Supporting Information

Visible-Light Photoredox Catalysis with 9,10-Phenanthrenedione as Catalyst: A Green Methodology for the Functionalisation of 3,4-dihydro-1,4-benzoxazin-2-ones through a Friedel-Crafts Reaction

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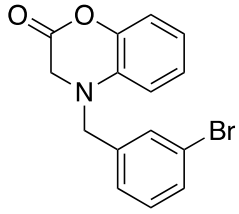
1. General Experimental Methods

Reactions were carried out in 5 mL vials under air unless otherwise indicated. Commercial reagents were used as purchased. Reactions were monitored by TLC analysis using Merck Silica Gel 60 F-254 thin layer plates and these are visualized using both an UV lamp (254 nm) and then a CAM solution (an aqueous solution of ceric ammonium molybdate). Flash column chromatography was performed on Merck Silica Gel 60, 0.040-0.063 mm. NMR spectra were run at 300 MHz for ^{1}H and 75 MHz for ^{13}C using residual nondeuterated solvent as internal standard ($CHCl_3$: δ 7.26 and δ 77.00 ppm respectively, MeOH: δ 3.34 ppm and δ 49.87 ppm respectively, Acetone: δ 2.05 ppm and δ 29.84 ppm respectively). Chemical shifts are given in ppm. The carbon multiplicity was established by DEPT experiments. High resolution mass spectra (HRMS-ESI) were recorded on a AB SCIEX Triple TOF^{TM} spectrometer equipped with an electrospray source with a capillary voltage of 4.5 kV (ESI).
All photocatalysts, indoles and related arenes were commercially available. 3,4-dihydro-benzoxazin-2-ones derivatives **2a**, **2b** and **2c** were synthesized according to a procedure published in the literature and the spectroscopic data (^{1}H-NMR and ^{13}C-NMR) match with those reported[1]. 3,4-dihydro-benzoxazin-2-ones derivatives **2d**, **2e**, **2f**, **2g** and **2h** were synthesized according to the same procedure and were characterized by ^{1}H-NMR, ^{13}C-NMR and HRMS.

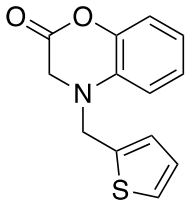
2. Characterization of the 3,4-dihidro-benzoxazin-2-ones derivatives 2d, 2e, 2f, 2g and 2h

4-(3-bromobenzyl)-3,4-dihydro-2*H*-benzo[*b*][1,4]oxazin-2-one (2d)



Compound **2d** was obtained as a white oil (445 mg, 28% yield) after column chromatography; ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.51 – 7.39 (m, 2H), 7.29 – 7.19 (m, 2H), 7.14 – 7.00 (m, 2H), 6.89 (td, *J* = 7.7, 1.4 Hz, 1H), 6.79 (dd, *J* = 8.0, 1.5 Hz, 1H), 4.34 (s, 2H), 3.81 (s, 2H); ^{13}C NMR (75 MHz, CDCl3) δ 164.60 (C), 141.77 (C), 138.15 (C), 134.41 (C), 131.11 (CH), 130.65 (CH), 130.53 (CH), 126.18 (CH), 125.32 (CH), 123.08 (C), 120.46 (CH), 117.18 (CH), 113.19 (CH), 53.10 (CH_2), 50.19 (CH_2); HRMS (ESI) *m/z*: $[M + H]^+$ calculated for $C_{15}H_{13}BrNO_2$, 318,0130; found, 318.0127.

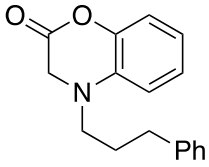
4-(thiophen-2-ylmethyl)-3,4-dihydro-2*H*-benzo[*b*][1,4]oxazin-2-one (2e)



Compound **2e** was obtained as a white solid (576 mg, 47% yield) after column chromatography; m.p. 73-74 °C; ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.27 (dd, *J* = 5.1, 1.3 Hz, 1H), 7.13 – 7.05 (m, 2H), 7.05 – 6.96 (m, 3H), 6.89 (ddd, *J* = 8.2, 7.2, 1.5 Hz, 1H), 4.58 (s, 2H), 3.80 (s, 2H). ^{13}C NMR (75 MHz, CDCl3) δ 164.75 (C), 141.85 (C), 137.64 (C), 133.88 (C), 127.15 (CH),

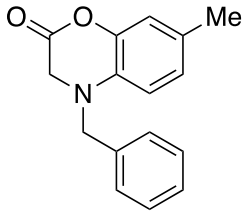
126.91 (CH), 125.91 (CH), 125.17 (CH), 120.37 (CH), 117.14 (CH), 113.21 (CH), 49.34 (CH_2), 48.16 (CH_2); HRMS (ESI) *m/z*: $[M + H]^+$ calculated for $C_{15}H_{12}NO_2S$, 246.0589; found, 246.0586.

4-(3-phenylpropyl)-3,4-dihydro-2*H*-benzo[*b*][1,4]oxazin-2-one (2f)



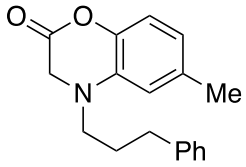
Compound **2f** was obtained as a greenish oil (734 mg, 58% yield) after column chromatography; ^{1}H NMR (300 MHz, CDCl3) δ 7.21 – 7.13 (m, 2H), 7.11 – 7.02 (m, 3H), 6.93 – 6.85 (m, 2H), 6.70 – 6.62 (m, 1H), 6.51 (dd, *J* = 8.4, 1.5 Hz, 1H), 3.62 (s, 2H), 3.08 – 2.97 (m, 2H), 2.54 (t, *J* = 7.5 Hz, 2H), 1.78 (dq, *J* = 9.1, 7.5 Hz, 2H); ^{13}C NMR (75 MHz, CDCl3) δ 164.60 (C), 141.46 (C), 140.76 (C), 134.18 (C), 128.32 (CH), 128.17 (CH), 125.98 (CH), 125.01 (CH), 119.14 (CH), 116.73 (CH), 112.35 (CH), 49.65 (CH_2), 48.24 (CH_2), 32.72 (CH_2), 26.35 (CH_2); HRMS (ESI) *m/z*: $[M + H]^+$ calculated for $C_{17}H_{18}NO_2$, 268.1338; found, 268.1340.

4-benzyl-7-methyl-3,4-dihydro-2*H*-benzo[*b*][1,4]oxazin-2-one (2g)



Compound **2g** was obtained as a colourless oil (899 mg, 71% yield) after column chromatography; ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.42 – 7.28 (m, 5H), 6.91 (d, *J* = 1.7 Hz, 1H), 6.86 (ddd, *J* = 8.2, 1.9, 0.7 Hz, 1H), 6.75 (d, *J* = 8.2 Hz, 1H), 4.33 (s, 2H), 3.74 (s, 2H), 2.29 (s, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 165.21 (C), 141.78 (C), 135.77 (C), 132.48 (C), 130.16 (C), 128.91 (CH), 127.87 (CH), 127.85 (CH), 125.60 (CH), 117.54 (CH), 113.21 (C), 53.76 (CH2), 50.08 (CH2), 20.44 (CH3); HRMS (ESI) *m/z*: $[M + H]^+$ calculated for $C_{16}H_{16}NO_2$, 254.1181; found, 254.1183.

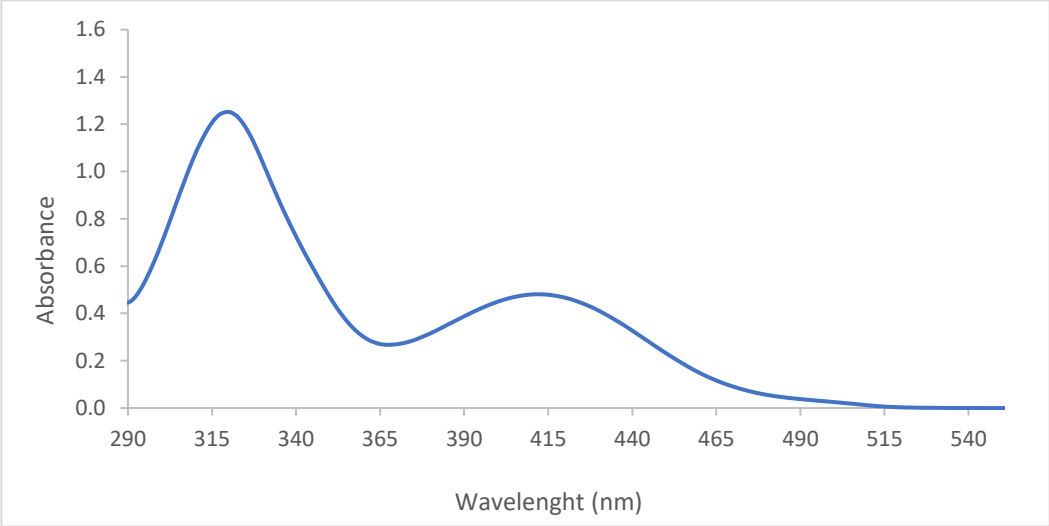
6-methyl-4-(3-phenylpropyl)-3,4-dihydro-2*H*-benzo[*b*][1,4]oxazin-2-one (2h)



Compound **2h** was obtained as a colourless oil (735 mg, 55% yield) after column chromatography; ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.36 – 7.28 (m, 2H), 7.24 – 7.19 (m, 3H), 6.92 (d, *J* = 8.1 Hz, 1H), 6.61 (ddd, *J* = 8.1, 1.9, 0.7 Hz, 1H), 6.40 (d, *J* = 1.5 Hz, 1H), 3.80 (s, 2H), 3.19 (dd, *J* = 8.3, 6.7 Hz, 2H), 2.71 (t, *J* = 7.4 Hz, 2H), 2.26 (s, 3H), 2.02 – 1.90 (m, 2H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 165.02 (C), 140.96 (C), 139.75 (C), 134.96 (C), 134.04 (C), 128.56 (CH), 128.44 (CH), 126.23 (CH), 119.91 (CH), 116.70 (CH), 113.15 (CH), 50.08 (CH_2), 48.35 (CH_2), 32.89 (CH_2), 26.59 (CH_2), 21.29 (CH_3). HRMS (ESI) *m/z*: $[M + H]^+$ calculated for $C_{18}H_{20}NO_2$, 282.1494; found, 282.1493.

3. UV-Vis absorption spectra of 9,10-phenanthrenedione

The UV-Vis absorption spectra was recorded in a double beam UV-Visible absorption spectrometer using a 0.8 mM solution of 9,10-phenanthrenedione in CH_3CN.



The spectra shows two maximums of absorption:

- A strong absorption at 320 nm (Ultraviolet)
- A medium absoption at 412 nm (Visible)

4. Reaction Setup:

<u>Reaction Setup:</u>

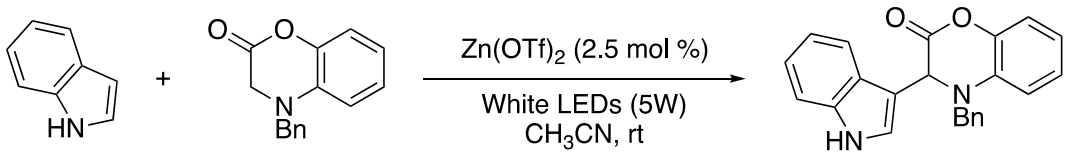
In all cases, the reaction mixture was irradiated with Hidalgo's Group Adjustable LED light (5W, 350 lumen, REF: 64180) from 2 cm away. The temperature at this distance was 26-28 ^{o}C.

5. **Reaction Setup and Procedure for the Friedel-Crafts reaction with sunlight as visible-light radiation source.**

In a 10 mL round-bottomed flask were placed indole (**1a**, 11.7 mg, 0.10 mmol), 4-benzyl-3,4-dihydro-2*H*-benzo[*b*][1,4]oxazin-2-one (**2a**, 35.8 mg, 0.15 mmol), $Zn(OTf)_2$ (0.0025 mmol, 2.5 mol %) and 9,10-phenanthrenedione (0.005 mmol, 5 mol %). Then, the mixture was dissolved in non-dried acetonitrile (1 mL) and was placed in the upper part of the building in sunny hours (*vide infra*). The reaction was monitored by TLC and was stopped when indole was consumed (5 hours after). The resulted reaction mixture was purified by column chromatography using hexane:AcOEt mixtures (from 95:5 to 85:15) to afford the pure product (**3aa**, 30.8 mg, 0.087 mmol, 87% yield) as a colourless oil.

6. **Specific Procedures for the Control Experiments.**

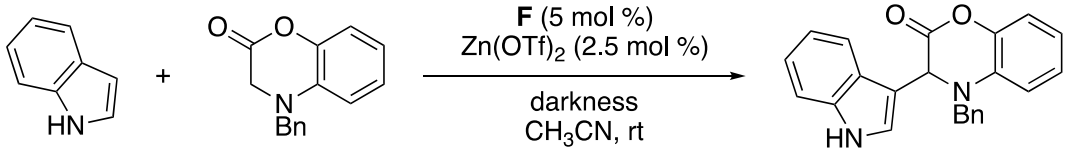
Control A: Friedel-Crafts reaction between 4-benzyl-3,4-dihydro-2*H*-benzo[*b*][1,4]oxazin-2-one and indole in the absence of 9,10-phenanthrenedione.



1a **2a** **3aa**, <5% conversion

Following the General Procedure A without the addition of 9,10-phenanthrenedione the reaction mixture was stirred for 72 h under the typical irradiation conditions. The crude reaction mixture was analysed by ^{1}H-NMR and <5% of conversion to **3aa** was observed.

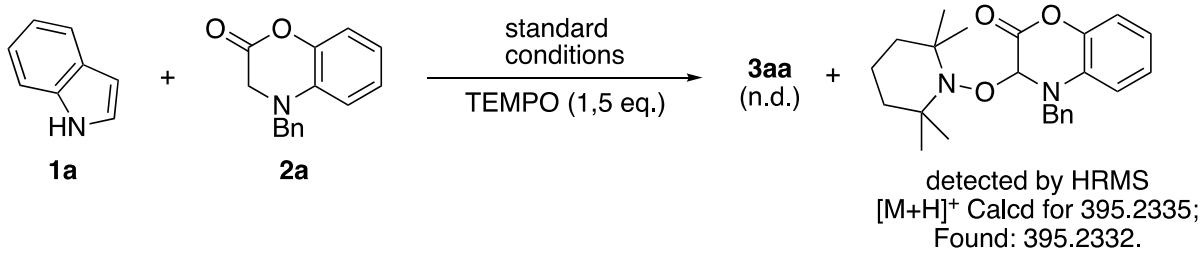
Control B: Friedel-Crafts reaction between 4-benzyl-3,4-dihydro-2*H*-benzo[*b*][1,4]oxazin-2-one and indole in the darkness.



1a **2a** **3aa**, trace

Following the General Procedure A the reaction mixture was stirred for 72 h in the darkness. The crude reaction mixture was analysed by TLC only a trace amount of **3aa** was observed.

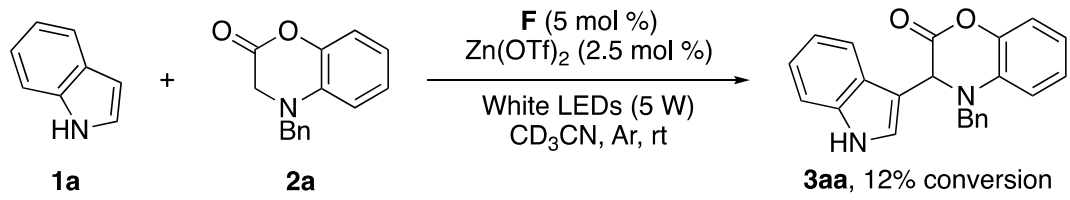
Control C: Friedel-Crafts reaction between 4-benzyl-3,4-dihydro-2*H*-benzo[*b*][1,4]oxazin-2-one and indole in the presence of TEMPO.



Following the General Procedure A with the addition of TEMPO (23.4 mg, 1.5 equivalents), the reaction mixture was stirred for 24 h under the typical irradiation conditions. The crude reaction mixture was analysed by HRMS and no conversion to **3aa** was observed, but the adduct of **2a** with TEMPO was detected.

Control D: Friedel-Crafts reaction between 4-benzyl-3,4-dihydro-2*H*-benzo[*b*][1,4]oxazin-2-one and indole under Ar.

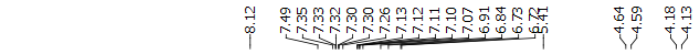
Following the General Procedure A but using CD_3CN instead of CH_3CN, the reaction mixture was stirred for 24 h under the typical irradiation conditions in argon atmosphere. The crude reaction mixture was analysed by ^{1}H-NMR (NOTE: it is important to fill the NMR tube with Ar prior to introduce the sample) and 12% of conversion to **3aa** was observed.

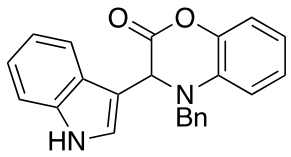


7. References

1. *Tetrahedron* **2008**, *64*, 5756 - 5761.
2. *RSC Adv.*, **2018**, *8*, 19580-19584.

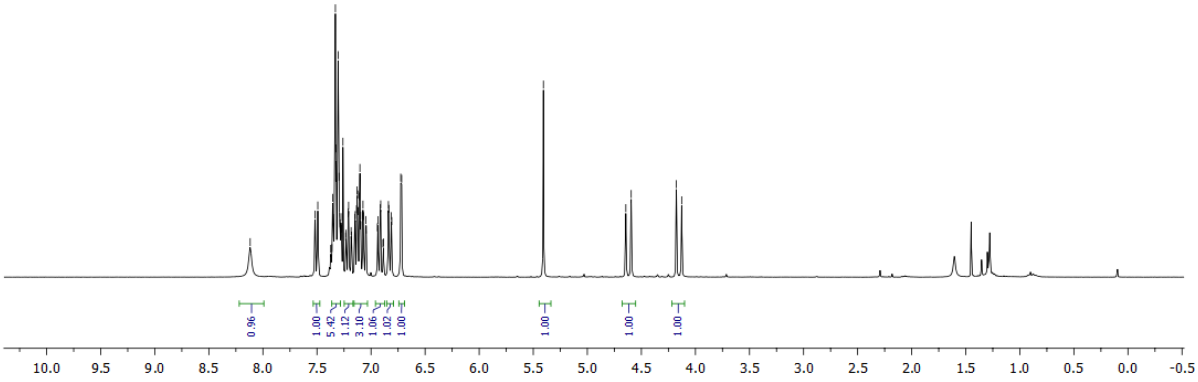
8. NMR spectra

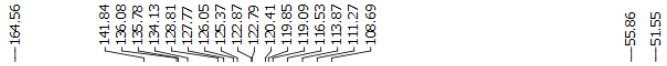


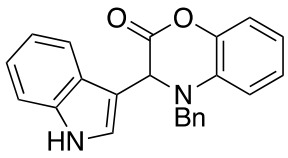


3aa

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

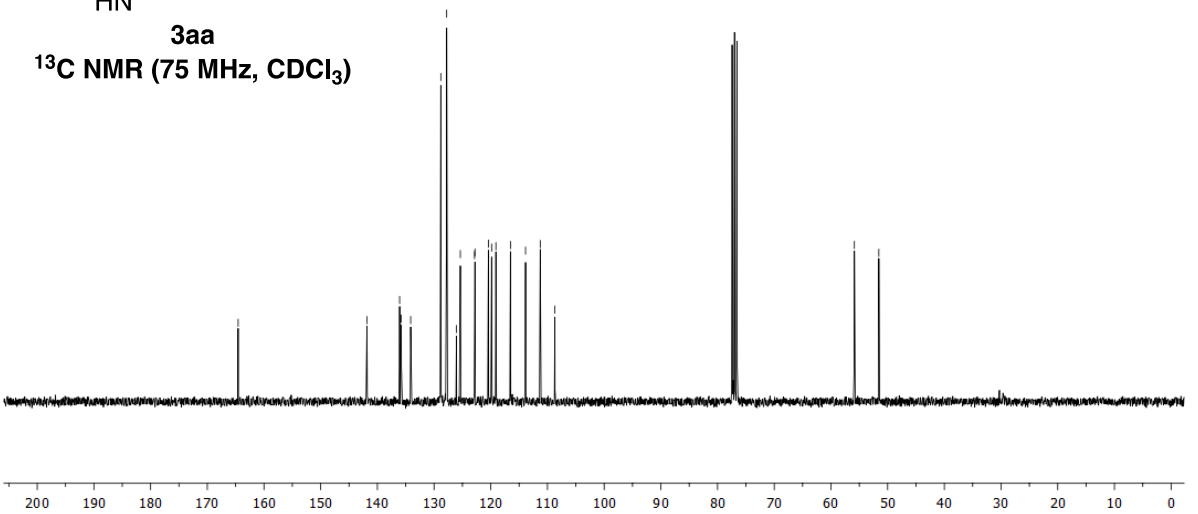


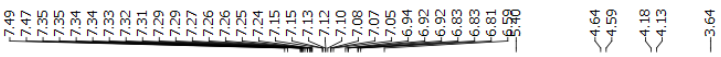


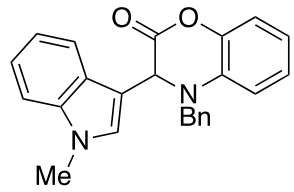


3aa

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

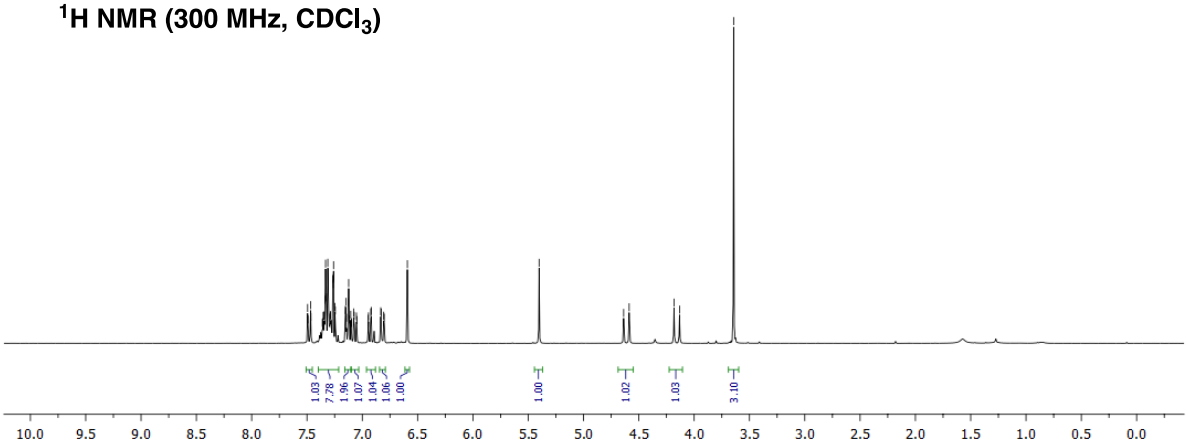


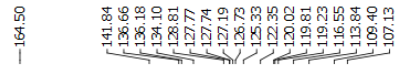


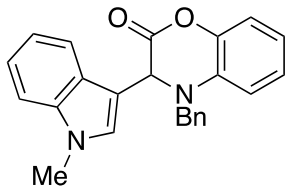


3ba

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

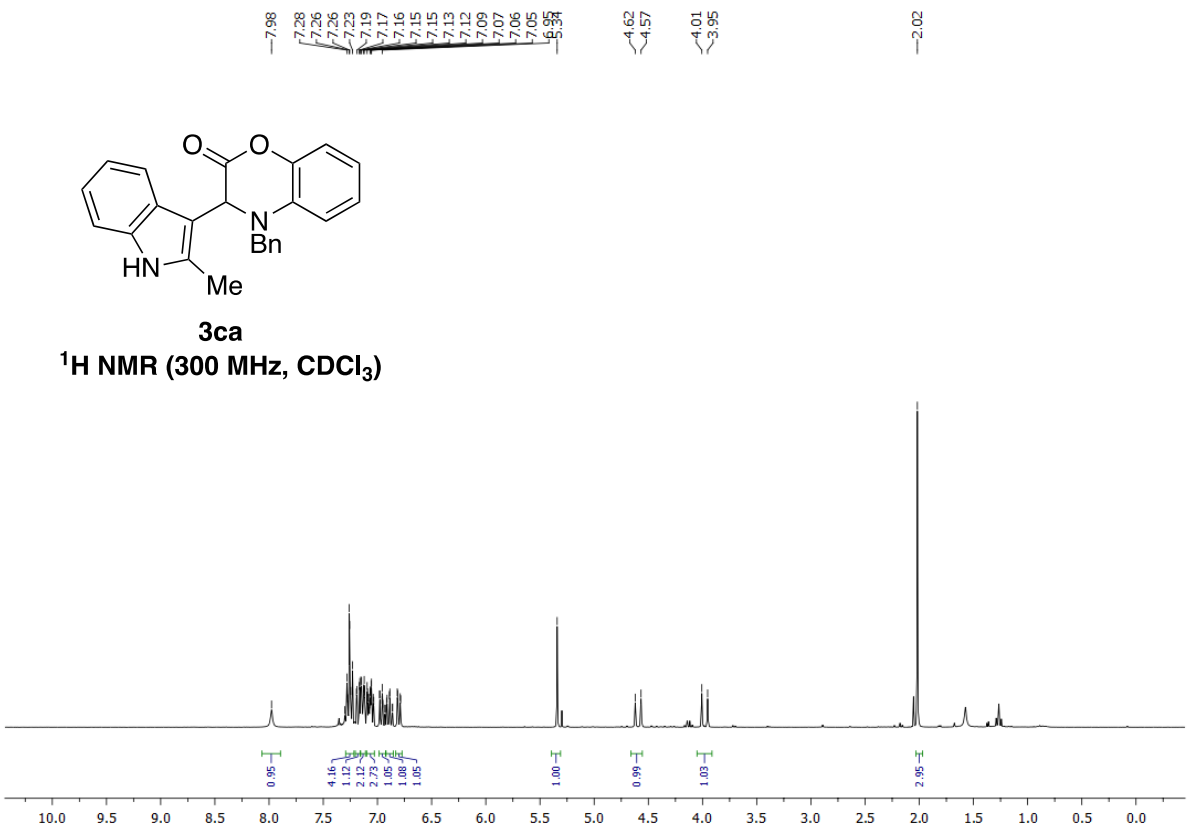






3ba

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



3ca

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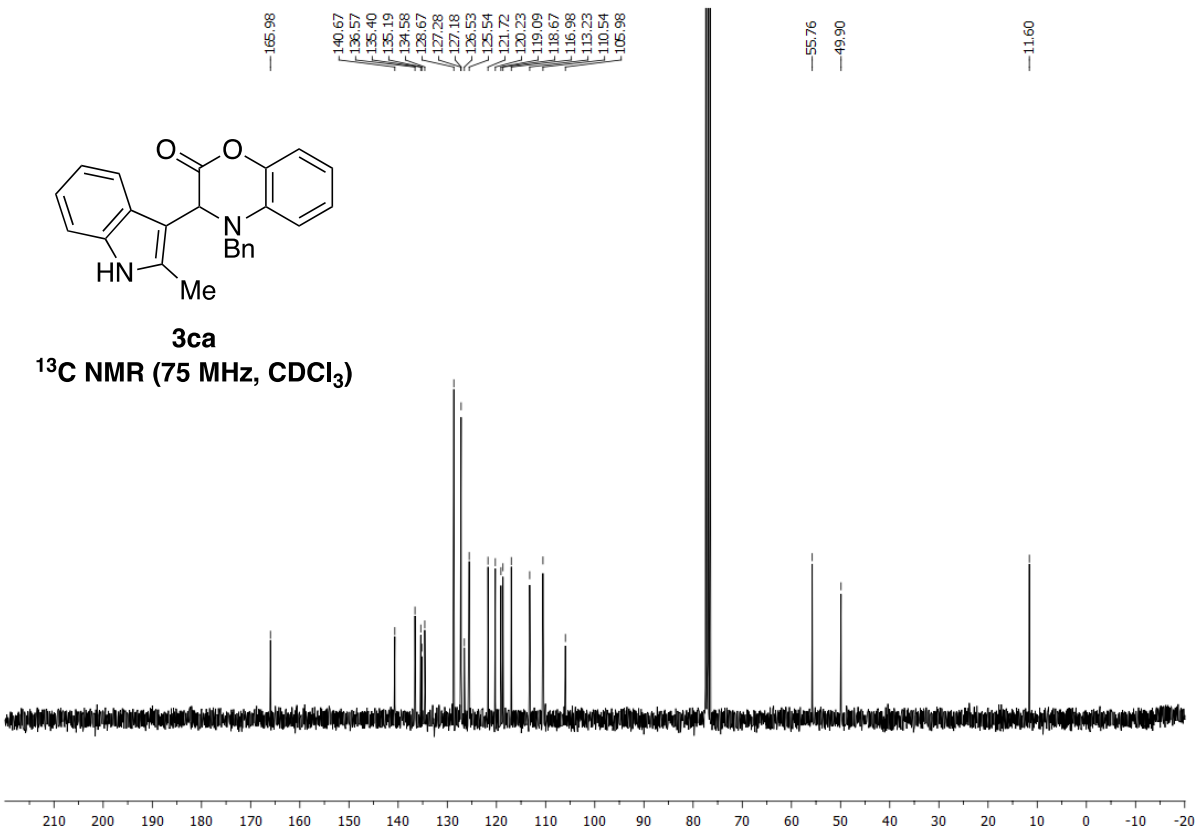

3ca

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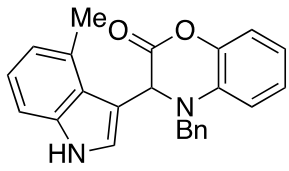
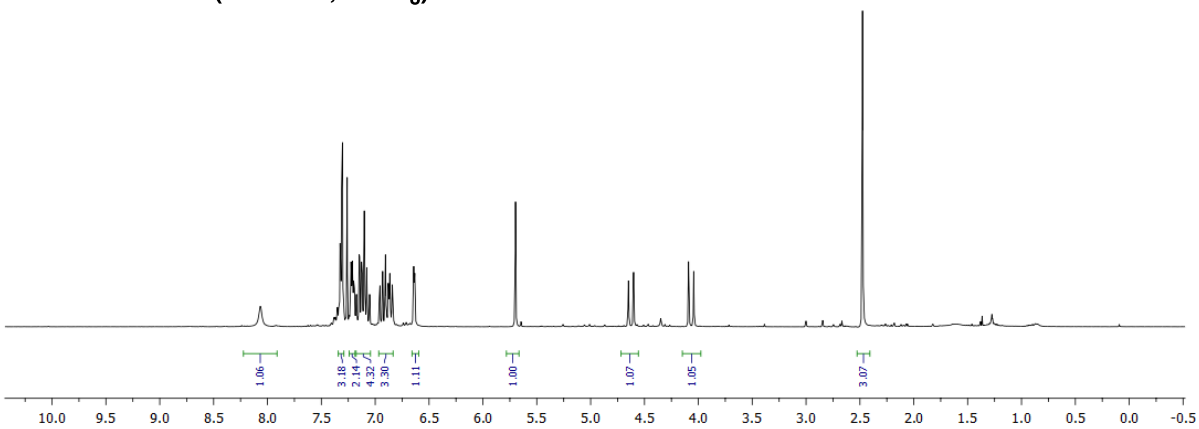
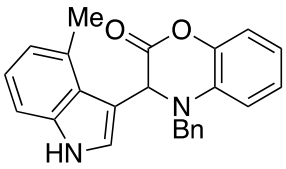


3da

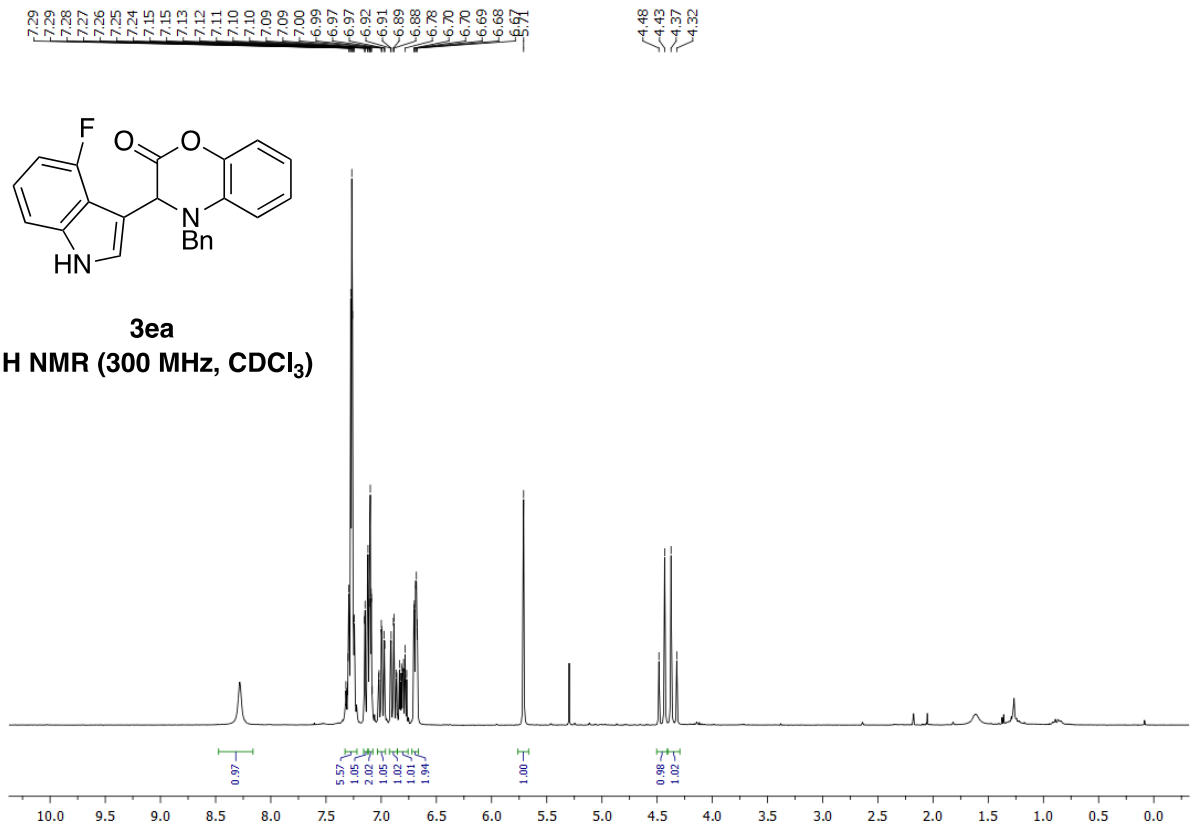
^{1}H NMR (300 MHz, $CDCl_3$)





3da

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



3ea

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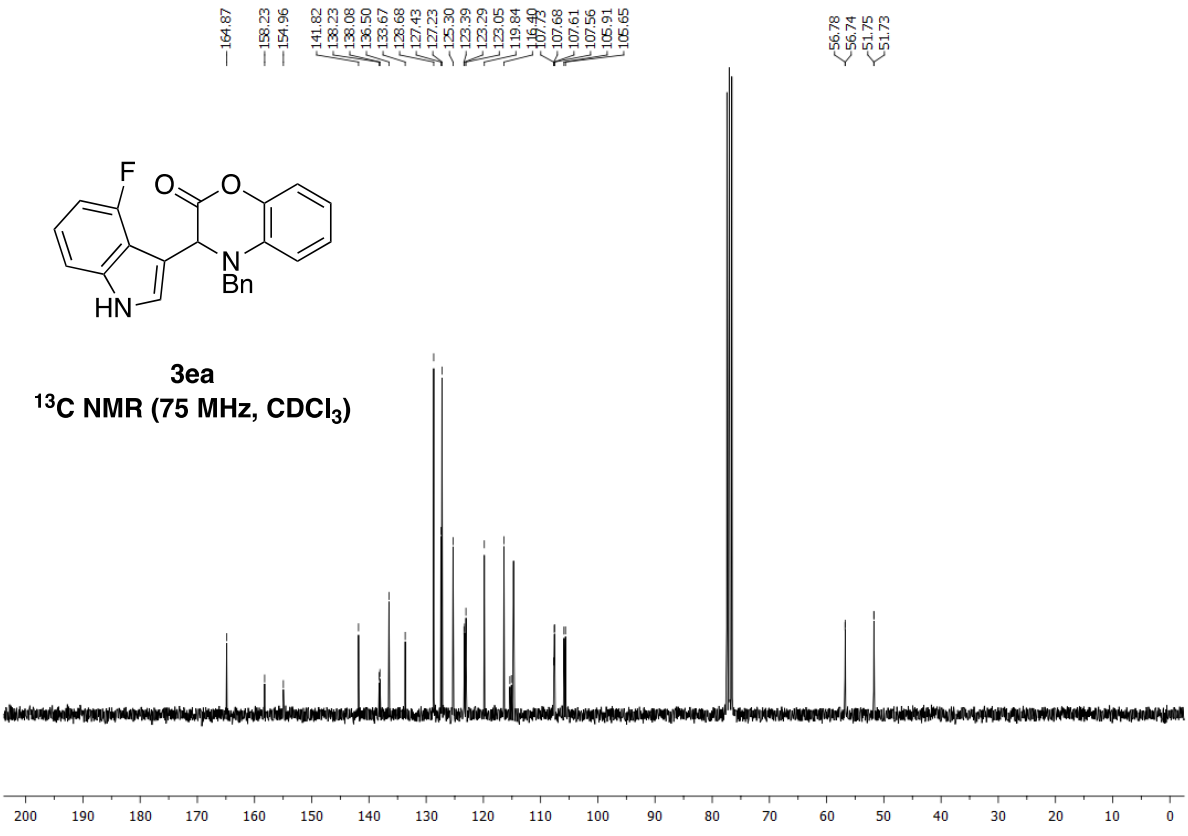
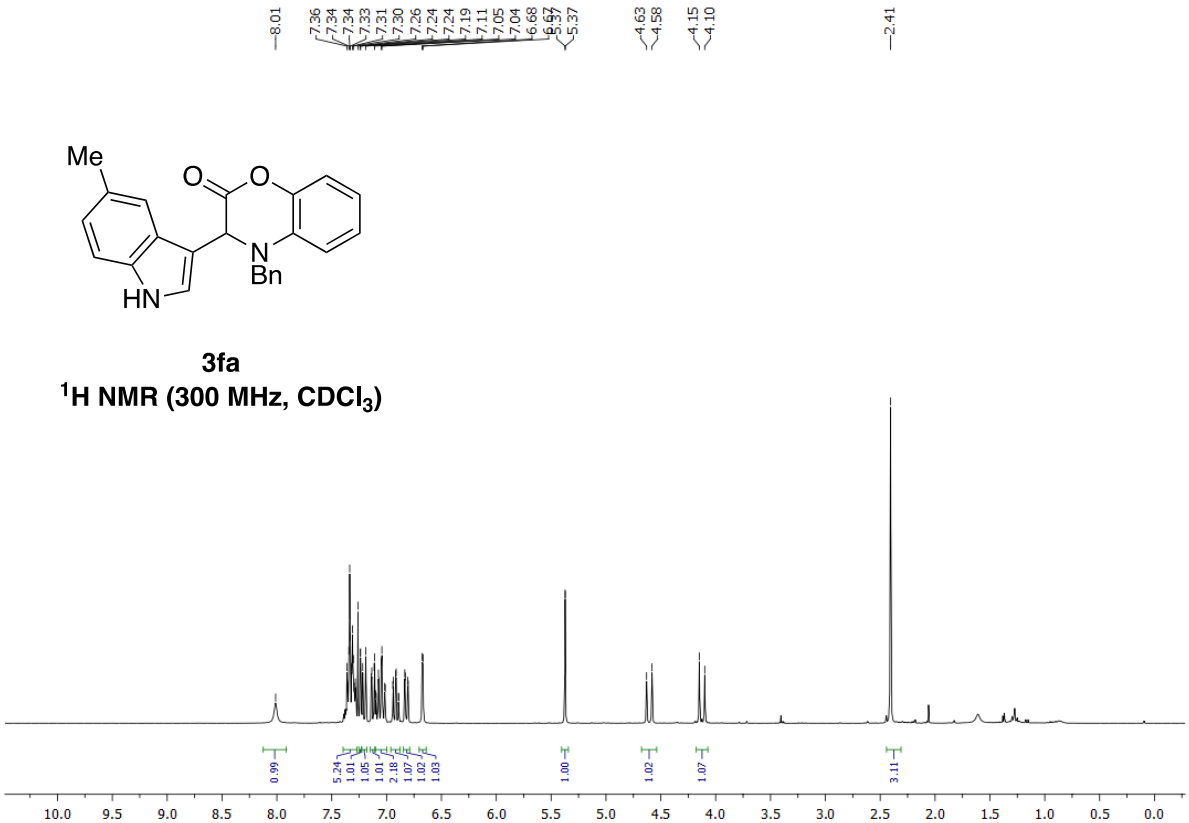


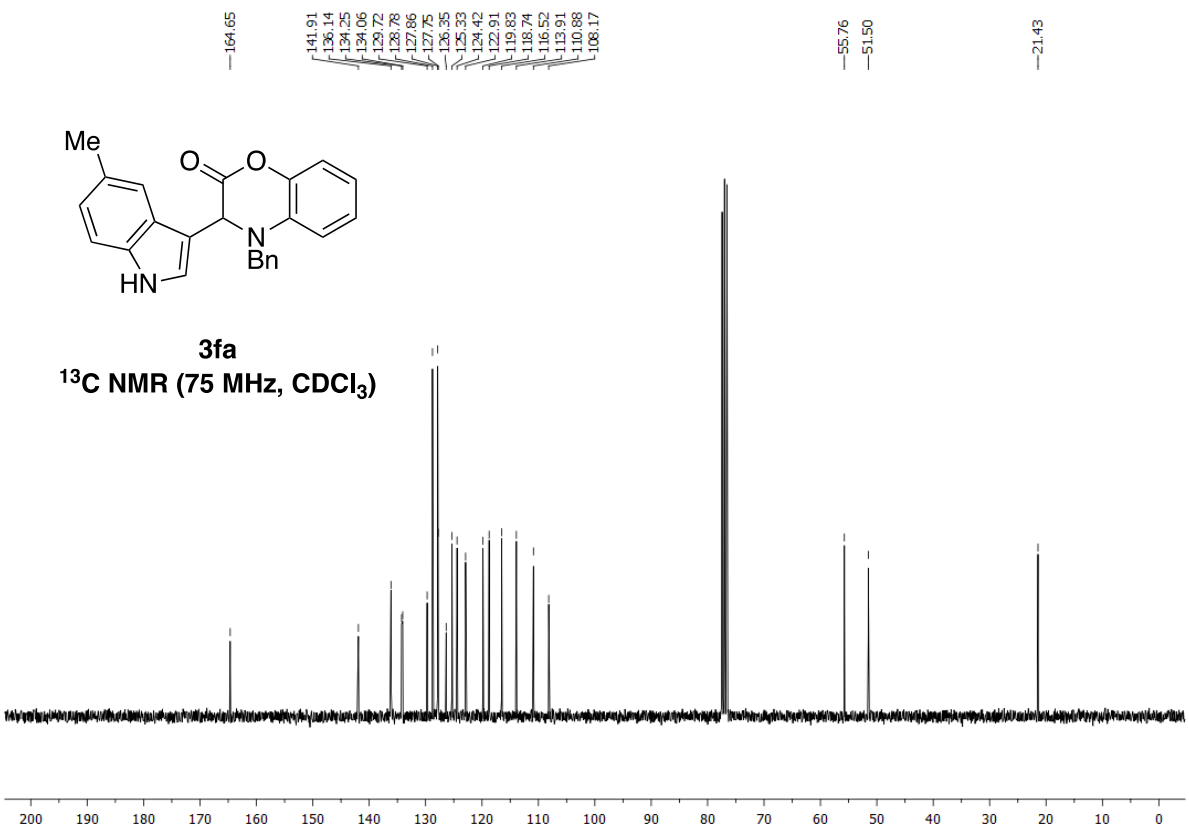
3ea

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



3fa

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



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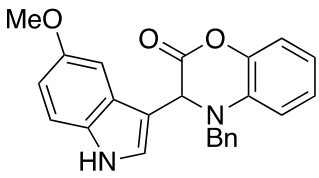
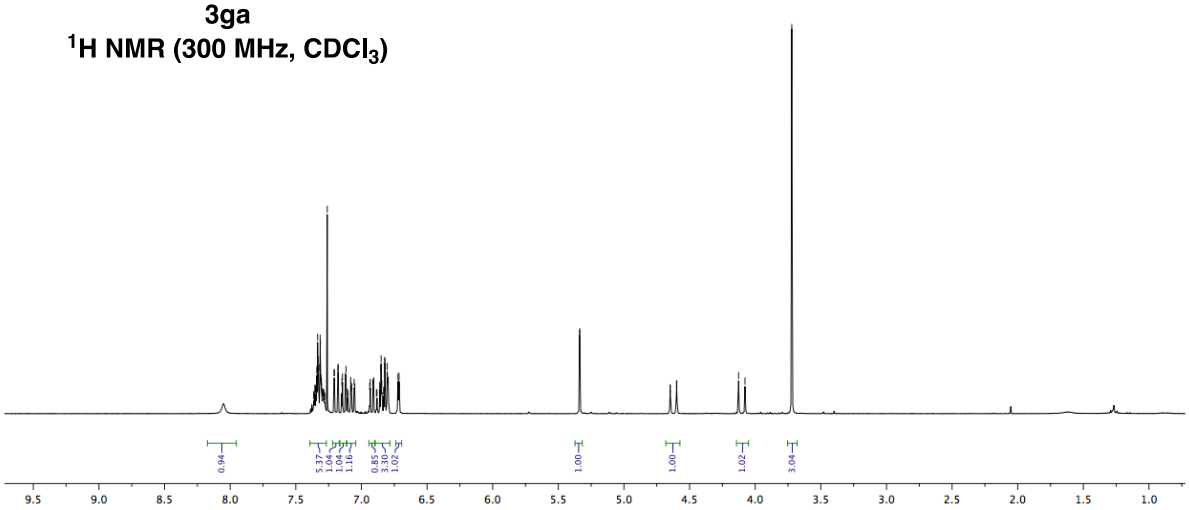
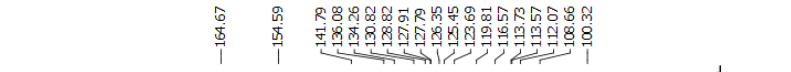
^{13}C NMR (75 MHz, $CDCl_3$)

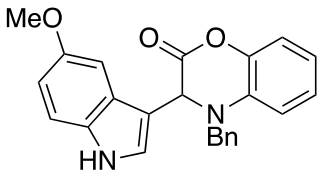


3ga

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







3ga

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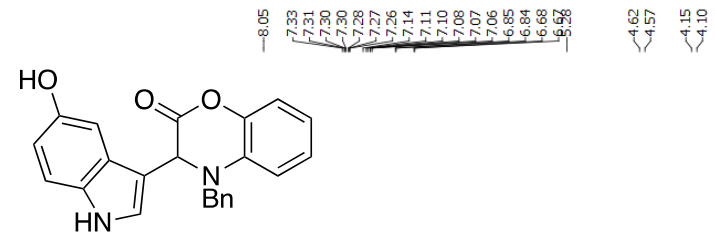
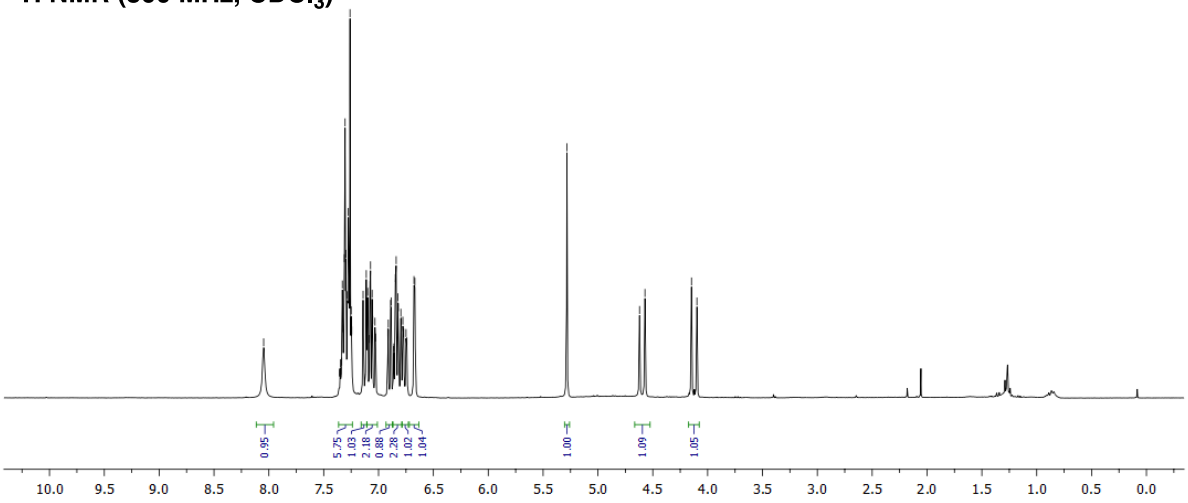
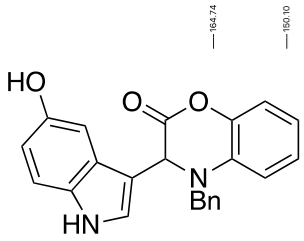


3ha

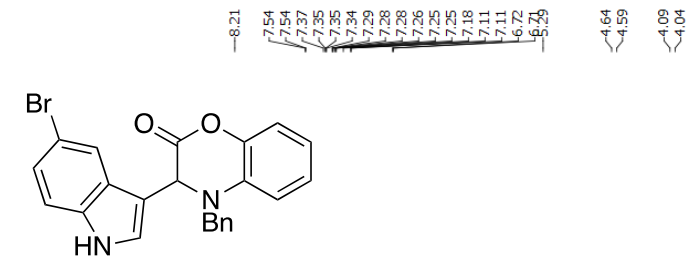
^{1}H NMR (300 MHz, $CDCl_3$)





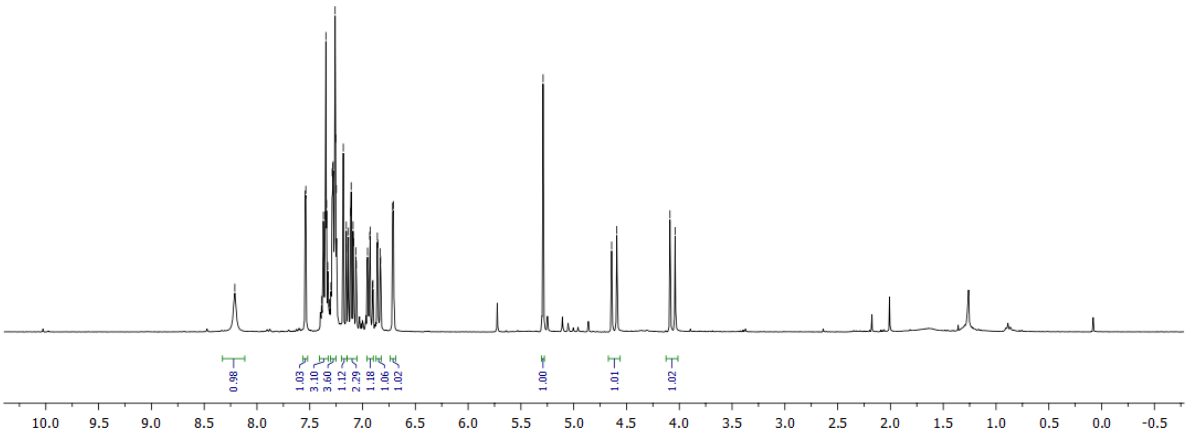
3ha

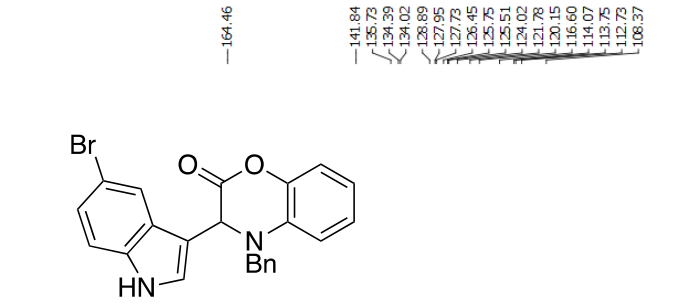
^{13}C NMR (75 MHz, $CDCl_3$)



3ia

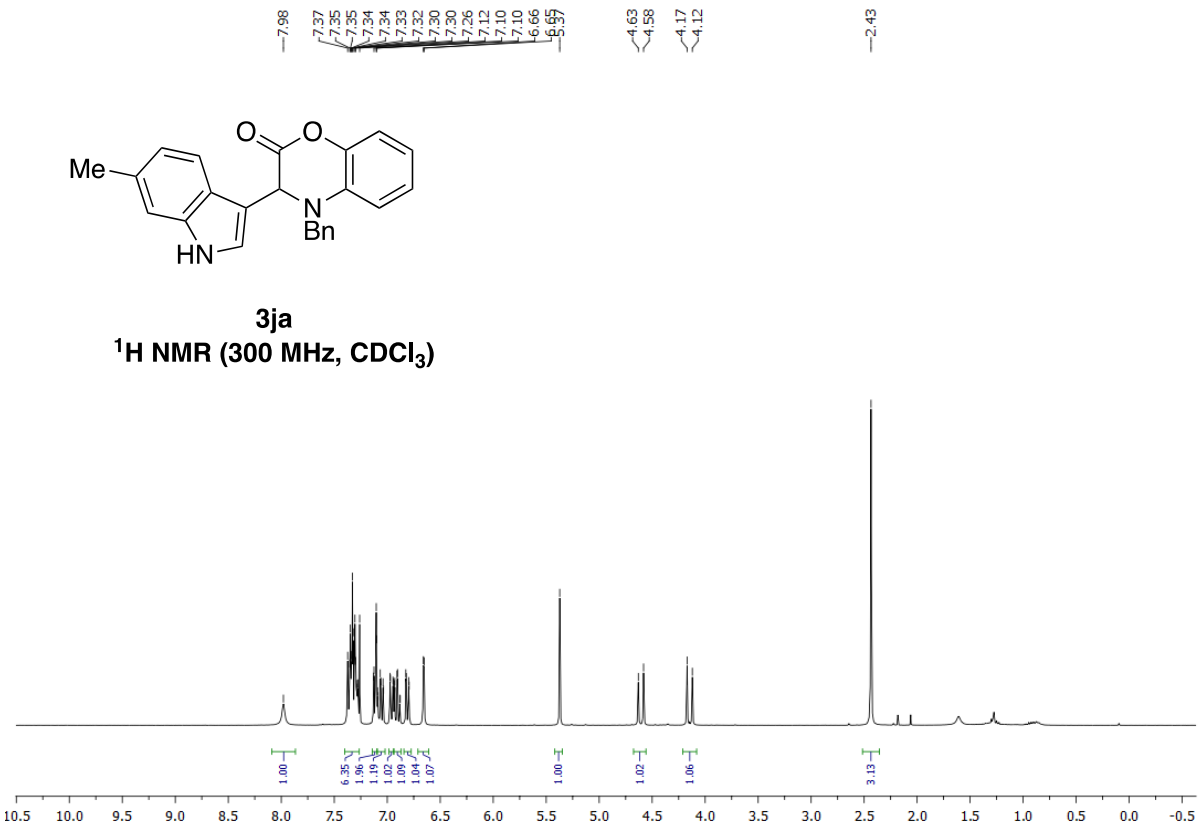
^{1}H NMR (300 MHz, $CDCl_3$)





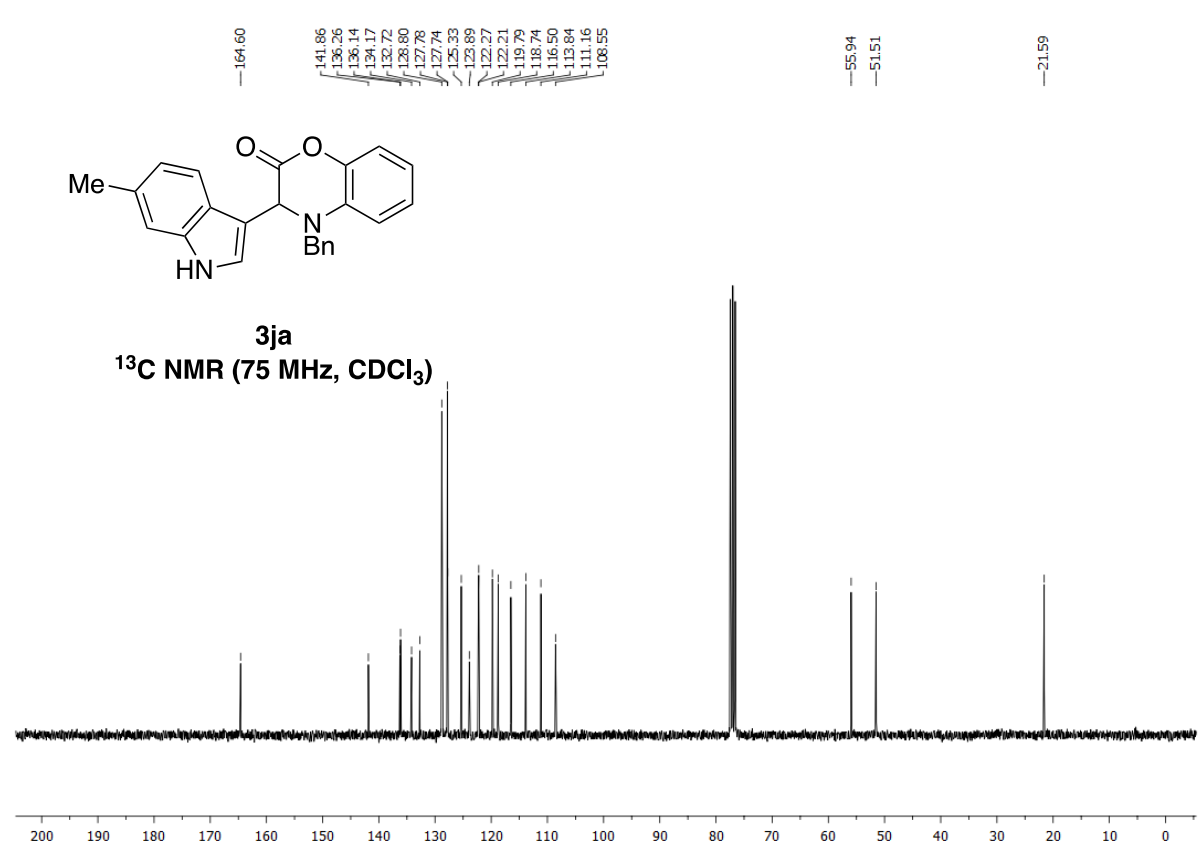
3ia

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



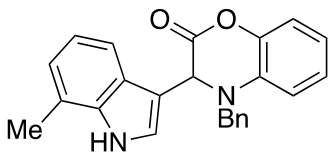
3ja

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



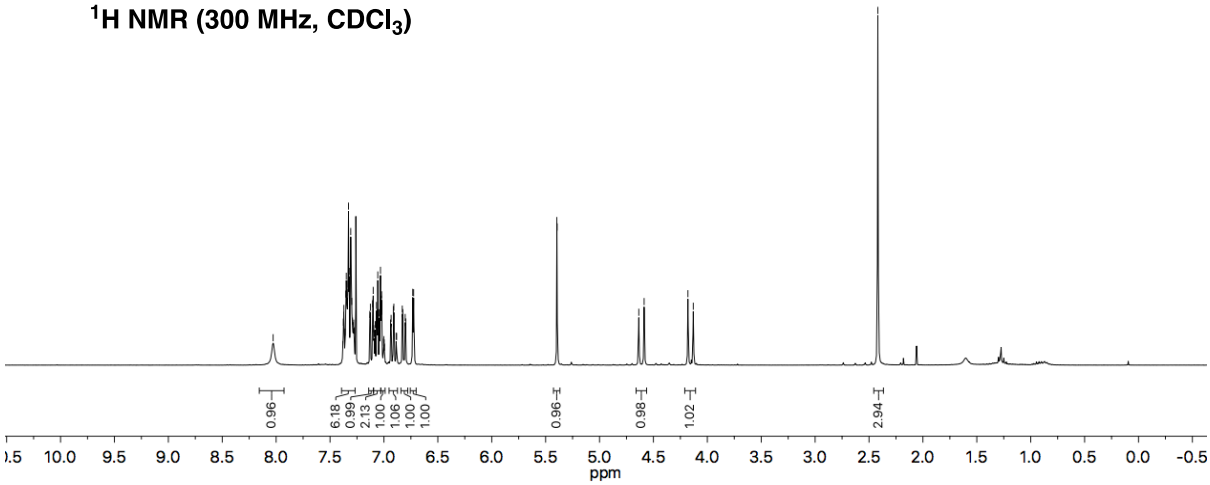
3ja

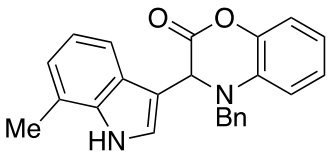
^{13}C NMR (75 MHz, $CDCl_3$)



3ka

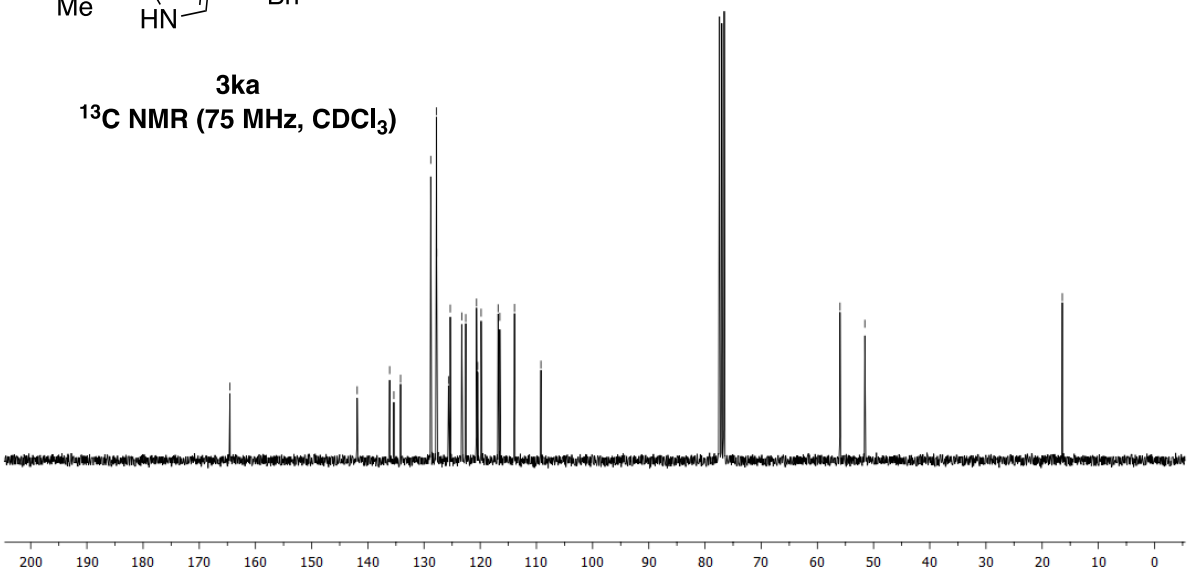
^{1}H NMR (300 MHz, $CDCl_3$)

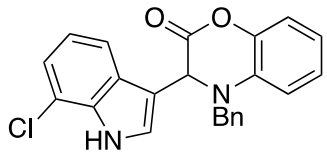




3ka

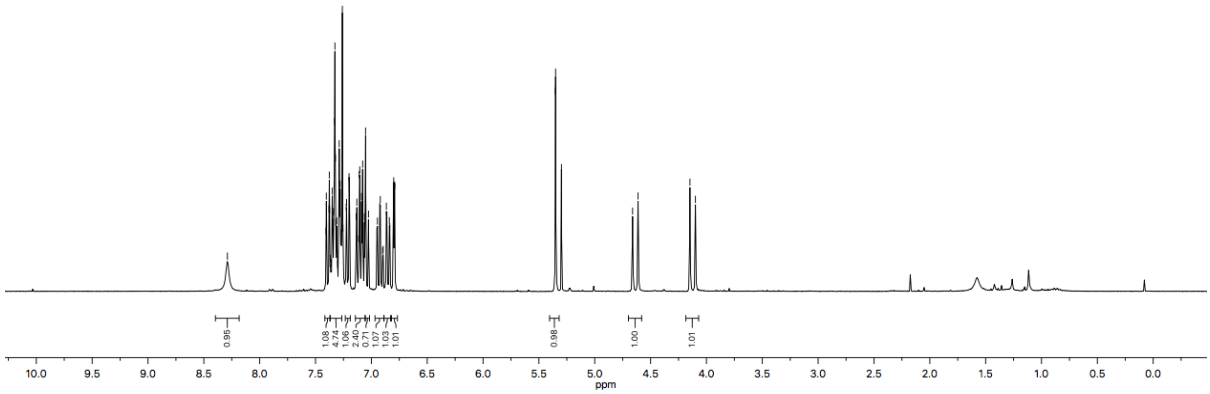
^{13}C NMR (75 MHz, $CDCl_3$)

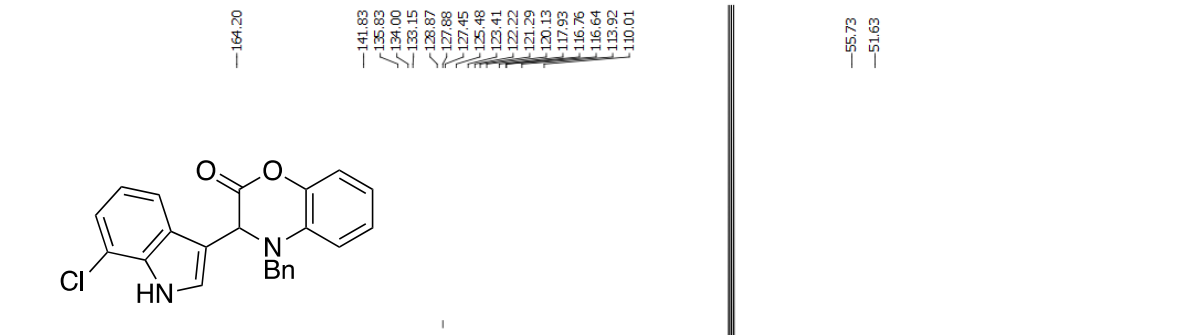




3la

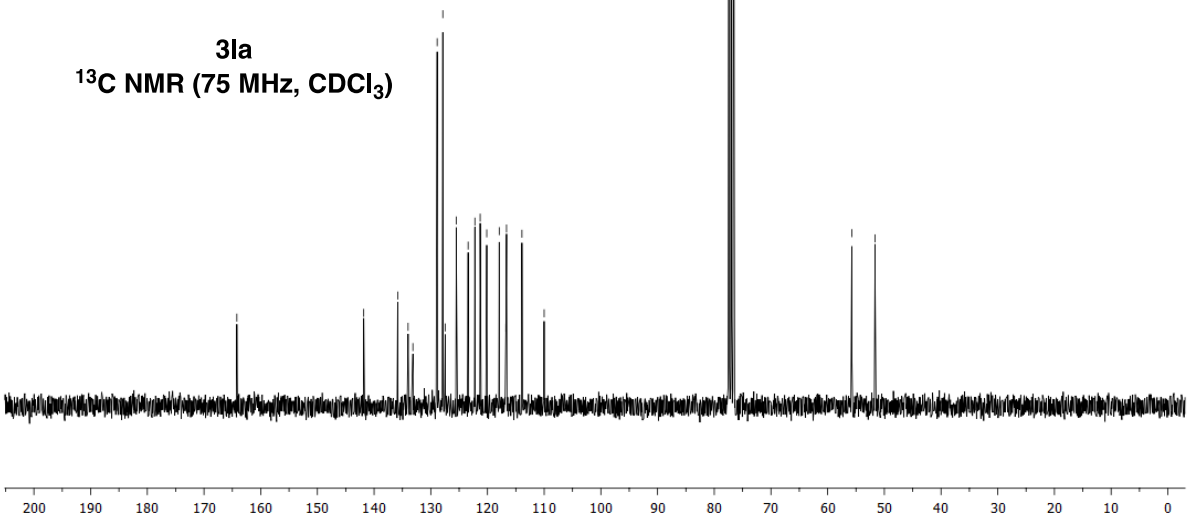
^{1}H NMR (300 MHz, $CDCl_3$)

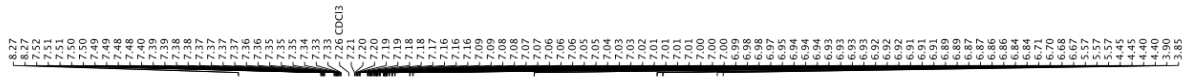


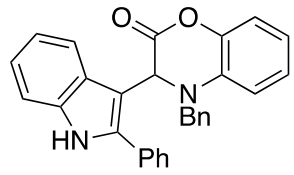


3la

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

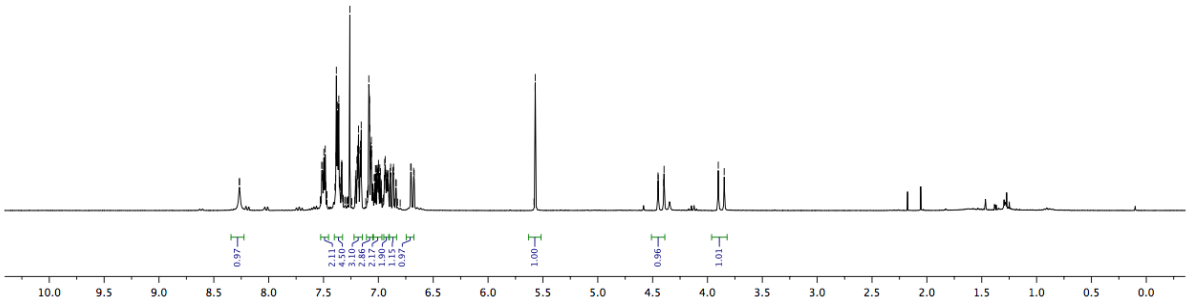


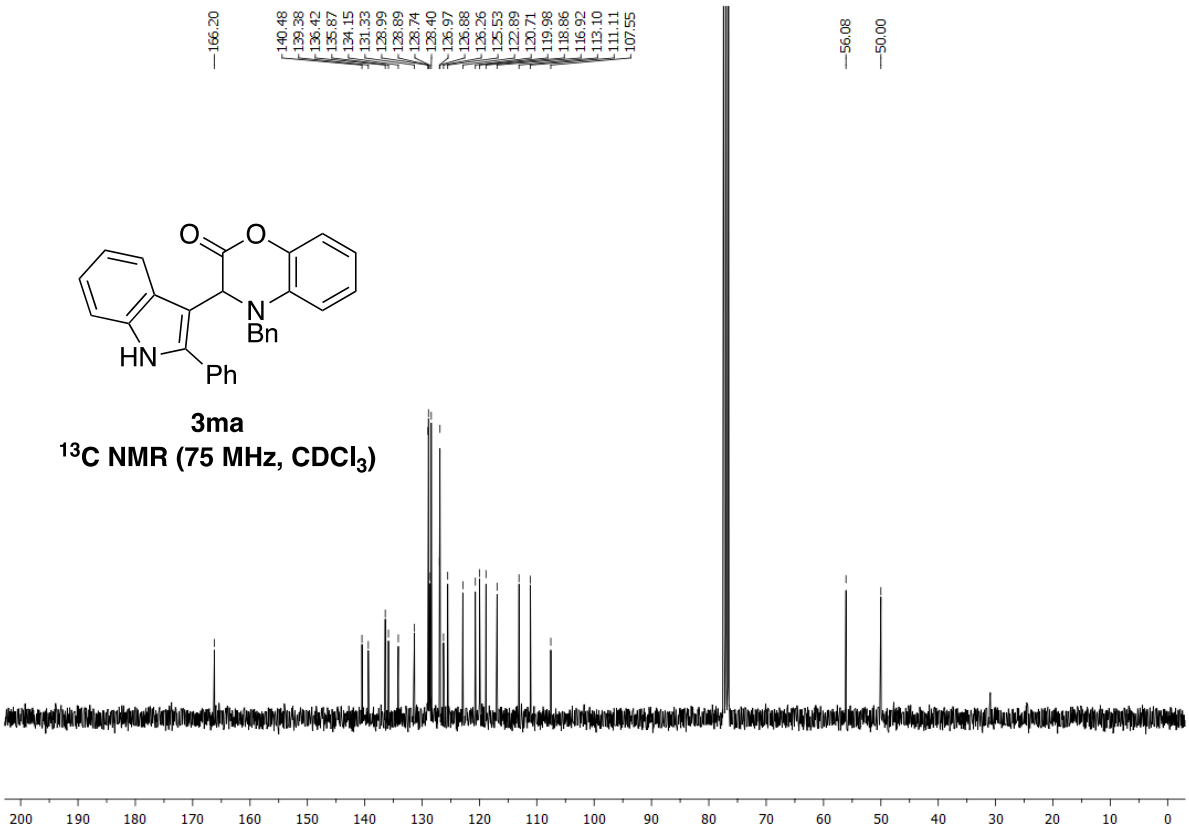




3ma

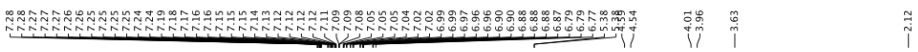
^{1}H NMR (300 MHz, $CDCl_3$)

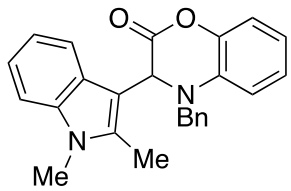




3ma

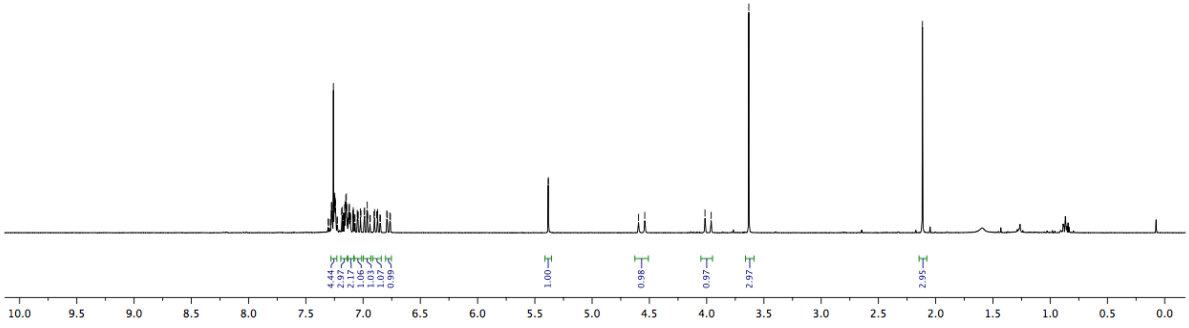
^{13}C NMR (75 MHz, $CDCl_3$)

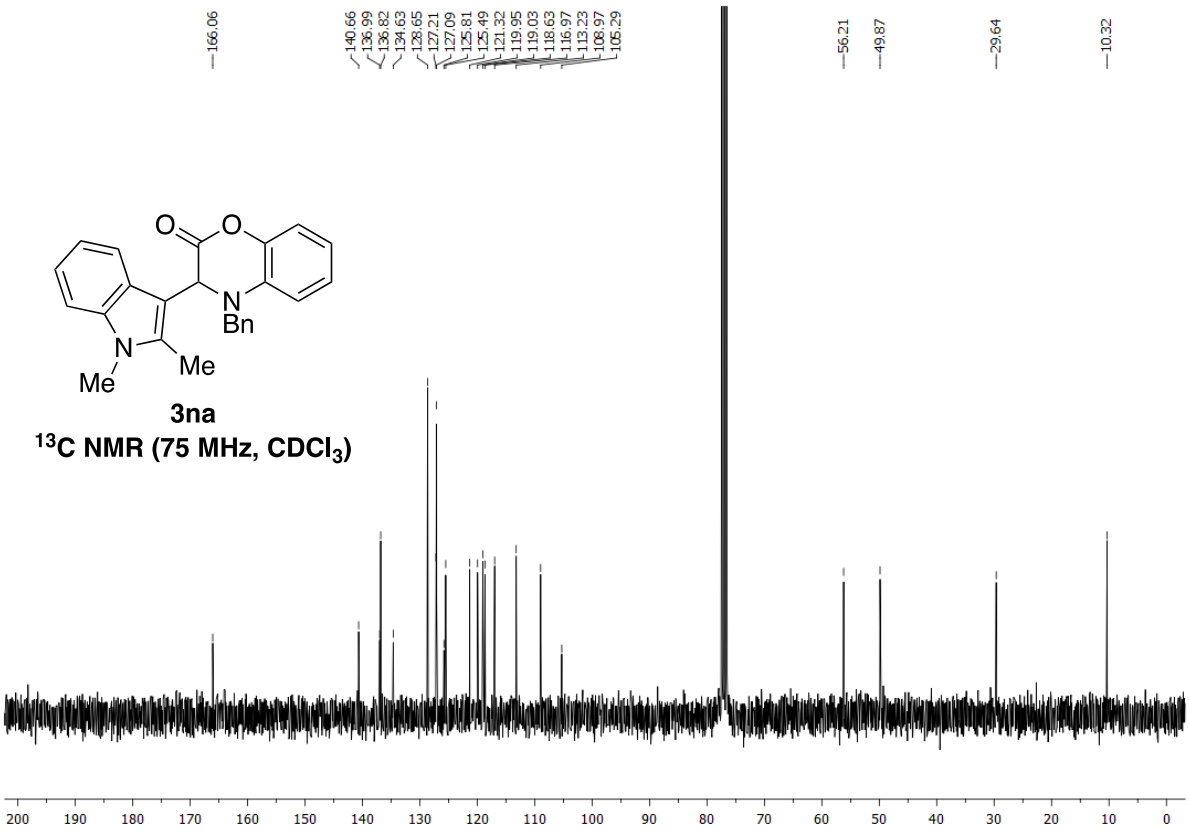




3na

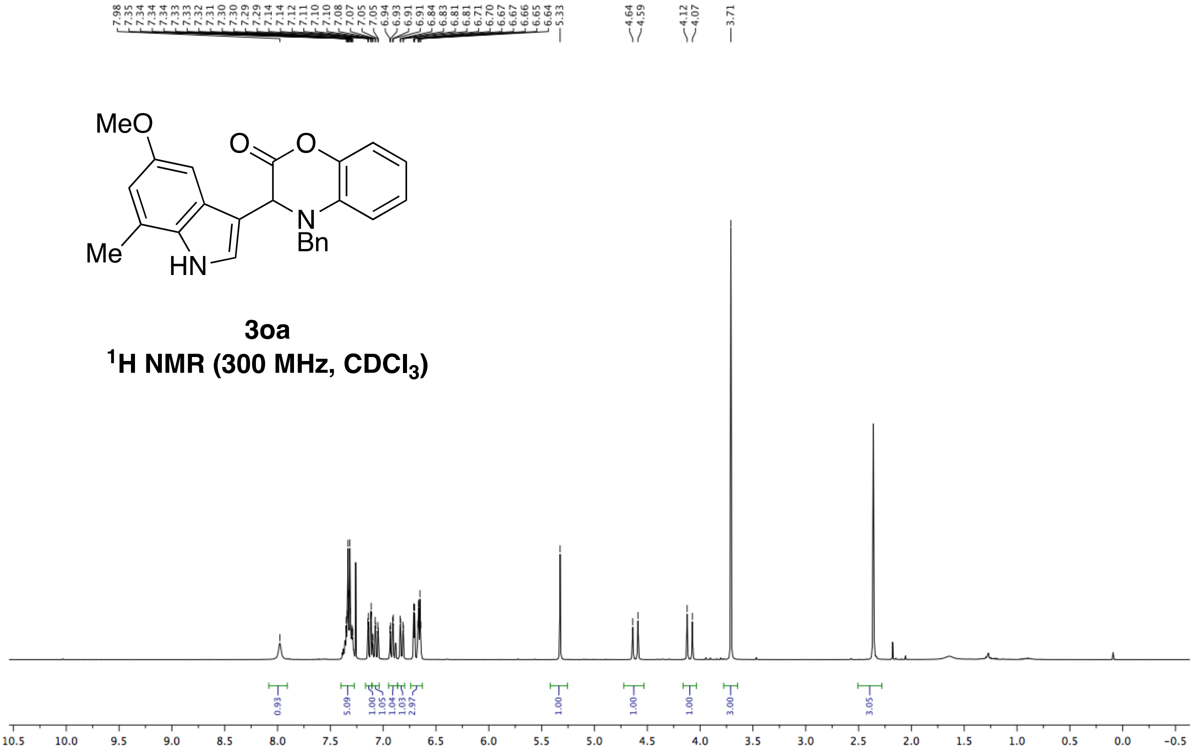
^{1}H NMR (300 MHz, $CDCl_3$)



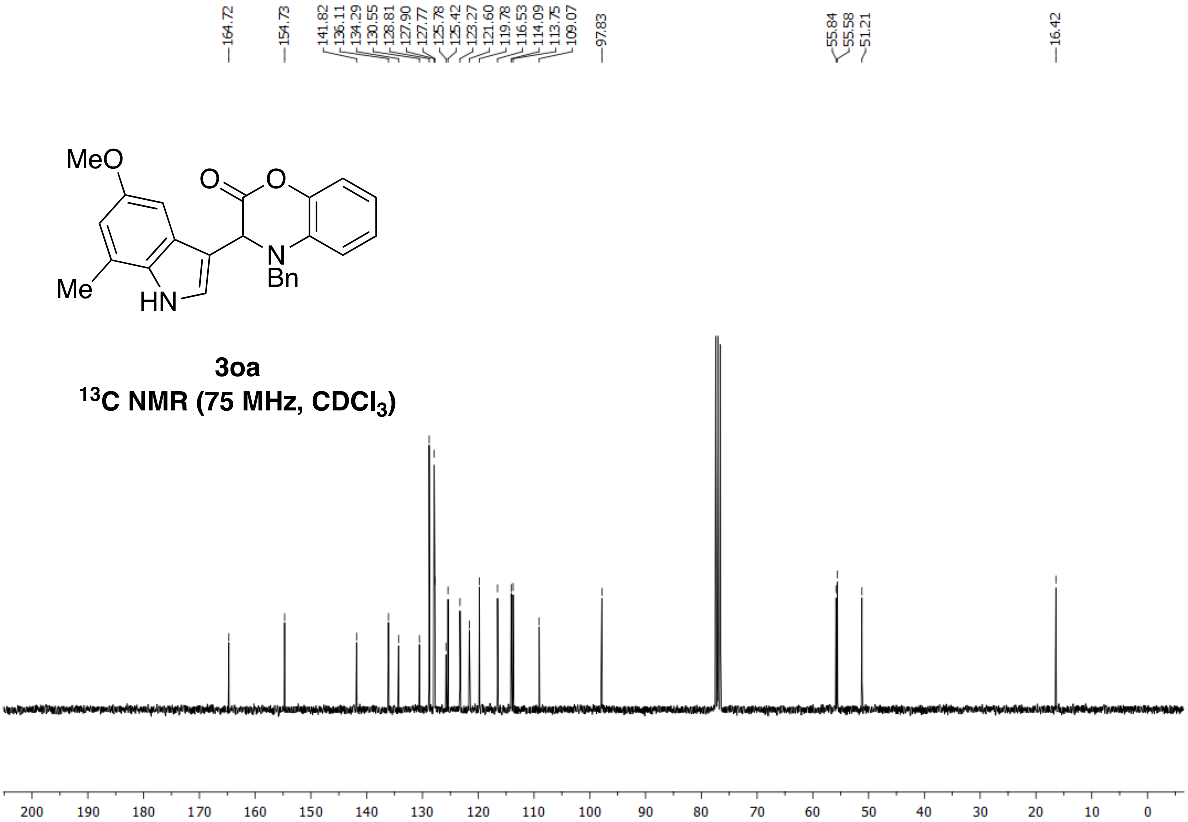


3na

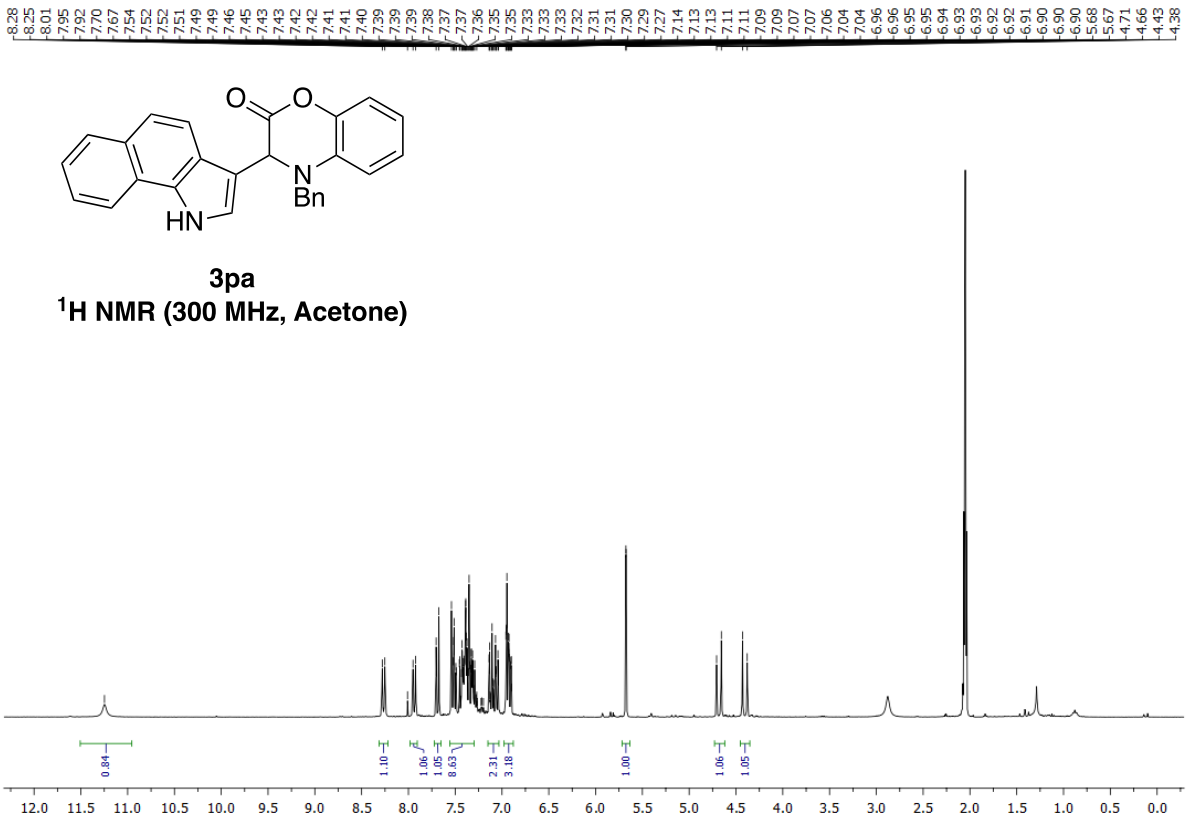
^{13}C NMR (75 MHz, $CDCl_3$)



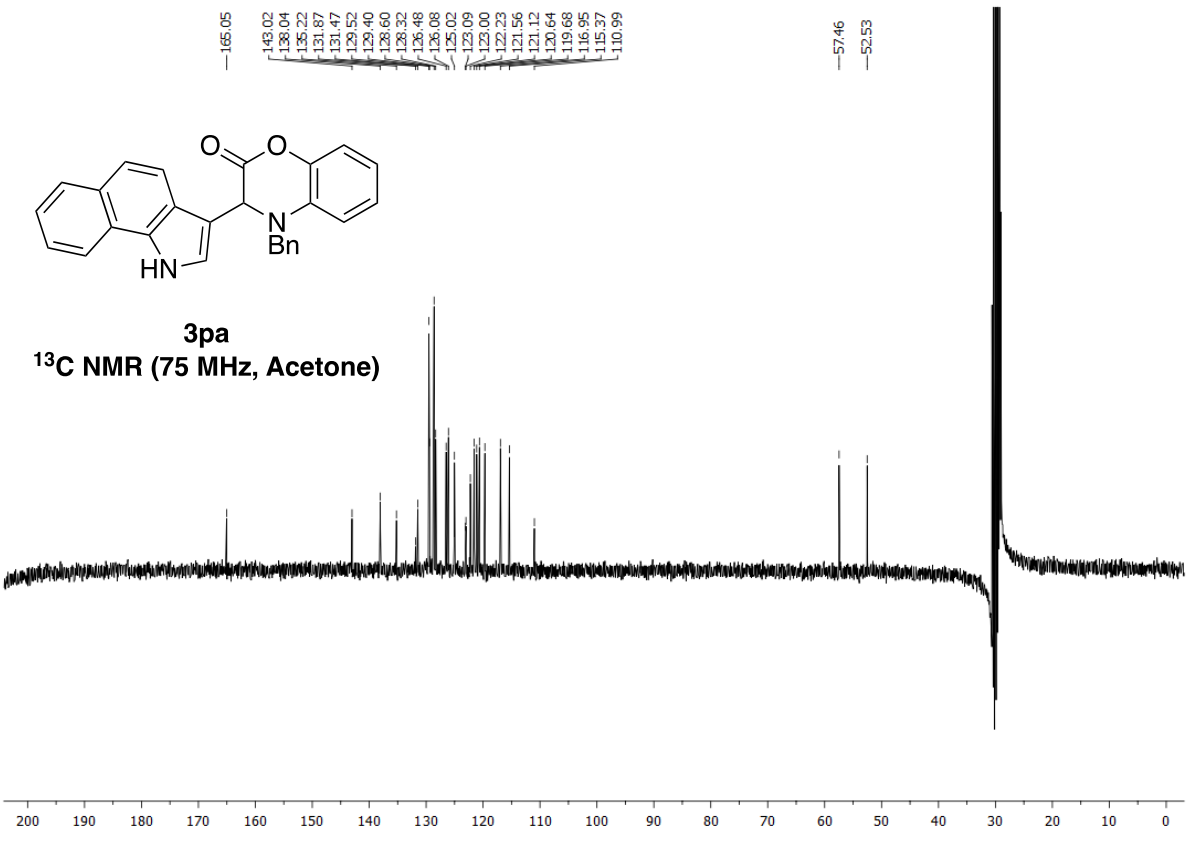
3oa
^{1}H NMR (300 MHz, CDCl$_3$)



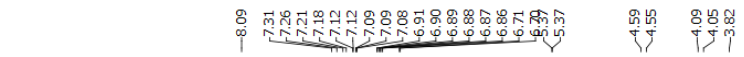
3oa
^{13}C NMR (75 MHz, CDCl$_3$)

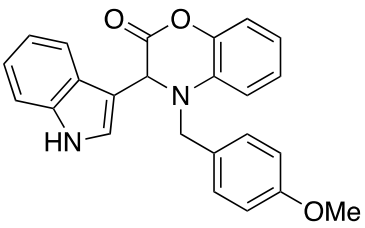


3pa
^{1}H NMR (300 MHz, Acetone)



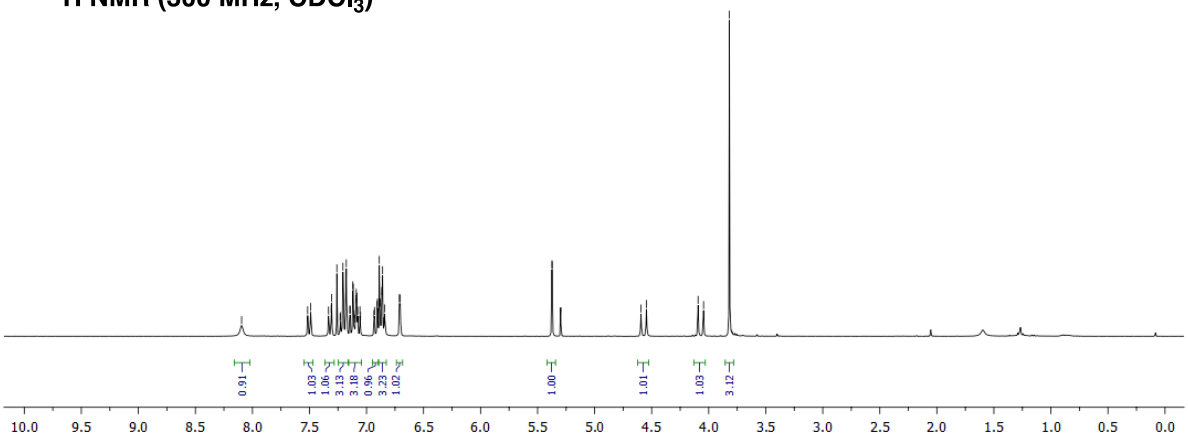
3pa
^{13}C NMR (75 MHz, Acetone)

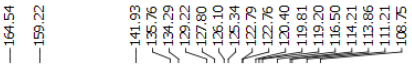


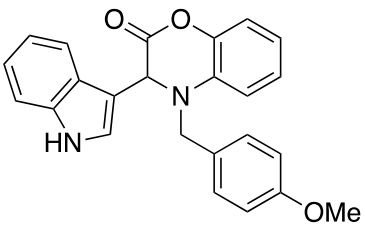


3ab

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

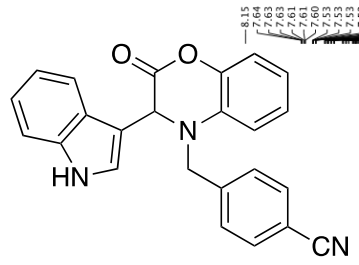






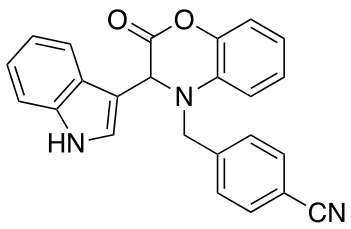
3ab

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



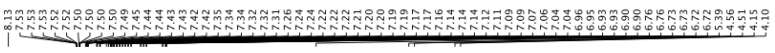
3ac

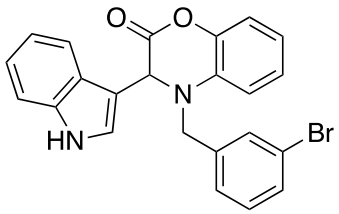
^{1}H NMR (300 MHz, $CDCl_3$)



3ac

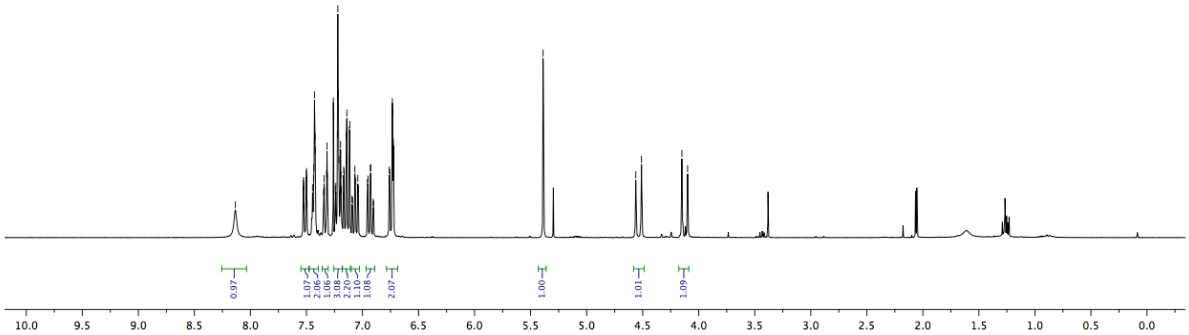
^{13}C NMR (75 MHz, $CDCl_3$)

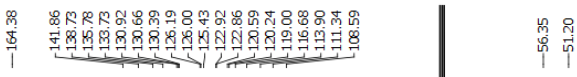


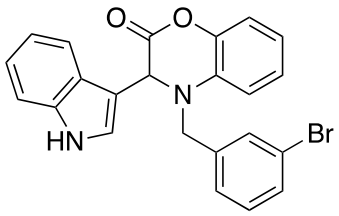


3ad

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

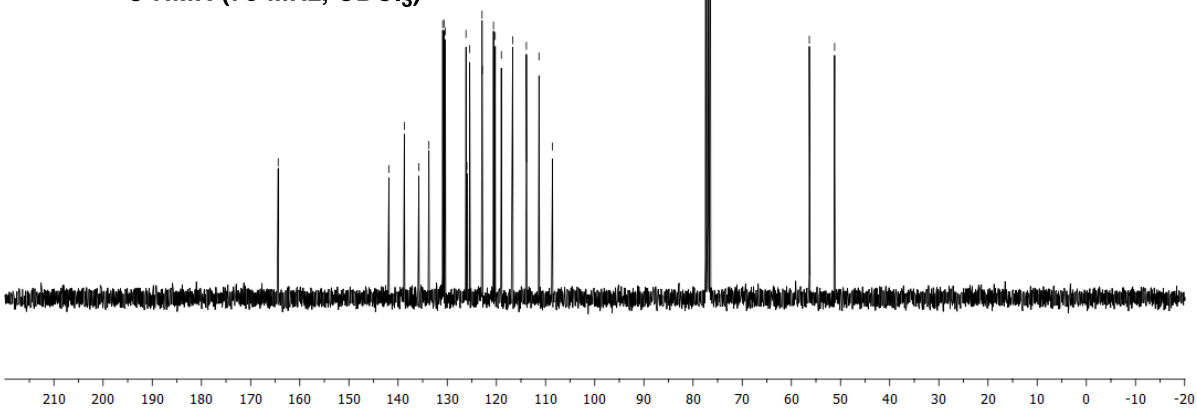


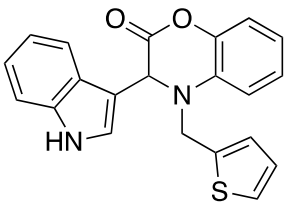




3ad

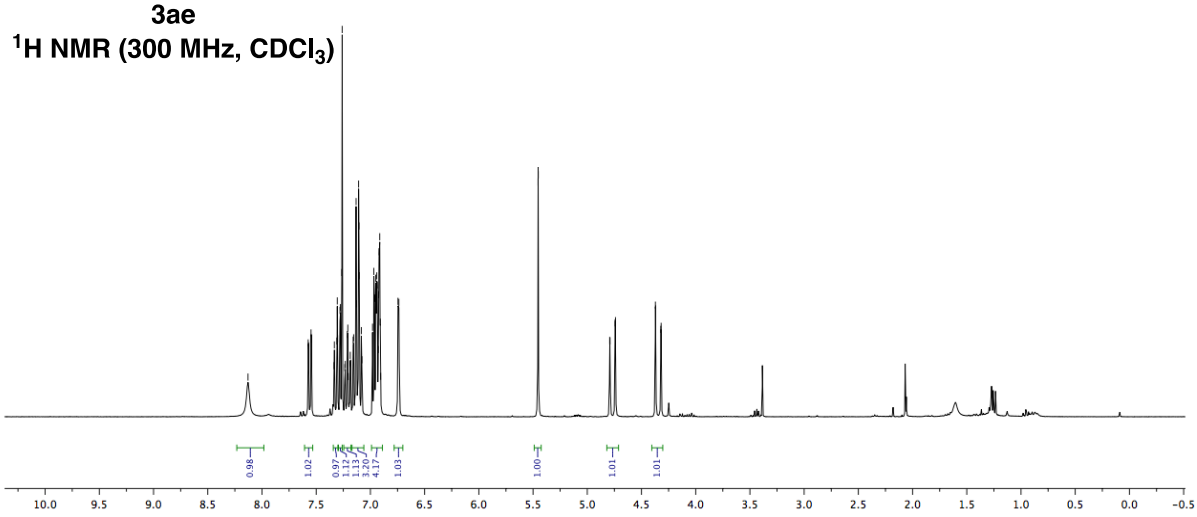
^{13}C NMR (75 MHz, $CDCl_3$)





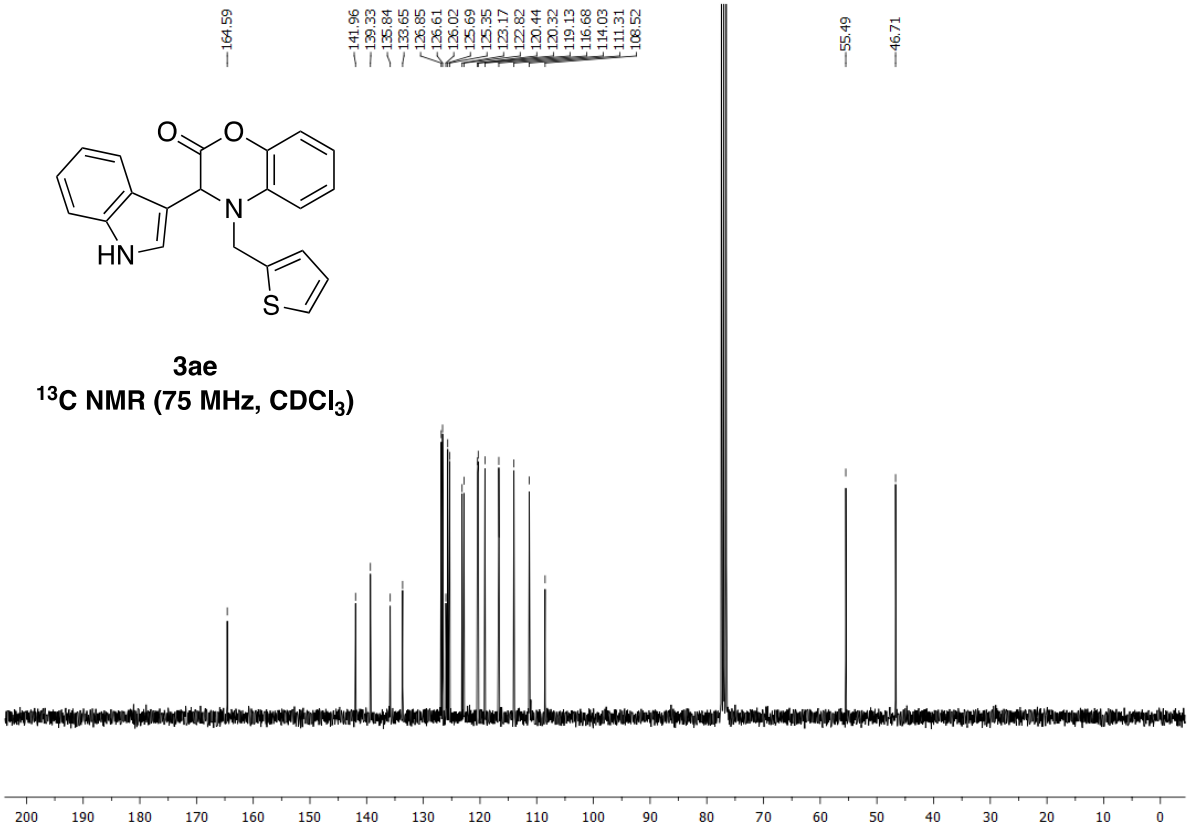
3ae

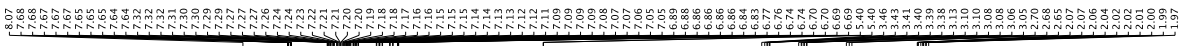
^{1}H NMR (300 MHz, $CDCl_3$)

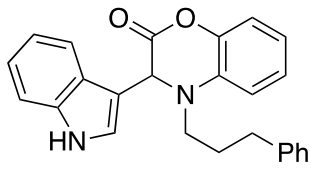


3ae

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

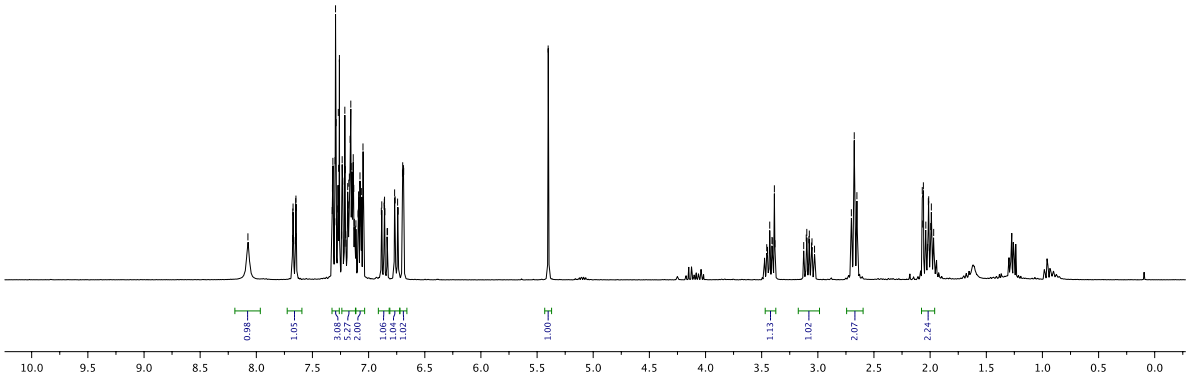


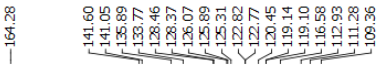


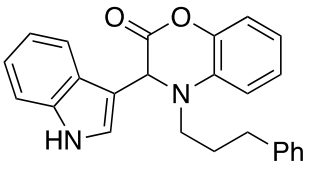


3af

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

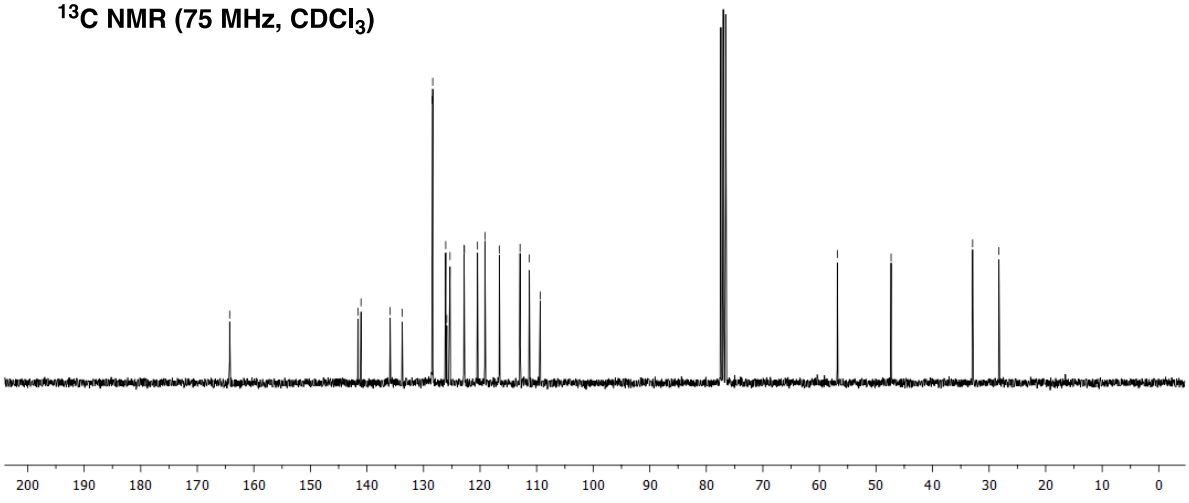


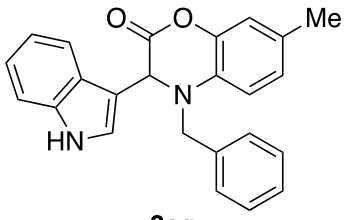




3af

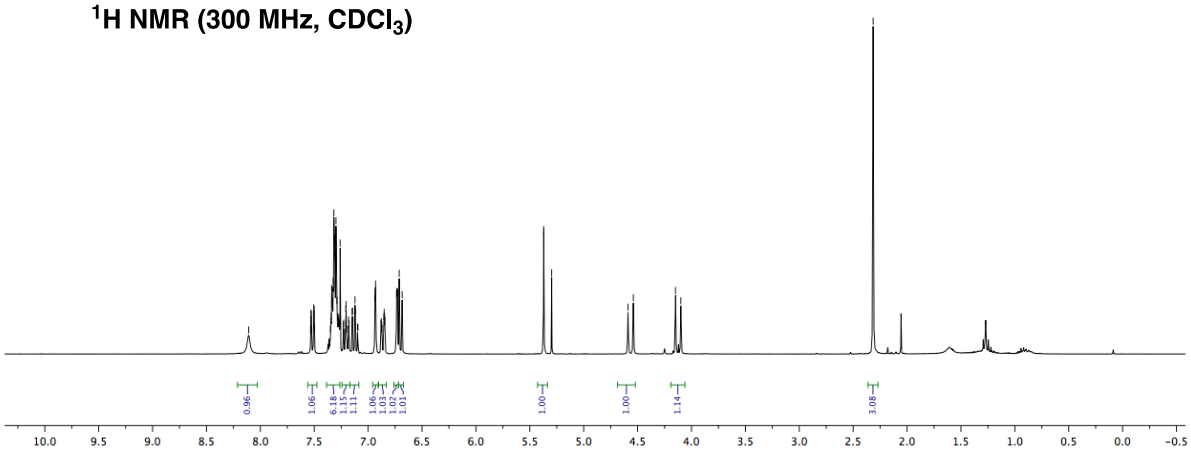
^{13}C NMR (75 MHz, $CDCl_3$)

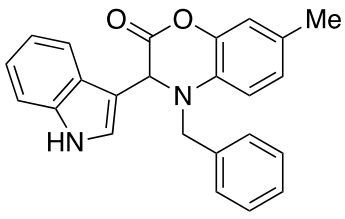




3ag

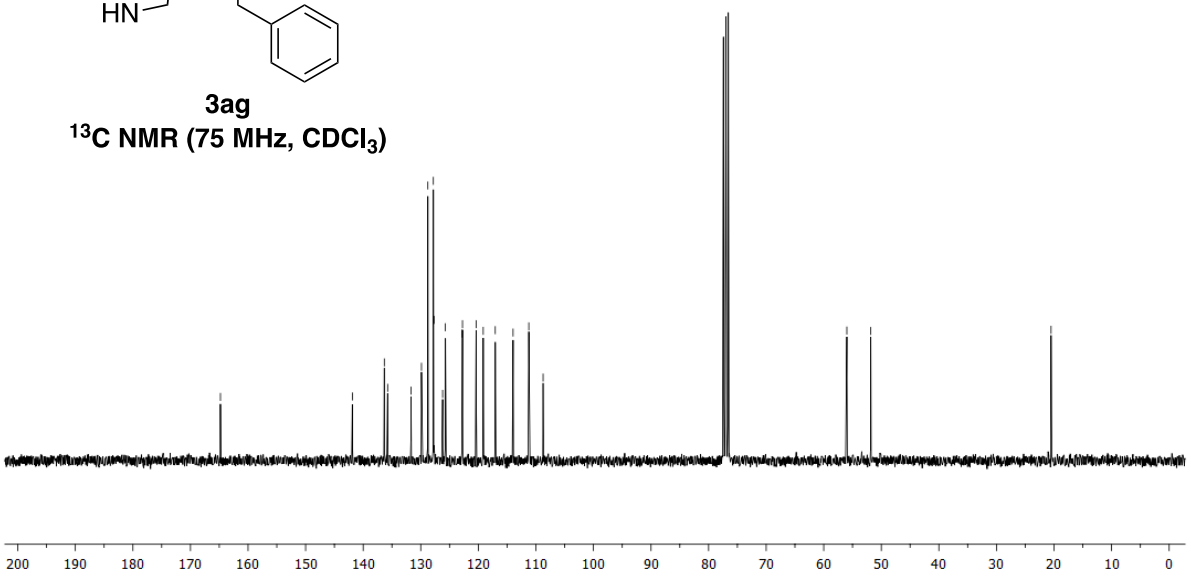
^{1}H NMR (300 MHz, $CDCl_3$)

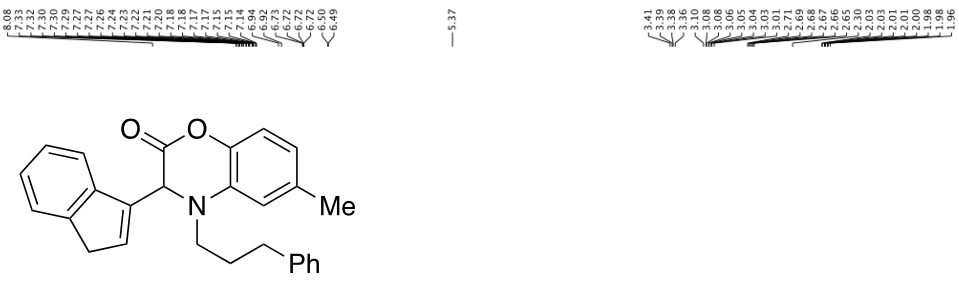




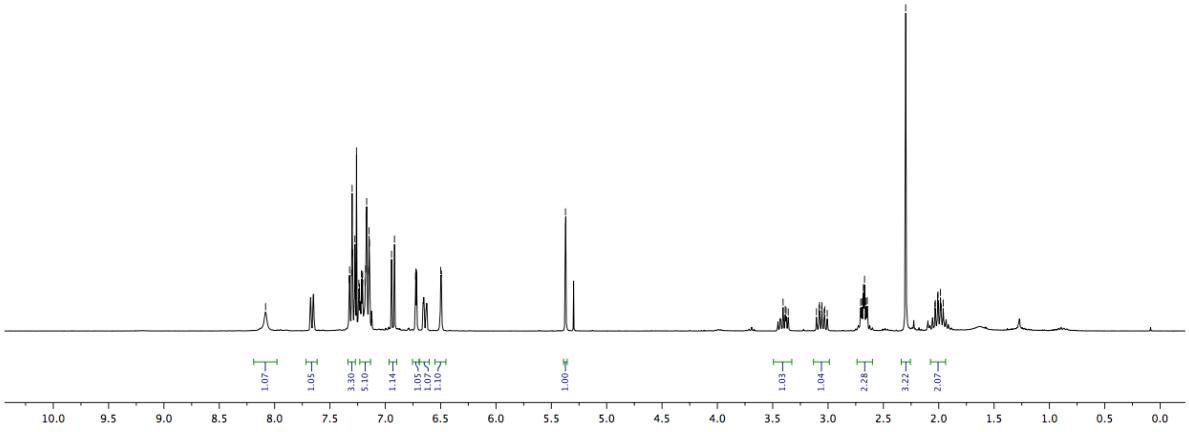
3ag

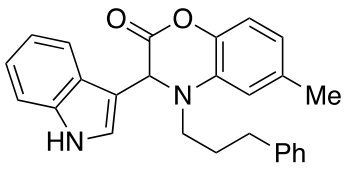
^{13}C NMR (75 MHz, $CDCl_3$)



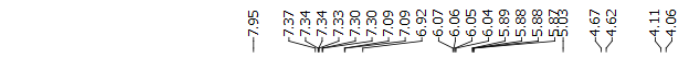


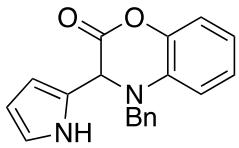
3ah
^{1}H NMR (300 MHz, $CDCl_3$)





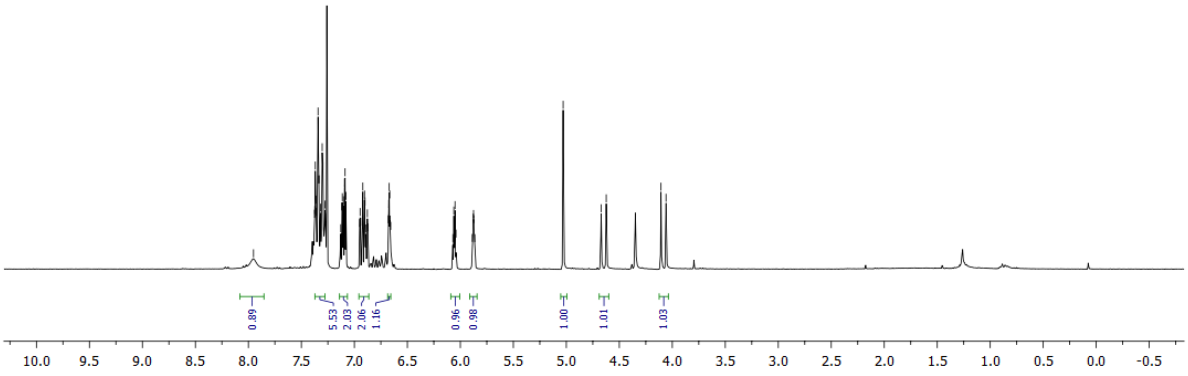
3ah
^{13}C NMR (75 MHz, $CDCl_3$)

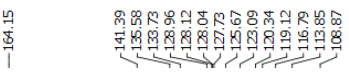


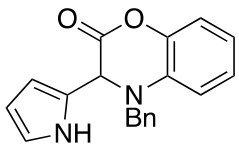


6a

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

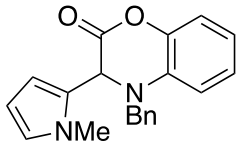






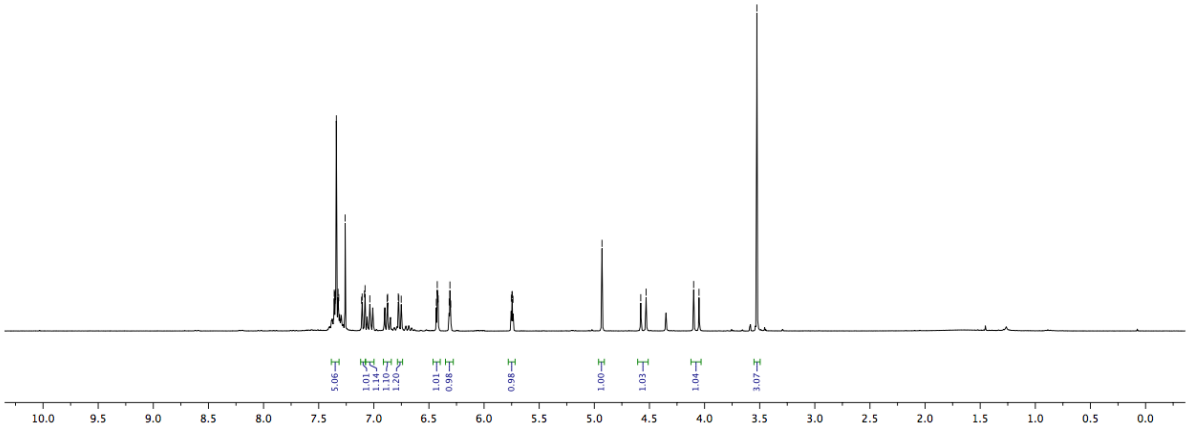
6a

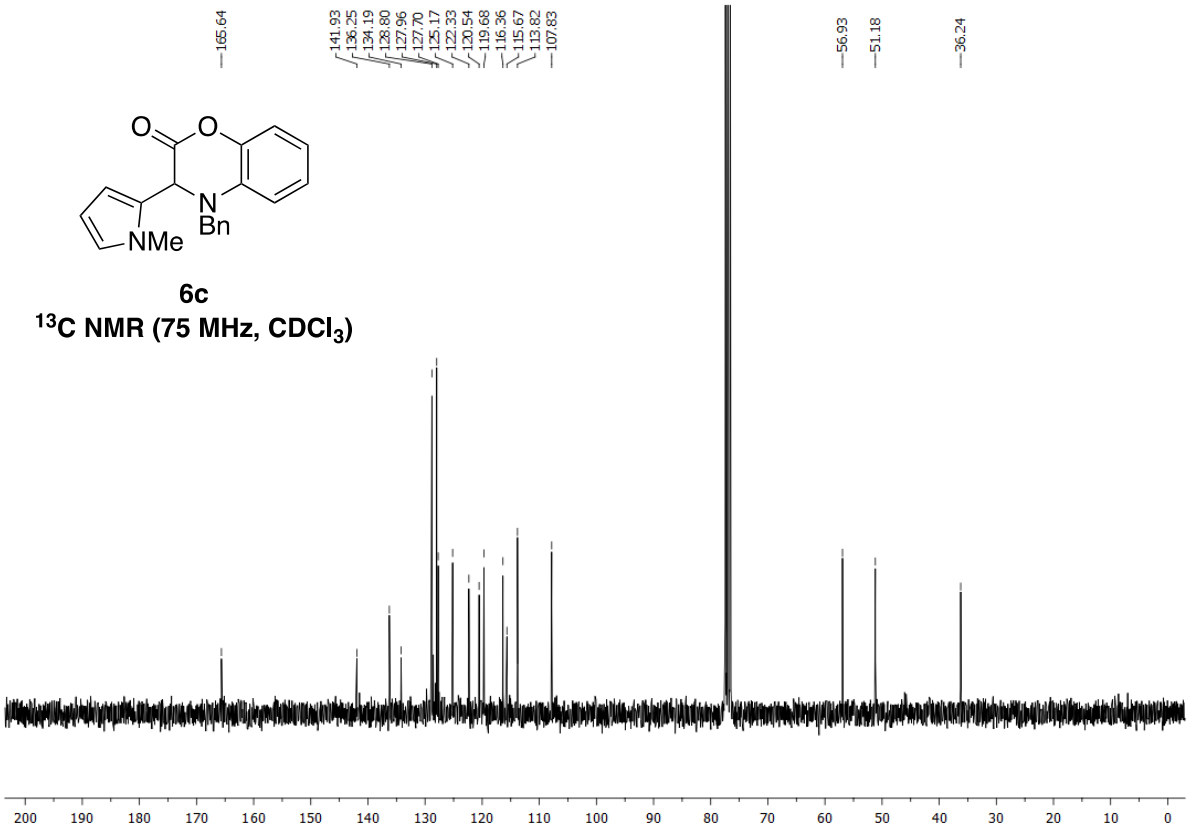
^{13}C NMR (75 MHz, $CDCl_3$)



6b

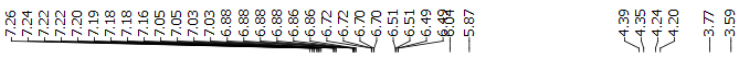
^{1}H NMR (300 MHz, $CDCl_3$)

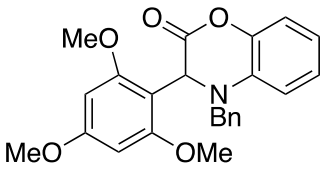




6c

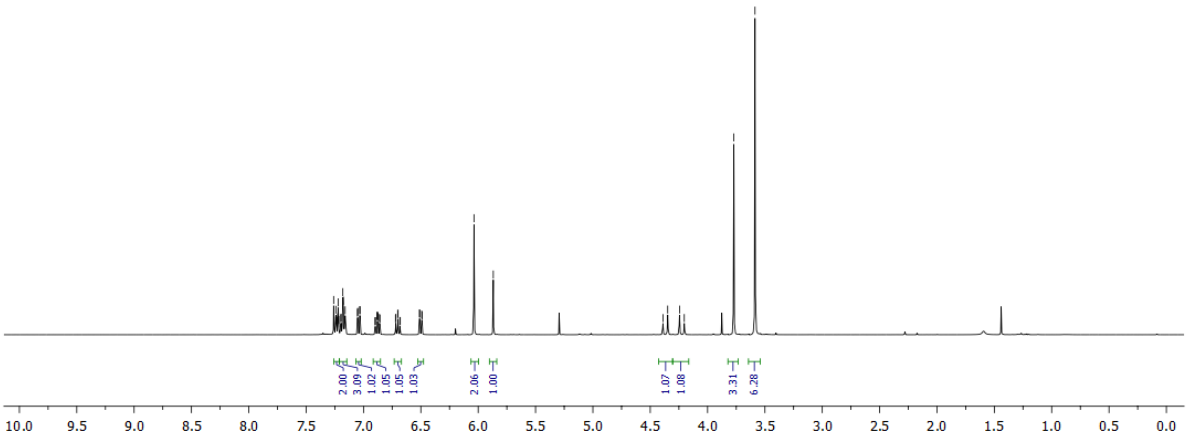
^{13}C NMR (75 MHz, $CDCl_3$)

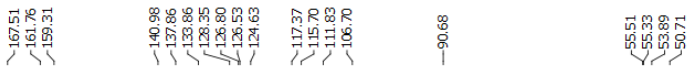


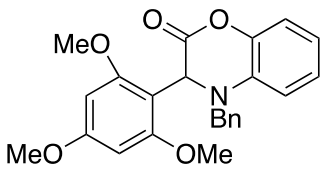


7

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

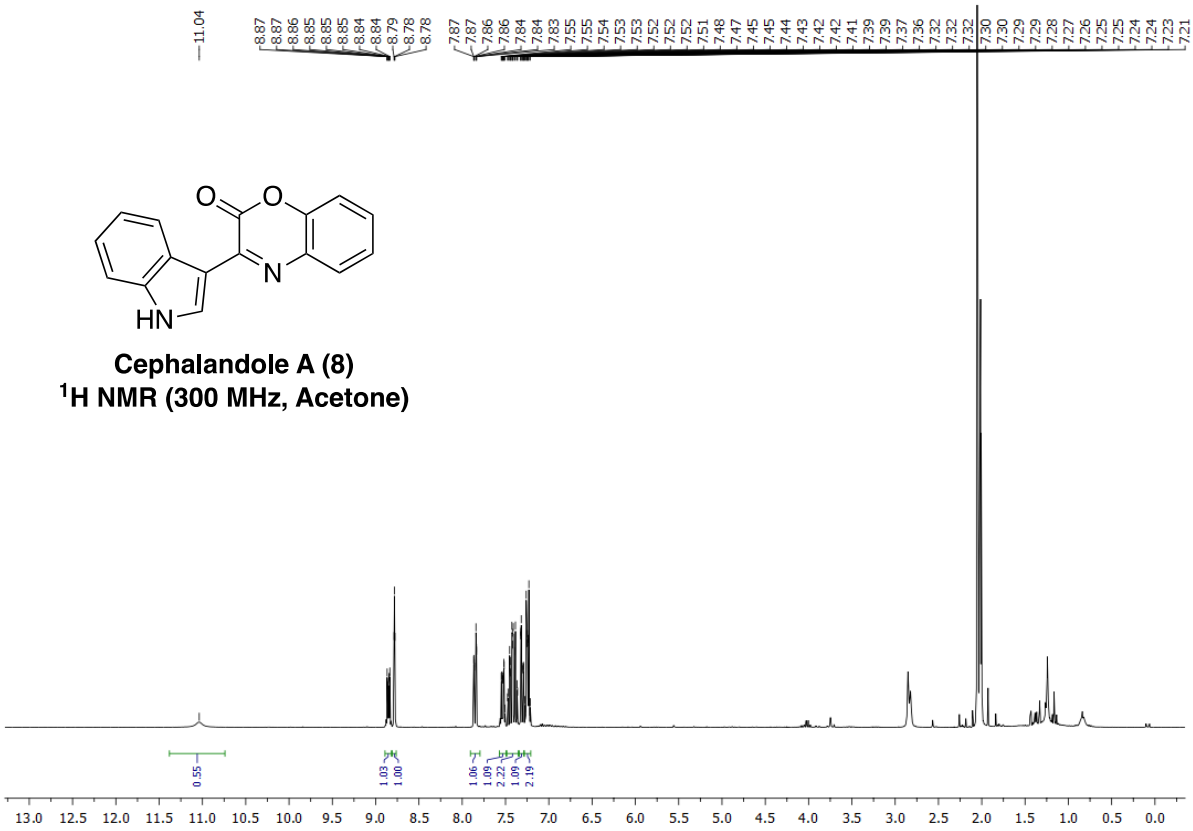




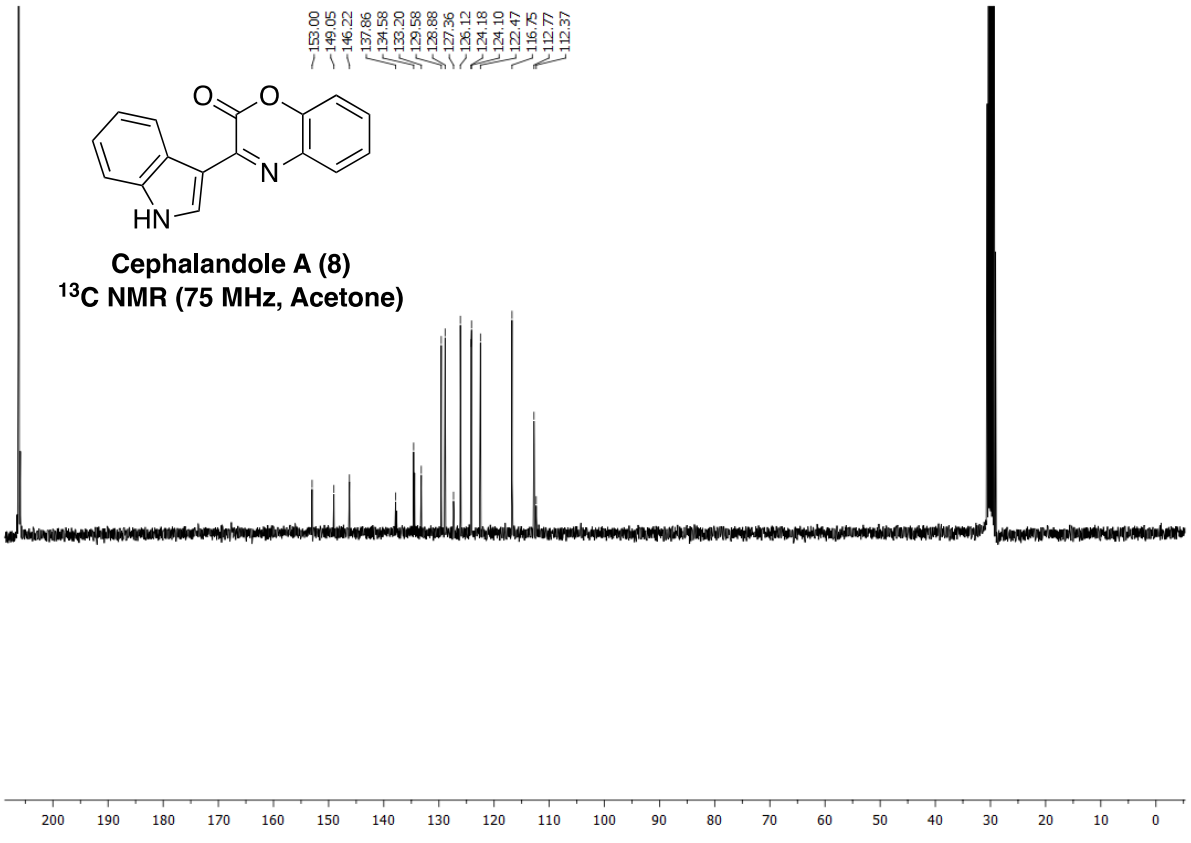


7

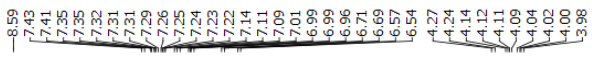
^{13}C NMR (75 MHz, $CDCl_3$)

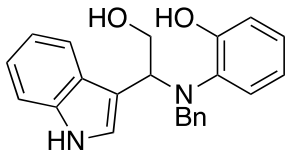


Cephalandole A (8)
^{1}H NMR (300 MHz, Acetone)



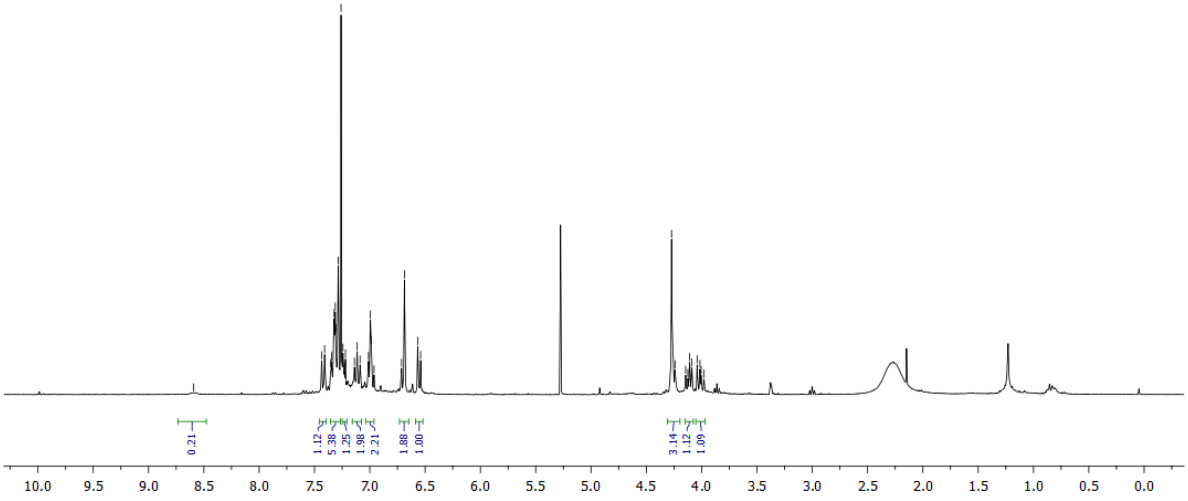
Cephalandole A (8)
^{13}C NMR (75 MHz, Acetone)

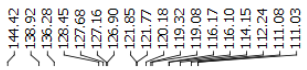


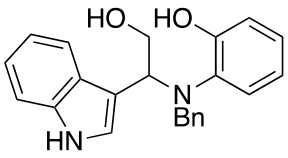


9

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







9

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