Facile construction of benzofulvene frameworks via a palladium-catalysed three-component reaction

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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 MHz or 600 MHz), ^{13}C NMR (100 MHz or 150 MHz) and ^{19}F NMR (375 MHz) spectra were recorded on Varian INOVA 400/54, Agilent DD2 600/54 or Bruker AscendTM 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 = doublet doublet, td = triple doublet, dt = double triplet, brs = broad singlet, m = multiplet, and coupling constants (*J*) are reported in Hertz (Hz). High resolution mass spectra (HRMS) were recorded on a Waters SYNAPT G2, 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 Bruker D8 venture diffractometer, and the data obtained were deposited at the Cambridge Crystallographic Data Centre (CCDC 2380456). Column chromatography was performed on silica gel (200–300 mesh) eluting with redistilled EtOAc and petroleum ether. TLC was performed on glass-backed silica plates. UV light (monitored at 254 nm), I_2 and solution of potassium permanganate were used to visualize products or starting materials. All chemicals were used without purification as commercially available unless otherwise noted. Toluene was freshly distilled from calcium hydride before use. 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 syringes. 1,3-enyne substrates **1a**–**1s** were prepared according to the literature procedures.[1,2] 2-Formyl arylboronic acids **2a**–**2i** and amines **3a** and **3b** were commercially available.

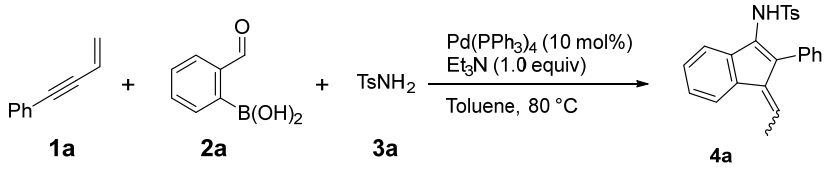
References

(1) Y. Zhang, B. Yu, B. Gao, T. Zhang and H. Huang, *Org. Lett*., 2019, **21**, 535.

(2) Q. He, L. Zhu, Z.-H. Yang, B. Zhu, Q. Ouyang, W. Du and Y.-C. Chen, *J. Am. Chem. Soc*., 2021, **143**, 17989.

2. Detailed condition optimisations

Table S2.1 Screening conditions of Pd^0-catalysed three-component reaction (concentration and time)[a]

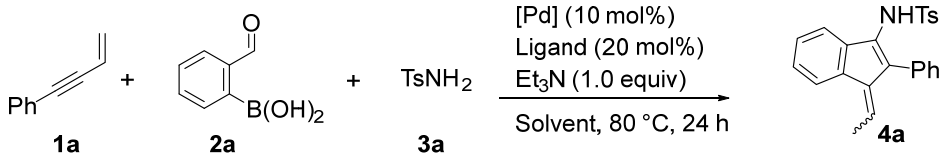


1a **2a** **3a** **4a**

Entry	Conc (mol/L)	Time (h)	Yield (%)[b]	*E*/*Z*[c]
1[d]	0.1	16	18	5:1
2	0.1	16	32	5:1
3	0.2	16	42	5:1
4	0.3	16	45	5:1
5	0.4	16	36	4:1
6	0.2	24	48	5:1
7	0.2	36	42	5:1
8[e]	0.2	24	46	5:1

[a] Unless noted otherwise, reactions were performed using **1a** (0.075 mmol), **2a** (0.075 mmol), **3a** (0.05 mmol), $Pd(PPh_3)_4$ (10 mol %) at 80 °C under Ar. [b] Combined yield of *Z* and *E* products. [c] Determined by ^1H NMR analysis of crude product. [d] Using **1a** (0.075 mmol), **2a** (0.05 mmol), **3a** (0.075 mmol). [e] With 4 Å MS (30 mg).

Table S2.2 Screening conditions of Pd^0-catalysed three-component reaction (palladium precursor, ligands and bases)[a]



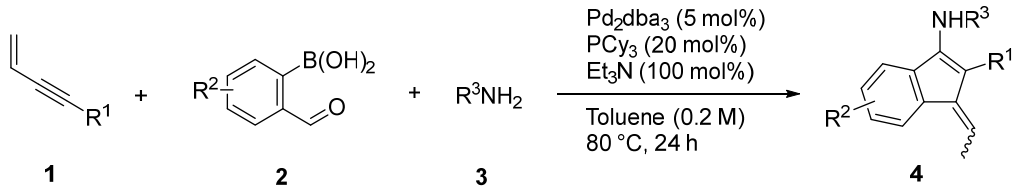
1a **2a** **3a** **4a**

Entry	[Pd]	Solvent	Ligand	Yield (%)[b]	*E*/*Z*[c]
1[d]	$Pd(PPh_3)_4$	Toluene	/	/	/
2	$Pd(PPh_3)_4$	Toluene	/	48	5:1
3	$Pd(OAc)_2$	Toluene	PPh_3	47	4:1
4	allylPdCp	Toluene	PPh_3	46	5:1
5	$Pd_2(dba)_3$	Toluene	PPh_3	62	6:1
6	$Pd_2(dba)_3$	Toluene	PCy_3	83	8:1
7	$Pd_2(dba)_3$	Toluene	P(*t*-Bu)$_3$	trace	/
8	$Pd_2(dba)_3$	THF	PCy_3	<20	/
9	$Pd_2(dba)_3$	1,4-Dioxane	PCy_3	<20	/
10	$Pd_2(dba)_3$	DMF	PCy_3	NR	/

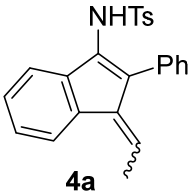
11	$Pd_2(dba)_3$	Xylene	PCy_3	78	7:1
12	$Pd_2(dba)_3$	$PhCF_3$	PCy_3	69	7:1
13	$Pd_2(dba)_3$	EtOAc	PCy_3	43	6:1
14[e]	$Pd_2(dba)_3$	Toluene	PCy_3	NR	/
15[f]	$Pd_2(dba)_3$	Toluene	PCy_3	54	7:1
16[g]	$Pd_2(dba)_3$	Toluene	PCy_3	62	6:1

[a] Unless noted otherwise, reactions were performed using **1a** (0.075 mmol), **2a** (0.075 mmol), **3a** (0.05 mmol), [Pd] (10 mol %), ligand (20 mol%), Et_3N (1.0 equiv) in solvent (0.25 mL) at 80 °C under Ar. [b] Combined yield of *Z* and *E* products. [c] Determined by ^1H NMR analysis of crude product. [d] Without **3a**. [e] Without Et_3N. [f] With Na_2CO_3 (1.0 equiv) instead of Et_3N. [g] With NaOAc (1.0 equiv) instead of Et_3N.

3. General procedure for the synthesis of products 4



To an oven-dried 10 mL Schlenk tube equipped with a magnetic stir bar were added 1,3-enyne **1** (0.150 mmol, 1.5 equiv), 2-formyl arylboronic acid **2** (0.150 mmol, 1.5 equiv), amine **3** (0.100 mmol, 1.0 equiv), $Pd_2(dba)_3$ (4.6 mg, 0.0050 mmol, 0.05 equiv) and PCy_3 (5.6 mg, 0.020 mmol, 0.2 equiv). The tube was capped, evacuated and back-filled with argon for three times. Then Et_3N (14 μL, 0.10 mmol, 1.0 equiv) and degassed dry toluene (0.5 mL) were added via syringe sequentially. The mixture was stirred at 80 °C for 24 h, and monitored by TLC. After completion, the mixture was purified by flash chromatography on silica gel (petroleum ether/EtOAc) to give product **4**.

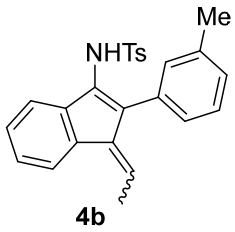


4a

To an oven-dried 10 mL Schlenk tube equipped with a magnetic stir bar were added enyne **1a** (19.2 mg, 0.150 mmol, 1.5 equiv), (2-formylphenyl)boronic acid **2a** (22.5 mg, 0.150 mmol, 1.5 equiv), $TsNH_2$ **3a** (17.1 mg, 0.100 mmol, 1.0 equiv), $Pd_2(dba)_3$ (4.6 mg, 0.0050 mmol, 0.05 equiv) and PCy_3 (5.6 mg, 0.020 mmol, 0.2 equiv). The tube was capped, evacuated and back-filled with argon for three times. Then Et_3N (14 μL, 0.10 mmol, 1.0 equiv) and degassed dry toluene (0.5 mL) were added via syringe sequentially. The mixture was stirred at 80 °C for 24 h, and monitored by TLC. After completion, the mixture was purified by flash chromatography on silica gel (petroleum ether/EtOAc = 10/1 to 8/1) to give product **4a**: 29.9 mg (0.0772 mmol), as a yellow solid, 77% yield; *E*/*Z* = 8:1, determined by ^1H NMR analysis of crude

product; mp = 63–65 °C; ***E*-4a**: ^{1}H NMR (400 MHz, $CDCl_3$): δ (ppm) 7.88 (d, *J* = 7.6 Hz, 1H), 7.77 (d, *J* = 7.5 Hz, 1H), 7.40–7.33 (m, 3H), 7.31 (dd, *J* = 7.6, 1.3 Hz, 1H), 7.25 (d, *J* = 6.2 Hz, 1H), 7.22–7.15 (m, 2H), 7.08 (d, *J* = 8.1 Hz, 2H), 6.59 (dt, *J* = 6.9, 1.4 Hz, 2H), 6.34 (s, 1H), 6.04 (q, *J* = 7.6 Hz, 1H), 2.40 (s, 3H), 2.29 (d, *J* = 7.6 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ (ppm) 143.7, 139.4, 139.2, 135.9, 134.7, 133.7, 133.6, 132.2, 131.2, 130.6, 129.4, 128.4, 127.7, 127.3, 126.2, 123.5, 121.1, 21.6, 16.0; HRMS (ESI-TOF) *m/z*: $[M + Na]^+$ Calcd for $C_{24}H_{21}NO_2SNa^+$ 410.1185; Found 410.1180.

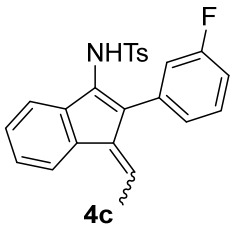
Synthesis of 4a on a 1.0 mmol scale: To an oven-dried 25 mL Schlenk tube equipped with a magnetic stir bar were added enyne **1a** (192 mg, 1.50 mmol, 1.5 equiv), (2-formylphenyl)boronic acid **2a** (225 mg, 1.50 mmol, 1.5 equiv), $TsNH_2$ **3a** (171 mg, 1.00 mmol, 1.0 equiv), $Pd_2(dba)_3$ (46 mg, 0.050 mmol, 0.05 equiv) and PCy_3 (56 mg, 0.020 mmol, 0.2 equiv). The tube was capped, evacuated and back-filled with argon for three times. Then Et_3N (140 μL, 1.0 mmol, 1.0 equiv) and degassed dry toluene (5.0 mL) were added via syringe sequentially. The mixture was stirred at 80 °C for 24 h, and monitored by TLC. After completion, the mixture was purified by flash chromatography on silica gel (petroleum ether/EtOAc = 10/1 to 8/1) to give product **4a**: 282 mg (0.728 mmol), as a yellow solid, 73% yield; *E*/*Z* = 8:1, determined by ^{1}H NMR analysis of crude product.



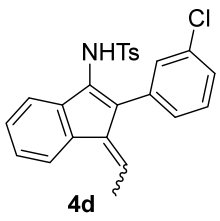
4b

To an oven-dried 10 mL Schlenk tube equipped with a magnetic stir bar were added enyne **1b** (21.3 mg, 0.150 mmol, 1.5 equiv), (2-formylphenyl)boronic acid **2a** (22.5 mg, 0.150 mmol, 1.5 equiv), $TsNH_2$ **3a** (17.1 mg, 0.100 mmol, 1.0 equiv), $Pd_2(dba)_3$ (4.6 mg, 0.0050 mmol, 0.05 equiv) and PCy_3 (5.6 mg, 0.020 mmol, 0.2 equiv). The tube was capped, evacuated and back-filled with argon for three times. Then Et_3N (14 μL, 0.10 mmol, 1.0 equiv) and degassed dry toluene (0.5 mL) were added via syringe sequentially. The mixture was stirred at 80 °C for 24 h, and monitored by TLC. After completion, the mixture was purified by flash chromatography on silica gel (petroleum ether/EtOAc = 10/1 to 8/1) to give product **4b**: 23.4 mg (0.0583 mmol), as a yellow solid, 58% yield; *E*/*Z* = 8:1, determined by ^{1}H NMR analysis of crude product; mp = 67–69 °C; ***E*-4b**: ^{1}H NMR (400 MHz, $CDCl_3$): δ (ppm) 7.92 (dd, *J* = 7.6, 1.1 Hz, 1H), 7.77 (d, *J* = 7.6 Hz, 1H), 7.44–7.27 (m, 4H), 7.14–7.03 (m, 4H), 6.44 (dt, *J* = 7.1, 1.8 Hz, 1H), 6.37–6.28 (m, 2H), 6.01 (q, *J* = 7.6 Hz, 1H), 2.40 (s, 3H), 2.28 (d, *J* = 7.7 Hz, 3H), 2.23 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ (ppm) 143.4, 139.4, 139.1, 137.9, 135.5, 135.2, 133.9,

133.1, 132.0, 131.9, 130.3, 129.4, 128.5, 128.2, 127.6, 127.5, 127.4, 126.9, 125.9, 123.3, 121.5, 21.6, 21.4, 15.9; HRMS (ESI-TOF) *m/z*: $[M + Na]^+$ Calcd for $C_{25}H_{23}NO_2SNa^+$ 424.1342; Found 424.1334.

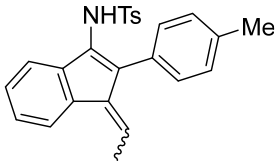


To an oven-dried 10 mL Schlenk tube equipped with a magnetic stir bar were added enyne **1c** (21.9 mg, 0.150 mmol, 1.5 equiv), (2-formylphenyl)boronic acid **2a** (22.5 mg, 0.150 mmol, 1.5 equiv), $TsNH_2$ **3a** (17.1 mg, 0.100 mmol, 1.0 equiv), $Pd_2(dba)_3$ (4.6 mg, 0.0050 mmol, 0.05 equiv) and PCy_3 (5.6 mg, 0.020 mmol, 0.2 equiv). The tube was capped, evacuated and back-filled with argon for three times. Then Et_3N (14 μL, 0.10 mmol, 1.0 equiv) and degassed dry toluene (0.5 mL) were added via syringe sequentially. The mixture was stirred at 80 °C for 24 h, and monitored by TLC. After completion, the mixture was purified by flash chromatography on silica gel (petroleum ether/EtOAc = 10/1 to 8/1) to give product **4c**: 24.7 mg (0.0631 mmol), as a yellow solid, 63% yield; *E*/*Z* = 5:1, determined by ^{1}H NMR analysis of crude product; mp = 78–80 °C; ***E*-4c**: ^{1}H NMR (400 MHz, $CDCl_3$): δ (ppm) 7.83–7.81 (m, 1H), 7.73 (d, *J* = 7.5 Hz, 1H), 7.37–7.30 (m, 3H), 7.28 (td, *J* = 7.6, 1.3 Hz, 1H), 7.25–7.11 (m, 1H), 7.06 (d, *J* = 8.0 Hz, 2H), 6.94–6.88 (m, 1H), 6.52 (dt, *J* = 7.6, 1.3 Hz, 1H), 6.32 (s, 1H), 6.07–6.03 (m, 1H), 6.00 (q, *J* = 7.6 Hz, 1H), 2.36 (s, 3H), 2.26 (d, *J* = 7.7 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ (ppm) 162.4 (d, $^1J_{FC}$ = 245.6 Hz), 144.0, 139.1 (d, $^3J_{FC}$ = 8.2 Hz), 135.4, 134.4 (d, $^3J_{FC}$ = 8.1 Hz), 134.2 (d, $^4J_{FC}$ = 2.0 Hz), 133.7, 133.5, 132.5, 129.9, 129.8, 129.5, 127.7, 127.3, 126.2, 125.3, 123.5, 121.5, 116.9 (d, $^2J_{FC}$ = 21.7 Hz), 114.6 (d, $^2J_{FC}$ = 20.9 Hz), 21.5, 16.0; ^{19}F NMR (375 MHz, $CDCl_3$): δ (ppm) –112.5; HRMS (ESI-TOF) *m/z*: $[M + Na]^+$ Calcd for $C_{24}H_{20}FNO_2SNa^+$ 428.1091; Found 428.1095.



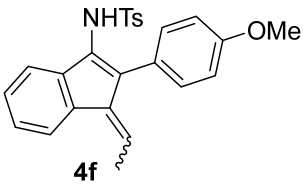
To an oven-dried 10 mL Schlenk tube equipped with a magnetic stir bar were added enyne **1d** (24.3 mg, 0.150 mmol, 1.5 equiv), (2-formylphenyl)boronic acid **2a** (22.5 mg, 0.150 mmol, 1.5 equiv), $TsNH_2$ **3a** (17.1 mg, 0.100 mmol, 1.0 equiv), $Pd_2(dba)_3$ (4.6 mg, 0.0050 mmol, 0.05 equiv) and PCy_3 (5.6 mg, 0.020 mmol, 0.2 equiv). The tube was capped, evacuated and back-filled with argon for three times. Then Et_3N (14 μL, 0.10 mmol, 1.0 equiv) and degassed dry toluene (0.5 mL) were added via syringe sequentially. The mixture was stirred at 80 °C for 24 h, and monitored by TLC. After completion, the mixture was purified by flash chromatography on silica gel (petroleum ether/EtOAc = 10/1 to 8/1) to give product **4d**: 26.7 mg (0.0638 mmol), as a yellow solid, 64% yield; *E*/*Z* = 7:1, determined by ^{1}H NMR analysis of crude product; mp = 79–81 °C; ***E*-4d**: ^{1}H NMR (400 MHz, $CDCl_3$): δ (ppm) 7.87 (dt, *J* = 7.7, 0.9 Hz, 1H),

7.77 (d, J = 7.5 Hz, 1H), 7.42–7.29 (m, 4H), 7.25–7.21 (m, 1H), 7.19–7.15 (m, 1H), 7.11 (d, J = 8.0 Hz, 2H), 6.70 (dt, J = 7.4, 1.5 Hz, 1H), 6.40 (s, 1H), 6.36 (t, J = 1.8 Hz, 1H), 6.00 (q, J = 7.6 Hz, 1H), 2.41 (s, 3H), 2.29 (d, J = 7.6 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ (ppm) 144.0, 139.13, 139.09, 135.3, 134.2, 134.0, 133.7, 133.6, 132.6, 129.8, 129.60, 129.58, 127.9, 127.8, 127.7, 127.3, 126.3, 123.5, 121.5, 21.7, 16.0; HRMS (ESI-TOF) *m/z*: $[M + Na]^+$ Calcd for $C_{24}H_{20}{}^{35}ClNO_2SNa^+$ 444.0795; Found 444.0793; Calcd for $C_{24}H_{20}{}^{37}ClNO_2SNa^+$ 446.0766; Found 446.0775.



4e

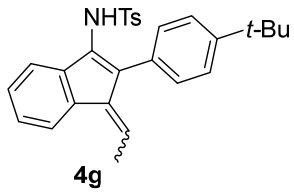
To an oven-dried 10 mL Schlenk tube equipped with a magnetic stir bar were added enyne **1e** (21.3 mg, 0.150 mmol, 1.5 equiv), (2-formylphenyl)boronic acid **2a** (22.5 mg, 0.150 mmol, 1.5 equiv), $TsNH_2$ **3a** (17.1 mg, 0.100 mmol, 1.0 equiv), $Pd_2(dba)_3$ (4.6 mg, 0.0050 mmol, 0.05 equiv) and PCy_3 (5.6 mg, 0.020 mmol, 0.2 equiv). The tube was capped, evacuated and back-filled with argon for three times. Then Et_3N (14 μL, 0.10 mmol, 1.0 equiv) and degassed dry toluene (0.5 mL) were added via syringe sequentially. The mixture was stirred at 80 °C for 24 h, and monitored by TLC. After completion, the mixture was purified by flash chromatography on silica gel (petroleum ether/EtOAc = 10/1 to 8/1) to give product **4e**: 28.7 mg (0.0721 mmol), as a yellow solid, 72% yield; E/Z = 7:1, determined by ^{1}H NMR analysis of crude product; mp = 69–71 °C; ***E*-4e**: ^{1}H NMR (400 MHz, $CDCl_3$): δ (ppm) 7.86 (dt, J = 7.7, 0.9 Hz, 1H), 7.76 (d, J = 7.5 Hz, 1H), 7.41–7.34 (m, 3H), 7.32–7.28 (m, 1H), 7.09 (d, J = 8.1 Hz, 2H), 7.00 (d, J = 7.7 Hz, 2H), 6.50–6.45 (m, 2H), 6.30 (s, 1H), 6.04 (q, J = 7.6 Hz, 1H), 2.40 (s, 3H), 2.35 (s, 3H), 2.28 (d, J = 7.6 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ (ppm) 143.5, 139.3, 139.2, 137.4, 135.6, 135.2, 133.9, 133.1, 131.9, 129.7, 129.4, 129.0, 127.5, 127.4, 125.8, 123.3, 121.3, 21.6, 21.3, 15.9; HRMS (ESI-TOF) *m/z*: $[M + Na]^+$ Calcd for $C_{25}H_{23}NO_2SNa^+$ 424.1342; Found 424.1342.



4f

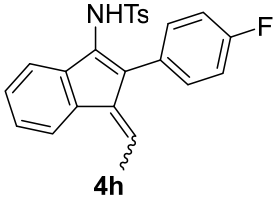
To an oven-dried 10 mL Schlenk tube equipped with a magnetic stir bar were added enyne **1f** (23.7 mg, 0.150 mmol, 1.5 equiv), (2-formylphenyl)boronic acid **2a** (22.5 mg, 0.150 mmol, 1.5 equiv), $TsNH_2$ **3a** (17.1 mg, 0.100 mmol, 1.0 equiv), $Pd_2(dba)_3$ (4.6 mg, 0.0050 mmol, 0.05 equiv) and PCy_3 (5.6 mg, 0.020 mmol, 0.2 equiv). The tube was capped, evacuated and back-filled with argon for three times. Then Et_3N (14 μL, 0.10 mmol, 1.0 equiv) and degassed dry toluene (0.5 mL) were added via syringe sequentially. The mixture was stirred at 80 °C for 24 h, and monitored by TLC. After completion, the mixture was purified by flash chromatography on silica gel (petroleum ether/EtOAc = 10/1 to 6/1) to

give product **4f**: 30.3 mg (0.0734 mmol), as a yellow solid, 73% yield; *E*/*Z* = 10:1, determined by ^{1}H NMR analysis of crude product; mp = 57–59 °C; ***E*-4f**: ^{1}H NMR (400 MHz, $CDCl_3$): δ (ppm) 7.82–7.78 (m, 1H), 7.72 (d, *J* = 7.5 Hz, 1H), 7.37–7.30 (m, 3H), 7.25–7.19 (m, 1H), 7.06 (d, *J* = 8.0 Hz, 2H), 6.72–6.66 (m, 2H), 6.52–6.46 (m, 2H), 6.29 (s, 1H), 6.00 (q, *J* = 7.6 Hz, 1H), 3.78 (s, 3H), 2.36 (s, 3H), 2.24 (d, *J* = 7.6 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ (ppm) 159.1, 143.5, 139.5, 139.3, 135.7, 135.1, 133.8, 133.1, 131.9, 131.0, 129.4, 127.5, 127.4, 125.8, 124.1, 123.3, 121.2, 113.7, 55.3, 21.6, 15.9; HRMS (ESI-TOF) *m/z*: $[M + Na]^+$ Calcd for $C_{25}H_{23}NO_3SNa^+$ 440.1291; Found 440.1294.



4g

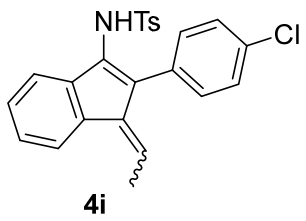
To an oven-dried 10 mL Schlenk tube equipped with a magnetic stir bar were added enyne **1g** (27.6 mg, 0.150 mmol, 1.5 equiv), (2-formylphenyl)boronic acid **2a** (22.5 mg, 0.150 mmol, 1.5 equiv), $TsNH_2$ **3a** (17.1 mg, 0.100 mmol, 1.0 equiv), $Pd_2(dba)_3$ (4.6 mg, 0.0050 mmol, 0.05 equiv) and PCy_3 (5.6 mg, 0.020 mmol, 0.2 equiv). The tube was capped, evacuated and back-filled with argon for three times. Then Et_3N (14 μL, 0.10 mmol, 1.0 equiv) and degassed dry toluene (0.5 mL) were added via syringe sequentially. The mixture was stirred at 80 °C for 24 h, and monitored by TLC. After completion, the mixture was purified by flash chromatography on silica gel (petroleum ether/EtOAc = 10/1 to 8/1) to give product **4g**: 30.9 mg (0.0702 mmol), as a yellow solid, 70% yield; *E*/*Z* = 8:1, determined by ^{1}H NMR analysis of crude product; mp = 81–83 °C; ***E*-4g**: ^{1}H NMR (400 MHz, $CDCl_3$): δ (ppm) 7.88 (d, *J* = 7.6 Hz, 1H), 7.77 (d, *J* = 7.6 Hz, 1H), 7.40–7.32 (m, 3H), 7.29 (td, *J* = 7.5, 1.3 Hz, 1H), 7.22–7.17 (m, 2H), 7.08–7.04 (m, 2H), 6.56–6.50 (m, 2H), 6.38 (s, 1H), 6.08 (q, *J* = 7.6 Hz, 1H), 2.40 (s, 3H), 2.29 (d, *J* = 7.7 Hz, 3H), 1.34 (s, 9H); ^{13}C NMR (100 MHz, $CDCl_3$): δ (ppm) 150.5, 143.4, 139.3, 139.2, 135.5, 135.2, 133.8, 133.3, 131.9, 129.4, 129.3, 128.9, 127.5, 127.3, 125.8, 125.2, 123.3, 121.4, 34.6, 31.3, 21.6, 15.9; HRMS (ESI-TOF) *m/z*: $[M + Na]^+$ Calcd for $C_{28}H_{29}NO_2SNa^+$ 466.1811; Found 466.1808.



4h

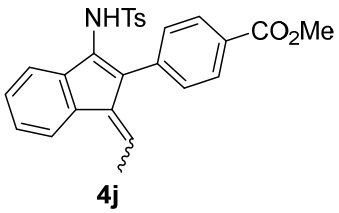
To an oven-dried 10 mL Schlenk tube equipped with a magnetic stir bar were added enyne **1h** (21.9 mg, 0.150 mmol, 1.5 equiv), (2-formylphenyl)boronic acid **2a** (22.5 mg, 0.150 mmol, 1.5 equiv), $TsNH_2$ **3a** (17.1 mg, 0.100 mmol, 1.0 equiv), $Pd_2(dba)_3$ (4.6 mg, 0.0050 mmol, 0.05 equiv) and PCy_3 (5.6 mg, 0.020 mmol, 0.2 equiv). The tube was capped, evacuated and back-filled with argon for three times. Then Et_3N (14 μL, 0.10 mmol, 1.0 equiv) and degassed dry toluene (0.5 mL) were added via syringe

sequentially. The mixture was stirred at 80 °C for 24 h, and monitored by TLC. After completion, the mixture was purified by flash chromatography on silica gel (petroleum ether/EtOAc = 10/1 to 8/1) to give product **4h**: 28.9 mg (0.0710 mmol), as a yellow solid, 71% yield; *E*/*Z* = 8:1, determined by ^{1}H NMR analysis of crude product; mp = 84–86 °C; ***E*-4h**: ^{1}H NMR (400 MHz, $CDCl_3$): δ (ppm) 7.78 (dd, *J* = 12.3, 7.6 Hz, 2H), 7.42–7.34 (m, 3H), 7.32–7.28 (m, 1H), 7.11 (d, *J* = 8.0 Hz, 2H), 6.93–6.84 (m, 2H), 6.65–6.57 (m, 2H), 6.30 (s, 1H), 6.01 (q, *J* = 7.6 Hz, 1H), 2.41 (s, 3H), 2.30 (d, *J* = 7.6 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ (ppm) 162.2 (d, $^{1}J_{FC}$ = 246.3 Hz), 143.7, 139.3 (d, $^{2}J_{FC}$ = 18.5 Hz), 135.8, 134.5, 133.7, 133.4, 132.3, 131.5 (d, $^{3}J_{FC}$ = 8.0 Hz), 129.5, 128.0 (d, $^{4}J_{FC}$ = 3.5 Hz), 127.6, 127.3, 126.1, 123.4, 121.2, 115.2 (d, $^{2}J_{FC}$ = 22.0 Hz), 21.6, 15.9; ^{19}F NMR (375 MHz, $CDCl_3$): δ (ppm) –113.9; HRMS (ESI-TOF) *m/z*: $[M + Na]^+$ Calcd for $C_{24}H_{20}FNO_2SNa^+$ 428.1091; Found 428.1090.



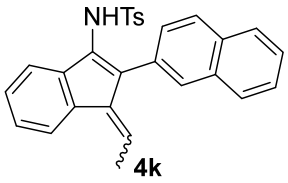
4i

To an oven-dried 10 mL Schlenk tube equipped with a magnetic stir bar were added enyne **1i** (24.3 mg, 0.150 mmol, 1.5 equiv, 1.5 equiv), (2-formylphenyl)boronic acid **2a** (22.5 mg, 0.150 mmol, 1.5 equiv, 1.5 equiv), $TsNH_2$ **3a** (17.1 mg, 0.100 mmol, 1.0 equiv), $Pd_2(dba)_3$ (4.6 mg, 0.0050 mmol, 0.05 equiv) and PCy_3 (5.6 mg, 0.020 mmol, 0.2 equiv). The tube was capped, evacuated and back-filled with argon for three times. Then Et_3N (14 μL, 0.10 mmol, 1.0 equiv) and degassed dry toluene (0.5 mL) were added via syringe sequentially. The mixture was stirred at 80 °C for 24 h, and monitored by TLC. After completion, the mixture was purified by flash chromatography on silica gel (petroleum ether/EtOAc = 10/1 to 8/1) to give product **4i**: 26.6 mg (0.0628 mmol), as a yellow solid, 63% yield; *E*/*Z* = 8:1, determined by ^{1}H NMR analysis of crude product; mp = 68–70 °C; ***E*-4i**: ^{1}H NMR (400 MHz, $CDCl_3$): δ (ppm) 7.81–7.75 (m, 2H), 7.41–7.35 (m, 3H), 7.32–7.29 (m, 1H), 7.18–7.13 (m, 2H), 7.09 (d, *J* = 8.0 Hz, 2H), 6.63–6.58 (m, 2H), 6.43 (s, 1H), 6.05 (q, *J* = 7.6 Hz, 1H), 2.42 (s, 3H), 2.30 (d, *J* = 7.6 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ (ppm) 143.7, 139.4, 139.2, 135.9, 134.7, 133.7, 133.6, 132.2, 131.2, 130.6, 129.4, 128.4, 127.7, 127.3, 126.2, 123.5, 121.1, 21.6, 16.0; HRMS (ESI-TOF) *m/z*: $[M + Na]^+$ Calcd for $C_{24}H_{20}{}^{35}ClNO_2S+Na^+$ 444.0795; Found 444.0792; Calcd for $C_{24}H_{20}{}^{37}ClNO_2SNa^+$ 446.0766; Found 440.0774.



4j

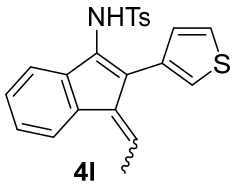
To an oven-dried 10 mL Schlenk tube equipped with a magnetic stir bar were added enyne **1j** (27.9 mg, 0.150 mmol, 1.5 equiv), (2-formylphenyl) boronic acid **2a** (22.5 mg, 0.150 mmol, 1.5 equiv), $TsNH_2$ **3a** (17.1 mg, 0.100 mmol, 1.0 equiv), $Pd_2(dba)_3$ (4.6 mg, 0.0050 mmol, 0.05 equiv) and PCy_3 (5.6 mg, 0.020 mmol, 0.2 equiv). The tube was capped, evacuated and back-filled with argon for three times. Then Et_3N (14 μL, 0.10 mmol, 1.0 equiv) and degassed dry toluene (0.5 mL) were added via syringe sequentially. The mixture was stirred at 80 °C for 24 h, and monitored by TLC. After completion, the mixture was purified by flash chromatography on silica gel (petroleum ether/EtOAc = 7/1 to 4/1) to give product **4j**: 24.4 mg (0.0548 mmol), as a yellow solid, 55% yield; *E*/*Z* = 7:1, determined by ^{1}H NMR analysis of crude product; mp = 151–153 °C; ***E*-4j**: ^{1}H NMR (400 MHz, $CDCl_3$): δ (ppm) 7.87–7.83 (m, 2H), 7.83–7.76 (m, 2H), 7.41–7.30 (m, 4H), 7.08–7.02 (m, 2H), 6.77–6.71 (m, 2H), 6.42 (s, 1H), 6.05 (q, *J* = 7.6 Hz, 1H), 3.96 (s, 3H), 2.39 (s, 3H), 2.30 (d, *J* = 7.6 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ (ppm) 166.7, 143.8, 139.3, 139.0, 137.2, 135.6, 134.7, 133.74, 133.70, 132.5, 129.9, 129.5, 129.3, 129.1, 127.7, 127.2, 126.3, 123.5, 121.3, 52.3, 21.5, 16.0; HRMS (ESI-TOF) *m/z*: $[M + Na]^+$ Calcd for $C_{25}H_{23}NO_2SNa^+$ 468.1240; Found 468.1231.



4k

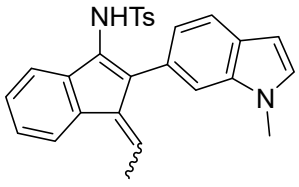
To an oven-dried 10 mL Schlenk tube equipped with a magnetic stir bar were added enyne **1k** (26.7 mg, 0.150 mmol, 1.5 equiv), (2-formylphenyl)boronic acid **2a** (22.5 mg, 0.150 mmol, 1.5 equiv), $TsNH_2$ **3a** (17.1 mg, 0.100 mmol, 1.0 equiv), $Pd_2(dba)_3$ (4.6 mg, 0.0050 mmol, 0.05 equiv) and PCy_3 (5.6 mg, 0.020 mmol, 0.2 equiv). The tube was capped, evacuated and back-filled with argon for three times. Then Et_3N (14 μL, 0.10 mmol, 1.0 equiv) and degassed dry toluene (0.5 mL) were added via syringe sequentially. The mixture was stirred at 80 °C for 24 h, and monitored by TLC. After completion, the mixture was purified by flash chromatography on silica gel (petroleum ether/EtOAc = 10/1 to 8/1) to give product **4k**: 27.2 mg (0.0630 mmol), as a yellow solid, 63% yield; *E*/*Z* = 6:1, determined by ^{1}H NMR analysis of crude product; mp = 89–91 °C; ***E*-4k**: ^{1}H NMR (600 MHz, $CDCl_3$): δ (ppm) 7.91 (d, *J* = 7.6 Hz, 1H), 7.86–7.78 (m, 2H), 7.67 (d, *J* = 8.3 Hz, 1H), 7.64–7.59 (m, 1H), 7.54–7.49 (m, 2H), 7.41–7.34 (m, 1H), 7.33–7.27 (m, 3H), 7.01 (s, 1H), 6.90 (d, *J* = 7.9 Hz, 2H), 6.82 (dd, *J* = 8.2, 1.7 Hz, 1H), 6.46 (s, 1H), 6.10 (q, *J* = 7.6 Hz, 1H), 2.30 (d, *J* = 7.9 Hz, 6H); ^{13}C NMR (150 MHz, $CDCl_3$): δ (ppm) 143.4, 139.41, 139.36, 135.6, 135.3, 133.8, 133.6, 132.9, 132.4, 132.3, 129.6, 129.3, 128.9,

127.8, 127.7, 127.6, 127.4, 127.2, 126.4, 126.3, 126.0, 123.4, 121.3, 21.5, 15.9; HRMS (ESI-TOF) *m/z*: $[M + Na]^+$ Calcd for $C_{28}H_{23}NO_2SNa^+$ 460.1342; Found 460.1348.



4l

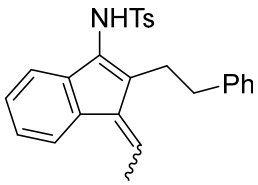
To an oven-dried 10 mL Schlenk tube equipped with a magnetic stir bar were added enyne **1l** (20.1 mg, 0.150 mmol, 1.5 equiv), (2-formylphenyl)boronic acid **2a** (22.5 mg, 0.150 mmol, 1.5 equiv), $TsNH_2$ **3a** (17.1 mg, 0.100 mmol, 1.0 equiv), $Pd_2(dba)_3$ (4.6 mg, 0.0050 mmol, 0.05 equiv) and PCy_3 (5.6 mg, 0.020 mmol, 0.2 equiv). The tube was capped, evacuated and back-filled with argon for three times. Then Et_3N (14 μL, 0.10 mmol, 1.0 equiv) and degassed dry toluene (0.5 mL) were added via syringe sequentially. The mixture was stirred at 80 °C for 24 h, and monitored by TLC. After completion, the reaction mixture was purified by flash chromatography on silica gel (petroleum ether/EtOAc = 10/1 to 6/1) to give product **4l**: 17.9 mg (0.0461 mmol), as a yellow solid, 46% yield; *E*/*Z* = 6:1, determined by ^{1}H NMR analysis of crude product; mp = 61–63 °C; ***E*-4l**: ^{1}H NMR (400 MHz, $CDCl_3$): δ (ppm) 7.80 (d, *J* = 7.0 Hz, 1H), 7.76 (d, *J* = 7.5 Hz, 1H), 7.48–7.42 (m, 2H), 7.35–7.32 (m, 1H), 7.31–7.26 (m, 1H), 7.23 (dd, *J* = 4.9, 2.9 Hz, 1H), 7.13 (d, *J* = 8.0 Hz, 2H), 6.55 (dd, *J* = 3.0, 1.3 Hz, 1H), 6.49 (dd, *J* = 4.9, 1.3 Hz, 1H), 6.37 (s, 1H), 6.17 (q, *J* = 7.6 Hz, 1H), 2.39 (s, 3H), 2.30 (d, *J* = 7.6 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ (ppm) 143.7, 139.3, 139.1, 135.7, 133.9, 133.1, 132.4, 132.1, 130.3, 129.5, 128.9, 127.5, 127.3, 126.0, 125.7, 124.3, 123.4, 121.3, 21.6, 15.9; HRMS (ESI-TOF) *m/z*: $[M + Na]^+$ Calcd for $C_{22}H_{19}NO_2S_2Na^+$ 416.0749; Found 416.0755.



4m

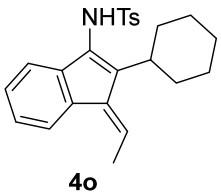
To an oven-dried 10 mL Schlenk tube equipped with a magnetic stir bar were added enyne **1m** (27.2 mg, 0.150 mmol, 1.5 equiv), (2-formylphenyl) boronic acid **2a** (22.5 mg, 0.150 mmol, 1.5 equiv), $TsNH_2$ **3a** (17.1 mg, 0.100 mmol, 1.0 equiv), $Pd_2(dba)_3$ (4.6 mg, 0.0050 mmol, 0.05 equiv) and PCy_3 (5.6 mg, 0.020 mmol, 0.2 equiv). The tube was capped, evacuated and back-filled with argon for three times. Then Et_3N (14 μL, 0.10 mmol, 1.0 equiv) and degassed dry toluene (0.5 mL) were added via syringe sequentially. The mixture was stirred at 80 °C for 24 h, and monitored by TLC. After completion, the mixture was purified by flash chromatography on silica gel (petroleum ether/EtOAc = 10/1 to 8/1) to give product **4m**: 26.3 mg (0.0601 mmol), as a yellow solid, 60% yield; *E*/*Z* = 6:1, determined by ^{1}H NMR analysis of crude product; mp = 90–92 °C; ***E*-4m**: ^{1}H NMR (400 MHz, $CDCl_3$): δ (ppm) 7.97–7.91 (m, 1H), 7.77 (d, *J* = 7.6 Hz, 1H), 7.42–7.37 (m, 1H), 7.35–7.31 (m, 2H), 7.30–

7.26 (m, 1H), 7.17 (d, J = 8.3 Hz, 1H), 7.08 (d, J = 3.1 Hz, 1H), 7.03 (d, J = 8.0 Hz, 2H), 6.58 (d, J = 1.6 Hz, 1H), 6.54–6.43 (m, 1H), 6.38 (s, 1H), 6.32–6.28 (m, 1H), 6.04 (q, J = 7.6 Hz, 1H), 3.81 (s, 3H), 2.39 (s, 3H), 2.27 (d, J = 7.6 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ (ppm) 143.4, 139.9, 139.3, 135.5, 134.0, 133.1, 131.9, 129.6, 129.3, 128.4, 127.5, 125.6, 123.3, 123.2, 122.5, 122.2, 121.3, 109.1, 100.1, 33.0, 21.6, 15.9; HRMS (ESI-TOF) *m/z*: $[M + Na]^+$ Calcd for $C_{27}H_{24}N_2O_2SNa^+$ 463.1451; Found 463.1444.



4n

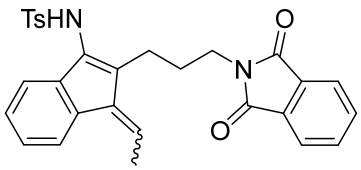
To an oven-dried 10 mL Schlenk tube equipped with a magnetic stir bar were added enyne **1n** (23.4 mg, 0.150 mmol, 1.5 equiv), (2-formylphenyl)boronic acid **2a** (22.5 mg, 0.150 mmol, 1.5 equiv), $TsNH_2$ **3a** (17.1 mg, 0.100 mmol, 1.0 equiv), $Pd_2(dba)_3$ (4.6 mg, 0.0050 mmol, 0.05 equiv) and PCy_3 (5.6 mg, 0.020 mmol, 0.2 equiv). The tube was capped, evacuated and back-filled with argon for three times. Then Et_3N (14 μL, 0.10 mmol, 1.0 equiv) and degassed dry toluene (0.5 mL) were added via syringe sequentially. The mixture was stirred at 80 °C for 24 h, and monitored by TLC. After completion, the mixture was purified by flash chromatography on silica gel (petroleum ether/EtOAc = 10/1 to 8/1) to give product **4n**: 20.7 mg (0.0493 mmol), as a yellow solid, 49% yield; E/Z = 11:1, determined by ^{1}H NMR analysis of crude product; mp = 58–60 °C; ^{1}H NMR (400 MHz, $CDCl_3$): δ (ppm) 7.62–7.59 (m, 1H), 7.58–7.54 (m, 2H), 7.24–7.18 (m, 3H), 7.14 (d, J = 8.0 Hz, 2H), 7.11–7.05 (m, 3H), 6.99–6.94 (m, 2H), 6.37 (q, J = 7.5 Hz, 1H), 5.14 (s, 1H), 2.56 (t, J = 7.3 Hz, 2H), 2.32 (s, 3H), 2.31–2.24 (m, 5H); ^{13}C NMR (100 MHz, $CDCl_3$): δ (ppm) 143.7, 141.5, 140.3, 138.2, 137.2, 136.4, 133.9, 132.0, 130.2, 129.6, 128.7, 128.5, 127.2, 127.1, 126.5, 125.2, 123.4, 119.2, 36.4, 25.8, 21.6, 15.9; HRMS (ESI-TOF) *m/z*: $[M + Na]^+$ Calcd for $C_{26}H_{25}NO_2SNa^+$ 438.1498; Found 438.1502.



4o

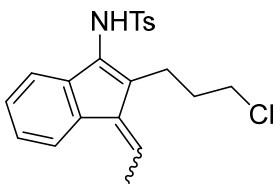
To an oven-dried 10 mL Schlenk tube equipped with a magnetic stir bar were added enyne **1o** (20.1 mg, 0.150 mmol, 1.5 equiv), (2-formylphenyl)boronic acid **2a** (22.5 mg, 0.150 mmol, 1.5 equiv), $TsNH_2$ **3a** (17.1 mg, 0.100 mmol, 1.0 equiv), $Pd_2(dba)_3$ (4.6 mg, 0.0050 mmol, 0.05 equiv) and PCy_3 (5.6 mg, 0.020 mmol, 0.2 equiv). The tube was capped, evacuated and back-filled with argon for three times. Then Et_3N (14 μL, 0.10 mmol, 1.0 equiv) and degassed dry toluene (0.5 mL) were added via syringe sequentially. The mixture was stirred at 80 °C for 24 h, and monitored by TLC. After completion, the mixture was purified by flash chromatography on silica gel (petroleum ether/EtOAc = 10/1 to 8/1) to give product **4o**: 30.7 mg

(0.0780 mmol), as a yellow solid, 78% yield; *E*/*Z* >19:1, determined by ^{1}H NMR analysis of crude product; mp = 106–108 °C; ^{1}H NMR (400 MHz, $CDCl_3$): δ (ppm) 7.69 (d, *J* = 8.2 Hz, 2H), 7.65–7.61 (m, 1H), 7.25–7.19 (m, 3H), 7.16–7.12 (m, 2H), 6.70 (q, *J* = 7.5 Hz, 1H), 6.21–6.12 (m, 1H), 2.45–2.39 (m, 1H), 2.37 (s, 3H), 2.32 (d, *J* = 7.5 Hz, 3H), 1.73–1.63 (m, 3H), 1.62–1.59 (m, 1H), 1.57–1.44 (m, 2H), 1.35–1.27 (m, 2H), 1.14–1.09 (m, 2H); ^{13}C NMR (100 MHz, $CDCl_3$): δ (ppm) 142.7, 140.8, 139.0, 136.9, 136.0, 133.0, 131.1, 129.2, 128.5, 126.5, 125.9, 124.1, 122.5, 118.3, 36.3, 31.8, 26.1, 25.1, 20.5, 15.1; HRMS (ESI-TOF) *m/z*: $[M + Na]^+$ Calcd for $C_{24}H_{27}NO_2SNa^+$ 416.1655; Found 416.1658.



4p

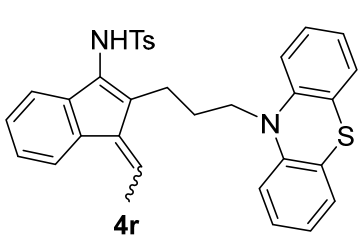
To an oven-dried 10 mL Schlenk tube equipped with a magnetic stir bar were added enyne **1p** (35.9 mg, 0.150 mmol, 1.5 equiv), (2-formyl phenyl)boronic acid **2a** (22.5 mg, 0.150 mmol, 1.5 equiv), $TsNH_2$ **3a** (17.1 mg, 0.100 mmol, 1.0 equiv), $Pd_2(dba)_3$ (4.6 mg, 0.0050 mmol, 0.05 equiv) and PCy_3 (5.6 mg, 0.020 mmol, 0.2 equiv). The tube was capped, evacuated and back-filled with argon for three times. Then Et_3N (14 μL, 0.10 mmol, 1.0 equiv) and degassed dry toluene (0.5 mL) were added via syringe sequentially. The mixture was stirred at 80 °C for 24 h, and monitored by TLC. After completion, the mixture was purified by flash chromatography on silica gel (petroleum ether/EtOAc = 8/1 to 4/1) to give product **4p**: 15.1 mg (0.0328 mmol), as a yellow solid, 33% yield; *E*/*Z* = 8:1, determined by ^{1}H NMR analysis of crude product; mp = 157–159 °C; ^{1}H NMR (400 MHz, $CDCl_3$): δ (ppm) 7.57 (dd, *J* = 8.7, 7.0 Hz, 3H), 7.22 (dd, *J* = 7.6, 1.5 Hz, 2H), 7.17–7.13 (m, 2H), 7.12–7.04 (m, 4H), 7.00–6.93 (m, 3H), 6.82 (dd, *J* = 8.2, 1.2 Hz, 2H), 6.14 (q, *J* = 7.5 Hz, 1H), 6.01 (s, 1H), 3.77 (t, *J* = 6.0 Hz, 2H), 2.31 (s, 3H), 2.28 (dd, *J* = 8.7, 6.7 Hz, 2H), 2.12 (d, *J* = 7.5 Hz, 3H), 1.91–1.81 (m, 2H); ^{13}C NMR (100 MHz, $CDCl_3$): δ (ppm) 168.8, 143.4, 140.5, 138.2, 137.1, 136.1, 134.1, 133.9, 132.5, 131.9, 130.5, 129.42, 129.39, 127.2, 127.1, 125.3, 123.3, 123.2, 119.3, 37.4, 28.6, 21.5, 20.7, 15.8; HRMS (ESI-TOF) *m/z*: $[M + Na]^+$ Calcd for $C_{23}H_{22}N_2O_4SNa^+$ 521.1505; Found 521.1513.



4q

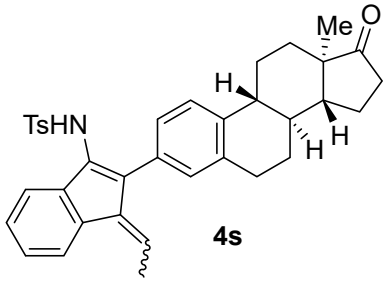
To an oven-dried 10 mL Schlenk tube equipped with a magnetic stir bar were added enyne **1q** (19.2 mg, 0.150 mmol, 1.5 equiv), (2-formylphenyl)boronic acid **2a** (22.5 mg, 0.150 mmol, 1.5 equiv), $TsNH_2$ **3a** (17.1 mg, 0.100 mmol, 1.0 equiv), $Pd_2(dba)_3$ (4.6 mg, 0.0050 mmol, 0.05 equiv) and PCy_3 (5.6 mg,

0.020 mmol, 0.2 equiv). The tube was capped, evacuated and back-filled with argon for three times. Then Et_3N (14 μL, 0.10 mmol, 1.0 equiv) and degassed dry toluene (0.5 mL) were added via syringe sequentially. The mixture was stirred at 80 °C for 24 h, and monitored by TLC. After completion, the mixture was purified by flash chromatography on silica gel (petroleum ether/EtOAc = 10/1 to 8/1) to give product **4q**: 15.9 mg (0.0413 mmol), as a yellow solid, 41% yield; *E*/*Z* = 12:1, determined by ^{1}H NMR analysis of crude product; mp = 79–80 °C; ^{1}H NMR (400 MHz, $CDCl_3$): δ (ppm) 7.71–7.62 (m, 3H), 7.21 (d, *J* = 8.1 Hz, 2H), 7.18 – 7.11 (m, 3H), 6.41 (q, *J* = 7.5 Hz, 1H), 6.30 (s, 1H), 3.44 (t, *J* = 6.2 Hz, 2H), 2.39 (s, 3H), 2.38–2.28 (m, 5H), 1.84–1.76 (m, 2H); ^{13}C NMR (100 MHz, $CDCl_3$): δ (ppm) 143.8, 140.0, 138.2, 136.8, 135.9, 133.9, 132.2, 130.7, 129.62, 129.60, 127.3, 127.2, 125.4, 123.4, 119.0, 44.8, 32.6, 21.6, 20.5, 15.9; HRMS (ESI-TOF) *m/z*: $[M + Na]^+$ Calcd for $C_{21}H_{22}{}^{35}ClNO_2SNa^+$ 410.0952; Found 410.0957; Calcd for $C_{21}H_{22}{}^{37}ClNO_2SNa^+$ 412.0922; Found 412.0930.



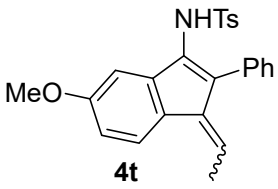
4r

To an oven-dried 10 mL Schlenk tube equipped with a magnetic stir bar were added enyne **1r** (43.6 mg, 0.150 mmol, 1.5 equiv), (2-formyl phenyl)boronic acid **2a** (22.5 mg, 0.150 mmol, 1.5 equiv), $TsNH_2$ **3a** (17.1 mg, 0.100 mmol, 1.0 equiv), $Pd_2(dba)_3$ (4.6 mg, 0.0050 mmol, 0.05 equiv) and PCy_3 (5.6 mg, 0.020 mmol, 0.2 equiv). The tube was capped, evacuated and back-filled with argon for three times. Then Et_3N (14 μL, 0.10 mmol, 1.0 equiv) and degassed dry toluene (0.5 mL) were added via syringe sequentially. The mixture was stirred at 80 °C for 24 h, and monitored by TLC. After completion, the mixture was purified by flash chromatography on silica gel (petroleum ether/EtOAc = 10/1 to 8/1) to give product **4r**: 27.4 mg (0.0510 mmol), as a yellow solid, 51% yield; *E*/*Z* = 12:1, determined by ^{1}H NMR analysis of crude product; mp = 99–100 °C; ^{1}H NMR (400 MHz, $CDCl_3$): δ (ppm) 7.57 (d, *J* = 7.7 Hz, 3H), 7.22 (d, *J* = 7.6 Hz, 2H), 7.16–7.13 (m, 2H), 7.12–7.04 (m, 4H), 7.00–6.93 (m, 3H), 6.82 (dd, *J* = 8.2, 1.2 Hz, 2H), 6.14 (q, *J* = 7.5 Hz, 1H), 6.01 (s, 1H), 3.77 (t, *J* = 6.0 Hz, 2H), 2.31 (s, 3H), 2.28 (dd, *J* = 8.7, 6.7 Hz, 2H), 2.12 (d, *J* = 7.5 Hz, 3H), 1.91–1.81 (m, 2H); ^{13}C NMR (100 MHz, $CDCl_3$): δ (ppm) 145.2, 143.6, 140.1, 138.0, 137.3, 136.8, 133.8, 131.4, 131.2, 129.4, 127.8, 127.7, 127.3, 126.9, 125.8, 125.1, 123.3, 122.8, 118.7, 115.9, 45.9, 27.2, 21.5, 20.2, 15.7; HRMS (ESI-TOF) *m/z*: $[M + Na]^+$ Calcd for $C_{33}H_{30}NO_2S_2Na^+$ 573.1641; Found 573.1643.



4s

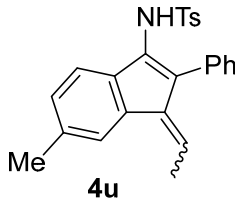
To an oven-dried 10 mL Schlenk tube equipped with a magnetic stir bar were added enyne **1s** (45.6 mg, 0.150 mmol, 1.5 equiv), (2-formyl phenyl) boronic acid **2a** (22.5 mg, 0.150 mmol, 1.5 equiv), $TsNH_2$ **3a** (17.1 mg, 0.100 mmol, 1.0 equiv), $Pd_2(dba)_3$ (4.6 mg, 0.0050 mmol, 0.05 equiv) and PCy_3 (5.6 mg, 0.020 mmol, 0.2 equiv). The tube was capped, evacuated and back-filled with argon for three times. Then Et_3N (14 μL, 0.10 mmol, 1.0 equiv) and degassed dry toluene (0.5 mL) were added via syringe sequentially. The mixture was stirred at 80 °C for 24 h, and monitored by TLC. After completion, the mixture was purified by flash chromatography on silica gel (petroleum ether/EtOAc = 10/1 to 8/1) to give product **4s**: 34.3 mg (0.0611 mmol), as a yellow solid, 61% yield; *E*/*Z* = 9:1, determined by ^{1}H NMR analysis of crude product; mp = 151–153 °C; ***E*-4s**: ^{1}H NMR (400 MHz, $CDCl_3$): δ (ppm) 7.92–7.88 (m, 1H), 7.76 (d, *J* = 7.5 Hz, 1H), 7.44–7.39 (m, 2H), 7.37–7.34 (m, 1H), 7.32–7.28 (m, 1H), 7.17–7.09 (m, 3H), 6.42 (dd, *J* = 8.0, 1.9 Hz, 1H), 6.34–6.25 (m, 2H), 6.05 (q, *J* = 7.6 Hz, 1H), 2.81–2.68 (m, 2H), 2.54 (dd, *J* = 18.7, 8.6 Hz, 1H), 2.41 (s, 4H), 2.29 (d, *J* = 7.6 Hz, 4H), 2.23–1.96 (m, 5H), 1.70–1.59 (m, 2H),1.54–1.41 (m, 4H), 0.96 (s, 3H); ^{13}C (100 MHz, $CDCl_3$): δ (ppm) 143.4, 139.4, 139.3, 139.0, 136.5, 135.6, 134.8, 134.0, 133.0, 132.0, 130.1, 129.4, 127.52, 127.50, 127.4, 125.8, 125.3, 123.3, 121.4, 50.5, 48.0, 44.4, 38.1, 35.9, 31.6, 29.3, 26.5, 25.7, 21.7, 21.6, 15.9, 13.9; HRMS (ESI-TOF) *m/z*: $[M + Na]^+$ Calcd for $C_{36}H_{37}NO_3SNa^+$ 586.2368; Found 586.2373.



4t

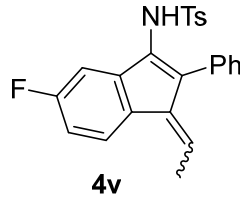
To an oven-dried 10 mL Schlenk tube equipped with a magnetic stir bar were added enyne **1a** (19.2 mg, 0.150 mmol, 1.5 equiv), (2-formyl-4-methoxy phenyl)boronic acid **2b** (27.0 mg, 0.150 mmol, 1.5 equiv), $TsNH_2$ **3a** (17.1 mg, 0.100 mmol, 1.0 equiv), $Pd_2(dba)_3$ (4.6 mg, 0.0050 mmol, 0.05 equiv) and PCy_3 (5.6 mg, 0.020 mmol, 0.2 equiv). The tube was capped, evacuated and back-filled with argon for three times. Then Et_3N (14 μL, 0.10 mmol, 1.0 equiv) and degassed dry toluene (0.5 mL) were added via syringe sequentially. The mixture was stirred at 80 °C for 24 h, and monitored by TLC. After completion, the mixture was purified by flash chromatography on silica gel (petroleum ether/EtOAc = 10/1 to 8/1) to give product **4t**: 29.6 mg (0.0712 mmol), as a yellow solid, 71% yield; *E*/*Z* = 8:1, determined by ^{1}H NMR analysis of crude product; mp = 156–158 °C; ***E*-4t**: ^{1}H NMR (400 MHz, $CDCl_3$): δ (ppm) 7.65 (d, *J* = 8.4 Hz, 1H), 7.44 (d, *J* = 2.5 Hz, 1H), 7.39–7.34 (m, 2H), 7.26–7.22 (m,

1H), 7.20–7.15 (m, 2H), 7.11–7.06 (m, 2H), 6.83 (dd, *J* = 8.4, 2.5 Hz, 1H), 6.63–6.56 (m, 2H), 6.36 (s, 1H), 5.92 (q, *J* = 7.6 Hz, 1H), 3.89 (s, 3H), 2.39 (s, 3H), 2.24 (d, *J* = 7.6 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ (ppm) 159.6, 143.6, 141.0, 138.8, 136.5, 135.5, 132.1, 131.64, 131.55, 129.7, 129.5, 128.2, 127.6, 127.4, 126.6, 124.2, 112.4, 106.3, 55.6, 21.6, 15.7; HRMS (ESI-TOF) *m/z*: $[M + Na]^+$ Calcd for $C_{25}H_{23}NO_3S+Na^+$ 440.1291; Found 440.1296.



4u

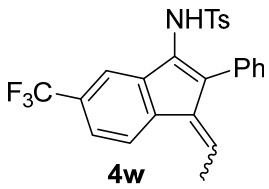
To an oven-dried 10 mL Schlenk tube equipped with a magnetic stir bar were added enyne **1a** (19.2 mg, 0.150 mmol, 1.5 equiv), (2-formyl-5-methylphenyl) boronic acid **2c** (24.6 mg, 0.150 mmol, 1.5 equiv), $TsNH_2$ **3a** (17.1 mg, 0.100 mmol, 1.0 equiv), $Pd_2(dba)_3$ (4.6 mg, 0.0050 mmol, 0.05 equiv) and PCy_3 (5.6 mg, 0.020 mmol, 0.2 equiv). The tube was capped, evacuated and back-filled with argon for three times. Then Et_3N (14 μL, 0.10 mmol, 1.0 equiv) and degassed dry toluene (0.5 mL) were added via syringe sequentially. The mixture was stirred at 80 °C for 24 h, and monitored by TLC. After completion, the reaction mixture was purified by flash chromatography on silica gel (petroleum ether/EtOAc = 10/1 to 8/1) to give product **4u**: 23.5 mg (0.0582 mmol), as a yellow solid, 58% yield; *E*/*Z* = 9:1, determined by ^{1}H NMR analysis of crude product; mp = 121–123 °C; ***E*-4u**: ^{1}H NMR (400 MHz, $CDCl_3$): δ (ppm) 7.75 (d, *J* = 7.8 Hz, 1H), 7.57 (s, 1H), 7.37–7.32 (m, 2H), 7.24–7.21 (m, 1H), 7.20–7.14 (m, 3H), 7.07 (d, *J* = 8.1 Hz, 2H), 6.56 (dt, *J* = 6.9, 1.4 Hz, 2H), 6.30 (s, 1H), 5.98 (q, *J* = 7.6 Hz, 1H), 2.45 (s, 3H), 2.38 (s, 3H), 2.27 (d, *J* = 7.6 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ (ppm) 143.5, 139.3, 136.6, 135.7, 135.5, 134.2, 132.7, 132.2, 132.1, 129.8, 129.4, 128.2, 127.5, 127.4, 124.4, 121.2, 21.9, 21.6, 15.9; HRMS (ESI-TOF) *m/z*: $[M + Na]^+$ Calcd for $C_{25}H_{23}NO_2SNa^+$ 424.1342; Found 424.1337.



4v

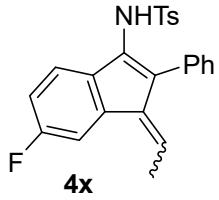
To an oven-dried 10 mL Schlenk tube equipped with a magnetic stir bar were added enyne **1a** (19.2 mg, 0.150 mmol, 1.5 equiv), (4-fluoro-2-formylphenyl) boronic acid **2d** (25.2 mg, 0.150 mmol, 1.5 equiv), $TsNH_2$ **3a** (17.1 mg, 0.100 mmol, 1.0 equiv), $Pd_2(dba)_3$ (4.6 mg, 0.0050 mmol, 0.05 equiv) and PCy_3 (5.6 mg, 0.020 mmol, 0.2 equiv). The tube was capped, evacuated and back-filled with argon for three times. Then Et_3N (14 μL, 0.10 mmol, 1.0 equiv) and degassed dry toluene (0.5 mL) were added via syringe sequentially. The mixture was stirred at 80 °C for 24 h, and monitored by TLC. After completion, the mixture was purified by flash chromatography on silica gel (petroleum ether/EtOAc = 10/1 to 8/1) to give product **4v**: 32.7 mg (0.0822 mmol), as a yellow solid, 82% yield; *E*/*Z* = 7:1,

determined by ^{1}H NMR analysis of crude product; mp = 113–115 °C; ***E*-4v**: ^{1}H NMR (400 MHz, $CDCl_3$): δ (ppm) 7.67 (d, *J* = 8.4 Hz, 1H), 7.55–7.49 (m, 1H), 7.36–7.32 (m, 2H), 7.28–7.23 (m, 1H), 7.18 (dd, *J* = 8.2, 6.6 Hz, 2H), 7.07 (d, *J* = 8.0 Hz, 2H), 6.95 (td, *J* = 8.7, 2.5 Hz, 1H), 6.60–6.53 (m, 2H), 6.33 (s, 1H), 6.00 (q, *J* = 7.6 Hz, 1H), 2.38 (s, 3H), 2.24 (d, *J* = 7.6 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$): δ (ppm) 162.6 (d, $^1J_{FC}$ = 244.7 Hz), 143.7, 141.5 (d, $^3J_{FC}$ = 9.5 Hz), 138.3, 137.1, 135.4, 133.40, 133.38, 131.6, 131.28, 131.25, 129.68, 129.65, 129.63, 129.5, 128.3, 127.8, 127.4, 124.3 (d, $^3J_{FC}$ = 9.0 Hz), 112.4 (d, $^2J_{FC}$ = 22.9 Hz), 109.0 (d, $^2J_{FC}$ = 24.9 Hz), 21.6, 15.8; ^{19}F NMR (375 MHz, $CDCl_3$): δ (ppm) –113.4; HRMS (ESI-TOF) *m/z*: $[M + Na]^+$ Calcd for $C_{24}H_{20}FNO_2SNa^+$ 428.1091; Found 428.1090.



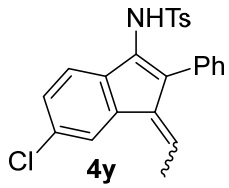
4w

To an oven-dried 10 mL Schlenk tube equipped with a magnetic stir bar were added enyne **1a** (19.2 mg, 0.150 mmol, 1.5 equiv), (2-formyl-4-(trifluoro methyl)phenyl) boronic acid **2e** (32.7 mg, 0.150 mmol, 1.5 equiv), $TsNH_2$ **3a** (17.1 mg, 0.100 mmol, 1.0 equiv), $Pd_2(dba)_3$ (4.6 mg, 0.0050 mmol, 0.05 equiv) and PCy_3 (5.6 mg, 0.020 mmol, 0.2 equiv). The tube was capped, evacuated and back-filled with argon for three times. Then Et_3N (14 μL, 0.10 mmol, 1.0 equiv) and degassed dry toluene (0.5 mL) were added via syringe sequentially. The mixture was stirred at 80 °C for 24 h, and monitored by TLC. After completion, the mixture was purified by flash chromatography on silica gel (petroleum ether/EtOAc = 10/1 to 8/1) to give product **4w**: 37.8 mg (0.0831 mmol), as a yellow solid, 83% yield; *E*/*Z* = 4:1, determined by ^{1}H- NMR analysis of crude product; mp = 163–165 °C; ***E*-4w**: ^{1}H NMR (400 MHz, $CDCl_3$): δ (ppm) 7.96–7.92 (m, 1H), 7.85 (d, *J* = 8.0 Hz, 1H), 7.56–7.50 (m, 1H), 7.42–7.36 (m, 2H), 7.33–7.27 (m, 1H), 7.26–7.20 (m, 2H), 7.11 (d, *J* = 8.0 Hz, 2H), 6.71–6.66 (m, 2H), 6.39 (s, 1H), 6.21 (q, *J* = 7.6 Hz, 1H), 2.41 (s, 3H), 2.33 (d, *J* = 7.7 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ (ppm) 143.9, 139.7, 138.5, 137.2, 136.5 (q, $^2J_{FC}$ = 29.6 Hz), 135.6, 131.44, 131.37, 129.8, 129.6, 129.3, 128.4, 128.0, 127.4, 124.4 (q, $^1J_{FC}$ = 270.5 Hz), 123.3, 122.8 (q, $^3J_{FC}$ = 3.9 Hz), 118.1 (q, $^3J_{FC}$ = 3.9 Hz), 21.6, 16.1; ^{19}F NMR (375 MHz, $CDCl_3$): δ (ppm) –62.0; HRMS (ESI-TOF) *m/z*: $[M + Na]^+$ Calcd for $C_{25}H_{20}F_3NO_2SNa^+$ 478.1059; Found 478.1056.



4x

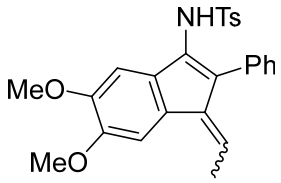
To an oven-dried 10 mL Schlenk tube equipped with a magnetic stir bar were added enyne **1a** (19.2 mg, 0.150 mmol, 1.5 equiv), (5-fluoro-2-formylphenyl)boronic acid **2f** (25.2 mg, 0.150 mmol, 1.5 equiv), $TsNH_2$ **3a** (17.1 mg, 0.100 mmol, 1.0 equiv), $Pd_2(dba)_3$ (4.6 mg, 0.0050 mmol, 0.05 equiv) and PCy_3 (5.6 mg, 0.020 mmol, 0.2 equiv). The tube was capped, evacuated and back-filled with argon for three times. Then Et_3N (14 μL, 0.10 mmol, 1.0 equiv) and degassed dry toluene (0.5 mL) were added via syringe sequentially. The mixture was stirred at 80 °C for 24 h, and monitored by TLC. After completion, the mixture was purified by flash chromatography on silica gel (petroleum ether/EtOAc = 10/1 to 8/1) to give product **4x**: 28.8 mg (0.0722 mmol), as a yellow solid, 72% yield; *E*/*Z* = 6:1, determined by ^{1}H NMR analysis of crude product; mp = 127–129 °C; ***E*-4x**: ^{1}H NMR (400 MHz, $CDCl_3$): δ (ppm) 7.83 (d, *J* = 7.5 Hz, 1H), 7.46 (d, *J* = 7.5 Hz, 1H), 7.38–7.32 (m, 2H), 7.29–7.25 (m, 1H), 7.22–7.16 (m, 2H), 7.12–7.04 (m, 3H), 6.62–6.54 (m, 2H), 6.35 (s, 1H), 6.07 (q, *J* = 7.6 Hz, 1H), 2.40 (s, 3H), 2.26 (d, *J* = 7.7 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ (ppm) 161.8 (d, $^1J_{FC}$ = 241.4 Hz), 143.7, 138.68, 138.65, 135.44, 135.36, 135.3, 135.09, 135.06, 134.8 (d, $^4J_{FC}$ = 3.9 Hz), 134.2, 131.8, 131.6, 129.7, 129.5, 128.3, 127.7, 127.3, 122.4 (d, $^3J_{FC}$ = 8.7 Hz), 114.0 (d, $^2J_{FC}$ = 22.6 Hz), 111.1 (d, $^2J_{FC}$ = 24.7 Hz), 21.6, 15.8; ^{19}F NMR (375 MHz, $CDCl_3$): δ (ppm) –116.3; HRMS (ESI-TOF) *m/z*: $[M + Na]^+$ Calcd for $C_{24}H_{20}FNO_2SNa^+$ 428.1091; Found 428.1100.



4y

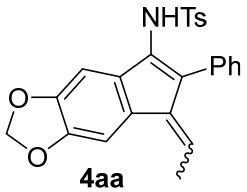
To an oven-dried 10 mL Schlenk tube equipped with a magnetic stir bar were added enyne **1a** (19.2 mg, 0.150 mmol, 1.5 equiv), (5-chloro-2-formylphenyl)boronic acid **2g** (27.6 mg, 0.150 mmol, 1.5 equiv), $TsNH_2$ **3a** (17.1 mg, 0.100 mmol, 1.0 equiv), $Pd_2(dba)_3$ (4.6 mg, 0.0050 mmol, 0.05 equiv) and PCy_3 (5.6 mg, 0.020 mmol, 0.2 equiv). The tube was capped, evacuated and back-filled with argon for three times. Then Et_3N (14 μL, 0.10 mmol, 1.0 equiv) and degassed dry toluene (0.5 mL) were added via syringe sequentially. The mixture was stirred at 80 °C for 24 h, and monitored by TLC. After completion, the mixture was purified by flash chromatography on silica gel (petroleum ether/EtOAc = 10/1 to 8/1) to give product **4y**: 33.5 mg (0.0802 mmol), as a yellow solid, 80% yield; *E*/*Z* = 7:1, determined by ^{1}H NMR analysis of crude product; mp = 164–166 °C; ***E*-4y**: ^{1}H NMR (400 MHz, $CDCl_3$): δ (ppm) 7.80 (d, *J* = 8.2 Hz, 1H), 7.75–7.68 (m, 1H), 7.36–7.31 (m, 3H), 7.29–7.25 (m, 1H), 7.19 (t, *J* = 7.4 Hz, 2H), 7.08 (d, *J* = 8.0 Hz, 2H), 6.61–6.53 (m, 2H), 6.33 (s, 1H), 6.08 (q, *J* = 7.6 Hz, 1H), 2.39 (s, 3H),

2.27 (d, J = 7.6 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ (ppm) 143.7, 138.5, 137.5, 135.4, 135.3, 135.2, 134.7, 131.8, 131.60, 131.57, 129.7, 129.5, 128.4, 127.8, 127.4, 127.3, 123.7, 122.4, 21.6, 15.9; HRMS (ESI-TOF) *m/z*: $[M + Na]^+$ Calcd for $C_{24}H_{20}{}^{35}ClNO_2SNa^+$444.0795; Found 444.0789; Calcd for $C_{24}H_{20}{}^{37}ClNO_2SNa^+$446.0766; Found 446.0770.



4z

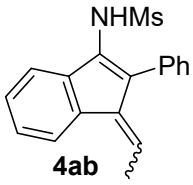
To an oven-dried 10 mL Schlenk tube equipped with a magnetic stir bar were added enyne **1a** (19.2 mg, 0.150 mmol, 1.5 equiv), (2-formyl-4,5-dimethoxy phenyl) boronic acid **2h** (31.5 mg, 0.150 mmol, 1.5 equiv), $TsNH_2$ **3a** (17.1 mg, 0.100 mmol, 1.0 equiv), $Pd_2(dba)_3$ (4.6 mg, 0.0050 mmol, 0.05 equiv) and PCy_3 (5.6 mg, 0.020 mmol, 0.2 equiv). The tube was capped, evacuated and back-filled with argon for three times. Then Et_3N (14 μL, 0.10 mmol, 1.0 equiv) and degassed dry toluene (0.5 mL) were added via syringe sequentially. The mixture was stirred at 80 °C for 24 h, and monitored by TLC. After completion, the reaction mixture was purified by flash chromatography on silica gel (petroleum ether/EtOAc = 7/1 to 3/1) to give product **4z**: 27.8 mg (0.0622 mmol), as a yellow solid, 62% yield; E/Z = 16:1, determined by ^{1}H NMR analysis of crude product; mp = 159–161 °C; ***E*-4z**: ^{1}H NMR (400 MHz, $CDCl_3$): δ (ppm) 7.49 (s, 1H), 7.40–7.35 (m, 2H), 7.32 (s, 1H), 7.25–7.22 (m, 1H), 7.21–7.15 (m, 2H), 7.12–7.08 (m, 2H), 6.60–6.54 (m, 2H), 6.36 (s, 1H), 5.96 (q, J = 7.6 Hz, 1H), 3.98 (s, 3H), 3.96 (s, 3H), 2.40 (s, 3H), 2.26 (d, J = 7.6 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ (ppm) 149.0, 147.6, 143.6, 139.2, 135.4, 133.7, 132.9, 132.2, 131.7, 131.6, 129.8, 129.5, 128.2, 127.4, 127.3, 126.4, 108.2, 105.1, 56.6, 56.1, 21.6, 15.7; HRMS (ESI-TOF) *m/z*: $[M + Na]^+$ Calcd for $C_{26}H_{25}NO_4SNa^+$ 470.1397; Found 470.1405.



4aa

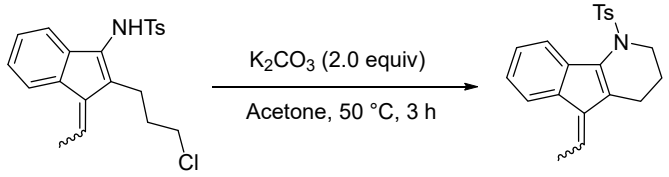
To an oven-dried 10 mL Schlenk tube equipped with a magnetic stir bar were added enyne **1a** (19.2 mg, 0.150 mmol, 1.5 equiv), (6-formylbenzo[*d*][1,3]dioxol-5-yl)boronic acid **2i** (29.1 mg, 0.150 mmol, 1.5 equiv), $TsNH_2$ **3a** $TsNH_2$ (17.1 mg, 0.100 mmol, 1.0 equiv), $Pd_2(dba)_3$ (4.6 mg, 0.0050 mmol, 0.05 equiv) and PCy_3 (5.6 mg, 0.020 mmol, 0.2 equiv). The tube was capped, evacuated and back-filled with argon for three times. Then Et_3N (14 μL, 0.10 mmol, 1.0 equiv) and degassed dry toluene (0.5 mL) were added via syringe sequentially. The mixture was stirred at 80 °C for 24 h, and monitored by TLC. After completion, the mixture was purified by flash chromatography on silica gel (petroleum ether/EtOAc = 6/1 to 3/1) to give product **4aa**: 23.1 mg (0.0512 mmol), as a yellow solid, 51% yield; E/Z = 17:1,

determined by ^{1}H NMR analysis of crude product; 158–160 °C; ***E*-4aa**: ^{1}H NMR (400 MHz, $CDCl_3$): δ (ppm) 7.41 (s, 1H), 7.37–7.32 (m, 2H), 7.27 (s, 1H), 7.24–7.21 (m, 1H), 7.19–7.15 (m 2H), 7.10–7.05 (m, 2H), 6.57–6.53 (m, 2H), 6.33 (s, 1H), 6.02 (s, 2H), 5.96 (q, *J* = 7.6 Hz, 1H), 2.40 (s, 3H), 2.22 (d, *J* = 7.6 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ (ppm) 147.2, 146.4, 143.6, 138.9, 135.3, 134.3, 134.0, 132.6, 132.1, 131.5, 129.8, 129.4, 128.2, 127.6, 127.4, 127.3, 104.9, 103.0, 101.3, 21.6, 15.6; HRMS (ESI-TOF) *m/z*: $[M + Na]^+$ Calcd for $C_{25}H_{21}NO_4SNa^+$ 454.1083; Found 454.1091.



4ab

To an oven-dried 10 mL Schlenk tube equipped with a magnetic stir bar were added enyne **1a** (19.2 mg, 0.150 mmol, 1.5 equiv), 2-formyl arylboronic acid **2a** (22.5 mg, 0.150 mmol, 1.5 equiv), amine **3b** (9.5 mg, 0.10 mmol), $Pd_2(dba)_3$ (4.6 mg, 0.0050 mmol, 0.05 equiv) and PCy_3 (5.6 mg, 0.020 mmol, 0.2 equiv). The tube was capped, evacuated and back-filled with argon for three times. Then Et_3N (14 μL, 0.10 mmol, 1.0 equiv) and degassed dry toluene (0.5 mL) were added via syringe sequentially. The mixture was stirred at 80 °C for 24 h, and monitored by TLC. After completion, the mixture was purified by flash chromatography on silica gel (petroleum ether/EtOAc = 10/1 to 8/1) to give product **4ab**: 14.9 mg (0.0482 mmol), as a yellow solid, 48% yield; *E*/*Z* = 9:1, determined by ^{1}H NMR analysis of crude product; mp = 59–61 °C; ***E*-4ab**: ^{1}H NMR (400 MHz, $CDCl_3$): δ (ppm) 7.80 (d, *J* = 7.6 Hz, 1H), 7.67 (d, *J* = 7.6 Hz, 1H), 7.50–7.45 (m, 2H), 7.44–7.34 (m, 2H), 7.33–7.28 (m, 3H), 6.36–6.26 (m, 2H), 2.57 (s, 3H), 2.36 (d, *J* = 7.6 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ (ppm) 139.5, 139.3, 136.3, 134.3, 133.7, 132.8, 131.9, 130.3, 128.9, 128.2, 127.7, 126.2, 123.7, 120.2, 40.4, 16.0; HRMS (ESI-TOF) *m/z*: $[M + Na]^+$ Calcd for $C_{18}H_{17}NO_2SNa^+$ 334.0872; Found 334.0872.



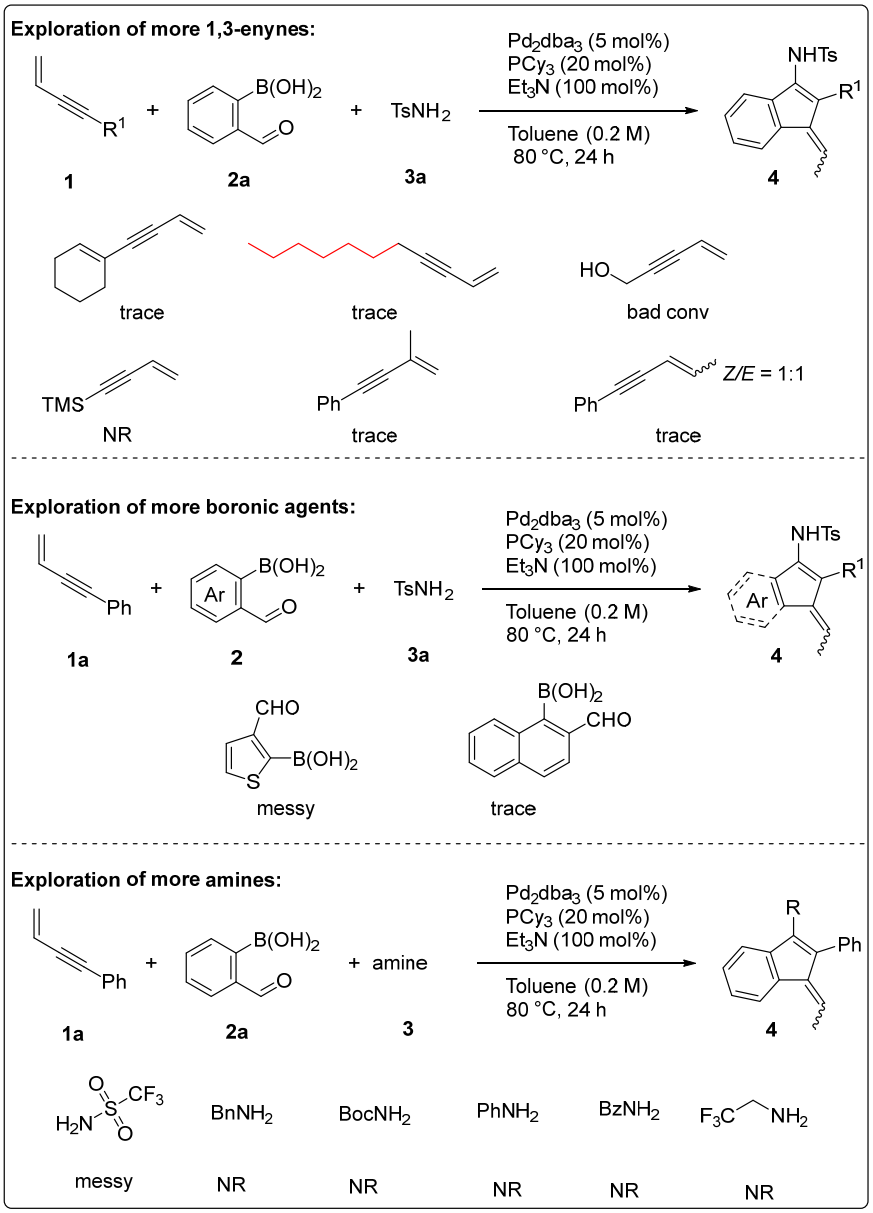
4q 12:1 *E/Z* **5** 85%, 11:1 *E/Z*

To a solution of **4q** (38.7 mg, 0.0999 mmol, 1.0 equiv) in acetone (2.0 mL) was added K_2CO_3 (27.6 mg, 0.200 mmol, 2.0 equiv). The mixture was stirred at 50 °C for 3 h, and monitored by TLC. After completion, the mixture was concentrated and purified by flash chromatography on silica gel (petroleum ether / EtOAc = 15/1) to give the product **5**: 29.8 mg (0.0851 mmol), as a yellow solid, 85% yield**;** *E*/*Z* = 11:1, determined by ^{1}H NMR analysis of crude product; 58–60 °C; ^{1}H NMR (400 MHz,

$CDCl_3$): δ (ppm) 7.91 (d, J = 7.7 Hz, 1H), 7.69 (d, J = 7.5 Hz, 1H), 7.65–7.59 (m, 2H), 7.32–7.27 (m, 1H), 7.25–7.14 (m, 3H), 6.18 (q, J = 7.6 Hz, 1H), 3.67–3.59 (m, 2H), 2.40 (s, 3H), 2.31 (d, J = 7.6 Hz, 2H), 2.29–2.25 (m, 2H), 1.34–1.27 (m, 2H); ^{13}C NMR (101 MHz, $CDCl_3$): δ (ppm) 143.7, 139.9, 138.7, 136.5, 136.0, 134.6, 129.71, 129.66, 129.1, 127.8, 127.1, 126.7, 125.1, 122.9, 122.0, 47.6, 21.6, 19.4, 18.8, 15.6; HRMS (ESI-TOF) *m/z*: $[M + H]^+$ Calcd for $C_{21}H_{22}NO_2S^+$ 352.1366; Found 352.1365.

4. Unsuccessful substrates investigation

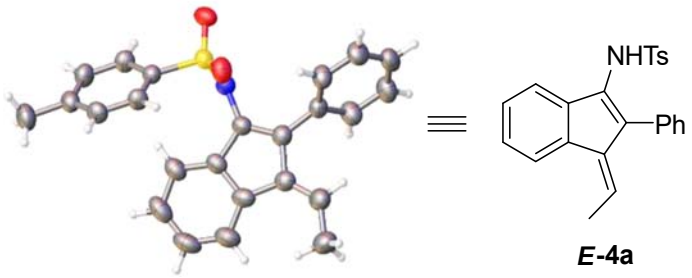
To further expand the substrate scope, several 1,3-enyne substrates, 2-formyl arylboronic acids and amines were investigated under the optimal conditions. Unfortunately, these substrates generally showed low reactivity, and no apparent transformations were observed.



In addition, no obvious conversions were observed by adding catalytic amounts of acids, such as BzOH, into the reaction mixture involving the aforementioned basic amines. Furthermore, no desired imine intermediates were formed by pre-mixing these amines with 2-formylphenylboronic acid **2a**, even under the catalysis of pyrrolidine. Most of the starting materials remained unconsumed.

5. Crystal data and structural refinement

Procedure for the recrystallization of *E*-4a: To a 10 mL tube containing **4a** (70 mg) were added petroleum ether (2.5 mL) and EtOAc (1.0 mL). The mixture was heated until a clear solution was formed, which was kept aside at room temperature to obtain crystals. The crystals were subjected for single crystal XRD to determine the configuration of ***E*-4a**. The data were collected by Bruker D8 venture CCD equipped with a Mo radiation source (Kα = 0.71073 Å) at 273.15 K. CCDC 2380456 (**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.



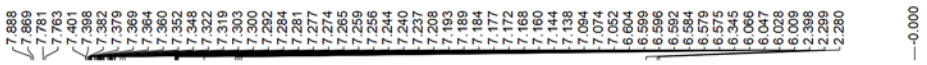
***E*-4a**

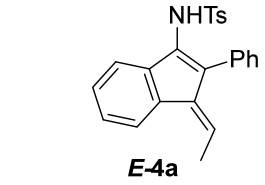
(ellipsoid contour probability 50%)

Identification code	***E*-4a**
Empirical formula	$C_{24}H_{21}NO_2S$
Formula weight	387.48
Temperature/K	270.0
Crystal system	triclinic
Space group	P-1
a/Å	8.0757(12)
b/Å	10.1099(15)
c/Å	12.7198(16)
α/°	98.635(5)
β/°	100.210(4)
γ/°	99.599(5)
Volume/Å^3	990.3(2)
Z	2

ρ_{calc}g/cm^3	1.299
μ/mm^{-1}	0.183
F(000)	408.0
Crystal size/mm^3	0.51 × 0.25 × 0.24
Radiation	MoKα (λ = 0.71073)
2Θ range for data collection/°	4.158 to 55.17
Index ranges	$-10 \leq h \leq 10$, $-13 \leq k \leq 13$, $-16 \leq l \leq 16$
Reflections collected	41463
Independent reflections	4572 [R_{int} = 0.0736, R_{sigma} = 0.0395]
Data/restraints/parameters	4572/0/255
Goodness-of-fit on F^2	1.039
Final R indexes [I>=2σ (I)]	R_1 = 0.0535, wR_2 = 0.1472
Final R indexes [all data]	R_1 = 0.0698, wR_2 = 0.1585
Largest diff. peak/hole / e Å^{-3}	0.59/-0.30

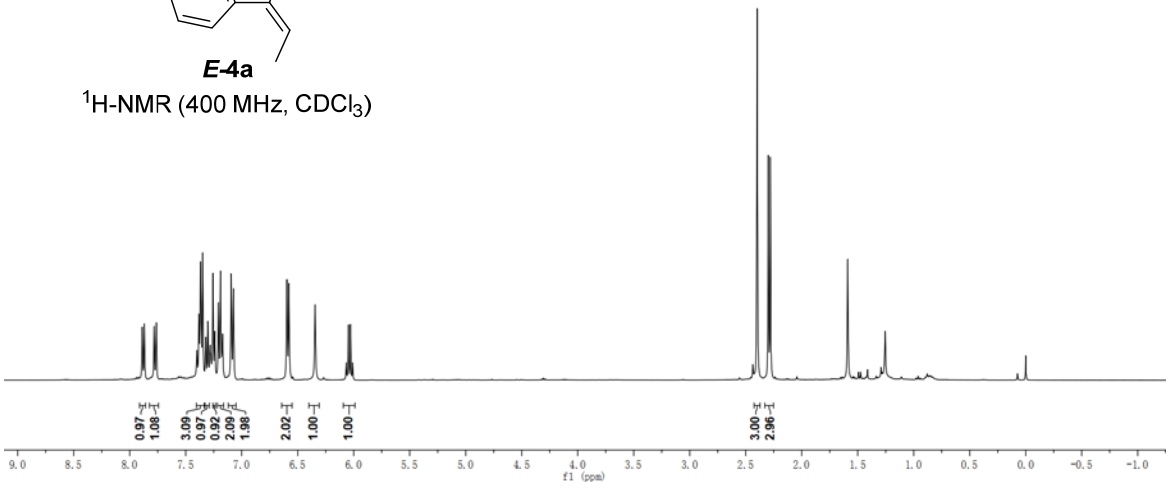
6. NMR and HRMS spectra

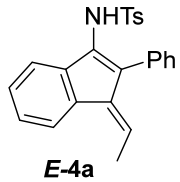




***E*-4a**

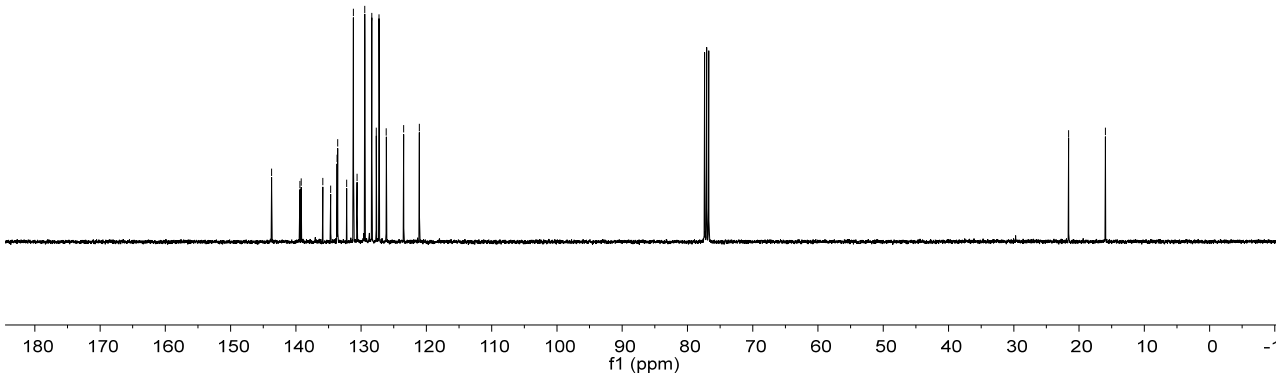
^{1}H-NMR (400 MHz, $CDCl_3$)

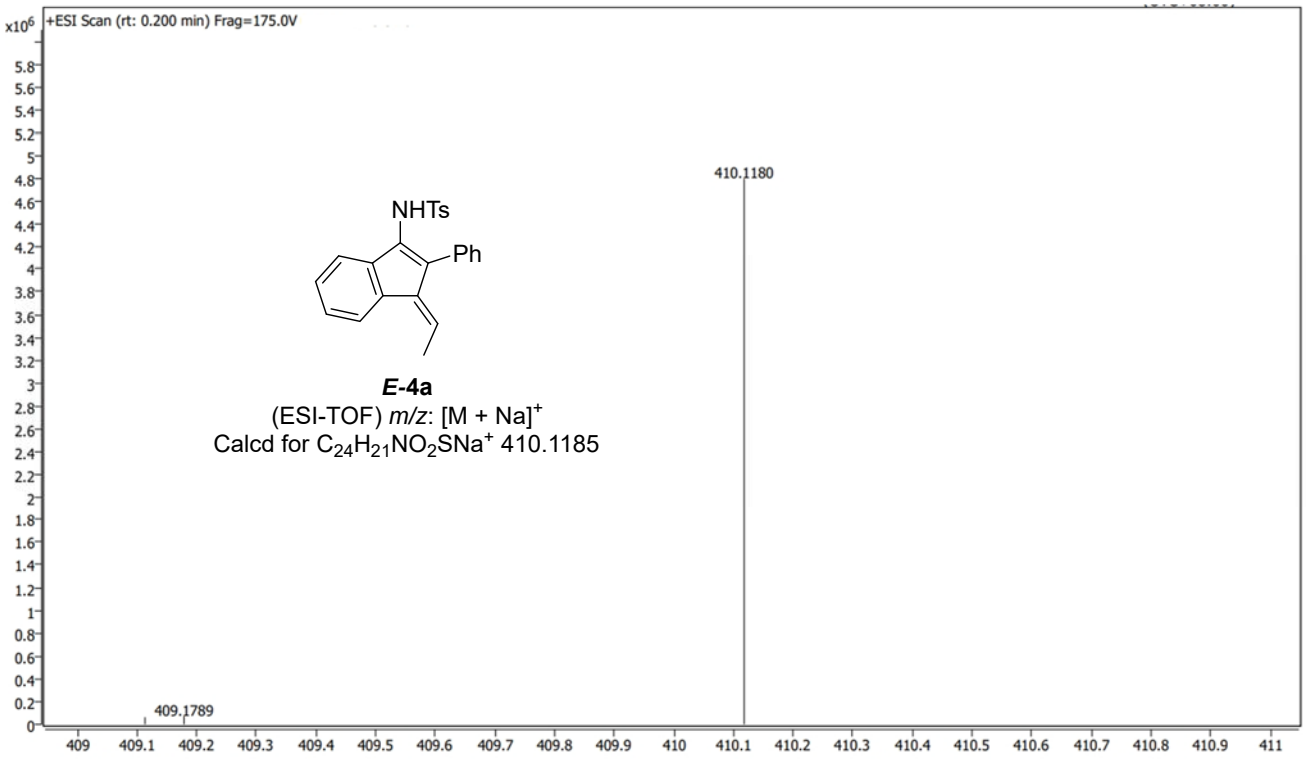




***E*-4a**

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

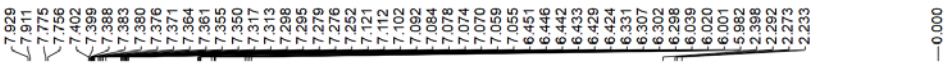


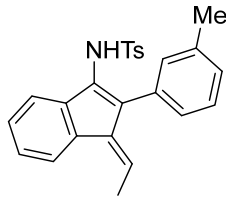


***E*-4a**

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

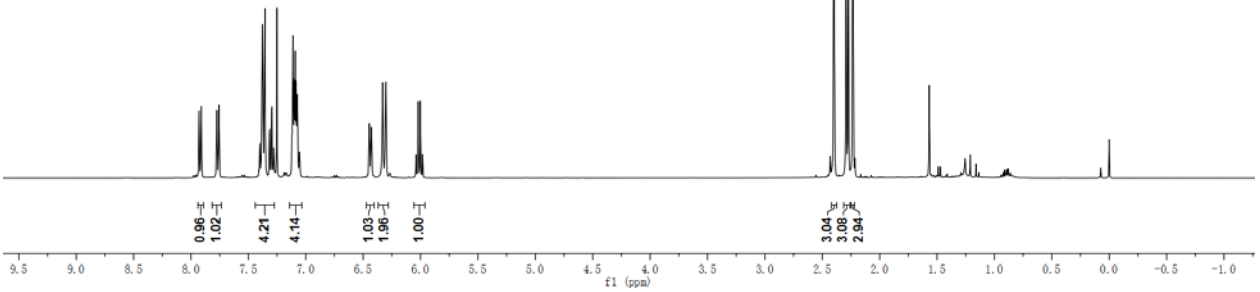
Calcd for $C_{24}H_{21}NO_2SNa^+$ 410.1185

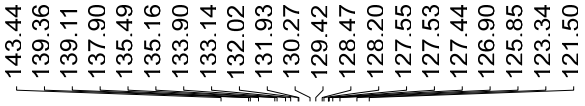


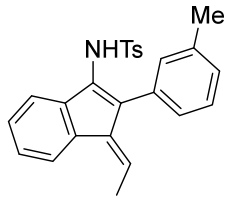


***E*-4b**

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

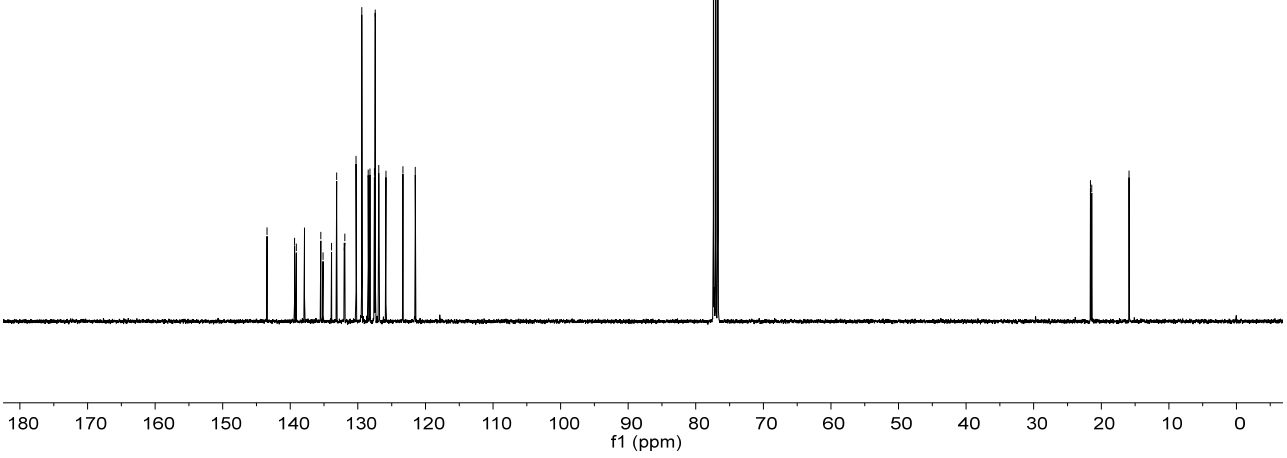


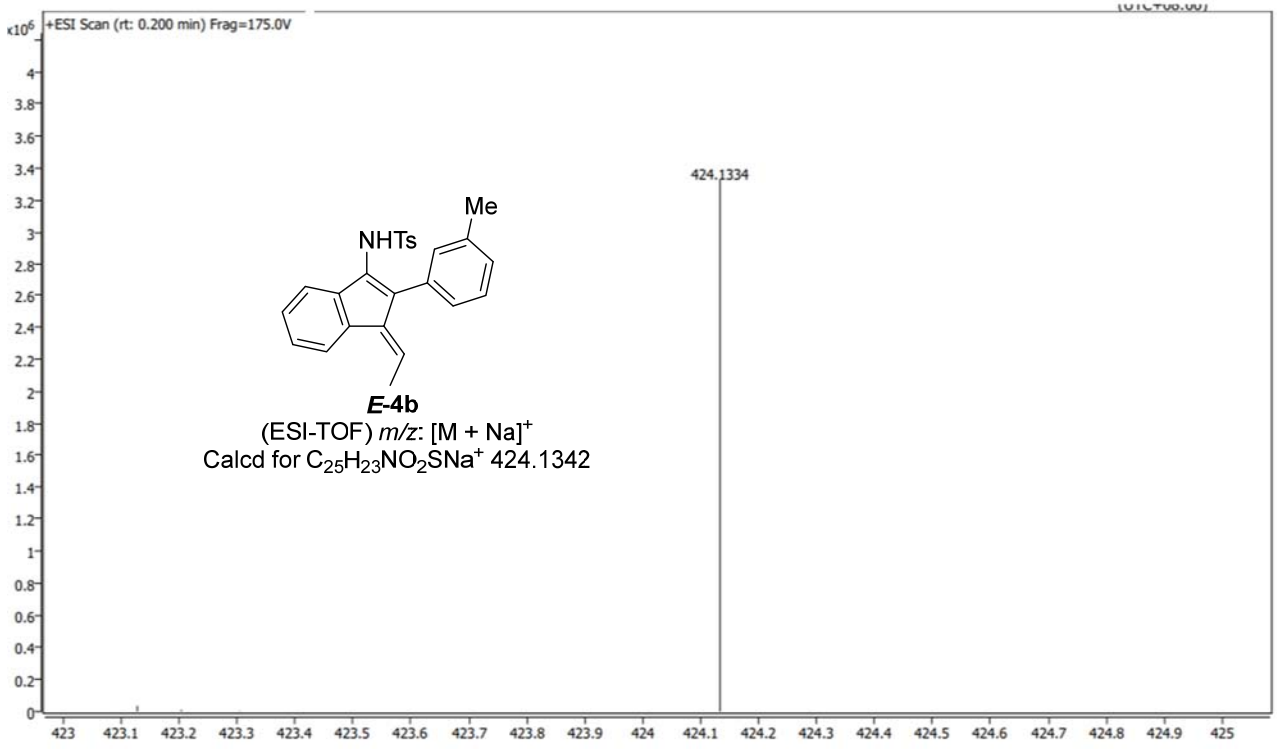


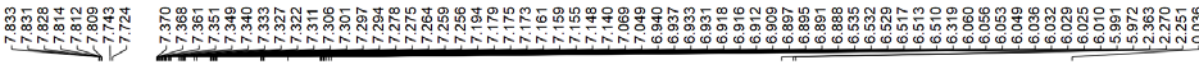


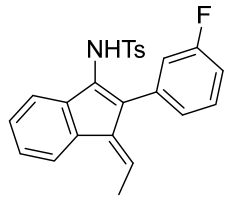
***E*-4b**

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



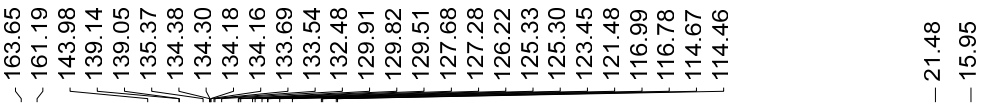

+ESI Scan (rt: 0.200 min) Frag=175.0V
x10^6
424.1334
Me
NHTs
E-4b
(ESI-TOF) m/z: [M + Na]+
Calcd for C25H23NO2SNa+ 424.1342

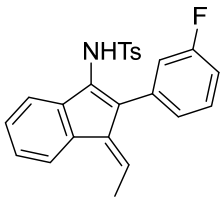




***E*-4c**

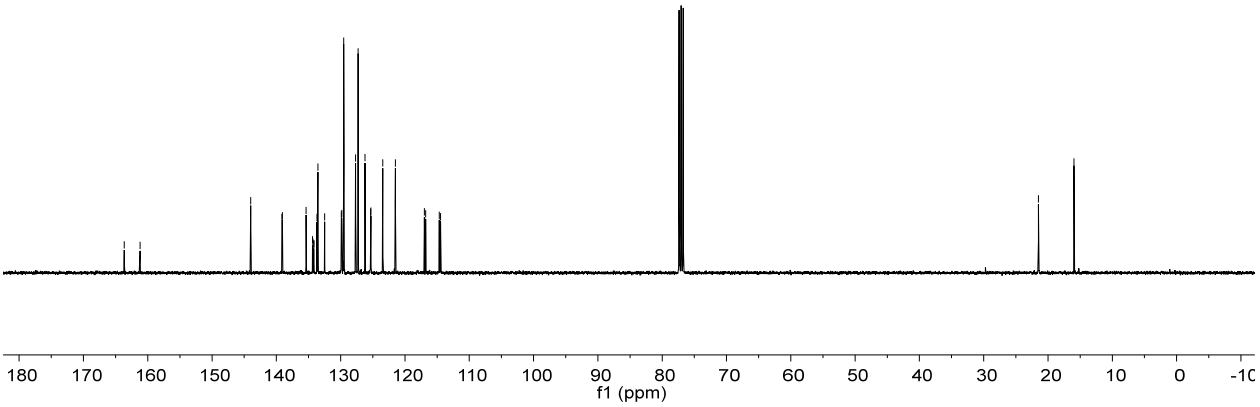
^{1}H NMR (400 MHz, $CDCl_3$)

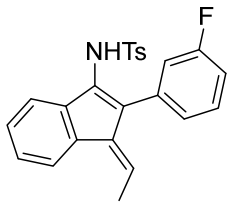




***E*-4c**

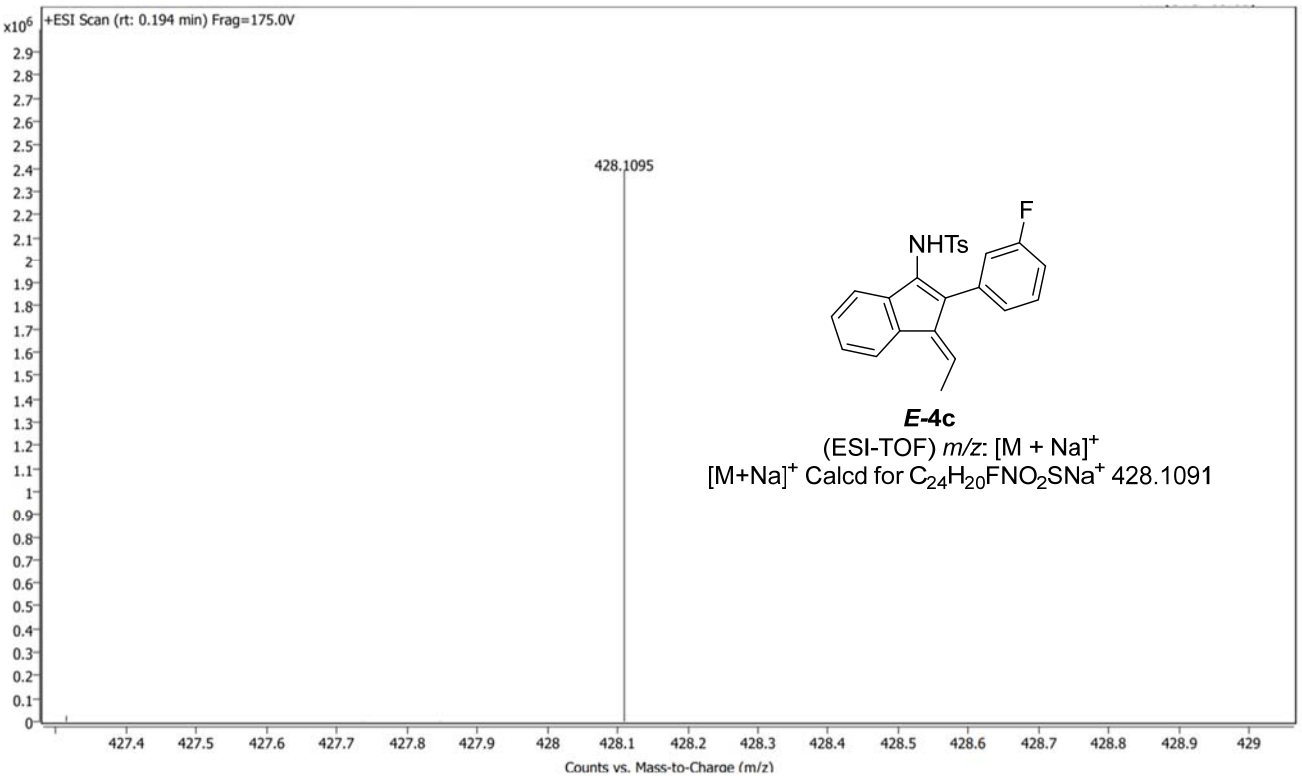
^{13}C NMR (100 MHz, $CDCl_3$)





***E*-4c**

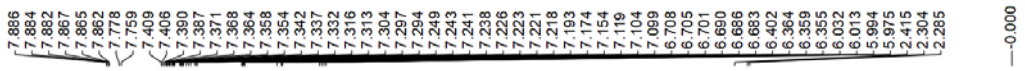
^{19}F NMR (375 MHz, $CDCl_3$)

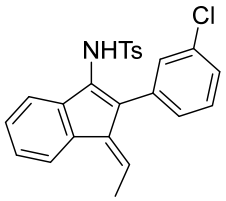


***E*-4c**

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

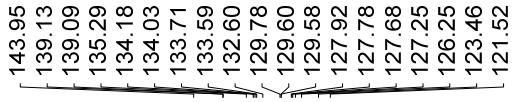
$[M+Na]^+$ Calcd for $C_{24}H_{20}FNO_2SNa^+$ 428.1091

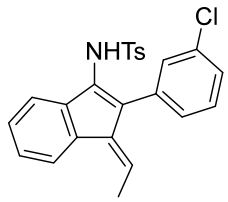




***E*-4d**

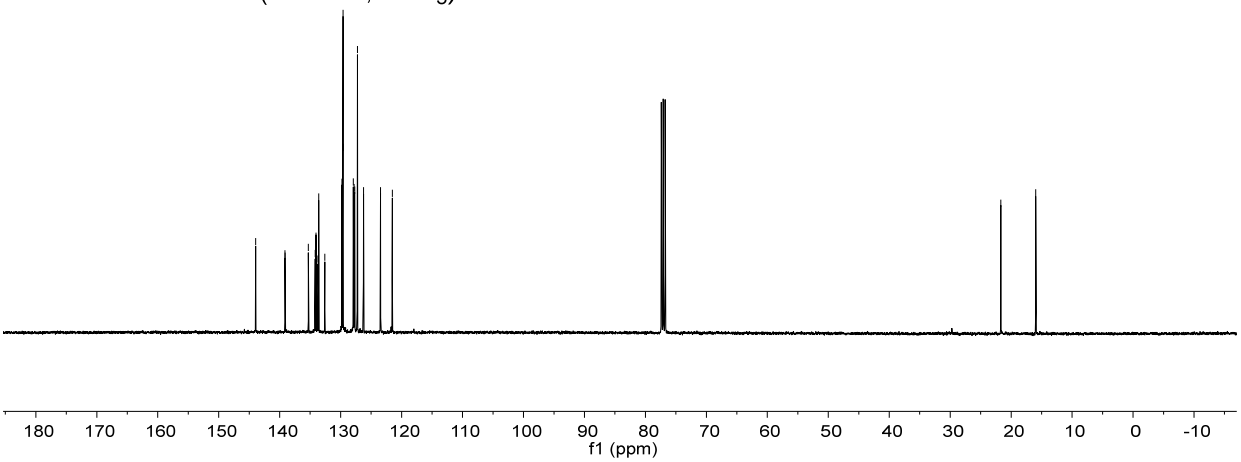
^{1}H NMR (400 MHz, $CDCl_3$)

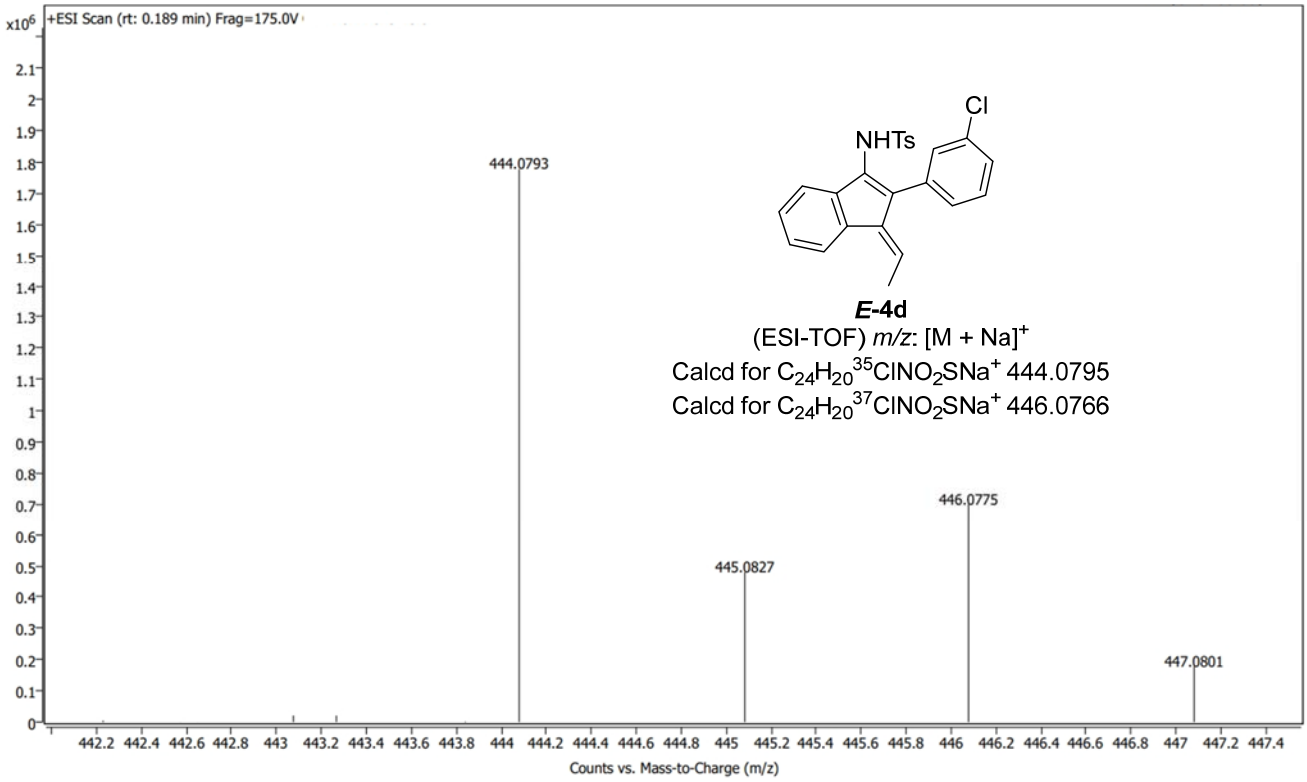




***E*-4d**

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



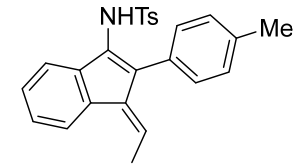


***E*-4d**

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

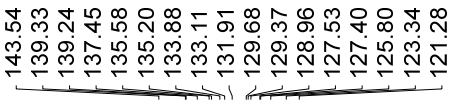
Calcd for $C_{24}H_{20}{}^{35}ClNO_2SNa^+$ 444.0795

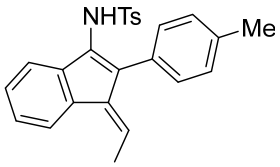
Calcd for $C_{24}H_{20}{}^{37}ClNO_2SNa^+$ 446.0766



***E*-4e**

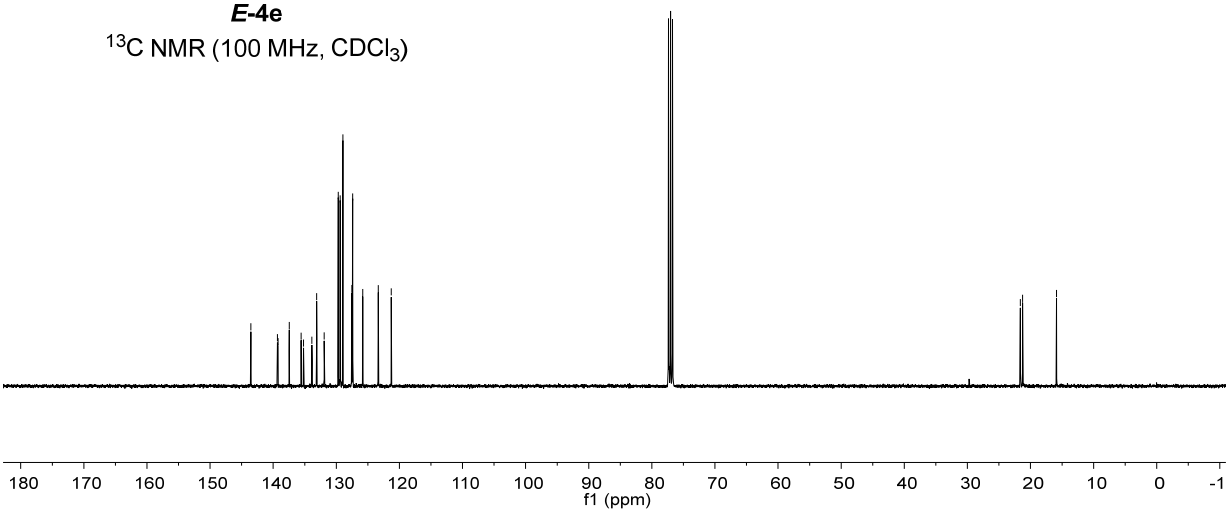
^{1}H NMR (400 MHz, $CDCl_3$)

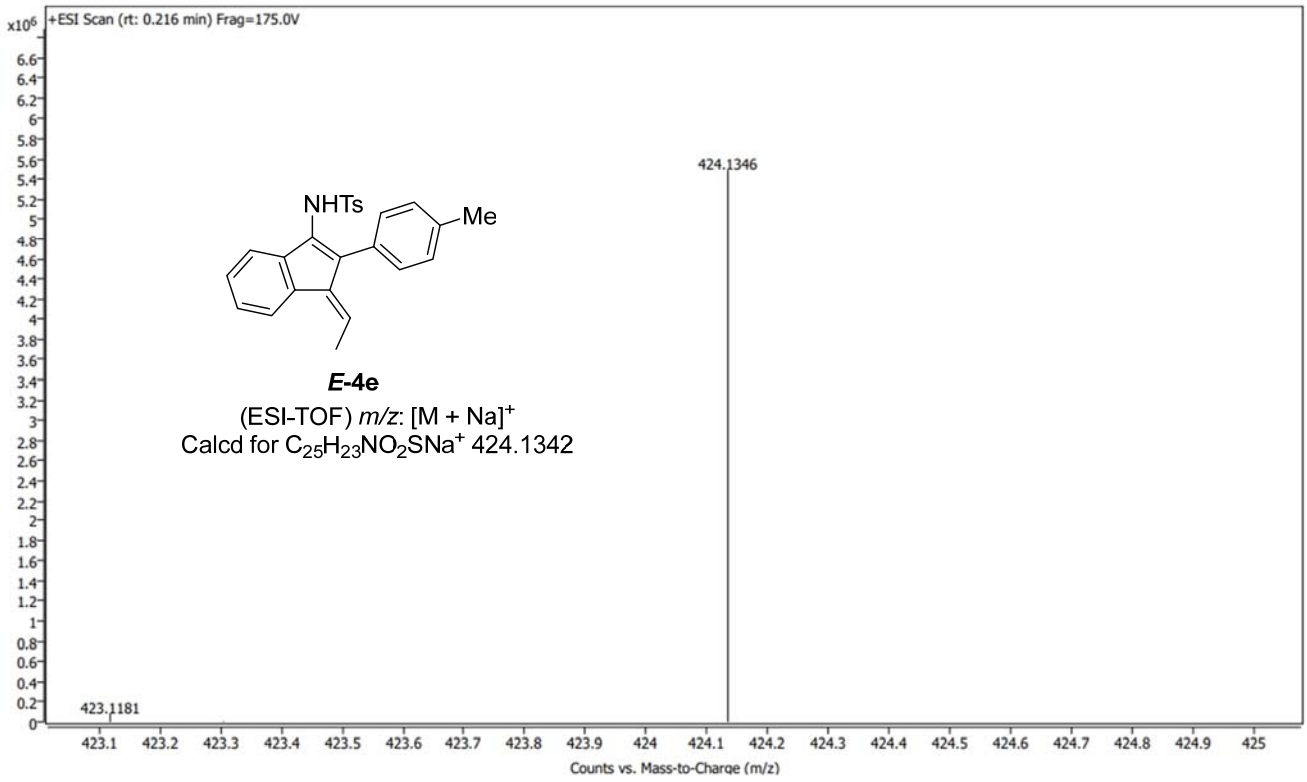




***E*-4e**

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

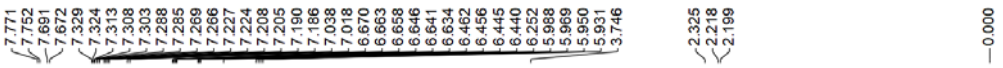


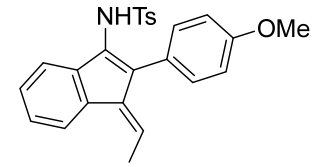


***E*-4e**

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

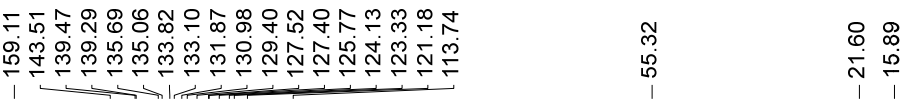
Calcd for $C_{25}H_{23}NO_2SNa^+$ 424.1342

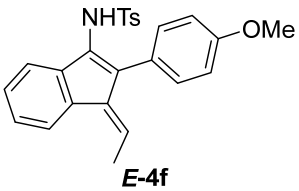




***E*-4f**

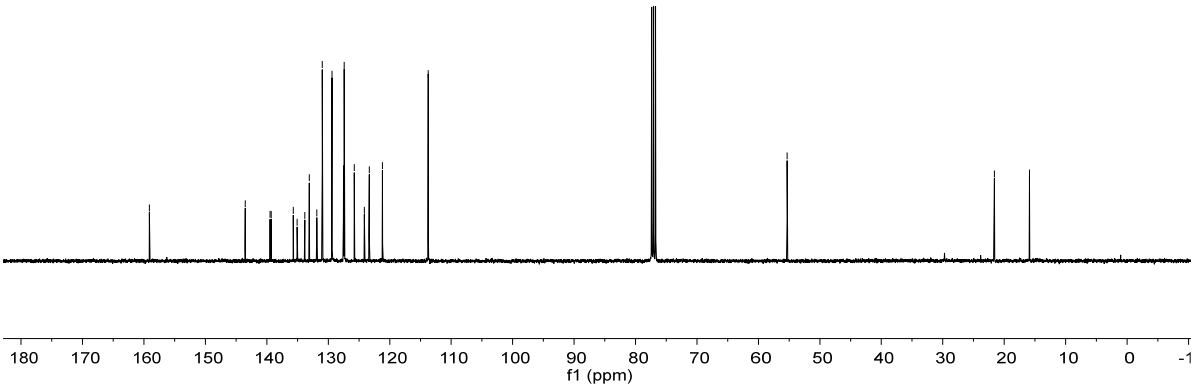
^{1}H NMR (400 MHz, $CDCl_3$)

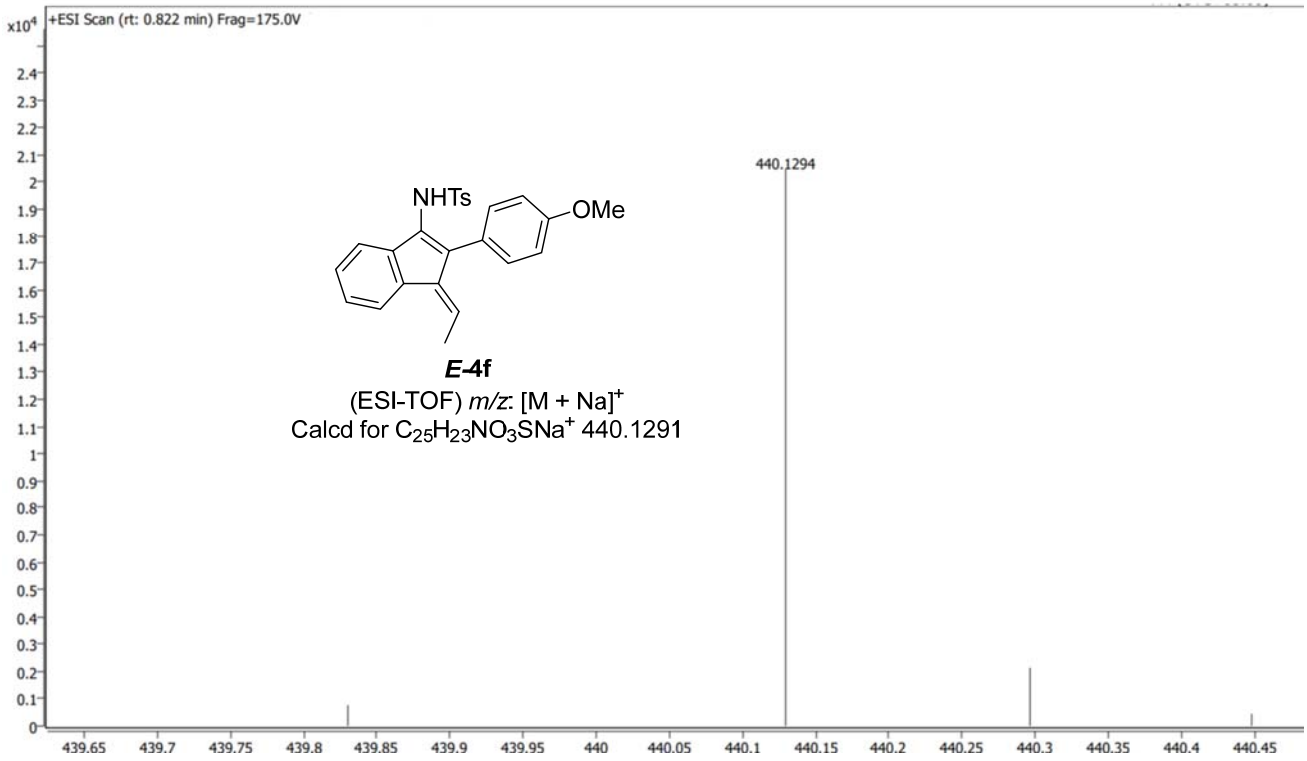




***E*-4f**

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

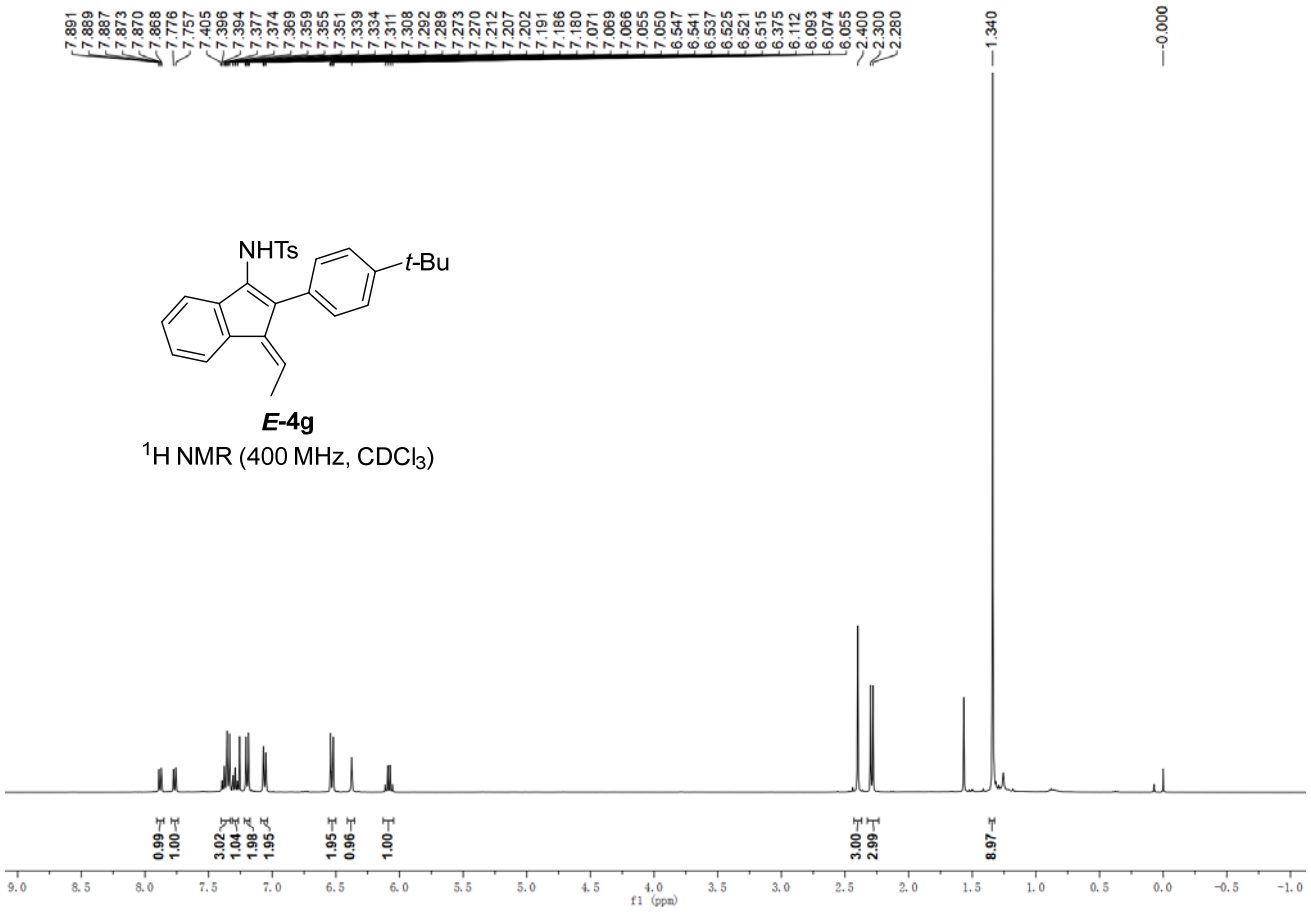




***E*-4f**

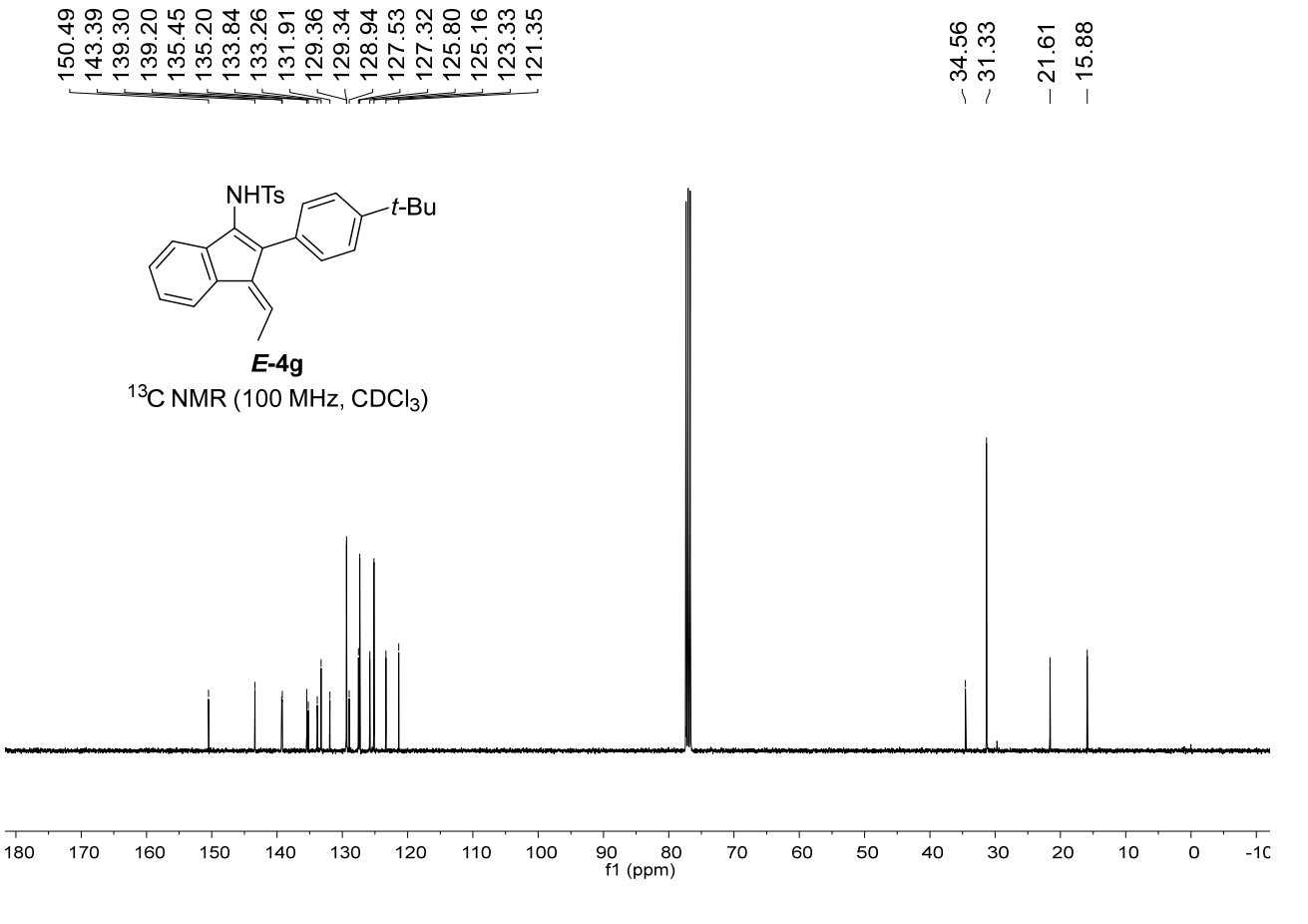
(ESI-TOF) *m/z*: $[M + Na]^+$

Calcd for $C_{25}H_{23}NO_3SNa^+$ 440.1291



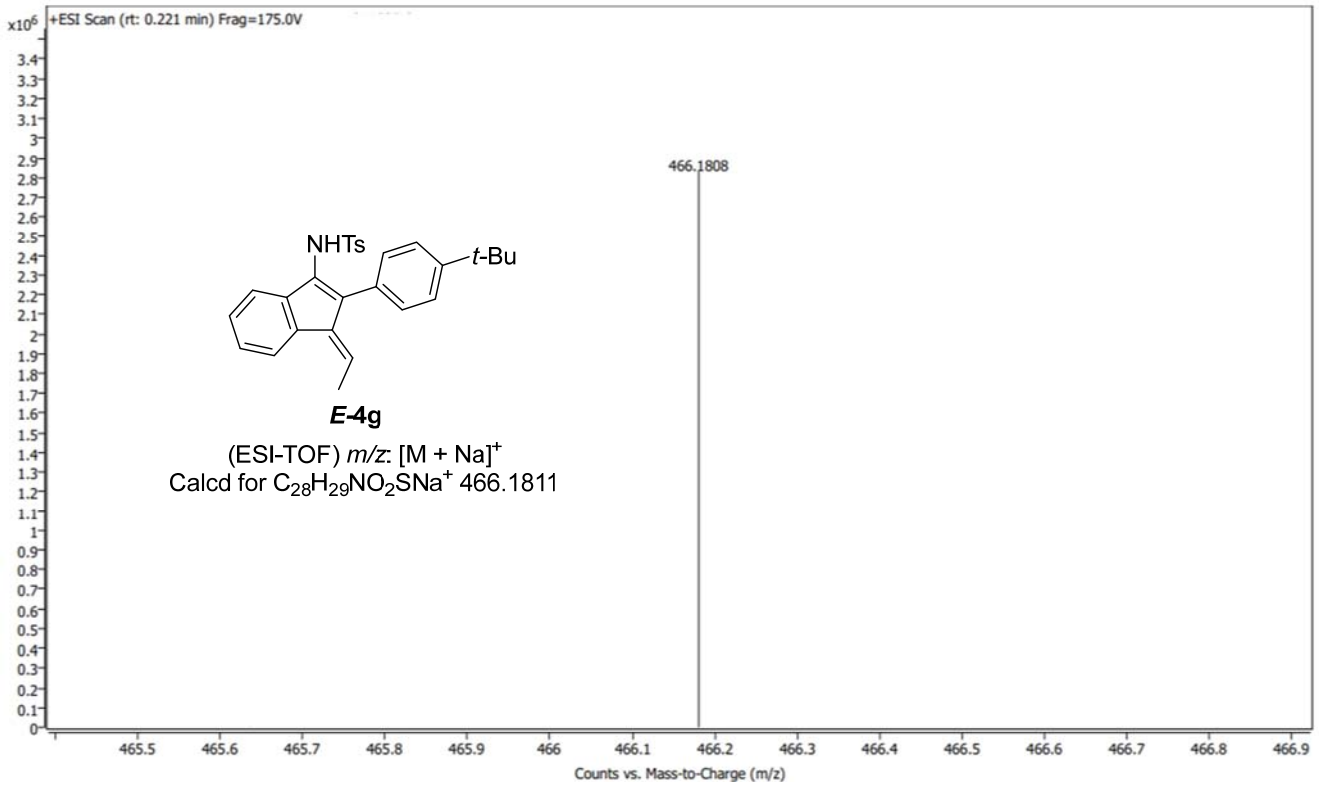
***E*-4g**

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



***E*-4g**

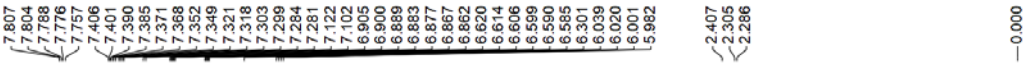
^{13}C NMR (100 MHz, $CDCl_3$)

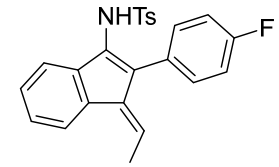


***E*-4g**

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

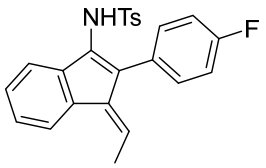
Calcd for $C_{28}H_{29}NO_2SNa^+$ 466.1811





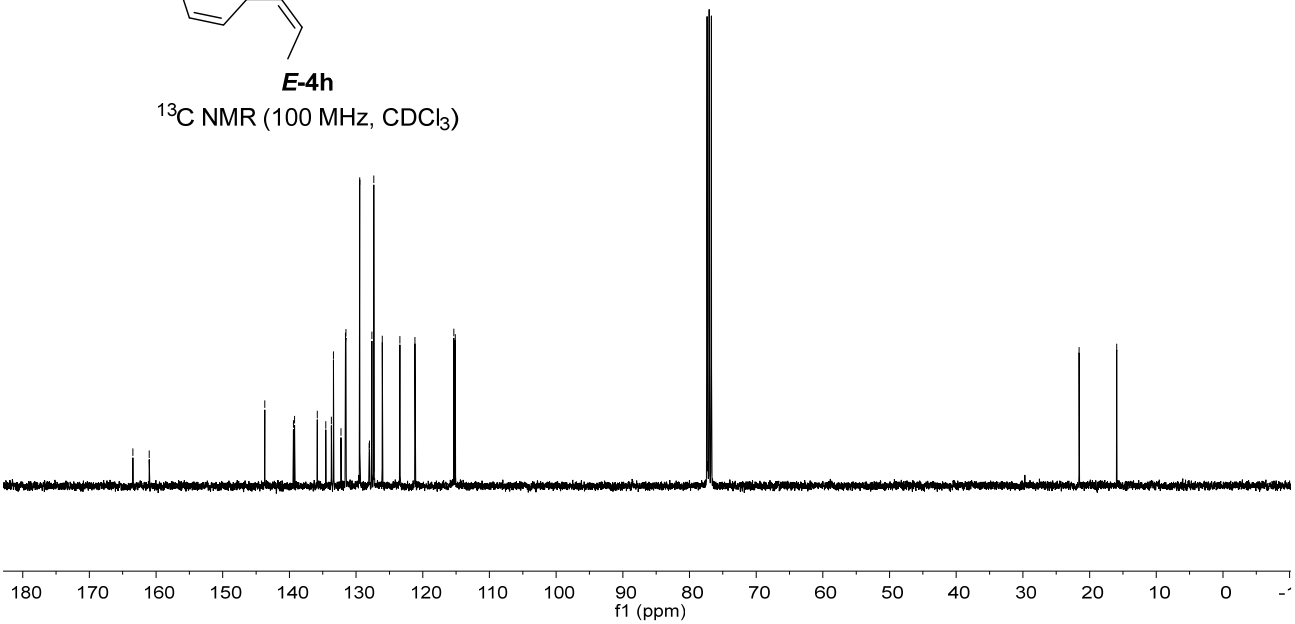
***E*-4h**

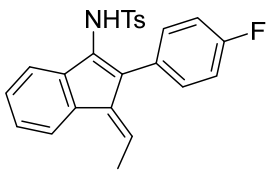
^{1}H NMR (400 MHz, $CDCl_3$)



***E*-4h**

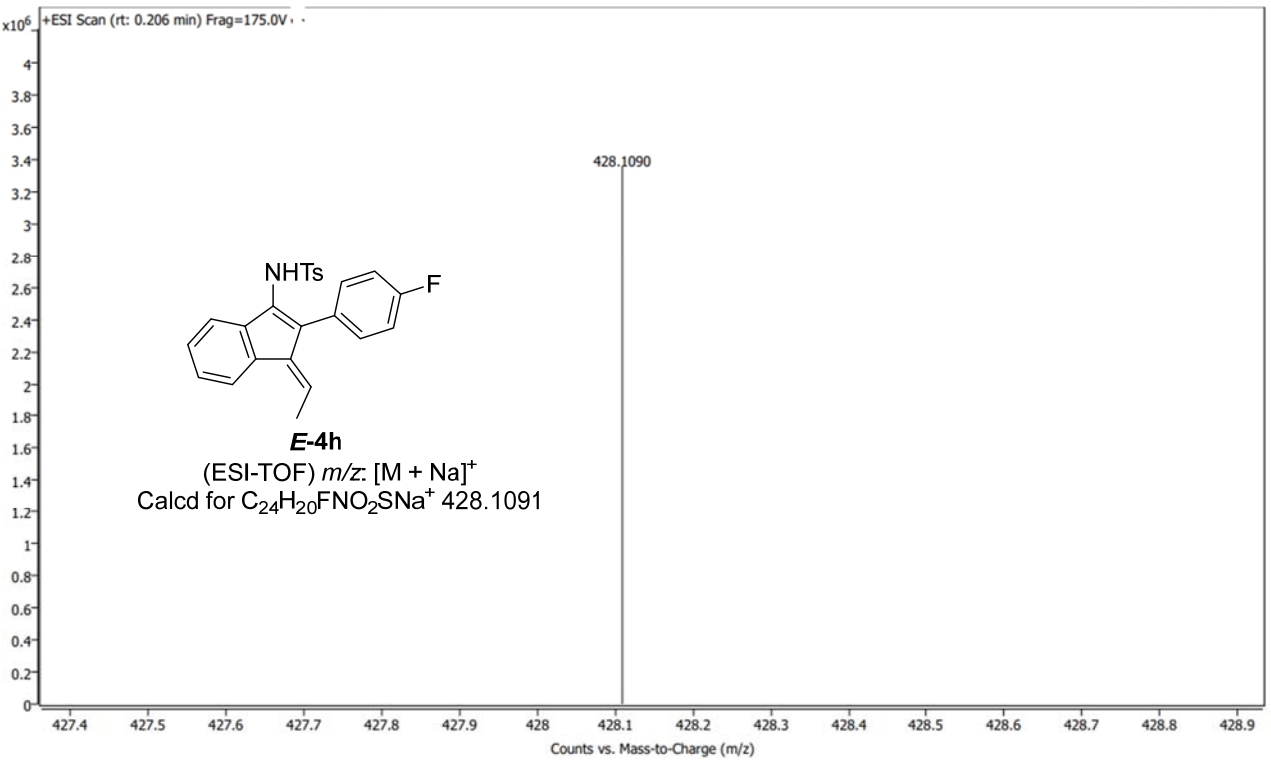
^{13}C NMR (100 MHz, $CDCl_3$)





***E*-4h**

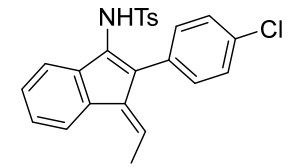
^{19}F NMR (375 MHz, $CDCl_3$)



***E*-4h**

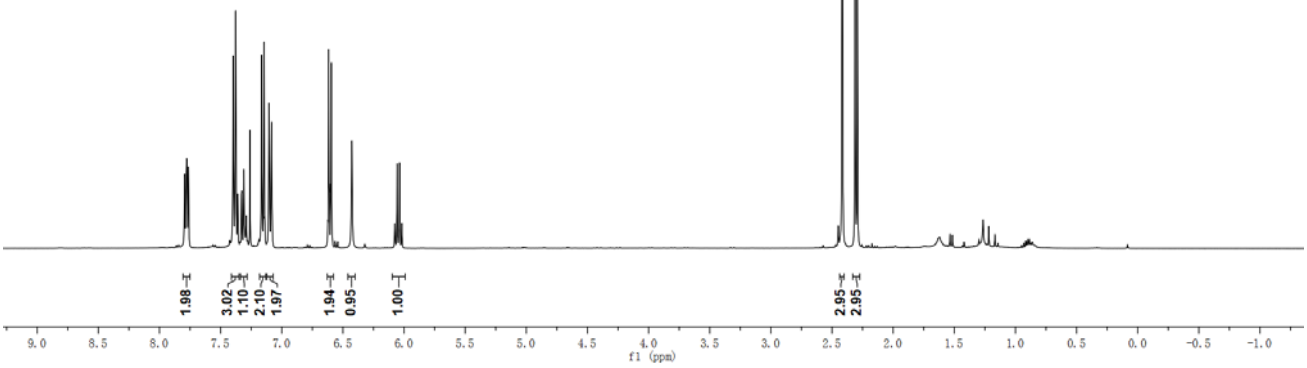
(ESI-TOF) *m/z*: $[M + Na]^+$

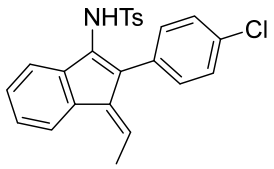
Calcd for $C_{24}H_{20}FNO_2SNa^+$ 428.1091



***E*-4i**

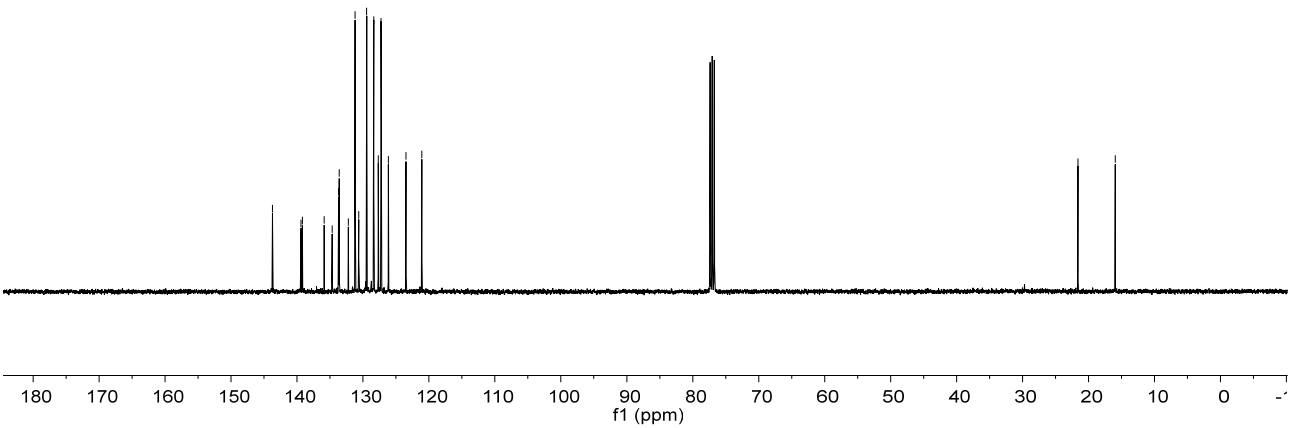
^{1}HNMR (400 MHz, $CDCl_3$)

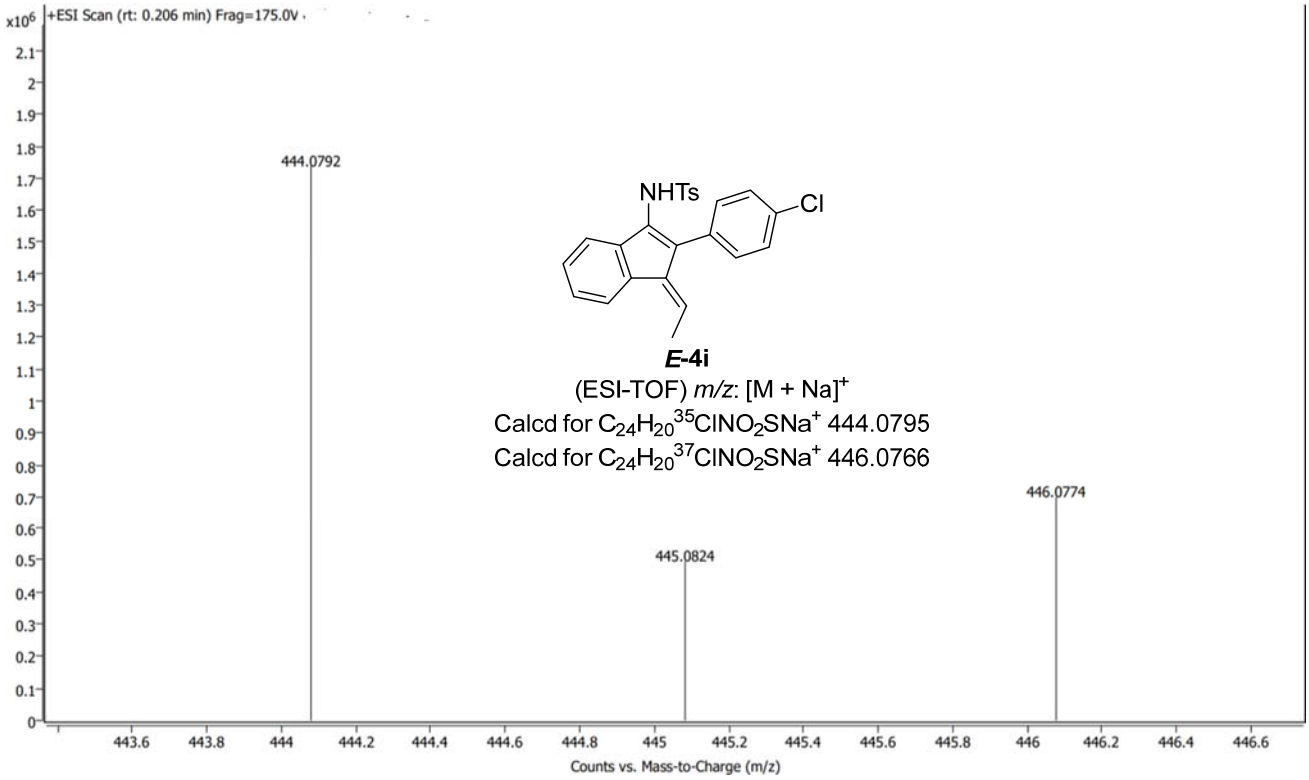




***E*-4i**

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



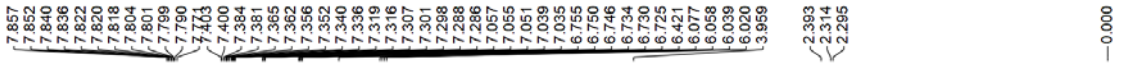


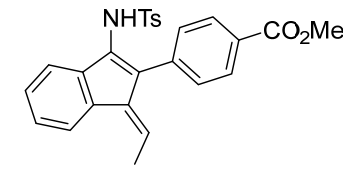
***E*-4i**

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

Calcd for $C_{24}H_{20}{}^{35}ClNO_2SNa^+$ 444.0795

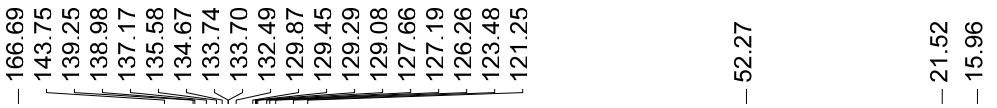
Calcd for $C_{24}H_{20}{}^{37}ClNO_2SNa^+$ 446.0766

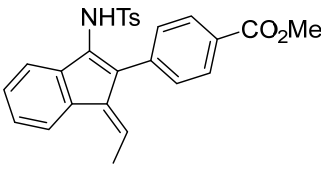




***E*-4j**

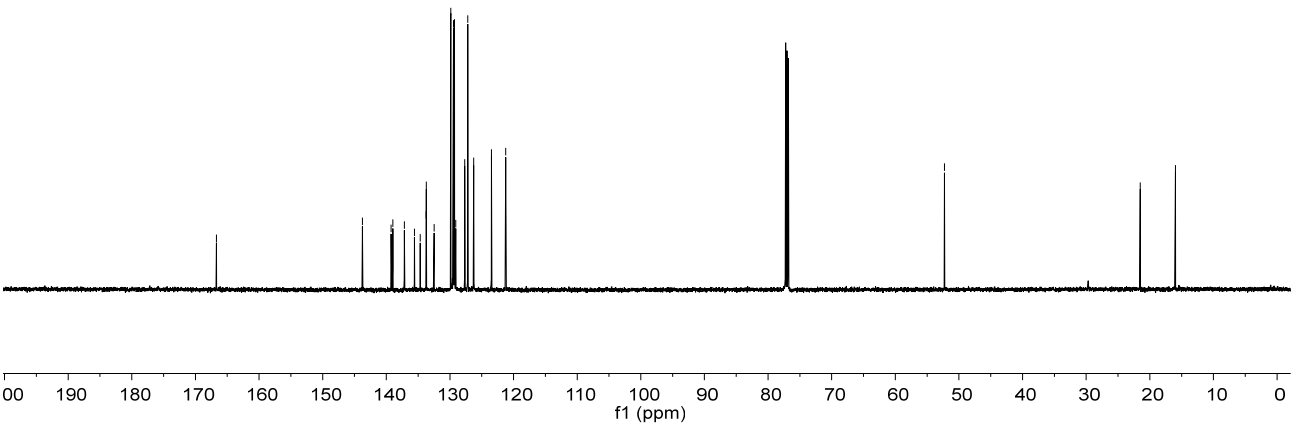
^{1}H NMR (400 MHz, $CDCl_3$)

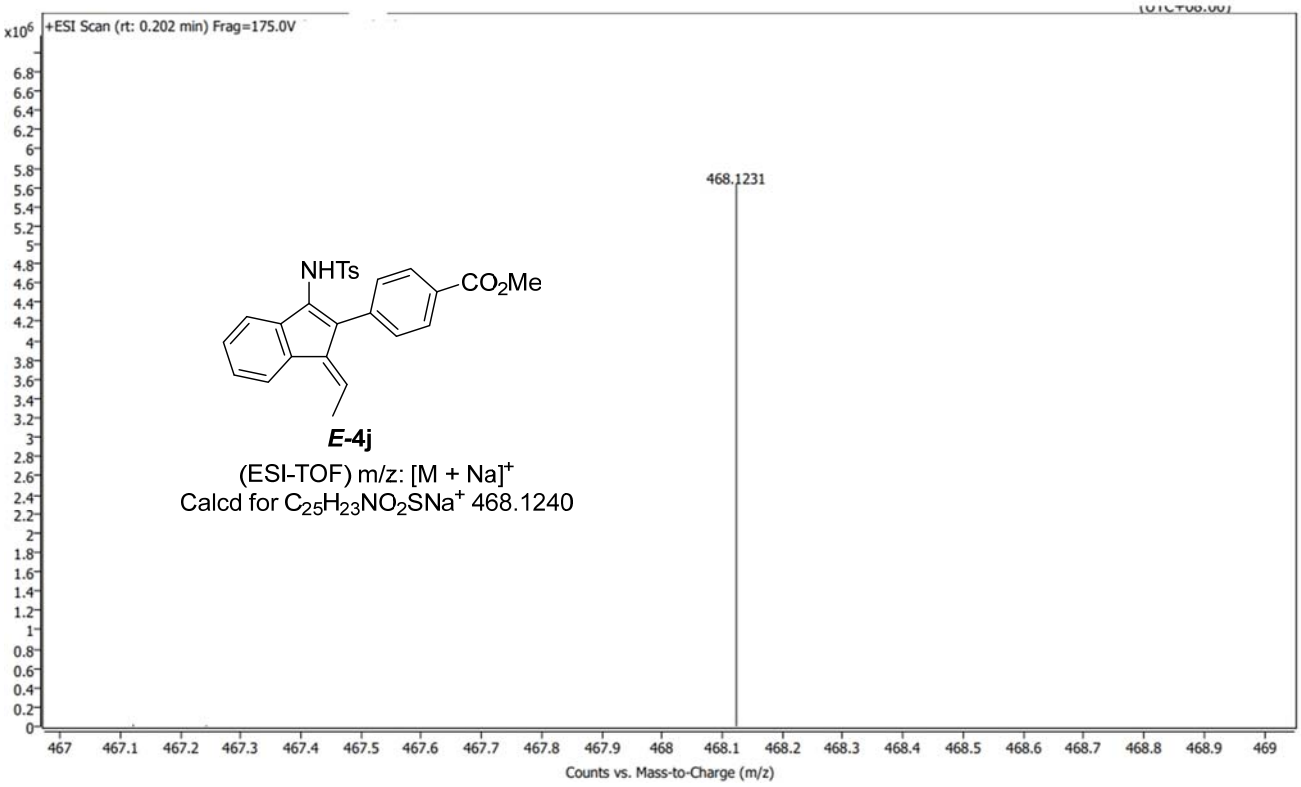




***E*-4j**

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

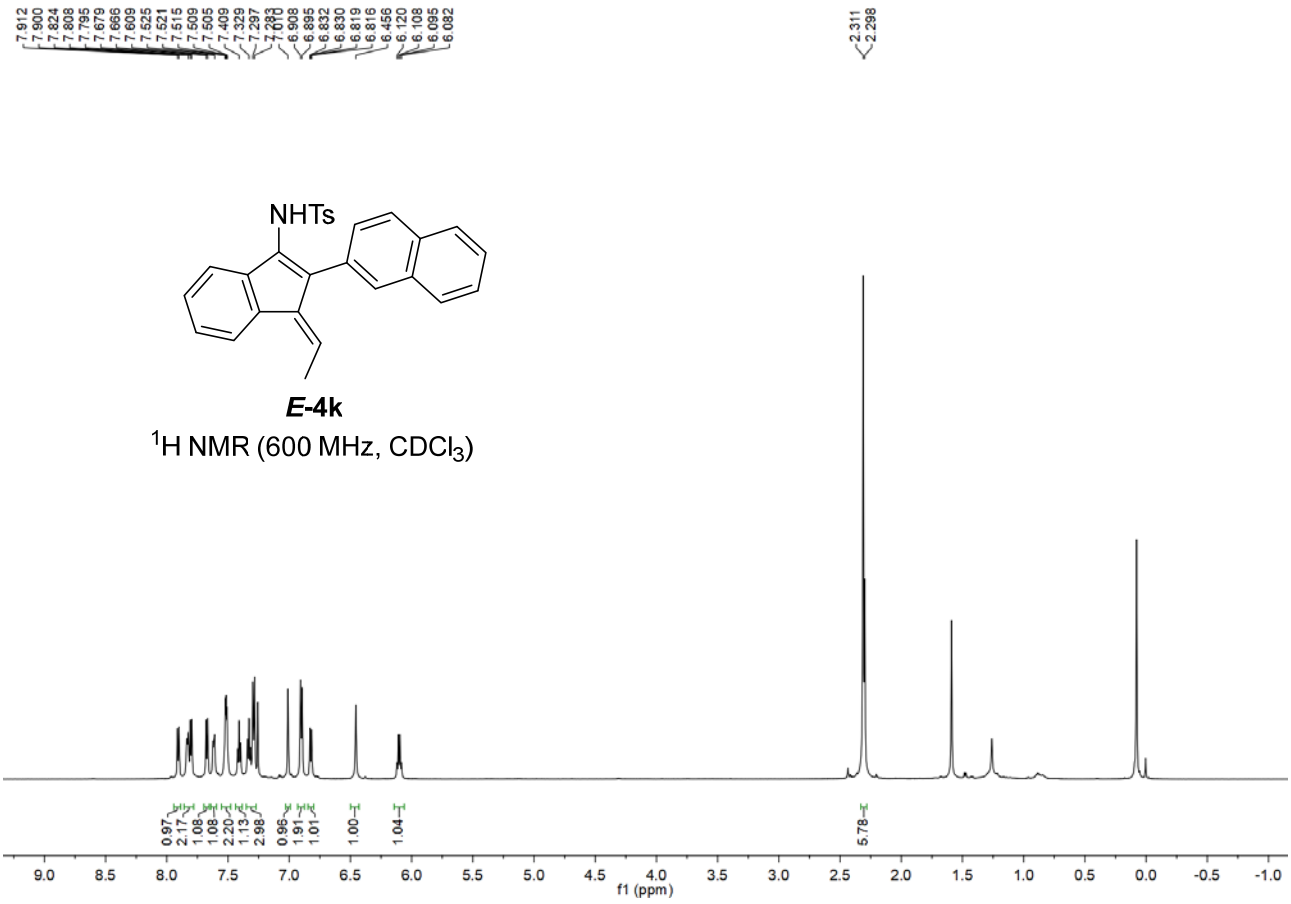


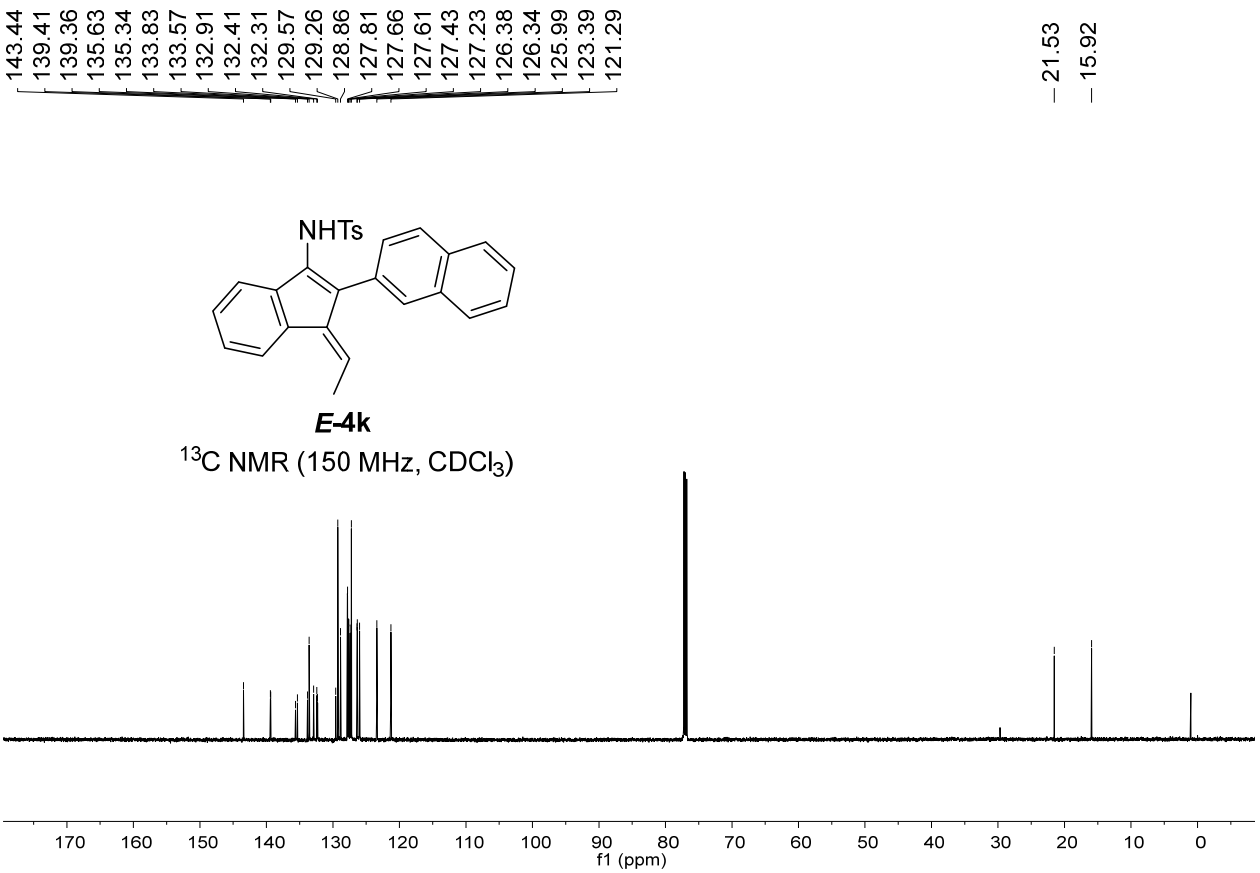


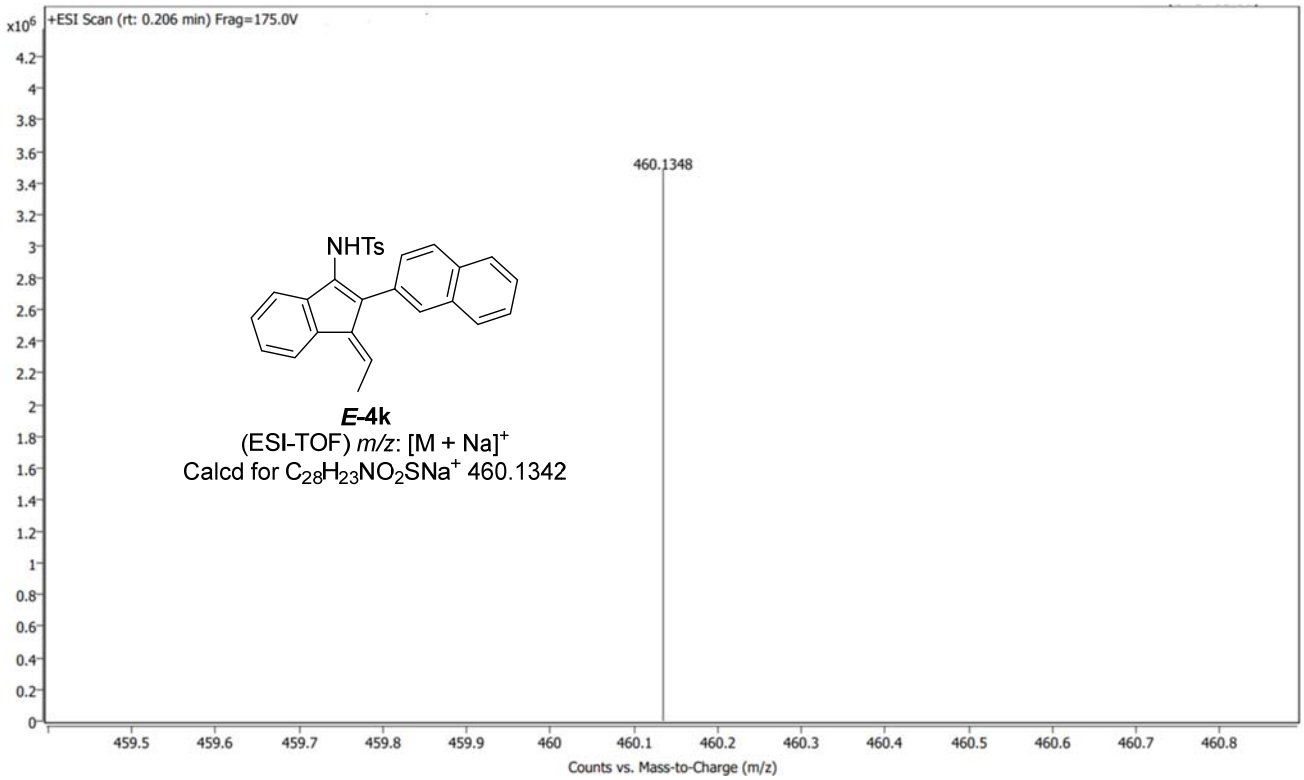
***E*-4j**

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

Calcd for $C_{25}H_{23}NO_2SNa^+$ 468.1240


7.912
7.900
7.824
7.808
7.795
7.679
7.666
7.609
7.525
7.521
7.515
7.509
7.505
7.409
7.329
7.297
7.283
7.033
6.908
6.895
6.832
6.830
6.819
6.816
6.456
6.120
6.108
6.095
6.082
2.311
2.298
NHTs
E-4k
1H NMR (600 MHz, CDCl3)
0.97
2.17
1.08
1.08
2.20
1.13
2.98
0.96
1.91
1.01
1.00
1.04
5.78
f1 (ppm)

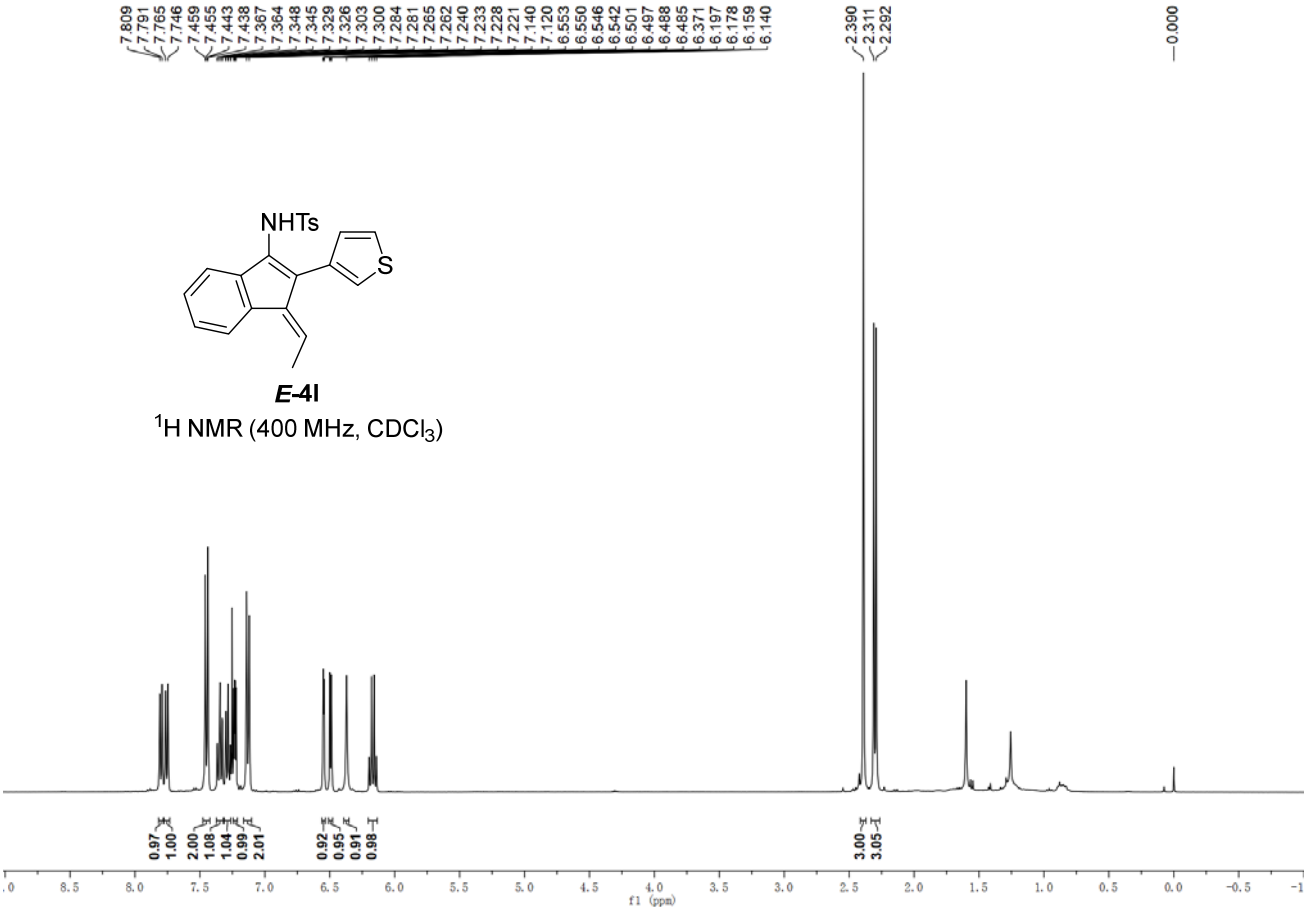

143.44
139.41
139.36
135.63
135.34
133.83
133.57
132.91
132.41
132.31
129.57
129.26
128.86
127.81
127.66
127.61
127.43
127.23
126.38
126.34
125.99
123.39
121.29
21.53
15.92
NHTs
E-4k
13C NMR (150 MHz, CDCl3)
f1 (ppm)



***E*-4k**

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

Calcd for $C_{28}H_{23}NO_2SNa^+$ 460.1342

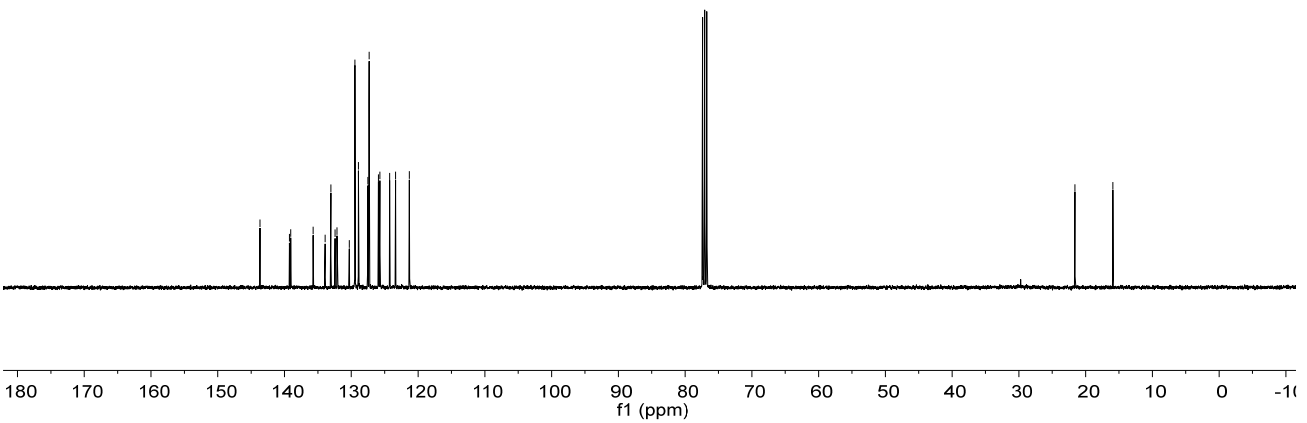


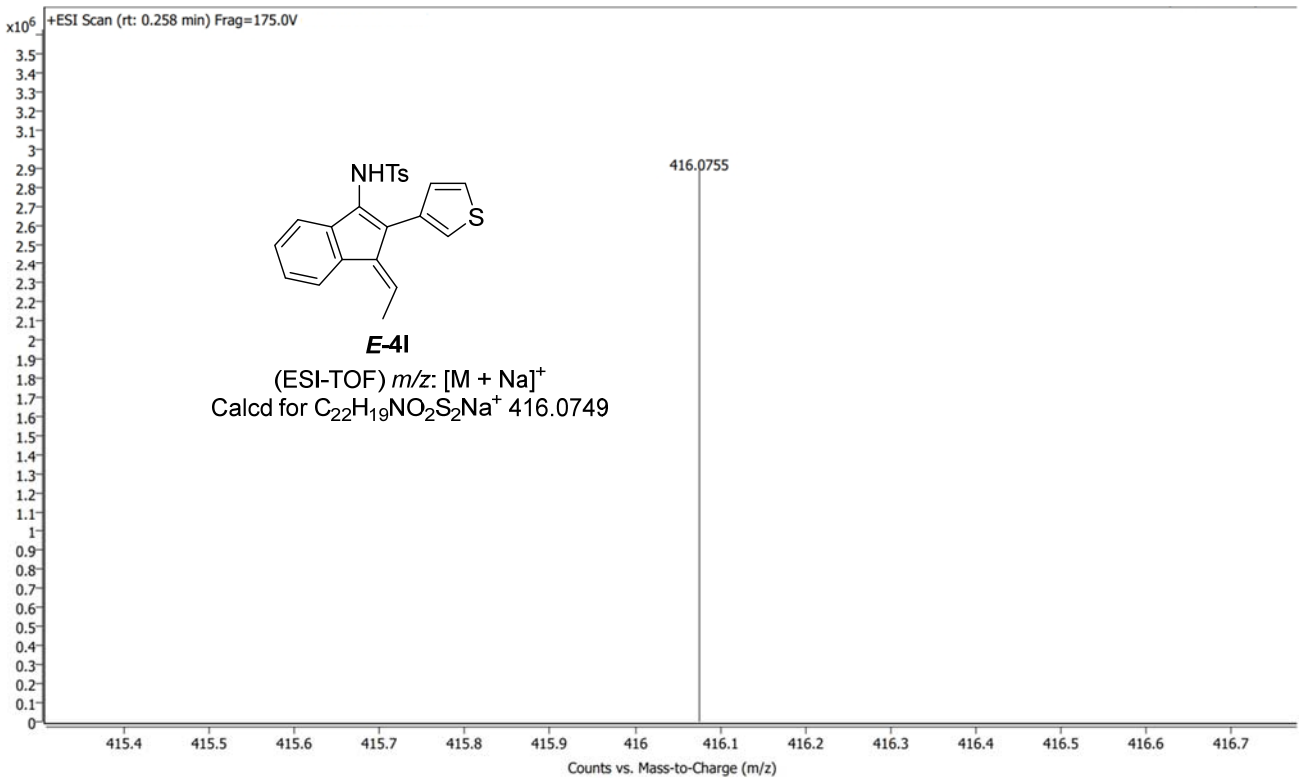
***E*-4l**

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

***E*-4l**

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

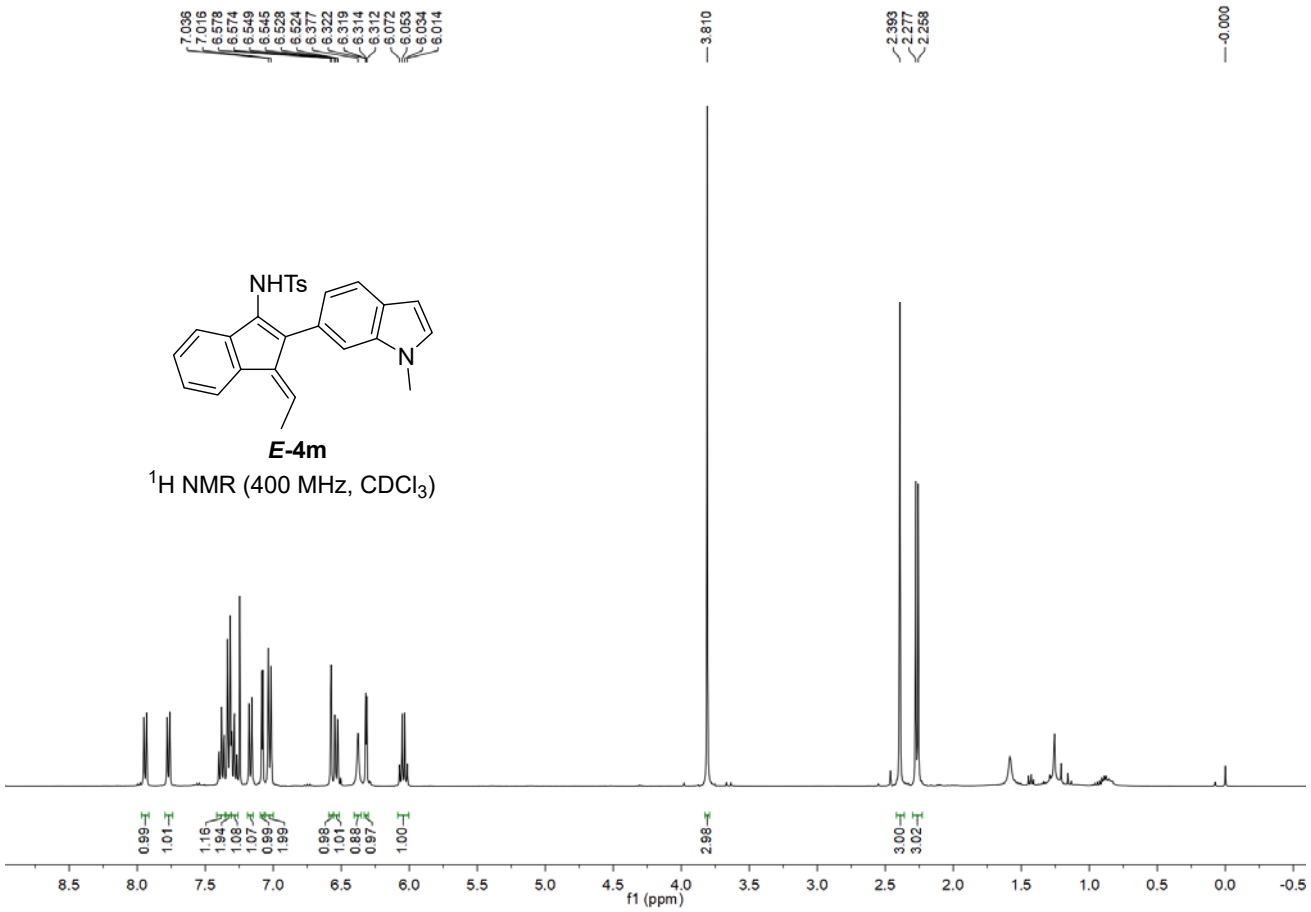




***E*-4l**

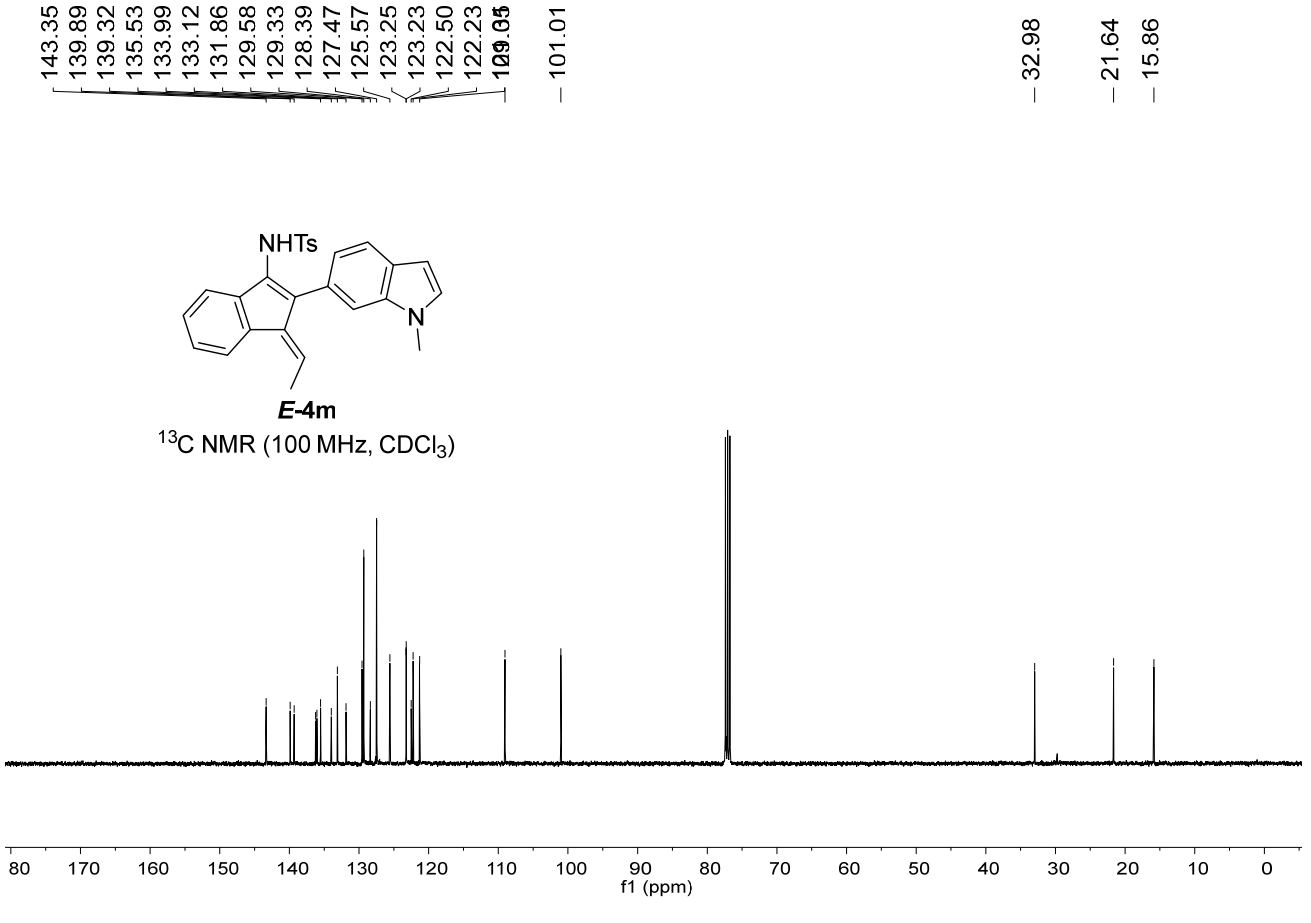
(ESI-TOF) *m/z*: $[M + Na]^+$

Calcd for $C_{22}H_{19}NO_2S_2Na^+$ 416.0749



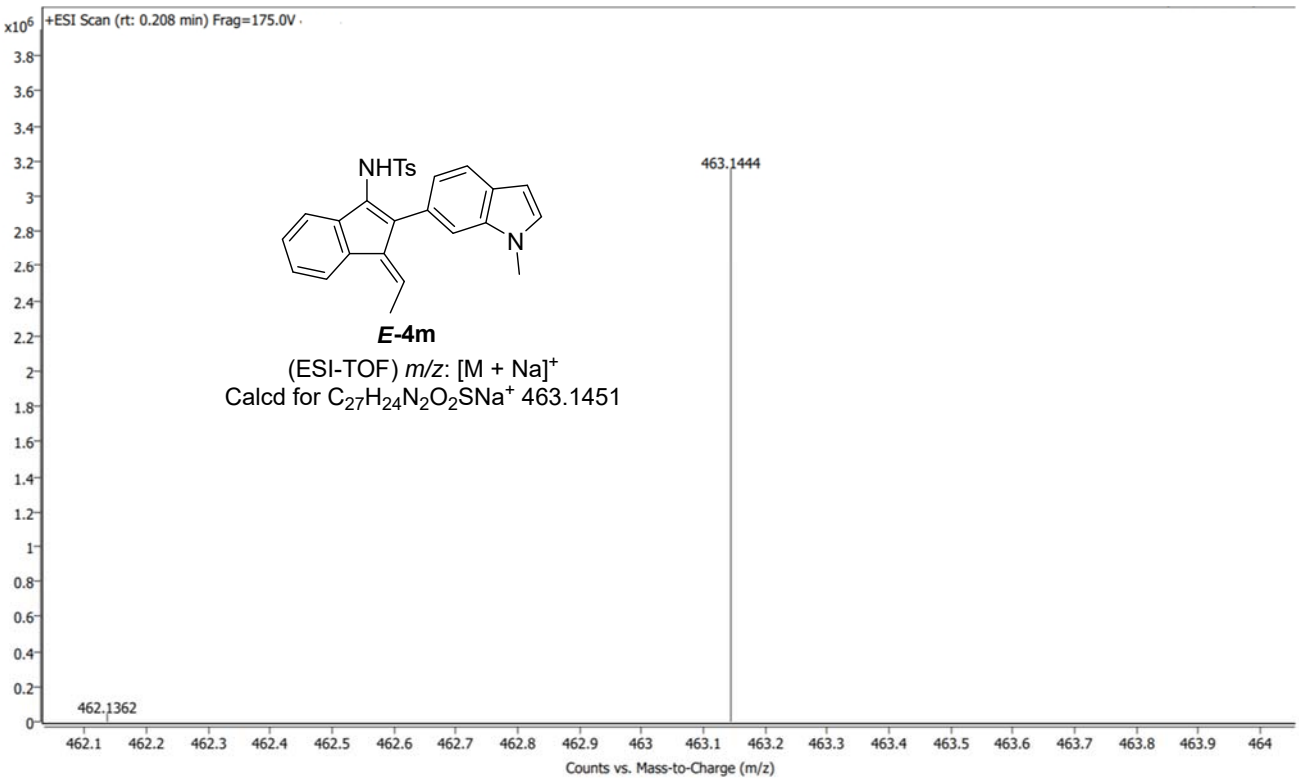
***E*-4m**

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



***E*-4m**

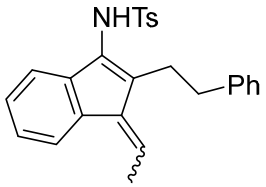
^{13}C NMR (100 MHz, $CDCl_3$)



***E*-4m**

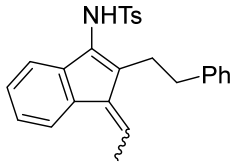
(ESI-TOF) *m/z*: $[M + Na]^+$

Calcd for $C_{27}H_{24}N_2O_2SNa^+$ 463.1451



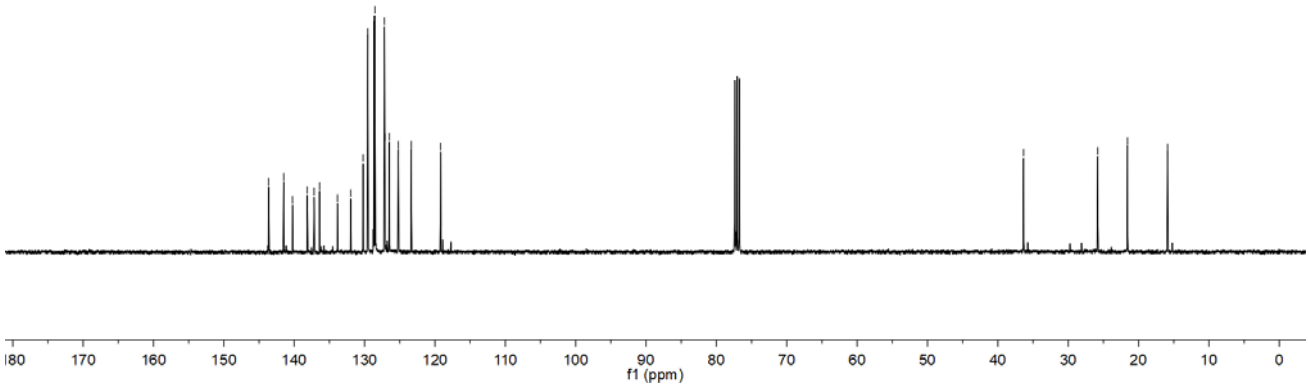
4n, *E*/*Z* = 11:1

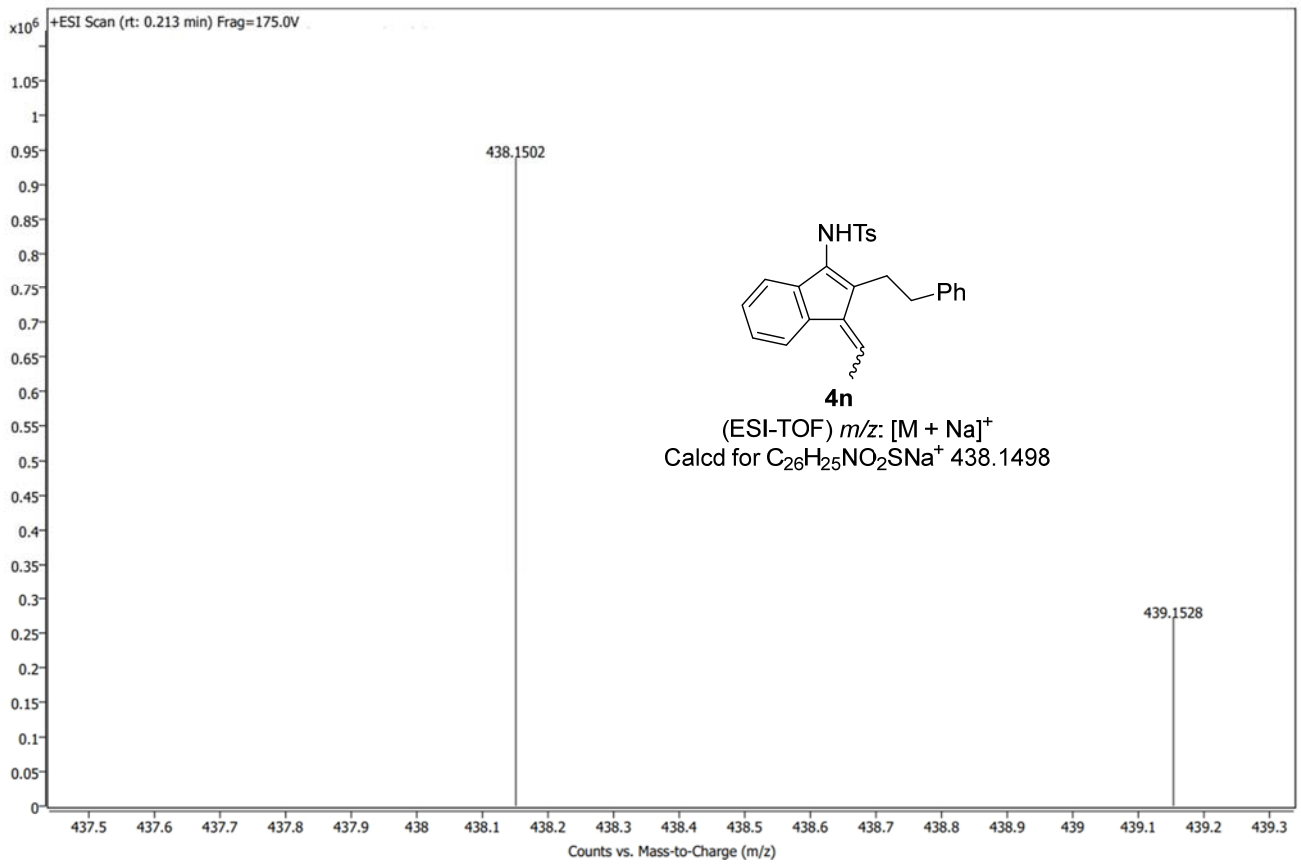
^{1}H NMR (400 MHz, $CDCl_3$)



4n

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

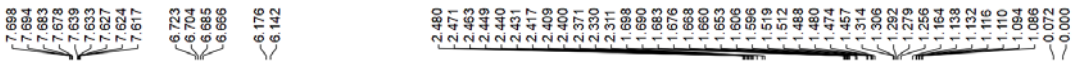


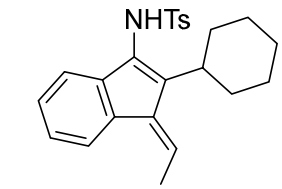


4n

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

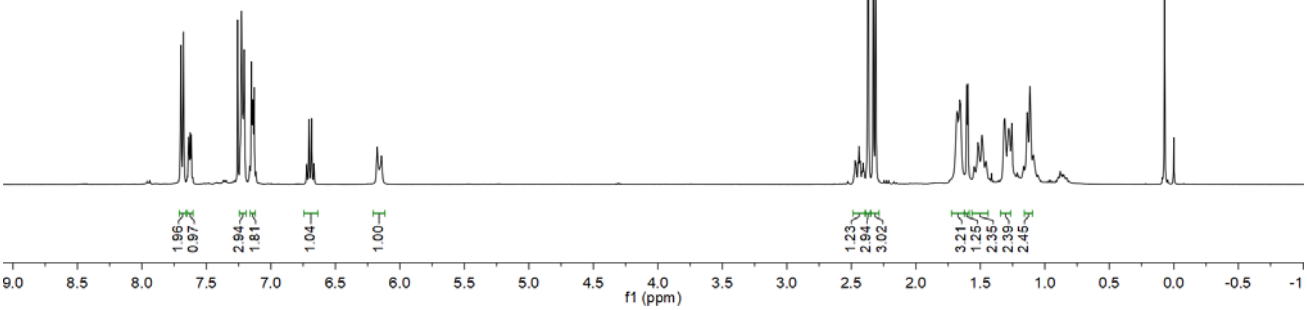
Calcd for $C_{26}H_{25}NO_2SNa^+$ 438.1498

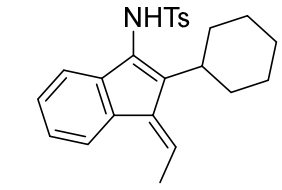




4o

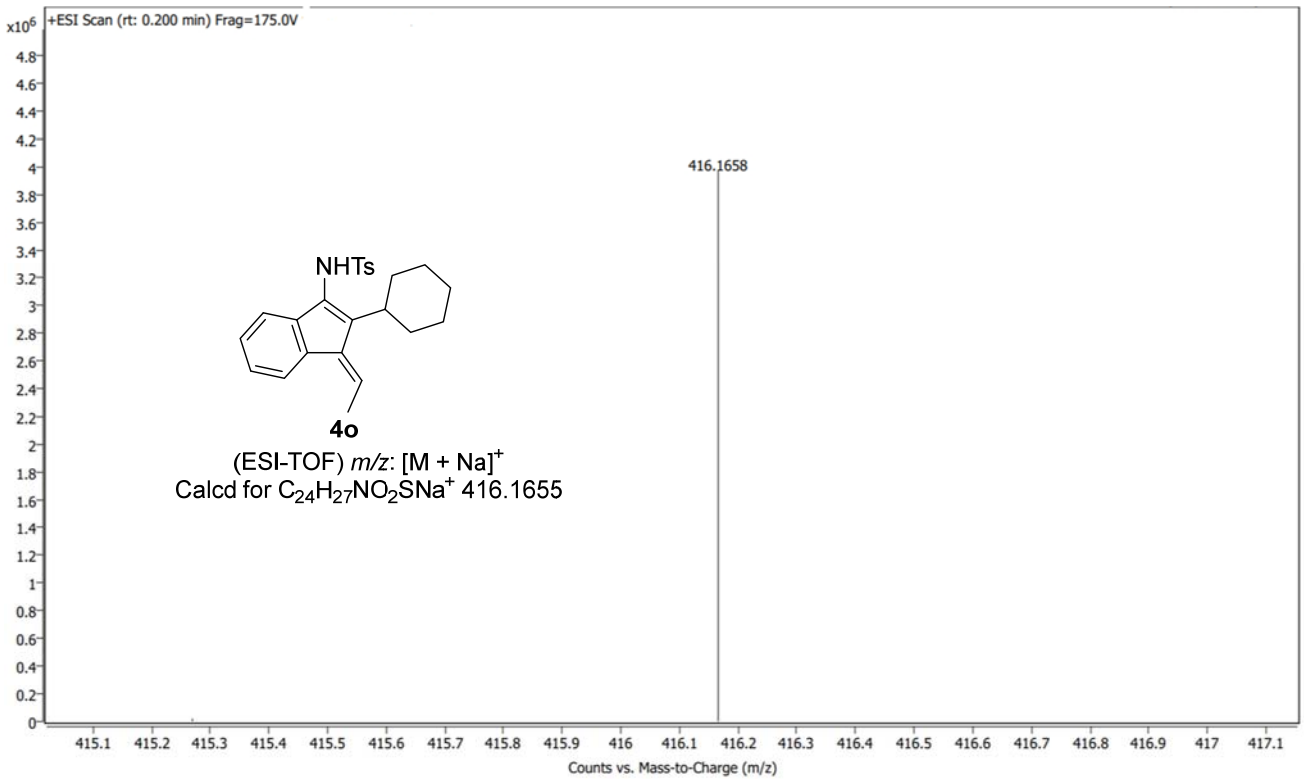
^{1}H NMR (400 MHz, $CDCl_3$)

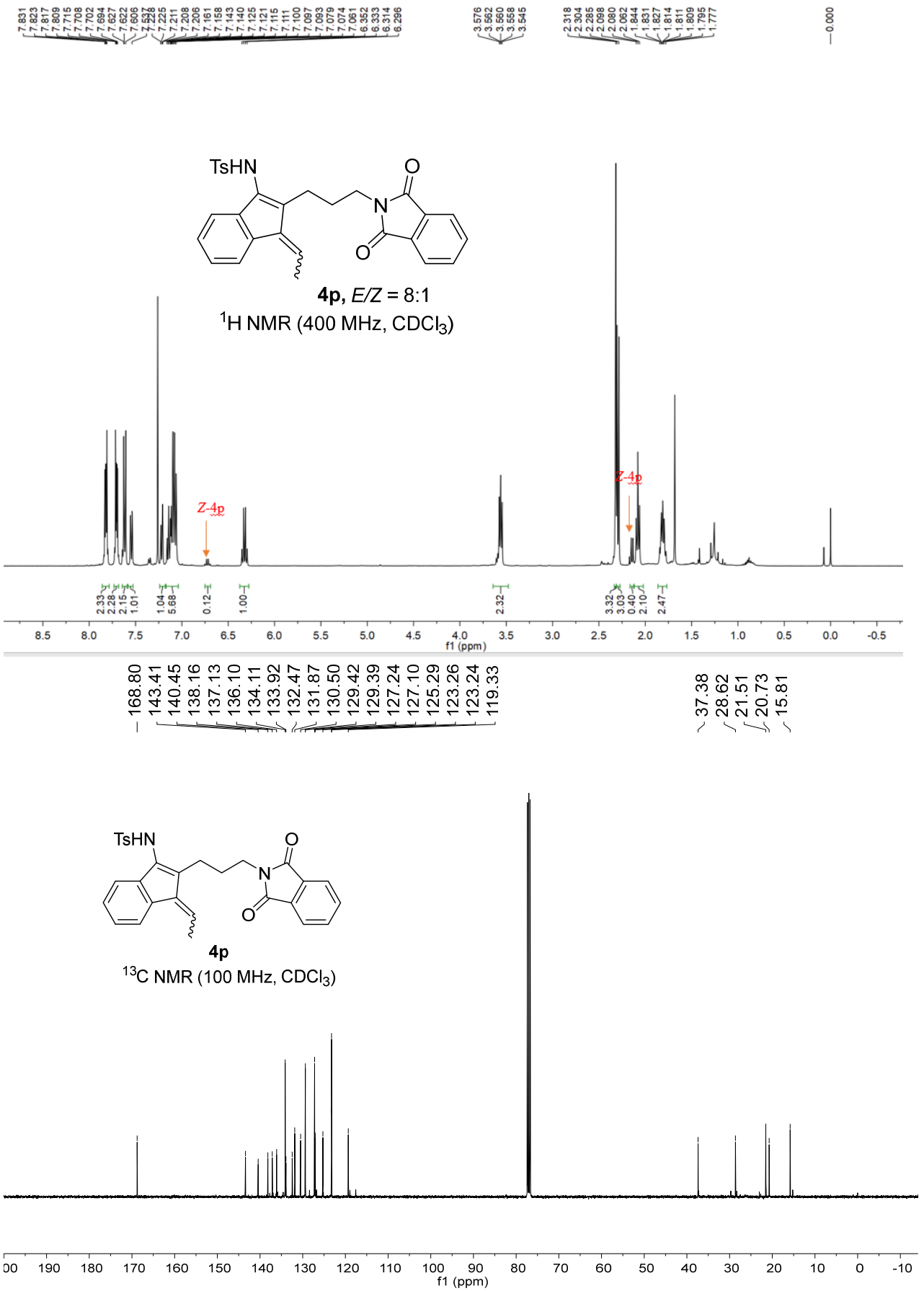


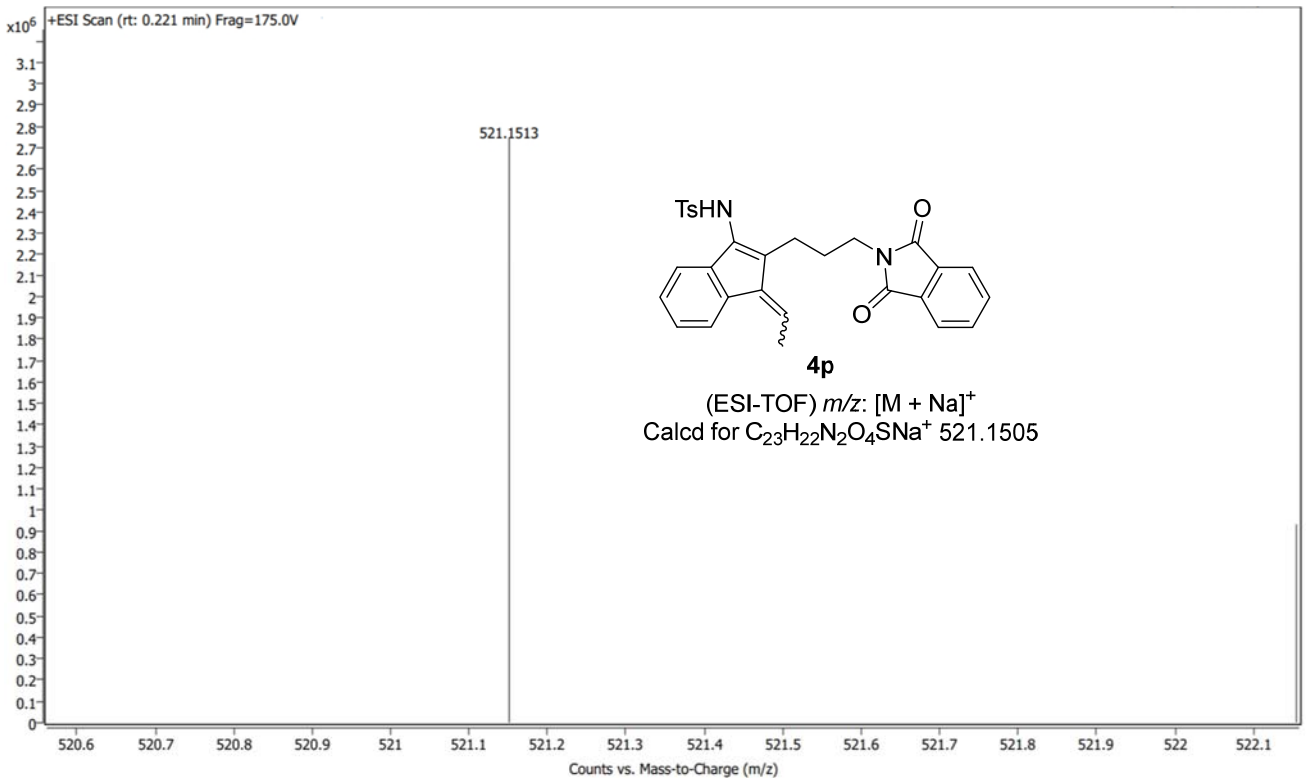


4o

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


+ESI Scan (rt: 0.200 min) Frag=175.0V
x10^6
4.8
4.6
4.4
4.2
4
3.8
3.6
3.4
3.2
3
2.8
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
416.1658
NHTs
4o
(ESI-TOF) m/z: [M + Na]+
Calcd for C24H27NO2SNa+ 416.1655
415.1
415.2
415.3
415.4
415.5
415.6
415.7
415.8
415.9
416
416.1
416.2
416.3
416.4
416.5
416.6
416.7
416.8
416.9
417
417.1
Counts vs. Mass-to-Charge (m/z)

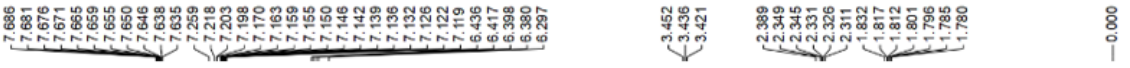

TsHN
O
N
O
4p, E/Z = 8:1
1H NMR (400 MHz, CDCl3)
Z-4p
Z-4p
f1 (ppm)
TsHN
O
N
O
4p
13C NMR (100 MHz, CDCl3)
f1 (ppm)

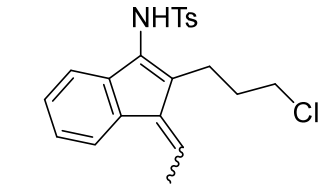


4p

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

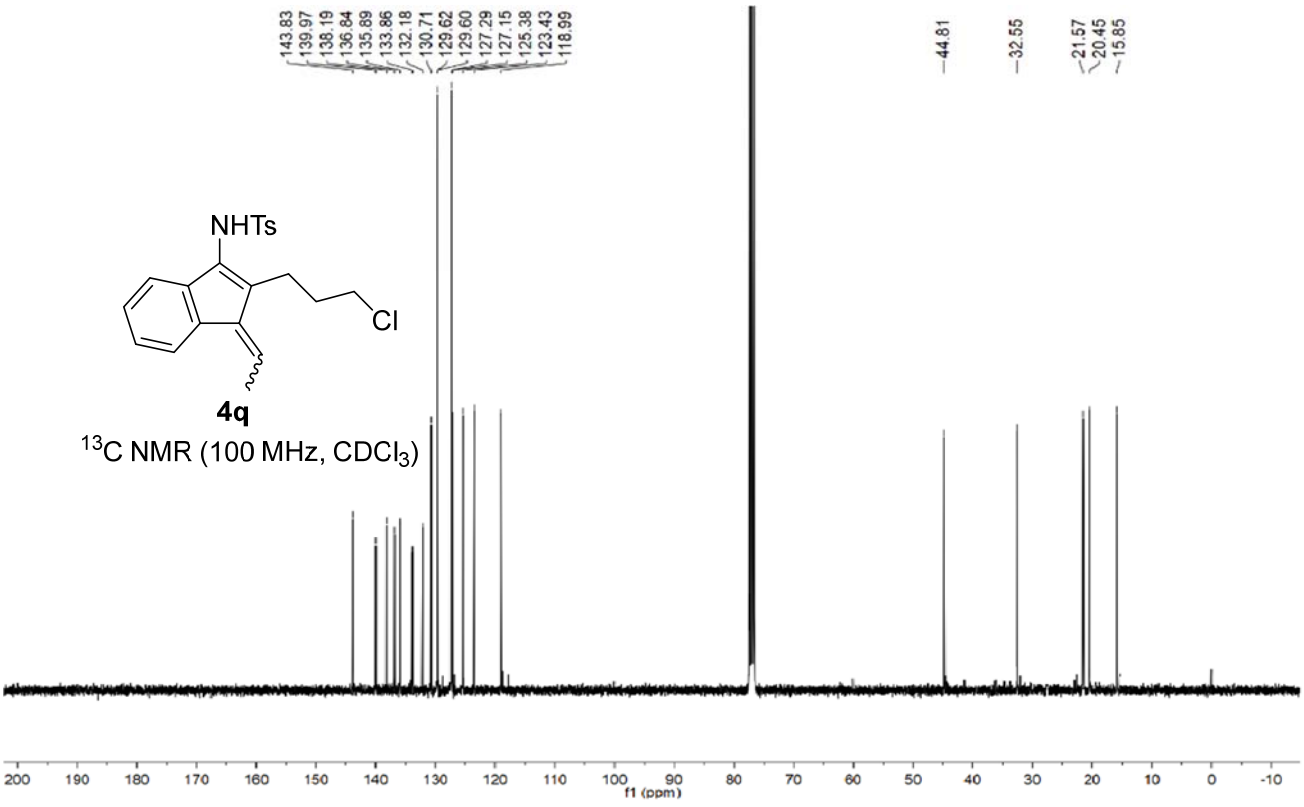
Calcd for $C_{23}H_{22}N_2O_4SNa^+$ 521.1505





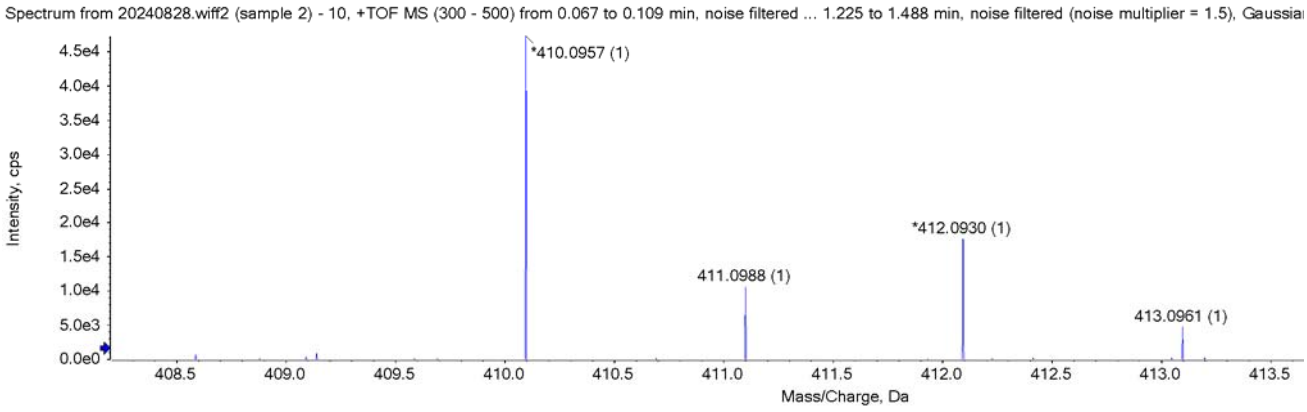
4q, *E/Z* = 12:1

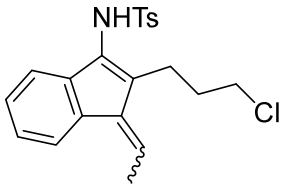
^{1}H NMR (400 MHz, $CDCl_3$)



4q

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



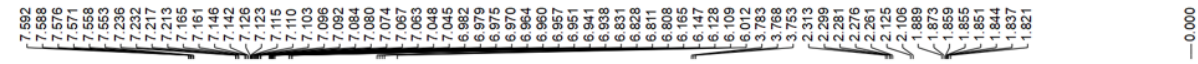


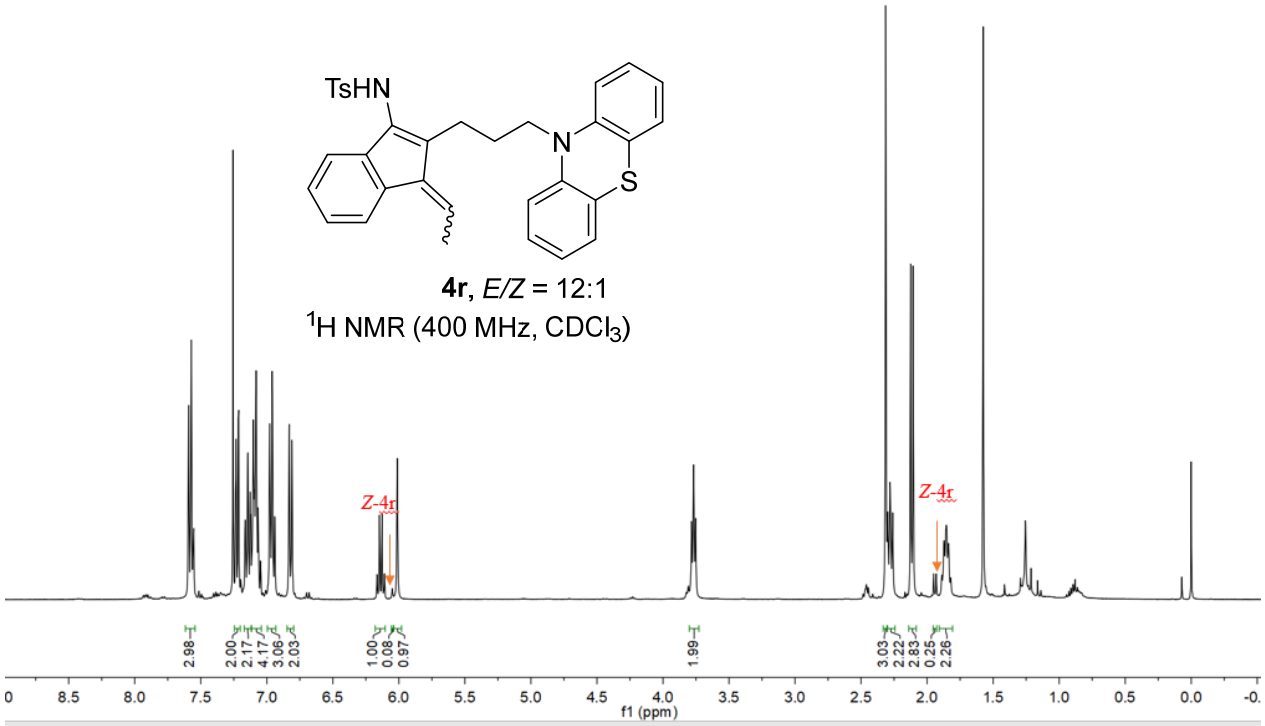
4q

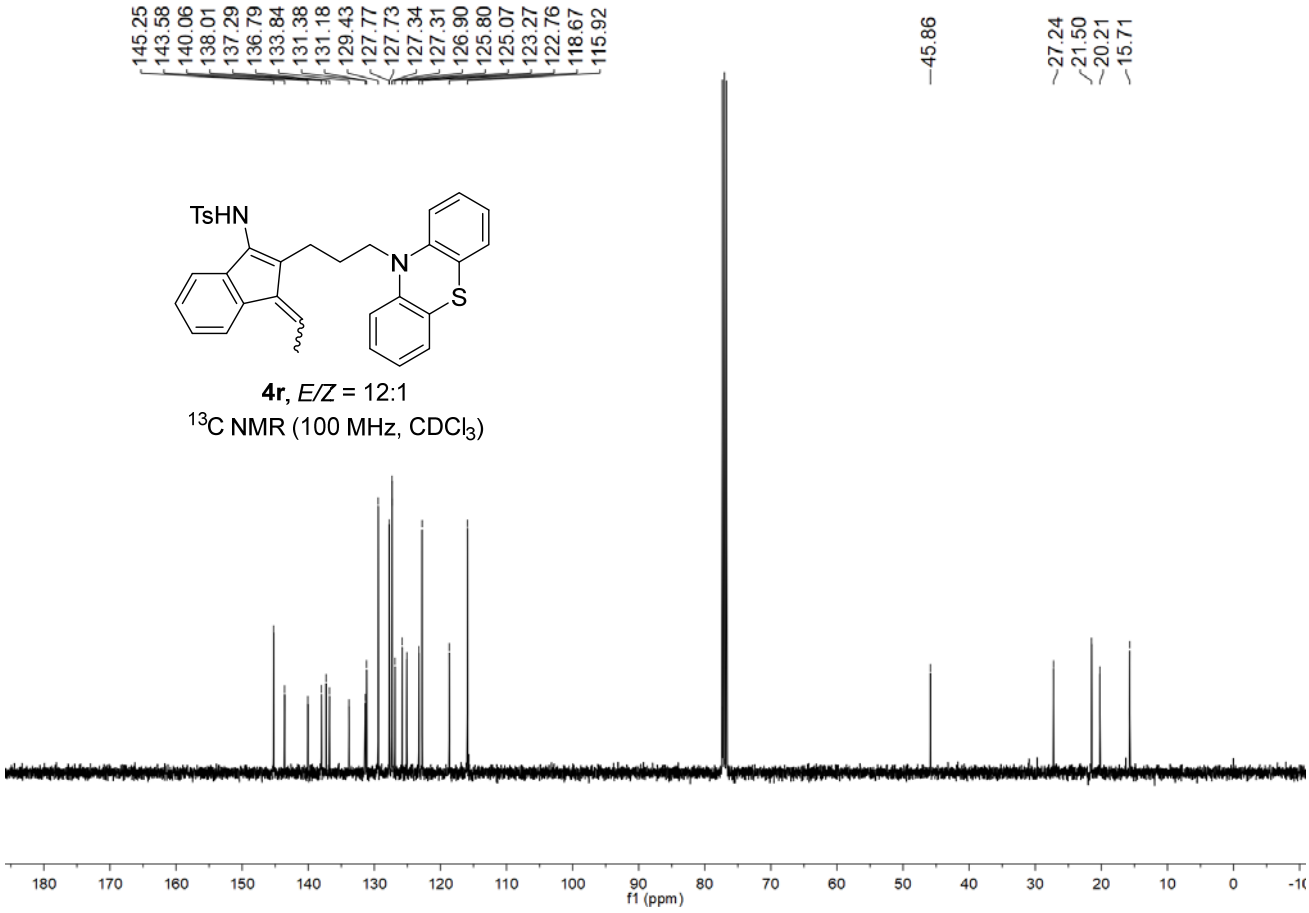
(ESI-TOF) *m/z*: $[M + Na]^+$

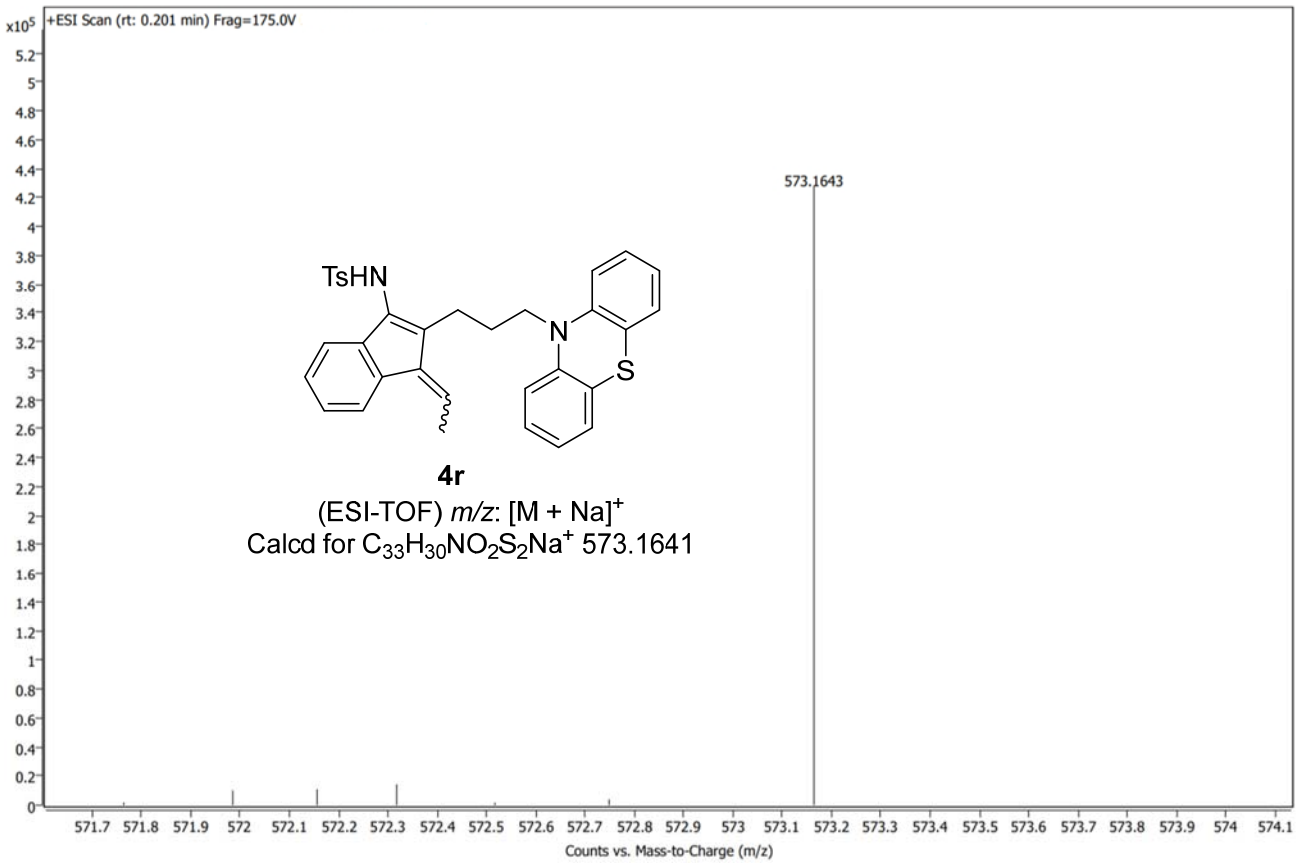
Calcd for $C_{21}H_{22}{}^{35}ClNO_2SNa^+$ 410.0952

Calcd for $C_{21}H_{22}{}^{37}ClNO_2SNa^+$ 412.0922




TsHN
N
S
4r, E/Z = 12:1
1H NMR (400 MHz, CDCl3)
Z-4r
Z-4r
f1 (ppm)

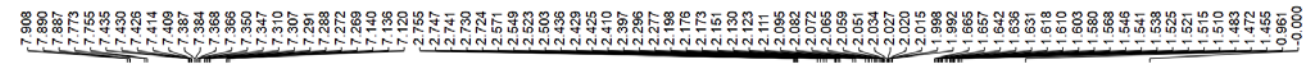

TsHN
N
S
4r, E/Z = 12:1
13C NMR (100 MHz, CDCl3)
f1 (ppm)

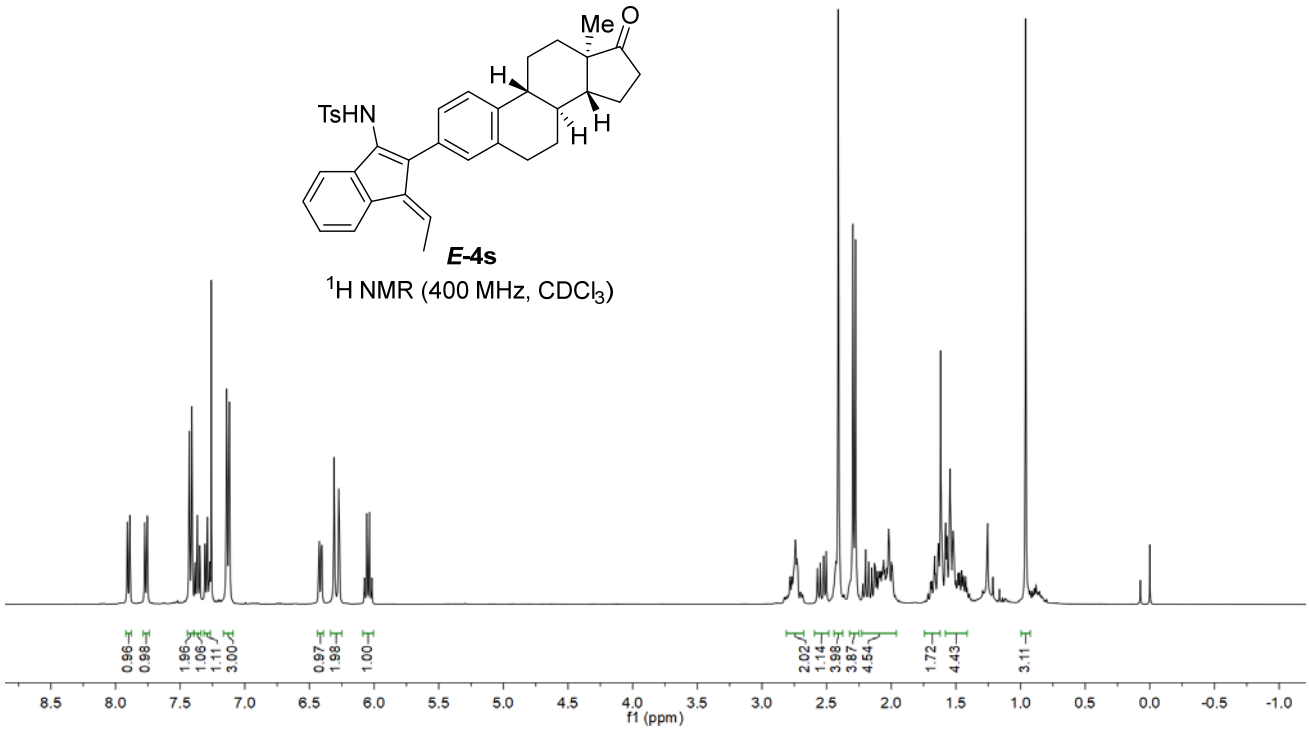


4r

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

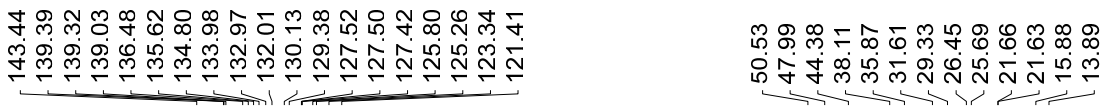
Calcd for $C_{33}H_{30}NO_2S_2Na^+$ 573.1641

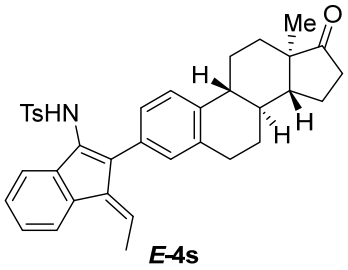




***E*-4s**

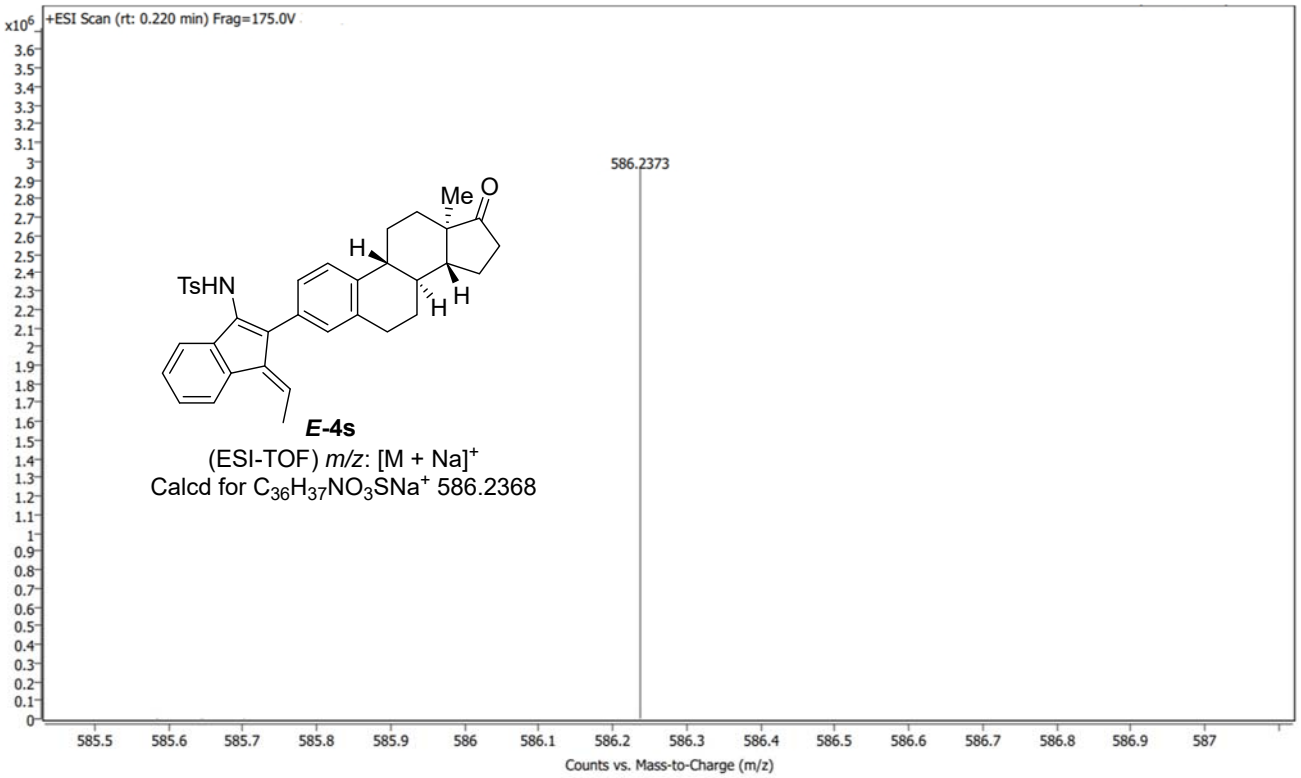
^{1}H NMR (400 MHz, $CDCl_3$)





***E*-4s**

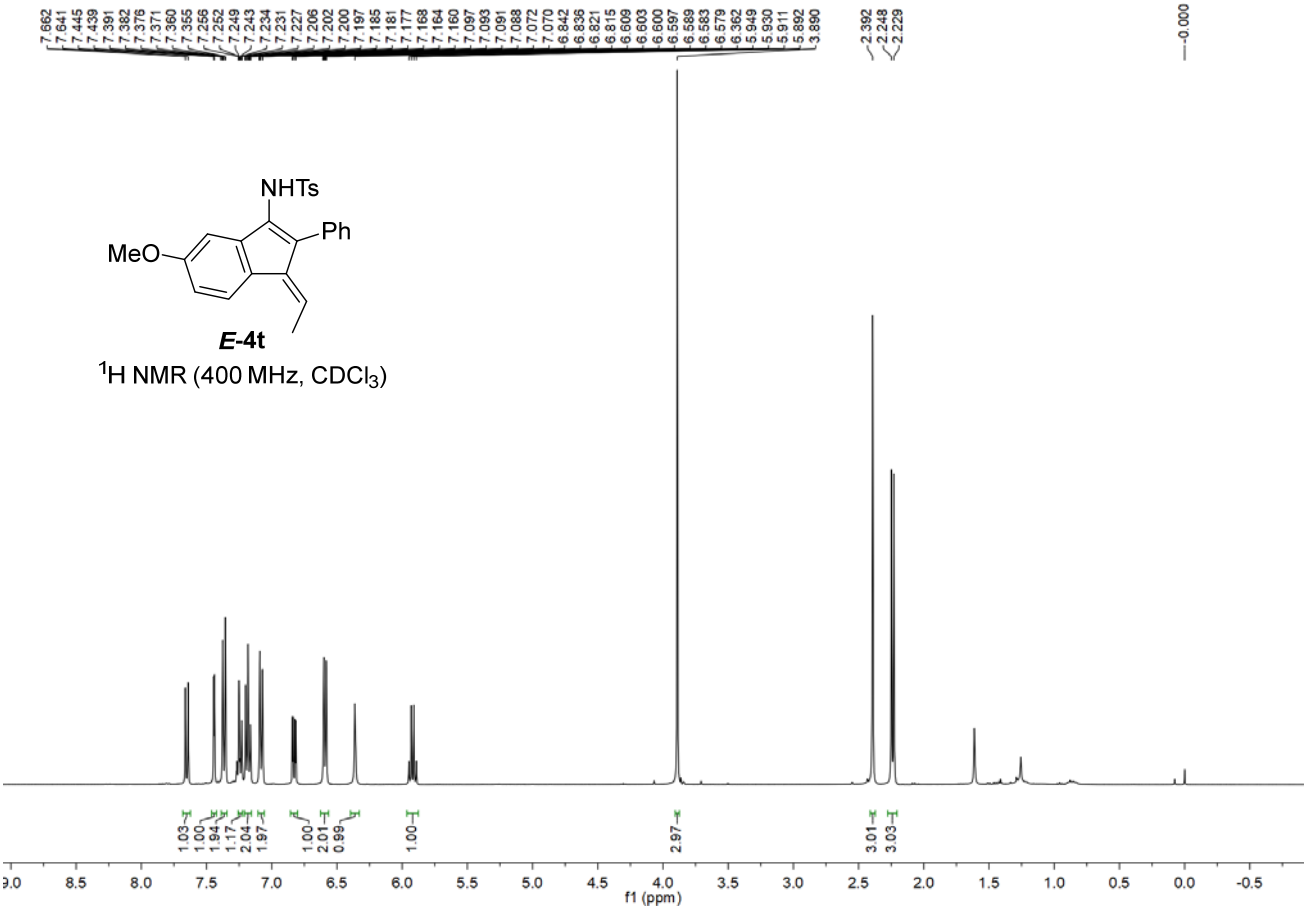
^{13}C NMR (100 MHz, $CDCl_3$)



***E*-4s**

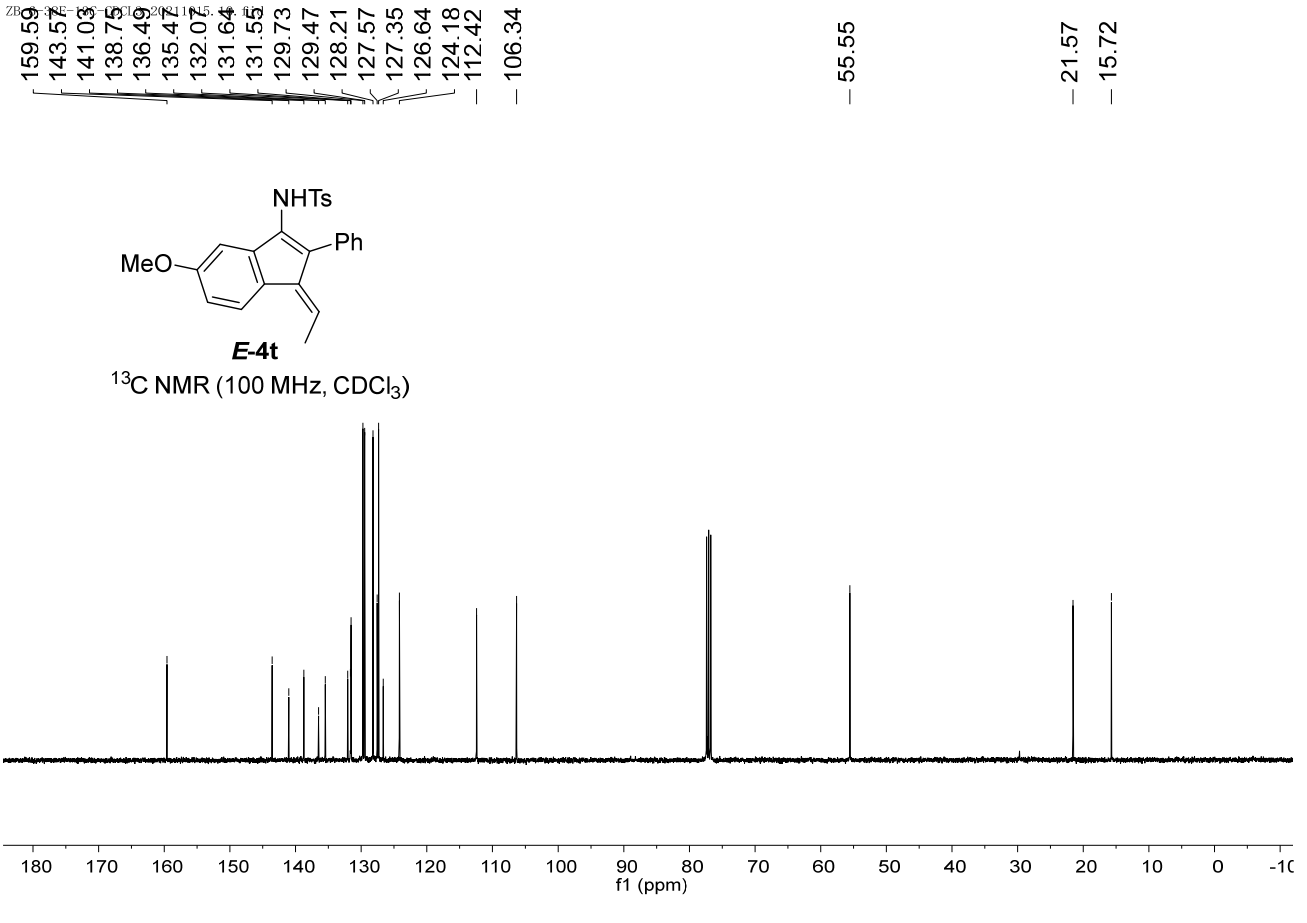
(ESI-TOF) *m/z*: $[M + Na]^+$

Calcd for $C_{36}H_{37}NO_3SNa^+$ 586.2368



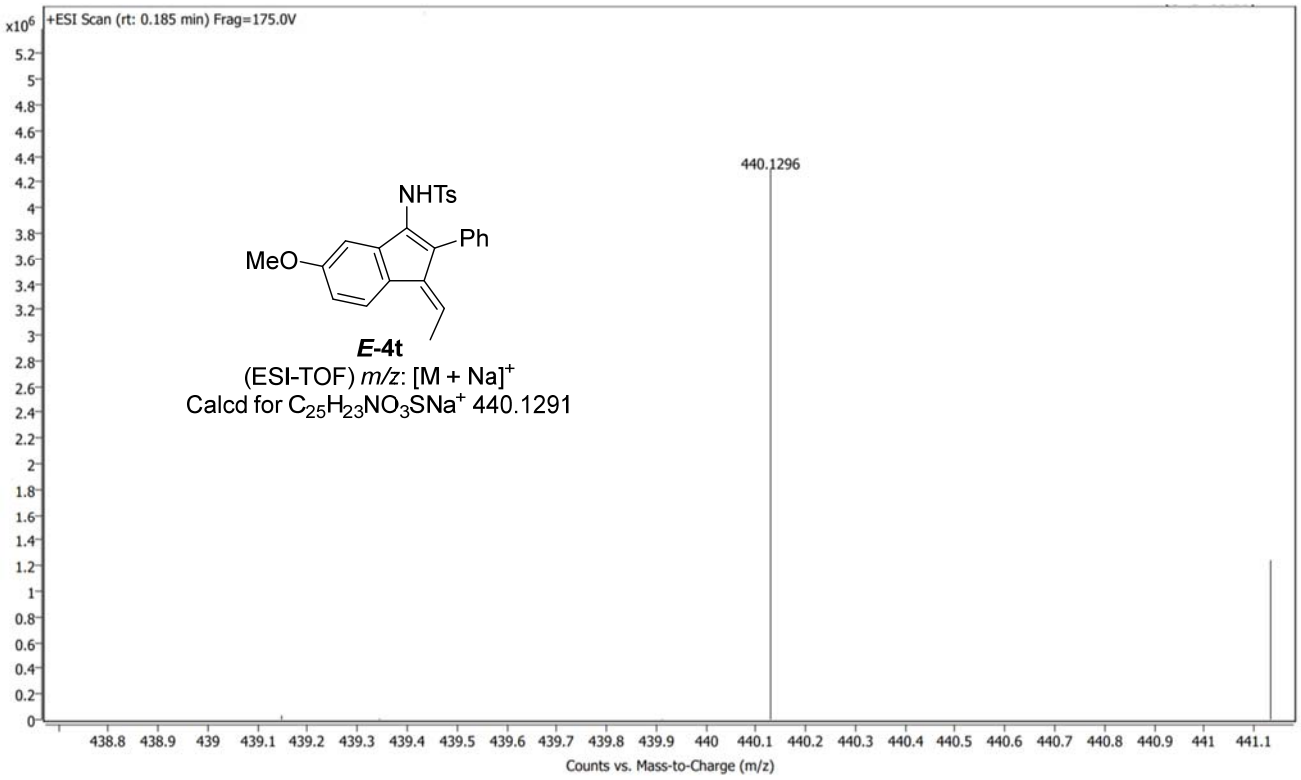
***E*-4t**

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



***E*-4t**

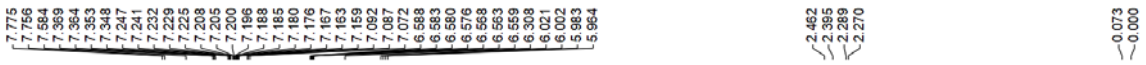
^{13}C NMR (100 MHz, $CDCl_3$)

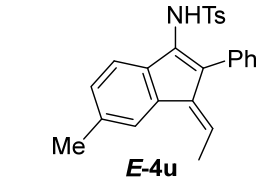


***E*-4t**

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

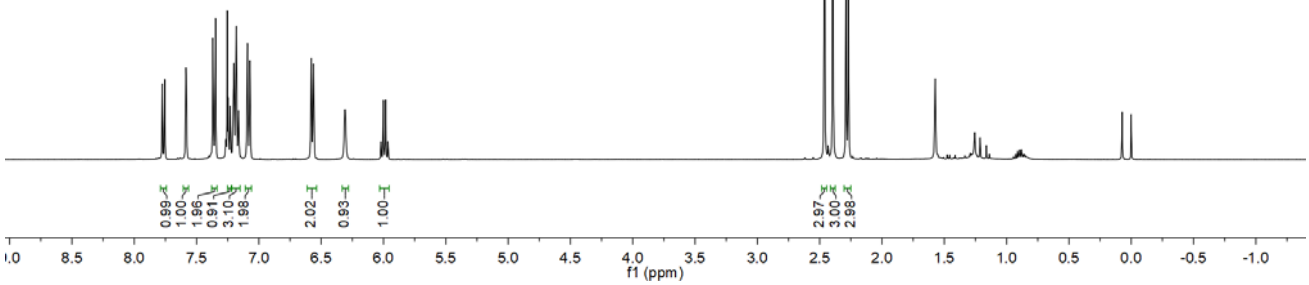
Calcd for $C_{25}H_{23}NO_3SNa^+$ 440.1291

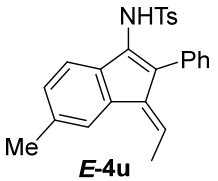




***E*-4u**

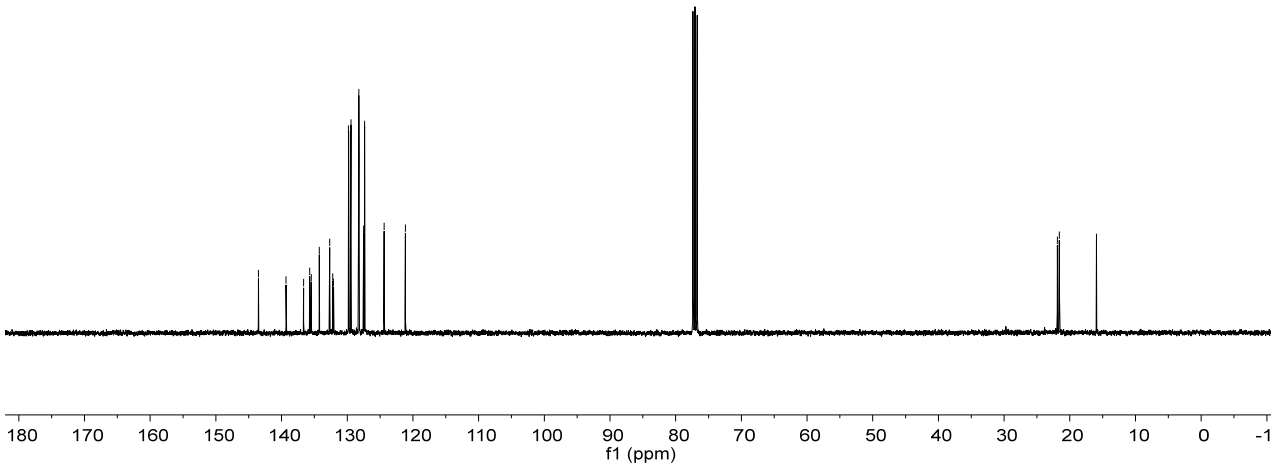
^{1}H NMR (400 MHz, $CDCl_3$)

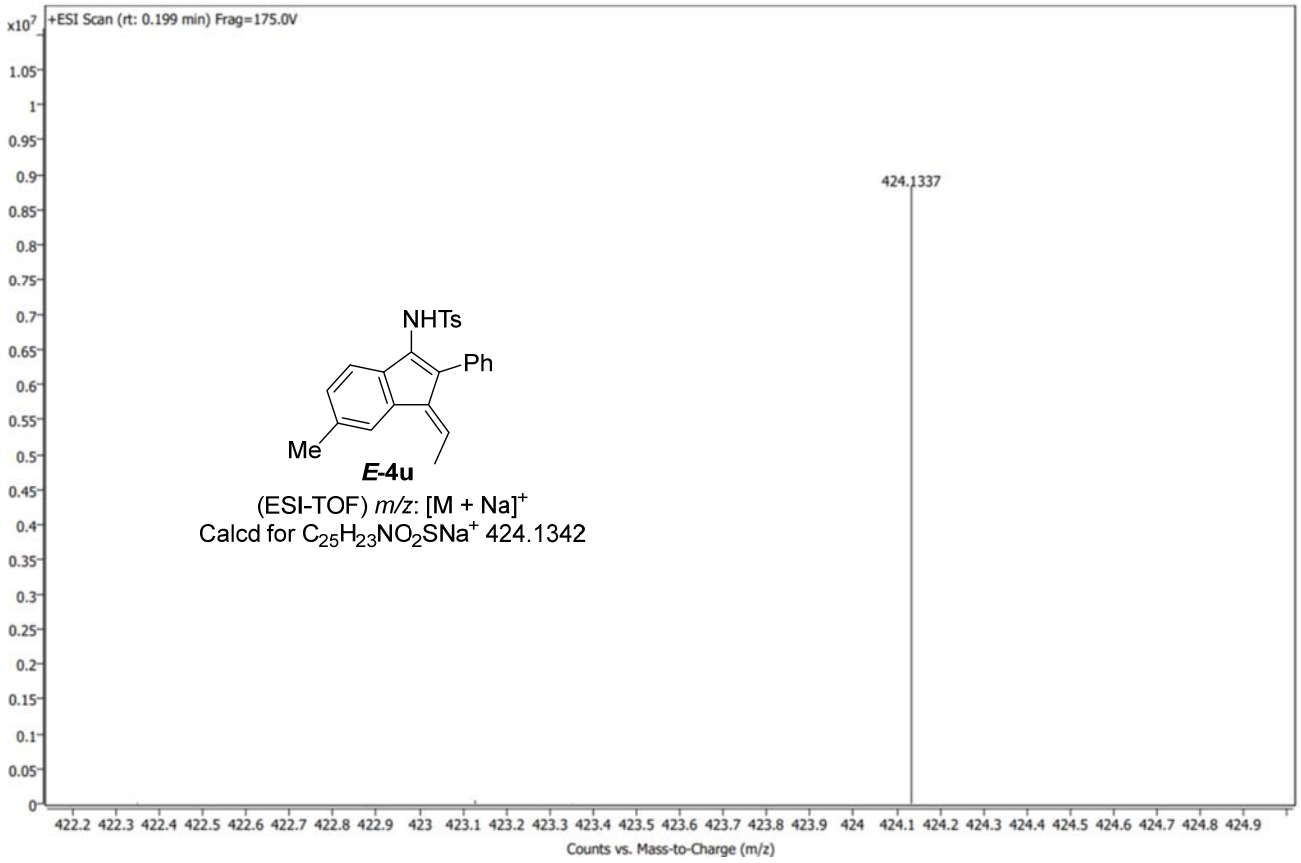




***E*-4u**

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

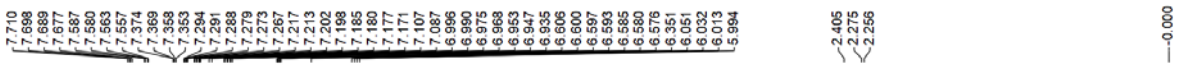


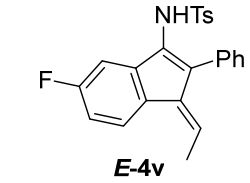


***E*-4u**

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

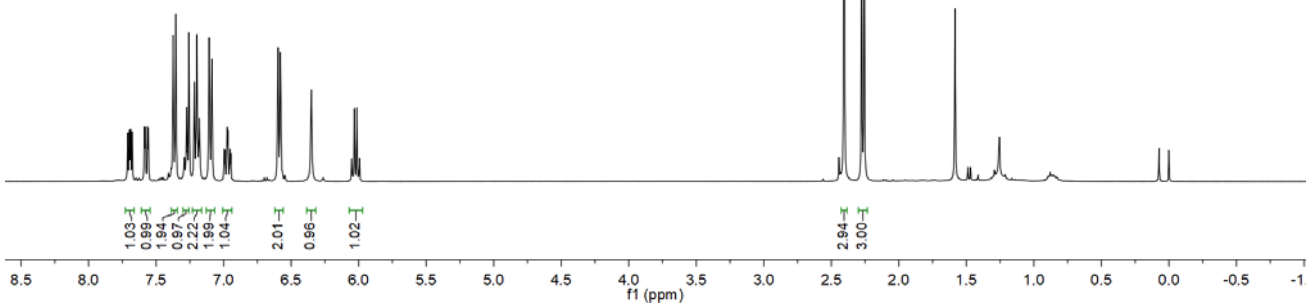
Calcd for $C_{25}H_{23}NO_2SNa^+$ 424.1342

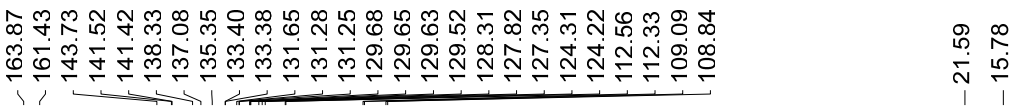


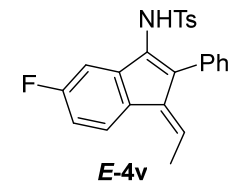


***E*-4v**

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

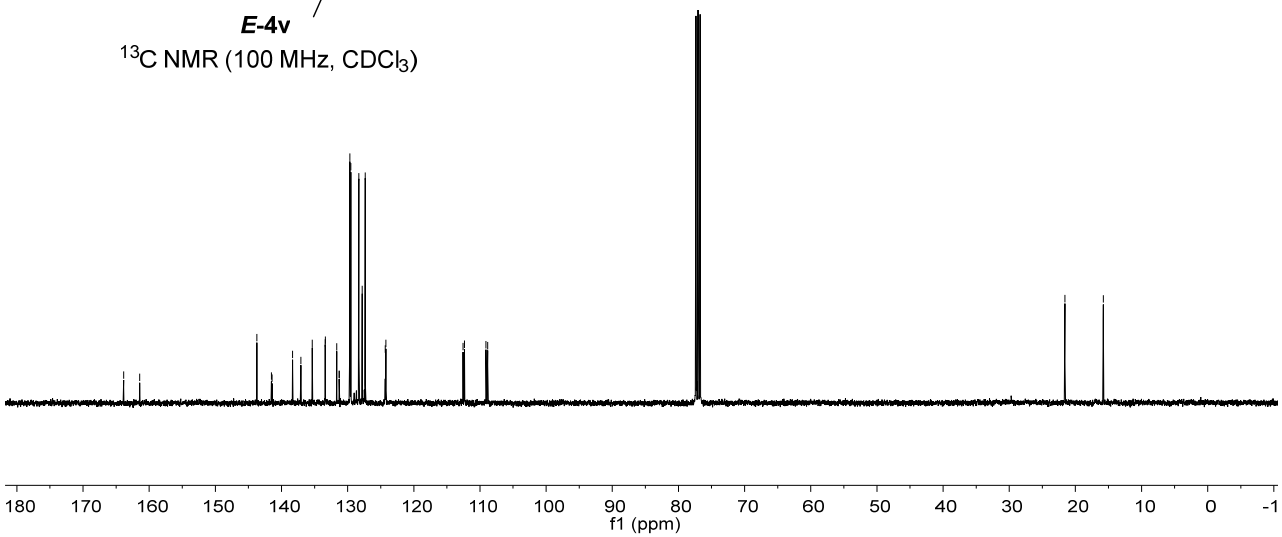


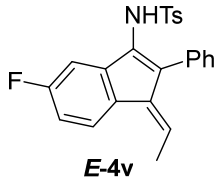




***E*-4v**

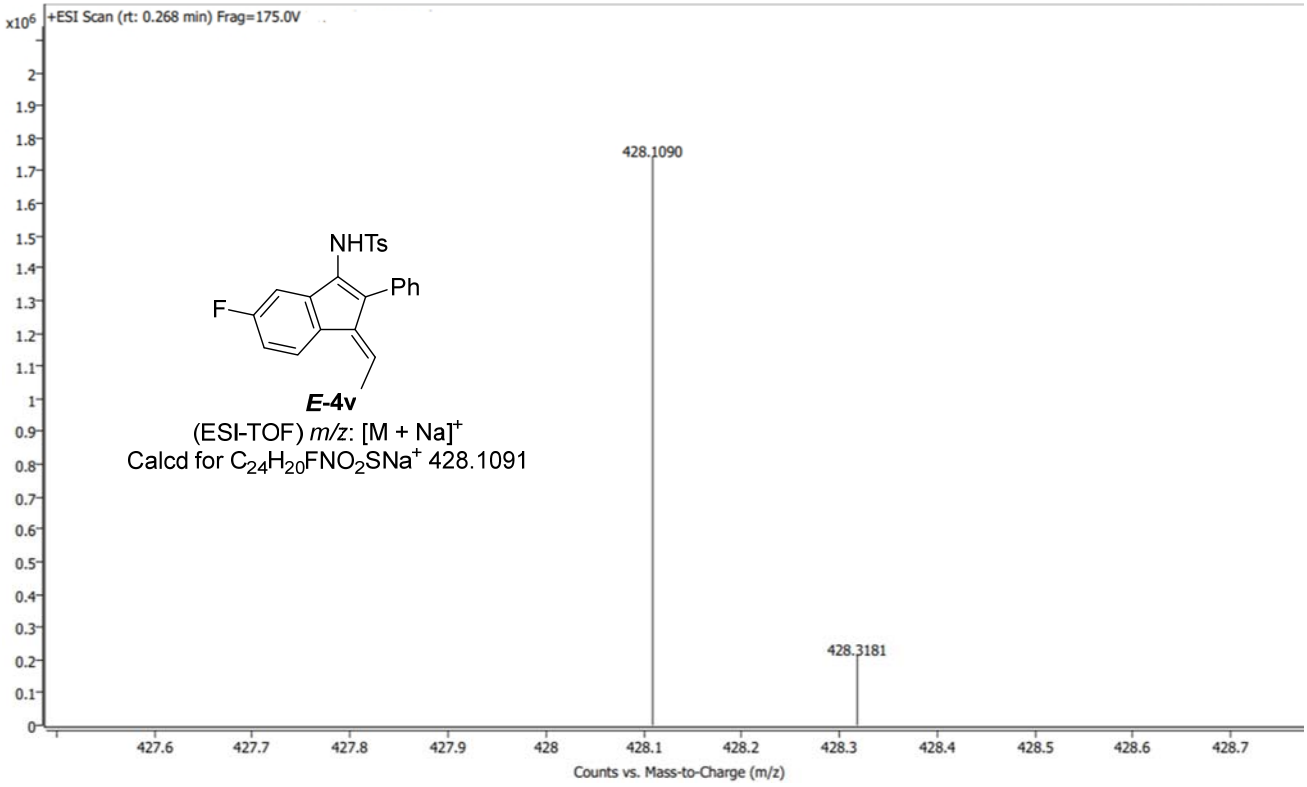
^{13}C NMR (100 MHz, $CDCl_3$)





***E*-4v**

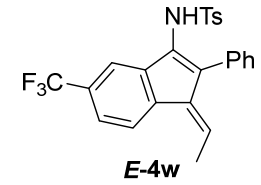
^{19}F NMR (375 MHz, $CDCl_3$))



***E*-4v**

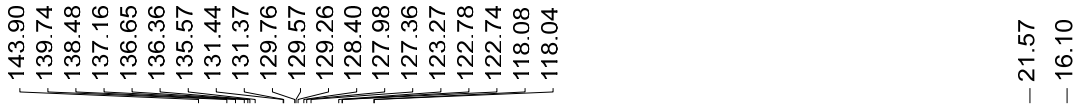
(ESI-TOF) *m/z*: $[M + Na]^+$

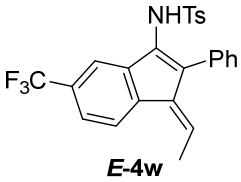
Calcd for $C_{24}H_{20}FNO_2SNa^+$ 428.1091



***E*-4w**

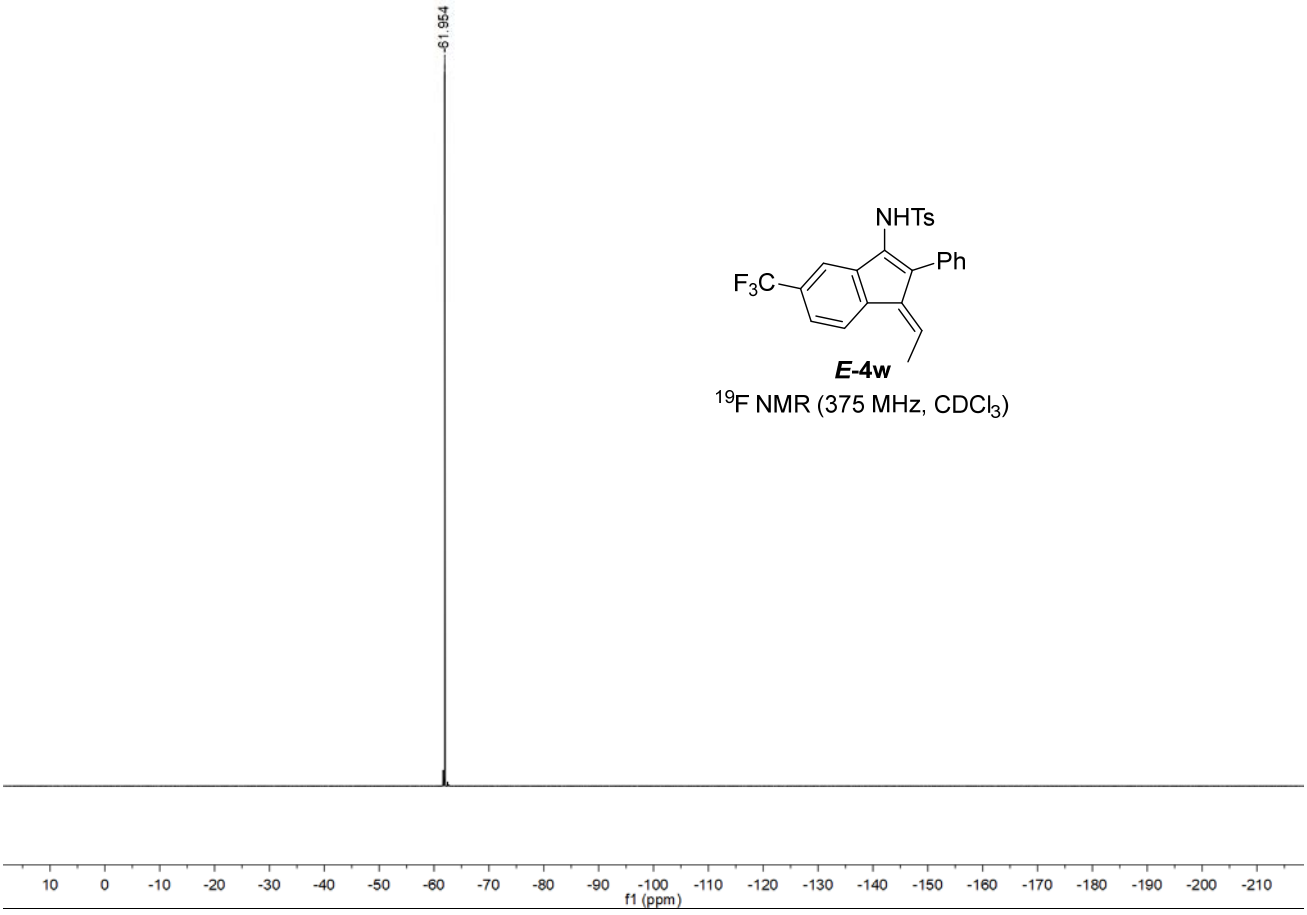
^{1}H NMR (400 MHz, $CDCl_3$)





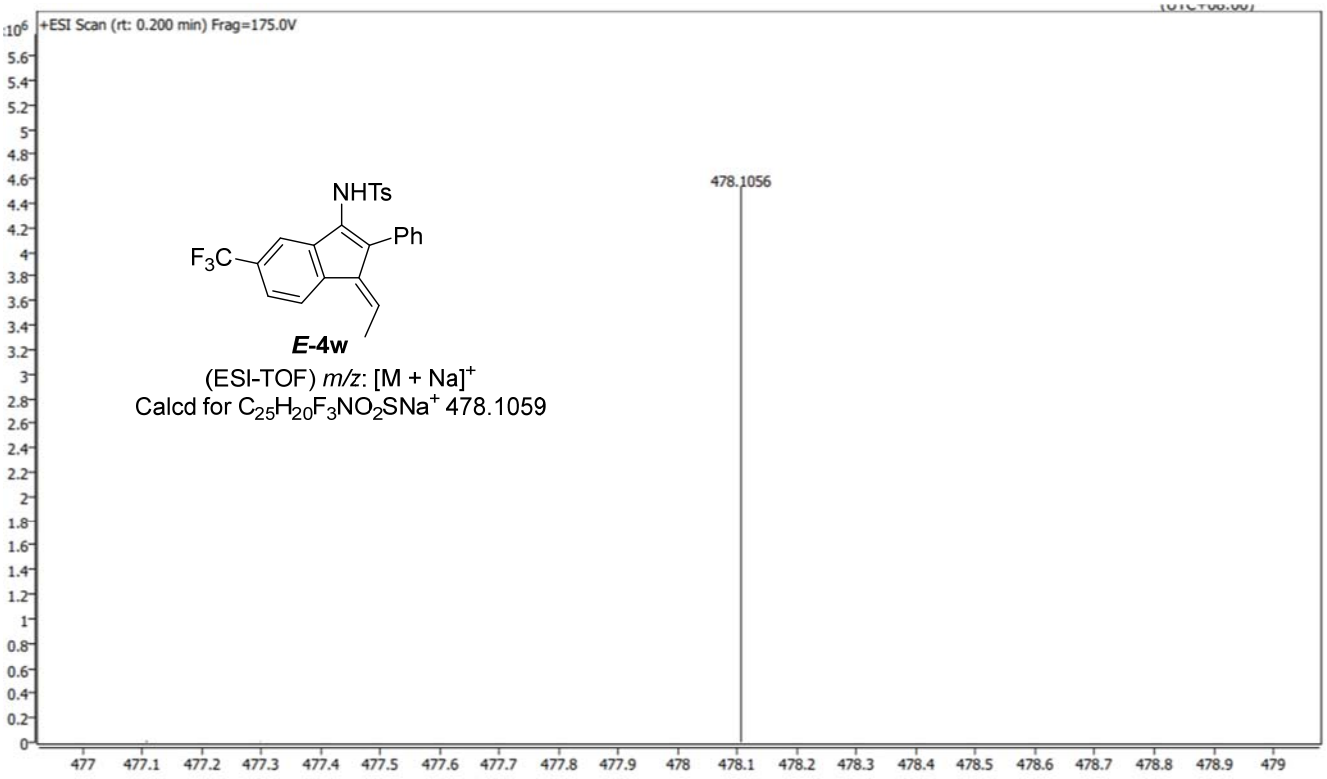
***E*-4w**

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



***E*-4w**

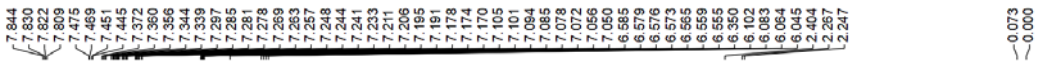
^{19}F NMR (375 MHz, $CDCl_3$)

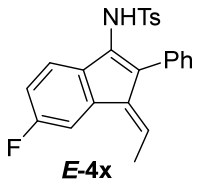


***E*-4w**

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

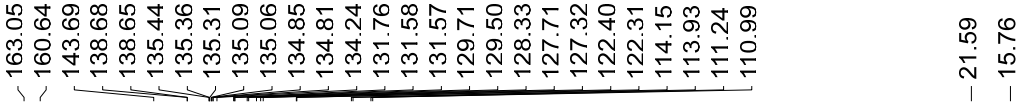
Calcd for $C_{25}H_{20}F_3NO_2SNa^+$ 478.1059

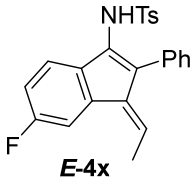




***E*-4x**

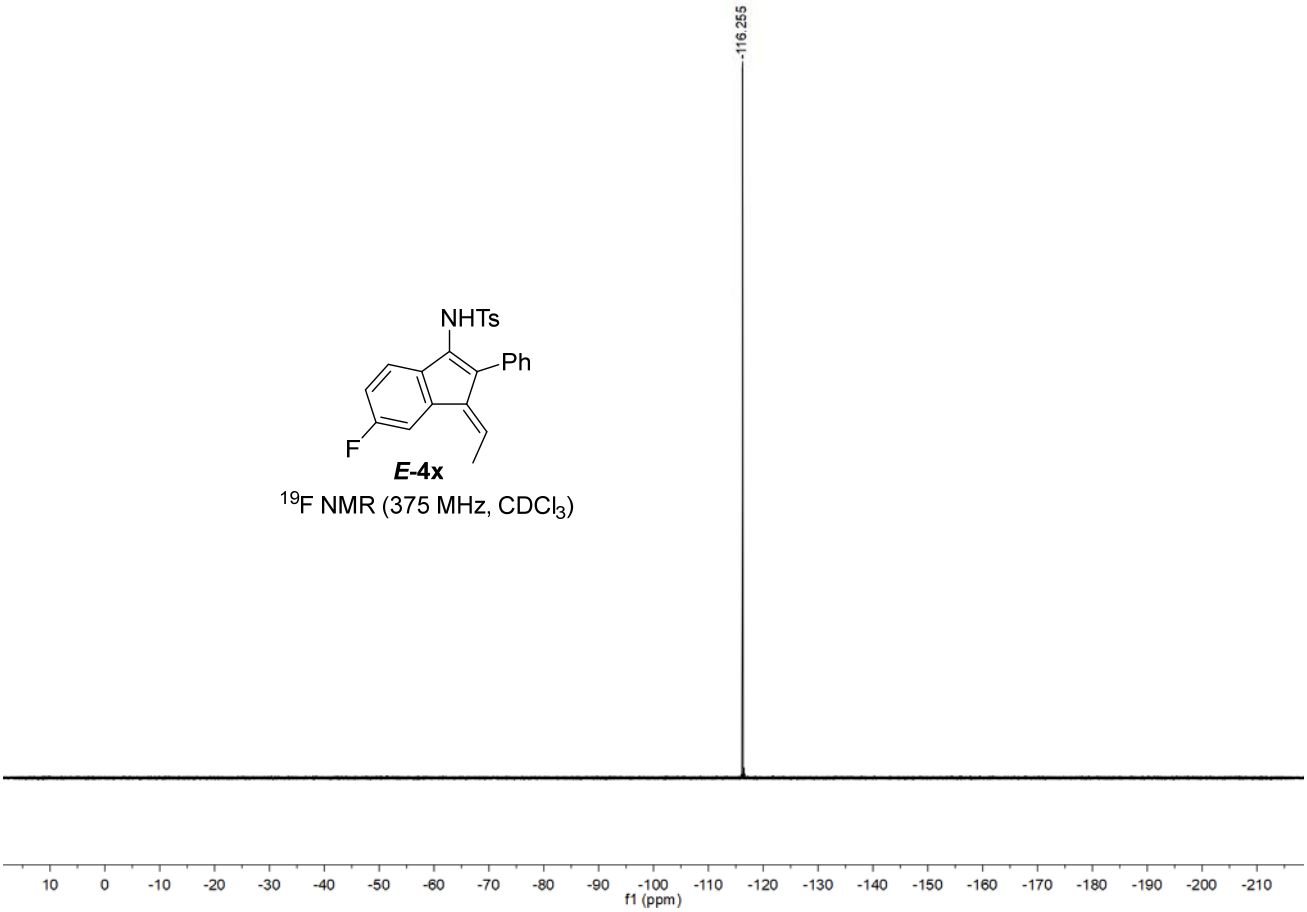
^{1}H NMR (400 MHz, $CDCl_3$)





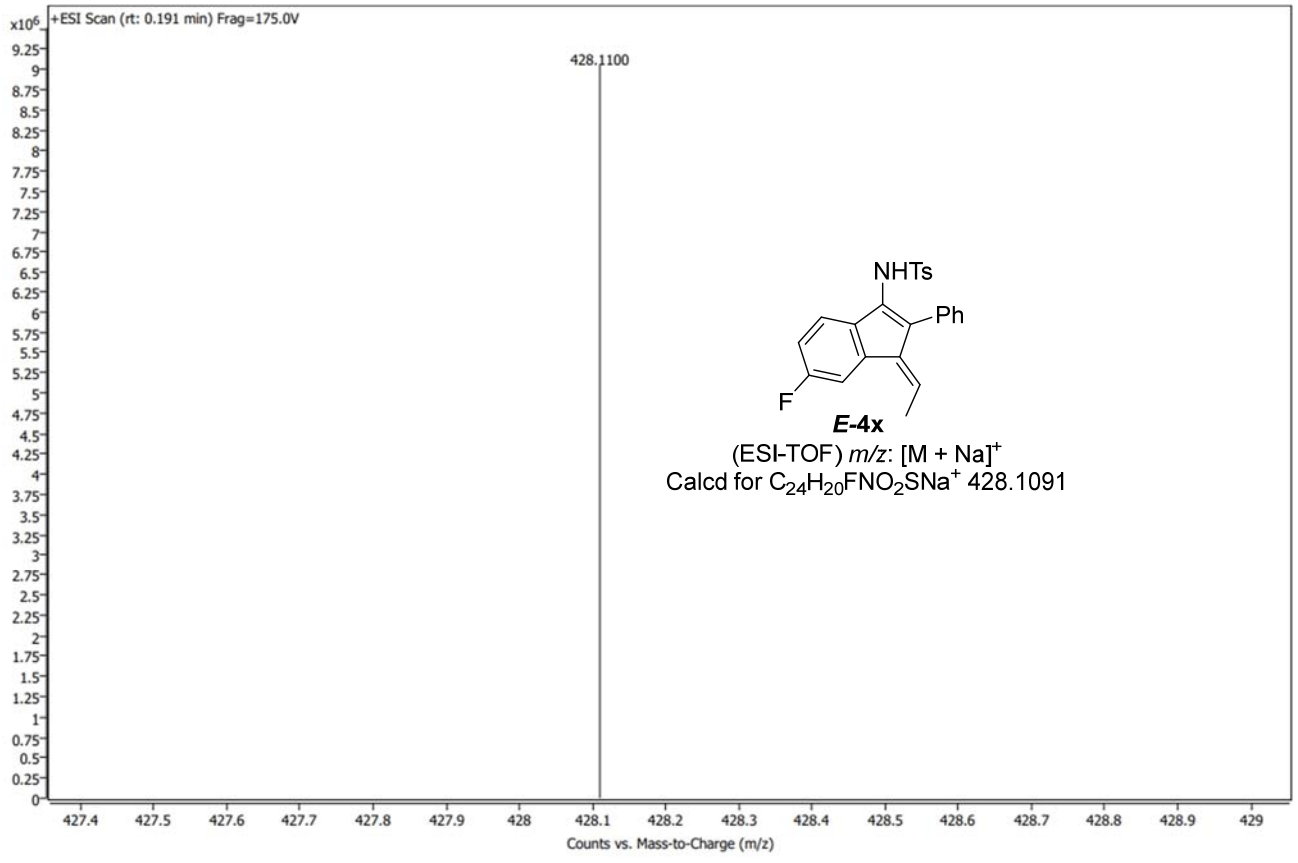
***E*-4x**

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



***E*-4x**

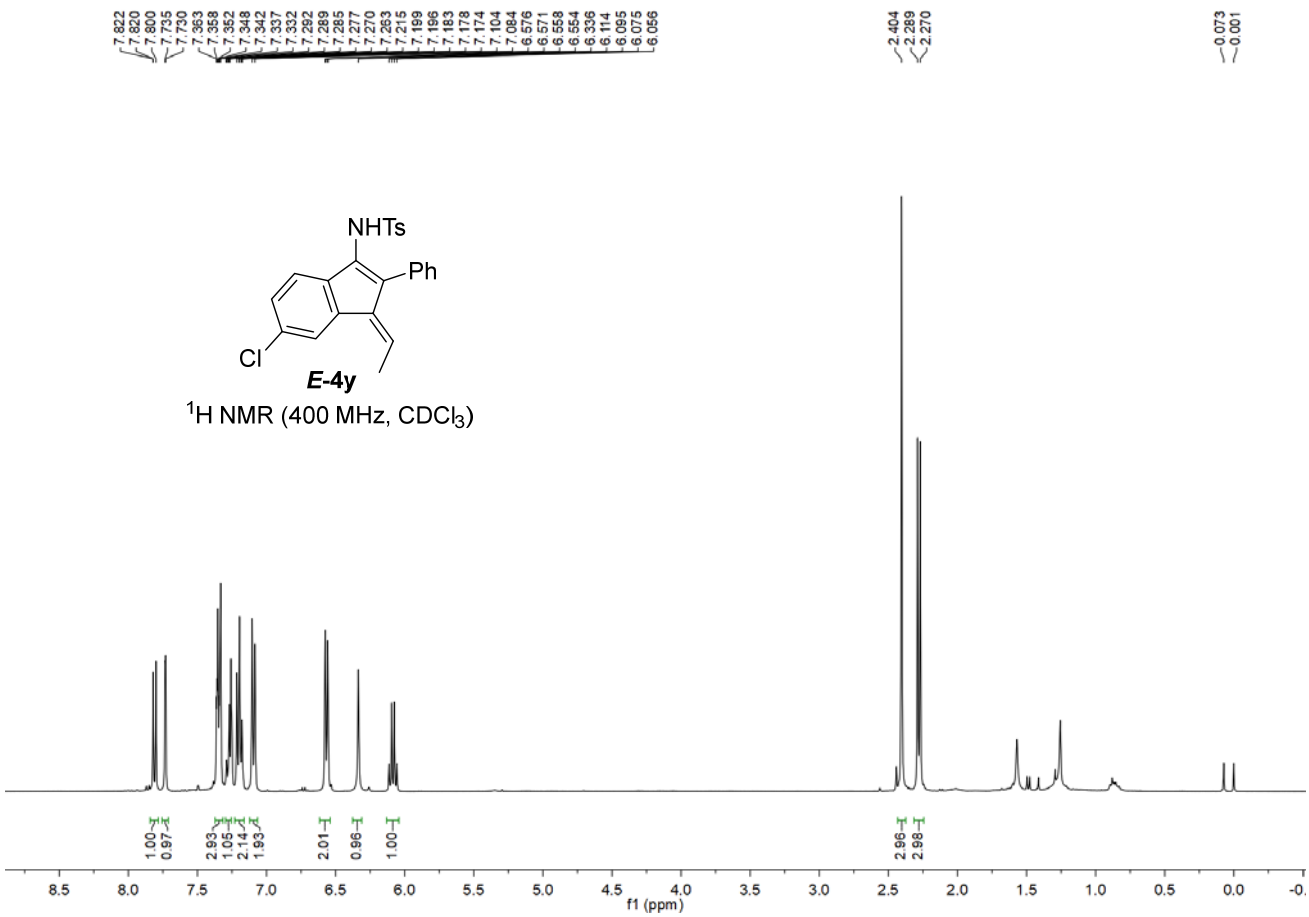
^{19}F NMR (375 MHz, $CDCl_3$)



***E*-4x**

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

Calcd for $C_{24}H_{20}FNO_2SNa^+$ 428.1091


7.822
7.820
7.800
7.735
7.730
7.363
7.358
7.352
7.348
7.342
7.337
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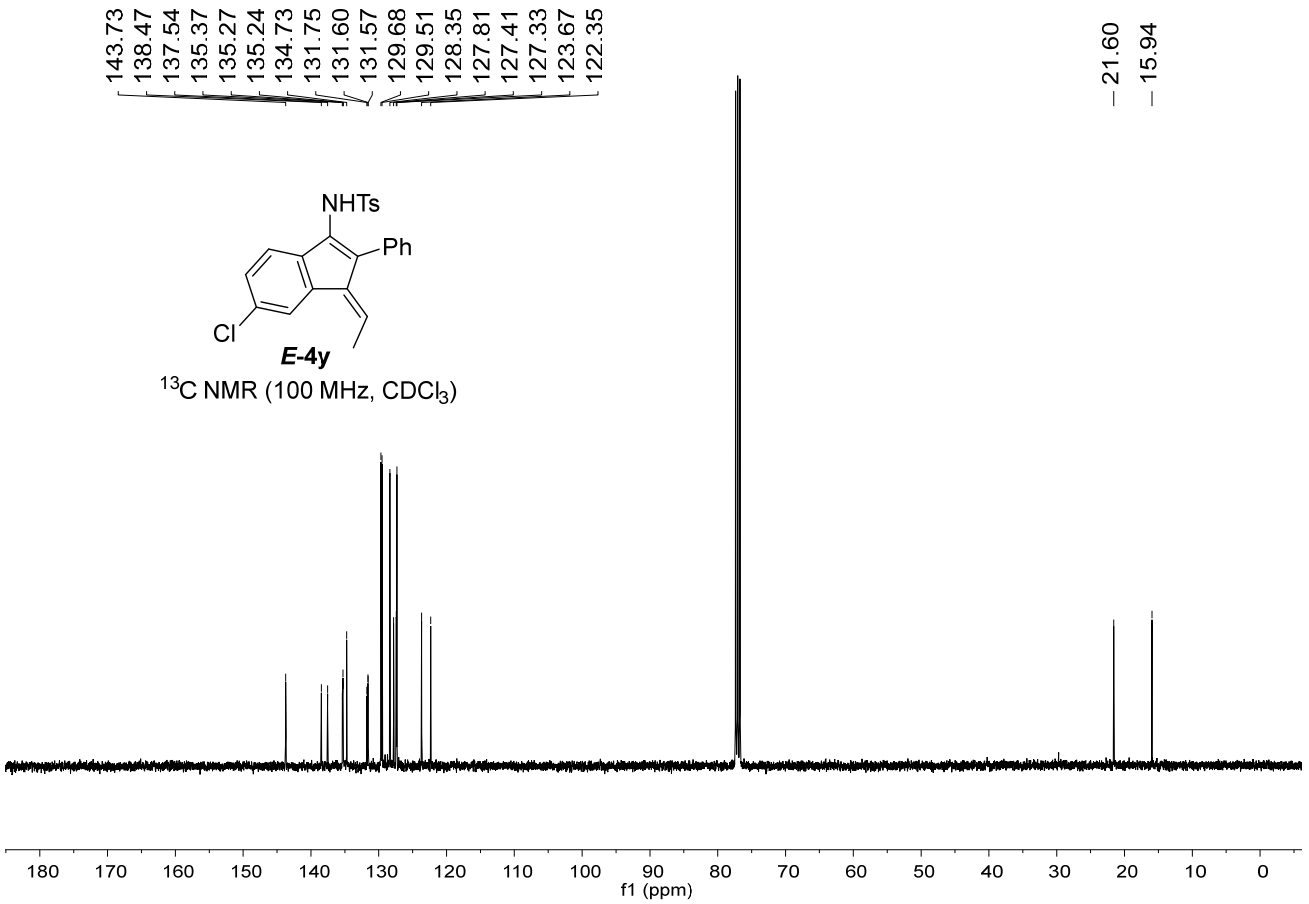
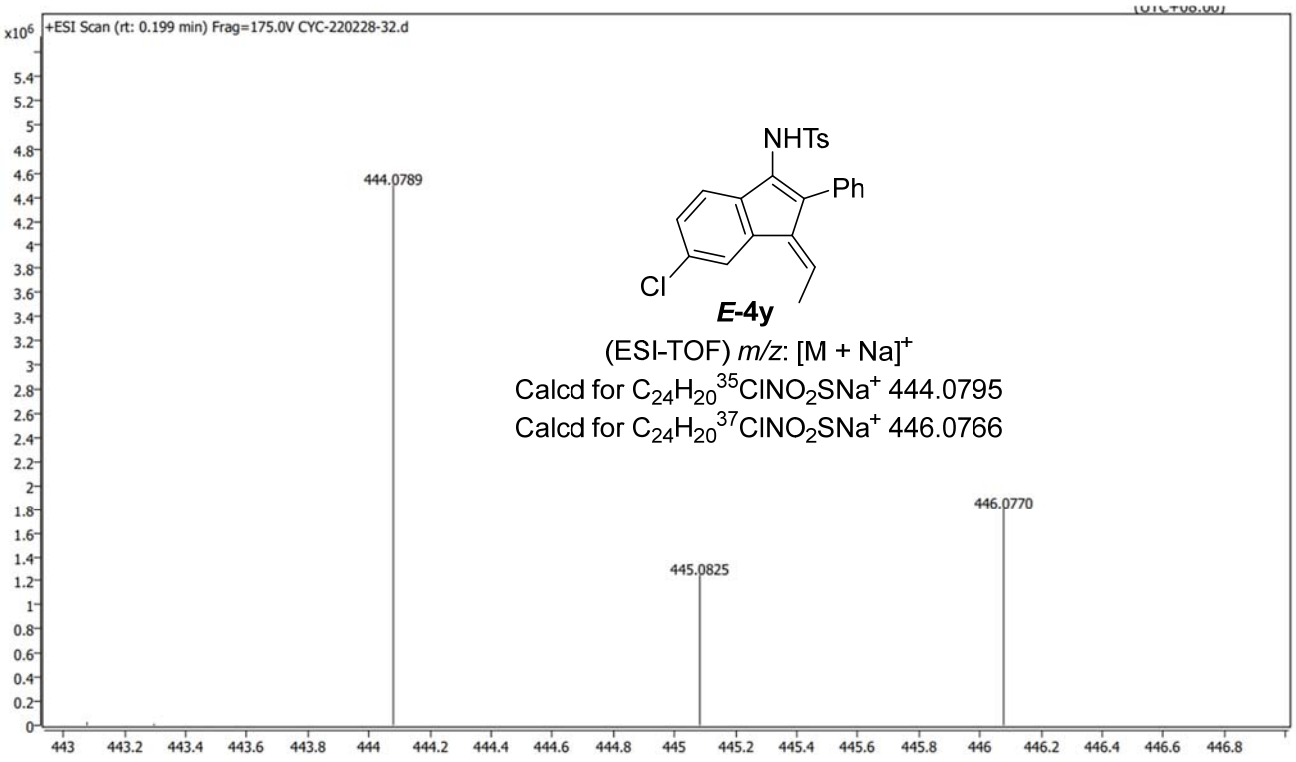
7.292
7.289
7.285
7.277
7.270
7.263
7.215
7.199
7.196
7.183
7.178
7.174
7.104
7.084
6.576
6.571
6.558
6.554
6.336
6.114
6.095
6.075
6.056
2.404
2.289
2.270
0.073
0.001
NHTs
Ph
Cl
E-4y
1H NMR (400 MHz, CDCl3)
1.00
0.97
2.93
1.05
2.14
1.93
2.01
0.96
1.00
2.96
2.98
f1 (ppm)


143.73
138.47
137.54
135.37
135.27
135.24
134.73
131.75
131.60
131.57
129.68
129.51
128.35
127.81
127.41
127.33
123.67
122.35
21.60
15.94
NHTs
Ph
Cl
E-4y
13C NMR (100 MHz, CDCl3)
f1 (ppm)

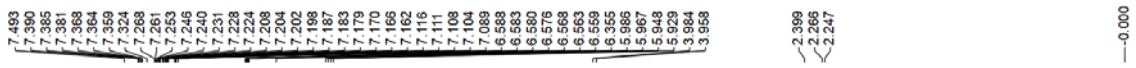


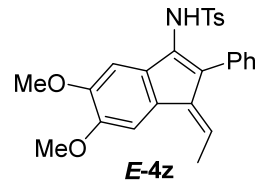
***E*-4y**

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

Calcd for $C_{24}H_{20}{}^{35}ClNO_2SNa^+$ 444.0795

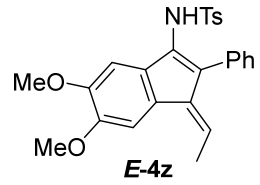
Calcd for $C_{24}H_{20}{}^{37}ClNO_2SNa^+$ 446.0766





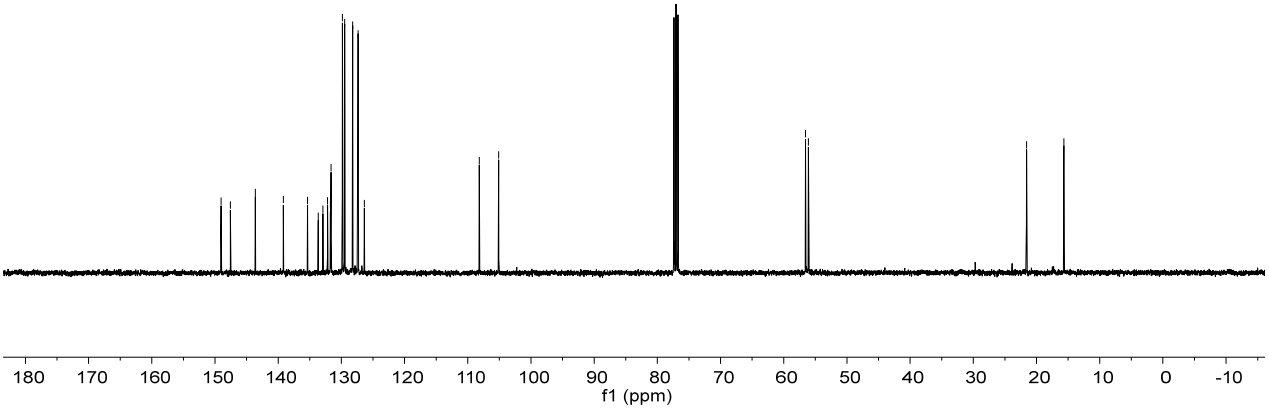
***E*-4z**

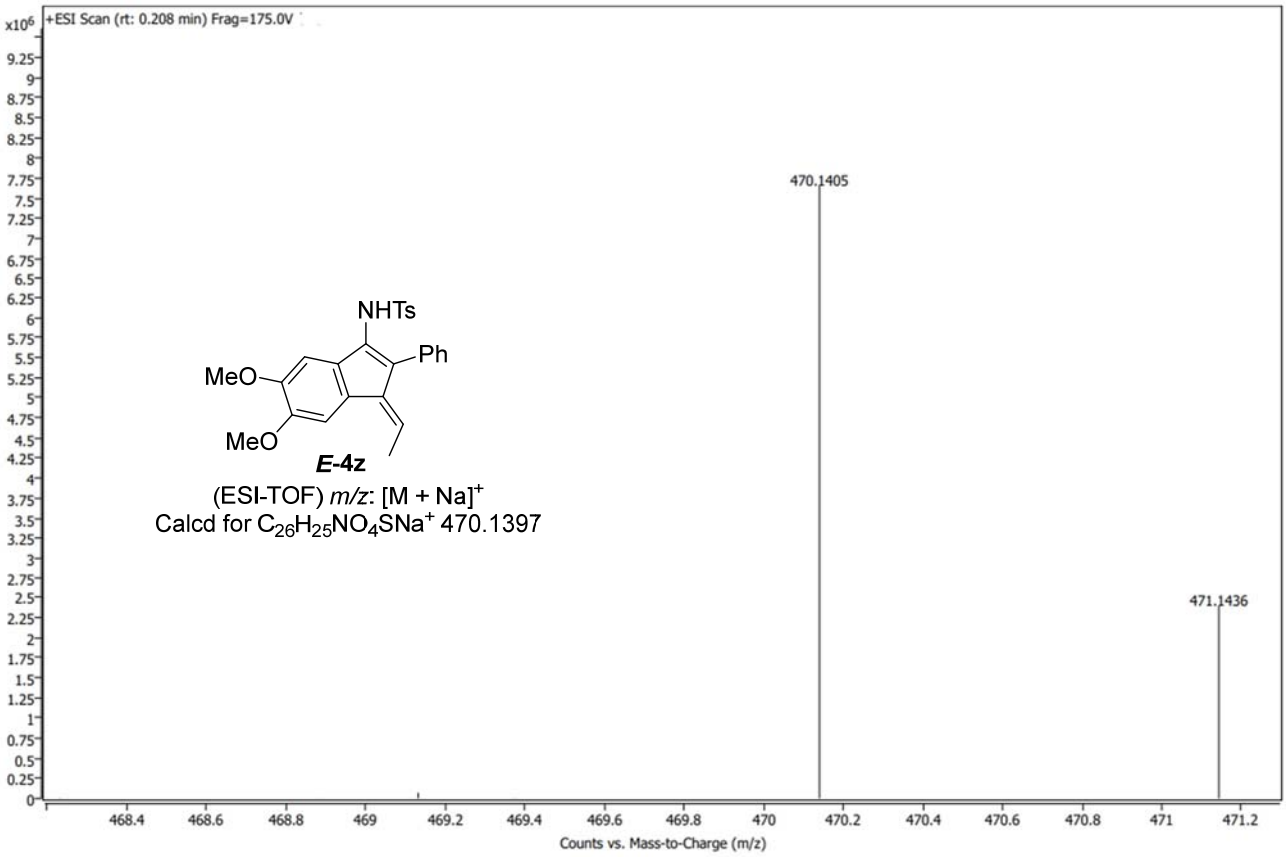
^{1}H NMR (400 MHz, $CDCl_3$)



***E*-4z**

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

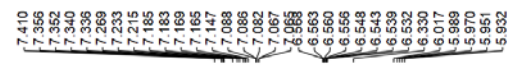


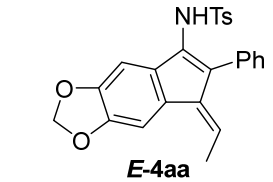


***E*-4z**

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

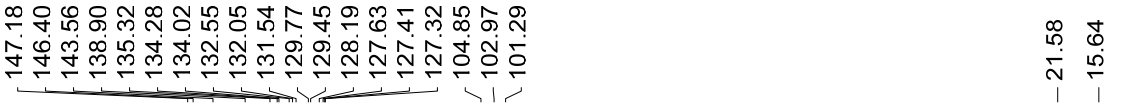
Calcd for $C_{26}H_{25}NO_4SNa^+$ 470.1397

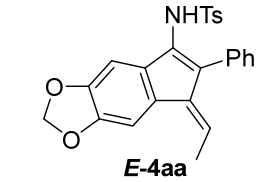




***E*-4aa**

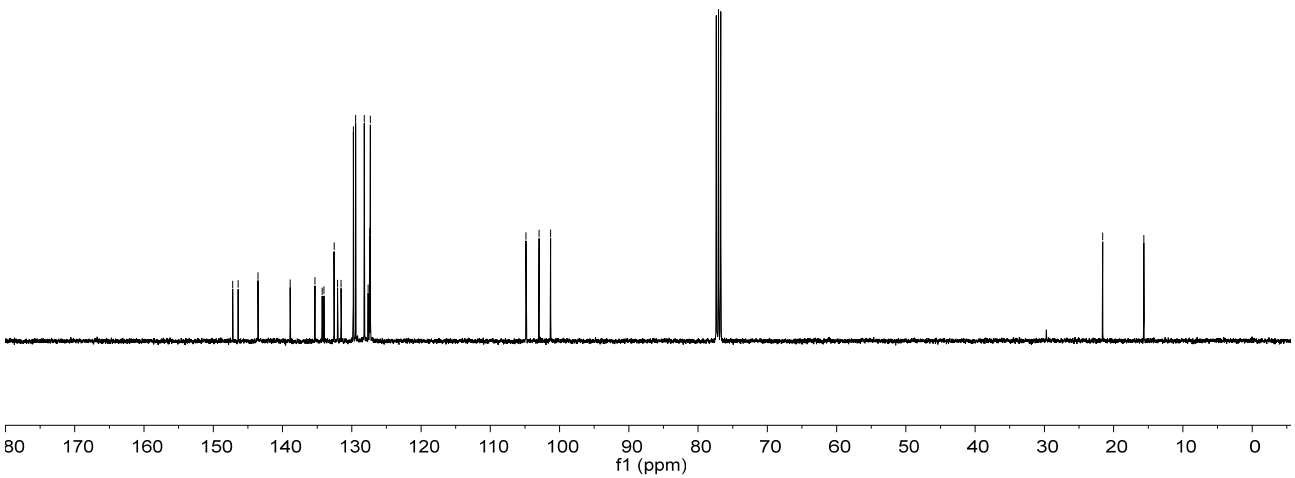
^{1}H NMR (400 MHz, $CDCl_3$)

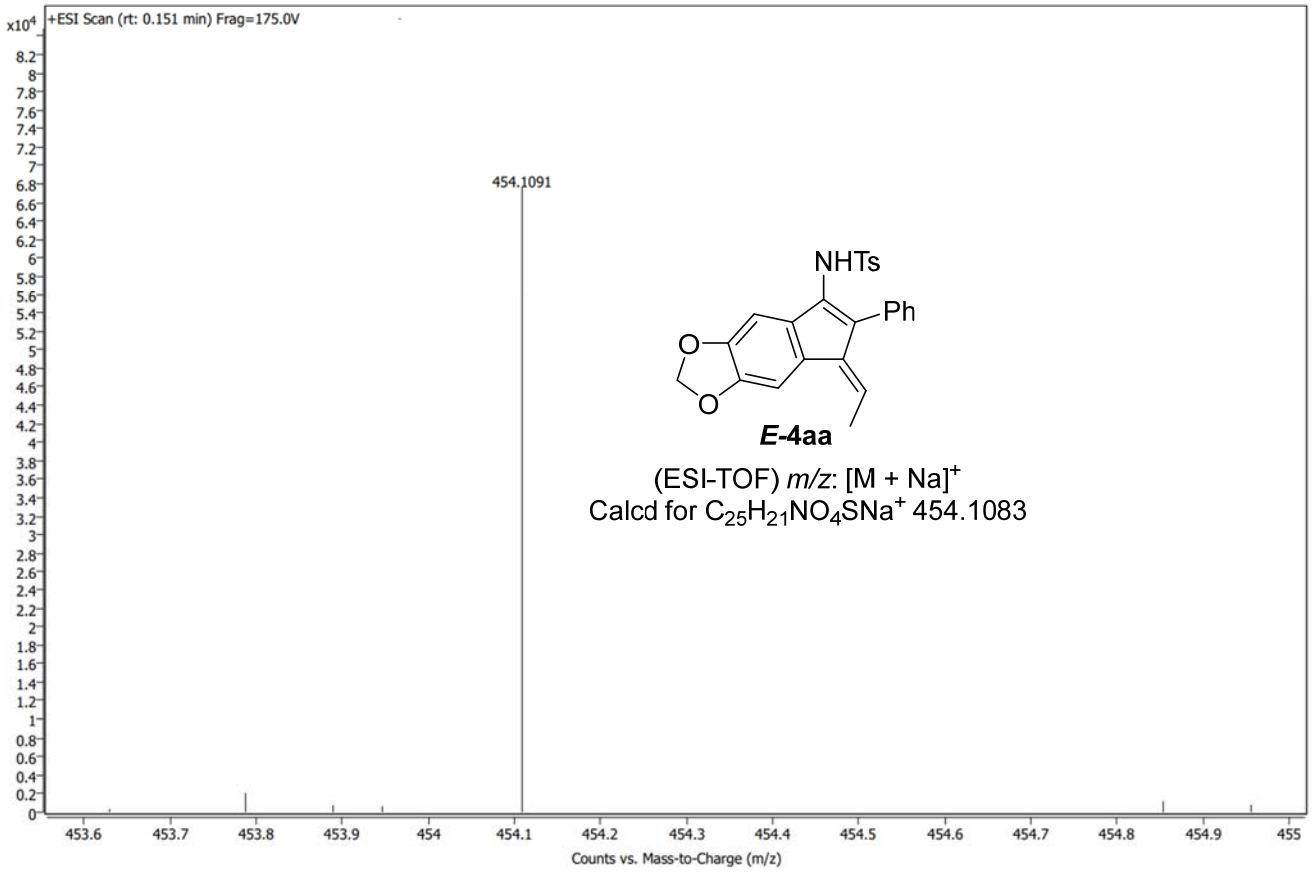




***E*-4aa**

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

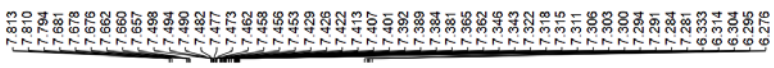


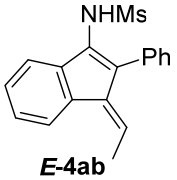


***E*-4aa**

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

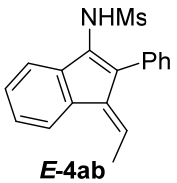
Calcd for $C_{25}H_{21}NO_4SNa^+$ 454.1083





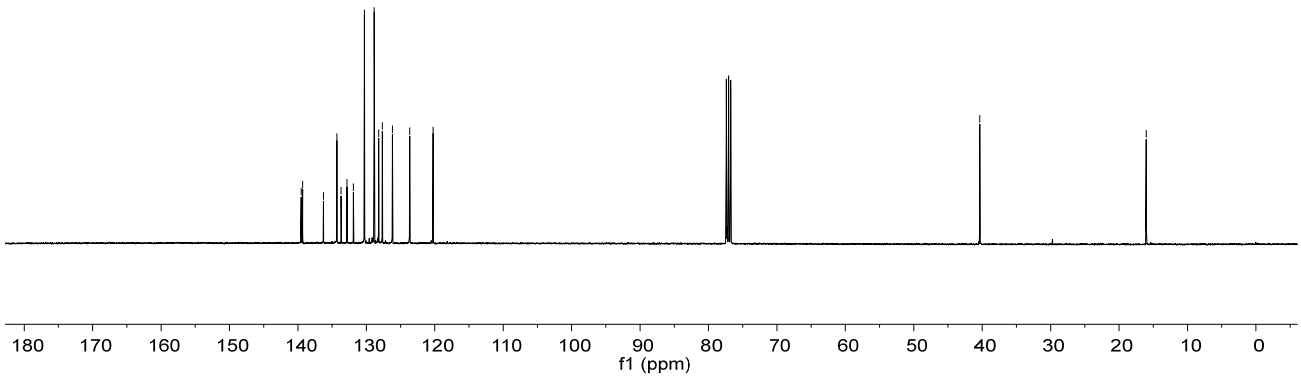
***E*-4ab**

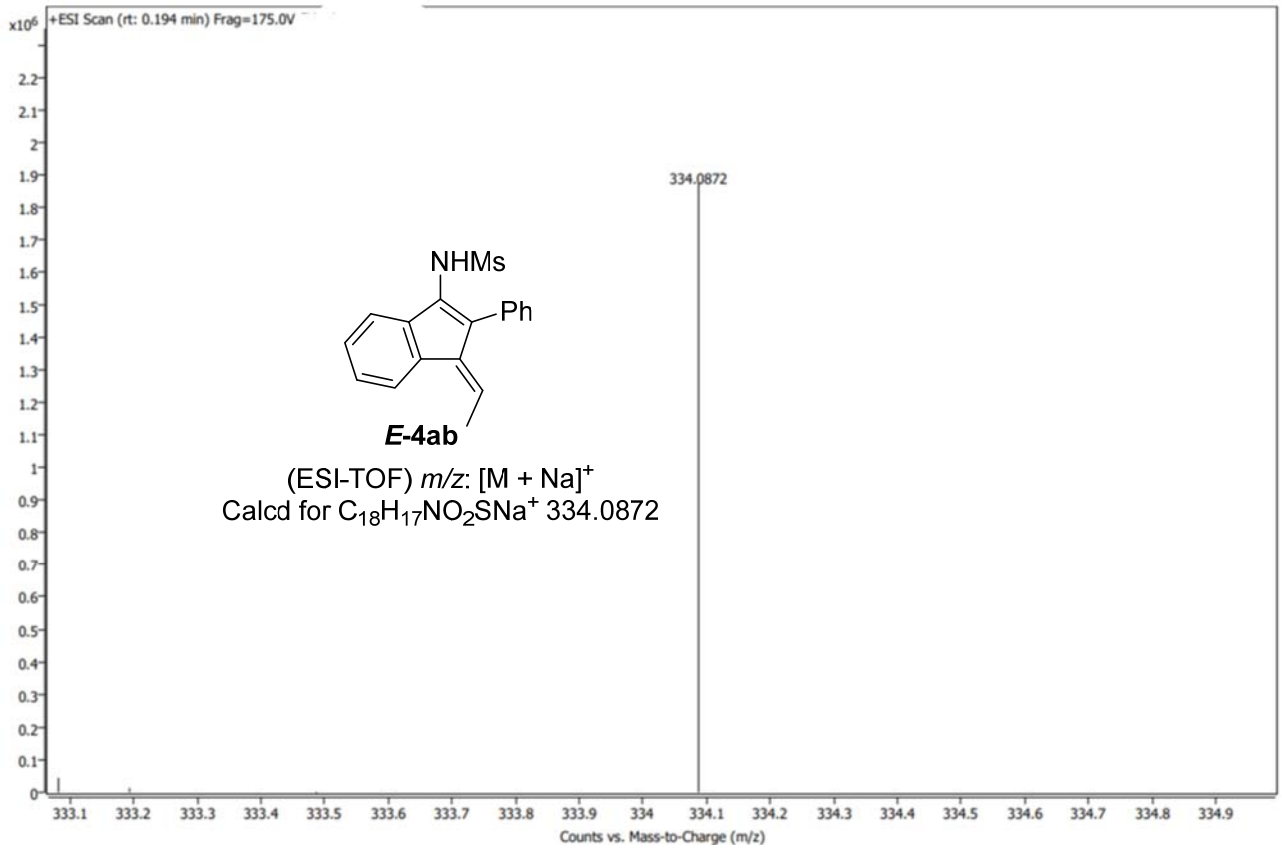
^{1}H NMR (400 MHz, $CDCl_3$)



***E*-4ab**

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

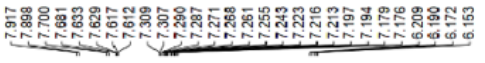


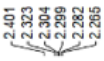


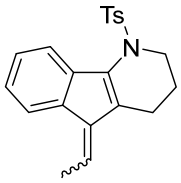
***E*-4ab**

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

Calcd for $C_{18}H_{17}NO_2SNa^+$ 334.0872

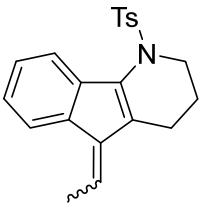






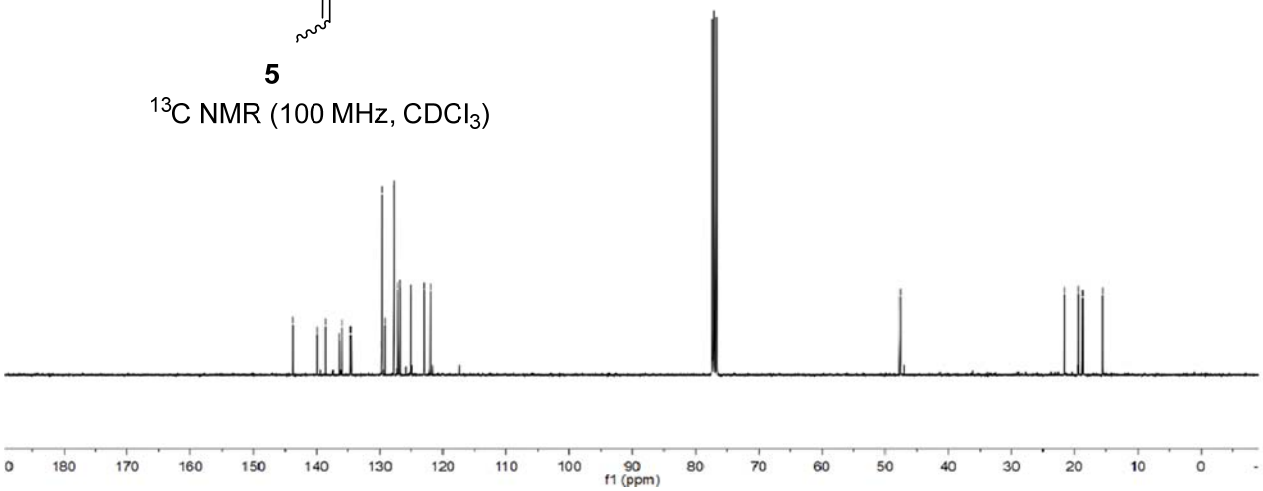
5 *E*/*Z* = 11:1

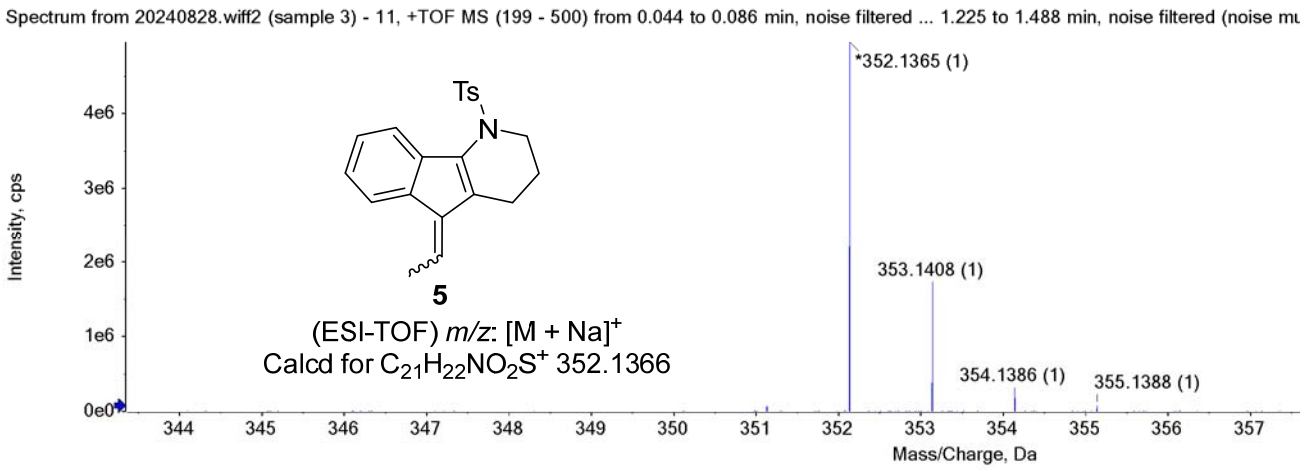
^{1}H NMR (400 MHz, $CDCl_3$)



5

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




Spectrum from 20240828.wiff2 (sample 3) - 11, +TOF MS (199 - 500) from 0.044 to 0.086 min, noise filtered ... 1.225 to 1.488 min, noise filtered (noise mu
Intensity, cps
4e6
3e6
2e6
1e6
0e0
344
345
346
347
348
349
350
351
352
353
354
355
356
357
Mass/Charge, Da
*352.1365 (1)
353.1408 (1)
354.1386 (1)
355.1388 (1)
Ts
N
5
(ESI-TOF) m/z: [M + Na]+
Calcd for C21H22NO2S+ 352.1366