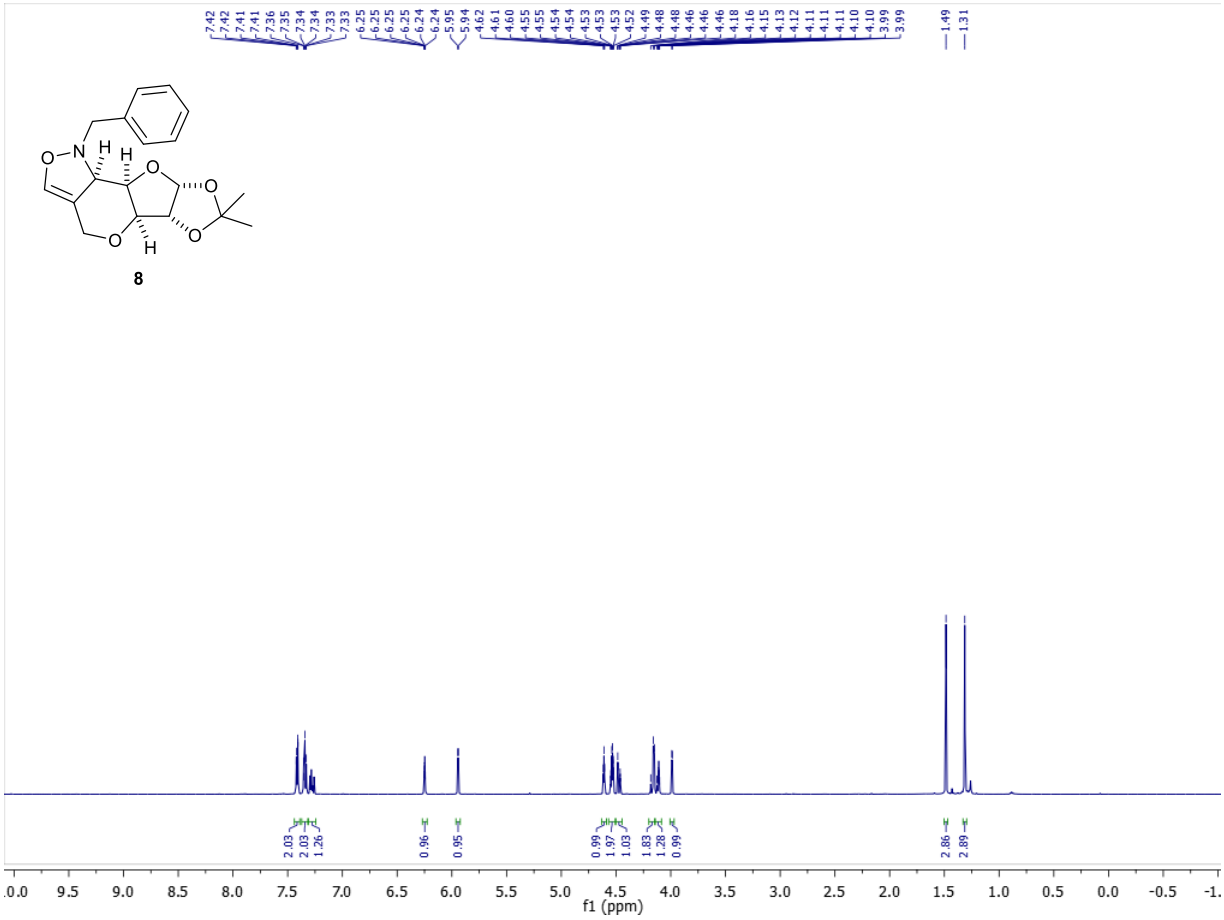
f1 (ppm)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4.11
4.10
4.10
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3.99
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1.31
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2.03
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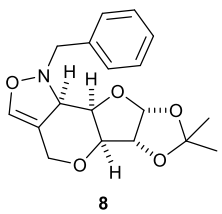

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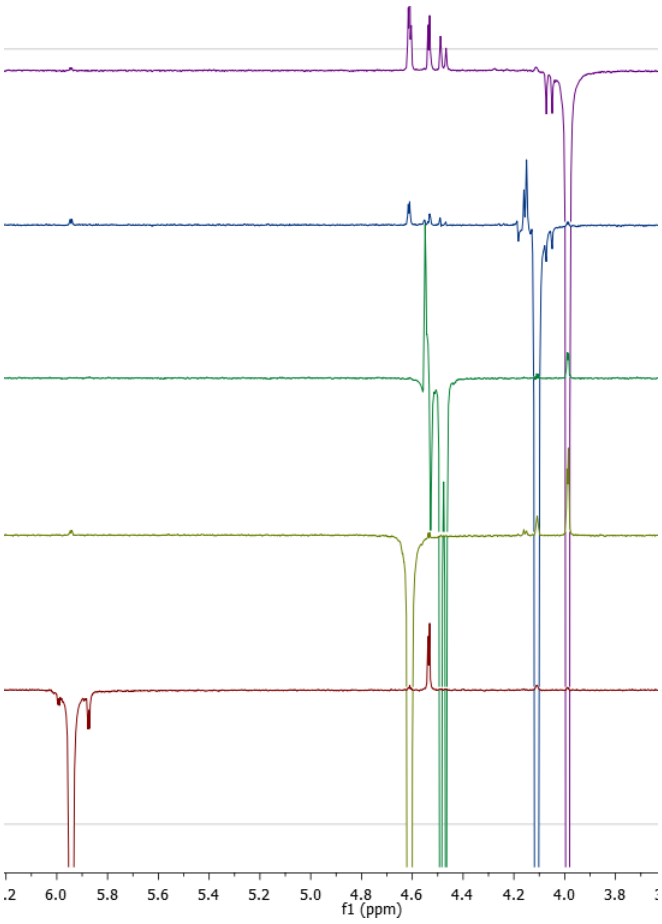

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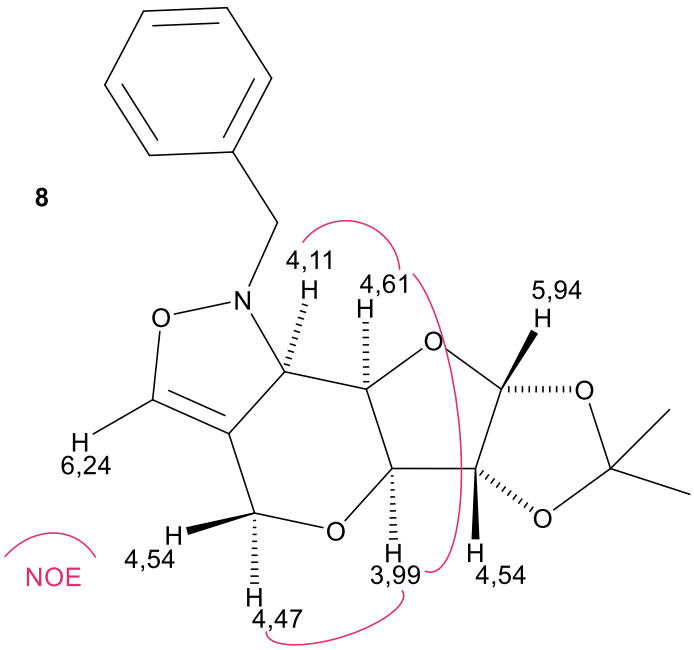

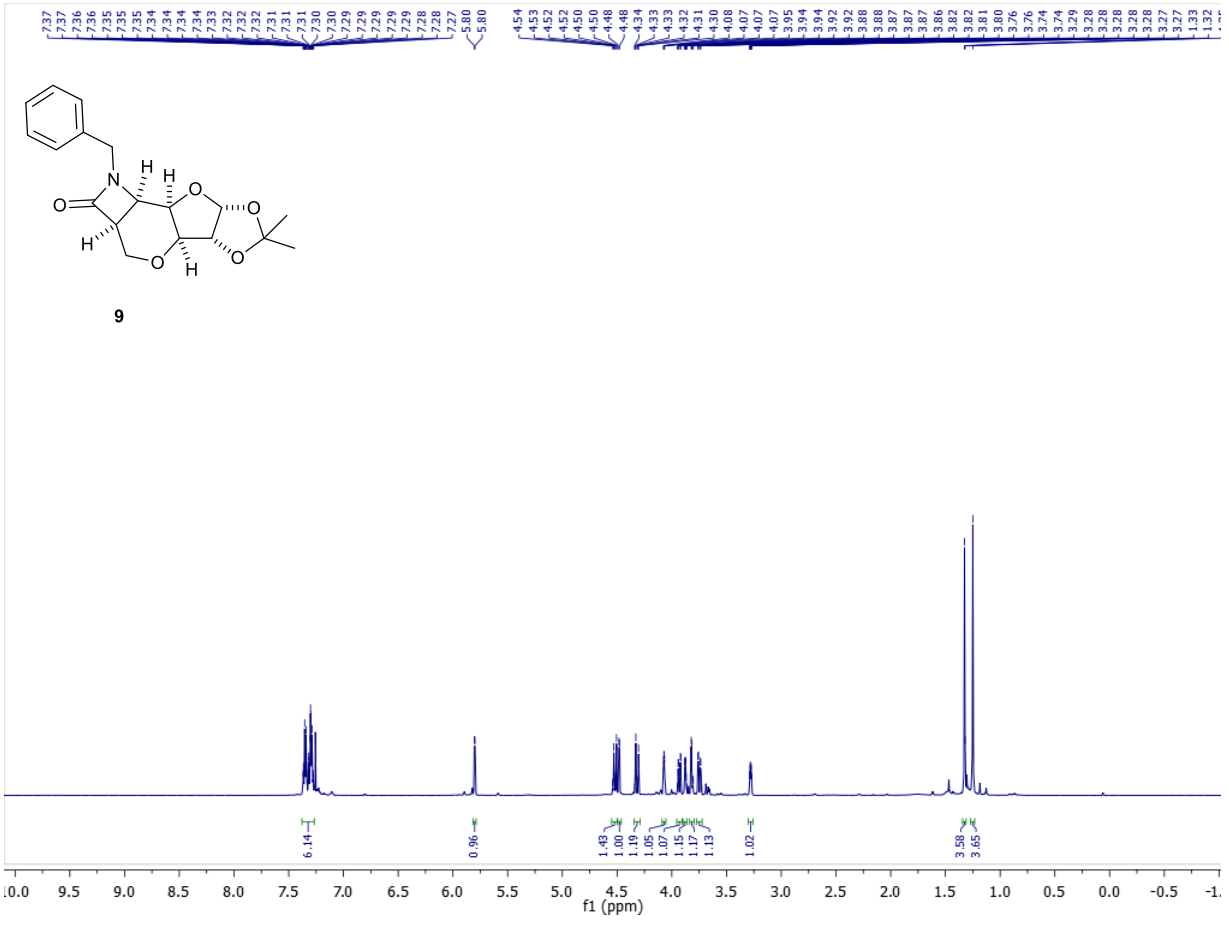
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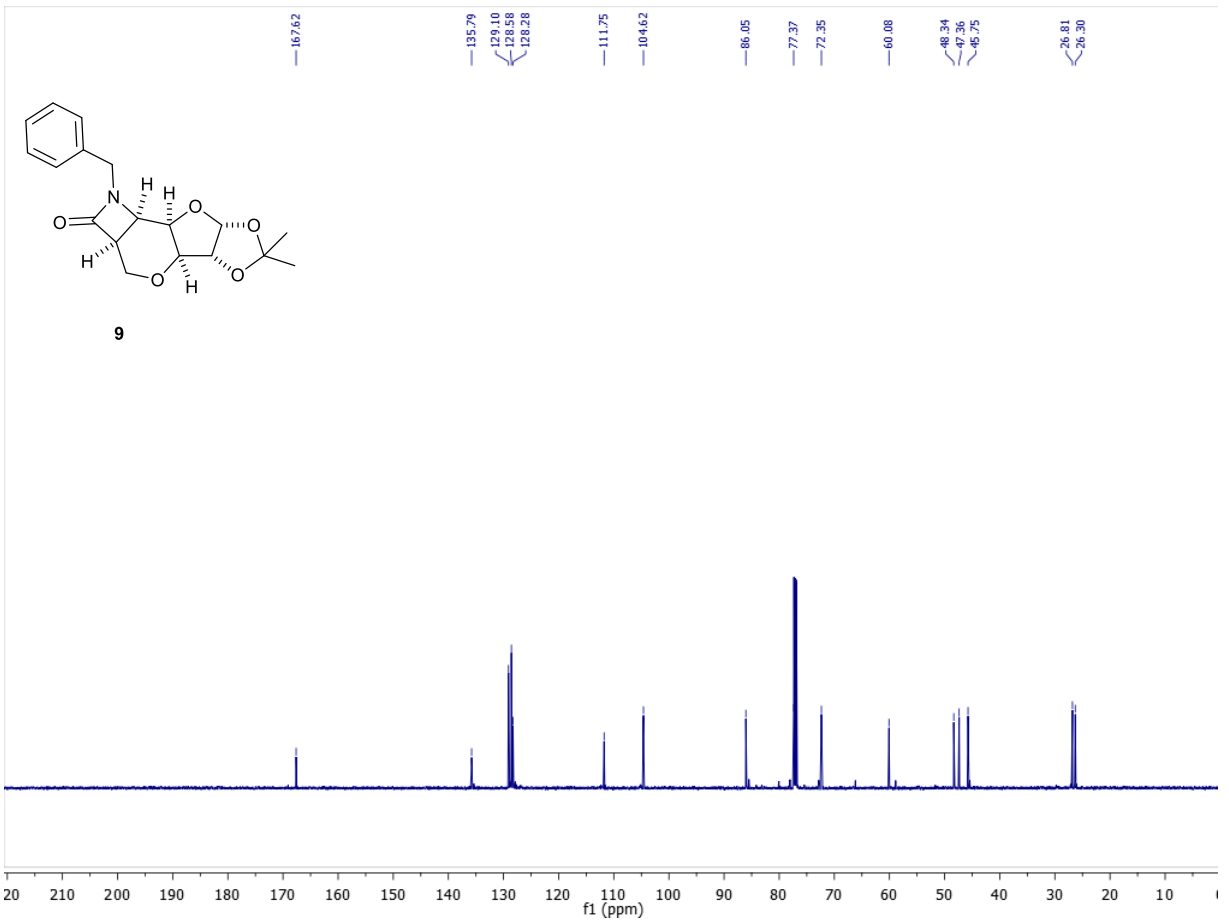
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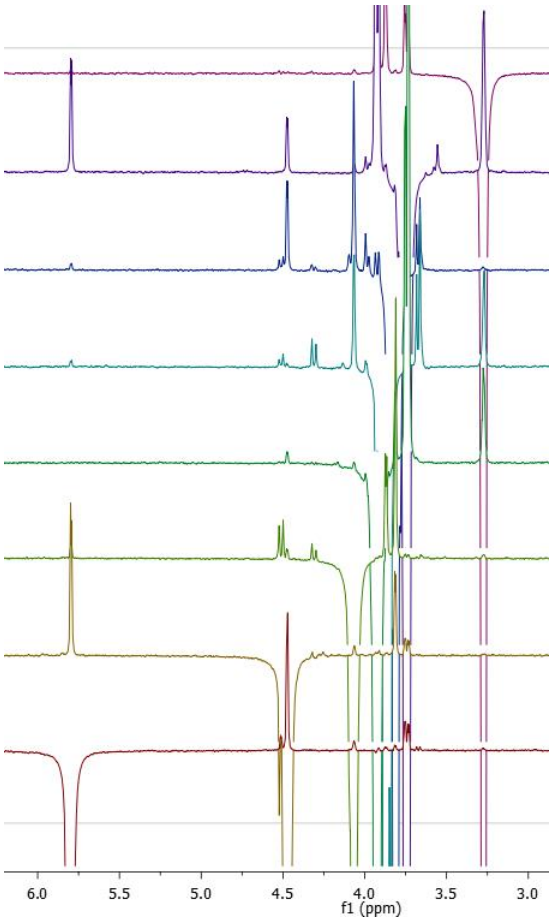

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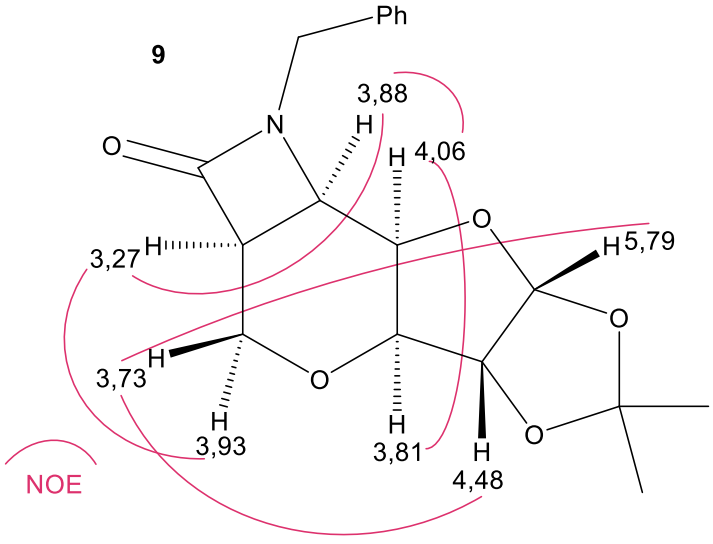

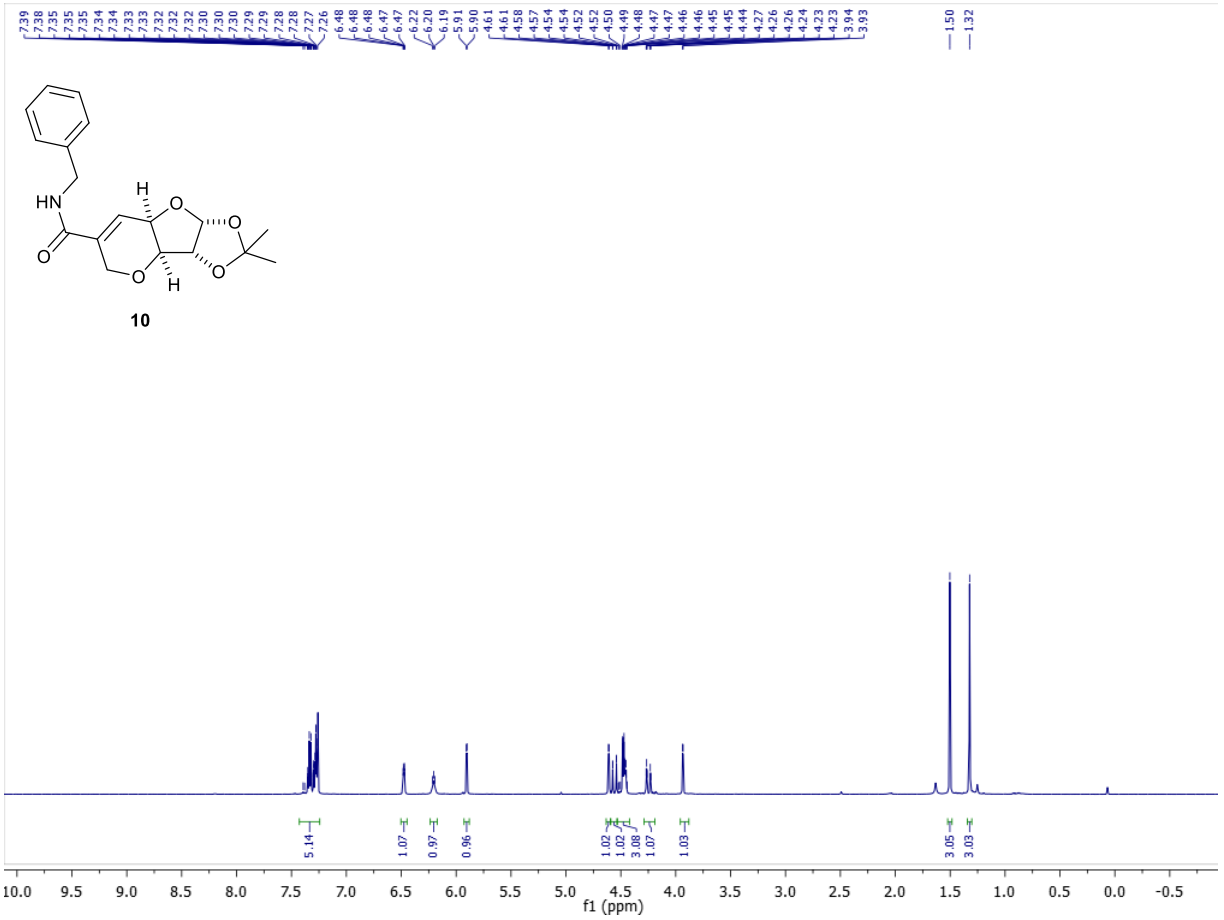
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6.48 6.48 6.48 6.47 6.47 6.22 6.20 6.19 5.91 5.90
4.61 4.61 4.58 4.57 4.54 4.54 4.52 4.52 4.50 4.49 4.48 4.47 4.47 4.46 4.46 4.45 4.45 4.44 4.27 4.26 4.26 4.24 4.23 4.23 3.94 3.93
1.50 1.32
HN
O
H
O
O
O
O
H
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5.14 1.07 0.97 0.96 1.02 1.02 3.08 1.07 1.03 3.05 3.03
10.0 9.5 9.0 8.5 8.0 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 -0.5
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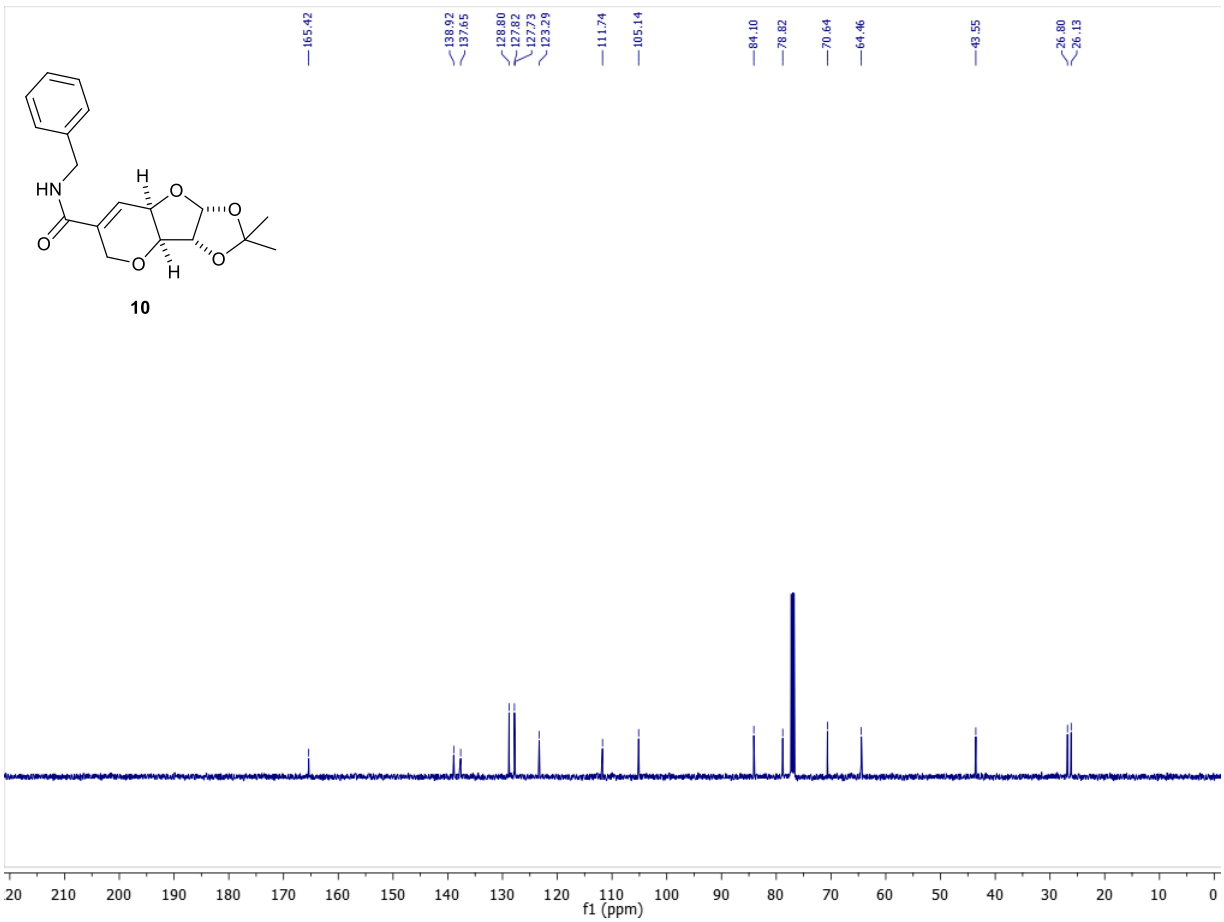
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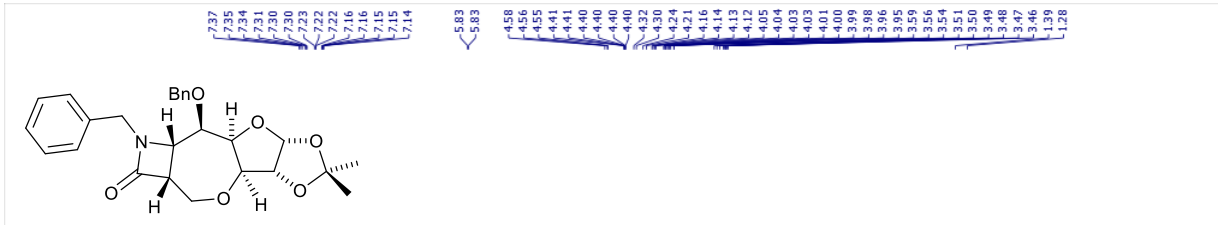
f1 (ppm)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N
O
O
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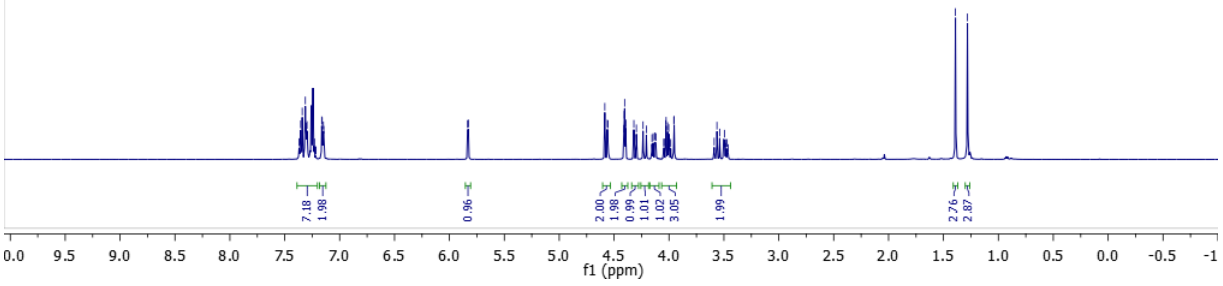
O
H
O
H

11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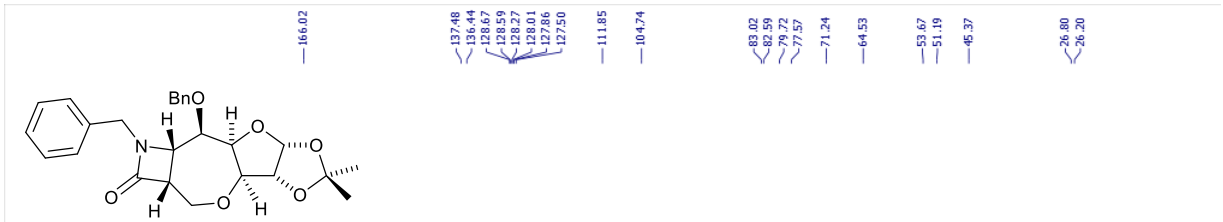
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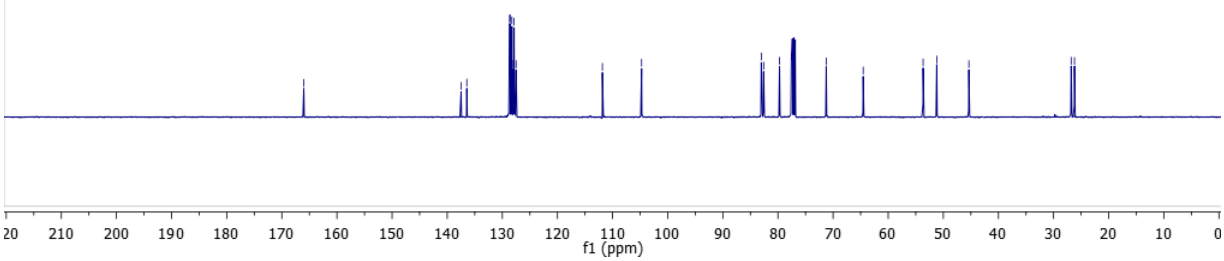
H

11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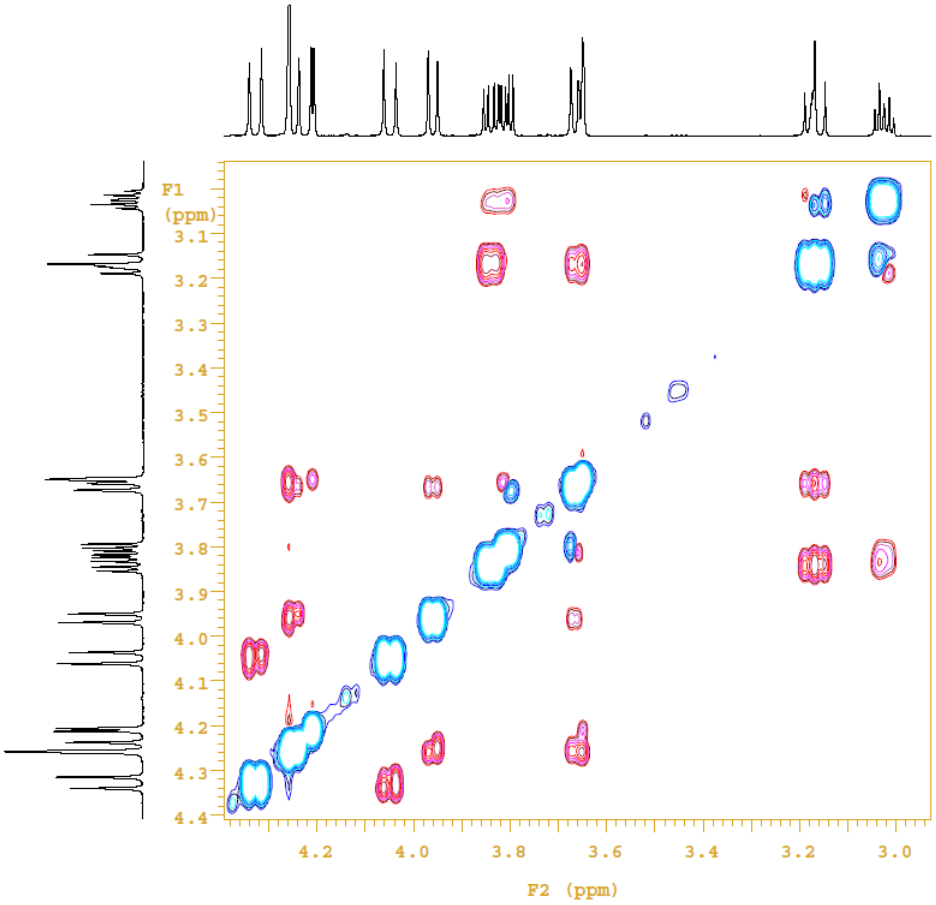
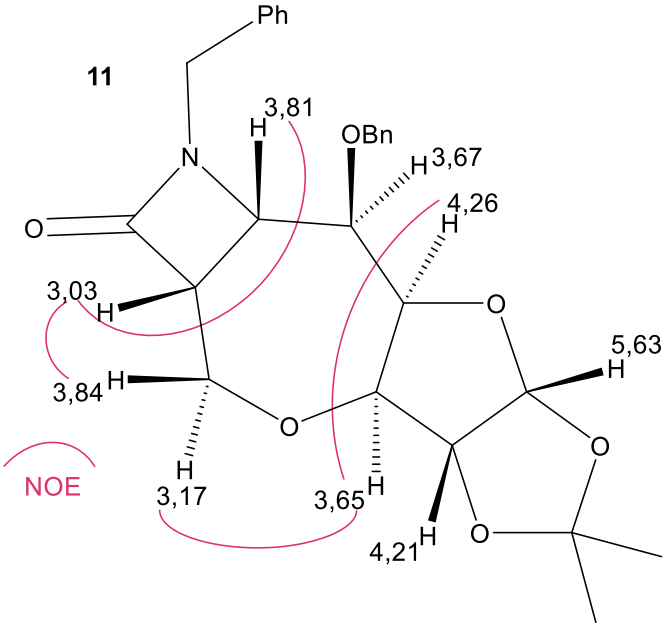
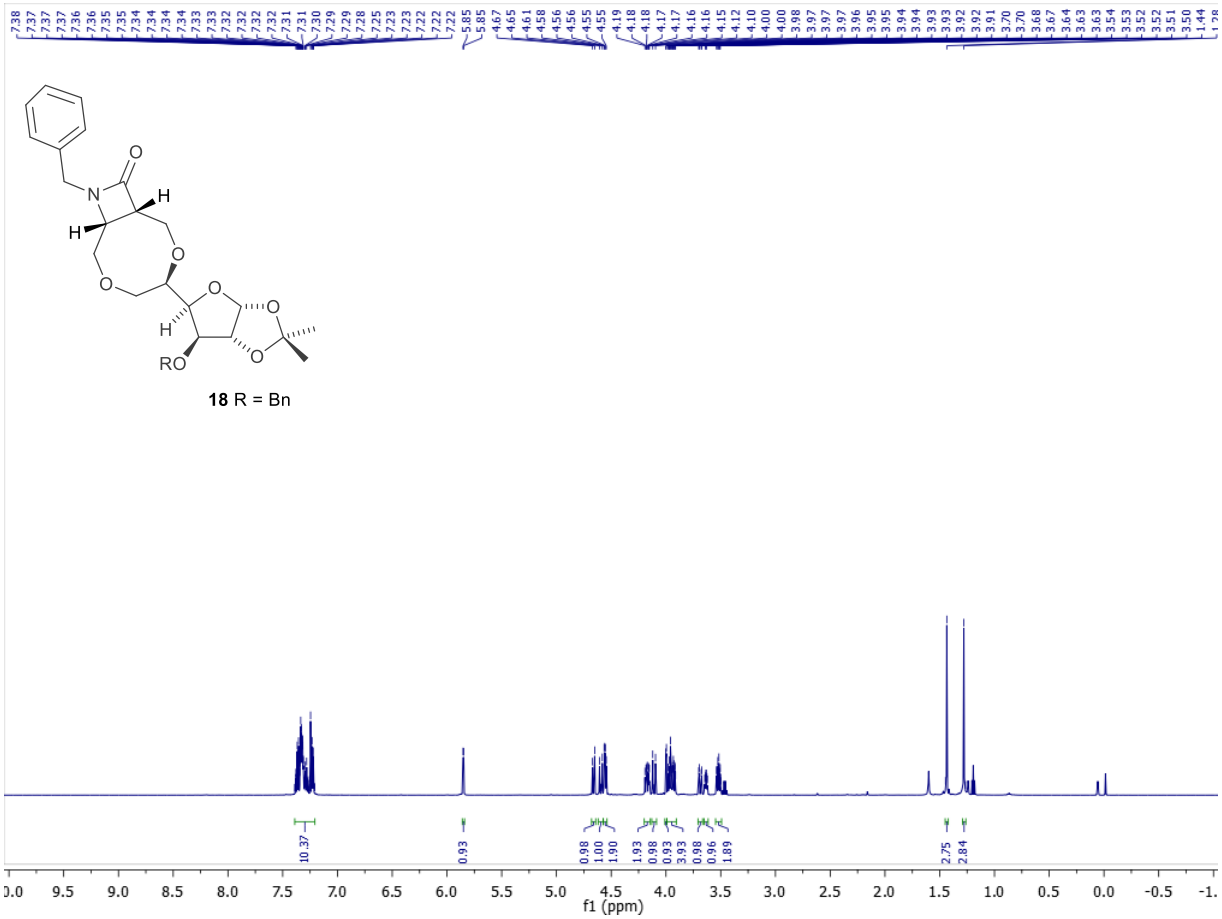
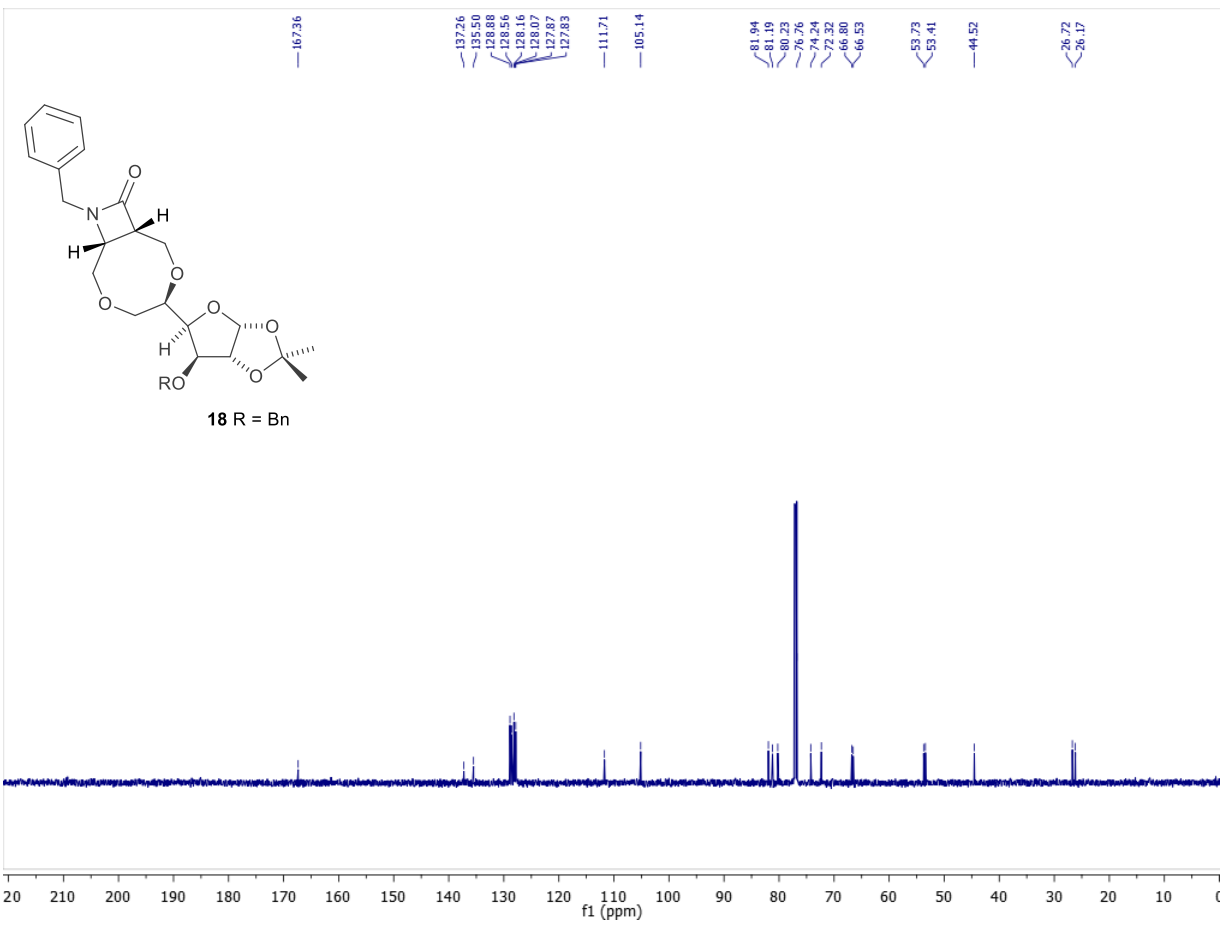
10
0
f1 (ppm)

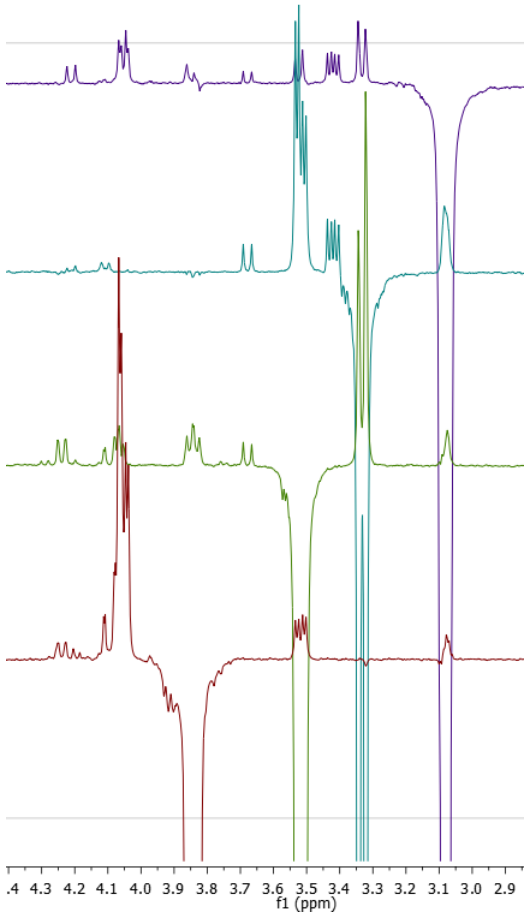


2D NOESY NMR, solvent C_6D_6 + CD_3OD

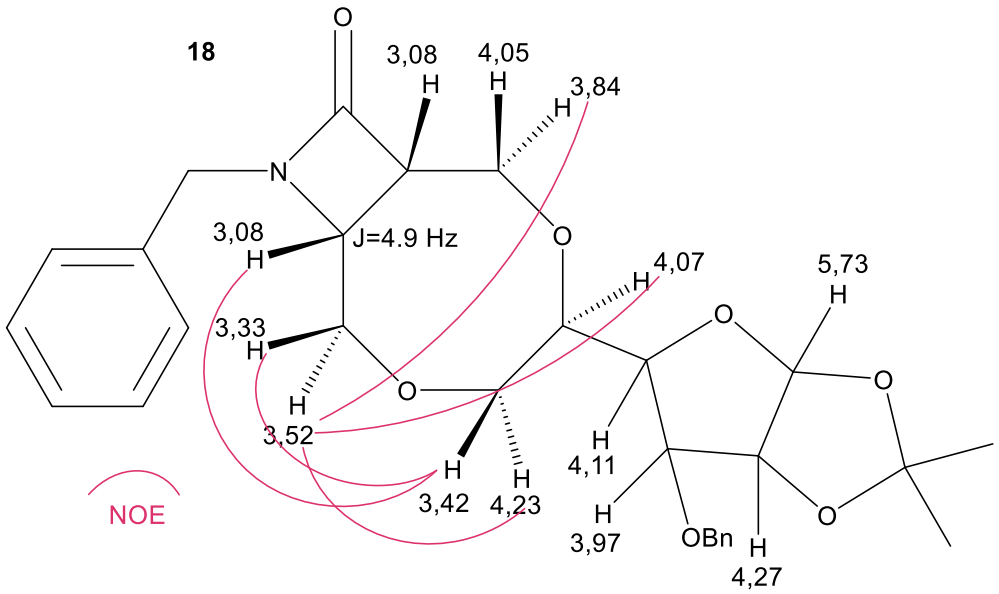


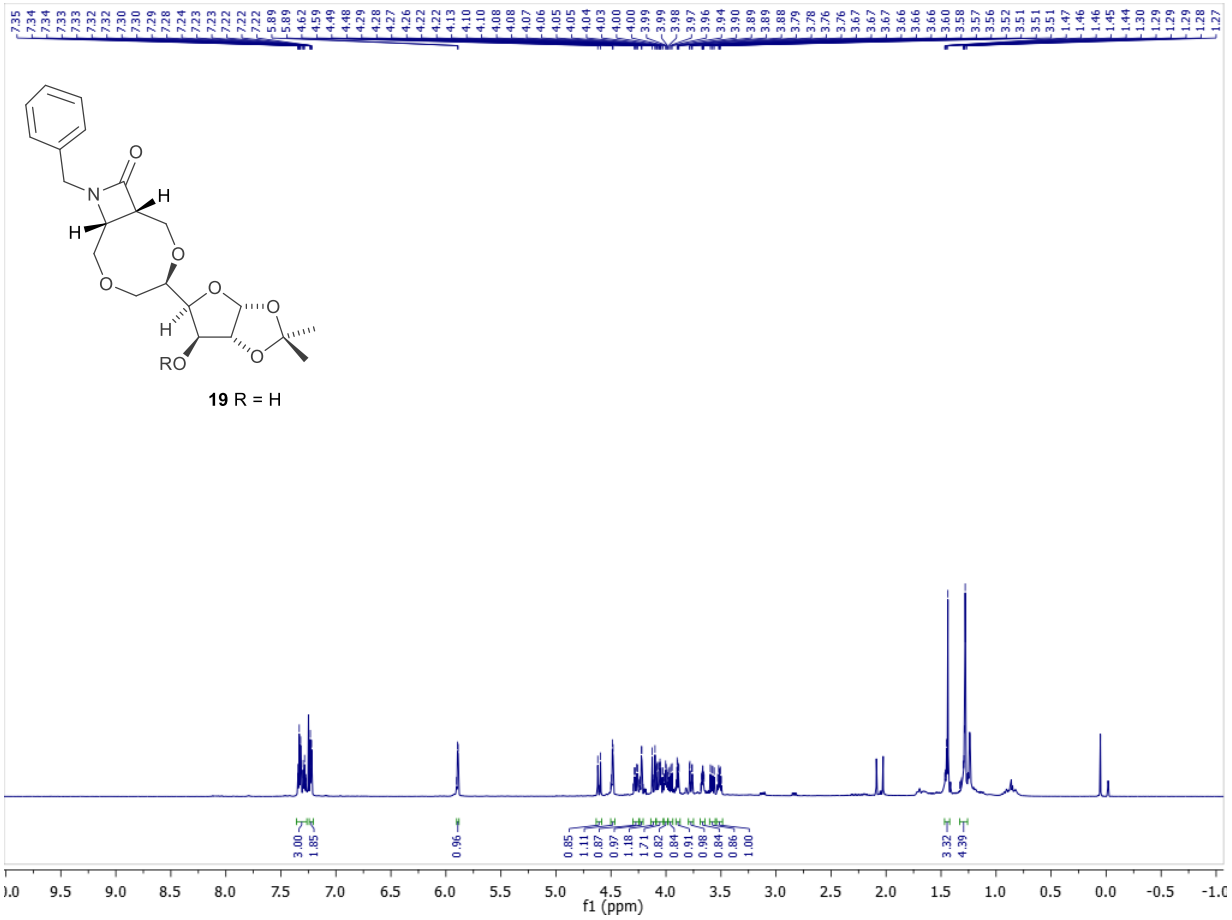

7.38 7.37 7.37 7.37 7.36 7.36 7.35 7.35 7.34 7.34 7.34 7.34 7.33 7.33 7.32 7.32 7.32 7.32 7.31 7.31 7.30 7.29 7.29 7.28 7.25 7.23 7.23 7.22 7.22 7.22
5.85 5.85
4.67 4.65 4.61 4.58 4.56 4.56 4.55 4.55 4.19 4.18 4.18 4.17 4.17 4.16 4.16 4.15 4.12 4.10 4.00 4.00 3.98 3.97 3.97 3.97 3.96 3.95 3.95 3.94 3.94 3.93 3.93 3.92 3.92 3.91 3.70 3.70 3.68 3.67 3.64 3.63 3.63 3.54 3.53 3.52 3.52 3.51 3.50 1.44
O
N
H
H
O
O
O
O
H
RO
O
O
O
18 R = Bn
10.37
0.93
0.98
1.00
1.90
1.93
0.98
0.93
3.93
0.98
0.96
1.89
2.75
2.84
f1 (ppm)


167.36
137.26
135.50
128.88
128.56
128.16
128.07
127.87
127.83
111.71
105.14
81.94
81.19
80.23
76.76
74.24
72.32
66.80
66.53
53.73
53.41
44.52
26.72
26.17
O
N
H
H
O
O
O
O
H
RO
O
O
O
18 R = Bn
f1 (ppm)

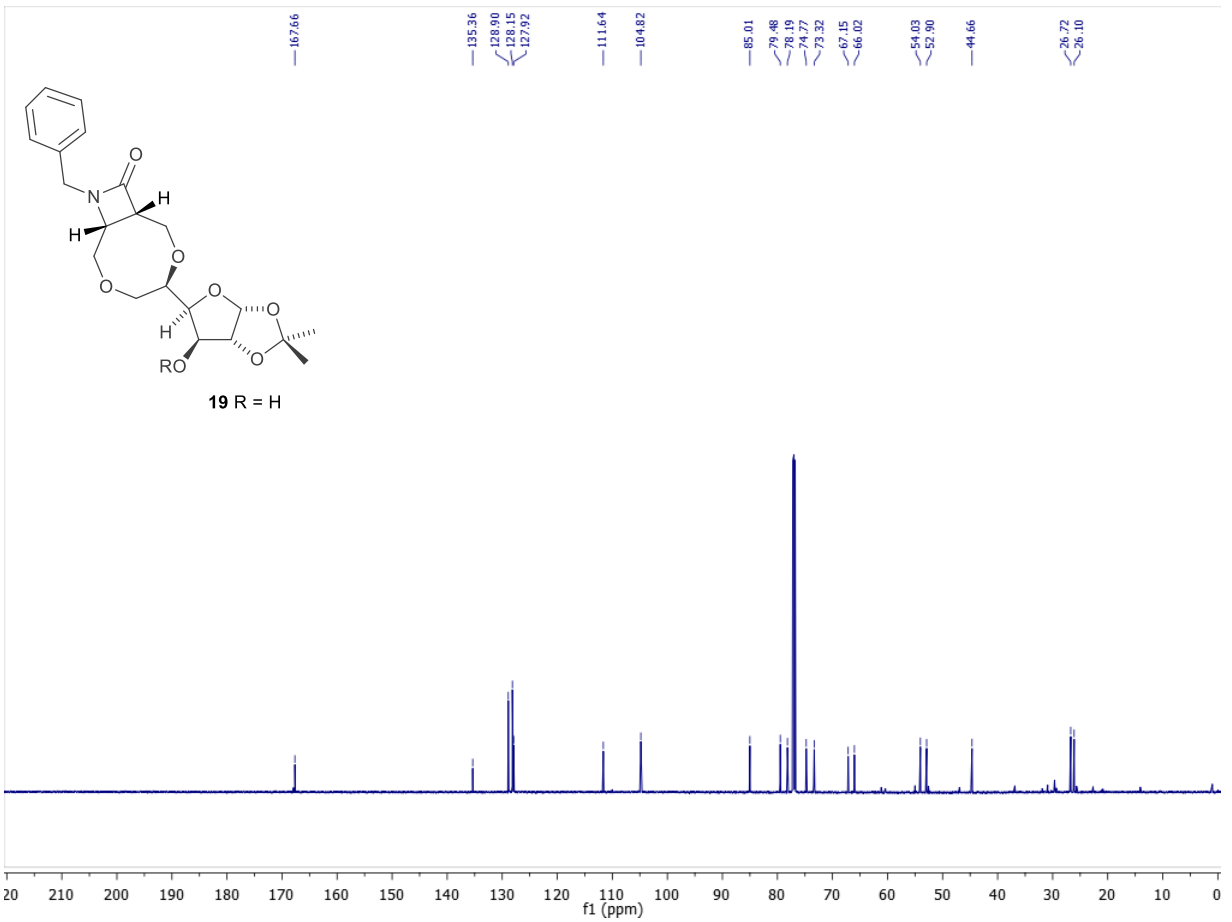


1D NOESY NMR, solvent C_6D_6

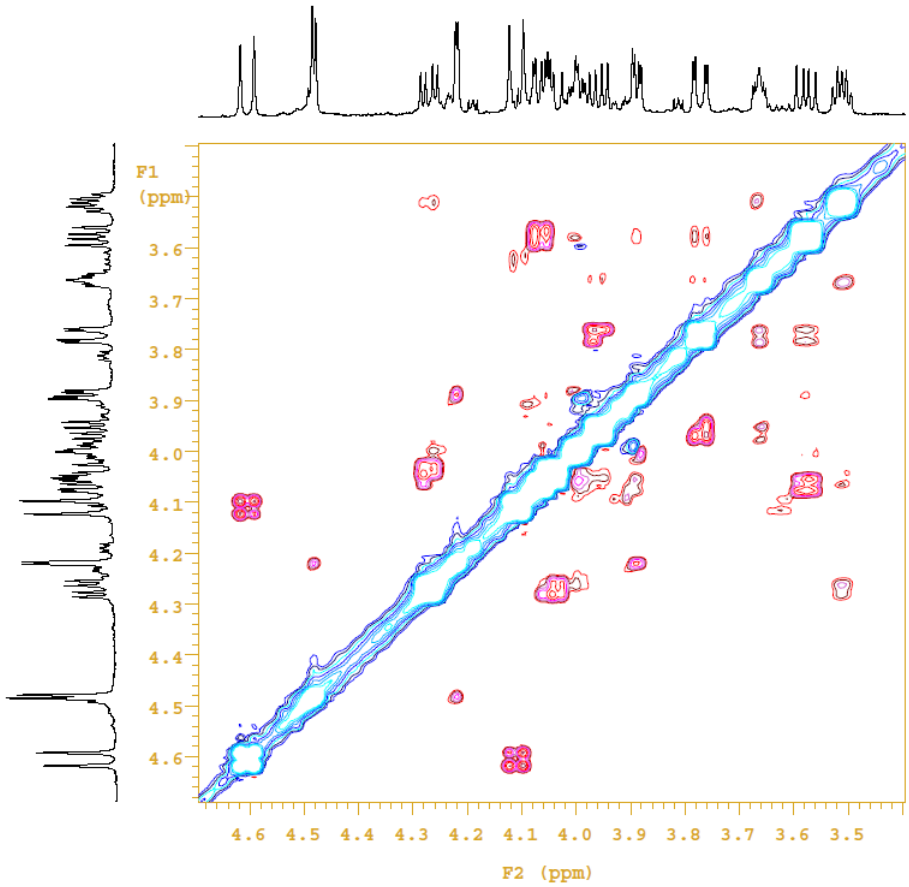




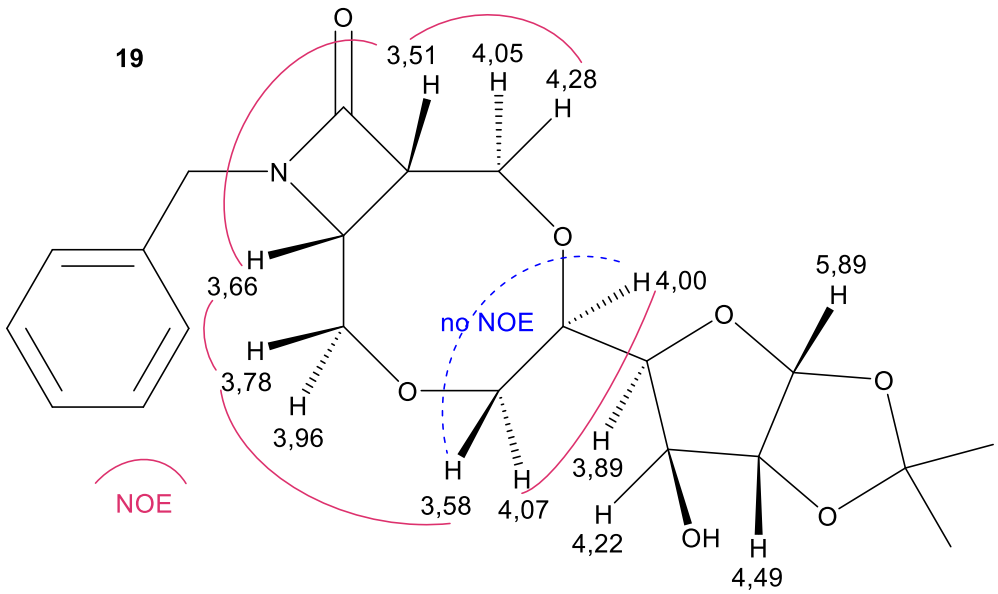
19 R = H

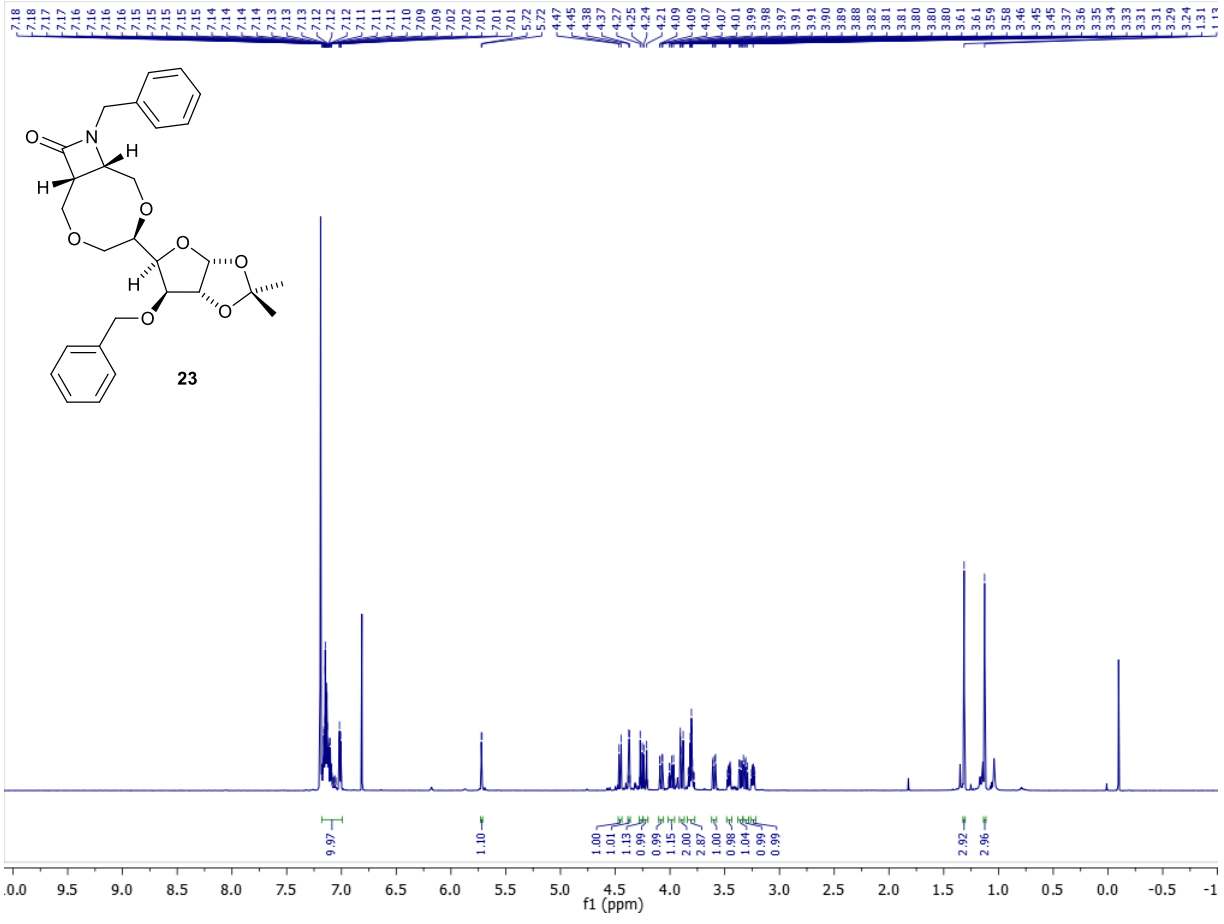


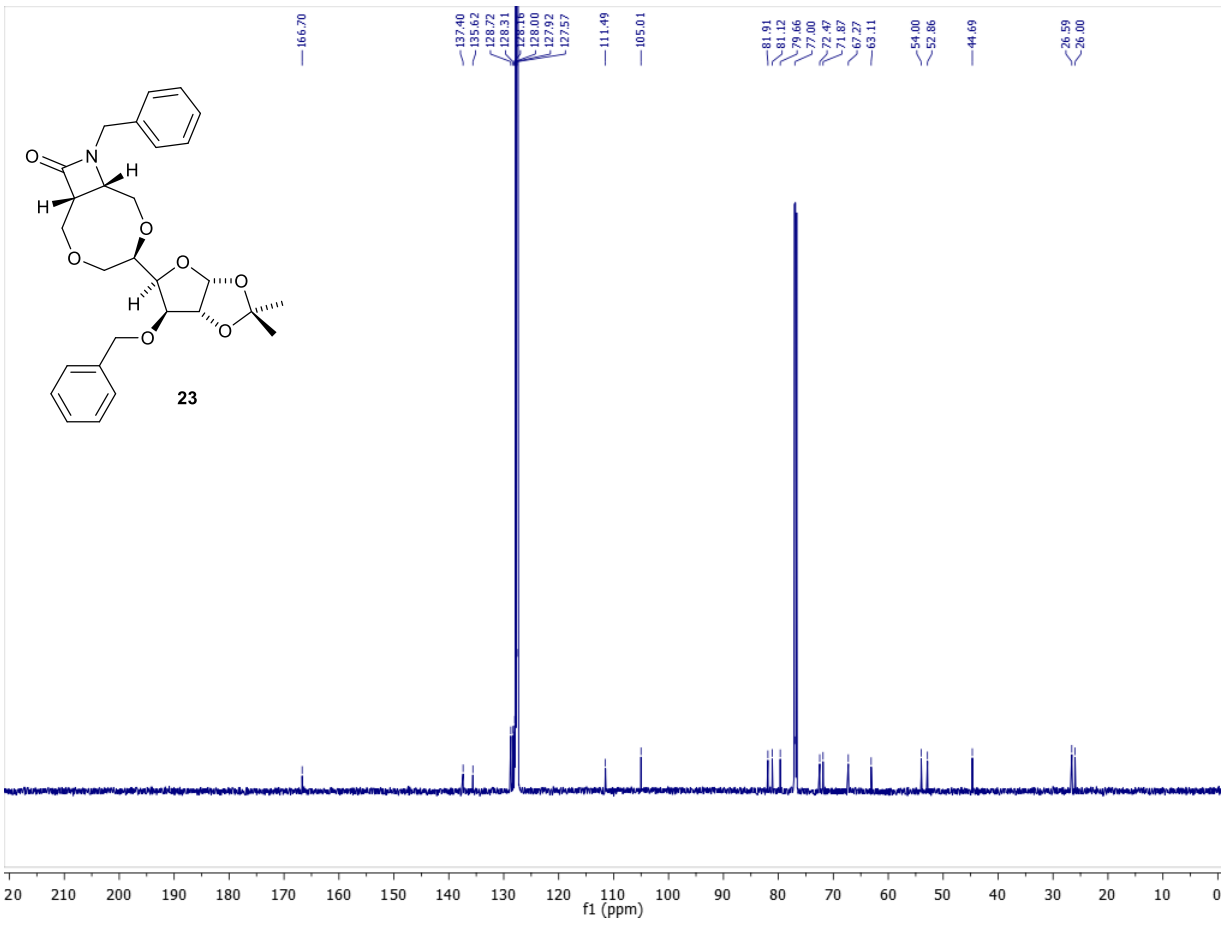
19 R = H

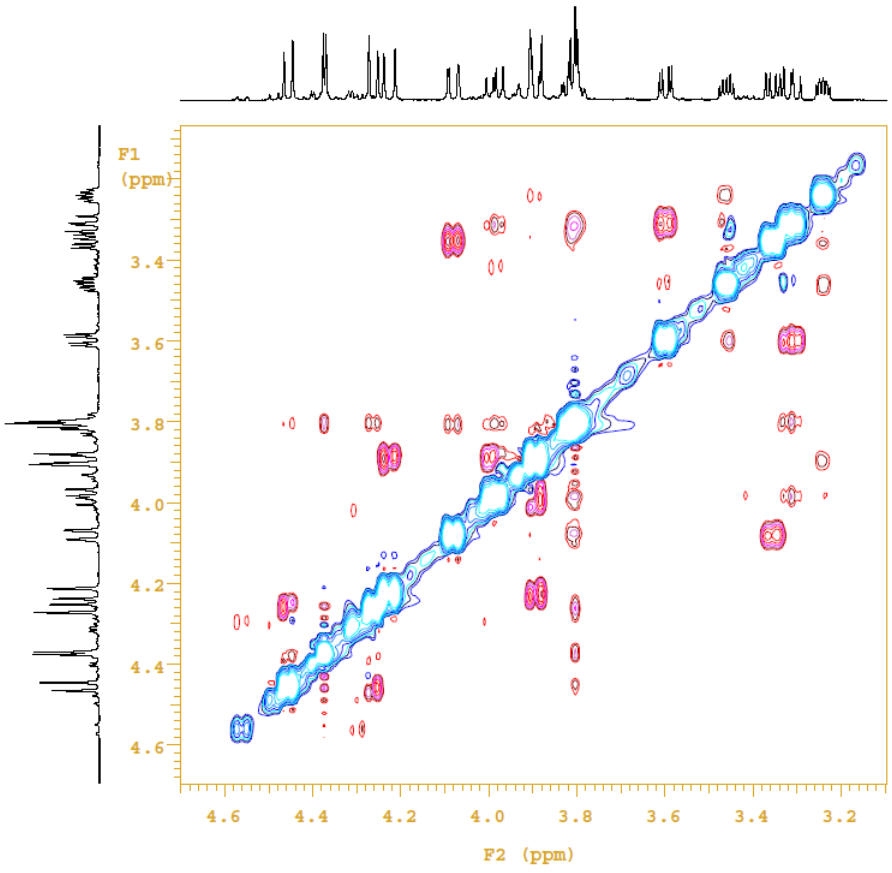


2D NOESY NMR, solvent $CDCl_3$

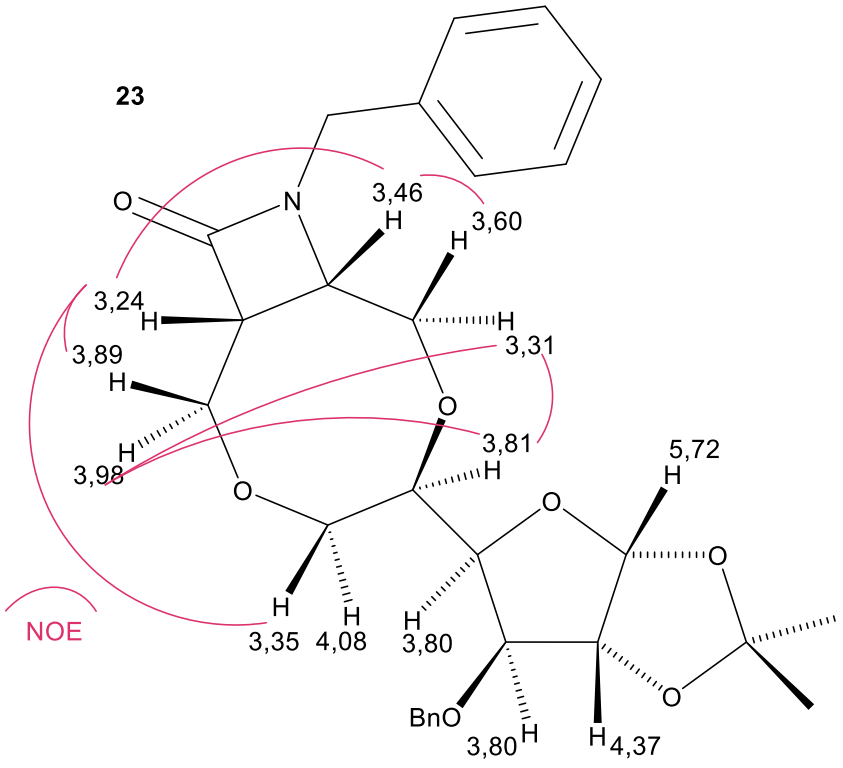


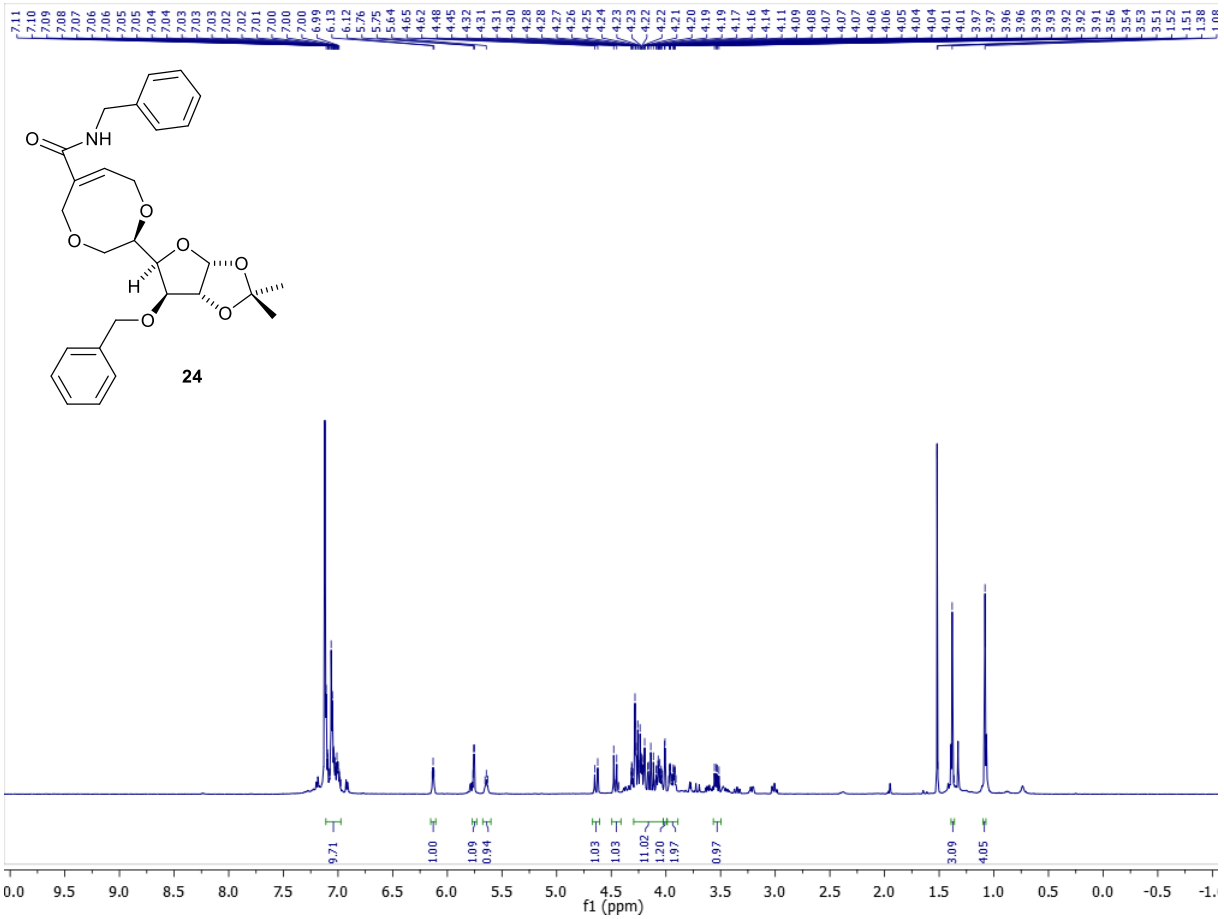

23
f1 (ppm)

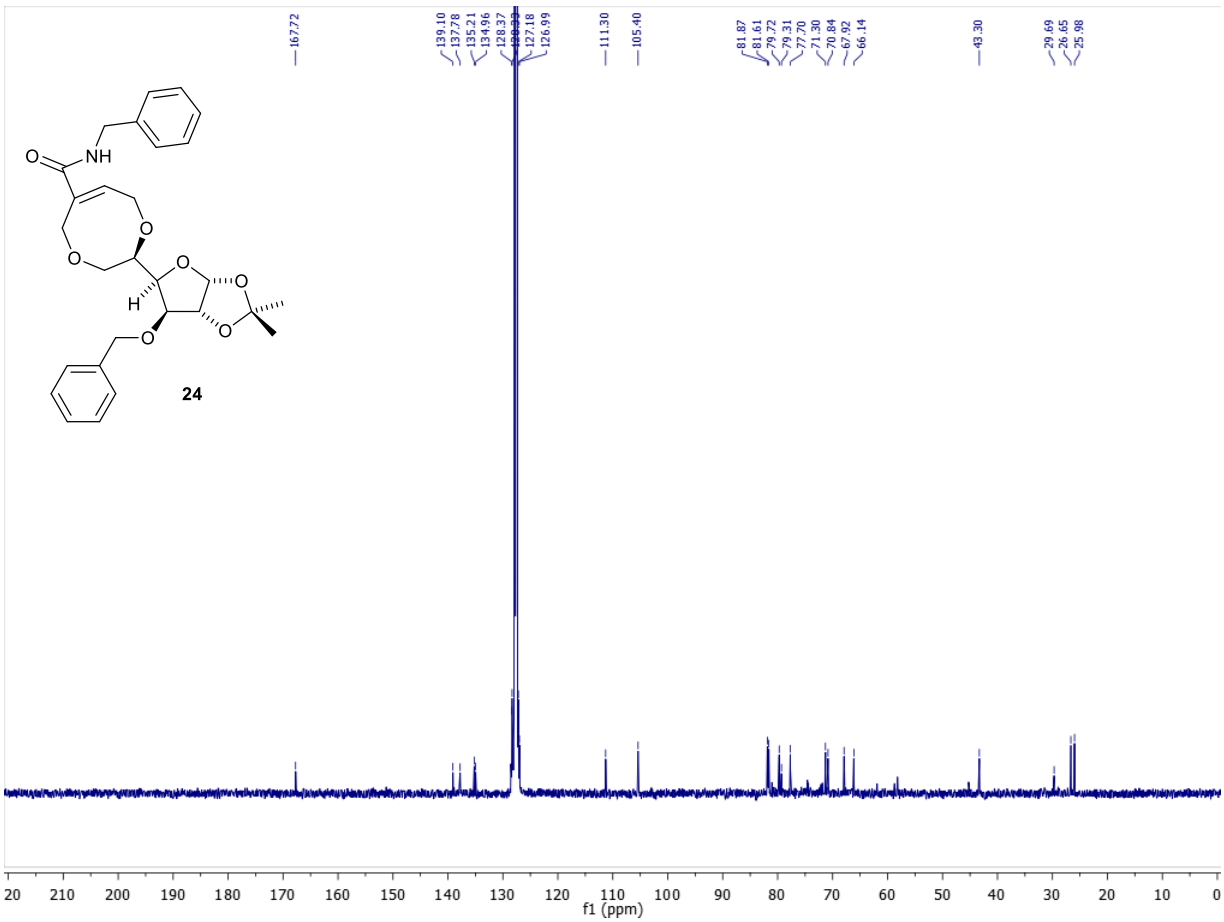

23
f1 (ppm)

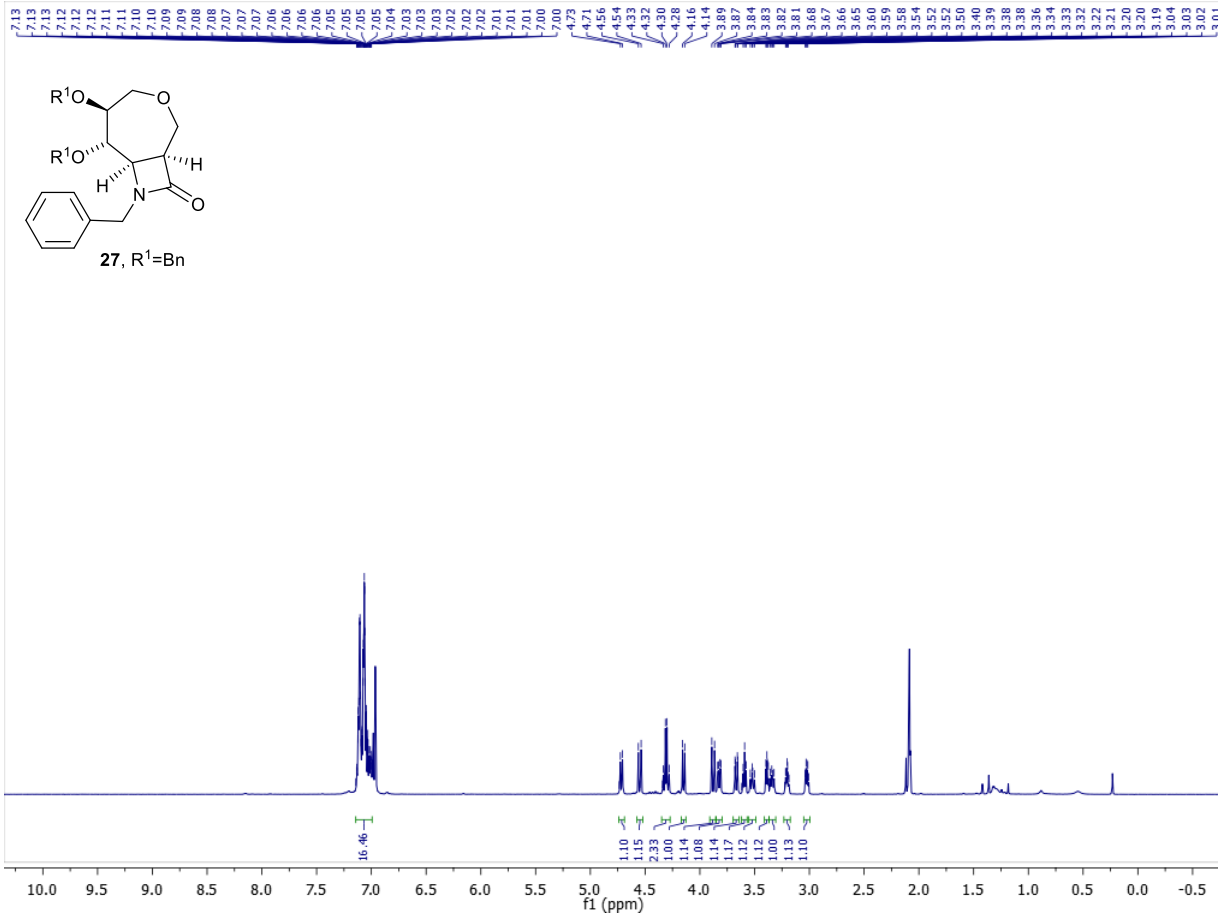


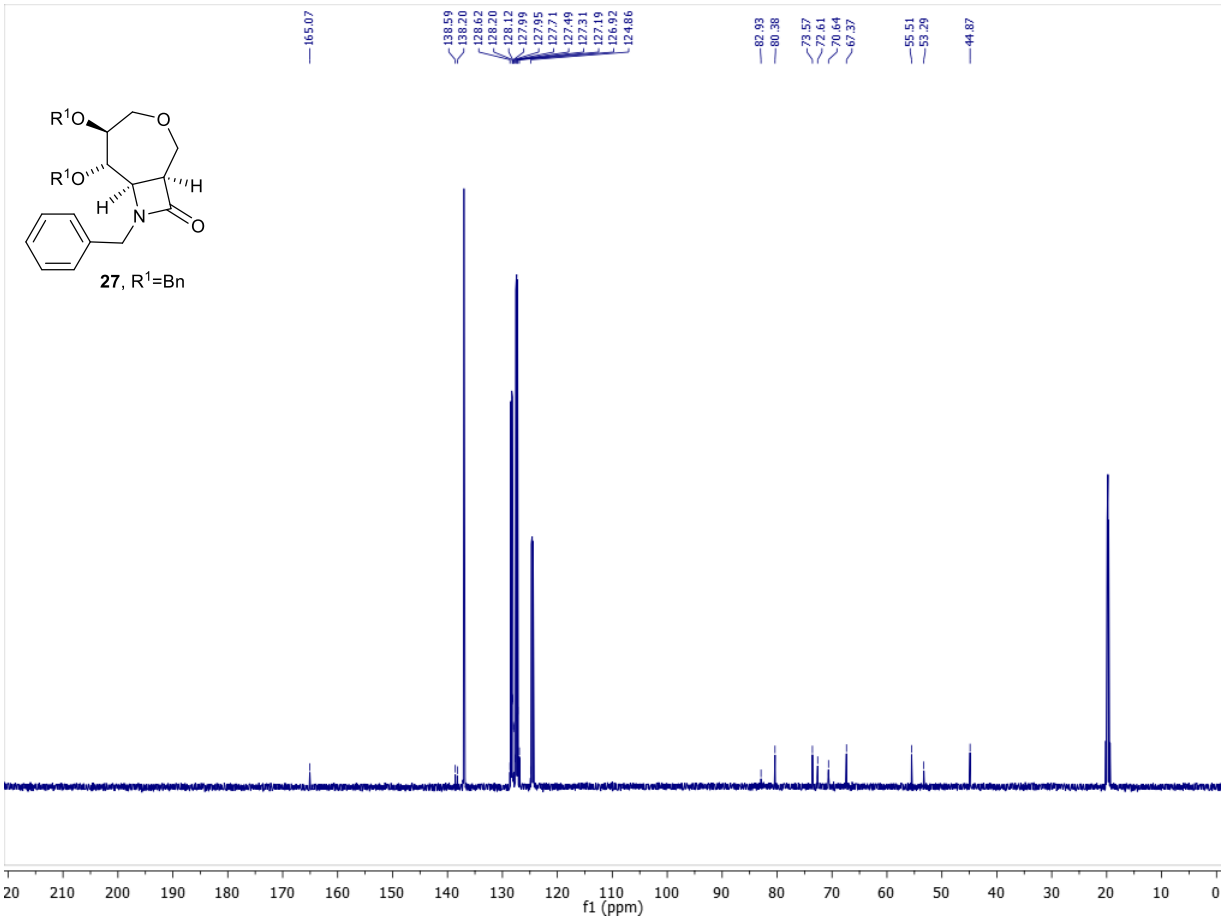
2D NOESY NMR, solvent $CDCl_3 + C_6D_6$

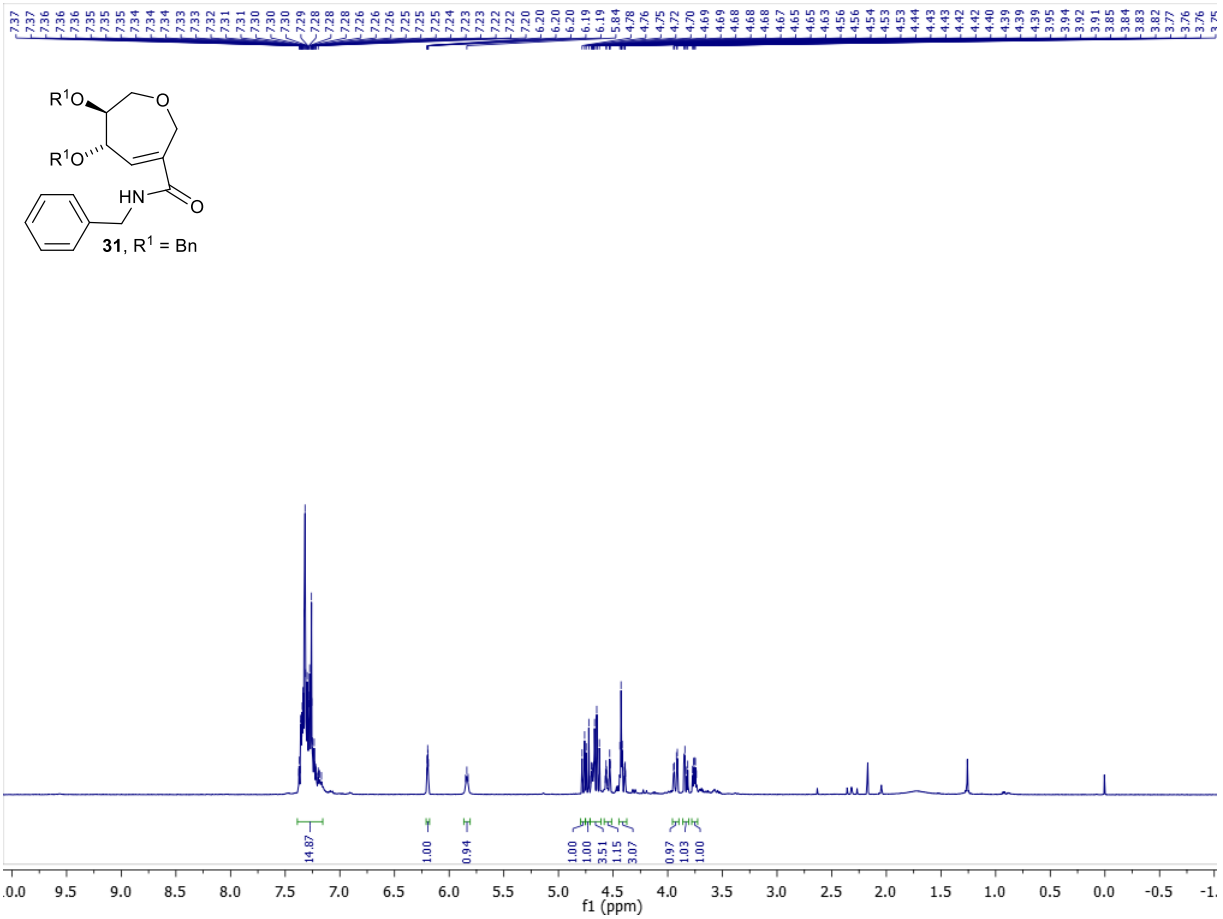


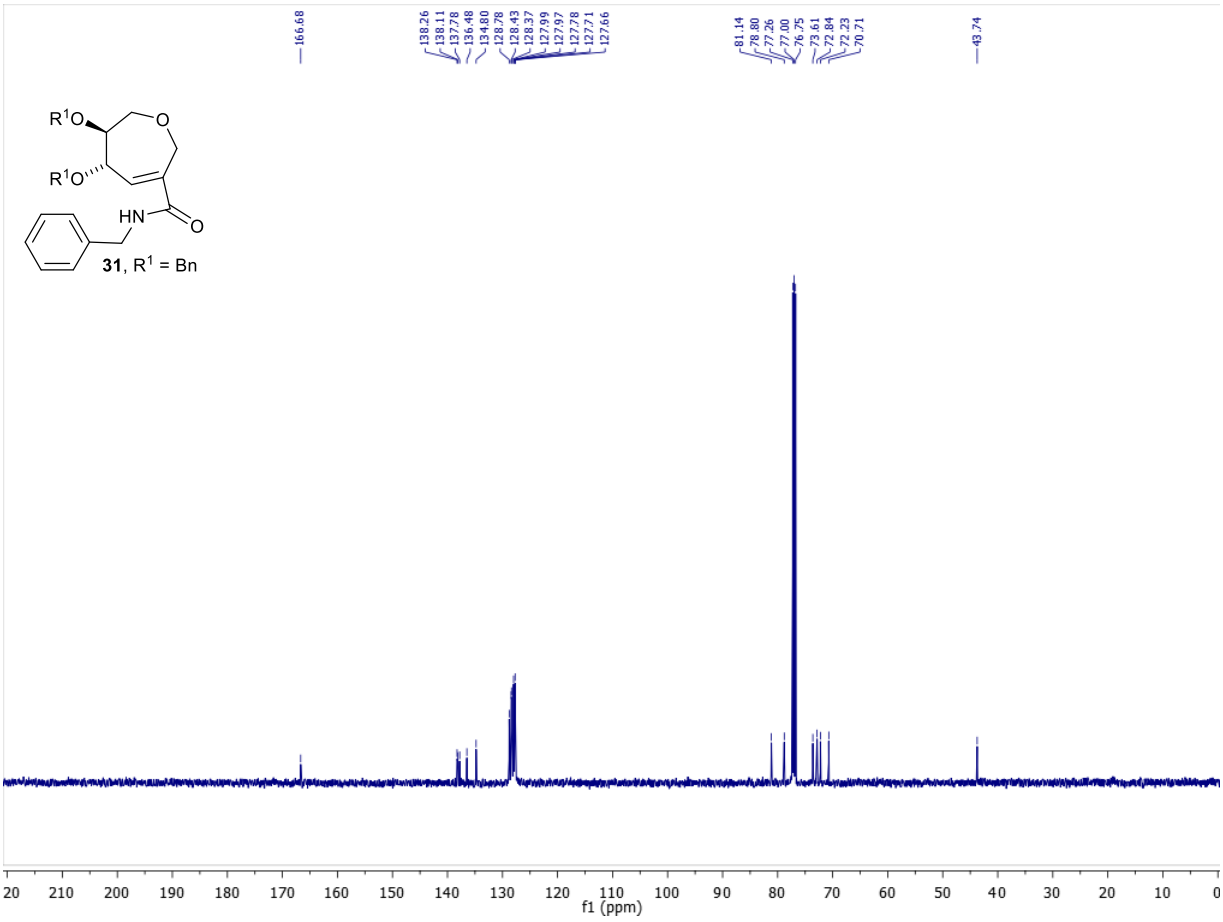

NH
O
O
O
O
O
H
O
O
24
9.71
1.00
1.09
0.94
1.03
1.03
11.02
1.20
1.97
0.97
3.09
4.05
f1 (ppm)

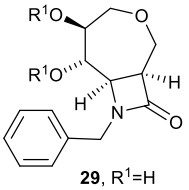

167.72
139.10
137.78
135.21
134.96
128.37
127.18
126.99
111.30
105.40
81.87
81.61
79.72
79.31
77.70
71.30
70.84
67.92
66.14
43.30
29.69
26.65
25.98
NH
O
O
O
O
O
H
O
O
24
f1 (ppm)


R1O
R1O
H
H
N
O
O
27, R1=Bn
16.46
1.10
1.15
2.33
1.00
1.14
1.08
1.14
1.17
1.12
1.12
1.00
1.13
1.10
f1 (ppm)


165.07
138.59
138.20
128.62
128.20
128.12
127.99
127.95
127.71
127.49
127.31
127.19
126.92
124.86
82.93
80.38
73.57
72.61
70.64
67.37
55.51
53.29
44.87
R1O
R1O
H
H
N
O
O
27, R1=Bn
f1 (ppm)

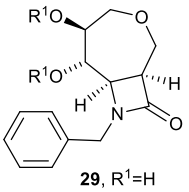

R1O
R1O
HN
O
O
31, R1 = Bn
14.87
1.00
0.94
1.00
1.00
3.51
1.15
3.07
0.97
1.03
1.00
f1 (ppm)


166.68
138.26
138.11
137.78
136.48
134.80
128.78
128.43
128.37
127.99
127.97
127.78
127.71
127.66
81.14
78.80
77.26
77.00
76.75
73.61
72.84
72.23
70.71
43.74
R1O
R1O
HN
O
O
31, R1 = Bn
f1 (ppm)



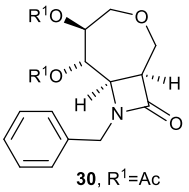
29, R^1=H

7.27 7.27 7.26 7.14 7.13 7.12 7.12 7.11 7.11 7.06 7.05 7.05 7.04 7.03 7.03 7.03 7.03
4.47 4.44 4.16 4.14 3.88 3.87 3.85 3.85 3.67 3.67 3.65 3.65
3.31 3.30 3.28 3.12 3.11 3.10 3.10 3.09 3.09 3.07 3.06 3.04 3.03 3.02 3.01 3.00 2.99 2.98 2.93 2.92 2.91 2.90 2.89 2.89 2.83 2.82 2.81 2.80 2.12 2.10 1.64 1.64
1.83 1.93 1.04 1.05 0.99 0.97 1.00 0.96 2.05 1.68 1.00 0.97 0.95 0.97
f1 (ppm)

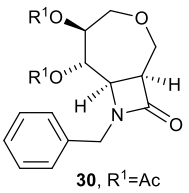


29, R^1=H

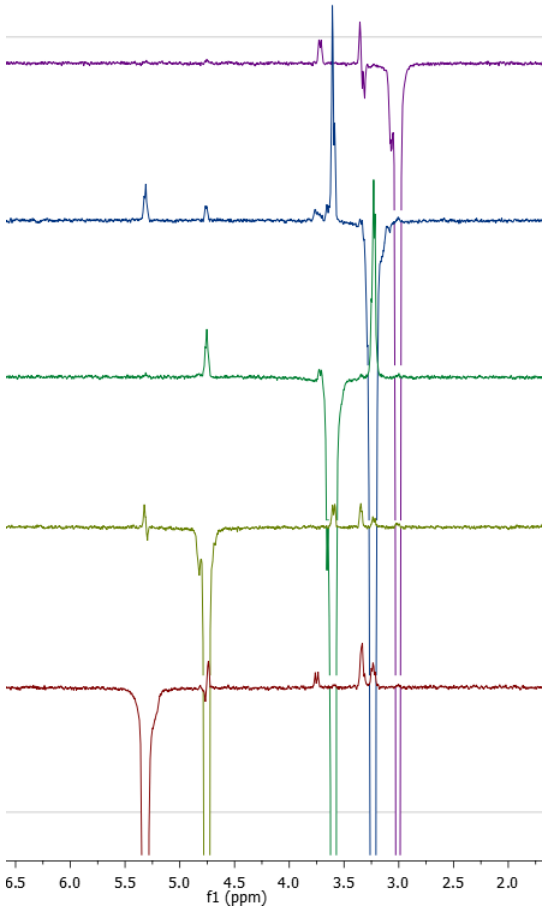
164.91
137.15
128.62
127.70
127.17
76.11
74.26
70.53
67.60
56.77
52.83
45.18
f1 (ppm)



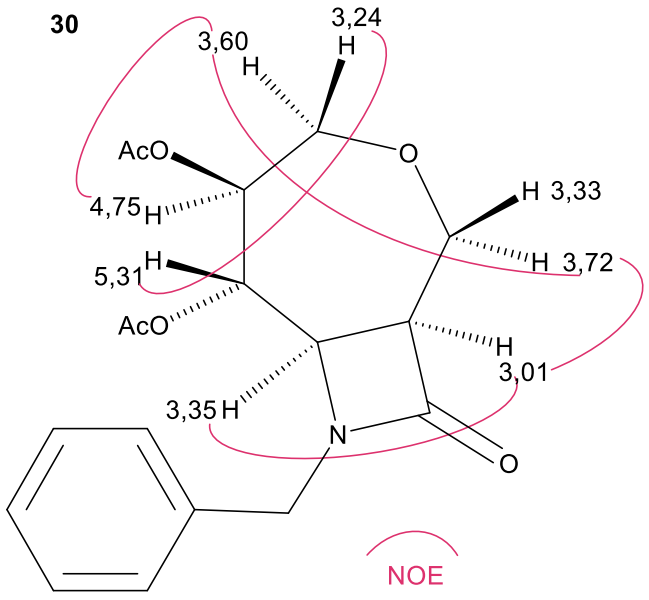
30, R^1=Ac

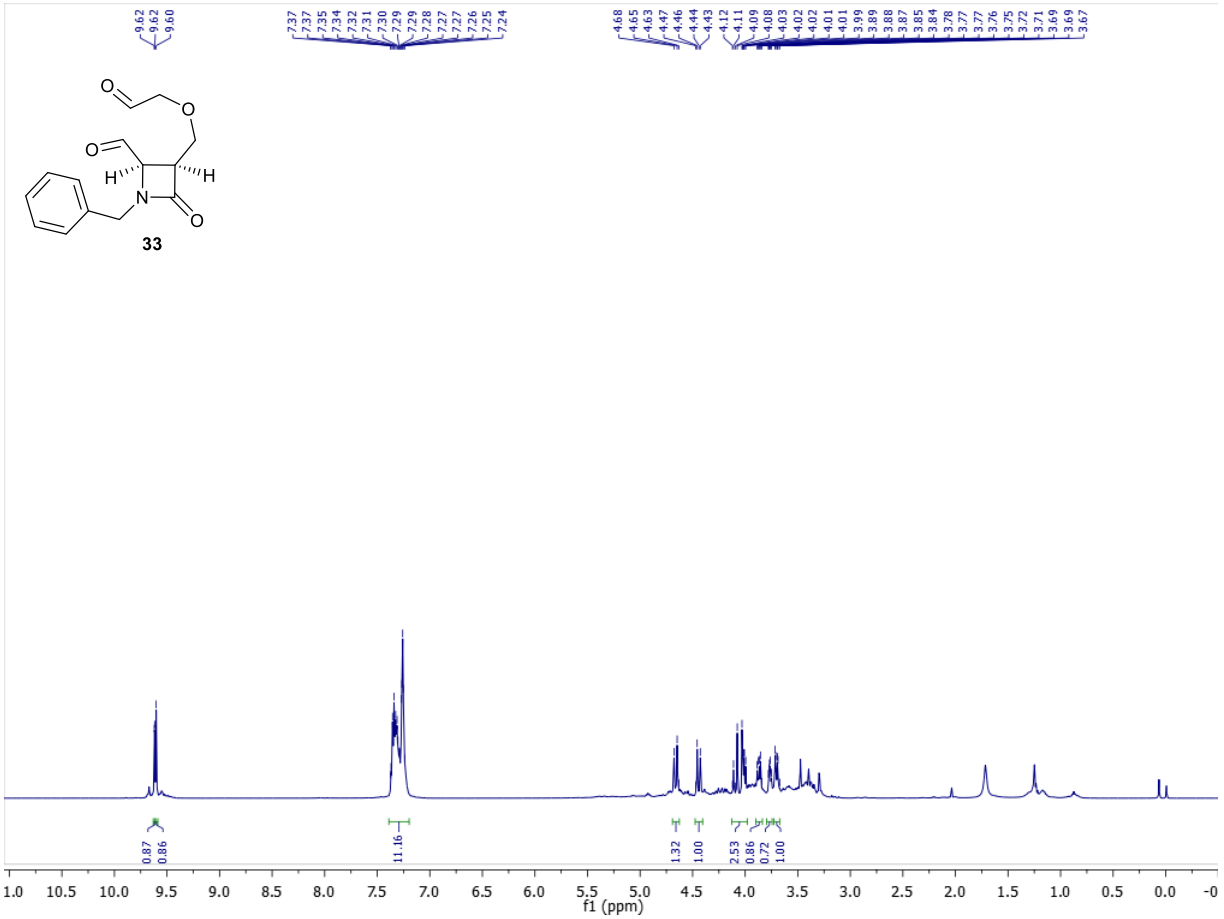


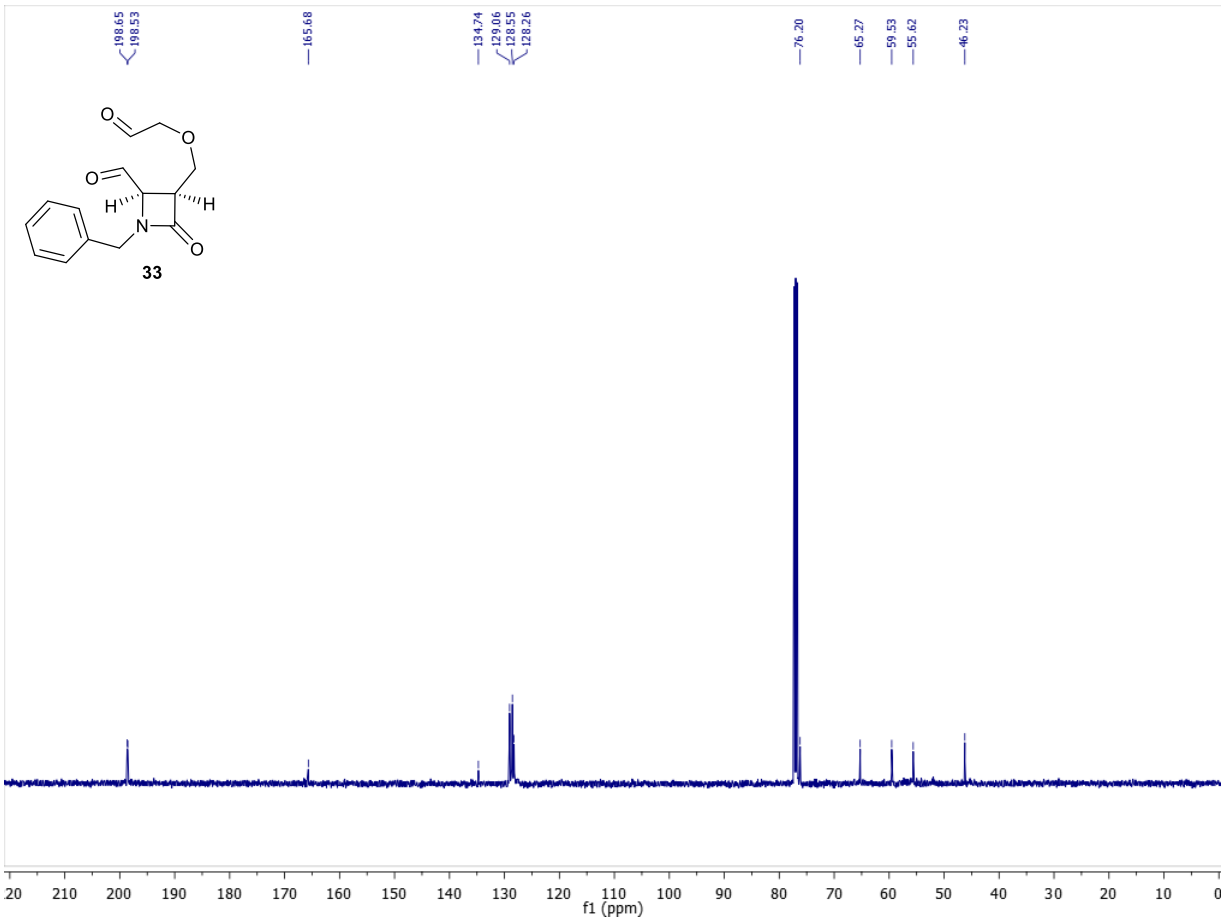
30, R^1=Ac

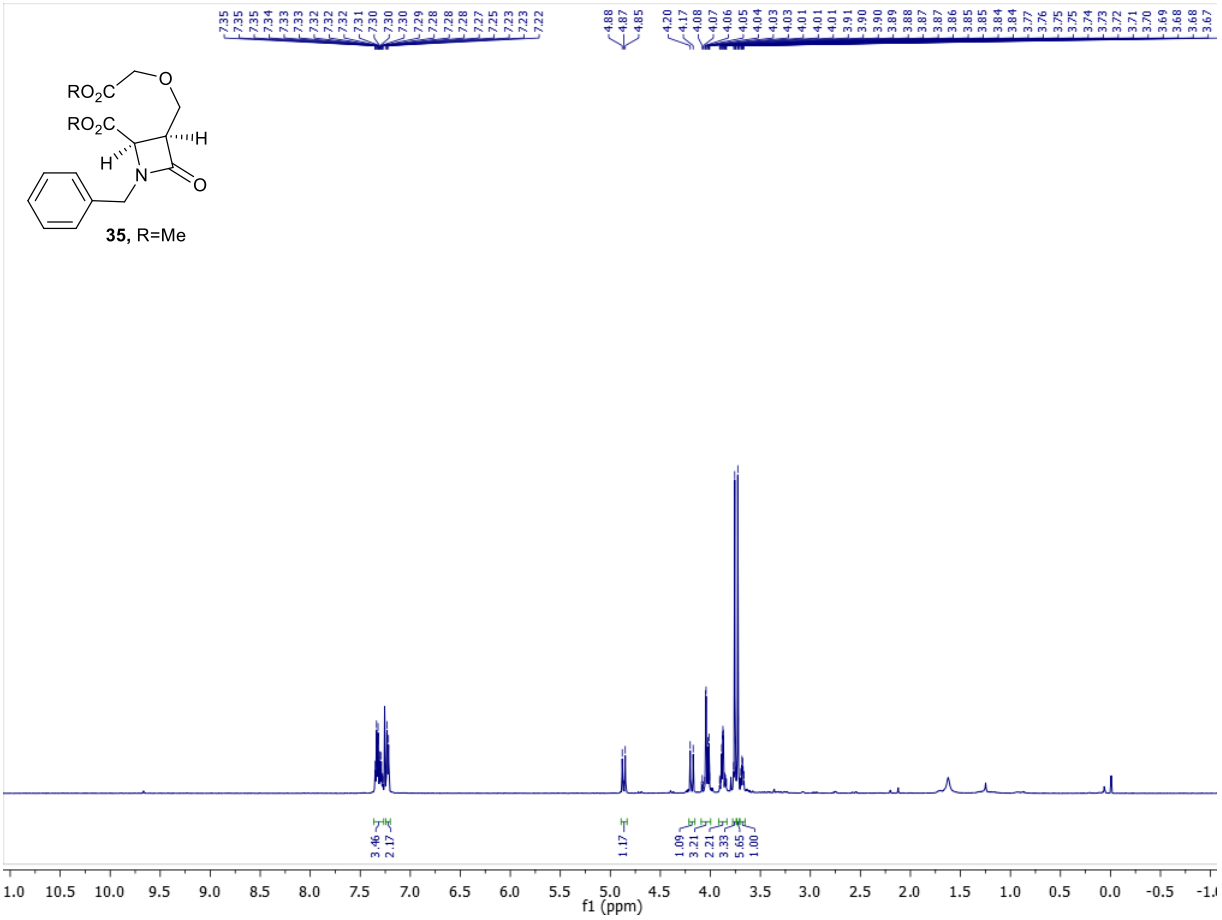


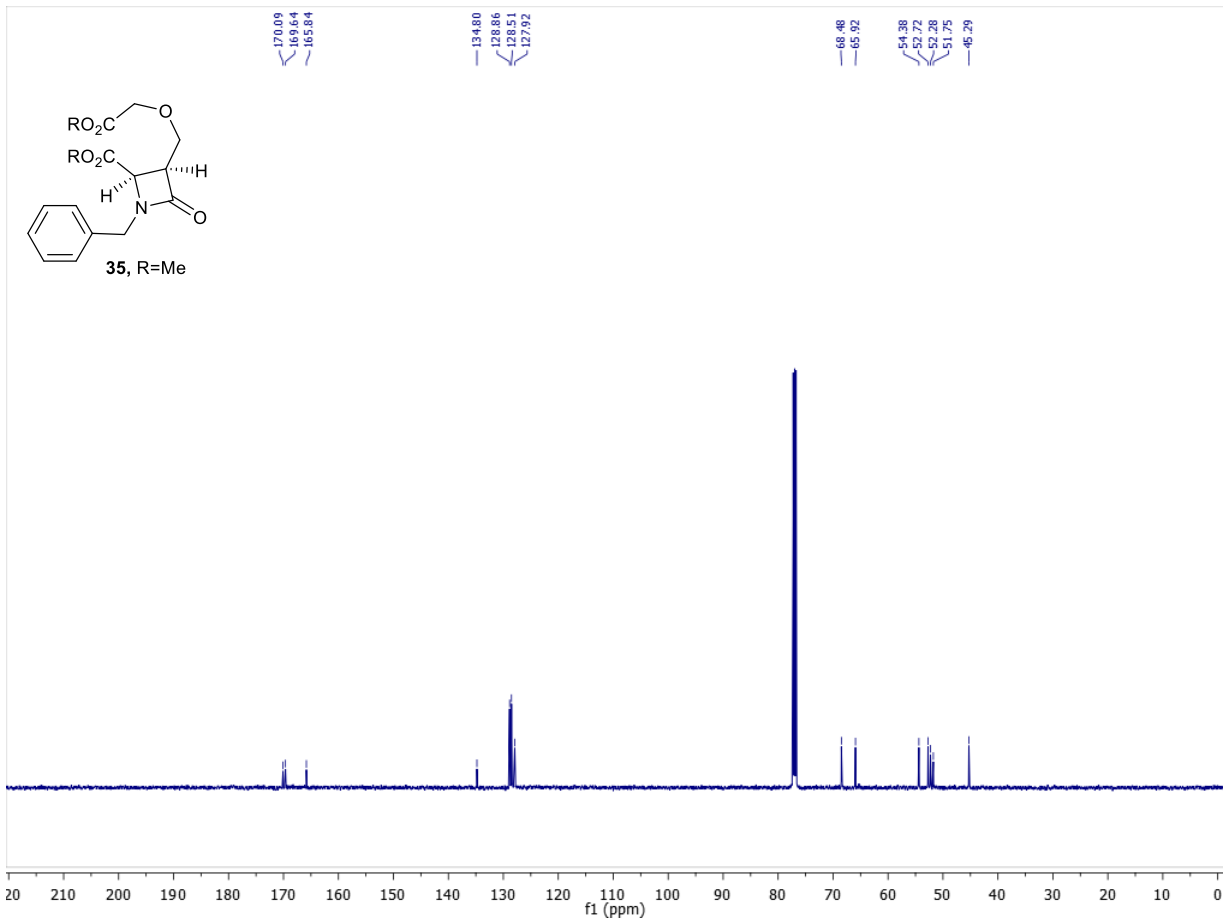
1D NOESY NMR, solvent toluene 80 °C

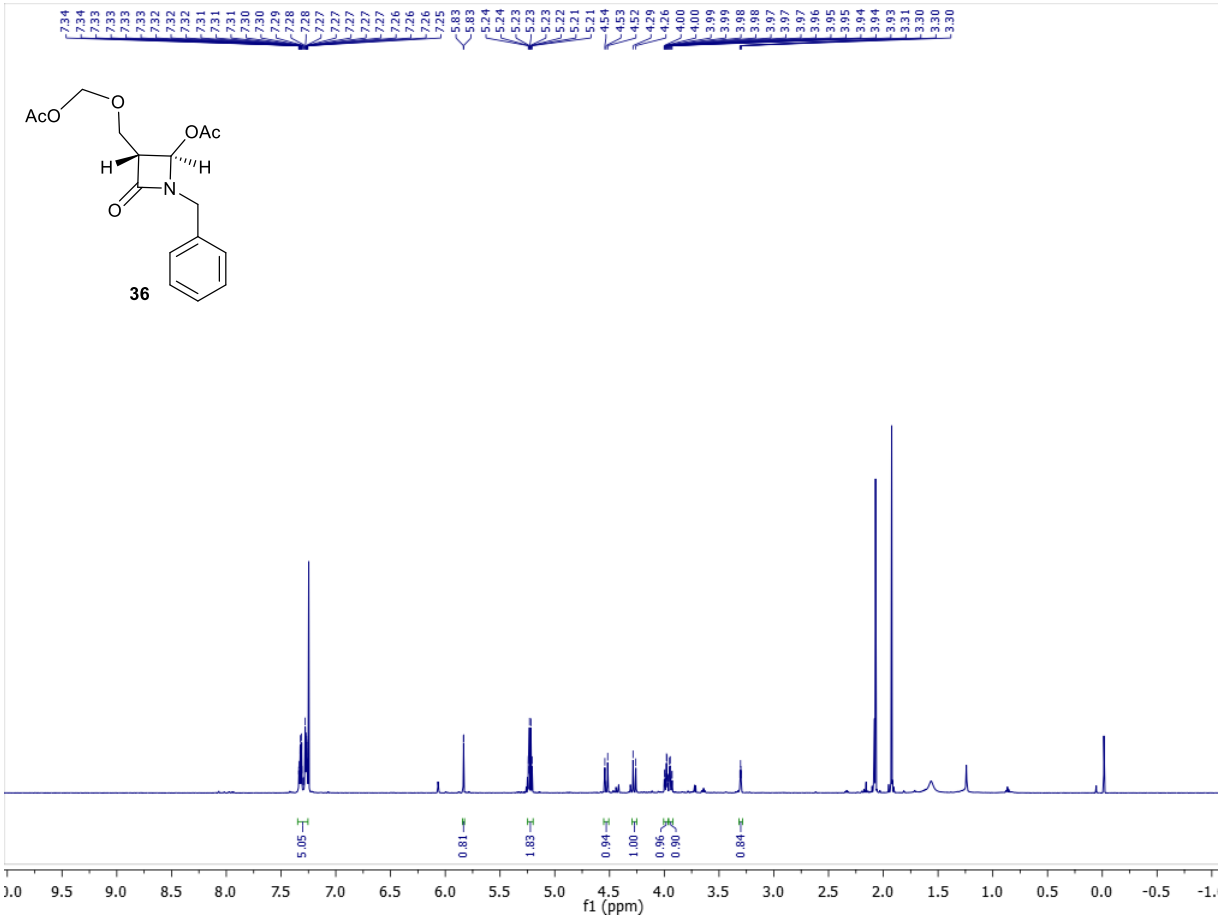


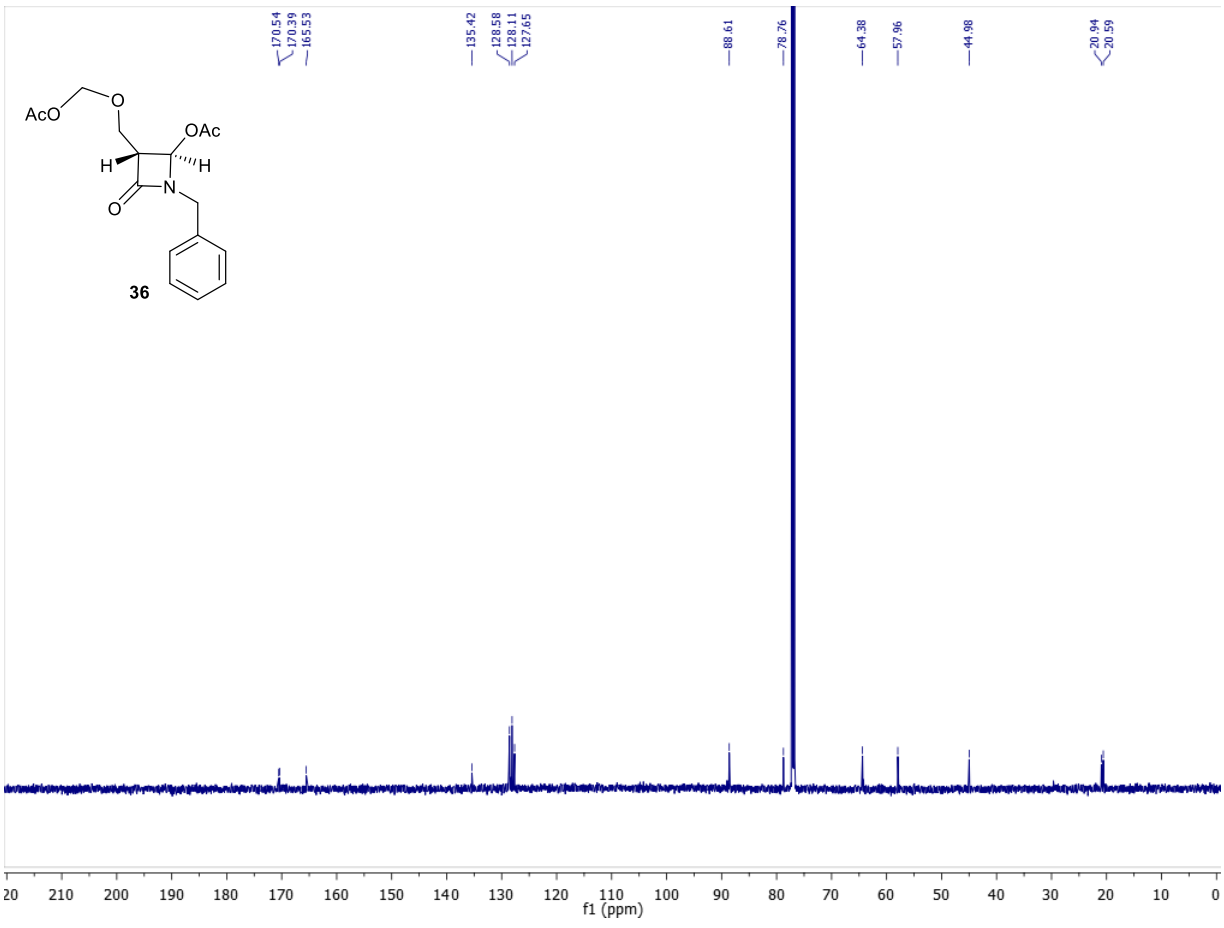

9.62
9.62
9.60
7.37
7.37
7.35
7.34
7.32
7.31
7.30
7.29
7.29
7.28
7.27
7.27
7.26
7.25
7.24
4.68
4.65
4.63
4.47
4.46
4.44
4.43
4.12
4.11
4.09
4.08
4.03
4.02
4.02
4.02
4.01
4.01
3.99
3.89
3.88
3.87
3.85
3.84
3.78
3.77
3.77
3.76
3.75
3.72
3.71
3.69
3.69
3.67
O
O
O
H
H
N
O
33
0.87
0.86
11.16
1.32
1.00
2.53
0.86
0.72
1.00
1.0
10.5
10.0
9.5
9.0
8.5
8.0
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
-0
f1 (ppm)

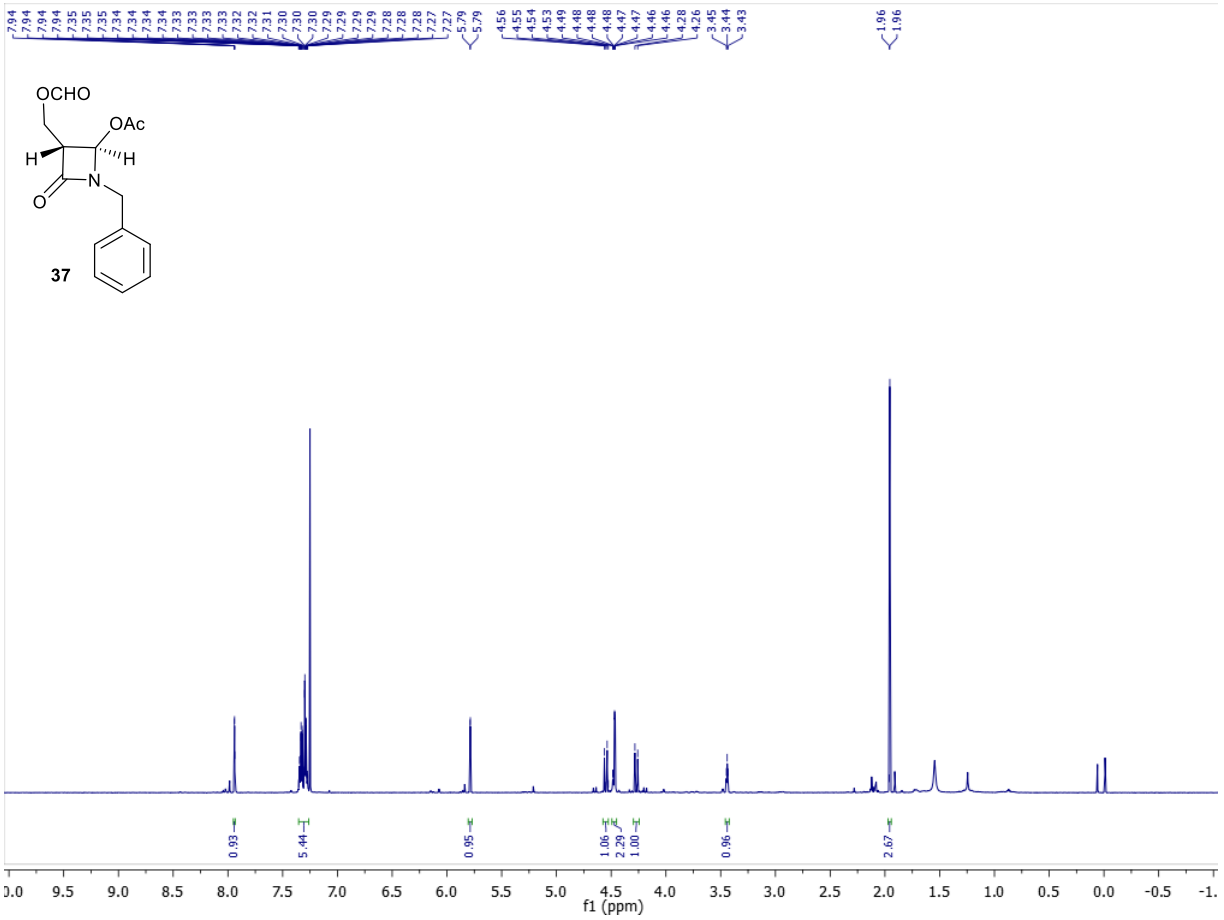

198.65
198.53
165.68
134.74
129.06
128.55
128.26
76.20
65.27
59.53
55.62
46.23
O
O
O
H
H
N
O
33
20
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)

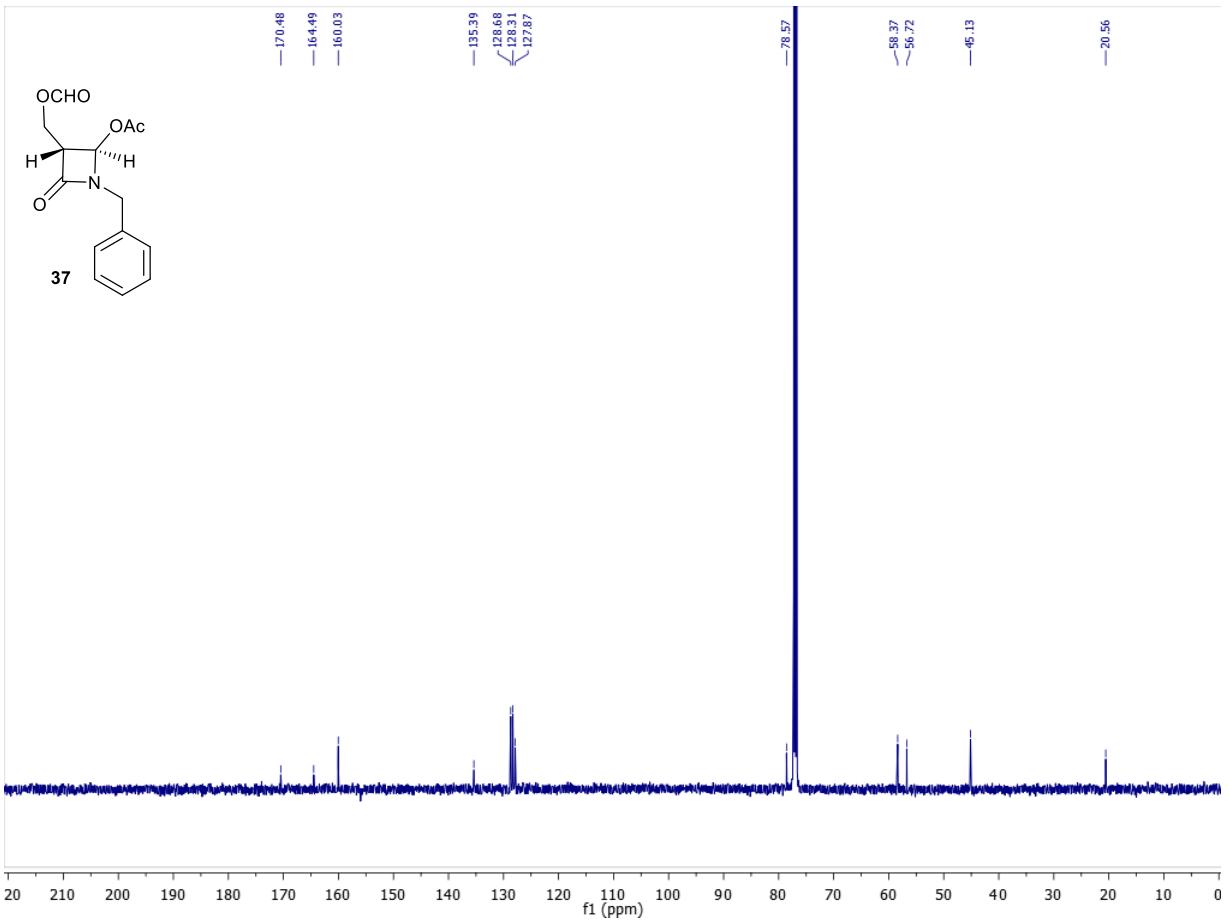

RO2C
RO2C
H
H
N
O
O
35, R=Me
7.35 7.35 7.35 7.34 7.33 7.33 7.32 7.32 7.32 7.31 7.30 7.30 7.30 7.29 7.28 7.28 7.28 7.27 7.25 7.23 7.23 7.22
4.88 4.87 4.85
4.20 4.17 4.08 4.07 4.06 4.05 4.04 4.03 4.03 4.01 4.01 4.01 3.91 3.90 3.90 3.89 3.88 3.87 3.87 3.86 3.85 3.85 3.84 3.84 3.77 3.76 3.75 3.75 3.74 3.73 3.72 3.71 3.70 3.69 3.68 3.68 3.67
3.46
2.17
1.17
1.09
3.21
2.21
3.33
5.65
1.00
1.0 10.5 10.0 9.5 9.0 8.5 8.0 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 -0.5
f1 (ppm)

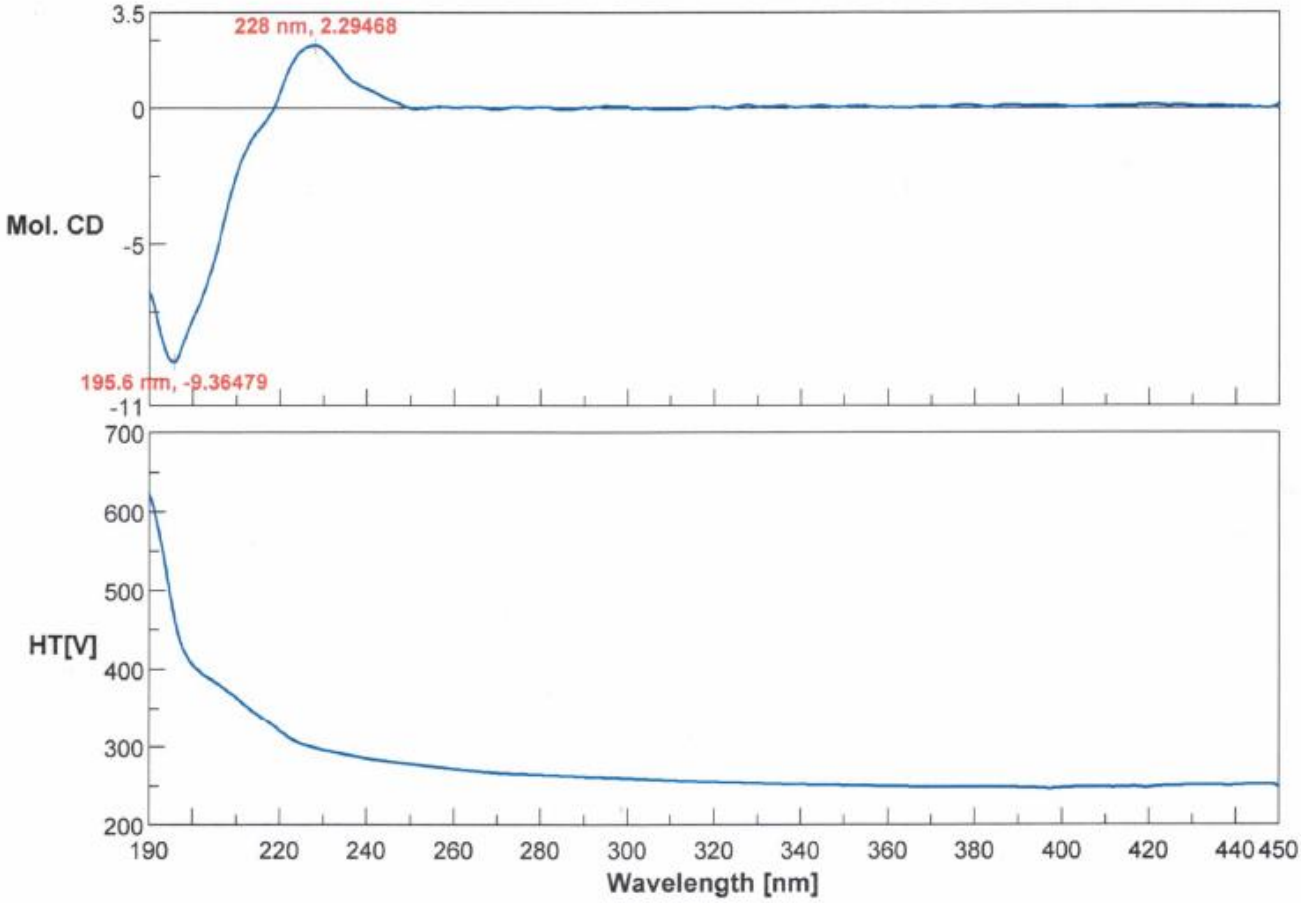

RO2C
RO2C
H
H
N
O
O
35, R=Me
170.09
169.64
165.84
134.80
128.86
128.51
127.92
68.48
65.92
54.38
52.72
52.28
51.75
45.29
220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0
f1 (ppm)


AcO
O
OAc
H
H
N
O
36
5.05
0.81
1.83
0.94
1.00
0.96
0.90
0.84
f1 (ppm)


AcO
O
OAc
H
H
N
O
36
170.54
170.39
165.53
135.42
128.58
128.11
127.65
88.61
78.76
64.38
57.96
44.98
20.94
20.59
f1 (ppm)

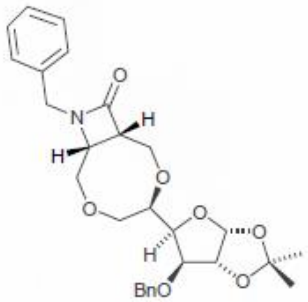

OCHO
OAc
H
H
N
O
37
7.94 7.94 7.94 7.94 7.35 7.35 7.34 7.34 7.34 7.34 7.33 7.33 7.33 7.33 7.32 7.32 7.31 7.30 7.30 7.30 7.29 7.29 7.29 7.29 7.28 7.28 7.28 7.27 7.27 5.79 5.79
4.56 4.55 4.54 4.53 4.49 4.48 4.48 4.48 4.47 4.47 4.46 4.46 4.46 4.28 4.26 3.45 3.44 3.43
1.96 1.96
0.93 5.44 0.95 1.06 2.29 1.00 0.96 2.67
f1 (ppm)

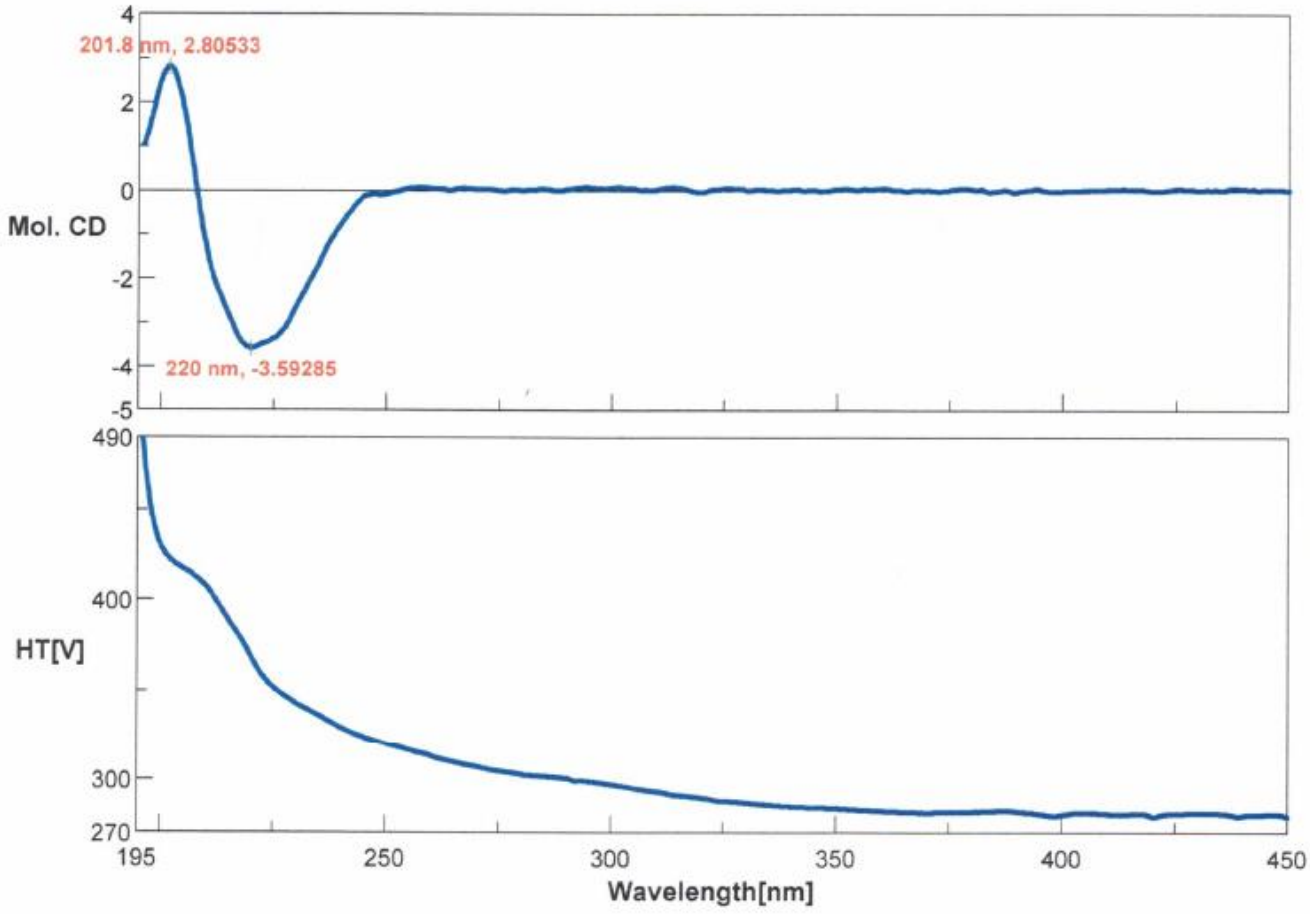

OCHO
OAc
H
H
N
O
37
170.48 164.49 160.03 135.39 128.68 128.31 127.87 78.57 58.37 56.72 45.13 20.56
f1 (ppm)



Date	2019-04-09 10:43
File name	5120b(de)
Model	J-815
Serial No.	A026861168
Band width	1 nm
Response	0.5 sec
Sensitivity	Standard
Measurement range	450 - 190 nm
Data pitch	0.2nm
Scanning speed	100 nm/min
Accumulation	5
Cell Length	0.1 cm
Concentration	0.0002069 mol/L
Solvent	MeCN
Temperature	Room Temperature
Sample name	Z-236-II
Operator	Ewa
Comment	

5120b(de)





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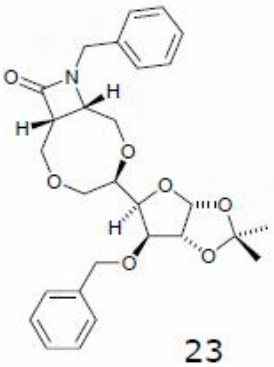

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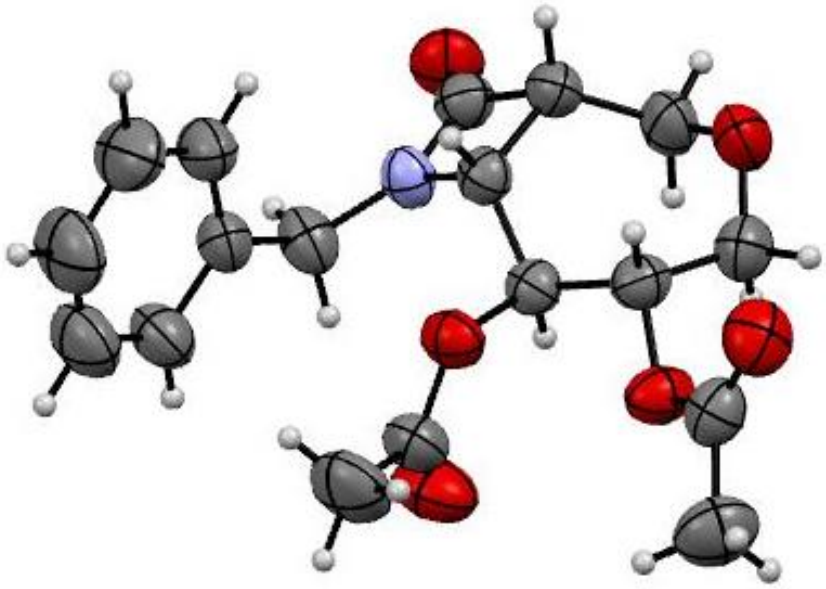

Figure S1. ORTEP plot of **30**, represented by thermal ellipsoids shown at the 50% probability level.

Colorless crystals suitable for X-ray structural analysis were obtained by slow evaporation of heptane–ethyl acetate solution of **30**. Crystal data were obtained on a Bruker X8 APEX II diffractometer with CCD detector employing graphite monochromated Cu-Kα radiation (λ=1.54178 Å) at 296(2) K and operating in the ϕ-ω scan mode. The structure was solved by direct methods SHELXS-2014[1] and refined with full-matrix least-squares calculations on F^2 using SHELX-2014. [1] All non-hydrogen atoms were refined anisotropically. The hydrogen atom positions were geometrically idealized and allowed to ride on their parent atoms. Crystallographic data for **30** have been deposited at the Cambridge Crystallographic Data Centre (deposition no. **CCDC 1975296**). Copies of these data can be obtained free of charge *via* www.ccdc.cam.ac.uk/conts/retrieving.html or from the Cambridge Crystallographic Data Centre, 12, Union Road, Cambridge CB21EZ, UK. [fax: (+44) 1223-336-033; or email: deposit@ccdc.cam.ac.uk].

[1] G. M. Sheldrick, SHELXL-2014. Program for the Refinement of Crystal Structures from Diffraction Data, University of Göttingen, Germany, 2014.

Table S1. Summary of the crystal parameters and refinement metrics for **30**.

Chemical formula	$C_{18}H_{21}NO_6$	**θ range [°]**	3.53 to 68.42
Formula weight	347.36 g/mol	**Index ranges**	-6<=h<=5, -20<=k<=19, -22<=l<=20
CCDC number	1975296	**Reflections collected**	14421
Crystal appearance	colorless needle	**Reflections unique**	3302 [R(int) = 0.0711]
Crystal size [mm]	0.070 x 0.103 x 0.558	**Completeness**	100%
Crystal system	Orthorhombic	**Absorption correction**	numerical
Space group	$P2_12_12_1$	**Max and min transmission**	0.9460 and 0.6630
***a* [Å]**	5.7158(8)	**Solution method**	direct methods
***b* [Å]**	16.615(2)	**Refinement method**	Full-matrix least-squares on F^2
***c* [Å]**	19.036(2)	**Data/restraints/parameters**	3302 / 0 / 258
***α* [°]**	90	**Goodness-of-fit on F^2**	1,017
***β* [°]**	90	**Final R indices [I>2σ(I)]**	2566 data; R_1 = 0.0427, wR2 = 0.1027
***γ* [°]**	90	**R indices (all data)**	R_1 = 0.0583, wR2 = 0.1132
***V* [Å^3]**	1807.8(4)	**Absolute structure parameter**	0.3(4)
Z	4	**Largest diff peak and hole [eÅ^{-3}]**	0.119 and -0.133
T [K]	296(2)	**Extinction coefficient**	0.0022(5)
***D*$_{calc.}$ [g/cm^3]**	1.276		
μ [mm^{-1}]	0.803		
F(000)	736		