Supplementary Information (SI) for Organic Chemistry Frontiers.

Supporting Information

Catalytic Atroposelective Friedel-Crafts Alkylation to Access Axially Chiral C2-arylindoles via Dynamic Kinetic Resolutions

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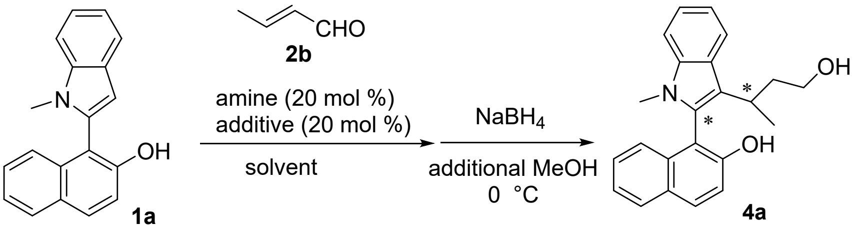
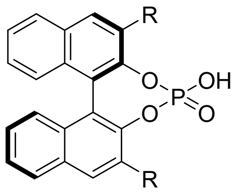
1. General Methods

NMR spectra were recorded with tetramethylsilane as the internal standard. ^{1}H NMR spectra were recorded at 400 MHz, ^{13}C NMR spectra were recorded at 100 MHz, and ^{19}F-NMR spectra were recorded at 376 MHz. Chemical shifts were reported in ppm downfield from $CDCl_3$ ($\delta = 7.26$ ppm) or $(CD_3)_2SO$ ($\delta = 2.50$ ppm) for ^{1}H NMR and relative to the central $CDCl_3$ resonance ($\delta = 77.0$ ppm) or $(CD_3)_2SO$ resonance ($\delta = 39.52$ ppm) for ^{13}C NMR spectroscopy. Coupling constants are given in Hz. UV detection was monitored at 254 nm. TLC was performed on glass-backed silica plates. UV light and I_2 were used to visualize products. Column chromatography was performed using silica gel (200–300 mesh) eluting with EtOAc/petroleum ether. Unless otherwise noted, commercial reagents were used as received and all reactions were carried out directly under air atmosphere.

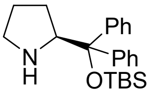
2. Optimization and preliminary substrate test of the atroposelective FC reaction of crotonaldehyde

Table S2, Condition optimizations for the atroposelective FC reaction of crotonaldehyde. [a]

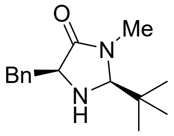




C1, R = 2,4,6-(iPr)$_3$C$_6$H$_2$



C2



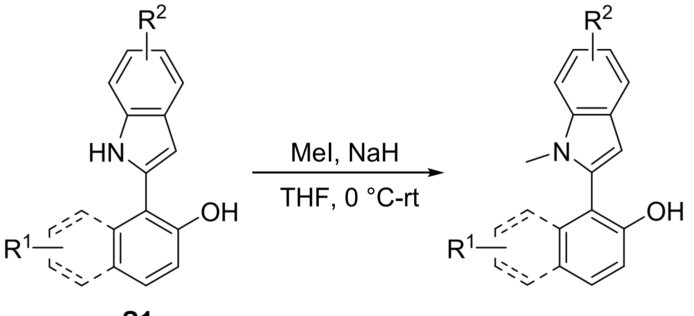
C3

Entry	Solvent	C	additive	T (°C)	t (h)	yield (%) [b]	ee (%) [c]	dr [c]
1	DCM	**C1**	--	25	30 h	--	--	--
2	DCM	**C2**	TEA	25	30 h	--	--	--
3	DCM	**C2**	BA	25	30 h	--	--	--
4	DCM	**C3**	BA	25	30 h	--	--	--
5	DCM	**C2**	SA	25	30 h	--	--	--

6	DCM	**C3**	SA	25	12 h	80	45	1:1
7	DCM	**C3**	OFBA	25	48 h	60	71	2:1
8	DCM	**C3**	PNBA	25	48 h	80	40	1.5:1
9	DCM	**C3**	2-SH-benzoic acid	25	48 h	65	53	1.5:1
10	DCM	**C3**	D-CSA	25	12 h	83	73	1.2:1
11	DCM	**C3**	L-CSA	25	12 h	65	50	1.2:1
12[d]	DCM	**C3**	D-CSA	25	12 h	85	90	1.2:1
13	DCM	**C3**	TsOH	25	12 h	85	81	1:1
14	DCM	**C3**	MsOH	25	12 h	83	71	1:1
15	THF	**C3**	D-CSA	25	12 h	73	63	4:1
16	MTBE	**C3**	D-CSA	25	12 h	81	53	4:1
17	EtOH	**C3**	D-CSA	25	12 h	--	--	--
18	Dioxane	**C3**	D-CSA	25	12 h	80	60	5:1
19	Et_2O	**C3**	D-CSA	25	12 h	--	--	--
20	IPA	**C3**	D-CSA	25	12 h	73	60	1.5:1
21	DCM	**C3**	D-CSA	0	12 h	80	71	1:1
22	DCM	**C3**	D-CSA	40	5 h	85	80	1:1

[a] Unless noted otherwise, the reactions were carried out with **1a** (0.05 mmol), **2b** (0.06 mmol), catalyst **C** (0.01 mmol) and additive (0.01 mmol) in 1 mL of anhydrous solvent at room temperature. [b] Isolated yield. [c] Determined by HPLC analysis on a chiral stationary phase. [d] Catalyst **C** (0.015 mmol) and additive (0.01 mmol).

3. General procedure for the preparation of 2-arylindole 1

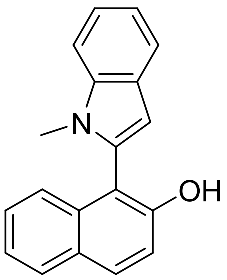


S1

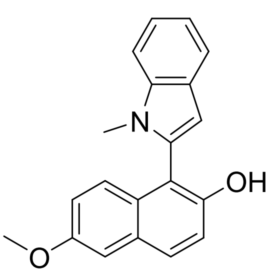
1

Procedure A: Compound **S1** (1.0 mmol), which were synthesized according to the reported procedures[1], was dissolved in anhydrous THF (5.0 mL) and followed by the slow addition of NaH

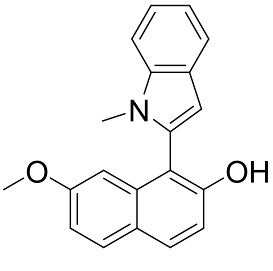
(48mg, 2.0 mmol) at 0 °C, then CH_3I (213 mg, 1.5 mmol) was added dropwise. After that, the reaction was removed to room temperature and stirred for additional 1 h to reach the full conversion. Subsequently, the reaction was quenched by the addition of ice water and extracted with ethyl acetate (3 × 10 mL). The combined organic extracts were dried over anhydrous Na_2SO_4, and the solvents were evaporated under reduced pressure. The residue was purified by chromatography on silica gel by using a 10/1 mixture of petroleum ether/ethyl acetate to provide the pure 2-arylindoles. **1-(1-methyl-1H-indol-2-yl)naphthalen-2-ol (1a):** ^1H NMR (400 MHz, $CDCl_3$): δ 7.85 (d, J = 8.9 Hz, 1H), 7.82–7.77 (m, 1H), 7.70 (d, J = 7.9 Hz, 1H), 7.41 (dd, J = 8.2, 0.6 Hz, 1H), 7.37–7.27 (m, 5H), 7.22–7.17 (m, 1H), 6.69 (d, J = 0.6 Hz, 1H), 5.81 (s, 1H), 3.40 (s, 3H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$): δ 152.8, 138.4, 133.9, 132.4, 131.2, 128.6, 128.2, 128.1, 127.3, 124.3, 123.6, 122.3, 120.8, 120.1, 117.2, 111.0, 109.8, 103.9, 30.5 ppm; ESI-HRMS: calcd for $C_{19}H_{15}NO + H^+$ 274.1226, found 274.1232.

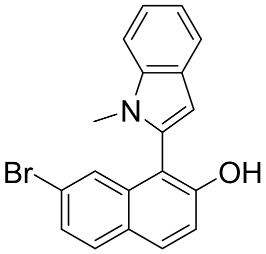


6-methoxy-1-(1-methyl-1H-indol-2-yl)naphthalen-2-ol (1b): ^1H NMR (400 MHz, $CDCl_3$): δ 7.75 (d, J = 8.9 Hz, 1H), 7.69 (dd, J = 8.5, 4.3 Hz, 1H), 7.41 (dd, J = 8.2, 0.5 Hz, 1H), 7.33–7.28 (m, 1H), 7.23 (d, J = 4.0 Hz, 1H), 7.22–7.17 (m, 2H), 7.14 (d, J = 2.6 Hz, 1H), 7.03 (dd, J = 9.1, 2.6 Hz, 1H), 6.68 (d, J = 0.6 Hz, 1H), 5.65 (s, 1H), 3.88 (s, 3H), 3.40 (s, 3H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$): δ 156.1, 151.1, 138.3, 132.5, 129.8, 129.5, 129.1, 128.1, 125.9, 122.2, 120.8, 120.1, 119.7, 117.6, 111.3, 109.8, 106.6, 103.8, 55.4, 30.4 ppm; ESI-HRMS: calcd for $C_{20}H_{17}NO_2 + H^+$ 304.1332, found 304.1323.

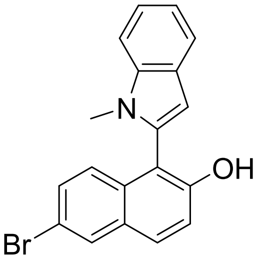


7-methoxy-1-(1-methyl-1H-indol-2-yl)naphthalen-2-ol (1c): ^1H NMR (400 MHz, $CDCl_3$): δ 7.68 (d, J = 8.8 Hz, 1H), 7.62 (dd, J = 8.4, 5.4 Hz, 2H), 7.34 (d, J = 8.2 Hz, 1H), 7.26–7.20 (m, 1H), 7.15–7.10 (m, 1H), 7.04 (d, J = 8.8 Hz, 1H), 6.91 (dd, J = 8.9, 2.5 Hz, 1H), 6.61 (s, 1H), 6.54 (d, J = 2.4 Hz, 1H), 5.70 (s, 1H), 3.56 (s, 3H), 3.35 (s, 3H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$): δ 159.1, 153.4, 138.4, 135.4, 132.7, 130.9, 129.8, 128.3, 124.0, 122.2, 120.9, 120.1, 115.7, 114.6, 110.3, 109.8, 103.7, 103.3, 55.3, 30.4 ppm; ESI-HRMS: calcd for $C_{20}H_{17}NO_2 + H^+$ 304.1332, found 304.1323.

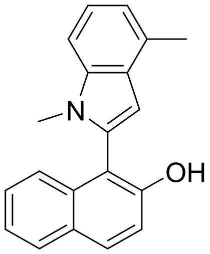




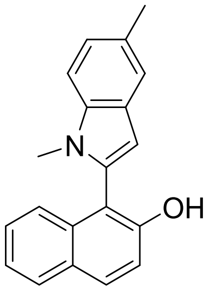
7-bromo-1-(1-methyl-1H-indol-2-yl)naphthalen-2-ol (1d): ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.86 (d, *J* = 8.9 Hz, 1H), 7.76 (d, *J* = 7.9 Hz, 1H), 7.71 (d, *J* = 8.7 Hz, 1H), 7.53–7.42 (m, 3H), 7.40–7.35 (m, 1H), 7.32 (d, *J* = 8.9 Hz, 1H), 7.28–7.23 (m, 1H), 6.74 (s, 1H), 5.87 (s, 1H), 3.46 (s, 3H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$): δ 153.6, 138.5, 135.2, 131.5, 131.1, 129.8, 128.1, 127.1, 127.1, 126.4, 122.5, 122.0, 121.0, 120.3, 117.7, 110.5, 110.0, 104.3, 30.5 ppm; ESI-HRMS: calcd for $C_{19}H_{14}BrNO + H^+$ 352.0332, found 352.0331.



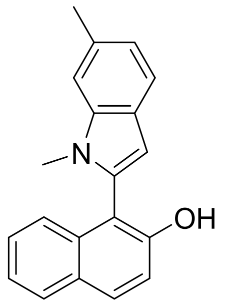
6-bromo-1-(1-methyl-1H-indol-2-yl)naphthalen-2-ol (1e): ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.03 (d, *J* = 2.0 Hz, 1H), 7.83 (d, *J* = 9.0 Hz, 1H), 7.77 (d, *J* = 7.9 Hz, 1H), 7.51–7.46 (m, 2H), 7.36 (d, *J* = 8.9 Hz, 2H), 7.29 (dd, *J* = 6.1, 1.7 Hz, 1H), 7.25 (d, *J* = 8.8 Hz, 1H), 6.76 (s, 1H), 5.89 (s, 1H), 3.46 (s, 3H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$): δ 153.1, 138.5, 132.5, 131.6, 130.5, 130.2, 130.2, 129.8, 128.1, 126.2, 122.5, 120.9, 120.3, 118.4, 117.4, 111.4, 109.9, 104.1, 30.5 ppm; ESI-HRMS: calcd for $C_{19}H_{14}BrNO + Na^+$ 374.0151, found 374.0156.



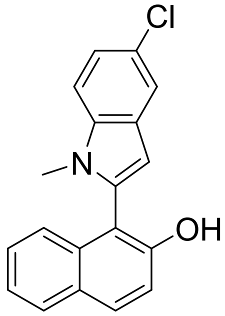
1-(1,4-dimethyl-1H-indol-2-yl)naphthalen-2-ol (1f): ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.90 (d, *J* = 8.9 Hz, 1H), 7.86–7.83 (m, 1H), 7.41–7.34 (m, 3H), 7.32 (brs, 1H), 7.31–7.27 (m, 2H), 7.26–7.23 (m, 1H), 7.04 (d, *J* = 6.7 Hz, 1H), 6.74 (d, *J* = 0.4 Hz, 1H), 5.87 (s, 1H), 3.44 (s, 3H), 2.63 (s, 3H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$): δ152.8, 138.2, 134.0, 131.7, 131.1, 130.5, 128.6, 128.2, 128.1, 127.2, 124.4, 123.6, 122.4, 120.3, 117.2, 111.2, 107.4, 102.4, 30.6, 18.7 ppm; ESI-HRMS: calcd for $C_{20}H_{17}NO_2 + H^+$ 288.1383, found 288.1385.



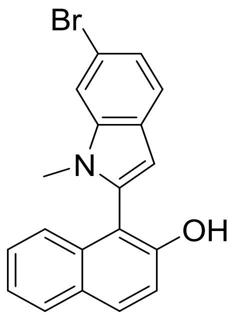
1-(1,5-dimethyl-1H-indol-2-yl)naphthalen-2-ol (1g): ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.89 (d, *J* = 8.9 Hz, 1H), 7.87–7.83 (m, 1H), 7.53 (s, 1H), 7.40–7.29 (m, 5H), 7.18 (dd, *J* = 8.4, 1.2 Hz, 1H), 6.65 (s, 1H), 5.89 (s, 1H), 3.43 (s, 3H), 2.53 (s, 3H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$): δ 152.7, 136.8, 133.9, 132.4, 131.1, 129.5, 128.6, 128.4, 128.2, 127.2, 124.4, 123.9, 123.6, 120.4, 117.2, 111.2, 109.5, 103.3, 30.5, 21.4 ppm; ESI-HRMS: calcd for $C_{20}H_{17}NO_2 + H^+$ 288.1383, found 288.1385.



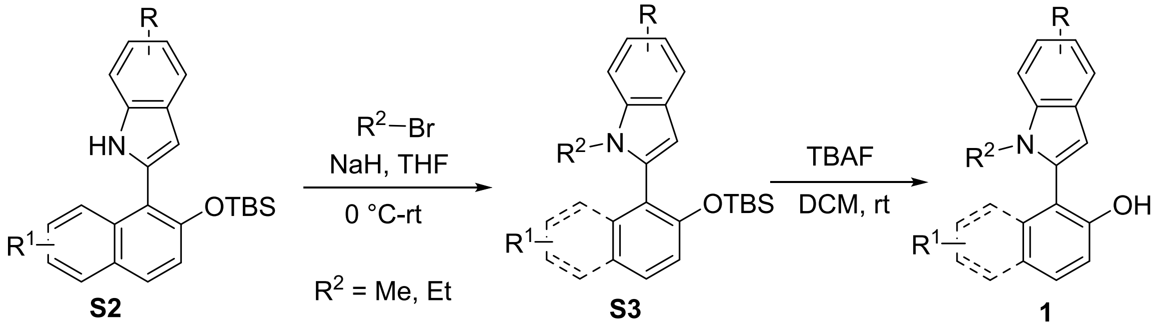
1-(1,6-dimethyl-1H-indol-2-yl)naphthalen-2-ol (1h): ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.77 (d, *J* = 8.9 Hz, 1H), 7.73 (dd, *J* = 6.3, 2.0 Hz, 1H), 7.51 (d, *J* = 8.0 Hz, 1H), 7.28–7.22 (m, 3H), 7.19 (d, *J* = 8.9 Hz, 1H), 7.15–7.13 (m, 1H), 6.96 (dd, *J* = 8.0, 1.0 Hz, 1H), 6.56 (d, *J* = 0.7 Hz, 1H), 5.77 (s, 1H), 3.29 (s, 3H), 2.46 (s, 3H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$): δ 152.8, 138.8, 134.0, 132.3, 131.7, 131.0, 128.7, 128.2, 127.2, 126.0, 124.4, 123.6, 121.9, 120.5, 117.2, 111.2, 109.8, 103.7, 30.4, 21.9 ppm; ESI-HRMS: calcd for $C_{20}H_{17}NO_2 + H^+$ 288.1383, found 288.1385.



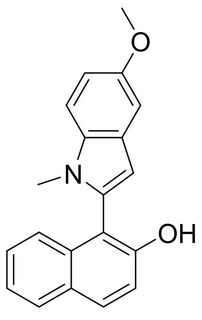
1-(5-chloro-1-methyl-1H-indol-2-yl)naphthalen-2-ol (1j): ^{1}H NMR (400 MHz, $CDCl_3$): 7.80 (d, *J* = 8.9 Hz, 1H), 7.77–7.73 (m, 1H), 7.59 (d, *J* = 1.7 Hz, 1H), 7.33–7.26 (m, 2H), 7.25–7.14 (m, 4H), 6.56 (s, 1H), 5.69 (s, 1H), 3.33 (s, 3H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$): δ 152.7, 136.7, 133.9, 133.7, 131.4, 129.0, 128.6, 128.3, 127.4, 125.9, 124.1, 123.7, 122.5, 120.1, 117.3, 110.8, 110.6, 103.4, 30.6 ppm; ESI-HRMS: calcd for $C_{19}H_{14}ClNO + H^+$ 308.0837, found 308.0840.



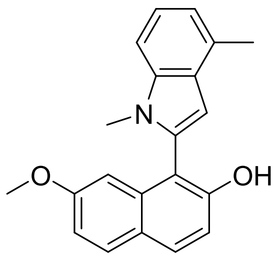
1-(6-bromo-1-methyl-1H-indol-2-yl)naphthalen-2-ol (1k): ^{1}H NMR (400 MHz, $CDCl_3$): 7.82 (d, *J* = 8.9 Hz, 1H), 7.79–7.74 (m, 1H), 7.53 (s, 1H), 7.50 (d, *J* = 8.4 Hz, 1H), 7.34–7.27 (m, 2H), 7.26–7.23 (m, 1H), 7.22–7.20 (m, 1H), 7.19–7.17 (m, 1H), 6.61 (s, 1H), 5.67 (s, 1H), 3.33 (s, 3H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$): δ 152.7, 139.2, 133.8, 133.2, 131.4, 128.7, 128.3, 127.4, 126.9, 124.1, 123.8, 123.4, 122.0, 117.3, 115.9, 112.9, 110.5, 104.0, 30.6 ppm; ESI-HRMS: calcd for $C_{19}H_{14}BrNO + H^+$ 352.0332, found 352.0331.



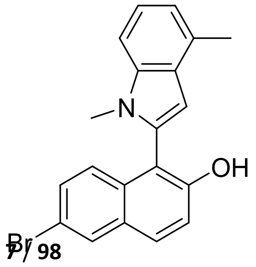
Procedure B: Compound **S2** (1 mmol) was dissolved with dry THF (5 mL), NaH (48 mg, 2.0 mmol) was added at 0°C, then CH_3I (213 mg, 1.5 mmol) or EtBr (163.5 mg, 1.5 mmol) was added slowly during 5 minutes. After that, the reaction mixture was removed to room temperature and stirred for 1 h. The reaction was monitored by TLC. Upon the full conversion, the reaction was quenched slowly by the addition of ice water, and extracted with ethyl acetate (3 × 10 mL). The organic layers were combined and dried over anhydrous Na_2SO_4, the solvents were evaporated under reduced pressure. The residue was purified by chromatography on silica gel by using a 10/1 mixture of petroleum ether/ethyl acetate to provide the pure 2-arylindoles **S3**. Compound **S3** (1 mmol) was dissolved in THF (5mL), and TBAF (1.5 mmol) was added, the reaction mixture was stirred at room temperature for 1 h. Then, the solvent was concentrated under reduced pressure, and the residue was purified by column chromatography to give the target compound **1**.



1-(5-methoxy-1-methyl-1H-indol-2-yl)naphthalen-2-ol (1i): ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.81 (d, J = 8.9 Hz, 1H), 7.78–7.74 (m, 1H), 7.34–7.23 (m, 4H), 7.19 (d, J = 15.0 Hz, 1H), 7.11 (d, J = 2.4 Hz, 1H), 6.93 (dd, J = 8.9, 2.5 Hz, 1H), 6.56 (d, J = 0.6 Hz, 1H), 5.79 (s, 1H), 3.83 (s, 3H), 3.34 (s, 3H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$): δ 154.5, 152.7, 133.9, 133.8, 132.8, 131.1, 128.6, 128.4, 128.2, 127.2, 124.3, 123.6, 117.2, 112.7, 111.2, 110.5, 103.3, 102.4, 56.0, 30.6 ppm; ESI-HRMS: calcd for $C_{20}H_{17}NO_2 + H^+$ 304.1332, found 304.1341.

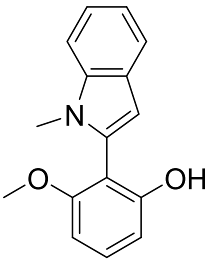


1-(1,4-dimethyl-1H-indol-2-yl)-7-methoxynaphthalen-2-ol (1l): ^{1}H NMR (400 MHz, DMSO-d_6): δ 9.81 (s, 1H), 7.84–7.75 (m, 2H), 7.31 (d, J = 8.2 Hz, 1H), 7.14 (d, J = 8.8 Hz, 1H), 7.10–7.05 (m, 1H), 6.99 (dd, J = 8.9, 2.5 Hz, 1H), 6.88 (d, J = 7.1 Hz, 1H), 6.78 (d, J = 2.4 Hz, 1H), 6.49 (s, 1H), 3.60 (s, 1H), 3.44 (s, 3H) ppm; ^{13}C NMR (100 MHz, DMSO-d_6): δ 158.1, 154.7, 136.8, 135.9, 134.7, 130.1, 129.7, 128.6, 127.7, 123.2, 120.7, 119.2, 115.5, 114.5, 110.7, 107.4, 103.4, 100.7, 54.9, 30.1, 18.5 ppm; ESI-HRMS: calcd for $C_{21}H_{19}NO_2 + H^+$ 318.1489, found 318.1486.

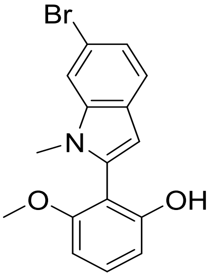


6-bromo-1-(1,4-dimethyl-1H-indol-2-yl)naphthalen-2-ol (1m): ^{1}H NMR (400 MHz, DMSO-d_6): δ 10.10 (s, 1H), 8.13 (s, 1H), 7.91 (d, J = 8.8 Hz, 1H), 7.44 (d, J = 8.9 Hz, 1H), 7.39–7.25 (m, 3H), 7.08 (t, J = 7.4 Hz, 1H), 6.88 (d, J = 6.7 Hz, 1H), 6.48 (s, 1H), 3.41 (s, 3H) ppm; ^{13}C NMR (100 MHz, DMSO-

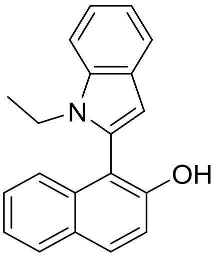
d$_6$): δ 154.6, 136.9, 133.8, 133.2, 129.7, 129.0, 128.7, 127.6, 126.5, 121.0, 119.4, 119.3, 115.8, 111.8, 107.5, 101.3, 40.2, 30.1, 18.5 ppm; ESI-HRMS: calcd for $C_{20}H_{16}NO_2 + H^+$ 388.0307, found 388.0297.



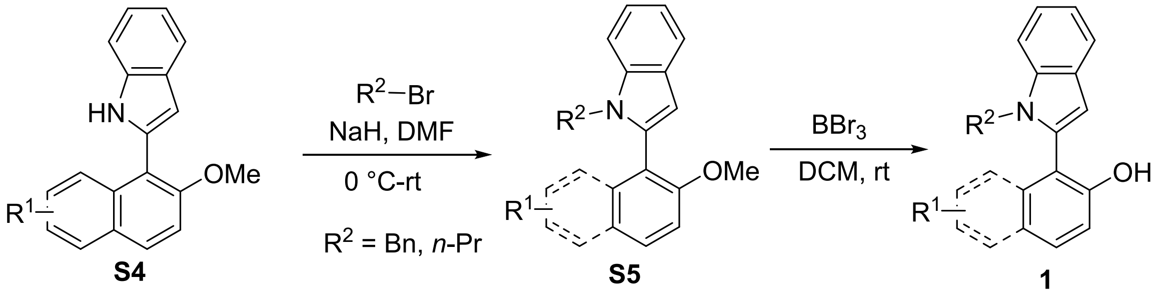
3-methoxy-2-(1-methyl-1H-indol-2-yl)phenol (1n) : ^{1}H NMR (400 MHz, DMSO-*d*$_6$): δ 9.50 (s, 1H), 7.50 (d, *J* = 7.8 Hz, 1H), 7.39 (d, *J* = 8.2 Hz, 1H), 7.23 (t, *J* = 8.3 Hz, 1H), 7.11 (t, *J* = 7.5 Hz, 1H), 7.01 (t, *J* = 7.4 Hz, 1H), 6.60 (dd, *J* = 18.6, 8.3 Hz, 2H), 6.30 (s, 1H), 3.65 (s, 3H), 3.44 (s, 3H) ppm; ^{13}C NMR (100 MHz, DMSO-*d*$_6$): δ 159.5, 157.6, 137.2, 134.1, 130.7, 128.1, 120.7, 120.0, 119.2, 110.0, 109.0, 108.4, 102.6, 102.4, 56.0, 30.4 ppm; ESI-HRMS: calcd. for $C_{16}H_{15}NO_2 + H^+$ 254.1176, found 254.1179.



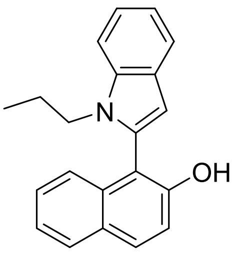
2-(6-bromo-1-methyl-1H-indol-2-yl)-3-methoxyphenol (1o): ^{1}H NMR (400 MHz, CDCl$_3$): 7.55 (d, *J* = 0.7 Hz, 1H), 7.51 (d, *J* = 8.4 Hz, 1H), 7.32 (t, *J* = 8.3 Hz, 1H), 7.27–7.23 (m, 1H), 6.72 (dd, *J* = 8.3, 0.8 Hz, 1H), 6.60 – 6.51 (m, 2H), 3.78 (s, 3H), 3.51 (s, 3H) ppm; ^{13}C NMR (100 MHz, CDCl$_3$): δ 158.4, 155.3, 139.0, 132.1, 131.2, 126.6, 123.0, 121.9, 115.7, 112.7, 108.4, 107.0, 102.6, 102.3, 55.7, 30.5 ppm; ESI-HRMS: calcd for $C_{16}H_{14}BrNO + H^+$ 332.0281, found 332.0279.



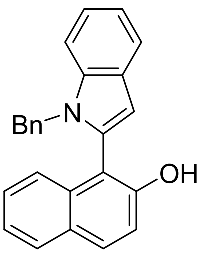
1-(1-ethyl-1H-indol-2-yl)naphthalen-2-ol (1q): ^{1}H NMR (400 MHz, CDCl$_3$): δ 7.81 (d, *J* = 8.9 Hz, 1H), 7.77–7.72 (m, 1H), 7.65 (d, *J* = 7.9 Hz, 1H), 7.39 (d, *J* = 8.2 Hz, 1H), 7.30–7.20 (m, 5H), 7.16–7.11 (m, 1H), 6.61 (s, 1H), 5.66 (s, 1H), 3.95–3.64 (m, 2H), 1.02 (t, *J* = 7.2 Hz, 3H) ppm; ^{13}C NMR (100 MHz, CDCl$_3$): δ 151.7, 136.2, 132.9, 130.4, 130.1, 127.6, 127.5, 127.1, 126.1, 123.4, 122.6, 121.2, 119.9, 119.0, 116.2, 110.4, 109.0, 103.4, 37.8 ppm; ESI-HRMS: calcd for $C_{20}H_{17}NO + H^+$ 288.1383, found 288.1385.



Procedure C: Compound **S4** (1 mmol) was dissolved with dry DMF (5 mL), NaH (36 mg, 1.5 mmol) was added at 0°C, then *n*Pr-Br (184.5 mg, 1.5 mmol) or BnBr (256.5mg, 1.5 mmol) was added slowly during 5 minutes. After that, the reaction mixture was removed to room temperature and stirred for 1 h. After completion (monitored by TLC), the reaction was quenched slowly by the addition of ice water, and extracted with ethyl acetate (3 × 10 mL). The organic layers were combined and dried over anhydrous Na_2SO_4, the solvents were evaporated under the reduced pressure. The residue was purified by chromatography on silica gel by using a 10/1 mixture of petroleum ether/ethyl acetate to provide the pure 2-arylindoles **S5**. Compound **S5** (1 mmol) was dissolved in dry DCM (5mL), and BBr_3 (1.5 mmol) was added, the reaction was stirred at room temperature, after the reaction was completed, the solvent was concentrated under reduced pressure, and the residue was purified by column chromatography to give the target compound **1**.

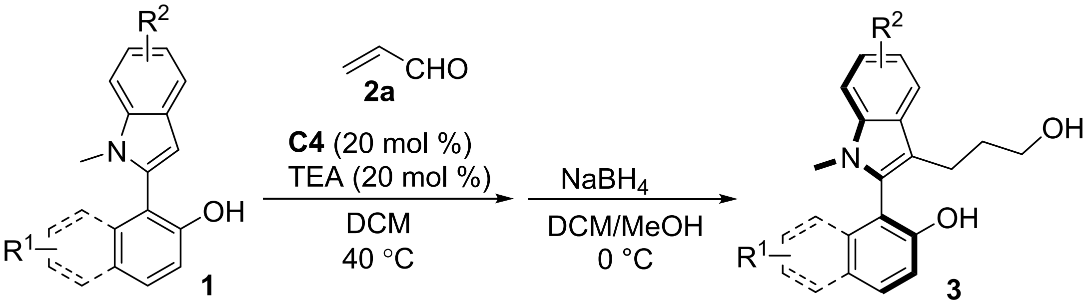


1-(1-propyl-1H-indol-2-yl)naphthalen-2-ol (1t): ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.79 (d, *J* = 8.9 Hz, 1H), 7.76–7.71 (m, 1H), 7.67–7.61 (m, 1H), 7.38 (d, *J* = 8.2 Hz, 1H), 7.31–7.18 (m, 5H), 7.15–7.09 (m, 1H), 6.60 (s, 1H), 3.84 (ddd, *J* = 14.3, 8.2, 6.1 Hz, 1H), 3.59 (ddd, *J* = 14.7, 8.4, 6.9 Hz, 1H), 1.53–1.34 (m, 2H), 0.54 (t, *J* = 7.4 Hz, 3H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$): δ 152.9, 137.9, 134.0, 132.0, 131.3, 128.8, 128.6, 128.3, 127.3, 124.5, 123.8, 122.3, 121.1, 120.1, 117.4, 111.6, 110.4, 104.4, 46.0, 23.3, 11.4 ppm; ESI-HRMS: calcd for $C_{20}H_{17}NO + H^+$ 302.1539, found 302.1540.



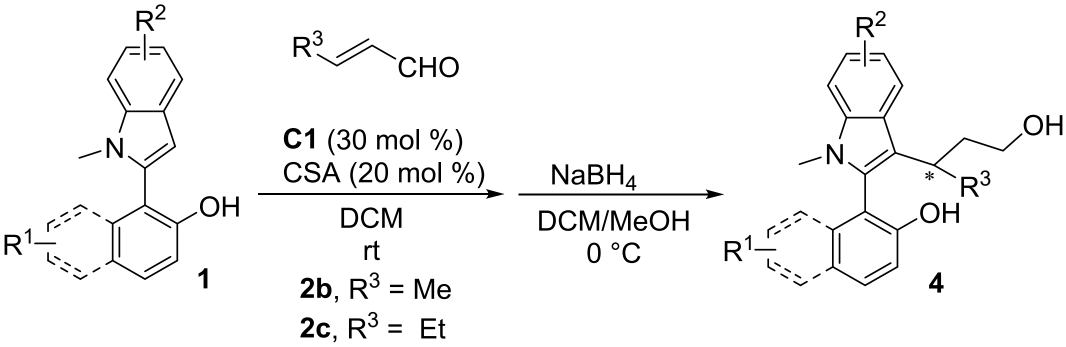
1-(1-benzyl-1H-indol-2-yl)naphthalen-2-ol (1u): ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.88–7.79 (m, 2H), 7.74 (dt, *J* = 7.7, 1.1 Hz, 1H), 7.41 (dd, *J* = 8.1, 1.0 Hz, 1H), 7.37–7.31 (m, 3H), 7.27 (ddd, *J* = 8.3, 7.1, 1.4 Hz, 1H), 7.24–7.19 (m, 2H), 7.13–7.06 (m, 3H), 6.81–6.73 (m, 3H), 5.71 (s, 1H), 5.13 (d, *J* = 16.0 Hz, 1H), 4.91 (d, *J* = 16.0 Hz, 1H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$): δ 153.1, 138.2, 137.3, 133.9, 132.3, 131.4, 128.8, 128.6, 128.3, 127.5, 127.4, 126.9, 124.4, 123.8, 122.7, 121.1, 120.4, 117.4, 111.3, 110.9, 105.1, 48.0 ppm; ESI-HRMS: calcd for $C_{20}H_{17}NO + H^+$ 350.1539, found 350.1541.

4. General procedure for the atroposelective FC alkylation with acrolein

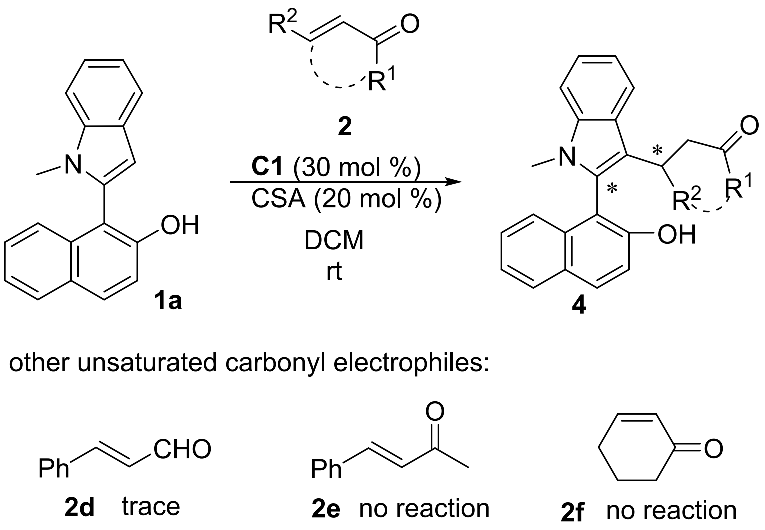


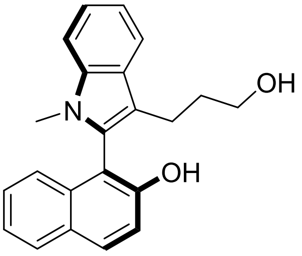
In a 10 mL sealed tube, compound **1a** (0.1 mmol), acrolein **2a** (8.4 mg, 0.15 mmol), **C4** (7.3 mg, 0.02 mmol) and Et_3N (2.05 mg, 0.02 mmol) were dissolved in DCM (2.0 mL), the mixture was stirred at 40 °C for about 30 h to reach the full conversion and monitored by TLC. After that, MeOH (0.5 mL) was added into the reaction mixture, then $NaBH_4$ (7.6 mg, 0.2 mmol) was added slowly at 0 °C for 30 min. Work up: the reaction mixture was quenched by addition of ice water (2 mL), subsequently extracted with EtOAc (3 x 20 mL) and dried with anhydrous Na_2SO_4, filtered and combined organic phase was concentrated in vacuo; The residue was purified by column chromatography (EtOAc/petroleum ether, 1/6) to afford the pure axially chiral product **3**.

5. General procedure for the atroposelective FC alkylation with 2b, 2c and attempts with other unsaturated carbonyl electrophiles



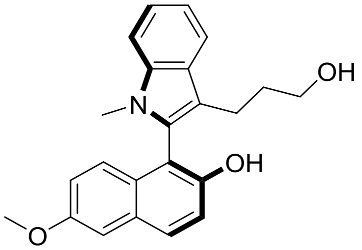
In a 10 mL flask, compound **1a** (0.1 mmol), crotonaldehyde **2b** (10.5 mg, 0.15 mmol) or trans-2-Pentenal **2c** (12.6 mg, 0.15 mmol), **C1** (7.4 mg, 0.03 mmol) and CSA (4.6 mg, 0.02 mmol) were dissolved in anhydrous DCM (2.0 mL). The reaction mixture was stirred at ambient and monitored by TLC. After completion, MeOH (0.5 mL) was added into the reaction mixture, and $NaBH_4$ (7.6 mg, 0.2 mmol) was added slowly at 0 °C for 30 min. Work up: the reaction mixture was quenched by addition of ice water (2 mL), subsequently extracted with EtOAc (3 x 20 mL) and dried over anhydrous Na_2SO_4; Combined extracts were concentrated in vacuo to give the residue, which was purified by column chromatography (EtOAc/petroleum ether, 1/6) to afford the pure axially and centrally chiral product **4**. Except for **4d**, other product (**4a, 4b, 4c**) could be isolated as a single diastereo-isomer via the column chromatography.



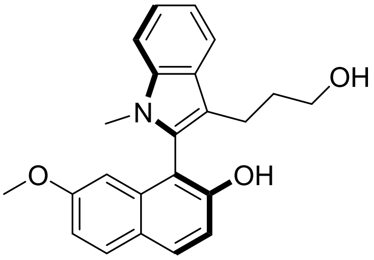


1-(3-(3-hydroxypropyl)-1-methyl-1H-indol-2-yl)naphthalen-2-ol (3a): 1-(1-methyl-1H-indol-2-yl)naphthalen-2-ol **1a** (27.3 mg, 0.1 mmol), acrolein **2a** (8.4 mg, 0.15 mmol), **C4** (7.3 mg, 0.02 mmol) and Et_3N (4.1 mg, 0.04 mmol) were dissolved in DCM (2.0 mL), the mixture was stirred at 40 °C for about 30 h. After the reaction was completed, MeOH (0.5 mL) was added into the reaction mixture, then $NaBH_4$ (7.6 mg, 0.2 mmol) was added slowly at 0 °C for 30 min. Upon workup, product **3a** was obtained as a white solid (21.8 mg, 66% yield). Mp = 76–78 °C; $[\alpha]_D^{20}$ = -11.3 (*c* = 1.0 in $CHCl_3$); 95:5 er, determined by HPLC analysis [Daicel chiralpak IB N-5, *n*-hexane/*i*-PrOH = 80/20, 1.0 mL/min, λ = 254 nm, t (minor) = 17.78 min, t (major) = 5.43 min]; ^1H NMR (400 MHz, DMSO-d_6): δ 9.79 (s, 1H), 7.92 (d, J = 8.9 Hz, 1H), 7.87 (d, J = 7.7 Hz, 1H), 7.62 (d, J = 7.8 Hz, 1H), 7.44 (d, J = 8.1 Hz, 1H), 7.36–7.27 (m, 3H), 7.21–7.04 (m, 3H), 4.23 (s, 1H), 3.34 (s, 3H), 3.23 (brs, 2H), 2.63–2.50 (m, 1H), 2.40–2.30 (m, 1H), 1.61–1.52 (m, 2H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$): δ 153.1, 138.1, 134.2, 131.3, 129.4, 128.8, 128.3, 127.5, 127.2, 124.1, 123.6, 122.2, 119.3, 119.3, 117.6, 115.9, 110.4, 109.7, 62.7, 32.7, 30.2, 21.4 ppm; ESI-HRMS:

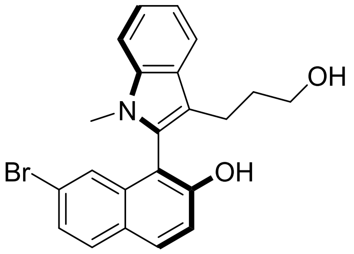
calcd for $C_{22}H_{21}NO_2 + Na^+$ 354.1465, found 354.1469.



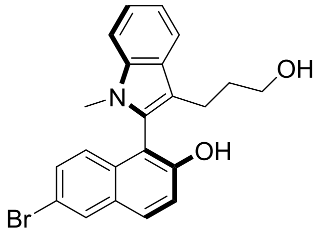
1-(3-(3-hydroxypropyl)-1-methyl-1H-indol-2-yl)-6-methoxynaphthalen-2-ol (3b): 6-methoxy-1-(1-methyl-1H-indol-2-yl)naphthalen-2-ol **1b** (30.3 mg, 0.1 mmol), acrolein **2a** (8.4 mg, 0.15 mmol), **C4** (7.3 mg, 0.02 mmol) and Et_3N (4.1 mg, 0.04 mmol) were dissolved in DCM (2.0 mL), the mixture was stirred at 40 °C for about 30 h. After the reaction was completed, MeOH (0.5 mL) was added into the reaction mixture, then $NaBH_4$ (7.6 mg, 0.2 mmol) was added slowly at 0 °C for 30 min. Upon workup, product **3b** was obtained as a milky white solid (20.2 mg, 56% yield). Mp = 72–74 °C; $[\alpha]_D^{20}$ = +7.0 (*c* = 1.0 in $CHCl_3$); 94:6 er, determined by HPLC analysis [Daicel chiralpak IB N-5, *n*-hexane/*i*-PrOH = 80/20, 1.0 mL/min, λ = 254 nm, t (minor) = 20.56 min, t (major) = 6.16 min]; ^1H NMR (400 MHz, $CDCl_3$): δ 7.77 (d, *J* = 8.9 Hz, 1H), 7.71 (d, *J* = 7.9 Hz, 1H), 7.37 (d, *J* = 8.2 Hz, 1H), 7.32–7.27 (m, 1H), 7.23 (d, *J* = 5.9 Hz, 1H), 7.20–7.09 (m, 3H), 7.00 (dd, *J* = 9.1, 2.6 Hz, 1H), 3.88 (s, 3H), 3.59–3.39 (m, 2H), 3.34 (s, 3H), 2.68 (td, *J* = 7.2, 2.7 Hz, 2H), 1.88–1.65 (m, 2H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$): δ 156.1, 151.5, 138.1, 129.9, 129.7, 129.5, 129.4, 127.5, 125.7, 122.2, 119.6, 119.3, 119.2, 118.0, 115.8, 110.7, 109.7, 106.7 , 62.7, 55.3, 32.7, 30.2, 21.3 ppm; ESI-HRMS: calcd for $C_{23}H_{23}NO_3 + H^+$ 362.1751, found 362.1747.



1-(3-(3-hydroxypropyl)-1-methyl-1H-indol-2-yl)-7-methoxynaphthalen-2-ol (3c): 7-methoxy-1-(1-methyl-1H-indol-2-yl)naphthalen-2-ol **1c** (30.3 mg, 0.1 mmol), acrolein **2a** (8.4 mg, 0.15 mmol), **C4** (7.3 mg, 0.02 mmol) and Et_3N (4.1 mg, 0.04 mmol) were dissolved in DCM (2.0 mL), the mixture was stirred at 40 °C for about 30 h. After the reaction was completed, MeOH (0.5 mL) was added into the reaction mixture, then $NaBH_4$ (7.6 mg, 0.2 mmol) was added slowly at 0 °C for 30 min. Upon workup, product **3c** was obtained as a white solid (21.3 mg, 59% yield). Mp = 74–76 °C; $[\alpha]_D^{20}$ = -2.0 (*c* = 1.0 in $CHCl_3$); 93:7 er, determined by HPLC analysis [Daicel chiralpak IB N-5, *n*-hexane/*i*-PrOH = 80/20, 1.0 mL/min, λ = 254 nm, t (minor) = 20.95 min, t (major) = 5.98 min]; ^1H NMR (400 MHz, $CDCl_3$): δ 7.82 (d, *J* = 8.8 Hz, 1H), 7.78–7.72 (m, 2H), 7.43 (d, *J* = 8.2 Hz, 1H), 7.37–7.31 (m, 1H), 7.25–7.20 (m, 1H), 7.15 (d, *J* = 8.8 Hz, 1H), 7.03 (dd, *J* = 8.9, 2.5 Hz, 1H), 6.56 (d, *J* = 2.4 Hz, 1H), 3.66 (s, 3H), 3.58–3.45 (m, 2H), 3.41 (s, 3H), 2.73 (t, *J* = 7.3 Hz, 2H), 1.90–1.74 (m, 2H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$): δ 159.1, 153.7, 138.2, 135.7, 131.1, 129.9, 129.5, 127.7, 124.2, 122.2, 119.3, 119.3, 115.8, 115.7, 114.9, 109.8, 109.7, 103.2, 62.7, 55.4, 32.9, 30.2, 21.3 ppm; ESI-HRMS: calcd for $C_{23}H_{23}NO_3 + H^+$ 362.1751, found 362.1747.

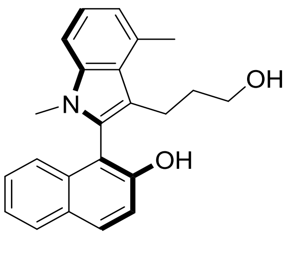


7-bromo-1-(3-(3-hydroxypropyl)-1-methyl-1H-indol-2-yl)naphthalen-2-ol (3d): 7-bromo-1-(1-methyl-1H-indol-2-yl)naphthalen-2-ol **1d** (35.2 mg, 0.1 mmol), acrolein **2a** (8.4 mg, 0.15 mmol), **C4** (7.3 mg, 0.02 mmol) and Et_3N (4.1 mg, 0.04 mmol) were dissolved in DCM (2.0 mL), the mixture was stirred at 40 °C for about 30 h. After the reaction was completed, MeOH (0.5 mL) was added into the reaction mixture, then $NaBH_4$ (7.6 mg, 0.2 mmol) was added slowly at 0 °C for 30 min. Upon workup, product **3d** was obtained as a white solid (22.5 mg, 55% yield). Mp = 91–92 °C; $[\alpha]_D^{20}$ = +2.6 (*c* = 1.0 in $CHCl_3$); 87:13 er, determined by HPLC analysis [Daicel chiralpak IB N-5, *n*-hexane/*i*-PrOH = 80/20, 1.0 mL/min, λ = 254 nm, t (minor) = 20.61 min, t (major) = 5.53 min]; ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.87 (d, *J* = 8.9 Hz, 1H), 7.77 (d, *J* = 7.9 Hz, 1H), 7.71 (d, *J* = 8.6 Hz, 1H), 7.46–7.41 (m, 2H), 7.40–7.29 (m, 3H), 7.26–7.21 (m, 1H), 6.26 (s, 1H), 3.63–3.47 (m, 2H), 3.38 (s, 3H), 2.81–2.61 (m, 2H), 1.95–1.71 (m, 2H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$): δ 154.1, 138.2, 135.6, 131.2, 129.9, 128.5, 127.5, 127.2, 127.1, 126.2, 122.5, 121.9, 119.5, 119.4, 118.2, 116.3, 110.0, 109.8, 62.9, 32.7, 30.2, 21.5 ppm; ESI-HRMS: calcd for $C_{22}H_{20}B_rNO_2 + H^+$ 410.0750, found 410.0753.

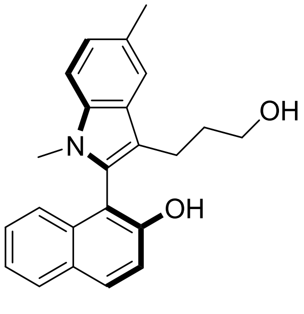


6-bromo-1-(3-(3-hydroxypropyl)-1-methyl-1H-indol-2-yl)naphthalen-2-ol (3e): 6-bromo-1-(1-methyl-1H-indol-2-yl)naphthalen-2-ol **1e** (35.2 mg, 0.1 mmol), acrolein **2a** (8.4 mg, 0.15 mmol), **C4** (7.3 mg, 0.02 mmol) and Et_3N (4.1 mg, 0.04 mmol) were dissolved in DCM (2.0 mL), the mixture was stirred at 40 °C for about 30 h. After the reaction was completed, MeOH (0.5 mL) was added into the reaction mixture, then $NaBH_4$ (7.6 mg, 0.2 mmol) was added slowly at 0 °C for 30 min. Upon workup, product **3e** was obtained as a white solid (20.9 mg, 51% yield). Mp = 70–72 °C; $[\alpha]_D^{20}$ = +7.0 (*c* = 1.0 in $CHCl_3$); 91:9 er, determined by HPLC analysis [Daicel chiralpak IB N-5, *n*-hexane/*i*-PrOH = 80/20, 1.0 mL/min, λ = 254 nm, t (minor) = 16.03 min, t (major) = 5.31 min]; ^{1}H NMR (400 MHz, $CDCl_3$): 8.24 (d, *J* = 8.3 Hz, 1H), 7.75 (d, *J*

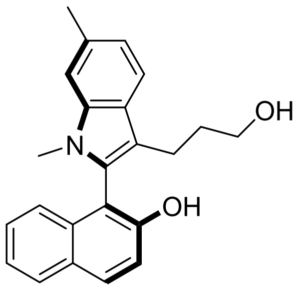
= 7.9 Hz, 1H), 7.68 (s, 1H), 7.49–7.30 (m, 4H), 7.25–7.19 (m, 2H), 3.64–3.43 (m, 2H), 3.38 (s, 3H), 2.80–2.61 (m, 2H), 1.94–1.69 (m, 2H) ppm;^{13}C NMR (100 MHz, CDCl$_3$): δ 153.0, 138.2, 135.0, 128.6, 128.0, 127.6, 127.5, 127.4, 125.4, 125.0, 124.6, 122.5, 122.1, 119.5, 119.4, 116.3, 110.9, 109.8, 63.0, 32.6, 30.2, 21.6 ppm ppm; ESI-HRMS: calcd for $C_{22}H_{20}B_rNO_2$ + H^+ 410.0750, found 410.0753.



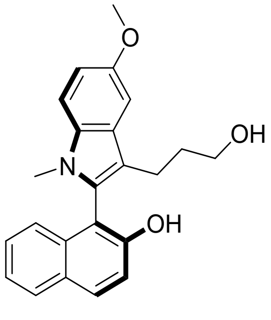
1-(3-(3-hydroxypropyl)-1,4-dimethyl-1H-indol-2-yl)naphthalen-2-ol (3f): 1-(1,4-dimethyl-1H-indol-2-yl)naphthalen-2-ol **1f** (28.7 mg, 0.1 mmol), acrolein **2a** (8.4 mg, 0.15 mmol), **C4** (7.3 mg, 0.02 mmol) and Et$_3$N (4.1 mg, 0.04 mmol) were dissolved in DCM (2.0 mL), the mixture was stirred at 40 °C for about 30 h. After the reaction was completed, MeOH (0.5 mL) was added into the reaction mixture, then NaBH$_4$ (7.6 mg, 0.2 mmol) was added slowly at 0 °C for 30 min. Upon workup, product **3f** was obtained as a white solid (18.3 mg, 53% yield). Mp = 71–76 °C; $[\alpha]_D^{20}$ = +1.0 (*c* = 1.0 in CHCl$_3$); 97:3 er, determined by HPLC analysis [Daicel chiralpak IB N-5, *n*-hexane/*i*-PrOH = 80/20, 1.0 mL/min, λ = 254 nm, t (minor) = 9.96 min, t (major) = 4.93 min]; ^{1}H NMR (400 MHz, CDCl$_3$): δ 7.81 (d, *J* = 8.9 Hz, 1H), 7.78–7.72 (m, 1H), 7.29–7.26 (m, 2H), 7.22 (d, *J* = 8.9 Hz, 1H), 7.19–7.15 (m, 2H), 7.14–7.09 (m, 1H), 6.88 (d, *J* = 6.8 Hz, 1H), 5.89 (s, 1H), 3.39 – 3.27 (m, 2H), 3.26 (s, 3H), 2.73–2.59 (m, 5H), 1.74–1.49 (m, 2H) ppm; ^{13}C NMR (100 MHz, CDCl$_3$): δ 153.0, 138.5, 134.2, 131.3, 131.0, 129.4, 128.8, 128.3, 127.2, 126.0, 124.2, 123.6, 122.2, 121.3, 117.5, 116.7, 110.5, 107.5, 62.5, 35.3, 30.3, 22.6, 20.2 ppm; ESI-HRMS: calcd for $C_{23}H_{23}NO_2$ + H^+ 346.1802, found 346.1798.



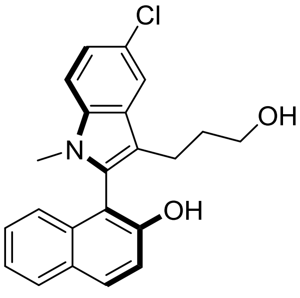
1-(3-(3-hydroxypropyl)-1,5-dimethyl-1H-indol-2-yl)naphthalen-2-ol (3g): 1-(1,5-dimethyl-1H-indol-2-yl)naphthalen-2-ol **1g** (28.7 mg, 0.1 mmol), acrolein **2a** (8.4 mg, 0.15 mmol), **C4** (7.3 mg, 0.02 mmol) and Et$_3$N (4.1 mg, 0.04 mmol) were dissolved in DCM (2.0 mL), the mixture was stirred at 40 °C for about 30 h. After the reaction was completed, MeOH (0.5 mL) was added into the reaction mixture, then NaBH$_4$ (7.6 mg, 0.2 mmol) was added slowly at 0 °C for 30 min. Upon workup, product **3g** was obtained as a milky white solid (18.9 mg, 55% yield). Mp = 78–79 °C; $[\alpha]_D^{20}$ = -4.0 (*c* = 1.0 in CHCl$_3$); 94:6 er, determined by HPLC analysis [Daicel chiralpak IB N-5, *n*-hexane/*i*-PrOH = 80/20, 1.0 mL/min, λ = 254 nm, t (minor) = 11.12 min, t (major) = 5.01 min]; ^{1}H NMR (400 MHz, CDCl$_3$): δ 7.90 (d, *J* = 8.9 Hz, 1H), 7.87–7.82 (m, 1H), 7.54 (s, 1H), 7.38–7.33 (m, 2H), 7.31 (d, *J* = 8.8 Hz, 2H), 7.25–7.21 (m, 1H), 7.17 (dd, *J* = 8.4, 1.1 Hz, 1H), 3.59–3.44 (m, 2H), 3.35 (s, 3H), 2.69 (t, *J* = 7.3 Hz, 2H), 2.54 (s, 3H), 1.91–1.70 (m, 2H) ppm; ^{13}C NMR (100 MHz, CDCl$_3$): δ 153.1, 136.6, 134.3, 131.2, 129.4, 128.8, 128.7, 128.2, 127.7, 127.2, 124.2, 123.9, 123.6, 118.9, 117.6, 115.4, 110.6, 109.4, 62.8, 32.8, 30.2, 21.5, 21.4 ppm; ESI-HRMS: calcd for $C_{23}H_{23}NO_2 + H^+$ 346.1802, found 346.1798.



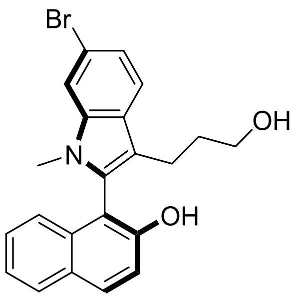
1-(3-(3-hydroxypropyl)-1,6-dimethyl-1H-indol-2-yl)naphthalen-2-ol (3h): 1-(1,6-dimethyl-1H-indol-2-yl)naphthalen-2-ol **1h** (28.7 mg, 0.1 mmol), acrolein **2a** (8.4 mg, 0.15 mmol), **C4** (7.3 mg, 0.02 mmol) and Et$_3$N (4.1 mg, 0.04 mmol) were dissolved in DCM (2.0 mL), the mixture was stirred at 40 °C for about 30 h. After the reaction was completed, MeOH (0.5 mL) was added into the reaction mixture, then NaBH$_4$ (7.6 mg, 0.2 mmol) was added slowly at 0 °C for 30 min. Upon workup, product **3h** was obtained as a milky white solid (17.3 mg, 50% yield). Mp = 72–74 °C; $[\alpha]_D^{20}$ =-15.4 (*c* = 1.0, CHCl$_3$); 91:9 er, determined by HPLC analysis [Daicel chiralpak IB N-5, *n*-hexane/*i*-PrOH = 80/20, 1.0 mL/min, λ = 254 nm, t (minor) = 6.49 min, t (major) = 5.12 min]; ^{1}H NMR (400 MHz, CDCl$_3$): δ 7.82 (d, *J* = 8.9 Hz, 1H), 7.78–7.74 (m, 1H), 7.56 (d, *J* = 8.1 Hz, 1H), 7.30–7.21 (m, 3H), 7.17–7.12 (m, 2H), 6.98 (dd, *J* = 8.1, 0.8 Hz, 1H), 3.50–3.35 (m, 2H), 3.26 (s, 3H), 2.61 (t, *J* = 7.3 Hz, 2H), 2.49 (s, 3H), 1.83–1.63 (m, 2H) ppm; ^{13}C NMR (100 MHz, CDCl$_3$): δ 153.1, 138.6, 134.3, 132.3, 131.2, 128.8, 128.6, 128.2, 127.2, 125.4, 124.2, 123.6, 121.1, 119.0, 117.6, 115.8, 110.6, 109.7, 62.7, 32.8, 30.1, 21.9, 21.4 ppm; ESI-HRMS: calcd for $C_{23}H_{23}NO_2 + H^+$ 346.1802, found 346.1798.



1-(3-(3-hydroxypropyl)-5-methoxy-1-methyl-1H-indol-2-yl)naphthalen-2-ol (3i): 1-(5-methoxy-1-methyl-1H-indol-2-yl)naphthalen-2-ol **1i** (30.3 mg, 0.1 mmol), acrolein **2a** (8.4 mg, 0.15 mmol), **C4** (7.3 mg, 0.02 mmol) and Et$_3$N (4.1 mg, 0.04 mmol) were dissolved in DCM (2.0 mL), the mixture was stirred at 40 °C for about 30 h. After the reaction was completed, MeOH (0.5 mL) was added into the reaction mixture, then NaBH$_4$ (7.6 mg, 0.2 mmol) was added slowly at 0 °C for 30 min. Upon workup, product **3i** was obtained as a white solid (20.9 mg, 58% yield). Mp = 71–72 °C; $[\alpha]_D^{20}$ = +12.368 (*c* = 1.0 in CHCl$_3$); 80:20 er, determined by HPLC analysis [Daicel chiralpak IB N-5, *n*-hexane/*i*-PrOH = 80/20, 1.0 mL/min, λ = 254 nm, t (minor) = 12.04 min, t (major) = 6.29 min]; ^{1}H NMR (400 MHz, CDCl$_3$): 7.90 (d, *J* = 8.9 Hz, 1H), 7.87–7.82 (m, 1H), 7.39–7.33 (m, 2H), 7.31 (d, J = 8.9 Hz, 2H), 7.25–7.21 (m, 1H), 7.19 (d, J = 2.4 Hz, 1H), 7.00 (dd, J = 8.8, 2.4 Hz, 1H), 3.93 (s, 3H), 3.57–3.43 (m, 2H), 3.35 (s, 3H), 2.68 (td, J = 7.2, 1.7 Hz, 2H), 1.88–1.70 (m, 2H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$): δ 154.1, 153.1, 134.2, 133.5, 131.2, 130.0, 128.8, 128.2, 127.8, 127.2, 124.1, 123.6, 117.6, 115.3, 112.3, 110.6, 110.4, 101.2, 62.7, 56.1, 32.6, 30.3, 21.3 ppm; ESI-HRMS: calcd for $C_{23}H_{23}NO_3 + H^+$ 362.1751, found 362.1747.

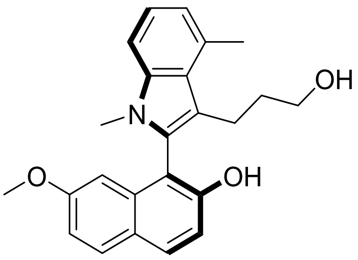


1-(5-chloro-3-(3-hydroxypropyl)-1-methyl-1H-indol-2-yl)naphthalen-2-ol (3j): 1-(5-methoxy-1-methyl-1H-indol-2-yl)naphthalen-2-ol **1j** (30.7 mg, 0.1 mmol), acrolein **2a** (8.4 mg, 0.15 mmol), **C4** (7.3 mg, 0.02 mmol) and Et_3N (4.1 mg, 0.04 mmol) were dissolved in DCM (2.0 mL), the mixture was stirred at 40 °C for about 30 h. After the reaction was completed, MeOH (0.5 mL) was added into the reaction mixture, then $NaBH_4$ (7.6 mg, 0.2 mmol) was added slowly at 0 °C for 30 min. Upon workup, product **3j** was obtained as a milky white solid (18.9 mg, 52% yield). Mp = 85–87 °C; $[\alpha]_D^{20}$ = -3.50 (c = 1.0 in $CHCl_3$); 93.5:6.5 er, determined by HPLC analysis [Daicel chiralpak IB N-5, n-hexane/i-PrOH = 80/20, 1.0 mL/min, λ = 254 nm, t (minor) = 7.17 min, t (major) = 5.35 min]; ^{1}H NMR (400 MHz, DMSO-d_6): δ 9.87 (s, 1H), 7.94 (d, J = 8.9 Hz, 1H), 7.90–7.85 (m, 1H), 7.64 (d, J = 1.9 Hz, 1H), 7.49 (d, J = 8.7 Hz, 1H), 7.37–7.27 (m, 3H), 7.16 (dd, J = 8.6, 2.0 Hz, 1H), 7.08 (d, J = 7.7 Hz, 1H), 4.24 (t, J = 5.2 Hz, 1H), 3.33 (s, 3H), 3.25 – 3.16 (m, 2H), 2.48–2.42 (m, 1H), 2.36–2.25 (m, 1H), 1.57–1.46 (m, 2H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$): δ 153.2, 138.9, 134.1, 131.5, 130.2, 128.8, 128.3, 127.4, 126.4, 123.9, 123.8, 122.6, 120.5, 117.8, 116.2, 116.0, 112.7, 110.0, 62.7, 32.6, 30.3, 21.4 ppm; ESI-HRMS: calcd for $C_{22}H_{20}ClNO_2 + H^+$ 366.1255, found 366.1250.

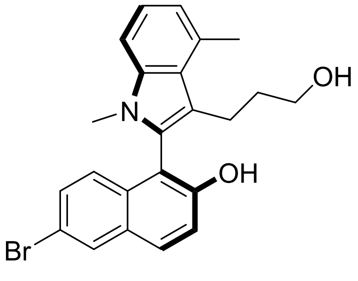


1-(6-bromo-3-(3-hydroxypropyl)-1-methyl-1H-indol-2-yl)naphthalen-2-ol (3k): 1-(6-bromo-1-methyl-1H-indol-2-yl)naphthalen-2-ol **1k** (35.2 mg, 0.1 mmol), acrolein **2a** (8.4 mg, 0.15 mmol), **C4** (7.3 mg, 0.02 mmol) and Et_3N (4.1 mg, 0.04 mmol) were dissolved in DCM (2.0 mL), the mixture was stirred at 40 °C for about 30 h. After the reaction was completed, MeOH (0.5 mL) was added into the reaction mixture, then $NaBH_4$ (7.6 mg, 0.2 mmol) was added slowly at 0 °C for 30 min. Upon workup, product **3k** was obtained as a white solid (20.9 mg, 51% yield). Mp = 83–85 °C; $[\alpha]_D^{20}$ = -21.6 (c = 1.0 in $CHCl_3$);

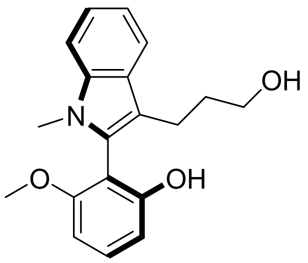
95:5 er, determined by HPLC analysis [Daicel chiralpak IB N-5, *n*-hexane/*i*-PrOH = 80/20, 1.0 mL/min, λ = 254 nm, t (minor) = 7.18 min, t (major) = 5.97 min]; ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.91 (d, *J* = 8.9 Hz, 1H), 7.88–7.83 (m, 1H), 7.60 (d, *J* = 8.4 Hz, 1H), 7.57 (d, *J* = 1.5 Hz, 1H), 7.39–7.34 (m, 2H), 7.32–7.28 (m, 2H), 7.19–7.14 (m, 1H), 6.16 (s, 1H), 3.58–3.45 (m, 2H), 3.33 (s, 3H), 2.77–2.60 (m, 2H), 1.88–1.70 (m, 2H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$): δ 153.2, 138.9, 134.1, 131.5, 130.2, 128.8, 128.3, 127.4, 126.4, 123.9, 123.7, 122.6, 120.5, 117.8, 116.2, 115.9, 112.7, 110.0, 62.7, 32.6, 30.3, 21.4 ppm; ESI-HRMS: calcd for $C_{22}H_{21}B_rNO_2 + H^+$ 410.0750, found 410.0745.



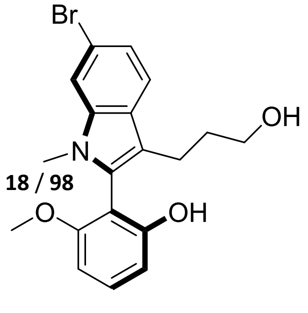
1-(3-(3-hydroxypropyl)-1,4-dimethyl-1H-indol-2-yl)-7-methoxynaphthalen-2-ol (3l): 1-(1,4-dimethyl-1H-indol-2-yl)-7-methoxynaphthalen-2-ol **1l** (31.7 mg, 0.1 mmol), acrolein **2a** (8.4 mg, 0.15 mmol), **C4** (7.3 mg, 0.02 mmol) and Et_3N (4.1 mg, 0.04 mmol) were dissolved in DCM (2.0 mL), the mixture was stirred at 40 °C for about 30 h. After the reaction was completed, MeOH (0.5 mL) was added into the reaction mixture, then $NaBH_4$ (7.6 mg, 0.2 mmol) was added slowly at 0 °C for 30 min. Upon workup, product **3l** was obtained as a white solid (19.9 mg, 53% yield). Mp = 78–79 °C; $[\alpha]_D^{20}$ = +21.250 (*c* = 1.0 in $CHCl_3$); 94:6 er, determined by HPLC analysis [Daicel chiralpak IB N-5, *n*-hexane/*i*-PrOH = 80/20, 1.0 mL/min, λ = 254 nm, t (minor) = 10.04 min, t (major) = 5.46 min]; ^{1}H NMR (400 MHz, DMSO-d_6): δ 9.69 (s, 1H), 7.86–7.76 (m, 2H), 7.25 (d, *J* = 8.1 Hz, 1H), 7.15 (d, *J* = 8.8 Hz, 1H), 7.05–6.95 (m, 2H), 6.80 (d, *J* = 7.1 Hz, 1H), 6.47 (d, *J* = 2.4 Hz, 1H), 3.56 (s, 3H), 3.30 (s, 3H), 3.24–3.10 (m, 2H), 2.69 (s, 3H), 2.66–2.56 (m, 1H), 2.47–2.37 (m, 1H), 1.60–1.45 (m, 2H) ppm; ^{13}C NMR (100 MHz, DMSO-d_6): δ 158.1, 155.2, 137.3, 136.0, 132.2, 130.2, 129.8, 129.4, 125.9, 123.2, 120.5, 120.2, 115.7, 114.4, 114.2, 109.9, 107.5, 103.1, 60.7, 54.9, 36.0, 29.8, 22.7, 19.9 ppm; ESI-HRMS: calcd for $C_{24}H_{25}NO_3 + H^+$ 375.1834, found 375.1832.



6-bromo-1-(3-(3-hydroxypropyl)-1,4-dimethyl-1H-indol-2-yl)naphthalen-2-ol (3m): 6-bromo-1-(1,4-dimethyl-1H-indol-2-yl)naphthalen-2-ol **1m** (36.6 mg, 0.1 mmol), acrolein **2a** (8.4 mg, 0.15 mmol), **C4** (7.3 mg, 0.02 mmol) and Et_3N (4.1 mg, 0.04 mmol) were dissolved in DCM (2.0 mL), the mixture was stirred at 40 °C for about 30 h. After the reaction was completed, MeOH (0.5 mL) was added into the reaction mixture, then $NaBH_4$ (7.6 mg, 0.2 mmol) was added slowly at 0 °C for 30 min. Upon workup, product **3m** was obtained as a white solid (22.1 mg, 52% yield). Mp = 98–100 °C; $[\alpha]_D^{20}$ = +19.375 (*c* = 1.0 in $CHCl_3$); 88:12 er, determined by HPLC analysis [Daicel chiralpak IB N-5, *n*-hexane/*i*-PrOH = 80/20, 1.0 mL/min, λ = 254 nm, t (minor) = 7.61 min, t (major) = 5.18 min]; ^1H NMR (400 MHz, DMSO-d_6): δ 9.99 (s, 1H), 8.15 (d, *J* = 2.0 Hz, 1H), 7.93 (d, *J* = 9.0 Hz, 1H), 7.44 (dd, *J* = 9.0, 2.1 Hz, 1H), 7.38 (d, *J* = 9.0 Hz, 1H), 7.26 (d, *J* = 8.2 Hz, 1H), 7.09–7.00 (m, 2H), 6.81 (d, *J* = 7.1 Hz, 1H), 3.28 (s, 3H), 3.24–3.10 (m, 2H), 2.68 (s, 3H), 2.65–2.58 (m, 1H), 2.41–2.31 (m, 1H), 1.60–1.41 (m, 2H) ppm; ^{13}C NMR (100 MHz, DMSO-d_6): δ 155.1, 137.3, 133.2, 131.3, 129.8, 129.7, 129.6, 129.5, 129.0, 126.2, 125.8, 120.7, 120.4, 119.6, 115.7, 114.6, 110.9, 107.5, 60.7, 35.9, 29.9, 22.7, 19.9 ppm; ESI-HRMS: calcd for $C_{23}H_{22}BrNO_2 + H^+$ 424.0907, found 424.0908.

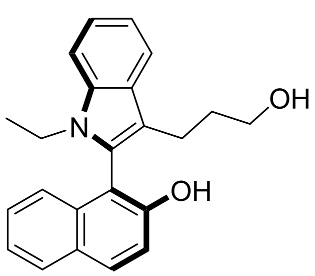


1-(6-bromo-3-(3-hydroxypropyl)-1-methyl-1H-indol-2-yl)naphthalen-2-ol (3n): 3-methoxy-2-(1-methyl-1H-indol-2-yl)phenol **3n** (25.3 mg, 0.1 mmol), acrolein **2a** (8.4 mg, 0.15 mmol), **C4** (7.3 mg, 0.02 mmol) and Et_3N (4.1 mg, 0.04 mmol) were dissolved in DCM (2.0 mL), the mixture was stirred at 40 °C for about 30 h. After the reaction was completed, MeOH (0.5 mL) was added into the reaction mixture, then $NaBH_4$ (7.6 mg, 0.2 mmol) was added slowly at 0 °C for 30 min. Upon workup, product **3n** was obtained as a white solid (17.1 mg, 55% yield). Mp = 78–80 °C; $[\alpha]_D^{20}$ = -5.0 (*c* = 1.0 in $CHCl_3$); 91:9 er, determined by HPLC analysis [Daicel chiralpak IB N-5, *n*-hexane/*i*-PrOH = 80/20, 1.0 mL/min, λ = 254 nm, t (minor) = 14.26 min, t (major) = 6.31 min]; ^1H NMR (400 MHz, $CDCl_3$): δ 7.61 (d, *J* = 7.9 Hz, 1H), 7.27 (dd, *J* = 16.0, 7.9 Hz, 2H), 7.23–7.20 (m, 1H), 7.10–7.02 (m, 1H), 6.64 (d, *J* = 8.3 Hz, 1H), 6.52 (d, *J* = 8.3 Hz, 1H), 3.68 (s, 3H), 3.48–3.40 (m, 2H), 3.39 (d, *J* = 6.3 Hz, 3H), 2.82–2.67 (m, 1H), 2.62–2.49 (m, 1H), 1.83–1.71 (m, 2H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$): δ 157.9, 154.4, 137.0, 130.2, 126.9, 126.4, 121.0, 118.2, 118.0, 113.4, 108.6, 107.4, 105.7, 101.6, 61.2, 54.7, 31.6, 29.0, 20.0 ppm; ESI-HRMS: calcd for $C_{19}H_{21}NO_3 + H^+$ 312.1589, found 312.1586.

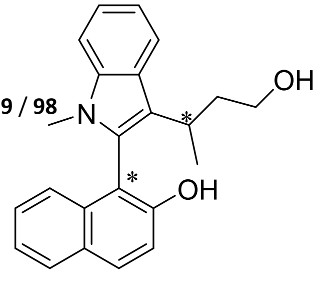


2-(6-bromo-3-(3-hydroxypropyl)-1-methyl-1H-indol-2-yl)-3-methoxyphenol (3o): 2-(6-bromo-1-methyl-1H-indol-2-yl)-3-methoxyphenol **1o** (33.2 mg, 0.1 mmol), acrolein **2a** (8.4 mg, 0.15 mmol),

C4 (7.3 mg, 0.02 mmol) and Et$_3$N (4.1 mg, 0.04 mmol) were dissolved in DCM (2.0 mL), the mixture was stirred at 40 °C for about 30 h. After the reaction was completed, MeOH (0.5 mL) was added into the reaction mixture, then NaBH$_4$ (7.6 mg, 0.2 mmol) was added slowly at 0 ^{o}C for 30 min. Upon workup, product **3o** was obtained as a white solid (20.3 mg, 52% yield). Mp = 96–97 °C; $[\alpha]_D^{20}$ = -16.0 (c = 1.0 in CHCl$_3$); 94:6 er, determined by HPLC analysis [Daicel chiralpak IB N-5, *n*-hexane/*i*-PrOH = 80/20, 1.0 mL/min, λ = 254 nm, t (minor) = 12.23 min, t (major) = 11.08 min]; ^{1}H NMR (400 MHz, CDCl$_3$): δ 7.55 – 7.49 (m, 2H), 7.34 (t, J = 8.3 Hz, 1H), 7.24 (dd, J = 8.4, 1.4 Hz, 1H), 6.70 (d, J = 8.3 Hz, 1H), 6.59 (d, J = 8.3 Hz, 1H), 5.58 (s, 1H), 3.75 (s, 3H), 3.57–3.45 (m, 2H), 3.43 (s, 3H), 2.83–2.73 (m, 1H), 2.68–2.53 (m, 1H), 1.88–1.74 (m, 2H) ppm; ^{13}C NMR (100 MHz, CDCl$_3$): δ 158.4, 155.3, 139.0, 132.1, 131.2, 126.6, 123.0, 121.9, 115.7, 112.7, 108.4, 107.0, 102.6, 102.3, 62.2, 55.7, 32.5, 30.2, 21.0 ppm; ESI-HRMS: calcd for $C_{19}H_{20}BrNO_3 + H^+$ 390.0627, found 390.0694.

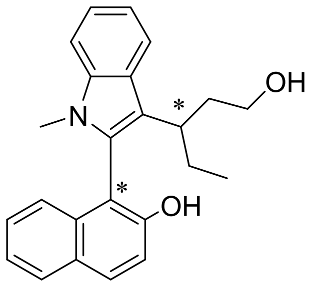


1-(1-ethyl-3-(3-hydroxypropyl)-1H-indol-2-yl)naphthalen-2-ol (3p): 1-(1-ethyl-1H-indol-2-yl)naphthalen-2-ol **1p** (28.7 mg, 0.1 mmol), acrolein **2a** (8.4 mg, 0.15 mmol), **C4** (7.3 mg, 0.02 mmol) and Et$_3$N (4.1 mg, 0.04 mmol) were dissolved in DCM (2.0 mL), the mixture was stirred at 40 °C for about 30 h. After the reaction was completed, MeOH (0.5 mL) was added into the reaction mixture, then NaBH$_4$ (7.6 mg, 0.2 mmol) was added slowly at 0 ^{o}C for 30 min. Upon workup, product **3p** was obtained as a white solid (17.9 mg, 52% yield). Mp = 79–81 °C; $[\alpha]_D^{20}$ = +2.0 (c = 1.0 in CHCl$_3$); 62:38 er, determined by HPLC analysis [Daicel chiralpak AD-H, *n*-hexane/*i*-PrOH = 80/20, 1.0 mL/min, λ = 254 nm, t (minor) = 25.52 min, t (major) = 4.76 min]; ^{1}H NMR (400 MHz, DMSO-d_6): δ9.79 (s, 1H), 7.92 (d, J = 8.8 Hz, 1H), 7.86 (d, J = 7.3 Hz, 1H), 7.62 (d, J = 7.7 Hz, 1H), 7.46 (d, J = 8.1 Hz, 1H), 7.37–7.25 (m, 3H), 7.15 (dd, J = 15.8, 7.6 Hz, 2H), 7.06 (t, J = 7.3 Hz, 1H), 4.23 (brs, 1H), 3.88–3.66 (m, 2H), 3.24 (d, J = 4.5 Hz, 2H), 2.48–2.40 (m, 1H), 2.36–2.25 (m, 1H), 1.62–1.47 (m, 2H), 0.96 (t, J = 6.8 Hz, 3H) ppm; ^{13}C NMR (100 MHz, DMSO-d_6): δ 154.5, 135.8, 134.5, 131.1, 130.4, 128.0, 127.8, 127.7, 126.7, 123.7, 122.8, 120.6, 118.5, 118.3, 118.2, 113.7, 110.6, 109.5, 60.8, 37.9, 33.4, 21.2, 15.2 ppm; ESI-HRMS: calcd for $C_{23}H_{23}NO_2 + H^+$ 346.1802, found 346.1798.

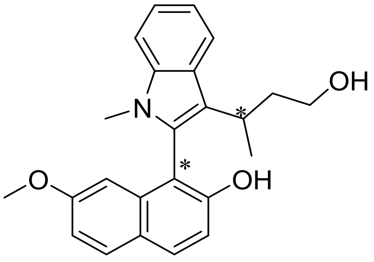


1-(3-(4-hydroxybutan-2-yl)-1-methyl-1H-indol-2-yl)naphthalen-2-ol (4a): 1-(1-methyl-1H-indol-2-yl)naphthalen-2-ol **1a** (27.3 mg, 0.1

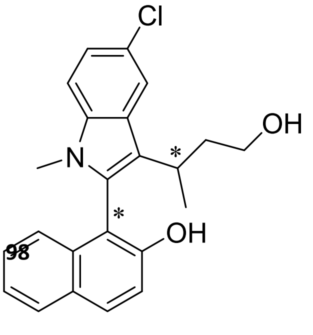
mmol), crotonaldehyde **2b** (10.5 mg, 0.15 mmol), **C1** (4.9 mg, 0.02 mmol) and CSA (4.6 mg, 0.02 mmol) were dissolved in anhydrous DCM (2.0 mL). The reaction mixture was stirred at ambient. After the reaction was completed, MeOH (0.5 mL) was added into the reaction mixture, and NaBH$_4$ (7.6 mg, 0.2 mmol) was added slowly at 0 °C for 30 min. Upon workup, product **4a′** (major) was obtained as a white solid (16 mg, 46% yield), Mp = 83–85 °C; $[\alpha]_D^{20}$ = +16.471 (*c* = 1.0 in CHCl$_3$); 95:5 er, determined by HPLC analysis [Daicel chiralpak AD-H, *n*-hexane/*i*-PrOH = 90/10, 1.0 mL/min, λ = 254 nm, t (minor) = 7.94 min, t (major) = 11.15 min; Product **4a″** (minor) was obtained as a white solid (13.2 mg, 38% yield). 70:30 er, determined by HPLC analysis [Daicel chiralpak AD-H, *n*-hexane/*i*-PrOH = 90/10, 1.0 mL/min, λ = 254 nm, t (minor) = 14.44 min, t (major) = 12.17 min]; ^{1}H NMR (**4a′**, 400 MHz, CDCl$_3$): δ 7.83–7.71 (m, 3H), 7.34 (d, *J* = 8.2 Hz, 1H), 7.29–7.26 (m, 1H), 7.25–7.24 (m, 1H), 7.23–7.18 (m, 2H), 7.11 (d, *J* = 7.0 Hz, 2H), 3.67–3.52 (m, 2H), 3.25 (s, 3H), 2.83–2.74 (m, 1H), 2.29–2.17 (m, 1H), 1.86–1.77 (m, 1H), 1.24 (d, *J* = 7.0 Hz, 3H) ppm; ^{13}C NMR (**4a′**, 100 MHz, CDCl$_3$): δ 153.5, 138.3, 134.9, 131.1, 129.8, 128.8, 128.1, 126.9, 125.8, 124.4, 123.5, 121.7, 120.3, 119.6, 118.9, 118.4, 111.5, 109.9, 62.8, 38.5, 30.1, 29.9, 22.6 ppm; ESI-HRMS: calcd for $C_{23}H_{23}NO_2 + H^+$ 346.1802, found 346.1806.



1-(3-(1-hydroxypentan-3-yl)-1-methyl-1H-indol-2-yl)naphthalen-2-ol (4b): 1-(1-methyl-1H-indol-2-yl)naphthalen-2-ol **1a** (27.4 mg, 0.1 mmol), trans-2-Pentenal **2c** (10.2 mg, 0.12 mmol), **C1** (7.4 mg, 0.03 mmol) and CSA (4.6 mg, 0.02 mmol) were dissolved in anhydrous DCM (2.0 mL). The reaction mixture was stirred at ambient. After the reaction was completed, MeOH (0.5 mL) was added into the reaction mixture, and NaBH$_4$ (7.6 mg, 0.2 mmol) was added slowly at 0 °C for 30 min. Upon workup, product **4b′** (major) was obtained as a white solid (15.0 mg, 42% yield). Mp = 102–106 °C; $[\alpha]_D^{20}$ = -1.250 (*c* = 1.0 in CHCl$_3$); 1:1 dr, 75:25 er, determined by HPLC analysis [Daicel chiralpak AD-H, *n*-hexane/*i*-PrOH = 90/10, 1.0 mL/min, λ = 254 nm, t (minor) = 7.64 min, t (major) = 8.49 min; Product **4b″** (minor) was obtained as a white solid (15.0 mg, 42% yield). 26:73 er, determined by HPLC analysis [Daicel chiralpak AD-H, *n*-hexane/*i*-PrOH = 90/10, 1.0 mL/min, λ = 254 nm, t (minor) = 13.11 min, t (major) = 9.86 min]; ^{1}H NMR (**4b′**, 400 MHz, DMSO-*d$_6$*): δ 9.82 (s, 1H), 7.96–7.83 (m, 2H), 7.68 (d, *J* = 7.9 Hz, 1H), 7.44 (d, *J* = 8.2 Hz, 1H), 7.36–7.25 (m, 3H), 7.19–7.11 (m, 2H), 7.03 (ddd, *J* = 8.0, 7.1, 1.0 Hz, 1H), 4.09 (t, *J* = 5.3 Hz, 1H), 3.29 (s, 3H), 3.22 (ddd, *J* = 19.6, 9.0, 4.8 Hz, 2H), 2.26 (qd, *J* = 8.4, 6.1 Hz, 1H), 1.86 (dtd, *J* = 13.0, 8.7, 5.6 Hz, 1H), 1.73 (dq, *J* = 13.0, 8.0 Hz, 2H), 1.63 (d, *J* = 6.9 Hz, 1H), 0.59 (t, *J* = 7.4 Hz, 3H) ppm; ^{13}C NMR (**4b′**, 100 MHz, DMSO-d_6): δ 159.8, 142.5, 139.8, 137.2, 135.7, 133.2, 132.9, 131.5, 131.5, 129.4, 128.0, 125.6, 124.9, 123.5, 123.3, 121.8, 115.9, 114.9, 65.2, 43.2, 40.9, 34.9, 32.9, 18.3 ppm; ESI-HRMS: calcd for $C_{24}H_{25}NO_2 + Na^+$ 382.1778, found 382.1776.



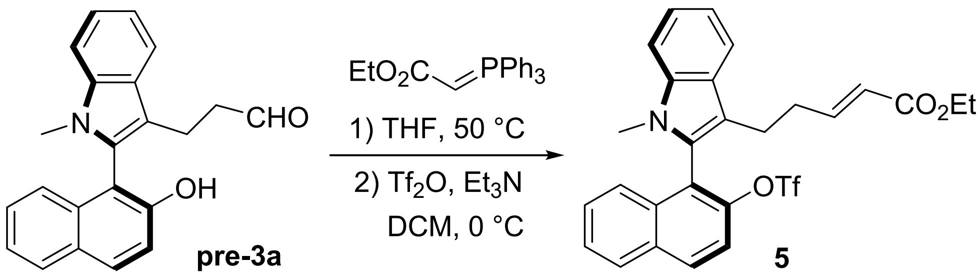
1-(3-(4-hydroxybutan-2-yl)-1-methyl-1H-indol-2-yl)-7-methoxynaphthalen-2-ol (4c): 6-methoxy-1-(1-methyl-1H-indol-2-yl)naphthalen-2-ol **1b** (30.3 mg, 0.1 mmol), crotonaldehyde **2b** (10.5 mg, 0.15 mmol), **C1** (4.9 mg, 0.02 mmol) and CSA (4.6 mg, 0.02 mmol) were dissolved in anhydrous DCM (2.0 mL). The reaction mixture was stirred at ambient. After the reaction was completed, MeOH (0.5 mL) was added into the reaction mixture, and $NaBH_4$ (7.6 mg, 0.2 mmol) was added slowly at 0 °C for 30 min. Upon workup, product **4c′** (major) was obtained as a pale yellow solid (20.4 mg, 56% yield). Mp = 84–86 °C; $[\alpha]_D^{20}$ = -10.625 (*c* = 1.0 in $CHCl_3$); 5:2 dr, 92:8 er, determined by HPLC analysis [Daicel chiralpak AD-H, *n*-hexane/*i*-PrOH = 90/10, 1.0 mL/min, λ = 254 nm, t (minor) = 9.43 min, t (major) = 13.32 min; Product **4c″** (minor) was obtained as a pale yellow solid (8.2 mg, 22% yield); 76:24 er, determined by HPLC analysis [Daicel chiralpak AD-H, *n*-hexane/*i*-PrOH = 90/10, 1.0 mL/min, λ = 254 nm, t (minor) = 18.39 min, t (major) = 17.32 min]; ^{1}H NMR (**4c′**, 400 MHz, $CDCl_3$): δ 7.85–7.76 (m, 2H), 7.73 (d, *J* = 8.9 Hz, 1H), 7.41 (d, *J* = 8.2 Hz, 1H), 7.30 (t, *J* = 7.6 Hz, 1H), 7.17 (t, *J* = 7.5 Hz, 1H), 7.11 (d, *J* = 8.8 Hz, 1H), 7.00 (d, *J* = 8.8 Hz, 1H), 6.53 (s, 1H), 3.71–3.56 (m, 5H), 3.35 (s, 3H), 2.90–2.80 (m, 1H), 2.34–2.22 (m, 1H), 1.93–1.82 (m, 1H), 1.37 (d, *J* = 7.1 Hz, 3H) ppm; ^{13}C NMR (**4c′**, 100 MHz, $CDCl_3$): δ 158.9, 154.2, 138.4, 136.3, 130.8, 129.8, 129.7, 125.9, 124.2, 121.6, 120.4, 119.7, 118.8, 115.8, 115.7, 110.8, 109.9, 103.2, 62.8, 55.3, 38.7, 30.2, 29.9, 22.7 ppm; ESI-HRMS: calcd for $C_{24}H_{25}NO_3 + H^+$ 376.1907, found 376.1902.



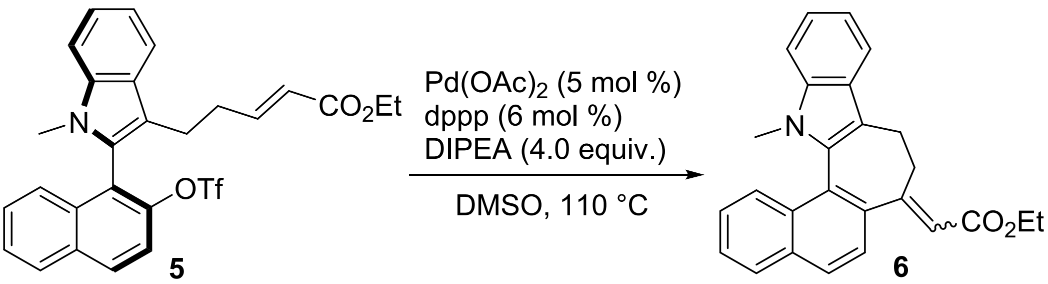
1-(5-chloro-3-(4-hydroxybutan-2-yl)-1-methyl-1H-indol-2-yl)naphthalen-2-ol (4d): 1-(5-chloro-1-methyl-1H-indol-2-yl)naphthalen-2-ol **1i** (30.7 mg, 0.1 mmol), crotonaldehyde **2b** (10.5 mg, 0.15 mmol), **C1** (4.9 mg, 0.02 mmol) and CSA (4.6 mg, 0.02

mmol) were dissolved in anhydrous DCM (2.0 mL). The reaction mixture was stirred at ambient. After the reaction was completed, MeOH (0.5 mL) was added into the reaction mixture, and $NaBH_4$ (7.6 mg, 0.2 mmol) was added slowly at 0 °C for 30 min. Upon workup, product **4d** (mixture of **4d′** and **4d″**) was obtained as a white solid (25.2 mg, 68% yield). Mp = 70–72 °C; 3:2 dr (determined by ^{1}H-NMR), 95:5 er (**4d′**, major isomer), determined by HPLC analysis [Daicel chiralpak IB N-5, *n*-hexane/*i*-PrOH = 90/10, 1.0 mL/min, λ = 254 nm, t (minor) = 10.94 min, t (major) = 5.81 min; 67:33 er (**4d″**, minor isomer) was determined by HPLC analysis [Daicel chiralpak IB N-5, *n*-hexane/*i*-PrOH = 90/10, 1.0 mL/min, λ = 254 nm, t (minor) = 9.54 min, t (major) = 10.98 min] (single diastereomer was obtained from TLC for the HPLC analysis); ^{1}H NMR (**4d′**, 400 MHz, DMSO-d_6): δ 9.90 (s, 1H), 9.82 (s, 1H), 7.93 (d, J = 8.9 Hz, 2H), 7.87 (d, J = 7.7 Hz, 2H), 7.70 (s, 2H), 7.49 (d, J = 8.6 Hz, 2H), 7.37–7.27 (m, 5H), 7.17 (d, J = 8.7 Hz, 2H), 7.12 (d, J = 8.0 Hz, 1H), 7.04 (d, J = 8.1 Hz, 1H), 4.11 (d, J = 5.1 Hz, 2H), 3.32 (s, 2H), 3.27 (s, 3H), 3.23–3.13 (m, 2H), 3.12–3.03 (m, 1H), 2.62 (dd, J = 14.5, 7.2 Hz, 1H), 2.47 (s, 1H), 1.95–1.77 (m, 2H), 1.65 (m, 6.5 Hz, 2H), 1.20 (d, J = 7.0 Hz, 2H), 1.16 (d, J = 7.0 Hz, 3H) ppm; ^{13}C NMR (**4d′**, 100 MHz, DMSO-d_6): δ 155.1, 155.0, 136.3, 136.2, 134.9, 134.9, 133.7, 133.6, 131.1, 128.6, 128.5, 128.2, 128.1, 127.5, 127.3, 124.2, 124.1, 123.3, 123.3, 120.7, 118.9, 118.8, 118.7, 118.5, 118.1, 111.8, 110.7, 110.7, 60.4, 60.2, 30.4, 30.3, 28.7, 28.6, 21.5, 21.1 ppm; ESI-HRMS: calcd for $C_{23}H_{22}ClNO_2 + H^+$ 380.1412, found 380.1413.

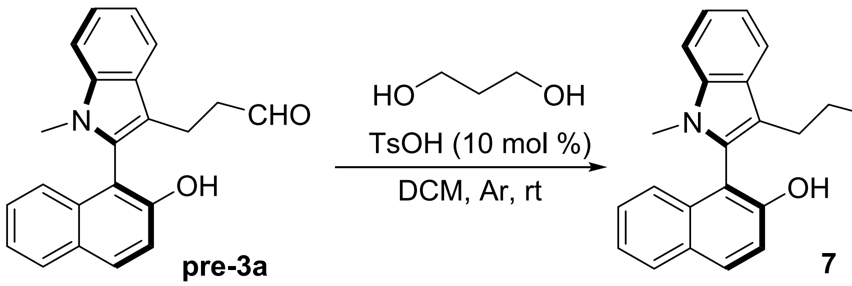
6. Synthetic transformations



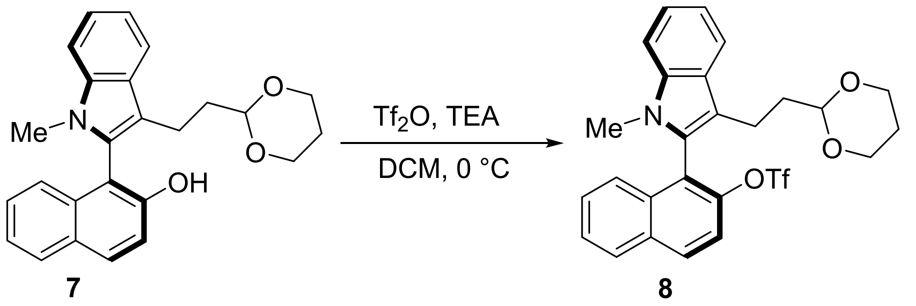
Synthesis of 5: Compound **pre-3a** (98.7 mg, 0.30 mmol), ethyl (triphenylphosphine) acetate (135.7 mg, 0.39 mmol) were dissolved in 5 ml of dry THF, the reaction was carried out at room temperature for 3 h. The reaction was monitored by TLC and was completed, the reaction was concentrated under reduced pressure, and the column chromatography purified the product to give a white solid (95.7 mg, 80% yield). The olefinic product was dissolved in DCM, and the olefinic product was slowly added to the mixture under ice bath with Et_3N (30.3 mg, 0.30 mmol) and Tf_2O (84.6 mg, 0.30 mmol), and the end, room temperature reaction for 10 minutes, TLC monitoring, the reaction was completed, add saturated sodium bicarbonate quenched under an ice bath, add water and DCM to take, DCM extraction for three times, the organic layer with anhydrous sodium sulfate drying, the combined organic layer, concentrated under reduced pressure Organic layer to get the crude product, t which was obtained as white solid **5** (114.7 mg, 72% yield) by silica gel column chromatography.



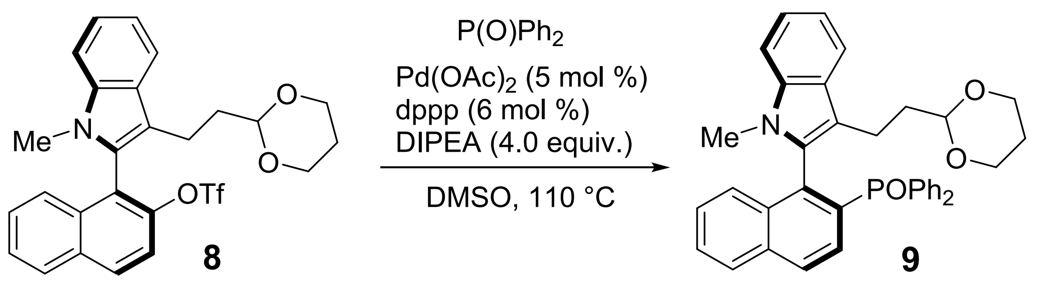
Synthesis of 6: Compound **5** (53.1 mg, 0.1 mmol), dppb (2.47 mg, 0.006 mmol), palladium acetate (1.12 mg, 0.005 mmol) and DIEA (51.6 mg, 0.4 mmol) were dissolved with 1 ml of DMSO, then the reacted at 110 °C for 12h in Ar atmosphere, monitored by TLC, the reaction was completed, monitored by TLC, and extracted with the addition of water and EA, the EA was extracted three times, the organic layer was dried with anhydrous Sodium sulfate was dried, the organic layers were combined and concentrated under reduced pressure, the organic layer yielded crude product, which was obtained as white solid **6** (34.3 mg, 90% yield) by silica gel column chromatography. However, this product was determined as a racemic product by HPLC analysis. ^1H NMR (400 MHz, DMSO-d_6): δ 8.12–8.02 (m, 2H), 7.80–7.73 (m, 1H), 7.69 (d, J = 7.9 Hz, 1H), 7.65–7.57 (m, 2H), 7.53 (dd, J = 8.3, 2.7 Hz, 2H), 7.27–7.19 (m, 1H), 7.13 (t, J = 7.4 Hz, 1H), 5.81 (d, J = 1.6 Hz, 1H), 4.08–3.92 (m, 2H), 3.48 (s, 3H), 3.08 (m, 5.7, 3.2 Hz, 2H), 1.27 (m, 8.9 Hz, 2H), 1.14 (t, J = 7.1 Hz, 3H) ppm; ^{13}C NMR (100 MHz, DMSO-d_6): δ 165.8, 162.6, 140.5, 138.5, 135.7, 133.6, 130.7, 129.3, 128.9, 127.9, 127.5, 127.4, 127.0, 126.5, 126.4, 122.2, 120.9, 119.9, 118.8, 115.5, 110.8, 60.0, 40.9, 32.8, 19.7, 14.5 ppm; ESI-HRMS: calcd for $C_{23}H_{23}NO_2 + H^+$ 346.1802, found 346.1798.



Synthesis of 7: Compound **pre-3a** (32.9 mg, 0.10 mmol) and TsOH (1.7 mg, 0.01 mmol) were dissolved in dry dichloromethane (2.0 mL) and 1,3 propanediol (18.2 mg, 0.24 mmol) was added in an argon atmosphere. The reaction was monitored by TLC at room temperature for 12 h. The reaction was completed and a white solid **7** (34.1 mg, 88% yield) was obtained by silica gel column chromatography.

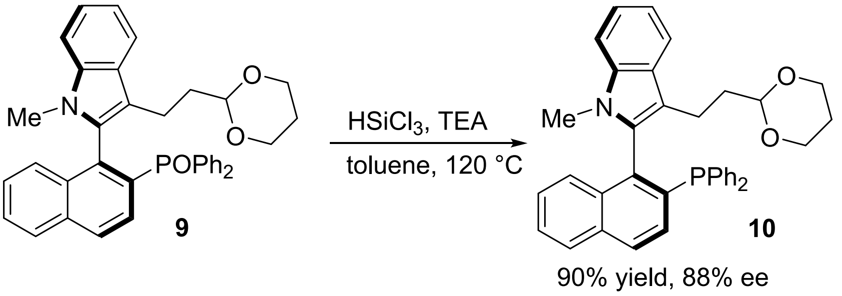


Synthesis of 8: Compound **7** (38.7 mg, 0.10 mmol) was dissolved with 2 ml of DCM and Et_3N (20.2 mg, 0.2 mmol) and Tf_2O (33.8 mg, 0.12 mmol) were added slowly under ice bath. Then it was moved to room temperature and the reaction was carried out for 12 h. The reaction was monitored by TLC and completed, quenched by the addition of saturated sodium bicarbonate, extracted three times with DCM, the organic layer was dried with anhydrous sodium sulfate, the organic layers were combined and concentrated under reduced pressure, the organic layer yielded the crude product, which was analyzed by silica gel column chromatography to give a white solid **8** (39.4 mg, 76% yield).

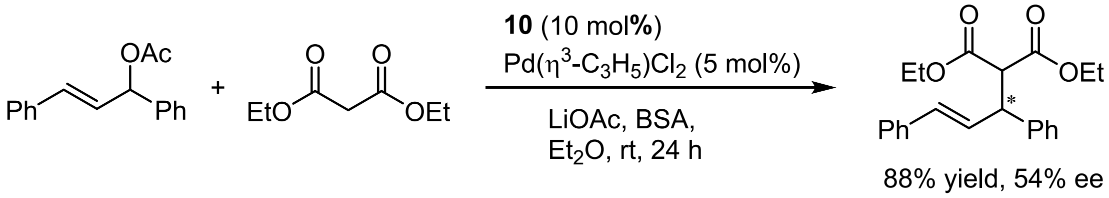


Synthesis of 9: Compound **8** (20.8 mg, 0.04 mmol), diphenylphosphine oxide (12.1 mg, 0.06 mmol), dppp (0.98 mg, 0.0024 mmol), palladium acetate (0.45 mg, 0.002 mmol), and DIEA (20.6

mg, 0.16 mmol) were dissolved in 1 ml of DMSO and reacted in an Ar atmosphere at 110 °C for 12 h. The reaction was monitored for completion by TLC, and was extracted by adding water and EA. EA was extracted three times, the organic layer was dried with anhydrous sodium sulfate, the organic layers were combined, and the organic layer was concentrated under reduced pressure to obtain the crude product, which was obtained as a white solid **9** (16.5 mg, 72% yield) by silica gel column.

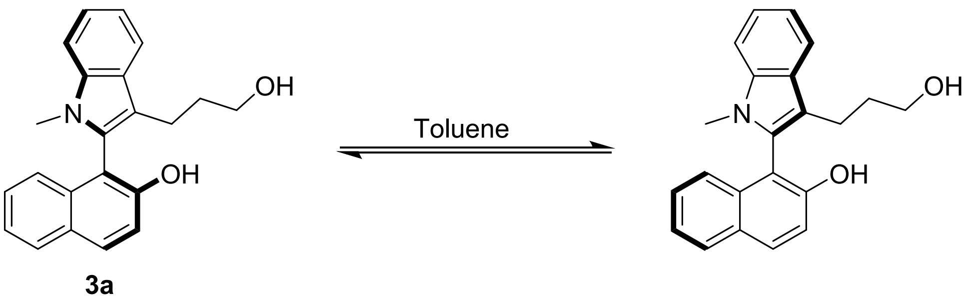


Synthesis of 10: Compound **7** (17.1 mg, 0.03 mmol) was dissolved with 1 ml of Tol, then in an argon atmosphere, Et_3N (90.9 mg, 0.9 mmol) and $HSiCl_3$ (40.5 mg, 0.3 mmol) were added slowly, after addition, moved to room temperature and stirred for 10 min, and then warmed up to 120 °C, the reaction was carried out for 12 h. The reaction was monitored by TLC and completed, the reaction was quenched by the addition of saturated sodium bicarbonate, extracted three times by DCM, and the organic layer was dried with anhydrous sodium sulphate, and the organic layers were combined. The organic layer was concentrated under reduced pressure, the organic layer yielded a crude product, which was analyzed by silica gel column chromatography to obtain a white solid **10** (14.9 mg, 90% yield). Mp = 78–80 °C; $[\alpha]_D^{20}$ = -20.250 (*c* = 1.0 in $CHCl_3$); 94:6 er, determined by HPLC analysis [Daicel chiralpak IB N-5, *n*-hexane/*i*-PrOH = 90/10, 1.0 mL/min, λ = 254 nm, t (minor) = 5.68 min, t (major) = 5.26 min]; ^{1}H NMR (400 MHz, DMSO-d_6): δ 8.07 (d, *J* = 8.6 Hz, 1H), 8.01 (d, *J* = 8.1 Hz, 1H), 7.61–7.54 (m, 2H), 7.49–7.44 (m, 1H), 7.41–7.32 (m, 7H), 7.28 (dd, *J* = 8.5, 2.7 Hz, 1H), 7.21–7.16 (m, 3H), 7.14–7.06 (m, 4H), 4.15 (t, *J* = 5.1 Hz, 1H), 3.84 (dd, *J* = 11.2, 4.8 Hz, 1H), 3.75 (dd, *J* = 11.2, 4.9 Hz, 1H), 3.45 (td, *J* = 12.2, 2.4 Hz, 1H), 3.27 (td, *J* = 12.3, 2.4 Hz, 1H), 3.03 (s, 3H), 2.33–2.25 (m, 2H), 1.76–1.63 (m, 1H), 1.52–1.43 (m, 2H), 1.16 (d, *J* = 13.3 Hz, 1H) ppm; ^{13}C NMR (100 MHz, DMSO-d_6): δ 137.6, 137.4, 136.9, 136.8, 136.7, 136.6, 136.2, 133.9, 133.8, 133.3, 133.3, 133.1, 133.0, 133.0, 132.9, 129.4, 128.8, 128.7, 128.7, 128.7, 128.2, 127.5, 127.3, 127.0, 125.6, 121.2, 118.8, 118.6, 113.8, 113.8, 109.7, 100.8, 34.9, 29.9, 29.9, 25.3, 19.2 ppm; ESI-HRMS: calcd for $C_{37}H_{34}NO_2P + H^+$ 556.2400, found 556.2401.



Synthesis of diethyl (*R*,*E*)-2-(1,3-diphenylallyl)malonate: In a 10 ml reaction tube, compounds (*E*)-1,3-diphenylallyl acetate (63 mg, 0.25 mmol), diethyl malonate (120 mg, 0.75 mmol), LiOAc (1.3 mg, 0.02 mmol), BSA (152 mg, 0.75 mmol), phosphine **10** (13.8 mg, 0.025 mmol), Pd(η^3-C_3H_5)Cl_2 (0.46 mg, 0.00125 mmol) were added and the solvent Et_2O (5 mL) was added and the reaction was carried out at room temperature for 24 h. The organic layer was concentrated under reduced pressure, the organic layer yielded a crude product, which was analyzed by silica gel column chromatography to obtain a clear oily liquid diethyl (*E*)-2-(1,3-diphenylallyl)malonate (77.4 mg, 88% yield). 77:23 er, determined by HPLC analysis [Daicel chiralpak IB N-5, *n*-hexane/*i*-PrOH = 90/10, 1.0 mL/min, λ = 254 nm, t (minor) = 10.02 min, t (major) = 13.32 min]; ^{1}H NMR (400 MHz, DMSO-d_6): δ 7.41–7.33 (m, 4H), 7.33–7.26 (m, 4H), 7.24–7.18 (m, 2H), 6.54–6.40 (m, 2H), 4.14–4.05 (m, 4H), 3.89 (qd, J = 7.1, 1.6 Hz, 2H), 1.10 (t, J = 7.1 Hz, 3H), 0.91 (t, J = 7.1 Hz, 3H) ppm; ^{13}C NMR (100 MHz, DMSO-d_6): δ 167.3, 166.9, 140.5, 136.5, 130.7, 129.9, 128.5, 128.4, 127.9, 127.6, 126.8, 126.0, 61.0, 60.7, 56.7, 48.9, 13.9, 13.5 ppm;

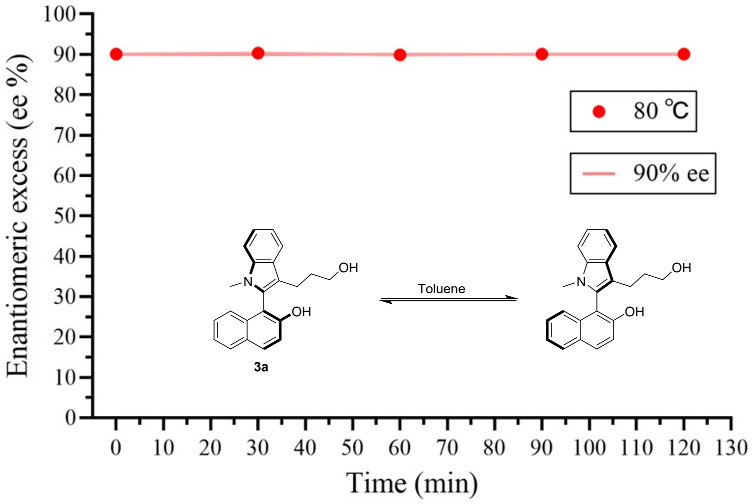
7. Thermal racemization experiments of 3a and 3j

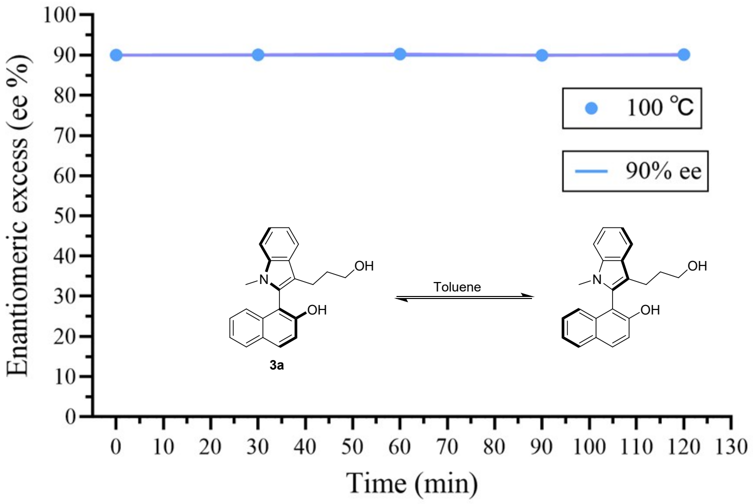


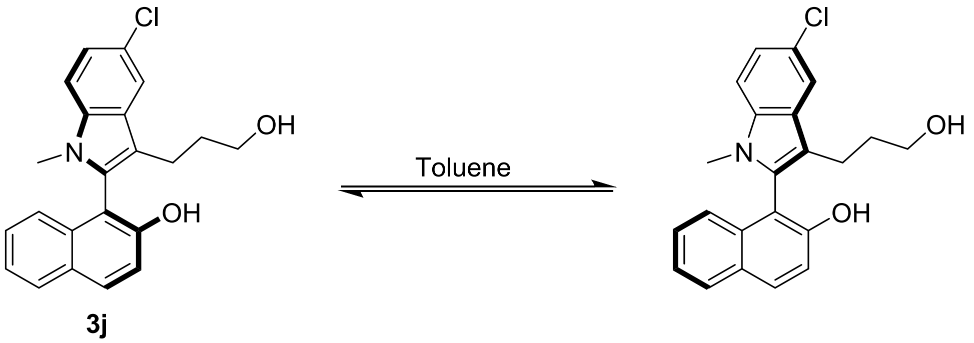
3a

Procedure: To a schlenk tube equipped with a magnetic stir bar was taken the 3a (5 mg) in toluene (10 mL). Then, the reaction mixture was allowed to stir at 80 °C and 100 °C in a heating block. After a period of time, the solution was then monitored and the enantioselectivity was determined using HPLC analysis. Based on the data obtained **3a** was found to be very stable in toluene.

Time Ee（%） T	0 min	30 min	60 min	90 min	120 min
80 °C	90.08	90.32	89.89	90.05	90.10
100 °C	90.02	90.06	90.28	89.92	90.16

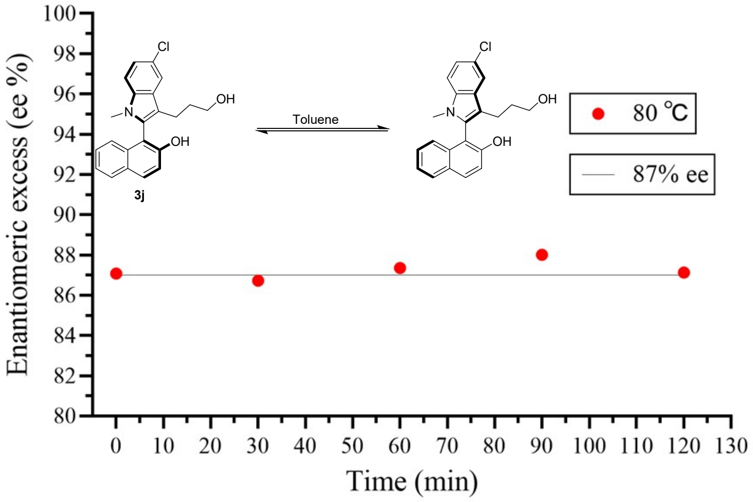


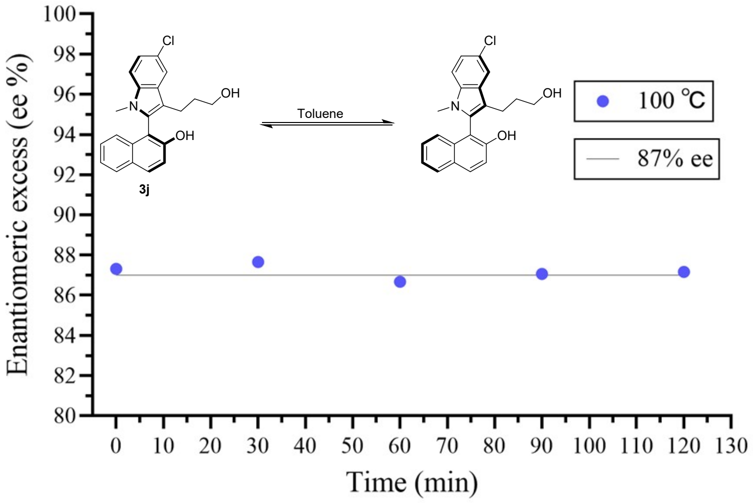




To make the rotational energy barriers of this class of compounds more convincing, we also determined the rotational energy barriers of **3j** for verification. Procedure: To a schlenk tube equipped with a magnetic stir bar was taken the **3j** (5 mg) in toluene (10 mL). Then, the reaction mixture was allowed to stir at 80 ℃ and 100 ℃ in a heating block. After a period of time, the solution was then monitored and the enantioselectivity was determined using HPLC analysis. Based on the data obtained 3j was found to be stable at different temperatures in toluene.

T \ Ee（%） \ Time	0 min	30 min	60 min	90 min	120 min
80 ℃	87.08	86.72	87.35	88.01	87.13
100 ℃	87.32	87.66	86.67	87.06	87.16



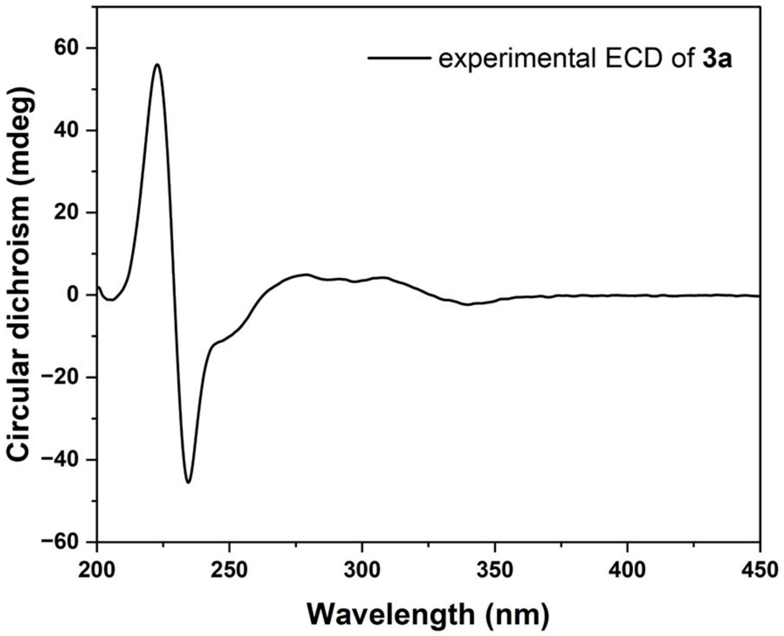


8. Assignment of the absolute configuration of 3a by the quantum chemical calculation of electronic circular dichroism (ECD)

As we failed to obtain the single crystal of the obtained products for X-ray crystallographic analysis to determine its absolute configuration, the electronic circular dichroism (ECD) spectra of **3a** was recorded in ethanol and compared with the theoretically calculated results.

*The experimental ECD spectrum of chiral **3a** catalyzed by catalyst **C4***

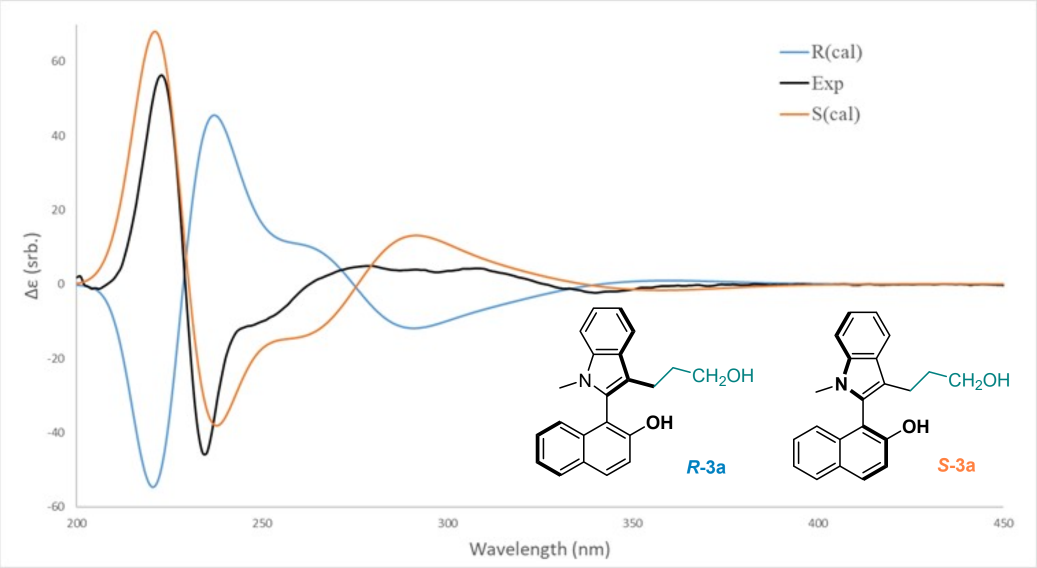
Experiment procedure: Prior to each use, the CD instrument was purged with nitrogen for 20 minutes and the chiller was set to equilibrate at 25.0 °C. Spectra were collected between 200 and 520 nm with a standard sensitivity of 100 mdeg, a data pitch of 1.0 nm, a band width of 1 nm, scanning speed of 500 nms^{-1} and a response of 0.5 s using a quartz cuvette (1 cm path length). The data were adjusted through baseline correction and binomial smoothing. The concentration of **3a** was 5.0×10^{-4} M in ethanol.



DFT calculation procedures:

In this work, CD spectroscopy was obtained by density functional theory (DFT) calculations. All the DFT calculations of structure of starting material (ground state) and the corresponding vibrational frequencies were performed at the pbe1pbe/6-311G(d, p) level in the Gaussian 09 program package.

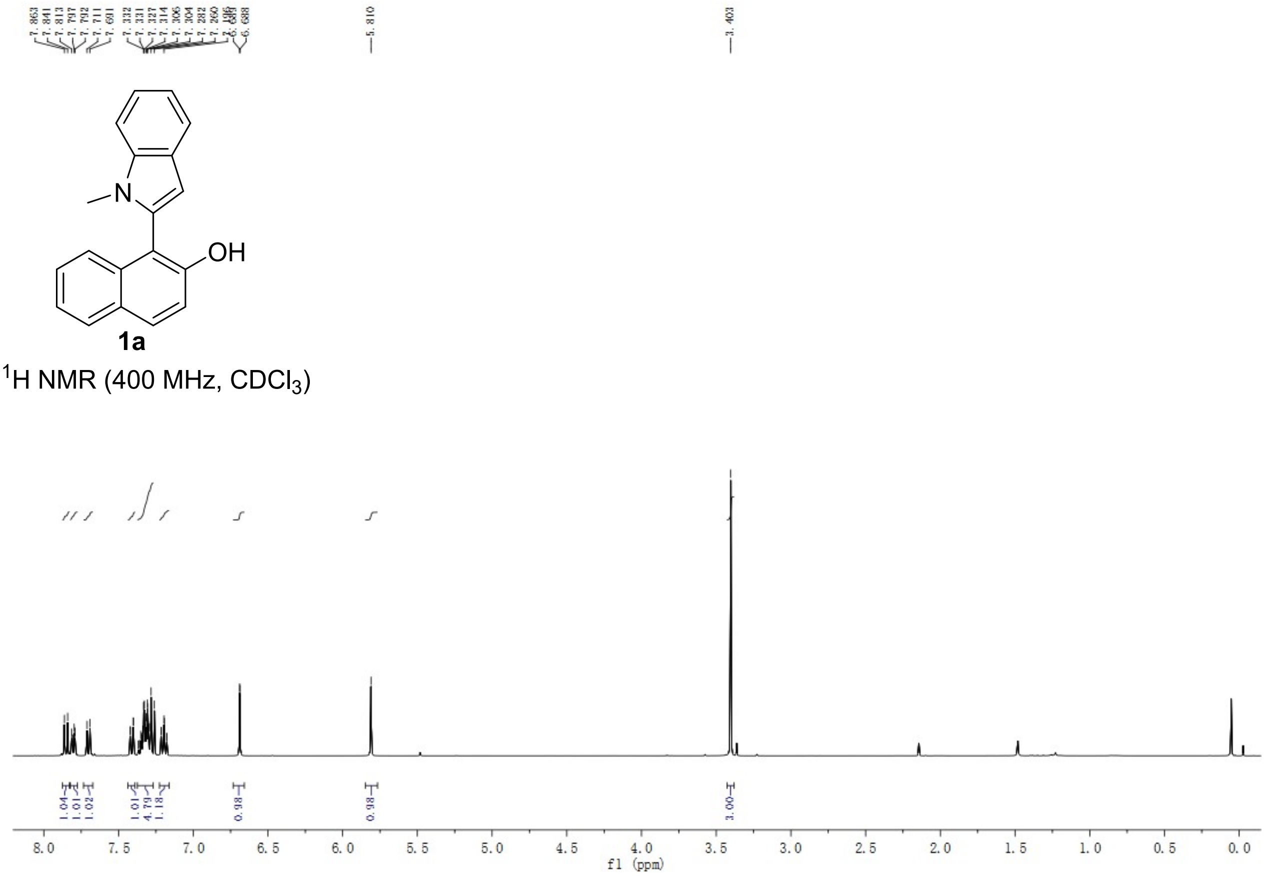
Comparison of experimental ECD spectrum of chiral **3a** in ethanol with the calculated ECD spectrum of (*S*)-**3a**. As shown below, the experimental ECD spectrum matches quite well to the calculated one of (*S*)-**3a**, indicating the axial *S*-configuration of the products.



9. Reference

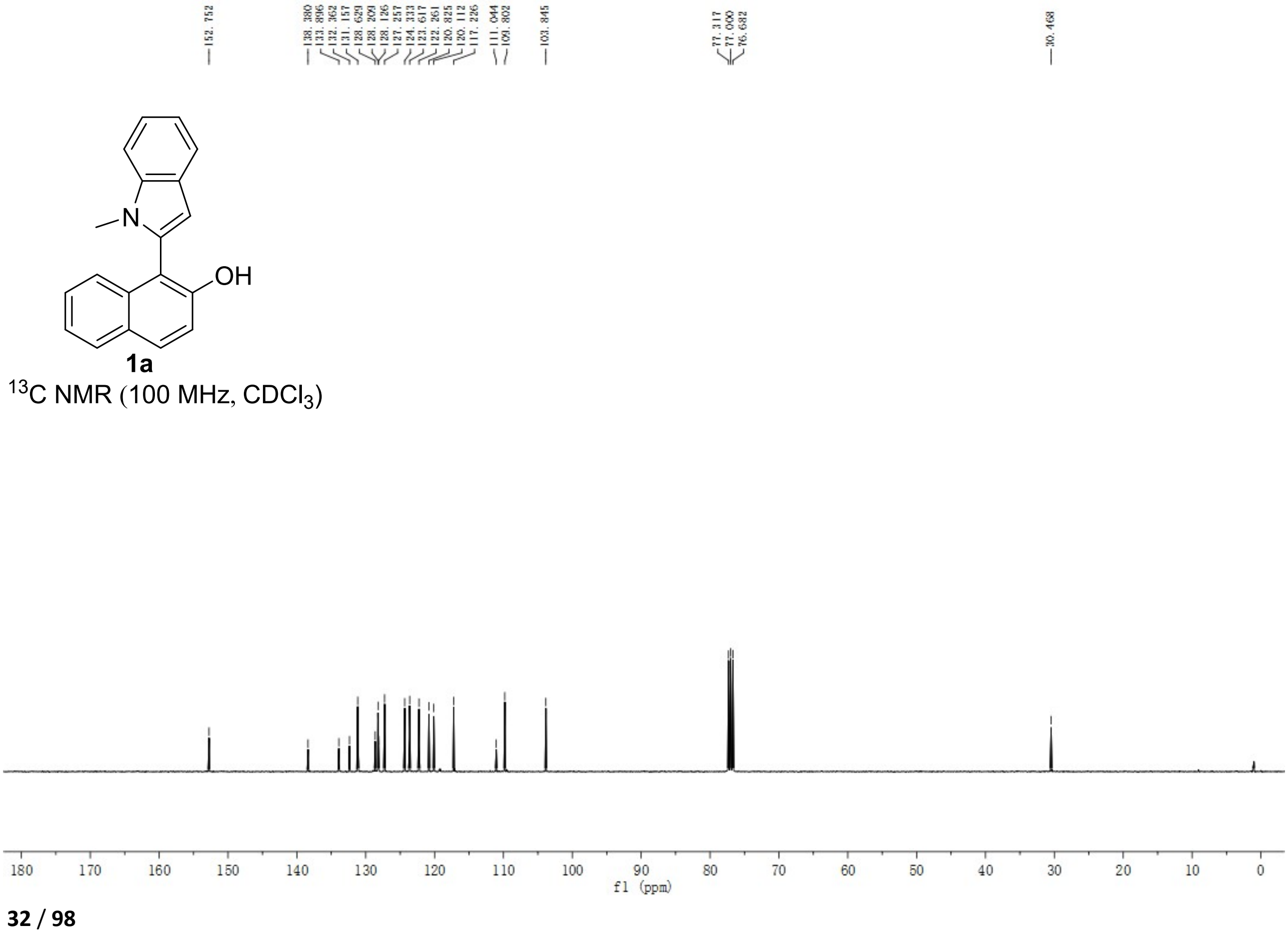
[1] a) Ghandi, M.; Salahi, S.; Hasani, M.; *Tetrahedron Lett.* **2011**, *52*, 270–273; b) Xu, X.-H.; Taniguchi, M.; Azuma, A.; Liu, G.-K.; Tokunaga, E.; Shibata, N.; *Org. Lett.* **2013**, *15*, 686.

10. NMR spectra and HPLC chromatograms



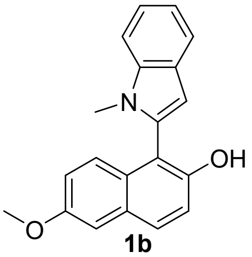
1a

^{1}H NMR (400 MHz, $CDCl_3$)



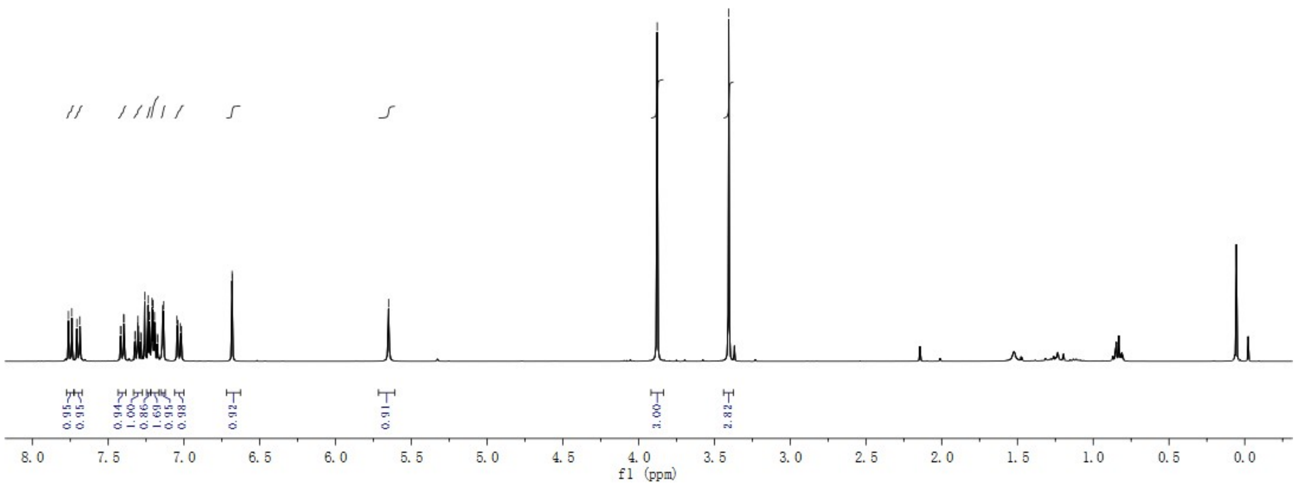
1a

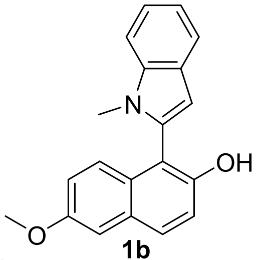
^{13}C NMR (100 MHz, $CDCl_3$)



1b

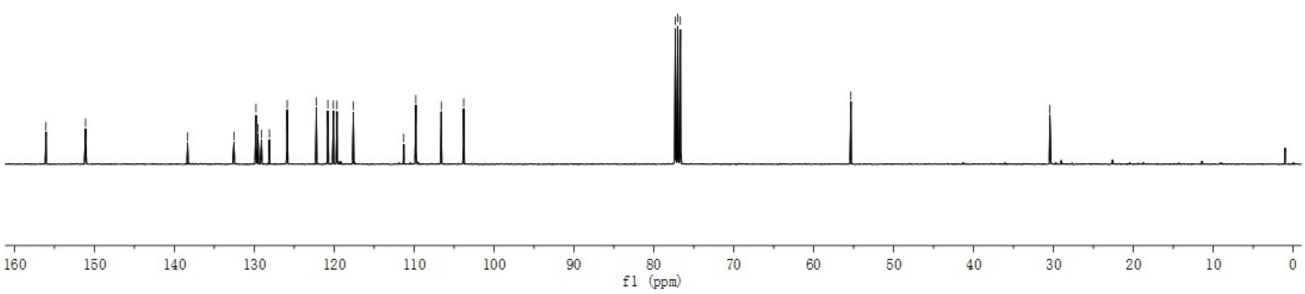
^{1}H NMR (400 MHz, $CDCl_3$)

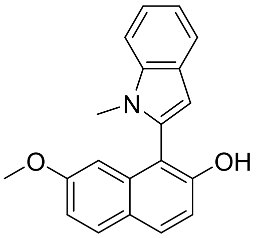




1b

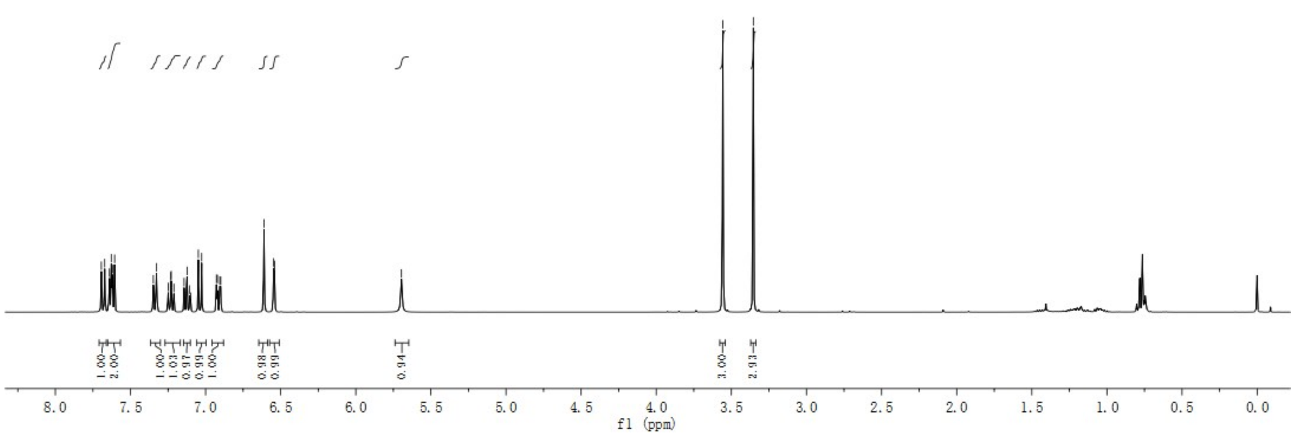
^{13}C NMR (100 MHz, $CDCl_3$)

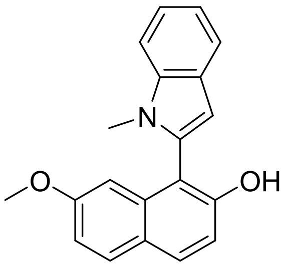




1c

^{1}H NMR (400 MHz, CDCl$_3$)





1c

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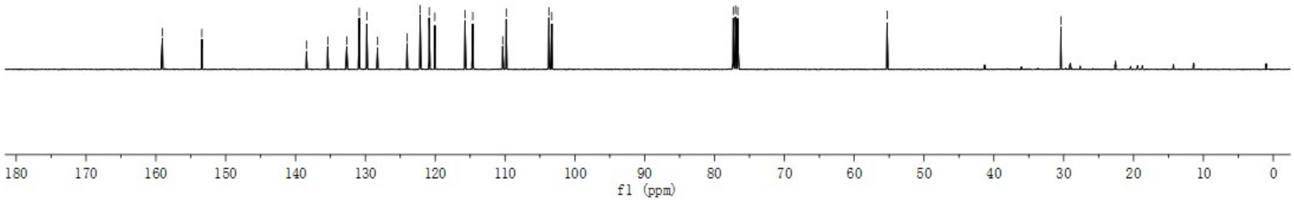
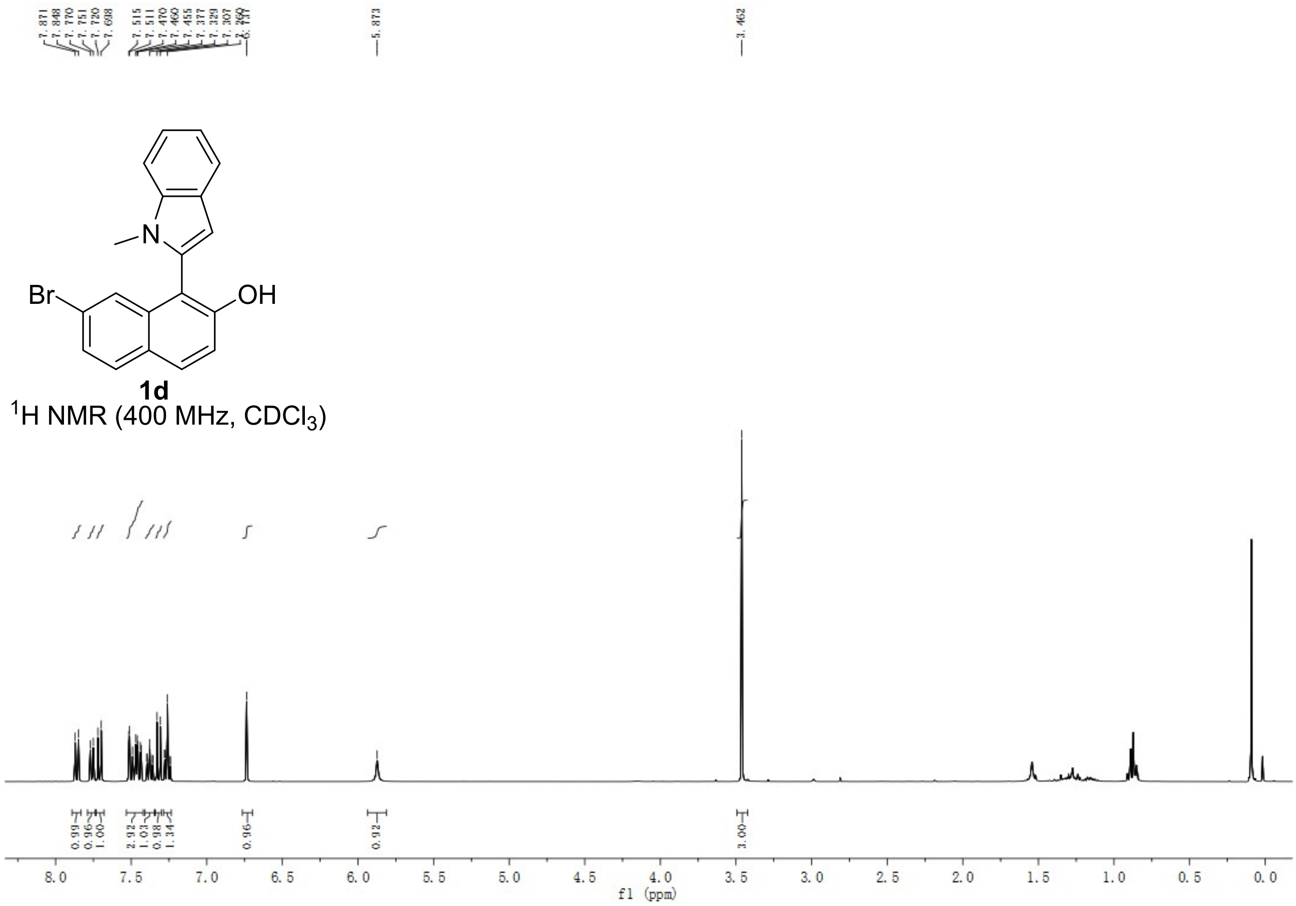
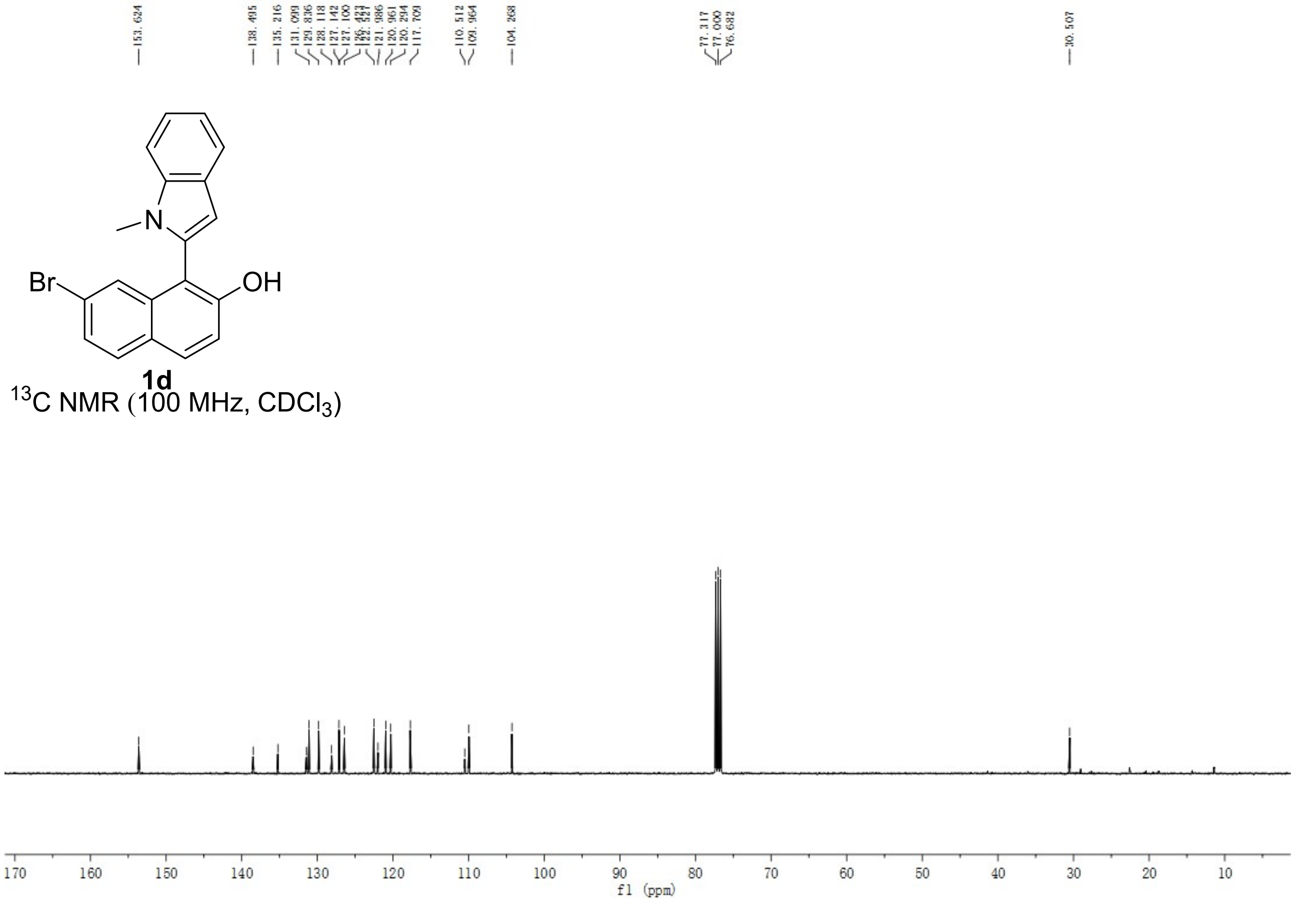




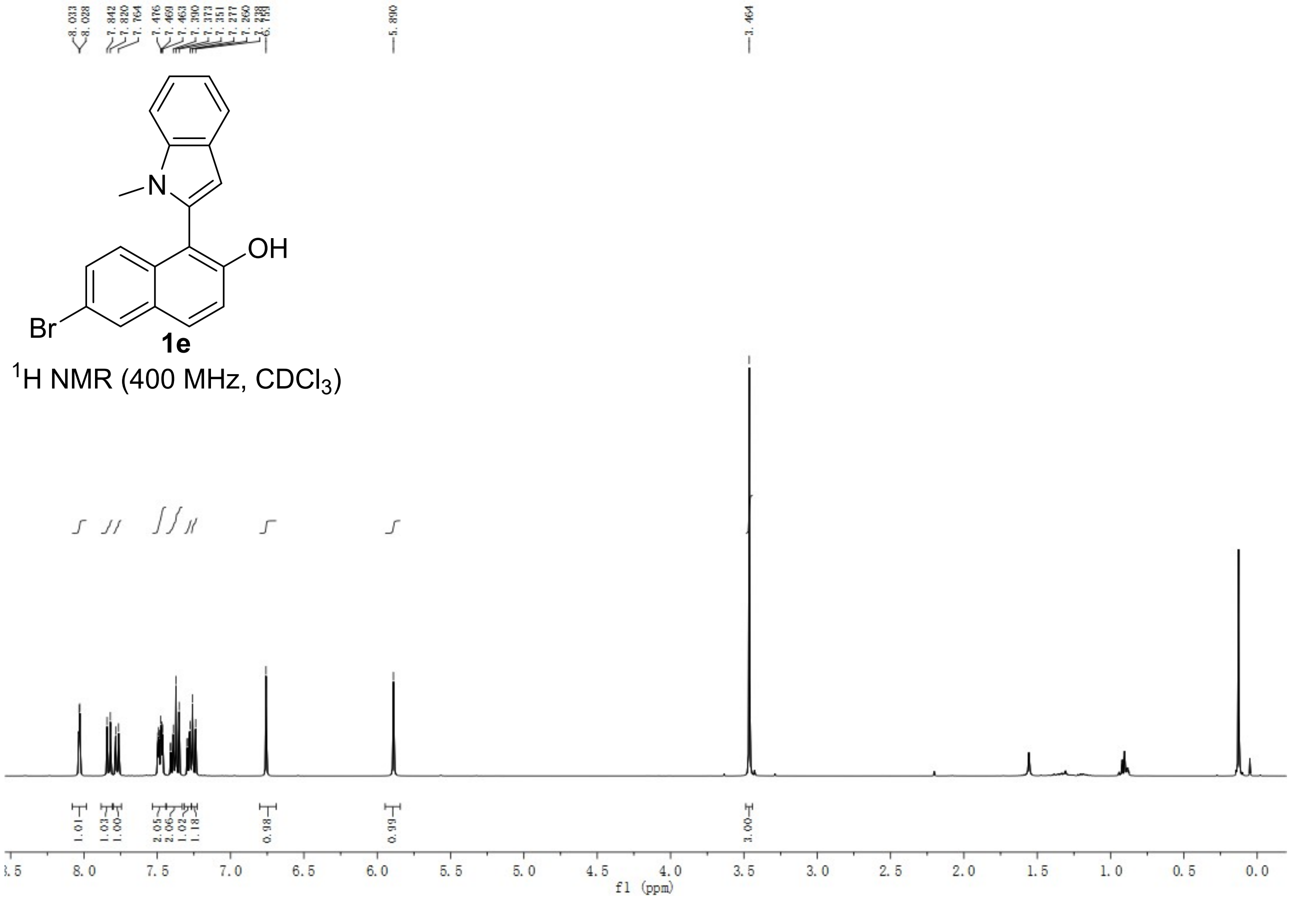
1d

^{1}H NMR (400 MHz, CDCl$_3$)



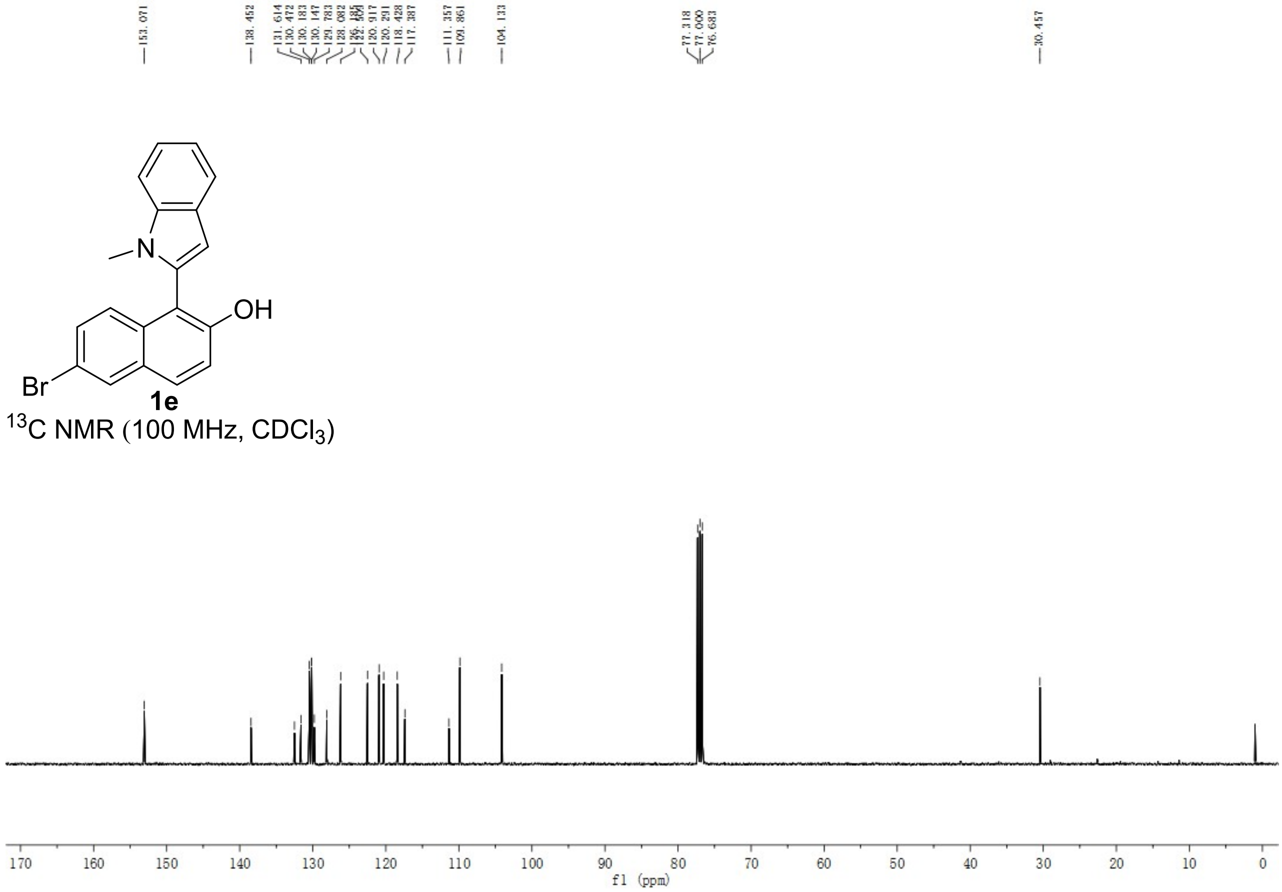
1d

^{13}C NMR (100 MHz, CDCl$_3$)



1e

^{1}H NMR (400 MHz, $CDCl_3$)



1e

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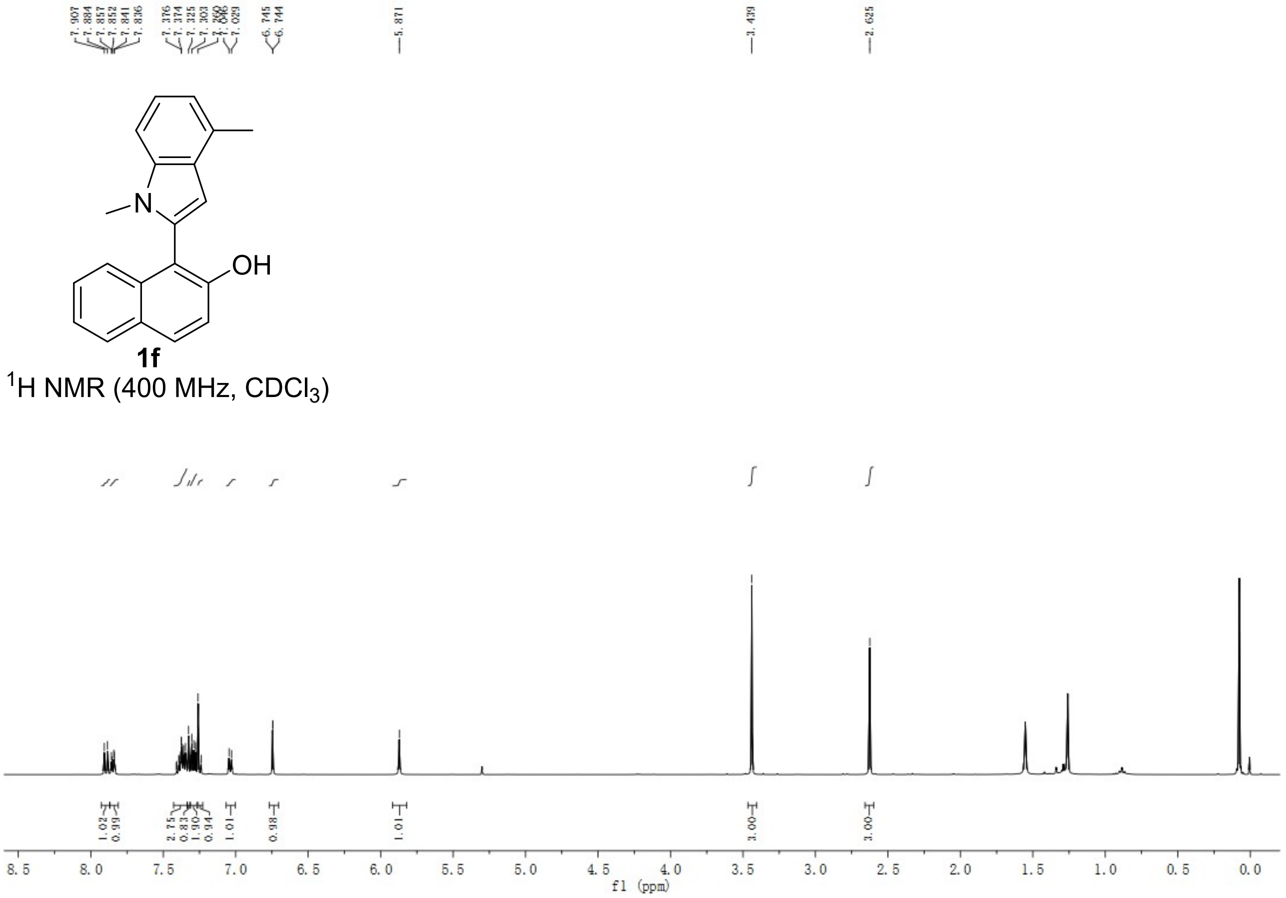

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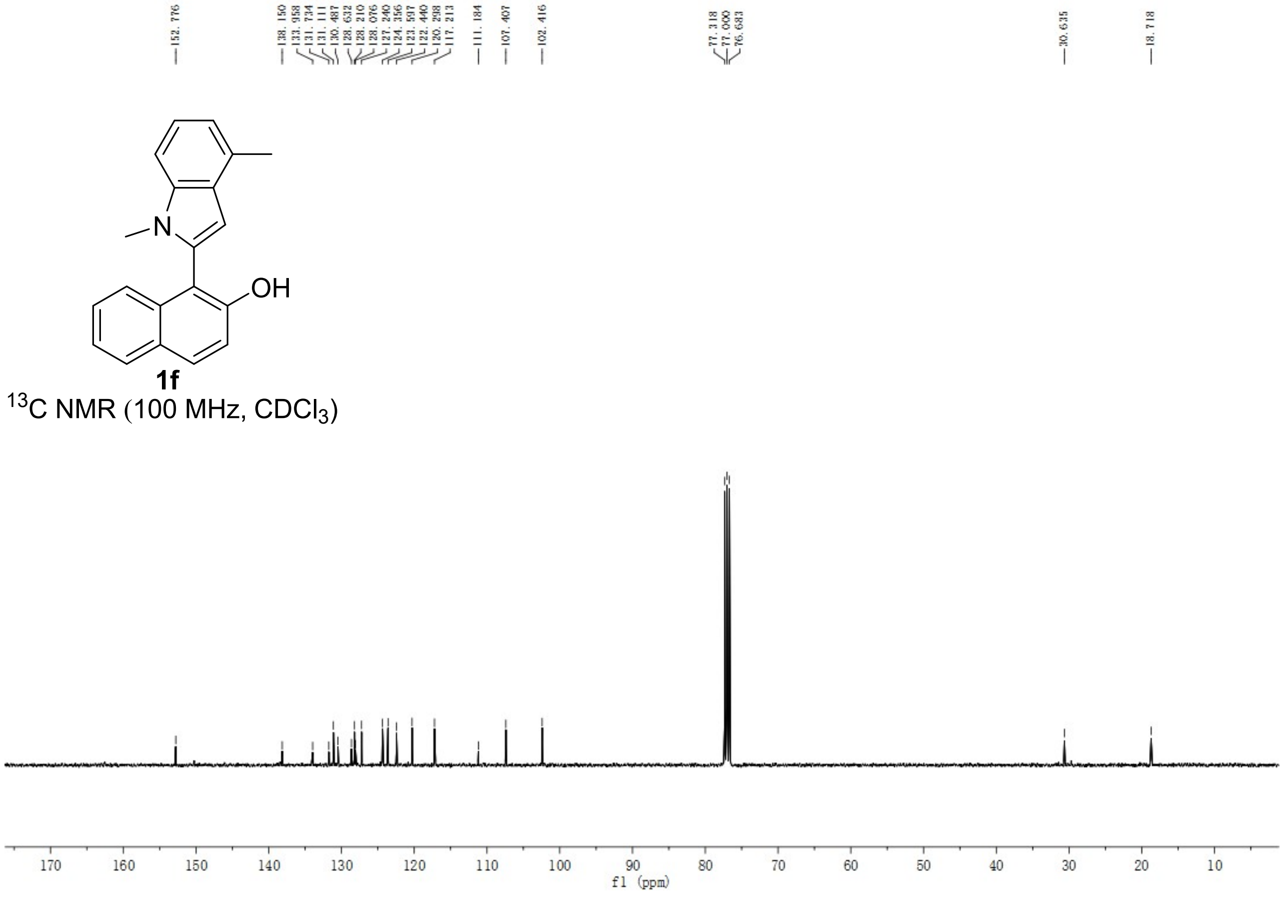

1f

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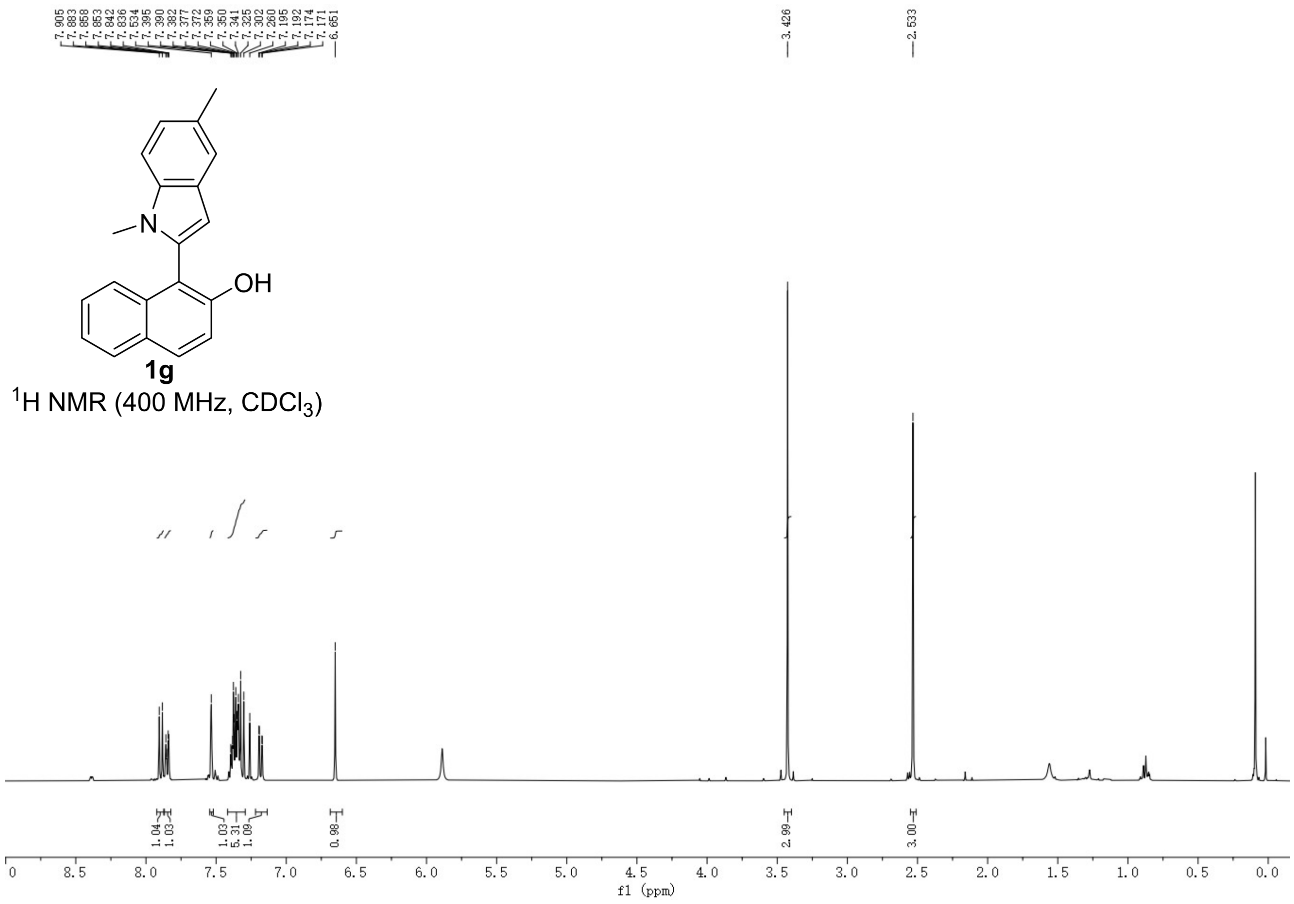

1g

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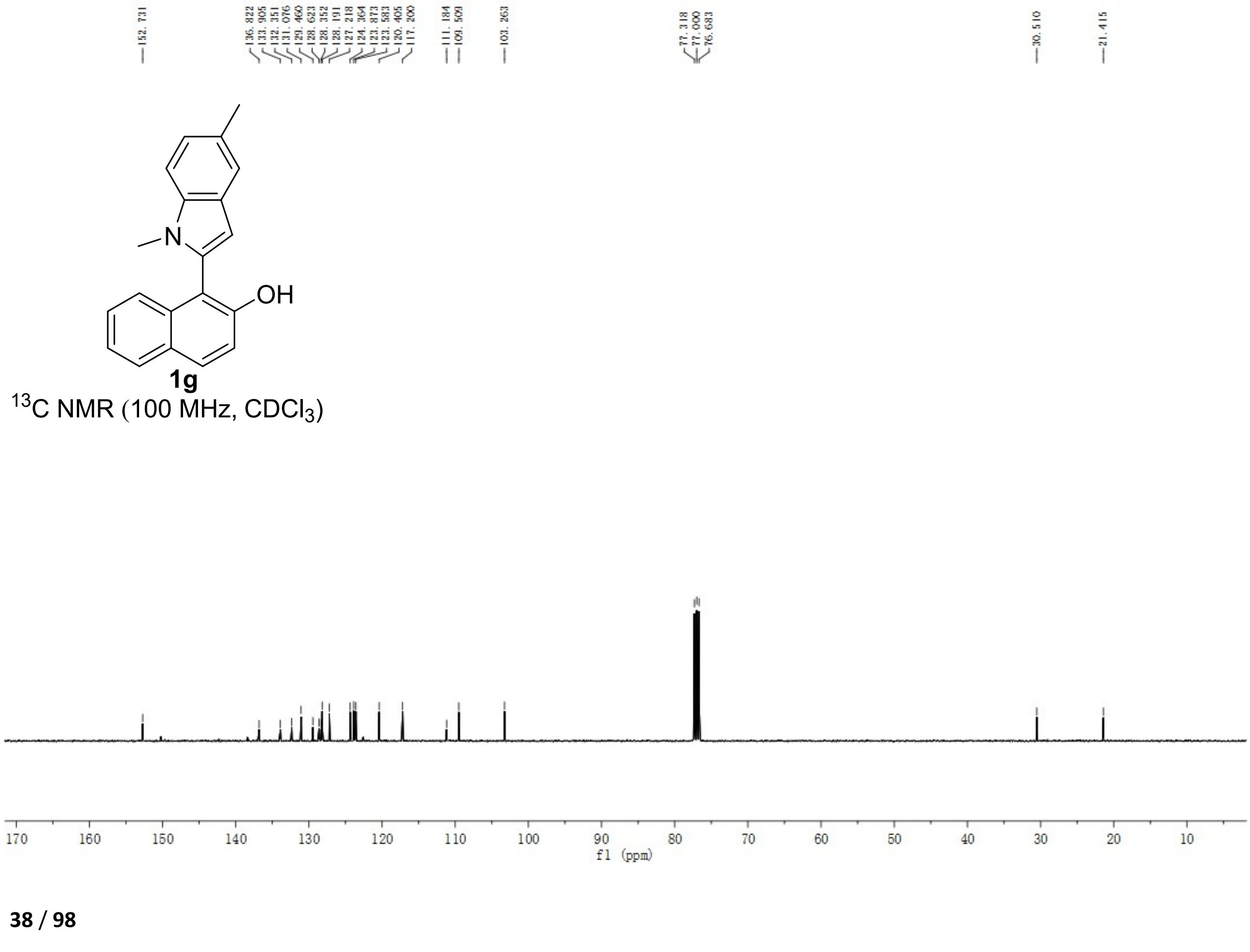
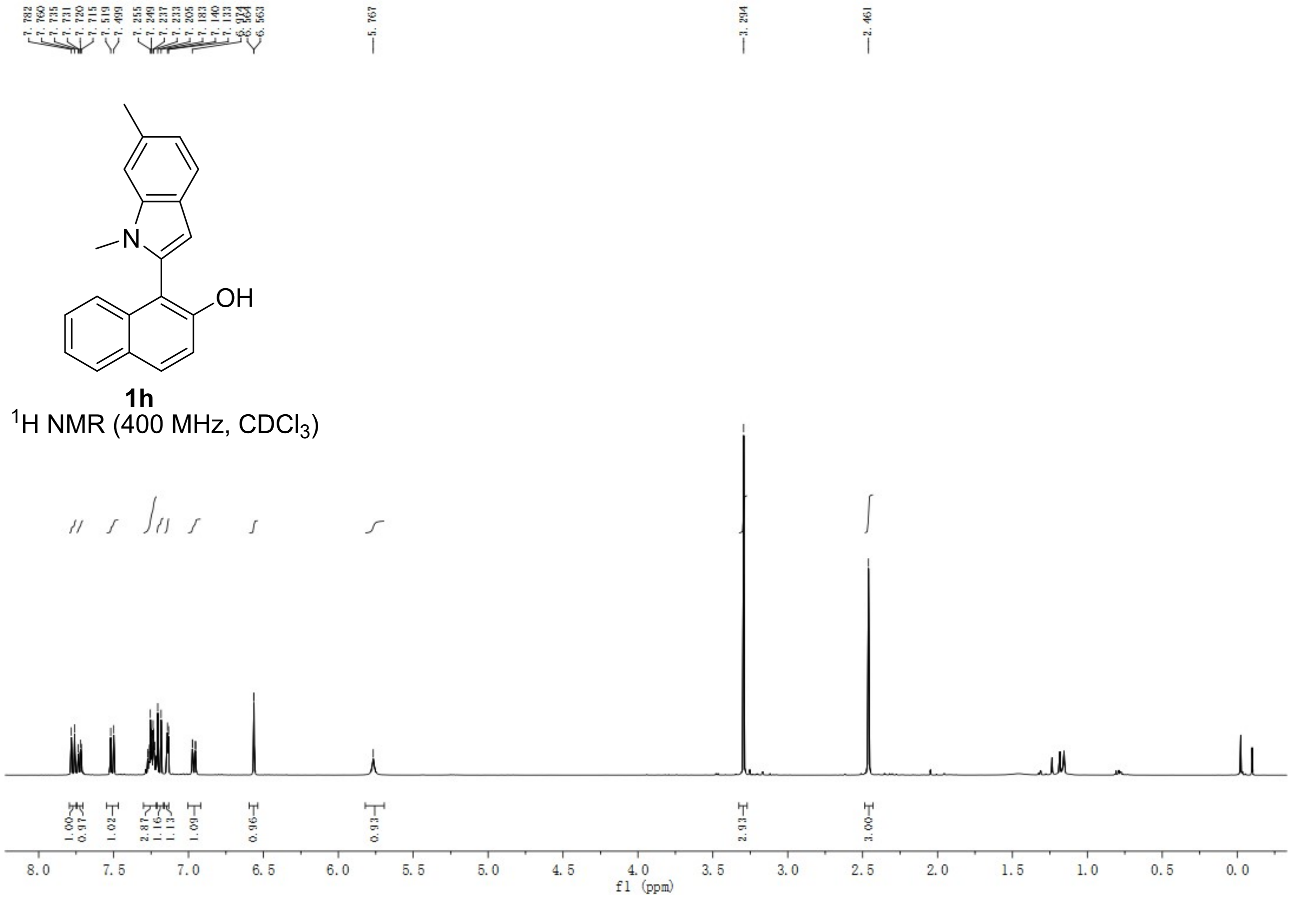


1g

^{13}C NMR (100 MHz, CDCl$_3$)



1h

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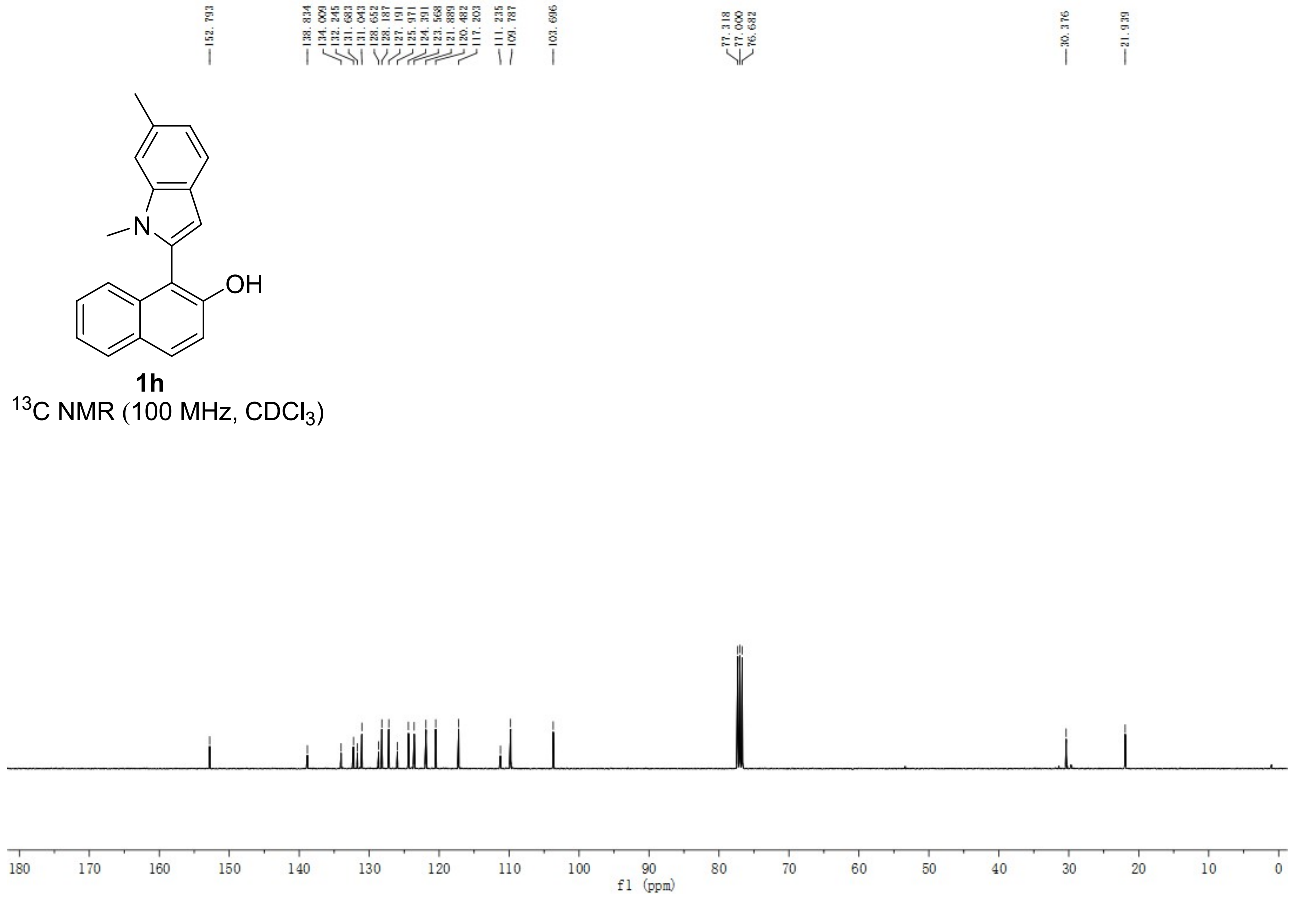
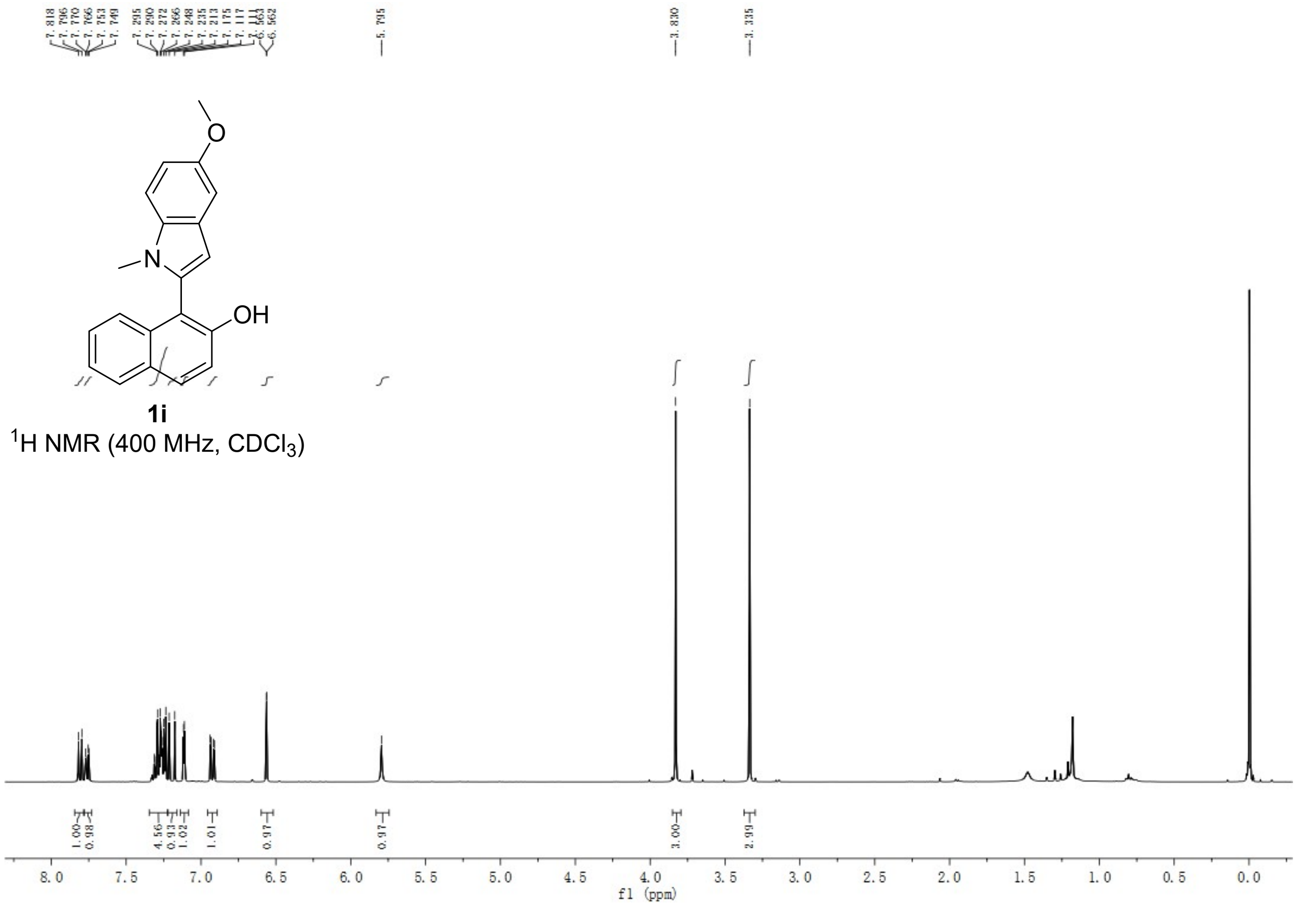


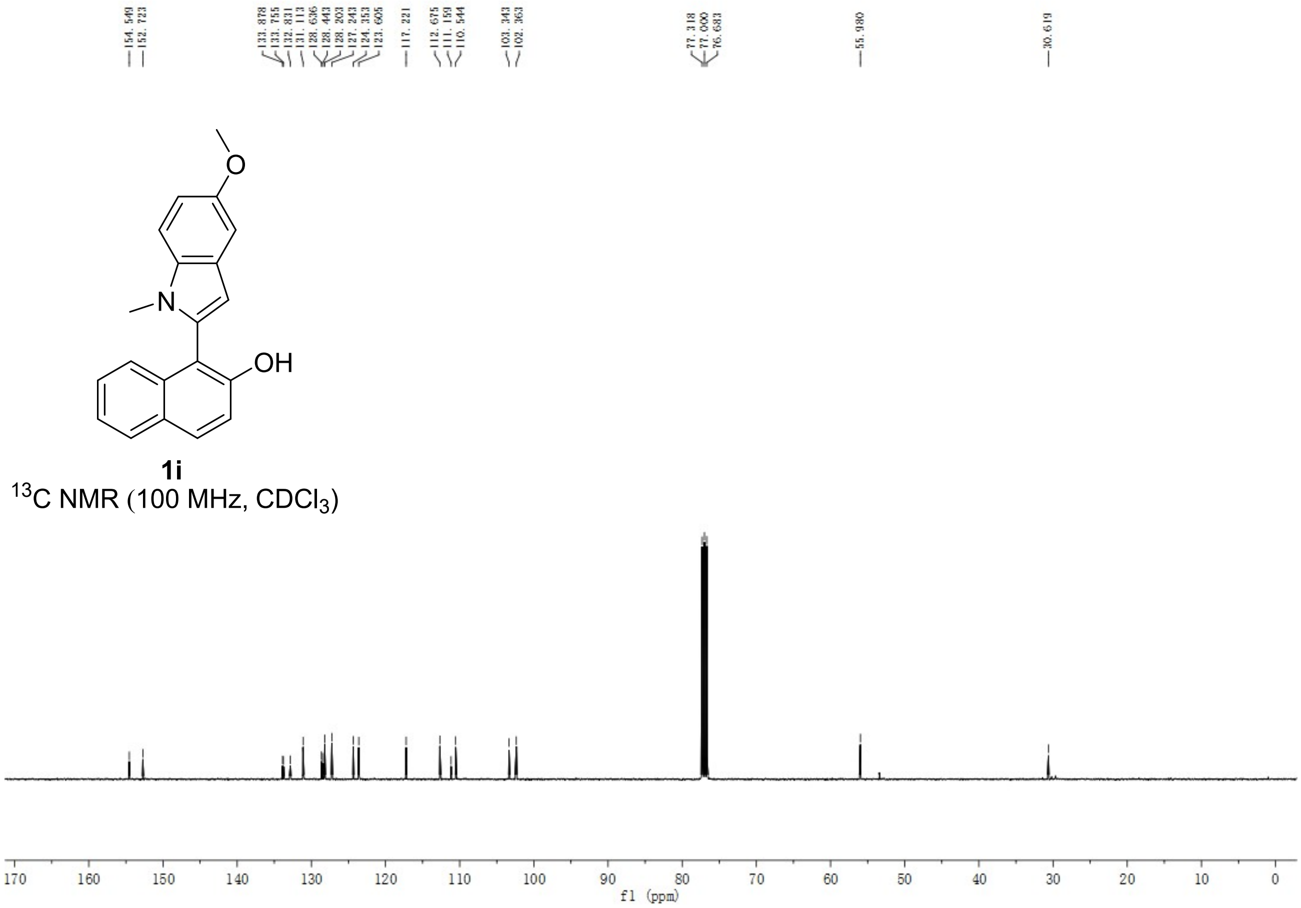
1h

^{13}C NMR (100 MHz, $CDCl_3$)



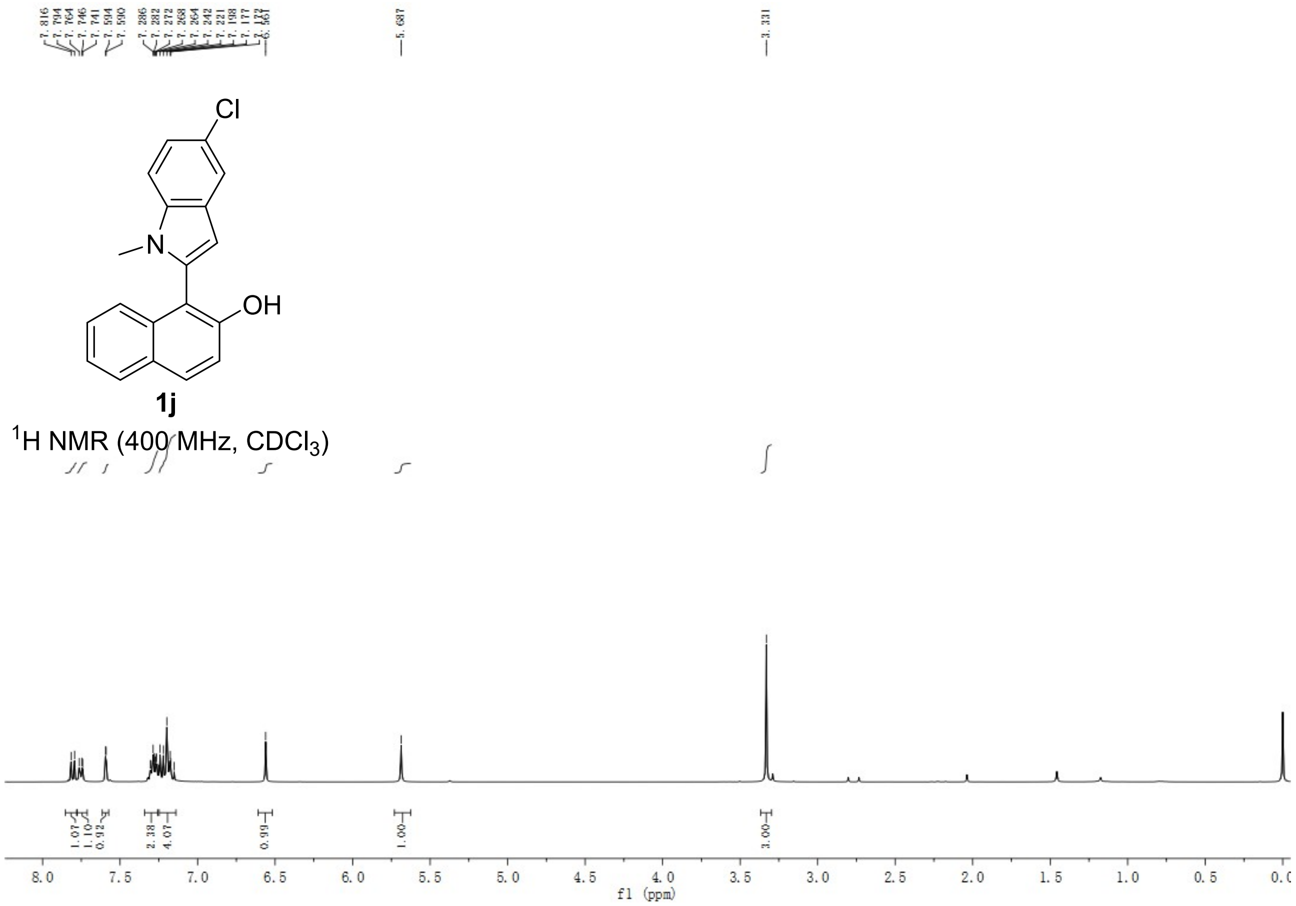
1i

^1H NMR (400 MHz, $CDCl_3$)



1i

^{13}C NMR (100 MHz, $CDCl_3$)



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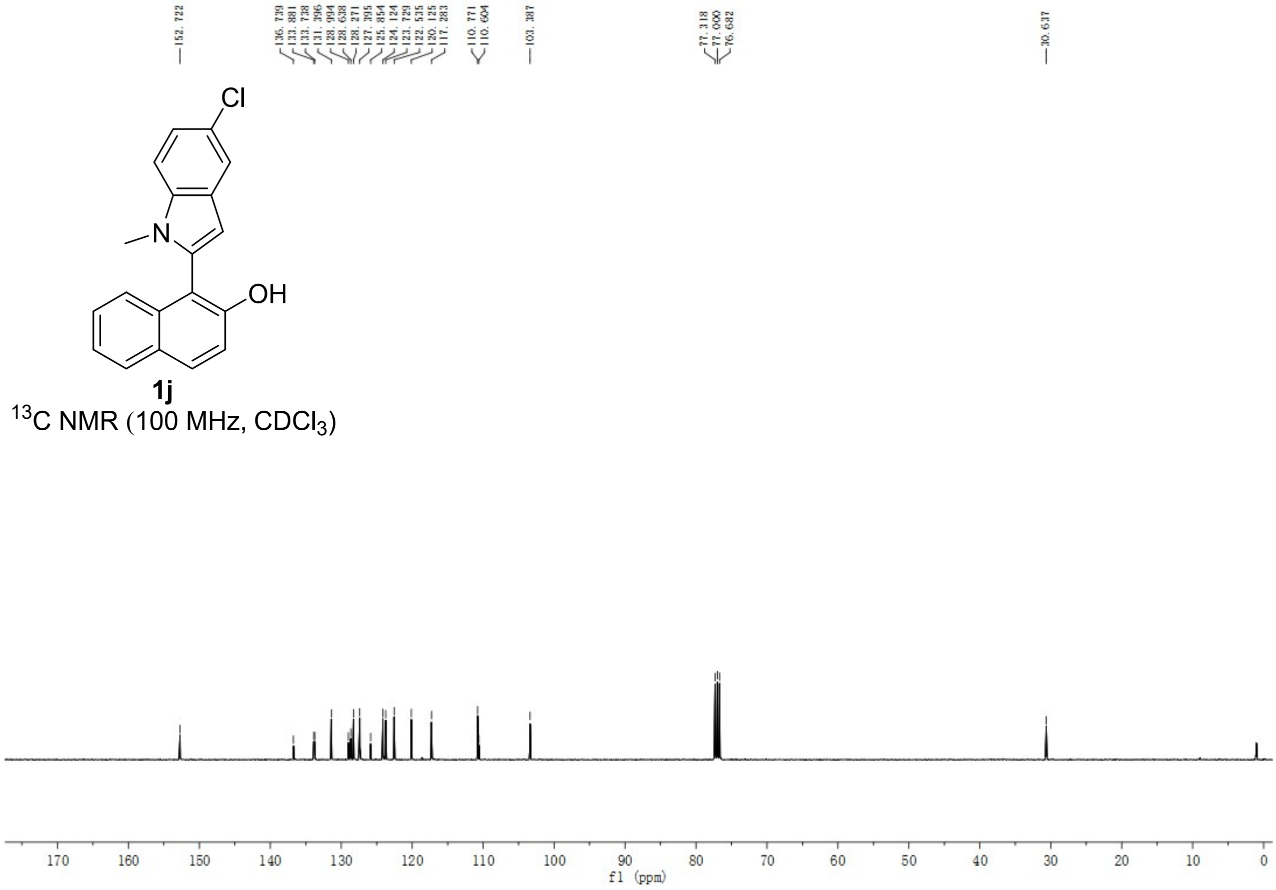

1j

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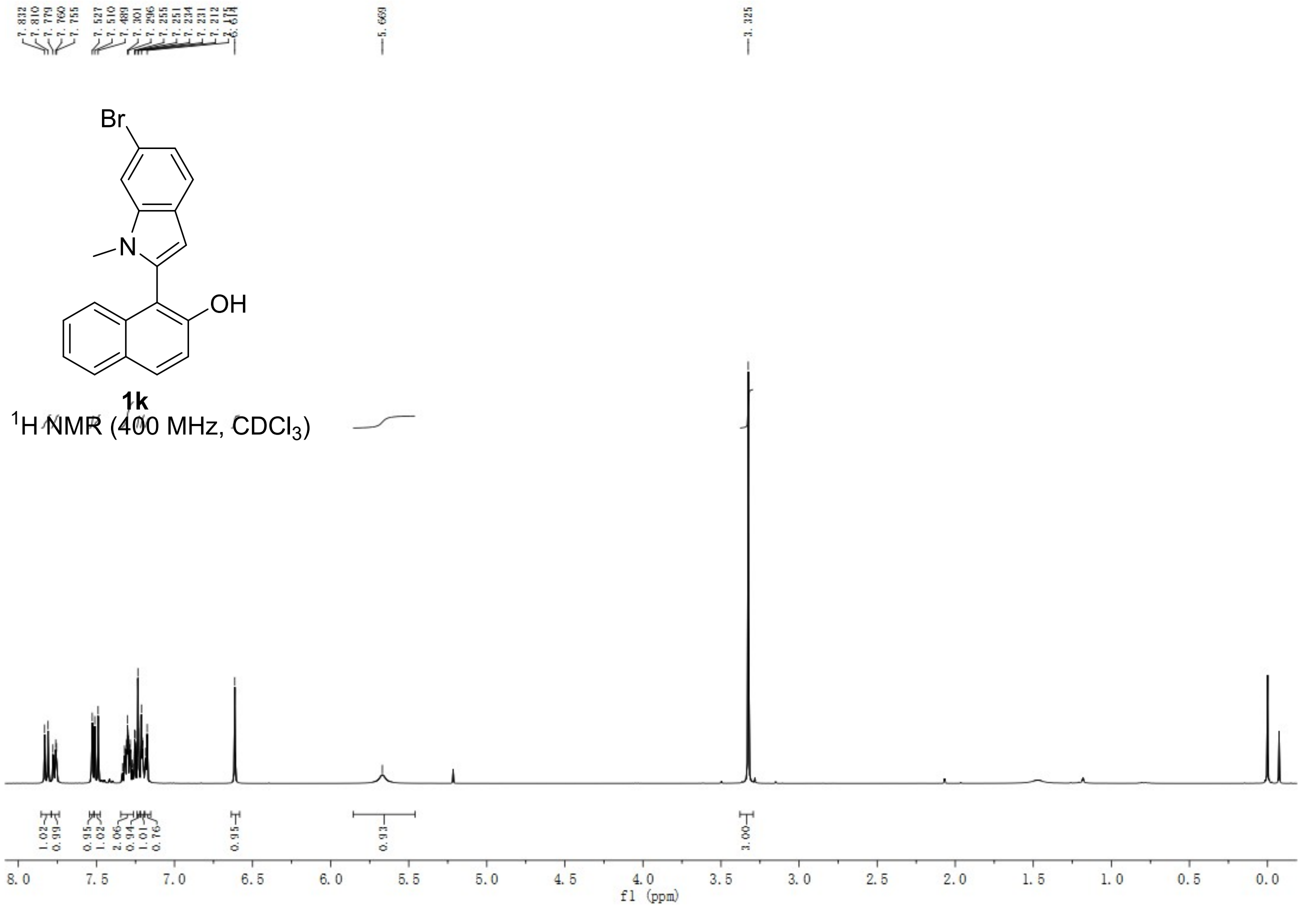

1k

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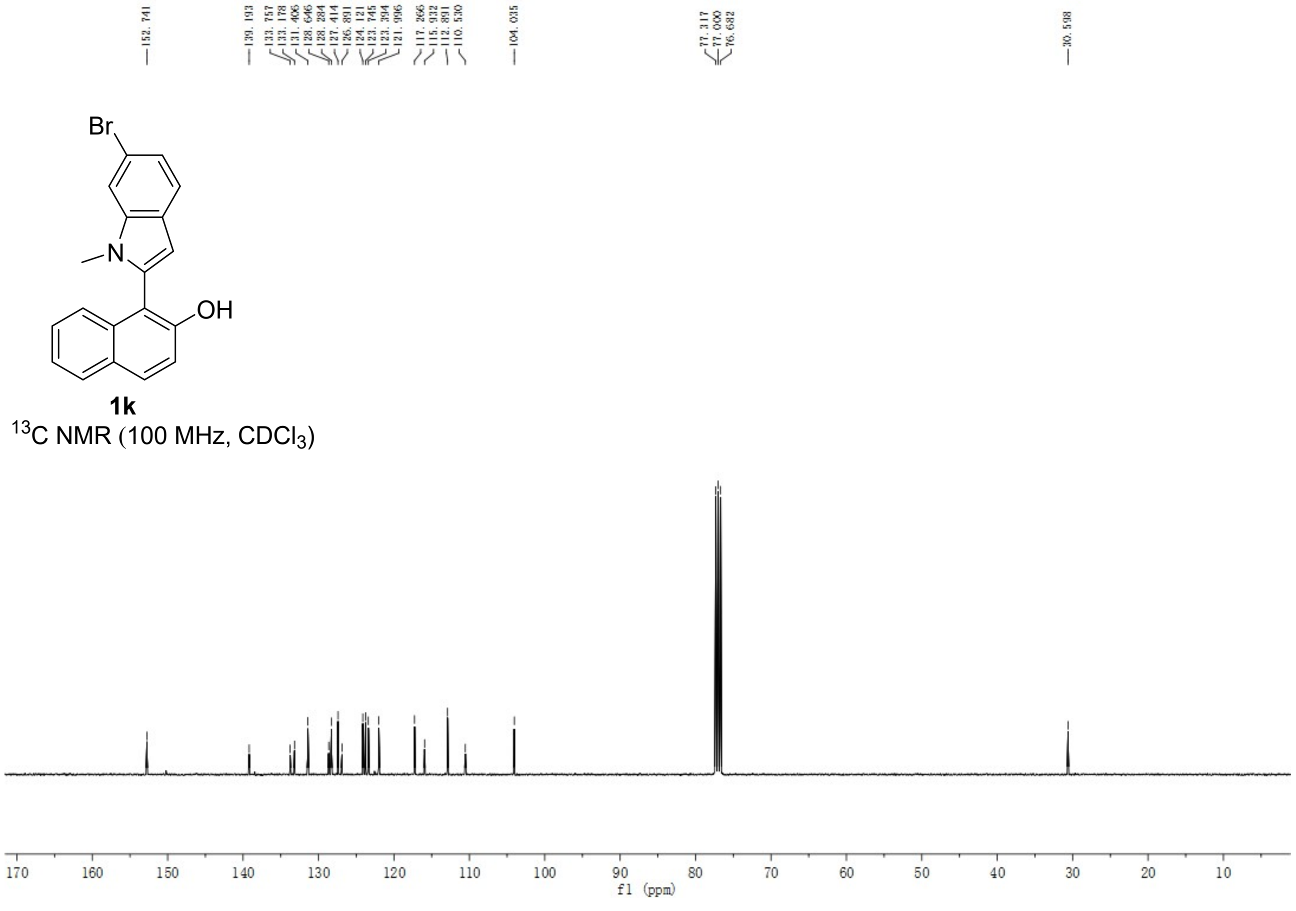

1k

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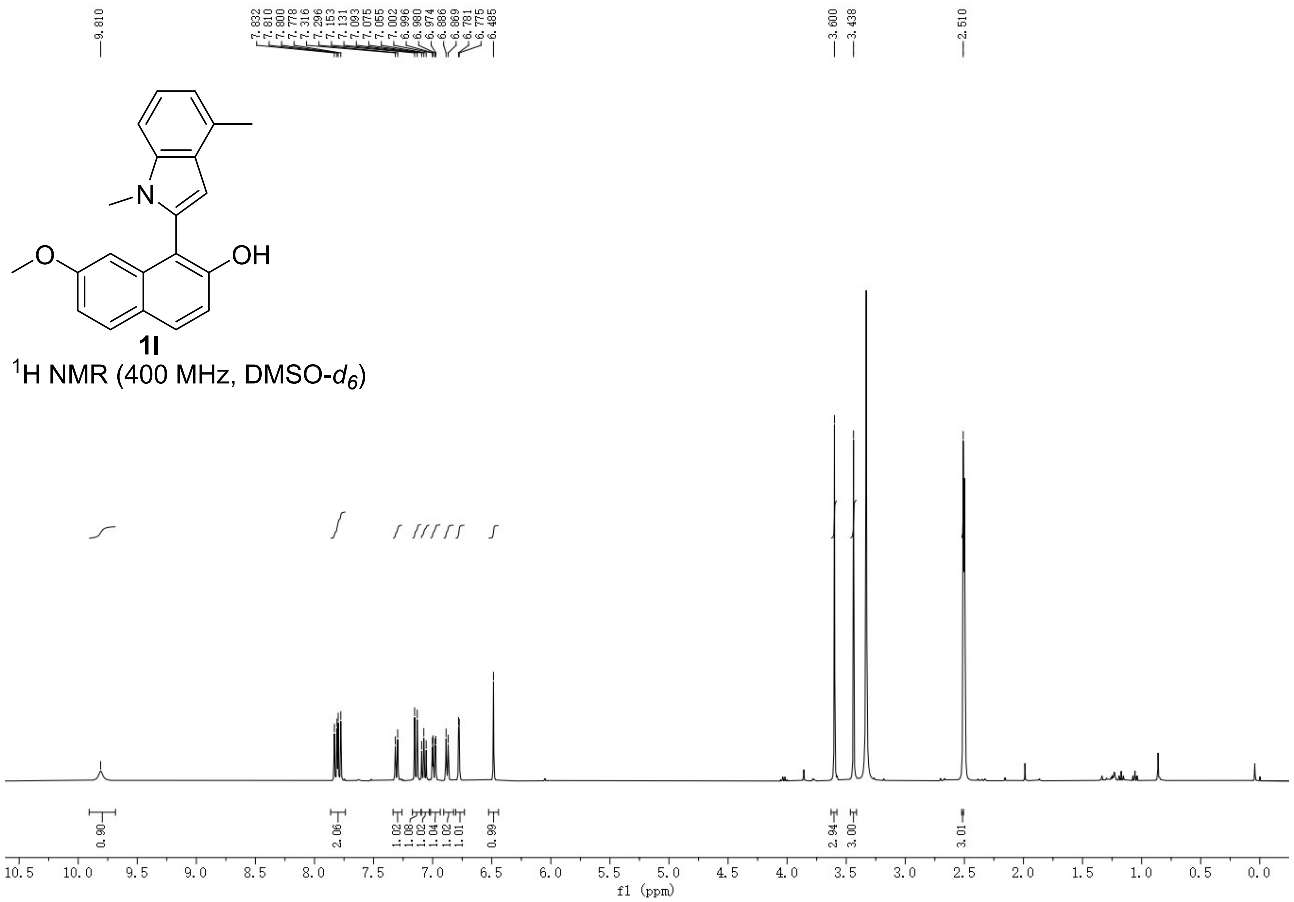

1l

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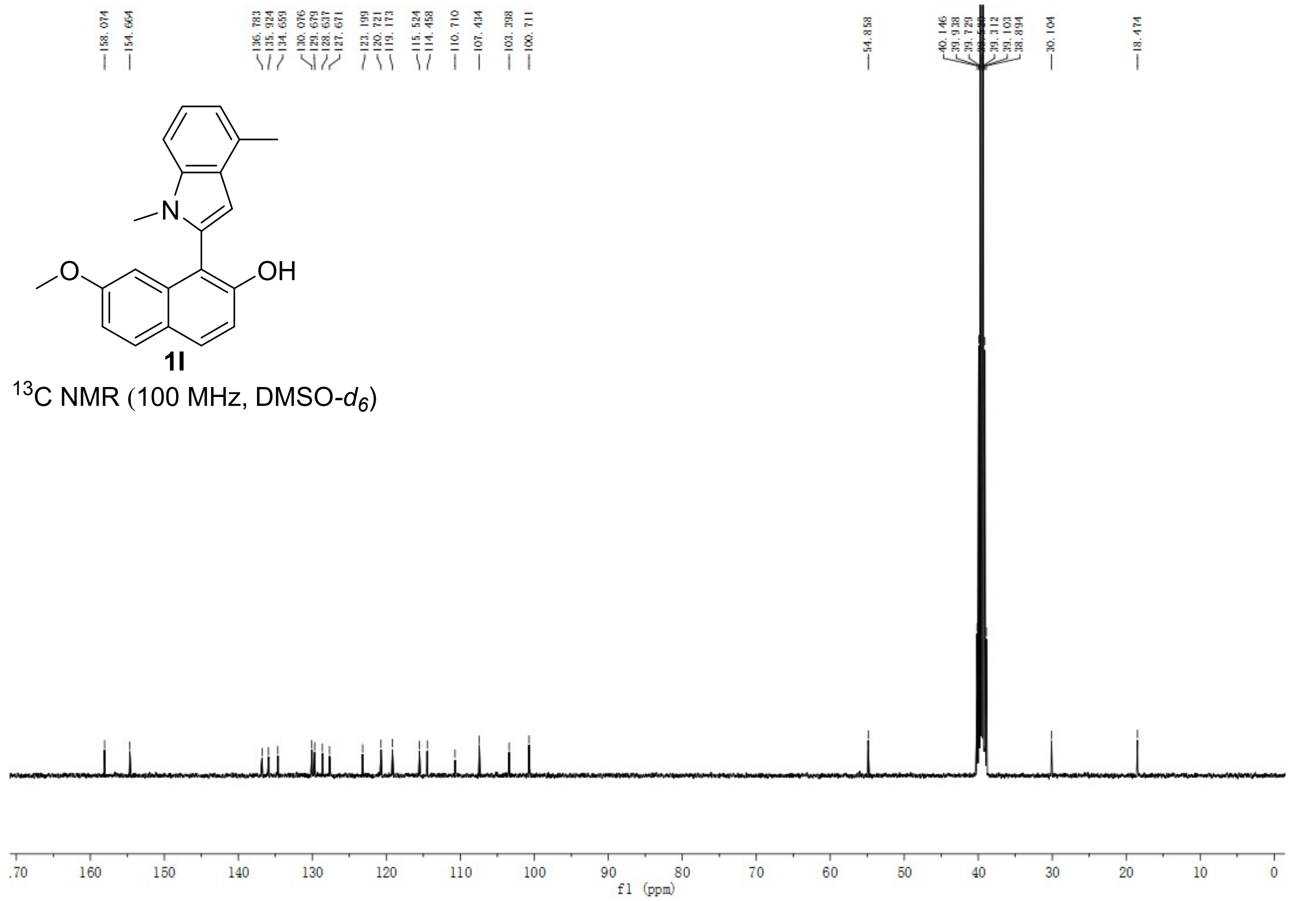

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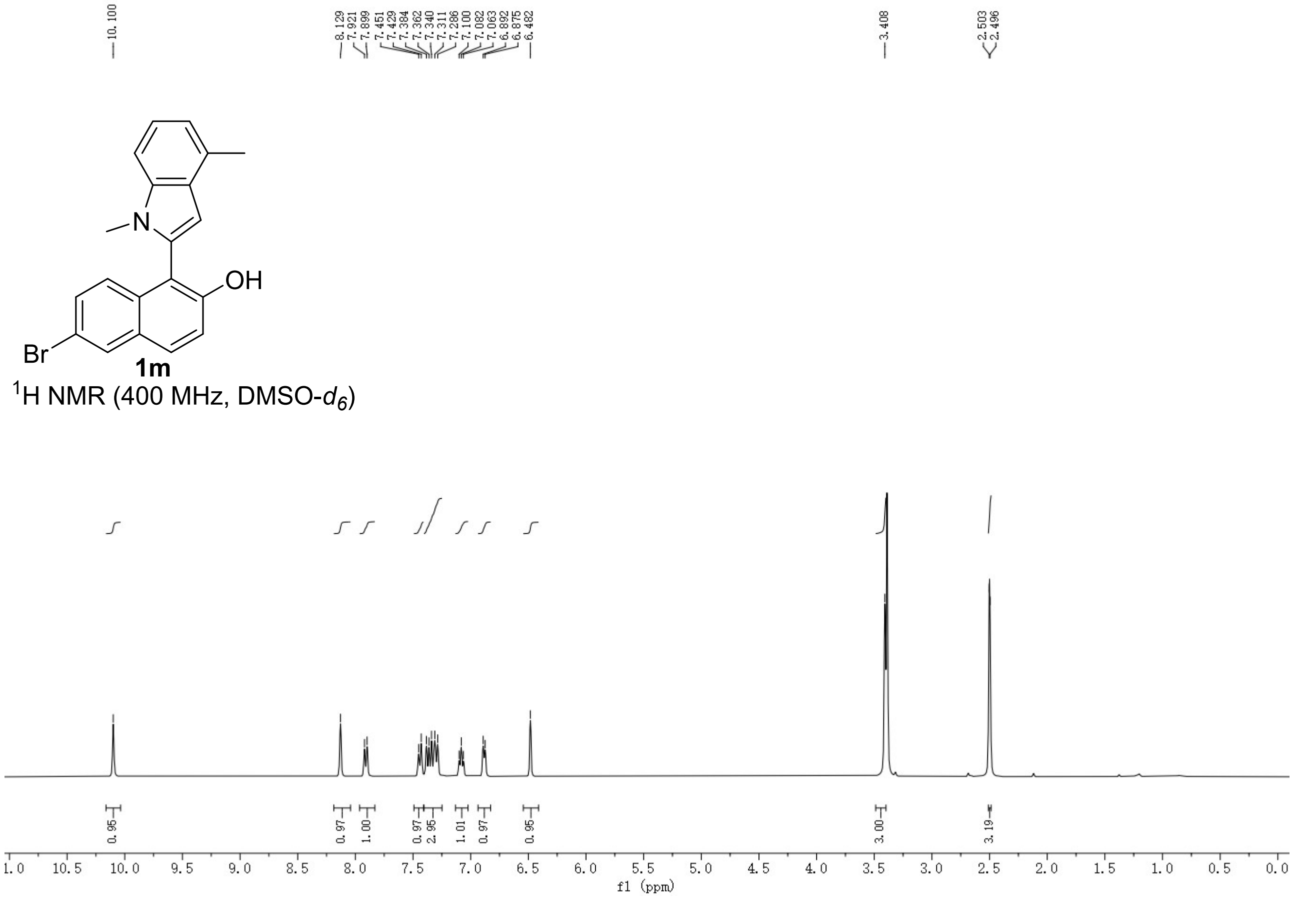

1m

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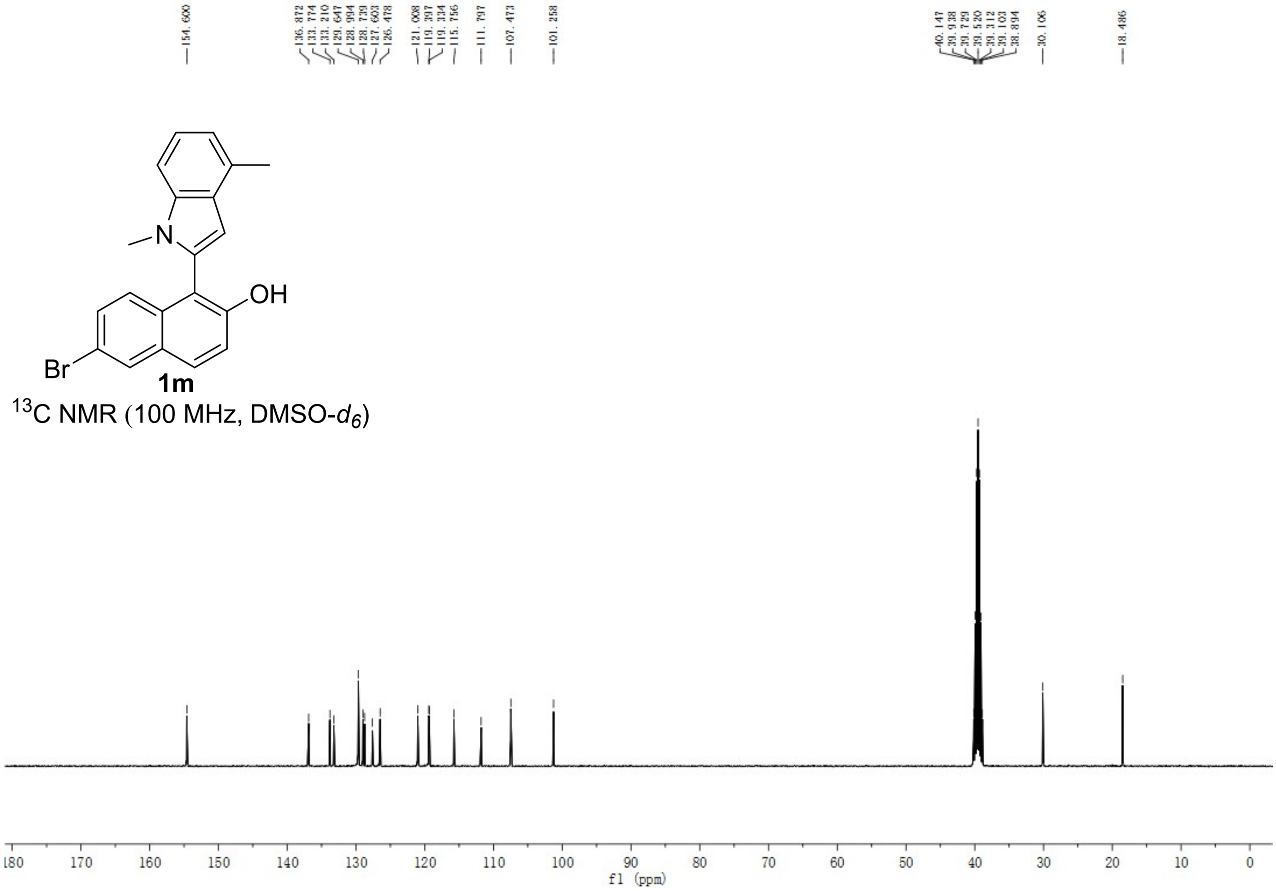

1m

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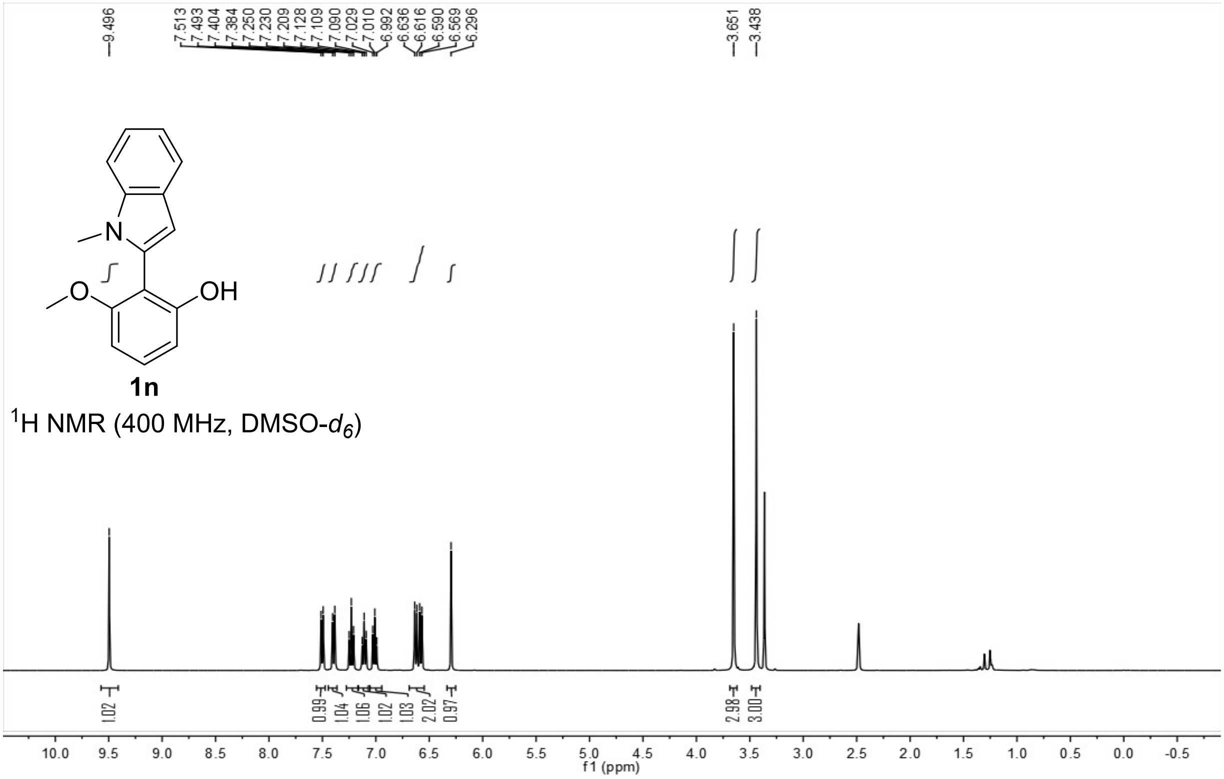
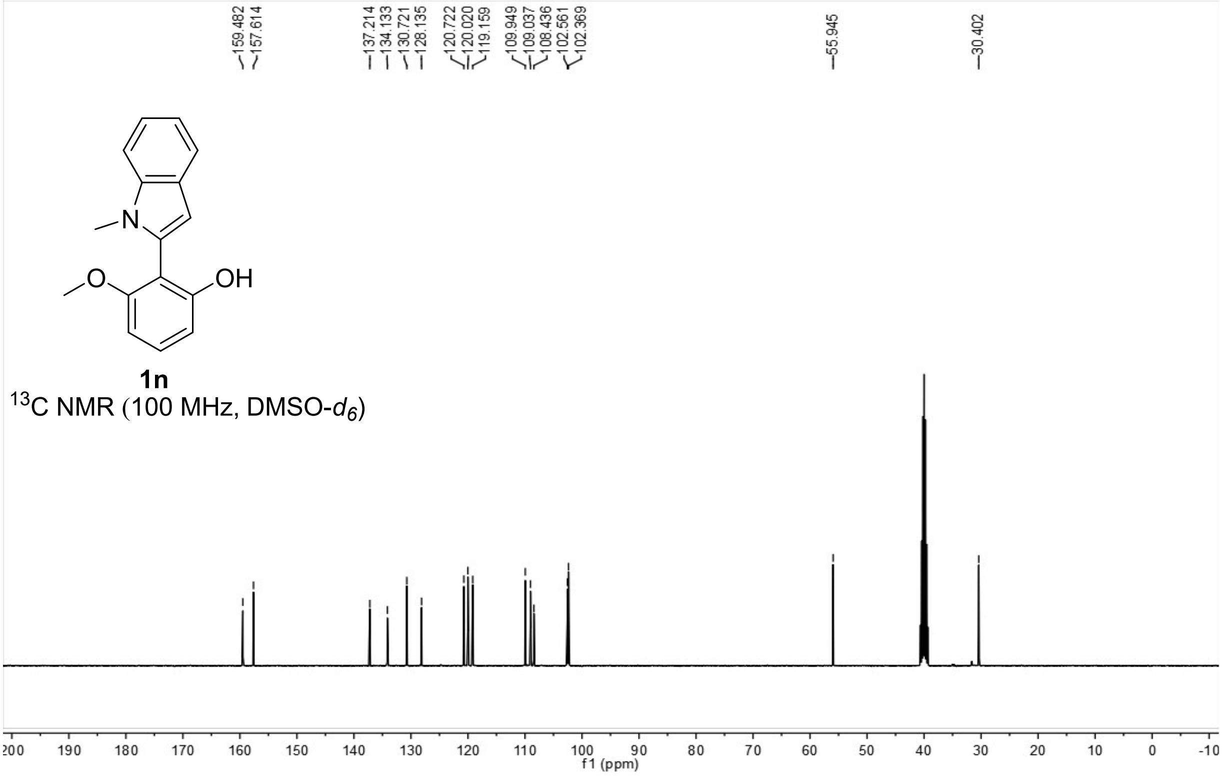

9.496
7.513
7.493
7.404
7.384
7.250
7.230
7.209
7.128
7.109
7.090
7.029
7.010
6.992
6.636
6.616
6.590
6.569
6.296
3.651
3.438
N
O
OH
1n
^{1}H NMR (400 MHz, DMSO-d_6)
1.02
0.99
1.04
1.06
1.02
1.03
2.02
0.97
2.98
3.00
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
f1 (ppm)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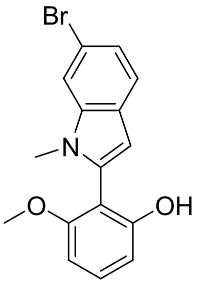
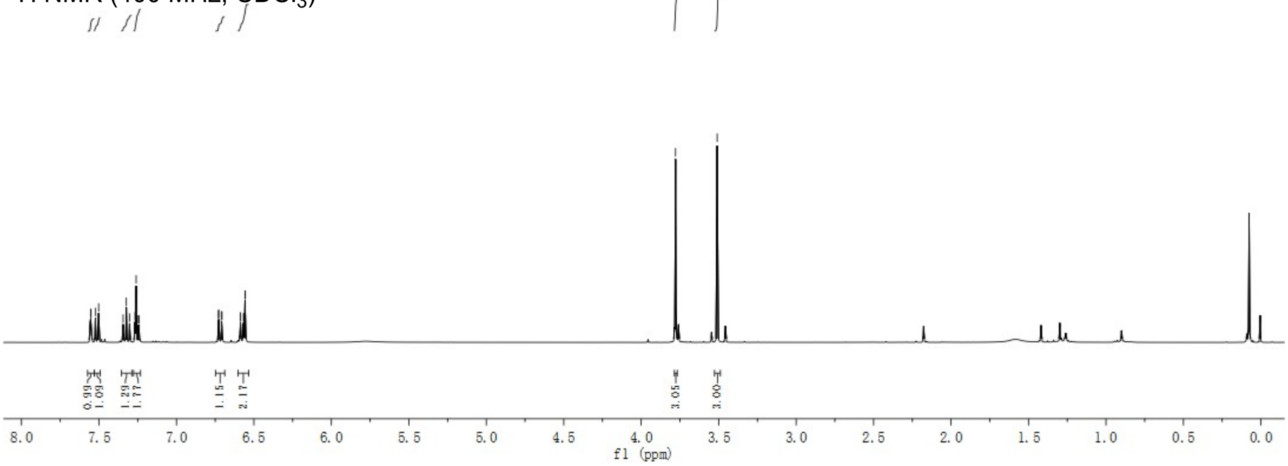
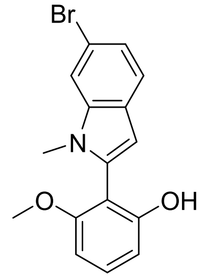
134.133
130.721
128.135
120.722
120.020
119.159
109.949
109.037
108.436
102.561
102.369
55.945
30.402
N
O
OH
1n
^{13}C NMR (100 MHz, DMSO-d_6)
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
-10
f1 (ppm)



1o

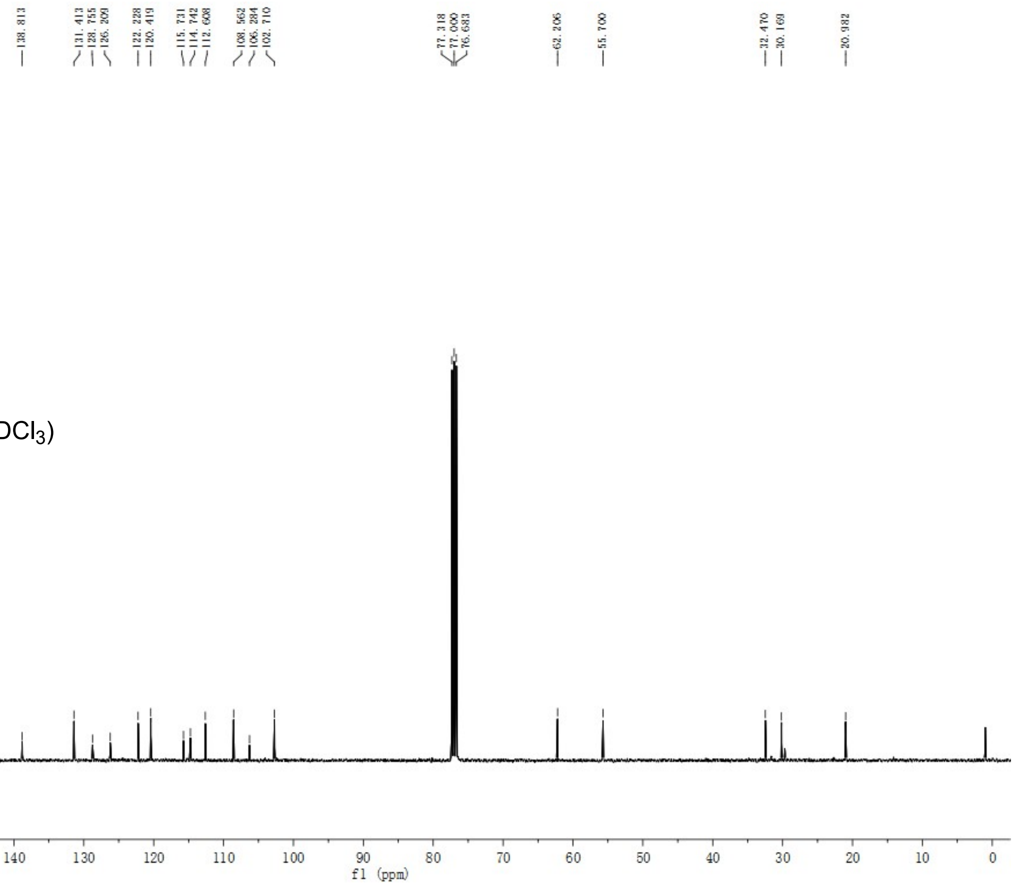
^{1}H NMR (400 MHz, $CDCl_3$)

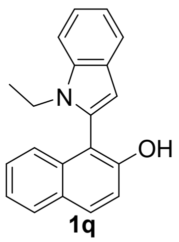




1o

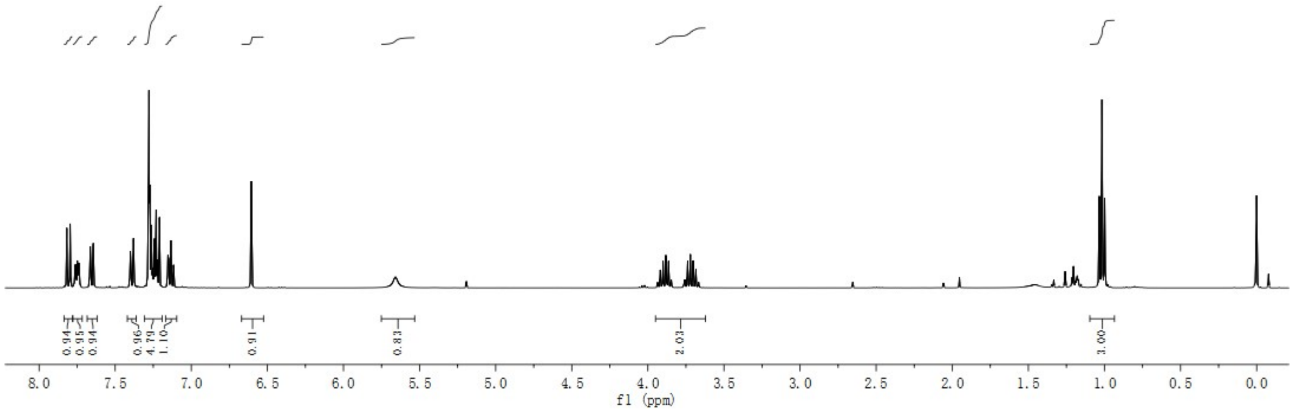
^{13}C NMR (100 MHz, $CDCl_3$)

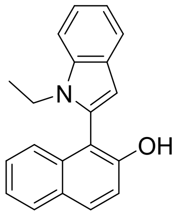




1q

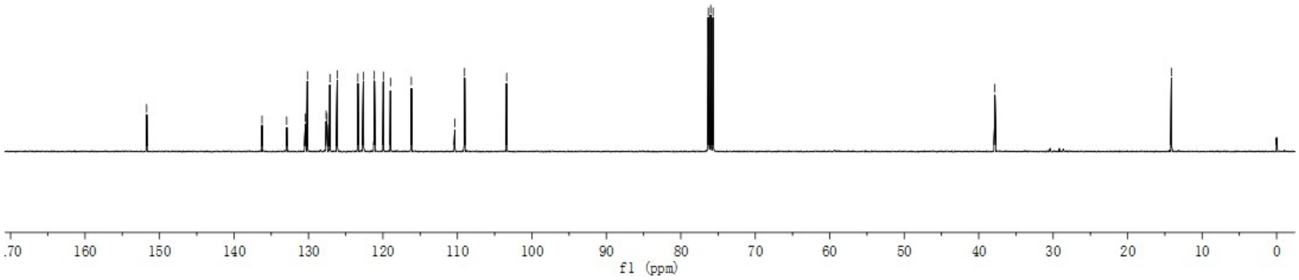
^{1}H NMR (400 MHz, CDCl$_3$)

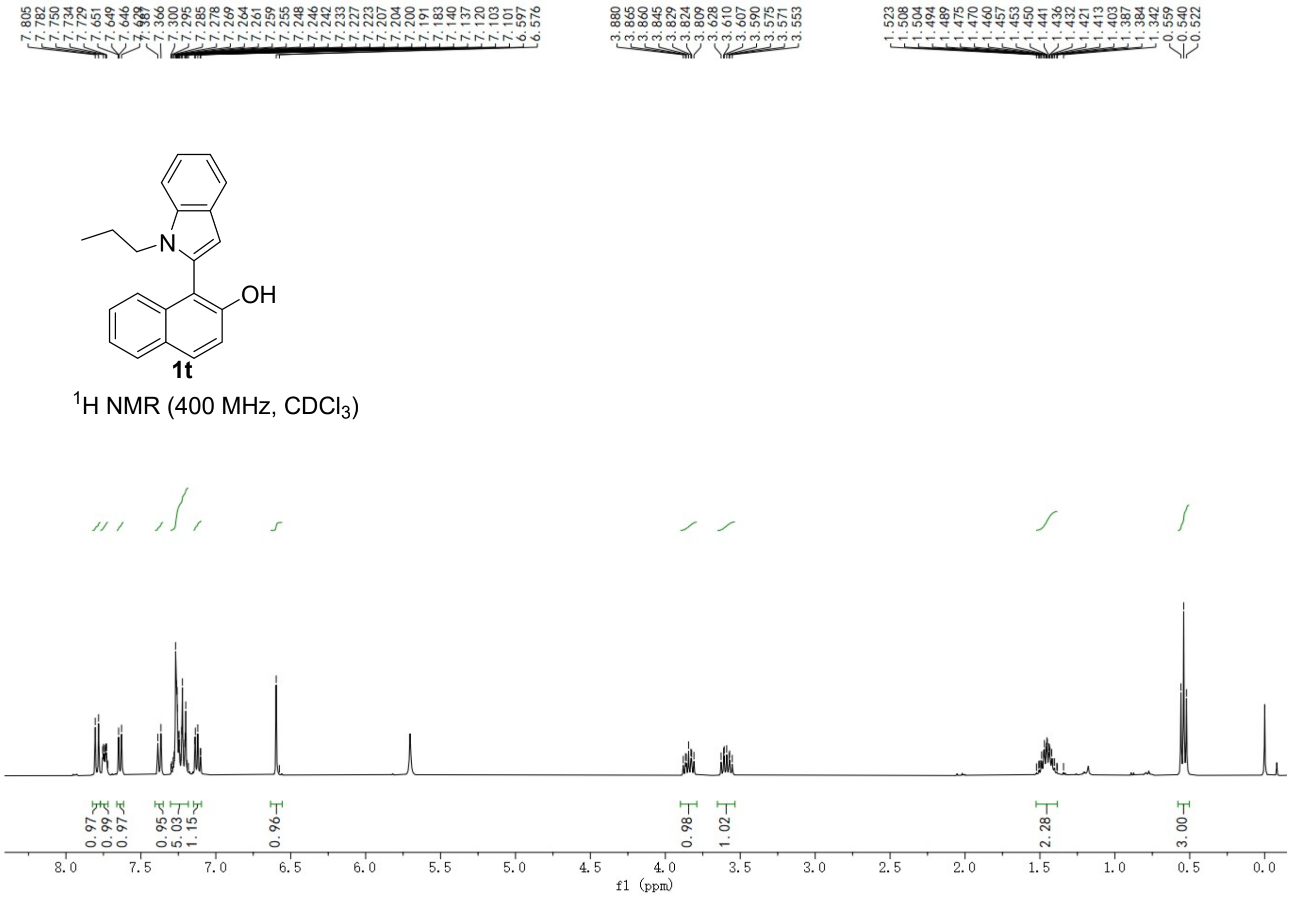




1q

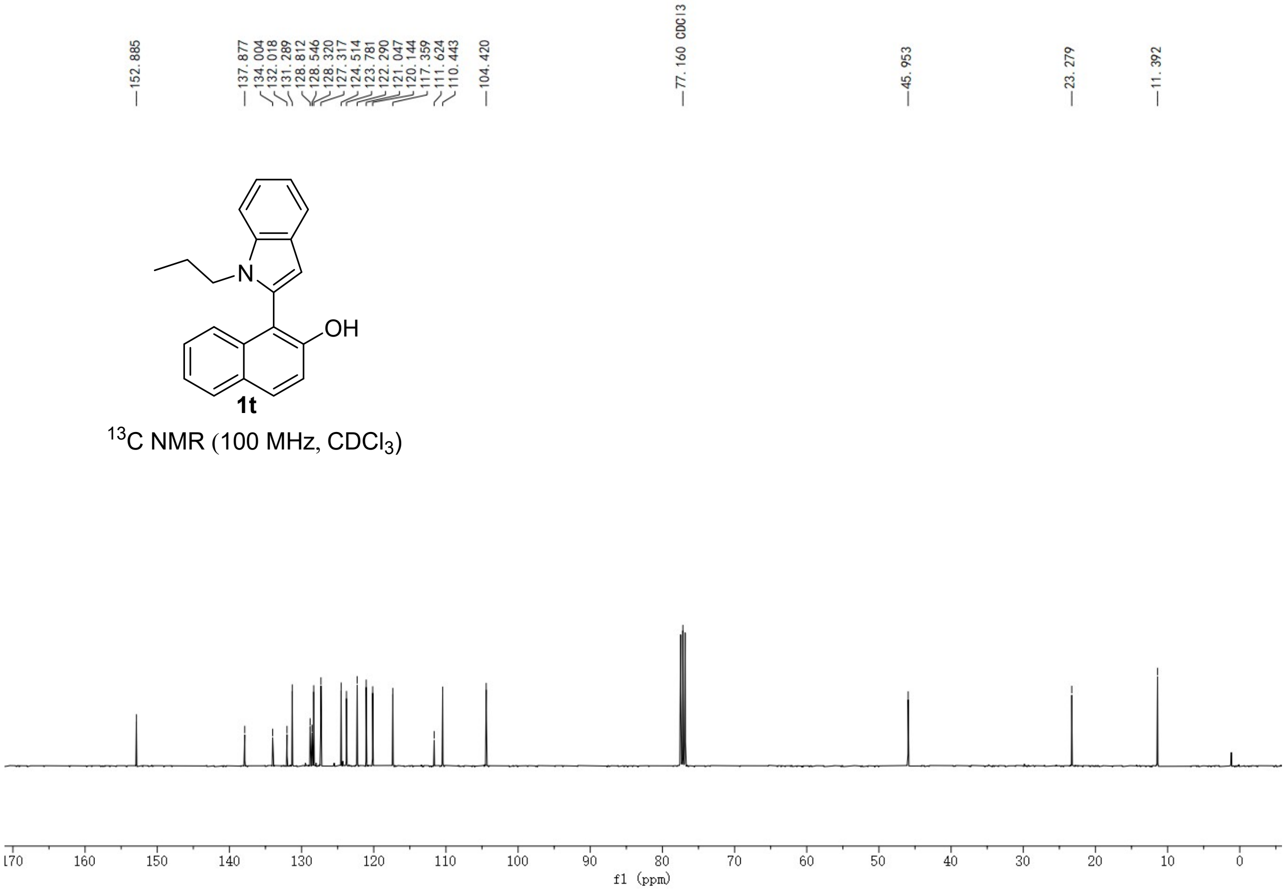
^{13}C NMR (100 MHz, CDCl$_3$)





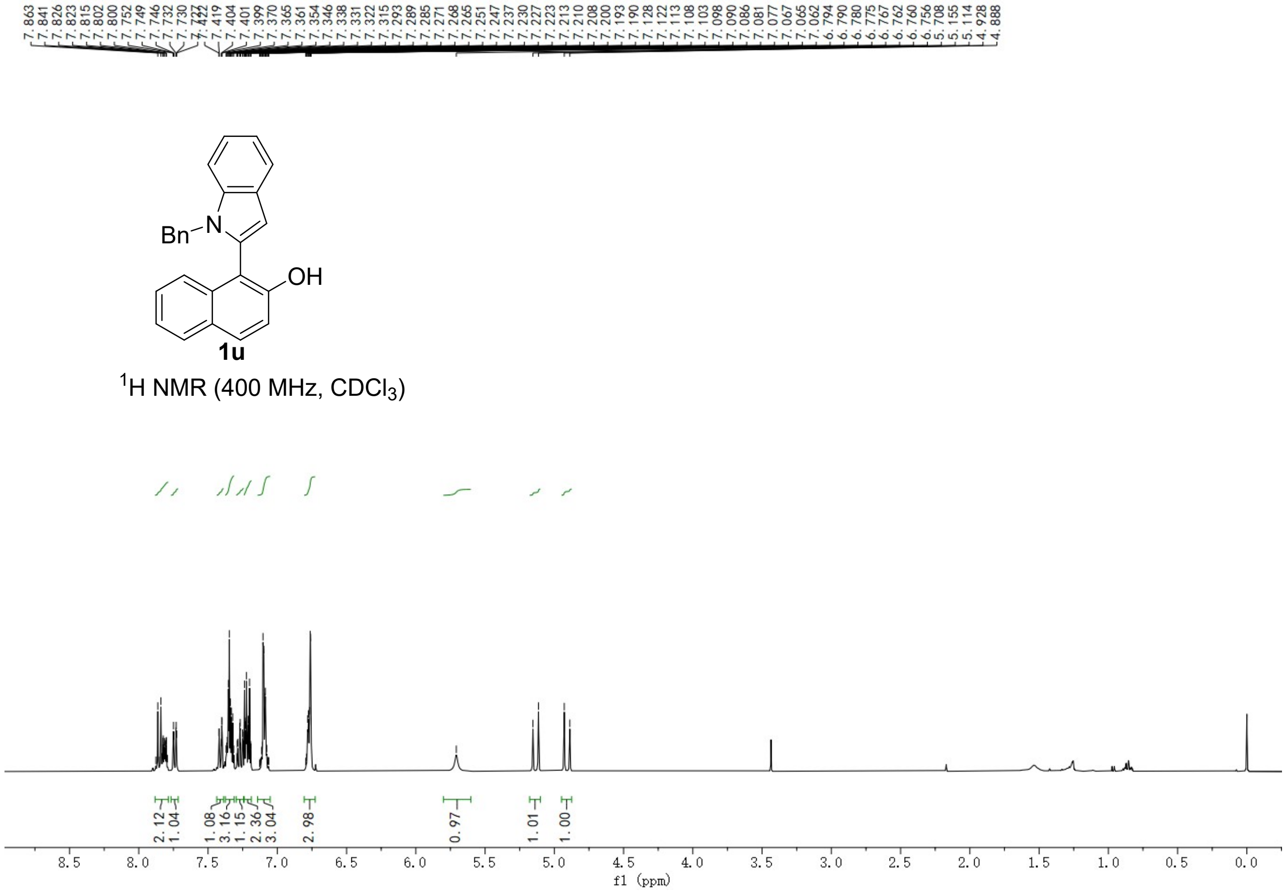
1t

^{1}H NMR (400 MHz, CDCl$_3$)



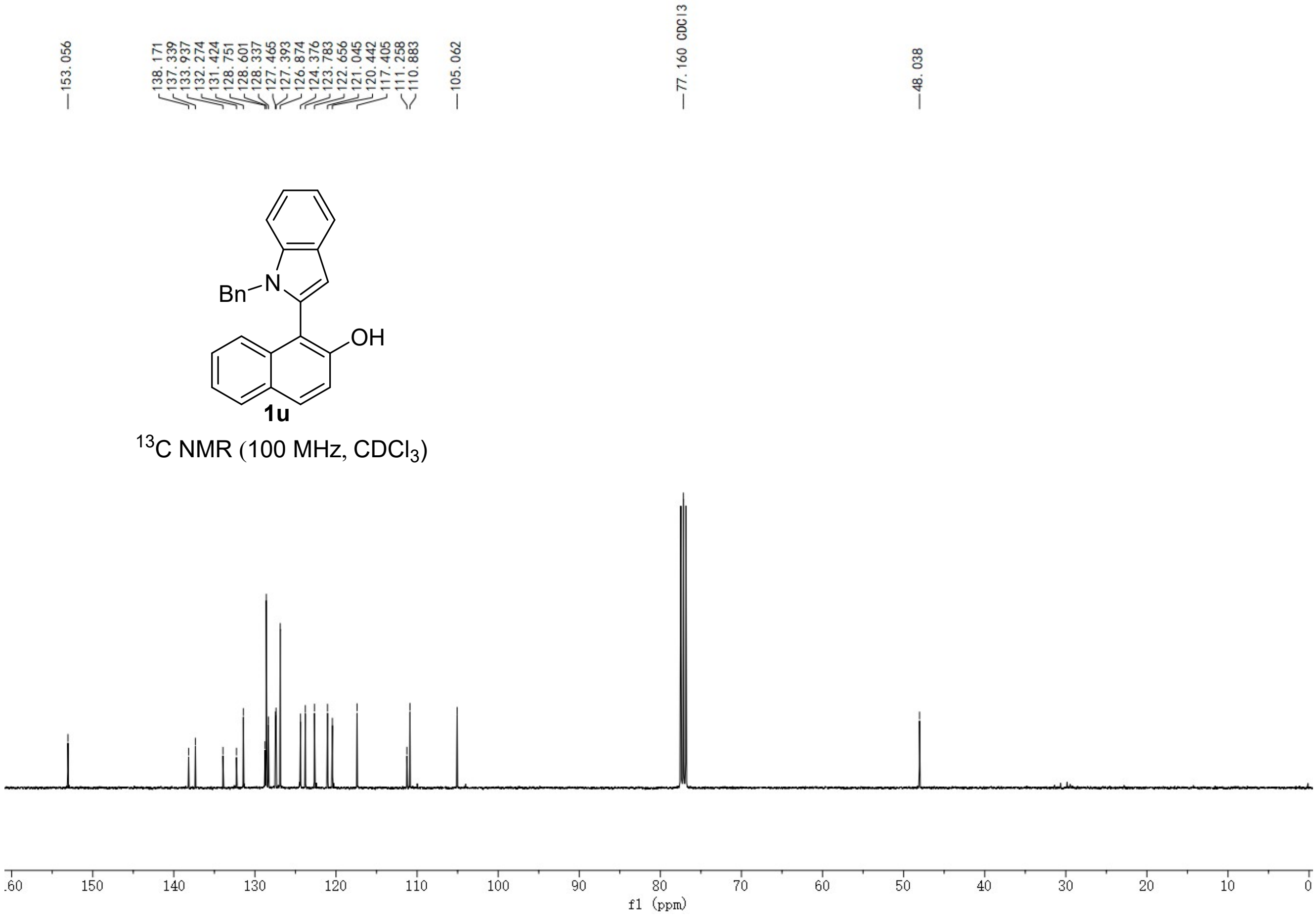
1t

^{13}C NMR (100 MHz, CDCl$_3$)



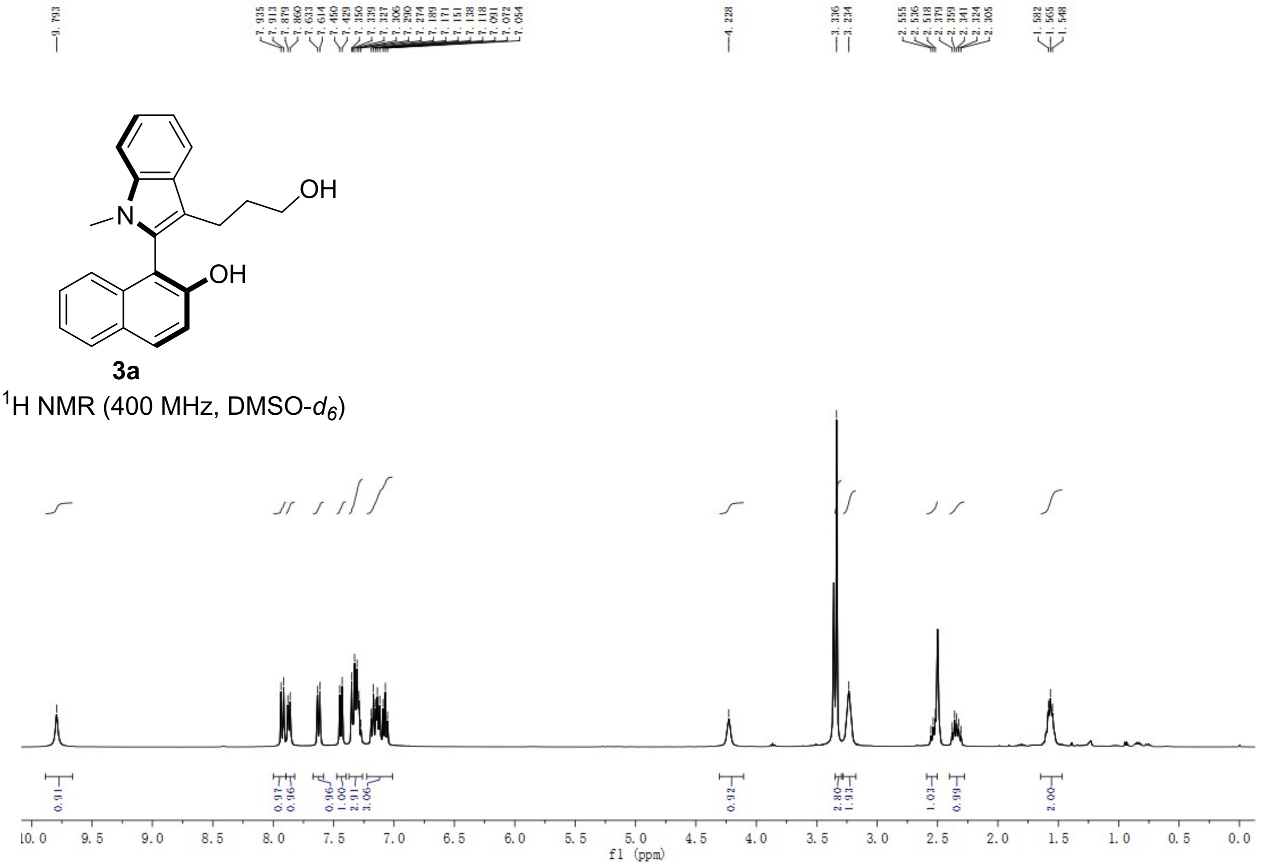
1u

^1H NMR (400 MHz, $CDCl_3$)



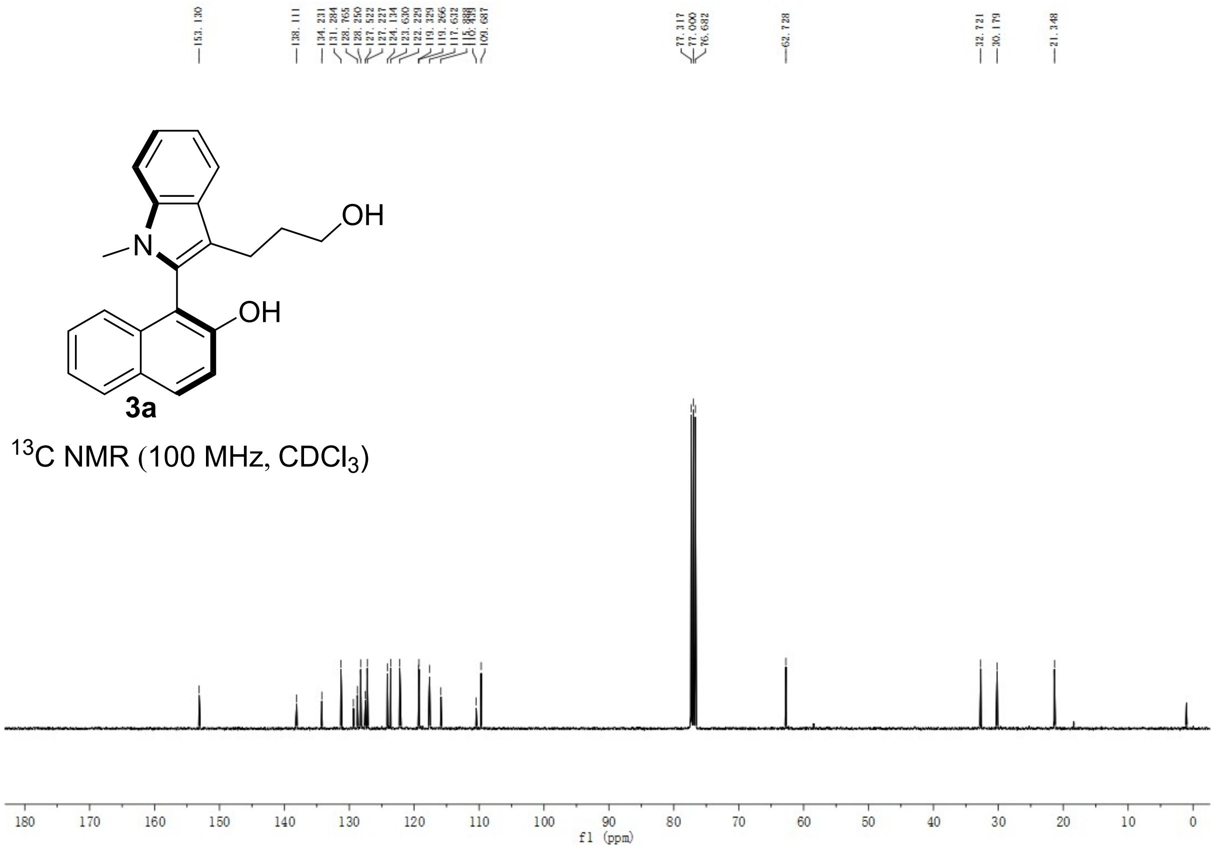
1u

^{13}C NMR (100 MHz, $CDCl_3$)



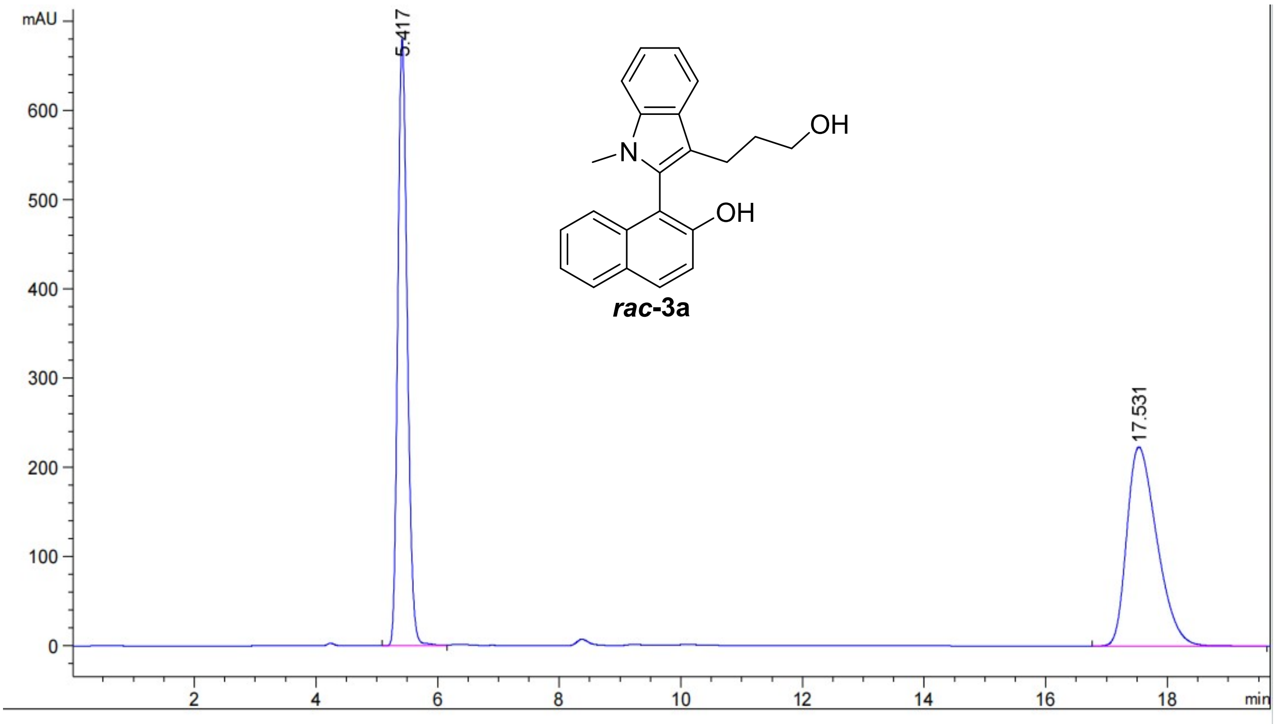
3a

^{1}H NMR (400 MHz, DMSO-d_6)

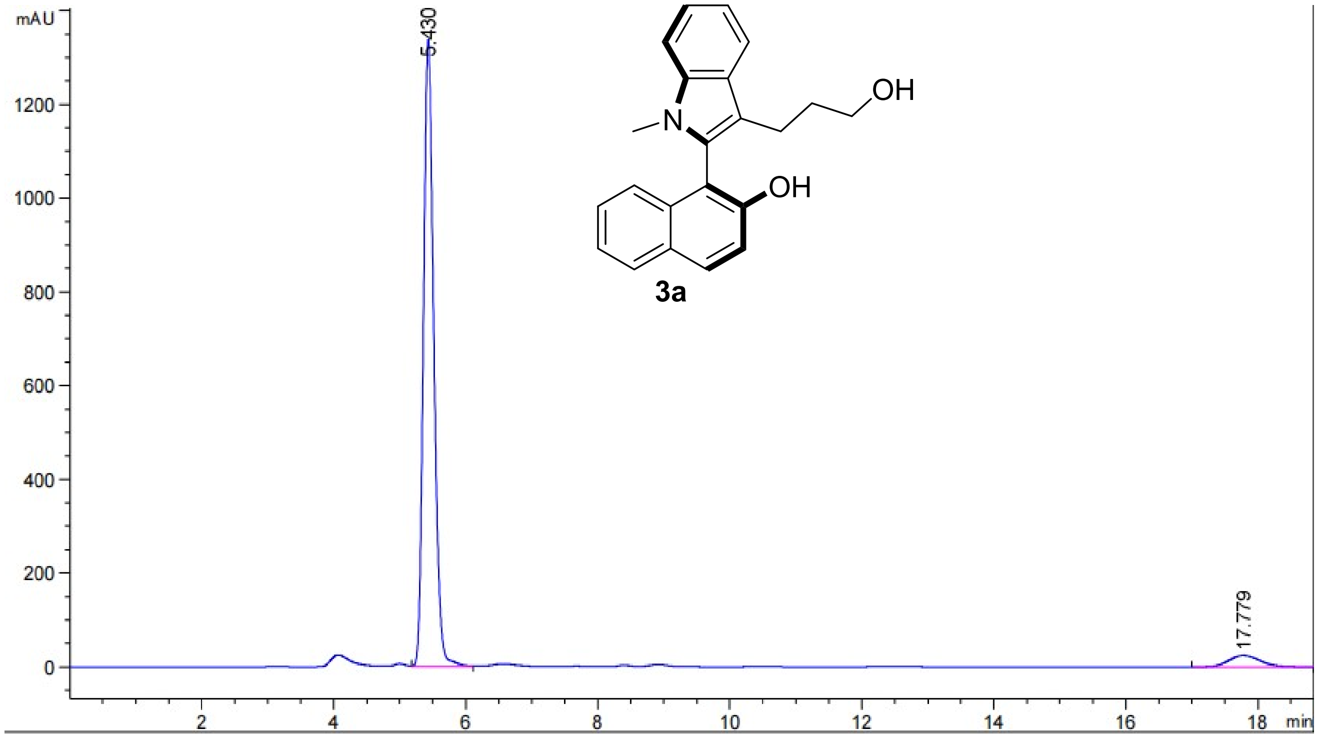


3a

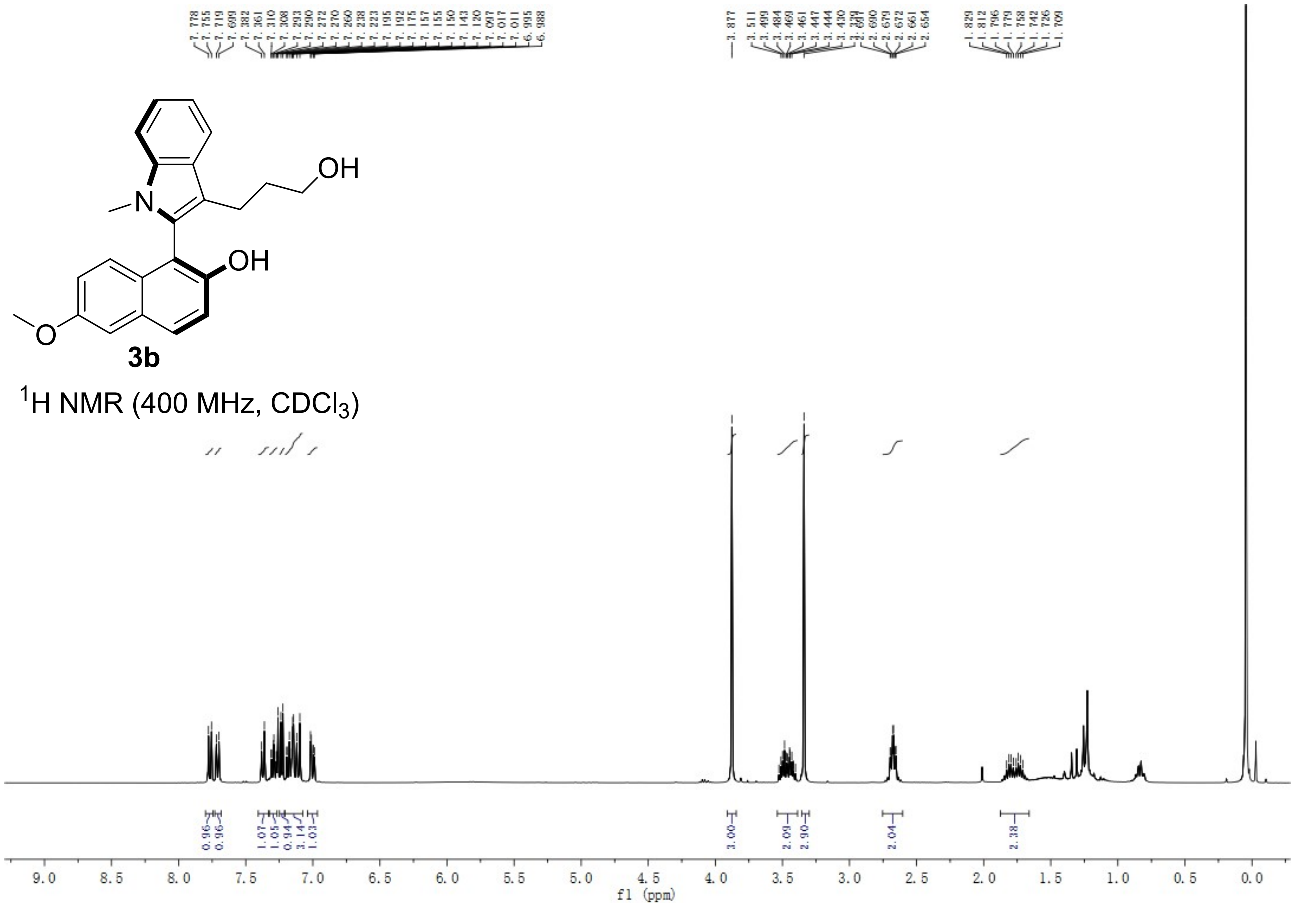
^{13}C NMR (100 MHz, CDCl$_3$)



Peak #	Ret Time [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	5.417	BV	0.1689	7393.05518	679.87708	49.0537
2	17.531	BB	0.5325	7678.28174	223.10687	50.9463

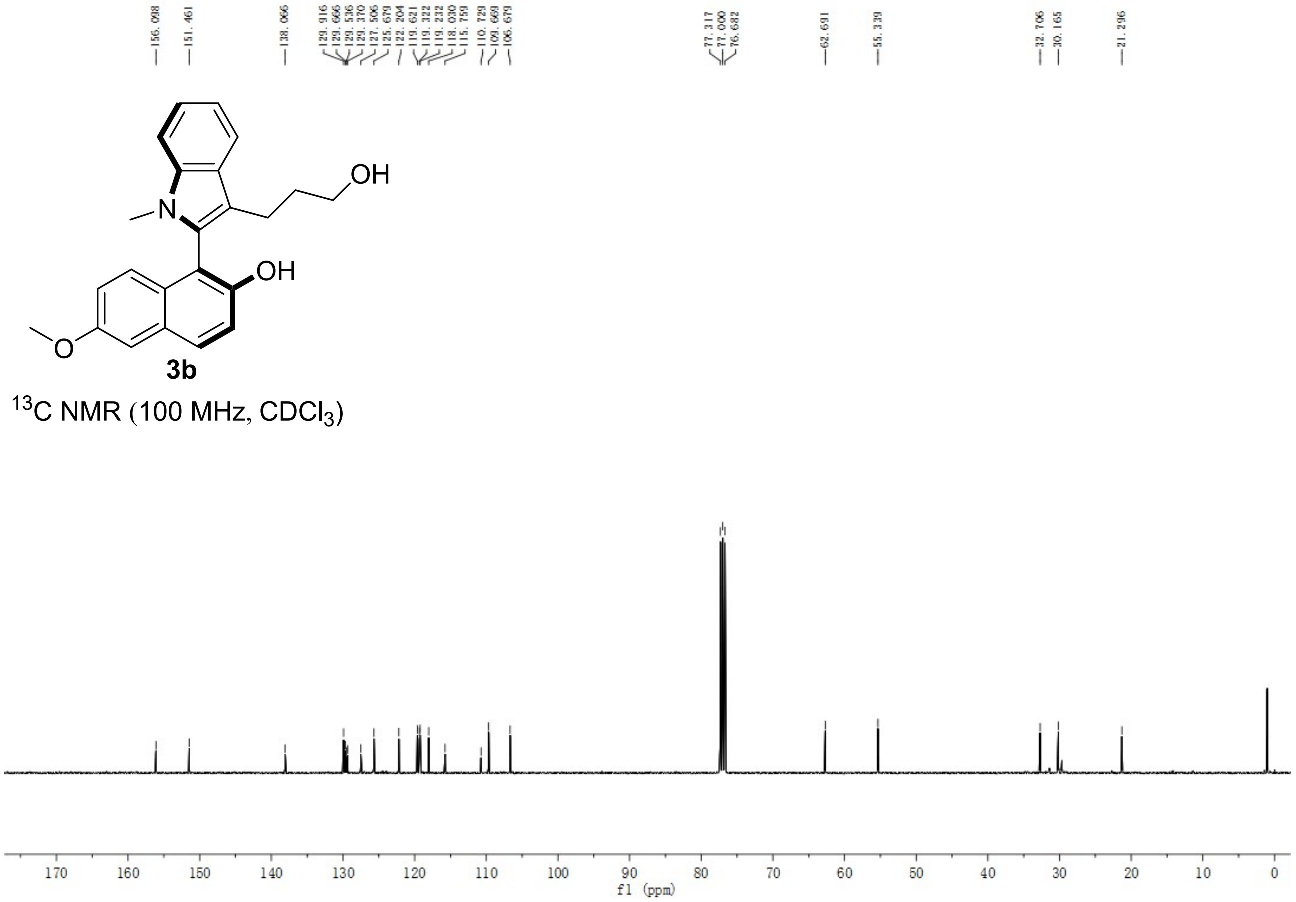


Peak #	Ret Time [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	5.430	VV	0.1718	1.47781e4	1338.38965	94.8172
2	17.779	BBA	0.5076	807.79211	24.63331	5.1828



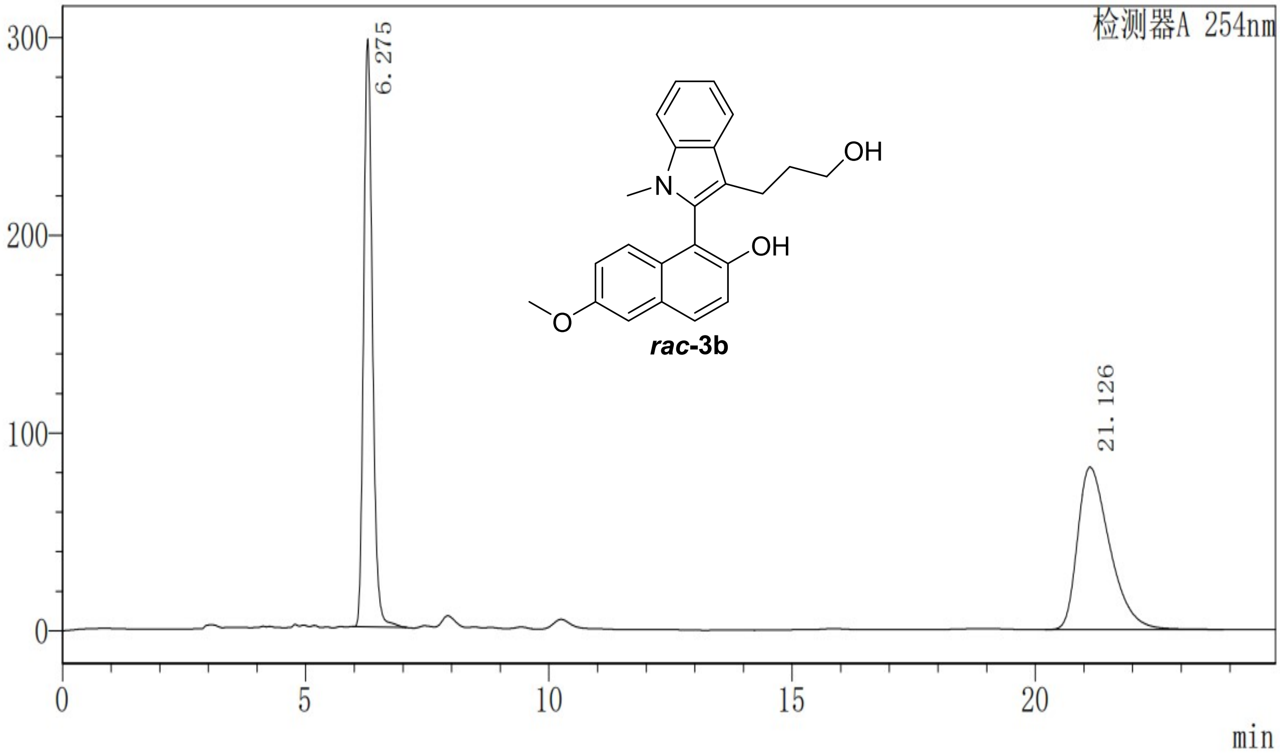
3b

^{1}H NMR (400 MHz, CDCl$_3$)

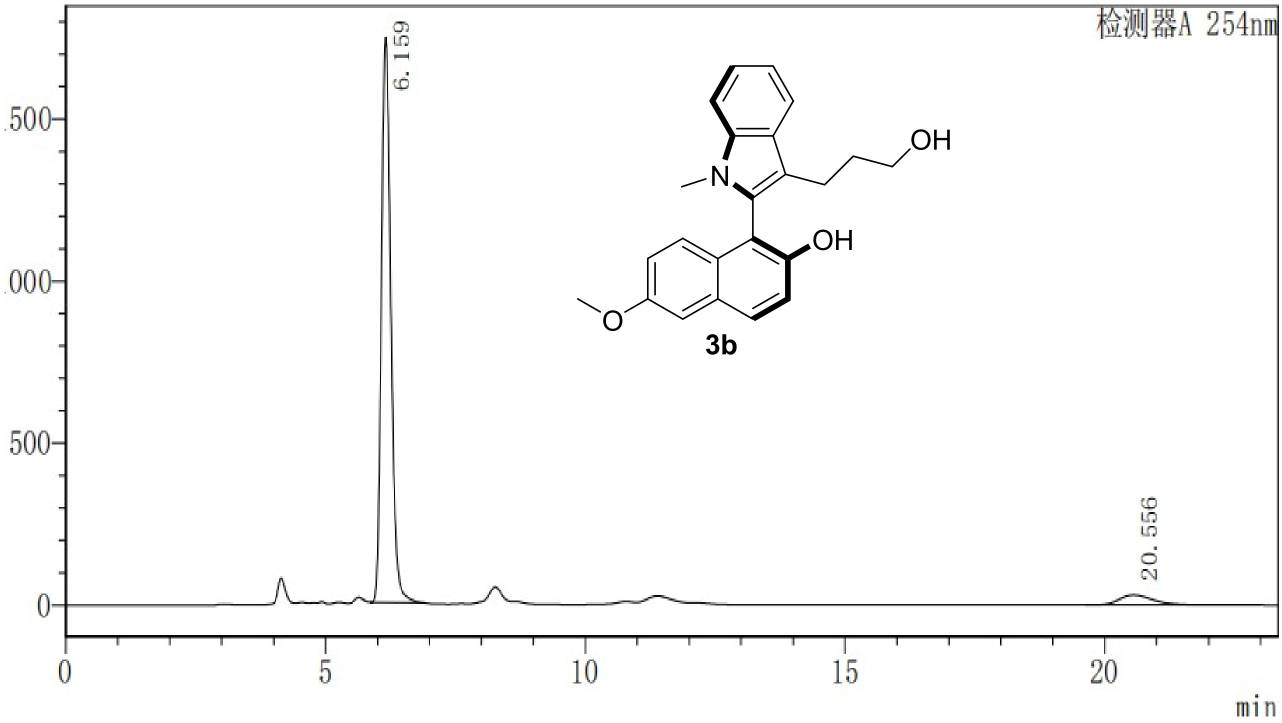


3b

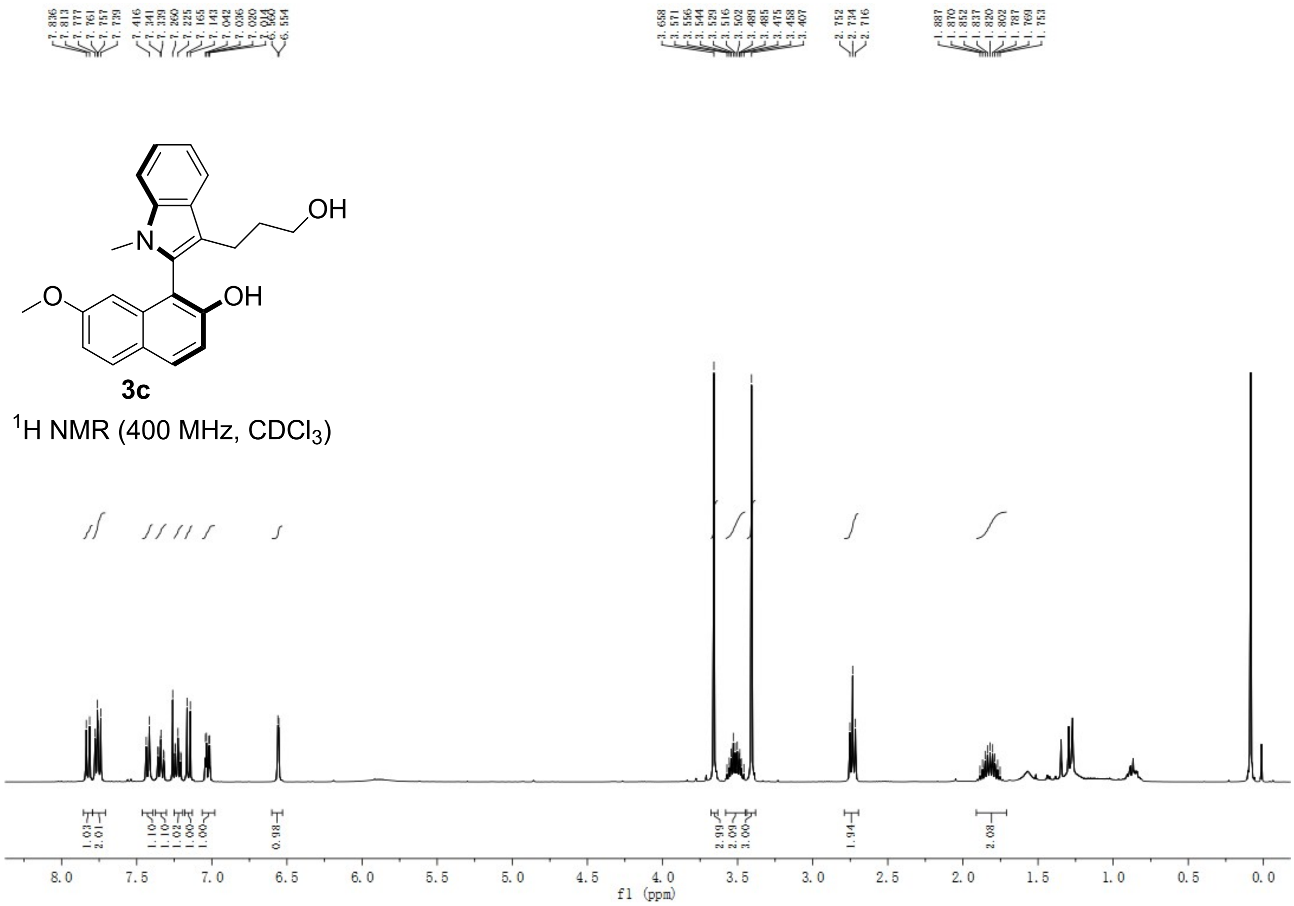
^{13}C NMR (100 MHz, CDCl$_3$)



Peak	Ret. Time	Area	Height	Area%
1	6.275	3736912	297206	49.709
2	21.126	3780625	82178	50.291

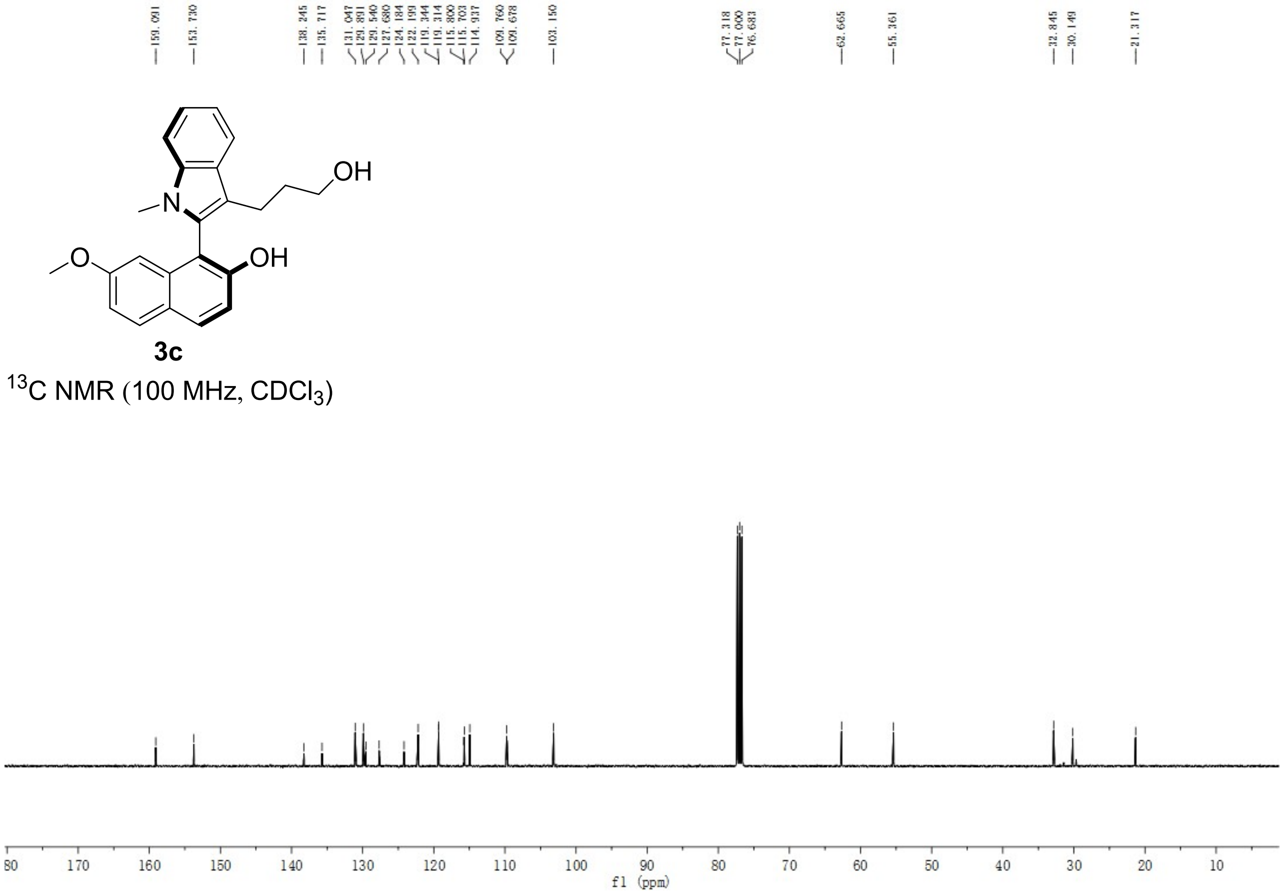


Peak	Ret. Time	Area	Height	Area%
1	6.159	22100485	1742952	94.044
2	20.556	1399586	30900	5.956



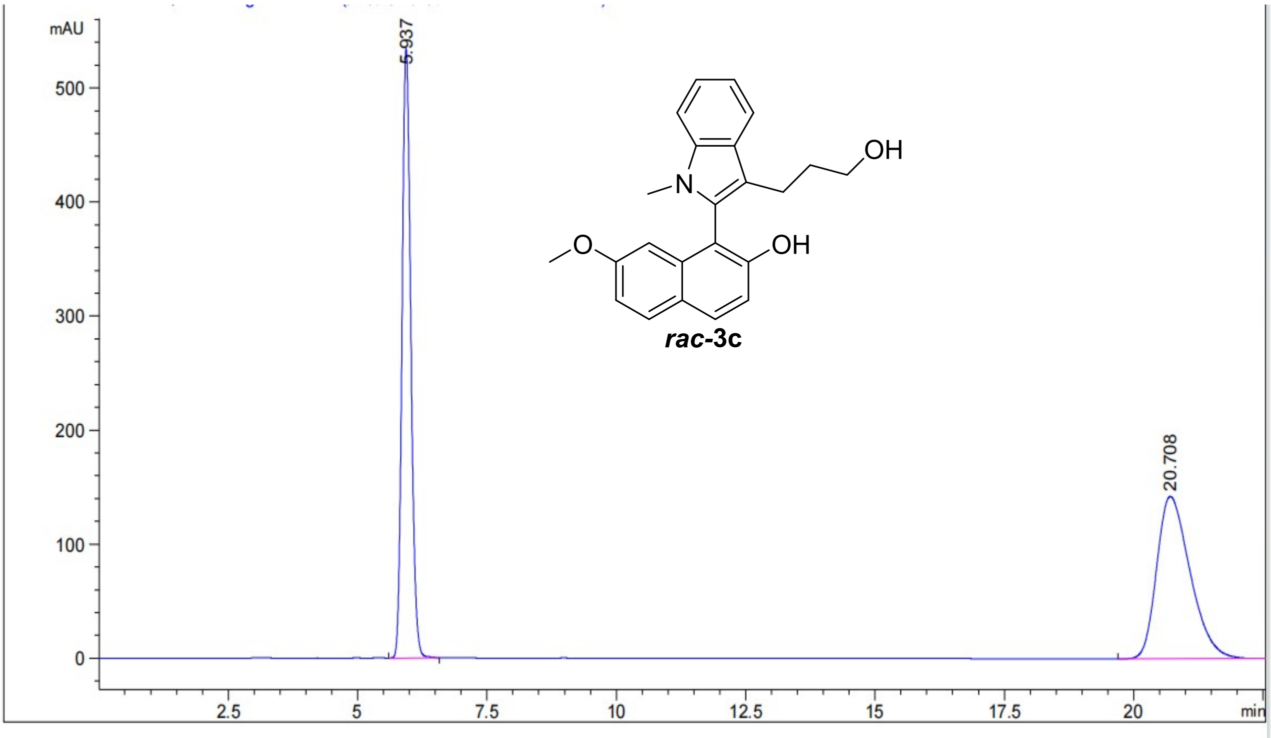
3c

^{1}H NMR (400 MHz, CDCl$_3$)

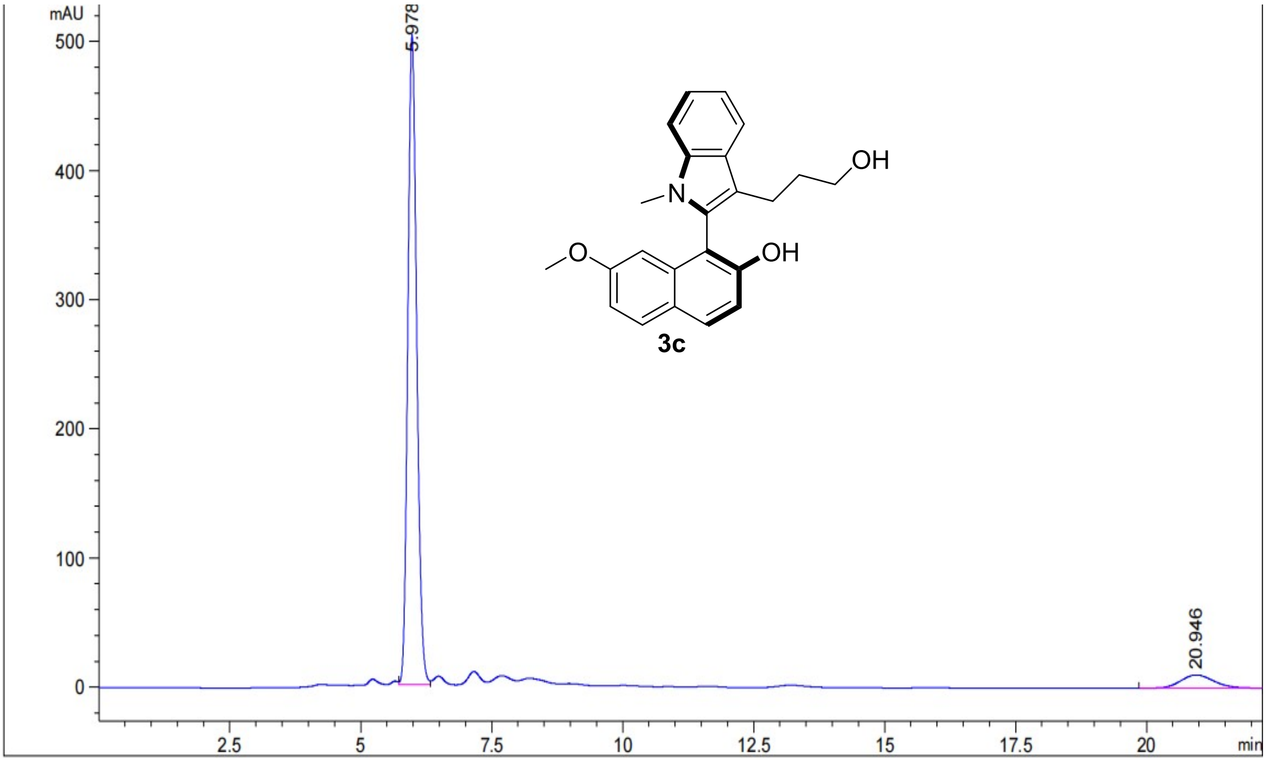


3c

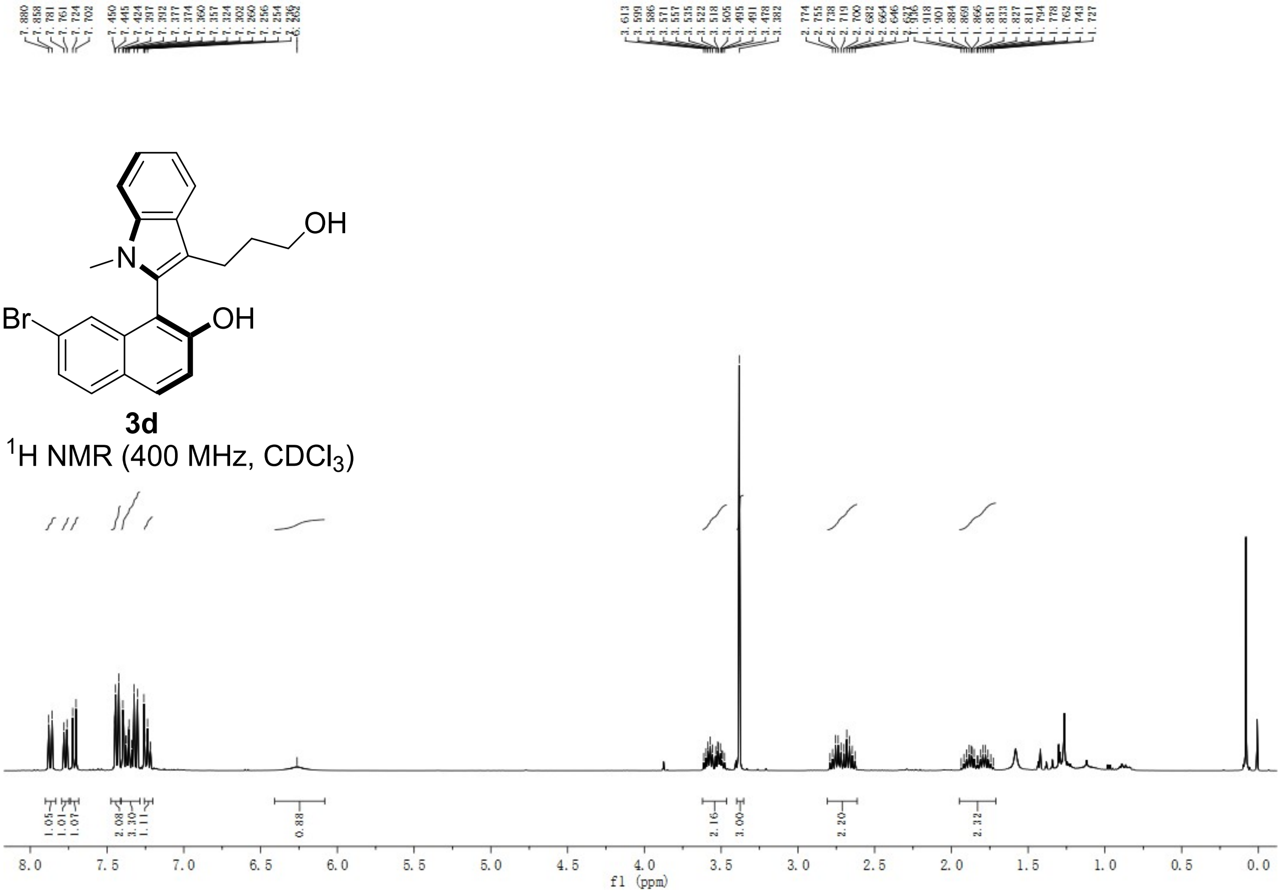
^{13}C NMR (100 MHz, CDCl$_3$)



```
Peak Ret time Type  Width      Area       Height       Area
 #    [min]         [min]    [mAU*s]      [mAU]         %
----|-------|----|-------|----------|----------|--------|
  1    5.937 BB    0.1837 6306.00635  534.15417  49.7061
  2   20.708 BBA   0.6925 6380.58350  142.19362  50.2939
```

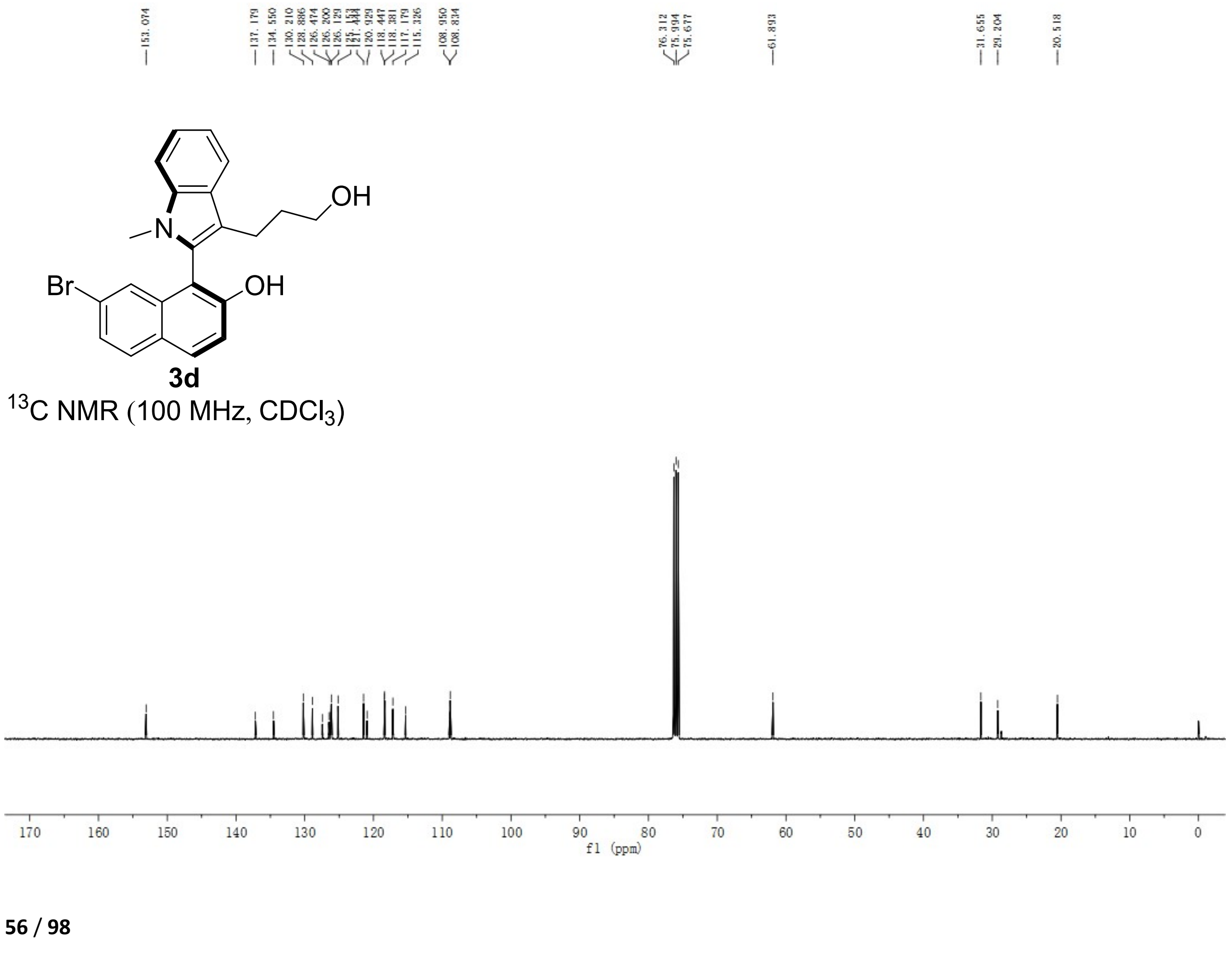


```
Peak Ret time Type  Width     Area       Height       Area
 #    [min]         [min]    [mAU*s]      [mAU]        %
----|-------|----|-------|----------|----------|--------|
  1    5.978 VV    0.1858 6034.51221  503.45880  93.1093
  2   20.946 BBA   0.6760  446.59113   10.19534   6.8907
```



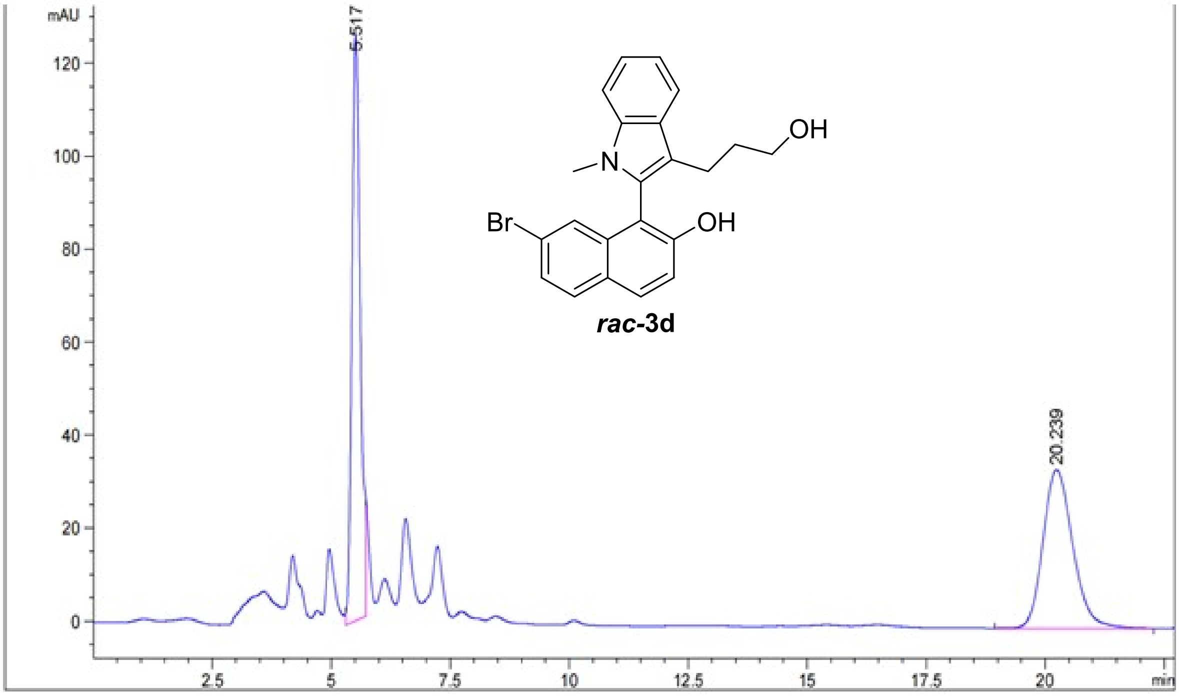
3d

^{1}H NMR (400 MHz, CDCl$_3$)



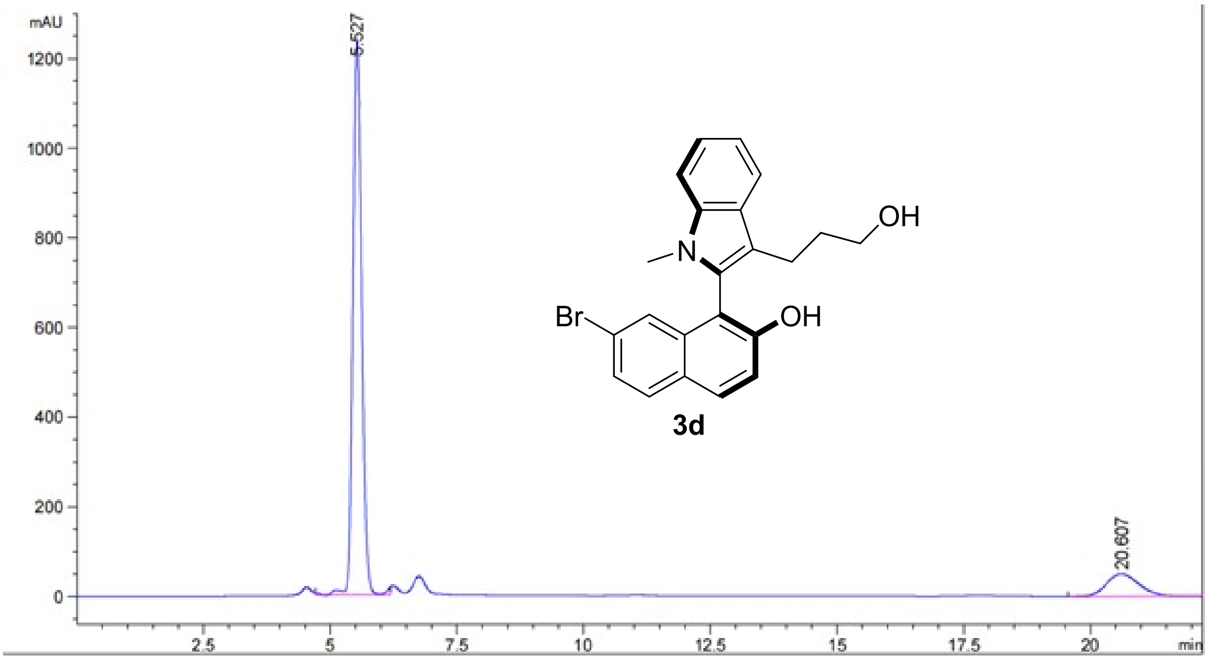
3d

^{13}C NMR (100 MHz, CDCl$_3$)



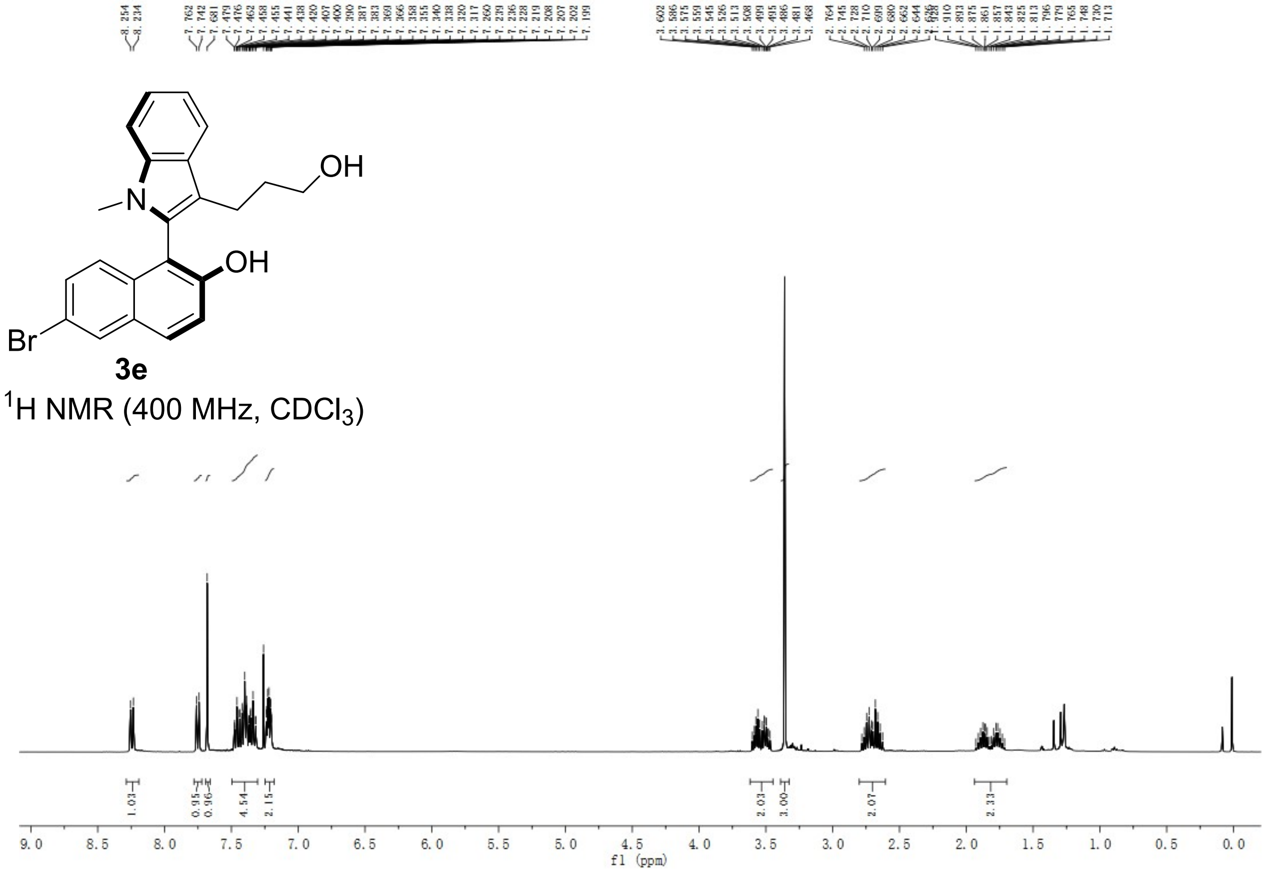
***rac*-3d**

```
Peak Ret time Type  Width     Area      Height      Area
  #   [min]         [min]   [mAU*s]     [mAU]        %
----|-------|----|-------|----------|----------|--------|
   1    5.517 MM    0.2024 1530.41101  126.00920  50.7432
   2   20.239 BB    0.6682 1485.58228   34.10380  49.2568
```

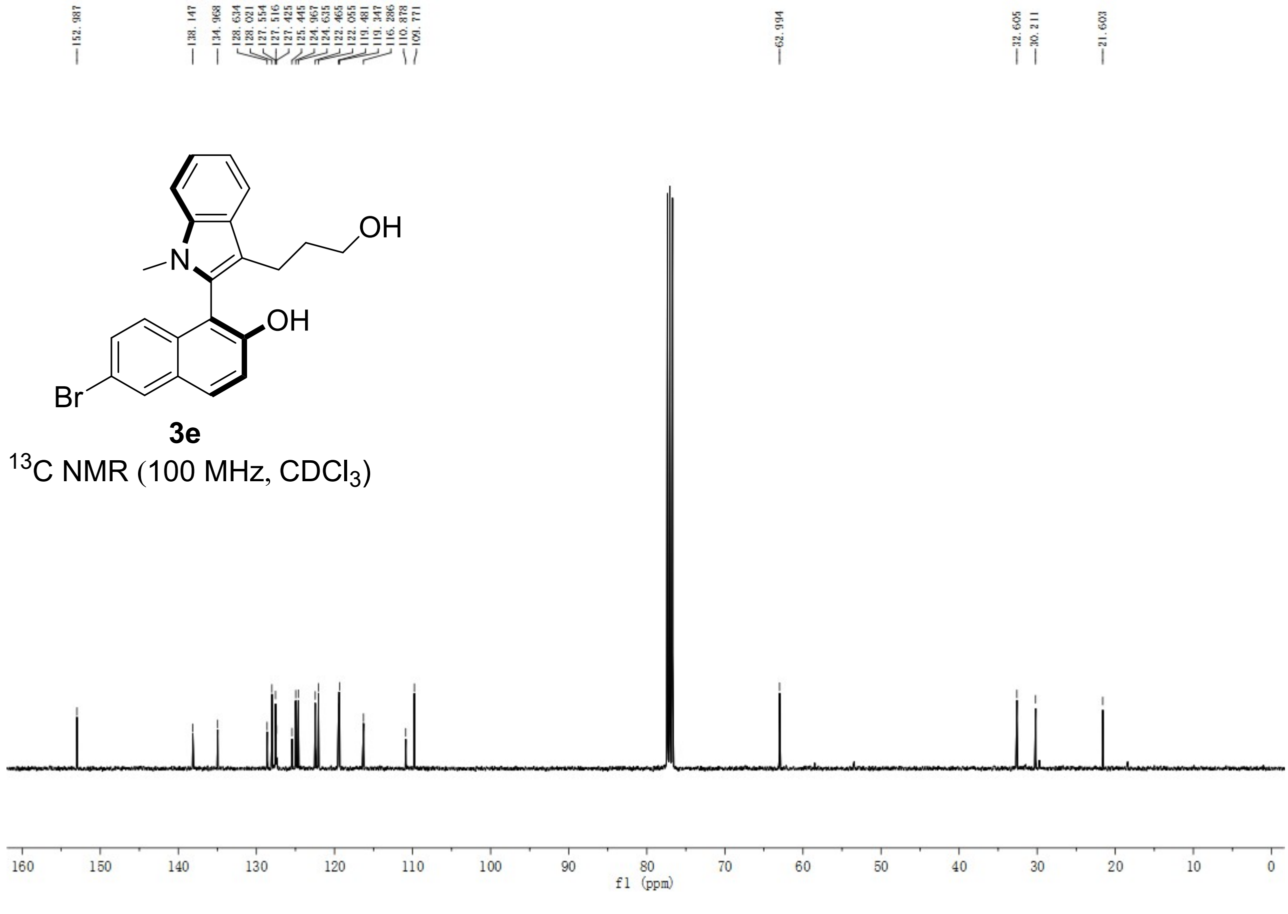


3d

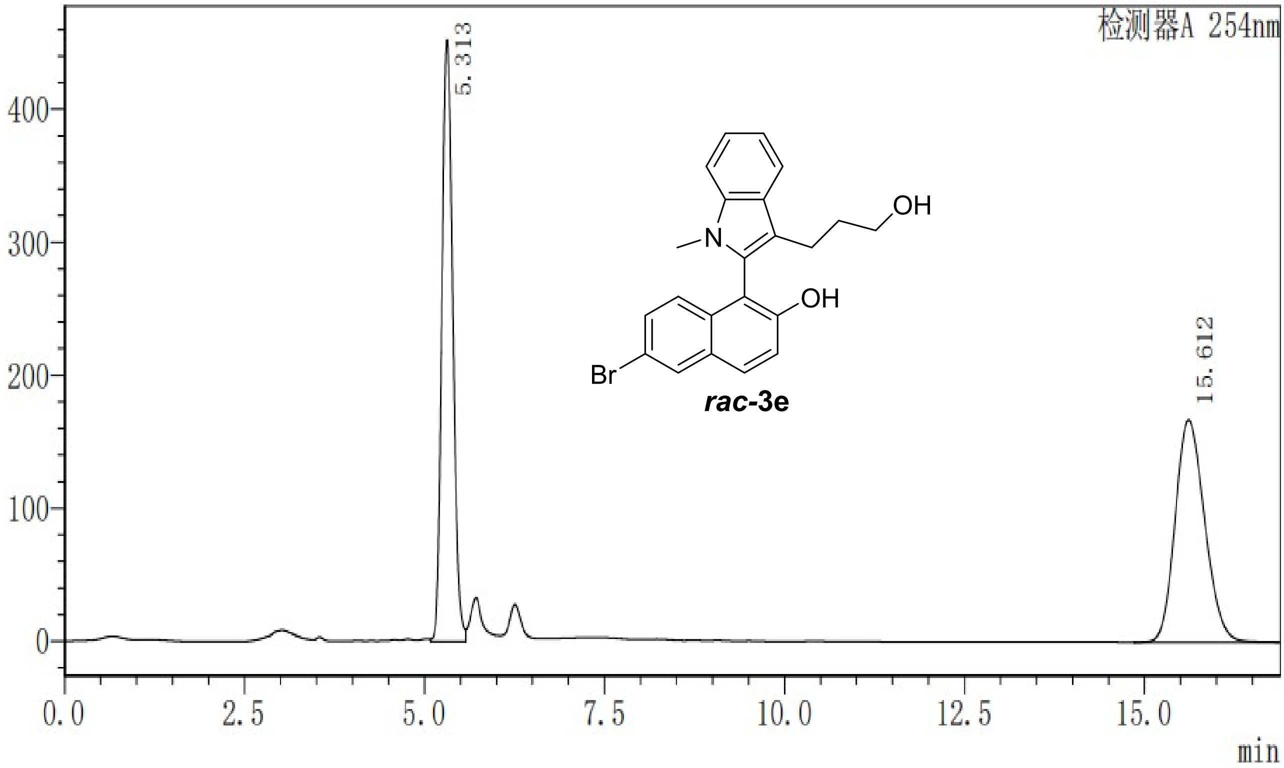
```
Peak Ret time Type  Width     Area      Height      Area
  #   [min]         [min]   [mAU*s]     [mAU]        %
----|-------|----|-------|----------|----------|--------|
   1    5.527 MM    0.2018 1.49754e4  1236.60522  86.9195
   2   20.607 BBA   0.6925 2253.64990   50.50942  13.0805
```


3e

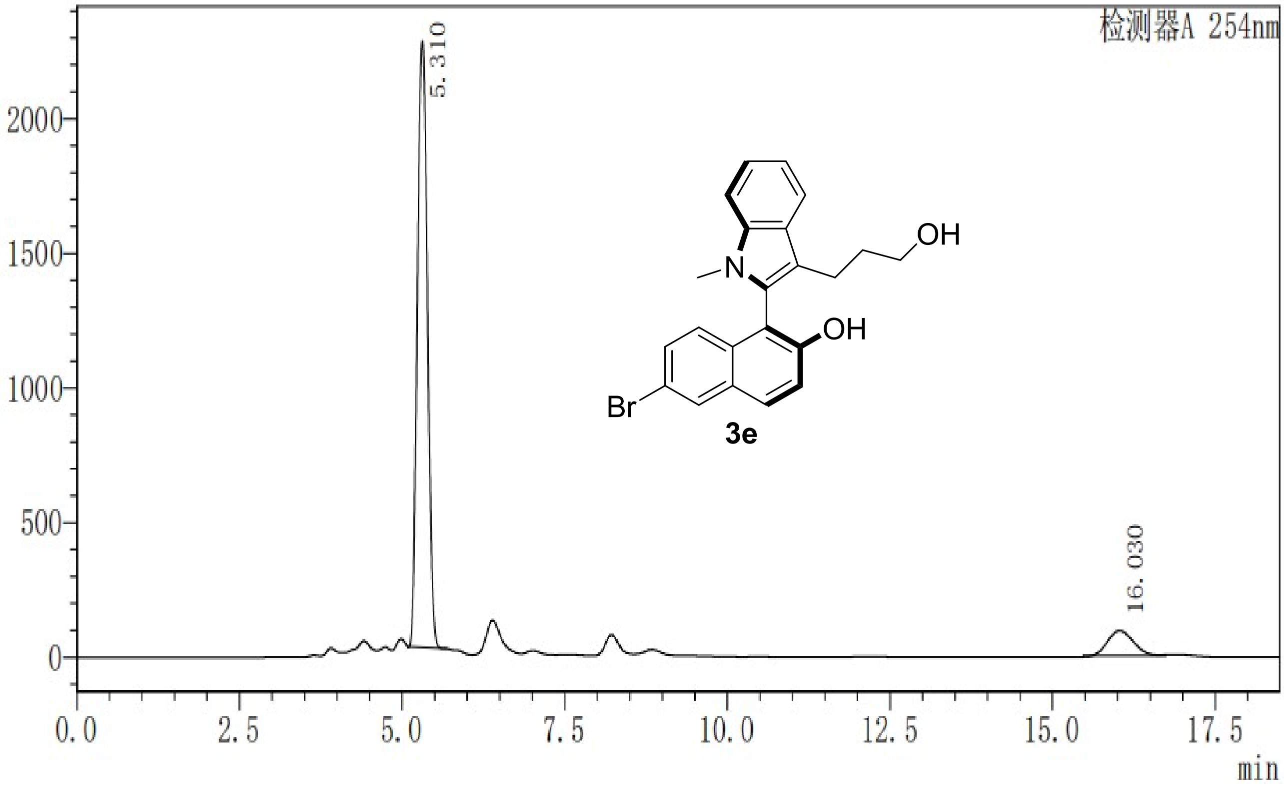
^{1}H NMR (400 MHz, $CDCl_3$)


3e

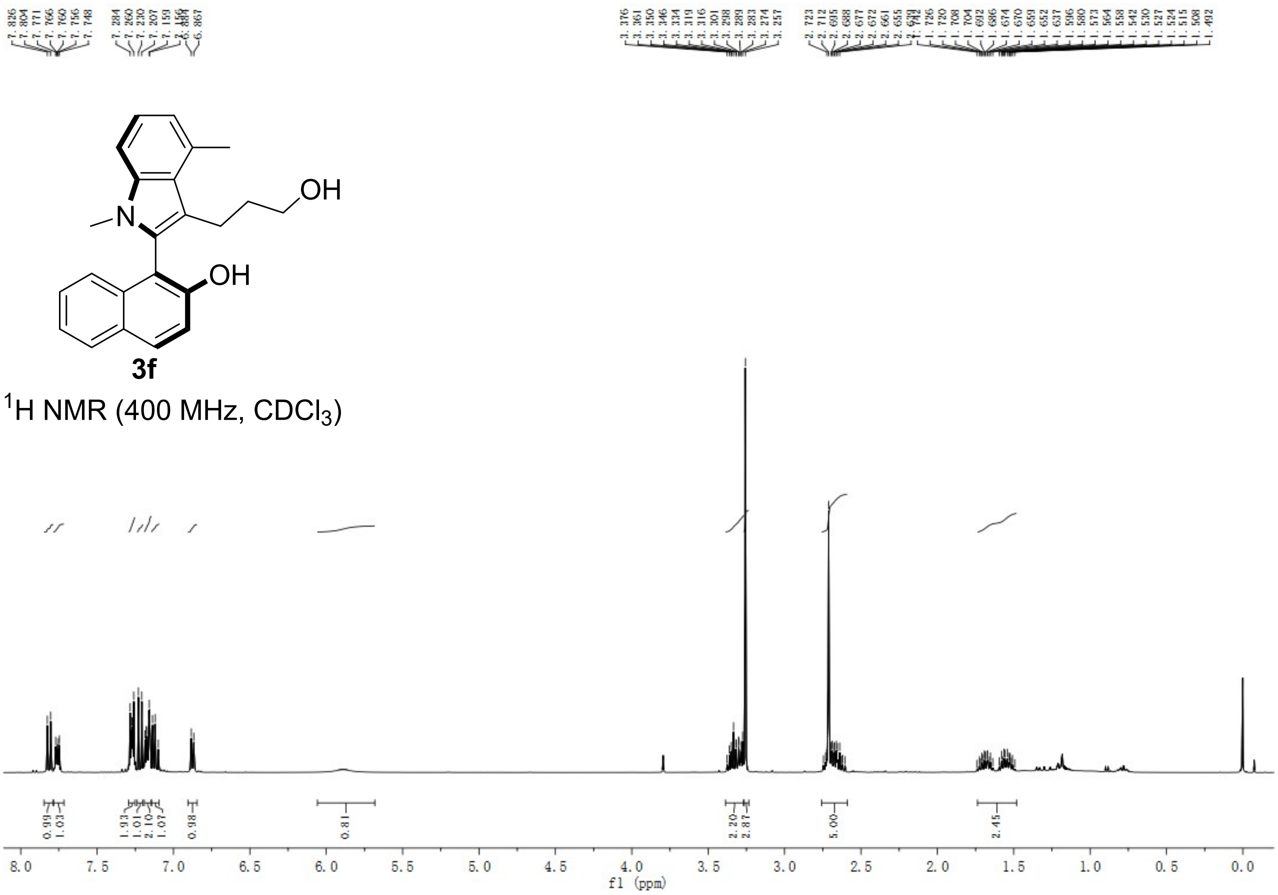
^{13}C NMR (100 MHz, $CDCl_3$)



Peak	Ret. Time	Area	Height	Area%
1	5.313	4816892	452378	50.241
2	15.612	4770763	167220	49.759

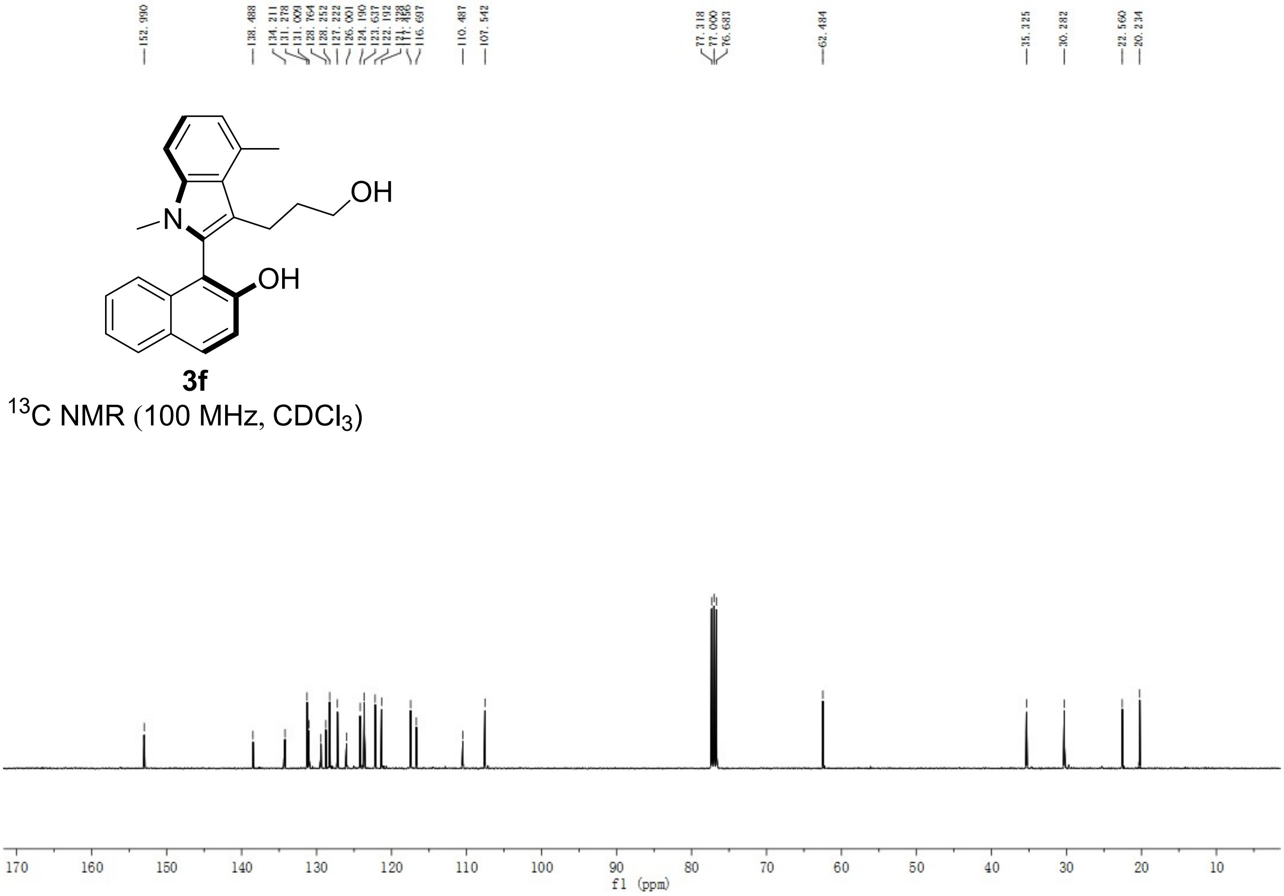


Peak	Ret. Time	Area	Height	Area%
1	5.310	24338910	2249820	90.705
2	16.030	2494210	92370	9.295



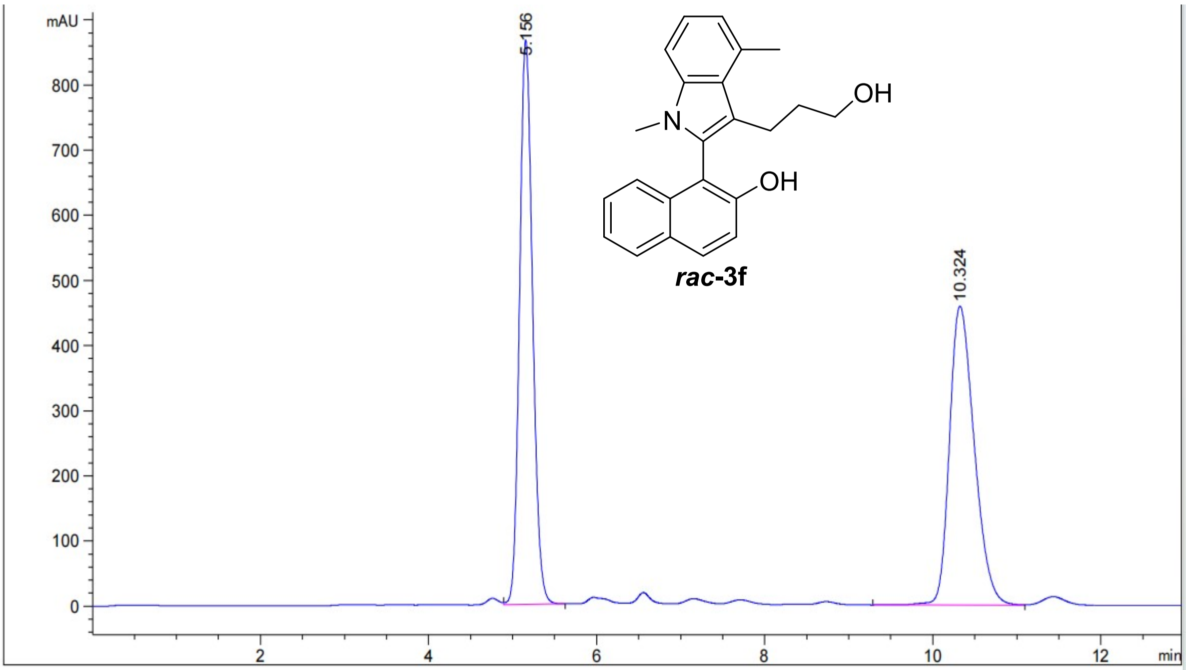
3f

^{1}H NMR (400 MHz, $CDCl_3$)

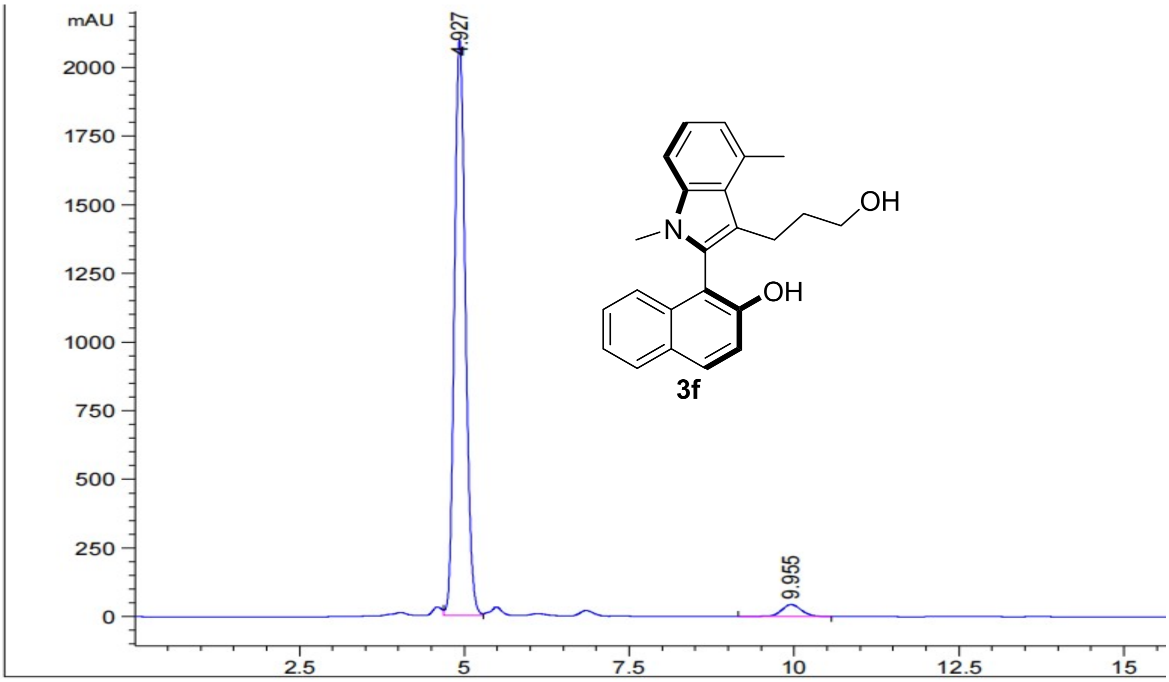


3f

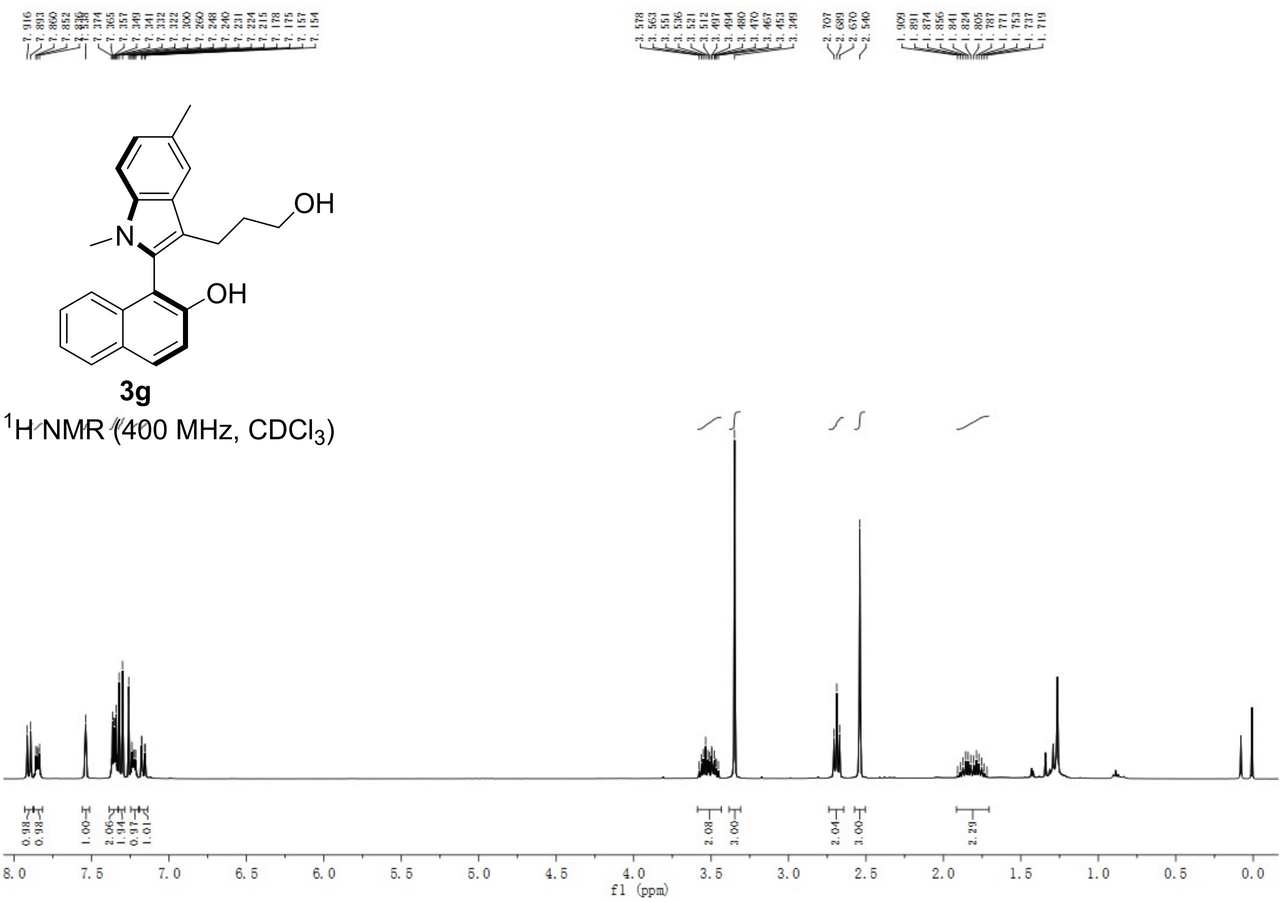
^{13}C NMR (100 MHz, $CDCl_3$)



```
Peak Ret time Type  Width     Area       Height      Area
  #   [min]         [min]   [mAU*s]      [mAU]        %
----|-------|----|-------|----------|----------|--------|
  1    5.156 VB    0.1676 9326.74707  866.27039  49.7648
  2   10.324 BV    0.3173 9414.89844  459.07233  50.2352
```

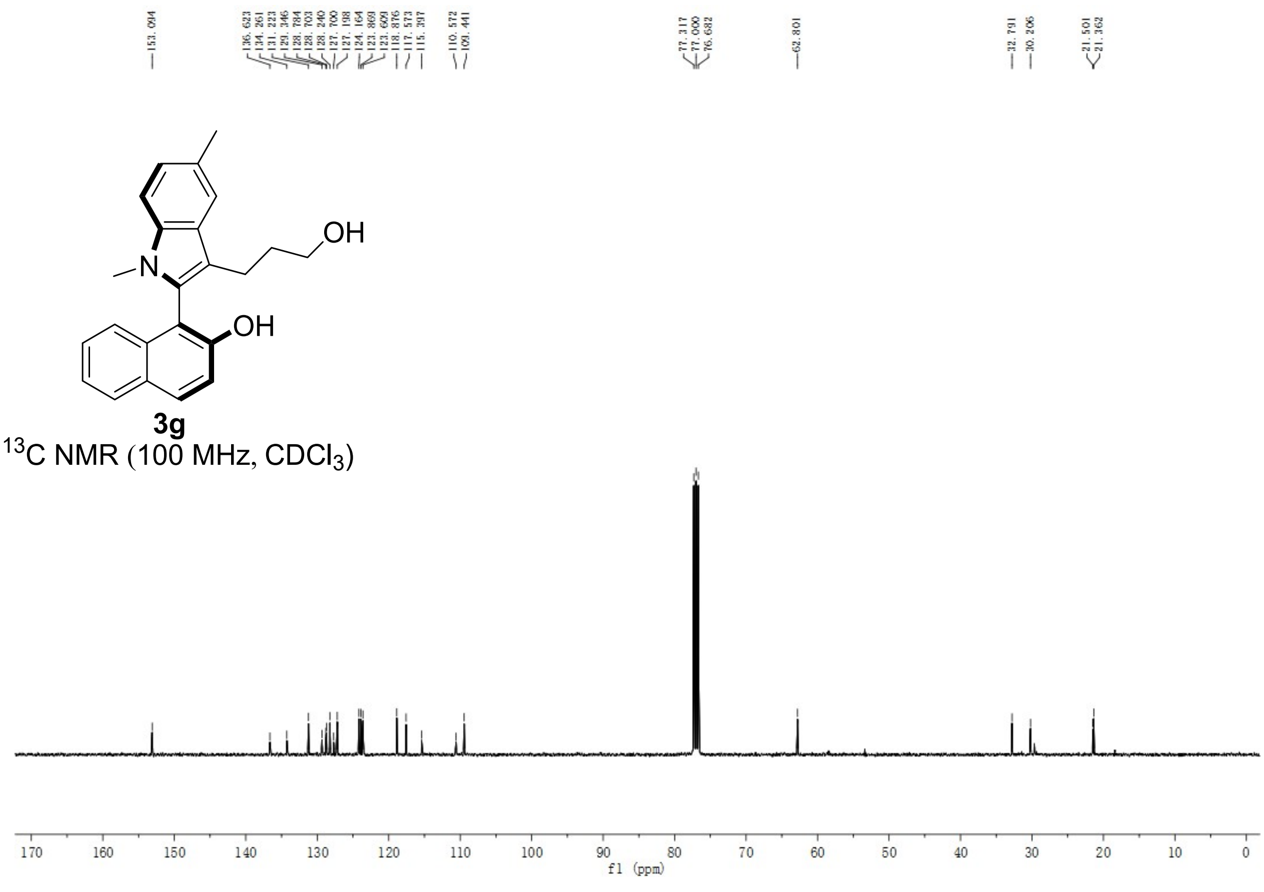


```
Peak Ret time Type  Width     Area       Height      Area
  #   [min]         [min]   [mAU*s]      [mAU]        %
----|-------|----|-------|----------|----------|--------|
  1    4.927 VV    0.1817 2.43910e4  2096.96655  96.3511
  2    9.955 BB    0.3256  923.71820   43.52632   3.6489
```



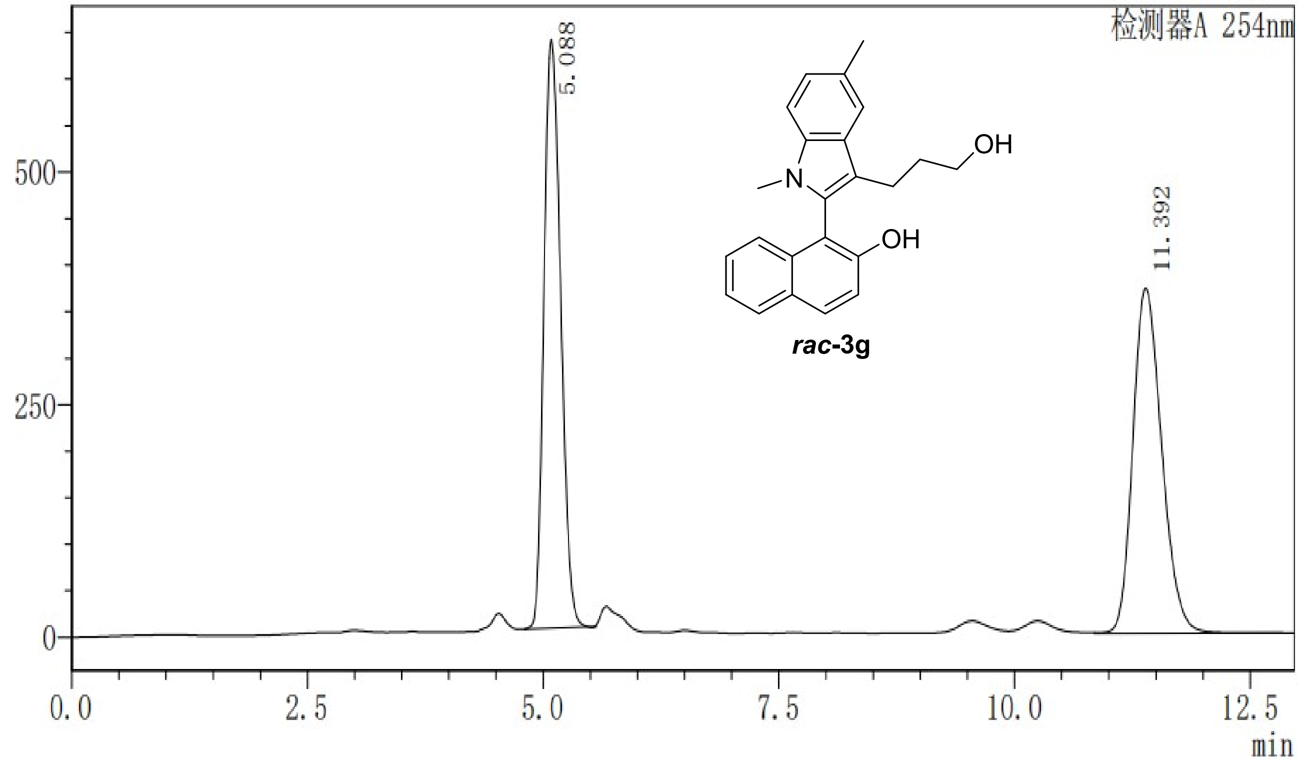
3g

^{1}H NMR (400 MHz, CDCl$_3$)

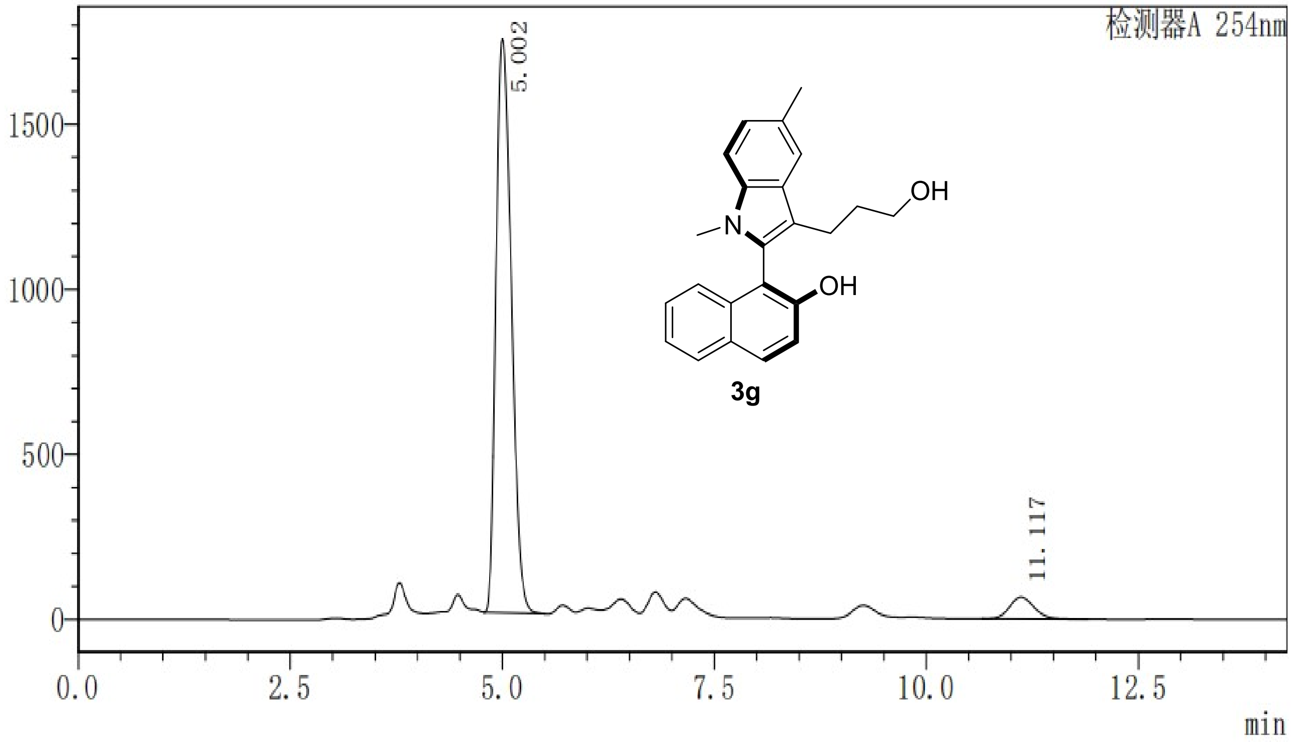


3g

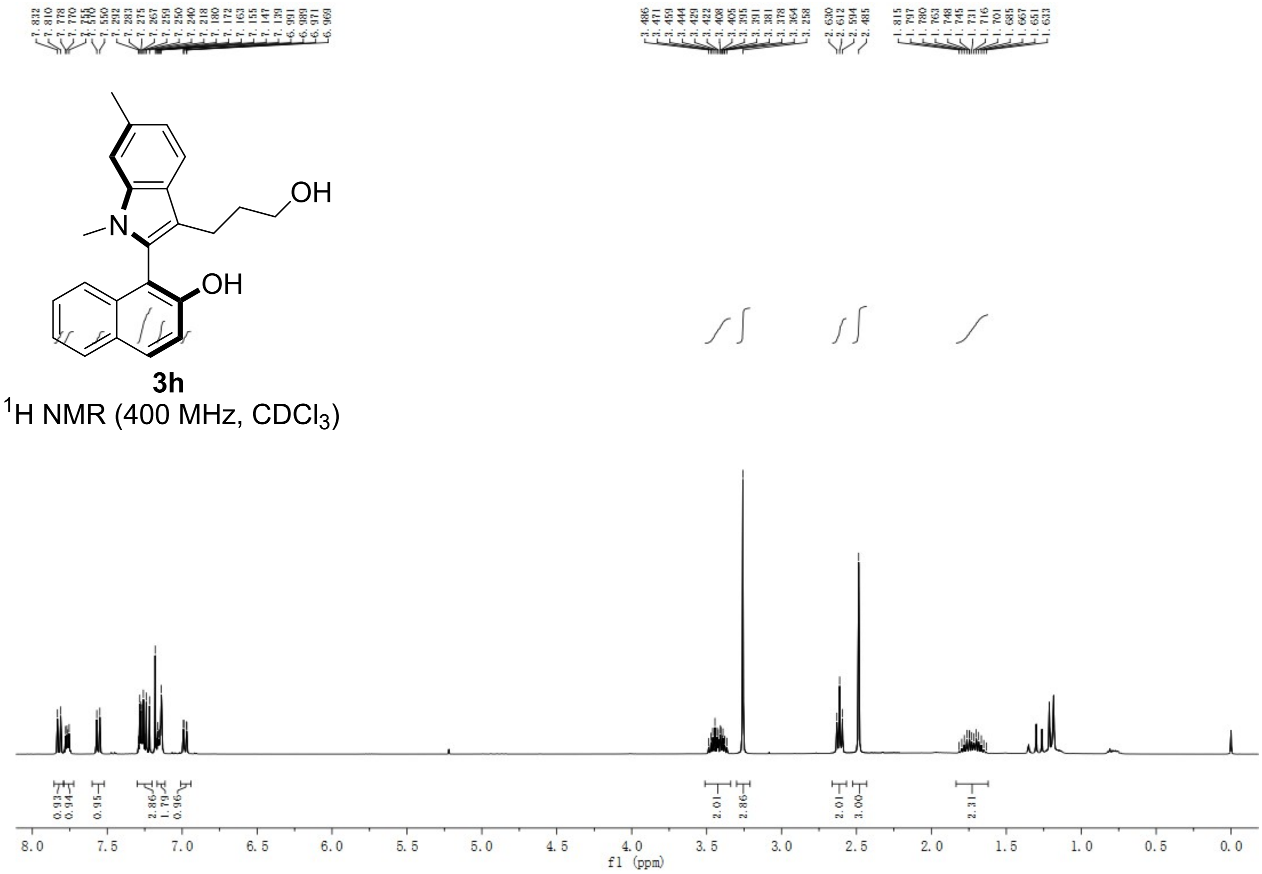
^{13}C NMR (100 MHz, CDCl$_3$)



Peak	Ret. Time	Area	Height	Area%
1	5.088	7863596	632637	49.832
2	11.392	7916601	371102	50.168

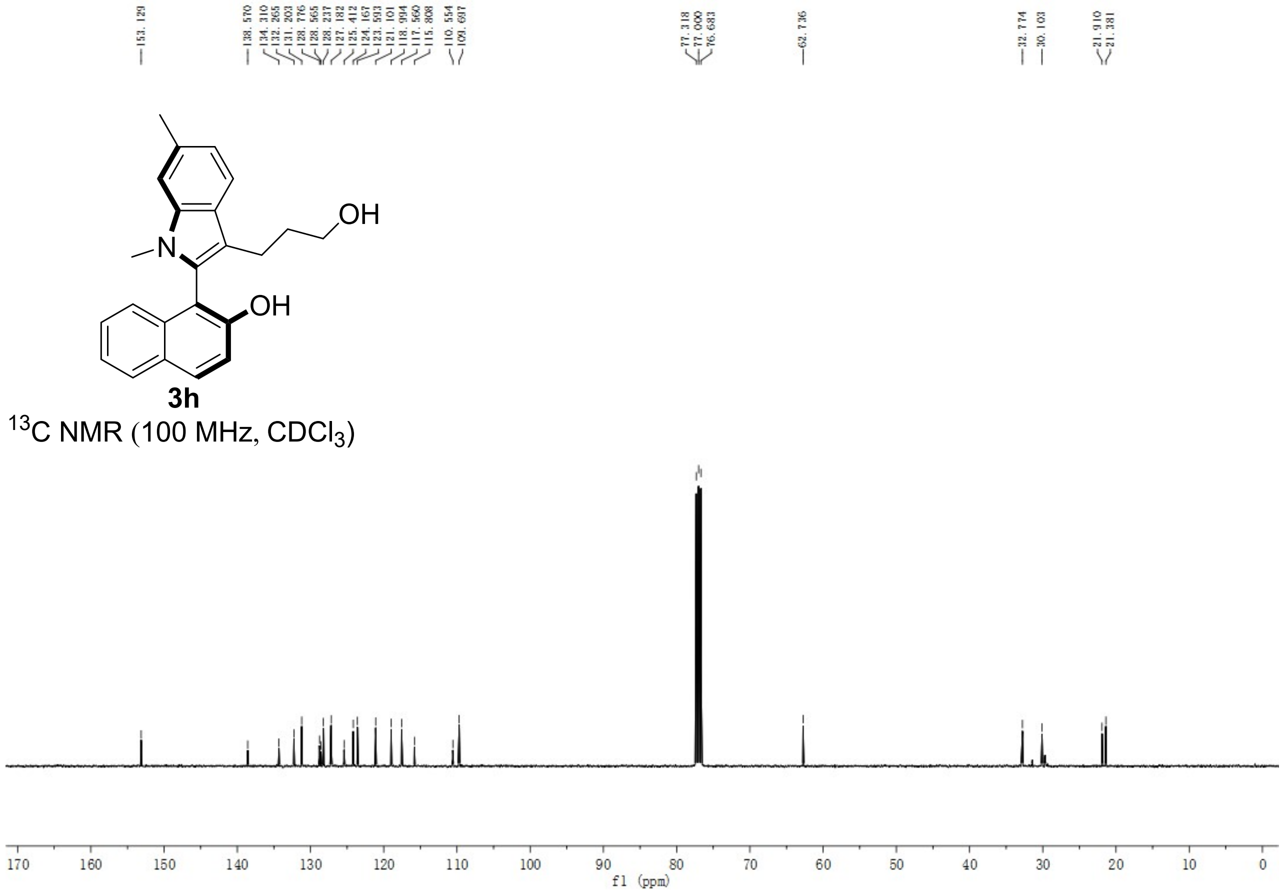


Peak	Ret. Time	Area	Height	Area%
1	5.002	21978369	1738198	94.311
2	11.117	1325687	66189	5.689



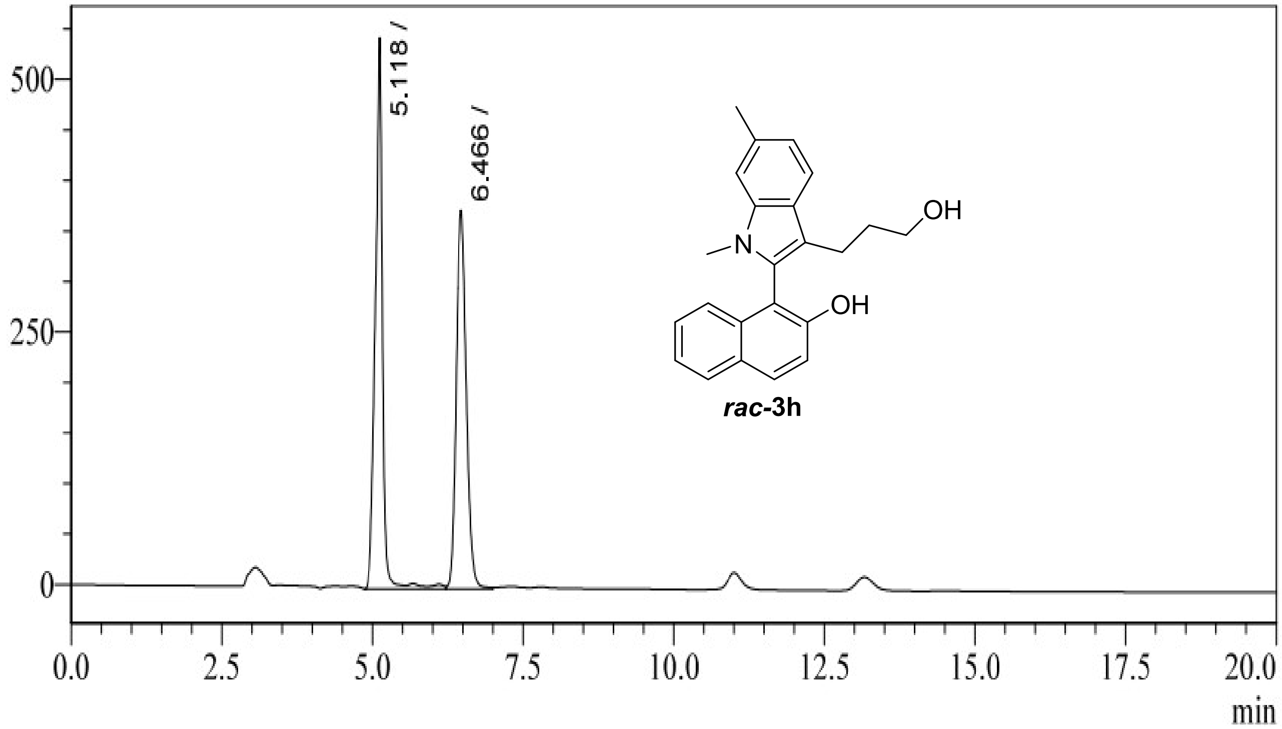
3h

^{1}H NMR (400 MHz, CDCl$_3$)

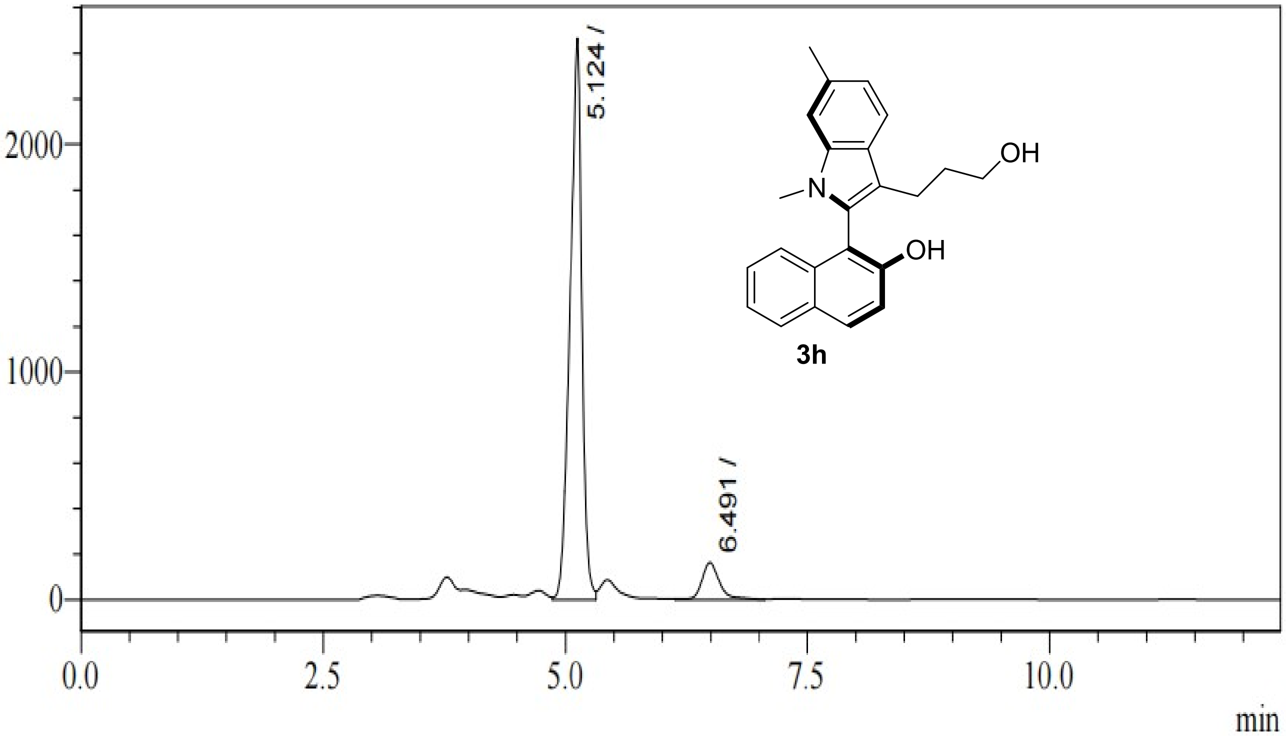


3h

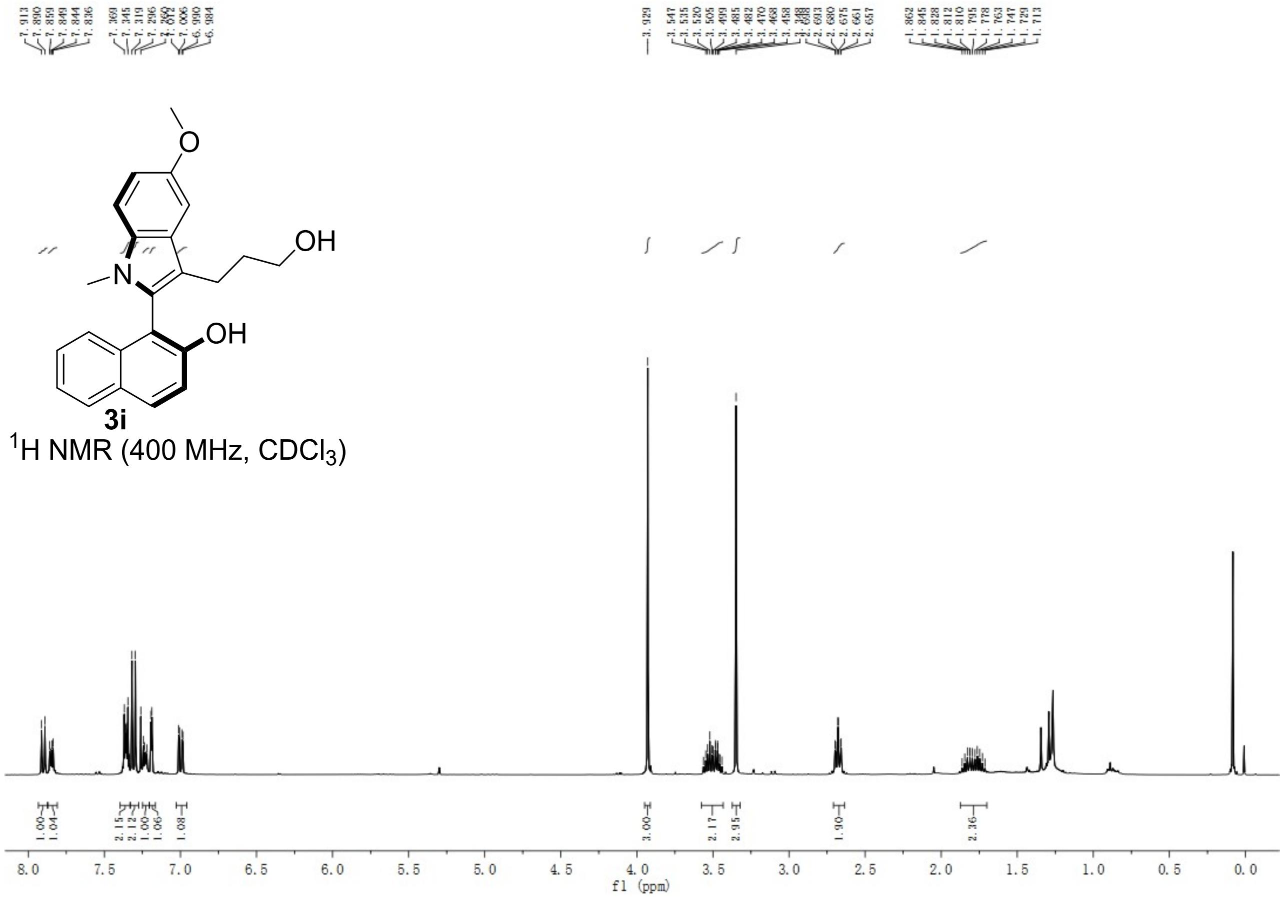
^{13}C NMR (100 MHz, CDCl$_3$)



Peak#	Ret. Time	Area	Area%	Height	Height%
1	5.118	4503918	50.638	546286	59.281
2	6.466	4390446	49.362	375241	40.719

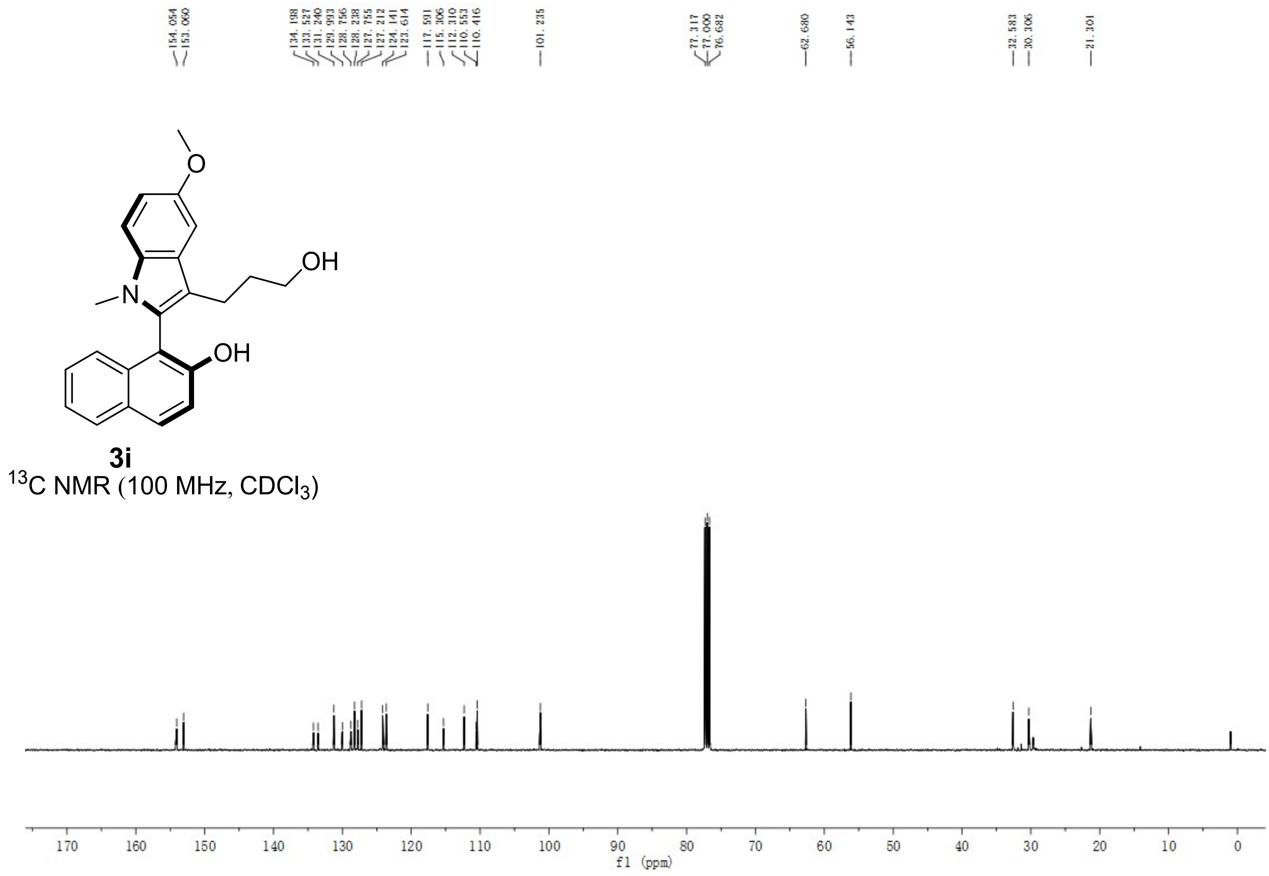


Peak#	Ret. Time	Area	Area%	Height	Height%
1	5.124	20922906	90.705	2467025	93.772
2	6.491	2144139	9.295	163839	6.228



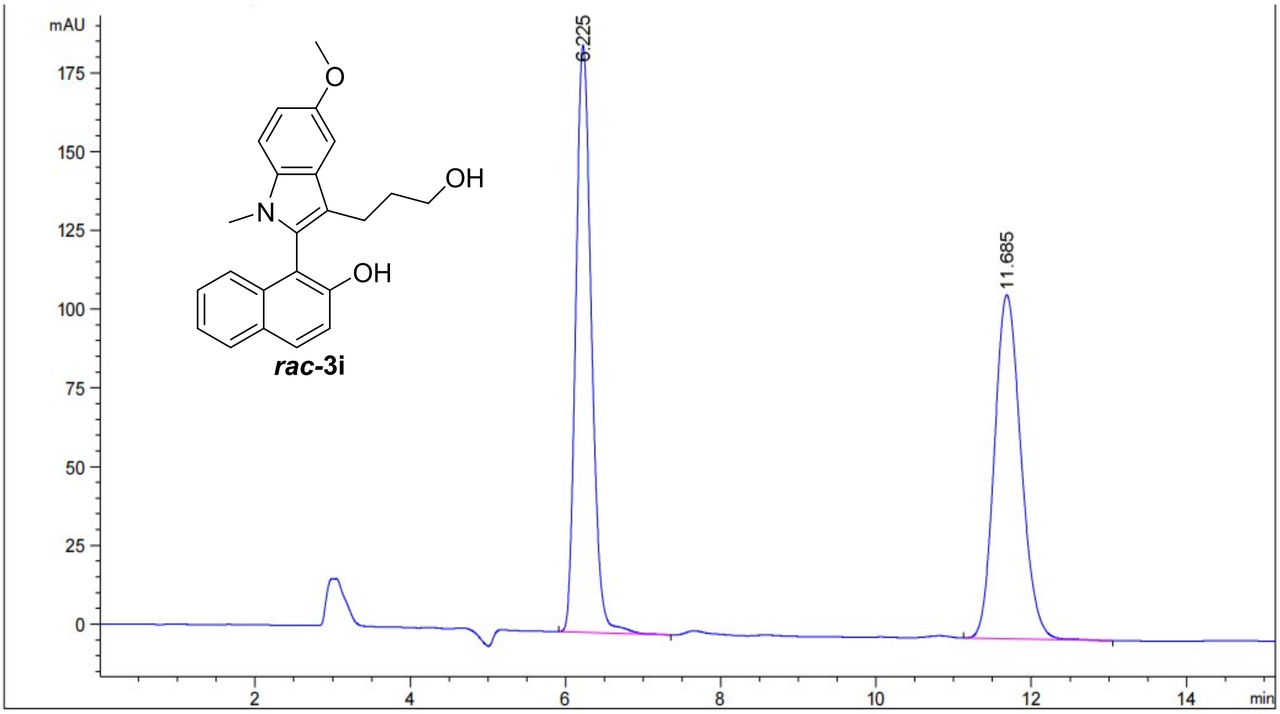
3i

^{1}H NMR (400 MHz, $CDCl_3$)



3i

^{13}C NMR (100 MHz, $CDCl_3$)



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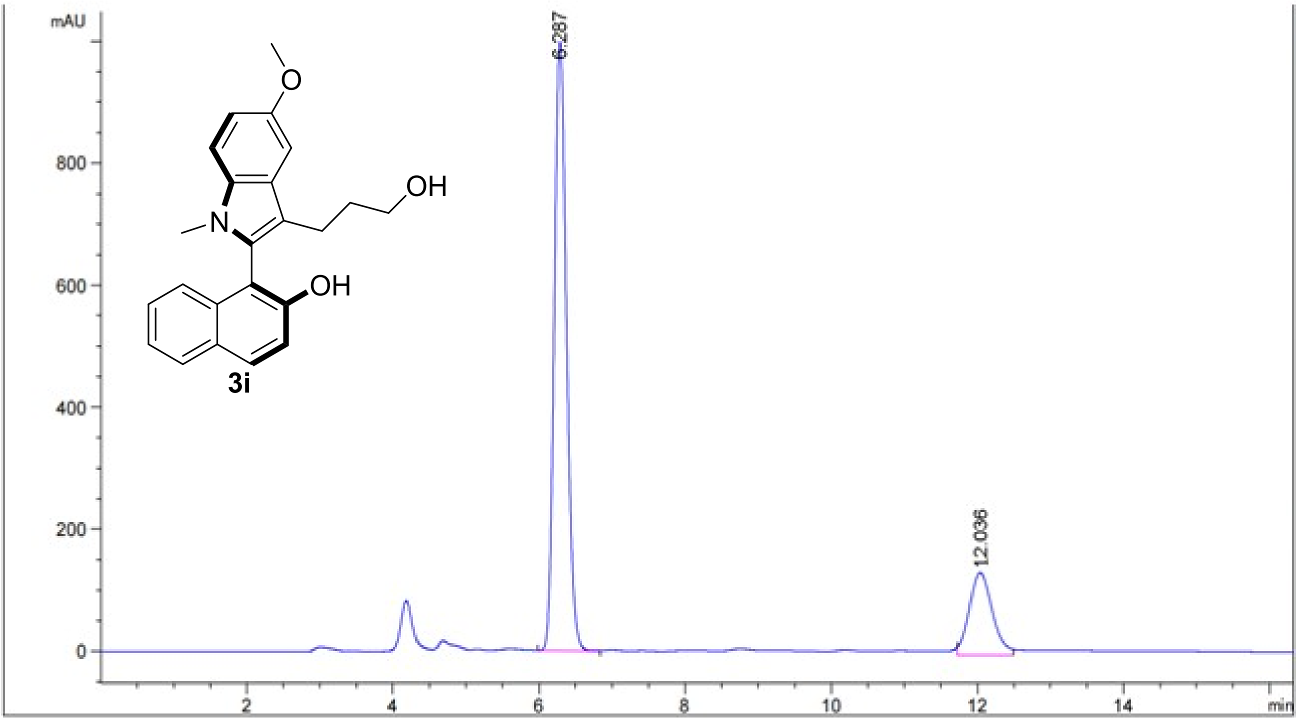
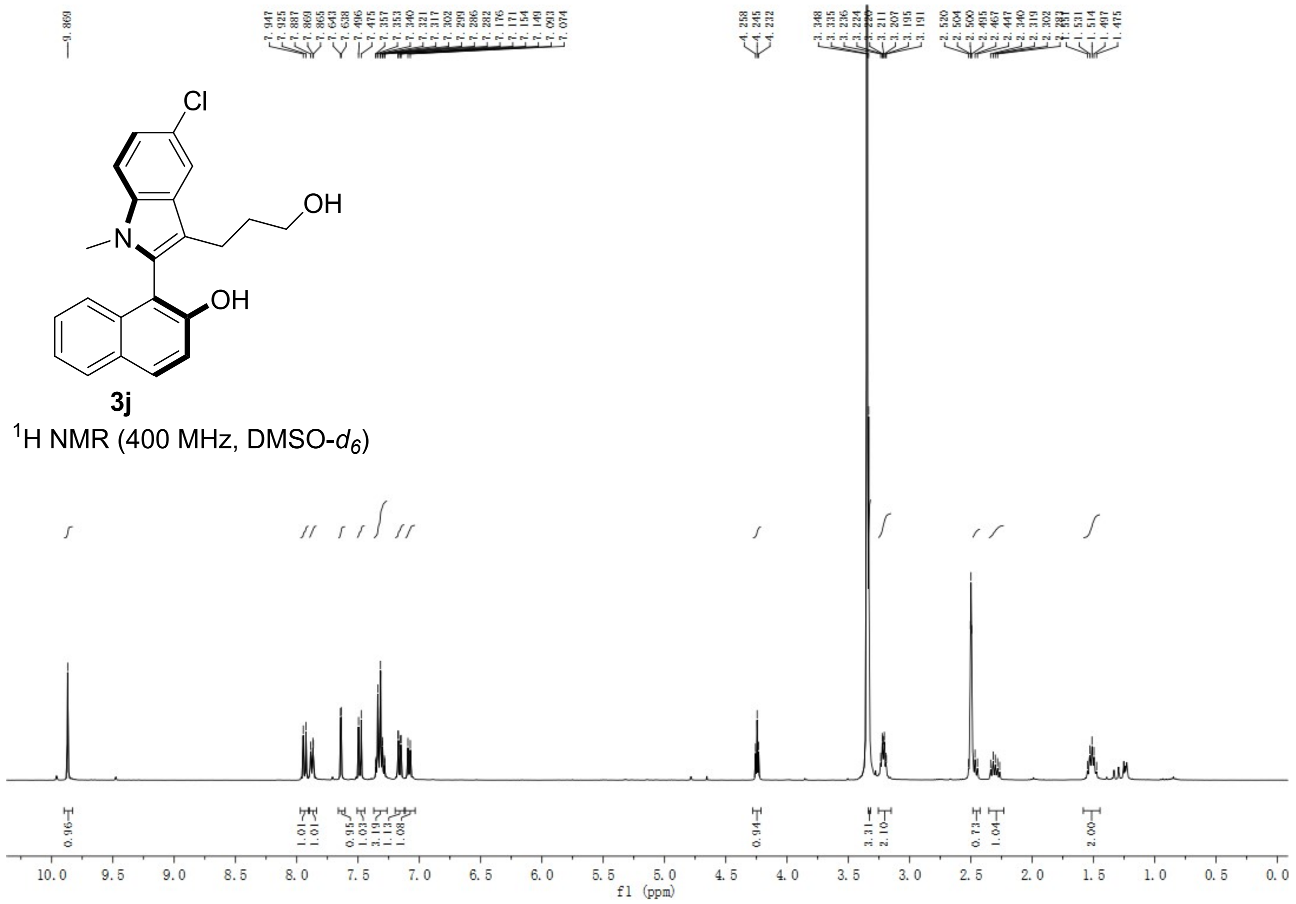
Peak Ret time Type  Width     Area      Height      Area
  #   [min]         [min]   [mAU*s]     [mAU]        %
----|-------|----|-------|----------|----------|--------|
   1   6.225 BB    0.2185 2610.92578  186.29720  50.1399
   2  11.685 BB    0.3691 2596.35181  109.30653  49.8601
```

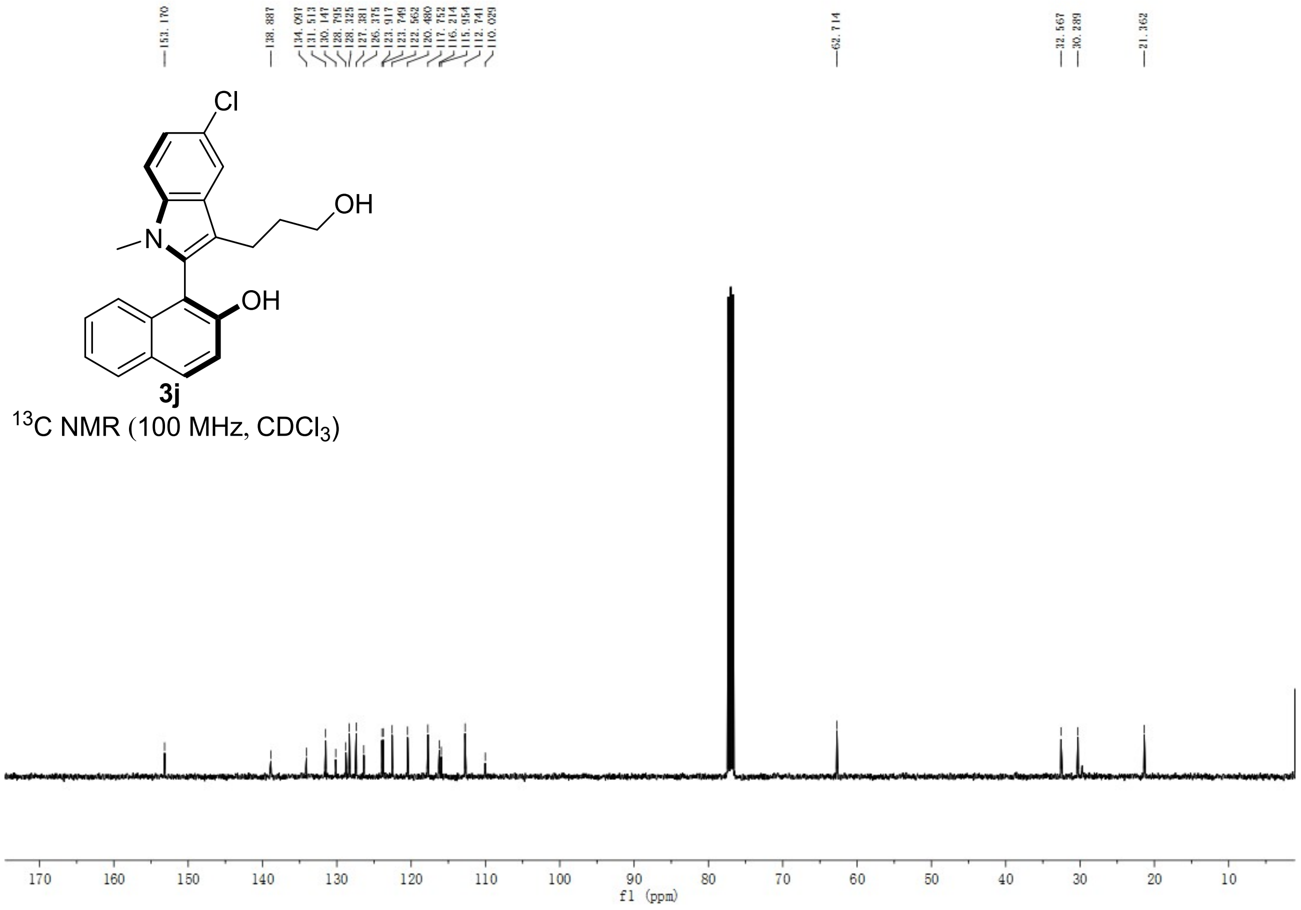


```
Peak Ret time Type  Width     Area      Height      Area
  #   [min]         [min]   [mAU*s]     [mAU]        %
----|-------|----|-------|----------|----------|--------|
   1   6.287 VV    0.1811 1.16456e4  998.53668  79.6904
   2  12.036 MM    0.3658 2967.94580  135.22986  20.3096
```



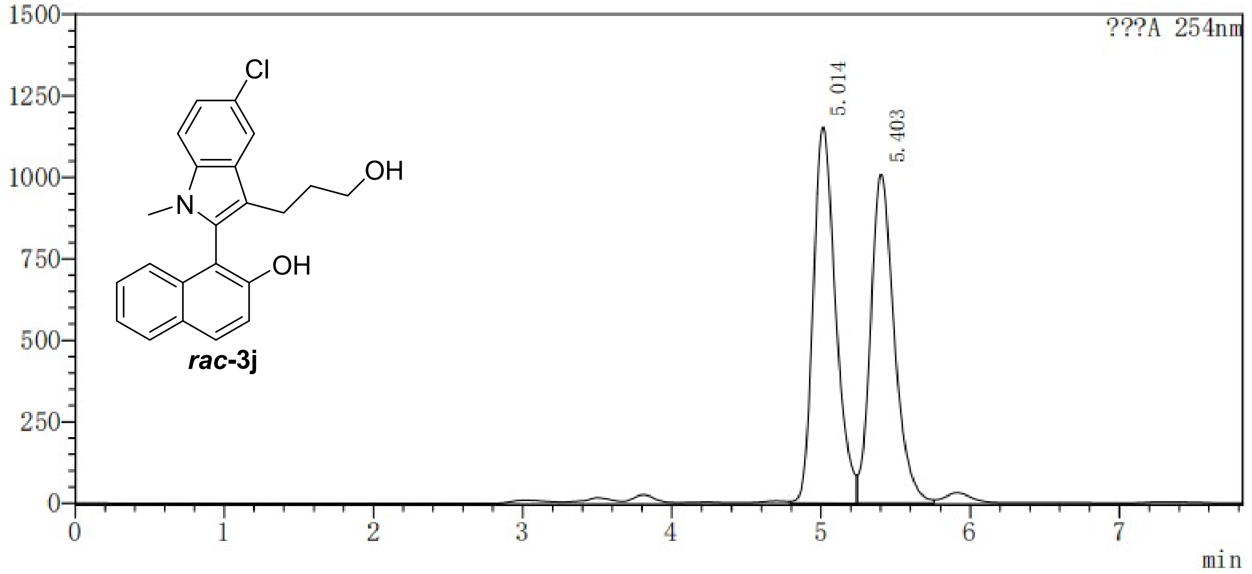
3j

^{1}H NMR (400 MHz, DMSO-d_6)

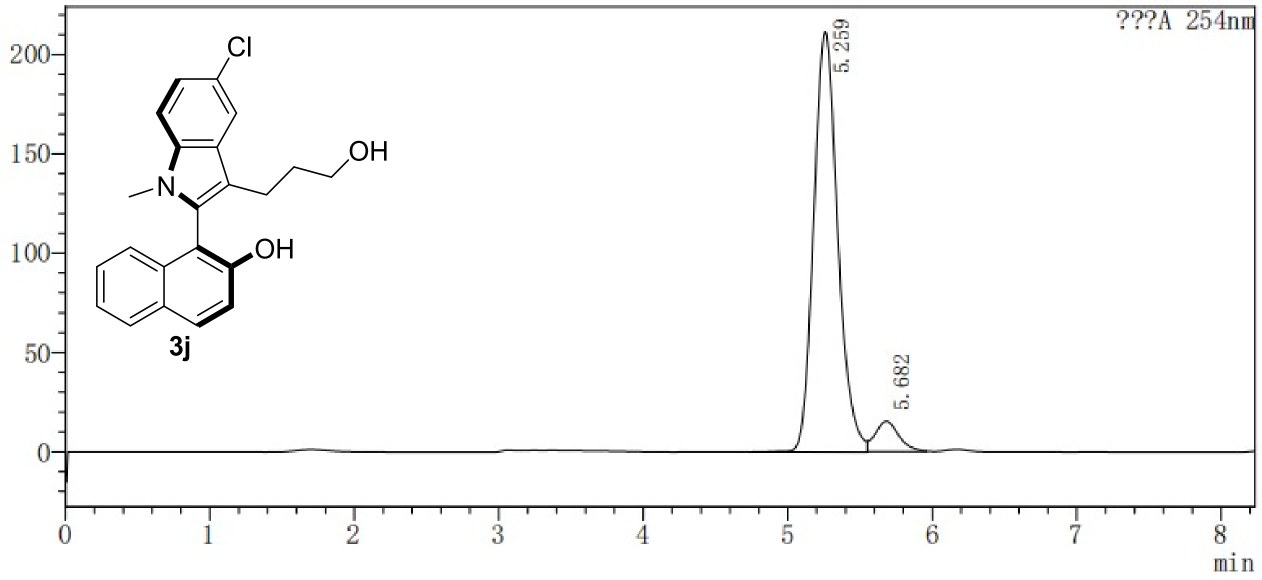


3j

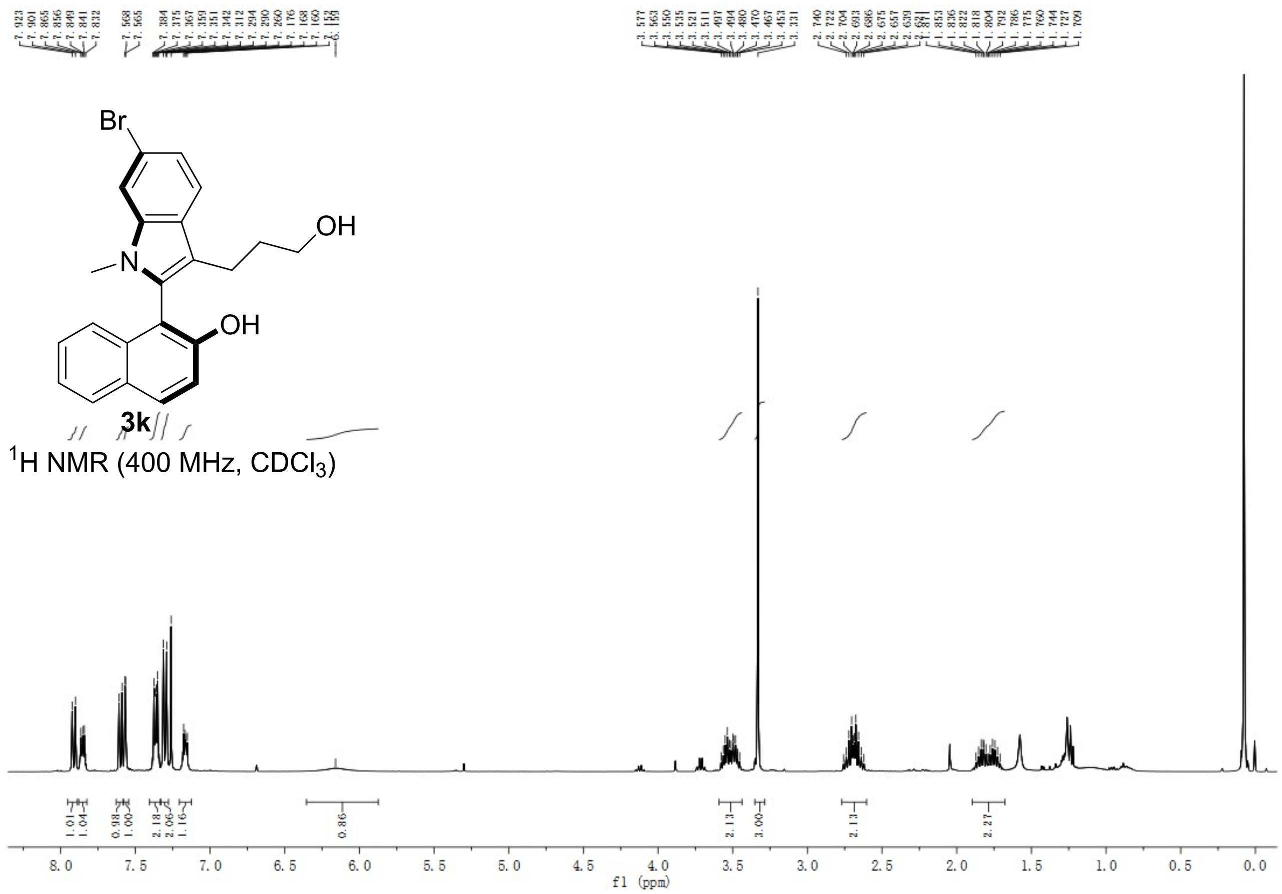
^{13}C NMR (100 MHz, CDCl$_3$)



Peak#	Ret. Time	Area	Height	Area%	Height%
1	5.014	12014291	1153562	51.856	53.336
2	5.403	11154110	1009251	48.144	46.664
Total		23168401	2162813	100.000	100.000

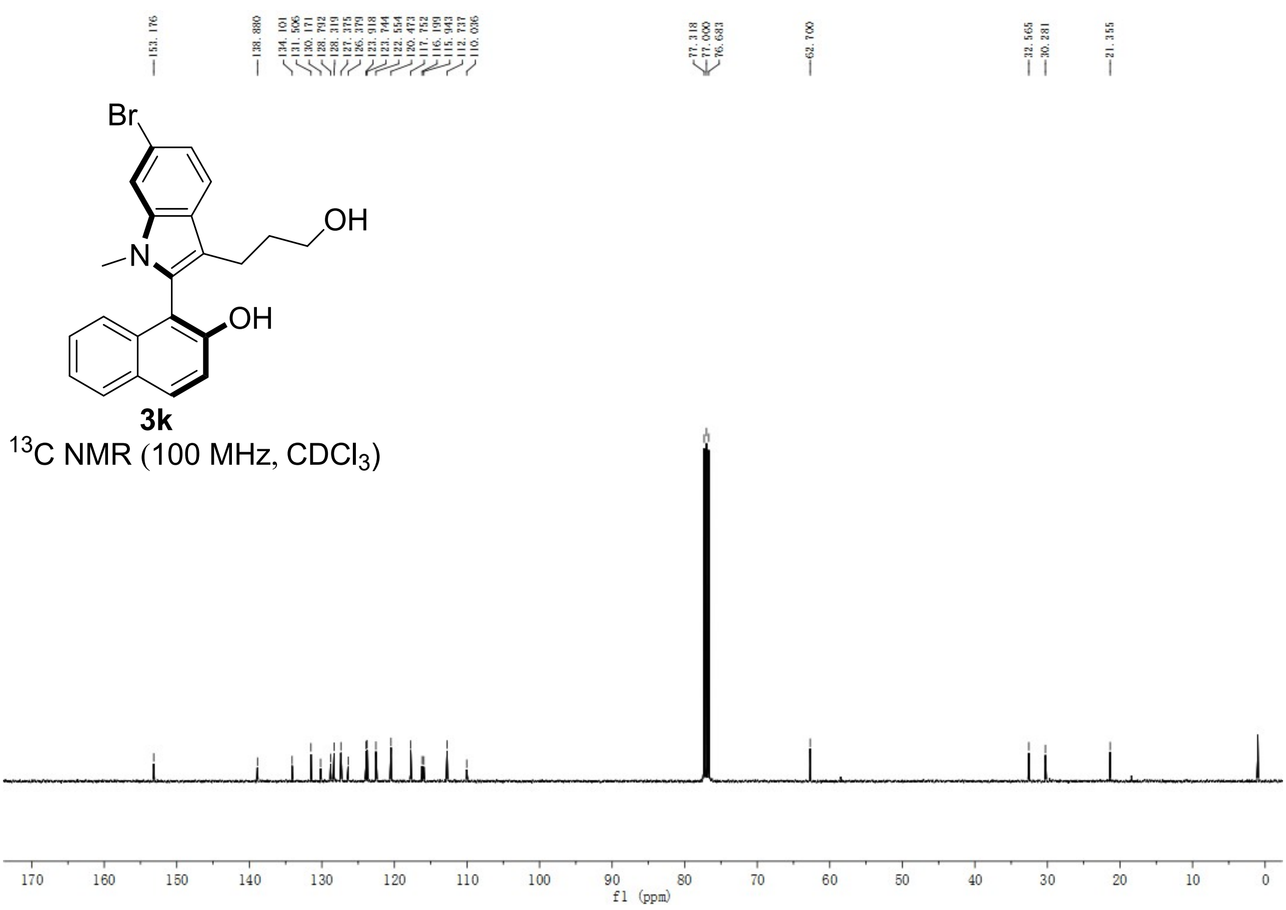


Peak#	Ret. Time	Area	Height	Area%	Height%
1	5.259	2445815	211540	93.408	93.315
2	5.682	172600	15155	6.592	6.685
Total		2618415	226696	100.000	100.000



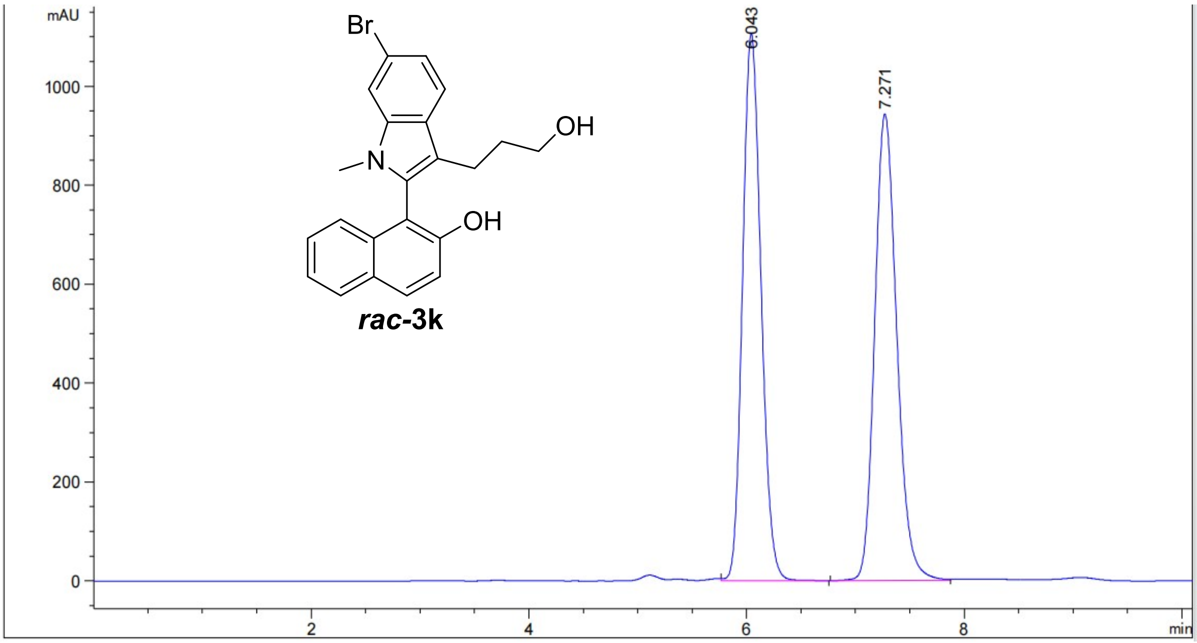
3k

^{1}H NMR (400 MHz, CDCl$_3$)

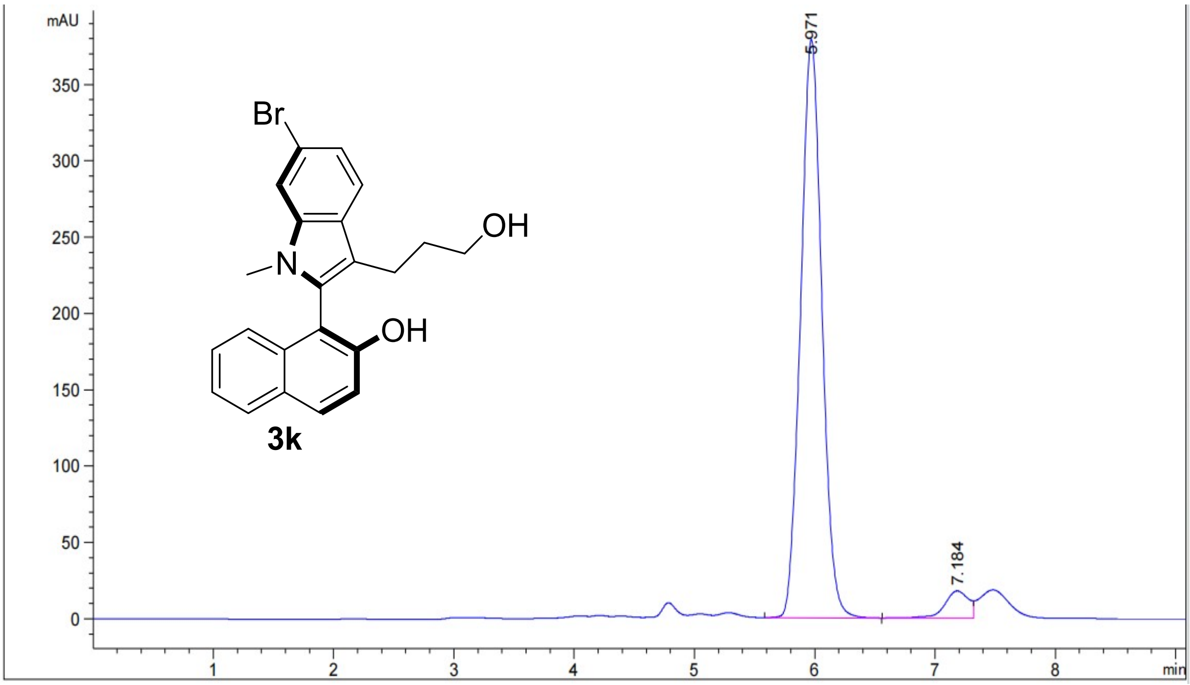


3k

^{13}C NMR (100 MHz, CDCl$_3$)



```
Peak Ret time Type  Width    Area       Height      Area
 #    [min]         [min]   [mAU*s]     [mAU]        %
----|-------|----|-------|----------|----------|--------
  1    6.043 VB    0.1834 1.30182e4  1105.70520  49.5158
  2    7.271 BV    0.2192 1.32728e4   942.86926  50.4842
```



```
Peak Ret time Type  Width    Area       Height      Area
 #    [min]         [min]   [mAU*s]     [mAU]        %
----|-------|----|-------|----------|----------|--------|
  1    5.971 BB    0.1872 4654.35791  379.06854  94.9340
  2    7.184 BV    0.2085  248.37227   17.83559   5.0660
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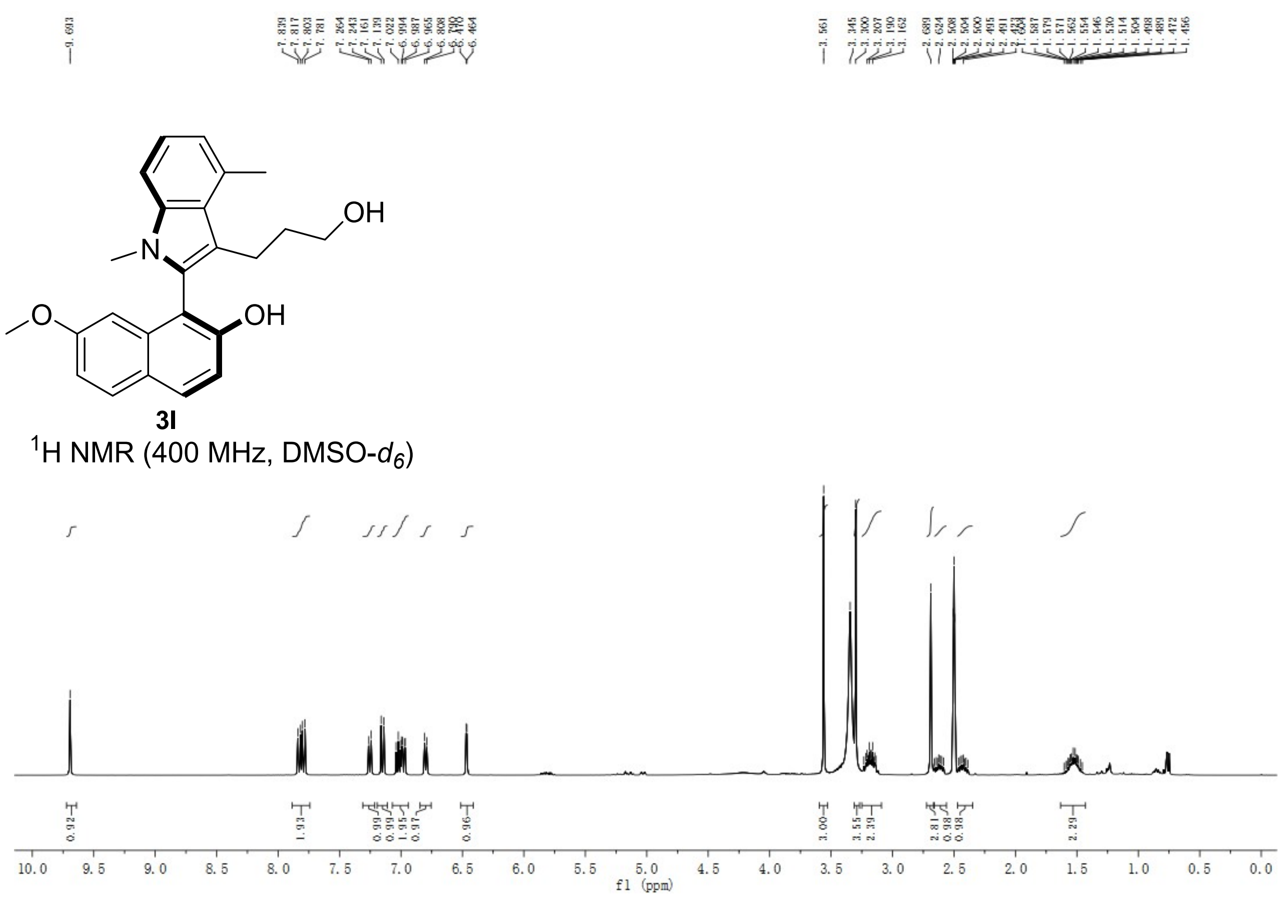
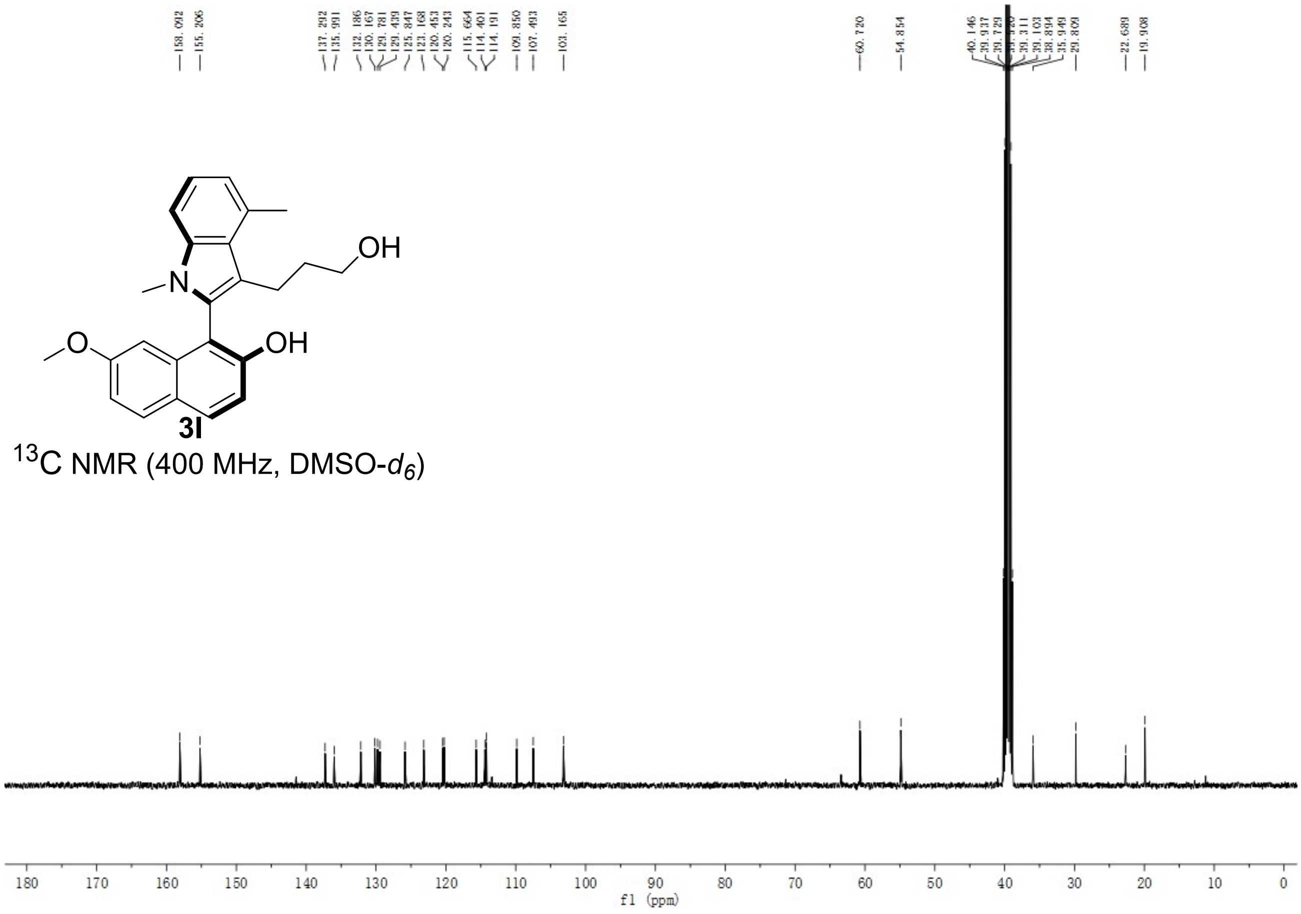
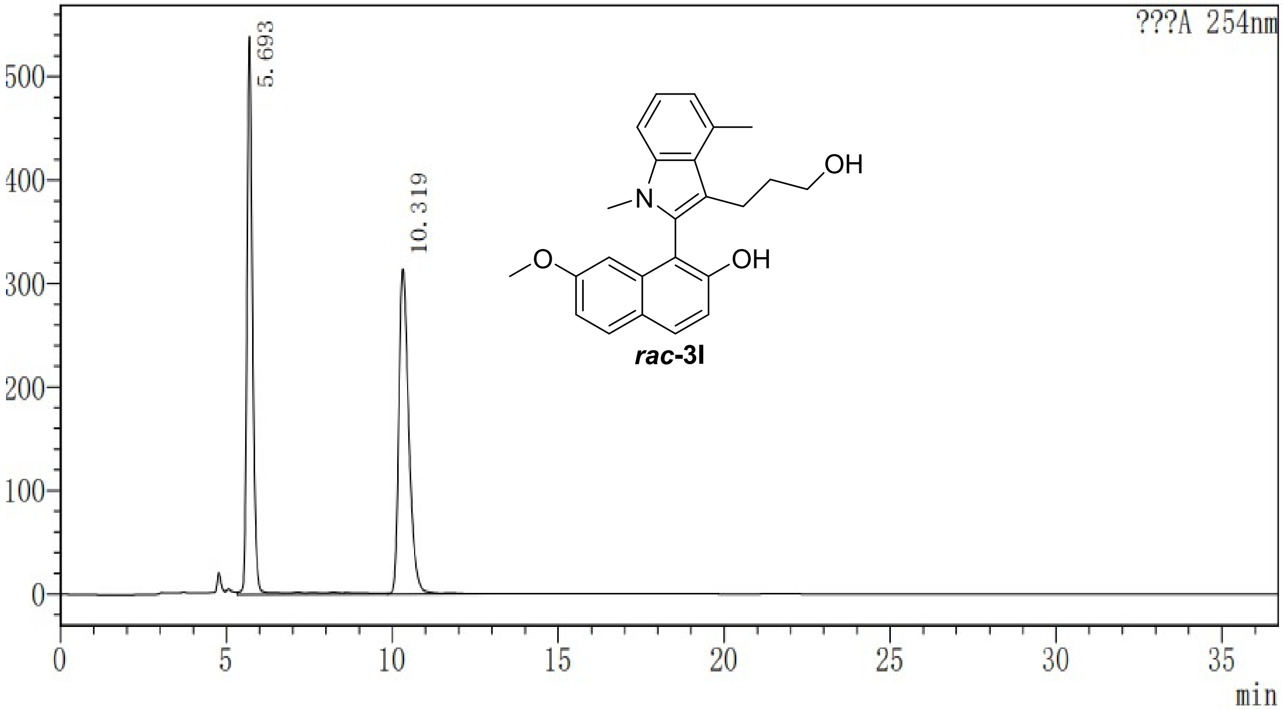

3l

^{1}H NMR (400 MHz, DMSO-d_6)

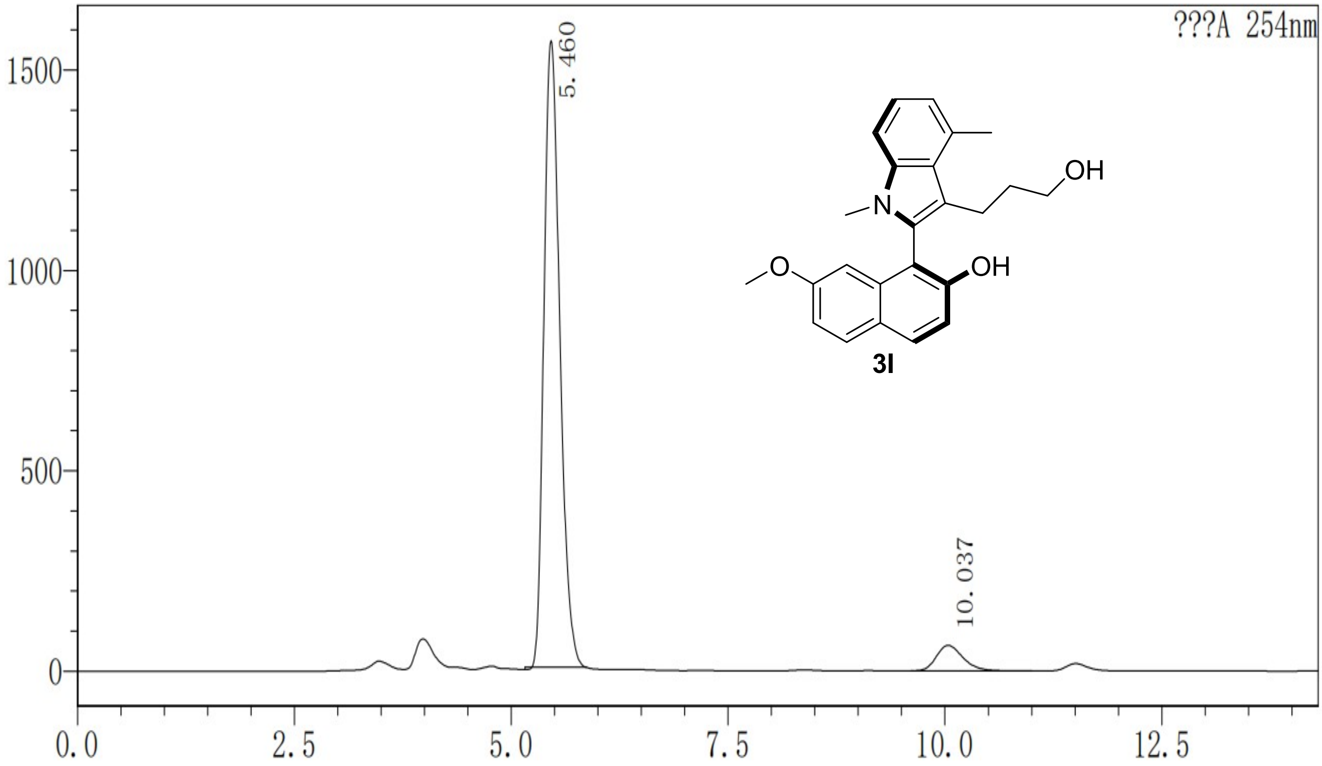

3l

^{13}C NMR (400 MHz, DMSO-d_6)



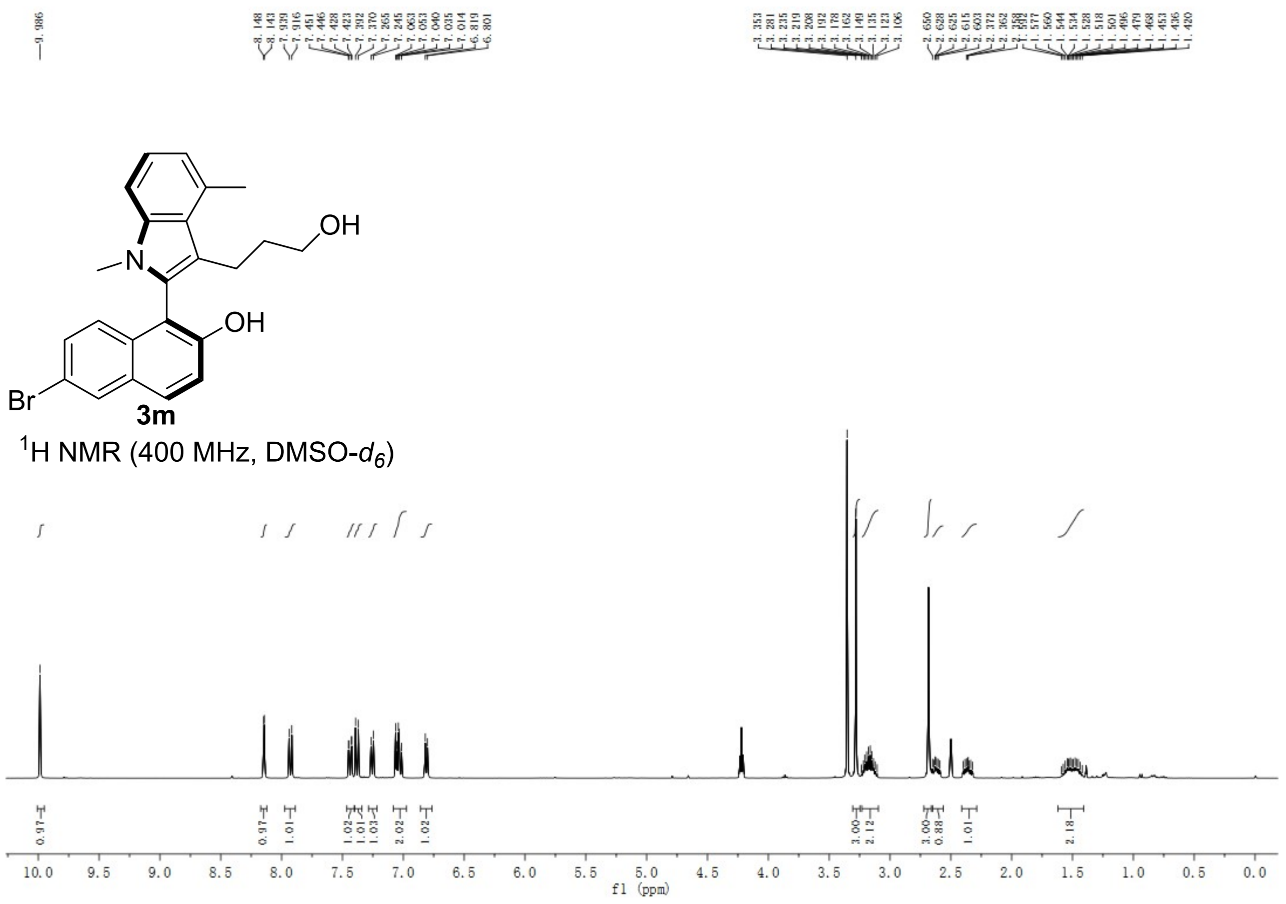
***rac*-3l**

Peak#	Ret. Time	Area	Height	Area%	Height%
1	5.693	6564568	539139	50.006	63.217
2	10.319	6562960	313695	49.994	36.783



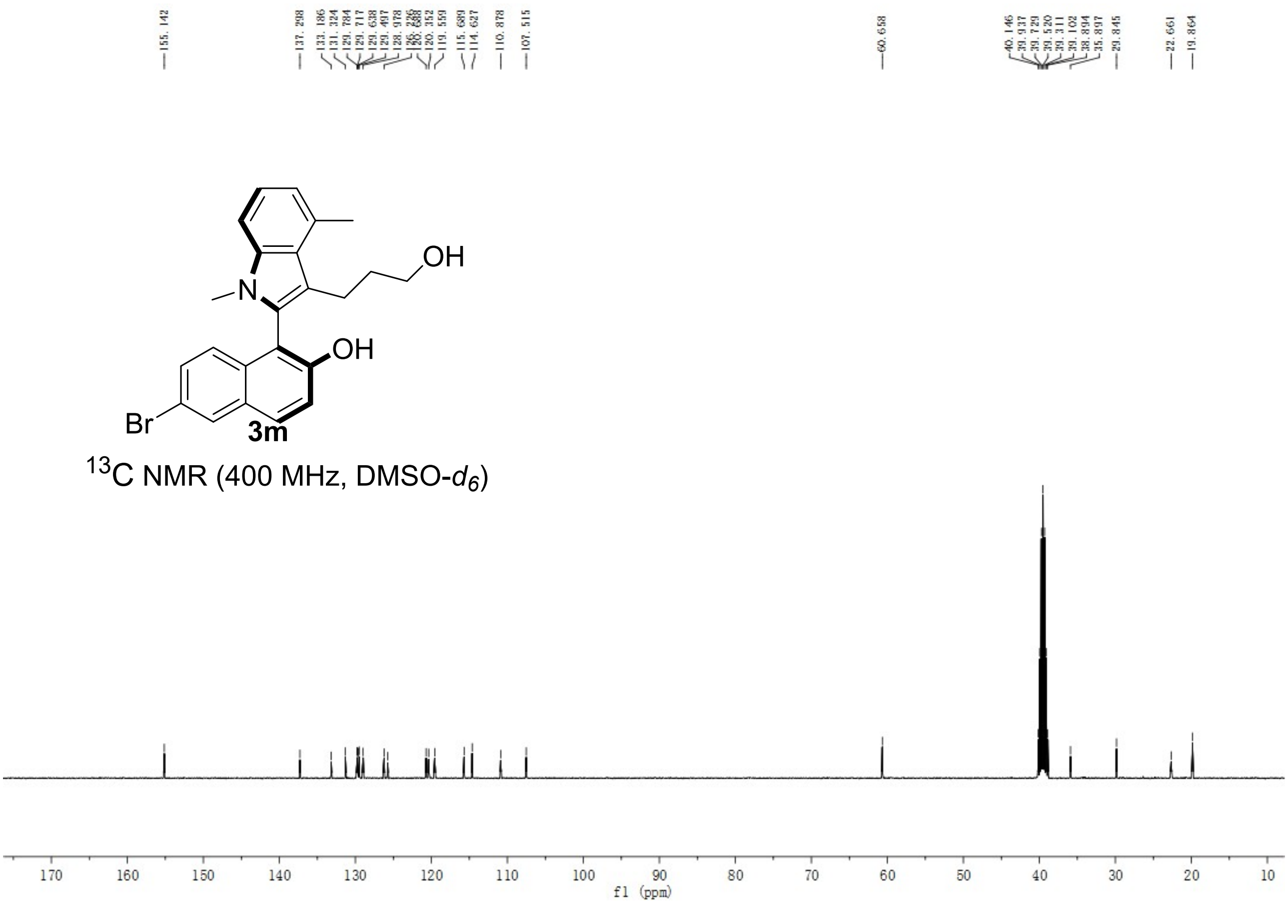
3l

Peak#	Ret. Time	Area	Height	Area%	Height%
1	5.460	19919114	1563637	93.510	96.061
2	10.037	1382401	64113	6.490	3.939



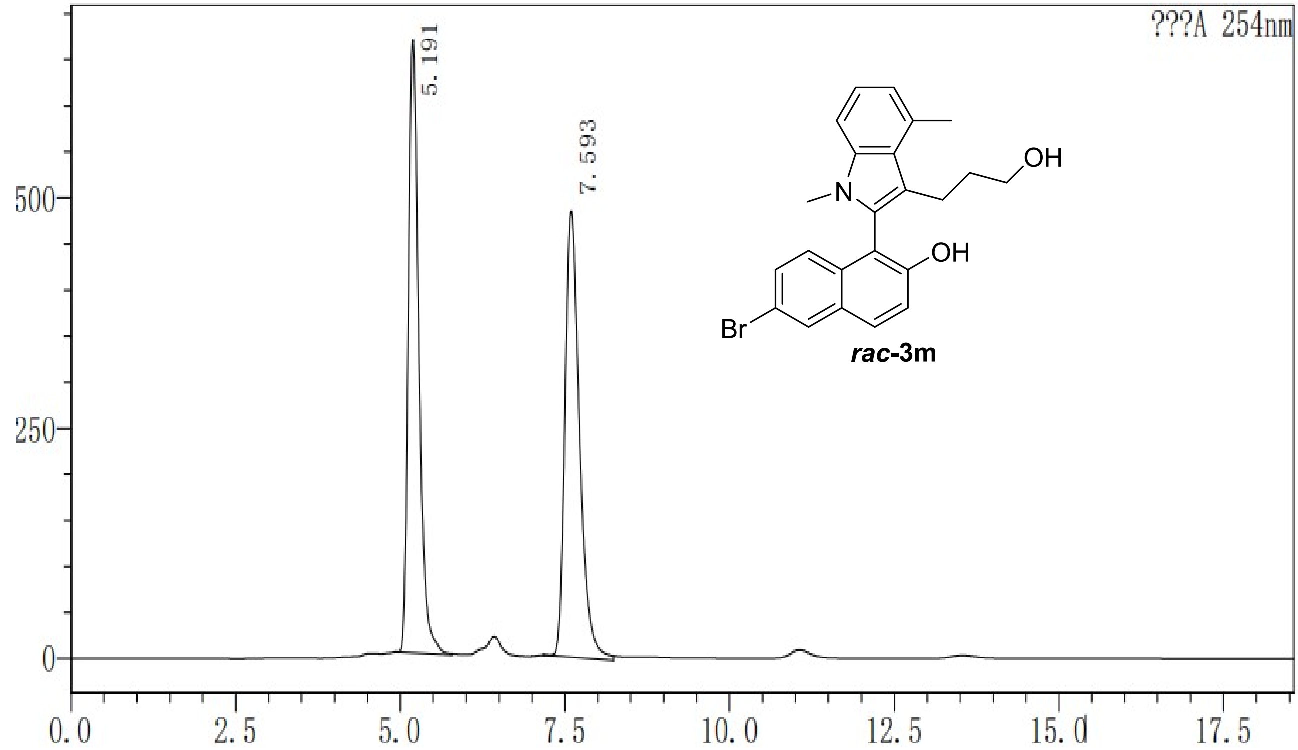
3m

^{1}H NMR (400 MHz, DMSO-d_6)

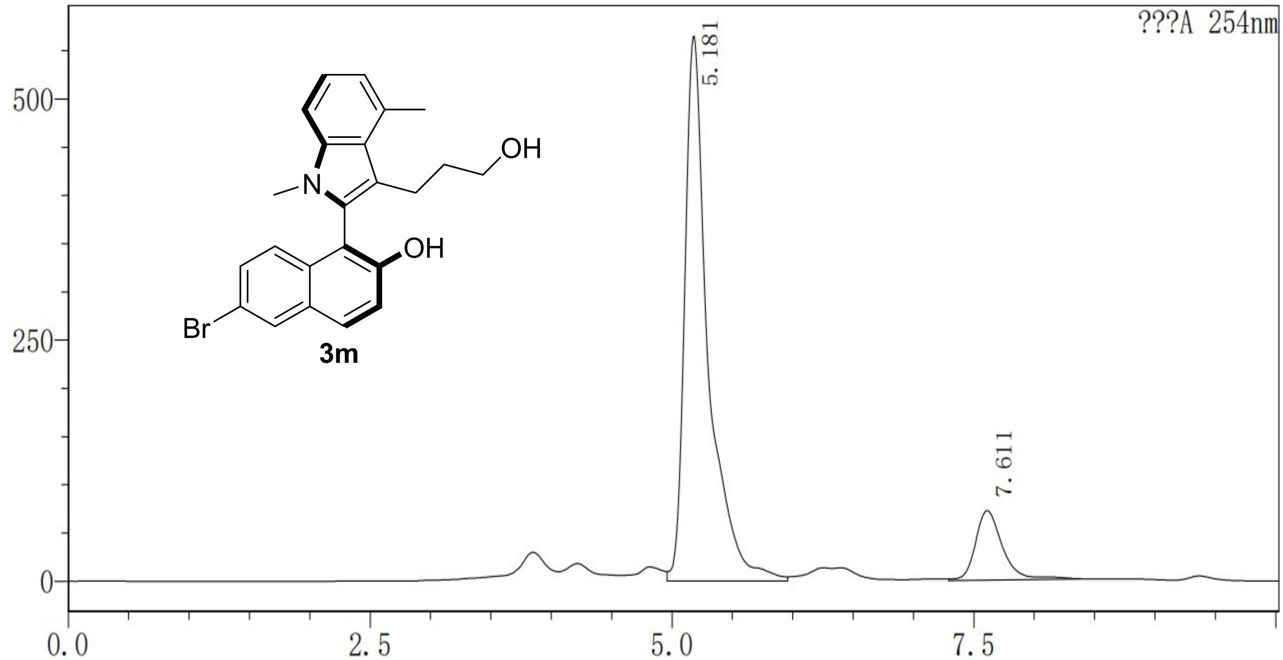


3m

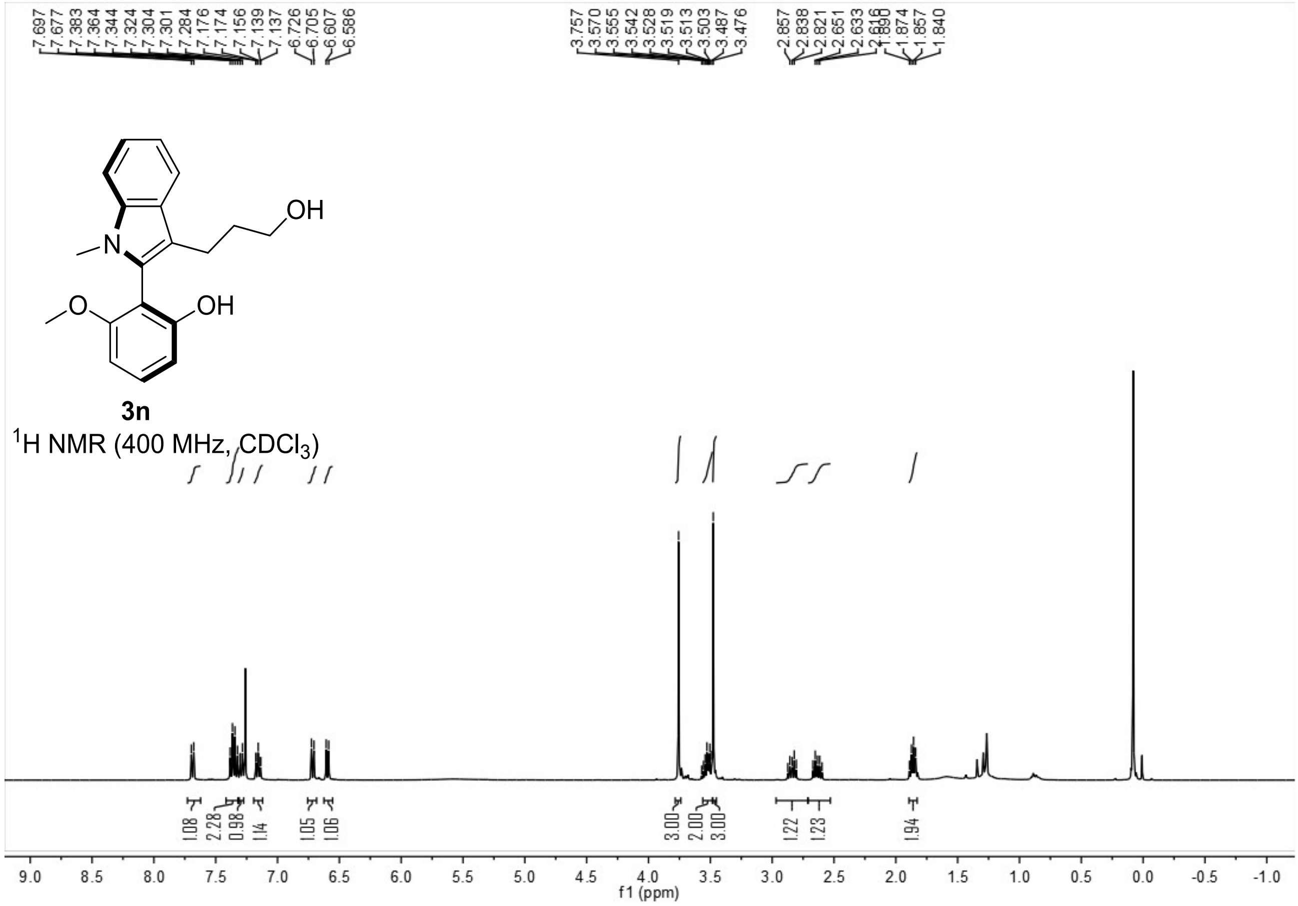
^{13}C NMR (400 MHz, DMSO-d_6)

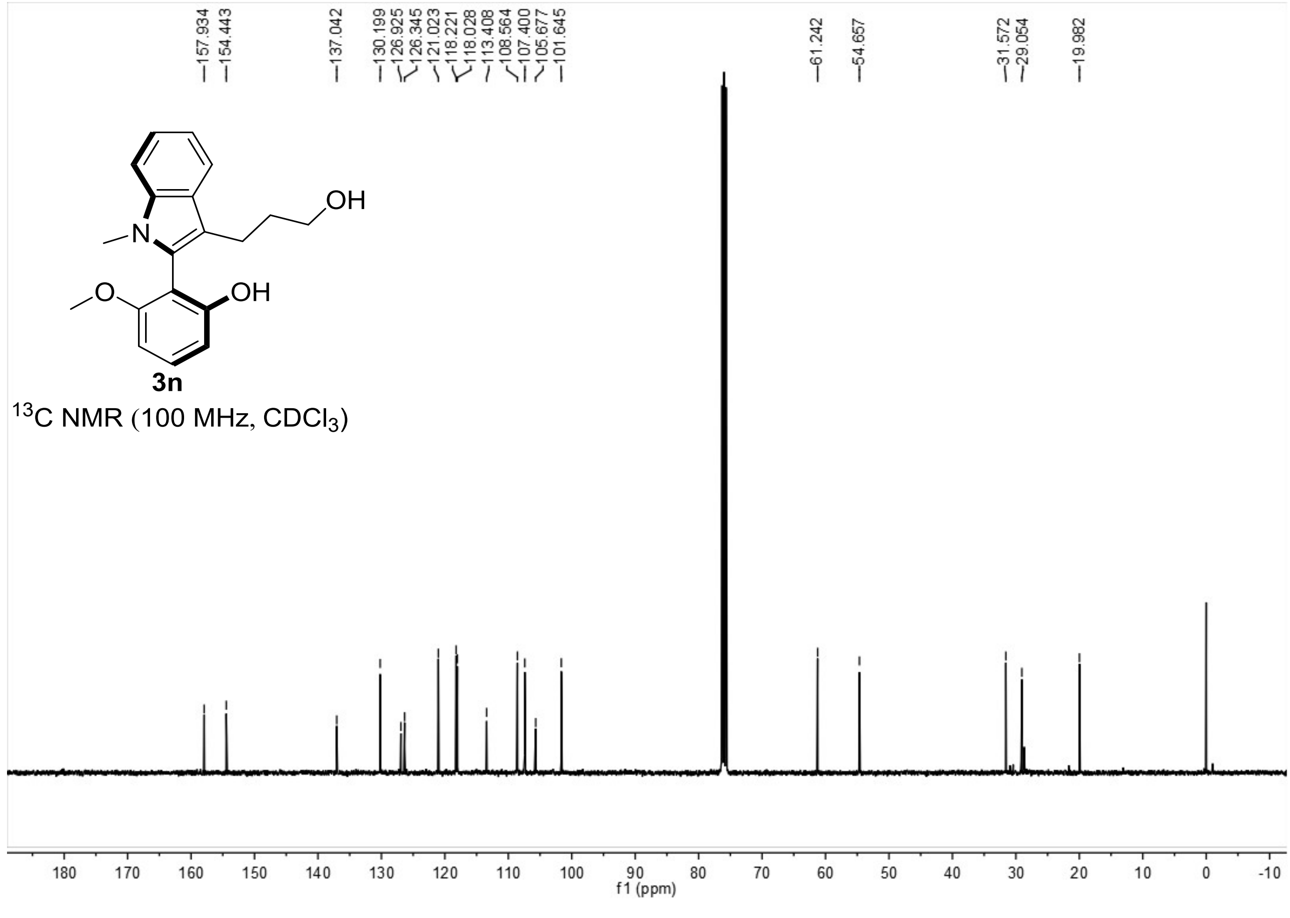


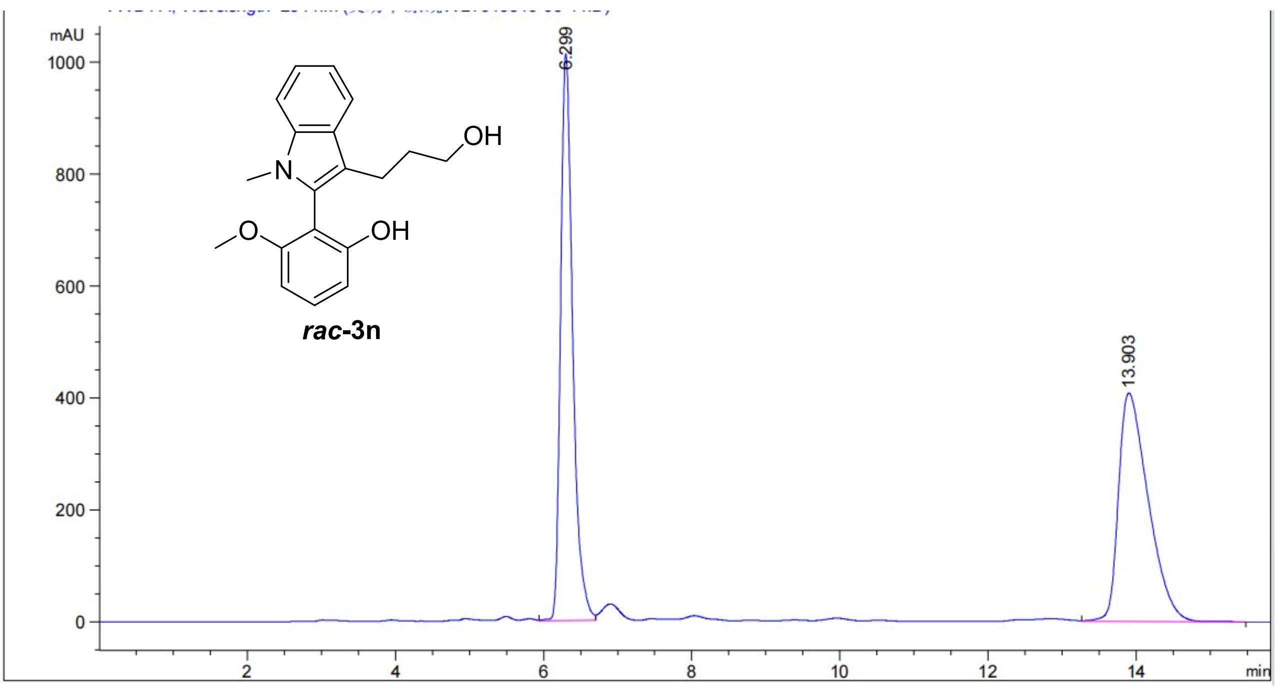
Peak#	Ret. Time	Area	Height	Area%	Height%
1	5.191	7396507	665189	49.893	57.861
2	7.593	7428381	484445	50.107	42.139



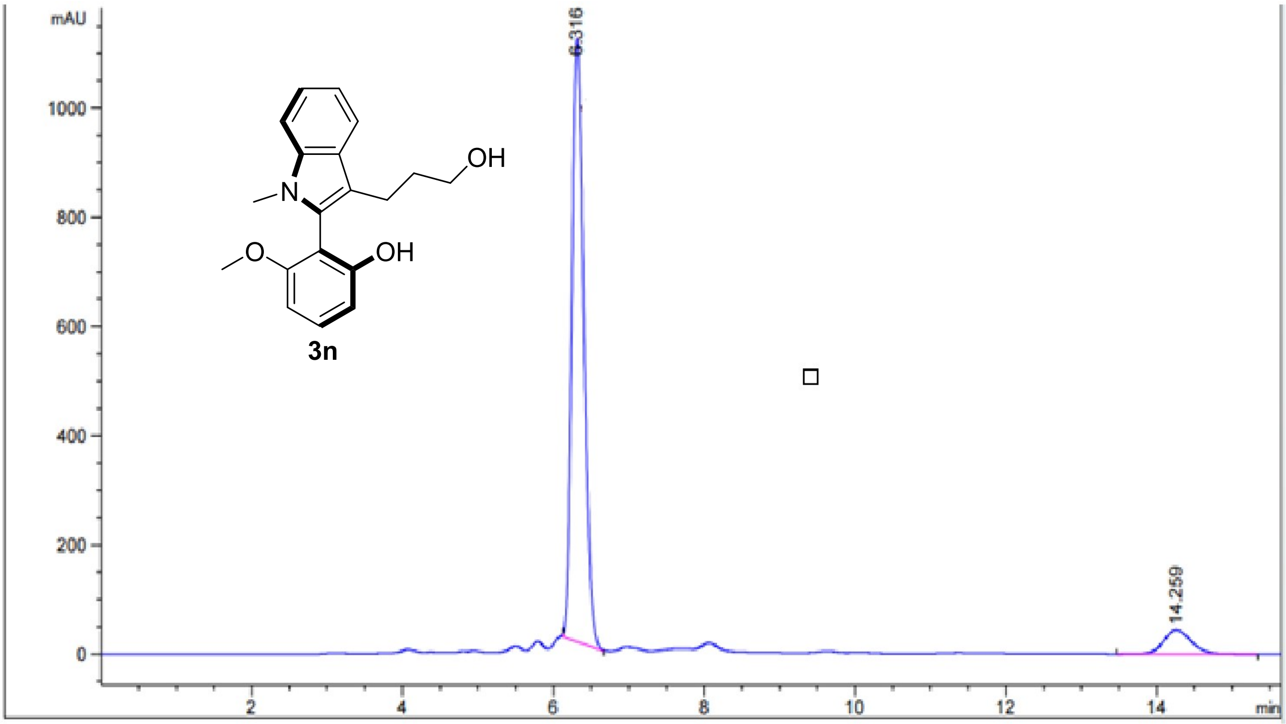
Peak#	Ret. Time	Area	Height	Area%	Height%
1	5.181	7549663	565845	88.053	88.837
2	7.611	1024301	71103	11.947	11.163


7.697
7.677
7.383
7.364
7.344
7.324
7.304
7.301
7.284
7.176
7.174
7.156
7.139
7.137
6.726
6.705
6.607
6.586
3.757
3.570
3.555
3.542
3.528
3.519
3.513
3.503
3.487
3.476
2.857
2.838
2.821
2.651
2.633
2.616
1.890
1.874
1.857
1.840
OH
N
O
OH
3n
^{1}H NMR (400 MHz, CDCl$_3$)
1.08
2.28
0.98
1.14
1.05
1.06
3.00
2.00
3.00
1.22
1.23
1.94
9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5 -1.0
f1 (ppm)

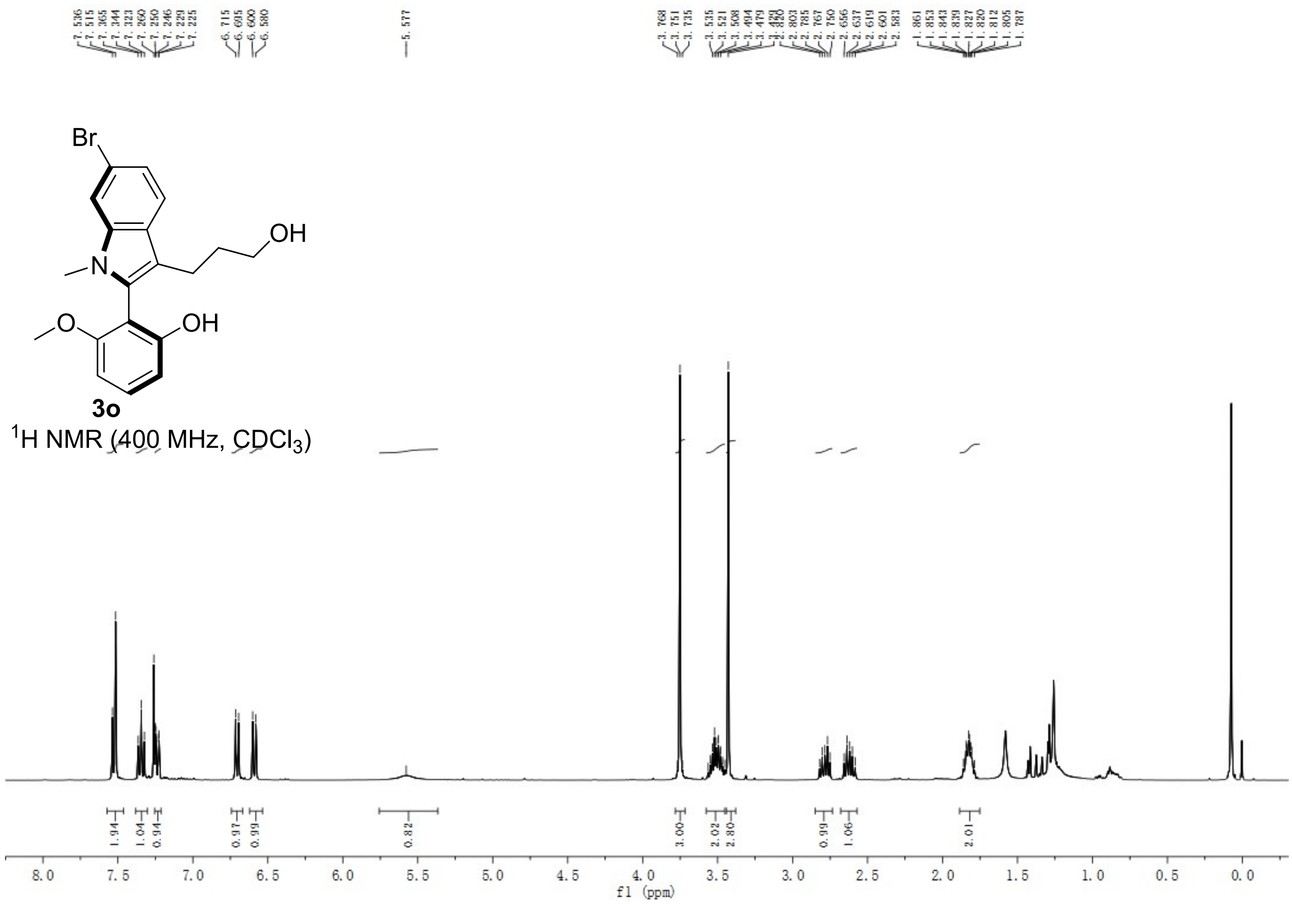

157.934
154.443
137.042
130.199
126.925
126.345
121.023
118.221
118.028
113.408
108.564
107.400
105.677
101.645
61.242
54.657
31.572
29.054
19.982
OH
N
O
OH
3n
^{13}C NMR (100 MHz, CDCl$_3$)
180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
f1 (ppm)



```
Peak Ret time Type  Width    Area      Height      Area
 #    [min]         [min]  [mAU*s]     [mAU]        %
----|-------|----|-------|----------|----------|--------
  1    6.299 VV    0.1750 1.15411e4 1012.21576  50.2597
  2   13.903 VB    0.4261 1.14218e4  408.61795  49.7403
```

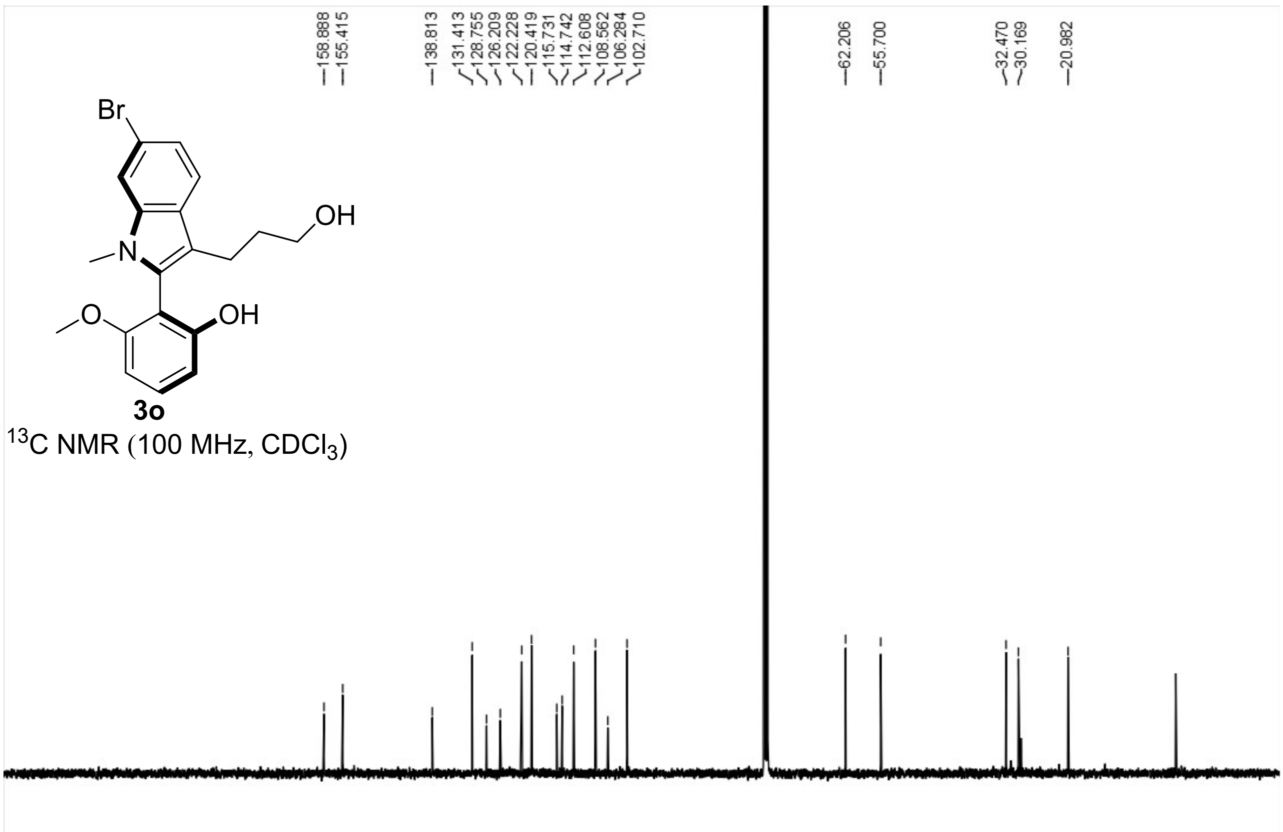


```
Peak Ret time Type  Width    Area      Height      Area
 #    [min]         [min]  [mAU*s]     [mAU]        %
----|-------|----|-------|----------|----------|--------|
  1    6.316 MM    0.1822 1.20722e4 1104.00256  91.4548
  2   14.259 BB    0.3964 1127.98364  44.09732   8.5452
```



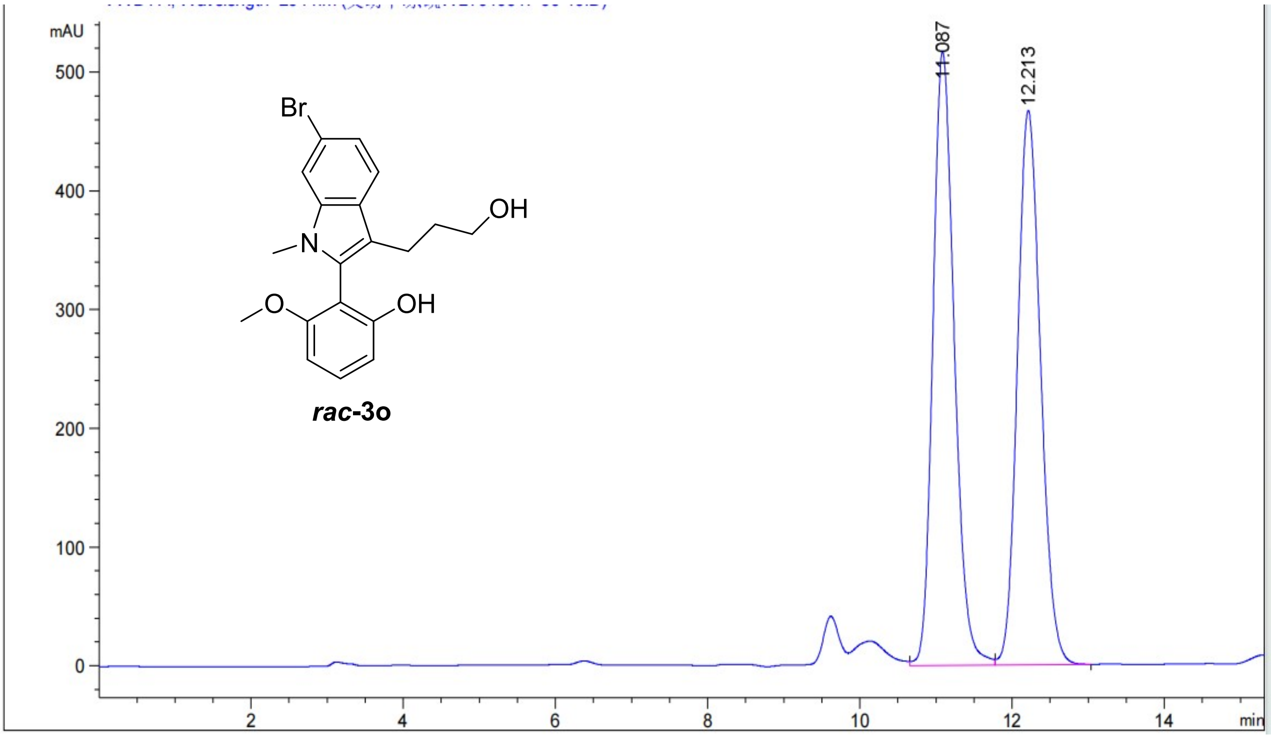
3o

^{1}H NMR (400 MHz, CDCl$_3$)



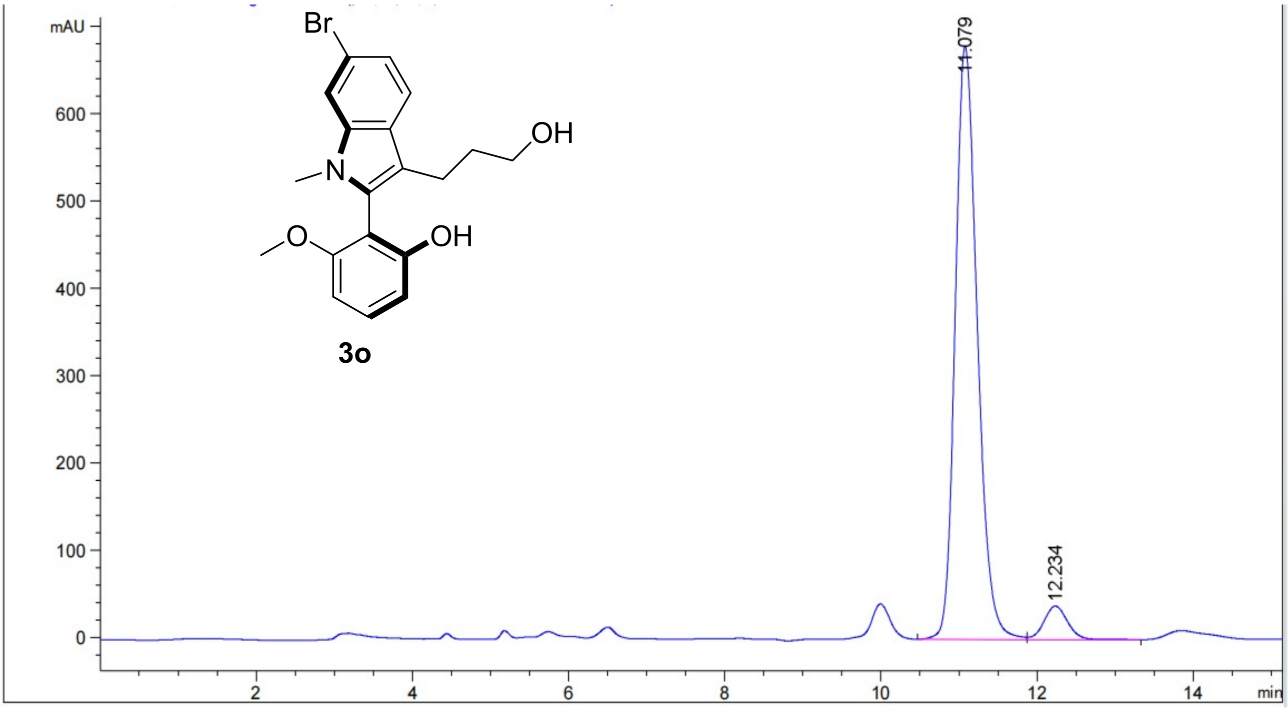
3o

^{13}C NMR (100 MHz, CDCl$_3$)



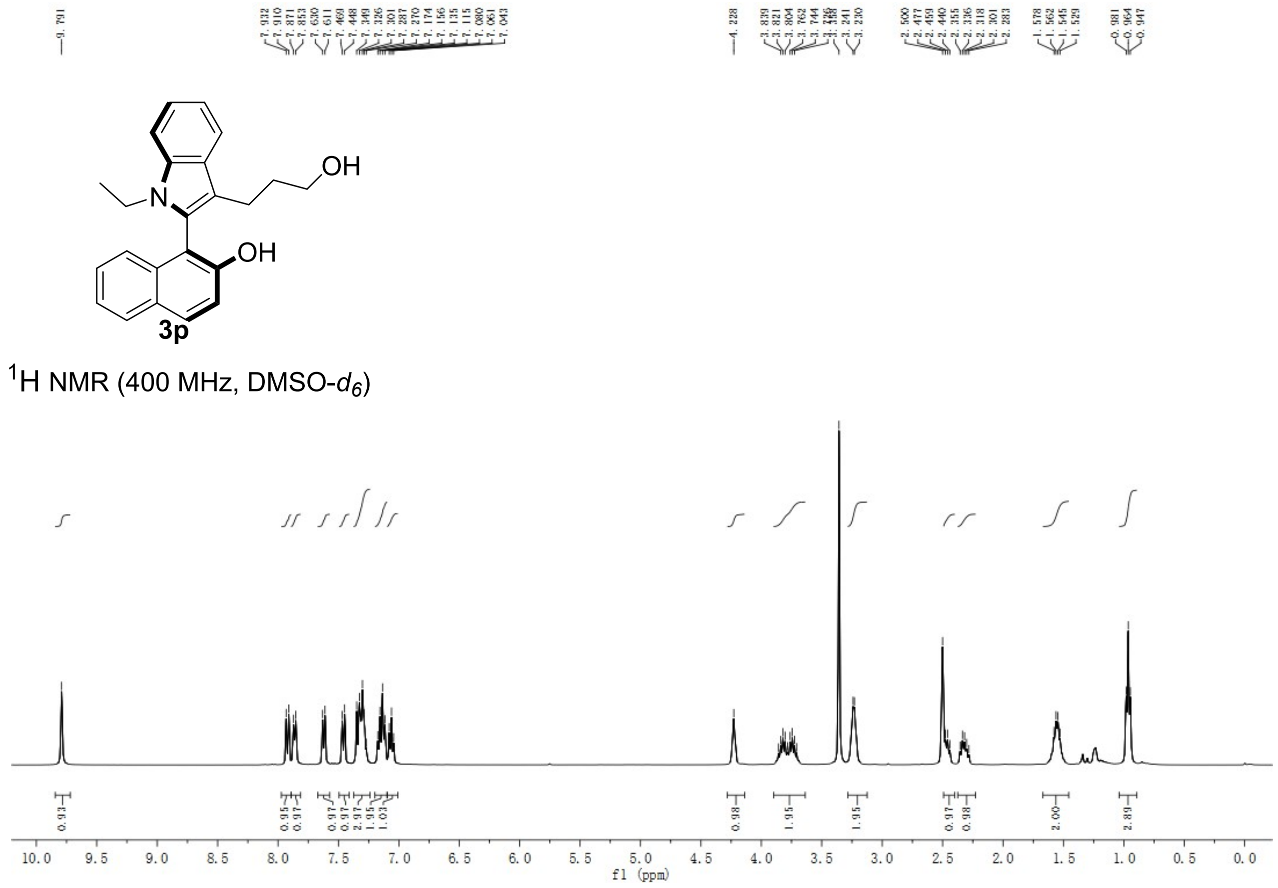
***rac*-3o**

```
Peak Ret time Type  Width     Area      Height      Area
 #    [min]         [min]   [mAU*s]     [mAU]        %
----|-------|----|-------|----------|----------|--------|
   1  11.087 VV    0.3029 1.00955e4   516.84070  50.5218
   2  12.213 VB    0.3301 9886.95508  466.87906  49.4782
```



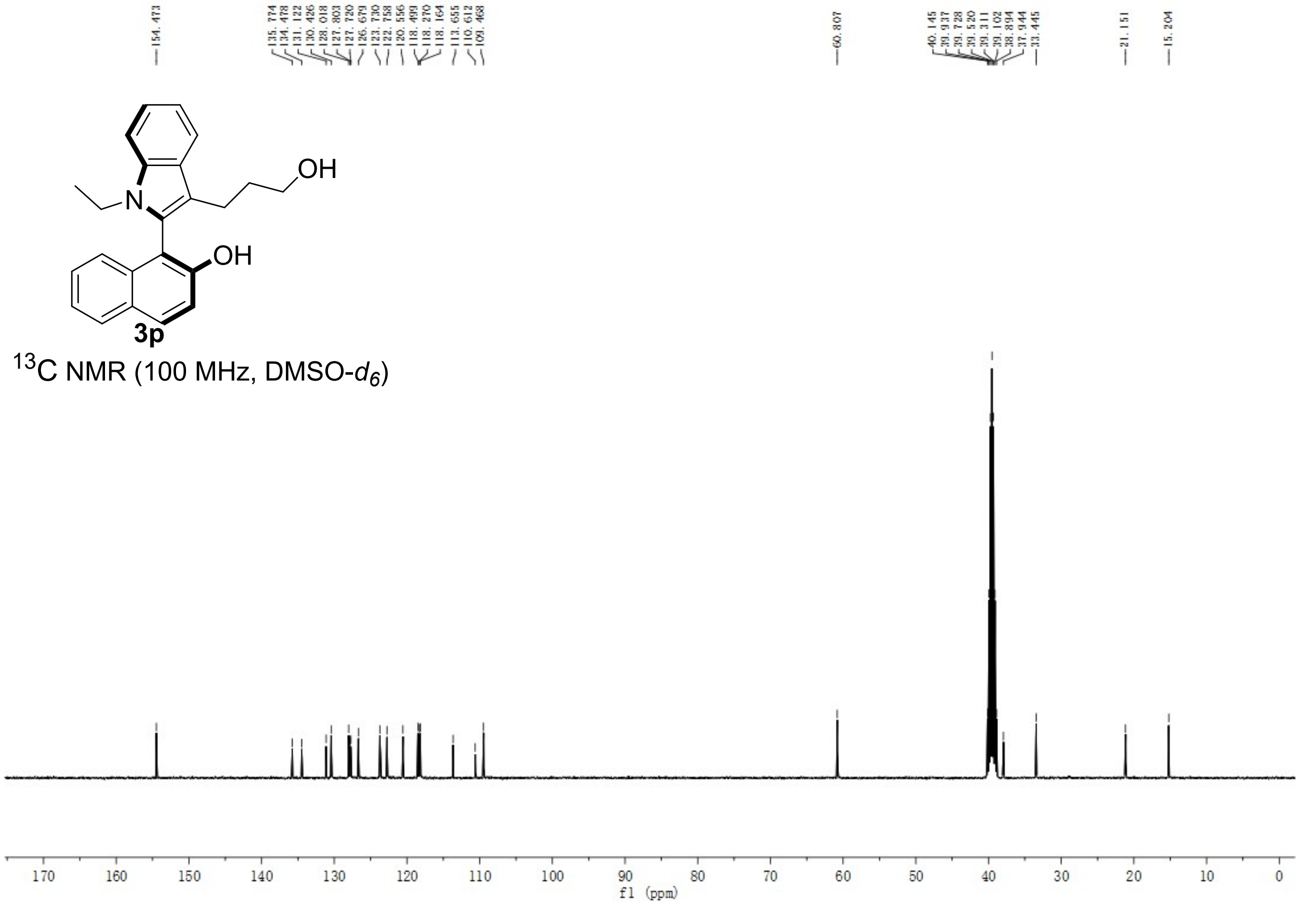
3o

```
Peak Ret time Type  Width     Area      Height      Area
 #    [min]         [min]   [mAU*s]     [mAU]        %
----|-------|----|-------|----------|----------|--------|
   1  11.079 VV    0.3045 1.33578e4   678.91650  94.2827
   2  12.234 VB    0.3254  810.02325   38.35352   5.7173
```



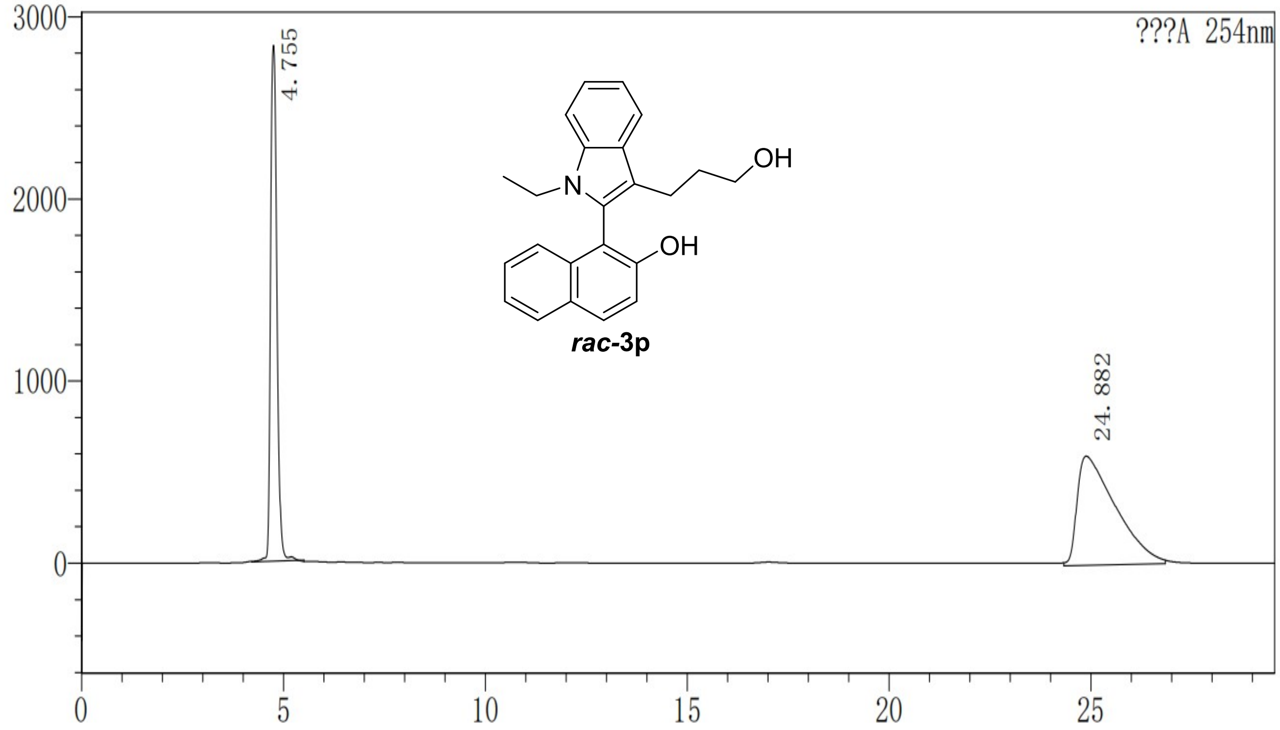
3p

^{1}H NMR (400 MHz, DMSO-d_6)



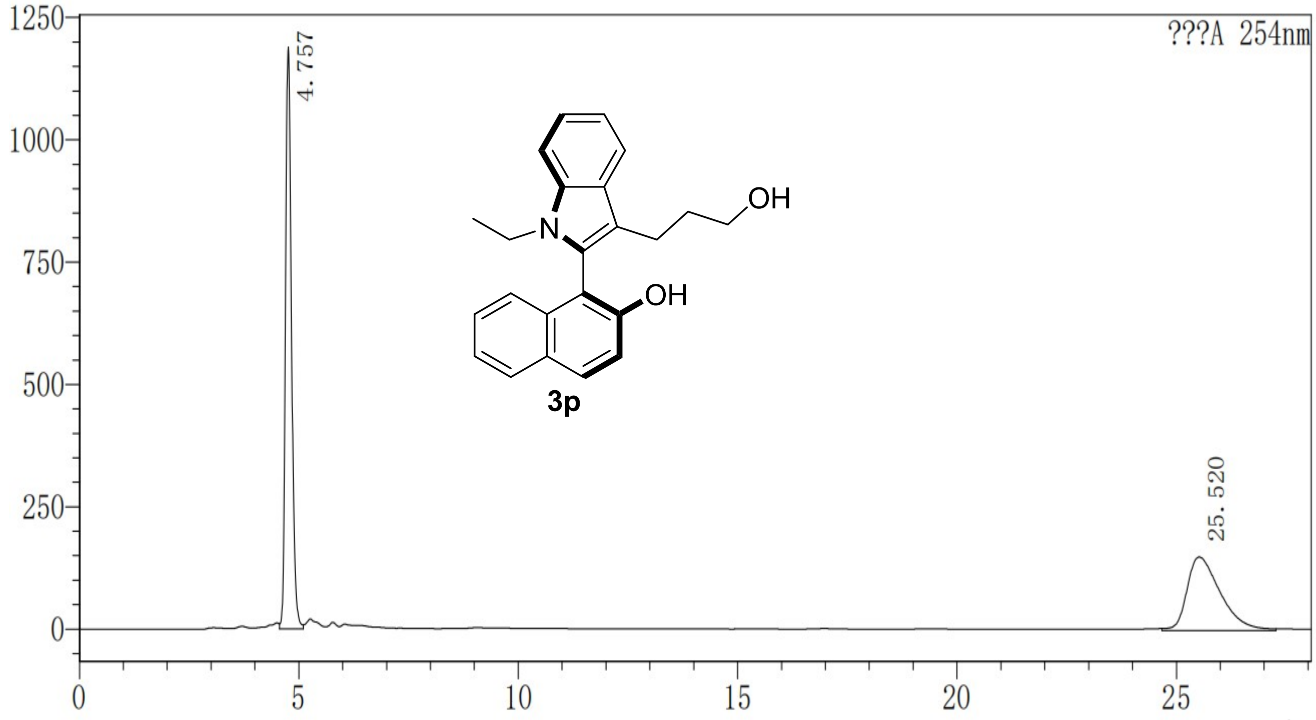
3p

^{13}C NMR (100 MHz, DMSO-d_6)



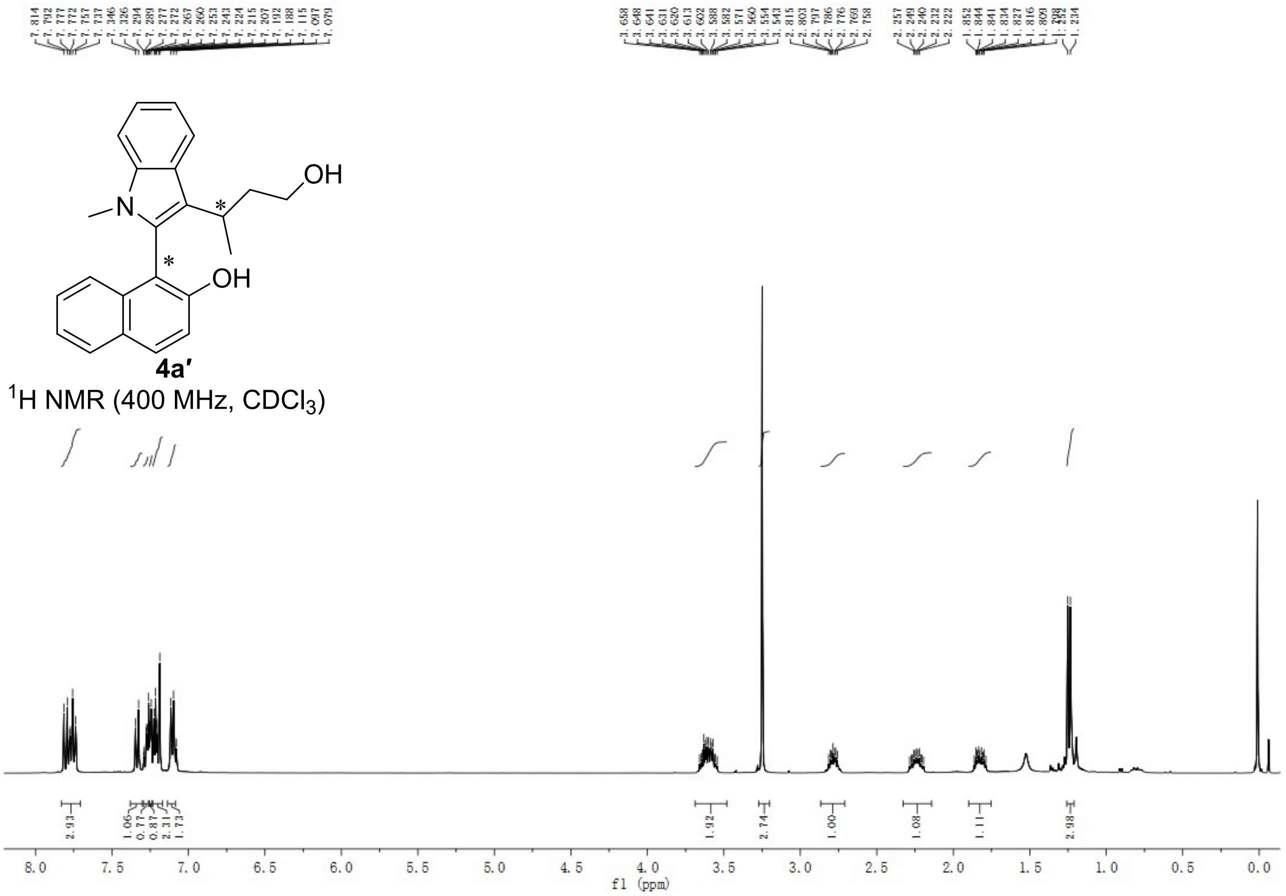
***rac*-3p**

Peak	Ret. Time	Area	Height	Area%
1	4.755	32692014	2859020	49.951
2	24.882	32756317	544738	50.049



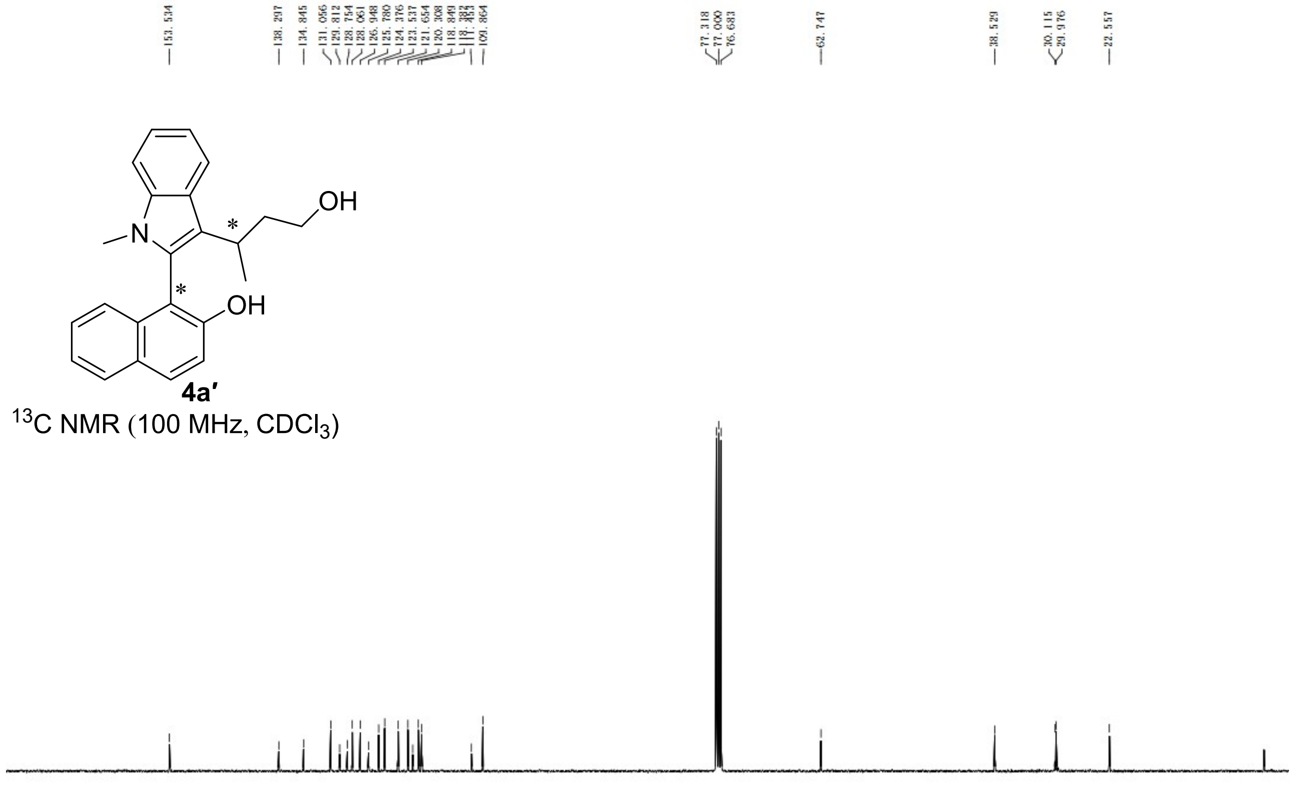
3p

Peak	Ret. Time	Area	Height	Area%
1	4.757	11305481	1188609	61.331
2	25.520	7127937	139693	38.669



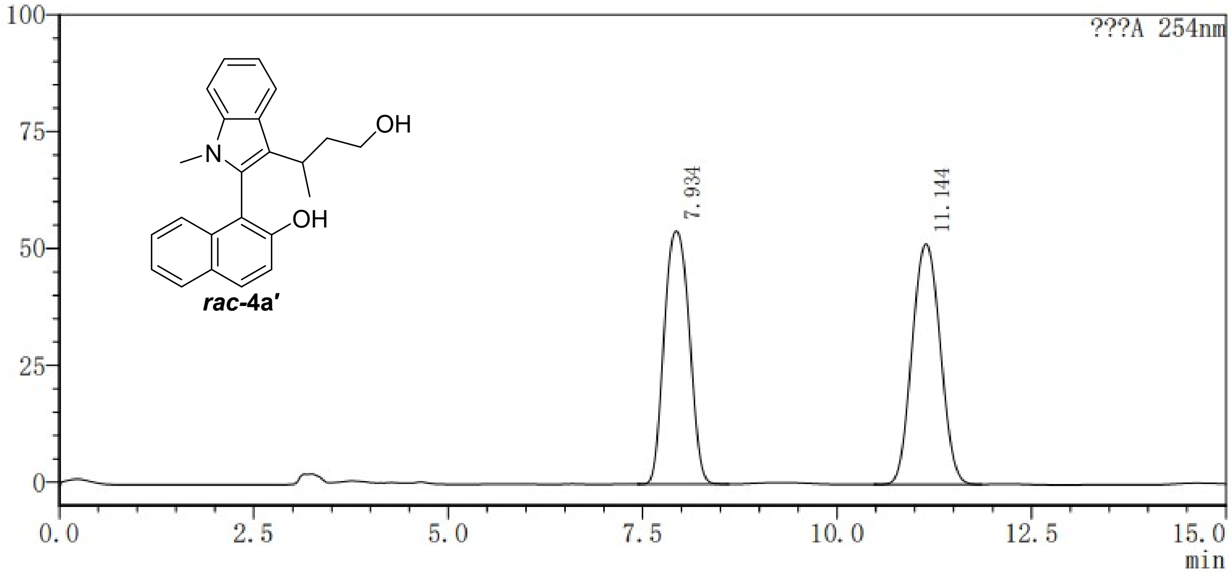
4a′

^1H NMR (400 MHz, $CDCl_3$)

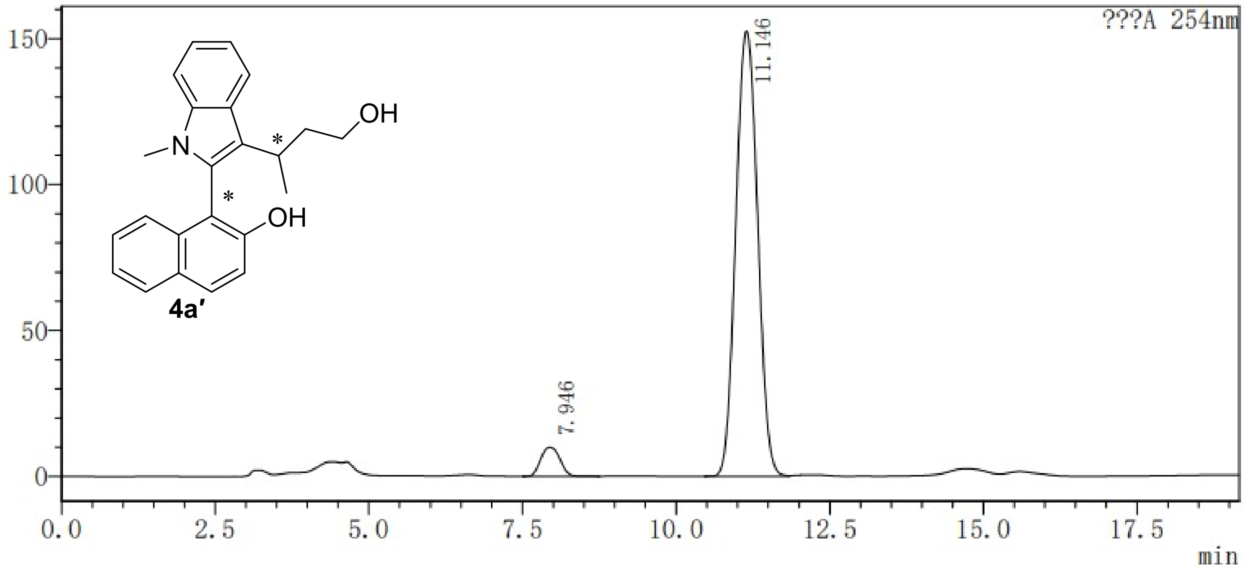


4a′

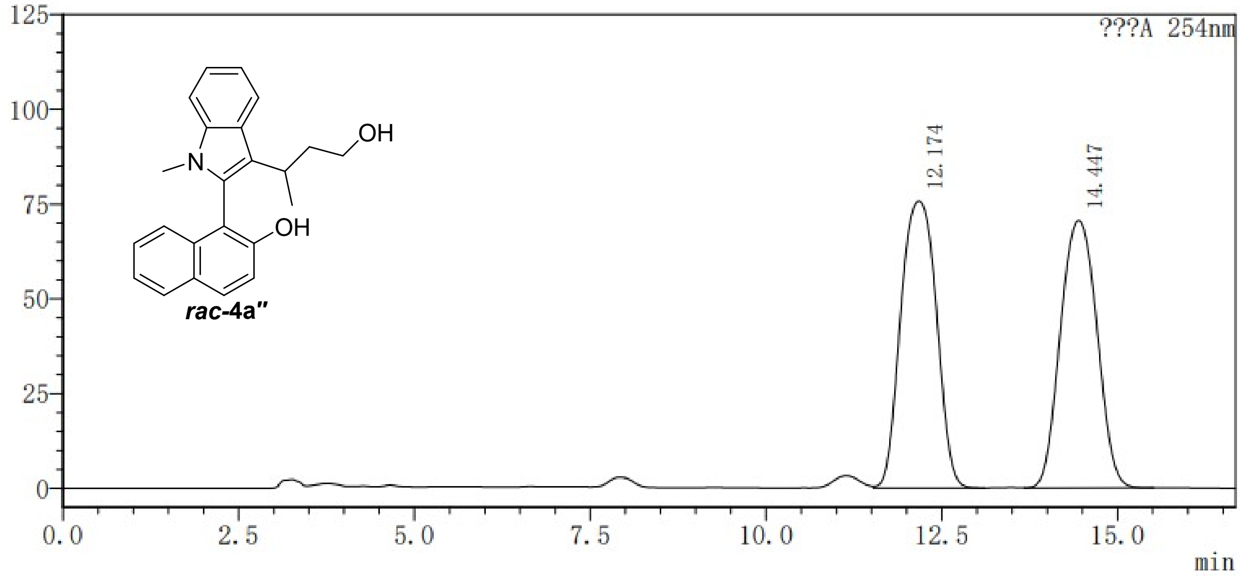
^{13}C NMR (100 MHz, $CDCl_3$)



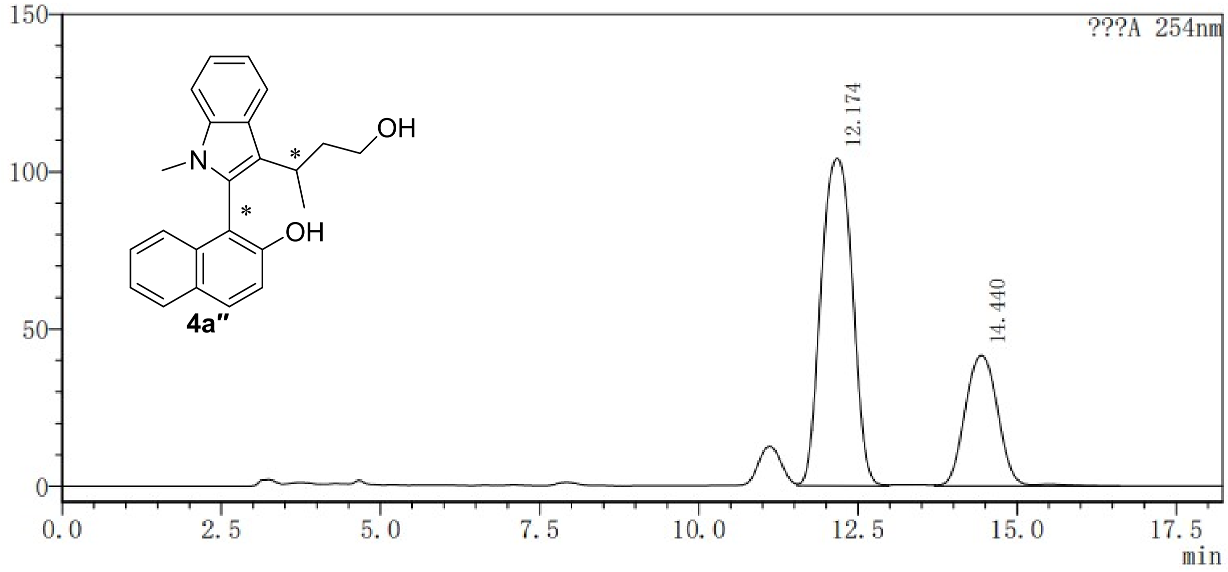
Peak#	Ret. Time	Area	Height	Area%	Height%
1	7.934	1215920	54187	48.367	51.291
2	11.144	1298001	51458	51.633	48.709
Total		2513921	105644	100.000	100.000



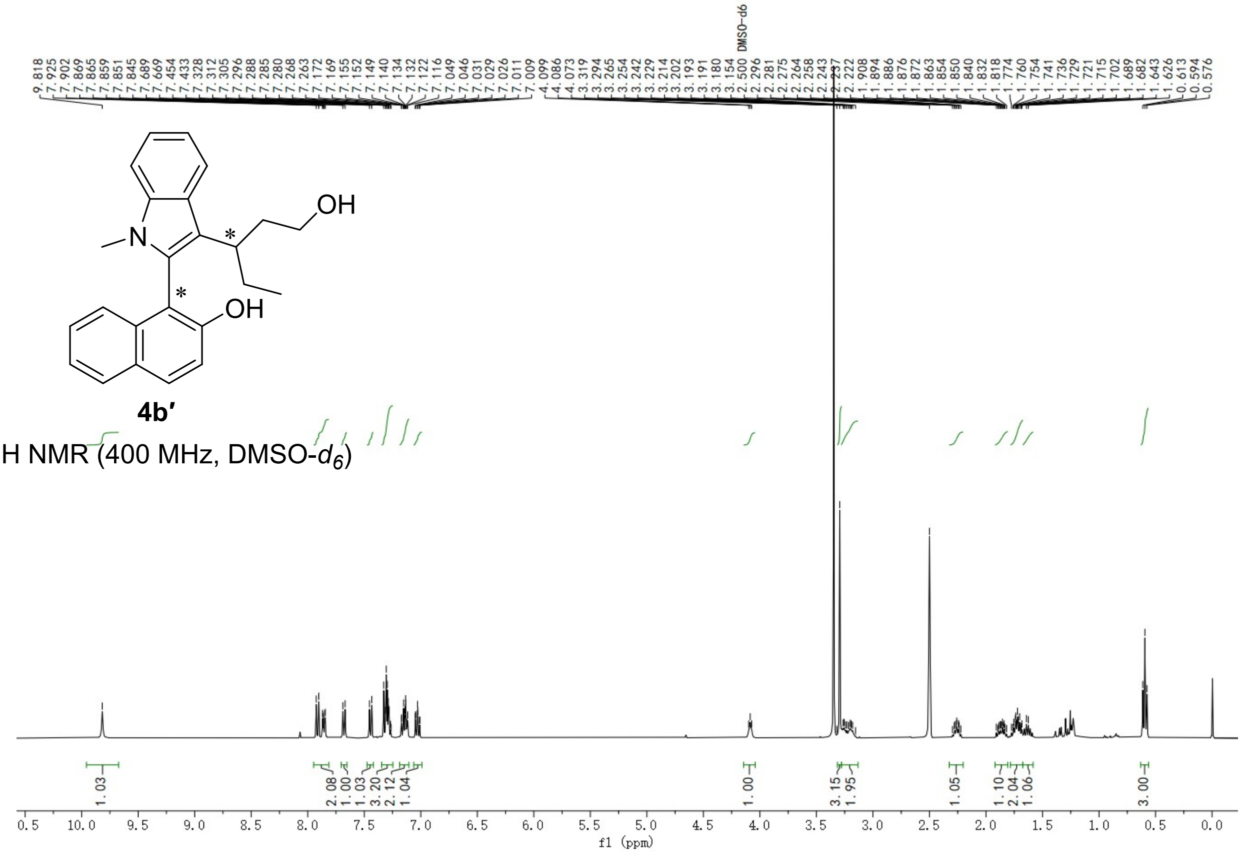
Peak#	Ret. Time	Area	Height	Area%	Height%
1	7.946	212947	9864	5.360	6.075
2	11.146	3760194	152515	94.640	93.925
Total		3973141	162379	100.000	100.000



Peak#	Ret. Time	Area	Height	Area%	Height%
1	12.174	2669529	75671	51.138	51.757
2	14.447	2550751	70534	48.862	48.243
Total		5220281	146205	100.000	100.000

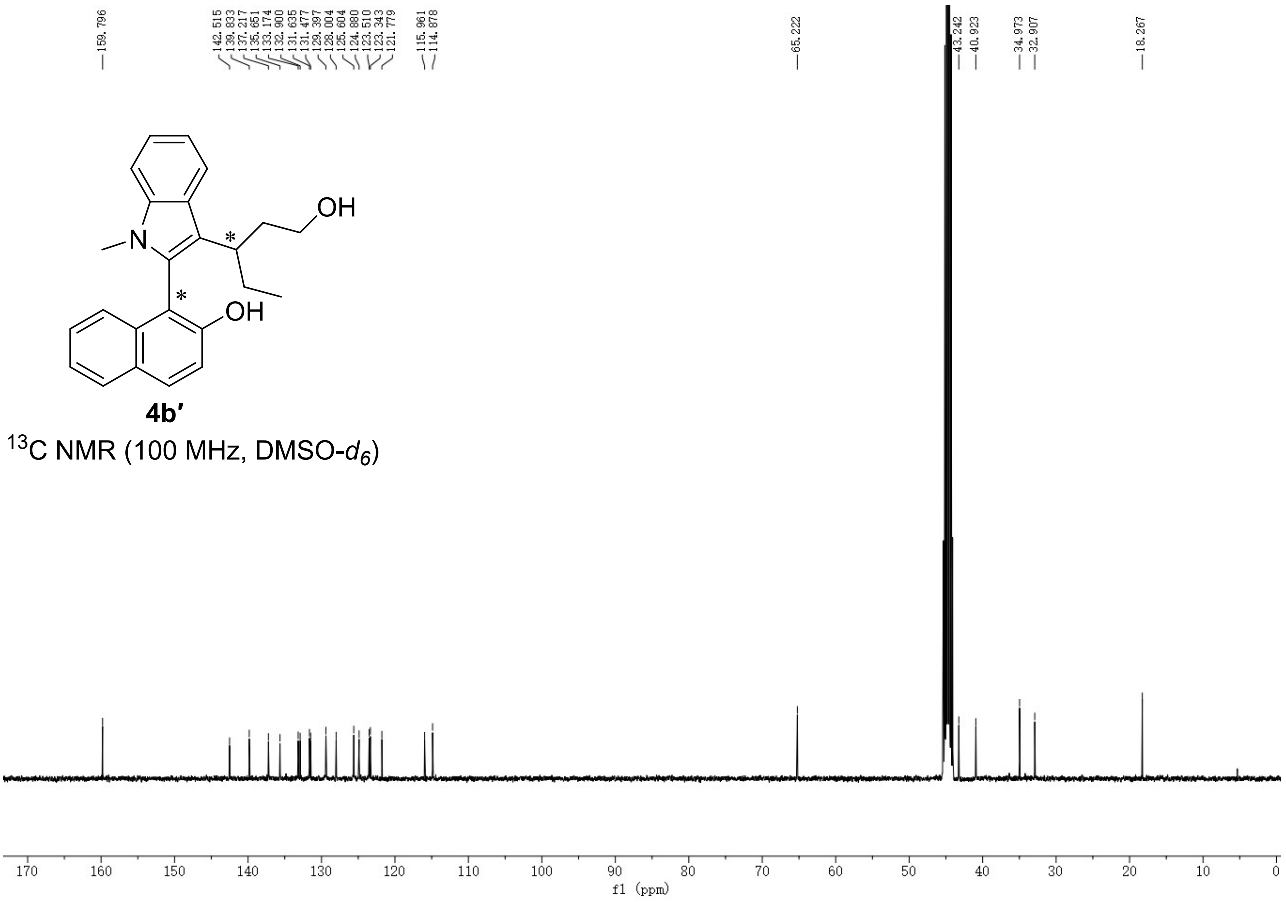


Peak#	Ret. Time	Area	Height	Area%	Height%
1	12.174	3574450	104168	70.494	71.516
2	14.440	1496099	41489	29.506	28.484
Total		5070549	145656	100.000	100.000



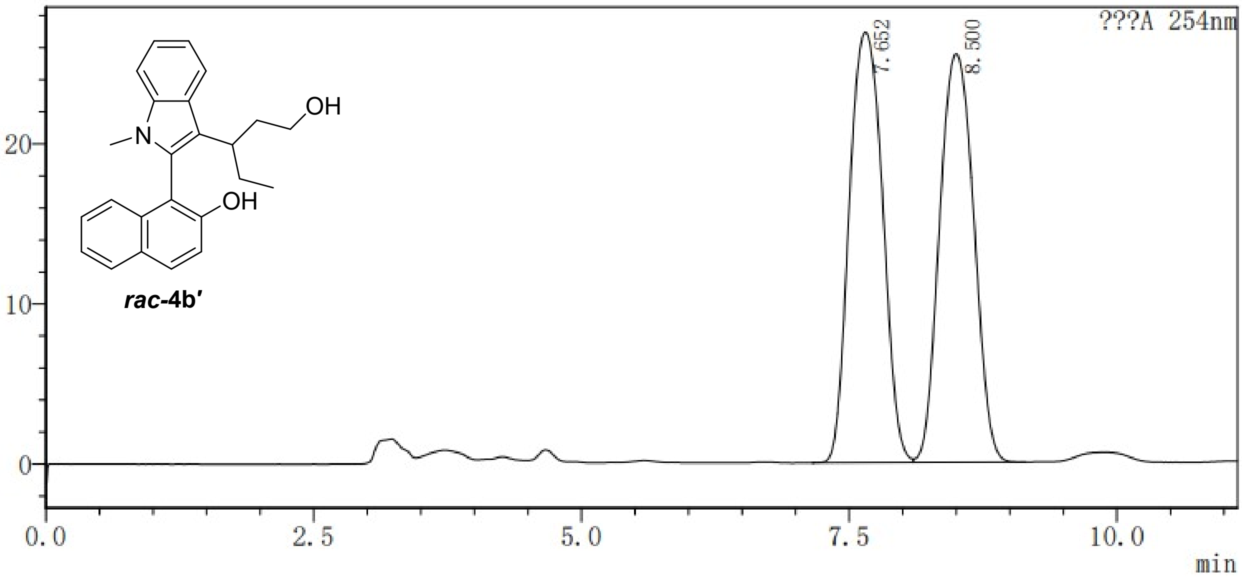
4b′

^{1}H NMR (400 MHz, DMSO-d_6)

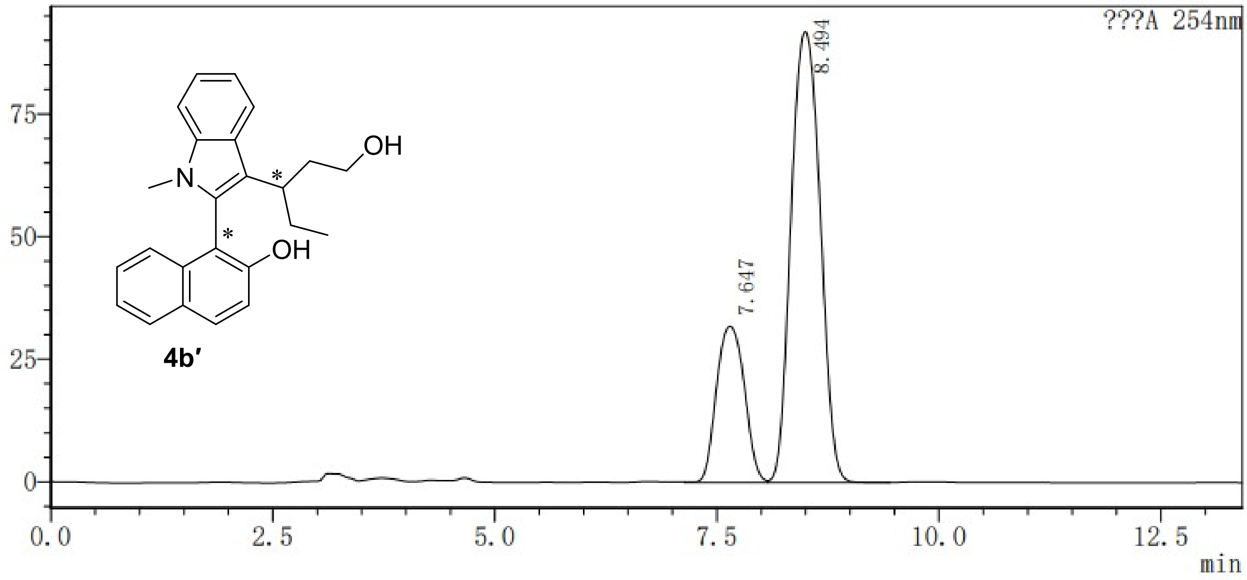


4b′

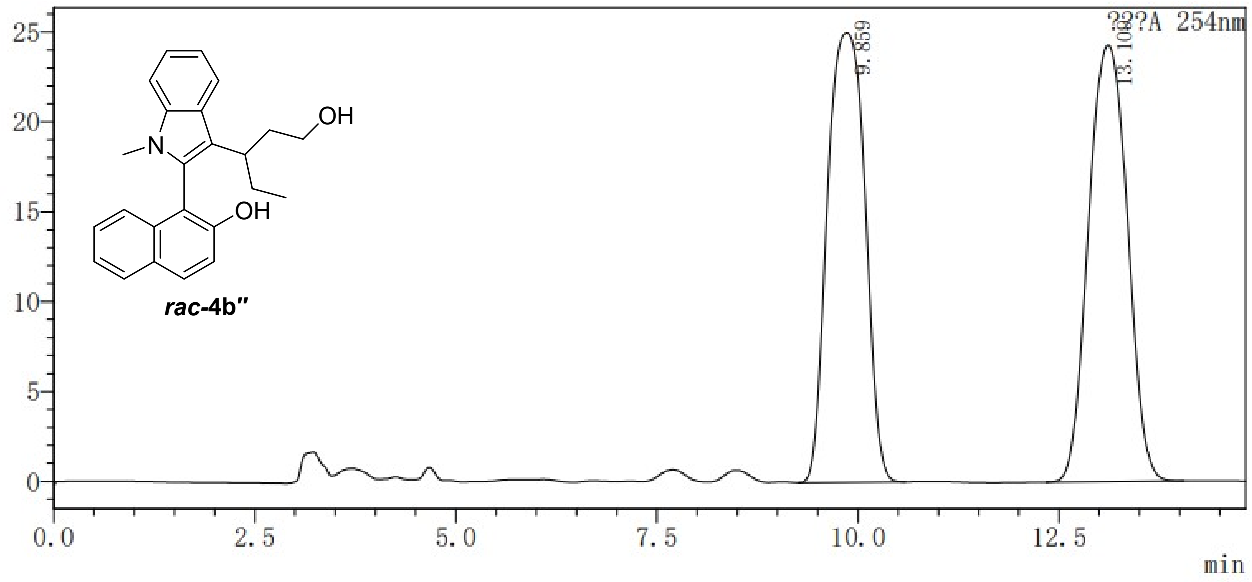
^{13}C NMR (100 MHz, DMSO-d_6)


***rac*-4b′**

Peak#	Ret. Time	Area	Height	Area%	Height%
1	7.652	581932	26856	50.624	51.301
2	8.500	567580	25494	49.376	48.699
Total		1149513	52349	100.000	100.000

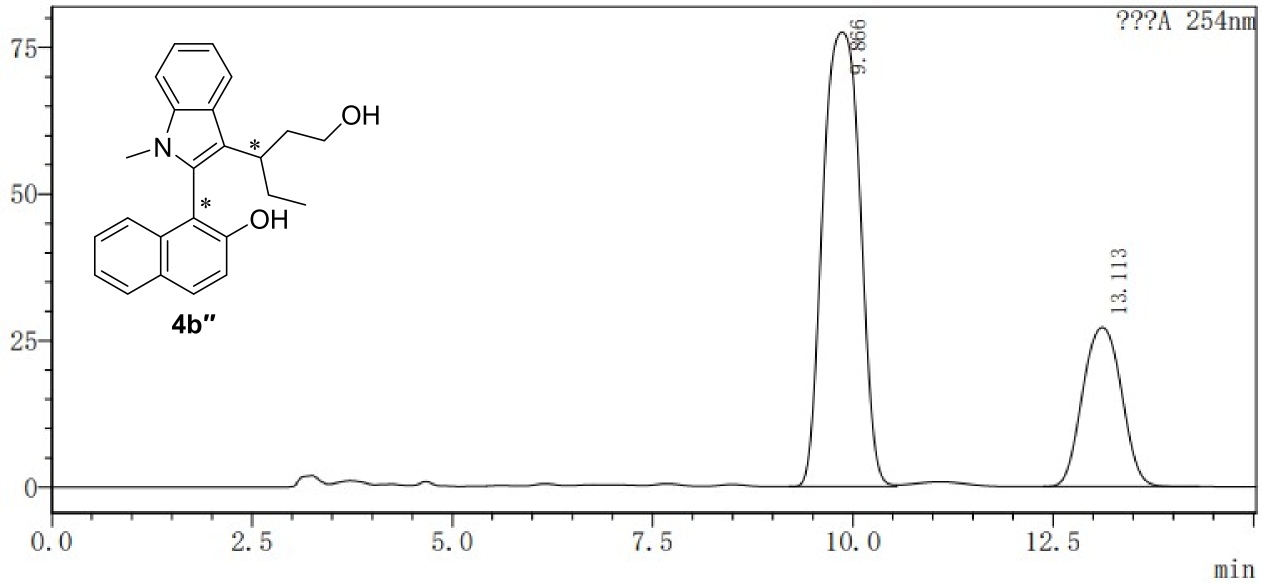

4b′

Peak#	Ret. Time	Area	Height	Area%	Height%
1	7.647	701246	31880	25.041	25.746
2	8.494	2099162	91947	74.959	74.254
Total		2800408	123827	100.000	100.000



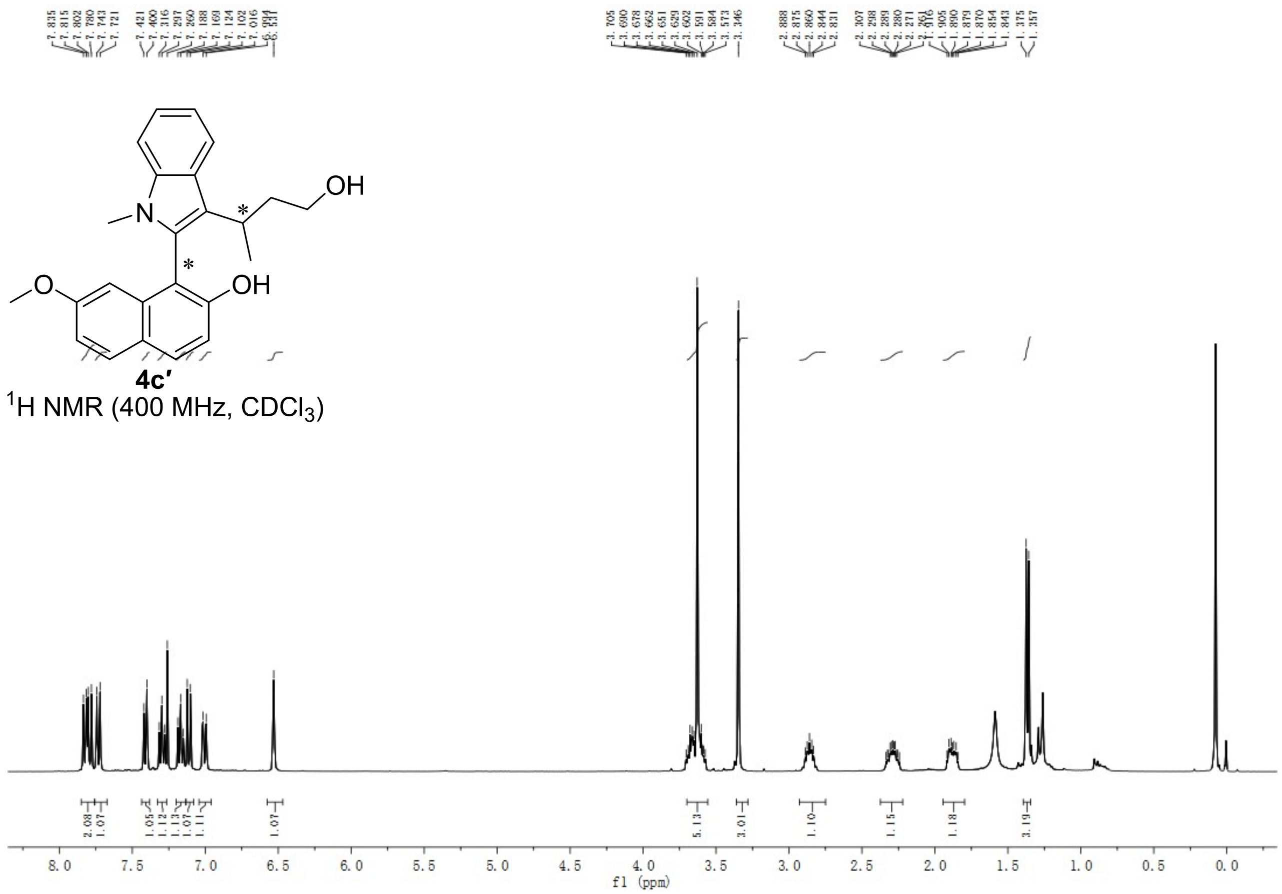
***rac*-4b″**

Peak#	Ret. Time	Area	Height	Area%	Height%
1	9.859	812177	24995	49.813	50.729
2	13.109	818276	24277	50.187	49.271
Total		1630453	49271	100.000	100.000



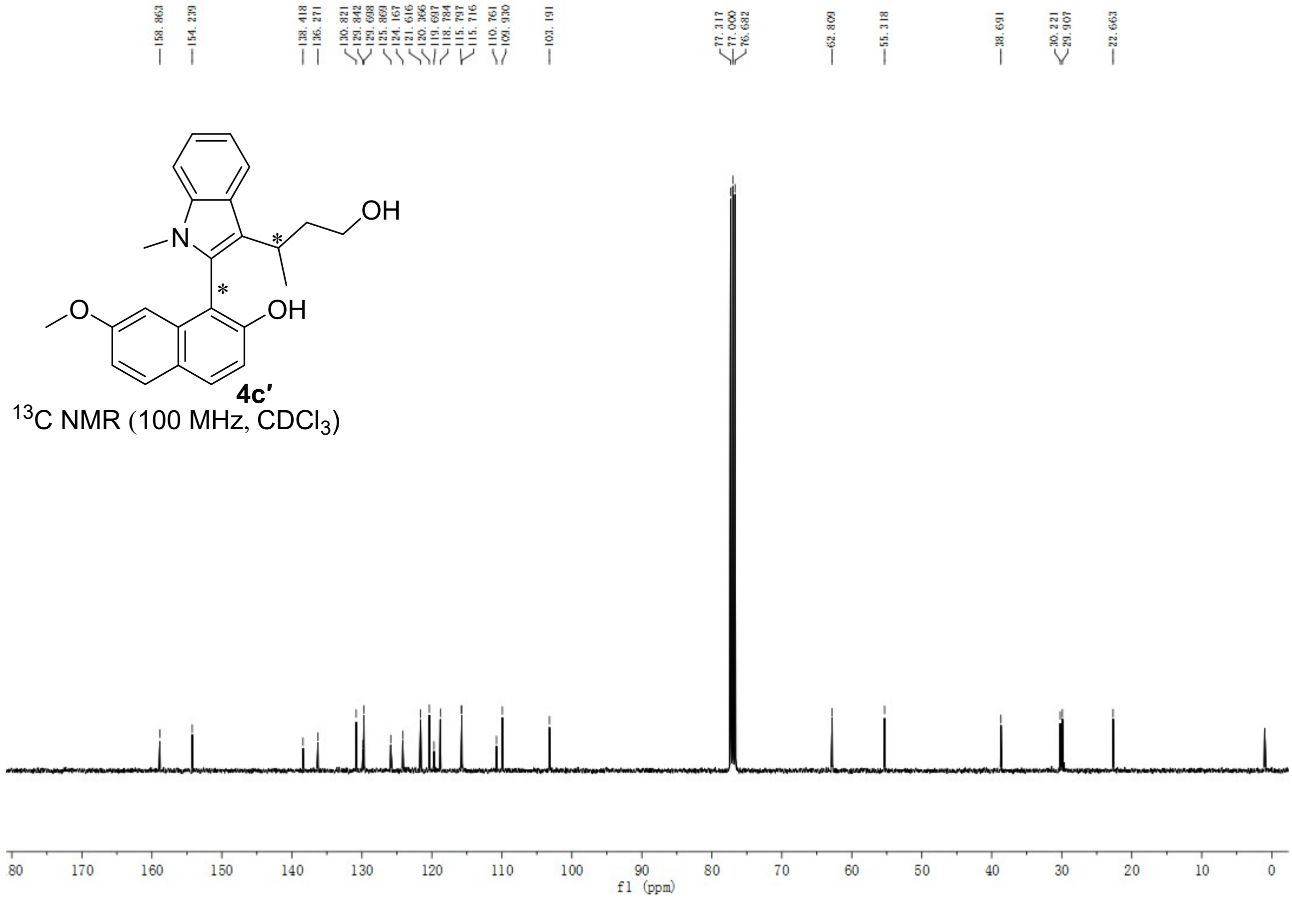
4b″

Peak#	Ret. Time	Area	Height	Area%	Height%
1	9.866	2523261	77535	73.295	74.049
2	13.113	919363	27172	26.705	25.951
Total		3442625	104707	100.000	100.000



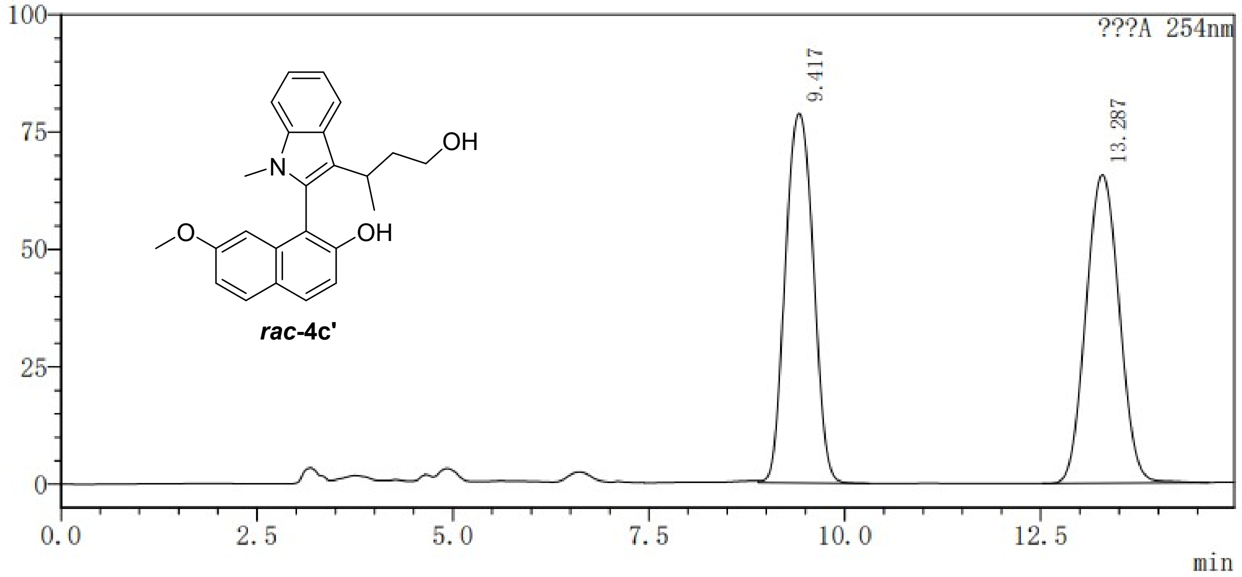
4c′

^{1}H NMR (400 MHz, $CDCl_3$)

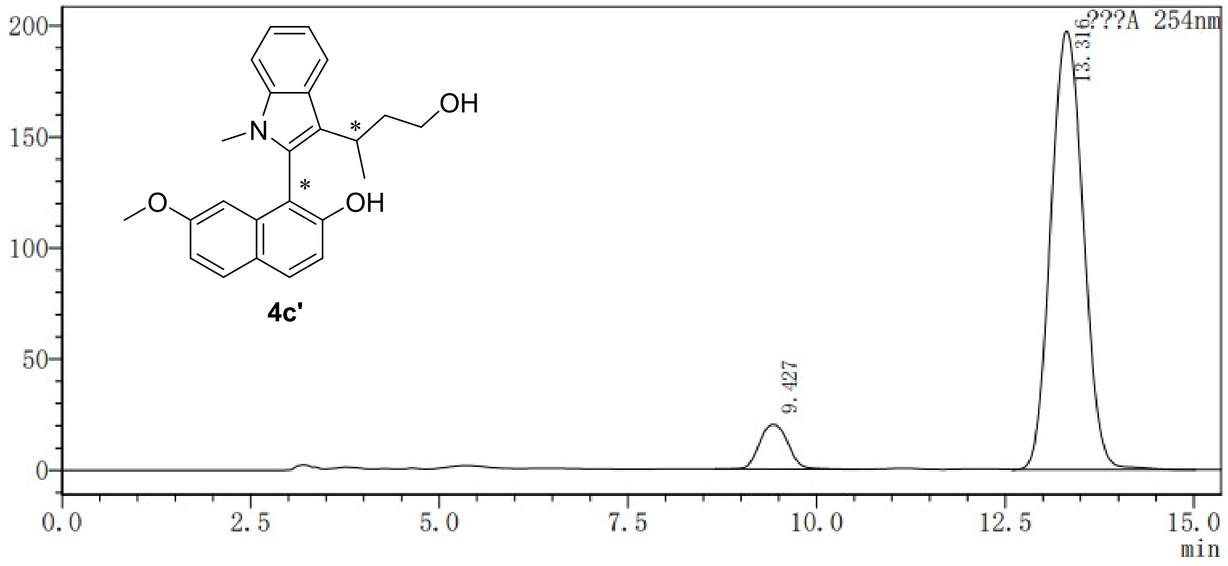


4c′

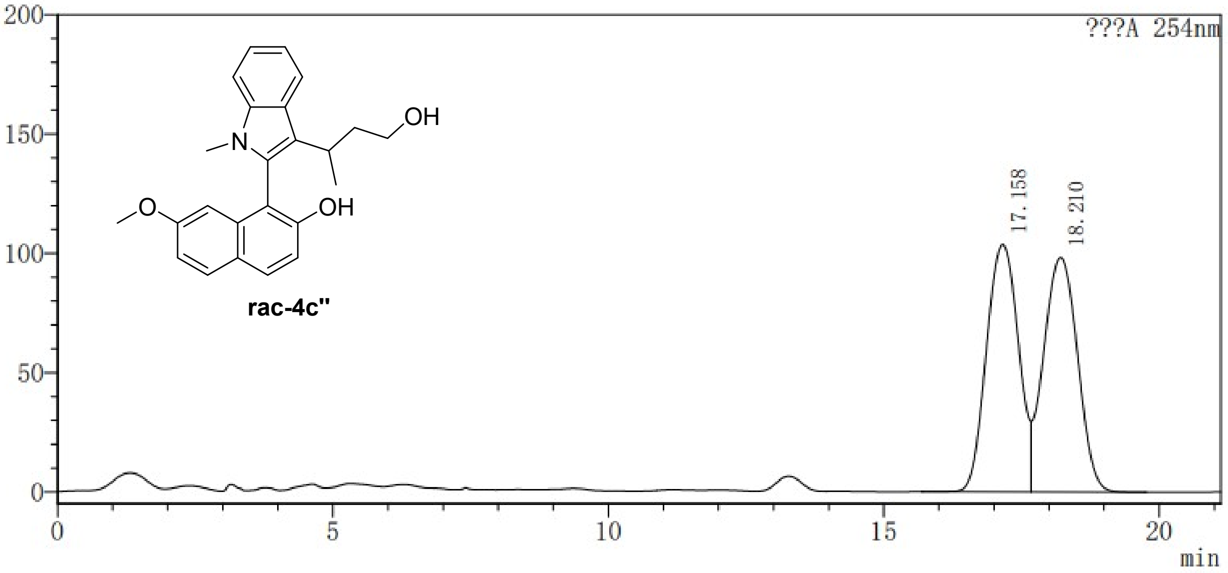
^{13}C NMR (100 MHz, $CDCl_3$)



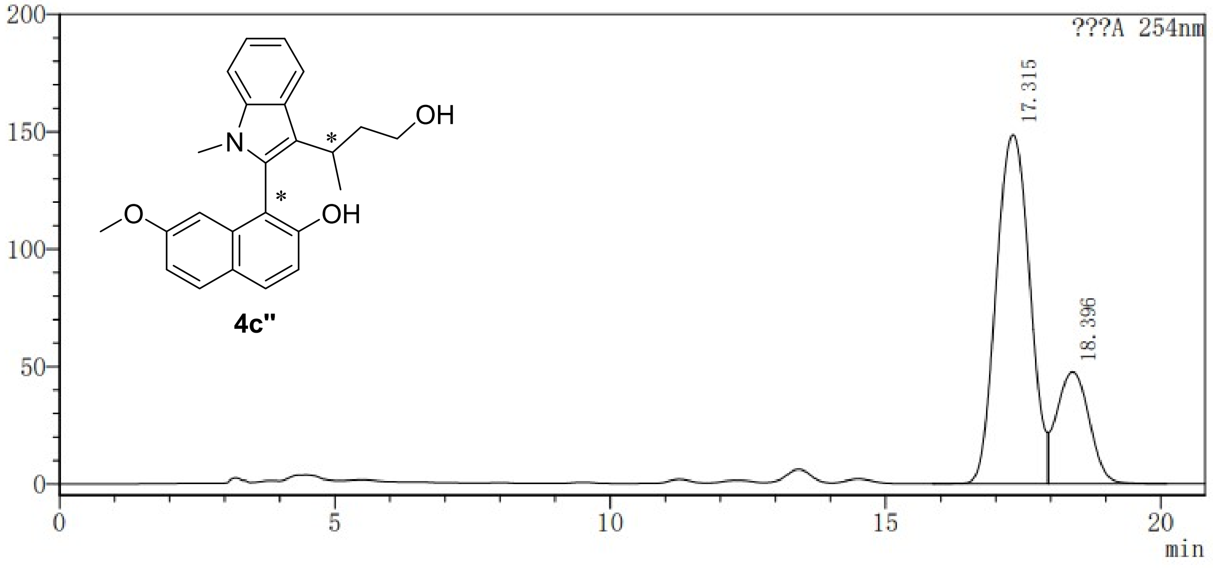
Peak#	Ret. Time	Area	Height	Area%	Height%
1	9.417	1953402	78704	50.036	54.496
2	13.287	1950614	65718	49.964	45.504
Total		3904016	144423	100.000	100.000



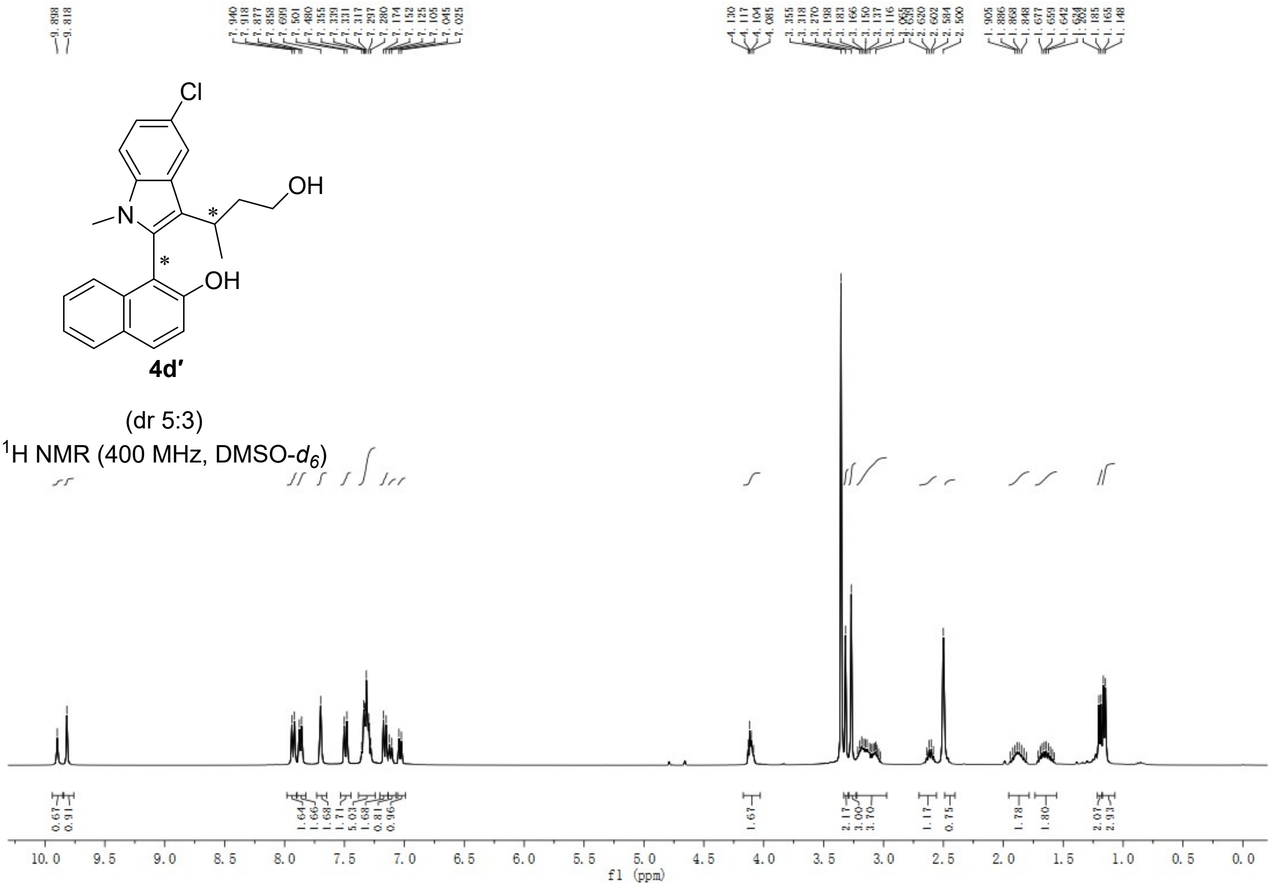
Peak#	Ret. Time	Area	Height	Area%	Height%
1	9.427	531228	20088	8.239	9.241
2	13.316	5916773	197285	91.761	90.759
Total		6448001	217373	100.000	100.000



Peak#	Ret. Time	Area	Height	Area%	Height%
1	17.158	4212449	103762	49.830	51.345
2	18.210	4241240	98325	50.170	48.655
Total		8453689	202088	100.000	100.000



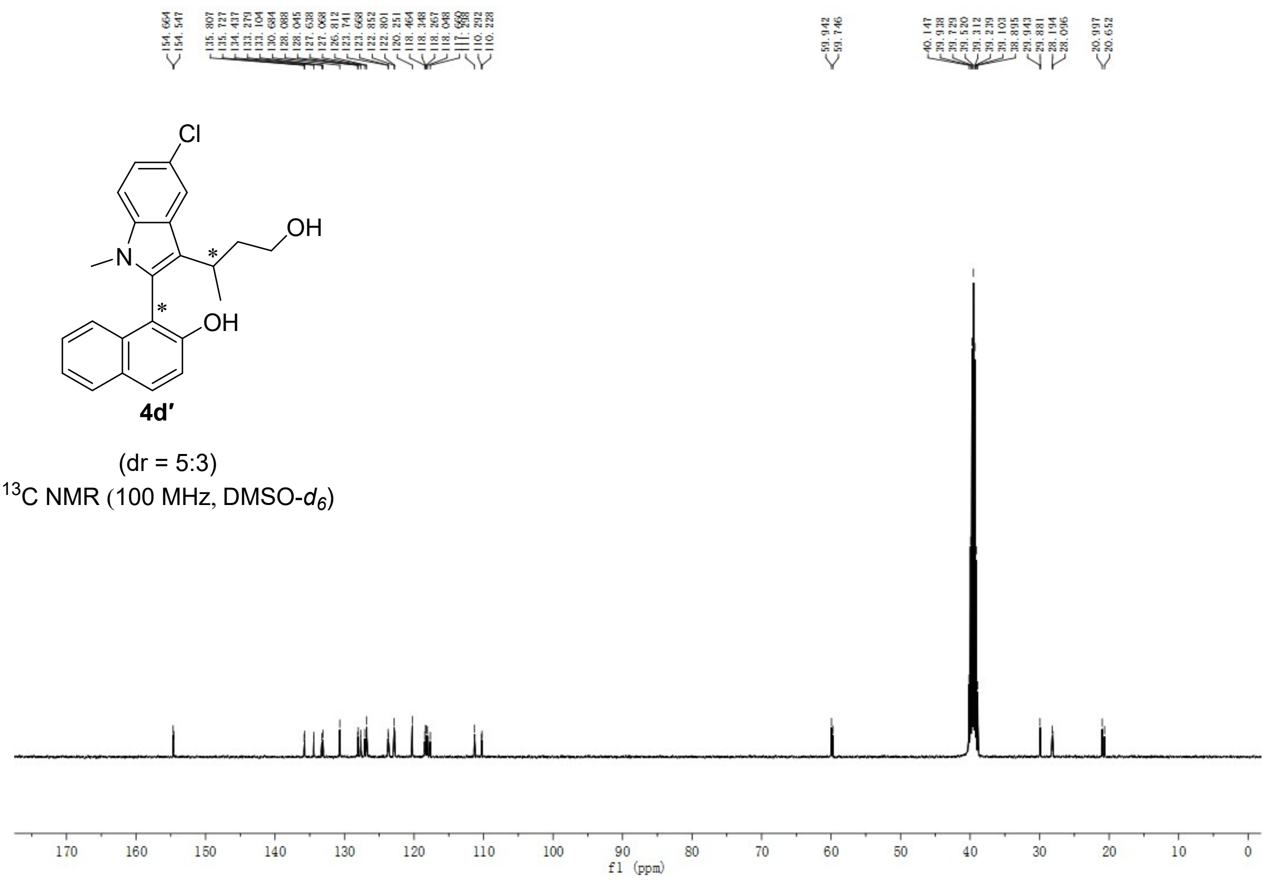
Peak#	Ret. Time	Area	Height	Area%	Height%
1	17.315	6287665	148734	76.115	75.738
2	18.396	1973110	47646	23.885	24.262
Total		8260775	196380	100.000	100.000



4d′

(dr 5:3)

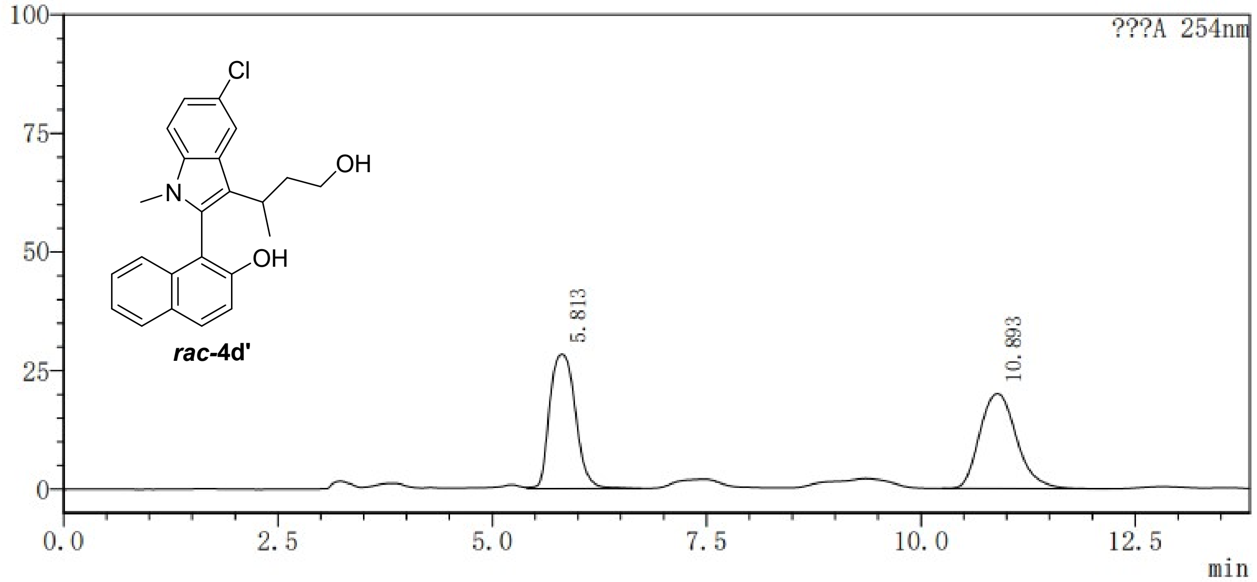
^{1}H NMR (400 MHz, DMSO-d_6)



4d′

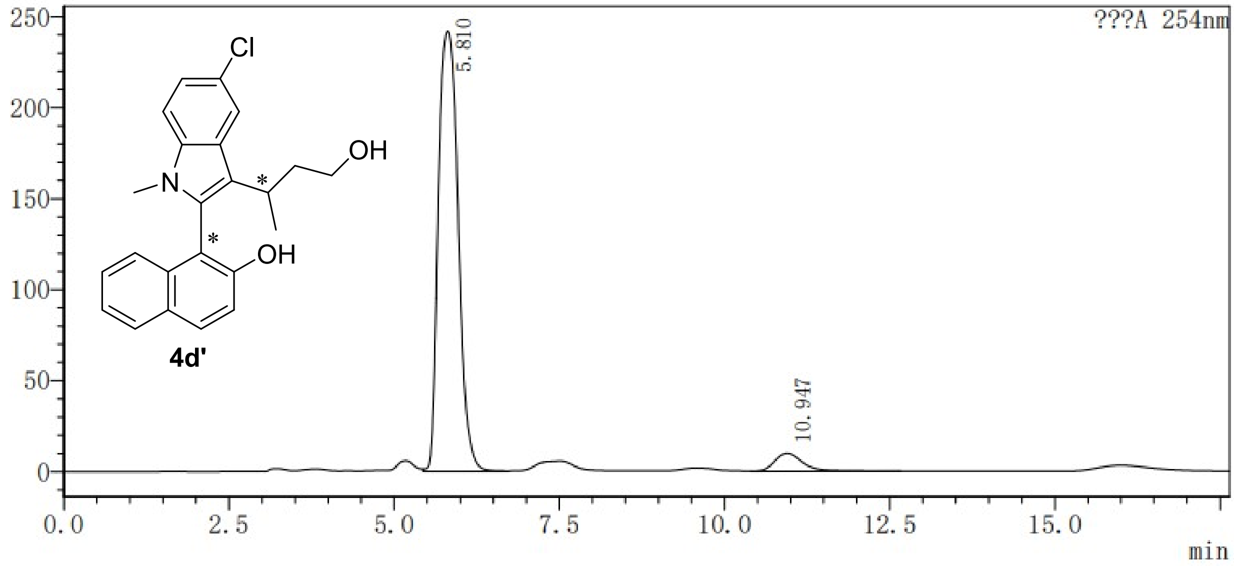
(dr = 5:3)

^{13}C NMR (100 MHz, DMSO-d_6)



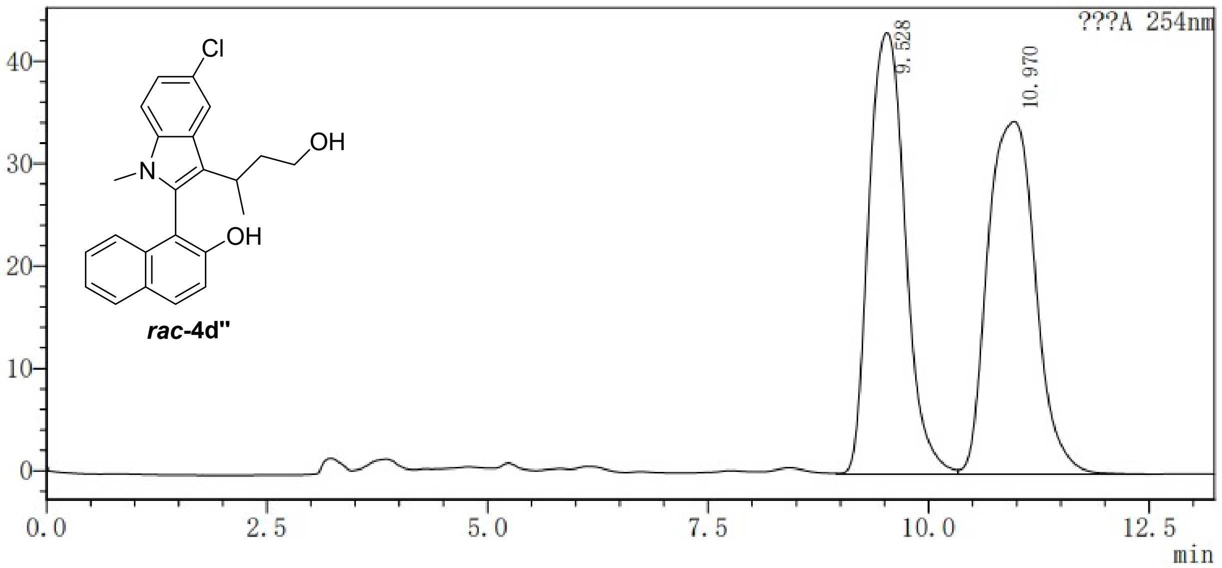
***rac*-4d'**

Peak#	Ret. Time	Area	Height	Area%	Height%
1	5.813	594499	28331	49.716	58.551
2	10.893	601294	20056	50.284	41.449
Total		1195793	48387	100.000	100.000

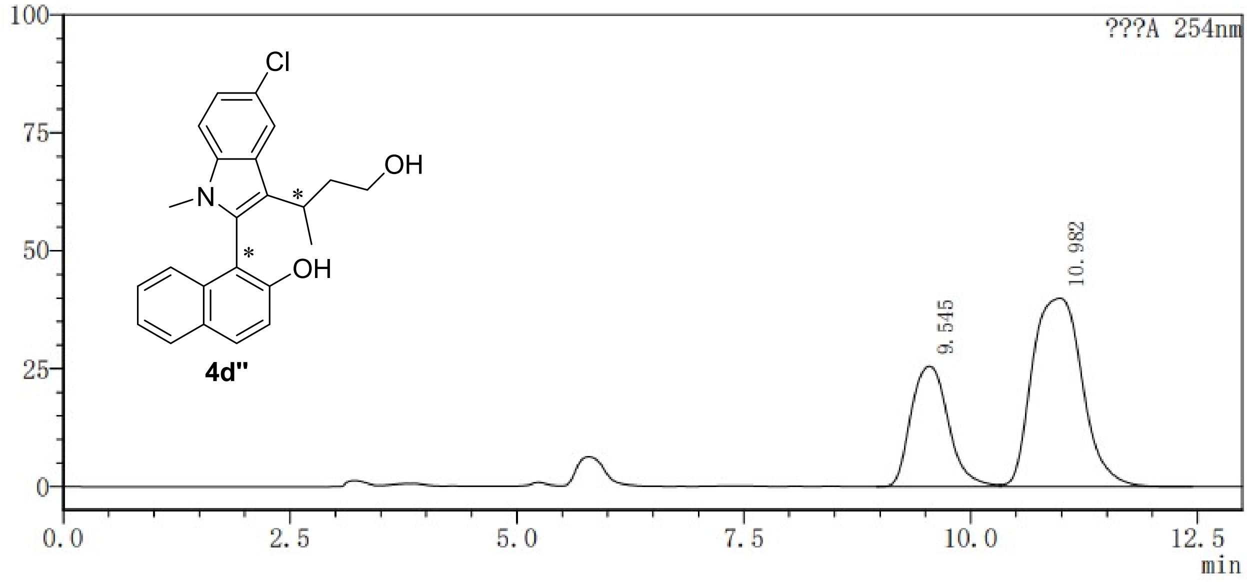


4d'

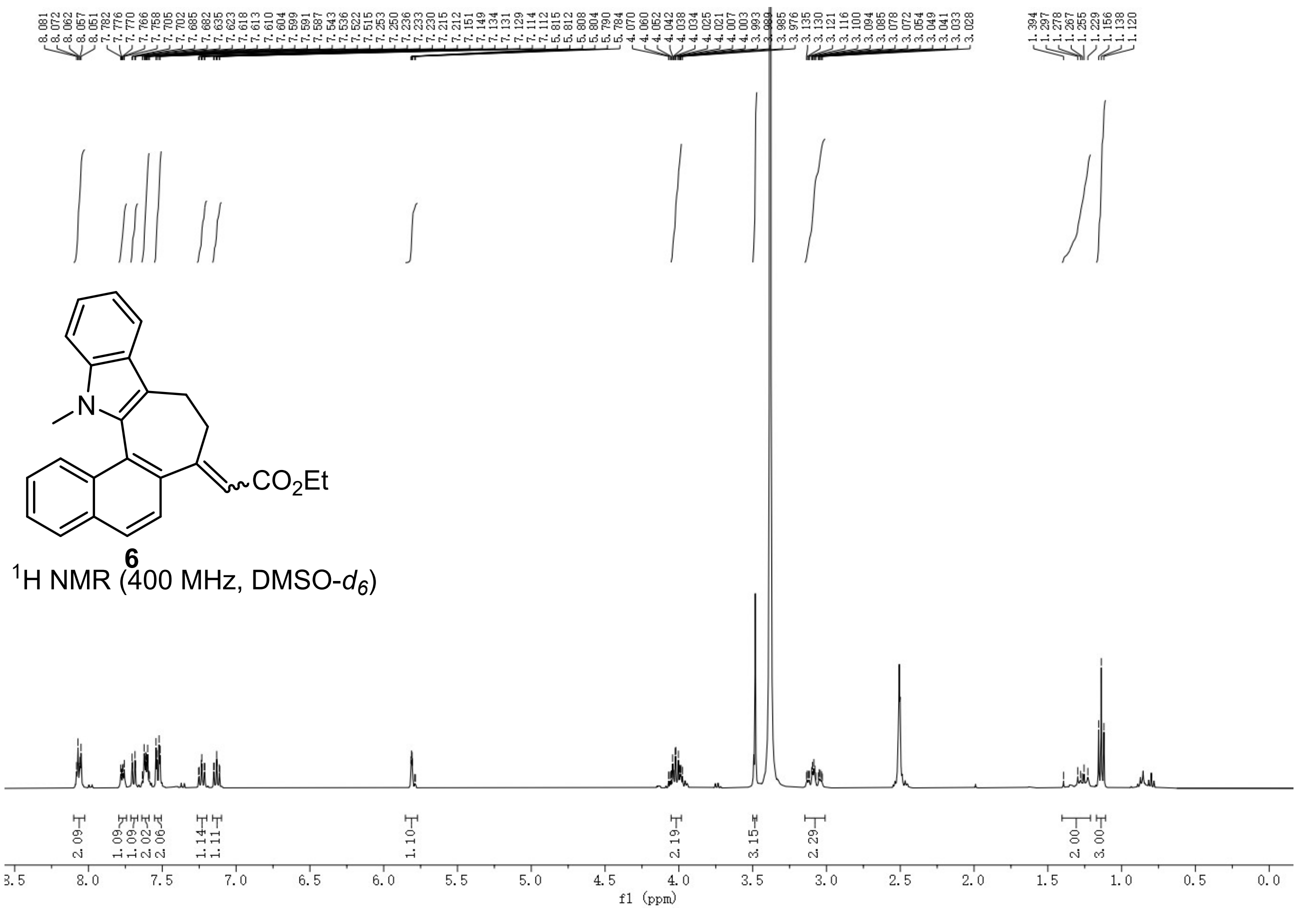
Peak#	Ret. Time	Area	Height	Area%	Height%
1	5.810	5071533	241992	94.486	96.077
2	10.947	295989	9881	5.514	3.923
Total		5367522	251873	100.000	100.000



Peak#	Ret. Time	Area	Height	Area%	Height%
1	9.528	1239904	43148	48.821	55.614
2	10.970	1299800	34437	51.179	44.386
Total		2539704	77585	100.000	100.000

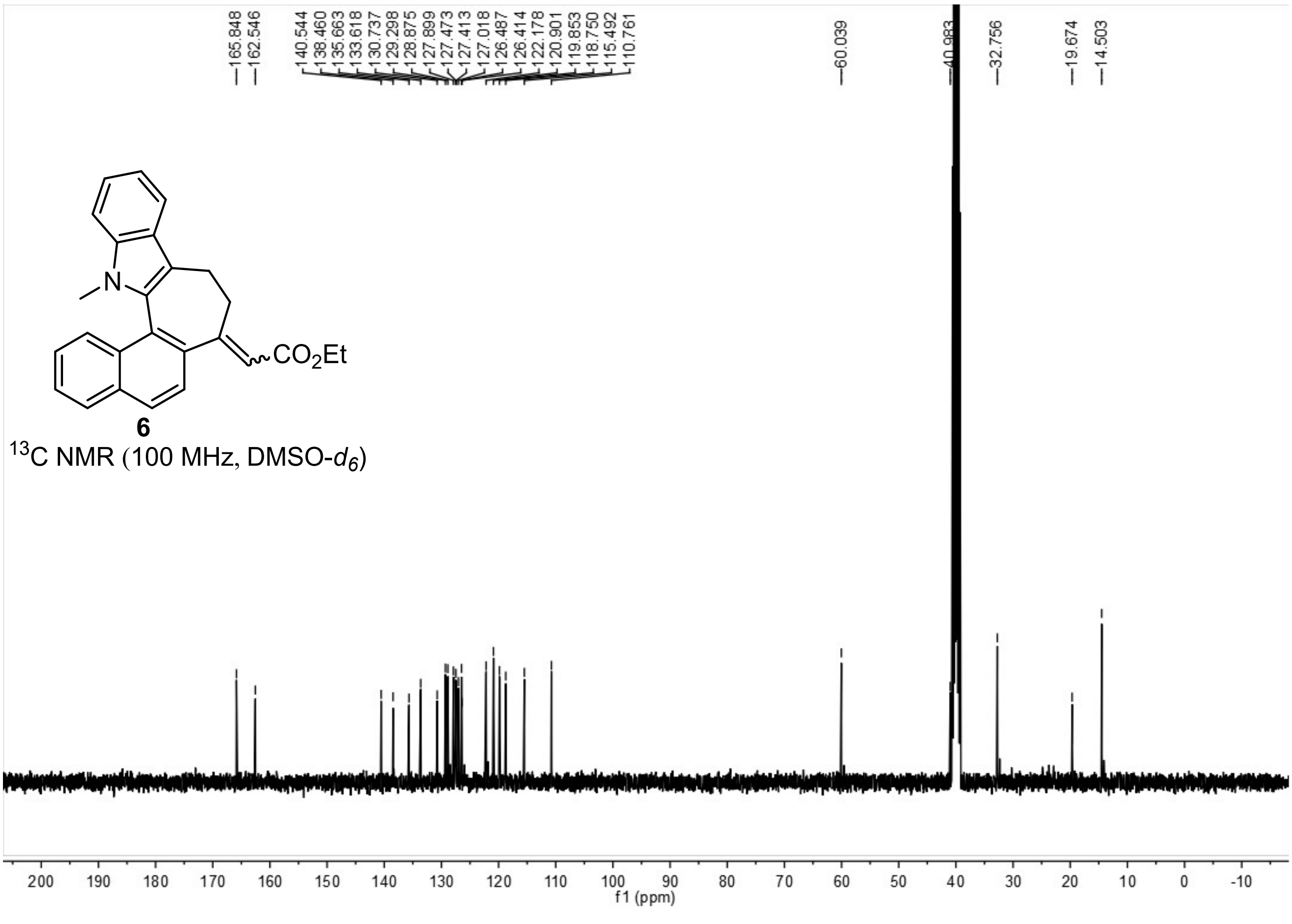


Peak#	Ret. Time	Area	Height	Area%	Height%
1	9.545	730030	25497	32.240	38.959
2	10.982	1534316	39948	67.760	61.041
Total		2264346	65445	100.000	100.000



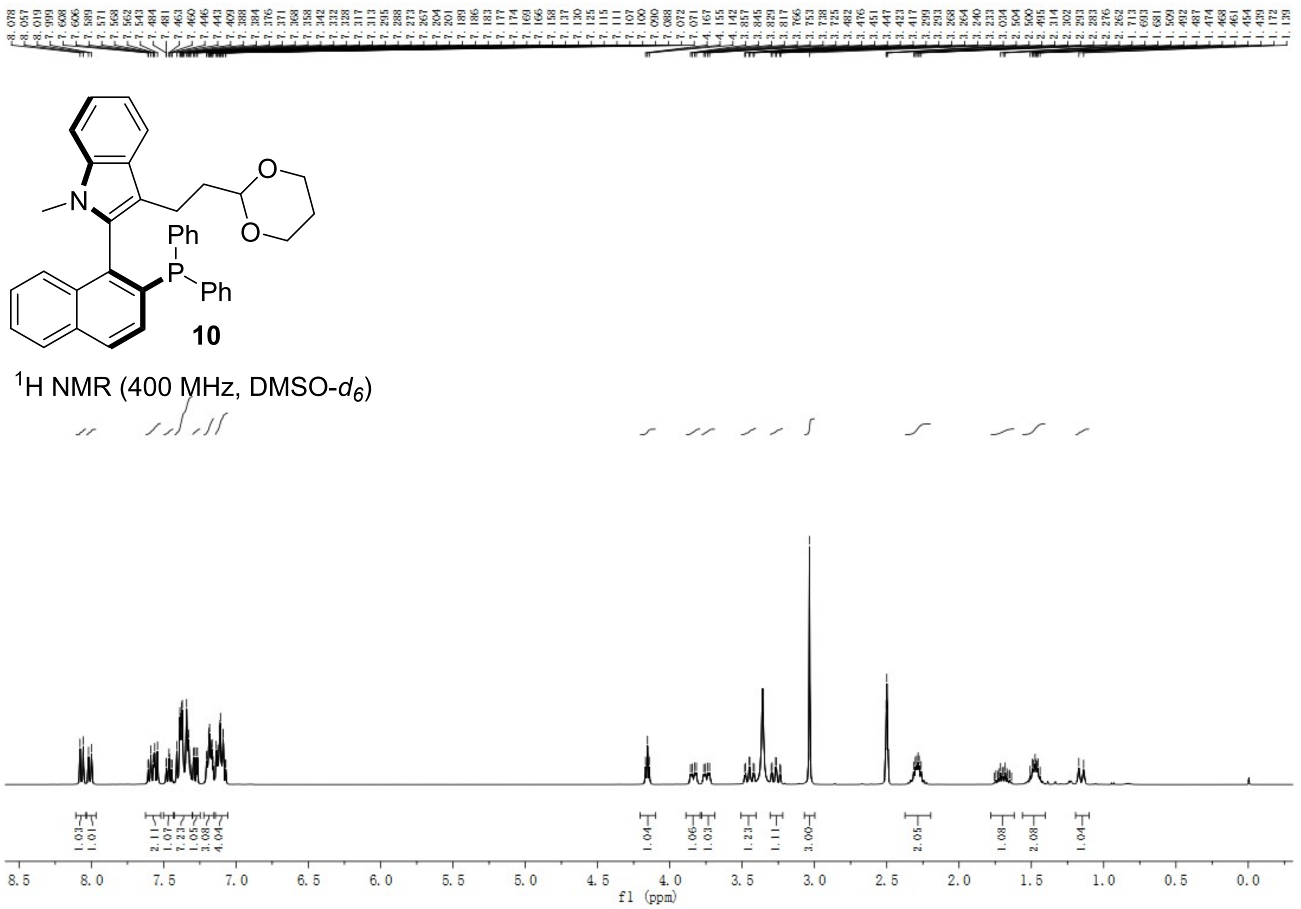
6

^{1}H NMR (400 MHz, DMSO-d_6)



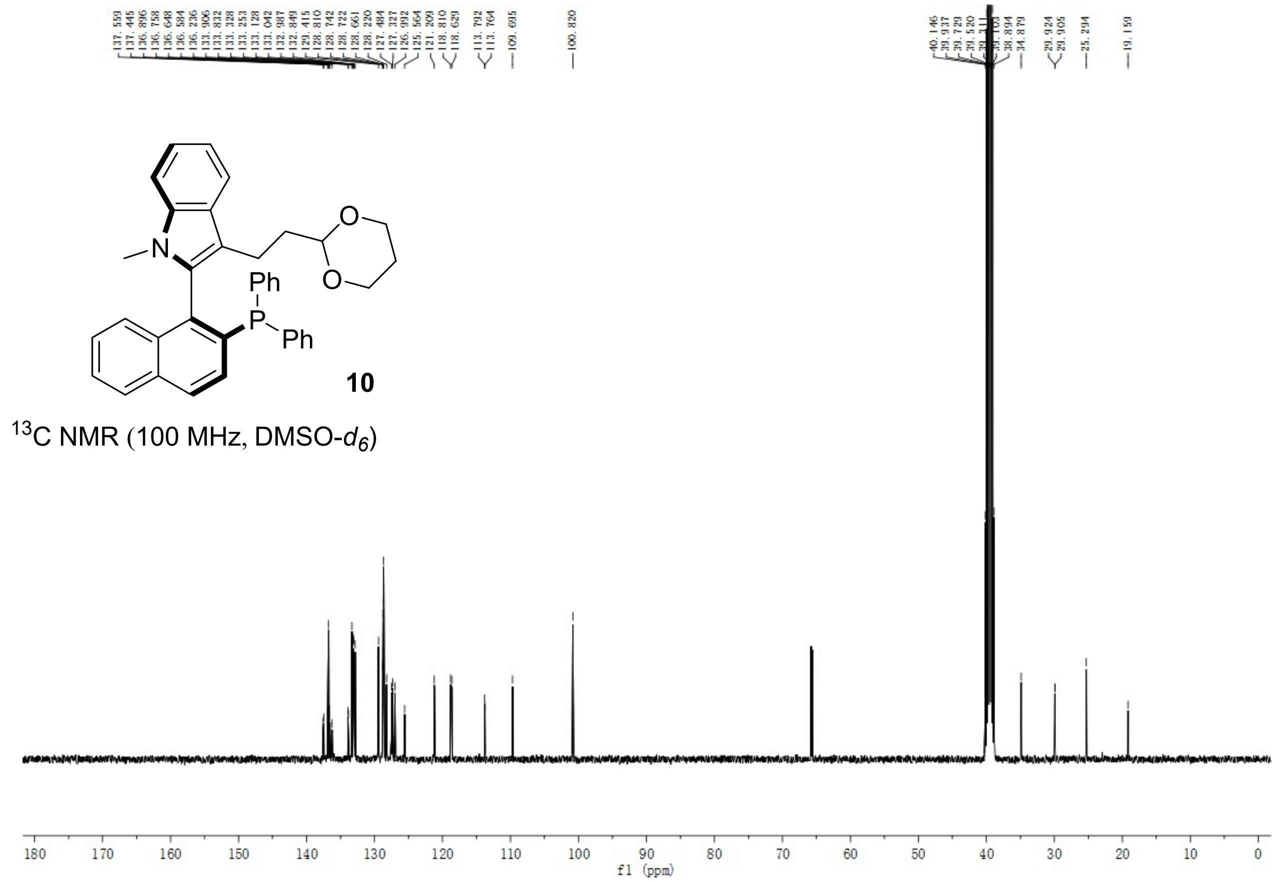
6

^{13}C NMR (100 MHz, DMSO-d_6)



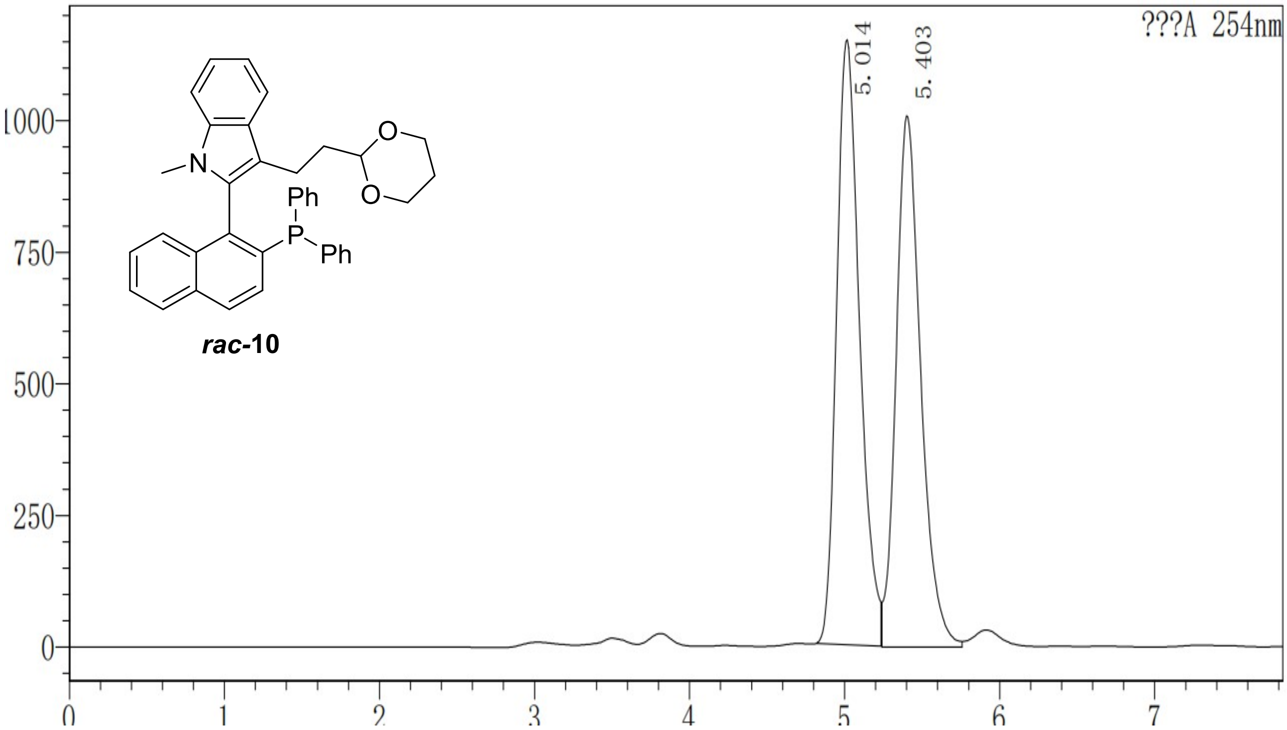
10

^{1}H NMR (400 MHz, DMSO-d_6)

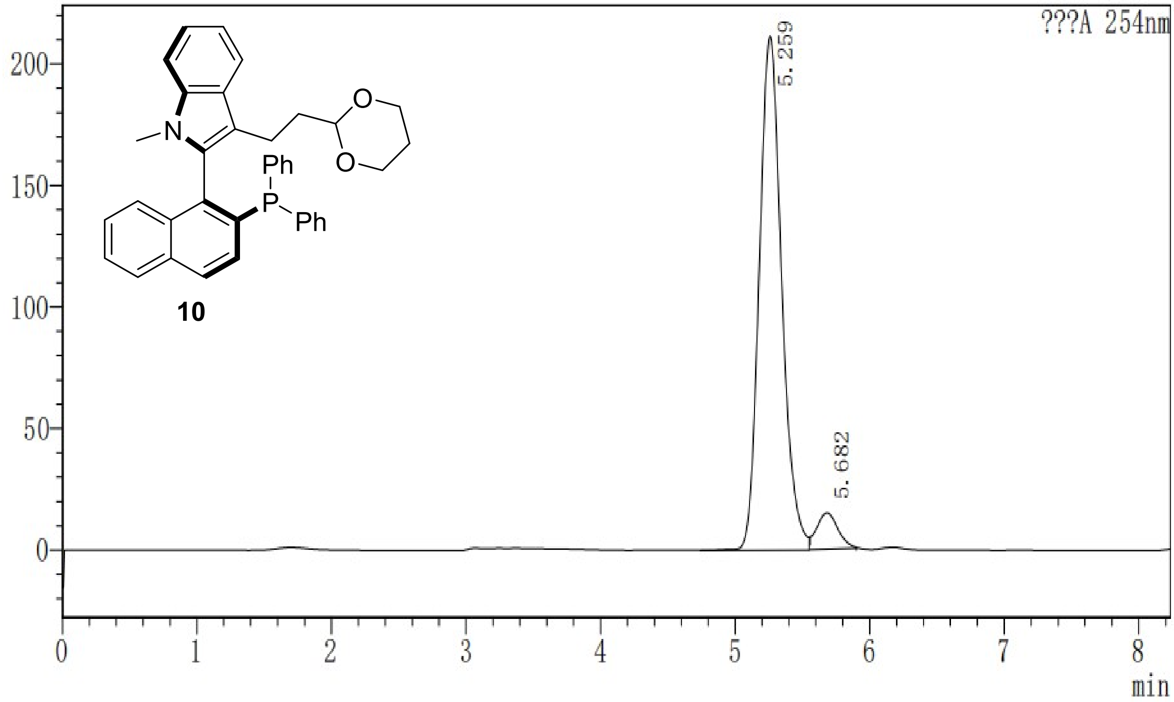


10

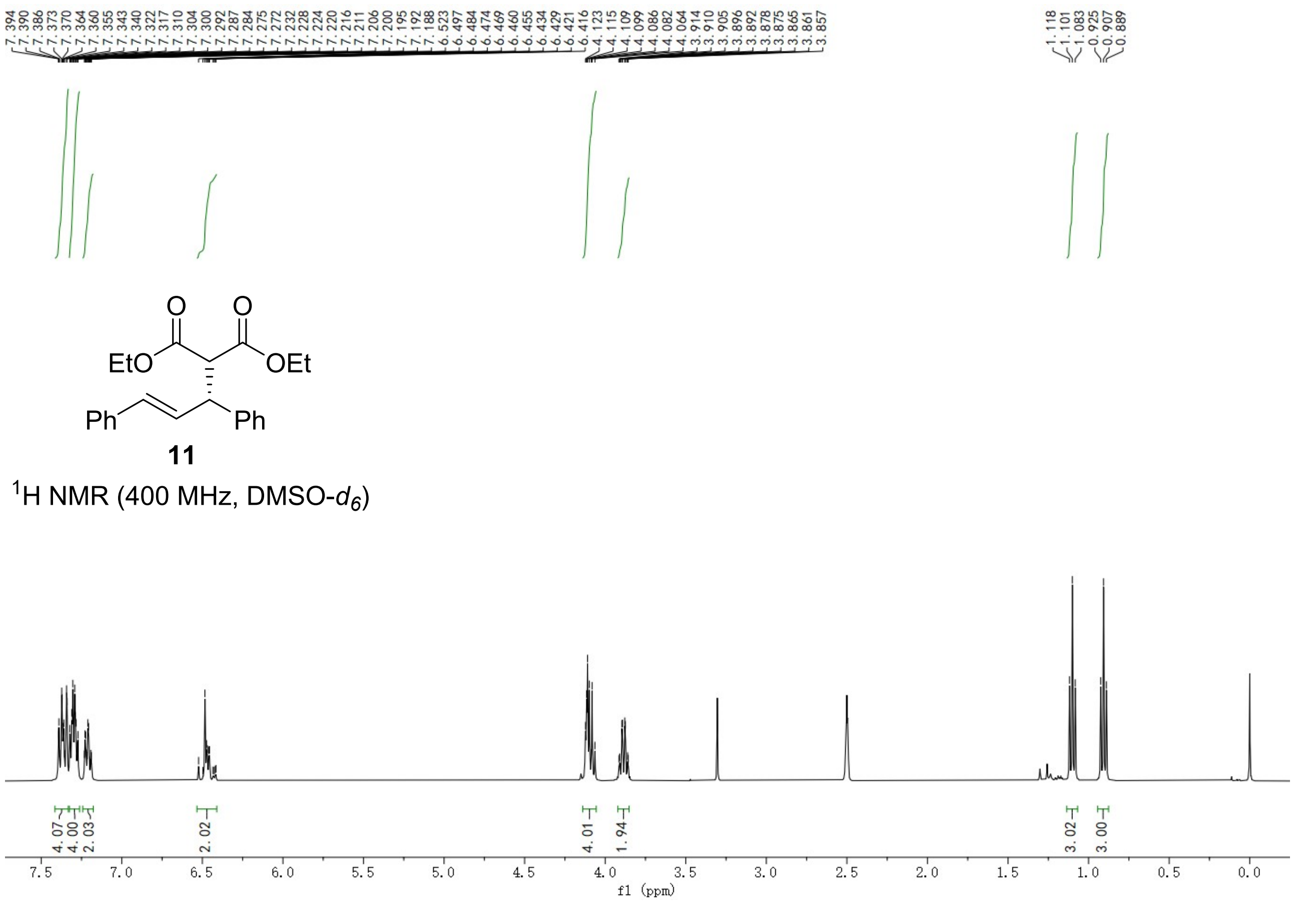
^{13}C NMR (100 MHz, DMSO-d_6)



Peak#	Ret. Time	Area	Height	Area%	Height%
1	5.014	11859897	1149324	50.533	53.245
2	5.403	11609710	1009251	49.467	46.755

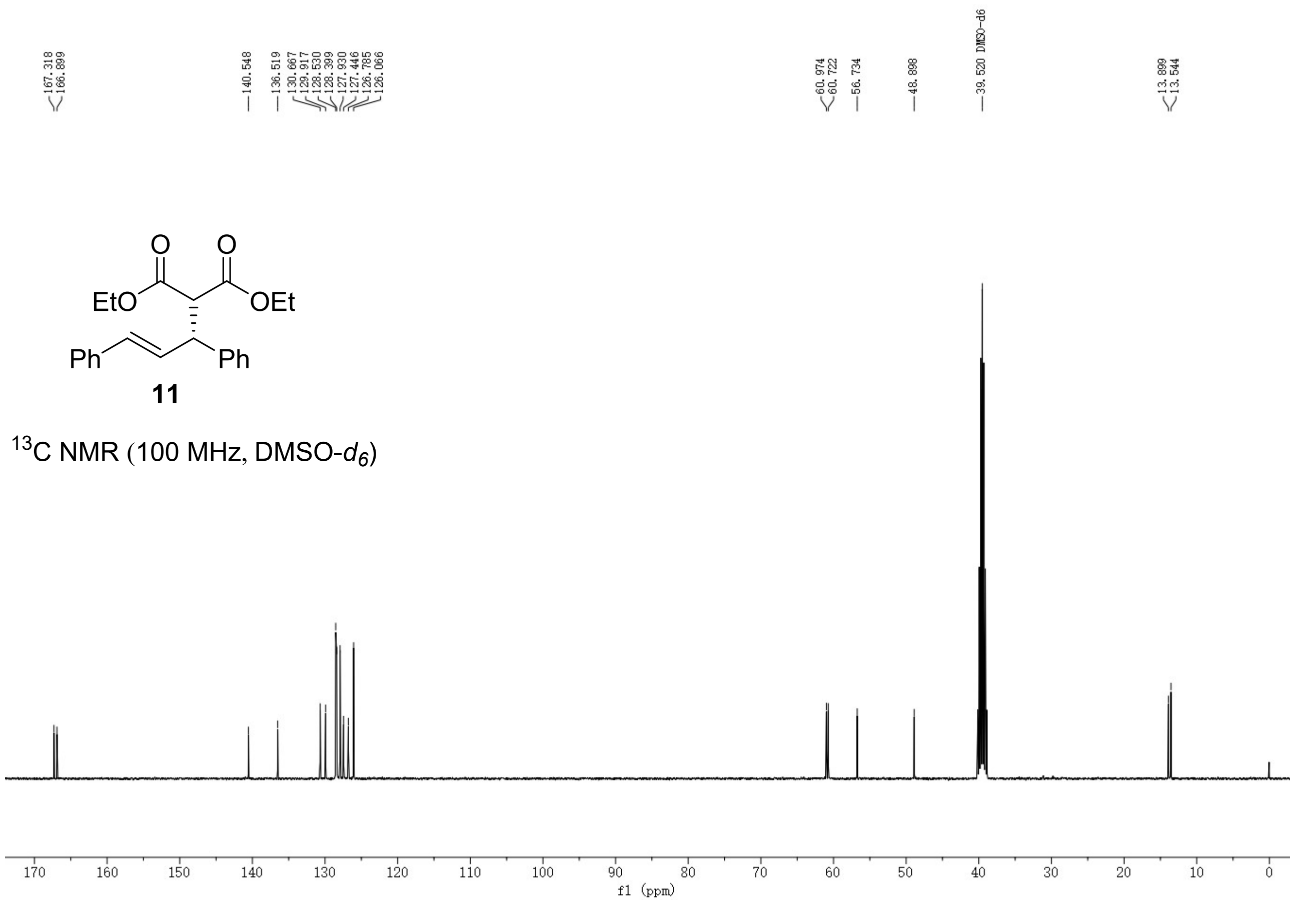


Peak#	Ret. Time	Area	Height	Area%	Height%
1	5.259	2445149	211515	94.273	93.829
2	5.682	148532	13912	5.727	6.171



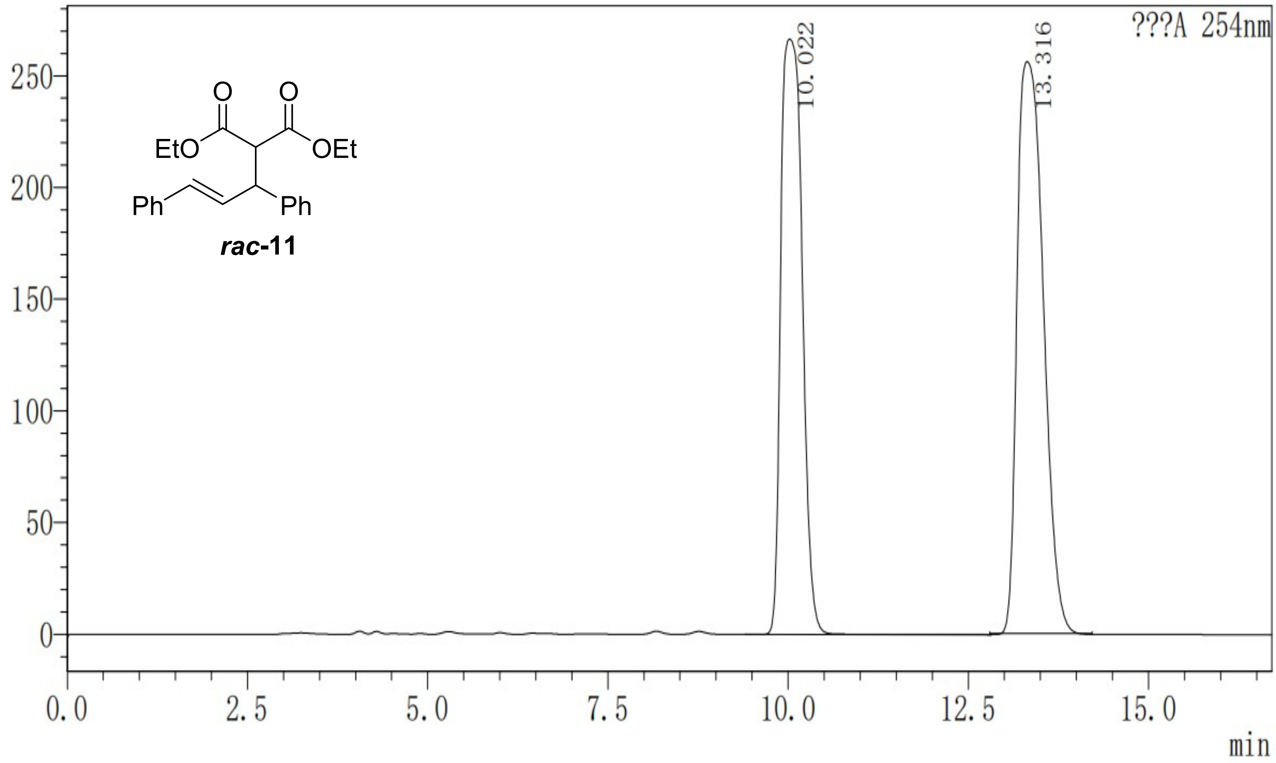
11

^{1}H NMR (400 MHz, DMSO-d_6)

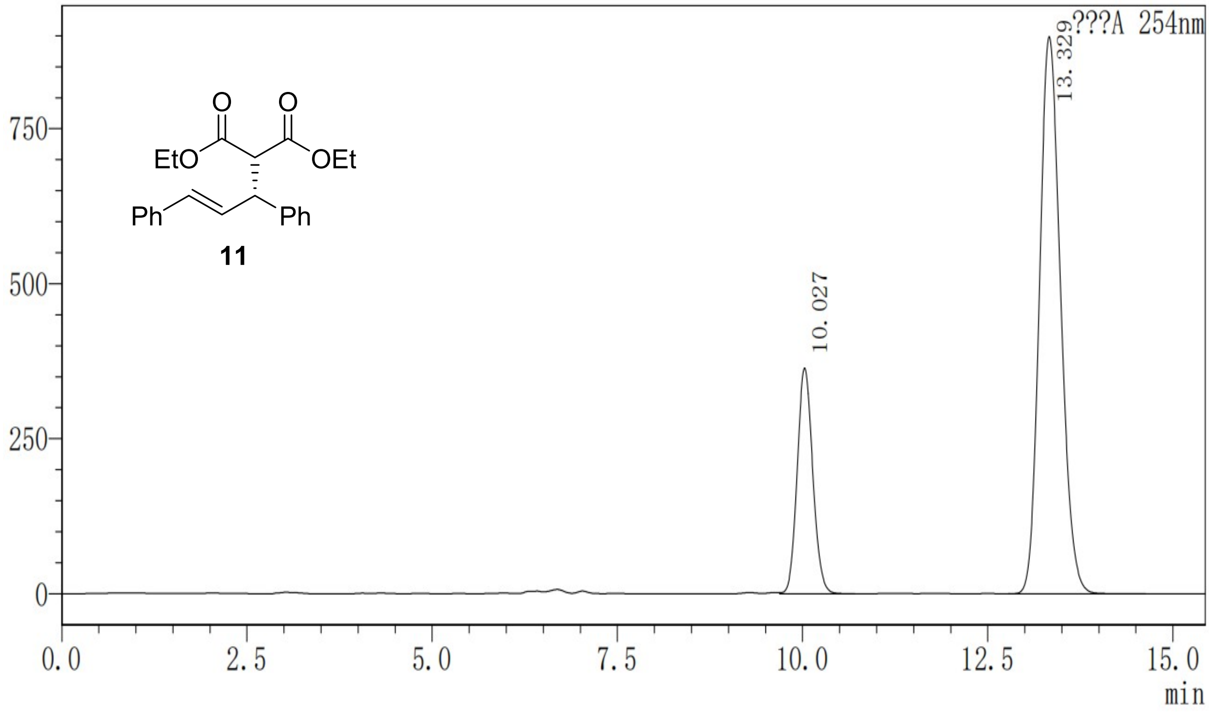


11

^{13}C NMR (100 MHz, DMSO-d_6)



Peak#	Ret. Time	Area	Height	Area%	Height%
1	10.022	5527576	2665253	49.290	51.075
2	13.316	5686211	2553057	50.710	48.925



Peak#	Ret. Time	Area	Height	Area%
1	10.027	5329672	364028	23.037
2	13.329	17805160	898396	76.963