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

Electronic Supplementary Information

Synthesis of azepane-fused pyrano[3,2-*b*]indoles by Lewis acid-catalysed oxa Diels-Alder reactions

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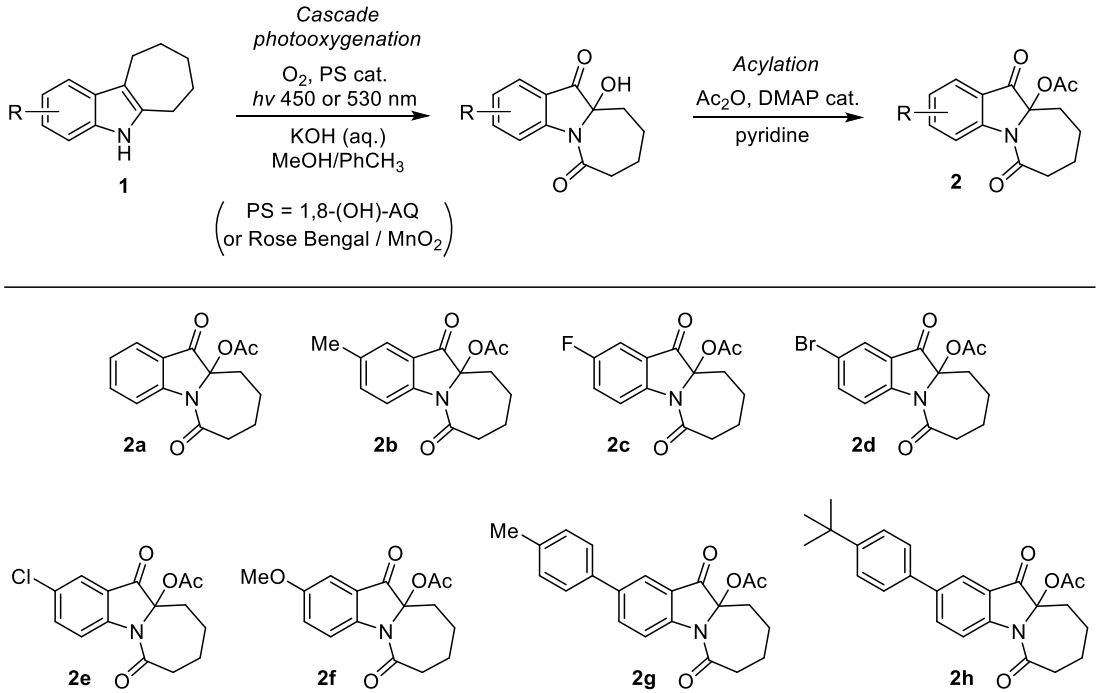
1 General information

Commercially available chemicals were used as received from suppliers unless otherwise noted. Dry solvents used were obtained from suppliers in serum-cap quality. Solvents for chromatographic separation were distilled twice prior to use. Thin-layer chromatography was carried out using silica-coated aluminium plates, silica 60 F_{254}, *Merck*. Column chromatography was performed with silica 60 (230-400 mesh, *Macherey-Nagel*). NMR spectra were recorded on *Bruker AVANCE 500 NEO* and *Bruker AVANCE 300 III* instruments, and spectra were calibrated against the (residual) solvent resonances of $CDCl_3$ (δ^H = 7.26 ppm, δ^C = 77.0 ppm), CD_3OD (δ^H = 3.31 ppm, δ^C = 49.0 ppm) and CD_3CN (δ^H = 1.94 ppm, δ^C = 118.3 ppm).^{1}H- and ^{13}C-NMR peak assignments were made based on 2D NMR spectra. IR spectra were obtained using a *Nicolet 380 FT-IR* spectrometer by *Thermo Fisher Scientific*. ESI-TOF HRMS spectrometry was performed using an *Agilent* 1200/6210 Time-of-Flight LC-MS instrument. EI HR mass spectra were obtained from a Thermo Electron MAT 95-XP instrument. X-Ray crystallographic analyses were performed on *Apex Kappa-II* and *D8 QUEST* instruments by *Bruker-AXS*.

2 Synthesis of substrates

The synthesis of the perhydroazepino[1,2-*a*]indole acetates **2** was performed by sensitized cascade photooxygenation of cycloheptaindoles **1** followed by acetylation, according to the protocols described in detail previously in references [1] and [2].



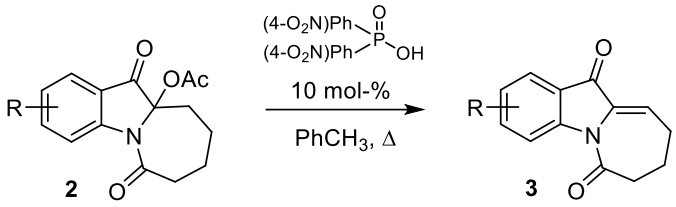
Scheme 1. Synthesis of perhydroazepino[1,2-*a*]indole acetates **2**.

[1] M. Frahm, T. von Drathen, L. M. Gronbach, A. Voss, F. Lorenz, J. Bresien, A. Villinger, F. Hoffmann, M. Brasholz, *Angew. Chem. Int. Ed.*, 2020, **59**, 12450-12454.

[2] L. M. Gronbach, A. Voss, M. Frahm, A. Villinger, J. Bresien, D. Michalik, M. Brasholz, *Org. Lett.*, 2021, **23**, 7834-7838.

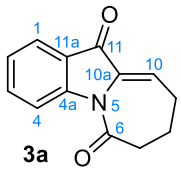
Acetates **2** were subsequently subjected to an organophosphate-catalysed dehydroacetoxylation to furnish tricyclic enones **3**.

General procedure 1:



Azepinoindole acetate **2** was dissolved in $PhCH_3$ in a 10 mL crimp cap vial. Bis(4-nitrophenyl)phosphoric acid (BNPP, 10 mol-%) was added. The vial was sealed and air was replaced by argon via cannula during three freeze-pump-thaw cycles. The mixture was stirred at 120 °C for 16 h (heating in an oil bath), then cooled to r.t. and concentrated to dryness. Column chromatography over silica gel afforded pure enone product **3**.

8,9-Dihydro-6*H*-azepino[1,2-*a*]indole-6,11(7*H*)-dione (3a)



According to general procedure 1, acetate **2a** (250.0 mg, 0.91 mmol), and BNPP (30.0 mg, 88.1 µmol) in $PhCH_3$ (3.00 mL) gave enone **3a** (colorless solid, 185.0 mg, 94%) after chromatography (silica gel, Et_2O/$PhCH_3$ 1:3).

R_f = 0.21 (silica, Et_2O/heptane 1:3), **m.p.** = 120-130°C.

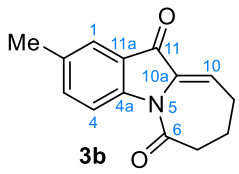
^{1}H-NMR (300 MHz, $CDCl_3$): δ = 8.48 (dt, *J* = 8.4, 0.7 Hz, 1 H, 4-H), 7.82 (ddd, *J* = 7.6, 1.4, 0.7 Hz, 1 H, 1-H), 7.64 (ddd, *J* = 8.4, 7.6, 1.4 Hz, 1 H, 3-H), 7.25 (td, *J* = 7.6, 0.7 Hz, 1 H, 2-H), 6.72 (t, *J* = 4.5 Hz, 1 H, 10-H), 2.88 – 2.81 (m, 2 H, 7-H), 2.64 (td, *J* = 6.3, 4.5 Hz, 2 H, 9-H), 2.12 – 2.00 (m, 2 H, 8-H) ppm.

^{13}C-NMR (126 MHz, $CDCl_3$): δ = 183.6 (C-11), 171.7 (C-6), 149.3 (C-4a), 136.5 (C-3), 134.3 (C-10a), 124.8 (C-2), 124.1 (C-1), 123.8 (C-11a), 122.3 (C-10), 118.7 (C-4), 39.1 (C-7), 29.4 (C-9), 19.9 (C-8) ppm.

IR: $\tilde{\nu}$ = 3330, 2950, 2840, 1720, 1660, 1470, 1450, 1405, 1310, 1120, 1025, 620 cm^{-1}.

HRMS (ESI+): *m/z* calc. for $C_{13}H_{12}NO_2^+$ $[M+H]^+$: 214.0868, found: 214.0873.

2-Methyl-8,9-dihydro-6*H*-azepino[1,2-*a*]indole-6,11(7*H*)-dione (3b)



3b

According to general procedure 1, acetate **2b** (261.0 mg, 0.91 mmol), and BNPP (30.0 mg, 88.1 µmol) in $PhCH_3$ (3.00 mL) gave enone **3b** (colorless solid, 125.0 mg, 60%) after chromatography (silica gel, $Et_2O/PhCH_3$ 1:3).

R_f = 0.41 (silica, $Et_2O/PhCH_3$ 1:3), **m.p.** = 122-129°C.

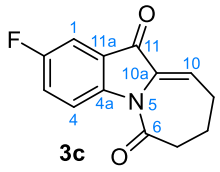
^{1}H-NMR (300 MHz, $CDCl_3$): δ = 8.42 (dd, *J* = 8.5, 0.7 Hz, 1 H, 4-H), 7.61 (dt, *J* = 2.0, 0.7 Hz, 1 H, 1-H), 7.45 (ddd, *J* = 8.5, 2.0, 0.7 Hz, 1 H, 3-H), 6.70 (t, *J* = 4.5 Hz, 1 H, 10-H), 2.86 – 2.81 (m, 2 H, 7-H), 2.63 (td, *J* = 6.4, 4.5 Hz, 2 H, 9-H), 2.40 (s, 3 H, Ar-CH_3), 2.11 – 2.00 (m, 2 H, 8-H) ppm.

^{13}C-NMR (75 MHz, $CDCl_3$): δ = 183.6 (C-11), 171.5 (C-6), 147.5 (C-4a), 137.5 (C-3), 134.7 (C-2), 134.6 (C-10a), 123.90 (C-1), 123.86 (C-11a), 122.0 (C-10), 118.4 (C-4), 39.1 (C-7), 29.4 (C-9), 20.8 (Ar-CH_3), 19.9 (C-8) ppm.

IR: $\tilde{\nu}$ = 3350, 3050, 2945, 1710, 1685, 1645, 1590, 1485, 1435, 1370, 1340, 1290, 1170, 1065, 960, 820, 770 cm^{-1}.

HRMS (ESI+): *m/z* calc. for $C_{14}H_{14}NO_2^+$ $[M+H]^+$: 228.1024, found: 228.1025.

2-Fluoro-8,9-dihydro-6*H*-azepino[1,2-*a*]indole-6,11(7*H*)-dione (3c)



3c

According to general procedure 1, acetate **2c** (131.0 mg, 0.45 mmol), and BNPP (16.9 mg, 49.7 µmol) in $PhCH_3$ (3.00 mL) gave enone **3c** (colorless solid, 75.0 mg, 72%) after chromatography (silica gel, $Et_2O/PhCH_3$ 1:3).

R*f* = 0.45 (silica, $Et_2O/PhCH_3$ 1:3), **m.p.** = 123-127°C.

^{1}H-NMR (300 MHz, $CDCl_3$): δ = 8.54 (ddd, $J_{H,H}$ = 9.1, 0.5 Hz, $J_{F,H}$ = 4.2 Hz, 1 H, 4-H), 7.45 (ddd, $J_{H,H}$ = 2.8, 0.5 Hz, $J_{F,H}$ = 6.8 Hz, 1 H, 1-H), 7.34 (ddd, $J_{H,H}$ = 9.1, 2.8 Hz, $J_{F,H}$ = 8.6 Hz, 1 H, 3-H), 6.74 (t, *J* = 4.6 Hz, 1 H, 10-H), 2.87 – 2.81 (m, 2 H, 7-H), 2.64 (td, *J* = 6.4, 4.6 Hz, 2 H, 9-H), 2.11 – 2.01 (m, 2 H, 8-H) ppm.

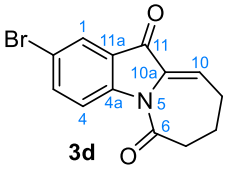
^{13}C-NMR (75 MHz, $CDCl_3$): δ = 182.7 (C-11), 171.5 (C-6), 159.7 (d, $J_{C,F}$ = 246.7 Hz, C-2), 145.6 (d, $J_{C,F}$ = 1.8 Hz, C-4a), 134.5 (C-10a), 125.2 (d, $J_{C,F}$ = 7.6 Hz, C-11a), 123.6 (d, $J_{C,F}$ = 23.8 Hz, C-3), 123.3 (C-10), 120.3 (d, $J_{C,F}$ = 7.4 Hz, C-4), 109.8 (d, $J_{C,F}$ = 23.5 Hz, C-1), 38.9 (C-7), 29.4 (C-9), 19.8 (C-8) ppm.

^{19}F-NMR (282 MHz, $CDCl_3$): δ = -116.74 ppm.

IR: $\tilde{\nu}$ = 3210, 2965, 2930, 2880, 1735, 1675, 1525, 1485, 1455, 1380, 1265, 1235, 1195, 1105, 1035, 810, 755 cm^{-1}.

HRMS (ESI+): *m/z* calc. for $C_{13}H_{11}FNO_2^+$ $[M+H]^+$: 232.0773, found: 232.0776.

2-Bromo-8,9-dihydro-6*H*-azepino[1,2-*a*]indole-6,11(7*H*)-dione (3d)



3d

According to general procedure 1, acetate **2d** (157.0 mg, 0.45 mmol), and BNPP (15.3 mg, 44.9 µmol) in $PhCH_3$ (3.00 mL) gave enone **3d** (colorless solid, 102.0 mg, 78%) after chromatography (silica gel, Et_2O/$PhCH_3$ 1:3).

R_f = 0.28 (silica, Et_2O/heptane 1:3), **m.p.** = 129-134°C.

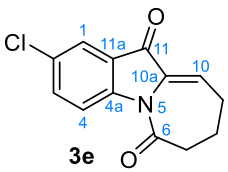
^{1}H-NMR (300 MHz, $CDCl_3$): δ = 8.44 (dd, *J* = 8.9, 0.4 Hz, 1 H, 4-H), 7.91 (dd, *J* = 2.2, 0.4 Hz, 1 H, 1-H), 7.71 (dd, *J* = 8.9, 2.2 Hz, 1 H, 3-H), 6.73 (t, *J* = 4.5 Hz, 1 H, 10-H), 2.87 – 2.80 (m, 2 H, 7-H), 2.64 (td, *J* = 6.3, 4.5 Hz, 2 H, 9-H), 2.10 – 2.00 (m, 2 H, 8-H) ppm.

^{13}C-NMR (75 MHz, $CDCl_3$): δ = 182.1 (C-11), 171.6 (C-6), 147.9 (C-4a), 138.8 (C-3), 134.0 (C-10a), 126.7 (C-1), 125.5 (C-11a), 123.2 (C-10), 120.3 (C-4), 117.9 (C-2), 39.0 (C-7), 29.4 (C-9), 19.7 (C-8) ppm.

IR: $\tilde{\nu}$ = 3315, 2970, 2925, 2880, 1715, 1675, 1600, 1515, 1465, 1380, 1260, 1185, 1100, 1030, 875, 800, 755 cm^{-1}.

HRMS (ESI+): *m/z* calc. for $C_{13}H_{11}{}^{79}BrNO_2^+$ $[M+H]^+$: 291.9973, found: 291.9973.

2-Chloro-8,9-dihydro-6*H*-azepino[1,2-*a*]indole-6,11(7*H*)-dione (3e)



3e

According to general procedure 1, acetate **2e** (138.0 mg, 0.45 mmol), and BNPP (16.9 mg, 49.7 µmol) in $PhCH_3$ (3.00 mL) gave enone **3e** (colorless solid, 96.0 mg, 86%) after chromatography (silica gel, Et_2O/$PhCH_3$ 1:3).

R_f = 0.28 (silica, Et_2O/heptane 1:3), **m.p.** = 127-132°C.

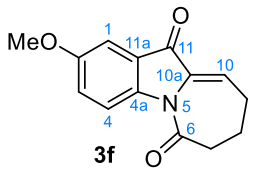
^{1}H-NMR (500 MHz, $CDCl_3$): δ = 8.49 (d, *J* = 8.9 Hz, 1 H, 4-H), 7.74 (d, *J* = 2.3 Hz, 1 H, 1-H), 7.56 (dd, *J* = 8.9, 2.3 Hz, 1 H, 3-H), 6.73 (t, *J* = 4.5 Hz, 1 H, 10-H), 2.86 – 2.82 (m, 2 H, 7-H), 2.64 (td, *J* = 6.4, 4.5 Hz, 2 H, 9-H), 2.08 – 2.02 (m, 2 H, 8-H) ppm.

^{13}C-NMR (126 MHz, $CDCl_3$): δ = 182.2 (C-11), 171.5 (C-6), 147.5 (C-4a), 136.0 (C-3), 134.1 (C-10a), 130.5 (C-2), 125.0 (C-11a), 123.6 (C-1), 123.3 (C-10), 119.9 (C-4), 38.9 (C-7), 29.4 (C-9), 19.7 (C-8) ppm.

IR: $\tilde{\nu}$ = 3315, 2970, 2925, 2880, 1715, 1680, 1600, 1515, 1465, 1375, 1265, 1185, 1100, 1030, 875, 800, 755 cm^{-1}.

HRMS (ESI+): *m/z* calc. for $C_{13}H_{11}ClNO_2^+$ $[M+H]^+$: 248.0478, found: 248.0485.

2-Methoxy-8,9-dihydro-6*H*-azepino[1,2-*a*]indole-6,11(7*H*)-dione (3f)



3f

According to general procedure 1, acetate **2f** (137.0 mg, 0.45 mmol), and BNPP (15.3 mg, 45.0 µmol) in $PhCH_3$ (3.00 mL) gave enone **3f** (colorless solid, 91.0 mg, 83%) after chromatography (silica gel, Et_2O/$PhCH_3$ 1:3).

R_f = 0.20 (silica, Et_2O/$PhCH_3$ 1:3), **m.p.** = 145-151°C.

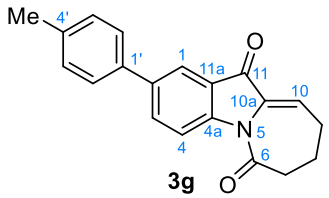
^{1}H-NMR (500 MHz, $CDCl_3$): δ = 8.47 (d, *J* = 9.0 Hz, 1 H, 4-H), 7.26 (d, *J* = 2.9 Hz, 1 H, 1-H), 7.23 (dd, *J* = 9.0, 2.9 Hz, 1 H, 3-H), 6.72 (t, *J* = 4.5 Hz, 1 H, 10-H), 3.84 (s, 3 H, O-CH_3), 2.86 – 2.81 (m, 2 H, 7-H), 2.63 (td, *J* = 6.3, 4.5 Hz, 2 H, 9-H), 2.09 – 2.03 (m, 2 H, 8-H) ppm.

^{13}C-NMR (126 MHz, $CDCl_3$): δ = 183.5 (C-11), 171.3 (C-6), 156.9 (C-2), 144.0 (C-4a), 134.7 (C-10a), 124.9 (C-3), 124.7 (C-11a), 122.5 (C-10), 119.9 (C-4), 105.4 (C-1), 55.8 (O-CH_3), 39.0 (C-7), 29.4 (C-9), 19.9 (C-8) ppm.

IR: $\tilde{\nu}$ = 2965, 2940, 2845, 1725, 1680, 1655, 1490, 1450, 1440, 1380, 1320, 1285, 1245, 1130, 1060, 1035, 940, 805, 740 cm^{-1}.

HRMS (ESI+): *m/z* calc. for $C_{14}H_{14}NO_3^+$ $[M+H]^+$: 244.0974, found: 244.0977.

2-(*p*-Tolyl)-8,9-dihydro-6*H*-azepino[1,2-*a*]indole-6,11(7*H*)-dione (3g)



3g

According to general procedure 1, acetate **2g** (163.0 mg, 0.45 mmol), and BNPP (15.3 mg, 45.0 µmol) in $PhCH_3$ (3.00 mL) gave enone **3g** (colorless solid, 78.0 mg, 57%) after chromatography (silica gel, $Et_2O/PhCH_3$ 1:3).

R_f = 0.25 (silica, $Et_2O/PhCH_3$ 1:3), **m.p.** = 129-136°C.

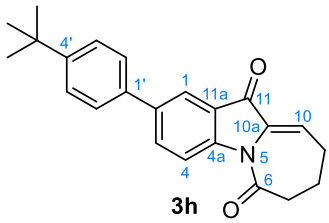
^{1}H-NMR (500 MHz, $CDCl_3$): δ = 8.58 (dd, *J* = 8.7, 0.6 Hz, 1 H, 4-H), 8.02 (dd, *J* = 2.1, 0.6 Hz, 1 H, 1-H), 7.88 (dd, *J* = 8.7, 2.1 Hz, 1 H, 3-H), 7.51 (m_c, 2 H, 2'-H), 7.26 (m_c, 2 H, 3'-H), 6.75 (t, *J* = 4.5 Hz, 1 H, 10-H), 2.90 – 2.83 (m, 2 H, 7-H), 2.65 (td, *J* = 6.3, 4.5 Hz, 2 H, 9-H), 2.40 (s, 3 H, Ar-CH_3), 2.13 – 2.03 (m, 2 H, 8-H) ppm.

^{13}C-NMR (126 MHz, $CDCl_3$): δ = 183.7 (C-11), 171.7 (C-6), 148.3 (C-4a), 137.9 (C-2), 137.6 (C-4'), 136.4 (C-1'), 135.1 (C-3), 134.6 (C-10a), 129.7 (C-3'), 126.7 (C-2'), 124.3 (C-11a), 122.5 (C-10), 121.8 (C-1), 118.9 (C-4), 39.1 (C-7), 29.4 (C-9), 21.1 (Ar-CH_3), 19.9 (C-8) ppm.

IR: $\tilde{\nu}$ = 3035, 2935, 2870, 1725, 1685, 1655, 1620, 1485, 1375, 1345, 1310, 1265, 1195, 1130, 1065, 815, 735 cm^{-1}.

HRMS (ESI+): *m/z* calc. for $C_{20}H_{18}NO_2^+$ $[M+H]^+$: 303.1337, found: 303.1344.

2-(4-(*tert*-Butyl)phenyl)-8,9-dihydro-6*H*-azepino[1,2-*a*]indole-6,11(7*H*)-dione (3h)



3h

According to general procedure 1, acetate **2h** (182.0 mg, 0.45 mmol), and BNPP (15.3 mg, 45.0 µmol) in $PhCH_3$ (3.00 mL) gave enone **3h** (colorless solid, 114.0 mg, 73%) after chromatography (silica gel, $Et_2O/PhCH_3$ 1:3).

R_f = 0.26 (silica, $Et_2O/PhCH_3$ 1:3), **m.p.** = 194-207°C.

^{1}H-NMR (500 MHz, $CDCl_3$): δ = 8.59 (d, *J* = 8.7 Hz, 1 H, 4-H), 8.05 (d, *J* = 2.1 Hz, 1 H, 1-H), 7.90 (dd, *J* = 8.7, 2.1 Hz, 1 H, 3-H), 7.56 (m_c, 2 H, 2'-H), 7.48 (m_c, 2 H, 3'-H), 6.76 (t, *J* = 4.5 Hz, 1 H, 10-H), 2.89 – 2.85 (m, 2 H, 7-H), 2.66 (td, *J* = 6.4, 4.5 Hz, 2 H, 9-H), 2.11 – 2.05 (m, 2 H, 8-H), 1.37 (s, 9 H, *t*-Bu) ppm.

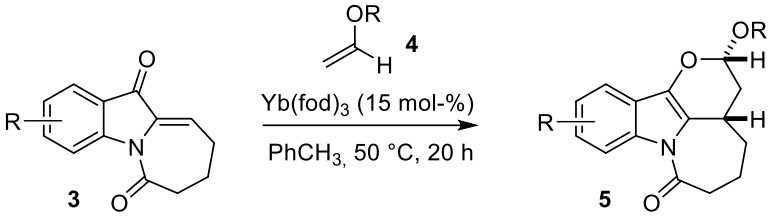
^{13}C-NMR (126 MHz, $CDCl_3$): δ = 183.6 (C-11), 171.7 (C-6), 150.9 (C-4'), 148.4 (C-4a), 137.8 (C-2), 136.4 (C-1'), 135.2 (C-3), 134.6 (C-10a), 126.5 (C-2'), 125.9 (C-3'), 124.3 (C-11a), 122.4 (C-10), 121.8 (C-1), 118.9 (C-4), 39.1 (C-7), 34.6 (*t*-Bu), 31.3 (*t*-Bu), 29.4 (C-9), 19.9 (C-8) ppm.

IR: $\tilde{\nu}$ = 2970, 2910, 2875, 1725, 1685, 1660, 1620, 1475, 1370, 1310, 1260, 1195, 1090, 1030, 800, 735 cm^{-1}.

HRMS (ESI+): *m/z* calc. for $C_{23}H_{24}NO_2^+$ $[M+H]^+$: 346.1807, found: 346.1811.

3 Lewis acid-catalysed oxa Diels-Alder reactions

General procedure 2:

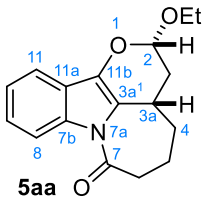


Enone **3** was dissolved in $PhCH_3$ in a 10 mL crimp cap vial. $Yb(fod)_3$ (15 mol-%) was added to the stirred solution, followed by vinyl ether **4** (10 equiv.). The vial was sealed and argon was bubbled through the mixture via cannula for 5 min. The mixture was stirred at 50°C for 20 h (heating in an oil bath). The mixture was concentrated to dryness, and the crude product was analyzed by ^{1}H-NMR spectroscopy to determine diastereomer ratio (*d.r.*). Thereafter, column chromatography over silica gel afforded the pure cycloadduct **5**.

Technical note:

Even though cycloadducts **5** are well-soluble in $CDCl_3$, several derivatives showed broadened ^{1}H-NMR signals in this solvent. In these cases, use of CD_3OD or CD_3CN led to well-resolved ^{1}H-NMR spectra.

(2*S,3a*S**)-2-Ethoxy-2,3,3a,4,5,6-hexahydro-7*H*-1-oxa-7a-azacyclohepta[*jk*]fluoren-7-one (5aa)**



According to general procedure 2, enone **3a** (21.3 mg, 0.10 mmol), ethyl vinyl ether (**4a**, 95.0 µL, 0.99 mmol) and $Yb(fod)_3$ (15.9 mg, 15 µmol) in $PhCH_3$ (1.00 mL) gave compound **5aa** (colorless solid, 20.0 mg, 70%) after chromatography (silica gel, $Et_2O/PhCH_3$ 1:3).

Reaction on 1 mmol scale:

Enone **3a** (213.0 mg, 1.00 mmol) was dissolved in $PhCH_3$ (5.00 mL) in a 10 mL crimp cap vial. $Yb(fod)_3$ (159.0 mg, 0.15 mmol) was added to the stirred solution, followed by ethyl vinyl ether (**4a**, 950.0 µL, 9.92 mmol). The vial was sealed and argon was bubbled through the mixture via cannula for 5 min. The mixture was stirred at 50°C for 20 h (heating in an oil bath). The mixture was concentrated to dryness, and column chromatography (silica gel, $Et_2O/PhCH_3$ 1:3) gave compound **5aa** (colorless solid, 227.0 mg, 79%).

R_f = 0.32 (silica, Et_2O/heptane 1:3), **m.p.** = 125-131°C.

^{1}H-NMR (500 MHz, CD_3CN): δ = 8.44 (dd, *J* = 8.1, 1.2 Hz, 1 H, 8-H), 7.47 (dt, *J* = 7.6, 1.2, Hz, 1 H, 11-H), 7.30 (ddd, *J* = 8.1, 7.6, 1.2 Hz, 1 H, 9-H), 7.26 (td, *J* = 7.6, 1.2 Hz, 1 H, 10-H), 5.34 (dd, *J* = 7.6, 2.1 Hz, 1 H, 2-H), 4.00 (dq, *J* = 9.7, 7.1 Hz, 1 H, O-CH_2^a), 3.72 (dq, *J* = 9.7, 7.1 Hz, 1 H, O -CH_2^b), 3.39 – 3.30 (m, 1 H, 3a-H), 3.04 (m_c, 1 H, 6-H^a), 2.67 (dt, *J* = 14.6, 3.7 Hz, 1 H, 6-H^b), 2.23 (ddd, *J* = 13.6, 6.7, 2.1 Hz, 1 H, 3-H^a), 2.04 – 1.88 (m, 3 H, 4-H^a, 5-H^a, 5-H^b), 1.81 – 1.69 (m, 2 H, 3-H^b, 4-H^b), 1.23 (t, *J* = 7.1 Hz, 3 H, CH_3) ppm.

^{13}C-NMR (126 MHz, CD_3CN): δ = 173.6 (C-7), 136.9 (C-11b), 134.9 (C-7b), 125.8 (C-9), 124.3 (C-10), 123.4 (C-11a), 120.5 (C-3a^1), 117.3 (C-11), 117.1 (C-8), 101.4 (C-2), 65.4 (O-CH_2), 36.6 (C-6), 35.5 (C-3), 30.5 (C-4), 30.2 (C-3a), 21.3 (C-5), 15.6 (CH_3) ppm.

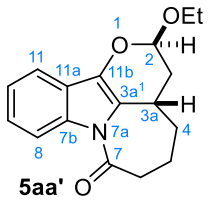
IR: $\tilde{\nu}$ = 3385, 2940, 1690, 1460, 1305, 1235, 1125, 985, 750 cm^{-1}.

HRMS (ESI+): *m/z* calc. for $C_{17}H_{20}NO_3^+$ $[M+H]^+$: 286.1443, found: 286.1446.

Minor diastereomer:

The minor *exo*-diastereomer could as well be isolated and characterized by NMR spectroscopy:

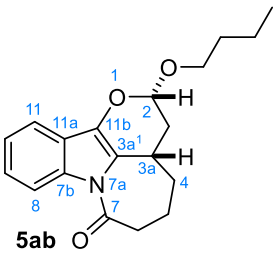
(2*R**,3a*S**)-2-Ethoxy-2,3,3a,4,5,6-hexahydro-7*H*-1-oxa-7a-azacyclohepta[*jk*]-fluoren-7-one (**5aa'**)



^{1}H-NMR (500 MHz, CD_3OD): δ = 8.38 (dt, *J* = 8.2, 1.2 Hz, 1 H, 8-H), 7.44 (m_c, 1 H, 11-H), 7.27 (ddd, *J* = 8.2, 7.3, 1.2 Hz, 1 H, 9-H), 7.23 (td, *J* = 7.3, 1.2 Hz, 1 H, 10-H), 5.41 (t, *J* = 2.5 Hz, 1 H, 2-H), 3.92 (dq, *J* = 9.8, 7.1 Hz, 1 H, O-CH_2^a), 3.75 (dq, *J* = 9.8, 7.1 Hz, 1 H, O -CH_2^b), 3.38 – 3.33 (m, 1 H, 3a-H), 3.13 – 3.05 (m, 1 H, 6-H^a), 2.66 (dt, *J* = 14.0, 4.1 Hz, 1 H, 6-H^b), 2.23 (ddd, *J* = 13.3, 6.0, 2.5 Hz, 1 H, 3-H^a), 2.15 – 2.01 (m, 3 H, 4-H^a, 5-H^a, 5-H^b), 1.66 (ddd, *J* = 13.3, 10.7, 2.5 Hz, 1 H, 3-H^b), 1.59 – 1.50 (m, 1 H, 4-H^b), 1.21 (t, *J* = 7.1 Hz, 3 H, CH_3) ppm.

^{13}C-NMR (126 MHz, CD_3OD): δ = 174.4 (C-7), 136.6 (C-11b), 135.1 (C-7b), 125.9 (C-9), 124.6 (C-10), 124.1 (C-11a), 120.7 (C-3a^1), 117.4 (C-11), 117.3 (C-8), 99.2 (C-2), 65.3 (O-CH_2), 37.0 (C-6), 35.6 (C-3), 31.1 (C-4), 27.8 (C-3a), 22.0 (C-5), 15.5 (CH_3) ppm.

(2*S,3a*S**)-2-Butoxy-2,3,3a,4,5,6-hexahydro-7*H*-1-oxa-7a-azacyclohepta[*jk*]fluoren-7-one (5ab)**



According to general procedure 2, enone **3a** (21.3 mg, 0.10 mmol), *n*-butyl vinyl ether (**4b**, 128.0 µL, 1.00 mmol) and Yb(fod)$_3$ (15.9 mg, 15 µmol) in $PhCH_3$ (1.00 mL) gave compound **5ab** (colorless solid, 24.0 mg, 77%) after chromatography (silica gel, Et_2O/$PhCH_3$ 1:3).

R*f* = 0.35 (silica, Et_2O/heptane 1:3), **m.p.** = 136-139°C.

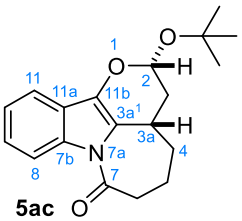
^{1}H-NMR (500 MHz, $CDCl_3$): δ = 8.48 (dt, *J* = 8.3, 1.0 Hz, 1 H, 8-H), 7.51 (dt, *J* = 7.6, 1.0 Hz, 1 H, 11-H), 7.32 (ddd, *J* = 8.3, 7.6, 1.0 Hz, 1 H, 9-H), 7.26 (td, *J* = 7.6, 1.0 Hz, 1 H, 10-H), 5.31 (dd, *J* = 6.9, 2.1 Hz, 1 H, 2-H), 4.00 (dt, *J* = 9.6, 6.6 Hz, 1 H, O-CH_2^a), 3.63 (dt, *J* = 9.6, 6.6 Hz, 1 H, O-CH_2^b), 3.28 (dtd, *J* = 11.5, 6.9, 3.5 Hz, 1 H, 3a-H), 3.01 – 2.92 (m, 1 H, 6-H^a), 2.77 (dt, *J* = 15.1, 4.0 Hz, 1 H, 6-H^b), 2.25 (ddd, *J* = 13.6, 6.9, 2.1 Hz, 1 H, 3-H^a), 2.03 – 1.95 (m, 3 H, 4-H^a, 5-H^a, 5-H^b), 1.90 (dt, *J* = 13.6, 6.9 Hz, 1 H, 3-H^b), 1.87 – 1.81 (m, 1 H, 4-H^b), 1.65 – 1.58 (m, 2 H, CH_2), 1.39 (m$_c$, 2 H, CH_2), 0.92 (t, *J* = 7.4 Hz, 3 H, CH_3) ppm.

^{13}C-NMR (126 MHz, $CDCl_3$): δ = 172.4 (C-7), 136.7 (C-11b), 134.1 (C-7b), 125.2 (C-9), 123.4 (C-10), 122.5 (C-11a), 118.2 (C-3a^1), 116.7 (C-11), 116.5 (C-8), 100.1 (C-2), 69.1 (O-CH_2), 35.9 (C-6), 34.4 (C-3), 31.7 (CH_2), 29.9 (C-4), 29.4 (C-3a), 20.6 (C-5), 19.2 (CH_2), 13.8 (CH_3) ppm.

IR: $\tilde{\nu}$ = 3360, 2945, 1735, 1655, 1470, 1380, 1305, 765 cm^{-1}.

HRMS (ESI+): *m/z* calc. for $C_{19}H_{24}NO_3^+$ $[M+H]^+$: 314.1756, found: 314.1760.

(2*S,3a*S**)-2-(*tert*-Butoxy)-2,3,3a,4,5,6-hexahydro-7*H*-1-oxa-7a-azacyclohepta[*jk*]-fluoren-7-one (5ac)**



According to general procedure 2, enone **3a** (21.3 mg, 0.10 mmol), *tert*-butyl vinyl ether (**4c**, 131.0 µL, 1.00 mmol) and Yb(fod)$_3$ (15.9 mg, 15 µmol) in $PhCH_3$ (1.00 mL) gave compound **5ac** (colorless solid, 28.0 mg, 89%) after chromatography (silica gel, Et_2O/$PhCH_3$ 1:3).

R_f = 0.34 (silica, Et_2O/heptane 1:3), **m.p.** = 110°C.

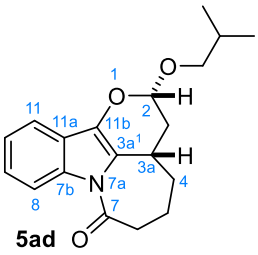
^{1}H-NMR (500 MHz, CD_3CN): δ = 8.44 (dt, *J* = 8.2, 1.1 Hz, 1 H, 8-H), 7.44 (dt, *J* = 7.6, 1.1 Hz, 1 H, 11-H), 7.30 (ddd, *J* = 8.2, 7.6, 1.1 Hz, 1 H, 9-H), 7.25 (td, *J* = 7.6, 1.1 Hz, 1 H, 10-H), 5.59 (dd, *J* = 7.8, 2.1 Hz, 1 H, 2-H), 3.42 – 3.35 (m, 1 H, 3a-H), 3.08 – 3.00 (m, 1 H, 6-H^a), 2.68 (dt, *J* = 14.4, 3.8 Hz, 1 H, 6-H^b), 2.14 (ddd, *J* = 13.5, 6.6, 2.1 Hz, 1 H, 3-H^a), 2.04 – 1.90 (m, 3 H, 4-H^a, 5-H^a, 5-H^b), 1.78 – 1.69 (m, 2 H, 3-H^b, 4-H^b), 1.32 (s, 3 H, ^{t}Bu) ppm.

^{13}C-NMR (126 MHz, CD_3CN): δ = 173.6 (C-7), 137.4 (C-11b), 134.9 (C-7b), 125.7 (C-9), 124.2 (C-10), 123.6 (C-11a), 120.3 (C-3a^1), 117.3 (C-11), 117.1 (C-8), 96.3 (C-2), 76.4 (O-^{t}Bu), 36.9 (C-3), 36.6 (C-6), 30.6 (C-4), 30.5 (C-3a), 28.9 (^{t}Bu), 21.3 (C-5) ppm.

IR: $\tilde{\nu}$ = 3375, 2975, 2930, 2875, 1730, 1685, 1465, 1380, 1345, 1260, 1185, 1155, 1120, 935, 760 cm^{-1}.

HRMS (ESI+): *m/z* calc. for $C_{19}H_{24}NO_3^+$ [M+H]$^+$: 314.1756, found: 314.1758.

(2*S,3a*S**)-2-Isobutoxy-2,3,3a,4,5,6-hexahydro-7*H*-1-oxa-7a-azacyclohepta[*jk*]-fluoren-7-one (5ad)**



According to general procedure 2, enone **3a** (21.3 mg, 0.10 mmol), isobutyl vinyl ether (**4d**, 130.0 µL, 1.00 mmol) and Yb(fod)$_3$ (15.9 mg, 15 µmol) in $PhCH_3$ (1.00 mL) gave compound **5ad** (colorless solid, 26.0 mg, 83%) after chromatography (silica gel, Et_2O/$PhCH_3$ 1:3).

R_f = 0.59 (silica, Et_2O/$PhCH_3$ 1:3), **m.p.** = 87-96°C.

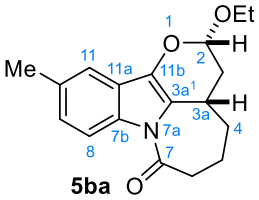
^{1}H-NMR (500 MHz, CD_3CN): δ = 8.40 (dt, *J* = 8.2, 0.8 Hz, 1 H, 8-H), 7.46 (dt, *J* = 7.4, 0.8 Hz, 1 H, 11-H), 7.30 (ddd, *J* = 8.4, 7.4, 0.8 Hz, 1 H, 9-H), 7.26 (td, *J* = 7.4, 0.8 Hz, 1 H, 10-H), 5.33 (dd, *J* = 6.5, 2.2 Hz, 1 H, 2-H), 3.71 (dd, *J* = 9.4, 6.6 Hz, 1 H, O-CH_2^a), 3.42 (dd, *J* = 9.4, 6.6 Hz, 1 H, O-CH_2^b), 3.35 (m_c, 1H, 3a-H), 3.06 – 2.98 (m, 1 H, 6-H^a), 2.68 – 2.62 (m, 1 H, 6-H^b), 2.24 (ddd, *J* = 13.7, 6.9, 2.2 Hz, 1 H, 3-H^a), 2.00 – 1.96 (m, 2 H, 4-H^a, 5-H^a), 1.89 – 1.80 (m, 4 H, 3-H^b, 4-H^b, 5-H^b, CH), 0.89 (d, *J* = 6.7 Hz, 3 H, CH_3), 0.88 (d, *J* = 6.7 Hz, 3 H, CH_3), ppm.

^{13}C-NMR (126 MHz, CD_3CN): δ = 173.6 (C-7), 136.6 (C-11b), 134.8 (C-7b), 125.7 (C-9), 124.2 (C-10), 123.4 (C-11a), 120.3 (C-3a^1), 117.2 (C-11), 117.0 (C-8), 101.3 (C-2), 76.4 (O-CH_2), 36.5 (C-6), 34.8 (C-3), 30.5 (C-4), 29.7 (C-3a), 29.3 (CH), 21.3 (C-5), 19.4 (2 × CH_3) ppm.

IR: $\tilde{\nu}$ = 3290, 2965, 2935, 2875, 1725, 1675, 1610, 1465, 1385, 1310, 1260, 1185, 920, 750, 670 cm^{-1}.

HRMS (ESI+): *m/z* calc. for $C_{19}H_{24}NO_3^+$ [M+H]$^+$: 314.1756, found: 314.1755.

(2*S,3a*S**)-2-Ethoxy-10-methyl-2,3,3a,4,5,6-hexahydro-7*H*-1-oxa-7a-azacyclohepta[*jk*]-fluoren-7-one (5ba)**



5ba

According to general procedure 2, enone **3b** (22.7 mg, 0.10 mmol), ethyl vinyl ether (**4a**, 95.0 µL, 0.99 mmol) and Yb(fod)$_3$ (15.9 mg, 15 µmol) in $PhCH_3$ (1.00 mL) gave compound **5ba** (colorless solid, 25.0 mg, 84%) after chromatography (silica gel, Et_2O/$PhCH_3$ 1:3).

R$_f$ = 0.61 (silica, Et_2O/$PhCH_3$ 1:3), **m.p.** = 107-109°C.

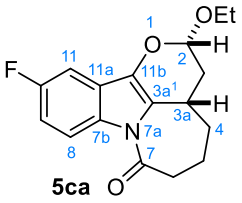
^{1}H-NMR (300 MHz, CD_3OD): δ = 8.22 (d, *J* = 8.5 Hz, 1 H, 8-H), 7.24 – 7.19 (m, 1 H, 11-H), 7.11 – 7.05 (m, 1 H, 9-H), 5.31 (dd, *J* = 7.1, 2.1 Hz, 1 H, 2-H), 4.01 (dq, *J* = 9.6, 7.1 Hz, 1 H, O-CH_2^a), 3.74 (dq, *J* = 9.6, 7.1 Hz, 1 H, O-CH_2^b), 3.35 – 3.24 (m, 1 H, 3a-H), 3.10 – 2.97 (m, 1 H, 6-H^a), 2.67 – 2.57 (m, 1 H, 6-H^b), 2.40 (s, 3 H, Ar-CH_3), 2.22 (ddd, *J* = 13.6, 6.8, 2.1 Hz, 1 H, 3-H^a), 2.05 – 1.90 (m, 3 H, 4-H^a, 5-H^a, 5-H^b), 1.82 – 1.68 (m, 2 H, 3-H^b, 4-H^b), 1.25 (t, *J* = 7.1 Hz, 3 H, CH3) ppm.

^{13}C-NMR (75 MHz, CD_3OD): δ = 174.4 (C-7), 137.7 (C-11b), 134.4 (C-10), 133.6 (C-7b), 127.2 (C-9), 124.2 (C-11a), 120.2 (C-3a^1), 117.4 (C-11), 117.1 (C-8), 101.6 (C-2), 65.8 (O-CH_2), 36.5 (C-6), 35.7 (C-3), 31.0 (C-4), 30.4 (C-3a), 21.7 (C-5), 21.4 (Ar-CH_3), 15.6 (CH_3) ppm.

IR: $\tilde{\nu}$ = 3335, 2935, 2875, 1725, 1685, 1490, 1460, 1380, 1320, 1170, 1135, 1065, 990, 815 cm^{-1}.

HRMS (ESI+): *m/z* calc. for $C_{18}H_{22}NO_3^+$ $[M+H]^+$: 300.1600, found: 300.1607.

(2*S,3a*S**)-2-Ethoxy-10-fluoro-2,3,3a,4,5,6-hexahydro-7*H*-1-oxa-7a-azacyclohepta[*jk*]-fluoren-7-one (5ca)**



5ca

According to general procedure 2, enone **3c** (23.1 mg, 0.10 mmol), ethyl vinyl ether (**4a**, 95.0 µL, 0.99 mmol) and Yb(fod)$_3$ (15.9 mg, 15 µmol) in $PhCH_3$ (1.00 mL) gave compound **5ca** (colorless solid, 28.0 mg, 92%) after chromatography (silica gel, Et_2O/$PhCH_3$ 1:3).

R*f* = 0.26 (silica, Et_2O/heptane 1:3), **m.p.** = 112-117°C.

^{1}H-NMR (300 MHz, $CDCl_3$): δ = 8.42 (ddd, $J_{H,H}$ = 9.1, 0.5 Hz, $J_{F,H}$ = 4.7 Hz, 1 H, 8-H), 7.15 (ddt, $J_{H,H}$ = 2.7, 0.5 Hz, $J_{F,H}$ = 9.1 Hz, 1 H, 11-H), 7.01 (td, $J_{H,H}$ = 9.1, 2.7 Hz, $J_{F,H}$ = 9.1 Hz, 1 H, 9-H), 5.30 (dd, J = 7.0, 2.1 Hz, 1 H, 2-H), 4.04 (dq, J = 9.6, 7.1 Hz, 1H, O-CH_2^a), 3.70 (dq, J = 9.6, 7.1 Hz, 1 H, O-CH_2^b), 3.26 (m_c, 1 H, 3a-H), 3.01 – 2.86 (m, 1 H, 6-H^a), 2.76 (dt, J = 15.0, 4.3 Hz, 1 H, 6-H^b), 2.26 (ddd, J = 13.6, 6.8, 2.1 Hz, 1 H, 3-H^a), 2.06 – 1.94 (m, 3 H, 4-H^a, 5-H^a, 5-H^b), 1.93 – 1.79 (m, 2 H, 3-H^b, 4-H^b), 1.27 (t, J = 7.1 Hz, 3 H, CH_3) ppm.

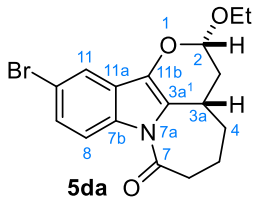
^{13}C-NMR (75 MHz, $CDCl_3$): δ = 172.1 (C-7), 159.5 (d, $J_{C,F}$ = 240.7 Hz, C-10), 136.3 (d, $J_{C,F}$ = 3.9 Hz, C-11b), 130.3 (d, $J_{C,F}$ = 1.1 Hz, C-7b), 123.4 (d, $J_{C,F}$ = 10.1 Hz, C-11a), 120.0 (C-3a^1), 117.7 (d, $J_{C,F}$ = 8.9 Hz, C-8), 112.6 (d, $J_{C,F}$ = 24.7 Hz, C-9), 102.6 (d, $J_{C,F}$ = 24.7 Hz, C-11), 100.0 (C-2), 64.8 (O-CH_2), 35.7 (C-6), 34.5 (C-3), 29.8 (C-4), 29.5 (C-3a), 20.5 (C-5), 15.2 (CH_3) ppm.

^{19}F-NMR (282 MHz, $CDCl_3$): δ = -118.93 ppm.

IR: $\tilde{\nu}$ = 3335, 2950, 2880, 1735, 1680, 1485, 1380, 1270, 840, 760 cm^{-1}.

HRMS (ESI+): *m/z* calc. for $C_{17}H_{19}FNO_3^+$ [M+H]$^+$: 304.1349, found: 304.1356.

(2*S,3a*S**)-10-Bromo-2-ethoxy-2,3,3a,4,5,6-hexahydro-7*H*-1-oxa-7a-azacyclohepta[*jk*]-fluoren-7-one (5da)**



5da

According to general procedure 2, enone **3d** (29.0 mg, 0.10 mmol), ethyl vinyl ether (**4a**, 95.0 µL, 0.99 mmol) and Yb(fod)$_3$ (15.9 mg, 15 µmol) in $PhCH_3$ (1.00 mL) gave compound **5da** (colorless solid, 23.0 mg, 63%) after chromatography (silica gel, Et_2O/$PhCH_3$ 1:3).

R*f* = 0.28 (silica, Et_2O/heptane 1:3), **m.p.** = 99-104°C.

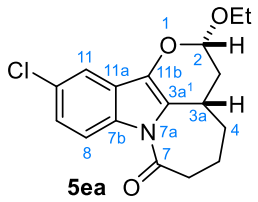
^{1}H-NMR (300 MHz, CD_3OD): δ = 8.27 (dd, J = 8.8, 0.5 Hz, 1 H, 8-H), 7.54 (dd, J = 2.0, 0.5 Hz, 1 H, 11-H), 7.36 (dd, J = 8.8, 2.0 Hz, 1 H, 9-H), 5.35 (dd, J = 6.8, 2.1 Hz, 1 H, 2-H), 4.01 (dq, J = 9.6, 7.1 Hz, 1 H, O-CH_2^a), 3.72 (dq, J = 9.6, 7.1 Hz, 1 H, O-CH_2^b), 3.36 (m_c, 1 H, 3a-H), 3.13 – 3.00 (m, 1 H, 6-H^a), 2.73 – 2.64 (m, 1 H, 6-H^b), 2.26 (ddd, J = 13.7, 6.8, 2.1 Hz, 1 H, 3-H^a), 2.08 – 1.93 (m, 2 H, 4-H^a, 5-H^a), 1.89 – 1.75 (m, 3 H, 3-H^b, 4-H^b, 5-H^b), 1.24 (t, J = 7.1 Hz, 3 H, CH_3) ppm.

^{13}C-NMR (75 MHz, CD_3OD): δ = 174.4 (C-7), 136.5 (C-11b), 133.9 (C-7b), 128.6 (C-9), 125.6 (C-11a), 121.9 (C-3a^1), 120.2 (C-11), 118.9 (C-8), 117.5 (C-10), 101.6 (C-2), 65.8 (O-CH_2), 36.5 (C-6), 35.4 (C-3), 30.9 (C-4), 30.3 (C-3a), 21.6 (C-5), 15.6 (CH_3) ppm.

IR: $\tilde{\nu}$ = 3325, 2940, 2880, 1735, 1680, 1465, 1375, 1340, 1315, 1270, 1185, 1120, 980, 840, 755 cm^{-1}.

HRMS (ESI+): *m/z* calc. for $C_{17}H_{19}{}^{79}BrNO_3^+$ [M+H]$^+$: 364.0548, found: 364.0550.

(2*S,3a*S**)-10-Chloro-2-ethoxy-2,3,3a,4,5,6-hexahydro-7*H*-1-oxa-7a-azacyclohepta[*jk*]-fluoren-7-one (5ea)**



5ea

According to general procedure 2, enone **3e** (24.7 mg, 0.10 mmol), ethyl vinyl ether (**4a**, 95.0 µL, 0.99 mmol) and Yb(fod)$_3$ (15.9 mg, 15 µmol) in $PhCH_3$ (1.00 mL) gave compound **5ea** (colorless solid, 21.0 mg, 66%) after chromatography (silica gel, Et_2O/$PhCH_3$ 1:3).

R*f* = 0.28 (silica, Et_2O/heptane1:3), **m.p.** = 89-95°C.

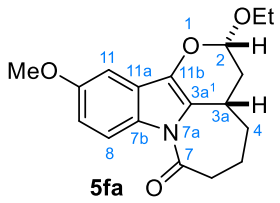
^{1}H-NMR (500 MHz, $CDCl_3$): δ = 8.69 (br. s, 1 H, 8-H), 7.51 (d, *J* = 2.2 Hz, 1 H, 11-H), 7.26 (dd, *J* = 8.8, 2.1 Hz, 1 H, 9-H), 5.35 (dd, *J* = 6.9, 2.1 Hz, 1 H, 2-H), 4.07 (dq, *J* = 9.6, 7.1 Hz, 1 H, O-CH_2^a), 3.72 (dq, *J* = 9.6, 7.1 Hz, 1 H, O-CH_2^b), 3.40 – 3.32 (m, 1 H, 3a-H), 3.19 – 3.00 (m, 2 H, 6-H^a, 6-H^b), 2.30 (ddd, *J* = 13.7, 6.8, 2.1 Hz, 1 H, 3-H^a), 2.14 – 2.00 (m, 3 H, 4-H^a, 5-H^a, 5-H^b), 1.98 – 1.89 (m, 2 H, 3-H^b,4-H^b), 1.29 (t, *J* = 7.1 Hz, 3 H, CH_3) ppm.

^{13}C-NMR (126 MHz, $CDCl_3$): δ = 173.1 (C-7), 136.0 (C-11b), 132.6 (C-7b), 129.1 (C-10), 125.2 (C-9), 123.8 (C-11a), 119.9 (C-3a^1), 117.8 (C-8), 116.6 (C-11), 100.0 (C-2), 64.9 (O-CH_2), 36.1 (C-6), 34.5 (C-3), 29.9 (C-4), 29.6 (C-3a), 20.6 (C-5), 15.2 (CH_3) ppm.

IR: $\tilde{\nu}$ = 3325, 2940, 2880, 1735, 1680, 1465, 1375, 1340, 1315, 1270, 1185, 1120, 980, 840, 755 cm^{-1}.

HRMS (ESI+): *m/z* calc. for $C_{17}H_{19}ClNO_3^+$ $[M+H]^+$: 320.1053, found: 320.1060.

(2*S,3a*S**)-2-Ethoxy-10-methoxy-2,3,3a,4,5,6-hexahydro-7*H*-1-oxa-7a-azacyclohepta[*jk*]-fluoren-7-one (5fa)**



5fa

According to general procedure 2, enone **3f** (24.3 mg, 0.10 mmol), ethyl vinyl ether (**4a**, 95.0 µL, 0.99 mmol) and Yb(fod)$_3$ (15.9 mg, 15 µmol) in $PhCH_3$ (1.00 mL) gave compound **5fa** (colorless solid, 24.1 mg, 76%) after chromatography (silica gel, Et_2O/$PhCH_3$ 1:3).

R*f* = 0.26 (silica, Et_2O/heptane 1:3), **m.p.** = 211-214°C.

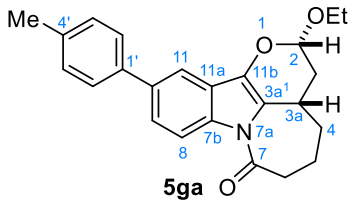
^{1}H-NMR (300 MHz, $CDCl_3$): δ = 8.41 (d, *J* = 9.0 Hz, 1 H, 8-H), 6.96 (d, *J* = 2.6 Hz, 1 H, 11-H), 6.90 (dd, *J* = 9.0, 2.6 Hz, 1 H, 9-H), 5.31 (dd, *J* = 7.2, 2.1 Hz, 1 H, 2-H), 4.08 (dq, *J* = 9.5, 7.1 Hz, 1 H, O-CH_2^a), 3.85 (s, 3 H, O-CH_3), 3.71 (dq, *J* = 9.6, 7.1 Hz, 1 H, O-CH_2^b), 3.27 (m_c, 1 H, 3a-H), 3.03 – 2.89 (m, 1 H, 6-H^a), 2.80 (dt, *J* = 14.7, 3.8 Hz, 1 H, 6-H^b), 2.26 (ddd, *J* = 13.7, 6.8, 2.1 Hz, 1 H, 3-H^a), 2.06 – 1.94 (m, 3 H, 4-H^a, 5-H^a, 5-H^b), 1.94 – 1.77 (m, 2 H, 3-H^b, 4-H^b), 1.29 (t, *J* = 7.1 Hz, 3 H, CH_3) ppm.

^{13}C-NMR (75 MHz, $CDCl_3$): δ = 172.1 (C-7), 156.4 (C-10), 136.7 (C-11b), 128.8 (C-7b), 123.3 (C-11a), 119.0 (C-3a^1), 117.6 (C-8), 113.6 (C-9), 100.1 (C-2), 99.4 (C-11), 64.8 (O-CH_2), 55.7 (O-CH_3), 35.7 (C-6), 34.7 (C-3), 29.9 (C-4), 29.6 (C-3a), 20.5 (C-5), 15.2 (CH_3) ppm.

IR: $\tilde{\nu}$ = 3380, 2980, 2850, 1730, 1680, 1490, 1460, 1340, 1380, 1330, 1260, 1190, 1120, 1040, 920, 845, 745 cm^{-1}.

HRMS (ESI+): *m/z* calc. for $C_{18}H_{22}NO_4^+$ $[M+H]^+$: 316.1549, found: 316.1550.

(2*S,3a*S**)-2-Ethoxy-10-(*p*-tolyl)-2,3,3a,4,5,6-hexahydro-7*H*-1-oxa-7a-azacyclohepta[*jk*]-fluoren-7-one (5ga)**



According to general procedure 2, enone **3g** (30.0 mg, 0.10 mmol), ethyl vinyl ether (**4a**, 95.0 µL, 0.99 mmol) and Yb(fod)$_3$ (15.9 mg, 15 µmol) in $PhCH_3$ (1.00 mL) gave compound **5ga** (colorless solid, 32.5 mg, 87%) after chromatography (silica gel, Et_2O/$PhCH_3$ 1:3).

R_f = 0.48 (silica, Et_2O/toluene 1:3), **m.p.** = 92-96°C.

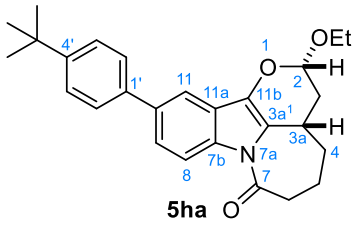
^{1}H-NMR (300 MHz, CD_3OD): δ = 8.41 (br. d, *J* = 8.6 Hz, 1 H, 8-H), 7.62 (m_c, 1 H, 11-H), 7.57 – 7.49 (m, 3 H, 9-H, 2'-H), 7.25 (d, *J* = 7.9 Hz, 2 H, 3'-H), 5.38 (dd, *J* = 7.1, 1.9 Hz, 1 H, 2-H), 4.05 (dq, *J* = 9.6, 7.1 Hz, 1H, O-CH_2^a), 3.73 (dq, *J* = 9.6, 7.1 Hz, 1 H, O-CH_2^b), 3.44 – 3.35 (m, 1 H, 3a-H), 3.17 – 3.02 (m, 1 H, 6-H^a), 2.73 – 2.62 (m, 1 H, 6-H^b), 2.37 (s, 3 H, Ar-CH_3), 2.29 (ddd, *J* = 13.7, 6.8, 1.9 Hz, 1 H, 3-H^a), 2.10 – 1.90 (m, 3 H, 4-H^a, 5-H^a, 5-H^b), 1.90 – 1.73 (m, 2 H, 3-H^b, 4-H^b),1.26 (t, *J* = 7.1 Hz, 3 H, CH_3) ppm.

^{13}C-NMR (75 MHz, CD_3OD): δ = 174.5 (C-7), 139.7 (C-1'), 138.2 (C-11b), 137.93 (C-10), 137.91 (C-4'), 134.6 (C-7b), 130.5 (C-3'), 128.0 (C-2'), 125.1 (C-9), 124.6 (C-11a), 120.8 (C-3a^1), 117.6 (C-8), 115.4 (C-11), 101.7 (C-2), 65.8 (O-CH_2), 36.5 (C-6), 35.8 (C-3), 31.0 (C-4), 30.5 (C-3a), 21.7 (C-5), 21.1 (Ar-CH_3), 15.6 (CH_3) ppm.

IR: $\tilde{\nu}$ = 3285, 2960, 2930, 2880, 1725, 1685, 1655, 1620, 1590, 1480, 1370, 1335, 1310, 1265, 1130, 1005, 810, 745 cm^{-1}.

HRMS (ESI+): *m/z* calc. for $C_{24}H_{26}NO_3^+$ $[M+H]^+$: 376.1913, found: 376.1913.

(2*S,3a*S**)-10-(4-(*tert*-Butyl)phenyl)-2-ethoxy-2,3,3a,4,5,6-hexahydro-7*H*-1-oxa-7a-aza-cyclohepta[*jk*]-fluoren-7-one (5ha)**



5ha

According to general procedure 2, enone **3h** (34.0 mg, 0.10 mmol), ethyl vinyl ether (**4a**, 95.0 µL, 0.99 mmol) and $Yb(fod)_3$ (15.9 mg, 15 µmol) in $PhCH_3$ (1.00 mL) gave compound **5ha** (colorless solid, 37.0 mg, 89%) after chromatography (silica gel, $Et_2O/PhCH_3$ 1:3).

R_f = 0.47 (silica, $Et_2O/PhCH_3$ 1:3), **m.p.** = 87-94°C.

^{1}H-NMR (500 MHz, $CDCl_3$): δ = 10.82 – 9.81 (br. m, 1 H, 8-H), 8.00 (br. s, 1 H, 11-H), 7.66 (m_c, 2 H, 2'-H), 7.63 (br. d, J = 7.1 Hz, 1 H, 9-H), 7.48 (m_c, 2 H, 3'-H), 5.66 – 5.57 (m, 1 H, 2-H), 4.31 – 4.22 (m, 1H, O-CH_2^a), 3.93 – 3.84 (m, 1 H, O-CH_2^b), 3.22 – 3.00 (br. m, 1 H, 3a-H), 2.89 – 2.69 (br. m, 1 H, 5-H^a), 2.61 – 2.53 (m, 1 H, 3-H^a), 2.49 – 2.30 (m, 3 H, 4-H^a, 4-H^b, 5-H^b), 2.28 – 2.17 (m, 1 H, 3-H^b), 1.41 (t, *J* = 7.0 Hz, 3 H, CH_3), 1.37 (s, 9 H, *t*-Bu) ppm.

Due to signal broadening, the signals of 6-H^a and 6-H^b could not be identified unambiguously.

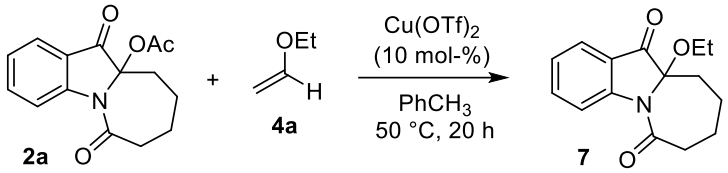
^{13}C-NMR (126 MHz, $CDCl_3$): δ = 171.1 (C-7), 150.0 (C-4'), 138.6 (C-1'), 137.6 (C-11b), 137.0 (C-10), 135.0 (C-7b), 127.0 (C-2'), 125.7 (C-3'), 124.9 (C-9), 123.8 (C-11a), 119.9 (C-$3a^1$), 118.0 (C-8), 115.3 (C-11), 100.4 (C-2), 65.0 (O-CH_2), 38.1 (C-6), 35.0 (C-3), 34.5 (*t*-Bu), 31.4 (*t*-Bu), 30.5 (C-3a), 30.3 (C-4), 21.5 (C-5), 15.3 (CH_3) ppm.

IR: $\tilde{\nu}$ = 3285, 2960, 2930, 2880, 1725, 1685, 1655, 1620, 1590, 1480, 1370, 1335, 1310, 1265, 1130, 1005, 810, 745 cm^{-1}.

HRMS (ESI+): *m/z* calc. for $C_{27}H_{32}NO_3^+$ $[M+H]^+$: 418.2382, found: 418.2386.

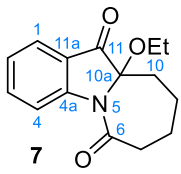
4 Additional synthetic experiments

$Cu(OTf)_2$-catalysed reaction of acetate **2a** with ethyl vinyl ether (**4a**):



Azepinoindole acetate **2a** (27.3 mg, 0.10 mmol) was dissolved in $PhCH_3$ (1.00 mL) in a 10 mL crimp cap vial. $Cu(OTf)_2$ (3.6 mg, 10.0 µmol) was added followed by ethyl vinyl ether (**4a**, 95.0 µL, 0.99 mmol). The vial was sealed and argon was bubbled through the mixture via cannula for 5 min. The mixture was stirred at 50°C for 20 h (heating in an oil bath). The mixture was concentrated to dryness and column chromatography (silica gel, $Et_2O/PhCH_3$ 1:3) afforded product **7** (23.0 mg, 90%).

10a-Ethoxy-8,9,10,10a-tetrahydro-6*H*-azepino[1,2-*a*]indole-6,11(7*H*)-dione (7)



R_f = 0.27 (silica, $Et_2O/PhCH_3$ 1:3), **m.p.** = 155-157°C.

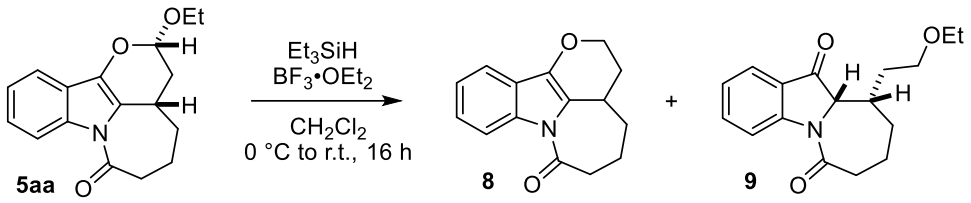
^{1}H-NMR (500 MHz, $CDCl_3$): δ = 8.62 (dt, *J* = 8.4, 0.6 Hz, 1 H, 4-H), 7.75 (ddd, *J* = 7.6, 1.4, 0.6 Hz, 1 H, 1-H), 7.70 (ddd, *J* = 8.4, 7.6, 1.4 Hz, 1 H, 3-H), 7.21 (td, *J* = 7.6, 0.6 Hz, 1 H, 2-H), 3.28 (dq, *J* = 10.3, 7.1 Hz, 2 H, O-CH_2^a, OCH_2-^{b}), 3.06 (td, *J* = 13.8, 1.8 Hz, 1 H, 7-H^a), 2.64 (ddt, *J* = 13.8, 7.3, 1.2 Hz, 1 H, 7-H^b), 2.33 (dtd, *J* = 14.2, 4.0, 1.2 Hz, 1 H, 10-H^a), 2.21 (qt, *J* = 13.6, 4.0 Hz, 1 H, 9-H^a), 2.03-1.95 (m, 1 H, 8-H^a), 1.82 (m_c, 1 H, 9-H^b), 1.62 (m_c, 1 H, 8-H^b), 1.48 (ddd, *J* = 14.2, 13.6, 4.0 Hz, 1 H, 10-H^b), 1.19 (t, *J* = 7.1 Hz, 3 H, CH_3) ppm.

^{13}C-NMR (126 MHz, $CDCl_3$): δ = 198.3 (C-11), 173.4 (C-6), 152.6 (C-4a), 138.2 (C-3), 124.3 (C-2), 123.9 (C-1), 121.6 (C-11a), 118.5 (C-4), 92.6 (C-10a), 59.6 (O-CH_2), 38.1 (C-7), 35.2 (C-10), 24.1 (C-8), 22.8 (C-9), 15.0 (CH_3) ppm.

IR: $\tilde{\nu}$ = 2985, 2950, 1730, 1670, 1605, 1465, 1385, 1340, 1305, 1080, 1060, 1045, 760, 705 cm^{-1}.

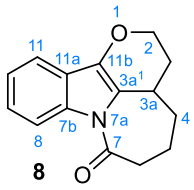
HRMS (ESI+): *m/z* calc. for $C_{15}H_{18}NO_3^+$ $[M+H]^+$: 260.1287, found: 260.1287.

Reaction of pyranoside **5aa** to compounds **8** and **9**:



Pyranoside **5aa** (28.5 mg, 0.10 mmol) was dissolved in CH_2Cl_2 (5.00 mL) at 0 °C. Et_3SiH (70.0 µL, 0.44 mmol) was added followed by dropwise addition of $BF_3{\cdot}OEt_2$ (30.0 µL, 0.23 mmol). The mixture was allowed to warm to r.t. over 16 h. $NaHCO_3$ (aq.) was added, the layers were separated and the aqueous layer was extracted with EtOAc (3 ×). The combined organic layer was dried with Na_2SO_4, filtered and concentrated. Purification of the crude product by column chromatography (silica gel, Et_2O/$PhCH_3$ 1:3) afforded compound **8** (colorless solid, 8.5 mg, 35%) and compound **9** (colorless oil, 13.5 mg, 47%).

2,3,3a,4,5,6-hexahydro-7*H*-1-oxa-7a-azacyclohepta[*jk*]fluoren-7-one (8)



R_f = 0.58 (silica, Et_2O/$PhCH_3$ 1:3), **m.p.** = 155-157°C.

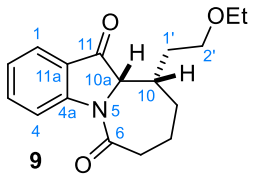
^{1}H-NMR (300 MHz, $CDCl_3$): δ = 8.48 (ddd, *J* = 7.6, 1.4, 0.7 Hz, 1 H, 8-H), 7.49 (m_c, 1 H, 11-H), 7.36 – 7.29 (m, 1 H, 9-H), 7.26 (td, *J* = 7.6, 1.4 Hz, 1 H, 10-H), 4.34 (ddd, *J* = 11.0, 5.7, 3.2 Hz, 1 H, 2-H^a), 4.25 (ddd, *J* = 11.0, 9.1, 2.6 Hz, 1 H, 2-H^b), 3.26 – 3.14 (m, 1 H, 3a-H), 3.05 – 2.92 (m, 1 H, 6-H^a), 2.78 (dt, *J* = 14.7, 4.0 Hz, 1 H, 6-H^b), 2.16 (dtd, *J* = 14.0, 6.0, 2.5 Hz, 1 H, 3-H^a), 2.11 – 1.96 (m, 3 H, 4-H^a, 5-H^a, 5-H^b), 1.76 (dddd, *J* = 14.0, 9.1, 7.5, 3.3 Hz, 1 H, 3-H^b), 1.63 – 1.53 (m, 1 H, 4-H^b) ppm.

^{13}C-NMR (75 MHz, $CDCl_3$): δ = 172.2 (C-7), 139.4 (C-11b), 133.8 (C-7b), 125.3 (C-9) , 123.5 (C-10), 122.4 (C-11a), 118.3 (C-3a^1), 116.6 (C-11), 116.5 (C-8), 65.8 (C-2), 36.0 (C-6), 30.7 (C-4), 30.4 (C-3a), 29.7 (C-3), 20.9 (C-5) ppm.

IR: $\tilde{\nu}$ = 3335, 2950, 2835, 1675, 1450, 1415, 1120, 1025, 630 cm^{-1}.

HRMS (EI): *m/z* calc. for $C_{15}H_{15}NO_2^+$ $[M]^+$: 241.1097, found: 241.1097.

(10*S,10a*S**)-10-(2-Ethoxyethyl)-8,9,10,10a-tetrahydro-6*H*-azepino[1,2-*a*]indole-6,11(7*H*)-dione (9)**



9

$\mathbf{R_f}$ = 0.23 (silica, Et_2O/$PhCH_3$ 1:3).

^{1}H-NMR (300 MHz, $CDCl_3$): δ = 8.57 (dt, *J* = 8.4, 0.8 Hz, 1 H, 4-H), 7.72 (ddd, *J* = 7.7, 1.5, 0.8 Hz, 1 H, 1-H), 7.65 (ddd, *J* = 8.4, 7.7, 1.5 Hz, 1 H, 3-H), 7.20 (td, *J* = 7.7, 0.8 Hz, 1 H, 2-H), 4.29 (d, *J* = 1.5 Hz, 1 H, 10a-H), 3.33 (m_c, 2 H, O-CH_2^a, O-CH_2^b), 3.30 – 3.23 (m, 2 H, 2'-H^a, 2'-H^b), 2.80 – 2.67 (m, 2 H, 7-H^a, 10-H), 2.66 – 2.54 (m, 1 H, 7-H^b), 2.19 – 2.09 (m, 1 H, 9-H^a), 1.95 – 1.71 (m, 3 H, 8-H^a, 8-H^b, 9-H^b), 1.49 (m_c, 1 H, 1'-H^a), 1.26 – 1.13 (m, 1 H, 1'-H^b), 1.11 (t, *J* = 7.1 Hz, 3 H, CH_3) ppm.

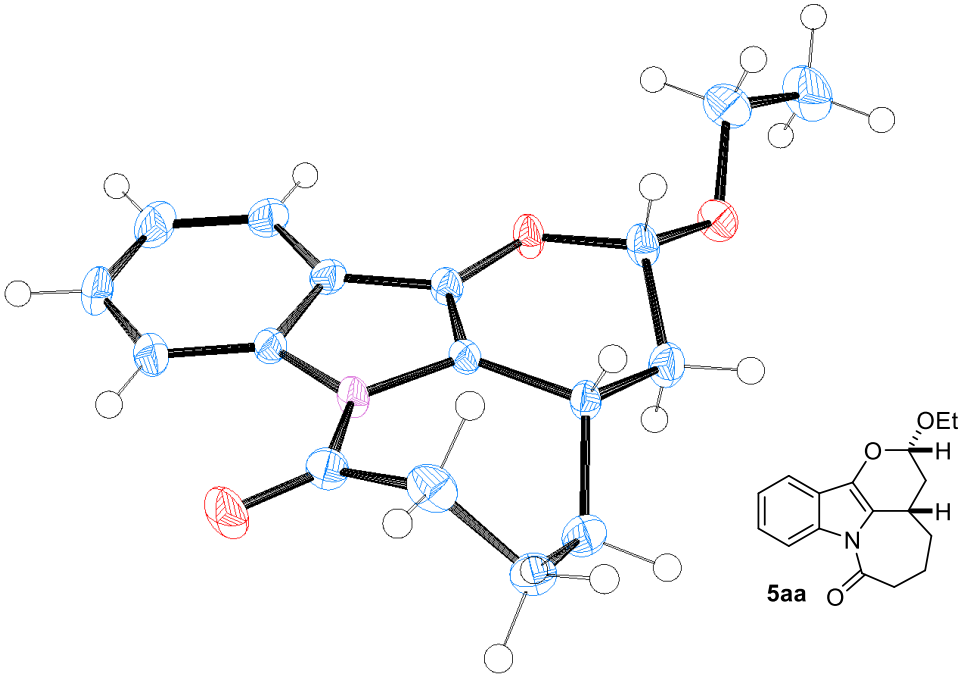
^{13}C-NMR (75 MHz, $CDCl_3$): δ = 198.3 (C-11), 172.4 (C-6), 153.7 (C-4a), 137.4 (C-3), 124.5 (C-11a), 124.2 (C-2), 123.5 (C-1), 118.5 (C-4), 69.7 (C-10a), 68.2 (C-2'), 66.1 (O-CH_2), 39.7 (C-7), 37.1 (C-10), 32.7 (C-9), 24.5 (C-1'), 18.9 (C-8), 15.1 (CH_3) ppm.

IR: $\tilde{\nu}$ = 3330, 2950, 2840, 1720, 1660, 1470, 1450, 1405, 1310, 1120, 1030, 620 cm^{-1}.

HRMS (EI): *m/z* calc. for $C_{17}H_{21}NO_2^+$ $[M]^+$: 287.1516, found: 287.1518.

5 X-Ray crystal structure of compound 5aa

A single crystal of compound **5aa** suitable for X-ray crystallographic analysis was obtained by the slow evaporation of a solution of the compound in EtOH, at ambient pressure and ambient temperature.



Crystal data			
Unit cell lengths (Å)	19.597	7.623	19.615
Unit cell angles (deg)	90.000	100.404	90.000
Space group Hall symbol	-P 2yn		
Space group HM symbol	P 1 21/n 1		
Crystal class	Monoclinic		
International tables #	14		
Space group multiplicity	4		

Figure 1. X-Ray crystal structure of compound **5aa**, CCDC No. 2237052. Thermal ellipsoid contours shown at 50% probability level. The crystal structure data can be retrieved from the Cambridge Crystallographic Data Centre, www.ccdc.cam.ac.uk.

6 Structure assignment by NOESY spectra

In addition to the X-ray crystal structure of compound **5aa**, all compounds **5** were analyzed by acquiring their NOESY spectra, confirming the C2,C3a-*cis*-configuration in all cases. As a typical example, the NOESY spectrum of compound **5ab** is depicted in Figure 2.

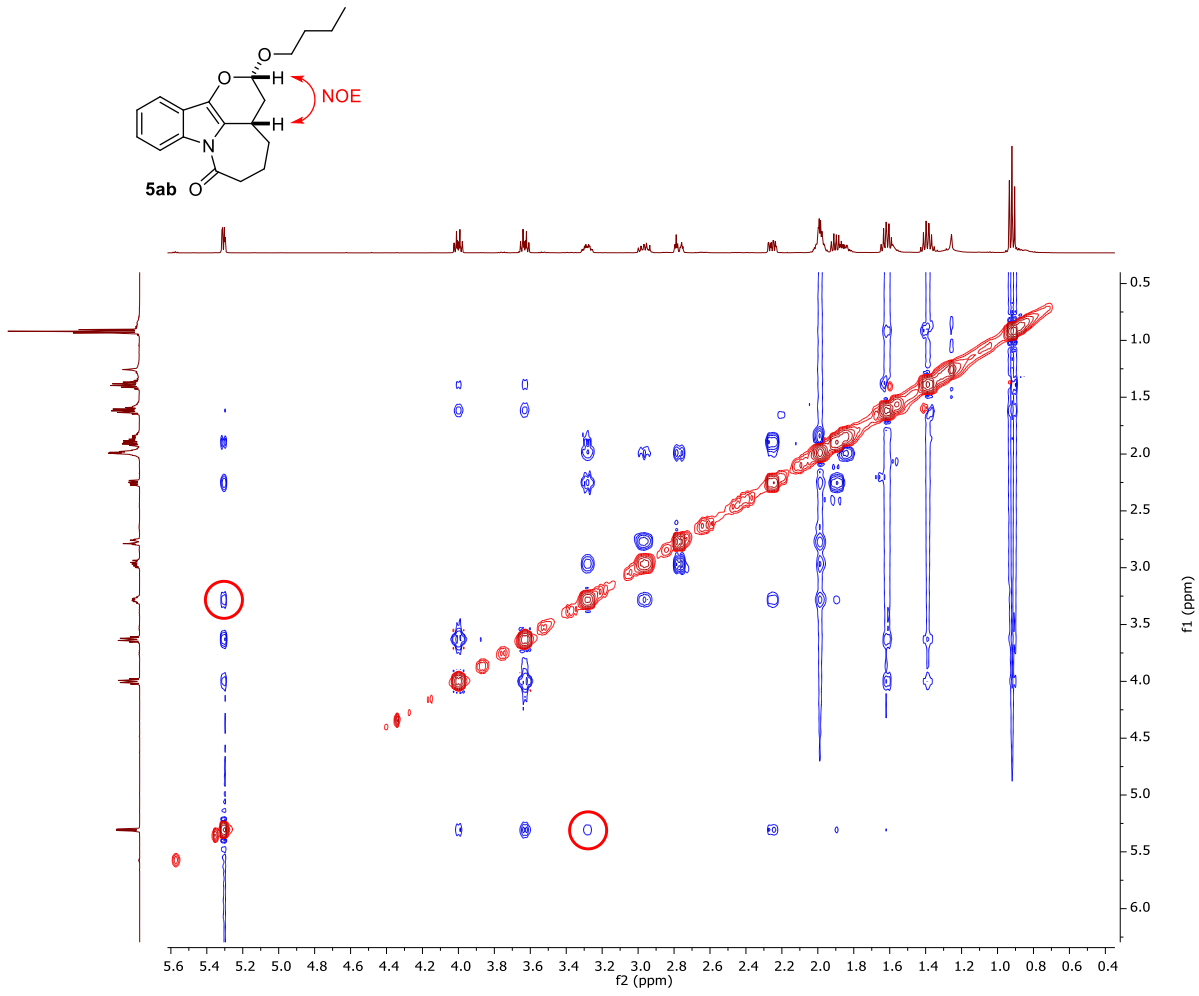
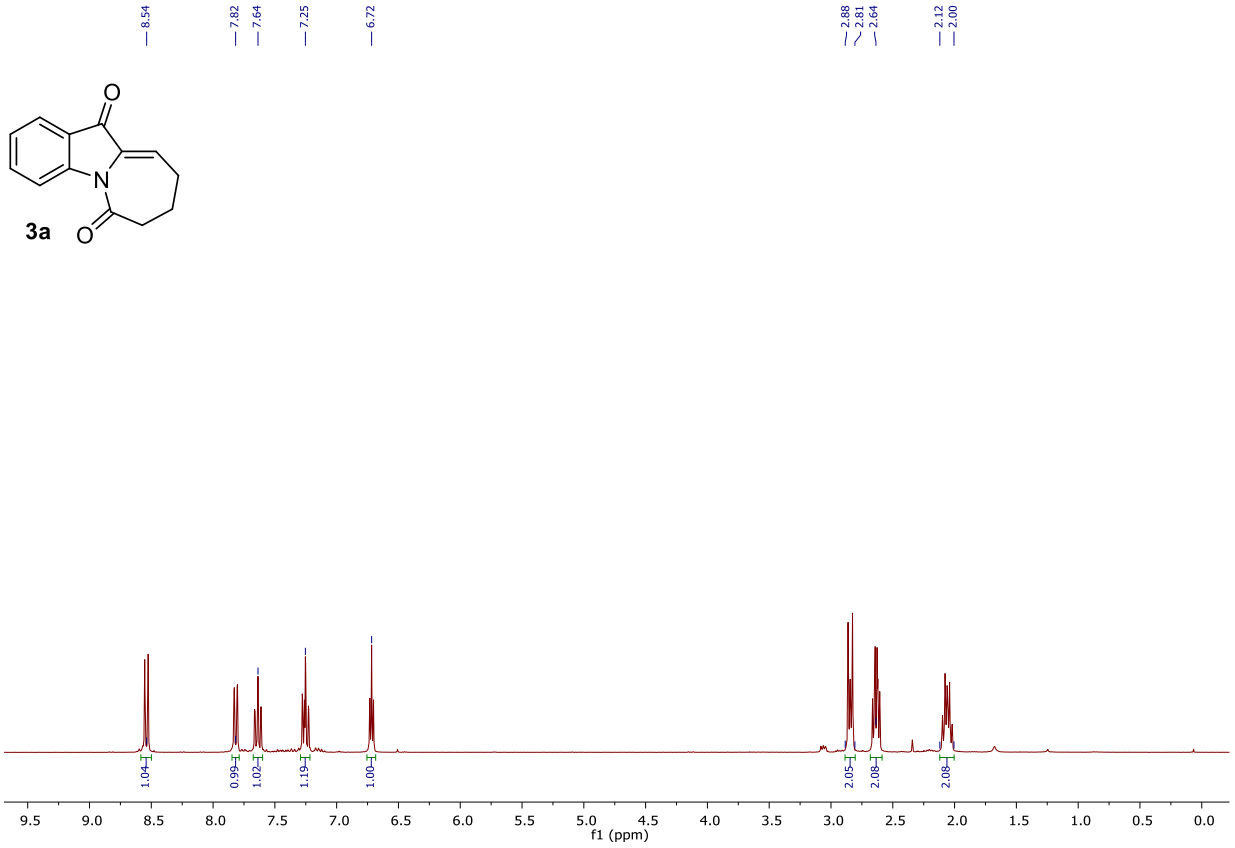
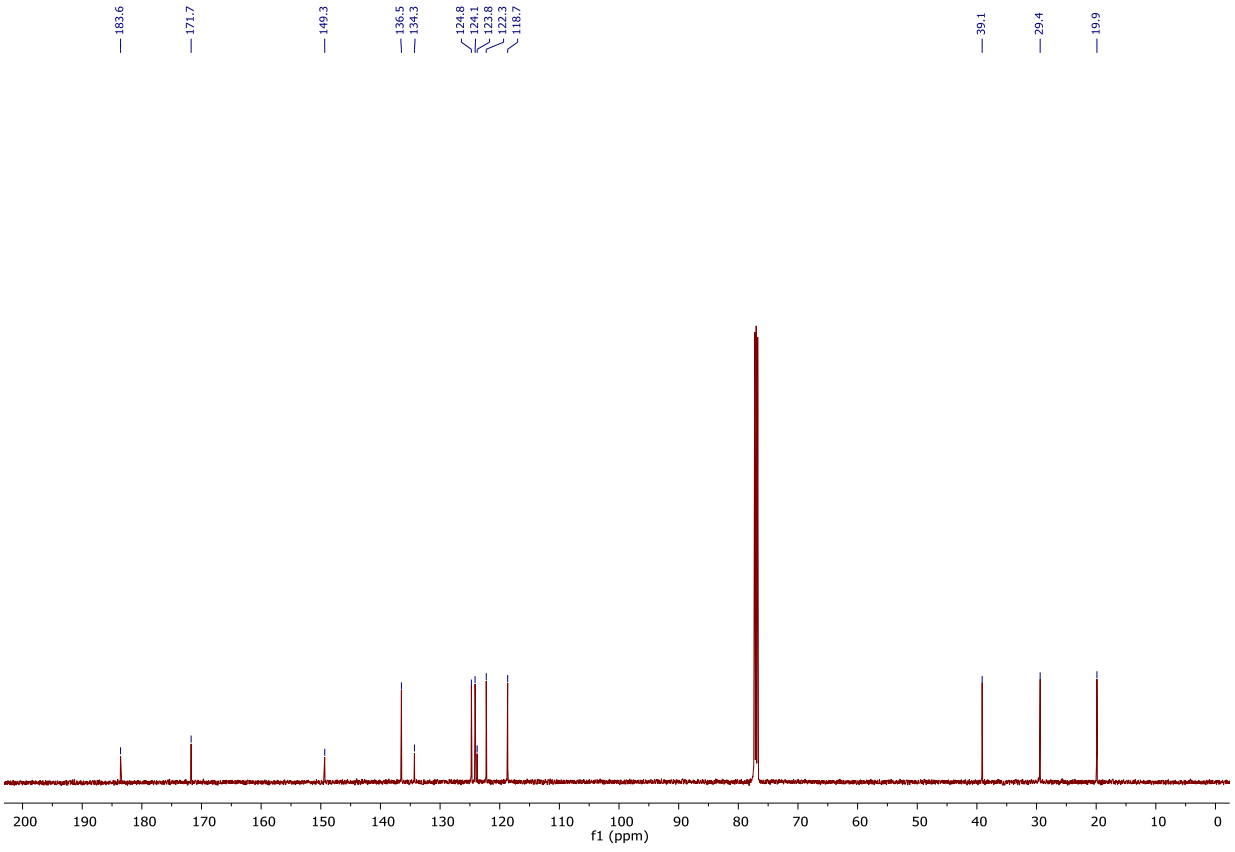


Figure 2. NOESY-spectrum of compound **5ab** (500 MHz, $CDCl_3$).

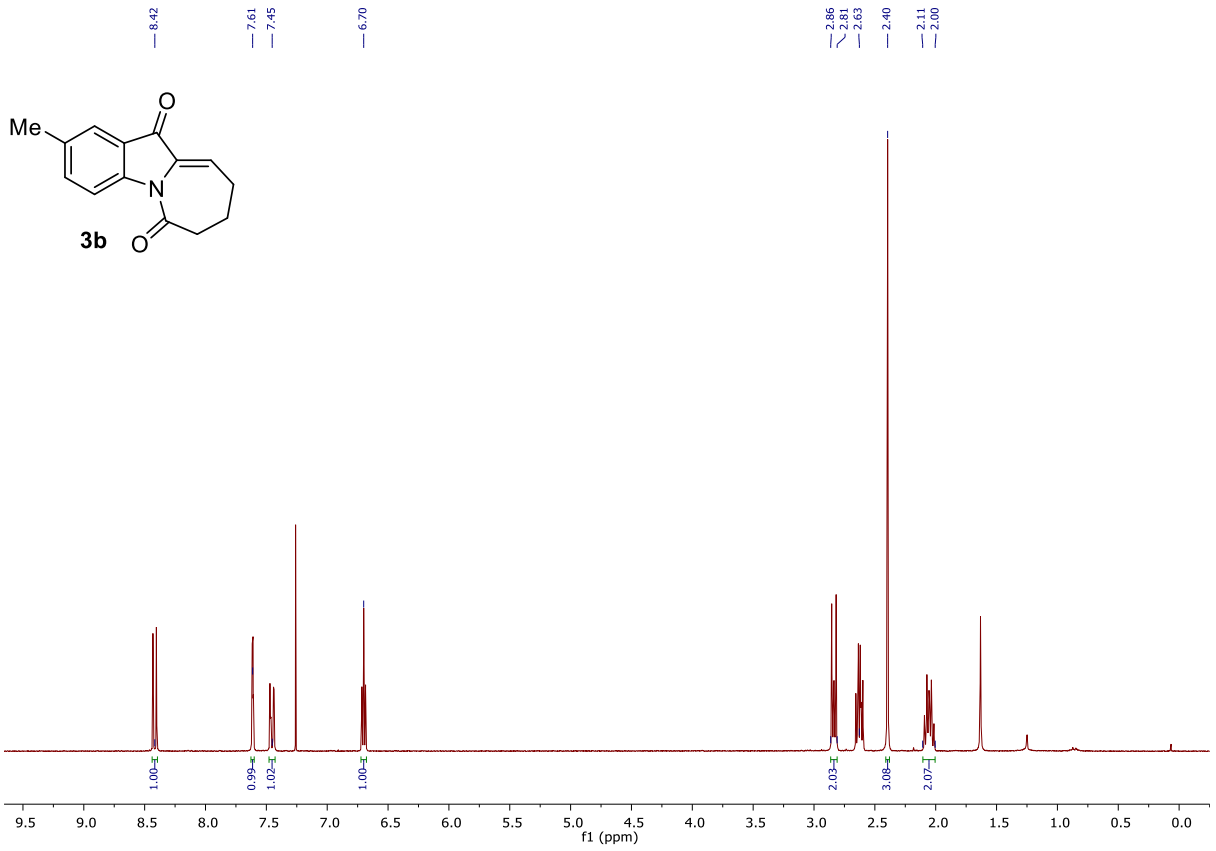
7 NMR spectra



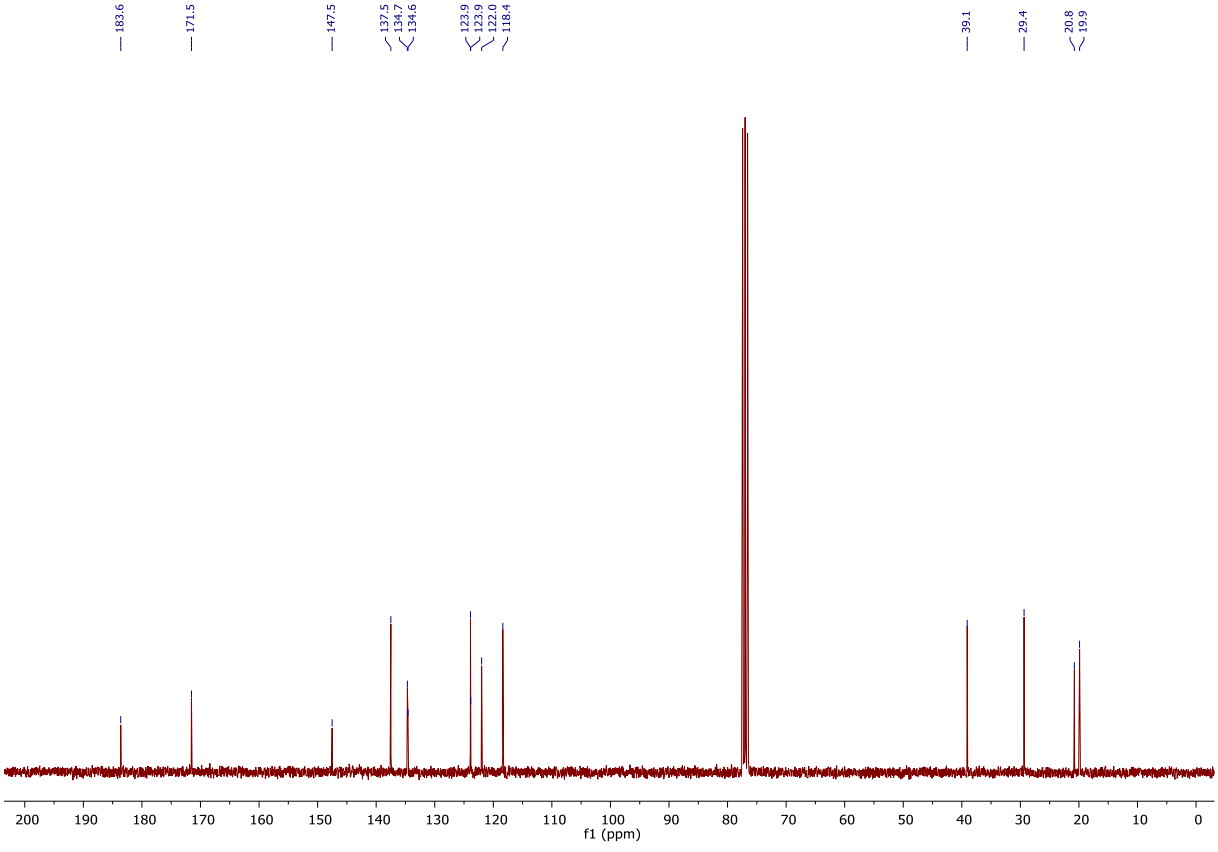
^{1}H-NMR (300 MHz, $CDCl_3$)



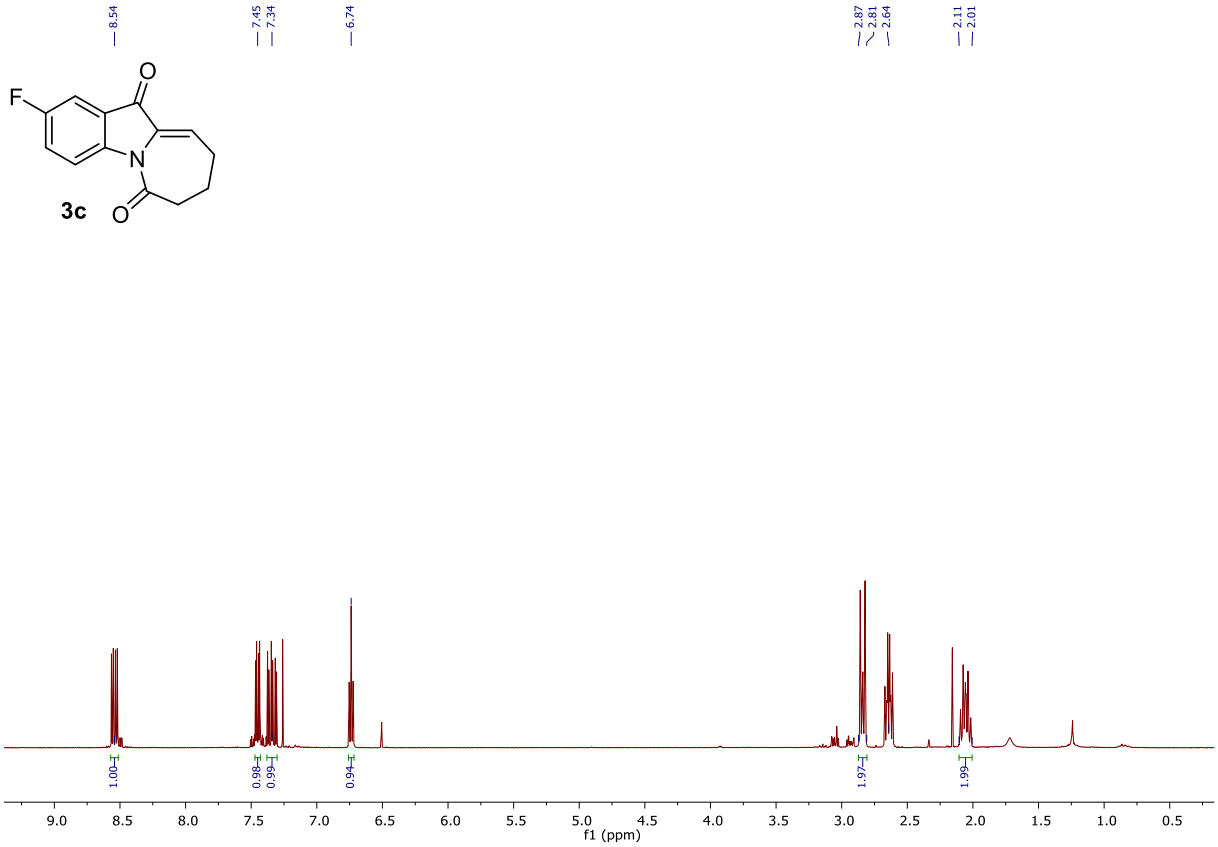
^{13}C-NMR (126 MHz, $CDCl_3$)



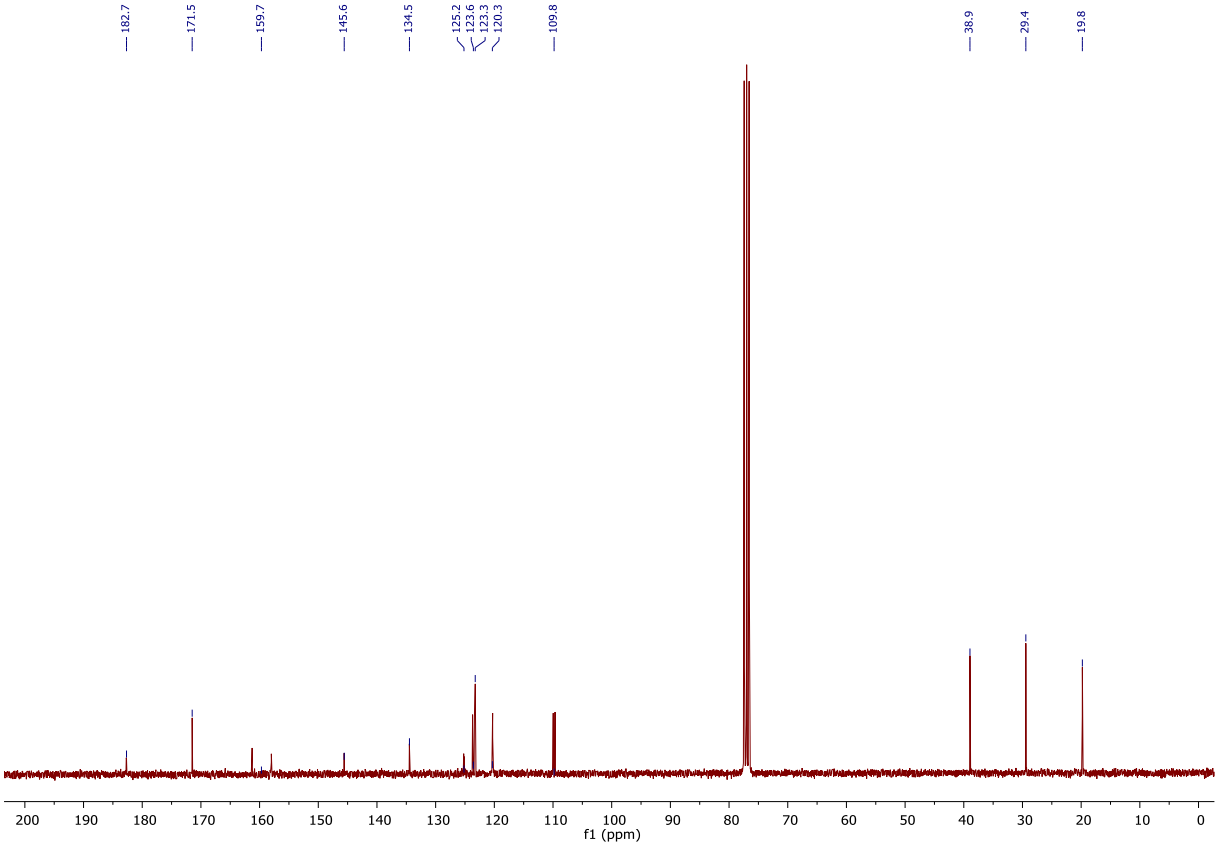
^{1}H-NMR (300 MHz, $CDCl_3$)



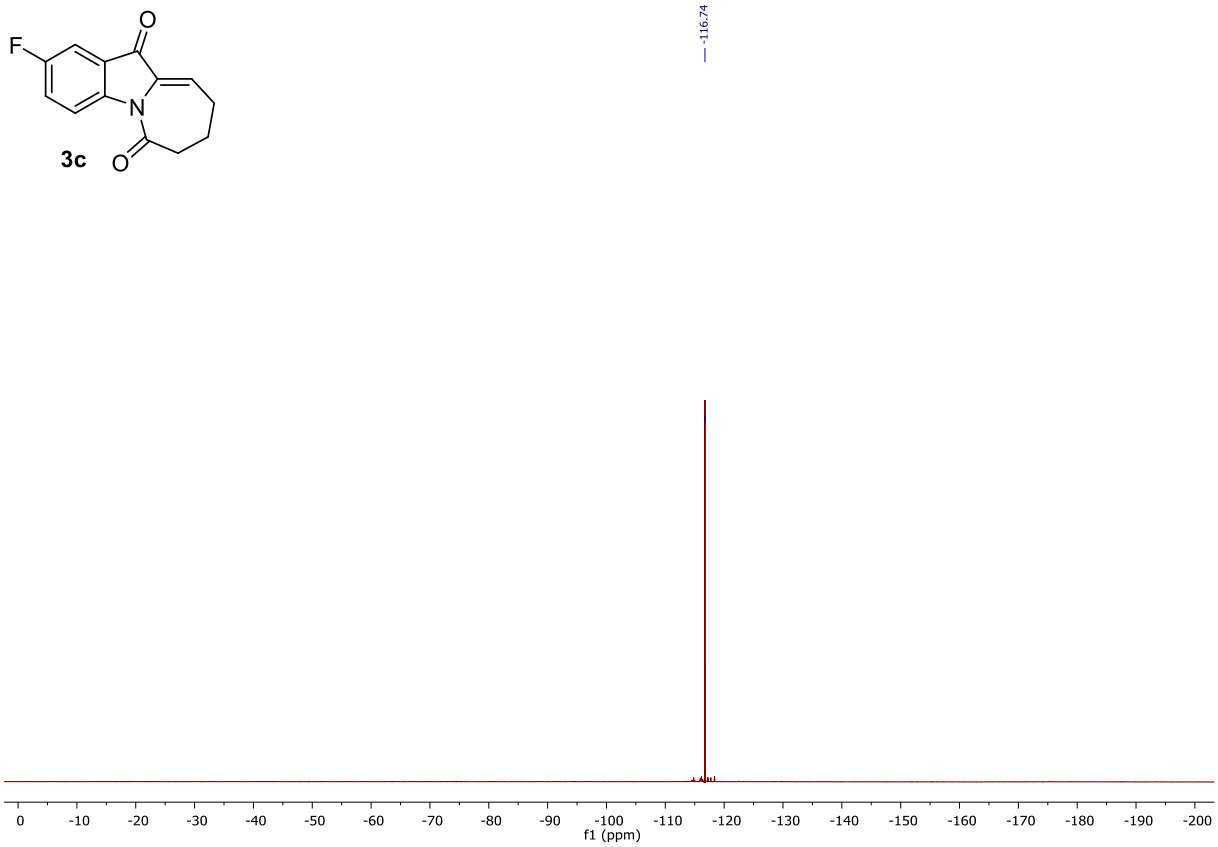
^{13}C-NMR (75 MHz, $CDCl_3$)



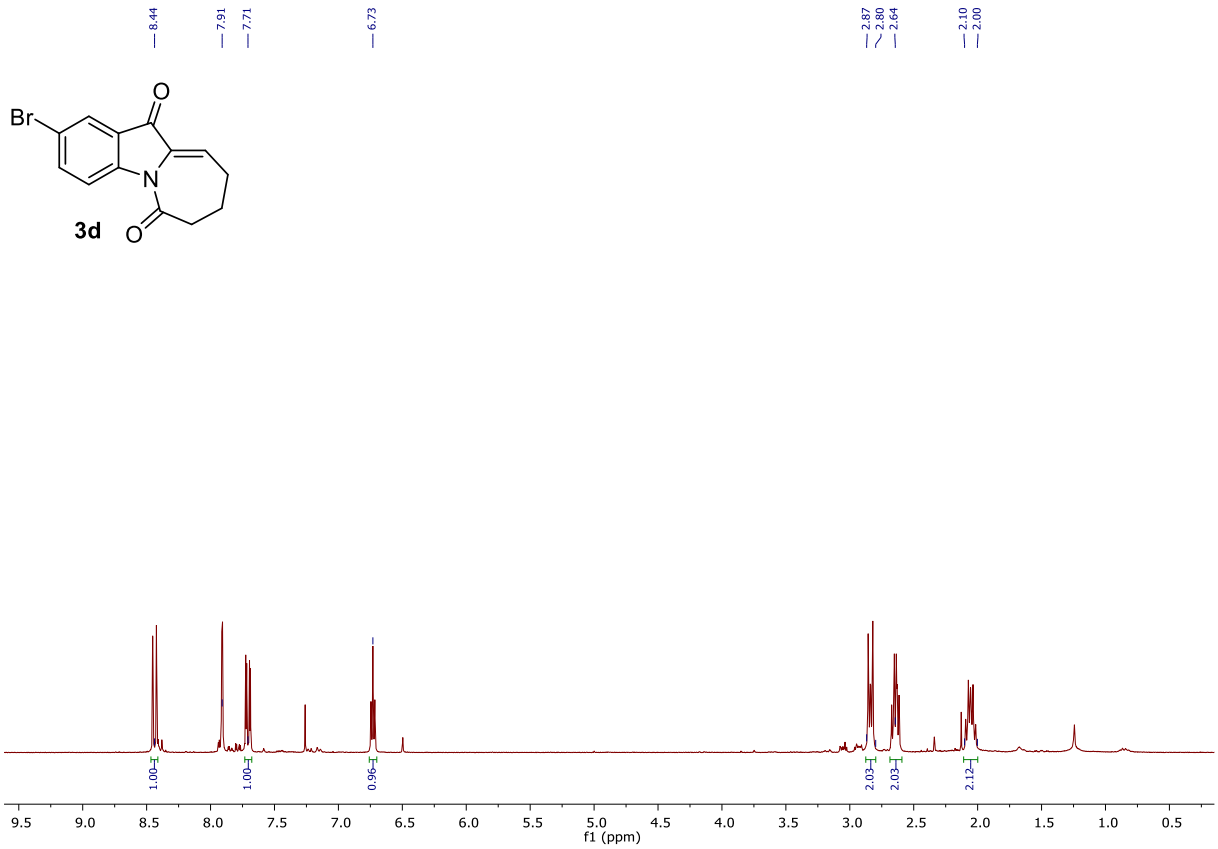
^{1}H-NMR (300 MHz, $CDCl_3$)



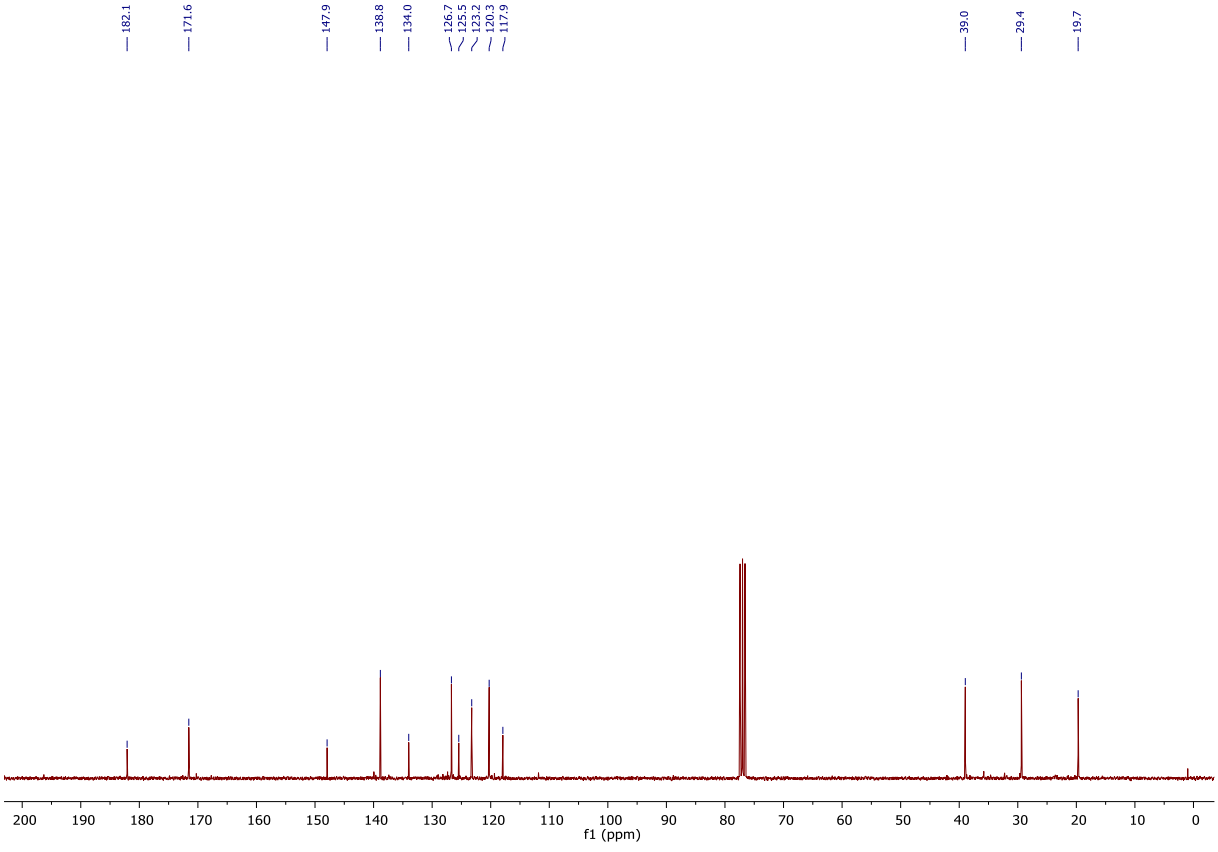
^{13}C-NMR (75 MHz, $CDCl_3$)



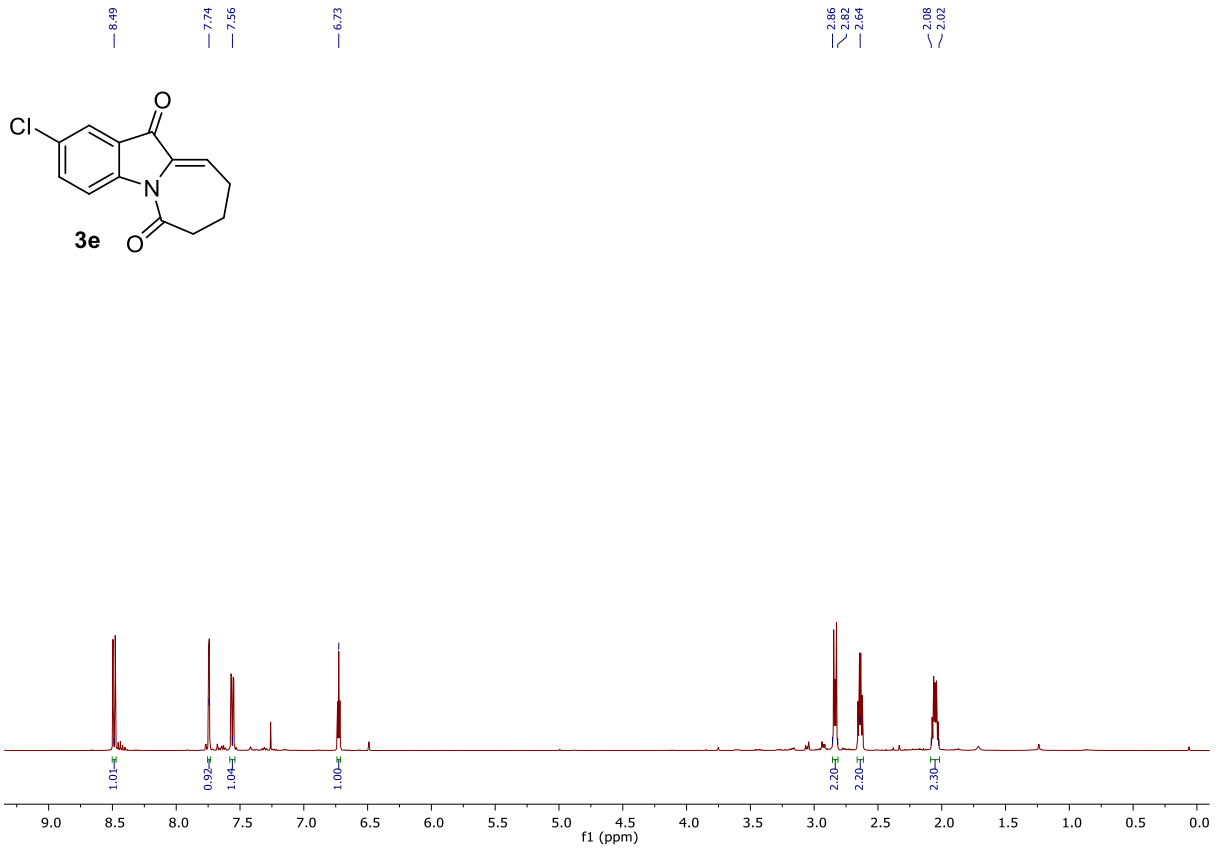
^{19}F-NMR (282 MHz, $CDCl_3$)



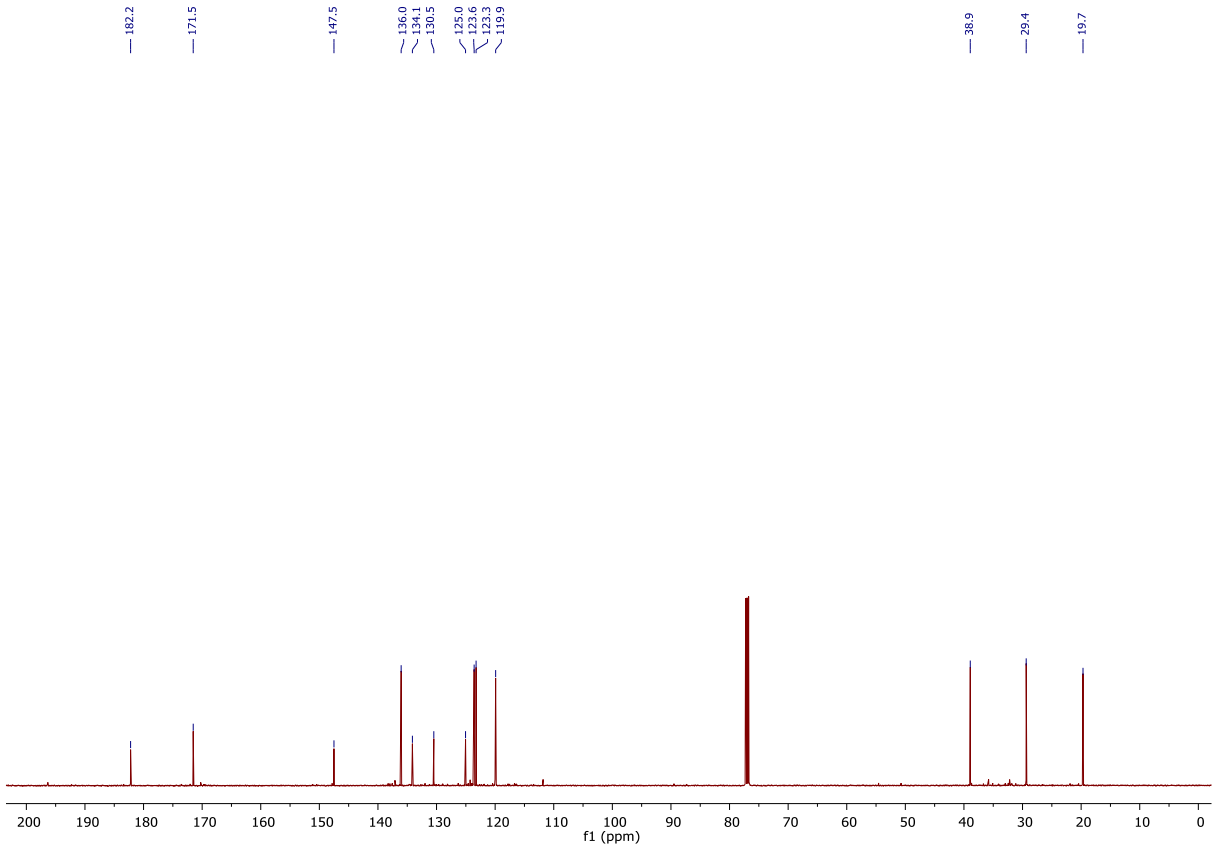
^{1}H-NMR (300 MHz, $CDCl_3$)



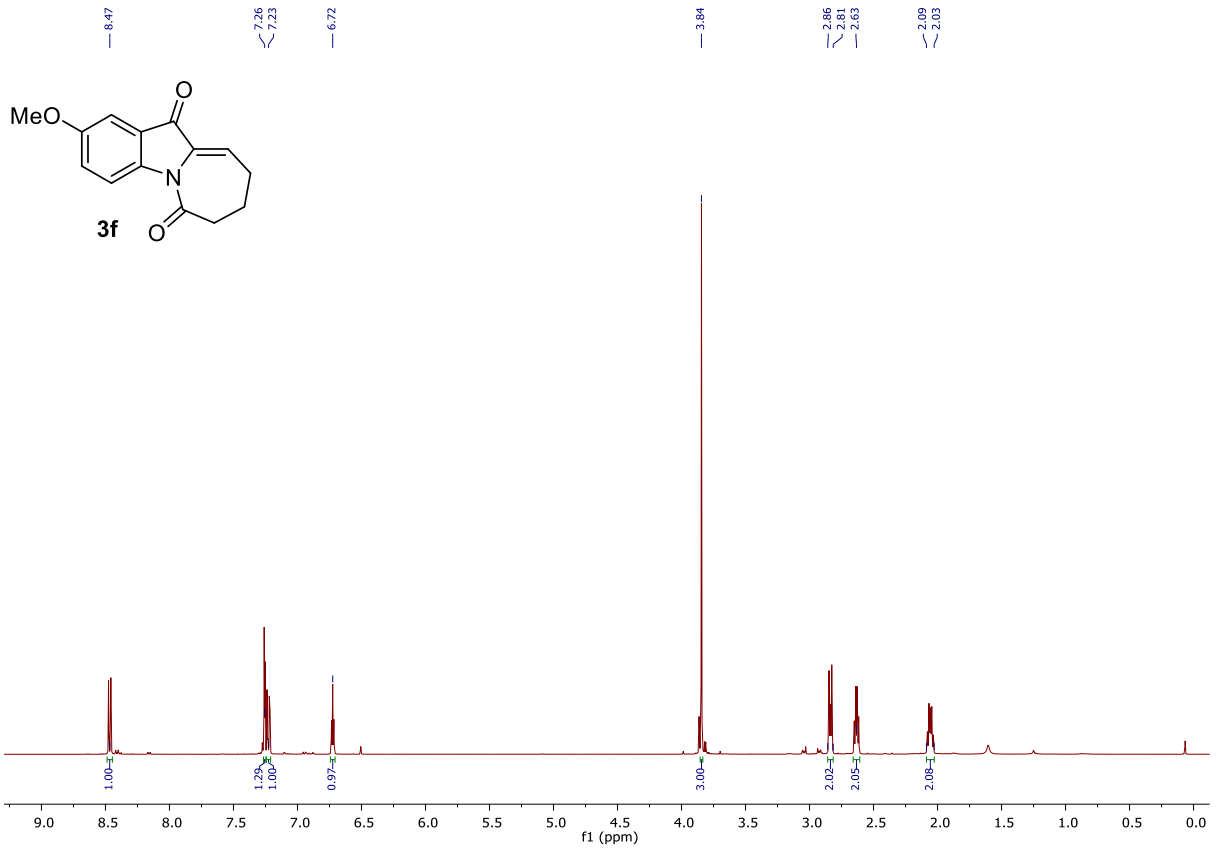
^{13}C-NMR (75 MHz, $CDCl_3$)



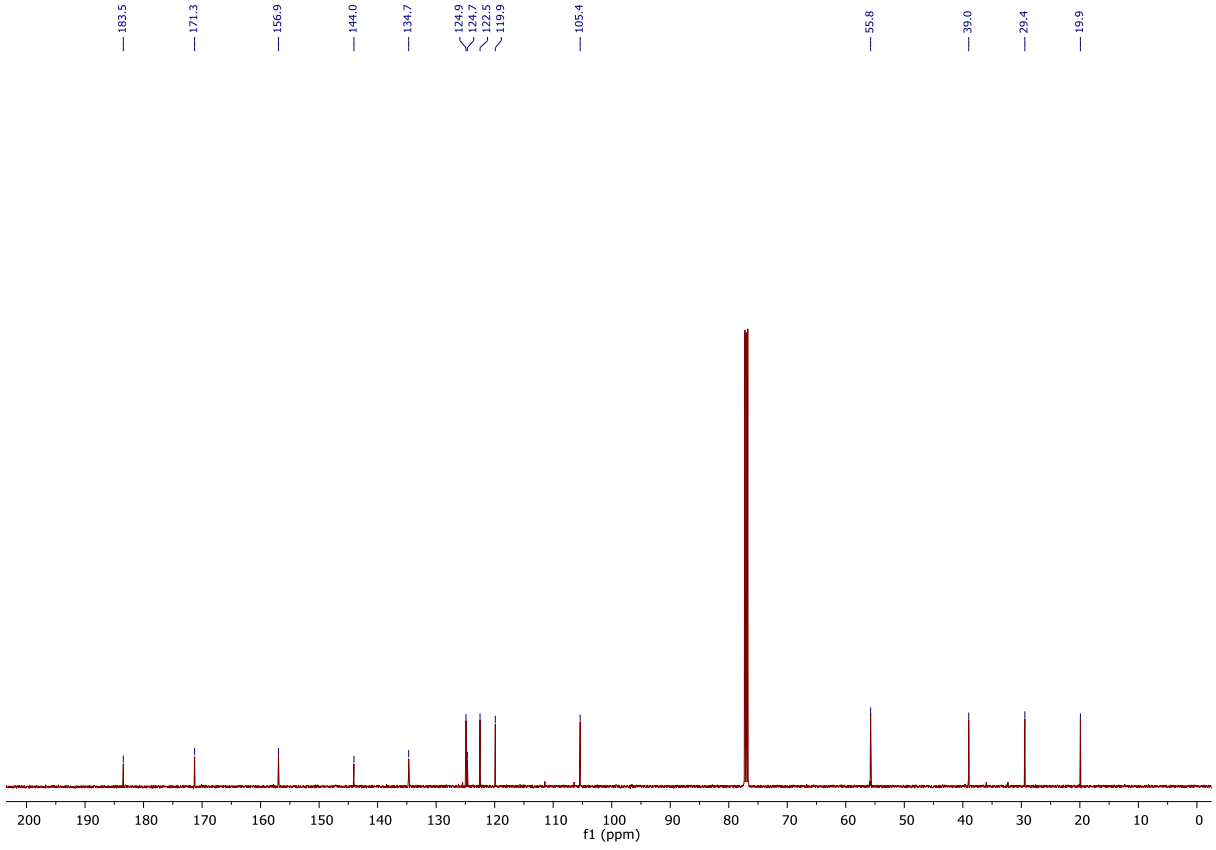
^{1}H-NMR (500 MHz, $CDCl_3$)



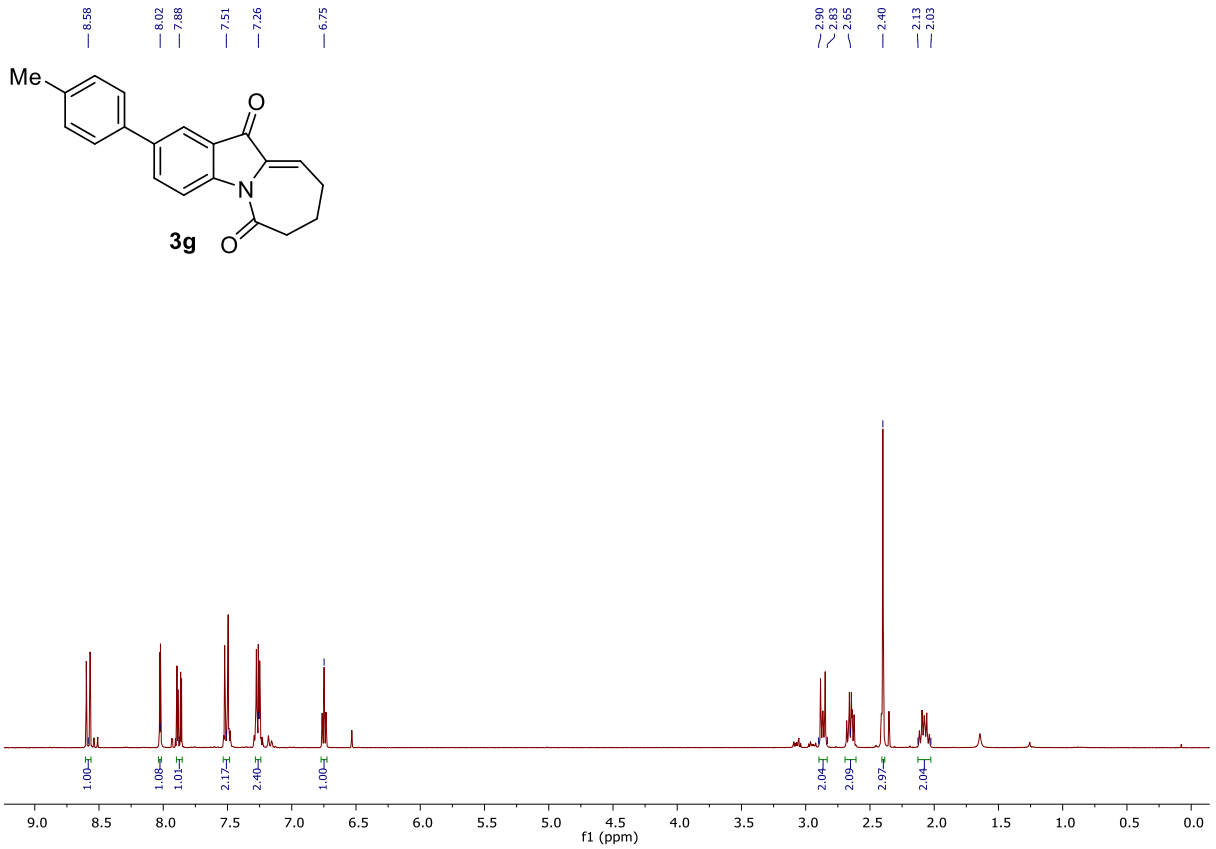
^{13}C-NMR (126 MHz, $CDCl_3$)



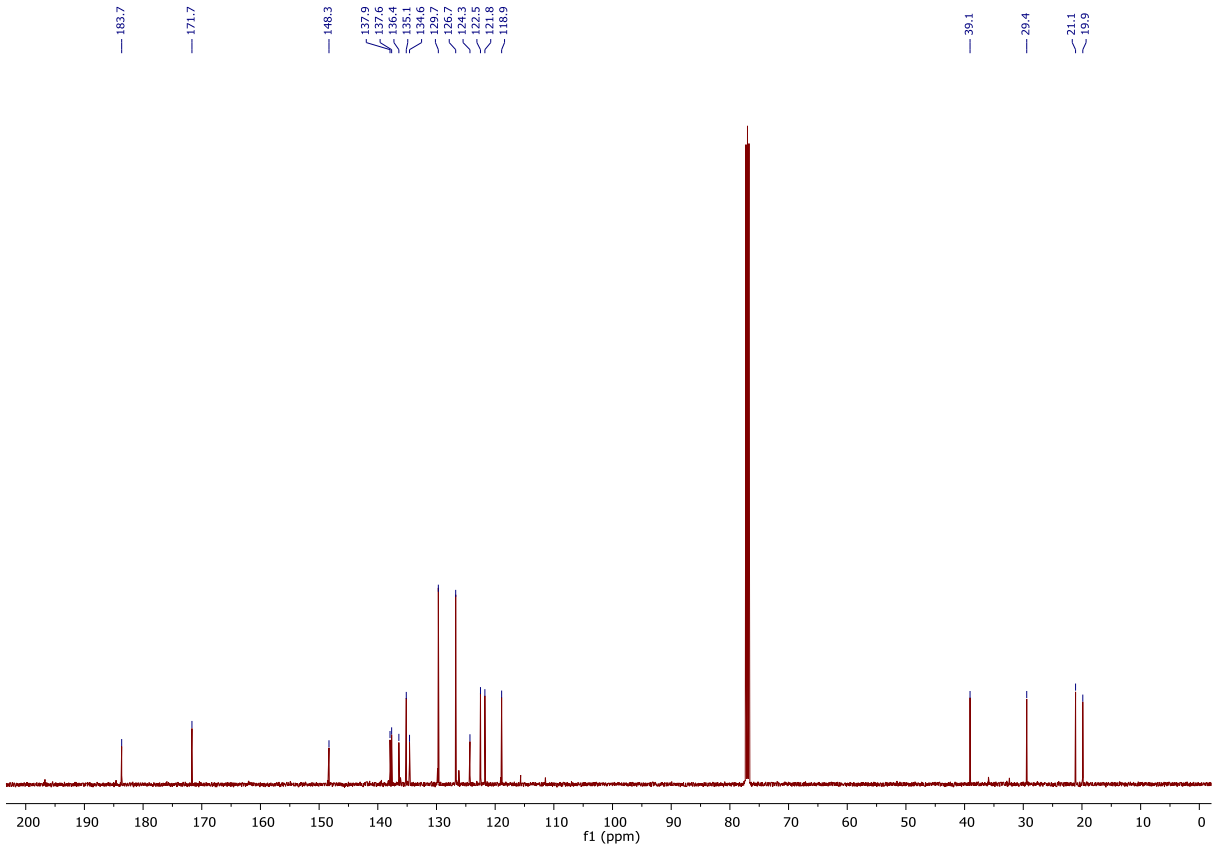
^{1}H-NMR (500 MHz, $CDCl_3$)



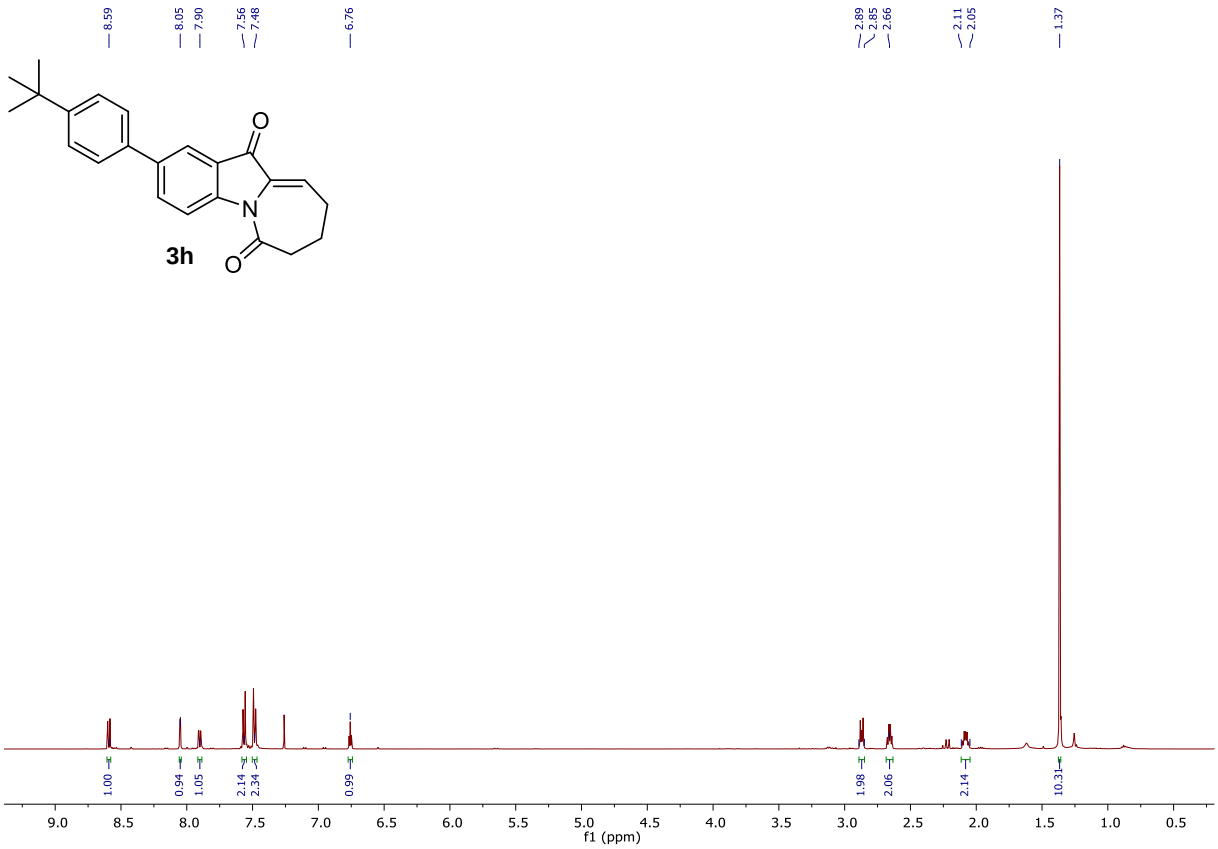
^{13}C-NMR (126 MHz, $CDCl_3$)



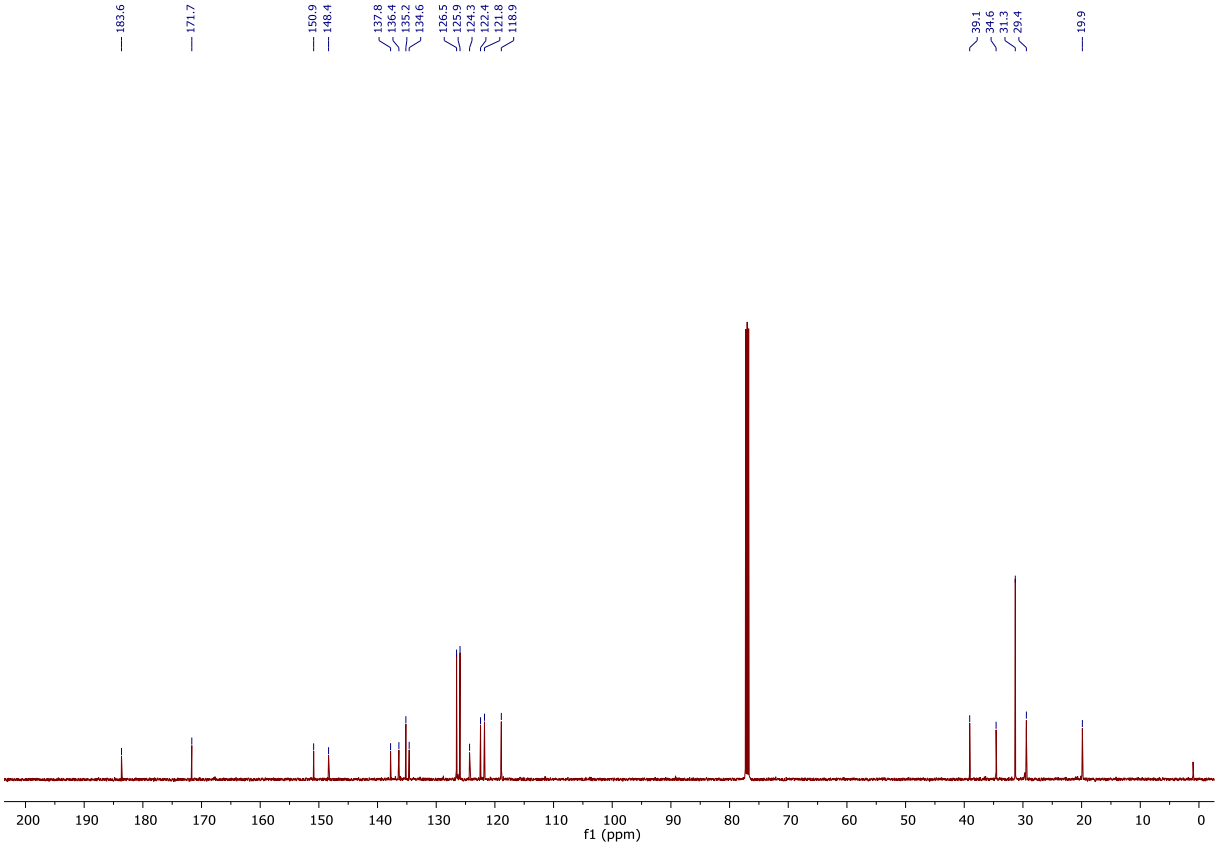
^{1}H-NMR (500 MHz, $CDCl_3$)



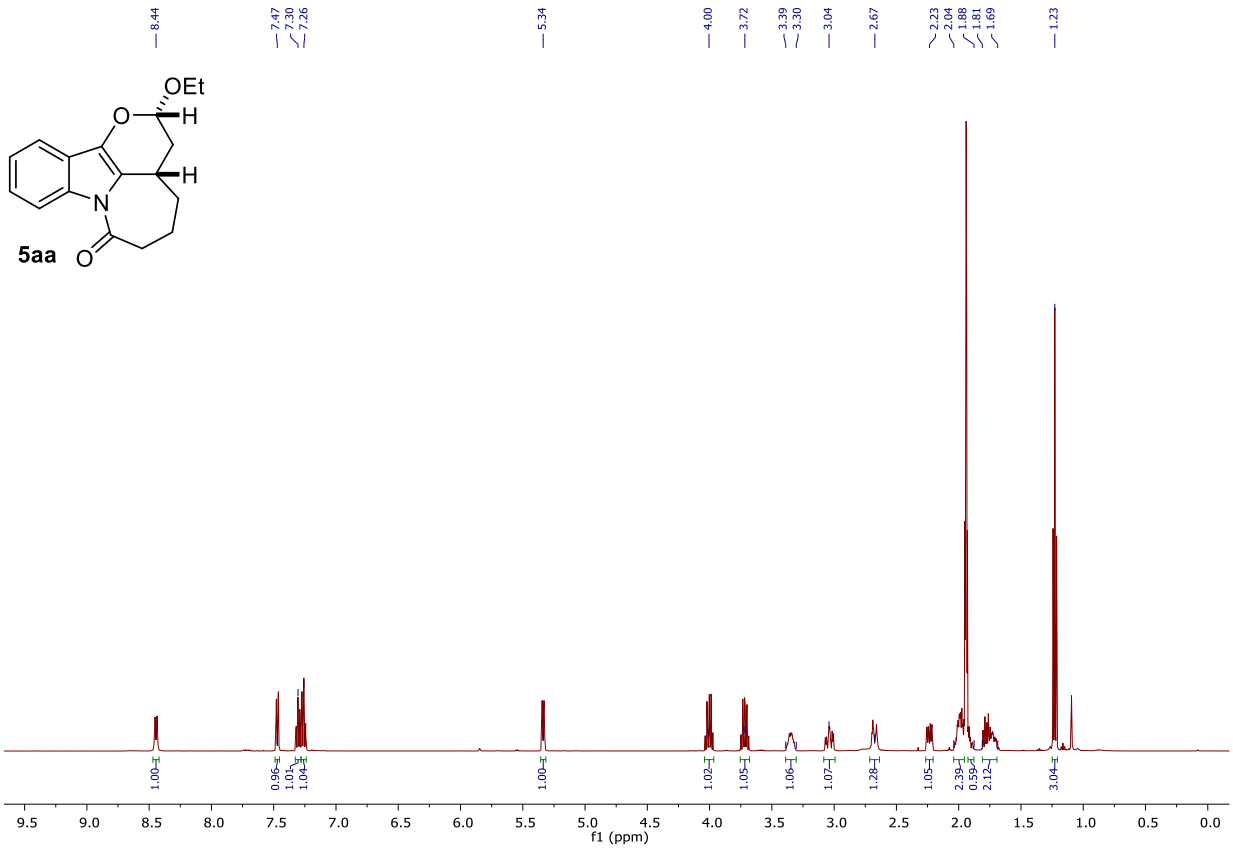
^{13}C-NMR (126 MHz, $CDCl_3$)



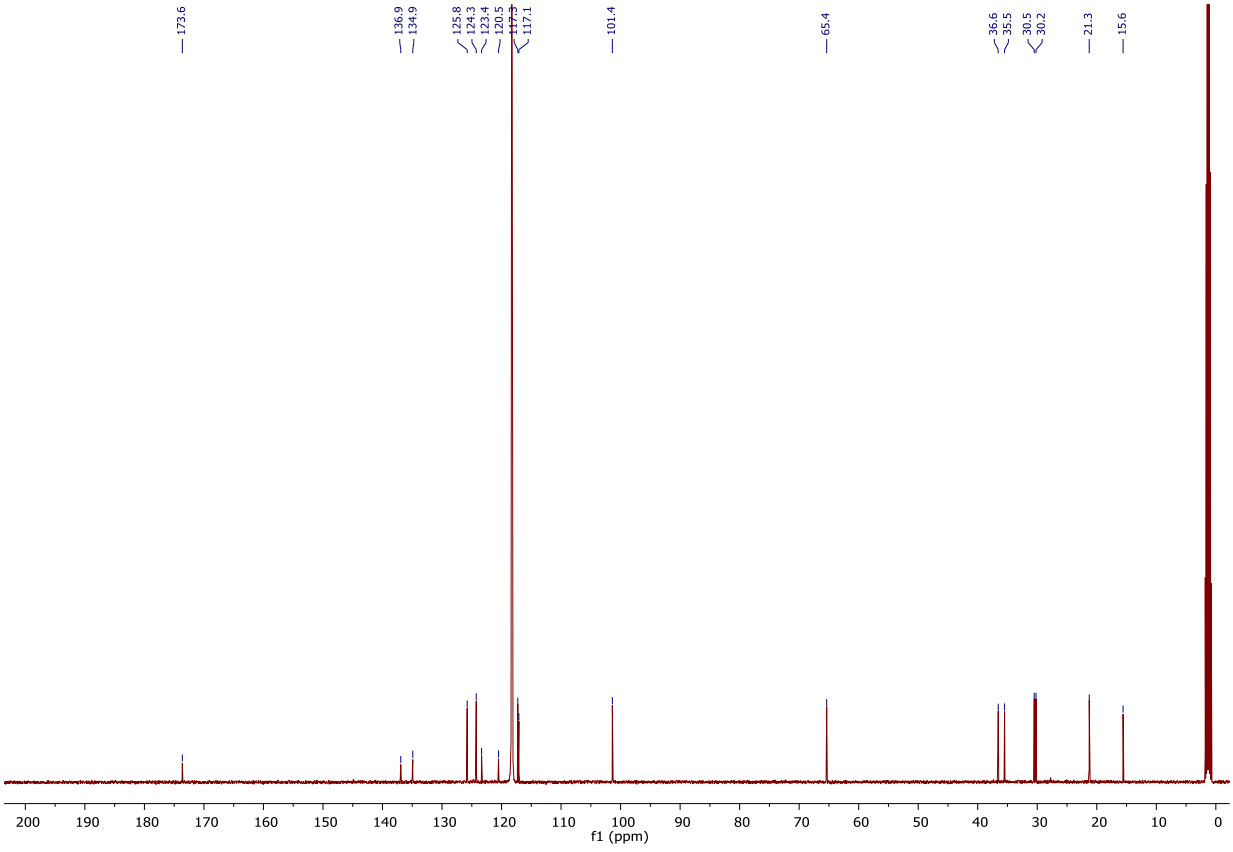
^{1}H-NMR (500 MHz, $CDCl_3$)



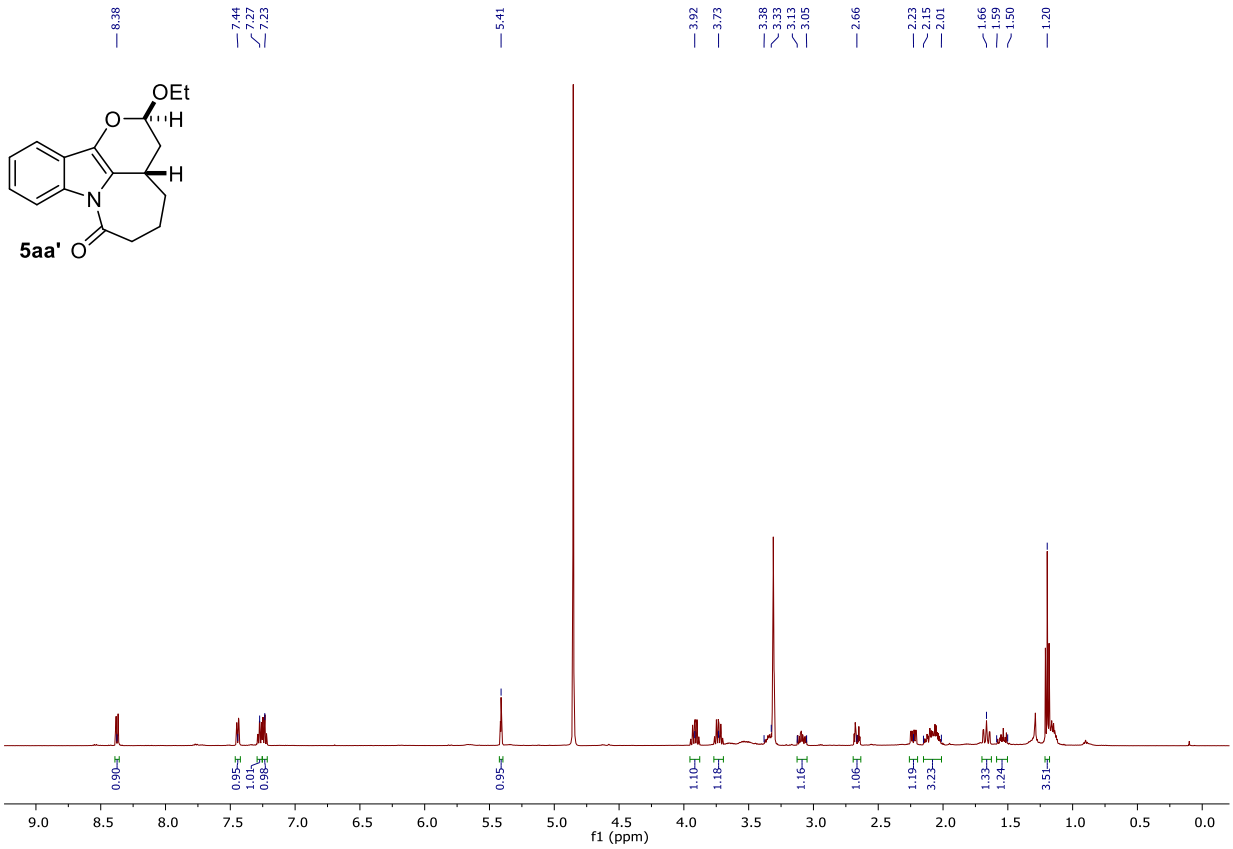
^{13}C-NMR (126 MHz, $CDCl_3$)



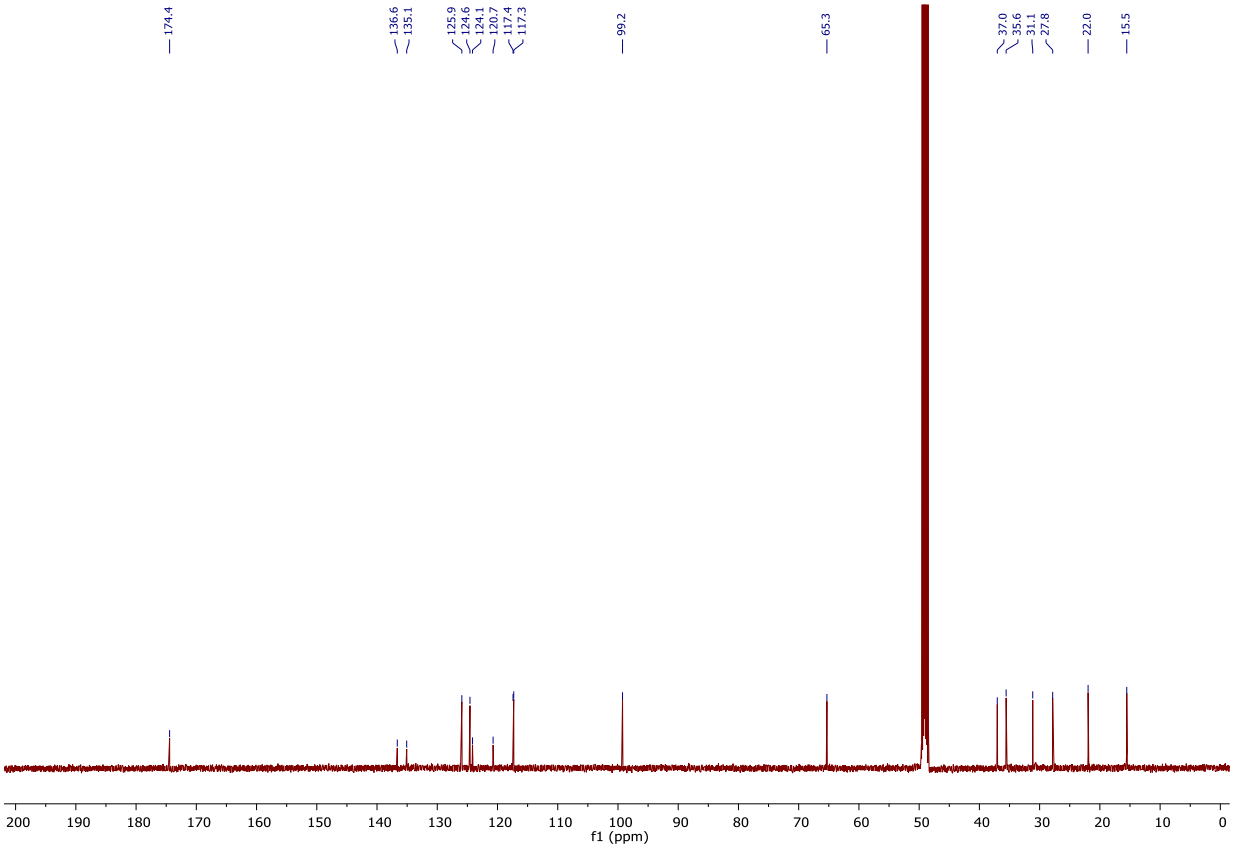
^{1}H-NMR (500 MHz, CD_3CN)



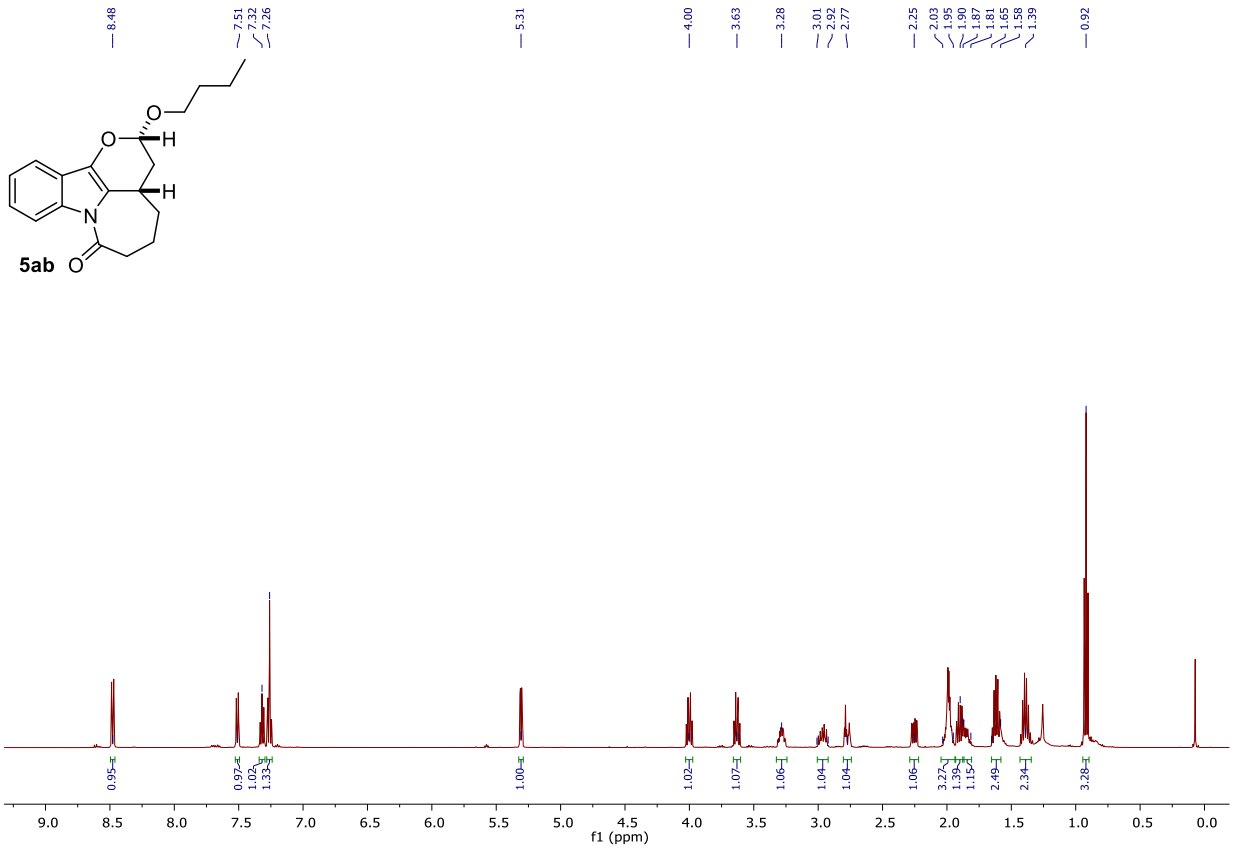
^{13}C-NMR (126 MHz, CD_3CN)



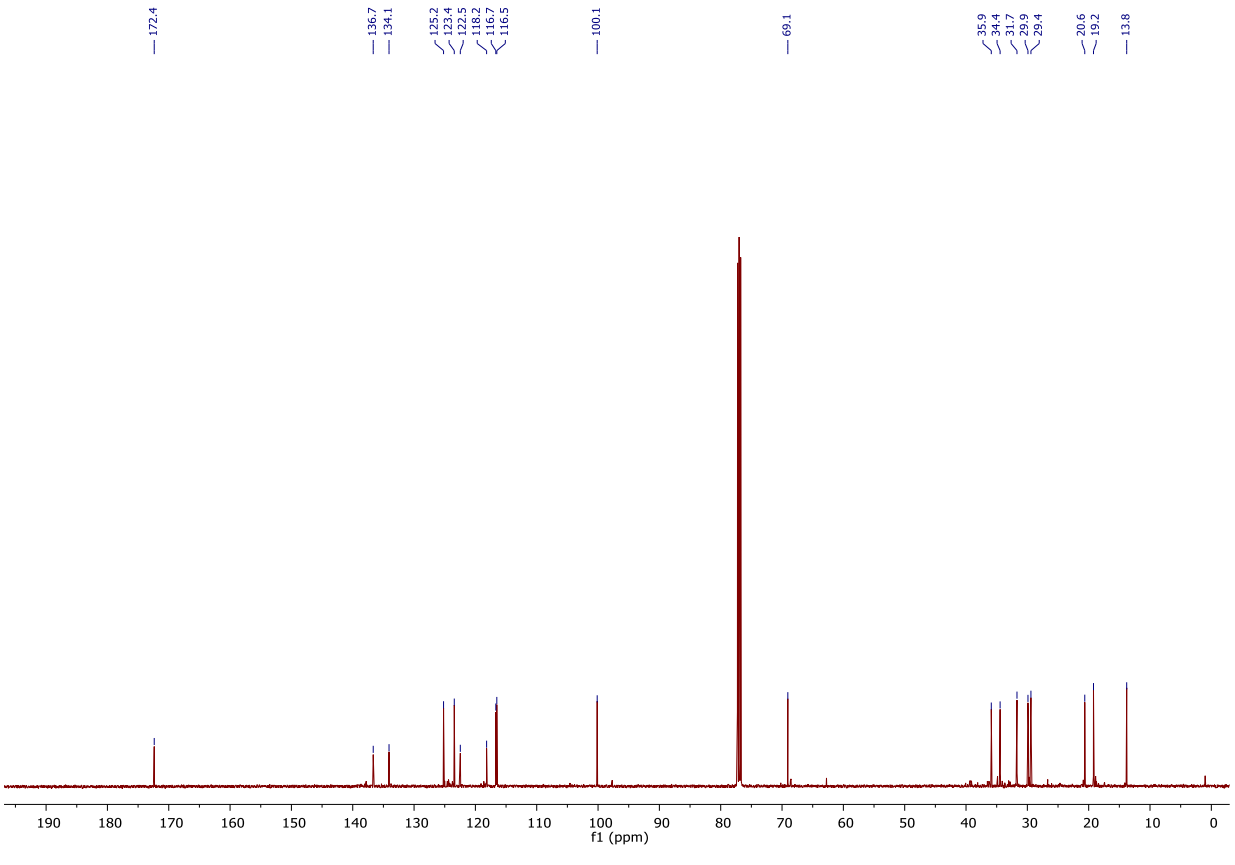
^{1}H-NMR (500 MHz, CD_3OD)



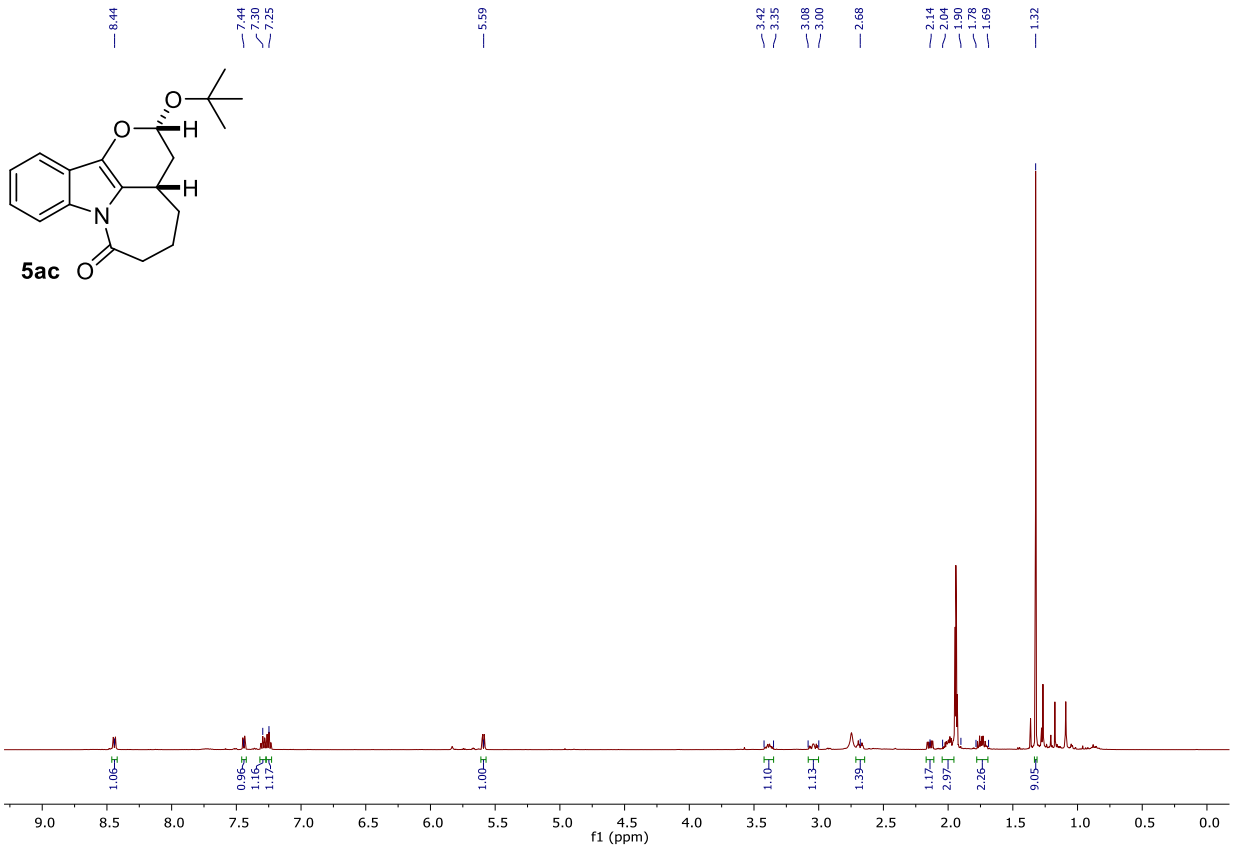
^{13}C-NMR (126 MHz, CD_3OD)



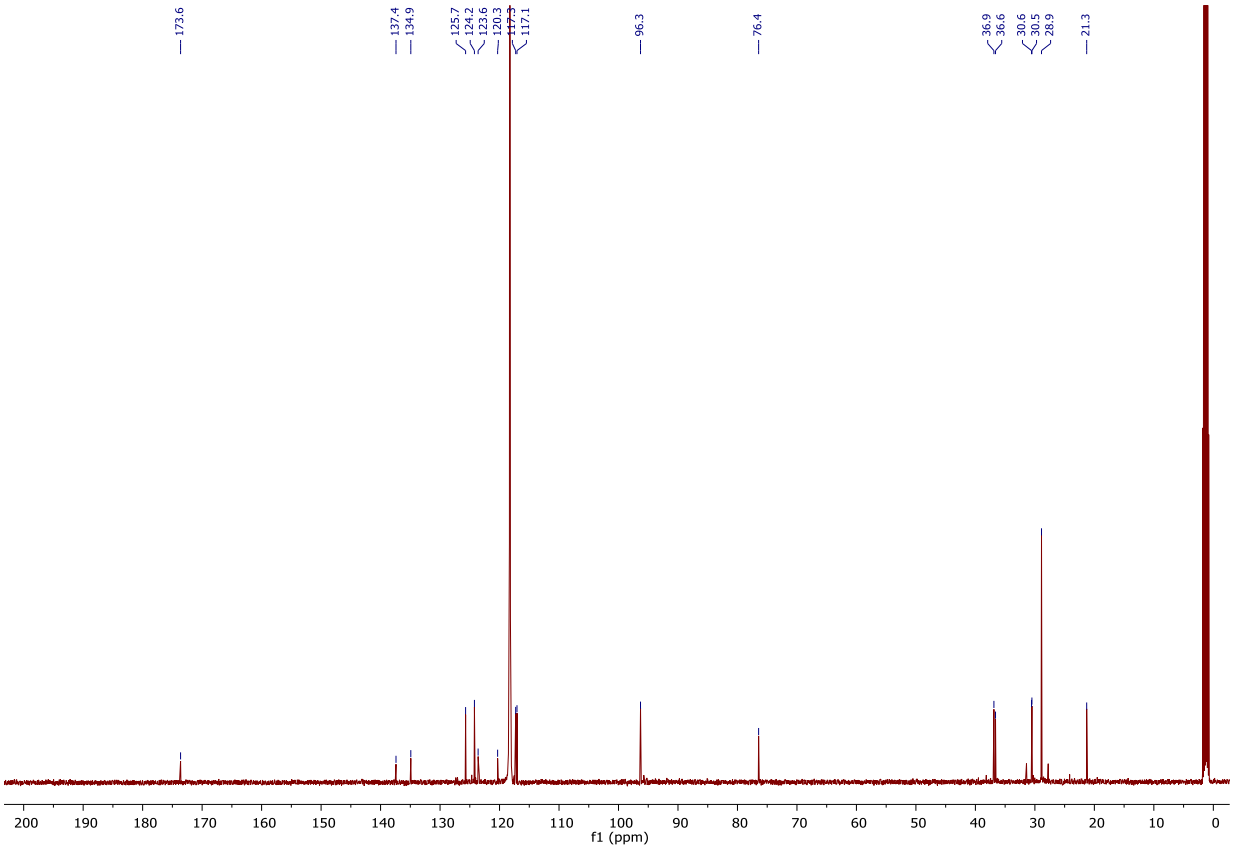
^{1}H-NMR (500 MHz, $CDCl_3$)



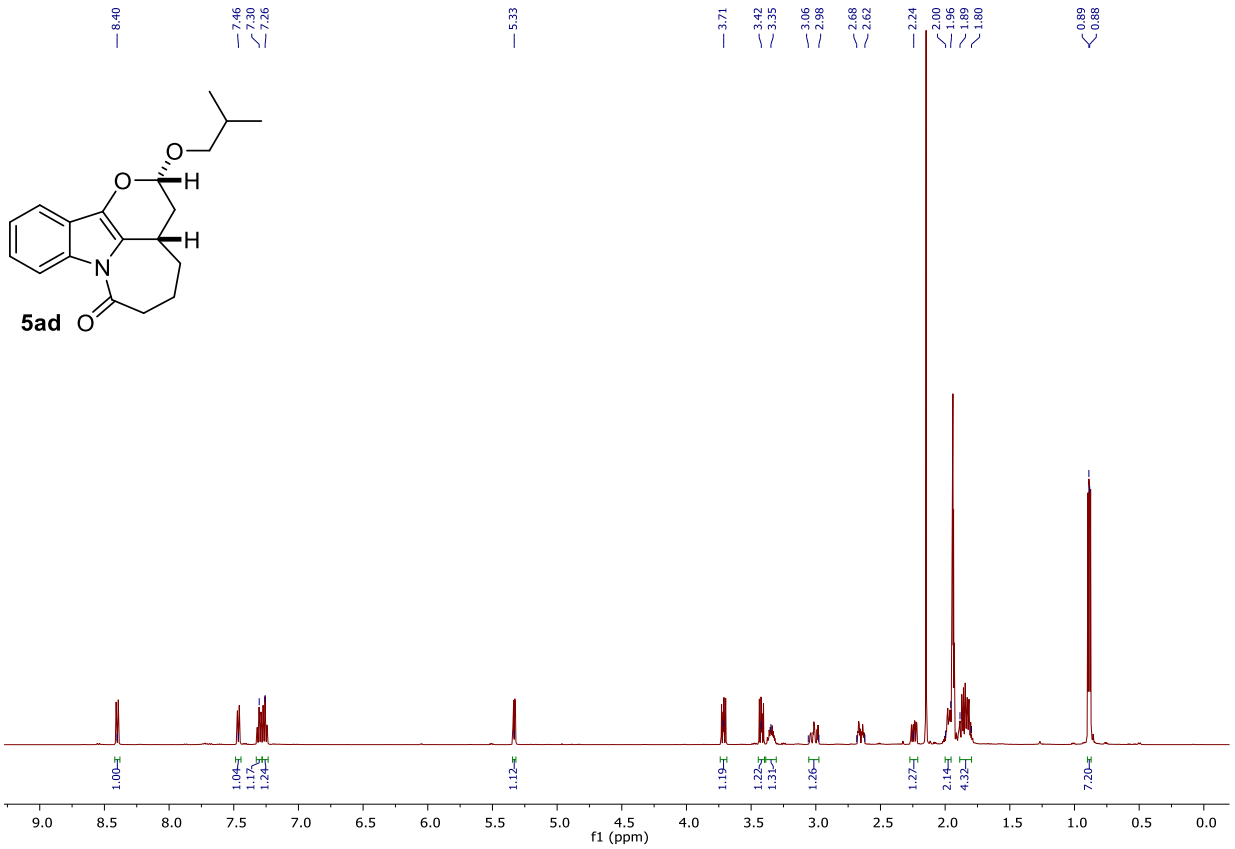
^{13}C-NMR (126 MHz, $CDCl_3$)



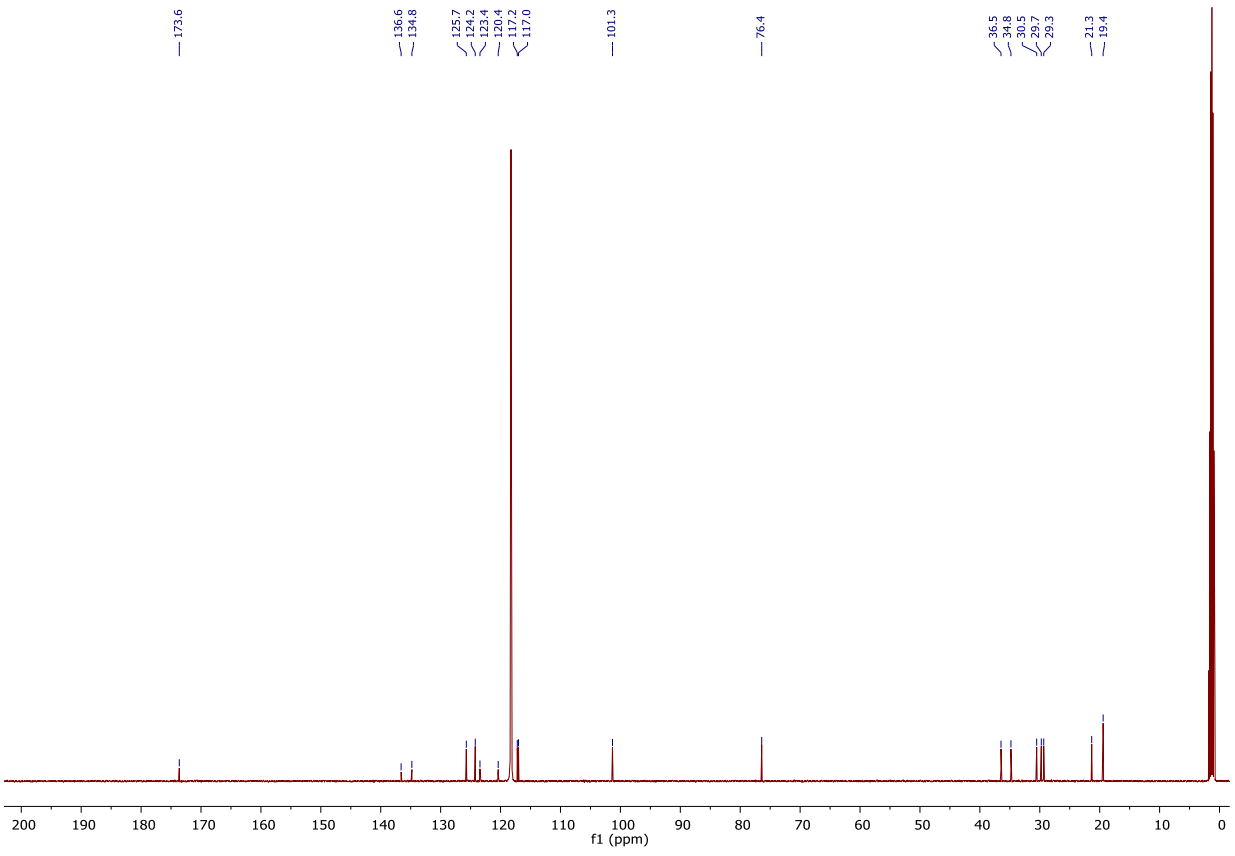
^{1}H-NMR (500 MHz, CD_3CN)



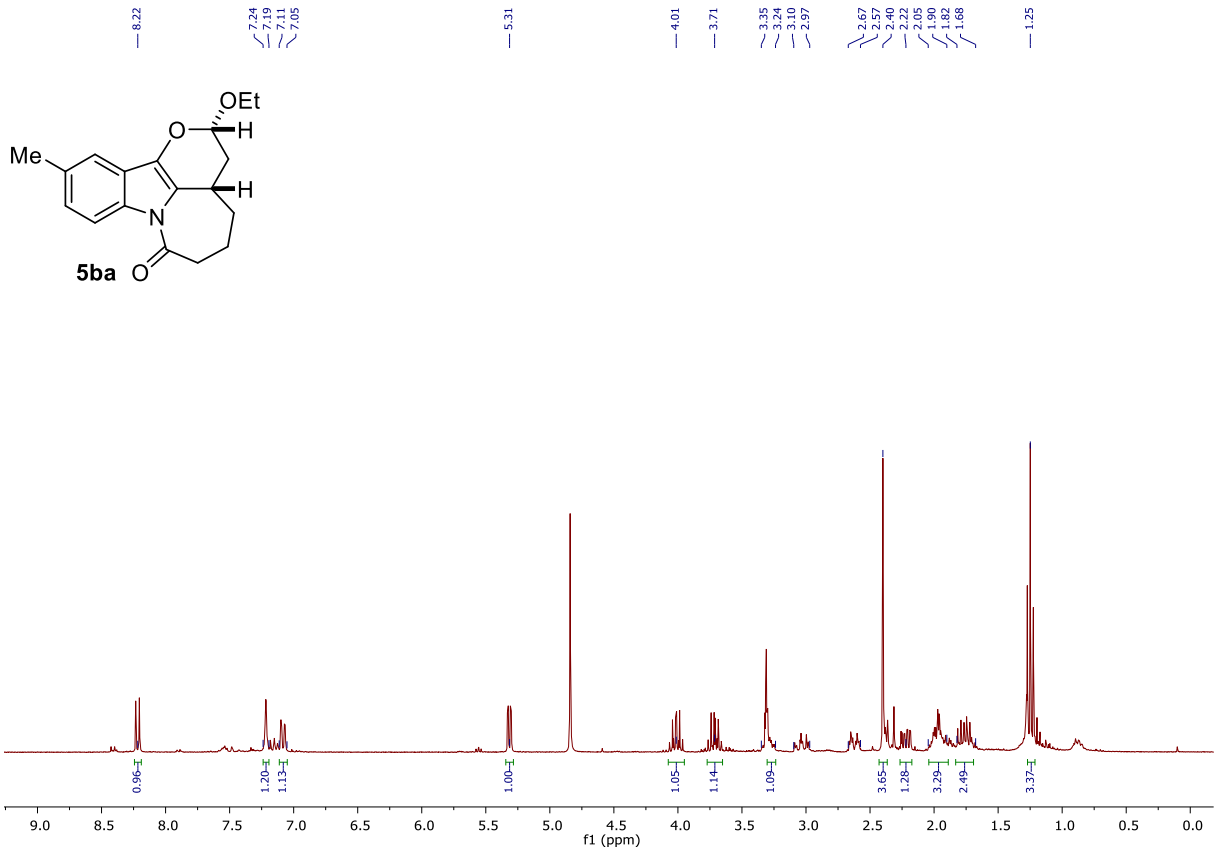
^{13}C-NMR (126 MHz, CD_3CN)



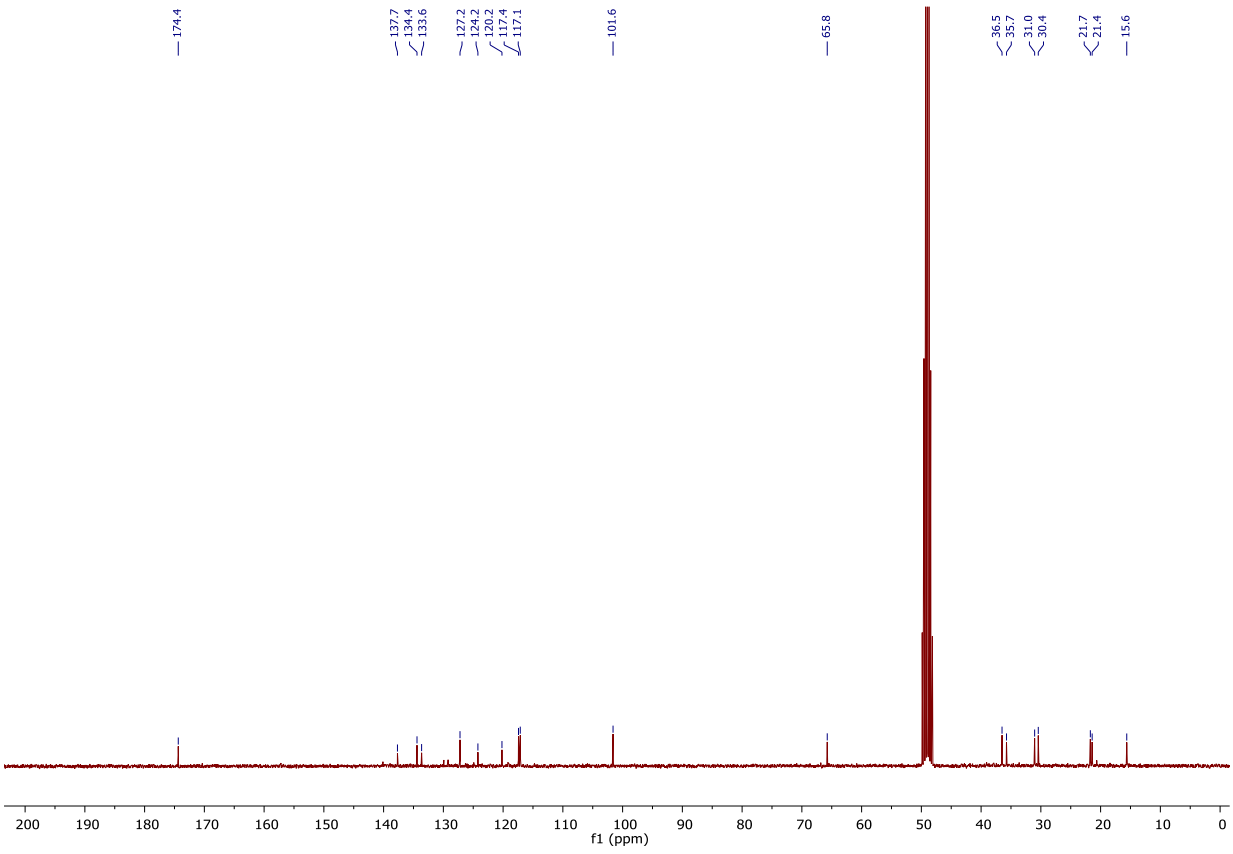
^{1}H-NMR (500 MHz, CD_3CN)



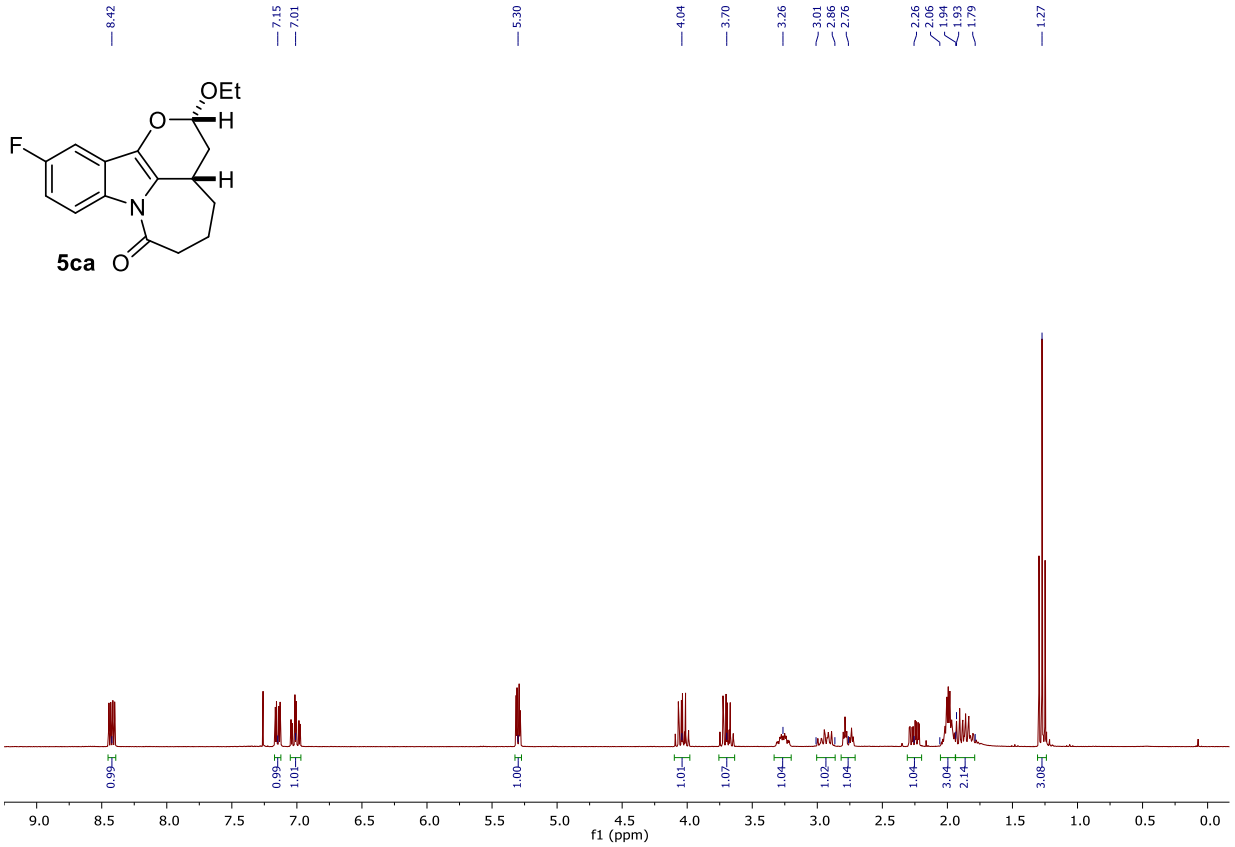
^{13}C-NMR (126 MHz, CD_3CN)



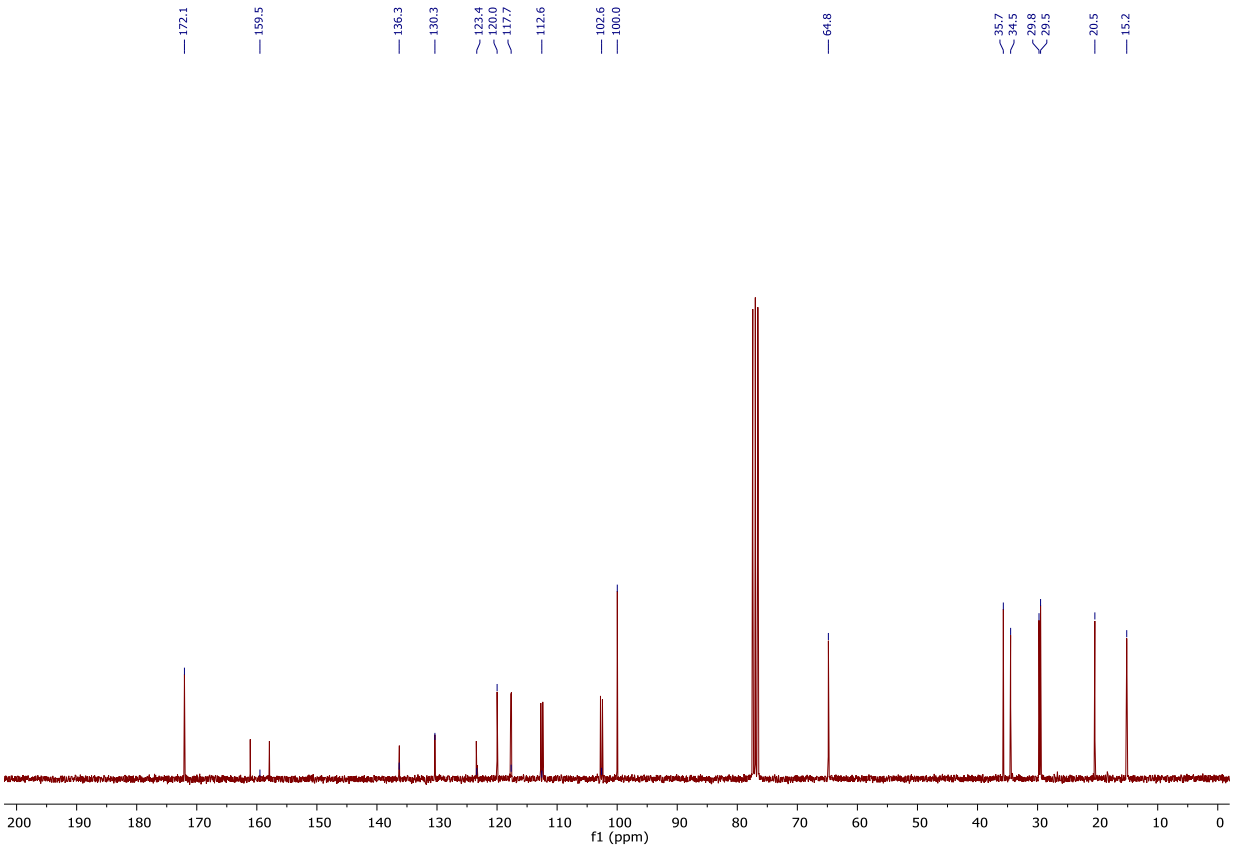
^{1}H-NMR (300 MHz, CD_3OD)



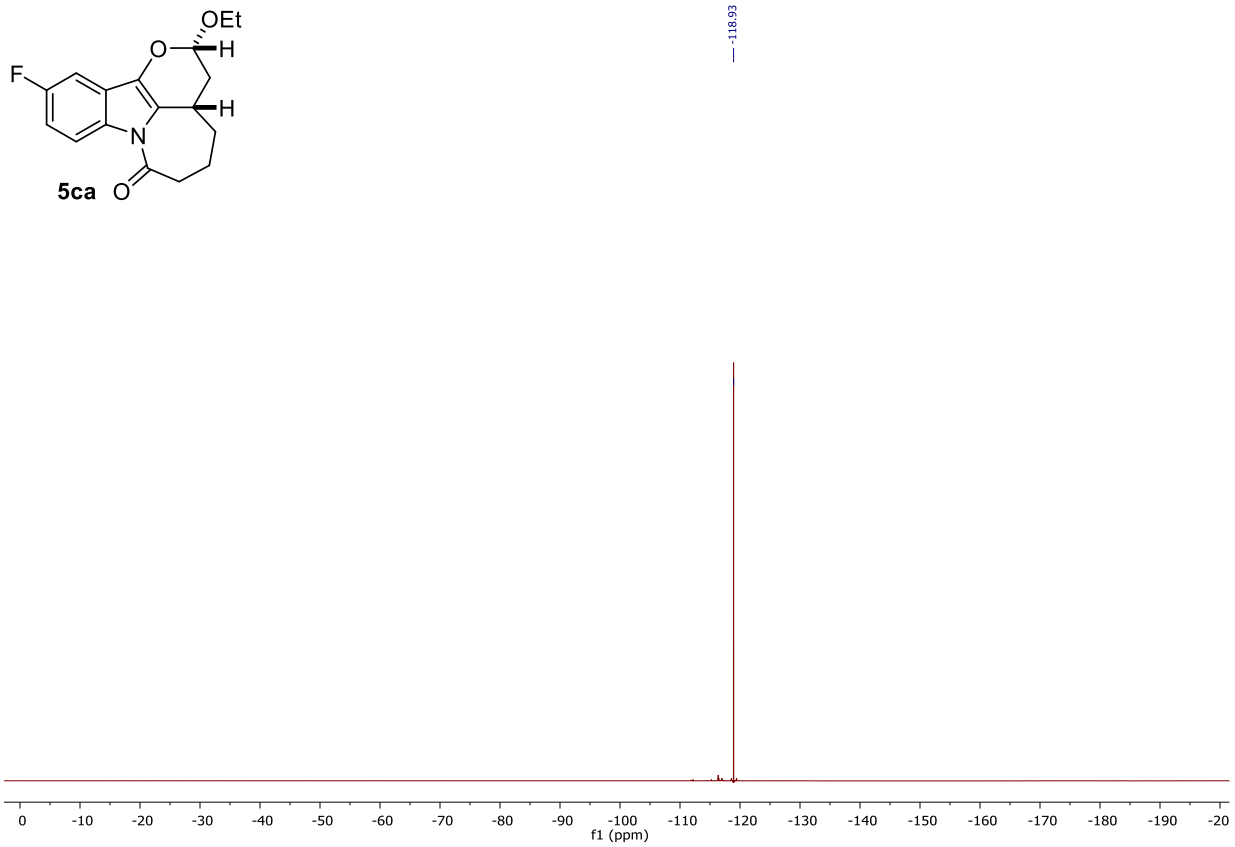
^{13}C-NMR (75 MHz, CD_3OD)



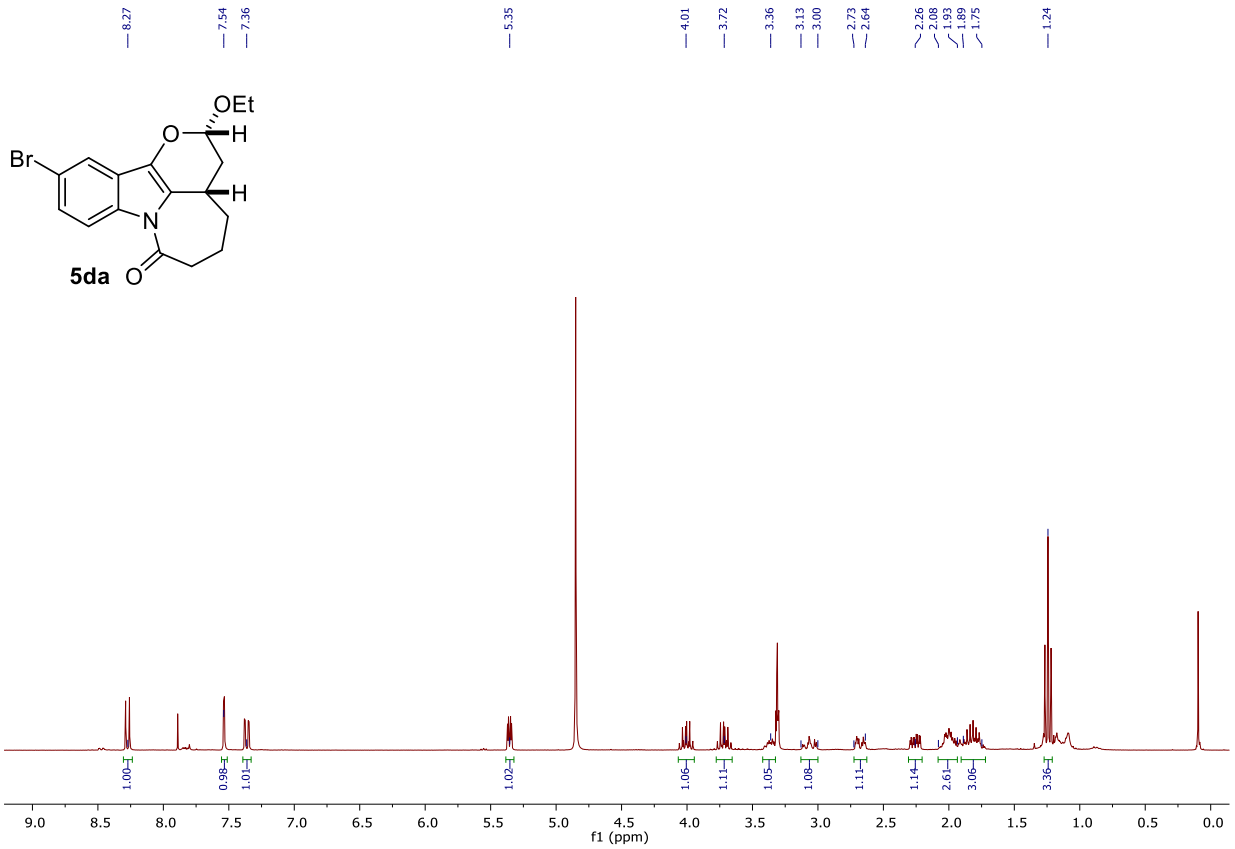
^{1}H-NMR (300 MHz, $CDCl_3$)



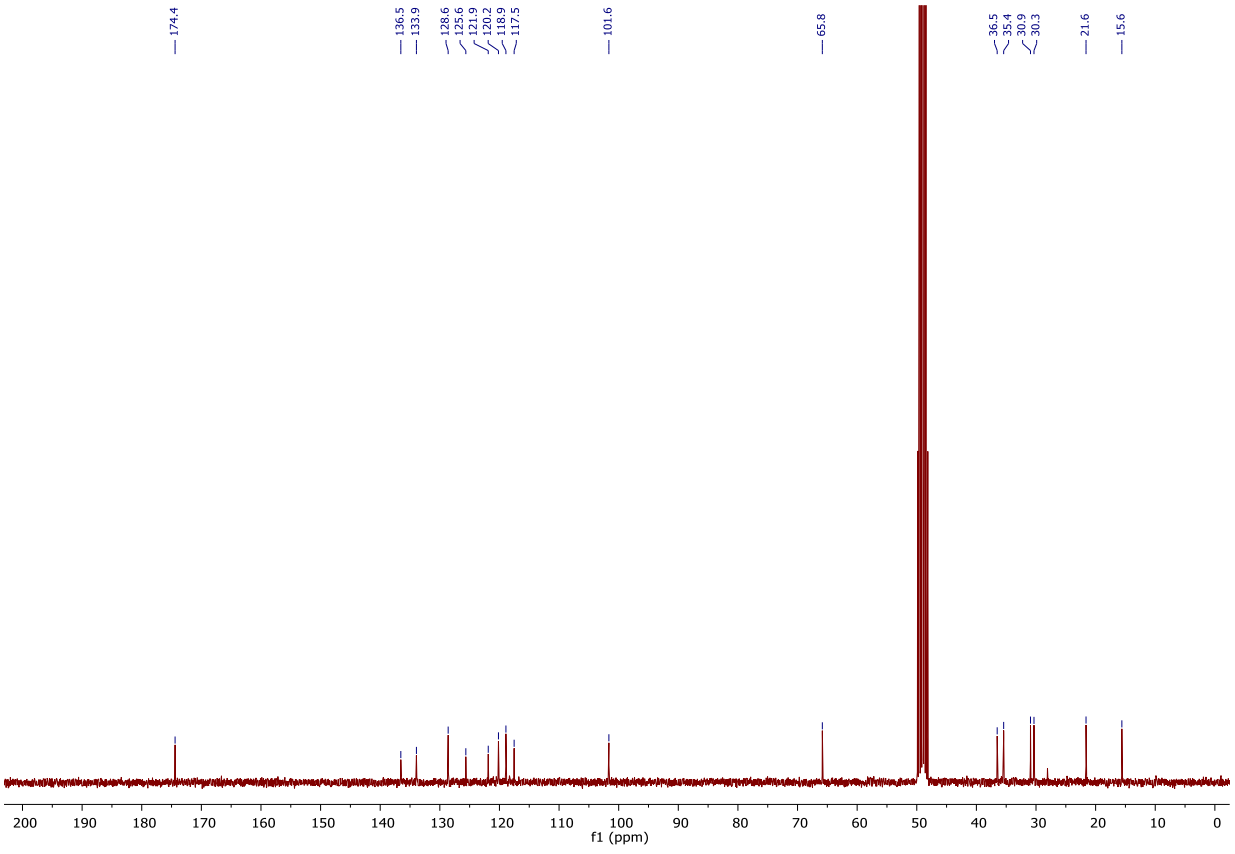
^{13}C-NMR (75 MHz, $CDCl_3$)



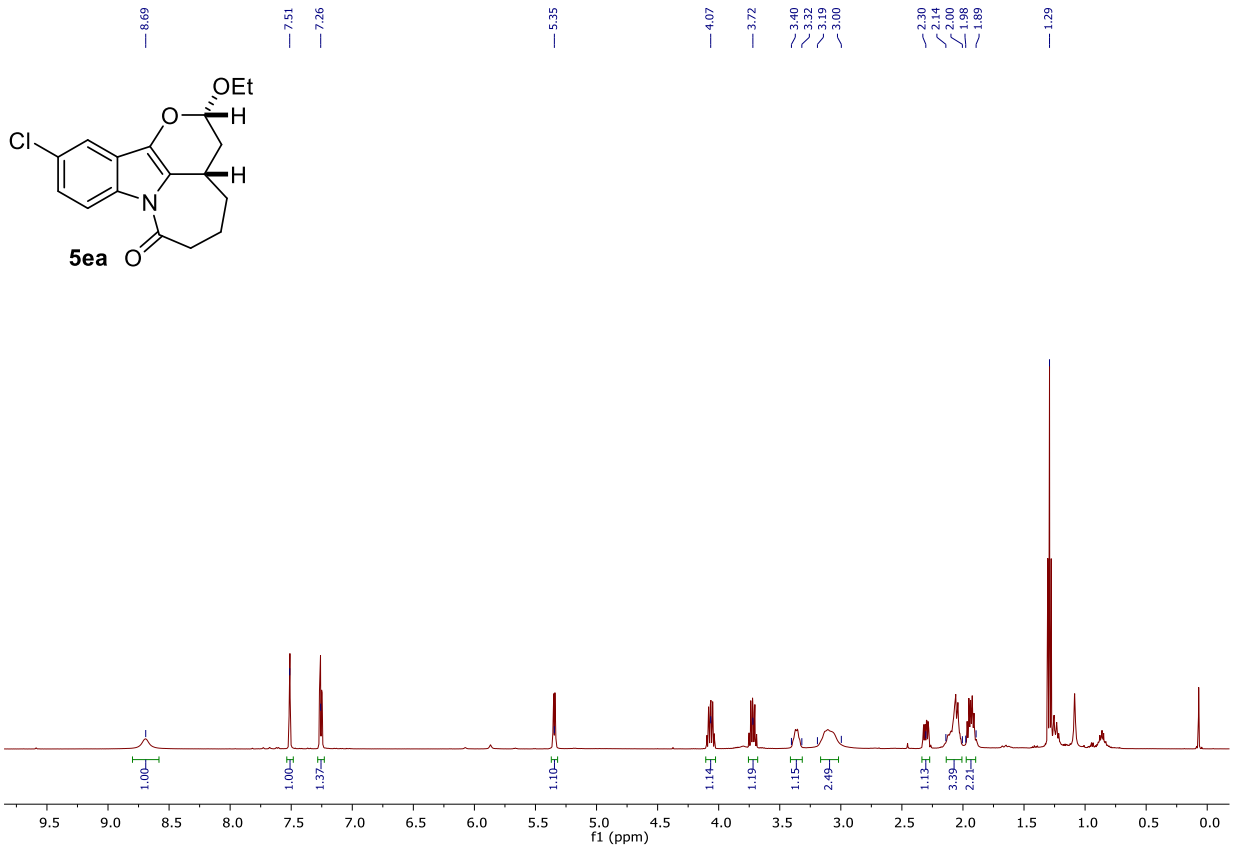
^{19}F-NMR (282 MHz, $CDCl_3$)



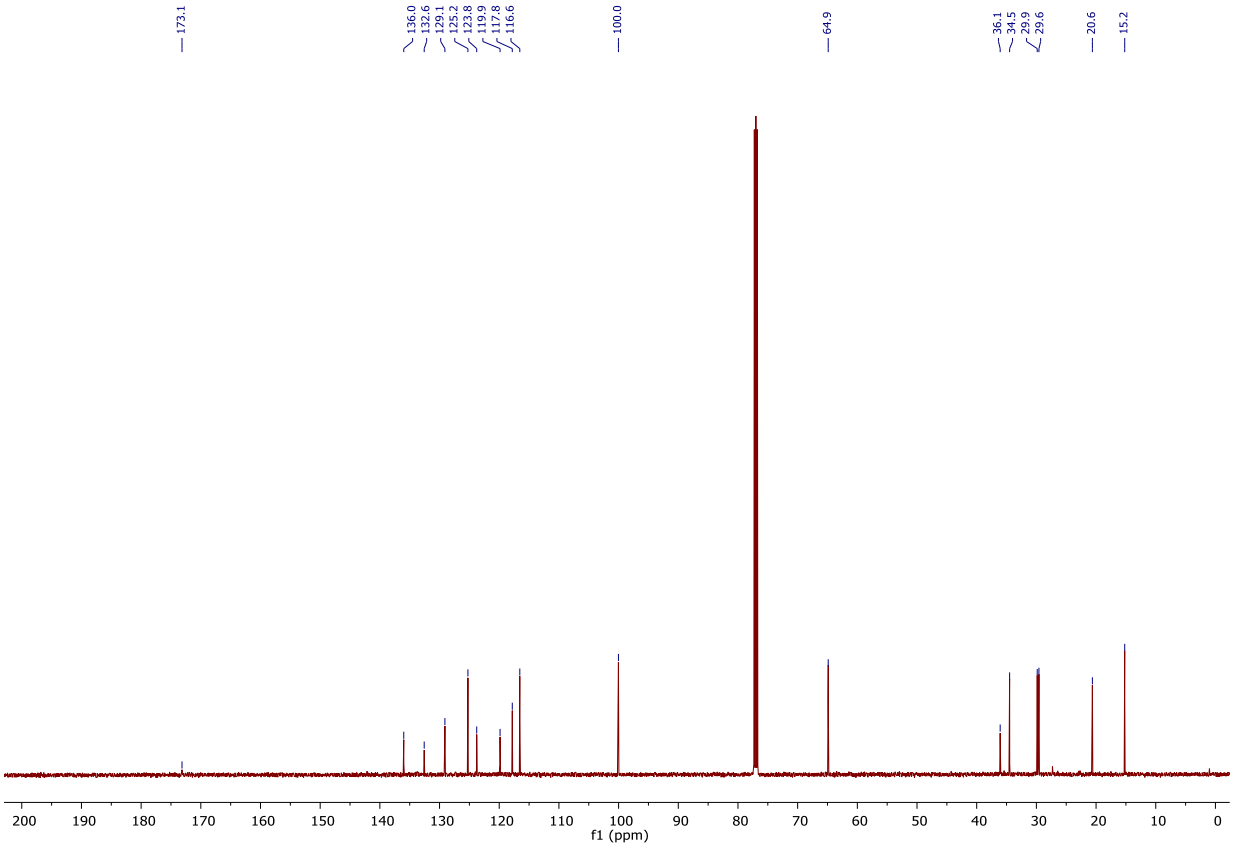
^{1}H-NMR (300 MHz, CD_3OD)



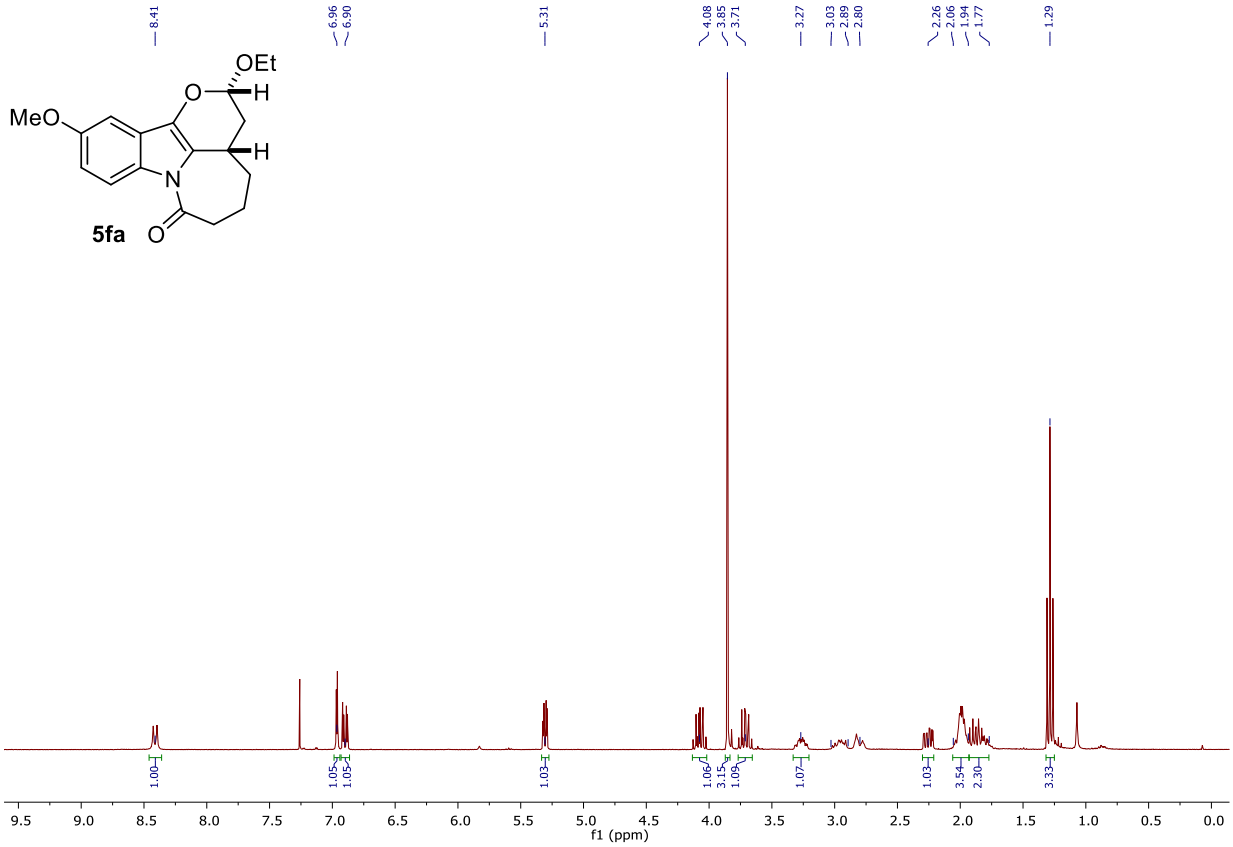
^{13}C-NMR (75 MHz, CD_3OD)



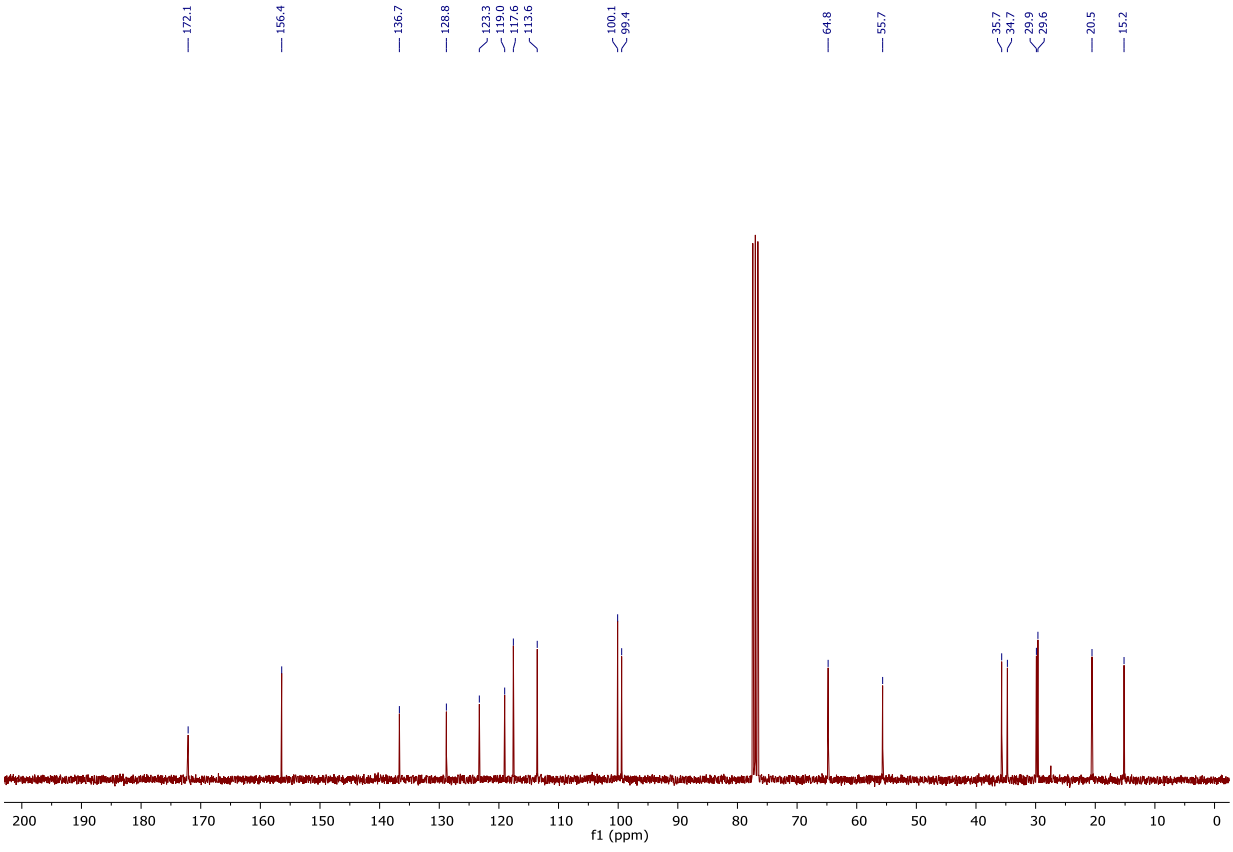
^{1}H-NMR (500 MHz, $CDCl_3$)



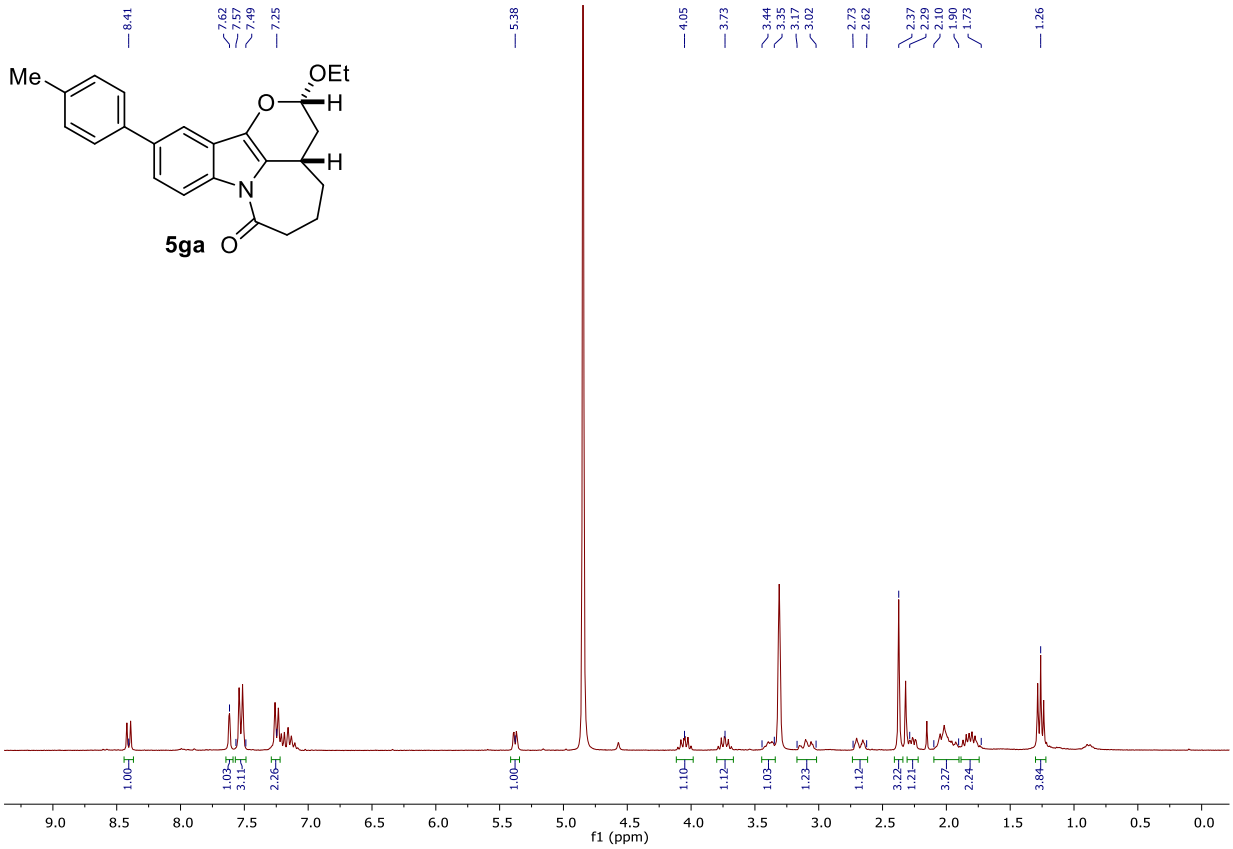
^{13}C-NMR (126 MHz, $CDCl_3$)



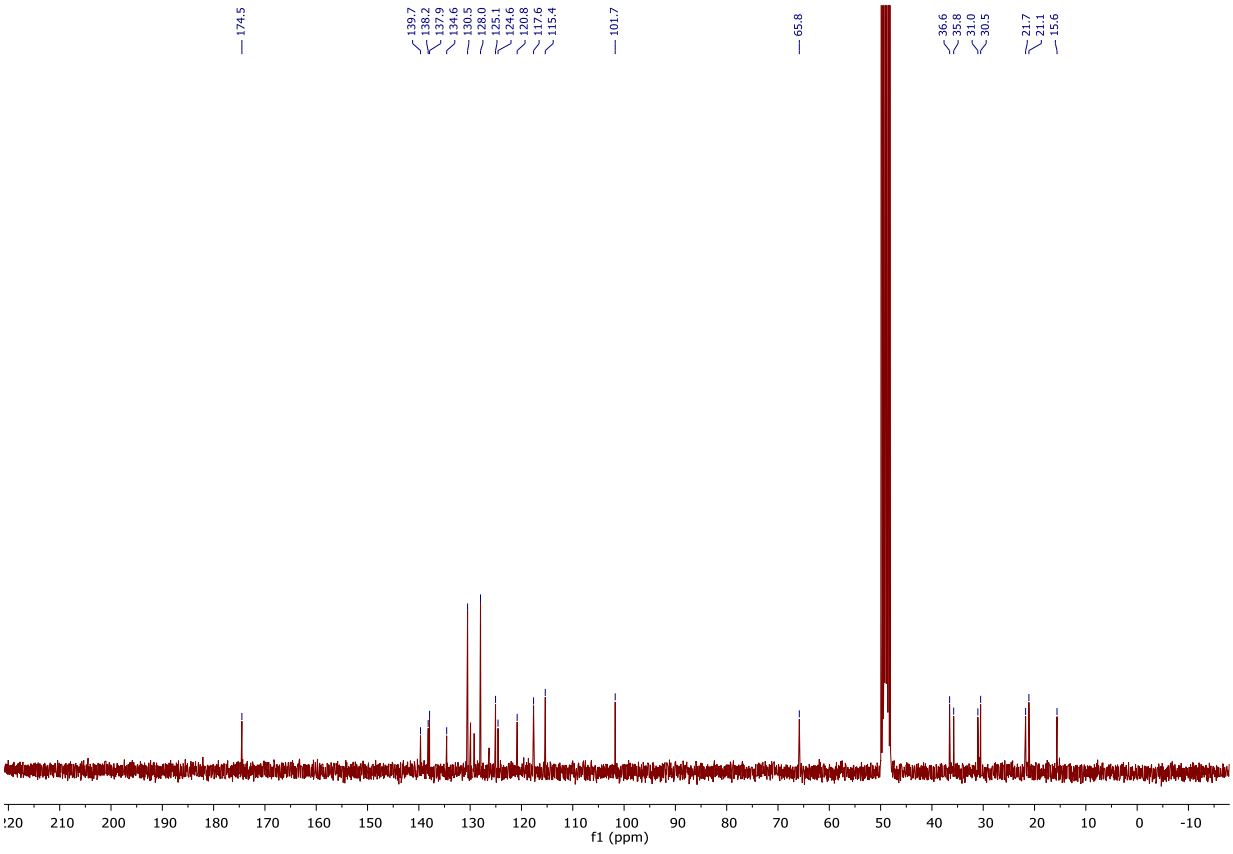
^{1}H-NMR (300 MHz, $CDCl_3$)



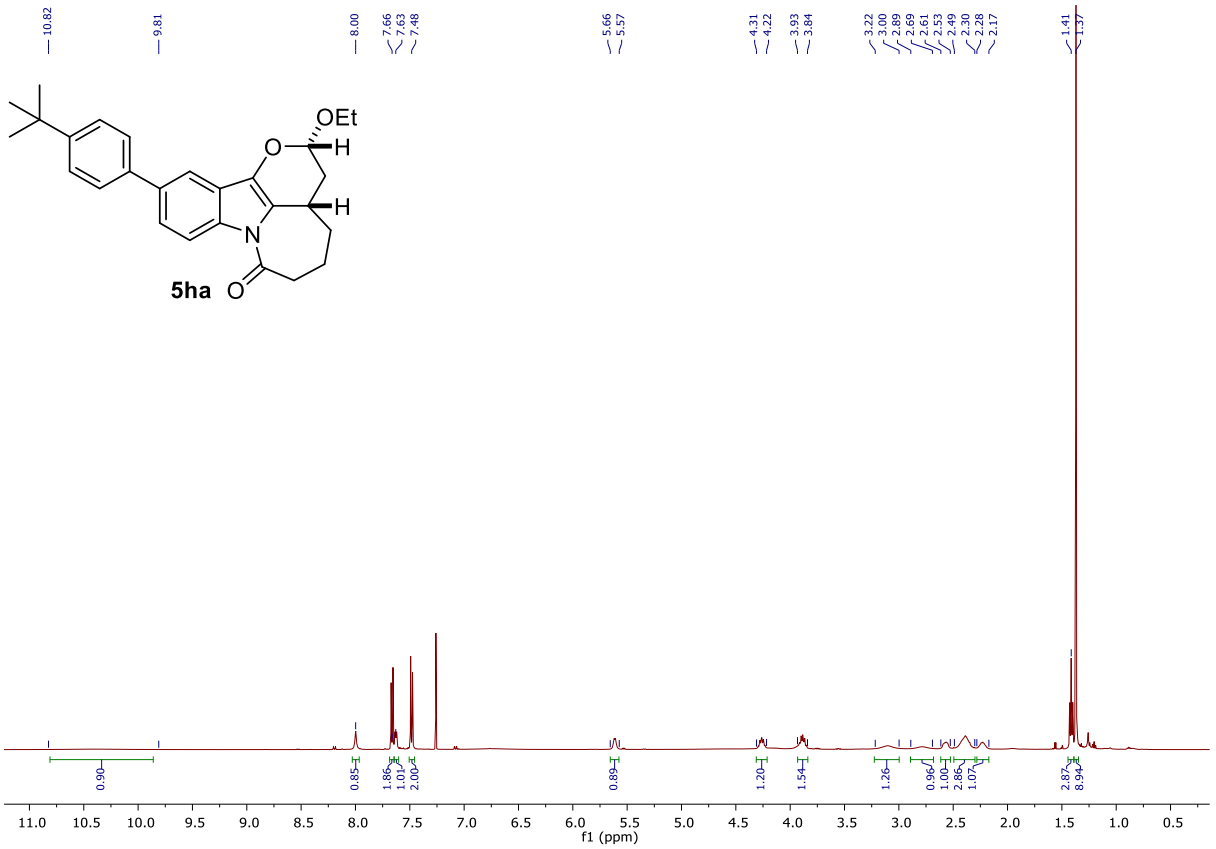
^{13}C-NMR (75 MHz, $CDCl_3$)



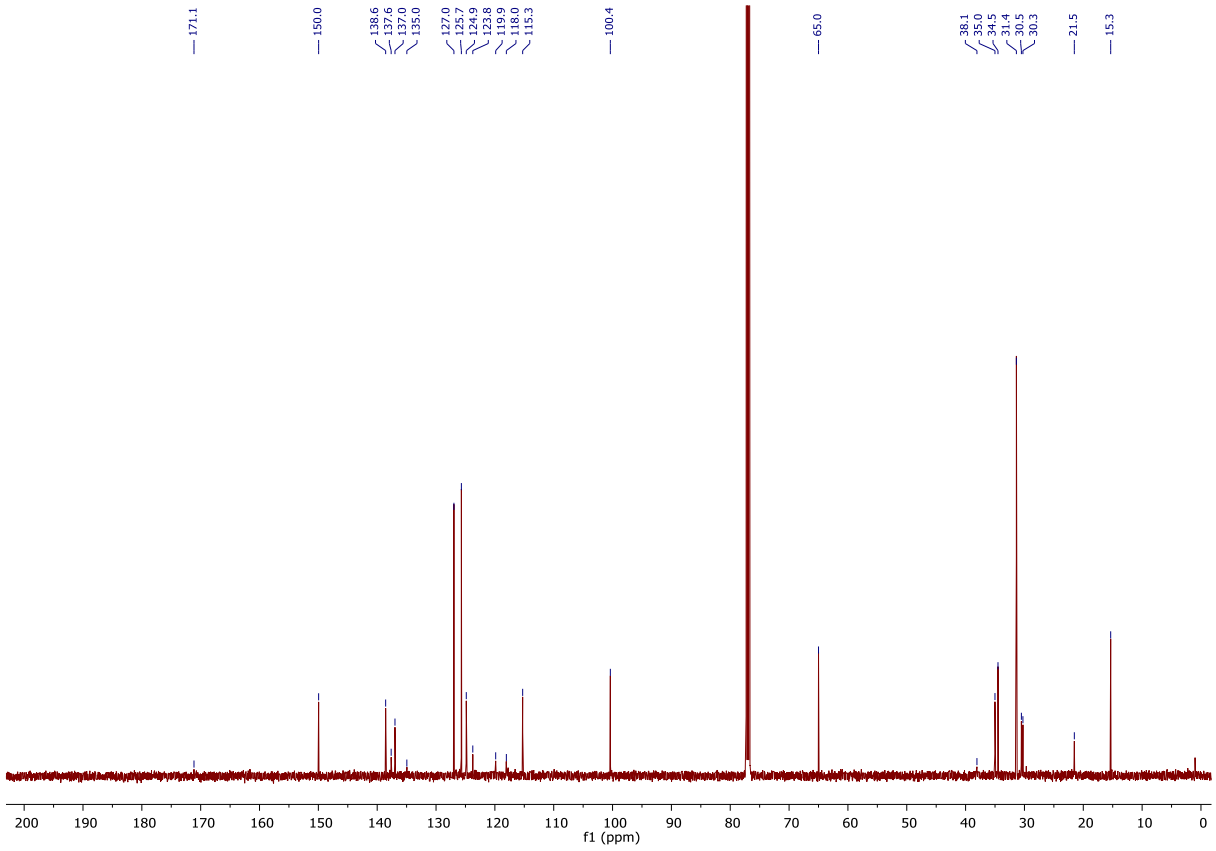
^{1}H-NMR (300 MHz, CD_3OD)



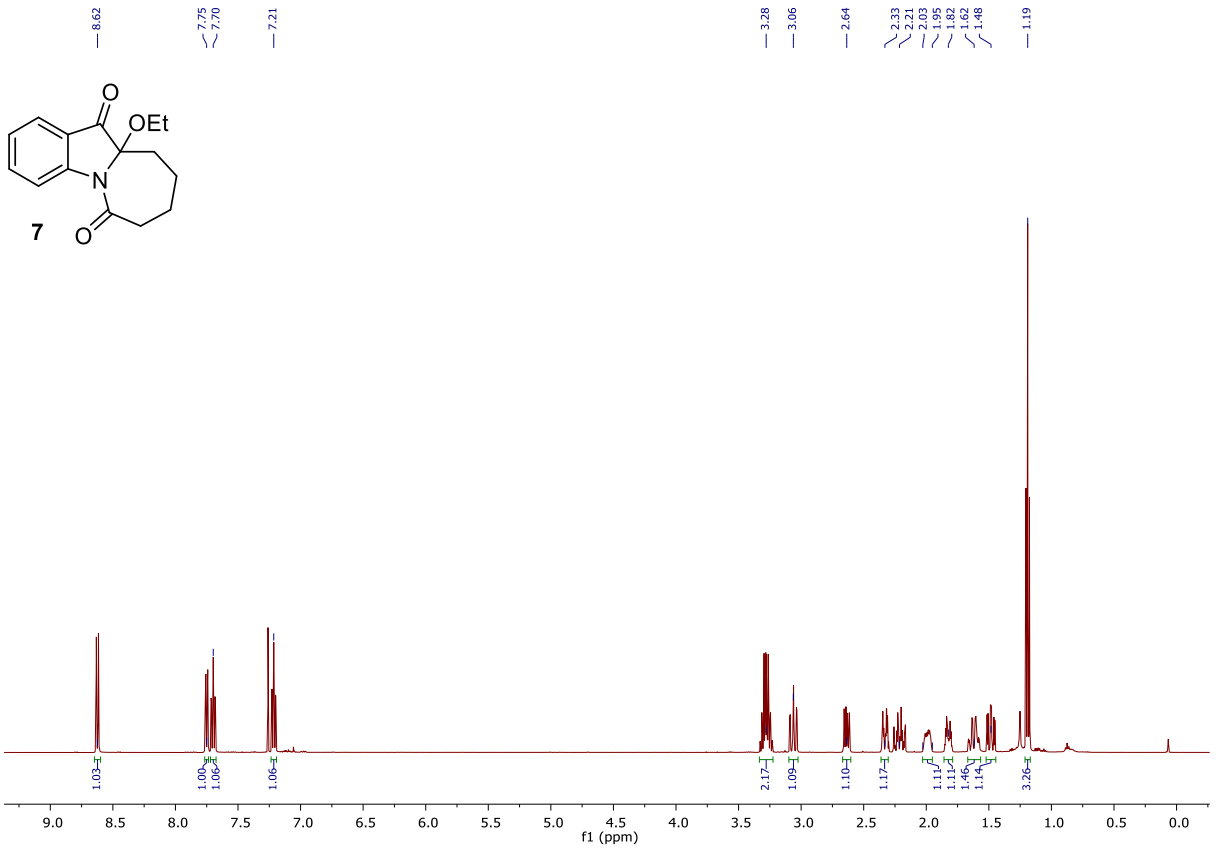
^{13}C-NMR (75 MHz, CD_3OD)



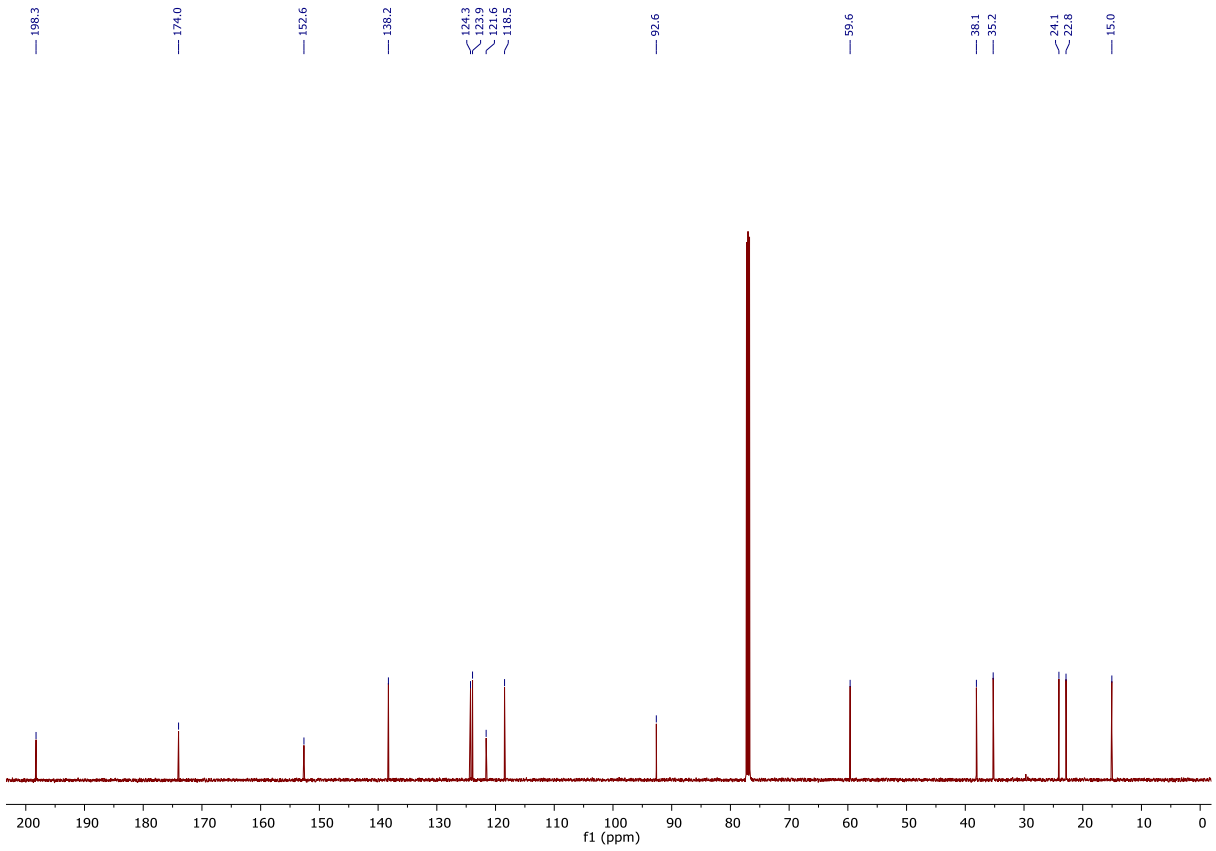
^{1}H-NMR (500 MHz, $CDCl_3$)



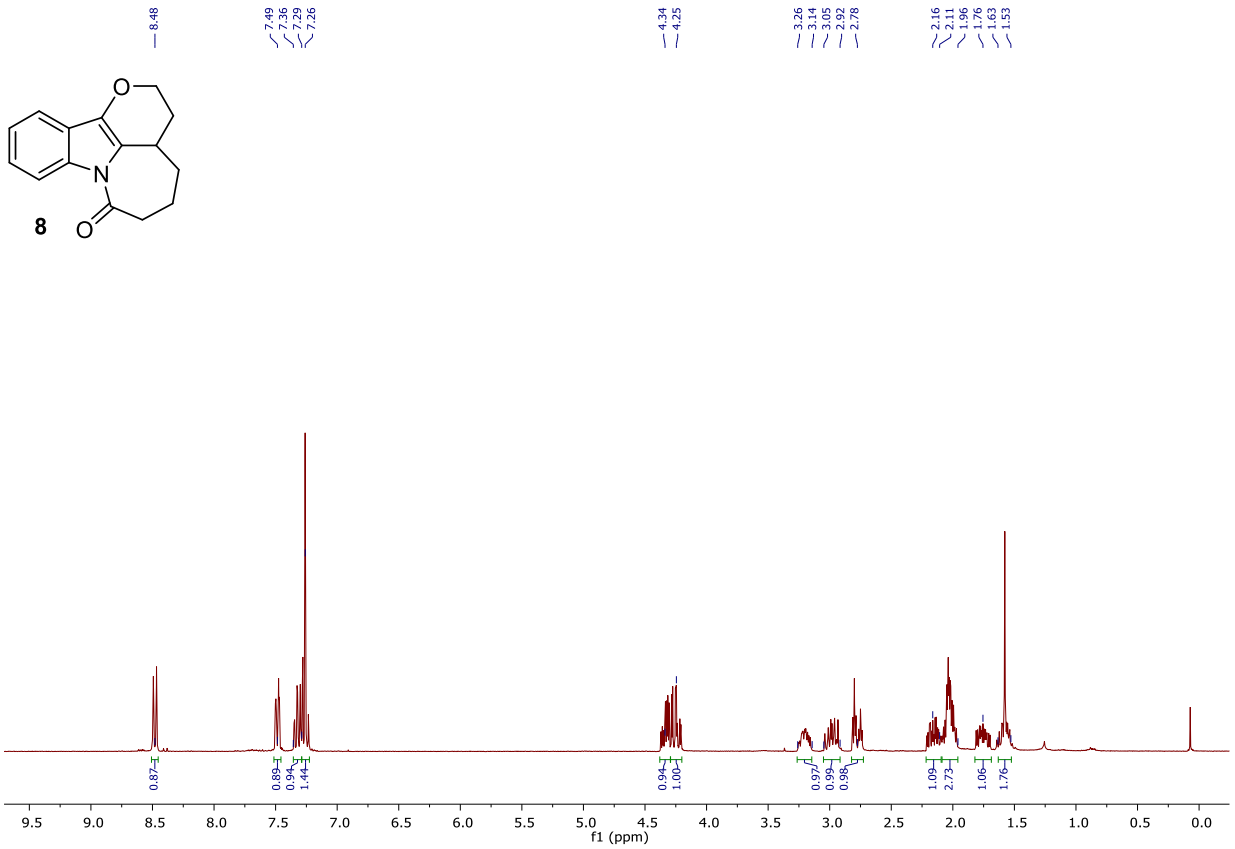
^{13}C-NMR (126 MHz, $CDCl_3$)



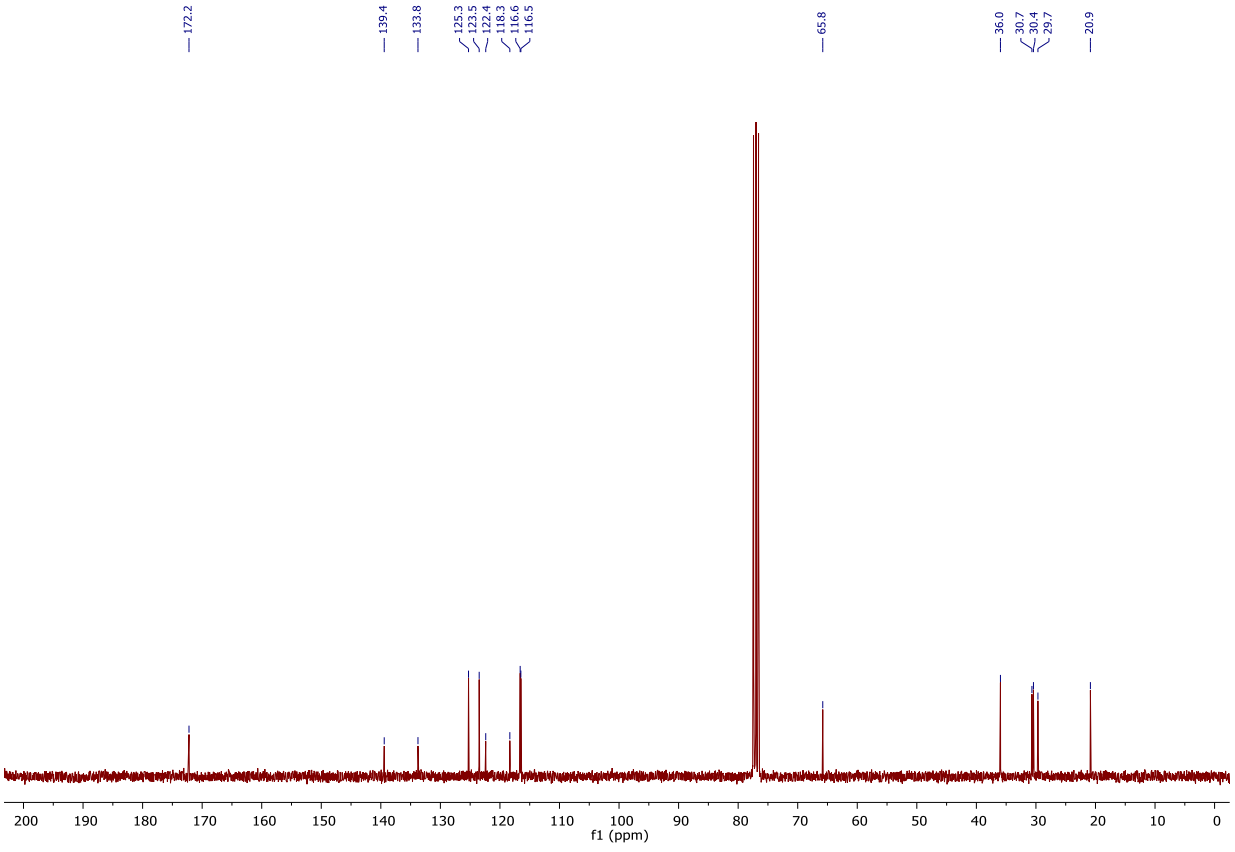
^{1}H-NMR (500 MHz, $CDCl_3$)



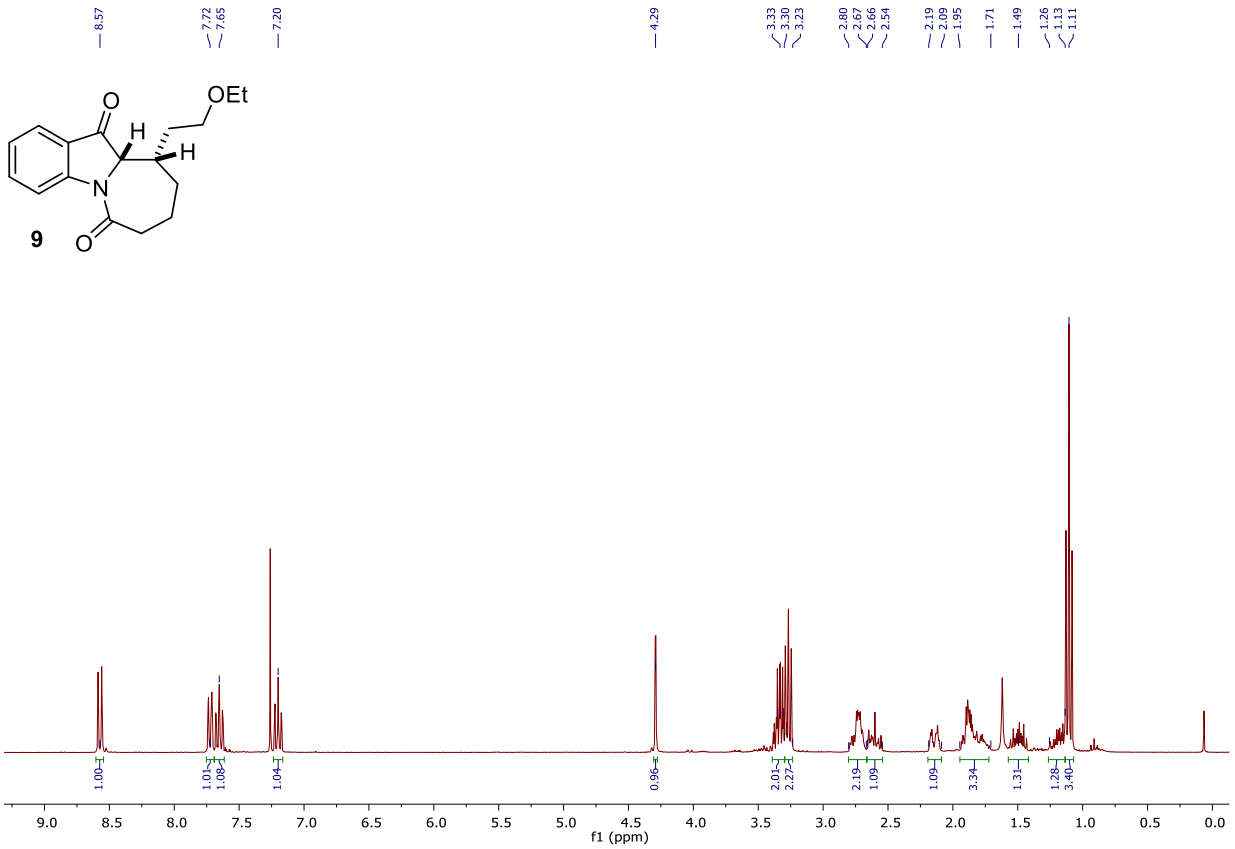
^{13}C-NMR (126 MHz, $CDCl_3$)



^{1}H-NMR (300 MHz, $CDCl_3$)



^{13}C-NMR (75 MHz, $CDCl_3$)



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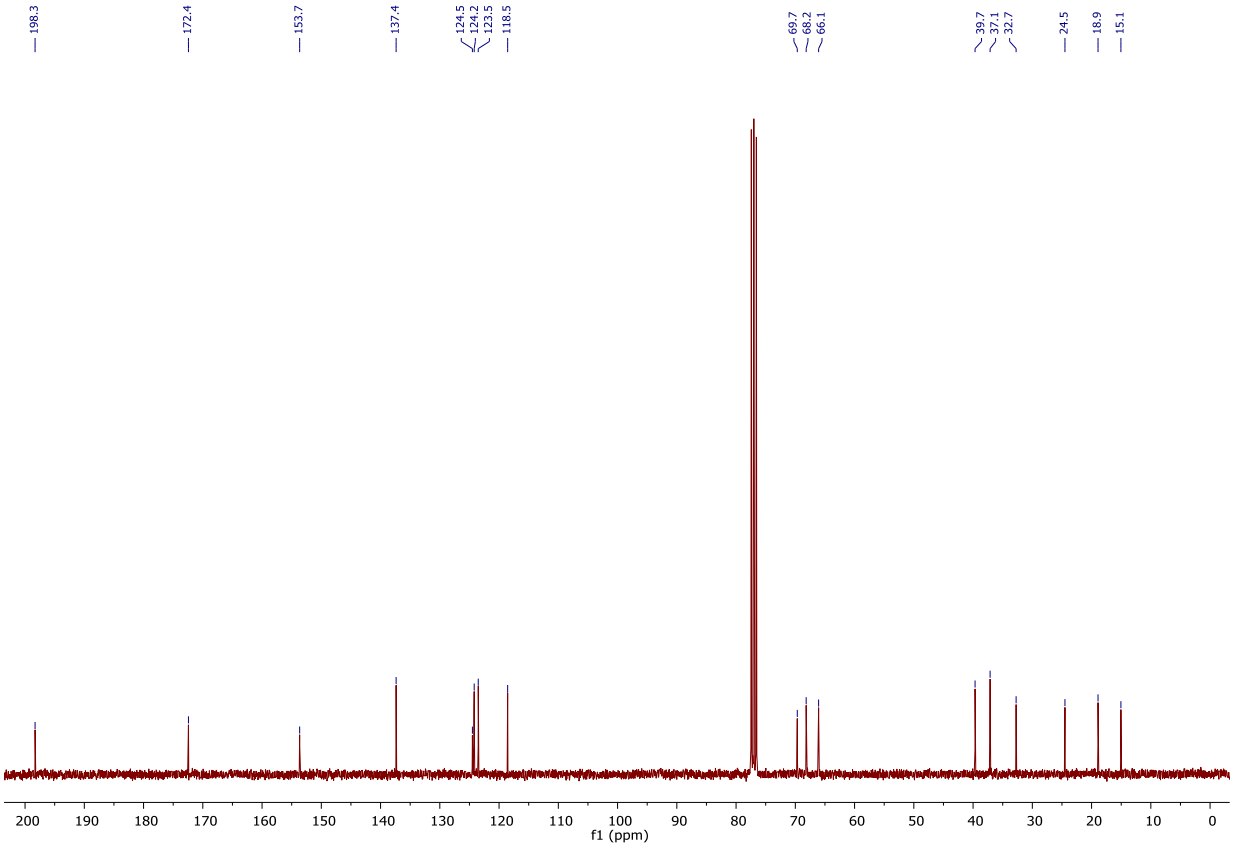
^{1}H-NMR (300 MHz, $CDCl_3$)



^{13}C-NMR (75 MHz, $CDCl_3$)