Aryl thiol-vinyl azide coupling reaction and thiol-vinyl azide coupling/cyclization cascade: efficient synthesis of β-ketosulfides and arene-fused 5-methylene-2-pyrrolidinone derivatives

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Supporting Information

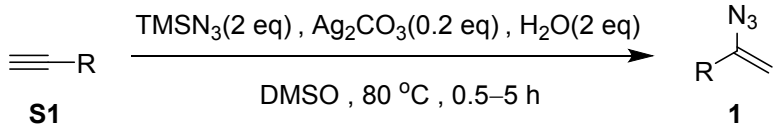
Contents

I. General Information and Materials

NMR spectra were recorded using Bruker AV-300 / AV-400 / AV500 spectrometers. The data are reported as follows: chemical shift in ppm from internal tetramethylsilane on the δ scale, multiplicity (s = singlet, d = doublet, t = triplet, q =quartet, m = multiplet, dd = doublet of doublets, dt = doublet of triplets, td = triplet of doublets), coupling constants (Hz) and integration. High resolution mass spectra were acquired on an agilent 6230 spectrometer and were obtained by peak matching. Analytical thin layer chromatography was performed on 0.25 mm extra hard silica gelplates with UV254 fluorescent indicator and/or by exposure to phosphormolybdic acid/ninhydrine followed by brief heating with a heat gun. Liquid chromatography (flash chromatography) was performed on 60Å (40–60 μm) mesh silica gel (SiO_2). All reagents were commercially obtained and, where appropriate, purified prior to use.

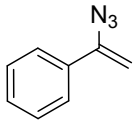
II. Preparation and Characterization of Vinyl Azide Substrates

General procedure



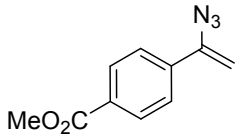
S1 **1**

Vinyl azides **1** were prepared from **S1** following Bi's method[1] with slight modification. To a solution of alkyne **S1** (1 eq), Ag_2CO_3 (0.2 eq) and H_2O (2 eq) in DMSO (0.25 M for **S1**) at 80 °C was added $TMSN_3$ (2 eq). The mixture was stirred under nitrogen atmosphere for 0.5–5 h until **S1** was consumed as indicated by TLC. H_2O was then added. The mixture was extracted with Et_2O three times and the combined organic layers were washed with brine, dried over anhydrous Na_2SO_4 and concentrated in vacuo. Purification by flash column chromatography on silica gel (PE:EA) gave corresponding vinyl azides **1**.



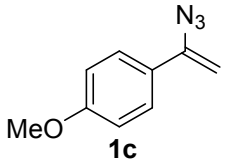
1a

1a: Following the general procedure, the tittle compound was obtained from the reaction of corresponding alkyne in 75% yield as a colorless oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.87–7.81 (m, 2H), 7.30–7.28 (m, 3H), 6.69 (d, *J* = 4.2 Hz, 1H), 6.33 (d, *J* = 4.2 Hz, 1H). The data are consistent with those reported in the literature.[1]



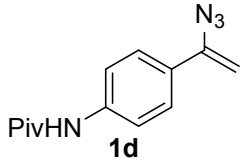
1b

1b: Following the general procedure, the tittle compound was obtained from the reaction of **c**orresponding alkyne in 67 % yield as a yellow solid. ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.02 (d, *J* = 7.7 Hz, 2H), 7.63 (d, *J* = 7.6 Hz, 2H), 5.56 (s, 1H), 5.06 (s, 1H), 3.92 (s, 3H). The data are consistent with those reported in the literature.[1]



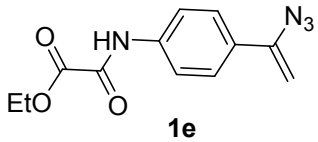
1c

1c: Following the general procedure, the tittle compound was obtained from the reaction of **c**orresponding alkyne in 70% yield as a colorless oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.45–7.43 (m, 2H), 6.83–6.80 (m, 2H), 5.26 (d, *J* = 2.3 Hz, 1H), 4.80 (d, *J* = 2.4 Hz, 1H), 3.76 (s, 3H). The data are consistent with those reported in the literature.[1]



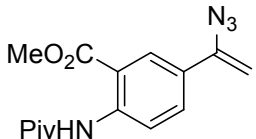
1d

1d: Following the general procedure, the tittle compound was obtained from the reaction of **c**orresponding alkyne in 63% yield as a white solid. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.54–7.47 (m, 4H), 5.37 (s, 1H), 4.89 (s, 1H), 1.30 (s, 9H). ^{13}C NMR (100 MHz, d_6-DMSO) δ 177.07, 143.94, 140.88, 132.51, 128.56, 125.99, 120.33, 120.24, 98.03, 39.72, 27.60.



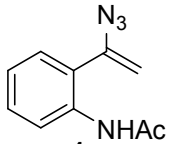
1e

1e: Following the general procedure, the tittle compound was obtained from the reaction of **c**orresponding alkyne in 60% yield as a yellow solid. ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.95 (s, 1H), 7.65–7.56 (m, 4H), 5.42 (d, J = 2.4 Hz, 1H), 4.94 (d, J = 2.4 Hz, 1H), 4.43 (q, J = 7.1 Hz, 2H), 1.44 (t, J = 7.1 Hz, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 160.87, 153.92, 144.21, 137.02, 133.14, 131.35, 126.46, 119.61, 97.69, 63.88, 14.02.



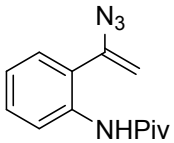
1f

1f: Following the general procedure, the tittle compound was obtained from the reaction of **c**orresponding alkyne in 65% yield as a yellow solid. ^{1}H NMR (400 MHz, $CDCl_3$) δ 11.38 (s, 1H), 8.78 (d, J = 8.9 Hz, 1H), 8.22 (d, J = 2.2 Hz, 1H), 7.74–7.71 (m, 1H), 5.44 (d, J = 2.6 Hz, 1H), 4.94 (d, J = 2.6 Hz, 1H), 3.95 (s, 3H), 1.34 (s, 9H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 178.06, 168.55, 143.74, 142.54, 131.48, 128.11, 127.88, 120.28, 114.74, 97.30, 52.55, 40.48, 27.58. HRMS (ESI) *m/z* Calculated for $C_{15}H_{18}N_4NaO_3^+$ $[M + Na]^+$ 325.1271, found 325.1276.



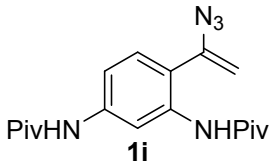
1g

1g: Following the general procedure, the tittle compound was obtained from the reaction of **c**orresponding alkyne in 51% yield as a red solid. ^{1}H NMR (300 MHz, $CDCl_3$) δ 8.12 (d, J = 8.2 Hz, 1H), 7.83 (s, 1H), 7.38–7.26 (m, 2H), 7.13–7.10 (m, 1H), 5.14 (s, 1H), 5.01(s, 1H), 2.17 (s, 3H). ^{13}C NMR (75 MHz, $CDCl_3$) δ 168.39, 143.29, 135.12, 130.08, 129.25, 125.59, 124.34, 122.43, 103.66, 24.69.



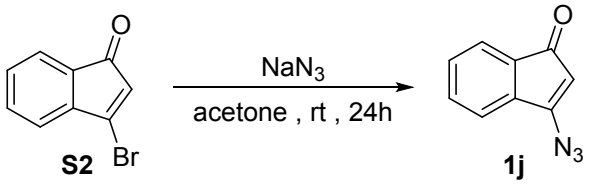
1h

1h: Following the general procedure, the tittle compound was obtained from the reaction of **c**orresponding alkyne in 63% yield as a white solid. ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.27 (d, *J* = 8.3 Hz, 1H), 8.17 (s, 1H), 7.43–7.35 (m, 1H), 7.30–7.26 (m, 1H), 7.11–7.08 (m, 1H), 5.18 (s, 1H), 5.02 (s, 1H), 1.31 (s, 9H). The data are consistent with those reported in the literature.[1]



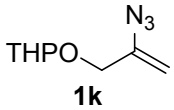
1i

1i: Following the general procedure, the tittle compound was obtained from the reaction of **c**orresponding alkyne in 49% yield as a yellow solid. ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.30 (s, 1H), 8.15 (d, *J* = 2.1 Hz, 1H), 7.89–7.86 (m, 1H), 7.40 (s, 1H), 7.28(d, *J* = 8.5 Hz, 1H), 5.15 (d, *J* = 1.6 Hz, 1H), 5.02 (d, *J* = 1.6 Hz, 1H),1.31 (s, 9H), 1.29 (s, 9H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 176.91, 176.84, 143.13, 139.88, 135.73, 130.01, 120.58, 115.56, 112.34, 103.33, 40.02, 39.72, 27.53, 27.48.



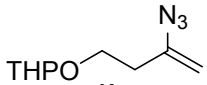
S2 **1j**

1j: This azide was prepared from S2 following Gudmundsdottir's method[2] with slight modification. 3-Bromo-1-indenone S2 (338 mg, 1.62 mmol) was dissolved in 30 mL of acetone in a 100 mL round bottomed flask. Sodium azide (126 mg, 1.94 mmol) was then added to the solution in portions over 10 min. The resulting solution was stirred under nitrogen atmosphere for 24 h for complete conversion, then the acetone was removed. The residue was dissolved in 40 mL of diethyl ether and washed with water. The organic layers were combined and dried over anhydrous sodium sulfate. The organic solvent was removed under reduced pressure. Purification of the crude product with flash column chromatography on silica gel (petroleum ether) gave α-vinyl azide **1j** (260 mg, 94% yield) as a yellow solid. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.45 (d, *J* = 7.0 Hz, 1H), 7.38–7.30 (m, 2H), 7.14 (d, *J* = 6.8 Hz, 1H), 5.60 (s, 1H). The data are consistent with those reported in the literature.[2]



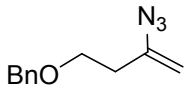
1k

1k: Following the general procedure, the tittle compound was obtained from the reaction of **c**orresponding alkyne in 69% yield as a white solid. ^{1}H NMR (400 MHz, $CDCl_3$) δ 4.83 (s, 1H), 4.76 (s, 1H), 4.65 (s, 1H), 4.15 (d, *J* = 12.9 Hz, 1H), 3.94 (d, *J* = 12.8 Hz, 1H), 3.82 (t, *J* = 10.0 Hz, 1H), 3.51–3.48 (m, 1H), 1.85–1.79 (m, 1H), 1.74–1.35 (m, 5H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 142.93, 100.77, 97.69, 66.55, 61.96, 30.30, 25.34, 19.04. HRMS (ESI) *m/z* Calculated for: $C_8H_{13}N_3NaO_2^+$ [M + Na]$^+$ 206.0900, found 206.0906.



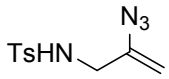
1l

1l: Following the general procedure, the tittle compound was obtained from the reaction of **c**orresponding alkyne in 68% yield as a white solid. ^{1}H NMR (400 MHz, $CDCl_3$) δ 4.72 (s, 1H), 4.68 (d, *J* = 1.2 Hz, 1H), 4.61–4.52 (m, 1H), 3.86–3.80 (m, 2H), 3.54–3.46 (m, 2H), 2.38–2.30 (m, 2H), 1.84–1.74 (m, 1H), 1.75–1.62 (m, 1H), 1.61–1.42 (m, 4H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 143.96, 99.52, 98.76, 64.88, 62.23, 34.14, 30.58, 25.44, 19.45. HRMS (ESI) *m/z* Calculated for $C_9H_{15}N_3NaO_2^+$ [M + Na]$^+$ 220.1026, found 220.1052



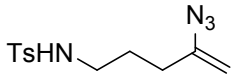
1m

1m: Following the general procedure, the tittle compound was obtained from the reaction of **c**orresponding alkyne in 76% yield as a white solid. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.39–7.29 (m, 5H), 4.80(s, 1H), 4.75 (d, *J* = 1.2 Hz, 1H), 4.55 (s, 2H), 3.61 (t, *J* = 6.6 Hz, 2H), 2.39 (t, *J* = 6.5 Hz, 2H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 160.83, 143.96, 138.20, 128.71, 128.45, 127.72, 99.60, 73.05, 67.49, 34.34.



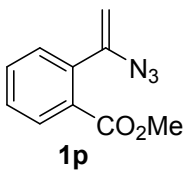
1n

1n: Following the general procedure, the tittle compound was obtained from the reaction of **c**orresponding alkyne in 75% yield as a white solid. ^{1}H NMR (400 MHz, d_6-DMSO) δ 8.31–8.29 (m, 1H), 7.69 (d, *J* = 8.0 Hz, 2H), 7.38 (d, *J* = 8.0 Hz, 2H), 4.85 (s, 1H), 4.68 (s, 1H), 3.43 (s, 2H), 2.37 (s, 3H). ^{13}C NMR (100 MHz, d_6–DMSO) δ 143.20, 142.25, 138.12, 129.99, 127.05, 101.62, 79.65, 44.98, 21.42. HRMS (ESI) *m/z* Calculated for $C_{10}H_{12}N_4NaO_2S^+$ [M + Na]$^+$ 275.0573, found 275.0577.



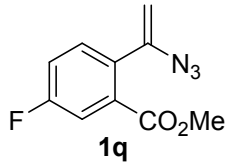
1o

1o: Following the general procedure, the tittle compound was obtained from the reaction of **c**orresponding alkyne in 77% yield as a white solid. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.74 (d, *J* = 8.1 Hz, 2H), 7.29 (d, *J* = 8.1 Hz, 2H), 4.61–4.58 (m, 2H), 2.91 (t, *J* = 6.9 Hz, 2H), 2.41 (s, 3H), 2.03 (t, *J* = 7.3 Hz, 2H), 1.65–1.58 (m, 2H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 145.48, 143.51, 136.80, 129.77, 127.11, 98.80, 42.11, 30.68, 27.11, 21.55. HRMS (ESI) *m/z* Calculated for $C_{11}H_{14}N_4NaO_2S^+$ [M + Na]$^+$ 303.0886, found 303.0886.



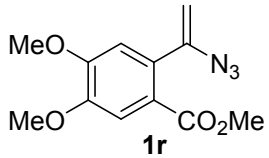
1p

1p: Following the general procedure, the tittle compound was obtained from the reaction of **c**orresponding alkyne in 79% yield as a white solid. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.87–7.84 (m, 1H), 7.54–7.50 (m, 1H), 7.46–7.39 (m, 2H), 5.02 (d, J = 1.4 Hz, 1H), 4.85 (d, J = 1.4 Hz, 1H), 3.91 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 167.49, 145.77, 135.76, 131.97, 130.43, 130.24, 130.00, 129.21, 101.80, 52.46.



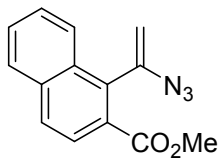
1q

1q: Following the general procedure, the tittle compound was obtained from the reaction of **c**orresponding alkyne in 79 % yield as a white solid. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.90–7.86 (m, 1H), 7.13–7.07 (m, 2H), 5.02 (d, J = 1.6 Hz, 1H), 4.85 (d, J = 1.6 Hz, 1H), 3.88 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 166.33, 164.25(d, J = 253.0 Hz), 144.85, 138.67 (d, J = 8.7 Hz), 132.70 (d, J = 9.3 Hz), 126.30 (d, J = 3.3 Hz), 117.72, (d, J = 22.7 Hz), 116.10(d, J = 21.2 Hz), 102.22, 52.46.



1r

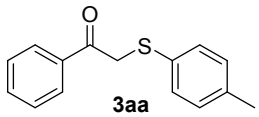
1r: Following the general procedure, the tittle compound was obtained from the reaction of **c**orresponding alkyne in 83% yield as a yellow solid. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.29 (s, 1H), 6.69 (s, 1H), 4.83 (s, 1H), 4.56 (s, 1H), 3.78 (s, 6H), 3.74 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 166.42, 151.62, 148.89, 145.84, 129.88, 121.86, 113.26, 112.54, 101.50, 56.07, 56.03, 52.15.



1s

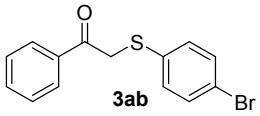
1s: Following the general procedure, the tittle compound was obtained from the reaction of **c**orresponding alkyne in 83% yield as a yellow solid. ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.21–8.18 (m, 1H), 7.96–7.88 (m, 3H), 7.63–7.61 (m, 2H), 5.28 (s, 1H), 4.62 (s, 1H), 3.97 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 167.54, 142.26, 134.90, 134.10, 131.39, 129.59, 128.42, 128.20, 127.73, 126.61, 125.12, 104.03, 52.52. HRMS (ESI) *m/z* Calculated for $C_{14}H_{11}N_3NaO_2^+$ [M + Na]$^+$ 276.0743, found 276.0746.

III. Characterization of β–Ketosulfides 3aa–ah



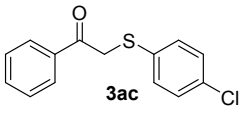
3aa

3aa: Obtained from the reaction of α-vinyl azide **1a** with 4-methylbenzenethiol **2a** in 84% yield as a yellow solid. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.95–7.93 (m, 2H), 7.60–7.56 (m, 1H), 7.48–7.44 (m, 2H), 7.30 (d, *J* = 8.0 Hz, 2H), 7.10 (d, *J* = 8.0 Hz, 2H), 4.22 (s, 2H), 2.32 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 194.27, 137.62, 135.50, 133.48, 131.60, 130.93, 129.97, 128.80, 128.74, 41.92, 21.19. The data are consistent with those reported in the literature.[4]



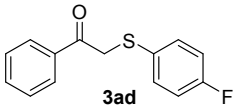
3ab

3ab: Obtained from the reaction of α-vinyl azide **1a** with 4-bromobenzenethiol **2b** in 86% yield as a yellow solid. ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.87–7.84 (m, 2H), 7.54–7.48 (m, 1H), 7.41–7.36 (m, 2H), 7.33–7.29 (m, 2H), 7.18–7.14 (m, 2H), 4.17 (s, 2H). ^{13}C NMR (75 MHz, $CDCl_3$) δ 193.78, 135.29, 134.01, 133.74, 132.22, 132.09, 128.86, 128.77, 121.28, 41.12. The data are consistent with those reported in the literature.[4]



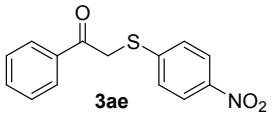
3ac

3ac: Obtained from the reaction of α-vinyl azide **1a** with 4-chlorobenzenethiol **2c** in 80% yield as a yellow solid. ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.87–7.84 (m, 2H), 7.54–7.47 (m, 1H), 7.43–7.36 (m, 2H), 7.26–7.14 (m, 4H), 4.16 (s, 2H). ^{13}C NMR (75 MHz, $CDCl_3$) δ 193.84, 135.31, 133.73, 133.38, 133.28, 132.04, 129.31, 128.85, 128.77, 41.31. The data are consistent with those reported in the literature.[4]



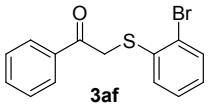
3ad

3ad: Obtained from the reaction of α-vinyl azide **1a** with 4-fluorobenzenethiol **2d** in 85% yield as a yellow solid. ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.94–7.91 (m, 2H), 7.64–7.56 (m, 1H), 7.49–7.44 (m, 2H), 7.42–7.36 (m, 2H), 7.01–6.95 (m, 2H), 4.20 (s, 2H). ^{13}C NMR (75 MHz, $CDCl_3$) δ 194.10, 162.60 (d, *J* = 246.8 Hz), 135.43, 134.09 (d, *J* = 8.2 Hz), 133.66, 129.50, 128.83(d, *J* = 2.4 Hz), 116.37 (d, *J* = 22.5 Hz), 42.22. The data are consistent with those reported in the literature.[4]



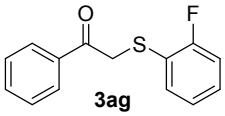
3ae

3ae: Obtained from the reaction of α-vinyl azide **1a** with 4-nitrobenzenethiol **2e** in 57% yield as a yellow solid. ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.14–8.12 (m, 2H), 8.00–7.98 (m, 2H), 7.70–7.61 (m, 1H), 7.55–7.50 (m, 2H), 7.44–7.41 (m, 2H), 4.45 (s, 2H). The data are consistent with those reported in the literature.[5]



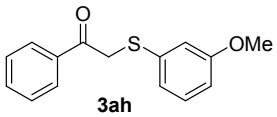
3af

3af: Obtained from the reaction of α-vinyl azide **1a** with 2-bromobenzenethiol **2f** in 58% yield as a yellow solid. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.91–7.89 (m, 2H), 7.55–7.45 (m, 2H), 7.42–7.39 (m, 2H), 7.33–7.30 (m, 1H), 7.20–7.16 (m, 1H), 7.02–6.98 (m, 1H), 4.26 (s, 2H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 193.74, 136.16, 135.40, 133.76, 133.23, 130.39, 128.85, 128.78, 128.07, 127.98, 124.82, 40.20. The data are consistent with those reported in the literature.[4]



3ag

3ag: Obtained from the reaction of α-vinyl azide **1a** with 2-fluorobenzenethiol **2g** in 60% yield as a yellow solid. ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.86–7.83 (m, 2H), 7.52–7.46 (m, 1H), 7.40–7.34 (m, 2H), 7.32–7.29 (m, 1H), 7.21–7.13 (m, 1H), 7.01–6.94 (m, 2H), 4.19 (s, 2H). ^{13}C NMR (75 MHz, $CDCl_3$) δ 193.93, 162.07 (d, J = 244.8 Hz), 135.43, 133.90 (d, J = 1.3 Hz), 133.61, 129.88 (d, J = 7.9 Hz), 128.74 (d, J = 6.7 Hz), 124.70 (d, J = 3.7 Hz), 121.29 (d, J = 17.5 Hz), 116.10, 115.80, 40.45 (d, J = 2.6 Hz). The data are consistent with those reported in the literature.[6]



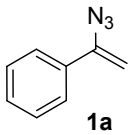
3ah

3ah: Obtained from the reaction of α-vinyl azide **1a** with 3-methoxybenzenethiol **2h** in 85% yield as a yellow solid. ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.95–7.92 (m, 2H), 7.59–7.53 (m, 1H), 7.47–7.41 (m, 2H), 7.21–7.15 (m, 1H), 6.97–6.93 (m, 2H), 6.76–6.73 (m, 1H), 4.28 (s, 2H), 3.74 (s, 3H). ^{13}C NMR (75 MHz, $CDCl_3$) δ 194.06, 159.82, 136.18, 135.35, 133.51, 129.88, 128.68, 128.65, 122.11, 115.29, 112.79, 55.23, 40.96. The data are consistent with those reported in the literature.[4]

IV. References

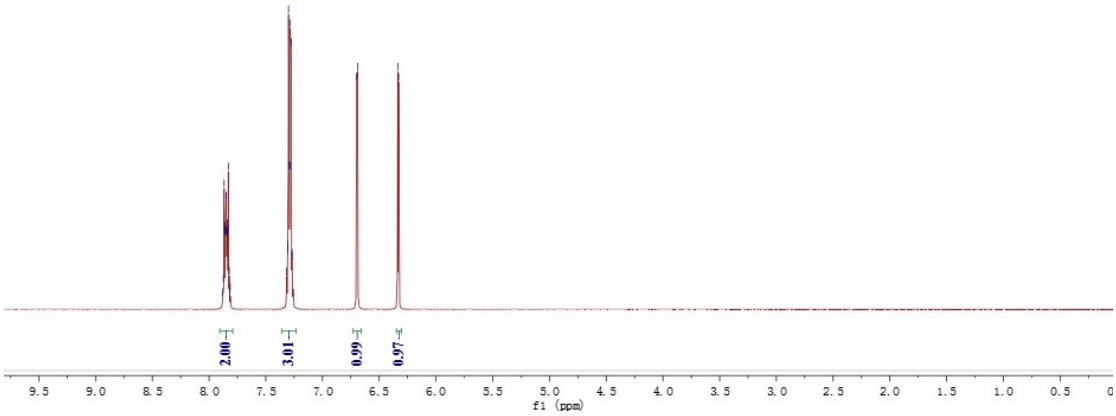
1. Z. Liu, P. Liao, X. Bi, *Org. Lett.* **2014**, *16*, 3368.
2. S. K. Sarkar, O. Osisioma, L. Karney, M. Abe, A. D. Gudmundsdottir, *J. Am. Chem. Soc.* **2016**, *138*, 14905.
3. P. C. Montevecchi, M. L. Navacchia, P. Spagnolo, *J. Org. Chem.*, **1997**, *62*, 5846.
4. H. Wang, G. Wang, A. Lei, *Chem. Eur. J.*, **2016**, *22*, 14489.
5. M. P. Dias and A. C. B. Burtoloso, *Org Lett.*, **2016**, *18*, 3034.
6. M. A. M. Capozzi, V. Frascaro, G. Pescitelli, C. Cardellicchio, *Tetrahedron*, **2019**, *75*, 2406.

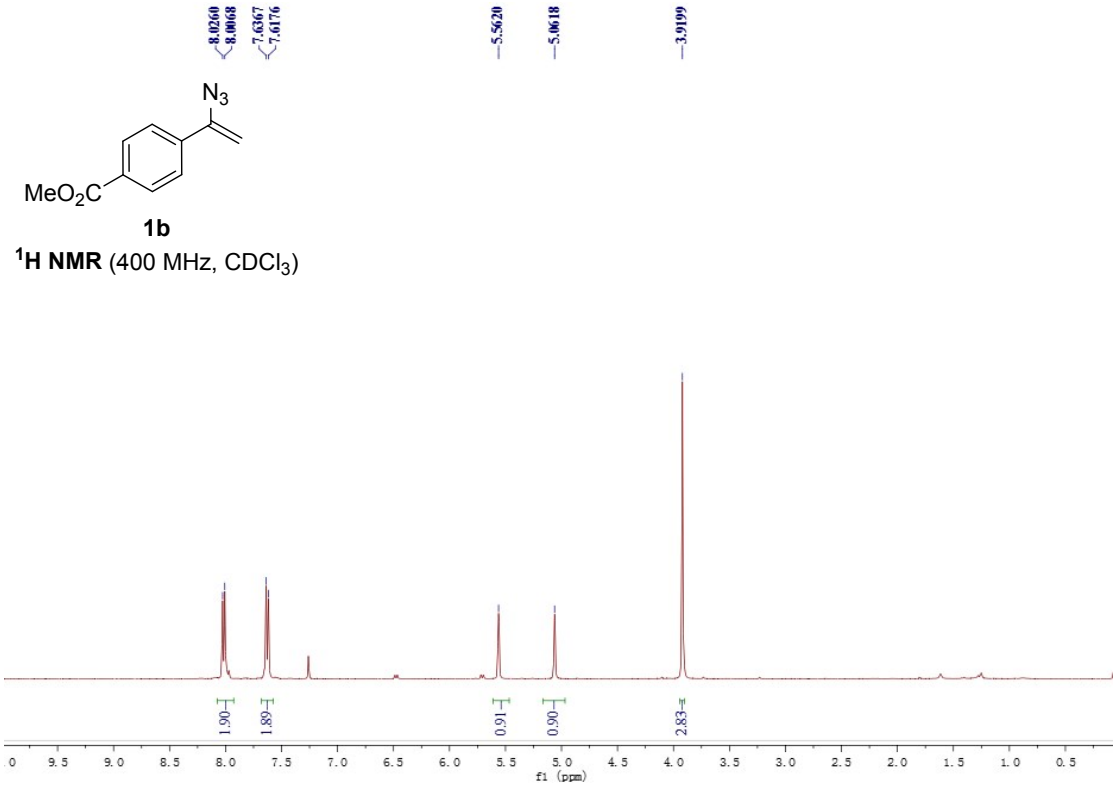
V. NMR Spectra of Compounds



1a

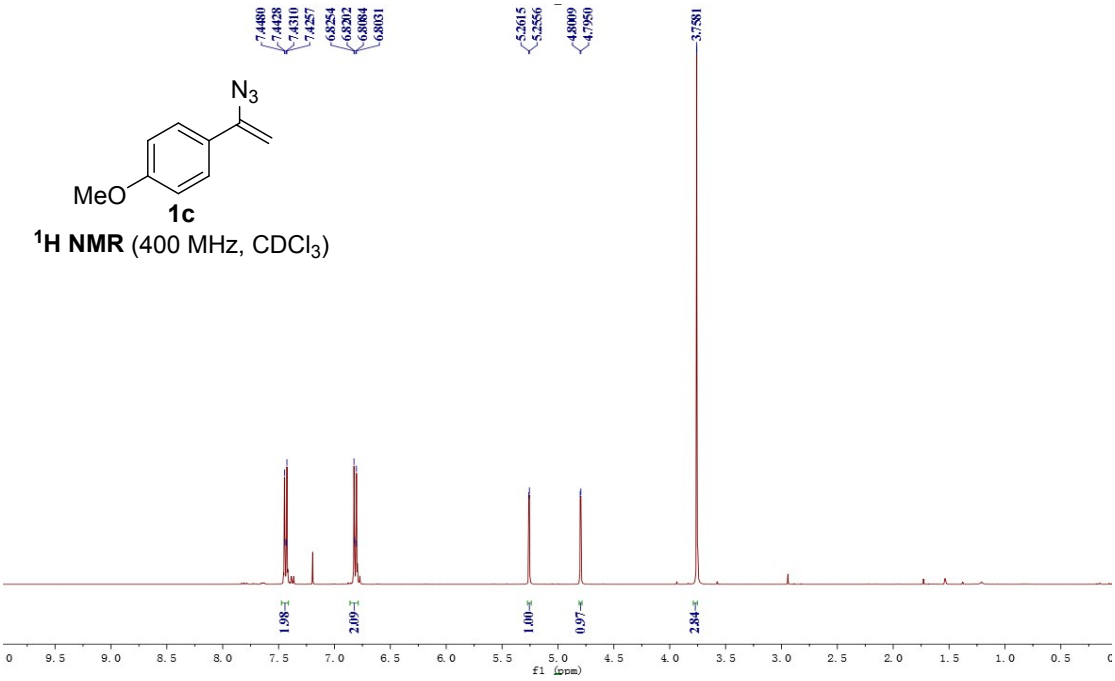
^{1}H NMR (400 MHz, $CDCl_3$)





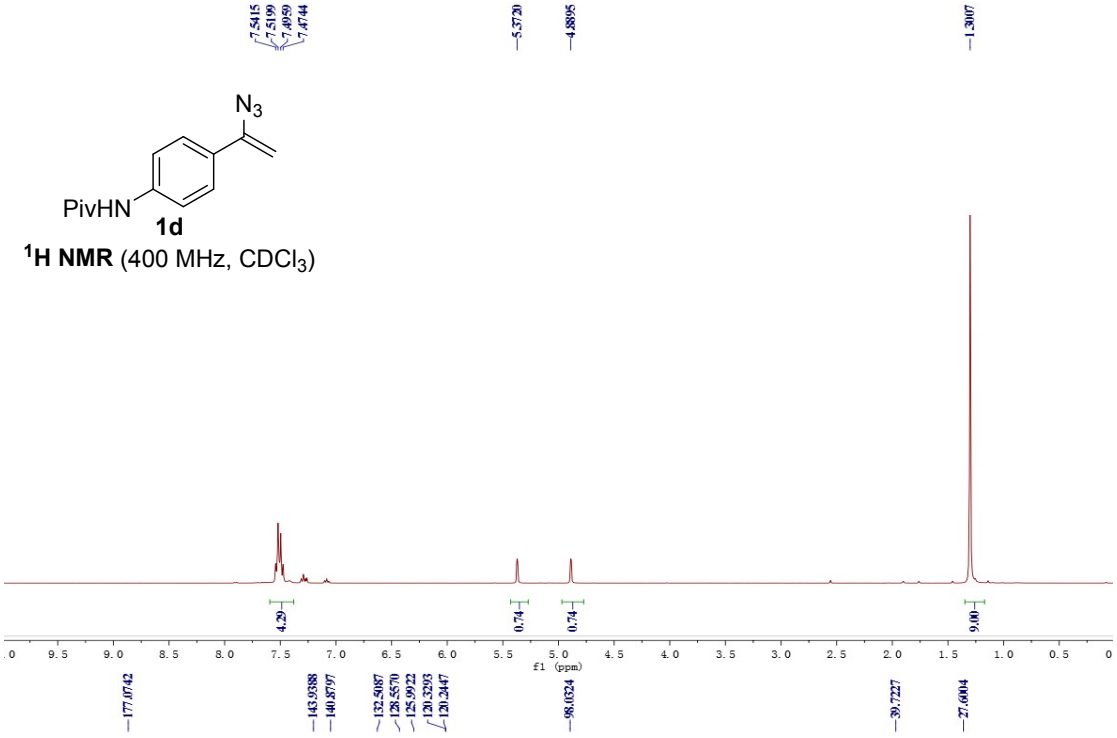
1b

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



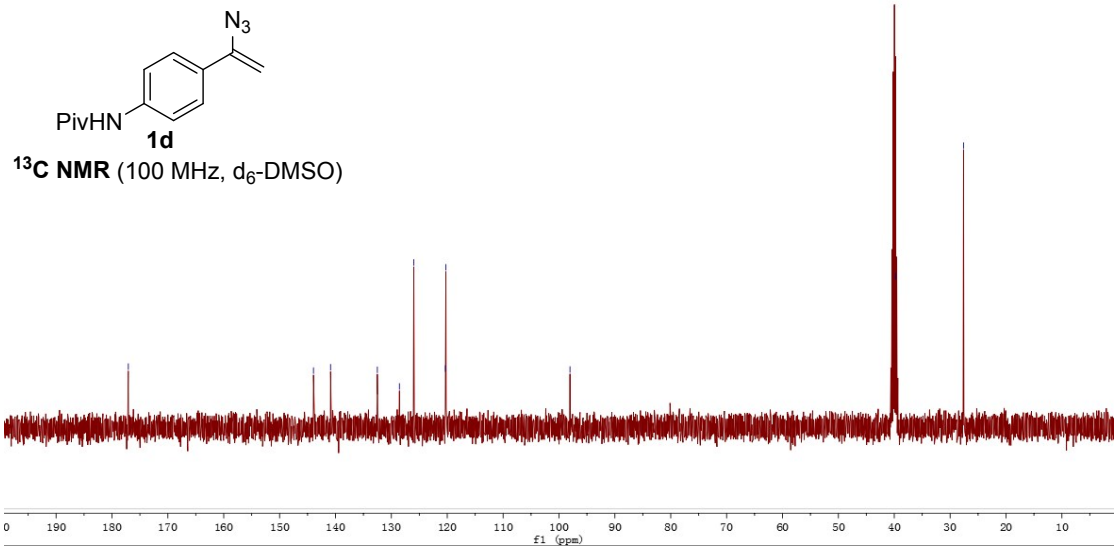
1c

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



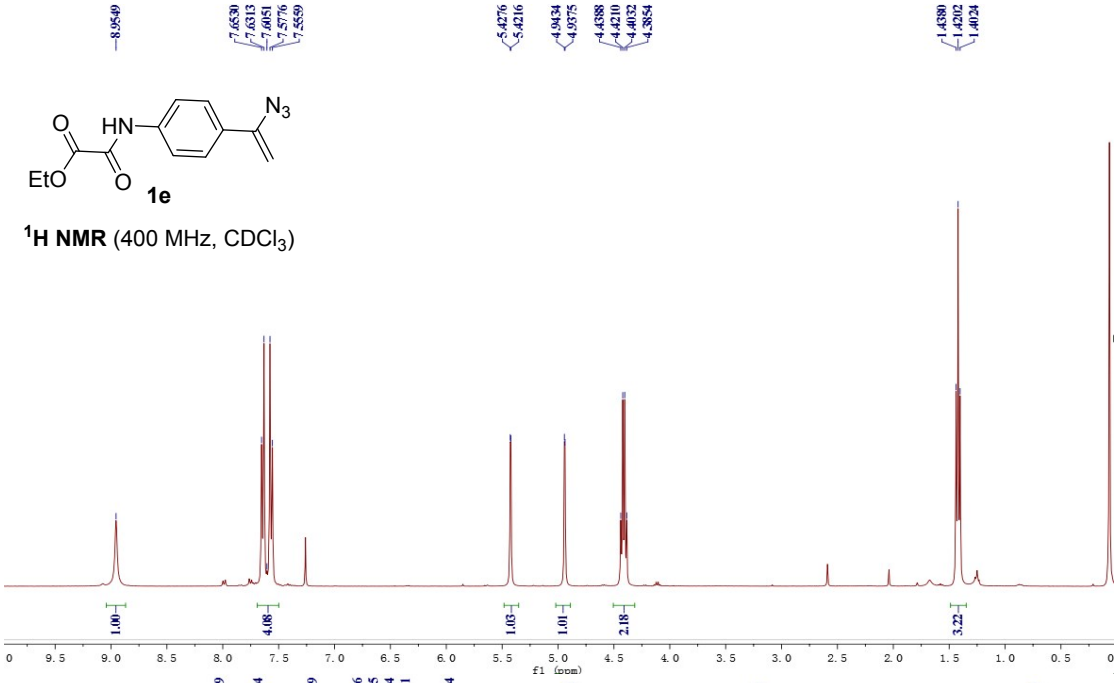
1d

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



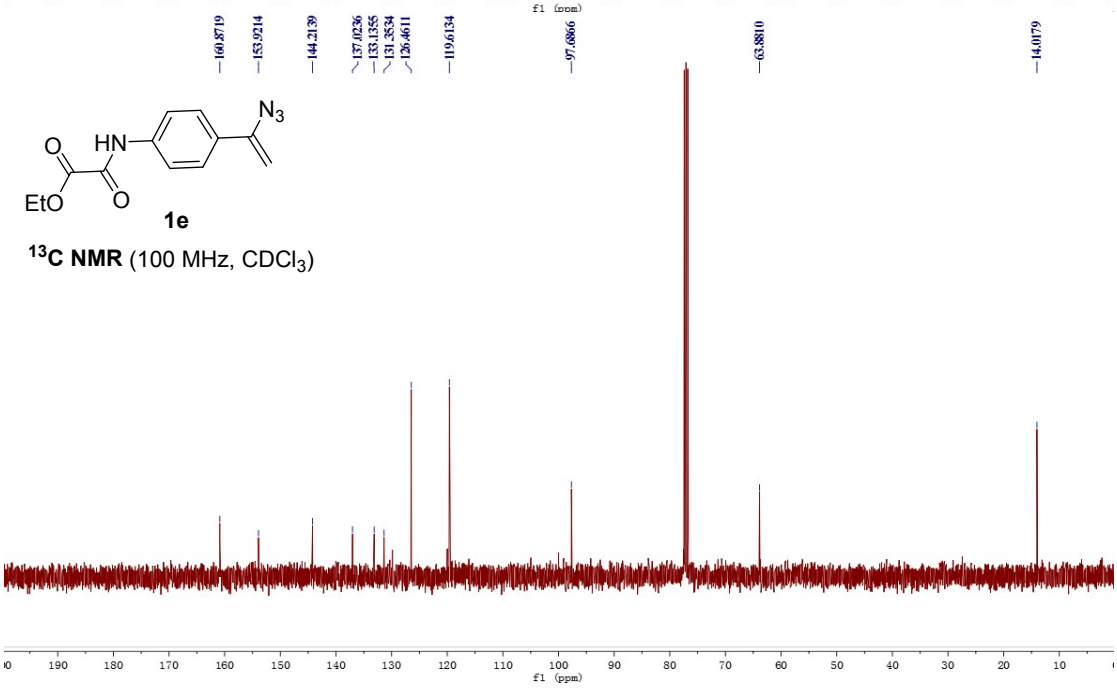
1d

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



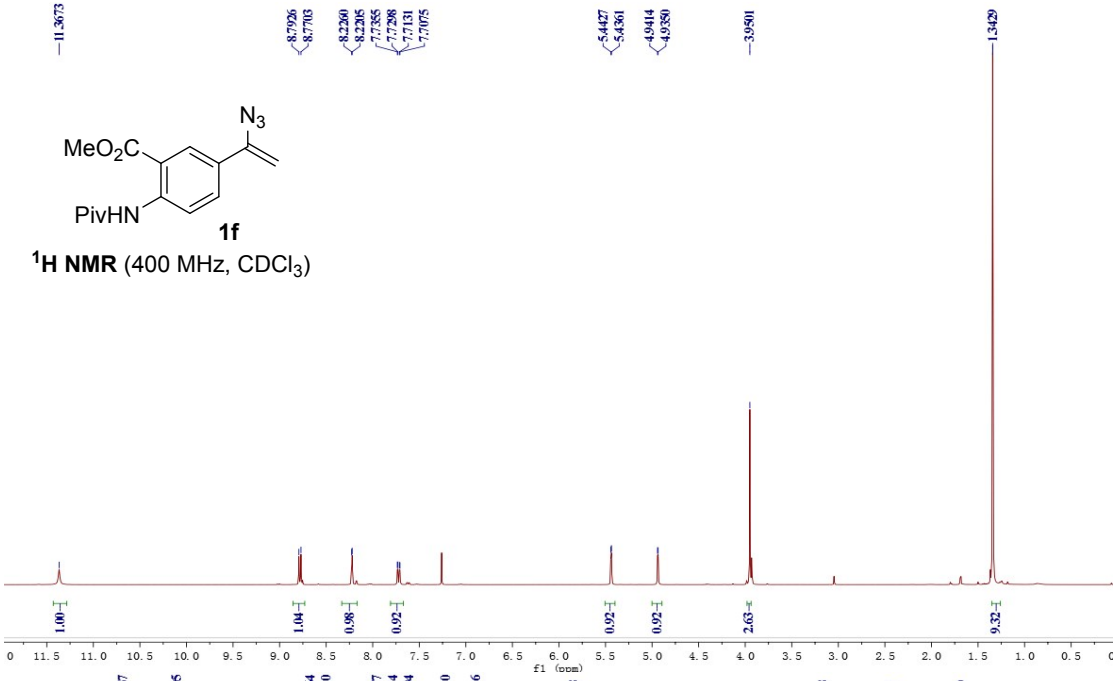
1e

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

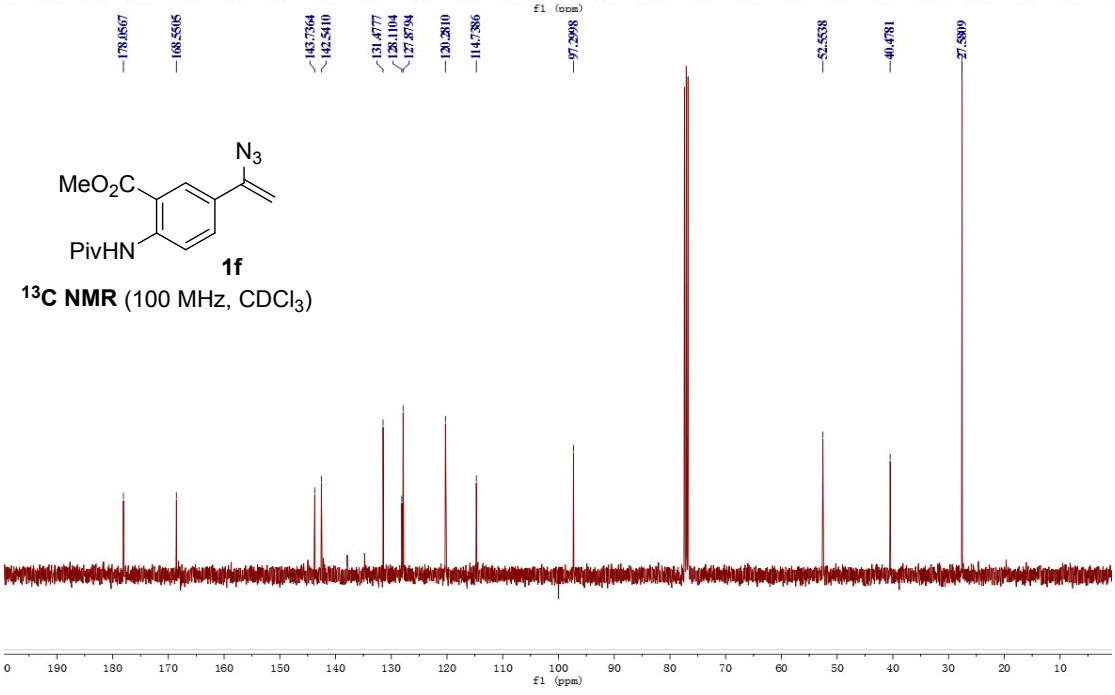


1e

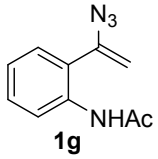
^{13}C NMR (100 MHz, $CDCl_3$)



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

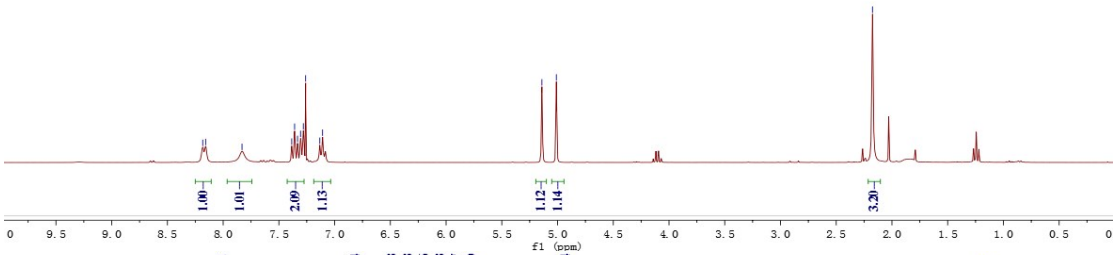


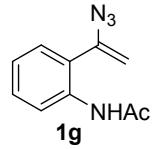
^{13}C NMR (100 MHz, $CDCl_3$)



1g

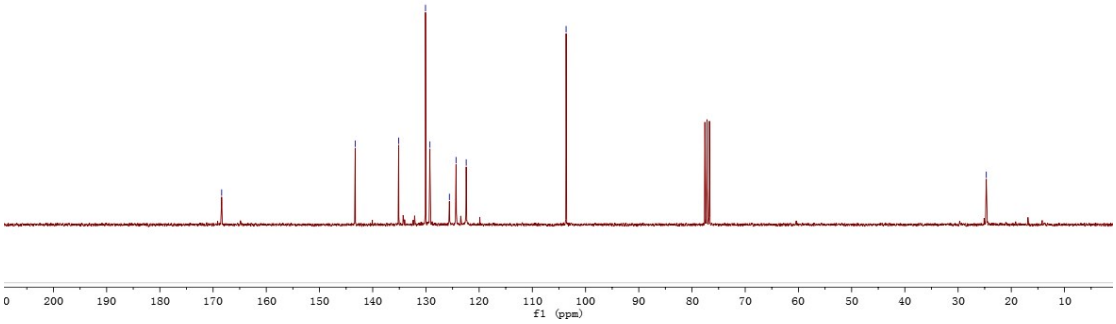
^{1}H NMR (300 MHz, $CDCl_3$)

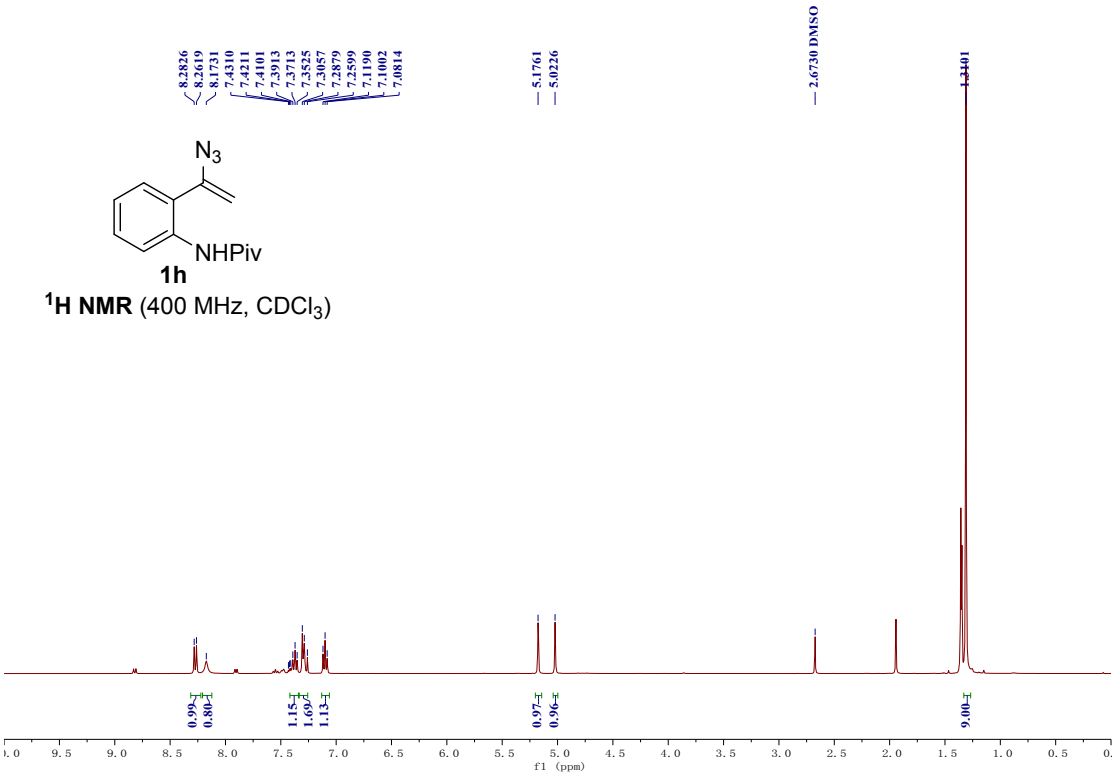




1g

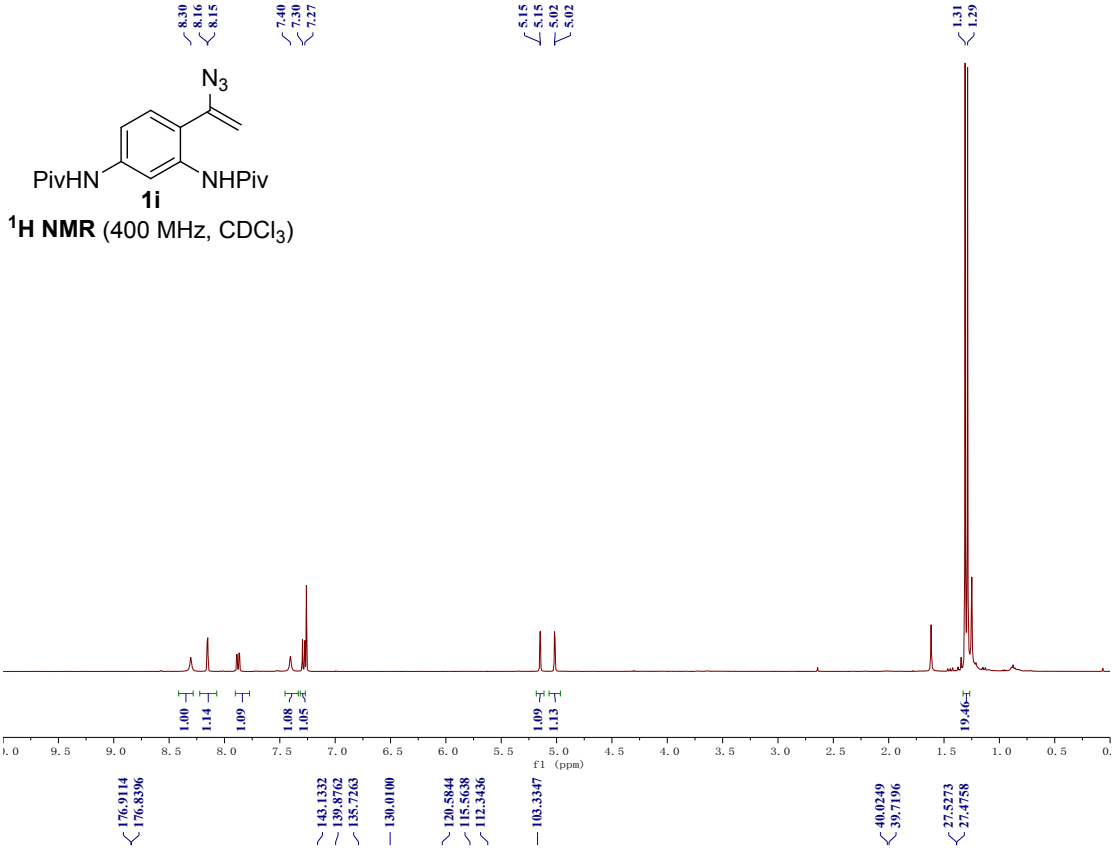
^{13}C NMR (75 MHz, $CDCl_3$)





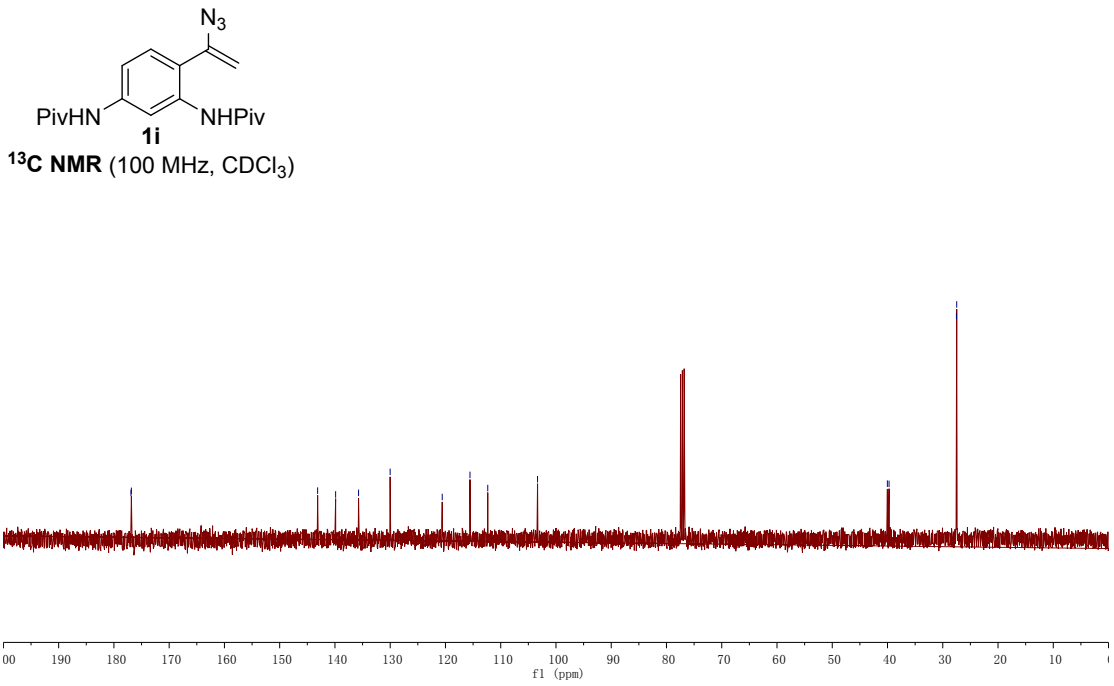
1h

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



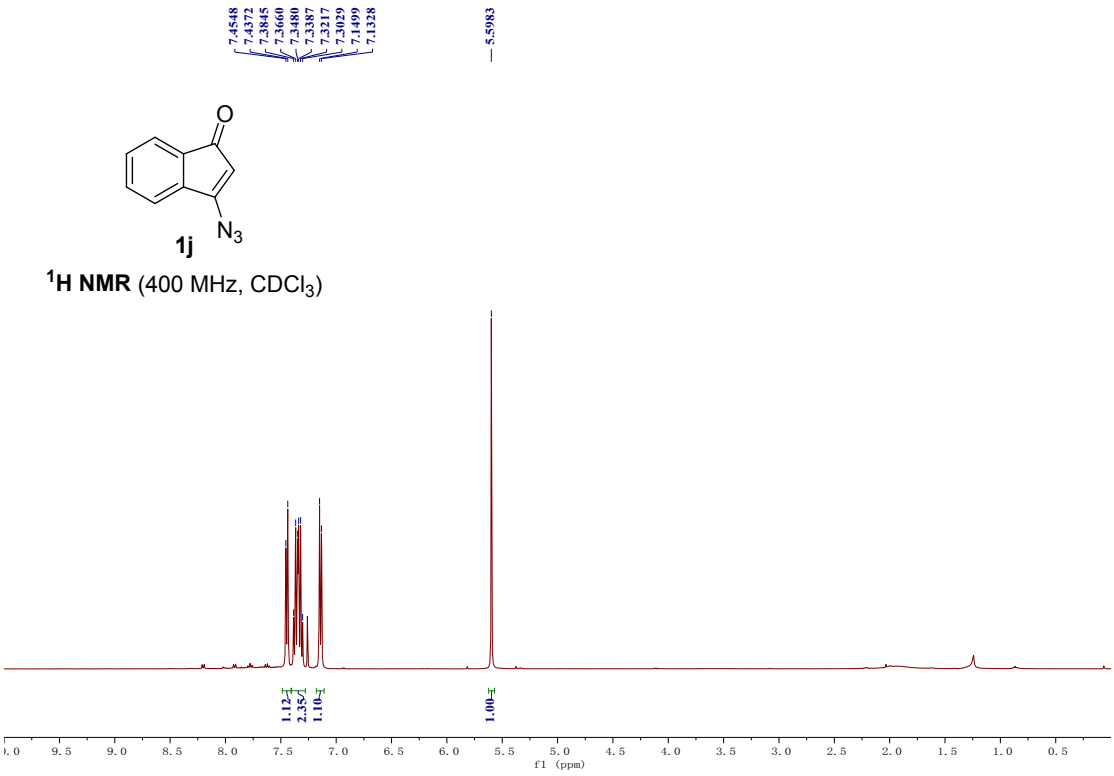
1i

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



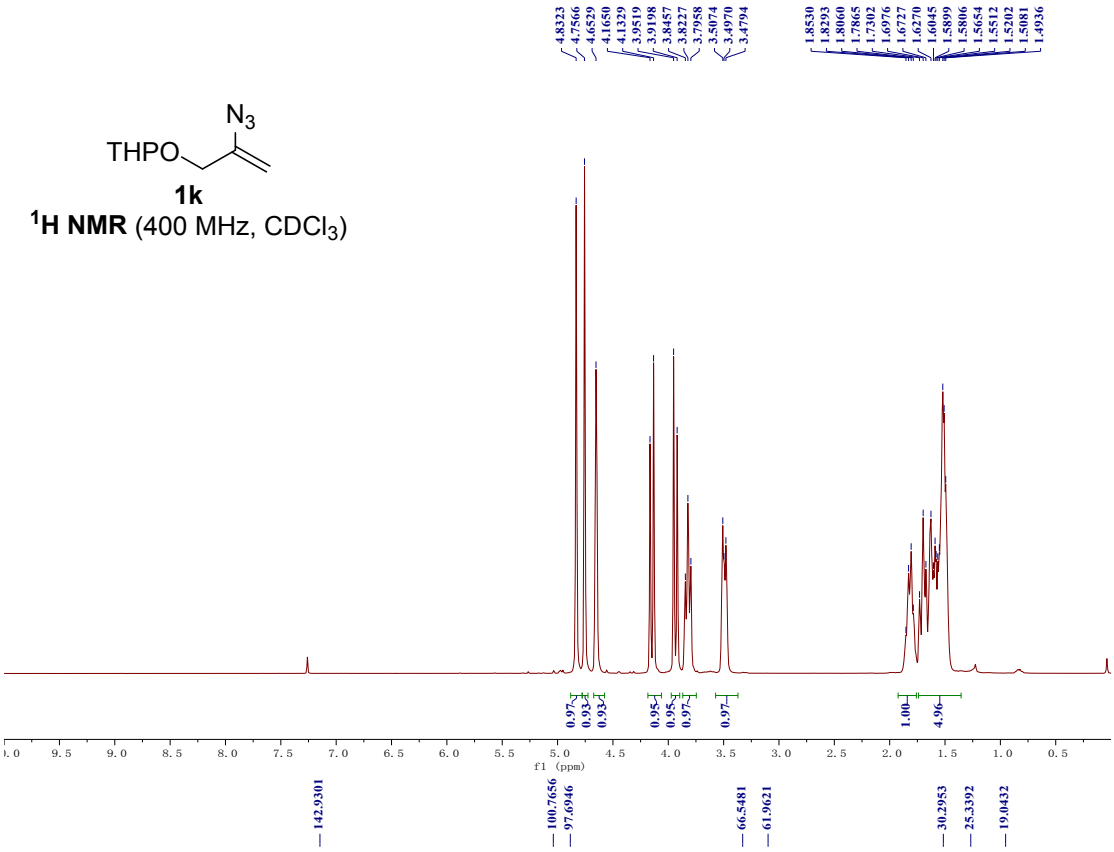
1i

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



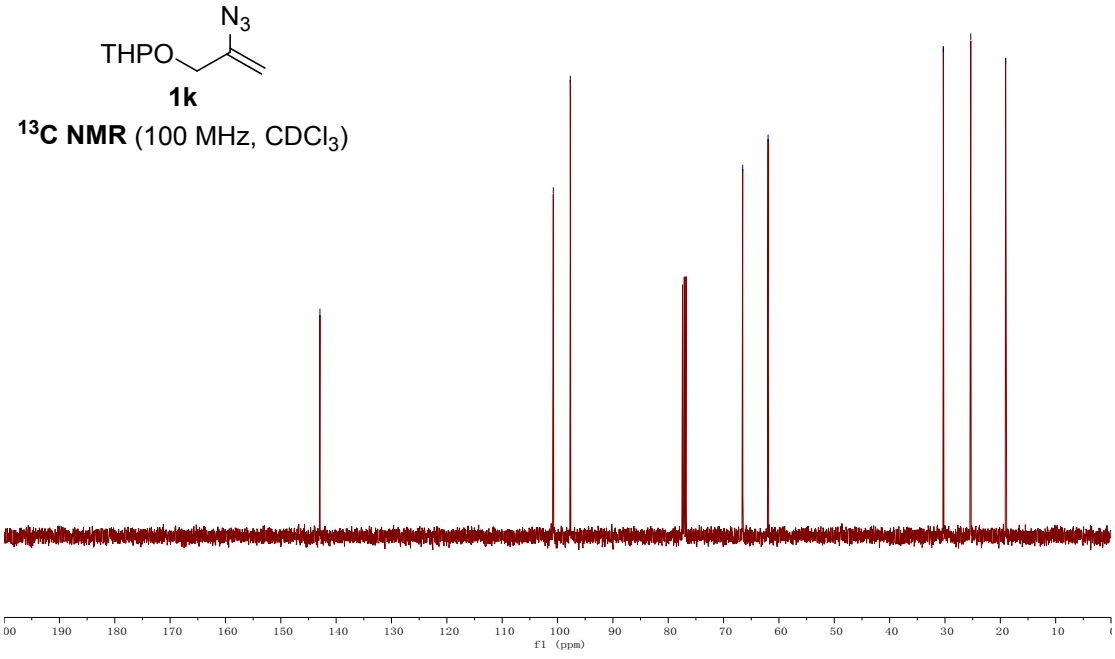
1j

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



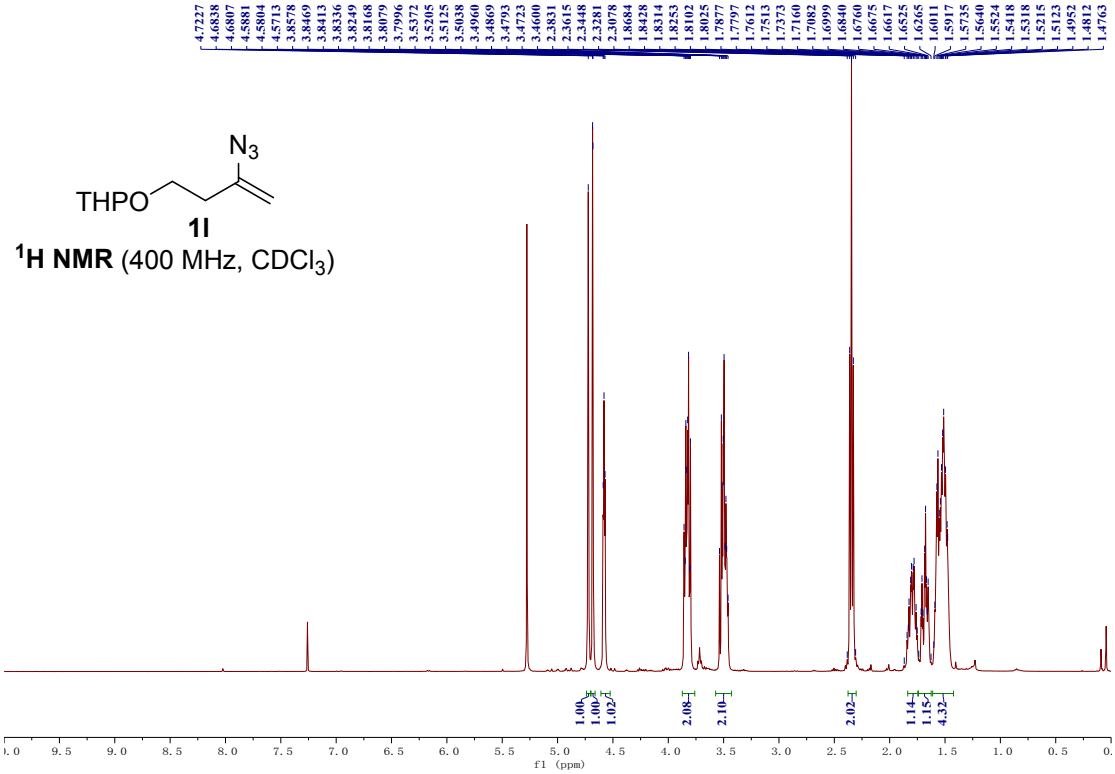
N_3
THPO
1k

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



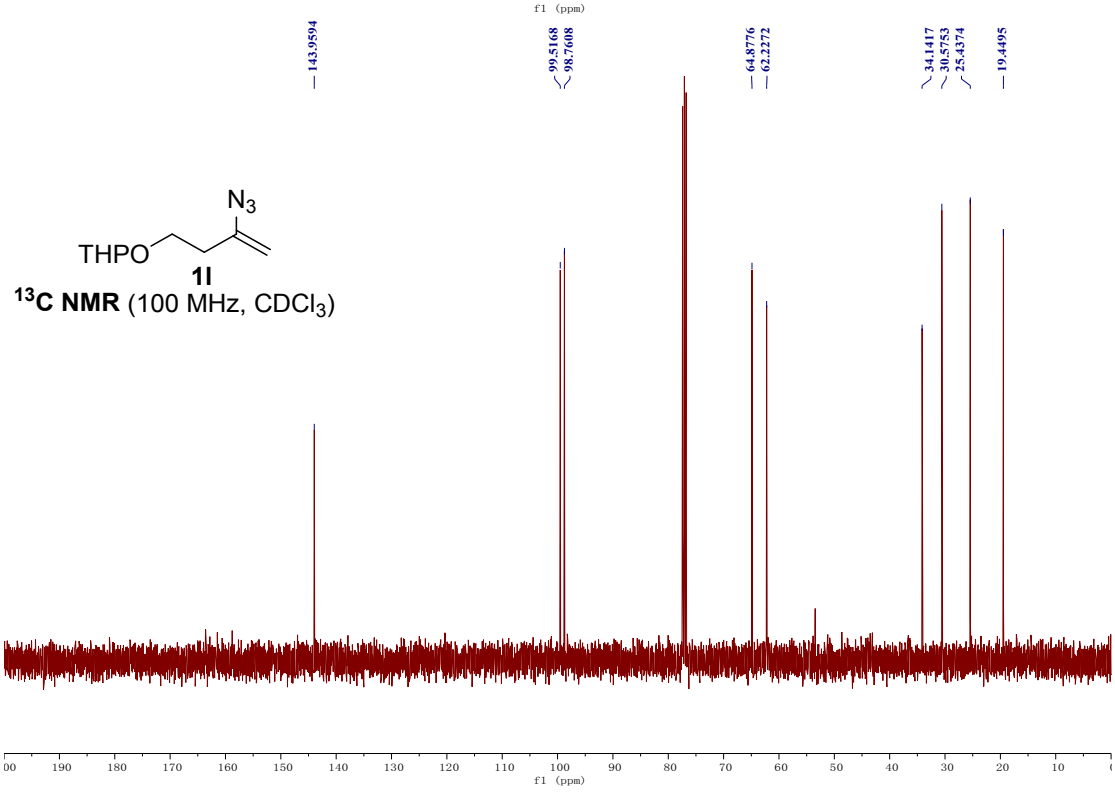
N_3
THPO
1k

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



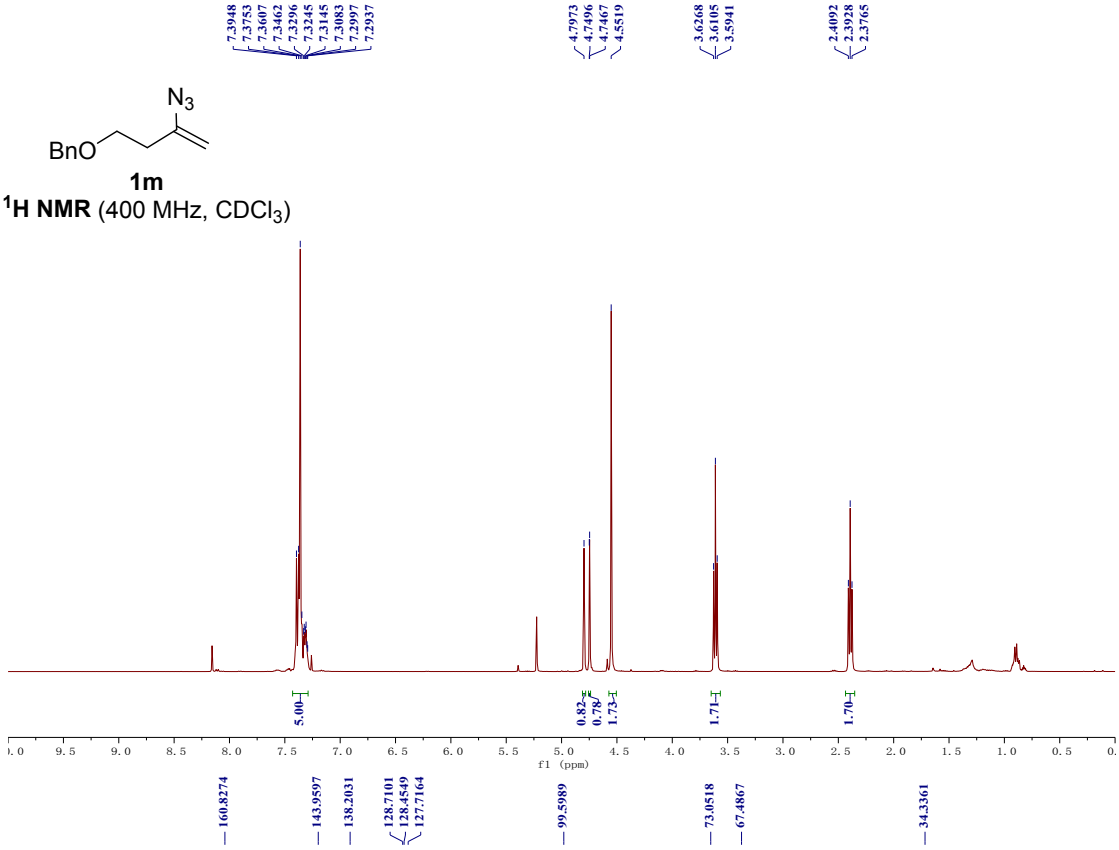
1I

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



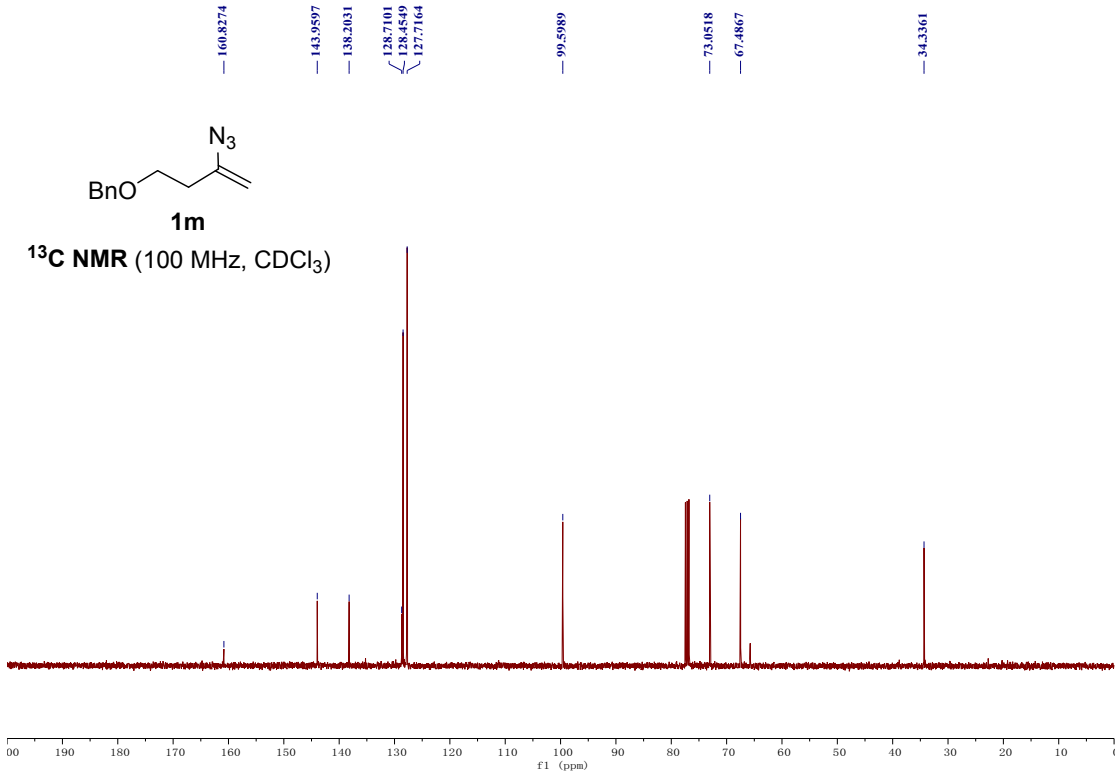
1I

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



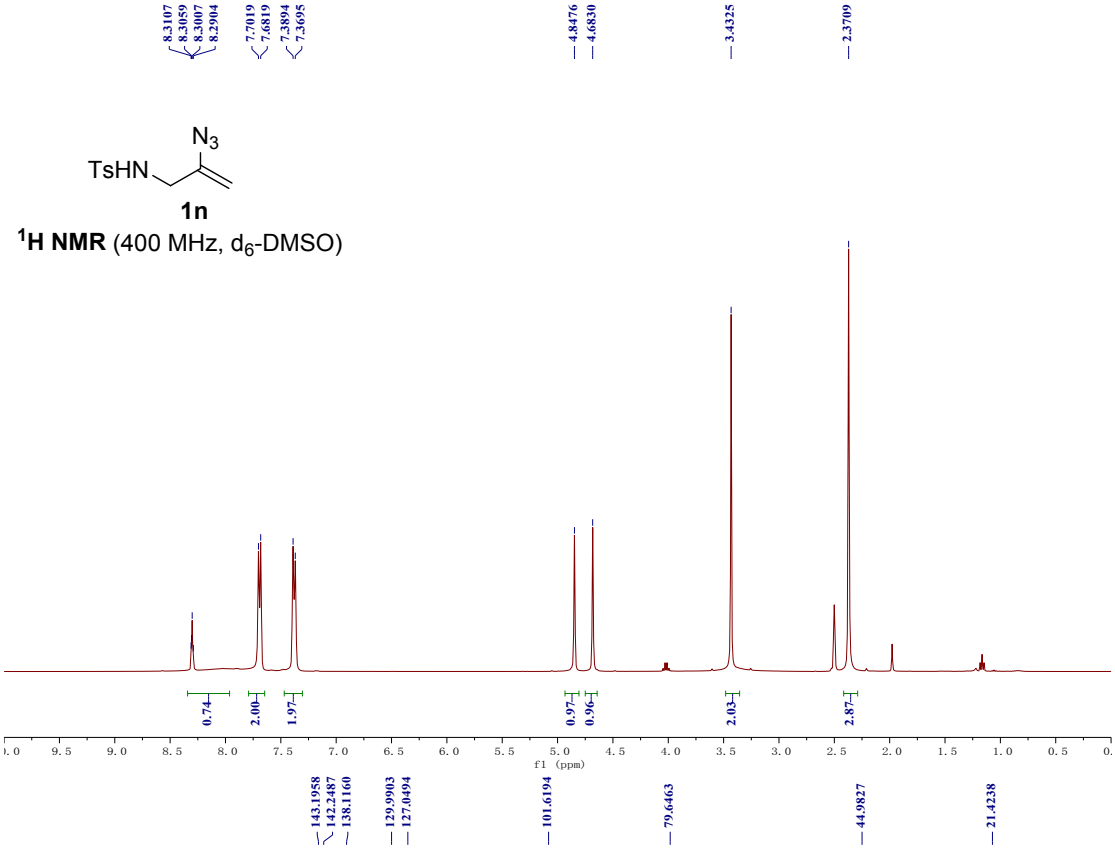
1m

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



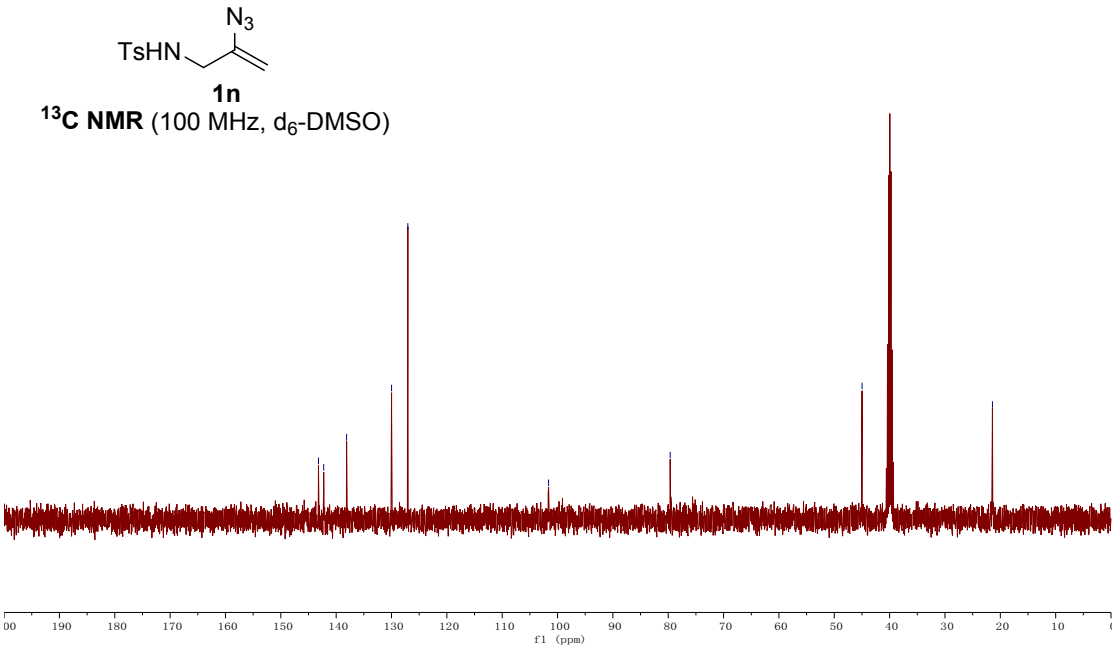
1m

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



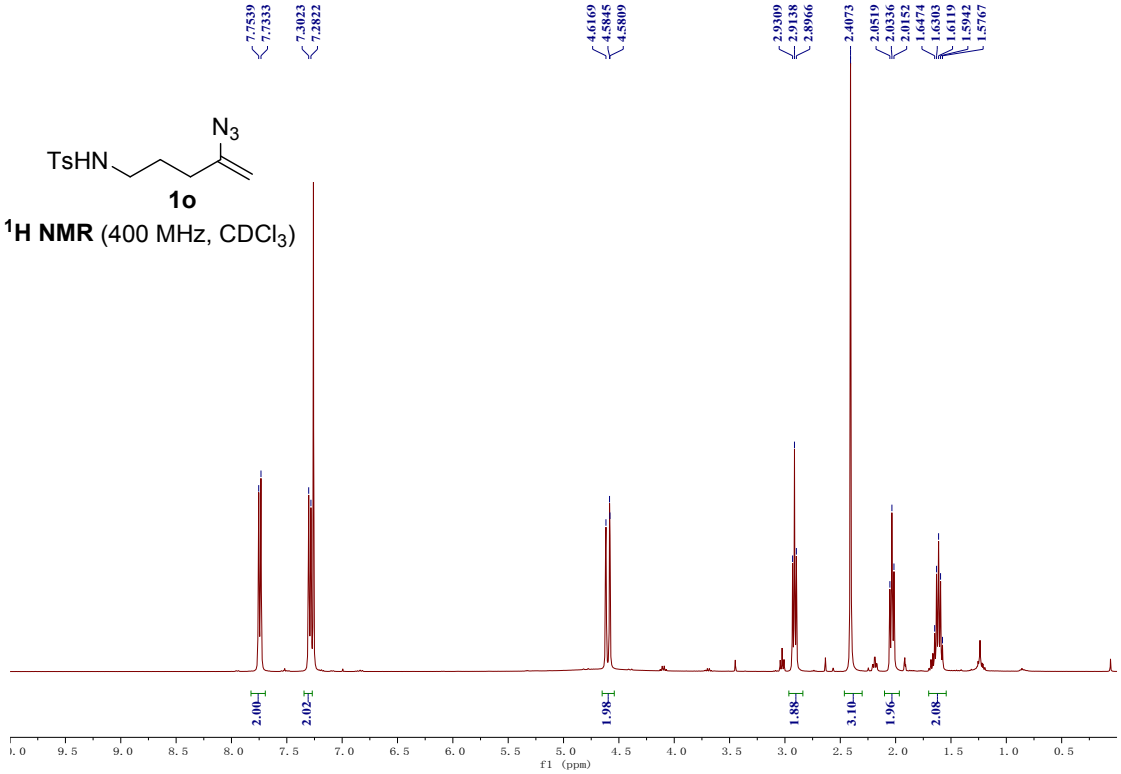
1n

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



1n

^{13}C NMR (100 MHz, d_6-DMSO)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2.0519
2.0336
2.0152
1.6474
1.6303
1.6119
1.5942
1.5767
N3
TsHN
1o
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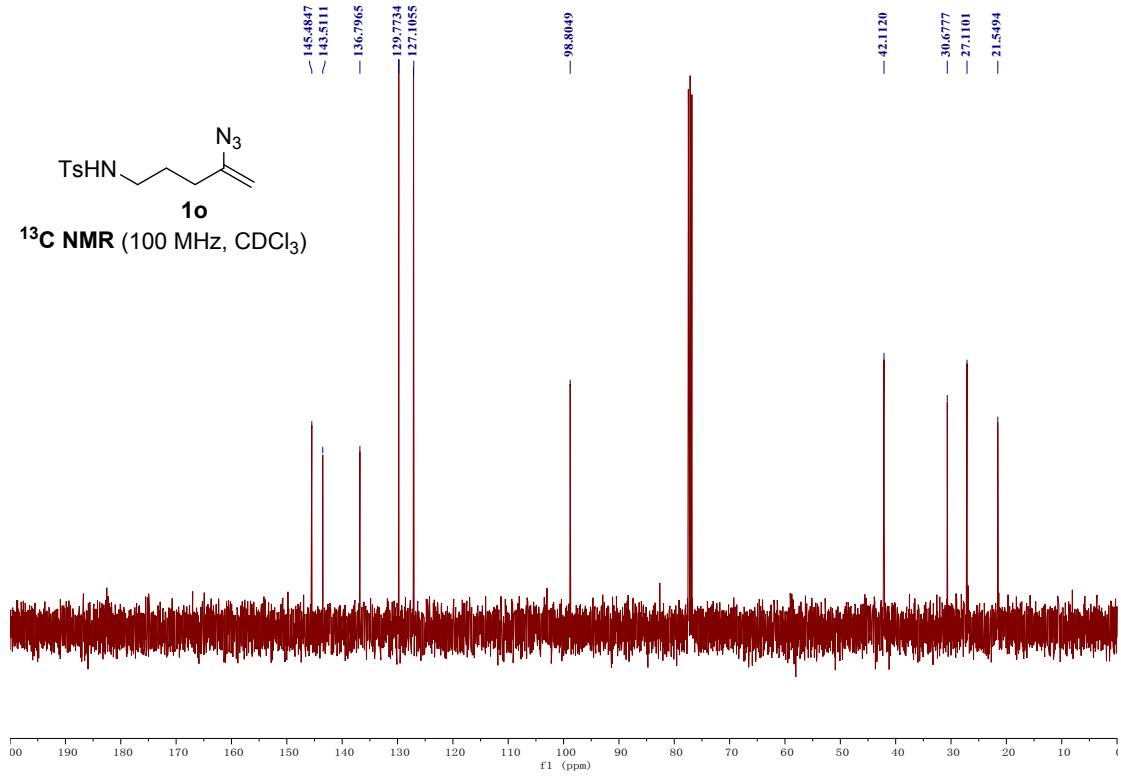
2.00
2.02
1.98
1.88
3.10
1.96
2.08
f1 (ppm)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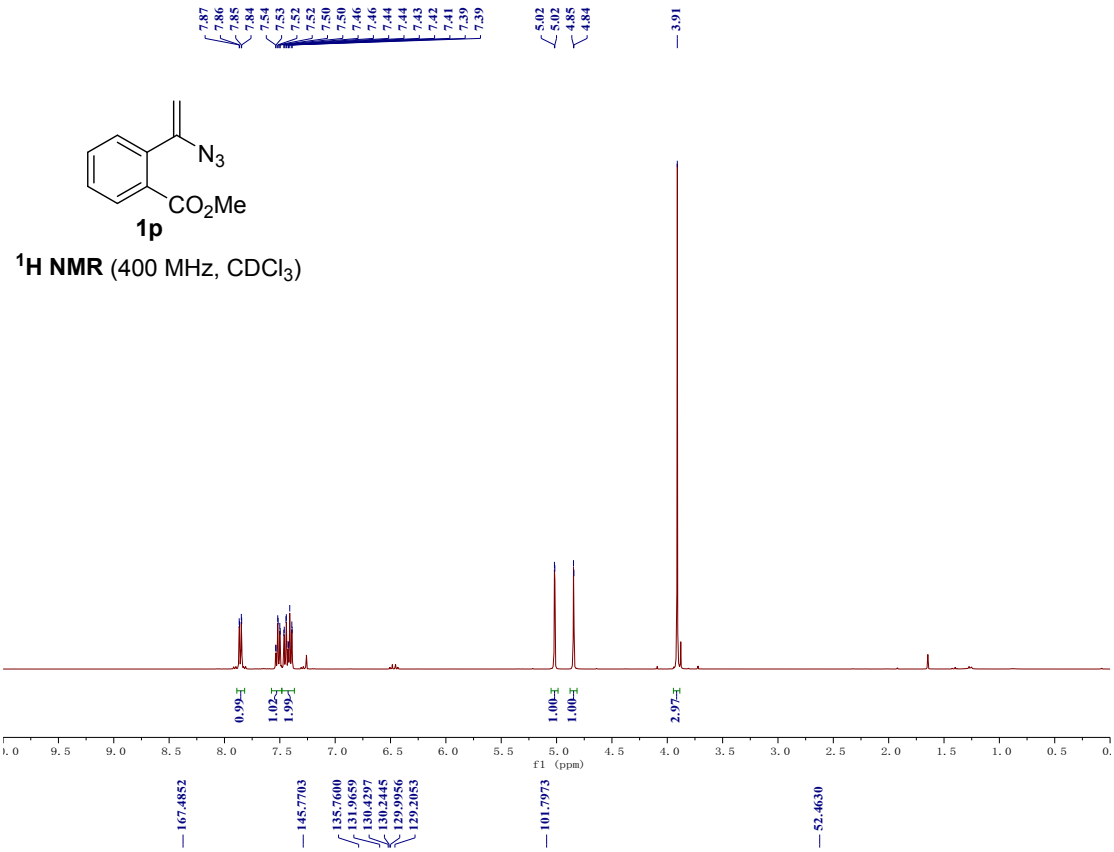
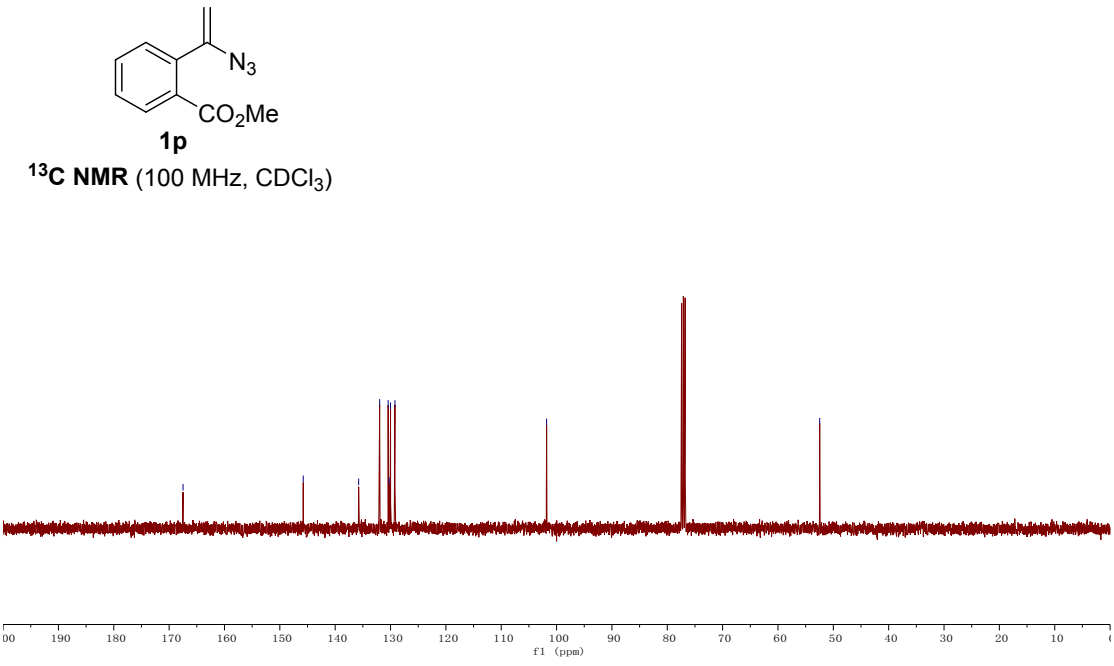
N3
TsHN
1o
13C NMR (100 MHz, CDCl3)
f1 (ppm)



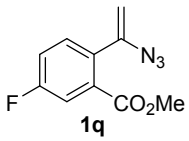
1p

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



1p

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



1q

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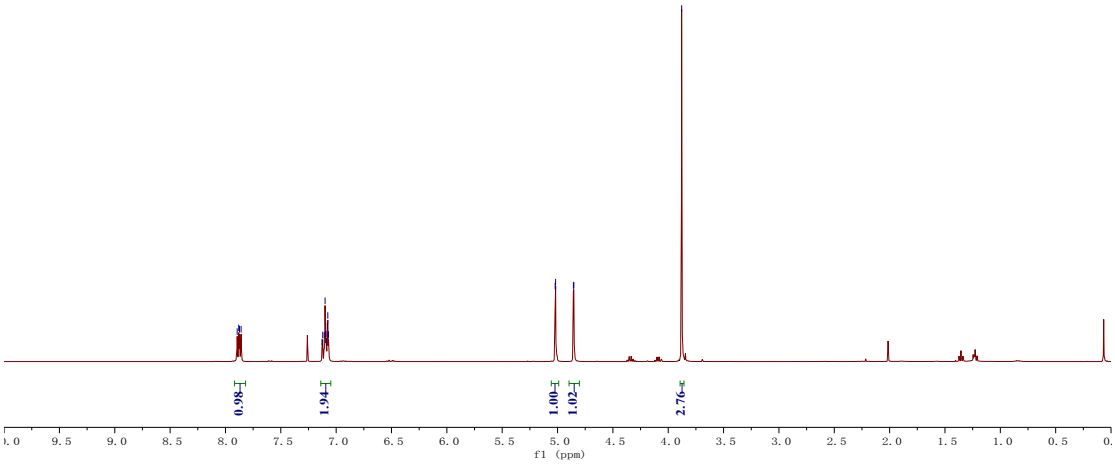

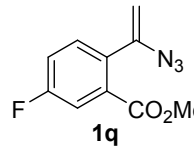

1q

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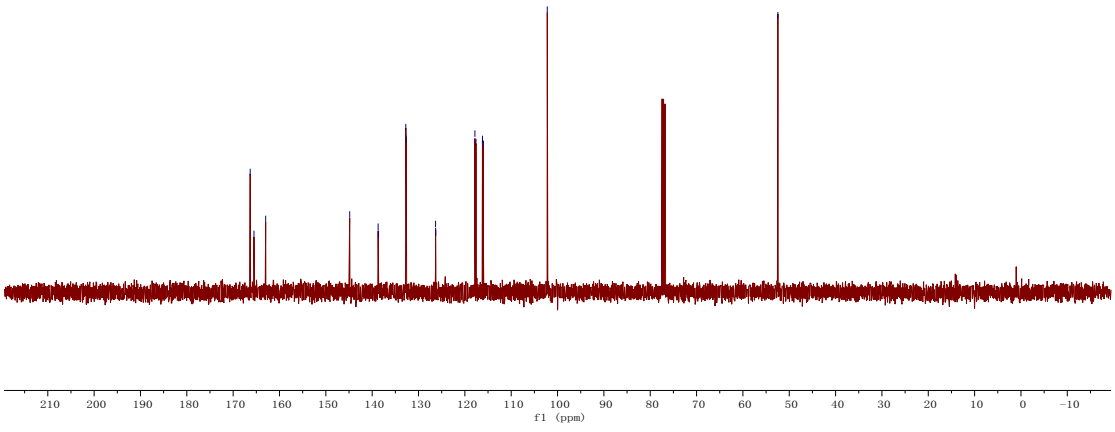
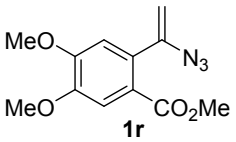
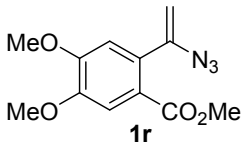




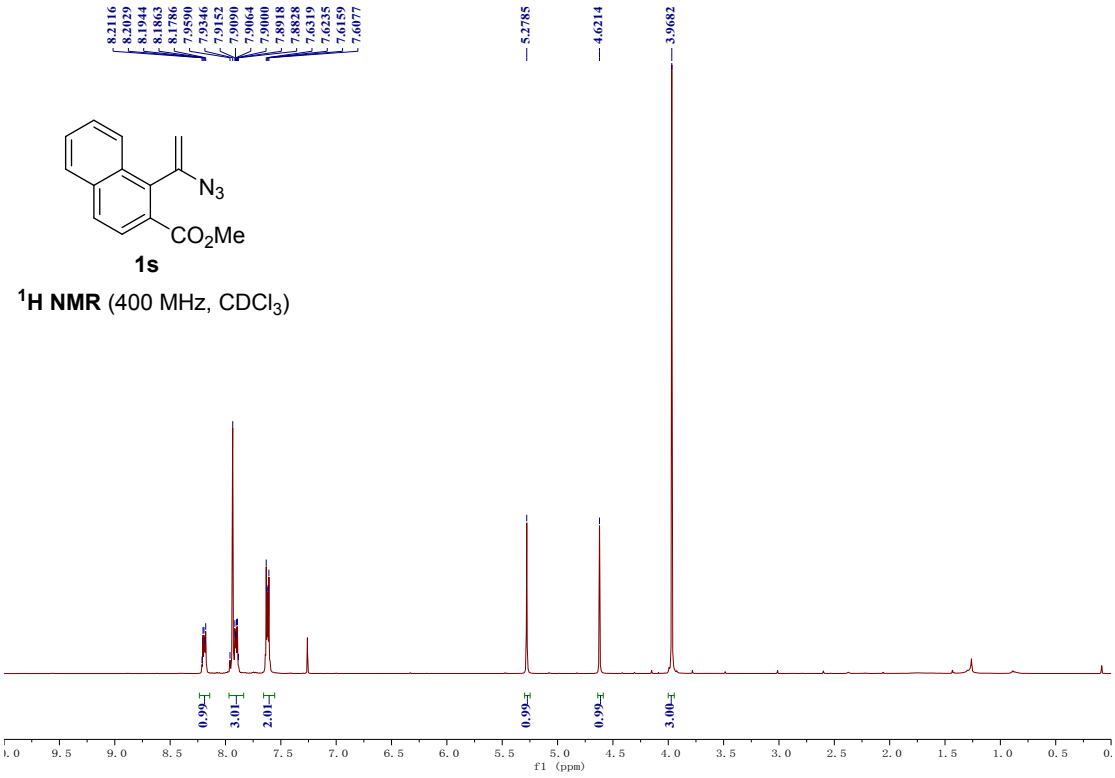
1r

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



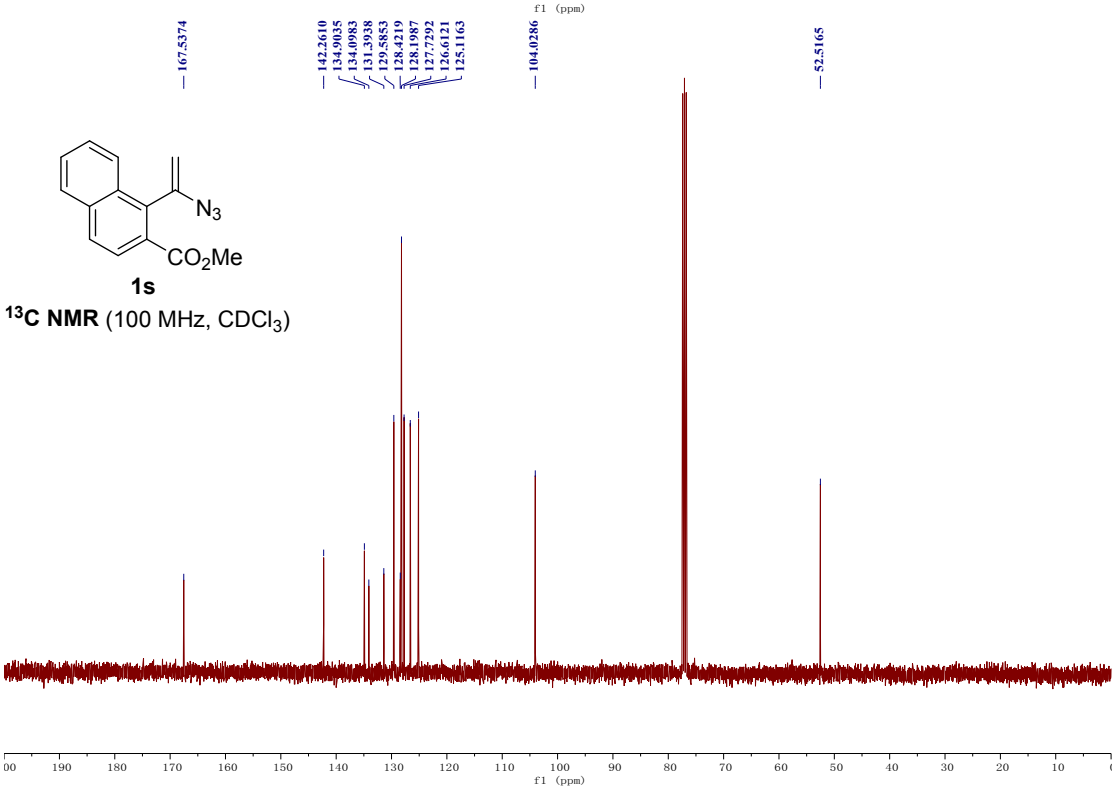
1r

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



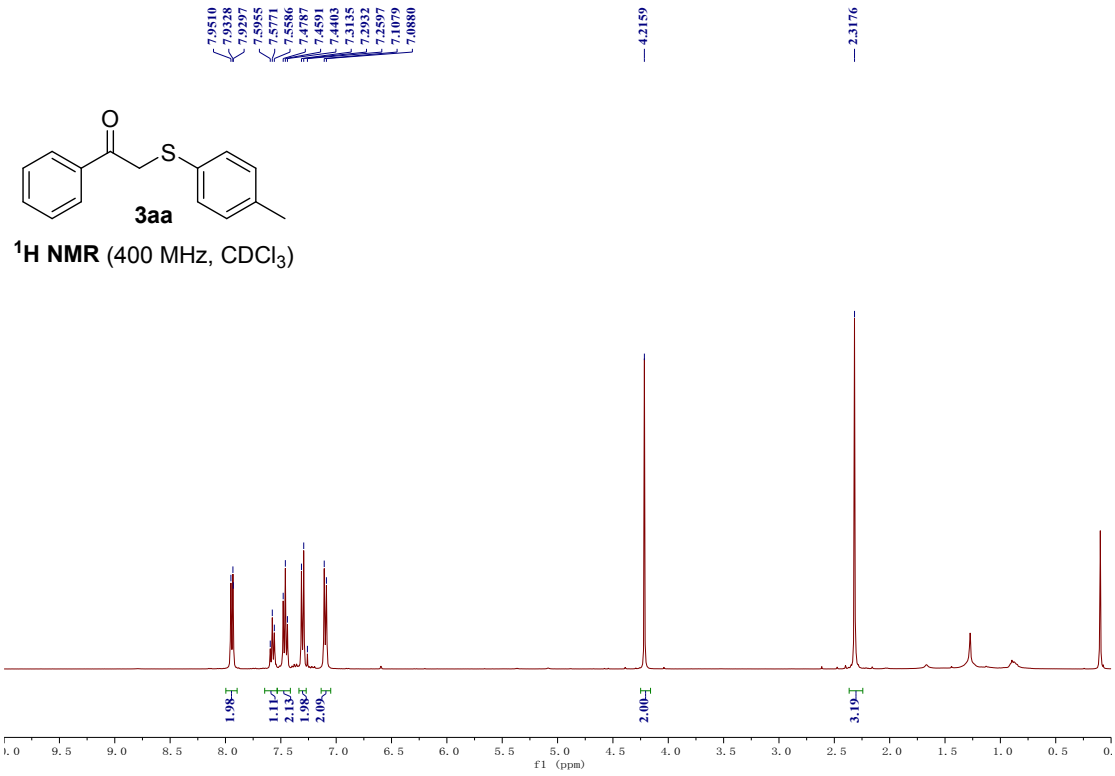
1s

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



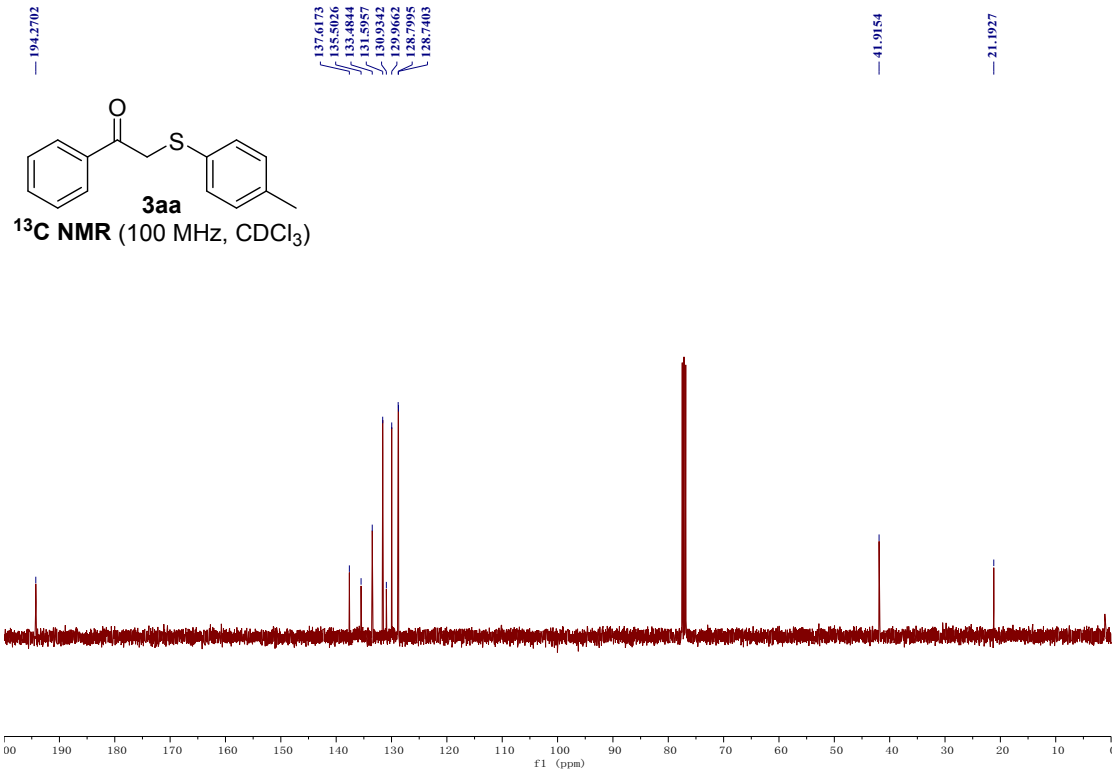
1s

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



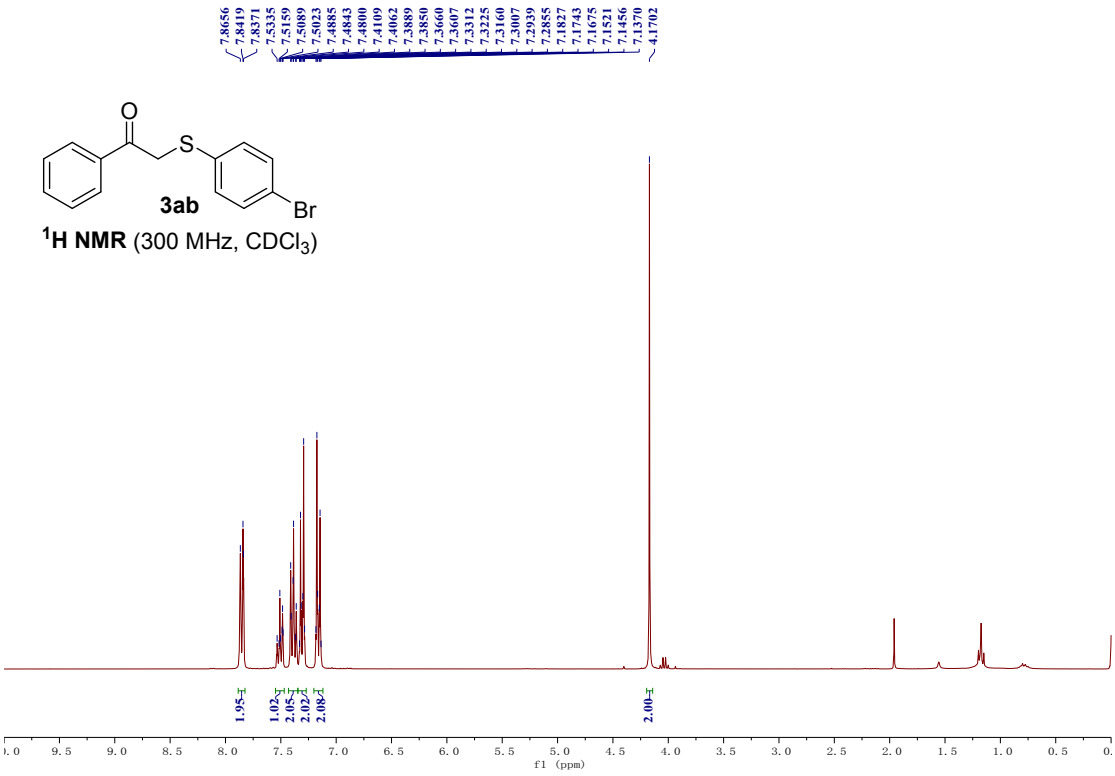
3aa

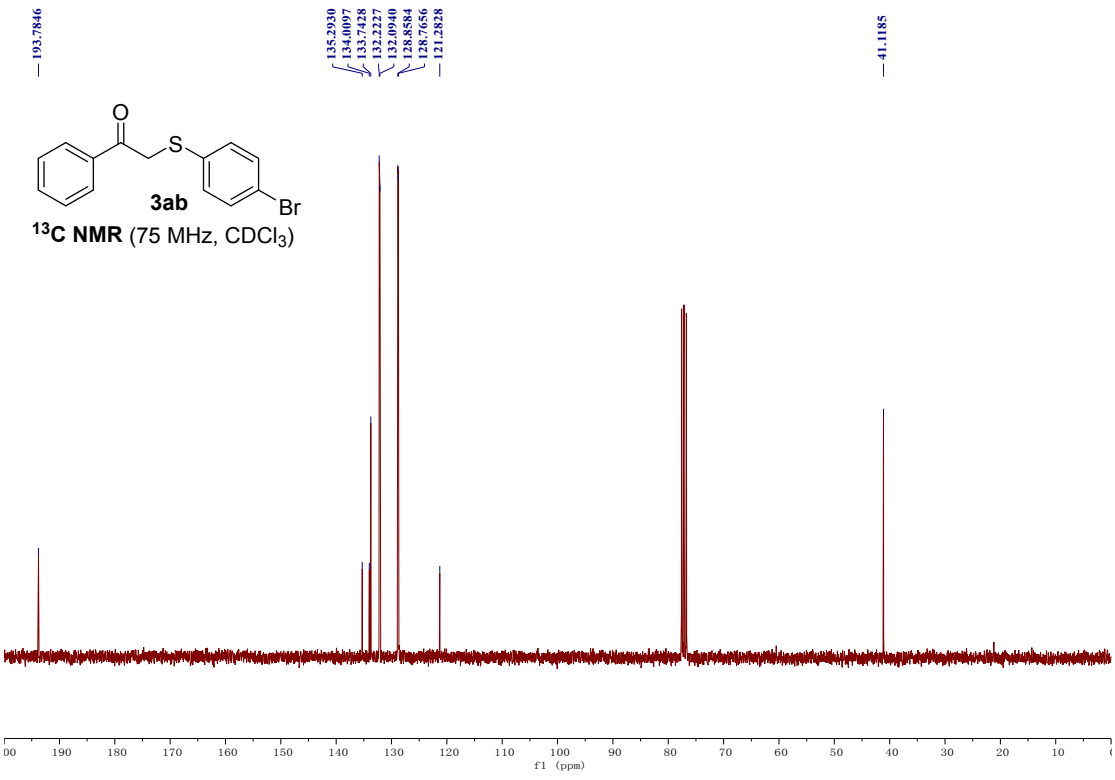
^{1}H NMR (400 MHz, $CDCl_3$)

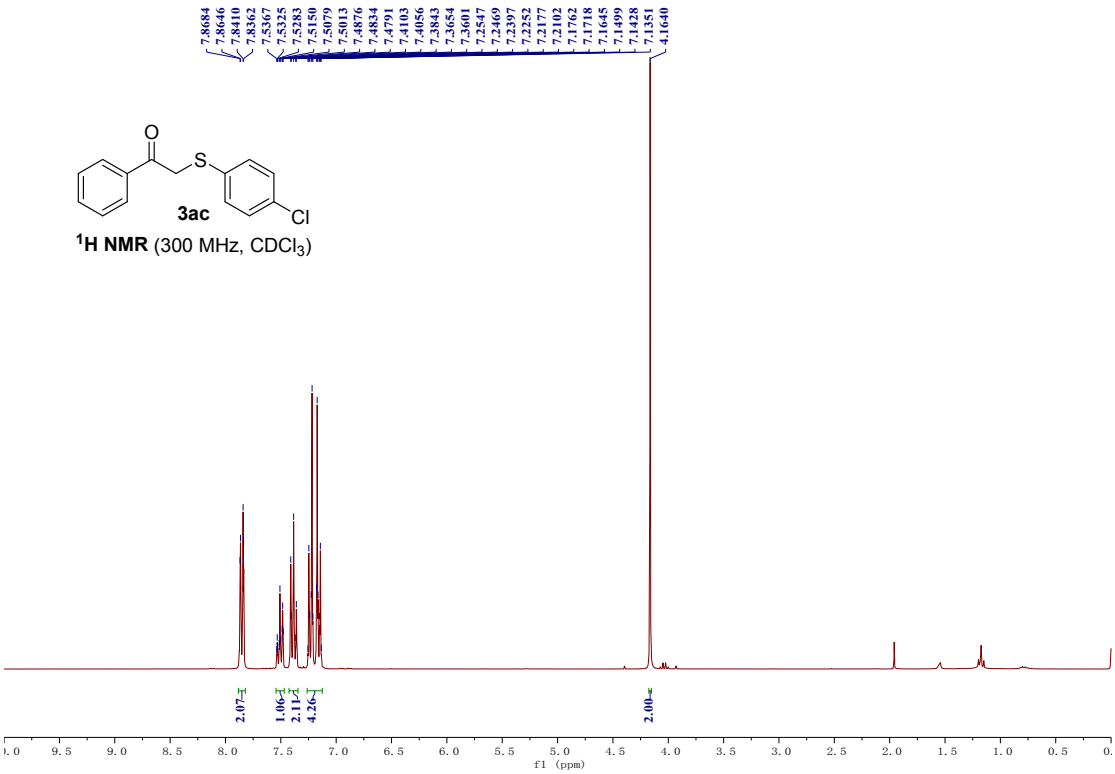


3aa

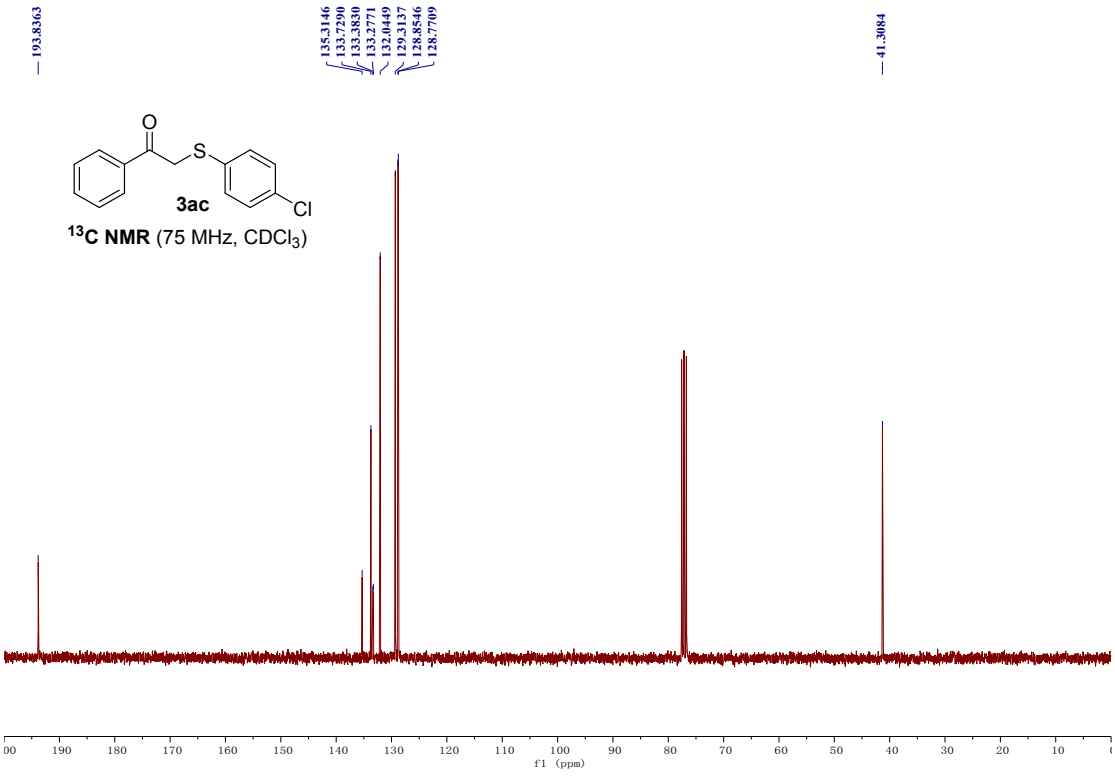
^{13}C NMR (100 MHz, $CDCl_3$)


7.8656
7.8419
7.8371
7.5335
7.5159
7.5089
7.5023
7.4885
7.4843
7.4800
7.4109
7.4062
7.3889
7.3850
7.3660
7.3607
7.3312
7.3225
7.3160
7.3007
7.2939
7.2855
7.1827
7.1743
7.1675
7.1521
7.1456
7.1370
4.1702
O
S
Br
3ab
1H NMR (300 MHz, CDCl3)
1.95
1.02
2.05
2.02
2.08
2.00
f1 (ppm)

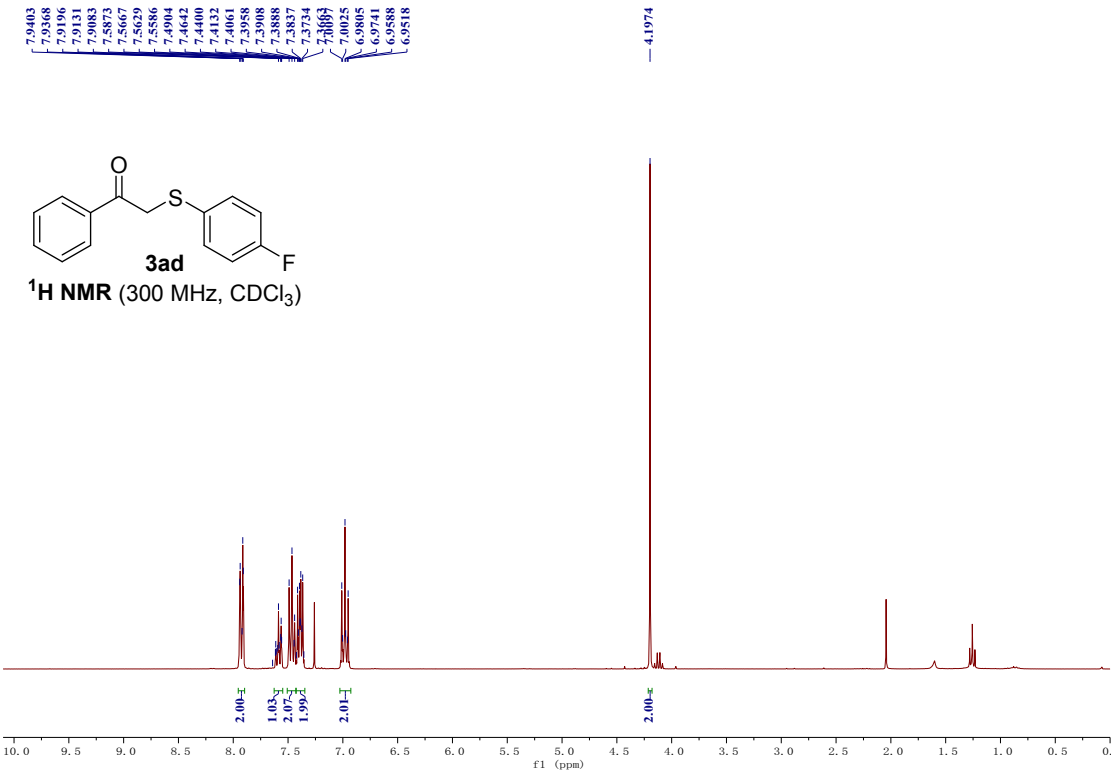

193.7846
135.2930
134.0097
133.7428
132.2227
132.0940
128.8584
128.7656
121.2828
41.1185
O
S
Br
3ab
13C NMR (75 MHz, CDCl3)
f1 (ppm)



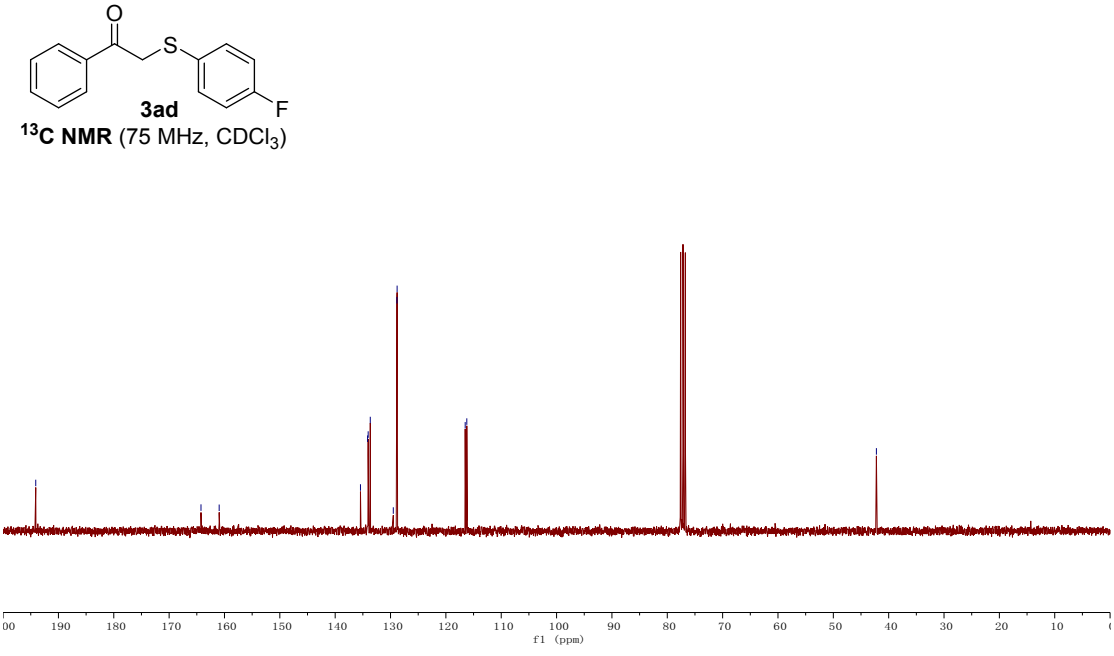
^{1}H NMR (300 MHz, $CDCl_3$)



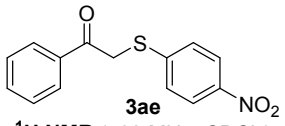
^{13}C NMR (75 MHz, $CDCl_3$)



^{1}H NMR (300 MHz, $CDCl_3$)

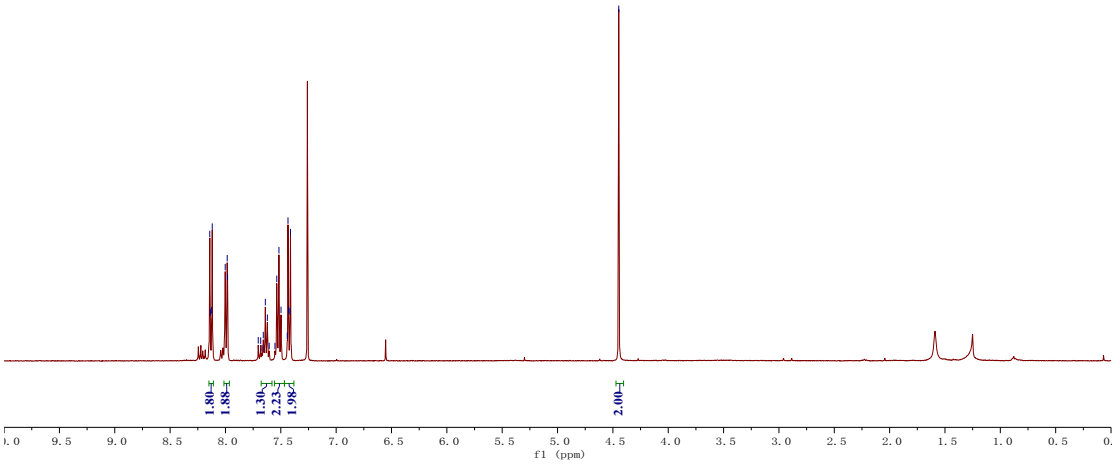


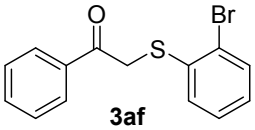
^{13}C NMR (75 MHz, $CDCl_3$)



3ae

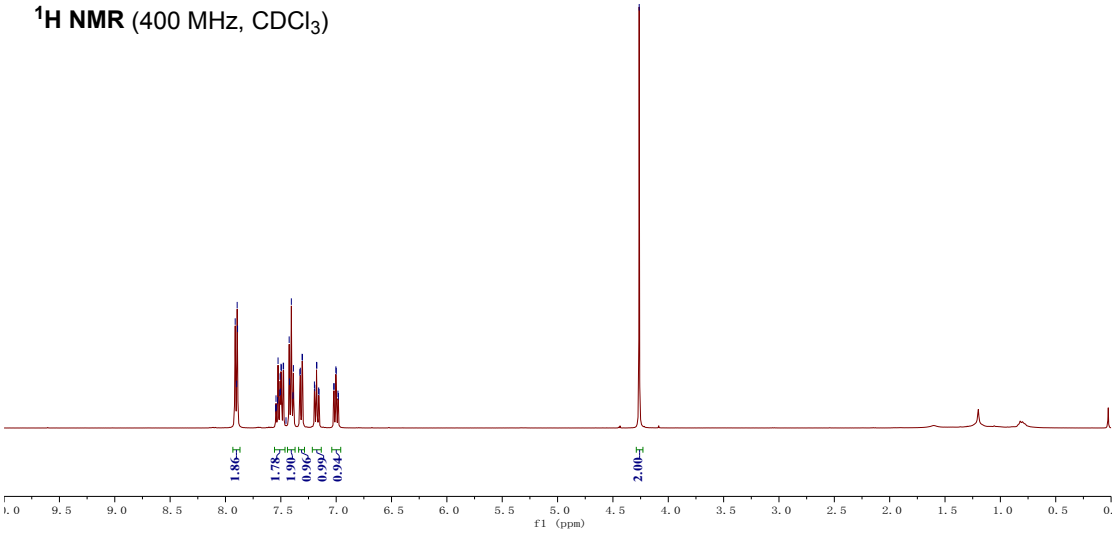
^{1}H NMR (400 MHz, $CDCl_3$)

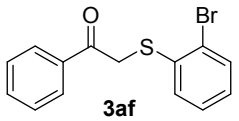




3af

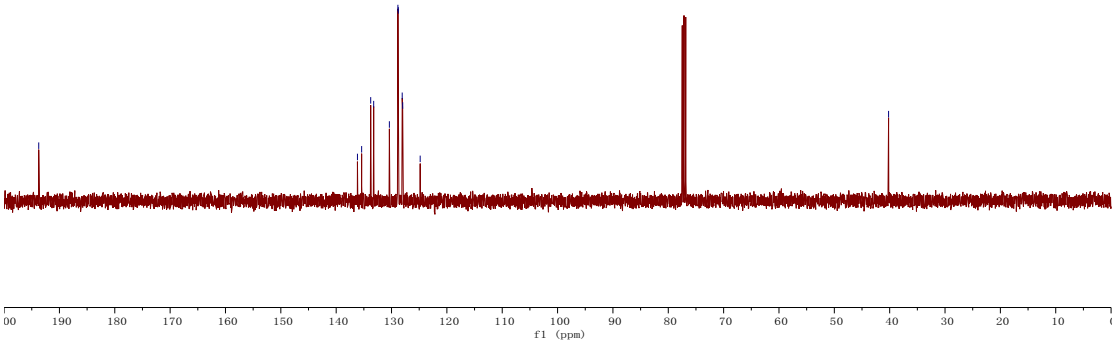
^{1}H NMR (400 MHz, $CDCl_3$)

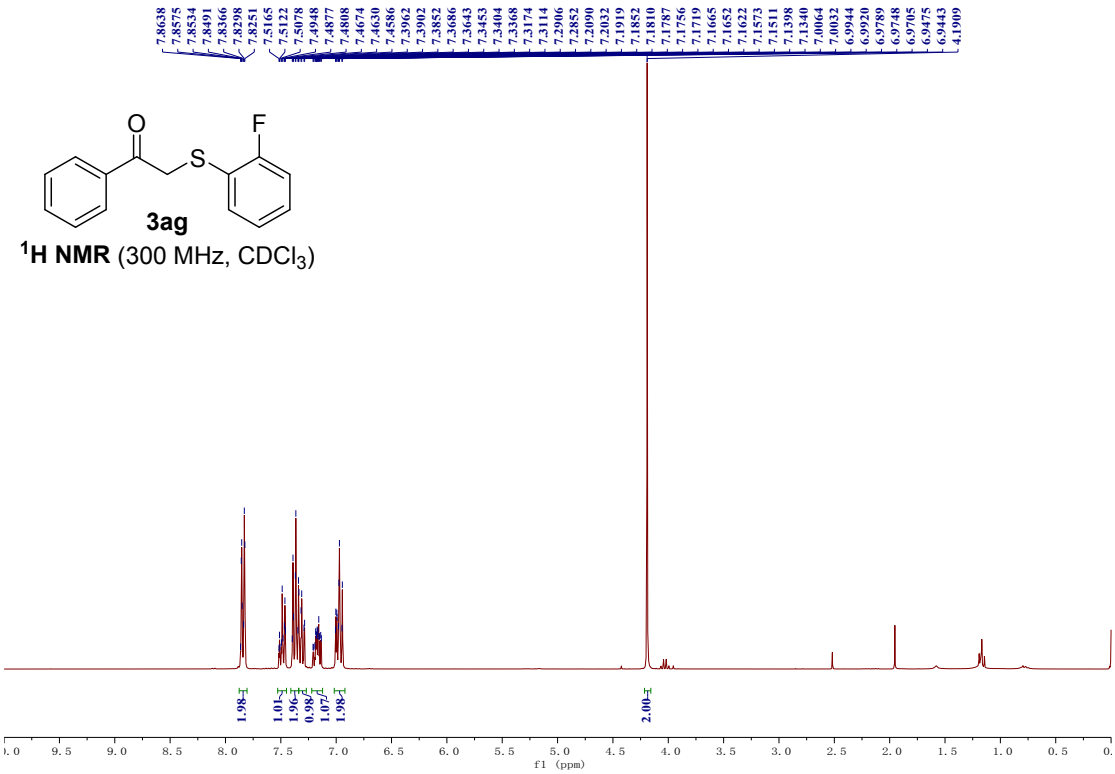


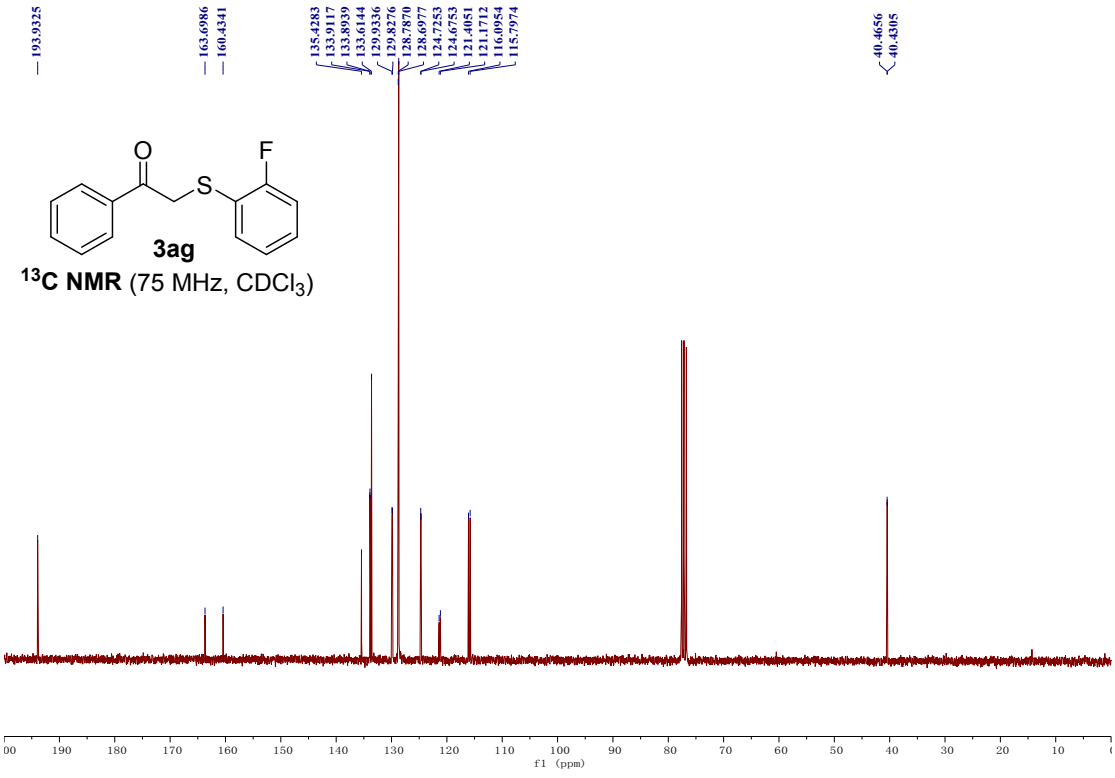


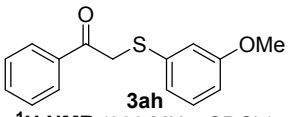
3af

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



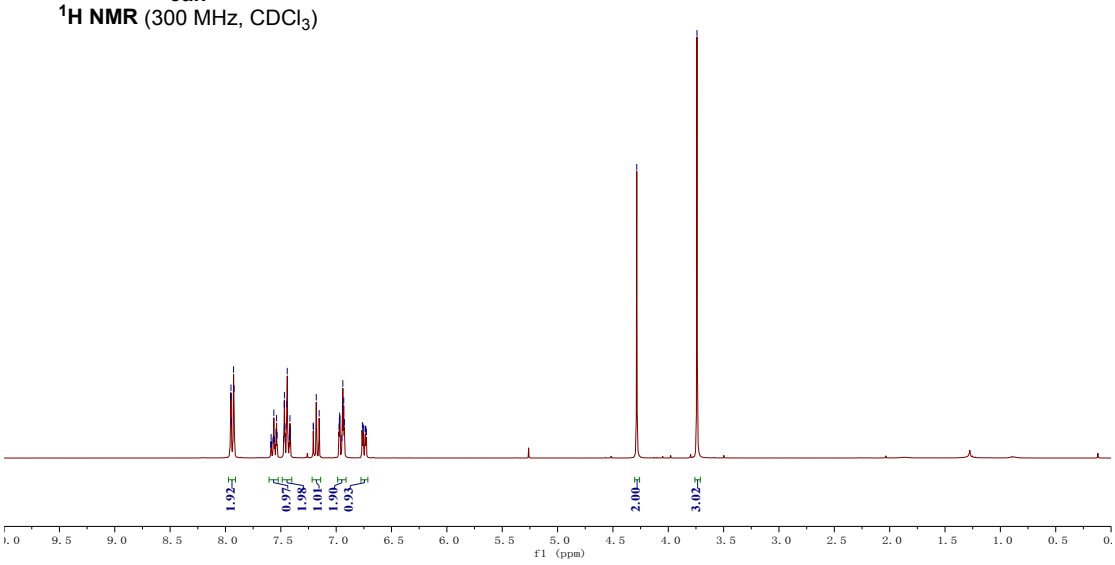

O
S
F
3ag
1H NMR (300 MHz, CDCl3)
f1 (ppm)

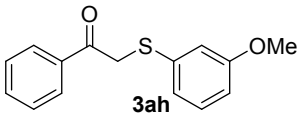

O
S
F
3ag
13C NMR (75 MHz, CDCl3)
f1 (ppm)



3ah

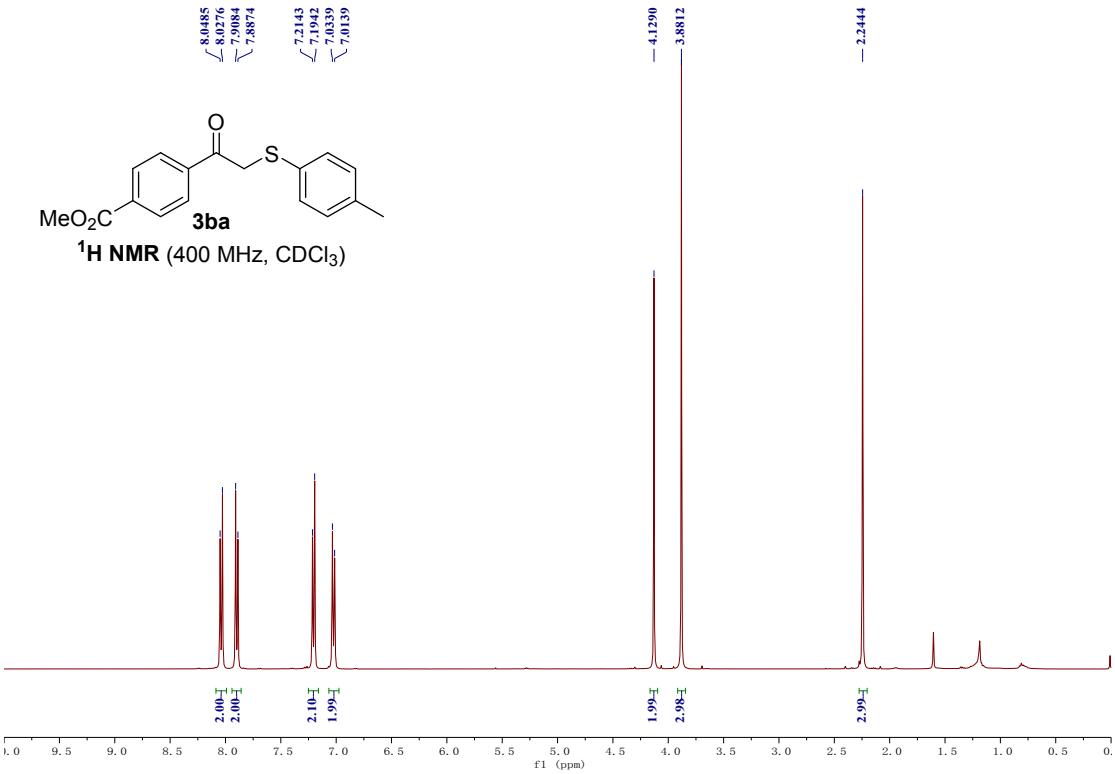
^{1}H NMR (300 MHz, $CDCl_3$)



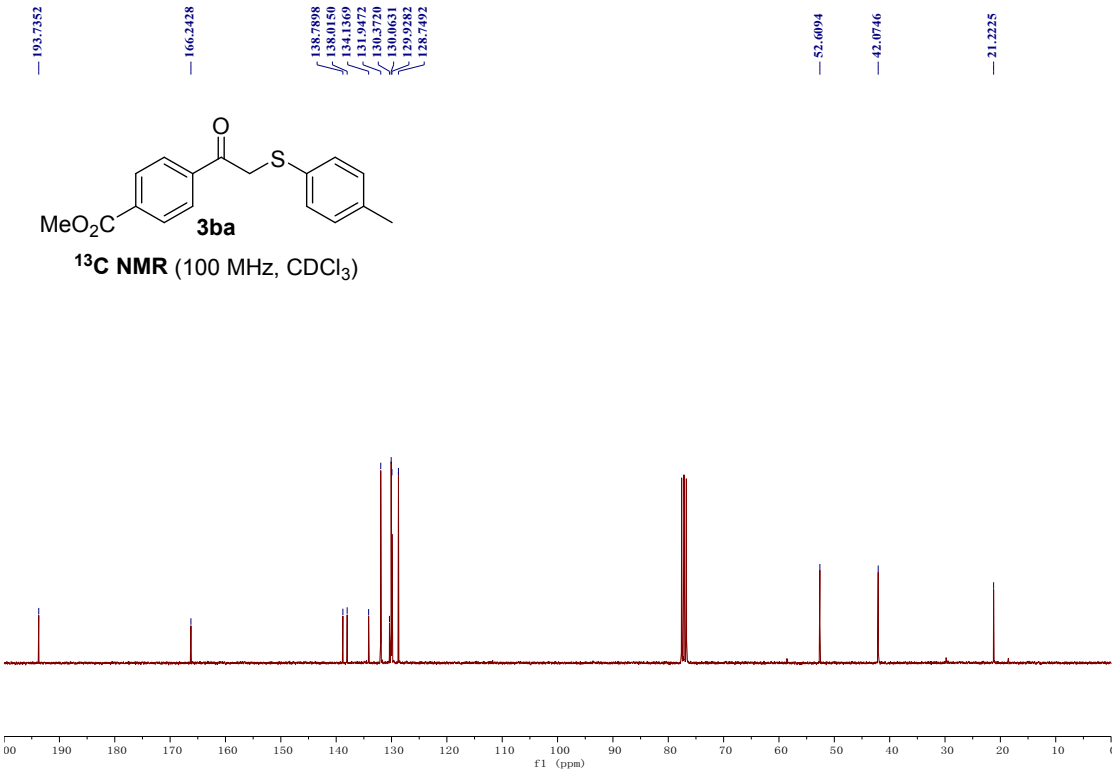


3ah

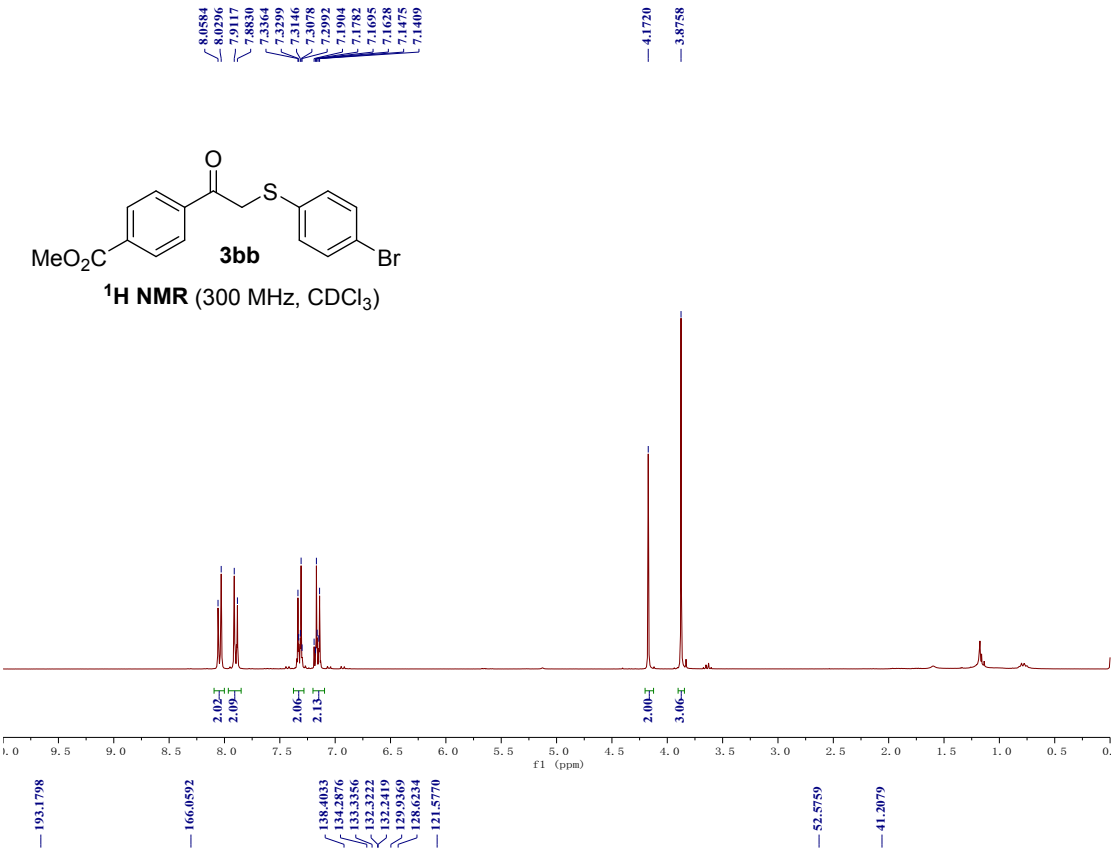
^{13}C NMR (75 MHz, $CDCl_3$)



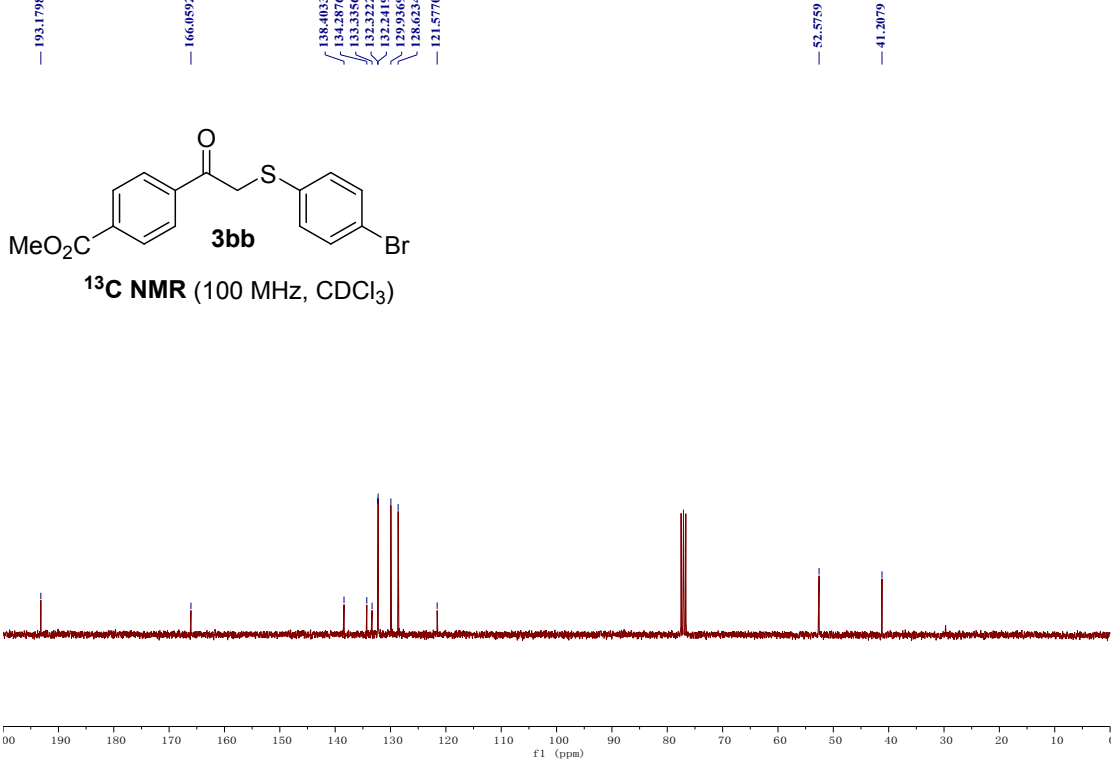
^{1}H NMR (400 MHz, $CDCl_3$)



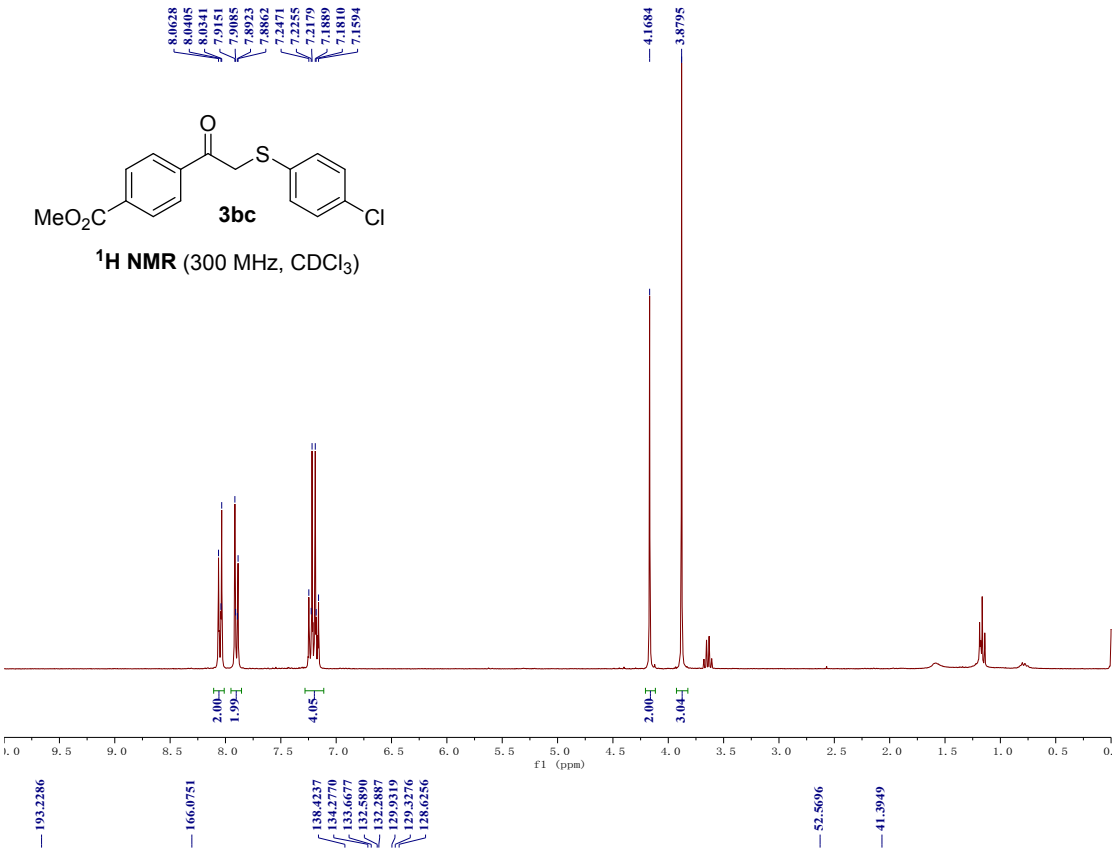
^{13}C NMR (100 MHz, $CDCl_3$)



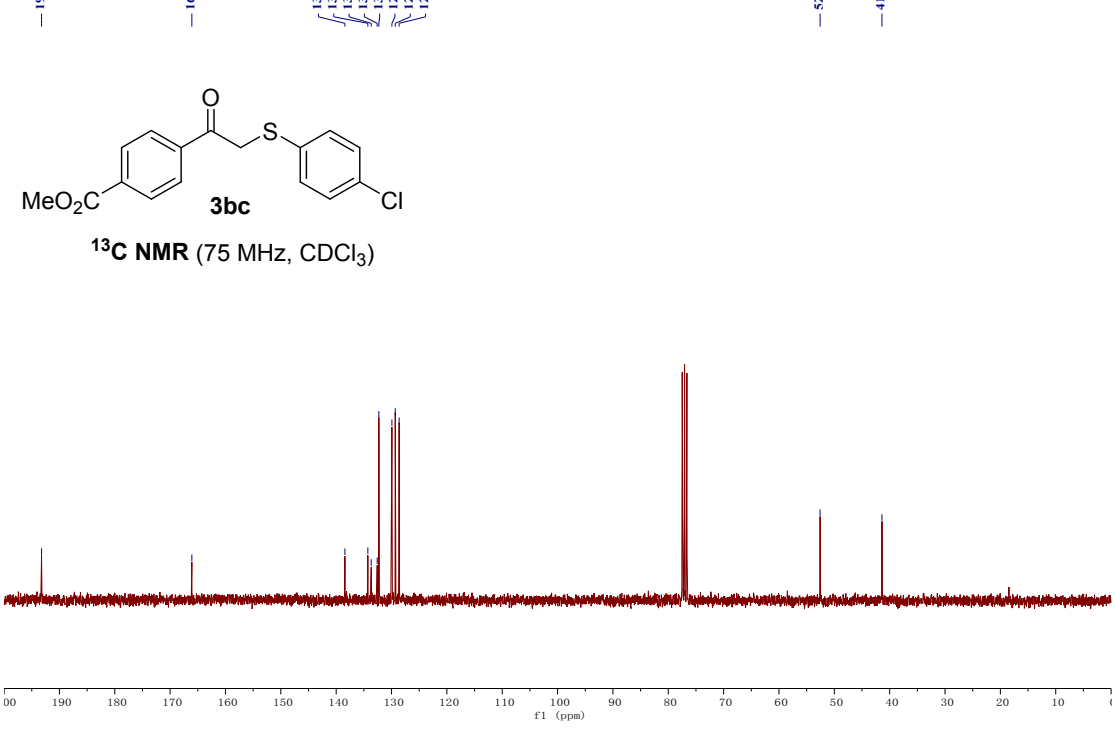
^{1}H NMR (300 MHz, $CDCl_3$)



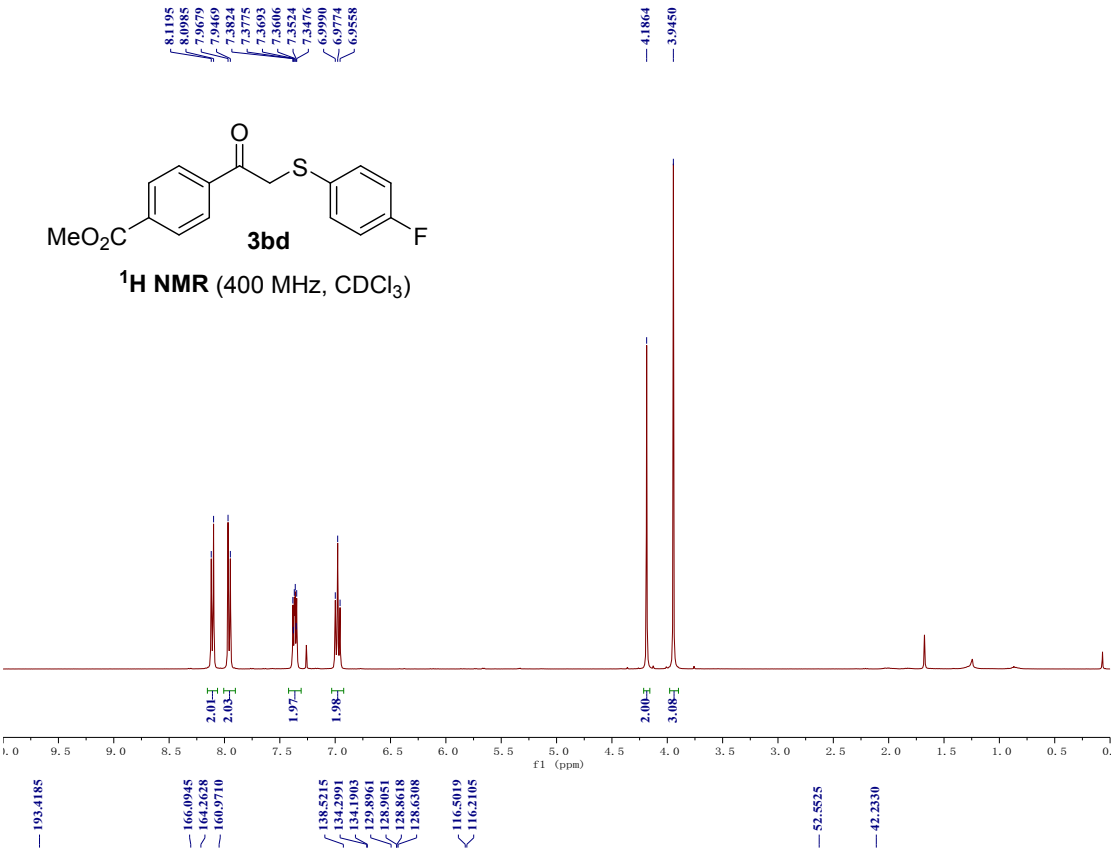
^{13}C NMR (100 MHz, $CDCl_3$)



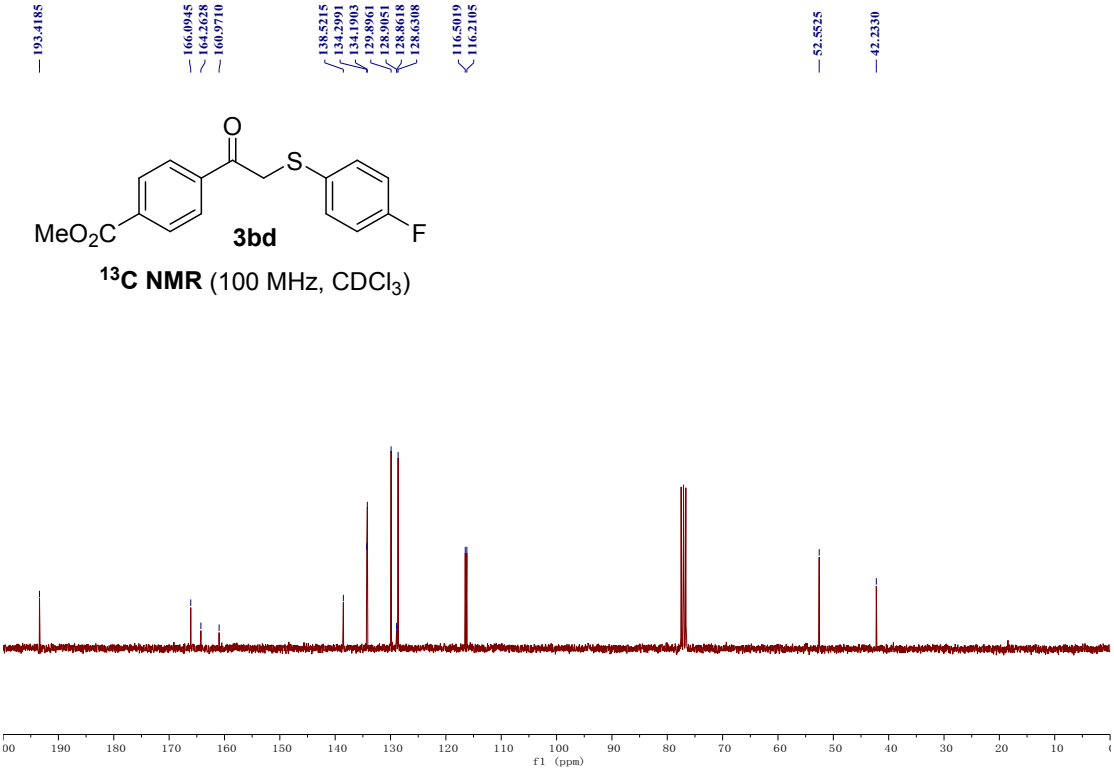
^{1}H NMR (300 MHz, $CDCl_3$)



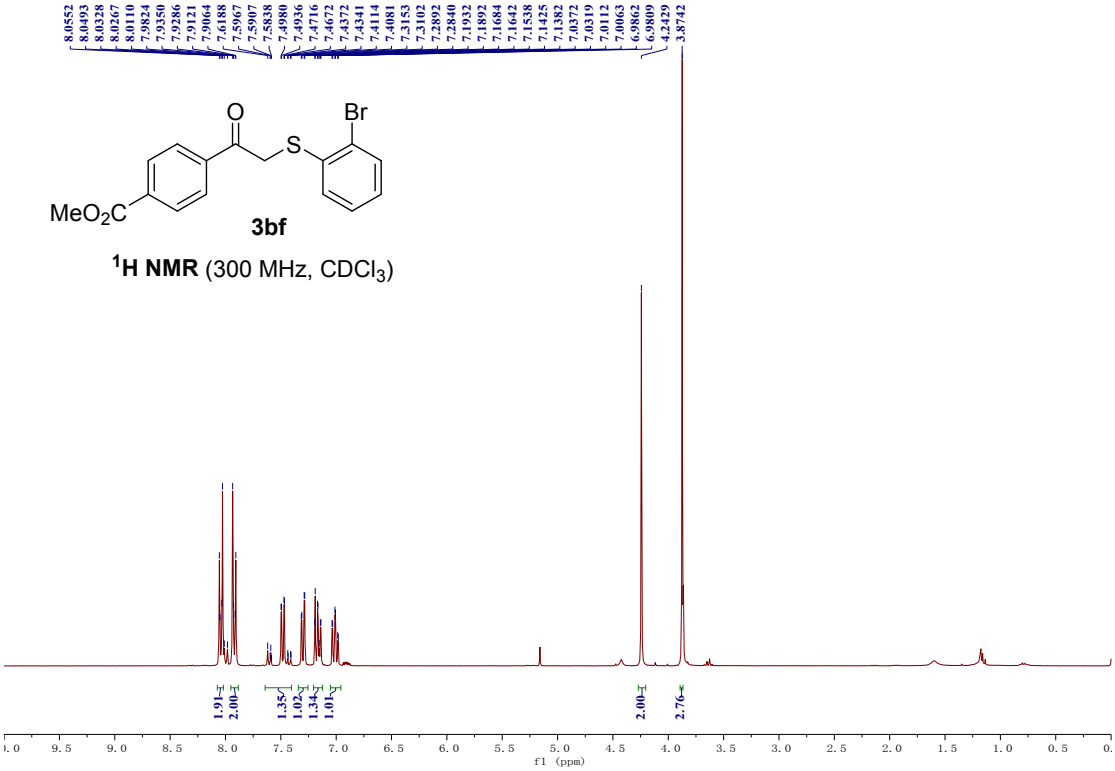
^{13}C NMR (75 MHz, $CDCl_3$)



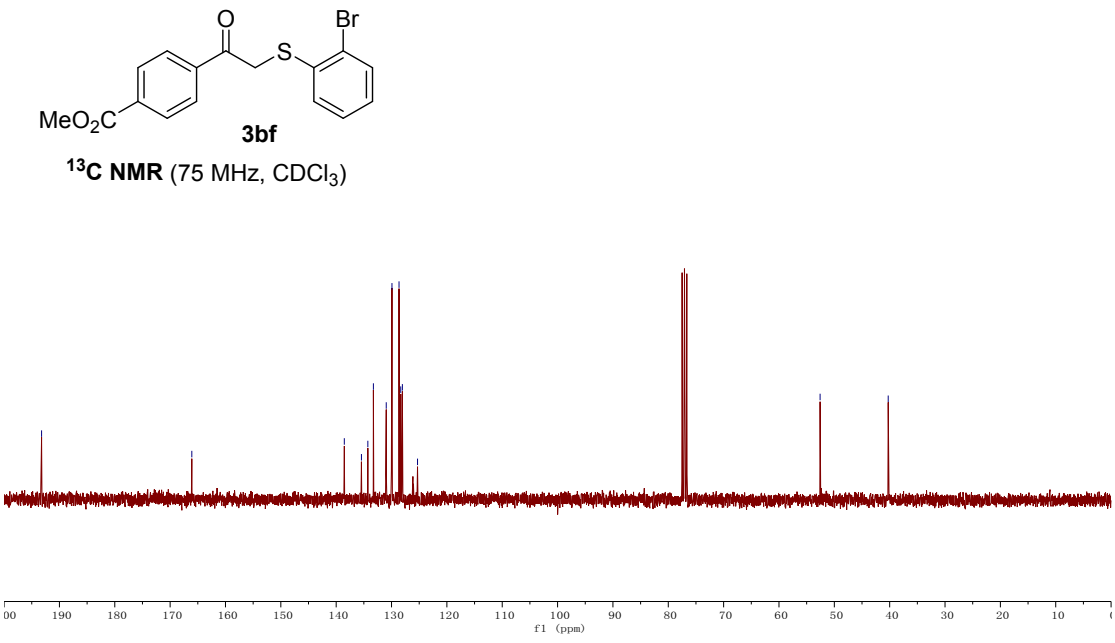
^{1}H NMR (400 MHz, $CDCl_3$)



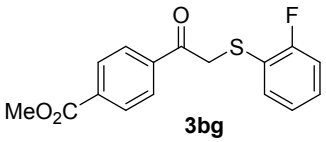
^{13}C NMR (100 MHz, $CDCl_3$)



^{1}H NMR (300 MHz, $CDCl_3$)

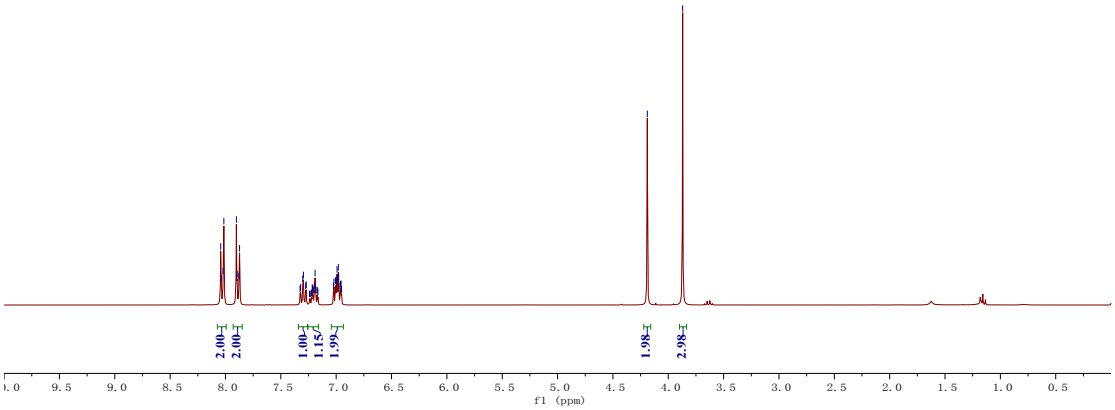


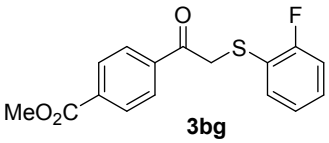
^{13}C NMR (75 MHz, $CDCl_3$)



3bg

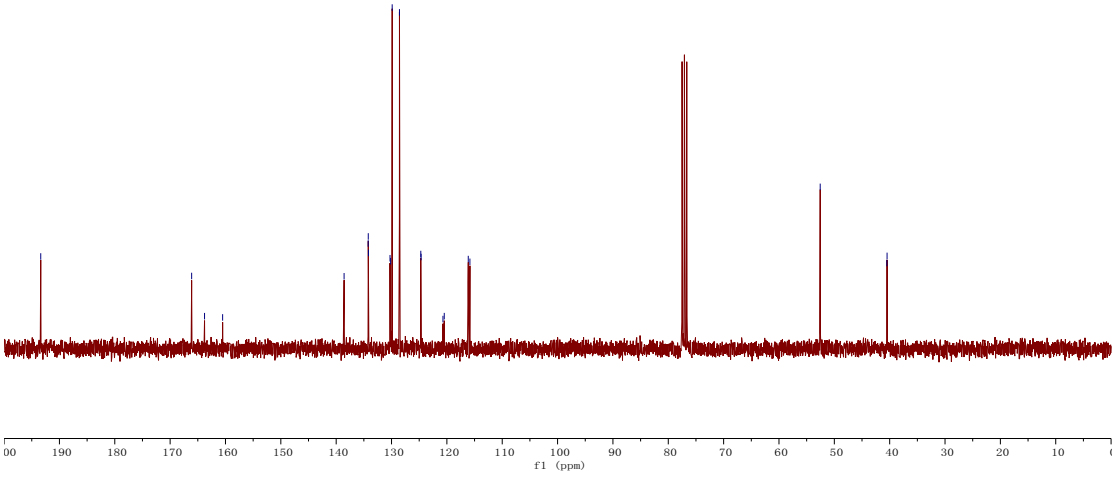
^{1}H NMR (300 MHz, $CDCl_3$)

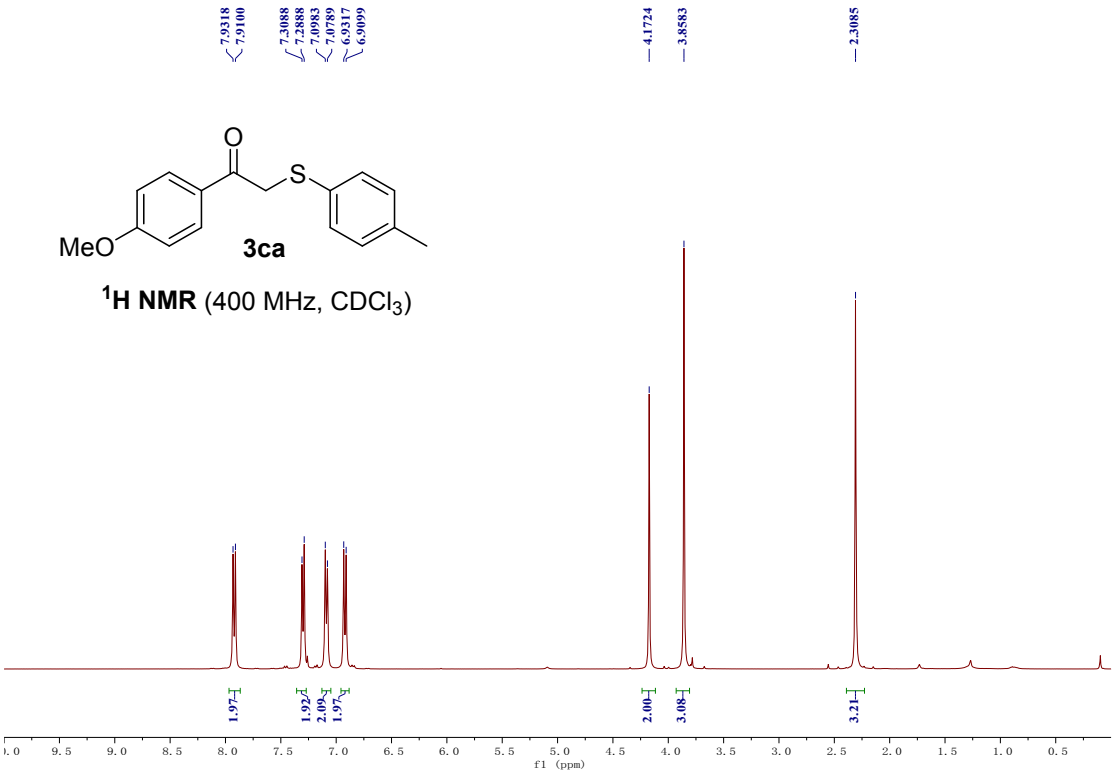




3bg

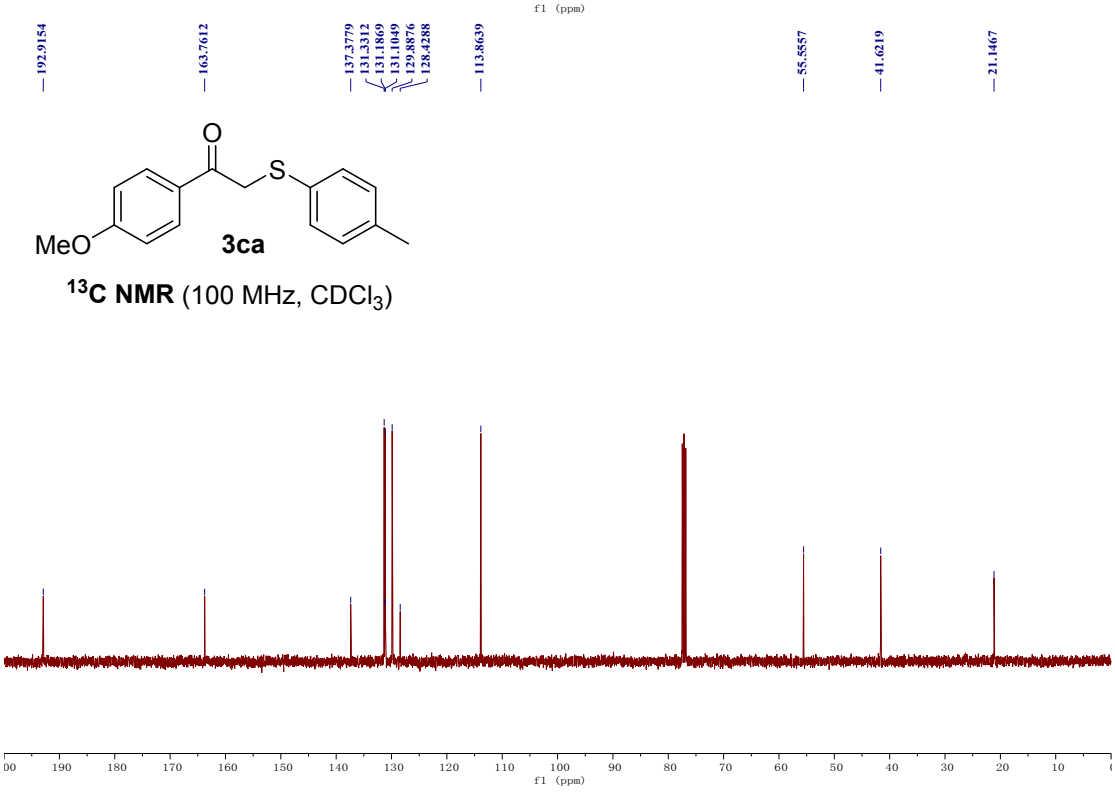
^{13}C NMR (75 MHz, $CDCl_3$)





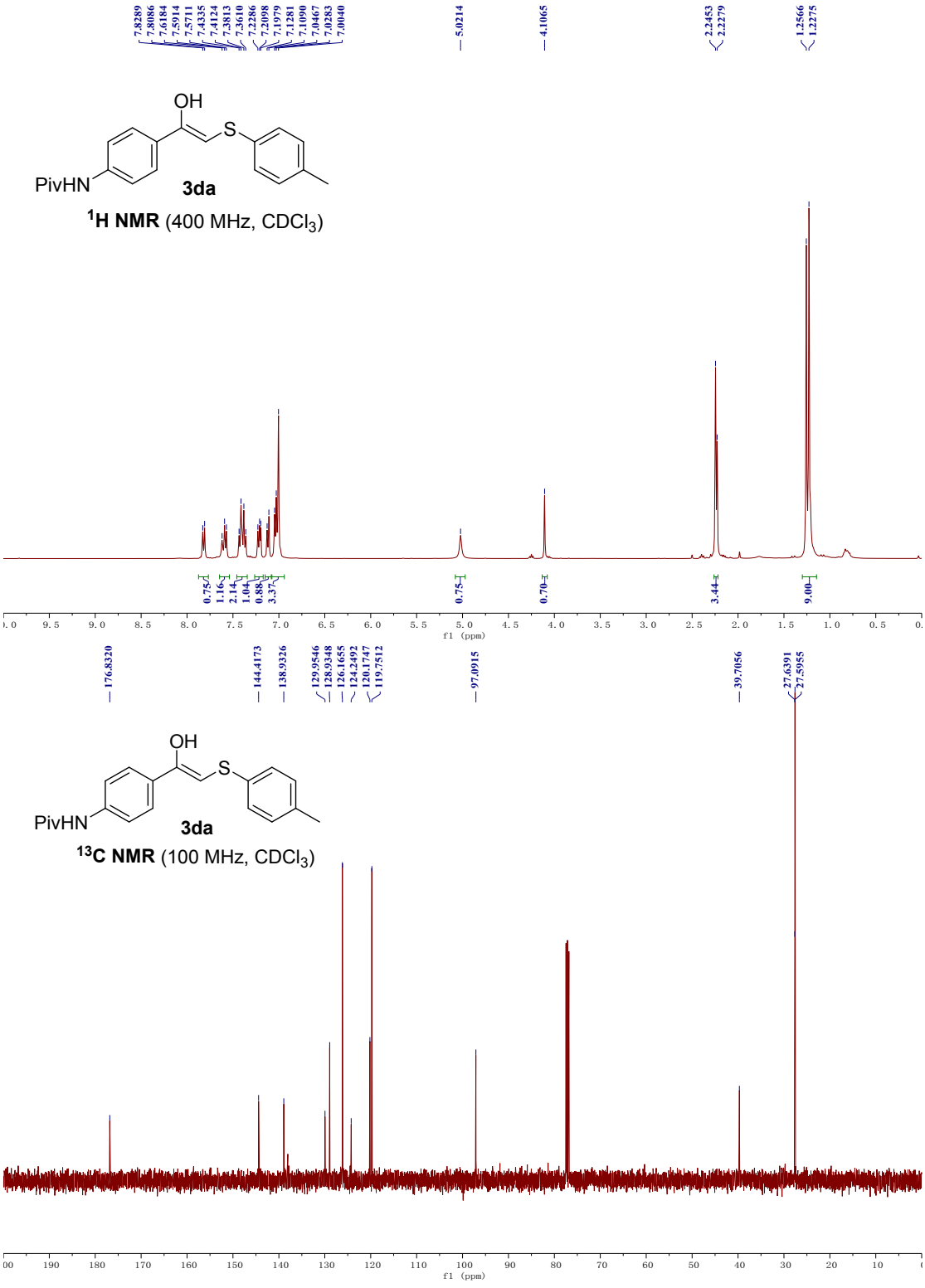
3ca

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



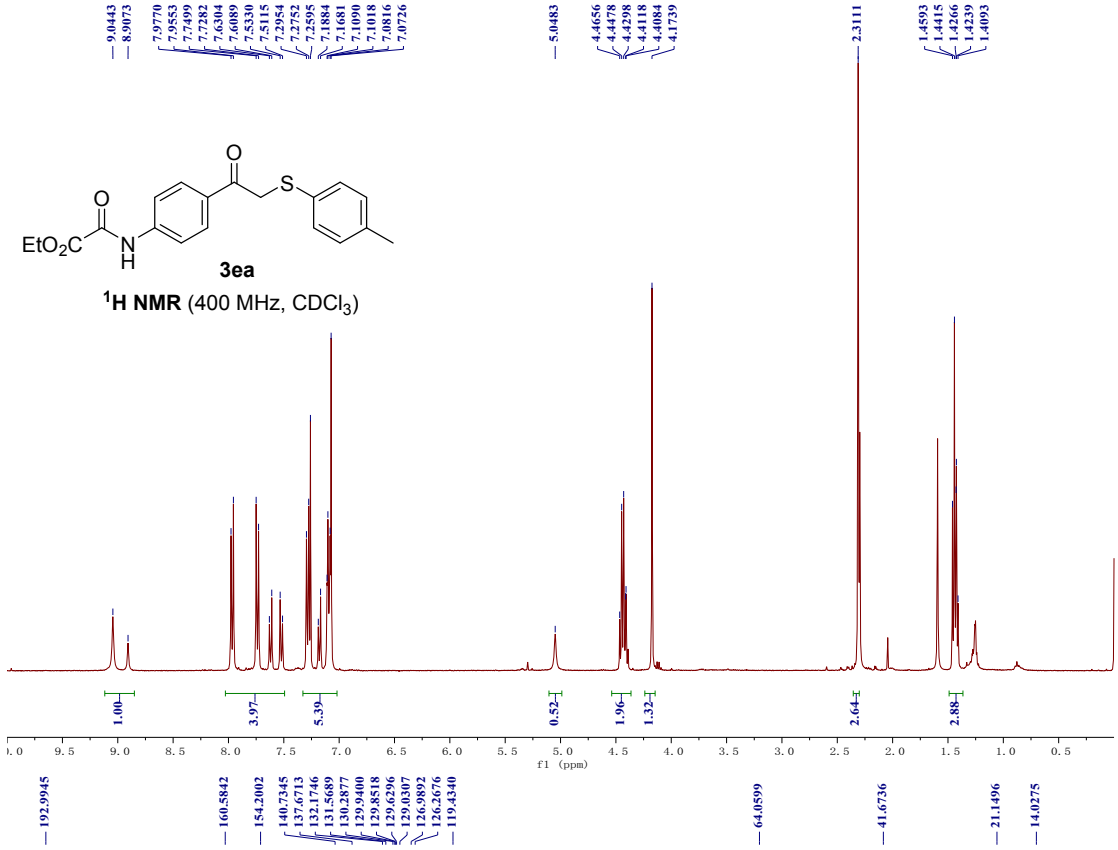
3ca

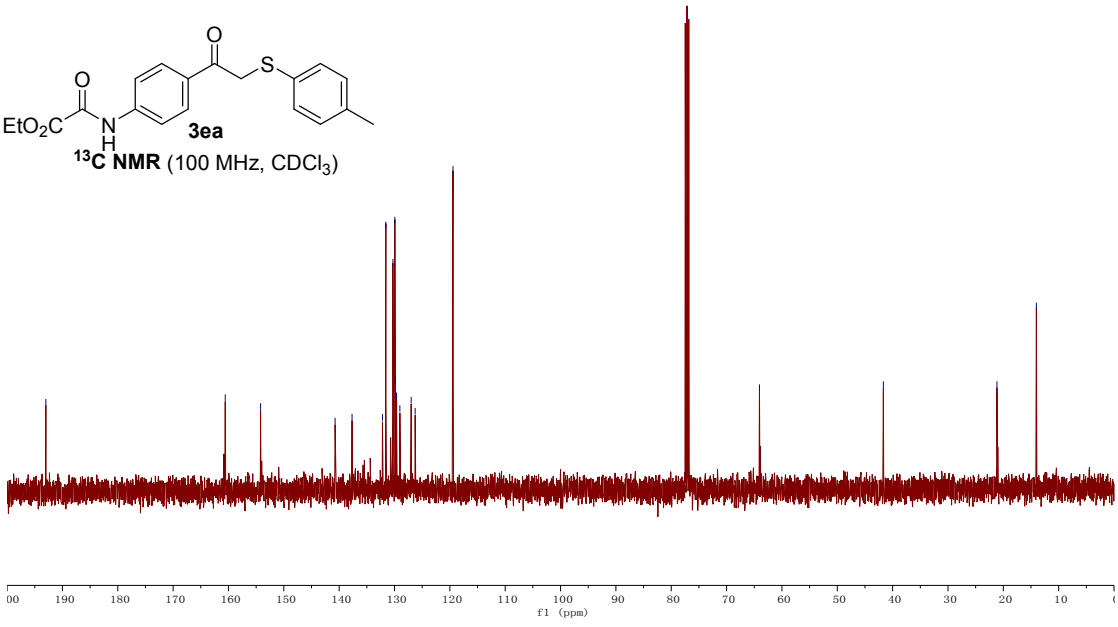
^{13}C NMR (100 MHz, $CDCl_3$)

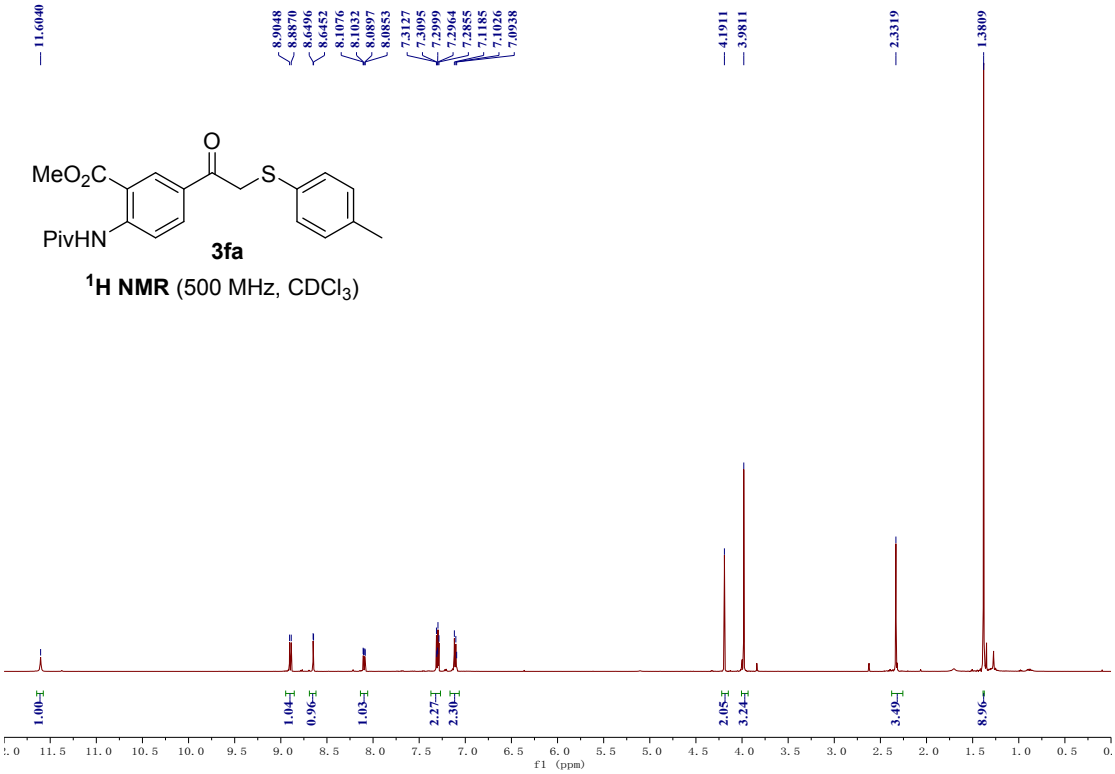


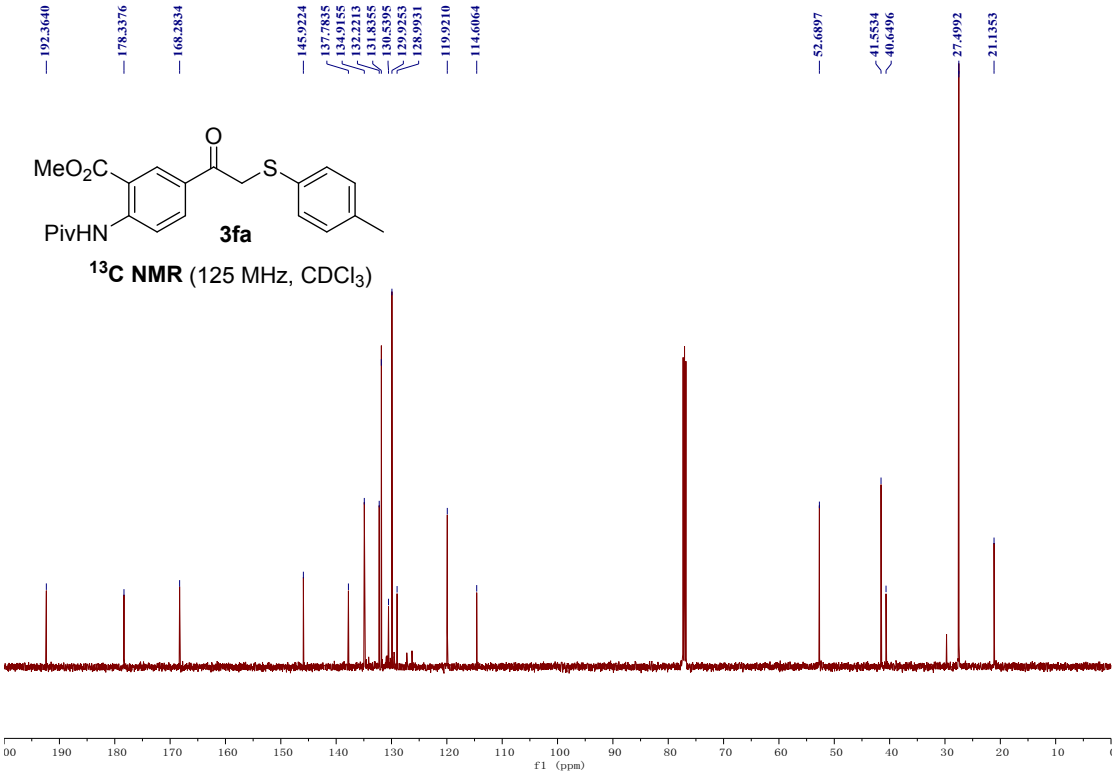
^{1}H NMR (400 MHz, $CDCl_3$)

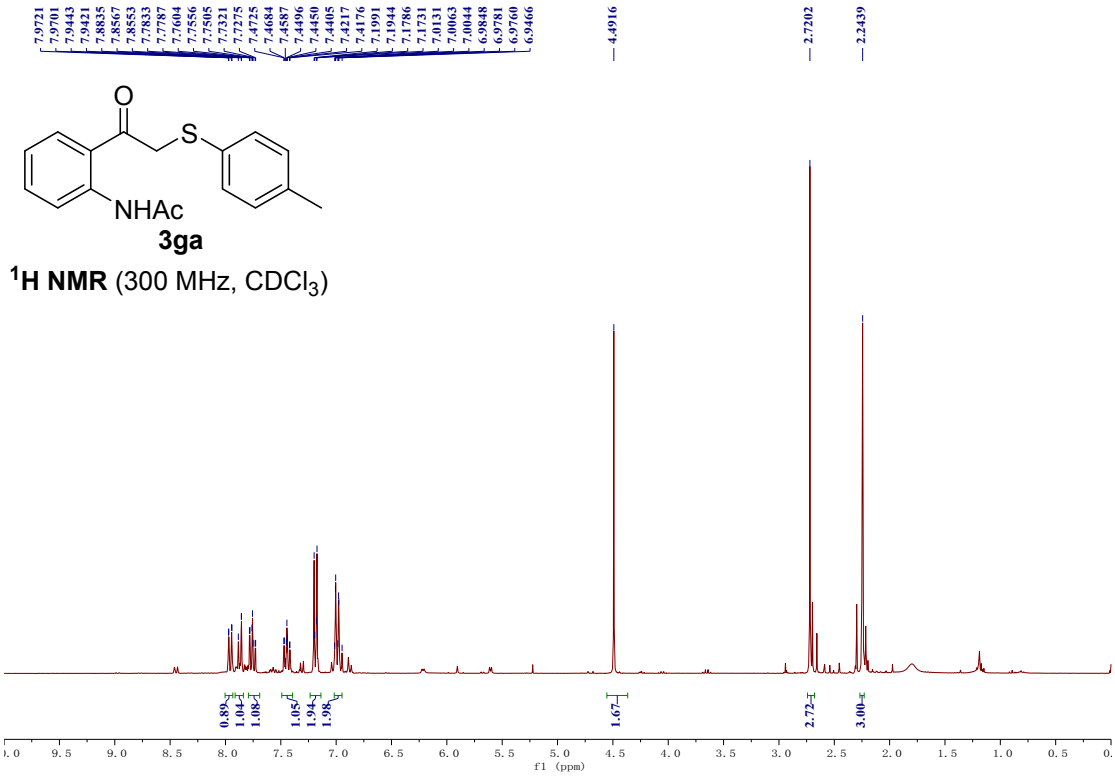
^{13}C NMR (100 MHz, $CDCl_3$)


9.0443
8.9073
7.9770
7.9553
7.7499
7.7282
7.6304
7.6089
7.5330
7.5115
7.2954
7.2752
7.2595
7.1884
7.1681
7.1090
7.1018
7.0816
7.0726
5.0483
4.4656
4.4478
4.4298
4.4118
4.4084
4.1739
2.3111
1.4593
1.4415
1.4266
1.4239
1.4093
EtO2C
N
H
O
O
S
3ea
1H NMR (400 MHz, CDCl3)
1.00
3.97
5.39
0.52
1.96
1.33
2.64
2.88
f1 (ppm)


192.9945
160.5842
154.2002
140.7345
137.6713
132.1746
131.5689
130.2877
129.9400
129.8518
129.6296
129.0307
126.9892
126.2676
119.4340
64.0599
41.6736
21.1496
14.0275
EtO2C
N
H
O
O
S
3ea
13C NMR (100 MHz, CDCl3)
f1 (ppm)

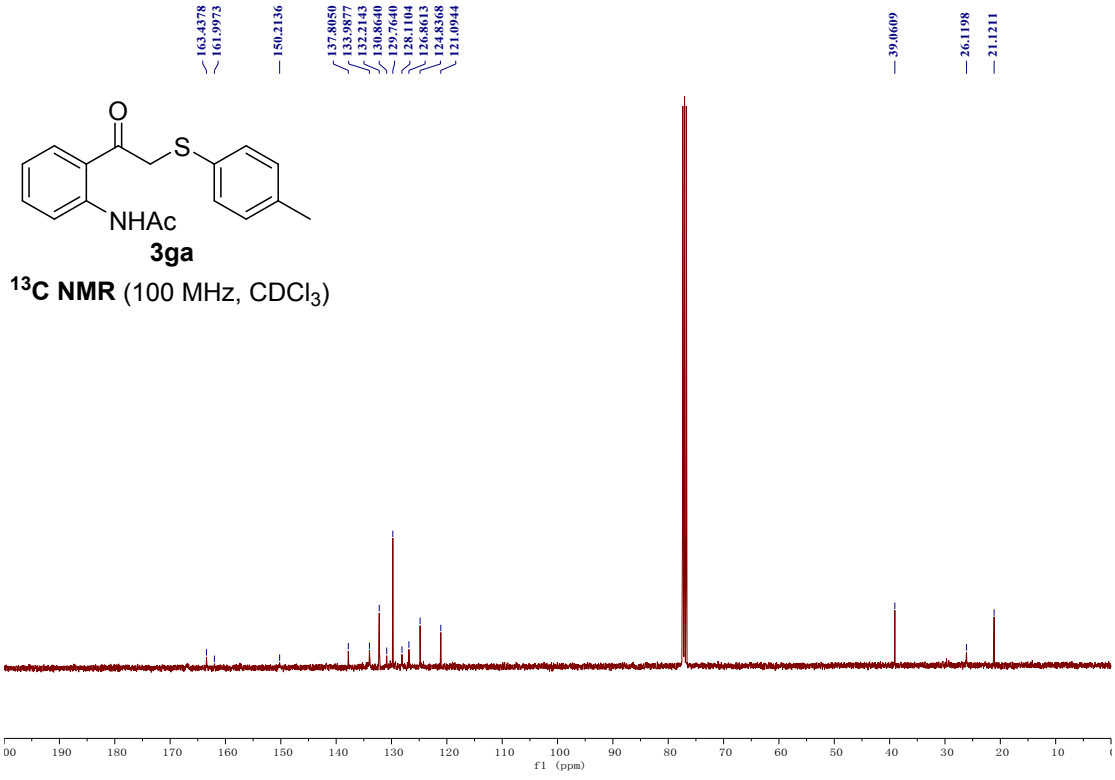

11.6040
8.9048
8.8870
8.6496
8.6452
8.1076
8.1032
8.0897
8.0853
7.3127
7.3095
7.2999
7.2964
7.2855
7.1185
7.1026
7.0938
4.1911
3.9811
2.3319
1.3809
MeO2C
PivHN
O
S
3fa
1H NMR (500 MHz, CDCl3)
1.00
1.04
0.96
1.03
2.27
2.30
2.05
3.24
3.49
8.96
f1 (ppm)


192.3640
178.3376
168.2834
145.9224
137.7835
134.9155
132.2213
131.8355
130.5395
129.9253
128.9931
119.9210
114.6064
52.6897
41.5534
40.6496
27.4992
21.1353
MeO2C
PivHN
O
S
3fa
13C NMR (125 MHz, CDCl3)
f1 (ppm)



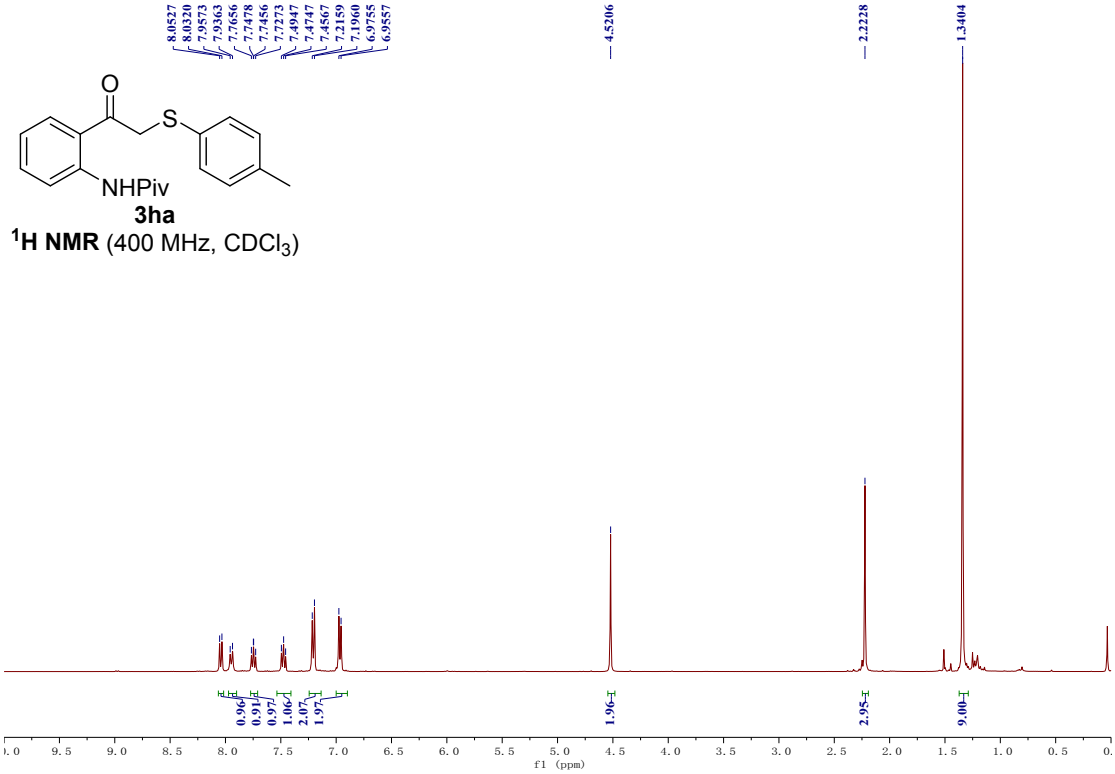
3ga

^{1}H NMR (300 MHz, $CDCl_3$)



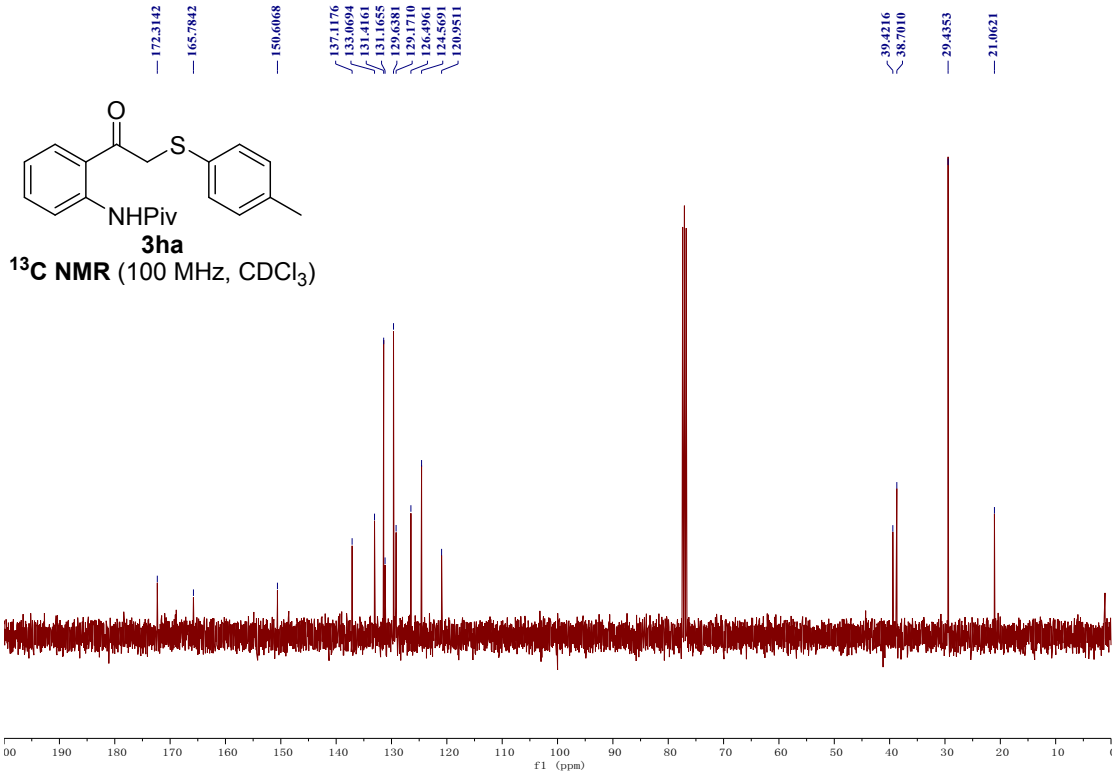
3ga

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



3ha

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

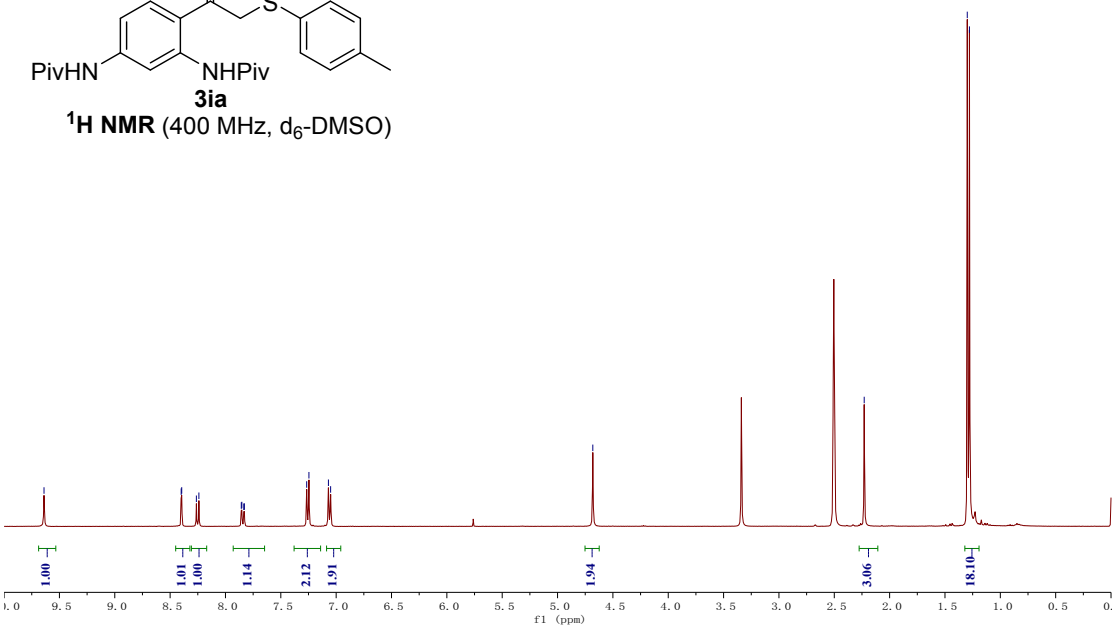


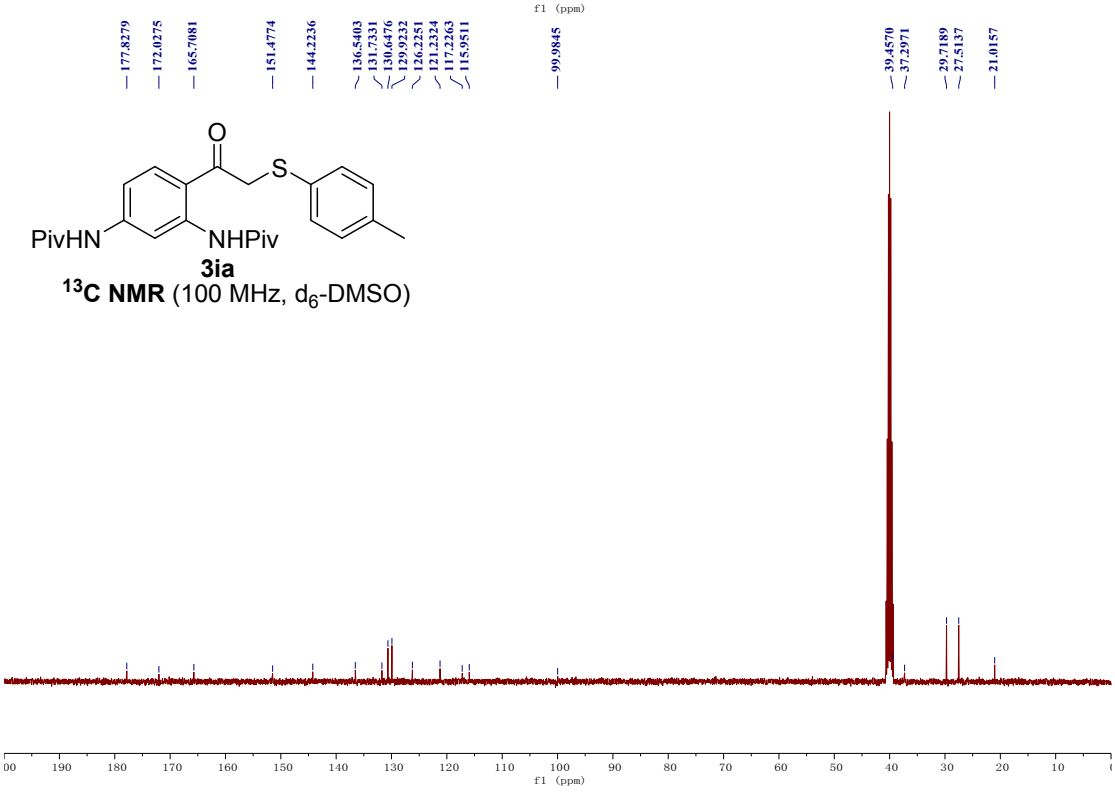
3ha

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

3ia

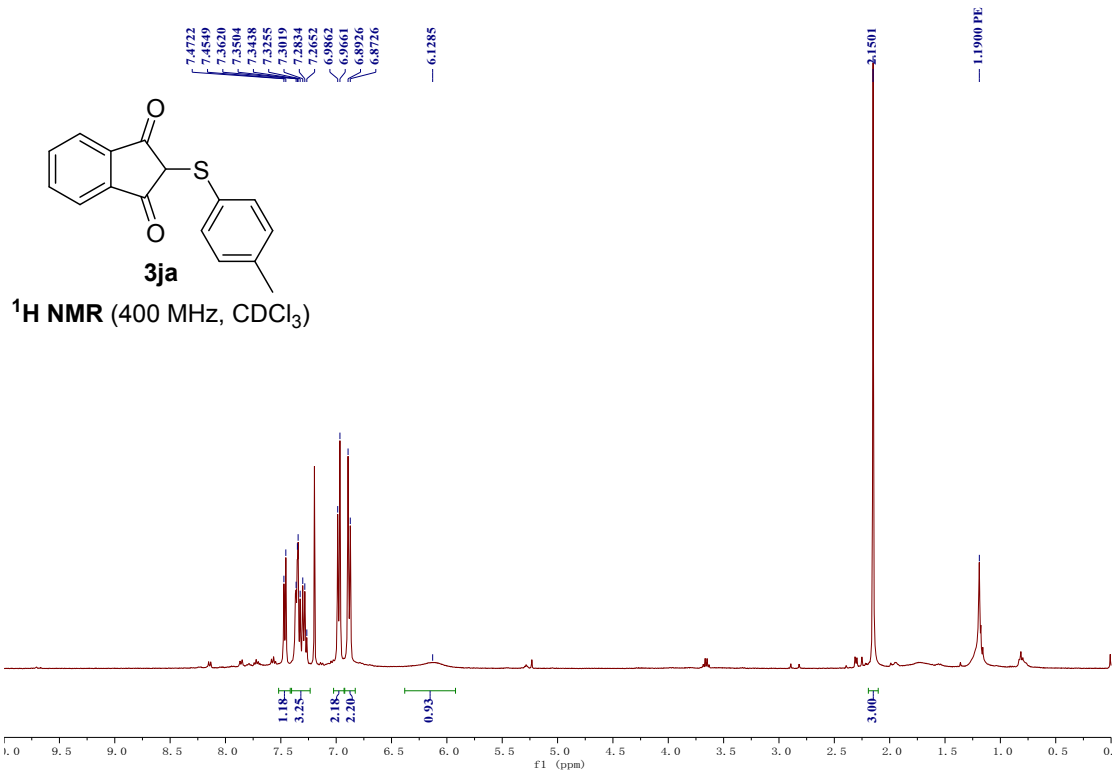
^{1}H NMR (400 MHz, d_6-DMSO)





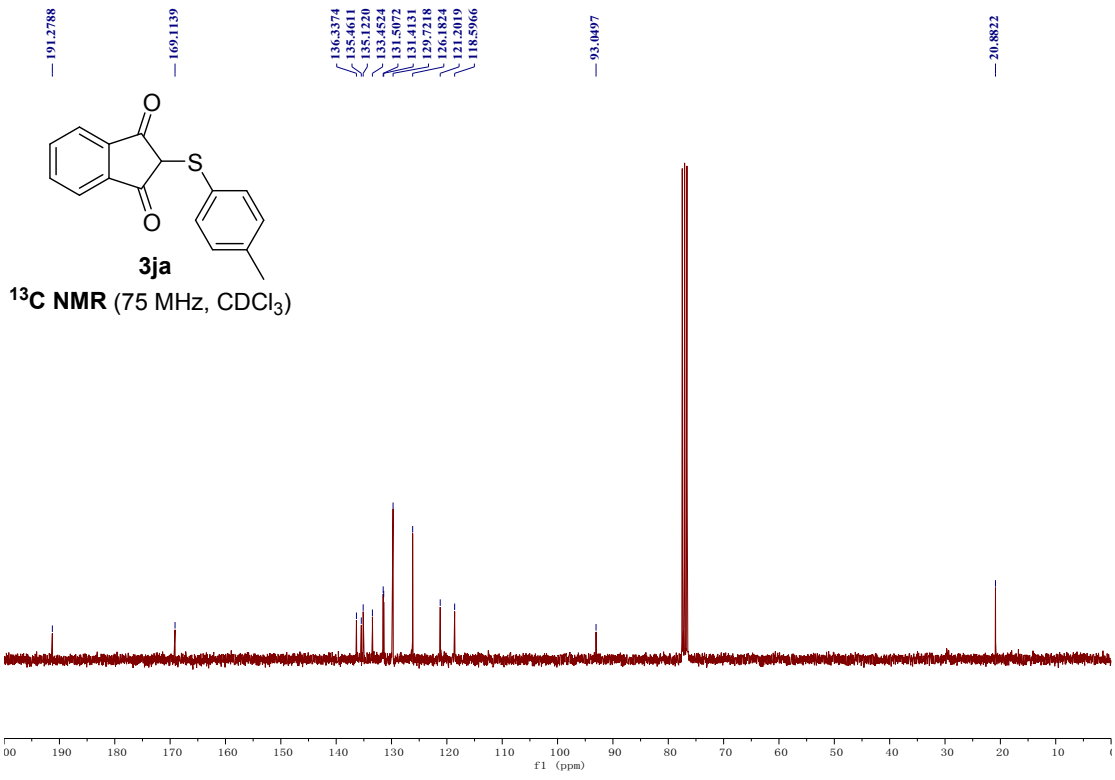
3ia

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



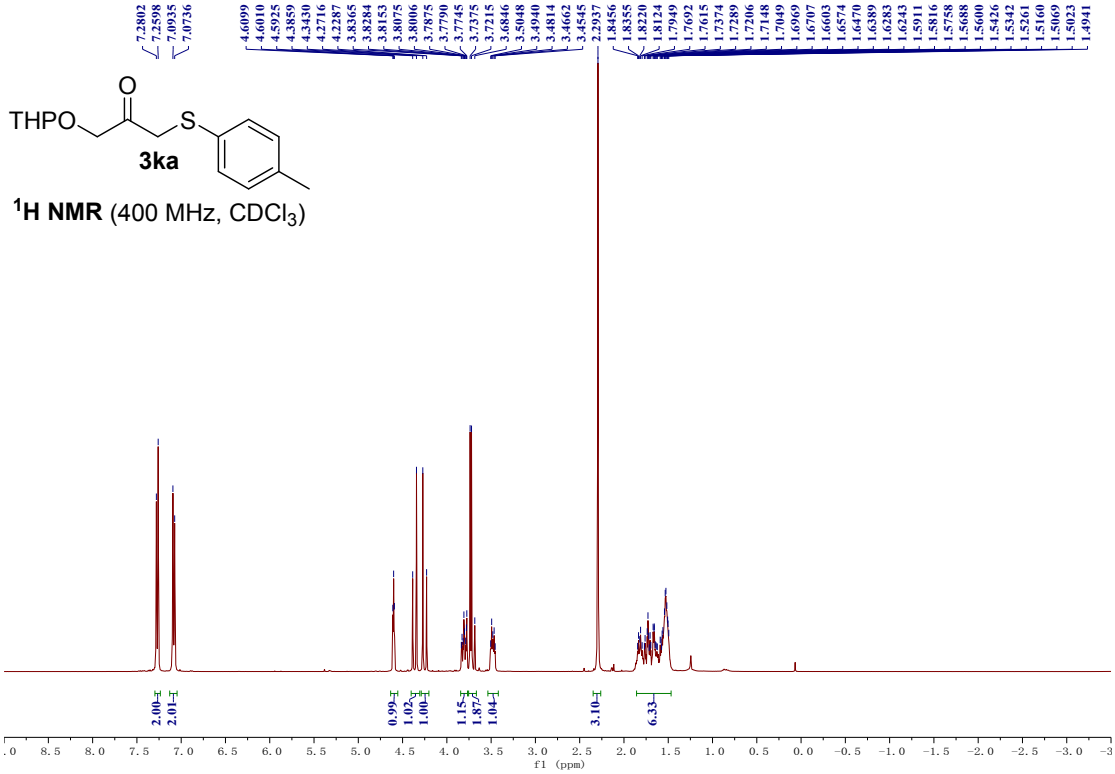
3ja

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

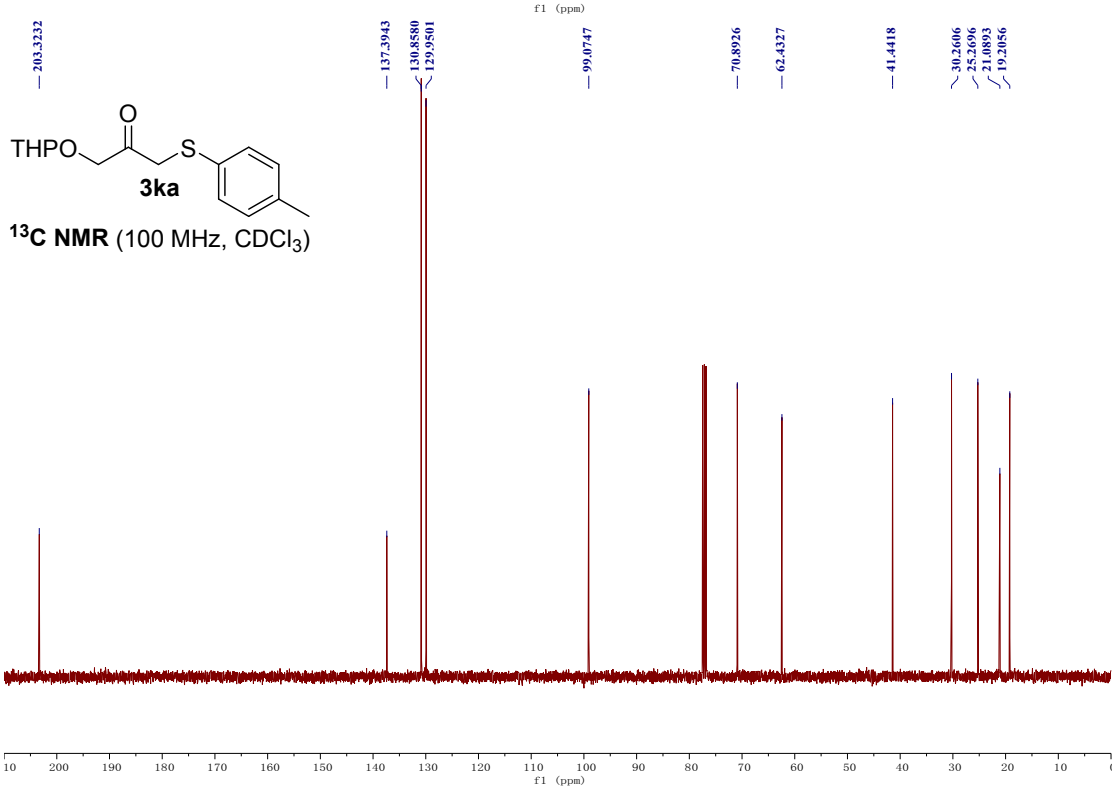


3ja

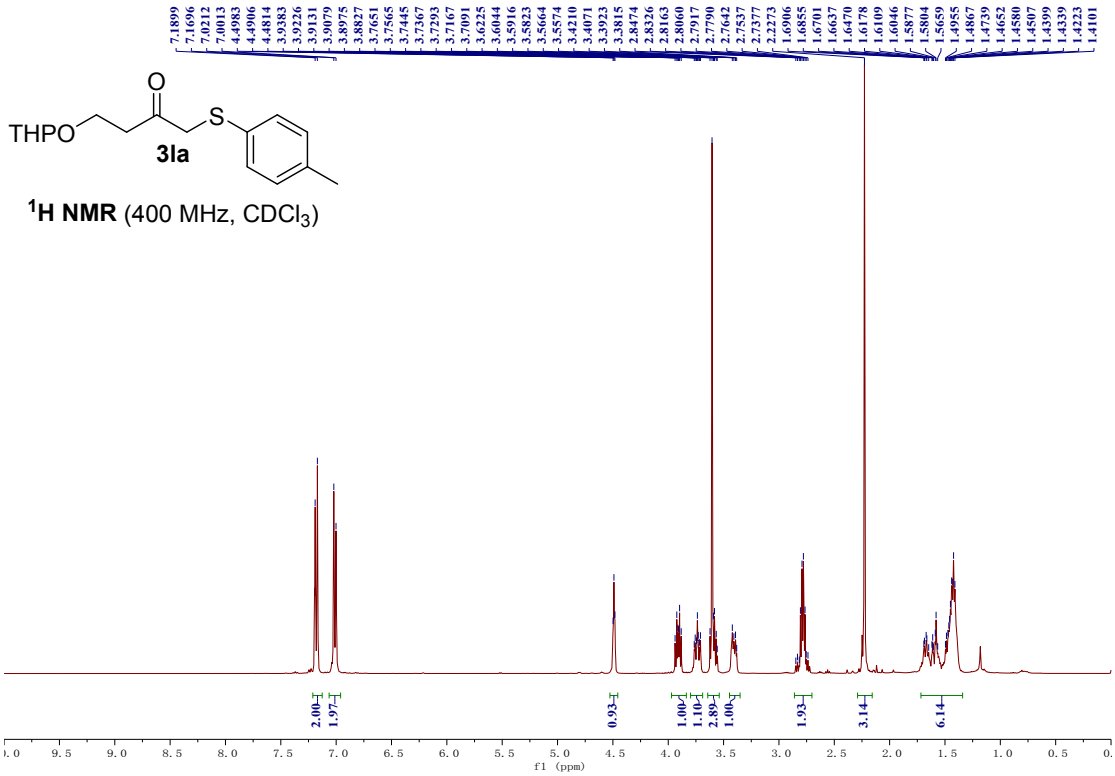
^{13}C NMR (75 MHz, $CDCl_3$)



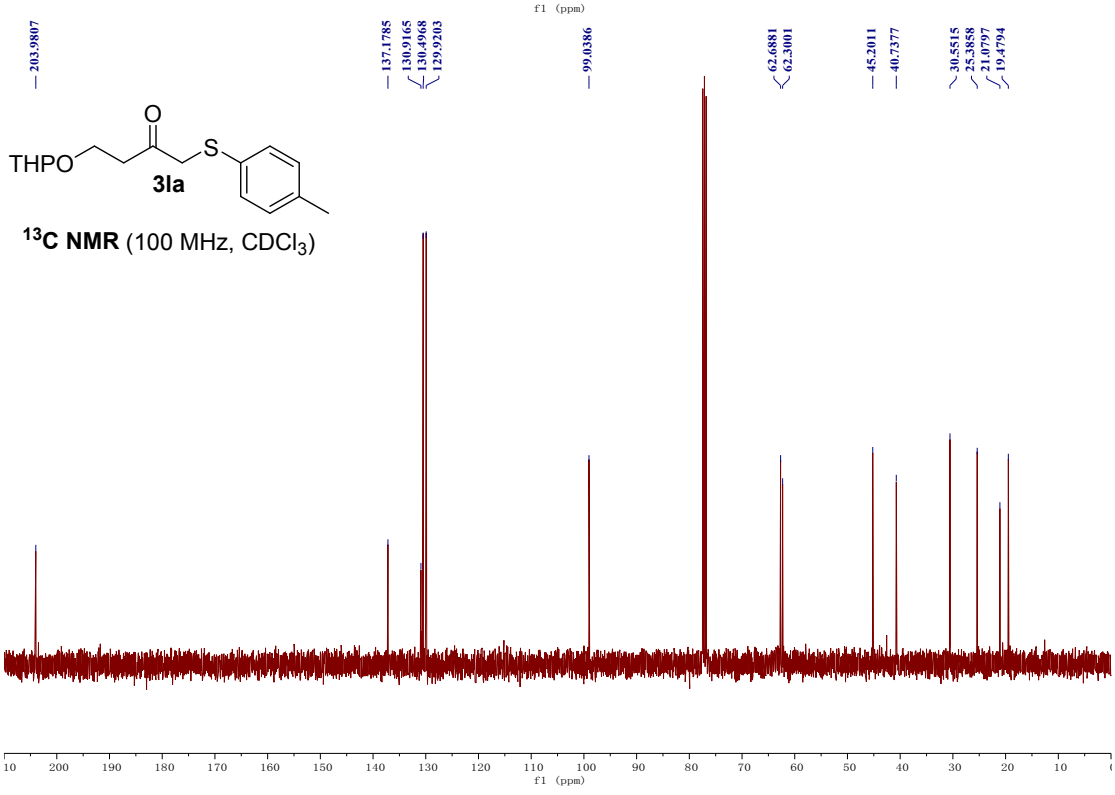
^{1}H NMR (400 MHz, $CDCl_3$)



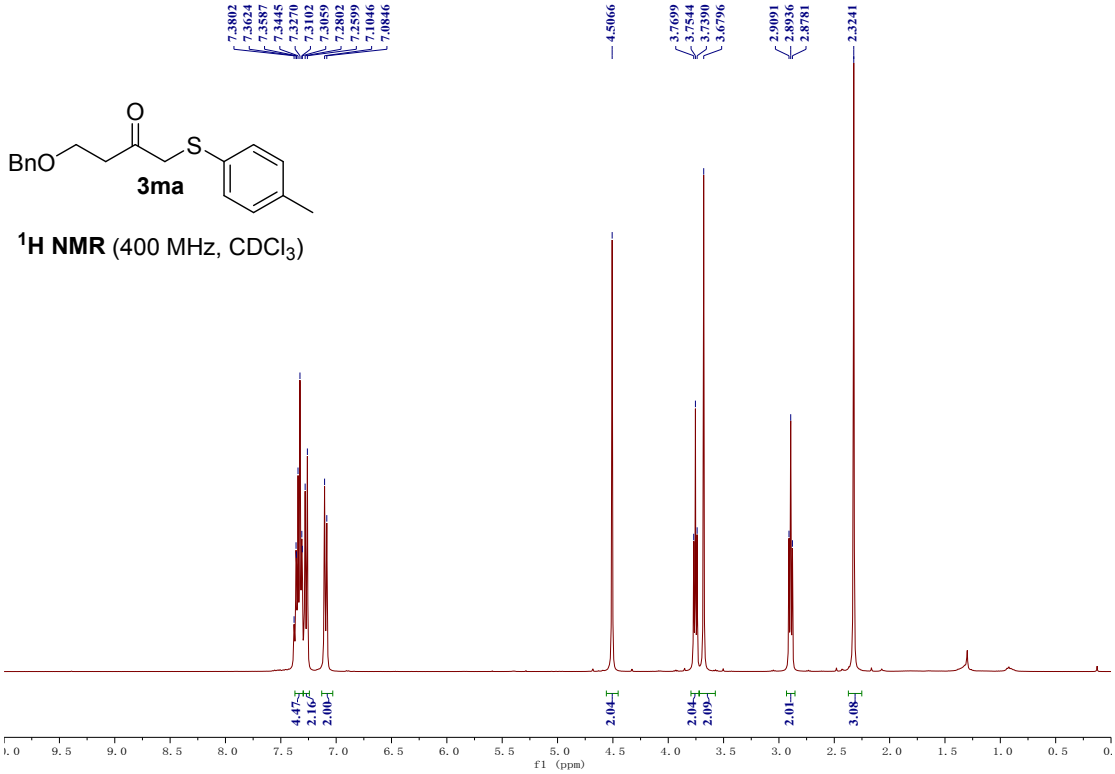
^{13}C NMR (100 MHz, $CDCl_3$)

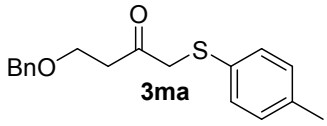


^{1}H NMR (400 MHz, $CDCl_3$)



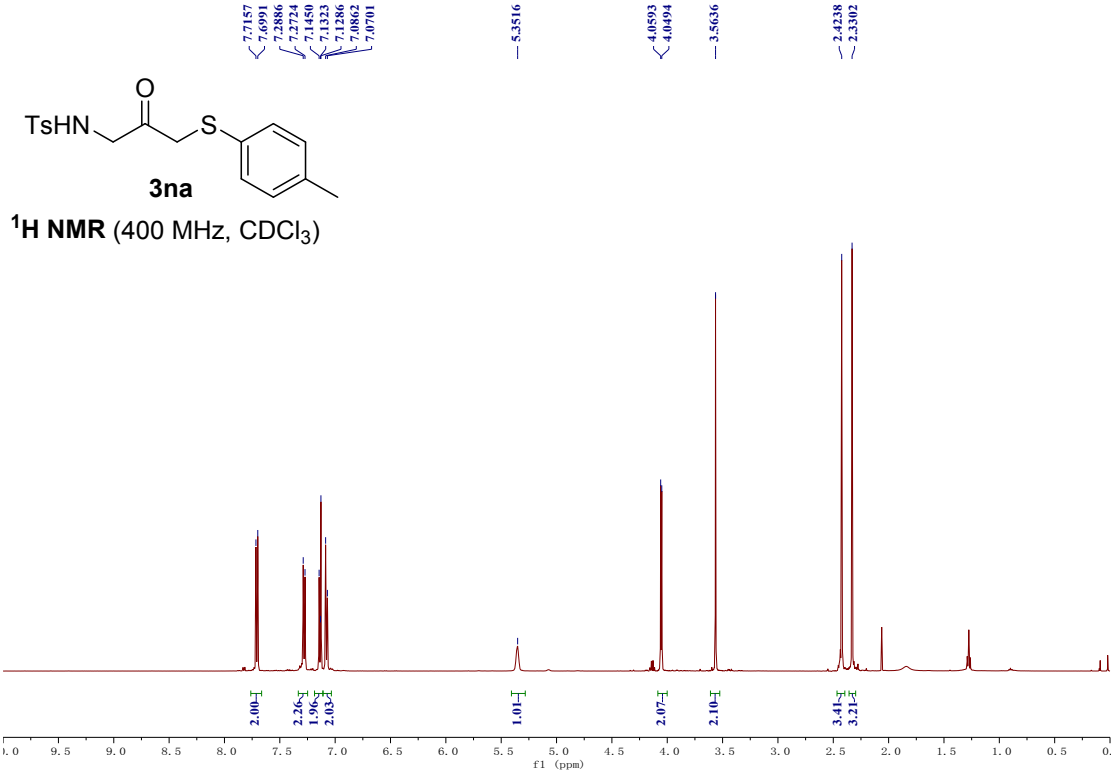
^{13}C NMR (100 MHz, $CDCl_3$)





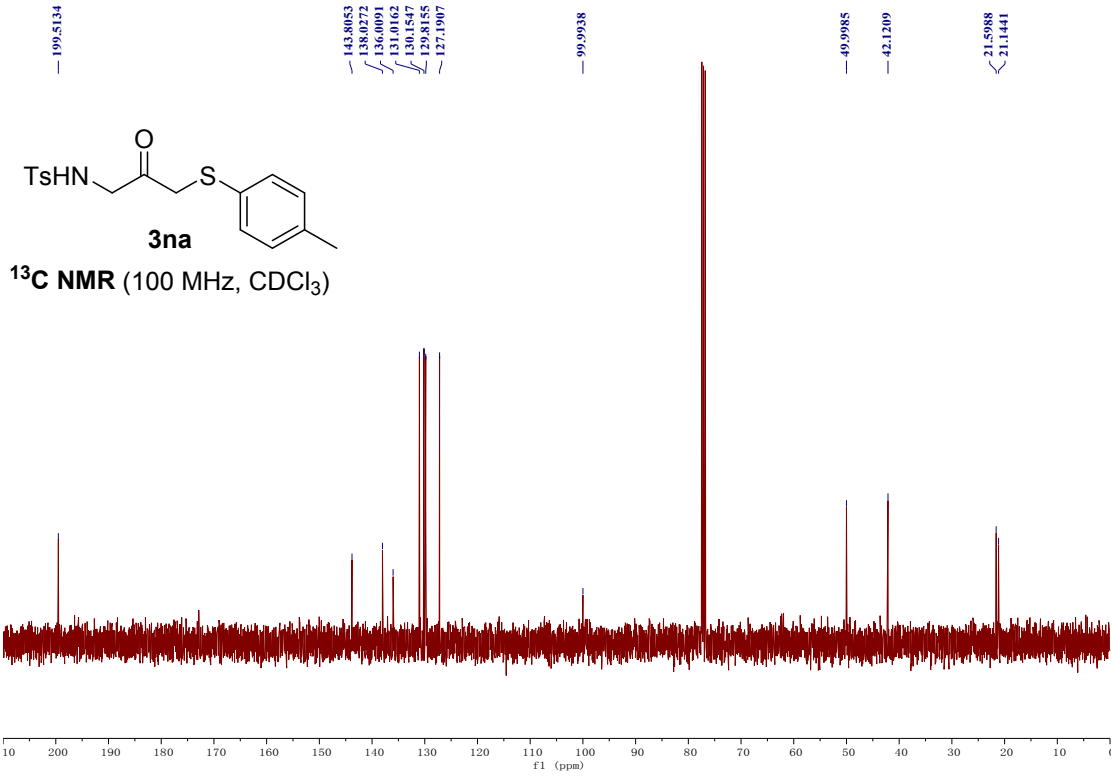
^{1}H NMR (400 MHz, $CDCl_3$)

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



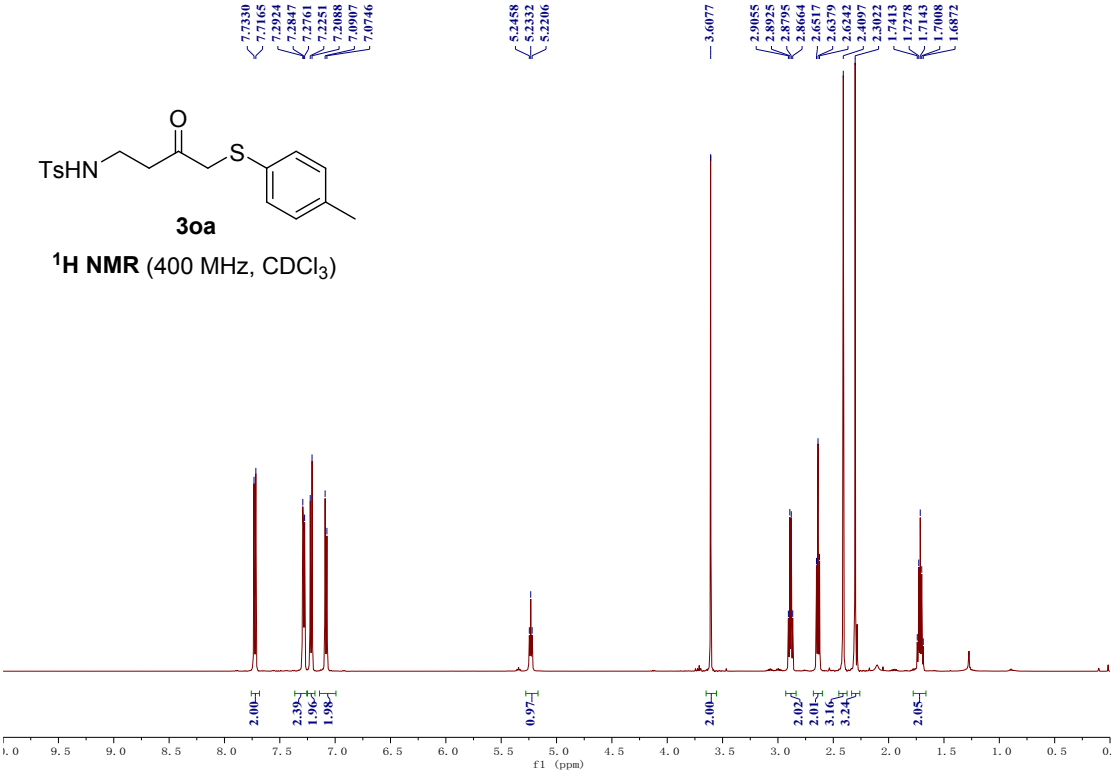
3na

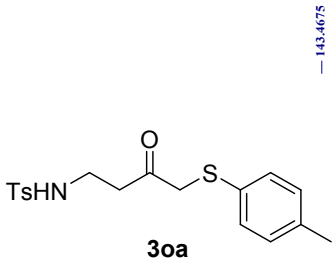
^{1}H NMR (400 MHz, $CDCl_3$)



3na

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



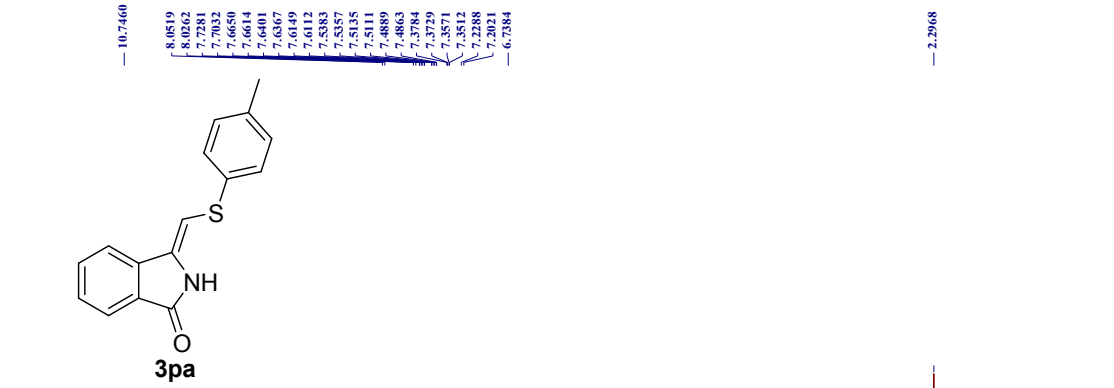


3oa

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

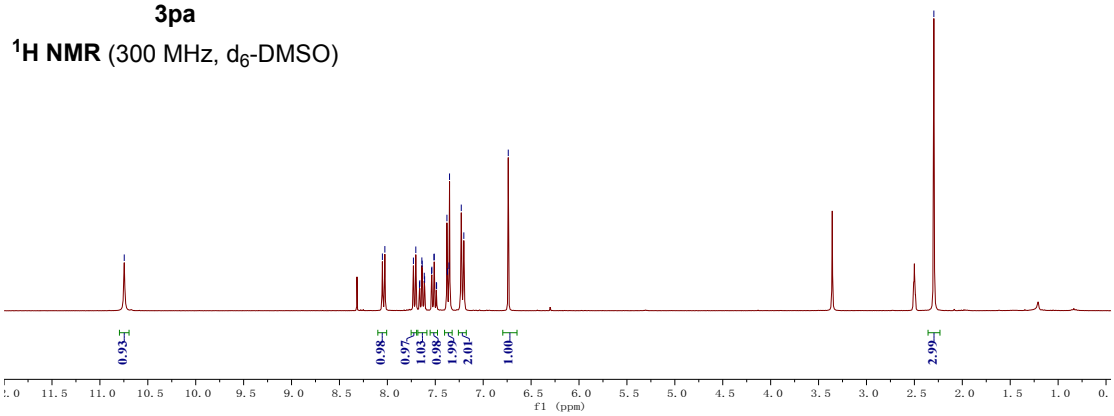
3oa

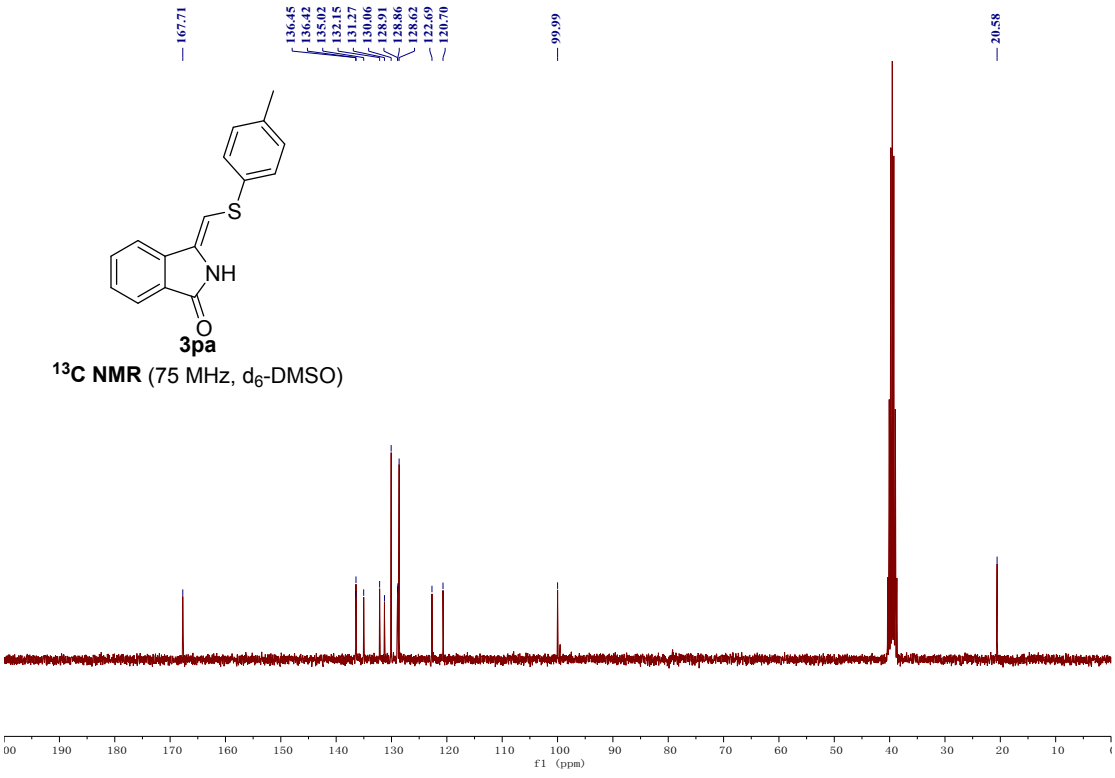
^{13}C NMR (100 MHz, $CDCl_3$)



3pa

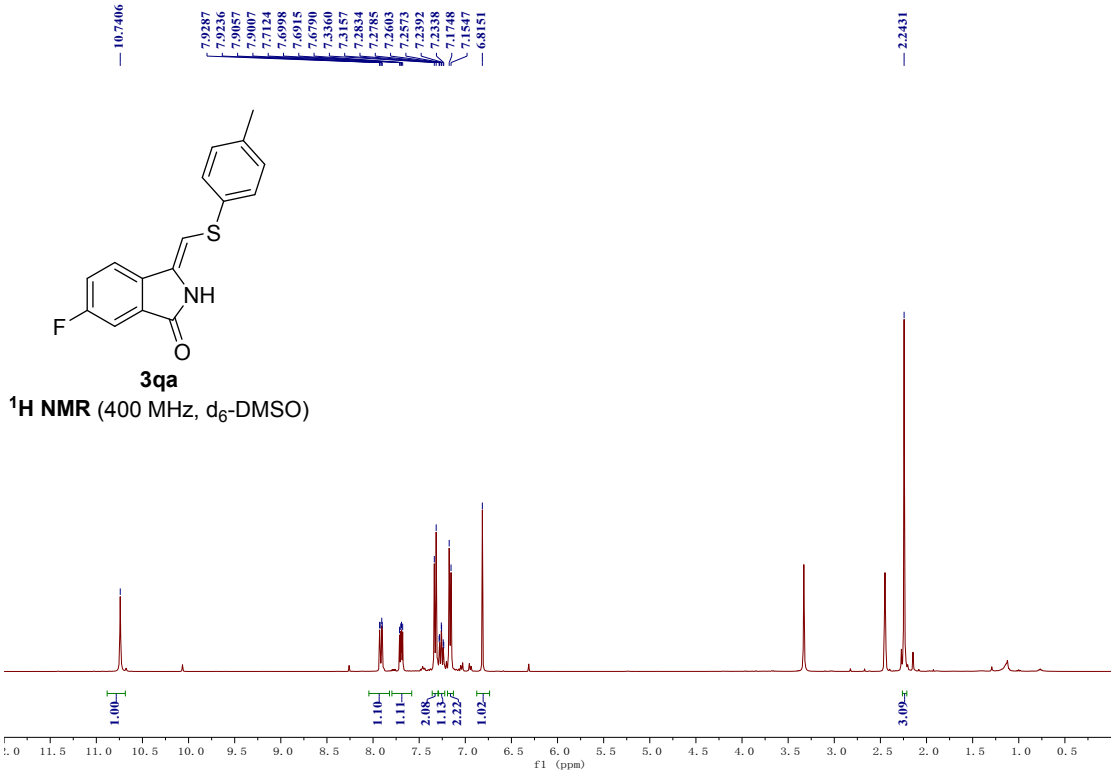
^{1}H NMR (300 MHz, d_6-DMSO)





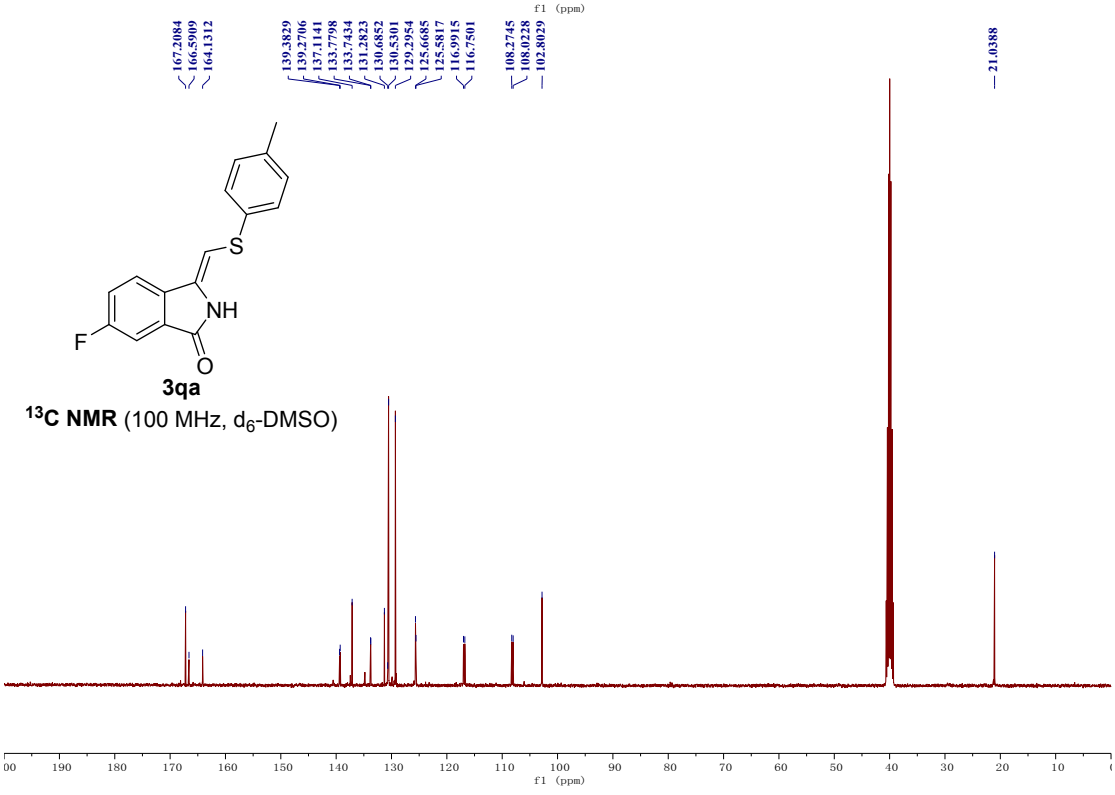
3pa

^{13}C NMR (75 MHz, d_6-DMSO)



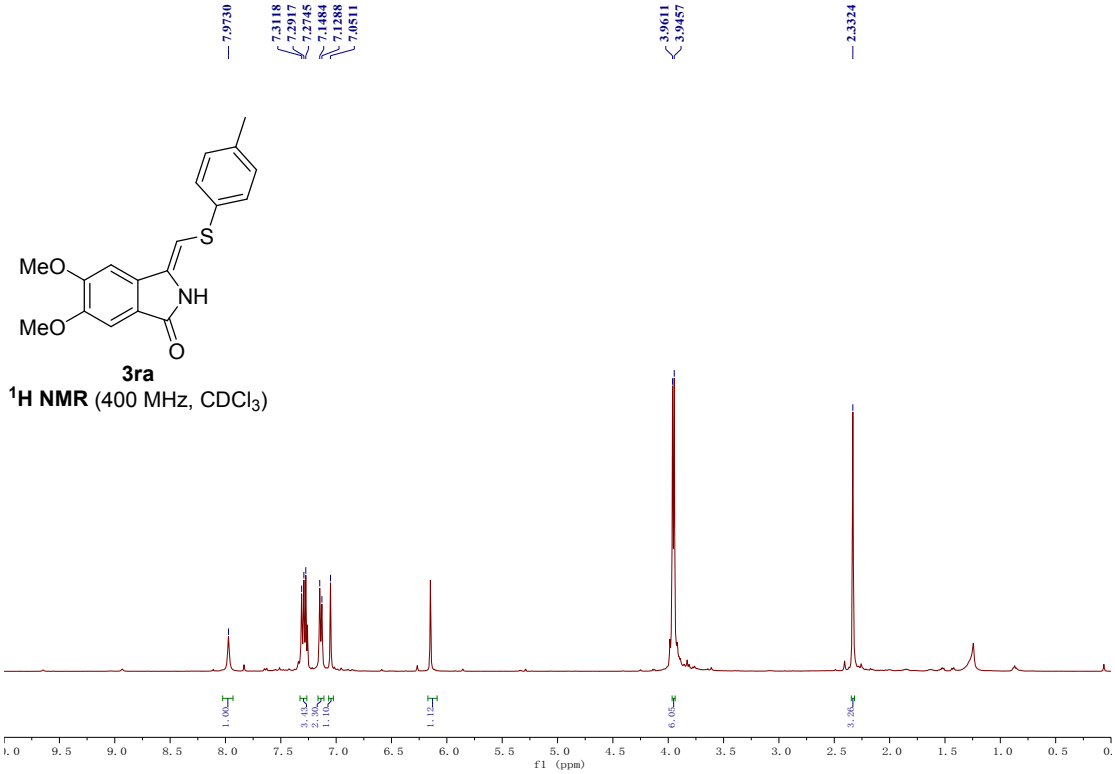
3qa

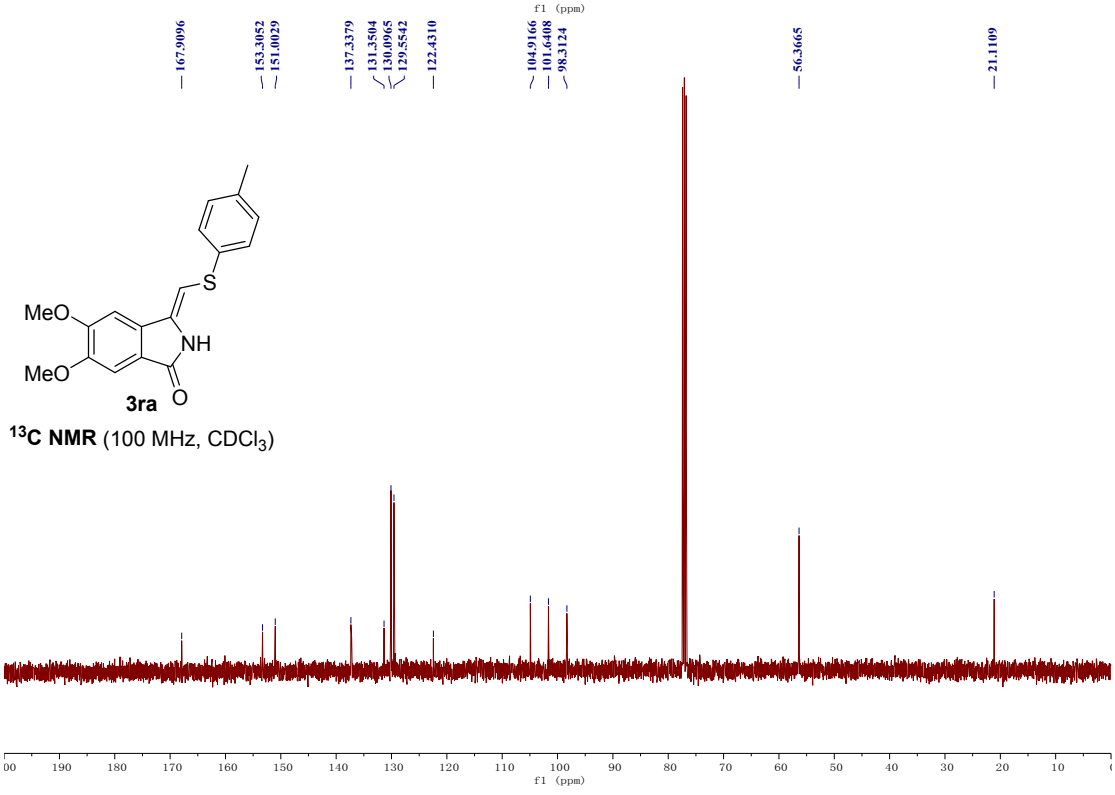
^{1}H NMR (400 MHz, d_6-DMSO)

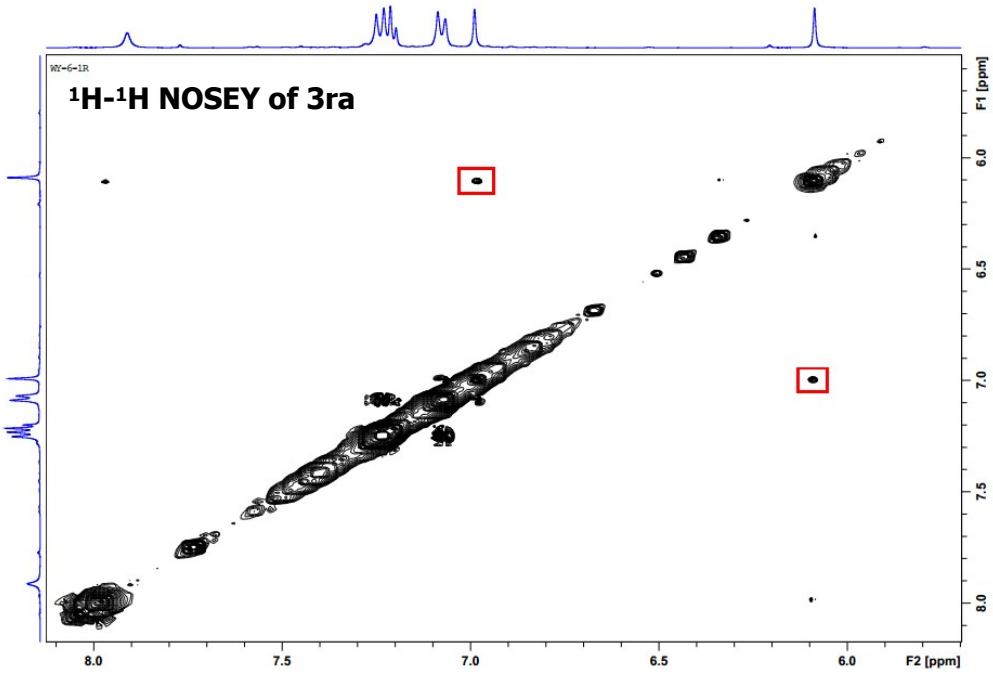


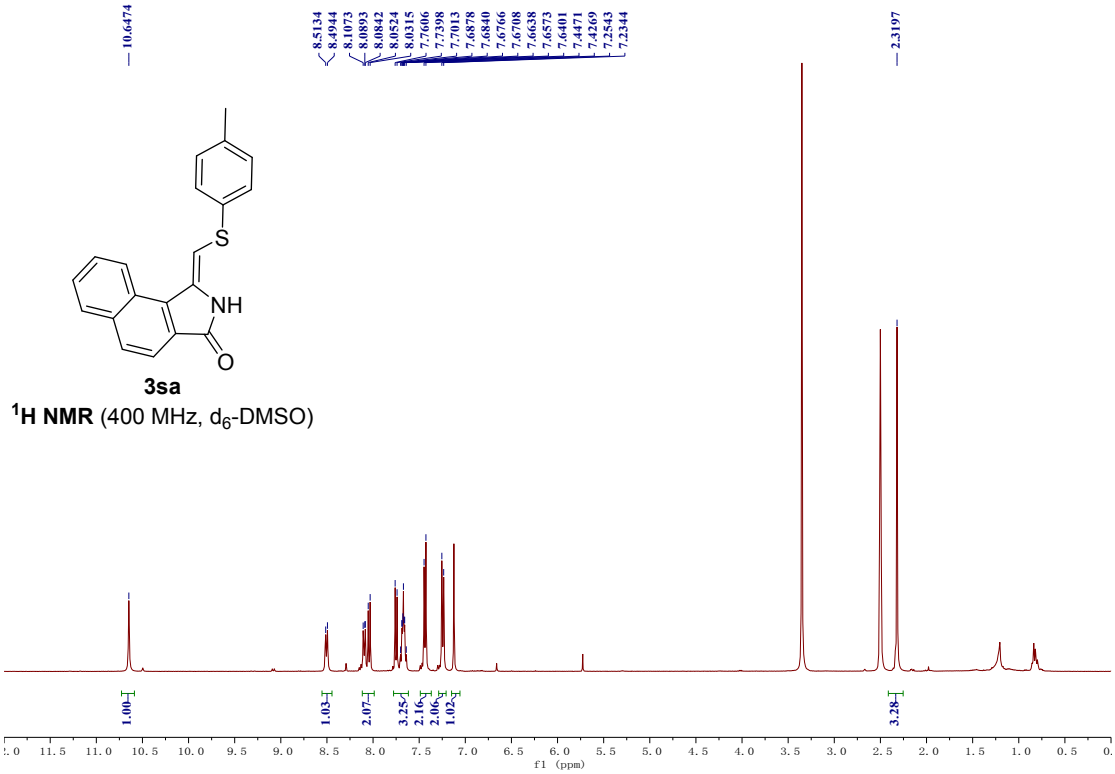
3qa

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


7.9730
7.3118
7.2917
7.2745
7.1484
7.1288
7.0511
3.9611
3.9457
2.3324
MeO
MeO
NH
S
O
3ra
1H NMR (400 MHz, CDCl3)
f1 (ppm)

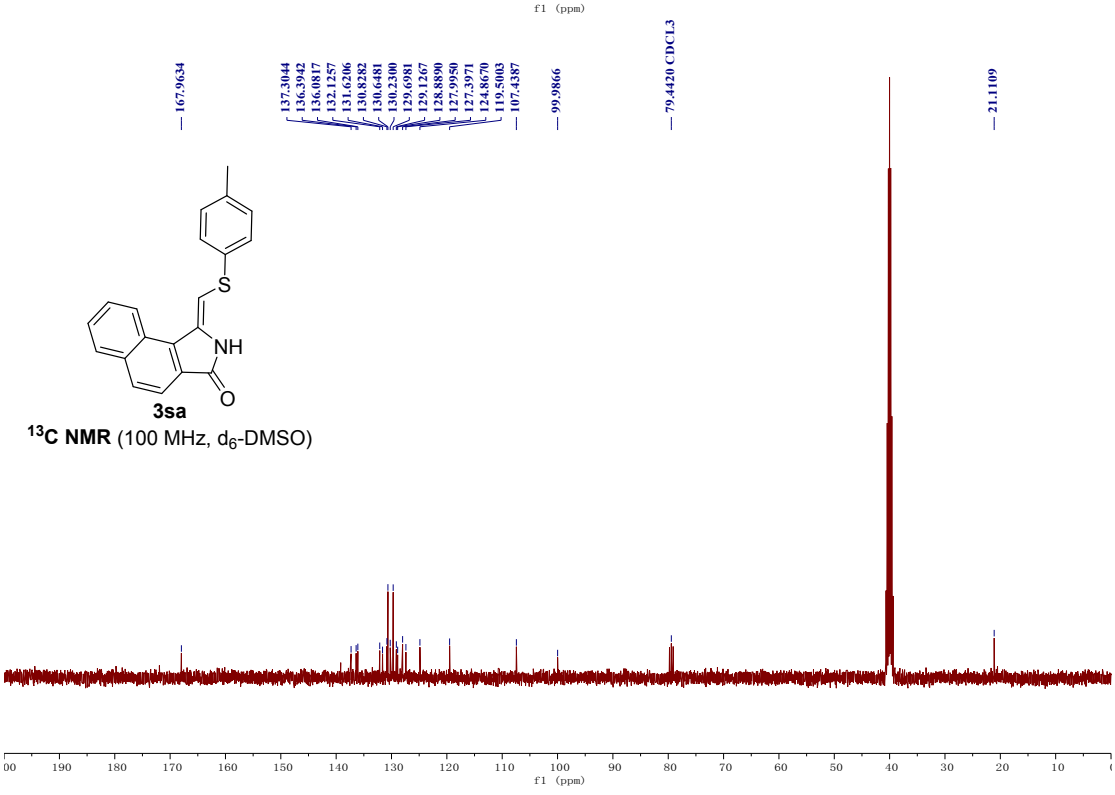

167.9096
153.3052
151.0029
137.3379
131.3504
130.0965
129.5542
122.4310
104.9166
101.6408
98.3124
56.3665
21.1109
MeO
MeO
NH
S
O
3ra
13C NMR (100 MHz, CDCl3)
f1 (ppm)


WY-6-1R
^{1}H-^{1}H NOSEY of 3ra
F1 [ppm]
6.0
6.5
7.0
7.5
8.0
8.0
7.5
7.0
6.5
6.0
F2 [ppm]



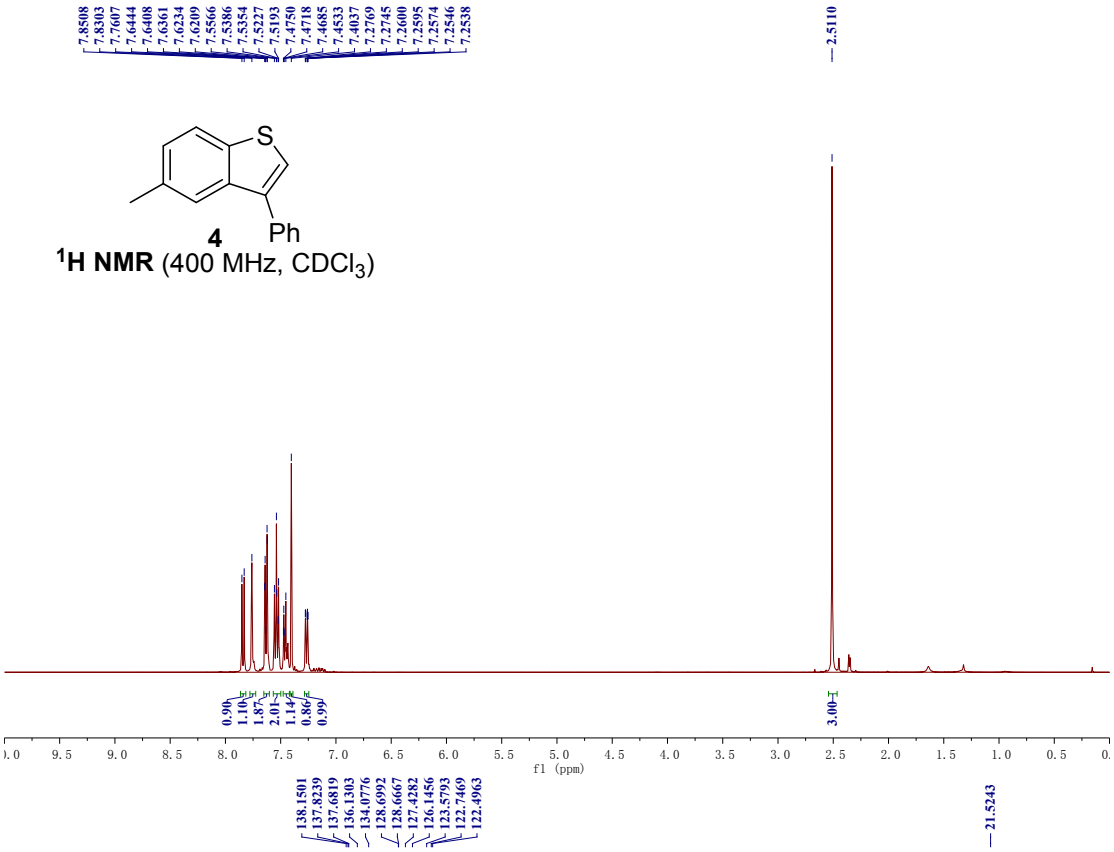
3sa

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



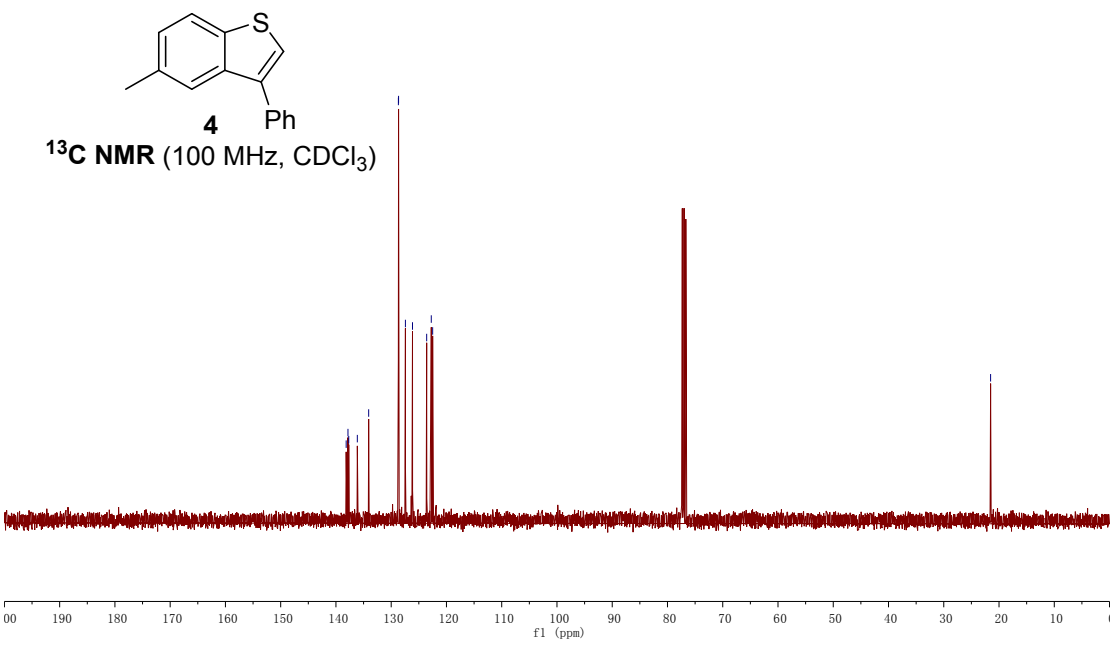
3sa

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



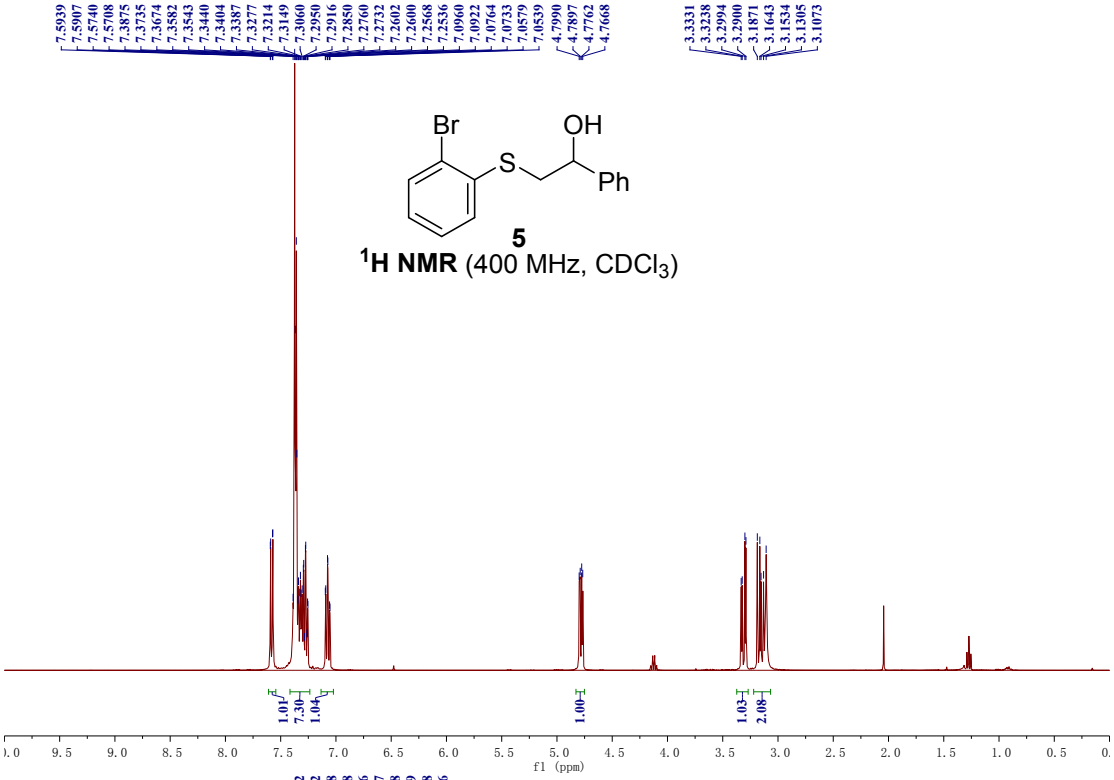
4

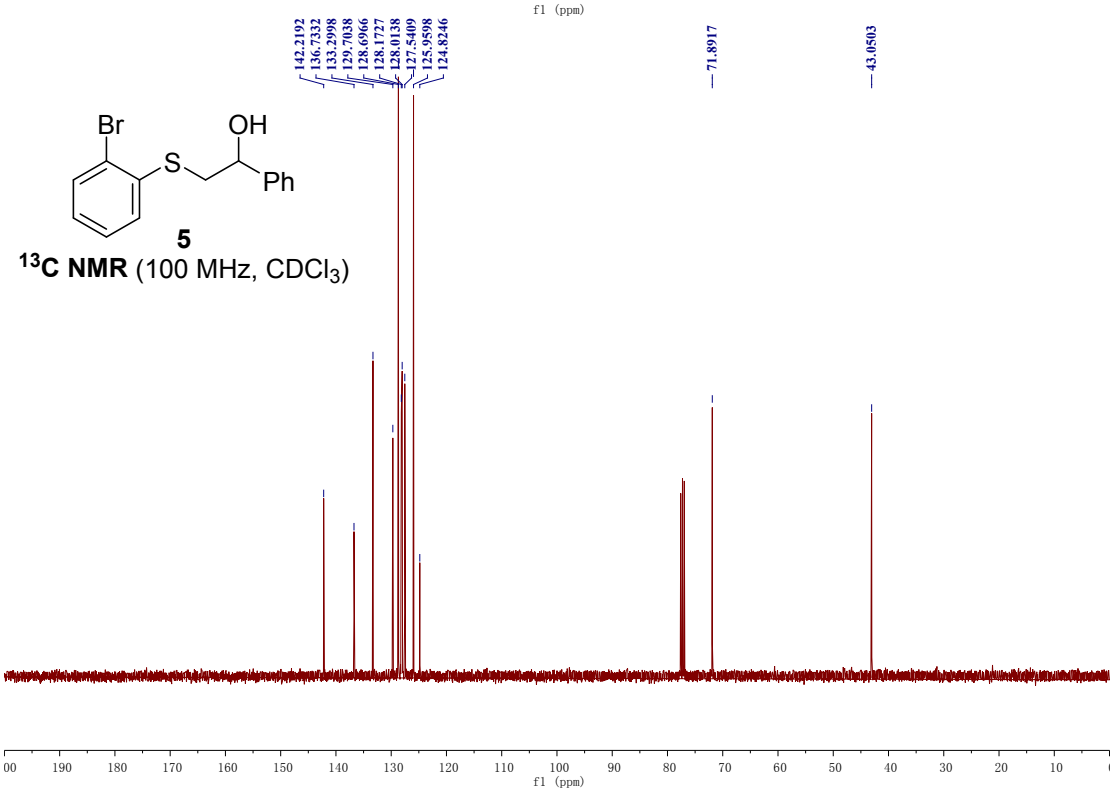
^{1}H NMR (400 MHz, $CDCl_3$)

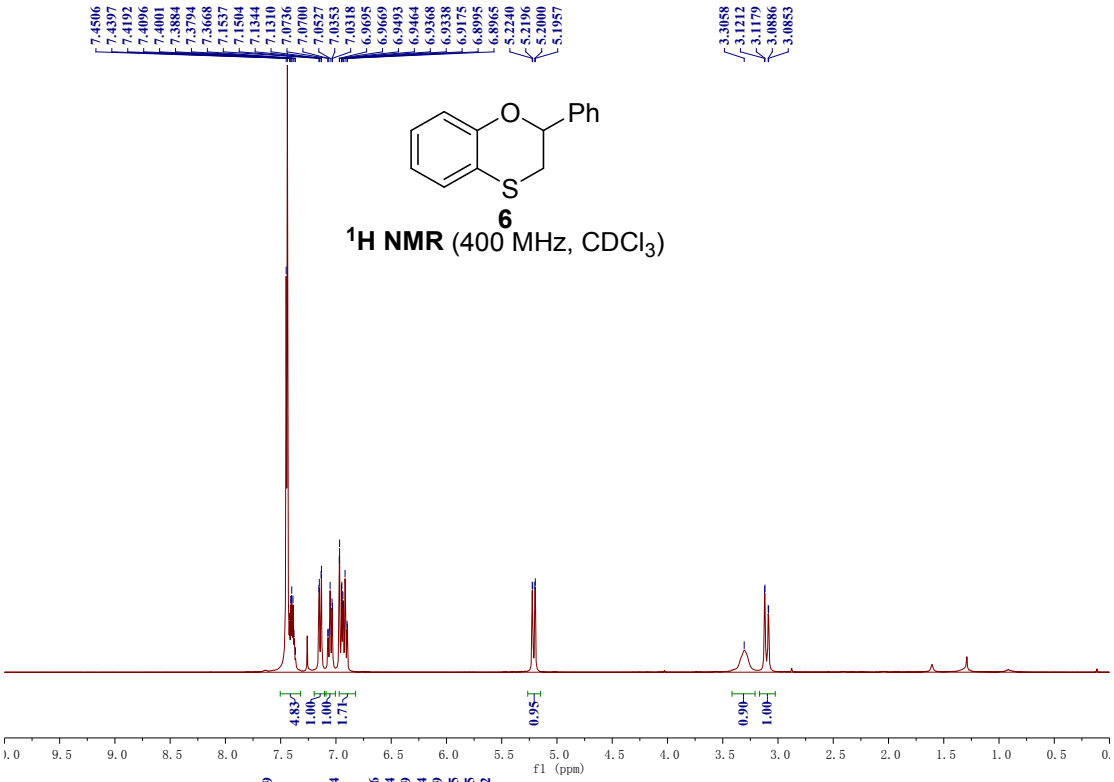


4

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

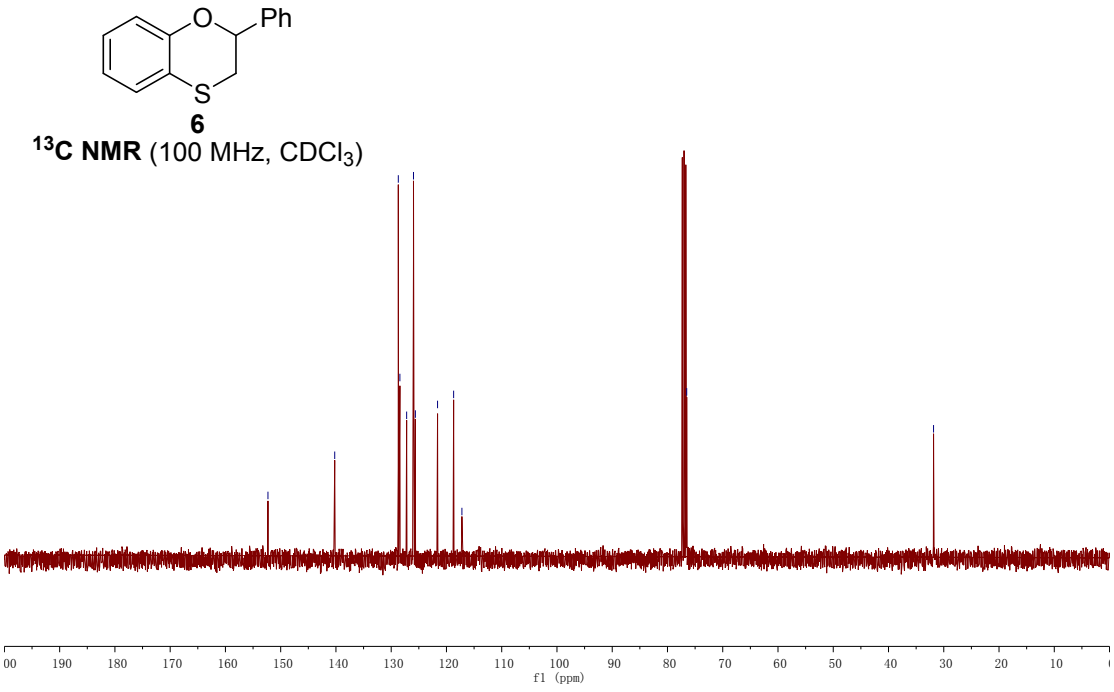

7.5939
7.5907
7.5740
7.5708
7.3875
7.3735
7.3674
7.3582
7.3543
7.3440
7.3404
7.3387
7.3277
7.3214
7.3149
7.3060
7.2950
7.2916
7.2850
7.2760
7.2732
7.2602
7.2600
7.2568
7.2536
7.0960
7.0922
7.0764
7.0733
7.0579
7.0539
4.7990
4.7897
4.7762
4.7668
3.3331
3.3238
3.2994
3.2900
3.1871
3.1643
3.1534
3.1305
3.1073
Br
OH
S
Ph
5
1H NMR (400 MHz, CDCl3)
1.01
7.30
1.04
1.00
1.03
2.08
f1 (ppm)


142.2192
136.7332
133.2998
129.7038
128.6966
128.1727
128.0138
127.5409
125.9598
124.8246
71.8917
43.0503
Br
OH
S
Ph
5
13C NMR (100 MHz, CDCl3)
f1 (ppm)



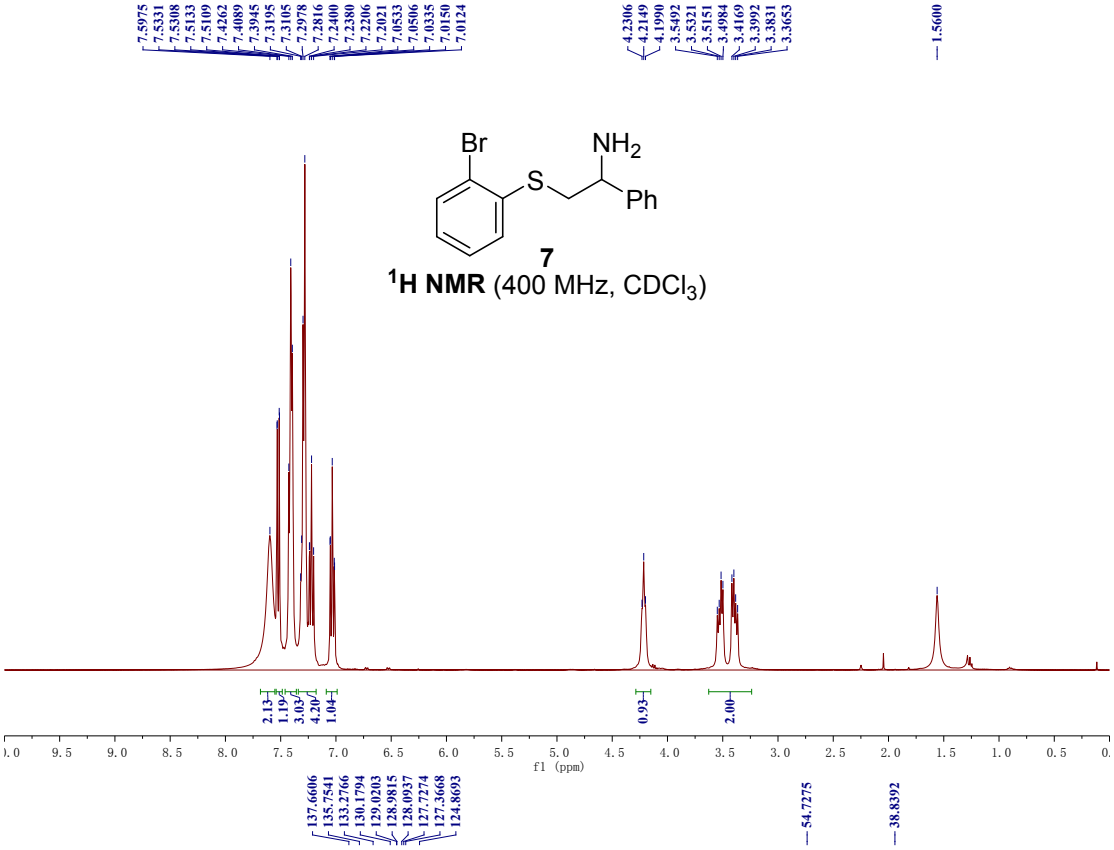
6

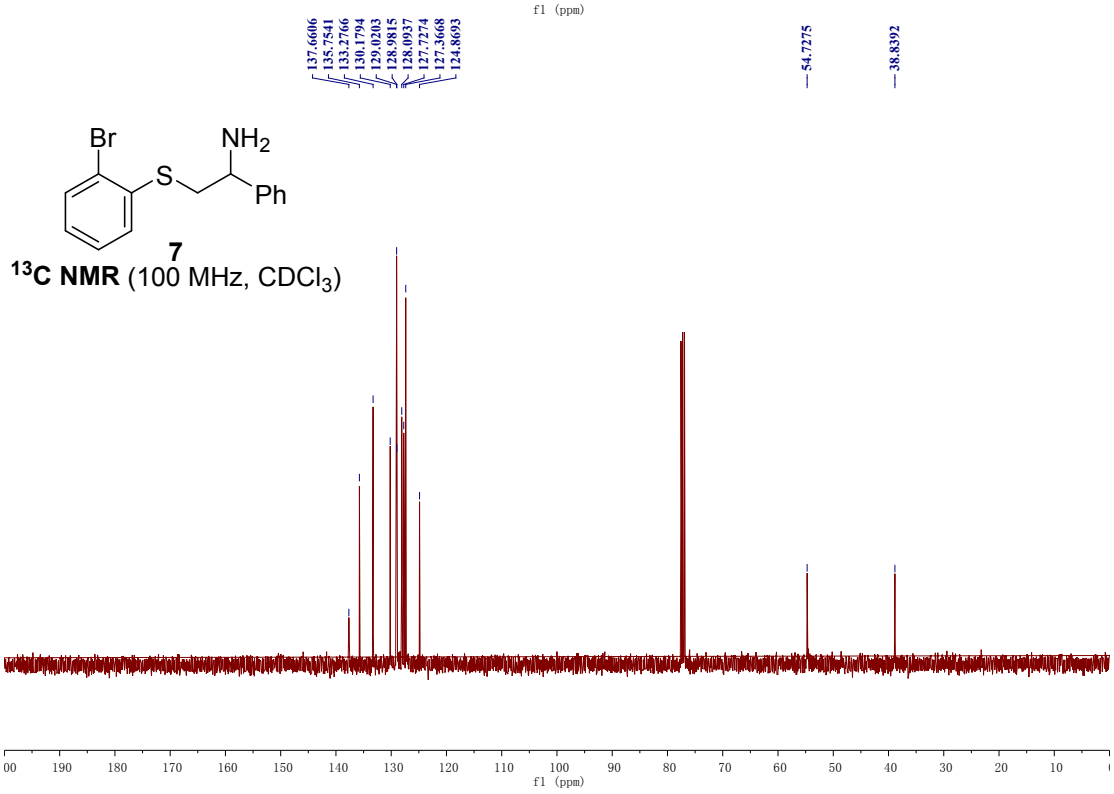
^{1}H NMR (400 MHz, $CDCl_3$)

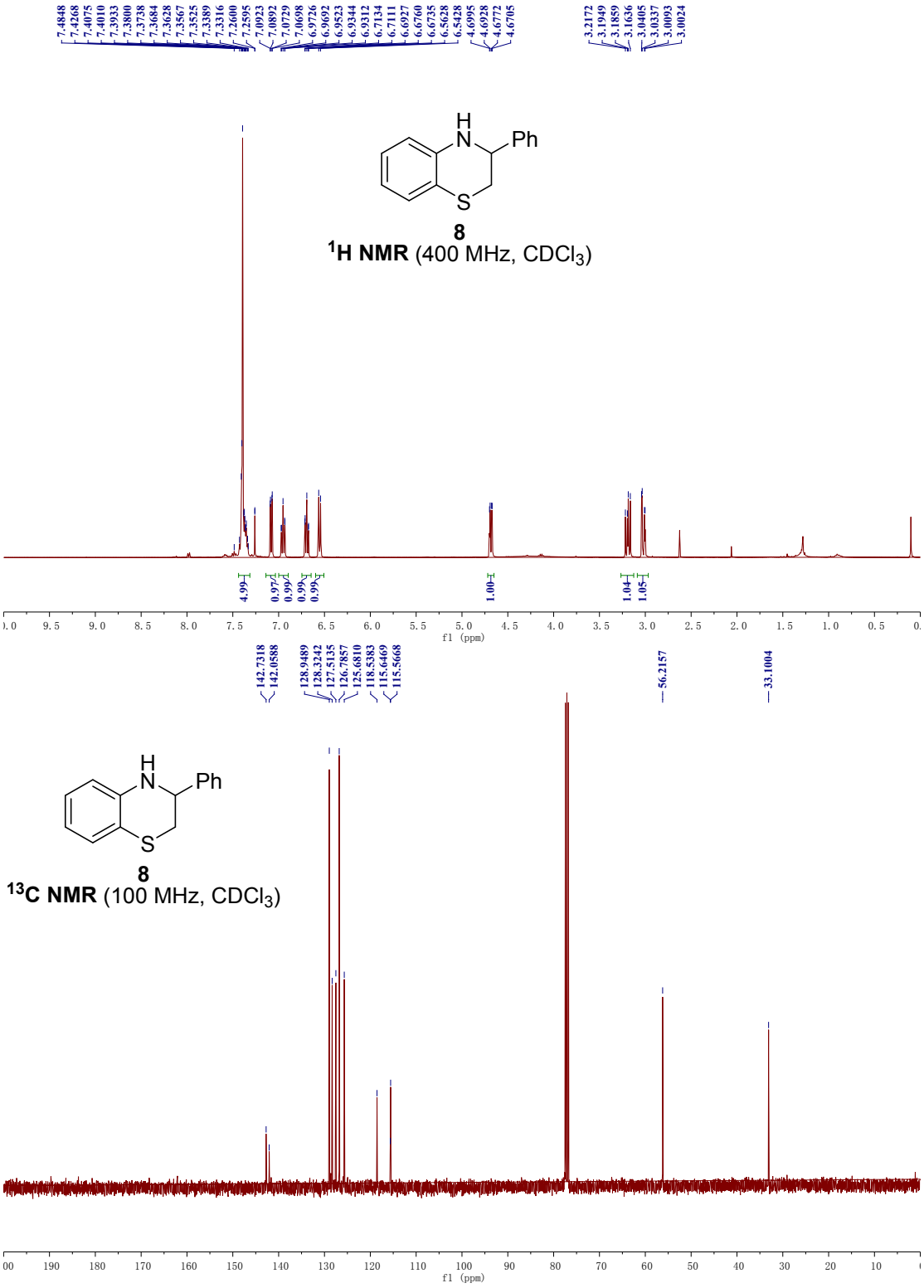


6

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


7.5975
7.5331
7.5308
7.5133
7.5109
7.4262
7.4089
7.3945
7.3195
7.3105
7.2978
7.2816
7.2400
7.2380
7.2206
7.2021
7.0533
7.0506
7.0335
7.0150
7.0124
4.2306
4.2149
4.1990
3.5492
3.5321
3.5151
3.4984
3.4169
3.3992
3.3831
3.3653
1.5600
Br
NH2
S
Ph
7
1H NMR (400 MHz, CDCl3)
2.13
1.19
3.03
4.20
1.04
0.93
2.00
f1 (ppm)


137.6606
135.7541
133.2766
130.1794
129.0203
128.9815
128.0937
127.7274
127.3668
124.8693
54.7275
38.8392
Br
NH2
S
Ph
7
13C NMR (100 MHz, CDCl3)
f1 (ppm)


7.4848
7.4268
7.4075
7.4010
7.3933
7.3800
7.3738
7.3684
7.3628
7.3567
7.3525
7.3389
7.3316
7.2600
7.2595
7.0923
7.0892
7.0729
7.0698
6.9726
6.9692
6.9523
6.9344
6.9312
6.7134
6.7111
6.6927
6.6760
6.6735
6.5628
6.5428
4.6995
4.6928
4.6772
4.6705
3.2172
3.1949
3.1859
3.1636
3.0405
3.0337
3.0093
3.0024
H
N
Ph
S
8
1H NMR (400 MHz, CDCl3)
4.99
0.97
0.99
0.99
1.00
1.04
1.05
f1 (ppm)
142.7318
142.0588
128.9489
128.3242
127.5135
126.7857
125.6810
118.5383
115.6469
115.5668
56.2157
33.1004
H
N
Ph
S
8
13C NMR (100 MHz, CDCl3)
f1 (ppm)