Asymmetric inverse-electron-demand 1,3-dipolar cycloadditions of cyclopentadienones and thiophene-1,1-dioxide with C,N-cyclic azomethine imines

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Supplementary Information

1. General methods

Unless otherwise noted, the reactions were carried out under ambient atmosphere; when the reactions required heating, the heat source was oil bath. ^{1}H NMR (400 or 600 MHz), ^{13}C NMR (100 or 150 MHz), ^{19}F NMR (376 MHz) and ^{31}P NMR (162 MHz) were recorded on Varian INOVA-400/54, Agilent DD2-600/54 or Bruker Ascend^{TM} 400 instruments (Chemical shifts were reported in ppm from tetramethylsilane with the solvent resonance as the internal standard in $CDCl_3$ solution, unless otherwise noted). The following abbreviations were used to explain the multiplicities: s = singlet, d = doublet, t = triplet, q = quartet, dd = double doublet, ddd = double double doublet, dt = double triplet, m = multiplet and coupling constants (*J*) are reported in Hertz (Hz). High resolution mass spectra (HRMS) were recorded on a Waters SYNAPT G2 or Agilent G1969-85000 or Shimadzu LCMS-IT-TOF using a time-of-flight mass spectrometer equipped with electrospray ionization (ESI) source. X-ray diffraction experiments were carried out on an Agilent Gemini or Bruker D8 VENTURE and the data obtained were deposited at the Cambridge Crystallographic Data Centre. In each case, diastereomeric ratio was determined by ^{1}H NMR analysis and enantiomeric excess was determined by HPLC analysis (Agilent Technologies: 1220 Infinity II, 1200 Series, 1260 Infinity) on a chiral column in comparison with authentic racemate, using a Daicel Chiralpak AD-H Column (250 × 4.6 mm), Daicel Chiralpak IA Column (250 × 4.6 mm). UV detection was monitored at 254 nm. Optical rotation was measured in $CHCl_3$ solution at 25 °C on Perkin-Elmer PL341. Column chromatography was performed on silica gel (300-400 mesh) eluting with ethyl acetate (EtOAc), acetone, dichloromethane (DCM) and petroleum ether. TLC was performed on glass-backed silica plates. UV light, I_2, and solution of potassium permanganate were used to visualise products or starting materials. All chemicals were used without purification as commercially available unless otherwise noted. Petroleum ether (60–90 °C) was distilled. THF was freshly distilled from sodium/benzophenone before use. $CHCl_3$ was washed with water and distilled from anhydrous $CaCl_2$. Dichloromethane (DCM) was treated with 5% Na_2CO_3 aqueous solution followed by water. Toluene was freshly distilled from CaH_2 under an atmosphere of dry argon. Experiments involving moisture and/or air sensitive components were performed under a positive pressure of argon in oven-dried glassware equipped with a rubber septum inlet. Dried solvents and liquid reagents were transferred by oven-dried syringe. The γ-functionalised 2-cyclopentenones **1**,[1] **2a–2u**,[2] and chiral ligands **L4–L9**,[1b,3] **L11**[1b,3] were prepared according to the literature procedures. Compounds **1a**,[1a] **1b–1f**,[1b]

2a–**2s**,[2a,2b] **2t–2u**,[2c,2d] **L4–L5**,[1b] **L7**,[1b] and **L11**[1b] are known compounds and the spectroscopic data were consistent with the literature report.

Table S1. Summary of data and instruments

Data	**Instrument**
^{1}H NMR and ^{13}C NMR	Varian INOVA-400/54 or Agilent DD2-600/54 or Bruker Ascend^{TM} 400
High resolution mass spectra (HRMS)	Waters SYNAPT G2 or Agilent G1969-85000 (ESI source)
X-ray diffraction	Agilent Gemini diffractometer or Bruker APEX-II CCD
HPLC analysis	Agilent 1220 Infinity II, 1200 Series, 1260 Infinity Daicel Chiralpak columns (AD-H, IA, IE, IF)
Optical rotation	Perkin-Elmer PL341
Melting point	WRX-4 melting-point apparatus (Shanghai YiCe Apparatus & Equiments Co., Ltd) with capillary

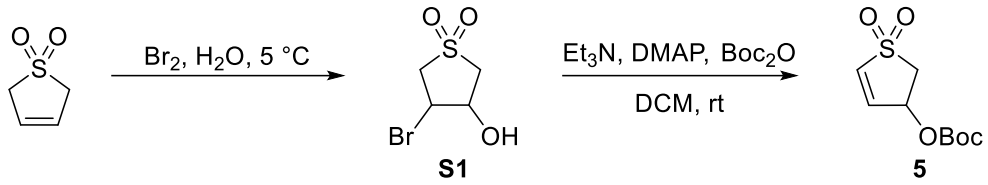
1 (*a*) K. Ulbrich, P. Kreitmeier, T. Vilaivan and O. Reiser, *J. Org. Chem.*, 2013, **78**, 4202; (*b*) X.-X. Yang, R.-J. Yan, G.-Y. Ran, C. Chen, J.-F. Yue, X. Yan, Q. Ouyang, W. Du and Y.-C. Chen, *Angew. Chem., Int. Ed.*, 2021, **60**, 26762.

2 (*a*) T. Hashimoto, Y. Maeda, M. Omote, H. Nakatsu and K. Maruoka, *J. Am. Chem. Soc*. 2010, **132**, 4076; (*b*) L. Chen, G.-M. Yang, J. Wang, Q.-F. Jia, J. Wei and Z.-Y. Du, *RSC Adv.*, 2015, **5**, 76696; (*c*) T. Wang, A.-L. Shao, H.-Y. Feng, S.-W. Yang, M. Gao, J. Tian and A.-W. Lei, *Tetrahedron*, 2015, **71**, 4473; (*d*) T. Wang, J.-H. Luo, C.-H. Gu, R. Li, X.-L. Yu, D.-H. Tang and J. Li, *Faming Zhuanli Shenqing*, CN 103172575, 2013.

3 G. S. Mahadik and S. R. Hitchcock, *Tetrahedron: Asymmetry*, 2010, **21**, 33.

2. Synthesis of new substrates and ligands

2.1 Preparation of *tert*-butyl (1,1-dioxido-2,3-dihydrothiophen-3-yl) carbonate 5



S1 **5**

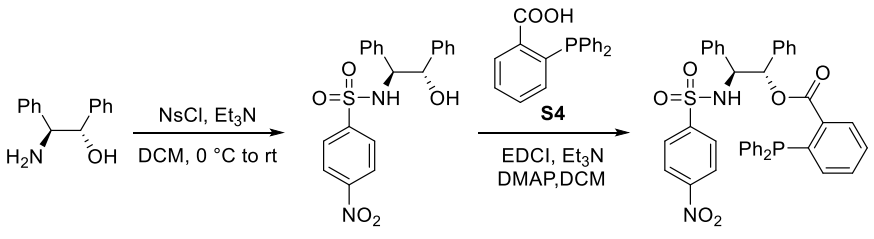
To a stirred solution of 2,5-dihydrothiophene 1,1-dioxide (1.18 g, 10.0 mmol, 1.0 equiv) in H_2O (250 mL, 0.04 M) was added Br_2 (0.650 mL, 12.0 mmol, 1.2 equiv) at room temperature. The resultant mixture was sealed and stirred at 5 °C for 3 days. The reaction was quenched with aqueous $Na_2S_2O_3$. Then the mixture was filtered and the solid was washed by water and EtOH. The solid compound **S1** was dried and used without further purification.

To a solution of 3-bromo-4-hydroxytetrahydrothiophene 1,1-dioxide **S1** (0.779 g, 3.64 mmol, 3.6 equiv) in DCM (36 mL, 0.1 M) was added Boc_2O (0.9 mL, 1 mmol, 1.1 equiv) followed by Et_3N (1.5 mL, 3.0 mmol, 3.0 equiv) and DMAP (89.0 mg, 0.202 mmol, 0.2 equiv). The resultant mixture was stirred at room temperature for 30 min, and was concentrated under reduced pressure. The residue was directly purified by flash chromatography on silica gel (EtOAc/petroleum ether = 1/10) to afford **5**: 704 mg (3.01 mmol) as a white solid, 83% yield; mp = 45–47 ℃; ^{1}H NMR (400 MHz, $CDCl_3$) δ (ppm) 6.84–6.81 (m, 1H), 6.79–6.75 (m, 1H), 5.81–5.76 (m, 1H), 3.74 (dd, *J* = 14.1, 7.7 Hz, 1H), 3.27 (dd, *J* = 14.1, 3.8 Hz, 1H), 1.51 (s, 9H); ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm) 152.2, 136.4, 135.7, 84.3, 71.2, 54.2, 27.7; HRMS (ESI-TOF) m/z: $[M + Na]^+$ Calcd for $C_9H_{14}O_5SNa^+$ 257.0454; Found 257.0456.

2.2 Preparation of new phosphine ligands

Synthesis of C_1-symmetric monophosphine ligand (1*S*,2*S*)-L6

C_1-symmetric monophosphine ligand (1*S*,2*S*)-**L6** was synthesized from (1*S*,2*S*)-**S2** according to the reported procedure.[1]



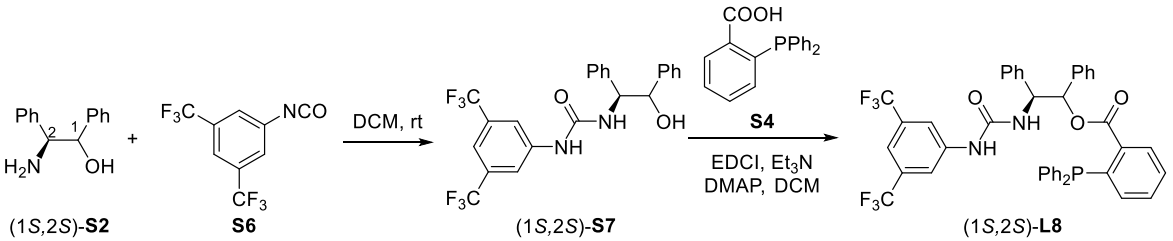
(1*S*,2*S*)-**S2** (1*S*,2*S*)-**S3** (1*S*,2*S*)-**L6**

To an oven dried round-bottom flask equipped with a stir bar, (1*S*,2*S*)-**S2** (0.709 g, 3.33 mmol, 1.0 equiv) was dissolved in dry DCM (35 mL, 0.1 M), and Et_3N (0.6 mL, 4 mmol, 1.2 equiv) were added

at 0 °C. NsCl (0.811 g, 3.66 mmol, 1.1 equiv) was added via syringe and the mixture was stirred for 2 h. After completion monitored by TLC, the reaction was quenched by water and extracted with DCM. The combined organic phases were dried over Na_2SO_4, and concentrated in vacuo. The residue was purified by flash chromatography on silica gel (MeOH/DCM = 1/200) to give (1*S*,2*S*)-**S3**: 1.20 g (3.02 mmol) as a white solid, 90 % yield**.**

To an oven-dried flask were added (1*S*,2*S*)-**S3** (1.2 g, 3.0 mmol, 1.0 equiv), 1-(3-dimethylaminopropyl)-3-ethylcarbodiimide hydrochloride (EDCI, 0.69 g, 3.6 mmol, 1.2 equiv), Et_3N (0.63 mL, 4.5 mmol, 1.5 equiv) and DMAP (73 mg, 0.60 mmol, 0.2 equiv) in dry DCM (60 mL, 0.05 M) under Ar atmosphere. The solution was stirred for 15 min, and **S4** (1.0 g, 3.3 mmol, 1.1 equiv) was added, and stirred overnight. The solvent was removed in vacuo and the mixture was purified by flash chromatography on silica gel (EtOAc/petroleum ether = 1/5) to give (1*S*,2*S*)-**L6**: 808 mg (1.18 mmol) as a yellow solid, 39 % yield; mp 90–92 °C; $[\alpha]_D^{25}$ = +30.0 (*c* = 0.12 in $CHCl_3$); ^{1}H NMR (400 MHz, $CDCl_3$) δ (ppm) 8.09–8.03 (m, 1H), 7.91 (d, *J* = 8.8 Hz, 2H), 7.61–7.55 (m, 2H), 7.46–7.35 (m, 8H), 7.35–7.26 (m, 4H), 7.15–7.07 (m, 2H), 7.06–6.97 (m, 7H), 6.94–6.88 (m, 1H), 6.80 (d, *J* = 7.6 Hz, 2H), 6.16 (d, *J* = 6.2 Hz, 1H), 4.81 (t, *J* = 6.8 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm) 165.7 (d, *J* = 2.3 Hz), 149.2, 146.5, 136.51, 136.50 (d, *J* = 14.1 Hz), 135.9, 135.2, 134.2, 133.9 (d, *J* = 9.5 Hz), 133.7, 133.5, 132.9, 132.2 (d, *J* = 4.2 Hz), 129.2, 129.1, 128.9 (d, *J* = 7.3 Hz), 128.83, 128.76, 128.3 (d, *J* = 10.1 Hz), 128.2, 128.1, 127.9, 127.6 (d, *J* = 1.6 Hz), 127.3, 126.8, 123.5, 123.1, 79.5, 63.2; ^{31}P NMR (162 MHz, $CDCl_3$) δ (ppm) –5.3; HRMS (ESI-TOF) m/z: $[M + H]^+$ Calcd for $C_{39}H_{32}N_2O_6PS^+$ 687.1713; Found 687.1704.

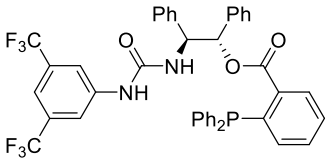
Synthesis of C_1-symmetric monophosphine ligand L8 and L9



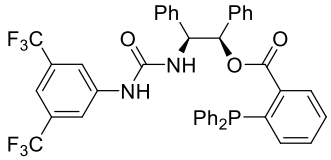
In an oven dried round-bottom flask equipped with a stir bar, (1*S*,2*S*)-**S2** or (1*R*,2*S*)-**S5** (1.0 equiv) was dissolved in dry DCM (0.1 M), and **S6** (1.0 equiv) was added at room temperature. The solution was stirred at room temperature for 4 h. After completion monitored by TLC, the reaction was filtered

to give (1*S*,2*S*)-**S7** or (1*R*,2*S*)-**S8**.

(1*S*,2*S*)-**S7** or (1*R*,2*S*)-**S8** was condensed with **S4** through a similar method for the preparation of (1*S*,2*S*)-**L6**, and finally monophosphine ligand (1*S*,2*S*)-**L8** or (1*R*,2*S*)-**L9** was obtained after purification by flash chromatography on silica gel (EtOAc/petroleum ether = 1/5).



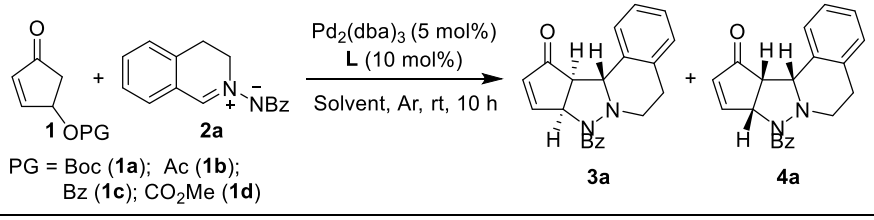
(1*S*,2*S*)-**L8**: 135 mg (0.179 mmol) as a white solid, 44% yield; mp 80–82 °C; $[\alpha]_D^{25}$ = +31.1 (*c* = 0.05 in $CHCl_3$); ^{1}H NMR (400 MHz, $CDCl_3$) δ (ppm) 8.13–8.04 (m, 1H), 7.75 (s, 2H), 7.43–7.37 (m, 4H), 7.35–7.26 (m, 6H), 7.25–7.03 (m, 14H), 7.00–6.92 (m, 1H), 6.40 (d, *J* = 8.0 Hz, 1H), 6.19 (d, *J* = 9.6 Hz, 1H), 5.33–5.21 (m, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm) 168.0 (d, *J* = 1.2 Hz), 153.9, 140.7, 138.2, 136.6 (d, *J* = 7.2 Hz), 136.1, 134.7, 134.2 (d, *J* = 19.8 Hz), 133.9 (d, *J* = 19.6 Hz), 133.3 (d, *J* = 19.5 Hz), 132.7, 132.0 (q, *J* = 33.3 Hz), 131.0 (d, *J* = 3.4 Hz), 129.1 (d, *J* = 10.9 Hz), 128.9 (d, *J* = 11.8 Hz), 128.8 (d, *J* = 2.2 Hz), 128.7, 128.6, 128.5, 128.4, 127.9, 127.6 (d, *J* = 15.4 Hz), 121.8 (q, *J* = 272.9 Hz), 118.1 (q, *J* = 33.3 Hz), 115.5 (dt, *J* = 7.1, 3.5 Hz), 79.5, 60.5; ^{31}P NMR (162 MHz, $CDCl_3$) δ (ppm) –5.1; ^{19}F NMR (376 MHz, $CDCl_3$) δ (ppm) –63.0; HRMS (ESI-TOF) m/z: $[M + H]^+$ Calcd for $C_{42}H_{32}F_6N_2O_3P^+$ 757.2049; Found 757.2054.

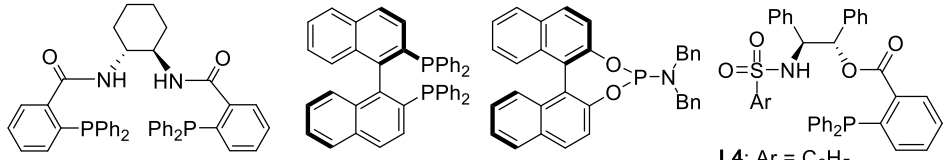


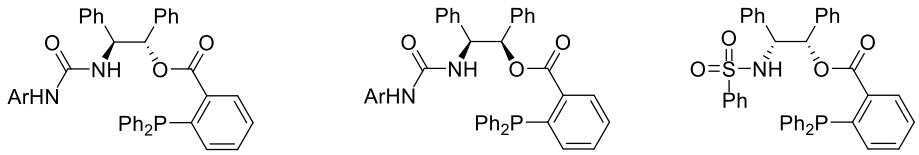
(1*R*,2*S*)-**L9**: 613 mg (0.811 mmol) as a white solid, 40% yield; mp 117–119 °C; $[\alpha]_D^{25}$ = –12.7 (*c* = 0.11 in $CHCl_3$); ^{1}H NMR (400 MHz, $CDCl_3$) δ (ppm) 8.32–8.22 (m, 1H), 7.46–7.40 (m, 1H), 7.40–7.33 (m, 3H), 7.31–7.26 (m, 5H), 7.25–7.19 (m, 3H), 7.18–7.12 (m, 2H), 7.09–6.89 (m, 11H), 6.82–6.78 (m, 2H), 6.78–6.72 (m, 1H), 6.35 (d, *J* = 2.4 Hz, 1H), 5.45 (dd, *J* = 9.1, 2.5 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm) 167.0 (d, *J* = 2.1 Hz), 153.8, 141.0 (d, *J* = 25.0 Hz), 140.4, 137.1 (d, *J* = 11.3 Hz), 136.7 (d, *J* = 3.6 Hz), 136.3 (d, *J* = 18.2 Hz), 135.0, 134.8 (d, *J* = 5.8 Hz), 133.3, 132.1 (d, *J* = 19.3 Hz), 131.5, 131.3 (d, *J* = 1.9 Hz), 131.2, 129.5, 128.9 (d, *J* = 7.2 Hz), 128.8 (d, *J* = 6.9 Hz), 128.6 (d, *J* = 7.8 Hz), 128.4, 128.1, 127.8, 125.4, 123.2 (q, *J* = 272.9 Hz), 117.7 (q, *J* = 272.9 Hz), 115.0 (q, *J* = 7.7, 5.9 Hz), 81.4, 58.8; ^{31}P NMR (162 MHz, $CDCl_3$) δ (ppm) –4.4; ^{19}F NMR (376 MHz, $CDCl_3$) δ (ppm) –62.7; HRMS (ESI-TOF) m/z: $[M + H]^+$ Calcd for $C_{42}H_{32}F_6N_2O_3P^+$ 757.2049; Found 757.2055.

3. Condition optimisation for asymmetric IED 1,3-DC of cyclopentadienone/thiophene-1,1-dioxide with C,N-azomethine imine 2a

Table S1 Condition optimisation for diastereodivergent IED 1,3-DC of cyclopentadienone with C,N-azomethine imine for synthesis of **3a** and **4a**[a]





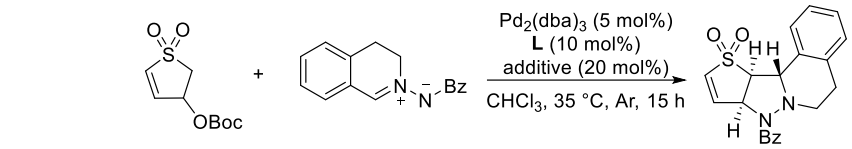


Entry	L	Solvent	Yield[b] (**3a**/**4a**, %)	dr[c]	ee[d] (%)
1[e]	-	DCM	Trace	-	-
2	**L1**	DCM	14/20	1/1.5	88/–87
3	**L2**	DCM	37/40	1/1	–6/3
4	**L3**	DCM	14/-	4/1	-
5	**L4**	DCM	70/-	15/1	97/-
6	**L5**	DCM	72/-	10/1	98/-
7	**L6**	DCM	80/-	15/1	97/-
8	**L7**	DCM	45/21	2/1	92/–72
9	**L6**	Toluene	34/-	10/1	99/-
10	**L6**	THF	24/-	7/1	82/-
11	**L6**	EtOAc	59/-	10/1	91/-
12	**L6**	DCE	87/-	10/1	99/-
13	**L6**	1,4-Dioxane	25/10	2.5/1	24/78
14	**L6**	CH_3CN	33/28	1/1	88/–70
15	**L6**	$CHCl_3$	95/-	15/1	98/-
16[f]	**L6**	$CHCl_3$	44/-	8/1	90/-
17[g]	**L6**	$CHCl_3$	68/-	8/1	99/-
18[h]	**L6**	$CHCl_3$	85/-	8/1	99/-
19[i]	**L6**	$CHCl_3$	73/-	6/1	98/-
20[j]	**L6**	$CHCl_3$	91/-	10/1	93/-
21[k]	**L6**	$CHCl_3$	91/-	10/1	95/-

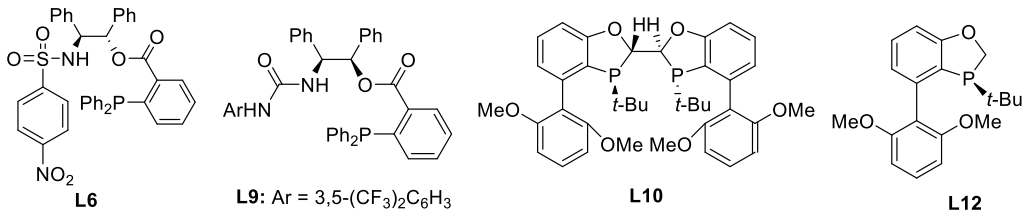
22[l]	**L6**	$CHCl_3$	29/15	2/1	95/–12
23	**L11**	$CHCl_3$	42/20	2/1	85/–60
24	**L8**	$CHCl_3$	40/48	1/1.2	98/–97
25	**L9**	$CHCl_3$	-/84	1/14	-/99

[a] Unless noted otherwise, reactions were performed with **1a** (0.2 mmol, 2.0 equiv), **2** (0.1 mmol, 1.0 equiv), $Pd_2(dba)_3$ (5 mol%) and **L** (10 mol%) in solvent (2.0 mL) at room temperature for 10 h under Ar. [b] Yield of the isolated **3a** or **4a**. [c] Determined by ^1H NMR analysis. [d] Determined by HPLC analysis on a chiral stationary phase. [e] With $Pd(PPh_3)_4$ (10 mol%). [f] With $Pd_2(dba)_3$ (2.5 mol%) and **L6** (5 mol%). [g] With $Pd_2(dba)_3$ (10 mol%) and **L6** (20 mol%). [h] In $CHCl_3$ (1.0 mL). [i] In $CHCl_3$ (0.5 mL). [j] With **1b**. [k] With **1c**. [l] With **1d**.

Table S2 Condition optimisation for asymmetric IED 1,3-DC between thiopene-1,1-dioxide **5** and C,N-azomethine imine **2a** for the synthesis of **6a**[a]



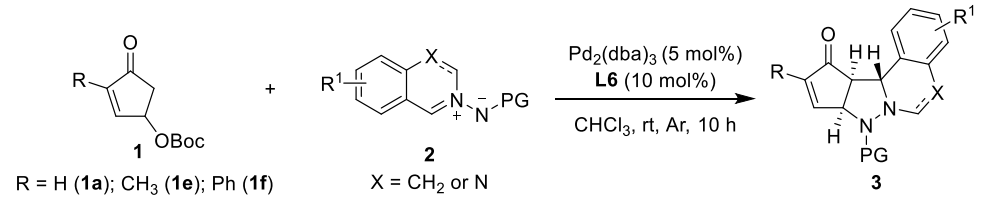
5 **2a** **6a**



Entry	L	Additive	Yield[b] (%)	dr[c]	ee[d] (%)
1	**L6**	-	20	10/1	0
2	**L9**	-	17	7/1	2
3	**L10**	-	<10	-	97
4	**L12**	-	-	-	-
5	**L10**	(+)-Dimethyl *L*-tartrate	34	6/1	99
6	**L10**	Salicylic acid	58	8/1	98
7[e]	**L10**	Salicylic acid	80 (80)[f]	6/1	98

[a] Unless noted otherwise, reactions were performed with **5** (0.05 mmol, 1.0 equiv), **2** (0.05 mmol, 1.0 equiv), $Pd_2(dba)_3$ (5 mol%) and **L** (10 mol%) in dry $CHCl_3$ (0.5 mL) under Ar at 35 °C for 15 h. [b] ^1H NMR yield of **6a** with acetanilide as the internal standard. [c] Determined by ^1H NMR analysis. [d] Determined by HPLC analysis on a chiral stationary phase. [e] For 24 h. [f] Isolated yield of **6a**.

4. Procedure for synthesis of cycloadducts 3



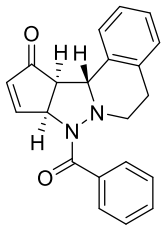
1 **2** **3**

R = H (**1a**); CH_3 (**1e**); Ph (**1f**) X = CH_2 or N

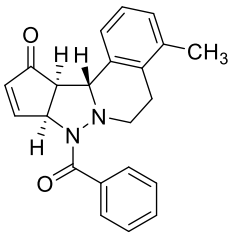
General procedure: To an oven-dried 10 mL Schlenk tube equipped with a stir bar were added

carbonate **1** (**1a** or **1e**) (0.20 mmol, 2.0 equiv), C,N-azomethine imine **2** (0.10 mmol, 1.0 equiv), $Pd_2(dba)_3$ (4.6 mg, 0.0050 mmol, 5.0 mol%) and **L6** (6.9 mg, 0.010 mmol, 10 mol%). The tube was evacuated and back-filled with argon for three times. Then anhydrous $CHCl_3$ (2.0 mL) was added via syringe and the mixture was stirred at room temperature (20–25 °C) for 10 h. After completion monitored by TLC, the crude product was concentrated and purified by flash chromatography on silica gel (EtOAc/petroleum ether) to afford the pure cycloadduct **3** (**3a–3v**).

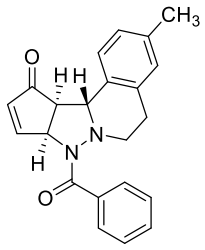
The corresponding racemates were generally obtained under the catalysis of $Pd_2(dba)_3$ (1.2 mg, 0.0013 mmol, 5.0 mol%) and (±)-**L6** (1.7 mg, 0.0025 mmol, 10 mol%) on a 0.025 mmol scale.



Synthesis of 3a: To an oven-dried 10 mL Schlenk tube equipped with a stir bar were added carbonate **1a** (40.0 mg, 0.200 mmol, 2.0 equiv), C,N-azomethine imine **2a** (25.0 mg, 0.100 mmol, 1.0 equiv), $Pd_2(dba)_3$ (4.6 mg, 0.0050 mmol, 5.0 mol%) and **L6** (6.9 mg, 0.010 mmol, 10 mol%). The tube was evacuated and back-filled with argon for three times. Then anhydrous $CHCl_3$ (2.0 mL) was added via syringe and the mixture was stirred at room temperature (20–25 °C) for 10 h. After completion monitored by TLC, the crude product (15/1 dr) was concentrated and purified by flash chromatography on silica gel (EtOAc/petroleum ether = 1/4) to afford the pure cycloadduct **3a**: 31.3 mg (0.0948 mmol) as a white solid, 95% yield; mp 195–197 °C; $[\alpha]_D^{25}$ = +265.5 (*c* = 0.15 in $CHCl_3$); 98% ee, determined by HPLC analysis (Chiralpak AD-H, *i*-PrOH/*n*-hexane = 20/80, flow rate = 1.0 mL/min, λ = 254 nm), t_R = 8.04 min (major), t_R = 12.07 min (minor); ^{1}H NMR (400 MHz, $CDCl_3$) δ (ppm) 8.26–8.20 (m, 1H), 8.04–7.96 (m, 2H), 7.65 (d, *J* = 7.8 Hz, 1H), 7.48–7.43 (m, 1H), 7.41–7.33 (m, 2H), 7.32–7.27 (m, 1H), 7.24–7.20 (m, 1H), 7.09–7.04 (m, 1H), 6.23 (d, *J* = 5.7 Hz, 1H), 5.54 (d, *J* = 7.0 Hz, 1H), 4.50 (d, *J* = 8.8 Hz, 1H), 3.43–3.33 (m, 1H), 3.02–2.94 (m, 1H), 2.91–2.81 (m, 2H), 2.65–2.57 (m, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm) 205.3, 166.8, 159.0, 133.9, 133.71, 133.69, 132.4, 131.3, 129.1, 128.3, 128.2, 127.8, 127.5, 126.9, 64.2, 63.0, 55.1, 49.3, 29.0; HRMS (ESI-TOF) m/z: $[M + Na]^+$ Calcd for $C_{21}H_{18}N_2O_2Na^+$ 353.1260; Found 353.1260.

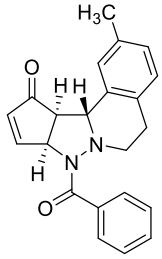


Synthesis of 3b: To an oven-dried 10 mL Schlenk tube equipped with a stir bar were added carbonate **1a** (40.0 mg, 0.200 mmol, 2.0 equiv), C,N-azomethine imine **2b** (26.5 mg, 0.100 mmol, 1.0 equiv), $Pd_2(dba)_3$ (4.6 mg, 0.0050 mmol, 5.0 mol%) and **L6** (6.9 mg, 0.010 mmol, 10 mol%). The tube was evacuated and back-filled with argon for three times. Then anhydrous $CHCl_3$ (2.0 mL) was added via syringe and the mixture was stirred at room temperature (20–25 °C) for 10 h. After completion monitored by TLC, the crude product (15/1 dr) was concentrated and purified by flash chromatography on silica gel (EtOAc/petroleum ether = 1/4) to afford the pure cycloadduct **3b**: 30.6 mg (0.0889mmol) as a white solid, 89% yield; mp 83–85 °C; $[\alpha]_D^{25}$ = +364.4 (*c* = 0.14 in $CHCl_3$); 99% ee, determined by HPLC analysis (Chiralpak AD-H, *i*-PrOH/*n*-hexane = 20/80, flow rate = 1.0 mL/min, λ = 254 nm), t_R = 8.62 min (major), t_R = 12.95 min (minor); ^{1}H NMR (400 MHz, $CDCl_3$) δ (ppm) 8.25–8.18 (m, 1H), 8.02–7.96 (m, 2H), 7.51–7.43 (m, 2H), 7.40–7.33 (m, 2H), 7.24–7.18 (m, 1H), 7.14–7.05 (m, 1H), 6.22 (dd, *J* = 5.6, 1.3 Hz, 1H), 5.57–5.51 (m, 1H), 4.47 (d, *J* = 8.8 Hz, 1H), 3.41 (dd, *J* = 8.8, 6.8 Hz, 1H), 3.03–2.87 (m, 2H), 2.65–2.58 (m, 2H), 2.18 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm) 205.3, 166.9, 158.9, 135.8, 133.9, 133.8, 133.5, 131.3, 131.1, 129.2, 128.8, 127.8, 126.7, 126.1, 64.1, 63.3, 55.0, 49.2, 26.5, 19.3; HRMS (ESI-TOF) m/z: $[M + H]^+$ Calcd for $C_{22}H_{21}N_2O_2^+$ 345.1598; Found 345.1595.

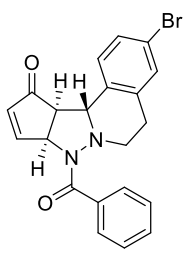


Synthesis of 3c: To an oven-dried 10 mL Schlenk tube equipped with a stir bar were added carbonate **1a** (40.0 mg, 0.200 mmol, 2.0 equiv), C,N-azomethine imine **2c** (26.5 mg, 0.100 mmol, 1.0 equiv), $Pd_2(dba)_3$ (4.6 mg, 0.0050 mmol, 5.0 mol%) and **L6** (6.9 mg, 0.010 mmol, 10 mol%). The tube was evacuated and back-filled with argon for three times. Then anhydrous $CHCl_3$ (2.0 mL) was added via syringe and the mixture was stirred at room temperature (20–25 °C) for 10 h. After completion monitored by TLC, the crude product (15/1 dr) was concentrated and purified by flash chromatography on silica gel (EtOAc/petroleum ether = 1/4) to afford the pure cycloadduct **3c**: 29.9 mg (0.0869 mmol) as a white solid, 87% yield; mp 200–201 °C; $[\alpha]_D^{25}$ = +343.5 (*c* = 0.26 in $CHCl_3$); 99% ee, determined by HPLC analysis (Chiralpak AD-H, *i*-PrOH/*n*-hexane = 20/80, flow rate = 1.0 mL/min, λ = 254 nm), t_R = 8.59 min (major), t_R = 15.03 min (minor); ^{1}H NMR (400 MHz, $CDCl_3$) δ (ppm) 8.25–8.19 (m, 1H), 8.03–7.96 (m, 2H), 7.52 (d, 1H), 7.48–7.41 (m, 1H), 7.40–7.33 (m, 2H), 7.14–7.08 (m, 1H), 6.90–6.87 (m,

1H), 6.22 (dd, *J* = 5.7, 1.2 Hz, 1H), 5.55–5.51 (m, 1H), 4.46 (d, *J* = 8.7 Hz, 1H), 3.35 (dd, *J* = 8.8, 6.8 Hz, 1H), 3.01–2.91 (m, 1H), 2.89–2.76 (m, 2H), 2.60–2.52 (m, 1H), 2.31 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm) 205.3, 166.8, 159.0, 137.2, 133.9, 133.8, 132.2, 131.3, 130.7, 129.2, 128.7, 128.2, 127.8, 127.7, 64.2, 63.0, 55.2, 49.4, 28.9, 21.0; HRMS (ESI-TOF) m/z: $[M + Na]^+$ Calcd for $C_{22}H_{21}N_2O_2^+$ 367.1417; Found 367.1411.

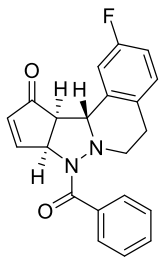


Synthesis of 3d: To an oven-dried 10 mL Schlenk tube equipped with a stir bar were added carbonate **1a** (40.0 mg, 0.200 mmol, 2.0 equiv), C,N-azomethine imine **2a** (26.5 mg, 0.100 mmol, 1.0 equiv), $Pd_2(dba)_3$ (4.6 mg, 0.0050 mmol, 5.0 mol%) and (1*S*,2*S*)-**L6** (6.9 mg, 0.010 mmol, 10 mol%). The tube was evacuated and back-filled with argon for three times. Then anhydrous $CHCl_3$ (2.0 mL) was added via syringe and the mixture was stirred at room temperature (20–25 °C) for 10 h. After completion monitored by TLC, the crude product (10/1 dr) was concentrated and purified by flash chromatography on silica gel (EtOAc/petroleum ether = 1/4) to afford the pure cycloadduct **3d**: 21.1 mg (0.0613 mmol) as a white solid, 61% yield; mp 191–193 °C; $[\alpha]_D^{25}$ = +317.2 (*c* = 0.15 in $CHCl_3$); 98% ee, determined by HPLC analysis (Chiralpak AD-H, *i*-PrOH/*n*-hexane = 20/80, flow rate = 1.0 mL/min, λ = 254 nm), t_R = 8.41 min (major), t_R = 14.42 min (minor); ^{1}H NMR (400 MHz, $CDCl_3$) δ (ppm) 8.25–8.20 (m, 1H), 8.02–7.96 (m, 2H), 7.48–7.42 (m, 2H), 7.40–7.33 (m, 2H), 7.06–7.01 (m, 1H), 6.98–6.94 (m, 1H), 6.22 (dd, *J* = 5.6, 1.2 Hz, 1H), 5.55–5.51 (m, 1H), 4.44 (d, *J* = 8.7 Hz, 1H), 3.37 (dd, *J* = 8.8, 6.8 Hz, 1H), 3.01–2.92 (m, 1H), 2.89–2.74 (m, 2H), 2.61–2.53 (m, 1H), 2.38 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm) 205.3, 166.8, 159.0, 136.5, 133.9, 133.7, 133.5, 131.3, 129.3, 129.2, 128.7, 128.4, 128.0, 127.8, 64.2, 63.1, 55.0, 495, 28.6, 21.2; HRMS (ESI-TOF) m/z: $[M + H]^+$ Calcd for $C_{22}H_{21}N_2O_2^+$ 367.1417; Found 367.1414.

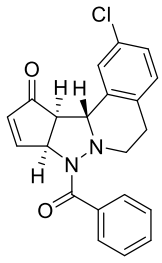


Synthesis of 3e: To an oven-dried 10 mL Schlenk tube equipped with a stir bar were added carbonate **1a** (40.0 mg, 0.200 mmol, 2.0 equiv), C,N-azomethine imine **2e** (32.9 mg, 0.100 mmol, 1.0 equiv), $Pd_2(dba)_3$ (4.6 mg, 0.0050 mmol, 5.0 mol%) and **L6** (6.9 mg, 0.010 mmol, 10 mol%). The tube was evacuated and back-filled with argon for three times. Then anhydrous $CHCl_3$ (2.0 mL) was added via syringe and the mixture was stirred at room temperature (20–25 °C) for 10 h. After completion monitored by TLC,

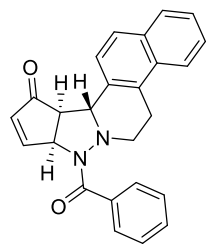
the crude product (10/1 dr) was concentrated and purified by flash chromatography on silica gel (EtOAc/petroleum ether = 1/4) to afford the pure cycloadduct **3e**: 36.5 mg (0.0894 mmol) as a white solid, 89% yield; mp 199–201 °C; $[\alpha]_D^{25}$ = +217.3 (*c* = 0.15 in $CHCl_3$); 99% ee, determined by HPLC analysis (Chiralpak AD-H, *i*-PrOH/*n*-hexane = 20/80, flow rate = 1.0 mL/min, λ = 254 nm), t_R = 14.43 min (major), t_R = 25.20 min (minor); ^{1}H NMR (400 MHz, $CDCl_3$) δ (ppm) 8.32–8.12 (m, 1H), 8.02–7.91 (m, 2H), 7.24–7.22 (m, 1H), 7.50–7.34 (m, 4H), 7.24–7.22 (m, 1H), 6.22 (dd, *J* = 5.6, 1.2 Hz, 1H), 5.53 (m, *J* = 6.8, 2.3, 1.2 Hz, 1H), 4.44 (d, *J* = 8.7 Hz, 1H), 3.34 (dd, *J* = 8.8, 6.8 Hz, 1H), 2.98–2.89 (m, 1H), 2.89–2.76 (m, 2H), 2.61–2.54 (m, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm) 205.3, 166.8, 159.2, 134.7, 133.9, 133.6, 132.7, 131.4, 131.0, 130.0, 129.1, 127.9, 121.4, 64.1, 62.6, 54.9, 48.9, 28.8; HRMS (ESI-TOF) m/z: $[M + H]^+$ Calcd for $C_{21}H_{18}{}^{79}BrN_2O_2^+$ 409.0546; Found 409.0544; Calcd for $C_{21}H_{18}{}^{81}BrN_2O_2^+$ 411.0526; Found 411.0529.



Synthesis of 3f: To an oven-dried 10 mL Schlenk tube equipped with a stir bar were added carbonate **1a** (40.0 mg, 0.200 mmol, 2.0 equiv), C,N-azomethine imine **2f** (26.9 mg, 0.100 mmol, 1.0 equiv), $Pd_2(dba)_3$ (4.6 mg, 0.0050 mmol, 5.0 mol%) and **L6** (6.9 mg, 0.010 mmol, 10 mol%). The tube was evacuated and back-filled with argon for three times. Then anhydrous $CHCl_3$ (2.0 mL) was added via syringe and the mixture was stirred at room temperature (20–25 °C) for 10 h. After completion monitored by TLC, the crude product (15/1 dr) was concentrated and purified by flash chromatography on silica gel (EtOAc/petroleum ether = 1/4) to afford the pure cycloadduct **3f**: 30.9 mg (0.0888 mmol) as a white solid, 89% yield; mp 136–138 °C; $[\alpha]_D^{25}$ = +318.7 (*c* = 0.15 in $CHCl_3$); 99% ee, determined by HPLC analysis (Chiralpak AD-H, *i*-PrOH/*n*-hexane = 20/80, flow rate = 1.0 mL/min, λ = 25dr4 nm), t_R = 11.93 min (major), t_R = 17.83 min (minor); ^{1}H NMR (400 MHz, $CDCl_3$) δ (ppm) 8.26–8.20 (m, 1H), 8.01–7.95 (m, 2H), 7.49–7.41 (m, 2H), 7.41–7.35 (m, 2H), 7.05–7.01 (m, 1H), 6.95–6.88 (m, 1H), 6.23 (dd, *J* = 5.7, 1.2 Hz, 1H), 5.55–5.51 (m, 1H), 4.45 (d, *J* = 8.7 Hz, 1H), 3.38 (dd, *J* = 8.8, 6.9 Hz, 1H), 3.00–2.91 (m, 1H), 2.90–2.74 (m, 2H), 2.63–2.53 (m, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm) 205.2, 166.9, 161.5 (d, *J* = 245.0 Hz),159.2, 135.6 (d, *J* = 8.1 Hz), 133.9, 133.6, 131.4, 129.7 (d, *J* = 8.1 Hz), 129.1, 128.1 (d, *J* = 3.2 Hz), 127.8, 114.9 (d, *J* = 11.3 Hz), 114.7 (d, *J* = 10.0 Hz) 64.0, 62.7, 54.9, 49.4, 28.4; ^{19}F NMR (376 MHz, $CDCl_3$) δ (ppm) –114.9; HRMS (ESI-TOF) m/z: $[M + Na]^+$ Calcd for $C_{21}H_{17}FN_2O_2Na^+$ 371.1166; Found 371.1170.

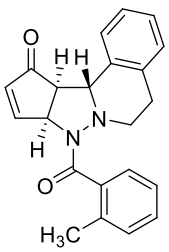


Synthesis of 3g: To an oven-dried 10 mL Schlenk tube equipped with a stir bar were added carbonate **1a** (40.0 mg, 0.200 mmol, 2.0 equiv), C,N-azomethine imine **2g** (28.4 mg, 0.100 mmol, 1.0 equiv), $Pd_2(dba)_3$ (4.6 mg, 0.0050 mmol, 5.0 mol%) and **L6** (6.9 mg, 0.010 mmol, 10 mol%). The tube was evacuated and back-filled with argon for three times. Then anhydrous $CHCl_3$ (2.0 mL) was added via syringe and the mixture was stirred at room temperature (20–25 °C) for 10 h. After completion monitored by TLC, the crude product (>19/1 dr) was concentrated and purified by flash chromatography on silica gel (EtOAc/petroleum ether = 1/4) to afford the pure cycloadduct **3g**: 34.0 mg (0.0934 mmol) as a white solid, 93% yield; mp 181–183 °C; $[\alpha]_D^{25}$ = +267.8 (*c* = 0.18 in $CHCl_3$); 99% ee, determined by HPLC analysis (Chiralpak AD-H, *i*-PrOH/*n*-hexane = 20/80, flow rate = 1.0 mL/min, λ = 254 nm), t_R = 13.52 min (major), t_R = 21.51 min (minor); ^{1}H NMR (400 MHz, $CDCl_3$) δ (ppm) 8.26–8.19 (m, 1H), 8.01–7.94 (m, 2H), 7.70–7.68 (m, 1H), 7.49–7.43 (m, 1H), 7.41–7.35 (m, 2H), 7.21–7.15 (m, 1H), 7.02–6.97 (m, 1H), 6.23 (dd, *J* = 5.6, 1.2 Hz, 1H), 5.56–5.49 (m, 1H), 4.44 (d, *J* = 8.7 Hz, 1H), 3.37 (dd, *J* = 8.8, 6.8 Hz, 1H), 2.99–2.90 (m, 1H), 2.89–2.73 (m, 2H), 2.62–2.54 (m, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm) 205.1, 166.9, 159.1, 135.5, 134.0, 133.6, 132.6, 131.4, 131.0, 129.5, 129.1, 128.2, 127.8, 127.7, 64.0, 62.6, 54.8, 49.1, 28.5; HRMS (ESI-TOF) m/z: $[M + Na]^+$ Calcd for $C_{21}H_{17}{}^{35}ClN_2O_2Na^+$ 387.0871; Found 387.0872; Calcd for $C_{21}H_{17}{}^{37}ClN_2O_2Na^+$ 389.0841; Found 389.0849.

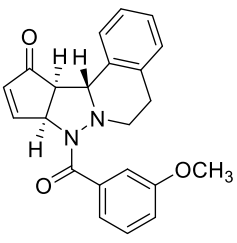


Synthesis of 3h: To an oven-dried 10 mL Schlenk tube equipped with a stir bar were added carbonate **1a** (40.0 mg, 0.200 mmol, 2.0 equiv), C,N-azomethine imine **2h** (30.0 mg, 0.100 mmol, 1.0 equiv), $Pd_2(dba)_3$ (4.6 mg, 0.0050 mmol, 5.0 mol%) and **L6** (6.9 mg, 0.010 mmol, 10 mol%). The tube was evacuated and back-filled with argon for three times. Then anhydrous $CHCl_3$ (2.0 mL) was added via syringe and the mixture was stirred at room temperature (20–25 °C) for 10 h. After completion monitored by TLC, the crude product (>19/1 dr) was concentrated and purified by flash chromatography on silica gel (EtOAc/petroleum ether = 1/4) to afford the pure cycloadduct **3h**: 35.6 mg (0.0936 mmol) as a white solid, 94% yield; mp 224–226 °C; $[\alpha]_D^{25}$ = +308.9 (*c* = 0.18 in $CHCl_3$); 99% ee, determined by HPLC analysis (Chiralpak AD-H, *i*-PrOH/*n*-hexane = 20/80, flow rate = 1.0 mL/min, λ = 254 nm), t_R = 21.00min (major), t_R = 25.19 min (minor); ^{1}H NMR (600 MHz, $CDCl_3$) δ (ppm) 8.28–8.24 (m,

1H), 8.05–8.01 (m, 2H), 7.85–7.78 (m, 3H), 7.77–7.74 (m, 1H), 7.55–7.43 (m, 3H), 7.42–7.34 (m, 2H), 6.29–6.21 (m, 1H), 5.62–5.55 (m, 1H), 4.58 (d, *J* = 8.8 Hz, 1H), 3.50–3.44 (m, 1H), 3.19–3.12 (m, 1H), 3.11–2.94 (m, 3H); ^{13}C NMR (150 MHz, $CDCl_3$) δ (ppm) 205.4, 166.9, 159.1, 133.9, 133.7, 132.6, 131.3, 131.1, 131.0, 129.2, 128.6, 128.2, 127.8, 127.3, 126.5, 126.0, 125.7, 122.9, 64.3, 63.5, 55.0, 49.0, 25.6; HRMS (ESI-TOF) m/z: $[M + Na]^+$ Calcd for $C_{25}H_{20}N_2O_2Na^+$ 403.1417; Found 403.1416.

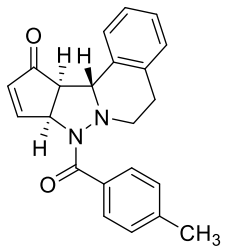


Synthesis of 3i: To an oven-dried 10 mL Schlenk tube equipped with a stir bar were added carbonate **1a** (40.0 mg, 0.200 mmol, 2.0 equiv), C,N-azomethine imine **2i** (26.4 mg, 0.100 mmol, 1.0 equiv), $Pd_2(dba)_3$ (4.6 mg, 0.0050 mmol, 5.0 mol%) and **L6** (6.9 mg, 0.010 mmol, 10 mol%). The tube was evacuated and back-filled with argon for three times. Then anhydrous $CHCl_3$ (2.0 mL) was added via syringe and the mixture was stirred at room temperature (20–25 °C) for 10 h. After completion monitored by TLC, the crude product (6/1 dr) was concentrated and purified by flash chromatography on silica gel (EtOAc/petroleum ether = 1/4) to afford the pure cycloadduct **3i**: 14.5 mg (0.0422 mmol) as a white solid, 42% yield; mp 132–135 °C; $[\alpha]_D^{25}$ = +157.5 (*c* = 0.08 in $CHCl_3$); 85% ee, determined by HPLC analysis (Chiralpak AD-H, *i*-PrOH/*n*-hexane = 20/80, flow rate = 1.0 mL/min, λ = 254 nm), t_R = 7.30 min (major), t_R = 9.53 min (minor); ^{1}H NMR (400 MHz, $CDCl_3$) δ (ppm) 8.38–8.34 (m, 1H), 7.63–7.56 (m, 1H), 7.39–7.33 (m, 1H), 7.30–7.22 (m, 2H), 7.21–7.12 (m, 3H), 7.05–6.97 (m, 1H), 6.28–6.22 (m, 1H), 5.52–5.46 (m, 1H), 4.36 (d, *J* = 8.8 Hz, 1H), 3.42 (dd, *J* = 8.9, 6.7 Hz, 1H), 3.01–2.91 (m, 1H), 2.87–2.80 (m, 1H), 2.69–2.48 (m, 2H), 2.32 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm) 205.0, 168.6, 158.7, 135.6, 135.1, 133.9, 133.5, 132.5, 130.0, 129.3, 128.3, 128.1, 127.4, 127.1, 126.8, 125.3, 63.5, 63.2, 55.7, 49.5, 28.9, 19.4; HRMS (ESI-TOF) m/z: $[M + Na]^+$ Calcd for $C_{22}H_{20}N_2O_2Na^+$ 367.1417; Found 367.1416.

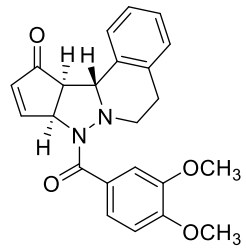


Synthesis of 3j: To an oven-dried 10 mL Schlenk tube equipped with a stir bar were added carbonate **1a** (40.0 mg, 0.200 mmol, 2.0 equiv), C,N-azomethine imine **2j** (28.0 mg, 0.100 mmol, 1.0 equiv), $Pd_2(dba)_3$ (4.6 mg, 0.0050 mmol, 5.0 mol%) and **L6** (6.9 mg, 0.010 mmol, 10 mol%). The tube was evacuated and back-filled with argon for three times. Then anhydrous $CHCl_3$ (2.0 mL) was

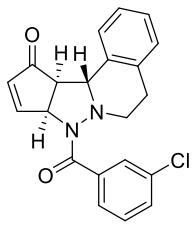
added via syringe and the mixture was stirred at room temperature (20–25 °C) for 10 h. After completion monitored by TLC, the crude product (8/1 dr) was concentrated and purified by flash chromatography on silica gel (EtOAc/petroleum ether = 1/4) to afford the pure cycloadduct **3j**: 23.3 mg (0.0647 mmol) as a white solid, 65% yield; mp 130–133 °C; $[\alpha]_D^{25}$ = +302.4 (*c* = 0.13 in $CHCl_3$); 99% ee, determined by HPLC analysis (Chiralpak AD-H, *i*-PrOH/*n*-hexane = 20/80, flow rate = 1.0 mL/min, λ = 254 nm), t_R = 13.52 min (major), t_R = 22.39 min (minor); ^{1}H NMR (400 MHz, $CDCl_3$) δ (ppm) 8.27–8.18 (m, 1H), 7.67–7.61 (m, 2H), 7.59–7.54 (m, 1H), 7.32–7.26 (m, 2H), 7.25–7.19 (m, 1H), 7.10–7.05 (m, 1H), 7.04–6.97 (m, 1H), 6.23 (dd, *J* = 5.7, 1.2 Hz, 1H), 5.57–5.50 (m, 1H), 4.49 (d, *J* = 8.8 Hz, 1H), 3.81 (s, 3H), 3.38 (dd, *J* = 8.8, 6.8 Hz, 1H), 3.03–2.94 (m, 1H), 2.94–2.83 (m, 2H), 2.67–2.57 (m, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm) 205.3, 166.4, 159.1, 159.0, 134.9, 133.9, 133.7, 132.4, 128.9, 128.3, 128.2, 127.4, 126.9, 121.6, 117.3, 114.3, 64.3, 63.0, 55.4, 55.0, 49.4, 29.0; HRMS (ESI-TOF) m/z: $[M + Na]^+$ Calcd for $C_{22}H_{20}N_2O_3Na^+$ 383.1366; Found 383.1359.



Synthesis of 3k: To an oven-dried 10 mL Schlenk tube equipped with a stir bar were added carbonate **1a** (40.0 mg, 0.200 mmol, 2.0 equiv), C,N-azomethine imine **2k** (26.4 mg, 0.100 mmol, 1.0 equiv), $Pd_2(dba)_3$ (4.6 mg, 0.0050 mmol, 5.0 mol%) and **L6** (6.9 mg, 0.010 mmol, 10 mol%). The tube was evacuated and back-filled with argon for three times. Then anhydrous $CHCl_3$ (2.0 mL) was added via syringe and the mixture was stirred at room temperature (20–25 °C) for 10 h. After completion monitored by TLC, the crude product (>19/1 dr) was concentrated and purified by flash chromatography on silica gel (EtOAc/petroleum ether = 1/4) to afford the pure cycloadduct **3k**: 32.6 mg (0.0947 mmol) as a white solid, 95% yield; mp 182–184 °C; $[\alpha]_D^{25}$ = +43.1 (*c* = 0.13 in $CHCl_3$); 99% ee, determined by HPLC analysis (Chiralpak AD-H, *i*-PrOH/*n*-hexane = 40/60, flow rate = 1.0 mL/min, λ = 254 nm), t_R = 7.25 min (major), t_R = 29.40 min (minor); ^{1}H NMR (600 MHz, $CDCl_3$) δ (ppm) 8.26–8.18 (m, 1H), 8.00–7.90 (m, 2H), 7.71–7.64 (m, 1H), 7.32–7.27 (m, 1H), 7.24–7.20 (m, 1H), 7.19–7.14 (m, 2H), 7.13–7.07 (m, 1H), 6.21 (d, *J* = 5.7 Hz, 1H), 5.58–5.47 (m, 1H), 4.49 (d, *J* = 8.8 Hz, 1H), 3.42–3.37 (m, 1H), 3.01–2.93 (m, 1H), 2.92–2.86 (m, 2H), 2.65–2.58 (m, 1H), 2.41 (s, 3H); ^{13}C NMR (150 MHz, $CDCl_3$) δ (ppm) 205.4, 166.6, 159.2, 141.7, 133.8, 133.7, 132.4, 130.7, 129.3, 128.5, 128.4, 128.31, 128.28, 128.2, 127.4, 126.8, 64.2, 63.0, 55.0, 49.2, 29.0, 21.5; HRMS (ESI-TOF) m/z: $[M + Na]^+$ Calcd for $C_{22}H_{20}N_2O_2Na^+$ 367.1417; Found 367.1412.

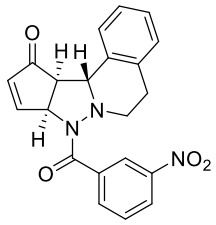


Synthesis of 3l: To an oven-dried 10 mL Schlenk tube equipped with a stir bar were added carbonate **1a** (40.0 mg, 0.200 mmol, 2.0 equiv), C,N-azomethine imine **2l** (31.0 mg, 0.100 mmol, 1.0 equiv), $Pd_2(dba)_3$ (4.6 mg, 0.0050 mmol, 5.0 mol%) and **L6** (6.9 mg, 0.010 mmol, 10 mol%). The tube was evacuated and back-filled with argon for three times. Then anhydrous $CHCl_3$ (2.0 mL) was added via syringe and the mixture was stirred at room temperature (20–25 °C) for 10 h. After completion monitored by TLC, the crude product (>19/1 dr) was concentrated and purified by flash chromatography on silica gel (EtOAc/petroleum ether = 1/4) to afford the pure cycloadduct **3l**: 36.3 mg (0.0930 mmol) as a white solid, 93% yield; mp 193–196 °C; $[\alpha]_D^{25}$ = +282.1 (*c* = 0.10 in $CHCl_3$); 99% ee, determined by HPLC analysis (Chiralpak AD-H, *i*-PrOH/*n*-hexane = 20/80, flow rate = 1.0 mL/min, λ = 254 nm), t_R = 19.42 min (major), t_R = 37.17 min (minor); ^{1}H NMR (400 MHz, $CDCl_3$) δ (ppm) 8.22–8.19 (m, 1H), 7.90–7.84 (m, 1H), 7.74–7.71 (m, 1H),, 7.68–7.64 (m, 1H), 7.34–7.28 (m, 1H), 7.26–7.20 (m, 1H), 7.12–7.08 (m, 1H), 6.84 (d, *J* = 8.6 Hz, 1H), 6.22 (dd, *J* = 5.7, 1.2 Hz, 1H), 5.57–5.53 (m, 1H), 4.52 (d, *J* = 8.7 Hz, 1H), 3.92 (s, 3H), 3.88 (s, 3H), 3.36 (dd, *J* = 8.8, 6.8 Hz, 1H), 3.04–2.89 (m, 3H), 2.73–2.61 (m, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm) 205.4, 165.8, 159.3, 151.7, 148.2, 133.8, 132.3, 128.4, 128.2, 127.4, 126.9, 125.7, 123.4, 112.5, 109.9, 64.5, 63.1, 56.1, 55.9, 54.8, 49.2, 29.1; HRMS (ESI-TOF) m/z: $[M + Na]^+$ Calcd for $C_{23}H_{22}N_2O_4Na^+$ 413.1472; Found 413.1480.

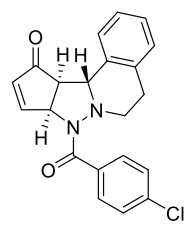


Synthesis of 3m: To an oven-dried 10 mL Schlenk tube equipped with a stir bar were added carbonate **1a** (40.0 mg, 0.200 mmol, 2.0 equiv), C,N-azomethine imine **2m** (28.4 mg, 0.100 mmol, 1.0 equiv), $Pd_2(dba)_3$ (4.6 mg, 0.0050 mmol, 5.0 mol%) and **L6** (6.9 mg, 0.010 mmol, 10 mol%). The tube was evacuated and back-filled with argon for three times. Then anhydrous $CHCl_3$ (2.0 mL) was added via syringe and the mixture was stirred at room temperature (20–25 °C) for 10 h. After completion monitored by TLC, the crude product (>19/1 dr) was concentrated and purified by flash chromatography on silica gel (EtOAc/petroleum ether = 1/4) to afford the pure cycloadduct **3m**: 35.8 mg (0.0983 mmol) as a white solid, 98% yield; mp 153–157 °C; $[\alpha]_D^{25}$ = +299.2 (*c* = 0.13 in $CHCl_3$); 99% ee, determined by HPLC analysis (Chiralpak AD-H, *i*-PrOH/*n*-hexane = 20/80, flow rate = 1.0 mL/min, λ = 254 nm), t_R = 10.08 min (major), t_R = 14.67 min (minor); ^{1}H NMR (600 MHz, $CDCl_3$) δ (ppm) 8.22–8.18 (m, 1H),

8.03–8.01 (m, 1H), 7.91–7.88 (m, 1H), 7.67–7.63 (m, 1H), 7.45–7.42 (m, 1H), 7.34–7.29 (m, 2H), 7.25–7.21 (m, 1H), 7.11–7.06 (m, 1H), 6.24 (dd, *J* = 5.6, 1.2 Hz, 1H), 5.56–5.49 (m, 1H), 4.50 (d, *J* = 8.8 Hz, 1H), 3.39 (dd, *J* = 8.8, 6.8 Hz, 1H), 3.03–2.97 (m, 1H), 2.93–2.83 (m, 2H), 2.67–2.61 (m, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm) 205.0, 165.2, 158.6, 135.4, 134.1, 133.9, 133.5, 132.3, 131.4, 129.21, 129.17, 128.3, 128.2, 127.5, 127.4, 126.9, 64.2, 63.1, 55.0, 49.6, 29.0; HRMS (ESI-TOF) m/z: $[M + Na]^+$ Calcd for $C_{21}H_{17}{}^{35}ClN_2O_2Na^+$ 387.0871 Found 387.0870; Calcd for $C_{21}H_{17}{}^{37}ClN_2O_2Na^+$ 389.0841; Found 389.0849.

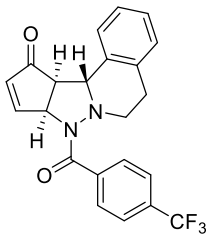


Synthesis of 3n: To an oven-dried 10 mL Schlenk tube equipped with a stir bar were added carbonate **1a** (40.0 mg, 0.200 mmol, 2.0 equiv), C,N-azomethine imine **2n** (29.5 mg, 0.100 mmol, 1.0 equiv), $Pd_2(dba)_3$ (4.6 mg, 0.0050 mmol, 5.0 mol%) and **L6** (6.9 mg, 0.010 mmol, 10 mol%). The tube was evacuated and back-filled with argon for three times. Then anhydrous $CHCl_3$ (2.0 mL) was added via syringe and the mixture was stirred at room temperature (20–25 °C) for 10 h. After completion monitored by TLC, the crude product (8/1 dr) was concentrated and purified by flash chromatography on silica gel (EtOAc/petroleum ether = 1/4) to afford the pure cycloadduct **3n**: 25.9 mg (0.0690mmol) as a white solid, 69% yield; mp 207–209 °C; $[\alpha]_D^{25}$ = +416.4 (*c* = 0.11 in $CHCl_3$); 98% ee, determined by HPLC analysis (Chiralpak AD-H, *i*-PrOH/*n*-hexane = 20/80, flow rate = 1.0 mL/min, λ = 254 nm), t_R = 18.64 min (major), t_R = 23.00 min (minor); ^{1}H NMR (400 MHz, $CDCl_3$) δ (ppm) 8.94–8.91 (m, 1H), 8.37–8.30 (m, 2H), 8.26–8.21 (m, 1H), 7.68–7.64 (m, 1H), 7.61–7.56 (m, 1H), 7.34–7.29 (m, 1H), 7.26–7.21 (m, 1H), 7.11–7.07 (m, 1H), 6.27 (dd, *J* = 5.7, 1.2 Hz, 1H), 5.58–5.54 (m, 1H), 4.54 (d, *J* = 8.8 Hz, 1H), 3.43 (dd, *J* = 8.8, 6.8 Hz, 1H), 3.11–3.01 (m, 1H), 2.94–2.82 (m, 2H), 2.69–2.61 (m, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm) 204.7, 164.0, 158.2, 147.9, 135.3, 135.1, 134.3, 133.3, 132.0, 129.0, 128.3, 128.2, 127.6, 127.0, 125.9, 124.4, 64.3, 63.2, 55.0, 49.9, 28.9; HRMS (ESI-TOF) m/z: $[M + H]^+$ Calcd for $C_{21}H_{18}N_3O_4^+$ 376.1292; Found 376.1297.



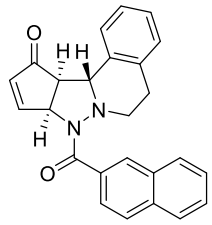
Synthesis of 3o: To an oven-dried 10 mL Schlenk tube equipped with a stir bar were added carbonate **1a** (40.0 mg, 0.200 mmol, 2.0 equiv), C,N-azomethine imine **2o** (28.4mg, 0.100 mmol, 1.0 equiv), $Pd_2(dba)_3$ (4.6 mg, 0.0050 mmol, 5.0 mol%) and **L6** (6.9 mg, 0.010 mmol, 10 mol%). The tube was evacuated and back-filled with

argon for three times. Then anhydrous $CHCl_3$ (2.0 mL) was added via syringe and the mixture was stirred at room temperature (20–25 °C) for 10 h. After completion monitored by TLC, the crude product (8/1 dr) was concentrated and purified by flash chromatography on silica gel (EtOAc/petroleum ether = 1/4) to afford the pure cycloadduct **3o**: 21.4 mg (0.0588 mmol) as a white solid, 59% yield; mp 192–193 °C; $[\alpha]_D^{25}$ = +377.9 (*c* = 0.24 in $CHCl_3$); 99% ee, determined by HPLC analysis (Chiralpak AD-H, *i*-PrOH/*n*-hexane = 40/60, flow rate = 1.0 mL/min, λ = 254 nm), t_R = 8.18 min (major), t_R = 20.11 min (minor); ^{1}H NMR (400 MHz, $CDCl_3$) δ (ppm) 8.26–8.16 (m, 1H), 8.03–7.96 (m, 2H), 7.68–7.61 (m, 1H), 7.38–7.33 (m, 2H), 7.33–7.28 (m, 1H), 7.26–7.21 (m, 1H), 7.13–7.05 (m, 1H), 6.24 (dd, 1H), 5.56–5.50 (m, 1H), 4.49 (d, *J* = 8.8 Hz, 1H), 3.39 (dd, *J* = 8.8, 6.8 Hz, 1H), 3.03–2.95 (m, 1H), 2.94–2.81 (m, 2H), 2.68–2.60 (m, 1H); ^{13}C NMR (150 MHz, $CDCl_3$) δ (ppm) 205.1, 165.5, 158.7, 137.4, 134.0, 133.5, 132.2, 132.0, 130.7, 128.3, 128.2, 128.1, 127.5, 126.9, 64.2, 63.0, 55.0, 49.4, 28.9; HRMS (ESI-TOF) m/z: $[M + H]^+$ Calcd for $C_{21}H_{18}{}^{35}ClN_2O_2^+$ 365.1051 Found 365.1046; Calcd for $C_{21}H_{18}{}^{37}ClN_2O_2^+$ 367.1022; Found 367.1024.

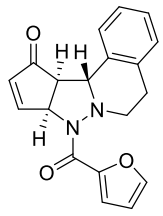


Synthesis of 3p: To an oven-dried 10 mL Schlenk tube equipped with a stir bar were added carbonate **1a** (40.0 mg, 0.200 mmol, 2.0 equiv), C,N-azomethine imine **2p** (31.8 mg, 0.100 mmol, 1.0 equiv), $Pd_2(dba)_3$ (4.6 mg, 0.0050 mmol, 5.0 mol%) and **L6** (6.9 mg, 0.010 mmol, 10 mol%). The tube was evacuated and back-filled with argon for three times. Then anhydrous $CHCl_3$ (2.0 mL) was added via syringe and the mixture was stirred at room temperature (20–25 °C) for 10 h. After completion monitored by TLC, the crude product (10/1 dr) was concentrated and purified by flash chromatography on silica gel (EtOAc/petroleum ether = 1/4) to afford the pure cycloadduct **3p**: 29.2mg (0.0733 mmol) as a white solid, 73% yield; mp 154–156 °C; $[\alpha]_D^{25}$ = +273.5 (*c* = 0.16 in $CHCl_3$); 99% ee, determined by HPLC analysis (Chiralpak AD-H, *i*-PrOH/*n*-hexane = 20/80, flow rate = 1.0 mL/min, λ = 254 nm), t_R = 10.22min (major), t_R = 14.81 min (minor); ^{1}H NMR (600 MHz, $CDCl_3$) δ (ppm) 8.25–8.20 (m, 1H), 8.13–8.07 (m, 2H), 7.68–7.61 (m, 3H), 7.34–7.28 (m, 1H), 7.25–7.21 (m, 1H), 7.11–7.06 (m, 1H), 6.26 (d, *J* = 5.8 Hz, 1H), 5.54 (d, *J* = 7.0 Hz, 1H), 4.50 (d, *J* = 8.8 Hz, 1H), 3.42 (dd, *J* = 8.8, 6.8 Hz, 1H), 3.05–2.99 (m, 1H), 2.89–2.80 (m, 2H), 2.67–2.60 (m, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm) 204.9, 165.4, 158.5, 137.1, 134.2, 133.4, 132.8 (q, *J* = 32.6 Hz), 132.2, 129.5, 128.3, 128.2, 127.6, 127.0, 124.8 (q, *J* = 3.8 Hz), 123.7 (q, *J* = 272.5 Hz), 64.2, 63.1, 55.1, 49.7, 28.9; ^{19}F NMR

(376 MHz, $CDCl_3$) δ (ppm) –63.0; HRMS (ESI-TOF) m/z: $[M + H]^+$ Calcd for $C_{22}H_{18}F_3N_2O_2^+$ 399.1315; Found 399.1316.

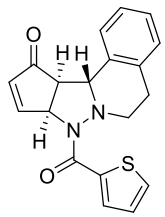


Synthesis of 3q: To an oven-dried 10 mL Schlenk tube equipped with a stir bar were added carbonate **1a** (40.0 mg, 0.200 mmol, 2.0 equiv), C,N-azomethine imine **2q** (30.0 mg, 0.100 mmol, 1.0 equiv), $Pd_2(dba)_3$ (4.6 mg, 0.0050 mmol, 5.0 mol%) and **L6** (6.9 mg, 0.010 mmol, 10 mol%). The tube was evacuated and back-filled with argon for three times. Then anhydrous $CHCl_3$ (2.0 mL) was added via syringe and the mixture was stirred at room temperature (20–25 °C) for 10 h. After completion monitored by TLC, the crude product (6/1 dr) was concentrated and purified by flash chromatography on silica gel (EtOAc/petroleum ether = 1/5) to afford the pure cycloadduct **3q**: 21.3 mg (0.0560 mmol) as a white solid, 56% yield; mp 151–153 °C; $[\alpha]_D^{25}$ = +200.0 (*c* = 0.19 in $CHCl_3$); 94% ee, determined by HPLC analysis (Chiralpa AD, *i*-PrOH/*n*-hexane = 20/80, flow rate = 1.0 mL/min, λ = 254 nm), t_R = 12.72 min (minor), t_R = 15.49 min (major); ^{1}H NMR (400 MHz, $CDCl_3$) δ (ppm) 8.43–8.39 (m, 1H), 7.88–7.83 (m, 1H), 7.82–7.74 (m, 2H), 7.54–7.49 (m, 2H), 7.44–7.34 (m, 3H), 7.18–7.13 (m, 1H), 7.09–7.02 (m, 1H), 6.88–6.83 (m, 1H), 6.25 (dd, *J* = 5.8, 1.2 Hz, 1H), 5.55–5.49 (m, 1H), 4.29 (d, *J* = 8.8 Hz, 1H), 3.37 (dd, *J* = 8.8, 6.8 Hz, 1H), 2.93–2.85 (m, 1H), 2.79–2.71 (m, 1H), 2.38–2.31 (m, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm) 205.1, 168.0, 158.7, 134.1, 133.5, 133.3, 132.4, 130.0, 129.8, 128.4, 128.2, 128.0, 127.3, 126.9, 126.7, 126.1, 125.2, 124.6, 63.7, 62.9, 55.9, 49.6, 28.8; HRMS (ESI-TOF) m/z: $[M + H]^+$ Calcd for $C_{25}H_{21}N_2O_2^+$ 381.1598; Found 381.1593.

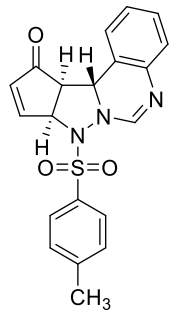


Synthesis of 3r: To an oven-dried 10 mL Schlenk tube equipped with a stir bar were added carbonate **1a** (40.0 mg, 0.200 mmol, 2.0 equiv), C,N-azomethine imine **2r** (24.0 mg, 0.100 mmol, 1.0 equiv), $Pd_2(dba)_3$ (4.6 mg, 0.0050 mmol, 5.0 mol%) and **L6** (6.9 mg, 0.010 mmol, 10 mol%). The tube was evacuated and back-filled with argon for three times. Then anhydrous $CHCl_3$ (2.0 mL) was added via syringe and the mixture was stirred at room temperature (20–25 °C) for 10 h. After completion monitored by TLC, the crude product (15/1 dr) was concentrated and purified by flash chromatography on silica gel (EtOAc/petroleum ether = 1/4) to afford the pure cycloadduct **3r**: 18.0 mg (0.0562 mmol) as a white solid, 56% yield; mp 192–194 °C; $[\alpha]_D^{25}$ = +313.8 (*c* = 0.13 in $CHCl_3$); 99% ee, determined by HPLC analysis (Chiralpak

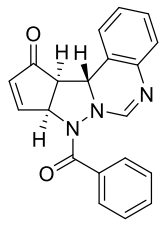
AD-H, *i*-PrOH/*n*-hexane = 20/80, flow rate = 1.0 mL/min, λ = 254 nm), t_R = 12.62 min (major), t_R = 32.00 min (minor); ^{1}H NMR (400 MHz, $CDCl_3$) δ (ppm) 8.36–8.30 (m, 1H), 7.65–7.57 (m, 2H), 7.55–7.49 (m, 1H), 7.33–7.28 (m, 1H), 7.26–7.23 (m, 1H), 7.18–7.13 (m, 1H), 6.49 (dd, *J* = 3.5, 1.7 Hz, 1H), 6.19 (d, *J* = 5.7 Hz, 1H), 5.51 (d, *J* = 5.7 Hz, 1H), 4.39 (d, *J* = 8.8 Hz, 1H), 3.39 (dd, *J* = 8.9, 6.7 Hz, 1H), 3.27–3.14 (m, 2H), 3.12–3.03 (m, 1H), 2.89–2.80 (m, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm) 204.8, 158.9, 156.1, 146.0, 145.6, 133.7, 133.5, 132.1, 128.4, 128.3, 127.6, 126.9, 117.6, 111.7, 64.4, 63.3, 54.7, 49.3, 29.1; HRMS (ESI-TOF) m/z: $[M + Na]^+$ Calcd for $C_{19}H_{16}N_2O_3Na^+$ 343.1053; Found 343.1054.



Synthesis of 3s: To an oven-dried 10 mL Schlenk tube equipped with a stir bar were added carbonate **1a** (40.0 mg, 0.200 mmol, 2.0 equiv), C,N-azomethine imine **2s** (25.6 mg, 0.100 mmol, 1.0 equiv), $Pd_2(dba)_3$ (4.6 mg, 0.0050 mmol, 5.0 mol%) and **L6** (6.9 mg, 0.010 mmol, 10 mol%). The tube was evacuated and back-filled with argon for three times. Then anhydrous $CHCl_3$ (2.0 mL) was added via syringe and the mixture was stirred at room temperature (20–25 °C) for 10 h. After completion monitored by TLC, the crude product (>19/1 dr) was concentrated and purified by flash chromatography on silica gel (EtOAc/petroleum ether = 1/4) to afford the pure cycloadduct **3s**: 32.3 mg (0.0953 mmol) as a white solid, 95% yield; mp 201–203 °C; $[\alpha]_D^{25}$ = +405.8 (*c* = 0.24 in $CHCl_3$); 99% ee, determined by HPLC analysis (Chiralpak AD-H, *i*-PrOH/*n*-hexane = 40/60, flow rate = 1.0 mL/min, λ = 254 nm), t_R = 9.13 min (major), t_R = 26.95 min (minor); ^{1}H NMR (400 MHz, $CDCl_3$) δ (ppm) 8.39–8.33 (m, 1H), 8.13–8.08 (m, 1H), 7.66–7.61 (m, 1H), 7.53–7.48 (m, 1H), 7.34–7.29 (m, 1H), 7.28–7.25 (m, 1H), 7.20–7.15 (m, 1H), 7.11–7.07 (m, 1H), 6.19 (dd, *J* = 5.7, 1.2 Hz, 1H), 5.51–5.45 (m, 1H), 4.41 (d, *J* = 8.8 Hz, 1H), 3.42 (dd, *J* = 8.8, 6.7 Hz, 1H), 3.39–3.20 (m, 2H), 3.14–3.06 (m, 1H), 2.85–2.78 (m, 1H); ^{13}C NMR (150 MHz, $CDCl_3$) δ (ppm) 204.8, 159.3, 158.7, 134.8, 134.1, 133.8, 133.56, 133.2, 132.3, 128.4, 128.3, 127.5, 126.9, 126.8, 64.1, 62.9, 55.5, 49.6, 28.8; HRMS (ESI-TOF) m/z: $[M + H]^+$ Calcd for $C_{19}H_{17}N_2O_2S^+$ 337.1005; Found 337.1013.

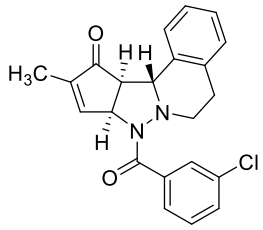


Synthesis of 3t: To an oven-dried 10 mL Schlenk tube equipped with a stir bar were added carbonate **1a** (40.0 mg, 0.200 mmol, 2.0 equiv), C,N-azomethine imine **2t** (29.9 mg, 0.100 mmol, 1.0 equiv), $Pd_2(dba)_3$ (4.6 mg, 0.0050 mmol, 5.0 mol%) and **L6** (6.9 mg, 0.010 mmol, 10 mol%). The tube was evacuated and back-filled with argon for three times. Then anhydrous $CHCl_3$ (2.0 mL) was added via syringe and the mixture was stirred at room temperature (20–25 °C) for 10 h. After completion monitored by TLC, the crude product (8/1 dr) was concentrated and purified by flash chromatography on silica gel (EtOAc/petroleum ether = 1/4) to afford the pure cycloadduct **3t**: 31.5 mg (0.0831 mmol) as a white solid, 83% yield; mp 120–123 °C; $[\alpha]_D^{25}$ = –19.0 (*c* = 0.20 in $CHCl_3$); 92% ee, determined by HPLC analysis (Chiralpak AD-H, *i*-PrOH/*n*-hexane = 20/80, flow rate = 1.0 mL/min, λ = 254 nm), t_R = 23.78 min (major), t_R = 29.37 min (minor); ^{1}H NMR (400 MHz, $CDCl_3$) δ (ppm) 7.91–7.85 (m, 2H), 7.52–7.48 (m, 1H), 7.40–7.35 (m, 2H), 7.26–7.22 (m, 1H), 7.21–7.16 (m, 1H), 7.11–7.04 (m, 2H), 6.69 (s, 1H), 6.15 (dd, *J* = 5.6, 1.4 Hz, 1H), 5.65–5.62 (m, 1H), 5.02 (d, *J* = 8.8 Hz, 1H), 3.32 (dd, *J* = 8.8, 5.9 Hz, 1H), 2.47 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm) 202.0, 157.2, 150.2, 146.1, 138.1, 137.85, 132.4, 130.2, 129.5, 129.1, 128.1, 126.6, 126.5, 119.4, 62.9, 61.5, 56.0, 21.8; HRMS (ESI-TOF) m/z: $[M + H]^+$ Calcd for $C_{20}H_{18}N_3O_3S^+$ 380.1063; Found 380.1060.

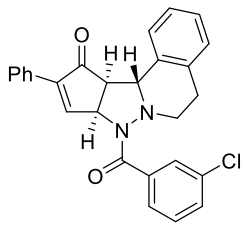


Synthesis of 3u: To an oven-dried 10 mL Schlenk tube equipped with a stir bar were added carbonate **1a** (40.0 mg, 0.200 mmol, 2.0 equiv), C,N-azomethine imine **2u** (24.9 mg, 0.100 mmol, 1.0 equiv), $Pd_2(dba)_3$ (4.6 mg, 0.0050 mmol, 5.0 mol%) and **L6** (6.9 mg, 0.010 mmol, 10 mol%). The tube was evacuated and back-filled with argon for three times. Then anhydrous $CHCl_3$ (2.0 mL) was added via syringe and the mixture was stirred at room temperature (20–25 °C) for 10 h. After completion monitored by TLC, the crude product (>19/1 dr) was concentrated and purified by flash chromatography on silica gel (EtOAc/petroleum ether = 1/4) to afford the pure cycloadduct **3u**: 16.7 mg (0.0508 mmol) as a white solid, 51% yield; mp 112-113 °C; $[\alpha]_D^{25}$ = –30.5 (*c* = 0.11 in $CHCl_3$); 95% ee, determined by HPLC analysis (Chiralpak AD-H, *i*-PrOH/*n*-hexane = 40/60, flow rate = 1.0 mL/min, λ = 254 nm), t_R = 13.60 min (major), t_R = 27.97 min (minor); ^{1}H NMR (400 MHz, $CDCl_3$) δ (ppm) 7.71–7.65 (m, 2H), 7.64–7.60 (m, 1H), 7.53–7.46 (m, 1H), 7.45–7.37 (m, 2H), 7.32–7.27 (m, 1H), 7.24–7.18 (m, 2H), 7.18–7.11 (m, 2H), 6.29 (d, *J* = 5.6 Hz, 1H), 6.08 (dd, *J* = 6.3, 2.4 Hz, 1H), 4.79 (d, *J* = 8.5 Hz, 1H), 3.32 (dd, *J* = 8.5, 5.9 Hz, 1H);

^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm) 202.5, 172.4, 156.9, 152.0, 139.0, 138.0, 132.5, 132.0, 129.8, 128.7, 128.4, 127.5, 126.8, 126.6, 120.0, 62.9, 61.6, 54.9; HRMS (ESI-TOF) m/z: $[M + H]^+$ Calcd for $C_{20}H_{16}N_3O_2^+$ 330.1237; Found 330.1237.



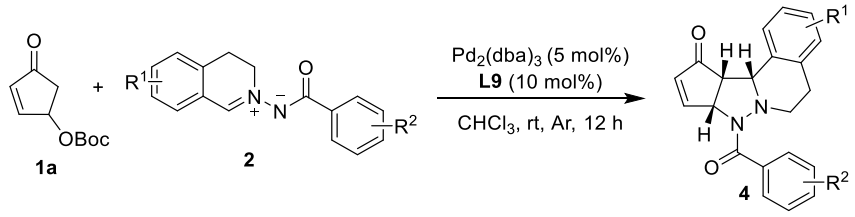
Synthesis of 3v: To an oven-dried 10 mL Schlenk tube equipped with a stir bar were added carbonate **1e** (42.4 mg, 0.200 mmol, 2.0 equiv), C,N-azomethine imine **2m** (28.4 mg, 0.100 mmol, 1.0 equiv), $Pd_2(dba)_3$ (4.6 mg, 0.0050 mmol, 5.0 mol%) and **L6** (6.9 mg, 0.010 mmol, 10 mol%). The tube was evacuated and back-filled with argon for three times. Then anhydrous $CHCl_3$ (2.0 mL) was added via syringe and the mixture was stirred at room temperature (20–25 °C) for 10 h. After completion monitored by TLC, the crude product (>19/1 dr) was concentrated and purified by flash chromatography on silica gel (EtOAc/petroleum ether = 1/5) to afford the pure cycloadduct **3v**: 25.2 mg (0.0667 mmol) as a white solid, 67% yield; mp 177–178 °C; $[\alpha]_D^{25}$ = +294.8 (*c* = 0.14 in $CHCl_3$); 97% ee, determined by HPLC analysis (Chiralpak IA, *i*-PrOH/*n*-hexane = 40/60, flow rate = 1.0 mL/min, λ = 254 nm), t_R = 6.84 min (major), t_R = 8.40 min (minor); ^{1}H NMR (400 MHz, $CDCl_3$) δ (ppm) 7.95–7.91 (m, 1H), 7.83–7.75 (m, 2H), 7.64–7.58 (m, 1H), 7.37–7.32 (m, 1H), 7.27–7.20 (m, 2H), 7.18–7.12 (m, 1H), 7.04–6.98 (m, 1H), 5.36–5.29 (m, 1H), 4.39 (d, *J* = 8.8 Hz, 1H), 3.35 (dd, *J* = 8.8, 6.8 Hz, 1H), 2.98–2.89 (m, 1H), 2.85–2.74 (m, 2H), 2.60–2.50 (m, 1H), 1.81 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm) 205.0, 165.2, 152.2, 142.4, 135.6, 133.82, 133.75, 132.3, 131.2, 129.2, 129.1, 128.4, 128.2, 127.4, 127.3, 126.9, 63.0, 62.2, 55.3, 49.6, 29.0, 10.4; HRMS (ESI-TOF) m/z: $[M + Na]^+$ Calcd for $C_{22}H_{19}{}^{35}ClN_2O_2Na^+$ 401.1027; Found 401.1025.



Synthesis of 3w: To an oven-dried 10 mL Schlenk tube equipped with a stir bar were added carbonate **1f** (54.8 mg, 0.200 mmol, 2.0 equiv), C,N-azomethine imine **2m** (28.4 mg, 0.100 mmol, 1.0 equiv), $Pd_2(dba)_3$ (4.6 mg, 0.0050 mmol, 5.0 mol%) and **L6** (6.9 mg, 0.010 mmol, 10 mol%). The tube was evacuated and back-filled with argon for three times. Then anhydrous toluene (2.0 mL) was added via syringe and it was allowed to stir at 40 °C for 12 h. After completion monitored by TLC, the crude product (15/1 dr) was concentrated and purified by flash chromatography on silica gel (acetone/petroleum ether = 1/10) to afford the pure cycloadduct **3w**: 19.5 mg (0.0441 mmol) as a

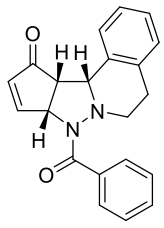
white solid, 44% yield; mp 172–174 °C; $[\alpha]_D^{25}$ = +58.9 (*c* = 0.10 in $CHCl_3$); 92% ee, determined by HPLC analysis (Chiralpak IA, *i*-PrOH/*n*-hexane = 40/60, flow rate = 1.0 mL/min, λ = 254 nm), t_R = 9.54 min (major), t_R = 14.79 min (minor); ^{1}H NMR (400 MHz, $CDCl_3$) δ (ppm) 8.35–8.31 (m, 1H), 8.06–8.02 (m, 1H), 7.95–7.88 (m, 1H), 7.86–7.78 (m, 2H), 7.75–7.68 (m, 1H), 7.47–7.36 (m, 4H), 7.35–7.29 (m, 2H), 7.27–7.22 (m, 1H), 7.14–7.08 (m, 1H), 5.55 (dd, *J* = 6.9, 2.5 Hz, 1H), 4.61 (d, *J* = 8.7 Hz, 1H), 3.60 (dd, *J* = 8.8, 6.9 Hz, 1H), 3.10–2.98 (m, 1H), 2.97–2.85 (m, 2H), 2.71–2.62 (m, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm) 203.0, 165.3, 151.8, 142.6, 135.5, 133.9, 133.6, 132.4, 131.4, 130.4, 129.4, 129.3, 129.2, 128.6, 128.4, 128.3, 127.7, 127.6, 127.4, 126.9, 63.3, 61.5, 56.5, 49.7, 29.0; HRMS (ESI-TOF) m/z: $[M + Na]^+$ Calcd for $C_{27}H_{21}{}^{35}ClN_2O_2Na^+$ 463.1184; Found 463.1186; Calcd for $C_{27}H_{21}{}^{37}ClN_2O_2Na^+$ 465.1154; Found 465.1161.

5. Procedure for synthesis of cycloadducts 4



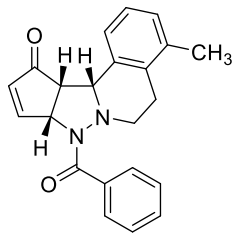
General procedure: To an oven-dried 10 mL Schlenk tube equipped with a stir bar were added carbonate **1a** (39.6 mg, 0.200 mmol, 2.0 equiv), C,N-azomethine imine **2** (0.100 mmol, 1.0 equiv), $Pd_2(dba)_3$ (4.6 mg, 0.0050 mmol, 5.0 mol%) and **L9** (7.8 mg, 0.010 mmol, 10 mol%). The tube was evacuated and back-filled with argon for three times. Then anhydrous $CHCl_3$ (2.0 mL) was added via syringe and the mixture was stirred at room temperature (20–25 °C) for 12 h. After completion monitored by TLC, the crude product was concentrated and purified by flash chromatography on silica gel (acetone/petroleum ether) to afford the pure cycloadduct **4** (**4a–4f**).

The corresponding racemates were generally obtained under the catalysis of $Pd_2(dba)_3$ (1.4 mg, 0.0015 mmol, 5.0 mol%) and (±)-**L9** (2.4mg, 0.0030 mmol, 10 mol%) on a 0.03 mmol scale.



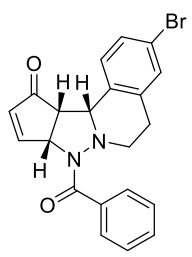
Synthesis of 4a: To an oven-dried 10 mL Schlenk tube equipped with a stir bar were added carbonate **1a** (39.6 mg, 0.200 mmol, 2.0 equiv), C,N-azomethine imine **2a** (25.0 mg, 0.100 mmol, 1.0 equiv), $Pd_2(dba)_3$ (4.6 mg, 0.0050 mmol, 5.0 mol%) and **L9** (7.8 mg, 0.010 mmol, 10 mol%). The tube was evacuated and back-filled with argon for

three times. Then anhydrous $CHCl_3$ (2.0 mL) was added via syringe and the mixture was stirred at room temperature (20–25 °C) for 12 h. After completion monitored by TLC, the crude product (14/1 dr) was concentrated and purified by flash chromatography on silica gel (acetone/petroleum ether = 1/6) to afford the pure cycloadduct **4a**: 27.6 mg (0.0836 mmol) as a white solid, 84% yield; mp 153–156 °C; $[\alpha]_D^{25}$ = +22.1 (*c* = 0.29 in $CHCl_3$); 99% ee, determined by HPLC analysis (Chiralpak AD-H, *i*-PrOH/*n*-hexane = 40/60, flow rate = 1.0 mL/min, λ = 254 nm), t_R = 11.27 min (minor), t_R = 16.74min (major); ^{1}H NMR (600 MHz, CDCl) δ (ppm) 8.05–8.01 (m, 1H), 7.89–7.83 (m, 2H), 7.46–7.42 (m, 1H), 7.42–7.39 (m, 1H), 7.38–7.35 (m, 2H), 7.33–7.28 (m, 1H), 7.24–7.19 (m, 1H), 7.08–7.03 (m, 1H), 6.07 (d, *J* = 5.7 Hz, 1H), 5.85 (dd, *J* = 6.7, 2.7 Hz, 1H), 4.91 (d, *J* = 8.9 Hz, 1H), 3.59 (dd, *J* = 8.9, 6.5 Hz, 1H), 3.15–3.08 (m, 1H), 3.06–3.01 (m, 1H), 2.84–2.74 (m, 1H), 2.55–2.49 (m, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm) 205.8, 168.5, 161.8, 136.1, 134.1, 133.1, 130.8, 130.2, 128.73, 128.66, 128.4, 127.8, 127.4, 126.0, 65.2, 64.2, 53.4, 50.4, 29.6; HRMS (ESI-TOF) m/z: [M + Na]$^+$ Calcd for $C_{21}H_{18}N_2O_2Na^+$ 353.1260; Found 353.1264.

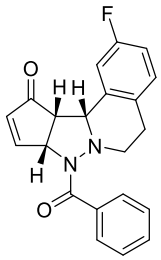


Synthesis of 4b: To an oven-dried 10 mL Schlenk tube equipped with a stir bar were added carbonate **1a** (39.6 mg, 0.200 mmol, 2.0 equiv), C,N-azomethine imine **2b** (26.4 mg, 0.100 mmol, 1.0 equiv), $Pd_2(dba)_3$ (4.6 mg, 0.0050 mmol, 5.0 mol%) and **L9** (7.8 mg, 0.010 mmol, 10 mol%). The tube was evacuated and back-filled with argon for three times. Then anhydrous $CHCl_3$ (2.0 mL) was added via syringe and the mixture was stirred at room temperature (20–25 °C) for 12 h. After completion monitored by TLC, the crude product (>19/1 dr) was concentrated and purified by flash chromatography on silica gel (acetone/petroleum ether = 1/6) to afford the pure cycloadduct **4b**: 30.5 mg (0.0886 mmol) as a white solid, 89% yield; mp 85–87 °C; $[\alpha]_D^{25}$ = +30.0 (*c* = 0.10 in $CHCl_3$); 99% ee, determined by HPLC analysis (Chiralpak AD-H, *i*-PrOH/*n*-hexane = 40/60, flow rate = 1.0 mL/min, λ = 254 nm), t_R = 7.30 min (minor), t_R = 10.15min (major); ^{1}H NMR (400 MHz, $CDCl_3$) δ (ppm) 8.05–8.02 (m, 1H), 7.89–7.83 (m, 2H), 7.46–7.40 (m, 1H), 7.40–7.33 (m, 2H), 7.26–7.18 (m, 2H), 7.10–7.05 (m, 1H), 6.06 (d, *J* = 5.6 Hz, 1H), 5.84 (dd, *J* = 6.8, 2.7 Hz, 1H), 4.88 (d, *J* = 8.9 Hz, 1H), 3.60 (dd, *J* = 8.9, 6.5 Hz, 1H), 3.11–3.03 (m, 2H), 2.56–2.48 (m, 2H), 2.16 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm) 205.9, 168.5, 161.8, 136.1, 135.9, 134.2, 131.8, 130.8, 130.1, 128.72,

128.68, 127.8, 126.5, 125.8, 65.5, 64.1, 53.4, 50.3, 27.0, 19.4; HRMS (ESI-TOF) m/z: $[M + Na]^+$ Calcd for $C_{22}H_{20}N_2O_2Na^+$ 367.1417; Found 367.1422.

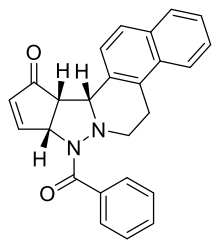


Synthesis of 4c: To an oven-dried 10 mL Schlenk tube equipped with a stir bar were added carbonate **1a** (39.6 mg, 0.200 mmol, 2.0 equiv), C,N-azomethine imine **2e** (32.8 mg, 0.100 mmol, 1.0 equiv), $Pd_2(dba)_3$ (4.6 mg, 0.0050 mmol, 5.0 mol%) and **L9** (7.8 mg, 0.010 mmol, 10 mol%). The tube was evacuated and back-filled with argon for three times. Then anhydrous $CHCl_3$ (2.0 mL) was added via syringe and the mixture was stirred at room temperature (20–25 °C) for 12 h. After completion monitored by TLC, the crude product (6/1 dr) was concentrated and purified by flash chromatography on silica gel (acetone/petroleum ether = 1/6) to afford the pure cycloadduct **4c**: 25.8 mg (0.0632 mmol) as a white solid, 63% yield; mp 195–196 °C; $[\alpha]_D^{25}$ = +58.9 (*c* = 0.10 in $CHCl_3$); 99% ee, determined by HPLC analysis (Chiralpak AD-H, *i*-PrOH/*n*-hexane = 40/60, flow rate = 1.0 mL/min, λ = 254 nm), t_R = 8.91 min (minor), t_R = 17.34 min (major); ^{1}H NMR (400 MHz, $CDCl_3$) δ (ppm) 8.06–7.99 (m, 1H), 7.87–7.79 (m, 2H), 7.49–7.32 (m, 4H), 7.29–7.26 (m, 1H), 7.26–7.19 (m, 1H), 6.07 (d, *J* = 5.7 Hz, 1H), 5.85 (d, *J* = 6.5 Hz, 1H), 4.83 (d, *J* = 8.9 Hz, 1H), 3.56 (dd, *J* = 8.6, 6.4 Hz, 1H), 3.12–2.96 (m, 2H), 2.82–2.68 (m, 1H), 2.55–2.42 (m, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm) 205.6, 168.6, 162.0, 136.1, 135.3, 134.0, 131.3, 130.9, 130.3, 129.24, 129.19, 128.6, 127.8, 121.2, 64.8, 64.1, 53.1, 50.0, 29.4; HRMS (ESI-TOF) m/z: $[M + Na]^+$ Calcd for $C_{21}H_{17}{}^{79}BrN_2O_2Na^+$ 431.0366; Found 431.0361; Calcd for $C_{21}H_{17}{}^{81}BrN_2O_2Na^+$ 433.0345; Found 433.0347.

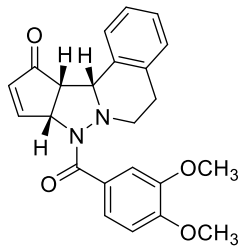


Synthesis of 4d: To an oven-dried 10 mL Schlenk tube equipped with a stir bar were added carbonate **1a** (39.6 mg, 0.200 mmol, 2.0 equiv), C,N-azomethine imine **2f** (26.8 mg, 0.100 mmol, 1.0 equiv), $Pd_2(dba)_3$ (4.6 mg, 0.0050 mmol, 5.0 mol%) and **L9** (7.8 mg, 0.010 mmol, 10 mol%). The tube was evacuated and back-filled with argon for three times. Then anhydrous $CHCl_3$ (2.0 mL) was added via syringe and the mixture was stirred at room temperature (20–25 °C) for 12 h. After completion monitored by TLC, the crude product (>19/1 dr) was concentrated and purified by flash chromatography on silica gel (acetone/petroleum ether = 1/6) to afford the pure cycloadduct **4d**: 33.1 mg (0.0951mmol) as a white solid, 95% yield; mp 67–69 °C; $[\alpha]_D^{25}$ = +16.3 (*c* = 0.16 in $CHCl_3$); 99% ee, determined by HPLC

analysis (Chiralpak AD-H, *i*-PrOH/*n*-hexane = 40/60, flow rate = 1.0 mL/min, λ = 254 nm), t_R = 9.80 min (minor), t_R = 13.18 min (major); ^{1}H NMR (400 MHz, $CDCl_3$) δ (ppm) 8.04–8.01 (m, 1H), 7.87–7.81 (m, 2H), 7.48–7.41 (m, 1H), 7.41–7.34 (m, 2H), 7.11–7.06 (m, 1H), 7.05–6.98 (m, 1H), 6.96–6.88 (m, 1H), 6.07 (d, *J* = 5.6 Hz, 1H), 5.85 (dd, *J* = 6.6, 2.7 Hz, 1H), 4.85 (d, *J* = 8.8 Hz, 1H), 3.56 (dd, *J* = 8.8, 6.5 Hz, 1H), 3.14–2.98 (m, 2H), 2.81–2.66 (m, 1H), 2.54–2.45 (m, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm) 205.5, 168.6, 161.8, 160.9 (d, *J* = 244.3 Hz), 136.1, 134.1, 132.1 (d, *J* = 7.9 Hz), 130.9, 129.9 (d, *J* = 8.0 Hz), 128.7 (d, *J* = 3.1 Hz),128.6, 127.8, 115.1 (d, *J* = 22.1 Hz), 114.8 (d, *J* = 21.6 Hz), 64.9 (d, *J* = 2.0 Hz), 64.1, 53.1, 50.4, 28.9; ^{19}F NMR (376 MHz, $CDCl_3$) δ (ppm) –116.4; HRMS (ESI-TOF) m/z: $[M + Na]^+$ Calcd for $C_{21}H_{17}FN_2O_2Na^+$ 371.1166; Found 371.1163.

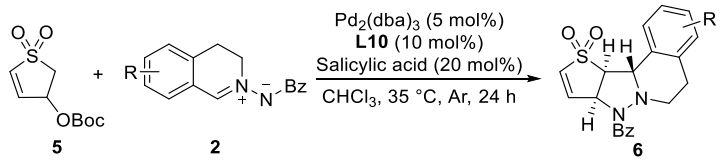


Synthesis of 4e: To an oven-dried 10 mL Schlenk tube equipped with a stir bar were added carbonate **1a** (39.6 mg, 0.200 mmol, 2.0 equiv), C,N-azomethine imine **2h** (30.0 mg, 0.100 mmol, 1.0 equiv), $Pd_2(dba)_3$ (4.6 mg, 0.0050 mmol, 5.0 mol%) and **L9** (7.8 mg, 0.010 mmol, 10 mol%). The tube was evacuated and back-filled with argon for three times. Then anhydrous $CHCl_3$ (2.0 mL) was added via syringe and the mixture was stirred at room temperature (20–25 °C) for 12 h. After completion monitored by TLC, the crude product (>19/1 dr) was concentrated and purified by flash chromatography on silica gel (acetone/petroleum ether = 1/6) to afford the pure cycloadduct **4e**: 36.8 mg (0.0968 mmol) as a white solid, 97% yield; mp 161–163 °C; $[\alpha]_D^{25}$ = +138.0 (*c* = 0.10 in $CHCl_3$); 99% ee, determined by HPLC analysis (Chiralpak AD-H, *i*-PrOH/*n*-hexane = 40/60, flow rate = 1.0 mL/min, λ = 254 nm), t_R = 9.42 min (minor), t_R = 25.22 min (major); ^{1}H NMR (400 MHz, $CDCl_3$) δ (ppm) 8.08–8.04 (m, 1H), 7.94–7.86 (m, 2H), 7.86–7.77 (m, 3H), 7.51–7.40 (m, 4H), 7.40–7.33 (m, 2H), 6.06 (d, *J* = 5.6 Hz, 1H), 5.89 (dd, *J* = 6.7, 2.6 Hz, 1H), 4.97 (d, *J* = 8.8 Hz, 1H), 3.73–3.67 (m, 1H), 3.24–3.18 (m, 2H), 3.14–3.04 (m, 1H), 2.98–2.86 (m, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm) 205.8, 168.5, 162.0, 136.1, 134.2, 132.7, 131.5, 130.9, 129.0, 128.73, 128.71, 127.9, 127.8, 126.5, 126.3, 126.1, 125.9, 122.9, 65.7, 64.4, 53.3, 50.2, 26.1; HRMS (ESI-TOF) m/z: $[M + Na]^+$ Calcd for $C_{25}H_{20}N_2O_2Na^+$ 403.1417; Found 403.1416.



Synthesis of 4f: To an oven-dried 10 mL Schlenk tube equipped with a stir bar were added carbonate **1a** (39.6 mg, 0.200 mmol, 2.0 equiv), C,N-azomethine imine **2l** (31.0 mg, 0.100 mmol, 1.0 equiv), $Pd_2(dba)_3$ (4.6 mg, 0.0050 mmol, 5.0 mol%) and **L9** (7.8 mg, 0.010 mmol, 10 mol%). The tube was evacuated and back-filled with argon for three times. Then anhydrous $CHCl_3$ (2.0 mL) was added via syringe and the mixture was stirred at room temperature (20–25 °C) for 12 h. After completion monitored by TLC, the crude product (10/1 dr) was concentrated and purified by flash chromatography on silica gel (acetone/petroleum ether = 1/6) to afford the pure cycloadduct **4f**: 30.2 mg (0.0774 mmol) as a white solid, 77% yield; mp 214–216 °C; $[\alpha]_D^{25}$ = +15.2 (*c* = 0.15 in $CHCl_3$); 99% ee, determined by HPLC analysis (Chiralpak AD-H, *i*-PrOH/*n*-hexane = 40/60, flow rate = 1.0 mL/min, λ = 254 nm), t_R = 14.80 min (major) t_R = 18.69 min (minor); ^{1}H NMR (400 MHz, $CDCl_3$) δ (ppm) 8.07–8.01 (m, 1H), 7.79–7.73 (m, 1H), 7.64–7.59 (m, 1H), 7.44–7.39 (m, 1H), 7.35–7.28 (m, 1H), 7.25–7.19 (m, 1H), 7.12–7.05 (m, 1H), 6.83 (d, *J* = 8.5 Hz, 1H), 6.05 (d, *J* = 5.6 Hz, 1H), 5.88–5.81 (m, 1H), 4.95 (d, *J* = 8.9 Hz, 1H), 3.91 (s, 3H), 3.89 (s, 3H), 3.57 (dd, *J* = 8.9, 6.5 Hz, 1H), 3.19–3.05 (m, 2H), 2.96–2.83 (m, 1H), 2.63–2.53 (m, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm) 205.9, 166.8, 161.9, 151.4, 148.1, 136.0, 132.9, 130.3, 128.8, 128.4, 127.4, 126.0, 123.0, 112.6, 109.8, 65.2, 64.5, 56.0, 55.9, 53.1, 50.3, 29.6; HRMS (ESI-TOF) m/z: $[M + Na]^+$ Calcd for $C_{23}H_{22}N_2O_4Na^+$ 413.1472; Found 413.1476.

6. Procedure for synthesis of cycloadducts 6

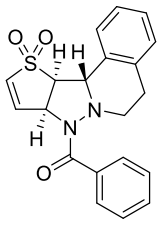


5 2 6

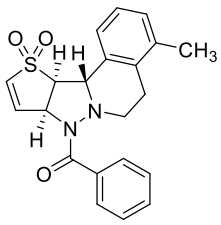
General procedure: To an oven-dried 10 mL Schlenk tube equipped with a stir bar were added carbonate **5** (23.4 mg, 0.100 mmol, 1.0 equiv), C,N-azomethine imine **2** (0.100 mmol, 1.0 equiv), $Pd_2(dba)_3$ (4.6 mg, 0.0050 mmol, 5.0 mol%), **L10** (6.6 mg, 0.010 mmol, 10 mol%) and salicylic acid (2.8 mg, 0.020 mmol, 20 mol%). The tube was evacuated and back-filled with argon for three times. Then anhydrous $CHCl_3$ (1.0 mL) was added via syringe and the mixture was stirred at 35 °C for 24 h. After completion monitored by TLC, the crude product was concentrated and purified by flash chromatography on silica gel (EtOAc/DCM/petroleum ether = 8/60/60) to afford the pure cycloadduct

6 (**6a–6c**).

The corresponding racemates were generally obtained under the catalysis of $Pd(PPh_3)_4$ (2.9 mg, 0.0025 mmol, 10 mol%) and salicylic acid (0.7 mg, 0.005 mmol, 20 mol%) on a 0.025 mmol scale.

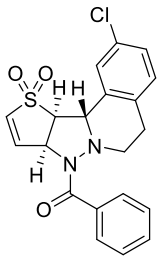


Synthesis of 6a: To an oven-dried 10 mL Schlenk tube equipped with a stir bar were added carbonate **5** (23.4 mg, 0.100 mmol, 1.0 equiv), C,N-azomethine imine **2a** (25.0 mg, 0.100 mmol, 1.0 equiv), $Pd_2(dba)_3$ (4.6 mg, 0.0050 mmol, 5.0 mol%), **L10** (6.6 mg, 0.010 mmol, 10 mol%) and salicylic acid (2.8 mg, 0.020 mmol, 20 mol%). The tube was evacuated and back-filled with argon for three times. Then anhydrous $CHCl_3$ (1.0 mL) was added via syringe and the mixture was stirred at 35 °C for 24 h. After completion monitored by TLC, the crude product (6/1 dr) was concentrated and purified by flash chromatography on silica gel (EtOAc/DCM/petroleum ether = 8/60/60) to afford the pure cycloadduct **6a**: 29.4 mg (0.0803 mmol) as a white solid, 80% yield; mp 130–132 °C; $[\alpha]_D^{25}$ = +185.5 (*c* = 0.06 in $CHCl_3$); 99% ee, determined by HPLC analysis (Chiralpak AD-H, *i*-PrOH/*n*-hexane = 40/60, flow rate = 1.0 mL/min, λ = 254 nm), t_R = 8.57 min (major), t_R = 9.71 min (minor); ^{1}H NMR (400 MHz, $CDCl_3$) δ (ppm) 8.01–7.95 (m, 2H), 7.82–7.77 (m, 1H), 7.53–7.44 (m, 2H), 7.43–7.37 (m, 2H), 7.34–7.28 (m, 1H), 7.26–7.22 (m, 1H), 7.12–7.07 (m, 1H), 6.70–6.64 (m, 1H), 5.75–5.70 (m, 1H), 5.15 (d, *J* = 8.8 Hz, 1H), 4.12–4.06 (m, 1H), 2.95–2.83 (m, 3H), 2.70–2.60 (m, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm) 167.7, 135.6, 133.0, 132.5, 132.2, 132.1, 131.9, 129.2, 128.4, 128.0, 127.9, 127.8, 127.5, 66.9, 63.3, 63.2, 49.6, 29.0; HRMS (ESI-TOF) m/z: $[M + Na]^+$ Calcd for $C_{20}H_{18}N_2O_3SNa^+$ 389.0930; Found 389.0921.



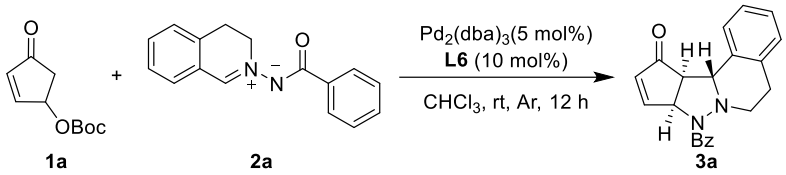
Synthesis of 6b: To an oven-dried 10 mL Schlenk tube equipped with a stir bar were added carbonate **5** (23.4 mg, 0.100 mmol, 1.0 equiv), C,N-azomethine imine **2b** (26.4 mg, 0.100 mmol, 1.0 equiv), $Pd_2(dba)_3$ (4.6 mg, 0.0050 mmol, 5.0 mol%), **L10** (6.6 mg, 0.010 mmol, 10 mol%) and salicylic acid (2.8 mg, 0.020 mmol, 20 mol%). The tube was evacuated and back-filled with argon for three times. Then anhydrous $CHCl_3$ (1.0 mL) was added via syringe and the mixture was stirred at 35 °C for 24 h. After completion monitored by TLC, the crude product (6/1 dr) was concentrated and purified by flash chromatography on silica gel (EtOAc/DCM/petroleum ether = 8/60/60) to afford the pure cycloadduct **6b**: 29.1 mg (0.0766 mmol) as a pale-yellow solid, 77% yield; mp 236–237 °C; $[\alpha]_D^{25}$ = +145.7 (*c* = 0.07 in $CHCl_3$);

98% ee, determined by HPLC analysis (Chiralpak AD-H, *i*-PrOH/*n*-hexane = 40/60, flow rate = 1.0 mL/min, λ = 254 nm), t_R = 8.60 min (minor), t_R = 9.67 min (major); ^{1}H NMR (400 MHz, $CDCl_3$) δ (ppm) 8.01–7.95 (m, 2H), 7.69–7.63 (m, 1H), 7.53–7.43 (m, 2H), 7.42–7.36 (m, 2H), 7.25–7.20 (m, 1H), 7.14–7.09 (m, 1H), 6.67 (dd, *J* = 6.8, 1.6 Hz, 1H), 5.75–5.69 (m, 1H), 5.13 (d, *J* = 8.7 Hz, 1H), 4.15–4.08 (m, 1H), 2.96–2.85 (m, 2H), 2.69–2.60 (m, 2H), 2.19 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm) 167.9, 136.0, 135.5, 133.0, 132.5, 132.0, 131.9, 130.9, 129.3, 129.2, 127.9, 127.3, 125.5, 66.9, 63.5, 63.2, 49.4, 26.5, 19.3; HRMS (ESI-TOF) m/z: $[M + Na]^+$ Calcd for $C_{21}H_{20}N_2O_3SNa^+$ 403.1087; Found 403.1089.



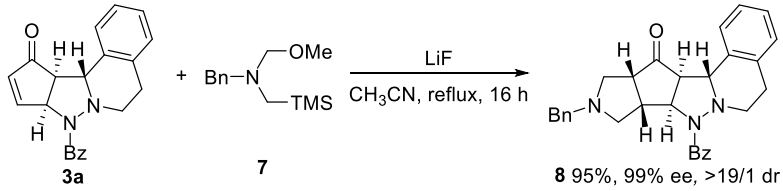
Synthesis of 6c: To an oven-dried 10 mL Schlenk tube equipped with a stir bar were added carbonate **5** (23.4 mg, 0.100 mmol, 1.0 equiv), C,N-azomethine imine **2g** (28.4 mg, 0.100 mmol, 1.0 equiv), $Pd_2(dba)_3$ (4.6 mg, 0.0050 mmol, 5.0 mol%), **L10** (6.6 mg, 0.010 mmol, 10 mol%) and salicylic acid (2.8 mg, 0.020 mmol, 20 mol%). The tube was evacuated and back-filled with argon for three times. Then anhydrous $CHCl_3$ (1.0 mL) was added via syringe and the mixture was stirred at 35 °C for 24 h. After completion monitored by TLC, the crude product (4/1 dr) was concentrated and purified by flash chromatography on silica gel (EtOAc/DCM/petroleum ether = 8/60/60) to afford the pure cycloadduct **6c**: 19.6 mg (0.0490 mmol) as a pale-yellow solid, 49% yield; mp 110–111 °C; $[\alpha]_D^{25}$ = +113.3 (*c* = 0.09 in $CHCl_3$); 99% ee, determined by HPLC analysis (Chiralpak AD-H, *i*-PrOH/*n*-hexane = 40/60, flow rate = 1.0 mL/min, λ = 254 nm), t_R = 8.81 min (major), t_R = 12.20 min (minor); ^{1}H NMR (400 MHz, $CDCl_3$) δ (ppm) 7.99–7.94 (m, 2H), 7.83–7.80 (m, 1H), 7.53–7.47 (m, 1H), 7.47–7.43 (m, 1H), 7.43–7.37 (m, 2H), 7.25–7.20 (m, 1H), 7.05–7.01 (m, 1H), 6.71–6.67 (m, 1H), 5.75–5.70 (m, 1H), 5.08 (d, *J* = 8.8 Hz, 1H), 4.12–4.03 (m, 1H), 2.90–2.75 (m, 3H), 2.67–2.58 (m, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm) 167.7, 135.6, 133.8, 133.2, 132.9, 132.4, 132.0, 130.7, 129.7, 129.2, 128.4, 128.0, 127.7, 66.5, 63.2, 63.0, 49.4, 28.5; HRMS (ESI-TOF) m/z: $[M + Na]^+$ Calcd for $C_{20}H_{17}{}^{35}ClN_2O_3SNa^+$ 423.0541 Found 423.0534; Calcd for $C_{20}H_{17}{}^{37}ClN_2O_3SNa^+$ 425.0511; Found 425.0515.

7. Asymmetric reaction on a 1.0 mmol scale



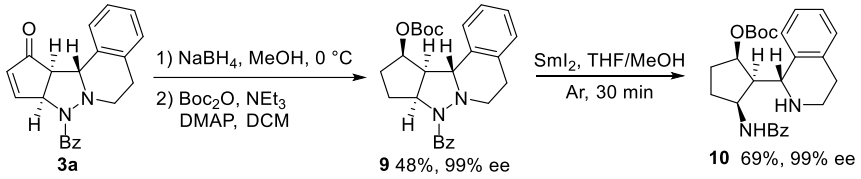
To an oven dried 100 mL Schlenk tube equipped with a stir bar were added C,N-azomethine imine **2a** (250 mg, 1.00 mmol, 1.0 equiv), $Pd_2(dba)_3$ (45.7 mg, 0.0500 mmol, 5.0 mol%) and **L6** (68.6mg, 0.100 mmol, 10 mol%). The tube was evacuated and back-filled with argon for three times. Then distilled and degassed $CHCl_3$ (16 mL) was added via syringe. Then carbonate **1a** (396 mg, 2.00 mmol, 2.0 equiv) in dry $CHCl_3$ (4.0 mL) was added in four potions for 4 h by syringe. The mixture was allowed to stir at room temperature for 12 h. After consumption of **2a** monitored by TLC, the crude product (14/1 dr) was concentrated and purified by flash chromatography on silica gel (EtOAc/petroleum ether = 1/4) to afford the pure cycloadduct **3a**: 272.0 mg (0.8242 mmol), as a white solid, 82% yield, 99% ee.

8. Synthetic transformations



To a solution of **3a** (33.0 mg, 0.100mmol, 1.0 equiv) and precursor **7** (95.0 mg, 0.400 mmol, 4.0 equiv) in dry CH_3CN (0.5 mL) was added LiF (11.7 mg, 0.450 mmol, 4.5 equiv) under argon. The mixture was refluxed for 17 h. After complete consumption of **3a** monitored by TLC (EtOAc/DCM/petroleum ether = 3/60/60), the solvent was evaporated under reduced pressure, and the residue was purified by flash chromatography on silica gel (EtOAc/DCM/petroleum ether = 3/60/60) to afford the desired product **8**: 44.1 mg (0.0952 mmol) as a white solid, 95% yield, >19/1 dr; mp 57–59 °C; $[\alpha]_D^{25}$ = +208.4 (*c* = 0.10 in $CHCl_3$); 99% ee, determined by HPLC analysis (Chiralpak AD-H, *i*-PrOH/*n*-hexane = 40/60, flow rate = 1.0 mL/min, λ = 254 nm), t_R = 7.28 min (major), t_R = 8.73 min (minor); ^{1}H NMR (600 MHz, $CDCl_3$) δ (ppm) 8.09–8.00 (m, 2H), 7.49–7.42 (m, 1H), 7.41–7.32 (m, 3H), 7.32–7.28 (m, 1H), 7.27–7.18 (m, 6H), 7.10–7.04 (m, 1H), 4.79–4.72 (m, 1H), 4.55 (d, *J* = 9.3 Hz, 1H), 3.64–3.52 (m, 2H), 3.44–3.39 (m, 1H), 3.37–3.29 (m, 1H), 3.27–

3.24 (m, 1H), 3.19–3.10 (m, 1H), 3.08–2.98 (m, 1H), 2.93–2.74 (m, 3H), 2.65–2.51 (m, 2H), 2.41–2.31 (m, 1H); ^{13}C NMR (150 MHz, $CDCl_3$) δ (ppm) 218.3, 166.5, 138.5, 134.2, 133.3, 132.5, 131.2, 129.1, 128.5, 128.3, 128.2, 127.8, 127.8, 127.5, 127.0, 126.6, 67.8, 63.9, 61.9, 60.5, 59.1, 58.5, 52.0, 48.8, 45.1, 29.1; HRMS (ESI-TOF) m/z: $[M + H]^+$ Calcd for $C_{30}H_{30}N_3O_2^+$ 464.2333; Found 464.2336.



To a solution of compound **3a** (66 mg, 0.20 mmol, 1.0 equiv) in MeOH (2.0 mL) was added $NaBH_4$ (23 mg, 0.60 mmol, 3.0 equiv) at 0 °C. The mixture was stirred at the same temperature for 0.5 h and then was quenched with saturated aqueous NH_4Cl (2.0 mL). The resulting solution was extracted with EtOAc (5 mL × 2), dried over Na_2SO_4 and concentrated under reduced pressure. The residue was used directly without purification.

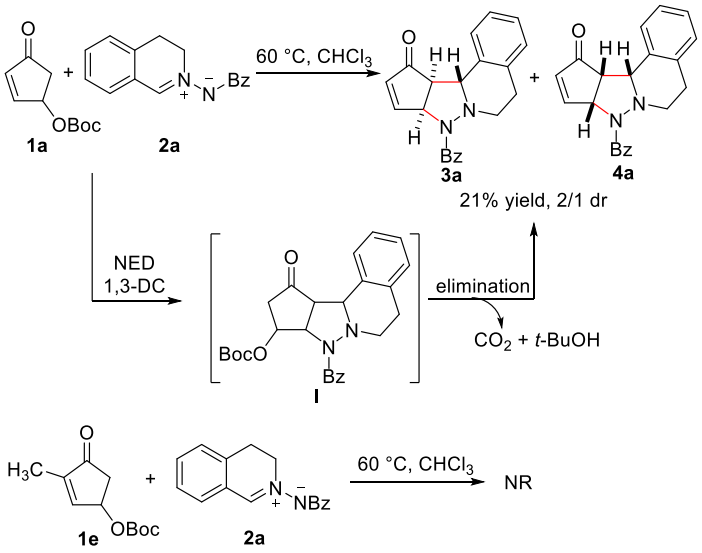
To a solution of the crude alcohol in DCM (1.5 mL) was added Boc_2O (40 μL, 0.18 mmol, 1.2 equiv) followed by triethylamine (25 μL, 0.18 mmol, 1.2 equiv) and DMAP (0.4 mg, 0.003 mmol, 0.02 equiv) at 0 °C. The mixture was stirred at the same temperature for 2.5 h. The reaction was directly and quickly purified by flash chromatography on silica gel (EtOAc/petroleum ether = 1/5) to give product **9**: 34 mg (0.078 mmol) as a white solid, 48% yield; mp 165–166 °C; $[\alpha]_D^{25}$ = +72.0 (*c* = 0.05 in $CHCl_3$); 99% ee, determined by HPLC analysis (Chiralpak AD-H, *i*-PrOH/*n*-hexane = 40/60, flow rate = 1.0 mL/min, λ = 254 nm), t_R = 5.40 min (major), t_R = 12.04 min (minor); ^{1}H NMR (400 MHz, $CDCl_3$) δ (ppm) 8.03–7.94 (m, 2H), 7.46–7.38 (m, 2H), 7.38–7.30 (m, 2H), 7.21–7.12 (m, 2H), 7.08–7.02 (m, 1H), 5.28–5.18 (m, 1H), 4.86 (d, *J* = 9.0 Hz, 1H), 4.79–4.71 (m, 1H), 3.31–3.19 (m, 1H), 3.05–2.93 (m, 1H), 2.88–2.70 (m, 2H), 2.65–2.55 (m, 1H), 2.32–1.99 (m, 4H), 1.54 (s, 9H); ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm) 167.2, 152.9, 135.4, 134.7, 132.9, 130.8, 129.3, 128.3, 127.9, 127.5, 126.8, 126.3, 82.5, 76.3, 62.4, 61.3, 53.0, 48.8, 31.7, 29.4, 27.9, 27.3; HRMS (ESI-TOF) m/z: $[M + H]^+$ Calcd for $C_{26}H_{31}N_2O_4^+$ 435.2278; Found 435.2279.

To a stirred solution of **9** (34 mg, 0.078 mmol, 1.0 equiv) in MeOH (0.8 mL) was added a 0.1 M THF solution of SmI_2 (3.1 mL, 0.31 mmol, 4.0 equiv) at room temperature. After stirring for 10 min at room temperature, the reaction solution was poured into saturated aqueous $NaHCO_3$ and extracted with EtOAc. The organic extracts were washed with brine, dried over Na_2SO_4 and evaporated in

vacuo. The residue was purified by column chromatography on silica gel (MeOH/DCM = 1/120) to give **10**: 24 mg (0.054 mmol) as a yellow solid, 69% yield; mp 127–129 °C; $[\alpha]_D^{25}$ = +17.6 (*c* = 0.13 in $CHCl_3$); 99% ee, determined by HPLC analysis (Chiralpak AD-H, *i*-PrOH/*n*-hexane = 40/60, flow rate = 1.0 mL/min, λ = 254 nm), t_R = 5.40 min (major), t_R = 9.04 min (minor); ^{1}H NMR (400 MHz, $CDCl_3$) δ (ppm) 8.16–8.10 (m, 1H), 7.84–7.77 (m, 2H), 7.54–7.47 (m, 1H), 7.46–7.37 (m, 2H), 7.16–7.06 (m, 2H), 7.02–6.92 (m, 2H), 5.12–5.03 (m, 1H), 4.84–4.73 (m, 1H), 4.33 (d, *J* = 8.3 Hz, 1H), 3.67 (s, 1H), 3.42–3.33 (m, 1H), 3.13–3.04 (m, 1H), 2.92–2.75 (m, 2H), 2.73–2.63 (m, 1H), 2.28–2.15 (m, 1H), 2.09–1.99 (m, 2H), 1.98–1.88 (m, 1H), 1.57 (s, 9H); ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm) 167.0, 152.4, 135.7, 134.7, 134.3, 131.5, 129.6, 128.5, 127.0, 126.9, 126.4, 125.9, 82.7, 80.8, 52.8, 51.0, 50.6, 39.7, 31.5, 31.0, 28.5, 27.8; HRMS (ESI-TOF) m/z: $[M + H]^+$ Calcd for $C_{26}H_{33}N_2O_4^+$ 437.2435; Found 437.2429.

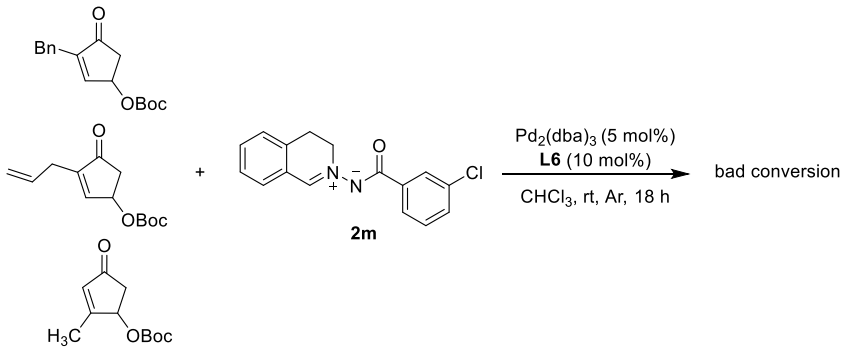
9. Control experiments

Upon heating at 60 °C, the α-unsubstituted 4-OBoc cyclic enone **1a** could undergo 1,3-DC with C,N-cyclic azomethine imine **2a** in 21% yield, whereas the α-methyl substituted cyclic enone **1e** failed to deliver the cycloadduct under the same conditions. This non-catalysed 1,3-DC pathway is probably a NED 1,3-DC to give intermediate **I**, followed by the elimination of BocO group to give racemic **3a** and **4a**. It should be noted that this non-catalysed 1,3-DC pathway showed lower reactivity compared to that with Pd(0) as the catalyst. In addition, α-methyl carbonate **1e** exhibited very low reactivity in the possible NED 1,3-DC reaction with **2a**.

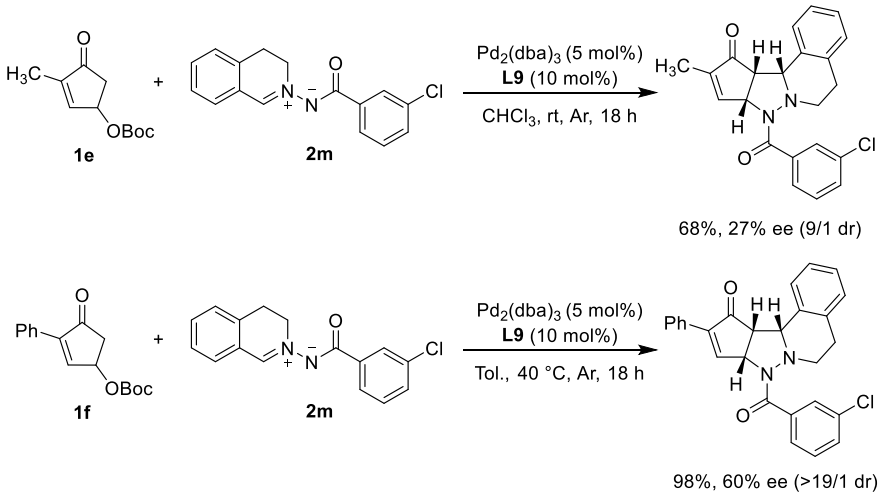


10. Exploration of other substrates

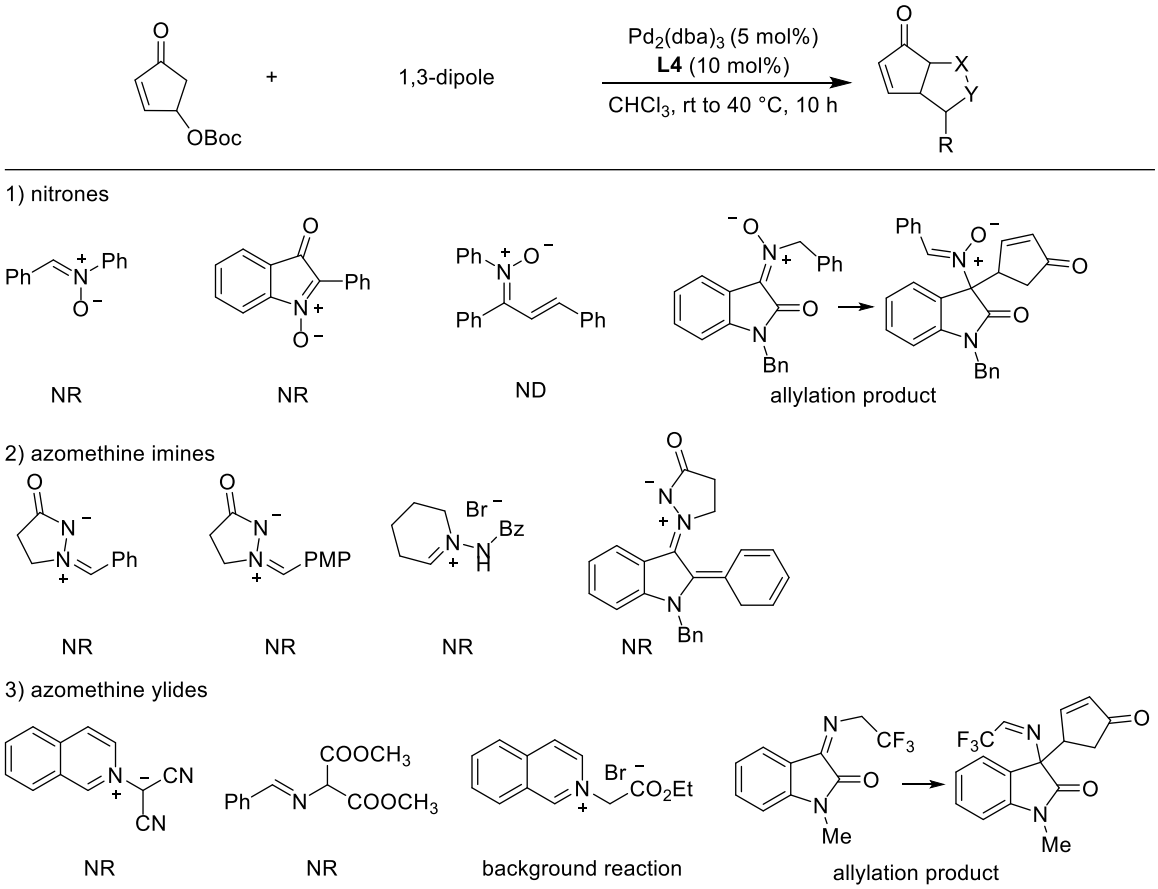
For the substrate scope investigation of the asymmetric IED 1,3-DC for the synthesis of diastereomer **3**, α-benzyl, α-allyl and β-methyl substituted cyclic enones were tested under the catalysis of $Pd_2(dba)_3$/**L6**. However, only bad conversions were observed in the assemblies with 1,3-dipole **2m**.



For the substrate scope investigation of the asymmetric IED 1,3-DC for the synthesis of diastereomer **4**, α-methyl and α-phenyl substituted cyclic enones **1e** and **1f** were tested under the catalysis of $Pd_2(dba)_3$/**L9**. Both reaction delivered the corresponding products in moderate to high yields, albeit with lower enantiocontrol.

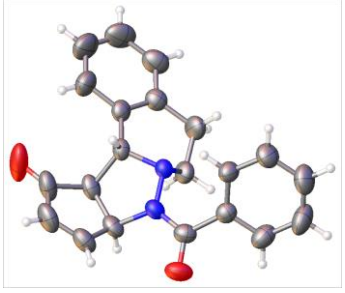


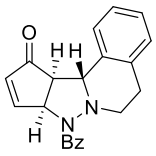
To expand the asymmetric IED 1,3-DC reaction, a number of 1,3-dipoles were further explored. However, most reactions failed, while background reactions (no enantiocontrol) or allylation reactions were observed for some dipoles.



11. Crystal data and structural refinement

Procedure for the recrystallization of 3a: To a 10 mL tube containing **3a** (20 mg) were added EtOAc (0.5 mL) and *n*-hexane (2.0 mL). The mixture was heated until a clear solution was formed, which was kept aside and sealed by a piece of weighing paper with a tiny hole at room temperature to obtain crystals. The crystals were subjected for single crystal XRD to determine the absolute configuration of **3a**. The data were collected by a New Gemini, Dual, Cu at home/near, EosS2 equipped with a Cu radiation source (Kα = 1.54184 Å) at 293.2(3) K. CCDC 2154066 (**3a**) contains the supplementary crystallographic data for this paper. These data can be obtained free of charge via www.ccdc.cam.ac.uk/data_request/cif.





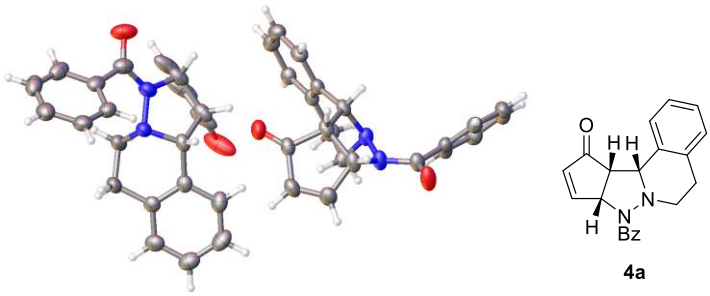
3a

(ellipsoid contour probability 50%)

Identification code	**3a**
Empirical formula	$C_{21}H_{18}N_2O_2$
Formula weight	330.37
Temperature/K	293.2(3)
Crystal system	orthorhombic
Space group	$P2_12_12_1$
a/Å	7.21864(13)
b/Å	10.5120(2)
c/Å	22.0152(4)
α/°	90
β/°	90
γ/°	90
Volume/Å^3	1670.57(6)
Z	4
ρ_{calc}g/cm^3	1.314
μ/mm^{-1}	0.683
F(000)	696.0
Crystal size/mm^3	0.5 × 0.4 × 0.2
Radiation	CuKα (λ = 1.54184)
2Θ range for data collection/°	9.322 to 142.63
Index ranges	$-5 \leq h \leq 8$, $-11 \leq k \leq 12$, $-26 \leq l \leq 26$
Reflections collected	9144
Independent reflections	3192 [R_{int} = 0.0422, R_{sigma} = 0.0364]
Data/restraints/parameters	3192/0/226
Goodness-of-fit on F^2	1.058
Final R indexes [I>=2σ (I)]	R_1 = 0.0654, wR_2 = 0.1571
Final R indexes [all data]	R_1 = 0.0687, wR_2 = 0.1634

Largest diff. peak/hole / e Å^{-3}	0.24/-0.38
Flack parameter	-0.1(2)

Procedure for the recrystallization of 4a: To a 10 mL tube containing **4a** (20 mg) were added EtOAc (0.5 mL) and *n*-hexane (2.0 mL). The mixture was heated until a clear solution was formed, which was kept aside and sealed by a piece of weighing paper with a tiny hole at room temperature to obtain crystals. The crystals were subjected for single crystal XRD to determine the absolute configuration of **4a**. The data were collected by a Bruker APEX-II CCD equipped with a Cu radiation source (Kα = 1.54178 Å) at 170.0 K. CCDC 2154067 (**4a**) contains the supplementary crystallographic data for this paper. These data can be obtained free of charge via www.ccdc.cam.ac.uk/data_request/cif.



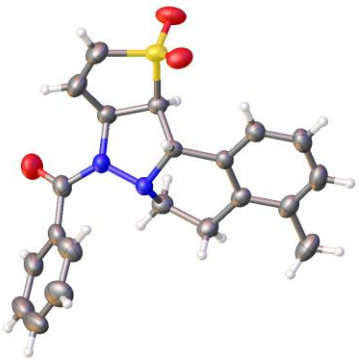
4a

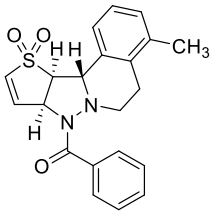
(ellipsoid contour probability 50%)

Identification code	**4a**
Empirical formula	$C_{21}H_{18}N_2O_2$
Formula weight	330.37
Temperature/K	170.0
Crystal system	monoclinic
Space group	$P2_1$
a/Å	8.2297(3)
b/Å	9.0042(3)
c/Å	22.3918(8)
α/°	90
β/°	88.206(2)
γ/°	90

Volume/Å^3	1658.46(10)
Z	4
ρ_{calc}g/cm^3	1.323
μ/mm^{-1}	0.688
F(000)	696.0
Crystal size/mm^3	0.49 × 0.29 × 0.07
Radiation	CuKα (λ = 1.54178)
2Θ range for data collection/°	3.948 to 136.794
Index ranges	-9 ≤ h ≤ 9, -10 ≤ k ≤ 10, -26 ≤ l ≤ 26
Reflections collected	43786
Independent reflections	6055 [R_{int} = 0.0682, R_{sigma} = 0.0342]
Data/restraints/parameters	6055/1/451
Goodness-of-fit on F^2	1.050
Final R indexes [I>=2σ (I)]	R_1 = 0.0351, wR_2 = 0.0850
Final R indexes [all data]	R_1 = 0.0374, wR_2 = 0.0868
Largest diff. peak/hole / e Å^{-3}	0.17/-0.24
Flack parameter	0.05(9)

Procedure for the recrystallization of 6b: To a 10 mL tube containing **6b** (20 mg) were added EtOAc (0.4 mL) and *n*-hexane (2.0 mL). The mixture was heated until a clear solution was formed, which was kept aside and sealed by a piece of weighing paper with a tiny hole at room temperature to obtain crystals. The crystals were subjected for single crystal XRD to determine the absolute configuration of **6b**. The data were collected by a Bruker APEX-II CCD equipped with a Mo radiation source (Kα = 0.71073 Å) at 297.0 K. CCDC 2154068 (**6b**) contains the supplementary crystallographic data for this paper. These data can be obtained free of charge via www.ccdc.cam.ac.uk/data_request/cif.





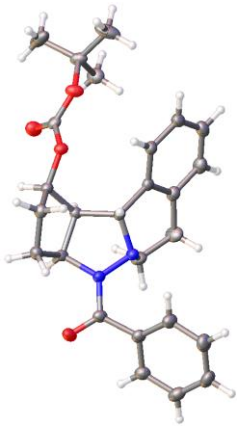
6b

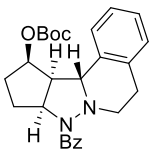
(ellipsoid contour probability 50%)

Identification code	**6b**
Empirical formula	$C_{21}H_{20}N_2O_3S$
Formula weight	380.45
Temperature/K	297.0
Crystal system	monoclinic
Space group	$P2_1$
a/Å	10.1467(5)
b/Å	6.1824(2)
c/Å	15.3256(6)
α/°	90
β/°	106.402(2)
γ/°	90
Volume/Å^3	922.26(7)
Z	2
ρ_{calc}g/cm^3	1.370
μ/mm^{-1}	0.200
F(000)	400.0
Crystal size/mm^3	0.43 × 0.29 × 0.26
Radiation	MoKα (λ = 0.71073)
2Θ range for data collection/°	4.184 to 55.084
Index ranges	-13 ≤ h ≤ 13, -8 ≤ k ≤ 8, -19 ≤ l ≤ 19

Reflections collected	31963
Independent reflections	4245 [R_{int} = 0.0714, R_{sigma} = 0.0463]
Data/restraints/parameters	4245/1/245
Goodness-of-fit on F^2	1.034
Final R indexes [I>=2σ (I)]	R_1 = 0.0350, wR_2 = 0.0802
Final R indexes [all data]	R_1 = 0.0467, wR_2 = 0.0851
Largest diff. peak/hole / e $Å^{-3}$	0.14/-0.28
Flack parameter	-0.02(4)

Procedure for the recrystallization of 9: To a 10 mL tube containing **9** (20 mg) were added EtOAc (0.4 mL) and *n*-hexane (2.0 mL). The mixture was heated until a clear solution was formed, which was kept aside and sealed by a piece of weighing paper with a tiny hole at room temperature to obtain crystals. The crystals were subjected for single crystal XRD to determine the absolute configuration of **9**. The data were collected by a Bruker APEX-II CCD equipped with a Cu radiation source (Kα = 1.54178 Å) at 150.0 K. CCDC 2154069 (**9**) contains the supplementary crystallographic data for this paper. These data can be obtained free of charge via www.ccdc.cam.ac.uk/data_request/cif.





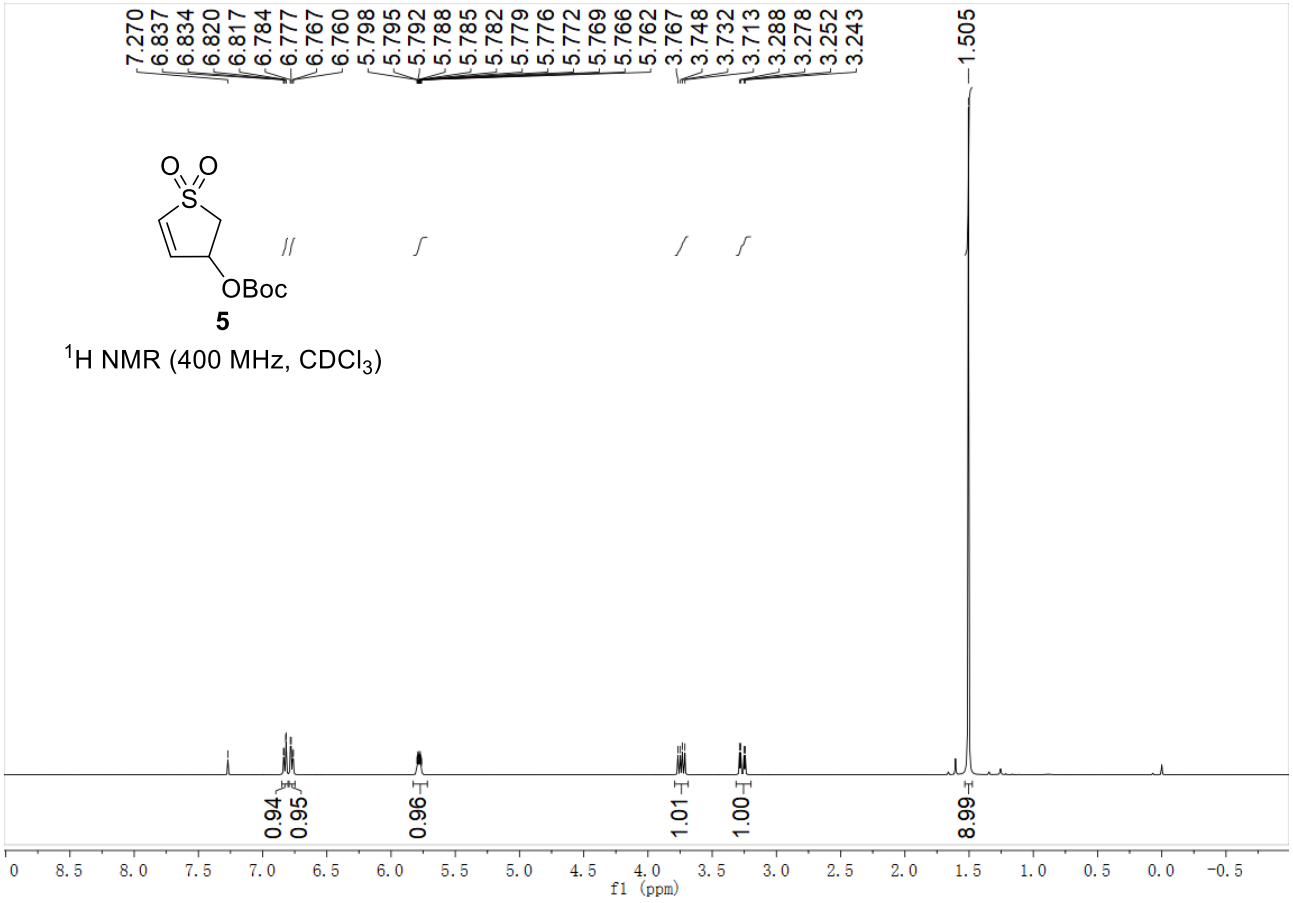
9

(ellipsoid contour probability 50%)

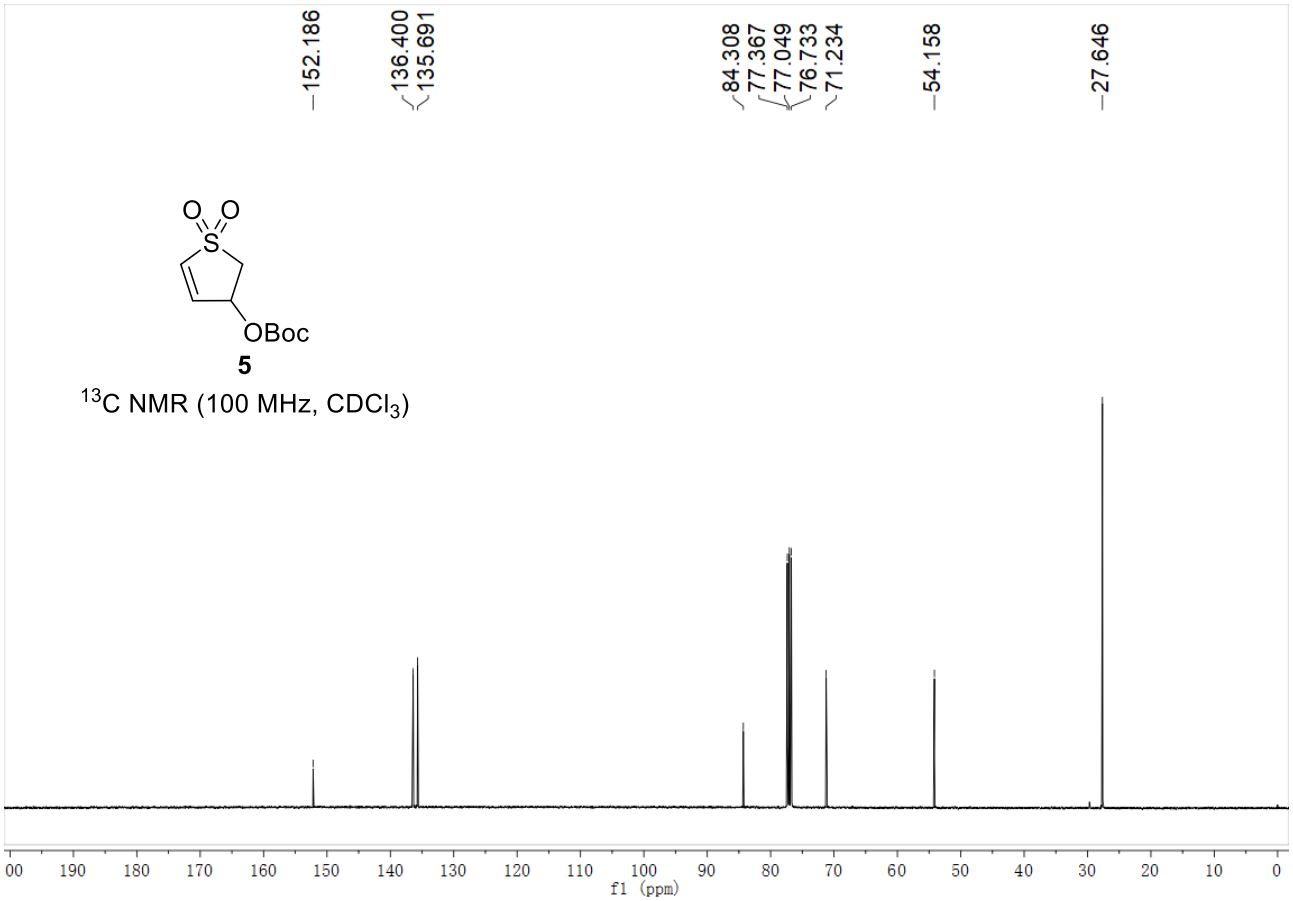
Identification code	**9**
Empirical formula	$C_{26}H_{30}N_2O_4$
Formula weight	434.52

Temperature/K	150.0
Crystal system	monoclinic
Space group	$P2_1$
a/Å	9.2049(5)
b/Å	9.6660(5)
c/Å	12.7809(6)
α/°	90
β/°	96.970(2)
γ/°	90
Volume/Å^3	1128.77(10)
Z	2
ρ_{calc}g/cm^3	1.278
μ/mm^{-1}	0.694
F(000)	464.0
Crystal size/mm^3	0.42 × 0.35 × 0.16
Radiation	CuKα (λ = 1.54178)
2Θ range for data collection/°	9.68 to 137.482
Index ranges	$-11 \leq h \leq 11$, $-11 \leq k \leq 11$, $-15 \leq l \leq 15$
Reflections collected	22485
Independent reflections	4155 [R_{int} = 0.0679, R_{sigma} = 0.0431]
Data/restraints/parameters	4155/1/292
Goodness-of-fit on F^2	1.089
Final R indexes [I>=2σ (I)]	R_1 = 0.0401, wR_2 = 0.0981
Final R indexes [all data]	R_1 = 0.0403, wR_2 = 0.0983
Largest diff. peak/hole / e Å^{-3}	0.20/-0.46
Flack parameter	-0.10(7)

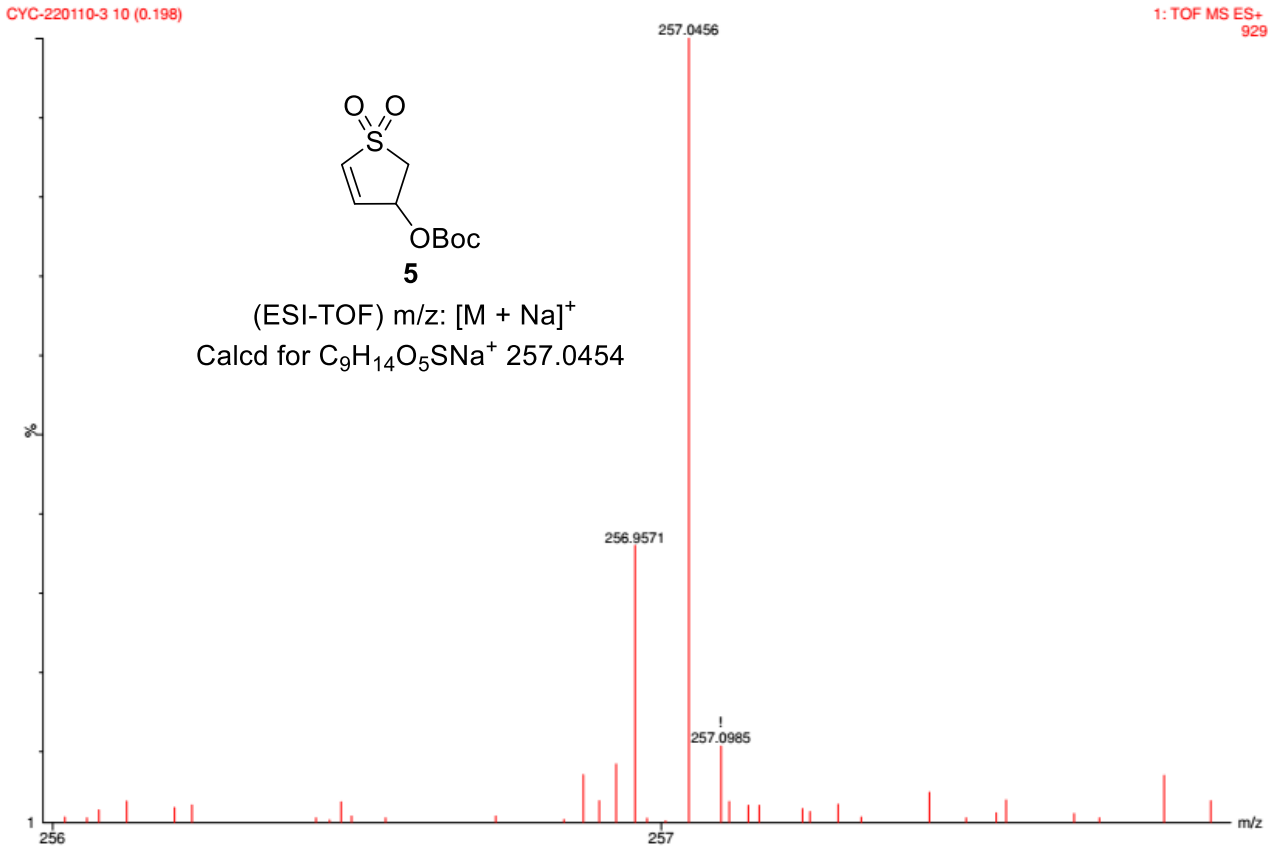
12. NMR, HRMS spectra and HPLC chromatograms

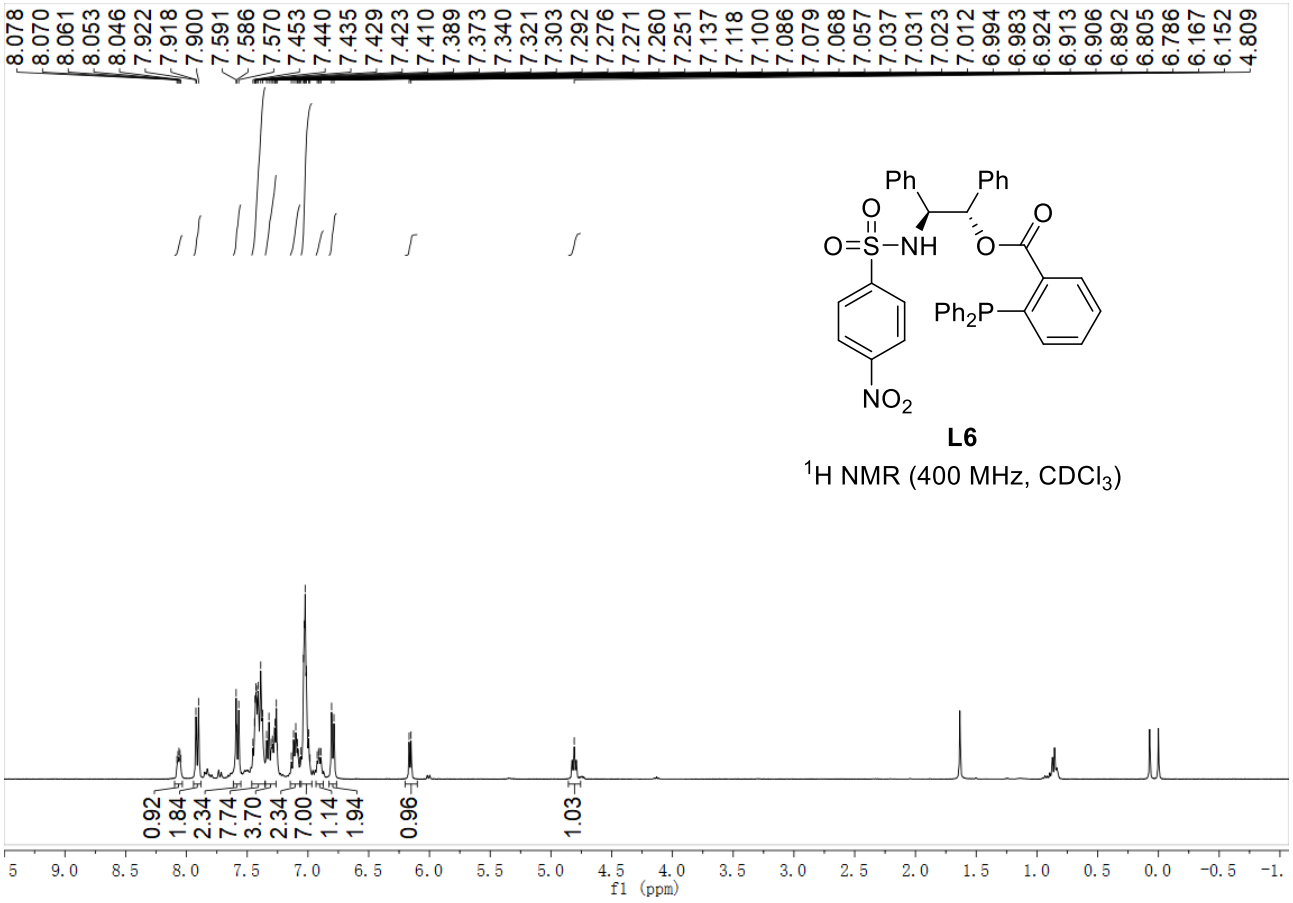


^{1}H NMR (400 MHz, $CDCl_3$)



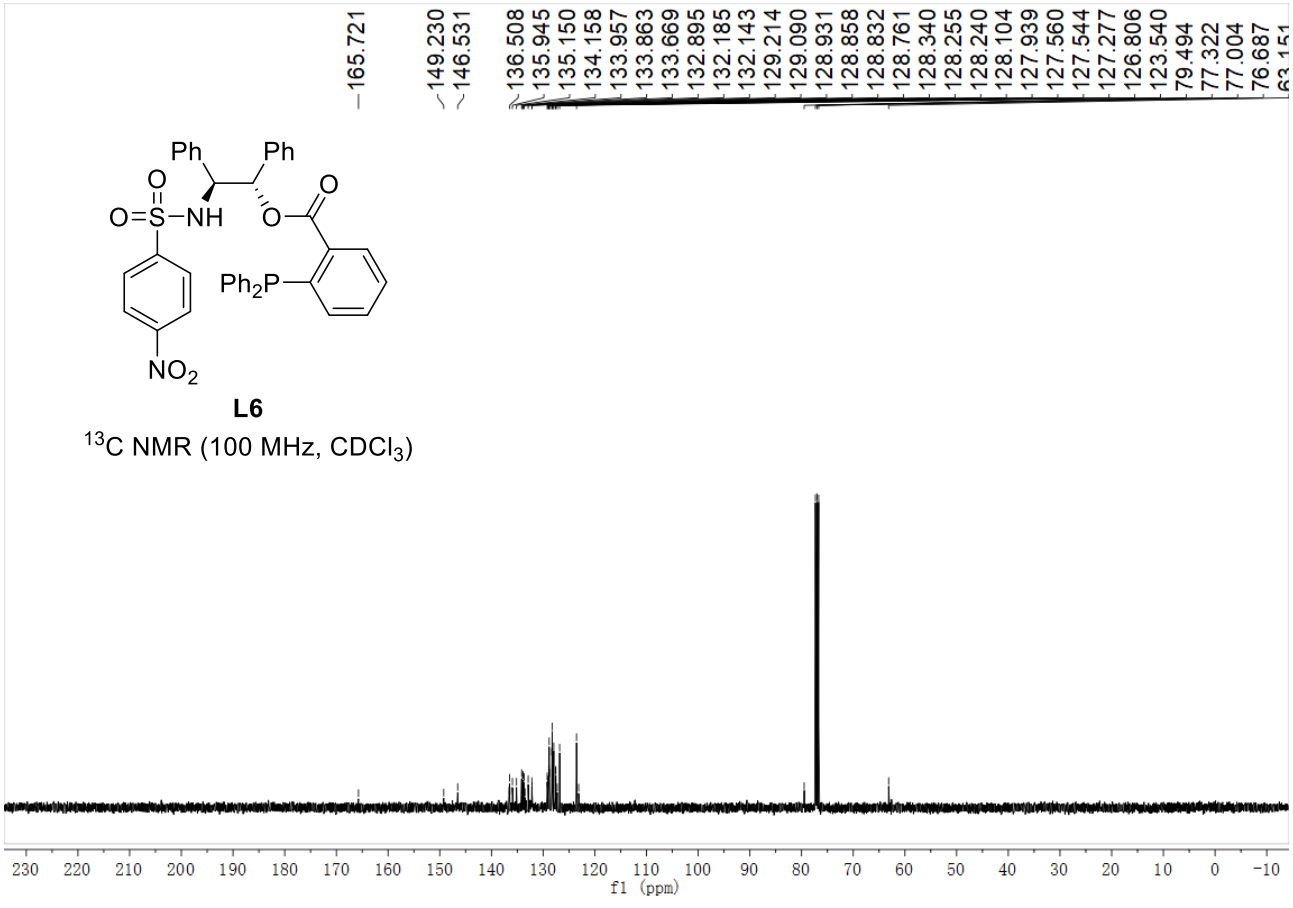
^{13}C NMR (100 MHz, $CDCl_3$)


CYC-220110-3 10 (0.198)
1: TOF MS ES+
929
257.0456
256.9571
257.0985
%
1
256
257
m/z
OBoc
5
(ESI-TOF) m/z: [M + Na]+
Calcd for C9H14O5SNa+ 257.0454



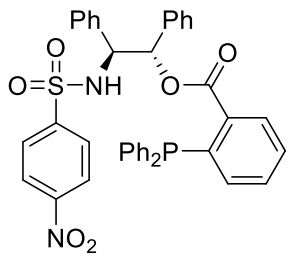
L6

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



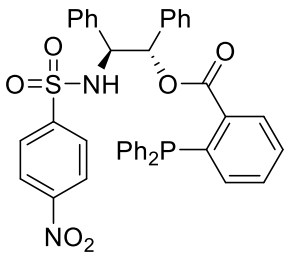
L6

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



L6

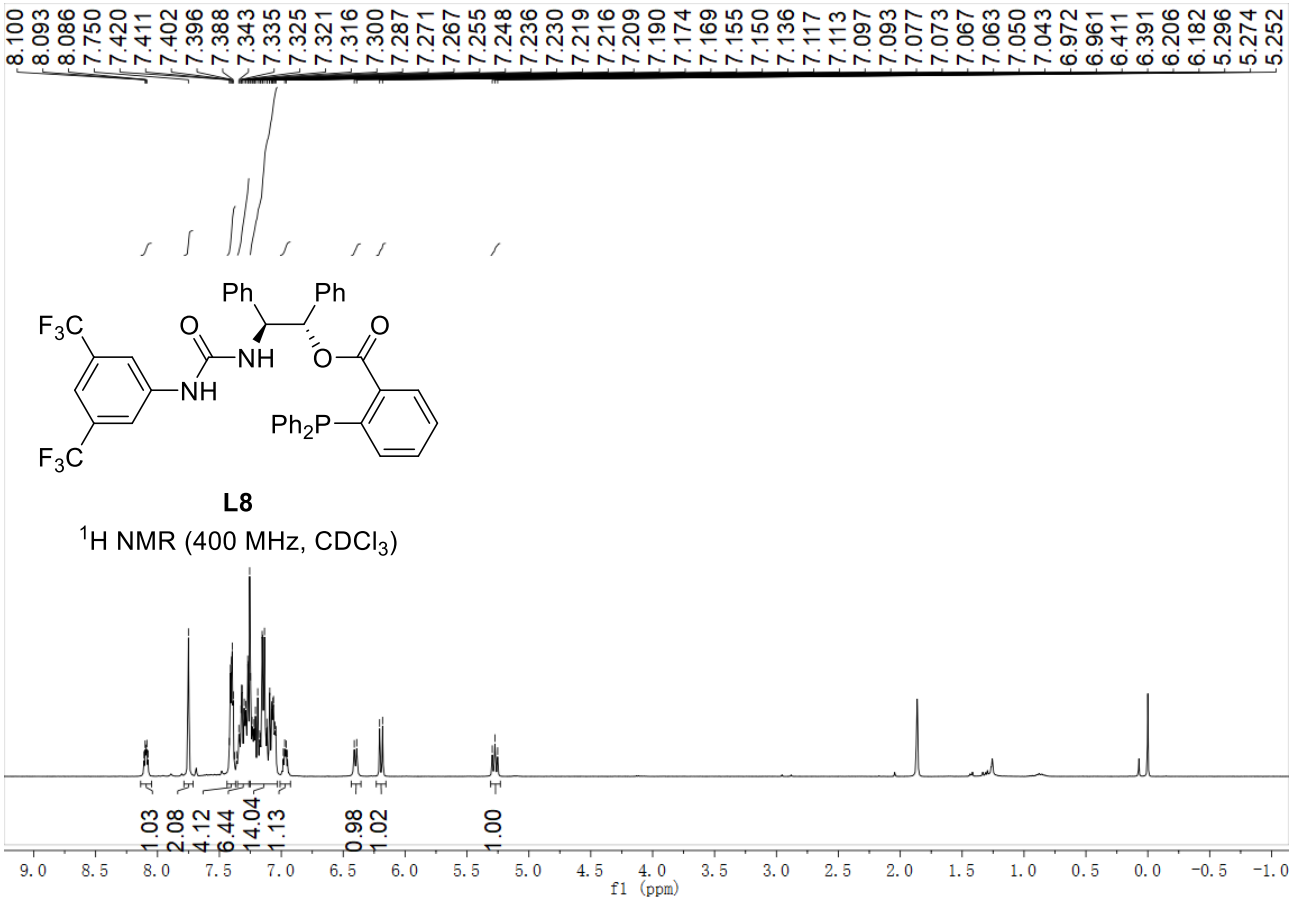
^{31}P NMR (162 MHz, $CDCl_3$)



L6

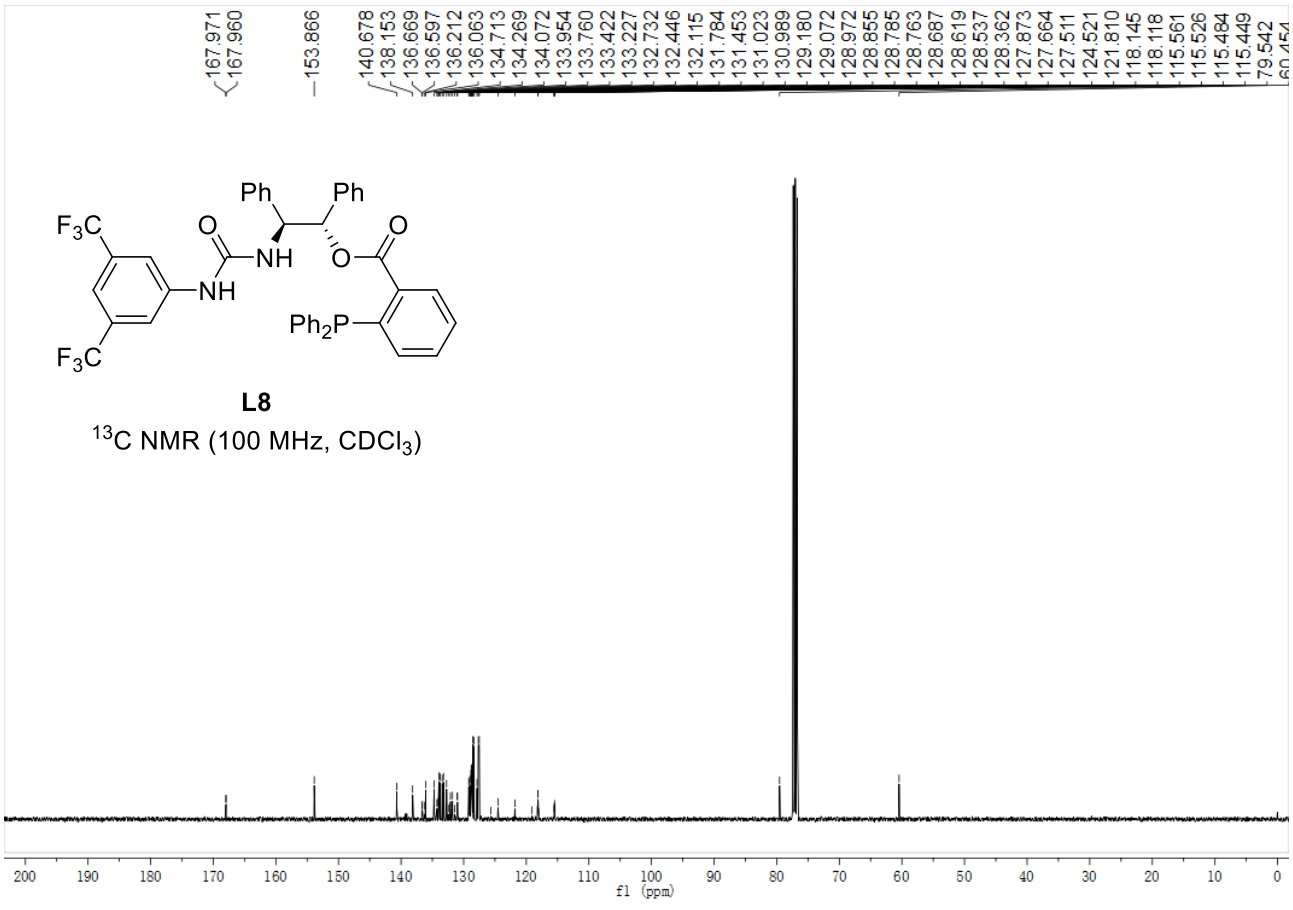
(ESI-TOF) m/z: $[M + H]^+$

Calcd for $C_{39}H_{32}N_2O_6PS^+$ 687.1713



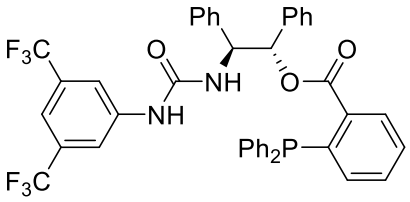
L8

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



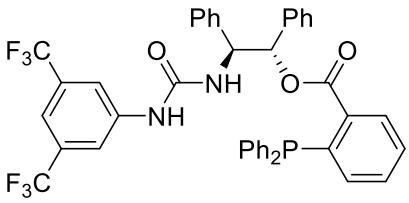
L8

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



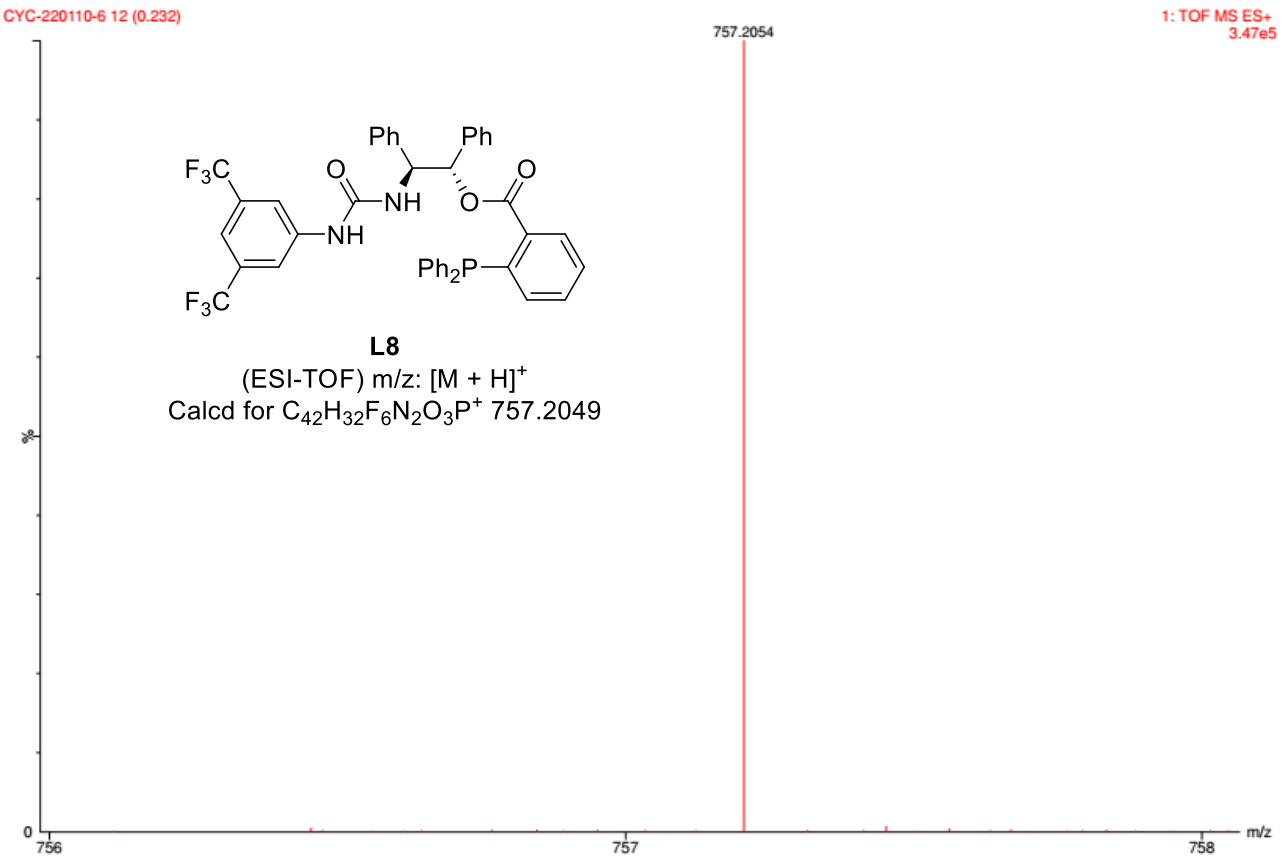
L8

^{31}P NMR (162 MHz, $CDCl_3$)



L8

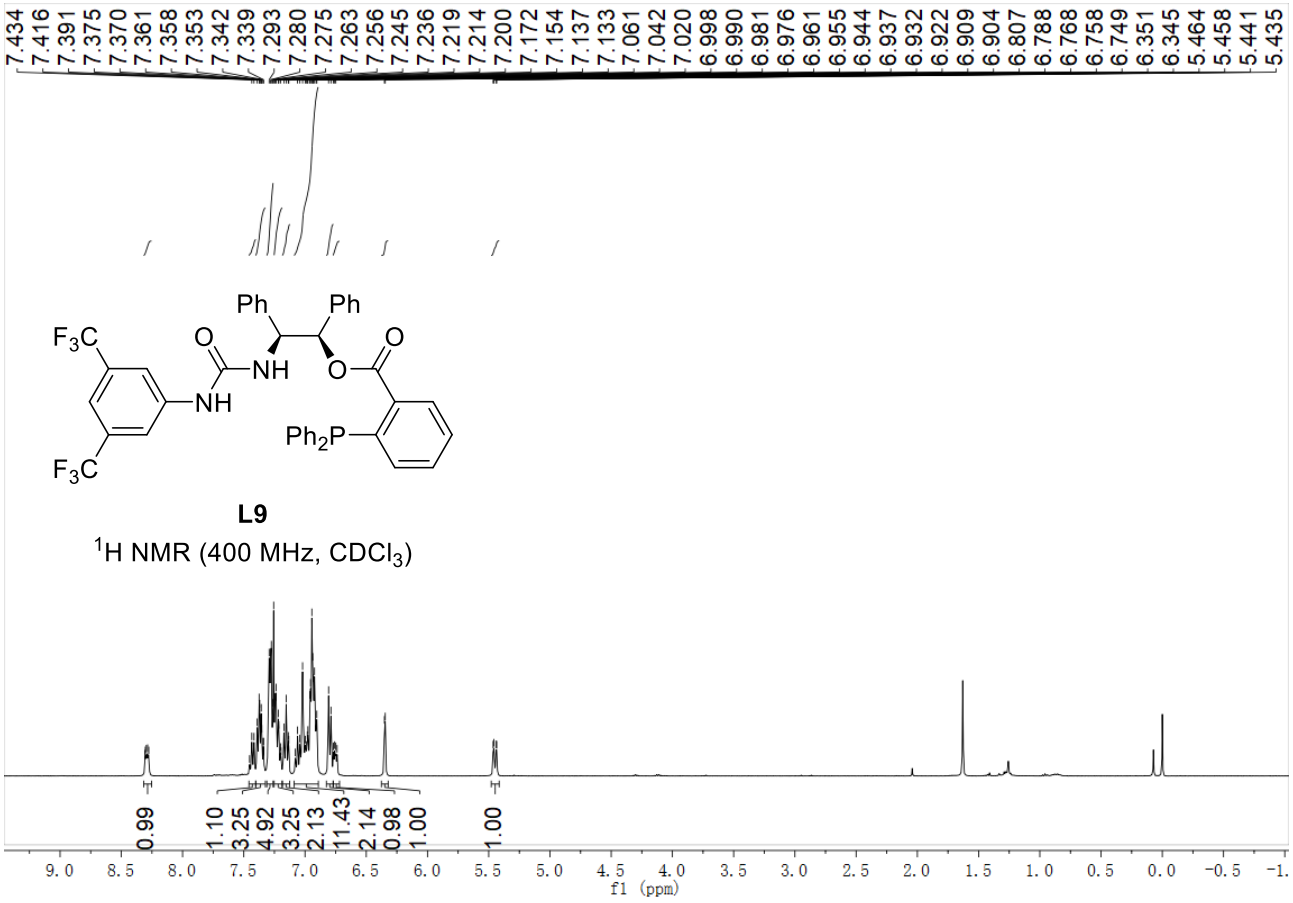
^{19}F NMR (376 MHz, $CDCl_3$)



L8

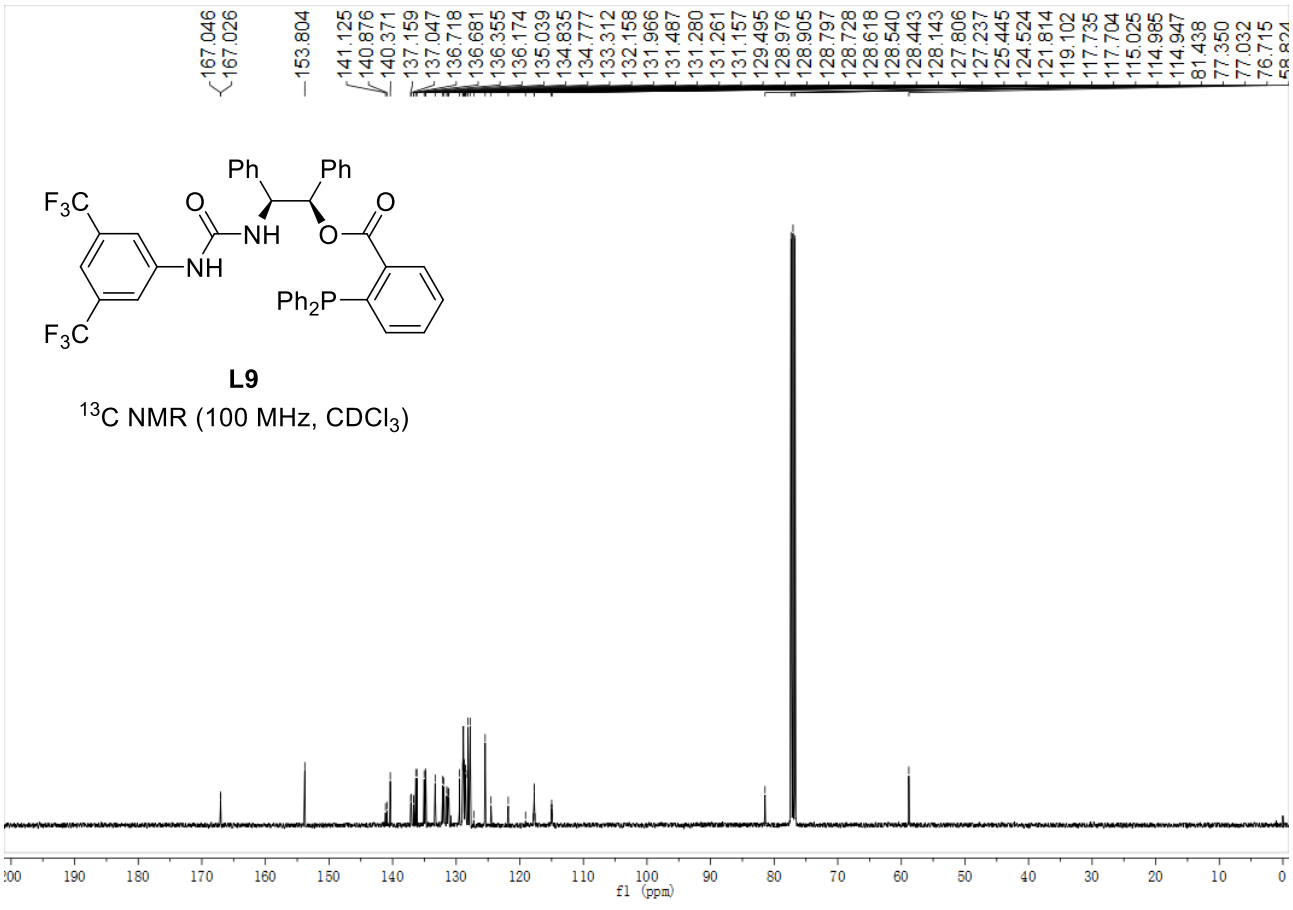
(ESI-TOF) m/z: $[M + H]^+$

Calcd for $C_{42}H_{32}F_6N_2O_3P^+$ 757.2049



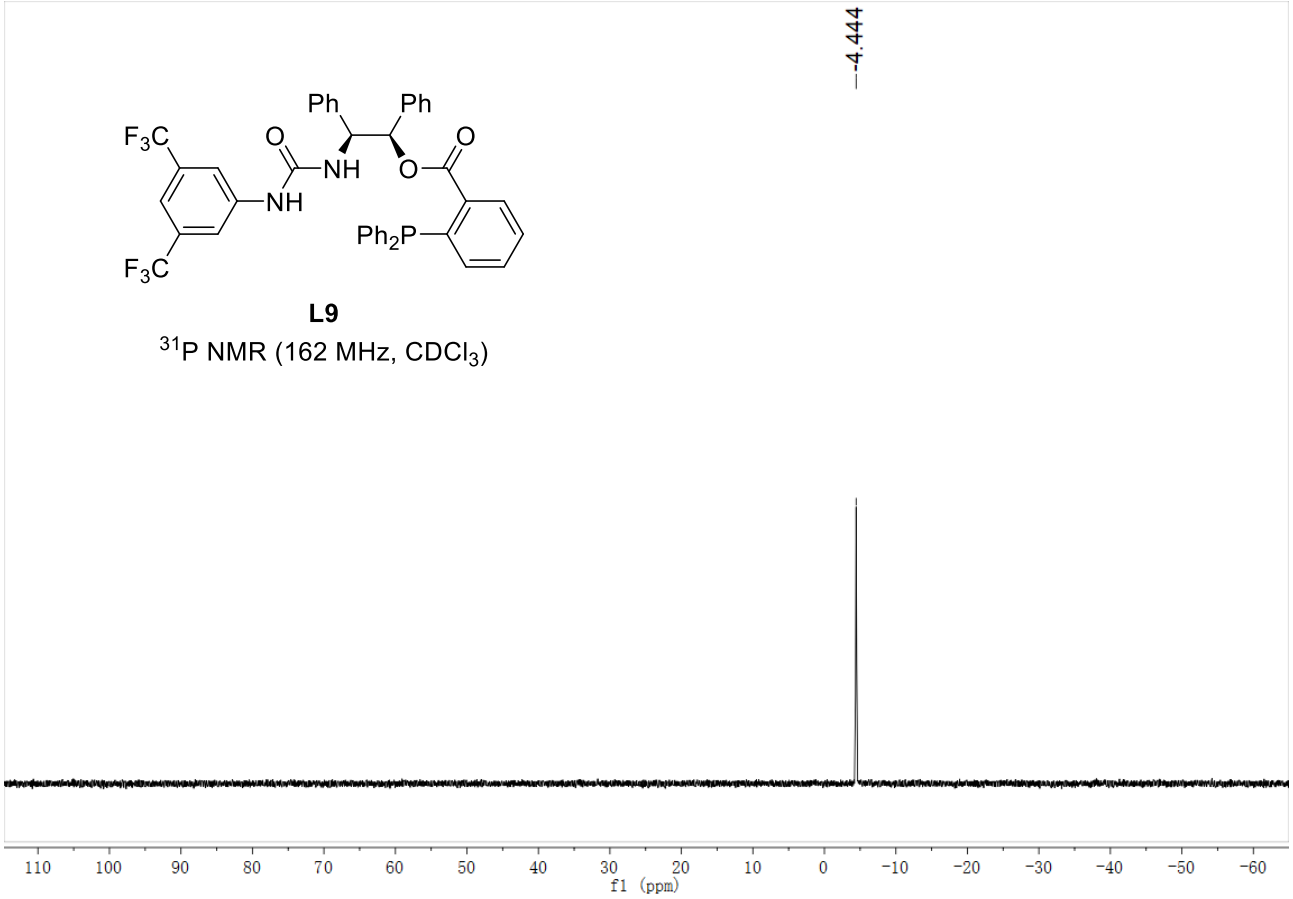
L9

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



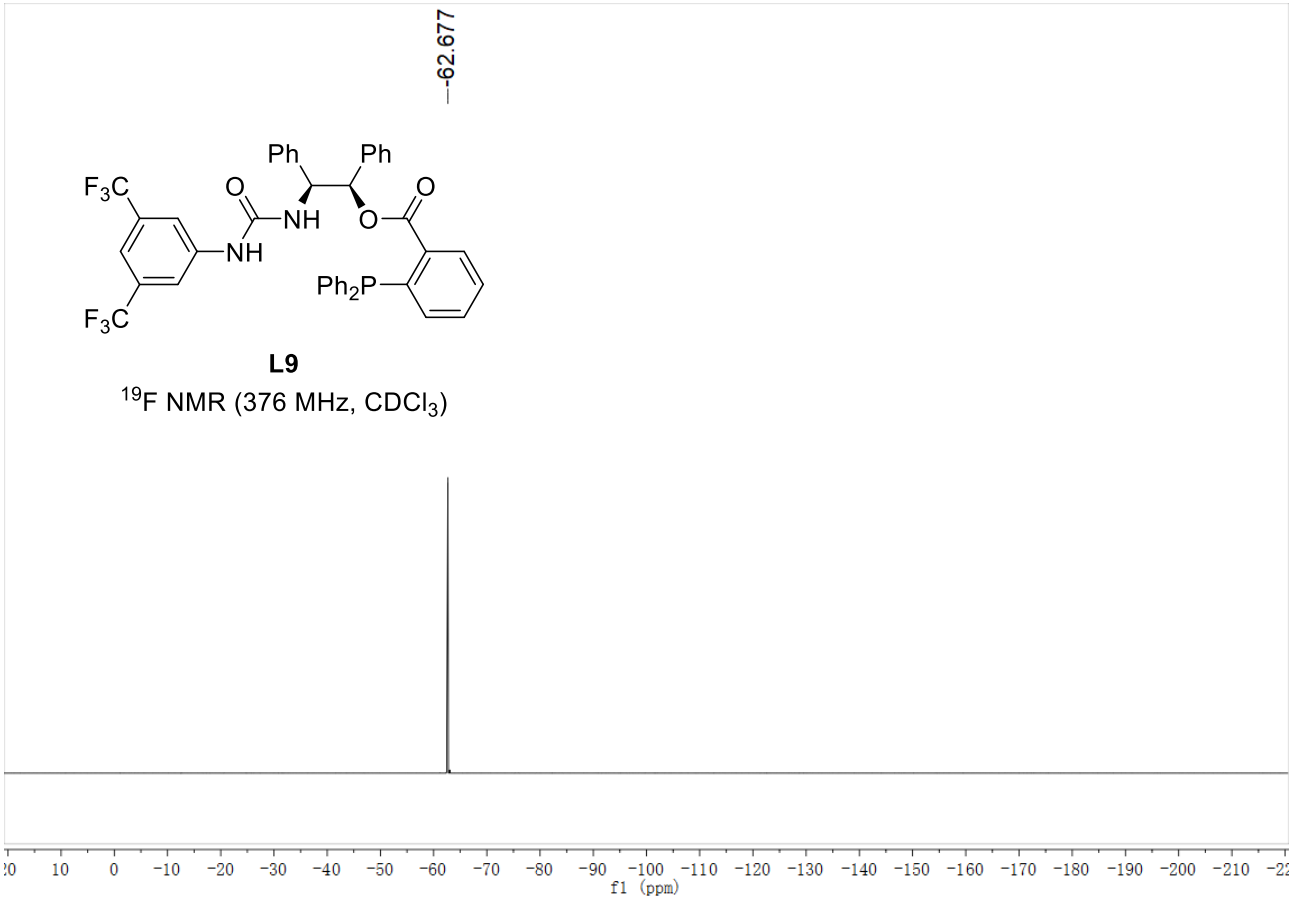
L9

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



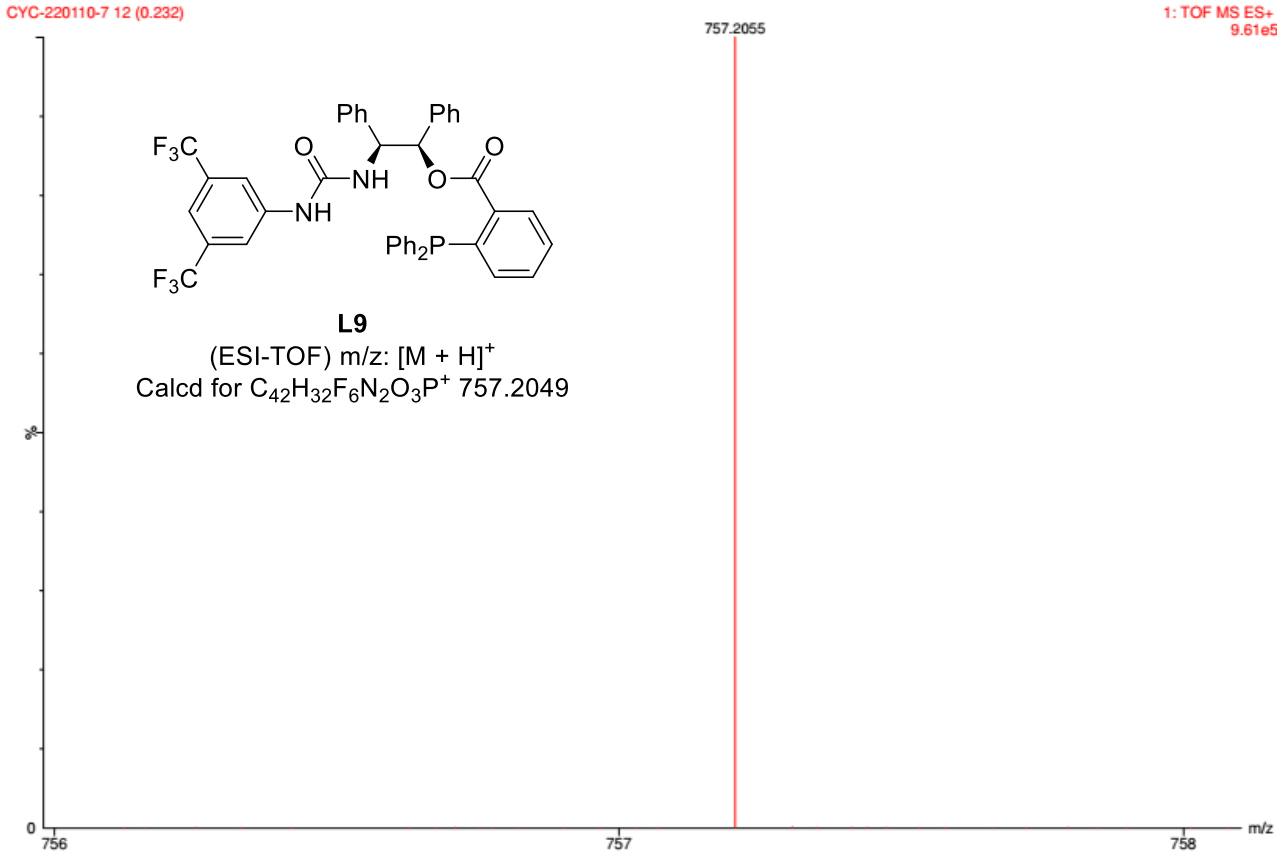
L9

^{31}P NMR (162 MHz, $CDCl_3$)



L9

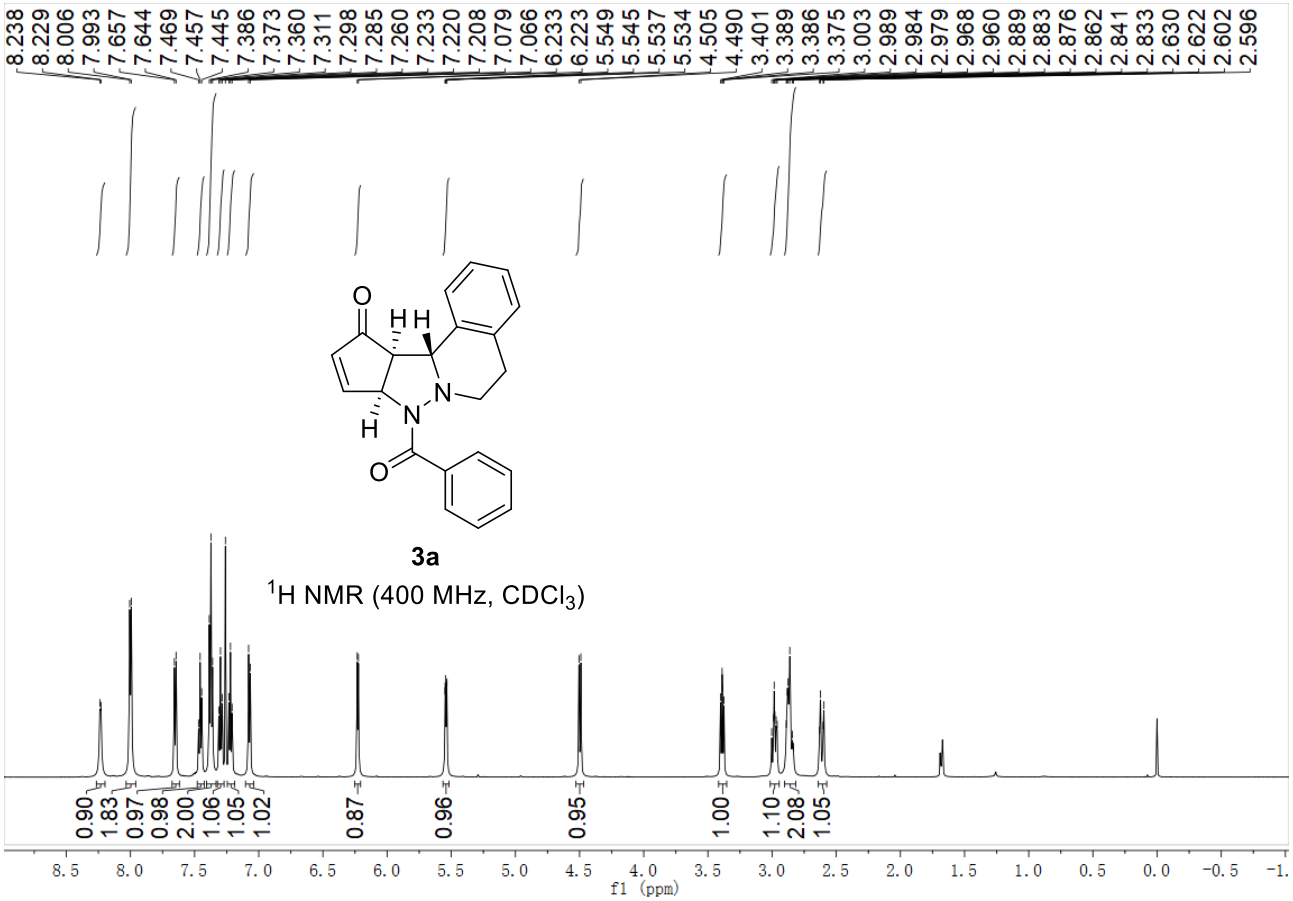
^{19}F NMR (376 MHz, $CDCl_3$)



L9

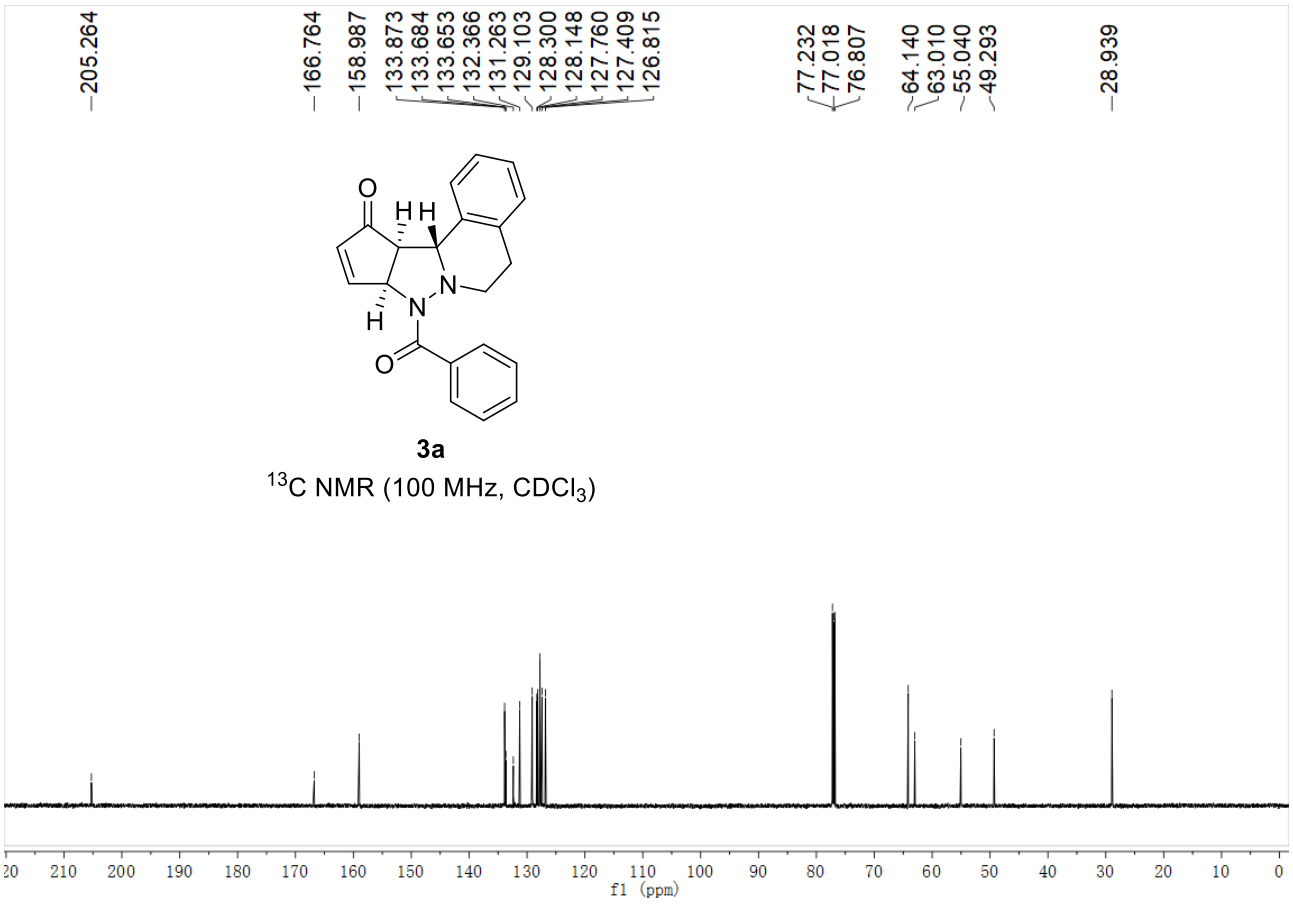
(ESI-TOF) m/z: $[M + H]^+$

Calcd for $C_{42}H_{32}F_6N_2O_3P^+$ 757.2049



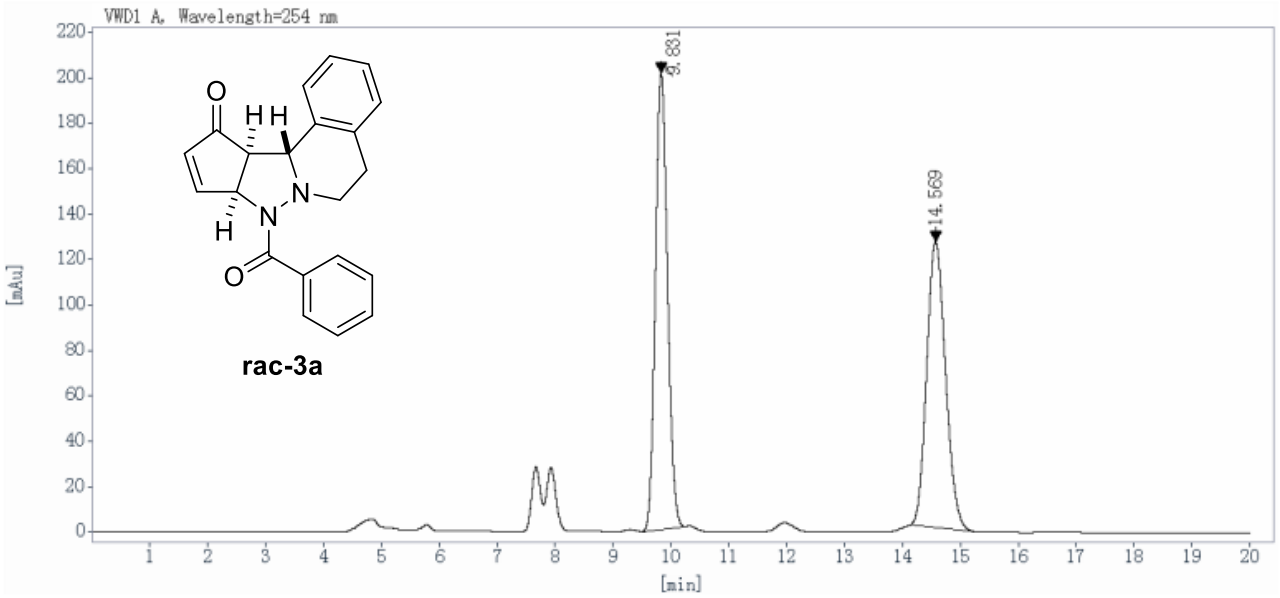
3a

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

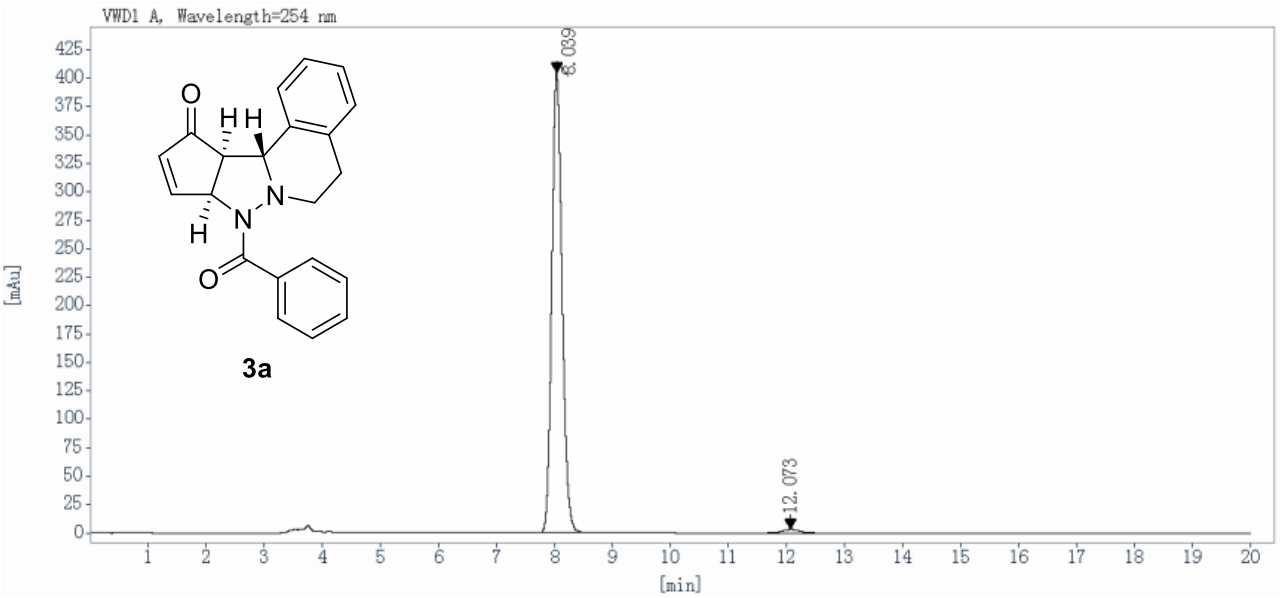


3a

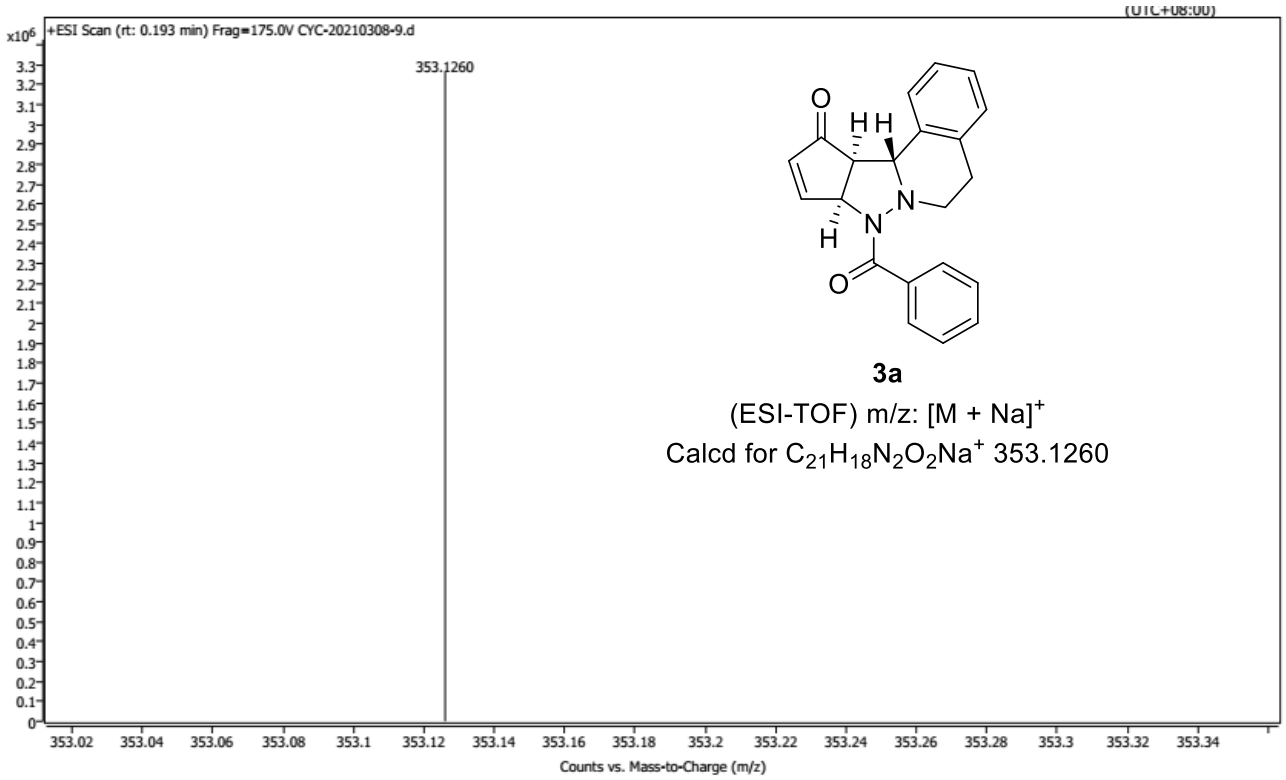
^{13}C NMR (100 MHz, $CDCl_3$)

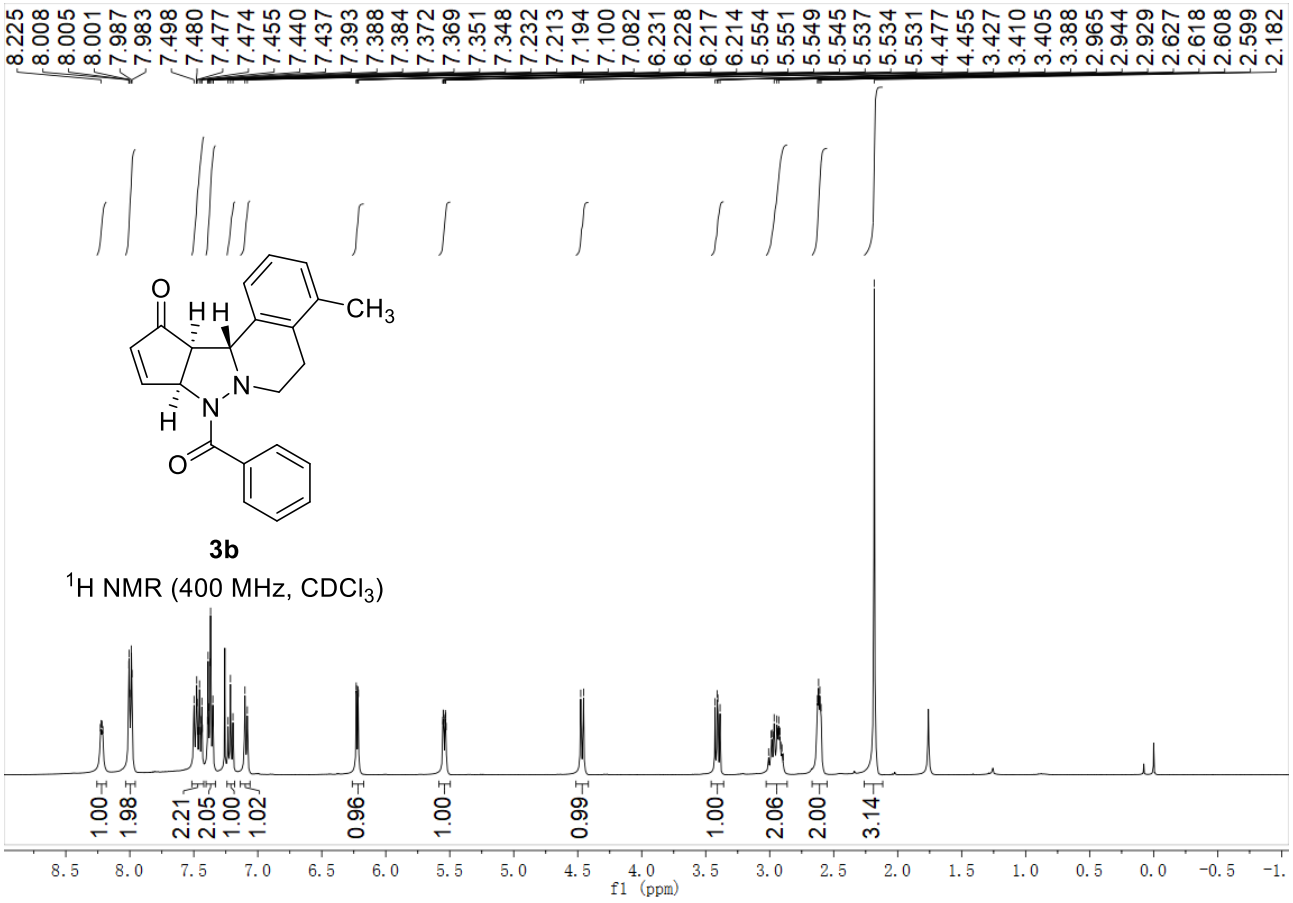


Ret Time [min]	Peak Type	Width [min]	Height [mAU]	Area [mAU*s]	Area [%]
9.831	BB	0.22	200.9469	2904.2739	50.5438
14.569	BBA	0.35	125.6884	2841.7766	49.4562
			Totals:	5746.0505	100.0000



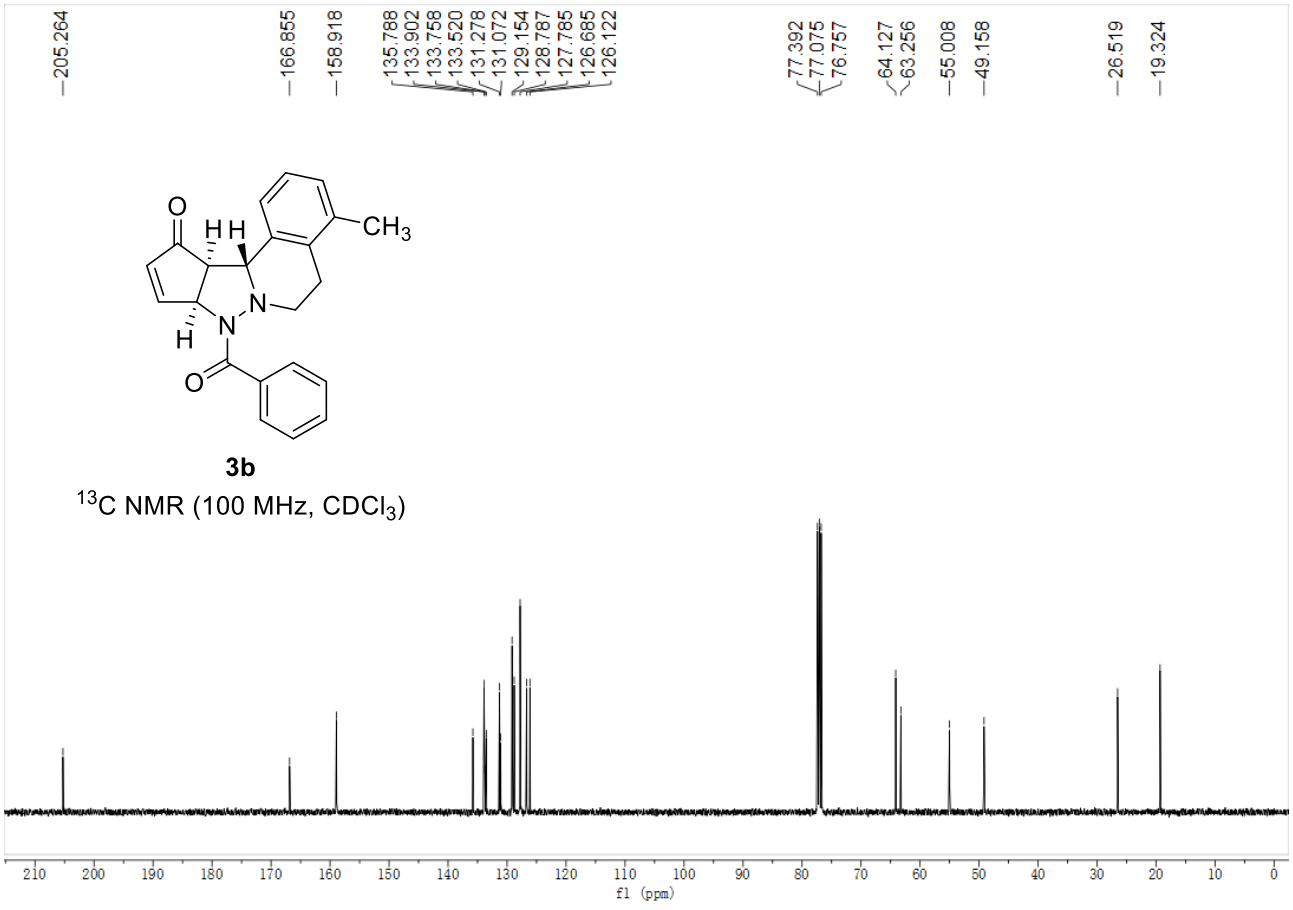
Ret Time [min]	Peak Type	Width [min]	Height [mAU]	Area [mAU*s]	Area [%]
8.039	BBA	0.19	404.8367	4976.7207	98.7290
12.073	BB	0.33	2.9987	64.0706	1.2710
			Totals:	5040.7913	100.0000


(UTC+08:00)
+ESI Scan (rt: 0.193 min) Frag=175.0V CYC-20210308-9.d
x10^6
353.1260
O
H H
N
N
H
O
3a
(ESI-TOF) m/z: [M + Na]+
Calcd for C21H18N2O2Na+ 353.1260
Counts vs. Mass-to-Charge (m/z)



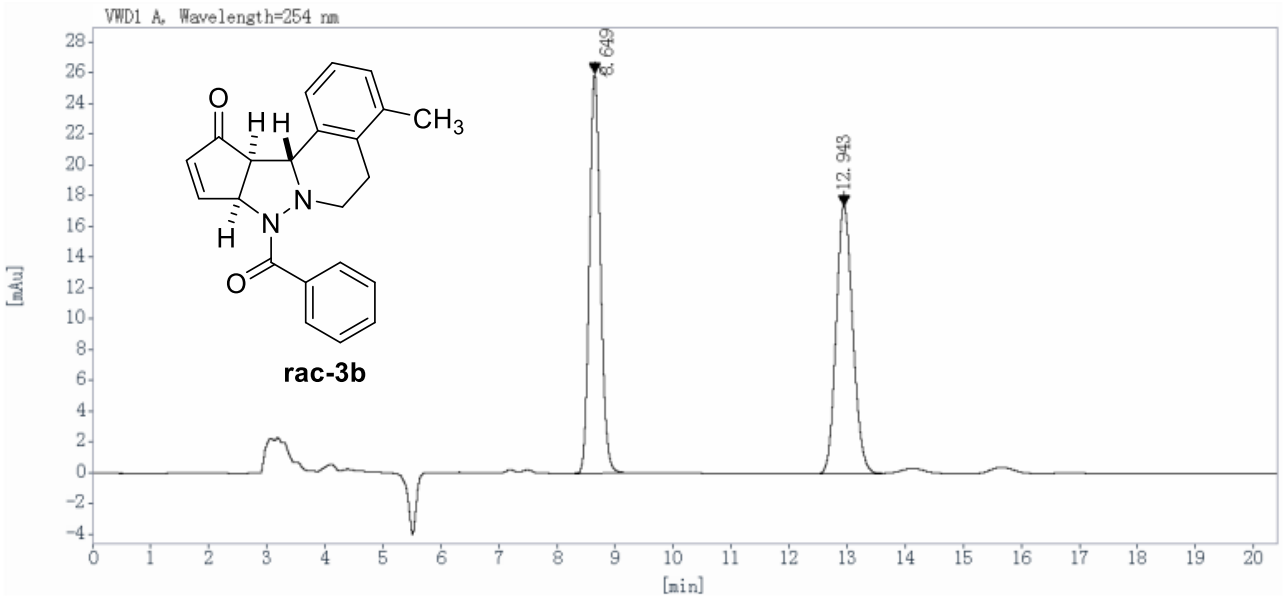
3b

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

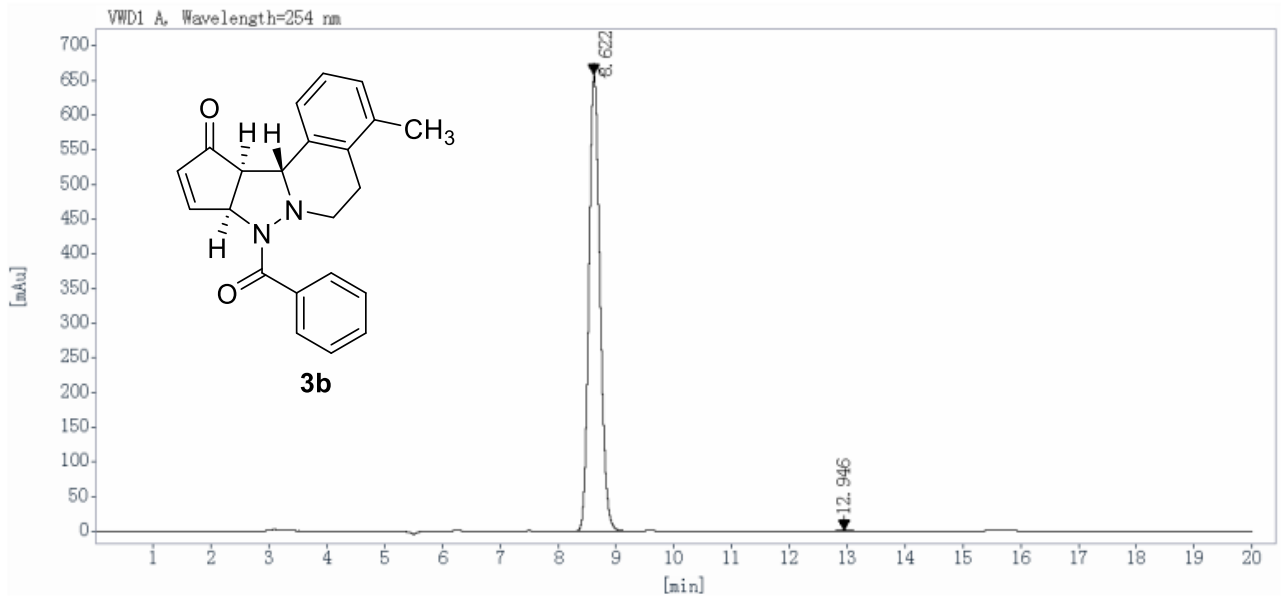


3b

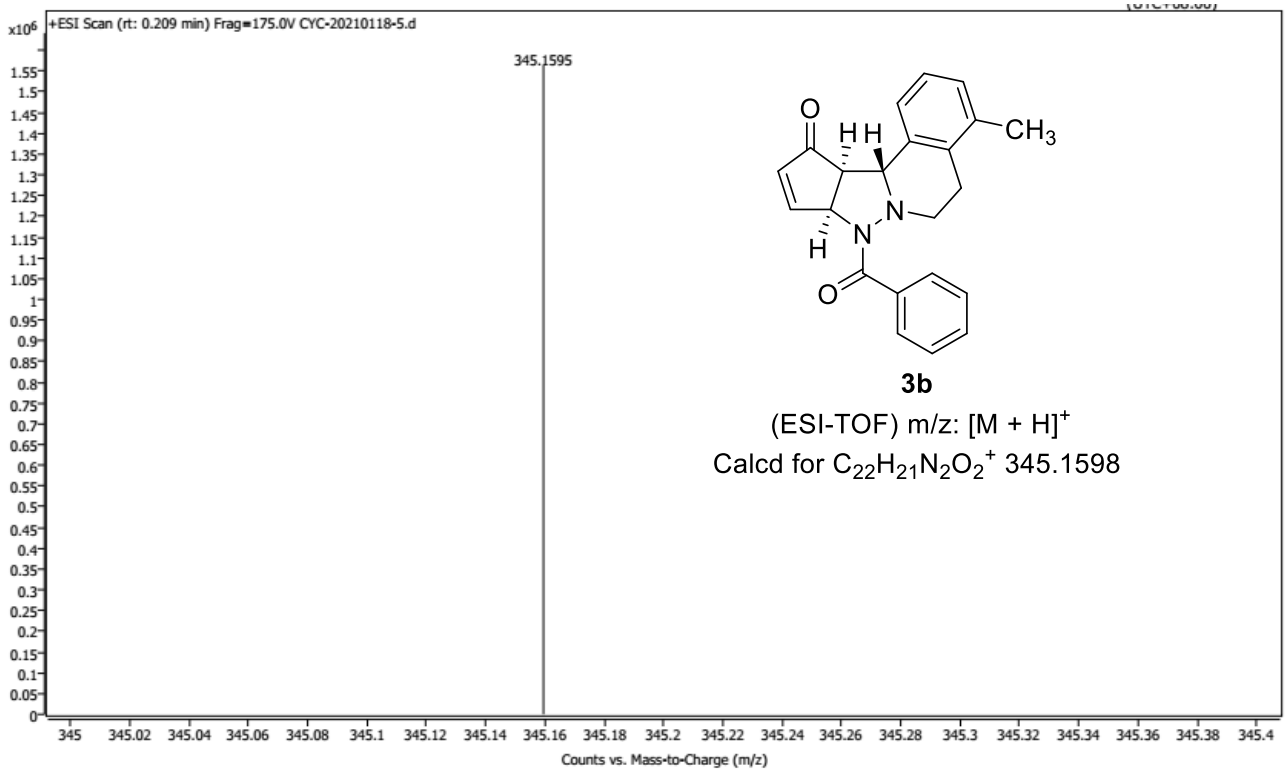
^{13}C NMR (100 MHz, $CDCl_3$)



Ret Time [min]	Peak Type	Width [min]	Height [mAU]	Area [mAU*s]	Area [%]
8.649	BB	0.20	26.0171	343.3367	49.7101
12.943	BB	0.31	17.4321	347.3406	50.2899
			Totals:	690.6773	100.0000



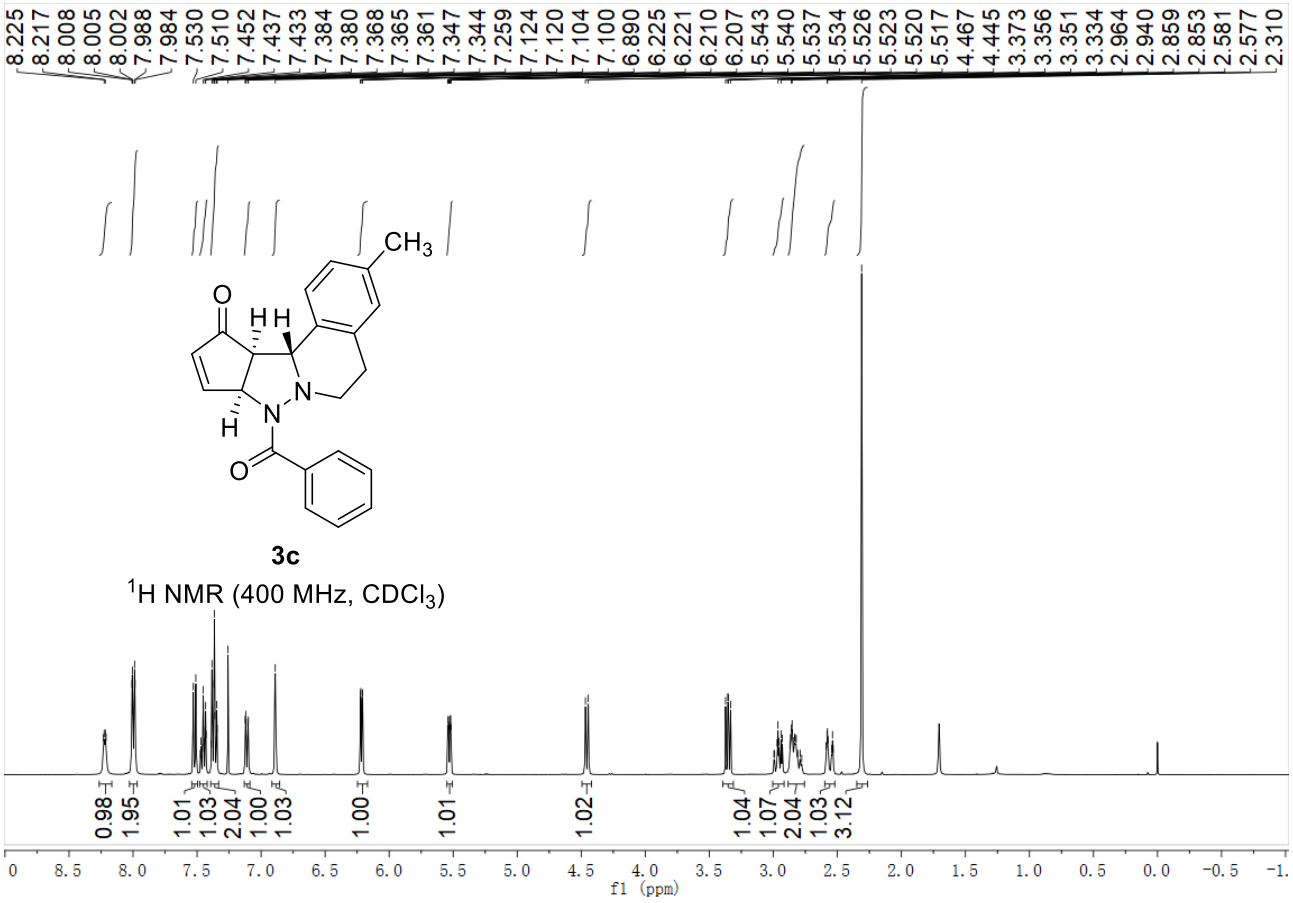
Ret Time [min]	Peak Type	Width [min]	Height [mAU]	Area [mAU*s]	Area [%]
8.622	BBA	0.21	658.4465	8774.6611	99.6404
12.946	BB	0.31	1.5954	31.6672	0.3596
			Totals:	8806.3283	100.0000



3b

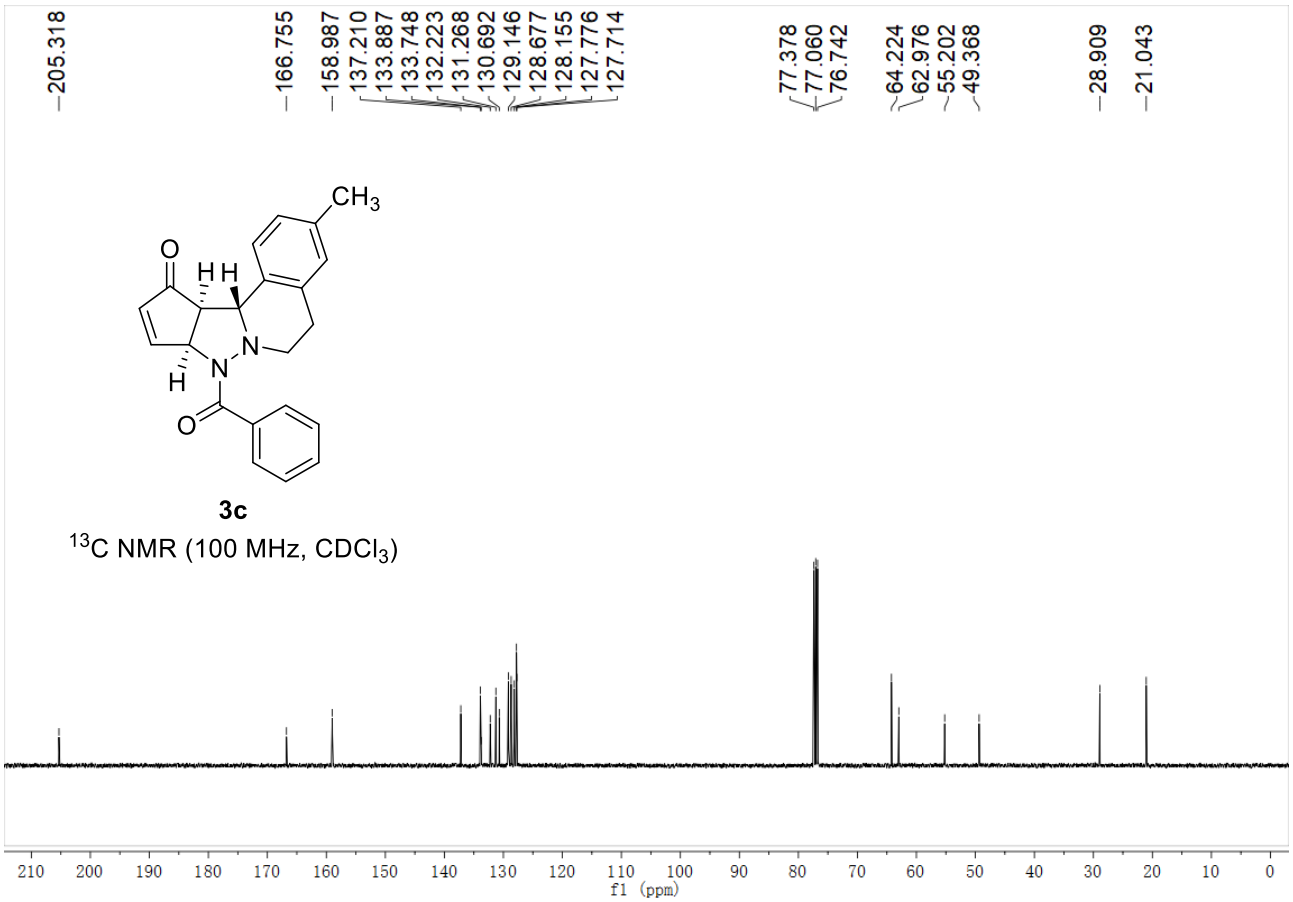
(ESI-TOF) m/z: $[M + H]^+$

Calcd for $C_{22}H_{21}N_2O_2^+$ 345.1598



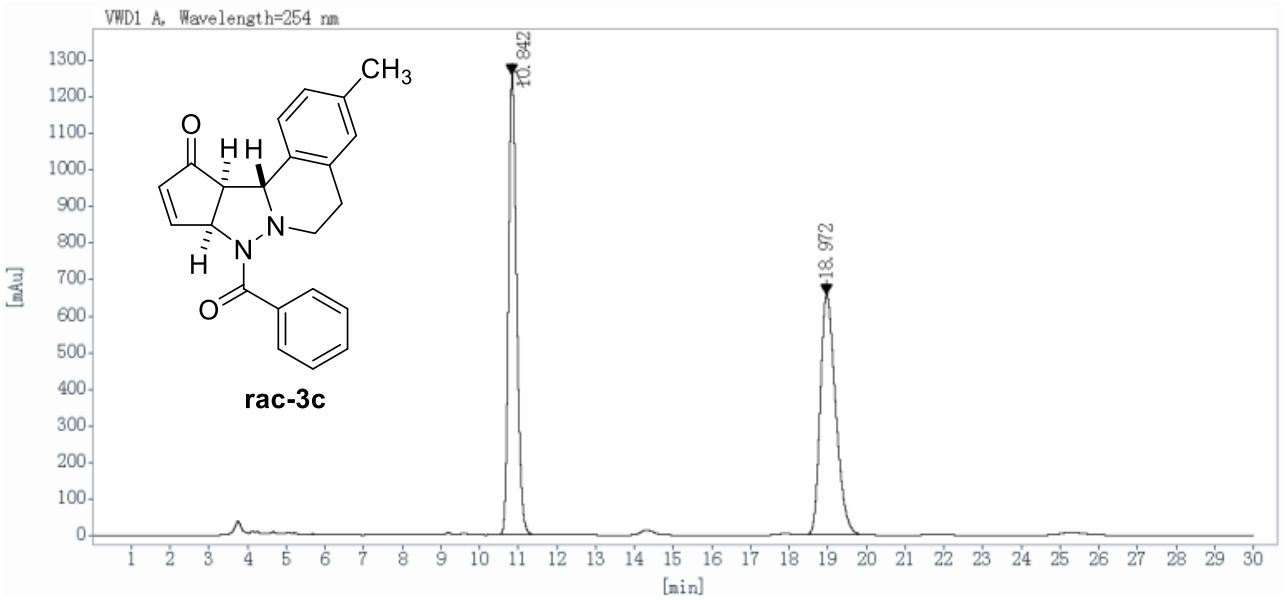
3c

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

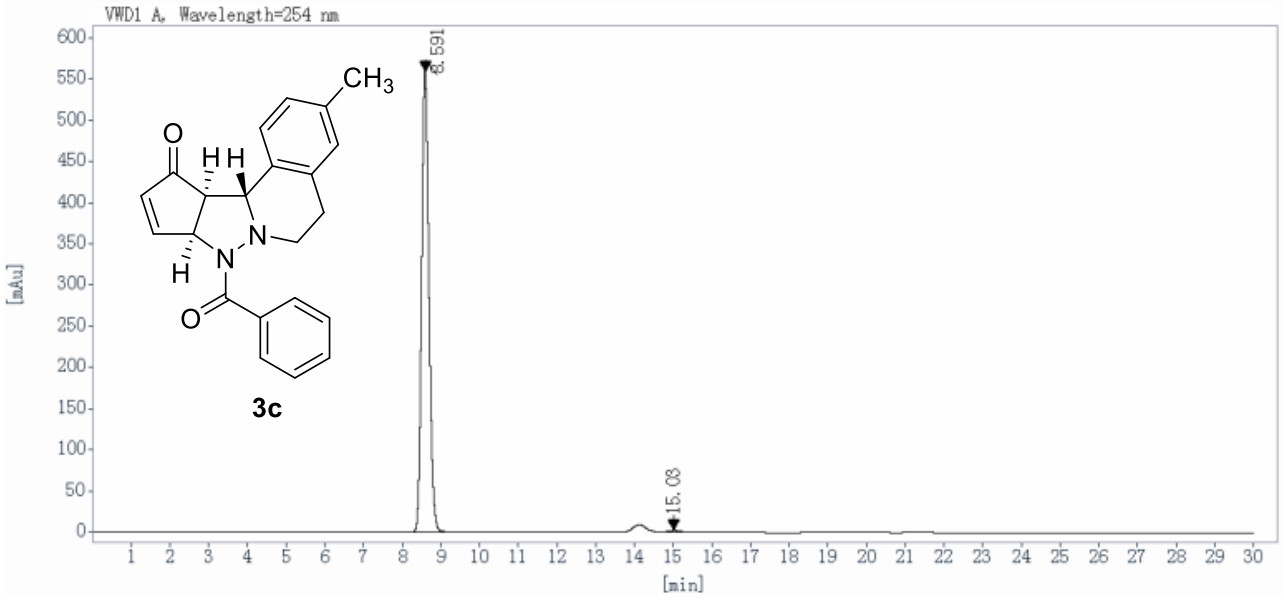


3c

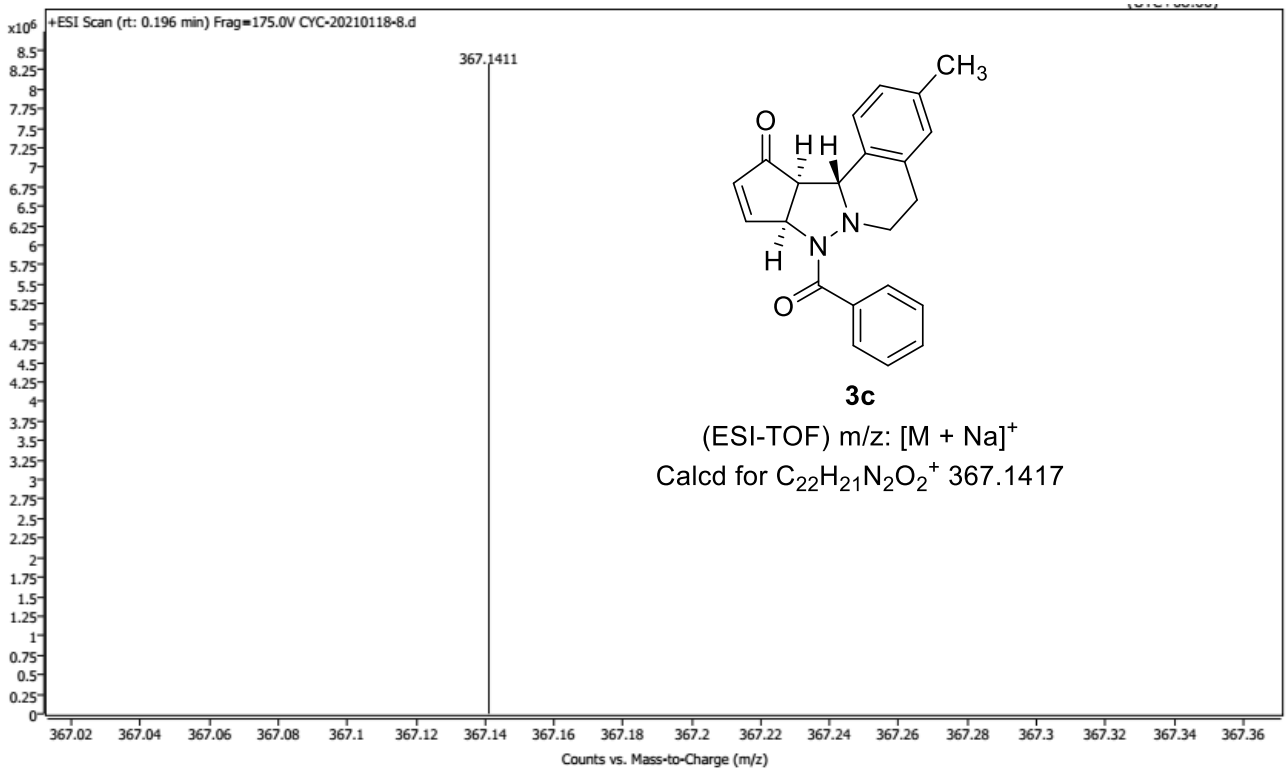
^{13}C NMR (100 MHz, $CDCl_3$)



Ret Time [min]	Peak Type	Width [min]	Height [mAU]	Area [mAU*s]	Area [%]
10.842	BBA	0.22	1261.9327	18364.4043	50.3466
18.972	BBA	0.42	656.9032	18111.5762	49.6534
			Totals:	36475.9805	100.0000



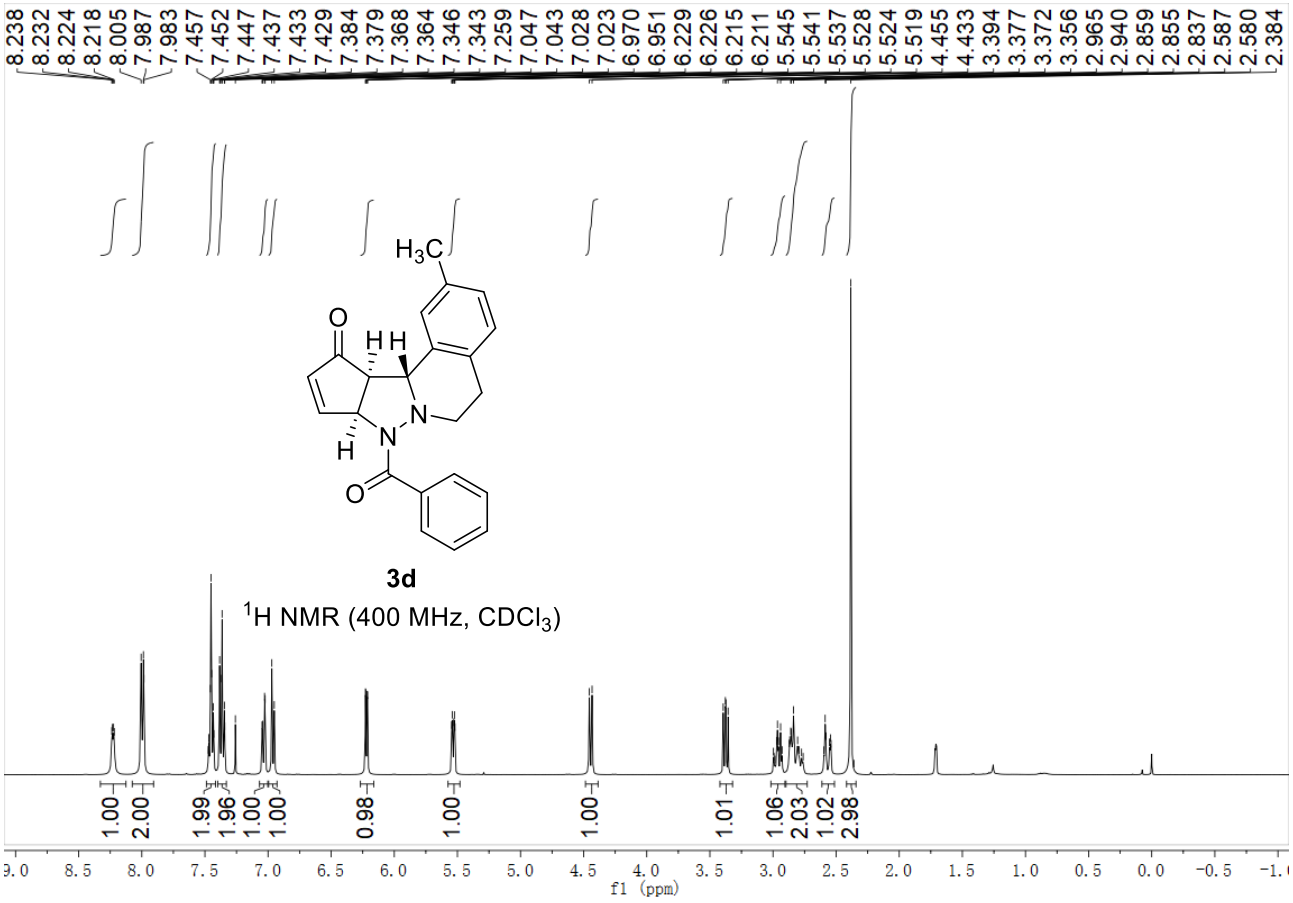
Ret Time [min]	Peak Type	Width [min]	Height [mAU]	Area [mAU*s]	Area [%]
8.591	BB	0.21	559.3552	7393.2075	99.3550
15.030	BB	0.34	2.2397	47.9936	0.6450
			Totals:	7441.2012	100.0000

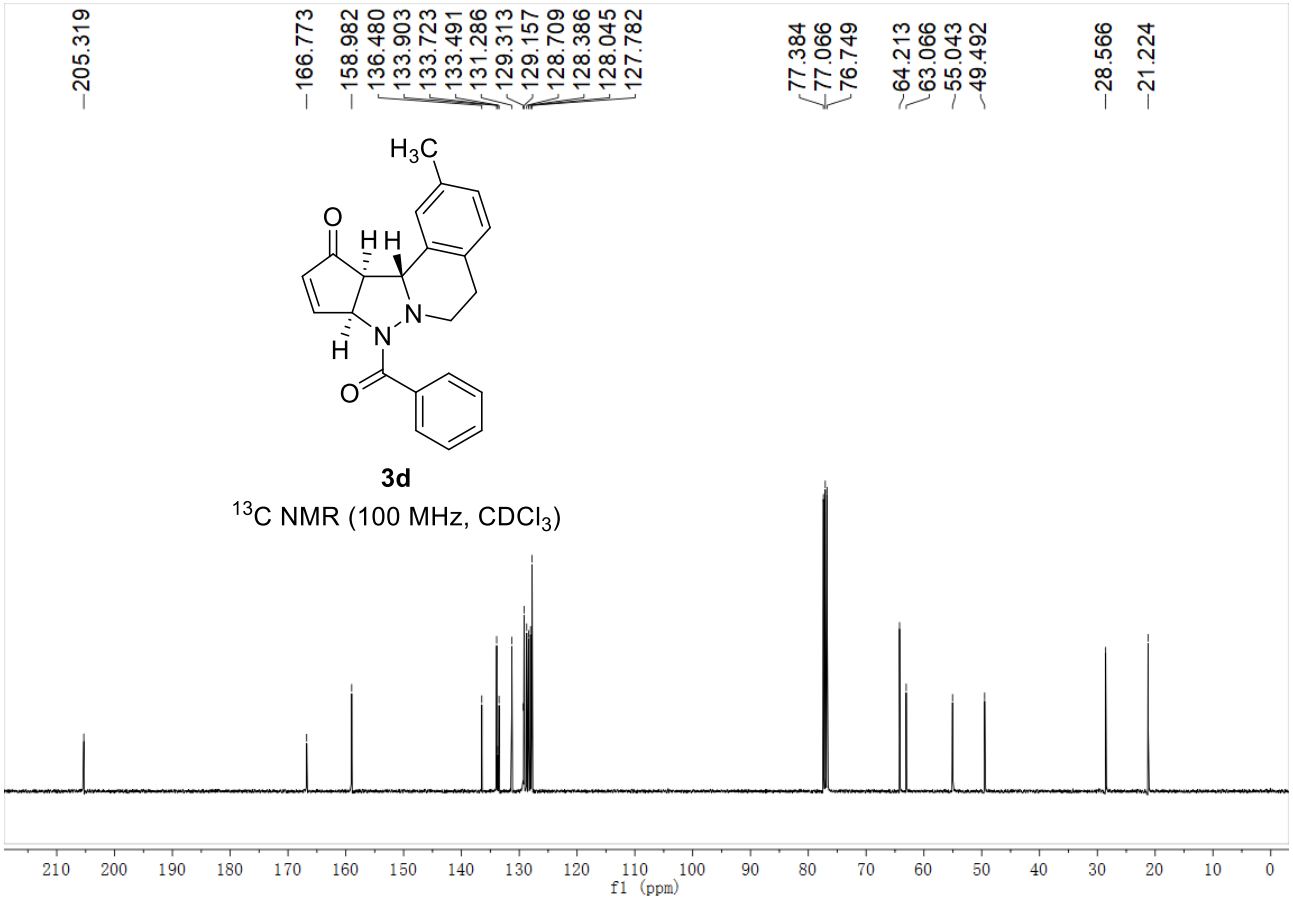


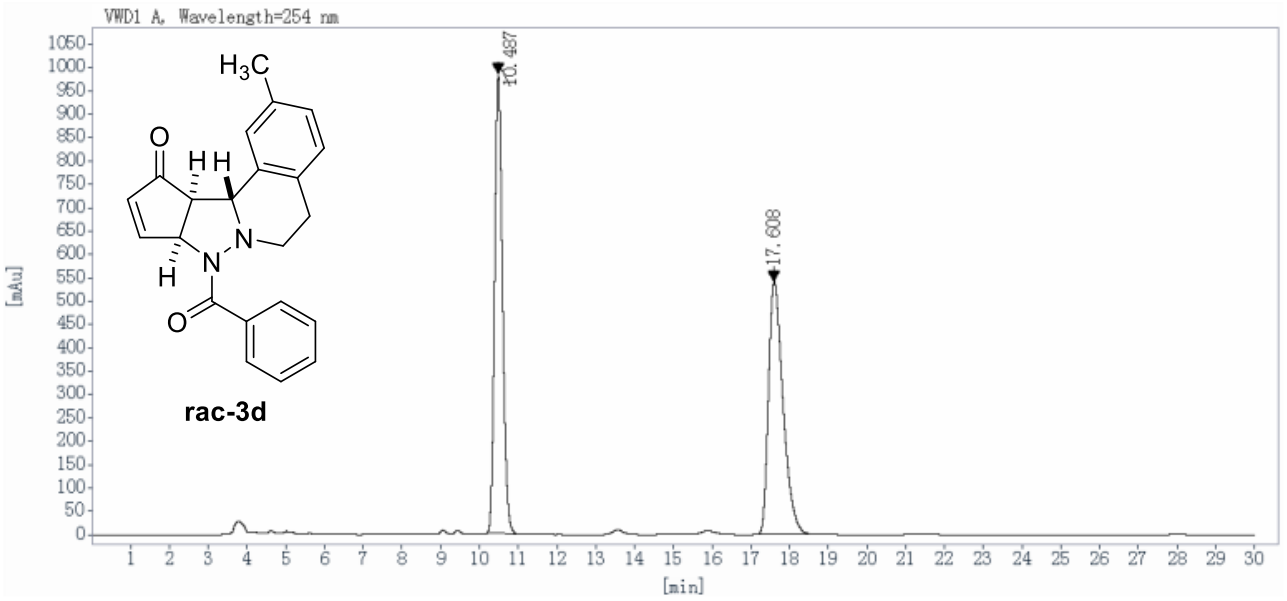
3c

(ESI-TOF) m/z: $[M + Na]^+$

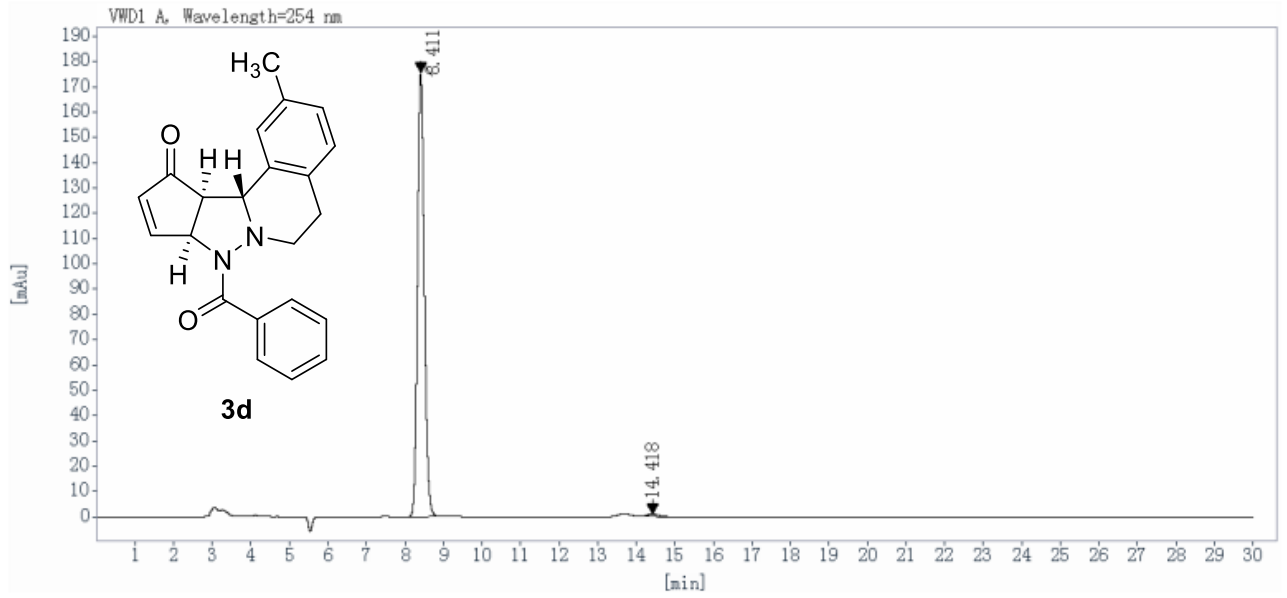
Calcd for $C_{22}H_{21}N_2O_2^+$ 367.1417


8.238
8.232
8.224
8.218
8.005
7.987
7.983
7.457
7.452
7.447
7.437
7.433
7.429
7.384
7.379
7.368
7.364
7.346
7.343
7.259
7.047
7.043
7.028
7.023
6.970
6.951
6.229
6.226
6.215
6.211
5.545
5.541
5.537
5.528
5.524
5.519
4.455
4.433
3.394
3.377
3.372
3.356
2.965
2.940
2.859
2.855
2.837
2.587
2.580
2.384
H3C
O
H H
N
N
H
O
3d
1H NMR (400 MHz, CDCl3)
1.00
2.00
1.99
1.96
1.00
1.00
0.98
1.00
1.00
1.01
1.06
2.03
1.02
2.98
f1 (ppm)

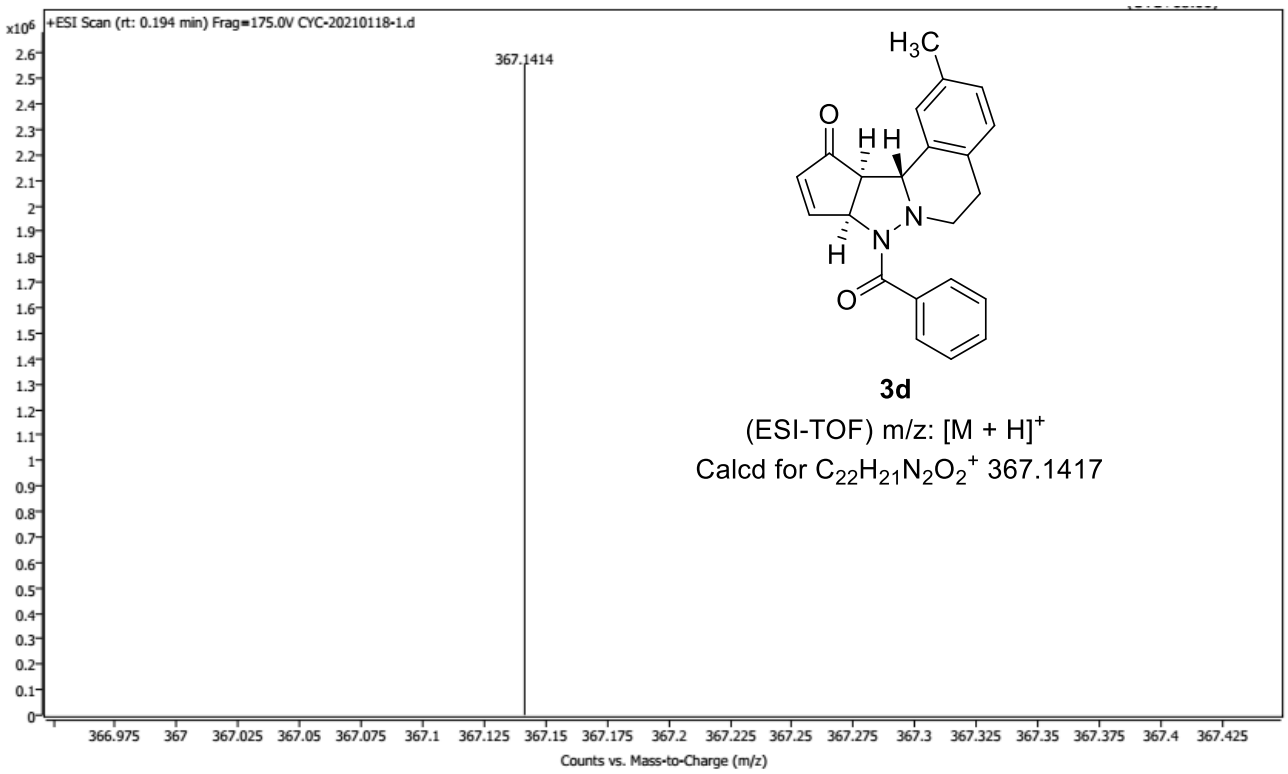

205.319
166.773
158.982
136.480
133.903
133.723
133.491
131.286
129.313
129.157
128.709
128.386
128.045
127.782
77.384
77.066
76.749
64.213
63.066
55.043
49.492
28.566
21.224
H3C
O
H H
N
N
H
O
3d
13C NMR (100 MHz, CDCl3)
f1 (ppm)



Ret Time [min]	Peak Type	Width [min]	Height [mAU]	Area [mAU*s]	Area [%]
10.487	BBA	0.22	980.9462	13847.6836	49.5651
17.608	BBA	0.40	539.5096	14090.6885	50.4349
			Totals:	27938.3721	100.0000



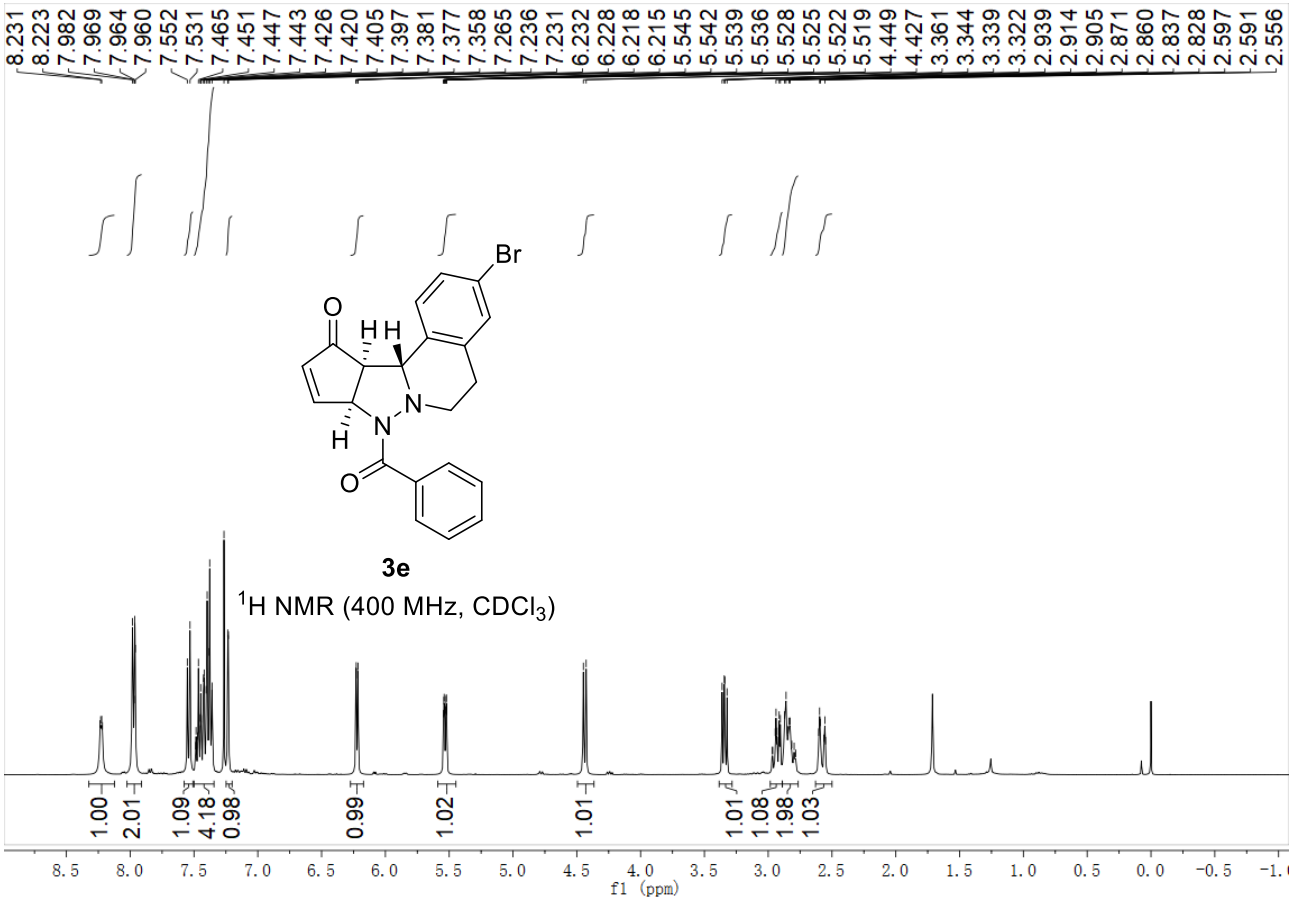
Ret Time [min]	Peak Type	Width [min]	Height [mAU]	Area [mAU*s]	Area [%]
8.411	BBA	0.19	175.4830	2153.4695	99.0113
14.418	BB	0.34	1.0133	21.5040	0.9887
			Totals:	2174.9735	100.0000



3d

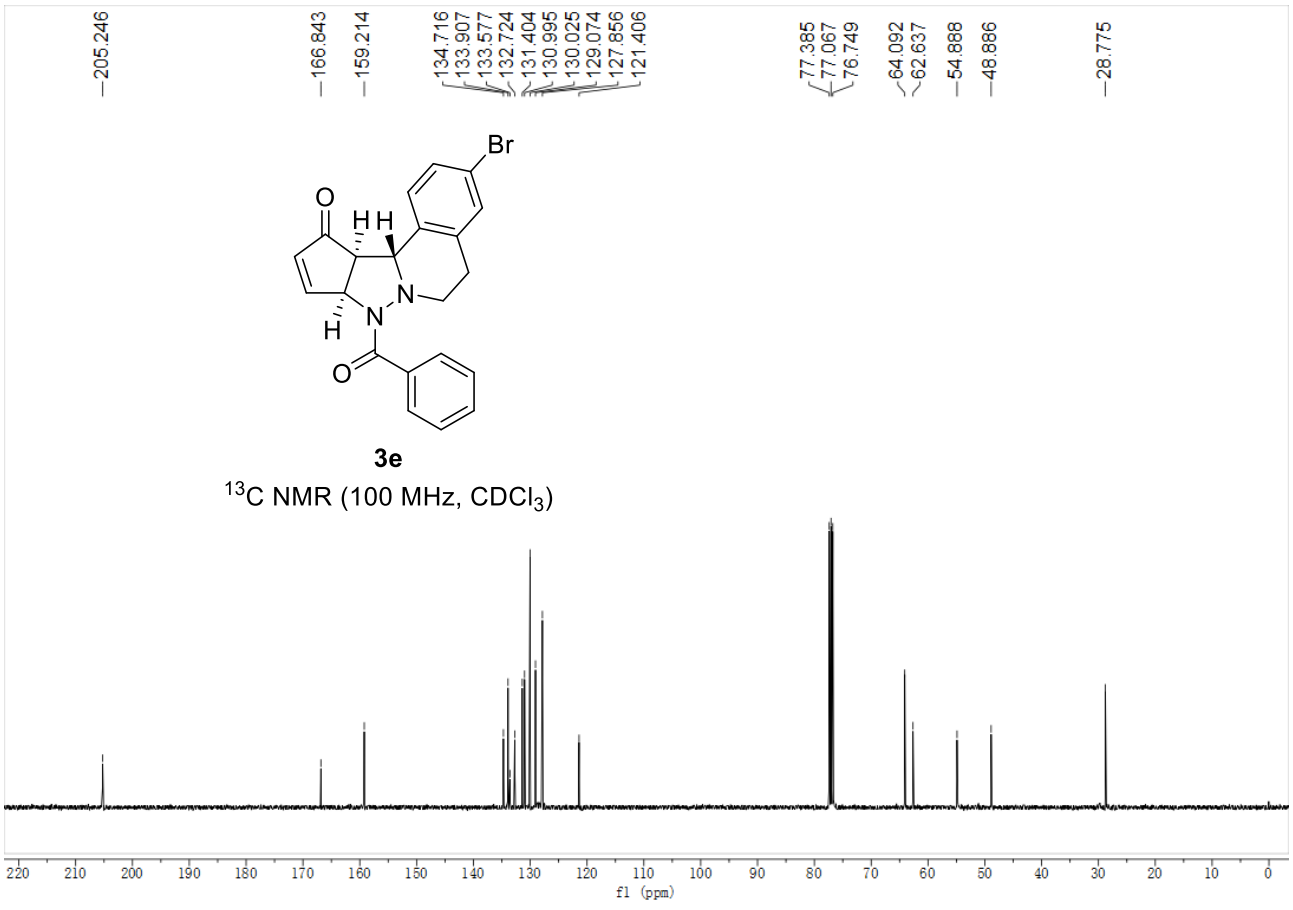
(ESI-TOF) m/z: $[M + H]^+$

Calcd for $C_{22}H_{21}N_2O_2^+$ 367.1417



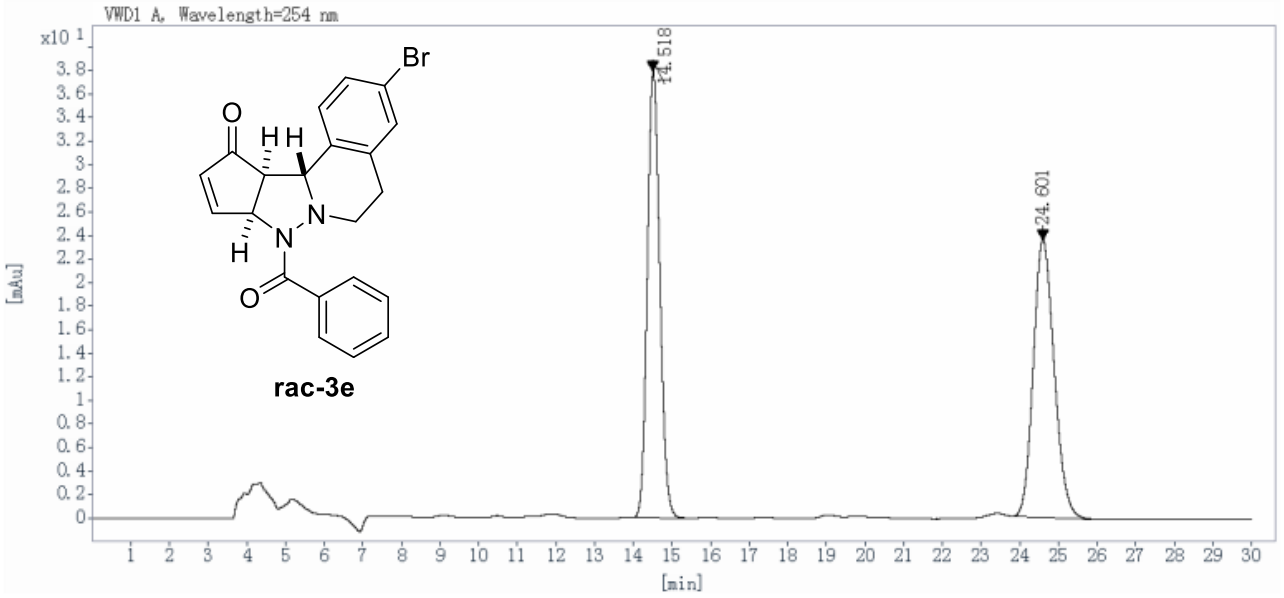
3e

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

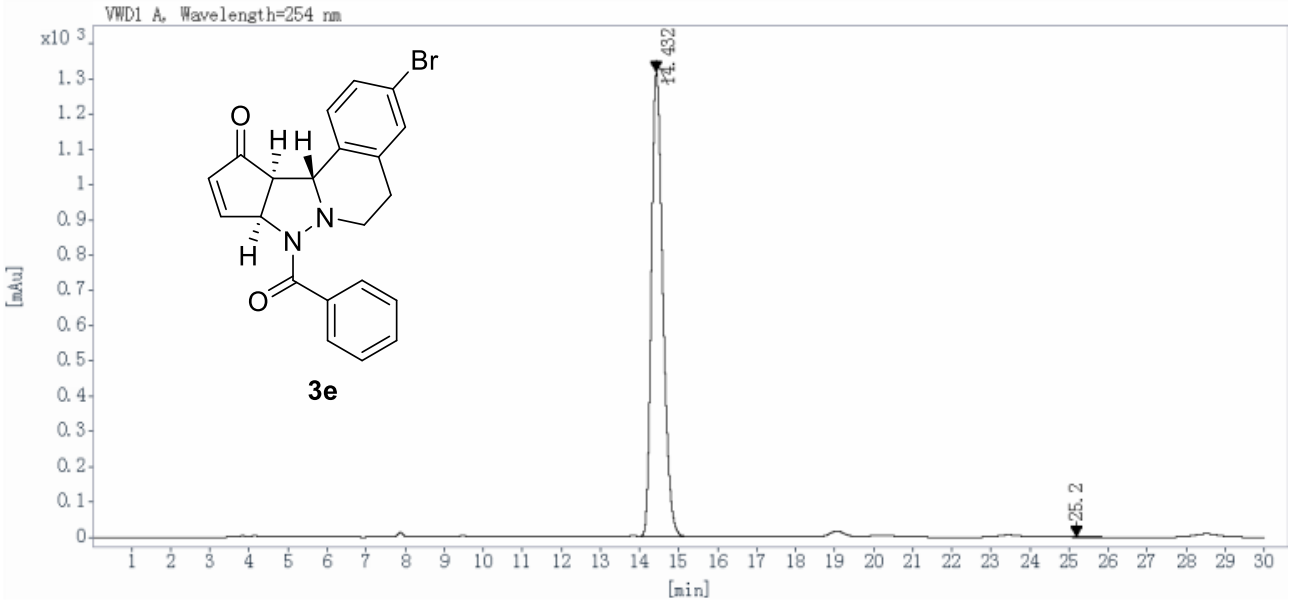


3e

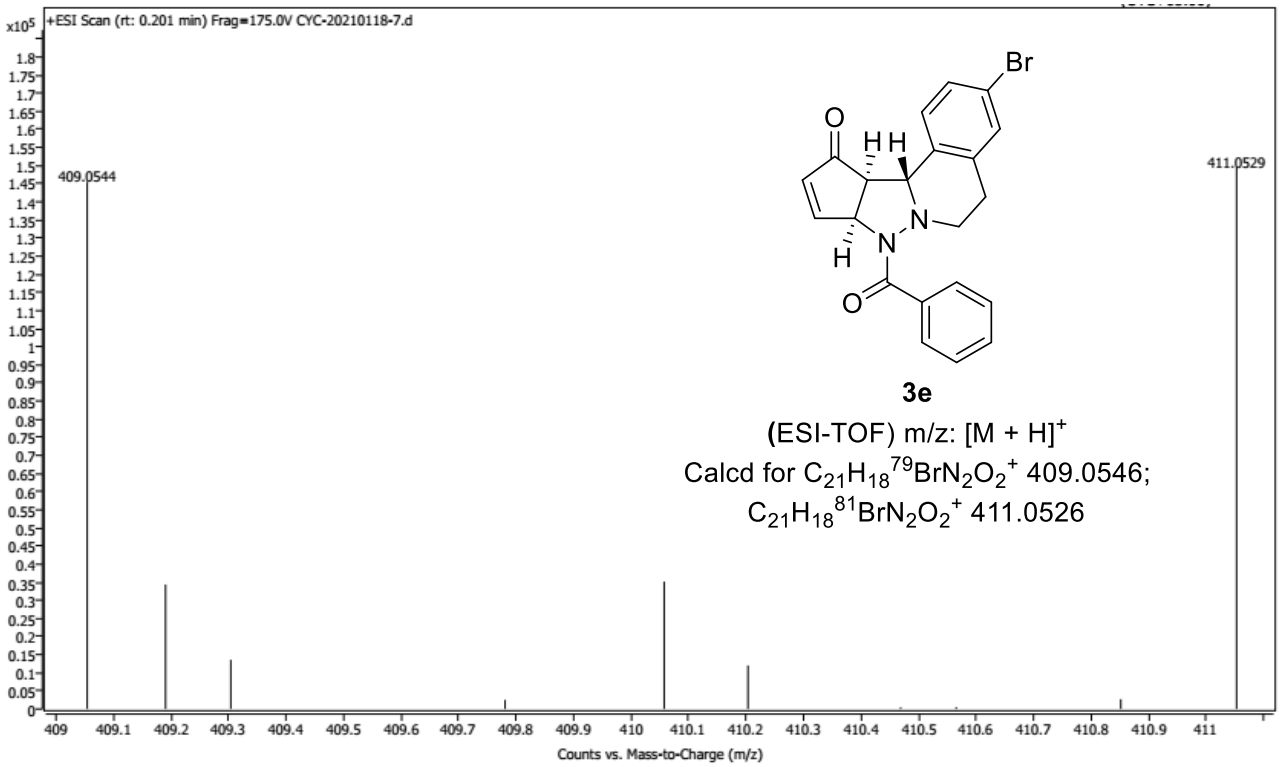
^{13}C NMR (100 MHz, $CDCl_3$)



Ret Time [min]	Peak Type	Width [min]	Height [mAU]	Area [mAU*s]	Area [%]
14.518	BB	0.35	37.9277	848.1010	48.9653
24.601	BB	0.58	23.5505	883.9448	51.0347
			Totals:	1732.0458	100.0000



Ret Time [min]	Peak Type	Width [min]	Height [mAU]	Area [mAU*s]	Area [%]
14.432	BB	0.32	1319.3119	26927.6270	99.4910
25.200	BB	0.74	2.5407	137.7645	0.5090
			Totals:	27065.3914	100.0000

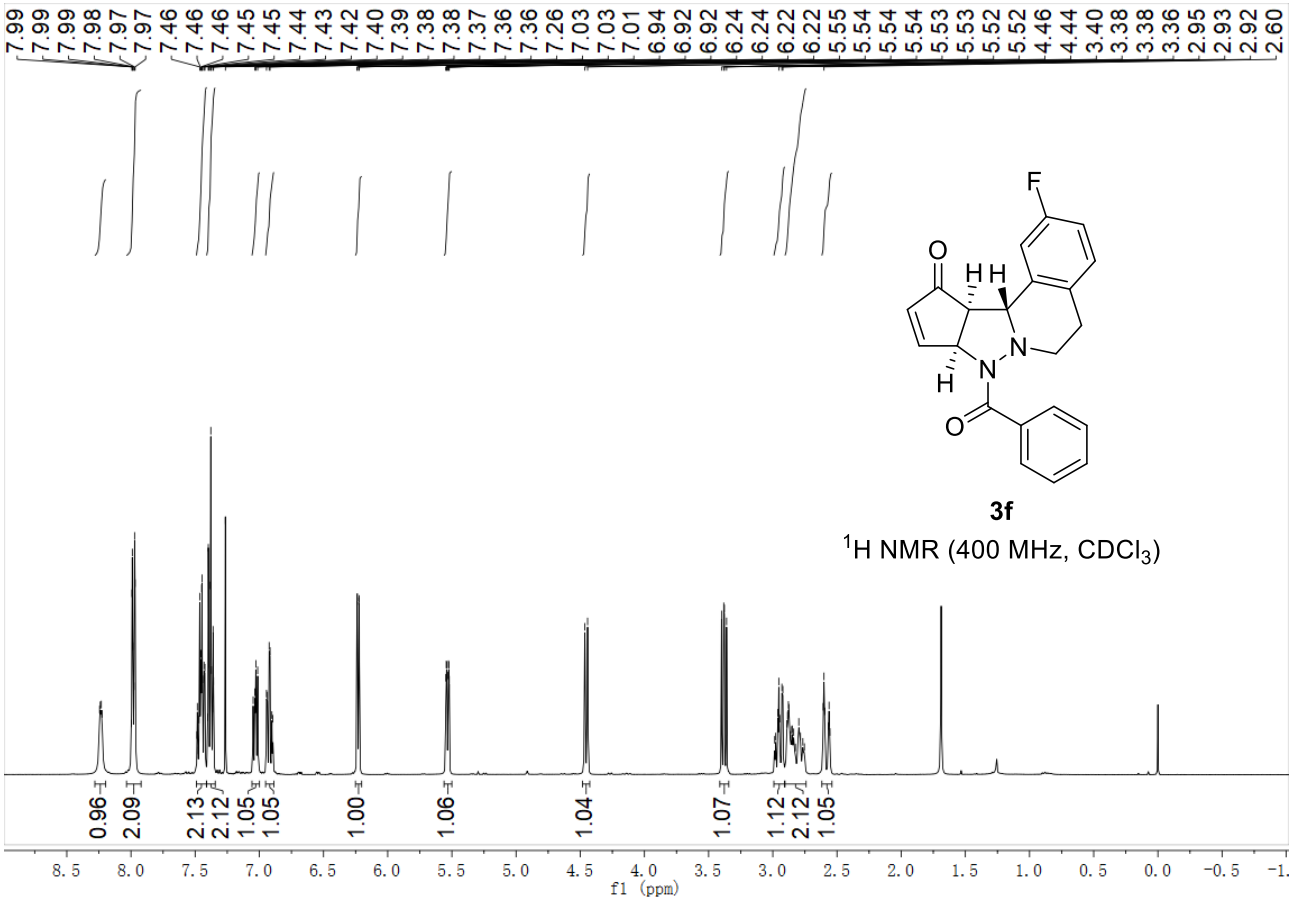


3e

(ESI-TOF) m/z: $[M + H]^+$

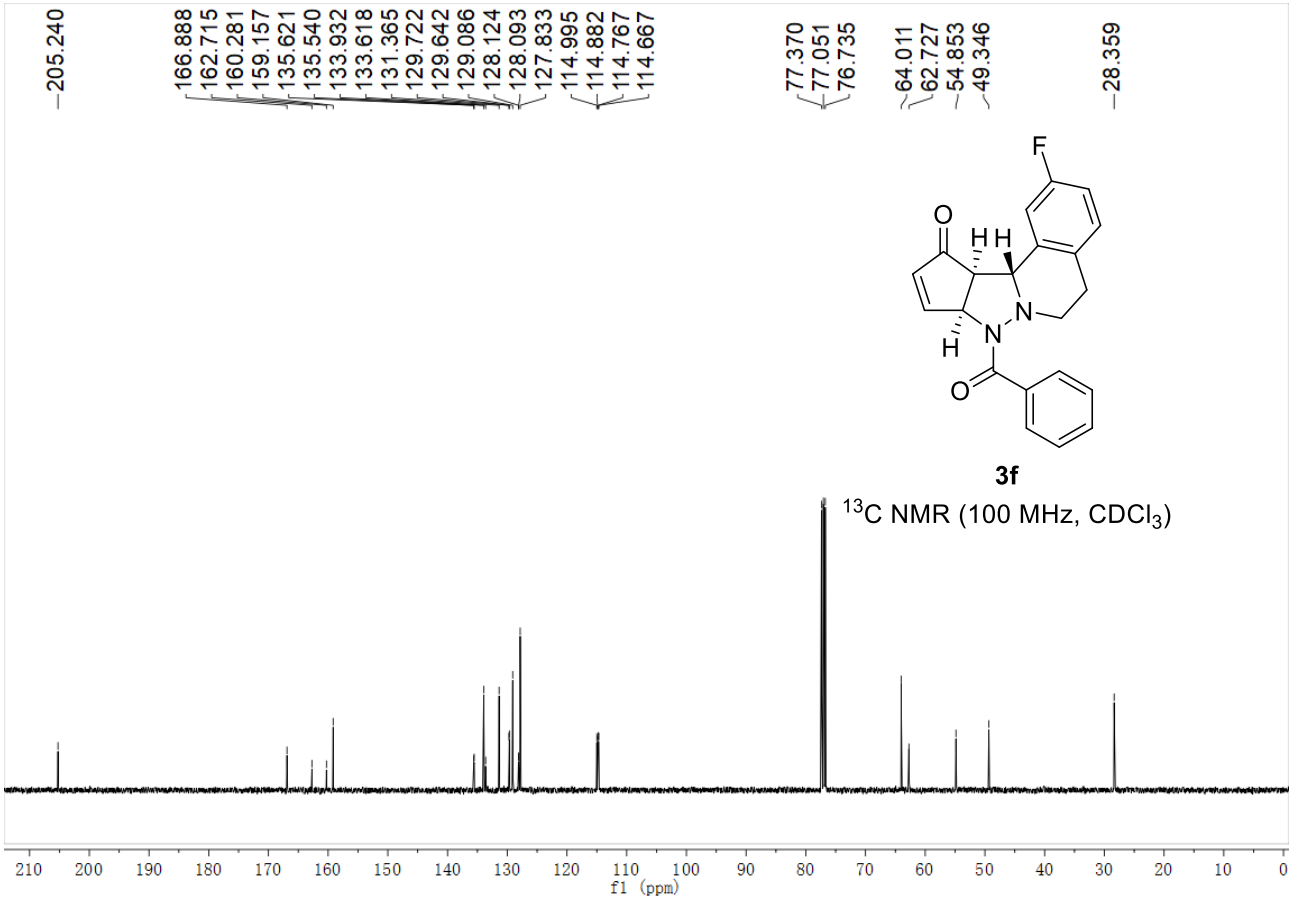
Calcd for $C_{21}H_{18}{}^{79}BrN_2O_2{}^+$ 409.0546;

$C_{21}H_{18}{}^{81}BrN_2O_2{}^+$ 411.0526



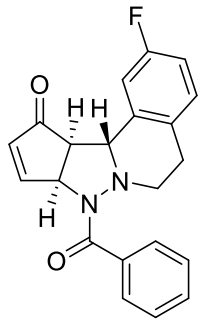
3f

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



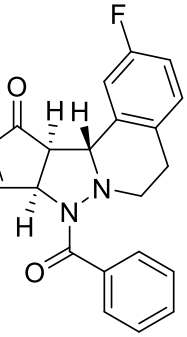
3f

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



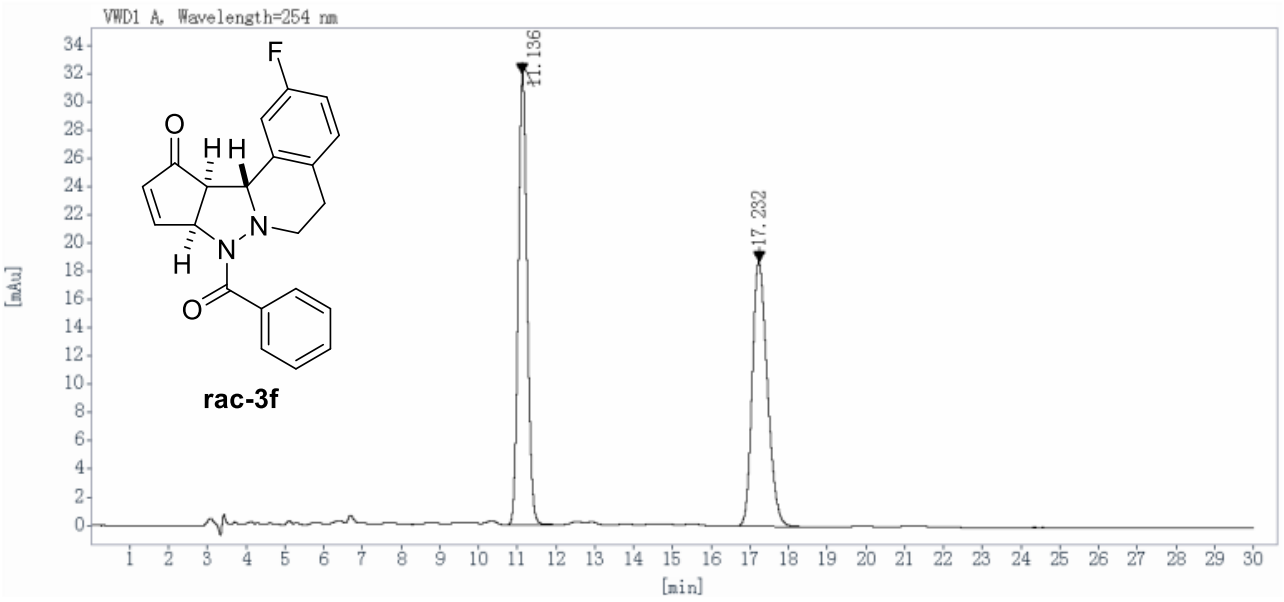
3f

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

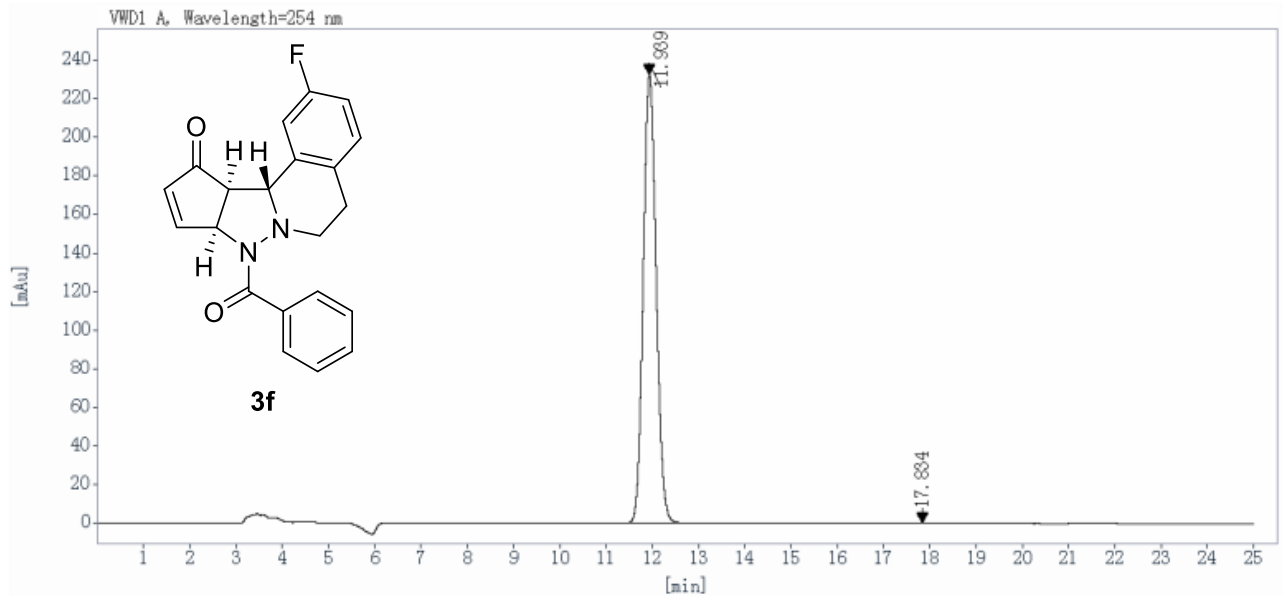


3f

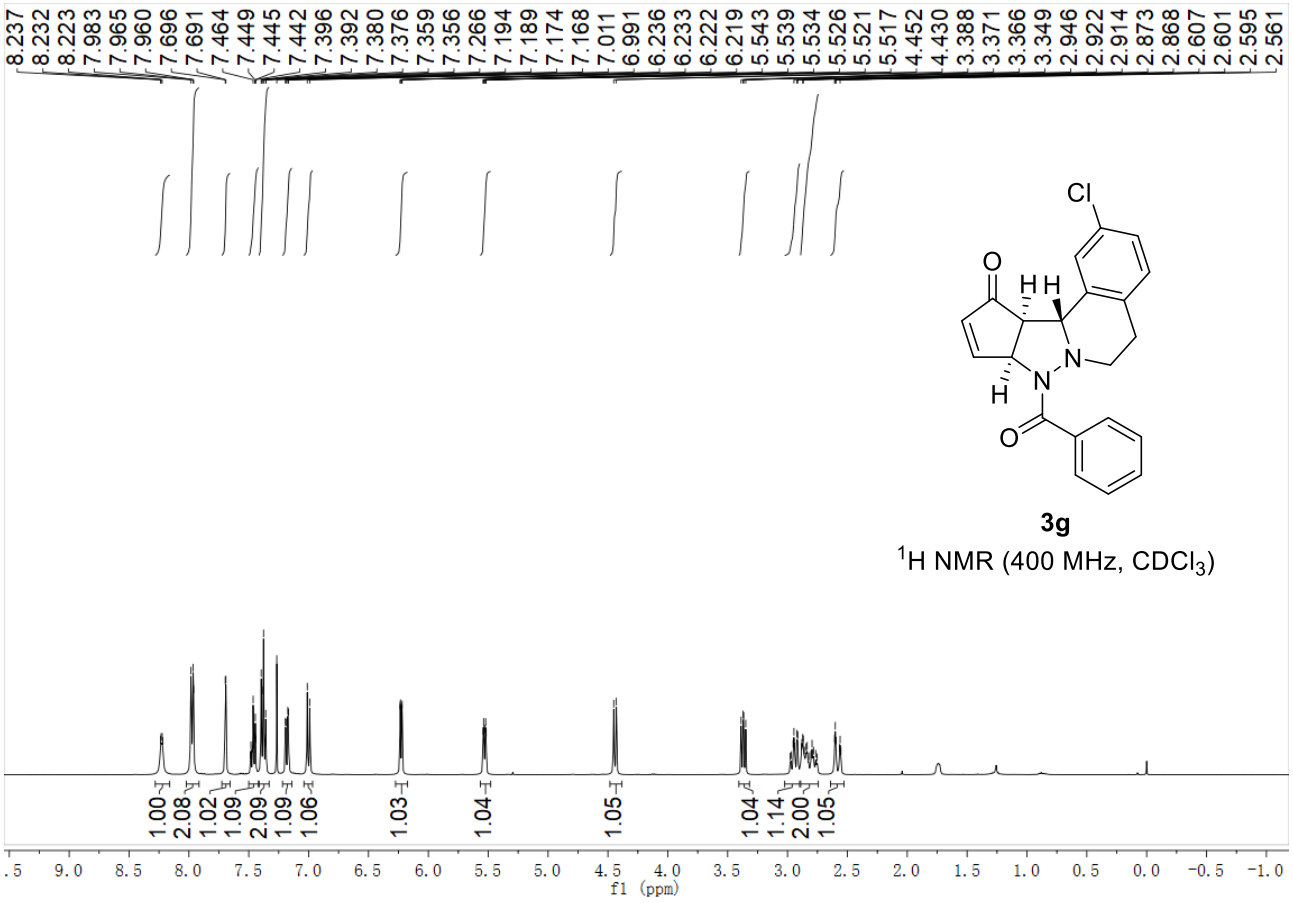
(ESI-TOF) m/z: $[M + Na]^+$ Calcd for $C_{21}H_{17}FN_2O_2Na^+$ 371.1166



Ret Time [min]	Peak Type	Width [min]	Height [mAU]	Area [mAU*s]	Area [%]
11.136	BB	0.24	31.9770	506.3520	49.9344
17.232	BB	0.42	18.7597	507.6825	50.0656
			Totals:	1014.0344	100.0000

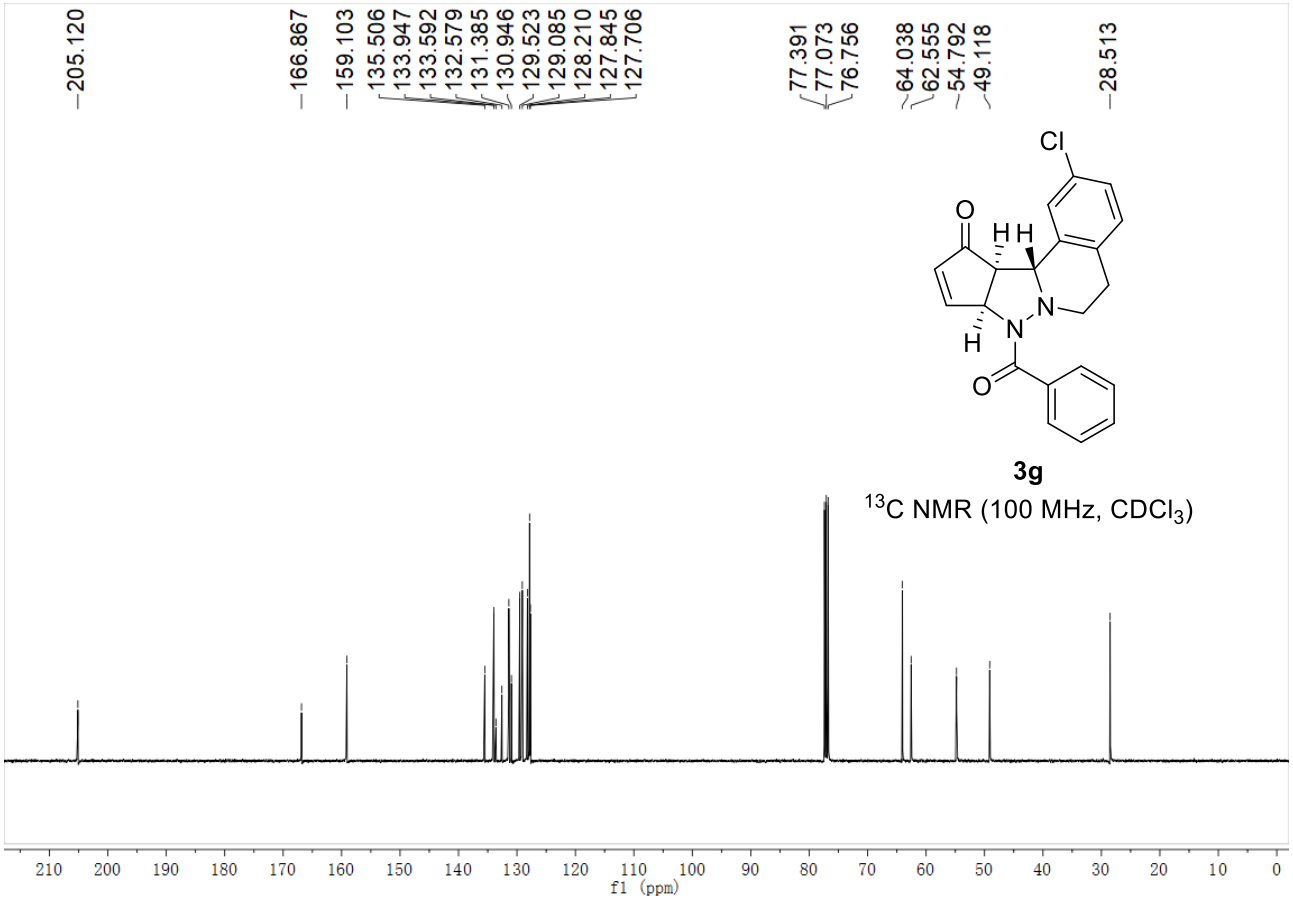


Ret Time [min]	Peak Type	Width [min]	Height [mAU]	Area [mAU*s]	Area [%]
11.939	BBA	0.30	232.4528	4506.3696	99.9036
17.834	BB	0.64	0.0845	4.3487	0.0964
			Totals:	4510.7184	100.0000



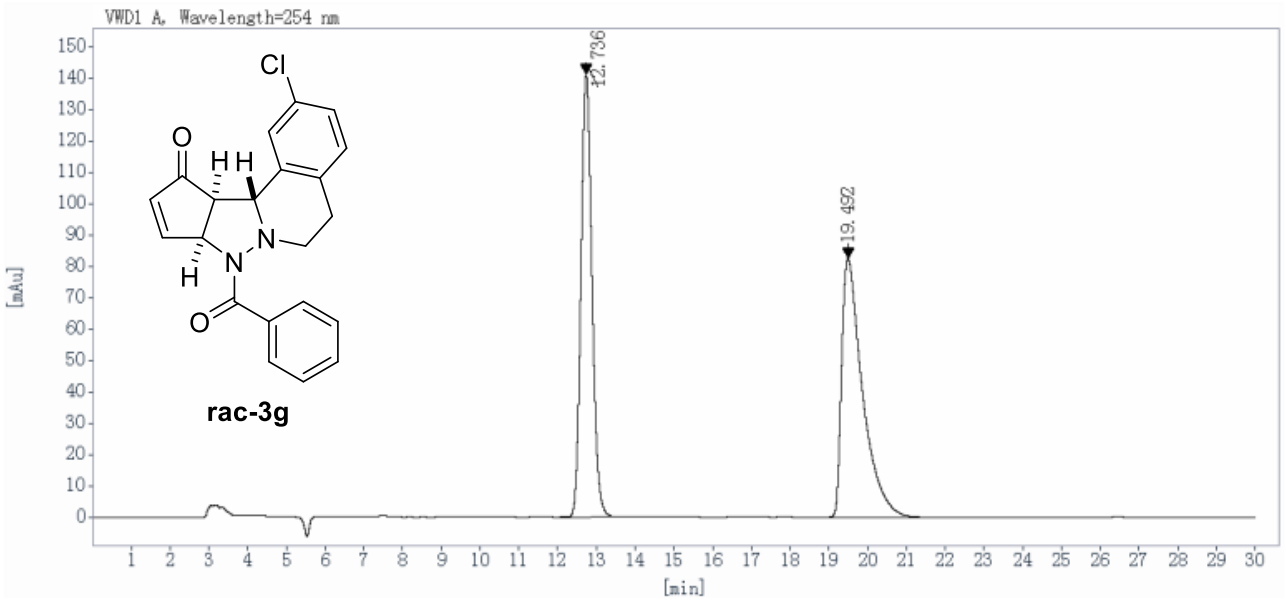
3g

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

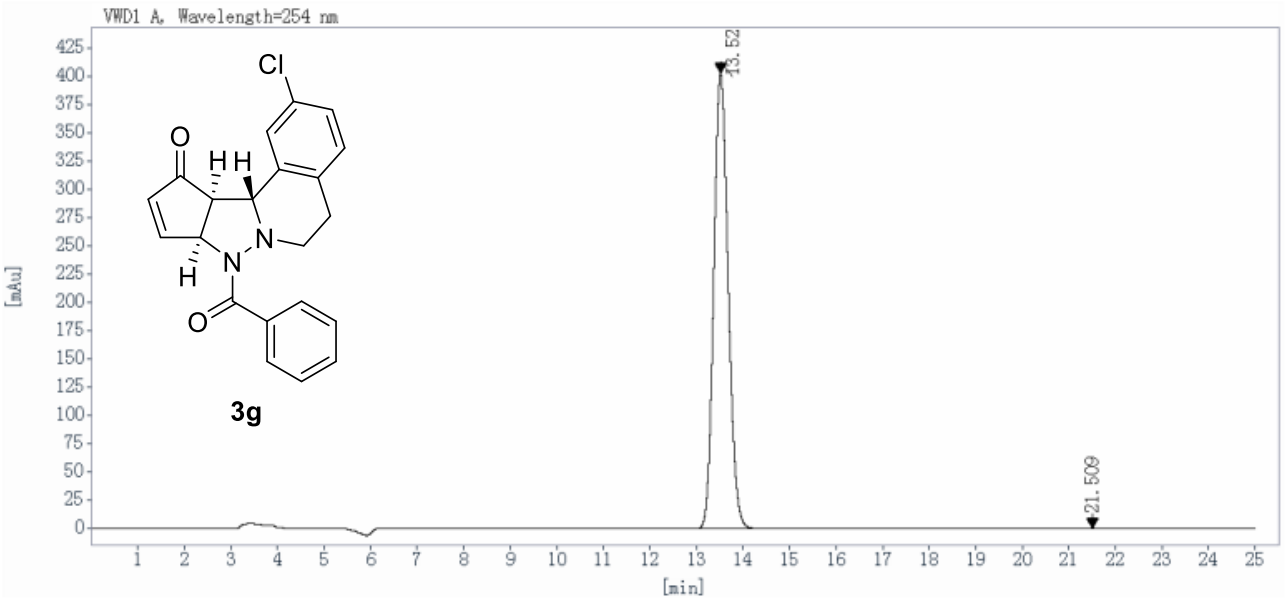


3g

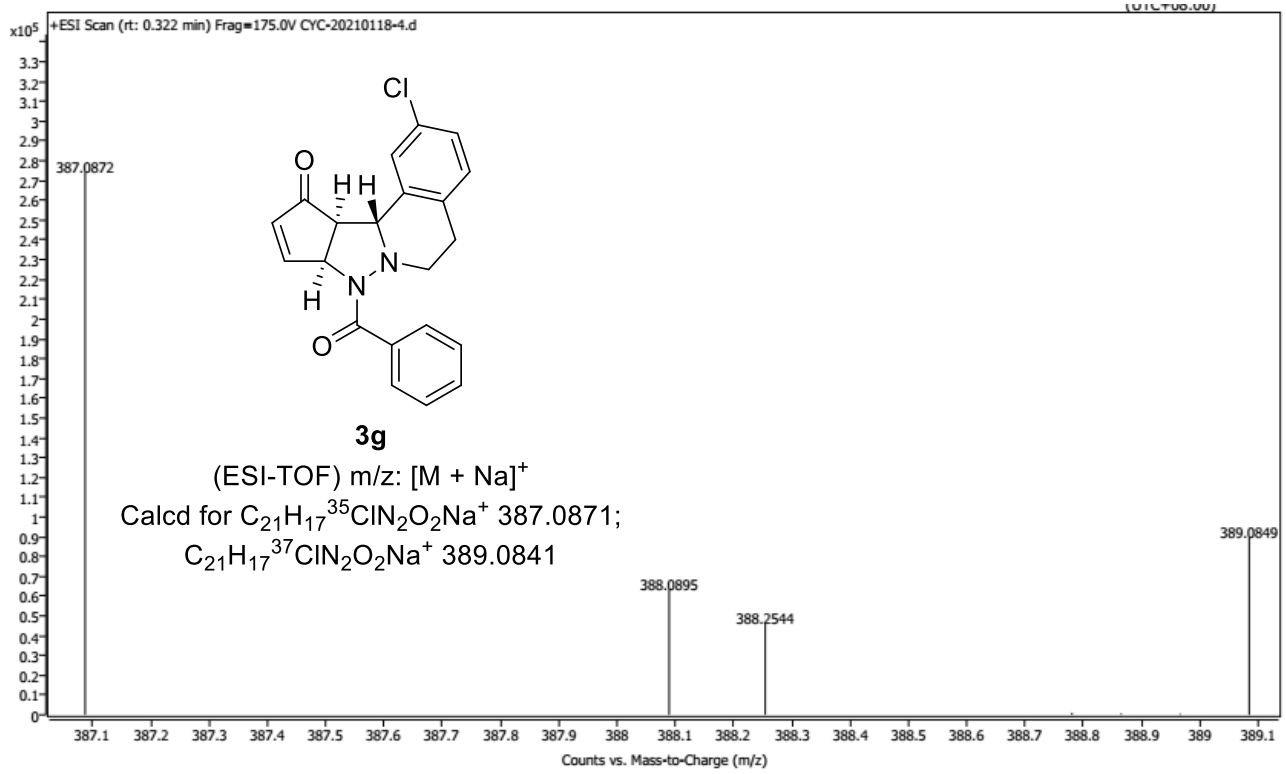
^{13}C NMR (100 MHz, $CDCl_3$)



Ret Time [min]	Peak Type	Width [min]	Height [mAU]	Area [mAU*s]	Area [%]
12.736	BB	0.30	141.2820	2777.3445	47.4249
19.492	BB	0.55	82.5154	3078.9602	52.5751
			Totals:	5856.3047	100.0000



Ret Time [min]	Peak Type	Width [min]	Height [mAU]	Area [mAU*s]	Area [%]
13.520	BBA	0.34	402.6420	8638.4912	99.6456
21.509	BBA	0.61	0.7865	30.7267	0.3544
			Totals:	8669.2179	100.0000

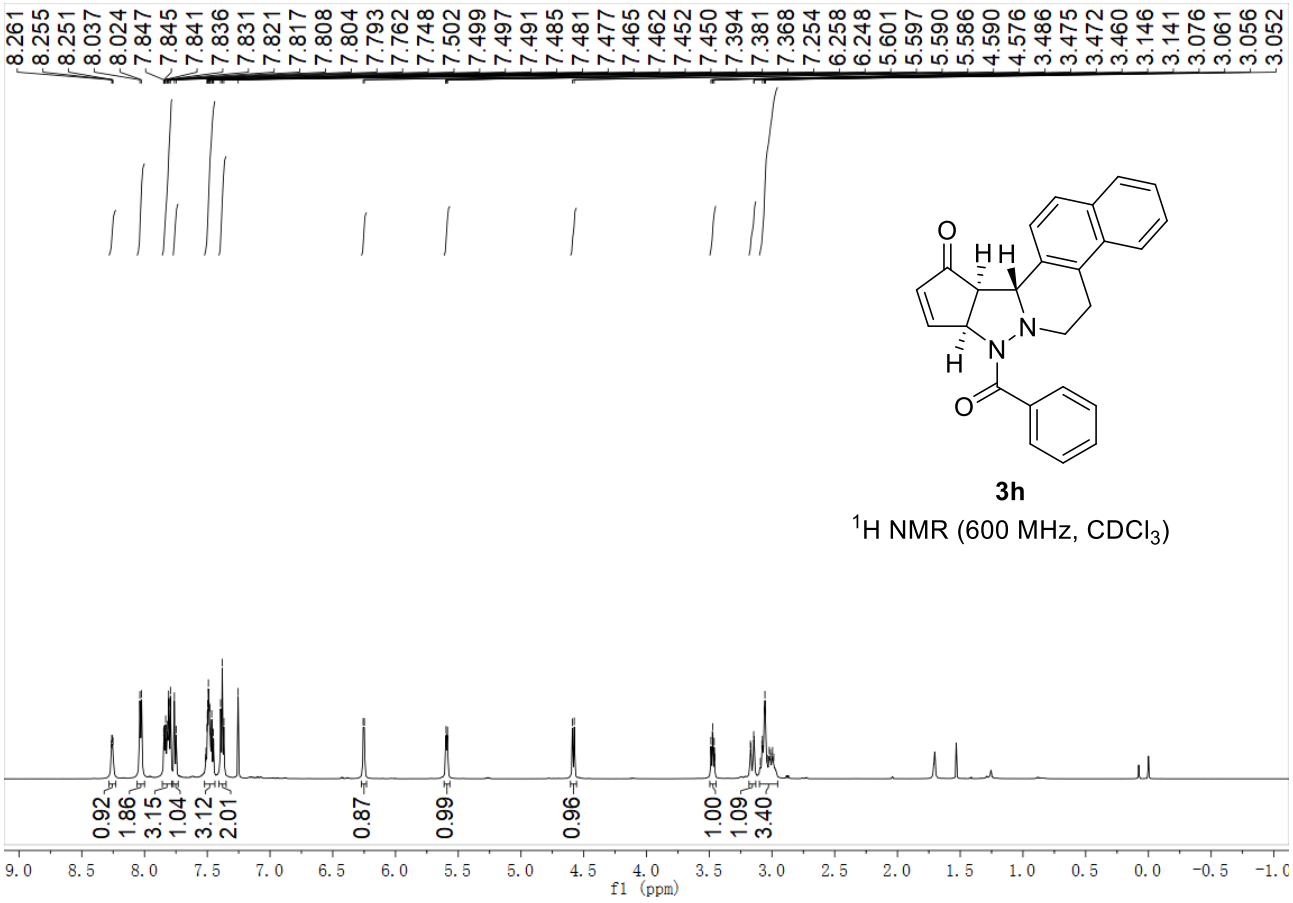


3g

(ESI-TOF) m/z: $[M + Na]^+$

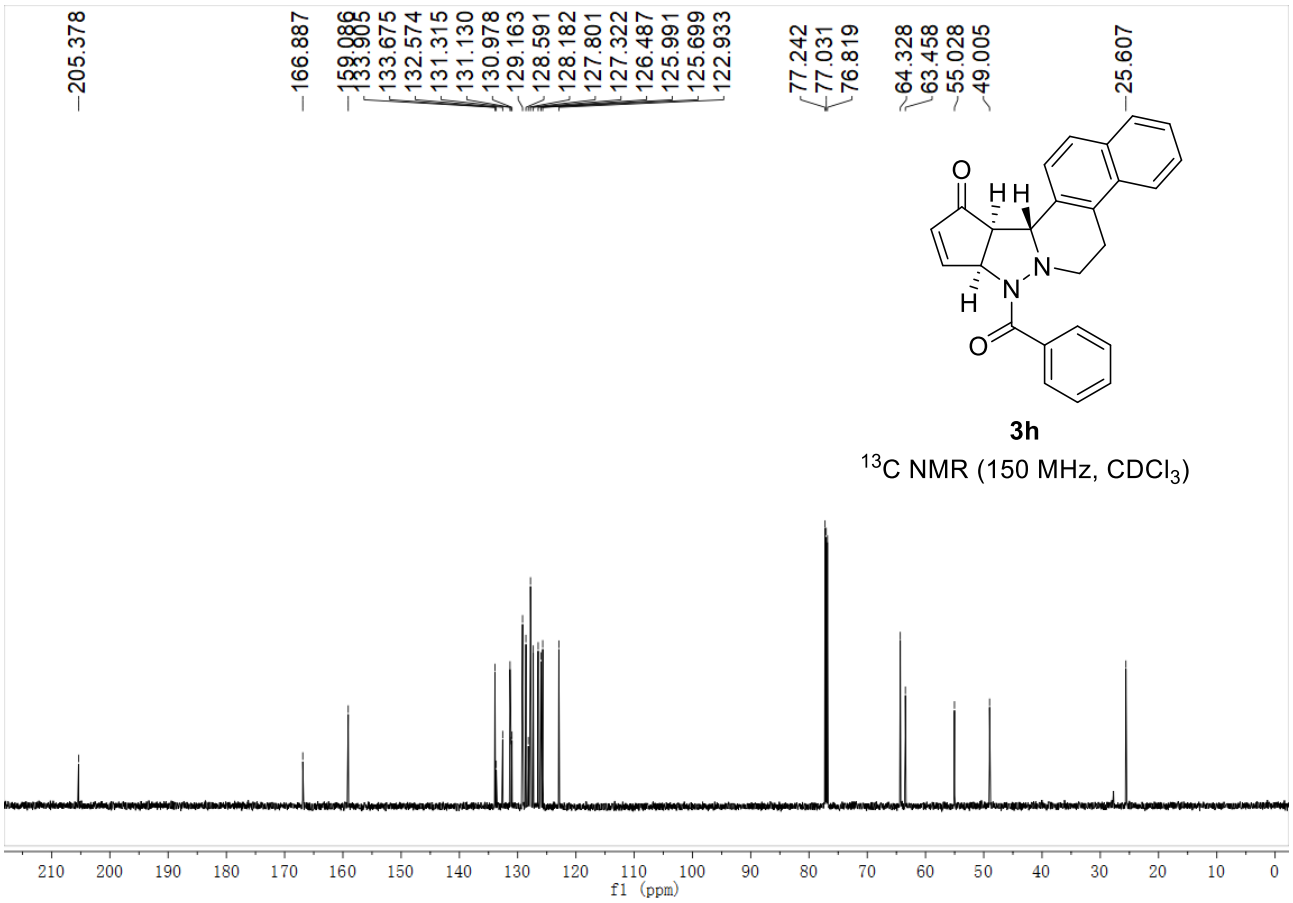
Calcd for $C_{21}H_{17}{}^{35}ClN_2O_2Na^+$ 387.0871;

$C_{21}H_{17}{}^{37}ClN_2O_2Na^+$ 389.0841



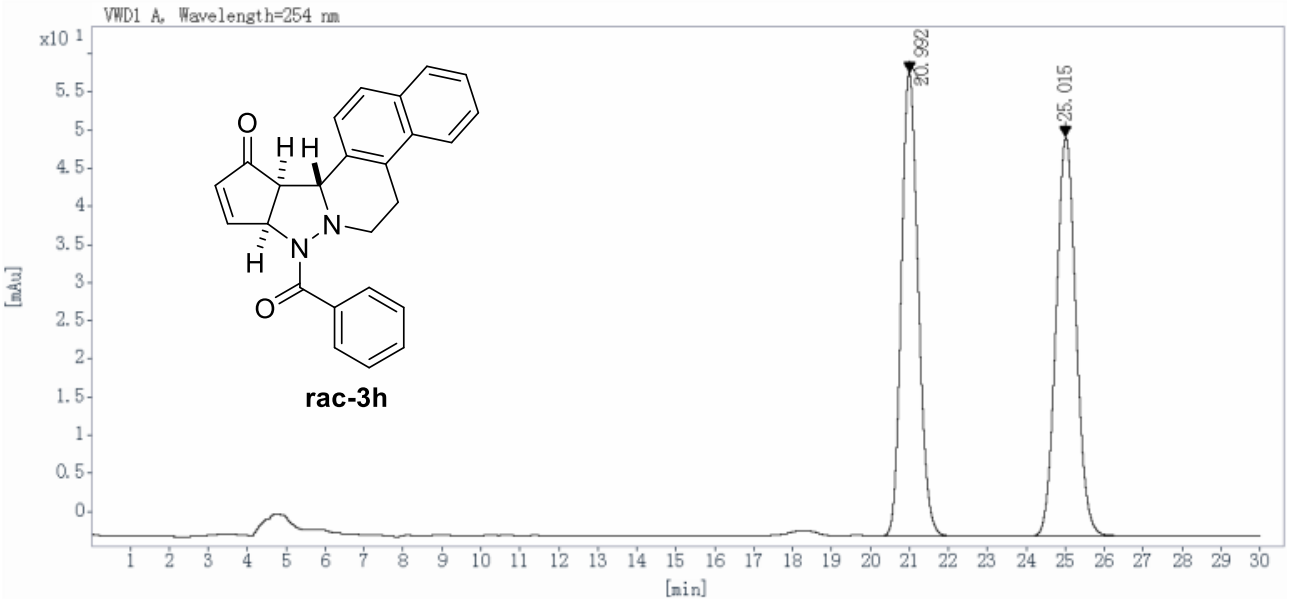
3h

^{1}H NMR (600 MHz, $CDCl_3$)

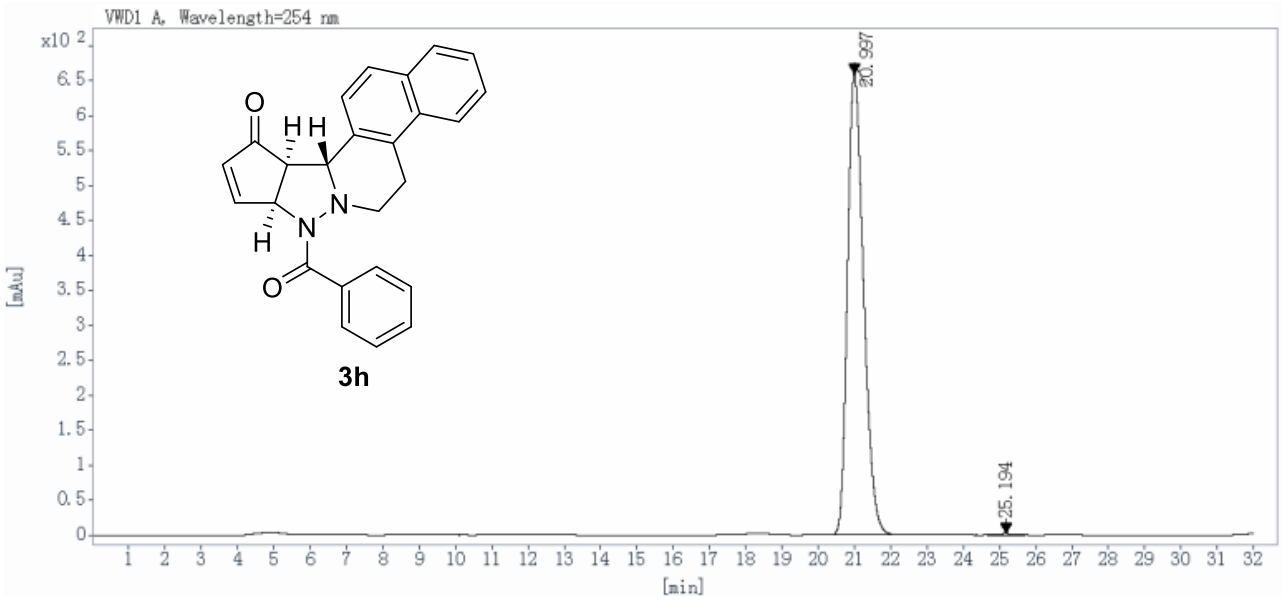


3h

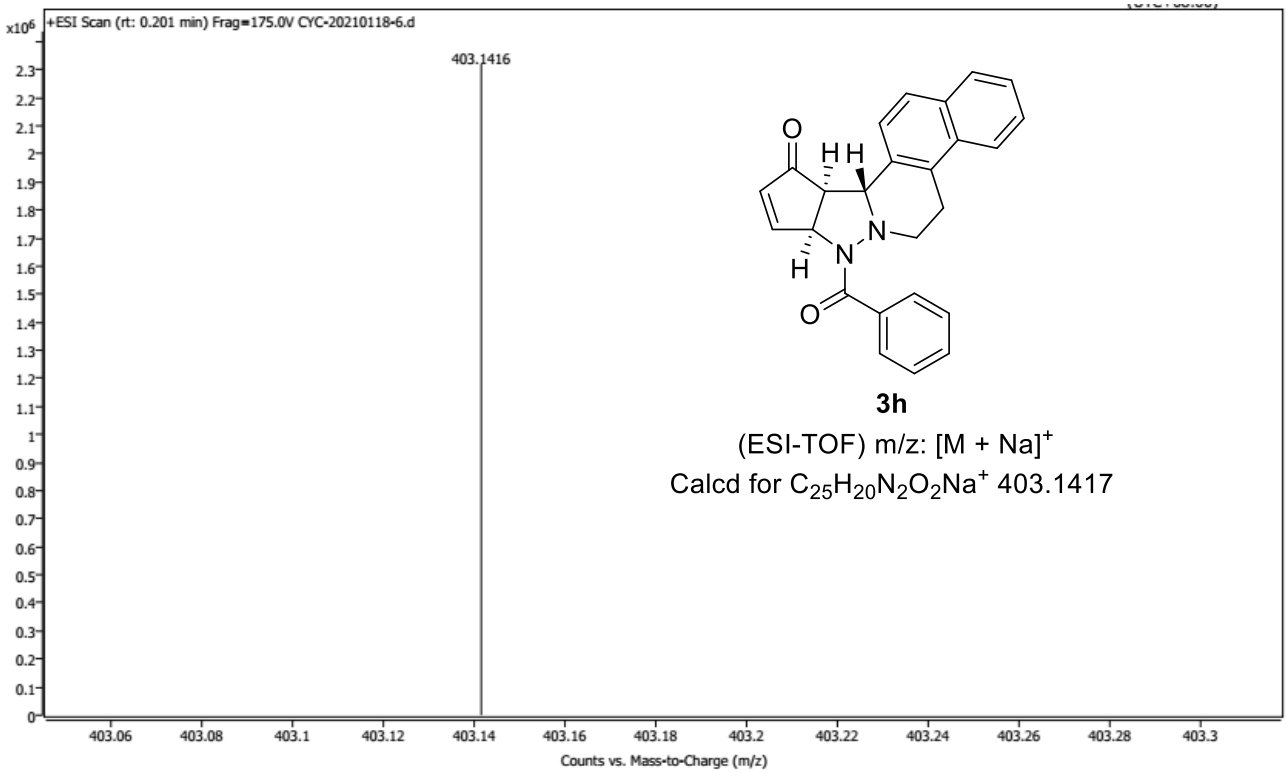
^{13}C NMR (150 MHz, $CDCl_3$)



Ret Time [min]	Peak Type	Width [min]	Height [mAU]	Area [mAU*s]	Area [%]
20.992	BB	0.47	60.8134	1821.4960	49.4746
25.015	BB	0.56	52.2727	1860.1803	50.5254
			Totals:	3681.6763	100.0000



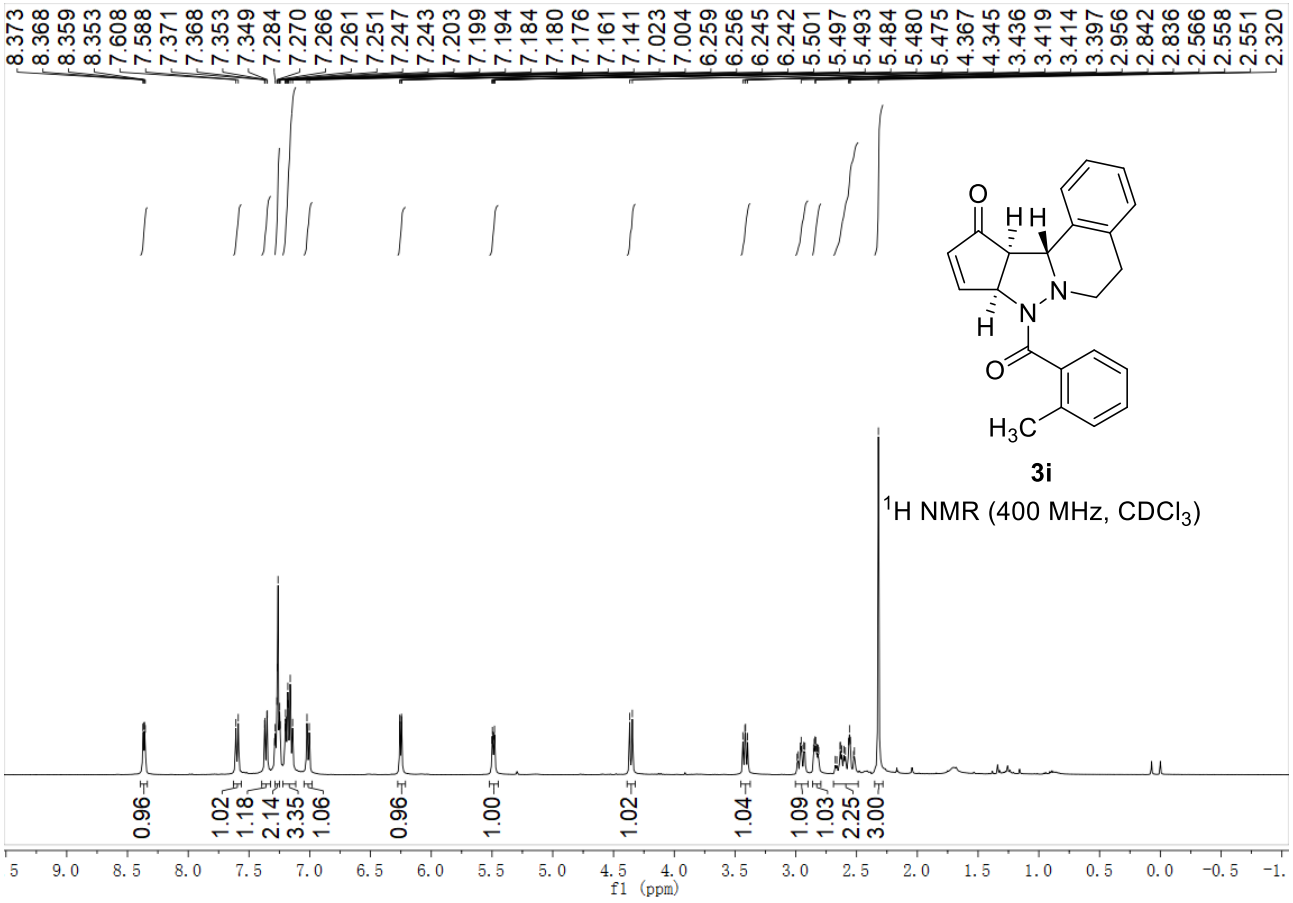
Ret Time [min]	Peak Type	Width [min]	Height [mAU]	Area [mAU*s]	Area [%]
20.997	BB	0.48	659.8284	20368.0234	99.5453
25.194	MM	0.69	2.2434	93.0437	0.4547
			Totals:	20461.0671	100.0000

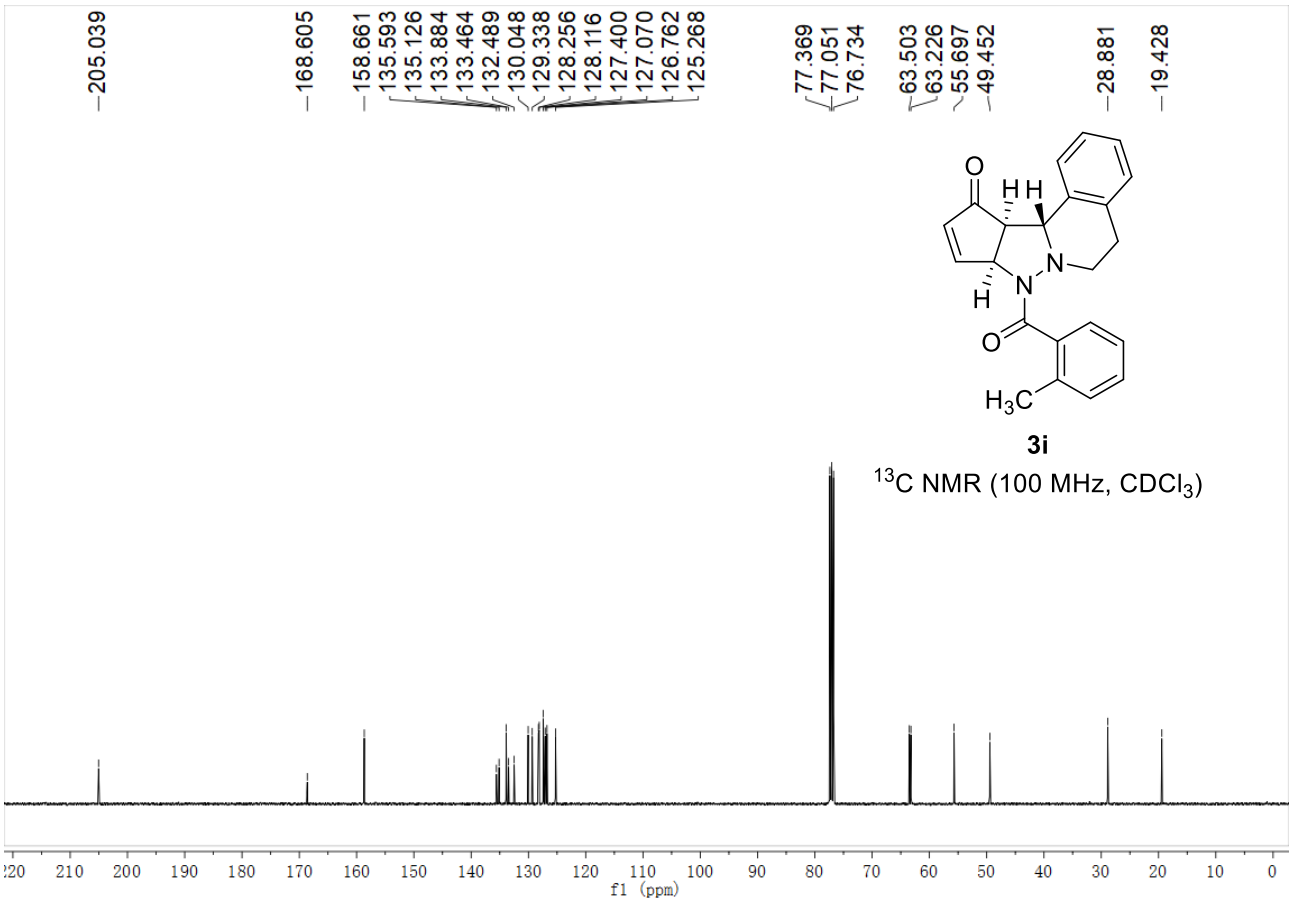


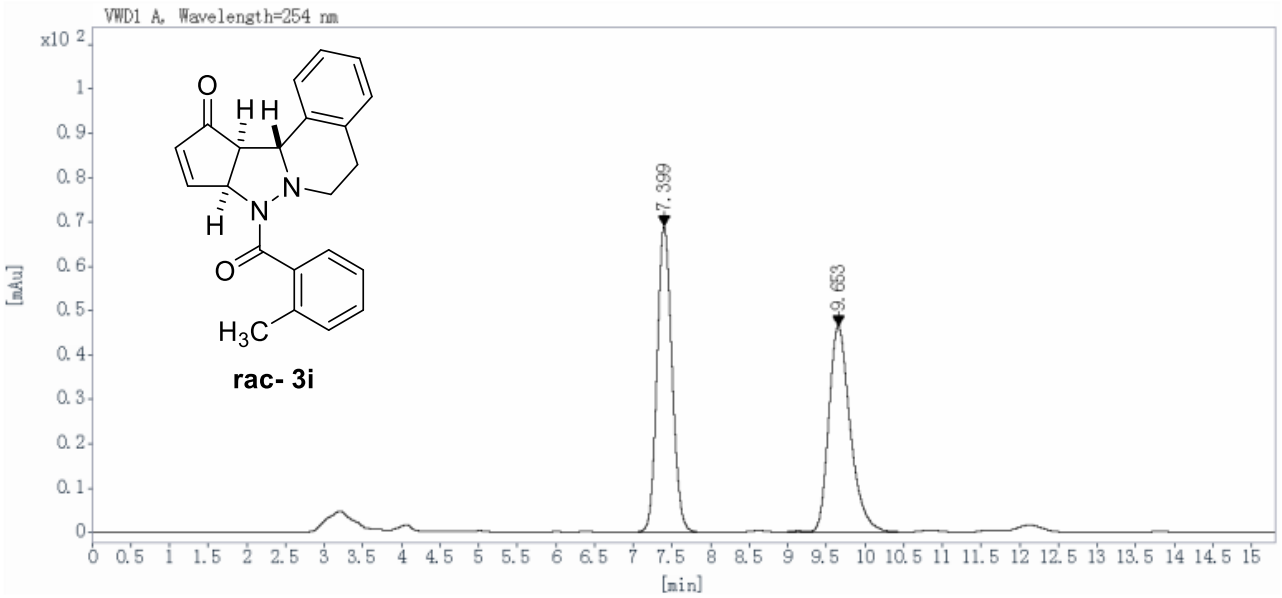
3h

(ESI-TOF) m/z: $[M + Na]^+$

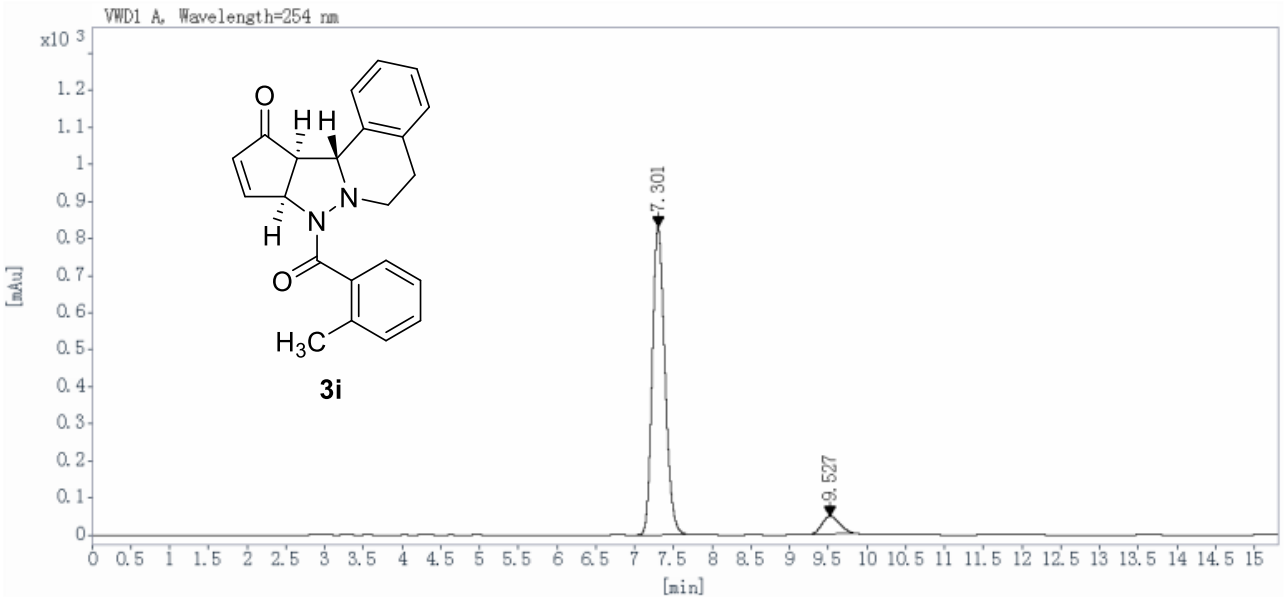
Calcd for $C_{25}H_{20}N_2O_2Na^+$ 403.1417


8.373
8.368
8.359
8.353
7.608
7.588
7.371
7.368
7.353
7.349
7.284
7.270
7.266
7.261
7.251
7.247
7.243
7.203
7.199
7.194
7.184
7.180
7.176
7.161
7.141
7.023
7.004
6.259
6.256
6.245
6.242
5.501
5.497
5.493
5.484
5.480
5.475
4.367
4.345
3.436
3.419
3.414
3.397
2.956
2.842
2.836
2.566
2.558
2.551
2.320
0.96
1.02
1.18
2.14
3.35
1.06
0.96
1.00
1.02
1.04
1.09
1.03
2.25
3.00
f1 (ppm)
3i
1H NMR (400 MHz, CDCl3)

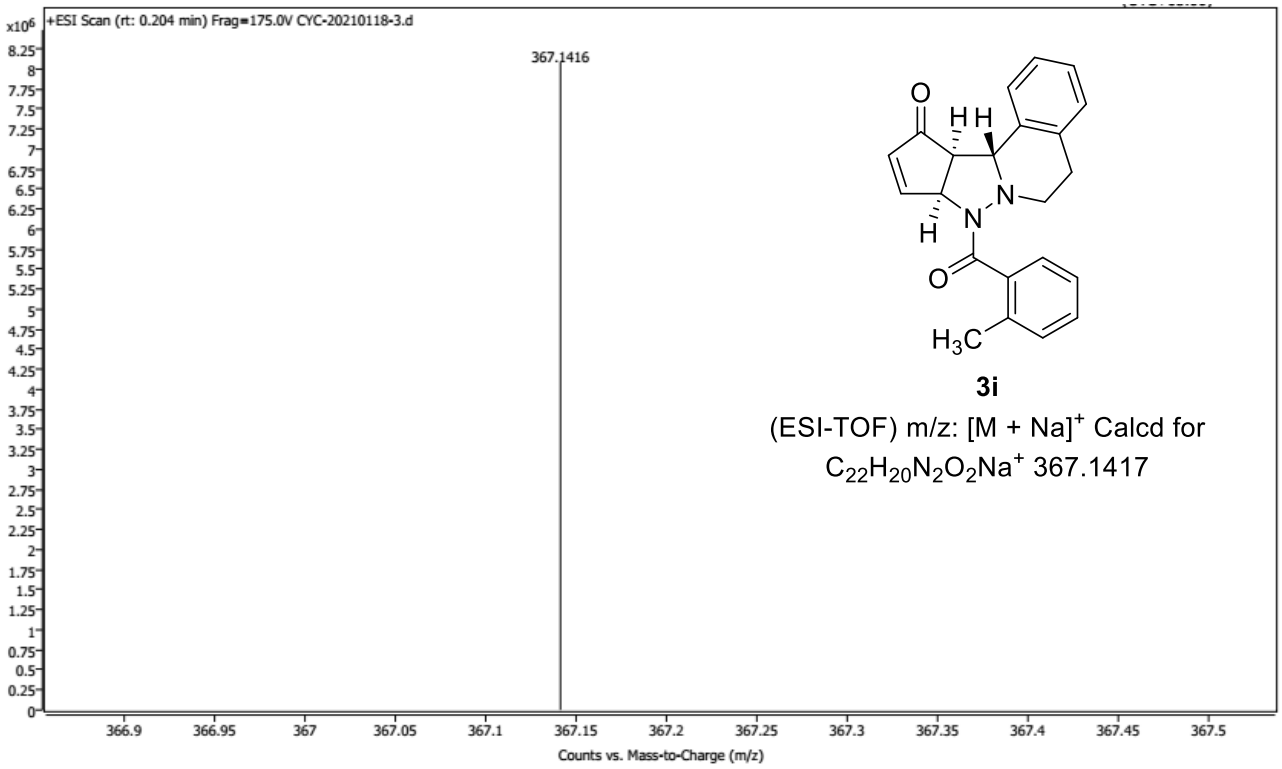

205.039
168.605
158.661
135.593
135.126
133.884
133.464
132.489
130.048
129.338
128.256
128.116
127.400
127.070
126.762
125.268
77.369
77.051
76.734
63.503
63.226
55.697
49.452
28.881
19.428
f1 (ppm)
3i
13C NMR (100 MHz, CDCl3)



Ret Time [min]	Peak Type	Width [min]	Height [mAU]	Area [mAU*s]	Area [%]
7.399	BB	0.21	69.0570	923.1672	50.4563
9.653	VB R	0.30	46.5571	906.4691	49.5437
			Totals:	1829.6363	100.0000

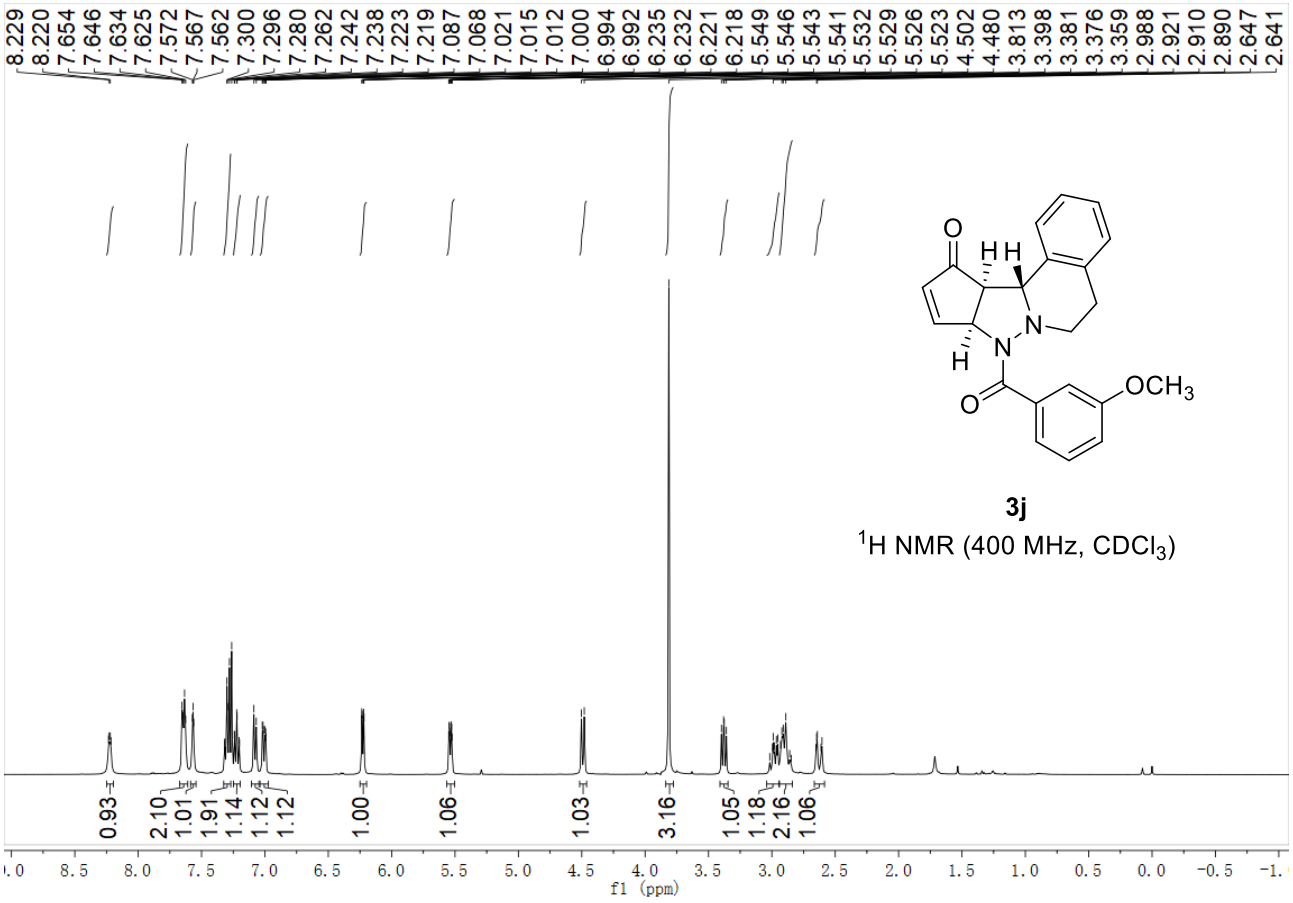


Ret Time [min]	Peak Type	Width [min]	Height [mAU]	Area [mAU*s]	Area [%]
7.301	BBA	0.17	829.9217	9381.7686	92.4930
9.527	BBA	0.25	47.7825	761.4489	7.5070
			Totals:	10143.2174	100.0000



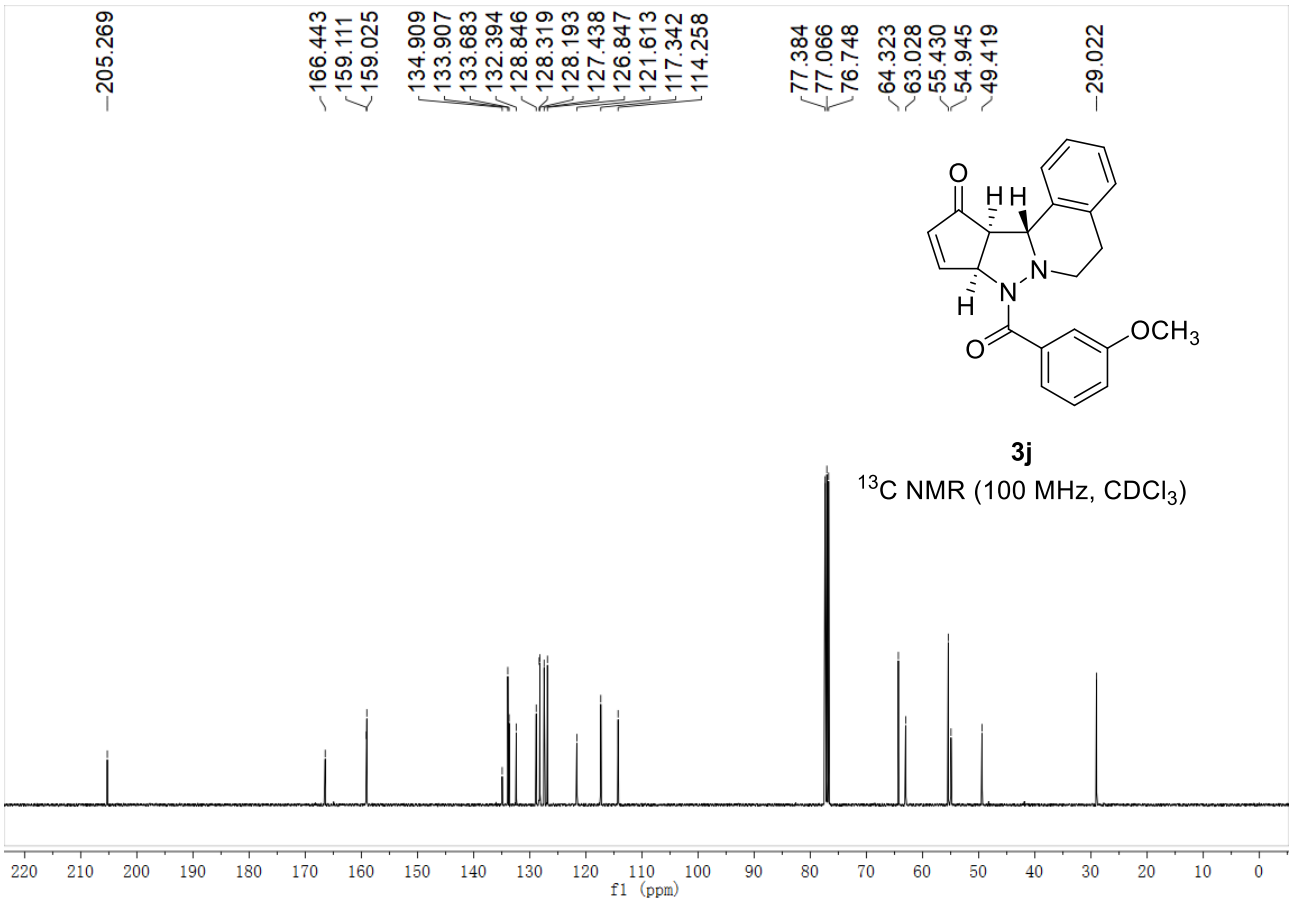
3i

(ESI-TOF) m/z: $[M + Na]^+$ Calcd for $C_{22}H_{20}N_2O_2Na^+$ 367.1417



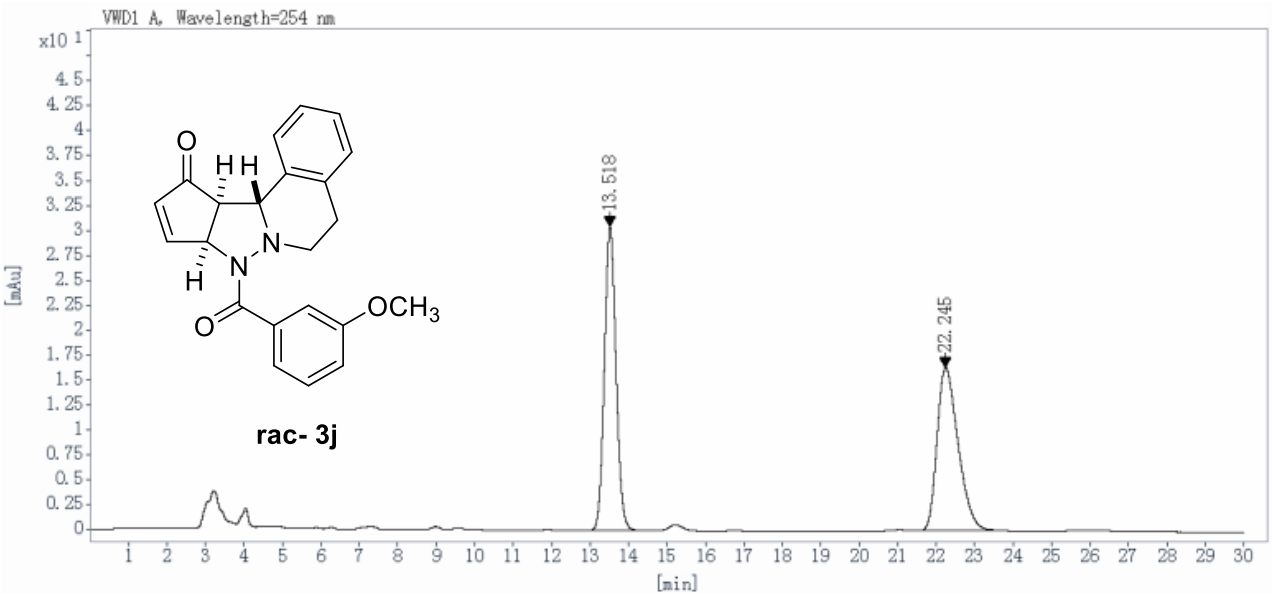
3j

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

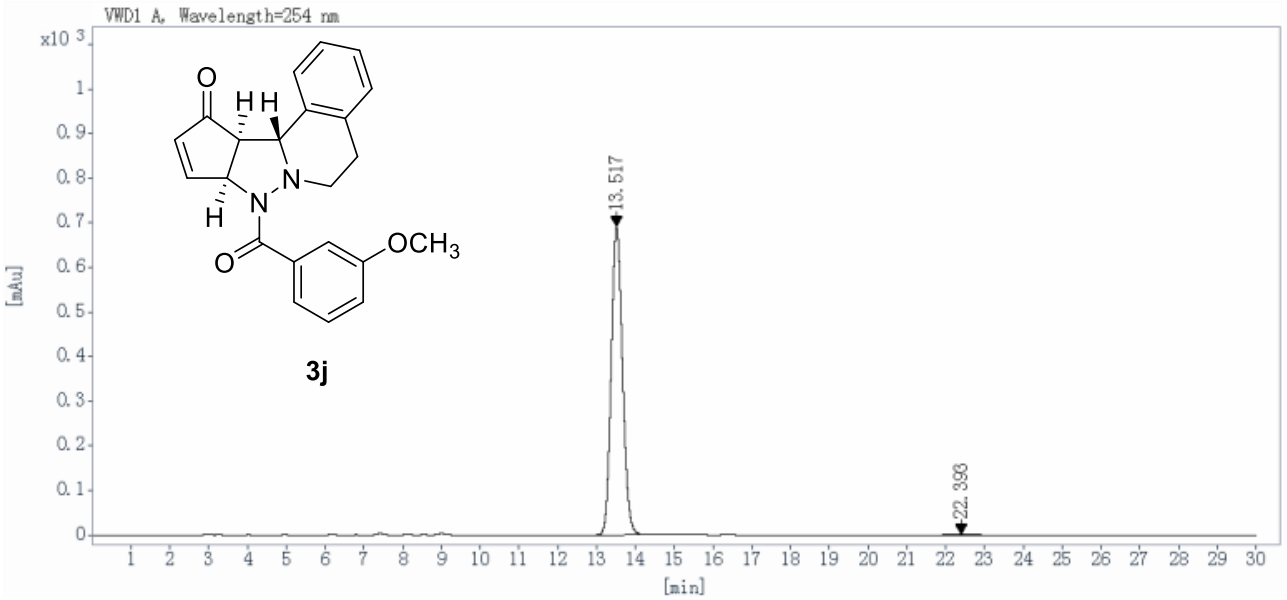


3j

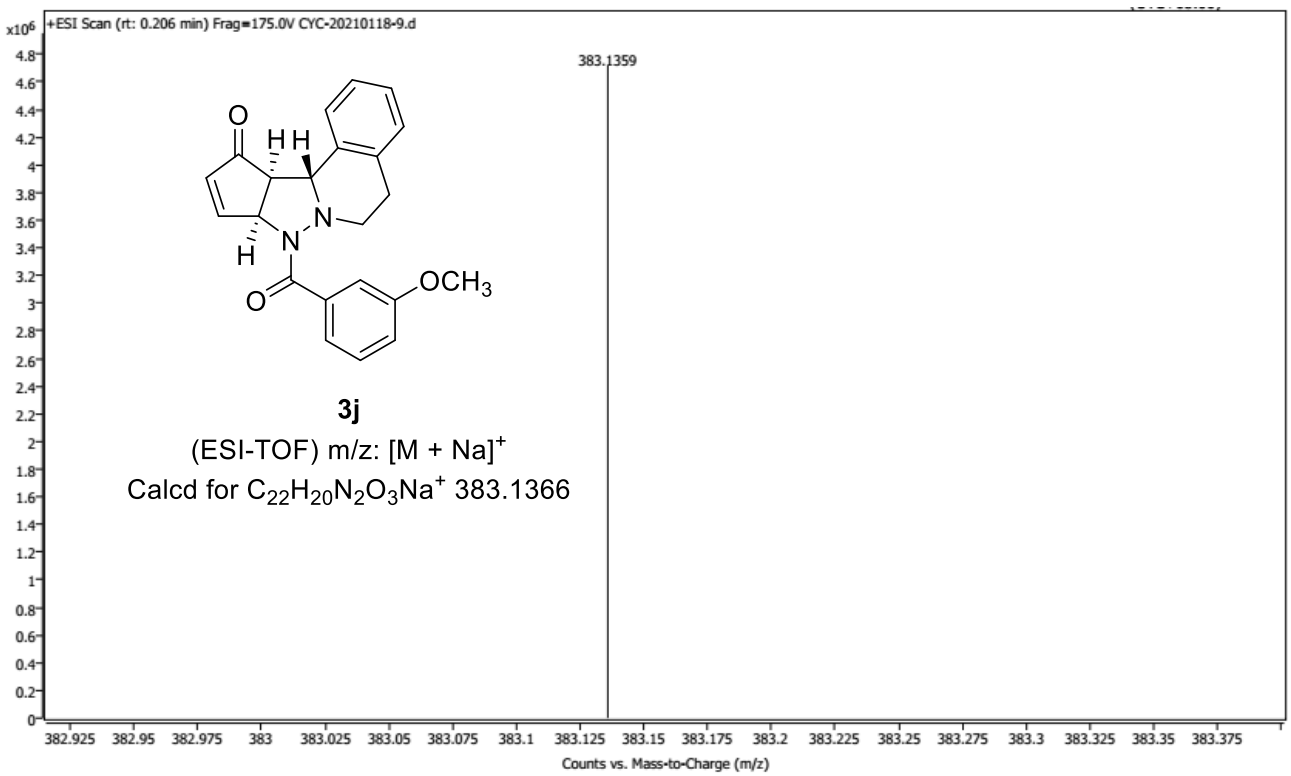
^{13}C NMR (100 MHz, $CDCl_3$)



Ret Time [min]	Peak Type	Width [min]	Height [mAU]	Area [mAU*s]	Area [%]
13.518	BBA	0.33	30.4696	640.0211	50.9014
22.245	BBA	0.58	16.3081	617.3542	49.0986
			Totals:	1257.3753	100.0000



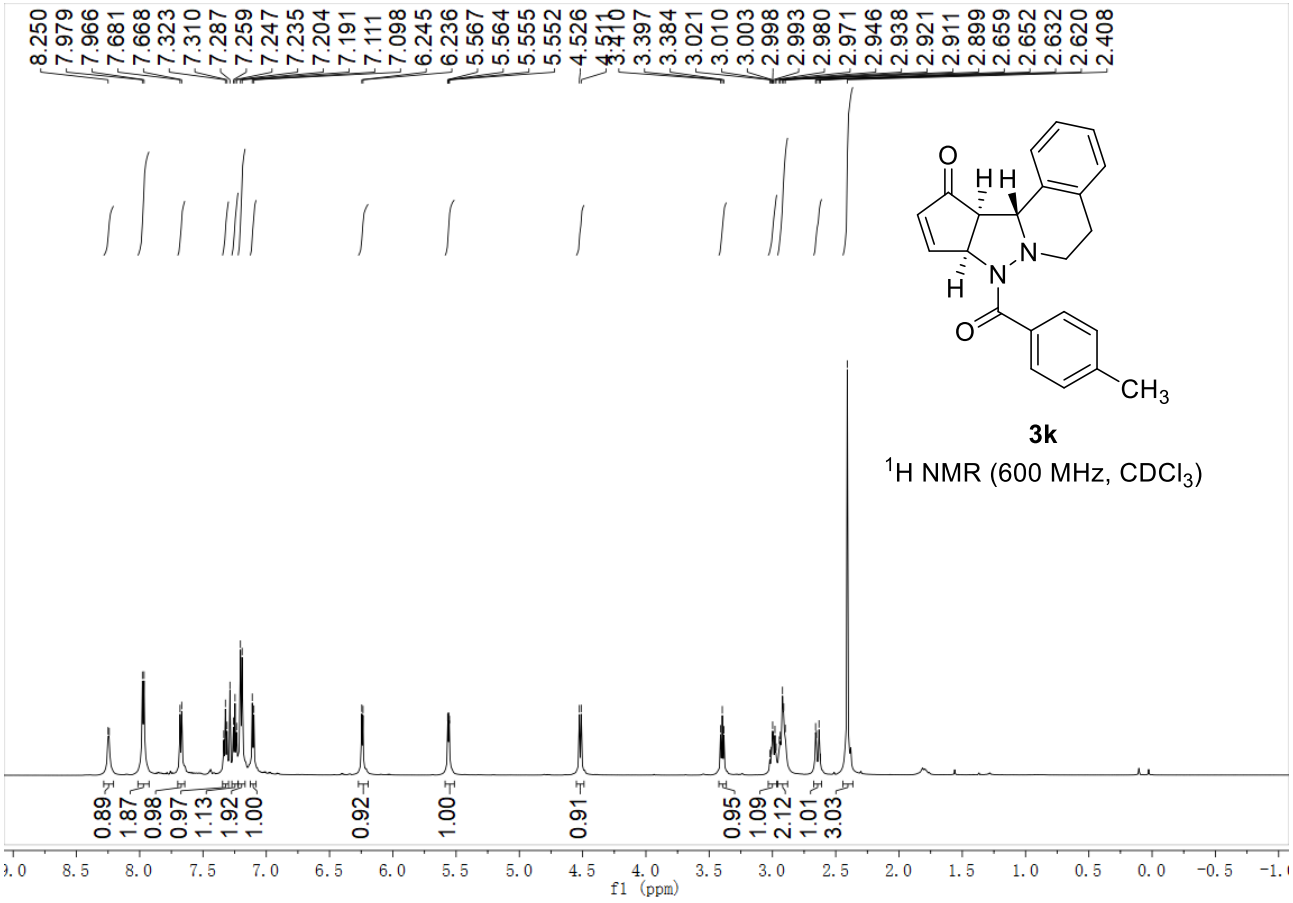
Ret Time [min]	Peak Type	Width [min]	Height [mAU]	Area [mAU*s]	Area [%]
13.517	BBA	0.31	691.1122	13910.4326	99.5868
22.393	BBA	0.56	1.3938	57.7200	0.4132
			Totals:	13968.1527	100.0000



3j

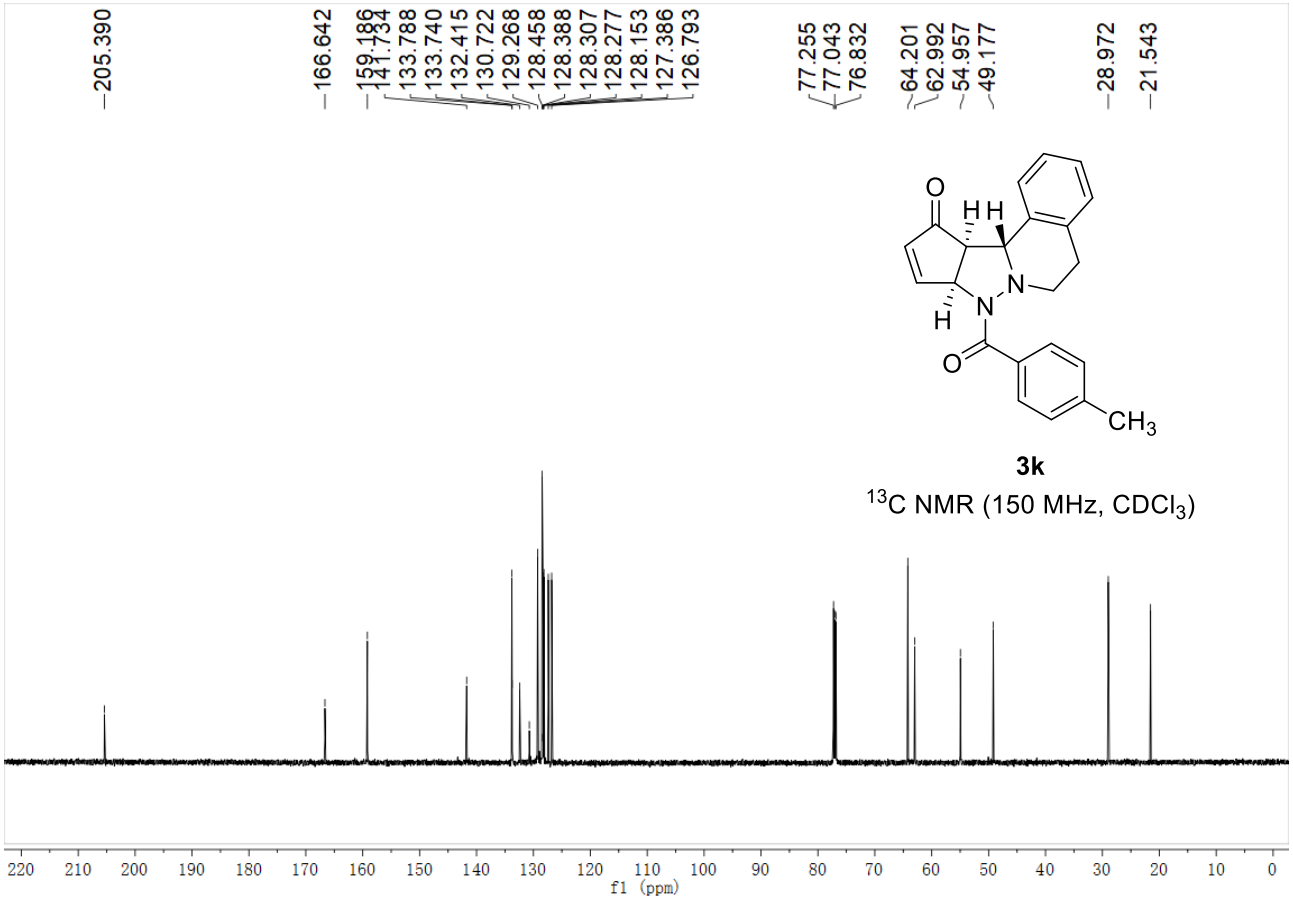
(ESI-TOF) m/z: $[M + Na]^+$

Calcd for $C_{22}H_{20}N_2O_3Na^+$ 383.1366



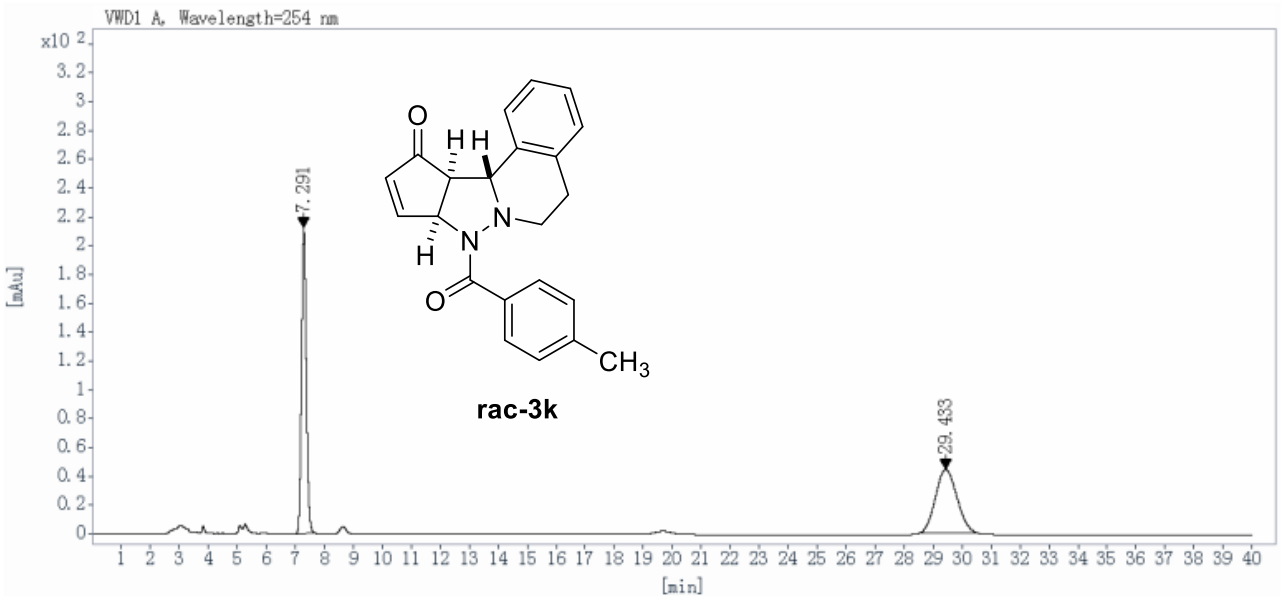
3k

^{1}H NMR (600 MHz, $CDCl_3$)

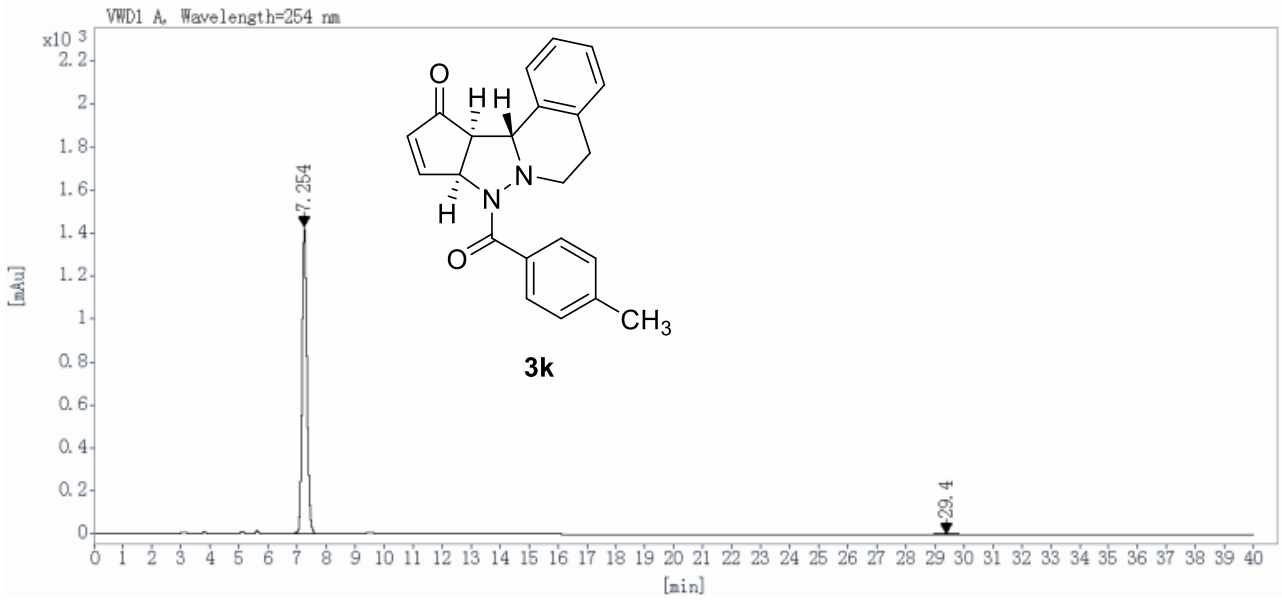


3k

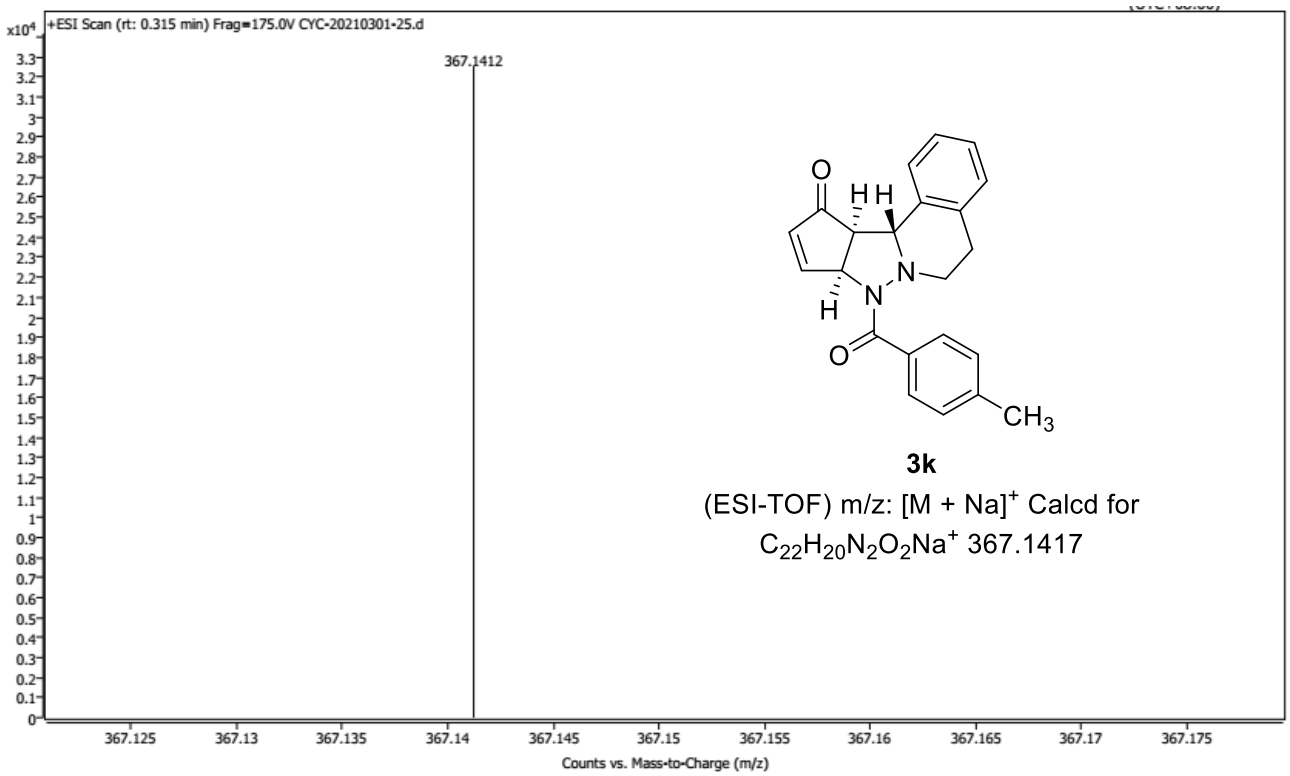
^{13}C NMR (150 MHz, $CDCl_3$)



Ret Time [min]	Peak Type	Width [min]	Height [mAU]	Area [mAU*s]	Area [%]
7.291	BBA	0.18	212.0766	2428.7693	51.8485
29.433	BBA	0.81	43.8144	2255.5854	48.1515
			Totals:	4684.3547	100.0000

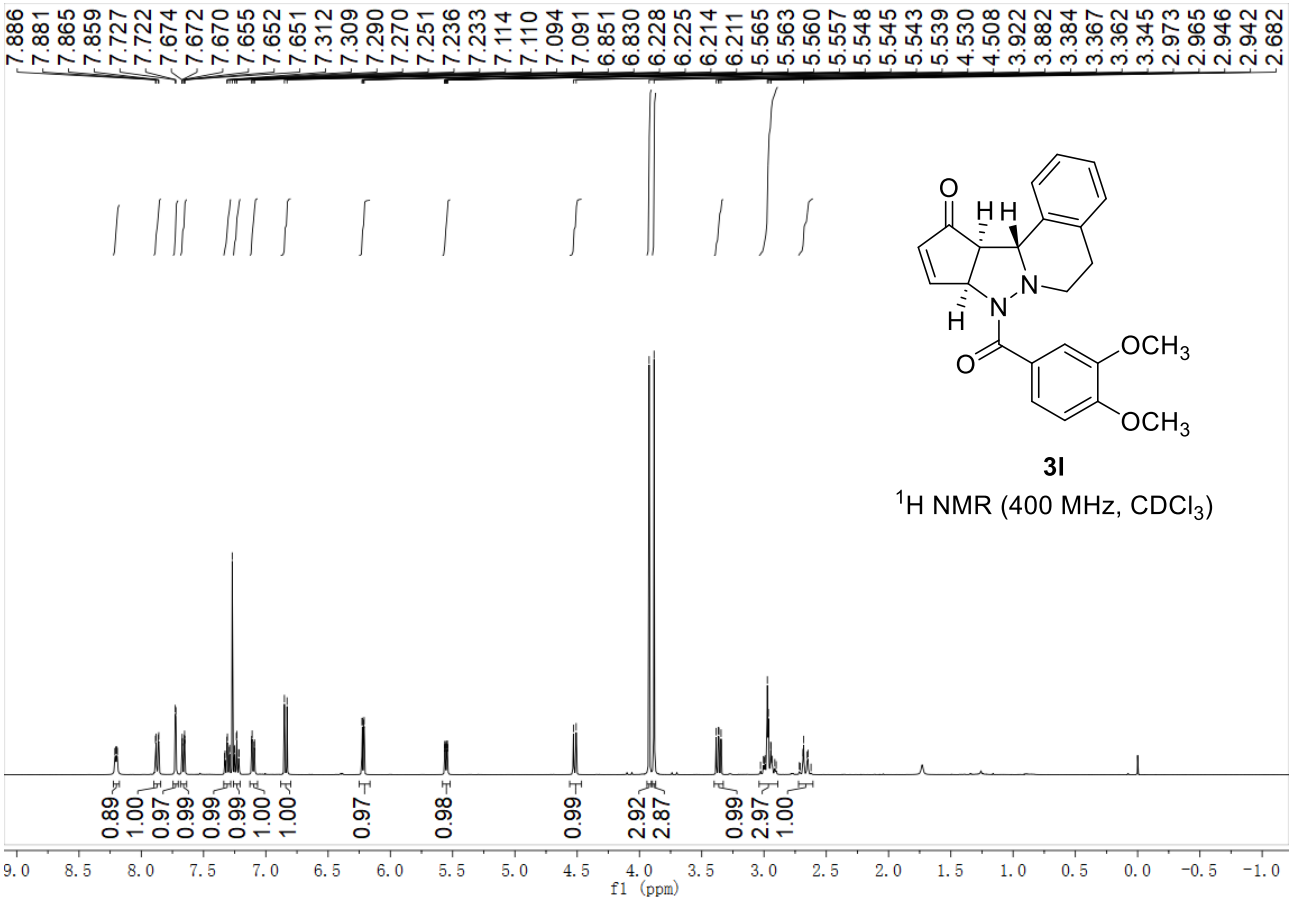


Ret Time [min]	Peak Type	Width [min]	Height [mAU]	Area [mAU*s]	Area [%]
7.254	BBA	0.18	1428.7936	16565.1152	99.6622
29.400	BB	0.64	1.0547	56.1430	0.3378
			Totals:	16621.2582	100.0000



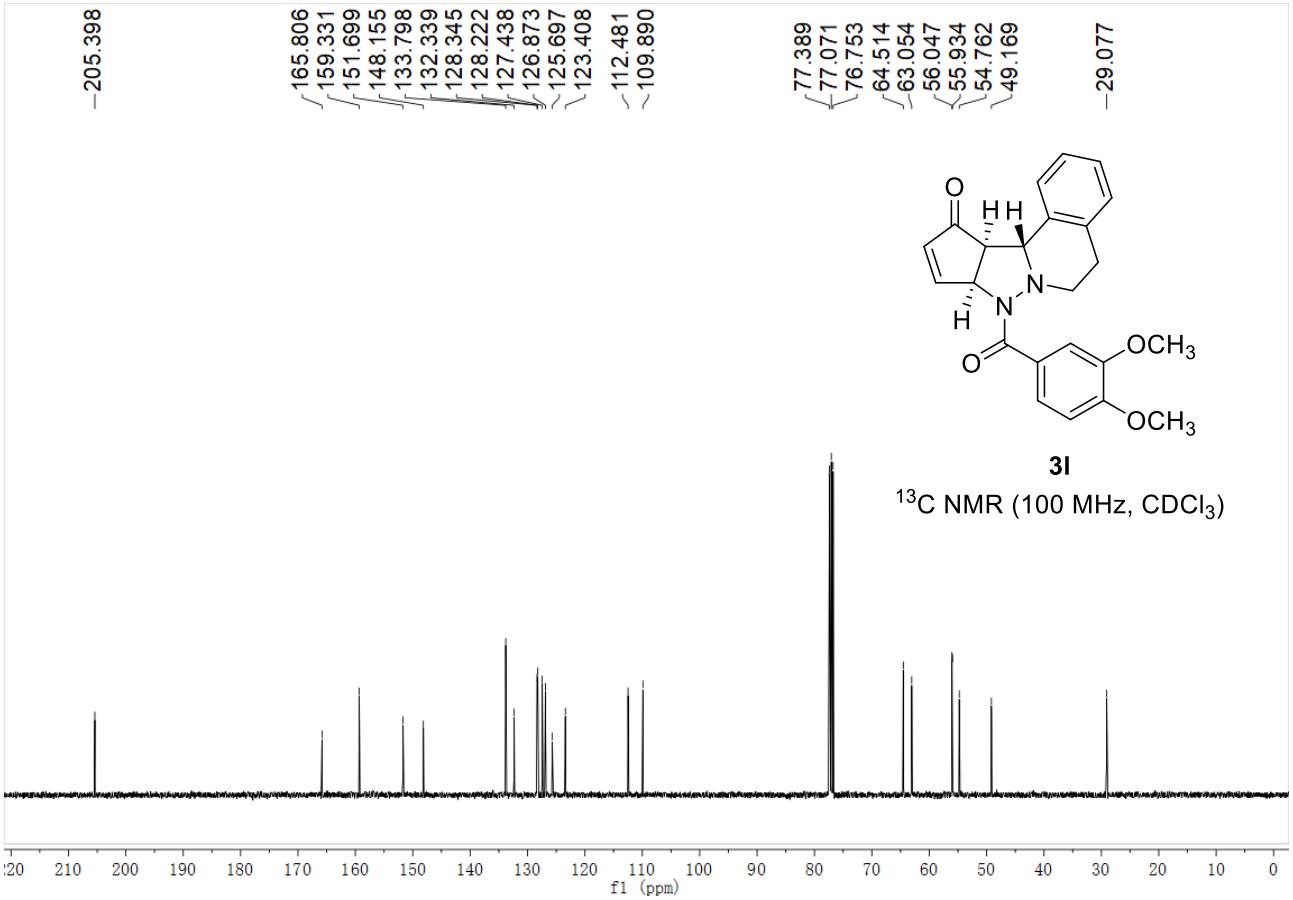
3k

(ESI-TOF) m/z: $[M + Na]^+$ Calcd for $C_{22}H_{20}N_2O_2Na^+$ 367.1417



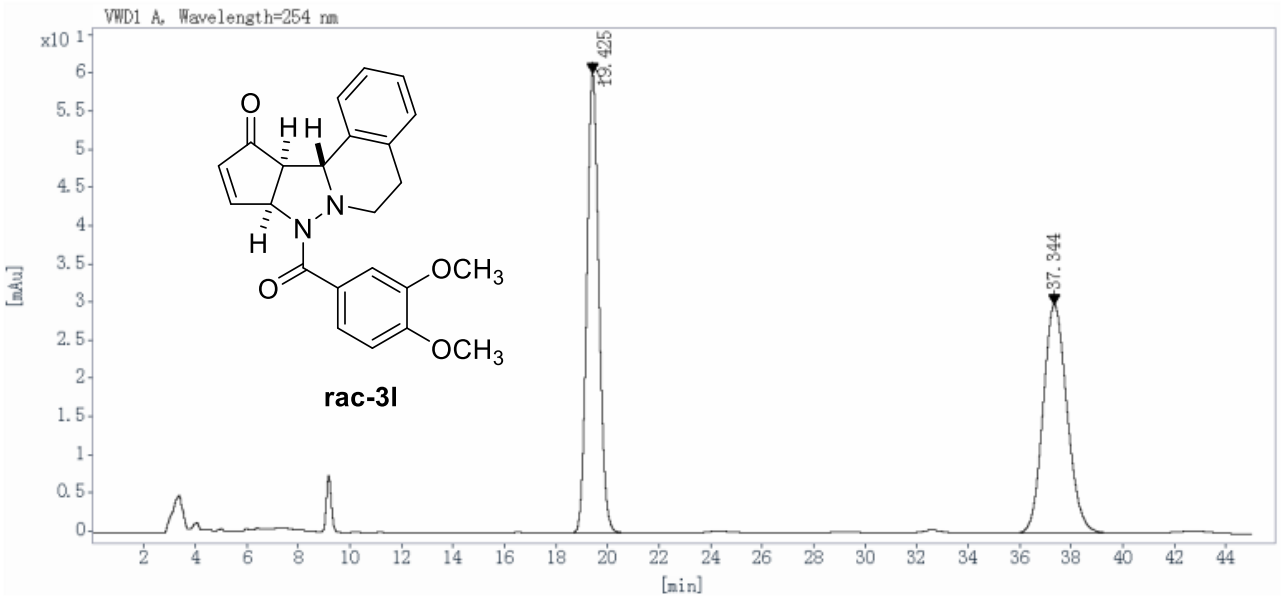
3l

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

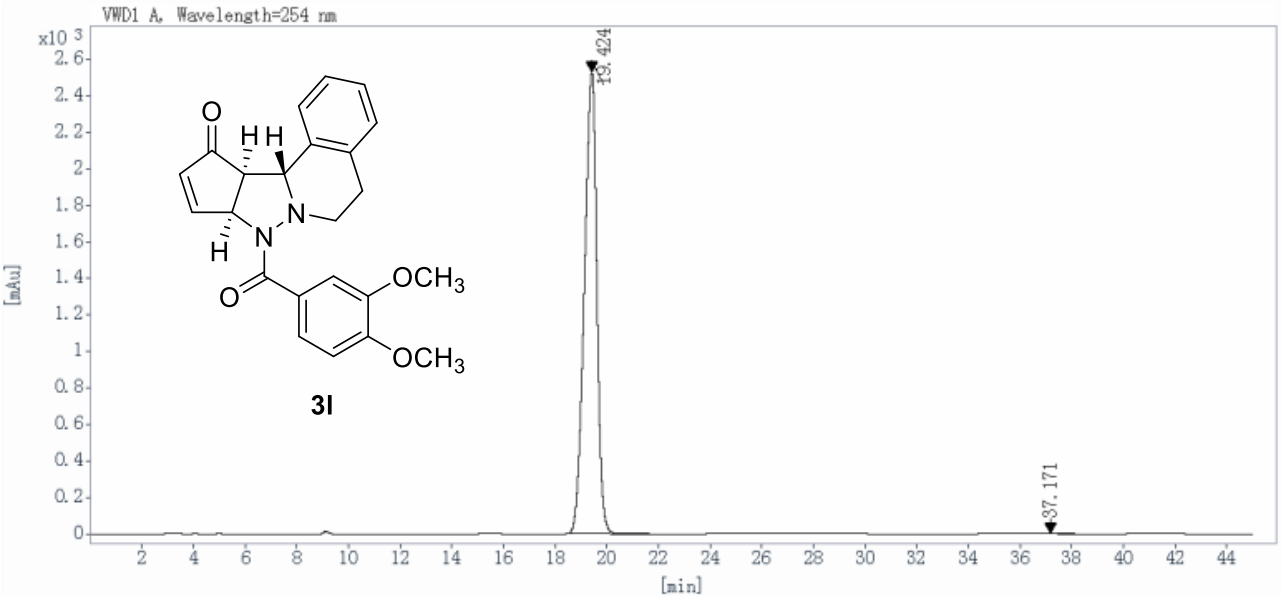


3l

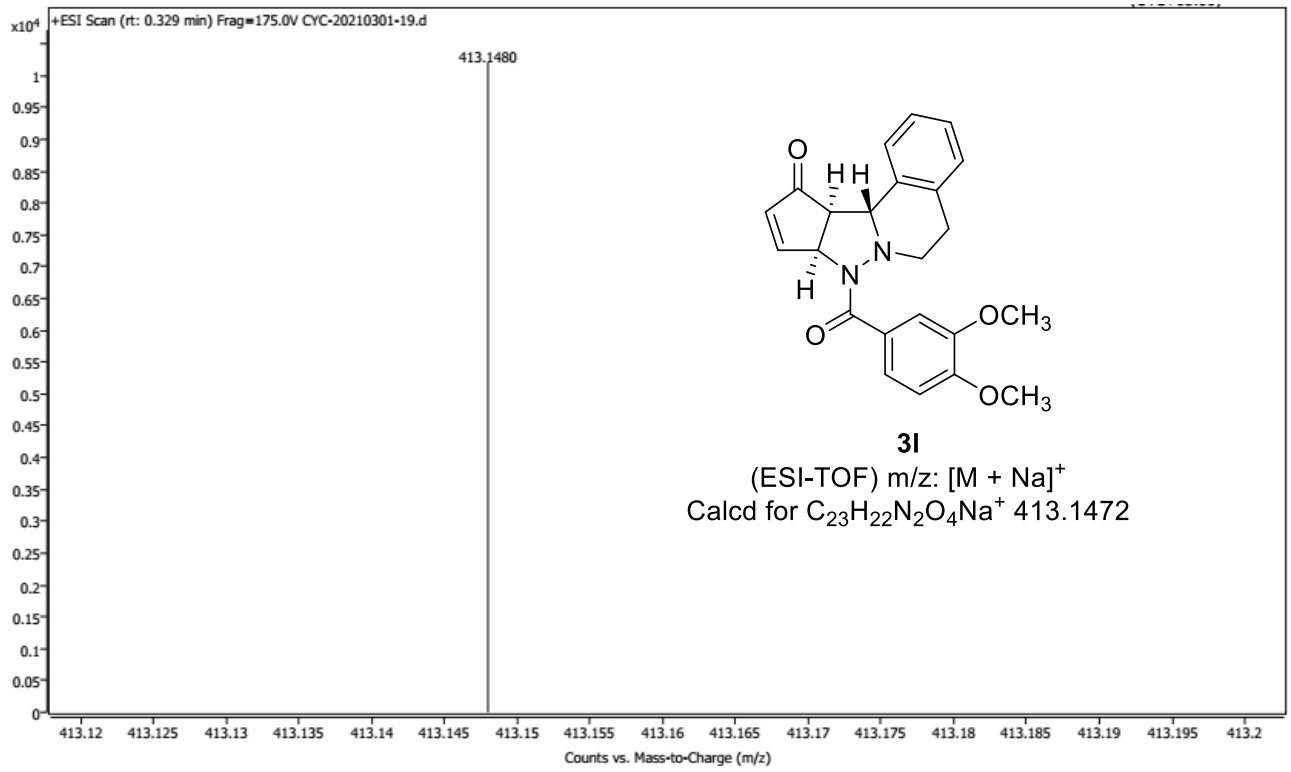
^{13}C NMR (100 MHz, $CDCl_3$)



Ret Time [min]	Peak Type	Width [min]	Height [mAU]	Area [mAU*s]	Area [%]
19.425	BB	0.50	60.2352	1953.8997	50.1886
37.344	BBA	1.00	29.9705	1939.2122	49.8114
			Totals:	3893.1118	100.0000



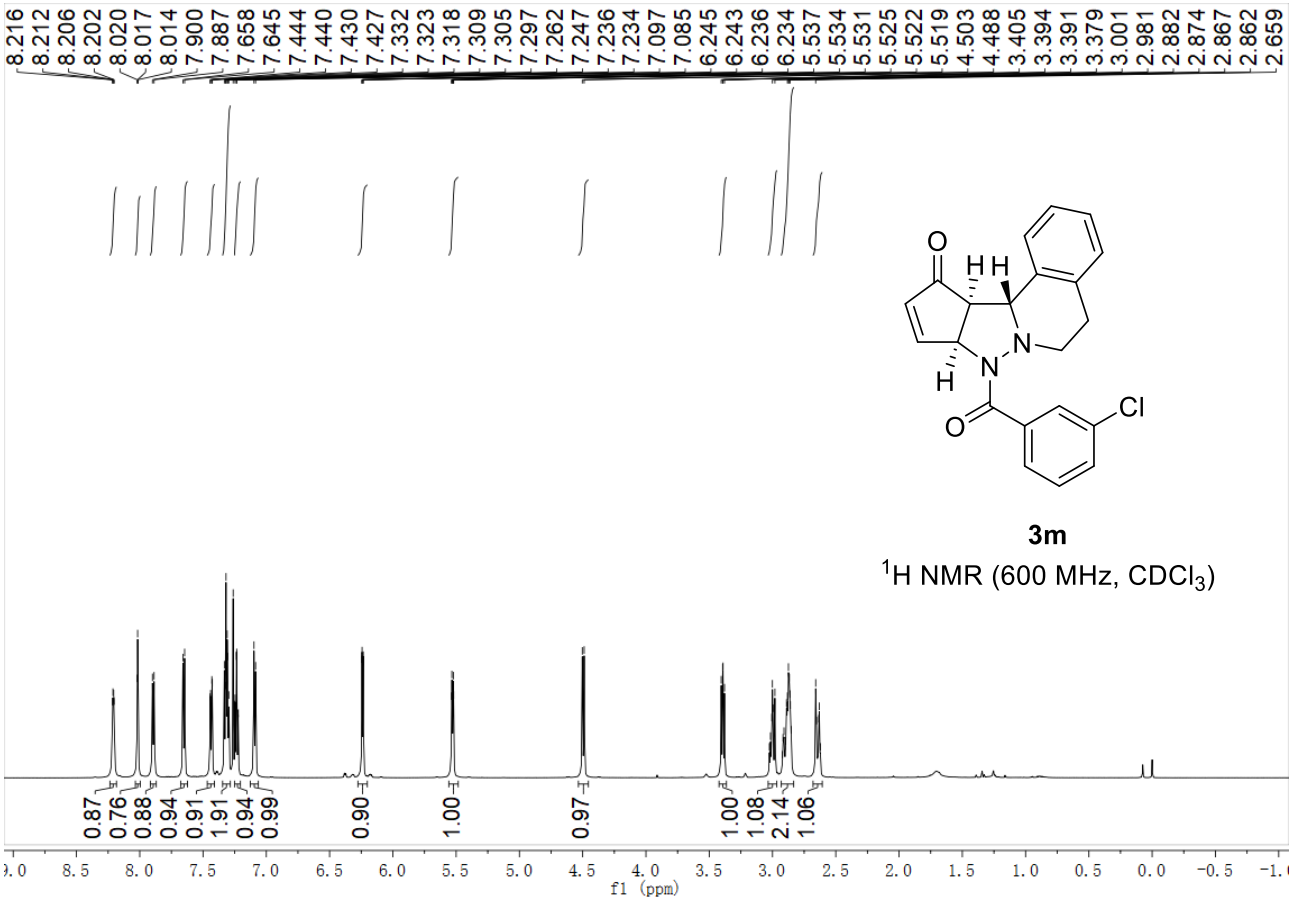
Ret Time [min]	Peak Type	Width [min]	Height [mAU]	Area [mAU*s]	Area [%]
19.424	BB	0.52	2532.0527	84595.3594	99.7394
37.171	BB	0.86	3.6809	221.0669	0.2606
			Totals:	84816.4263	100.0000



3l

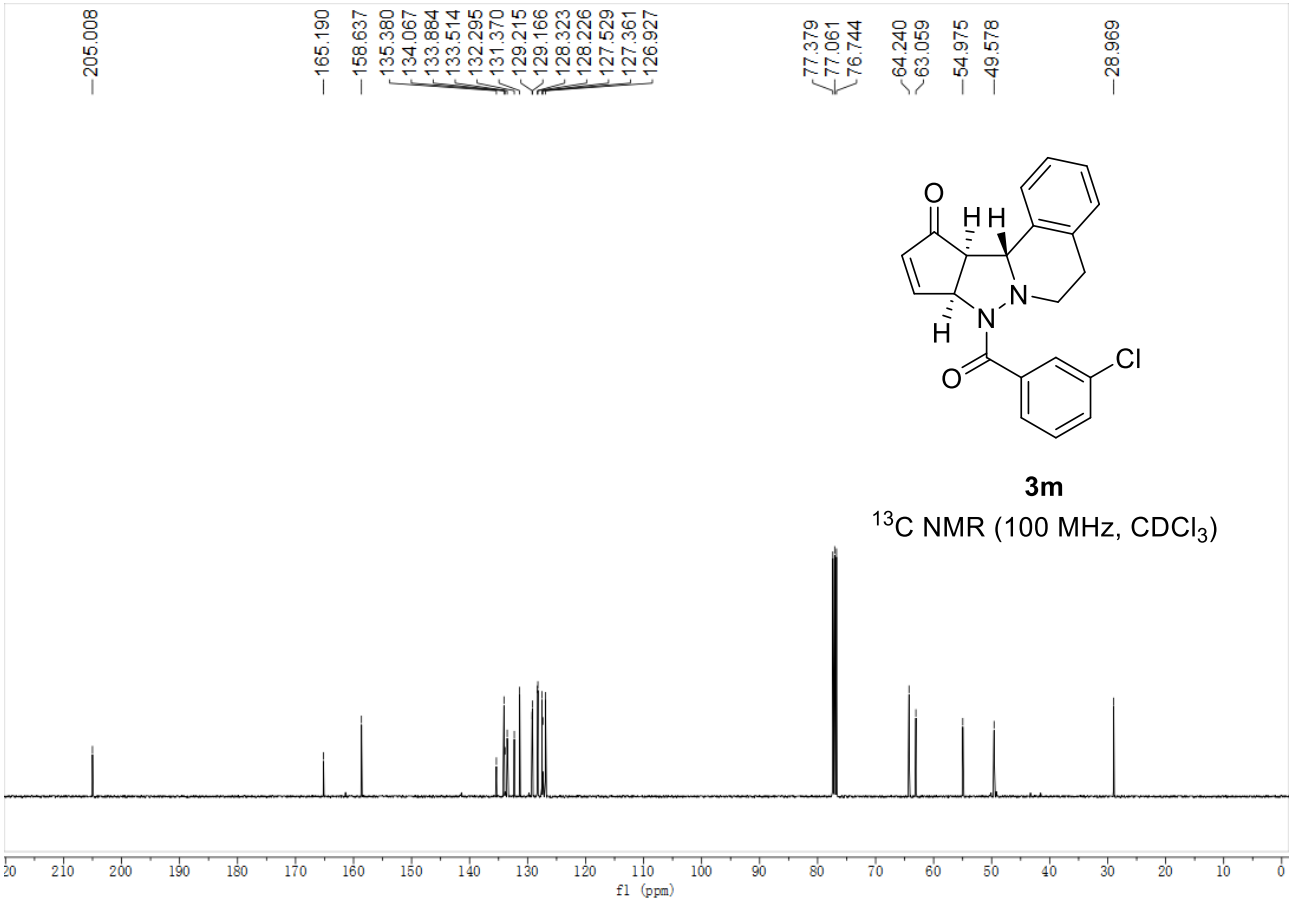
(ESI-TOF) m/z: $[M + Na]^+$

Calcd for $C_{23}H_{22}N_2O_4Na^+$ 413.1472



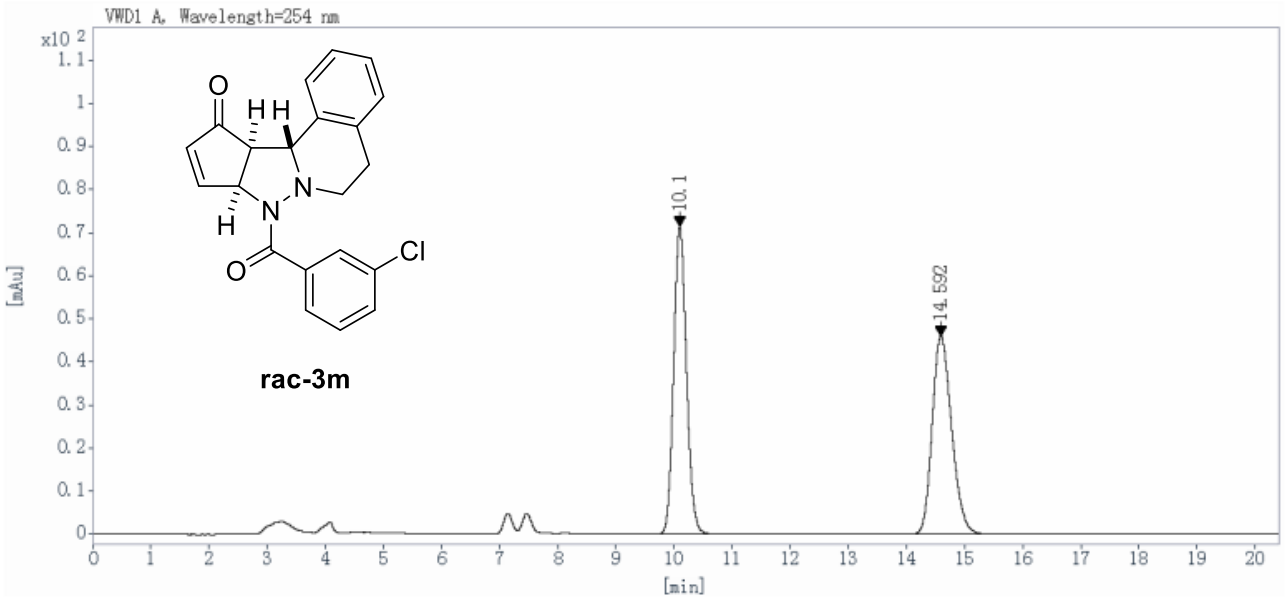
3m

^{1}H NMR (600 MHz, $CDCl_3$)

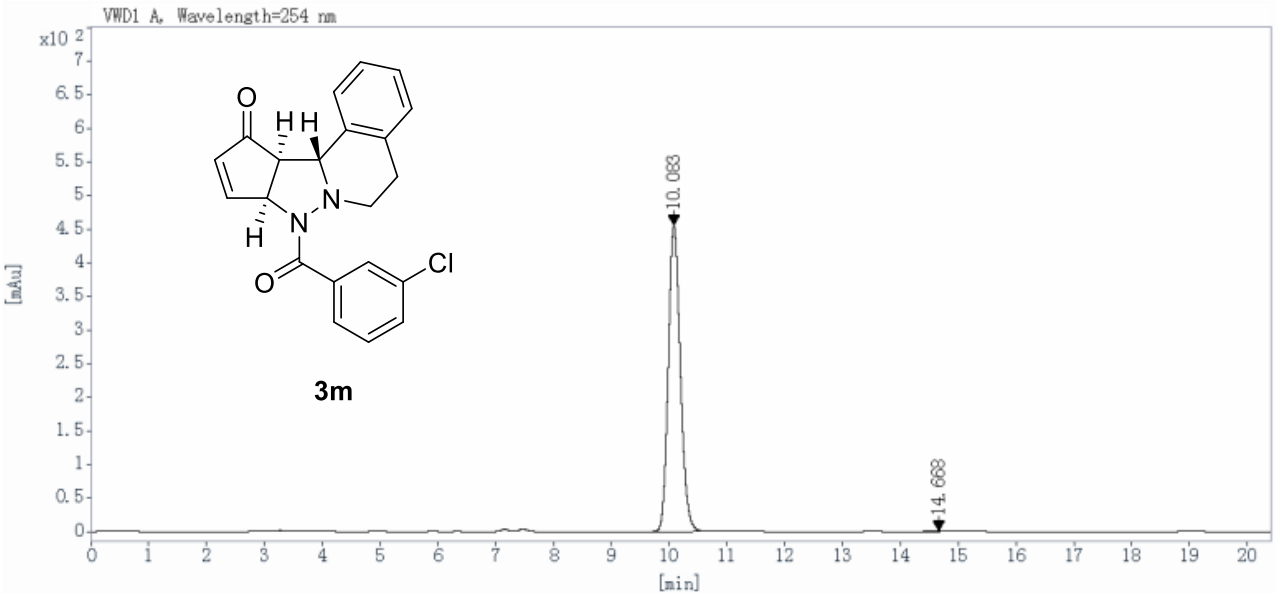


3m

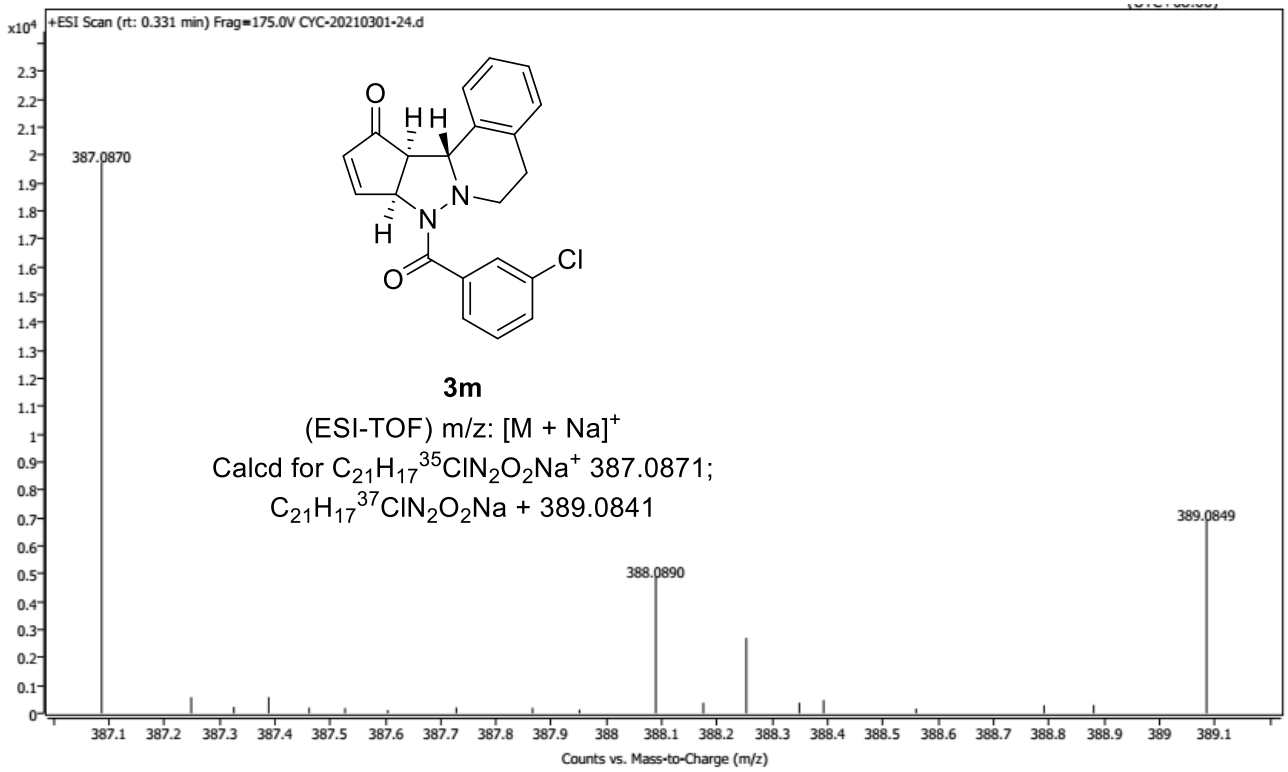
^{13}C NMR (100 MHz, $CDCl_3$)



Ret Time [min]	Peak Type	Width [min]	Height [mAU]	Area [mAU*s]	Area [%]
10.100	BB	0.24	71.3052	1090.1667	50.6116
14.592	BB	0.36	45.8782	1063.8171	49.3884
			Totals:	2153.9839	100.0000



Ret Time [min]	Peak Type	Width [min]	Height [mAU]	Area [mAU*s]	Area [%]
10.083	BB	0.22	455.5820	6600.8755	99.7694
14.668	BB	0.32	0.7138	15.2587	0.2306
			Totals:	6616.1342	100.0000

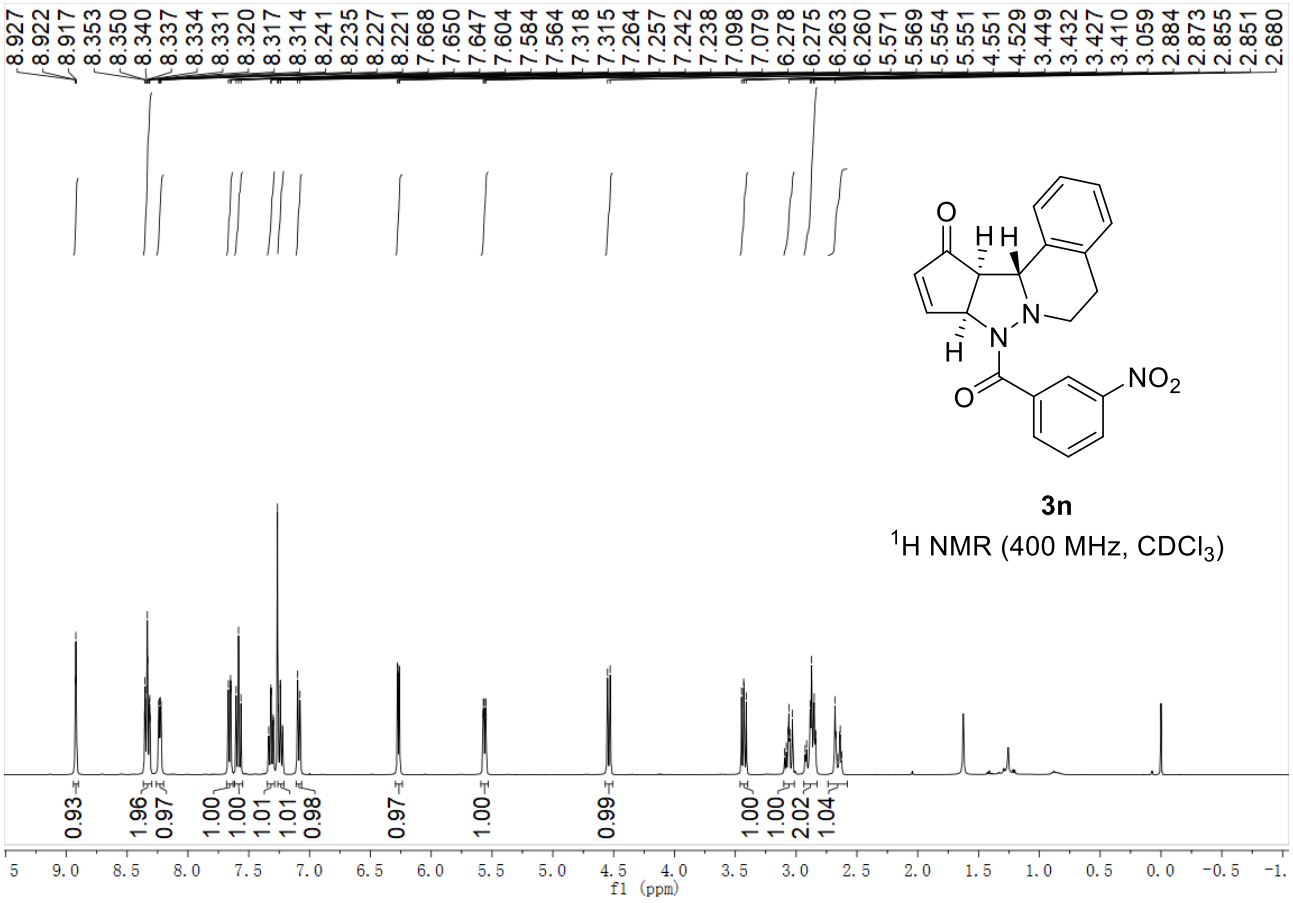


3m

(ESI-TOF) m/z: $[M + Na]^+$

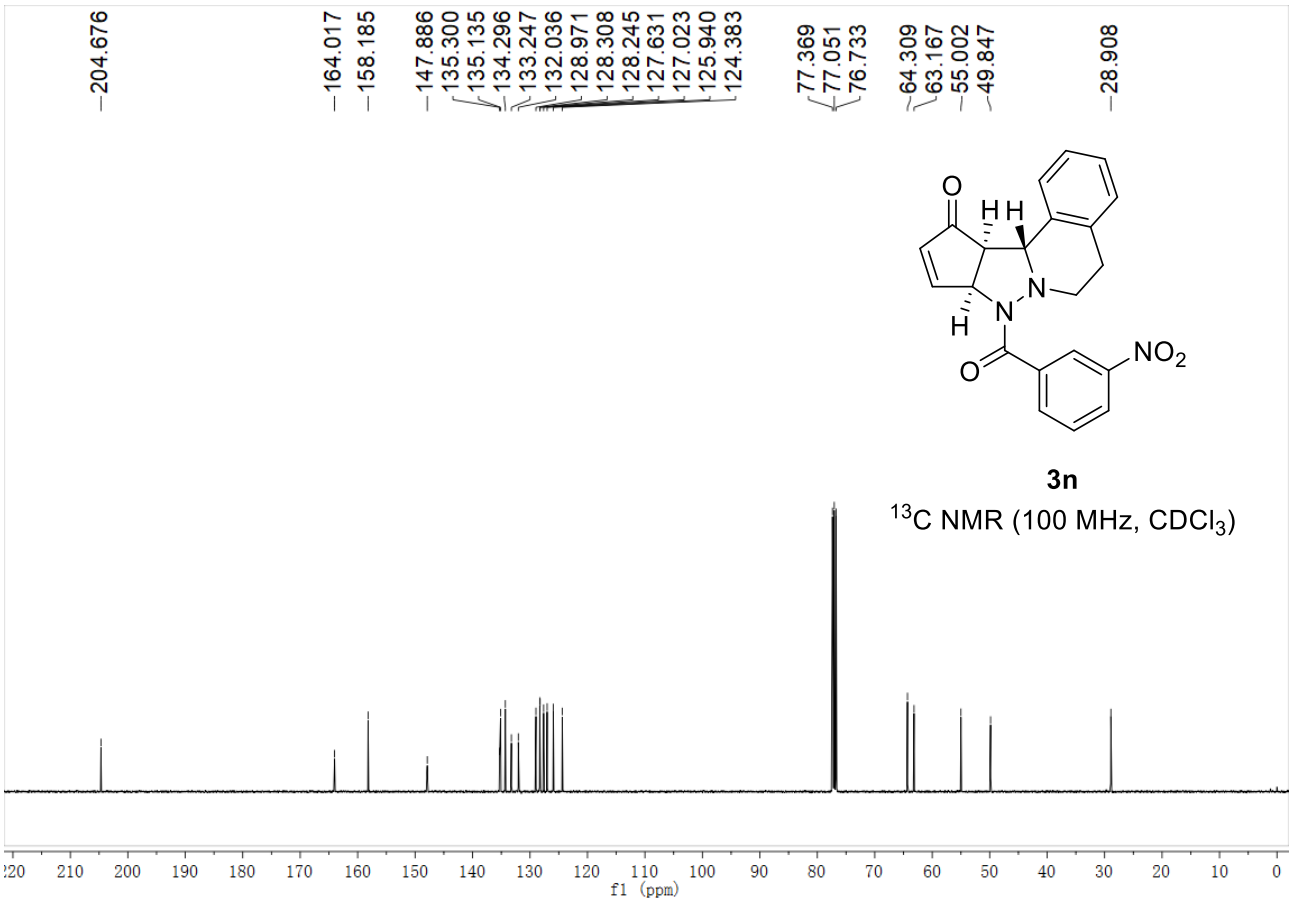
Calcd for $C_{21}H_{17}{}^{35}ClN_2O_2Na^+$ 387.0871;

$C_{21}H_{17}{}^{37}ClN_2O_2Na$ + 389.0841



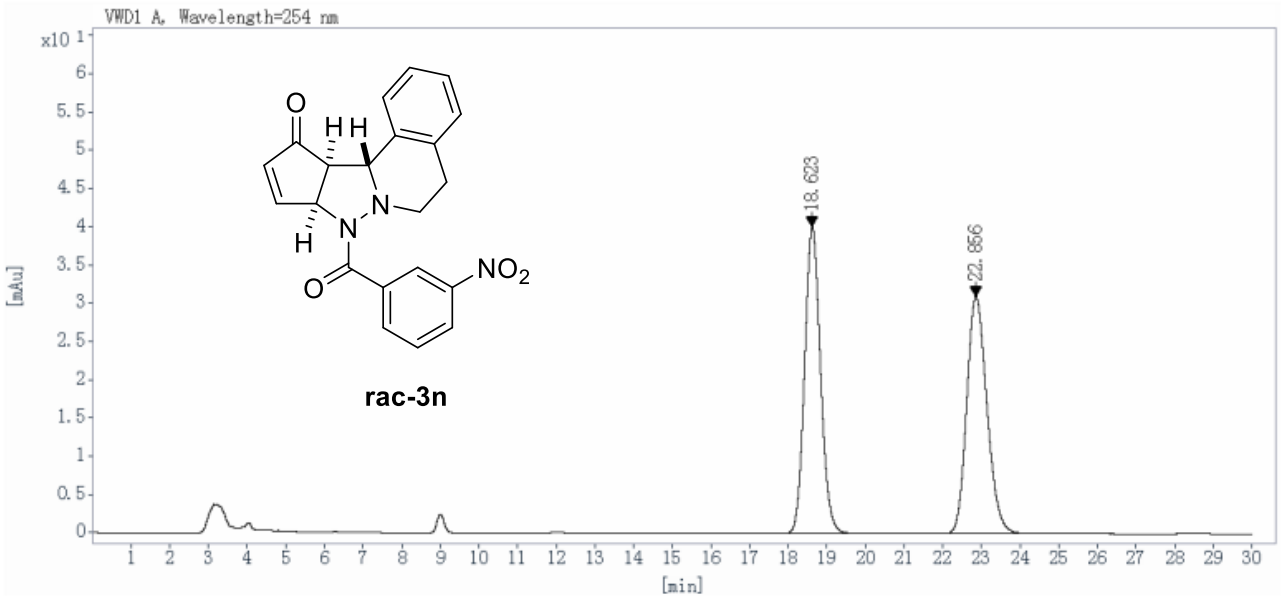
3n

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

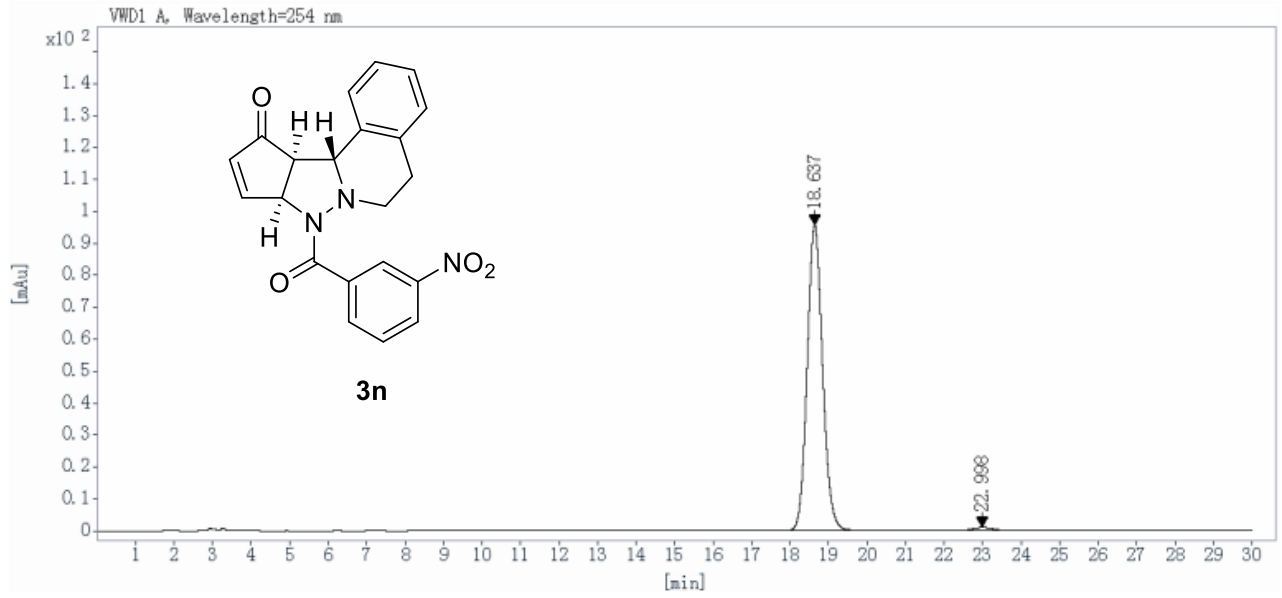


3n

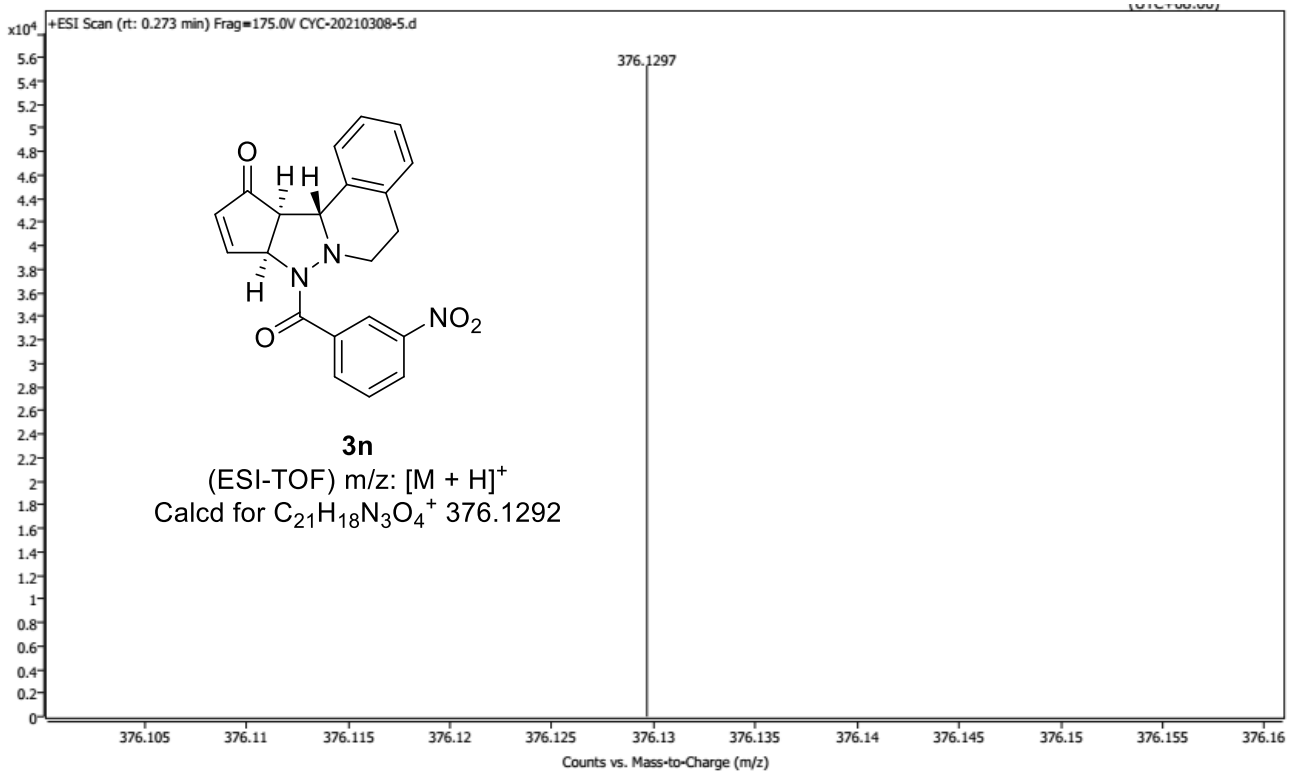
^{13}C NMR (100 MHz, $CDCl_3$)

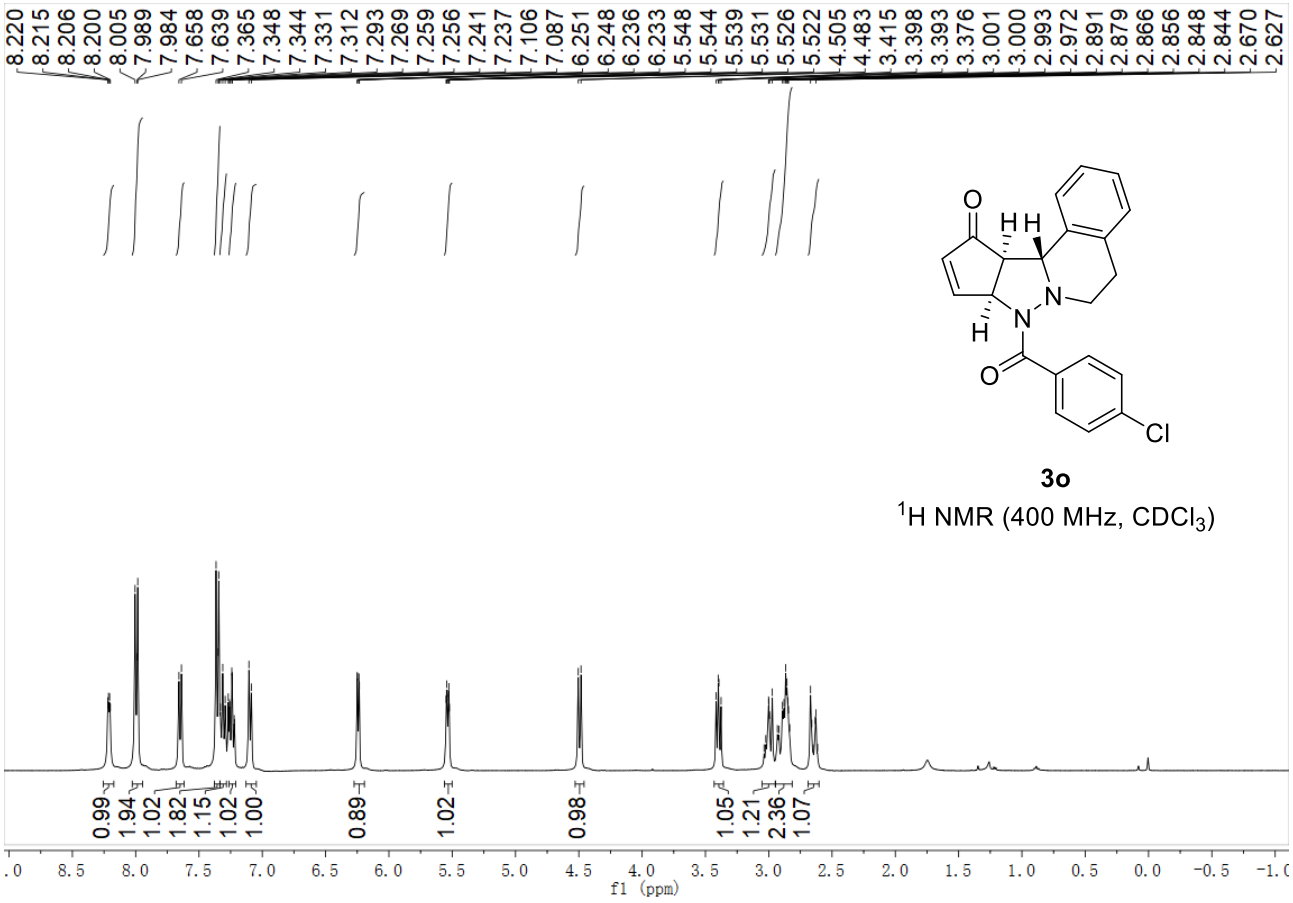


Ret Time [min]	Peak Type	Width [min]	Height [mAU]	Area [mAU*s]	Area [%]
18.623	BB	0.44	40.0911	1144.5367	50.3887
22.856	BB	0.56	31.0314	1126.8800	49.6113
			Totals:	2271.4167	100.0000



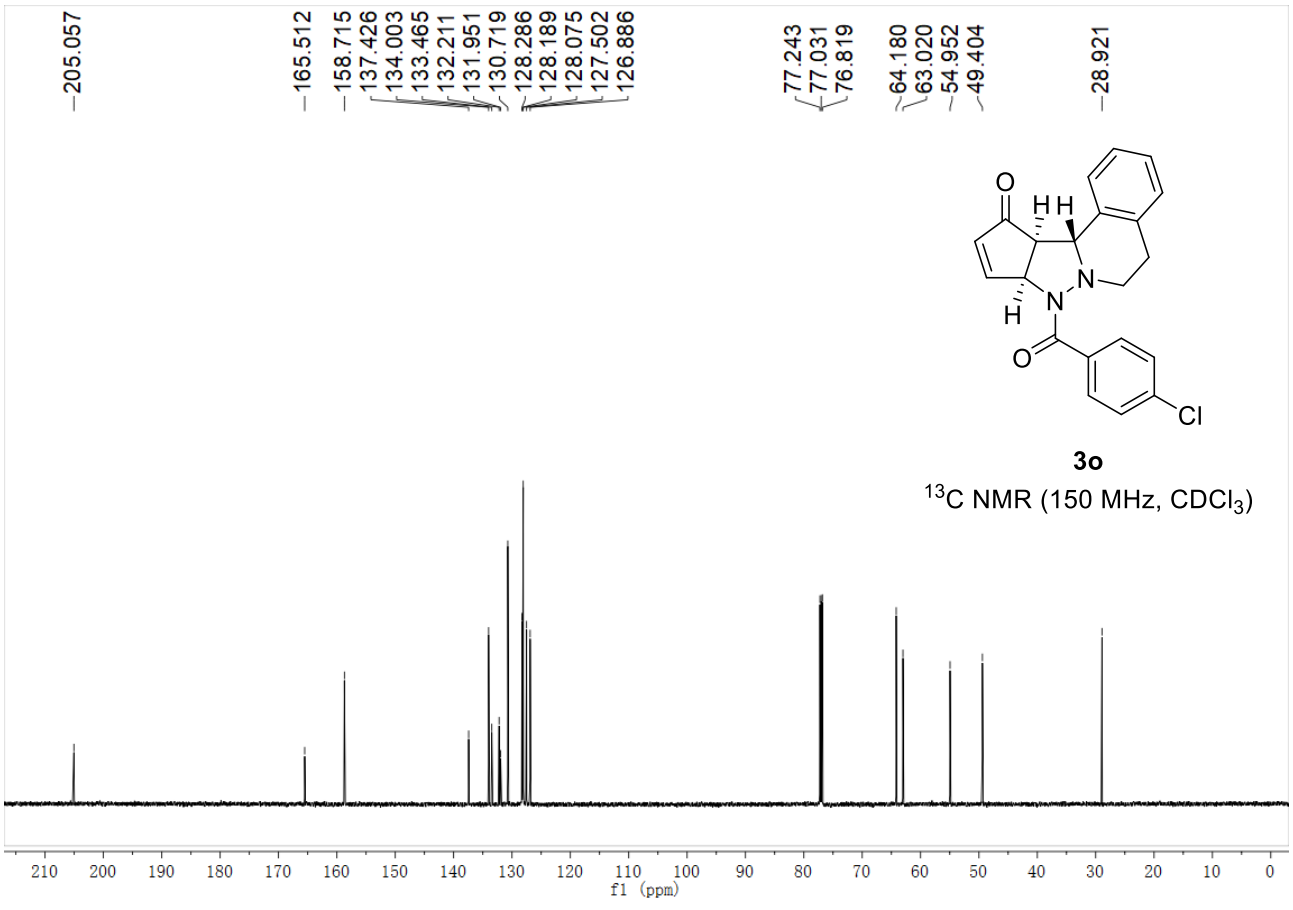
Ret Time [min]	Peak Type	Width [min]	Height [mAU]	Area [mAU*s]	Area [%]
18.637	BB	0.43	95.5740	2650.6958	98.7585
22.998	BB	0.51	0.9398	33.3221	1.2415
			Totals:	2684.0179	100.0000


+ESI Scan (rt: 0.273 min) Frag=175.0V CYC-20210308-5.d
x10^4
376.1297
O
H H
N
N
H
O
NO2
3n
(ESI-TOF) m/z: [M + H]+
Calcd for C21H18N3O4+ 376.1292
376.105
376.11
376.115
376.12
376.125
376.13
376.135
376.14
376.145
376.15
376.155
376.16
Counts vs. Mass-to-Charge (m/z)



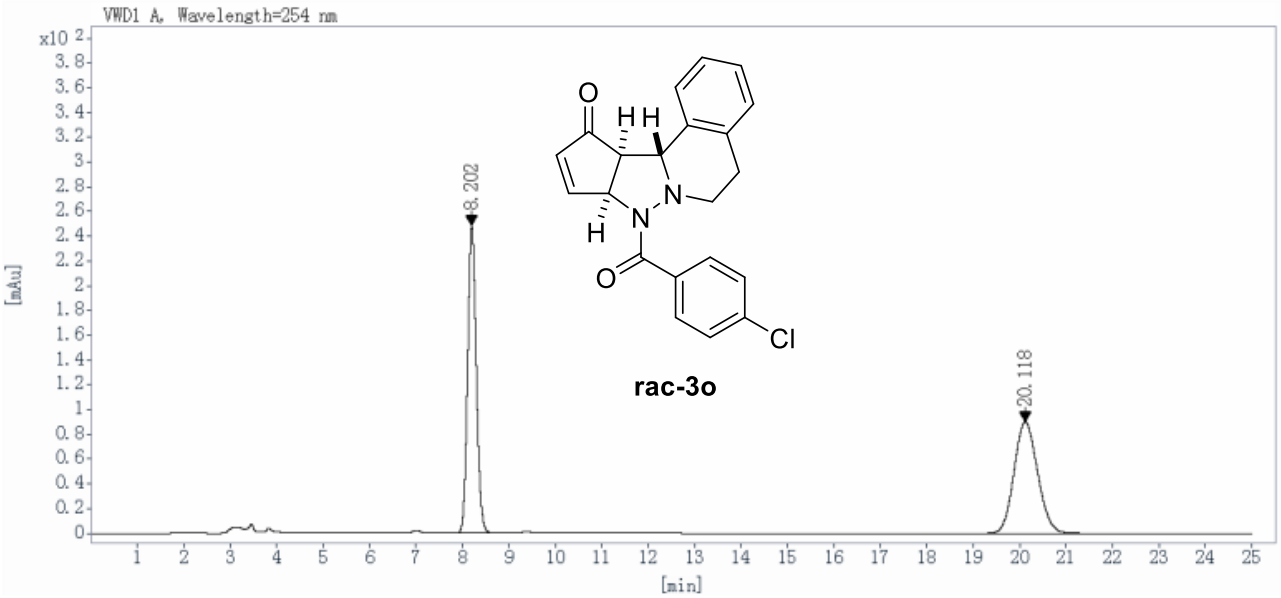
3o

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

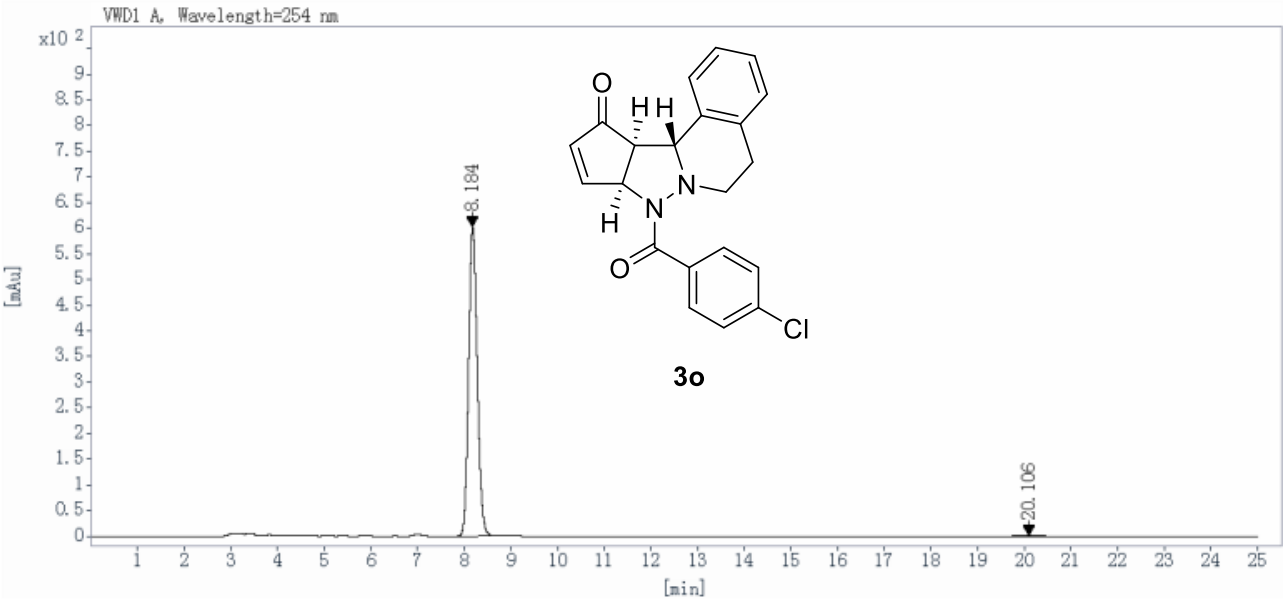


3o

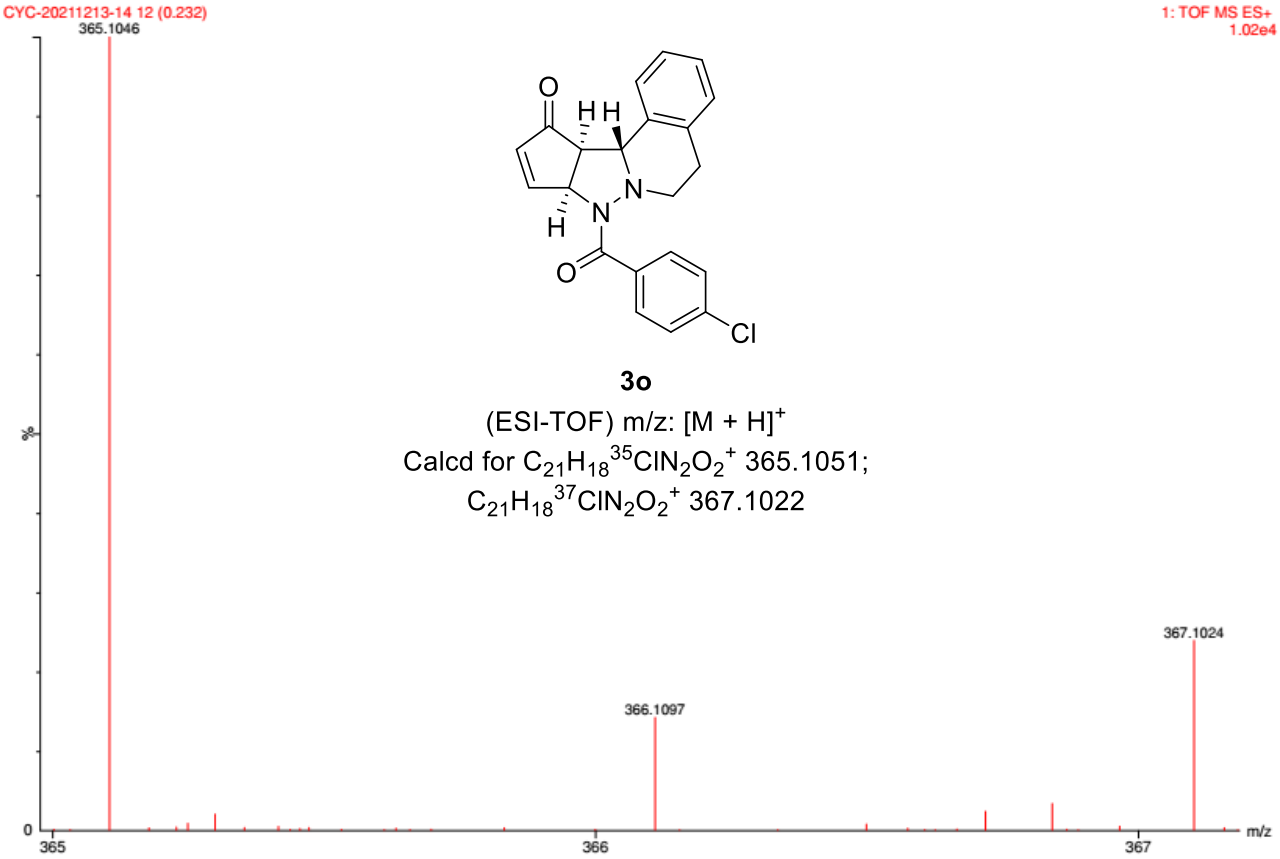
^{13}C NMR (150 MHz, $CDCl_3$)



Ret Time [min]	Peak Type	Width [min]	Height [mAU]	Area [mAU*s]	Area [%]
8.202	BB	0.20	248.3606	3207.7917	50.2671
20.118	BB	0.55	90.1166	3173.7009	49.7329
			Totals:	6381.4927	100.0000



Ret Time [min]	Peak Type	Width [min]	Height [mAU]	Area [mAU*s]	Area [%]
8.184	BB	0.20	602.3094	7784.0024	99.5842
20.106	BB	0.48	0.8583	32.5004	0.4158
			Totals:	7816.5028	100.0000

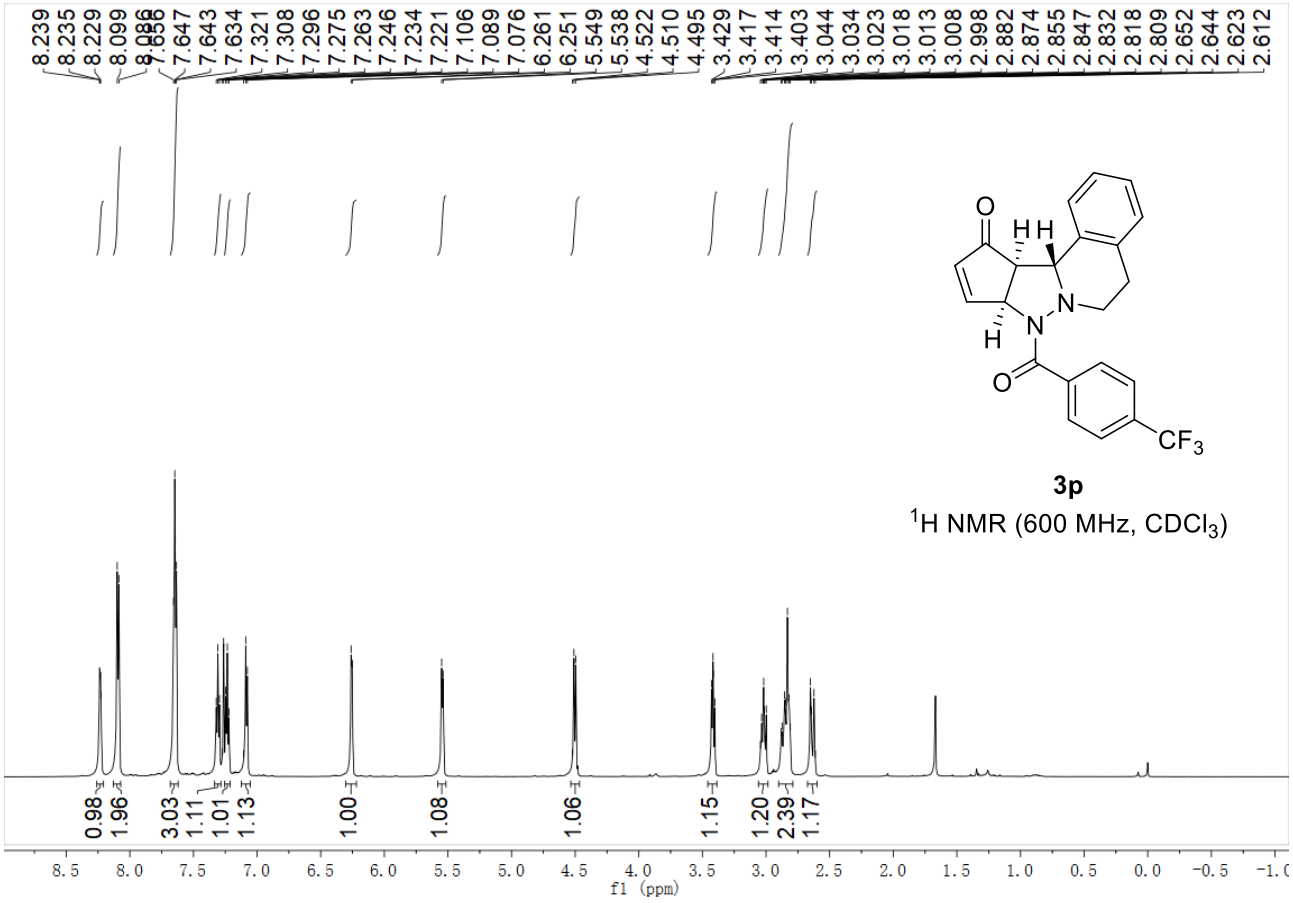


3o

(ESI-TOF) m/z: $[M + H]^+$

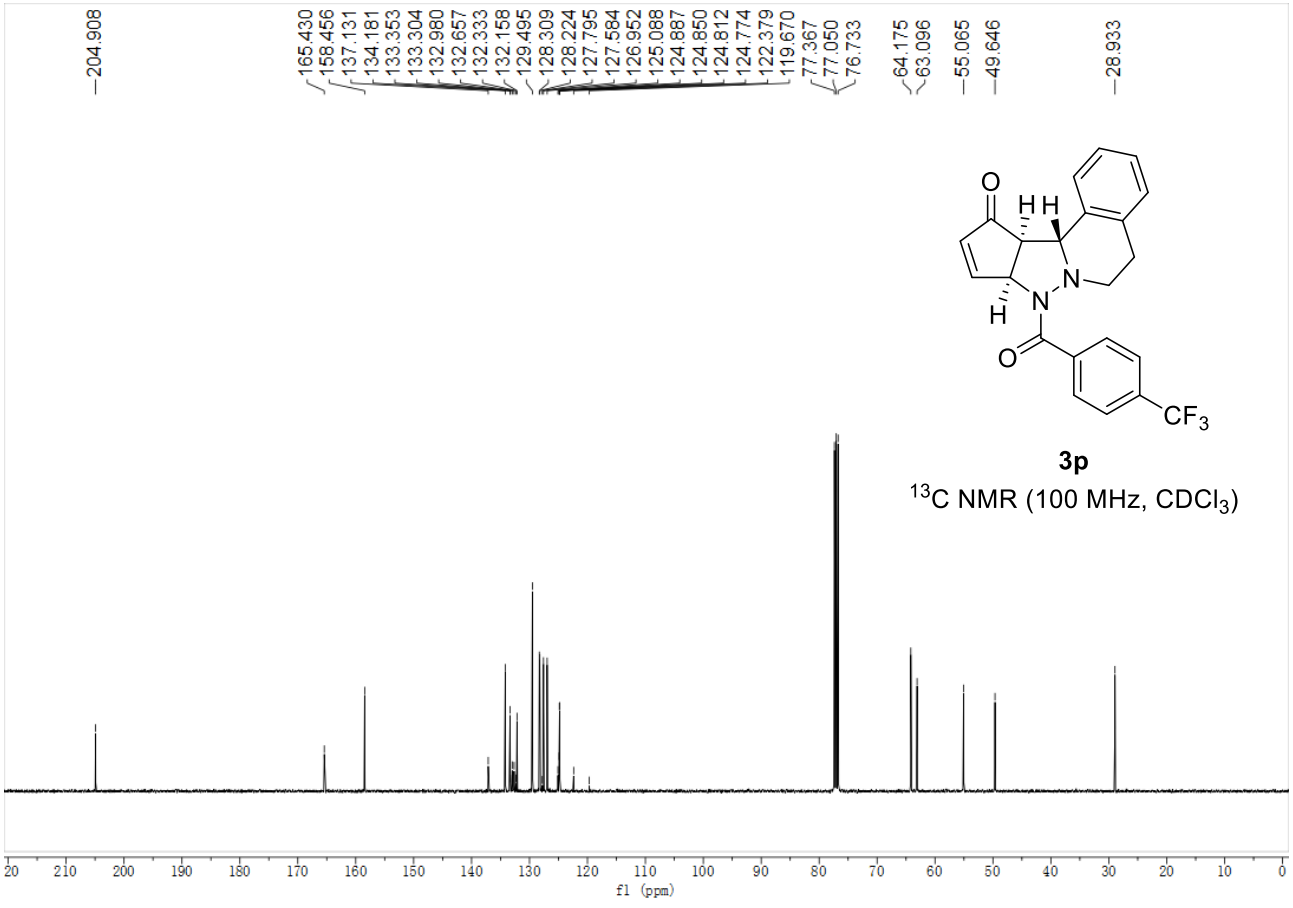
Calcd for $C_{21}H_{18}{}^{35}ClN_2O_2{}^+$ 365.1051;

$C_{21}H_{18}{}^{37}ClN_2O_2{}^+$ 367.1022



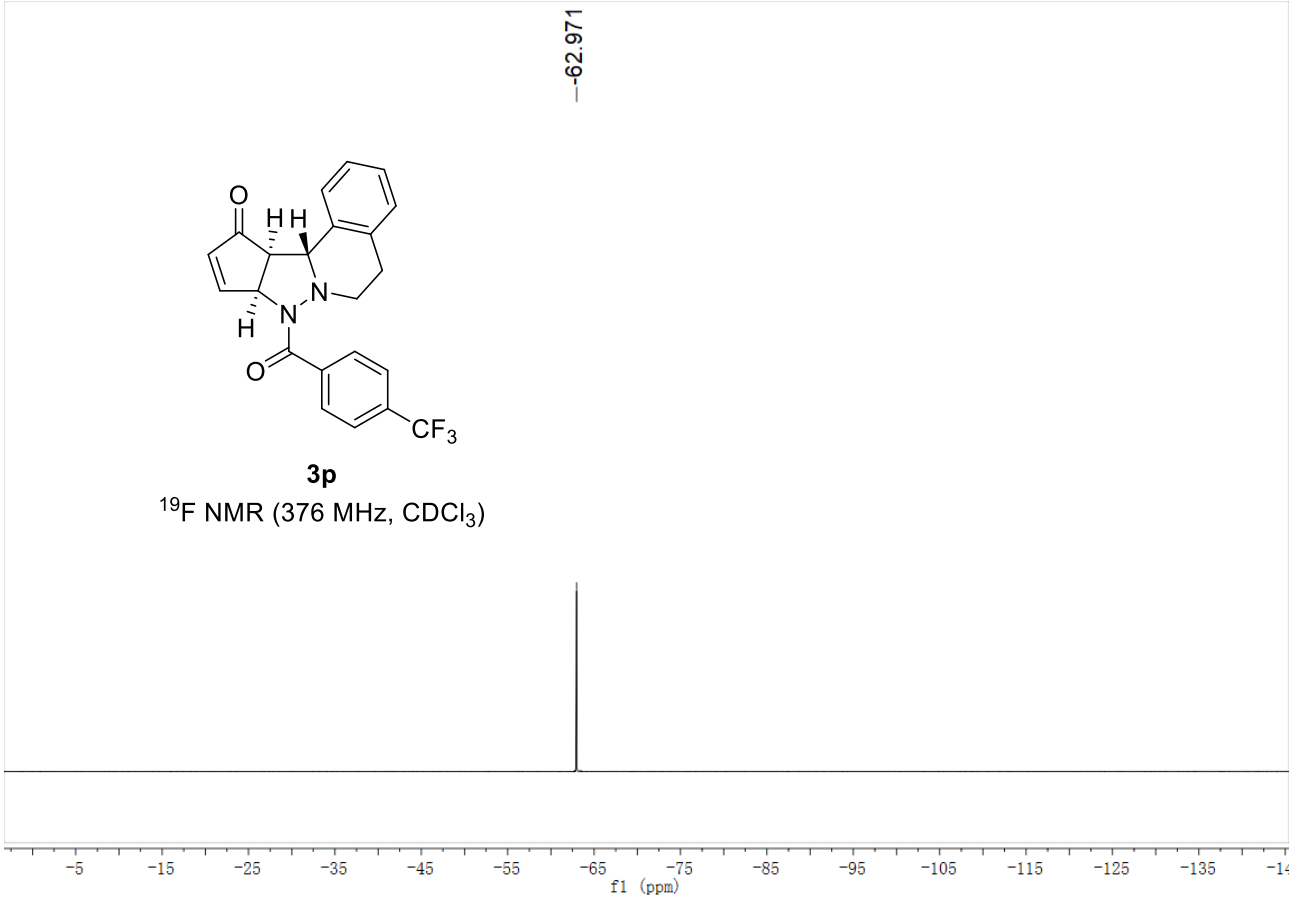
3p

^{1}H NMR (600 MHz, $CDCl_3$)



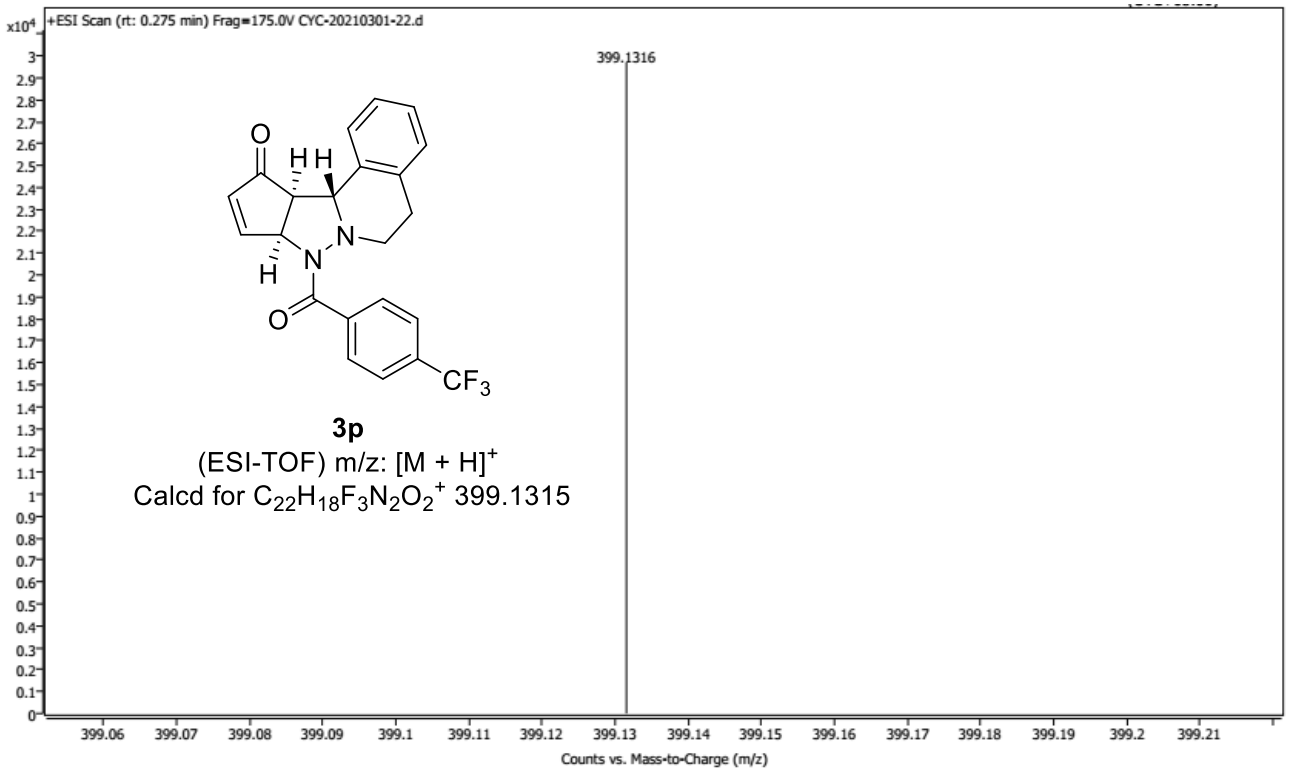
3p

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



3p

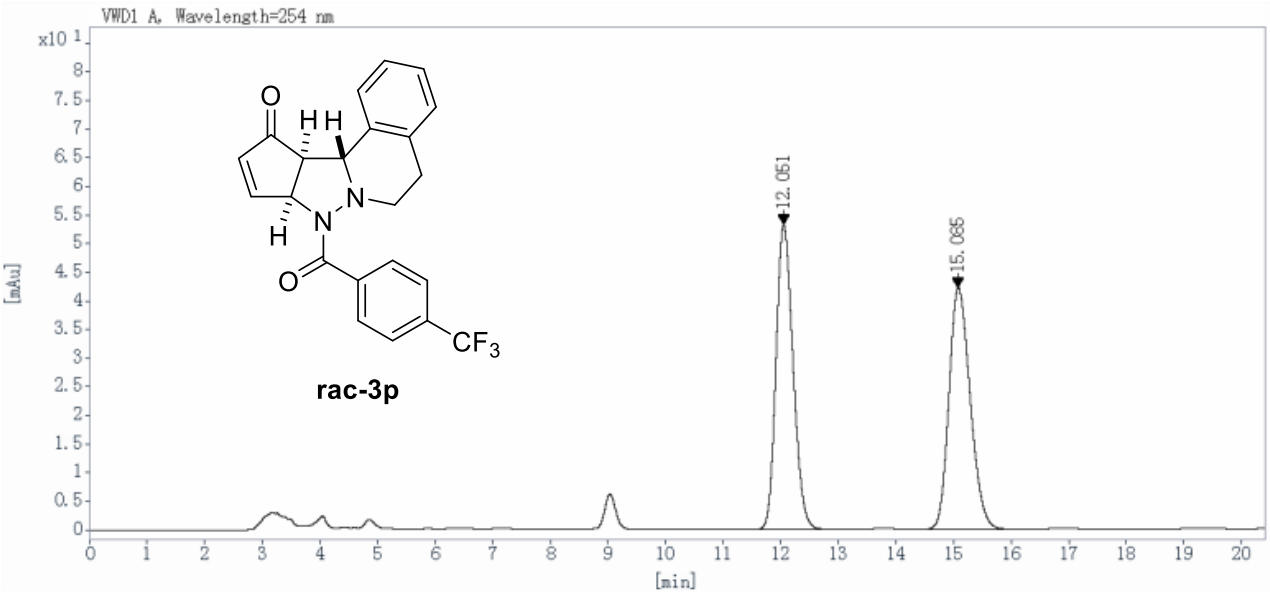
^{19}F NMR (376 MHz, $CDCl_3$)



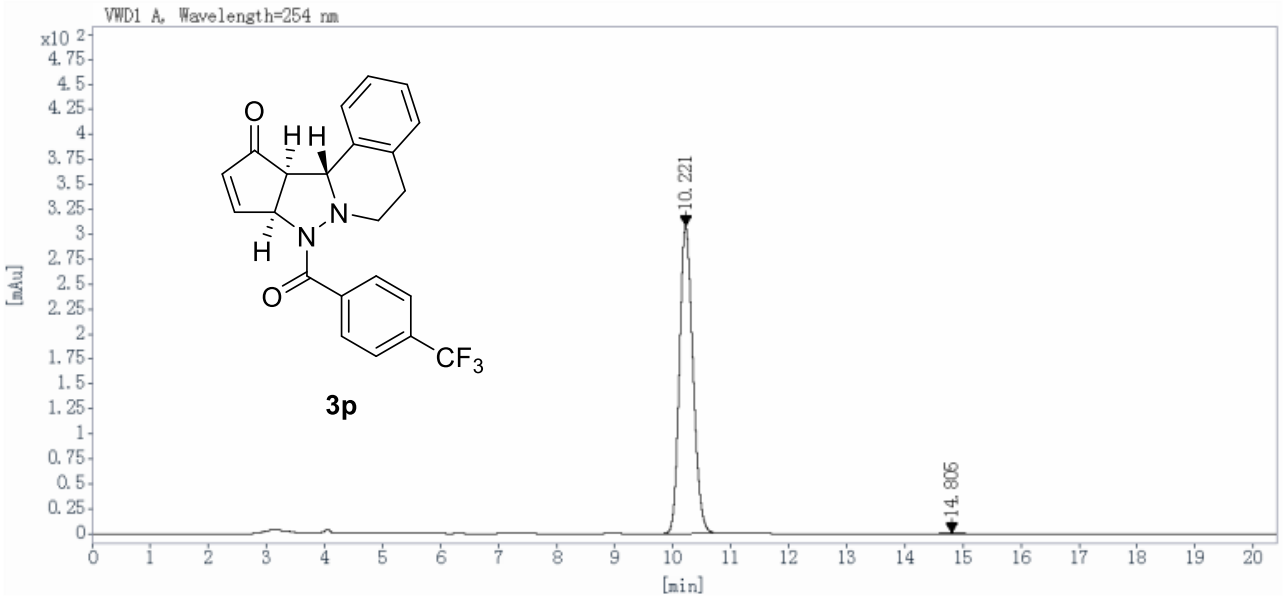
3p

(ESI-TOF) m/z: $[M + H]^+$

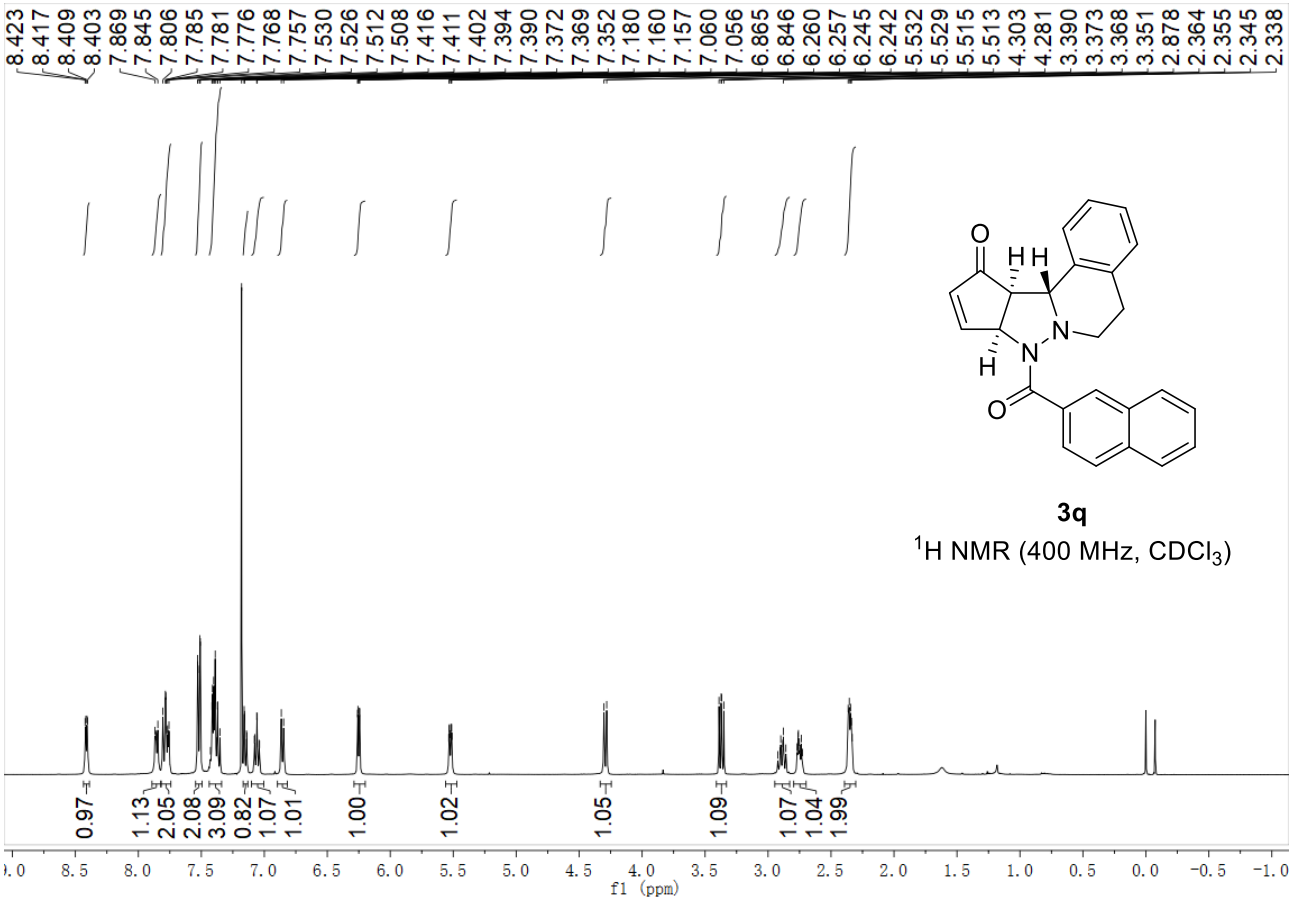
Calcd for $C_{22}H_{18}F_3N_2O_2^+$ 399.1315



Ret Time [min]	Peak Type	Width [min]	Height [mAU]	Area [mAU*s]	Area [%]
12.051	BB	0.32	53.2048	1091.2866	50.2428
15.085	BB	0.40	42.1717	1080.7396	49.7572
			Totals:	2172.0262	100.0000

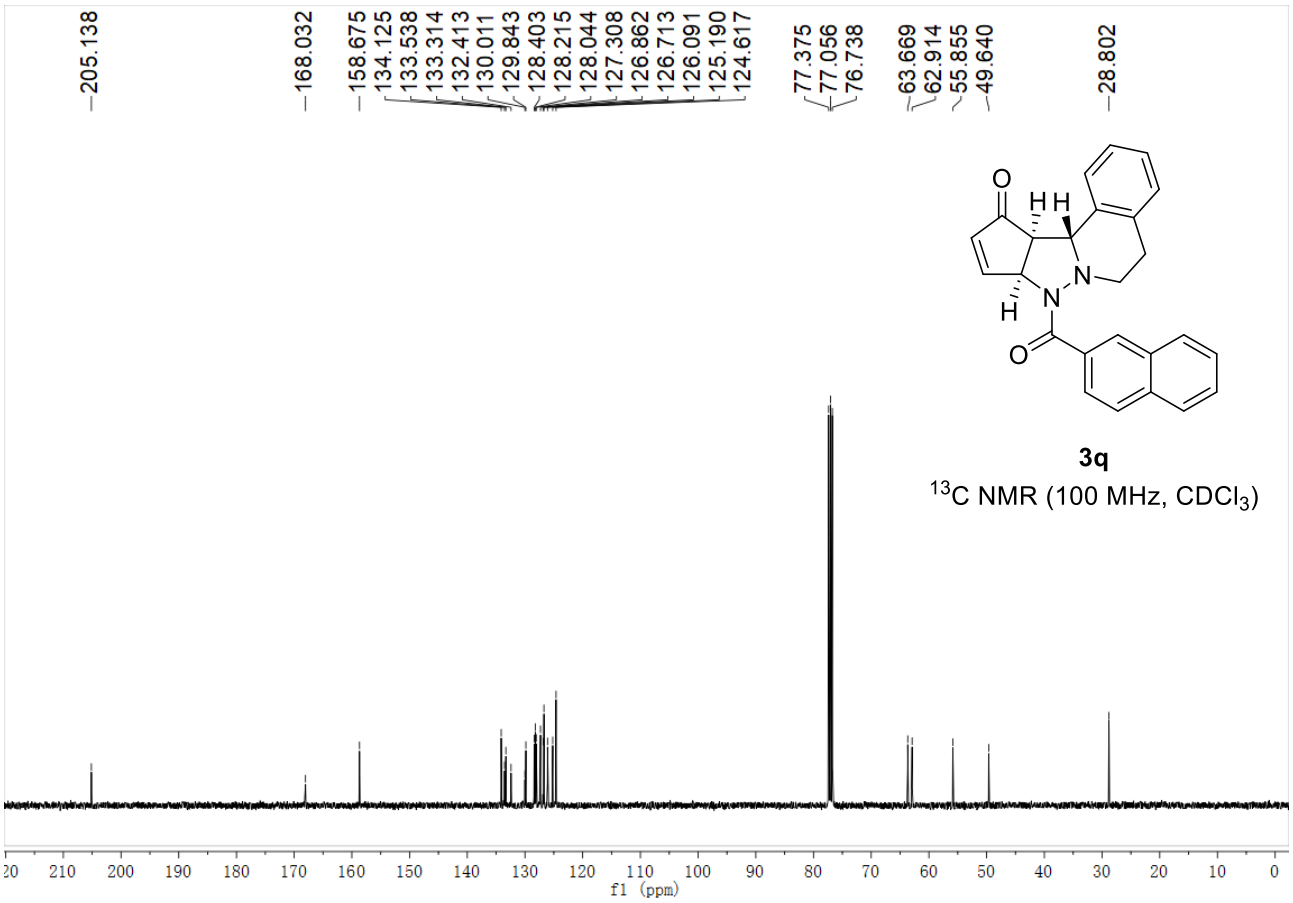


Ret Time [min]	Peak Type	Width [min]	Height [mAU]	Area [mAU*s]	Area [%]
10.221	BBA	0.25	308.1007	4973.4253	99.8406
14.805	BB	0.33	0.3221	7.9383	0.1594
			Totals:	4981.3636	100.0000



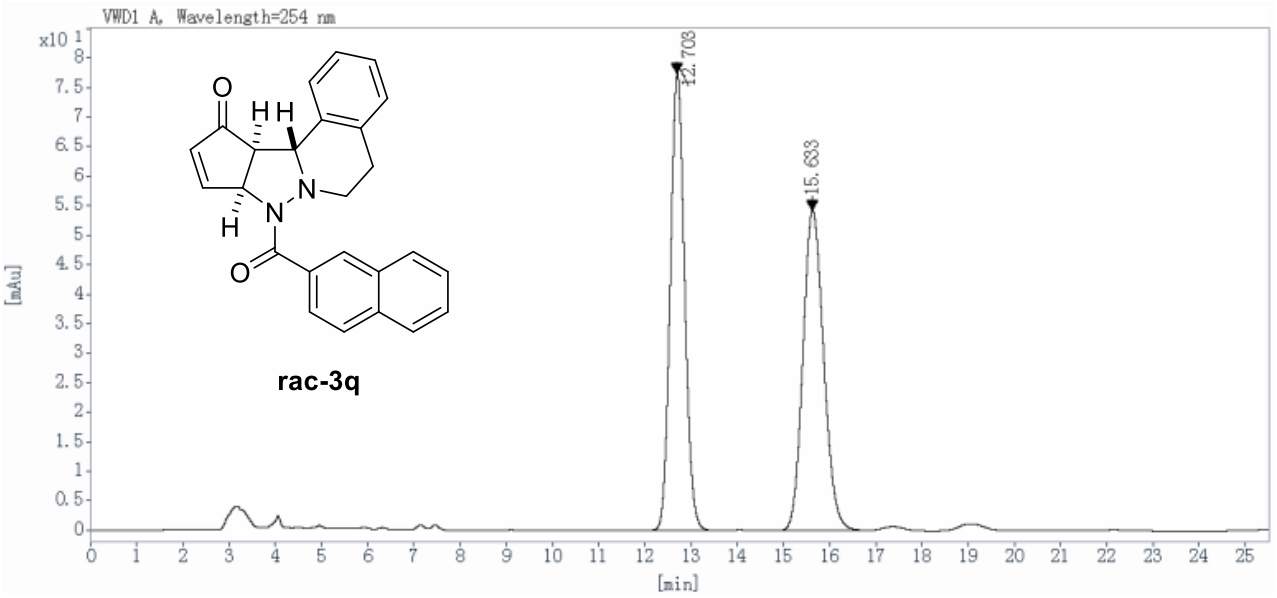
3q

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

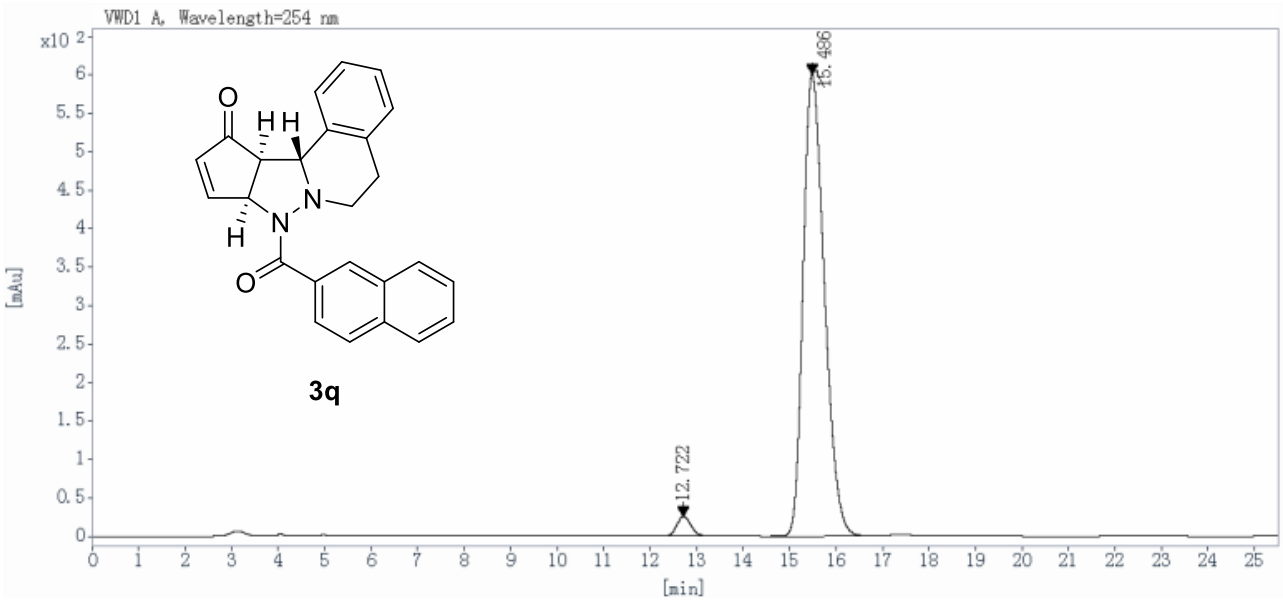


3q

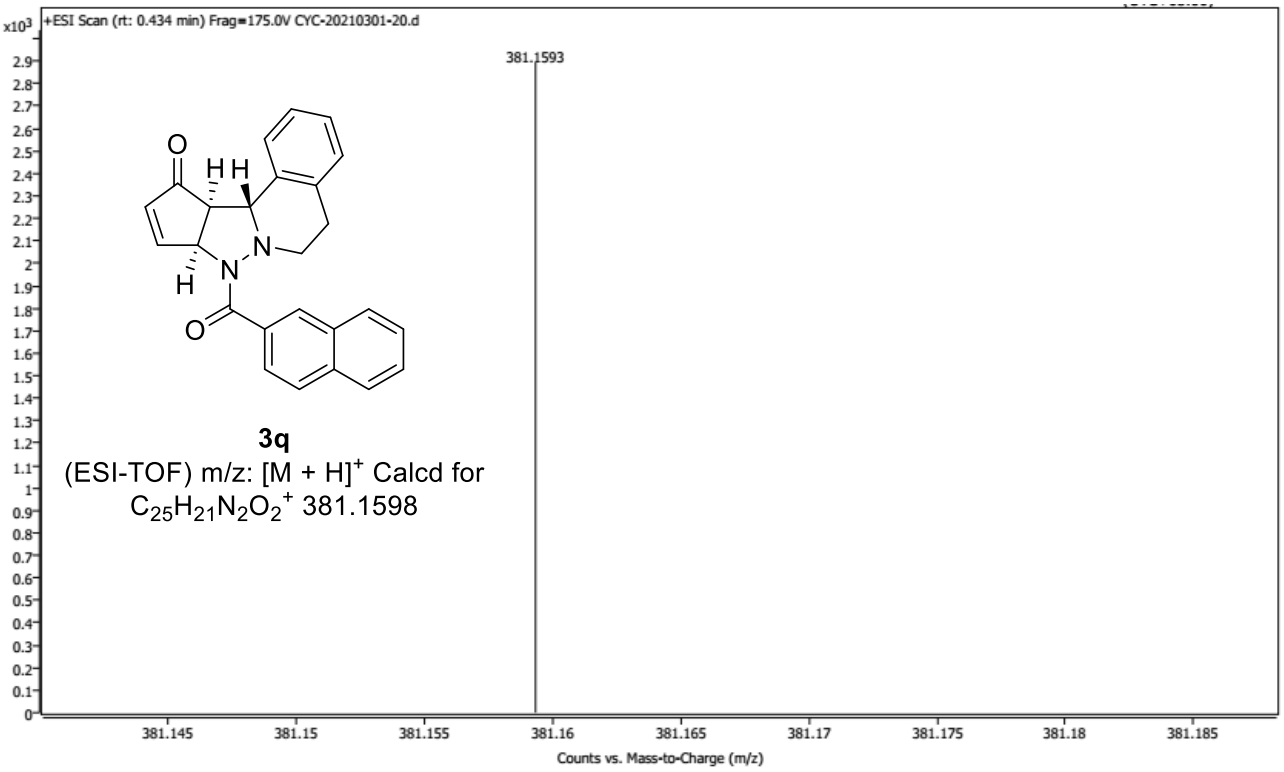
^{13}C NMR (100 MHz, $CDCl_3$)

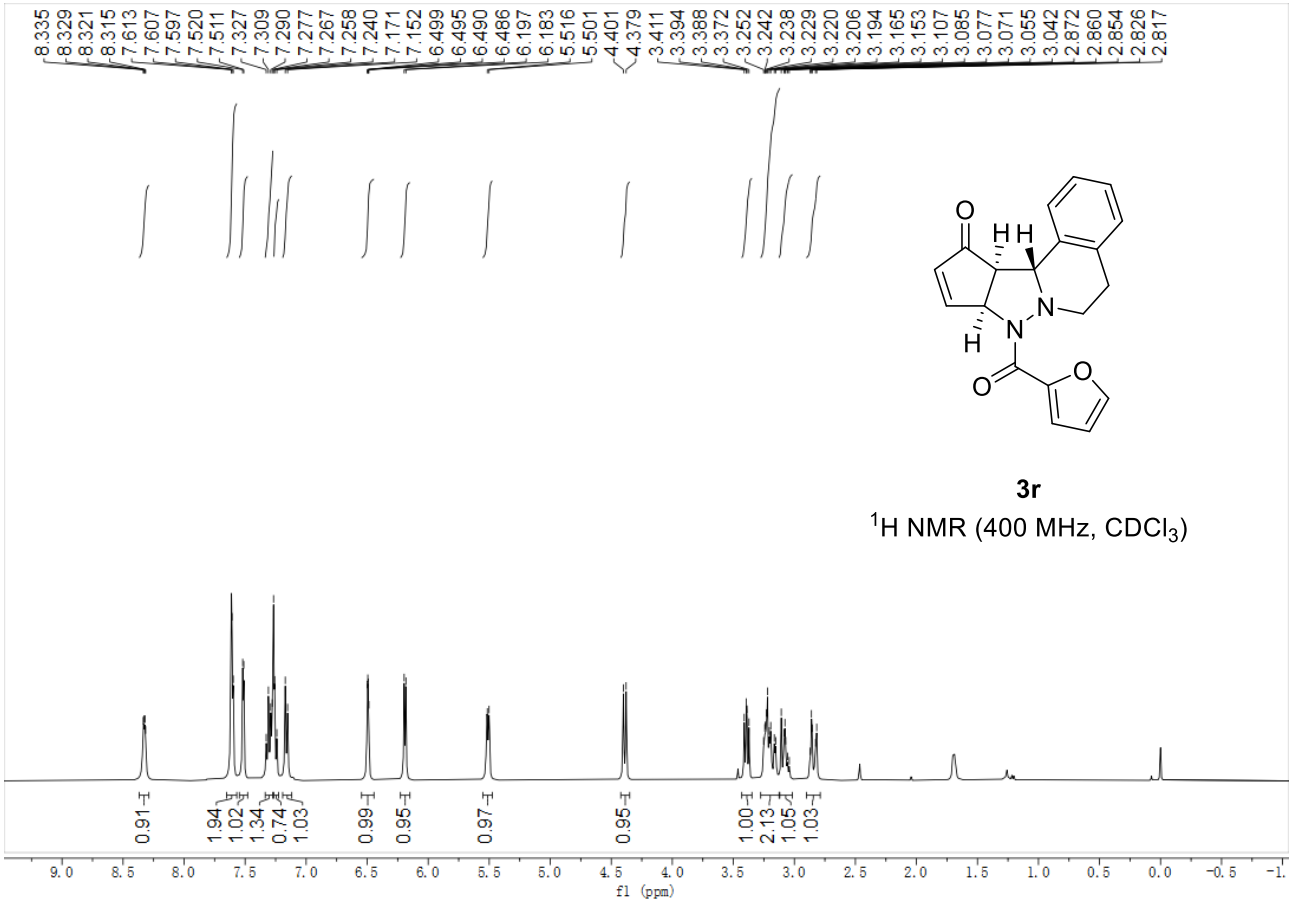


Ret Time [min]	Peak Type	Width [min]	Height [mAU]	Area [mAU*s]	Area [%]
12.703	BB	0.34	77.5425	1675.9316	49.7166
15.633	BB	0.49	54.3025	1695.0370	50.2834
			Totals:	3370.9686	100.0000



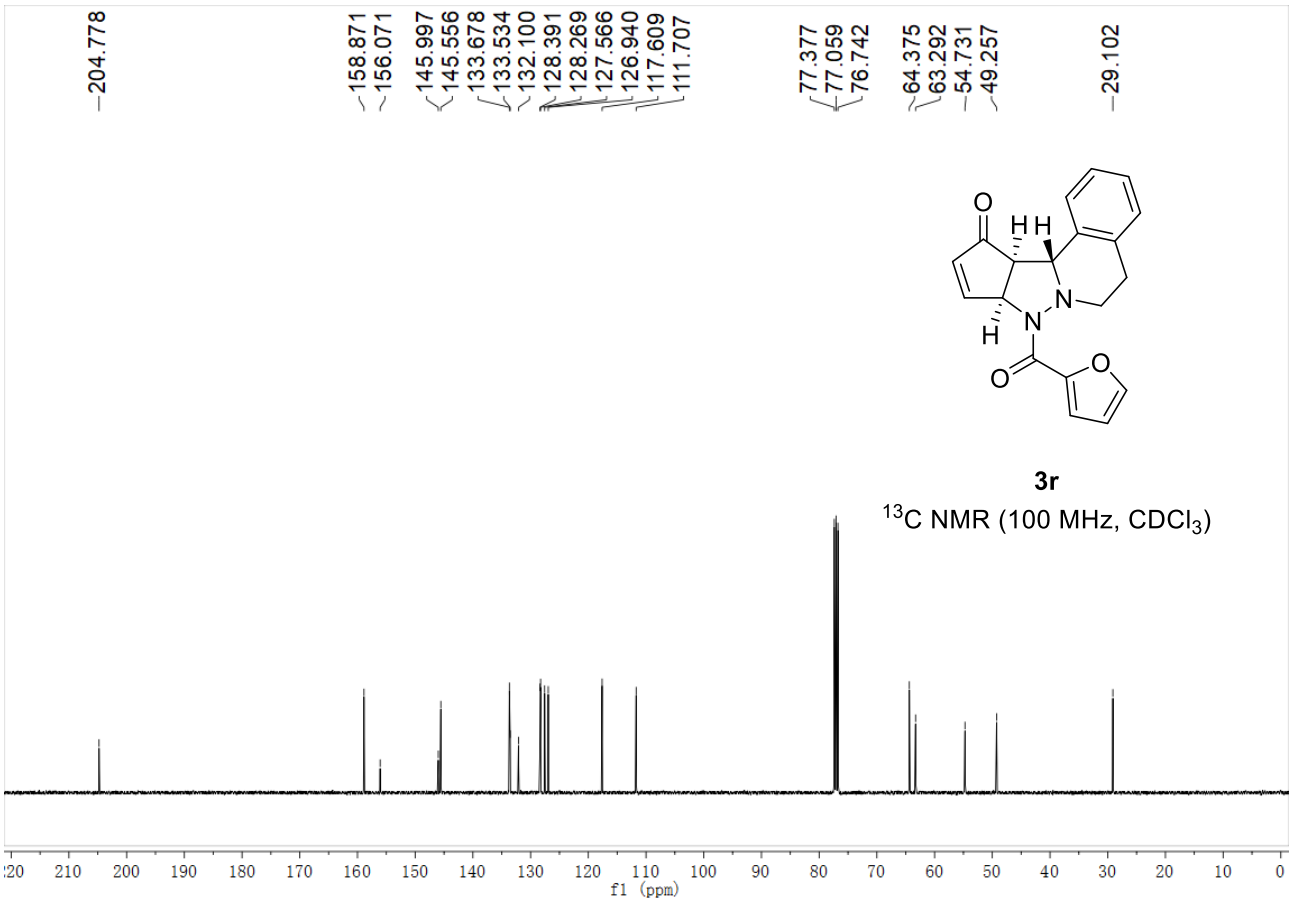
Ret Time [min]	Peak Type	Width [min]	Height [mAU]	Area [mAU*s]	Area [%]
12.722	BB	0.33	25.7412	549.2831	2.8034
15.486	BB	0.49	600.6813	19043.9141	97.1966
			Totals:	19593.1971	100.0000


+ESI Scan (rt: 0.434 min) Frag=175.0V CYC-20210301-20.d
x10^3
381.1593
O
H H
N
N
H
O
3q
(ESI-TOF) m/z: [M + H]+ Calcd for
C25H21N2O2+ 381.1598
381.145
381.15
381.155
381.16
381.165
381.17
381.175
381.18
381.185
Counts vs. Mass-to-Charge (m/z)



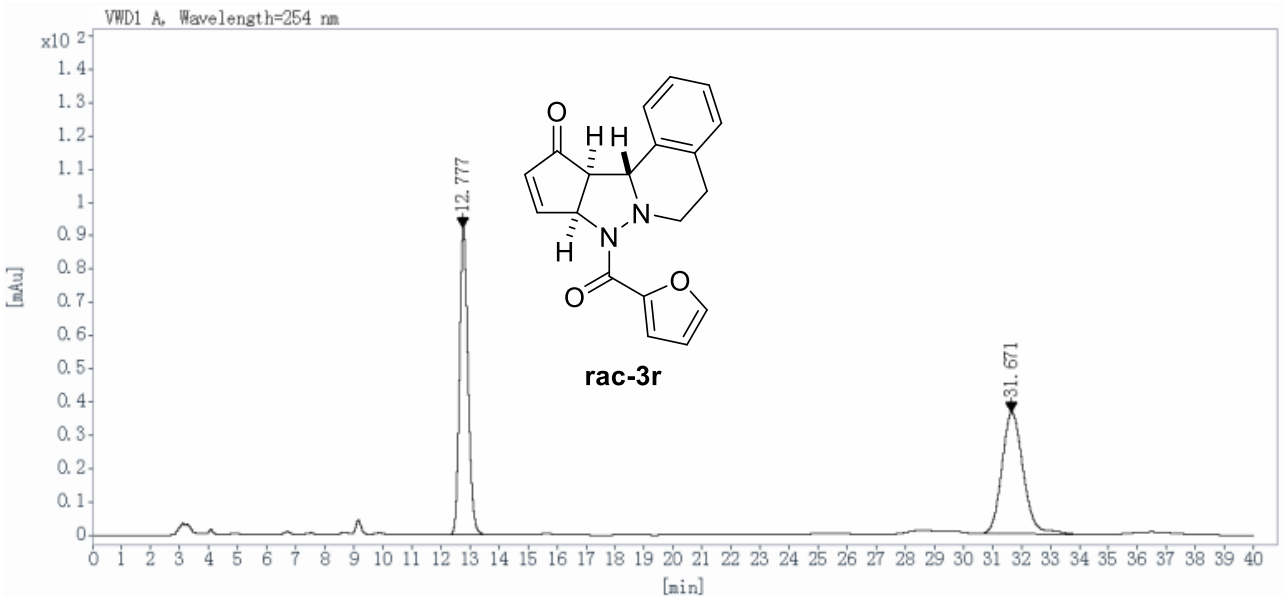
3r

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

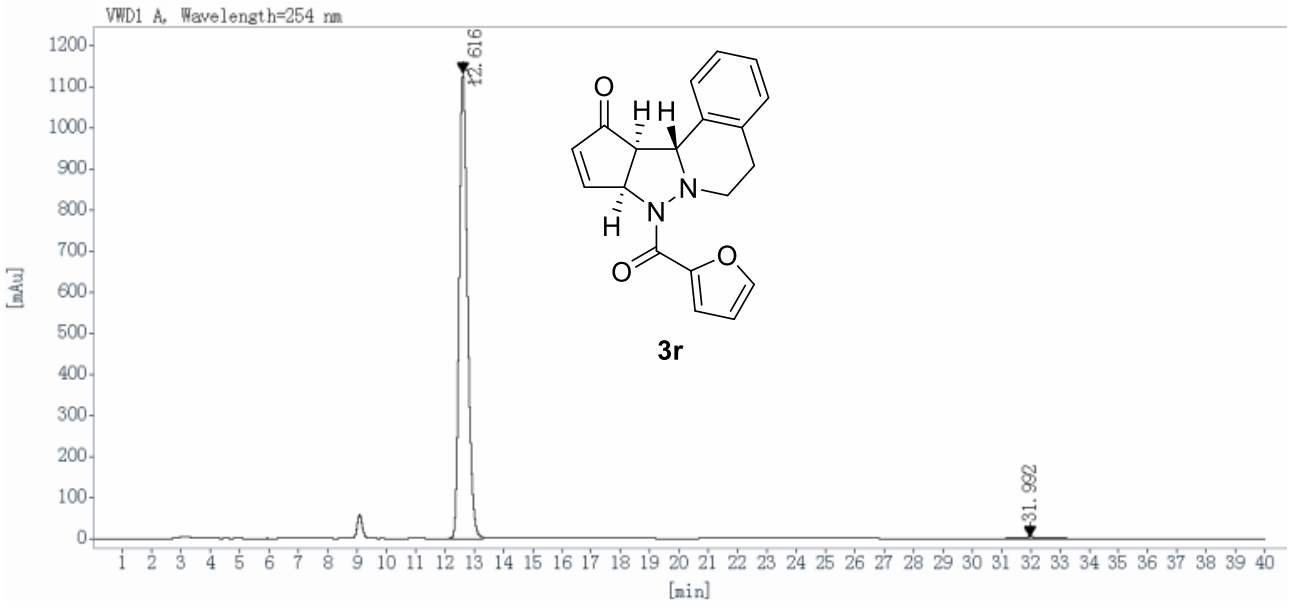


3r

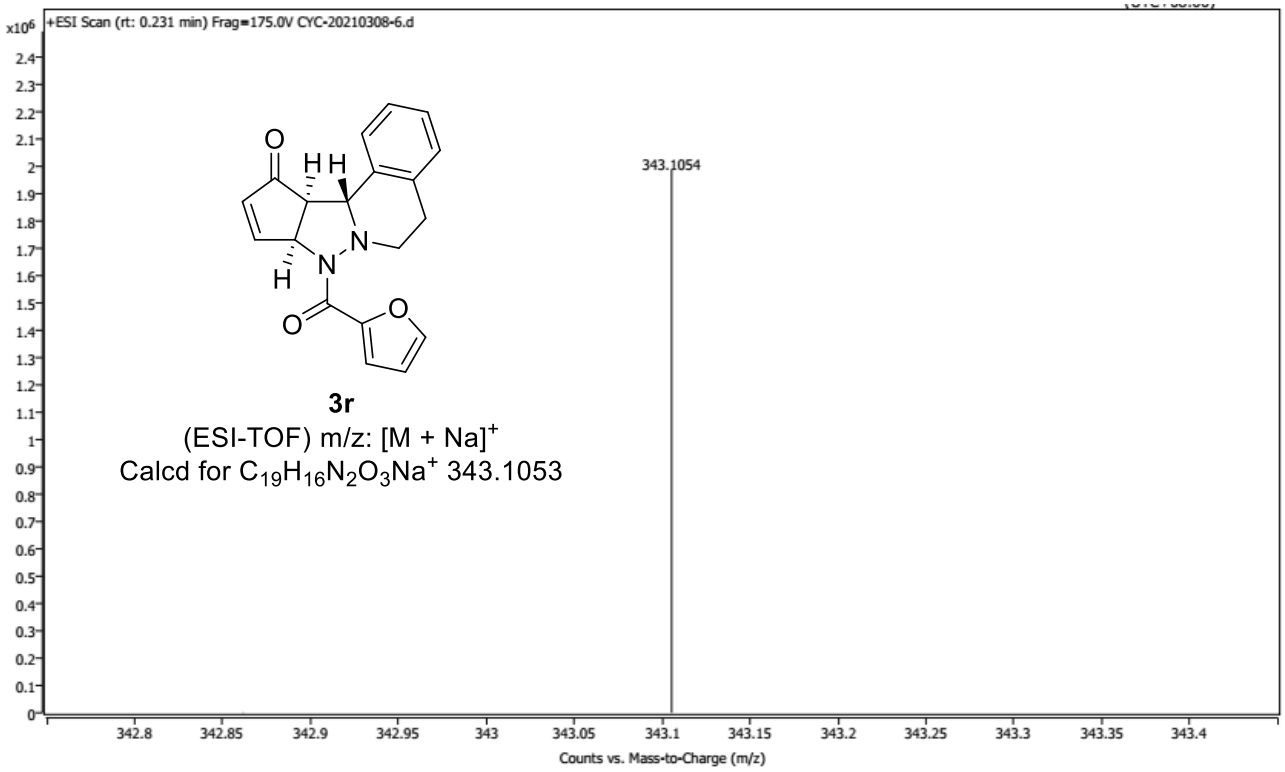
^{13}C NMR (100 MHz, $CDCl_3$)



Ret Time [min]	Peak Type	Width [min]	Height [mAU]	Area [mAU*s]	Area [%]
12.777	BB	0.31	92.1561	1870.4873	49.7903
31.671	BB	0.80	36.6021	1886.2430	50.2097
			Totals:	3756.7303	100.0000



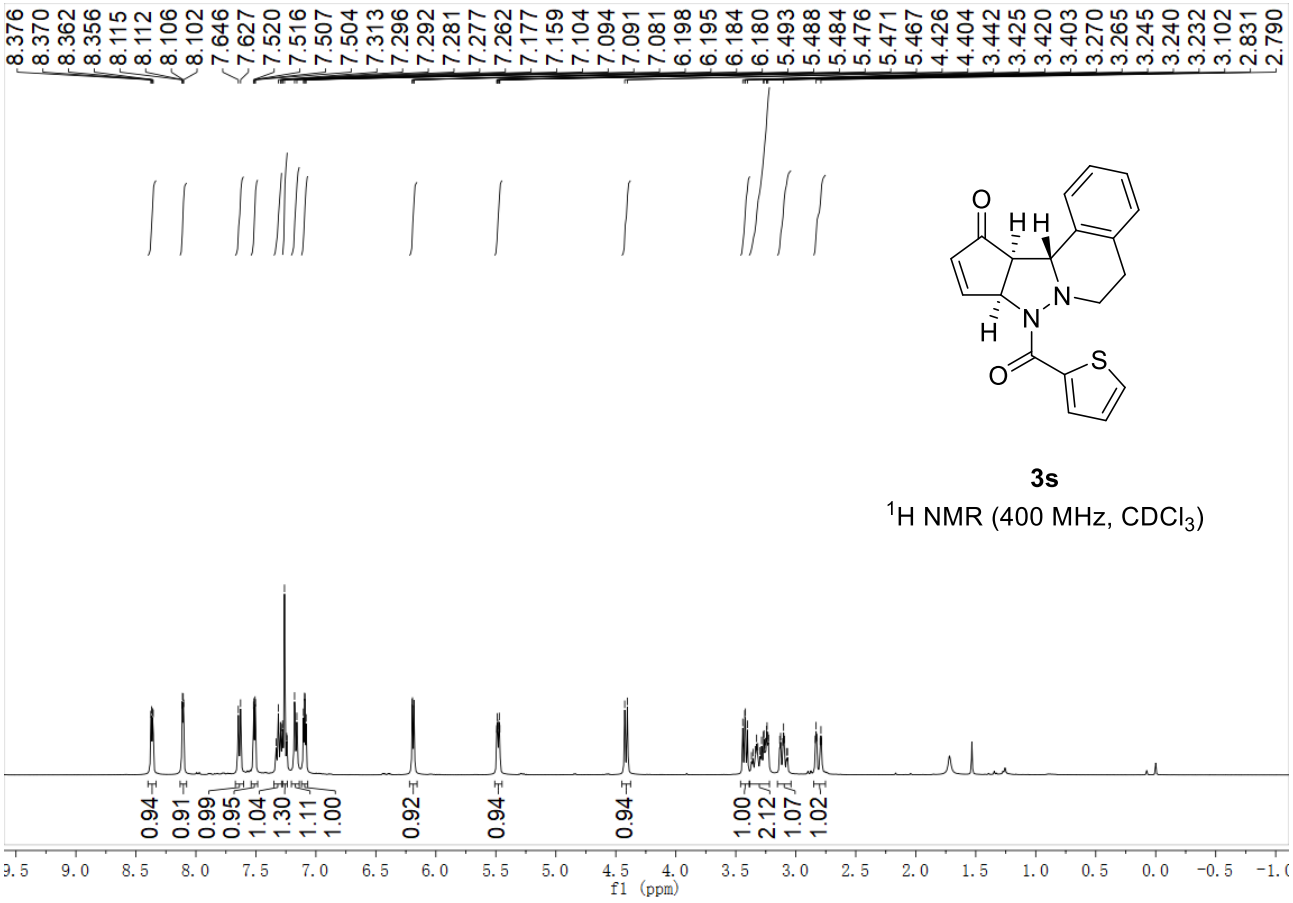
Ret Time [min]	Peak Type	Width [min]	Height [mAU]	Area [mAU*s]	Area [%]
12.616	BB	0.30	1133.4751	22319.0469	99.2857
31.992	BB	0.81	2.7385	160.5765	0.7143
			Totals:	22479.6233	100.0000



3r

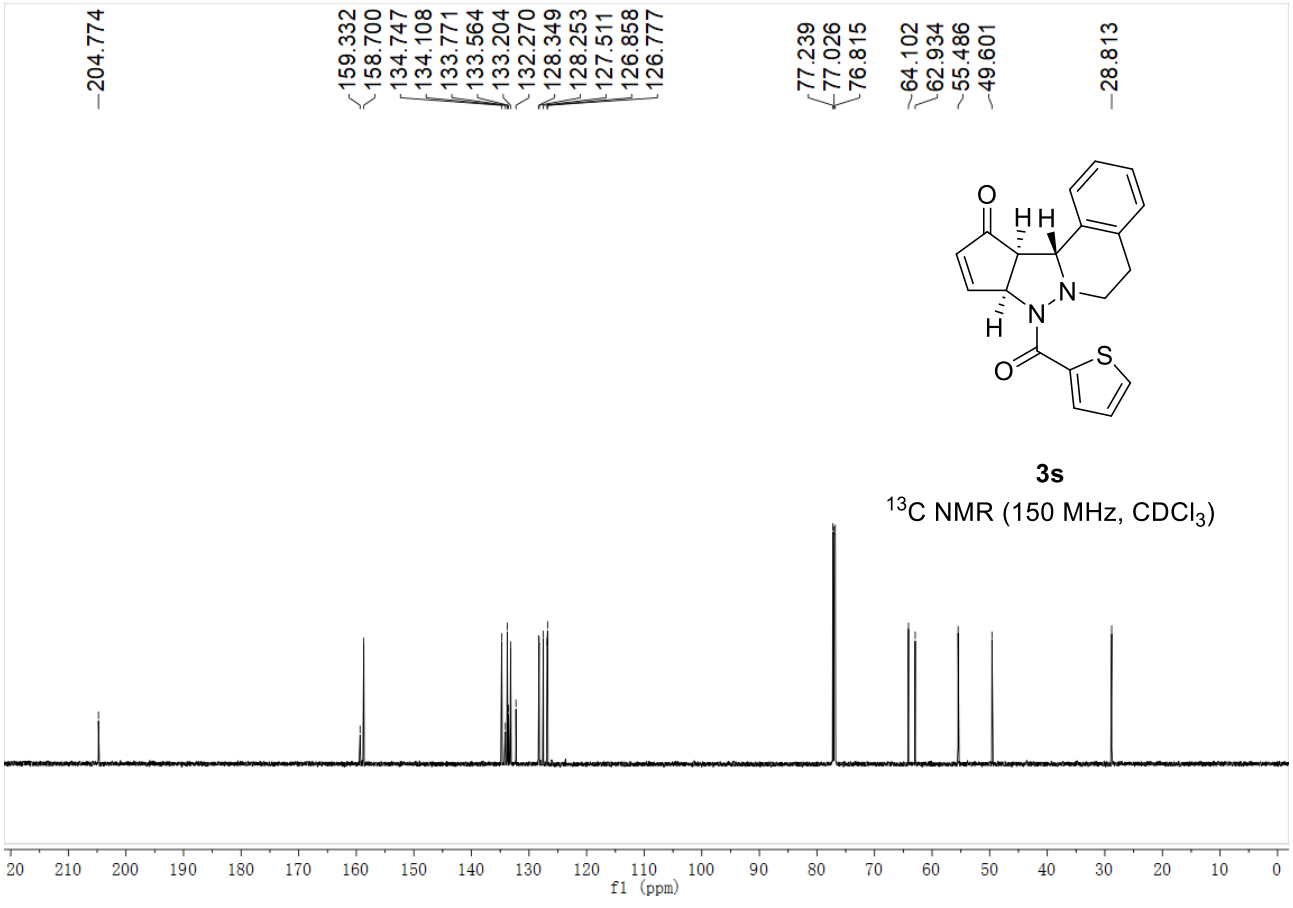
(ESI-TOF) m/z: $[M + Na]^+$

Calcd for $C_{19}H_{16}N_2O_3Na^+$ 343.1053



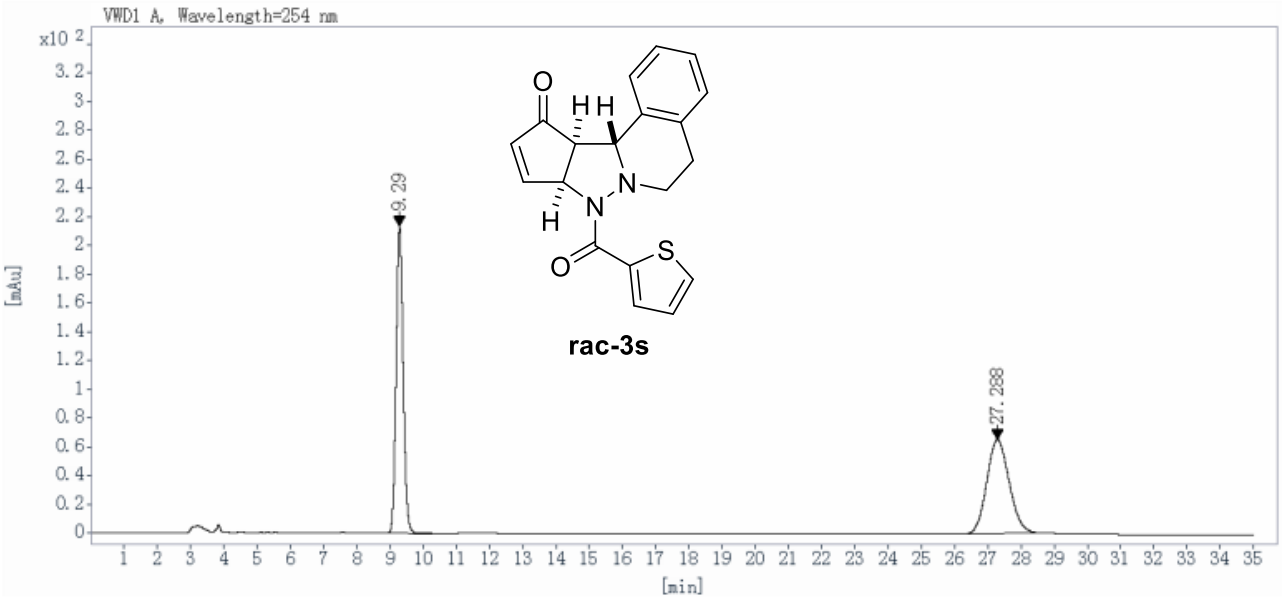
3s

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

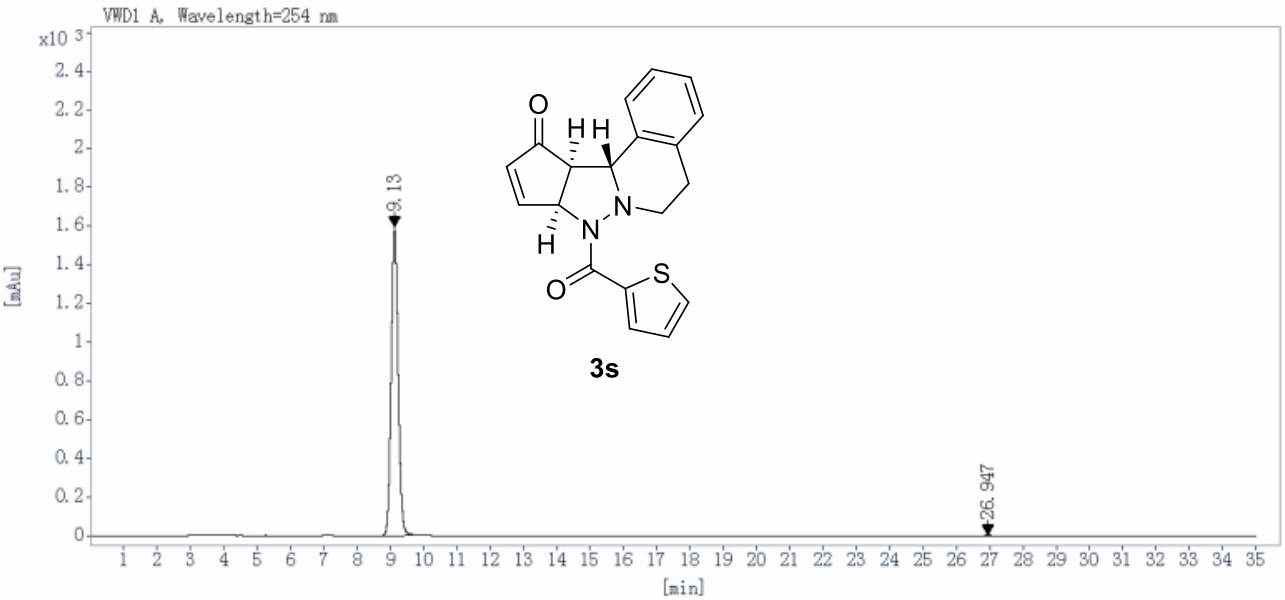


3s

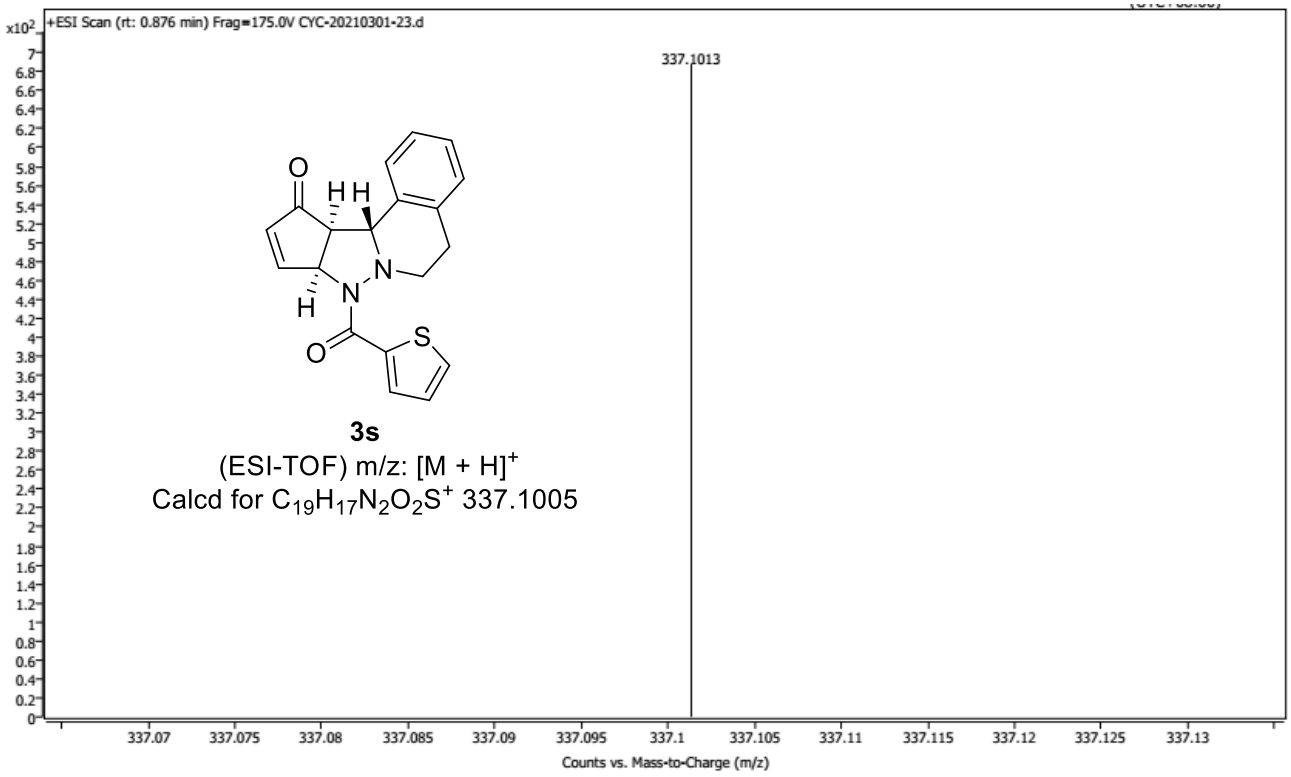
^{13}C NMR (150 MHz, $CDCl_3$)



Ret Time [min]	Peak Type	Width [min]	Height [mAU]	Area [mAU*s]	Area [%]
9.290	VB R	0.23	213.5968	3156.5396	50.5098
27.288	BBA	0.74	65.3472	3092.8223	49.4902
			Totals:	6249.3618	100.0000



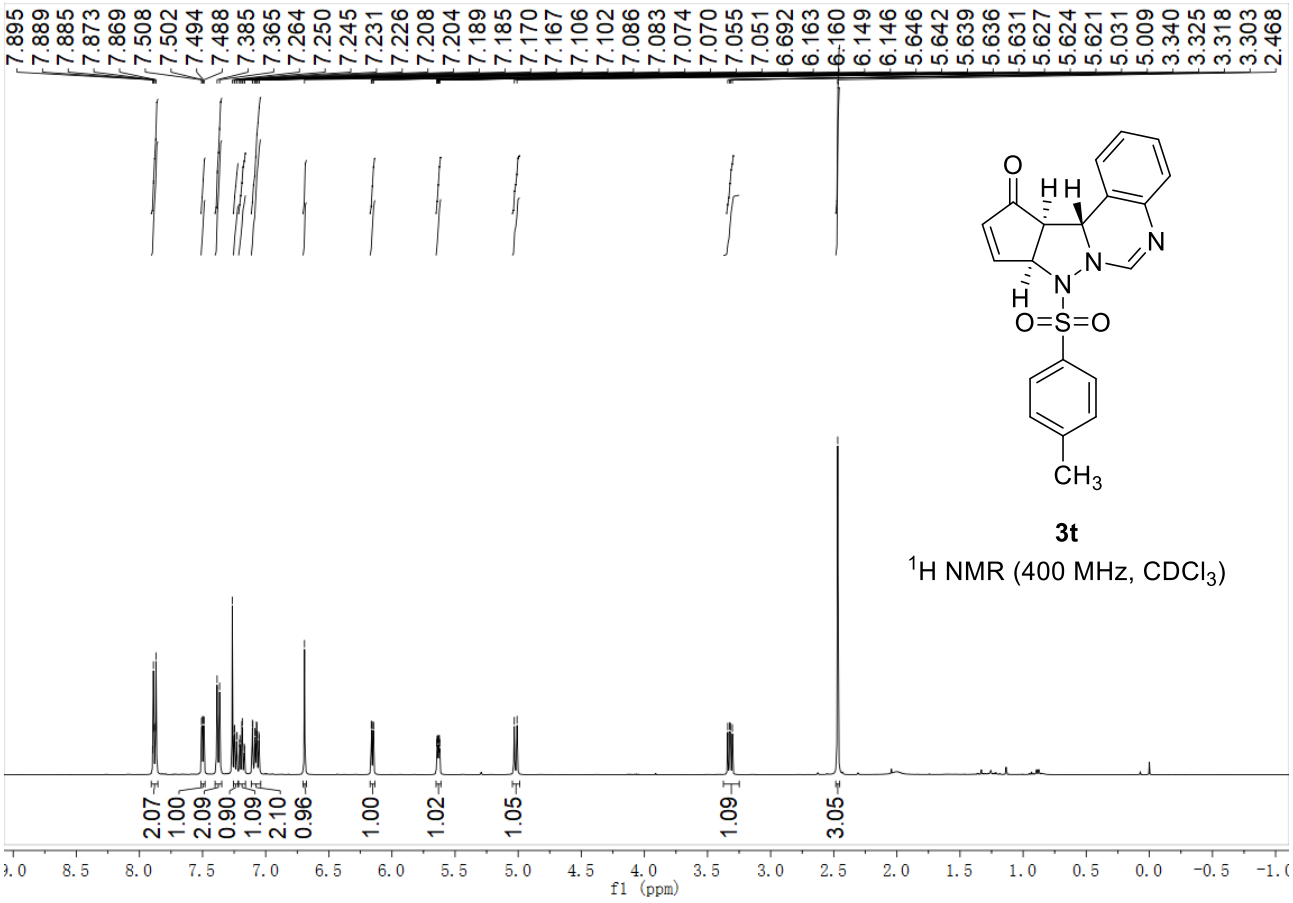
Ret Time [min]	Peak Type	Width [min]	Height [mAU]	Area [mAU*s]	Area [%]
9.130	BBA	0.22	1595.9366	23092.2070	99.8324
26.947	BB	0.56	0.8403	38.7788	0.1676
			Totals:	23130.9858	100.0000



3s

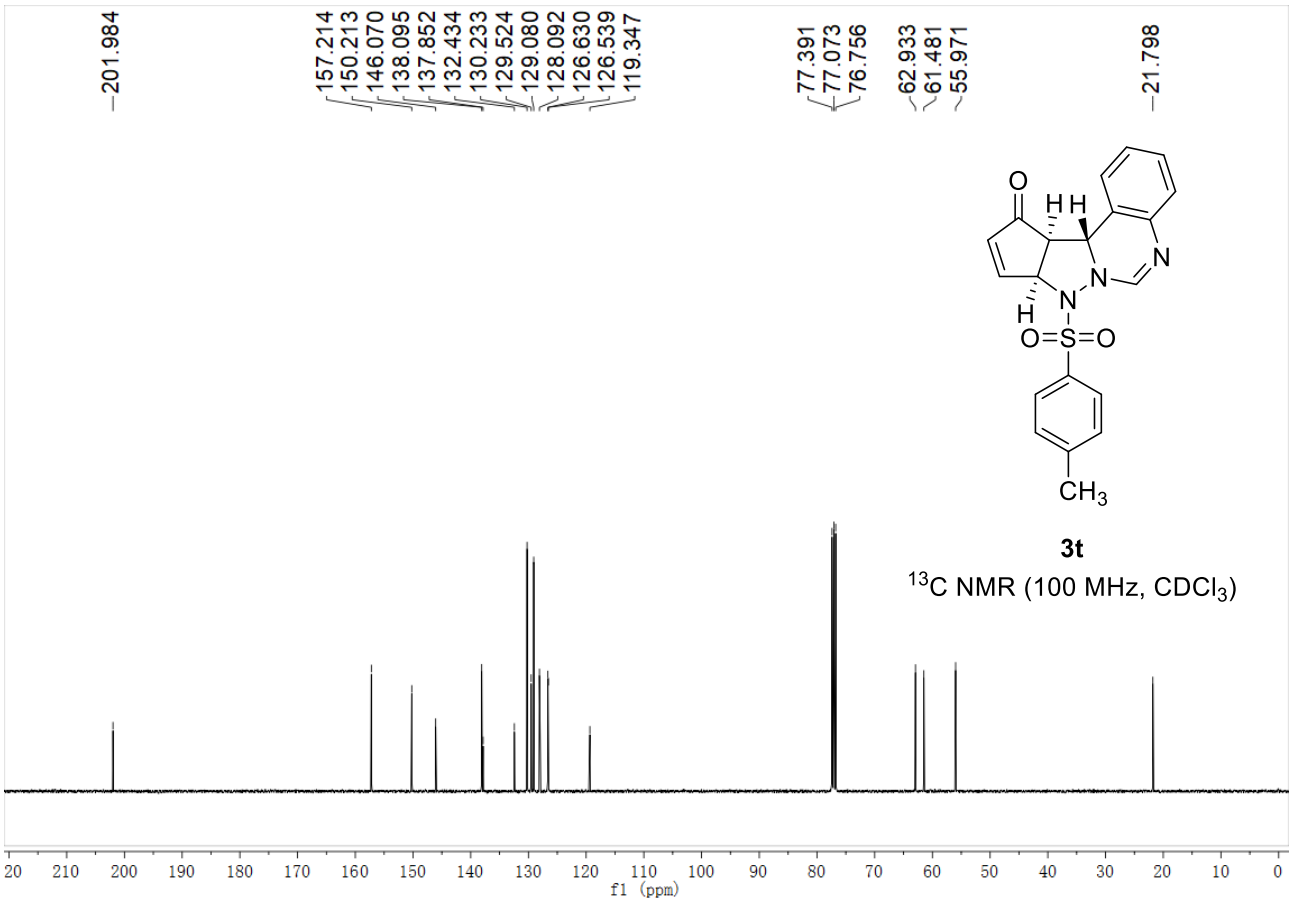
(ESI-TOF) m/z: $[M + H]^+$

Calcd for $C_{19}H_{17}N_2O_2S^+$ 337.1005



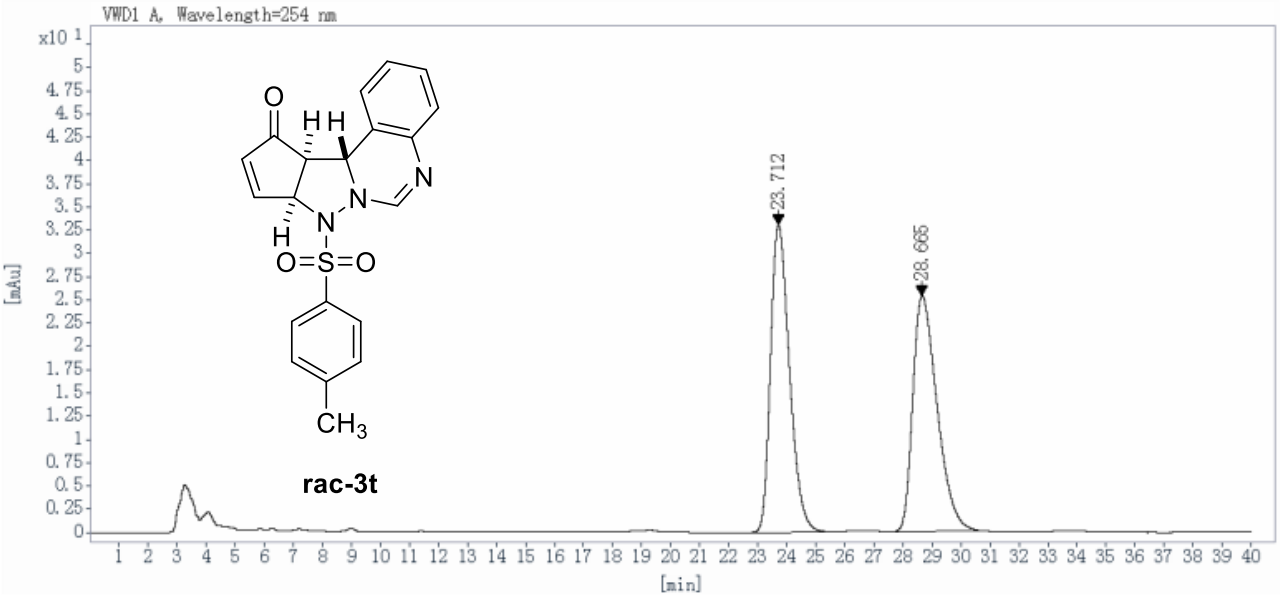
3t

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

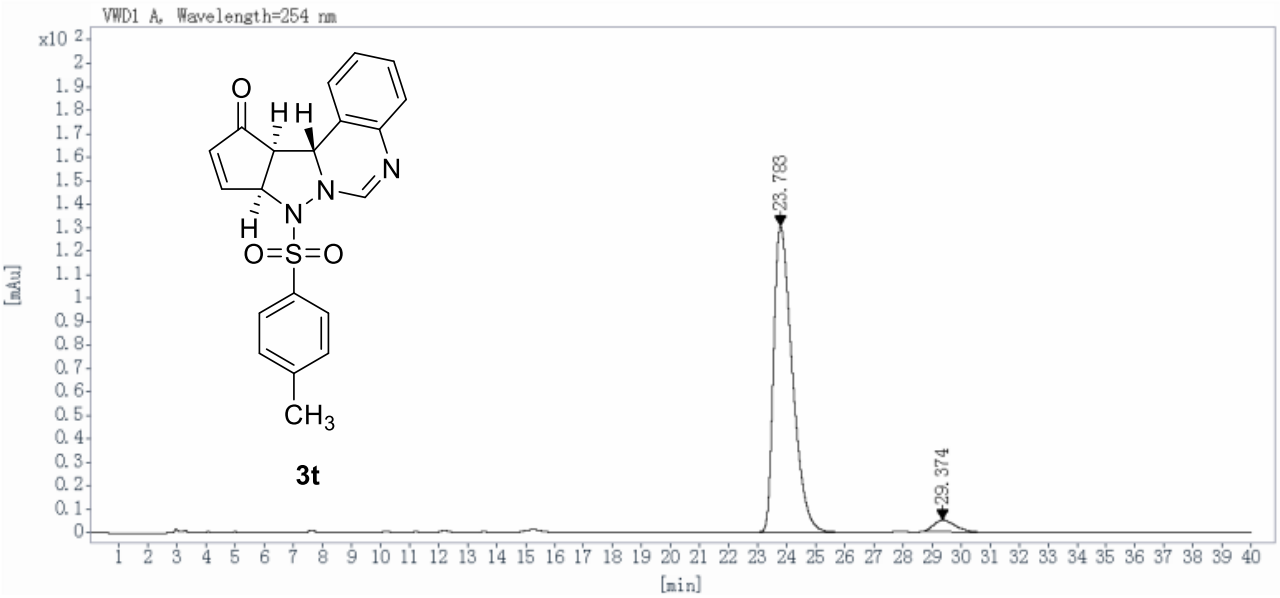


3t

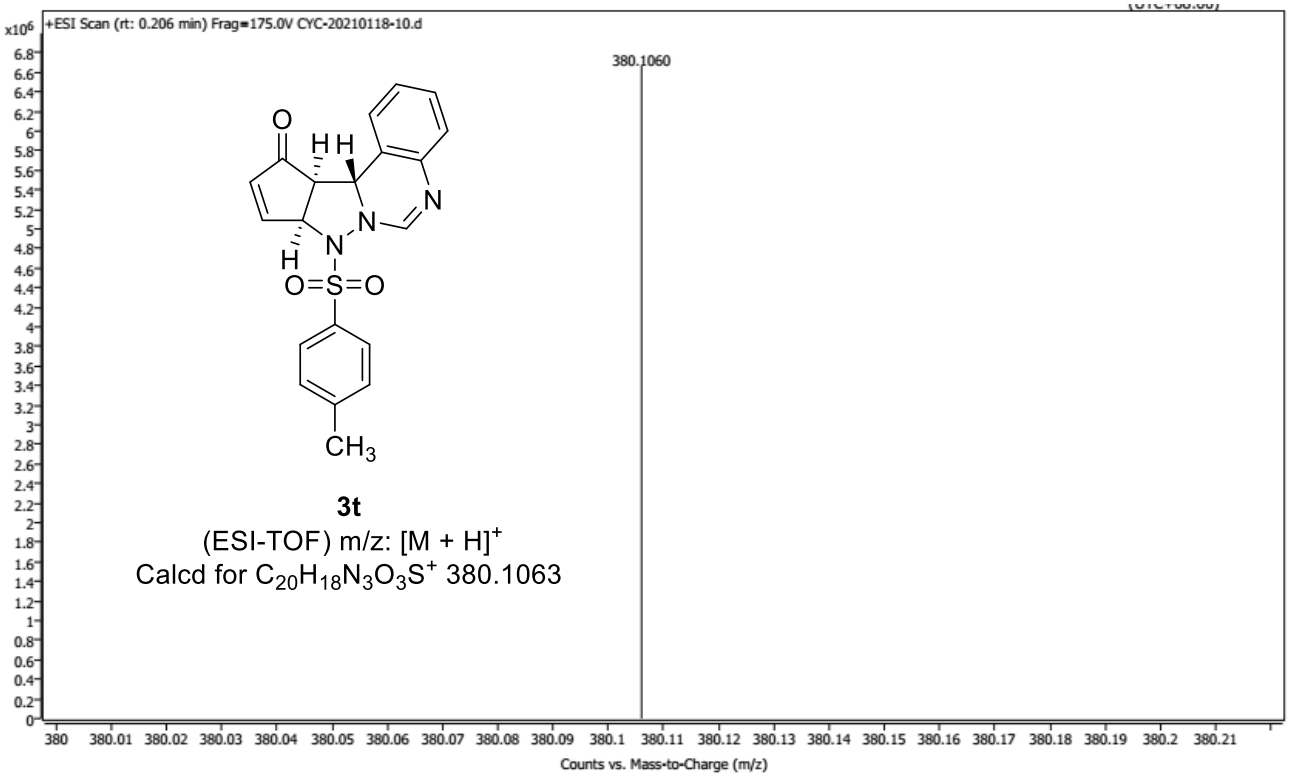
^{13}C NMR (100 MHz, $CDCl_3$)



Ret Time [min]	Peak Type	Width [min]	Height [mAU]	Area [mAU*s]	Area [%]
23.712	BB	0.70	33.0472	1497.1547	50.4542
28.665	BBA	0.88	25.3137	1470.1998	49.5458
			Totals:	2967.3545	100.0000



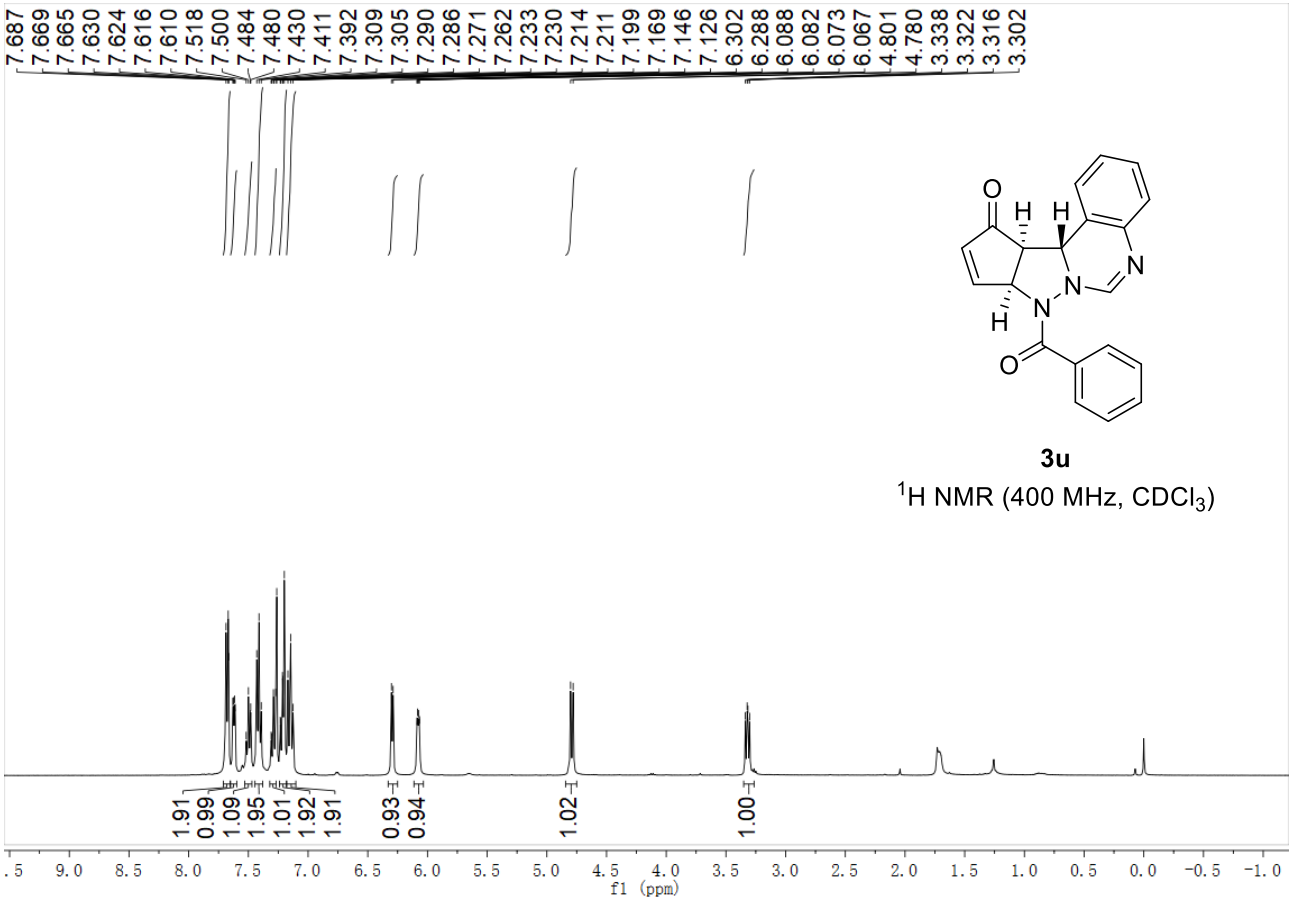
Ret Time [min]	Peak Type	Width [min]	Height [mAU]	Area [mAU*s]	Area [%]
23.783	BBA	0.69	130.4875	5828.7412	95.7758
29.374	BBA	0.78	4.9307	257.0769	4.2242
			Totals:	6085.8181	100.0000



3t

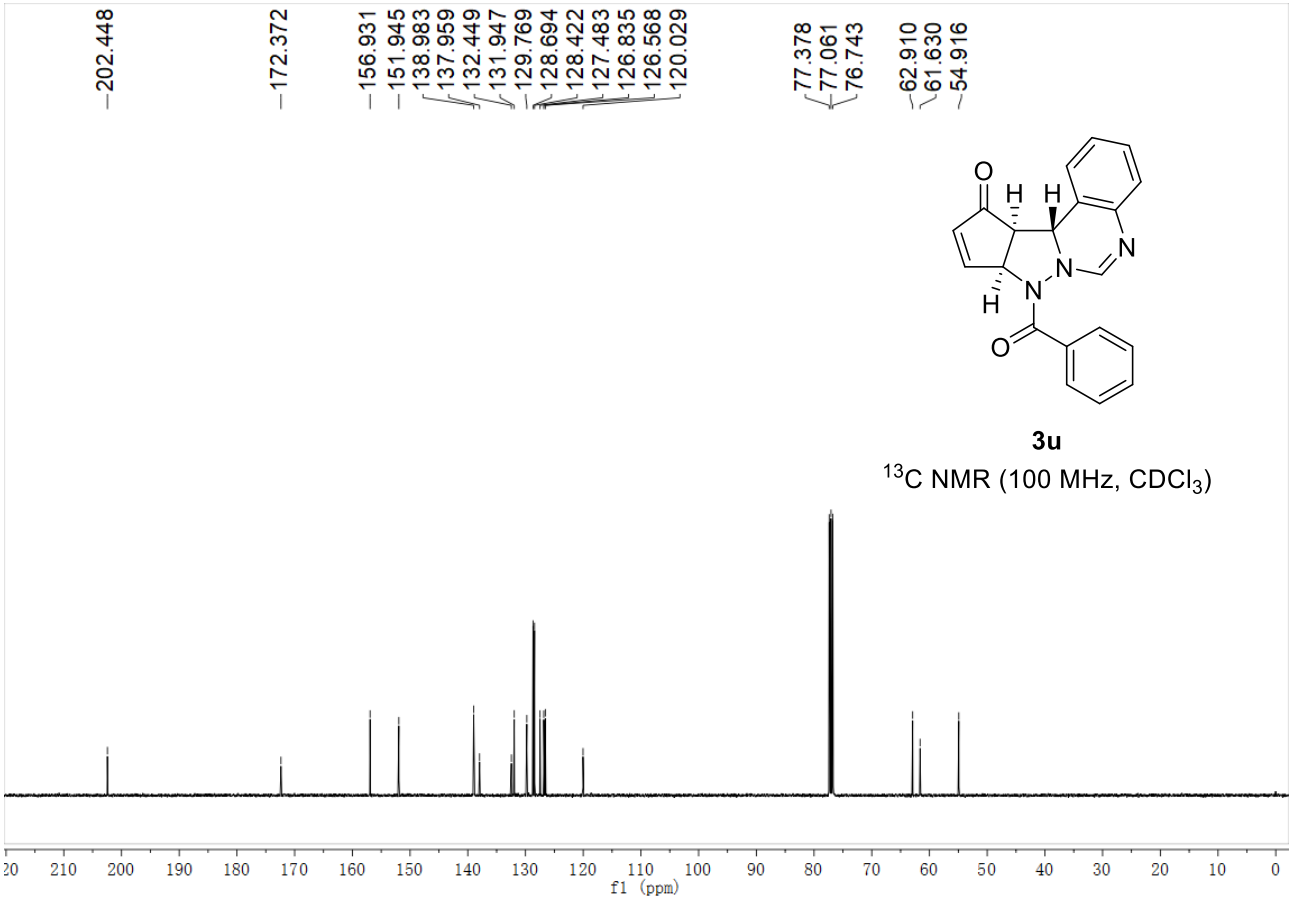
(ESI-TOF) m/z: $[M + H]^+$

Calcd for $C_{20}H_{18}N_3O_3S^+$ 380.1063



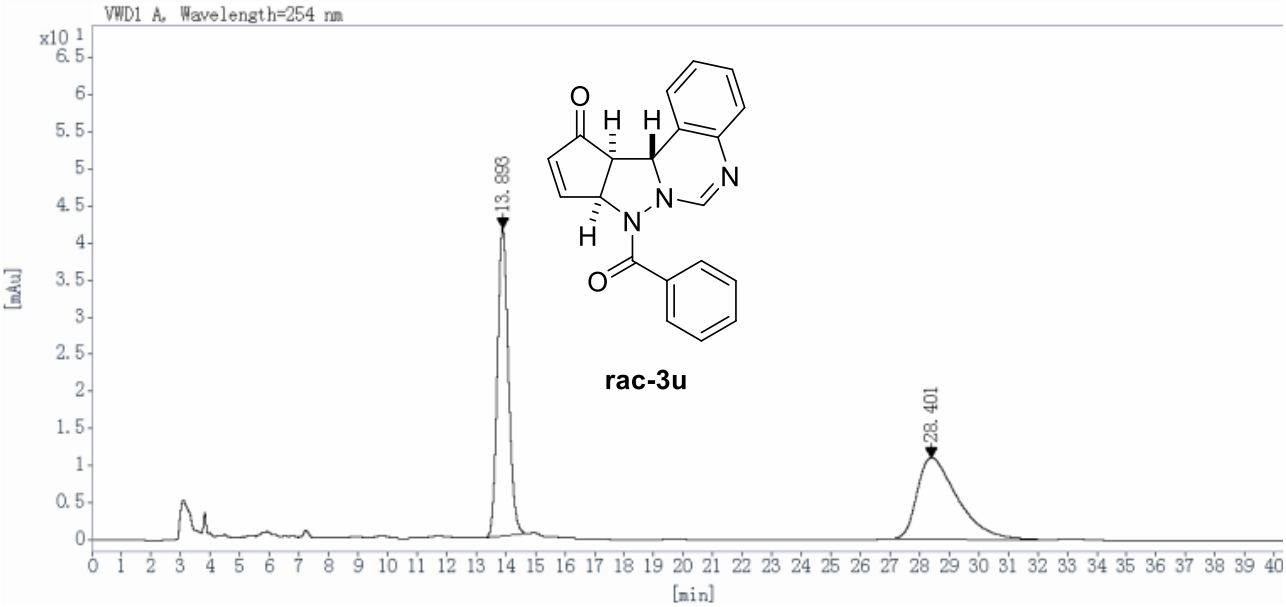
3u

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

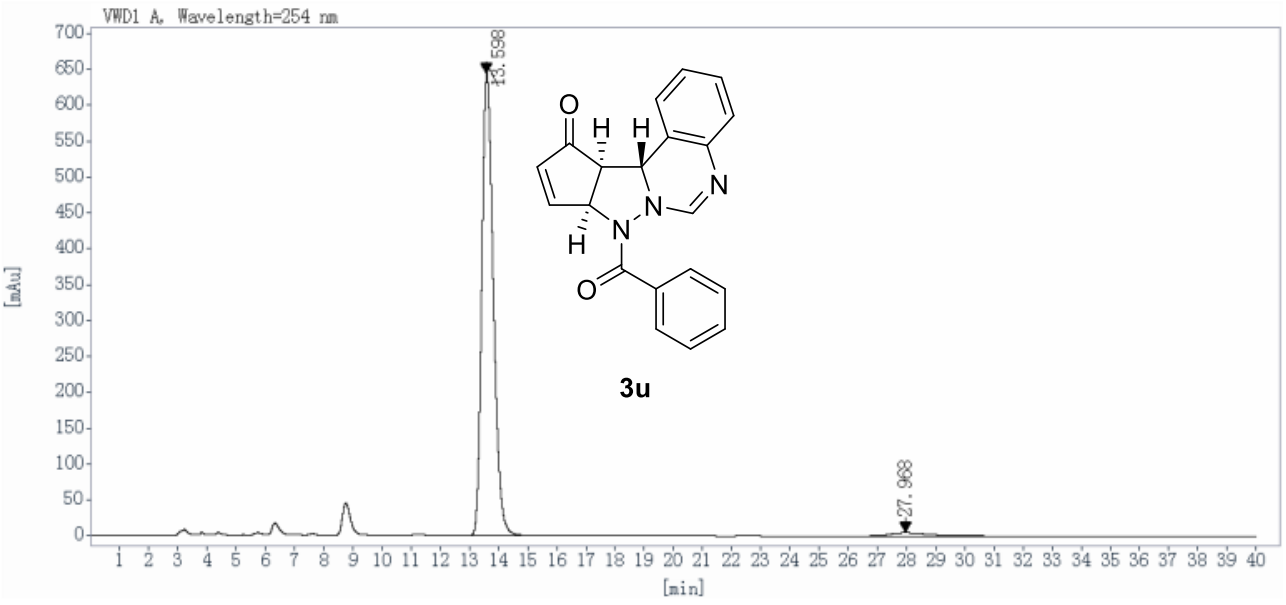


3u

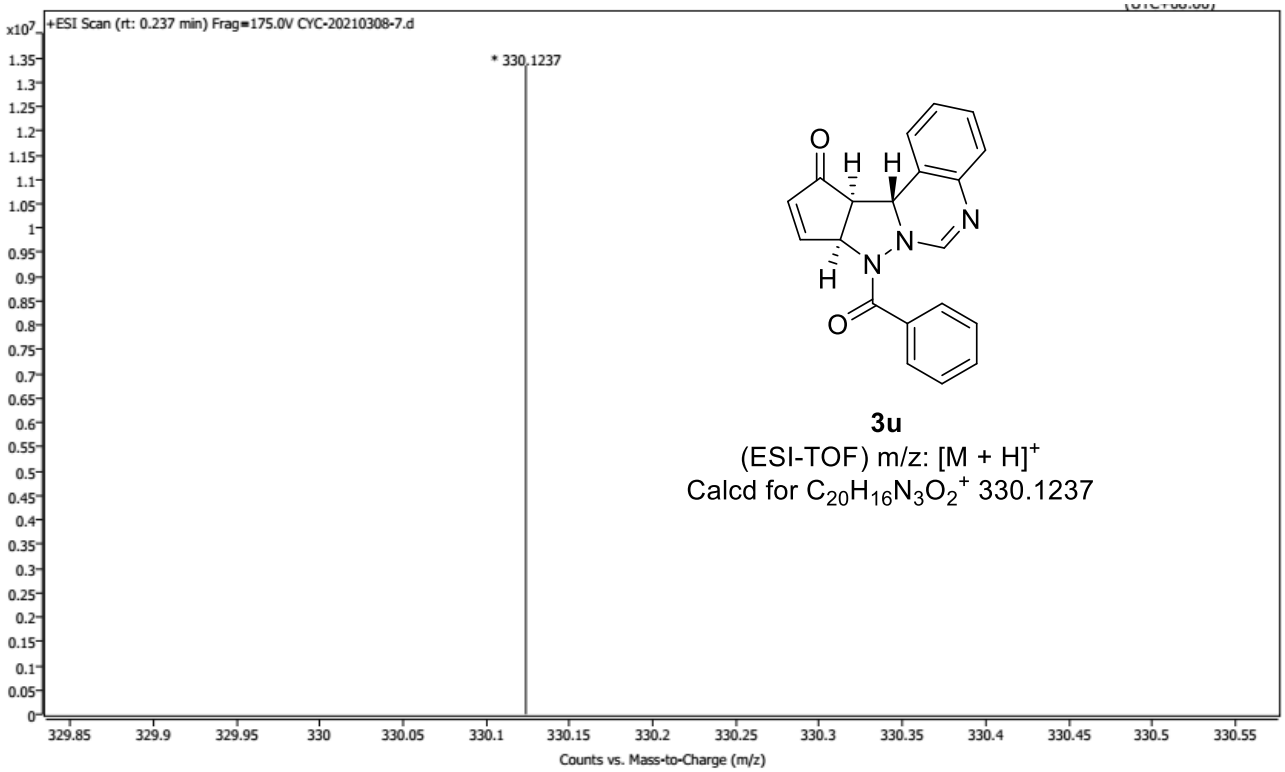
^{13}C NMR (100 MHz, $CDCl_3$)



Ret Time [min]	Peak Type	Width [min]	Height [mAU]	Area [mAU*s]	Area [%]
13.893	BB	0.40	41.4287	1070.1135	50.6217
28.401	BBA	1.33	11.0022	1043.8302	49.3783
			Totals:	2113.9437	100.0000



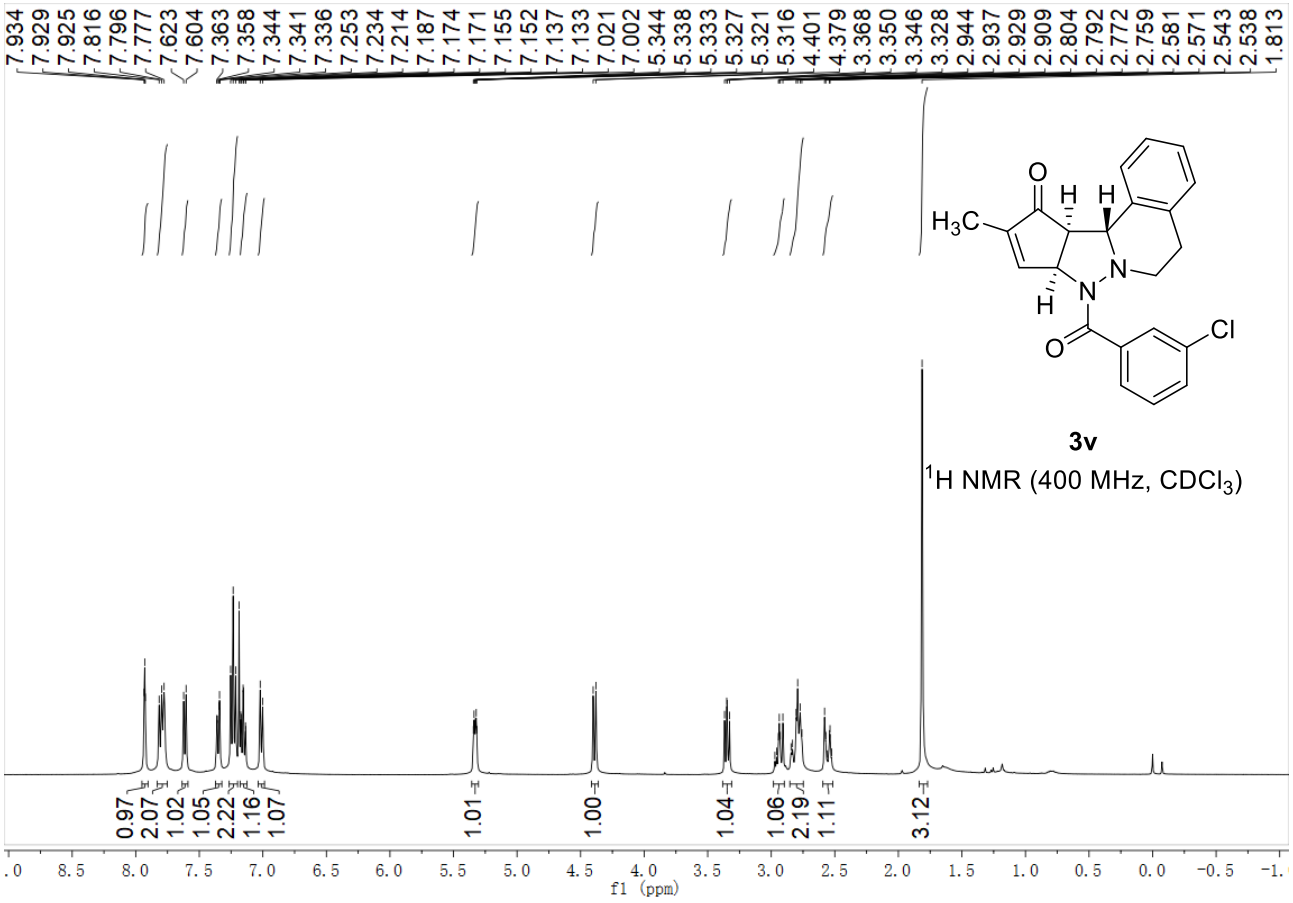
Ret Time [min]	Peak Type	Width [min]	Height [mAU]	Area [mAU*s]	Area [%]
13.598	BB	0.43	644.5720	17791.6934	97.6304
27.968	BB	1.21	4.6154	431.8213	2.3696
			Totals:	18223.5146	100.0000



3u

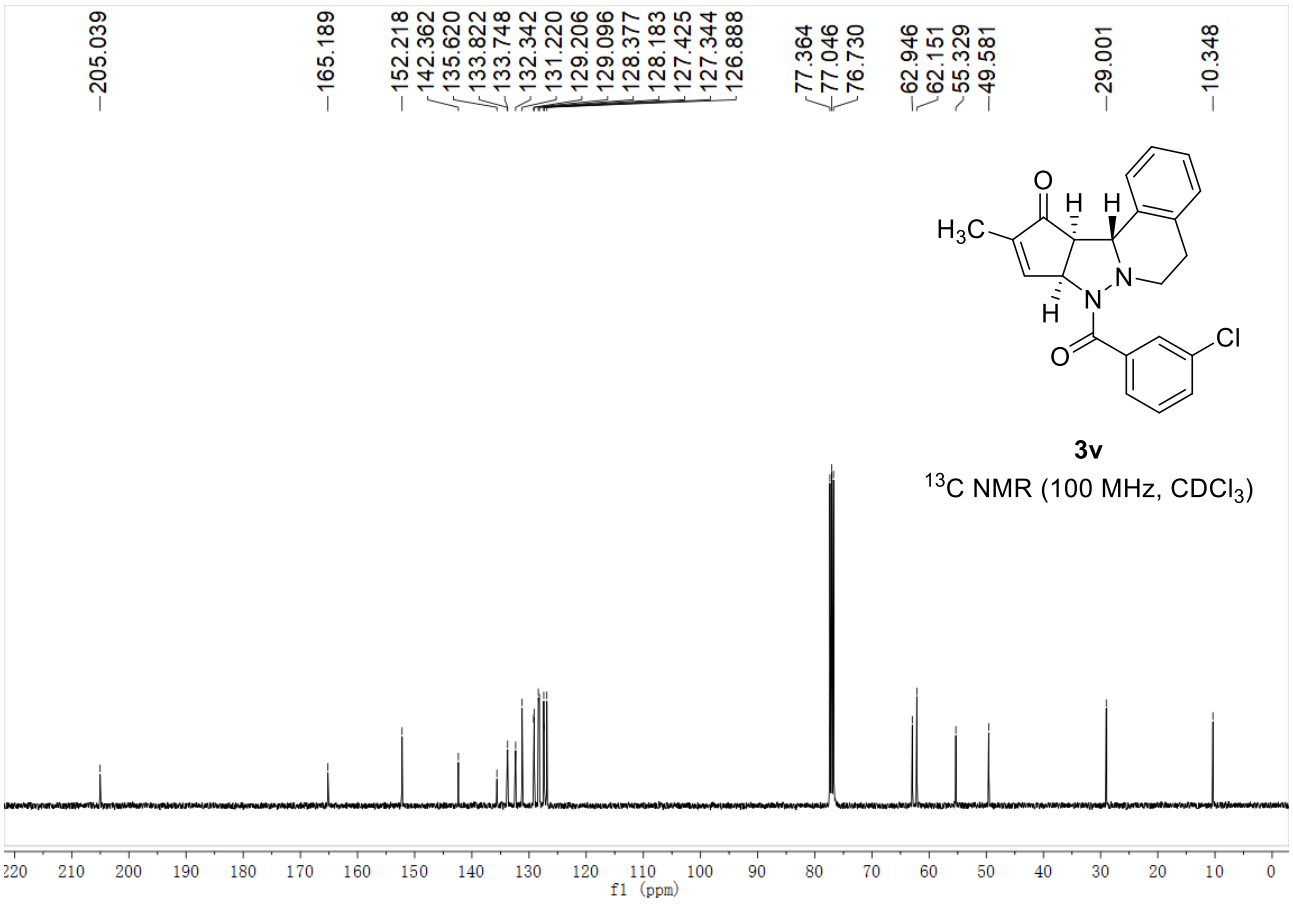
(ESI-TOF) m/z: $[M + H]^+$

Calcd for $C_{20}H_{16}N_3O_2^+$ 330.1237



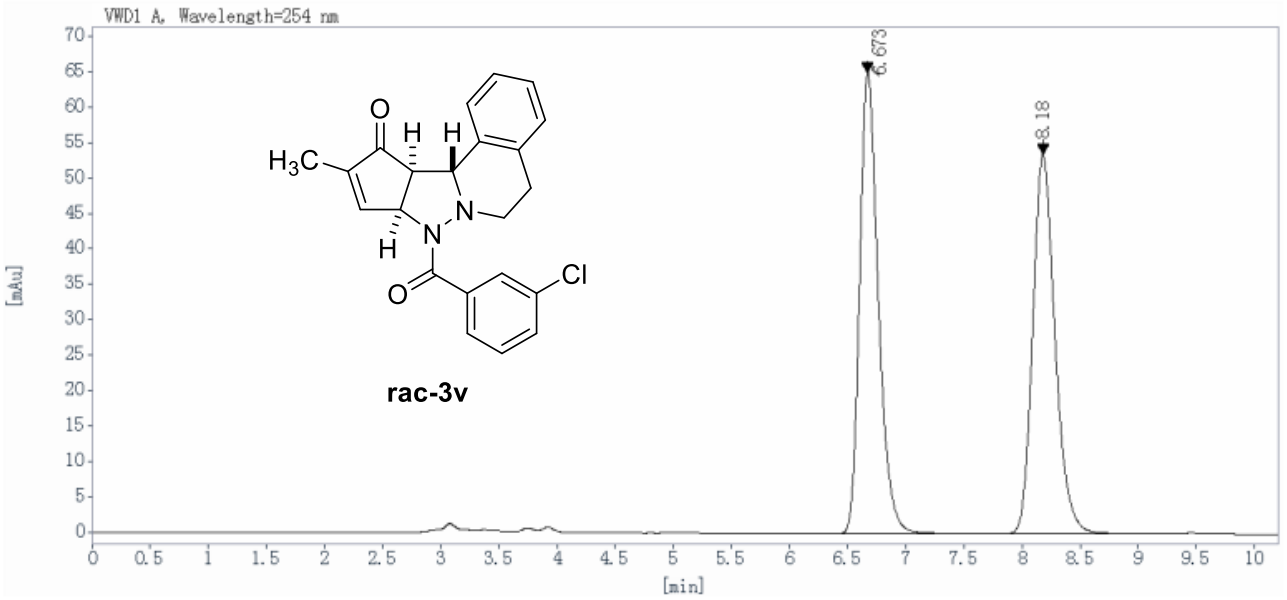
3v

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

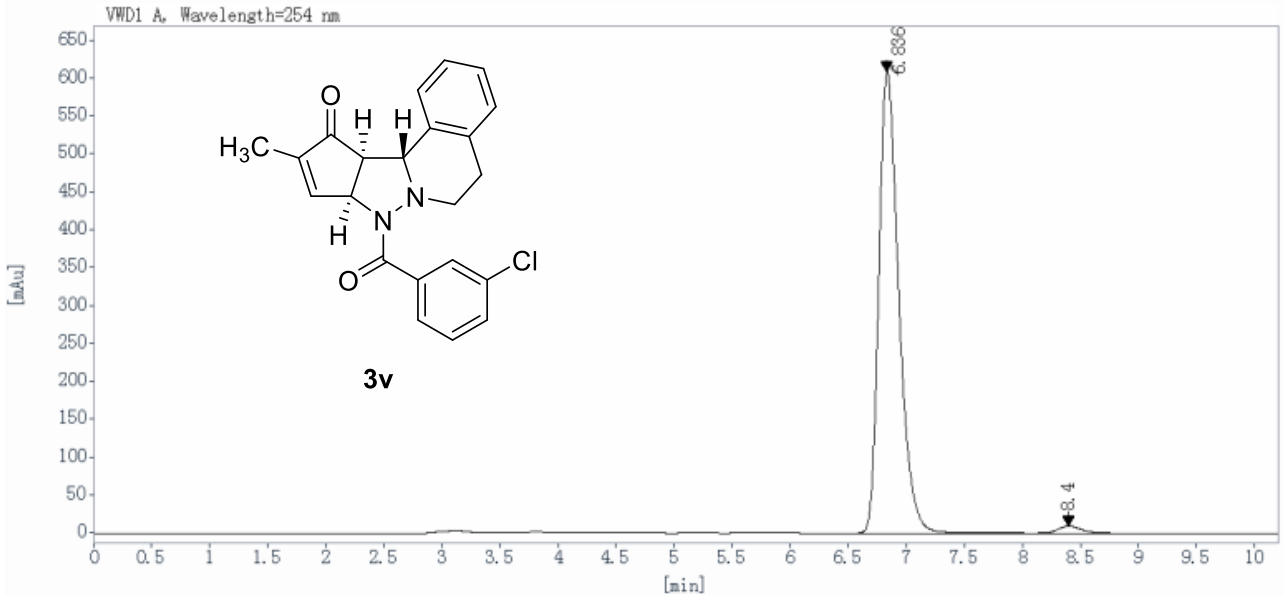


3v

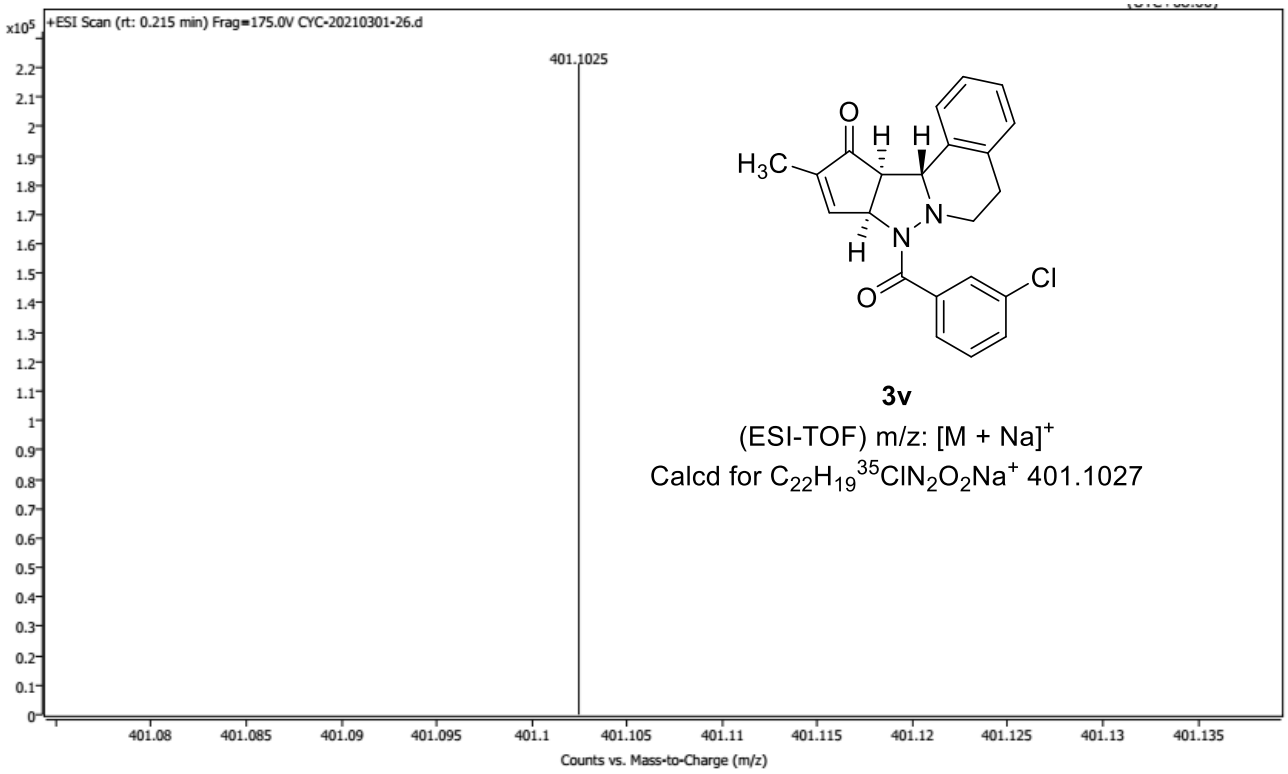
^{13}C NMR (100 MHz, $CDCl_3$)



Ret Time [min]	Peak Type	Width [min]	Height [mAU]	Area [mAU*s]	Area [%]
6.673	BB	0.17	65.1140	729.1856	50.5203
8.180	BB	0.20	53.5955	714.1675	49.4797
			Totals:	1443.3531	100.0000



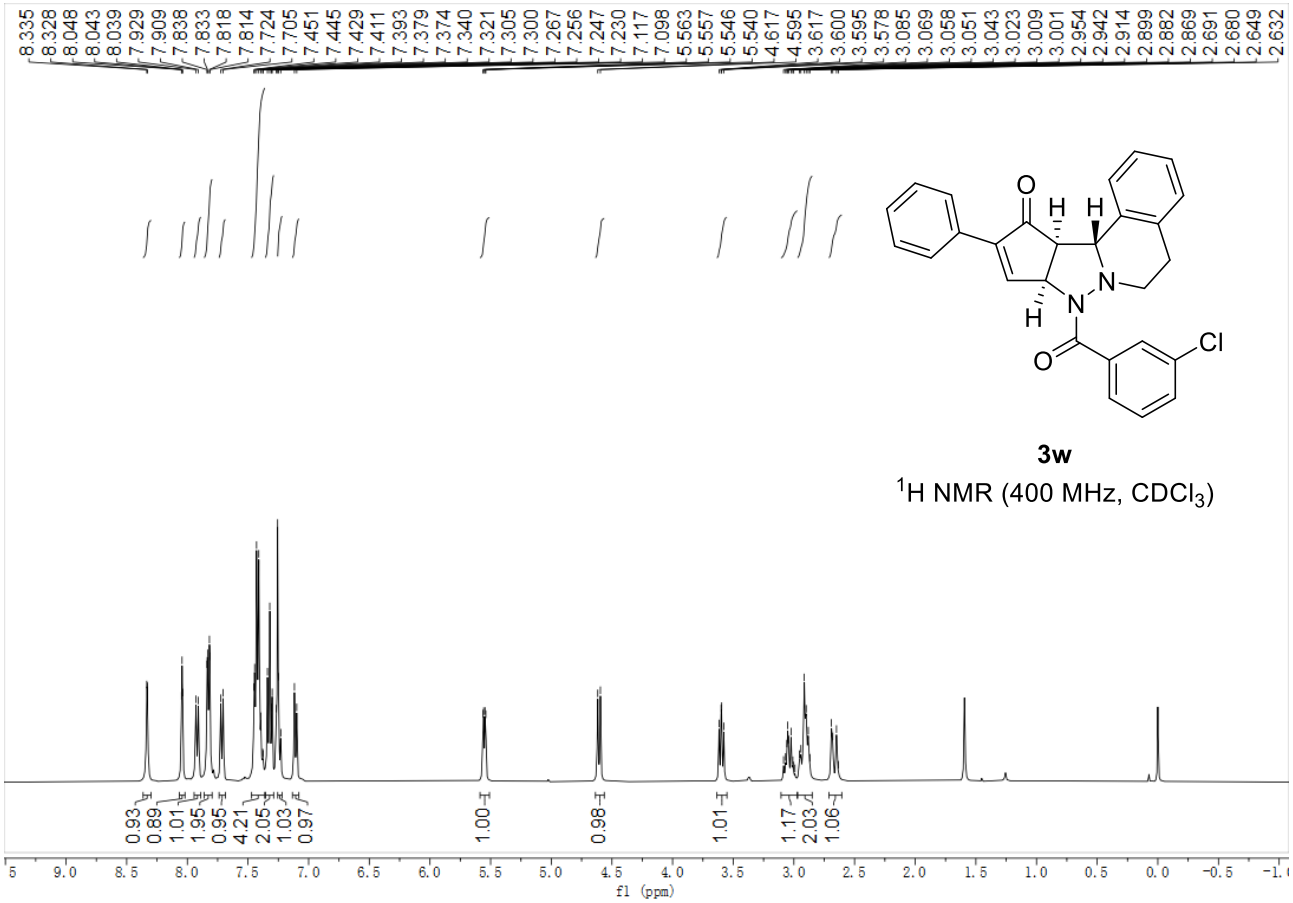
Ret Time [min]	Peak Type	Width [min]	Height [mAU]	Area [mAU*s]	Area [%]
6.836	BB	0.18	609.0971	7277.0513	98.2528
8.400	BB	0.21	9.3161	129.4060	1.7472
			Totals:	7406.4572	100.0000



3v

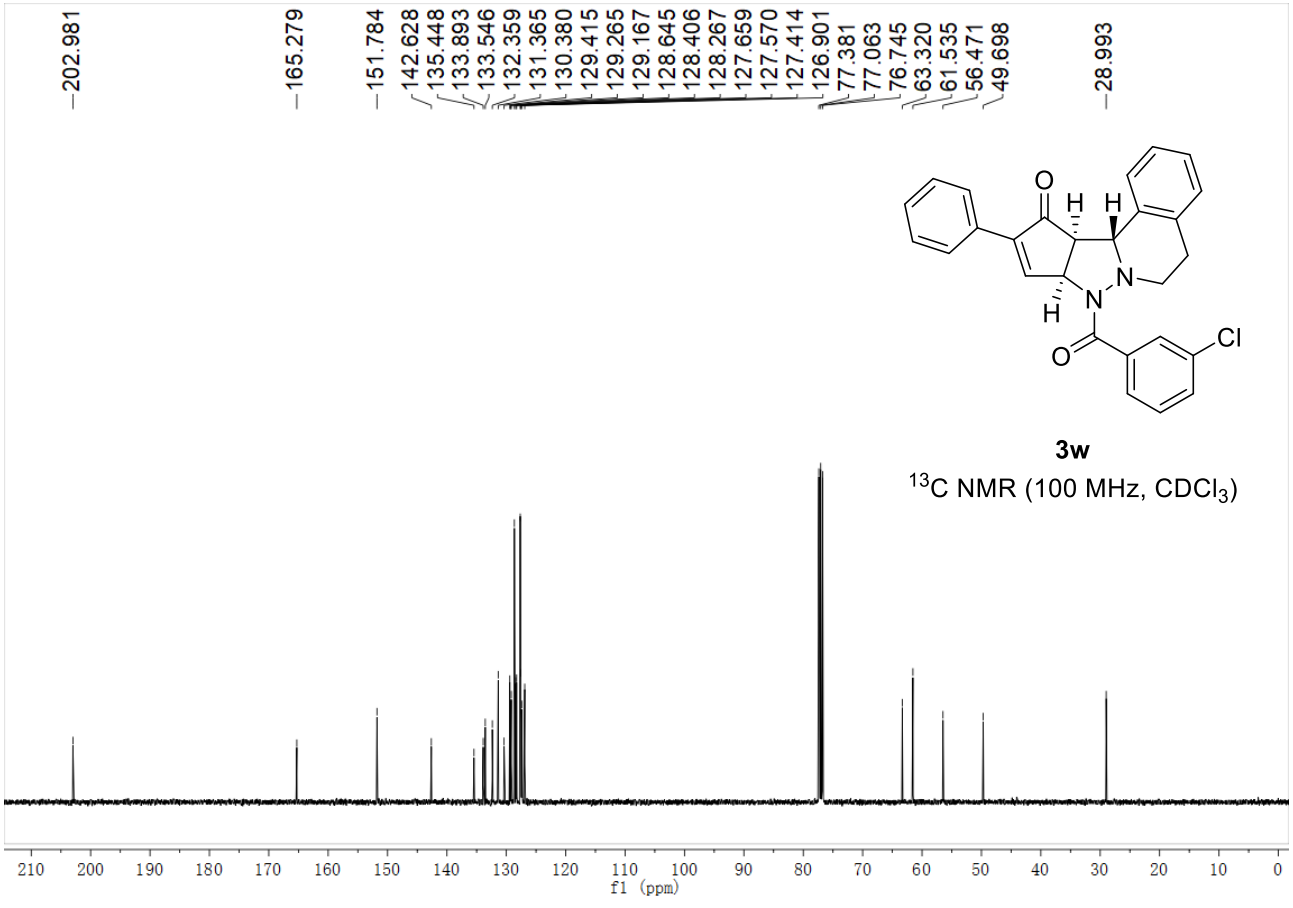
(ESI-TOF) m/z: $[M + Na]^+$

Calcd for $C_{22}H_{19}{}^{35}ClN_2O_2Na^+$ 401.1027



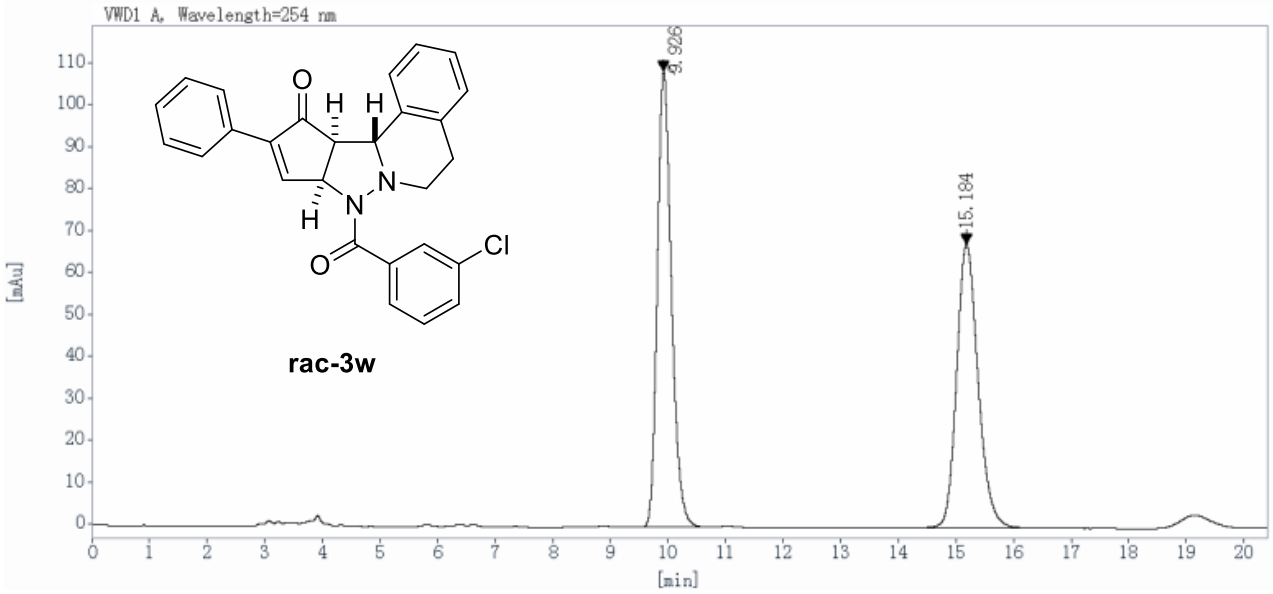
3w

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

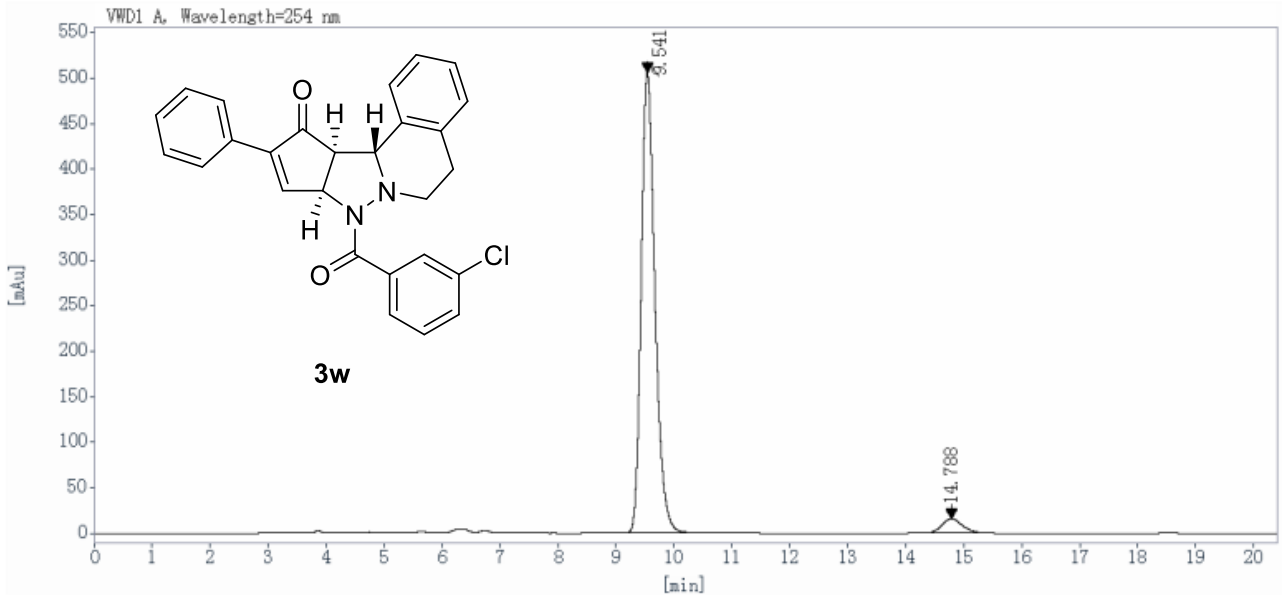


3w

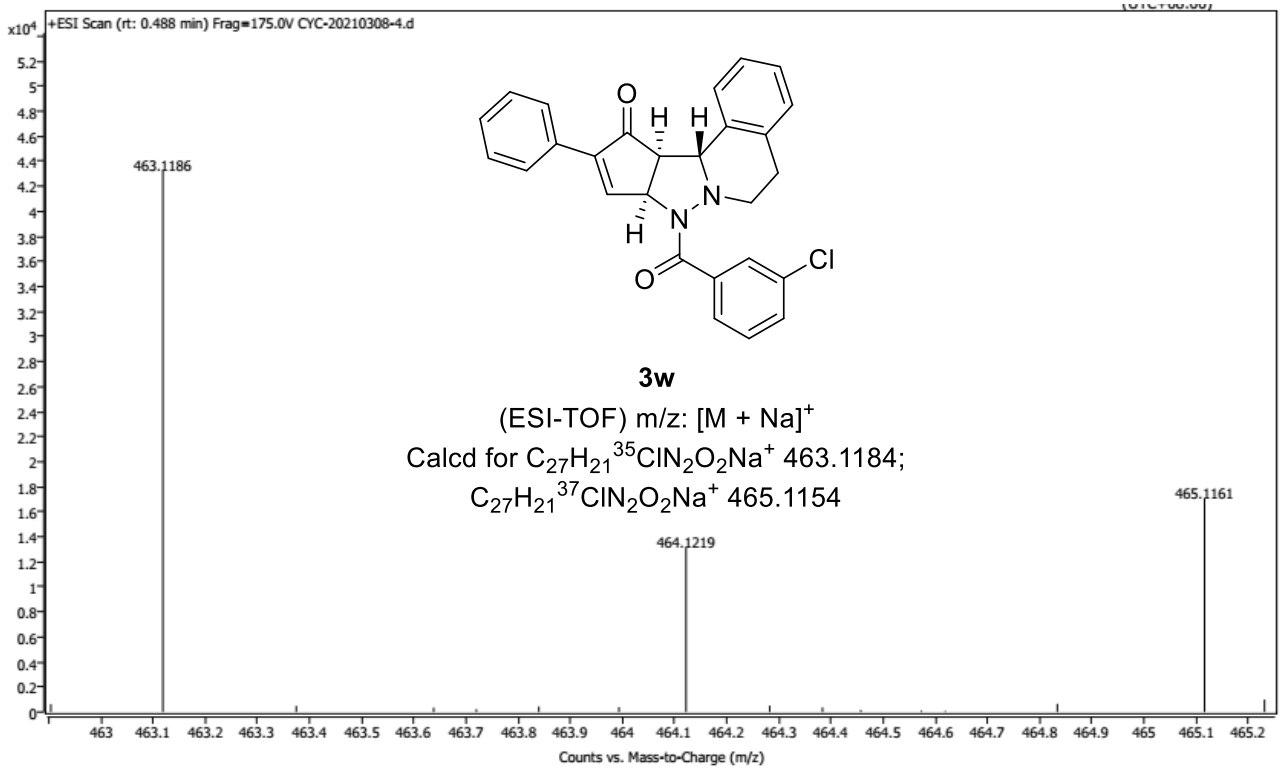
^{13}C NMR (100 MHz, $CDCl_3$)



Ret Time [min]	Peak Type	Width [min]	Height [mAU]	Area [mAU*s]	Area [%]
9.926	BB	0.26	108.7386	1851.1559	51.2659
15.184	BB	0.40	67.8529	1759.7385	48.7341
			Totals:	3610.8944	100.0000



Ret Time [min]	Peak Type	Width [min]	Height [mAU]	Area [mAU*s]	Area [%]
9.541	BBA	0.25	505.4901	8318.6455	95.7585
14.788	BBA	0.37	15.2614	368.4615	4.2415
			Totals:	8687.1070	100.0000

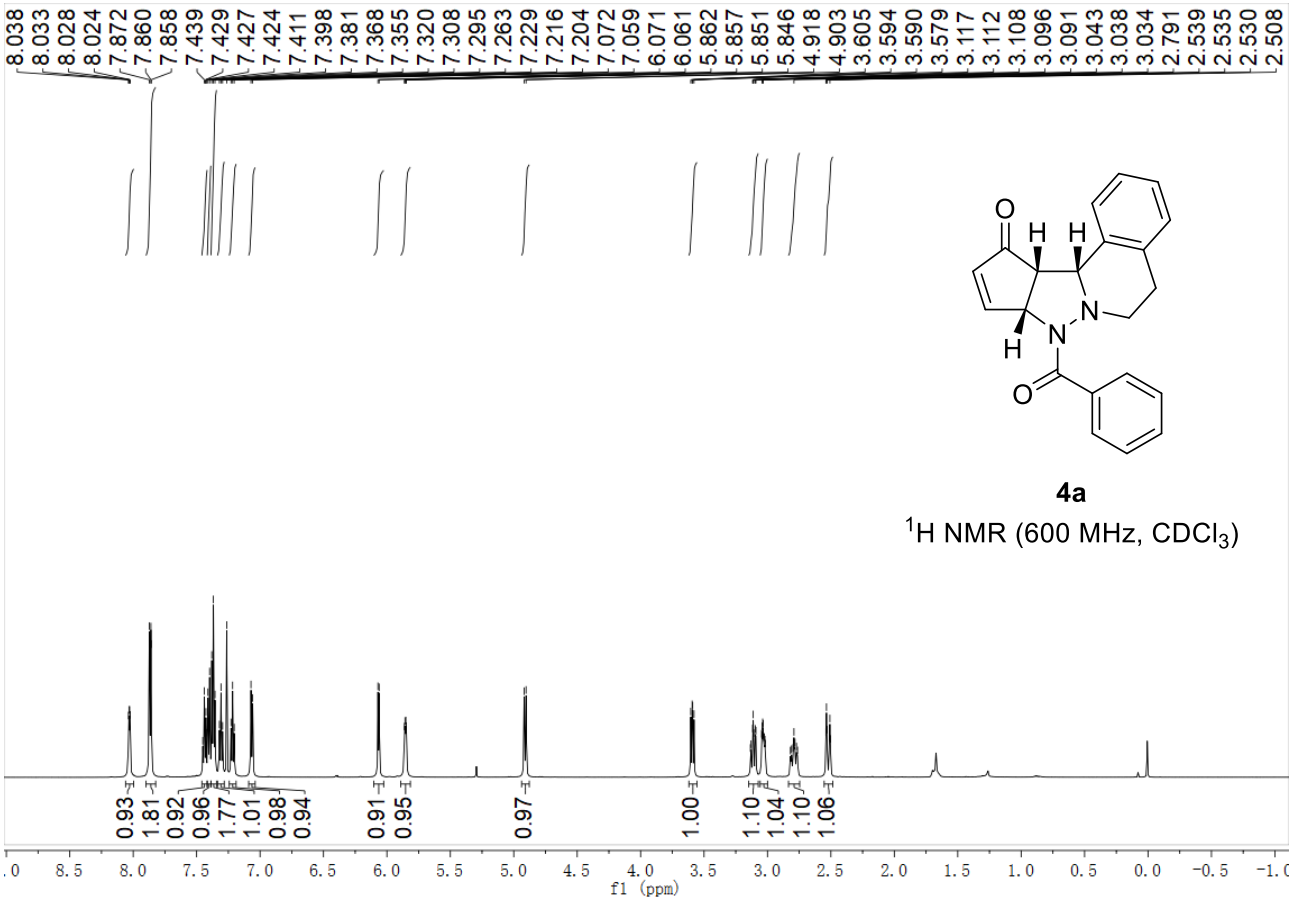


3w

(ESI-TOF) m/z: $[M + Na]^+$

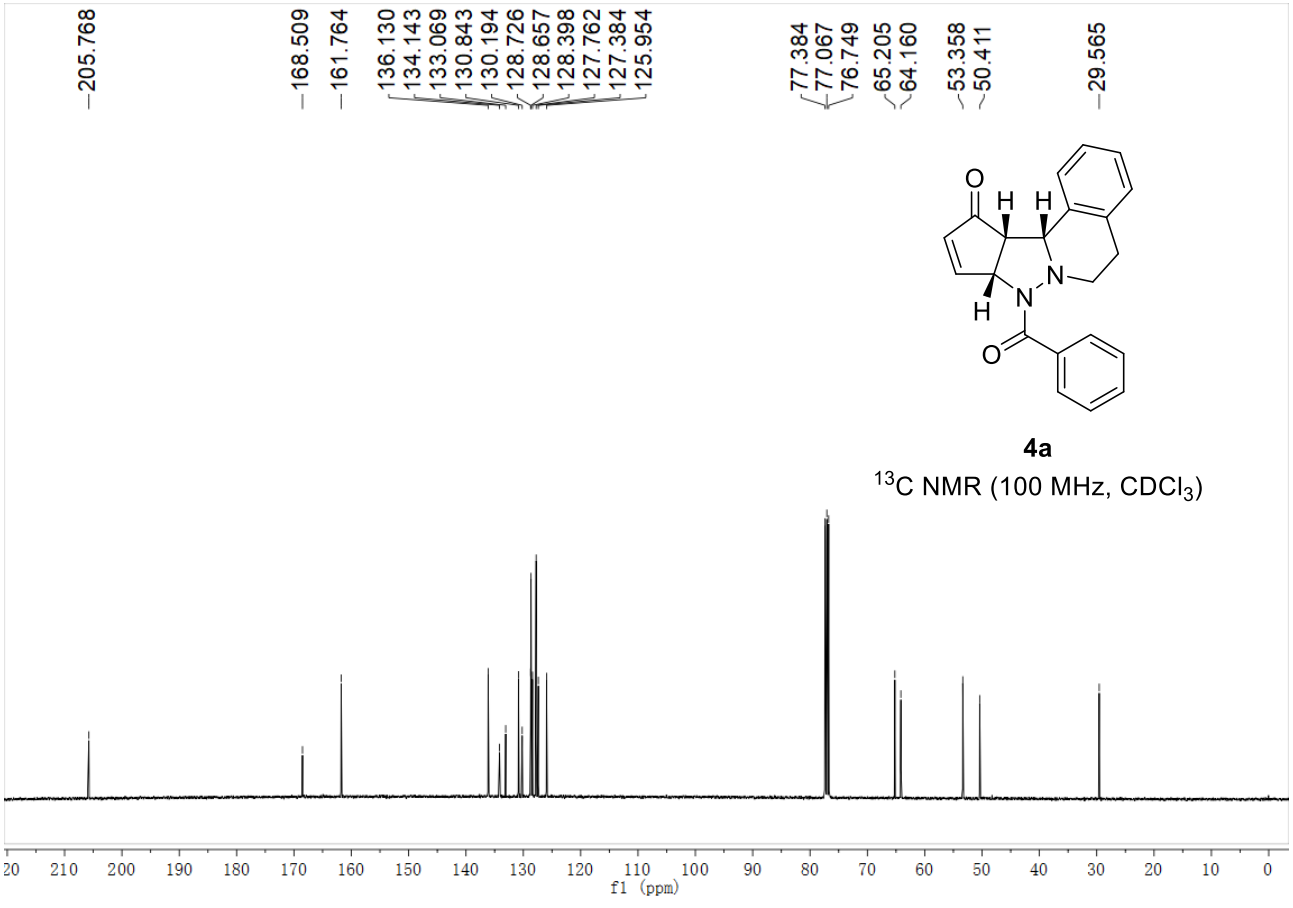
Calcd for $C_{27}H_{21}{}^{35}ClN_2O_2Na^+$ 463.1184;

$C_{27}H_{21}{}^{37}ClN_2O_2Na^+$ 465.1154



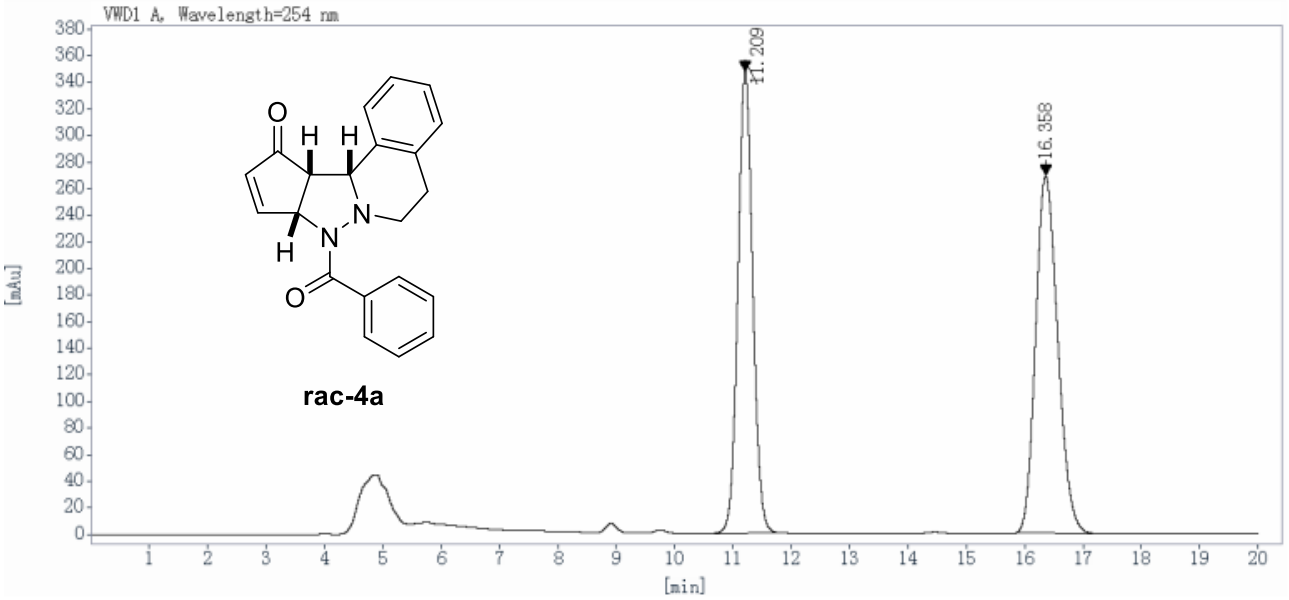
4a

^{1}H NMR (600 MHz, $CDCl_3$)

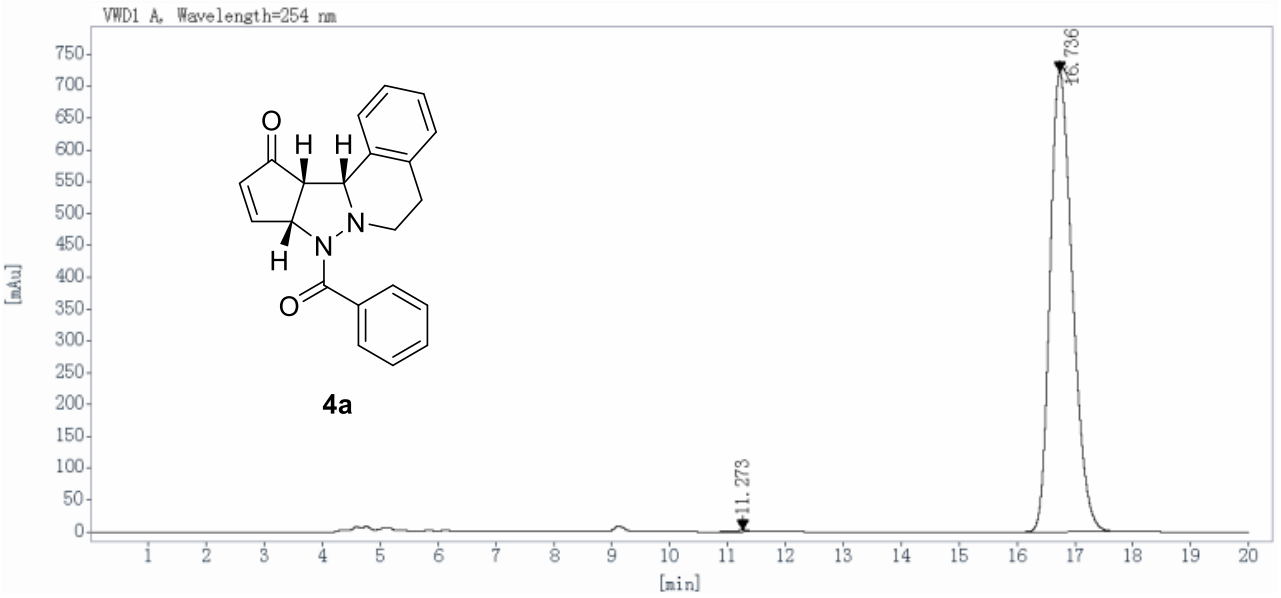


4a

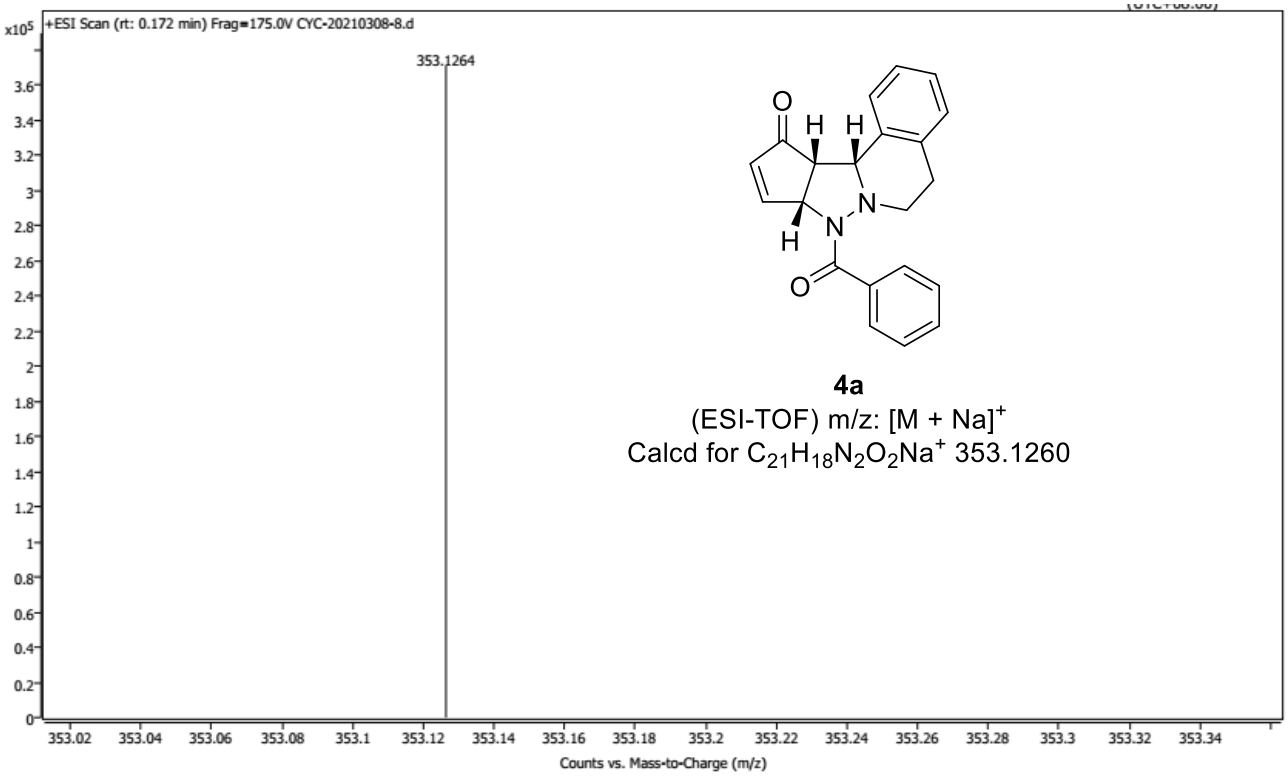
^{13}C NMR (100 MHz, $CDCl_3$)



Ret Time [min]	Peak Type	Width [min]	Height [mAU]	Area [mAU*s]	Area [%]
11.209	BBA	0.27	347.7797	6160.3613	46.5347
16.358	BBA	0.41	268.8688	7077.8433	53.4653
			Totals:	13238.2046	100.0000



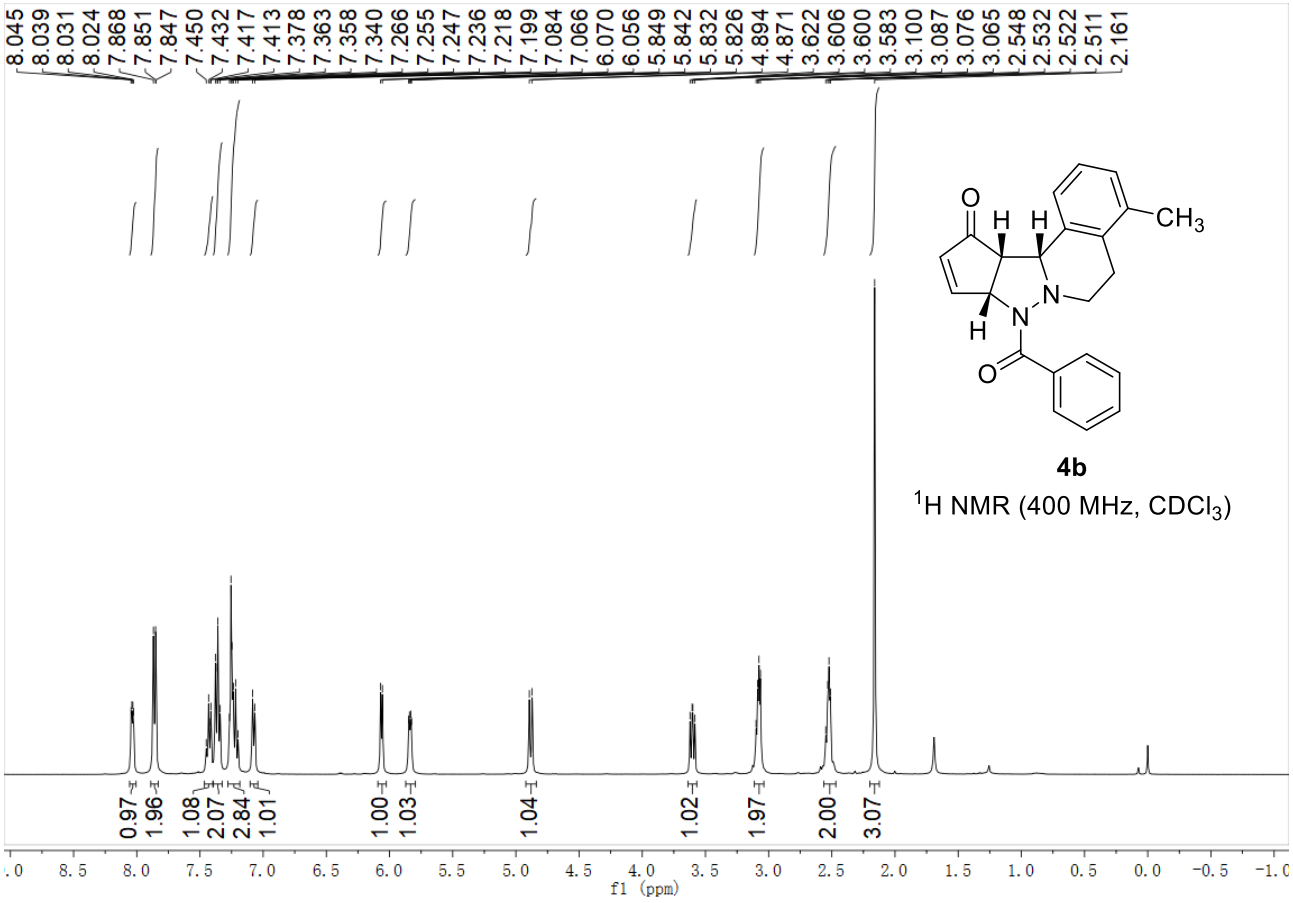
Ret Time [min]	Peak Type	Width [min]	Height [mAU]	Area [mAU*s]	Area [%]
11.273	BB	0.30	2.0372	40.6583	0.2095
16.736	BBA	0.42	721.9362	19362.9590	99.7905
			Totals:	19403.6173	100.0000



4a

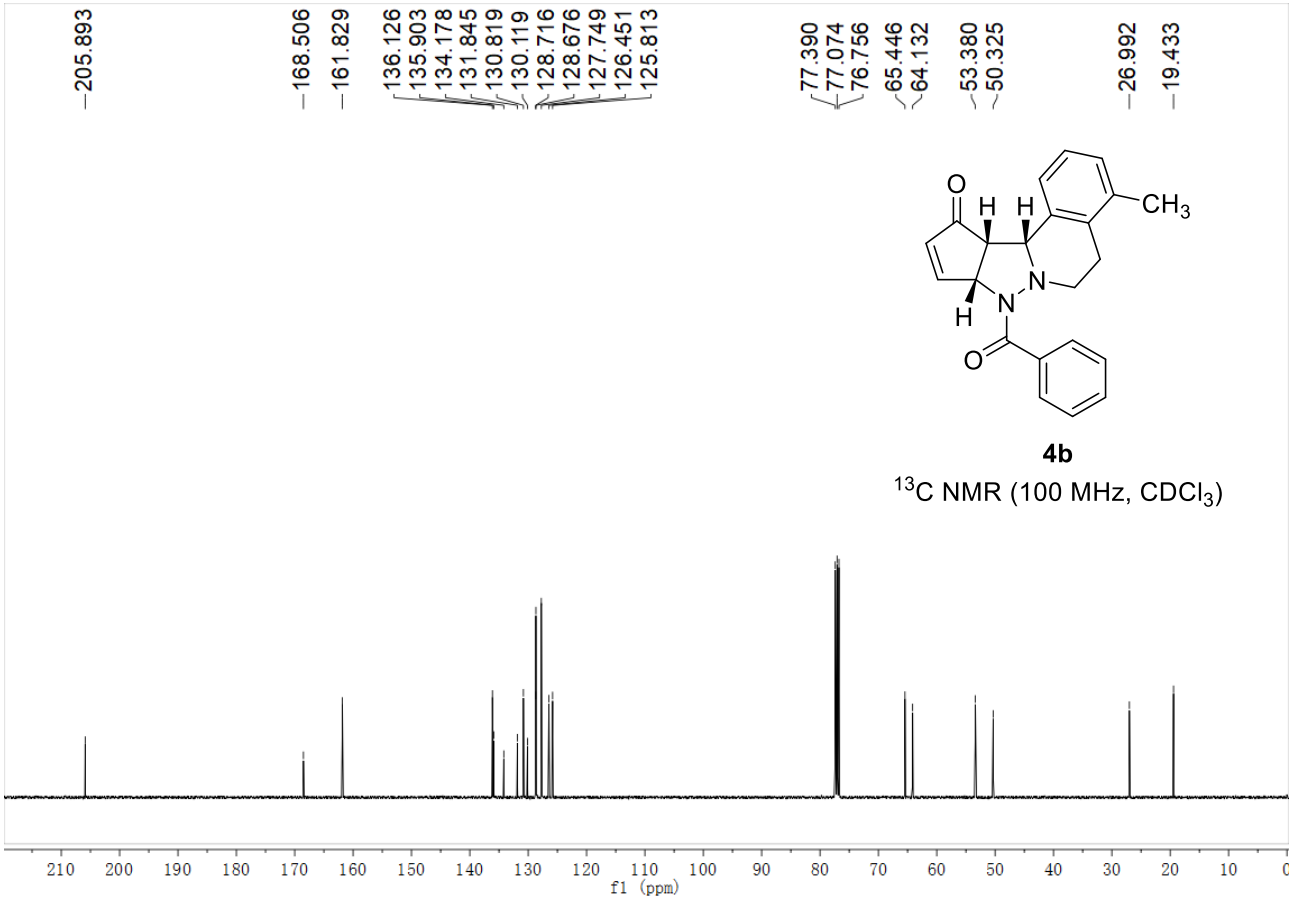
(ESI-TOF) m/z: $[M + Na]^+$

Calcd for $C_{21}H_{18}N_2O_2Na^+$ 353.1260



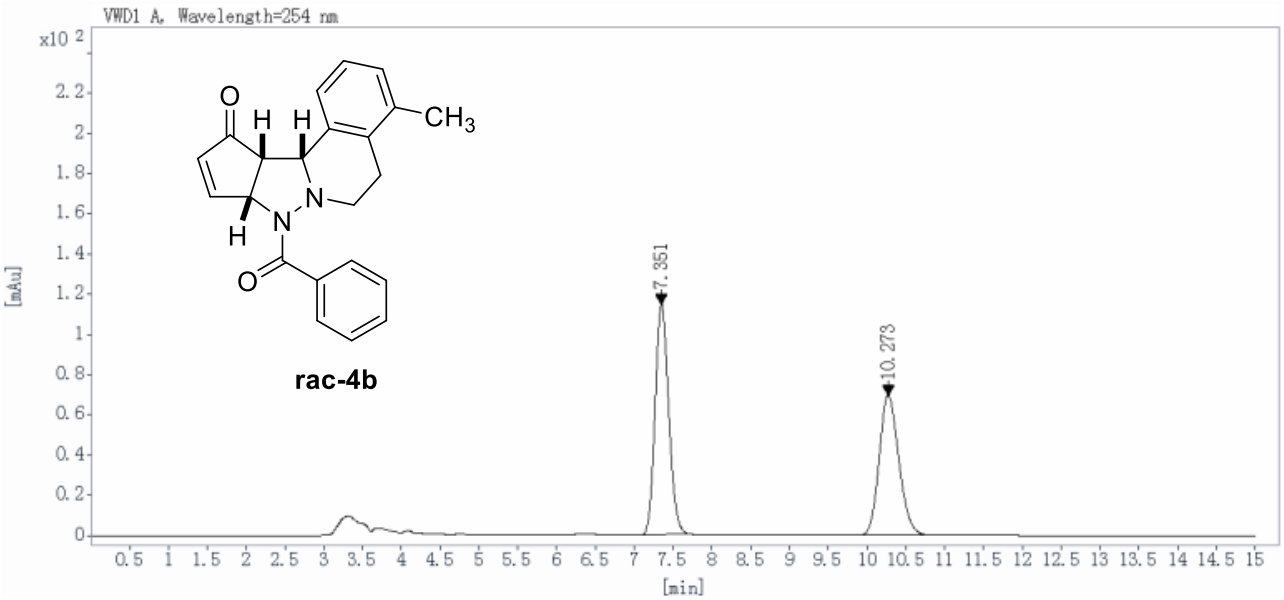
4b

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

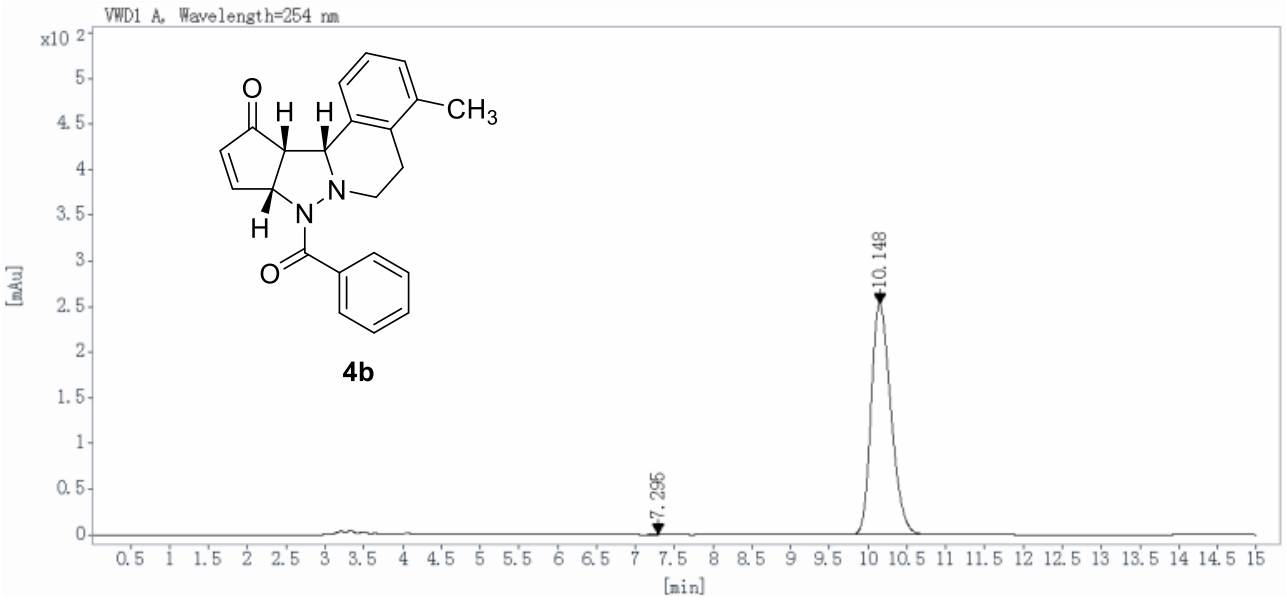


4b

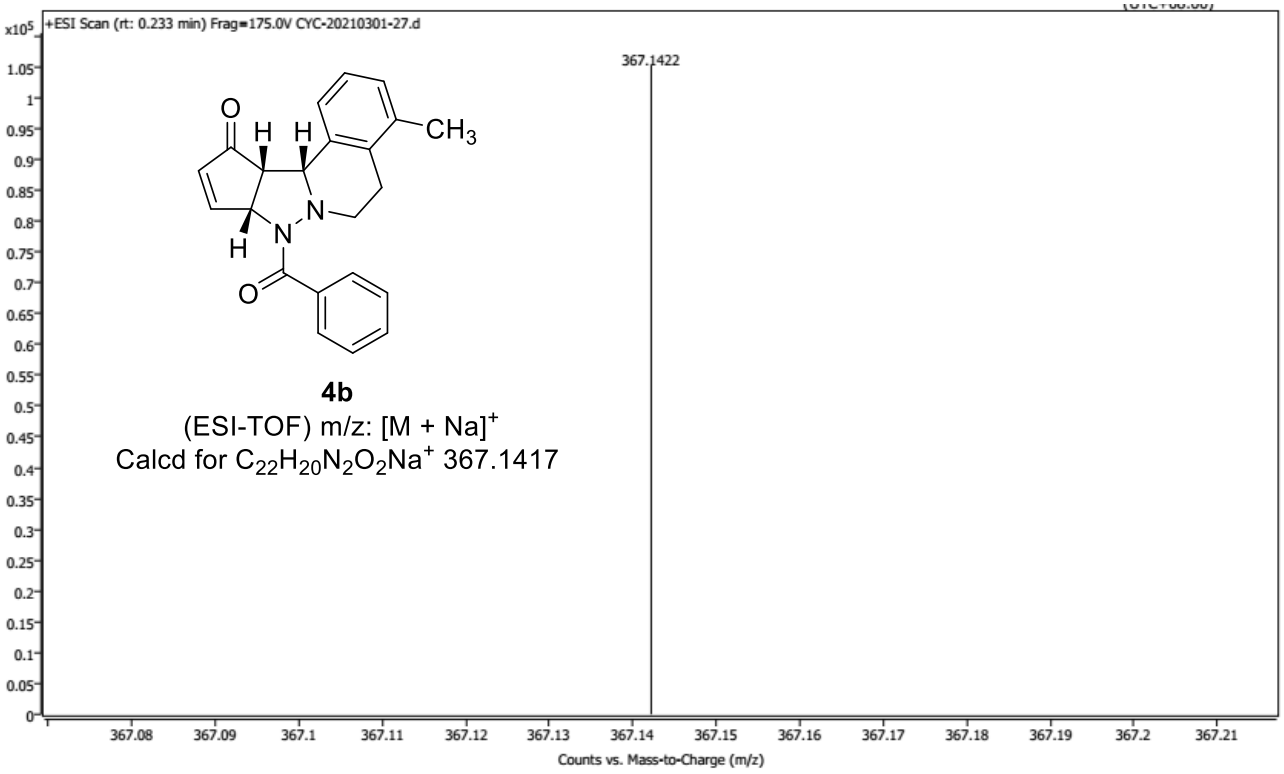
^{13}C NMR (100 MHz, $CDCl_3$)



Ret Time [min]	Peak Type	Width [min]	Height [mAU]	Area [mAU*s]	Area [%]
7.351	BBA	0.19	114.7504	1393.8202	52.9748
10.273	BBA	0.28	69.7221	1237.2791	47.0252
			Totals:	2631.0992	100.0000



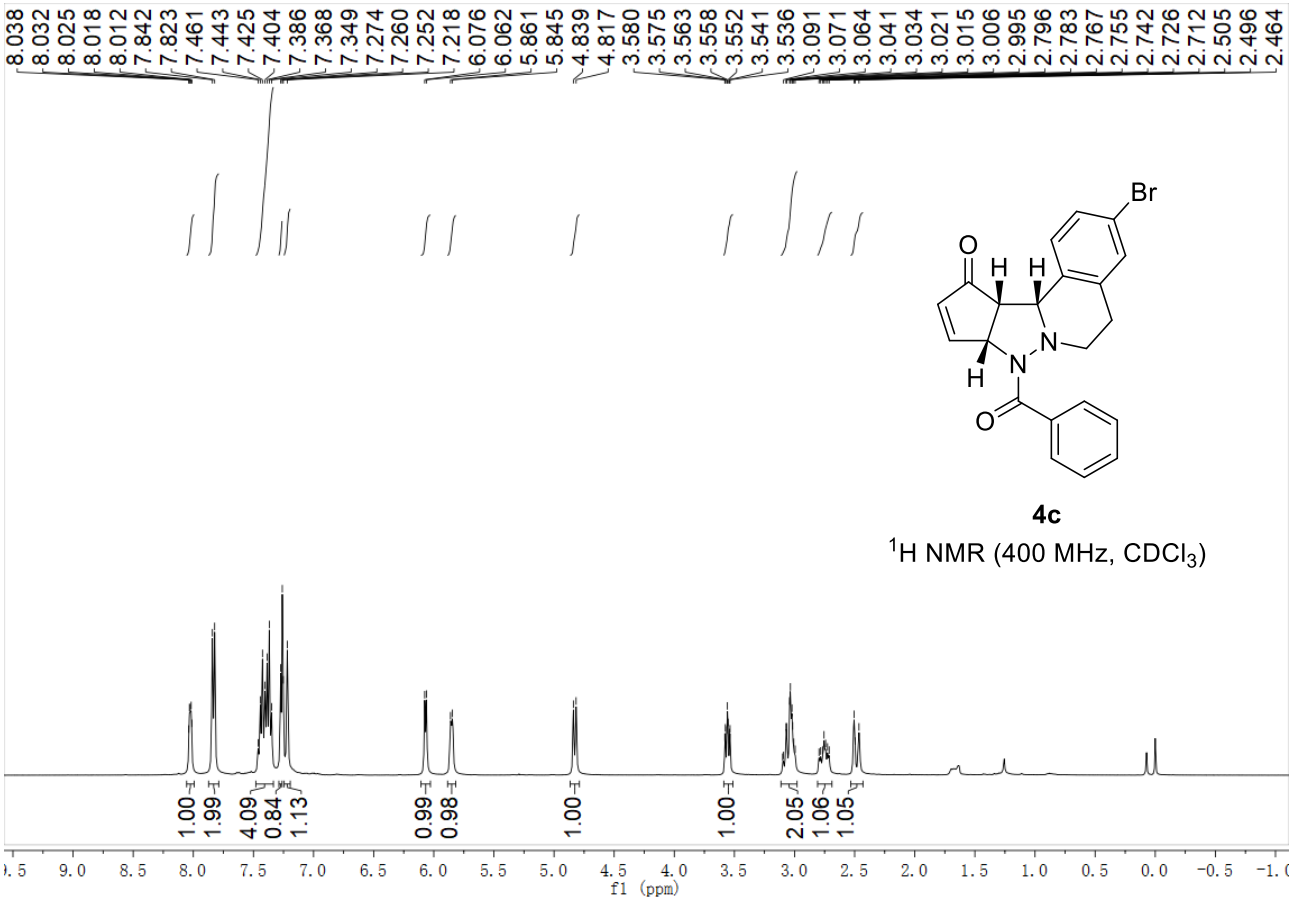
Ret Time [min]	Peak Type	Width [min]	Height [mAU]	Area [mAU*s]	Area [%]
7.295	BB	0.15	0.1529	1.4627	0.0329
10.148	BBA	0.27	252.4176	4445.3462	99.9671
			Totals:	4446.8089	100.0000



4b

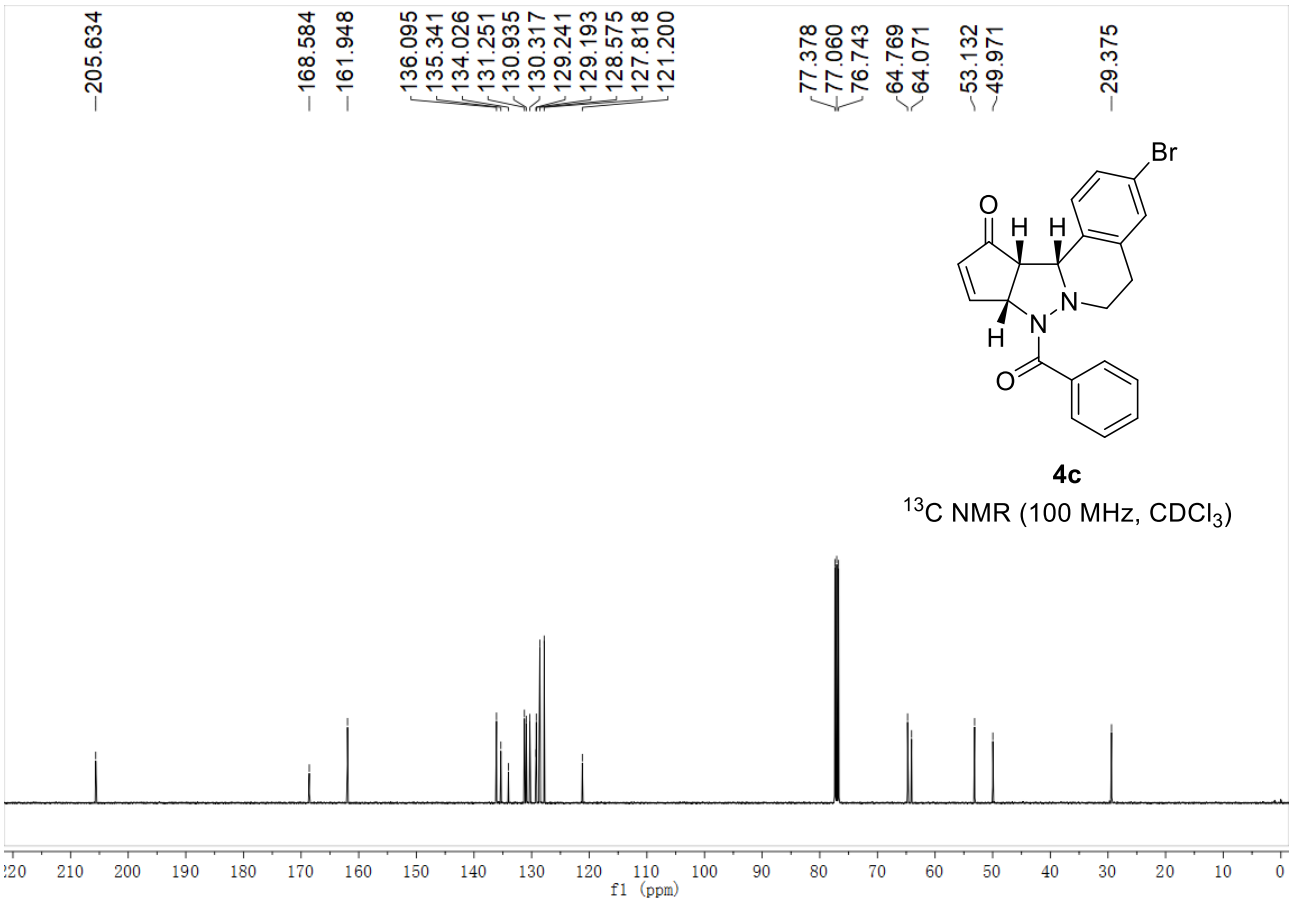
(ESI-TOF) m/z: $[M + Na]^+$

Calcd for $C_{22}H_{20}N_2O_2Na^+$ 367.1417



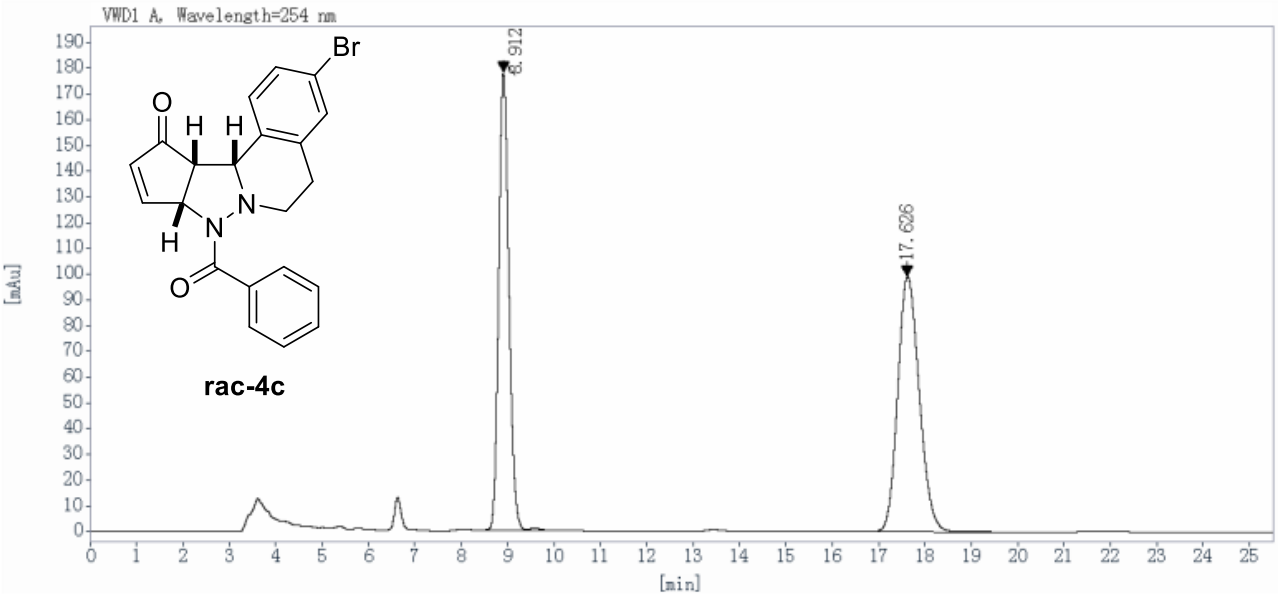
4c

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



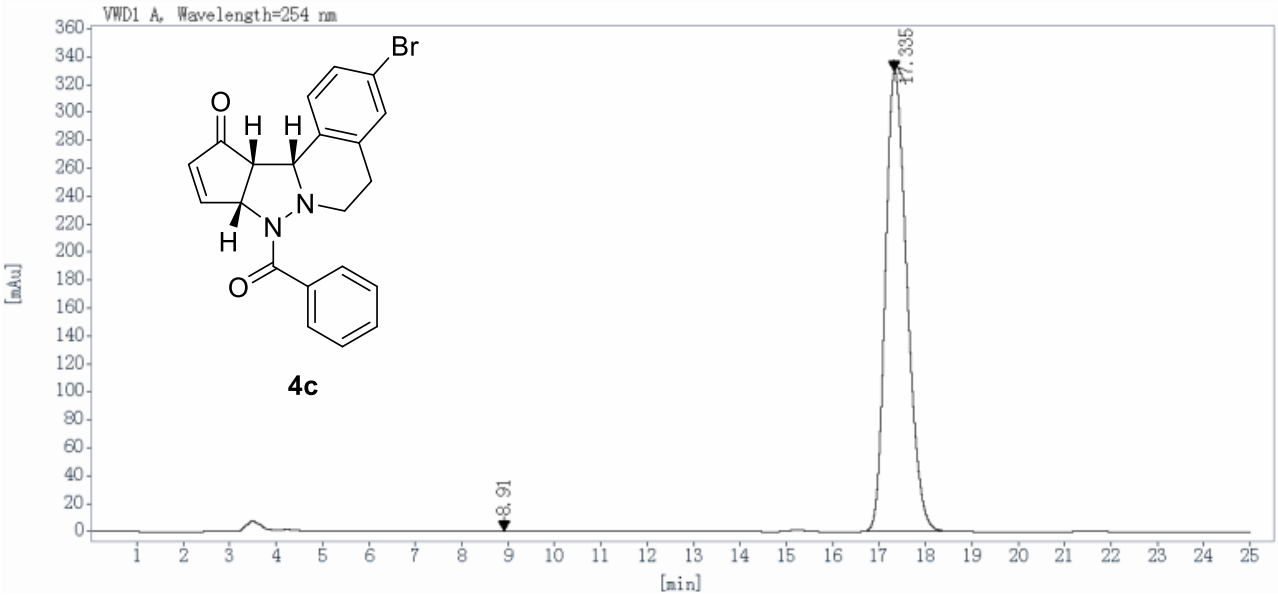
4c

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



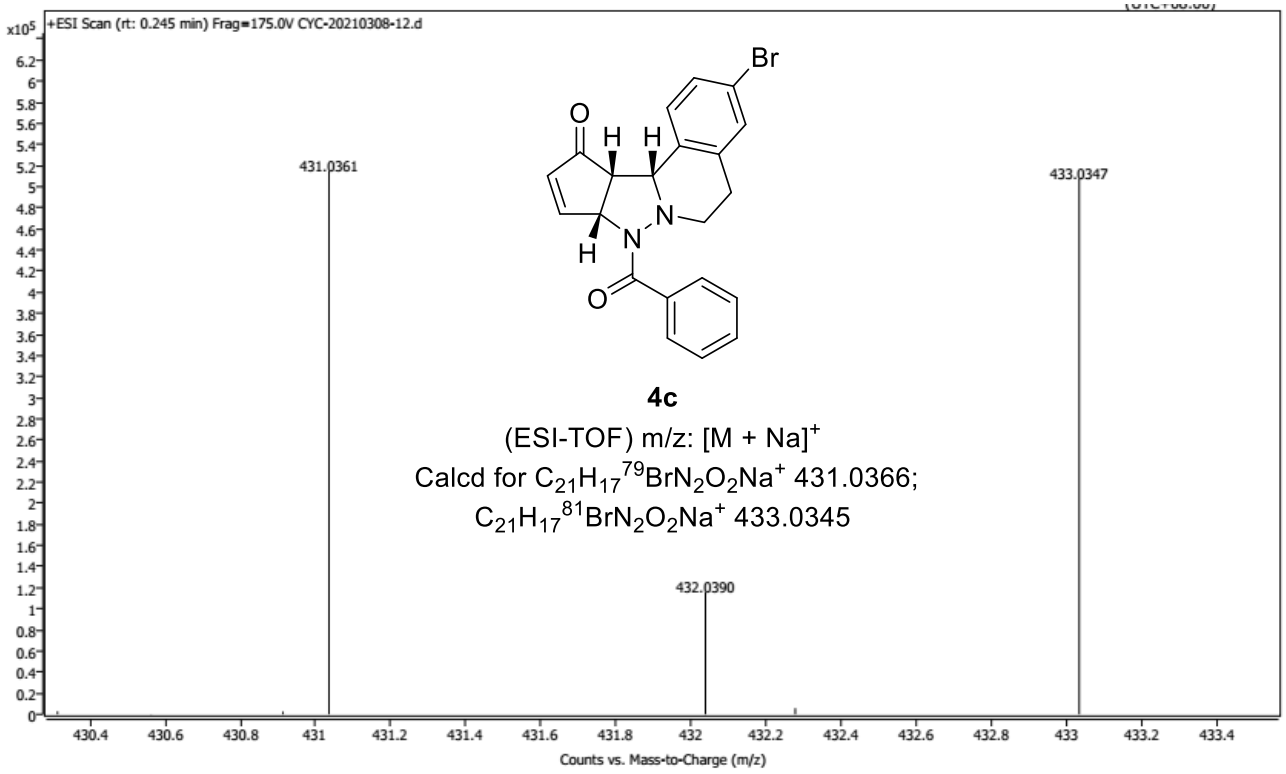
rac-4c

Ret Time [min]	Peak Type	Width [min]	Height [mAU]	Area [mAU*s]	Area [%]
8.912	BV R	0.24	178.2514	2740.8855	46.2379
17.626	BB	0.50	99.1898	3186.9097	53.7621
			Totals:	5927.7952	100.0000



4c

Ret Time [min]	Peak Type	Width [min]	Height [mAU]	Area [mAU*s]	Area [%]
8.910	BB	0.25	0.4039	6.7651	0.0638
17.335	BBA	0.50	329.1867	10597.3193	99.9362
			Totals:	10604.0845	100.0000

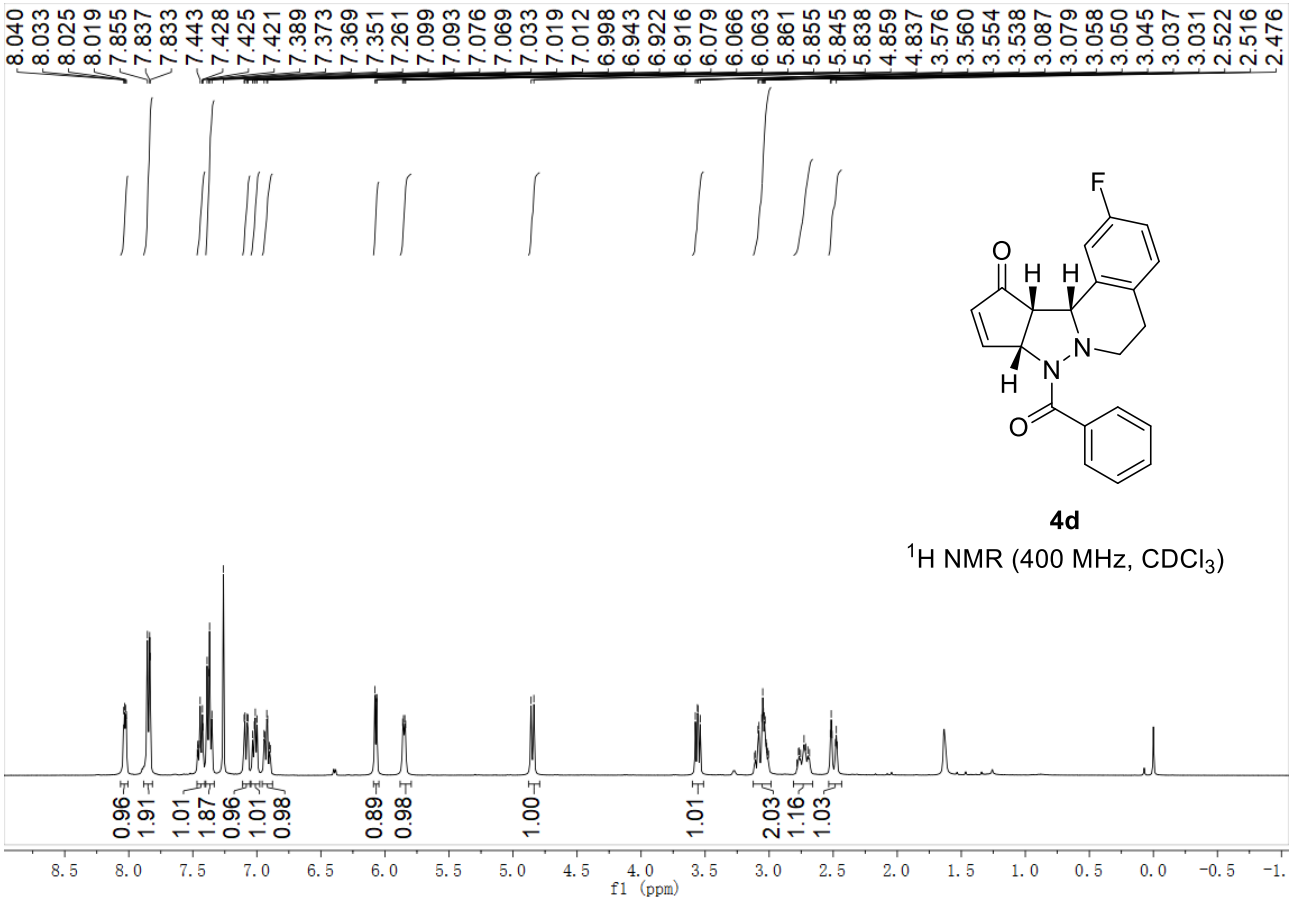


4c

(ESI-TOF) m/z: $[M + Na]^+$

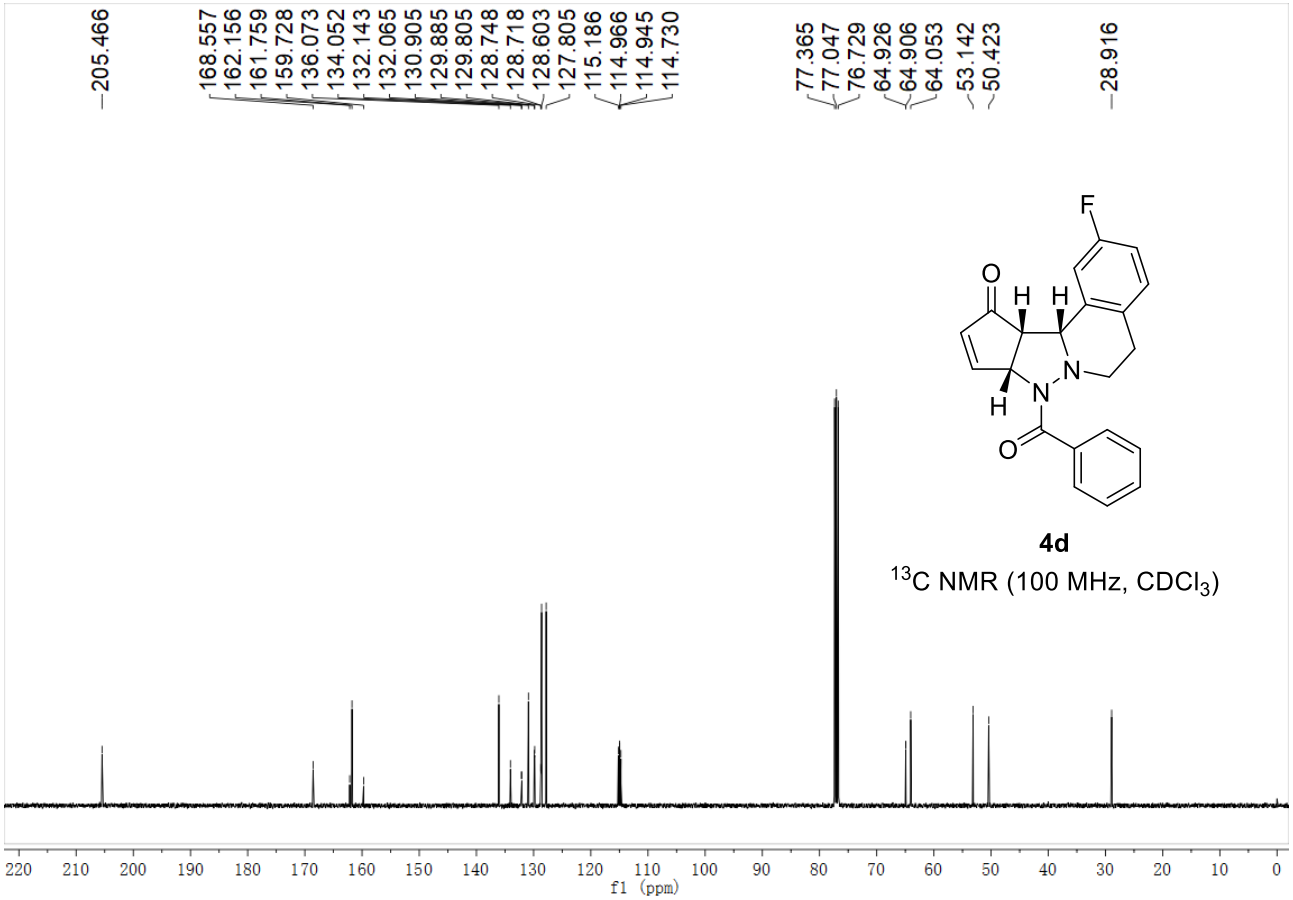
Calcd for $C_{21}H_{17}{}^{79}BrN_2O_2Na^+$ 431.0366;

$C_{21}H_{17}{}^{81}BrN_2O_2Na^+$ 433.0345



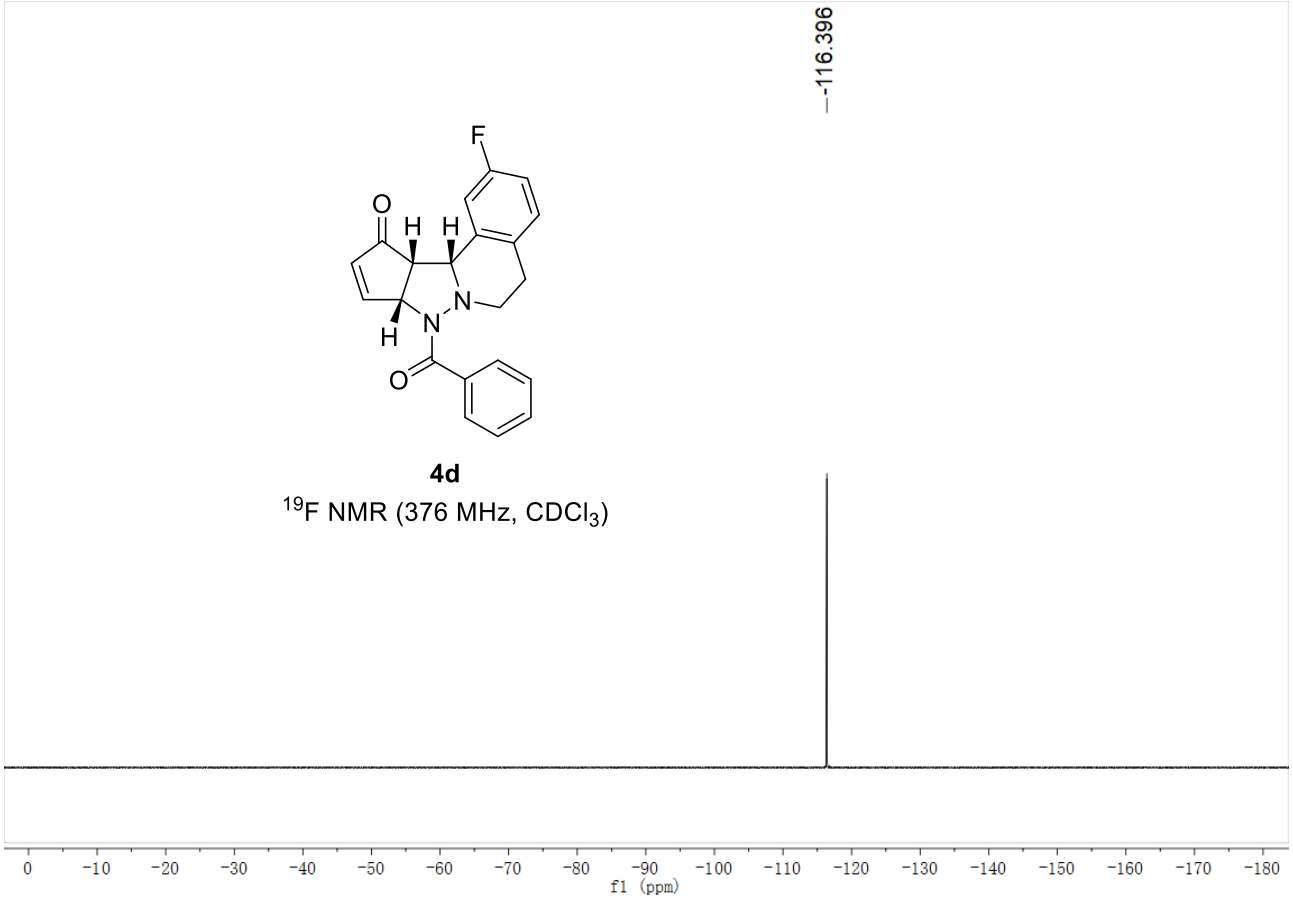
4d

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



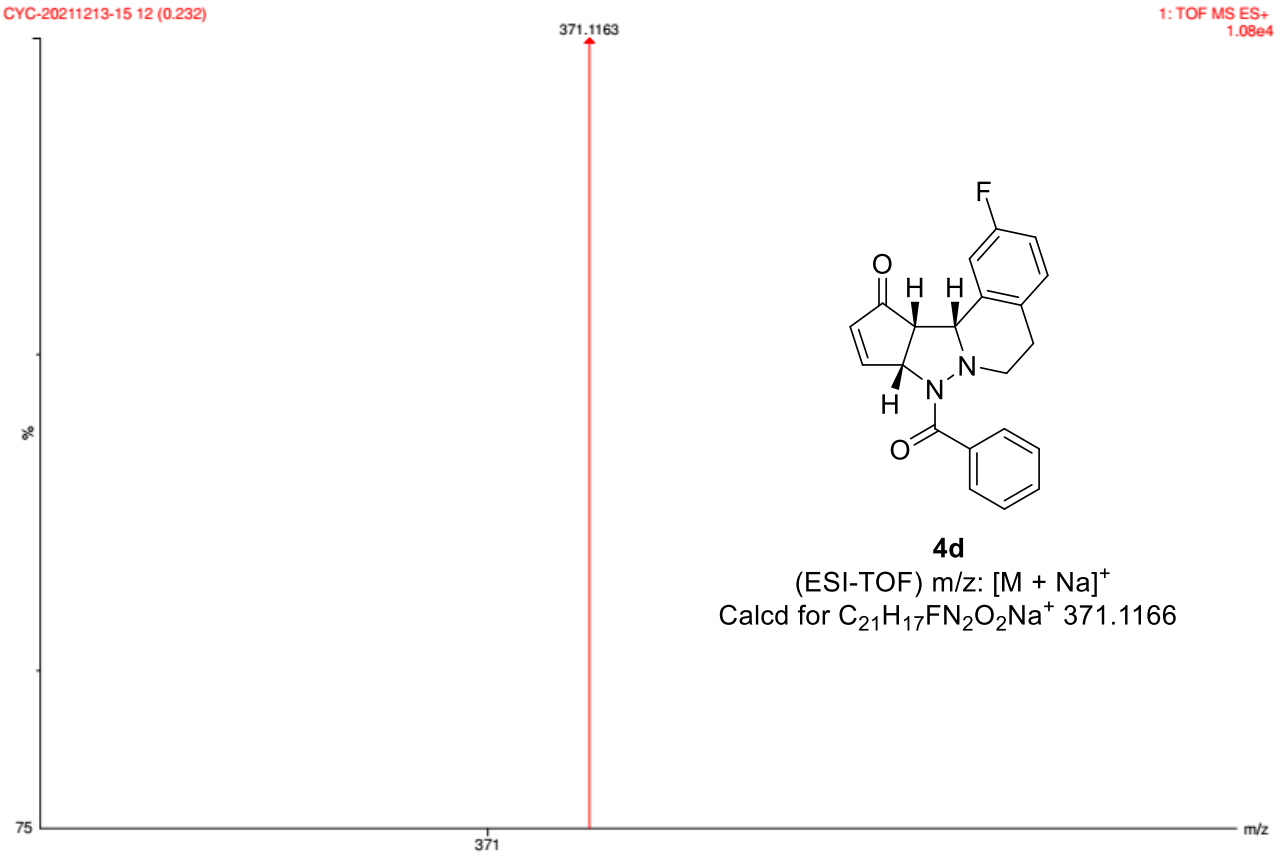
4d

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



4d

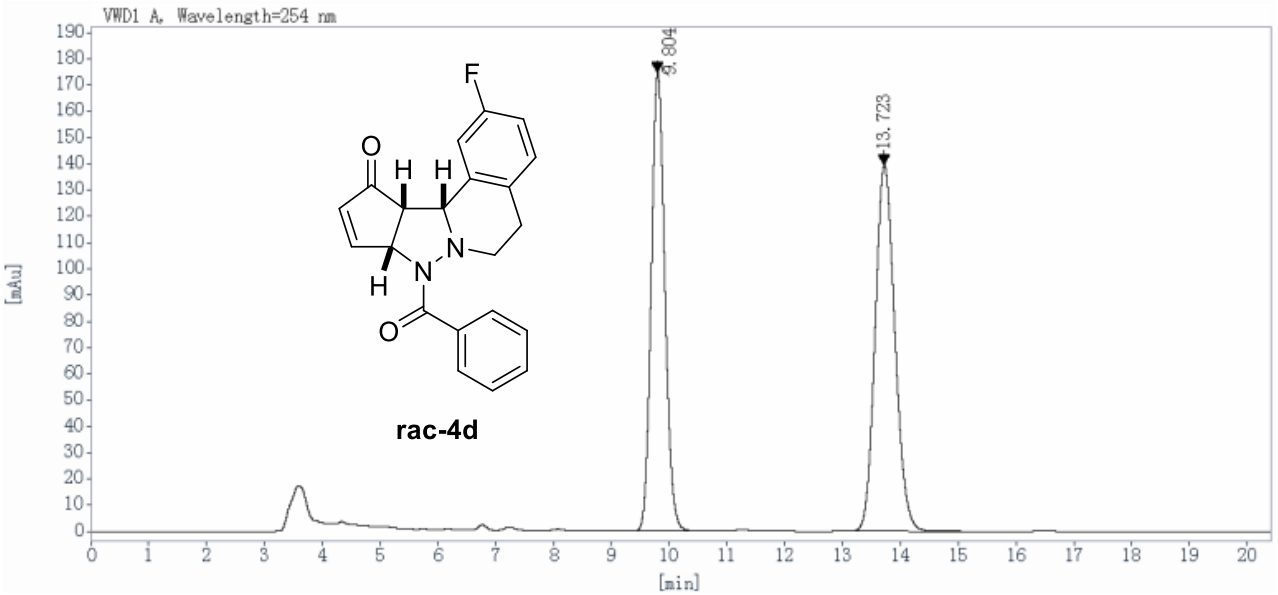
^{19}F NMR (376 MHz, $CDCl_3$)



4d

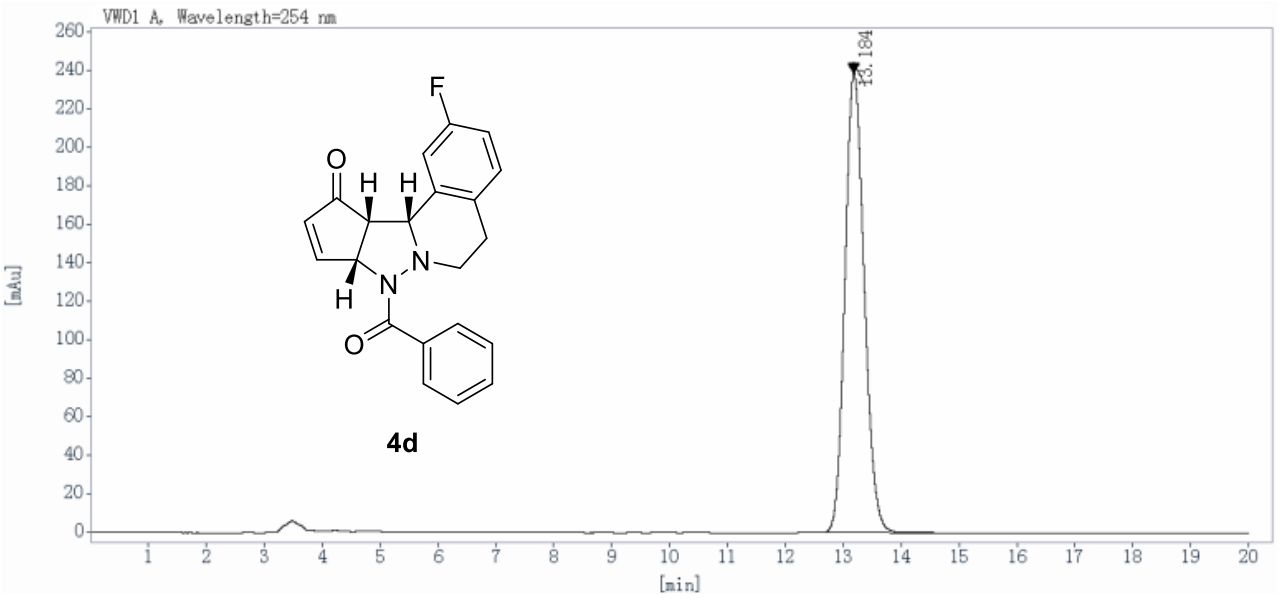
(ESI-TOF) m/z: $[M + Na]^+$

Calcd for $C_{21}H_{17}FN_2O_2Na^+$ 371.1166



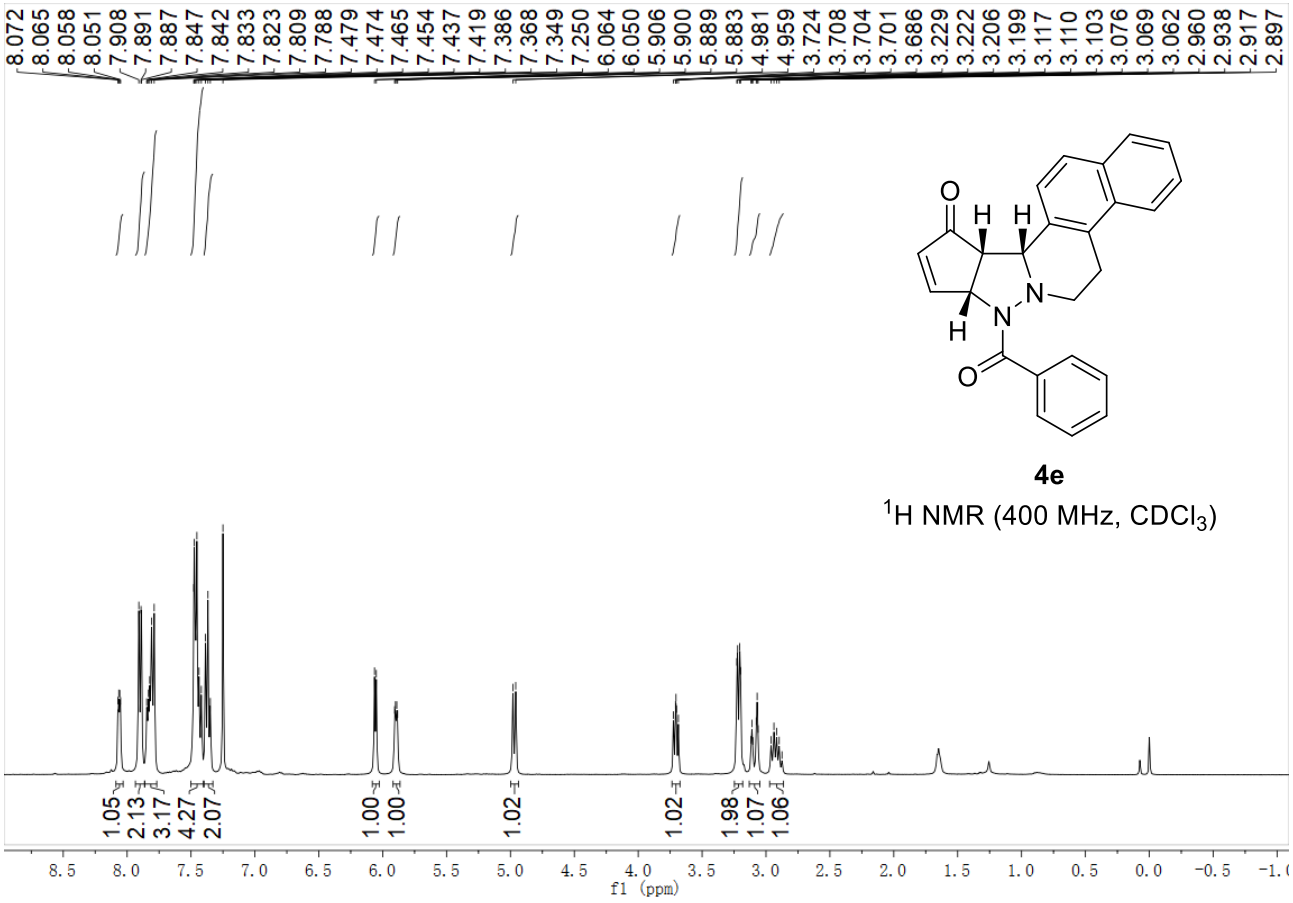
rac-4d

Ret Time [min]	Peak Type	Width [min]	Height [mAU]	Area [mAU*s]	Area [%]
9.804	BB	0.25	174.7984	2853.1973	46.3292
13.723	BB	0.37	139.4898	3305.3313	53.6708
			Totals:	6158.5286	100.0000



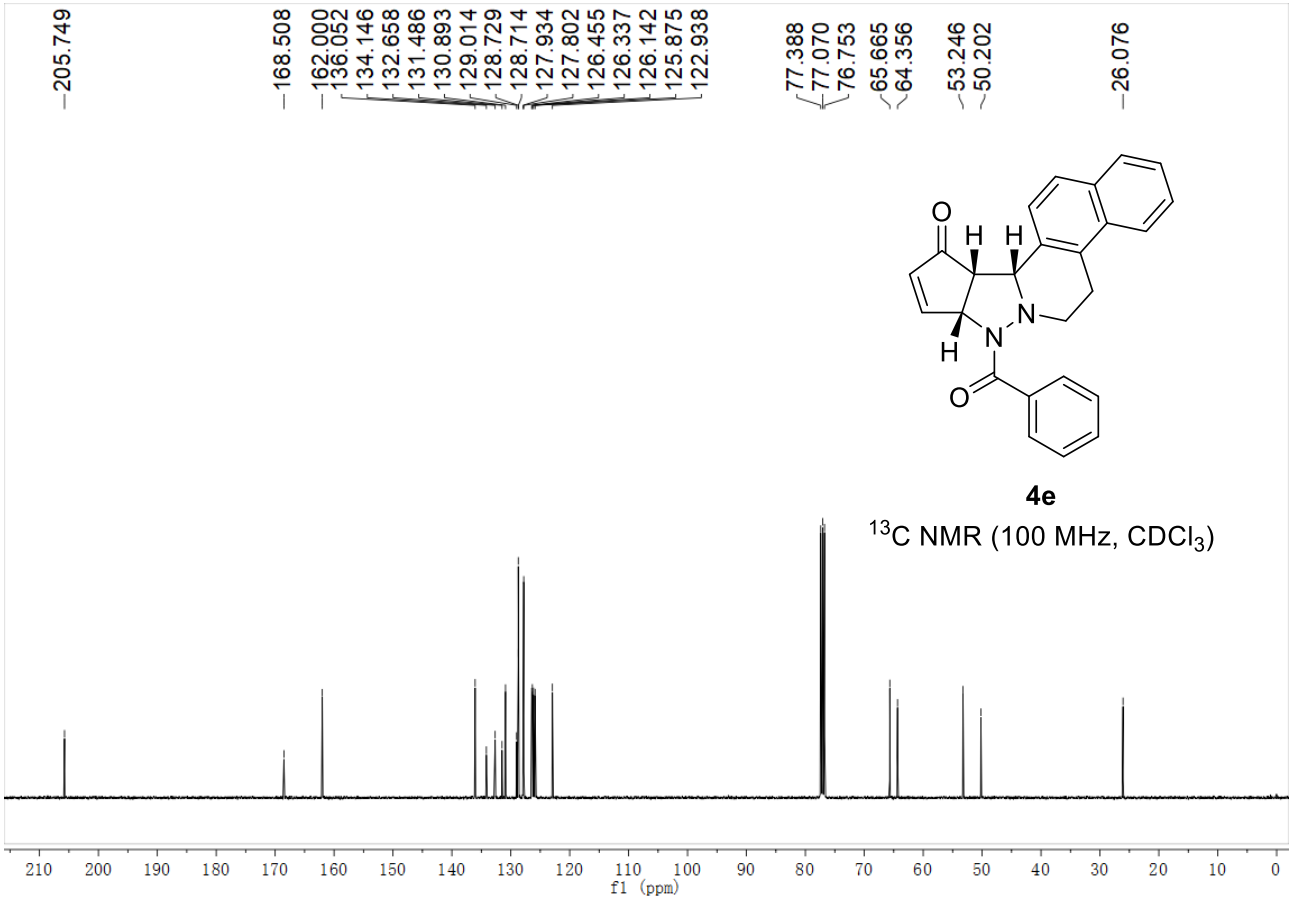
4d

Ret Time [min]	Peak Type	Width [min]	Height [mAU]	Area [mAU*s]	Area [%]
13.184	BB	0.36	238.3766	5512.7329	100.0000
			Totals:	5512.7329	100.0000



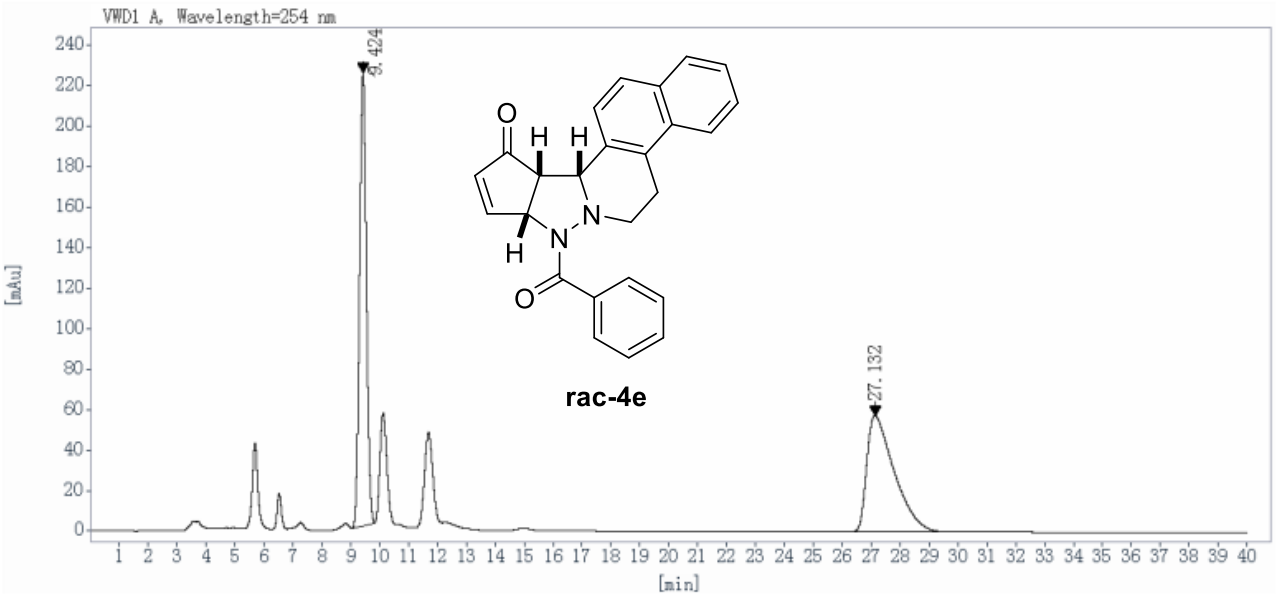
4e

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

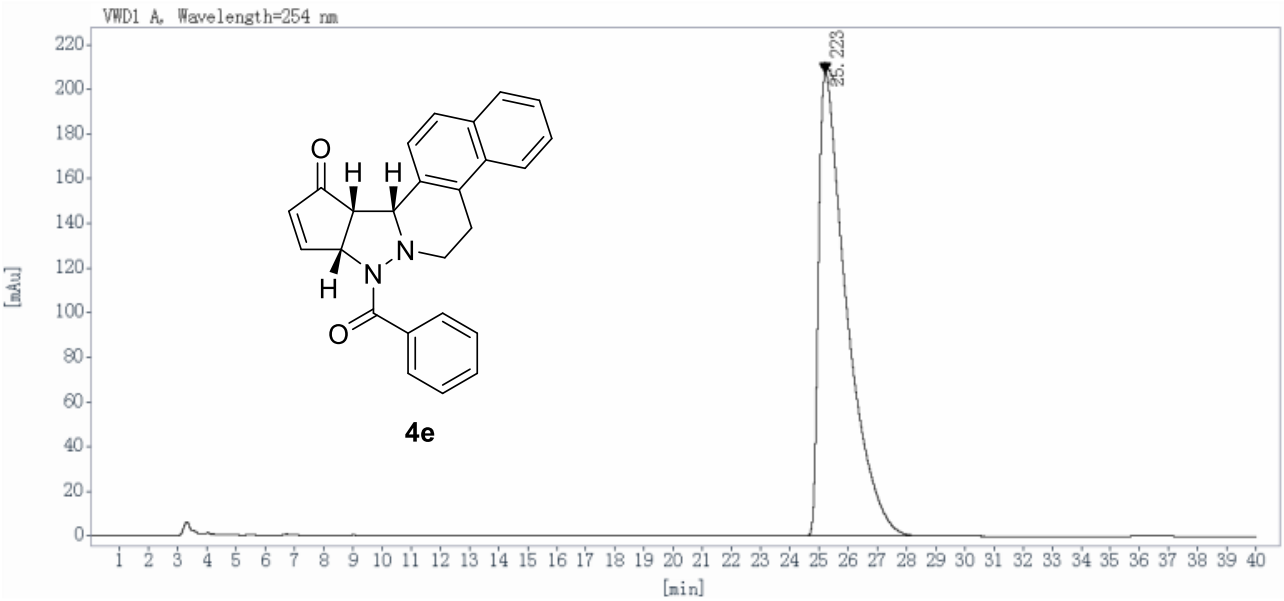


4e

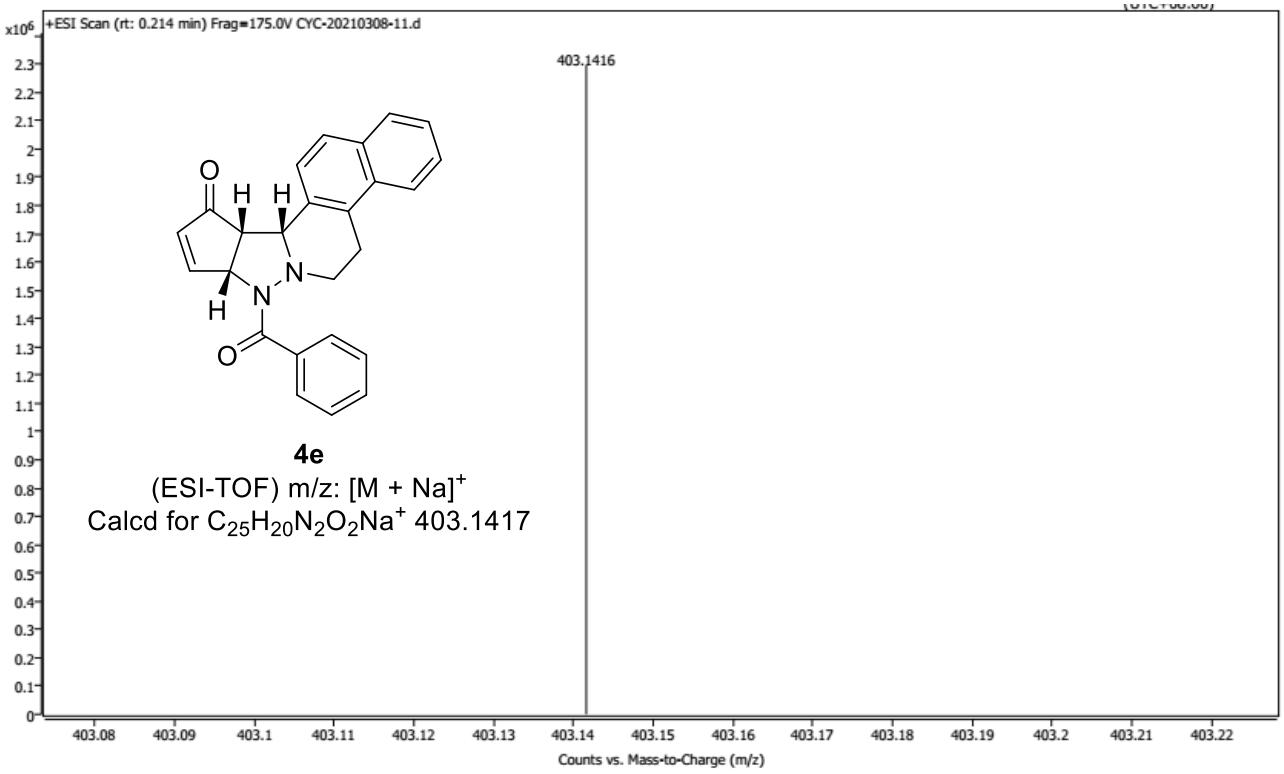
^{13}C NMR (100 MHz, $CDCl_3$)



Ret Time [min]	Peak Type	Width [min]	Height [mAU]	Area [mAU*s]	Area [%]
9.424	BB	0.25	223.9108	3658.7043	49.1860
27.132	BBA	0.98	57.3667	3779.8049	50.8140
			Totals:	7438.5093	100.0000



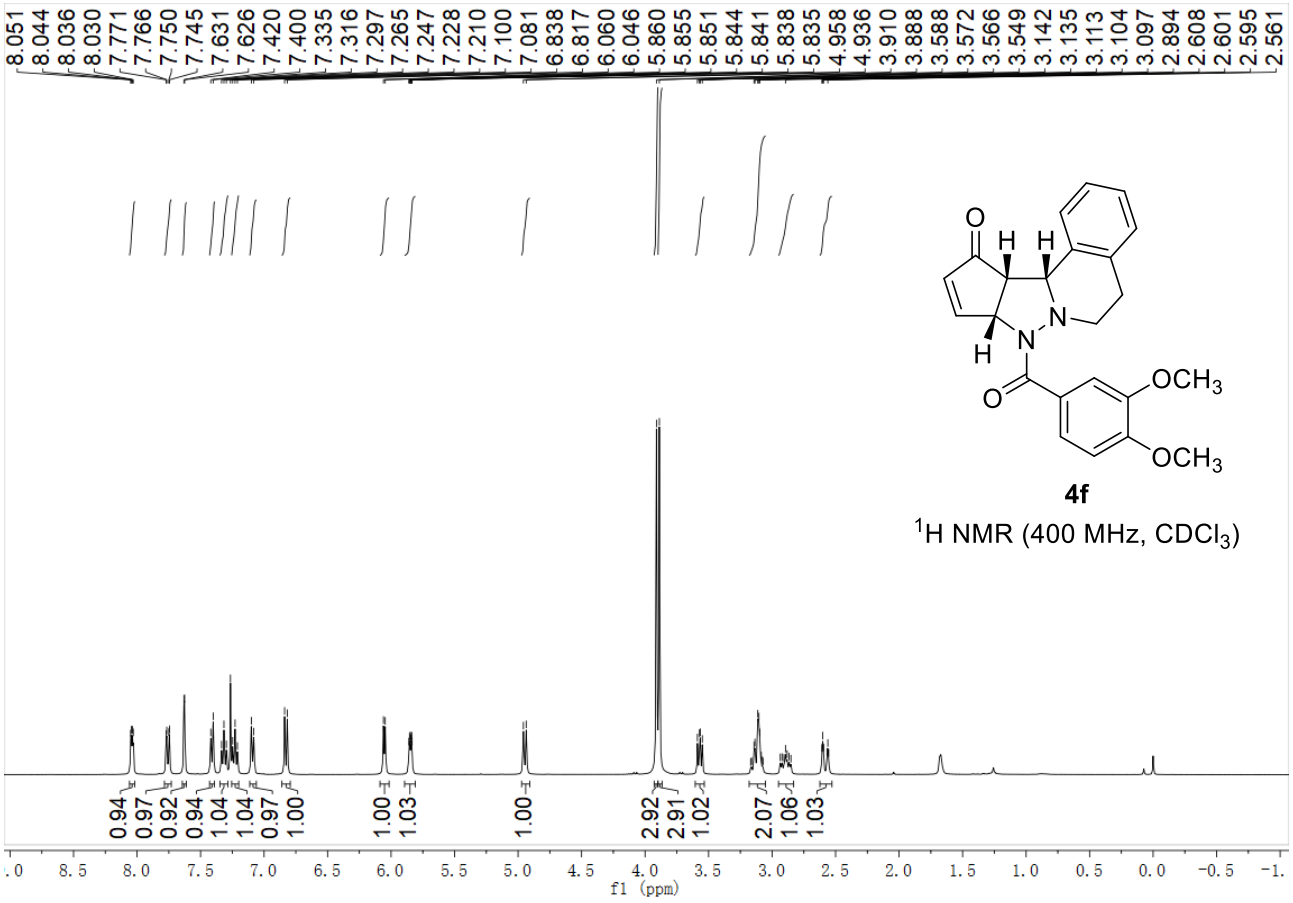
Ret Time [min]	Peak Type	Width [min]	Height [mAU]	Area [mAU*s]	Area [%]
25.223	BB	0.96	207.3128	13840.5352	100.0000
			Totals:	13840.5352	100.0000



4e

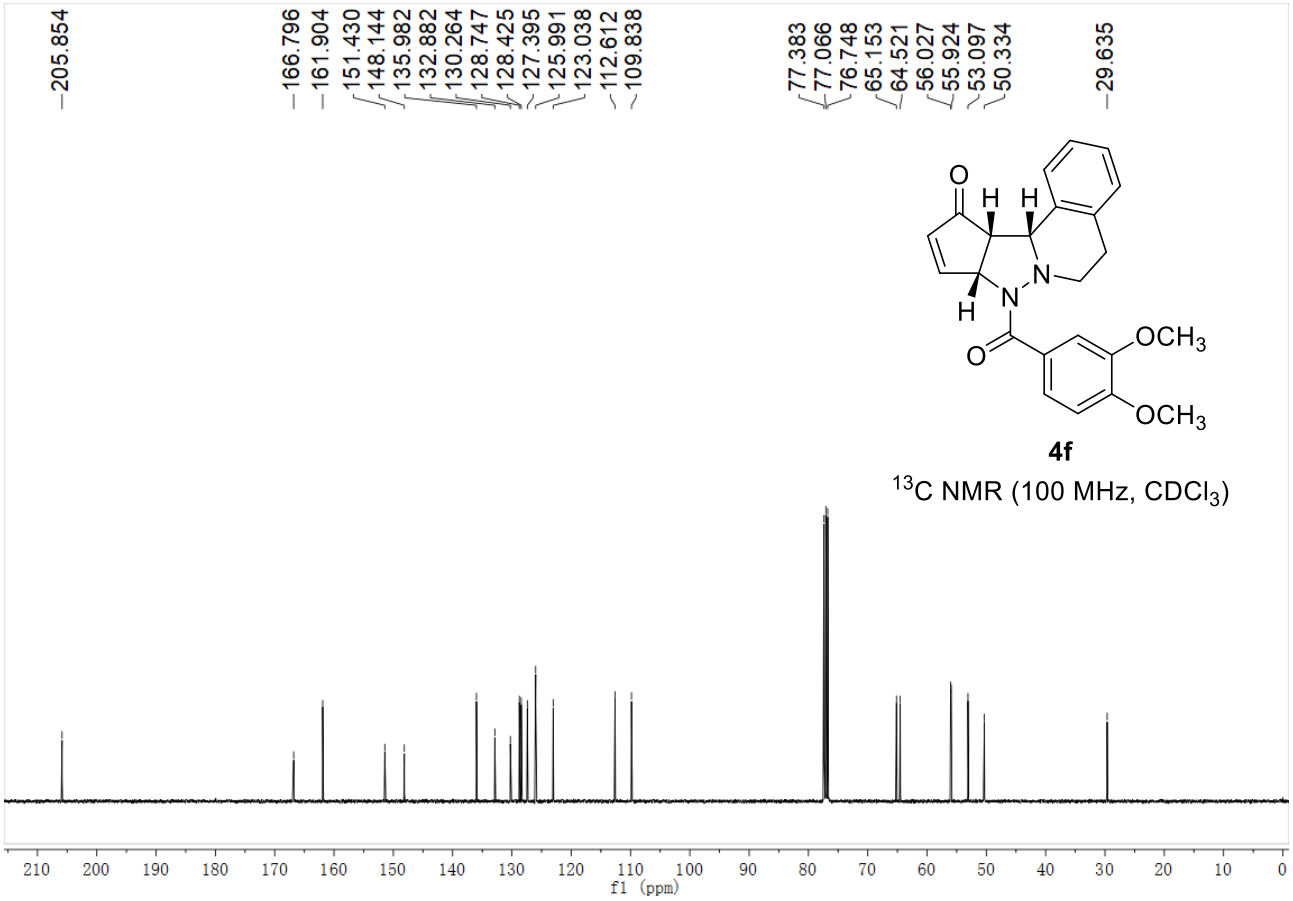
(ESI-TOF) m/z: $[M + Na]^+$

Calcd for $C_{25}H_{20}N_2O_2Na^+$ 403.1417



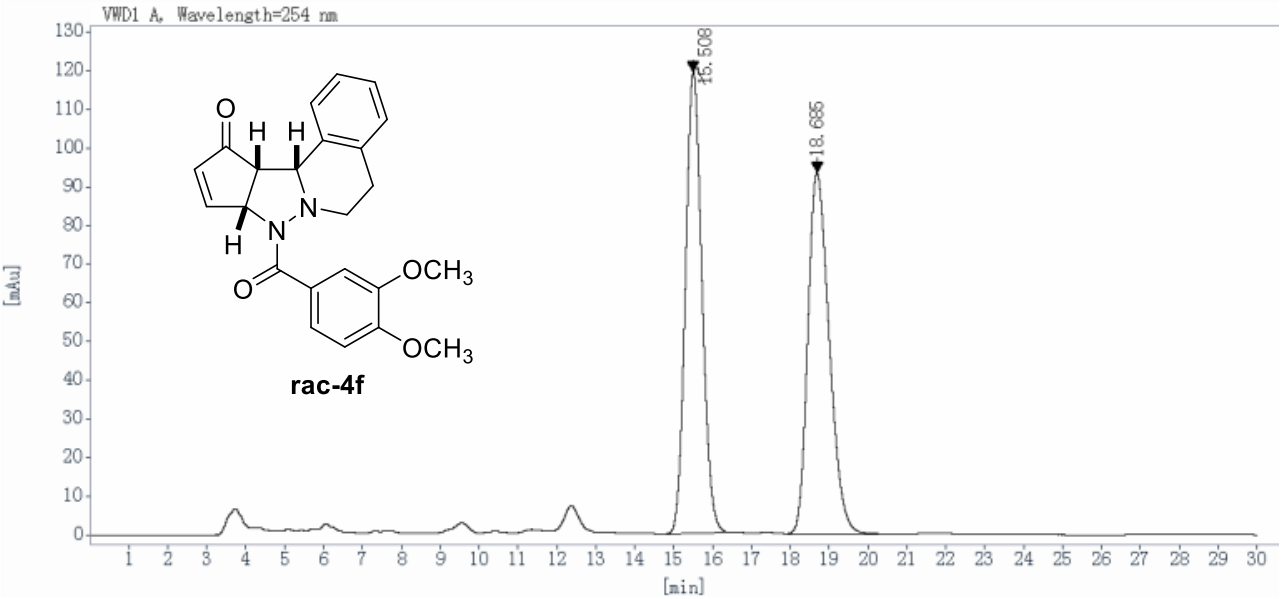
4f

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

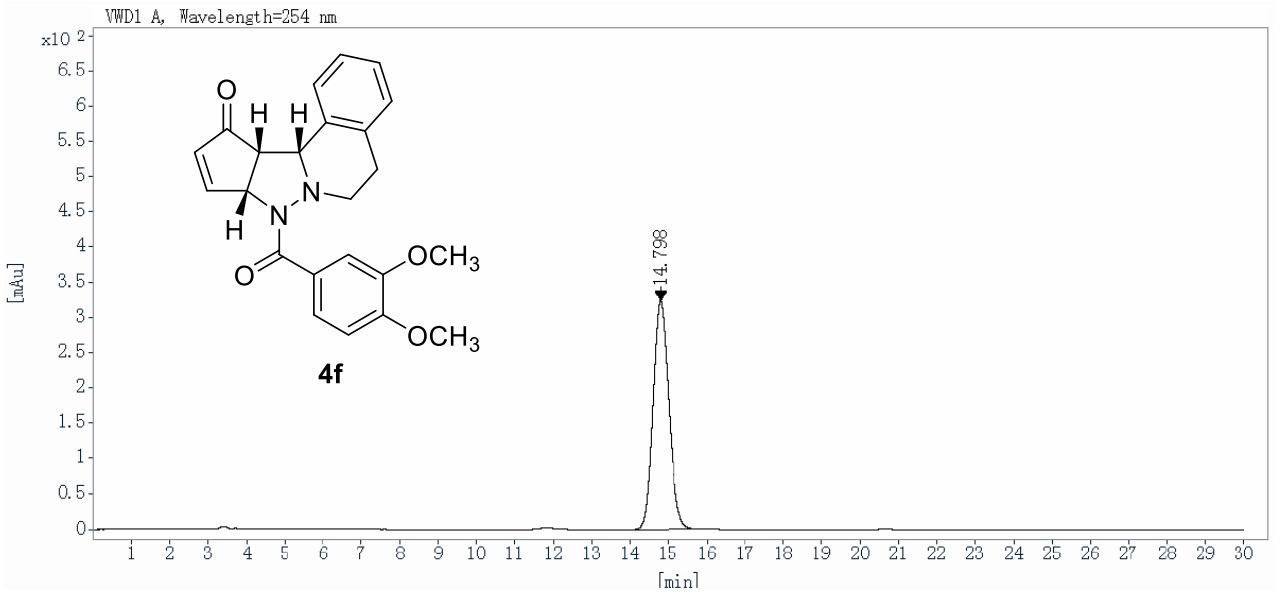


4f

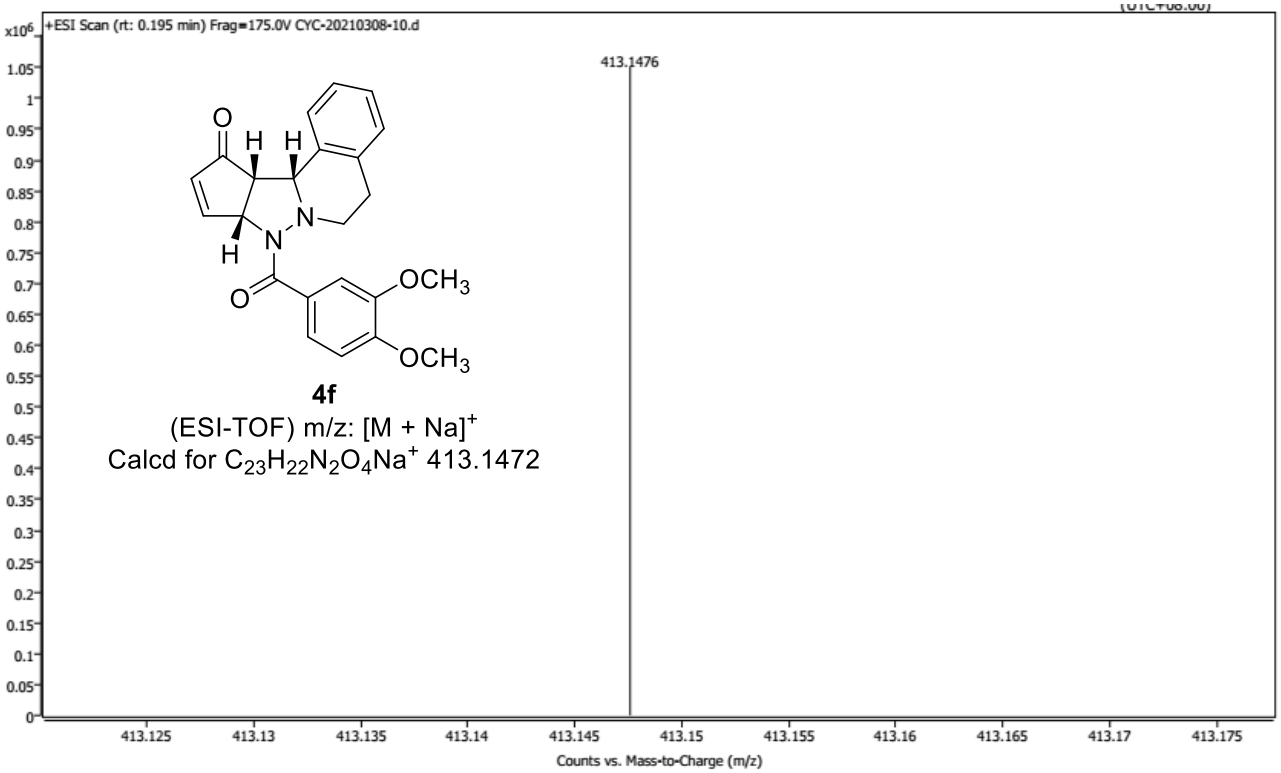
^{13}C NMR (100 MHz, $CDCl_3$)



Ret Time [min]	Peak Type	Width [min]	Height [mAU]	Area [mAU*s]	Area [%]
15.508	BB	0.46	119.4188	3512.2380	49.6670
18.685	BB	0.59	93.3531	3559.3328	50.3330
			Totals:	7071.5708	100.0000



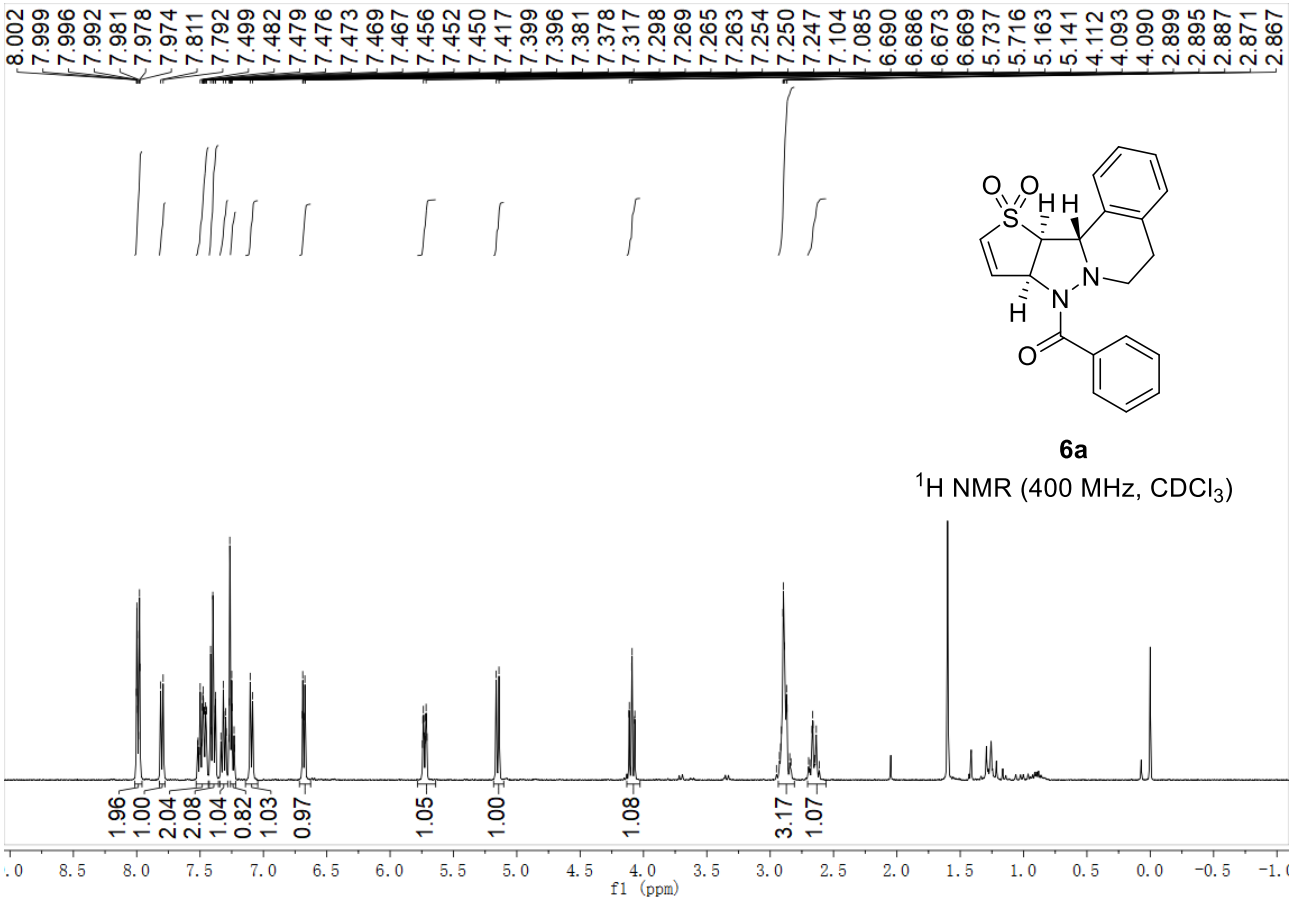
Ret Time [min]	Peak Type	Width [min]	Height [mAU]	Area [mAU*s]	Area [%]
14.798	BBA	0.44	323.4599	9124.7246	100.0000
			Totals:	9124.7246	100.0000



4f

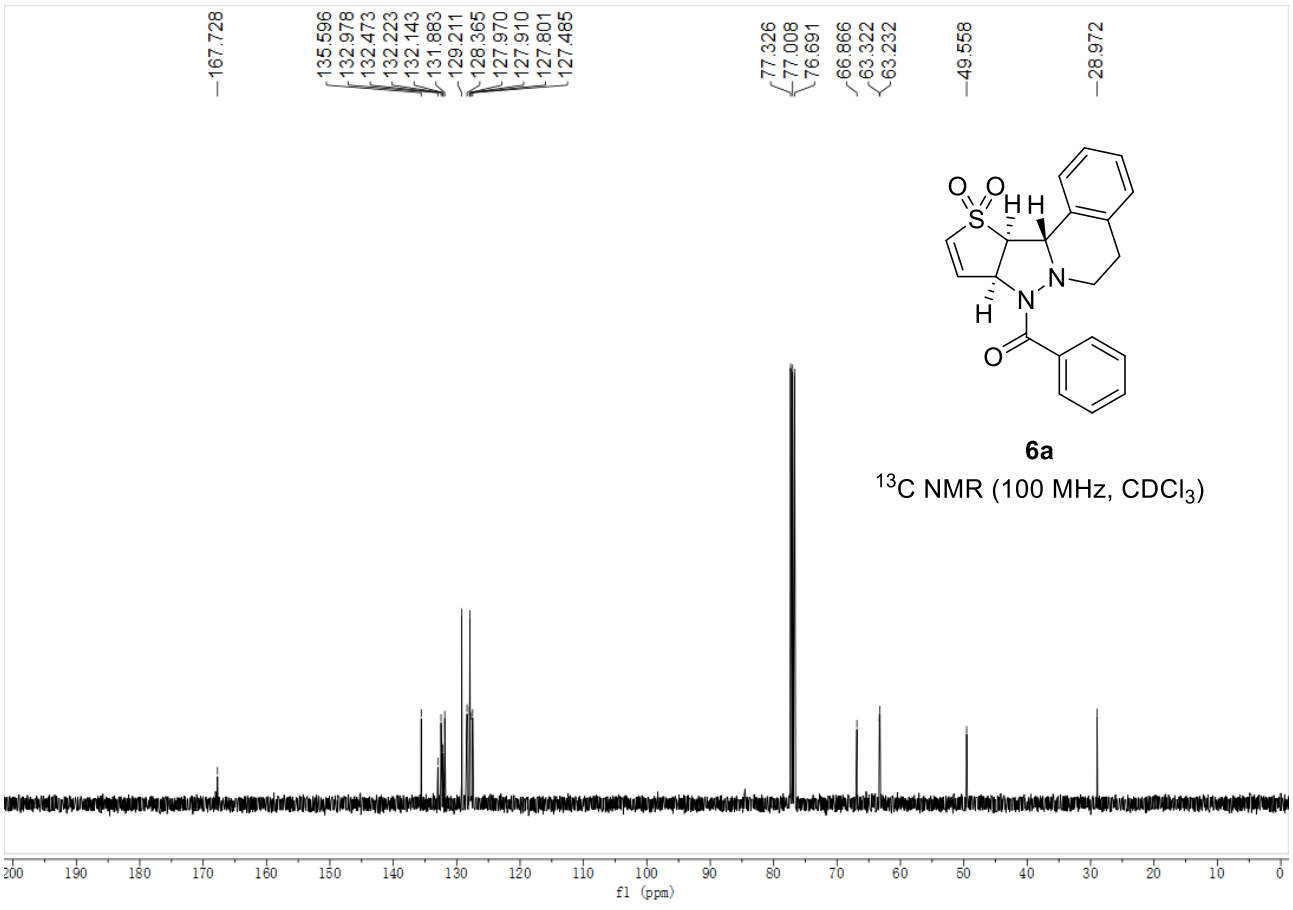
(ESI-TOF) m/z: $[M + Na]^+$

Calcd for $C_{23}H_{22}N_2O_4Na^+$ 413.1472



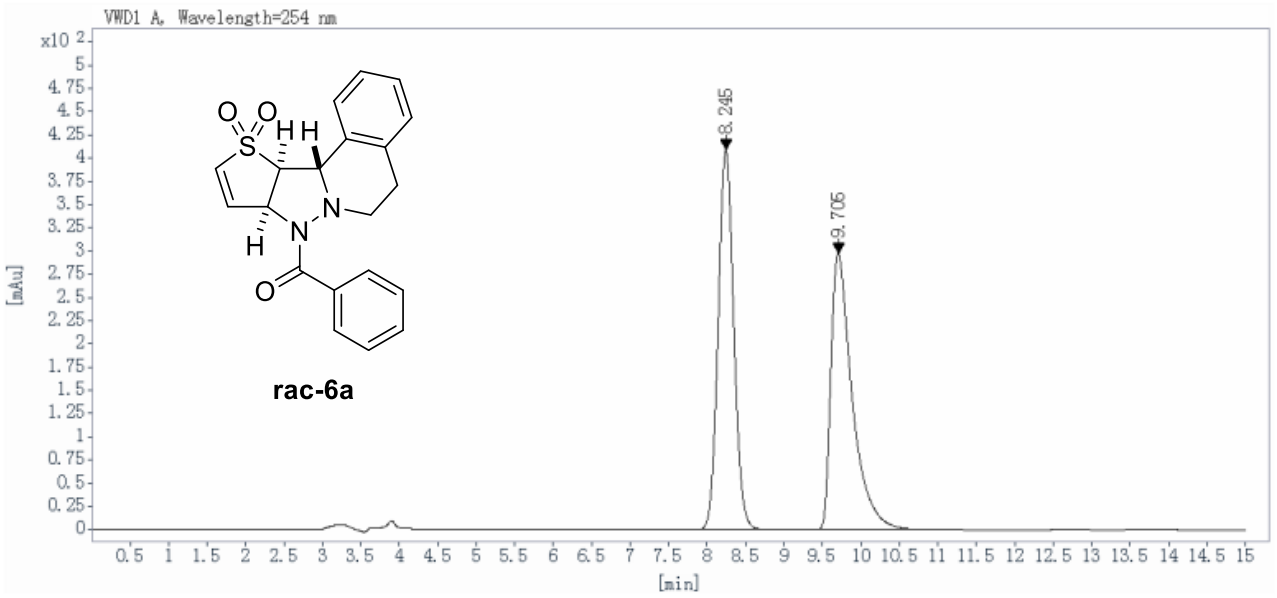
6a

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

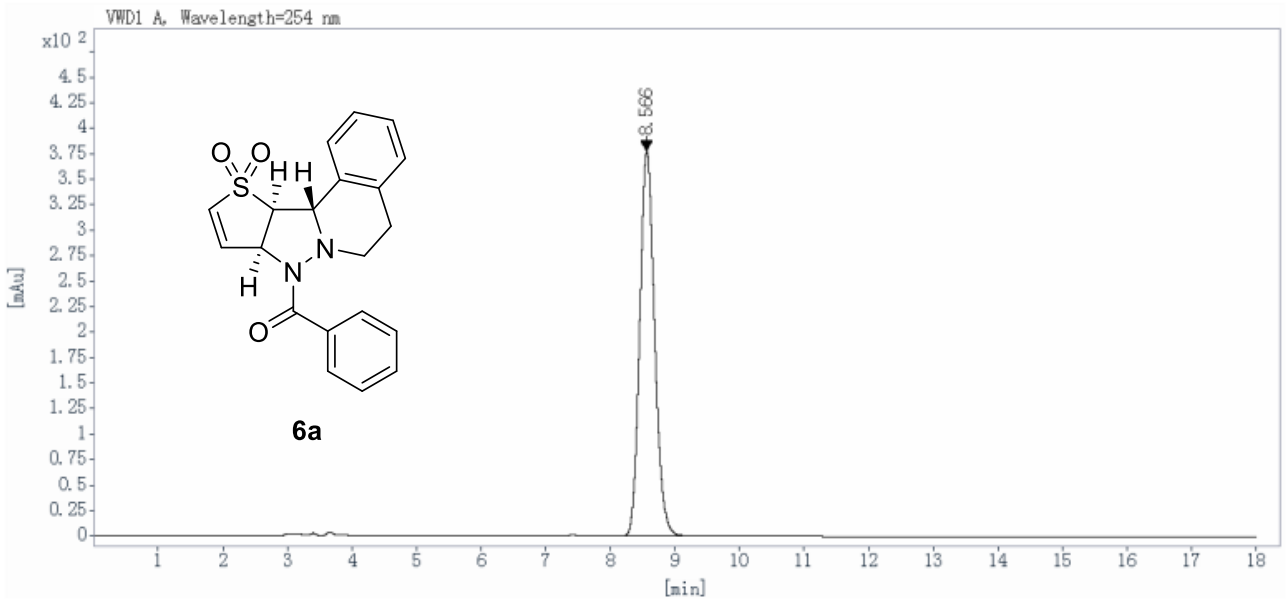


6a

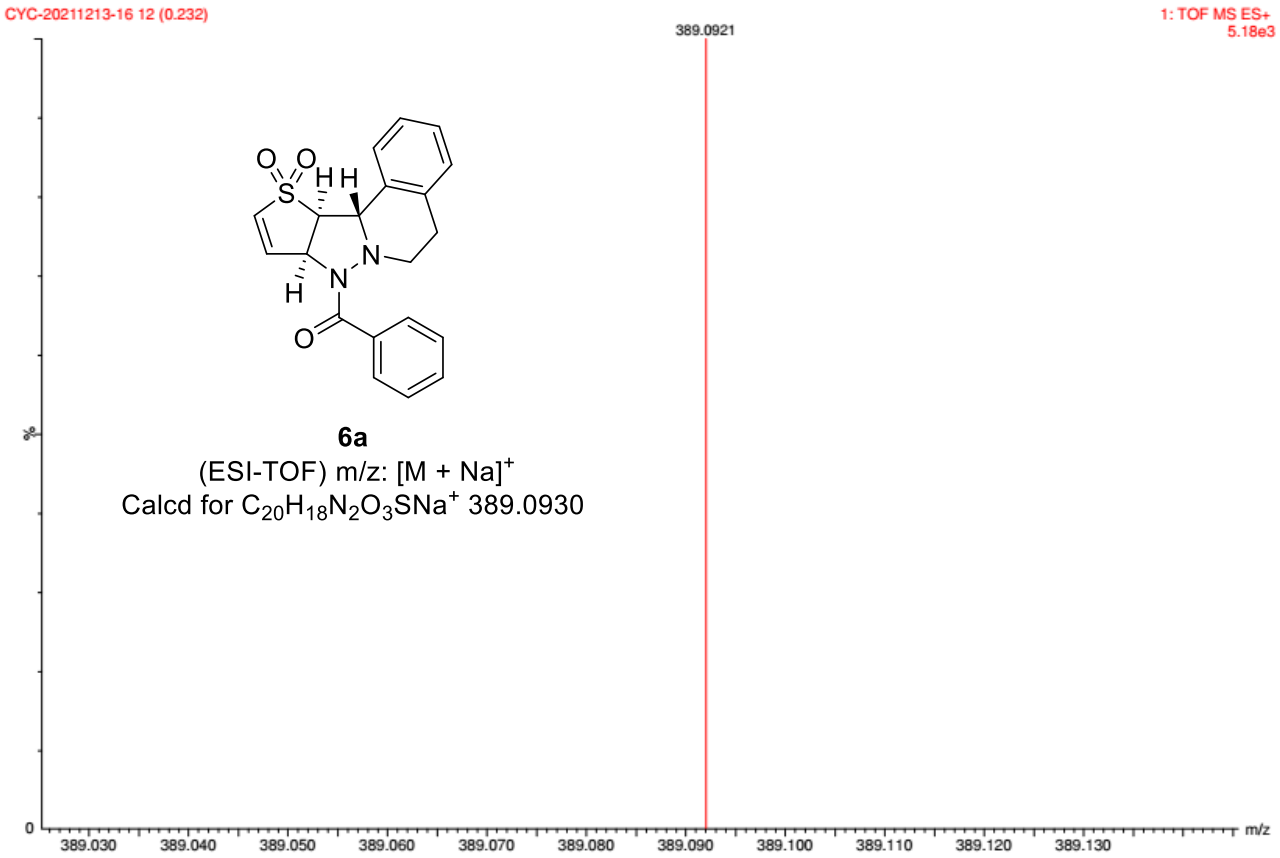
^{13}C NMR (100 MHz, $CDCl_3$)



Ret Time [min]	Peak Type	Width [min]	Height [mAU]	Area [mAU*s]	Area [%]
8.245	BB	0.22	408.5493	5773.7051	50.2978
9.705	BBA	0.29	297.4714	5705.3306	49.7022
			Totals:	11479.0356	100.0000



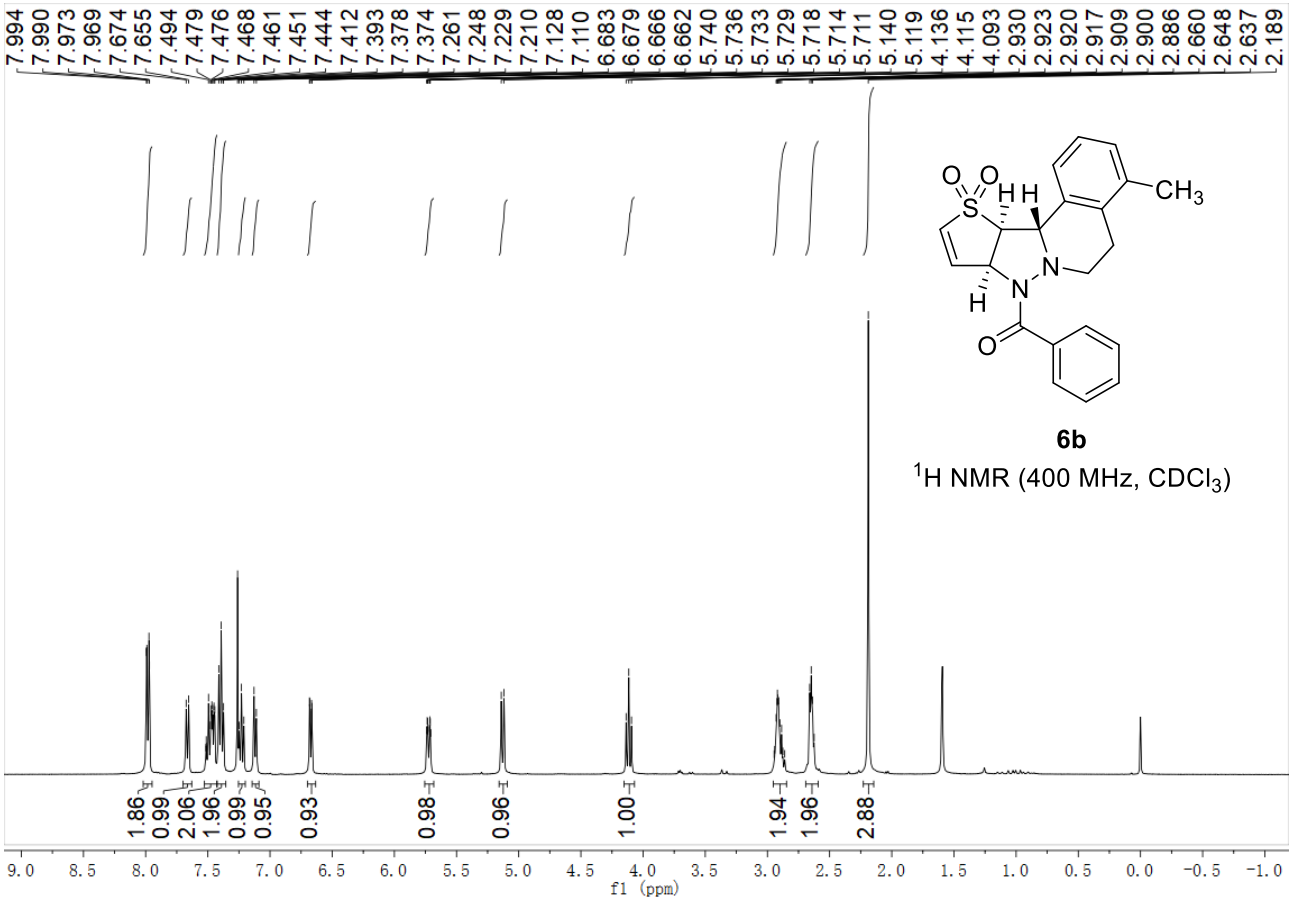
Ret Time [min]	Peak Type	Width [min]	Height [mAU]	Area [mAU*s]	Area [%]
8.566	BBA	0.25	377.2751	6044.0786	100.0000
			Totals:	6044.0786	100.0000



6a

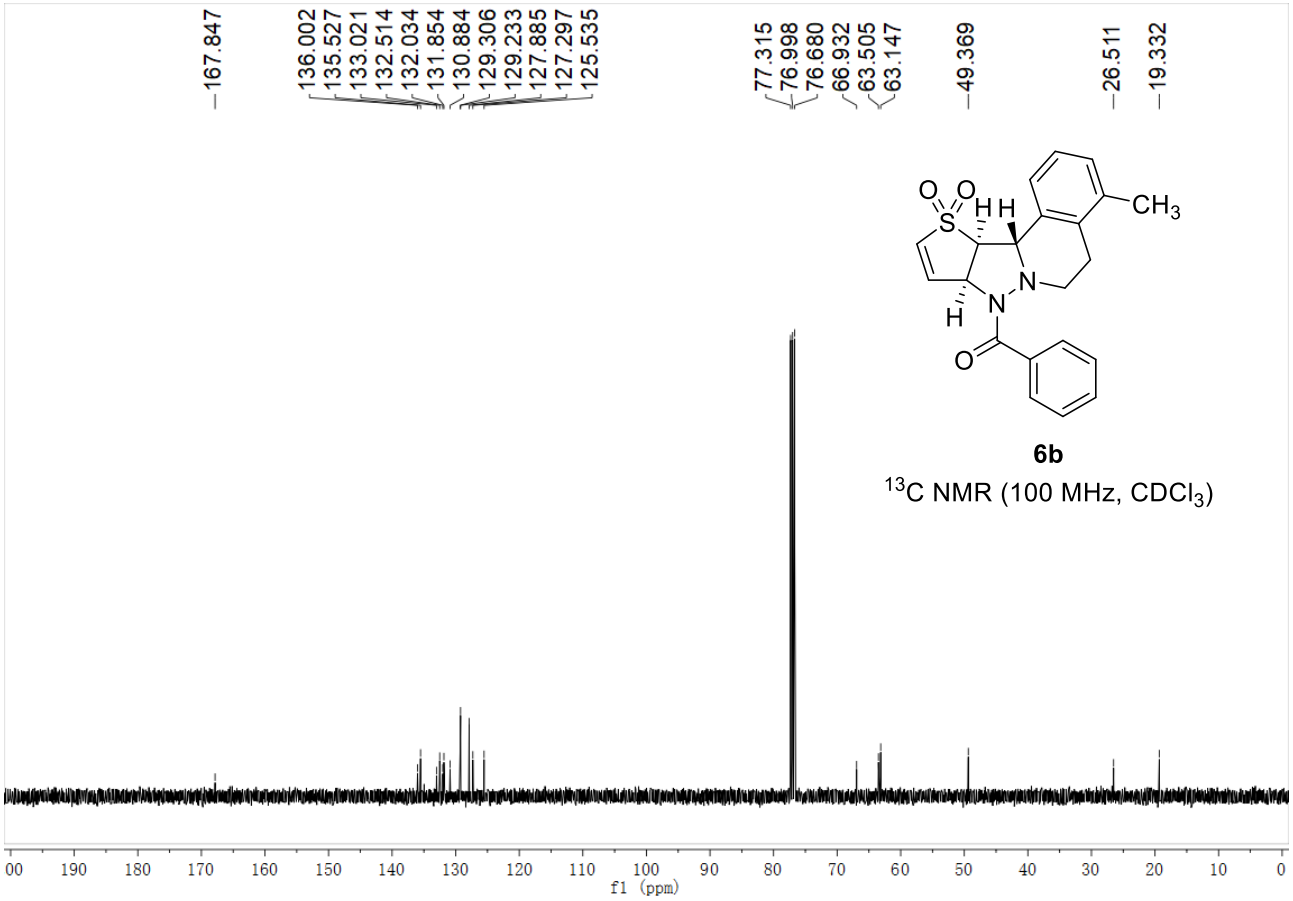
(ESI-TOF) m/z: $[M + Na]^+$

Calcd for $C_{20}H_{18}N_2O_3SNa^+$ 389.0930



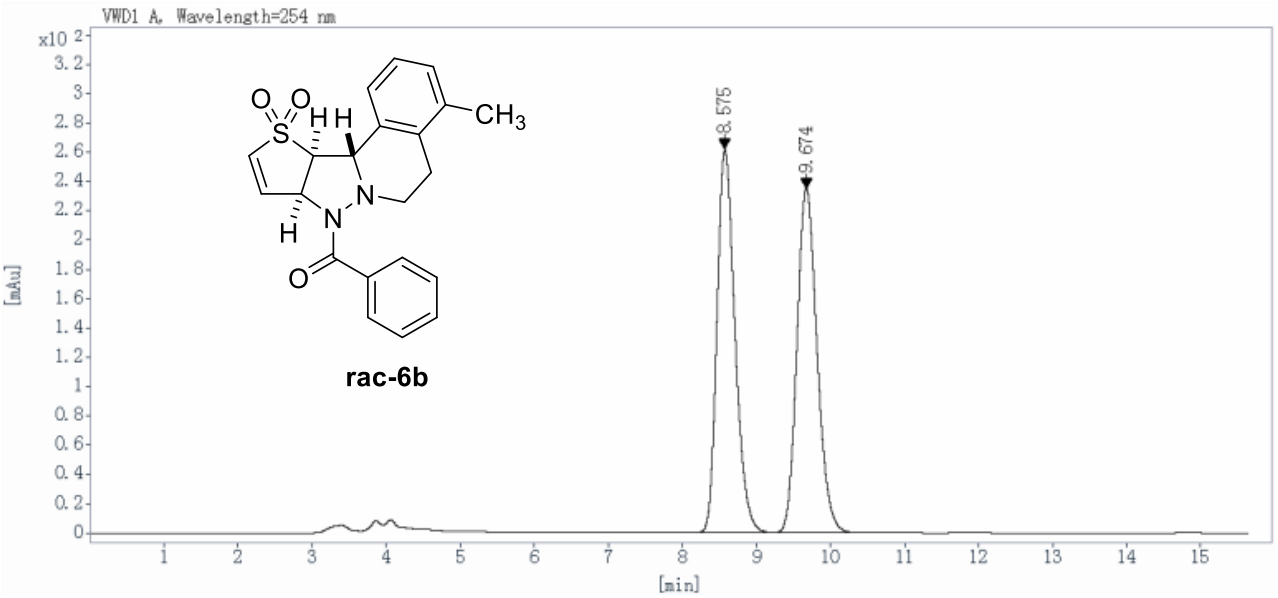
6b

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

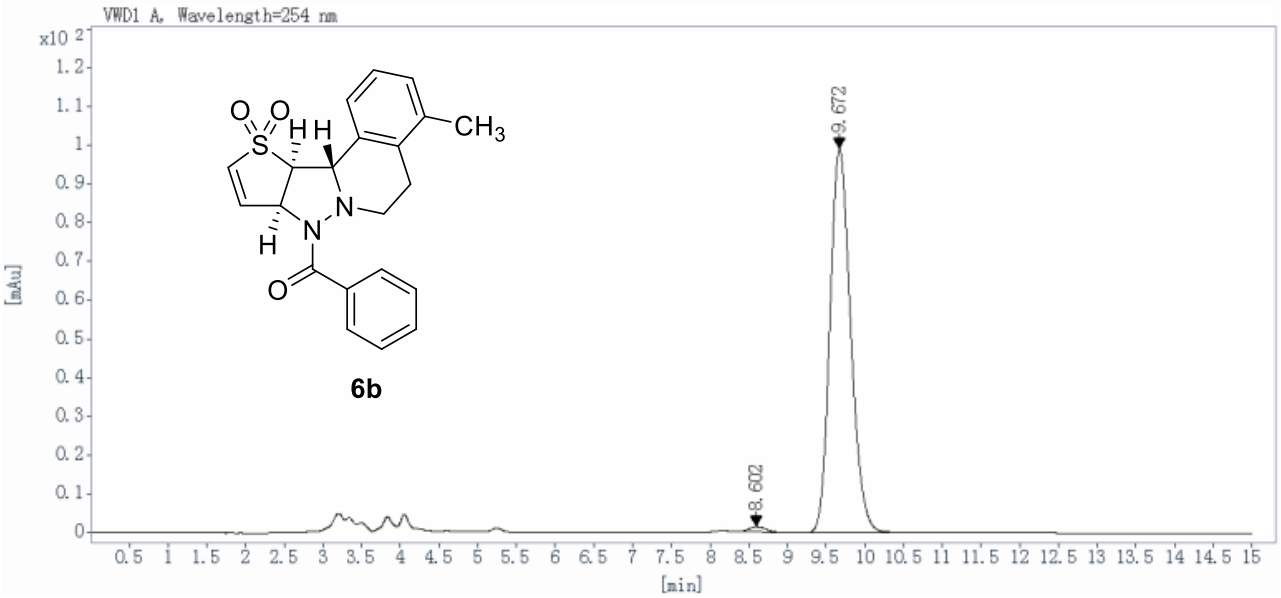


6b

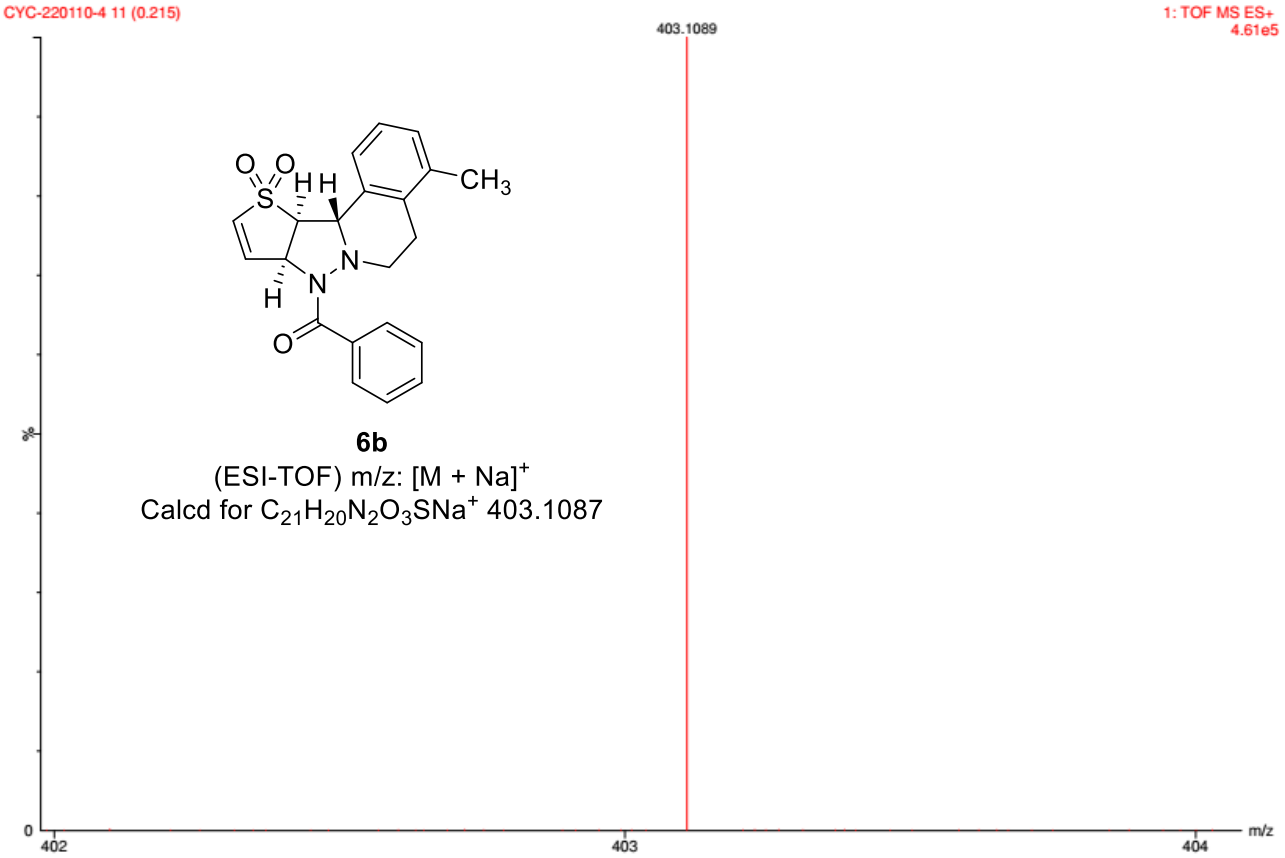
^{13}C NMR (100 MHz, $CDCl_3$)



Ret Time [min]	Peak Type	Width [min]	Height [mAU]	Area [mAU*s]	Area [%]
8.575	BB	0.26	261.6302	4401.6992	49.8701
9.674	BBA	0.29	235.2340	4424.6377	50.1299
			Totals:	8826.3369	100.0000



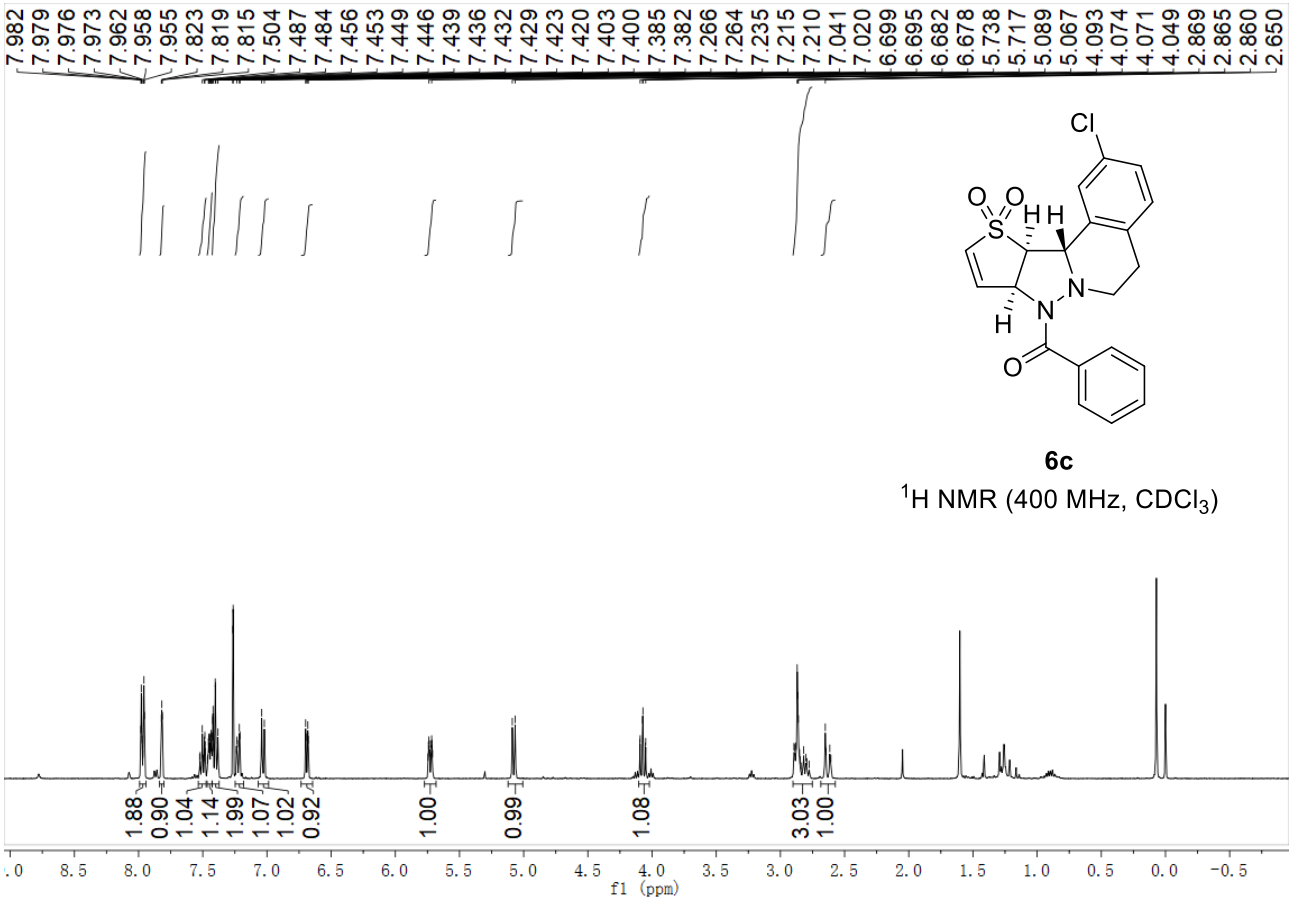
Ret Time [min]	Peak Type	Width [min]	Height [mAU]	Area [mAU*s]	Area [%]
8.602	BB	0.24	1.3860	21.3495	1.1477
9.672	BBA	0.29	99.0793	1838.9199	98.8523
			Totals:	1860.2694	100.0000



6b

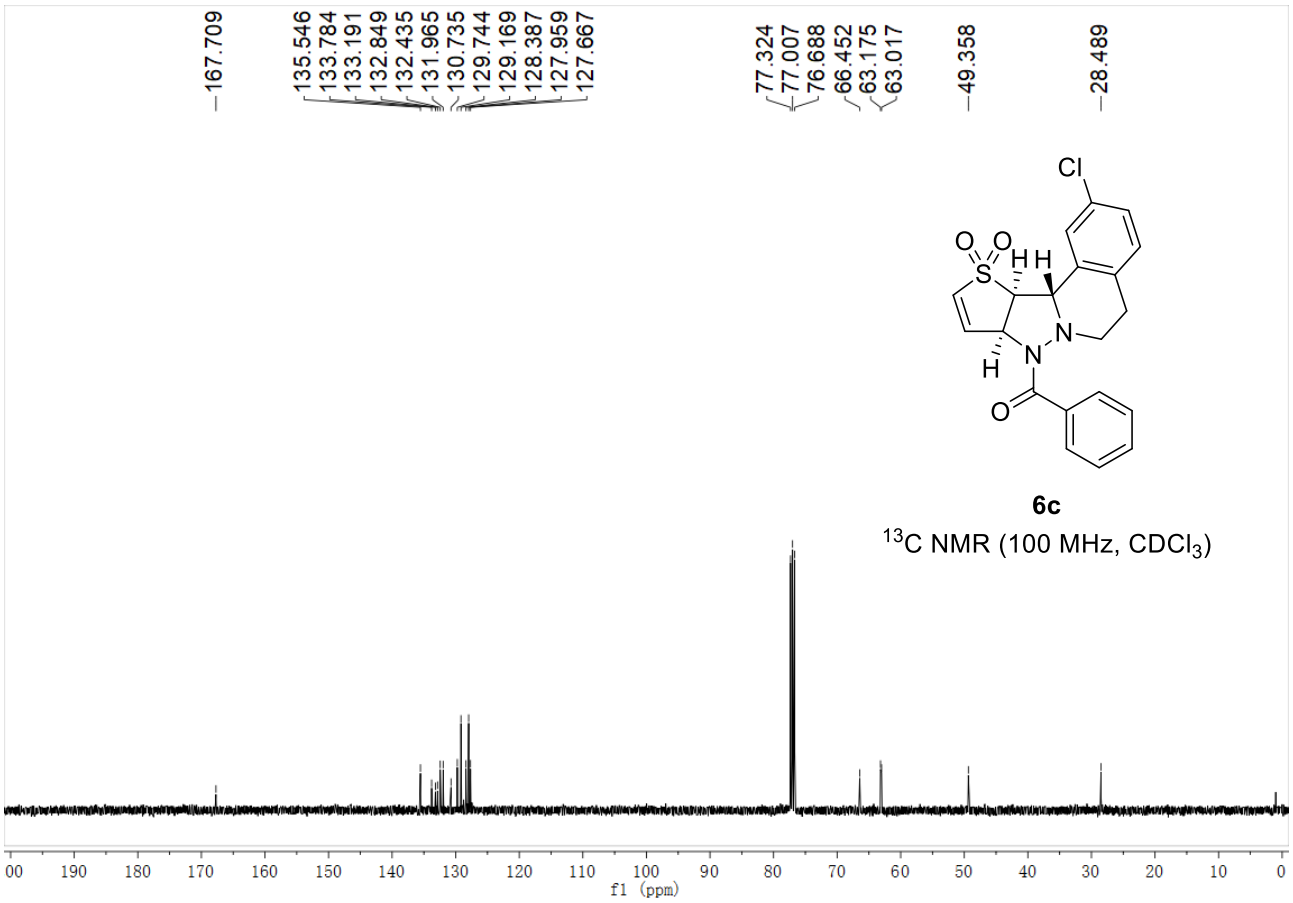
(ESI-TOF) m/z: $[M + Na]^+$

Calcd for $C_{21}H_{20}N_2O_3SNa^+$ 403.1087



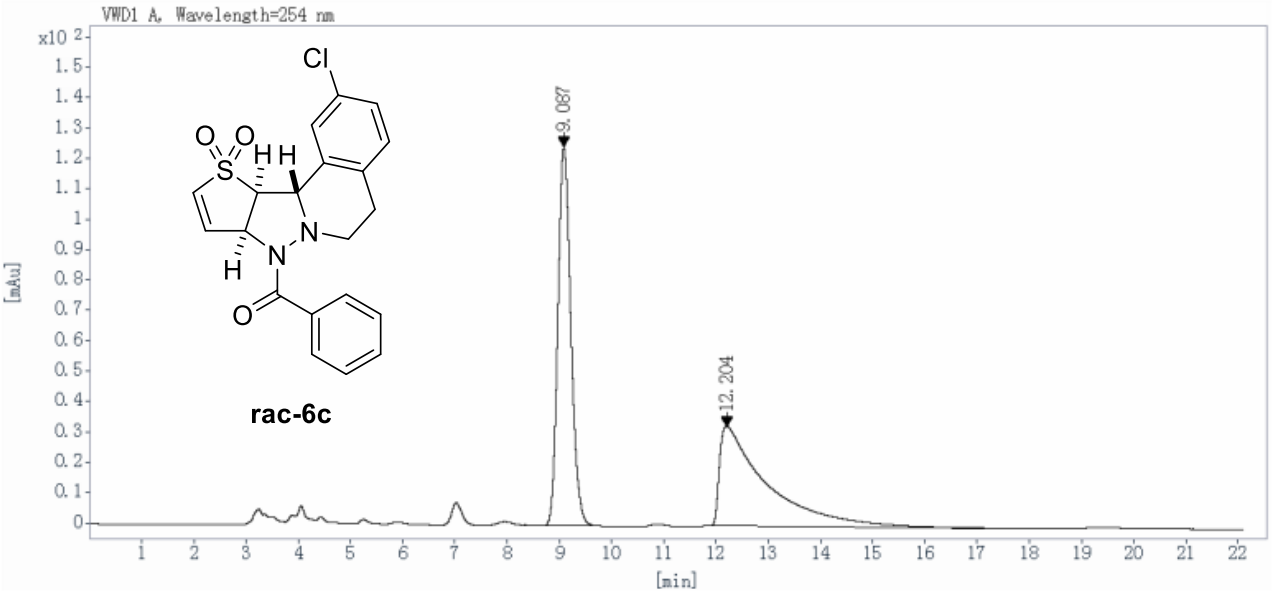
6c

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

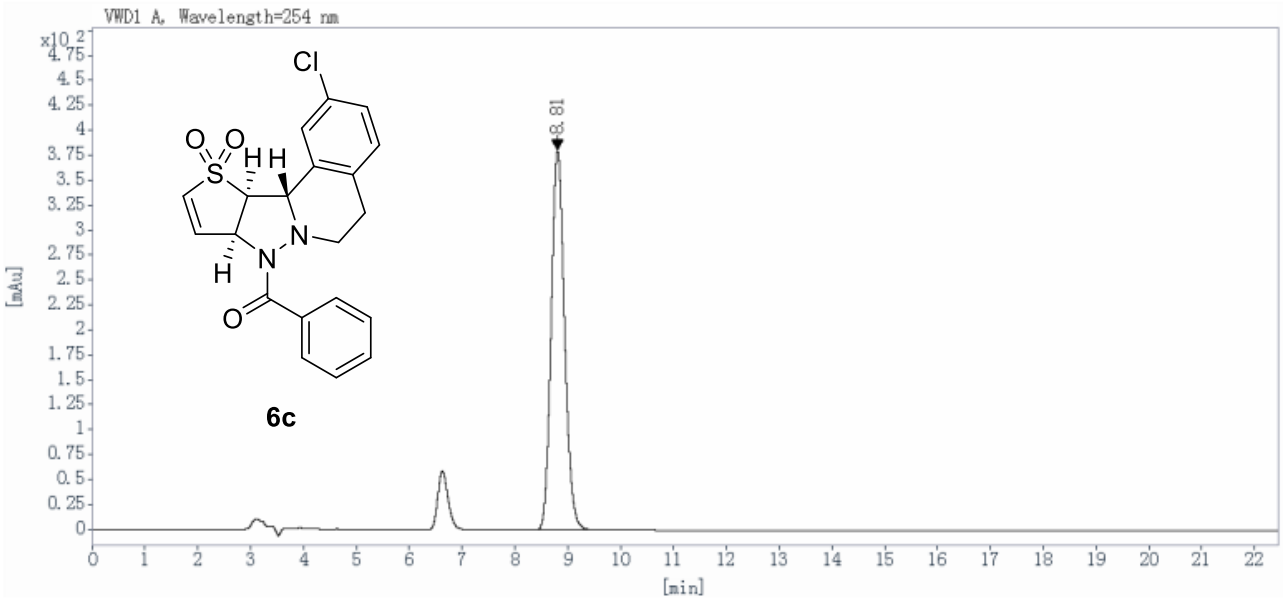


6c

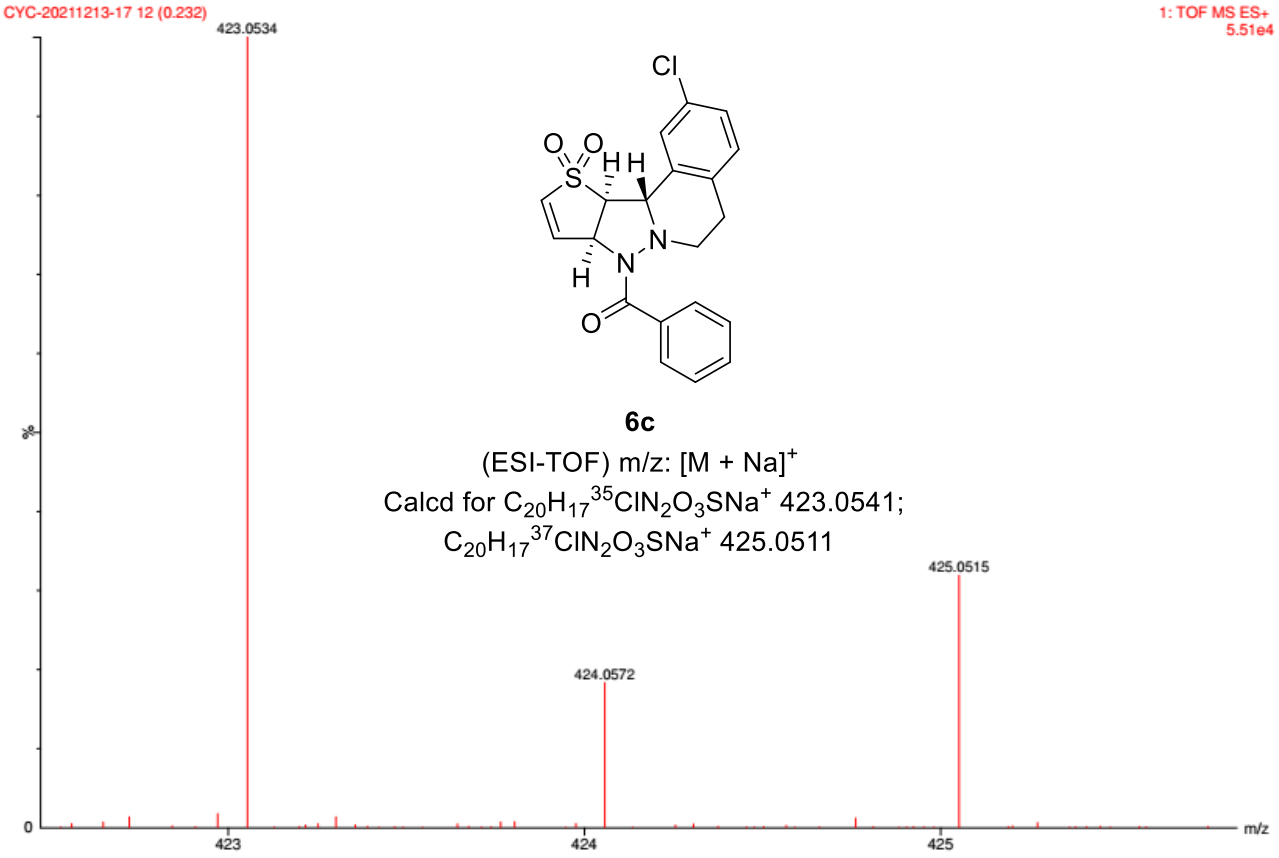
^{13}C NMR (100 MHz, $CDCl_3$)



Ret Time [min]	Peak Type	Width [min]	Height [mAU]	Area [mAU*s]	Area [%]
9.087	BBA	0.27	124.4833	2143.0078	50.9027
12.204	BB	0.84	32.7395	2067.0044	49.0973
			Totals:	4210.0122	100.0000



Ret Time [min]	Peak Type	Width [min]	Height [mAU]	Area [mAU*s]	Area [%]
8.810	BBA	0.27	380.5880	6696.1875	100.0000
			Totals:	6696.1875	100.0000

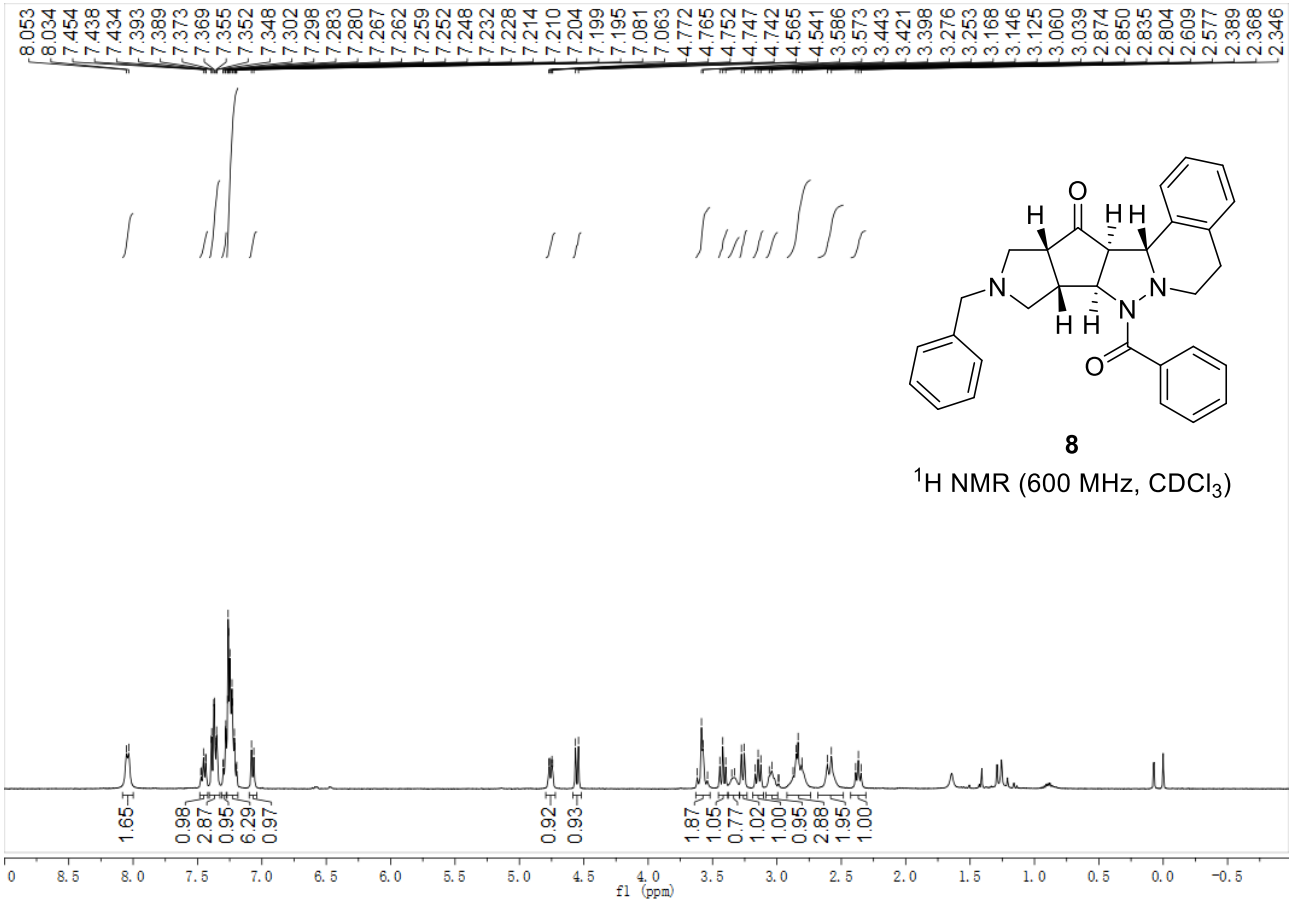


6c

(ESI-TOF) m/z: $[M + Na]^+$

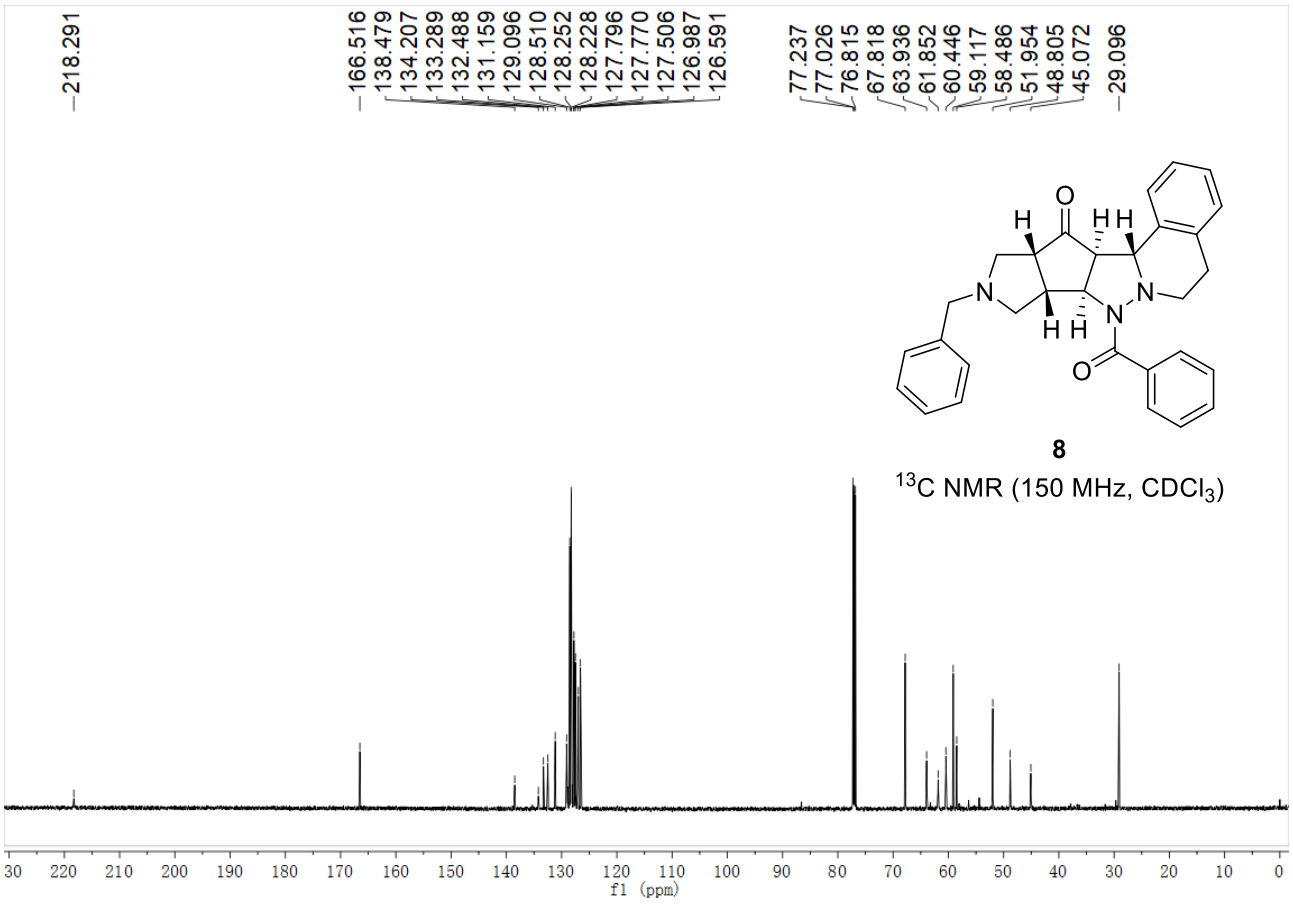
Calcd for $C_{20}H_{17}{}^{35}ClN_2O_3SNa^+$ 423.0541;

$C_{20}H_{17}{}^{37}ClN_2O_3SNa^+$ 425.0511



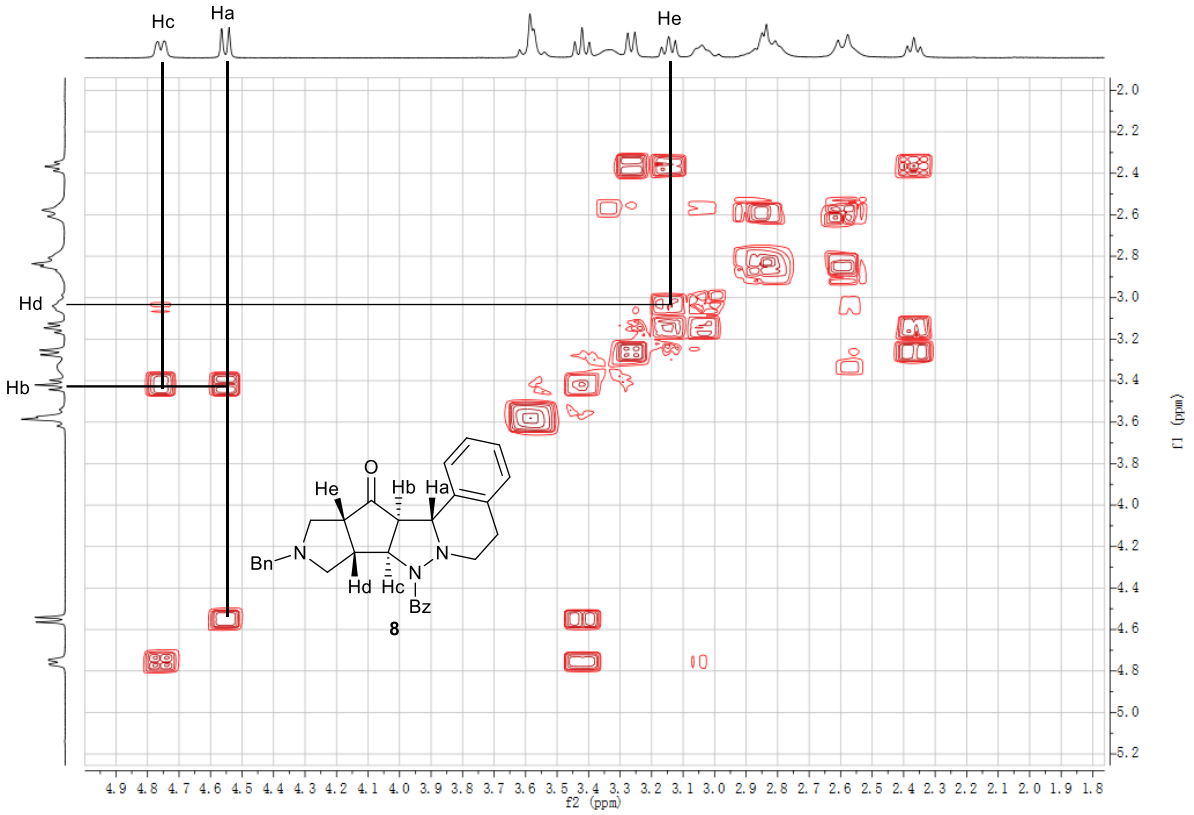
8

^{1}H NMR (600 MHz, $CDCl_3$)

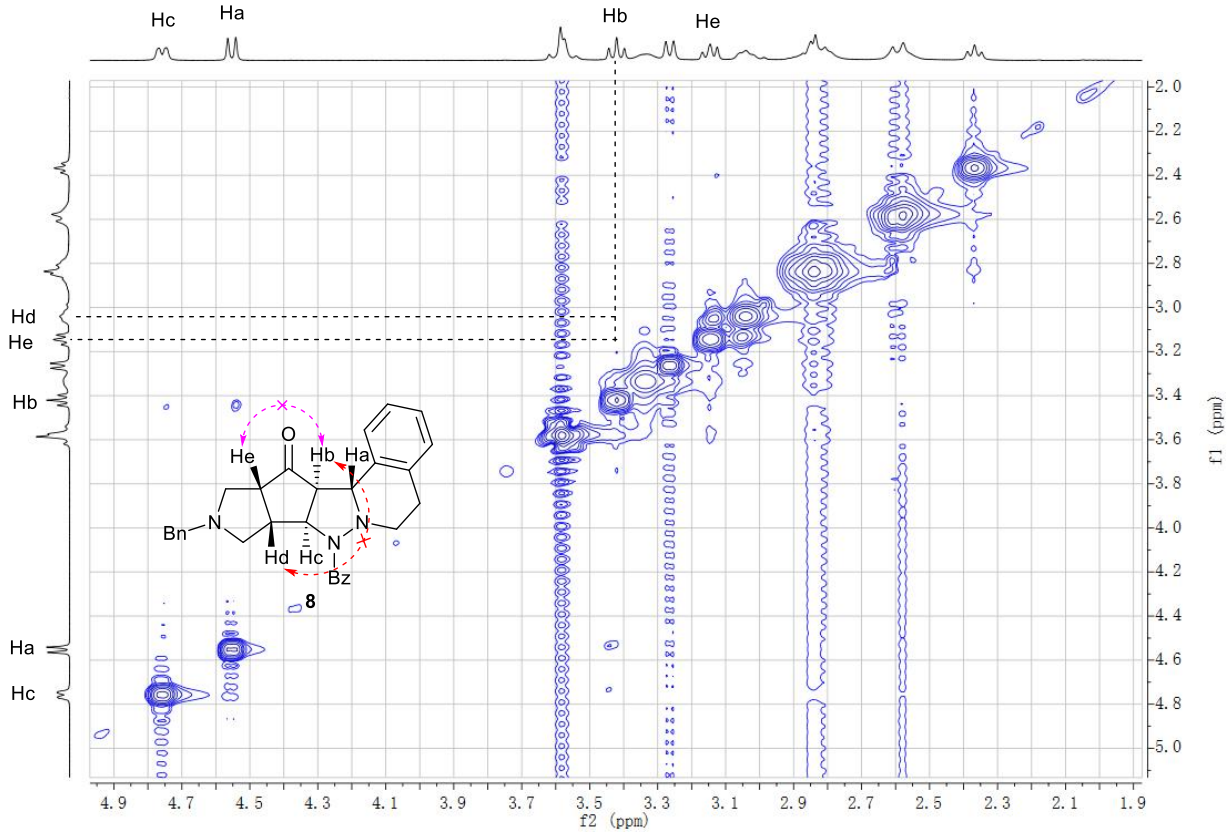


8

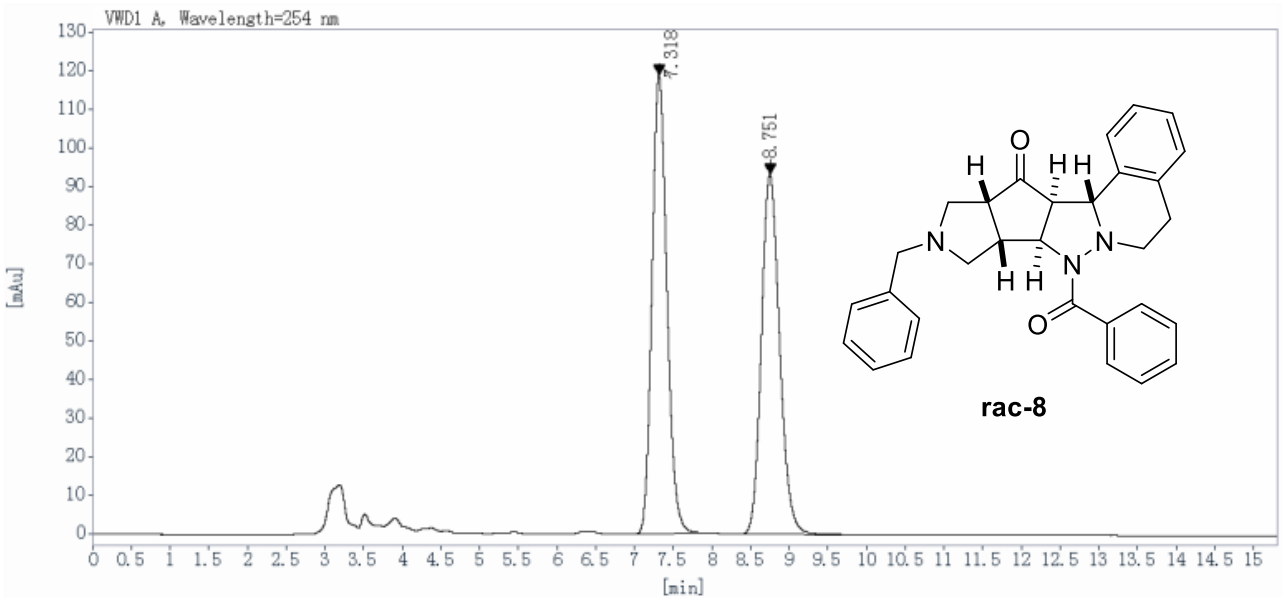
^{13}C NMR (150 MHz, $CDCl_3$)



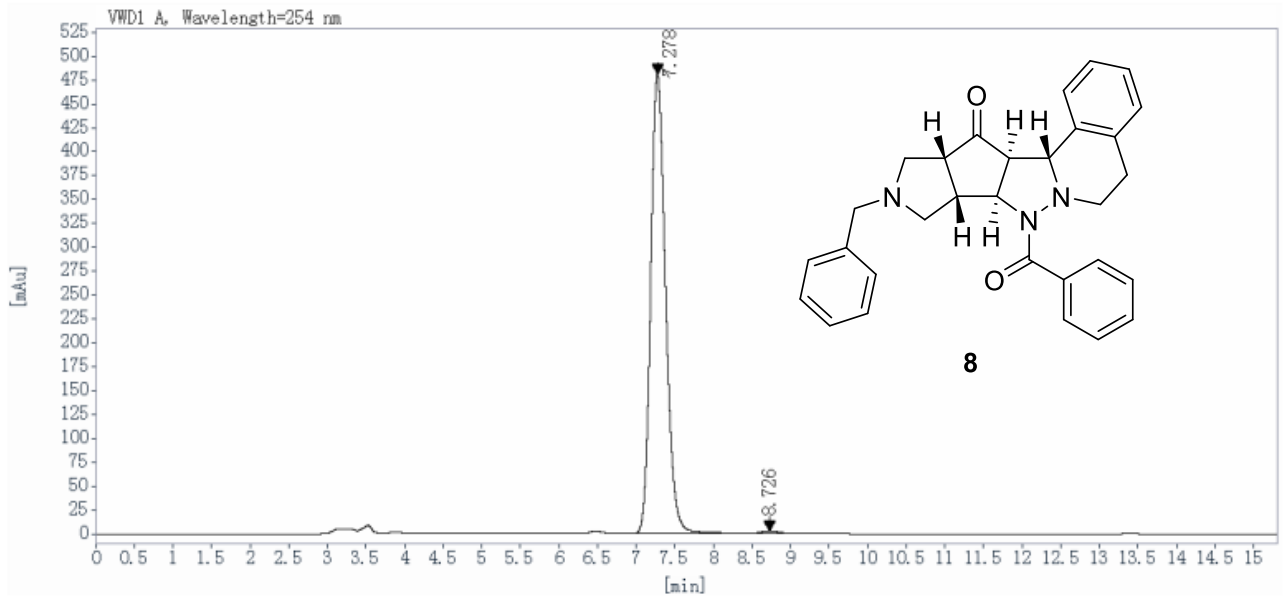
$^1H/^1H$ COSY spectrum of **8** (400MHz, $CDCl_3$)



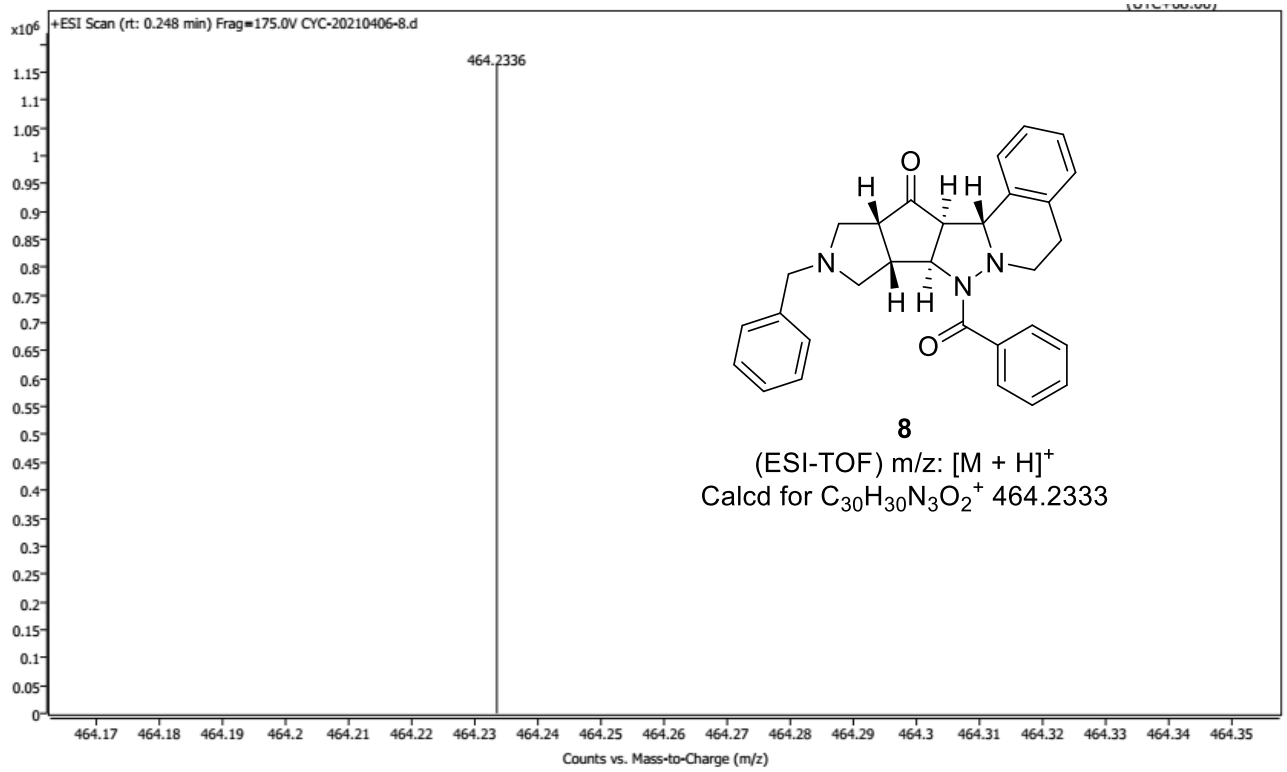
Two-dimensional NOESY spectrum of **8** (400MHz, $CDCl_3$)



Ret Time [min]	Peak Type	Width [min]	Height [mAU]	Area [mAU*s]	Area [%]
7.318	BBA	0.21	118.8829	1582.7490	50.9278
8.751	BBA	0.25	93.1644	1525.0815	49.0722
			Totals:	3107.8306	100.0000



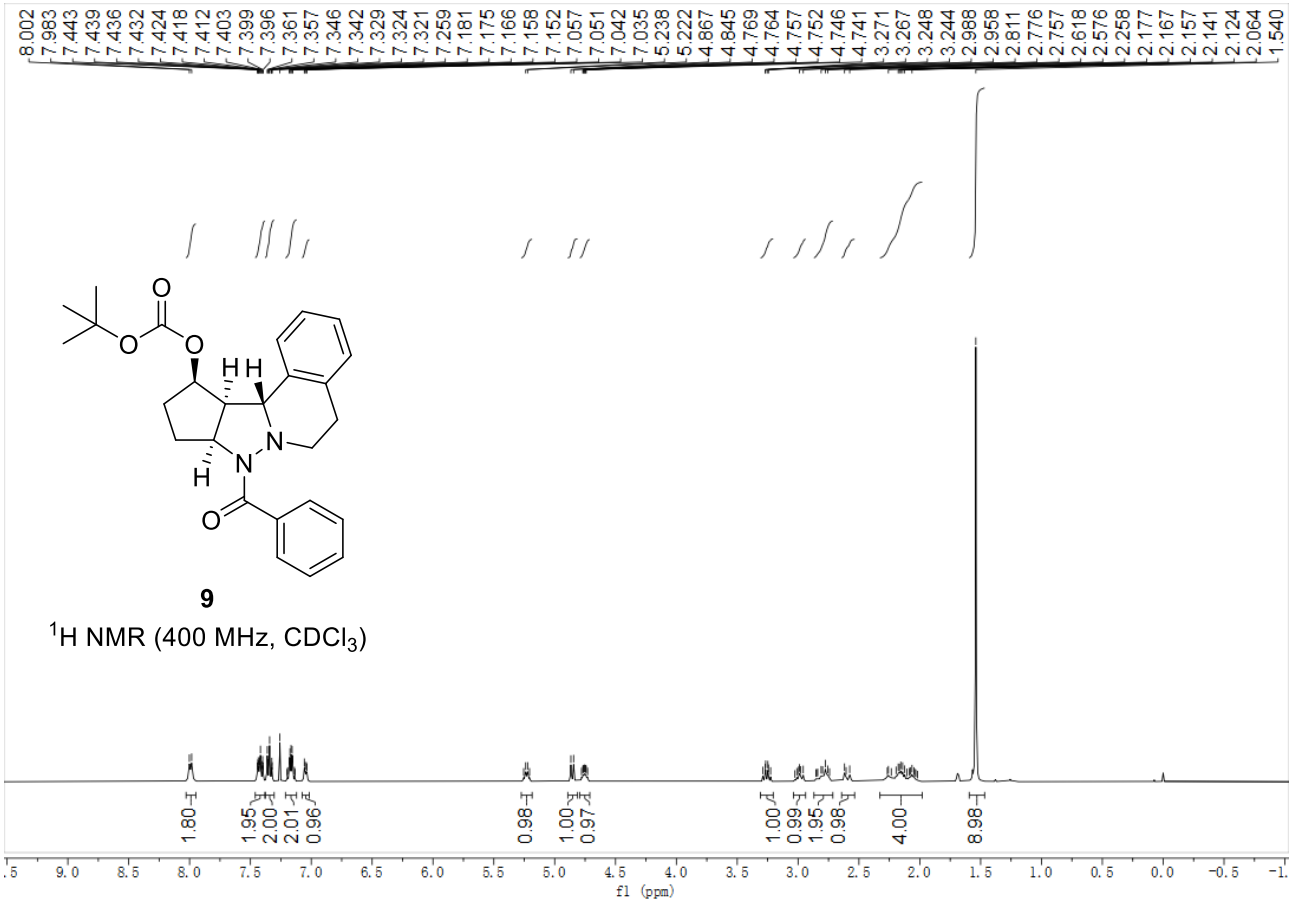
Ret Time [min]	Peak Type	Width [min]	Height [mAU]	Area [mAU*s]	Area [%]
7.278	BB	0.21	481.0872	6447.4214	99.2602
8.726	BB	0.25	2.9771	48.0558	0.7398
			Totals:	6495.4772	100.0000



8

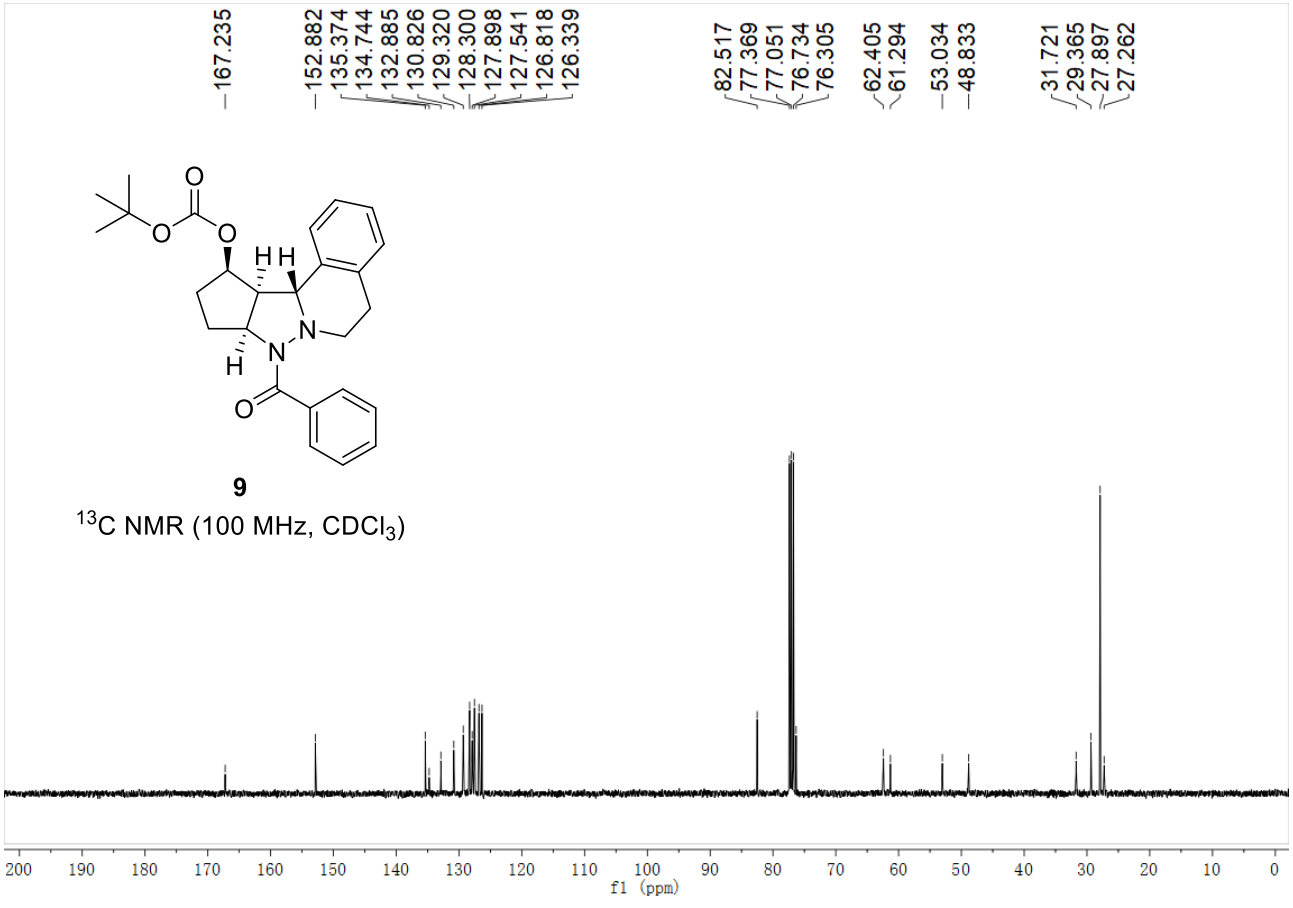
(ESI-TOF) m/z: $[M + H]^+$

Calcd for $C_{30}H_{30}N_3O_2^+$ 464.2333



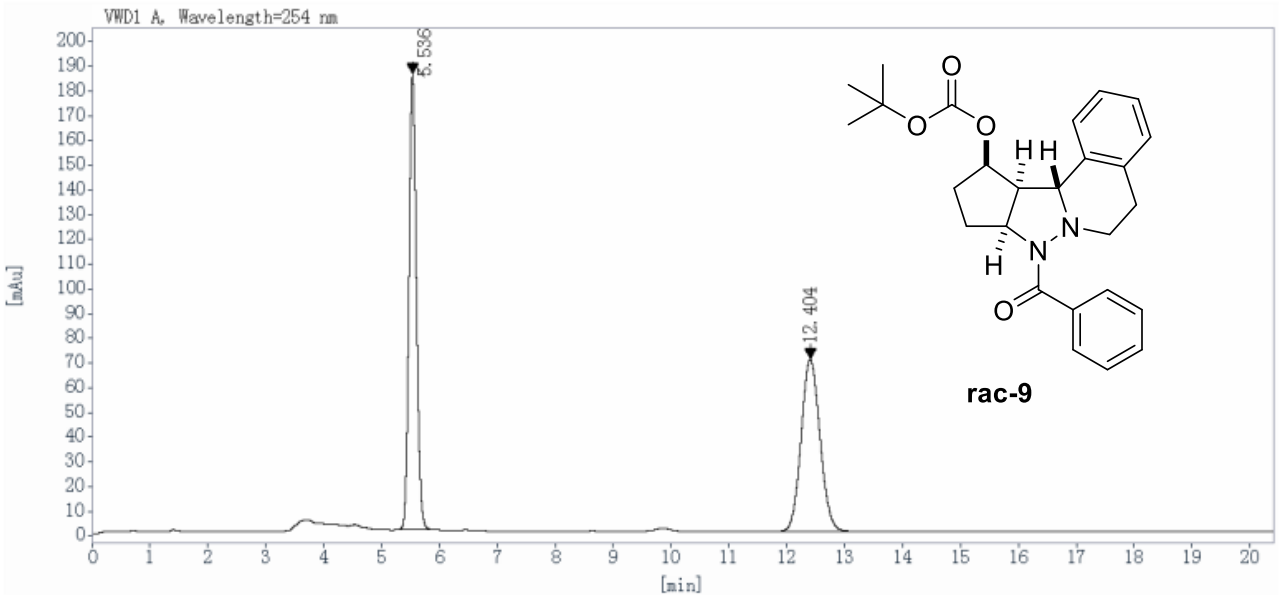
9

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

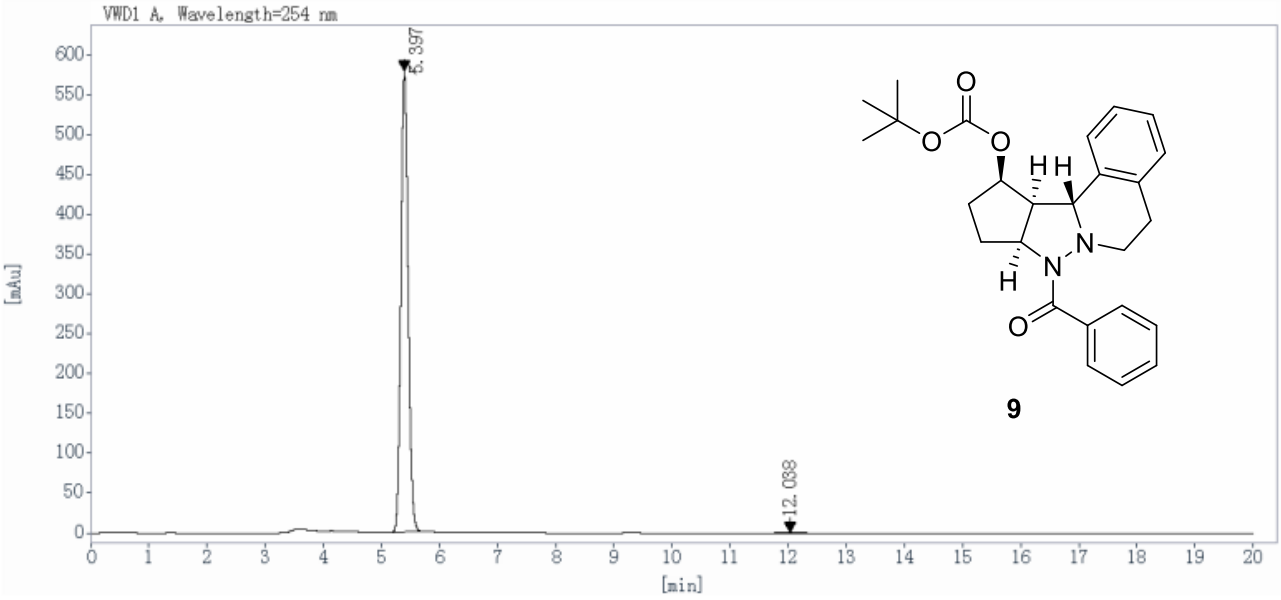


9

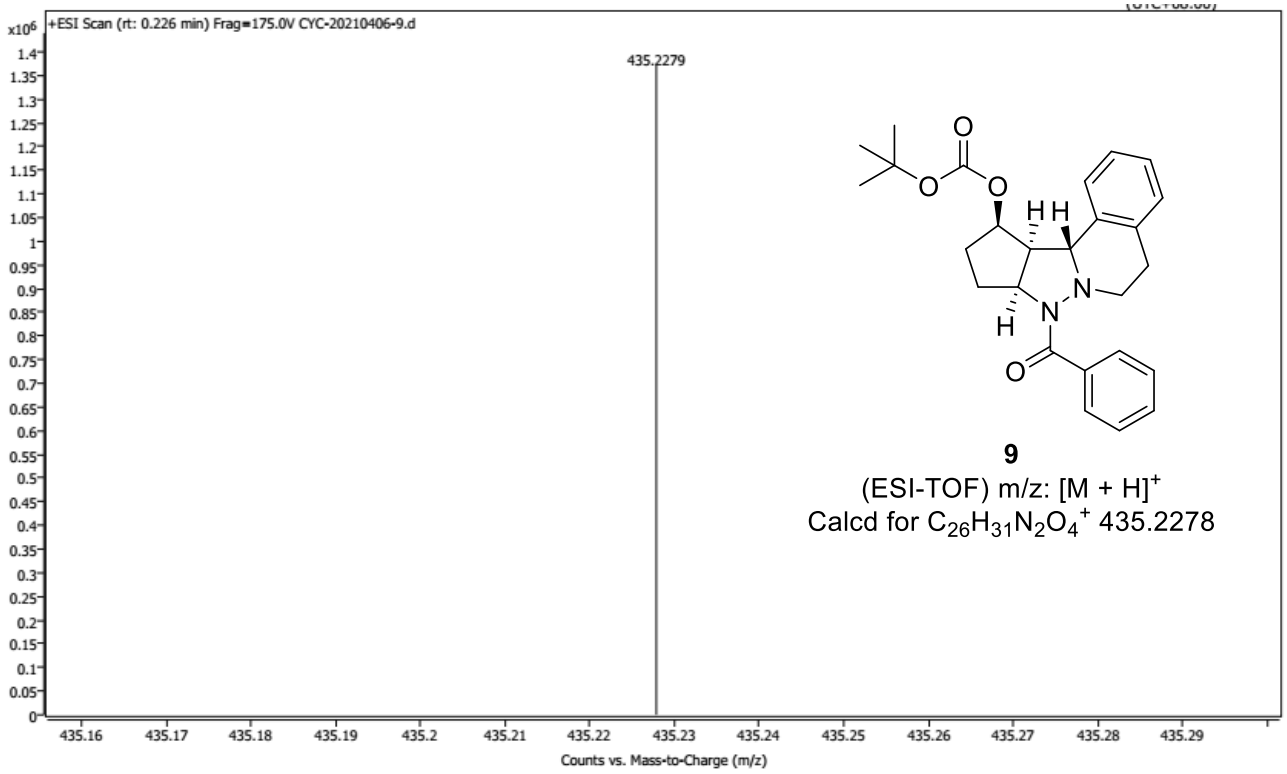
^{13}C NMR (100 MHz, $CDCl_3$)



Ret Time [min]	Peak Type	Width [min]	Height [mAU]	Area [mAU*s]	Area [%]
5.536	BB	0.14	184.4476	1638.6830	50.9670
12.404	BB	0.35	69.6302	1576.4988	49.0330
			Totals:	3215.1818	100.0000



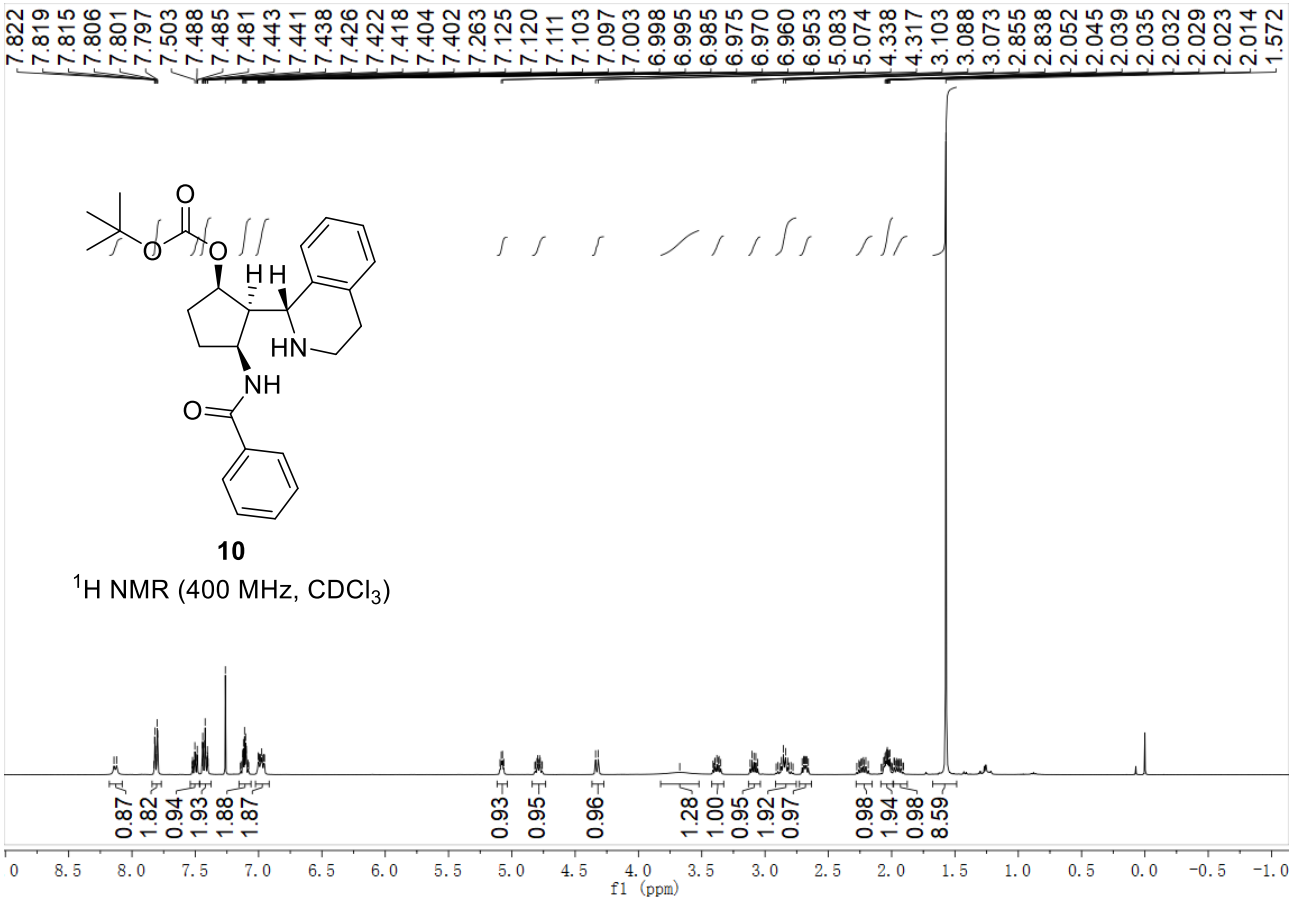
Ret Time [min]	Peak Type	Width [min]	Height [mAU]	Area [mAU*s]	Area [%]
5.397	BBA	0.13	579.0763	5002.0747	99.6387
12.038	BB	0.33	0.8207	18.1404	0.3613
			Totals:	5020.2151	100.0000



9

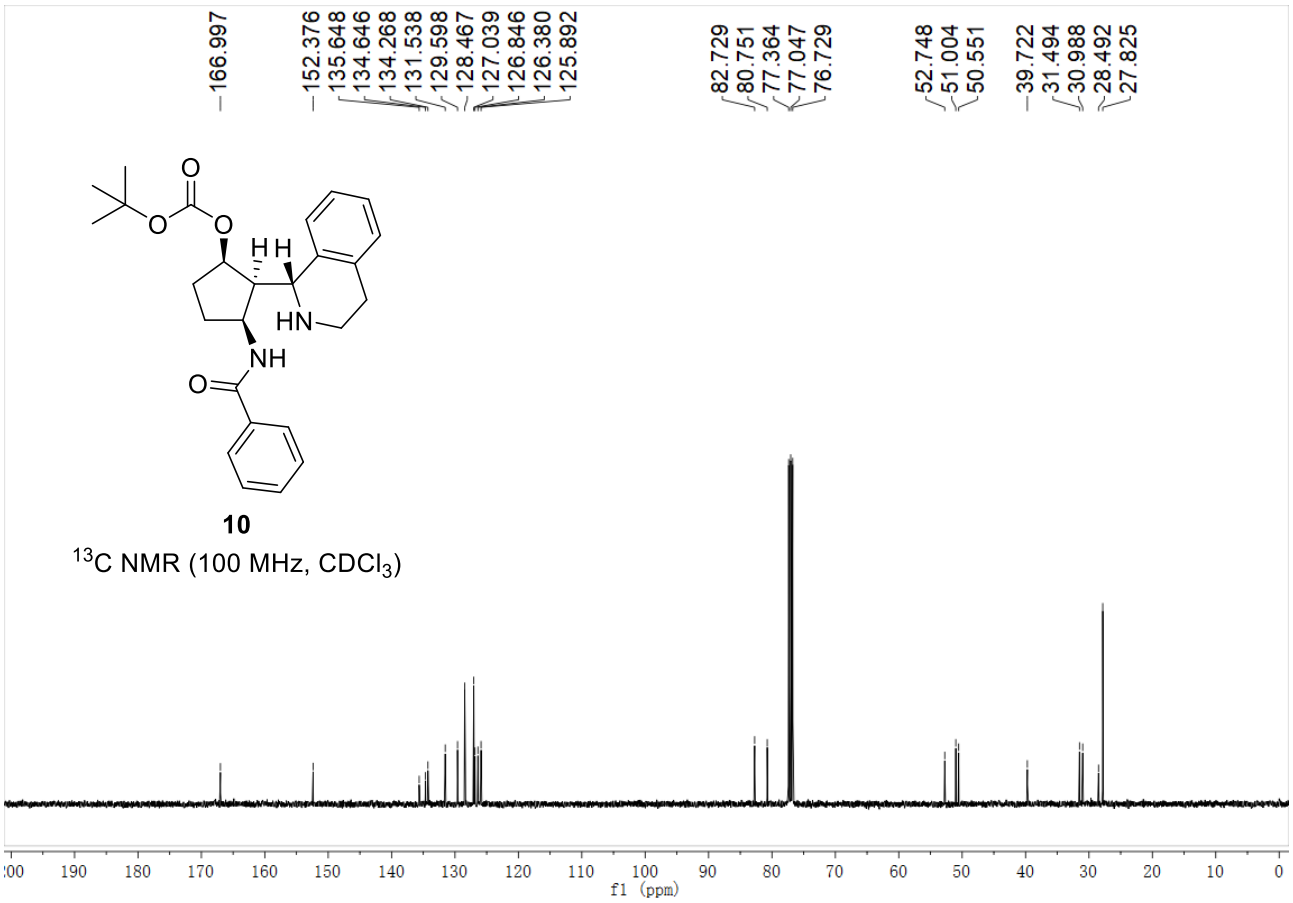
(ESI-TOF) m/z: $[M + H]^+$

Calcd for $C_{26}H_{31}N_2O_4^+$ 435.2278



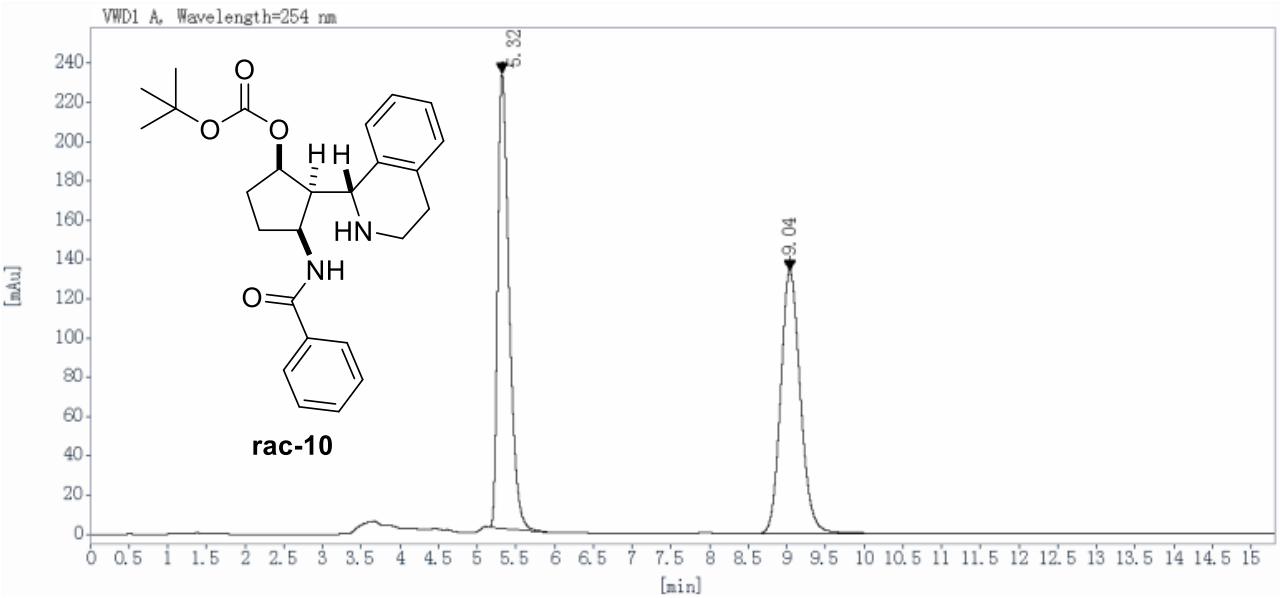
10

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

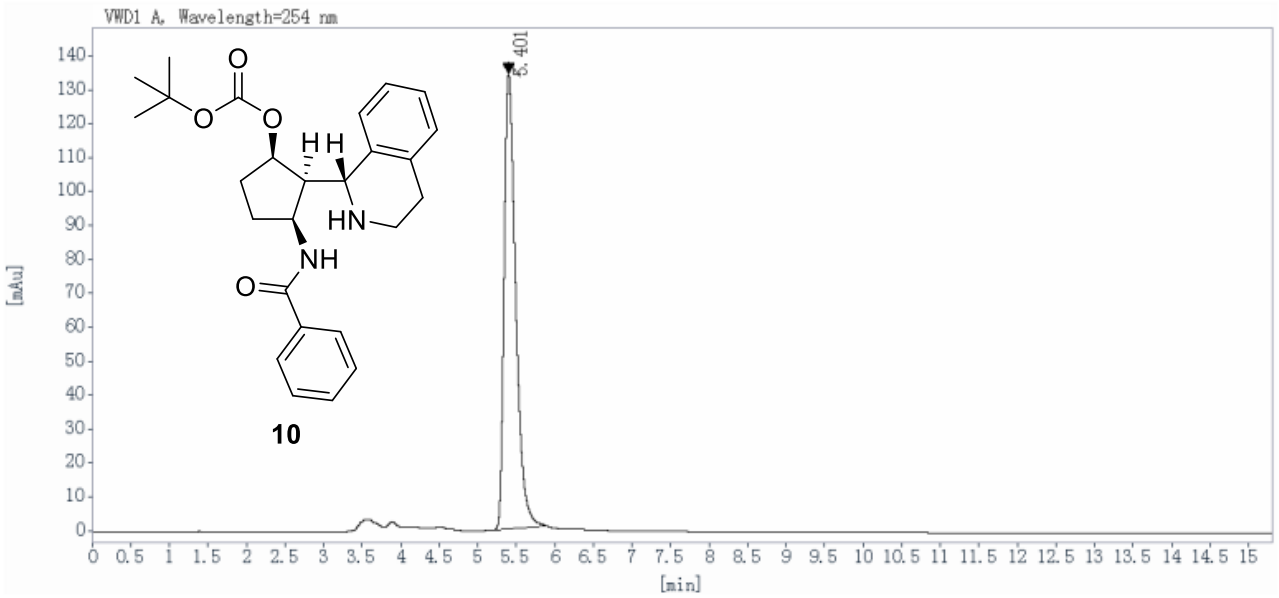


10

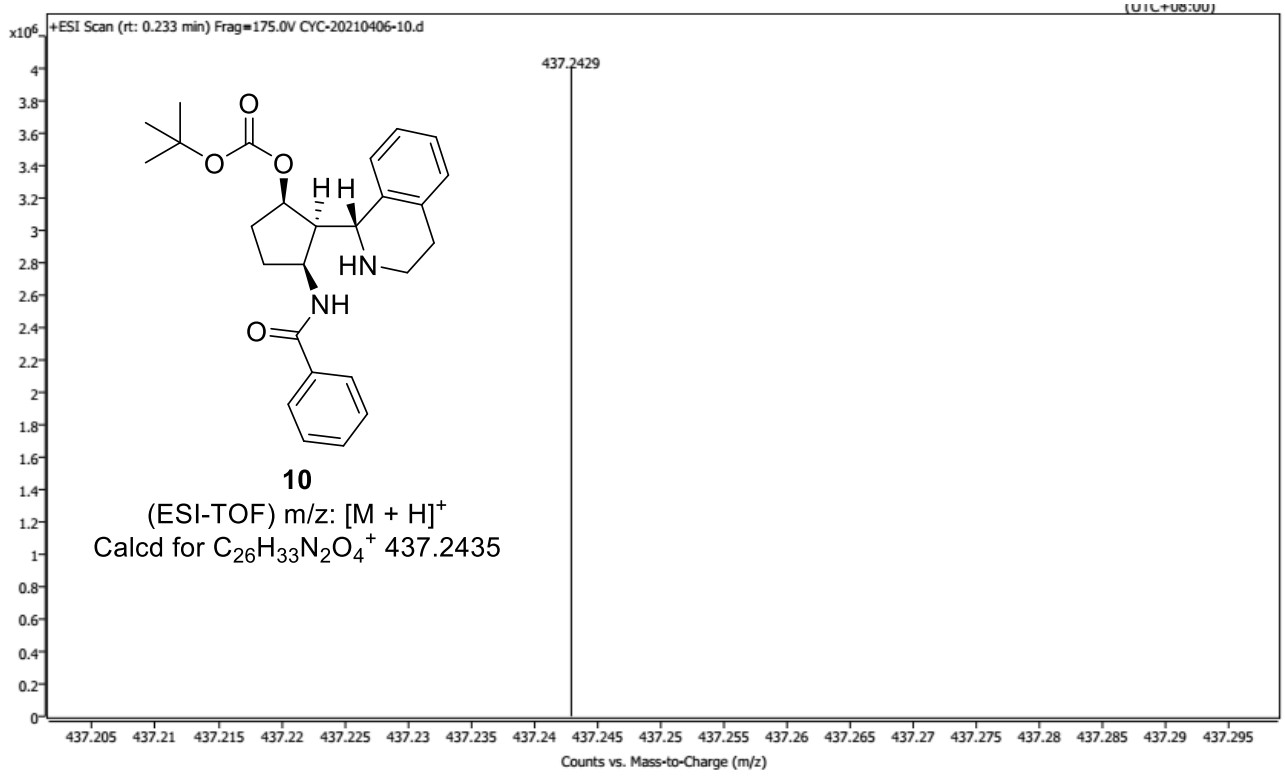
^{13}C NMR (100 MHz, $CDCl_3$)



Ret Time [min]	Peak Type	Width [min]	Height [mAU]	Area [mAU*s]	Area [%]
5.320	BB	0.16	232.2401	2379.1873	49.8109
9.040	BB	0.28	134.2615	2397.2527	50.1891
			Totals:	4776.4399	100.0000



Ret Time [min]	Peak Type	Width [min]	Height [mAU]	Area [mAU*s]	Area [%]
5.401	BBA	0.16	134.1970	1388.3989	100.0000
			Totals:	1388.3989	100.0000


+ESI Scan (rt: 0.233 min) Frag=175.0V CYC-20210406-10.d
x10^6
437.2429
O
O
O
H H
HN
NH
O
10
(ESI-TOF) m/z: [M + H]+
Calcd for C26H33N2O4+ 437.2435
437.205 437.21 437.215 437.22 437.225 437.23 437.235 437.24 437.245 437.25 437.255 437.26 437.265 437.27 437.275 437.28 437.285 437.29 437.295
Counts vs. Mass-to-Charge (m/z)