

Palladium(II)-Catalyzed Asymmetric Tandem Cyclization of 2-Aminoaryl Alkynones: An Approach to Chiral 1,2,3,4-Tetrahydro- β -carbolines

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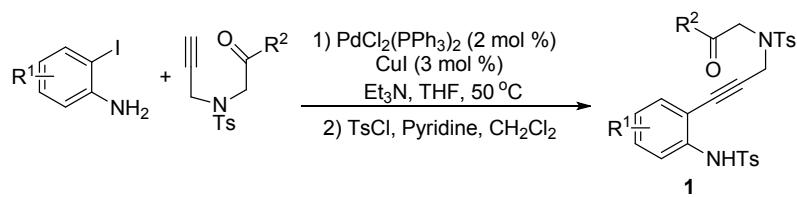
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1. General methods

NMR spectra were recorded on a Varian Mercury V x 400 spectrometer or Agilent 400 MR DD2. Infrared spectra were obtained on a Bio-Rad FTS-185 instrument. Mass spectra were provided on Agilent 5973 or Agilent 1100 instruments. ESI high resolution MS were obtained on Agilent Technologies 6224 TOF LC/MS. All melting points were uncorrected. Palladium acetate was purchased from ACROS. All solvents were dried and distilled before use according to the standard procedure. All reactions were performed in dried tube and monitored by TLC to ensure the completion of the reactions.

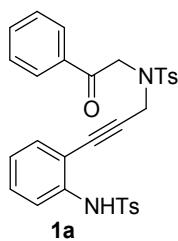
2. General procedure for the synthesis of 1a-1u



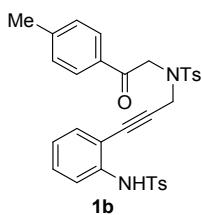
In a 25 mL two neck flask, 2-iodoanilines (2.0 mmol, 1.0 equiv.), NTs tethered alkynone¹ (2.2 mmol, 1.1 equiv.), $\text{PdCl}_2(\text{PPh}_3)_2$ (28 mg, 0.04 mmol), CuI (11 mg, 0.06 mmol) were added under nitrogen atmosphere. Then THF (5 mL) and trimethylamine (2 mL) were added to the mixture and the resulting solution was stirred for 3-5 hours at 50 °C. After completion of the reaction as checked by TLC, the crude reaction mixture

was quenched by water (10 mL), then extracted with ethyl acetate (3 x 10 mL). The organic layer was dried over anhydrous Na₂SO₄, and then evaporated under reduced pressure. The residue was purified by flash chromatography (petroleum ether : ethyl acetate = 10:1-4:1) to give the coupling product which was used for the next step directly.

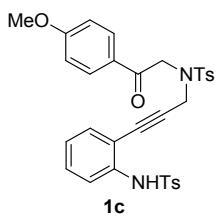
The above Sonogashira coupling product was dissolved in CH₂Cl₂ (7 mL) in a 25 mL flask, then pyridine (0.32 mL, 4 mmol) and TsCl (457 mg, 2.4 mmol) were added to the solution. The resulting mixture was stirred at room temperature overnight. After the reaction was completed, the organic layer was washed with 20 mL of 1 M HCl solution and the aqueous phase was extracted with CH₂Cl₂ (3 x 10 mL). The combined organic phase was dried with anhydrous Na₂SO₄. The solvent was evaporated under reduced pressure and the residue was purified by flash chromatography (petroleum ether: ethyl acetate = 4:1) to give the products **1a-1u**.



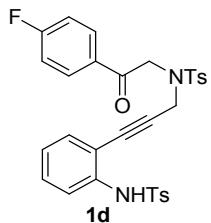
White solid; m.p.: 122-123 °C; (652 mg; 57% yield for two steps); **¹H NMR (400 MHz, CDCl₃)**: δ 8.02 (d, *J* = 7.2 Hz, 2H), 7.80 (d, *J* = 8.4 Hz, 2H), 7.67-7.61 (m, 3H), 7.52-7.48 (m, 3H), 7.30 (d, *J* = 8 Hz, 2H), 7.23-7.17 (m, 4H), 7.00-6.94 (m, 2H), 4.79 (s, 2H), 4.36 (s, 2H), 2.36 (s, 3H), 2.34 (s, 3H); **¹³C NMR (100 MHz, CDCl₃)**: δ 193.6, 144.5, 144.1, 138.3, 136.5, 135.5, 134.7, 134.3, 132.3, 130.0, 129.7, 129.1, 128.5, 127.9, 127.4, 124.1, 119.9, 113.1, 89.1, 81.0, 52.4, 38.5, 21.7; **IR (neat, cm⁻¹)**: ν 3236, 2961, 2122, 1730, 1326, 1155, 1090, 905, 758, 659; **HRMS** calculated for C₃₁H₃₂N₃O₅S₂ (M+NH₄)⁺: 590.1778; Found: 590.1771.



White solid; m.p.: 122-123 °C; (727 mg; 62% yield for two steps); **1H NMR (400 MHz, CDCl₃)**: δ 7.91 (d, *J* = 8.4 Hz, 2H), 7.79 (d, *J* = 8.0 Hz, 2H), 7.66 (d, *J* = 8.4 Hz, 2H), 7.51 (d, *J* = 8.4 Hz, 1H), 7.29-7.21 (m, 6H), 7.16 (d, *J* = 8.4 Hz, 2H), 6.99-6.93 (m, 2H), 4.75 (s, 2H), 4.35 (s, 2H), 2.41 (s, 3H), 2.35 (s, 3H), 2.33 (s, 3H); **13C NMR (100 MHz, CDCl₃)**: δ 193.1, 145.2, 144.4, 144.0, 138.2, 136.4, 135.5, 132.2, 129.9, 129.7, 129.6, 128.5, 127.8, 127.4, 124.1, 120.0, 113.2, 89.1, 81.0, 52.3, 38.4, 21.9, 21.6; **IR (neat, cm⁻¹)**: ν 3235, 2918, 2117, 1698, 1594, 1325, 1154, 1090, 911, 804, 759; **HRMS** calculated for C₃₂H₃₄N₃O₅S₂ (M+NH₄)⁺: 604.1934; Found: 604.1926.

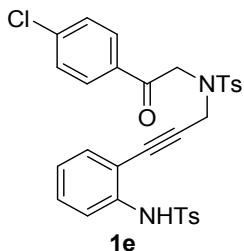


White solid; m.p.: 134-135 °C; (602 mg; 50% yield for two steps); **1H NMR (400 MHz, CDCl₃)**: δ 8.02 (d, *J* = 9.2 Hz, 2H), 7.78 (d, *J* = 8.0 Hz, 2H), 7.66 (d, *J* = 8.4 Hz, 2H), 7.51 (d, *J* = 8.0 Hz, 1H), 7.28-7.20 (m, 4H), 7.17 (d, *J* = 8.0 Hz, 2H), 6.99-6.92 (m, 4H), 4.72 (s, 2H), 4.33 (s, 2H), 3.86 (s, 3H), 2.34 (s, 3H), 2.33 (s, 3H); **13C NMR (100 MHz, CDCl₃)**: δ 192.0, 164.3, 144.4, 144.0, 138.3, 136.4, 135.4, 132.2, 130.9, 129.9, 129.7, 127.9, 127.7, 127.4, 124.1, 120.0, 114.2, 113.3, 89.0, 81.0, 55.7, 52.2, 38.5, 21.6; **IR (neat, cm⁻¹)**: ν 3242, 2922, 2120, 1687, 1597, 1333, 1089, 905, 812, 658; **HRMS** calculated for C₃₂H₃₄N₃O₆S₂ (M+NH₄)⁺: 620.1884; Found: 620.1879.

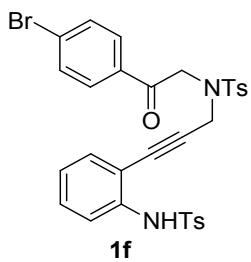


Yellow solid; m.p.: 127-128 °C; (578 mg; 49% yield for two steps); **1H NMR (400 MHz, CDCl₃)**: δ 8.08-8.05 (m, 2H), 7.78 (d, *J* = 8.0 Hz, 2H), 7.66 (d, *J* = 8.0 Hz, 2H), 7.49 (d, *J* = 8.4 Hz, 1H), 7.29-7.12 (m, 8H), 6.98-6.92 (m, 2H), 4.75 (s, 2H), 4.35 (s, 2H), 2.34 (s, 6H); **13C NMR (100 MHz, CDCl₃)**: δ 192.1, 166.2 (d, *J* = 255.8 Hz), 144.5, 144.1, 138.2, 136.3, 135.3, 132.2, 131.2 (d, *J* = 9.1 Hz), 131.0 (d, *J* = 3.1 Hz), 129.9, 129.7, 127.8, 127.3, 124.1, 119.9, 116.3, 116.1, 113.2, 88.8, 81.1, 52.5, 38.6,

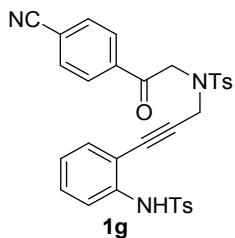
21.6, 21.5; **¹⁹F NMR (376 MHz, CDCl₃)**: δ -102.9; **IR (neat, cm⁻¹)**: ν 3258, 2923, 2148, 1697, 1595, 1334, 1227, 1155, 1089, 905, 812; **HRMS** calculated for C₃₁H₃₁N₃O₅S₂F (M+NH₄)⁺: 608.1684; Found: 608.1679.



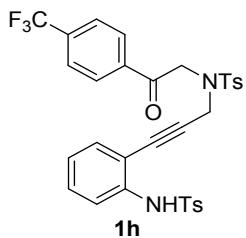
Yellow solid; m.p.: 132-133 °C; (522 mg; 43% yield for two steps); **¹H NMR (400 MHz, CDCl₃)**: δ 7.97 (d, *J* = 8.4 Hz, 2H), 7.78 (d, *J* = 8.0 Hz, 2H), 7.67 (d, *J* = 8.0 Hz, 2H), 7.46-7.44 (m, 3H), 7.30-7.17 (m, 6H), 7.00-6.94 (m, 2H), 4.74 (s, 2H), 4.34 (s, 2H), 2.35 (s, 6H); **¹³C NMR (100 MHz, CDCl₃)**: δ 192.6, 144.6, 144.1, 140.8, 138.3, 136.4, 135.3, 133.0, 132.2, 130.1, 130.0, 129.9, 129.7, 129.4, 127.9, 127.4, 124.1, 119.8, 113.1, 88.9, 81.2, 52.5, 38.6, 21.7, 21.6; **IR (neat, cm⁻¹)**: ν 3261, 2920, 2099, 1697, 1590, 1489, 1334, 1146, 1089, 905, 756, 658; **HRMS** calculated for C₃₁H₃₁N₃O₅S₂Cl (M+NH₄)⁺: 624.1388; Found: 624.1386.



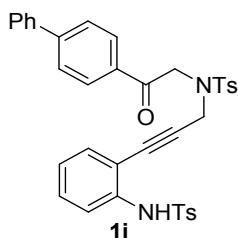
White solid; m.p.: 134-135 °C; (520 mg; 40% yield for two steps); **¹H NMR (400 MHz, CDCl₃)**: δ 7.89 (d, *J* = 8.4 Hz, 2H), 7.78 (d, *J* = 8.4 Hz, 2H), 7.67-7.60 (m, 4H), 7.48 (d, *J* = 8.0 Hz, 1H), 7.30-7.18 (m, 6H), 6.98-6.94 (m, 2H), 4.73 (s, 2H), 4.34 (s, 2H), 2.35 (s, 6H); **¹³C NMR (100 MHz, CDCl₃)**: δ 192.8, 144.5, 144.1, 138.2, 136.4, 135.3, 133.4, 132.3, 132.2, 130.0, 129.7, 129.5, 127.8, 127.3, 124.1, 119.8, 113.1, 88.8, 81.2, 52.5, 38.6, 21.7, 21.6; **IR (neat, cm⁻¹)**: ν 3253, 2942, 1695, 1583, 1400, 1332, 1160, 1089, 994, 901, 813, 743; **HRMS** calculated for C₃₁H₃₁N₃O₅S₂Br (M+NH₄)⁺: 668.0883; Found: 668.0879.



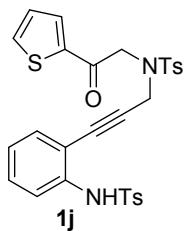
Yellow oil; (620 mg; 52% yield for two steps); **$^1\text{H NMR}$ (400 MHz, CDCl_3):** δ 8.11 (d, $J = 8.4$ Hz, 2H), 7.78-7.73 (m, 4H), 7.66 (d, $J = 8.0$ Hz, 2H), 7.43 (d, $J = 8.4$ Hz, 1H), 7.28 (d, $J = 8.0$ Hz, 2H), 7.21-7.19 (m, 4H), 6.96-6.94 (m, 2H), 4.78 (s, 2H), 4.35 (s, 2H), 2.35 (s, 6H); **$^{13}\text{C NMR}$ (100 MHz, CDCl_3):** δ 192.8, 144.6, 144.2, 138.1, 137.6, 136.3, 135.1, 132.7, 132.3, 130.1, 130.0, 129.7, 128.9, 127.8, 127.3, 124.2, 119.8, 117.8, 117.1, 113.1, 88.7, 81.3, 53.0, 38.7, 21.6; **IR (neat, cm⁻¹):** ν 3263, 2923, 2230, 1704, 1597, 1334, 1156, 1089, 907, 813, 659; **HRMS** calculated for $\text{C}_{32}\text{H}_{31}\text{N}_4\text{O}_5\text{S}_2(\text{M}+\text{NH}_4)^+$: 615.1730; Found: 615.1728.



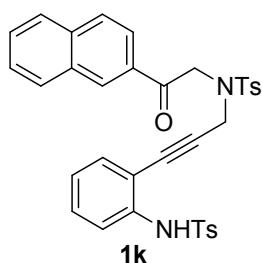
White solid; m.p.: 146-147 °C; (742 mg; 58% yield for two steps); **$^1\text{H NMR}$ (400 MHz, CDCl_3):** δ 8.14 (d, $J = 8.0$ Hz, 2H), 7.80-7.73 (m, 4H), 7.67 (d, $J = 8.4$ Hz, 2H), 7.47 (d, $J = 8.4$ Hz, 1H), 7.30 (d, $J = 8.0$ Hz, 2H) 7.26-7.19 (m, 3H), 7.12 (s, 1H), 6.98-6.94 (m, 2H), 4.79 (s, 2H), 4.35 (s, 2H), 2.36 (s, 3H), 2.35 (s, 3H); **$^{13}\text{C NMR}$ (100 MHz, CDCl_3):** δ 193.0, 144.5, 144.1, 138.1, 137.3, 136.3, 135.2, 135.0 (q, $J = 32.9$ Hz), 132.3, 129.9, 129.7, 128.8, 127.8, 127.3, 125.9 (q, $J = 3.6$ Hz), 124.1, 123.5 (q, $J = 271.6$ Hz), 119.9, 113.2, 88.8, 81.1, 52.9, 38.7, 21.5; **$^{19}\text{F NMR}$ (376 MHz, CDCl_3):** δ -63.2; **IR (neat, cm⁻¹):** ν 3260, 2974, 1707, 1490, 1321, 1156, 1092, 913, 768; **HRMS** calculated for $\text{C}_{32}\text{H}_{31}\text{N}_3\text{O}_5\text{S}_2\text{F}_3(\text{M}+\text{NH}_4)^+$: 658.1652; Found: 658.1645.



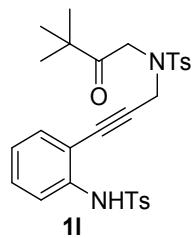
Yellow solid; m.p.: 107-108 °C; (505 mg; 39% yield for two steps); **¹H NMR (400 MHz, CDCl₃)**: δ 8.10 (d, *J* = 8.8 Hz, 2H), 7.81 (d, *J* = 8.4 Hz, 2H), 7.72-7.61 (m, 6H), 7.50-7.40 (m, 4H), 7.30 (d, *J* = 8.4 Hz, 2H), 7.20-7.17 (m, 4H), 7.00 (d, *J* = 6.4 Hz, 1H), 6.94 (t, *J* = 7.2 Hz, 1H), 4.81 (s, 2H), 4.37 (s, 2H), 2.36 (s, 3H), 2.33 (s, 3H); **¹³C NMR (100 MHz, CDCl₃)**: δ 193.2, 146.9, 144.5, 144.1, 139.7, 138.3, 136.5, 135.4, 133.4, 132.3, 130.0, 129.7, 129.2, 129.1, 128.6, 127.9, 127.6, 127.4, 124.1, 119.9, 113.2, 89.0, 81.1, 52.5, 38.5, 21.7; **IR (neat, cm⁻¹)**: ν 3291, 2979, 1735, 1678, 1598, 1490, 1158, 1089, 902, 752; **HRMS** calculated for C₃₇H₃₆N₃O₅S₂ (M+NH₄)⁺: 666.2091; Found: 666.2090.



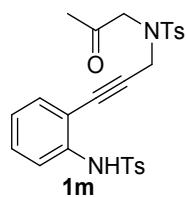
Yellow oil; (531 mg; 46% yield for two steps); **¹H NMR (400 MHz, CDCl₃)**: δ 7.95 (d, *J* = 4.0 Hz, 1H), 7.78 (d, *J* = 8.0 Hz, 2H), 7.71-7.66 (m, 3H), 7.50 (d, *J* = 8.4 Hz, 1H), 7.29-7.15 (m, 7H), 6.99-6.92 (m, 2H), 4.67 (s, 2H), 4.35 (s, 2H), 2.34 (s, 6H); **¹³C NMR (100 MHz, CDCl₃)**: δ 186.6, 144.5, 144.1, 141.0, 138.2, 136.4, 135.2, 135.1, 133.5, 132.2, 130.0, 129.7, 128.7, 127.8, 127.3, 124.1, 120.0, 113.2, 88.8, 81.2, 52.6, 38.6, 21.6; **IR (neat, cm⁻¹)**: ν 3257, 2921, 1670, 1408, 1334, 1156, 1089, 897, 727, 658; **HRMS** calculated for C₂₉H₃₀N₃O₅S₃ (M+NH₄)⁺: 596.1342; Found: 596.1330.



Brown solid; m.p.: 149-150 °C; (460 mg; 37% yield for two steps); **¹H NMR (400 MHz, CDCl₃)**: δ 8.58 (s, 1H), 8.05-7.96 (m, 2H), 7.91-7.81 (m, 4H), 7.67-7.49 (m, 5H), 7.30 (d, *J* = 8.0 Hz, 2H), 7.23-7.20 (m, 2H), 7.13 (d, *J* = 8.0 Hz, 2H), 7.00 (d, *J* = 7.6 Hz, 1H), 6.92 (t, *J* = 7.6 Hz, 1H), 4.93 (s, 2H), 4.40 (s, 2H), 2.36 (s, 3H), 2.29 (s, 3H); **¹³C NMR (100 MHz, CDCl₃)**: δ 193.5, 144.5, 144.1, 138.3, 136.4, 136.0, 135.5, 132.5, 132.2, 132.0, 130.6, 130.0, 129.9, 129.7, 129.2, 128.9, 127.9, 127.4, 127.2, 124.1, 123.6, 119.8, 113.2, 89.1, 81.1, 52.5, 38.5, 21.7, 21.6; **IR (neat, cm⁻¹)**: ν 3253, 2974, 2099, 1701, 1596, 1327, 1155, 1091, 906, 810, 657; **HRMS** calculated for C₃₅H₃₄N₃O₅S₂ (M+NH₄)⁺: 640.1934; Found: 640.1931.

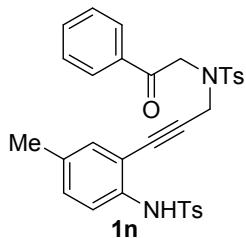


White solid; m.p.: 89-90 °C; (629 mg; 57% yield for two steps); **¹H NMR (400 MHz, CDCl₃)**: δ 7.76 (d, *J* = 8.0 Hz, 2H), 7.69 (d, *J* = 8.4 Hz, 2H), 7.51 (d, *J* = 8.4 Hz, 1H), 7.30-7.22 (m, 5H), 7.14 (s, 1H), 7.05 (dd, *J* = 8.0 Hz, 1.6 Hz, 1H), 6.97 (d, *J* = 7.6 Hz, 1H), 4.37 (s, 2H), 4.32 (s, 2H), 2.37 (s, 6H), 1.17 (s, 9H); **¹³C NMR (100 MHz, CDCl₃)**: δ 209.3, 144.2, 144.1, 138.2, 136.4, 135.9, 132.2, 130.0, 129.9, 129.7, 127.7, 127.4, 124.2, 119.9, 113.2, 89.5, 80.5, 50.1, 43.6, 38.1, 26.3, 21.7, 21.6; **IR (neat, cm⁻¹)**: ν 3264, 2967, 2189, 1719, 1597, 1333, 1155, 1090, 903, 812, 739, 657; **HRMS** calculated for C₂₉H₃₆N₃O₅S₂ (M+NH₄)⁺: 570.2091; Found: 570.2082.

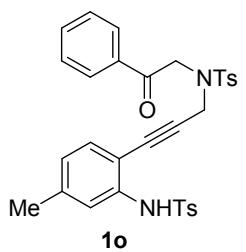


White solid; m.p.: 132-133 °C; (633 mg; 62% yield for two steps); **¹H NMR (400 MHz, CDCl₃)**: δ 7.73 (d, *J* = 8.4 Hz, 2H), 7.67 (d, *J* = 8.0 Hz, 2H), 7.50 (d, *J* = 8.4 Hz, 1H), 7.29-7.22 (m, 5H), 7.10 (s, 1H), 7.00-6.94 (m, 2H), 4.30 (s, 2H), 4.06 (s, 2H), 2.37 (s, 3H), 2.35 (s, 3H), 2.23 (s, 3H); **¹³C NMR (100 MHz, CDCl₃)**: δ 203.4, 144.5, 144.2,

138.1, 136.3, 135.2, 132.3, 130.1, 130.0, 129.7, 127.7, 127.3, 124.2, 120.1, 113.2, 88.7, 81.0, 55.9, 38.9, 27.3, 21.7, 21.6; **IR (neat, cm⁻¹)**: ν 3237, 2952, 1738, 1596, 1489, 1335, 1157, 1089, 1007, 900, 811, 752, 679; **HRMS** calculated for C₂₆H₃₀N₃O₅S₂ (M+NH₄)⁺: 528.1621; Found: 528.1612.

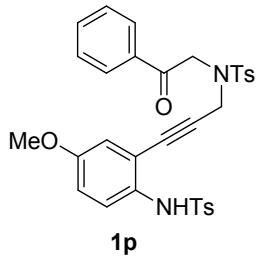


White solid; m.p.: 125-127 °C; (645 mg; 55% yield for two steps); **¹H NMR (400 MHz, CDCl₃)**: δ 8.01 (d, J = 7.6 Hz, 2H), 7.78 (d, J = 8.4 Hz, 2H), 7.62-7.60 (m, 3H), 7.48 (t, J = 8.0 Hz, 2H), 7.40 (d, J = 8.4 Hz, 1H), 7.29 (d, J = 7.6 Hz, 2H), 7.15 (d, J = 8.0 Hz, 2H), 7.04-7.00 (m, 2H), 6.75 (s, 1H), 4.77 (s, 2H), 4.34 (s, 2H), 2.37 (s, 3H), 2.32 (s, 3H), 2.18 (s, 3H); **¹³C NMR (100 MHz, CDCl₃)**: δ 193.5, 144.3, 143.9, 136.4, 135.6, 135.5, 134.7, 134.2, 132.5, 130.8, 129.9, 129.6, 129.0, 128.4, 127.8, 127.3, 120.8, 113.6, 88.3, 81.2, 52.3, 38.4, 21.6, 20.6; **IR (neat, cm⁻¹)**: ν 3250, 2972, 1698, 1337, 1161, 1090, 903, 744; **HRMS** calculated for C₃₂H₃₄N₃O₅S₂ (M+NH₄)⁺: 604.1934; Found: 604.1925.

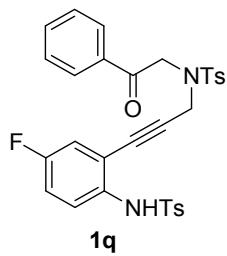


White solid; m.p.: 135-136 °C; (668 mg; 57% yield for two steps); **¹H NMR (400 MHz, CDCl₃)**: δ 7.99 (d, J = 8.4 Hz, 2H), 7.78 (d, J = 8.0 Hz, 2H), 7.65-7.57 (m, 3H), 7.46 (t, J = 7.6 Hz, 2H), 7.33 (s, 1H), 7.27 (d, J = 7.6 Hz, 2H), 7.16-7.13 (m, 3H), 6.83 (d, J = 8.0 Hz, 1H), 6.74 (d, J = 8.0 Hz, 1H), 4.77 (s, 2H), 4.35 (s, 2H), 2.34 (s, 3H), 2.31 (s, 3H), 2.27 (s, 3H); **¹³C NMR (100 MHz, CDCl₃)**: δ 193.5, 144.2, 143.9, 140.5, 137.9, 136.3, 135.4, 134.6, 134.1, 131.9, 129.8, 129.5, 128.9, 128.3, 127.7, 127.2, 125.2, 120.9,

110.4, 88.1, 81.1, 52.3, 38.4, 21.8, 21.5; **IR (neat, cm⁻¹):** ν 3262, 2971, 1697, 1596, 1333, 1154, 1089, 902, 812, 746, 665; **HRMS** calculated for C₃₂H₃₄N₃O₅S₂ (M+NH₄)⁺: 604.1934; Found: 604.1930.

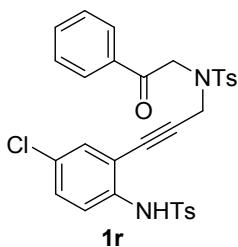


Colorless oil; (614 mg; 51% yield for two steps); **¹H NMR (400 MHz, CDCl₃):** δ 8.00 (d, J = 7.2 Hz, 2H), 7.76 (d, J = 8.4 Hz, 2H), 7.60-7.53 (m, 3H), 7.49-7.41 (m, 3H), 7.29 (d, J = 8.0 Hz, 2H), 7.14 (d, J = 8.0 Hz, 2H), 6.84-6.79 (m, 2H), 6.45 (d, J = 2.8 Hz, 1H), 4.76 (s, 2H), 4.30 (s, 2H), 3.68 (s, 3H), 2.37 (s, 3H), 2.32 (s, 3H); **¹³C NMR (100 MHz, CDCl₃):** δ 193.5, 156.6, 144.4, 143.8, 136.2, 135.5, 134.6, 134.2, 130.9, 129.9, 129.5, 129.0, 128.3, 127.8, 127.3, 124.2, 116.8, 116.2, 115.9, 88.1, 81.1, 55.5, 52.3, 38.3, 21.6; **IR (neat, cm⁻¹):** ν 3228, 1969, 1700, 1490, 1320, 1154, 1091, 803, 745, 662; **HRMS** calculated for C₃₂H₃₄N₃O₆S₂ (M+NH₄)⁺: 620.1884; Found: 620.1879.

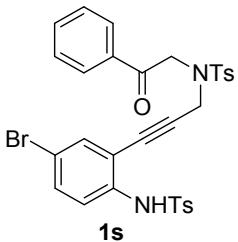


White solid; m.p.: 115-116 °C; (554 mg; 47% yield for two steps); **¹H NMR (400 MHz, CDCl₃):** δ 8.01 (d, J = 7.6 Hz, 2H), 7.77 (d, J = 8.0 Hz, 2H), 7.62-7.59 (m, 3H), 7.52-7.47 (m, 3H), 7.30 (d, J = 8.4 Hz, 2H), 7.18 (d, J = 8.0 Hz, 2H), 7.10 (s, 1H), 6.99-6.94 (m, 1H), 6.60 (dd, J = 8.4 Hz, 3.2 Hz, 1H), 4.76 (s, 2H), 4.31 (s, 2H), 2.38 (s, 3H), 2.34 (s, 3H); **¹³C NMR (100 MHz, CDCl₃):** δ 193.5, 159.0 (d, J = 244.5 Hz), 144.5, 144.2, 136.2, 135.4, 134.6, 134.4 (d, J = 2.3 Hz), 134.3, 1230.0, 129.7, 129.1, 128.4, 127.8, 127.3, 123.2 (d, J = 8.4 Hz), 118.5 (d, J = 24.3 Hz), 117.2 (d, J = 22.0 Hz), 115.7 (d, J = 9.9 Hz), 89.7, 80.1, 52.5, 38.4, 21.7, 21.6; **¹⁹F NMR (376 MHz, CDCl₃):** δ -117.2;

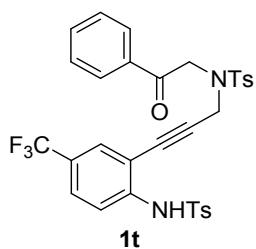
IR (neat, cm⁻¹): ν 3239, 2963, 1704, 1493, 1326, 1156, 1091, 875, 745, 683; **HRMS** calculated for C₃₁H₃₁N₃O₅S₂F (M+NH₄)⁺: 608.1684; Found: 608.1678.



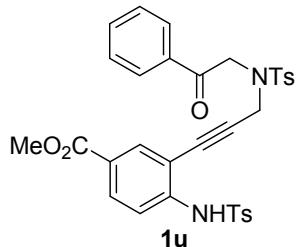
White solid; m.p.: 131-133 °C; (582 mg; 48% yield for two steps); **¹H NMR (400 MHz, CDCl₃):** δ 8.01 (d, J = 7.6 Hz, 2H), 7.77 (d, J = 8.0 Hz, 2H), 7.66-7.59 (m, 3H), 7.50-7.45 (m, 3H), 7.29-7.26 (m, 3H), 7.19-7.17 (m, 3H), 6.85 (d, J = 1.6 Hz, 1H), 4.76 (s, 2H), 4.34 (s, 2H), 2.38 (s, 3H), 2.34 (s, 3H); **¹³C NMR (100 MHz, CDCl₃):** δ 193.5, 144.5, 144.3, 136.9, 136.1, 135.4, 134.6, 134.2, 131.7, 130.0, 129.9, 129.8, 129.3, 129.0, 128.4, 127.8, 127.3, 121.5, 114.9, 90.1, 79.7, 52.5, 38.4, 21.6; **IR (neat, cm⁻¹):** ν 3252, 2978, 1698, 1483, 1335, 1161, 1089, 901, 812, 664; **HRMS** calculated for C₃₁H₃₁N₃O₅S₂Cl (M+NH₄)⁺: 624.1388; Found: 624.1384.



White solid; m.p.: 148-149 °C; (559 mg; 43% yield for two steps); **¹H NMR (400 MHz, CDCl₃):** δ 8.02 (d, J = 7.2 Hz, 2H), 7.78 (d, J = 8.4 Hz, 2H), 7.67-7.63 (m, 3H), 7.50 (t, J = 8.0 Hz, 2H), 7.41 (d, J = 8.8 Hz, 1H), 7.34-7.29 (m, 3H), 7.26 (s, 1H), 7.20 (d, J = 8.0 Hz, 2H), 7.04 (d, J = 2.4 Hz, 1H), 4.76 (s, 2H), 4.34 (s, 2H), 2.39 (s, 3H), 2.35 (s, 3H); **¹³C NMR (100 MHz, CDCl₃):** δ 193.5, 144.6, 144.3, 137.5, 136.1, 135.4, 134.6, 134.3, 132.9, 130.0, 129.8, 129.1, 128.5, 127.9, 127.4, 121.5, 116.7, 115.0, 90.3, 79.7, 52.6, 38.5, 21.7, 21.6; **IR (neat, cm⁻¹):** ν 3253, 2980, 1699, 1480, 1389, 1163, 1089, 900, 810, 656; **HRMS** calculated for C₃₁H₃₁N₃O₅S₂Br (M+NH₄)⁺: 668.0883; Found: 668.0882.

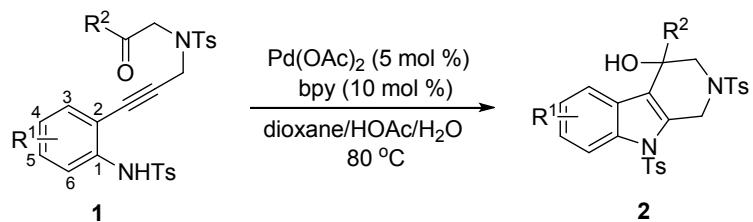


Colorless oil; (666 mg; 52% yield for two steps); **¹H NMR (400 MHz, CDCl₃)**: δ 8.03 (d, *J* = 7.6 Hz, 2H), 7.81-7.75 (m, 4H), 7.69 (s, 1H), 7.63-7.61 (m, 2H), 7.51-7.43 (m, 3H), 7.30-7.22 (m, 5H), 4.81 (s, 2H), 4.38 (s, 2H), 2.36 (s, 3H), 2.35 (s, 3H); **¹³C NMR (100 MHz, CDCl₃)**: δ 193.5, 144.5, 144.4, 141.3, 136.1, 135.3, 134.5, 134.2, 129.9, 129.8, 129.2 (q, *J* = 3.8 Hz), 128.9, 128.3, 127.8, 127.3, 126.6 (q, *J* = 3.8 Hz), 125.5 (q, *J* = 32.6 Hz), 123.4 (q, *J* = 271.0 Hz), 118.3, 112.5, 91.0, 79.4, 52.7, 38.5, 21.7, 21.5, 21.4; **¹⁹F NMR (376 MHz, CDCl₃)**: δ -62.4; **IR (neat, cm⁻¹)**: ν 3256, 2922, 1698, 1331, 1159, 1121, 1090, 901, 813, 747, 660; **HRMS** calculated for C₃₂H₃₁N₃O₅S₂F₃ (M+NH₄)⁺: 658.1652; Found: 658.1644.

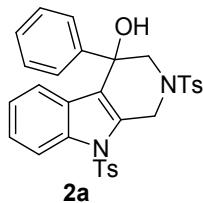


Yellow oil; (478 mg; 38% yield for two steps); **¹H NMR (400 MHz, CDCl₃)**: δ 8.03 (d, *J* = 7.6 Hz, 2H), 7.87 (dd, *J* = 8.8 Hz, 2.0 Hz, 1H), 7.81 (d, *J* = 8.4 Hz, 2H), 7.76 (d, *J* = 8.4 Hz, 2H), 7.71 (d, *J* = 2.0 Hz, 1H), 7.66-7.56 (m, 3H), 7.50 (t, *J* = 8.0 Hz, 2H), 7.30 (d, *J* = 7.6 Hz, 2H), 7.22 (d, *J* = 8.0 Hz, 2H), 4.81 (s, 2H), 4.39 (s, 2H), 3.86 (s, 3H), 2.35 (s, 3H), 2.34 (s, 3H); **¹³C NMR (100 MHz, CDCl₃)**: δ 193.6, 165.7, 144.6, 144.5, 142.3, 136.1, 135.2, 134.6, 134.3, 133.8, 131.2, 130.0, 129.9, 129.1, 128.5, 127.9, 127.4, 125.2, 117.5, 111.9, 90.3, 79.9, 52.6, 52.4, 38.6, 21.7, 21.6; **IR (neat, cm⁻¹)**: ν 3253, 2951, 1700, 1339, 1158, 1089, 903, 813, 746, 661; **HRMS** calculated for C₃₃H₃₄N₃O₇S₂ (M+NH₄)⁺: 648.1833; Found: 648.1830.

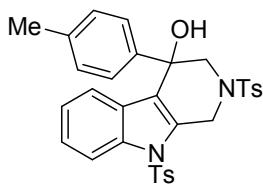
3. General procedure for Pd(OAc)₂/bpy-catalyzed cyclization of 1



To a dried Schlenk tube were added substrate **1** (0.1 mmol, 1.0 equiv.), palladium acetate (1.3 mg, 0.005 mmol), and bipyridine (1.6 mg, 0.01 mmol), and then 1 mL of dioxane, 0.1 mL of acetic acid, 0.1 mL of H₂O were added sequentially. The resulting mixture was stirred at 80 °C. The progress of the reaction was monitored by TLC. After completion of the reaction, the solvents were evaporated under reduced pressure and the residue was purified by flash column chromatography (petroleum ether : ethyl acetate = 10:1-4:1) to give product **2**.

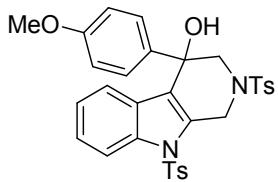


White solid; m.p.: 156-157 °C; (52 mg; 91% yield); **1H NMR (400 MHz, CDCl₃):** δ 8.05 (d, *J* = 8.0 Hz, 1H), 7.78-7.73 (m, 4H), 7.36-7.20 (m, 10H), 6.95 (t, *J* = 7.6 Hz, 1H), 6.67 (d, *J* = 2.0 Hz, 1H), 5.28 (d, *J* = 16.8 Hz, 1H), 4.19 (d, *J* = 16.8 Hz, 1H), 3.96 (d, *J* = 12.4 Hz, 1H), 3.02 (s, 1H), 2.87 (d, *J* = 12.4 Hz, 1H), 2.43 (s, 3H), 2.38 (s, 3H); **13C NMR (100 MHz, CDCl₃):** δ 145.8, 144.4, 141.4, 136.3, 135.2, 133.6, 132.5, 130.4, 130.2, 128.5, 127.9, 127.8, 126.7, 126.8, 126.3, 125.0, 123.7, 121.6, 121.1, 114.0, 71.5, 58.9, 45.3, 21.8, 21.7; **IR (neat, cm⁻¹):** ν 3479, 3053, 2921, 1449, 1373, 1350, 1164, 1092, 956, 768, 702, 658; **HRMS** calculated for C₃₁H₃₂N₃O₅S₂ (M+NH₄)⁺: 590.1778; Found: 590.1778.



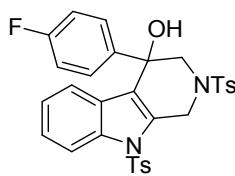
2b

White solid; m.p.: 149-150 °C; (53 mg; 90% yield); **1H NMR (400 MHz, CDCl₃):** δ 8.05 (d, *J* = 8.8 Hz, 1H), 7.78-7.72 (m, 4H), 7.34 (d, *J* = 8.4 Hz, 2H), 7.28 (d, *J* = 8.4 Hz, 2H), 7.24-7.19 (m, 3H), 7.08 (d, *J* = 8.0 Hz, 2H), 6.96 (t, *J* = 8.0 Hz, 1H), 6.71 (d, *J* = 8.0 Hz, 1H), 5.26 (d, *J* = 16.8 Hz, 1H), 4.18 (d, *J* = 16.4 Hz, 1H), 3.94 (d, *J* = 12.8 Hz, 1H), 2.99 (s, 1H), 2.85 (d, *J* = 12.8 Hz, 1H), 2.43 (s, 3H), 2.37 (s, 3H), 2.32 (s, 3H); **13C NMR (100 MHz, CDCl₃):** δ 145.7, 144.4, 138.1, 137.6, 136.3, 135.2, 133.5, 132.4, 130.4, 130.2, 129.1, 127.8, 126.8, 126.7, 126.1, 124.9, 123.7, 121.7, 121.1, 114.0, 71.4, 59.0, 45.3, 21.8, 21.7, 21.2; **IR (neat, cm⁻¹):** ν 3508, 2921, 1596, 1448, 1350, 1166, 1090, 1029, 957, 812, 747, 661; **HRMS** calculated for C₃₂H₃₄N₃O₅S₂ (M+NH₄)⁺: 604.1934; Found: 604.1934.



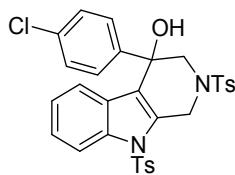
2c

White solid; m.p.: 139-140 °C; (52 mg; 87% yield); **1H NMR (400 MHz, CDCl₃):** δ 8.05 (d, *J* = 8.4 Hz, 1H), 7.78-7.72 (m, 4H), 7.34 (d, *J* = 8.0 Hz, 2H), 7.29-7.20 (m, 5H), 6.97 (t, *J* = 7.6 Hz, 1H), 6.80 (d, *J* = 8.8 Hz, 2H), 6.73 (d, *J* = 7.6 Hz, 1H), 5.25 (d, *J* = 16.8 Hz, 1H), 4.18 (d, *J* = 16.4 Hz, 1H), 3.92 (d, *J* = 12.4 Hz, 1H), 3.77 (s, 3H), 3.00 (s, 1H), 2.84 (d, *J* = 12.4 Hz, 1H), 2.43 (s, 3H), 2.37 (s, 3H); **13C NMR (100 MHz, CDCl₃):** δ 159.2, 145.7, 144.4, 136.2, 135.2, 133.5, 133.2, 132.3, 130.4, 130.2, 127.8, 127.5, 126.8, 126.7, 124.9, 123.7, 121.7, 121.2, 114.0, 113.7, 71.2, 58.9, 55.3, 45.3, 21.7, 21.7; **IR (neat, cm⁻¹):** ν 3500, 2920, 1597, 1510, 1348, 1165, 1089, 1028, 955, 811, 660; **HRMS** calculated for C₃₂H₂₉N₂O₅S₂ (M+H-H₂O)⁺: 585.1512; Found: 585.1511.



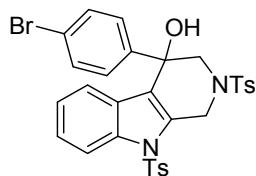
2d

White solid; m.p.: 148-150 °C; (48 mg; 82% yield); **1H NMR (400 MHz, CDCl₃):** δ 8.05 (d, *J* = 8.4 Hz, 1H), 7.78-7.72 (m, 4H), 7.36-7.21 (m, 7H), 7.00-6.93 (m, 3H), 6.69 (d, *J* = 8.0 Hz, 1H), 5.25 (d, *J* = 16.8 Hz, 1H), 4.21 (d, *J* = 16.8 Hz, 1H), 3.91 (d, *J* = 12.4 Hz, 1H), 3.09 (s, 1H), 2.86 (d, *J* = 12.8 Hz, 1H), 2.43 (s, 3H), 2.38 (s, 3H); **13C NMR (100 MHz, CDCl₃):** δ 162.4 (d, *J* = 245.2 Hz), 145.8, 144.8, 136.9 (d, *J* = 3.1 Hz), 136.2, 135.1, 133.4, 132.5, 130.4, 130.2, 128.1 (d, *J* = 8.4 Hz), 127.7, 126.7, 126.5, 125.1, 123.7, 121.2, 120.9, 115.3 (d, *J* = 21.2 Hz), 114.0, 71.2, 58.8, 45.2, 21.7, 21.6; **19F NMR (376 MHz, CDCl₃):** δ -114.5; **IR (neat, cm⁻¹):** ν 3509, 2924, 1597, 1506, 1259, 1158, 1088, 1017, 798, 747, 660; **HRMS** calculated for C₃₁H₂₆N₂O₄S₂F (M+H-H₂O)⁺: 573.1313; Found: 573.1309.



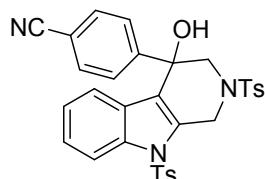
2e

Yellow solid; m.p.: 152-153 °C; (50 mg; 83% yield); **1H NMR (400 MHz, CDCl₃):** δ 8.06 (d, *J* = 8.8 Hz, 1H), 7.78 (d, *J* = 8.4 Hz, 2H), 7.74 (d, *J* = 8.0 Hz, 2H), 7.36 (d, *J* = 8.0 Hz, 2H), 7.31-7.22 (m, 7H), 7.00 (t, *J* = 7.6 Hz, 1H), 6.69 (d, *J* = 8.0 Hz, 1H), 5.25 (d, *J* = 16.8 Hz, 1H), 4.20 (d, *J* = 16.8 Hz, 1H), 3.91 (d, *J* = 12.4 Hz, 1H), 3.02 (s, 1H), 2.83 (d, *J* = 12.4 Hz, 1H), 2.44 (s, 3H), 2.39 (s, 3H); **13C NMR (100 MHz, CDCl₃):** δ 145.9, 144.6, 139.7, 136.2, 135.1, 133.9, 133.4, 132.6, 130.5, 130.3, 128.7, 127.8, 127.7, 126.8, 126.5, 125.1, 123.8, 120.9, 114.1, 71.2, 58.8, 45.3, 21.8, 21.7; **IR (neat, cm⁻¹):** ν 3485, 2922, 1596, 1448, 1375, 1350, 1165, 1089, 1015, 956, 808, 745, 660; **HRMS** calculated for C₃₁H₂₆N₂O₄S₂Cl (M+H-H₂O)⁺: 589.1017; Found: 589.1012.



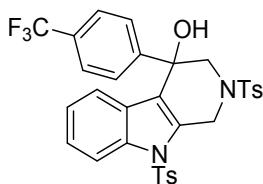
2f

White solid; m.p.: 155-156 °C; (54 mg; 83% yield); **1H NMR (400 MHz, CDCl₃):** δ 8.05 (d, *J* = 8.0 Hz, 1H), 7.78-7.72 (m, 4H), 7.40-7.34 (m, 4H), 7.29-7.19 (m, 5H), 6.99 (t, *J* = 8.0 Hz, 1H), 6.70 (d, *J* = 8.0 Hz, 1H), 5.24 (d, *J* = 16.4 Hz, 1H), 4.21 (d, *J* = 16.8 Hz, 1H), 3.90 (d, *J* = 12.4 Hz, 1H), 3.08 (s, 1H), 2.84 (d, *J* = 12.4 Hz, 1H), 2.43 (s, 3H), 2.38 (s, 3H); **13C NMR (100 MHz, CDCl₃):** δ 145.8, 144.5, 140.3, 136.2, 135.1, 133.4, 132.6, 131.6, 130.4, 130.2, 128.1, 127.7, 126.7, 126.4, 125.1, 123.8, 122.1, 120.9, 120.8, 114.0, 71.3, 58.7, 45.2, 21.8, 21.7; **IR (neat, cm⁻¹):** ν 3499, 2962, 1595, 1375, 1165, 1089, 1028, 956, 808, 746, 660; **HRMS** calculated for C₃₁H₃₁N₃O₅S₂Br (M+NH₄)⁺: 668.0883; Found: 668.0884.



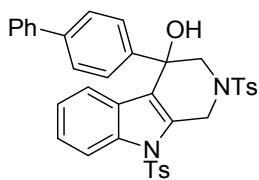
2g

White solid; m.p.: 117-118 °C; (46 mg; 78% yield); **1H NMR (400 MHz, CDCl₃):** δ 8.06 (d, *J* = 8.4 Hz, 1H), 7.79 (d, *J* = 8.4 Hz, 2H), 7.73 (d, *J* = 8.4 Hz, 2H), 7.57 (d, *J* = 8.8 Hz, 2H), 7.47 (d, *J* = 8.0 Hz, 2H), 7.36 (d, *J* = 8.0 Hz, 2H), 7.30 (d, *J* = 8.0 Hz, 2H), 7.25 (t, *J* = 8.0 Hz, 1H), 6.99 (t, *J* = 7.6 Hz, 1H), 6.62 (d, *J* = 8.0 Hz, 1H), 5.24 (d, *J* = 17.2 Hz, 1H), 4.27 (d, *J* = 16.8 Hz, 1H), 3.90 (d, *J* = 12.4 Hz, 1H), 3.23 (br, 1H), 2.90 (d, *J* = 12.4 Hz, 1H), 2.44 (s, 3H), 2.39 (s, 3H); **13C NMR (100 MHz, CDCl₃):** δ 146.6, 145.9, 144.6, 136.2, 135.0, 133.4, 132.9, 132.3, 130.5, 130.3, 127.7, 127.2, 126.7, 126.1, 125.3, 123.9, 120.5, 120.2, 118.7, 114.2, 111.9, 71.5, 58.4, 45.2, 21.8, 21.7; **IR (neat, cm⁻¹):** ν 3464, 2961, 2228, 1260, 1164, 1088, 1020, 799, 748, 660; **HRMS** calculated for C₃₂H₂₆N₃O₄S₂ (M+H-H₂O)⁺: 580.1359; Found: 580.1358.



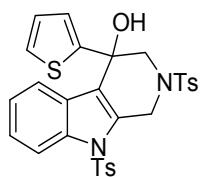
2h

White solid; m.p.: 139-140 °C; (61 mg; 96% yield); **1H NMR (400 MHz, CDCl₃):** δ 8.06 (d, *J* = 8.0 Hz, 1H), 7.79 (d, *J* = 8.4 Hz, 2H), 7.73 (d, *J* = 8.0 Hz, 2H), 7.54 (d, *J* = 8.4 Hz, 2H), 7.46 (d, *J* = 8.0 Hz, 2H), 7.35 (d, *J* = 8.0 Hz, 2H), 7.30 (d, *J* = 8.4 Hz, 2H), 7.24 (t, *J* = 7.6 Hz, 1H), 6.99 (t, *J* = 8.0 Hz, 1H), 6.65 (d, *J* = 8.0 Hz, 1H), 5.26 (d, *J* = 16.4 Hz, 1H), 4.25 (d, *J* = 16.8 Hz, 1H), 3.93 (d, *J* = 12.8 Hz, 1H), 3.16 (br, 1H), 2.89 (d, *J* = 12.4 Hz, 1H), 2.44 (s, 3H), 2.39 (s, 3H); **13C NMR (100 MHz, CDCl₃):** δ 145.9, 145.3, 144.6, 136.2, 135.1, 133.4, 132.8, 130.5, 130.3, 130.2 (q, *J* = 266.5 Hz), 127.8, 126.8, 126.4, 125.5, 125.4, 125.2, 124.1 (t, *J* = 7.6 Hz), 123.8, 120.7, 120.6, 114.1, 71.5, 58.7, 45.3, 21.8, 21.7; **19F NMR (376 MHz, CDCl₃):** δ -62.4; **IR (neat, cm⁻¹):** ν 3497, 2923, 1323, 1162, 1121, 1090, 956, 811, 749, 661; **HRMS** calculated for C₃₂H₃₁N₃O₅S₂F₃ (M+NH₄)⁺: 658.1652; Found: 658.1651.



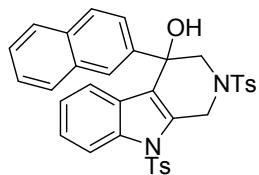
2i

Yellow solid; m.p.: 123-125 °C; (58 mg; 89% yield); **1H NMR (400 MHz, CDCl₃):** δ 8.06 (d, *J* = 8.4 Hz, 1H), 7.79-7.74 (m, 4H), 7.56 (d, *J* = 8.4 Hz, 2H), 7.51 (d, *J* = 8.8 Hz, 2H), 7.42-7.27 (m, 9H), 7.24-7.21 (m, 1H), 6.97 (t, *J* = 7.6 Hz, 1H), 6.77 (d, *J* = 8.0 Hz, 1H), 5.29 (d, *J* = 16.8 Hz, 1H), 4.22 (d, *J* = 16.8 Hz, 1H), 3.99 (d, *J* = 12.4 Hz, 1H), 3.09 (br, 1H), 2.92 (d, *J* = 12.4 Hz, 1H), 2.42 (s, 3H), 2.37 (s, 3H); **13C NMR (100 MHz, CDCl₃):** δ 145.8, 144.4, 140.6, 140.5, 140.2, 136.3, 135.2, 133.5, 132.5, 130.4, 130.2, 128.9, 127.8, 127.5, 127.1, 127.0, 126.7, 125.0, 123.7, 121.4, 121.1, 114.0, 71.4, 58.9, 45.3, 21.7, 21.6; **IR (neat, cm⁻¹):** ν 3501, 3029, 1374, 1164, 1089, 955, 728, 660; **HRMS** calculated for C₃₇H₃₁N₂O₄S₂ (M+H-H₂O)⁺: 631.1720; Found: 631.1719.



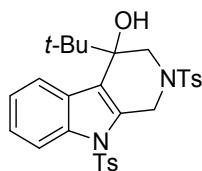
2j

White solid; m.p.: 142-143 °C; (43 mg; 74% yield); **1H NMR (400 MHz, CDCl₃):** δ 8.04 (d, *J* = 8.4 Hz, 1H), 7.76-7.74 (m, 4H), 7.35 (d, *J* = 8.4 Hz, 2H), 7.27-7.22 (m, 4H), 7.06-7.00 (m, 2H), 6.89 (dd, *J* = 4.8 Hz, 4.4 Hz, 1H), 6.68 (d, *J* = 3.6 Hz, 1H), 5.15 (d, *J* = 16.8 Hz, 1H), 4.29 (d, *J* = 16.8 Hz, 1H), 3.97 (d, *J* = 12.4 Hz, 1H), 3.23 (br, 1H), 3.11 (d, *J* = 12.8 Hz, 1H), 2.44 (s, 3H), 2.36 (s, 3H); **13C NMR (100 MHz, CDCl₃):** δ 145.8, 145.7, 144.4, 136.1, 135.1, 133.5, 132.1, 130.4, 130.2, 127.8, 127.1, 126.7, 125.3, 125.1, 125.0, 123.8, 121.1, 121.0, 114.0, 70.7, 59.0, 45.2, 21.8, 21.7; **IR (neat, cm⁻¹):** ν 3483, 2921, 1448, 1350, 1166, 1089, 955, 812, 703, 662; **HRMS** calculated for C₂₉H₃₀N₃O₅S₃ (M+NH₄)⁺: 596.1342; Found: 596.1342.



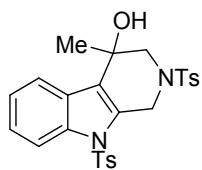
2k

Yellow solid; m.p.: 119-120 °C; (43 mg; 69% yield); **1H NMR (400 MHz, CDCl₃):** δ 8.06 (d, *J* = 8.4 Hz, 2H), 7.81-7.78 (m, 4H), 7.73-7.67 (m, 3H), 7.48 (dd, *J* = 6.4 Hz, 3.2 Hz, 2H), 7.31 (d, *J* = 8.0 Hz, 4H), 7.24-7.15 (m, 2H), 6.88 (t, *J* = 8.0 Hz, 1H), 6.68 (d, *J* = 8.0 Hz, 1H), 5.32 (d, *J* = 16.4 Hz, 1H), 4.24 (d, *J* = 16.8 Hz, 1H), 4.01 (d, *J* = 12.4 Hz, 1H), 3.16 (br, 1H), 2.96 (d, *J* = 12.4 Hz, 1H), 2.41 (s, 3H), 2.40 (s, 3H); **13C NMR (100 MHz, CDCl₃):** δ 145.8, 144.4, 138.5, 136.3, 135.2, 133.4, 133.2, 132.9, 132.6, 130.5, 130.2, 128.5, 128.2, 127.7, 127.7, 126.8, 126.4, 125.5, 125.0, 124.1, 123.8, 121.3, 121.1, 114.0, 71.7, 58.8, 45.4, 21.8, 21.7; **IR (neat, cm⁻¹):** ν 3501, 3053, 1348, 1165, 1089, 954, 813, 747, 659; **HRMS** calculated for C₃₅H₂₉N₂O₄S₂ (M+H-H₂O)⁺: 605.1563; Found: 605.1561.



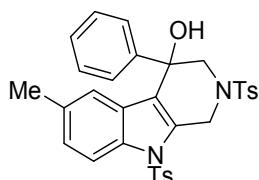
2l

White solid; m.p.: 168-169 °C; (45 mg; 81% yield); **1H NMR (400 MHz, CDCl₃):** δ 8.07 (d, *J* = 8.0 Hz, 1H), 7.74 (d, *J* = 8.0 Hz, 3H), 7.61 (d, *J* = 8.4 Hz, 2H), 7.35 (d, *J* = 8.0 Hz, 2H), 7.25-7.15 (m, 4H), 5.03 (d, *J* = 16.8 Hz, 1H), 4.35 (d, *J* = 12.0 Hz, 1H), 3.98 (d, *J* = 16.8 Hz, 1H), 2.43 (s, 3H), 2.34 (s, 3H), 2.25 (d, *J* = 12.0 Hz, 1H), 1.81 (br, 1H), 1.08 (s, 9H); **13C NMR (100 MHz, CDCl₃):** δ 145.5, 144.2, 136.7, 134.8, 132.5, 131.0, 130.1, 130.0, 128.4, 127.8, 126.5, 124.7, 123.8, 123.0, 122.4, 114.5, 75.9, 52.2, 44.6, 39.8, 26.9, 21.7, 21.6; **IR (neat, cm⁻¹):** ν 3540, 2958, 1349, 1166, 1092, 979, 728, 662; **HRMS** calculated for C₂₉H₃₆N₃O₅S₂ (M+NH₄)⁺: 570.2091; Found: 570.2087.



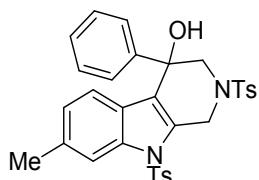
2m

White solid; m.p.: 145-146 °C; (46 mg; 91% yield); **1H NMR (400 MHz, CDCl₃):** δ 8.03 (d, *J* = 8.4 Hz, 1H), 7.77-7.67 (m, 5H), 7.37 (d, *J* = 8.0 Hz, 2H), 7.29-7.20 (m, 4H), 4.63 (d, *J* = 16.4 Hz, 1H), 4.46 (d, *J* = 16.8 Hz, 1H), 3.29 (d, *J* = 12.0 Hz, 1H), 3.23 (d, *J* = 12.0 Hz, 1H), 2.58 (s, 1H), 2.44 (s, 3H), 2.32 (s, 3H), 1.65 (s, 3H); **13C NMR (100 MHz, CDCl₃):** δ 145.5, 144.2, 136.1, 135.0, 133.5, 130.2, 130.1, 127.7, 126.9, 126.5, 124.8, 123.7, 122.2, 120.8, 114.1, 68.3, 56.7, 45.0, 25.2, 21.6; **IR (neat, cm⁻¹):** ν 3506, 2978, 1594, 1448, 1353, 1223, 1157, 1092, 951, 817, 739, 653; **HRMS** calculated for C₂₆H₃₀N₃O₅S₂ (M+NH₄)⁺: 528.1621; Found: 528.1619.



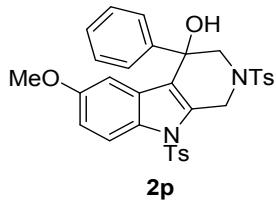
2n

White solid; m.p.: 145-146 °C; (51 mg; 87% yield); **1H NMR (400 MHz, CDCl₃):** δ 7.92 (d, *J* = 8.4 Hz, 1H), 7.74 (t, *J* = 8.4 Hz, 4H), 7.35-7.25 (m, 9H), 7.03 (d, *J* = 8.8 Hz, 1H), 6.46 (s, 1H), 5.24 (d, *J* = 16.8 Hz, 1H), 4.17 (d, *J* = 16.8 Hz, 1H), 3.93 (d, *J* = 12.8 Hz, 1H), 3.02 (br, 1H), 2.87 (d, *J* = 12.4 Hz, 1H), 2.43 (s, 3H), 2.37 (s, 3H), 2.12 (s, 3H); **13C NMR (100 MHz, CDCl₃):** δ 145.6, 144.3, 141.1, 135.1, 134.5, 133.4, 132.5, 130.4, 130.2, 128.5, 127.9, 127.8, 127.0, 126.7, 126.4, 126.2, 121.4, 120.9, 113.7, 71.5, 58.9, 45.3, 21.8, 21.7, 21.3; **IR (neat, cm⁻¹):** ν 3499, 2920, 1448, 1351, 1160, 1090, 959, 808, 700, 663; **HRMS** calculated for C₃₂H₃₄N₃O₅S₂ (M+NH₄)⁺: 604.1934; Found: 604.1930.

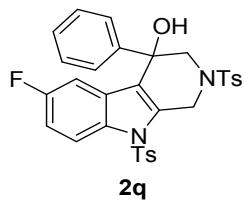


2o

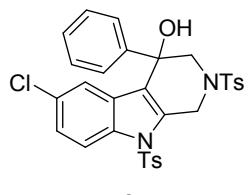
White solid; m.p.: 140-141 °C; (52 mg; 89% yield); **1H NMR (400 MHz, CDCl₃):** δ 7.86 (s, 1H), 7.77-7.72 (m, 4H), 7.35-7.25 (m, 9H), 6.78 (d, *J* = 8.0 Hz, 1H), 6.54 (d, *J* = 8.0 Hz, 1H), 5.24 (d, *J* = 16.8 Hz, 1H), 4.16 (d, *J* = 16.8 Hz, 1H), 3.95 (d, *J* = 12.4 Hz, 1H), 2.99 (br, 1H), 2.85 (d, *J* = 12.4 Hz, 1H), 2.43 (s, 3H), 2.39 (s, 3H), 2.38 (s, 3H); **13C NMR (100 MHz, CDCl₃):** δ 145.6, 144.4, 141.2, 136.7, 135.3, 135.2, 133.5, 131.7, 130.4, 130.2, 128.4, 127.9, 127.8, 126.6, 126.3, 125.2, 124.4, 121.5, 120.6, 114.2, 71.4, 58.9, 45.3, 22.1, 21.8, 21.7; **IR (neat, cm⁻¹):** ν 3501, 2920, 1350, 1164, 1090, 1019, 811, 727, 701, 662; **HRMS** calculated for C₃₂H₃₄N₃O₅S₂ (M+NH₄)⁺: 604.1934; Found: 604.1935.



White solid; m.p.: 148-149 °C; (49 mg; 81% yield); **¹H NMR (400 MHz, CDCl₃):** δ 7.93 (d, *J* = 9.2 Hz, 1H), 7.75-7.71 (m, 4H), 7.36-7.25 (m, 9H), 6.80 (dd, *J* = 9.2 Hz, 2.4 Hz, 1H), 6.04 (d, *J* = 2.4 Hz, 1H), 5.26 (d, *J* = 16.4 Hz, 1H), 4.15 (d, *J* = 16.8 Hz, 1H), 3.96 (d, *J* = 12.4 Hz, 1H), 3.42 (s, 3H), 3.04 (br, 1H), 2.87 (d, *J* = 12.4 Hz, 1H), 2.43 (s, 3H), 2.37 (s, 3H); **¹³C NMR (100 MHz, CDCl₃):** δ 156.2, 145.6, 144.4, 140.9, 135.0, 133.4, 132.9, 130.8, 130.4, 130.2, 128.4, 127.9, 127.8, 127.7, 126.6, 126.3, 121.7, 114.9, 113.9, 103.2, 71.4, 58.8, 55.3, 45.4, 21.8, 21.7; **IR (neat, cm⁻¹):** ν 3511, 2925, 1349, 1161, 1089, 1024, 960, 810, 724, 700, 665; **HRMS** calculated for C₃₂H₃₄N₃O₆S₂ (M+NH₄)⁺: 620.1884; Found: 620.1880.

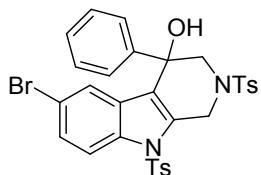


White solid; m.p.: 158-159 °C; (52 mg; 88% yield); **¹H NMR (400 MHz, CDCl₃):** δ 8.00 (dd, *J* = 8.8 Hz, 4.0 Hz, 1H), 7.76-7.72 (m, 4H), 7.35 (d, *J* = 8.0 Hz, 2H), 7.31-7.25 (m, 7H), 6.94 (td, *J* = 8.8 Hz, 2.4 Hz, 1H), 7.32 (dd, *J* = 8.8 Hz, 2.8 Hz, 1H), 5.27 (d, *J* = 16.4 Hz, 1H), 4.18 (d, *J* = 16.8 Hz, 1H), 3.95 (d, *J* = 12.4 Hz, 1H), 3.09 (br, 1H), 2.88 (d, *J* = 12.8 Hz, 1H), 2.34 (s, 3H), 2.39 (s, 3H); **¹³C NMR (100 MHz, CDCl₃):** δ 159.4 (d, *J* = 240.6 Hz), 150.0, 144.5, 140.6, 134.9, 134.1, 133.4, 132.5, 130.5, 130.2, 128.6, 128.1, 127.9 (d, *J* = 9.8 Hz), 127.8, 126.7, 126.1, 121.5 (d, *J* = 4.6 Hz), 115.1 (d, *J* = 9.1 Hz), 112.9 (d, *J* = 25.8 Hz), 106.8 (d, *J* = 25.0 Hz), 71.3, 58.8, 45.3, 21.8, 21.7; **¹⁹F NMR (376 MHz, CDCl₃):** δ -118.3; **IR (neat, cm⁻¹):** ν 3490, 3061, 1447, 1376, 1160, 1089, 1022, 808, 700, 663; **HRMS** calculated for C₃₁H₃₁N₃O₅S₂F (M+NH₄)⁺: 608.1684; Found: 608.1684.



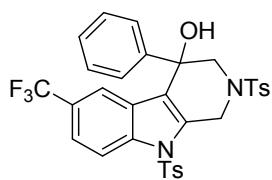
2r

White solid; m.p.: 162-163 °C; (54 mg; 90% yield); **1H NMR (400 MHz, CDCl₃):** δ 7.98 (d, *J* = 9.2 Hz, 1H), 7.74 (t, *J* = 8.4 Hz, 4H), 7.35 (d, *J* = 8.0 Hz, 2H), 7.31-7.25 (m, 7H), 7.18 (dd, *J* = 8.8 Hz, 2.0 Hz, 1H), 6.64 (d, *J* = 2.0 Hz, 1H), 5.26 (d, *J* = 16.8 Hz, 1H), 4.18 (d, *J* = 16.8 Hz, 1H), 3.93 (d, *J* = 12.4 Hz, 1H), 3.05 (br, 1H), 2.88 (d, *J* = 12.4 Hz, 1H), 2.44 (s, 3H), 2.40 (s, 3H); **13C NMR (100 MHz, CDCl₃):** δ 146.1, 144.5, 140.6, 134.9, 134.6, 133.9, 133.4, 130.5, 130.2, 129.6, 128.6, 128.2, 128.1, 127.8, 126.7, 126.1, 125.3, 121.1, 120.6, 115.1, 71.3, 58.9, 45.2, 21.8, 21.7; **IR (neat, cm⁻¹):** ν 3520, 2925, 1442, 1351, 1167, 1088, 1028, 958, 767, 681; **HRMS** calculated for C₃₁H₂₆N₂O₄S₂Cl (M+H-H₂O)⁺: 589.1017; Found: 589.1015.



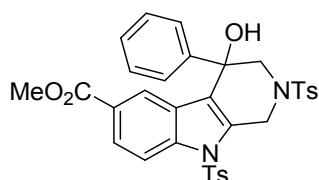
2s

White solid; m.p.: 166-167 °C; (57 mg; 88% yield); **1H NMR (400 MHz, CDCl₃):** δ 7.93 (d, *J* = 8.8 Hz, 1H), 7.74 (t, *J* = 8.4 Hz, 4H), 7.55-7.22 (m, 10H), 6.80 (d, *J* = 2.0 Hz, 1H), 5.25 (d, *J* = 17.2 Hz, 1H), 4.19 (d, *J* = 16.8 Hz, 1H), 3.92 (d, *J* = 12.8 Hz, 1H), 3.04 (br, 1H), 2.88 (d, *J* = 12.8 Hz, 1H), 2.43 (s, 3H), 2.40 (s, 3H); **13C NMR (100 MHz, CDCl₃):** δ 146.1, 144.5, 140.6, 135.0, 134.8, 133.7, 133.4, 130.5, 130.2, 128.6, 128.5, 128.2, 128.0, 127.8, 126.7, 126.1, 123.7, 121.0, 117.3, 115.4, 71.4, 58.9, 45.2, 21.8, 21.7; **IR (neat, cm⁻¹):** ν 3519, 2896, 1441, 1347, 1167, 1088, 1028, 957, 802, 662; **HRMS** calculated for C₃₁H₂₆N₂O₄S₂Br (M+H-H₂O)⁺: 633.0512; Found: 633.0504.



2t

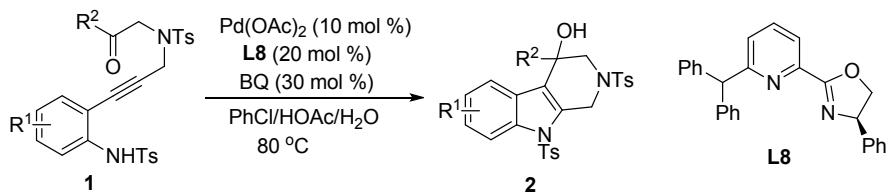
White solid; m.p.: 152-153 °C; (59 mg; 93% yield); **1H NMR (400 MHz, CDCl₃):** δ 8.16 (d, *J* = 8.8 Hz, 1H), 7.80 (d, *J* = 8.4 Hz, 2H), 7.75 (d, *J* = 8.4 Hz, 2H), 7.46 (d, *J* = 8.8 Hz, 1.2 Hz, 1H), 7.37-7.31 (m, 9H), 6.92 (s, 1H), 5.30 (d, *J* = 16.8 Hz, 1H), 4.22 (d, *J* = 16.8 Hz, 1H), 3.98 (d, *J* = 12.8 Hz, 1H), 3.11 (br, 1H), 2.91 (d, *J* = 12.8 Hz, 1H), 2.44 (s, 3H), 2.41 (s, 3H); **13C NMR (100 MHz, CDCl₃):** δ 146.4, 144.6, 140.5, 137.8, 134.9, 134.2, 133.4, 130.7, 130.3, 128.6, 128.3, 127.8, 126.8, 126.6, 126.1, 126.0 (q, *J* = 32.2 Hz), 124.1 (q, *J* = 270.4 Hz), 121.8 (q, *J* = 3.1 Hz), 121.6, 118.4 (q, *J* = 4.6 Hz), 114.3, 71.3, 58.8, 45.2, 21.8, 21.7; **IR (neat, cm⁻¹):** ν 3481, 2924, 1324, 1163, 1120, 1091, 959, 813, 700, 631; **¹⁹F NMR (376 MHz, CDCl₃):** δ -61.6; **HRMS** calculated for C₃₂H₃₁N₃O₅S₂F₃ (M+NH₄)⁺: 658.1652; Found: 658.1649.



2u

White solid; m.p.: 125-126 °C; (53 mg; 84% yield); **1H NMR (400 MHz, CDCl₃):** δ 8.09 (d, *J* = 8.8 Hz, 1H), 7.91 (dd, *J* = 8.8 Hz, 1.2 Hz, 1H), 7.78 (d, *J* = 8.4 Hz, 2H), 7.73 (d, *J* = 8.0 Hz, 2H), 7.40 (s, 1H), 7.36-7.26 (m, 9H), 5.24 (d, *J* = 16.4 Hz, 1H), 4.23 (d, *J* = 16.8 Hz, 1H), 3.94 (d, *J* = 12.4 Hz, 1H), 3.73 (s, 3H), 3.13 (br, 1H), 2.94 (d, *J* = 12.4 Hz, 1H), 2.44 (s, 3H), 2.39 (s, 3H); **13C NMR (100 MHz, CDCl₃):** δ 166.8, 146.2, 144.5, 140.8, 138.8, 134.8, 133.8, 133.4, 130.6, 130.2, 128.5, 128.2, 127.8, 126.8, 126.7, 126.2, 126.1, 125.8, 123.0, 121.9, 113.7, 71.4, 58.8, 52.1, 45.2, 21.8, 21.7; **IR (neat, cm⁻¹):** ν 3477, 2951, 1717, 1446, 1294, 1165, 1091, 957, 767, 664; **HRMS** calculated for C₃₃H₃₄N₃O₇S₂ (M+NH₄)⁺: 648.1833; Found: 648.1829.

4. General procedure for asymmetric cyclization of 1



To a dried Schlenk tube were added substrate **1** (0.1 mmol, 1.0 equiv.), palladium acetate (2.3 mg, 0.01 mmol), **L8**² (7.8 mg, 0.02 mmol) and BQ (3.3 mg, 0.03 mmol), then 1 mL of PhCl, 0.1 ml of acetic acid, 0.1 mL of H₂O were added sequentially. The resulting mixture was stirred at 80 °C. The progress of the reaction was monitored by TLC. After completion of the reaction, the solvents were evaporated under reduced pressure and the residue was purified by flash chromatography (petroleum ether : ethyl acetate = 10:1-4:1) to give chiral product **2**.

(-)-2a:

Yield: 82%; $[\alpha]_D^{29} = -97.60$ ($c = 1.0$, in CDCl₃); ee: 93%; The ee value was determined by chiral HPLC using a Chiralpak IC column with hexane : isopropanol = 50 : 50 at a flow rate 0.7 mL/min detected at 214 nm wavelength. Elution time: t (minor) = 11.10 min; t (major) = 14.02 min.

(-)-2b:

Yield: 87%; $[\alpha]_D^{19} = -154.72$ ($c = 0.5$, in CDCl₃); ee: 91%; The ee value was determined by chiral HPLC using a Chiralpak IC column with hexane : isopropanol = 50 : 50 at a flow rate 0.7 mL/min detected at 214 nm wavelength. Elution time: t (minor) = 11.95 min; t (major) = 14.39 min.

(-)-2c:

Yield: 42%; $[\alpha]_D^{17} = -58.60$ ($c = 0.1$, in CDCl₃); ee: 85%; The ee value was determined by chiral HPLC using a Chiralpak IC column with hexane : isopropanol = 50 : 50 at a flow rate 0.7 mL/min detected at 214 nm wavelength. Elution time: t (minor) = 14.13 min; t (major) = 18.41 min.

(-)-2d:

Yield: 70%; $[\alpha]_D^{17} = -103.17$ ($c = 0.5$, in CDCl_3); ee: 90%; The ee value was determined by chiral HPLC using a Chiraldapak IC column with hexane : isopropanol = 50 : 50 at a flow rate 0.7 mL/min detected at 214 nm wavelength. Elution time: t (minor) = 9.25 min; t (major) = 11.79 min.

(-)-2e:

Yield: 69%; $[\alpha]_D^{17} = -135.27$ ($c = 0.5$, in CDCl_3); ee: 92%; The ee value was determined by chiral HPLC using a Chiraldapak IC column with hexane : isopropanol = 50 : 50 at a flow rate 0.7 mL/min detected at 214 nm wavelength. Elution time: t (minor) = 9.12 min; t (major) = 11.13 min.

(-)-2f:

Yield: 74%; $[\alpha]_D^{18} = -87.24$ ($c = 0.5$, in CDCl_3); ee: 92%; The ee value was determined by chiral HPLC using a Chiraldapak IC column with hexane : isopropanol = 50 : 50 at a flow rate 0.7 mL/min detected at 214 nm wavelength. Elution time: t (minor) = 9.37 min; t (major) = 11.38 min.

(-)-2g:

Yield: 73%; $[\alpha]_D^{16} = -104.62$ ($c = 0.5$, in CDCl_3); ee: 89%; The ee value was determined by chiral HPLC using a Chiraldapak IC column with hexane : isopropanol = 50 : 50 at a flow rate 0.7 mL/min detected at 214 nm wavelength. Elution time: t (minor) = 14.78 min; t (major) = 21.93 min.

(-)-2h:

Yield: 92%; $[\alpha]_D^{18} = -112.40$ ($c = 0.5$, in CDCl_3); ee: 92%; The ee value was determined by chiral HPLC using a Chiraldapak IC column with hexane : isopropanol = 50 : 50 at a flow rate 0.7 mL/min detected at 214 nm wavelength. Elution time: t (minor) = 6.88 min; t (major) = 8.02 min.

(-)-2i:

Yield: 84%; $[\alpha]_D^{18} = -115.97$ ($c = 0.5$, in CDCl_3); ee: 92%; The ee value was determined by chiral HPLC using a Chiraldapak IC column with hexane : isopropanol = 50 : 50 at a flow rate 0.7 mL/min detected at 214 nm wavelength. Elution time: t (minor) = 12.69 min; t (major) = 16.85 min.

(-)-2j:

Yield: 63%; $[\alpha]_D^{21} = -68.45$ ($c = 0.5$, in CDCl_3); ee: 85%; The ee value was determined by chiral HPLC using a Chiraldak IA column with hexane : isopropanol : acetonitrile= 88 : 10 : 2 at a flow rate 0.7 mL/min detected at 214 nm wavelength. Elution time: t (minor) = 61.98 min; t (major) = 72.80 min.

(-)-2k:

Yield: 52%; $[\alpha]_D^{19} = -82.15$ ($c = 0.5$, in CDCl_3); ee: 88%; The ee value was determined by chiral HPLC using a Chiraldak IC column with hexane : isopropanol = 50 : 50 at a flow rate 0.7 mL/min detected at 214 nm wavelength. Elution time: t (minor) = 11.75 min; t (major) = 13.97 min.

(+)-2l:

Yield: 72%; $[\alpha]_D^{17} = 30.02$ ($c = 0.5$, in CDCl_3); ee: 81%; The ee value was determined by chiral HPLC using a Chiraldak IC column with hexane : isopropanol = 50 : 50 at a flow rate 0.7 mL/min detected at 214 nm wavelength. Elution time: t (major) = 6.35 min; t (minor) = 6.94 min.

(-)-2m:

Yield: 83%; $[\alpha]_D^{29} = -7.89$ ($c = 0.5$, in CDCl_3); ee: 90%; The ee value was determined by chiral HPLC using a Chiraldak IA column with hexane : isopropanol = 60 : 40 at a flow rate 0.7 mL/min detected at 214 nm wavelength. Elution time: t (minor) = 10.86 min; t (major) = 13.86 min.

(-)-2n:

Yield: 58%; $[\alpha]_D^{21} = -80.08$ ($c = 0.5$, in CDCl_3); ee: 91%; The ee value was determined by chiral HPLC using a Chiraldak IC column with hexane : isopropanol = 50 : 50 at a flow rate 0.7 mL/min detected at 214 nm wavelength. Elution time: t (minor) = 10.61 min; t (major) = 13.96 min.

(-)-2o:

Yield: 65%; $[\alpha]_D^{18} = -79.99$ ($c = 0.5$, in CDCl_3); ee: 90%; The ee value was determined by chiral HPLC using a Chiraldak IC column with hexane : isopropanol = 50 : 50 at a flow rate 0.7 mL/min detected at 214 nm wavelength. Elution time: t (minor) = 10.91 min; t (major) = 12.07 min.

(-)2p:

Yield: 32%; $[\alpha]_D^{28} = -126.93$ ($c = 0.5$, in CDCl_3); ee: 81%; The ee value was determined by chiral HPLC using a Chiraldapak IC column with hexane : isopropanol = 50 : 50 at a flow rate 0.7 mL/min detected at 214 nm wavelength. Elution time: t (minor) = 12.49 min; t (major) = 18.17 min.

(-)2q:

Yield: 85%; $[\alpha]_D^{19} = -141.52$ ($c = 0.5$, in CDCl_3); ee: 91%; The ee value was determined by chiral HPLC using a Chiraldapak IC column with hexane : isopropanol = 70 : 30 at a flow rate 0.7 mL/min detected at 214 nm wavelength. Elution time: t (minor) = 13.39 min; t (major) = 16.14 min.

(-)2r:

Yield: 86%; $[\alpha]_D^{17} = -208.14$ ($c = 0.5$, in CDCl_3); ee: 87%; The ee value was determined by chiral HPLC using a Chiraldapak IC column with hexane : isopropanol = 70 : 30 at a flow rate 0.7 mL/min detected at 214 nm wavelength. Elution time: t (minor) = 13.21 min; t (major) = 15.53 min.

(-)2s:

Yield: 87%; $[\alpha]_D^{20} = -225.24$ ($c = 0.5$, in CDCl_3); ee: 89%; The ee value was determined by chiral HPLC using a Chiraldapak IC column with hexane : isopropanol = 70 : 30 at a flow rate 0.7 mL/min detected at 214 nm wavelength. Elution time: t (minor) = 13.37 min; t (major) = 16.31 min.

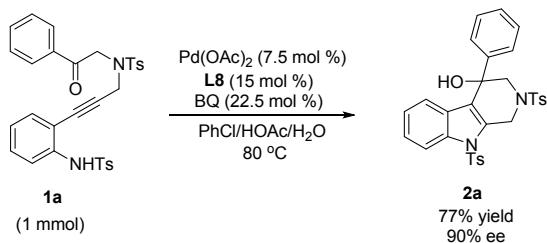
(-)2t:

Yield: 89%; $[\alpha]_D^{22} = -118.29$ ($c = 0.5$, in CDCl_3); ee: 82%; The ee value was determined by chiral HPLC using a Chiraldapak IC column with hexane : isopropanol = 90 : 10 at a flow rate 0.7 mL/min detected at 214 nm wavelength. Elution time: t (minor) = 23.27 min; t (major) = 31.84 min.

(-)2u:

Yield: 80%; $[\alpha]_D^{21} = -35.56$ ($c = 0.5$, in CDCl_3); ee: 56%; The ee value was determined by chiral HPLC using a Chiraldapak IC column with hexane : isopropanol = 50 : 50 at a flow rate 0.7 mL/min detected at 214 nm wavelength. Elution time: t (minor) = 14.53 min; t (major) = 31.13 min.

5. Procedure for asymmetric cyclization of **1a** at 1 mmol scale

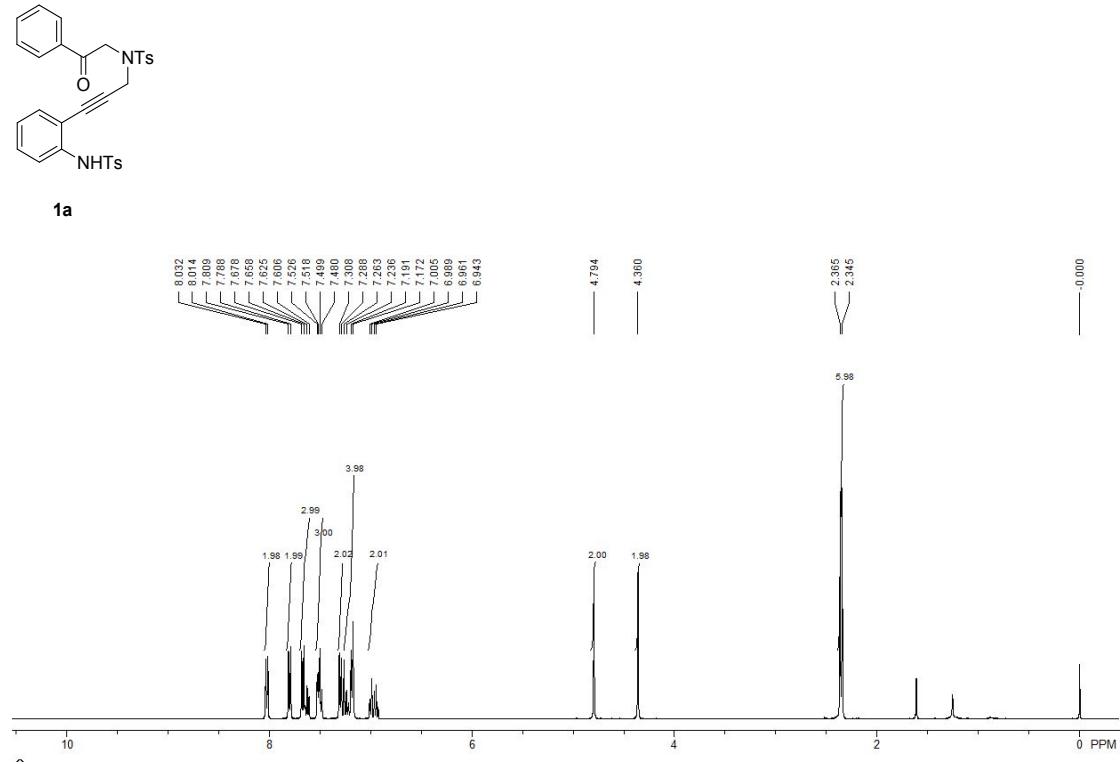


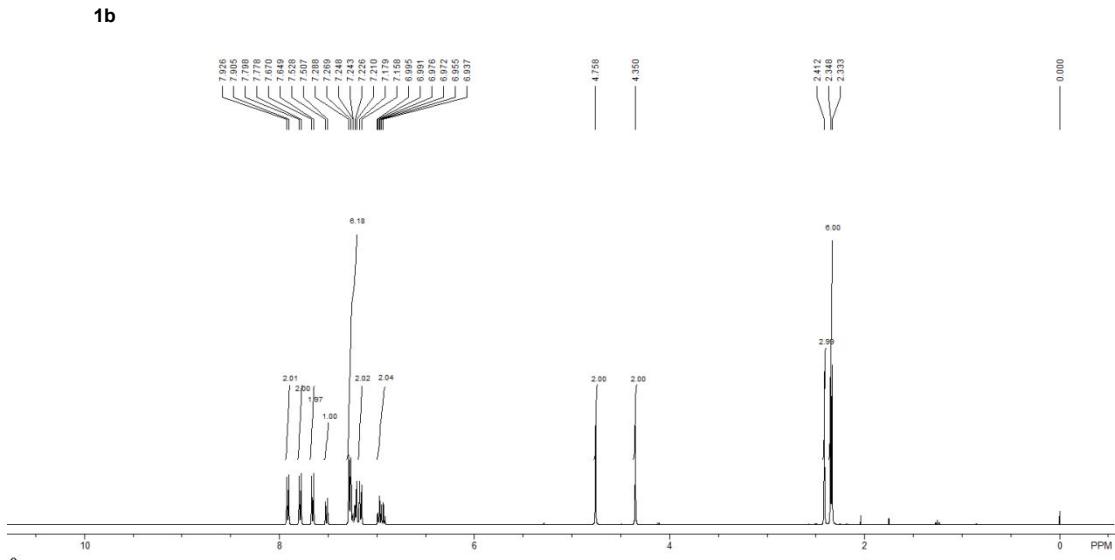
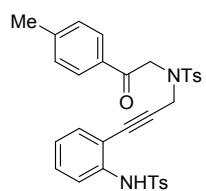
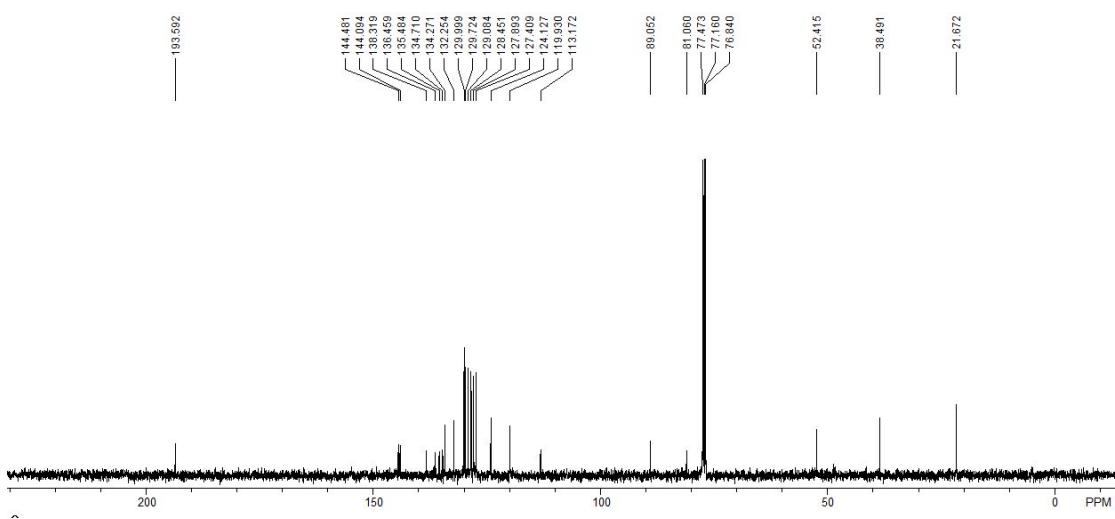
To a dried Schlenk tube were added substrate **1a** (572 mg, 1.0 mmol, 1.0 equiv.), palladium acetate (16.8 mg, 0.075 mmol), **L8**² (58 mg, 0.15 mmol), and BQ (24 mg, 0.225 mmol), then 7 mL of dioxane, 0.75 mL of acetic acid, 0.75 mL of H₂O were added sequentially. The resulting mixture was stirred at 80 °C. The progress of the reaction was monitored by TLC. After completion of the reaction, the solvents were evaporated under reduced pressure and the residue was purified by flash column chromatography (petroleum ether : ethyl acetate = 10:1-4:1) to give product **2a** (441 mg, 77% yield, 90% ee).

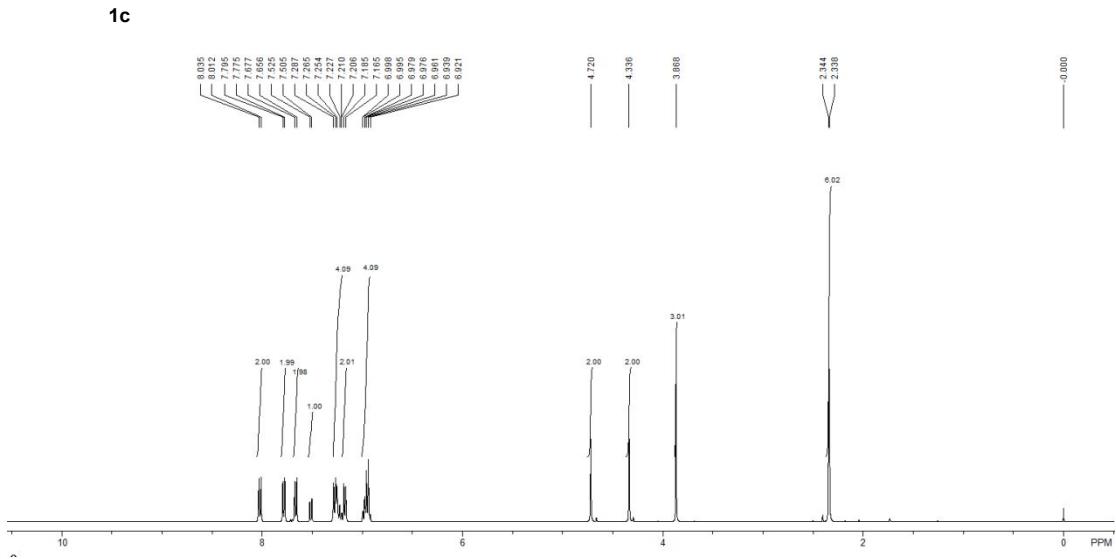
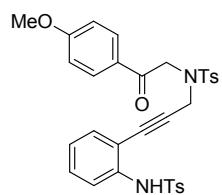
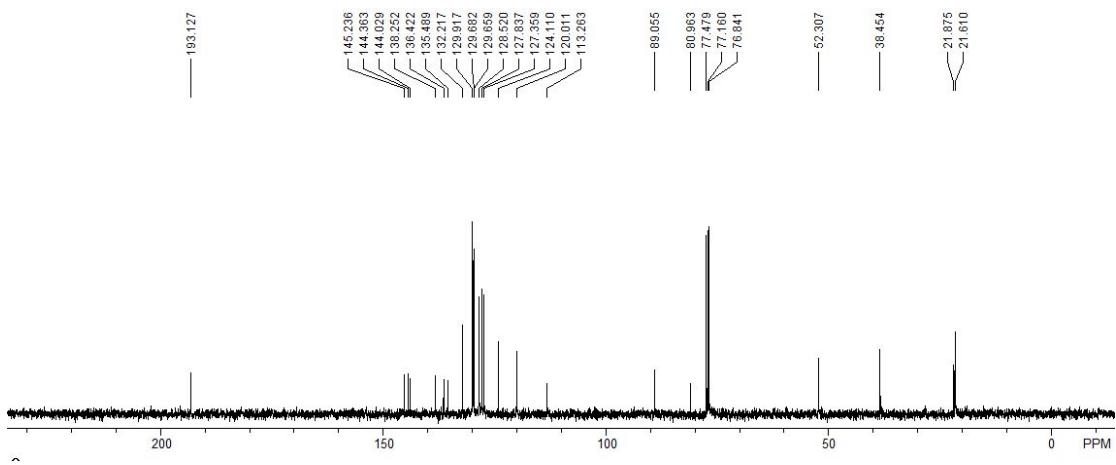
6. References:

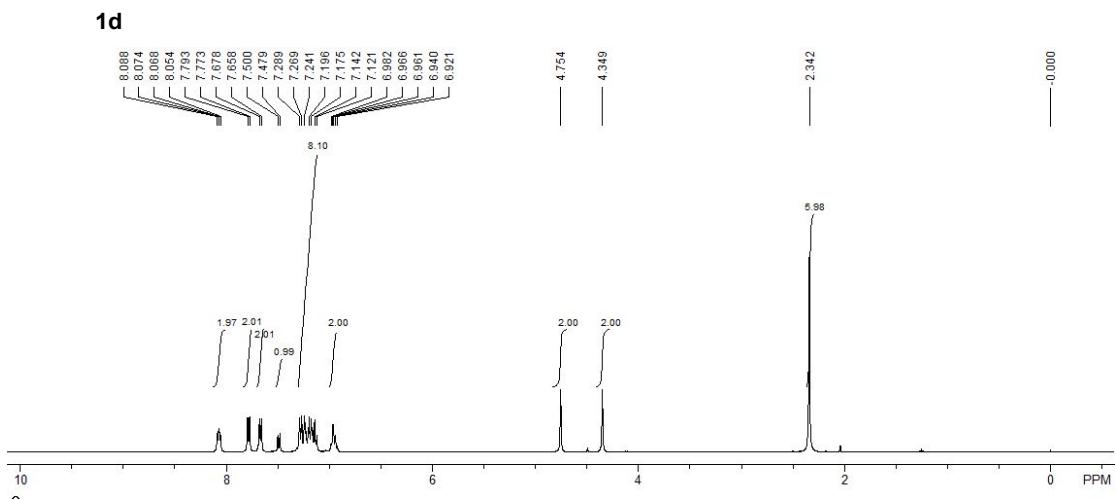
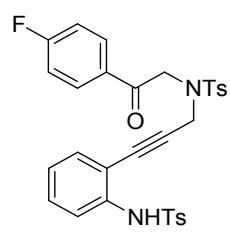
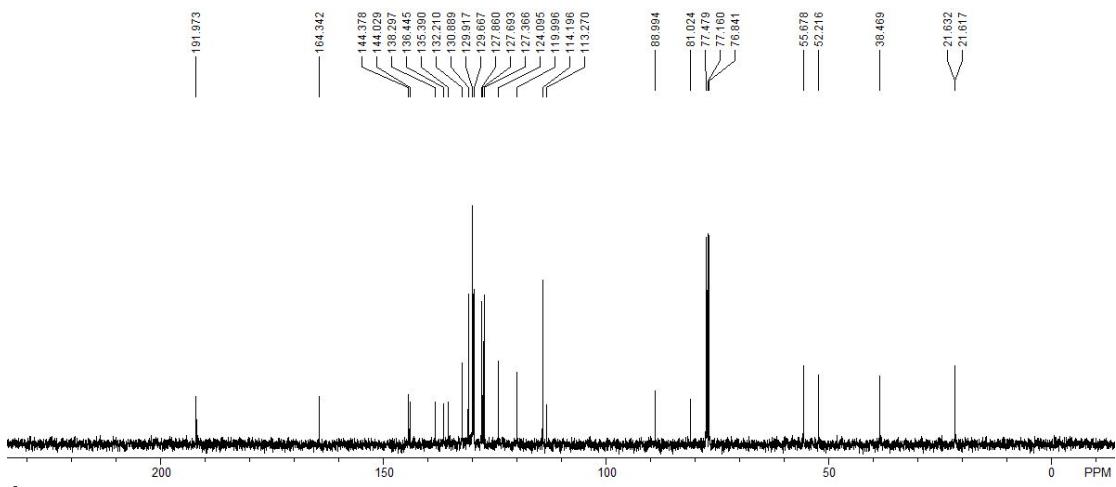
- (1) Boominathan, S. S. K.; Hu, W.-P.; Senadi, G. C.; Wang, J.-J. *Adv. Synth. Catal.* **2013**, *355*, 3570.
- (2) Qi, X.; Chen, C.; Hou, C.; Fu, L.; Chen, P.; Liu, G. *J. Am. Chem. Soc.* **2018**, *140*, 7415.

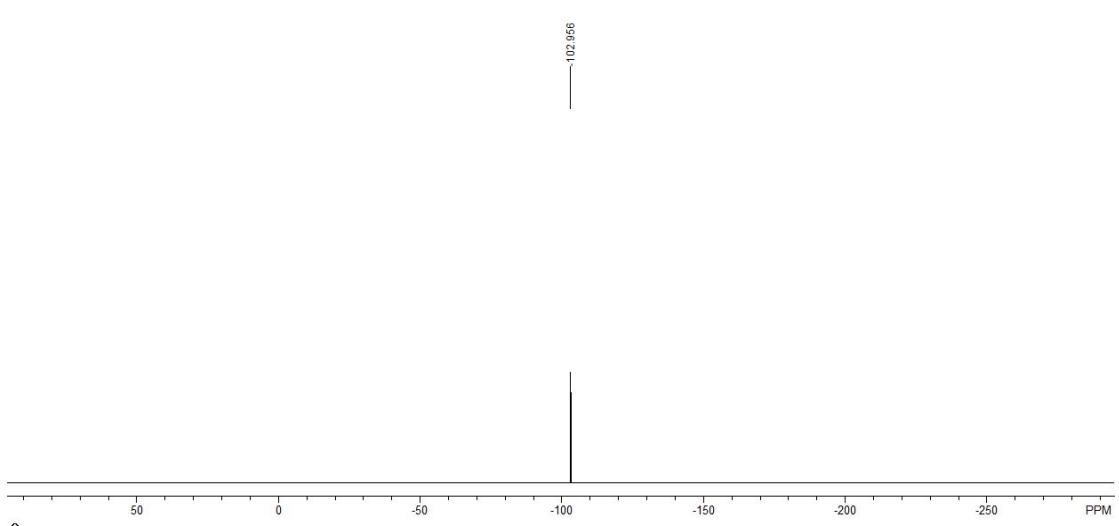
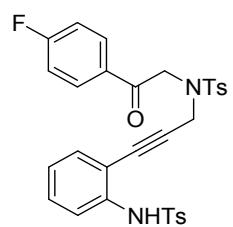
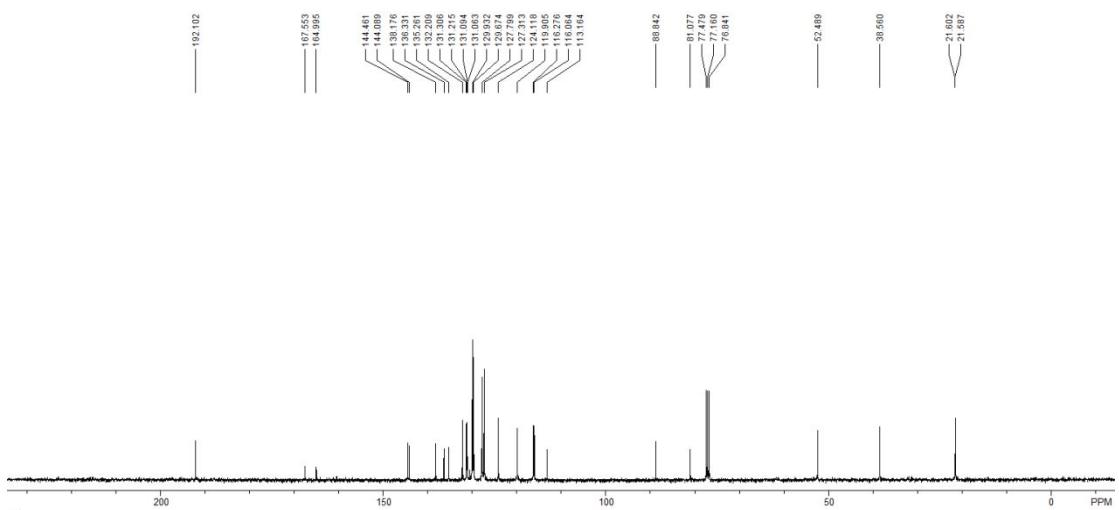
7. Copies of ^1H NMR, ^{13}C NMR and ^{19}F NMR spectra

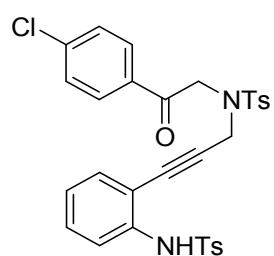




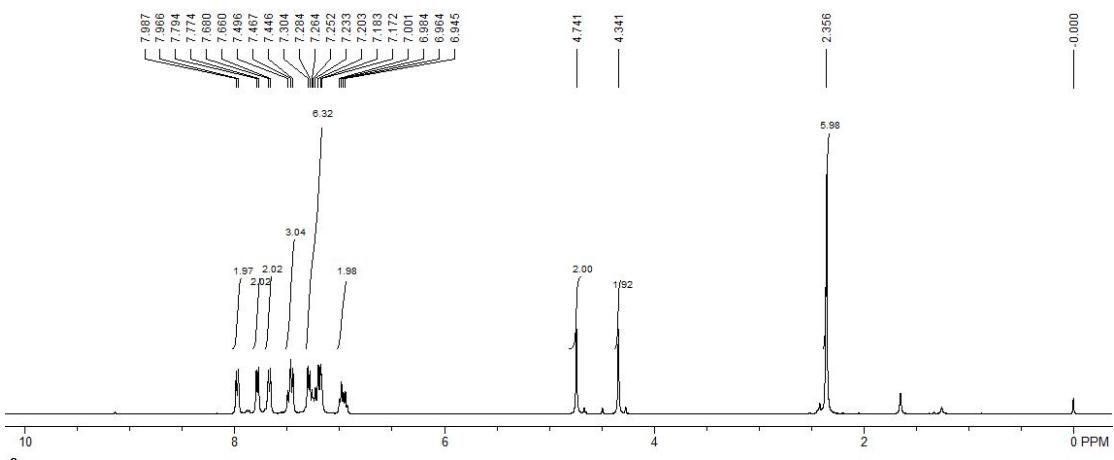


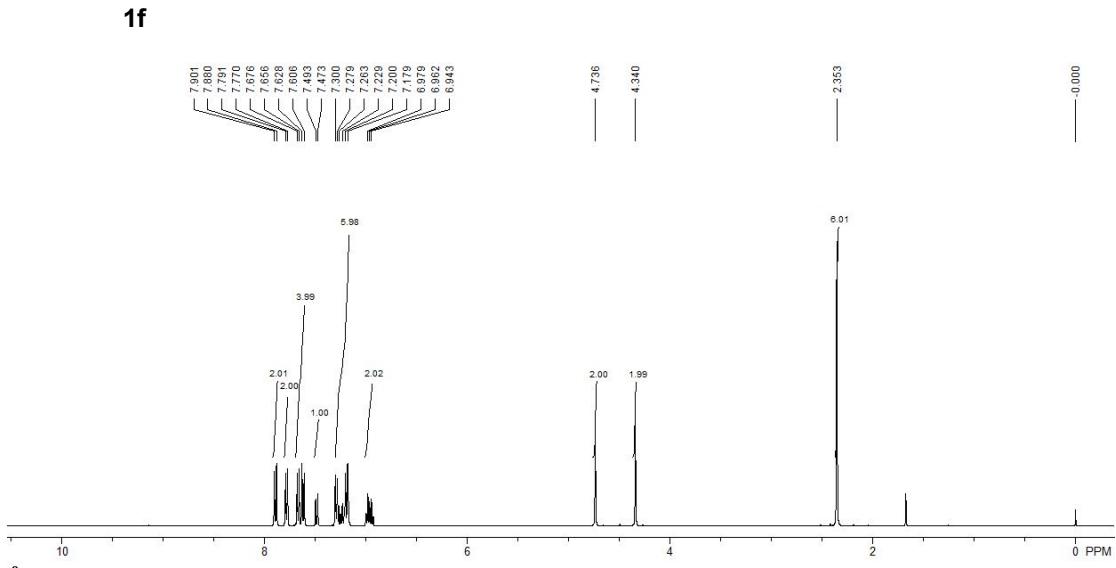
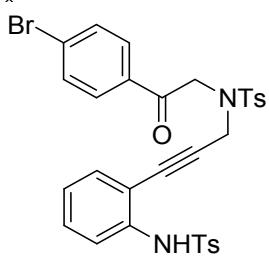
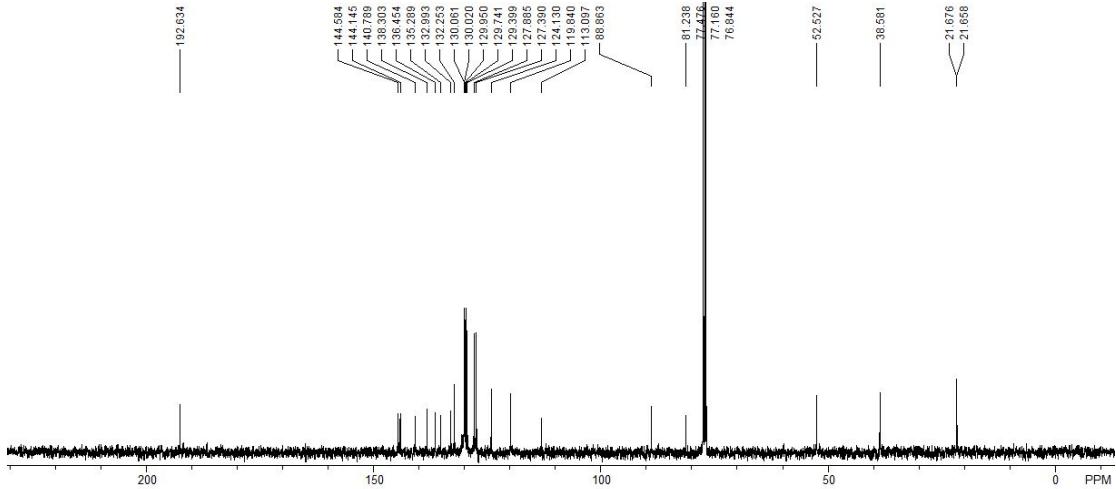


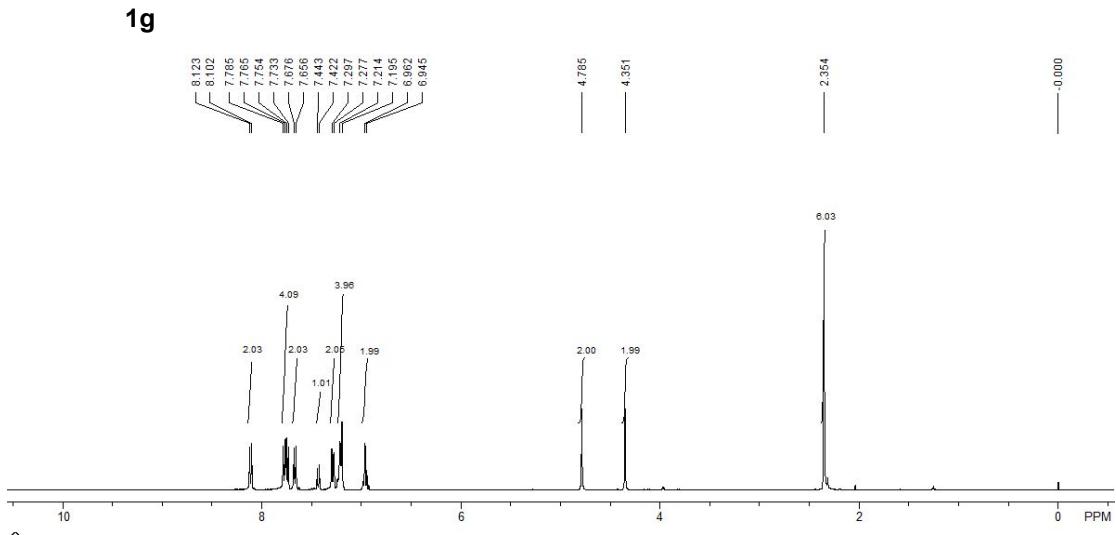
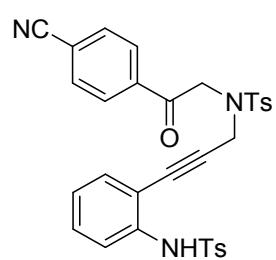
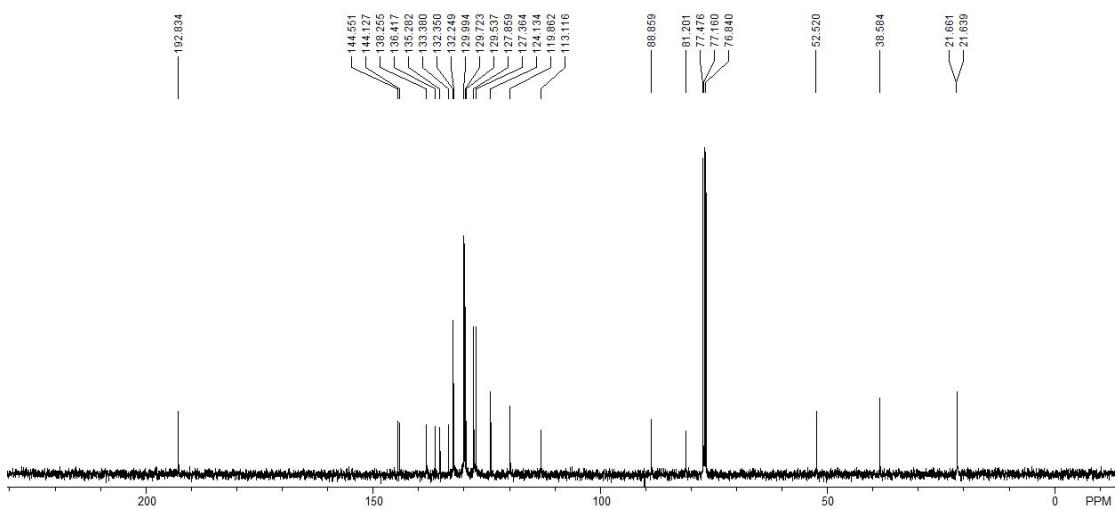


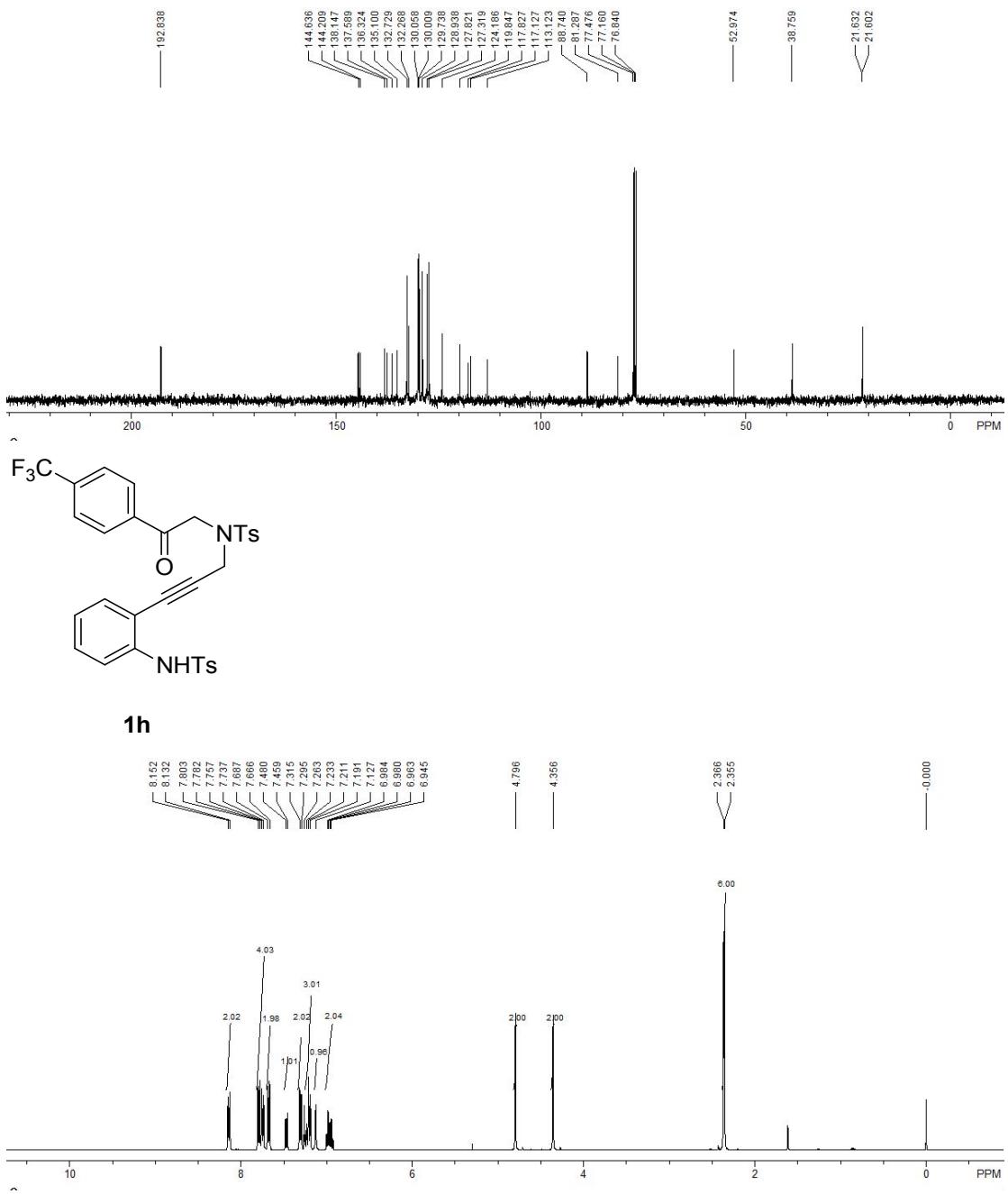


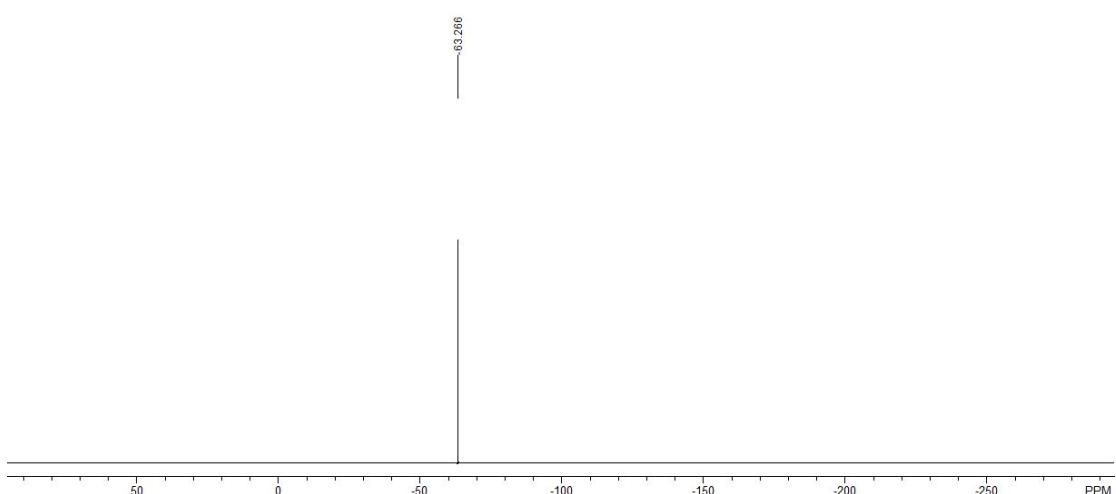
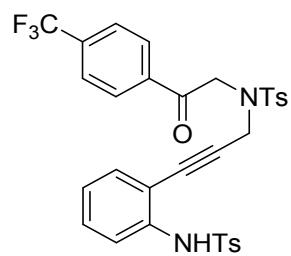
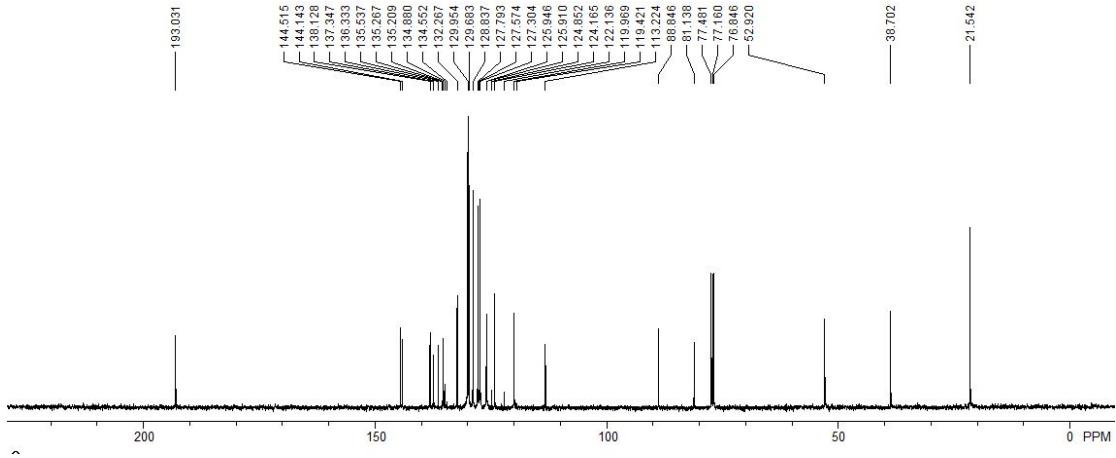
1e

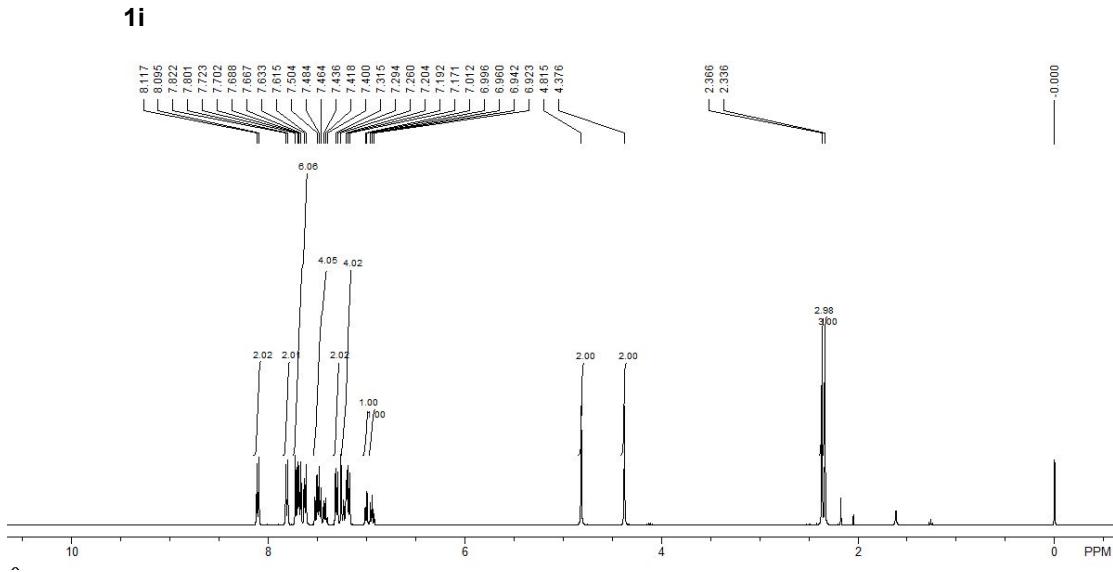
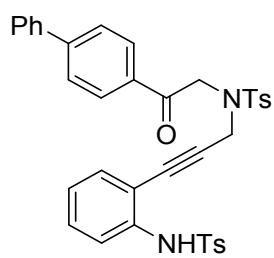


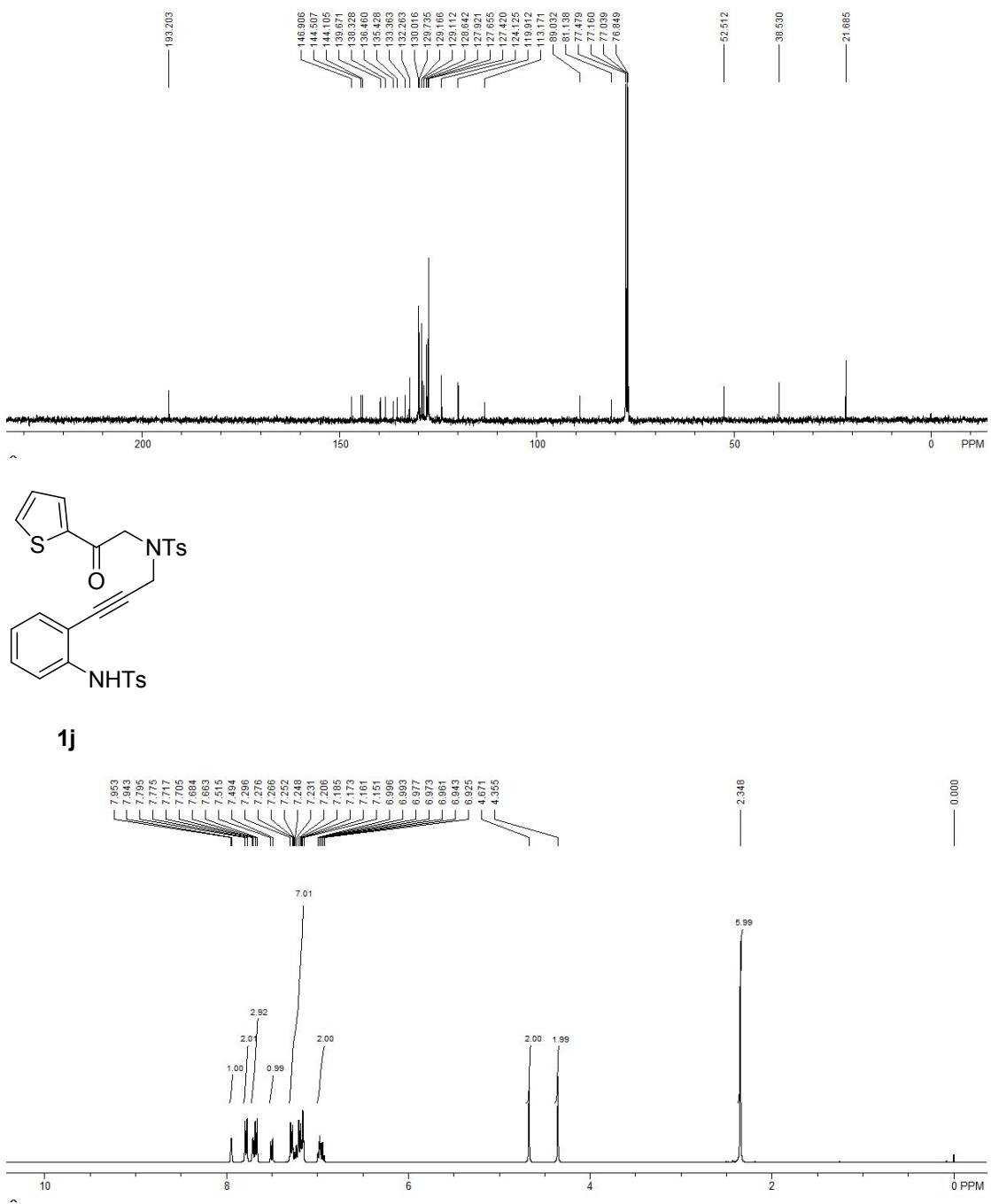


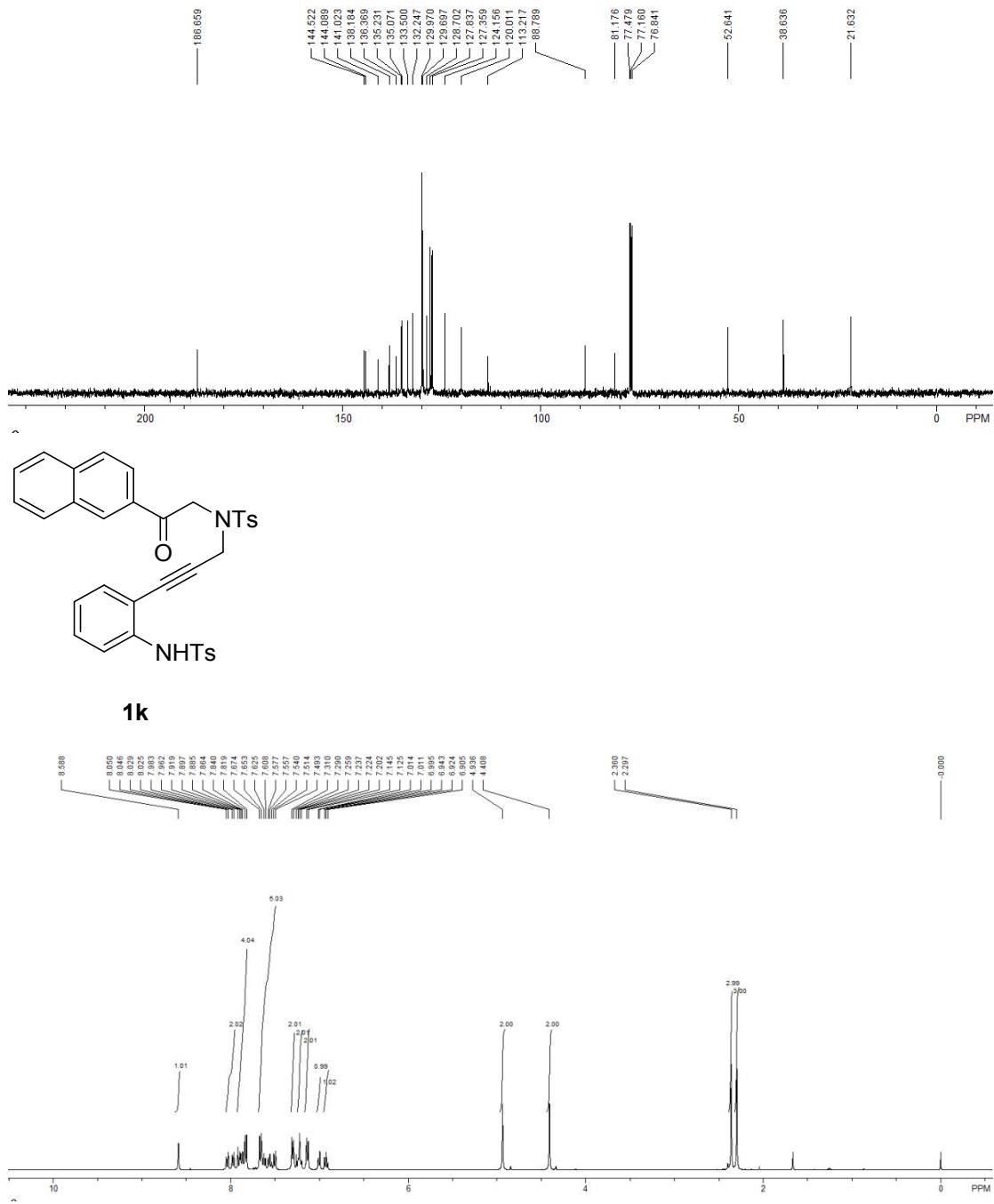


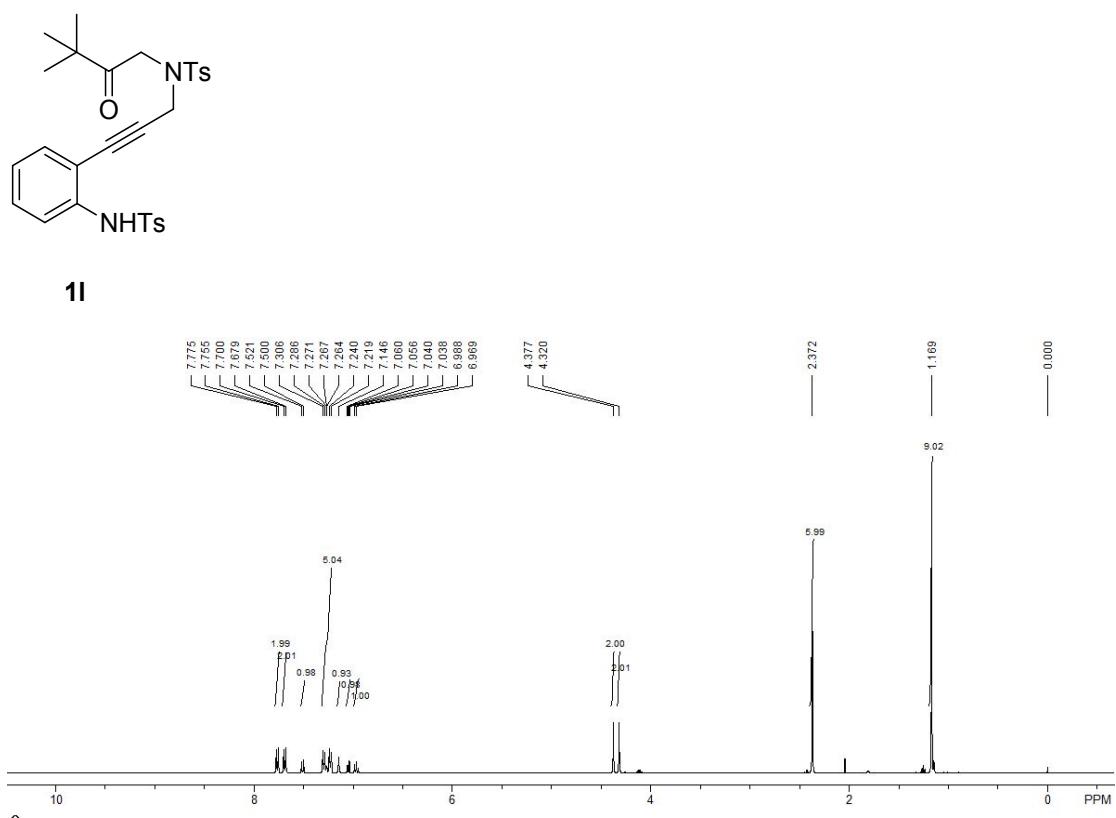
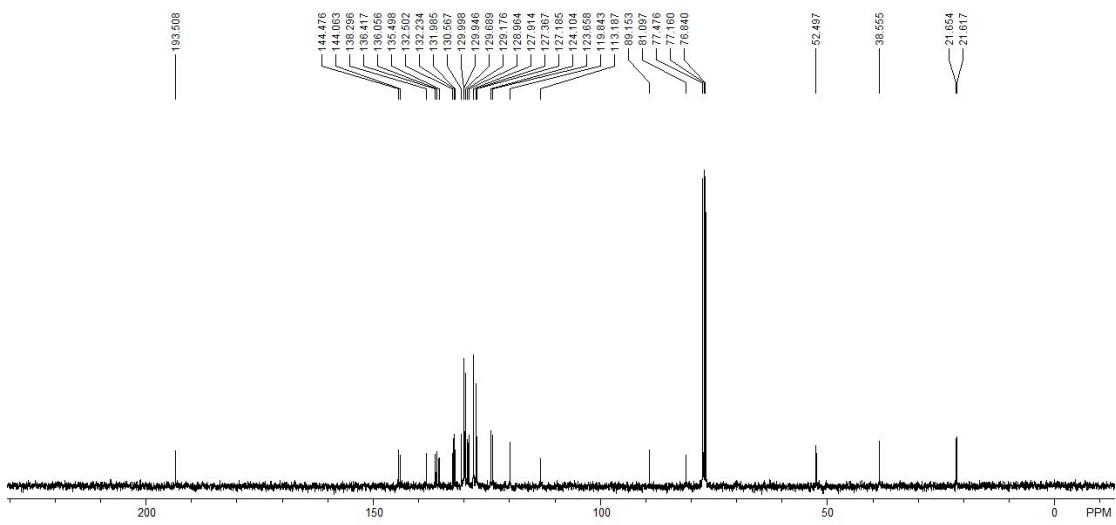


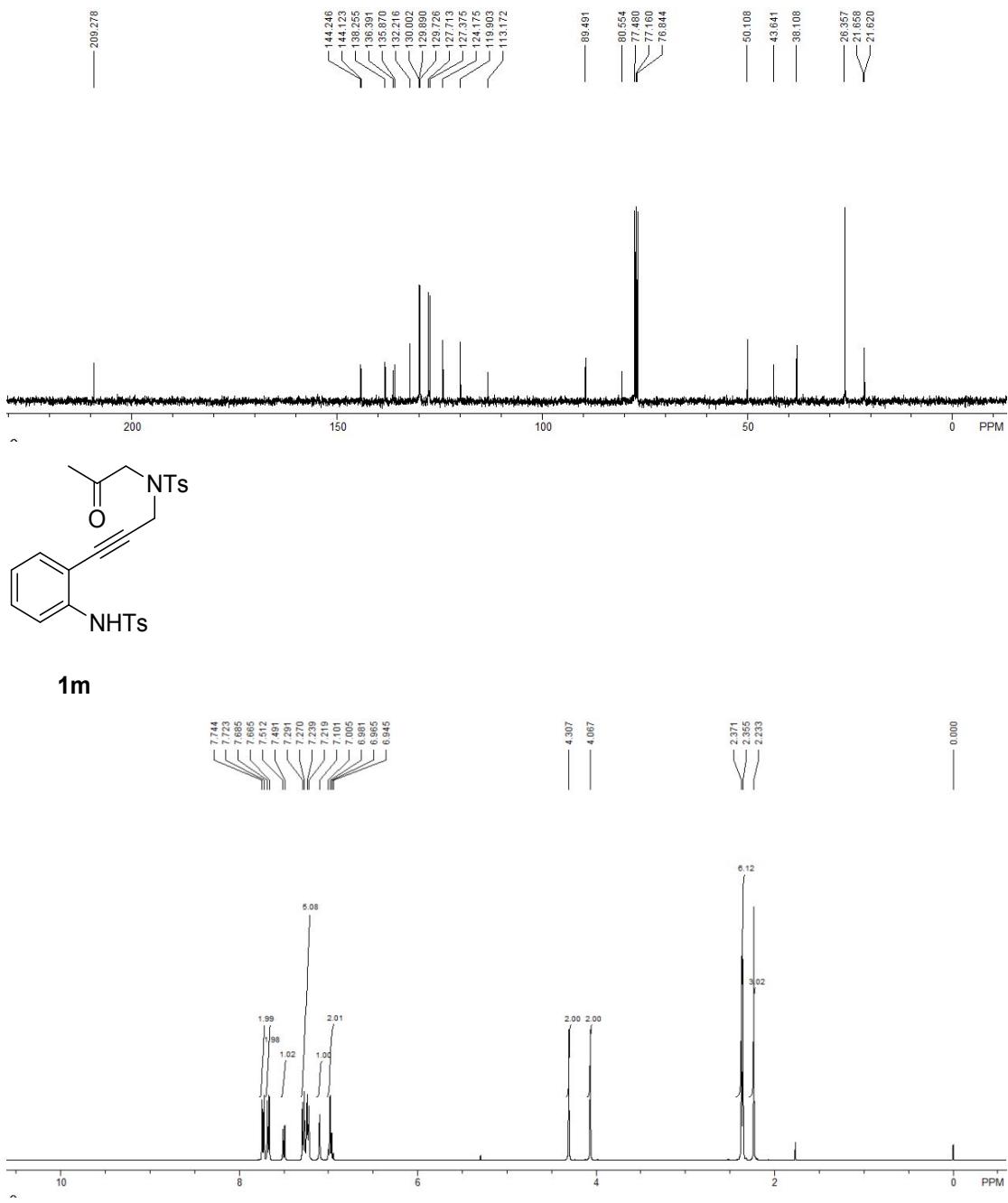


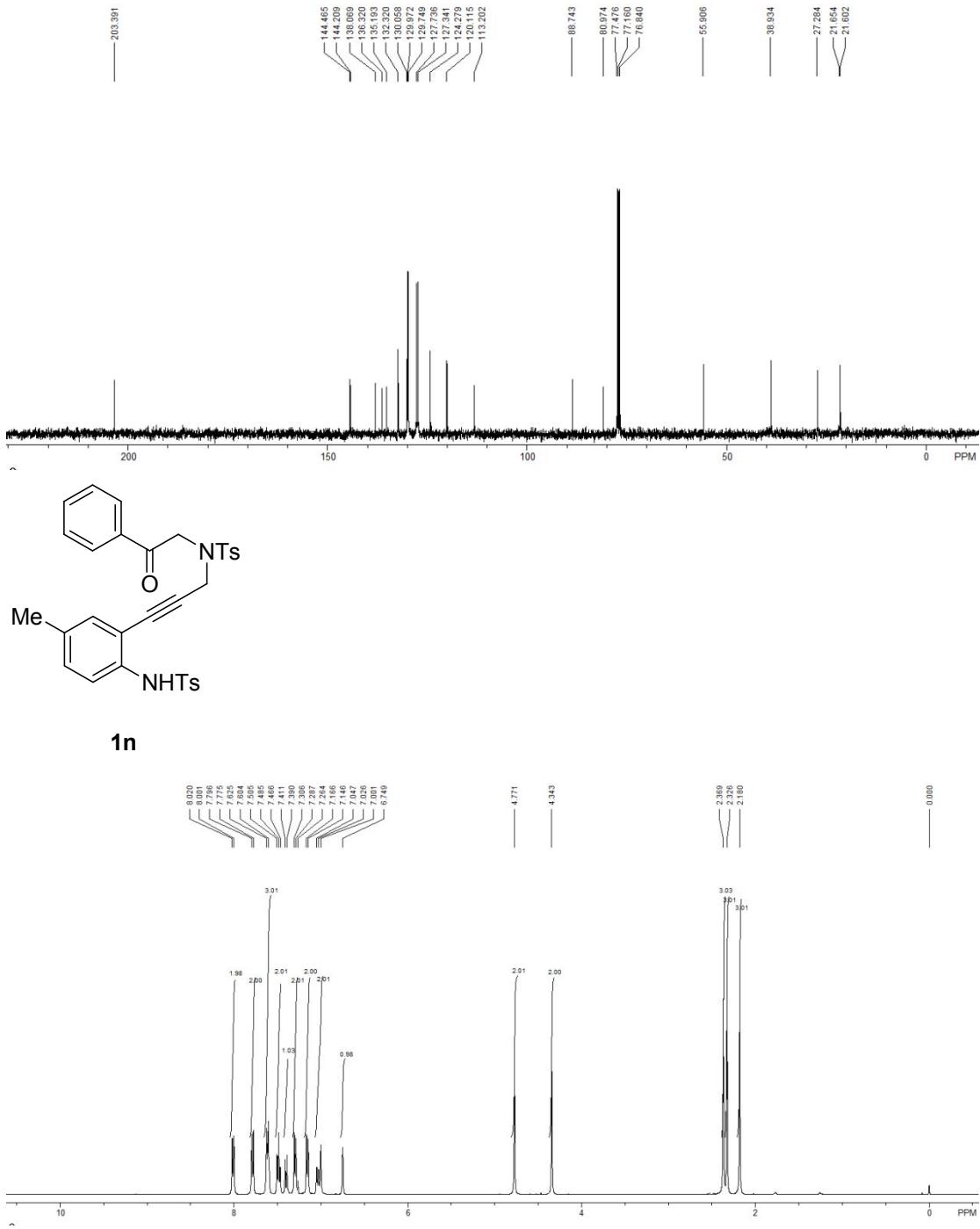


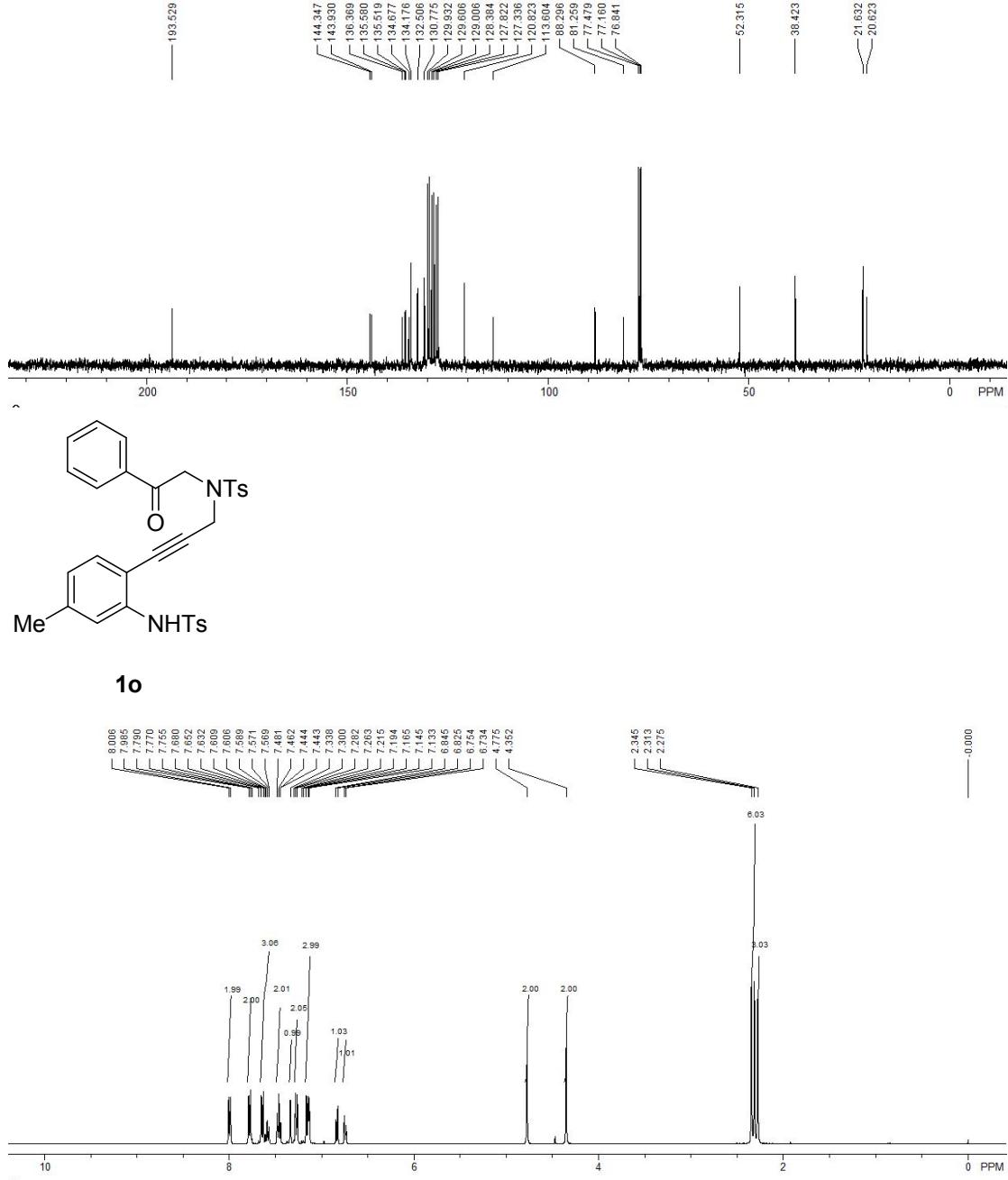


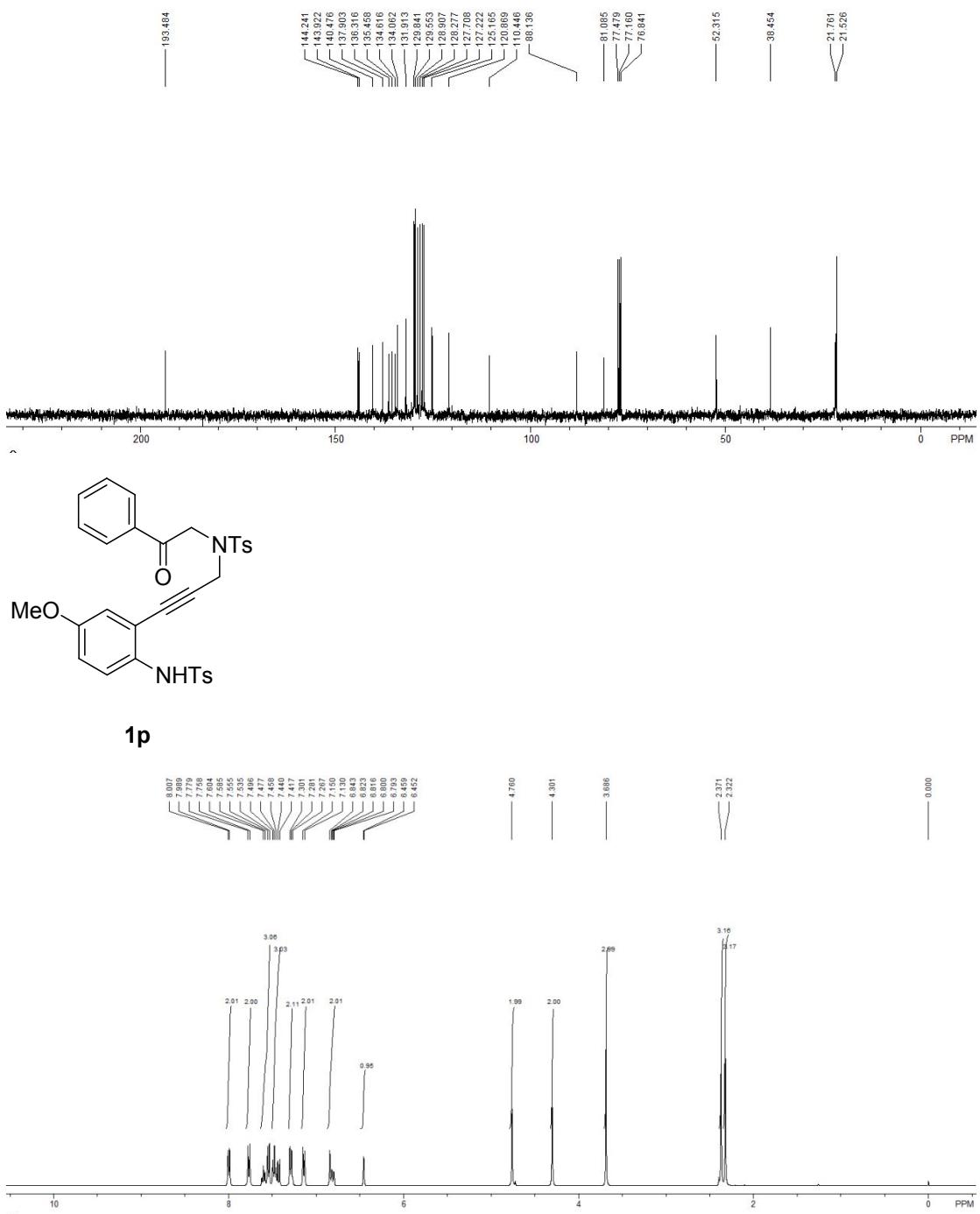


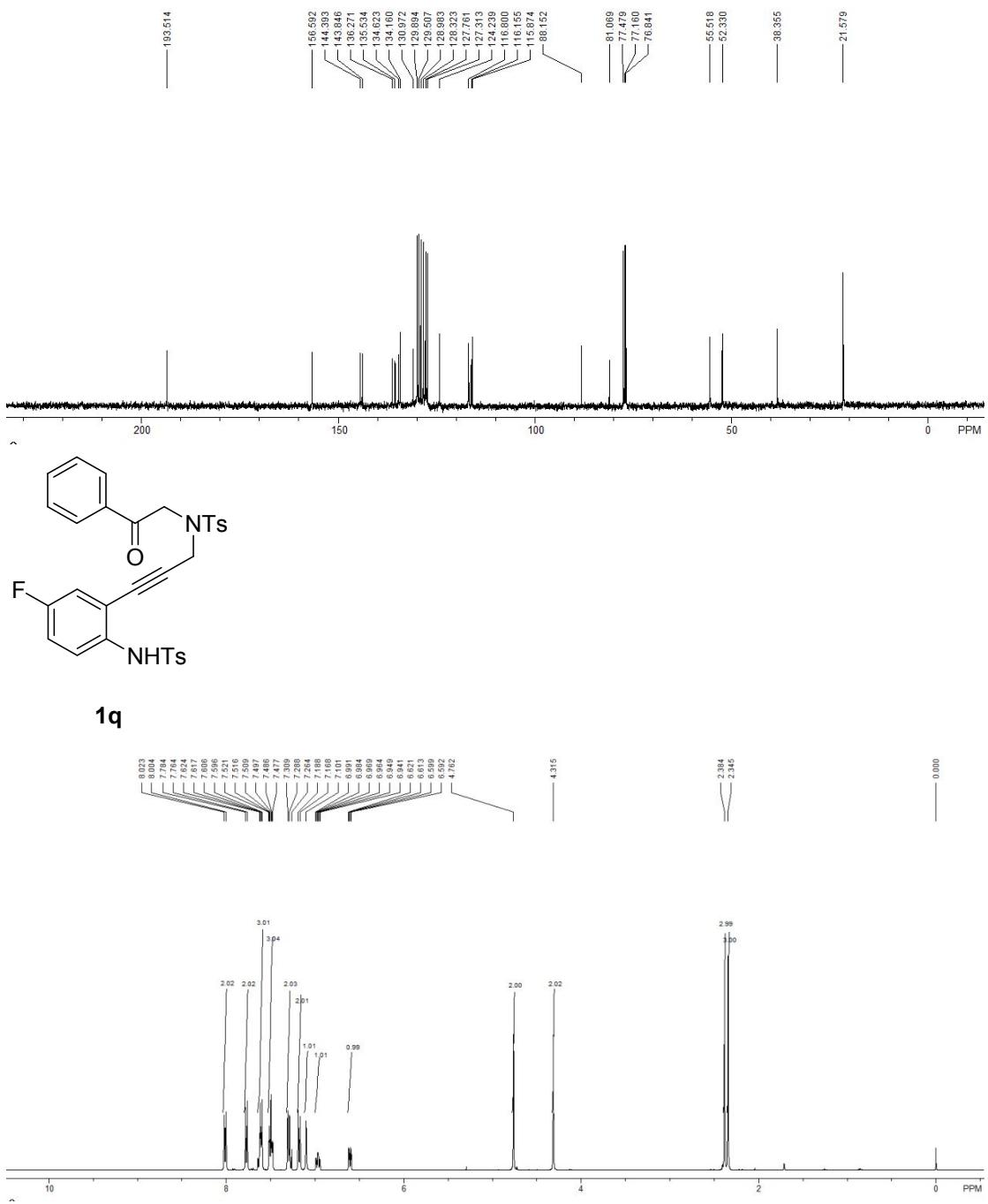


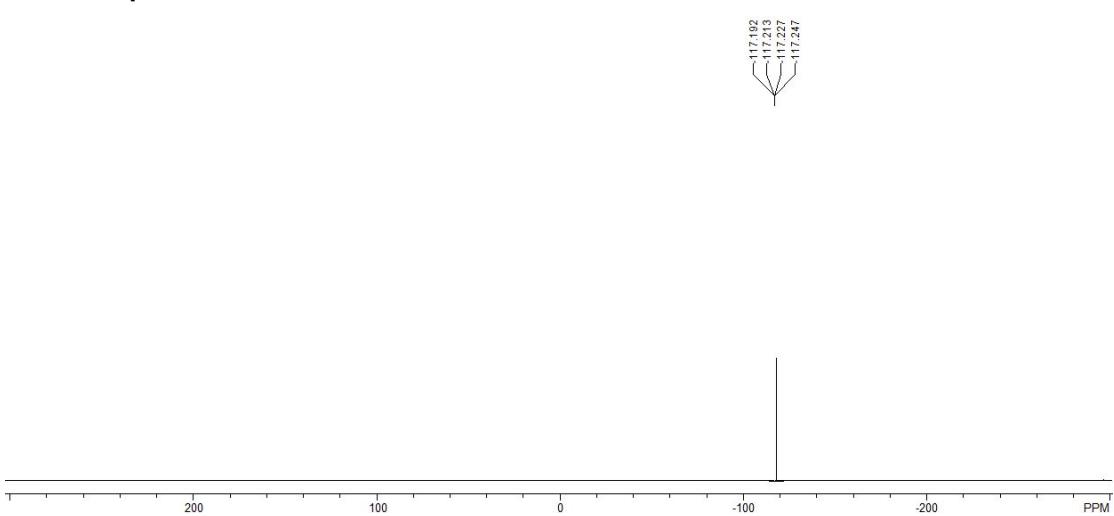
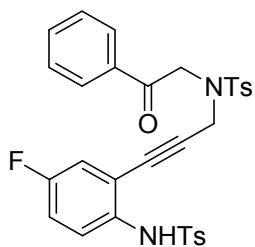
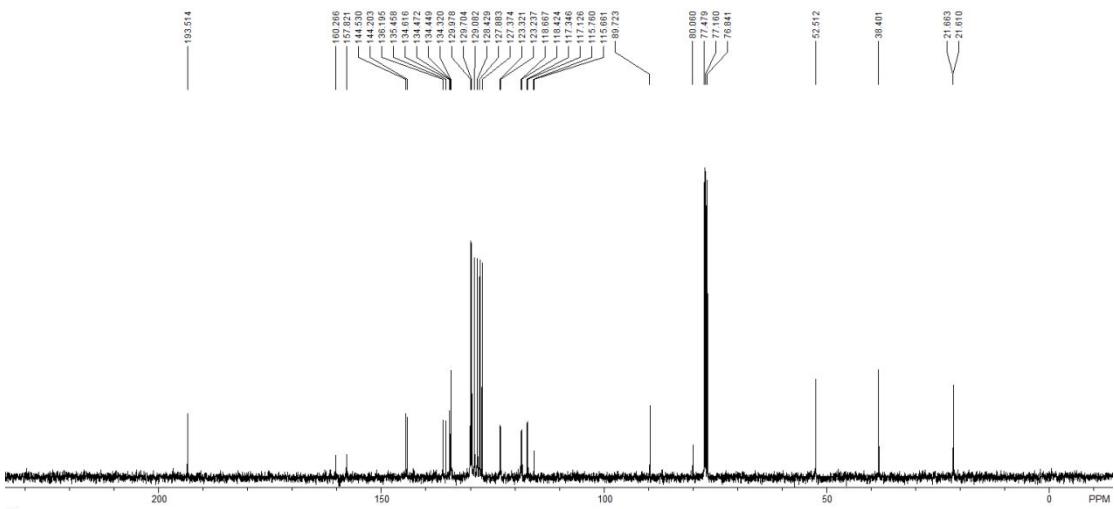


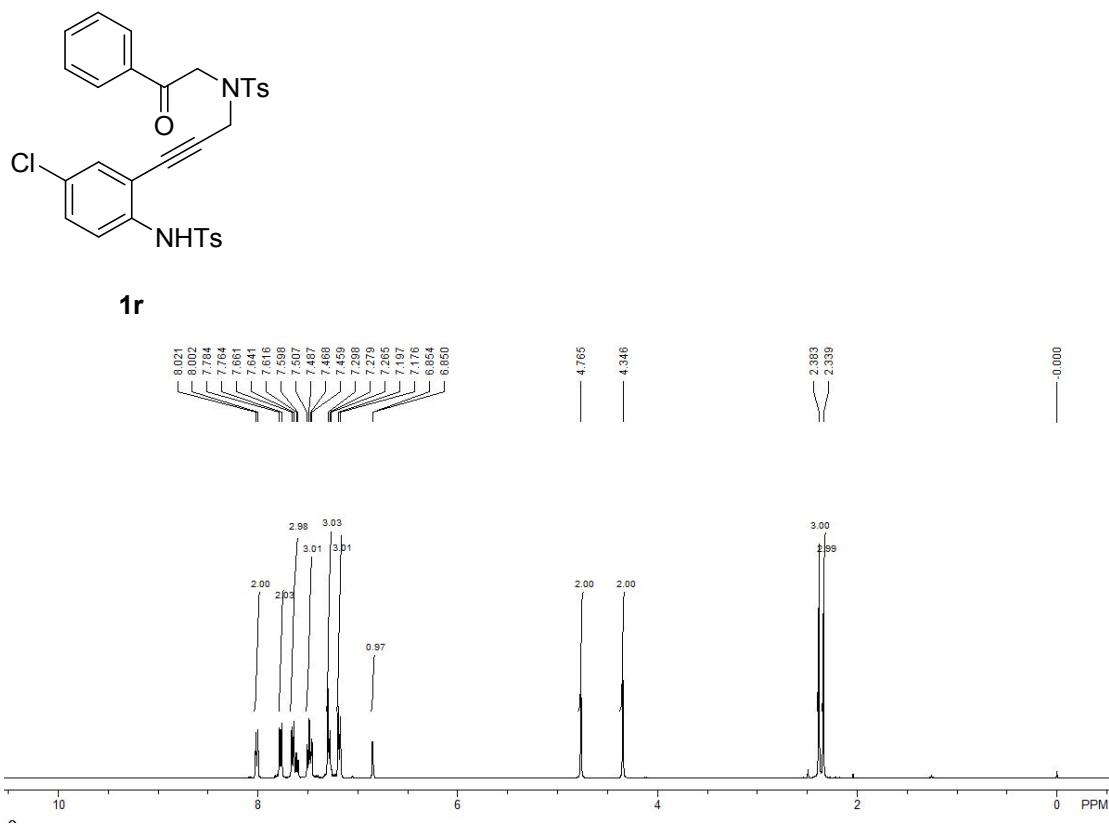


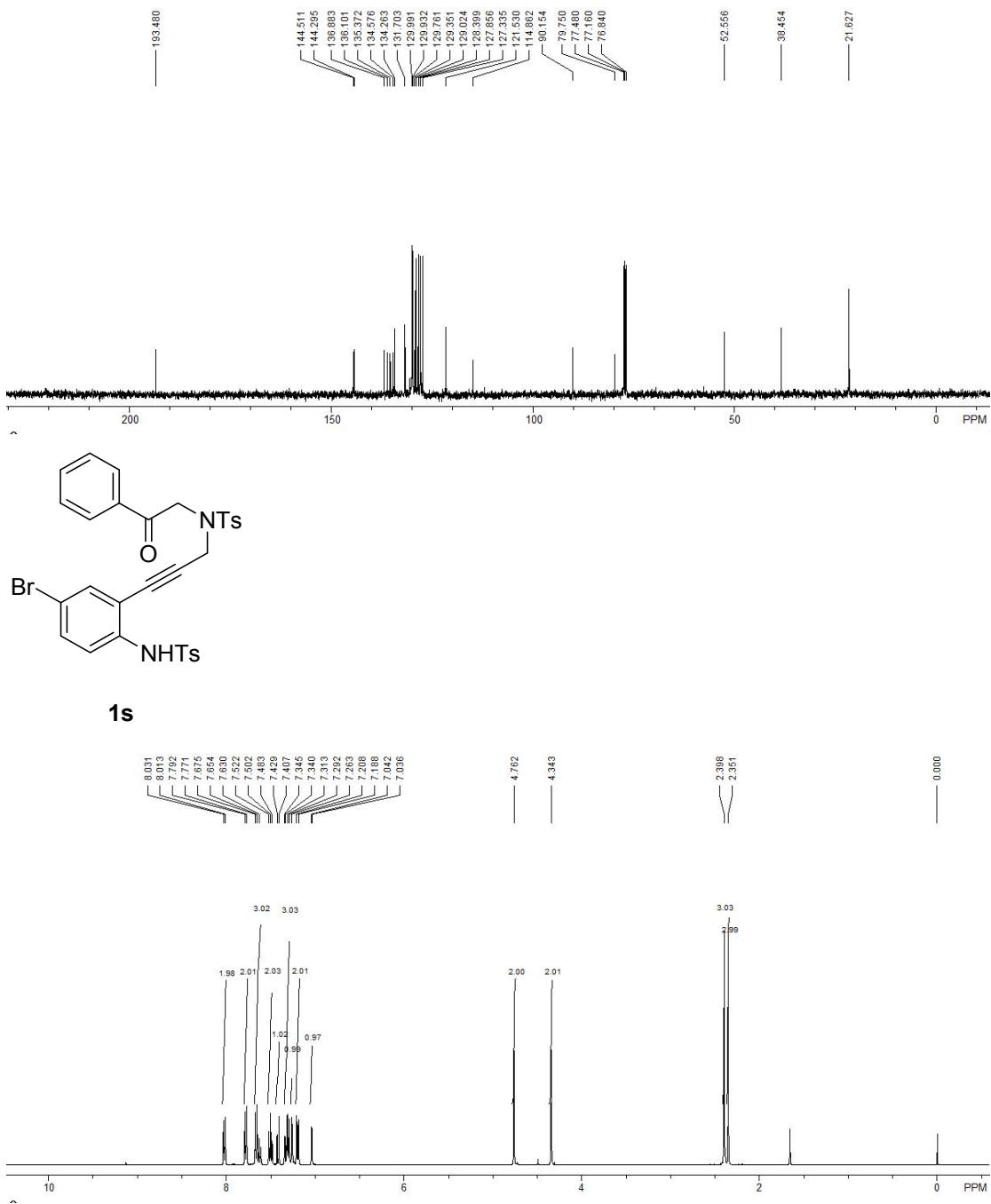


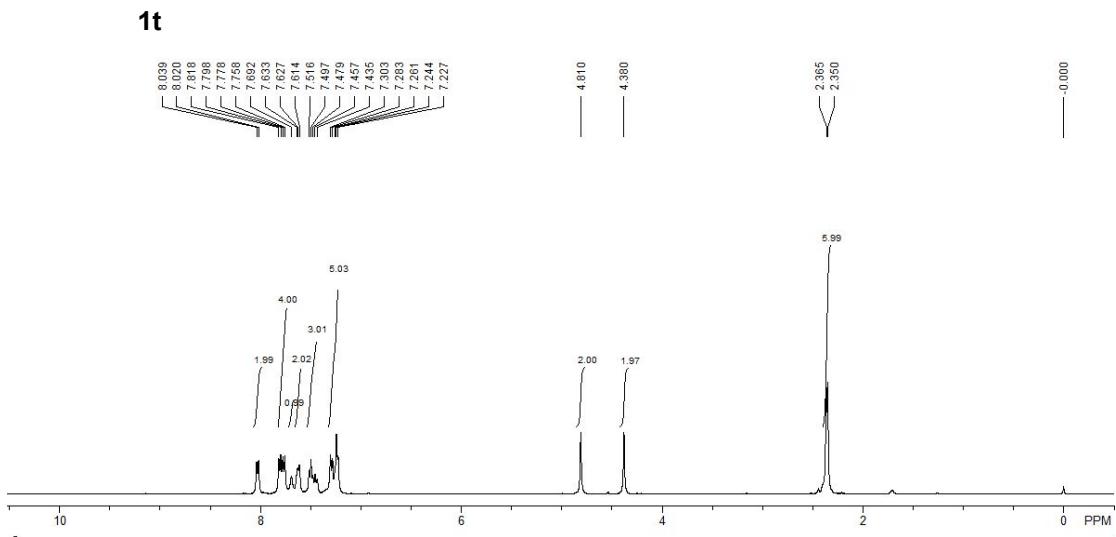
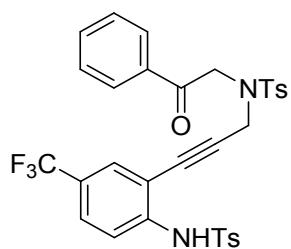
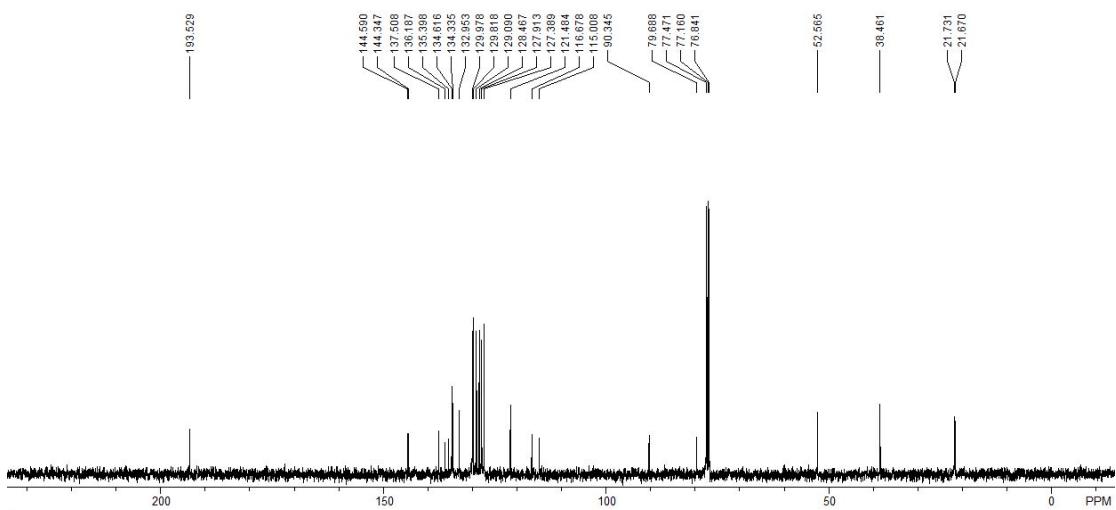


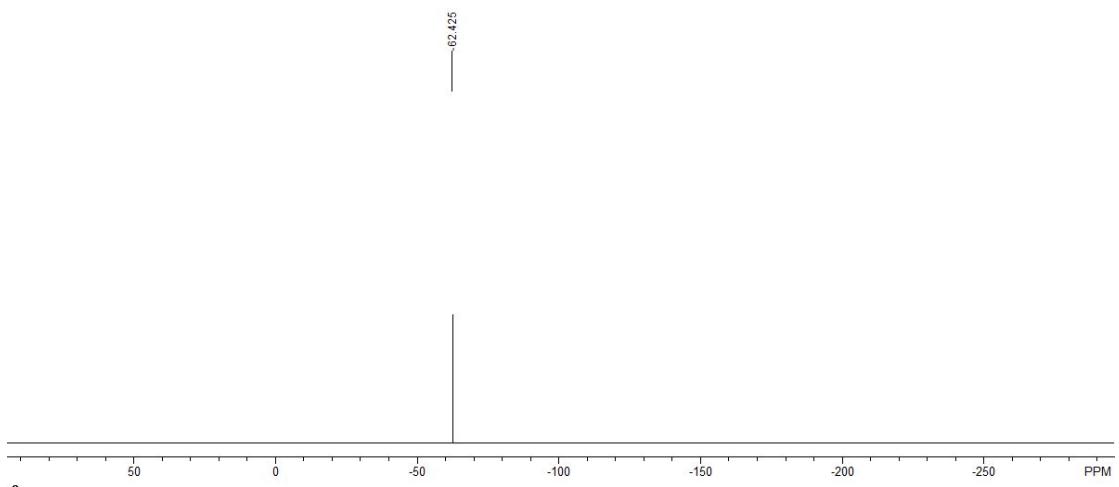
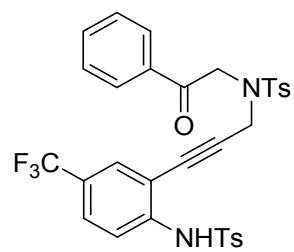
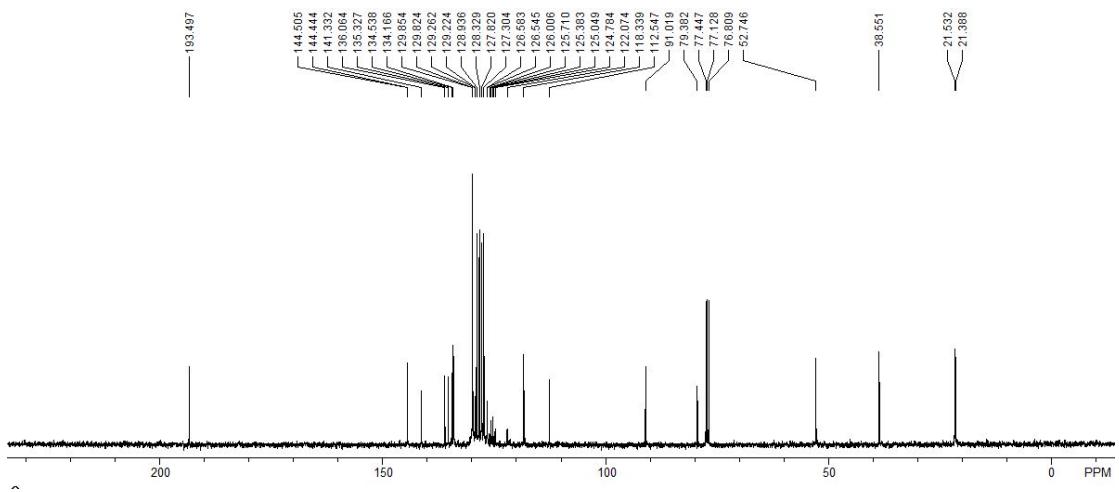


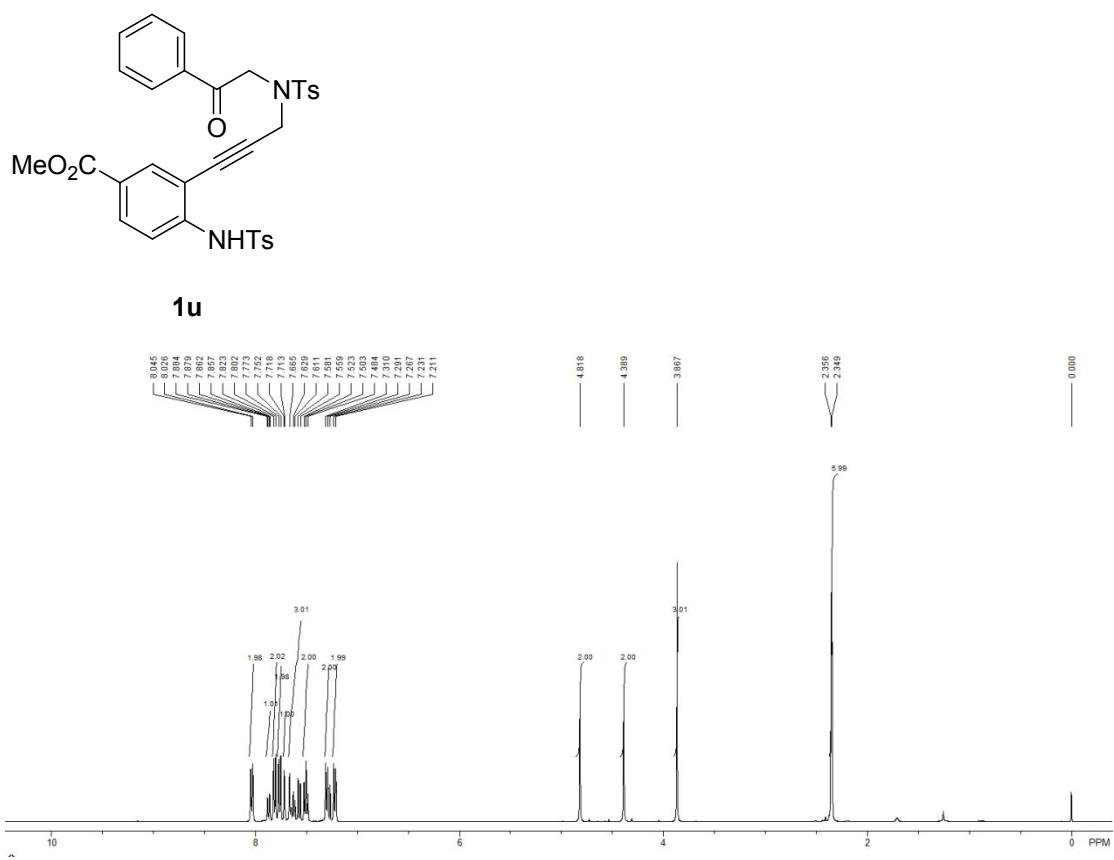


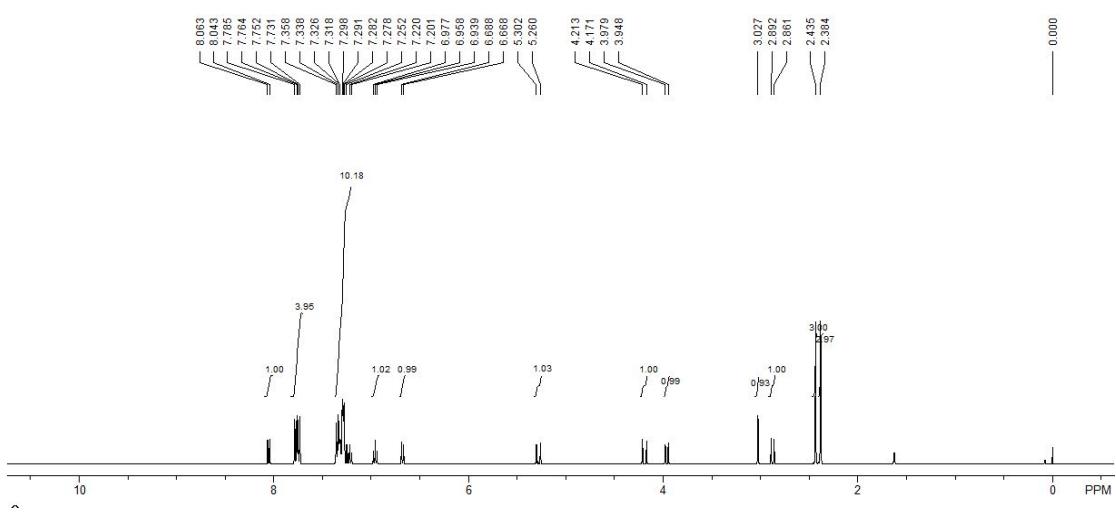
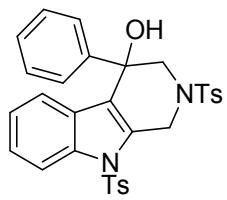
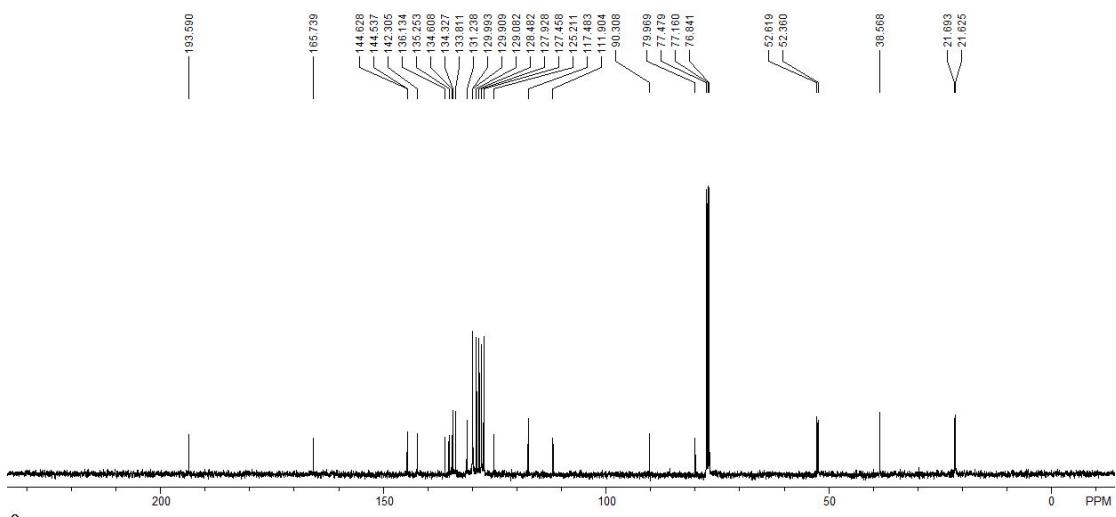


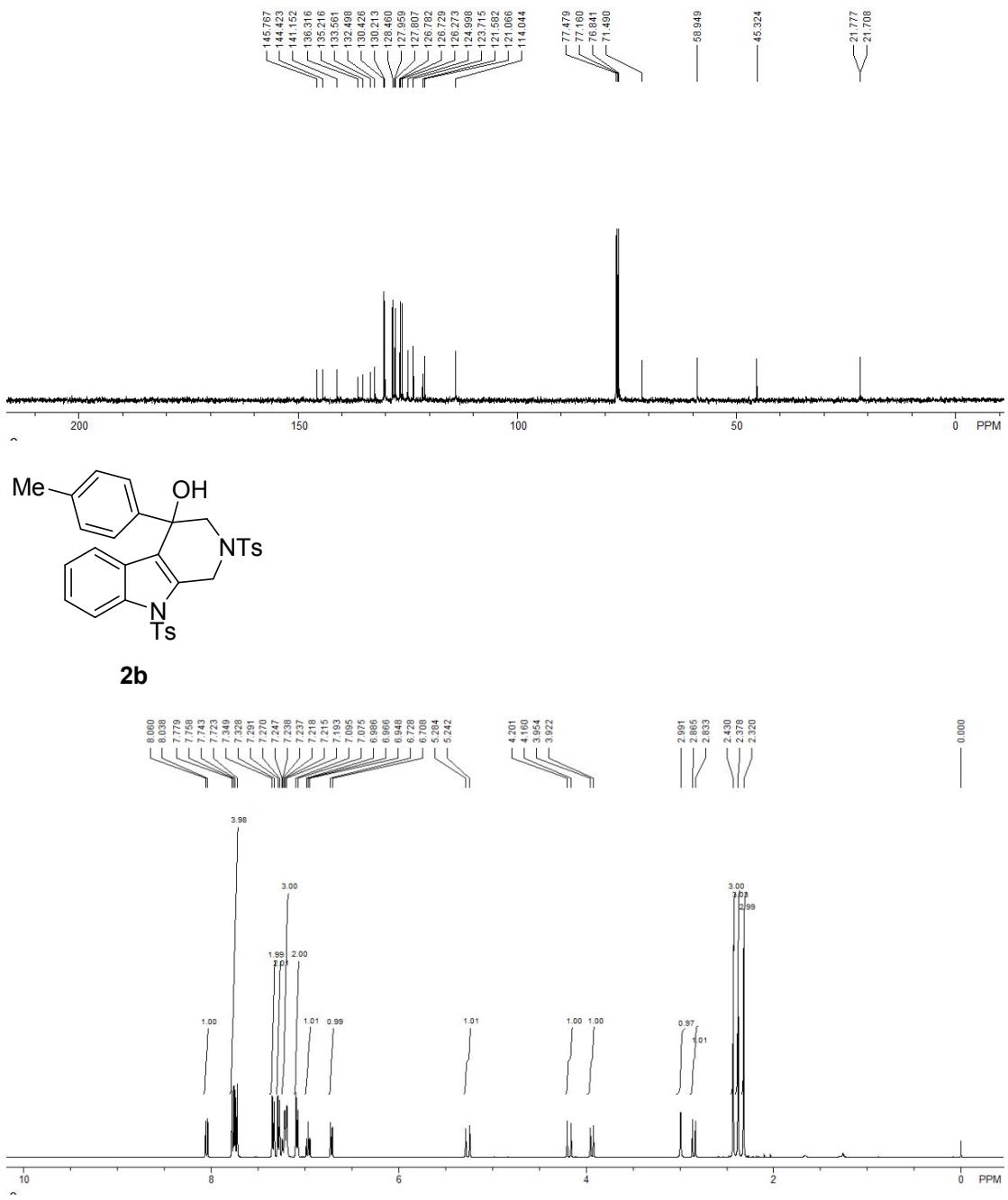


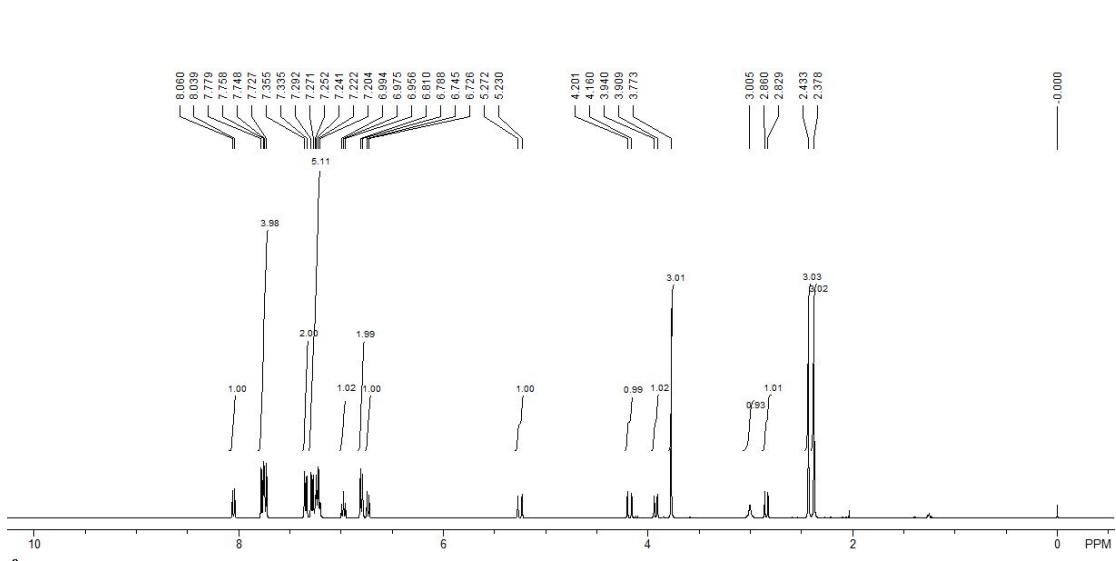
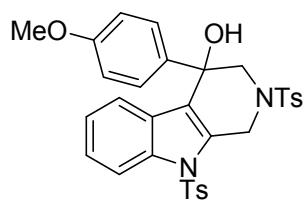
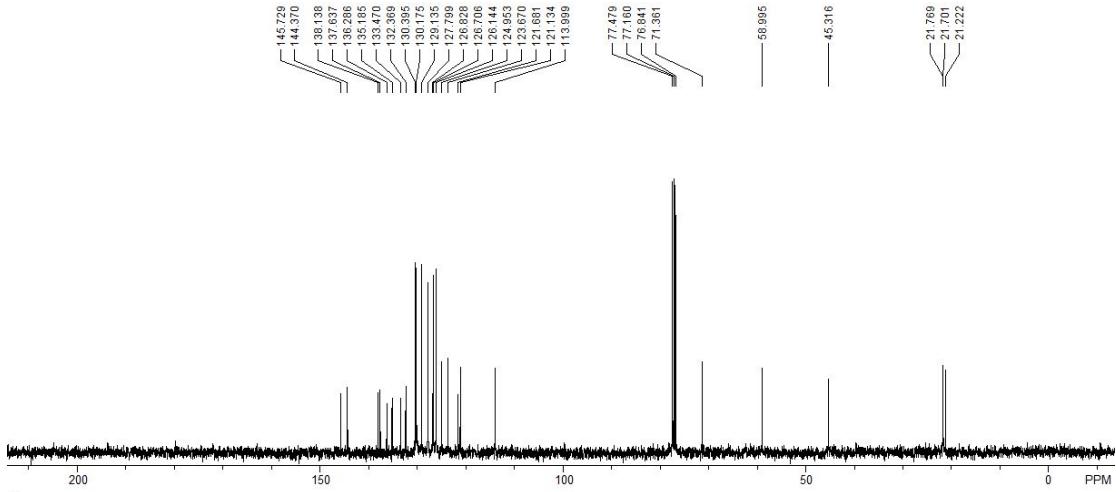


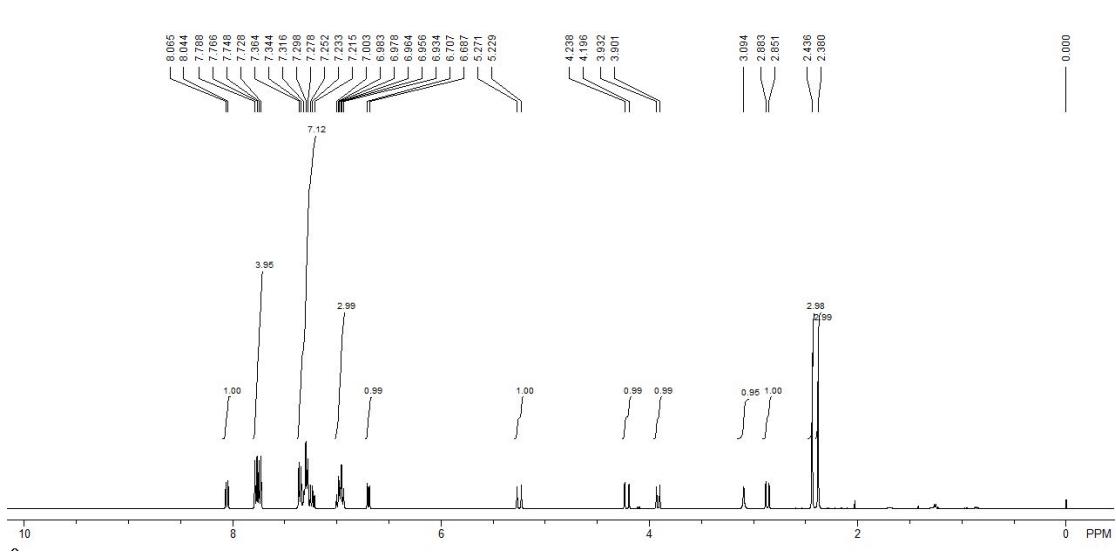
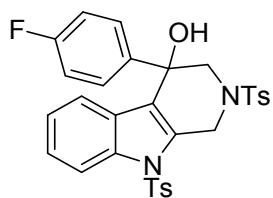
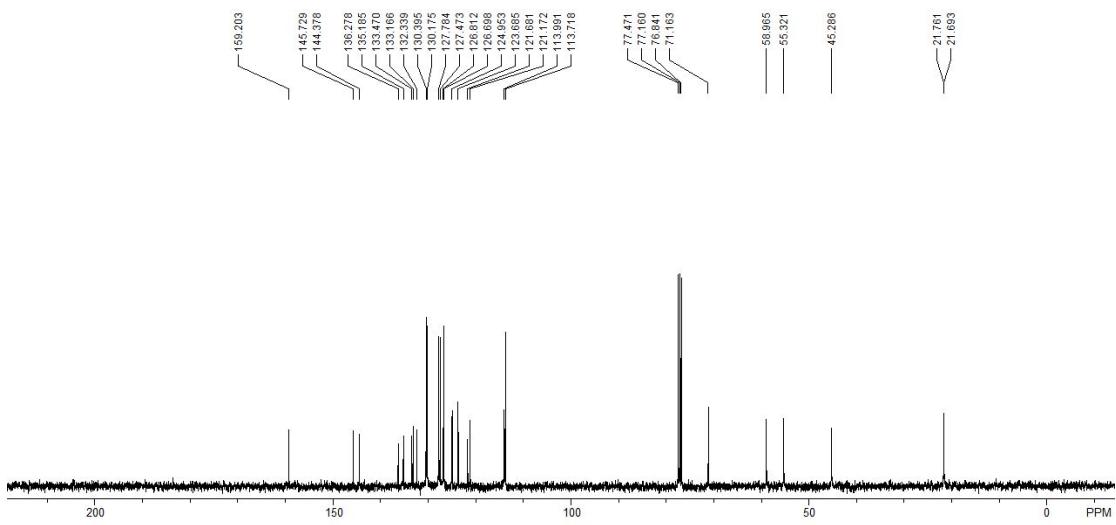


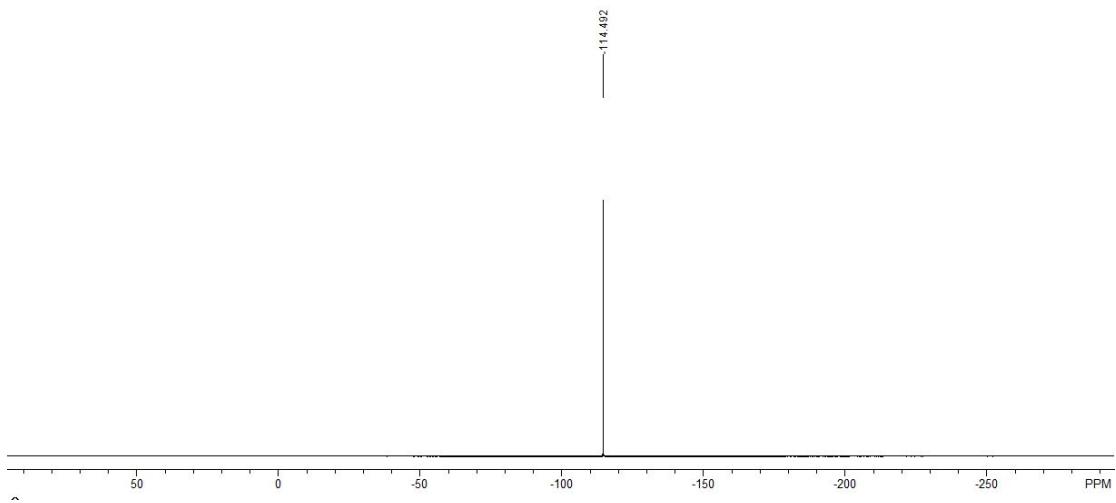
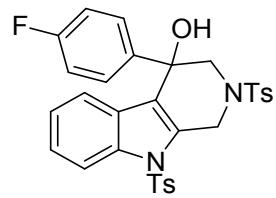
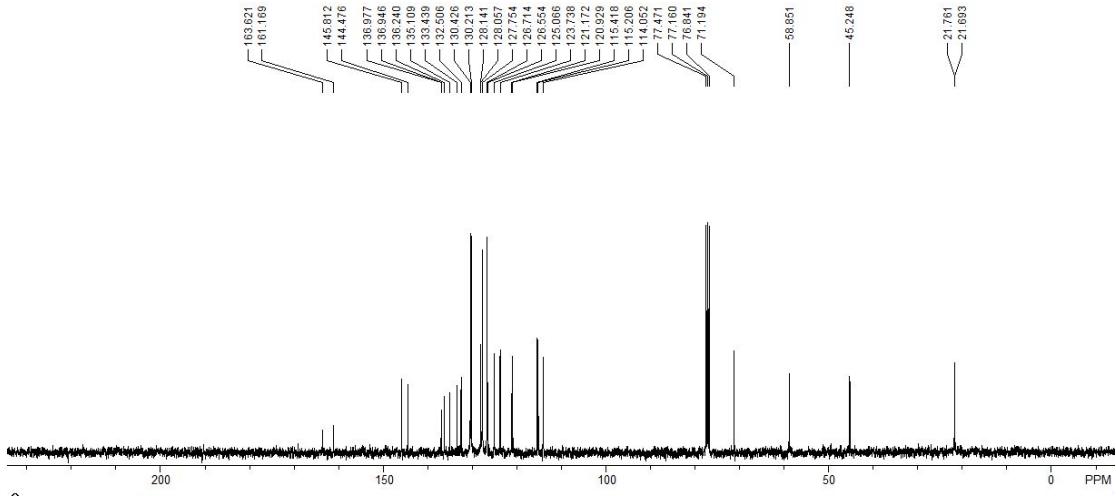


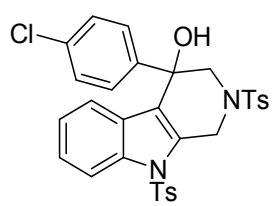




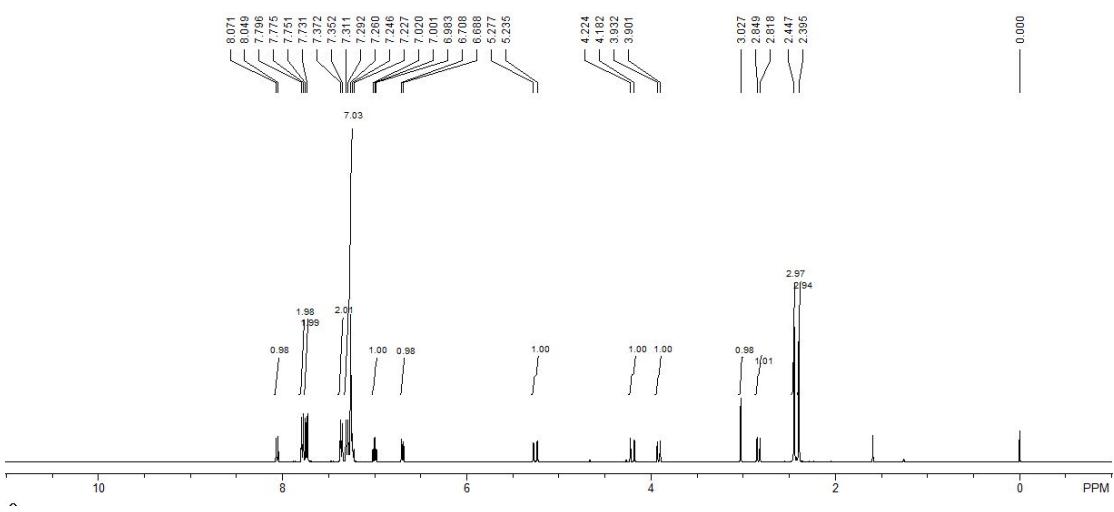


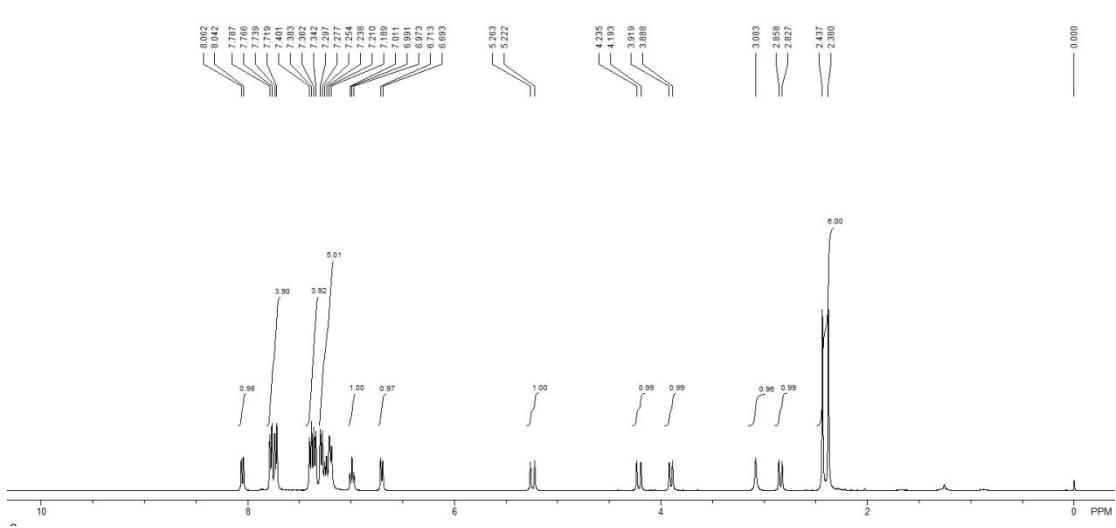
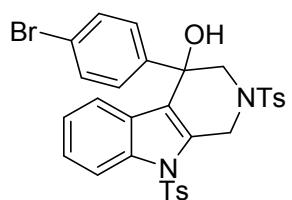
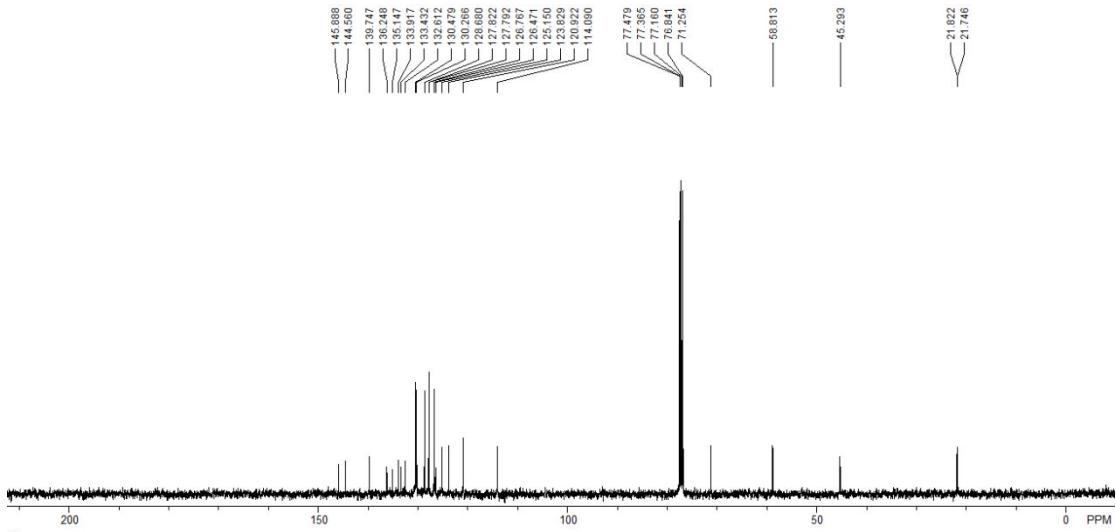


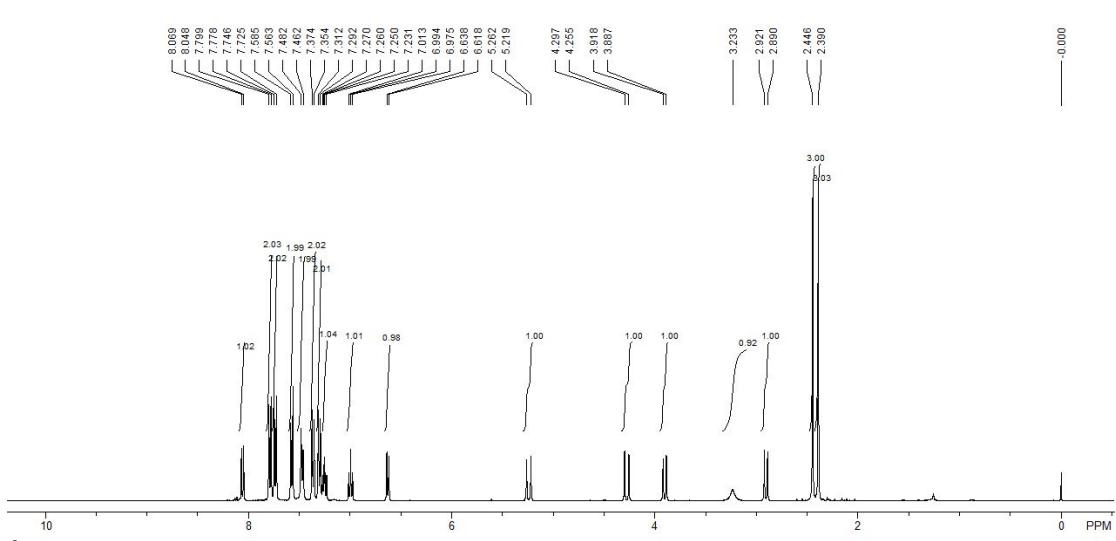
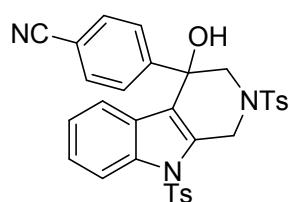
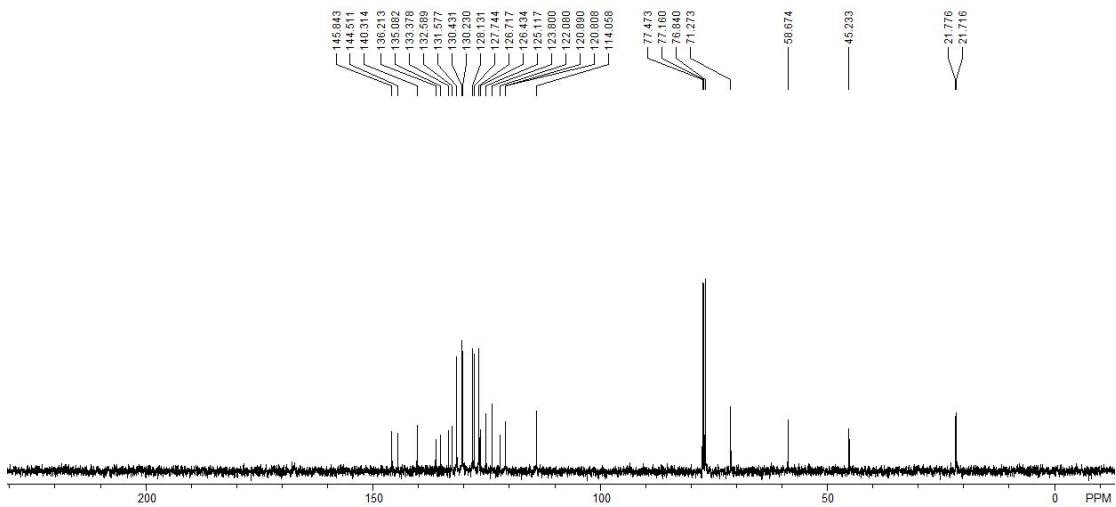


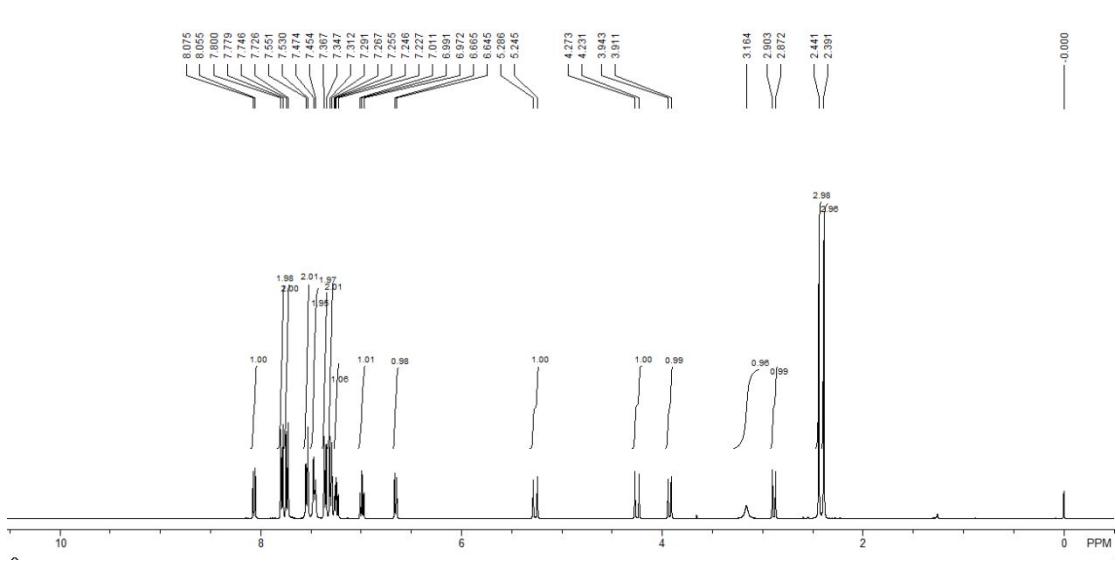
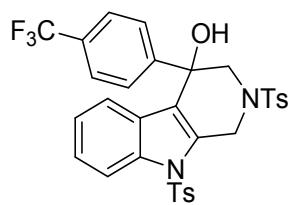
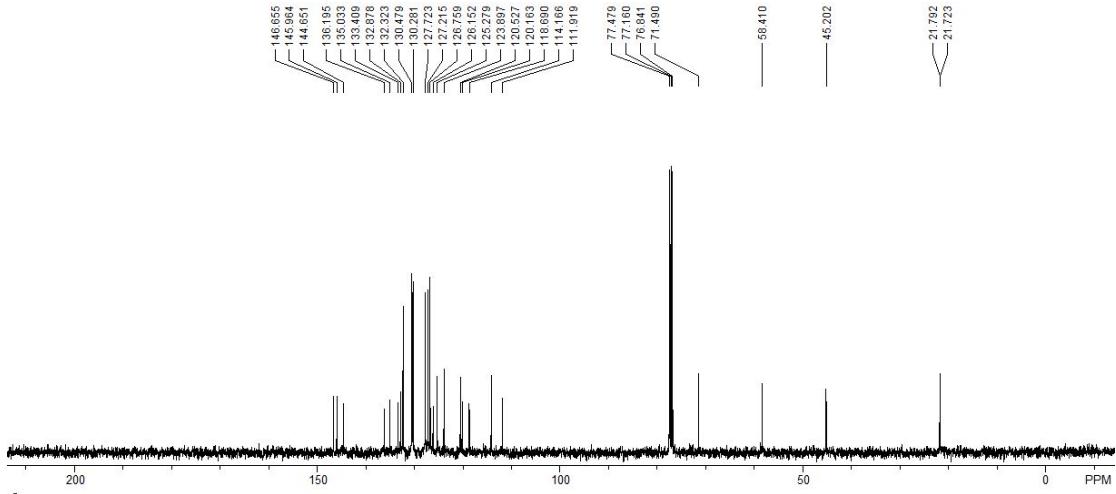


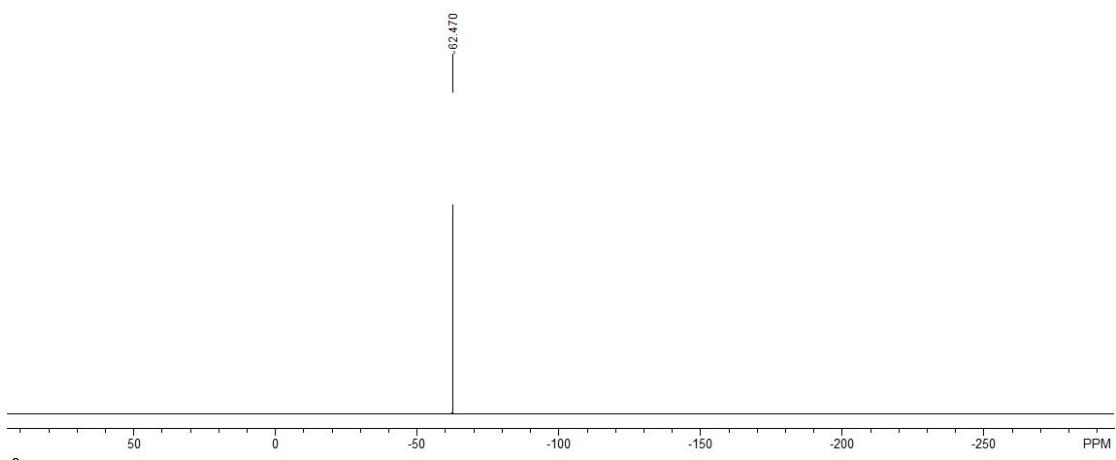
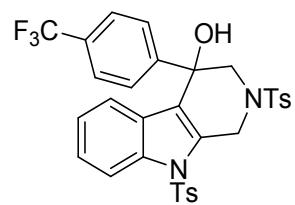
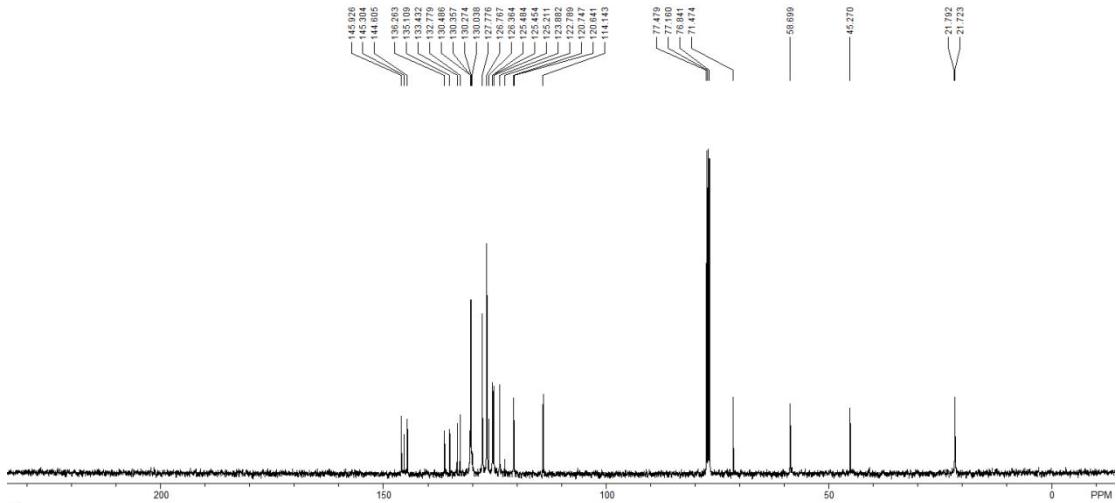
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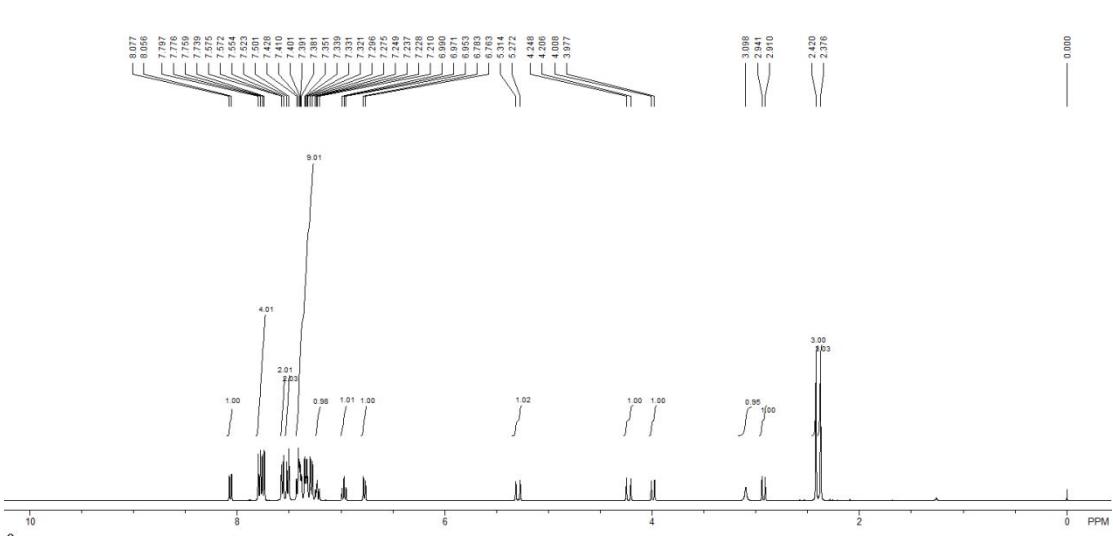
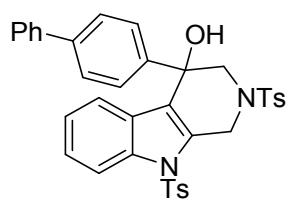


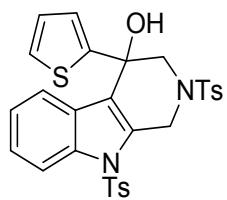
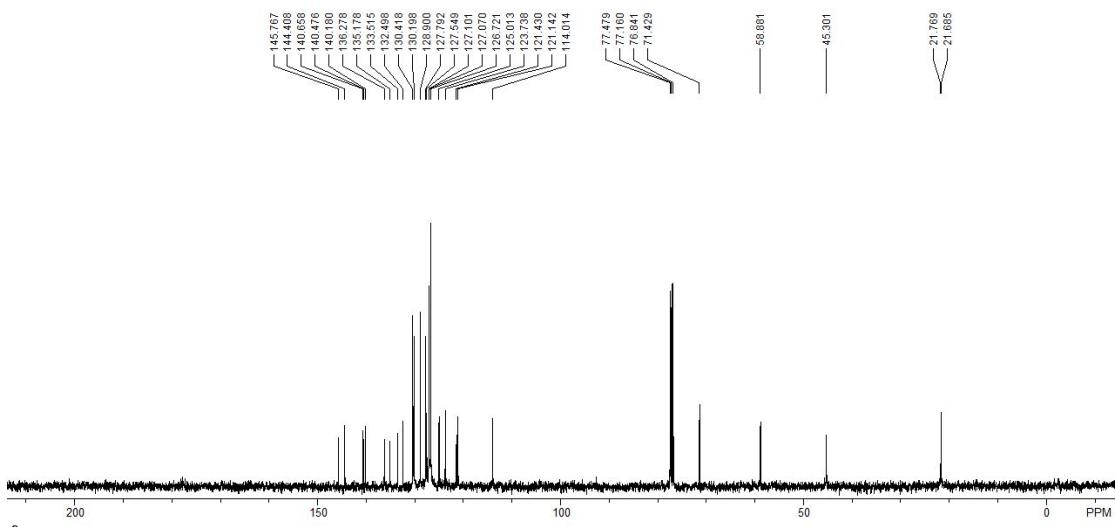




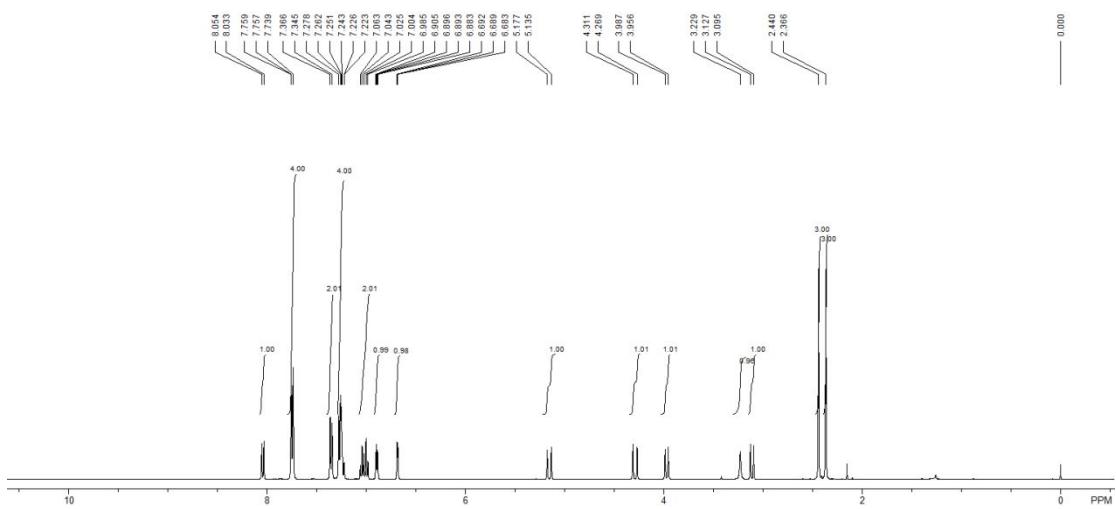


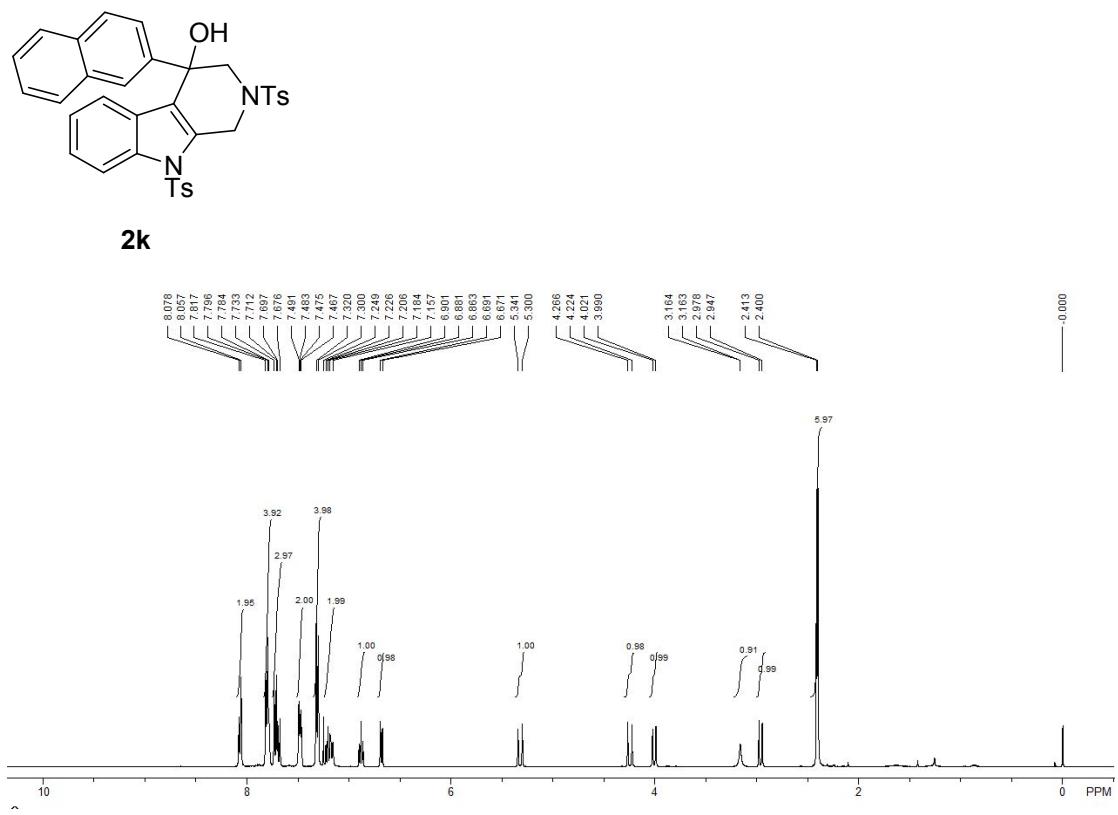
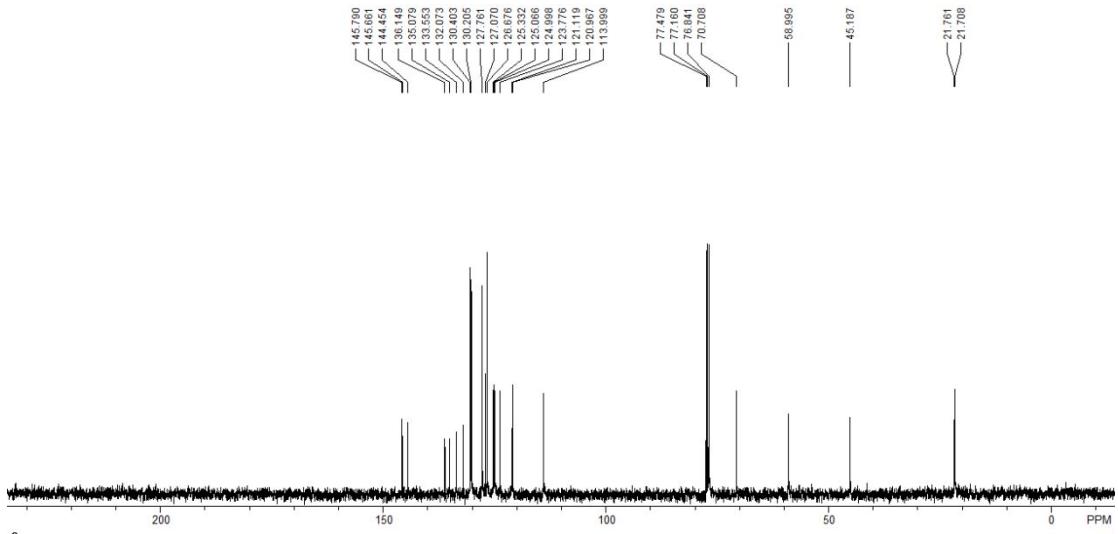


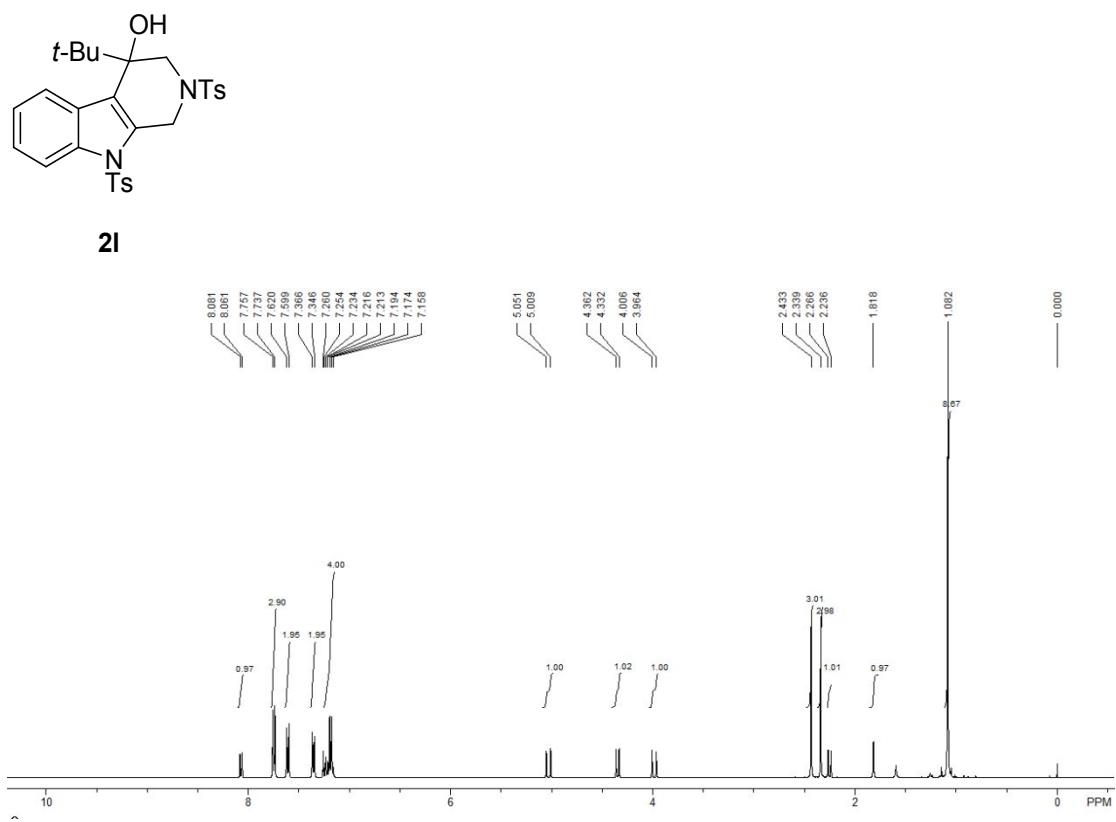
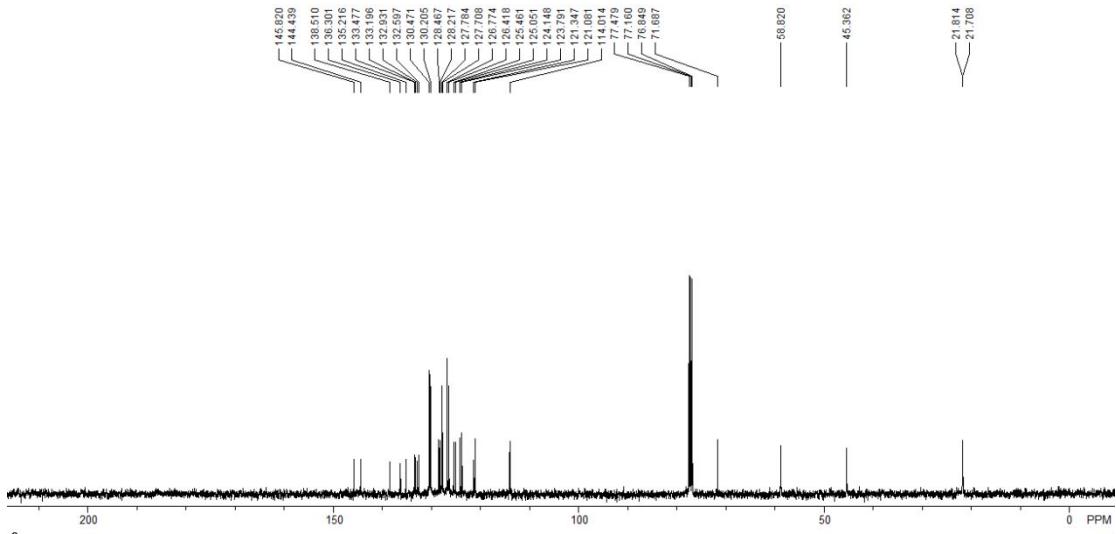


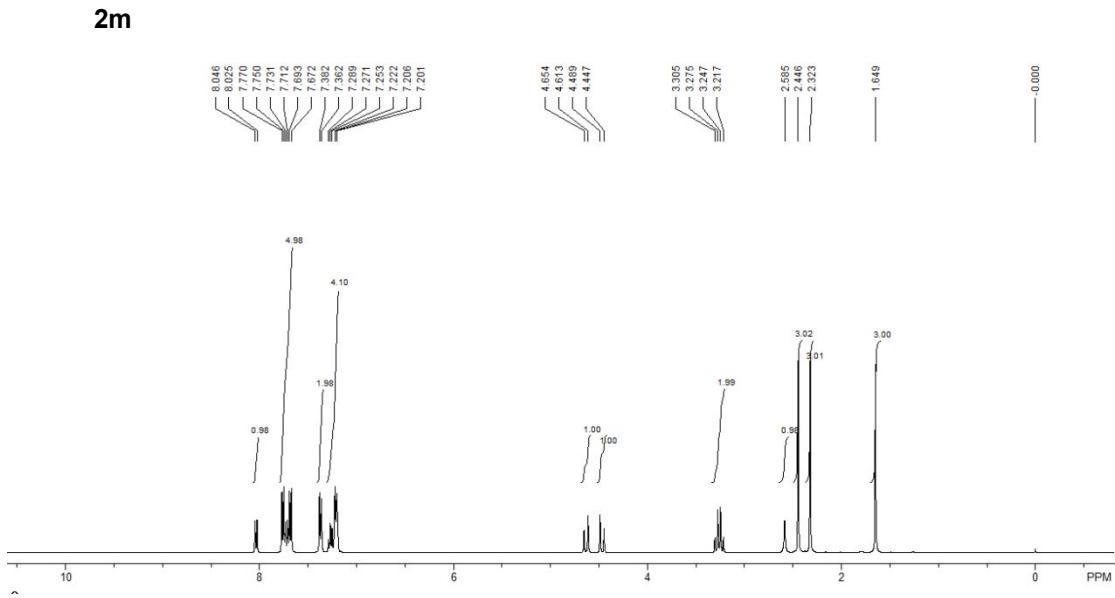
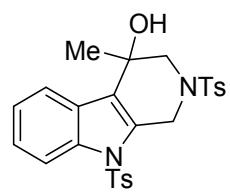
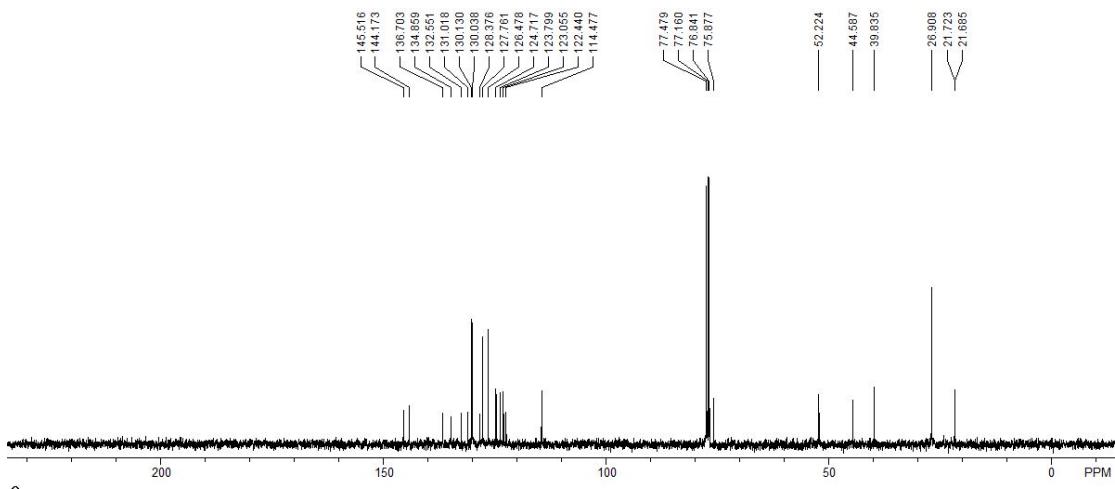


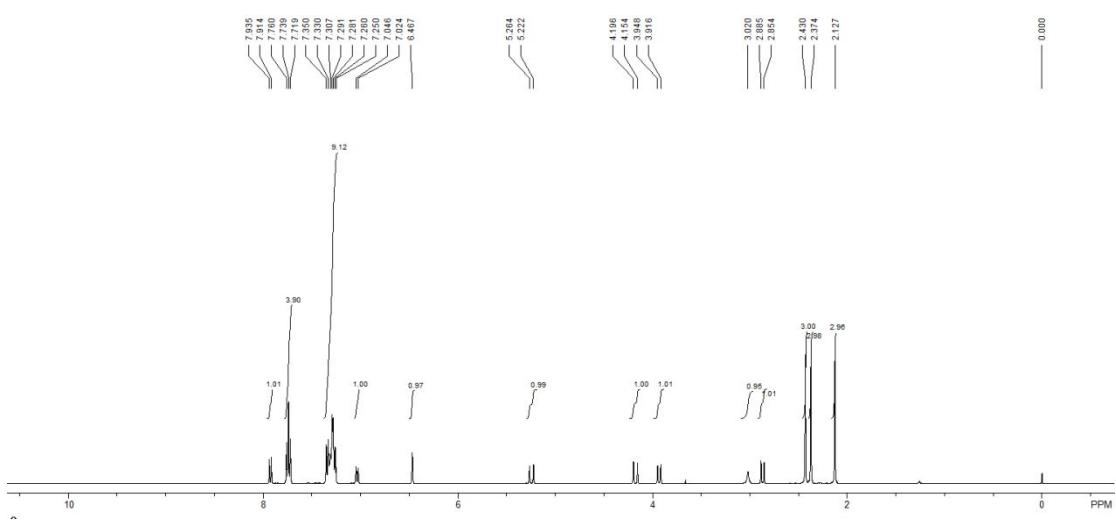
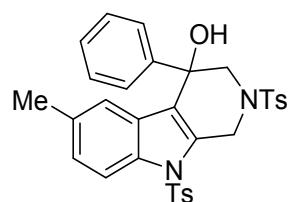
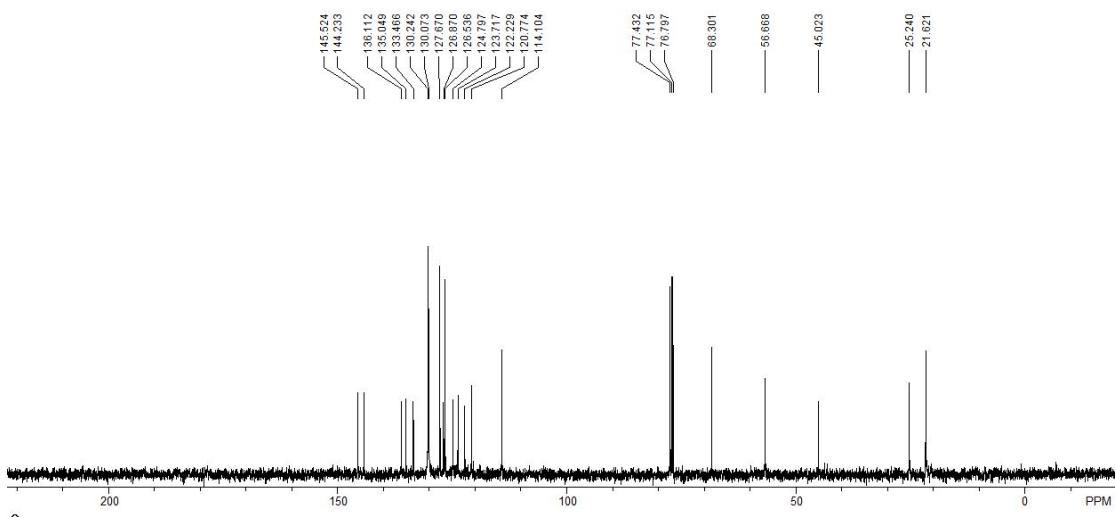
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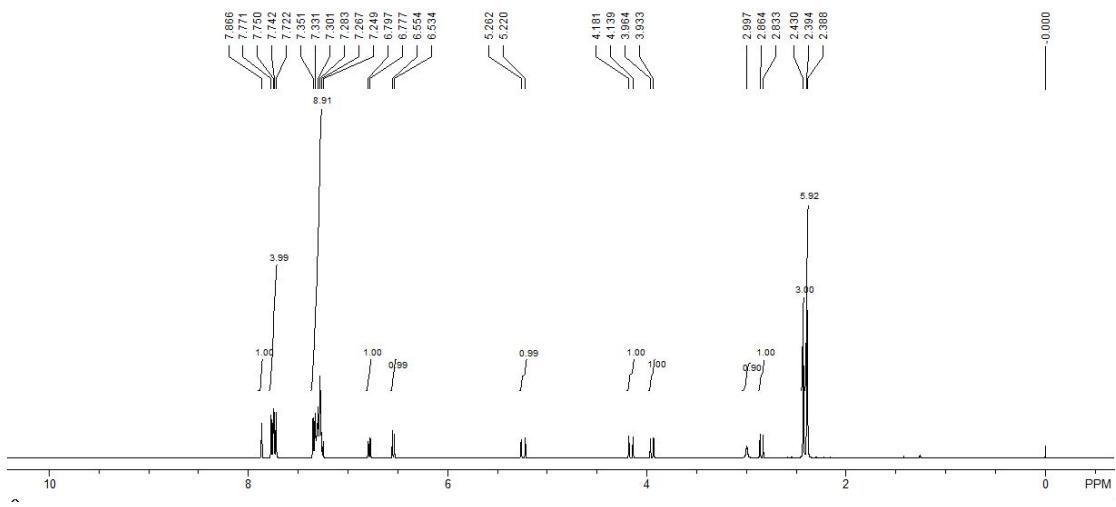
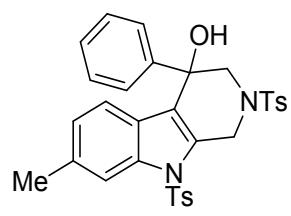
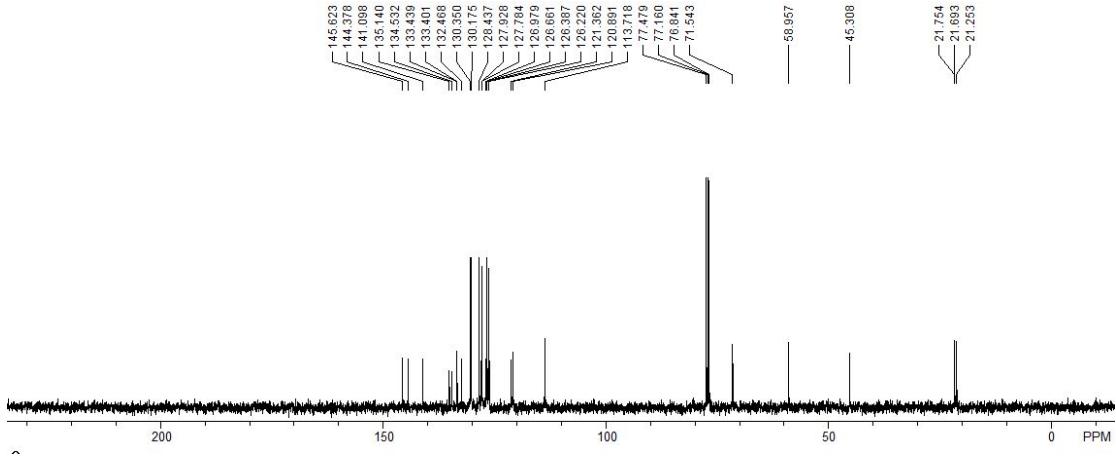


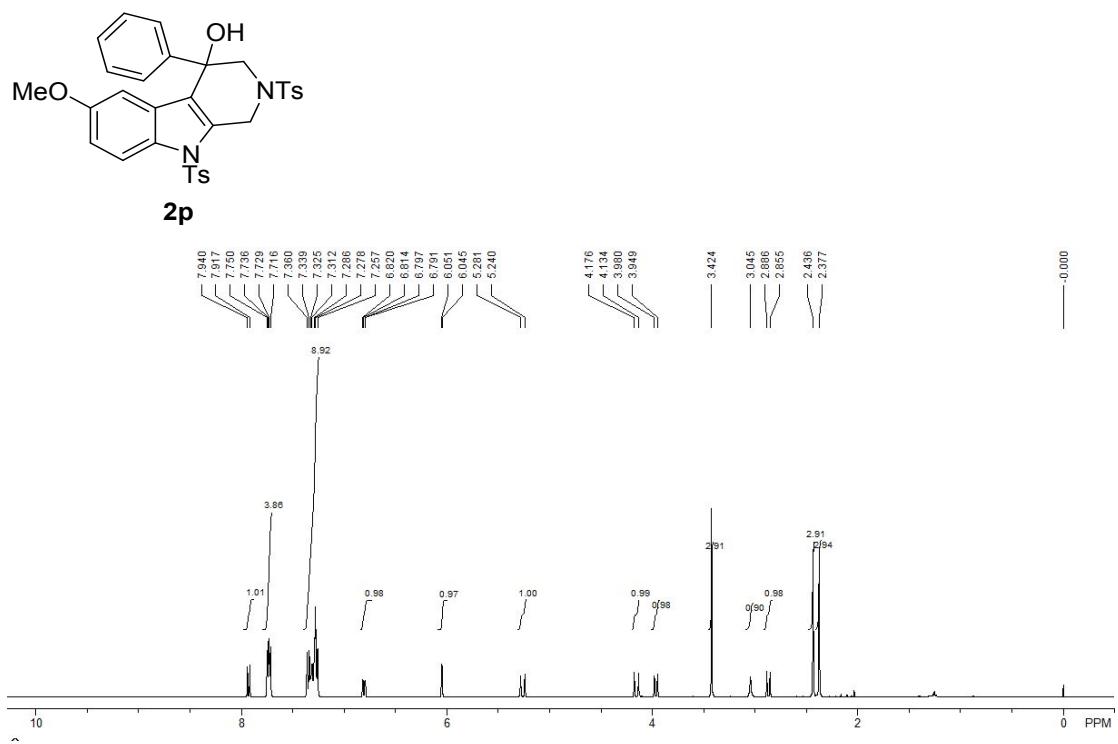
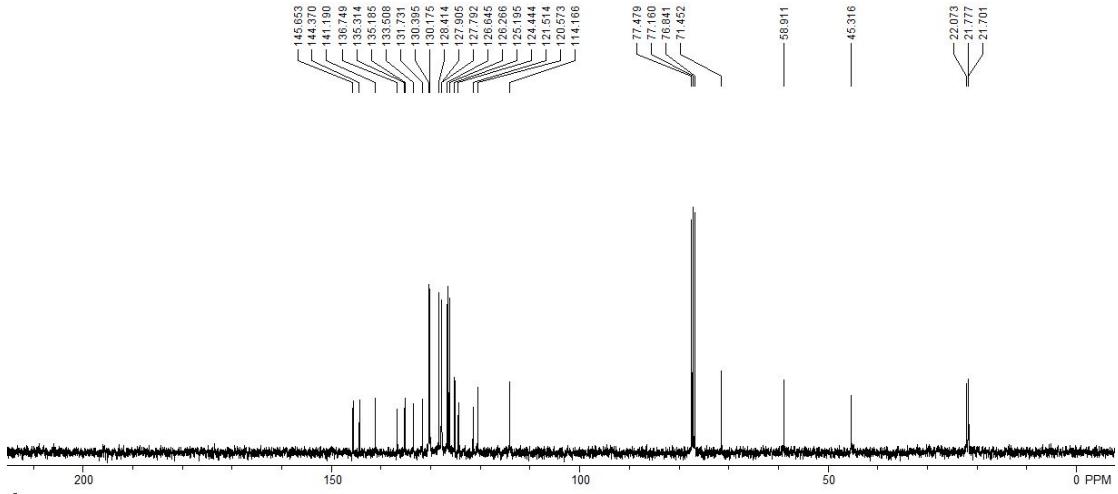


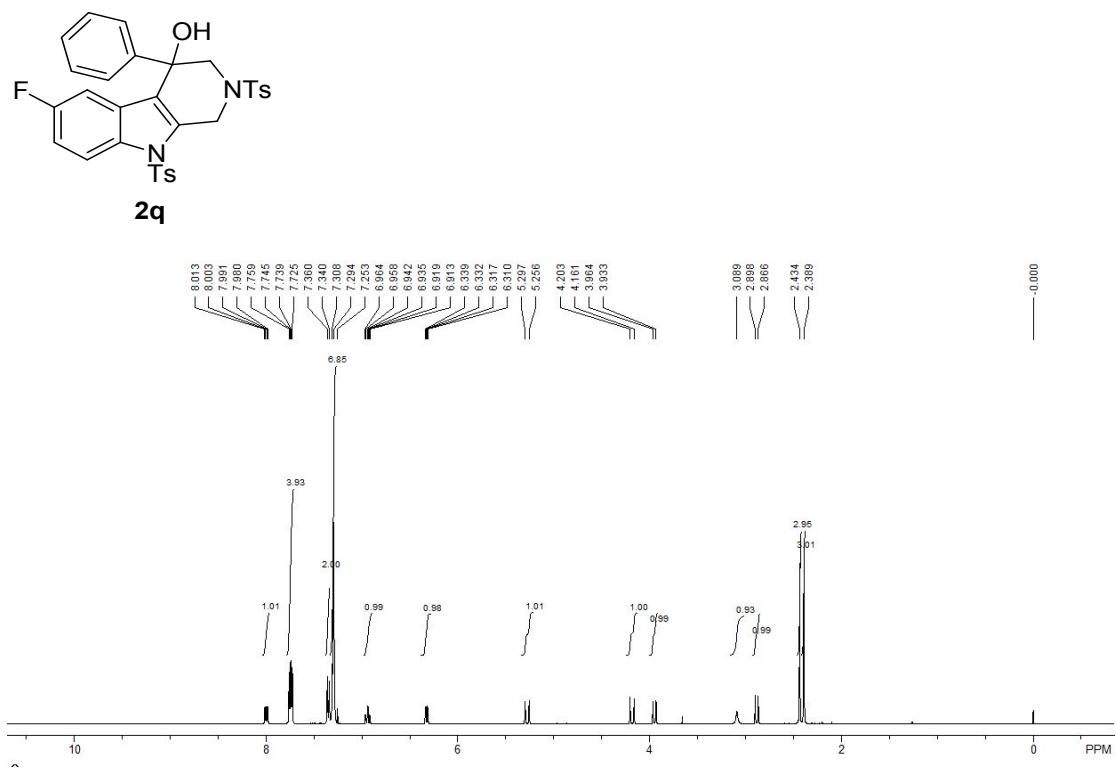
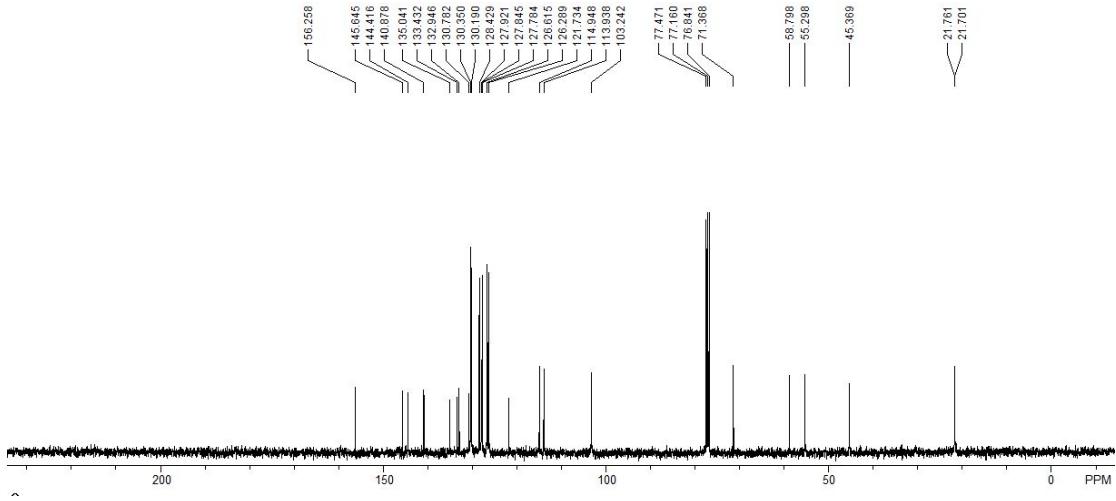


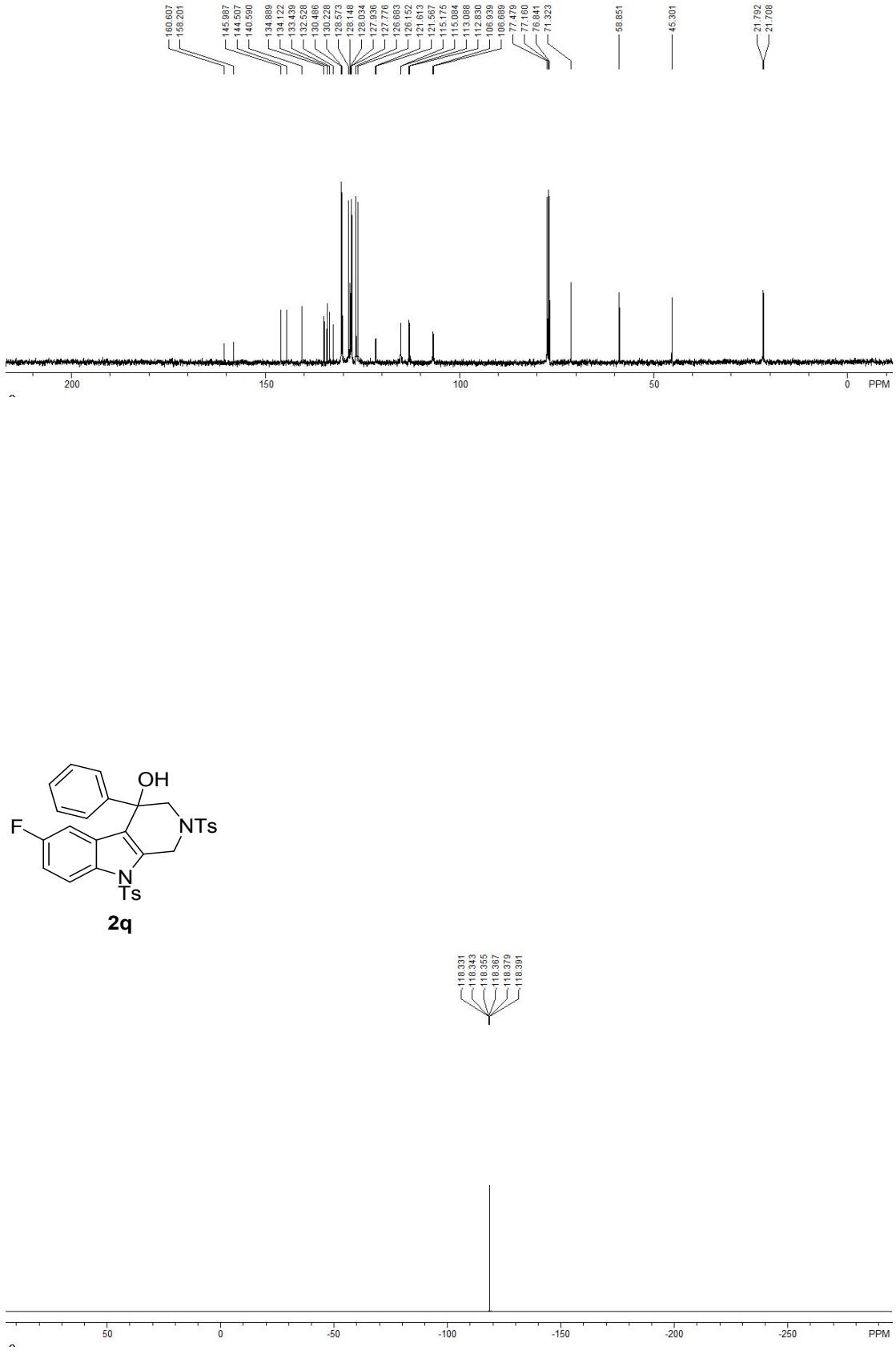


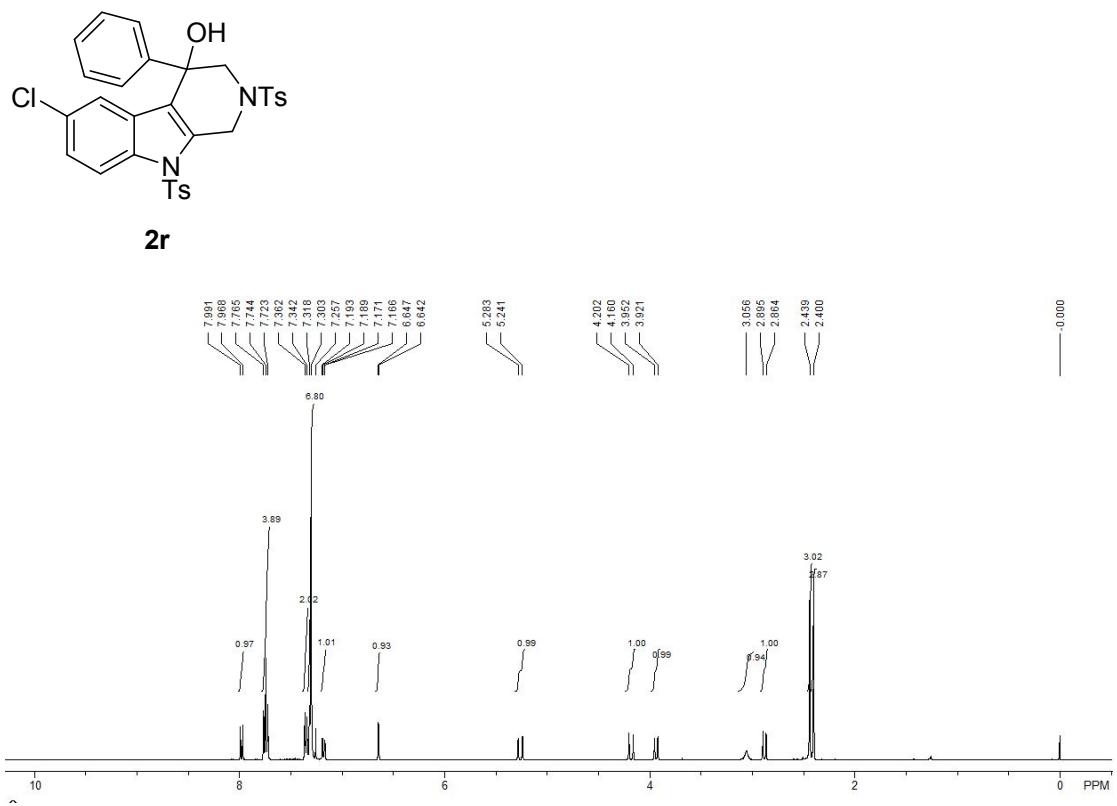


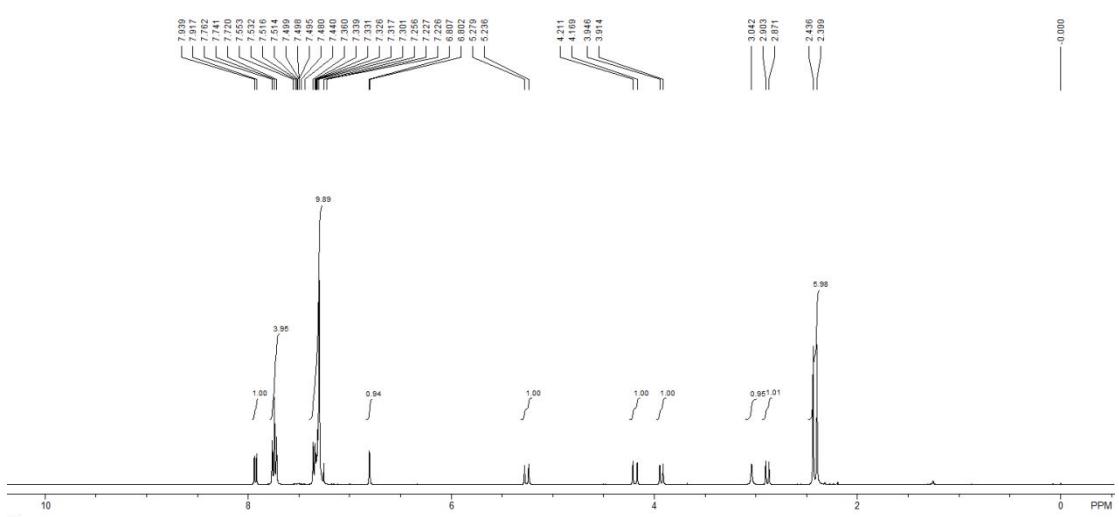
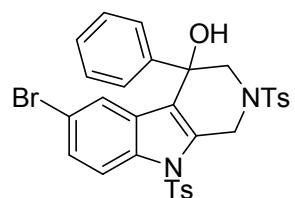
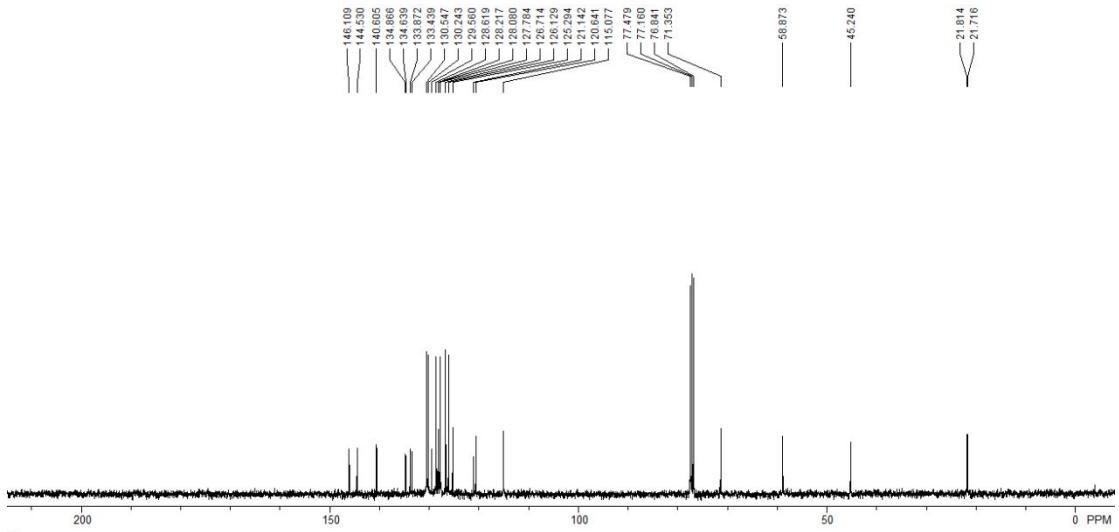


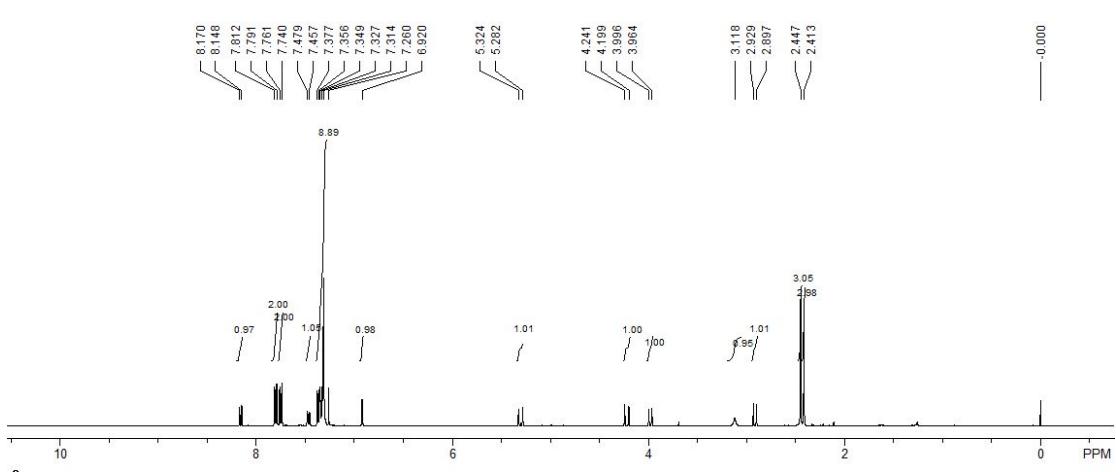
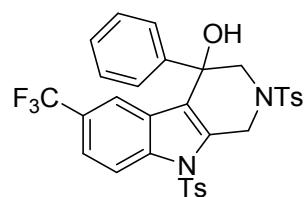
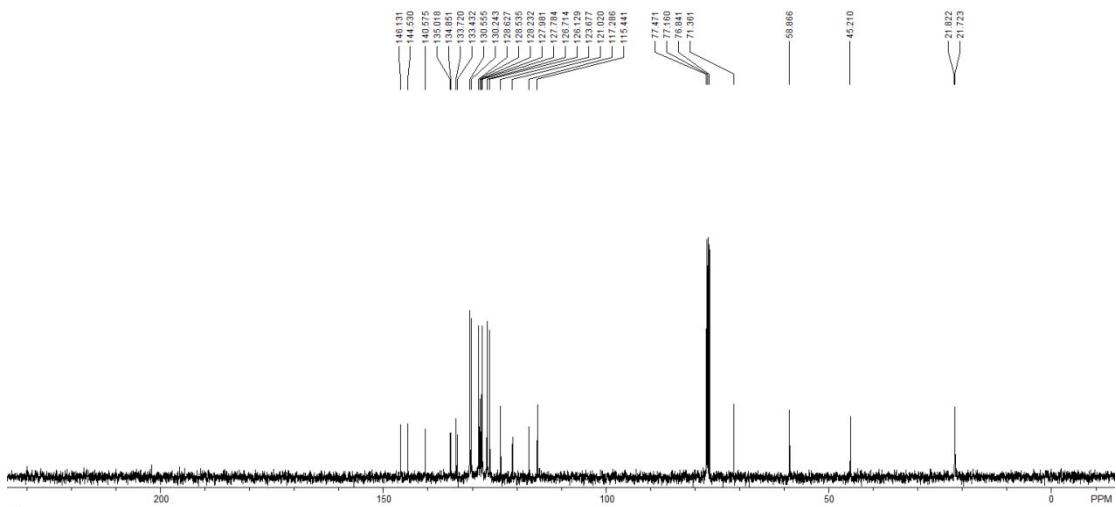


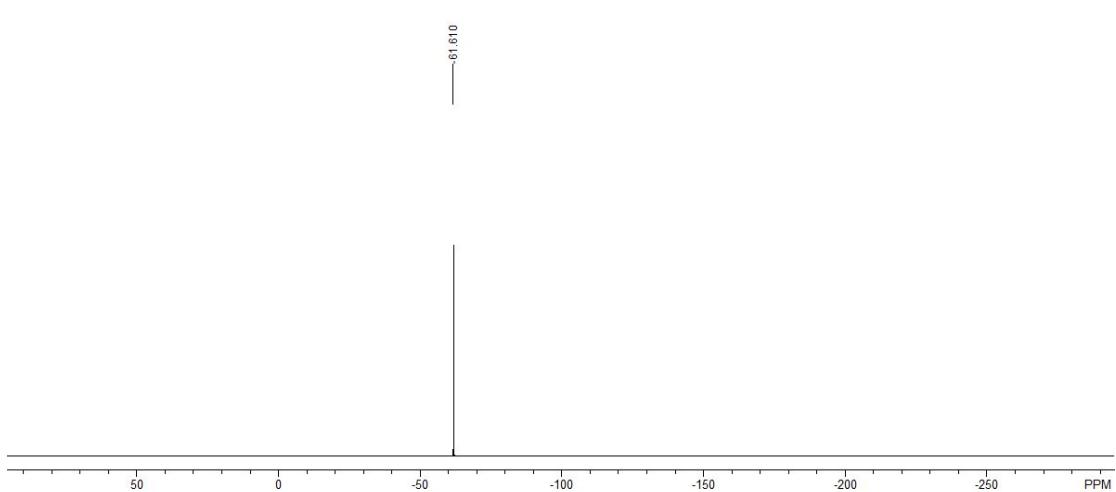
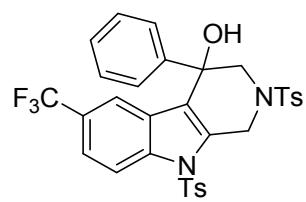
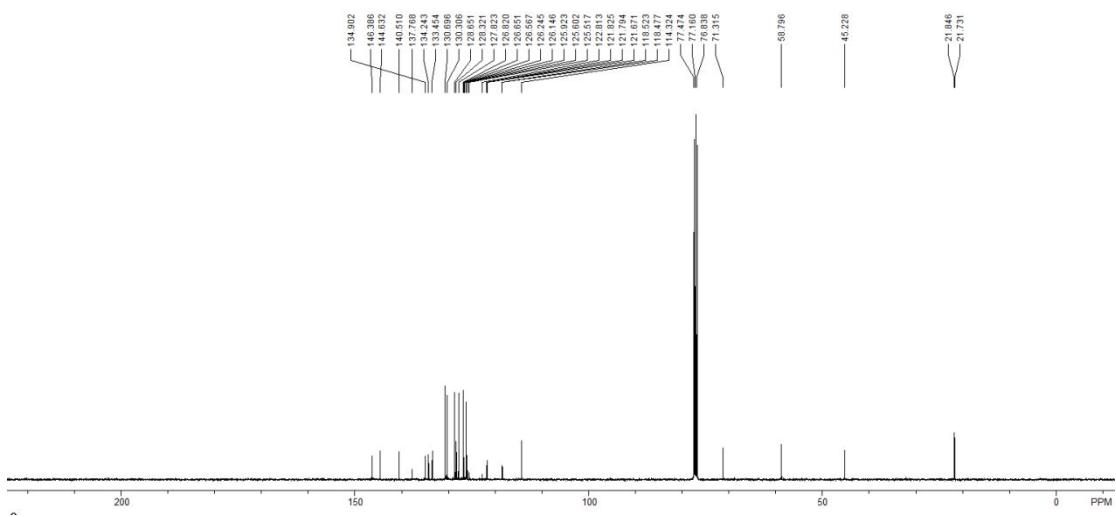


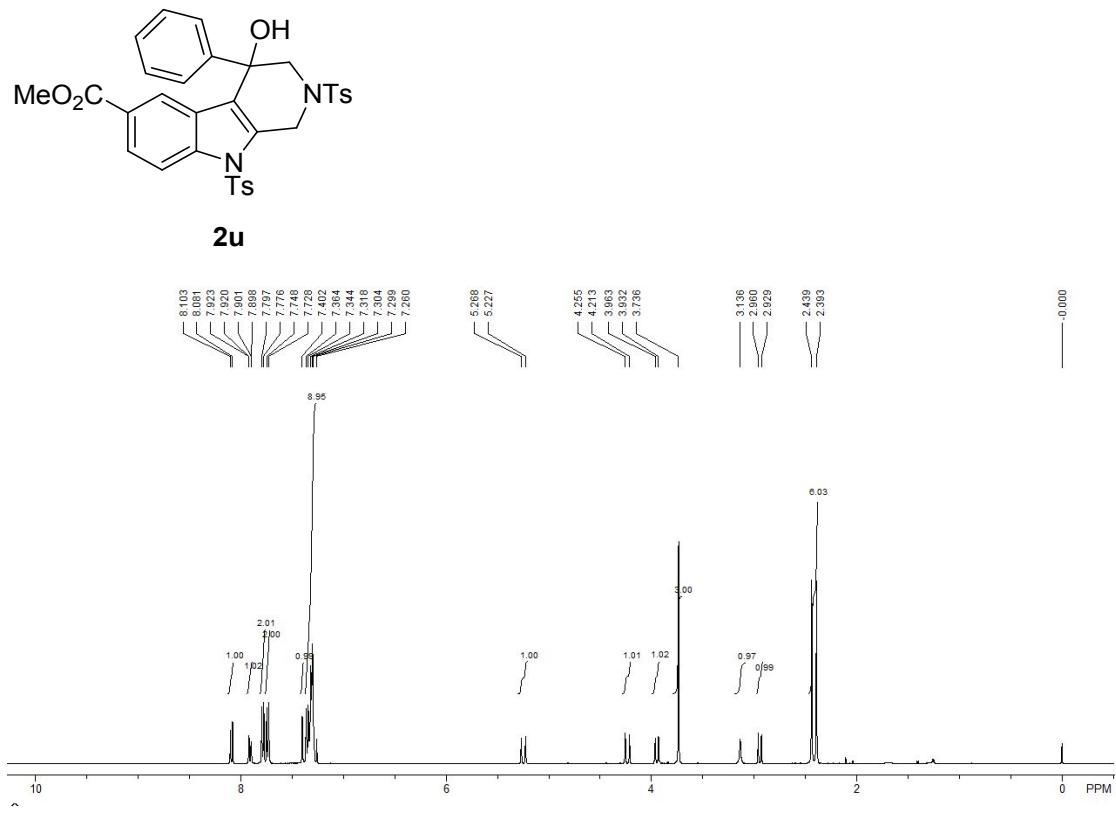


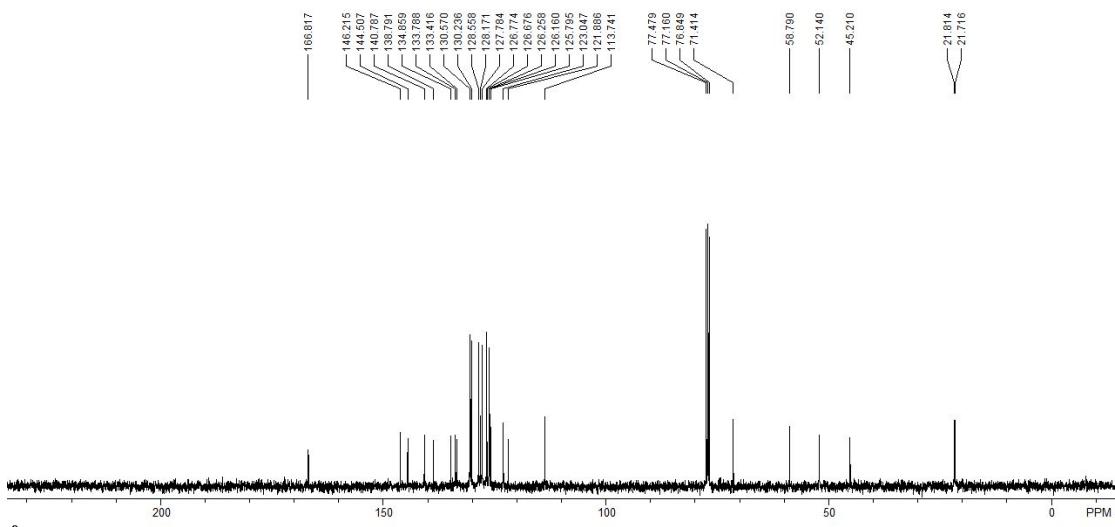




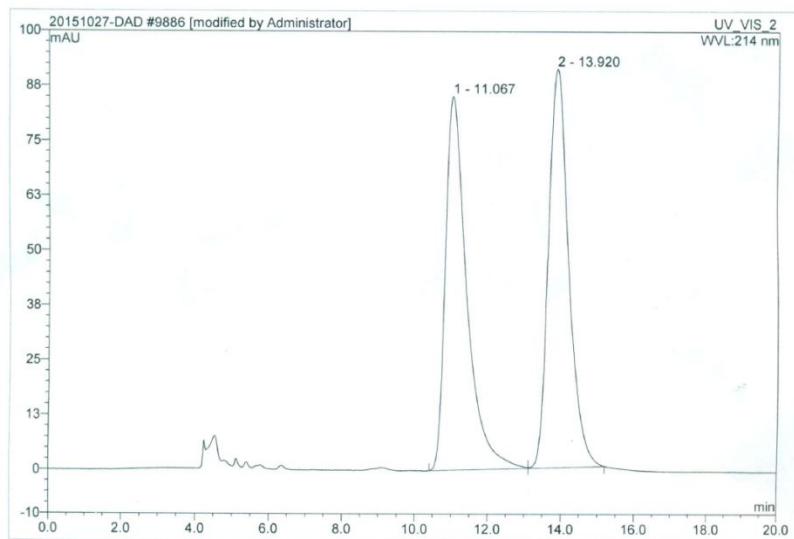
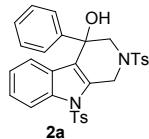




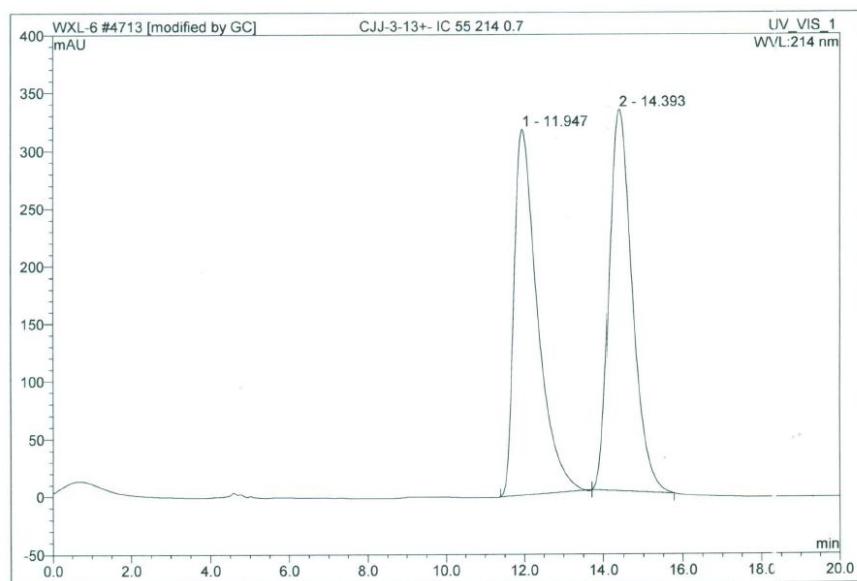
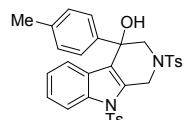
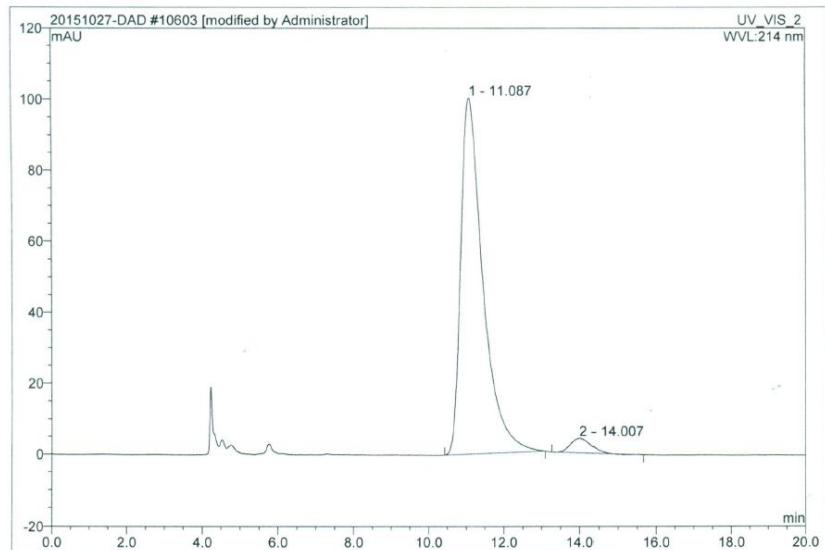




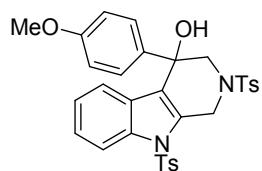
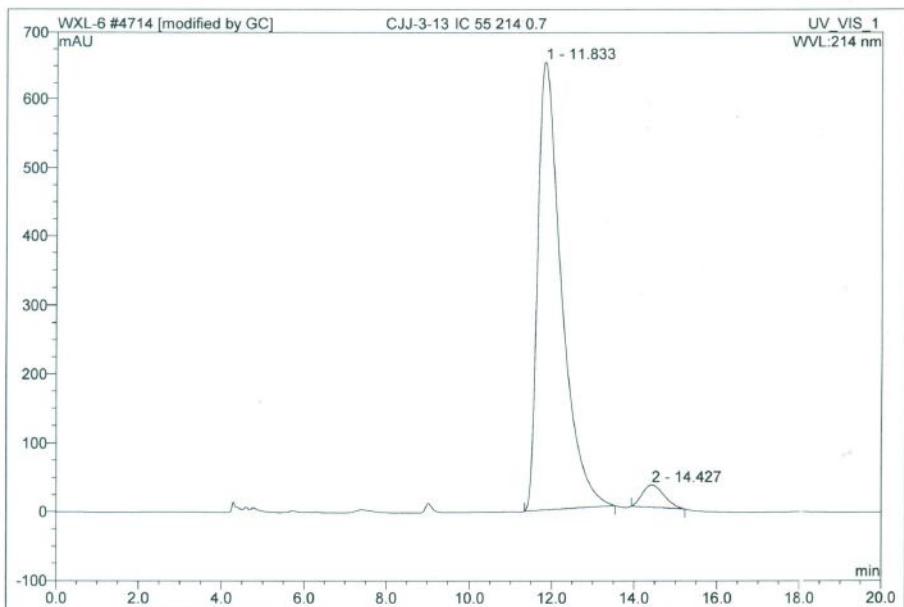
8. HPLC analysis reports of chiral products 2



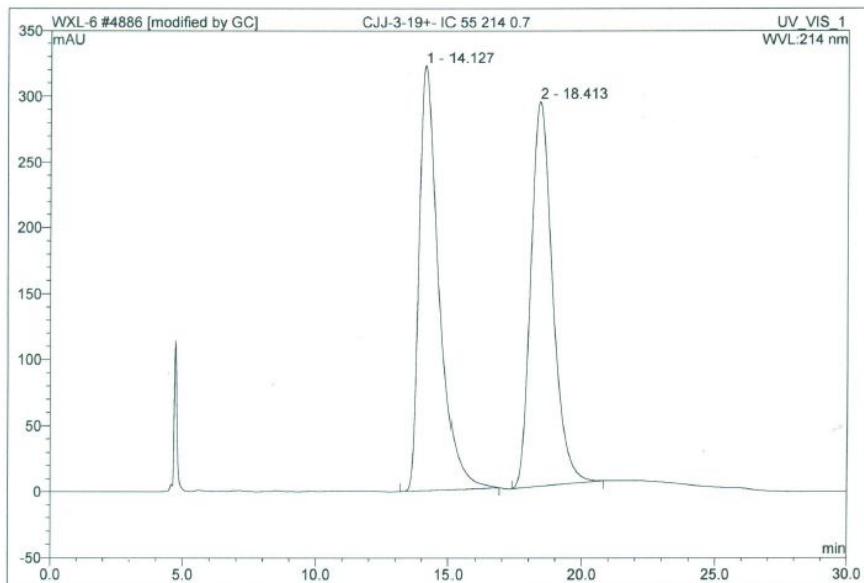
No.	Ret.Time min	Peak Name	Height mAU	Area mAU*min	Rel.Area %	Amount	Type
1	11.07	n.a.	85.250	58.069	49.68	n.a.	BM
2	13.92	n.a.	90.858	58.810	50.32	n.a.	MB
Total:			176.108	116.879	100.00	0.000	



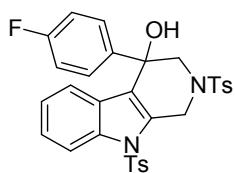
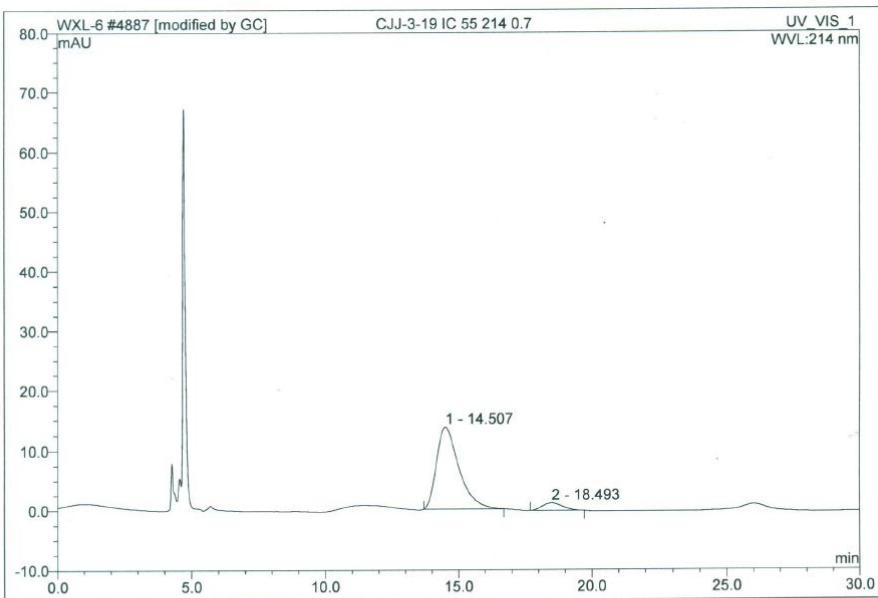
No.	Ret.Time min	Peak Name	Height mAU	Area mAU*min	Rel.Area %	Amount	Type
1	11.95	n.a.	317.208	219.489	49.63	n.a.	BMB*
2	14.39	n.a.	330.370	222.758	50.37	n.a.	bMB*
Total:			647.577	442.248	100.00	0.000	



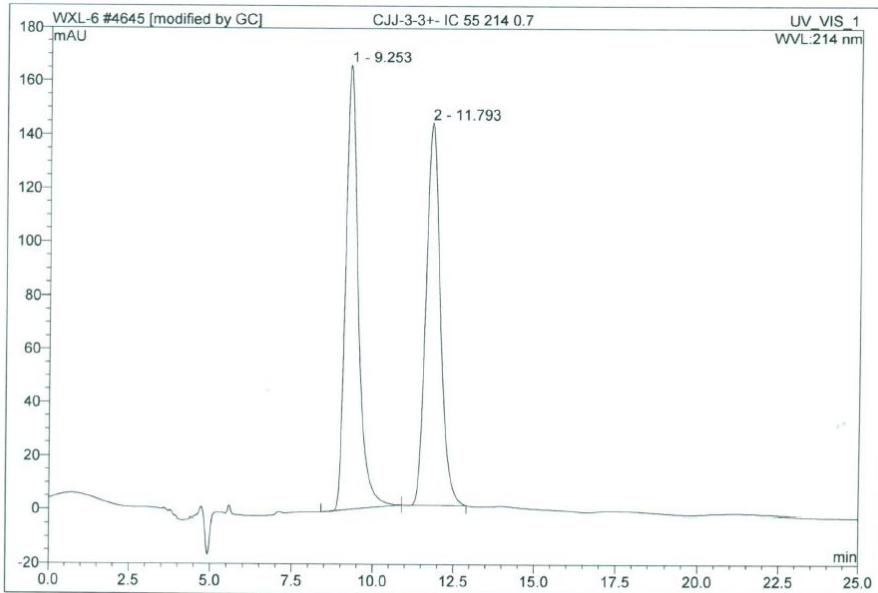
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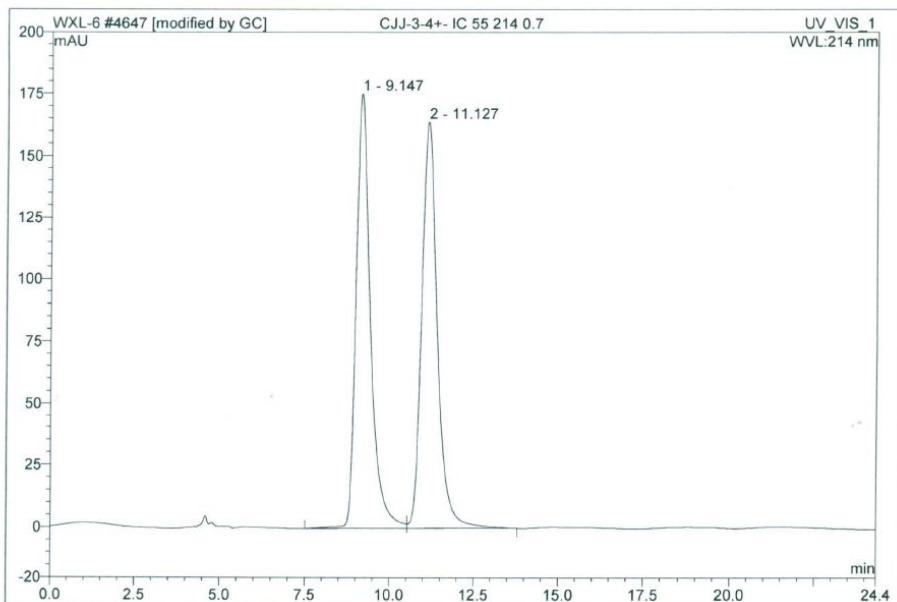
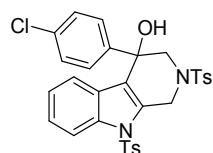
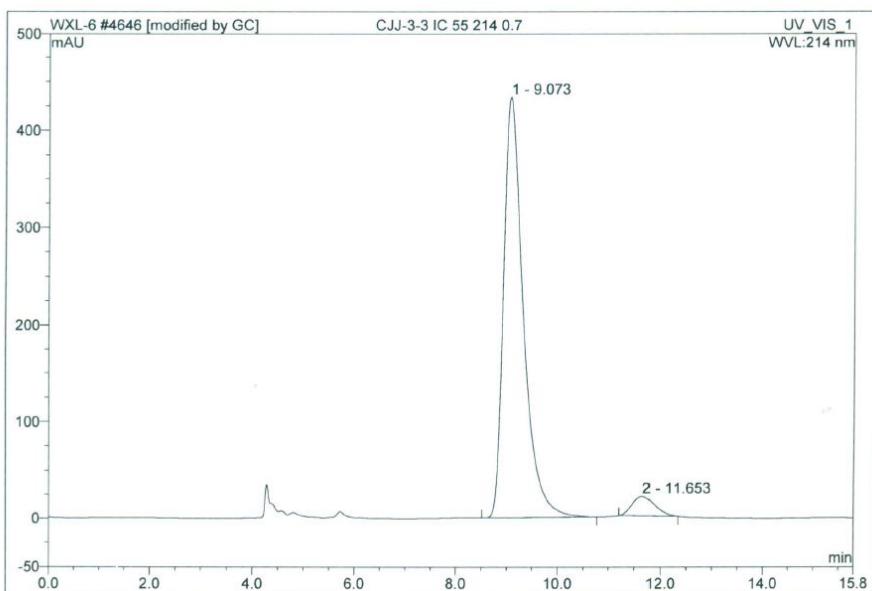
No.	Ret.Time min	Peak Name	Height mAU	Area mAU*min	Rel.Area %	Amount	Type
1	14.13	n.a.	321.977	277.628	50.09	n.a.	BMB*
2	18.41	n.a.	291.581	276.607	49.91	n.a.	BMB*
Total:			613.558	554.235	100.00	0.000	

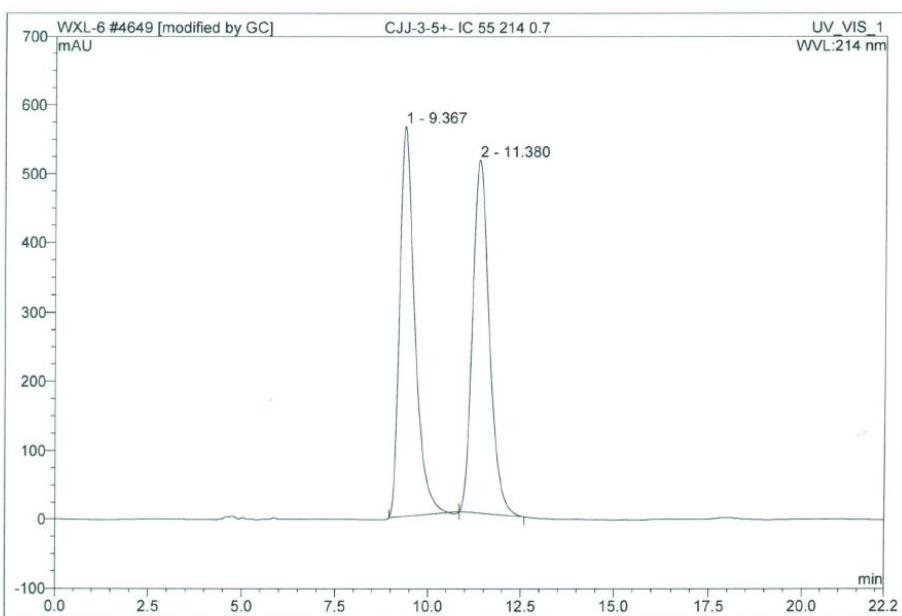
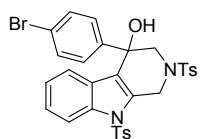
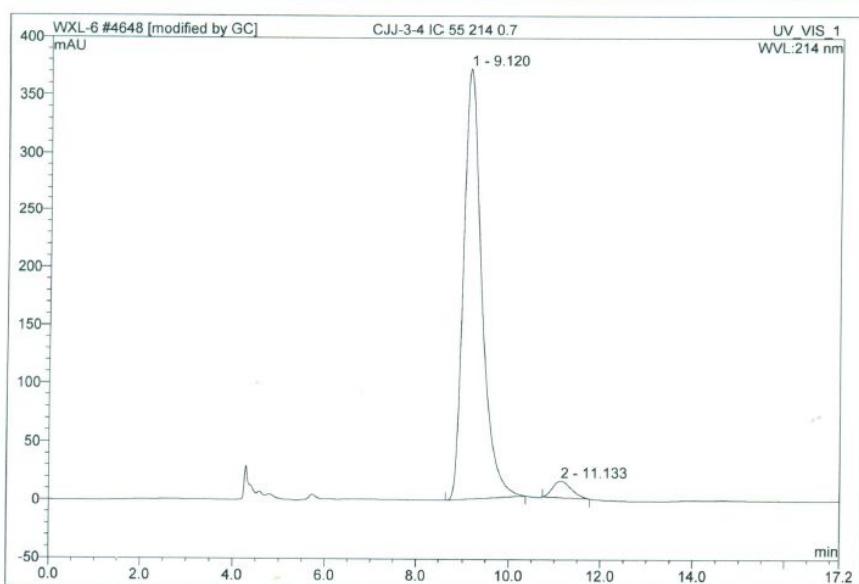


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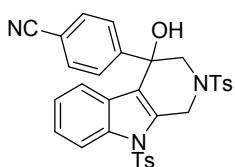
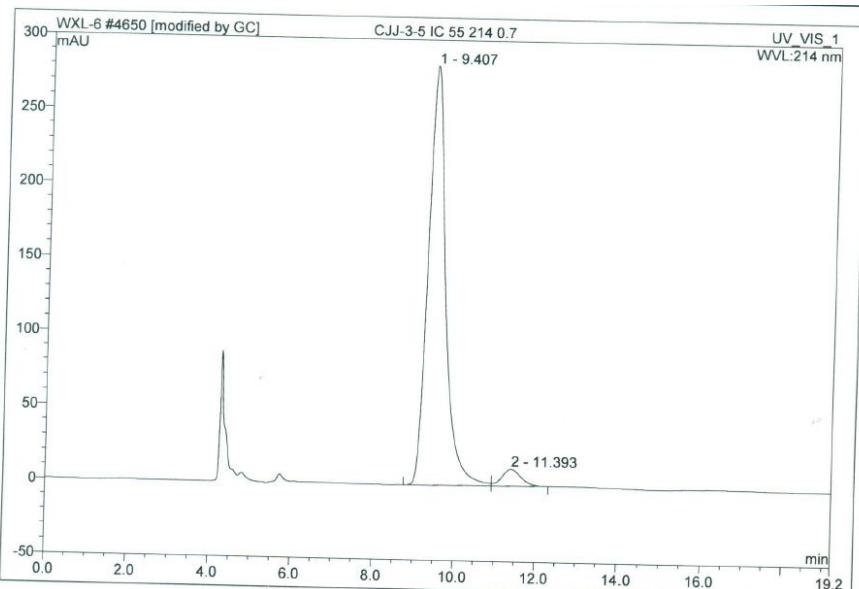


No.	Ret.Time min	Peak Name	Height mAU	Area mAU*min	Rel.Area %	Amount	Type
1	9.25	n.a.	165.990	75.743	50.51	n.a.	BMB*
2	11.79	n.a.	142.867	74.213	49.49	n.a.	bMB*
Total:			308.857	149.956	100.00	0.000	

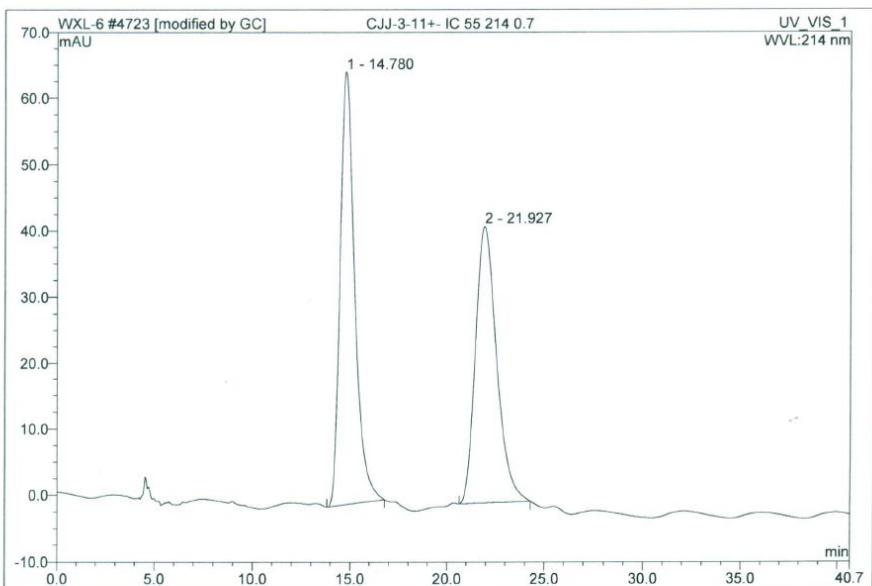




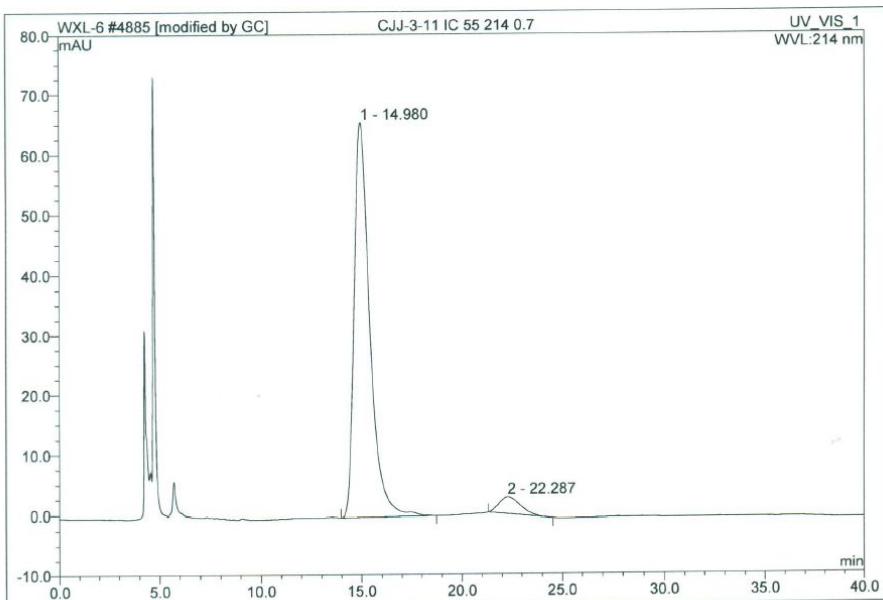
No.	Ret.Time min	Peak Name	Height mAU	Area mAU*min	Rel.Area %	Amount	Type
1	9.37	n.a.	565.159	267.233	49.82	n.a.	BMB*
2	11.38	n.a.	511.286	269.161	50.18	n.a.	bMB*
Total:			1076.444	536.394	100.00	0.000	



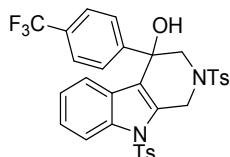
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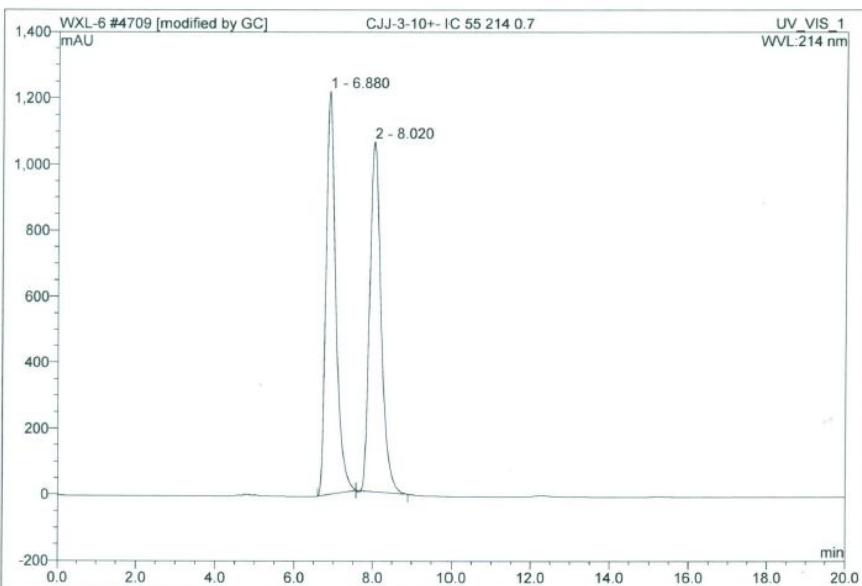
No.	Ret.Time min	Peak Name	Height mAU	Area mAU*min	Rel.Area %	Amount	Type
1	14.78	n.a.	65.410	56.664	51.74	n.a.	BMB*
2	21.93	n.a.	41.856	52.860	48.26	n.a.	BMB*
Total:			107.266	109.525	100.00	0.000	



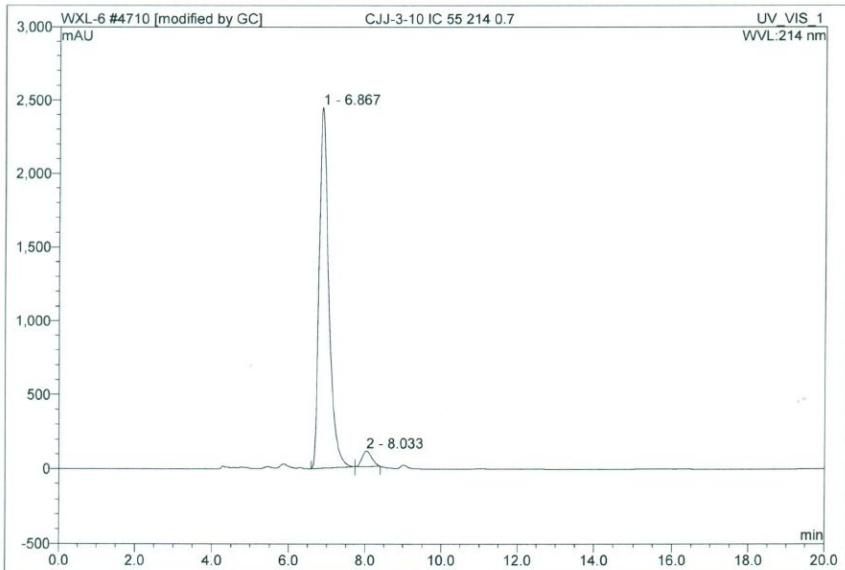
No.	Ret.Time min	Peak Name	Height mAU	Area mAU*min	Rel.Area %	Amount	Type
1	14.98	n.a.	65.724	59.152	94.59	n.a.	BMB*
2	22.29	n.a.	2.743	3.384	5.41	n.a.	BMB*
Total:			68.467	62.536	100.00	0.000	



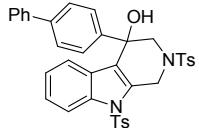
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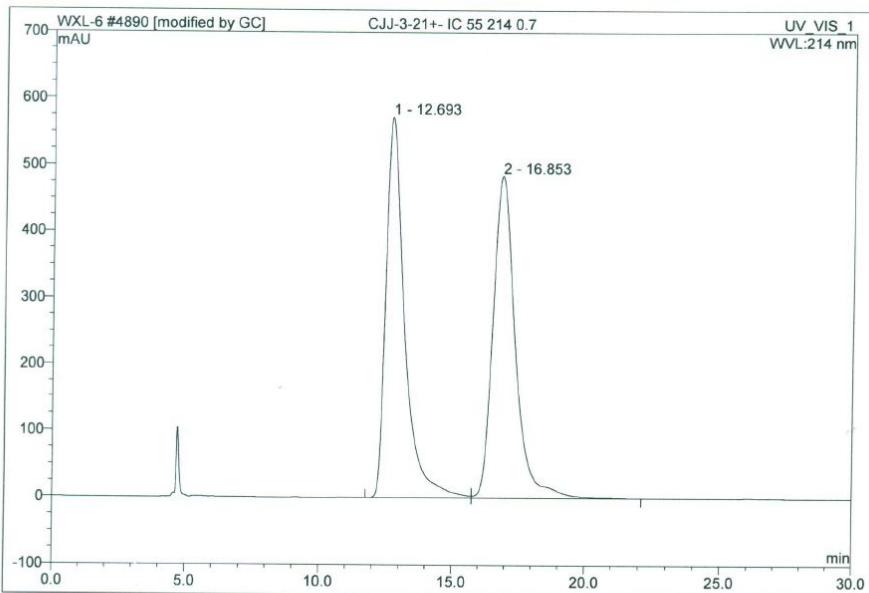
No.	Ret.Time min	Peak Name	Height mAU	Area mAU*min	Rel.Area %	Amount	Type
1	6.88	n.a.	1220.269	355.977	49.81	n.a.	BMB*
2	8.02	n.a.	1061.541	358.653	50.19	n.a.	bMB*
Total:			2281.809	714.630	100.00	0.000	



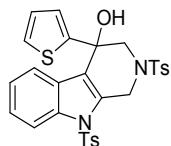
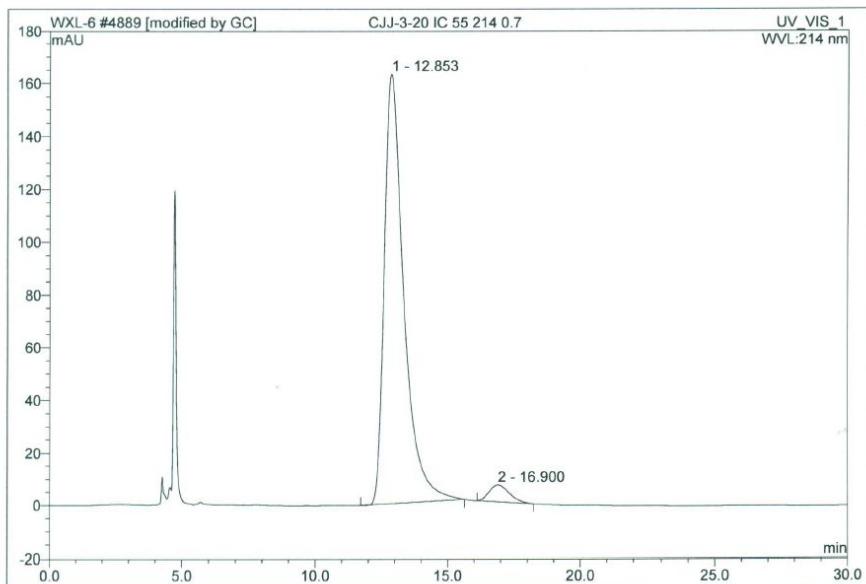
No.	Ret.Time min	Peak Name	Height mAU	Area mAU*min	Rel.Area %	Amount	Type
1	6.87	n.a.	2447.577	715.512	95.79	n.a.	BMb*
2	8.03	n.a.	105.660	31.433	4.21	n.a.	bMB*
Total:			2553.237	746.945	100.00	0.000	



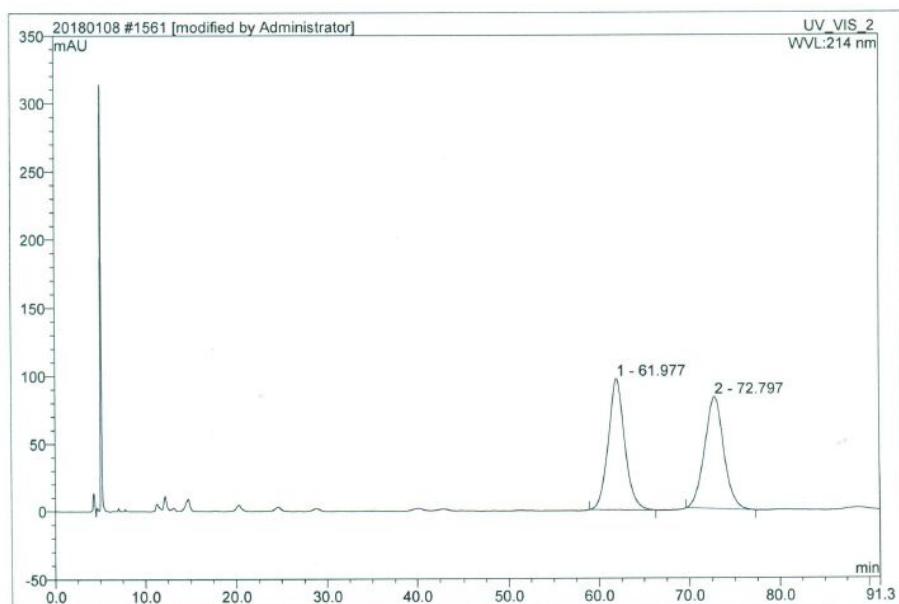
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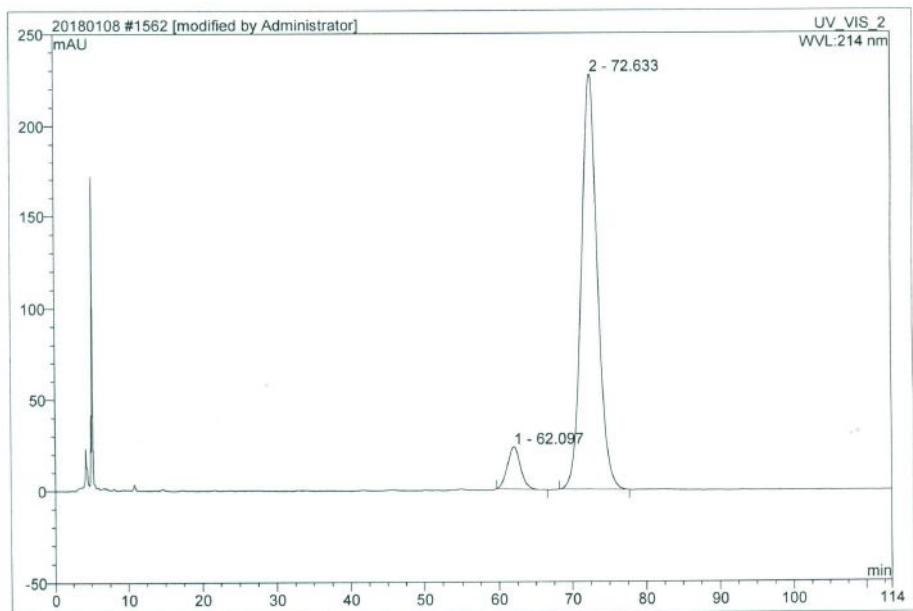
No.	Ret.Time min	Peak Name	Height mAU	Area mAU*min	Rel.Area %	Amount	Type
1	12.69	n.a.	572.068	470.162	49.83	n.a.	BM
2	16.85	n.a.	484.438	473.456	50.17	n.a.	MB
Total:			1056.507	943.618	100.00	0.000	



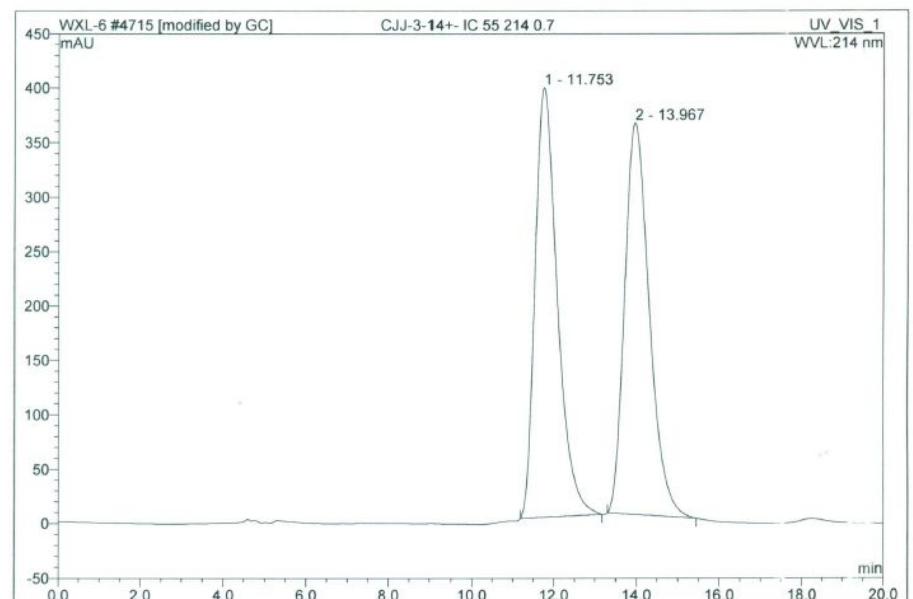
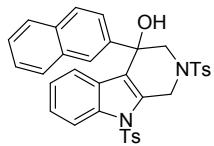
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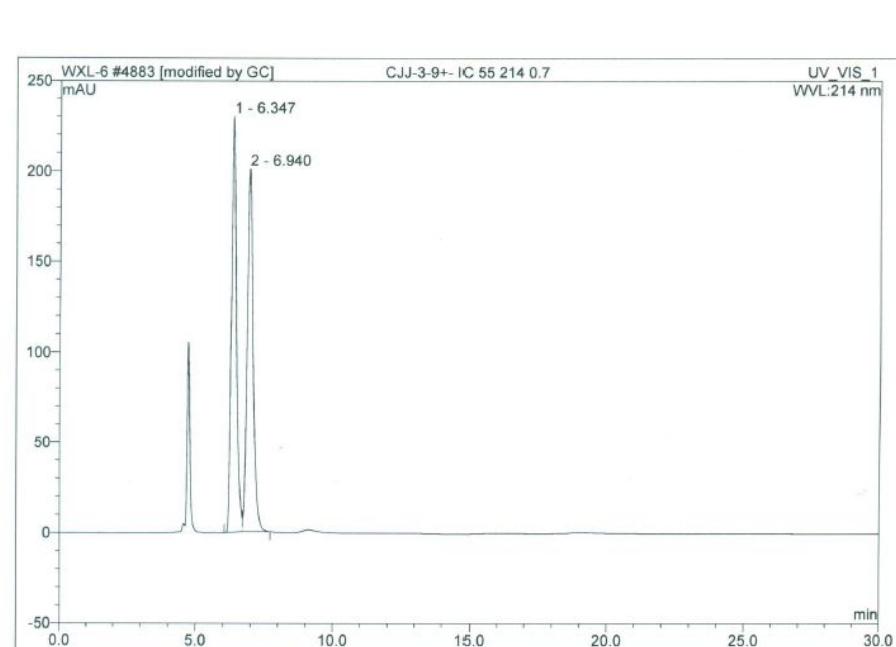
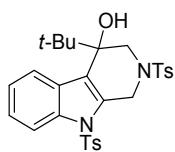
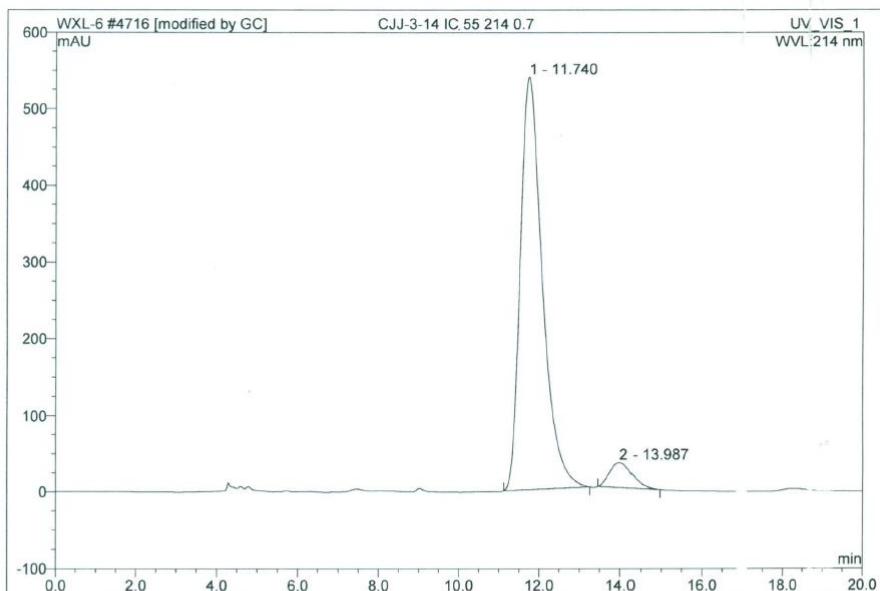
No.	Ret.Time min	Peak Name	Height mAU	Area mAU*min	Rel.Area %	Amount	Type
1	61.98	n.a.	97.040	204.257	49.98	n.a.	BMB*
2	72.80	n.a.	83.028	204.451	50.02	n.a.	BMB*
Total:			180.068	408.708	100.00	0.000	



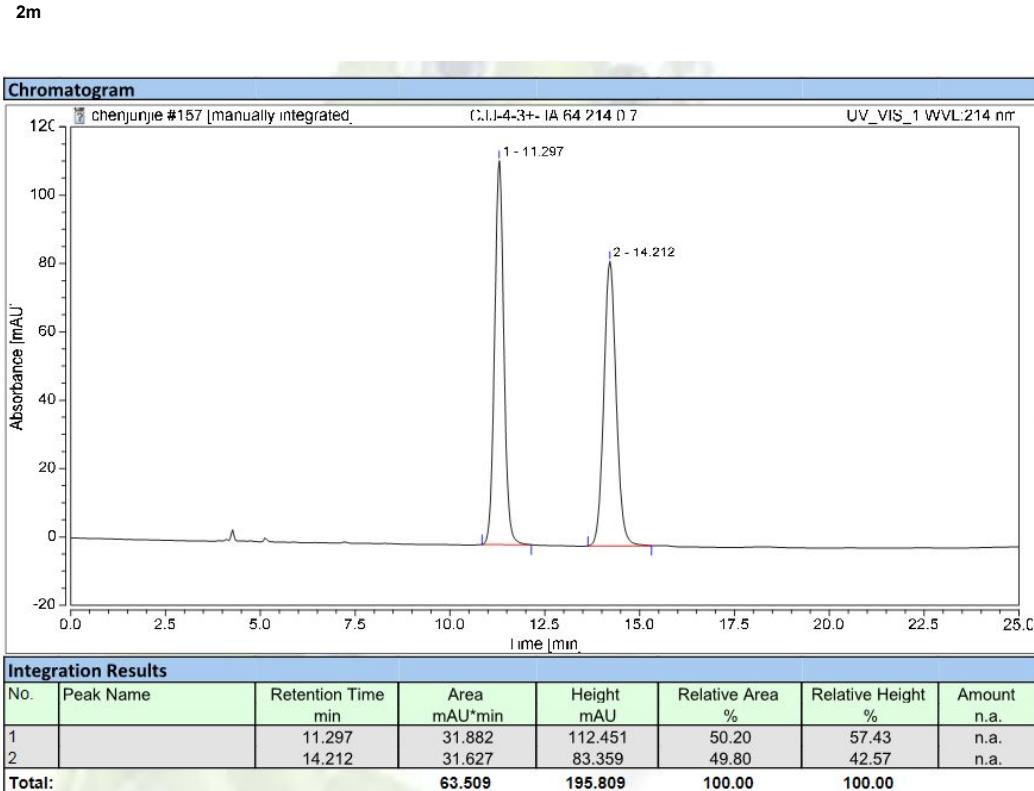
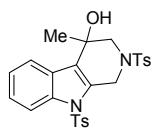
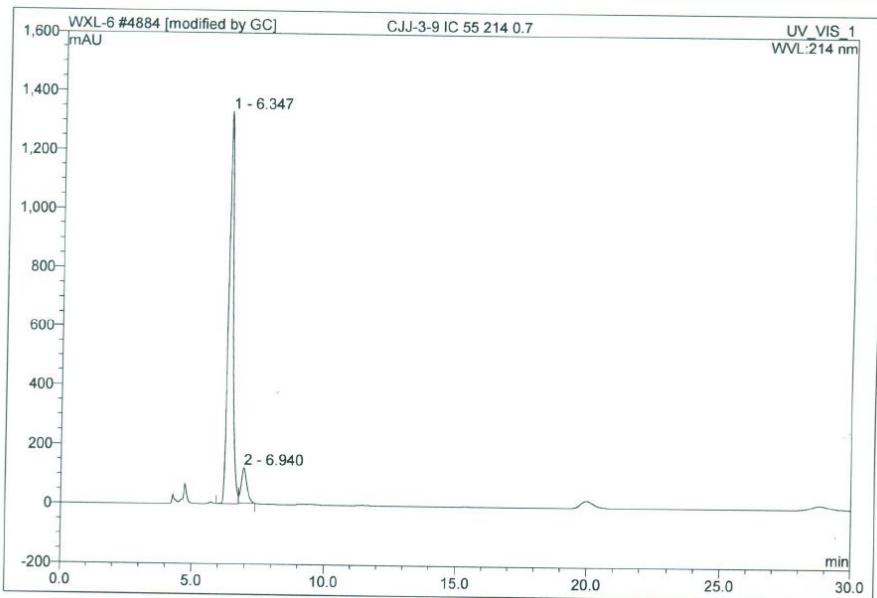
No.	Ret.Time min	Peak Name	Height mAU	Area mAU*min	Rel.Area %	Amount	Type
1	62.10	n.a.	23.160	47.969	7.72	n.a.	BMB*
2	72.63	n.a.	227.317	573.277	92.28	n.a.	BMB*
Total:			250.477	621.246	100.00	0.000	

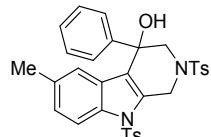
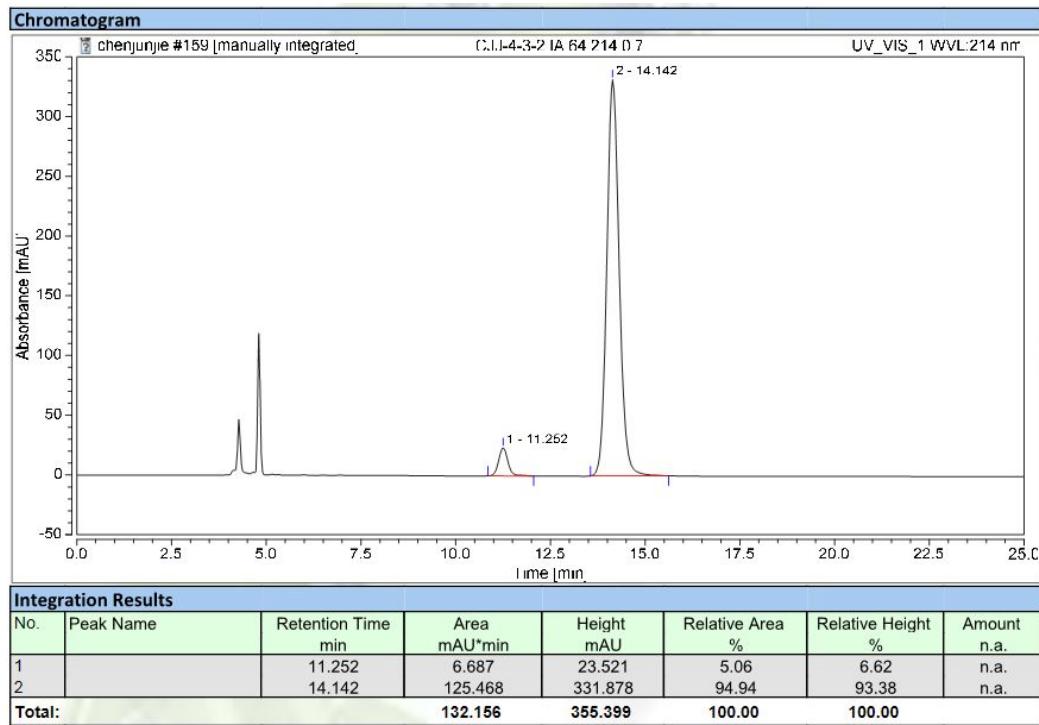


No.	Ret.Time min	Peak Name	Height mAU	Area mAU*min	Rel.Area %	Amount	Type
1	11.75	n.a.	394.571	247.702	49.86	n.a.	BMB*
2	13.97	n.a.	359.860	249.062	50.14	n.a.	BMB*
Total:			754.431	496.764	100.00	0.000	

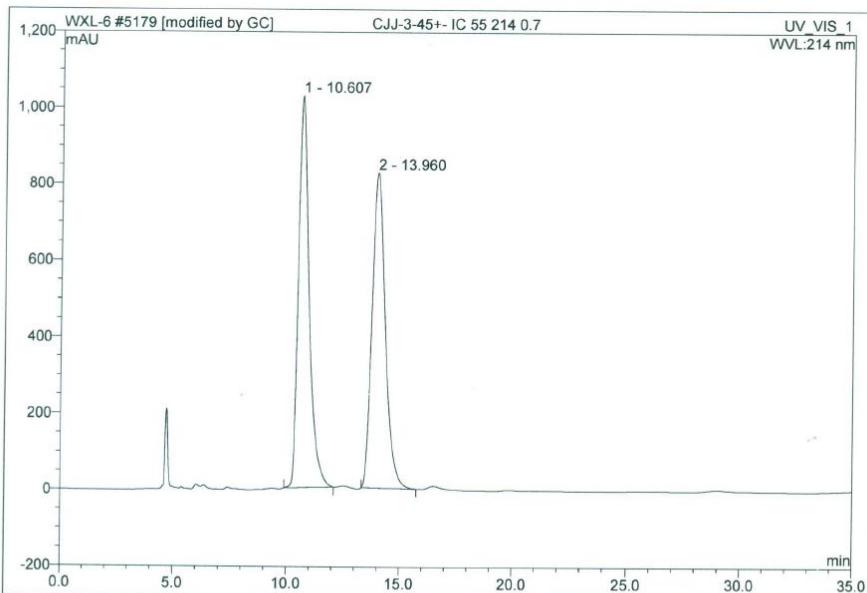


No.	Ret.Time min	Peak Name	Height mAU	Area mAU*min	Rel.Area %	Amount	Type
1	6.35	n.a.	229.969	49.212	49.49	n.a.	BM *
2	6.94	n.a.	200.657	50.235	50.51	n.a.	MB*
Total:			430.627	99.447	100.00	0.000	

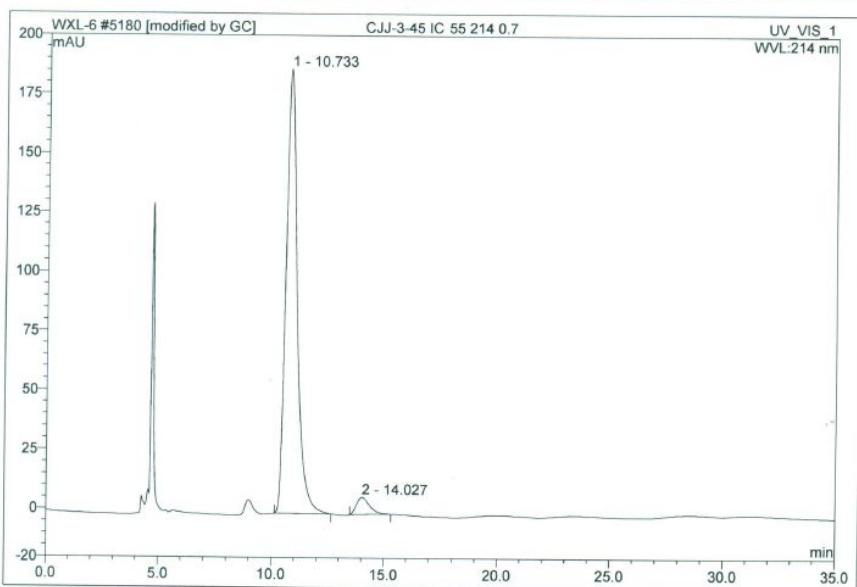




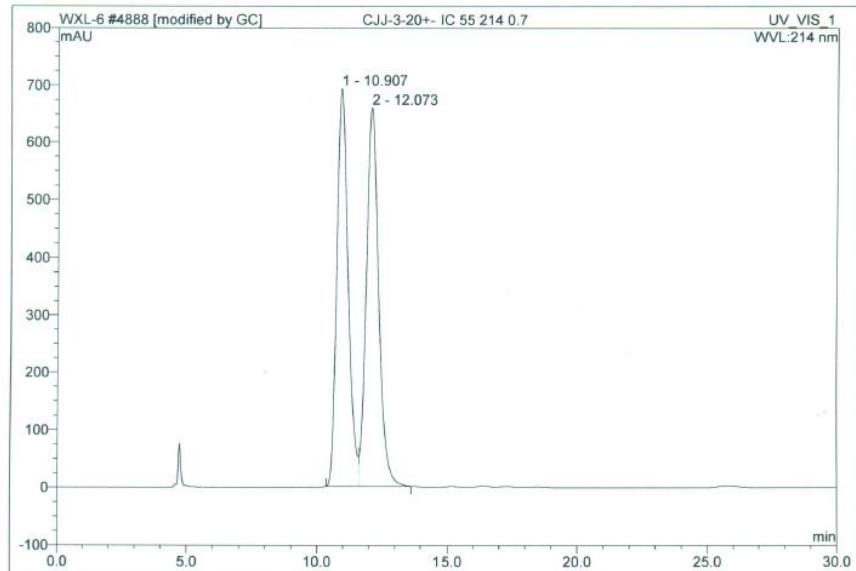
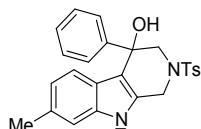
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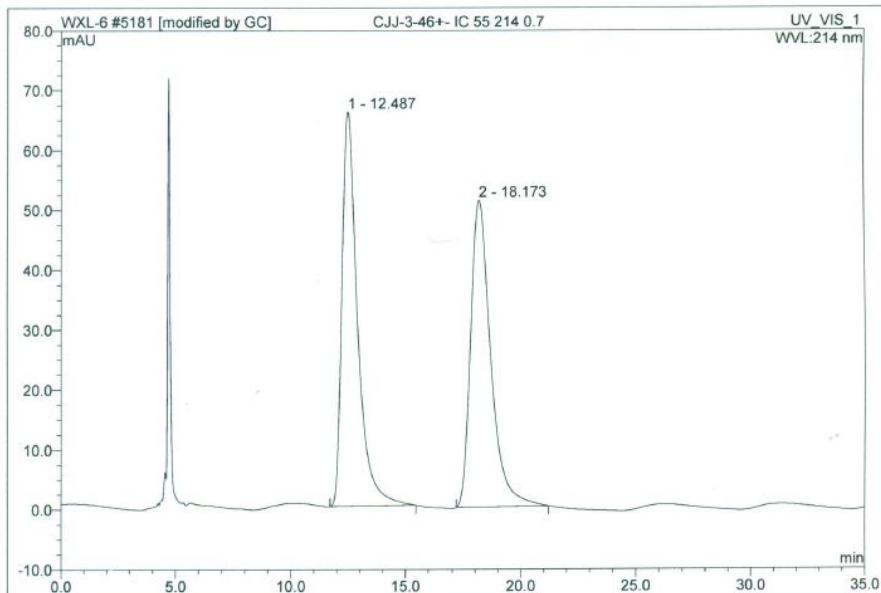
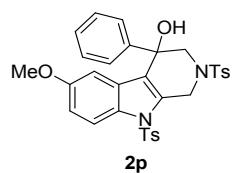
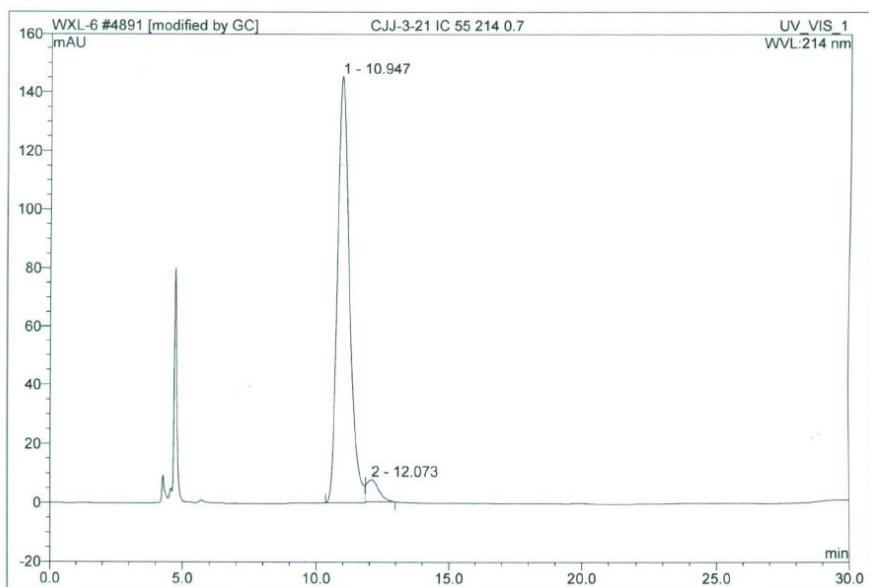
No.	Ret.Time min	Peak Name	Height mAU	Area mAU*min	Rel.Area %	Amount	Type
1	10.61	n.a.	1026.543	565.184	50.15	n.a.	BMB*
2	13.96	n.a.	824.981	561.854	49.85	n.a.	BMB*
Total:			1851.523	1127.037	100.00	0.000	



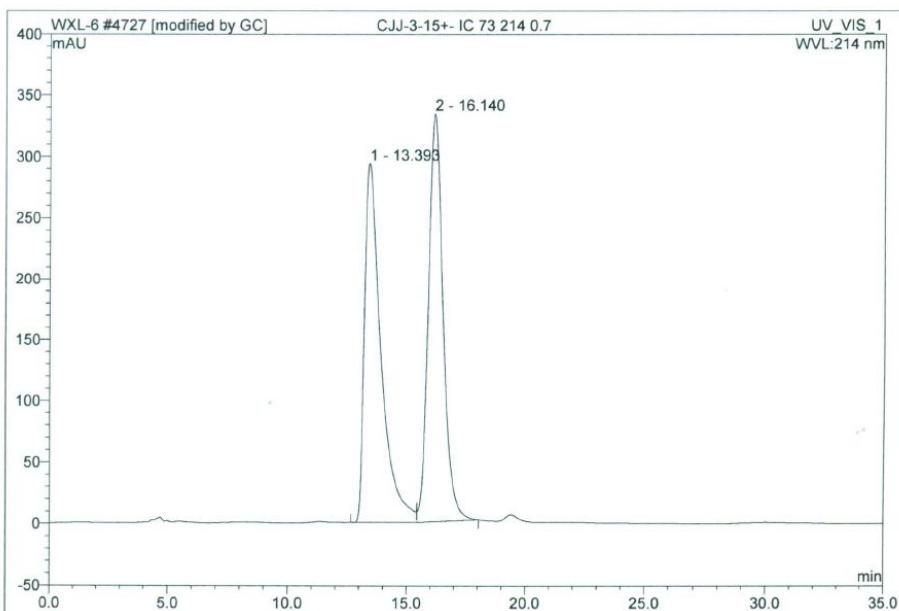
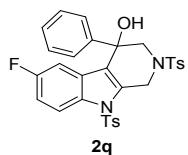
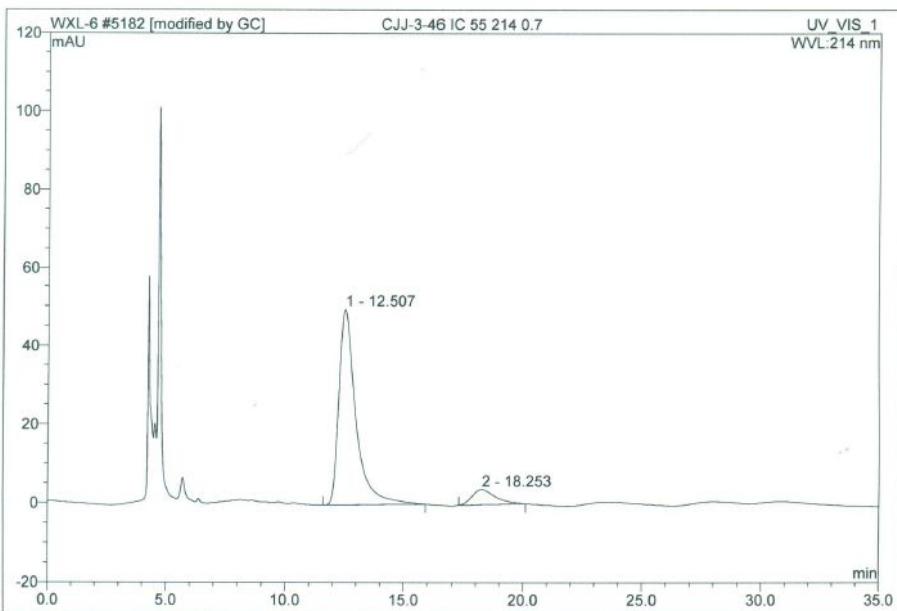
No.	Ret.Time min	Peak Name	Height mAU	Area mAU*min	Rel.Area %	Amount	Type
1	10.73	n.a.	187.346	108.309	95.68	n.a.	BMB*
2	14.03	n.a.	7.178	4.896	4.32	n.a.	BMB*
Total:			194.524	113.204	100.00	0.000	



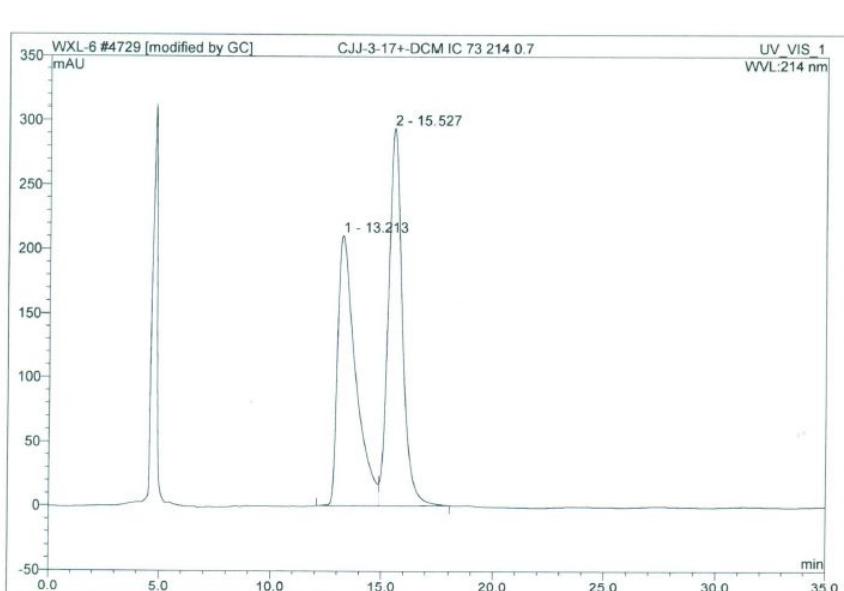
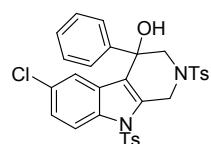
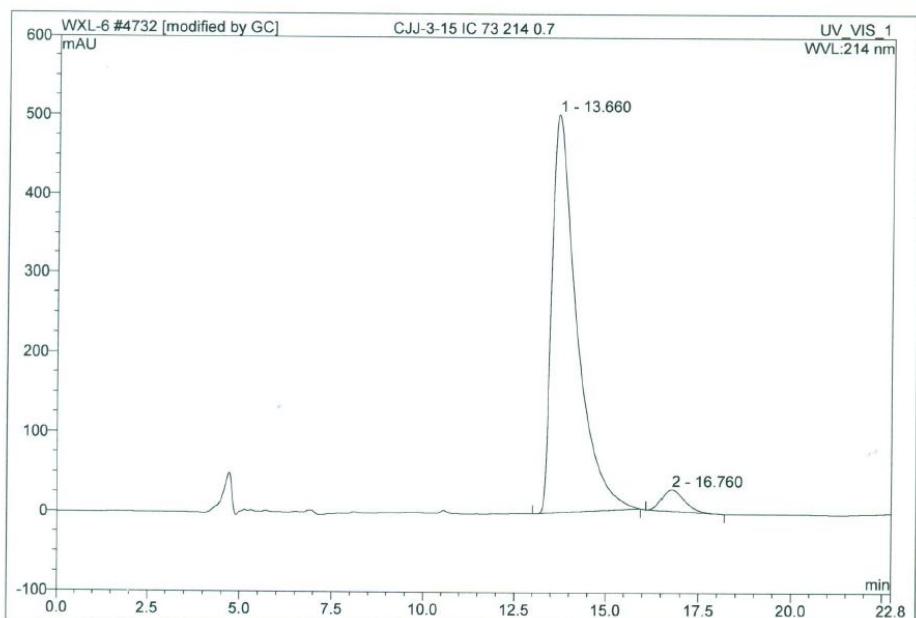
No.	Ret.Time min	Peak Name	Height mAU	Area mAU*min	Rel.Area %	Amount	Type
1	10.91	n.a.	692.929	350.401	49.04	n.a.	BM *
2	12.07	n.a.	659.458	364.164	50.96	n.a.	MB*
Total:			1352.387	714.566	100.00	0.000	



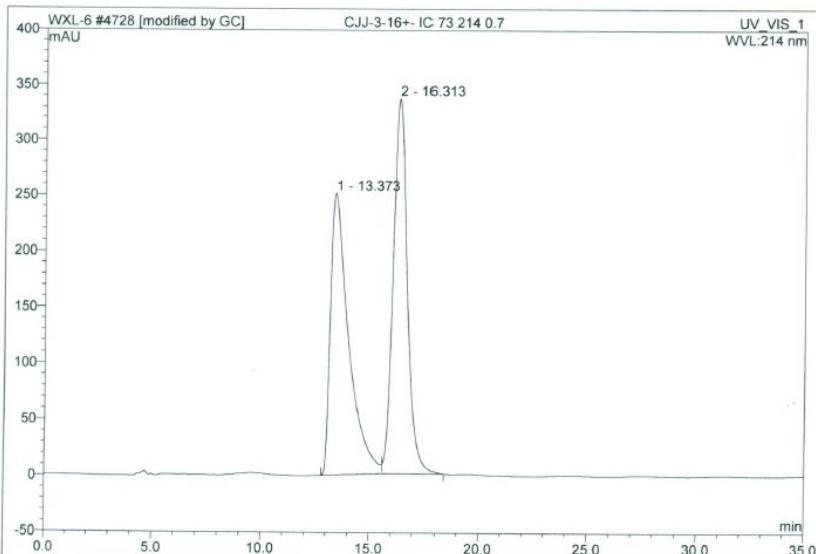
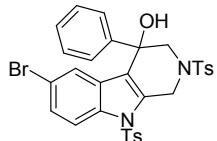
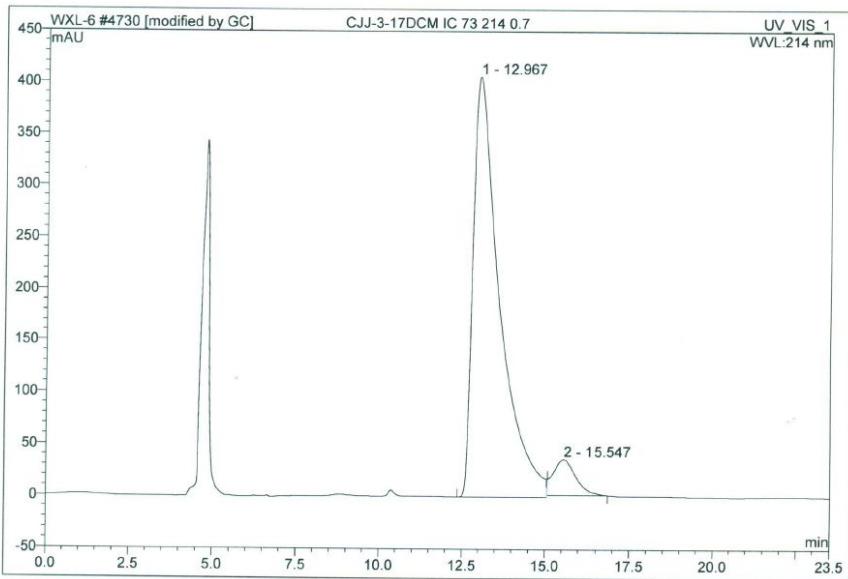
No.	Ret.Time min	Peak Name	Height mAU	Area mAU*min	Rel.Area %	Amount	Type
1	12.49	n.a.	65.886	52.147	49.91	n.a.	BMB*
2	18.17	n.a.	51.243	52.344	50.09	n.a.	BMB*
Total:			117.128	104.491	100.00	0.000	



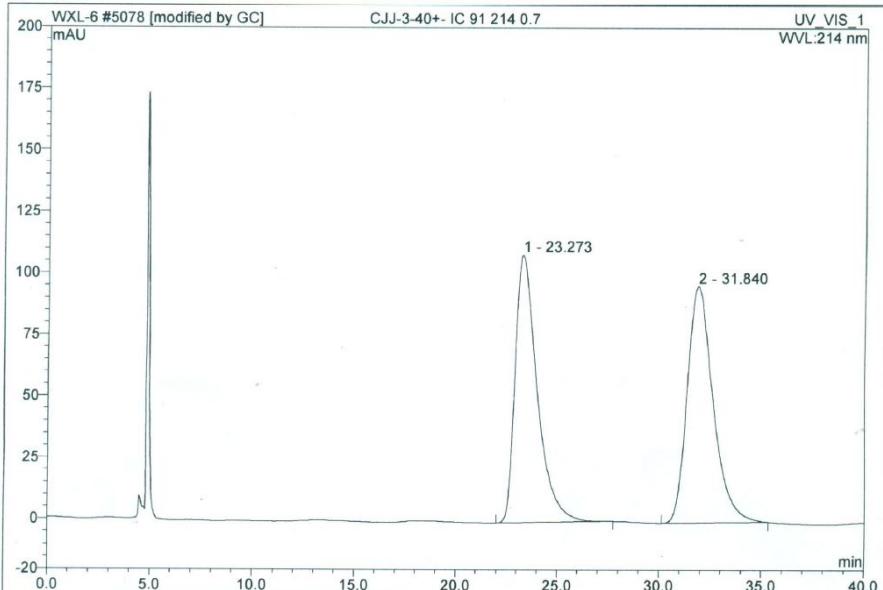
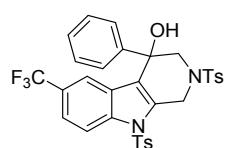
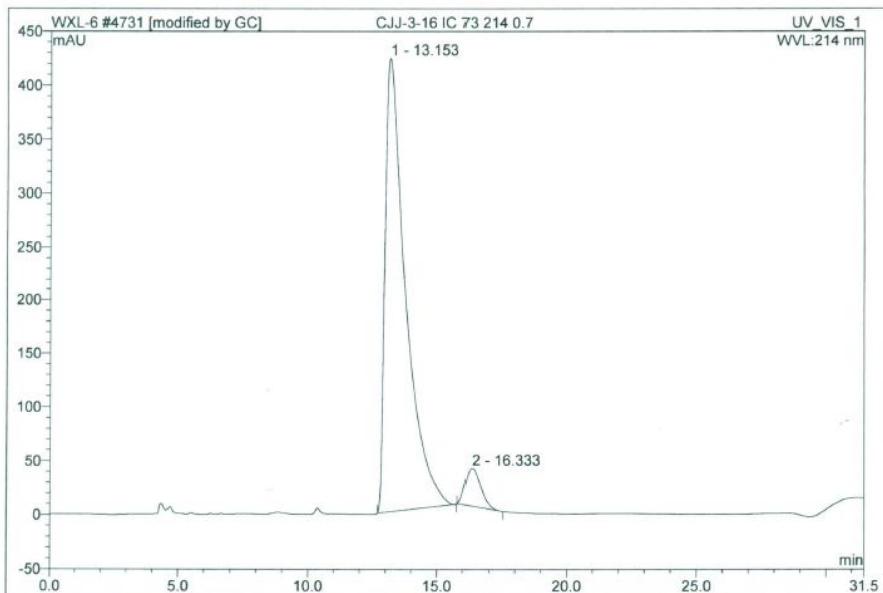
No.	Ret.Time min	Peak Name	Height mAU	Area mAU*min	Rel.Area %	Amount	Type
1	13.39	n.a.	293.580	237.077	49.72	n.a.	BM *
2	16.14	n.a.	333.585	239.742	50.28	n.a.	MB*
Total:			627.165	476.820	100.00	0.000	

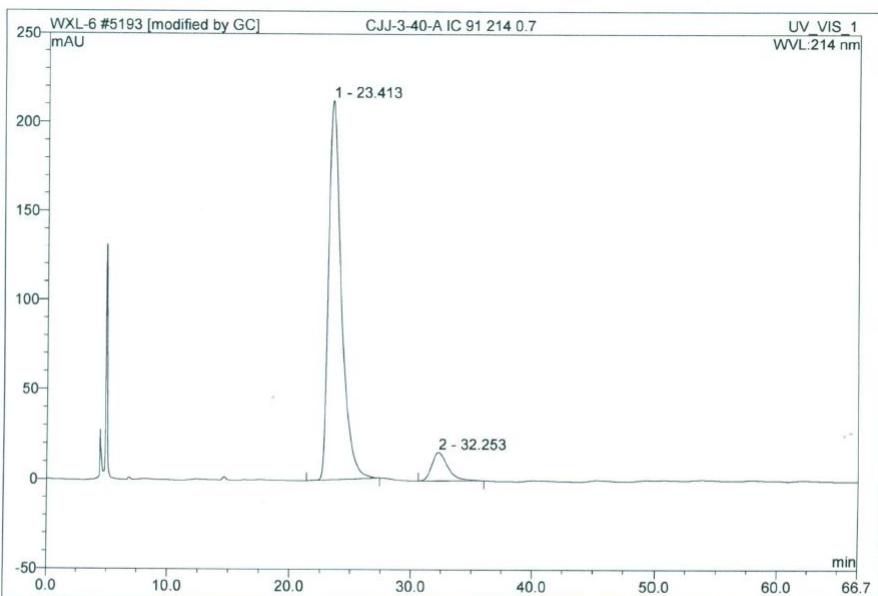


No.	Ret.Time min	Peak Name	Height mAU	Area mAU*min	Rel.Area %	Amount	Type
1	13.21	n.a.	210.467	198.202	47.84	n.a.	BM *
2	15.53	n.a.	293.711	216.095	52.16	n.a.	MB*
Total:			504.179	414.297	100.00	0.000	

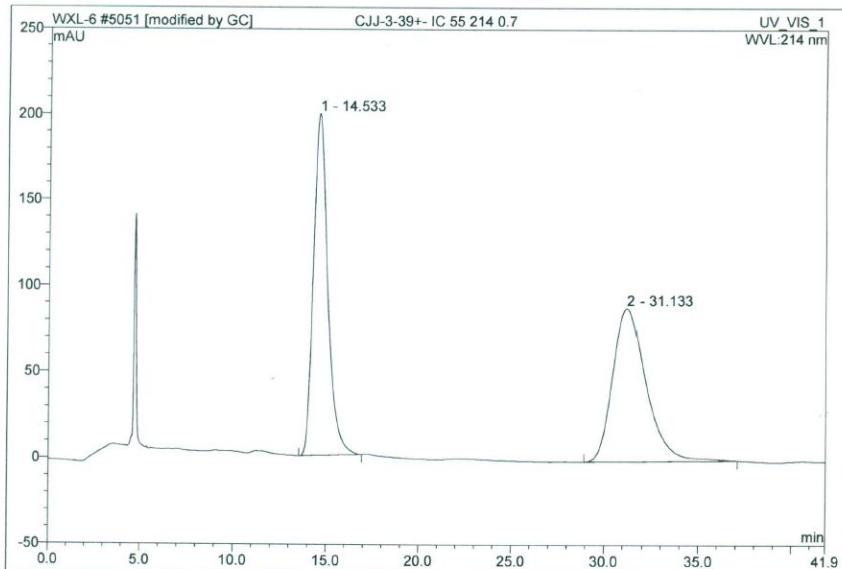
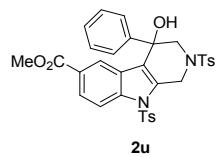


No.	Ret.Time min	Peak Name	Height mAU	Area mAU*min	Rel.Area %	Amount	Type
1	13.37	n.a.	251.154	244.946	49.10	n.a.	BM *
2	16.31	n.a.	336.142	253.875	50.90	n.a.	MB*
Total:			587.296	498.821	100.00	0.000	

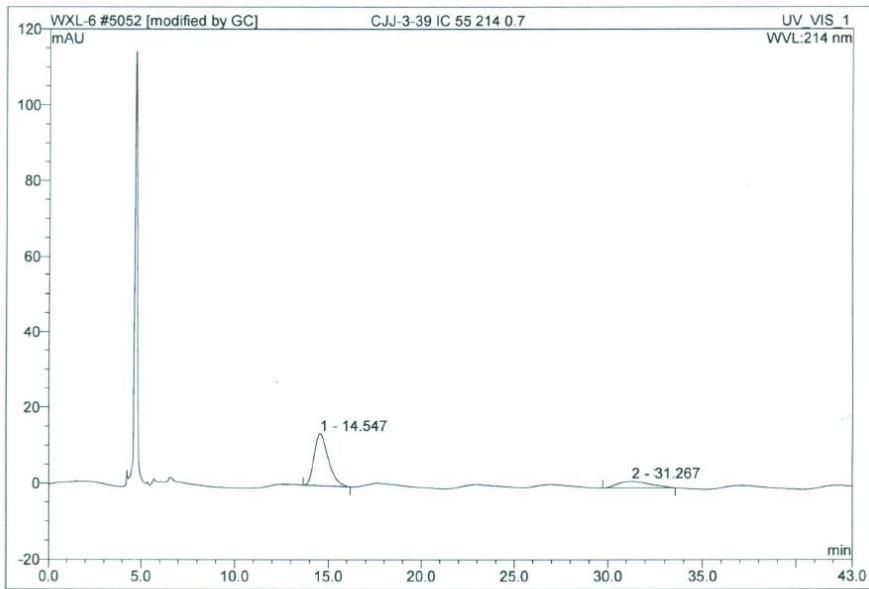




No.	Ret.Time min	Peak Name	Height mAU	Area mAU*min	Rel.Area %	Amount	Type
1	23.41	n.a.	212.285	259.555	91.32	n.a.	BMB
2	32.25	n.a.	15.758	24.661	8.68	n.a.	BMB
Total:			228.043	284.215	100.00	0.000	



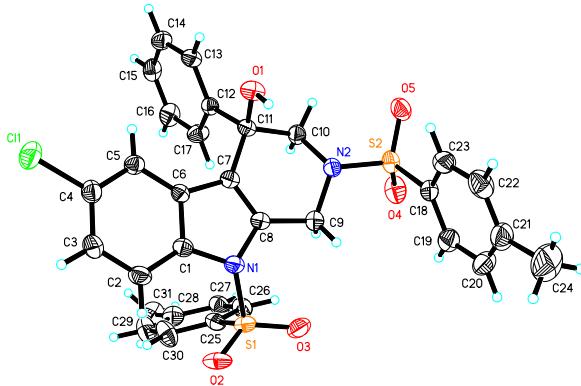
No.	Ret.Time min	Peak Name	Height mAU	Area mAU*min	Rel.Area %	Amount	Type
1	14.53	n.a.	198.961	177.555	49.40	n.a.	BMB*
2	31.13	n.a.	88.779	181.900	50.60	n.a.	BMB
Total:			287.740	359.455	100.00	0.000	



No.	Ret.Time min	Peak Name	Height mAU	Area mAU*min	Rel.Area %	Amount	Type
1	14.55	n.a.	13.676	12.007	77.83	n.a.	BMB
2	31.27	n.a.	1.716	3.421	22.17	n.a.	BMB
Total:			15.391	15.428	100.00	0.000	

9. Crystal structure analyses for product (*R*)-2r (CCDC no.1866405)

The thermal ellipsoid drawn at 50% probability level.



Crystal data and structure refinement for (*R*)-2r.

Identification code	mo_d8v18723_0m
Empirical formula	C ₃₁ H ₂₇ ClN ₂ O ₅ S ₂
Formula weight	607.11
Temperature	296(2) K

Wavelength	0.71073 Å
Crystal system	Orthorhombic
Space group	P 21 21 21
Unit cell dimensions	a = 11.2282(5) Å b = 11.2506(4) Å c = 46.079(2) Å
	α= 90°. β= 90°. γ = 90°.
Volume	5820.9(4) Å ³
Z	8
Density (calculated)	1.386 Mg/m ³
Absorption coefficient	0.318 mm ⁻¹
F(000)	2528
Crystal size	0.190 x 0.150 x 0.130 mm ³
Theta range for data collection	1.326 to 24.999°.
Index ranges	-13<=h<=13, -13<=k<=12, -54<=l<=54
Reflections collected	55208
Independent reflections	10232 [R(int) = 0.0564]
Completeness to theta = 25.242°	97.3 %
Absorption correction	Semi-empirical from equivalents
Max. and min. transmission	0.7456 and 0.6261
Refinement method	Full-matrix least-squares on F ²
Data / restraints / parameters	10232 / 0 / 749
Goodness-of-fit on F ²	1.059
Final R indices [I>2sigma(I)]	R1 = 0.0415, wR2 = 0.1038
R indices (all data)	R1 = 0.0478, wR2 = 0.1100
Absolute structure parameter	0.04(2)
Extinction coefficient	n/a
Largest diff. peak and hole	0.179 and -0.330 e.Å ⁻³