Modified Cinchona Alkaloid-Catalysed Enantioselective [4 + 4] Annulations of Cyclobutenones and 1-Azadienes

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Supplementary Information

1. General methods

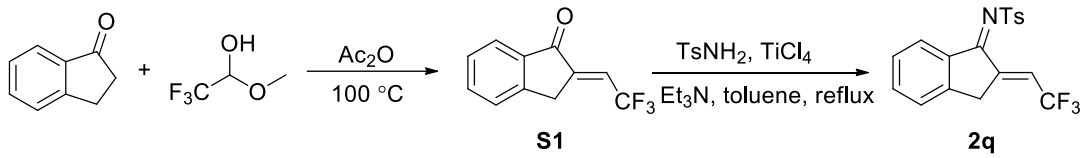
NMR data were obtained for ^{1}H at 400 MHz or 600 MHz, and for ^{13}C at 100 MHz. Chemical shifts were reported in ppm from tetramethylsilane with the solvent resonance as the internal standard in $CDCl_3$ solution. ESI HRMS was recorded on a Waters SYNAPT G2. In each case, enantiomeric ratio was determined by HPLC analysis on a chiral column in comparison with the authentic racemate, using a Daicel Chiralpak AD-H Column (250 × 4.6 mm), Chiralpak IB Column (250 × 4.6 mm), Chiralpak IE Column (250 × 4.6 mm) or Chiralpak IC Column (250 × 4.6 mm). UV detection was monitored at 254 nm. Column chromatography was performed on silica gel (200-300 mesh) eluting with ethyl acetate (EtOAc) and petroleum ether or dichloromethane (DCM)/methanol (MeOH). TLC was performed on glass-backed silica plates. UV light, solution of potassium permanganate were used to visualize products or starting materials. All chemicals were used without purification as commercially available unless otherwise noted. Petroleum ether were redistilled. Cyclobutenones **1**,[1] 1-azadienes **2a–2p**,[2] chiral tertiary amine catalysts **C1** and **C3**[3] were synthesized following the literature procedures.

(1) (*a*) K. Sugimoto, R. Hayashi, H. Nemoto, N. Toyooka and Y. Matsuya, *Org. Lett*., 2012, **14**, 3510; (*b*) B.-S. Li, Y. Wang, Z. Jin, P. Zheng, R. Ganguly and Y. R. Chi, *Nat. Commun*., 2015, **6**, 6027.

(2) (*a*) Z. Q. Rong, M. Wang, C. H. E. Chow and Y. Zhao, *Chem. - Eur. J*., 2016, **22**, 9483; (*b*) Z. Gu, J. Zhou, G.-F. Jiang and Y.-G. Zhou, *Org. Chem. Front.*, 2018, **5**, 1148.

(3) (*a*) M. Shi, Z.-Y. Lei, M.-X. Zhao and J.-W. Shi, *Tetrahedron Lett.*, 2007, **48**, 5743; (*b*) W.-Q. Jia, X.-Y. Chen, L.-H. Sun and S. Ye, *Org. Biomol. Chem*., 2014, **12**, 2167.

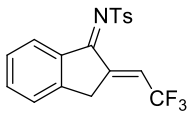
2. Typical procedure for the preparation of indanone-derived substrate 2q



S1 **2q**

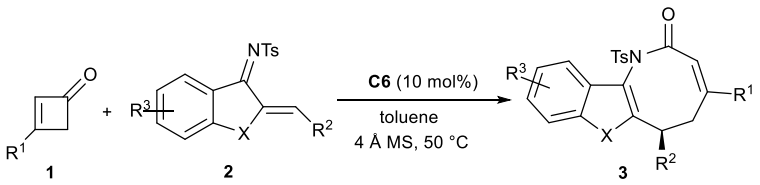
To a stirred solution of indanone (1.3 g, 10 mmol) in Ac_2O (5 mL) in a sealed tube was added 2,2,2-trifluoro-1-methoxy-ethanol (2.86 mL, 30 mmol). The resulting mixture was warmed to 100 ℃ and stirred for 24 h. After cooling down to room temperature, the mixture was transferred into a separatory funnel and saturated aqueous $NaHCO_3$ (100 mL) and diethyl ether (100 mL) were added. The organic layer was separated, dried over anhydrous Na_2SO_4, and evaporated under reduced pressure. The residue was purified by column chromatography (SiO_2; petroleum ether/EtOAc = 30/1) to give **S1** as a yellow solid (710 mg, 33% yield).

A solution of **S1** (710 mg, 1.0 equiv) and $TsNH_2$ (515 mg, 0.9 equiv) in toluene was added to a two necked flask equipped with a magnetic stirring bar and a condenser. Then Et_3N (0.85 mL, 2.0 equiv) and $TiCl_4$ (0.33 mL, 0.9 equiv) were added successively at 0 ℃ under argon atmosphere, and the mixture was hearted for reflux for 5 h. The solution was cooled to room temperature, quenched with water and extracted with DCM. The organic layer was separated, dried over anhydrous Na_2SO_4, filtered and evaporated under reduced pressure. The crude product was purified by column chromatography (SiO_2; petroleum ether/EtOAc = 20/1) to give 4-methyl-*N*-((*E*)-2-(2,2,2-trifluoroethylidene)-2,3-dihydro-1*H*-inden-1-ylidene)benzenesulfonamide **2q** (284.3 mg, 24% yield).



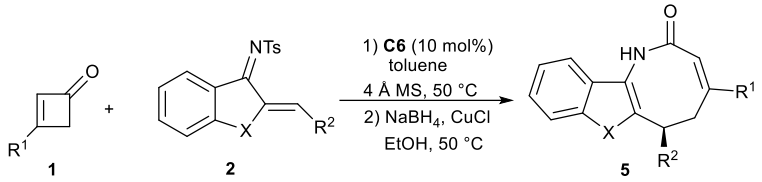
2q: yellow solid, mp 137–138 ℃; ^{1}H NMR (400 MHz, $CDCl_3$): δ (ppm) 8.92 (s, 1H), 7.96 (d, *J* = 8.2 Hz, 2H), 7.75–7.63 (m, 1H), 7.53 (t, *J* = 7.6 Hz, 2H), 7.38 (d, *J* = 8.0 Hz, 2H), 6.75 (s, 1H), 3.98 (t, *J* = 2.9 Hz, 2H), 2.48 (s, 3H); ^{13}C NMR (100 MHz, CDCl3): δ (ppm) 172.5, 149.8 (q, J_{FC} = 3.4 Hz), 143.7, 138.8, 136.4, 131.2 (q, J_{FC} = 14.5 Hz), 129.5, 128.5, 126.9, 125.9, 124.5, 121.8, 106.1 (q, J_{FC} = 253.9 Hz), 31.9, 21.6; ^{19}F NMR (376 MHz, $CDCl_3$): δ (ppm) –60.2.

3. General procedure for asymmetric tertiary amine catalysed [4 + 4] annulations of cyclobutenones 1 and 1-azadienes 2

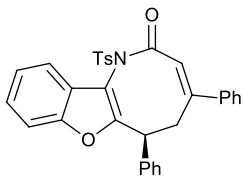


General procedure A: To a solution of cyclobutenone **1** (0.15 mmol, 1.5 equiv), catalyst **C6** (7.8 mg, 10 mol%) and 4 Å MS (100.0 mg) in toluene (1.0 mL) was added 1-azadiene **2** (0.1 mmol,

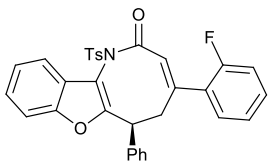
1.0 equiv). The mixture was stirred at 50 ℃. After completion (monitored by TLC, EtOAc/petroleum ether = 1/15), the pure product **3** was obtained by flash chromatography on silica gel (EtOAc/petroleum ether = 1/17). **3z** and **3aa** were obtained after recrystallisation by ethanol/ petroleum ether for further purification.



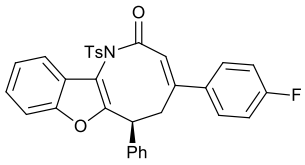
General procedure B: To a solution of cyclobutenone **1** (0.15 mmol, 1.5 equiv), catalyst **C6** (7.8 mg, 10 mol%) and 4 Å MS (100.0 mg) in toluene (1.0 mL) was added 1-azadiene **2** (0.1 mmol, 1.0 equiv). The mixture was stirred at 50 ℃. After completion (monitored by TLC, EtOAc/petroleum ether = 1/15), the crude annulation product was purified by flash chromatography on silica gel (EtOAc/petroleum ether = 1/17). Then the crude product was added to a solution of CuCl (4.0 equiv) in EtOH, and $NaBH_4$ (4.0 equiv) was added in one portion. The mixture was stirred at 50 ℃ for 2–4 h. After completion (monitored by TLC, EtOAc/petroleum ether = 1/6), the mixture was concentrated and the pure product **5** was obtained by flash chromatography on silica gel (EtOAc/petroleum ether = 1/8).



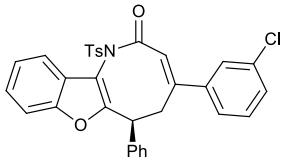
Synthesis of 3a: **General procedure A**: To a solution of cyclobutenone **1a** (21.6 mg, 0.15 mmol, 1.5 equiv), catalyst **C6** (7.8 mg, 10 mol%) and 4 Å MS (100.0 mg) in toluene (1.0 mL) was added 1-azadiene **2a** (37.5 mg, 0.1 mmol, 1.0 equiv). The mixture was stirred at 50 ℃ for 48 h. After completion, it was purified by flash chromatography on silica gel (EtOAc/petroleum ether = 1/17) to give product **3a**: 51.7 mg, 99% yield, white solid; mp 106–108 ℃; $[\alpha]_D^{25}$ = +336.8 (*c* = 0.25 in $CHCl_3$); 98% ee, determined by HPLC analysis [Chiralpak IC, *n*-hexane/*i*-PrOH = 60/40, 1.0 mL/min, λ = 254 nm, t (major) =7.82 min, t (minor) =12.00 min]; ^{1}H NMR (400 MHz, $CDCl_3$): δ (ppm) 8.05 (d, *J* = 8.4 Hz, 2H), 7.63–7.60 (m, 1H), 7.50–7.47 (m, 2H), 7.45–7.40 (m, 2H), 7.38–7.33 (m, 7H), 7.31–7.26 (m, 4H), 6.10 (s, 1H), 4.35 (dd, *J* = 14.0, 4.8 Hz, 1H), 3.50–3.31 (m, 1H), 3.11 (ddd, *J* = 14.0, 4.8, 1.2 Hz, 1H), 2.43 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ (ppm) 167.9, 154.5, 152.8, 148.6, 145.5, 140.1, 138.0, 135.2, 130.1, 129.5, 129.3, 129.1, 129.0, 127.6, 127.5, 127.2, 126.2, 125.1, 123.6, 121.0, 119.9, 116.5, 111.5, 43.7, 36.4, 21.7; ESI-HRMS: calcd. for $C_{32}H_{25}NO_4S + H^+$ 520.1583, found 520.1578.



Synthesis of 3b: **General procedure A**: To a solution of cyclobutenone **1b** (24.3 mg, 0.15 mmol, 1.5 equiv), catalyst **C6** (7.8 mg, 10 mol%) and 4 Å MS (100.0 mg) in toluene (1.0 mL) was added 1-azadiene **2a** (37.5 mg, 0.1 mmol, 1.0 equiv). The mixture was stirred at 50 ℃ for 48 h (after 24 h, another 0.5 equiv cyclobutenone **1b** was added). After completion, it was purified by flash chromatography on silica gel (EtOAc/petroleum ether = 1/17) to give product **3b**: 40.6 mg, 76% yield, white solid; mp 184–187 ℃; $[\alpha]_D^{25}$ = +228.8 (*c* = 0.25 in $CHCl_3$); 99% ee, determined by HPLC analysis [Chiralpak IC, *n*-hexane/*i*-PrOH = 60/40, 1.0 mL/min, λ = 254 nm, t (major) =6.45 min, t (minor) =9.54 min]; ^{1}H NMR (400 MHz, $CDCl_3$): δ (ppm) 8.02 (d, *J* = 8.4 Hz, 2H), 7.67–7.63 (m, 1H), 7.45–7.37 (m, 6H), 7.35–7.29 (m, 3H), 7.27 (d, *J* = 8.2 Hz, 2H), 7.12–7.02 (m, 3H), 5.99 (s, 1H), 4.35 (dd, *J* = 14.0, 4.8 Hz, 1H), 3.42–3.28 (m, 1H), 3.03 (ddd, *J* = 14.0, 4.8, 1.2 Hz, 1H), 2.43 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ (ppm) 167.7, 163.5 (d, J_{FC} = 248.8 Hz), 154.4, 152.8, 147.6, 145.6, 139.9, 135.2, 134.1 (d, J_{FC} = 3.6 Hz), 130.2, 129.4, 129.2, 128.2 (d, J_{FC} = 8.2 Hz), 127.7, 127.5, 127.2, 125.1, 123.6, 121.0, 119.9, 116.5, 116.0 (d, J_{FC} = 21.6 Hz), 111.5, 43.7, 36.5, 21.7; ^{19}F NMR (376 MHz, $CDCl_3$): δ (ppm) −113.4; ESI-HRMS: calcd. for $C_{32}H_{24}FNO_4S + H^+$ 538.1488, found 538.1496.

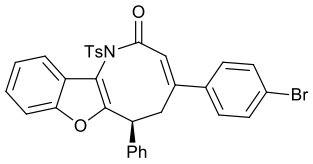


Synthesis of 3c: **General procedure A**: To a solution of cyclobutenone **1c** (24.3 mg, 0.15 mmol, 1.5 equiv), catalyst **C6** (7.8 mg, 10 mol%) and 4 Å MS (100.0 mg) in toluene (1.0 mL) was added 1-azadiene **2a** (37.5 mg, 0.1 mmol, 1.0 equiv). The mixture was stirred at 50 ℃ for 36 h. After completion, it was purified by flash chromatography on silica gel (EtOAc/petroleum ether = 1/17) to give product **3c**: 53.5 mg, 99% yield, white solid; mp 119–120 ℃; $[\alpha]_D^{25}$ = +227.2 (*c* = 0.25 in $CHCl_3$); 99% ee, determined by HPLC analysis [Chiralpak IC, *n*-hexane/*i*-PrOH = 60/40, 1.0 mL/min, λ = 254 nm, t (major) = 7.53 min, t (minor) = 11.85 min]; ^{1}H NMR (400 MHz, $CDCl_3$): δ (ppm) 8.04 (d, *J* = 8.4 Hz, 2H), 7.64–7.58 (m, 1H), 7.51–7.40 (m, 4H), 7.38–7.27 (m, 8H), 7.09–7.01 (m, 2H), 6.05 (s, 1H), 4.31 (dd, *J* = 14.0, 4.8 Hz, 1H), 3.44 (t, *J* = 14.0 Hz, 1H), 3.05 (dd, *J* = 14.0, 4.0 Hz, 1H), 2.43 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ (ppm) 167.7, 163.5 (d, J_{FC} = 248.9 Hz), 154.4, 152.8, 147.6, 145.6, 139.9, 135.2, 134.1 (d, J_{FC} = 3.5 Hz), 130.2, 129.4, 129.2, 128.2 (d, J_{FC} = 8.4 Hz), 127.8, 127.5, 127.2, 125.2, 123.6, 121.0, 119.9, 116.5, 116.1 (d, J_{FC} = 21.6 Hz), 111.5, 43.7, 36.6, 21.7; ^{19}F NMR (376 MHz, $CDCl_3$): δ (ppm) −111.2; ESI-HRMS: calcd. for $C_{32}H_{24}FNO_4S + Na^+$ 560.1308, found 560.1308.

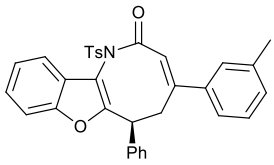


Synthesis of 3d: **General procedure A**: To a solution of cyclobutenone **1d** (26.7 mg, 0.15 mmol, 1.5 equiv), catalyst **C6** (7.8 mg, 10 mol%) and 4 Å MS (100.0 mg) in toluene (1.0 mL) was added 1-azadiene **2a** (37.5 mg, 0.1

mmol, 1.0 equiv). The mixture was stirred at 50 ℃ for 48 h. After completion, it was purified by flash chromatography on silica gel (EtOAc/petroleum ether = 1/17) to give product **3d**: 55.2 mg, 99% yield, white solid; mp 98–100 ℃; $[\alpha]_D^{25}$ = +201.6 (*c* = 0.25 in $CHCl_3$); 98% ee, determined by HPLC analysis [Chiralpak IC, *n*-hexane/*i*-PrOH = 60/40, 1.0 mL/min, λ = 254 nm, t (major) = 7.61 min, t (minor) = 12.19 min]; ^{1}H NMR (400 MHz, $CDCl_3$): δ (ppm) 8.04 (d, *J* = 8.4 Hz, 2H), 7.64–7.59 (m, 1H), 7.50–7.40 (m, 4H), 7.38–7.27 (m, 8H), 7.25–7.20 (m, 2H), 6.08 (s, 1H), 4.32 (dd, *J* = 14.0, 4.8 Hz, 1H), 3.41 (t, *J* = 14.0 Hz, 1H), 3.04 (ddd, *J* = 14.0, 4.8, 1.2 Hz, 1H), 2.42 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ (ppm) 167.5, 154.3, 152.9, 147.2, 145.7, 140.1, 139.9, 135.2, 135.1, 130.3, 130.2, 129.6, 129.4, 129.3, 127.8, 127.6, 127.2, 126.5, 125.3, 124.5, 123.7, 122.1, 119.9, 116.5, 111.6, 43.7, 36.4, 21.8; ESI-HRMS: calcd. for $C_{32}H_{24}ClNO_4S$ + Na^+ 576.1012 (^{35}Cl), 577.1046 (^{37}Cl), found 576.1019, 577.1054.

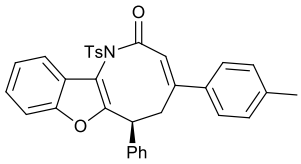


Synthesis of 3e: **General procedure A**: To a solution of cyclobutenone **1e** (33.5 mg, 0.15 mmol, 1.5 equiv), catalyst **C6** (7.8 mg, 10 mol%) and 4 Å MS (100.0 mg) in toluene (1.0 mL) was added 1-azadiene **2a** (37.5 mg, 0.1 mmol, 1.0 equiv). The mixture was stirred at 50 ℃ for 24 h. After completion, it was purified by flash chromatography on silica gel (EtOAc/petroleum ether = 1/17) to give product **3e**: 59.3 mg, 99% yield, white solid; mp 119–120 ℃; $[\alpha]_D^{25}$ = +186.4 (*c* = 0.25 in $CHCl_3$); 99% ee, determined by HPLC analysis [Chiralpak IC, *n*-hexane/*i*-PrOH = 60/40, 1.0 mL/min, λ = 254 nm, t (major) = 7.80 min, t (minor) = 12.52 min]; ^{1}H NMR (400 MHz, $CDCl_3$): δ (ppm) 8.04 (d, *J* = 8.4 Hz, 2H), 7.63–7.58 (m, 1H), 7.50–7.45 (m, 4H), 7.45–7.39 (m, 2H), 7.37–7.32 (m, 2H), 7.31–7.27 (m, 3H), 7.25–7.19 (m, 3H), 6.08 (d, *J* = 1.2 Hz, 1H), 4.30 (dd, *J* = 14.0, 4.8 Hz, 1H), 3.48–3.34 (m, 1H), 3.04 (ddd, *J* = 14.0, 4.8, 1.2 Hz, 1H), 2.42 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ (ppm) 167.2, 160.8, 158.3, 154.5, 152.9, 145.6, 144.9, 139.9, 135.1, 130.9, 130.1, 129.8, 129.4, 129.1, 127.5, 127.2, 125.1, 124.8, 124.5, 123.6, 119.9, 116.5, 111.5, 43.2, 37.5, 21.7; ESI-HRMS: calcd. for $C_{32}H_{24}BrNO_4S$ + Na^+ 620.0507 (^{79}Br), 622.0487 (^{81}Br), found 620.0520, 622.0507.

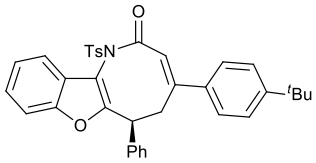


Synthesis of 3f: **General procedure A**: To a solution of cyclobutenone **1f** (23.7 mg, 0.15 mmol, 1.5 equiv), catalyst **C6** (7.8 mg, 10 mol%) and 4 Å MS (100.0 mg) in toluene (1.0 mL) was added 1-azadiene **2a** (37.5 mg, 0.1 mmol, 1.0 equiv). The mixture was stirred at 50 ℃ for 36 h. After completion, it was purified by flash chromatography on silica gel (EtOAc/petroleum ether = 1/17) to give product **3f**: 51.3 mg, 96% yield, white solid; mp 89–91 ℃; $[\alpha]_D^{25}$ = +142.4 (*c* = 0.25 in $CHCl_3$); 98% ee, determined by HPLC analysis [Chiralpak IC, *n*-hexane/*i*-PrOH = 60/40, 1.0 mL/min, λ = 254 nm, t (major) = 7.37 min, t (minor) = 11.34 min]; ^{1}H NMR (400 MHz, $CDCl_3$): δ (ppm) 8.05 (d, *J* = 8.4

Hz, 2H), 7.64–7.60 (m, 1H), 7.51–7.46 (m, 2H), 7.46–7.40 (m, 2H), 7.38–7.33 (m, 2H), 7.32–7.28 (m, 3H), 7.25–7.22 (m, 2H), 7.20–7.13 (m, 3H), 6.08 (s, 1H), 4.34 (dd, *J* = 14.0, 4.8 Hz, 1H), 3.42 (t, *J* = 14.0 Hz, 1H), 3.11 (ddd, *J* = 14.0, 4.8, 1.2 Hz, 1H), 2.43 (s, 3H), 2.33 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ (ppm) 167.9, 154.5, 152.8, 148.9, 145.5, 140.2, 138.7, 138.1, 135.2, 130.4, 130.2, 129.3, 129.1, 128.8, 127.6, 127.5, 127.2, 127.0, 125.0, 123.5, 123.3, 120.8, 119.9, 116.5, 111.5, 43.7, 36.4, 21.7, 21.4; ESI-HRMS: calcd. for $C_{33}H_{27}NO_4S + H^+$ 534.1739, found 534.1738.

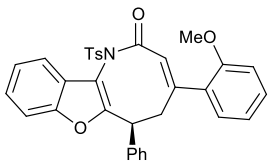


Synthesis of 3g: **General procedure A**: To a solution of cyclobutenone **1g** (23.7 mg, 0.15 mmol, 1.5 equiv), catalyst **C6** (7.8 mg, 10 mol%) and 4 Å MS (100.0 mg) in toluene (1.0 mL) was added 1-azadiene **2a** (37.5 mg, 0.1 mmol, 1.0 equiv). The mixture was stirred at 50 ℃ for 24 h. After completion, it was purified by flash chromatography on silica gel (EtOAc/petroleum ether = 1/17) to give product **3g**: 52.6 mg, 98% yield, white solid; mp 104–105 ℃; $[\alpha]_D^{25}$ = +188 (*c* = 0.25 in $CHCl_3$); 99% ee, determined by HPLC analysis [Chiralpak IC, *n*-hexane/*i*-PrOH = 60/40, 1.0 mL/min, λ = 254 nm, t (major) = 7.93 min, t (minor) = 11.42 min]; ^{1}H NMR (400 MHz, $CDCl_3$): δ (ppm) 8.05 (d, *J* = 6.8 Hz, 2H), 7.64–7.59 (m, 1H), 7.52–7.46 (m, 2H), 7.45–7.39 (m, 2H), 7.37–7.32 (m, 2H), 7.30–7.25 (m, 6H), 7.16 (d, *J* = 8.0 Hz, 2H), 6.08 (s, 1H), 4.34 (ddd, *J* = 14.0, 4.4, 1.6 Hz, 1H), 3.42 (t, *J* = 14.0 Hz, 1H), 3.11 (dd, *J* = 14.0, 4.4 Hz, 1H), 2.42 (s, 3H), 2.34 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ (ppm) 168.0, 154.6, 152.8, 148.6, 145.5, 140.2, 139.9, 135.2, 134.9, 130.1, 129.7, 129.3, 129.1, 127.6, 127.5, 127.2, 126.1, 125.0, 123.5, 120.0, 119.9, 116.5, 111.5, 43.8, 36.2, 21.7, 21.1; ESI-HRMS: calcd. for $C_{33}H_{27}NO_4S + H^+$ 534.1739, found 534.1730.

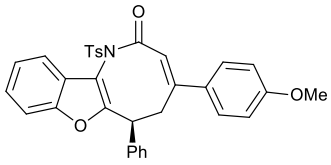


Synthesis of 3h: **General procedure A**: To a solution of cyclobutenone **1h** (30.0 mg, 0.15 mmol, 1.5 equiv), catalyst **C6** (7.8 mg, 10 mol%) and 4 Å MS (100.0 mg) in toluene (1.0 mL) was added 1-azadiene **2a** (37.5 mg, 0.1 mmol, 1.0 equiv). The mixture was stirred at 50 ℃ for 24 h. After completion, it was purified by flash chromatography on silica gel (EtOAc/petroleum ether = 1/17) to give product **3h**: 57.3 mg, 99% yield, yellow solid; mp 126–128 ℃; $[\alpha]_D^{25}$ = +193.6 (*c* = 0.25 in $CHCl_3$); 98% ee, determined by HPLC analysis [Chiralpak IC, *n*-hexane/*i*-PrOH = 60/40, 1.0 mL/min, λ = 254 nm, t (major) = 6.63 min, t (minor) = 9.36 min]; ^{1}H NMR (400 MHz, $CDCl_3$): δ (ppm) 8.05 (d, *J* = 8.4 Hz, 2H), 7.64–7.59 (m, 1H), 7.53–7.48 (m, 2H), 7.46–7.39 (m, 2H), 7.39–7.35 (m, 2H), 7.35–7.30 (m, 4H), 7.29–7.25 (m, 4H), 6.11 (s, 1H), 4.38 (ddd, *J* = 14.0, 4.8, 2.0 Hz, 1H), 3.43 (td, *J* = 14.0, 2.0 Hz, 1H), 3.19–3.09 (m, 1H), 2.41 (s, 3H), 1.30 (s, 9H); ^{13}C NMR (100 MHz, $CDCl_3$): δ (ppm) 168.1, 154.6, 153.0, 152.8, 148.4, 145.5, 140.2, 135.3, 134.8, 130.1, 129.3, 129.1, 127.6, 127.5, 127.2, 125.9, 125.9, 125.0, 123.5, 120.1, 119.9, 116.5, 111.5, 43.8, 36.2, 34.7, 31.1, 21.7; ESI-HRMS:

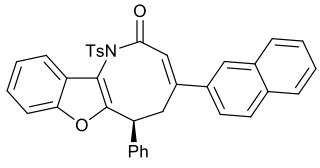
calcd. for $C_{36}H_{33}NO_4S$ + Na^+598.2028, found 598.2036.



Synthesis of 3i: **General procedure A**: To a solution of cyclobutenone **1i** (26.1 mg, 0.15 mmol, 1.5 equiv), catalyst **C6** (7.8 mg, 10 mol%) and 4 Å MS (100.0 mg) in toluene (1.0 mL) was added 1-azadiene **2a** (37.5 mg, 0.1 mmol, 1.0 equiv). The mixture was stirred at 50 ℃ for 60 h (after 24 h, another 0.5 equiv cyclobutenone **1i** was added). After completion, it was purified by flash chromatography on silica gel (EtOAc/petroleum ether = 1/17) to give product **3i**: 36.8 mg, 67% yield, white solid; mp 96–98 ℃; $[\alpha]_D^{25}$ = +323.2 (*c* = 1.5 in $CHCl_3$); 98% ee, determined by HPLC analysis [Chiralpak IC, *n*-hexane/*i*-PrOH = 60/40, 1.0 mL/min, λ = 254 nm, t (major) = 7.17 min, t (minor) = 11.86 min]; ^{1}H NMR (400 MHz, $CDCl_3$): δ (ppm) 8.03 (d, *J* = 8.4 Hz, 2H), 7.65–7.59 (m, 1H), 7.44–7.39 (m, 3H), 7.39–7.35 (m, 2H), 7.33–7.25 (m, 6H), 6.91–6.79 (m, 3H), 5.82 (s, 1H), 4.33 (dd, *J* = 14.0, 4.8 Hz, 1H), 3.66 (s, 3H), 3.40–3.28 (m, 1H), 3.06 (ddd, *J* = 13.2, 4.8, 1.2 Hz, 1H), 2.43 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ (ppm) 167.8, 156.3, 155.3, 152.9, 149.2, 145.4, 140.3, 135.4, 130.1, 129.6, 129.3, 129.1, 129.0, 127.6, 127.4, 127.3, 124.9, 123.6, 123.5, 120.6, 119.9, 116.5, 111.4, 111.0, 55.3, 43.1, 37.8, 21.7; ESI-HRMS: calcd. for $C_{33}H_{27}NO_5S$ + H^+ 550.1688, found 550.1683.

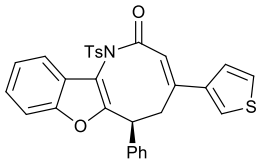


Synthesis of 3j: **General procedure A**: To a solution of cyclobutenone **1j** (26.1 mg, 0.15 mmol, 1.5 equiv), catalyst **C6** (7.8 mg, 10 mol%) and 4 Å MS (100.0 mg) in toluene (1.0 mL) was added 1-azadiene **2a** (37.5 mg, 0.1 mmol, 1.0 equiv). The mixture was stirred at 50 ℃ for 24 h. After completion, it was purified by flash chromatography on silica gel (EtOAc/petroleum ether = 1/17) to give product **3j**: 54.3 mg, 99% yield, white solid; mp 106–107 ℃; $[\alpha]_D^{25}$ = +289.6 (*c* = 0.25 in $CHCl_3$); 98% ee, determined by HPLC analysis [Chiralpak IC, *n*-hexane/*i*-PrOH = 60/40, 1.0 mL/min, λ = 254 nm, t (major) = 10.53 min, t (minor) = 16.04 min]; ^{1}H NMR (400 MHz, $CDCl_3$): δ (ppm) 8.05 (d, *J* = 8.4 Hz, 2H), 7.63–7.58 (m, 1H), 7.52–7.47 (m, 2H), 7.45–7.39 (m, 2H), 7.36–7.30 (m, 4H), 7.29–7.24 (m, 4H), 6.89–6.84 (m, 2H), 6.05 (s, 1H), 4.34 (dd, *J* = 14.0, 4.4 Hz, 1H), 3.79 (s, 3H), 3.43 (t, *J* = 14.0 Hz, 1H), 3.10 (dd, *J* = 14.0, 3.6 Hz, 1H), 2.41 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ (ppm) 168.1, 160.8, 154.6, 152.7, 148.2, 145.5, 140.2, 135.3, 130.9, 130.1, 129.9, 129.3, 129.1, 127.6, 127.5, 127.2, 125.0, 123.5, 119.9, 119.0, 116.5, 114.3, 111.4, 55.5, 43.8, 36.1, 21.6; ESI-HRMS: calcd. for $C_{33}H_{27}NO_5S$ + H^+ 550.1688, found 550.1681.

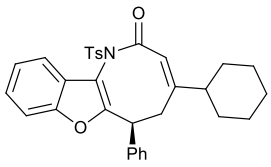


Synthesis of 3k: **General procedure A**: To a solution of cyclobutenone **1k** (29.1 mg, 0.15 mmol, 1.5 equiv), catalyst **C6** (7.8 mg, 10 mol%) and 4 Å MS (100.0 mg) in toluene (1.0 mL) was added 1-azadiene **2a** (37.5

mg, 0.1 mmol, 1.0 equiv). The mixture was stirred at 50 ℃ for 48 h. After completion, it was purified by flash chromatography on silica gel (EtOAc/petroleum ether = 1/17) to give product **3k**: 55.8 mg, 98% yield, white solid; mp 89–92 ℃; $[\alpha]_D^{25}$ = +174.4 (*c* = 0.25 in $CHCl_3$); 99% ee, determined by HPLC analysis [Chiralpak IC, *n*-hexane/*i*-PrOH = 60/40, 1.0 mL/min, λ = 254 nm, t (major) = 9.02 min, t (minor) = 14.81 min]; ^{1}H NMR (400 MHz, $CDCl_3$): δ (ppm) 8.07 (d, *J* = 8.4 Hz, 2H), 7.86–7.78 (m, 4H), 7.67–7.62 (m, 1H), 7.53–7.47 (m, 4H), 7.47–7.41 (m, 3H), 7.35 (dt, *J* = 6.2, 1.2 Hz, 2H), 7.32–7.27 (m, 4H), 6.24 (s, 1H), 4.40 (dd, *J* = 14.0, 4.4 Hz, 1H), 3.52 (t, *J* = 14.0 Hz, 1H), 3.31–3.23 (m, 1H), 2.43 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ (ppm) 167.9, 154.6, 152.8, 148.5, 145.6, 140.1, 135.2, 135.1, 133.6, 133.1, 130.2, 129.3, 129.2, 128.8, 128.5, 127.7, 127.6, 127.5, 127.2, 127.1, 126.8, 125.9, 125.1, 123.59, 123.57, 121.3, 119.9, 116.5, 111.5, 43.8, 36.3, 21.7; ESI-HRMS: calcd. for $C_{36}H_{27}NO_4S$ + Na^+ 592.1558, found 592.1552.

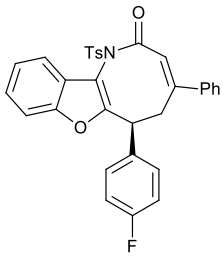


Synthesis of 3l: **General procedure A**: To a solution of cyclobutenone **1l** (22.5 mg, 0.15 mmol, 1.5 equiv), catalyst **C6** (7.8 mg, 10 mol%) and 4 Å MS (100.0 mg) in toluene (1.0 mL) was added 1-azadiene **2a** (37.5 mg, 0.1 mmol, 1.0 equiv). The mixture was stirred at 50 ℃ for 20 h. After completion, it was purified by flash chromatography on silica gel (EtOAc/petroleum ether = 1/17) to give product **3l**: 51.3 mg, 98% yield, white solid; mp 191–192 ℃; $[\alpha]_D^{25}$ = +146.4 (*c* = 0.25 in $CHCl_3$); 99% ee, determined by HPLC analysis [Chiralpak IC, *n*-hexane/*i*-PrOH = 60/40, 1.0 mL/min, λ = 254 nm, t (major) = 9.42 min, t (minor) = 13.75 min]; ^{1}H NMR (400 MHz, $CDCl_3$): δ (ppm) 7.97 (dd, *J* = 8.4, 1.6 Hz, 2H), 7.51–7.43 (m, 3H), 7.41–7.33 (m, 3H), 7.28–7.22 (m, 1H), 7.23–7.13 (m, 6H), 7.05 (dt, *J* = 5.2, 1.4 Hz, 1H), 6.07 (s, 1H), 4.37 (ddd, *J* = 14.0, 4.4, 1.6 Hz, 1H), 3.46–3.32 (m, 1H), 2.98 (dd, *J* = 14.0, 4.4 Hz, 1H), 2.33 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ (ppm) 168.0, 154.7, 152.8, 145.5, 142.6, 140.1, 139.5, 135.2, 130.1, 129.3, 129.2, 127.7, 127.5, 127.2, 127.1, 125.2, 125.1, 123.8, 123.5, 119.9, 119.2, 116.4, 111.4, 44.2, 36.3, 21.7; ESI-HRMS: calcd. for $C_{30}H_{23}NO_4S_2$ + H^+ 526.1147, found 526.1140.

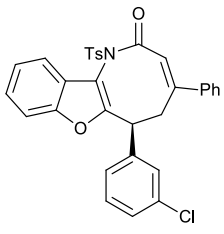


Synthesis of 3m: **General procedure A**: To a solution of cyclobutenone **1m** (22.5 mg, 0.15 mmol, 1.5 equiv), catalyst **C6** (7.8 mg, 10 mol%) and 4 Å MS (100.0 mg) in toluene (1.0 mL) was added 1-azadiene **2a** (37.5 mg, 0.1 mmol, 1.0 equiv). The mixture was stirred at 50 ℃ for 54 h (after 24 h, another 0.5 equiv cyclobutenone **1m** was added). After completion, it was purified by flash chromatography on silica gel (EtOAc/petroleum ether = 1/17) to give product **3m**: 50.2 mg, 95% yield, white solid; mp 98–100 ℃; $[\alpha]_D^{25}$ = +172 (*c* = 0.25 in $CHCl_3$); 99% ee, determined by HPLC analysis [Chiralpak IC, *n*-hexane/*i*-PrOH = 60/40, 1.0 mL/min, λ = 254 nm, t (major) = 6.93 min, t (minor) = 11.80 min]; ^{1}H

NMR (400 MHz, $CDCl_3$): δ (ppm) 7.99 (d, *J* = 8.4 Hz, 2H), 7.58–7.55 (m, 1H), 7.51–7.47 (m, 2H), 7.45–7.39 (m, 2H), 7.39–7.26 (m, 4H), 7.25 (d, *J* = 1.2 Hz, 1H), 7.24–7.22 (m, 1H), 5.64 (d, *J* = 1.0 Hz, 1H), 4.37 (dd, *J* = 14.0, 4.8 Hz, 1H), 3.14–3.02 (m, 1H), 2.58–2.51 (m, 1H), 2.41 (s, 3H), 1.98 (tt, *J* = 11.2, 3.2 Hz, 1H), 1.86–1.64 (m, 4H), 1.33–1.05 (m, 6H); ^{13}C NMR (100 MHz, $CDCl_3$): δ (ppm) 168.8, 156.5, 154.6, 152.8, 145.3, 140.3, 135.4, 130.1, 129.3, 129.1, 127.6, 127.5, 127.2, 124.9, 123.5, 119.9, 119.3, 116.6, 111.4, 45.9, 43.8, 36.3, 32.6, 31.5, 26.5, 26.1, 25.8, 21.7; ESI-HRMS: calcd. for $C_{32}H_{31}NO_4S + H^+$ 526.2052, found 526.2045.

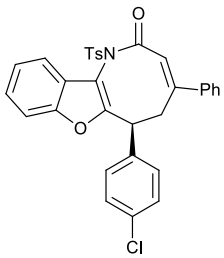


Synthesis of 3n: **General procedure A**: To a solution of cyclobutenone **1a** (21.6 mg, 0.15 mmol, 1.5 equiv), catalyst **C6** (7.8 mg, 10 mol%) and 4 Å MS (100.0 mg) in toluene (1.0 mL) was added *N*-((*Z*)-2-(4-fluorobenzylidene)benzofuran-3(2*H*)-ylidene)-4-methylbenzenesulfonamide **2b** (39.3 mg, 0.1 mmol, 1.0 equiv). The mixture was stirred at 50 ℃ for 48 h. After completion, it was purified by flash chromatography on silica gel (EtOAc/petroleum ether = 1/17) to give product **3n**: 53.5 mg, 99% yield, white solid; mp 83–85 ℃; $[\alpha]_D^{25}$ = +203.2 (*c* = 0.25 in $CHCl_3$); 98% ee, determined by HPLC analysis [Chiralpak IC, *n*-hexane/*i*-PrOH = 60/40, 1.0 mL/min, λ = 254 nm, t (major) = 7.42 min t (minor) = 9.89 min]; ^1H NMR (400 MHz, $CDCl_3$): δ (ppm) 8.06 (d, *J* = 8.5 Hz, 2H), 7.56–7.51 (m, 1H), 7.50–7.44 (m, 2H), 7.38–7.33 (m, 6H), 7.33–7.29 (m, 3H), 7.29–7.26 (m, 1H), 7.14–7.08 (m, 2H), 6.09 (s, 1H), 4.32 (dd, *J* = 14.0, 4.4 Hz, 1H), 3.49 (t, *J* = 14.0 Hz, 1H), 3.14–3.05 (m, 1H), 2.45 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ (ppm) 167.8, 162.2 (d, J_{FC} = 245.1 Hz), 154.4, 152.8, 148.7, 145.7, 138.0, 135.8 (d, J_{FC} = 3.2 Hz), 135.3, 130.1, 129.6, 129.4, 129.3 (J_{FC} = 8.0 Hz), 129.0, 127.0, 126.3, 125.2, 123.6, 121.1, 119.8, 116.5, 116.0 (J_{FC} = 21.4 Hz), 111.5, 43.1, 36.5, 21.7; ^{19}F NMR (376 MHz, $CDCl_3$): δ (ppm) –114.6; ESI-HRMS: calcd. for $C_{32}H_{24}FNO_4S + H^+$ 538.1488, found 538.1483.

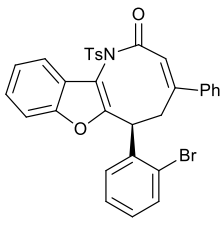


Synthesis of 3o: **General procedure A**: To a solution of cyclobutenone **1a** (21.6 mg, 0.15 mmol, 1.5 equiv), catalyst **C6** (7.8 mg, 10 mol%) and 4 Å MS (100.0 mg) in toluene (1.0 mL) was added *N*-((*Z*)-2-(3-chlorobenzylidene)benzofuran-3(2*H*)-ylidene)-4-methylbenzenesulfonamide **2c** (41.0 mg, 0.1 mmol, 1.0 equiv). The mixture was stirred at 50 ℃ for 48 h. After completion, it was purified by flash chromatography on silica gel (EtOAc/petroleum ether = 1/17) to give product **3o**: 55.1 mg, 99% yield, white solid; mp 90–92 ℃; $[\alpha]_D^{25}$ = +201.6 (*c* = 0.25 in $CHCl_3$); 97% ee, determined by HPLC analysis [Chiralpak IC, *n*-hexane/*i*-PrOH = 60/40, 1.0 mL/min, λ = 254 nm, t (major) = 7.60 min, t (minor) = 9.85 min]; ^1H NMR (400 MHz, $CDCl_3$): δ (ppm) 8.08 (d, *J* = 8.4 Hz, 2H), 7.61–7.57 (m, 1H), 7.49 (t, *J* = 1.8 Hz, 1H), 7.43–7.28 (m, 13H), 6.10 (s, 1H), 4.30 (dd, *J* = 14.0, 4.4 Hz, 1H), 3.43

(t, *J* = 14.0 Hz, 1H), 3.13–3.03 (m, 1H), 2.45 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ (ppm) 167.7, 153.7, 152.9, 148.4, 145.7, 142.0, 137.9, 135.2, 134.9, 130.5, 130.2, 129.6, 129.4, 129.0, 127.9, 127.7, 127.0, 126.2, 125.8, 125.3, 123.6, 121.2, 120.0, 116.7, 111.5, 43.4, 36.2, 21.7; ESI-HRMS: calcd. for $C_{32}H_{24}ClNO_4S + H^+$ 554.1193, found 554.1186.

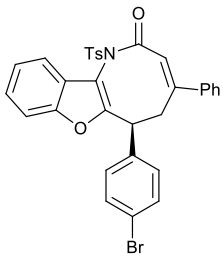


Synthesis of 3p: **General procedure A**: To a solution of cyclobutenone **1a** (21.6 mg, 0.15 mmol, 1.5 equiv), catalyst **C6** (7.8 mg, 10 mol%) and 4 Å MS (100.0 mg) in toluene (1.0 mL) was added *N*-((*Z*)-2-(4-chlorobenzylidene)benzofuran-3(2*H*)-ylidene)-4-methylbenzenesulfonamide **2d** (41.0 mg, 0.1 mmol, 1.0 equiv). The mixture was stirred at 50 ℃ for 48 h. After completion, it was purified by flash chromatography on silica gel (EtOAc/petroleum ether = 1/17) to give product **3p**: 55.2 mg, 98% yield, white solid; mp 95–96 ℃; $[\alpha]_D^{25}$ = +234.4 (*c* = 0.25 in $CHCl_3$); 99% ee, determined by HPLC analysis [Chiralpak IC, *n*-hexane/*i*-PrOH = 60/40, 1.0 mL/min, λ = 254 nm, t (major) = 7.41 min, t (minor) = 10.30 min]; ^{1}H NMR (400 MHz, $CDCl_3$): δ (ppm) 8.05 (d, *J* = 8.4 Hz, 2H), 7.56–7.52 (m, 1H), 7.44 (d, *J* = 8.6 Hz, 2H), 7.40 (d, *J* = 2.4 Hz, 1H), 7.39–7.32 (m, 8H), 7.31 (d, *J* = 1.4 Hz, 2H), 7.29–7.26 (m, 1H), 6.09 (s, 1H), 4.31 (dd, *J* = 14.0, 4.4 Hz, 1H), 3.48 (t, *J* = 14.0 Hz, 1H), 3.08 (ddd, *J* = 14.0, 4.4, 1.0 Hz, 1H), 2.45 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ (ppm) 167.8, 154.1, 152.9, 148.6, 145.7, 138.5, 138.0, 135.2, 133.5, 130.1, 129.6, 129.4, 129.3, 129.0, 128.9, 127.0, 126.3, 125.2, 123.6, 121.1, 119.9, 116.6, 111.5, 43.2, 36.2, 21.7; ESI-HRMS: calcd. for $C_{32}H_{24}ClNO_4S + Na^+$ 576.1012, found 576.1002.

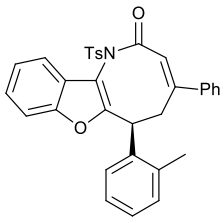


Synthesis of 3q: **General procedure A**: To a solution of cyclobutenone **1a** (21.6 mg, 0.15 mmol, 1.5 equiv), catalyst **C6** (7.8 mg, 10 mol%) and 4 Å MS (100.0 mg) in toluene (1.0 mL) was added *N*-((*Z*)-2-(2-bromobenzylidene)benzofuran-3(2*H*)-ylidene)-4-methylbenzenesulfonamide **2e** (45.4 mg, 0.1 mmol, 1.0 equiv). The mixture was stirred at 50 ℃ for 48 h. After completion, it was purified by flash chromatography on silica gel (EtOAc/petroleum ether = 1/17) to give product **3q**: 57.3 mg, 96% yield, white solid; mp 157–158 ℃; $[\alpha]_D^{25}$ = +152 (*c* = 0.25 in $CHCl_3$); 95% ee, determined by HPLC analysis [Chiralpak IA, *n*-hexane/*i*-PrOH = 80/20, 1.0 mL/min, λ = 254 nm, t (major) = 13.99 min, t (minor) = 15.48 min]; ^{1}H NMR (400 MHz, $CDCl_3$): δ (ppm) 8.11 (d, *J* = 8.4 Hz, 2H), 7.78 (dd, *J* = 7.8, 1.6 Hz, 1H), 7.72–7.67 (m, 1H), 7.64 (dd, *J* = 8.0, 1.2 Hz, 1H), 7.46–7.42 (m, 2H), 7.39–7.29 (m, 9H), 7.23–7.17 (m, 1H), 6.07 (s, 1H), 4.70 (dd, *J* = 13.2, 4.8 Hz, 1H), 3.34–3.28 (m, 1H), 3.22 (t, *J* = 13.2 Hz, 1H), 2.43 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ (ppm) 167.7, 153.8, 152.8, 149.6, 145.7, 139.2, 137.7, 135.2, 133.5, 130.2, 129.6, 129.5, 129.4, 129.3, 128.7, 128.5, 127.0, 126.9, 125.3, 123.7, 123.6, 121.2, 120.0, 117.7, 111.5, 43.7, 34.2, 21.7; ESI-HRMS: calcd. for $C_{32}H_{24}BrNO_4S + Na^+$

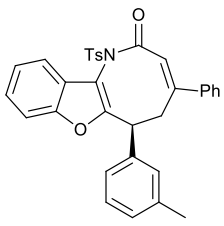
620.0507 (^{79}Br), 622.0487 (^{81}Br), found 620.0507, 622.0486.



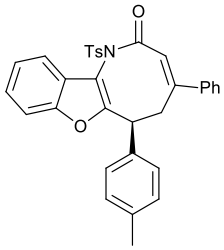
Synthesis of 3r: **General procedure A**: To a solution of cyclobutenone **1a** (21.6 mg, 0.15 mmol, 1.5 equiv), catalyst **C6** (7.8 mg, 10 mol%) and 4 Å MS (100.0 mg) in toluene (1.0 mL) was added *N*-((*Z*)-2-(4-bromobenzylidene)benzofuran-3(2*H*)-ylidene)-4-methylbenzenesulfonamide **2f** (45.4 mg, 0.1 mmol, 1.0 equiv). The mixture was stirred at 50 ℃ for 38 h. After completion, it was purified by flash chromatography on silica gel (EtOAc/petroleum ether = 1/17) to give product **3r**: 57.6 mg, 99% yield, white solid; mp 151–152 ℃; $[\alpha]_D^{25}$ = +215.2 (*c* = 0.25 in $CHCl_3$); 96% ee, determined by HPLC analysis [Chiralpak IC, *n*-hexane/*i*-PrOH = 60/40, 1.0 mL/min, λ = 254 nm, t (major) = 7.62 min, t (minor) = 10.76 min]; ^{1}H NMR (400 MHz, $CDCl_3$): δ (ppm) 8.05 (d, *J* = 8.4 Hz, 2H), 7.58–7.52 (m, 3H), 7.40–7.33 (m, 8H), 7.32 (d, *J* = 1.2 Hz, 2H), 7.28 (dd, *J* = 6.8, 1.8 Hz, 2H), 6.09 (s, 1H), 4.29 (dd, *J* = 14.0, 4.4 Hz, 1H), 3.48 (t, *J* = 14.0 Hz, 1H), 3.08 (dd, *J* = 14.0, 4.4 Hz, 1H), 2.46 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ (ppm) 167.8, 154.0, 152.9, 148.6, 145.7, 139.1, 138.0, 135.2, 132.3, 130.1, 129.7, 129.4, 129.3, 129.0, 127.0, 126.3, 125.3, 123.6, 121.7, 121.2, 119.9, 116.7, 111.5, 43.3, 36.2, 21.7; ESI-HRMS: calcd. for $C_{32}H_{24}BrNO_4S + Na^+$ 620.0507 (^{79}Br), 622.0487 (^{81}Br), found 620.0513, 622.0481.



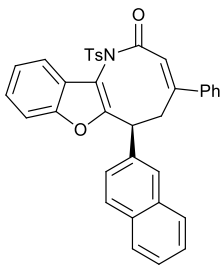
Synthesis of 3s: **General procedure A**: To a solution of cyclobutenone **1a** (21.6 mg, 0.15 mmol, 1.5 equiv), catalyst **C6** (7.8 mg, 10 mol%) and 4 Å MS (100.0 mg) in toluene (1.0 mL) was added 4-methyl-*N*-((*Z*)-2-(2-methylbenzylidene) benzofuran-3(2*H*)-ylidene)benzenesulfonamide **2g** (38.9 mg, 0.1 mmol, 1.0 equiv). The mixture was stirred at 50 ℃ for 36 h. After completion, it was purified by flash chromatography on silica gel (EtOAc/petroleum ether = 1/17) to give product **3s**: 53.2 mg, 99% yield, white solid; mp 103–104 ℃; $[\alpha]_D^{25}$ = +258.4 (*c* = 0.25 in $CHCl_3$); 97% ee, determined by HPLC analysis [Chiralpak IC, *n*-hexane/*i*-PrOH = 60/40, 1.0 mL/min, λ = 254 nm, t (major) = 7.75 min, t (minor) = 10.52 min]; ^{1}H NMR (400 MHz, $CDCl_3$): δ (ppm) 8.15 (d, *J* = 8.4 Hz, 2H), 7.73–7.68 (m, 1H), 7.66 (d, *J* = 7.2 Hz, 1H), 7.38–7.34 (m, 3H), 7.34–7.26 (m, 8H), 7.26–7.24 (m, 1H), 7.21 (dd, *J* = 7.4, 1.4 Hz, 1H), 6.04 (s, 1H), 4.40 (dd, *J* = 16, 4.0 Hz, 1H), 3.34 (t, *J* = 13.6 Hz, 1H), 3.03–2.96 (m, 1H), 2.43 (s, 3H), 2.32 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ (ppm) 167.7, 154.8, 152.7, 149.8, 145.6, 138.4, 138.3, 135.2, 135.0, 131.1, 130.3, 129.6, 129.4, 128.9, 127.64, 127.62, 127.2, 127.0, 126.5, 125.1, 123.5, 121.2, 120.0, 117.1, 111.4, 40.5, 35.1, 21.7, 19.0; ESI-HRMS: calcd. for $C_{33}H_{27}NO_4S + Na^+$ 556.1558, found 556.1543.



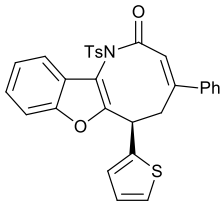
Synthesis of 3t: **General procedure A**: To a solution of cyclobutenone **1a** (21.6 mg, 0.15 mmol, 1.5 equiv), catalyst **C6** (7.8 mg, 10 mol%) and 4 Å MS (100.0 mg) in toluene (1.0 mL) was added 4-methyl-*N*-((*Z*)-2-(3-methylbenzylidene) benzofuran-3(2*H*)-ylidene)benzenesulfonamide **2h** (38.9 mg, 0.1 mmol, 1.0 equiv). The mixture was stirred at 50 ℃ for 48 h. After completion, it was purified by flash chromatography on silica gel (EtOAc/petroleum ether = 1/17) to give product **3t**: 53.5 mg, 99% yield, white solid; mp 93–95 ℃; $[\alpha]_D^{25}$ = +264.8 (*c* = 0.25 in $CHCl_3$); 99% ee, determined by HPLC analysis [Chiralpak IC, *n*-hexane/*i*-PrOH = 60/40, 1.0 mL/min, λ = 254 nm, t (major) = 7.38 min, t (minor) = 9.83 min]; ^{1}H NMR (400 MHz, $CDCl_3$): δ (ppm) 8.07 (d, *J* = 8.4 Hz, 2H), 7.67–7.62 (m, 1H), 7.38–7.34 (m, 6H), 7.34–7.31 (m, 2H), 7.31–7.27 (m, 5H), 7.17–7.13 (m, 1H), 6.09 (s, 1H), 4.31 (dd, *J* = 14.0, 4.4 Hz, 1H), 3.41 (t, *J* = 14.0 Hz, 1H), 3.09 (ddd, *J* = 14.0, 4.4, 1.2 Hz, 1H), 2.43 (s, 3H), 2.39 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ (ppm) 167.9, 154.6, 152.8, 148.7, 145.5, 140.0, 138.9, 138.1, 135.3, 130.2, 129.5, 129.3, 129.1, 128.9, 128.4, 128.2, 127.2, 126.3, 125.0, 124.5, 123.6, 120.9, 119.9, 116.4, 111.5, 43.8, 36.6, 21.7, 21.4; ESI-HRMS: calcd. for $C_{33}H_{27}NO_4S + Na^+$ 556.1558, found 556.1549.



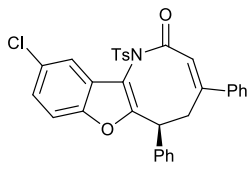
Synthesis of 3u: **General procedure A**: To a solution of cyclobutenone **1a** (21.6 mg, 0.15 mmol, 1.5 equiv), catalyst **C6** (7.8 mg, 10 mol%) and 4 Å MS (100.0 mg) in toluene (1.0 mL) was added 4-methyl-*N*-((*Z*)-2-(4-methylbenzylidene) benzofuran-3(2*H*)-ylidene)benzenesulfonamide **2i** (38.9 mg, 0.1 mmol, 1.0 equiv). The mixture was stirred at 50 ℃ for 54 h (after 24 h, another 0.5 equiv cyclobutenone **1a** was added). After completion, it was purified by flash chromatography on silica gel (EtOAc/petroleum ether = 1/17) to give product **3u**: 52.2 mg, 98% yield, white solid; mp 88–89 ℃; $[\alpha]_D^{25}$ = +254.4 (*c* = 0.25 in $CHCl_3$); 98% ee, determined by HPLC analysis [Chiralpak IC, *n*-hexane/*i*-PrOH = 60/40, 1.0 mL/min, λ = 254 nm, t (major) = 7.53 min, t (minor) = 12.84 min]; ^{1}H NMR (400 MHz, $CDCl_3$): δ (ppm) 8.06 (d, *J* = 8.4 Hz, 2H), 7.63–7.59 (m, 1H), 7.38 (d, *J* = 2.0 Hz, 1H), 7.37–7.34 (m, 6H), 7.34–7.33 (m, 1H), 7.31–7.29 (m, 2H), 7.29–7.27 (m, 2H), 7.23 (d, *J* = 8.0 Hz, 2H), 6.09 (s, 1H), 4.31 (dd, *J* = 14.0, 4.4 Hz, 1H), 3.43 (t, *J* = 14.0 Hz, 1H), 3.09 (ddd, *J* = 14.0, 4.4, 1.2 Hz, 1H), 2.44 (s, 3H), 2.37 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ (ppm) 168.0, 154.8, 152.8, 148.7, 145.5, 138.1, 137.4, 137.1, 135.3, 130.2, 129.8, 129.5, 129.4, 129.0, 127.4, 127.2, 126.3, 125.0, 123.5, 120.9, 119.9, 116.3, 111.5, 43.4, 36.5, 21.7, 21.1; ESI-HRMS: calcd. for $C_{33}H_{27}NO_4S + Na^+$ 556.1558, found 556.1548.



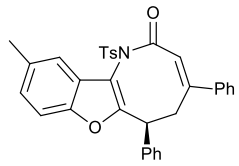
Synthesis of 3v: **General procedure A**: To a solution of cyclobutenone **1a** (21.6 mg, 0.15 mmol, 1.5 equiv), catalyst **C6** (7.8 mg, 10 mol%) and 4 Å MS (100.0 mg) in toluene (1.0 mL) was added 4-methyl-*N*-((*Z*)-2-(naphthalen-2-yl methylene)benzofuran-3(2*H*)-ylidene)benzenesulfonamide **2j** (42.5 mg, 0.1 mmol, 1.0 equiv). The mixture was stirred at 50 ℃ for 36 h. After completion, it was purified by flash chromatography on silica gel (EtOAc/petroleum ether = 1/17) to give product **3v**: 55.7 mg, 98% yield, white solid; mp 105–107 ℃; $[\alpha]_D^{25}$ = +294.4 (*c* = 0.25 in $CHCl_3$); 98% ee, determined by HPLC analysis [Chiralpak IC, *n*-hexane/*i*-PrOH = 60/40, 1.0 mL/min, λ = 254 nm, t (major) = 8.38 min, t (minor) = 11.03 min]; ^{1}H NMR (400 MHz, $CDCl_3$): δ (ppm) 8.06 (d, *J* = 8.4 Hz, 2H), 7.96 (d, *J* = 1.8 Hz, 1H), 7.91 (d, *J* = 8.4 Hz, 1H), 7.88–7.83 (m, 2H), 7.71–7.67 (m, 1H), 7.61 (dd, *J* = 8.4, 2.0 Hz, 1H), 7.50–7.46 (m, 2H), 7.40–7.34 (m, 6H), 7.33–7.29 (m, 2H), 7.18 (d, *J* = 8.2 Hz, 2H), 6.12 (s, 1H), 4.52 (dd, *J* = 14.0, 4.4 Hz, 1H), 3.47 (t, *J* = 14.0 Hz, 1H), 3.25–3.16 (m, 1H), 2.37 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ (ppm) 167.9, 154.5, 152.9, 148.6, 145.5, 138.1, 137.6, 135.2, 133.6, 132.7, 130.1, 129.6, 129.3, 129.0, 128.9, 128.0, 127.7, 127.3, 126.5, 126.29, 126.27, 126.2, 125.5, 125.1, 123.6, 121.1, 119.9, 116.7, 111.5, 43.9, 36.7, 21.6; ESI-HRMS: calcd. for $C_{36}H_{27}NO_4S$ + H^+ 570.1739, found 570.1730.



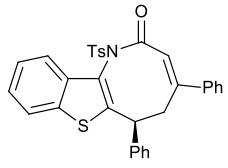
Synthesis of 3w: **General procedure A**: To a solution of cyclobutenone **1a** (21.6 mg, 0.15 mmol, 1.5 equiv), catalyst **C6** (7.8 mg, 10 mol%) and 4 Å MS (100.0 mg) in toluene (1.0 mL) was added 4-methyl-*N*-((*Z*)-2-(thiophen-2-ylmethylene) benzofuran-3(2*H*)-ylidene)benzenesulfonamide **2k** (38.1 mg, 0.1 mmol, 1.0 equiv). The mixture was stirred at 50 ℃ for 48 h. After completion, it was purified by flash chromatography on silica gel (EtOAc/petroleum ether = 1/17) to give product **3w**: 50.2 mg, 96% yield, white solid; mp 96–97 ℃; $[\alpha]_D^{25}$ = +152 (*c* = 0.25 in $CHCl_3$); 98% ee, determined by HPLC analysis [Chiralpak IC, *n*-hexane/*i*-PrOH = 60/40, 1.0 mL/min, λ = 254 nm, t (major) = 10.02min, t (minor) = 19.49 min]; ^{1}H NMR (400 MHz, $CDCl_3$): δ (ppm) 7.95 (d, *J* = 8.4 Hz, 2H), 7.68–7.64 (m, 1H), 7.42–7.39 (m, 1H), 7.35–7.29 (m, 8H), 7.27 (d, *J* = 8.2 Hz, 2H), 7.07 (dd, *J* = 3.6, 1.2 Hz, 1H), 7.03 (dd, *J* = 5.2, 3.6 Hz, 1H), 6.10 (s, 1H), 4.62–4.54 (m, 1H), 3.38 (t, *J* = 13.6 Hz, 1H), 3.23 (ddd, *J* = 13.6, 5.0, 1.2 Hz, 1H), 2.43 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ (ppm) 167.7, 153.7, 152.8, 147.3, 145.5, 142.7, 137.7, 135.1, 130.1, 129.6, 129.3, 129.0, 127.2, 127.18, 126.2, 125.5, 125.2, 124.9, 123.7, 121.2, 120.0, 115.7, 111.5, 38.7, 36.3, 21.7; ESI-HRMS: calcd. for $C_{30}H_{23}NO_4S_2$ + H^+ 526.1147, found 526.1143.



Synthesis of 3x: **General procedure A**: To a solution of cyclobutenone **1a** (21.6 mg, 0.15 mmol, 1.5 equiv), catalyst **C6** (7.8 mg, 10 mol%) and 4 Å MS (100.0 mg) in toluene (1.0 mL) was added *N*-((*Z*)-2-benzylidene-5-chloro benzofuran-3(2*H*)-ylidene)-4-methylbenzenesulfonamide **2l** (41.0 mg, 0.1 mmol, 1.0 equiv). The mixture was stirred at 50 ℃ for 24 h. After completion, it was purified by flash chromatography on silica gel (EtOAc/petroleum ether = 1/17) to give product **3x**: 55.1 mg, 92% yield, white solid; mp 163–164 ℃; $[\alpha]_D^{25}$ = +233.6 (*c* = 0.25 in $CHCl_3$); 98% ee, determined by HPLC analysis [Chiralpak IC, *n*-hexane/*i*-PrOH = 60/40, 1.0 mL/min, λ = 254 nm, t (major) = 8.01 min, t (minor) = 8.72 min]; ^{1}H NMR (400 MHz, $CDCl_3$): δ (ppm) 8.06 (d, *J* = 8.2 Hz, 2H), 7.51–7.46 (m, 2H), 7.46–7.42 (m, 2H), 7.39–7.33 (m, 6H), 7.34–7.29 (m, 3H), 7.27–7.23 (m, 2H), 6.11 (s, 1H), 4.31 (dd, *J* = 14.0, 4.4 Hz, 1H), 3.50 (t, *J* = 14.0 Hz, 1H), 3.13 (dd, *J* = 14.0, 4.4 Hz, 1H), 2.45 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ (ppm) 167.6, 156.3, 151.2, 149.0, 145.8, 139.7, 138.0, 135.1, 130.1, 129.7, 129.5, 129.4, 129.2, 129.0, 128.3, 127.8, 127.5, 126.3, 125.4, 120.9, 119.6, 116.1, 112.6, 43.9, 36.3, 21.7; ESI-HRMS: calcd. for $C_{32}H_{24}ClNO_4S + Na^+$ 576.1012 (^{35}Cl), 577.1046 (^{37}Cl), found 576.1006, 577.1044.

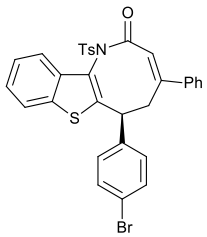


Synthesis of 3y: **General procedure A**: To a solution of cyclobutenone **1a** (21.6 mg, 0.15 mmol, 1.5 equiv), catalyst **C6** (7.8 mg, 10 mol%) and 4 Å MS (100.0 mg) in toluene (1.0 mL) was added *N*-((*Z*)-2-benzylidene-5-methylbenzofuran-3(2*H*)-ylidene)-4-methylbenzenesulfonamide **2m** (38.9 mg, 0.1 mmol, 1.0 equiv). The mixture was stirred at 50 ℃ for 58 h. After completion, it was purified by flash chromatography on silica gel (EtOAc/petroleum ether = 1/17) to give product **3y**: 52.6 mg, 99% yield, white solid; mp 191–193 ℃; $[\alpha]_D^{25}$ = +244 (*c* = 0.25 in $CHCl_3$); 98% ee, determined by HPLC analysis [Chiralpak IC, *n*-hexane/*i*-PrOH = 60/40, 1.0 mL/min, λ = 254 nm, t (major) = 7.64 min, t (minor) = 8.59 min]; ^{1}H NMR (400 MHz, $CDCl_3$): δ (ppm) 8.05 (d, *J* = 8.4 Hz, 2H), 7.51–7.46 (m, 2H), 7.45–7.39 (m, 2H), 7.38–7.33 (m, 6H), 7.31 (dd, *J* = 2.0, 1.2 Hz, 1H), 7.28 (d, *J* = 8.2 Hz, 2H), 7.24–7.20 (m, 1H), 7.10 (dd, *J* = 8.4, 1.6 Hz, 1H), 6.09 (s, 1H), 4.32 (dd, *J* = 14.0, 4.4 Hz, 1H), 3.42 (t, *J* = 14.0 Hz, 1H), 3.10 (ddd, *J* = 14.0, 4.4, 1.2 Hz, 1H), 2.43 (s, 3H), 2.41 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ (ppm) 167.9, 154.5, 151.3, 148.8, 145.5, 140.2, 138.1, 135.3, 133.2, 130.2, 129.5, 129.3, 129.1, 129.0, 127.6, 127.5, 127.2, 126.3, 126.28, 121.0, 119.6, 116.2, 111.0, 43.8, 36.4, 21.7, 21.3; ESI-HRMS: calcd. for $C_{33}H_{27}NO_4S + Na^+$ 556.1558, found 556.1553.

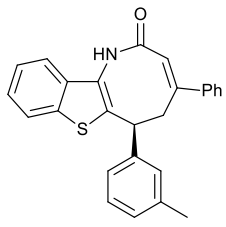


Synthesis of 3z: **General procedure A**: To a solution of cyclobutenone **1a** (21.6 mg, 0.15 mmol, 1.5 equiv), catalyst **C6** (7.8 mg, 10 mol%) and 4 Å MS (100.0 mg) in toluene (1.0 mL) was added *N*-((*Z*)-2-benzylidenebenzo[*b*]thiophen-

3(2*H*)-ylidene)-4-methylbenzenesulfonamide **2n** (39.1 mg, 0.1 mmol, 1.0 equiv). The mixture was stirred at 50 ℃ for 24 h. After completion, it was purified by flash chromatography on silica gel (EtOAc/petroleum ether = 1/17) and recrystallization to give product **3z**: 40.2 mg, 76% yield, white solid; mp 101–102 ℃; $[\alpha]_D^{25}$ = +369.6 (*c* = 0.25 in $CHCl_3$); 99% ee, determined by HPLC analysis [Chiralpak IC, *n*-hexane/*i*-PrOH = 60/40, 1.0 mL/min, λ = 254 nm, t (major) = 8.60 min, t (minor) = 16.27 min]; ^{1}H NMR (400 MHz, $CDCl_3$): δ (ppm) 8.01 (d, *J* = 7.6 Hz, 1H), 7.78 (d, *J* = 8.4 Hz, 2H), 7.73 (dd, *J* = 7.6, 1.2 Hz, 1H), 7.53–7.47 (m, 2H), 7.45 (d, *J* = 1.2 Hz, 1H), 7.45–7.41 (m, 2H), 7.41–7.31 (m, 4H), 7.30–7.26 (m, 2H), 7.13 (d, *J* = 8.0 Hz, 2H), 6.01 (s, 1H), 4.50 (dd, *J* = 13.2, 5.6 Hz, 1H), 3.37 (t, *J* = 13.2 Hz, 1H), 3.21 (ddd, *J* = 13.2, 5.6, 1.2 Hz, 1H), 2.39 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ (ppm) 168.3, 148.9, 145.3, 142.3, 141.7, 138.9, 138.3, 135.8, 135.0, 130.5, 129.4, 129.1, 128.9, 128.8, 128.5, 127.7, 127.4, 126.3, 125.4, 125.2, 122.4, 122.2, 121.1, 44.6, 37.4, 21.6; ESI-HRMS: calcd. for $C_{32}H_{25}NO_3S_2$ + Na^+ 558.1174, found 558.1169.

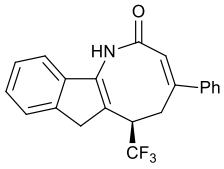


Synthesis of 3aa: **General procedure A**: To a solution of cyclobutenone **1a** (21.6 mg, 0.15 mmol, 1.5 equiv), catalyst **C6** (7.8 mg, 10 mol%) and 4 Å MS (100.0 mg) in toluene (1.0 mL) was added *N*-((*Z*)-2-(4-bromobenzylidene)benzo[*b*]thiophen-3(2*H*)-ylidene)-4-methylbenzenesulfonamide **2o** (47.0 mg, 0.1 mmol, 1.0 equiv). The mixture was stirred at 50 ℃ for 10 h. After completion, it was purified by flash chromatography on silica gel(EtOAc/petroleum ether = 1/17) and recrystallization to give product **3aa**: 44.6 mg, 73% yield, white solid; mp 185–186 ℃; $[\alpha]_D^{25}$ = +252 (*c* = 0.25 in $CHCl_3$); 99% ee, determined by HPLC analysis [Chiralpak IC, *n*-hexane/*i*-PrOH = 60/40, 1.0 mL/min, λ = 254 nm, t (major) = 8.11 min, t (minor) = 12.14 min]; ^{1}H NMR (400 MHz, $CDCl_3$): δ (ppm) 7.92–7.88 (m, 1H), 7.83 (d, *J* = 8.4 Hz, 2H), 7.73 (dd, *J* = 6.8, 2.0 Hz, 1H), 7.57–7.53 (m, 2H), 7.45–7.37 (m, 5H), 7.36–7.30 (m, 3H), 7.27 (d, *J* = 2.0 Hz, 1H), 7.20 (d, *J* = 8.4 Hz, 2H), 6.01 (s, 1H), 4.42 (dd, *J* = 13.2, 5.2 Hz, 1H), 3.46 (t, *J* = 13.2 Hz, 1H), 3.16 (dd, *J* = 13.2, 5.2 Hz, 1H), 2.42 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ (ppm) 168.2, 148.9, 145.6, 141.7, 140.7, 138.7, 138.2, 135.8, 135.0, 132.0, 130.4, 129.49, 129.46, 129.2, 128.9, 126.4,126.3, 125.5, 125.3, 122.3, 122.2, 121.4, 121.2, 44.1, 37.2, 21.7; ESI-HRMS: calcd. for $C_{32}H_{24}BrNO_3S_2$+ Na^+ 636.0279 (^{79}Br), 638.0258 (^{81}Br), found 636.0280, 638.0254.

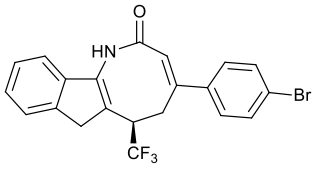


Synthesis of 5ab: **General procedure B**: To a solution of cyclobutenone **1a** (21.6 mg, 0.15 mmol, 1.5 equiv), catalyst **C6** (7.8 mg, 10 mol%) and 4 Å MS (100.0 mg) in toluene (1.0 mL) was added 4-methyl-*N*-((*Z*)-2-(3-methylbenzylidene) benzo[*b*]thiophen-3(2*H*)-ylidene)benzenesulfonamide **2p** (40.5 mg, 0.1 mmol, 1.0 equiv). The mixture was stirred at 50 ℃ for 35 h. The crude annulation product was purified by flash chromatography on silica gel (EtOAc/petroleum ether = 1/17). Then

the crude product was added to a solution of CuCl (39.6 mg, 4.0 equiv) in EtOH (1.0 mL), and $NaBH_4$ (15.2 mg, 4.0 equiv) was added in one portion. The mixture was stirred at 50 ℃ for 5 h. After completion, the mixture was concentrated and and it was purified by flash chromatography on silica gel (EtOAc/petroleum ether = 1/8) to give product **5ab**: 24.9 mg, 63% yield, white solid; mp 104–106 ℃; $[\alpha]_D^{25} = -32$ (*c* = 0.25 in $CHCl_3$); 95% ee, determined by HPLC analysis [Chiralpak AD, *n*-hexane/*i*-PrOH = 80/20, 1.0 mL/min, λ = 254 nm, t (minor) = 7.37 min, t (major) = 11.71 min]; ^{1}H NMR (400 MHz, $CDCl_3$): δ (ppm) 7.86 (s, 1H), 7.76 (d, *J* = 8.0 Hz, 1H), 7.64 (d, *J* = 8.0 Hz, 1H), 7.48–7.42 (m, 3H), 7.42–7.32 (m, 4H), 7.20–7.16 (m, 1H), 7.09–7.02 (m, 3H), 6.24 (s, 1H), 4.35 (dd, *J* = 14.0, 4.8 Hz, 1H), 3.84 (t, *J* = 14.0Hz, 1H), 3.15 (dd, *J* = 14.0, 4.8 Hz, 1H), 2.31 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ (ppm) 171.5, 147.3, 143.6, 138.7, 138.2, 137.2, 136.4, 129.0, 128.9, 128.8, 128.2, 127.7, 126.9, 126.3, 125.7, 125.1, 124.7, 124.2, 122.4, 120.4, 120.2, 45.2, 39.3, 21.5; ESI-HRMS: calcd. for $C_{26}H_{21}NOS + Na^+$ 418.1242, found 418.1243.

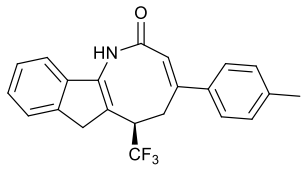


Synthesis of 5ac: **General procedure B**: To a solution of cyclobutenone **1a** (21.6 mg, 0.15 mmol, 1.5 equiv), catalyst **C6** (7.8 mg, 10 mol%) and 4 Å MS (100.0 mg) in toluene (1.0 mL) was added 4-methyl-*N*-((*E*)-2-(2,2,2-trifluoro ethylidene)-2,3-dihydro-1*H*-inden-1-ylidene)benzenesulfonamide **2q** (26.5 mg, 0.1 mmol, 1.0 equiv). The mixture was stirred at 50 ℃ for 27 h. The crude annulation product was purified by flash chromatography on silica gel (EtOAc/petroleum ether = 1/17) . Then the crude product was added to a solution of CuCl (39.6 mg, 4.0 equiv) in EtOH (1.0 mL), and $NaBH_4$ (15.2 mg, 4.0 equiv) was added in one portion. The mixture was stirred at 50 ℃ for 5 h. After completion, the mixture was concentrated and it was purified by flash chromatography on silica gel (EtOAc/petroleum ether = 1/6) to give product **5ac**: 26.6 mg, 75% yield, colorless semisolid; $[\alpha]_D^{25} = -147.2$ (*c* = 0.25 in $CHCl_3$); 99% ee, determined by HPLC analysis [Chiralpak AD, *n*-hexane/*i*-PrOH = 90/10, 1.0 mL/min, λ = 254 nm, t (minor) = 23.40 min, t (major) = 34.03 min]; ^{1}H NMR (400 MHz, $CDCl_3$): δ (ppm) 7.56 (s, 1H), 7.44–7.33 (m, 8H), 7.30 (dd, *J* = 7.2, 1.4 Hz, 1H), 6.25 (s, 1H), 3.72 (d, *J* = 23.0 Hz, 1H), 3.61 (t, *J* = 13.4 Hz, 1H), 3.48–3.35 (m, 1H), 3.25 (d, *J* = 23.0 Hz, 1H), 3.17 (dd, *J* = 13.4, 4.4 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$): δ (ppm) 170.5, 144.8, 142.3, 140.8, 137.8, 137.3, 129.4, 129.0, 127.9, 126.9, 126.5, 126.08, 126.1 (q, J_{FC} = 280.2 Hz), 123.8, 121.2, 118.1, 43.1 (q, J_{FC} = 27.3 Hz), 40.8, 29.7; ^{19}F NMR (376 MHz, $CDCl_3$) δ (ppm) –60.4; ESI-HRMS: calcd. for $C_{21}H_{16}F_3NO + Na^+$ 378.1082, found 378,1076.



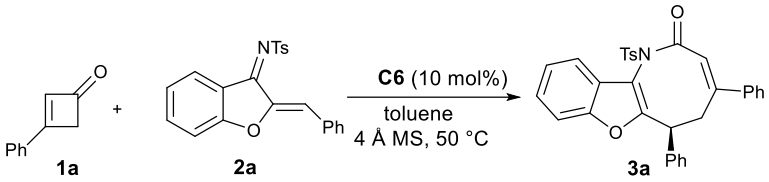
Synthesis of 5ad: **General procedure B**: To a solution of cyclobutenone **1e** (33.5 mg, 0.15 mmol, 1.5 equiv), catalyst **C6** (7.8 mg, 10 mol%) and 4 Å MS (100.0 mg) in toluene (1.0 mL) was added 4-methyl-*N*-((*E*)-2-

(2,2,2-trifluoroethylidene)-2,3-dihydro-1*H*-inden-1-ylidene)benzenesulfonamide **2q** (26.5 mg, 0.1 mmol, 1.0 equiv). The mixture was stirred at 50 ℃ for 18 h. The crude annulation product was purified by flash chromatography on silica gel (EtOAc/petroleum ether = 1/17). Then the crude product was added to a solution of CuCl (39.6 mg, 4.0 equiv) in EtOH (1.0 mL), and $NaBH_4$ (15.2 mg, 4.0 equiv) was added in one portion. The mixture was stirred at 50 ℃ for 5 h. After completion, the mixture was concentrated and it was purified by flash chromatography on silica gel (EtOAc/petroleum ether = 1/6) to give product **5ad**: 19.0 mg, 44% yield, colorless semisolid; $[\alpha]_D^{25}$ = –98.3 (*c* = 0.6 in $CHCl_3$); 95% ee, determined by HPLC analysis [Chiralpak AD *n*-hexane/*i*-PrOH = 90/10, 1.0 mL/min, λ = 254 nm, t (minor) =20.98 min, t (major) =33.11 min]; ^{1}H NMR (400 MHz, $CDCl_3$): δ (ppm) 7.46–7.41 (m, 2H), 7.37–7.27 (m, 5H), 7.26–7.22 (m, 1H), 7.20 (d, *J* = 8.8 Hz, 2H), 6.17 (d, *J* = 4.4 Hz, 1H), 3.65 (d, *J* = 23.0 Hz, 1H), 3.59–3.47 (m, 1H), 3.38–3.27 (m, 1H), 3.18 (dd, *J* = 23.0, 3.0 Hz, 1H), 3.07 (ddd, *J* = 24.8, 13.6, 4.4 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$): δ (ppm) 170.0, 144.8, 143.6, 142.1, 140.8, 137.3, 132.2, 129.0, 127.7, 126.9, 126.7, 126.1, 125.1 (q, J_{FC} = 287.1 Hz), 123.9, 121.7, 118.0, 43.0 (q, J_{FC} = 21.6 Hz), 40.8, 29.6; ^{19}F NMR (376 MHz, $CDCl_3$) δ (ppm) –69.1; ESI-HRMS: calcd. for $C_{21}H_{15}BrF_3NO + Na^+$ 456.0187 (^{79}Br), 458.0166 (^{81}Br), found 456.0167, 458.0163.



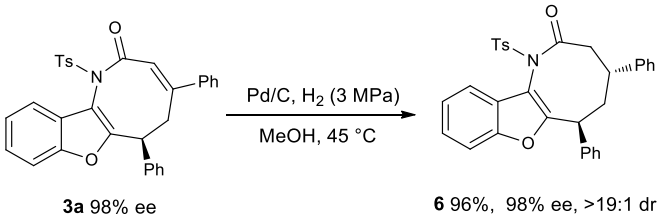
Synthesis of 5ae: **General procedure B**: To a solution of cyclobutenone **1g** (23.7 mg, 0.15 mmol, 1.5 equiv), catalyst **C6** (7.8 mg, 10 mol%) and 4 Å MS (100.0 mg) in toluene (1.0 mL) was added 4-methyl-*N*-((*E*)-2-(2,2,2-trifluoroethylidene)-2,3-dihydro-1*H*-inden-1-ylidene)benzenesulfonamide **2q** (40.5 mg, 0.1 mmol, 1.0 equiv). The mixture was stirred at 50 ℃ for 30 h. The crude annulation product was purified by flash chromatography on silica gel (EtOAc/petroleum ether = 1/17). Then the crude product was added to a solution of CuCl (39.6 mg, 4.0 equiv) in EtOH (1.0 mL), and $NaBH_4$ (15.2 mg, 4.0 equiv) was added in one portion. The mixture was stirred at 50 ℃ for 5 h. After completion, the mixture was concentrated and it was purified by flash chromatography on silica gel (EtOAc/petroleum ether = 1/6) to give product **5ae**: 22.8 mg, 62% yield, colorless semisolid; $[\alpha]_D^{25}$ = –119.4 (*c* = 1.0 in $CHCl_3$); 99% ee, determined by HPLC analysis [Chiralpak AD, *n*-hexane/*i*-PrOH = 90/10, 1.0 mL/min, λ = 254 nm, t (minor) =24.17 min, t (major) =29.02 min]; ^{1}H NMR (400 MHz, $CDCl_3$): δ (ppm) 7.66 (s, 1H), 7.45–7.36 (m, 3H), 7.33–7.27 (m, 3H), 7.18 (d, *J* = 8.0 Hz, 2H), 6.24 (s, 1H), 3.71 (d, *J* = 23.0 Hz, 1H), 3.60 (t, *J* = 13.4 Hz, 1H), 3.46–3.33 (m, 1H), 3.23 (d, *J* = 23.0 Hz, 1H), 3.15 (dd, *J* = 13.4, 4.4 Hz, 1H), 2.36 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ (ppm) 170.7, 144.7, 142.3, 140.8, 139.5, 137.3, 134.7, 129.6, 127.8, 126.8, 126.4, 126.1 (q, J_{FC} = 280.1 Hz), 126.0, 123.7, 120.3, 118.1, 43.0 (q, J_{FC} = 27.3 Hz), 40.8, 29.4, 21.1; ^{19}F NMR (376 MHz, $CDCl_3$) δ (ppm) –69.1; ESI-HRMS: calcd. for $C_{22}H_{18}F_3NO + Na^+$ 392.1238, found 392.1237.

4. Asymmetric reaction on a 1.0 mmol scale

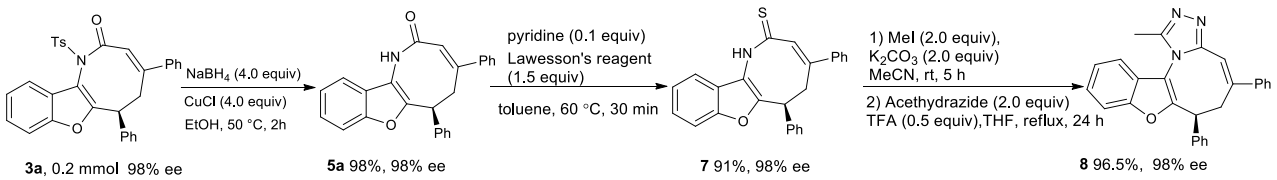


To a solution of cyclobutenone **1a** (216 mg, 1.5 mmol, 1.5 equiv), catalyst **C6** (78 mg, 10 mol%) and 4 Å MS (1000 mg) in toluene (10.0 mL) was added 1-azadiene **2a** (375 mg, 1 mmol, 1.0 equiv). The mixture was stirred at 50 ℃ for 60 h. After completion, the pure product **3a** (519.8 mg) was obtained by flash chromatography on silica gel (EtOAc/petroleum ether = 1/17) in 99% yield and 98% ee.

5. Transformations of product 3a



To a solution of **3a** (51.9 mg, 0.1 mmol, 1.0 equiv) in MeOH (1.0 mL) was added Pd/C (15 wt%). The mixture was stirred at 45 ℃ for 24 h under H_2 (3 MPa), then MeOH was evaporated under reduced pressure and the resulting was purified by flash chromatography on silica gel (EtOAc/petroleum ether = 1/20) to give product **6**: 50.1 mg, 96% yield; white solid, mp 201–202 ℃; $[\alpha]_D^{25}$ = +234.4 (*c* = 0.25 in $CHCl_3$); >19:1 dr; 98% ee, determined by HPLC analysis [Chiralpak AD, *n*-hexane/*i*-PrOH = 60/40, 1.0 mL min^{-1}, λ = 254 nm, t (major) = 10.20 min, t (minor) = 19.69 min]; ^{1}H NMR (400 MHz, $CDCl_3$): δ (ppm) 8.11 (d, *J* = 8.0 Hz, 2H), 7.80–7.74 (m, 1H), 7.45–7.40 (m, 1H), 7.39–7.33 (m, 3H), 7.33–7.26 (m, 6H), 7.23–7.19 (m, 1H), 7.13–7.01 (m, 4H), 4.16 (dd, *J* = 13.6, 3.6 Hz, 1H), 3.52–3.42 (m, 1H), 3.19 (t, *J* = 12.4 Hz, 1H), 2.59–2.47 (m, 2H), 2.44 (s, 3H), 2.00 (dt, *J* = 15.2, 3.6 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$): δ (ppm) 172.4, 154.6, 153.3, 145.5, 141.6, 141.3, 135.2, 130.1, 129.3, 128.84, 128.81, 127.4, 127.2, 127.1, 126.6, 126.2, 125.3, 123.7, 120.1, 117.9, 111.6, 41.4, 40.9, 37.8, 37.0, 21.7; ESI-HRMS: calcd. for $C_{32}H_{27}NO_4S$ +Na^+ 418.1242, found 418.1243.



To a solution of **3a** (103.8 mg, 0.2 mmol, 1.0 equiv) in EtOH (2.0 mL) was added CuCl (79.0 mg, 0.8 mmol, 4.0 equiv), and $NaBH_4$ (30.0 mg, 0.8 mmol, 4.0 equiv) was added in one portion. The mixture was stirred at 50 ℃ for 2 h. After completion (determined by TLC analysis), it was quenched with water (3.0 mL). Then EtOH was evaporated under reduced pressure and the resulting aqueous phase was extracted with DCM (3 × 5 mL). The combined organic layers were dried (Na_2SO_4) and evaporated. The crude was purified by flash chromatography on silica gel (EtOAc/petroleum ether = 1/6) to give product **5a**: 72.3 mg, white solid, 98% yield, mp 101–103 ℃; $[\alpha]_D^{25}$ = –53.3 (*c* = 0.3 in $CHCl_3$); 98% ee, determined by HPLC analysis [Chiralpak IB, *n*-hexane/*i*-PrOH = 95/5, 1.0 mL min^{-1}, λ = 254 nm, t (major) = 16.03 min, t (minor) = 18.65 min]; ^{1}H NMR (400 MHz, $CDCl_3$): δ (ppm) 8.34 (s, 1H), 7.67–7.60 (m, 1H), 7.54–7.47 (m, 2H), 7.43–7.37 (m, 3H), 7.31–7.34 (m, 1H), 7.28–7.31 (m, 1H), 7.25–7.28 (m, 3H), 7.20–7.25 (m, 2H), 7.24–7.22 (m, 1H), 6.31 (s, 1H), 4.32 (dd, *J* = 13.6, 4.0 Hz, 1H), 3.70 (t, *J* = 13.6 Hz, 1H), 3.22–3.02 (m, 1H); ^{13}C NMR (100 MHz, $CDCl_3$): δ (ppm) 171.3, 152.5, 150.4, 147.3, 141.6, 138.4, 129.2, 129.0, 128.9, 127.4, 127.3, 126.3, 126.0, 124.9, 123.0, 120.2, 118.0, 116.5, 111.3, 43.7, 37.2; ESI-HRMS: calcd. for $C_{25}H_{19}NO_2$ + Na^+388.1313, found 388.1304. (*Both excess $NaBH_4$ and CuCl are important to the effective N-detosylation process*)

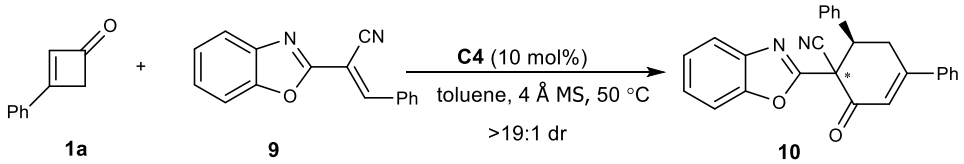
5a (72.3 mg, 0.198 mmol, 1.0 equiv) was dissolved in toluene (2.0 mL), then the Lawesson's reagent (120 mg, 0.297 mmol, 1.5 equiv) and pyridine (2.0 μL, 0.198 mmol, 0.1 equiv) were added. Then the mixture was stirred at 60 ℃ for 30 min. After completion (determined by TLC analysis), it was purified by flash chromatography on silica gel (EtOAc/petroleum ether = 1/20) to give product **7**: 68.4 mg, yellow solid, 91% yield, mp 105–107 ℃; $[\alpha]_D^{25}$ = –150.36 (*c* = 0.2 in $CHCl_3$); 98% ee, determined by HPLC analysis [Chiralpak ID, *n*-hexane/*i*-PrOH = 90/10, 1.0 mL min^{-1}, λ = 254 nm, t (minor) = 10.11 min, t (major) = 11.01 min]; ^{1}H NMR (400 MHz, $CDCl_3$): δ (ppm) 9.38 (s, 1H), 7.61 (dd, *J* = 6.8, 2.8 Hz, 1H), 7.52 (dd, *J* = 6.8, 2.8 Hz, 2H), 7.45–7.36 (m, 3H), 7.34–7.27 (m, 6H), 7.24–7.19 (m, 2H), 6.73 (s, 1H), 4.28 (dd, *J* = 13.6, 4.2 Hz, 1H), 3.47 (t, *J* = 13.6 Hz, 1H), 3.11 (dd, *J* = 13.6, 4.2 Hz, 1H);^{13}C NMR (100 MHz, $CDCl_3$): δ (ppm) 200.7, 152.3, 152.2, 142.8, 141.2, 138.0, 129.3, 129.0, 128.9, 127.6, 127.2, 126.9, 126.4, 125.4, 124.9, 123.4, 118.4, 117.9, 111.5, 43.3, 36.0; ESI-HRMS: calcd. for $C_{25}H_{19}NOS$ + Na^+ 404.1085, found 404.1091.

7 (68.4 mg, 0.179 mmol, 1.0 equiv) was dissolved in MeCN (2.0 mL), then MeI (30.0 μL, 0.359 mmol, 2.0 equiv) and K_2CO_3 (37.2 mg, 0.269 mmol, 1.5 equiv) were added. The mixture was stirred at room temperature until completion (determined by TLC analysis), and it was purified by flash chromatography on silica gel (EtOAc/petroleum ether = 1/50) to give methylation product. The product was dissolved in THF (2.0 mL), then acethydrazide (26.6 mg, 0.359 mmol, 2.0 equiv) and TFA (6.7 μL, 0.089 mmol, 0.5 equiv) were added. The reaction was stirred at 70 ℃ for 24 h. Then the mixture was purified by flash chromatography on silica gel (from EtOAc/petroleum ether = 1/3 to DCM/MeOH = 80/1) to give product **8**: 69.9 mg, white solid, 96% yield, mp 104–106 ℃; $[\alpha]_D^{25}$ = +490.4 (*c* = 0.25 in $CHCl_3$); 98% ee, determined by HPLC analysis [Chiralpak AD, *n*-hexane/*i*-

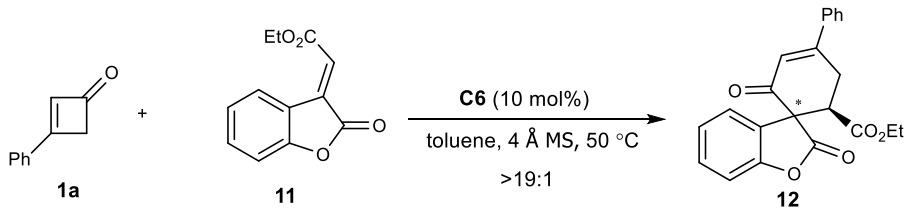
PrOH = 80/20, 1.0 mL min^{-1}, λ = 254 nm, t (minor) = 13.66 min, t (major) = 17.68 min]; ^{1}H NMR (400 MHz, $CDCl_3$): δ (ppm) 7.56–7.50 (m, 2H), 7.46–7.39 (m, 3H), 7.37–7.30 (m, 4H), 7.30–7.27 (m, 2H), 7.23 (dd, *J* = 7.2, 1.6 Hz, 1H), 7.20–7.16 (m, 2H), 6.90 (s, 1H), 4.42 (dd, *J* = 13.2, 5.4 Hz, 1H), 3.16–3.00 (m, 2H), 2.64 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ (ppm) 153.9, 153.0, 151.8, 149.4, 140.7, 138.0, 129.4, 129.2, 129.0, 127.8, 127.0, 126.3, 125.6, 124.2, 123.8, 118.5, 114.1, 113.4, 112.1, 44.0, 36.8, 12.0; ESI-HRMS: calcd. for $C_{27}H_{21}N_3O$ + Na^+ 404.1763, found 404.1758.

6. More screening studies on diverse cyclobutenones and 4C-type substrates

[4+2] annulations



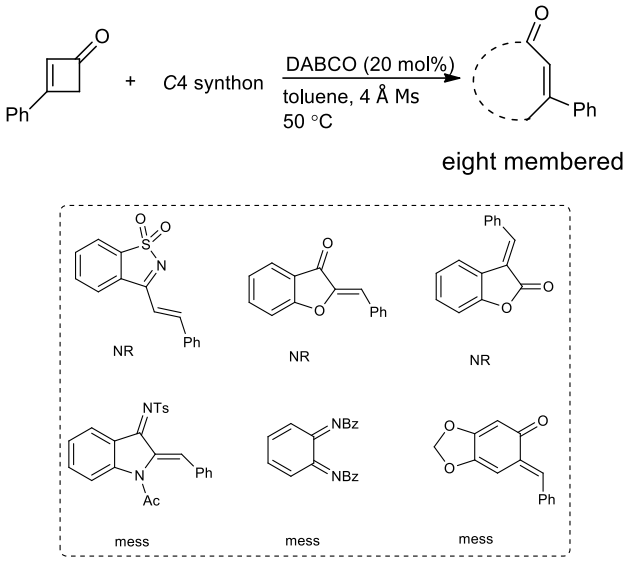
To a solution of cyclobutenone **1a** (21.6 mg, 0.15 mmol, 1.5 equiv), catalyst **C4** (8.6 mg, 10 mol%) and 4 Å MS (100.0 mg) in toluene (1.0 mL) was added 1-azadiene-type substrate **9** (24.6 mg, 0.1 mmol, 1.0 equiv). The mixture was stirred at 50 ℃ for 48 h. After completion, it was purified by flash chromatography on silica gel (EtOAc/petroleum ether = 1/10) to give the [4 + 2] product **10**: 36.6 mg, 94% yield, white solid; mp 163–164 ℃; $[\alpha]_D^{25}$ = –82.4 (*c* = 0.25 in $CHCl_3$); >19:1 dr; 80% ee, determined by HPLC analysis [Chiralpak IA, *n*-hexane/*i*-PrOH = 90/10, 1.0 mL/min, λ = 254 nm, t (minor) = 20.93 min, t (major) = 23.33 min]; ^{1}H NMR (400 MHz, $CDCl_3$): δ (ppm) 7.69–7.65 (m, 1H), 7.62 (dd, *J* = 8.0, 1.6 Hz, 2H), 7.50–7.46 (m, 3H), 7.46–7.42 (m, 3H), 7.32–7.26 (m, 2H), 7.24–7.18 (m, 3H), 6.72 (d, *J* = 2.2 Hz, 1H), 4.37 (dd, *J* = 11.6, 4.0 Hz, 1H), 3.70 (ddd, *J* = 18.8, 11.6, 2.4 Hz, 1H), 3.31 (dd, *J* = 18.8, 4.0 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$): δ (ppm) 185.1, 161.5, 158.2, 151.0, 140.5, 136.8, 136.7, 131.5, 129.2, 129.0, 128.8, 127.9, 126.5, 125.7, 124.8, 121.5, 120.7, 113.6, 110.8, 56.2, 47.8, 33.0; ESI-HRMS: calcd. for $C_{26}H_{18}N_2O_2$ + Na^+ 413.1266, found 413.1265.



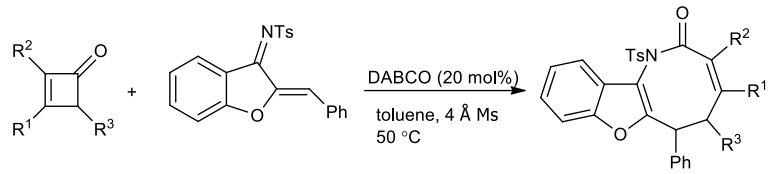
To a solution of cyclobutenone **1a** (21.6 mg, 0.15 mmol, 1.5 equiv), catalyst **C6** (7.8 mg, 10 mol%) and 4 Å MS (100.0 mg) in toluene (1.0 mL) was added 1-oxadiene-type substrate **11** (21.8 mg, 0.1 mmol, 1.0 equiv). The mixture was stirred at 50 ℃ for 48 h. After completion, it was purified by flash chromatography on silica gel (EtOAc/petroleum ether = 1/6) to give the [4 + 2] product **12**: 35.9 mg, 99% yield, faint yellow solid; mp 147–148 ℃; $[\alpha]_D^{25}$ = +239.4 (*c* = 0.25 in $CHCl_3$); >19:1 dr; 73% ee, determined by HPLC analysis [Chiralpak AD, *n*-hexane/*i*-PrOH = 80/20, 1.0 mL/min, λ =

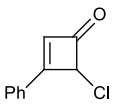
254 nm, t (major) = 21.68 min, t (minor) = 23.91 min]; ^{1}H NMR (400 MHz, $CDCl_3$): δ (ppm) 7.79–7.67 (m, 2H), 7.57–7.46 (m, 3H), 7.38–7.32 (m, 1H), 7.23–7.18 (m, 1H), 7.15–7.02 (m, 2H), 6.62 (d, *J* = 2.4, 1H), 4.12–3.92 (m, 3H), 3.56–3.47 (m, 1H), 3.40 (ddd, *J* = 19.4, 11.6, 2.4 Hz, 1H), 1.05 (t, *J* = 7.2 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ (ppm) 190.9, 174.4, 169.4, 158.1, 154.2, 136.9, 131.4, 130.2, 129.2, 126.4, 125.2, 124.2, 123.3, 122.8, 111.6, 61.9, 59.9, 44.8, 27.0, 13.5; ESI-HRMS: calcd. for $C_{22}H_{18}O_5$ + H^+ 363.1232, found 363.1237.

To further expand the substrate scope for [4 + 4] annulation reaction protocol, more 4C synthons were tested with cyclobutenone **1a** under the catalysis of DABCO. As exemplified below, the following electron-deficient dienes showed low reactivity.

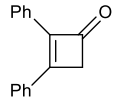


In addition, we explored other types cyclobutenones for the [4 + 4] annulation reactions with 1-azadiene **2a** under the catalysis of DABCO. Unfortunately, the cyclobutenones bearing a substituent at 2- or 4-position were inert probably due to the steric effect. Besides, the benzocyclobutenones were not reactive either.

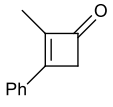

R2
O
R1
R3
+
NTs
O
Ph
DABCO (20 mol%)
toluene, 4 Å Ms
50 °C
TsN
O
R2
R1
O
R3
Ph


O
Ph
Cl

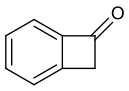
NR


Ph
O
Ph

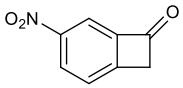
NR


O
Ph

NR

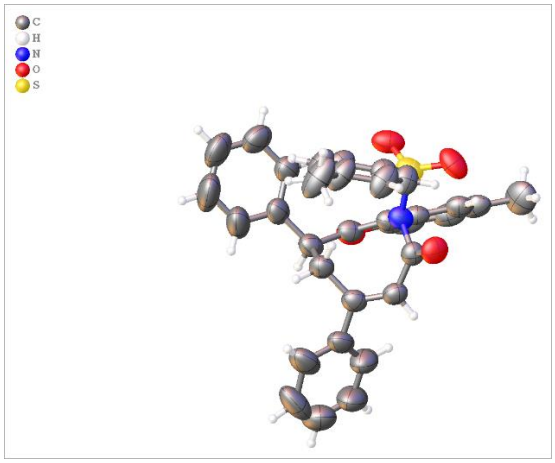

O

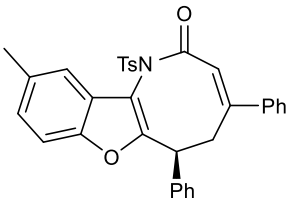
NR


O2N
O

NR

7. Crystal data and structural refinement for enantiopure 3y

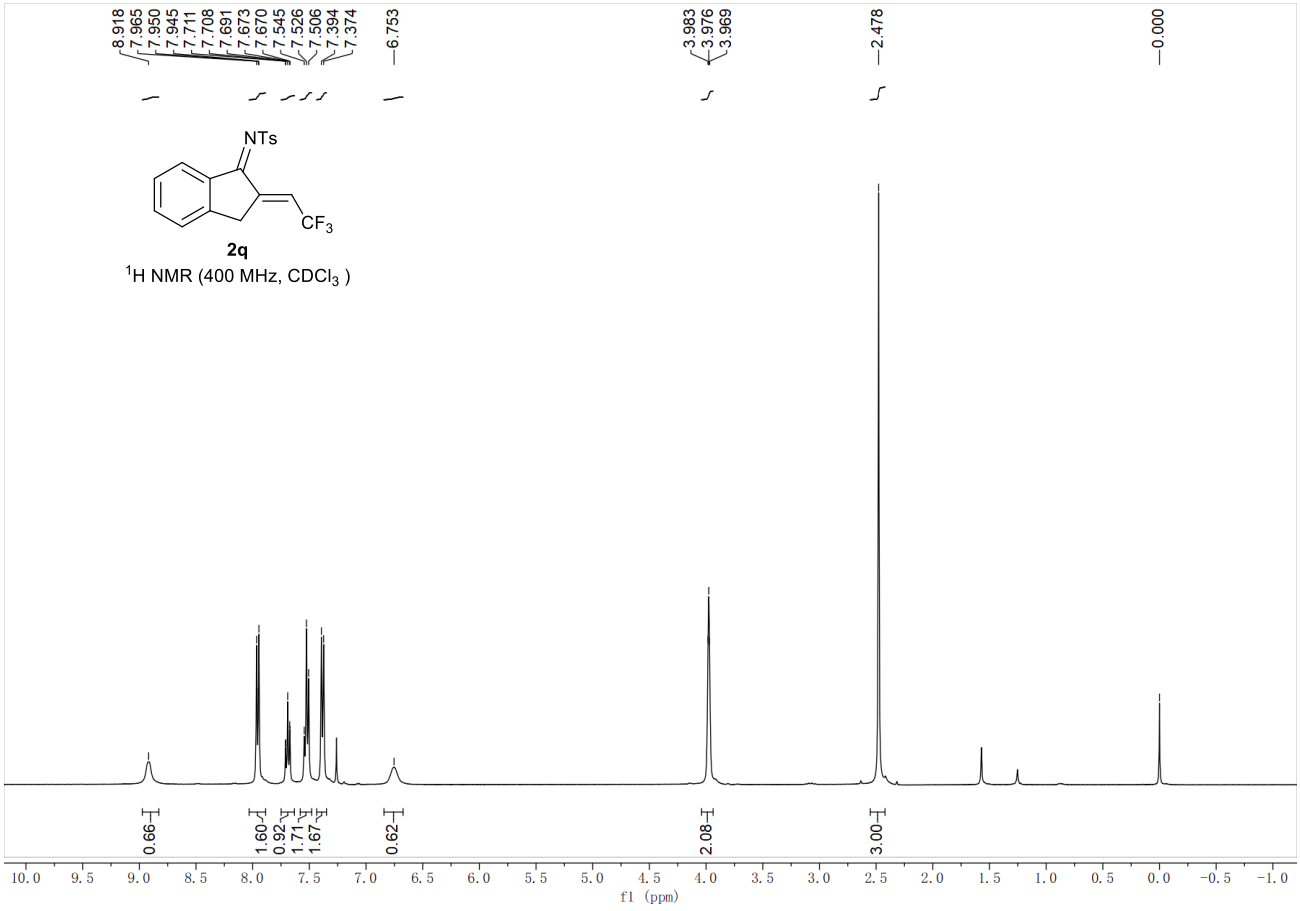


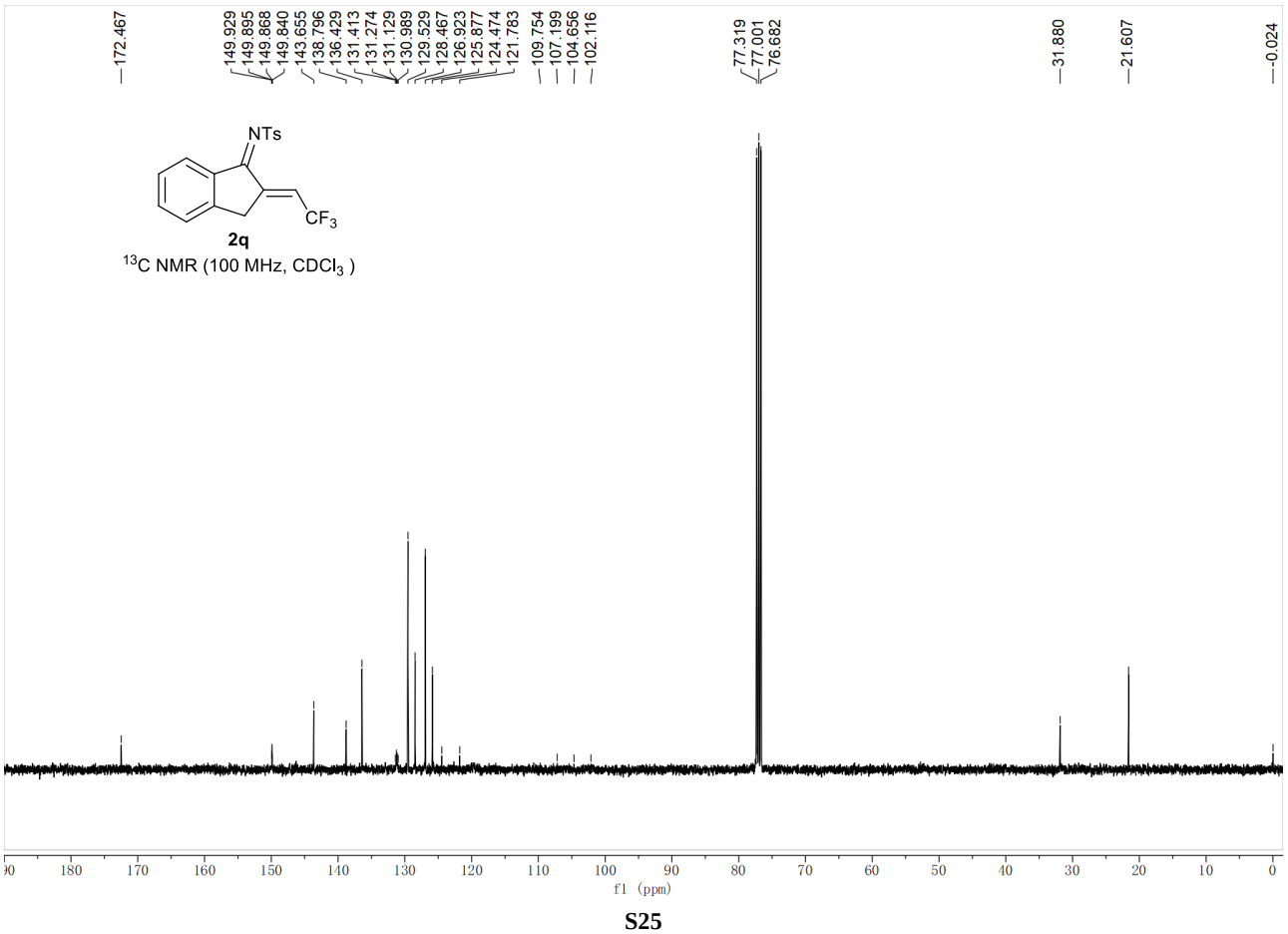


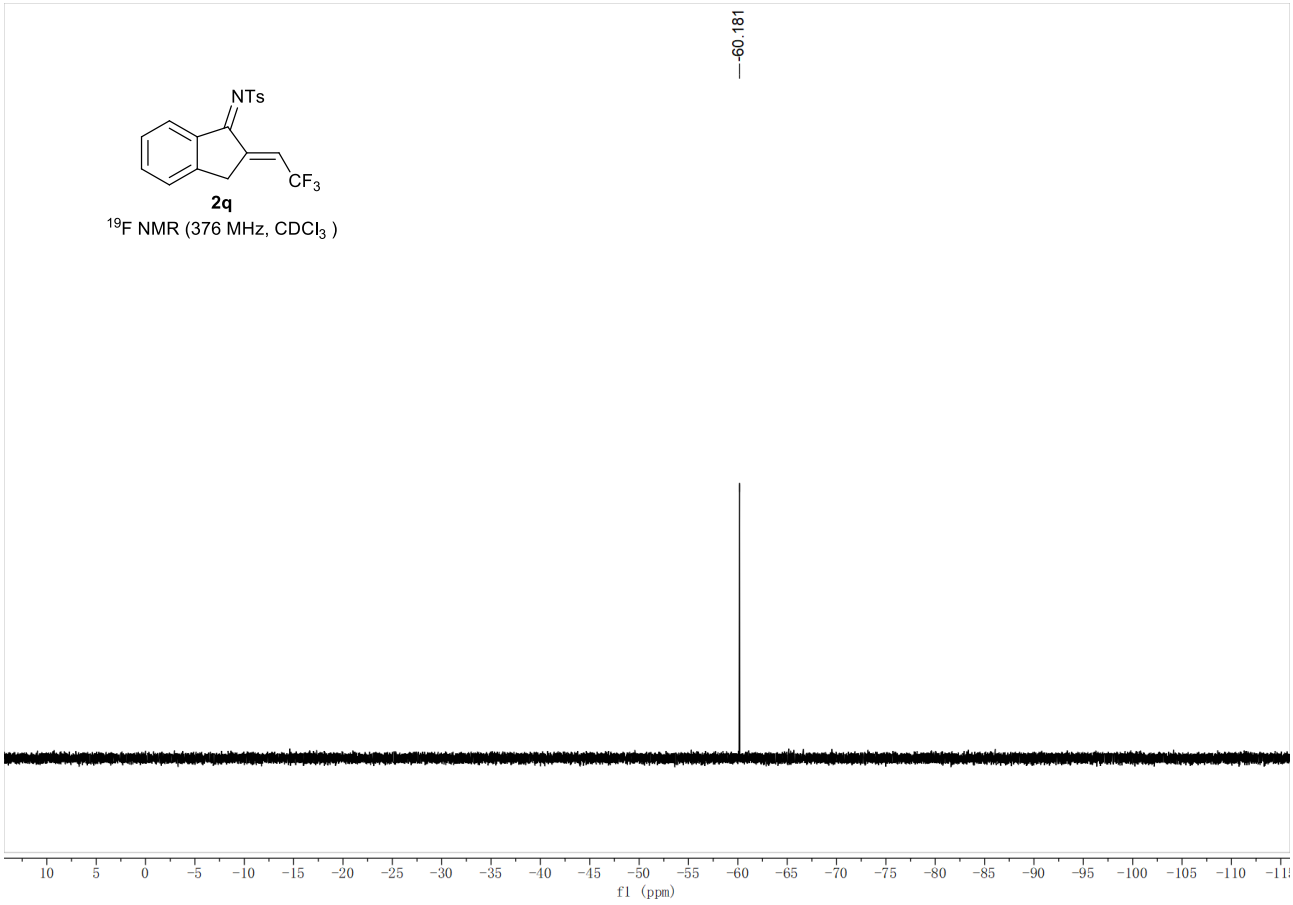
3y (CCDC 1997811)

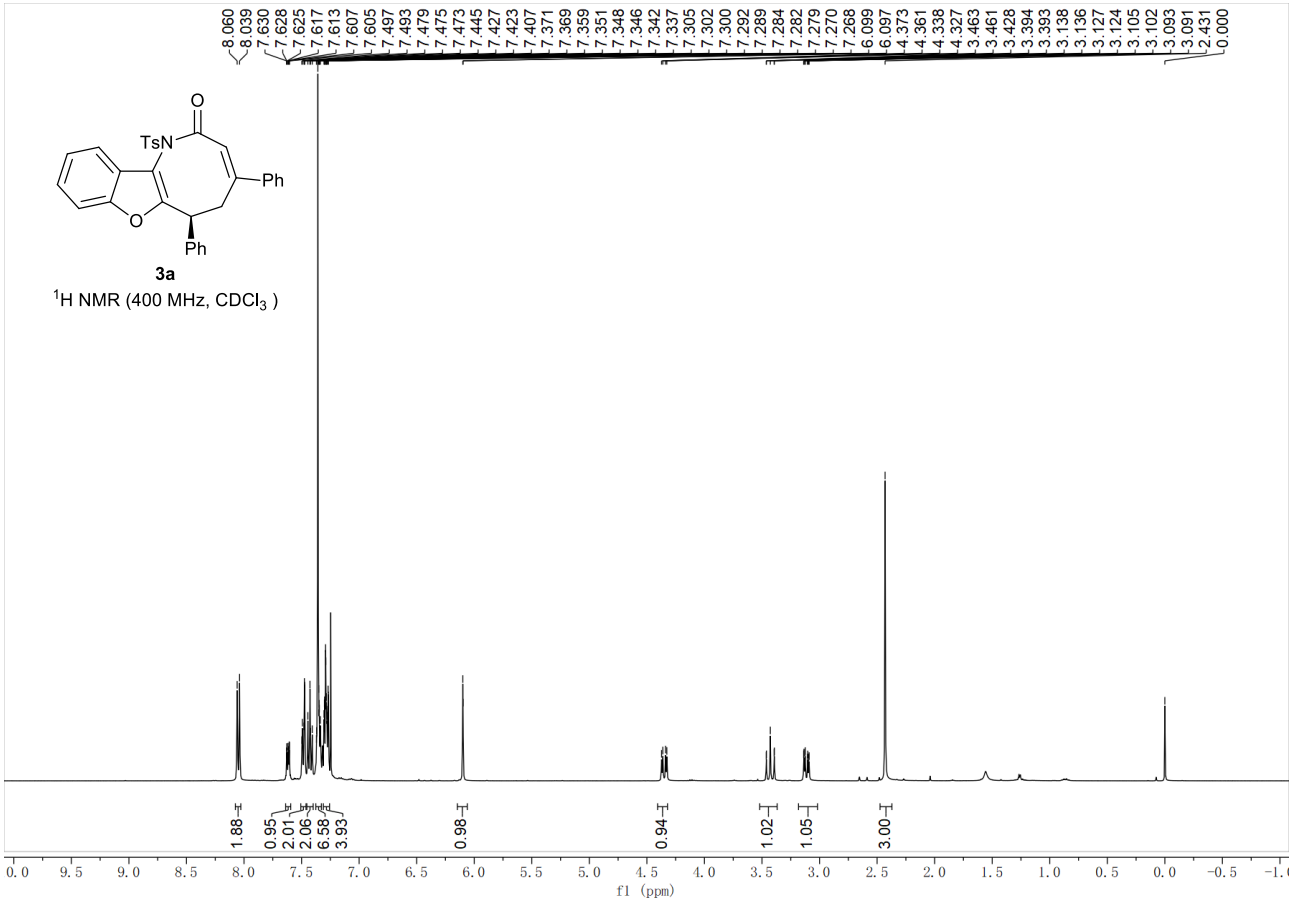
Identification code	**3y**
Empirical formula	$C_{33}H_{27}NO_4S$
Formula weight	533.61
Temperature/K	293.3(7)
Crystal system	trigonal
Space group	R3
a/Å	27.6807(5)
b/Å	27.6807(5)
c/Å	9.6164(3)
α/°	90
β/°	90
γ/°	120
Volume/Å^3	6381.2(3)
Z	9
ρ_{calc}g/cm^3	1.250
μ/mm^{-1}	1.318
F(000)	2520.0
Crystal size/mm^3	0.6 × 0.35 × 0.35
Radiation	CuKα (λ = 1.54184)
2Θ range for data collection/°	9.91 to 143.366
Index ranges	-34 ≤ h ≤ 27, -32 ≤ k ≤ 33, -11 ≤ l ≤ 9
Reflections collected	13695
Independent reflections	4776 [R_{int} = 0.0309, R_{sigma} = 0.0272]
Data/restraints/parameters	4776/1/354
Goodness-of-fit on F^2	1.056
Final R indexes [I>=2σ (I)]	R_1 = 0.0507, wR_2 = 0.1402
Final R indexes [all data]	R_1 = 0.0527, wR_2 = 0.1448
Largest diff. peak/hole / e Å^{-3}	0.40/-0.22
Flack parameter	-0.009(14)

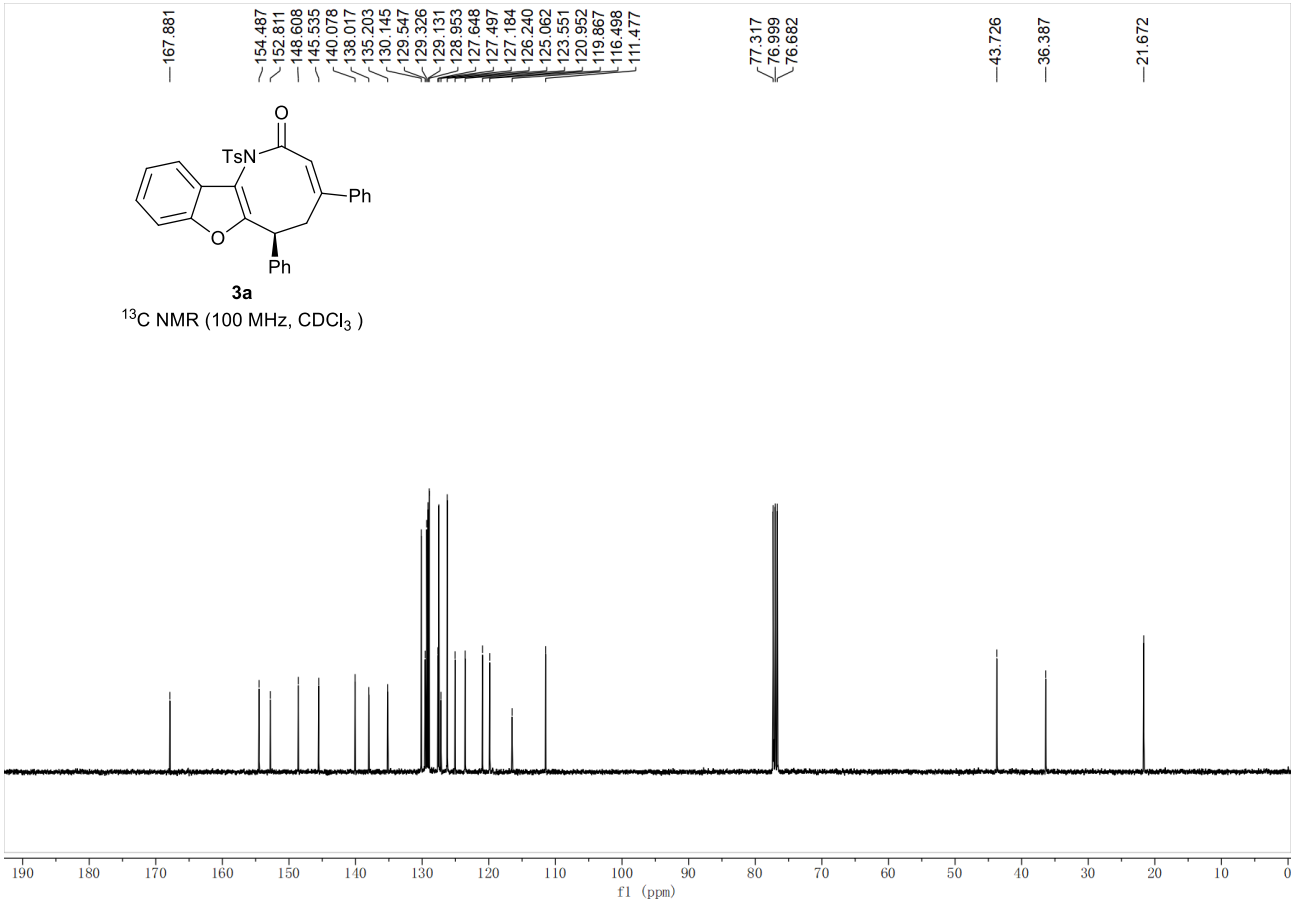
8. NMR spectra and HPLC chromatograms

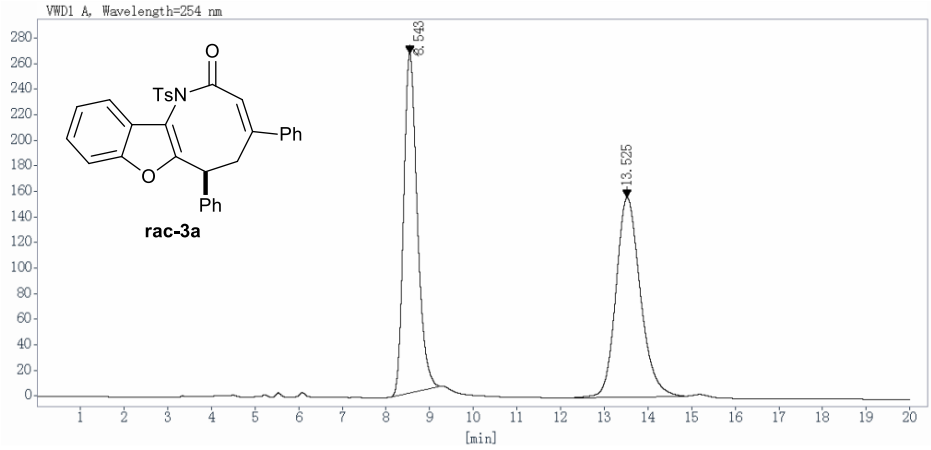




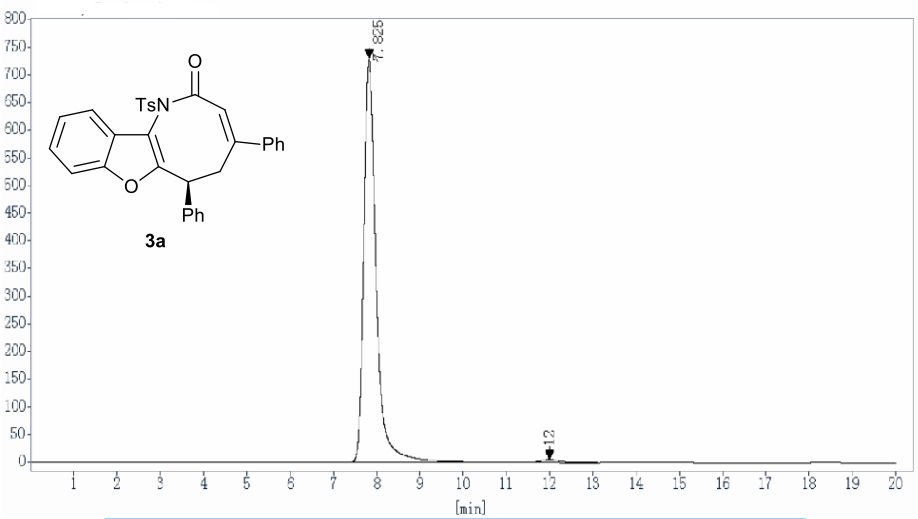

NTs
CF3
2q
19F NMR (376 MHz, CDCl3)
-60.181
10 5 0 -5 -10 -15 -20 -25 -30 -35 -40 -45 -50 -55 -60 -65 -70 -75 -80 -85 -90 -95 -100 -105 -110
f1 (ppm)


8.060
8.039
7.630
7.628
7.625
7.617
7.613
7.607
7.605
7.497
7.493
7.479
7.475
7.473
7.445
7.427
7.423
7.407
7.371
7.369
7.359
7.351
7.348
7.346
7.342
7.337
7.305
7.302
7.300
7.292
7.289
7.284
7.282
7.279
7.270
7.268
6.099
6.097
4.373
4.361
4.338
4.327
3.463
3.461
3.428
3.394
3.393
3.138
3.136
3.127
3.124
3.105
3.102
3.093
3.091
2.431
0.000
O
TsN
Ph
O
Ph
3a
1H NMR (400 MHz, CDCl3)
1.88
0.95
2.01
2.06
6.58
3.93
0.98
0.94
1.02
1.05
3.00
f1 (ppm)

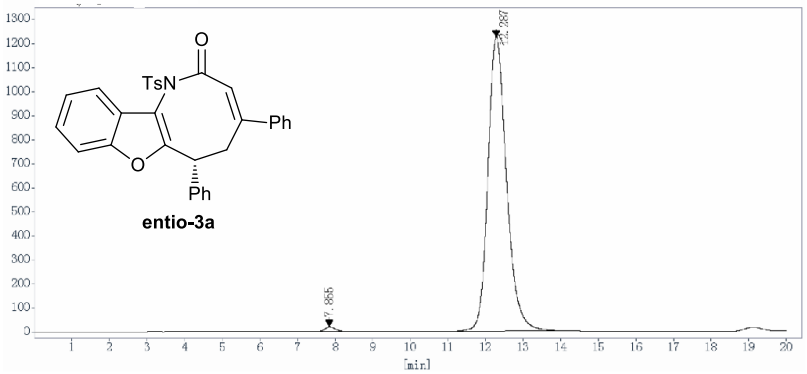

167.881
154.487
152.811
148.608
145.535
140.078
138.017
135.203
130.145
129.547
129.326
129.131
128.953
127.648
127.497
127.184
126.240
125.062
123.551
120.952
119.867
116.498
111.477
77.317
76.999
76.682
43.726
36.387
21.672
O
TsN
Ph
O
Ph
3a
13C NMR (100 MHz, CDCl3)
f1 (ppm)



Ret Time [min]	Peak Type	Width [min]	Height [mAU]	Area [mAU*s]	Area [%]
8.543	BB	0.33	265.6270	5728.5845	48.6382
13.525	BB	0.59	156.1209	6049.3687	51.3618
			Totals:	11777.9531	100.0000



Ret Time [min]	Peak Type	Width [min]	Height [mAU]	Area [mAU*s]	Area [%]
7.825	BV R	0.30	730.0637	14594.8477	98.8507
12.000	BB	0.49	5.2868	169.6904	1.1493
			Totals:	14764.5380	100.0000



Ret Time [min]	Peak Type	Width [min]	Height [mAU]	Area [mAU*s]	Area [%]
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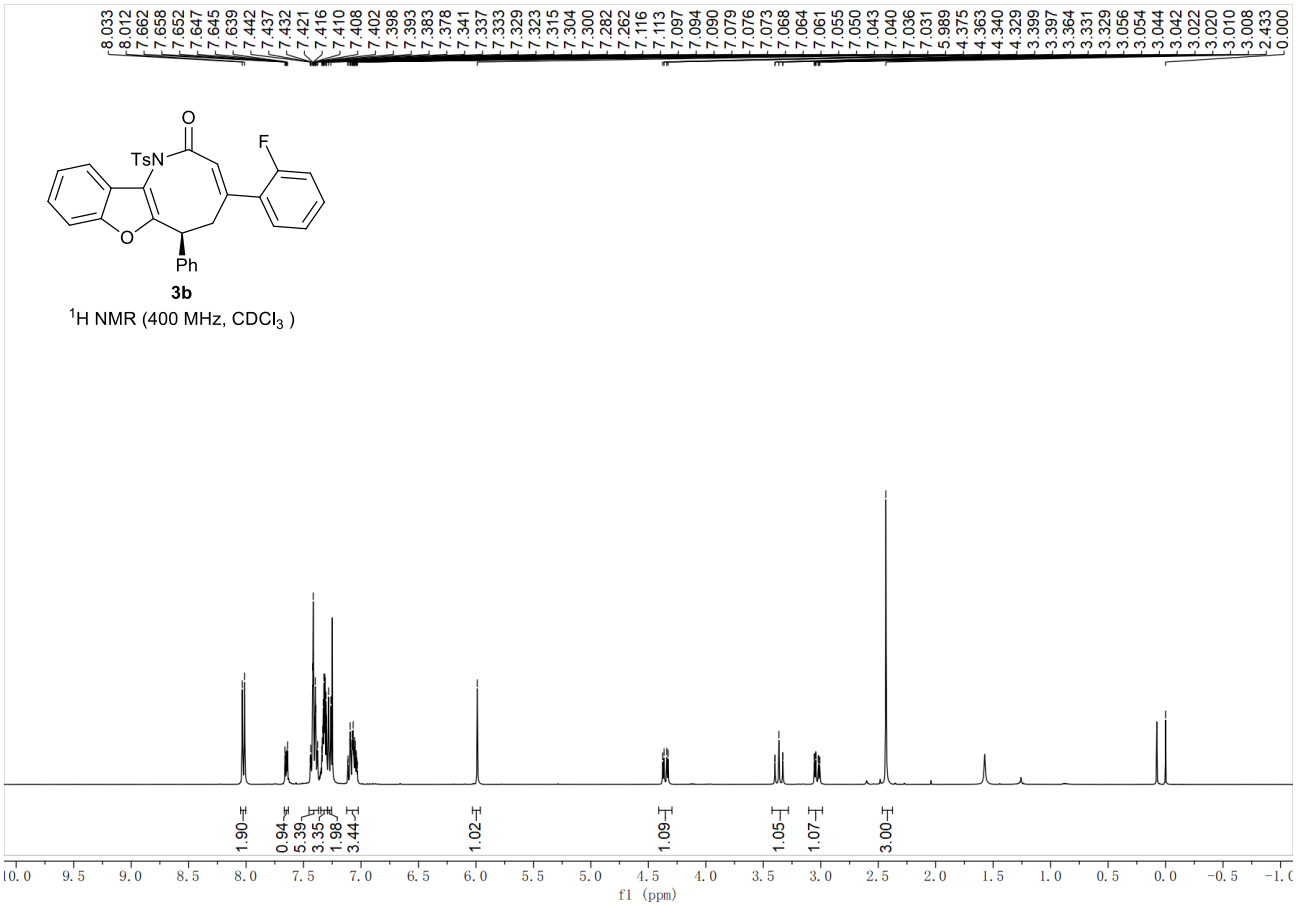
12.287	BB	0.53	1224.8676	42199.4766	99.1529
			Totals:	42560.0143	100.0000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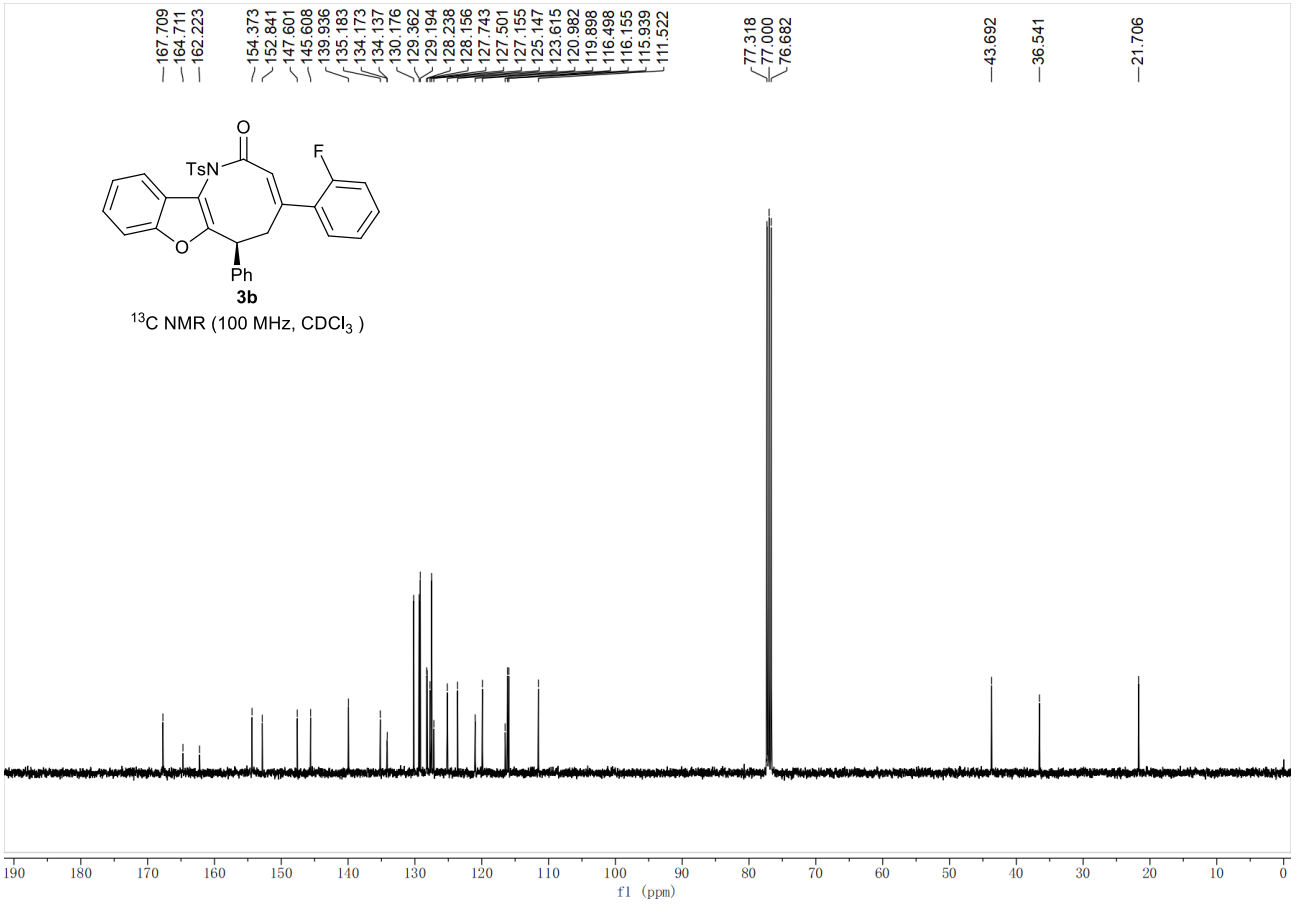
7.652
7.647
7.645
7.639
7.442
7.437
7.432
7.421
7.416
7.410
7.408
7.402
7.398
7.393
7.383
7.378
7.341
7.337
7.333
7.329
7.323
7.315
7.304
7.300
7.282
7.262
7.116
7.113
7.097
7.094
7.090
7.079
7.076
7.073
7.068
7.064
7.061
7.055
7.050
7.043
7.040
7.036
7.031
5.989
4.375
4.363
4.340
4.329
3.399
3.397
3.364
3.331
3.329
3.056
3.054
3.044
3.042
3.022
3.020
3.010
3.008
2.433
0.000
O
TsN
F
O
Ph
3b
1H NMR (400 MHz, CDCl3)
1.90
0.94
5.39
3.35
1.98
3.44
1.02
1.09
1.05
1.07
3.00
f1 (ppm)


167.709
164.711
162.223
154.373
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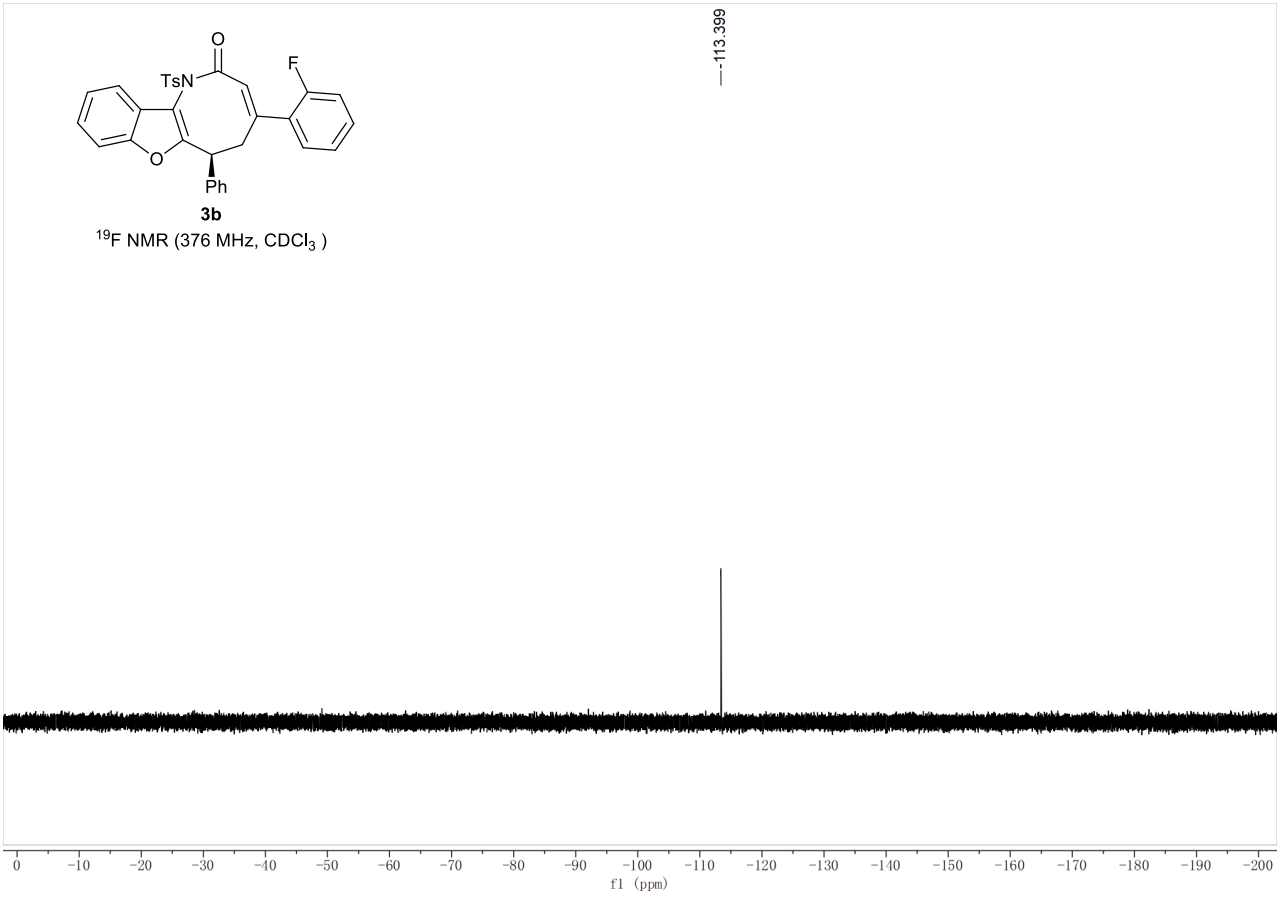
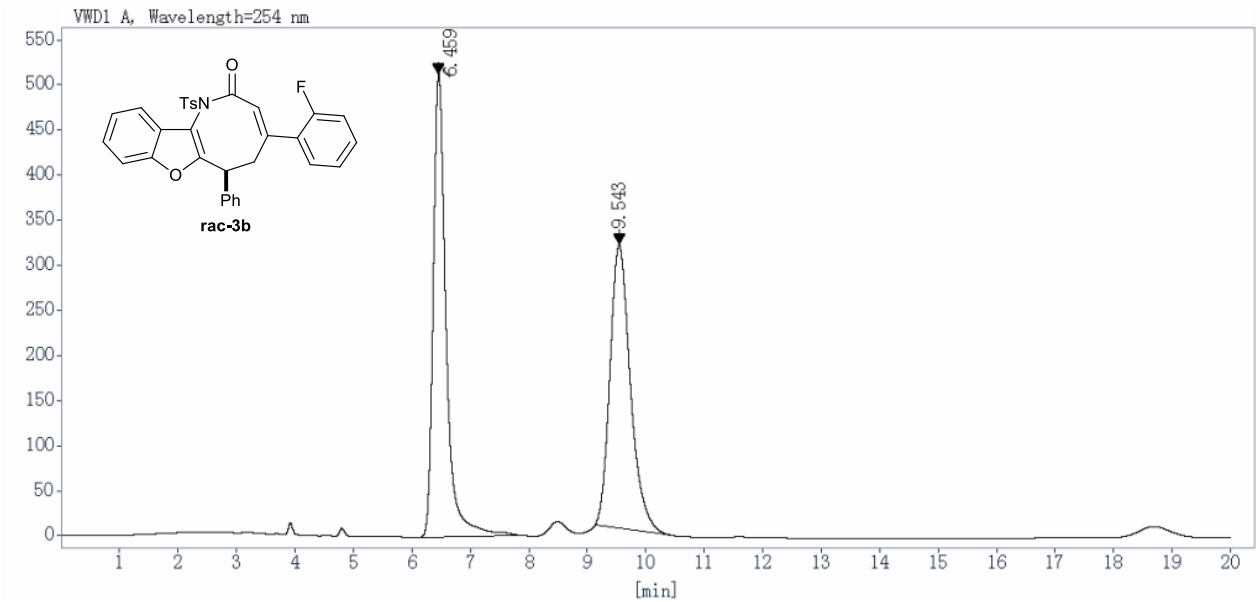
147.601
145.608
139.936
135.183
134.173
134.137
130.176
129.362
129.194
128.238
128.156
127.743
127.501
127.155
125.147
123.615
120.982
119.898
116.498
116.155
115.939
111.522
77.318
77.000
76.682
43.692
36.541
21.706
O
TsN
F
O
Ph
3b
13C NMR (100 MHz, CDCl3)
f1 (ppm)

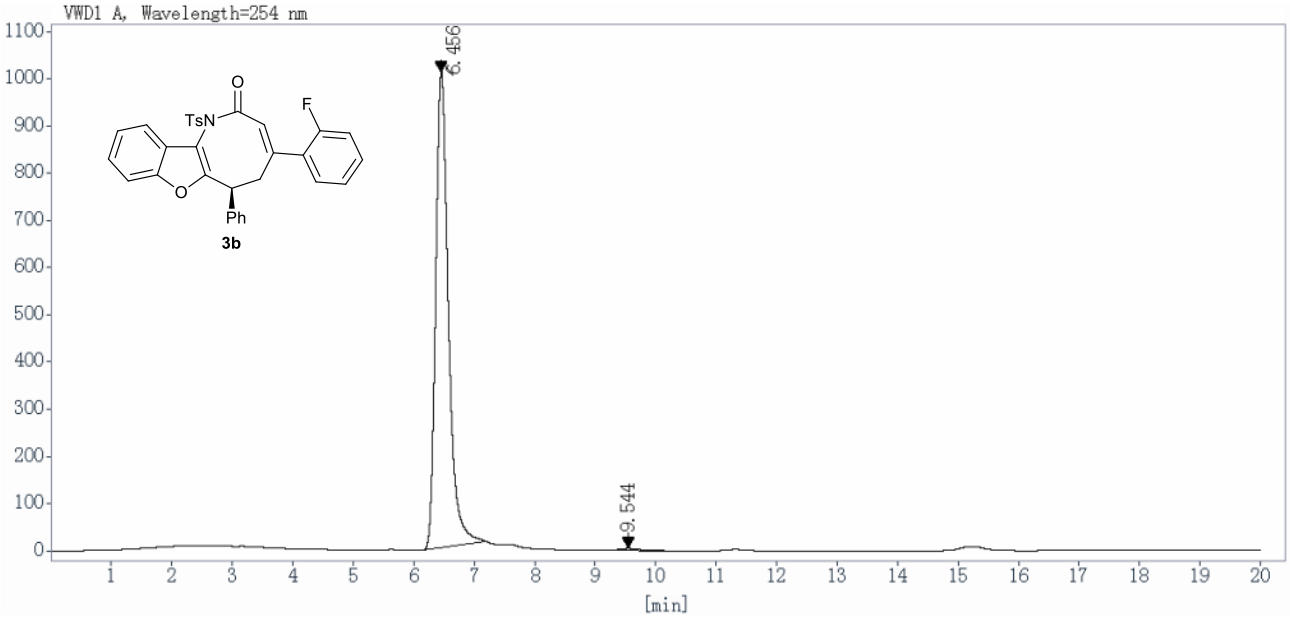


3b

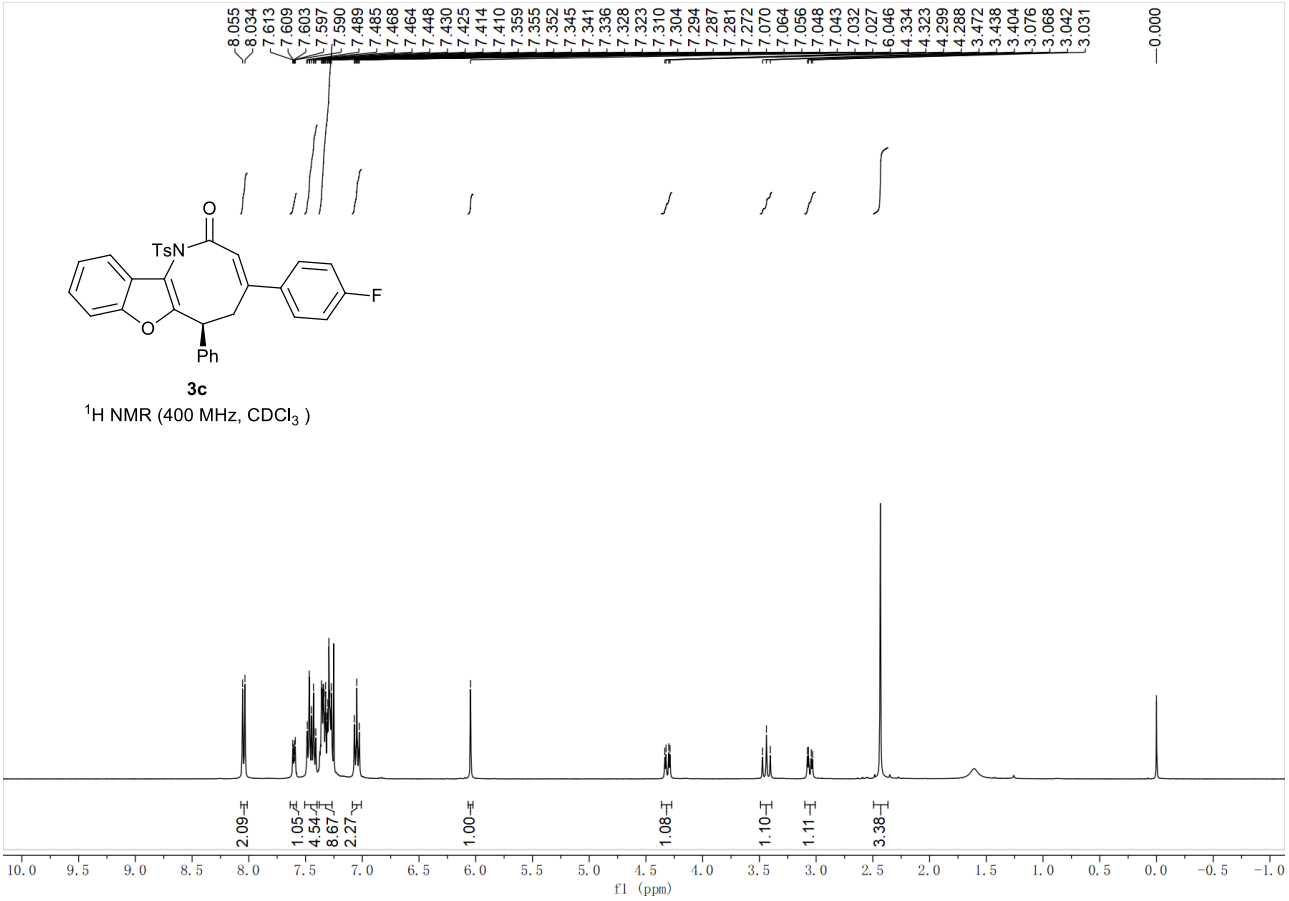
^{19}F NMR (376 MHz, $CDCl_3$)



Ret Time [min]	Peak Type	Width [min]	Height [mAU]	Area [mAU*s]	Area [%]
6.459	BBA	0.23	513.6871	7826.8584	50.6077
9.543	BB	0.37	314.5721	7638.8843	49.3923
			Totals:	15465.7427	100.0000

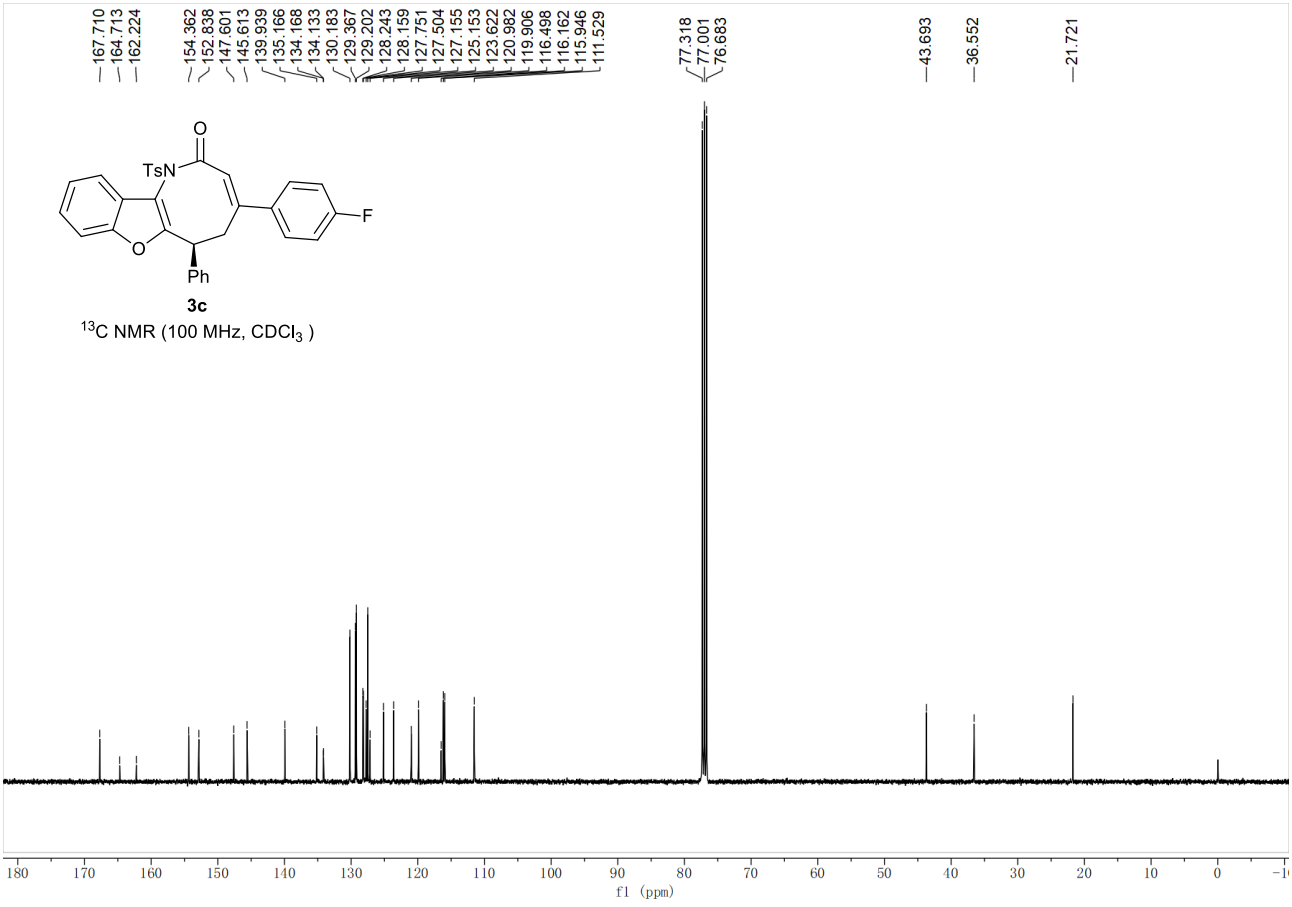


Ret Time [min]	Peak Type	Width [min]	Height [mAU]	Area [mAU*s]	Area [%]
6.456	BBA	0.22	1008.2946	14724.0850	99.2814
9.544	BBA	0.36	4.5328	106.5724	0.7186
			Totals:	14830.6574	100.0000



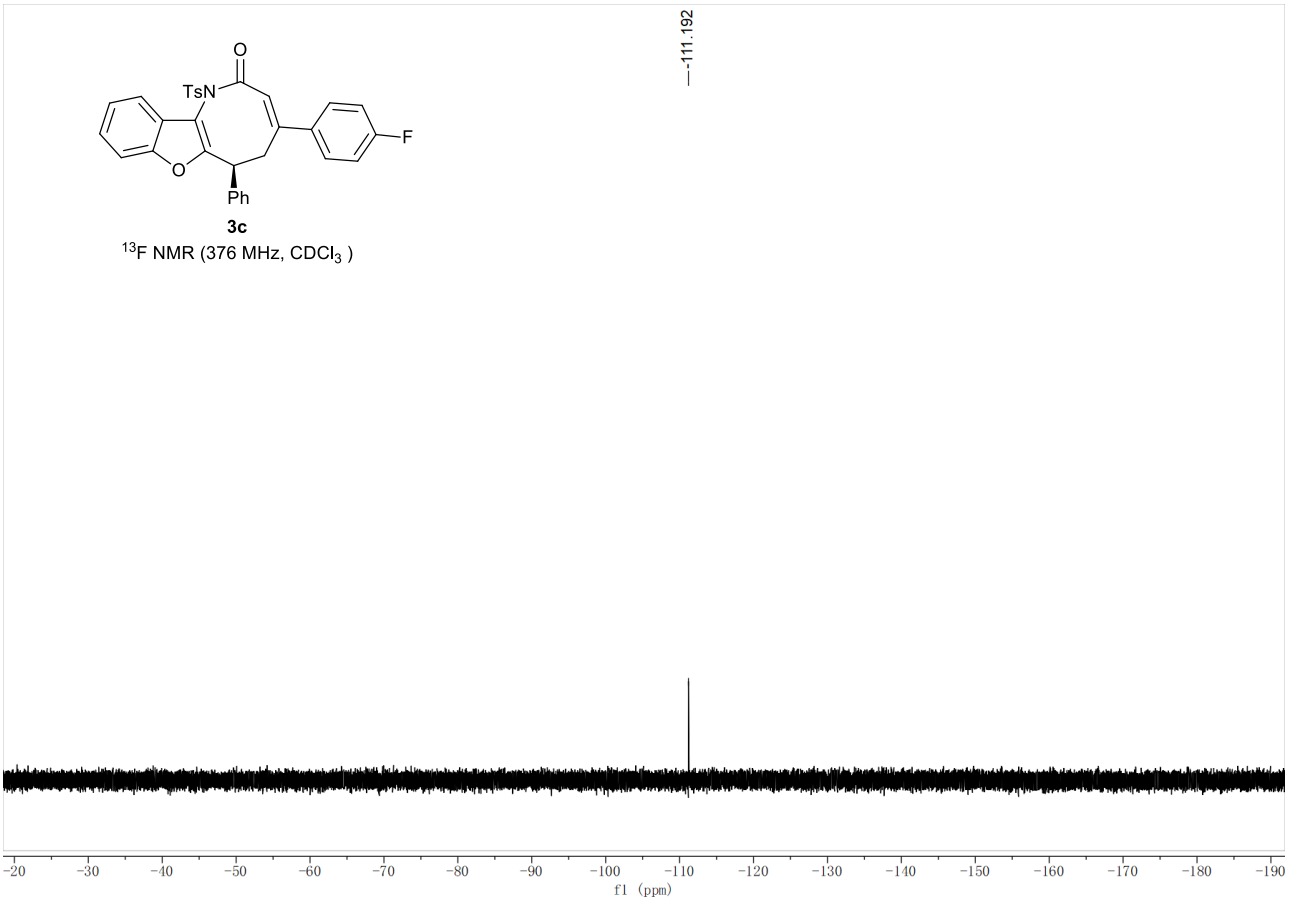
3c

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



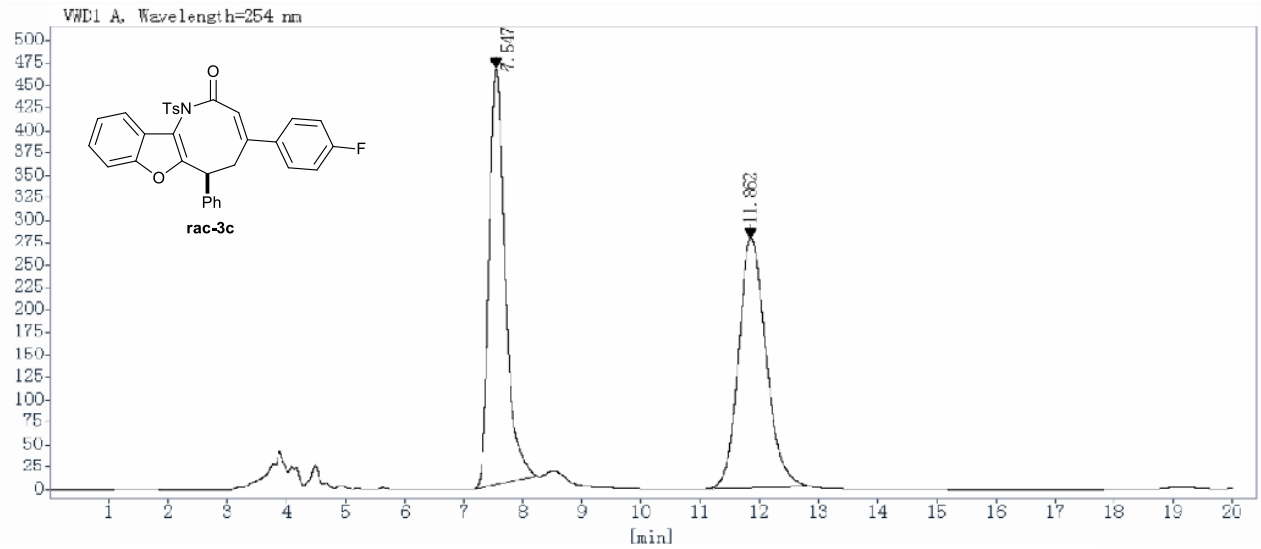
3c

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

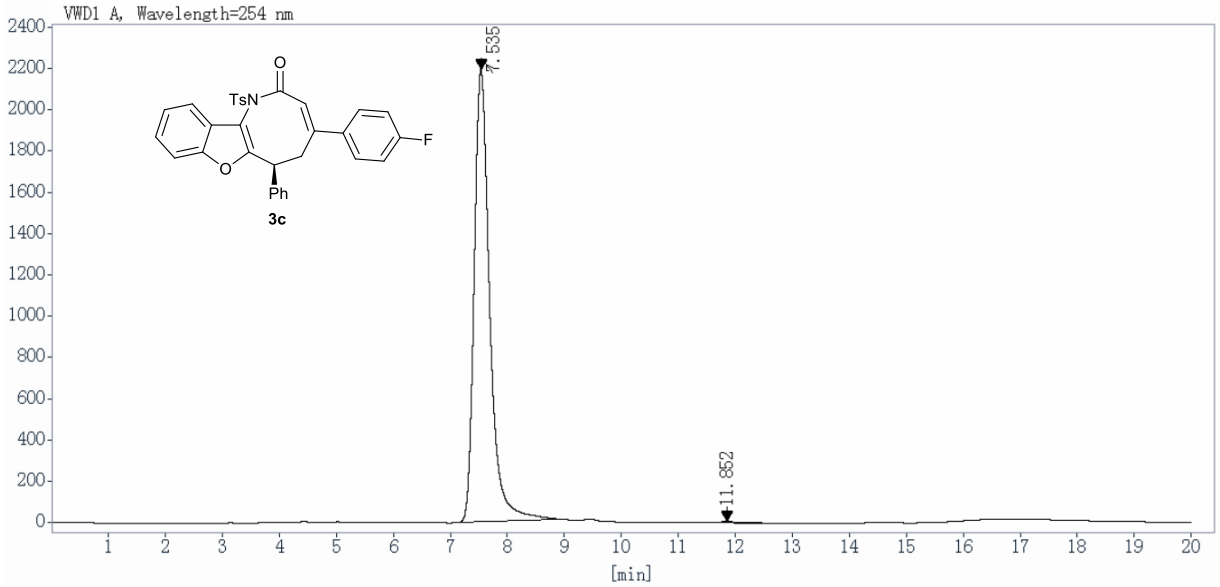


3c

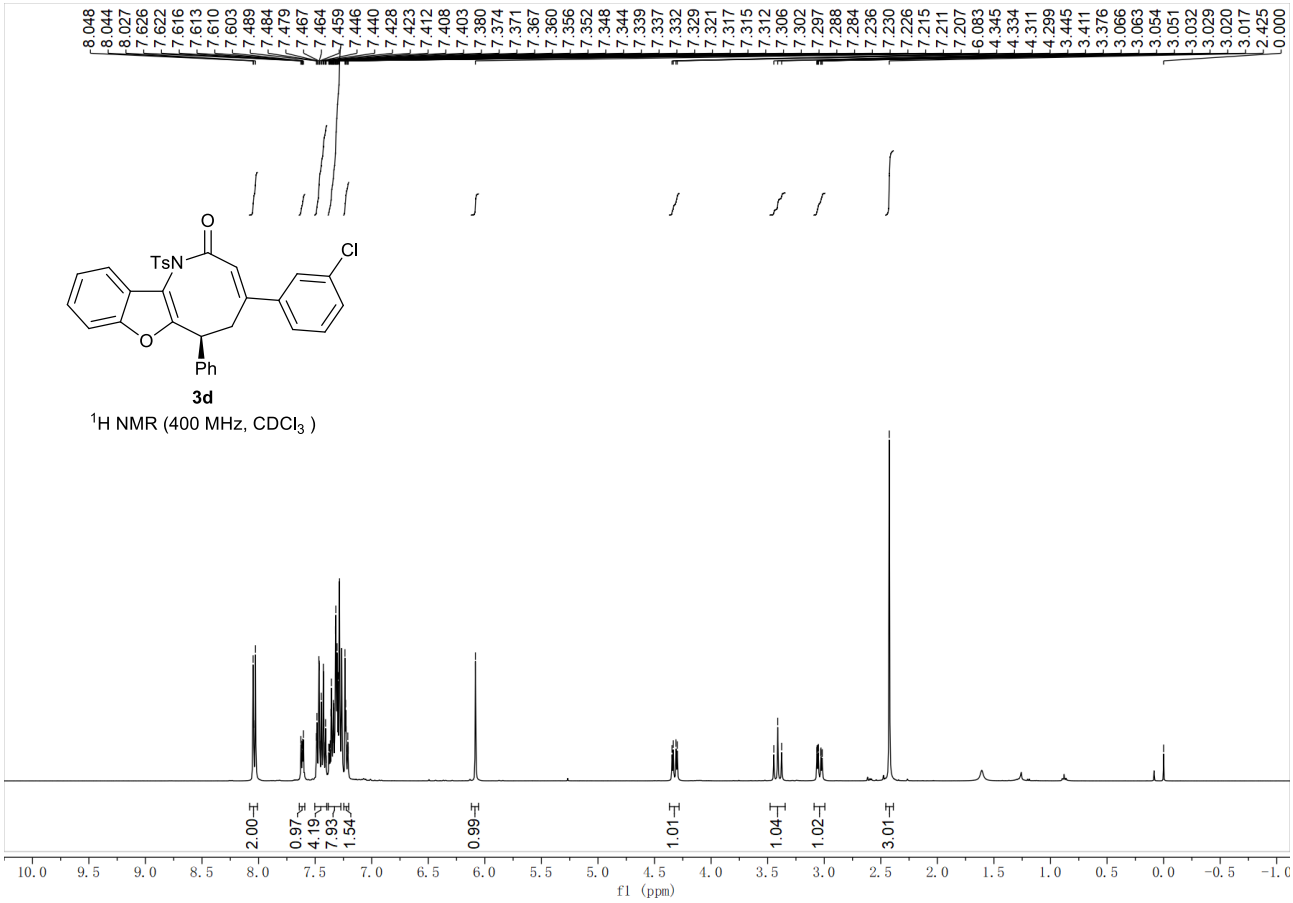
^{13}F NMR (376 MHz, $CDCl_3$)

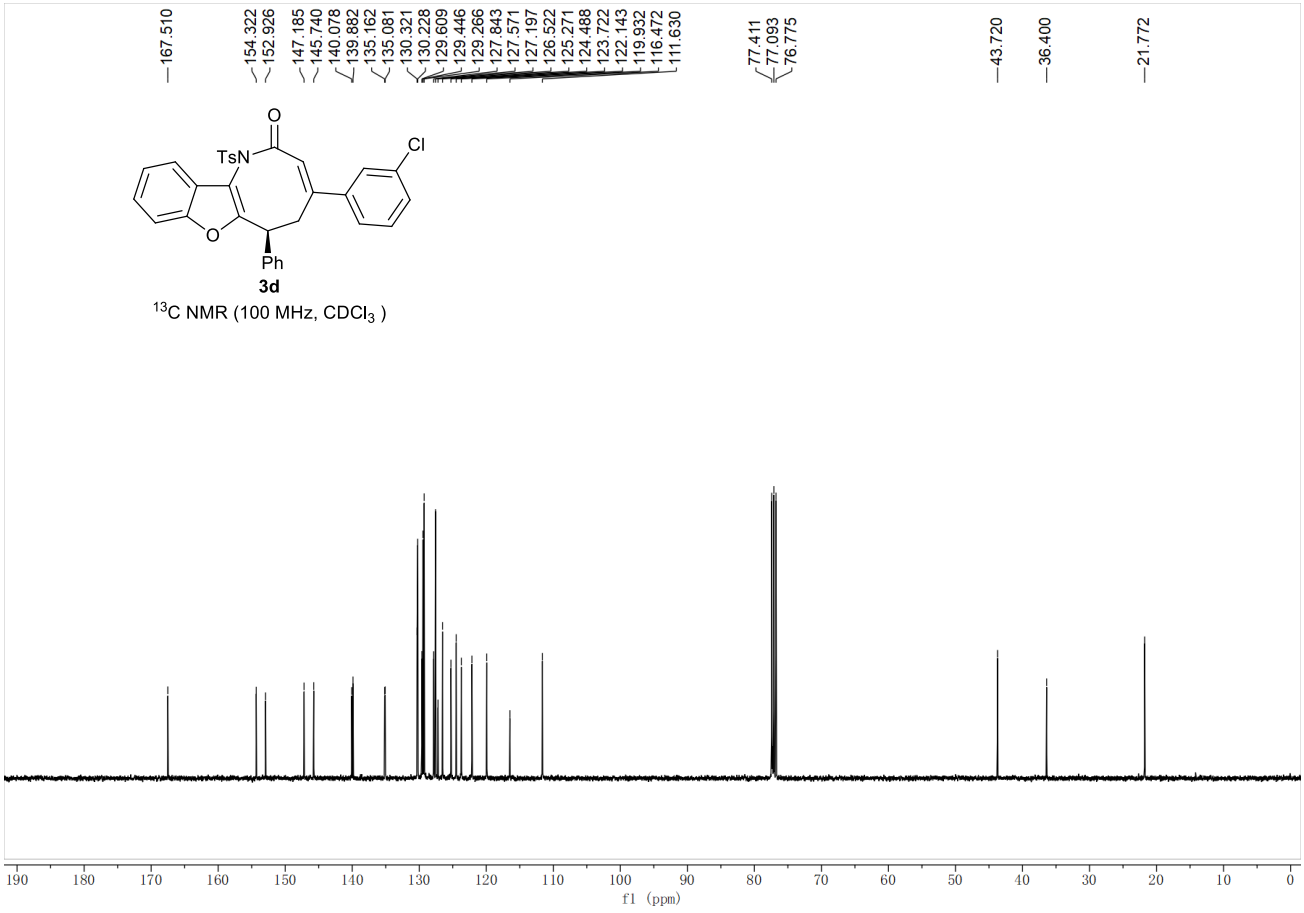


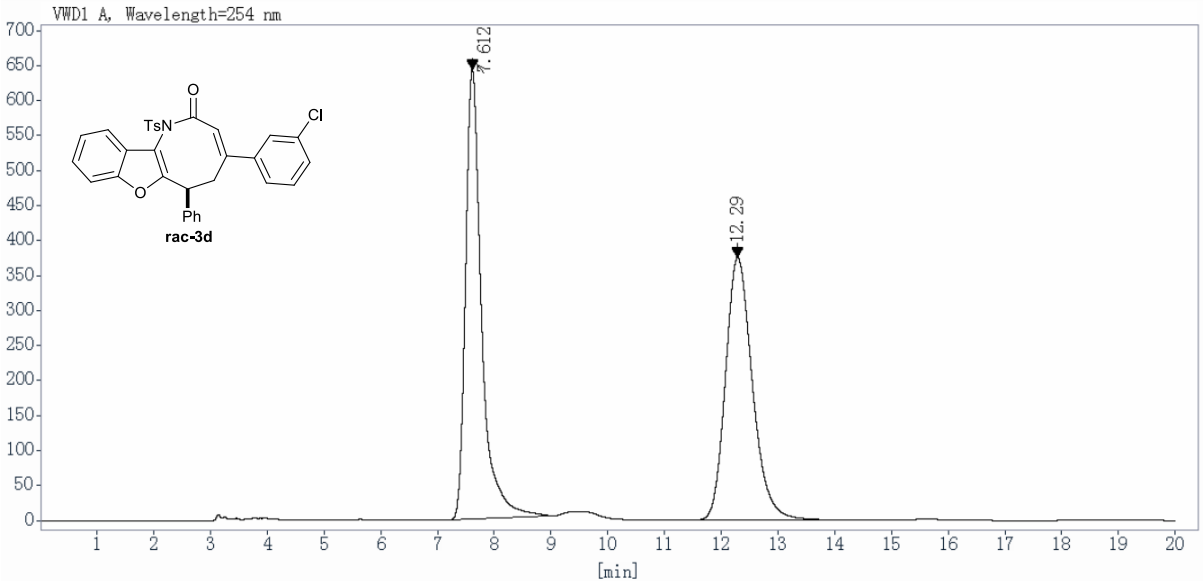
Ret Time [min]	Peak Type	Width [min]	Height [mAU]	Area [mAU*s]	Area [%]
7.547	BBA	0.28	464.7840	8673.1406	49.1942
11.862	BBA	0.49	278.4893	8957.2715	50.8058
			Totals:	17630.4121	100.0000



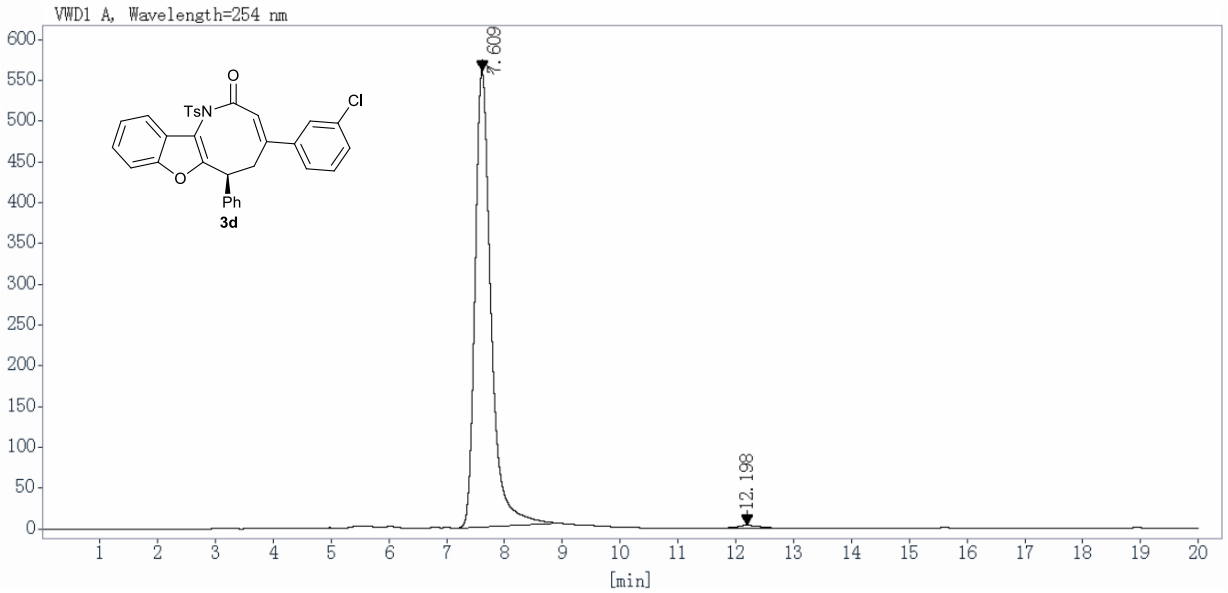
Ret Time [min]	Peak Type	Width [min]	Height [mAU]	Area [mAU*s]	Area [%]
7.535	BBA	0.29	2192.6633	41412.1094	99.6293
11.852	BB	0.47	5.0714	154.0827	0.3707
			Totals:	41566.1921	100.0000


8.048
8.044
8.027
7.626
7.622
7.616
7.613
7.610
7.603
7.489
7.484
7.479
7.467
7.464
7.459
7.446
7.440
7.428
7.423
7.412
7.408
7.403
7.380
7.374
7.371
7.367
7.360
7.356
7.352
7.348
7.344
7.339
7.337
7.332
7.329
7.321
7.317
7.315
7.312
7.306
7.302
7.297
7.288
7.284
7.236
7.230
7.226
7.215
7.211
7.207
6.083
4.345
4.334
4.311
4.299
3.445
3.411
3.376
3.066
3.063
3.054
3.051
3.032
3.029
3.020
3.017
2.425
0.000
O
TsN
Cl
O
Ph
3d
1H NMR (400 MHz, CDCl3)
2.00
0.97
4.19
7.93
1.54
0.99
1.01
1.04
1.02
3.01
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)

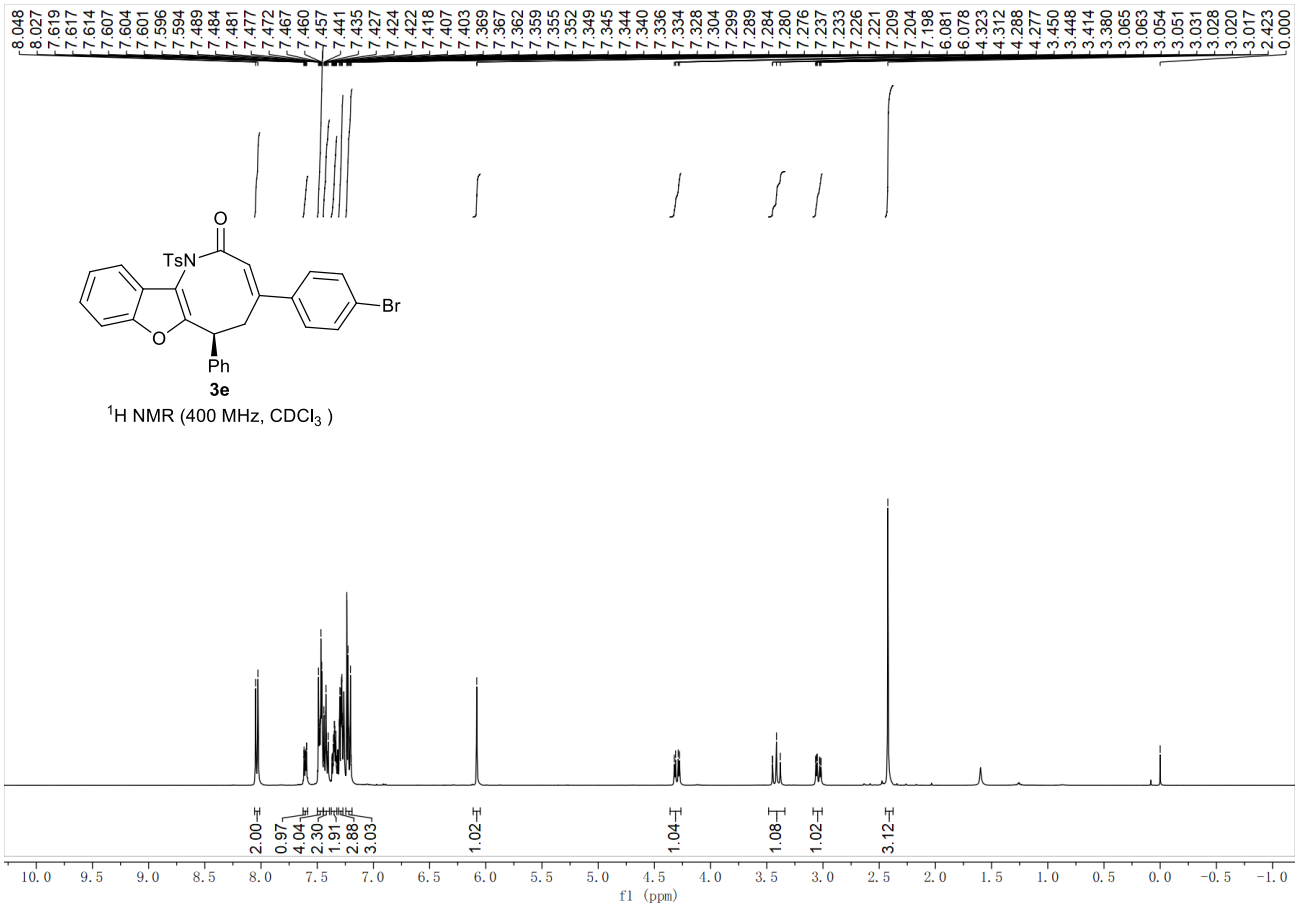

167.510
154.322
152.926
147.185
145.740
140.078
139.882
135.162
135.081
130.321
130.228
129.609
129.446
129.266
127.843
127.571
127.197
126.522
125.271
124.488
123.722
122.143
119.932
116.472
111.630
77.411
77.093
76.775
43.720
36.400
21.772
O
TsN
Cl
O
Ph
3d
13C NMR (100 MHz, CDCl3)
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)



Ret Time [min]	Peak Type	Width [min]	Height [mAU]	Area [mAU*s]	Area [%]
7.612	BBA	0.30	642.2421	12630.7959	50.7179
12.290	BBA	0.50	374.4158	12273.2363	49.2821
			Totals:	24904.0322	100.0000

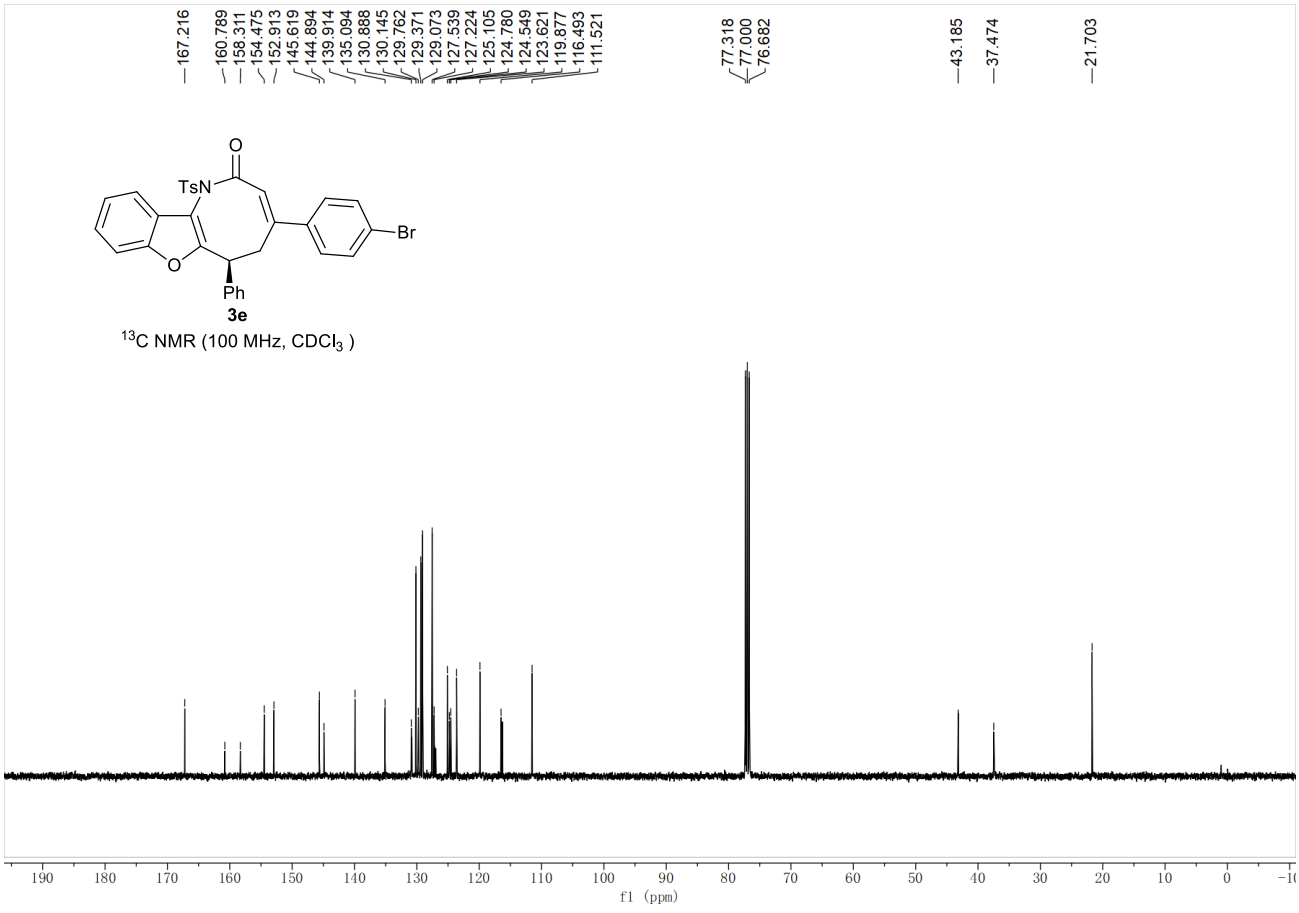


Ret Time [min]	Peak Type	Width [min]	Height [mAU]	Area [mAU*s]	Area [%]
7.609	BBA	0.29	559.6750	10764.9600	99.0074
12.198	BB	0.42	3.6254	107.9294	0.9926
			Totals:	10872.8894	100.0000



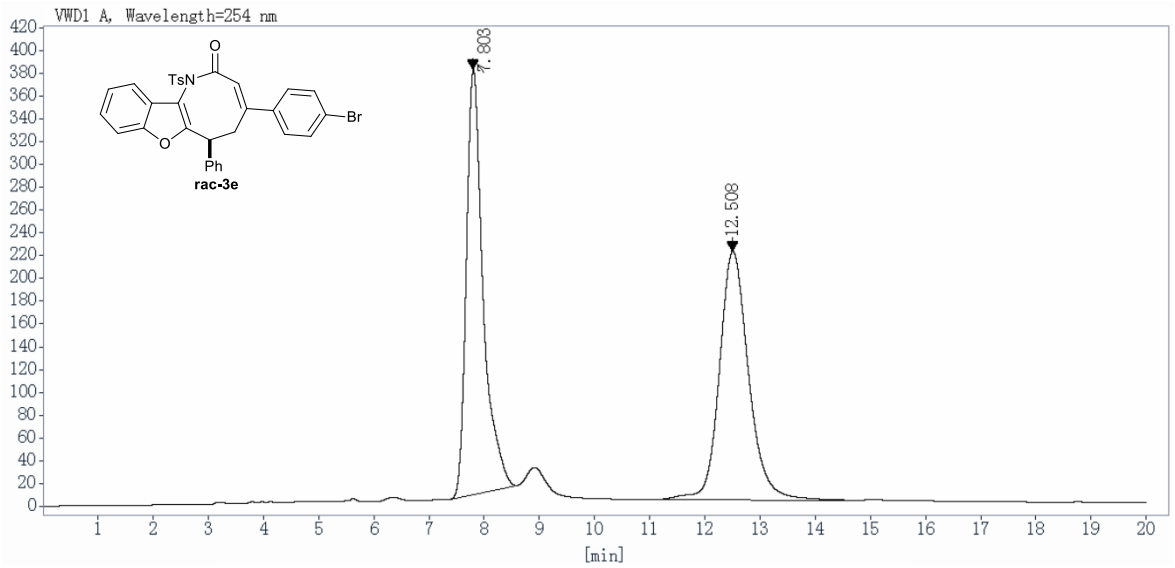
3e

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

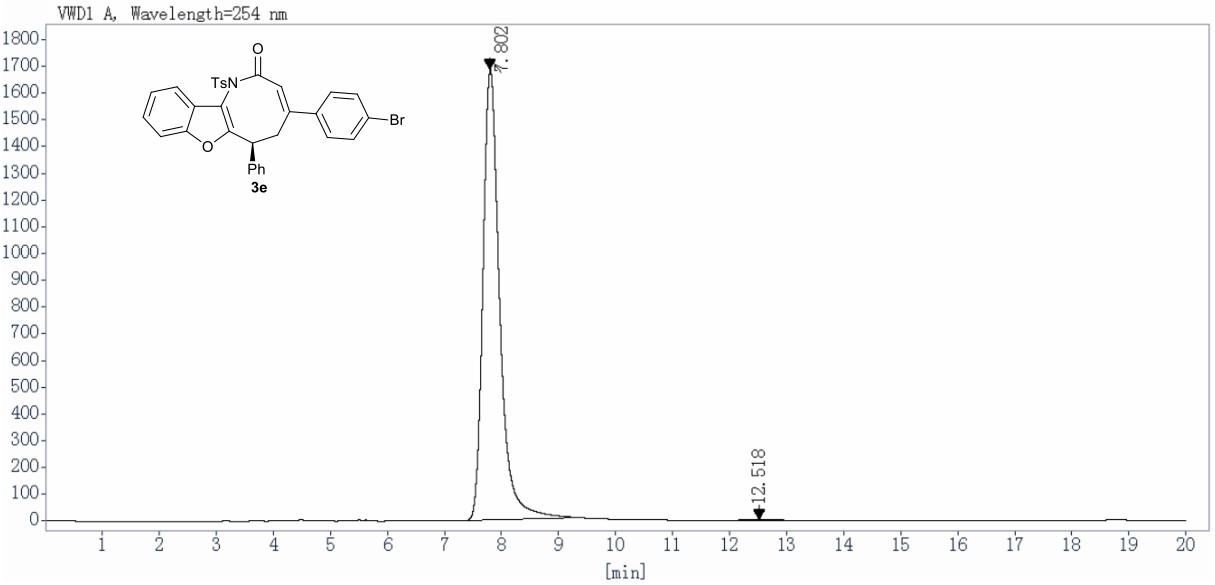


3e

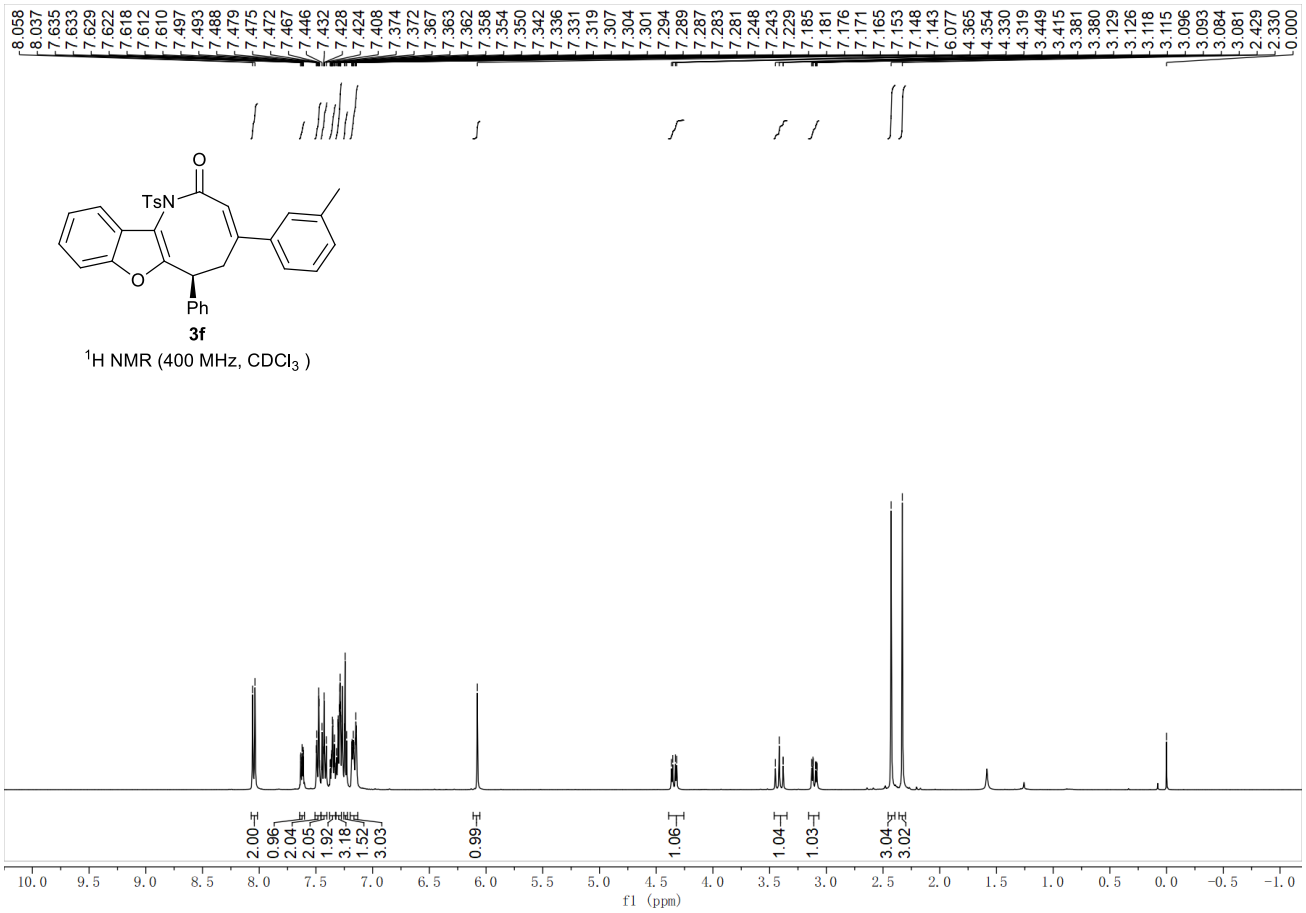
^{13}C NMR (100 MHz, $CDCl_3$)



Ret Time [min]	Peak Type	Width [min]	Height [mAU]	Area [mAU*s]	Area [%]
7.803	BB	0.32	373.2682	7887.0215	49.5256
12.508	BB	0.56	218.2064	8038.1118	50.4744
			Totals:	15925.1333	100.0000

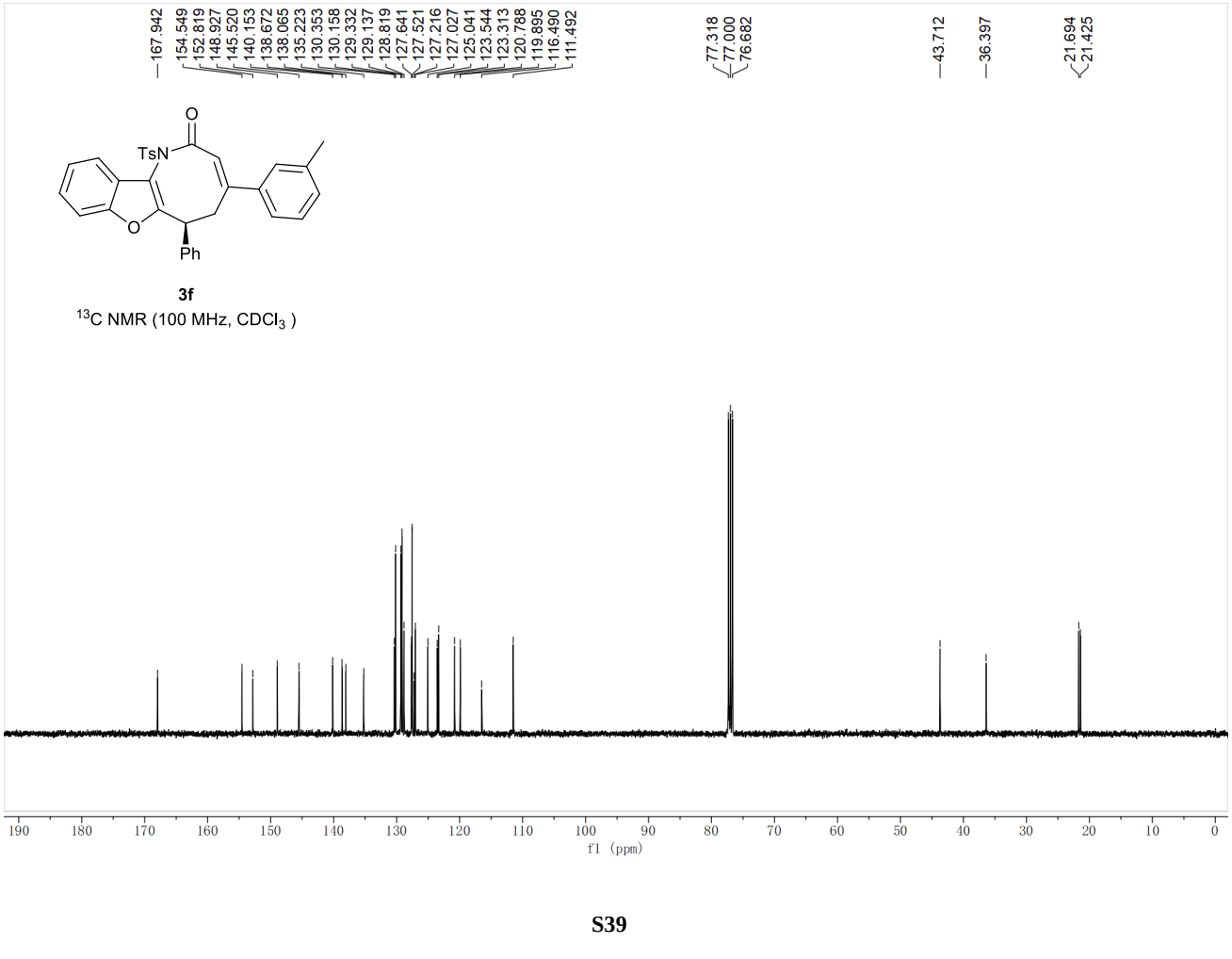


Ret Time [min]	Peak Type	Width [min]	Height [mAU]	Area [mAU*s]	Area [%]
7.802	BBA	0.31	1687.0439	34501.7266	99.6506
12.518	BB	0.52	3.4751	120.9570	0.3494
			Totals:	34622.6836	100.0000



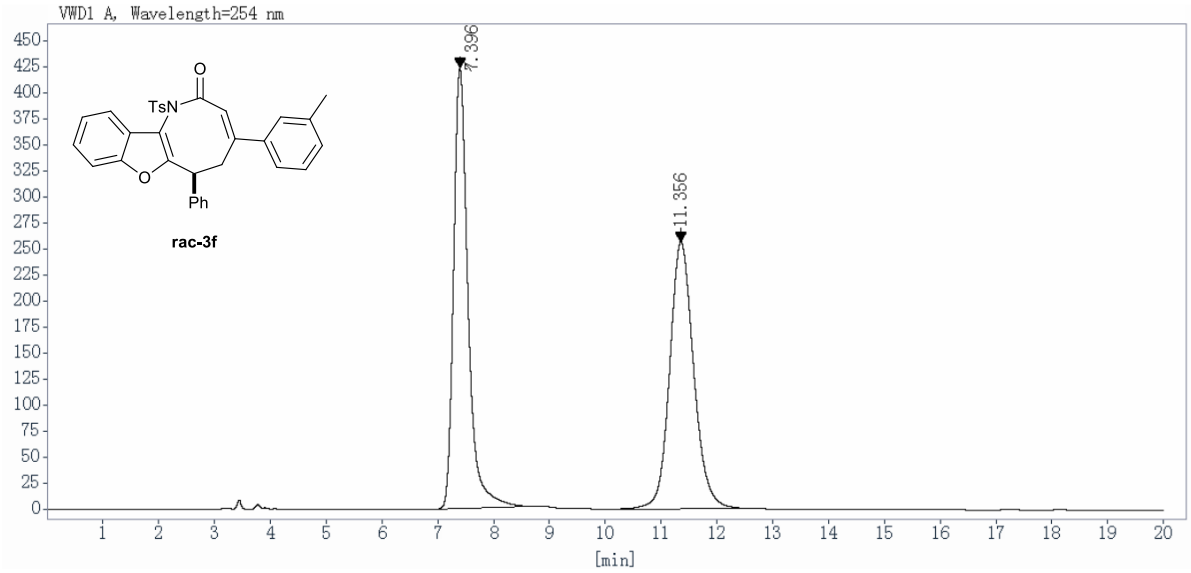
3f

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

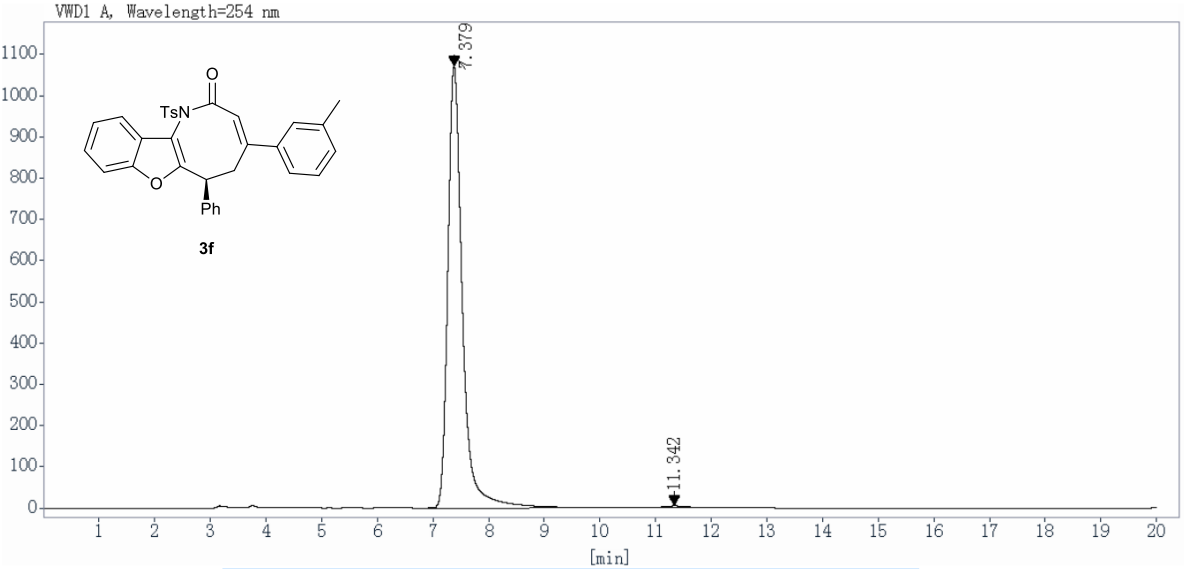


3f

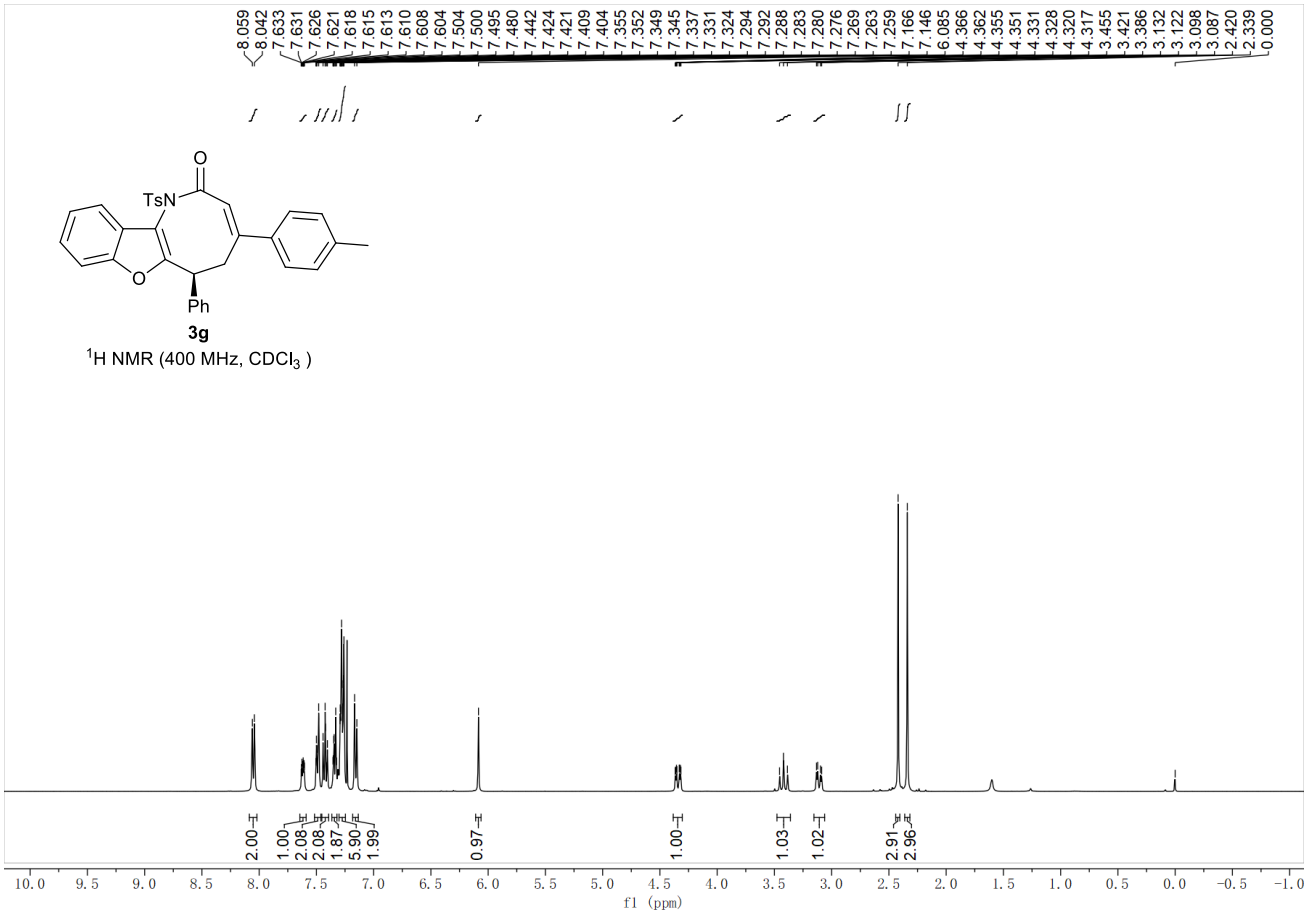
^{13}C NMR (100 MHz, $CDCl_3$)



Ret Time [min]	Peak Type	Width [min]	Height [mAU]	Area [mAU*s]	Area [%]
7.396	BB	0.27	423.5606	7580.3252	49.7508
11.356	BB	0.46	256.1749	7656.2671	50.2492
			Totals:	15236.5923	100.0000

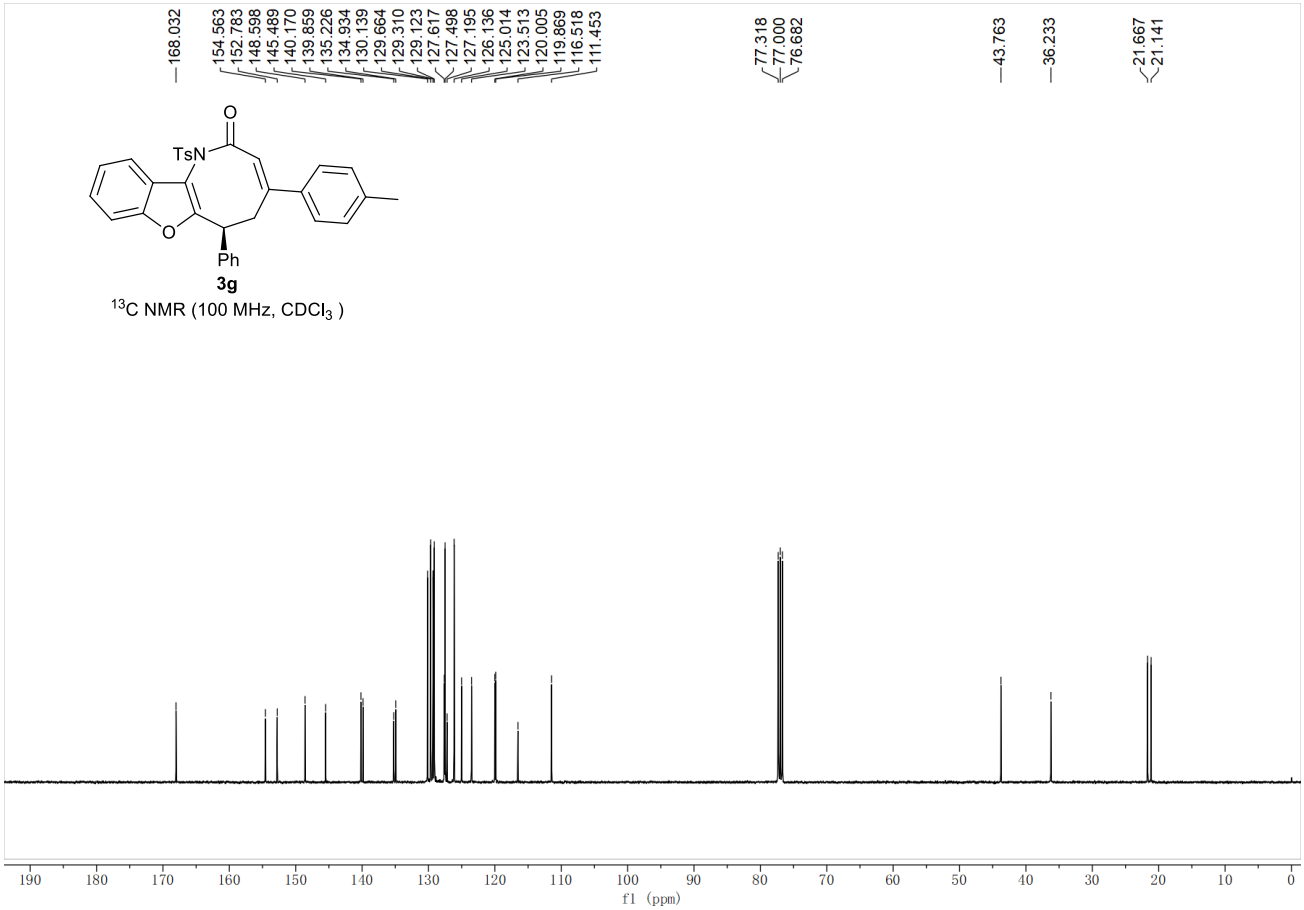


Ret Time [min]	Peak Type	Width [min]	Height [mAU]	Area [mAU*s]	Area [%]
7.379	BB	0.27	1072.4150	19527.4414	99.2060
11.342	BB	0.49	4.7969	156.2906	0.7940
			Totals:	19683.7320	100.0000



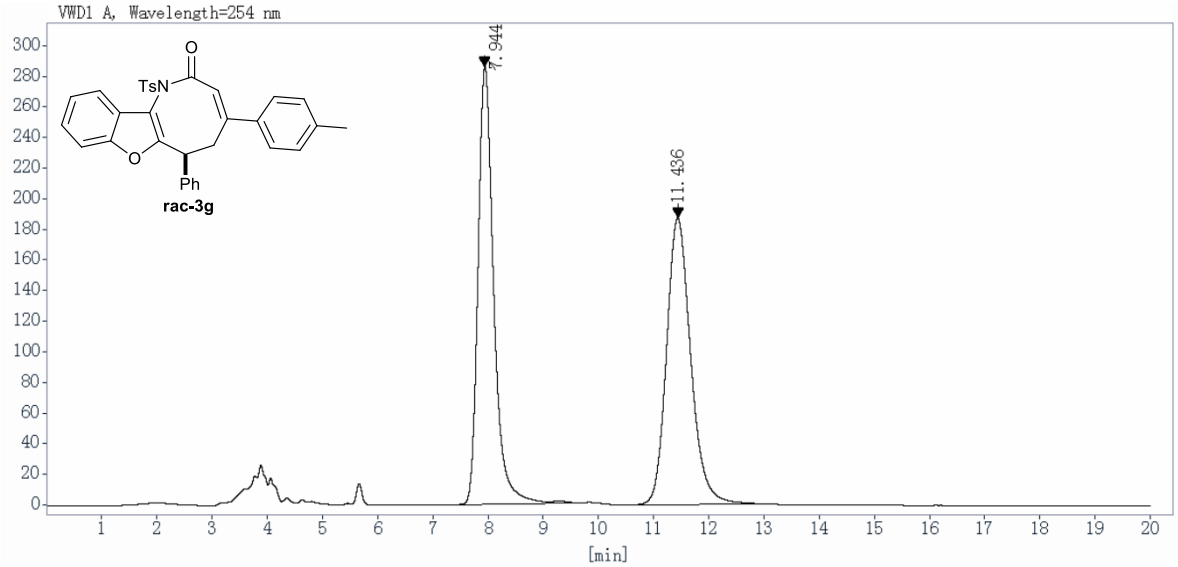
3g

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

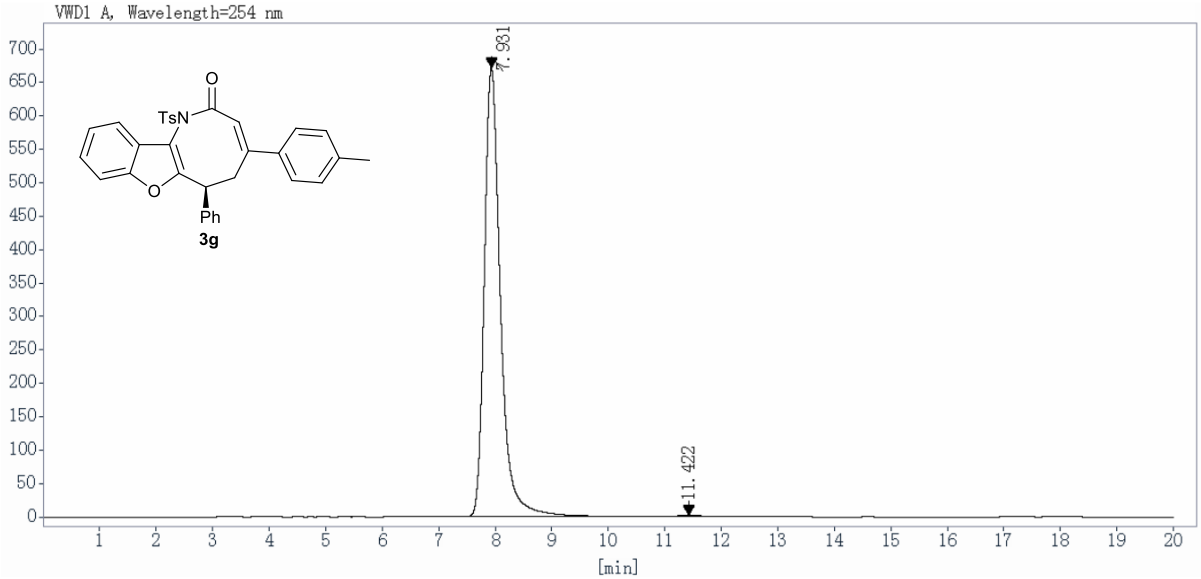


3g

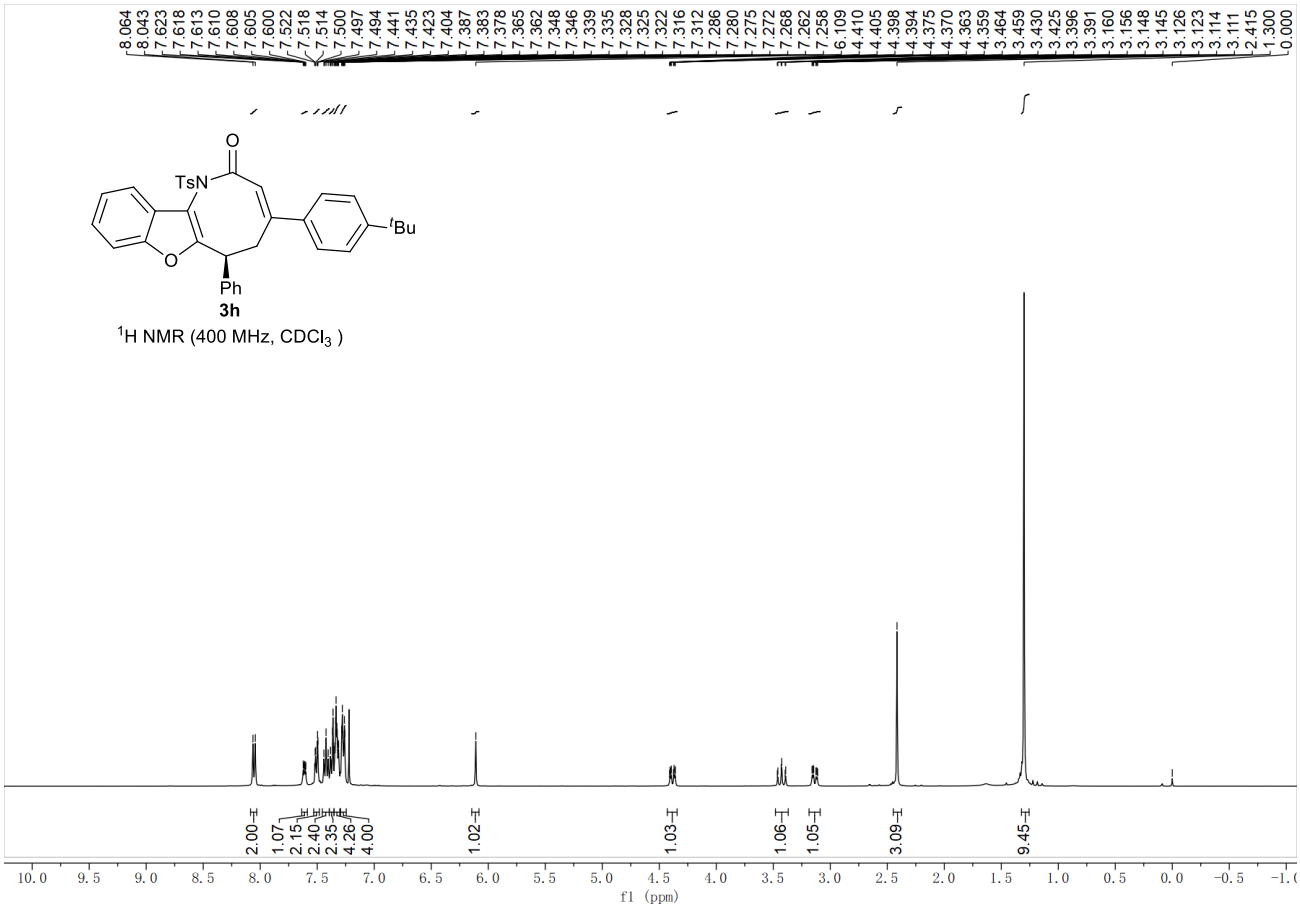
^{13}C NMR (100 MHz, $CDCl_3$)

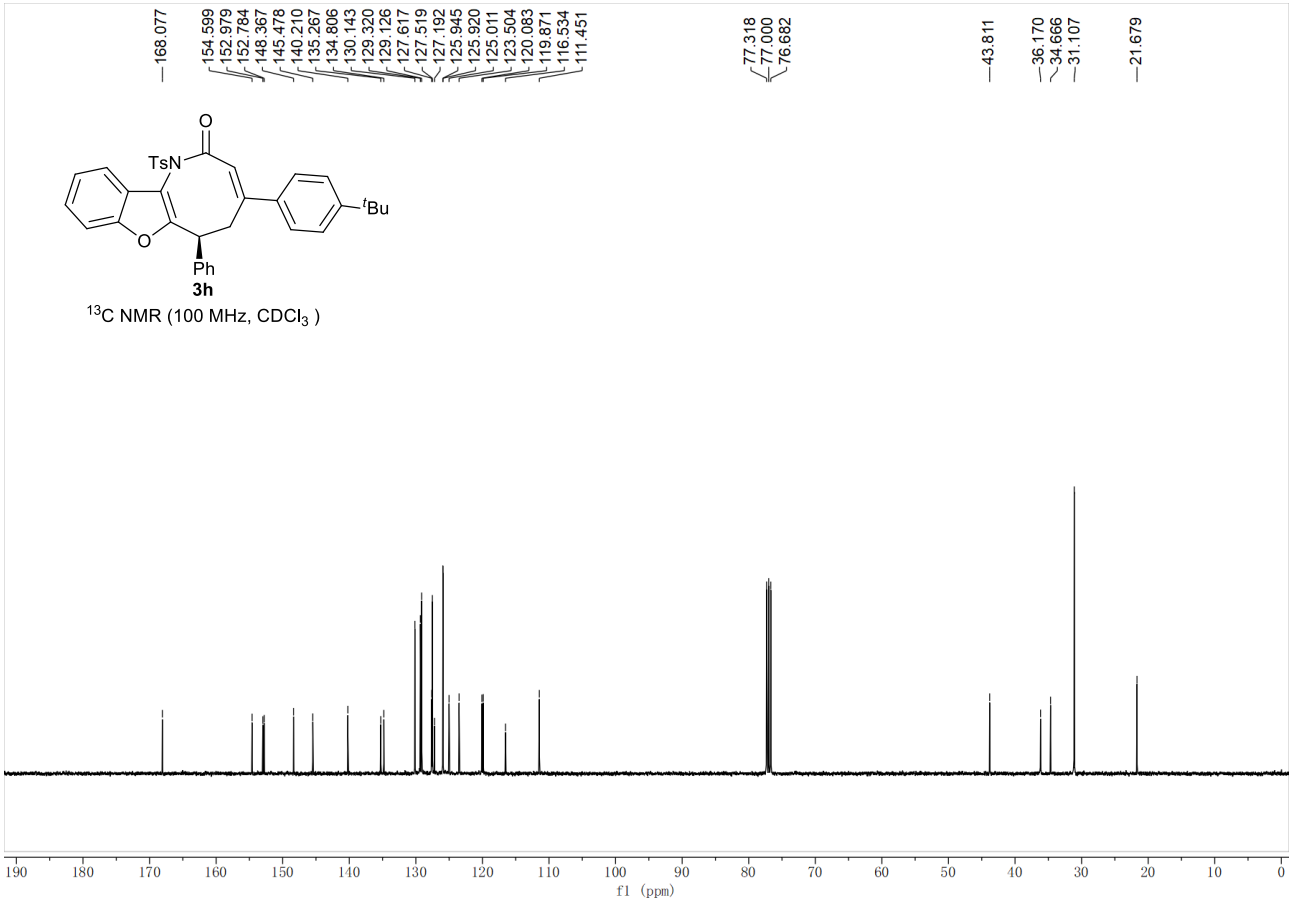


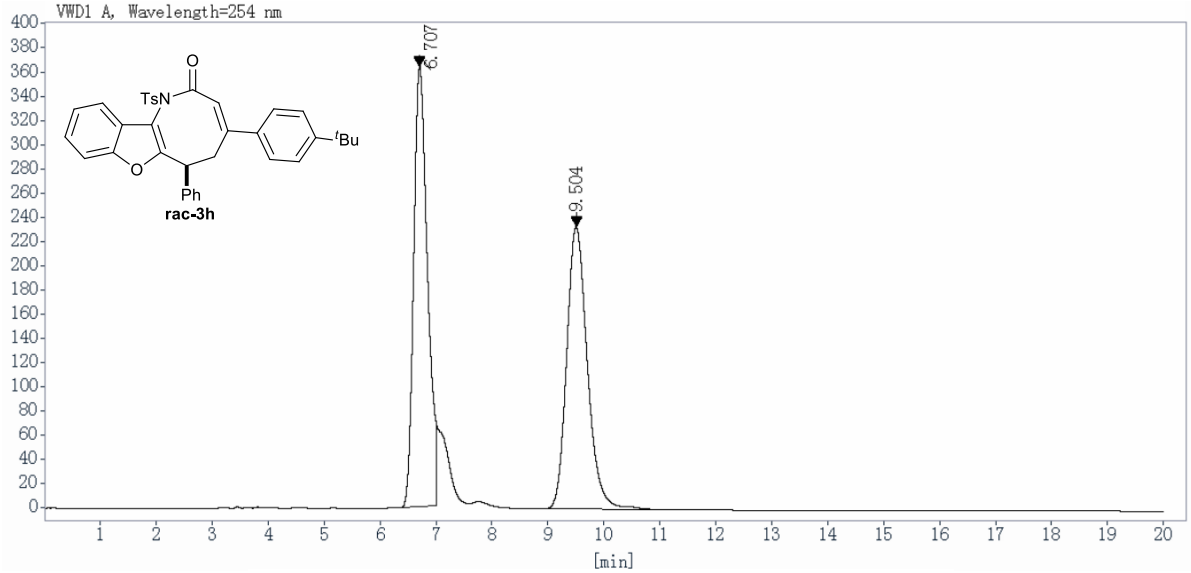
Ret Time [min]	Peak Type	Width [min]	Height [mAU]	Area [mAU*s]	Area [%]
7.944	BV R	0.30	285.9954	5664.2954	49.7728
11.436	BBA	0.47	187.1574	5716.0176	50.2272
			Totals:	11380.3130	100.0000



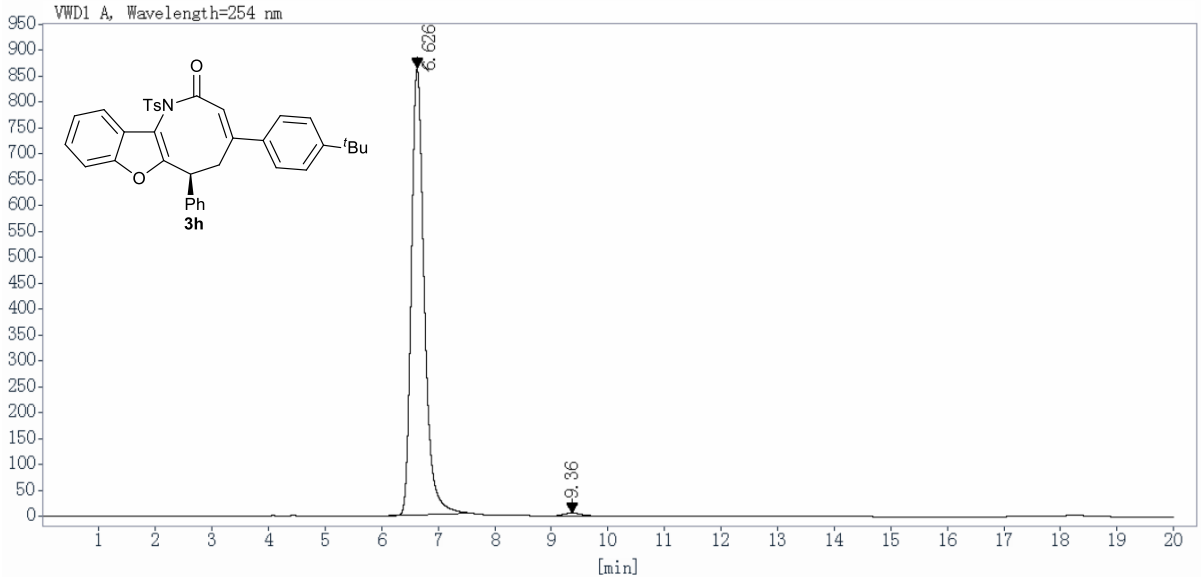
Ret Time [min]	Peak Type	Width [min]	Height [mAU]	Area [mAU*s]	Area [%]
7.931	BV R	0.30	672.0048	13354.0410	99.6007
11.422	BB	0.41	2.0415	53.5379	0.3993
			Totals:	13407.5789	100.0000


TsN
O
O
tBu
Ph
3h
1H NMR (400 MHz, CDCl3)
f1 (ppm)

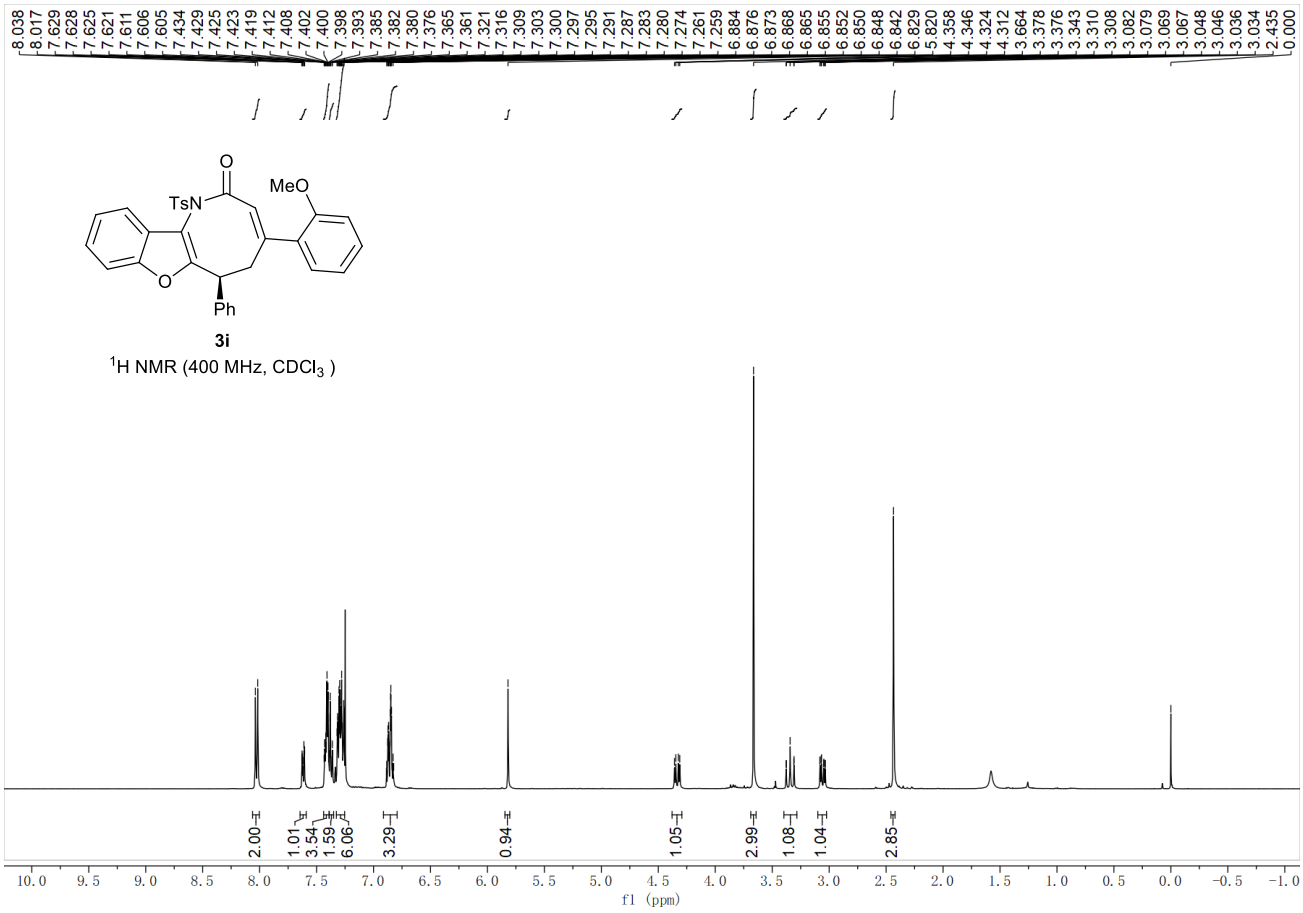

TsN
O
O
tBu
Ph
3h
13C NMR (100 MHz, CDCl3)
f1 (ppm)



Ret Time [min]	Peak Type	Width [min]	Height [mAU]	Area [mAU*s]	Area [%]
6.707	MF	0.28	363.9224	6216.5728	50.9612
9.504	BBA	0.39	233.4729	5982.0693	49.0388
			Totals:	12198.6421	100.0000

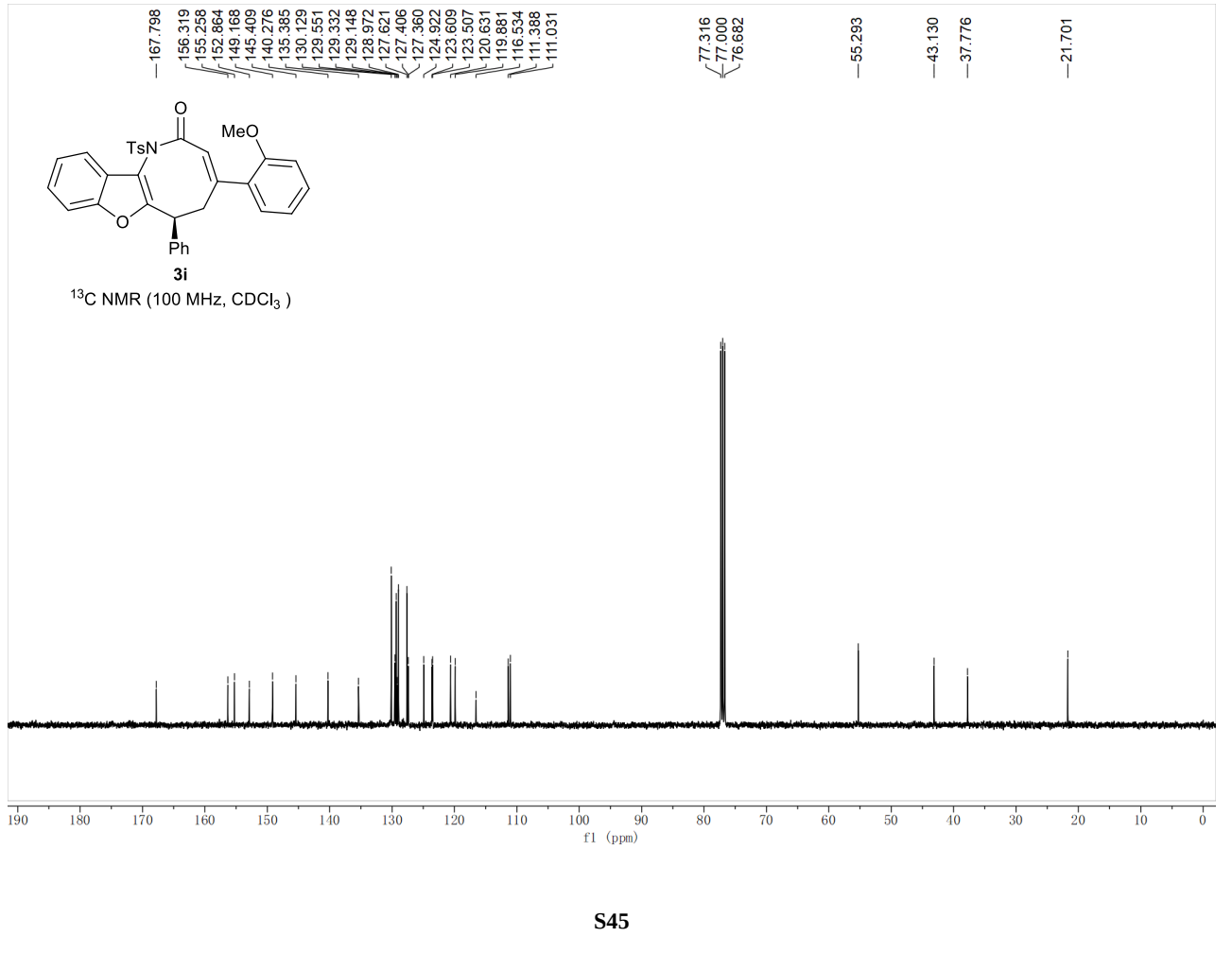


Ret Time [min]	Peak Type	Width [min]	Height [mAU]	Area [mAU*s]	Area [%]
6.626	VBAR	0.24	863.7394	13750.2773	98.9577
9.360	BB	0.38	5.9559	144.8279	1.0423
			Totals:	13895.1052	100.0000



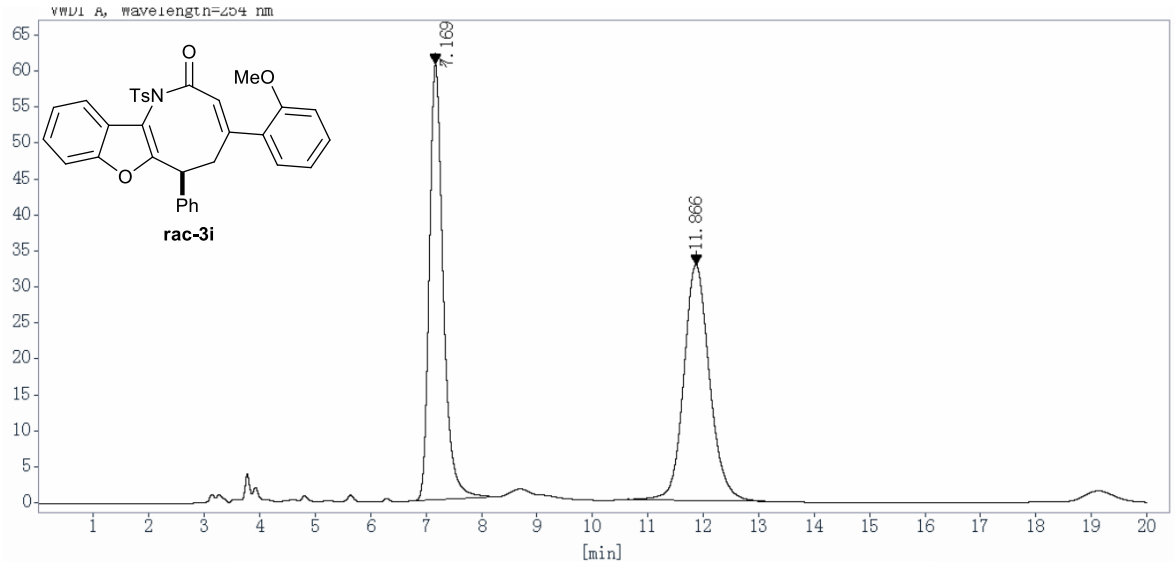
3i

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

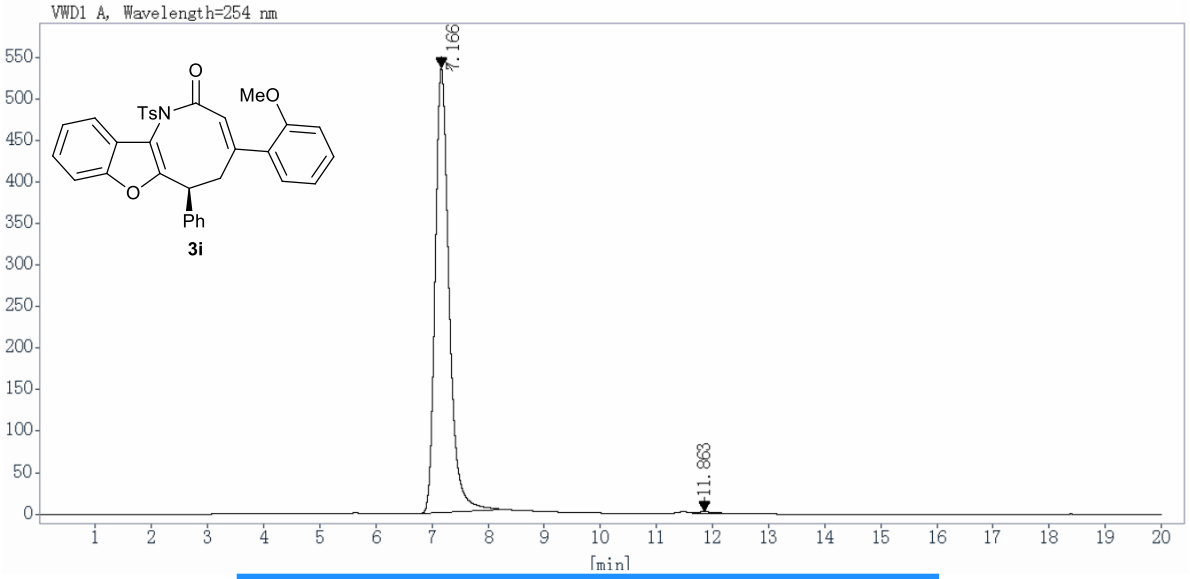


3i

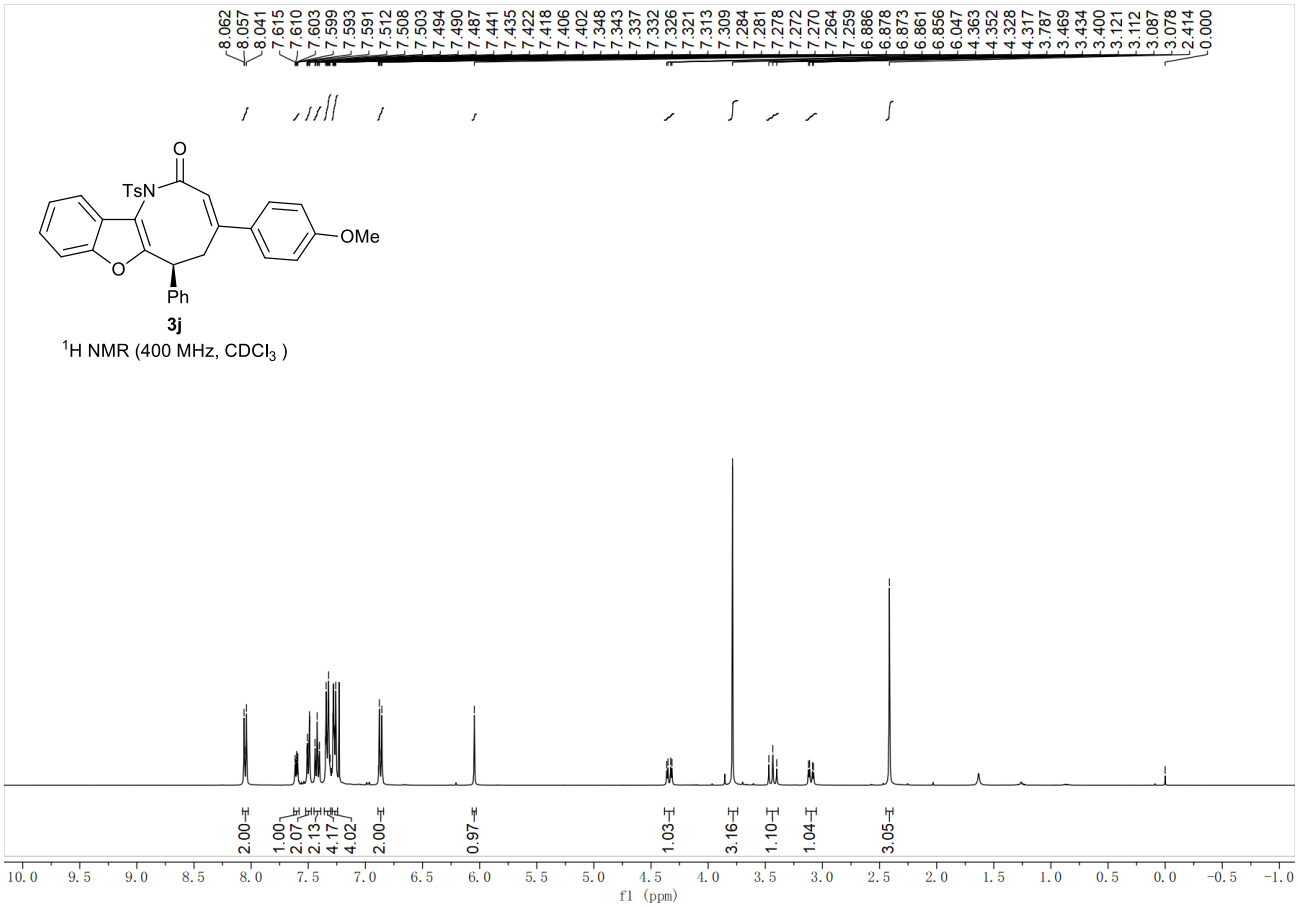
^{13}C NMR (100 MHz, $CDCl_3$)



Ret Time [min]	Peak Type	Width [min]	Height [mAU]	Area [mAU*s]	Area [%]
7.169	BB	0.26	60.5549	1050.1989	49.8369
11.866	BB	0.49	32.7701	1057.0718	50.1631
			Totals:	2107.2706	100.0000

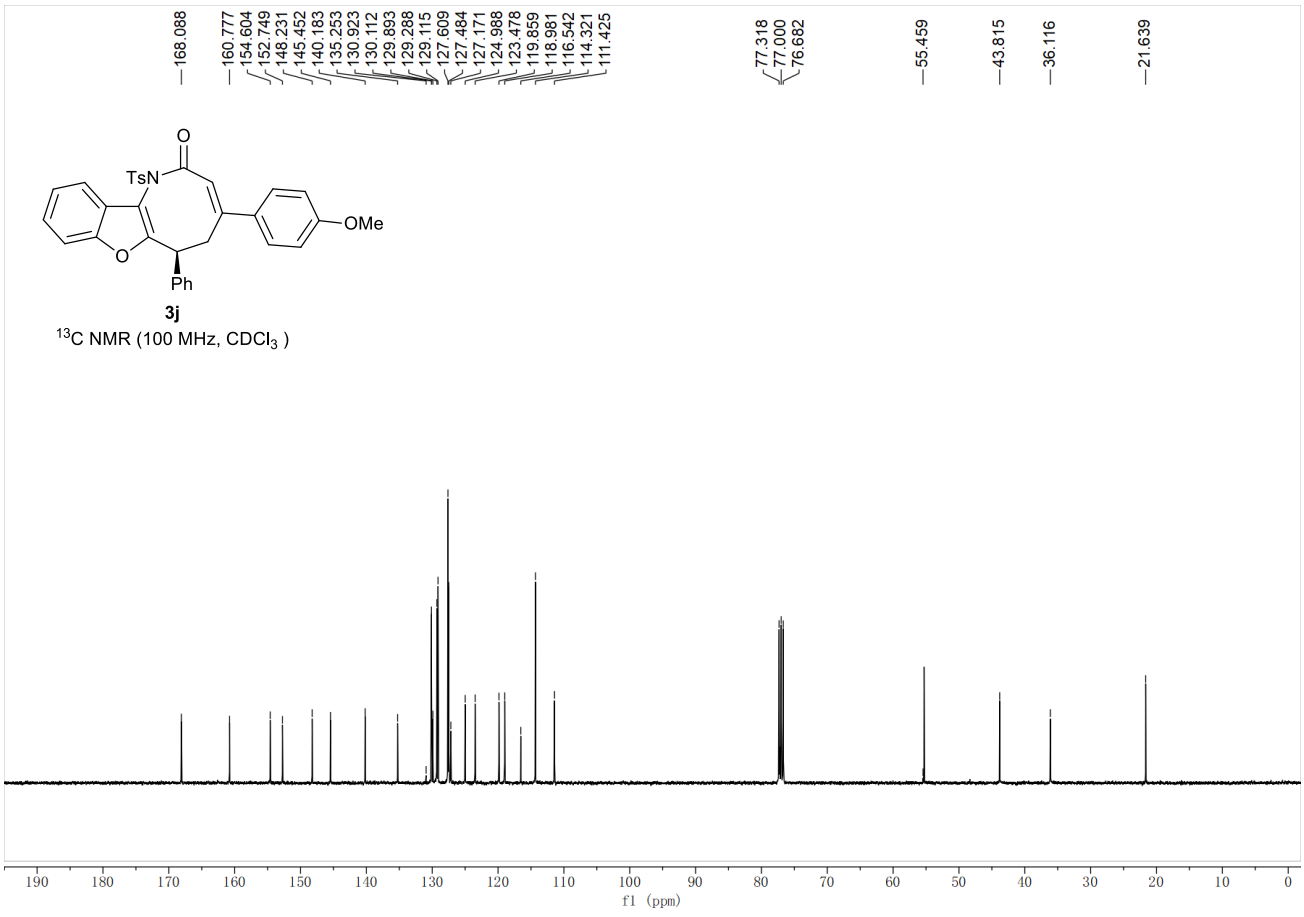


Ret Time [min]	Peak Type	Width [min]	Height [mAU]	Area [mAU*s]	Area [%]
7.166	BBA	0.26	536.1495	9218.4229	99.2965
11.863	VBA	0.43	2.2034	65.3081	0.7035
			Totals:	9283.7309	100.0000



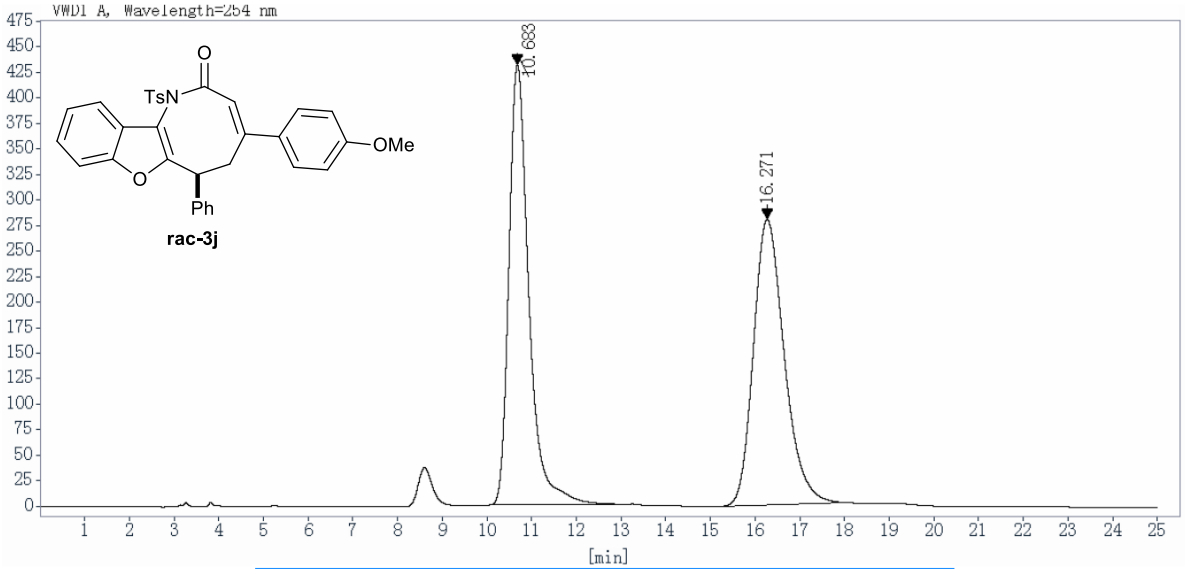
3j

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

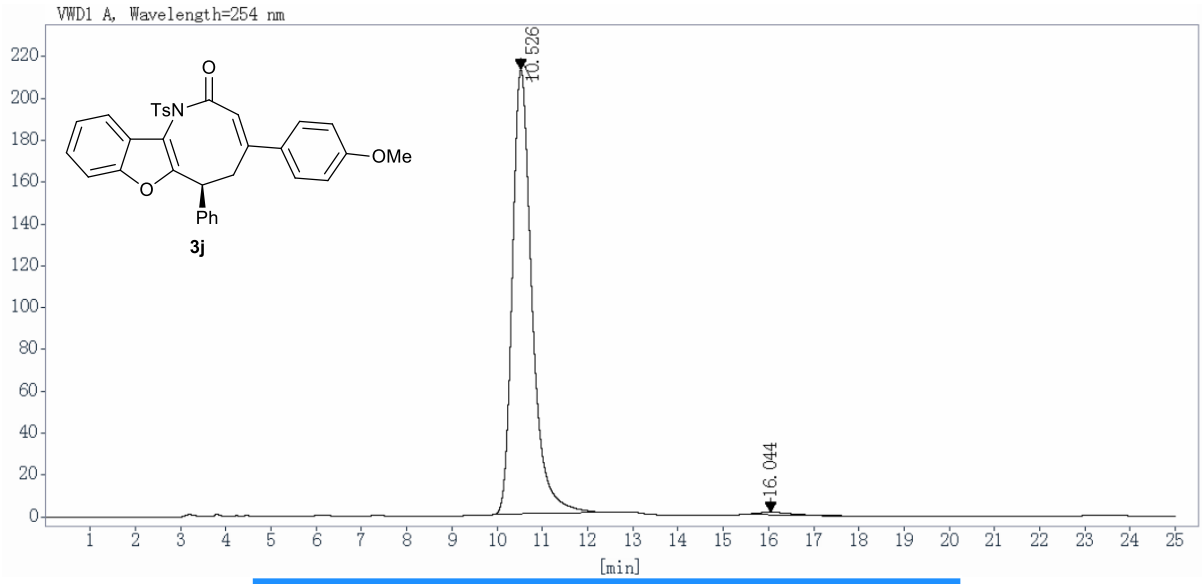


3j

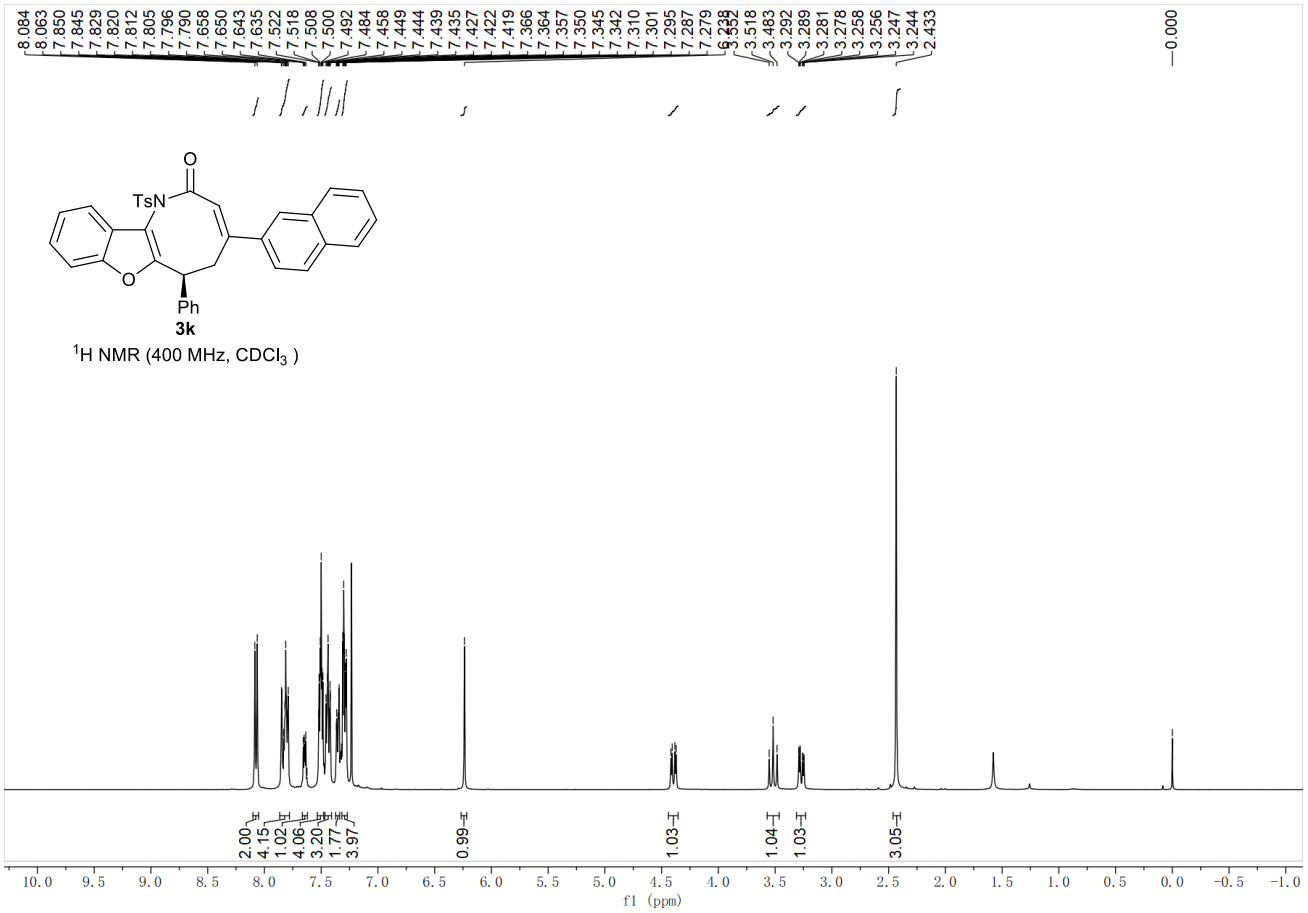
^{13}C NMR (100 MHz, $CDCl_3$)



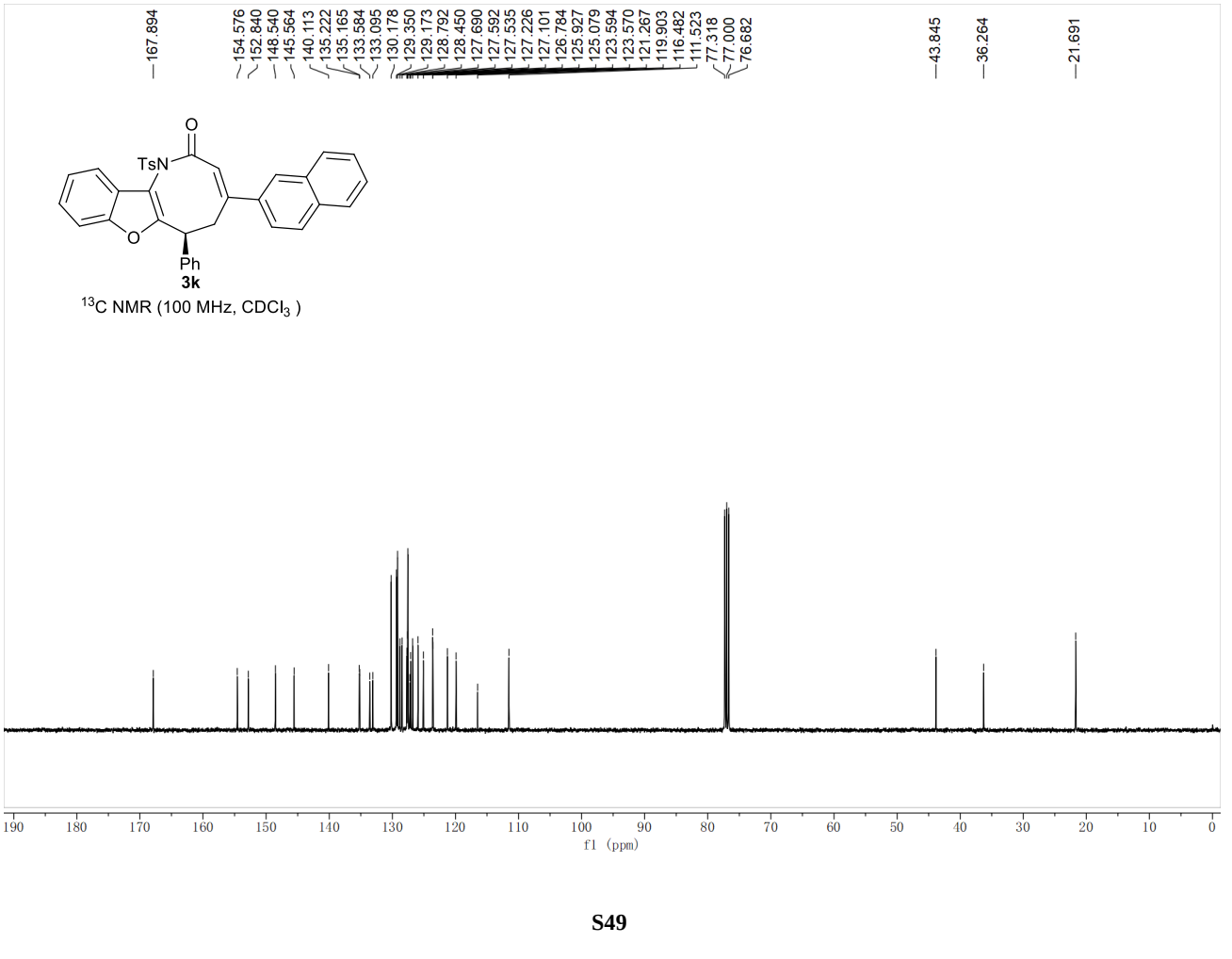
Ret Time [min]	Peak Type	Width [min]	Height [mAU]	Area [mAU*s]	Area [%]
10.683	BB	0.47	431.3660	13347.9854	49.8635
16.271	BBA	0.74	279.9297	13421.0742	50.1365
			Totals:	26769.0596	100.0000



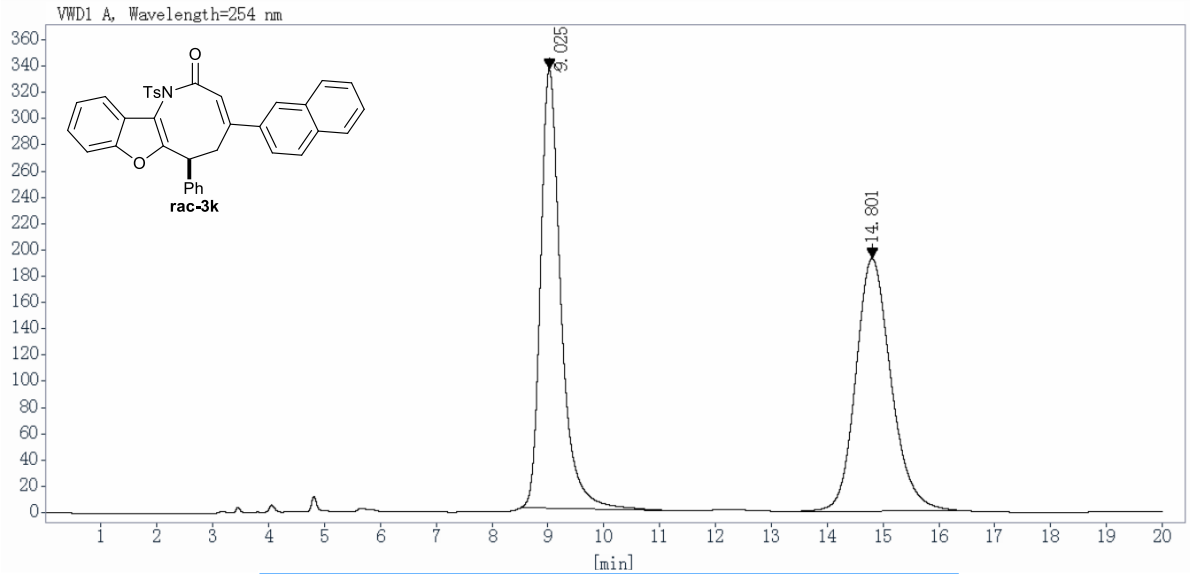
Ret Time [min]	Peak Type	Width [min]	Height [mAU]	Area [mAU*s]	Area [%]
10.526	BB	0.46	212.7926	6387.8257	98.8965
16.044	BBA	0.68	1.2863	71.2738	1.1035
			Totals:	6459.0994	100.0000



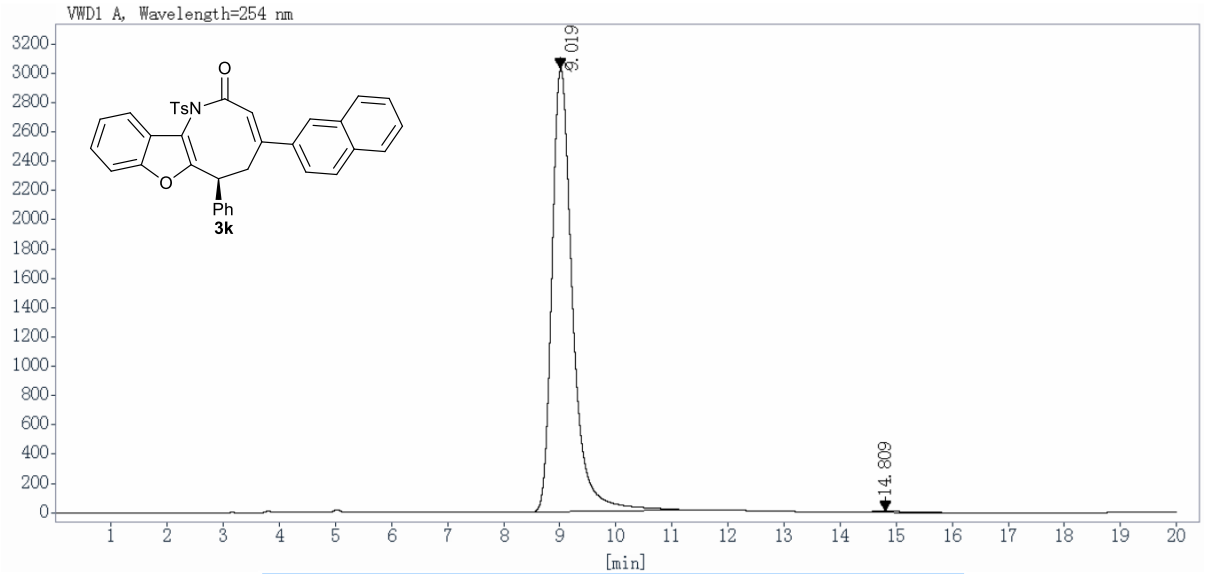
^{1}H NMR (400 MHz, $CDCl_3$)



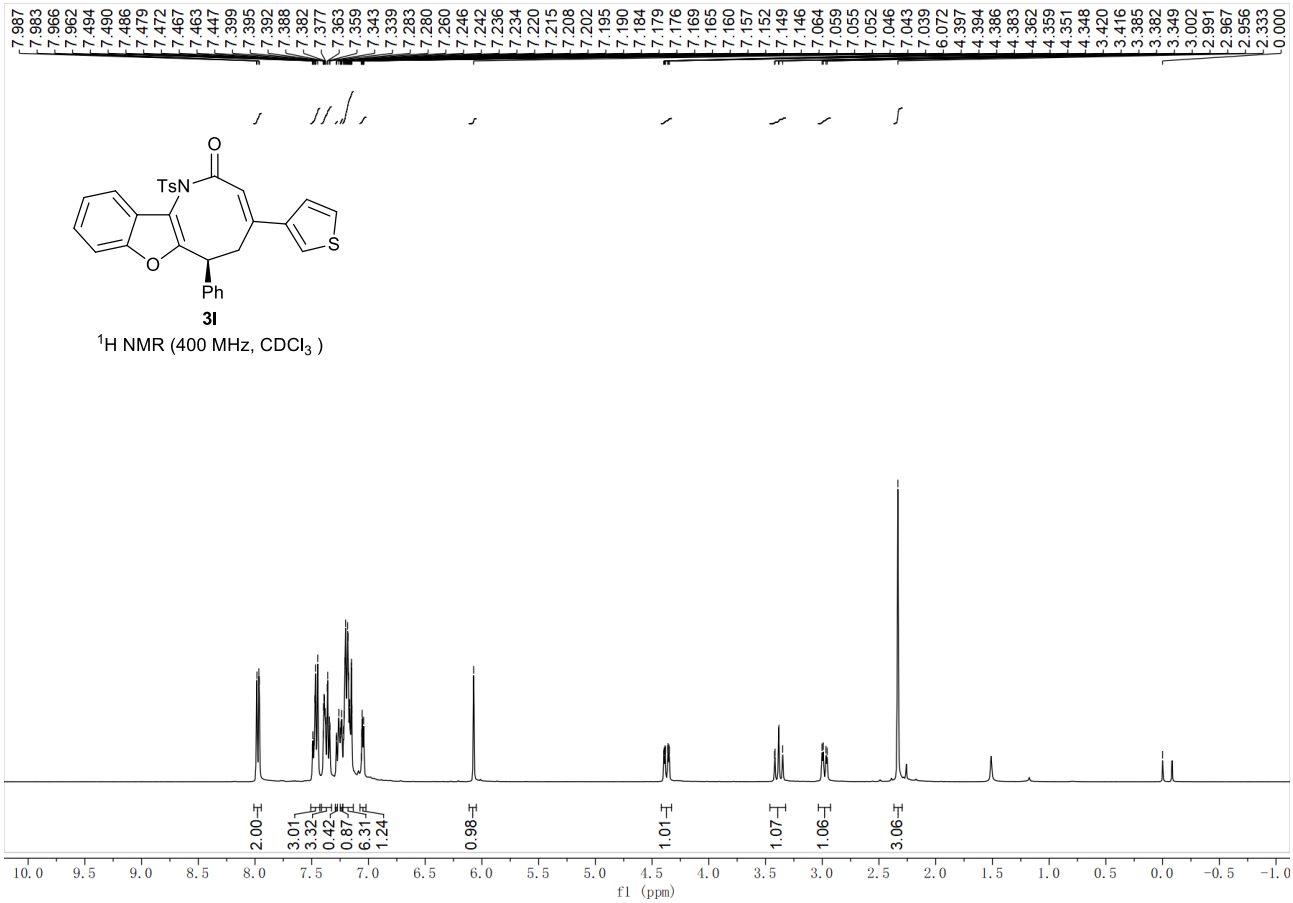
^{13}C NMR (100 MHz, $CDCl_3$)



Ret Time [min]	Peak Type	Width [min]	Height [mAU]	Area [mAU*s]	Area [%]
9.025	BBA	0.38	334.3492	8416.6875	49.8715
14.801	BBA	0.67	192.3931	8460.0586	50.1285
			Totals:	16876.7461	100.0000

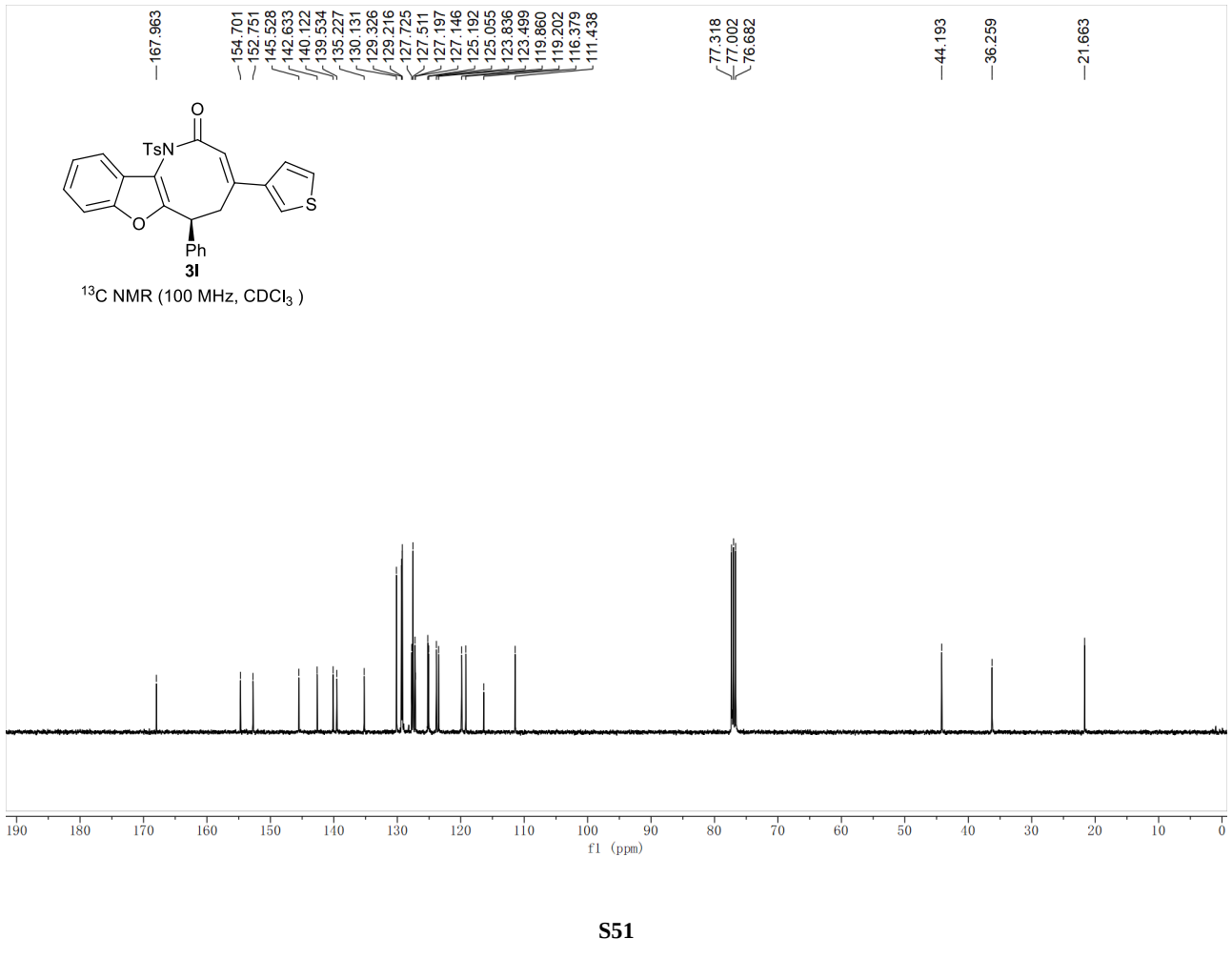


Ret Time [min]	Peak Type	Width [min]	Height [mAU]	Area [mAU*s]	Area [%]
9.019	BBA	0.39	3027.6592	76755.3828	99.5534
14.809	BBA	0.65	8.0464	344.3551	0.4466
			Totals:	77099.7379	100.0000



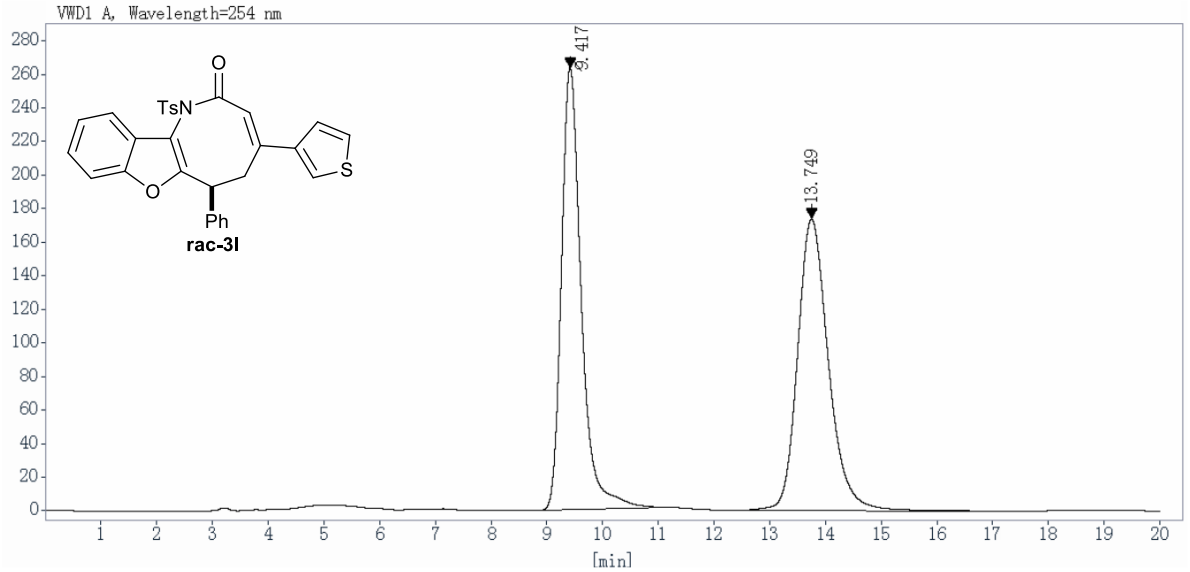
3l

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

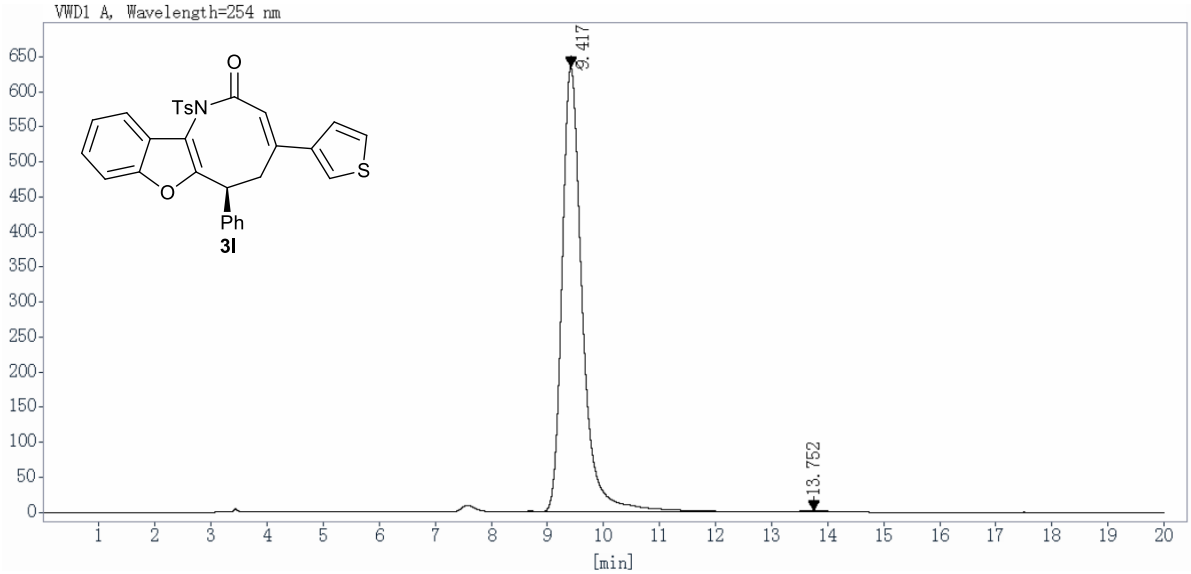


3l

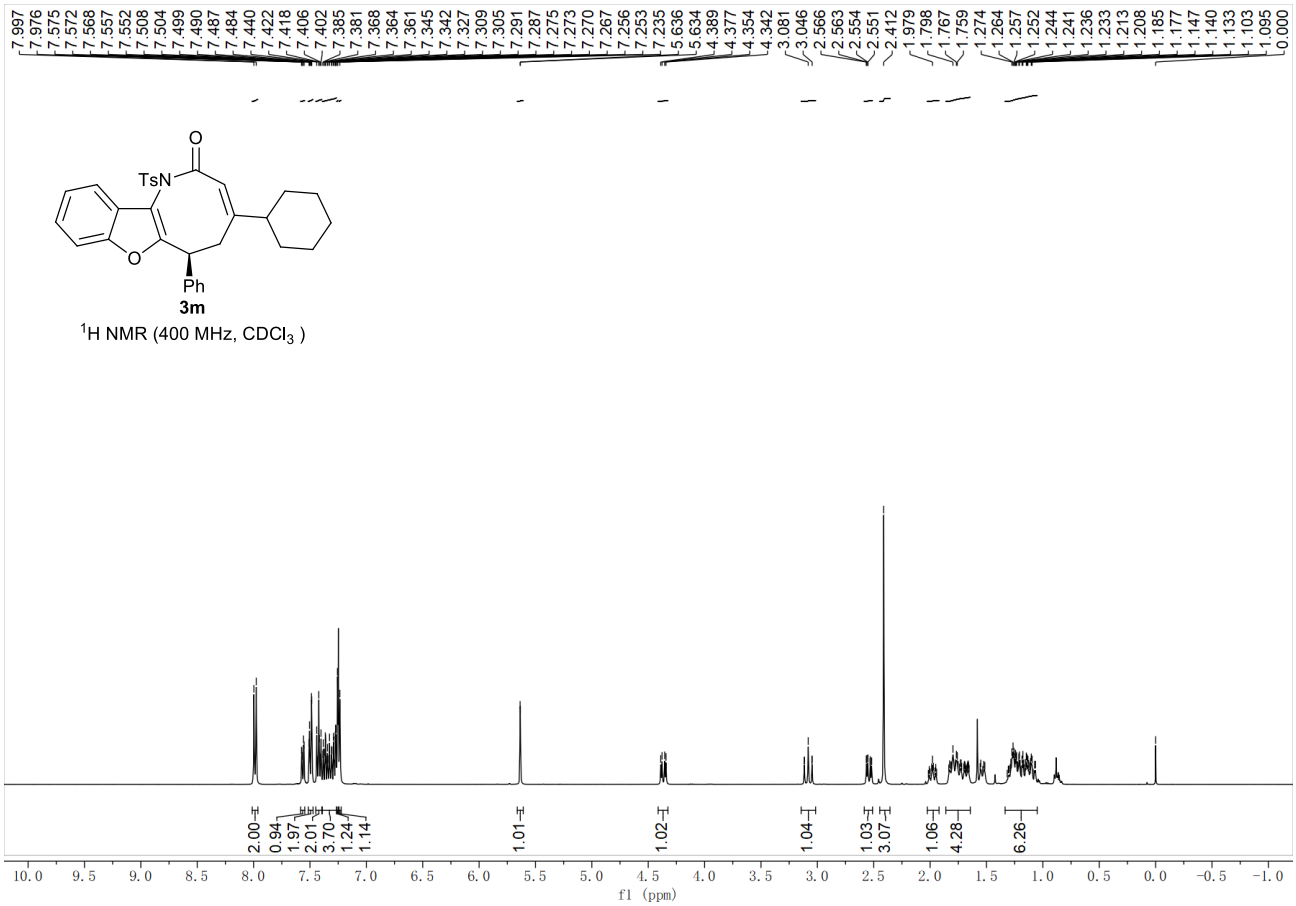
^{13}C NMR (100 MHz, $CDCl_3$)

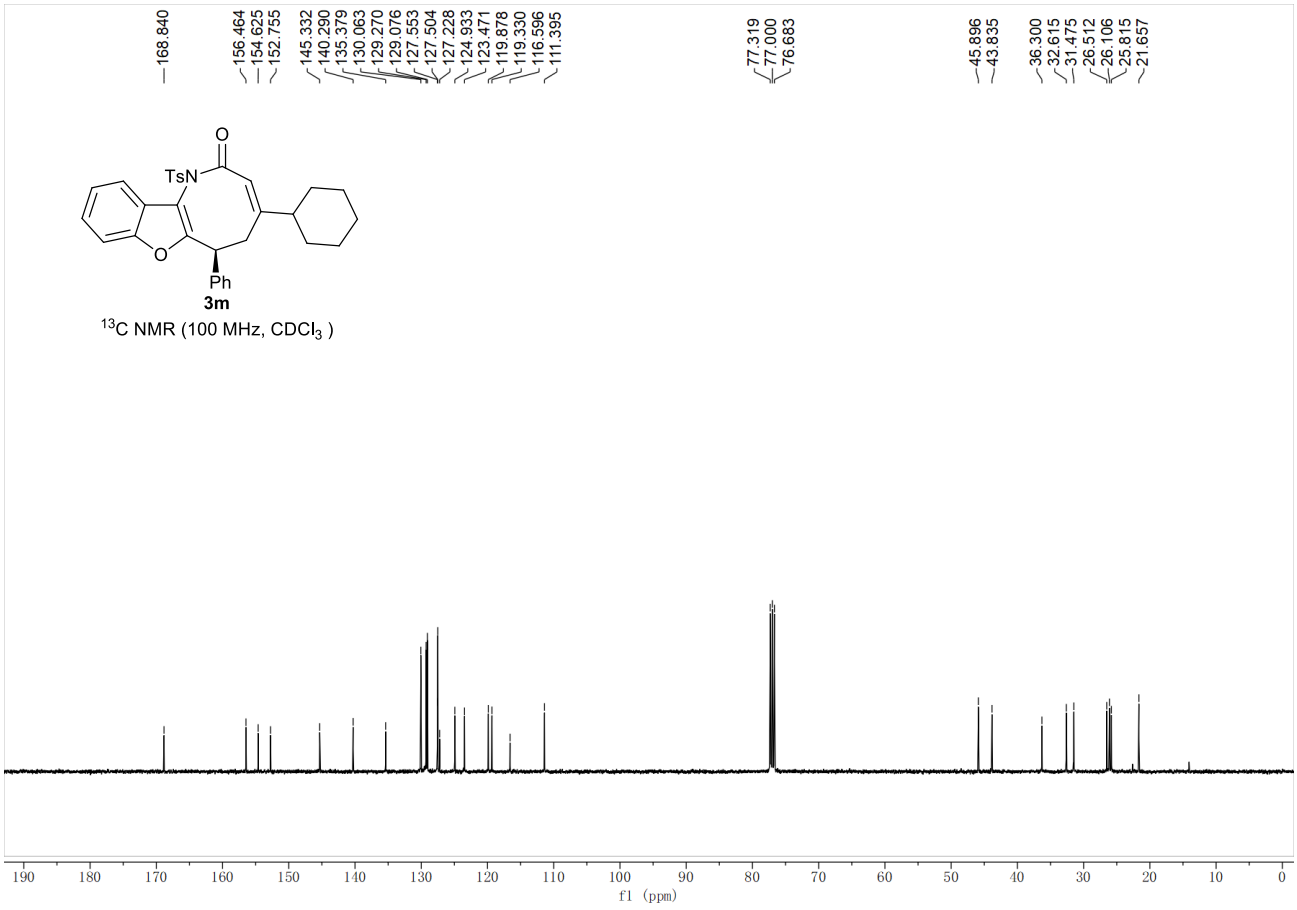


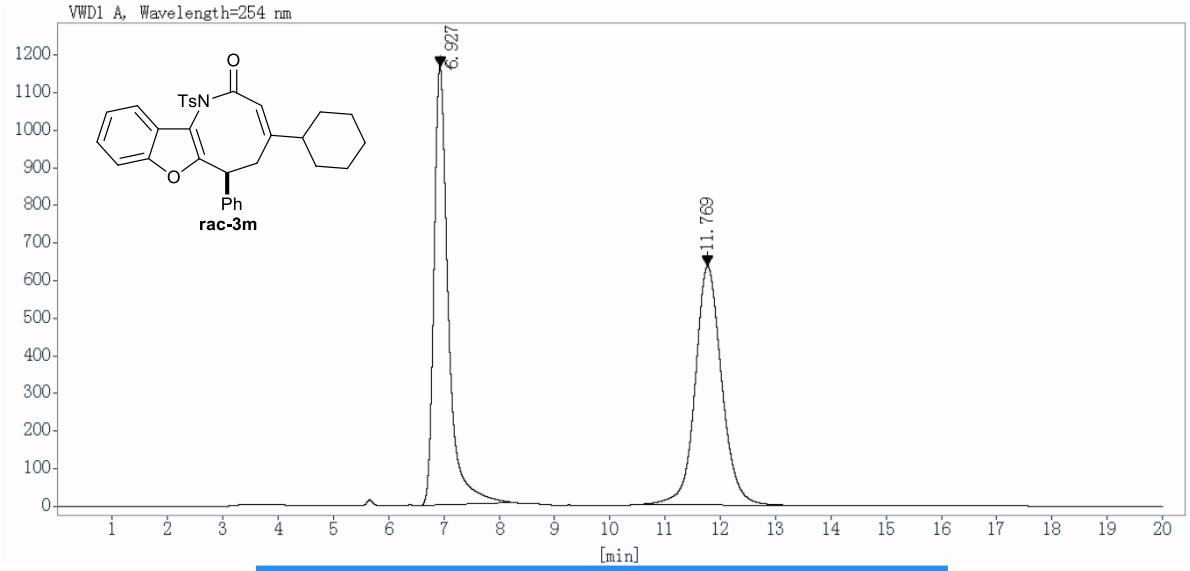
Ret Time [min]	Peak Type	Width [min]	Height [mAU]	Area [mAU*s]	Area [%]
9.417	BB	0.37	263.4530	6513.8037	49.4289
13.749	BB	0.59	173.8287	6664.3164	50.5711
			Totals:	13178.1201	100.0000



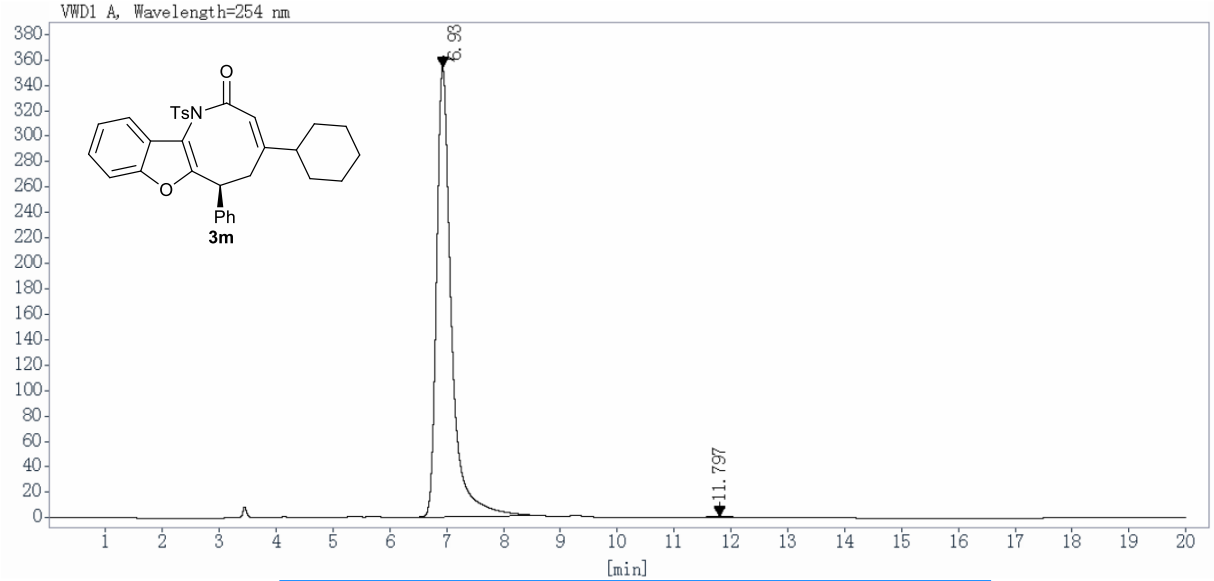
Ret Time [min]	Peak Type	Width [min]	Height [mAU]	Area [mAU*s]	Area [%]
9.417	VB R	0.38	635.5698	15894.7959	99.5647
13.752	BB	0.53	1.9722	69.4982	0.4353
			Totals:	15964.2941	100.0000


7.997
7.976
7.575
7.572
7.568
7.557
7.552
7.508
7.504
7.499
7.490
7.487
7.484
7.440
7.422
7.418
7.406
7.402
7.385
7.381
7.368
7.364
7.361
7.345
7.342
7.327
7.309
7.305
7.291
7.287
7.275
7.273
7.270
7.267
7.256
7.253
7.235
5.636
5.634
4.389
4.377
4.354
4.342
3.081
3.046
2.566
2.563
2.554
2.551
2.412
1.979
1.798
1.767
1.759
1.274
1.264
1.257
1.252
1.244
1.241
1.236
1.233
1.213
1.208
1.185
1.177
1.147
1.140
1.133
1.103
1.095
0.000
O
TsN
O
Ph
3m
1H NMR (400 MHz, CDCl3)
2.00
0.94
1.97
2.01
3.70
1.24
1.14
1.01
1.02
1.04
1.03
3.07
1.06
4.28
6.26
f1 (ppm)

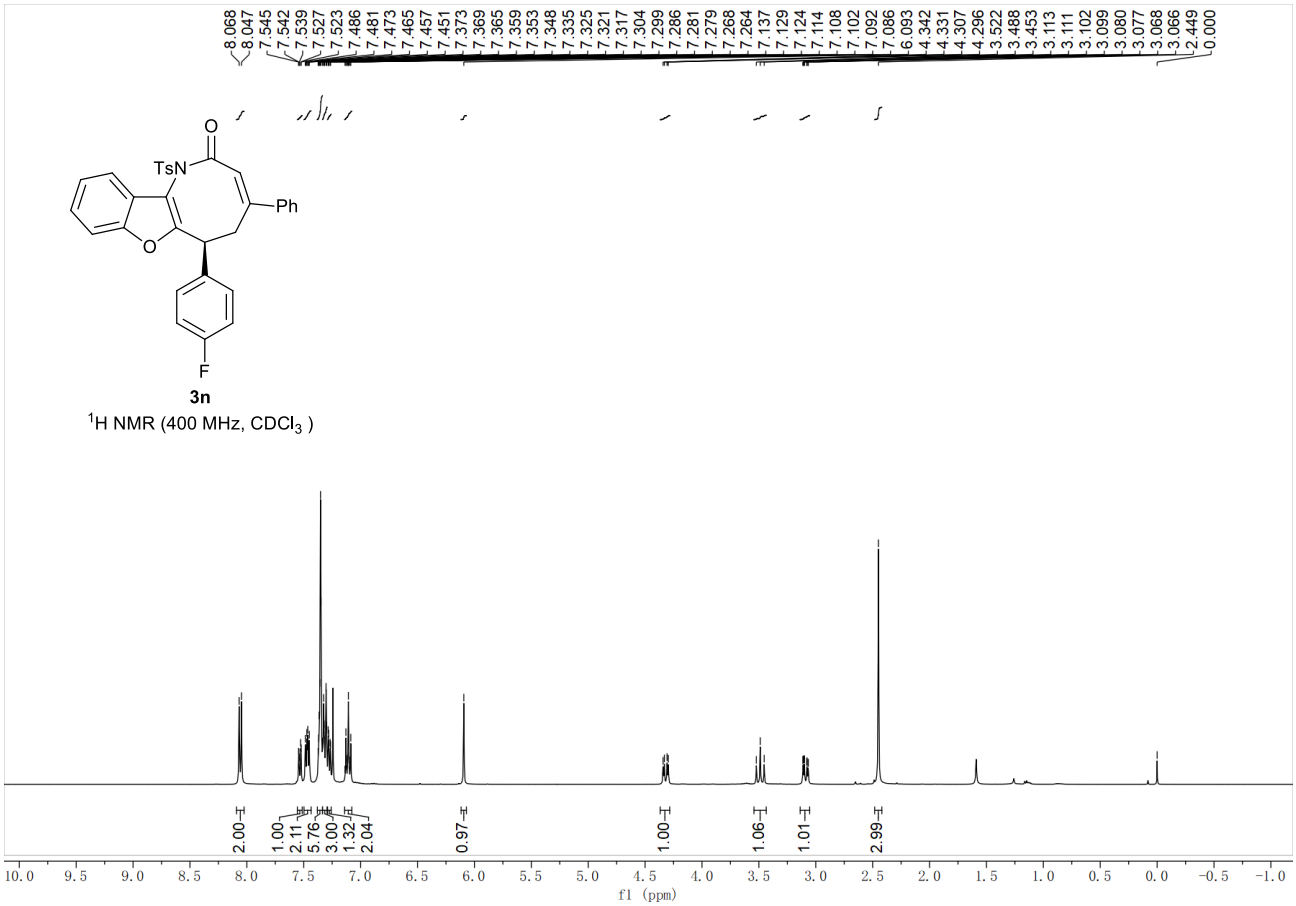

168.840
156.464
154.625
152.755
145.332
140.290
135.379
130.063
129.270
129.076
127.553
127.504
127.228
124.933
123.471
119.878
119.330
116.596
111.395
77.319
77.000
76.683
45.896
43.835
36.300
32.615
31.475
26.512
26.106
25.815
21.657
O
TsN
O
Ph
3m
13C NMR (100 MHz, CDCl3)
f1 (ppm)



Ret Time [min]	Peak Type	Width [min]	Height [mAU]	Area [mAU*s]	Area [%]
6.927	BBA	0.27	1166.4375	20958.7441	49.8845
11.769	BBA	0.51	634.7198	21055.8320	50.1155
			Totals:	42014.5762	100.0000

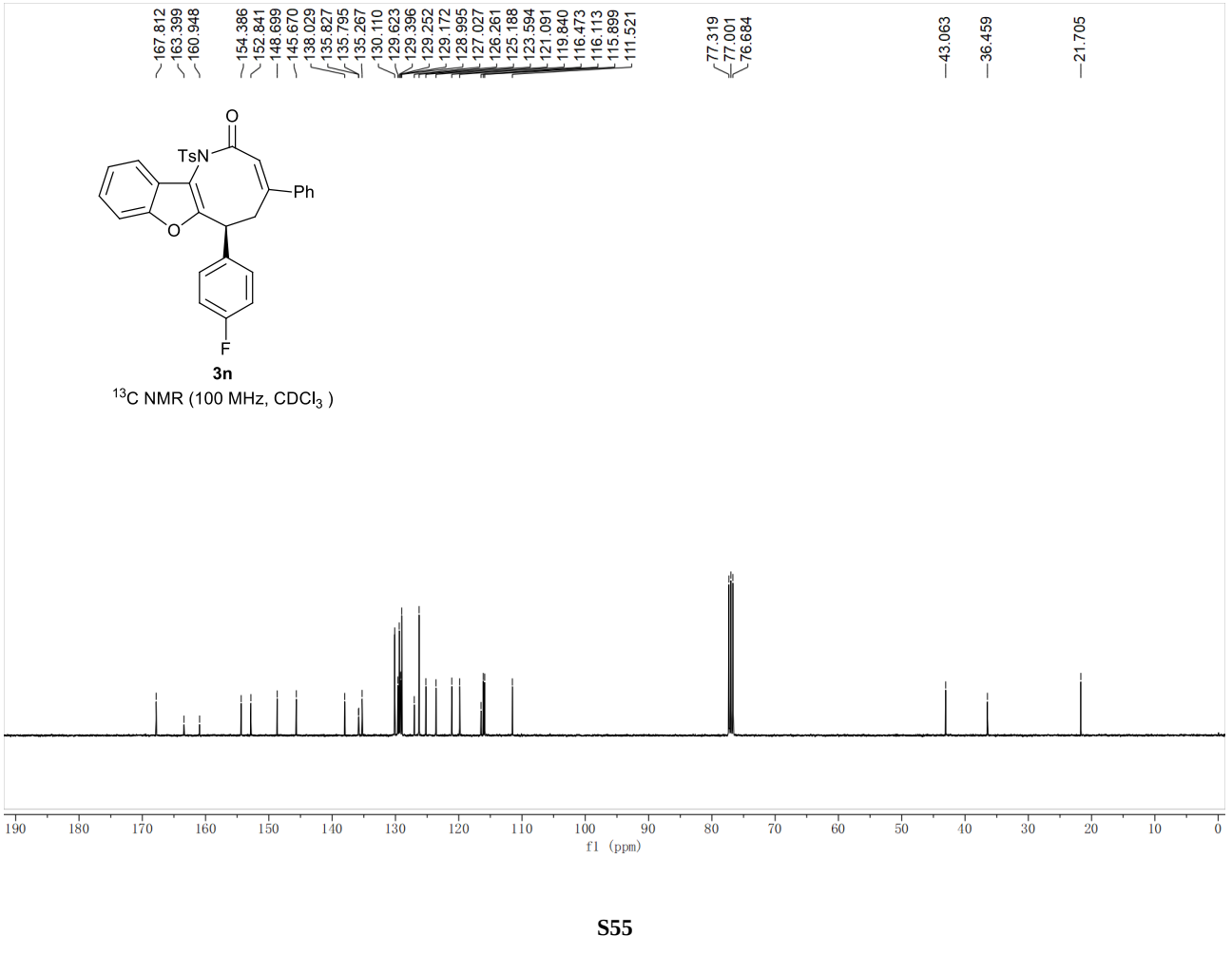


Ret Time [min]	Peak Type	Width [min]	Height [mAU]	Area [mAU*s]	Area [%]
6.930	BBA	0.27	353.9284	6420.7729	99.4757
11.797	BB	0.44	1.1277	33.8421	0.5243
			Totals:	6454.6150	100.0000



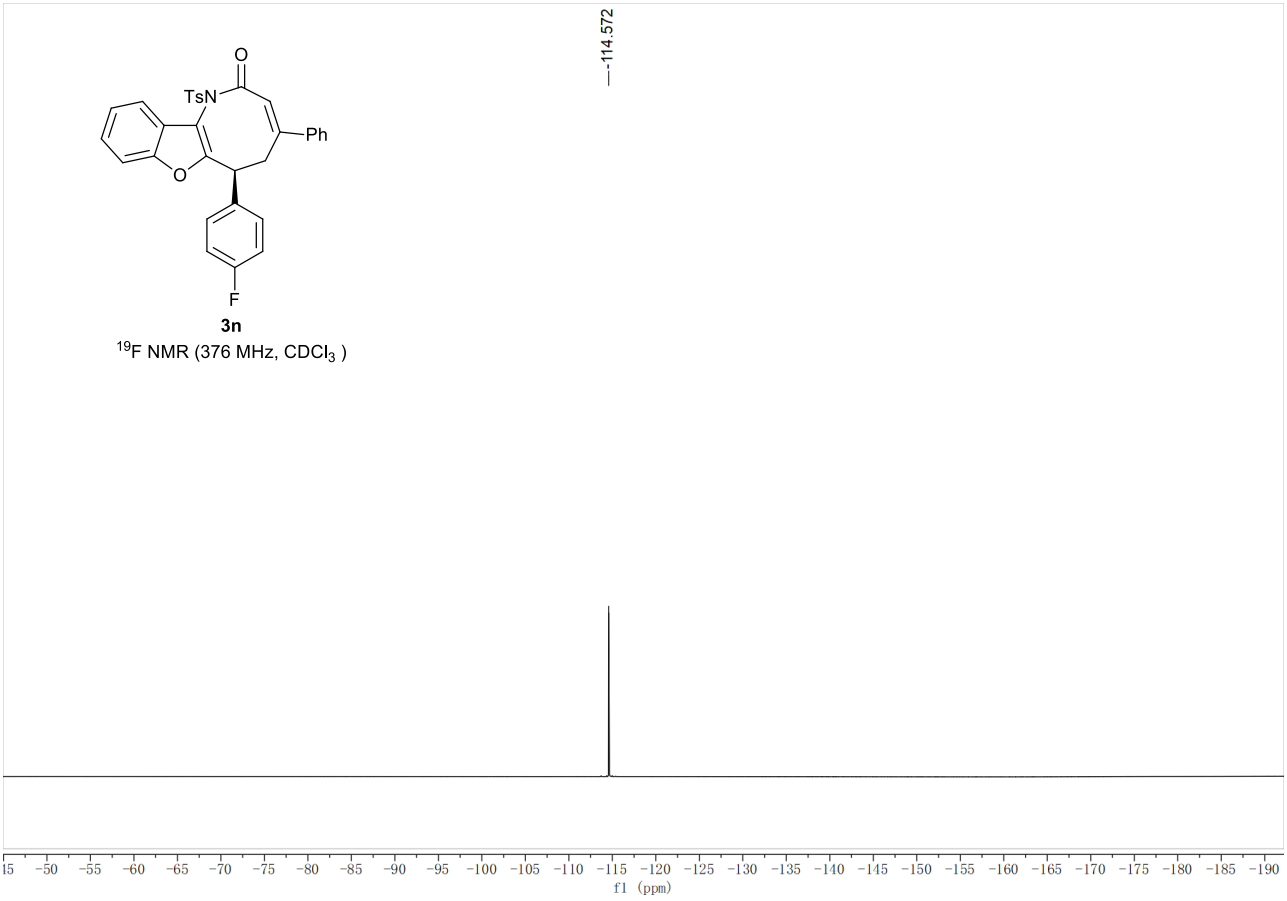
3n

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



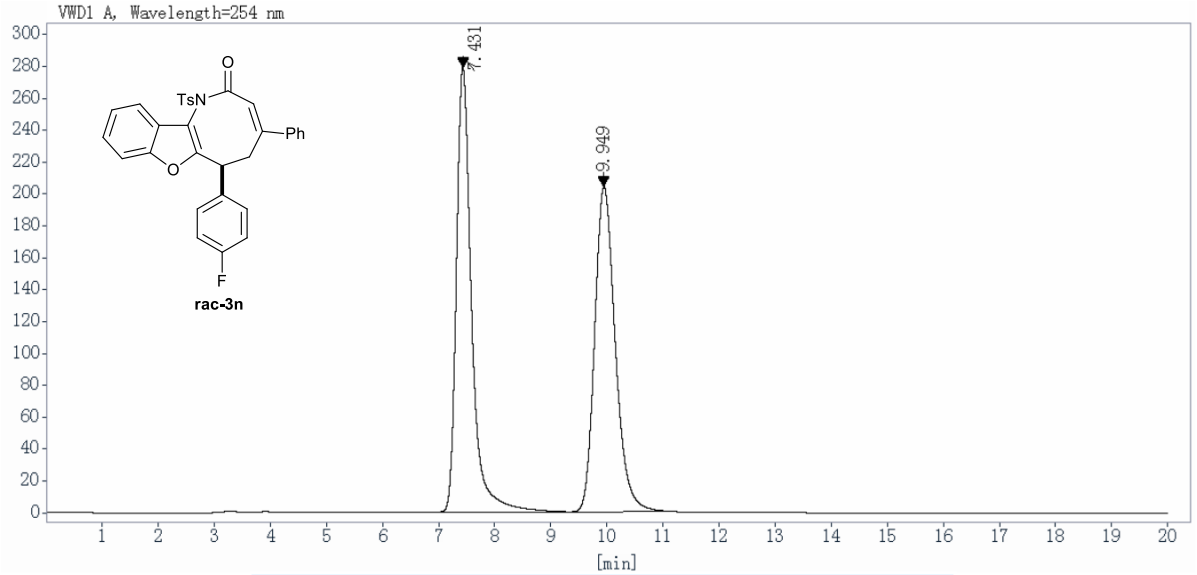
3n

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

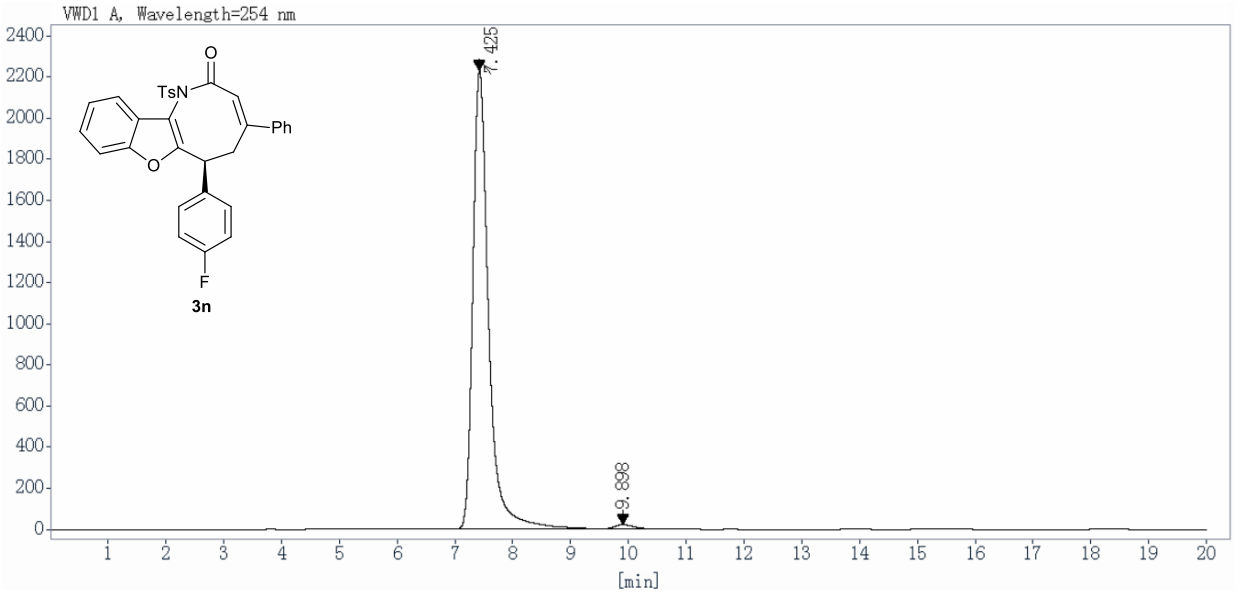


3n

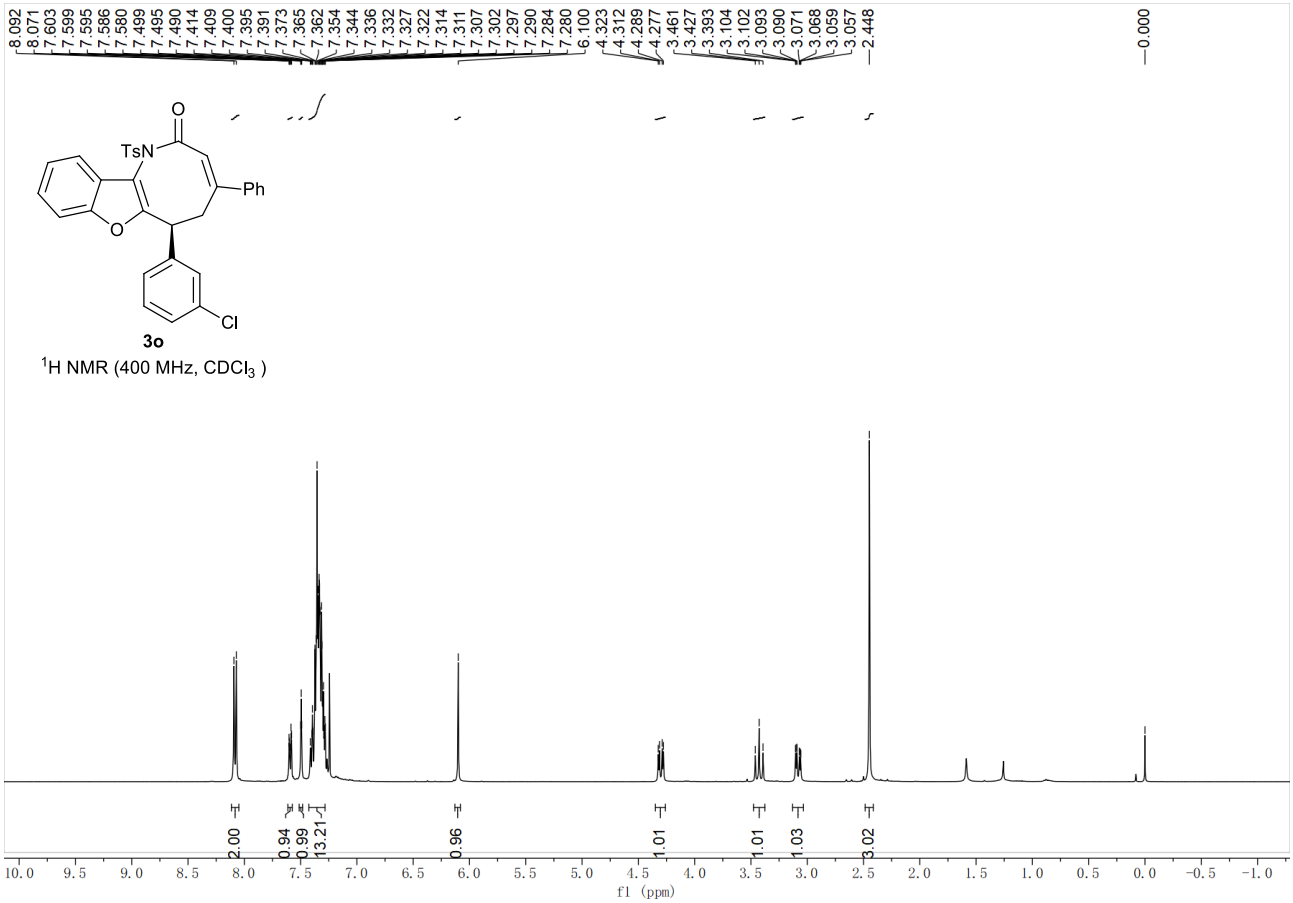
^{19}F NMR (376 MHz, $CDCl_3$)



Ret Time [min]	Peak Type	Width [min]	Height [mAU]	Area [mAU*s]	Area [%]
7.431	BB	0.28	279.0585	5240.0254	50.1881
9.949	BBA	0.39	204.1430	5200.7554	49.8119
			Totals:	10440.7808	100.0000

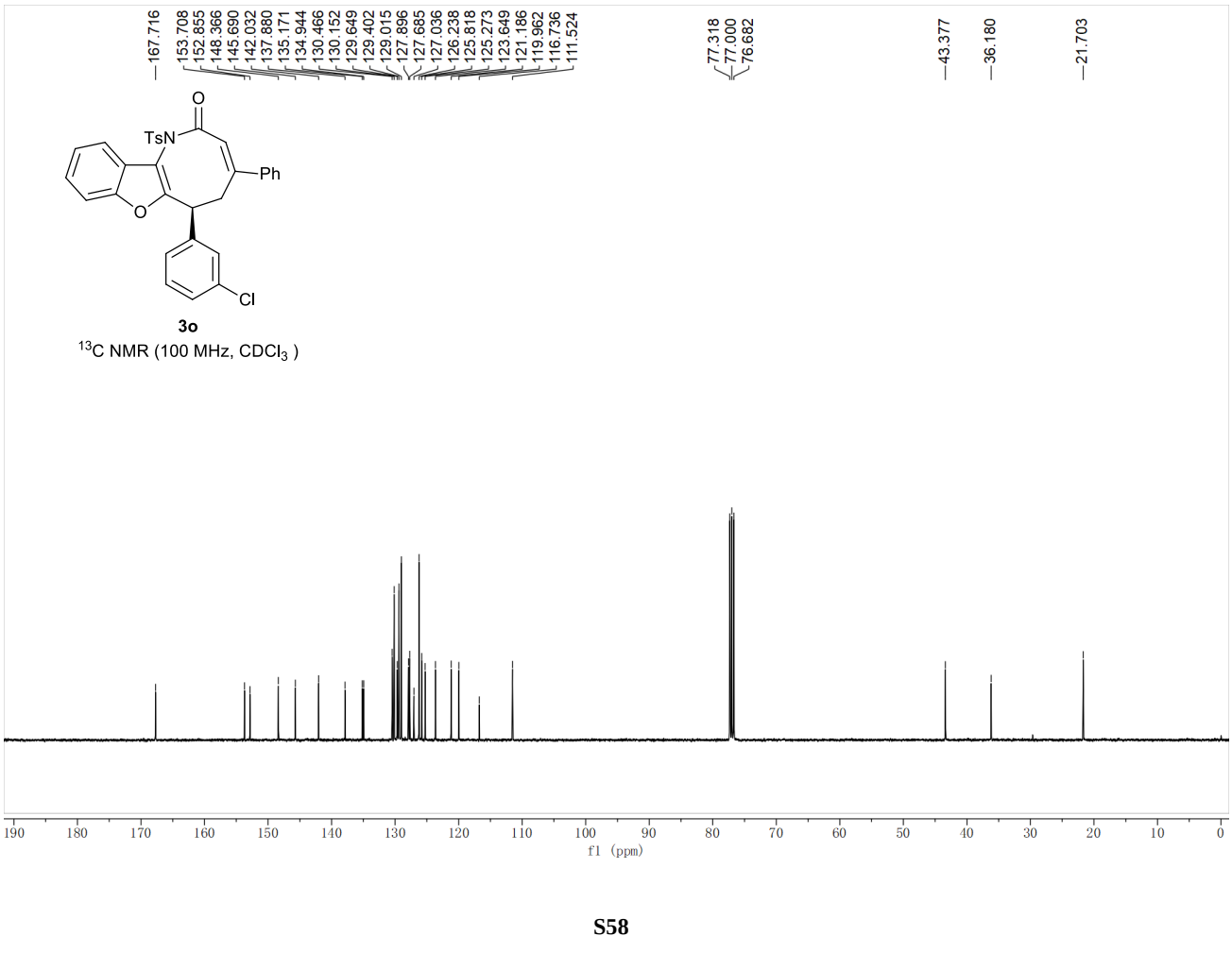


Ret Time [min]	Peak Type	Width [min]	Height [mAU]	Area [mAU*s]	Area [%]
7.425	BV R	0.29	2232.8481	42571.4063	98.7607
9.898	VBAE	0.37	21.5281	534.2011	1.2393
			Totals:	43105.6074	100.0000



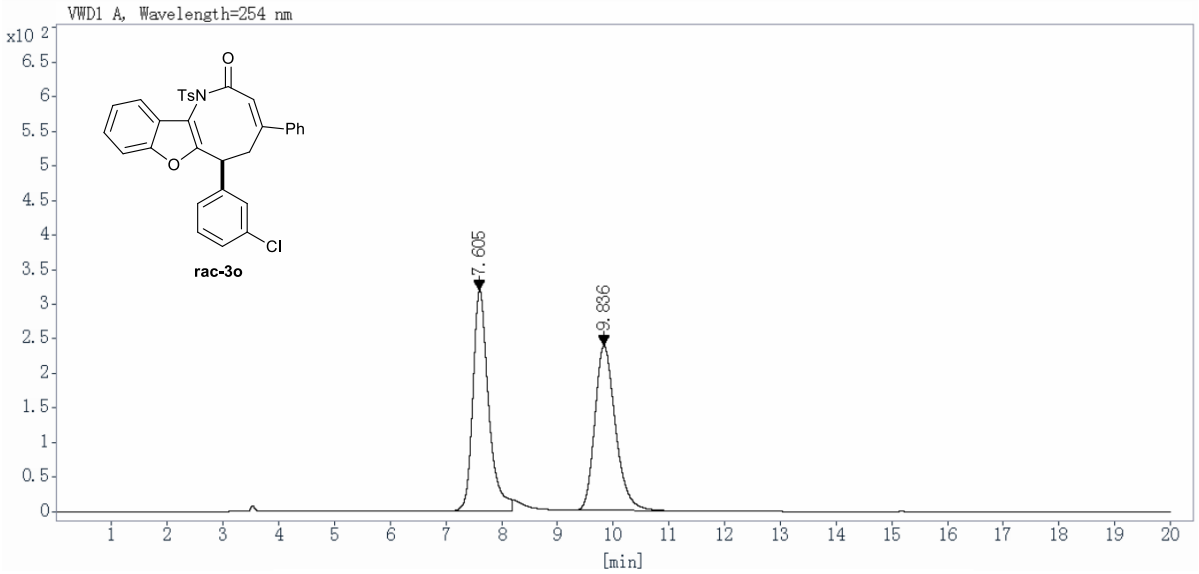
3o

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

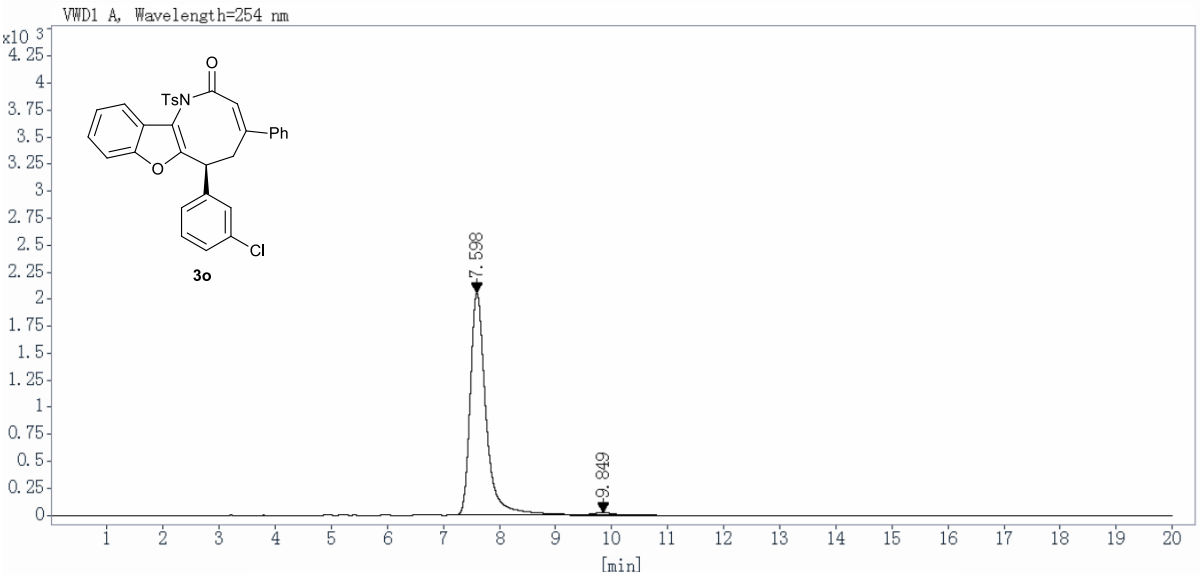


3o

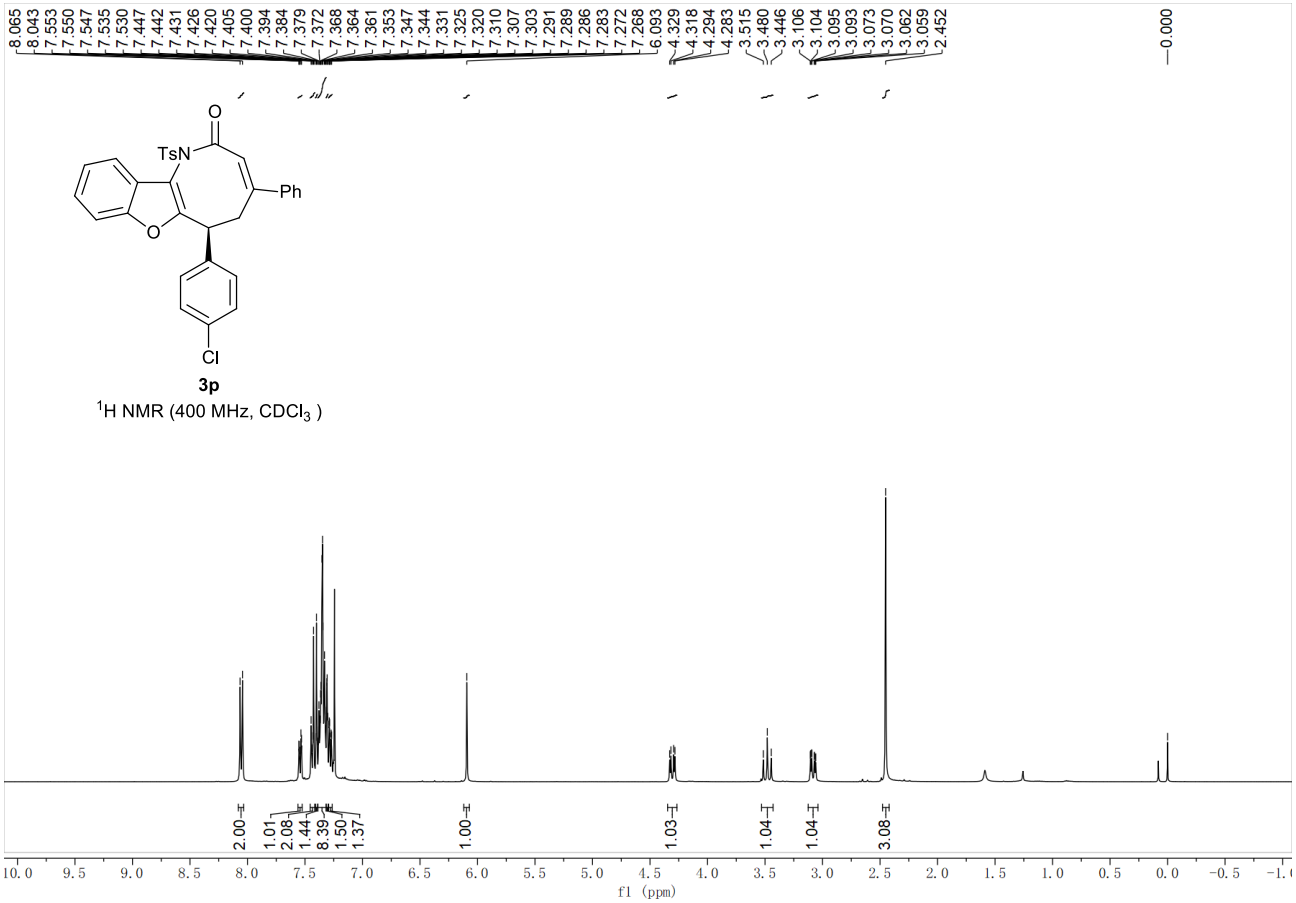
^{13}C NMR (100 MHz, $CDCl_3$)

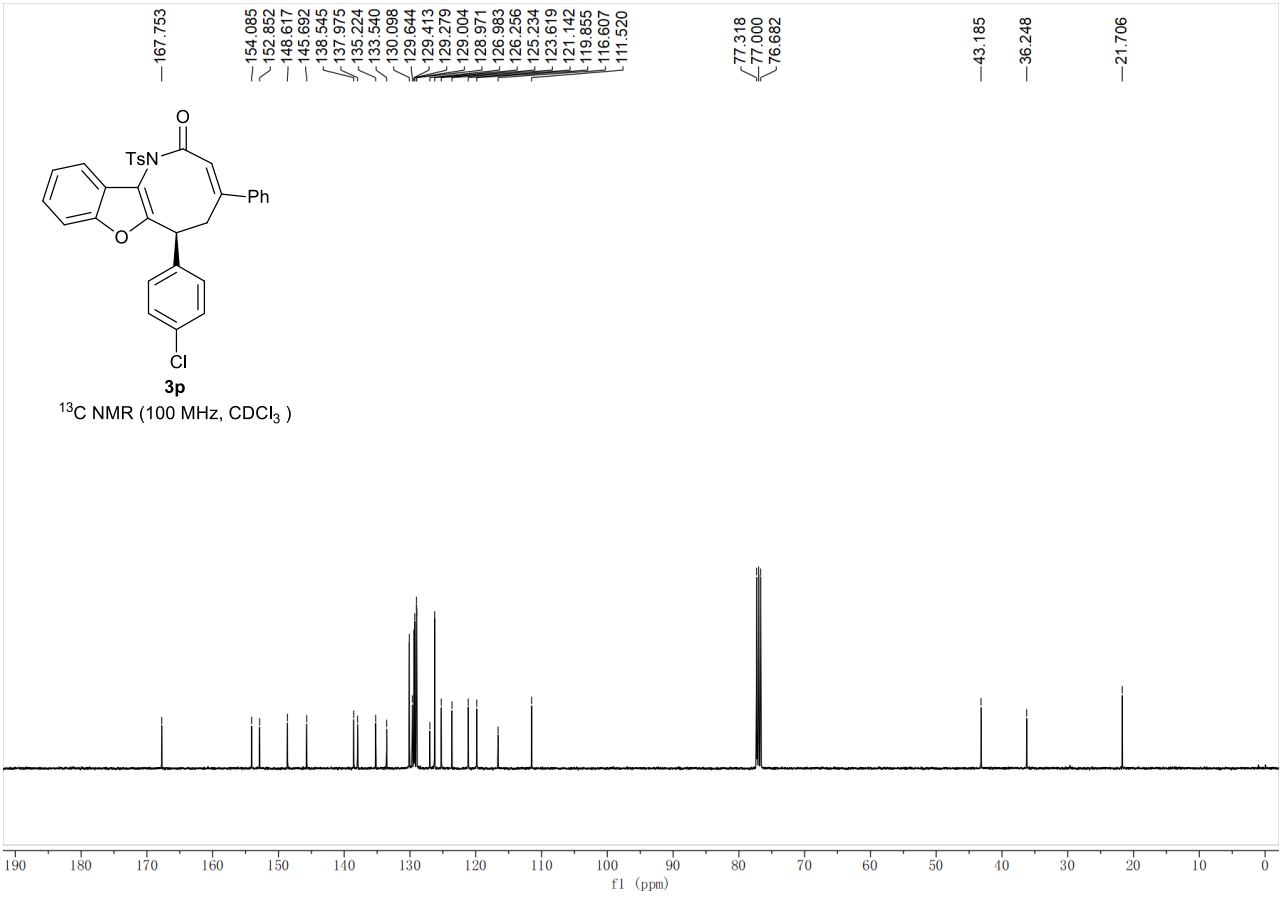


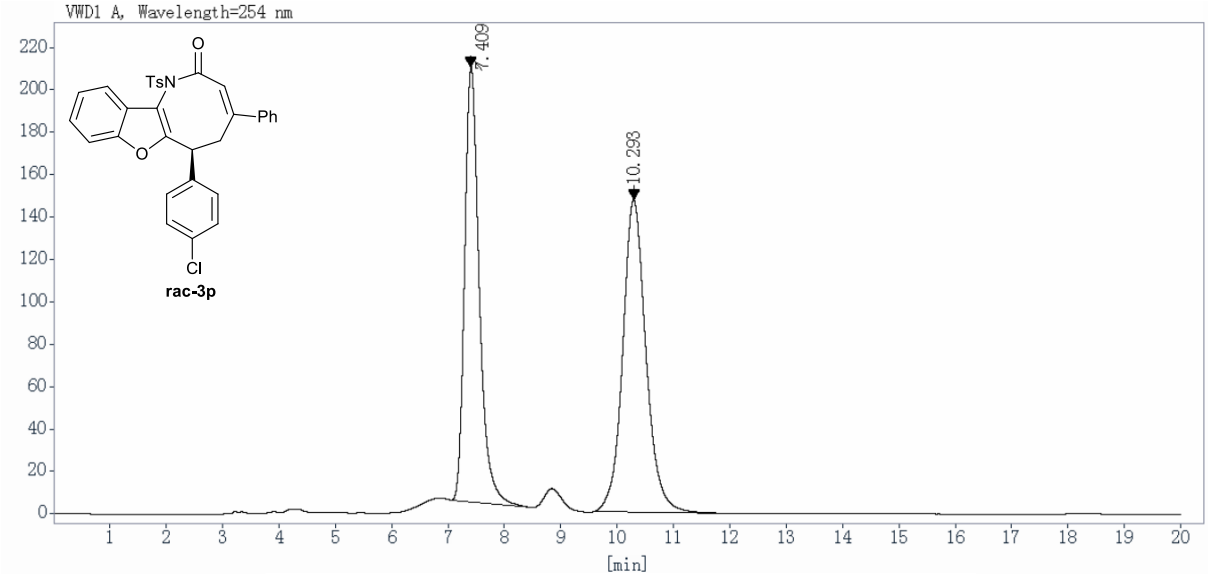
Ret Time [min]	Peak Type	Width [min]	Height [mAU]	Area [mAU*s]	Area [%]
7.605	BBAS	0.29	320.1003	6253.8408	50.3664
9.836	BBA	0.40	238.8536	6162.8618	49.6336
			Totals:	12416.7026	100.0000



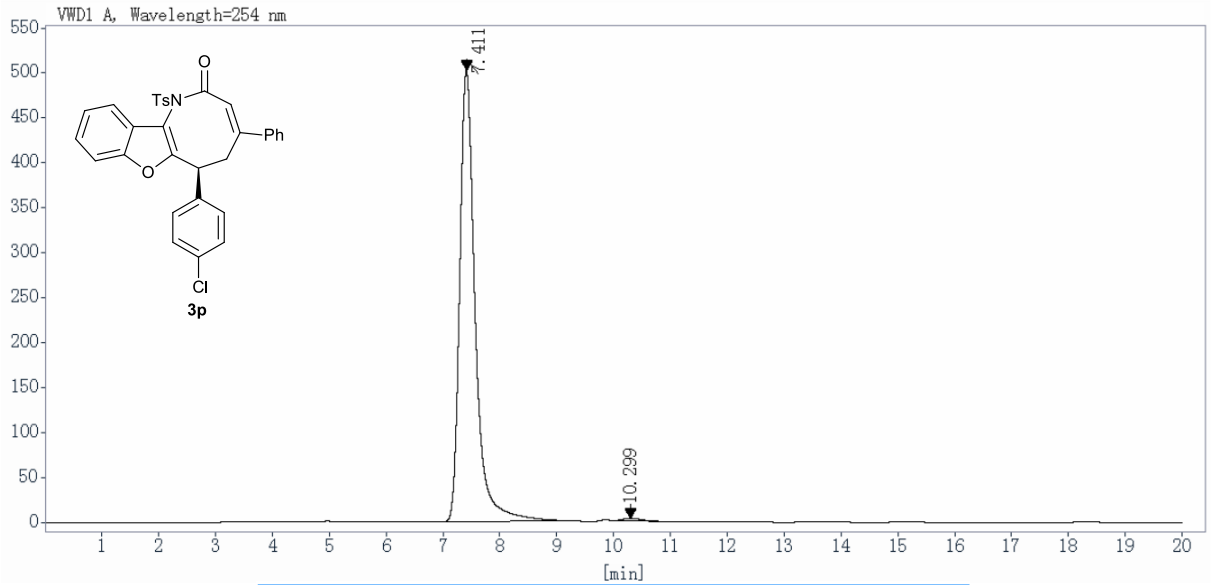
Ret Time [min]	Peak Type	Width [min]	Height [mAU]	Area [mAU*s]	Area [%]
7.598	BV R	0.30	2060.0847	40488.2813	98.5892
9.849	VB E	0.33	24.9636	579.3787	1.4108
			Totals:	41067.6599	100.0000


8.065
8.043
7.553
7.550
7.547
7.535
7.530
7.447
7.442
7.431
7.426
7.420
7.405
7.400
7.394
7.384
7.379
7.372
7.368
7.364
7.361
7.353
7.347
7.344
7.331
7.325
7.320
7.310
7.307
7.303
7.291
7.289
7.286
7.283
7.272
7.268
6.093
4.329
4.318
4.294
4.283
3.515
3.480
3.446
3.106
3.104
3.095
3.093
3.073
3.070
3.062
3.059
2.452
0.000
O
TsN
Ph
O
Cl
3p
1H NMR (400 MHz, CDCl3)
2.00
1.01
2.08
1.44
8.39
1.50
1.37
1.00
1.03
1.04
1.04
3.08
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)

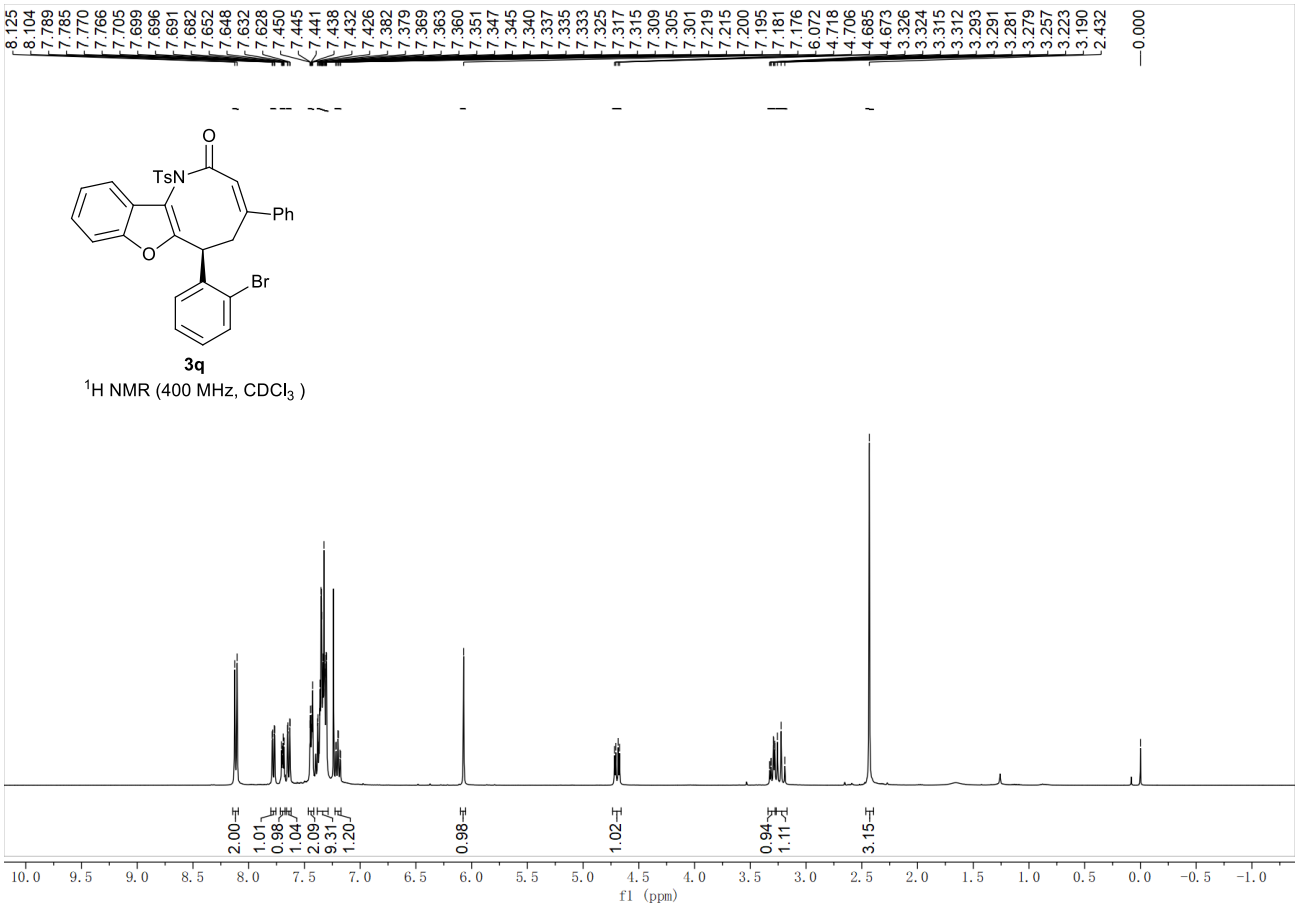

167.753
154.085
152.852
148.617
145.692
138.545
137.975
135.224
133.540
130.098
129.644
129.413
129.279
129.004
128.971
126.983
126.256
125.234
123.619
121.142
119.855
116.607
111.520
77.318
77.000
76.682
43.185
36.248
21.706
O
TsN
Ph
O
Cl
3p
13C NMR (100 MHz, CDCl3)
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)



Ret Time [min]	Peak Type	Width [min]	Height [mAU]	Area [mAU*s]	Area [%]
7.409	BB	0.27	205.2454	3687.1990	46.5773
10.293	BB	0.43	147.4498	4229.1021	53.4227
			Totals:	7916.3010	100.0000

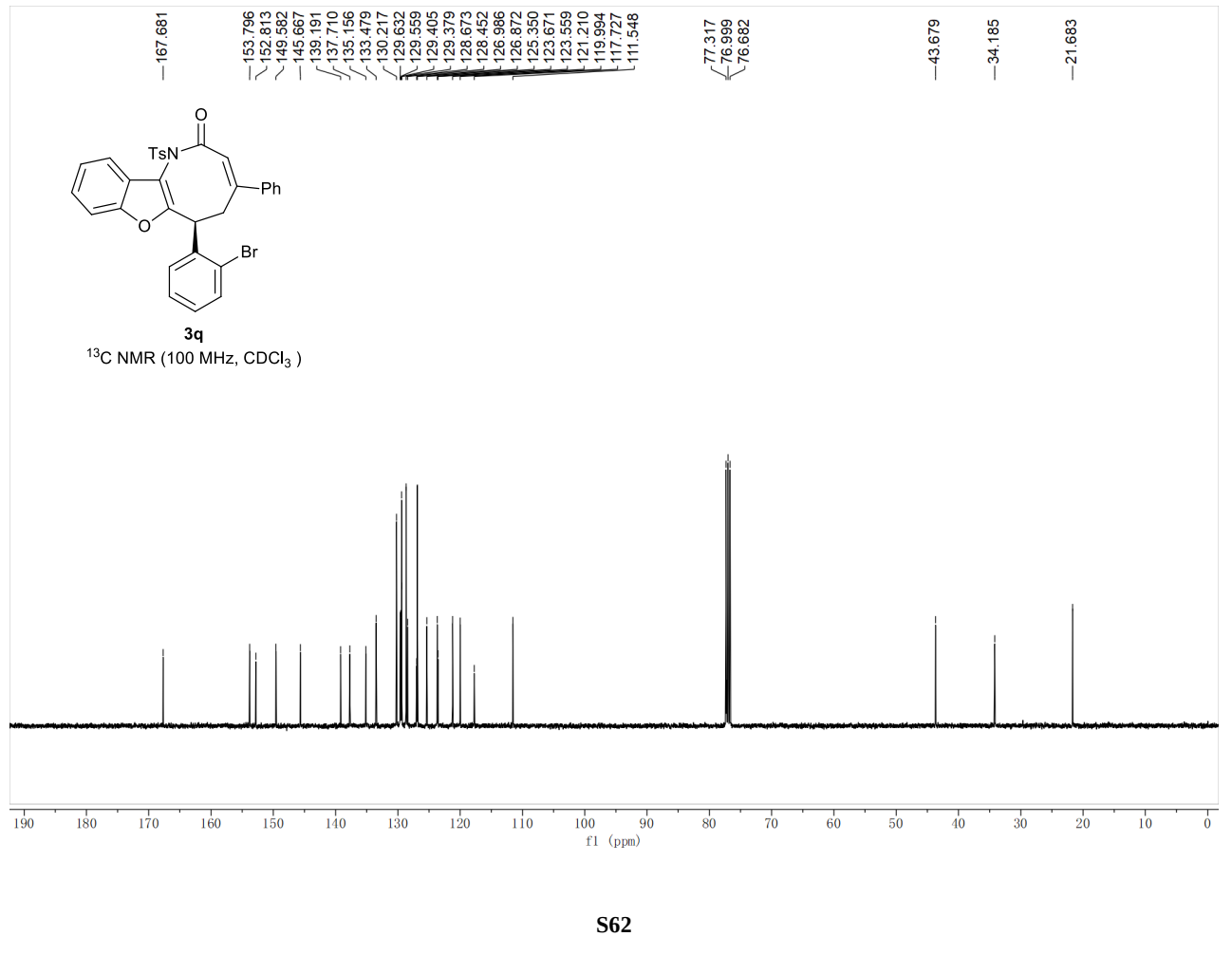


Ret Time [min]	Peak Type	Width [min]	Height [mAU]	Area [mAU*s]	Area [%]
7.411	BBA	0.28	502.5486	9516.1807	99.2598
10.299	BB	0.37	2.9117	70.9623	0.7402
			Totals:	9587.1430	100.0000



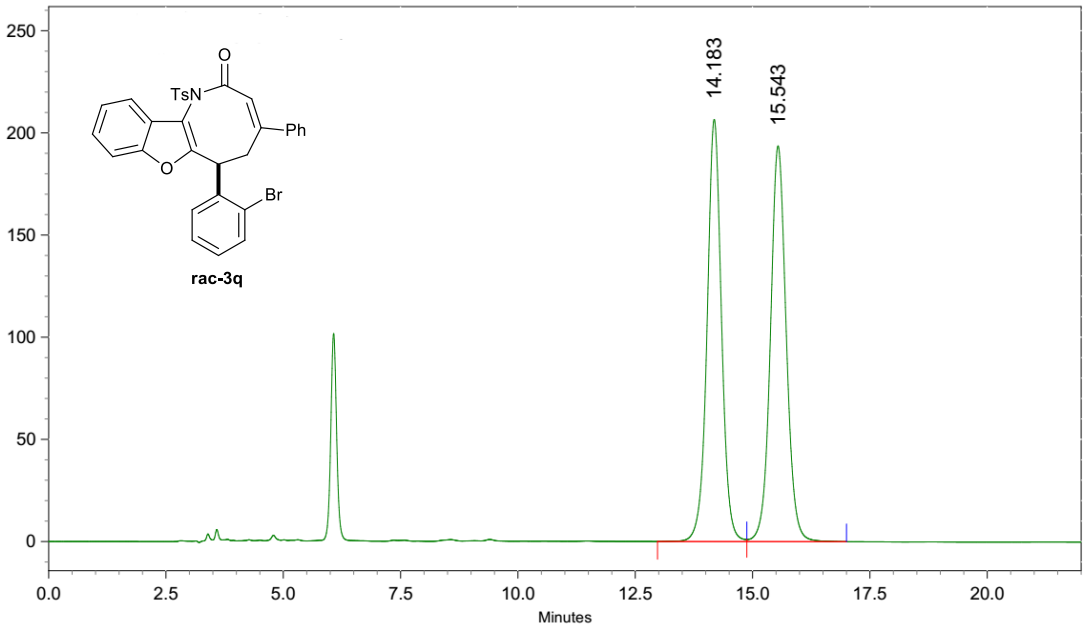
3q

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

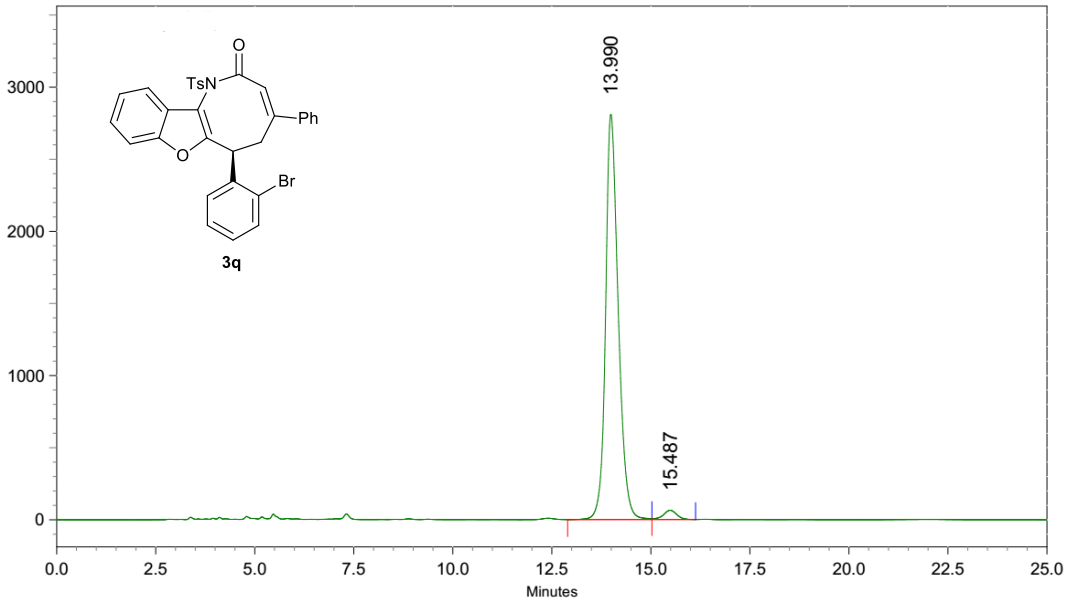


3q

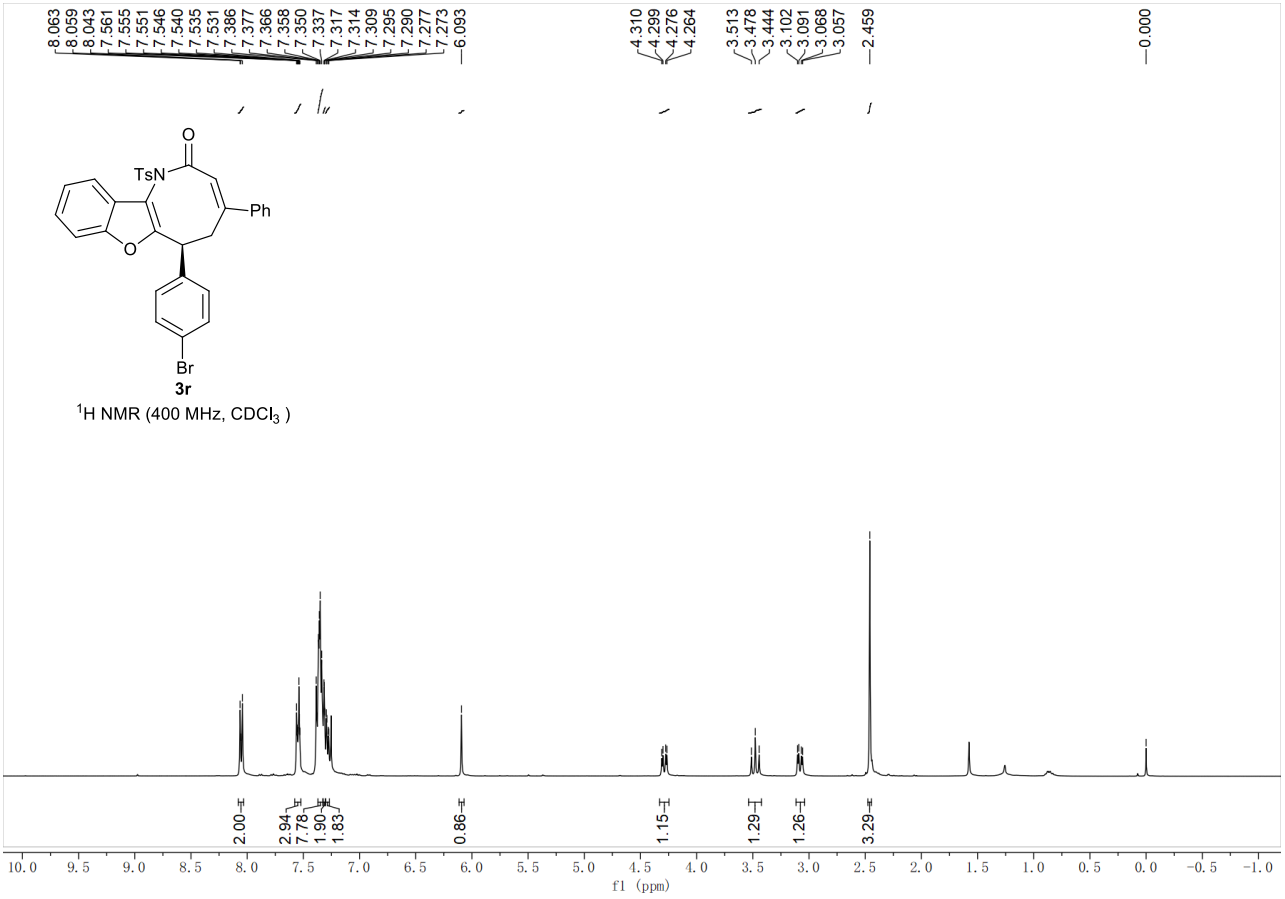
^{13}C NMR (100 MHz, $CDCl_3$)



Peak No.	Ret Time	Width	Height	Area	Area [%]
1	14.183	1.903	3467009	74044143	49.2823
2	15.543	2.123	3249764	76200725	50.7177
Totals			6716773	150244868	100.0000

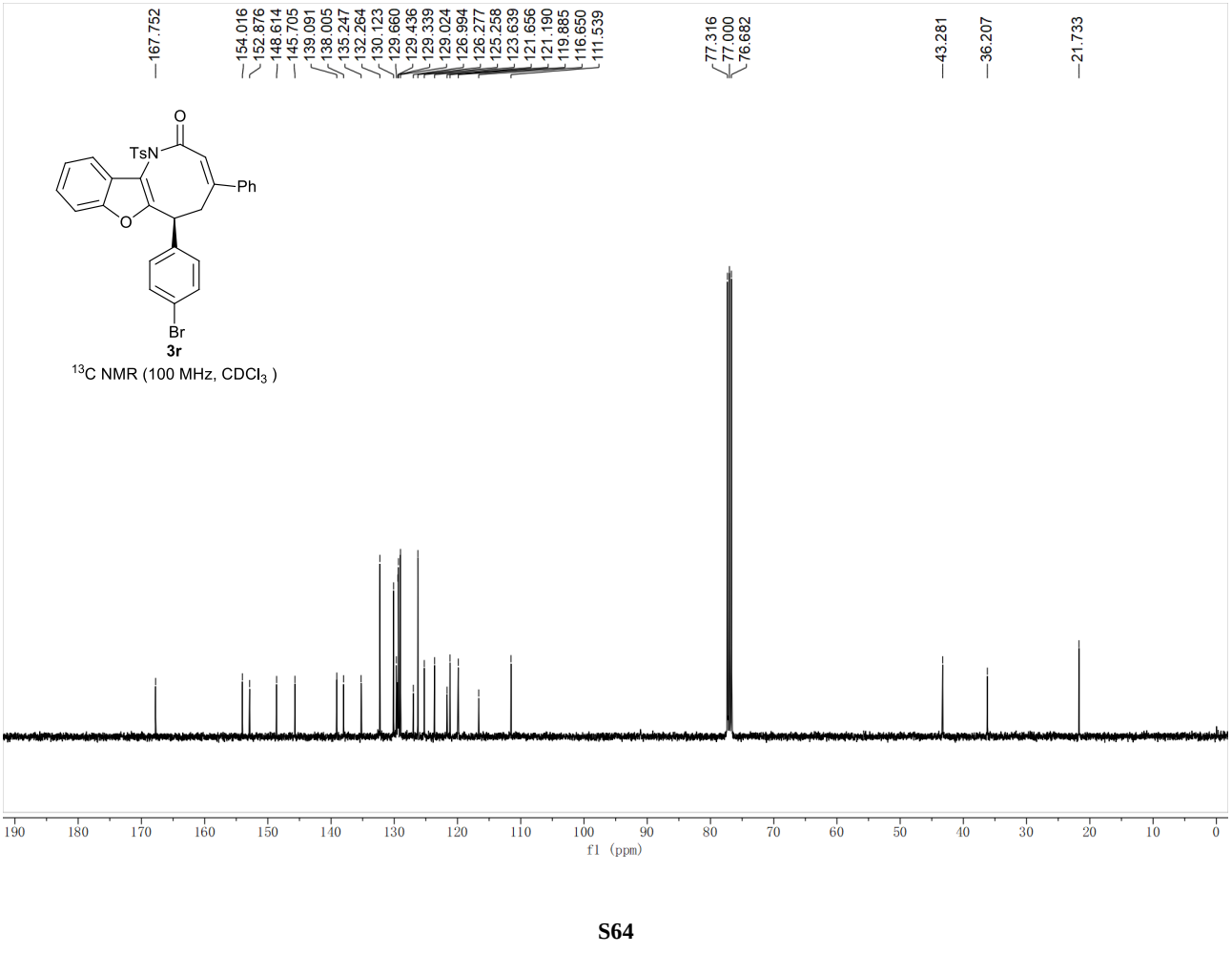


Peak No.	Ret Time	Width	Height	Area	Area [%]
1	13.990	2.127	47152489	1044504402	97.6231
2	15.487	1.103	1075695	25431594	2.3769
Totals			48228184	1069935996	100.0000



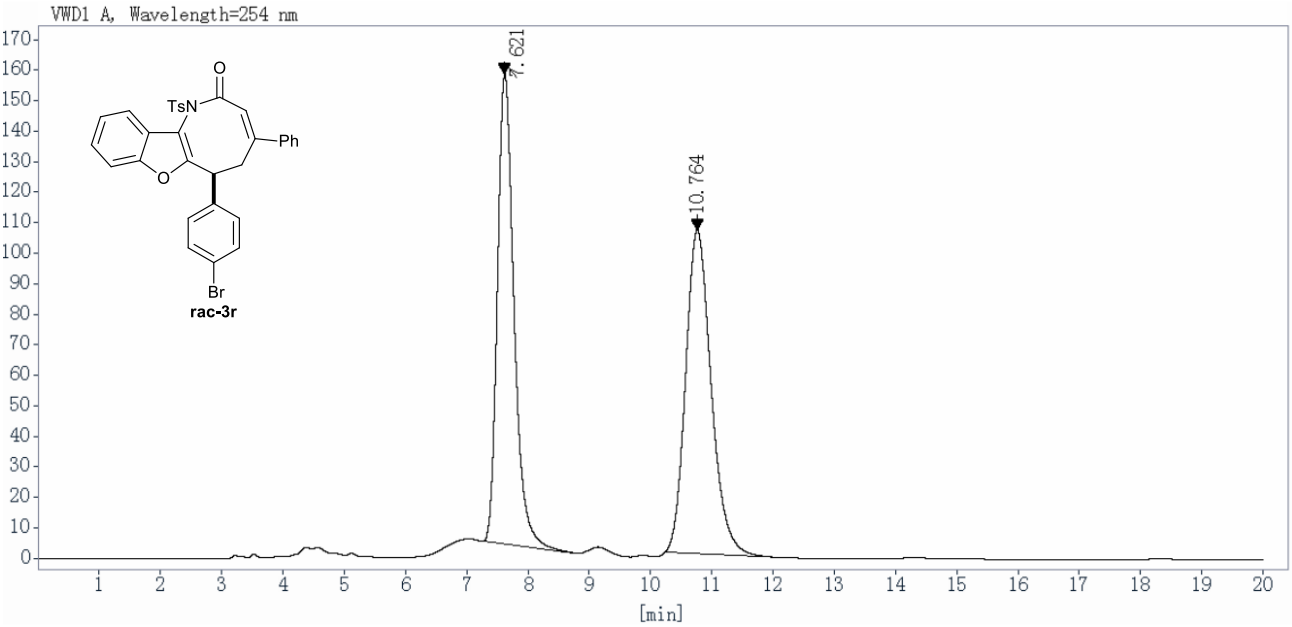
3r

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

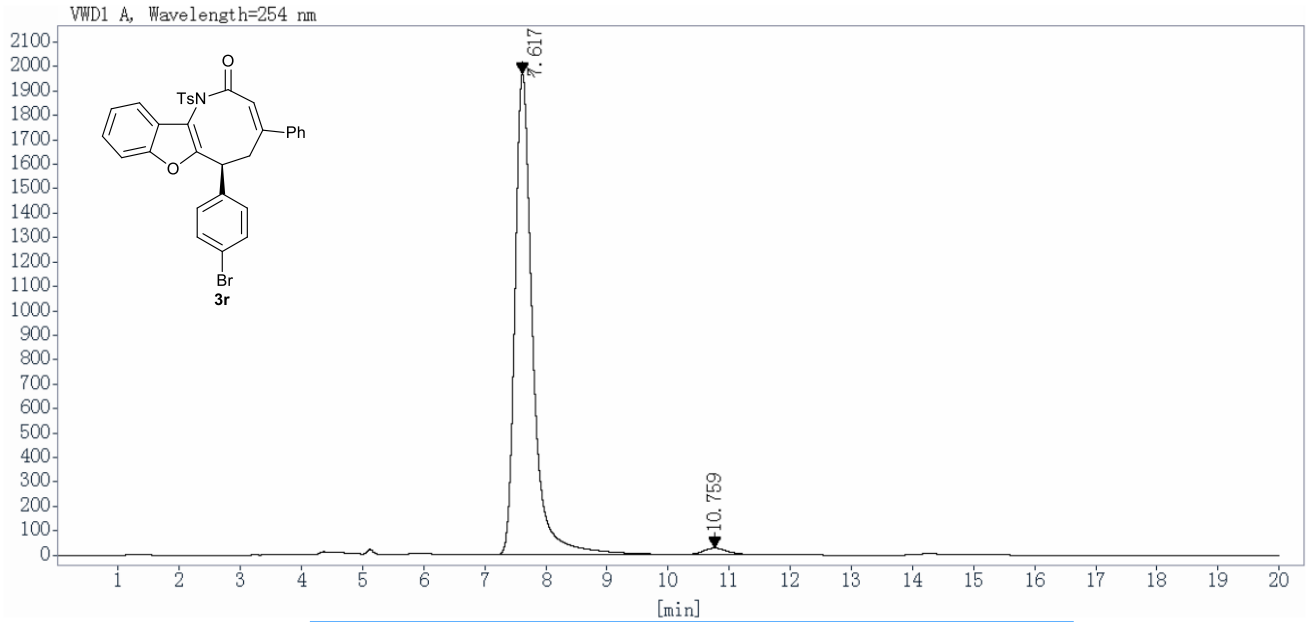


3r

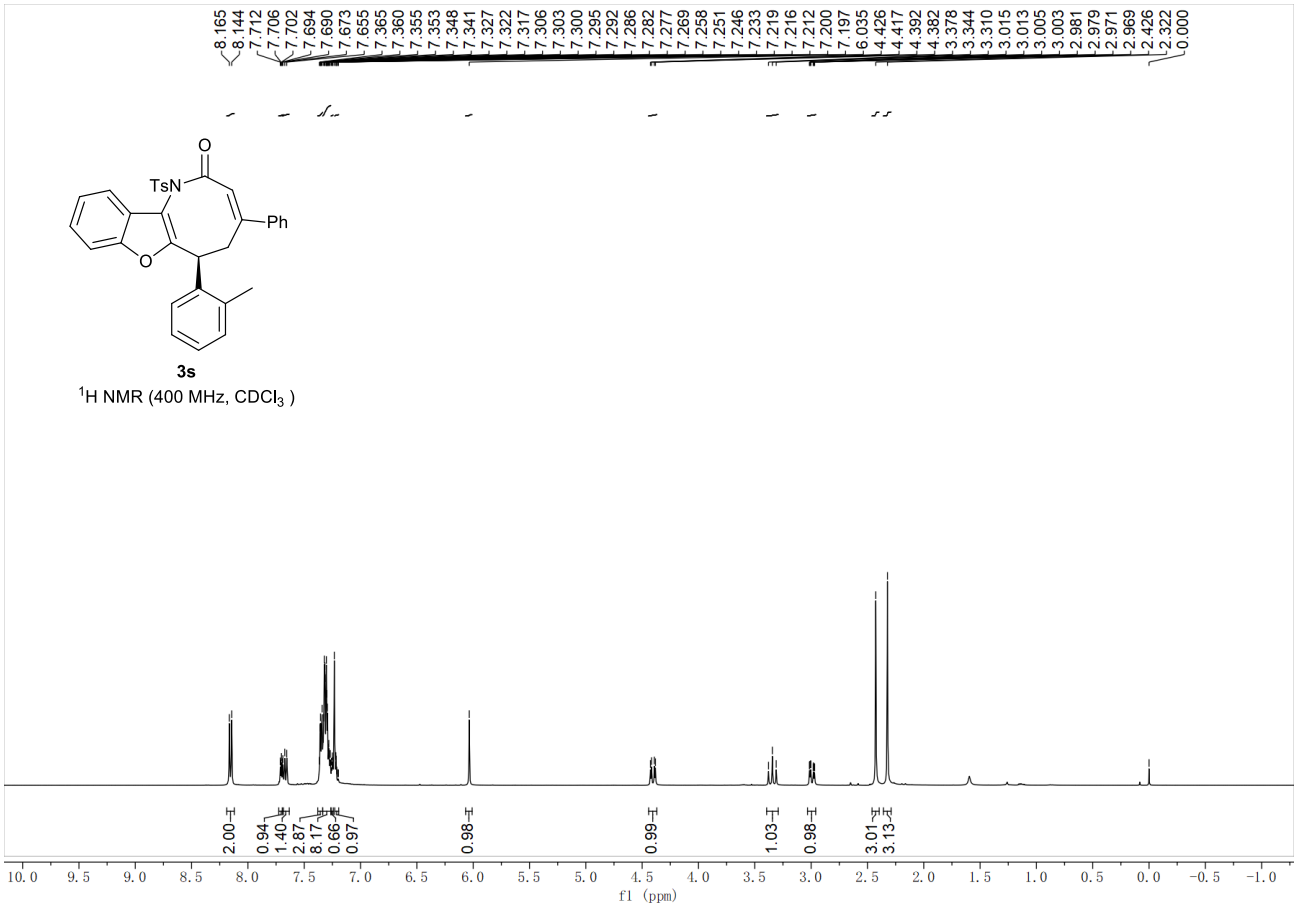
^{13}C NMR (100 MHz, $CDCl_3$)



Ret Time [min]	Peak Type	Width [min]	Height [mAU]	Area [mAU*s]	Area [%]
7.621	BBA	0.29	154.0291	2885.5017	48.4456
10.764	BB	0.44	106.0464	3070.6709	51.5544
			Totals:	5956.1726	100.0000

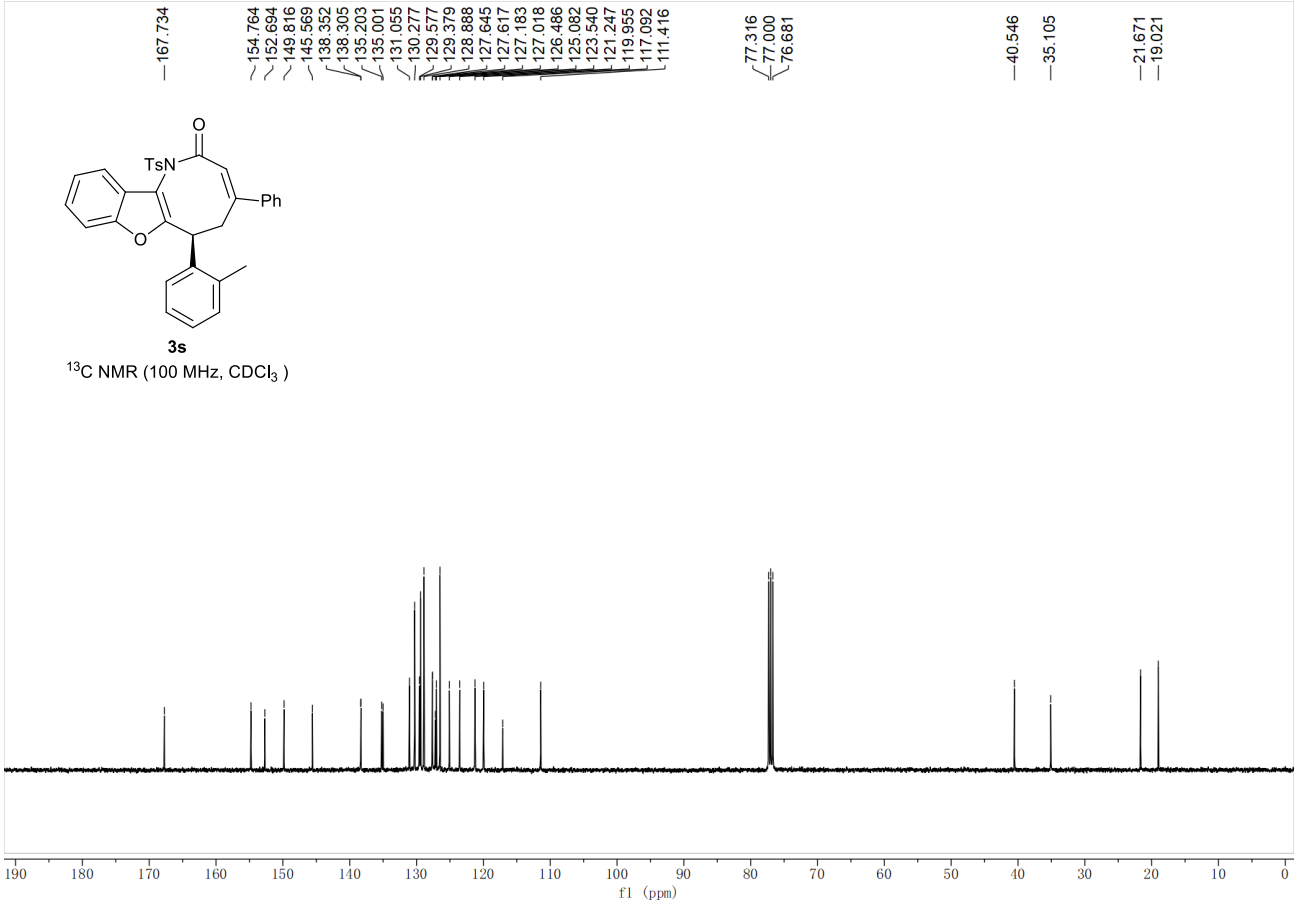


Ret Time [min]	Peak Type	Width [min]	Height [mAU]	Area [mAU*s]	Area [%]
7.617	BV R	0.30	1971.0920	39808.8828	97.9480
10.759	VB E	0.46	27.1093	833.9889	2.0520
			Totals:	40642.8717	100.0000



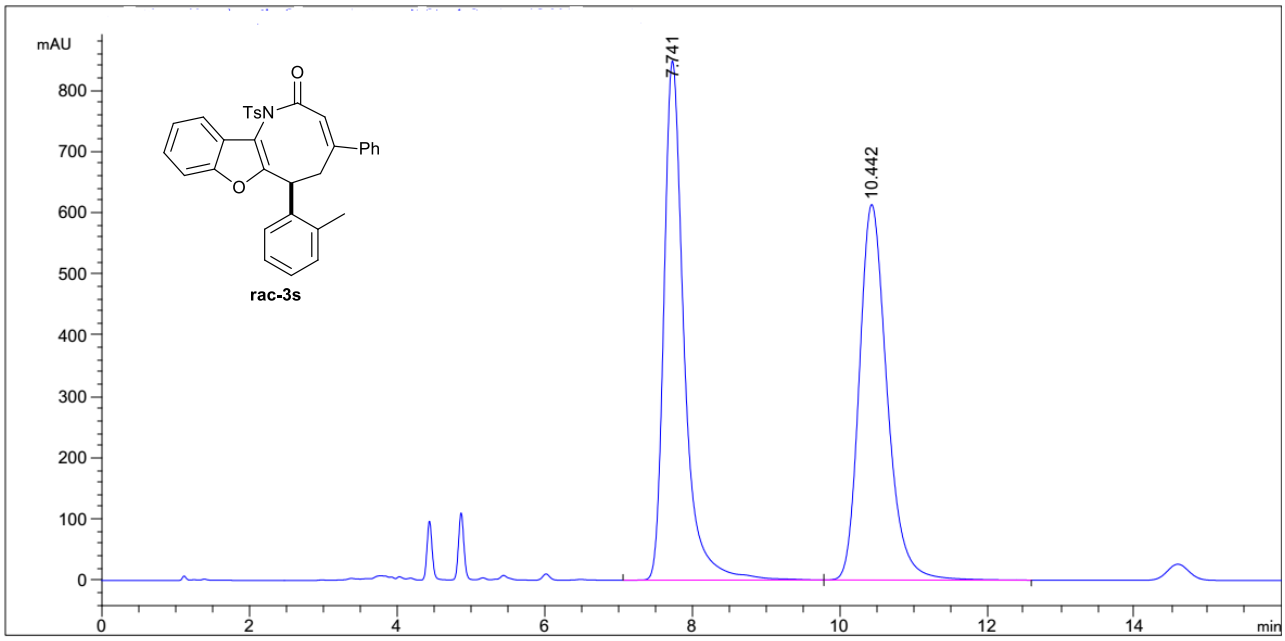
3s

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

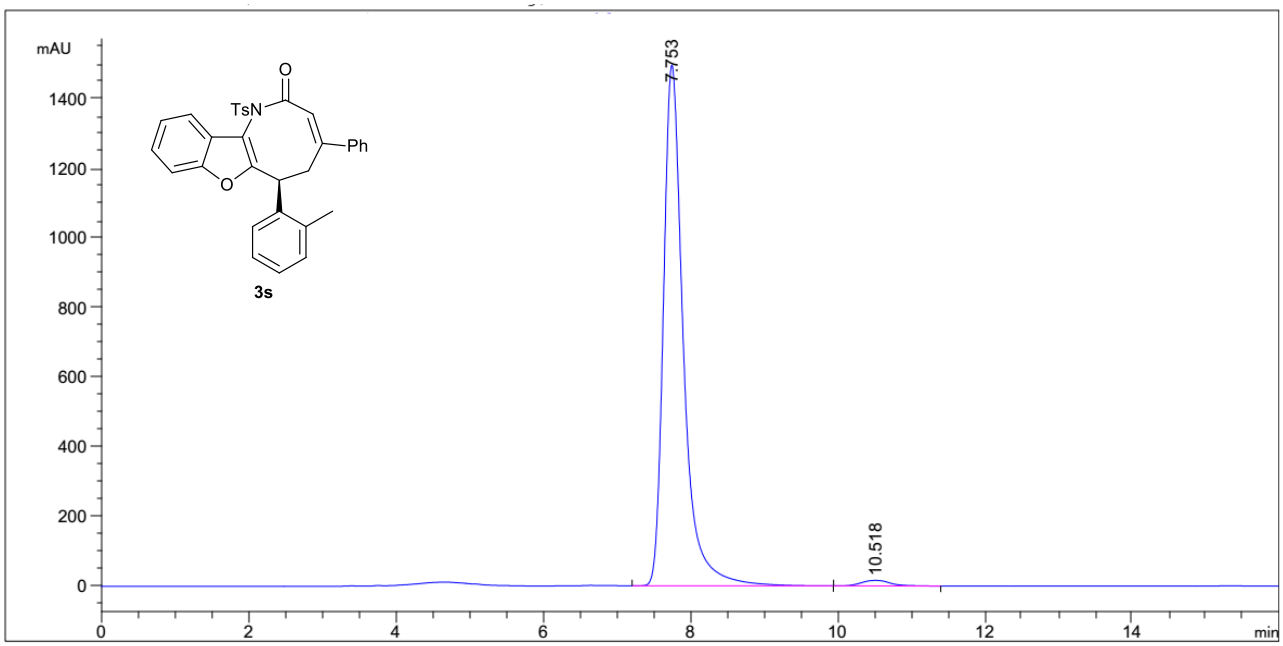


3s

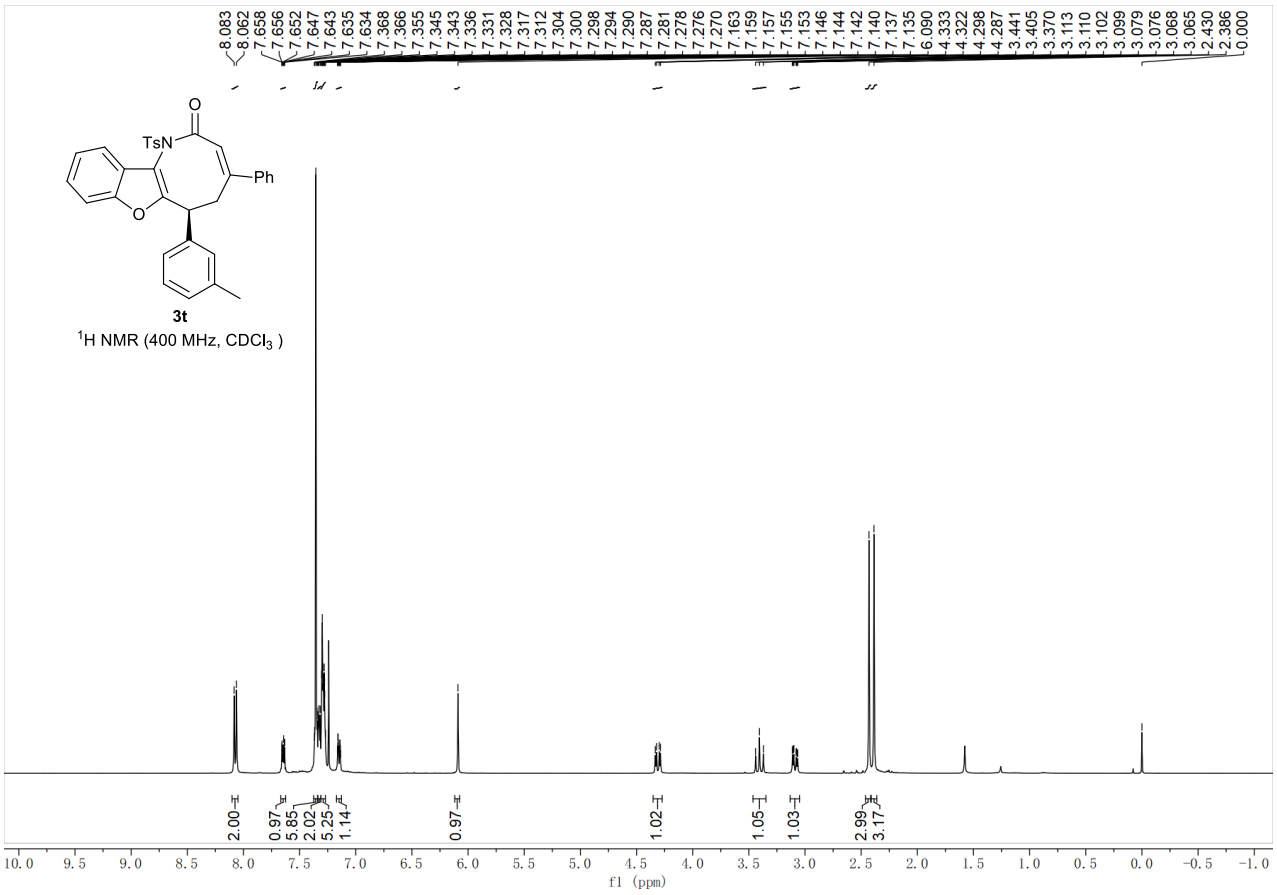
^{13}C NMR (100 MHz, $CDCl_3$)



Peak #	RetTime [min]	Type	Width [min]	Area mAU *s	Height [mAU]	Area %
1	7.741	BB	0.2845	1.60071e4	847.27454	50.1066
2	10.442	BBA	0.3996	1.59390e4	612.64893	49.8934
Totals :				3.19462e4	1459.92346	



Peak #	RetTime [min]	Type	Width [min]	Area mAU *s	Height [mAU]	Area %
1	7.753	BB	0.2832	2.80819e4	1494.92029	98.4621
2	10.518	BB	0.4343	438.60648	15.88174	1.5379
Totals :				2.85205e4	1510.80203	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7.652
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7.635
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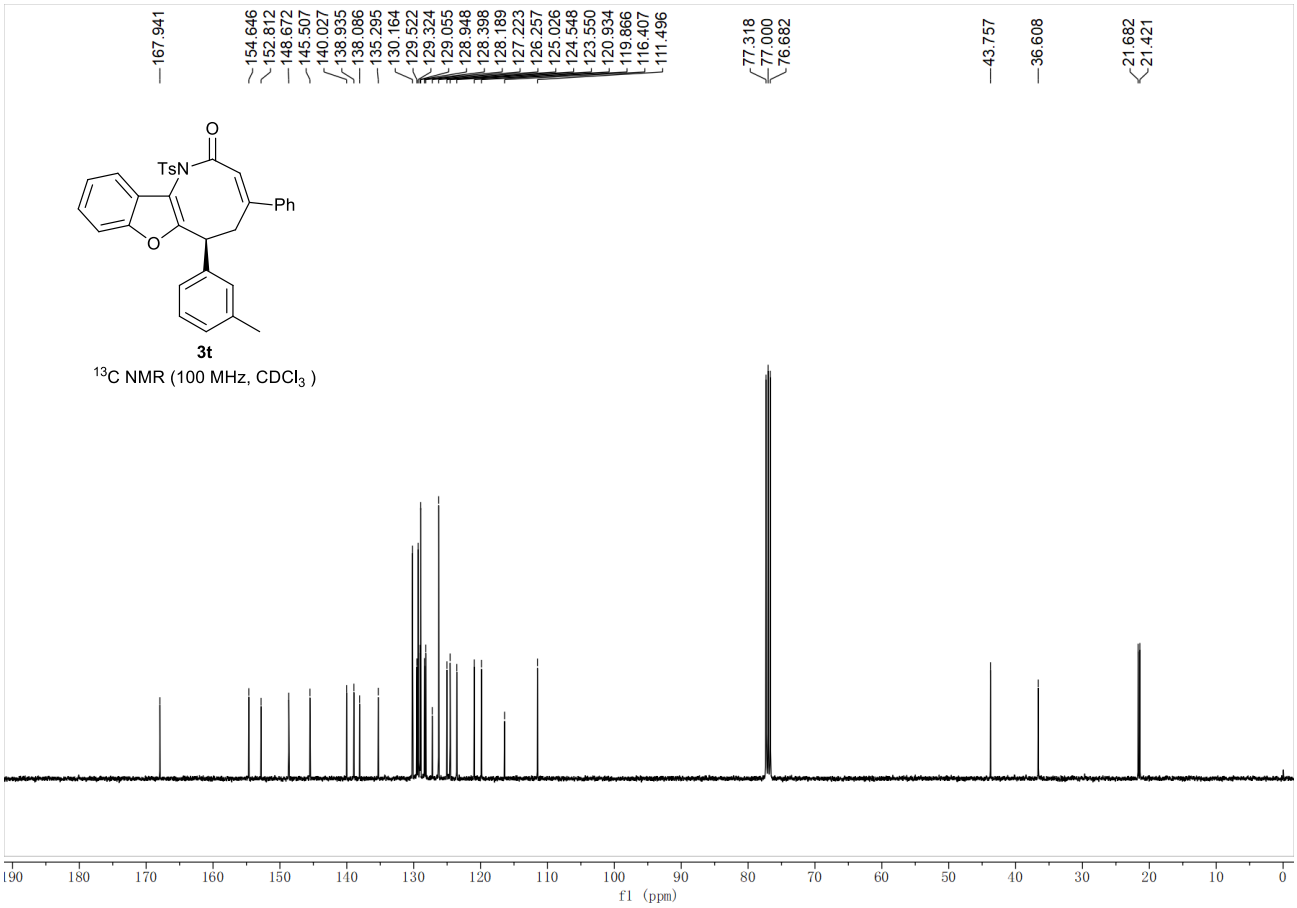
7.343
7.336
7.331
7.328
7.317
7.312
7.304
7.300
7.298
7.294
7.290
7.287
7.281
7.278
7.276
7.270
7.163
7.159
7.157
7.155
7.153
7.146
7.144
7.142
7.140
7.137
7.135
6.090
4.333
4.322
4.298
4.287
3.441
3.405
3.370
3.113
3.110
3.102
3.099
3.079
3.076
3.068
3.065
2.430
2.386
0.000
TsN
O
Ph
O
3t
1H NMR (400 MHz, CDCl3)
2.00
0.97
5.85
2.02
5.25
1.14
0.97
1.02
1.05
1.03
2.99
3.17
f1 (ppm)


167.941
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152.812
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138.086
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129.055
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128.398
128.189
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126.257
125.026
124.548
123.550
120.934
119.866
116.407
111.496
77.318
77.000
76.682
43.757
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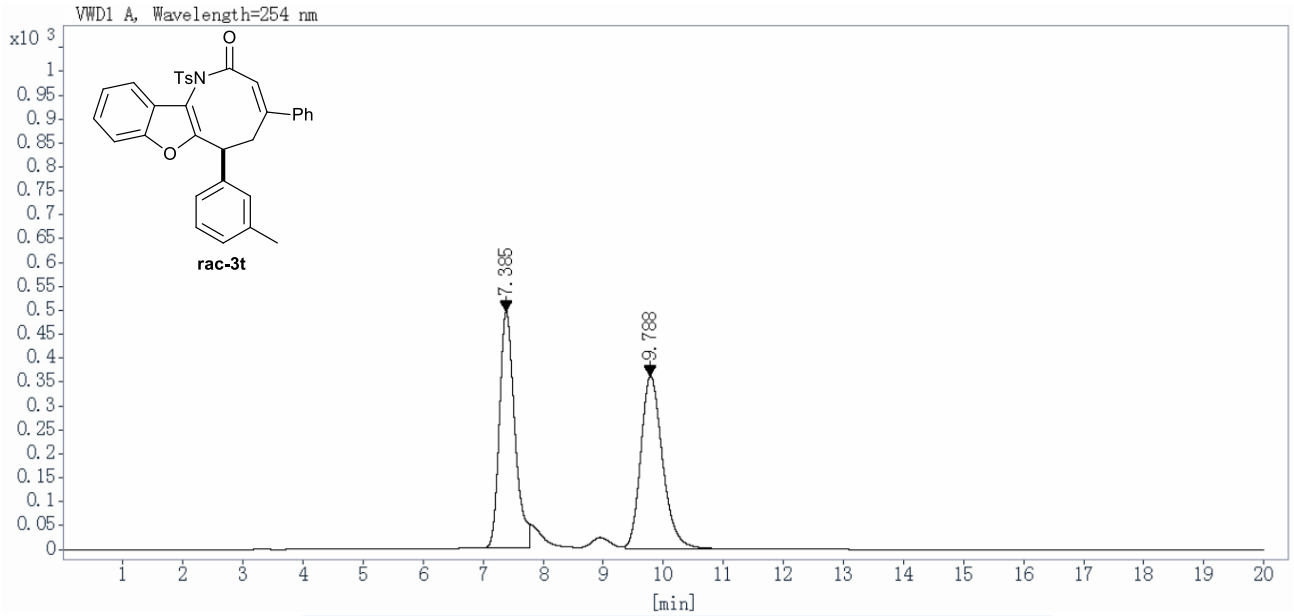
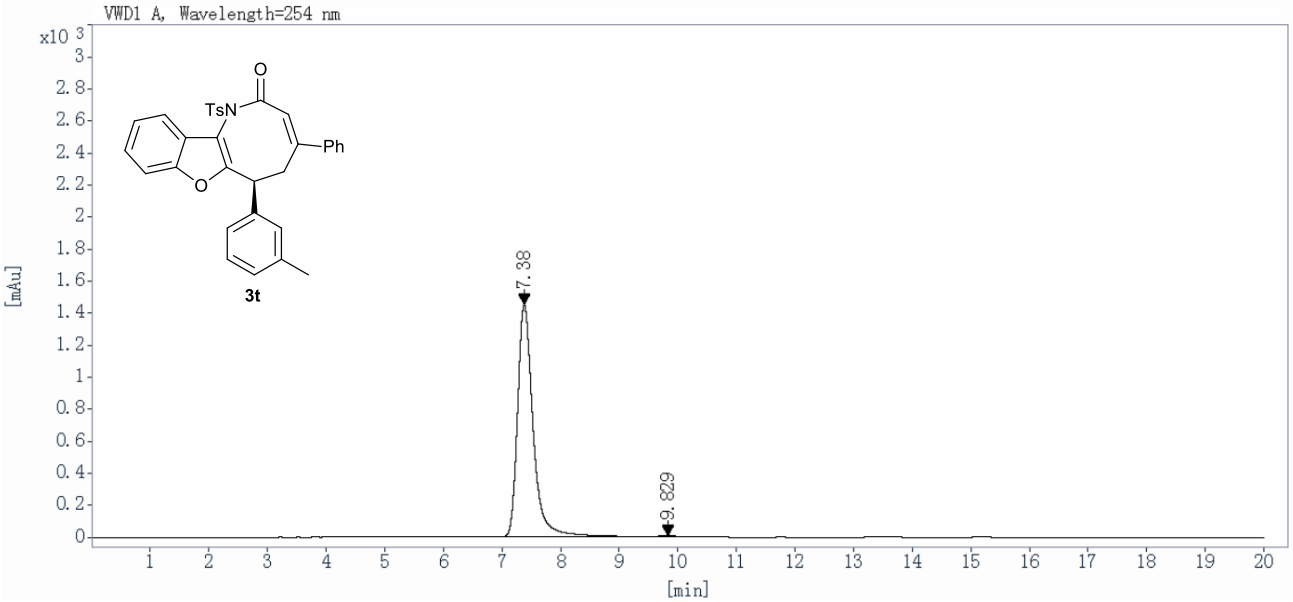
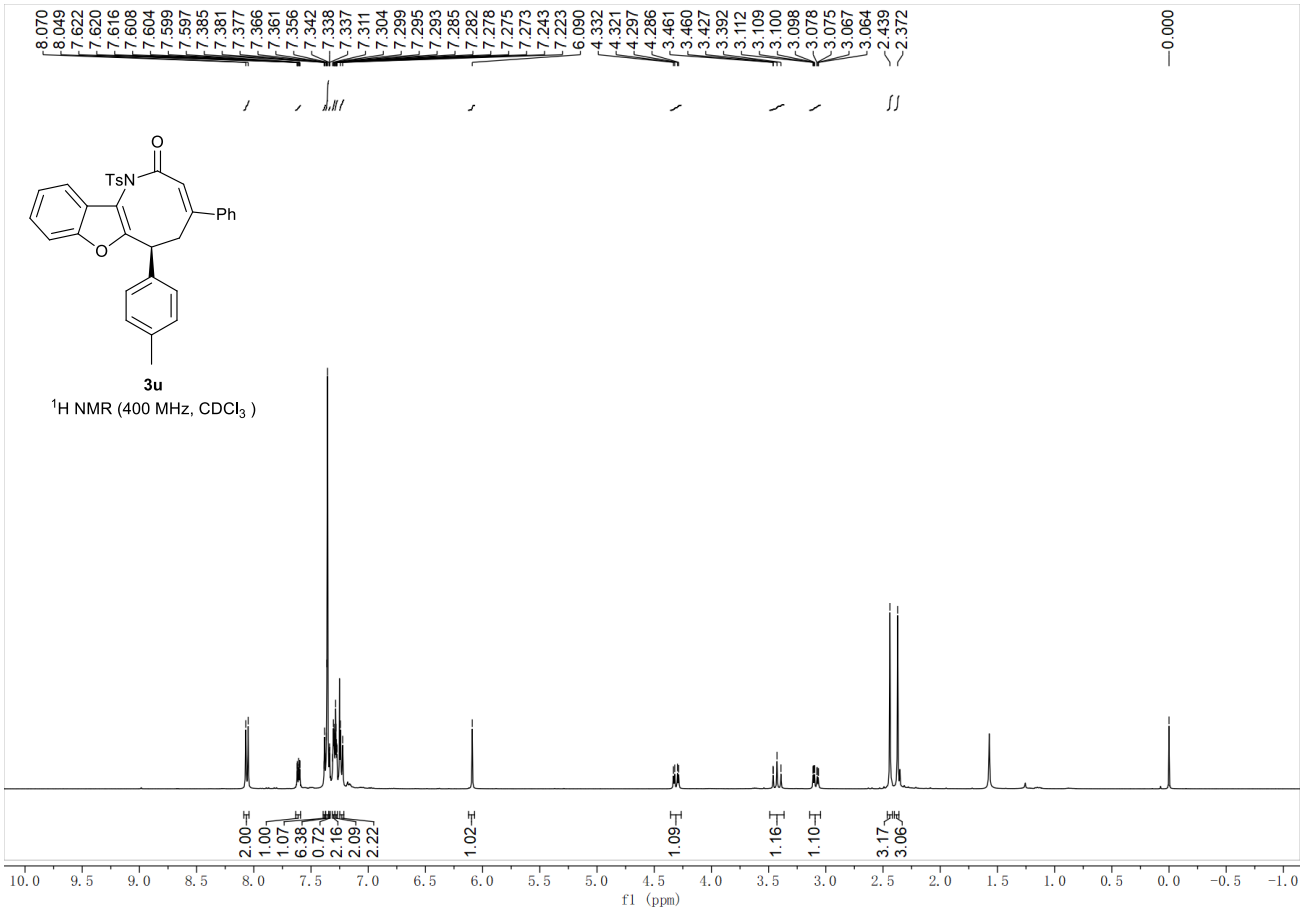
21.682
21.421
TsN
O
Ph
O
3t
13C NMR (100 MHz, CDCl3)
f1 (ppm)



Ret Time [min]	Peak Type	Width [min]	Height [mAU]	Area [mAU*s]	Area [%]
7.385	BBAS	0.27	494.9925	8743.0723	48.6594
9.788	BB S	0.39	362.6009	9224.8369	51.3406
			Totals:	17967.9092	100.0000



Ret Time [min]	Peak Type	Width [min]	Height [mAU]	Area [mAU*s]	Area [%]
7.380	BV R	0.28	1456.2152	27111.1523	99.2400
9.829	VB E	0.33	9.4161	207.6152	0.7600
			Totals:	27318.7675	100.0000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7.608
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7.599
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7.385
7.381
7.377
7.366
7.361
7.356
7.342
7.338
7.337
7.311
7.304
7.299
7.295
7.293
7.285
7.282
7.278
7.275
7.273
7.243
7.223
6.090
4.332
4.321
4.297
4.286
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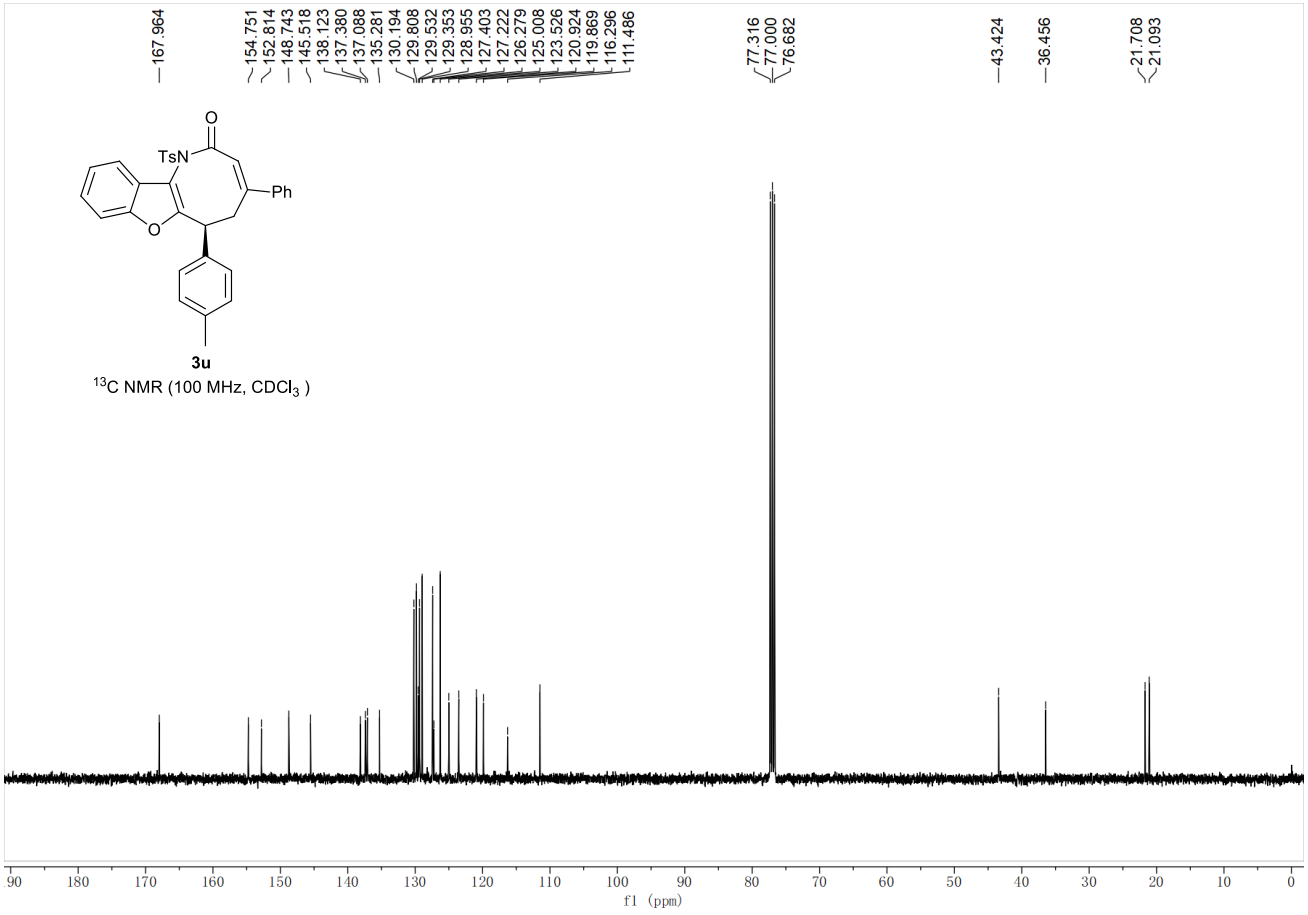
3.460
3.427
3.392
3.112
3.109
3.100
3.098
3.078
3.075
3.067
3.064
2.439
2.372
0.000
TsN
O
Ph
O
3u
1H NMR (400 MHz, CDCl3)
2.00
1.00
1.07
6.38
0.72
2.16
2.09
2.22
1.02
1.09
1.16
1.10
3.17
3.06
f1 (ppm)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152.814
148.743
145.518
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137.380
137.088
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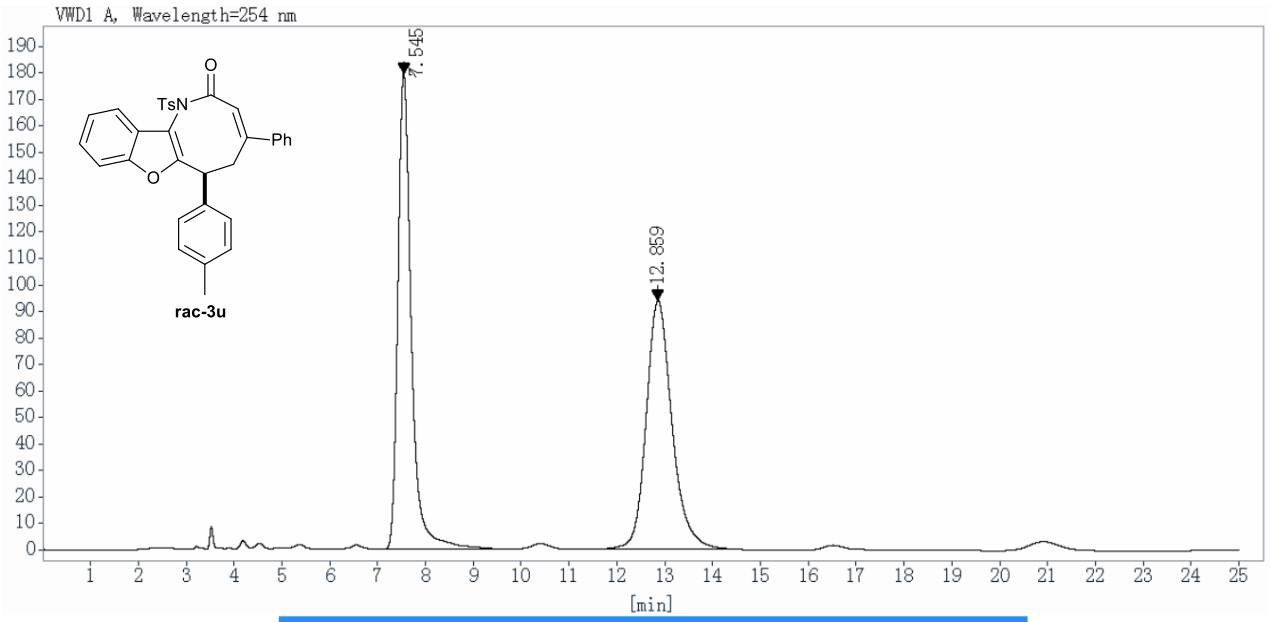
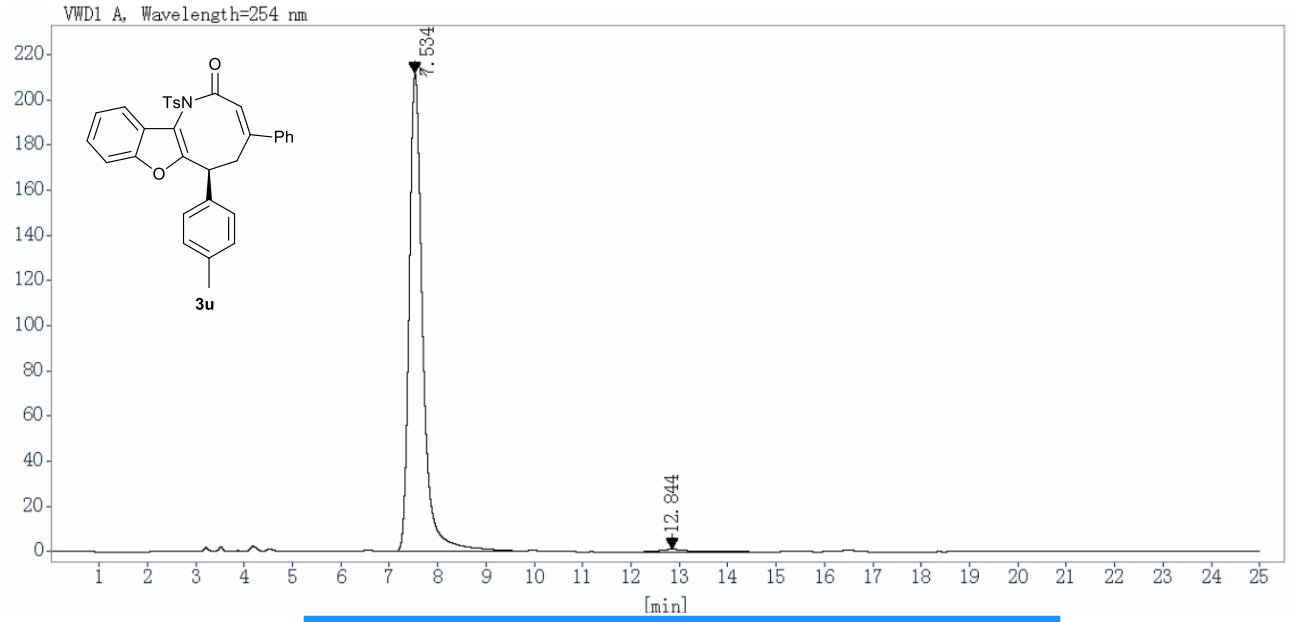
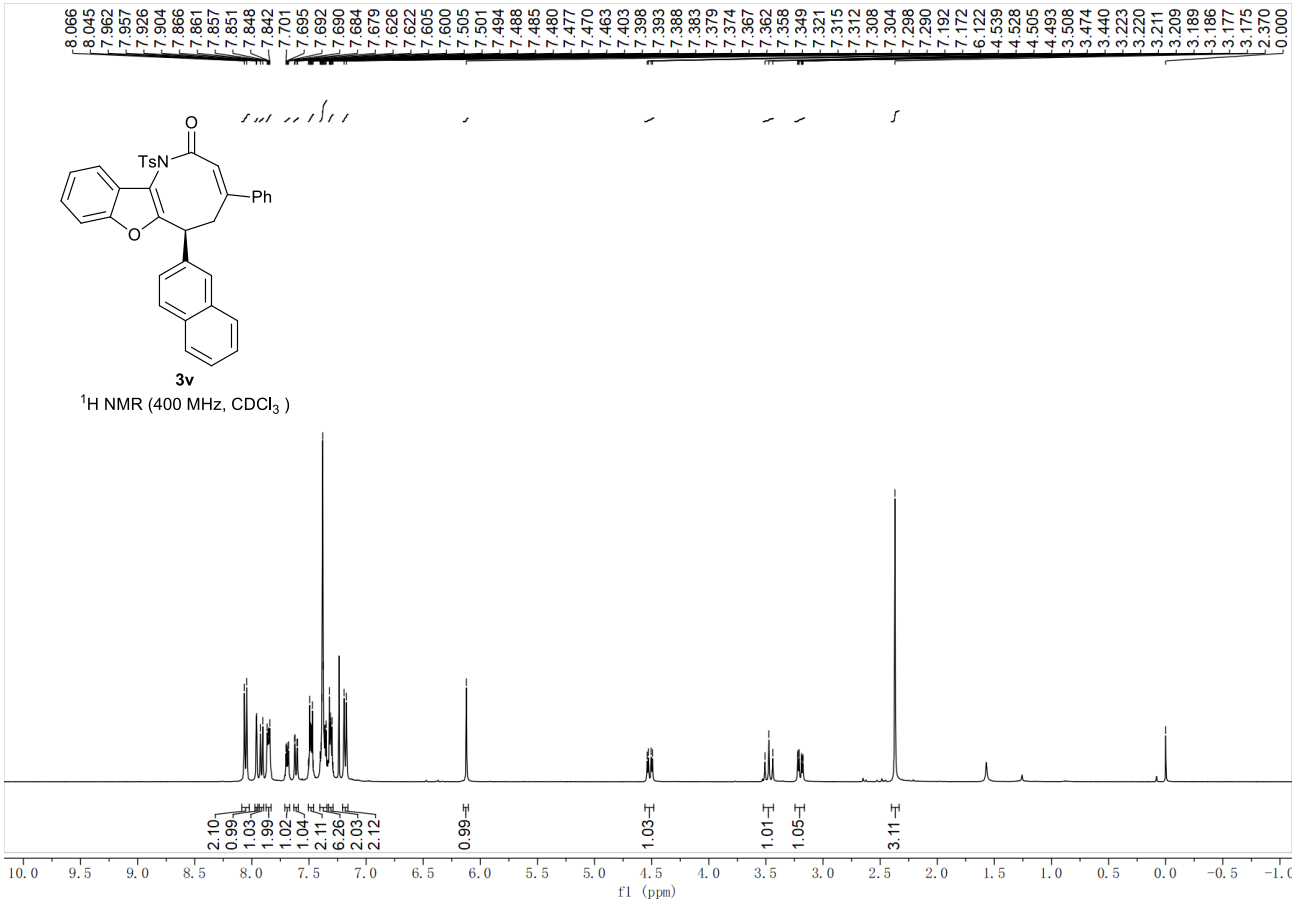
130.194
129.808
129.532
129.353
128.955
127.403
127.222
126.279
125.008
123.526
120.924
119.869
116.296
111.486
77.316
77.000
76.682
43.424
36.456
21.708
21.093
TsN
O
Ph
O
3u
13C NMR (100 MHz, CDCl3)
f1 (ppm)



Ret Time [min]	Peak Type	Width [min]	Height [mAU]	Area [mAU*s]	Area [%]
7.545	BBA	0.30	179.5573	3510.8516	49.9437
12.859	BBA	0.57	93.8605	3518.7734	50.0563
			Totals:	7029.6250	100.0000

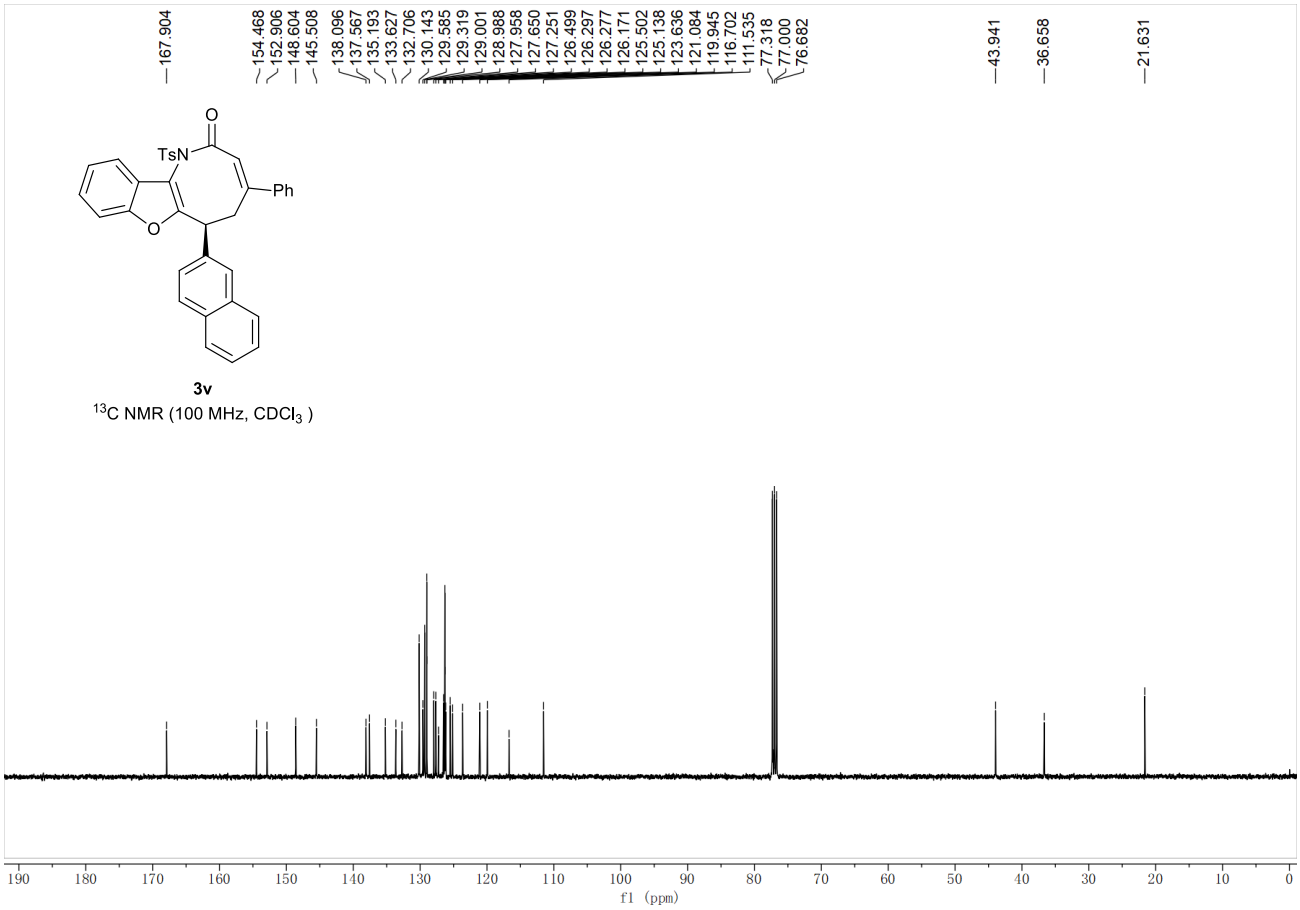


Ret Time [min]	Peak Type	Width [min]	Height [mAU]	Area [mAU*s]	Area [%]
7.534	BBA	0.29	211.8346	4107.8076	98.8977
12.844	BB	0.60	1.0964	45.7838	1.1023
			Totals:	4153.5914	100.0000



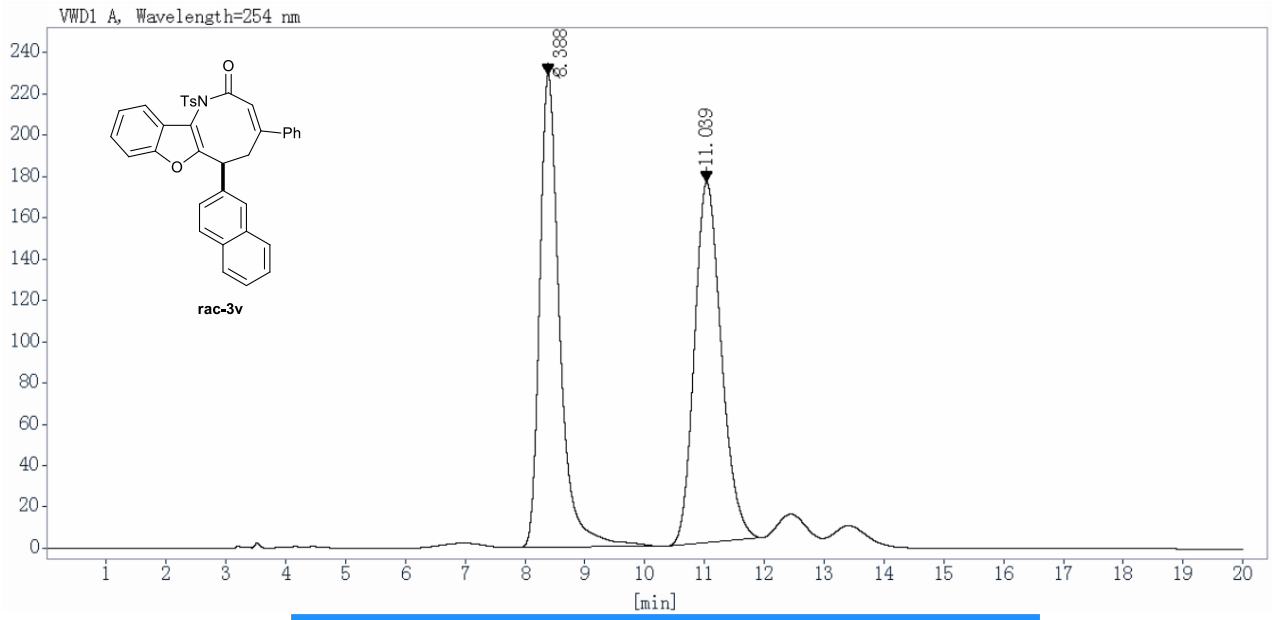
3v

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

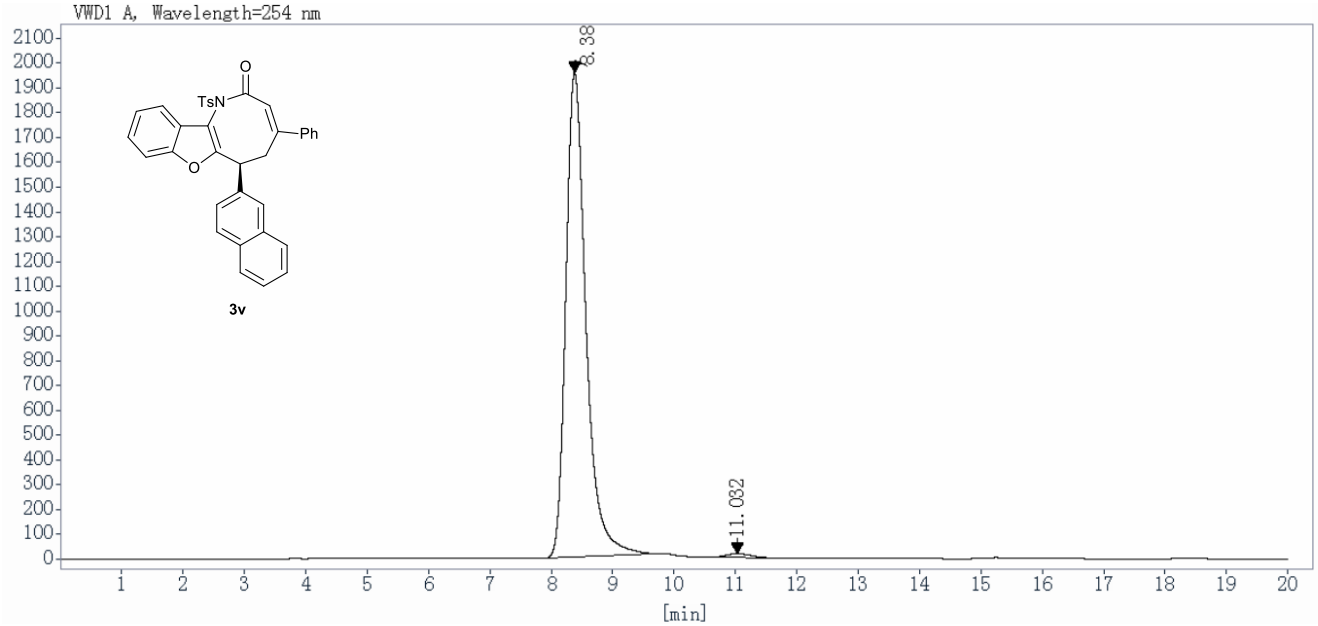


3v

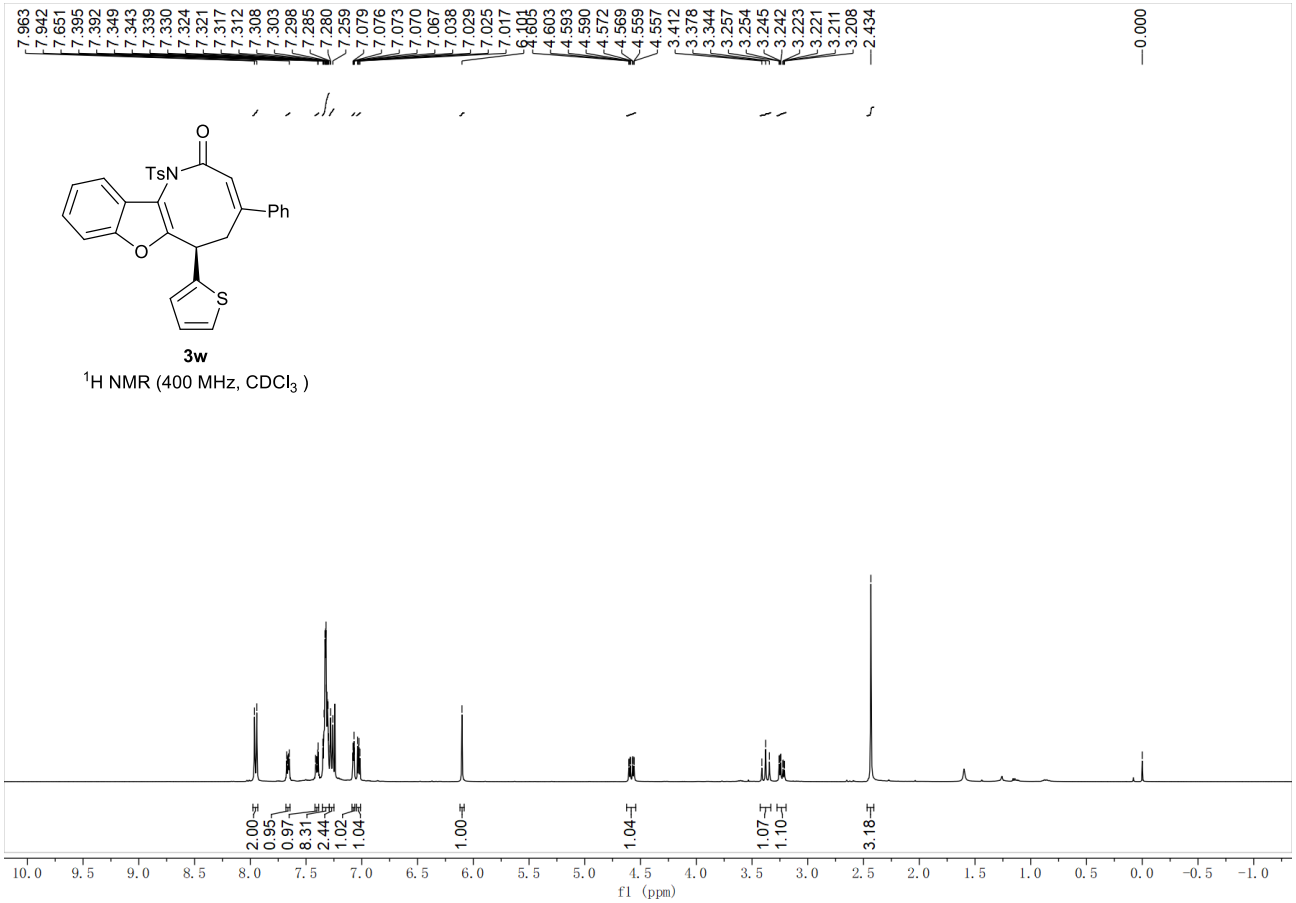
^{13}C NMR (100 MHz, $CDCl_3$)



Ret Time [min]	Peak Type	Width [min]	Height [mAU]	Area [mAU*s]	Area [%]
8.388	BB	0.35	229.0321	5347.0718	49.4554
11.039	BB	0.48	174.5441	5464.8330	50.5446
			Totals:	10811.9048	100.0000

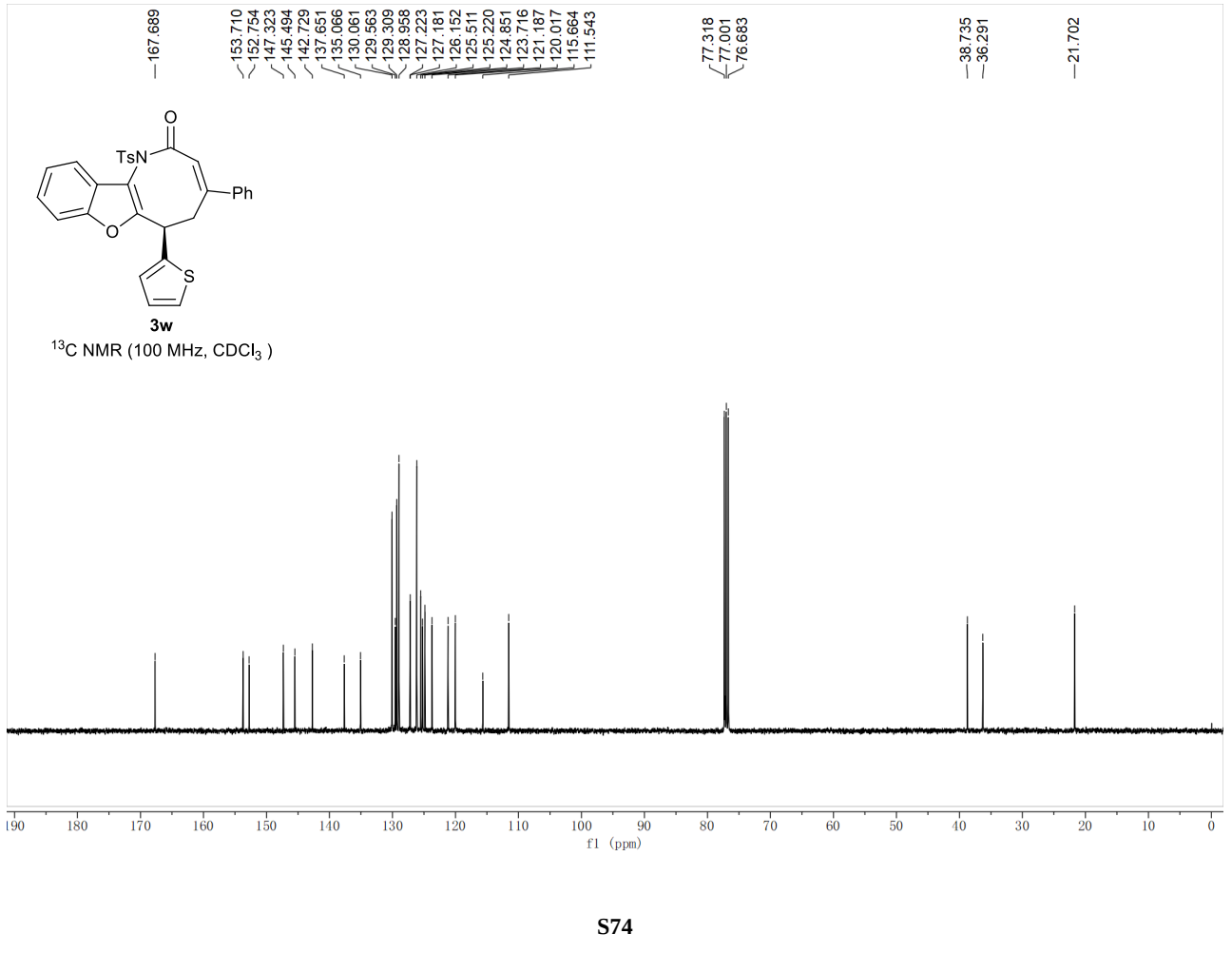


Ret Time [min]	Peak Type	Width [min]	Height [mAU]	Area [mAU*s]	Area [%]
8.380	BBA	0.35	1956.2250	44461.4570	99.0122
11.032	BBA	0.44	15.6411	443.5534	0.9878
			Totals:	44905.0104	100.0000



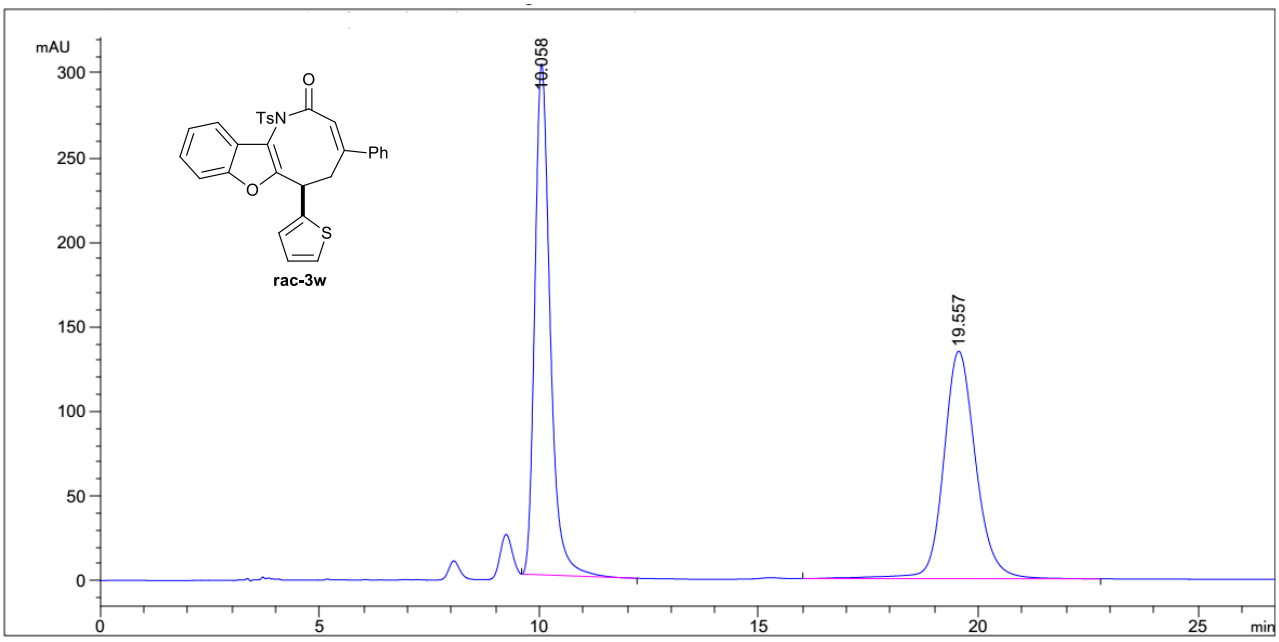
3w

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

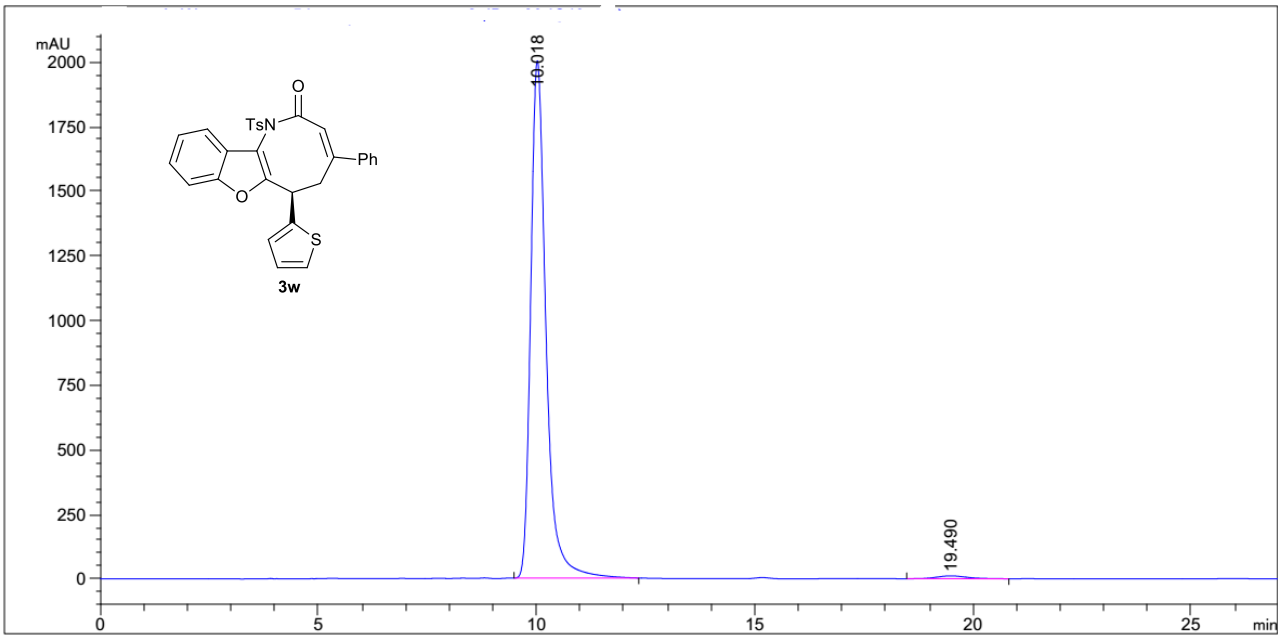


3w

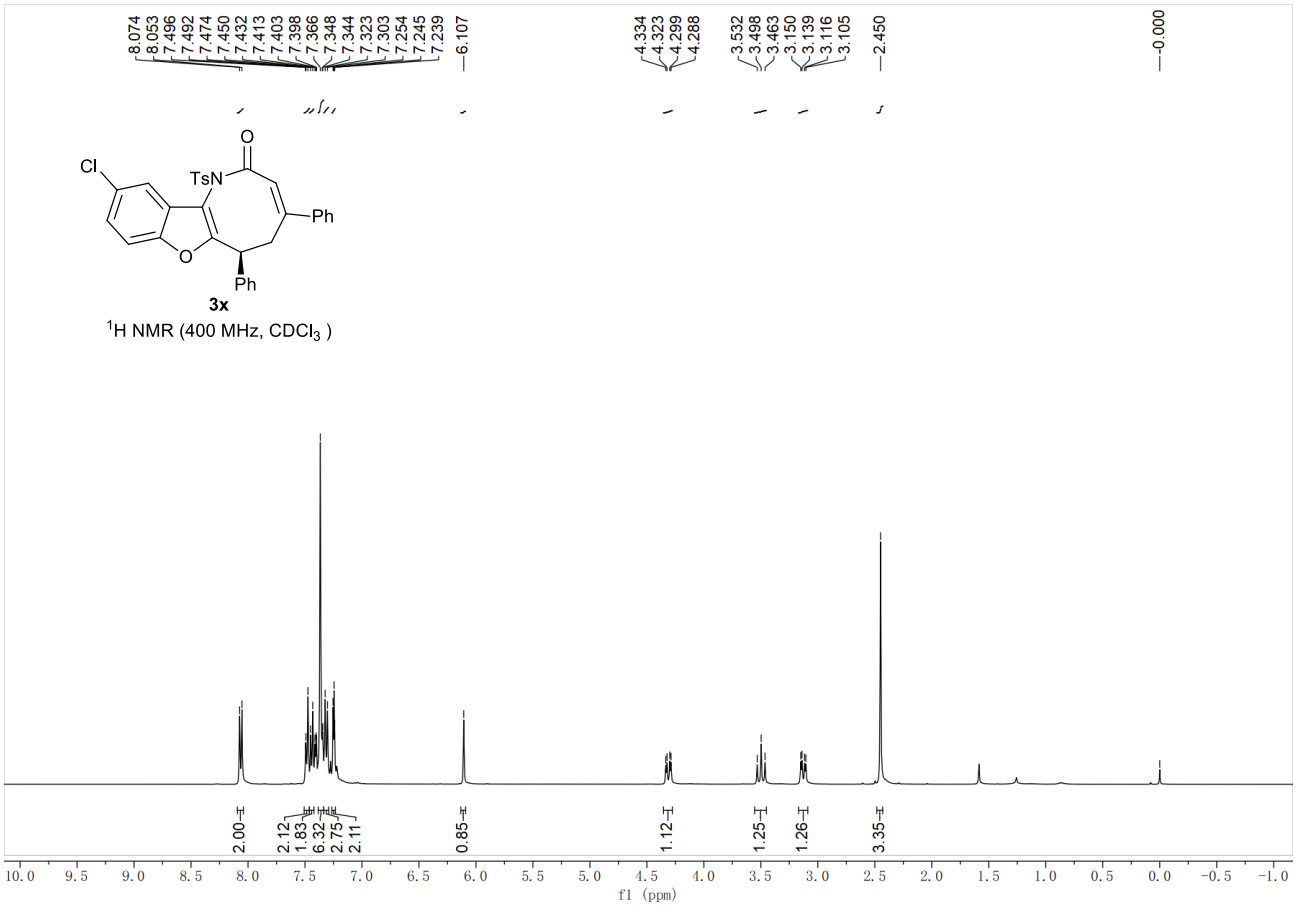
^{13}C NMR (100 MHz, $CDCl_3$)



Peak #	RetTime [min]	Type	Width [min]	Area mAU *s	Height [mAU]	Area %
1	10.058	BBA	0.3718	7325.52490	302.05582	51.7060
2	19.557	BB	0.7771	6842.13037	134.47630	48.2940
Totals :				1.41677e4	436.53212	

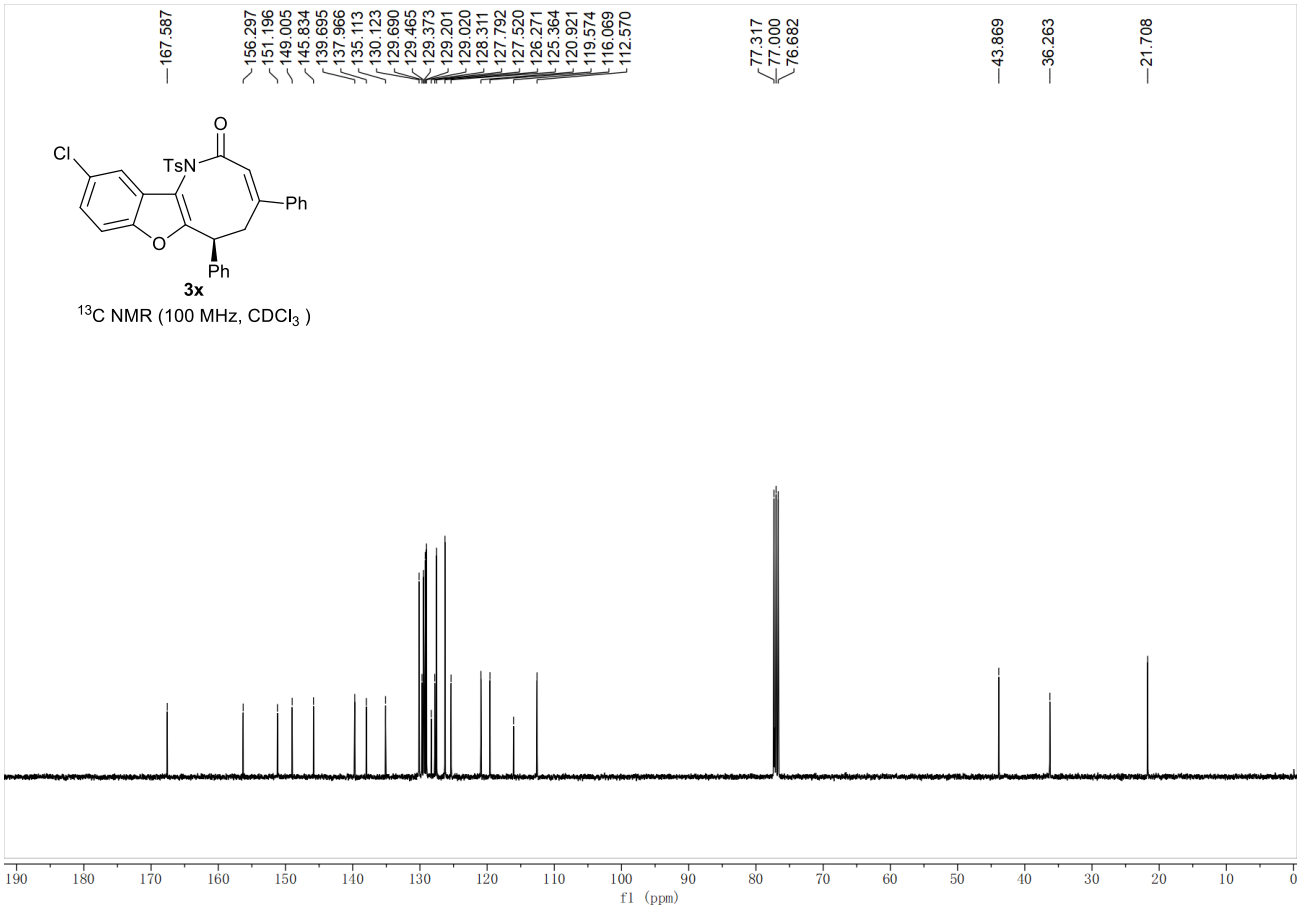


Peak #	RetTime [min]	Type	Width [min]	Area mAU *s	Height [mAU]	Area %
1	10.018	BBA	0.3700	4.87386e4	2001.58337	98.9292
2	19.490	BB	0.7312	527.54663	11.00182	1.0708
Totals :				4.92662e4	2012.58520	



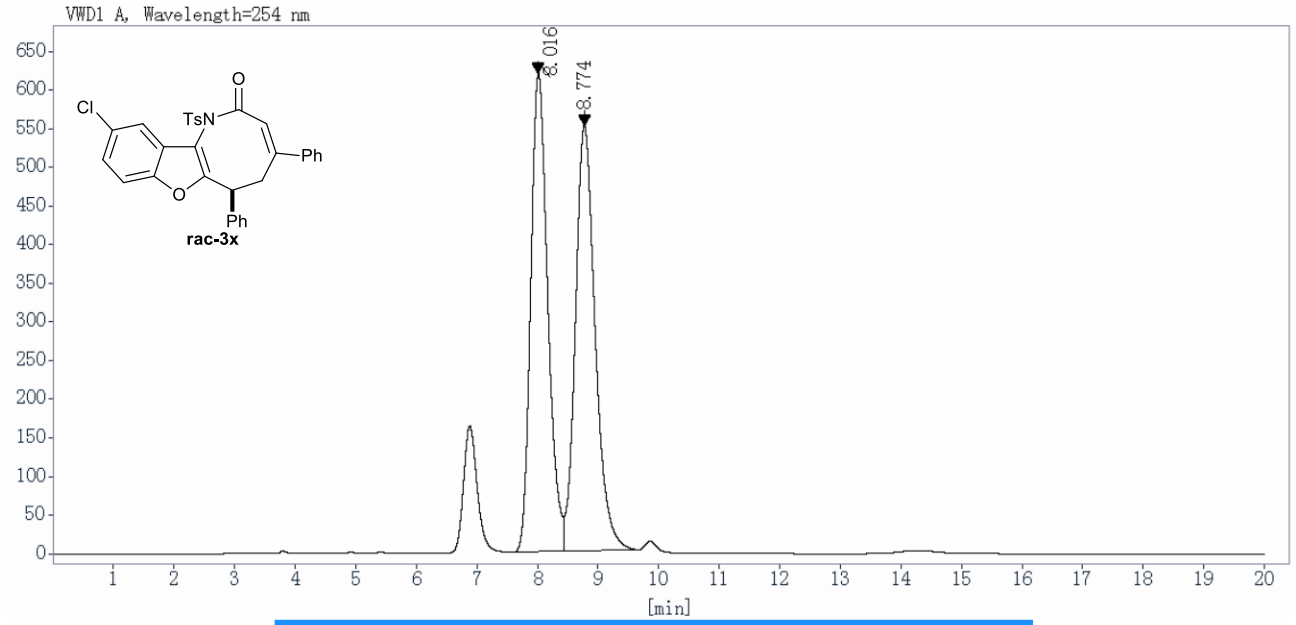
3x

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

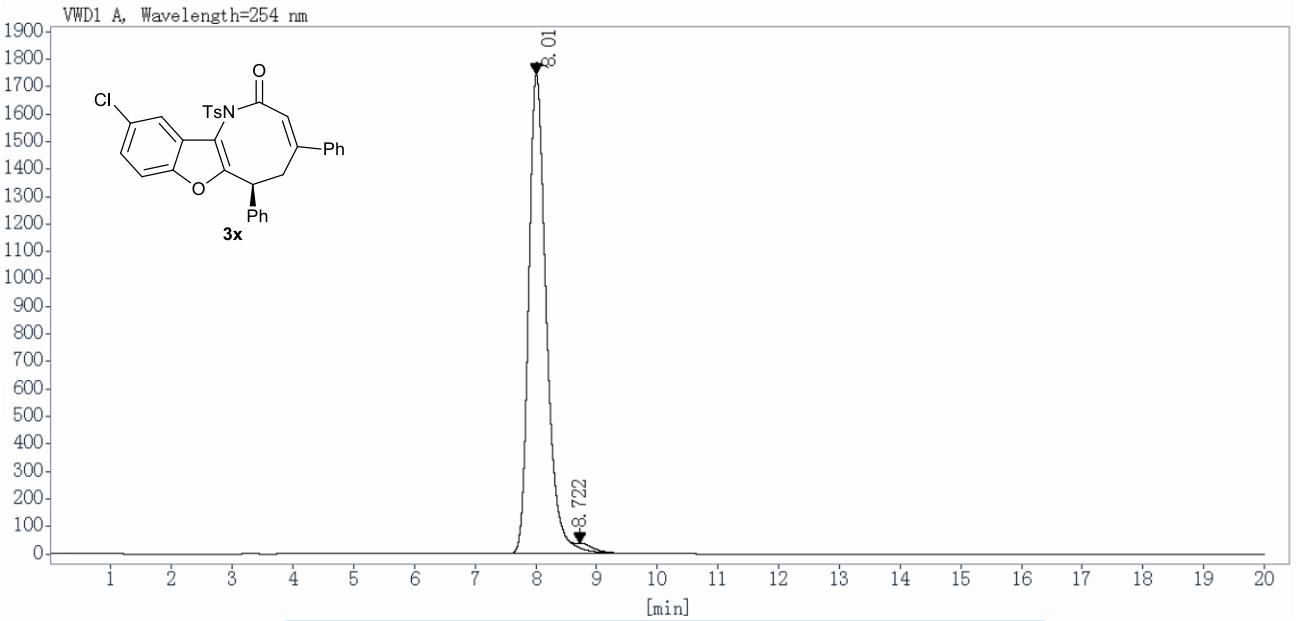


3x

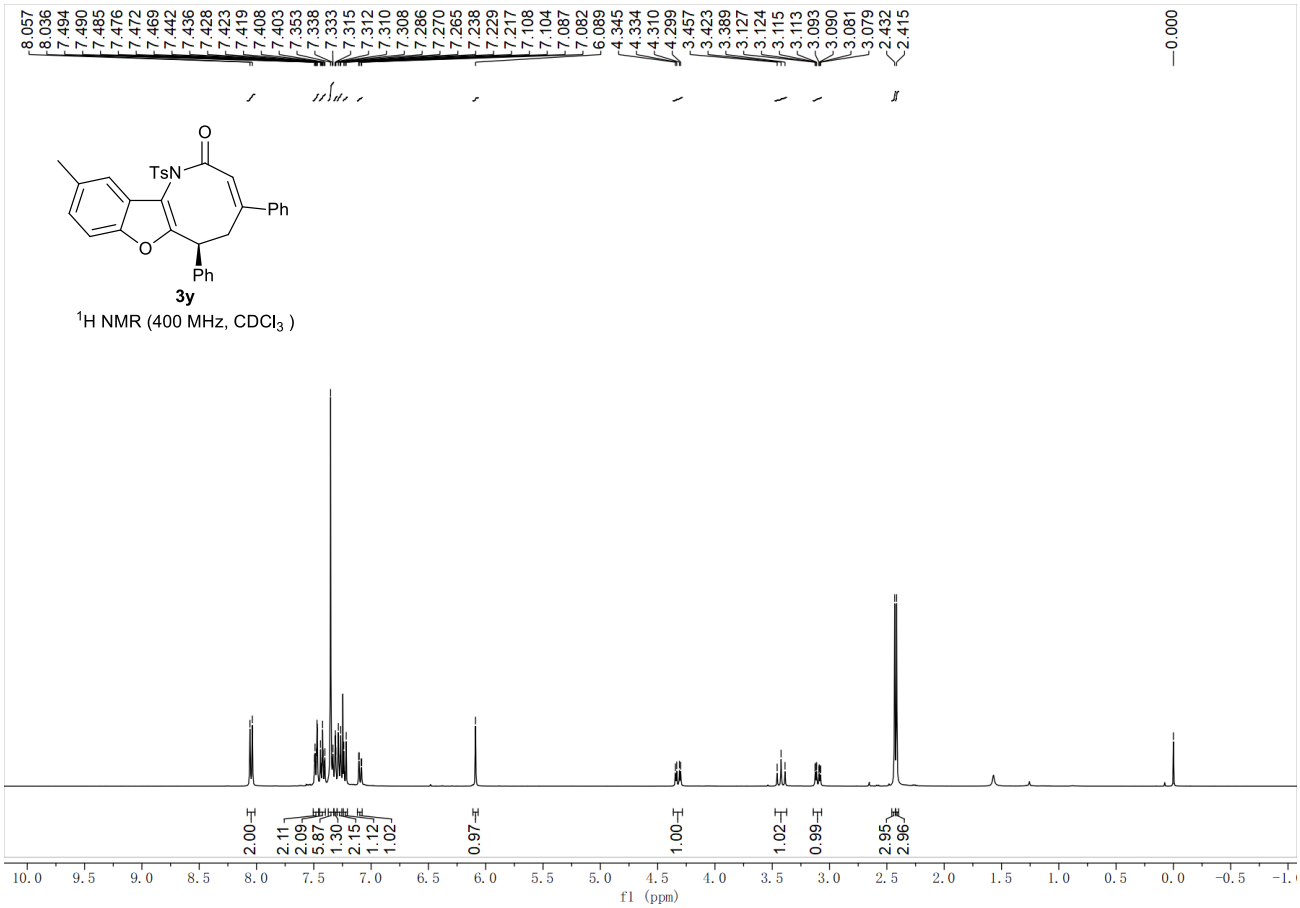
^{13}C NMR (100 MHz, $CDCl_3$)



Ret Time [min]	Peak Type	Width [min]	Height [mAU]	Area [mAU*s]	Area [%]
8.016	BV	0.30	619.1596	12074.5703	49.1901
8.774	VBA	0.35	550.1202	12472.1768	50.8099
			Totals:	24546.7471	100.0000



Ret Time [min]	Peak Type	Width [min]	Height [mAU]	Area [mAU*s]	Area [%]
8.010	BV R	0.31	1744.1387	35100.7578	98.8019
8.722	VBAE	0.35	17.1886	425.6340	1.1981
			Totals:	35526.3918	100.0000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7.485
7.476
7.472
7.469
7.442
7.436
7.428
7.423
7.419
7.408
7.403
7.353
7.338
7.333
7.315
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7.310
7.308
7.286
7.270
7.265
7.238
7.229
7.217
7.108
7.104
7.087
7.082
6.089
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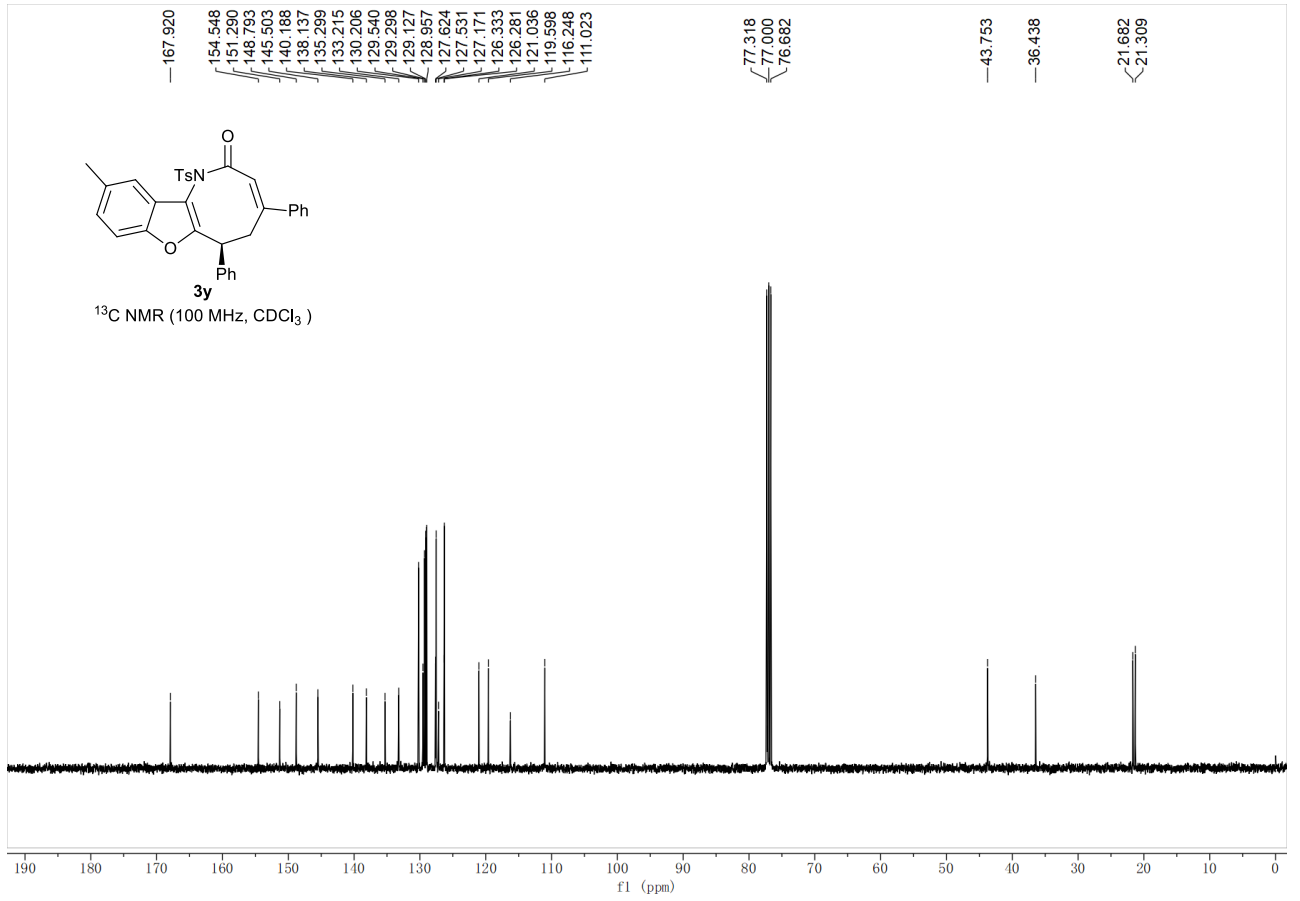
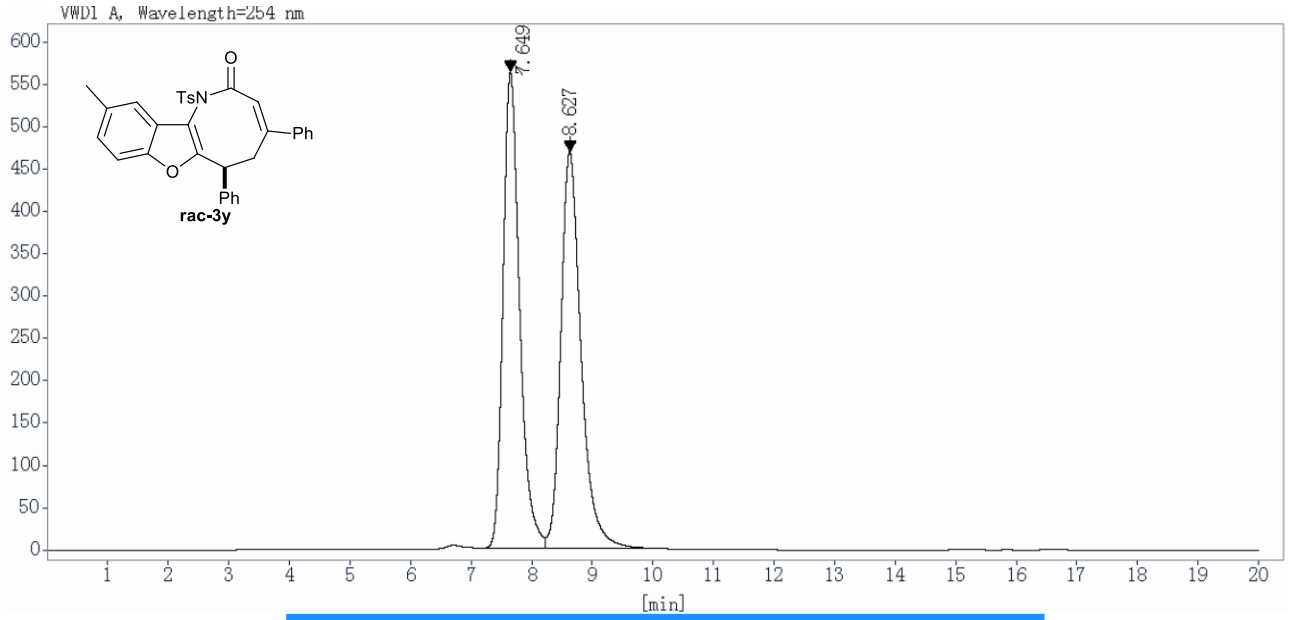
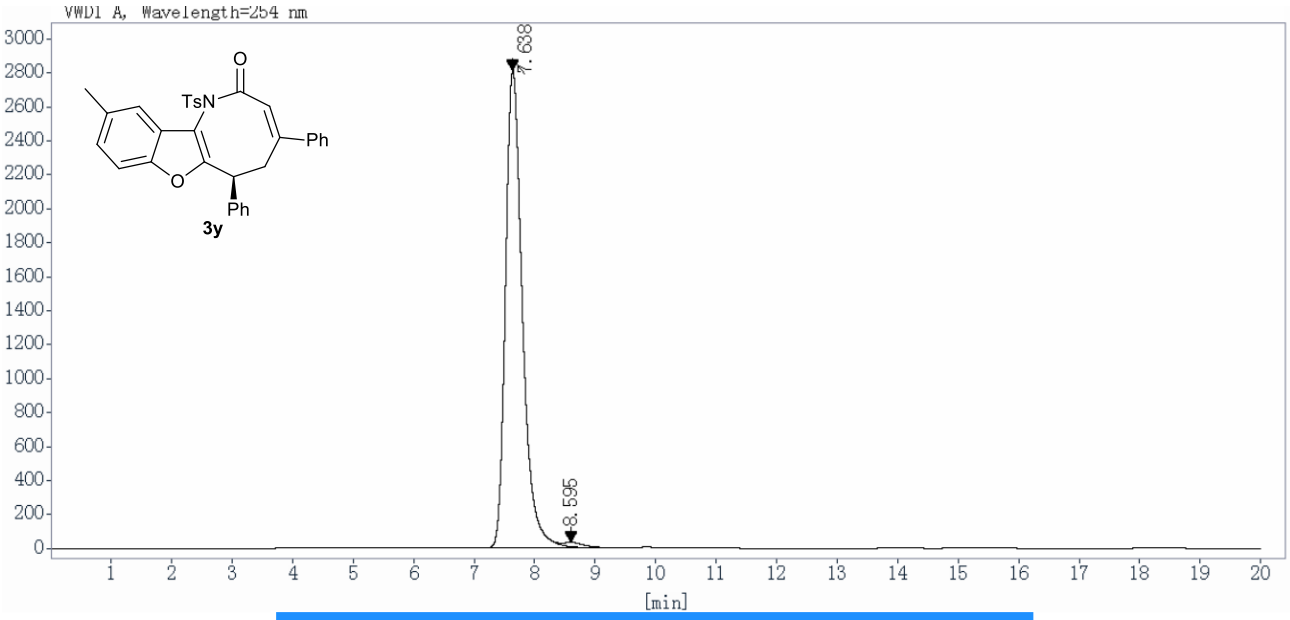
3.423
3.389
3.127
3.124
3.115
3.113
3.093
3.090
3.081
3.079
2.432
2.415
0.000
O
TsN
Ph
O
Ph
3y
1H NMR (400 MHz, CDCl3)
2.00
2.11
2.09
5.87
1.30
2.15
1.12
1.02
0.97
1.00
1.02
0.99
2.95
2.96
f1 (ppm)

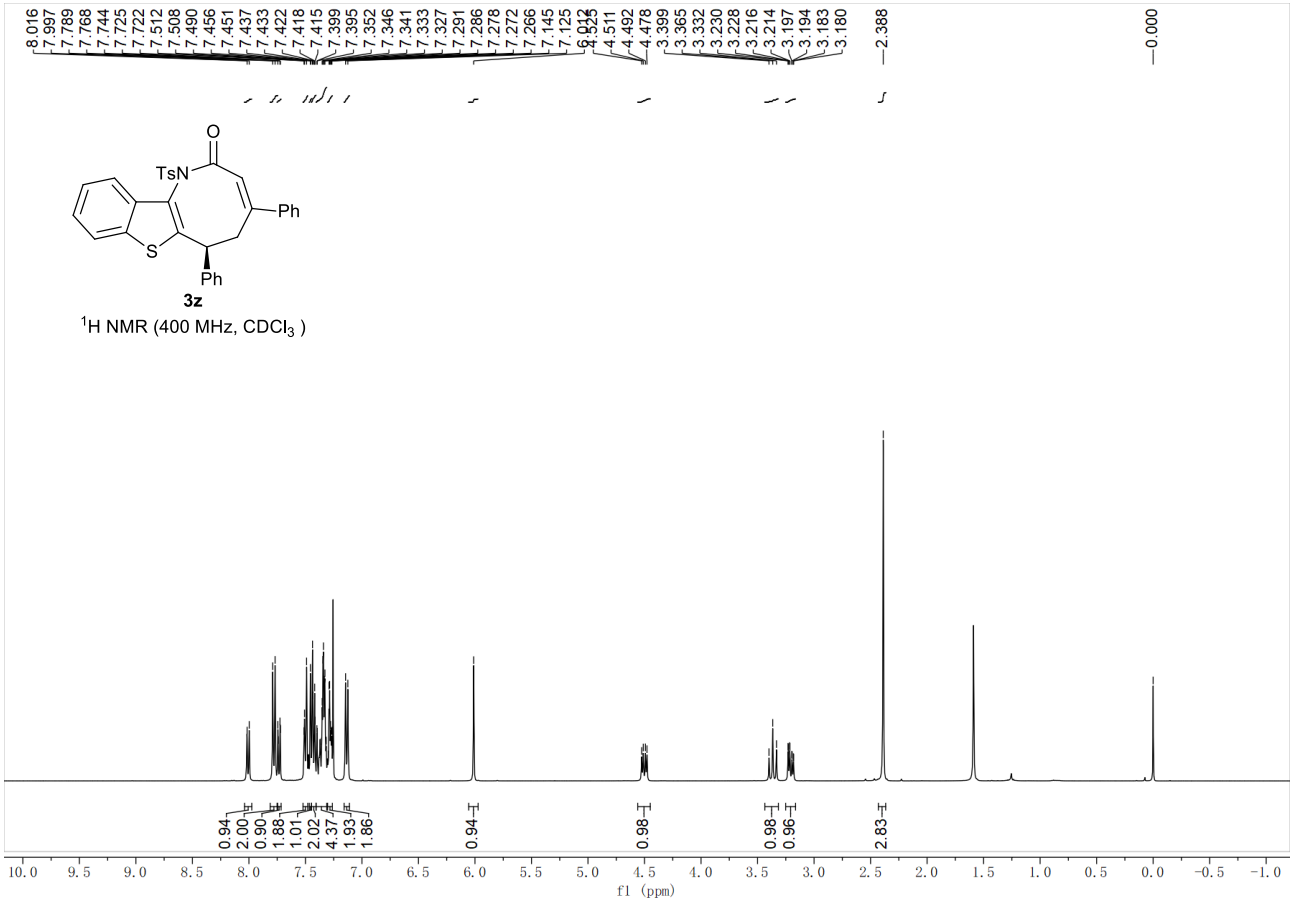

167.920
154.548
151.290
148.793
145.503
140.188
138.137
135.299
133.215
130.206
129.540
129.298
129.127
128.957
127.624
127.531
127.171
126.333
126.281
121.036
119.598
116.248
111.023
77.318
77.000
76.682
43.753
36.438
21.682
21.309
O
TsN
Ph
O
Ph
3y
13C NMR (100 MHz, CDCl3)
f1 (ppm)



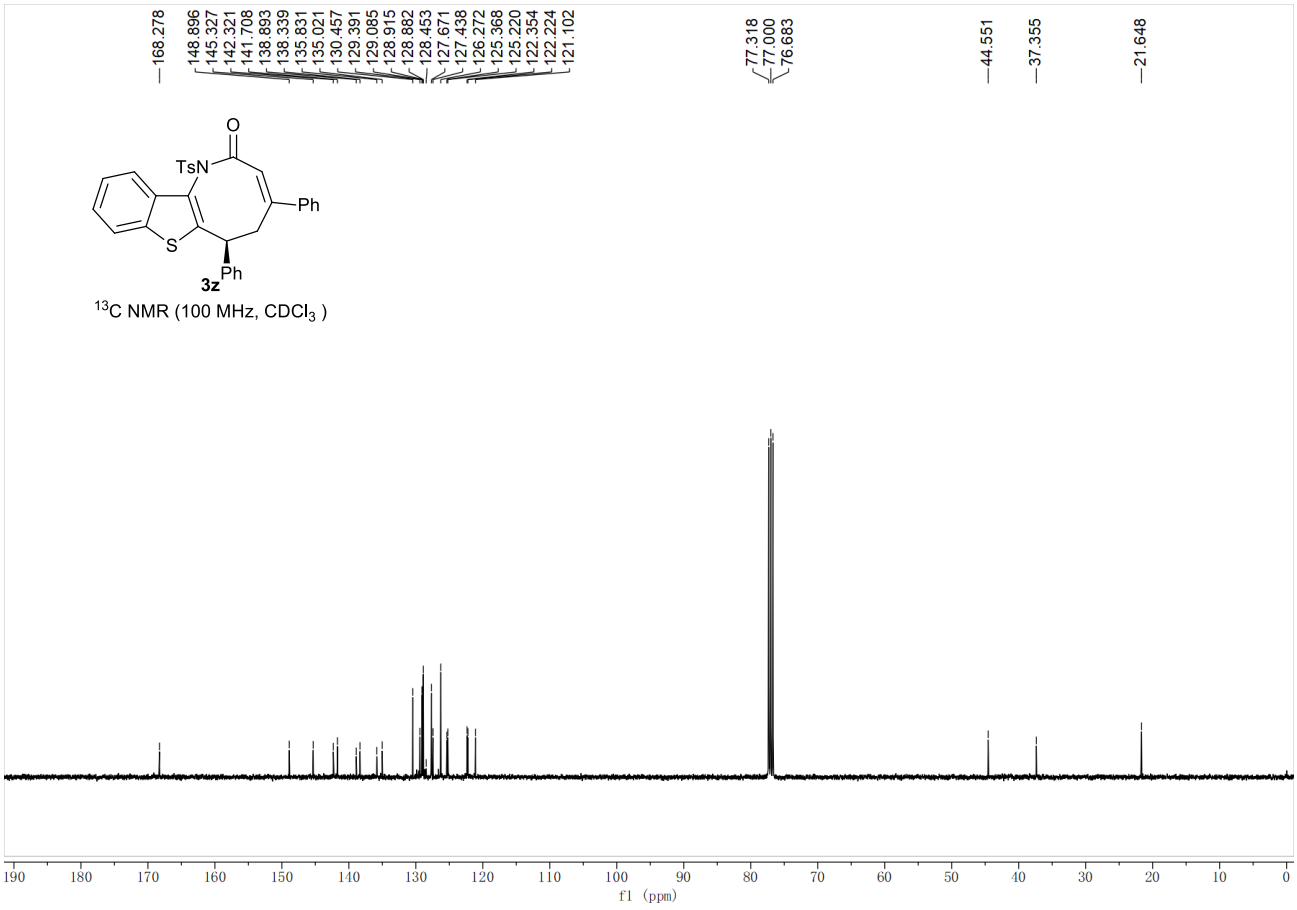
Ret Time [min]	Peak Type	Width [min]	Height [mAU]	Area [mAU*s]	Area [%]
7.649	BV	0.29	563.2698	10671.5527	49.7027
8.627	VBA	0.35	467.7425	10799.2041	50.2973
			Totals:	21470.7568	100.0000



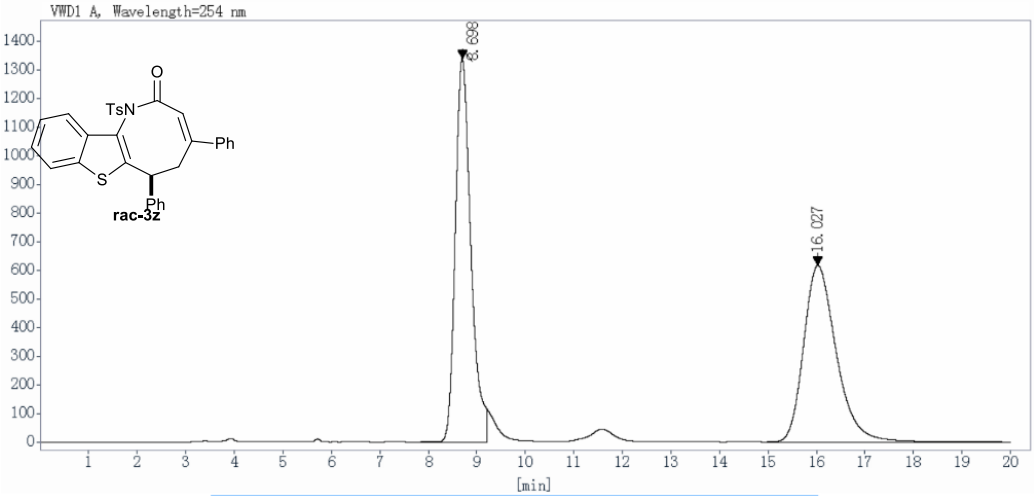
Ret Time [min]	Peak Type	Width [min]	Height [mAU]	Area [mAU*s]	Area [%]
7.638	BV R	0.30	2812.6589	54495.1719	98.8278
8.595	VB E	0.38	24.6431	646.3926	1.1722
			Totals:	55141.5645	100.0000



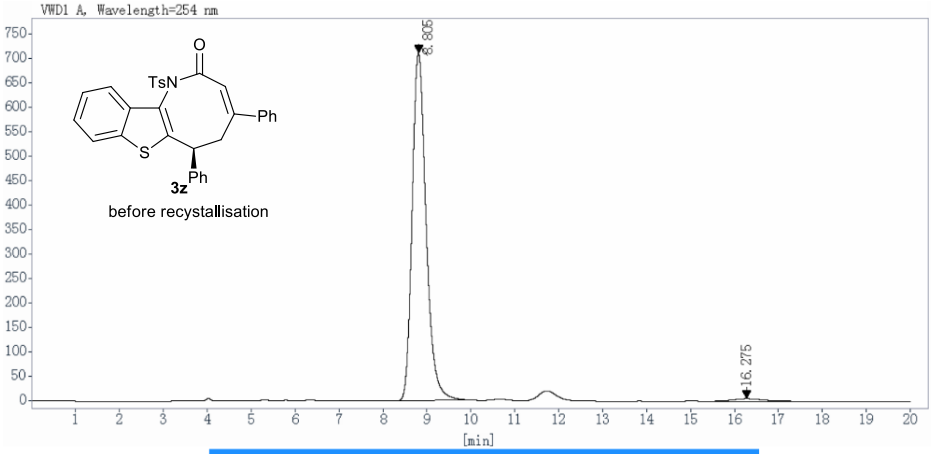
^{1}H NMR (400 MHz, $CDCl_3$)



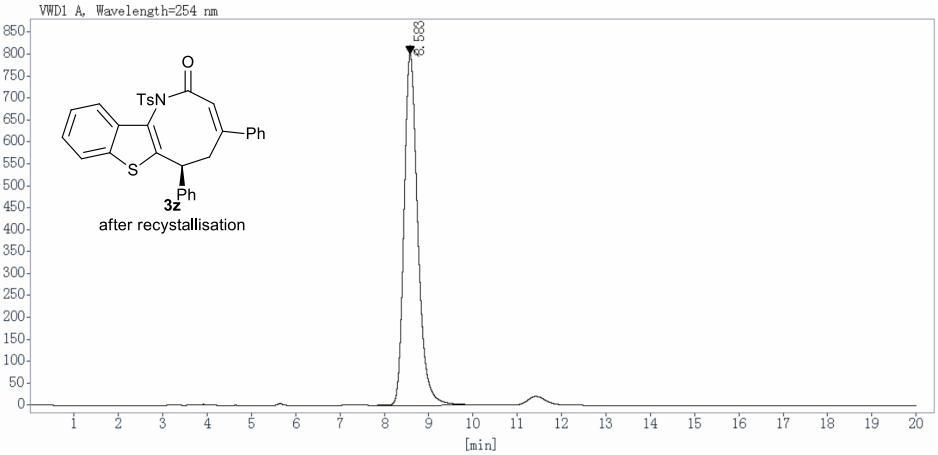
^{13}C NMR (100 MHz, $CDCl_3$)



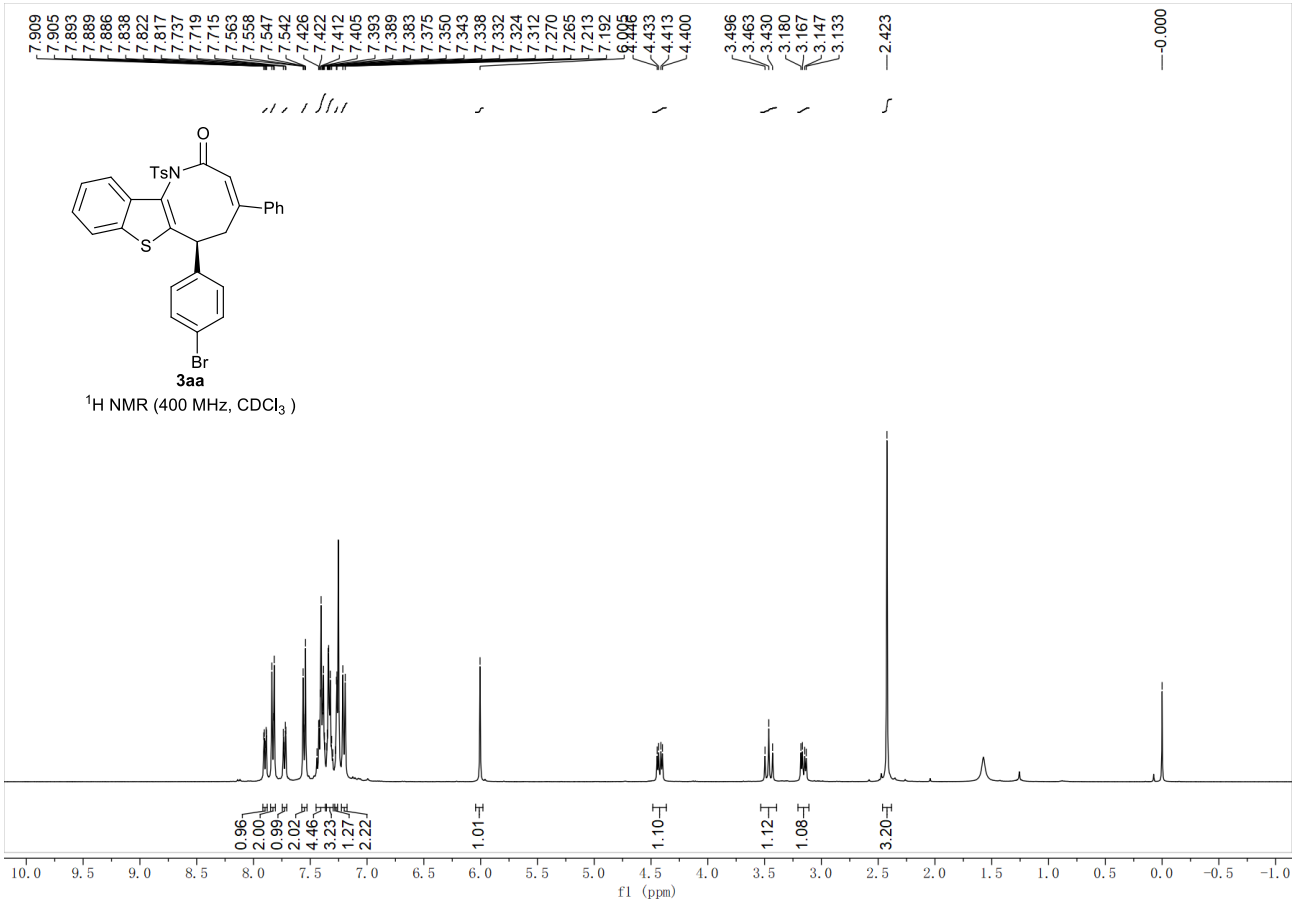
Ret Time [min]	Peak Type	Width [min]	Height [mAU]	Area [mAU*s]	Area [%]
8.698	BBAS	0.34	1339.7388	29828.3633	50.8614
16.027	BBA	0.71	616.0794	28818.0605	49.1386
			Totals:	58646.4238	100.0000



Ret Time [min]	Peak Type	Width [min]	Height [mAU]	Area [mAU*s]	Area [%]
8.805	BBA	0.34	710.7318	15696.8389	98.4999
16.275	BB	0.71	5.0705	239.0467	1.5001
			Totals:	15935.8856	100.0000



Ret Time [min]	Peak Type	Width [min]	Height [mAU]	Area [mAU*s]	Area [%]
8.583	BB	0.33	800.7976	17242.3281	100.0000
			Totals:	17242.3281	100.0000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7.563
7.558
7.547
7.542
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7.422
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7.389
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7.343
7.338
7.332
7.324
7.312
7.270
7.265
7.213
7.192
6.005
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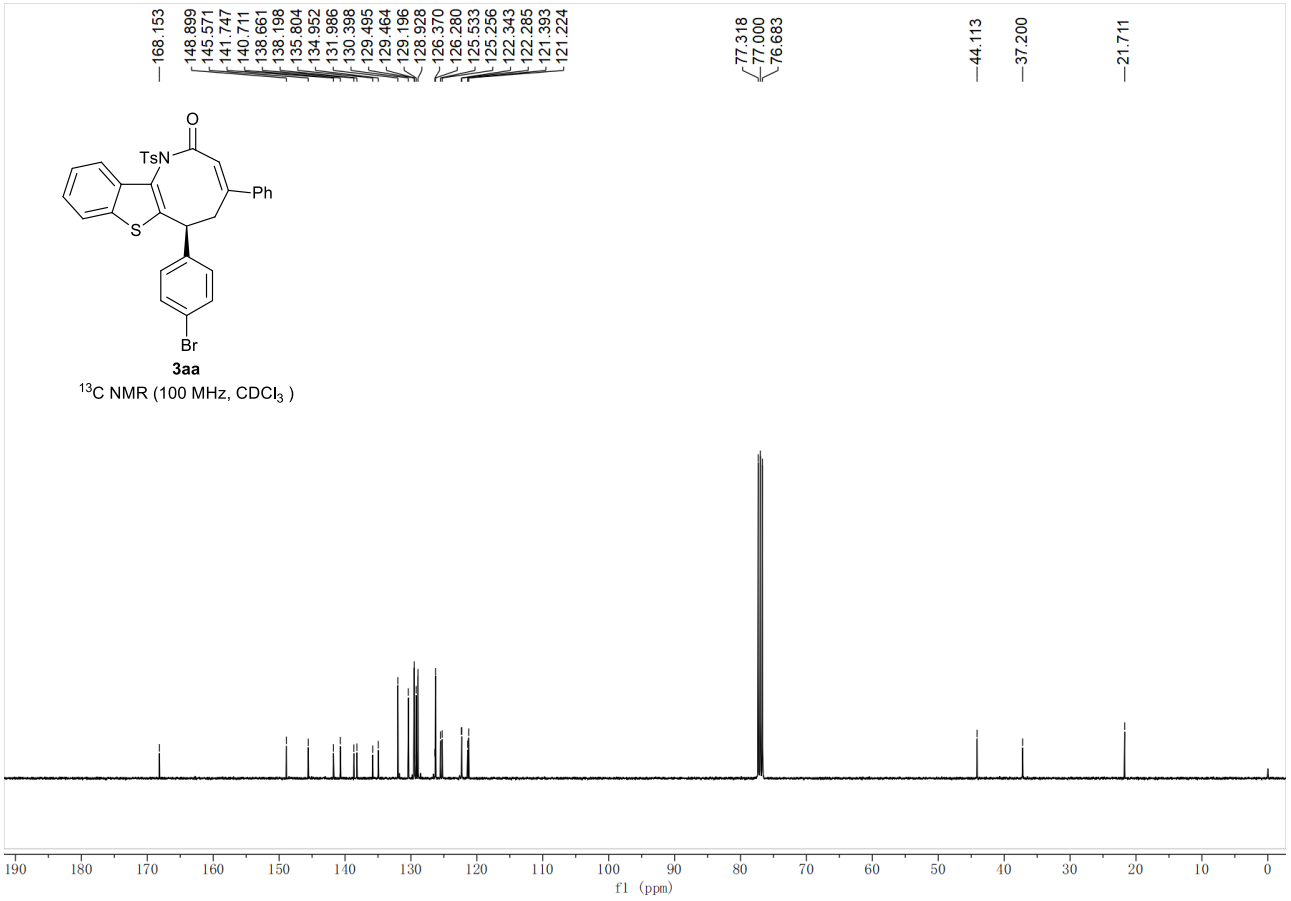
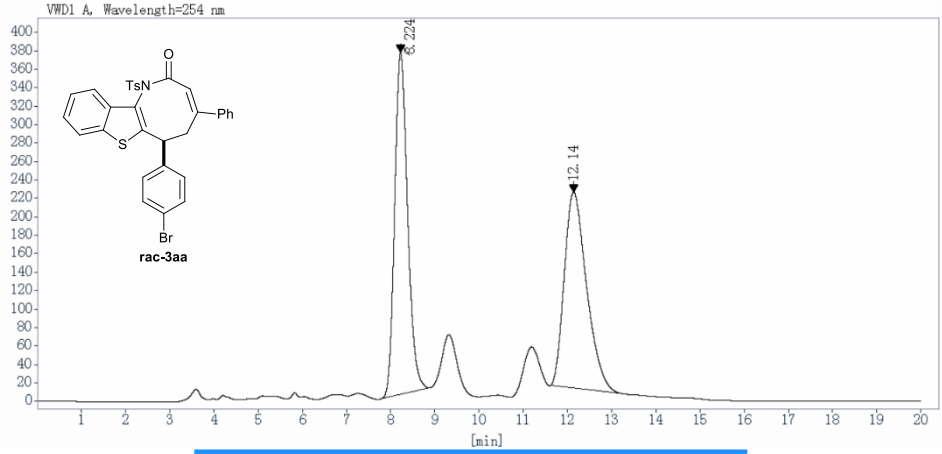
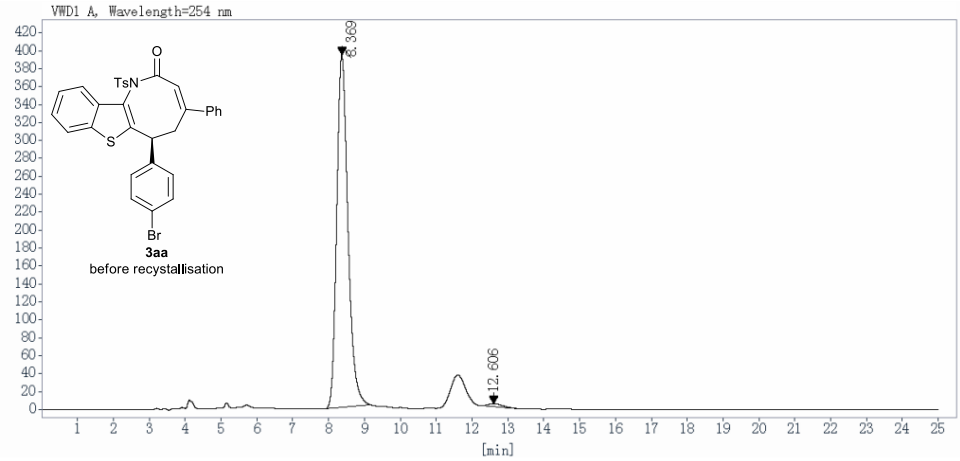
4.413
4.400
3.496
3.463
3.430
3.180
3.167
3.147
3.133
2.423
-0.000
O
TsN
Ph
S
Br
3aa
1H NMR (400 MHz, CDCl3)
0.96
2.00
0.99
2.02
4.46
3.23
1.27
2.22
1.01
1.10
1.12
1.08
3.20
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
f1 (ppm)

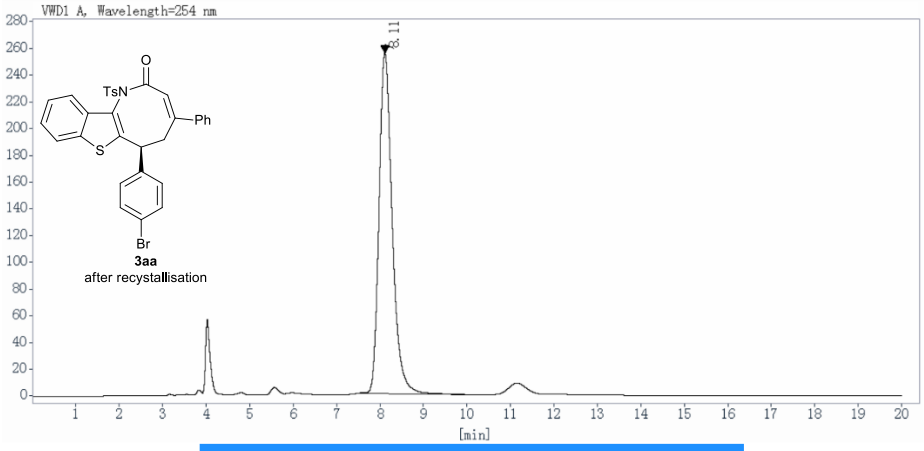

168.153
148.899
145.571
141.747
140.711
138.661
138.198
135.804
134.952
131.986
130.398
129.495
129.464
129.196
128.928
126.370
126.280
125.533
125.256
122.343
122.285
121.393
121.224
77.318
77.000
76.683
44.113
37.200
21.711
O
TsN
Ph
S
Br
3aa
13C NMR (100 MHz, CDCl3)
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)



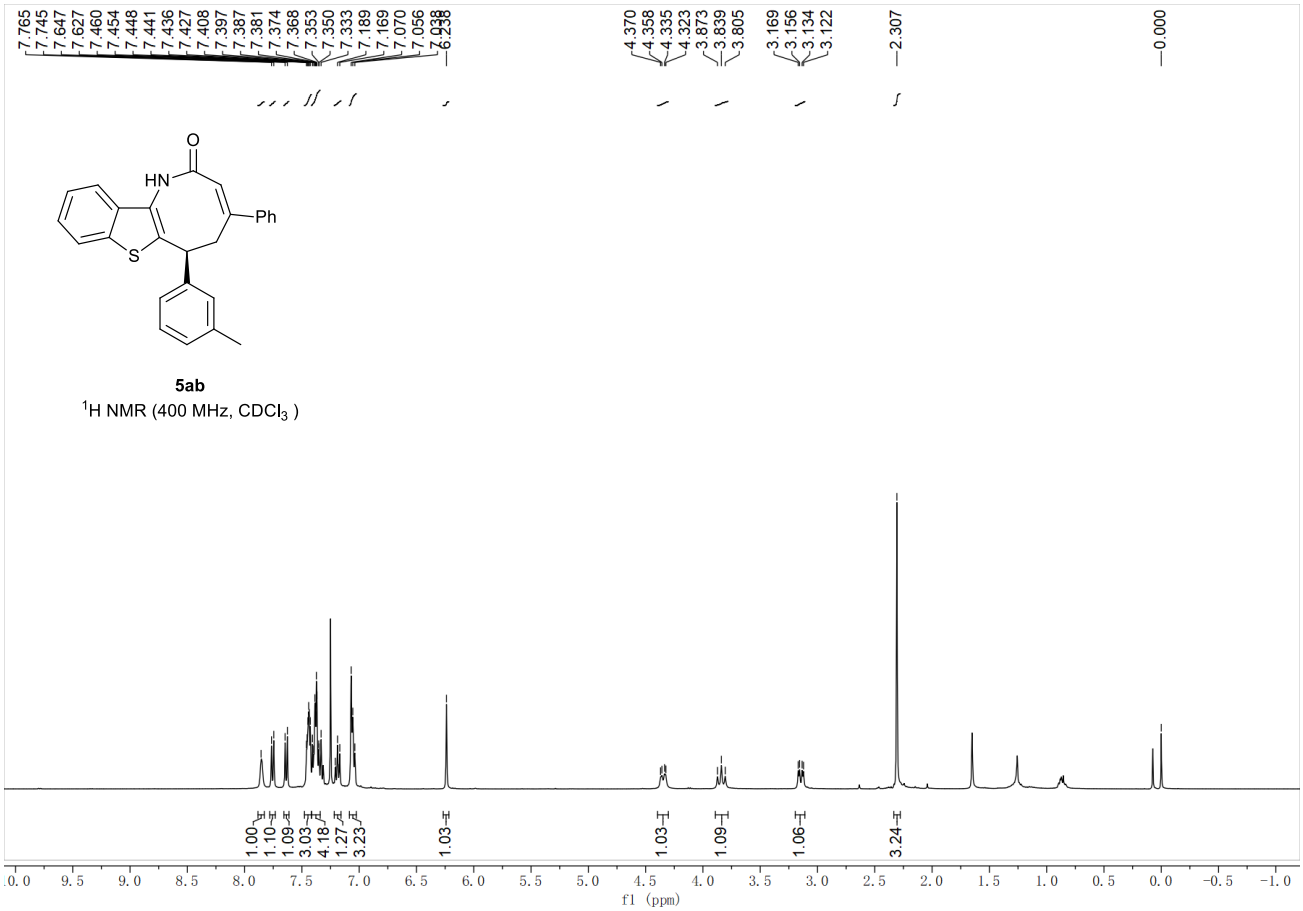
Ret Time [min]	Peak Type	Width [min]	Height [mAU]	Area [mAU*s]	Area [%]
8.224	BB	0.31	370.8836	7532.4697	50.1769
12.140	BBA	0.54	212.4927	7479.3721	49.8231
			Totals:	15011.8418	100.0000



Ret Time [min]	Peak Type	Width [min]	Height [mAU]	Area [mAU*s]	Area [%]
8.369	BBA	0.33	392.8734	8514.4375	98.8566
12.606	BBA	0.46	3.4363	98.4780	1.1434
			Totals:	8612.9155	100.0000

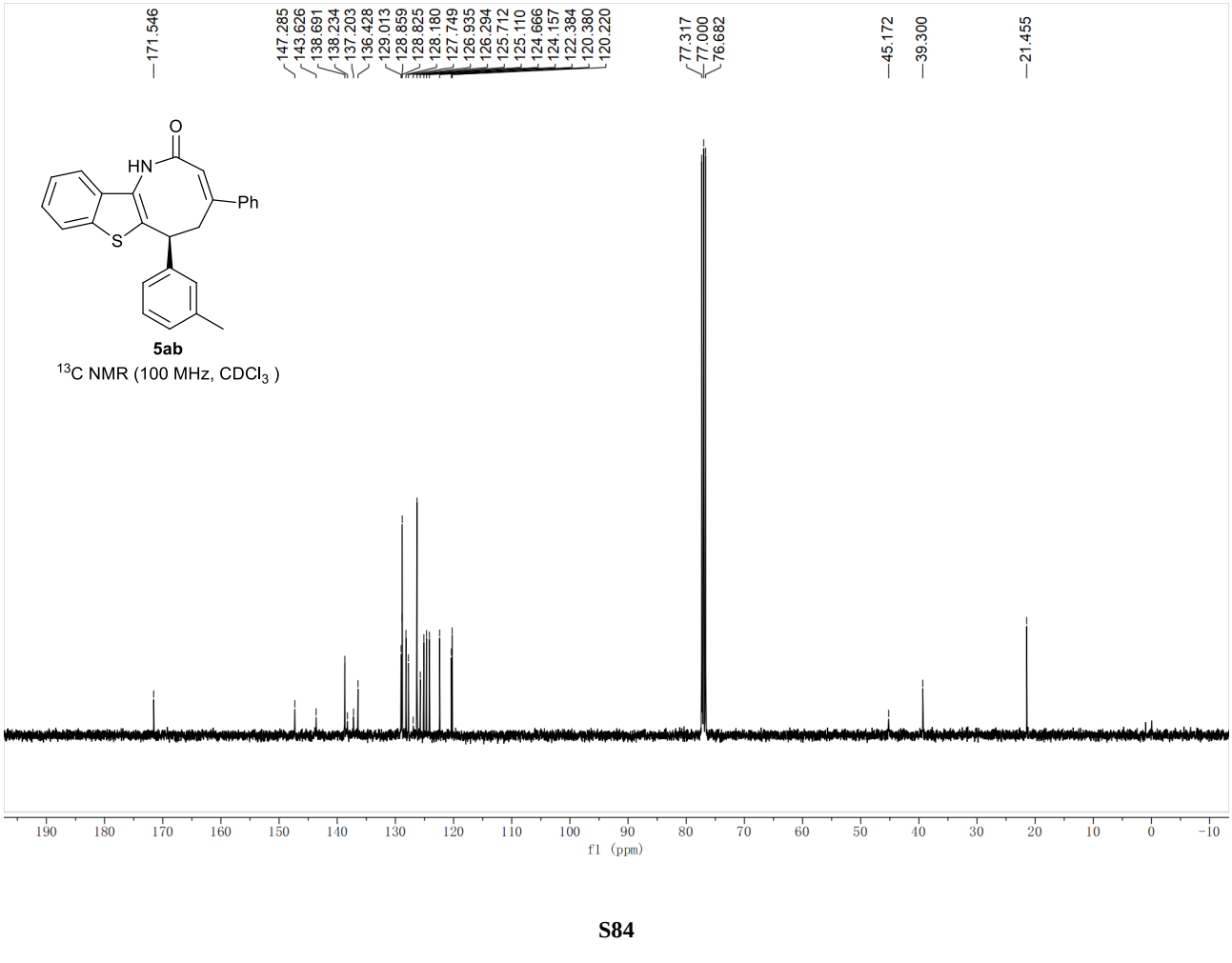


Ret Time [min]	Peak Type	Width [min]	Height [mAU]	Area [mAU*s]	Area [%]
8.110	VBAR	0.32	254.9309	5383.2529	100.0000
			Totals:	5383.2529	100.0000



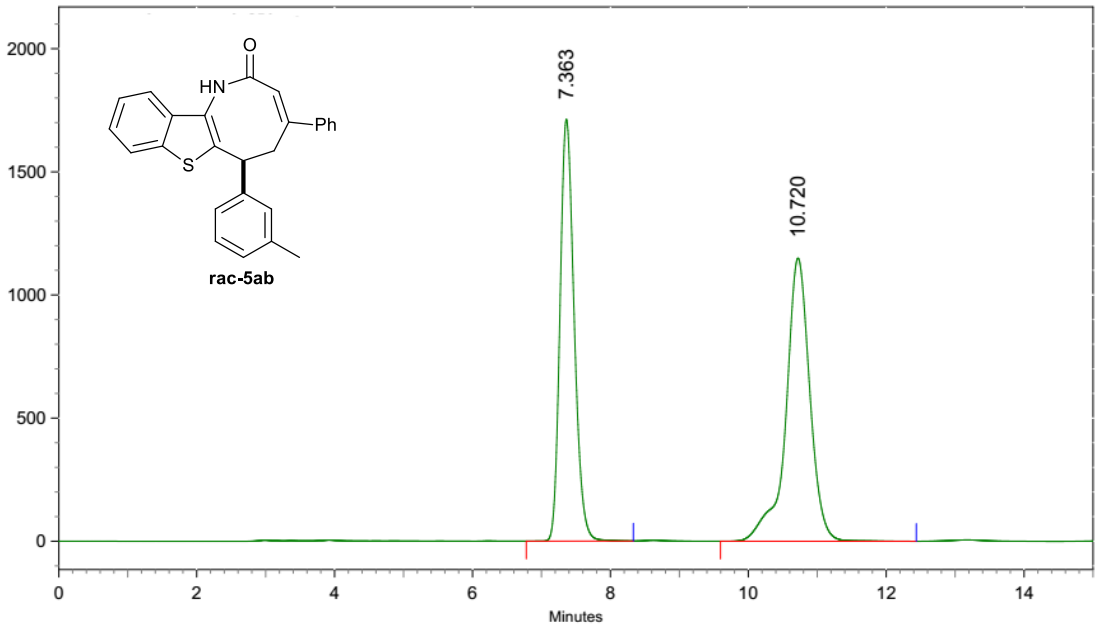
5ab

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

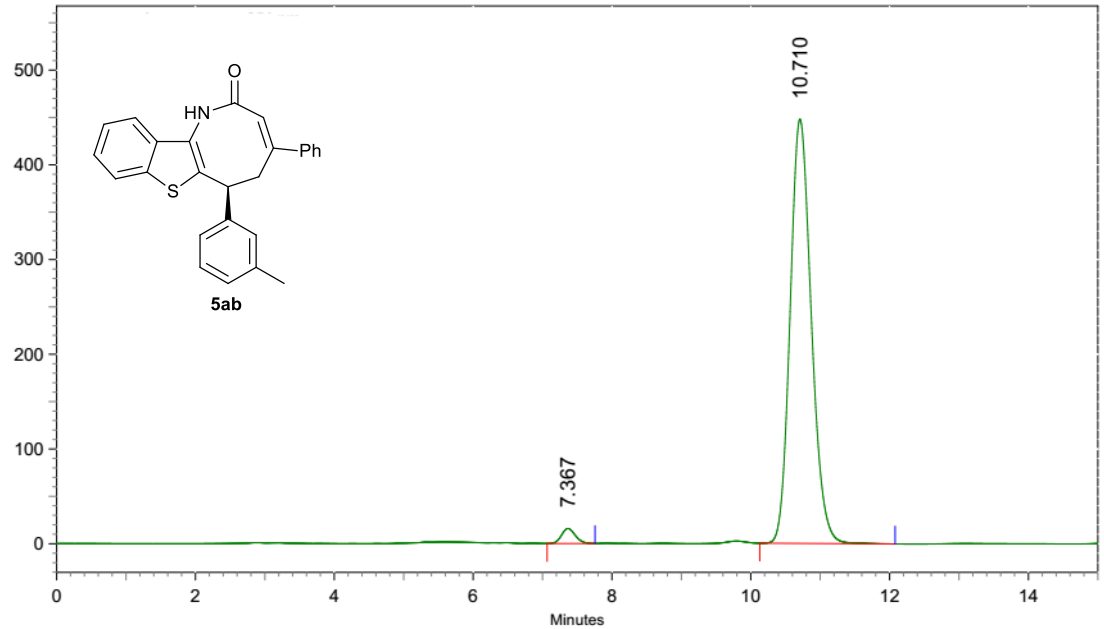


5ab

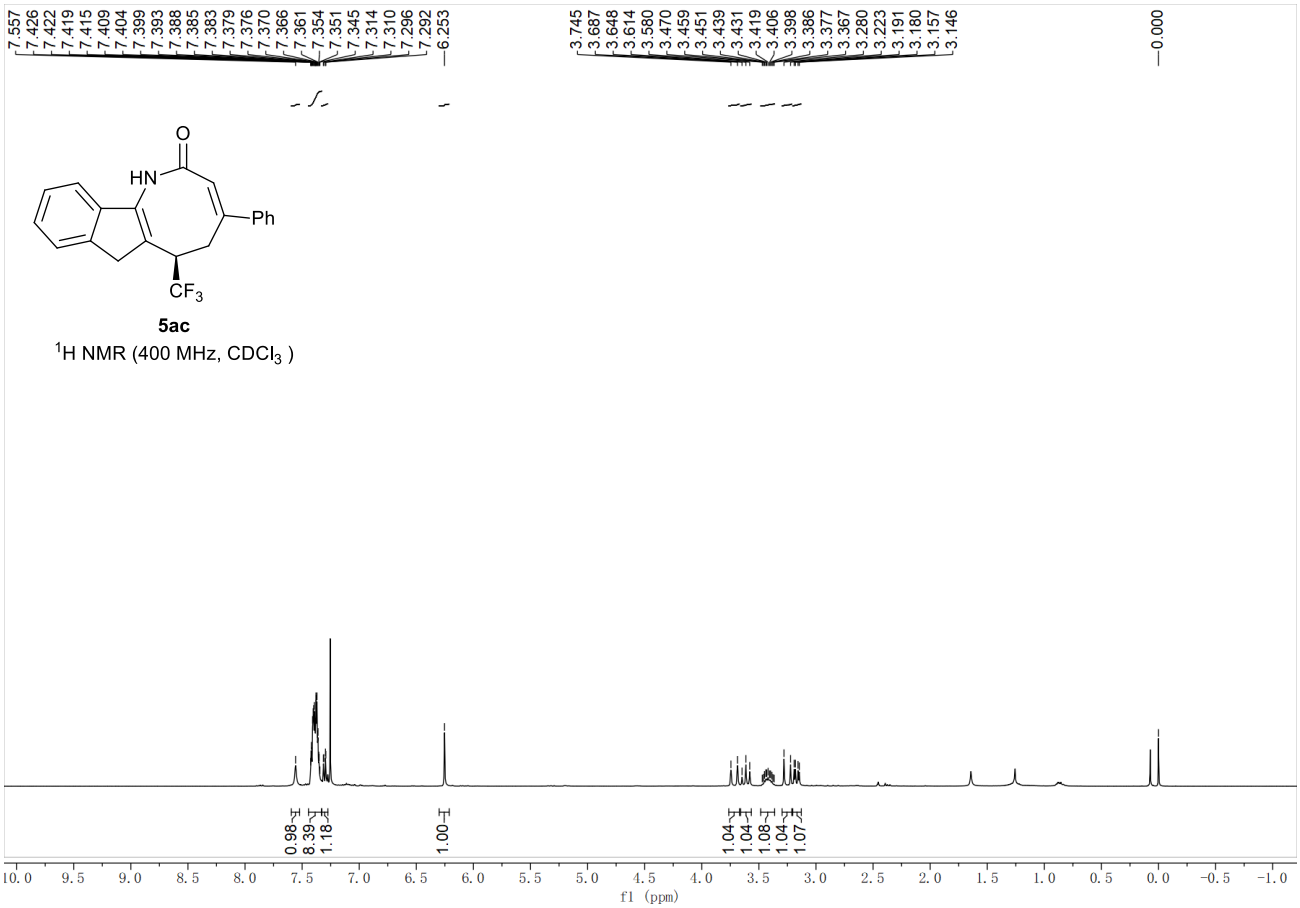
^{13}C NMR (100 MHz, $CDCl_3$)



Peak No.	Ret Time	Width	Height	Area	Area [%]
1	7.363	1.553	28730469	409538995	46.6257
2	10.720	2.840	19284372	468815391	53.3743
Totals			48014841	878354386	100.0000

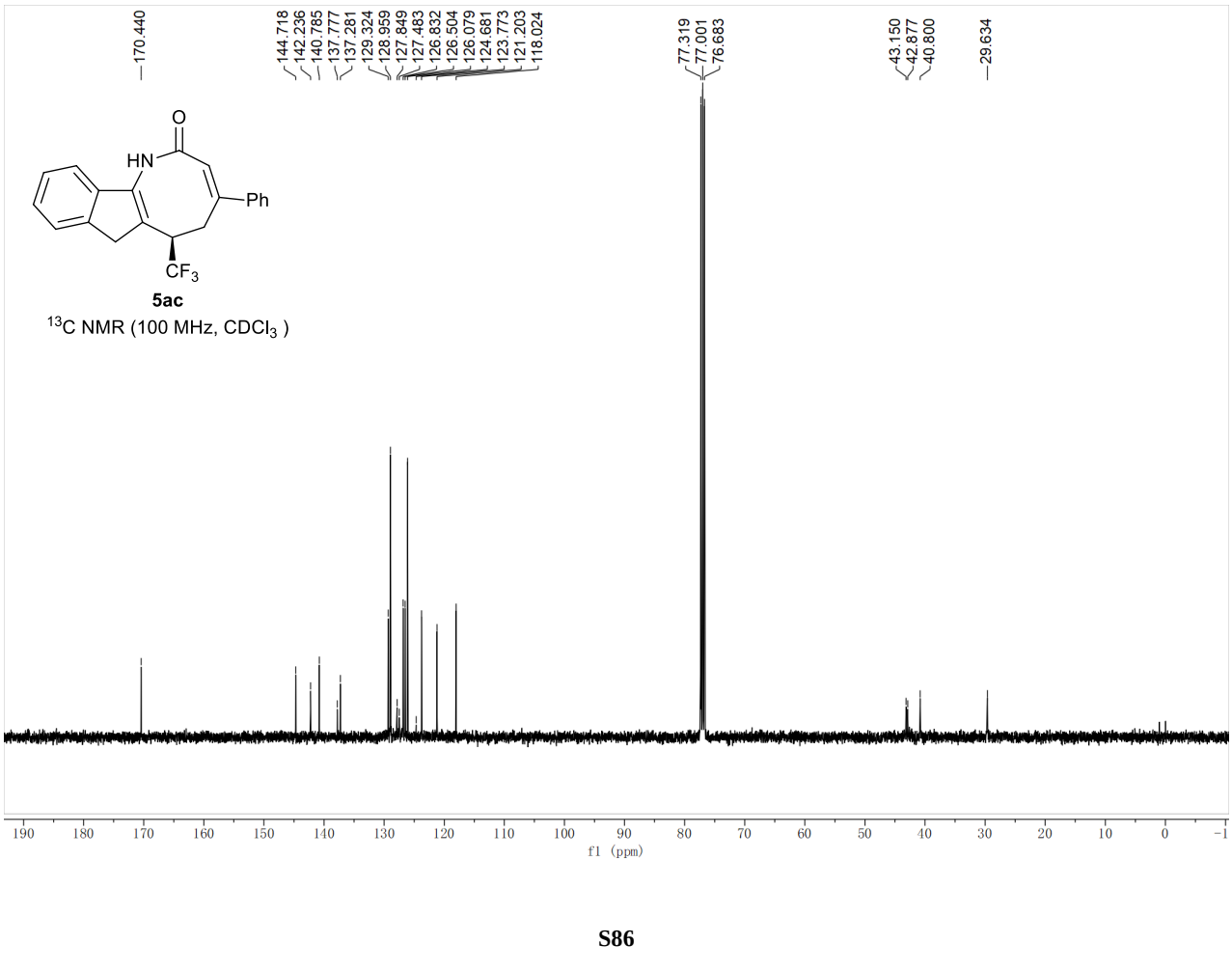


Peak No.	Ret Time	Width	Height	Area	Area [%]
1	7.367	0.690	265744	3677714	2.2611
2	10.710	1.950	7513484	158970626	97.7389
Totals			7779228	162648340	100.0000



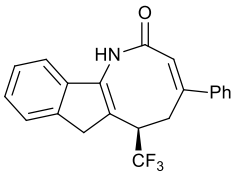
5ac

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



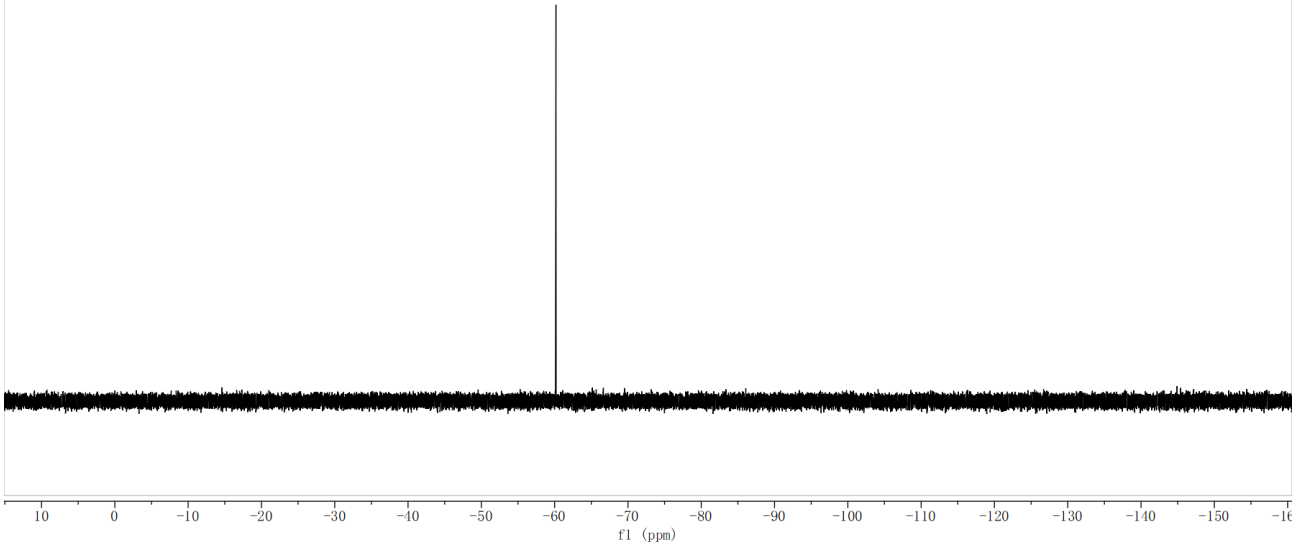
5ac

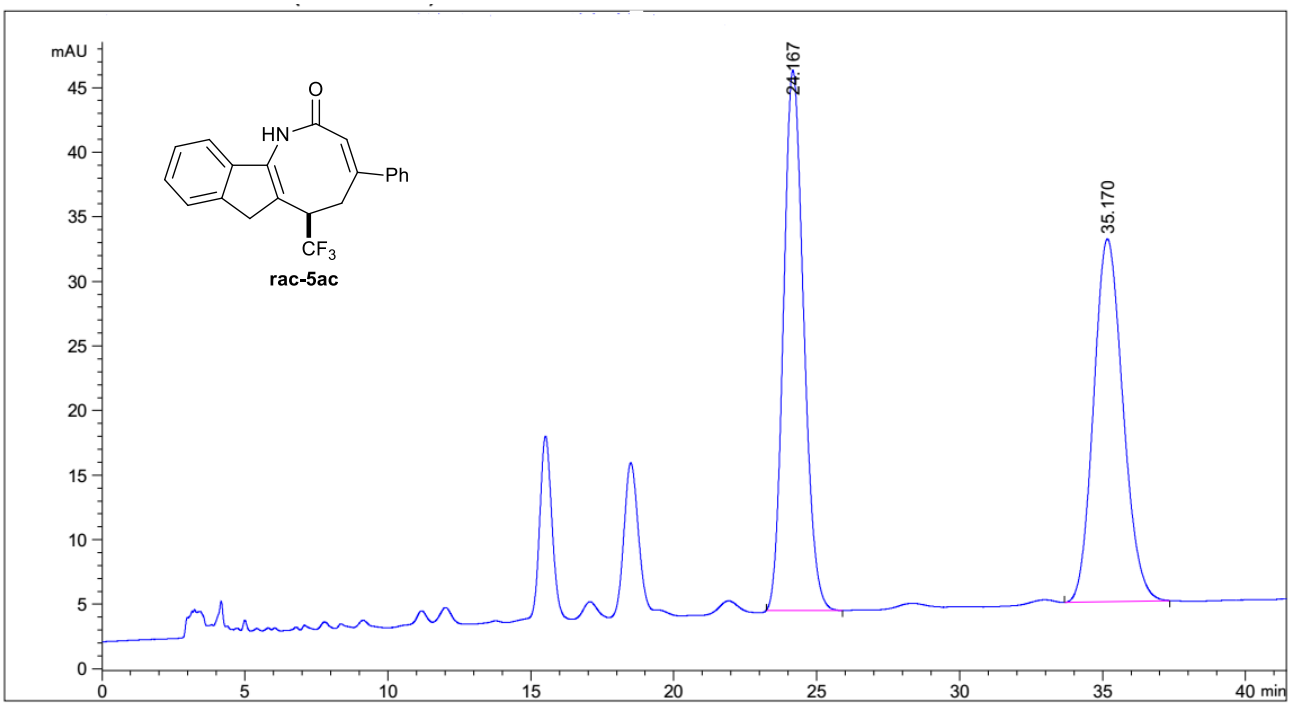
^{13}C NMR (100 MHz, $CDCl_3$)



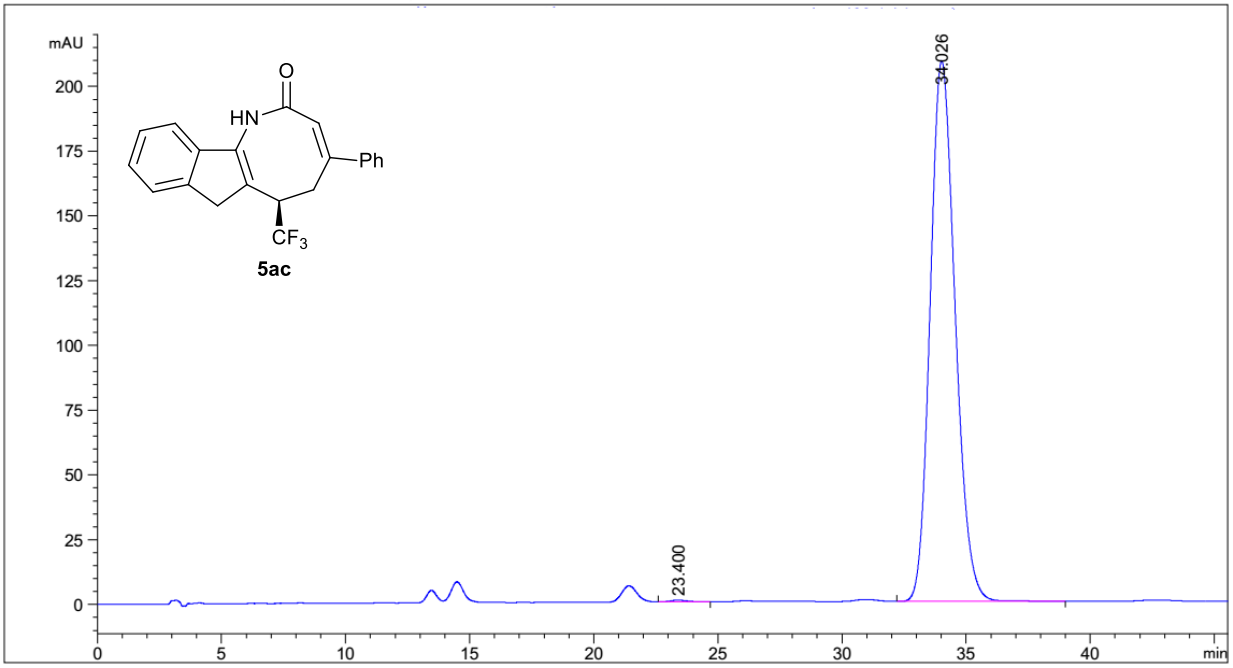
5ac

^{19}F NMR (376 MHz, $CDCl_3$)

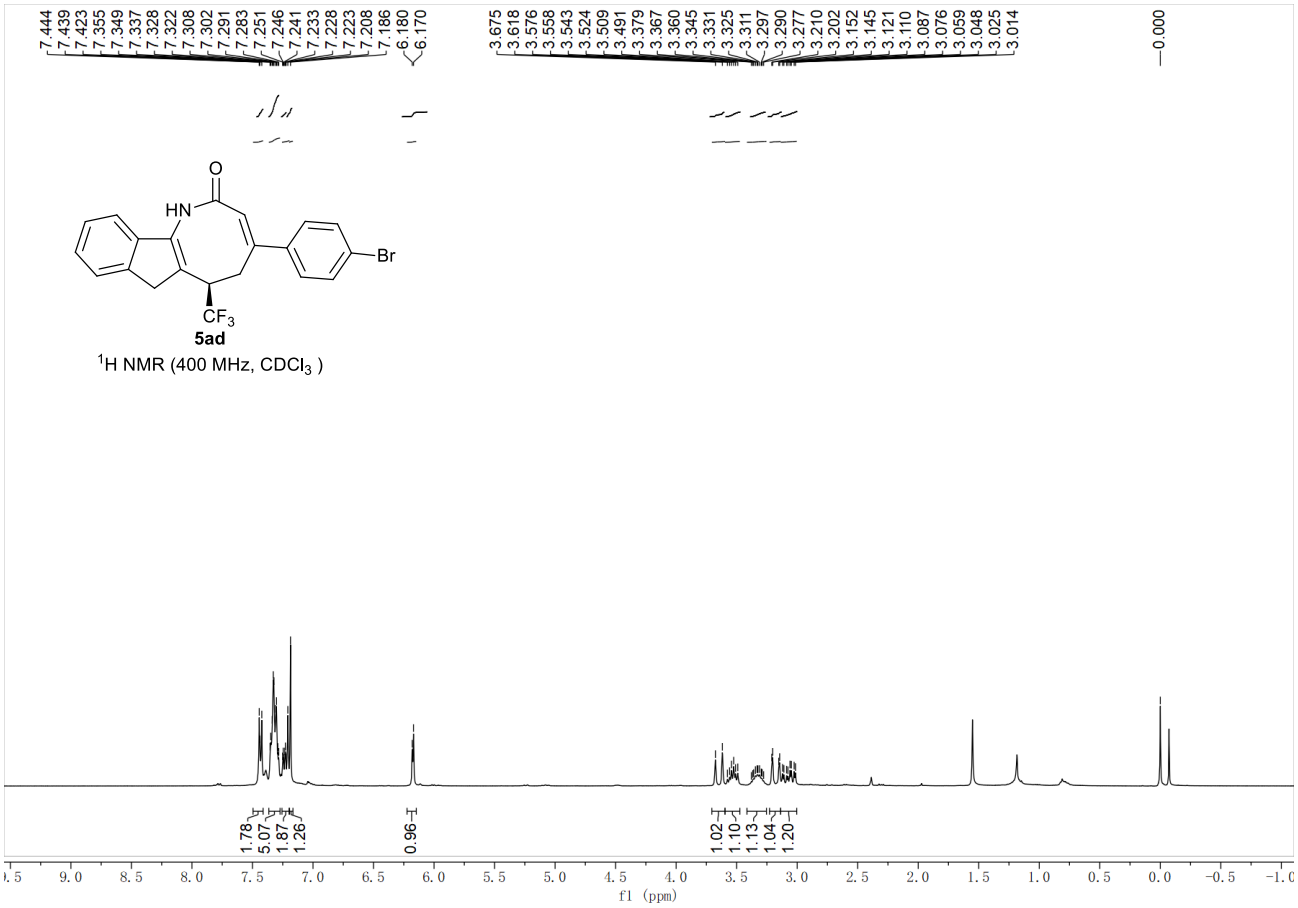


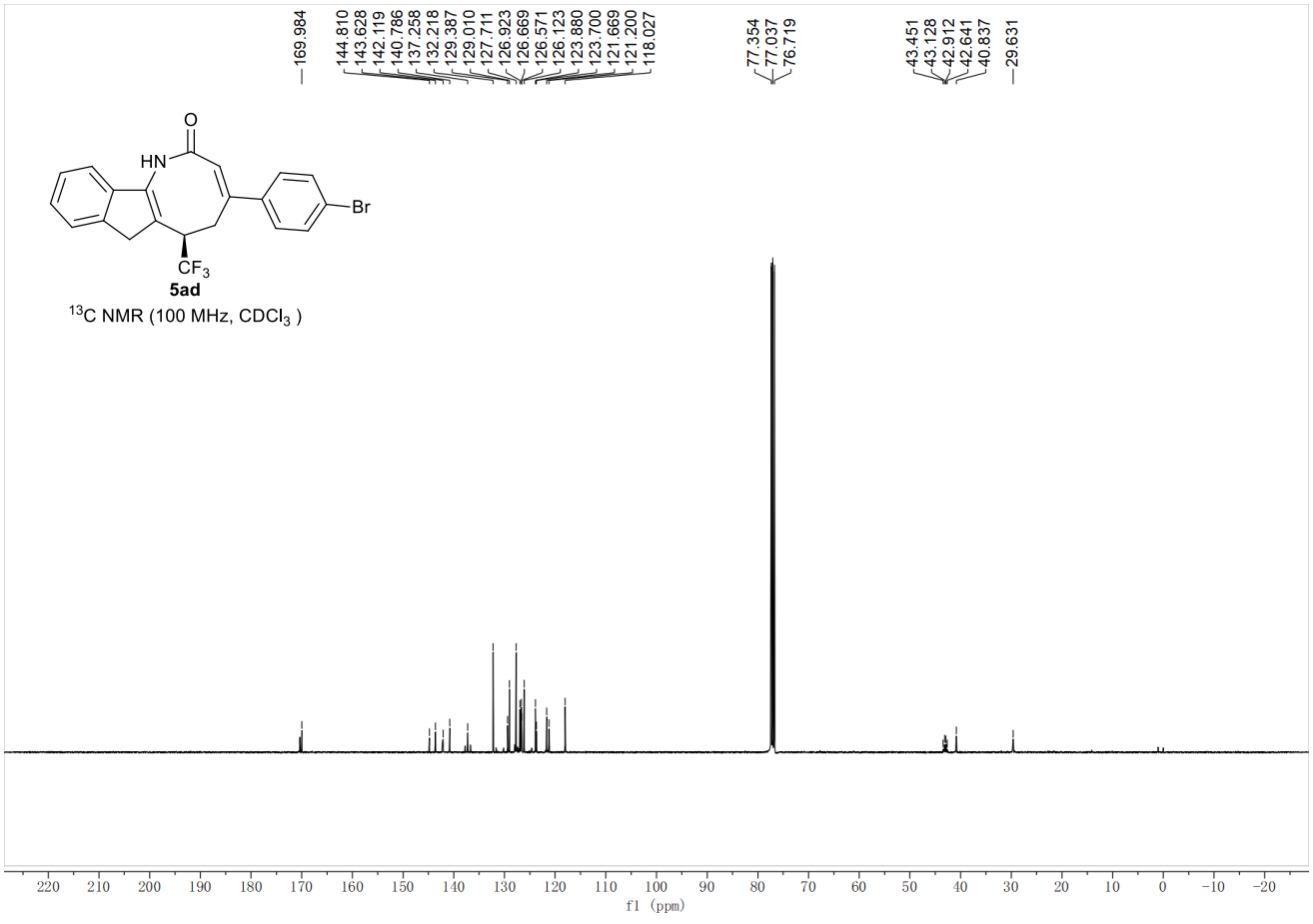


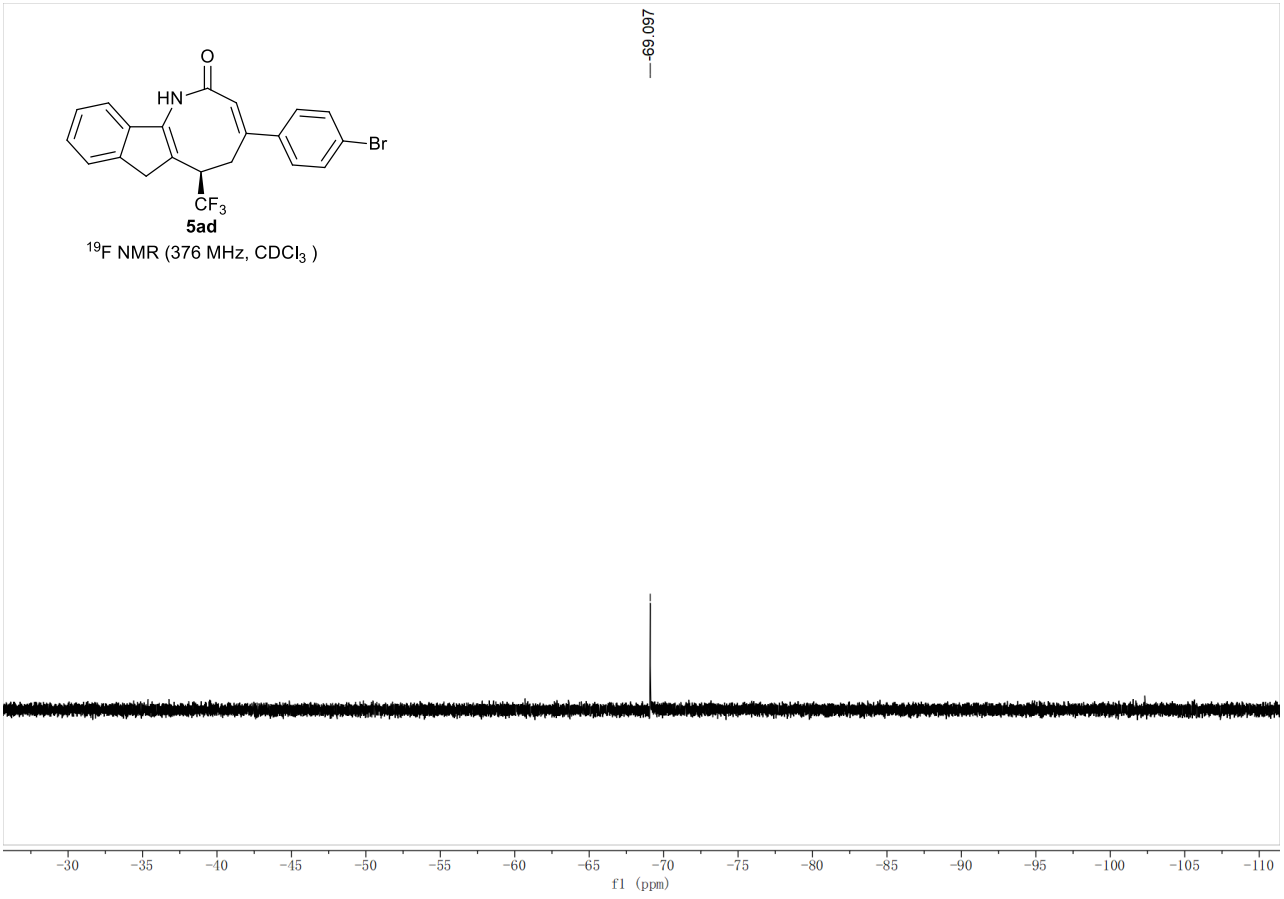
#	[min]		[min]	[mAU*s]	[mAU]	%
1	24.167	BV	0.7243	2053.46069	41.82023	50.5903
2	35.170	BBA	1.0935	2005.54321	28.09335	49.4097
				4059.00391	69.91358	



#	[min]		[min]	[mAU*s]	[mAU]	%
1	23.400	BBA	0.7292	29.16349	6.26736e-1	0.1994
2	34.026	BBA	1.1026	1.45930e4	206.84700	99.8006
				1.46221e4	207.47374	

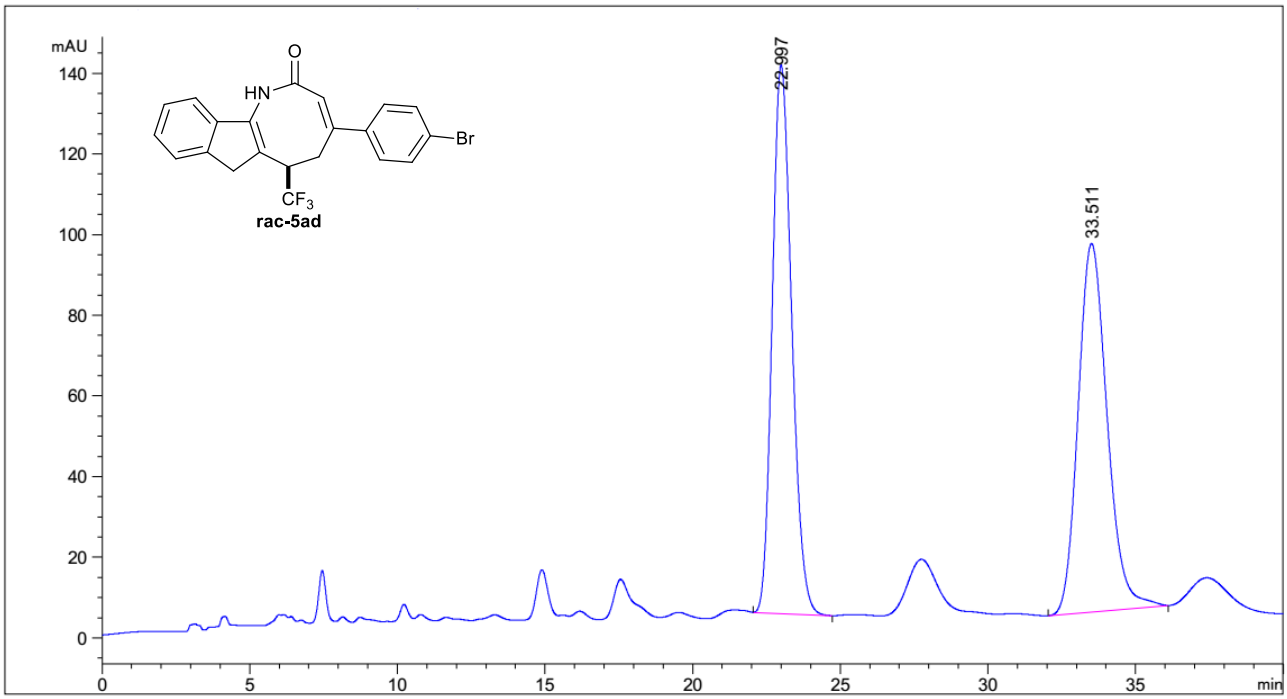

7.444
7.439
7.423
7.355
7.349
7.337
7.328
7.322
7.308
7.302
7.291
7.283
7.251
7.246
7.241
7.233
7.228
7.223
7.208
7.186
6.180
6.170
3.675
3.618
3.576
3.558
3.543
3.524
3.509
3.491
3.379
3.367
3.360
3.345
3.331
3.325
3.311
3.297
3.290
3.277
3.210
3.202
3.152
3.145
3.121
3.110
3.087
3.076
3.059
3.048
3.025
3.014
0.000
O
HN
Br
CF3
5ad
1H NMR (400 MHz, CDCl3)
1.78
5.07
1.87
1.26
0.96
1.02
1.10
1.13
1.04
1.20
f1 (ppm)


169.984
144.810
143.628
142.119
140.786
137.258
132.218
129.387
129.010
127.711
126.923
126.669
126.571
126.123
123.880
123.700
121.669
121.200
118.027
77.354
77.037
76.719
43.451
43.128
42.912
42.641
40.837
29.631
O
HN
Br
CF3
5ad
13C NMR (100 MHz, CDCl3)
f1 (ppm)

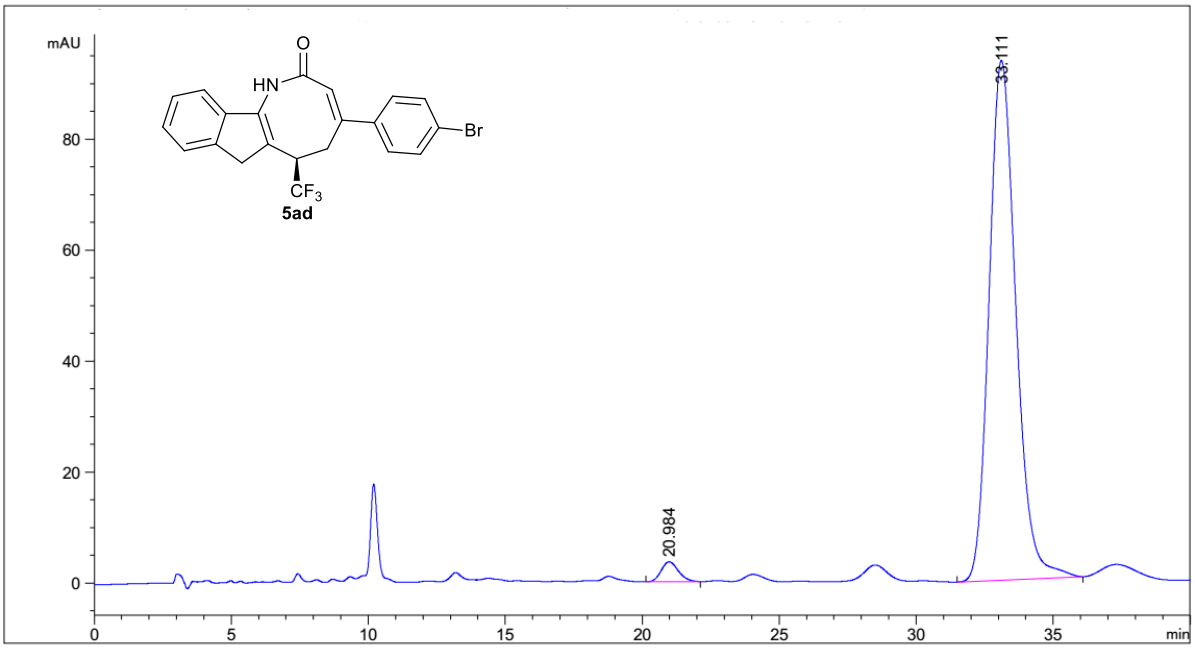


5ad

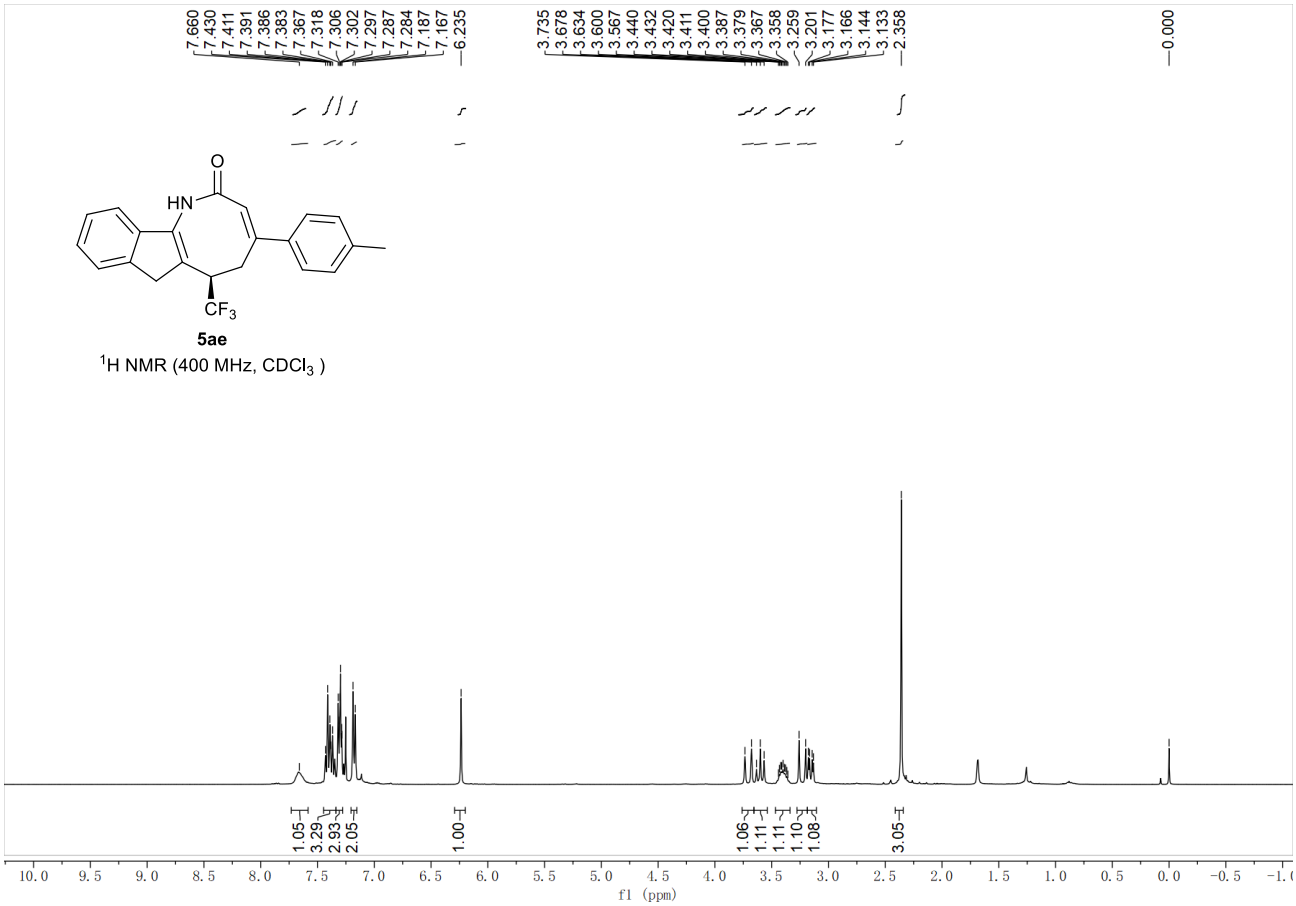
^{19}F NMR (376 MHz, $CDCl_3$)



#	[min]		[min]	[mAU*s]	[mAU]	%
1	22.997	BB	0.7103	6226.45215	136.00800	49.9625
2	33.511	BB	1.0566	6235.79834	91.39545	50.0375
				1.24623e4	227.40345	

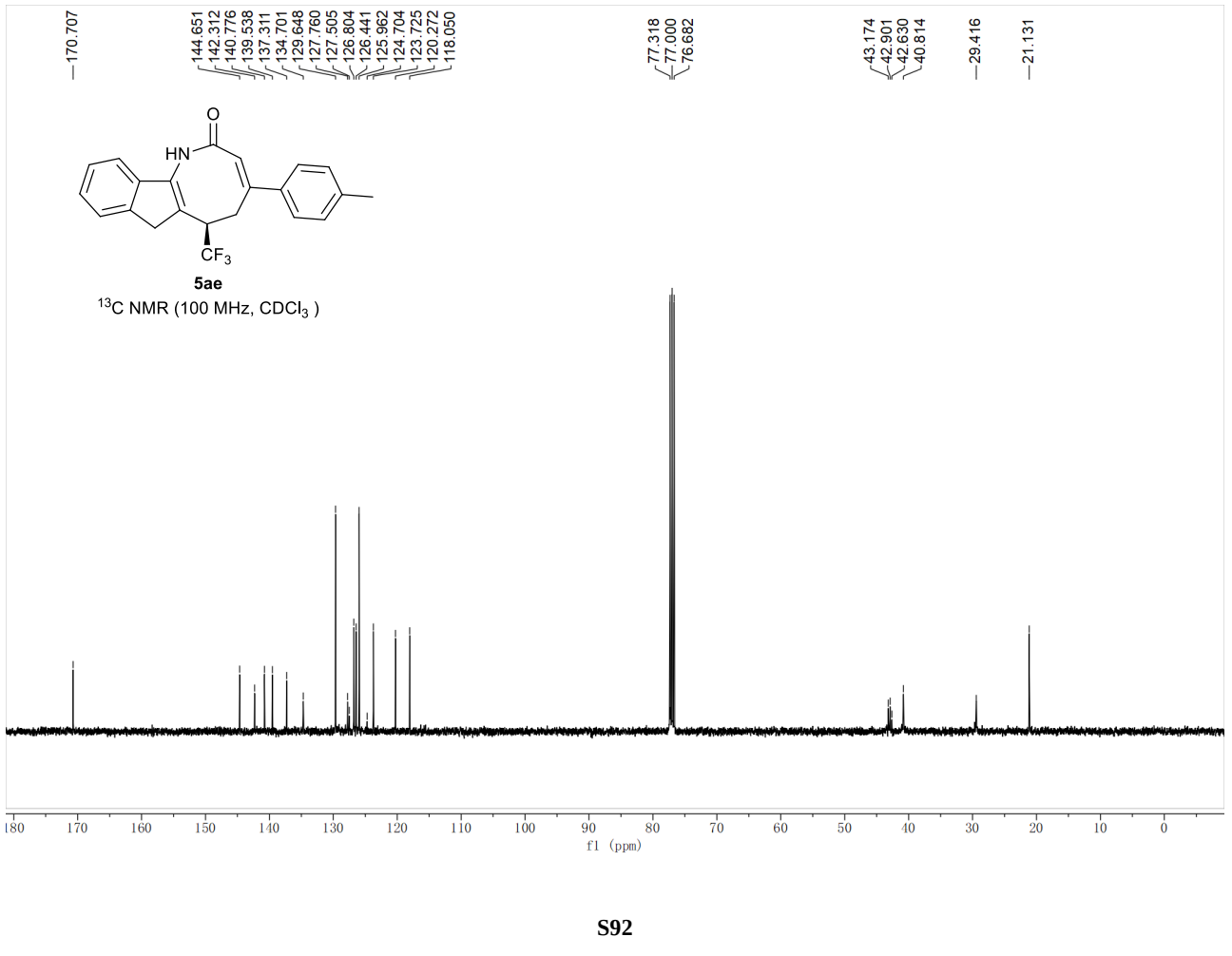


#	[min]		[min]	[mAU*s]	[mAU]	%
1	20.984	BB	0.6534	157.63657	3.59097	2.4185
2	33.111	BB	1.0458	6360.43799	93.63577	97.5815
				6518.07455	97.22673	



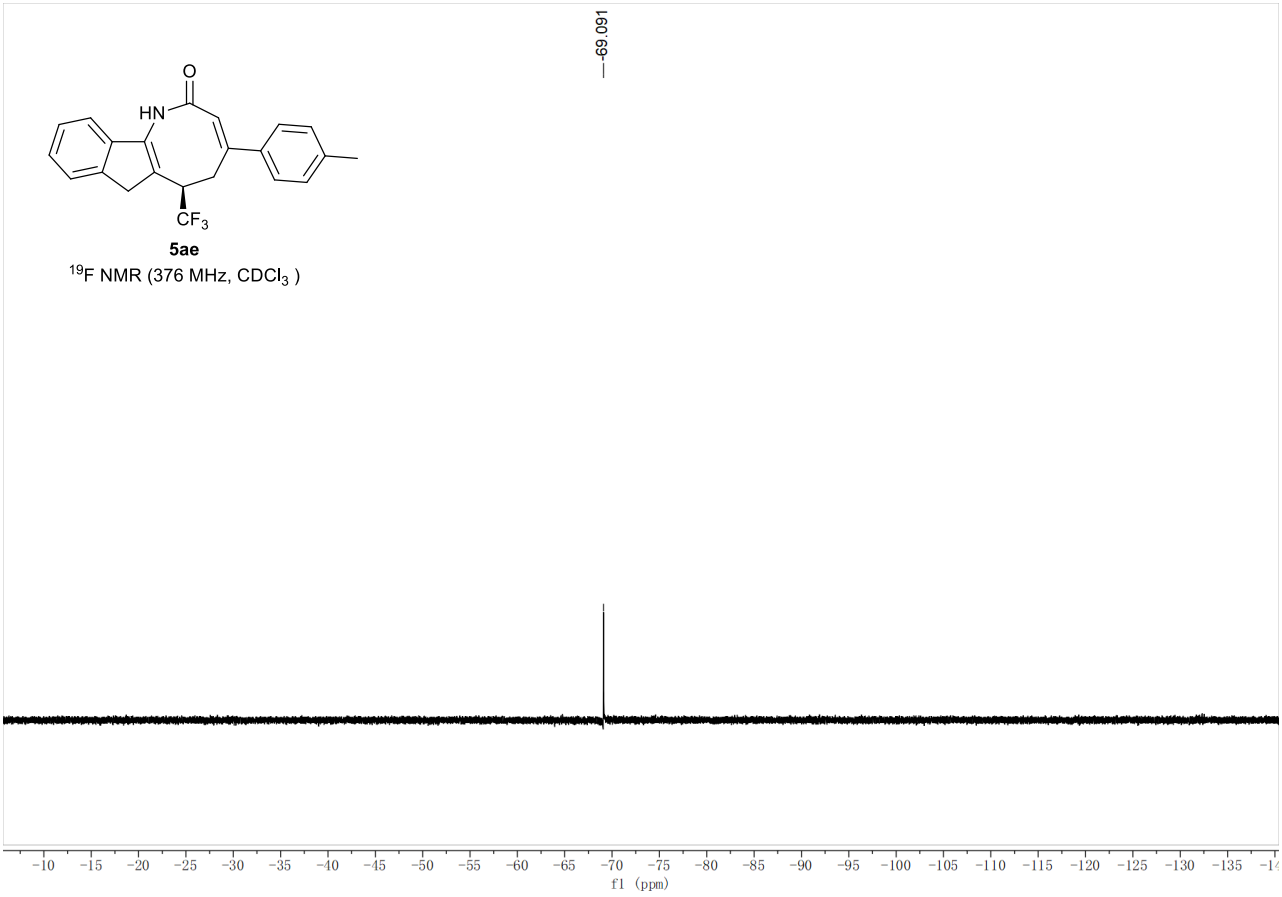
5ae

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



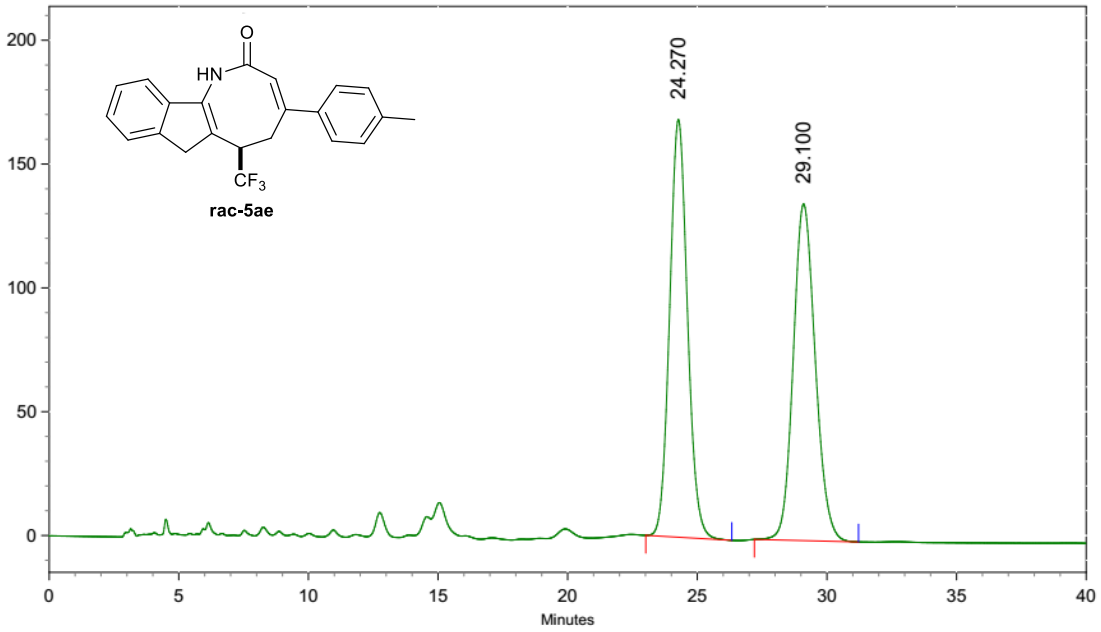
5ae

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

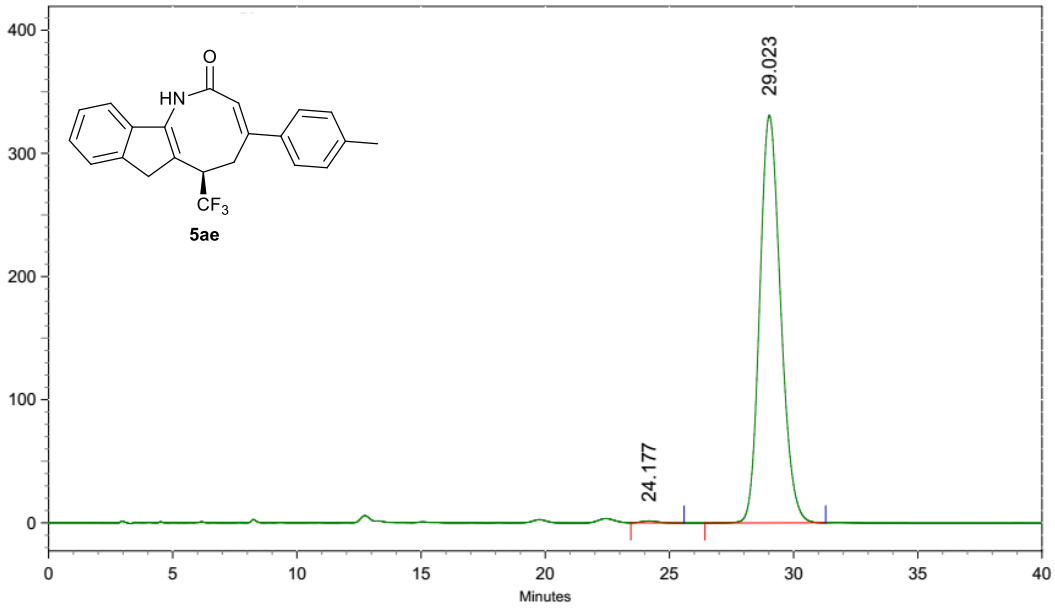


5ae

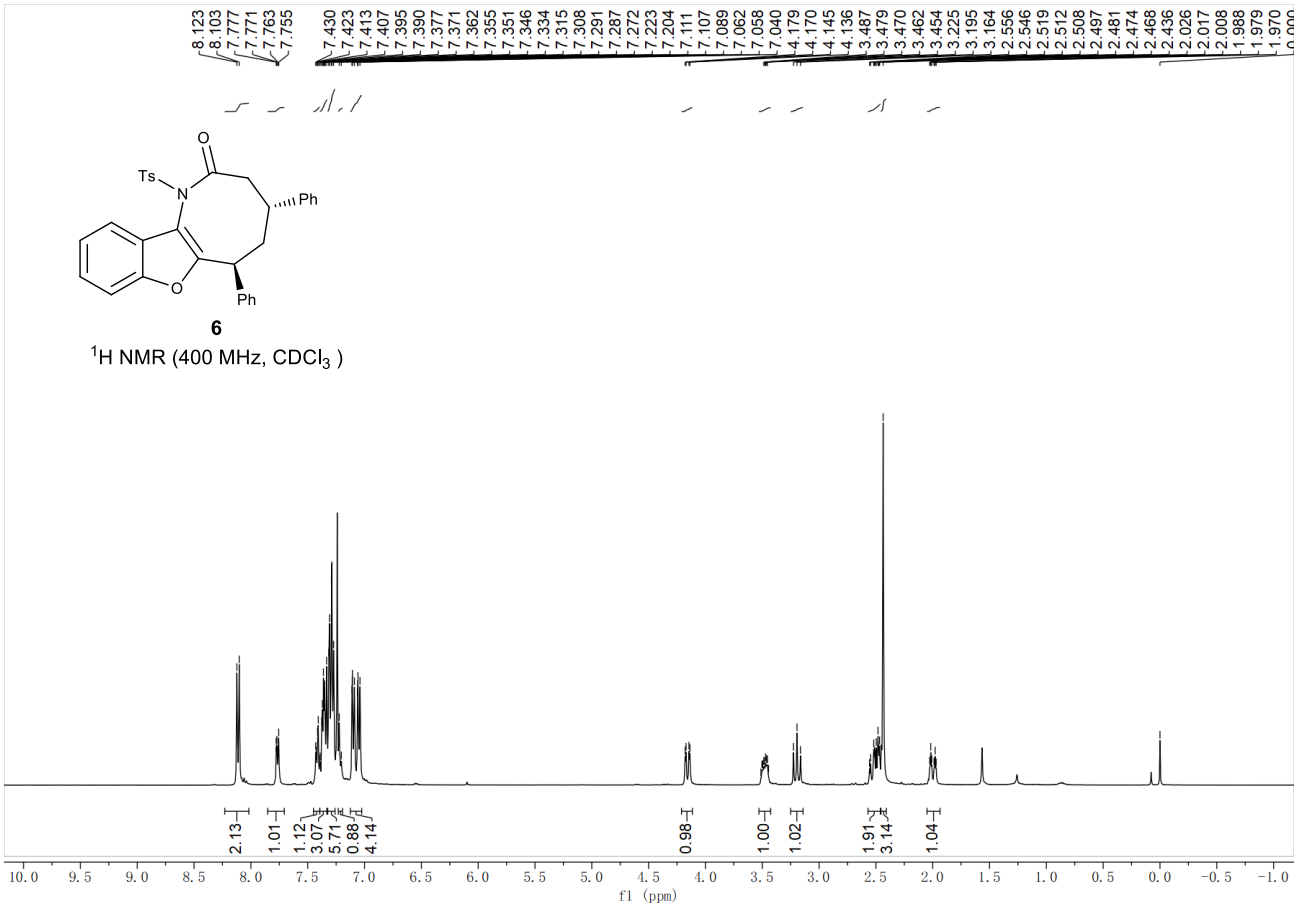
^{19}F NMR (376 MHz, $CDCl_3$)



Peak No.	Ret Time	Width	Height	Area	Area [%]
1	24.270	3.317	2830035	135308111	50.0873
2	29.100	4.017	2280886	134836533	49.9127
Totals			5110921	270144644	100.0000

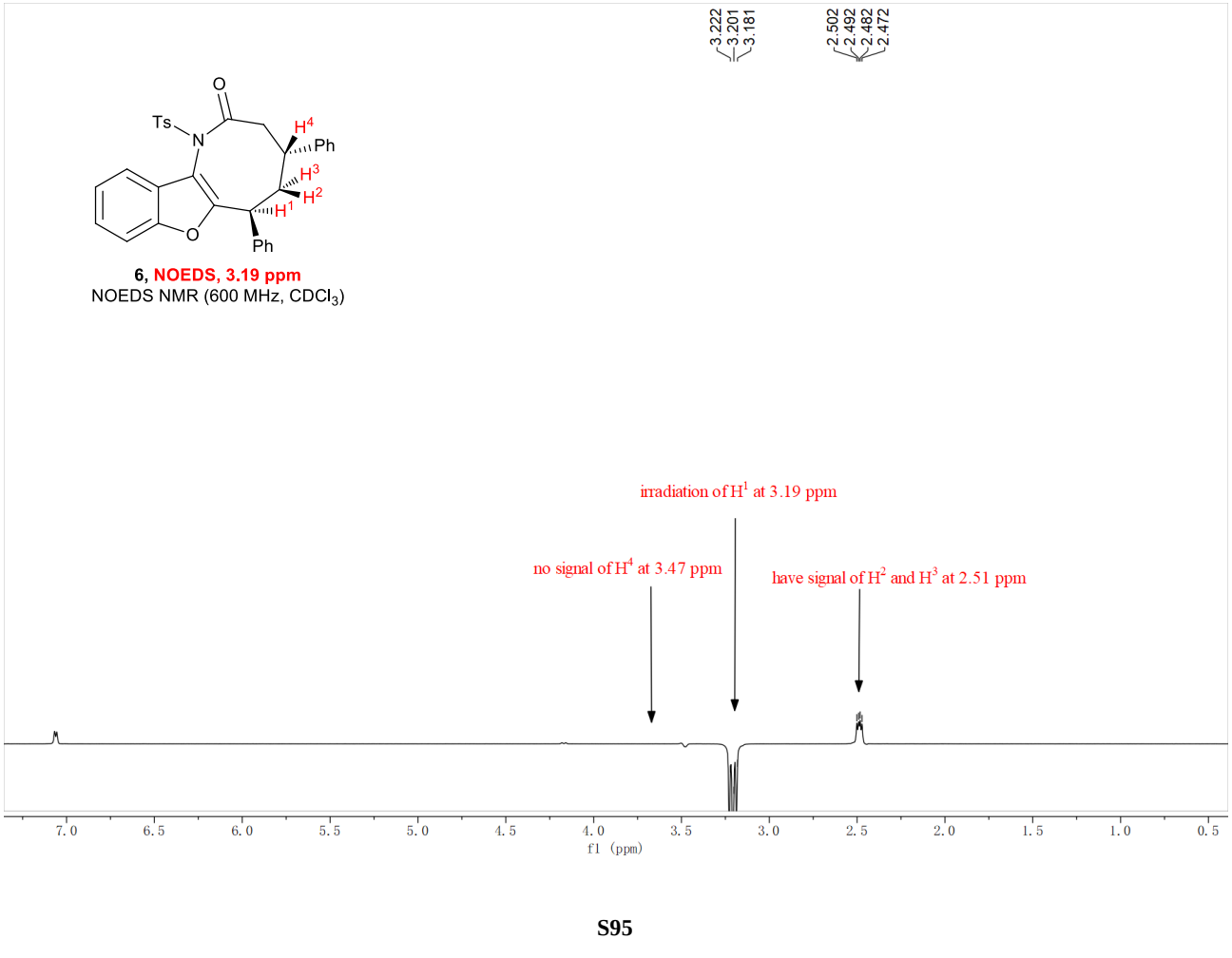


Peak No.	Ret Time	Width	Height	Area	Area [%]
1	24.177	2.143	25113	1139108	0.3497
2	29.023	4.860	5553125	324592664	99.6503
Totals			5578238	325731772	100.0000



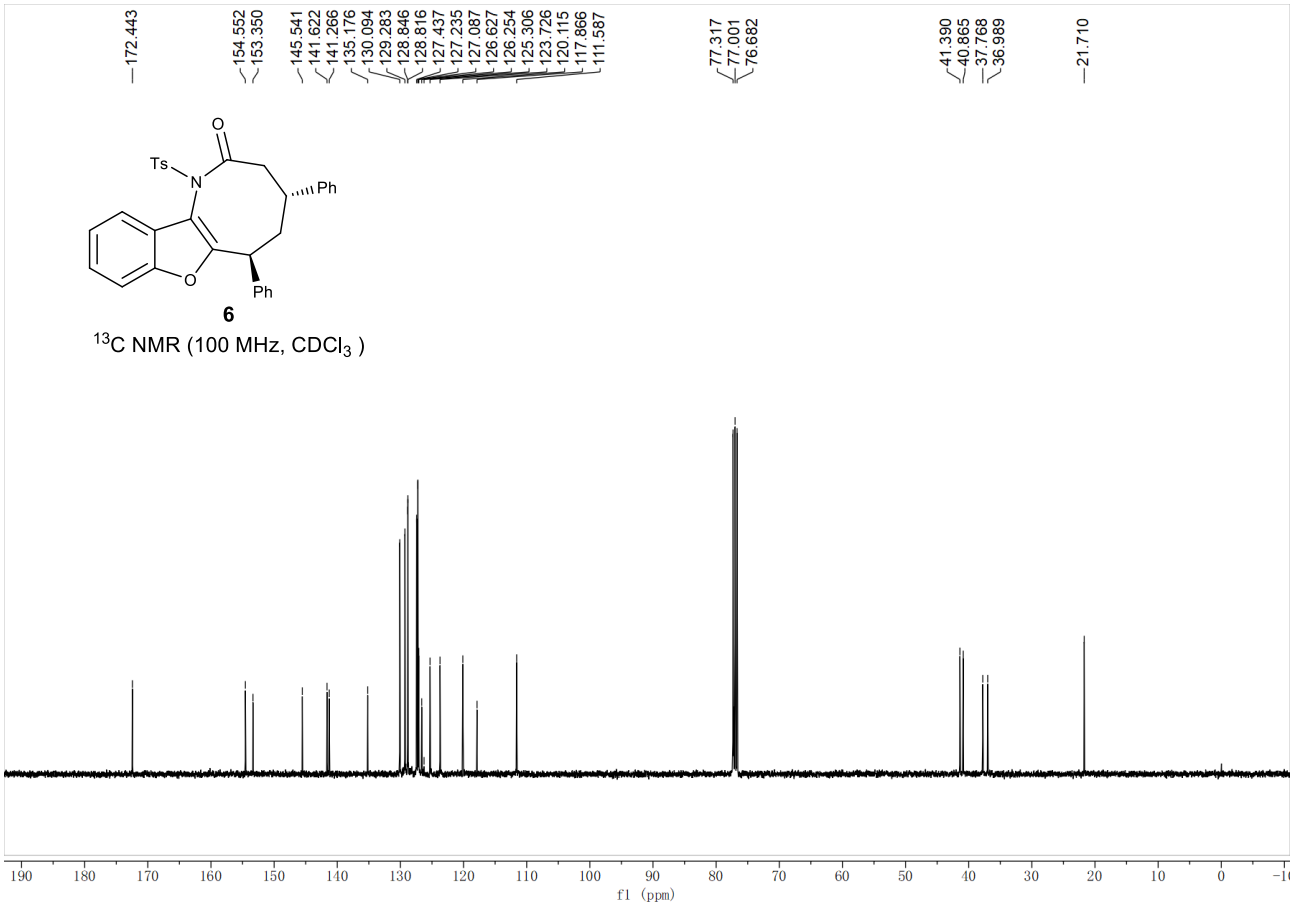
6

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



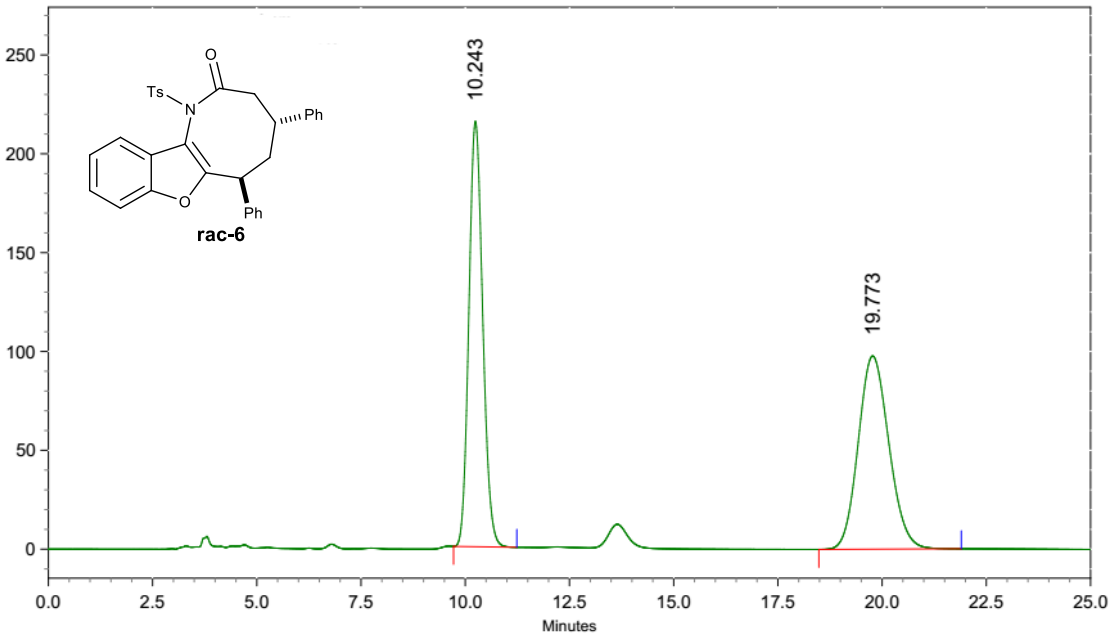
6, NOEDS, 3.19 ppm

NOEDS NMR (600 MHz, $CDCl_3$)

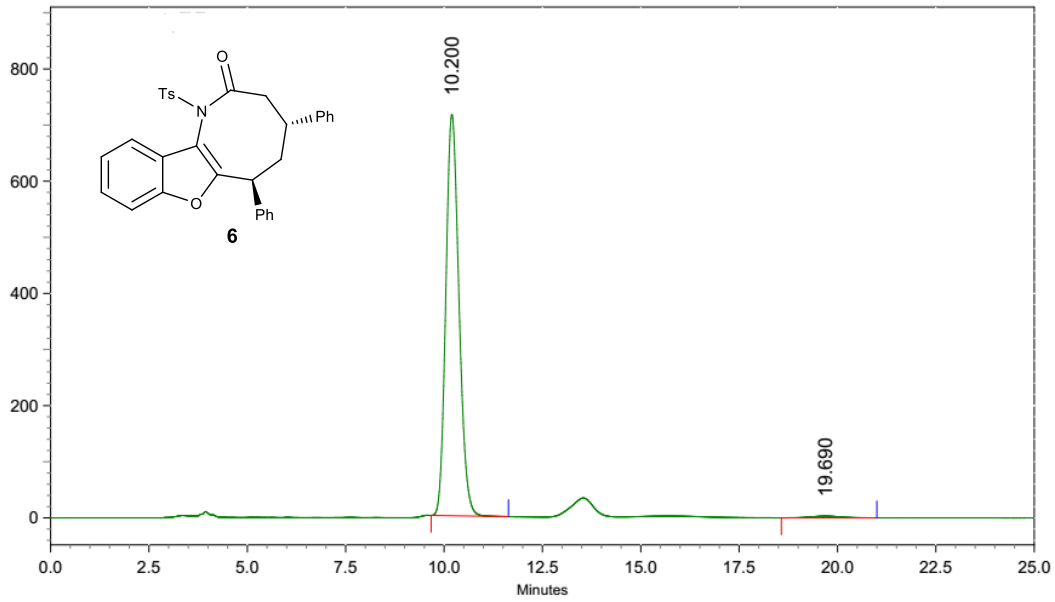


6

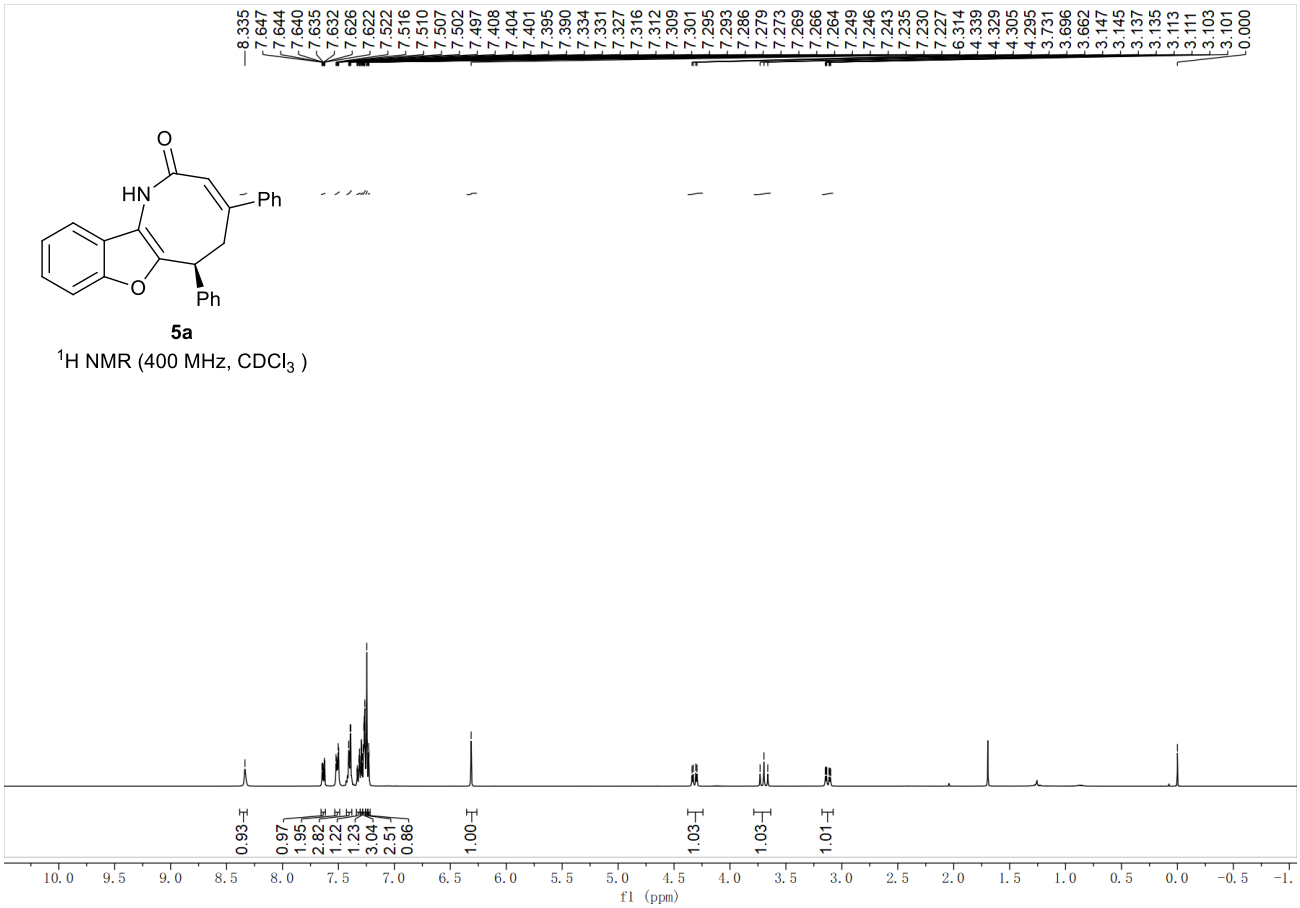
^{13}C NMR (100 MHz, $CDCl_3$)



Peak No.	Ret Time	Width	Height	Area	Area [%]
1	10.243	1.517	3609774	83344887	49.8282
2	19.773	3.417	1639757	83919444	50.1718
Totals			5249531	167264331	100.0000

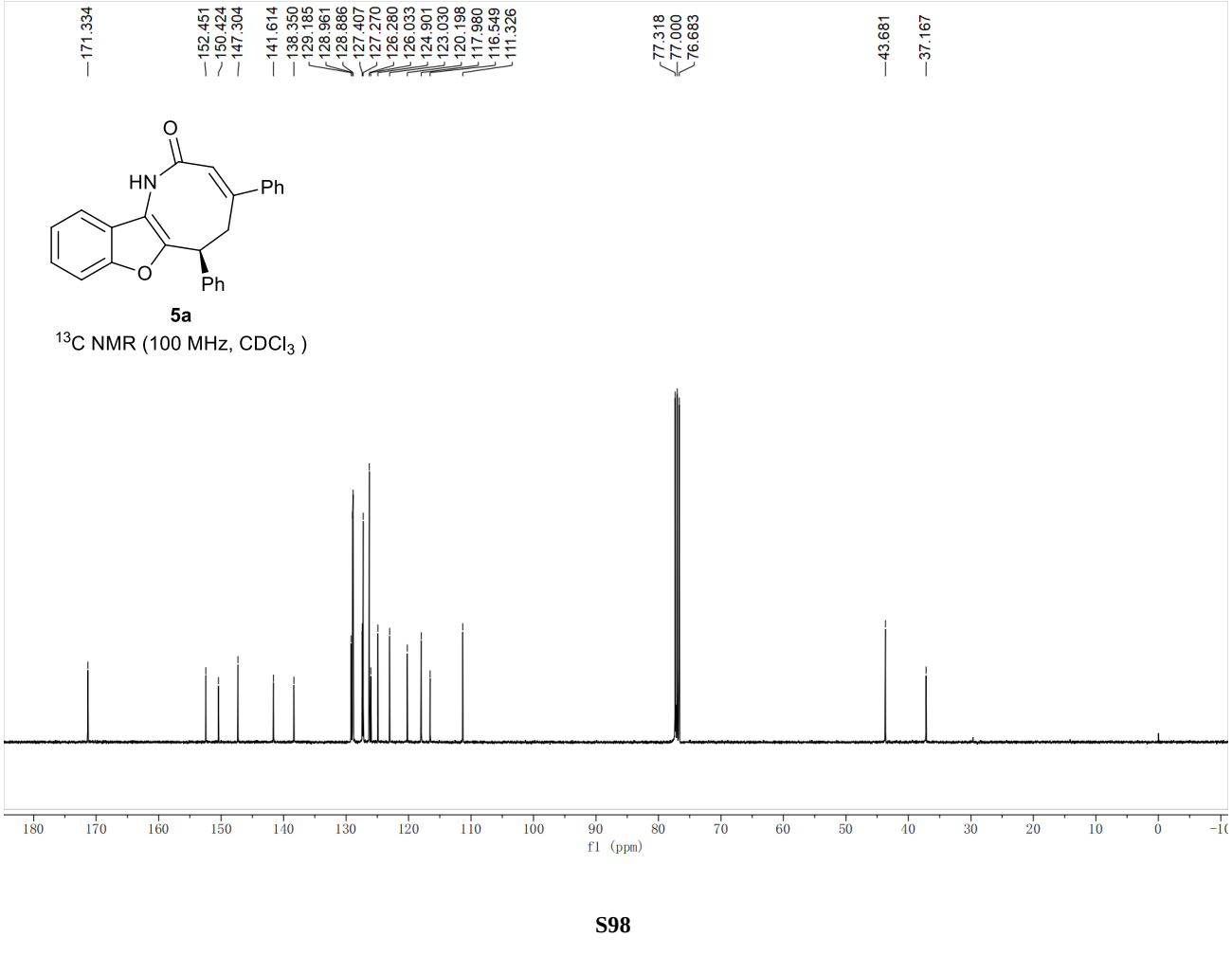


Peak No.	Ret Time	Width	Height	Area	Area [%]
1	10.200	1.963	11994157	278490106	99.0605
2	19.690	2.427	52789	2641244	0.9395
Totals			12046946	281131350	100.0000



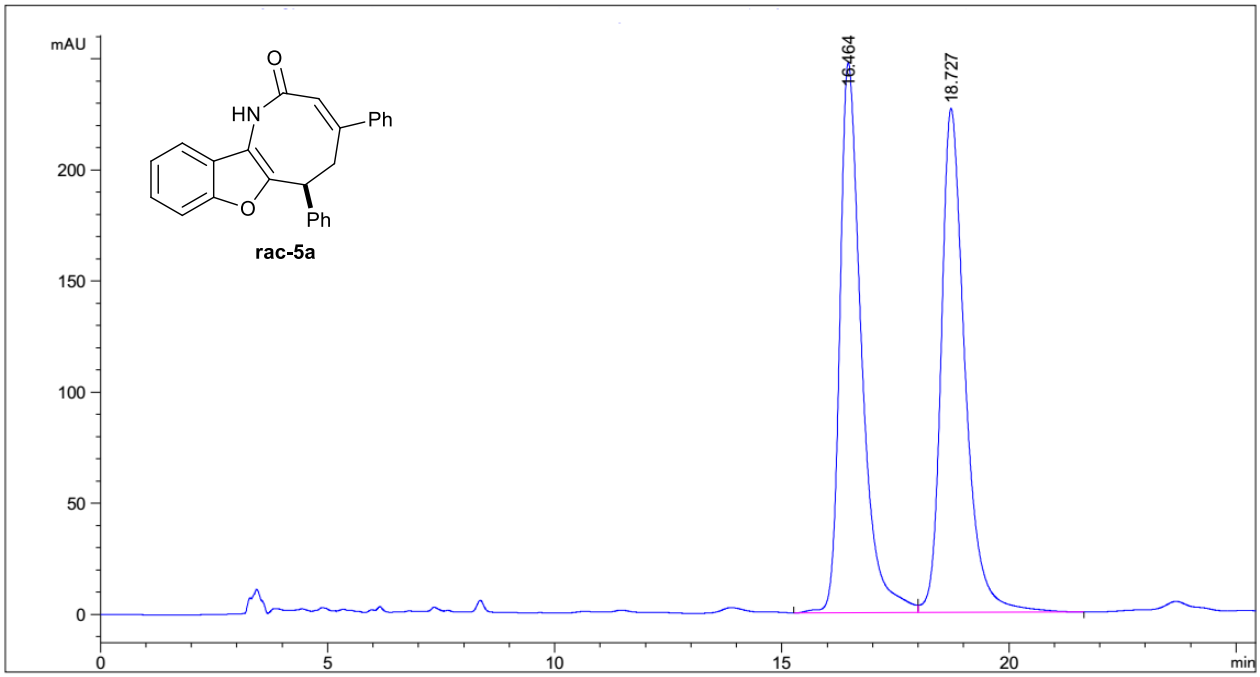
5a

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

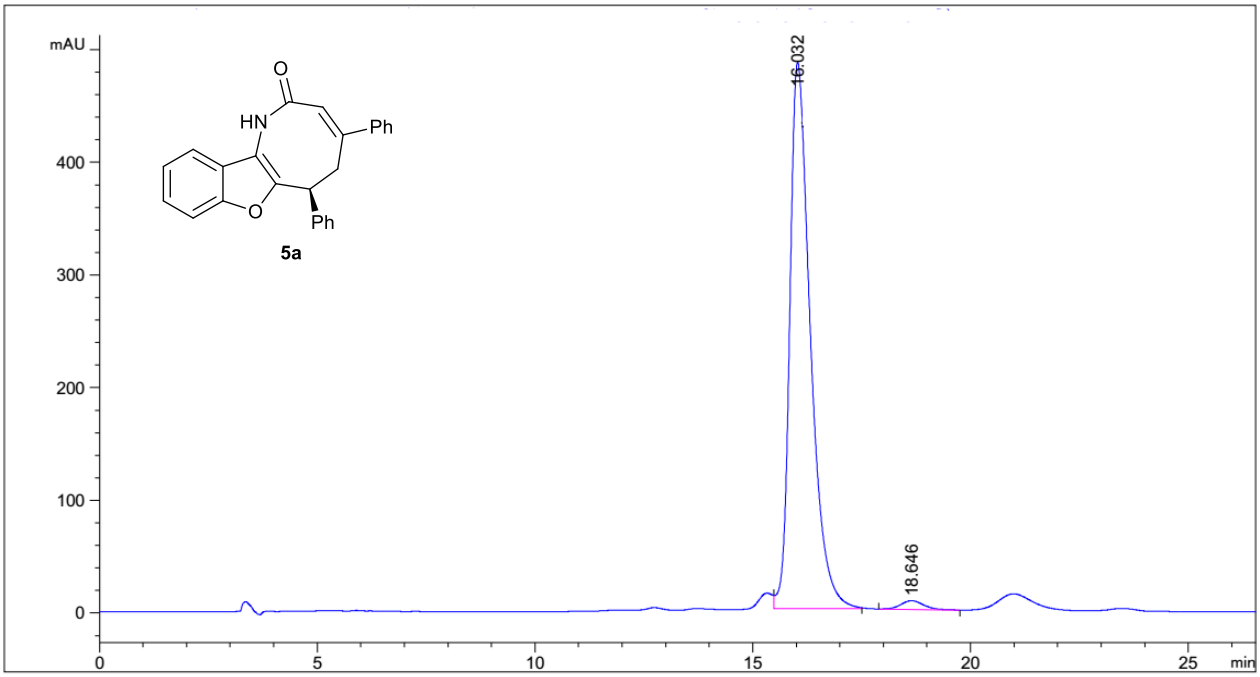


5a

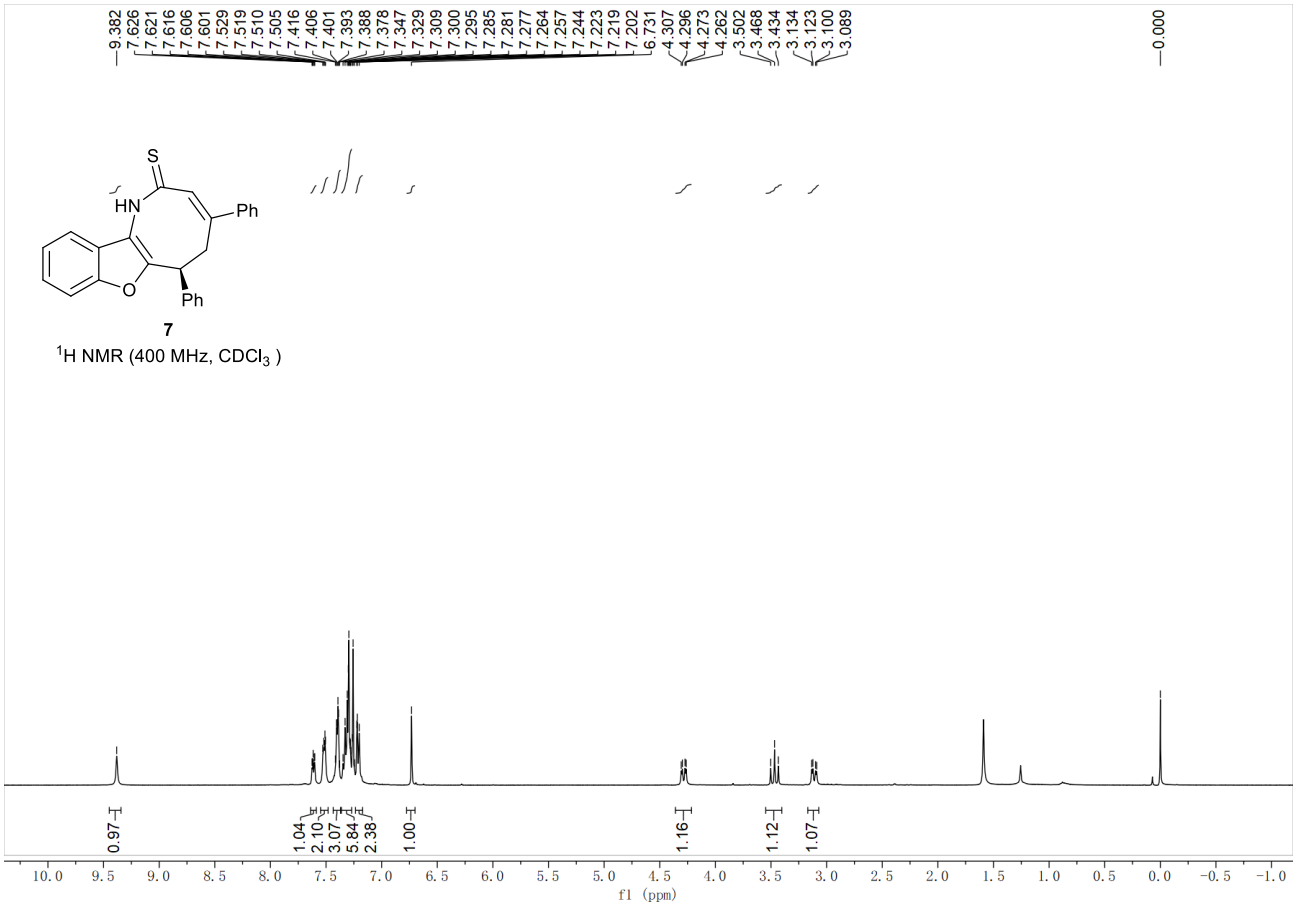
^{13}C NMR (100 MHz, $CDCl_3$)



#	[min]		[min]	[mAU*s]	[mAU]	%
1	16.464	BV	0.4988	8240.23047	247.67259	49.9546
2	18.727	VB	0.5468	8255.20703	226.89015	50.0454
				1.64954e4	474.56274	

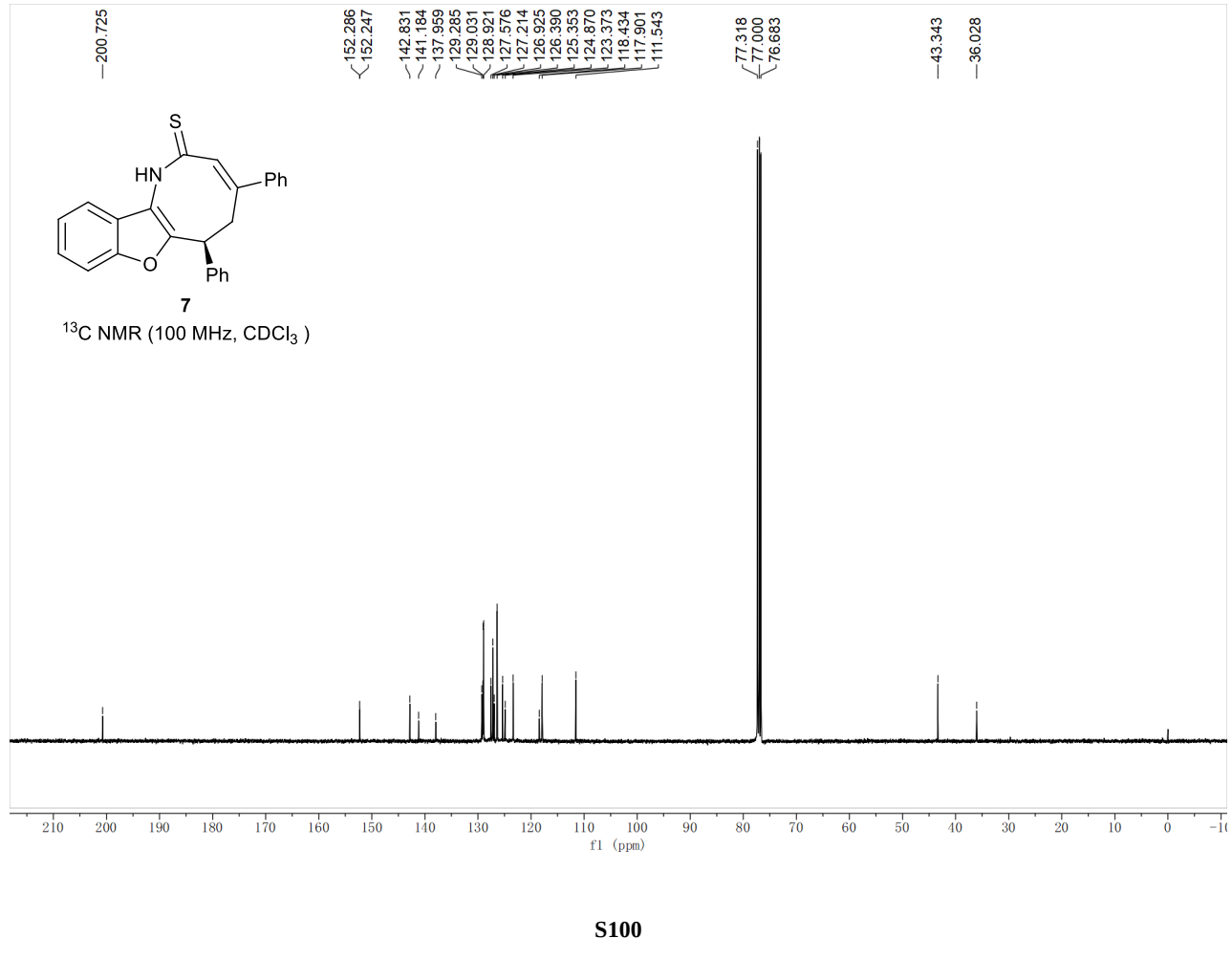


#	[min]		[min]	[mAU*s]	[mAU]	%
1	16.032	MM	0.5458	1.58771e4	484.78506	98.2839
2	18.646	BB	0.5505	277.22614	7.71047	1.7161
				1.61544e4	492.49553	



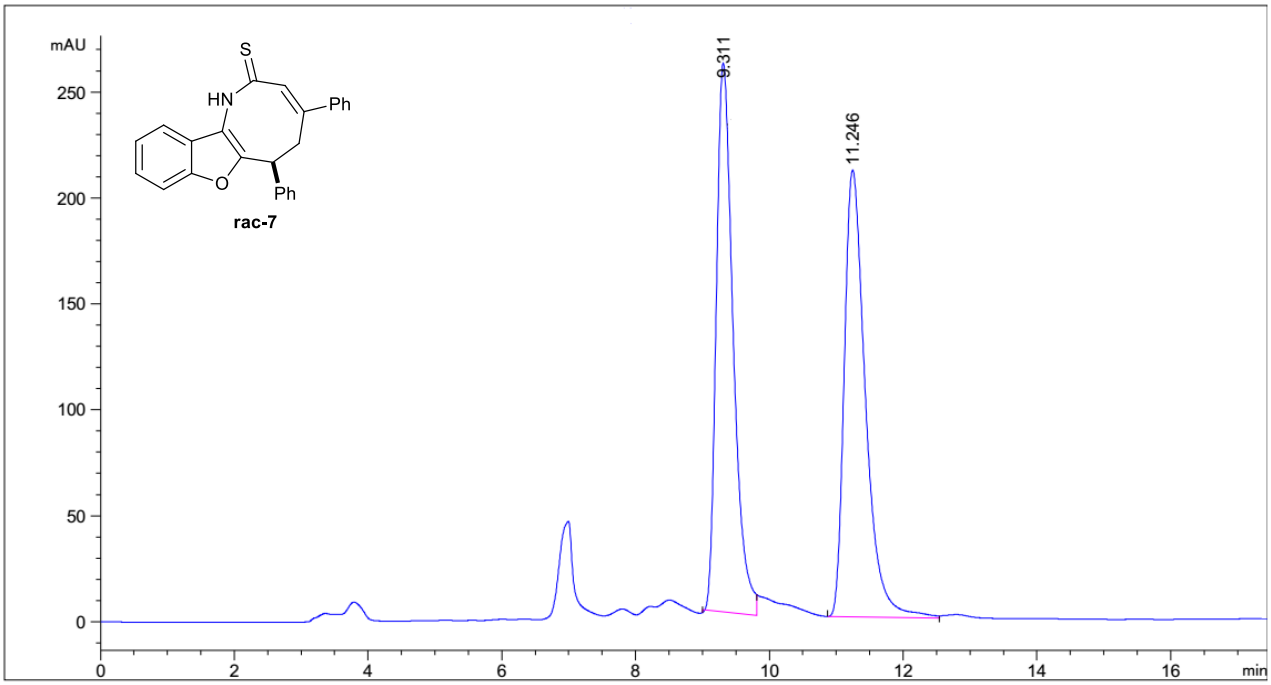
7

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

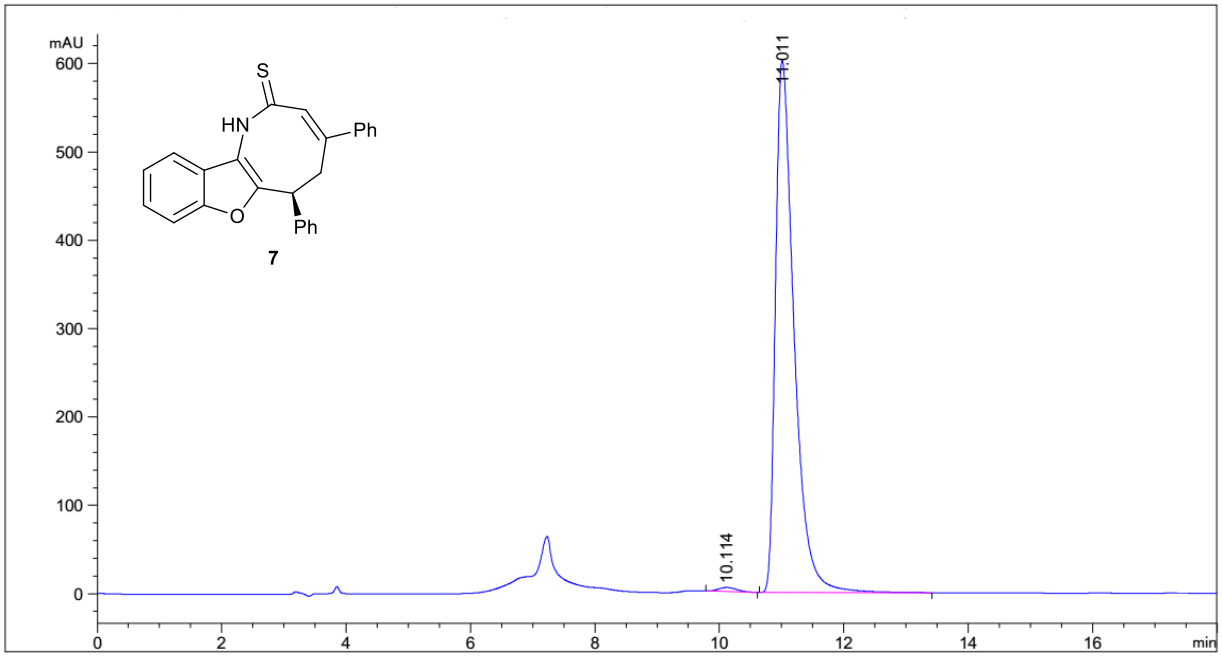


7

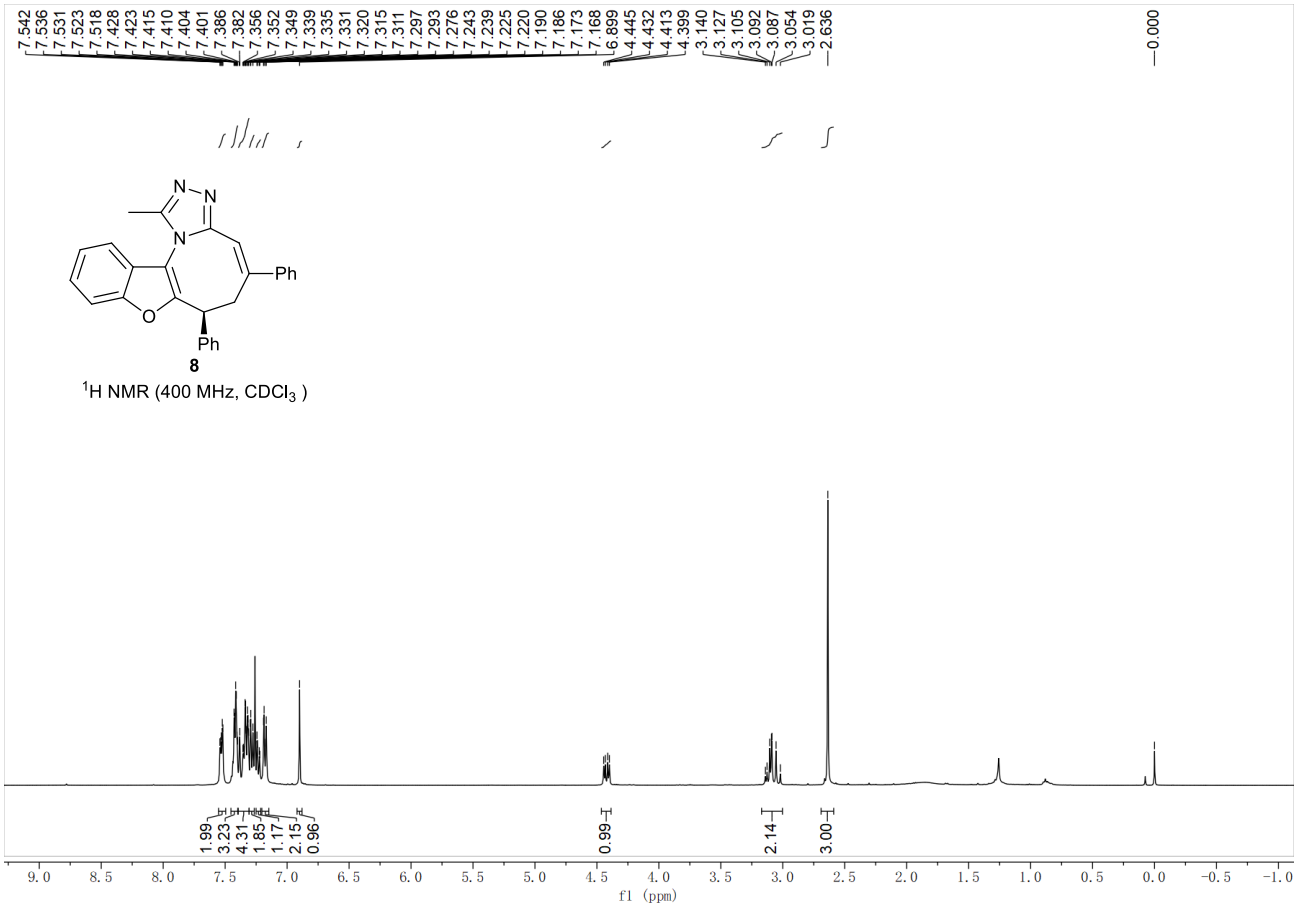
^{13}C NMR (100 MHz, $CDCl_3$)



#	[min]		[min]	[mAU*s]	[mAU]	%
1	9.311	MM	0.2928	4550.14746	258.95801	49.5799
2	11.246	BV	0.3346	4627.25439	210.87970	50.4201
				9177.40186	469.83771	

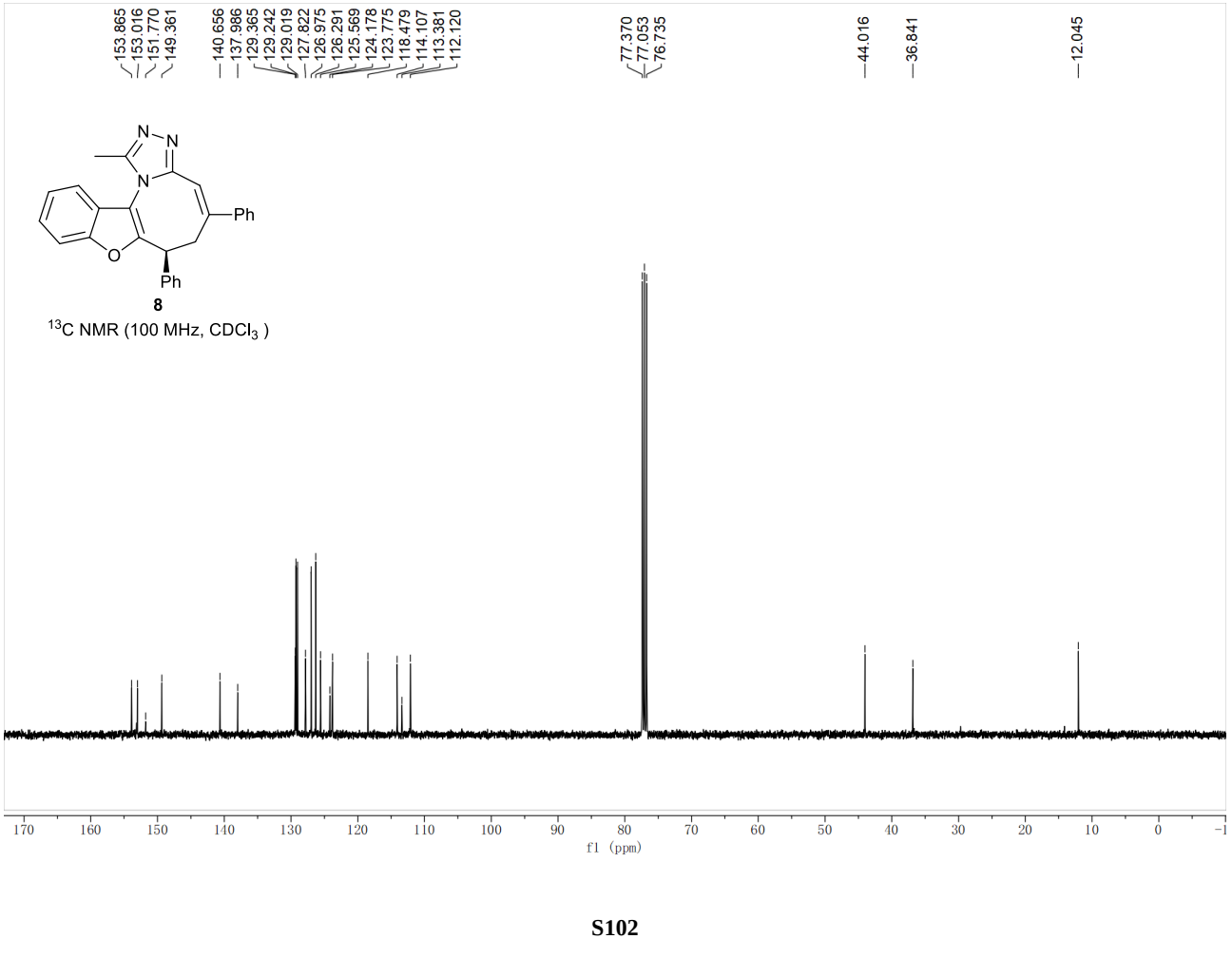


#	[min]		[min]	[mAU*s]	[mAU]	%
1	10.114	BB	0.3219	92.91978	4.59394	0.7379
2	11.011	BB	0.3121	1.24995e4	602.12390	99.2621
				1.25924e4	606.71784	



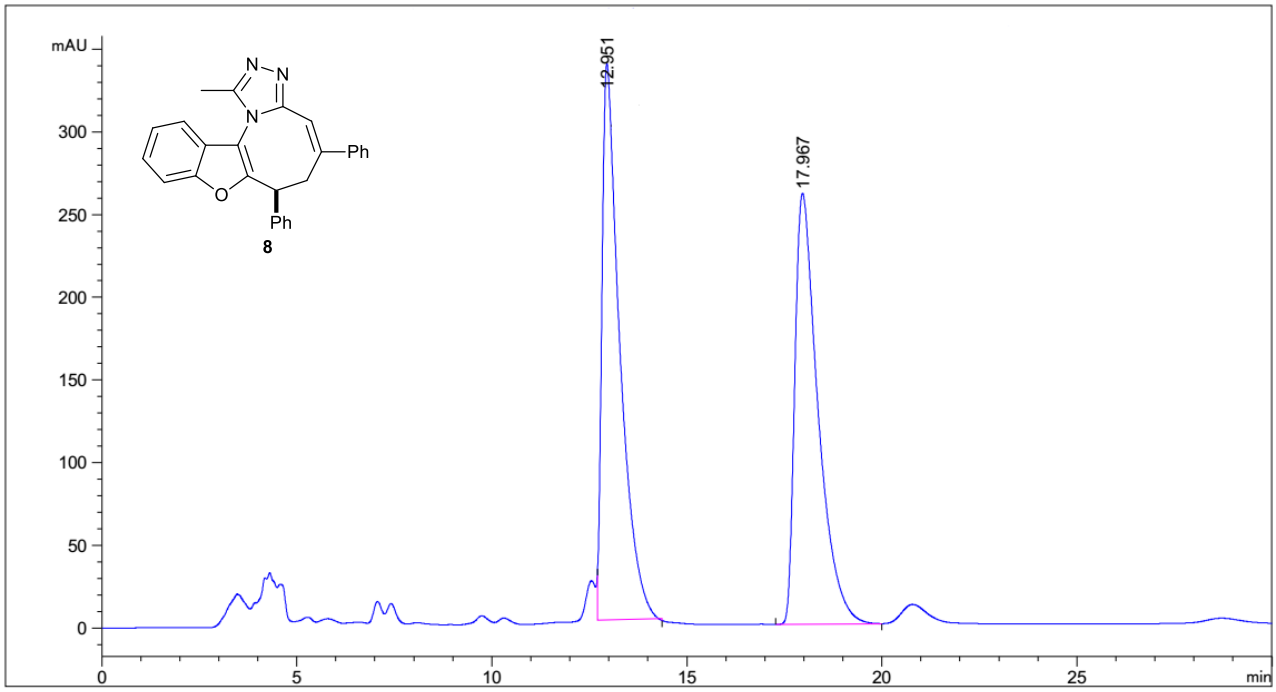
8

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

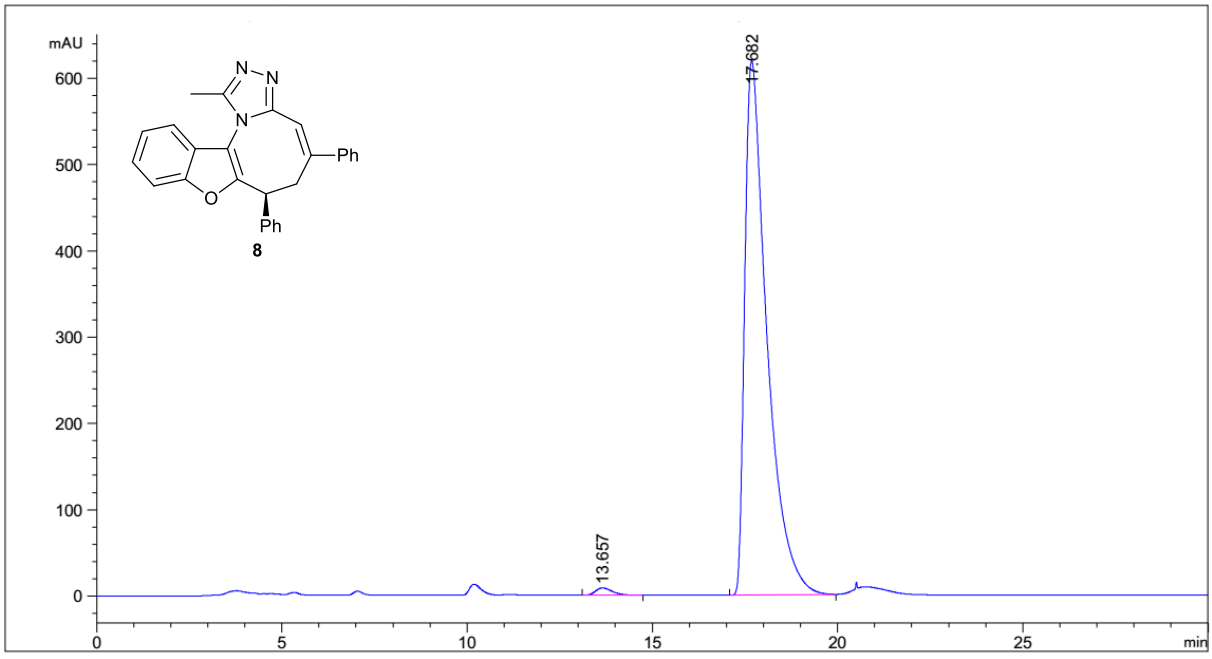


8

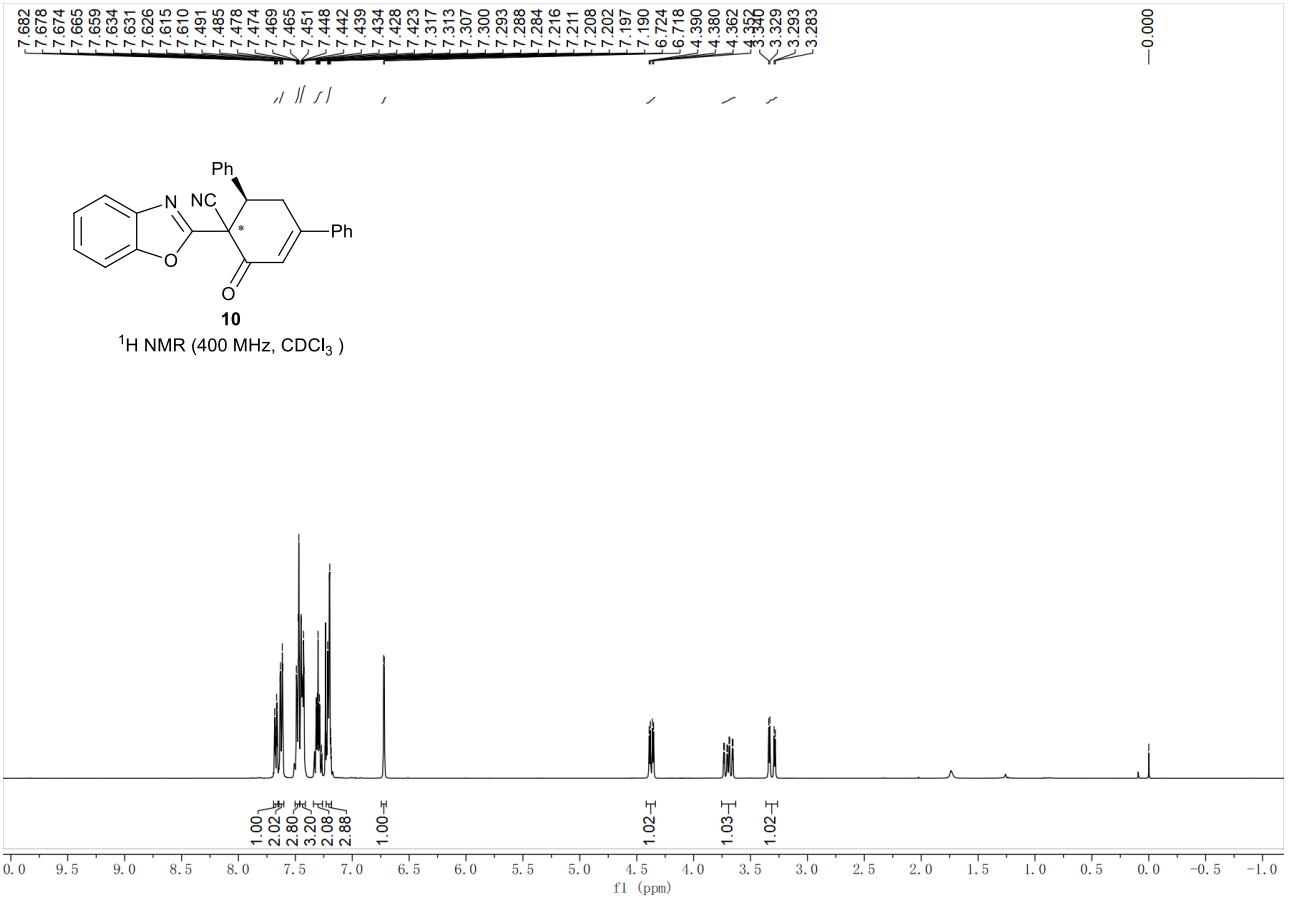
^{13}C NMR (100 MHz, $CDCl_3$)



#	[min]		[min]	[mAU*s]	[mAU]	%
1	12.951	MM	0.5308	1.07195e4	336.58038	49.9223
2	17.967	BB	0.6156	1.07529e4	260.48227	50.0777
				2.14725e4	597.06265	

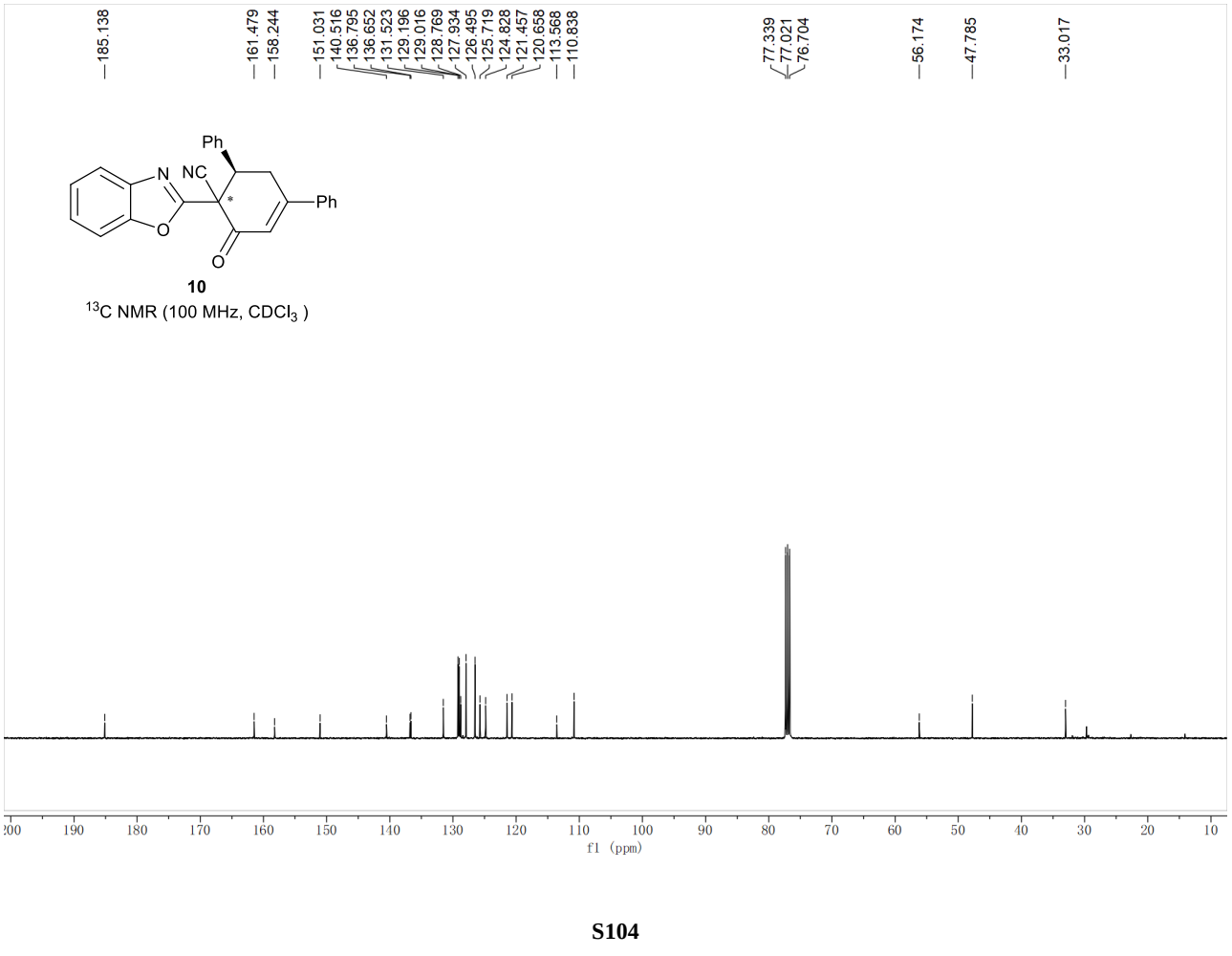


#	[min]		[min]	[mAU*s]	[mAU]	%
1	13.657	BB	0.4678	264.54446	8.50269	1.0156
2	17.682	BB	0.6125	2.57828e4	619.14099	98.9844
				2.60474e4	627.64368	



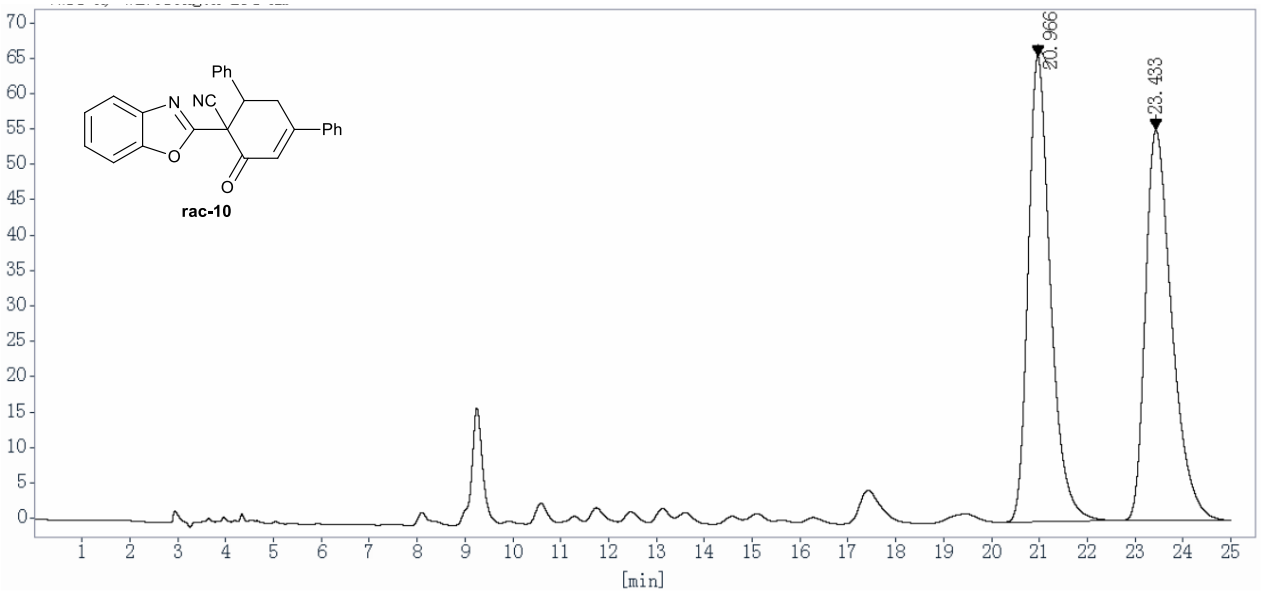
10

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

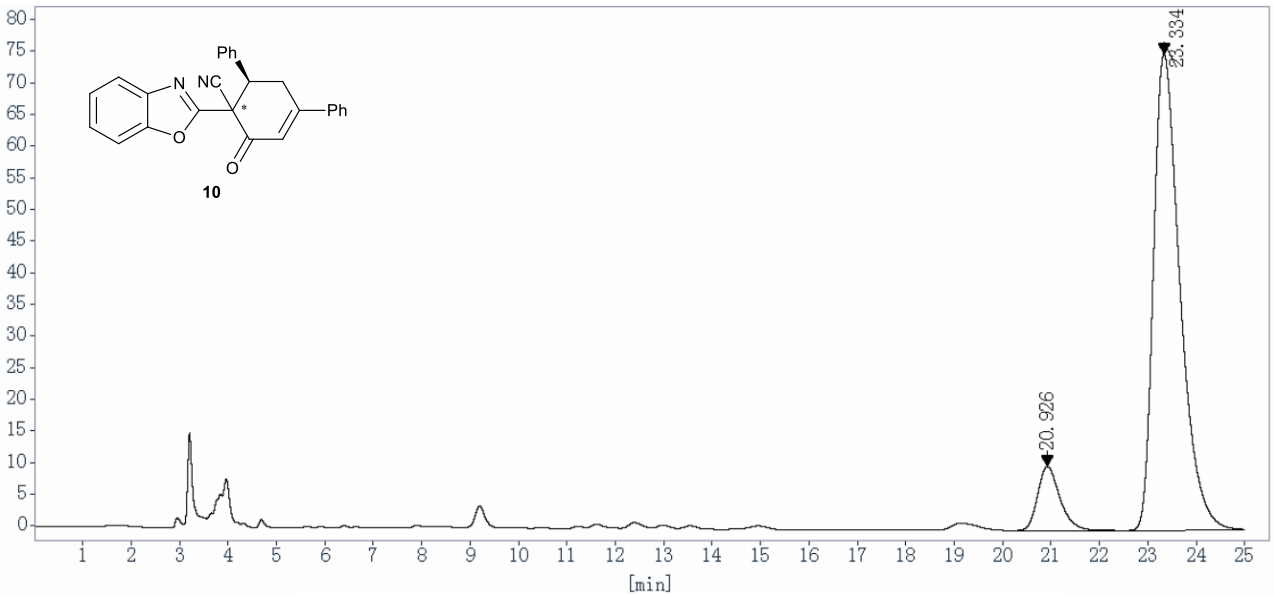


10

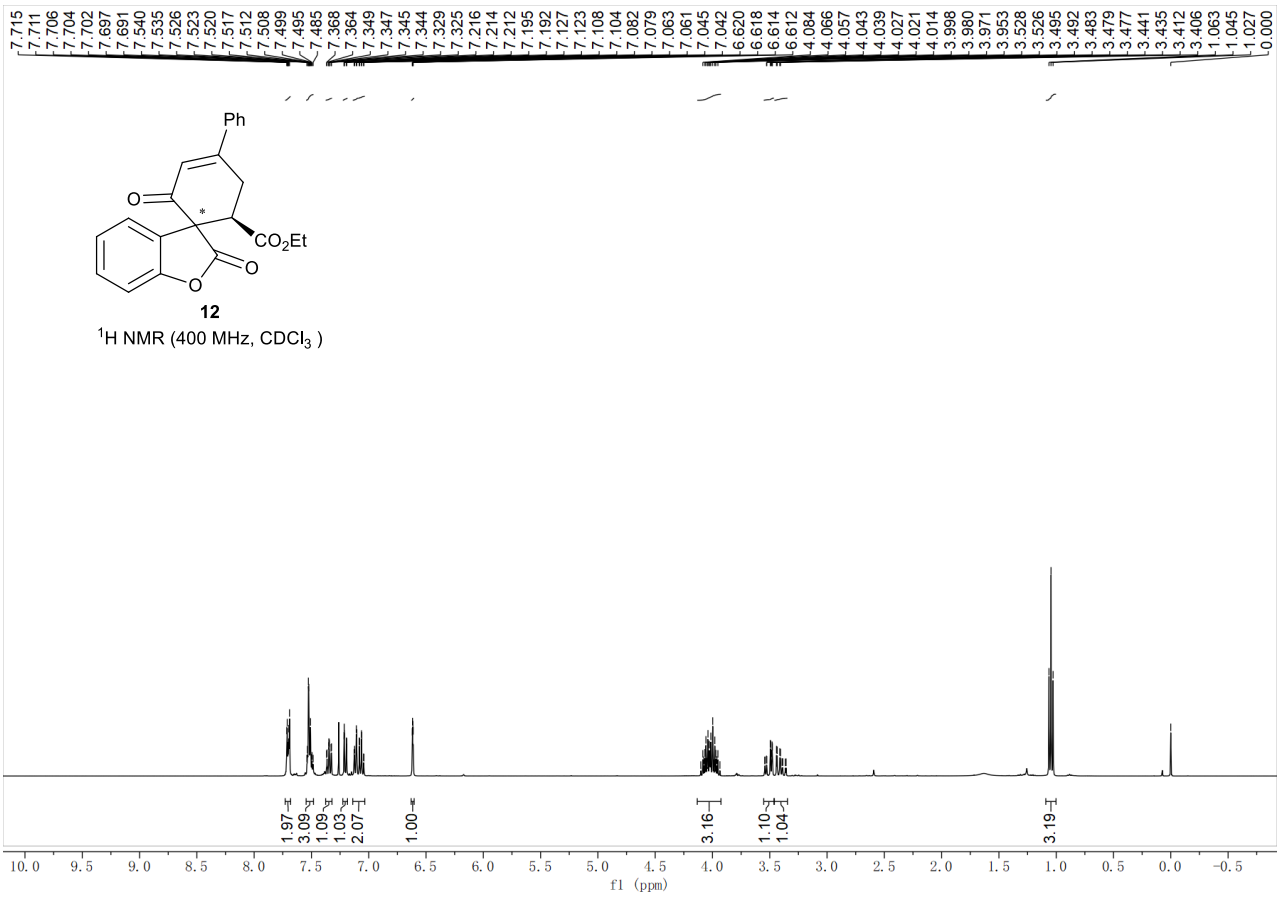
^{13}C NMR (100 MHz, $CDCl_3$)

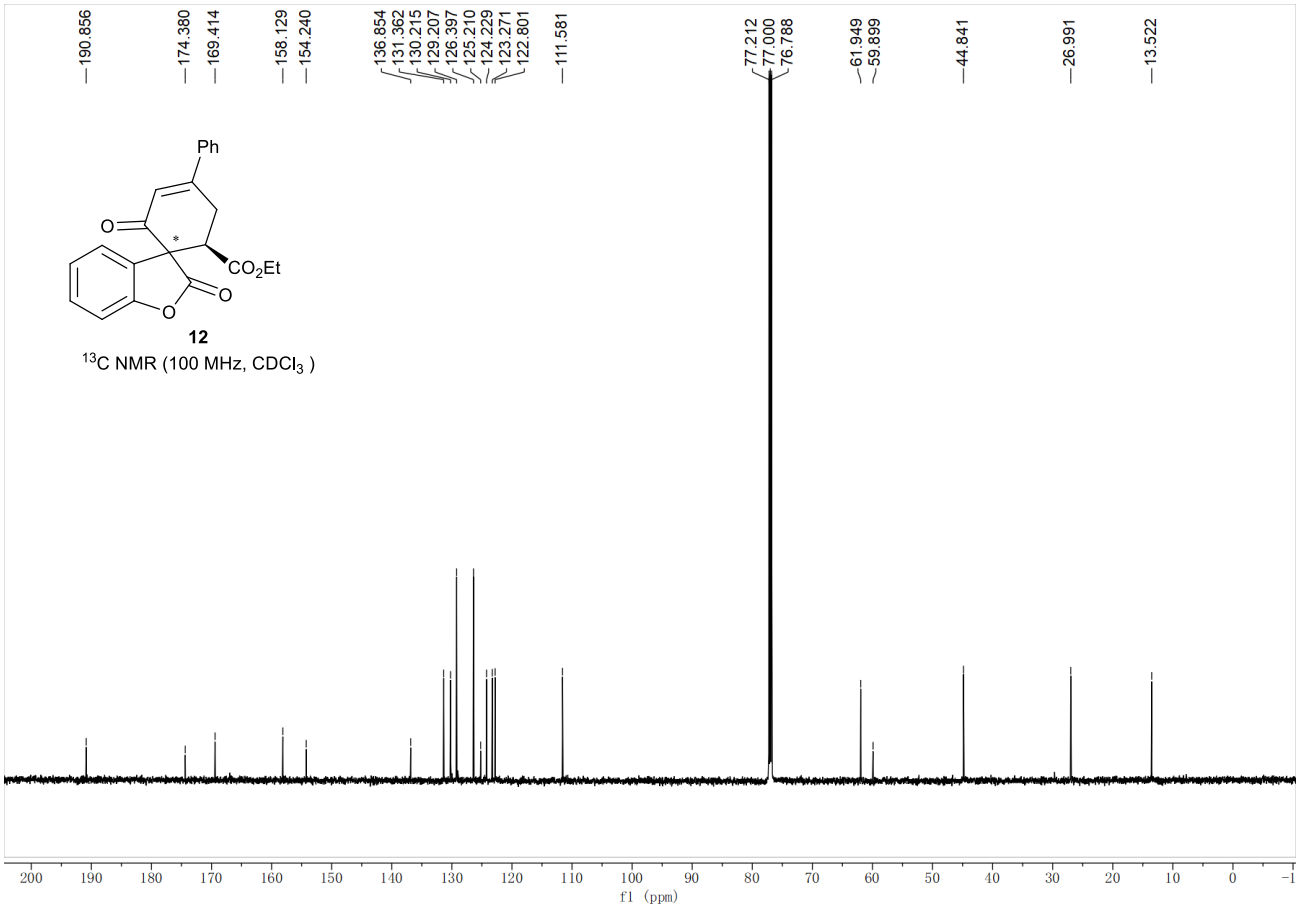


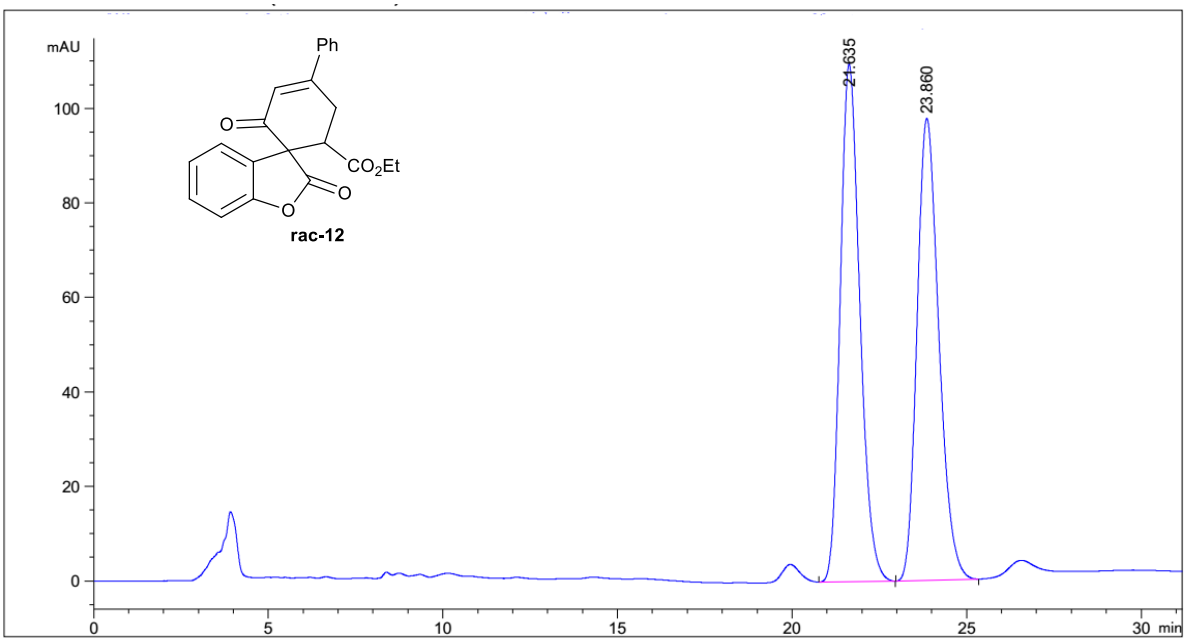
Ret Time [min]	Peak Type	Width [min]	Height [mAU]	Area [mAU*s]	Area [%]
20.966	BB	0.49	65.8056	2132.8022	50.1934
23.433	BBA	0.58	55.1336	2116.3645	49.8066
			Totals:	4249.1667	100.0000



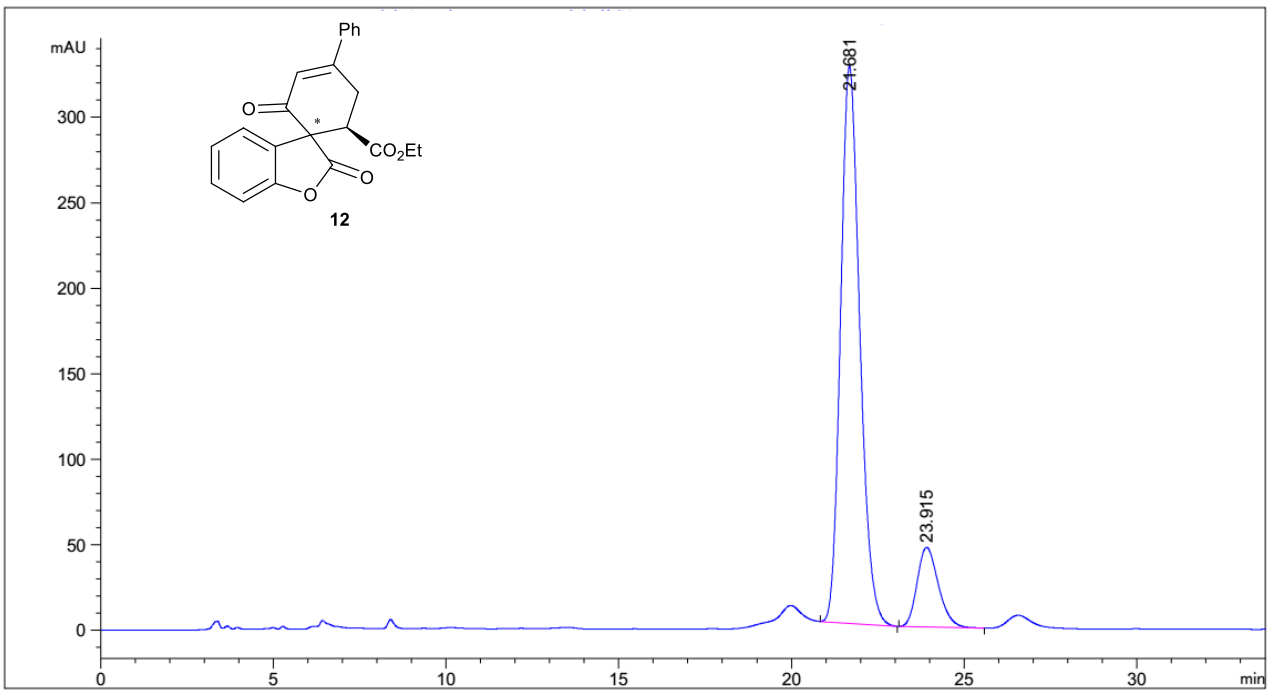
Ret Time [min]	Peak Type	Width [min]	Height [mAU]	Area [mAU*s]	Area [%]
20.926	BB	0.49	10.0844	323.3529	10.1765
23.334	BBA	0.58	75.2440	2854.0901	89.8235
			Totals:	3177.4430	100.0000


Ph
O
O
O
CO2Et
12
1H NMR (400 MHz, CDCl3)
f1 (ppm)


Ph
O
O
O
CO2Et
12
13C NMR (100 MHz, CDCl3)
f1 (ppm)



#	[min]		[min]	[mAU*s]	[mAU]	%
1	21.635	BB	0.6044	4281.87988	109.56980	50.2005
2	23.860	BB	0.6686	4247.67480	97.74590	49.7995
				8529.55469	207.31570	



#	[min]		[min]	[mAU*s]	[mAU]	%
1	21.681	BB	0.5941	1.25764e4	326.07428	86.3117
2	23.915	BB	0.6619	1994.50977	46.64372	13.6883
				1.45709e4	372.71800	