Advanced Synthesis & Catalysis

Supporting Information

Palladium-Catalyzed Alkene Carboamination Reactions of Electron-Poor Nitrogen Nucleophiles

Luke J. Peterson, and John P. Wolfe*

Department of Chemistry, University of Michigan, 930 N. University Avenue, Ann Arbor, Michigan 48109-1055

Supporting Information

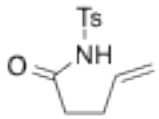
Experimental procedures and characterization data for new compounds in Tables 2–5, Scheme 2, and Equations 3–4.

Table of Contents

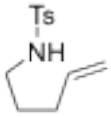
General: All reactions were carried out at under a nitrogen atmosphere in flame-dried glassware. Palladium(II) acetate and RuPhos were purchased from Strem Chemical Co. and used without purification, and CPhos was purchased from Sigma-Aldrich Co. and was used without further purification. Aryl triflates were prepared according to a procedure published by Frantz and coworkers,[1] except the compounds were purified by column chromatography. All other reagents were obtained from commercial sources and were used as obtained unless otherwise noted. (±)-4-Methyl-*N*-{2-methyl-2-[(trimethylsilyl)oxy]pent-4-en-1-yl}benzenesulfonamide (**10**) was prepared as previously reported.[2] Bulk quantities of lithium *tert*-butoxide and sodium *tert*-butoxide were stored in nitrogen-filled glove box and small amounts were removed shortly before use. Toluene, THF, dichloromethane and diethyl ether were purified using a GlassContour solvent purification system. Ratios of diastereomers were determined by ^{1}H NMR analysis. Yields refer to isolated yields of compounds estimated to be ≥95% pure as determined by ^{1}H NMR analysis unless otherwise noted. The yields reported in the supporting information describe the result of a single experiment, whereas yields reported in Tables 2–5, Scheme 2, and equations 3–4 are average yields of two or more experiments. Thus, the yields reported in the supporting information may differ from those shown in Tables 2–5, Scheme 2, and equations 3–4. Due to the presence of diastereomers for compounds **8b**–**8e**

and **9b**–**9e**, it was not possible to accurately determine coupling constants for fluorine-coupled carbons. As such, for these compounds a simple list of all ^{13}C signals observed for the mixture is provided.

Experimental Procedures and Compound Characterization Data

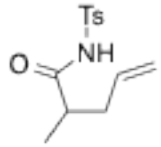


***N*-Tosylpent-4-enamide (S1).**[3] A flame-dried flask equipped with a rubber septum and a stirbar was cooled under a stream of nitrogen and charged with 4-pentenoic acid (1 g, 10 mmol) and THF (20 mL), then *p*-toluenesulfonyl isocyanate (1.5 mL, 10 mmol) was added. After stirring at rt for 10 min the septum was removed and triethylamine (1.4 mL, 10 mmol) was added dropwise to the open flask, allowing for the release of the formed CO_2. The resulting mixture was stirred at rt for 3 h then was diluted with 20 mL EtOAc, transferred to a separatory funnel, and then washed with HCl and brine. The organic layer was then dried over anhydrous Na_2SO_4, filtered, and concentrated *in vacuo* to yield 2.42 g (96%) of a white crystalline solid that was used without further purification. ^1H NMR (400 MHz, $CDCl_3$) δ 8.04 (s, br, 1 H), 7.94 (d, J = 8.5 Hz, 2 H), 7.34 (d, J = 8.0 Hz, 2 H), 5.76–5.69 (m, 1 H), 5.02–4.97 (m, 2 H), 2.45 (s, 3 H), 2.37–2.3 (m, 4 H).

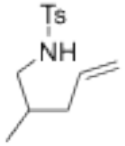


4-Methyl-*N*-(pent-4-en-1-yl)benzenesulfonamide (5a).[4] A flame dried flask was cooled under a stream of nitrogen and charged with **S1** (2.42 g, 9.05 mmol) and THF (27 mL). The mixture was cooled to 0 °C then lithium aluminum hydride (27.2 mL, 1 M in THF) was added slowly, and the reaction mixture was warmed to rt and stirred overnight. The mixture was then cooled to °C and quenched with H_2O (9 mL). Diethyl ether (27 mL) was added, followed by a solution of 10 M aqueous NaOH (27 mL). The organic layer was decanted, and the remaining white solid was washed with diethyl ether (2 x 27 mL). The combined organic layers were then dried over Na_2SO_4, filtered, and evaporated *in vacuo* to afford a clear, colorless oil. The crude product was purified via flash chromatography on silica gel to afford 1.54 g (71%) of the desired product as a colorless oil. Spectroscopic data for the compound are consistent with those previously reported.[4] ^1H NMR (500 MHz, $CDCl_3$) δ 7.75 (d, J = 8.0 Hz, 2 H), 7.30 (d, J = 8.0 Hz, 2 H),

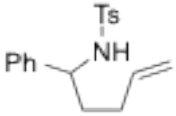
5.73–5.68 (m, 1 H), 4.99–4.95 (m, 2 H), 4.38 (s, br, 1 H), 2.96 (q, *J* = 6.8 Hz, 2 H), 2.43 (s, 3 H), 2.05 (q, *J* = 7.1 Hz, 2 H), 1.56 (p, *J* = 7.0 Hz, 2 H).



2-Methyl-*N*-tosylpent-4-enamide (S2). A procedure similar to that for used for the preparation of **S1** was employed for the conversion of 2-methyl-4-pentenoic acid (0.685 g, 6.0 mmol) to the title compound. This procedure afforded 1.53 g (95%) of the desired product as a white solid that was used without further purification. ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.15 (s, br, 1 H), 7.94 (d, *J* = 8.0 Hz, 2 H), 7.34 (d, *J* = 8.0 Hz, 2 H), 5.66–5.56 (m, 1 H), 5.00–4.94 (m, 2 H), 2.45 (s, 3 H), 2.35–2.14 (m, 2 H), 2.15–2.08 (m, 1 H), 1.11 (d, *J* = 6.8 Hz, 3 H).

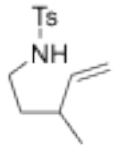


4-Methyl-*N*-(2-methylpent-4-en-1-yl)benzenesulfonamide (5b).[5] A procedure similar to that used for the preparation of **5a** was employed for the conversion of **S2** to the title compound. This procedure afforded 0.60 g (42%) of the desired product as a colorless oil. Spectroscopic data for the compound are consistent with those previously reported.[5] ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.73 (d, *J* = 8.0 Hz, 2 H), 7.31 (d, *J* = 8.0 Hz, 2 H), 5.72–5.64 (m, 1 H), 5.02–4.94 (m, 2 H), 4.35 (s, br, 1 H), 2.86 (dt, *J* = 12.8, 6.4 Hz, 1 H), 2.76 (dt, 12.8, 6.4 Hz, 1 H), 2.43 (s, 3 H), 2.10–2.01 (m, 1 H), 1.96–1.84 (m, 1 H), 1.74–1.61 (m, 1 H), 0.87 (d, *J* = 6.8 Hz, 3 H).

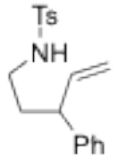


4-Methyl-*N*-(1-phenylpent-4-en-1-yl)benzensulfonamide (5c).[4] A flame dried flask was cooled under a stream of nitrogen and charged with 1-phenylpent-4-en-1-amine[6] (0.39 g, 2.4 mmol) and THF (24 mL). Tosyl chloride (0.52 g, 2.9 mmol) was then added, followed by triethylamine (0.4 mL, 2.9 mmol) and the solution was stirred at rt overnight. The reaction was then quenched with 2 M HCl (12 mL) and the mixture was transferred to a separatory funnel. The layers were separated, the aqueous layer was extracted with diethyl ether (3 x 20 mL), and the combined organic layers were dried over Na_2SO_4, filtered, and concentrated *in vacuo* to

afford an off-white solid. The crude product was purified via flash chromatography on silica gel to yield 0.52 g (69%) of a white solid, mp 66–68 °C. Spectroscopic data for the compound are consistent with those previously reported.[4] ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.52 (d, *J* = 8.0 Hz, 2 H), 7.16–7.15 (m, 3 H), 7.12 (d, *J* = 8.0 Hz, 2 H), 7.00–6.98 (m, 2 H), 5.75–5.60 (m, 1 H), 4.97–4.91 (m, 2 H), 4.75 (s, br, 1 H), 4.29 (q, *J* = 7.2 Hz, 1 H), 2.35 (s, 3 H), 1.99–1.88 (m, 3 H), 1.86–1.75 (m, 1 H).

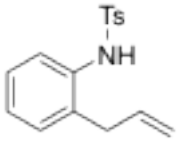


4-Methyl-*N*-(3-methylpent-4-en-1-yl)benzensulfonamide (5d).[7] A flame dried flask was cooled under a stream of nitrogen and charged with a solution of 3-methylpent-4-en-1-amine[7] (85 mL, 8.5 mmol, 0.1 M in diethyl ether). *p*-Toluenesulfonyl chloride (1.94 g, 10.2 mmol) was then added, followed by triethylamine (1.4 mL, 10.2 mL) and the resulting solution was stirred at rt overnight. The reaction was then quenched with 2 M HCl (50 mL) and the mixture was transferred to a separatory funnel. The layers were separated, the aqueous layer was extracted with diethyl ether (3 x 50 mL), and the combined organic layers were dried over Na_2SO_4, filtered, and concentrated *in vacuo* to afford a colorless oil. The crude product was purified via flash chromatography on silica gel to yield 1.19 g (55%) of the desired product as a colorless oil. Spectroscopic data for the compound are consistent with those previously reported.[7] ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.46 (d, *J* = 8.0 Hz, 2 H), 7.31 (d, *J* = 8.0 Hz, 2 H), 5.61–5.54 (m, 1 H), 4.94–4.90 (m, 2 H), 4.36 (s, br, 1 H), 3.00–2.90 (m, 2 H), 2.43 (s, 3 H), 2.17–2.12 (m, 1 H), 1.51–1.41 (m, 2 H), 0.95 (d, *J* = 7.0 Hz, 3 H).

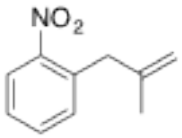


4-Methyl-*N*-(3-phenylpent-4-en-1-yl)benzenesulfonamide (5e). A flame dried flask was cooled under a stream of nitrogen and charged with 3-phenylpent-4-en-1-amine[6] (0.30 g, 1.86 mmol) and diethyl ether (19 mL). *p*-Toluenesulfonyl chloride (0.43 g, 2.2 mmol) was then added, followed by triethylamine (0.31 mL, 2.2 mmol) and the resulting solution was stirred at rt overnight. The reaction was then quenched with 2 M HCl (20 mL) and the mixture was transferred to a separatory funnel. The layers were separated, the aqueous layer was extracted with diethyl ether (3 x 20 mL), and the combined organic layers were dried over Na_2SO_4,

filtered, and concentrated *in vacuo* to afford a yellow oil. The crude product was purified via flash chromatography on silica gel to yield 1.19 g (55%) of the desired product as a pale yellow oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.69 (d, *J* = 8.0 Hz, 2 H), 7.30–7.26 (m, 4 H), 7.22–7.10 (m, 1 H), 7.09 (d, 8.0 Hz, 2 H), 5.91–5.82 (m, 1 H), 5.04–4.98 (m 2 H), 4.26 (s, br, 1 H), 3.28 (q, *J* = 7.6 Hz, 1 H), 2.92 (q, *J* = 7.0 Hz, 2 H), 2.43 (s, 3 H), 1.94–1.82 (m, 2 H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 143.4, 142.8, 140.9, 136.9, 129.7, 128.7, 127.4, 127.1, 126.6, 114.9, 47.0, 41.4, 35.0, 21.5; IR (film) 3277, 2930, 1320, 1154 cm^{-1}; MS (ESI+) 316.1371 (316.1366 calcd for $C_{18}H_{21}NO_2S$, M + H$^+$).

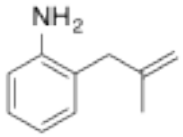


***N*-(2-Allylphenyl)-4-methylbenzenesulfonamide (5f).**[8] A flame-dried flask was cooled under a stream of nitrogen and charged with 2-allylaniline[9] (1.00 g, 7.50 mmol) and diethyl ether (55 mL). *p*-Toluenesulfonyl chloride (1.72 g, 9.00 mmol) was added followed by triethylamine (1.25 mL, 9.00 mmol), at which point the solution became cloudy. The reaction mixture was stirred at rt overnight then was concentrated *in vacuo* to yield a brown, viscous oil. The crude product was purified via flash chromatography on silica gel to afford 1.40 g (65%) of the title compound as a tan solid, mp 68–69 °C. Spectroscopic data for the compound are consistent with those previously reported.[8] ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.59 (d, *J* = 8.0 Hz, 2 H), 7.41 (d, *J* = 8.0 Hz, 1 H), 7.21–7.19 (m, 3 H), 7.12 (t, *J* = 7.0 Hz, 1 H), 7.07 (d, *J* = 7.0 Hz, 1 H), 6.49 (s, br, 1 H), 5.82–5.74 (m, 1 H), 5.12 (d, *J* = 10.0 Hz, 1 H), 4.94 (d, *J* = 17.0 Hz, 1 H), 3.01 (d, *J* = 4.0 Hz, 2 H), 2.39 (s, 3 H).

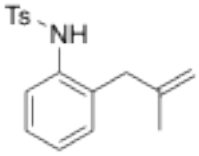


1-(2-Methylallyl)-2-nitrobenzene (S3). A flame-dried flask was cooled under a stream of nitrogen and charged with nitrobenzene (2.26 g, 9.09 mmol) and THF (36 mL) and cooled to –40 ºC. A solution of phenylmagnesium bromide (10 mL, 10 mmol, 1 M in THF) was then added dropwise, and the resulting mixture stirred at –40 °C for 5 min. A solution of CuCN·LiCl (18.2 mL, 18.2 mmol, 1 M in THF) was then added dropwise. The mixture was stirred at –40 °C for 30 min then 3-bromo-2-methylpropene (1.1 mL, 10.91 mmol) was added dropwise and the solution was stirred at -40 ºC for 1.5 hours. The reaction was quenched with NH_4Cl (40 mL) and the

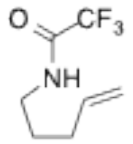
mixture was transferred to a separatory funnel. The layers were separated and the organic layer was washed with water (40 mL) and brine (40 mL), and then was dried over Na_2SO_4, filtered, and concentrated *in vacuo* to yield a brown oil. The crude product was purified via flash chromatography to afford 0.76 g (47%) of the title compound as a brown oil. ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.89 (d, *J* = 8.0 Hz, 2 H), 7.52 (t, *J* = 7.6 Hz, 1 H), 7.38–7.35 (m, 2 H), 4.84 (s, 1 H), 4.51 (s, 1 H), 3.64 (s, 2 H), 1.74 (s, 3 H).



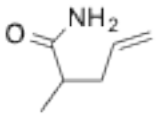
2-(2-Methylallyl)aniline (S4). A flame-dried flask was cooled under a stream of nitrogen and charged with zinc dust (2.77 g, 4.24 mmol), then 1-(2-methylallyl)-2-nitrobenzene (0.50 g, 2.8 mmol) in distilled ethanol (20 mL) was added, followed by acetic acid (2.4 mL, 4.24 mmol). The reaction mixture was stirred at rt for 1 h, then was filtered through a plug of celite. The celite was rinsed with ethyl acetate and the combined organic layers were concentrated. A solution of saturated aqueous $NaHCO_3$ (15 mL) was added to the resulting crude product, then the mixture was extracted with ethyl acetate (3 x 15 mL), dried over Na_2SO_4, filtered, and concentrated *in vacuo* to yield 0.292 g (70%) of an orange oil that was used without further purification. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.09–7.02 (m, 2 H), 6.75 (t, *J* = 7.2 Hz, 1 H), 6.67 (d, *J* = 8.0 Hz, 1 H), 4.87 (s, 1 H), 4.74 (s, 1 H), 3.72 (s, br, 2 H), 3.28 (s, 2 H), 1.74 (s, 3 H).



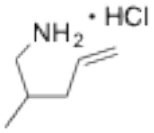
4-Methyl-*N*-[2-(2-methylallyl)phenyl]benzenesulfonamide (5g).[10] A flame-dried flask was cooled under a stream of nitrogen and charged with 2-(2-methylallyl)aniline (0.29 g, 1.99 mmol) and dichloromethane (20 mL). The solution was cooled to 0 ºC, *p*-toluenesulfonyl chloride (0.38 g, 1.99 mmol) was added, followed by triethylamine (0.42 mL, 2.98 mmol), and the reaction mixture was stirred at rt overnight. The mixture was then concentrated *in vacuo* to yield a crude oil that was purified via flash chromatography on silica gel to afford 0.42 g (71%) of the title compound as a viscous orange oil. Spectroscopic data for the compound are consistent with those previously reported.[10] ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.60 (d, *J* = 8.0 Hz, 2 H), 7.46 (d, *J* = 8.0 Hz, 1 H), 7.23–7.20 (m, 3 H), 7.11 (t, *J* = 7.0 Hz, 1 H), 7.03 (d, *J* = 7.5 Hz, 1H), 6.68 (s, br, 1 H), 4.89 (s, 1 H), 4.62 (s, 1 H), 2.92 (s, 2 H), 3.93 (s, 3 H), 1.57 (s, 3 H).



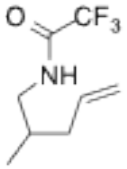
2,2,2-Trifluoro-*N*-(pent-4-en-1-yl)acetamide (8a).[11] A flame-dried flask was cooled under a stream of nitrogen and charged with a solution of pent-4-en-1-amine (50 mL, 5.0 mmol, 0.1 M in diethyl ether) and cooled to 0 ºC. Triethylamine (1.4 mL, 10.0 mmol) was added, followed by trifluoroacetic anhydride (0.77 mL, 5.5 mmol). The resulting mixture was stirred at rt overnight then was diluted with water (20 mL). The mixture was transferred to a separatory funnel, the layers were separated, and the aqueous layer was extracted with diethyl ether (2 x 20 mL). The combined organic layers were washed with brine, dried over Na_2SO_4, filtered, and concentrated *in vacuo* to afford a red-orange oil. The crude product was purified via flash chromatography to yield 412 mg (45%) of the title compound as a clear, colorless oil. The compound was found to exist as a mixture of rotamers by 1H NMR analysis; data are for the major rotamer. Spectroscopic data for the compound are consistent with those previously reported.[11] ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.23 (s, br, 1 H), 5.75 (ddt, 17.0, 10.2, 6.7 Hz, 1 H), 5.14–4.84 (m, 2 H), 3.35 (q, *J* = 6.8 Hz, 2 H), 2.05 (q, *J* = 7.2 Hz, 2 H), 1.68 (p, *J* = 7.2 Hz, 2 H).



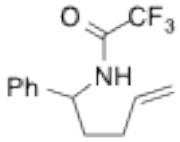
2-Methylpent-4-enamide (S5). A flame-dried flask was cooled under a stream of nitrogen and charged with 2-methylpent-4-enoic acid (1.71 g, 15 mmol) and benzene (30 mL), and was then cooled to 0 ºC. Oxalyl chloride (2.6 mL, 30 mmol) was then added slowly, and the reaction mixture was stirred at rt for 3 h. The mixture was then concentrated *in vacuo*, and the resulting crude material was dissolved in THF (30 mL) and then slowly added to aqueous NH_4OH at 0 ºC. The resulting mixture was then stirred at rt overnight. The mixture was concentrated, then diluted with water (15 mL) and ethyl acetate (30 mL) and transferred to a separatory funnel. The layers were separated, the aqueous layer was extracted with ethyl acetate (3 x 30 mL), and the combined organic layes were dried over NaSO4, filtered, and concentrated *in vacuo* to afford 1.53 g (90%) of a white solid that was used without further purification.



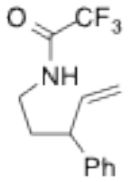
2-Methylpent-4-en-1-aminium chloride (S6). A flame-dried flask was cooled under a stream of nitrogen and charged with 2-methylpent-4-enamide (1.53 g, 13.5 mmol) and THF (40 mL), and the solution was cooled to 0 ºC. Lithium aluminum hydride (40.5 mL, 40.5 mmol, 1 M in THF) was added slowly then the mixture was warmed to rt and stirred for 24 h. The mixture was then cooled to 0 ºC and quenched with water (13.5 mL), 1 M NaOH (13.5 mL), then additional water (40.5 mL). The organic layer was decanted and the remaining solids were washed with ether and the ether solution was decanted. The combined ether layers were dried over Na_2SO_4 and filtered to afford a solution of 2-methylpent-4-en-1-amine in ether. To this solution HCl (5 mL, 4 M in dioxanes) was slowly added, and then the mixture was concentrated *in vacuo* to afford 1.46 g (80%) of the title compound as an off-white solid. ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.23 (s, br, 3 H), 5.80–5.67 (m, 1 H), 5.13–5.08 (m, 2 H), 3.0–2.94 (m, 1 H), 2.79–2.72 (m, 1 H), 2.19–2.15 (m, 1 H), 2.09–1.99 (m, 2 H), 1.07 (d, *J* = 6.5 Hz, 3 H).



2,2,2-Trifluoro-*N*-(2-methylpent-4-en-1-yl)acetamide (8b). A flame-dried flask was cooled under a stream of nitrogen and charged with 2-methylpent-4-en-1-aminium chloride (1.46 g, 10.8 mmol) and dichloromethane (20 mL), and then the solution was cooled to 0 ºC. Triethylamine (4.5 mL, 32.5 mmol) was added, followed by trifluoroacetic anhydride (1.8 mL, 13.0 mmol). The solution was then allowed to stir at rt overnight, and the reaction was treated with water (15 mL), then separated. The aqueous layer was extracted with dichloromethane (10 mL), and the combined organics were washed with brine. The layers were separated, and the organic phase was dried over Na_2SO_4, filtered, and concentrated *in vacuo* to afford a yellow oil. The crude product was purified via column chromatography on silica gel to yield 1.48 g (70%) of the title compound as a pale yellow oil. ^{1}H NMR (500 MHz, $CDCl_3$) δ 6.47 (s, br, 1 H), 5.81–5.73 (m, 1 H), 5.09–5.05 (m, 2 H), 3.32–3.27 (m, 1 H), 3.25–3.19 (m, 1 H), 2.13–2.07 (m, 1 H), 2.03–1.98 (m, 1 H), 1.09–1.80 (m, 1 H), 0.95 (d, *J* = 6.8 Hz, 3 H), ^{13}C NMR (125 MHz, $CDCl_3$) δ 157.4, 157.1, 135.8, 117.1, 115.9 (q, *J* = 286 Hz), 45.3, 38.8, 32.8, 17.4; IR (film) 3307, 2966, 1701, 1154 cm^{-1}; MS (ESI+) 196.0939 (196.0944 calcd for $C_8H_{12}F_3NO$, M + H^+).

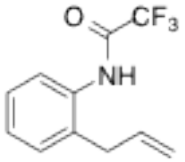


2,2,2-Trifluoro-*N*-(1-phenylpent-4-en-1-yl)acetamide (8c). A flame-dried flask was cooled under a stream of nitrogen and charged with 1-phenylpent-4-en-1-amine[6] (0.678 g, 4.2 mmol) and dichloromethane (5 mL). The solution was cooled to 0 ºC, and then triethylamine (1.17 mL, 8.4 mmol) was added followed by trifluoroacetic anhydride (0.64 mL, 4.6 mmol). The resulting mixture was stirred at rt overnight, then water was added (5 mL) and the mixture was transferred to a separatory funnel. The layers were separated, the aqueous layer was extracted with dichloromethane (10 mL), and then the combined organics layers were washed with brine, dried over Na_2SO_4, filtered, and concentrated *in vacuo* to afford a yellow oil. The crude product was purified via flash column chromatography on silica gel to yield 0.69 g (64%) of the title compound as a pale yellow oil. ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.42–7.32 (m, 2 H), 7.33–7.31 (m, 1 H), 7.29–7.28 (m, 2 H), 6.43 (s, br, 1 H), 5.83–5.76 (m, 1 H), 5.08–4.96 (m, 3 H), 2.13–1.99 (m, 4 H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 156.5, 156.2, 155.9, 139.7, 136.8, 129.0, 128.2, 126.6, 116, 115.8 (q, *J* = 287.3 Hz), 53.9, 34.5, 30.1; IR (film) 3296, 1696, 1162 cm^{-1}; MS (ESI+) 258.1095 (258.1100 calcd for $C_{13}H_{14}F_3NO$, M + H$^+$).



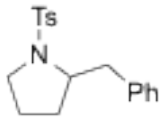
2,2,2-Trifluoro-*N*-(3-phenylpent-4-en-1-yl)acetamide (8d). A flame-dried flask was cooled under a stream of nitrogen and charged with 3-phenylpent-4-en-1-amine[6] (0.69 g, 4.3 mmol) and dichloromethane (5 mL). The solution was cooled to 0 ºC then triethylamine (1.2 mL, 8.6 mmol) was added followed by trifluoroacetic anhydride (0.66 mL, 4.7 mmol). The resulting mixture was stirred at rt overnight then water (5 mL) was added and the mixture was transferred to a separatory funnel. The layers were separated, the aqueous layer was extracted with dichloromethane (10 mL), and then the combined organic layers were washed with brine, dried over Na_2SO_4, filtered, and concentrated *in vacuo* to afford a red-orange oil. The crude product was purified via flash chromatography to yield 0.49 g (44%) of the title compound as a pale yellow oil. ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.34–7.31 (m, 2 H), 7.29–7.21 (m, 1 H), 7.20–7.18 (m, 2 H), 6.19 (s, br, 1 H), 5.96 (m, 1 H), 5.10 (dd, *J* = 13.9, 3.2 Hz, 2 H), 3.45–3.38 (m, 1 H), 3.34–3.26 (m, 2 H), 2.10–1.99 (m, 2 H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 157.5, 157.2, 156.9, 156.6,

142.7, 140.8, 128.9, 127.4, 126.9, 115.8 (q, 286 Hz), 115.1, 47.7, 38.6, 34.1; IR (film) 3300, 3084, 1700, 1152 cm^{-1}; MS (ESI+) 258.1096 (258.1100 calcd for $C_{13}H_{14}F_3NO$, M + H^+).

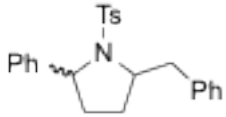


***N*-(2-Allylphenyl)-2,2,2-trifluoroacetamide (8e).** A flame-dried flask was cooled under a stream of nitrogen and charged with 2-allylaniline (0.75 g, 5.6 mmol) and dichloromethane (5.6 mL). The solution was cooled to 0 ºC, and then triethylamine (1.6 mL, 11.2 mmol) was added followed by trifluoroacetic anhydride (0.9 mL, 6.2 mmol). The resulting mixture was stirred at rt overnight then water (10 mL) was added and the mixture was transferred to a separatory funnel. The layers were separated, the aqueous layer was extracted with dichloromethane (10 mL), and then the combined organic layers were washed with brine, dried over Na_2SO_4, filtered, and concentrated *in vacuo* to afford a yellow oil. The crude product was purified via column chromatography to yield 1.03 g (80%) of the title compound as a pale yellow oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.13 (s, br, 1 H), 7.89 (d, *J* = 8.0 Hz, 1 H), 7.35–7.29 (m, 1 H), 7.26–7.20 (m, 2 H), 6.00–5.91 (m, 1 H), 5.26–5.14 (m, 2 H), 3.42 (d, *J* = 6.0 Hz, 2 H), ^{13}C NMR (125 MHz, $CDCl_3$) δ 155.4, 155.1, 154.8, 154.5, 135.5, 133.6, 130.7, 130.3, 127.9, 127.0, 123.3, 117.5, 115.9 (q, *J* = 287 Hz), 37.1; IR (film) 3276, 1703, 1159 cm^{-1}; MS (ESI+) 230.0785 (230.0787 calcd for $C_{11}H_{10}F_3NO$, M + H^+).

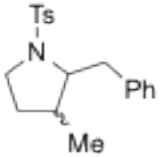
General Procedure for Pd-Catalyzed Carboamination Reactions of Aryl Triflates. An oven dried test tube equipped with a magnetic stirbar and a rubber septum was cooled under a stream of nitrogen and charged with $Pd(OAc)_2$ (2 mol %), CPhos or RuPhos (5 mol %), and LiO^tBu (1.4 equiv). The tube was purged with nitrogen and then a solution of the aryl triflate (1.2 equiv) in $PhCF_3$ (1 mL) was added and the resulting mixture was stirred at rt for 1 min. A solution of the *N*-protected amine substrate (1 equiv) in $PhCF_3$ (1.5 mL) was added, and the mixture was heated to 100 ºC for 15 h. The mixture was then cooled to rt, saturated aq NH_4Cl (2 mL) was added, the organic layer was removed, and the aqueous layer was extracted with dichloromethane (4 x 2 mL). The combined organic layers were dried over anhydrous Na_2SO_4, filtered, and concentrated *in vacuo*. The crude product was then purified via flash chromatography.



2-Benzyl-1-tosylpyrrolidine (6a).[4] The general procedure was employed for the reaction of phenyl trifluoromethanesulfonate (49 μL, 0.30 mmol) with 4-methyl-*N*-(pent-4-en-1-yl)benzenesulfonamide (**5a**) (60 mg, 0.25 mmol). This procedure afforded 60 mg (76%) of the title compound as a white solid, m.p. 91–93 °C. Spectroscopic data for the compound are consistent with those previously reported.[4] ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.76 (d, *J* = 8.5 Hz, 2 H), 7.32–7.20 (m, 6 H), 3.85–3.79 (m, 1 H), 3.43–3.36 (m, 1 H), 3.25 (dd, *J* = 13.3, 3.5 Hz, 1 H), 3.16–3.10 (m, 1 H), 2.75 (dd, *J* = 13.3, 9.6 Hz, 1 H), 2.42 (s, 3 H), 1.68–1.60 (m, 2 H), 1.49–1.40 (m, 2 H).

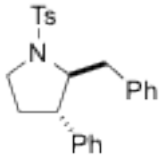


2-Benzyl-5-phenyl-1-tosylpyrrolidine (6b).[4] The general procedure was employed for the reaction of phenyl trifluoromethanesulfonate (40 μL, 0.24 mmol) with 4-methyl-*N*-(1-phenylpent-4-en-1-yl)benzensulfonamide (**5c**) (62.8 mg, 0.20 mmol). This procedure afforded 70 mg (90%) of the title compound as a pale yellow viscous oil. This compound was found to exist as a 2.2:1 mix of diastereomers by ^{1}H NMR analysis; data are for the major diastereomer. Spectroscopic data for the compound are consistent with those previously reported.[4] ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.71 (d, *J* = 8.0 Hz, 2 H), 7.39–7.20 (m, 9 H), 7.12–7.02 (m, 2 H), 6.95 (d, *J* = 7.5 Hz, 1 H), 4.73–4.70 (m, 1 H), 4.01–3.94 (m, 1 H), 3.54 (ddd, *J* = 13.0, 5.5, 3.2 Hz, 1 H), 2.78 (ddd, *J* = 13.0, 10.7, 2.1 Hz, 1 H), 2.40 (s, 3 H), 1.90-1.86 (m, 2 H), 1.68–1.55 (m, 1 H), 1.48–1.42 (m, 1 H).

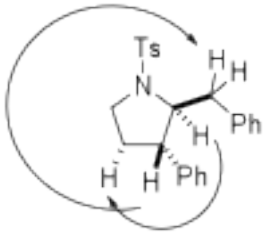


2-Benzyl-3-methyl-1-tosylpyrrolidine (6c). The general procedure was employed for the reaction of phenyl trifluoromethanesulfonate (40 μL, 0.24 mmol) with 4-methyl-*N*-(3-methylpent-4-en-1-yl)benzensulfonamide (**5d**) (50.7 mg, 0.20 mmol) using 2 mL of benzotrifluoride. This procedure afforded 46 mg (70%) of the title compound as a pale yellow solid, m.p. 80–82 °C. This compound was found to exist as a 2.6:1 mix of diastereomers by ^{1}H NMR analysis; data are for the mixture. ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.77 (d, *J* = 8.0 Hz, 2 H), 7.70 (d, *J* = 8.0 Hz,

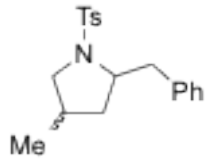
0.8 H), 7.34–7.26 (m, 9.8 H), 3.94 (td, *J* = 7.9, 4.4 Hz, 0.4 H), 3.43–3.38 (m, 1.4 H), 3.31–3.16 (m, 3.4 H), 3.07 (m, 0.4 H), 2.91–2.85 (m, 1.4 H), 2.42 (s, 4.2 H), 1.98 (ddp, *J* = 10.8, 6.8, 3.9, 3.3 Hz, 1 H), 1.81–1.55 (m, 1.8 H), 1.25–1.20 (m, 0.4 H), 1.08 (ddt, *J* = 12.1, 7.0, 5.0 Hz, 1 H), 0.92 (d, *J* = 6.9 Hz, 1.2 H), 0.37 (d, *J* = 6.9 Hz, 3 H); ^{13}C NMR (175 MHz, $CDCl_3$) δ 143.3, 143.2, 139.1, 138.3, 134.9, 134.6, 129.7, 129.6, 129.5, 128.3, 128.2, 127.5, 127.4, 126.3, 126.1, 68.3, 64.4, 47.5, 47.4, 42.1, 37.7, 37.2, 36.8, 31.5, 31.2, 21.5, 18.5, 14.4; IR (film) 2954, 1338, 1157 cm^{-1}; MS (ESI+) 330.01524 (330.1522 calcd for $C_{19}H_{23}NO_2S$, M + H$^+$).



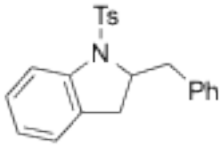
(±)-(2*S*,3*S*)-2-Benzyl-3-phenyl-1-tosylpyrrolidine (6d). The general procedure was employed for the reaction of phenyl trifluoromethanesulfonate (40 μL, 0.24 mmol) with 4-methyl-*N*-(3-phenylpent-4-en-1-yl)benzenesulfonamide (**5e**) (63 mg, 0.20 mmol) in 2 mL benzotrifluoride using RuPhos (4.7 mg, 5 mol %) as the ligand. This procedure afforded 40 mg (51%) of the title compound as a white solid, m.p. 160–162 °C. This compound was found to exist as an 8:1 mixture of diastereomers by ^{1}H NMR analysis; data are for the major isomer. ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.78 (d, *J* = 8.5 Hz, 2 H), 7.38–7.27 (m, 6 H), 7.25–7.20 (m, 1 H), 7.15–7.04 (m, 3 H), 6.58 (d, *J* = 7.0 Hz, 2 H), 3.91 (ddd, *J* = 7.1, 6.0, 3.2 Hz, 1 H), 3.54 (ddd, *J* = 11.8, 7.2, 5.1 Hz, 1 H), 3.19 (m, 2 H), 3.10–2.99 (m, 2 H), 2.46 (s, 3 H), 1.90–1.78 (m, 1 H), 1.45 (dq, *J* = 12.6, 7.7 Hz, 1 H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 143.5, 141.7, 137.4, 134.9, 130.4, 129.7, 128.5, 128.3, 127.5, 126.9, 126.5, 126.4, 67.9, 49.1, 48.1, 40.6, 32.3, 21.6; IR (film) 2926, 1339, 1159 cm^{-1}. MS (ESI+) 392.1683 (392.1679 calcd for $C_{24}H_{25}NO_2S$, M + H$^+$).



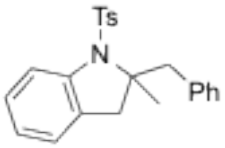
The stereochemistry of the above compound was determined by ^{1}H NMR nOe analysis as shown above.



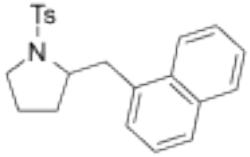
2-Benzyl-4-methyl-1-tosylpyrrolidine (6e). The general procedure was employed for the reaction of phenyl trifluoromethanesulfonate (49 μL, 0.30 mmol) with 4-methyl-*N*-(2-methylpent-4-en-1-yl)benzenesulfonamide (**5b**) (63.3 mg, 0.25 mmol). This procedure afforded 60 mg (73%) of the title compound as a white solid, m.p. 115–117 °C. This compound was found to exist as a 1.8:1 mix of diastereomers by ^{1}H NMR analysis; data are for the mixture. ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.76 (d, *J* = 8.0 Hz, 3 H), 7.33–7.18 (m, 10.5 H), 3.84 (dddd, *J* = 10.1, 8.5, 3.6, 2.0 Hz, 0.5 H), 3.75 (tdd, *J* = 9.3, 6.9, 3.7 Hz, 1 H), 3.59–3.52 (m, 1.5 H), 3.45 (dd, *J* = 13.2, 3.7 Hz, 1 H), 3.26 (dd, *J* = 13.3, 3.4 Hz, 0.4 H), 2.84–2.71 (m, 2.5 H), 2.56 (t, *J* = 9.4 Hz, 0.5 H), 2.43 (s, 4.7 H), 2.22–2.08 (m, 0.4 H), 1.84–1.77 (m, 1 H), 1.72 (ddt, *J* = 12.6, 6.1, 1.2 Hz, 0.5 H), 1.58–1.39 (m, 1 H), 1.26–1.18 (m, 1.4 H), 1.06–1.0 (m, 0.5 H), 0.83 (d, *J* = 6.5 Hz, 3 H), 0.80 (d, *J* = 6.5 Hz, 1.5 H); ^{13}C (125 MHz, $CDCl_3$) δ 143.3, 138.6, 138.3, 135.2, 134.3, 129.7, 129.6, 128.4, 128.3, 127.6, 127.4, 126.4, 126.3, 62.4, 61.7, 56.3, 55.9, 43.0, 42.9, 40.1, 37.6, 32.5, 31.2, 21.5, 16.9, 16.5; IR (film) 2926, 1341, 1156 cm^{-1}. MS (ESI+) 330.1523 (331.0522 calcd for $C_{19}H_{23}NO_2S$, M + H^+).



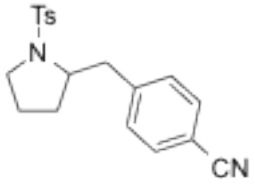
2-Benzyl-1-tosylindoline (6f).[12] The general procedure was employed for the reaction of phenyl trifluoromethanesulfonate (49 μL, 0.30 mmol), with *N*-(2-allylphenyl)-4-methylbenzenesulfonamide (**5f**) (71.8 mg, 0.25 mmol). This procedure afforded 82 mg (87%) of the title compound as a white solid, m.p. 124–126 °C. Spectroscopic data for the compound are consistent with those previously reported.[12] ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.67 (d, *J* = 8.0 Hz, 1 H), 7.56 (d, *J* = 8.0 Hz, 2 H), 7.34–7.27 (m, 2 H), 7.26–7.20 (m, 4 H), 7.15 (d, *J* = 8.0 Hz, 2 H), 7.01 (d, *J* = 3.5 Hz, 2 H), 4.45 (ddt, *J* = 11.1, 6.7, 4.7 Hz, 1 H), 3.35 (dd, *J* = 13.4, 4.3 Hz, 1 H), 2.78 (dd, *J* = 13.4, 10.2 Hz, 1 H), 2.59 (d, *J* = 5.5 Hz, 2 H), 2.33 (s, 3 H).



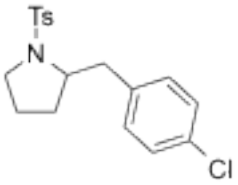
2-Benzyl-2-methyl-1-tosylindoline (6g). The general procedure was employed for the reaction of phenyl trifluoromethanesulfonate (49 μL, 0.30 mmol), with 4-methyl-*N*-[2-(2-methylallyl)phenyl]benzenesulfonamide (**5g**) (75.3 mg, 0.25 mmol). This procedure afforded 28 mg (30%) of the title compound as a white solid, m.p. 50–52 °C. ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.81 (d, *J* = 8.5 Hz, 2 H), 7.51 (d, *J* = 8.2 Hz, 1 H), 7.26–7.20 (m, 7 H), 7.14–7.07 (m, 1 H), 7.00 (dd, *J* = 7.4, 1.3 Hz, 1 H), 6.89 (td, *J* = 7.4, 1.0 Hz, 1 H), 3.40 (d, *J* = 13.2 Hz, 1 H), 3.21 (t, *J* = 13.0 Hz, 2 H), 2.65 (d, *J* = 16.0 Hz, 1 H), 2.19 (s, 3 H), 1.68 (s, 3 H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 143.4, 142.3, 139.4, 136.7, 130.8, 129.6, 12834, 128.0, 127.5, 126.6, 124.7, 122.7, 114.2, 73.1, 46.4, 41.8, 25.9, 21.5; IR (film) 2923, 1343, 1160 cm^{-1}. MS (ESI+) 378.1524 (378.1522 calcd for $C_{23}H_{23}NO_2S$, M + H$^+$).



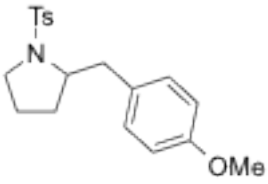
2-(Naphthalen-1-ylmethyl)-1-tosylpyrrolidine (6h). The general procedure was employed for the reaction of 1-napthyl trifluoromethanesulfonate (59 μL, 0.30 mmol), with 4-methyl-*N*-(pent-4-en-1-yl)benzenesulfonamide (**5a**) (60 mg, 0.25 mmol). This procedure afforded 61 mg (67%) of the title compound as a white solid, m.p. 139–140 °C. ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.48 (d, *J* = 8.5 Hz, 1 H), 7.87 (d, *J* = 8.2 Hz, 1 H), 7.78–7.74 (m, 3 H), 7.65 (ddd, *J* = 8.2, 6.7, 1.3 Hz, 1 H), 7.57–7.50 (m, 1 H), 7.38 (t, *J* = 7.6 Hz, 1 H), 7.29–7.26 (m, 3 H), 4.00 (ddd, *J* = 9.4, 6.3, 3.3 Hz, 2 H), 3.56 (ddd, *J* = 10.5, 7.0, 4.0 Hz, 1 H), 3.16 (td, *J* = 9.2, 6.8 Hz, 1 H), 2.92 (dd, *J* = 14.0, 11.6 Hz, 1 H), 2.39 (s, 3 H), 1.95–1.85 (m, 1 H), 1.67 (ddt, *J* = 13.2, 6.7, 3.6 Hz, 1 H), 1.56–1.52 (m, 1 H), 1.25–1.19 (m, 1 H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 143.3, 134.9, 134.5, 133.9, 132.2, 129.7, 128.7, 127.7, 127.5, 127.4, 126.3, 125.8, 125.4, 124.5, 60.4, 49.3, 40.6, 29.9, 23.8, 21.5; IR (film) 2943, 1340, 1156 cm^{-1}; MS (ESI+) 366.1525 (366.1522 calcd for $C_{22}H_{23}NO_2S$, M + H$^+$).



4-[(1-Tosylpyrrolidin-2-yl)methyl]benzonitrile (6i). The general procedure was employed for the reaction of 4-cyanophenyl trifluoromethanesulfonate (60.2 mg, 0.24 mmol) with 4-methyl-*N*-(pent-4-en-1-yl)benzenesulfonamide (**5a**) (59.8 mg, 0.25 mmol) in 2 mL of benzotrifluoride. This procedure afforded 42 mg (61%) of the title compound as a white solid, m.p. 110–112 °C. ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.73 (d, *J* = 8.0 Hz, 2 H), 7.59 (d, *J* = 8.0 Hz, 2 H), 7.37 (d, *J* = 8.0 Hz, 2 H), 7.32 (d, *J* = 8.0 Hz, 2 H), 3.83–3.79 (m, 1 H), 3.36–3.31 (m, 1 H), 3.22 (dd, *J* = 13.4, 3.6 Hz, 1 H), 3.15–3.10 (m, 1 H), 2.91 (dd, *J* = 13.3, 8.8 Hz, 1 H), 2.43 (s, 3 H), 1.58–1.43 (m, 4 H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 143.9, 143.6, 134.3, 132.2, 130.5, 129.8, 127.5, 118.9, 110.4, 60.9, 49.2, 42.7, 30.0, 23.8, 21.5; IR (film) 2955, 1338, 1158 cm^{-1}; MS (ESI+) 341.1323 (341.1318 calcd for $C_{19}H_{20}N_2O_2S$, M + H^+).

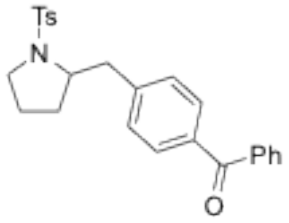


2-(4-Chlorobenzyl)-1-tosylpyrrolidine (6j).[4] The general procedure was employed for the reaction of 4-chlorophenyl trifluoromethanesulfonate (62.5 mg, 0.24 mmol) with 4-methyl-*N*-(pent-4-en-1-yl)benzenesulfonamide (**5a**) (47.8 mg, 0.20 mmol). This procedure afforded 46 mg (67%) of the title compound as a white solid, m.p. 95–96 °C. Spectroscopic data for the compound are consistent with those previously reported.[4] ^{1}H NMR (700 MHz, $CDCl_3$) δ 7.74 (d, *J* = 8.0 Hz, 2 H), 7.31 (d, *J* = 8.0 Hz, 2 H), 7.26 (d, *J* = 8.0 Hz, 2 H), 7.18 (d, *J* = 8.1 Hz, 2 H), 3.78 (tt, *J* = 7.5, 3.5 Hz, 1 H), 3.36–3.34 (m, 1 H), 3.17–3.10 (m, 2 H), 2.79 (dd, *J* = 13.4, 9.1 Hz, 1 H), 2.43 (s, 3 H), 1.61–1.55 (m, 2 H), 1.47–1.44 (m, 2 H).

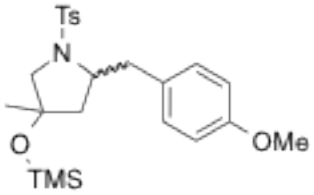


2-(4-Methoxybenzyl)-1-tosylpyrrolidine (6k). The general procedure was employed for the reaction of 4-methoxyphenyl trifluoromethanesulfonate (61.4 mg, 0.24 mmol) with 4-methyl-*N*-

(pent-4-en-1-yl)benzenesulfonamide (**5a**) (59.8 mg, 0.25 mmol) in 2 mL of benzotrifluoride. This procedure afforded 43 mg (62%) of the title compound as a pale yellow solid, m.p. 98–100 °C. ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.75 (d, *J* = 8.0 Hz, 2 H), 7.31 (d, *J* = 8.0 Hz, 2 H), 7.16 (d, *J* = 8.5 Hz, 2 H), 6.84 (d, *J* = 8.5 Hz, 2 H), 3.80-3.75 (m, 1 H), 3.79 (s, 3H), 3.39–3.33 (m, 1 H), 3.17–3.12 (m, 2 H), 2.72 (dd, *J* = 13.5, 9.5 Hz, 1 H), 2.42 (s, 3 H), 1.62–1.58 (m, 2 H), 1.47–1.40 (m, 2 H); ^{13}C NMR δ 158.2, 143.3, 134.8, 130.6, 130.5, 129.6, 127.5, 113.8, 61.7, 55.2, 19.2, 41.7, 29.8, 23.8, 21.5; IR (film) 2952, 1340, 1156 cm^{-1}; MS (ESI+) 346.1771 (346.1471 calcd for $C_{19}H_{23}NO_3S$, M + H^+).

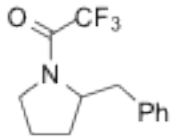


Phenyl-{4-[(1-tosylpyrrolidin-2-yl)methyl]phenyl}methanone (6l). The general procedure was employed for the reaction of 4-benzoylphenyl trifluoromethanesulfonate (99 mg, 0.30 mmol) with 4-methyl-*N*-(pent-4-en-1-yl)benzenesulfonamide (**5a**) (59.8 mg, 0.25 mmol) in 2 mL of benzotrifluoride. This procedure afforded 66 mg (63%) of the title compound as a white solid, m.p. 44–46 °C. ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.80–7.75 (m, 6 H), 7.61–7.57 (m, 1 H), 7.50–7.47 (m, 2 H), 7.35 (d, *J* = 8.0 Hz, 2 H), 7.30 (d, *J* = 7.5 Hz, 2 H), 3.90–3.84 (m, 1 H), 3.42–3.35 (m, 1 H), 3.31 (dd, *J* = 13.3, 3.6 Hz, 1 H), 3.18–3.14 (m, 1 H), 2.89 (dd, *J* = 13.3, 9.3 Hz, 1 H), 2.43 (s, 3 H), 1.66–1.61 (m, 2 H), 1.54–1.42 (m, 2 H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 143.5, 137.7, 135.8, 134.5, 132.3, 130.3, 130.0, 129.7, 129.6, 128.3,127.5, 61.2, 49.2, 42.7, 30.0, 23.8, 21.5; IR (film) 2928, 1653, 1340, 1156 cm^{-1}; MS (ESI+) 420.1635 (420.1628 calcd for $C_{25}H_{25}NO_3S$, M + H^+).

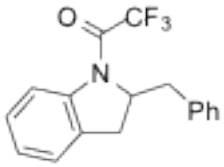


2-(4-Methoxybenzyl)-4-methyl-1-tosyl-4-[(trimethylsilyl)oxy]pyrrolidine (10). The general procedure was employed for the reaction of 4-methoxyphenyl trifluoromethanesulfonate (54 µL, 0.30 mmol), with (±)-4-methyl-*N*-{2-methyl-2-[(trimethylsilyl)oxy]pent-4-en-1-yl}benzenesulfonamide[b] (85.4 mg, 0.25 mmol). This procedure afforded 92 mg (82%) of the title compound as a viscous oil. This compound was found to exist as a 1:1 mixture of diastereomers

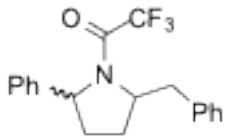
by ^{1}H NMR analysis; data are for the mixture. ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.79–7.74 (m, 4 H), 7.31 (d, *J* = 7.7 Hz, 4 H), 7.16–7.13 (m, 4 H), 6.89–6.80 (m, 4 H), 3.80–3.75 (m, 1 H), 3.79 (s, 6 H), 3.49–3.38 (m, 3 H), 3.33 (d, *J* = 3.8 Hz, 1 H), 3.22 (d, *J* = 11.3 Hz, 1 H), 3.12 (d, *J* = 10.5 Hz, 1 H), 2.97 (dd, *J* = 13.1, 10.4 Hz, 1 H), 2.87 (dd, *J* = 13.6, 9.1 Hz, 1 H), 2.42 (s, 6 H), 1.86–1.69 (m, 2 H), 1.61–1.50 (m, 1 H), 1.49–1.39 (m, 1 H), 1.25–1.19 (m, 1 H), 1.24 (s, 3 H), 1.02 (s, 3 H), 0.12 (s, 9 H), –0.23 (s, 9 H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 158.1, 143.4, 143.1, 135.0, 130.8, 130.6, 130.2, 129.6, 129.5, 128.0, 127.7, 127.5, 114.0, 113.7, 78.3, 77.5, 63.9, 61.9, 61.2, 61.1, 55.2, 46.2, 44.6, 41.4, 40.7, 26.1, 25.2, 21.5, 2.1, 1.9; IR (film) 2954, 1512,1340, 1248, 1157 cm^{-1}; MS (ESI+) 448.1976 (448.1972 calcd for $C_{23}H_{33}NO_4SSi$, M + H$^+$).



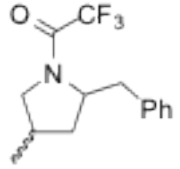
1-(2-Benzylpyrrolidin-1-yl)-2,2,2-trifluoroethan-1-one (9a).[13] The general procedure was employed for the reaction of phenyl trilfuoromethanesulfonate (40 µL, 0.24 mmol) with 2,2,2-trifluoro-*N*-(pent-4-en-1-yl)acetamide (**8a**) (36.2 mg, 0.20 mmol) in 2 mL benzotrifluoride for 13 hours. This procedure afforded 33 mg (64%) of the title compound as a colorless oil. This compound was found to exist as a 6:1 mixture of rotamers via ^{1}H NMR; data are for the major rotamer. Spectroscopic data for the compound are consistent with those previously reported.[13] ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.32–7.21 (m, 2 H), 7.23–7.10 (m, 3 H), 4.37–4.32 (m, 1 H), 3.70–3.41 (m, 2 H), 3.1 (dd, *J* = 13.1, 3.4 Hz, 1 H), 2.67–2.55 (m, 1 H), 1.98–1.70 (m, 4 H).



1-(2-Benzylindolin-1-yl)-2,2,2-trifluoroethan-1-one (9b). The general procedure was employed for the reaction of phenyl trifluoromethanesulfonate (78 µL, 0.48 mmol) with *N*-(2-allylphenyl)-2,2,2-trifluoroacetamide (**8e**) (91.7 mg, 0.4 mmol) in 2 mL of benzotrifluoride for 15 hours. This procedure afforded 89 mg (73%) of the title compound as a white solid, m.p. 66–67 °C. ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.14 (d, *J* = 8.1 Hz, 1 H), 7.35–7.26 (m, 5 H), 7.21–7.18 (m, 3 H), 4.86 (t, *J* = 10 Hz, 1 H), 3.19–3.12 (m, 2 H), 2.89 (d, *J* = 15.7 Hz, 1 H), 2.67 (dd, *J* = 13.4, 11.1 Hz, 1 H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 154.3, 154.0, 140.8, 136.3, 130.9, 129.4, 128.8, 127.8, 127.1, 126.2, 125.4, 119.0, 116.4 (q, 285.4 Hz), 61.8, 40.8, 33.2; IR (film) 1690, 1146 cm^{-1}; MS (ESI+) 306.1097 (306.1100 calcd for $C_{17}H_{14}F_3NO$ M + H$^+$).

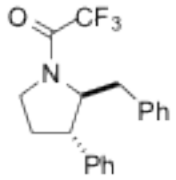


1-(2-Benzyl-5-phenylpyrrolidin-1-yl)-2,2,2-trifluoroethan-1-one (9c). The general procedure was employed for the reaction of phenyl trifluoromethanesulfonate (49 µL, 0.30 mmol) with 2,2,2-trifluoro-*N*-(1-phenylpent-4-en-1-yl)acetamide (**8c**) (64.3 mg, 0.25 mmol) in 1.25 mL benzotrifluoride. This procedure afforded 73 mg (88%) of the title compound as a colorless oil. This compound was found to exist as a mixture of rotamers and as a 2:1 mixture of diastereomers via ^{1}H NMR analysis; data are for the mixture. ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.40–7.04 (m, 15 H), 5.33–5.27 (m, 1.55 H), 5.11 (t, *J* = 9.0 Hz, 1 H), 4.65 (td, *J* = 8.9, 2.9 Hz, 0.41 H), 4.47 (ddd, *J* = 10.9, 7.2, 2.7 Hz, 1 H), 4.34 (ddt, *J* = 10.6, 7.6, 3.8 Hz, 1 H), 3.77 (dd, *J* = 12.5, 3.1 Hz, 1 H), 3.32 (dd, *J* = 13.1, 3.0 Hz, 0.35 H), 3.26 (dd, *J* = 13.3, 3.0 Hz, 1 H), 3.11 (dd, *J* = 13.5, 3.0 Hz, 0.10 H), 2.76 (t, *J* = 12.5 Hz, 1 H), 2.73–2.64 (m, 1.50 H), 2.53–2.44 (m, 1 H), 2.24–2.20 (m, 1.50 H), 2.14–2.02 (m, 2.30 H), 1.97–1.57 (m, 5.80 H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 157.6, 157.3, 156.4, 156.0, 143.3, 141.5, 141.4, 138.3, 138.2, 137.4, 129.5, 129.2, 129.1, 128.8, 128.7, 128.6, 128.5, 127.4, 127.3, 127.0, 126.7, 126.6, 125.4, 125.3, 124.9, 124.7, 116.5 (q, 286.3 Hz), 116.1 (q, 286.3 Hz), 64.0, 63.4, 62.9, 62.6, 62.3, 61.2, 41.0, 40.0, 37.3, 35.0, 33.7, 31.7, 28.8, 27.7, 23.7; IR (film) 2951 cm^{-1}, 1684 cm^{-1}, 1145 cm^{-1}; IR (film) 2951, 1684, 1145 cm^{-1}; MS (ESI+) 334.1411 (334.1413 calcd for $C_{19}H_{18}F_3NO$, M + H$^+$).

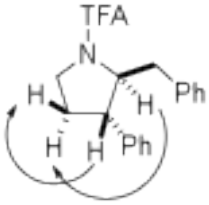


1-(2-Benzyl-4-methylpyrrolidin-1-yl)-2,2,2-trifluoroethan-1-one (9d). The general procedure was employed for the reaction of phenyl trifluoromethanesulfonate (146 µL, 0.90 mmol) with 2,2,2-trifluoro-*N*-(2-methylpent-4-en-1-yl)acetamide (**8b**) (146 mg, 0.75 mmol) in 1.5 mL benzotrifluoride for 18 hours. This procedure afforded 135.5 mg (67%) of the title compound as a pale yellow oil. This compound was found to exist as a mixture of rotamers and as a 1.3:1 mixture of diastereomers via ^{1}H NMR analysis; data are for the mixture. ^{1}H NMR (500 MHz $CDCl_3$) δ 7.34–7.15 (m, 9 H), 4.42 (t, 8.8 Hz, 0.8 H), 4.35–4.39 (m, 1 H), 3.85–3.82 (m, 1 H), 3.78–3.72 (m, 0.8 H), 3.36 (dd, *J* = 13.1, 3.3 Hz, 1 H), 3.22–3.14 (m, 1.7 H), 3.02 (dd, *J* = 13.3, 3.4 Hz, 0.1 H), 2.78–2.66 (m, 2 H), 2.66–2.61 (m, 1 H), 2.34–2.27 (m, 0.8 H), 2.15–2.06 (m, 2 H), 1.97 (dd, *J* = 12.7, 6.3 Hz, 0.2 H), 1.89 (ddd, *J* = 12.8, 6.2, 2.4 Hz, 0.9 H), 1.47 (ddd, *J* =

12.6, 10.0, 8.1 Hz, 1 H), 1.38–1.24 (m, 1 H), 1.10 (d, *J* = 6.5 Hz, 0.6 H), 1.02–0.99 (m, 5.5 H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 155.7, 155.6, 155.4, 155.3, 138.0, 137.4, 129.6, 129.5, 129.2, 128.8, 128.5, 128.4, 126.9, 126.6, 126.5, 116.3 (q, 286.4 Hz), 116.2 (q, 286.3 Hz), 60.9, 60.7, 54.4, 54.2, 53.8, 40.9, 38.9, 38.4, 38.1, 37.7, 37.6, 35.7, 33.3, 31.6, 31.1, 28.3, 18.0, 17.4, 16.4; IR (film) 2954, 1686, 1144 cm^{-1}; MS (ESI+) 272.1255 (272.1257 calcd for $C_{14}H_{16}F_3NO$, M + H$^+$).



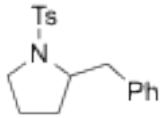
(±)-(2*S*,3*S*)-1-(2-Benzyl-3-phenylpyrrolidin-1-yl)-2,2,2-trifluoroethan-1-one (9e). The general procedure was employed, using 4 mol % $Pd(OAc)_2$ and 10 mol % CPhos, for the reaction of phenyl trifluoromethanesulfonate (146 μL, 0.90 mmol) with 2,2,2-trifluoro-*N*-(3-phenylpent-4-en-1-yl)acetamide (**8d**) (192.8 mg, 0.75 mmol) in 1.5 mL benzotrifluoride for 24 hours. This procedure afforded 143.2 mg (57%) of the title compound as a pale yellow oil. This compound was found to exist as a 7:1 mixture of diastereomers by ^{1}H NMR analysis; data are for the major diastereomer. ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.40–7.18 (m, 8 H), 7.11 (d, *J* = 7.5 Hz, 2 H), 4.52 (ddd, *J* = 7.9, 5.9, 3.2 Hz, 1 H), 3.85–3.81 (m, 1 H), 3.36–3.32 (m, 1 H), 3.23 (q, *J* = 6.7 Hz, 1 H), 3.14 (dd, *J* = 13.7, 7.3 Hz, 1 H), 3.02 (dd, *J* = 13.7, 3.2 Hz, 1 H), 2.24–2.17 (m, 1 H), 2.02–1.94 (m, 1 H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 155.7, 155.4, 141.4, 136.8, 129.9, 128.8, 128.5, 127.1, 127.0, 126.8, 116.3 (q, 285.3 Hz), 66.2, 46.7, 45.6, 36.3, 32.9; IR (film) 2928, 1685, 1143 cm^{-1}; MS (ESI+) 334.1416 (334.1413 calcd for $C_{19}H_{18}F_3NO$, M + H$^+$).



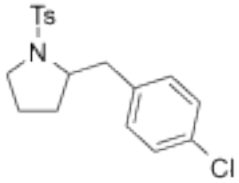
The stereochemistry of the above compound was determined by ^{1}H NMR nOe analysis as shown above.

General Procedure for Pd-Catalyzed Carboamination Reactions of Aryl Bromides. An oven dried test tube equipped with a magnetic stirbar and a rubber septum was cooled under a stream of nitrogen and charged with $Pd(OAc)_2$ (2 mol %), RuPhos (5 mol %), LiOTf (2 equiv) and NaO^{t}Bu (2 equiv). The tube was purged with nitrogen and then a solution of the aryl bromide (2 equiv) in $PhCF_3$ (1 mL) was added and the resulting mixture was stirred at rt for 1

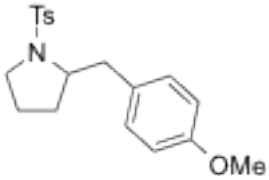
min. A solution of the *N*-protected amine substrate (1 equiv) in $PhCF_3$ (1.5 mL) was added, and the mixture was heated to 100 ºC for 15 h. The mixture was then cooled to rt, saturated aq NH_4Cl (2 mL) was added, the organic layer was removed, and the aqueous layer was extracted with dichloromethane (4 x 2 mL). The combined organic layers were dried over anhydrous Na_2SO_4, filtered, and concentrated *in vacuo*. The crude product was then purified via flash chromatography.



2-Benzyl-1-tosylpyrrolidine (6a).[4] General procedure 2 was employed for the reaction of bromobenzene (79 mg, 0.5 mmol) with 4-methyl-*N*-(pent-4-en-1-yl)benzenesulfonamide (**5a**) (60 mg, 0.25 mmol). This procedure afforded 57 mg (72%) of the title compound as a white solid. Spectroscopic data for the compound were identical to those reported above.

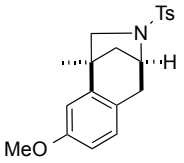


2-(4-Chlorobenzyl)-1-tosylpyrrolidine (6j).[4] General procedure 2 was employed for the reaction of 4-bromochlorobenzene (95.7 mg, 0.5 mmol) with 4-methyl-*N*-(pent-4-en-1-yl)benzenesulfonamide (**5a**) (60 mg, 0.25 mmol). This procedure afforded 53 mg (61%) of the title compound as a white solid. Spectroscopic data for the compound were identical to those reported above.



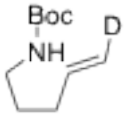
2-(4-Methoxybenzyl)-1-tosylpyrrolidine (6k). General procedure 2 was employed for the reaction of 4-bromoanisole (93.5 mg, 0.5 mmol) with 4-methyl-*N*-(pent-4-en-1-yl)benzenesulfonamide (**5a**) (60 mg, 0.25 mmol). This procedure afforded 48 mg (56%) of the title compound as a white solid. Spectroscopic data for the compound were identical to those reported above.

Conversion of 11 to 12



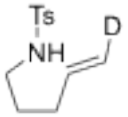
(±)-(1*S*,4*S*)-8-methoxy-1-methyl-3-tosyl-2,3,4,5-tetrahydro-1H-1,4-methanobenzo[*d*]azepine (12).[14] A flame-dried flask was cooled under a stream of nitrogen and charged with aluminum chloride (149 mg, 1.12 mmol) and dichloromethane (1 mL). The reaction mixture was then cooled to 0 °C and a solution of 2-(4-methoxybenzyl)-4-methyl-1-tosyl-4-[(trimethylsilyl)oxy]pyrrolidine (**11**) (50 mg, 0.11 mmol) in dichloromethane (1 mL) was slowly added. The reaction mixture was warmed to rt and stirred overnight, then was poured into a saturated aqueous solution of sodium bicarbonate (2 mL). The mixture was transferred to a separatory funnel, the layers were separated, and the aqueous phase was extracted with dichlormethane (2 x 2 mL). The combined organic phases were dried over Na_2SO_4, filtered, and concentrated *in vacuo* to afford a yellow oil. The crude product was purified via flash chromatography on silica gel to afford 17 mg (42%) of the title compound as a pale yellow solid, mp 137–139 °C. Spectroscopic data for the compound are consistent with those previously reported.[14] ^{1}H NMR (400 MHz, CDCl3), δ 7.70 (d, *J* = 8.4 Hz, 2 H), 7.28 (d, *J* = 8.0 Hz, 2 H), 6.97 (d, *J* = 8.4 Hz, 1 H), 6.78 (d, *J* = 2.5 Hz, 1 H), 6.72 (dd, *J* = 8.3, 2.6 Hz, 1 H), 4.41–4.35 (m, 1 H), 3.78 (s, 3 H), 3.40 (dd, *J* = 8.7, 1.2 Hz, 1 H), 3.11 (d, *J* = 16.6 Hz, 1 H), 3.02 (d, *J* = 8.6 Hz, 1 H), 2.93 (dd, *J* = 16.5, 2.8 Hz, 1 H), 2.42 (s, 3 H), 1.79 (d, *J* = 11.5 Hz, 1 H), 1.50–1.38 (m, 4 H).

Deuterium Labeling Experiments

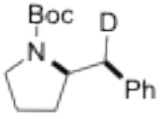


(*E*)-*Tert*-butyl (pent-4-en-1-yl-5-d)carbamate (13). A flame dried flask was cooled under a stream of nitrogen and charged with (*E*)-2-(pent-4-en-1-yl-5-d)isoindoline-1,3-dione[15] (0.96 g, 3.6 mmol) and ethanol (40 mmol). Hydrazine hydrate (198 µL, 7.2 mmol) was then added, and the reaction was heated to reflux for 24 hours. The reaction was then allowed to cool to rt, then diethyl ether (100 mL) was added and a white precipitate formed. The mixture was then charged with Boc anhydride (2.34 g, 10.7 mmol), and the reaction was stirred at rt overnight. The

reaction was then concentrated *in vacuo*, and the aqueous layer was extracted with diethyl ether (2 x 50 mL). The combined organic layers were dried over Na_2SO_4, filtered, and concentrated *in vacuo* to afford a yellow oil. The crude product was purified via flash column chromatography on silica gel to afford 67 mg (10%) of the title compound as a pale yellow oil with 80% deuterium incorporation as judged by ^{1}H NMR analysis. Spectroscopic data for the compound are consistent with those previously reported.[15] ^{1}H NMR (400 MHz, $CDCl_3$) δ 5.84–5.77 (m, 1 H), 5.05–4.97 (m, 1 H), 4.52 (s, br, 1 H), 3.13 (q, *J* = 5.6 Hz, 2 H), 2.08 (q, *J* = 7.2 Hz, 2 H), 1.62–1.54 (m, 2 H), 1.45 (s, 9 H).

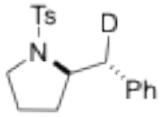


(*E*)-4-Methyl-*N*-(pent-4-en-1-yl-5-d)benzenesulfonamide (15). A flame-dried flask was cooled under a stream of nitrogen and charged with (*E*)-2-(pent-4-en-1-yl-5-d)isoindoline-1,3-dione[15] (0.400 g, 1.5 mmol) and ethanol (30 mL). Hydrazine hydrate (294 µL, 6.0 mol) was then added, and the reaction was heated to reflux for 24 hours. The reaction was allowed to cool to rt, then diethyl ether (80 mL) was added and a white precipitate formed. *p*-toluenesulfonyl chloride (0.343 g, 1.8 mmol) and triethylamine (251 µL, 1.8 mmol) were then added, and the reaction mixture was stirred at rt for 5 h. The reaction was then quenched with 2 M HCl (20 mL), the mixture was transferred to a separatory funnel, and the layers were separated. The aqueous layer was extracted with diethyl ether (30 mL), and then the combined organic layers were dried over Na_2SO_4, filtered, and concentrated *in vacuo*. The crude product was purified via flash chromatography on silica gel to afford 75 mg (21%) of the title compound as a colorless oil with 80% deuterium incorporation as judged by ^{1}H NMR analysis. Spectroscopic data for the compound are consistent with those previously reported.[3] ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.74 (d, *J* = 8.0 Hz, 2 H), 7.31 (d, *J* = 8.0 Hz, 2 H), 5.74–5.68 (m, 1 H), 4.99–4.94 (m, 1 H), 4.33 (s, br, 1 H), 2.96 (q, *J* = 6.8 Hz, 2 H), 2.43 (s, 3 H), 2.06 (q, *J* = 7.2 Hz, 2 H), 2.08–2.02 (m, 2 H).



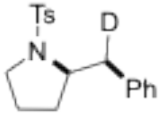
(1'*S*,2*R*)-*N*-Boc-2-[1'd-phenylmethyl]pyrrolidine (14).[2] An oven dried test tube equipped with a magnetic stirbar was cooled under a stream of nitrogen and charged with $Pd(OAc)_2$ (2 mol %), Dpe-Phos (5 mol %), and NaO^{t}Bu (1.4 equiv). The tube was purged with nitrogen and then a solution of bromobenzene (0.68 mg, 0.43 mmol) in toluene (1 mL) was added, and the solution stirred at rt for 1 minute. A solution of (*E*)-*tert*-butyl (pent-4-en-1-yl-5-d)carbamate (**13**) (0.67 mg,

0.36 mmol) in toluene (1.5 mL) was added, and the solution was heated to 90 °C with stirring for 15 h. The reaction mixture was cooled to rt and saturated aq NH_4Cl (2 mL) was added. The layers were separated, and the aqueous layer was then extracted with dichloromethane (4 x 2 mL). The organic layers were combined, dried over anhydrous Na_2SO_4, filtered, and concentrated *in vacuo*. The crude product was then purified via flash column chromatography on silica gel to afford 67.3 mg (71%) of the title compound as a pale yellow oil. Spectroscopic data for the compound are consistent with those previously reported.[2] ^{1}H NMR (500 MHz, $C_6D_5CD_3$, 100 ºC) δ 7.13–6.98 (m, 5 H), 4.00–3.94 (m, 1 H), 3.32–3.23 (m, 1 H), 3.17–3.04 (m, 2 H), 1.50–1.30 (m, 13 H).



(1'*R*,2*R*)-*N*-Tosyl-2-[1'd-phenylmethyl]pyrrolidine (16).[4] The general procedure was employed for the reaction of phenyl trifluoromethanesulfonate (39 µL, 0.24 mmol) with (*E*)-4-methyl-*N*-(pent-4-en-1-yl-5-d)benzenesulfonamide (**15**) (48 mg, 0.20 mmol) in 2 mL of benzotrifluoride for 15 hours. This procedure afforded 48.4 mg (76%) of the title compound as a white solid, mp 91–92 °C. Spectroscopic data for the compound are consistent with those previously reported.[4] ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.76 (d, *J* = 8.0 Hz, 2 H), 7.30 (dd, *J* = 10.3, 7.9 Hz, 4 H), 7.28–7.19 (m, 3 H), 3.84–3.78 (m, 1 H), 3.44–3.36 (m, 1 H), 3.13 (dt, *J* = 9.8, 7.1 Hz, 1 H), 2.80–2.70 (m, 1 H), 2.42 (s, 3 H), 1.70–1.59 (m, 2 H), 1.52–1.38 (m, 2 H).

Confirmation of change in stereochemistry. In order to further confirm the change in the stereochemical outcome of the carboamination of **12** to **13** vs. **14** to **15**, a sample of product **13** was transformed to **S7**, the C1' epimer of **15** via cleavage of the boc group followed by *N*-tosylation as described below.



(1'*S*,2*R*)-*N*-Tosyl-2-[1'd-phenylmethyl]pyrrolidine (S7).[4] A flame dried vial was cooled under a stream of nitrogen and charged with (1'*S*,2*R*)-*N*-boc-2-[1'd-phenylmethyl]pyrrolidine (**14**) (67.3 mg, 0.26 mmol). Dichloromethane (0.5 mL) and trifluoroacetic acid (0.5 mL) were then added, and the reaction mixture was stirred at rt for 2 h. The reaction mixture was concentrated *in vacuo*, then toluene (1 mL) was added and the mixture was concentrated again. This dilution/concentration sequence was repeated two additional times to facilitate azeotropic

removal of the trifluoroacetic acid. The resulting crude oil was dissolved in dichloromethane (1 mL) and K_2CO_3 was added. After stirring for 15 minutes, the mixture was filtered and concentrated *in vacuo* to afford a brown oil that was dissolved in dichloromethane and treated with aqueous NH_4OH until a pH of >12 was reached. The layers were separated, and the aqueous layer was extracted with dichloromethane (2 x 5 mL). The organic layer was dried, filtered and concentrated *in vacuo* to afford a brown oil. The oil was then converted to the *N*-tosyl pyrrolidine using a procedure analogous to that reported above for **5c** to afford 60 mg (63%) of the title compound as a white solid, mp 91–93 °C. Spectroscopic data for the compound are consistent with those previously reported.[4] ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.76 (d, 8.0 Hz, 2 H), 7.35–7.26 (m, 4 H), 7.25–7.18 (m, 3 H), 3.82 (dt, *J* = 6.9, 3.2 Hz, 1 H), 3.42–3.37 (m, 1 H), 3.27–3.24 (m, 1 H), 3.13 (qd, *J* = 7.2, 3.5 Hz, 1 H), 2.43 (s, 3 H), 1.63 (qt, *J* = 14.7, 9.1 Hz, 2 H), 1.50–1.40 (m, Hz, 2 H).

References

[1] D. E. Frantz, D. G. Weaver, J. P. Carey, M. H. Kress, U. H. Dolling, *Org. Lett*. **2002**, *4*, 4717–4718.

[2] D. N. Mai, J. P. Wolfe, *J. Am. Chem. Soc*. **2010**, *132*, 12157–12159.

[3] P. Pinkho, A. J. Minnaard, B. L. Feringa, *Org. Lett*. **2003**, *5*, 239.

[4] G. Zhang, L. Cui, Y. Wang, L. Zhang, *J. Am. Chem. Soc*. **2010**, *132*, 1474–1475.

[5] T. Wu, G. Yin, G. Liu, *J. Am. Chem. Soc*. **2009**, *131*, 16354–16355.

[6] Q. Yang, J. E. Ney, J. P Wolfe, *Org. Lett*. **2005**, *7*, 2575–2578.

[7] K. Thai, L. Wang, T. Dudding, F. Bilodeau, M. Gravel, *Org. Lett*. **2010**, *12*, 5708–5711.

[8] L. Dang, L. Liang, C. Qian, M. Fu, T. Ma, D. Xu, H. Jiang, W. Zeng, *J. Org. Chem*. **2014**, *79*, 769–776.

[9] W. K. Anderson, G. Lai, *Synthesis* **1995**, 1287–1290.

[10] Z. Pan, S. M. Pound, N. R. Rondla, C. J. Douglas, *Angew. Chem. Int. Ed*. **2014**, *53*, 5170–5174.

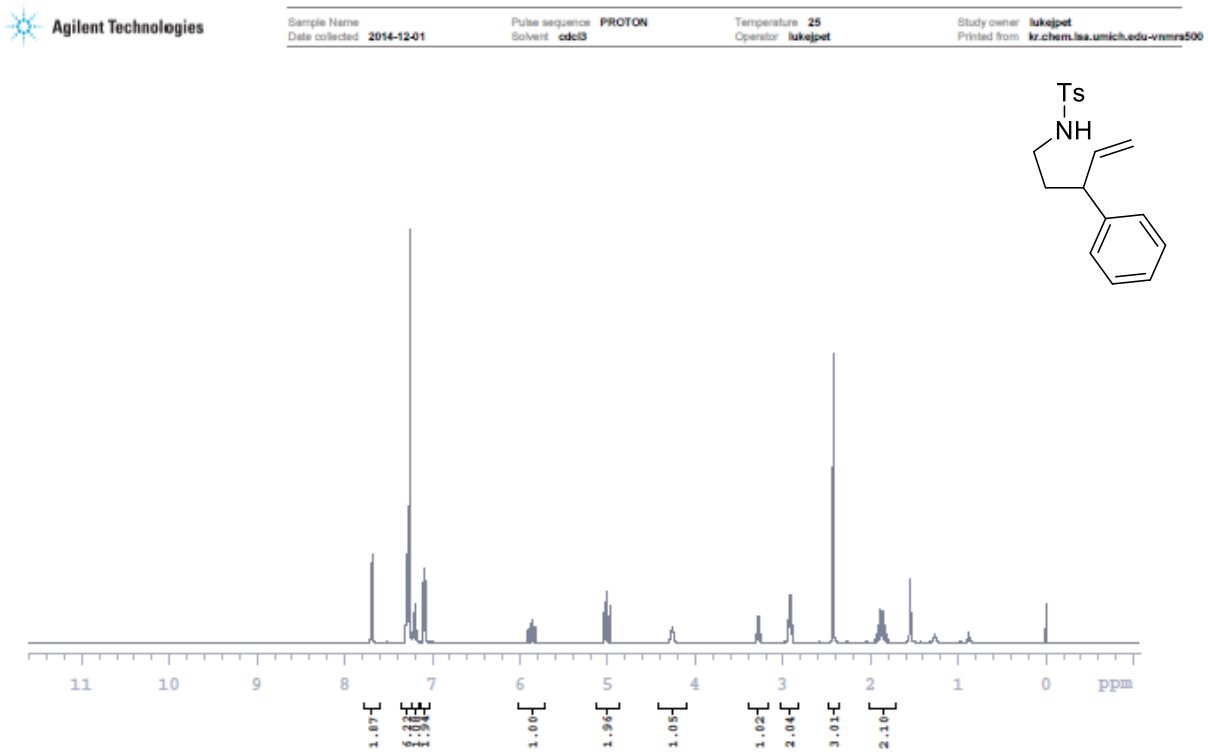
[11] J. F. Teichert, M. Fananas-Mastral, B. L. Feringa, *Angew. Chem. Int. Ed*. **2011**, *50*, 688–691.

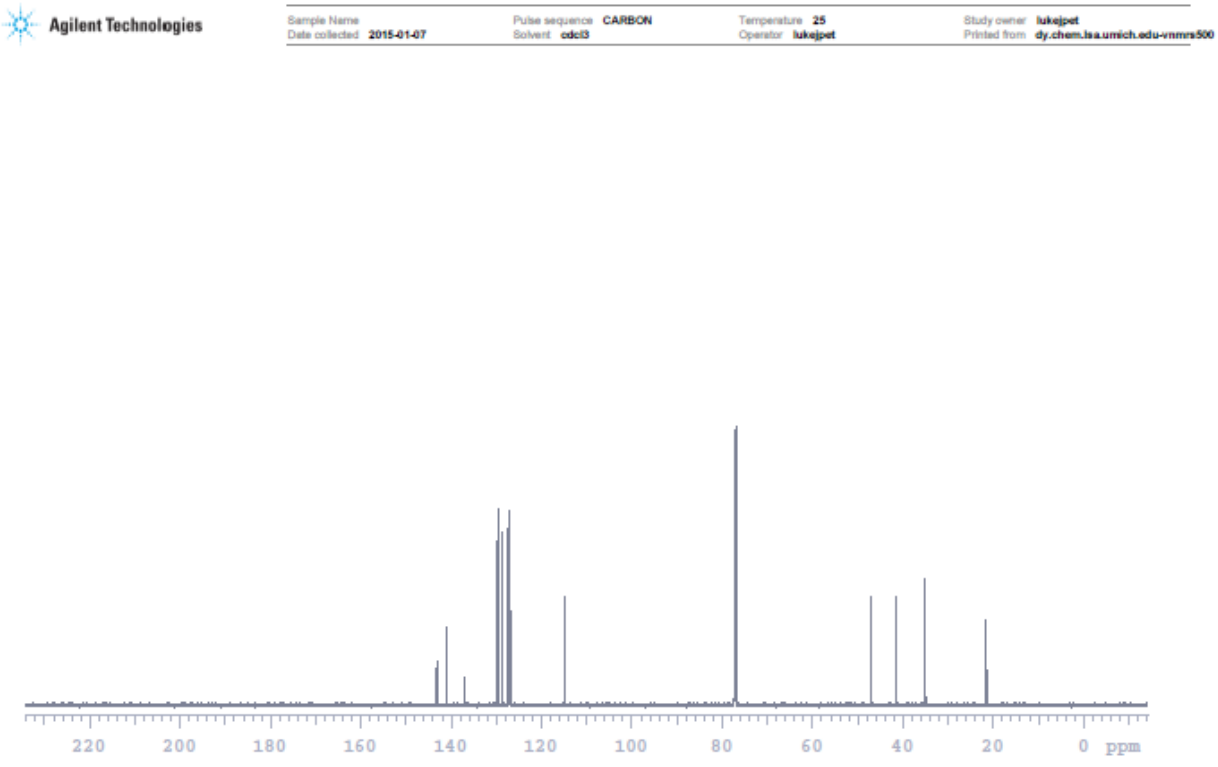
[12] S. Zhu, L. Ye, W. Wu, H. Jiang, *Tetrahedron*. **2013**, *69*, 10375–10383.

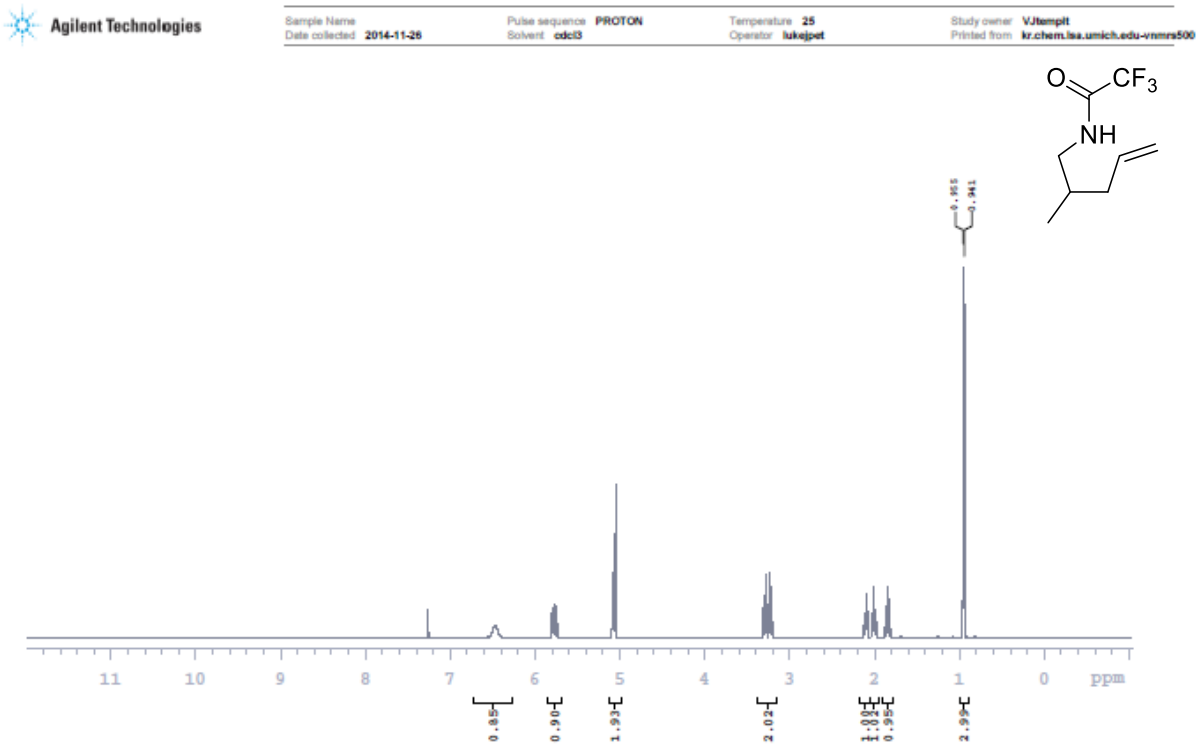
[13] A. R. Massah, A. J. Ross, R. F. W. Jackson, *J. Org. Chem*. **2010**, *75*, 8275–8278.

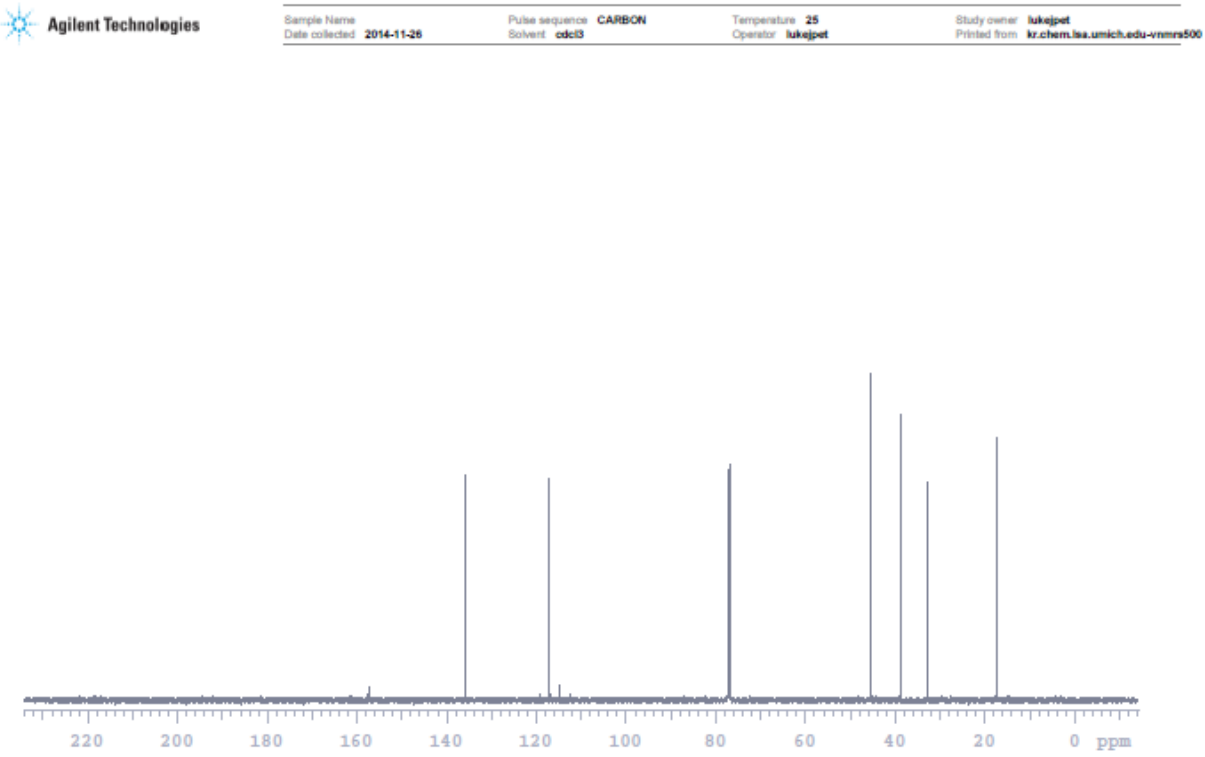
[14] D. N. Mai, B. R. Rosen, J. P. Wolfe, *Org. Lett.* **2011**, *13*, 2932–2935.

[15] M. B. Bertrand, J. D. Neukom, J. P. Wolfe, *J. Org. Chem*. **2008**, *73*, 8851–8860.


Agilent Technologies
Sample Name
Date collected 2014-12-01
Pulse sequence PROTON
Solvent cdcl3
Temperature 25
Operator lukejpet
Study owner lukejpet
Printed from kr.chem.lsa.umich.edu-vnmrs500
Ts
NH
11 10 9 8 7 6 5 4 3 2 1 0 ppm
1.87
1.00
1.96
1.05
1.02
2.04
3.01
2.10

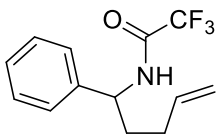

Agilent Technologies
Sample Name
Date collected 2015-01-07
Pulse sequence CARBON
Solvent cdcl3
Temperature 25
Operator lukejpet
Study owner lukejpet
Printed from dy.chem.lsa.umich.edu-vnmrs500
220 200 180 160 140 120 100 80 60 40 20 0 ppm

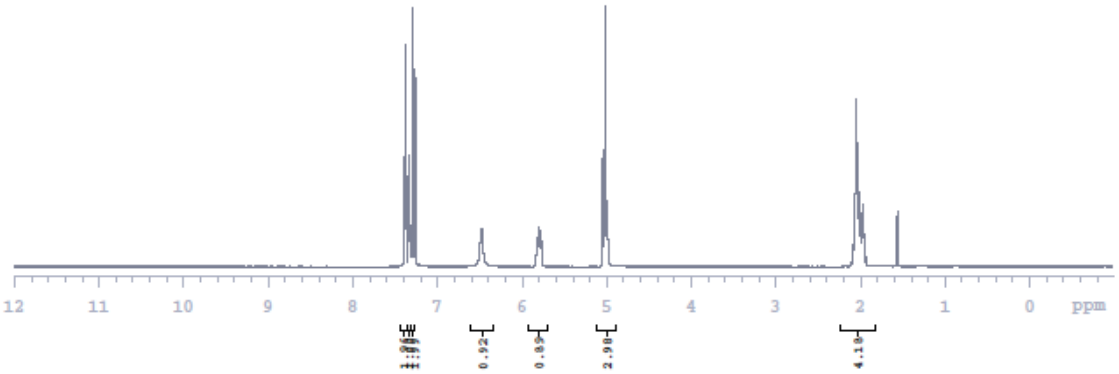

Agilent Technologies
Sample Name
Date collected 2014-11-26
Pulse sequence PROTON
Solvent cdcl3
Temperature 25
Operator lukejpet
Study owner VJtemplt
Printed from kr.chem.lsa.umich.edu-vnmrs500
O
CF3
NH
0.955
3.941
11
10
9
8
7
6
5
4
3
2
1
0
ppm
0.85
0.90
1.93
2.02
1.00
1.02
0.95
2.99


Agilent Technologies
Sample Name
Date collected 2014-11-26
Pulse sequence CARBON
Solvent cdcl3
Temperature 25
Operator lukejpet
Study owner lukejpet
Printed from kr.chem.lsa.umich.edu-vnmrs500
220
200
180
160
140
120
100
80
60
40
20
0
ppm

Agilent Technologies

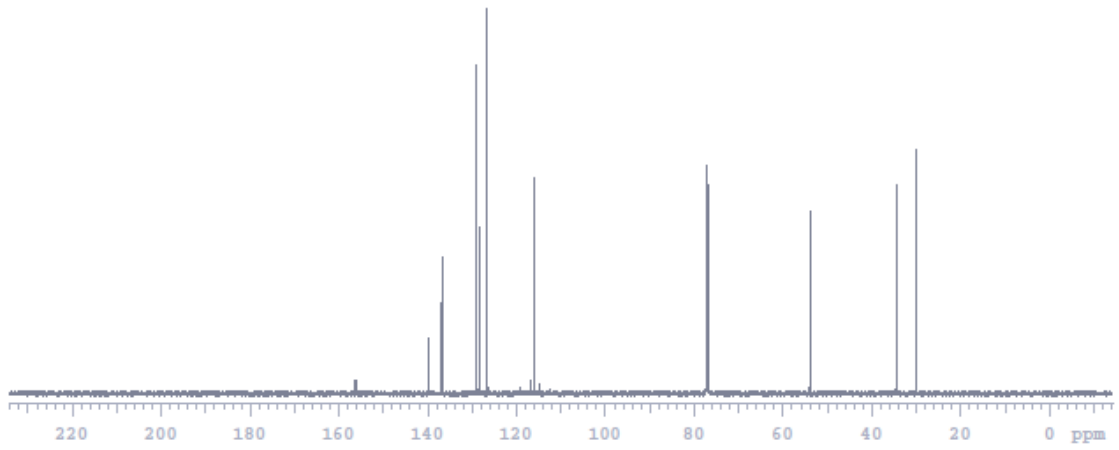
Sample Name	Pulse sequence PROTON	Temperature 25	Study owner VJtempIt
Date collected 2014-11-26	Solvent cdcl3	Operator lukejpet	Printed from kr.chem.lsa.umich.edu-vnmrs500

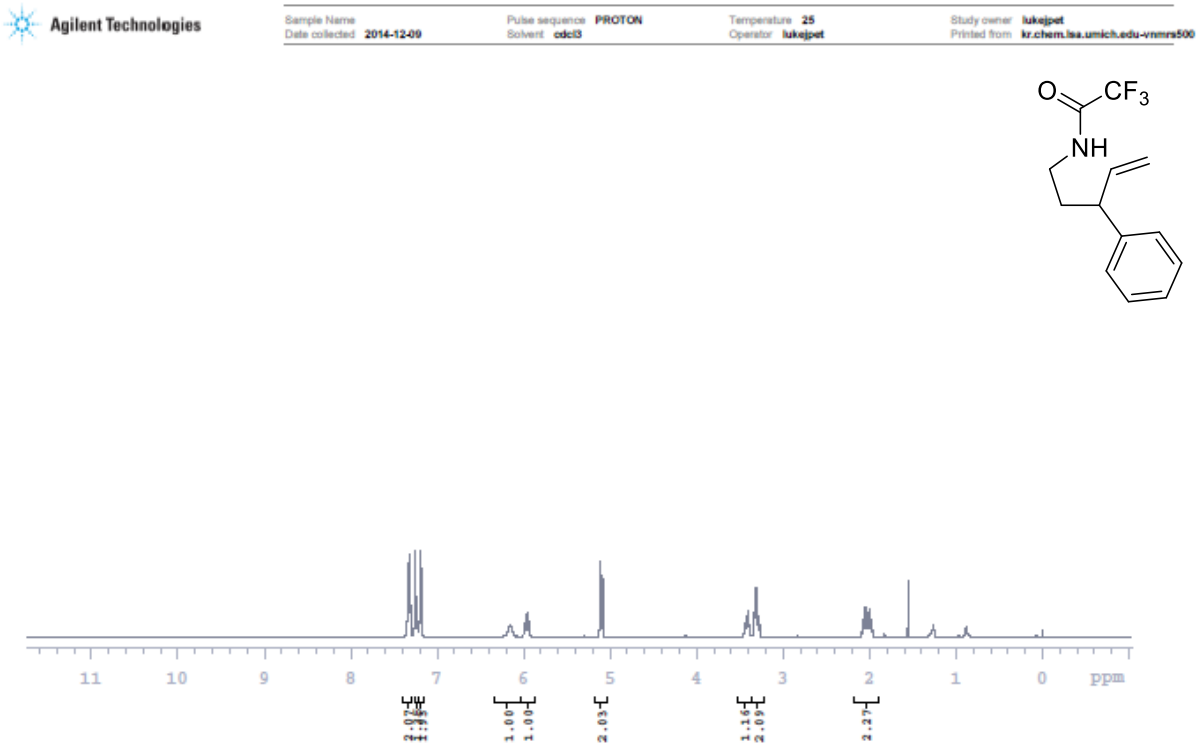


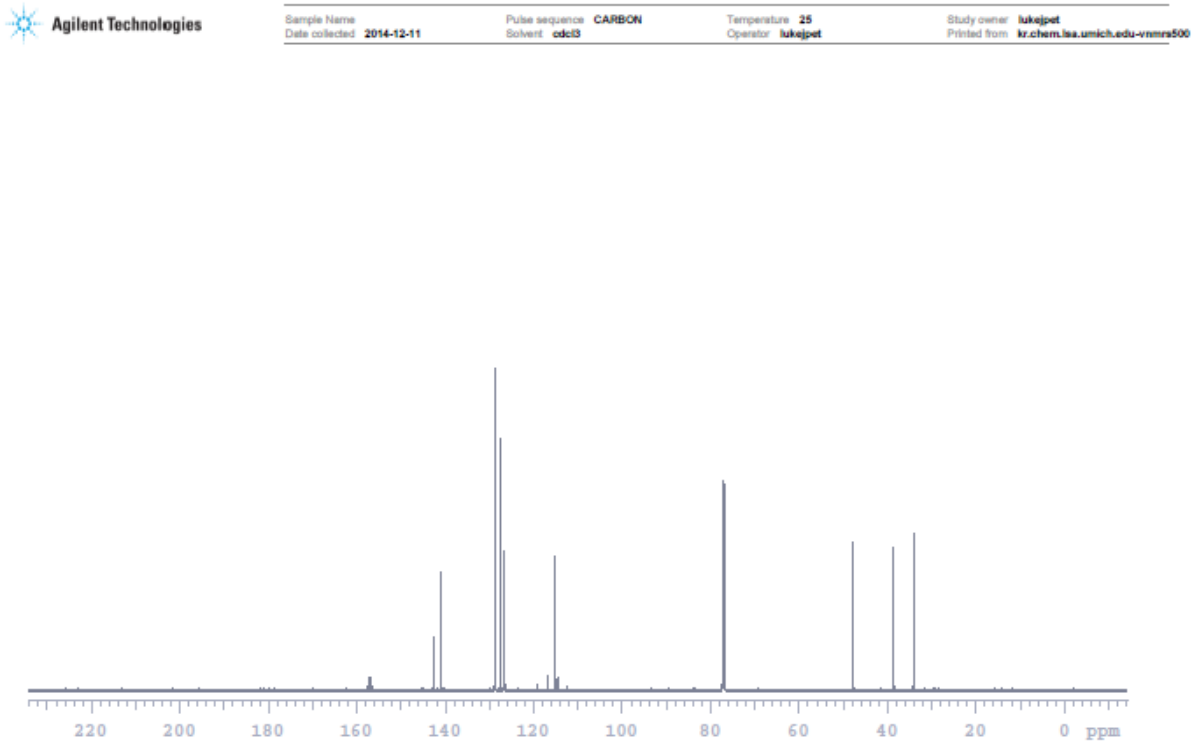


Agilent Technologies

Sample Name	Pulse sequence CARBON	Temperature 25	Study owner lukejpet
Date collected 2014-12-01	Solvent cdcl3	Operator lukejpet	Printed from kr.chem.lsa.umich.edu-vnmrs500

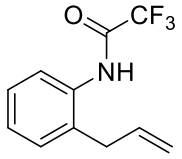


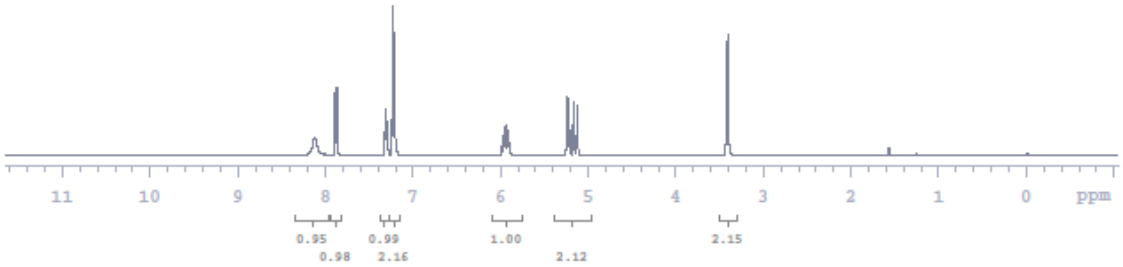

Agilent Technologies
Sample Name
Date collected 2014-12-09
Pulse sequence PROTON
Solvent cdcl3
Temperature 25
Operator lukejpet
Study owner lukejpet
Printed from kr.chem.lsa.umich.edu-vnmrs500
O
CF3
NH
11
10
9
8
7
6
5
4
3
2
1
0
ppm
2.07
1.00
1.00
2.03
1.16
2.09
2.27


Agilent Technologies
Sample Name
Date collected 2014-12-11
Pulse sequence CARBON
Solvent cdcl3
Temperature 25
Operator lukejpet
Study owner lukejpet
Printed from kr.chem.lsa.umich.edu-vnmrs500
220
200
180
160
140
120
100
80
60
40
20
0
ppm

Agilent Technologies

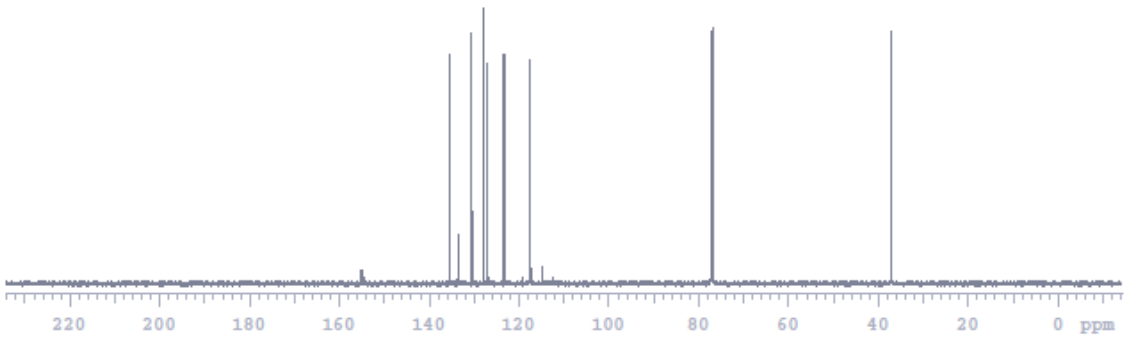
Sample Name	Pulse sequence PROTON	Temperature 25	Study owner lukejpet
Date collected 2014-12-01	Solvent cdcl3	Operator lukejpet	Printed from kr.chem.lsa.umich.edu-vnmrs500

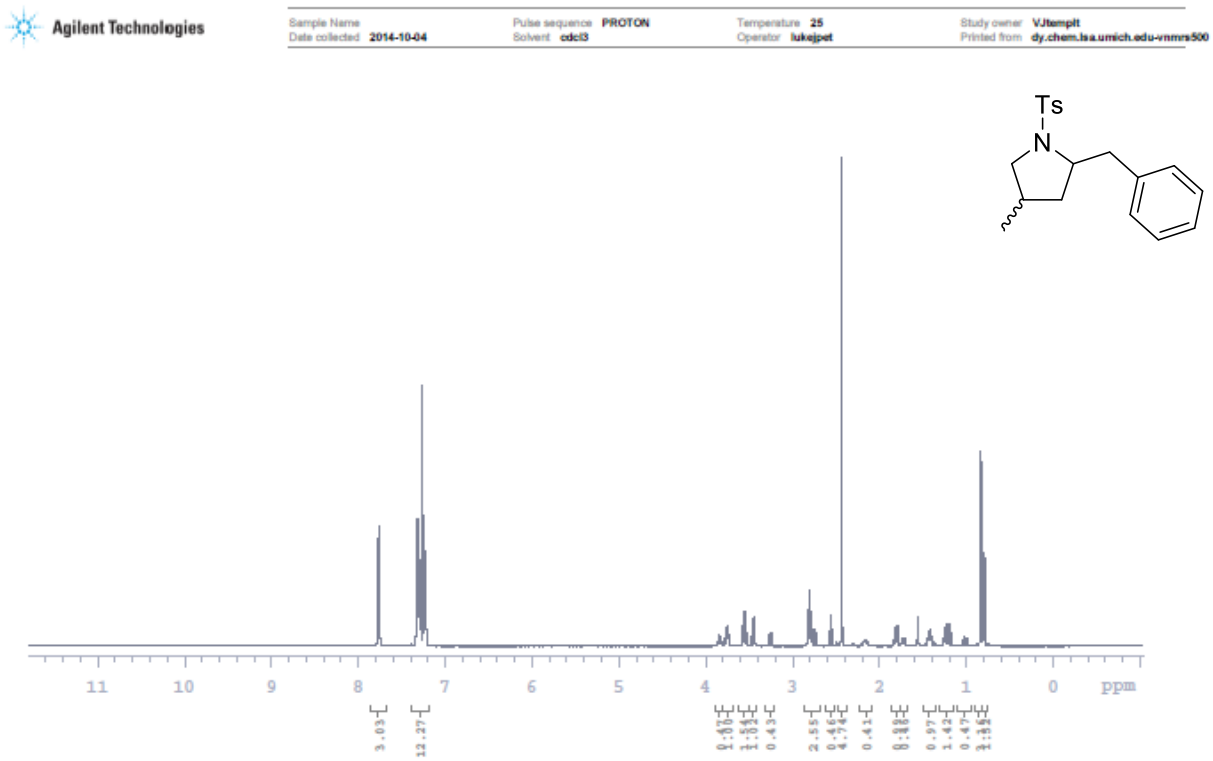


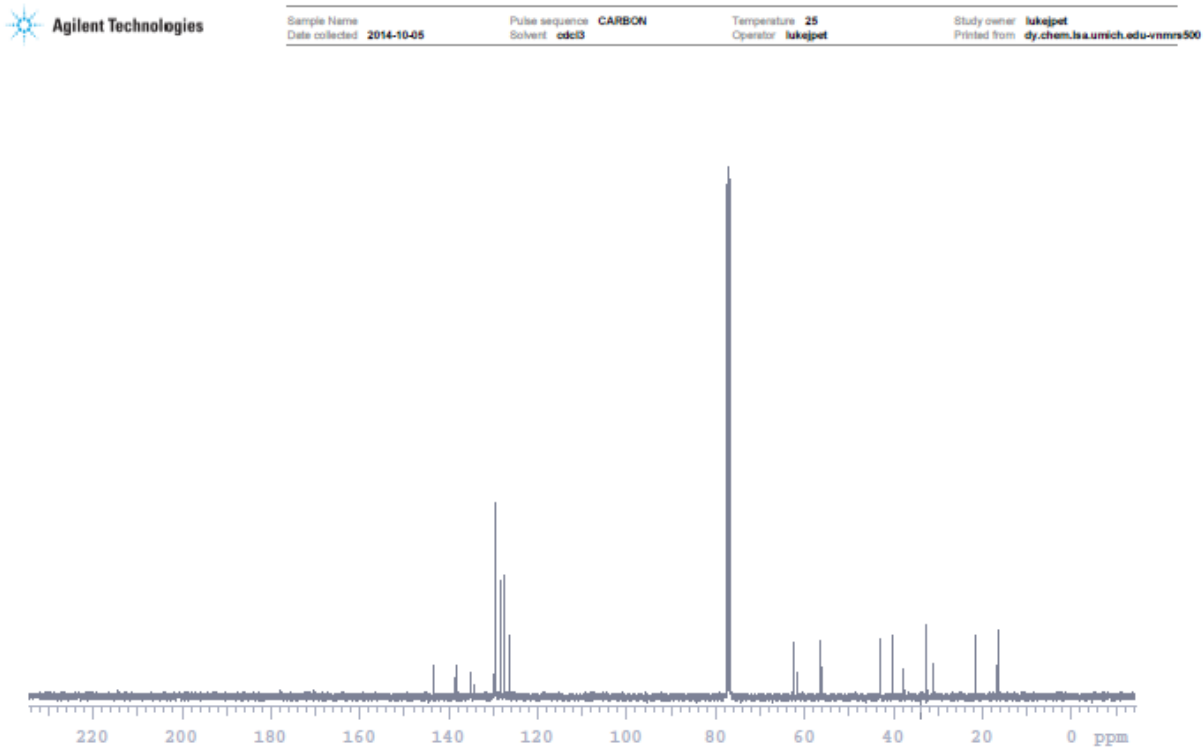


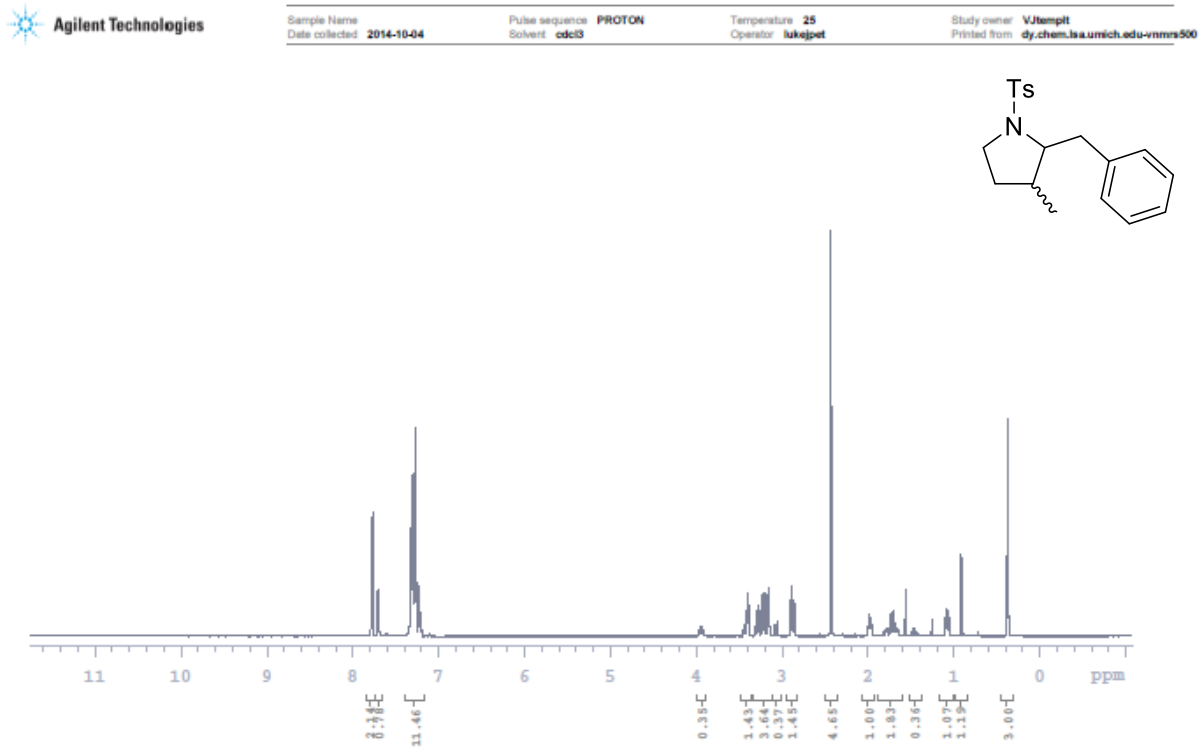
Agilent Technologies

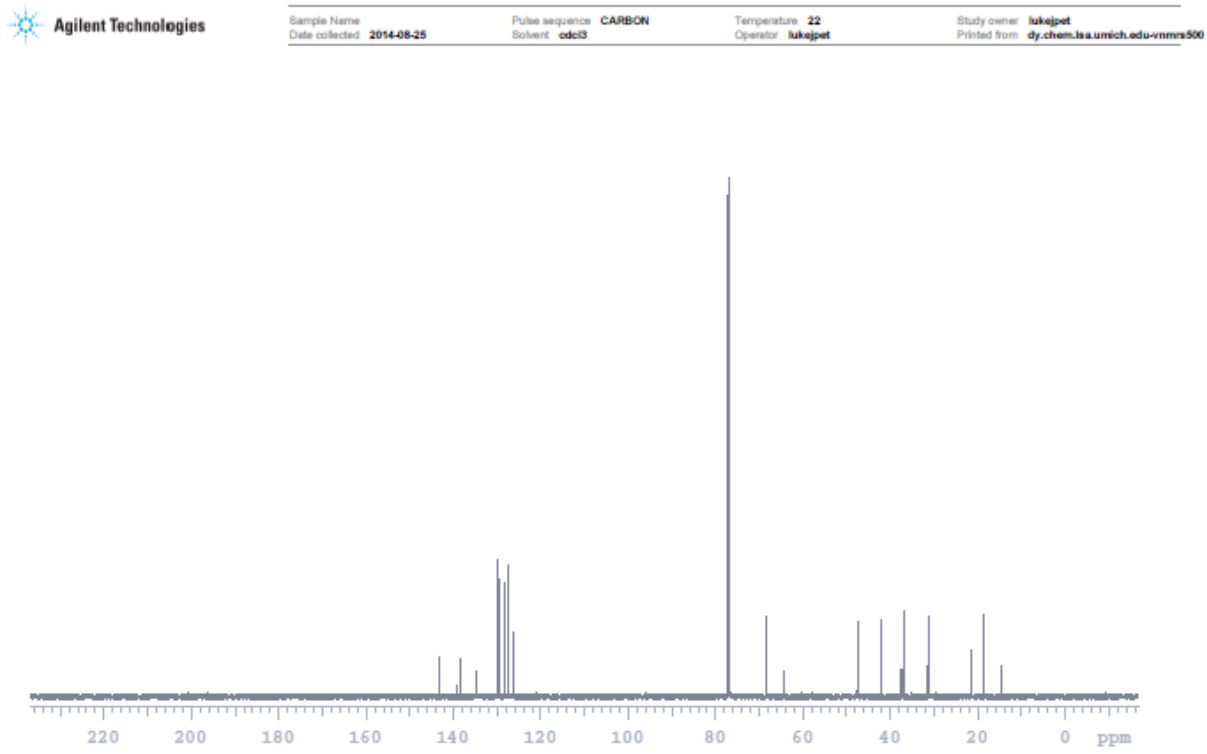
Sample Name	Pulse sequence CARBON	Temperature 25	Study owner lukejpet
Date collected 2014-12-01	Solvent cdcl3	Operator lukejpet	Printed from kr.chem.lsa.umich.edu-vnmrs500

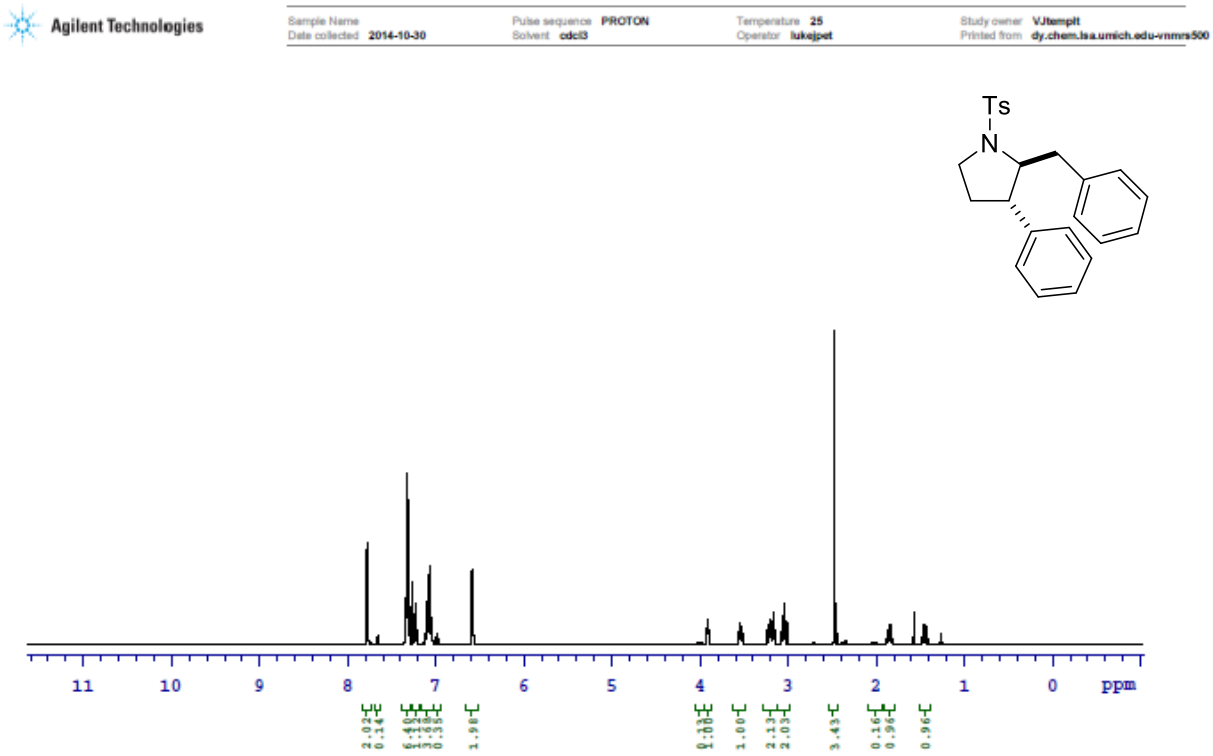


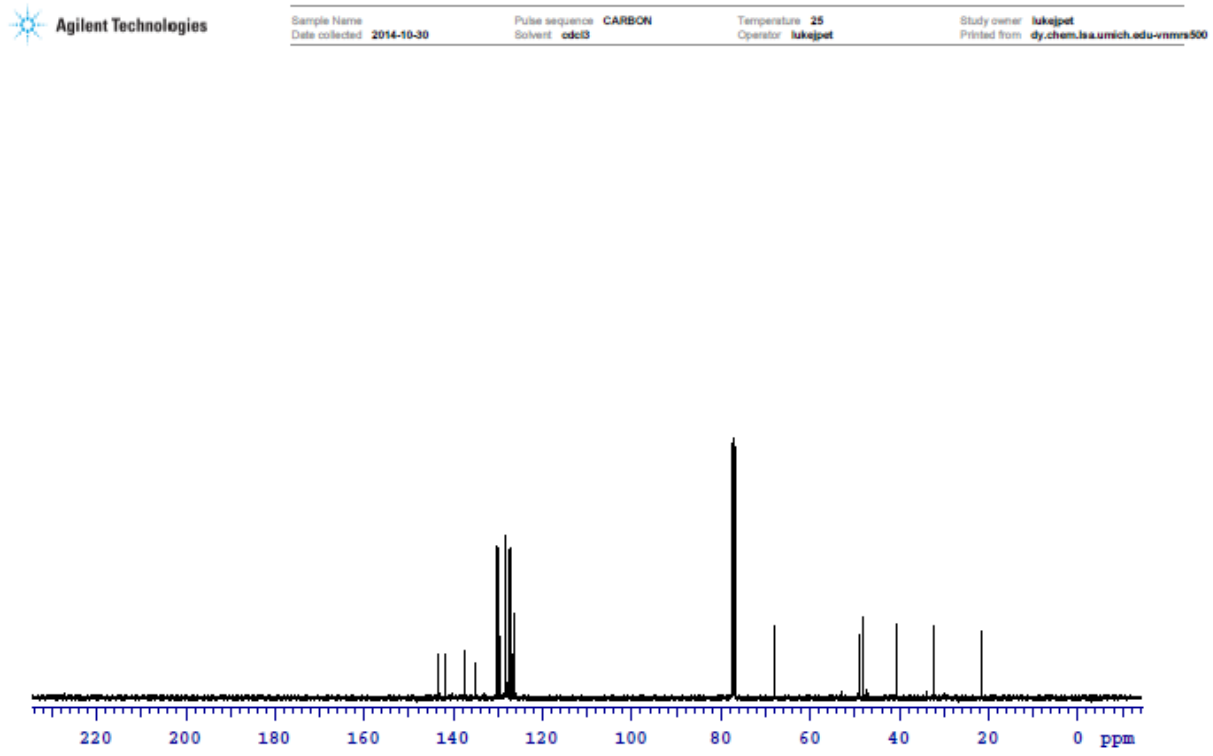

Agilent Technologies
Sample Name
Date collected 2014-10-04
Pulse sequence PROTON
Solvent cdcl3
Temperature 25
Operator lukejpet
Study owner VJtempIt
Printed from dy.chem.lsa.umich.edu-vnmrs500
Ts
N
11
10
9
8
7
6
5
4
3
2
1
0
ppm
3.03
12.27
0.40
1.15
1.15
0.43
2.55
0.46
4.74
0.41
0.98
0.97
1.42
0.47
3.84


Agilent Technologies
Sample Name
Date collected 2014-10-05
Pulse sequence CARBON
Solvent cdcl3
Temperature 25
Operator lukejpet
Study owner lukejpet
Printed from dy.chem.lsa.umich.edu-vnmrs500
220
200
180
160
140
120
100
80
60
40
20
0
ppm


Agilent Technologies
Sample Name
Date collected 2014-10-04
Pulse sequence PROTON
Solvent cdcl3
Temperature 25
Operator lukejpet
Study owner VJtempIt
Printed from dy.chem.lsa.umich.edu-vnmrs500
Ts
N
11
10
9
8
7
6
5
4
3
2
1
0
ppm
0.98
11.46
0.35
1.43
3.64
0.37
1.48
4.65
1.00
1.03
0.36
1.07
1.15
3.00

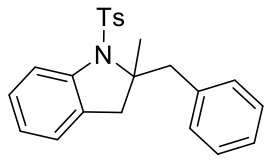

Agilent Technologies
Sample Name
Date collected 2014-08-25
Pulse sequence CARBON
Solvent cdcl3
Temperature 22
Operator lukejpet
Study owner lukejpet
Printed from dy.chem.lsa.umich.edu-vnmrs500
220
200
180
160
140
120
100
80
60
40
20
0
ppm

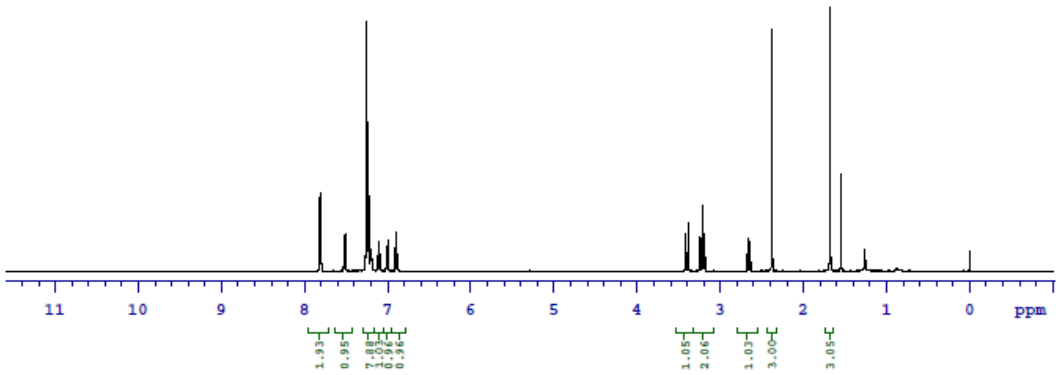

Agilent Technologies
Sample Name
Date collected 2014-10-30
Pulse sequence PROTON
Solvent cdcl3
Temperature 25
Operator lukejpet
Study owner VJtempIt
Printed from dy.chem.lsa.umich.edu-vnmrs500
Ts
N
11
10
9
8
7
6
5
4
3
2
1
0
ppm
2.02
0.14
6.40
1.10
1.05
1.98
1.03
1.00
2.13
2.03
3.43
0.16
0.96
0.96


Agilent Technologies
Sample Name
Date collected 2014-10-30
Pulse sequence CARBON
Solvent cdcl3
Temperature 25
Operator lukejpet
Study owner lukejpet
Printed from dy.chem.lsa.umich.edu-vnmrs500
220
200
180
160
140
120
100
80
60
40
20
0
ppm

Agilent Technologies

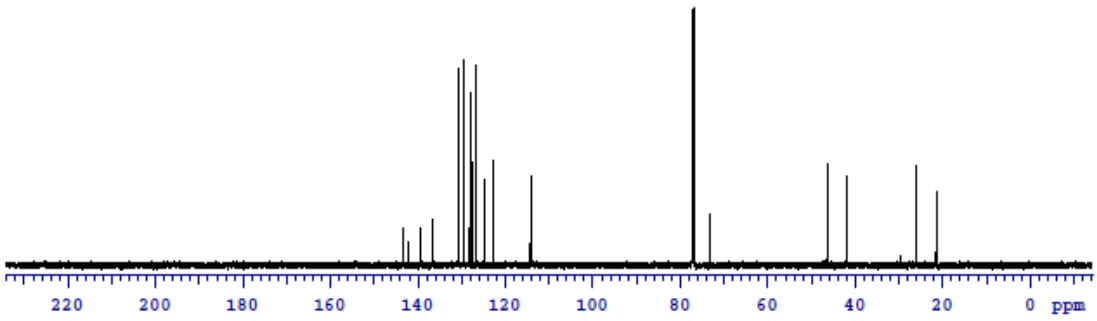
Sample Name		Pulse sequence	PROTON	Temperature	25	Study owner	lukejpet
Date collected	2014-08-01	Solvent	cdcl3	Operator	lukejpet	Printed from	dy.chem.lsa.umich.edu-vnmrs500

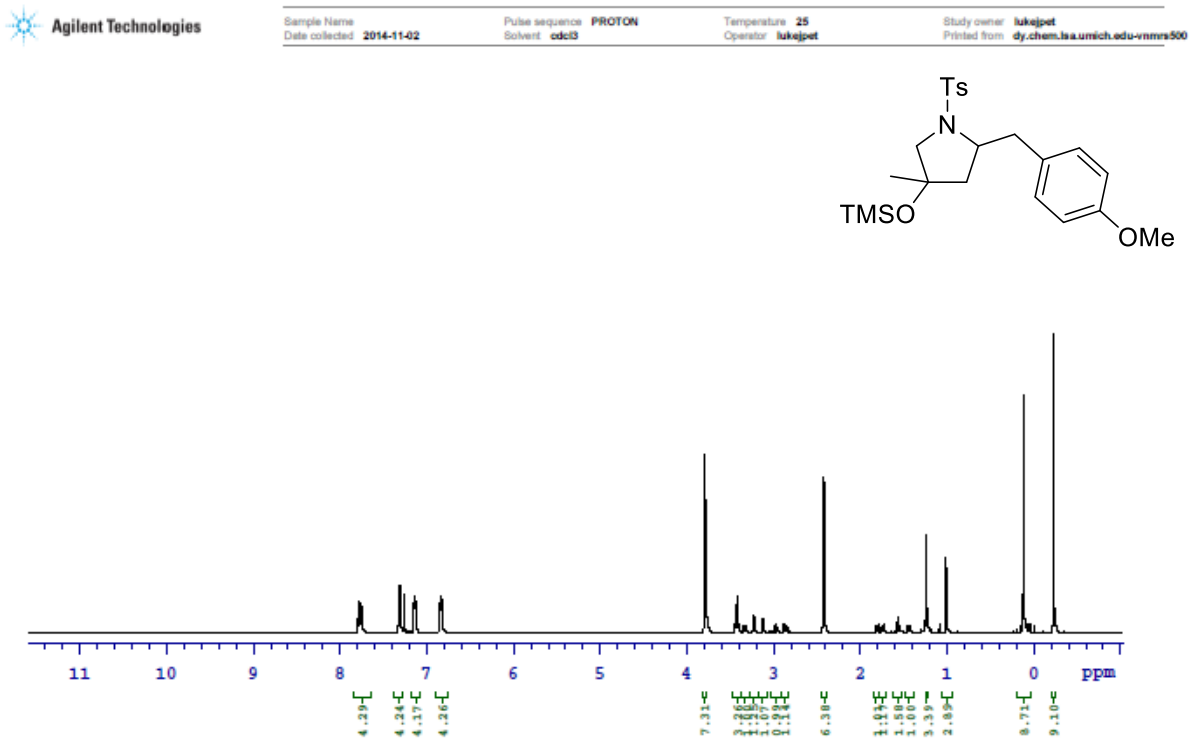


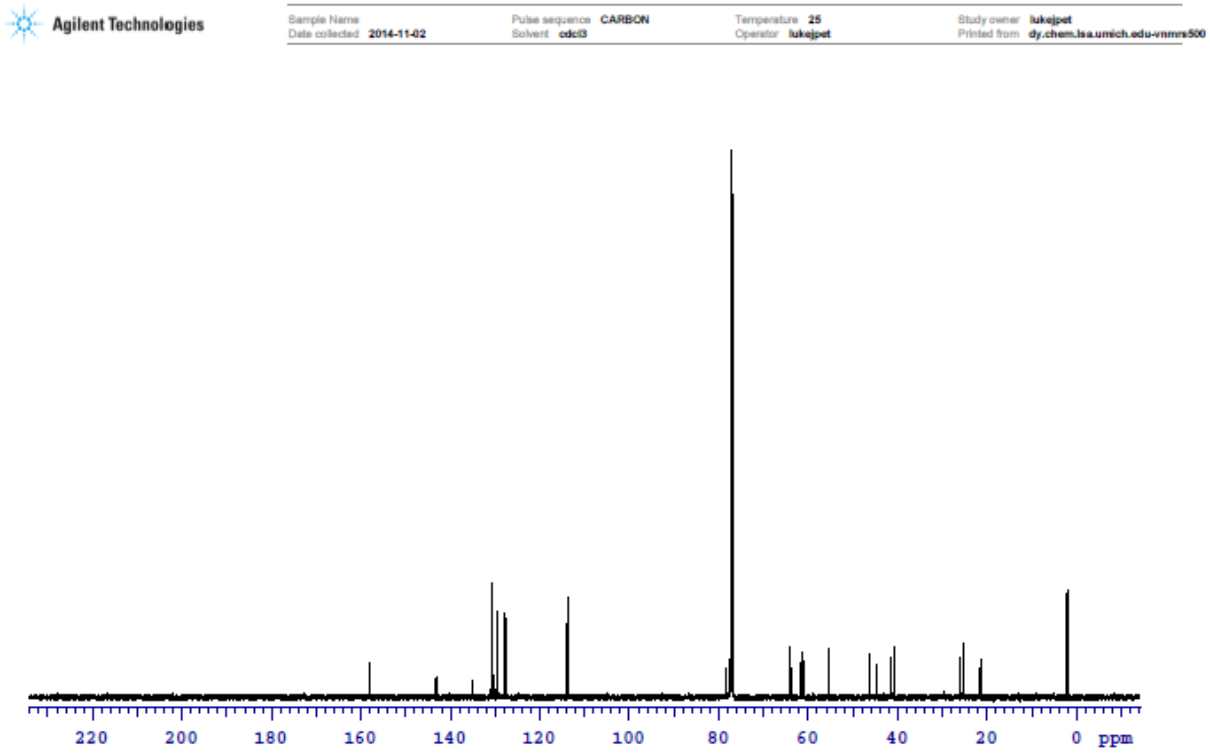


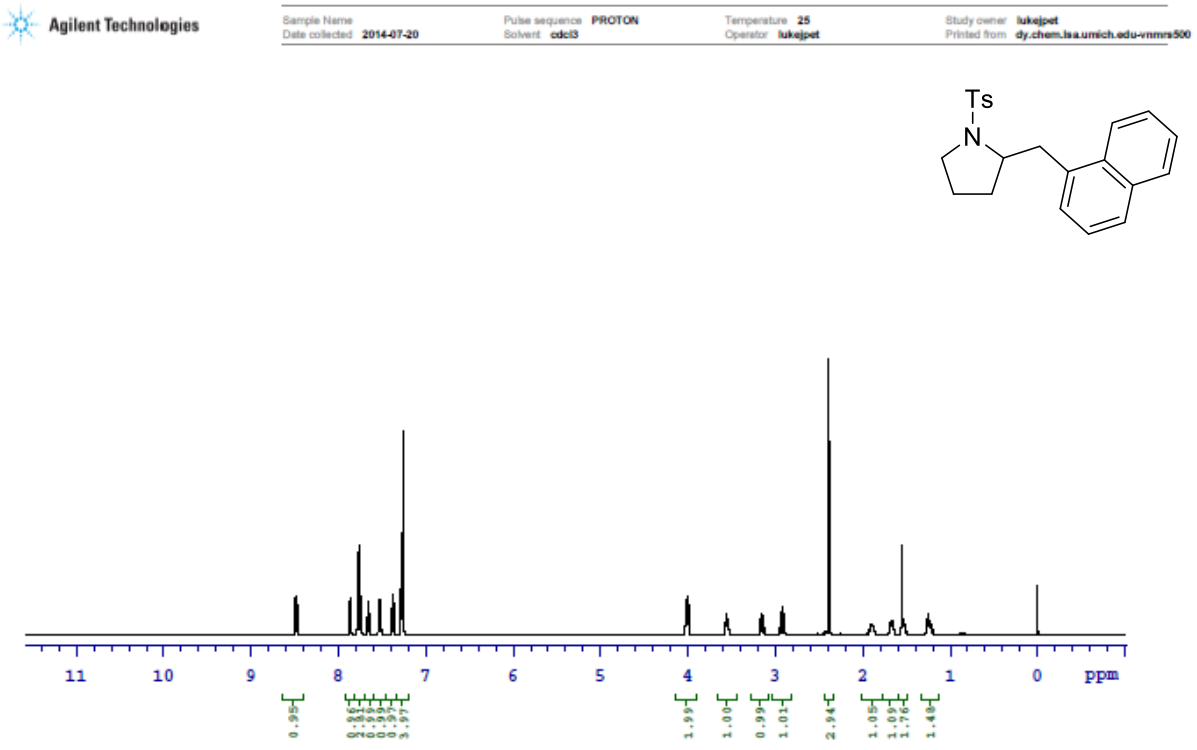
Agilent Technologies

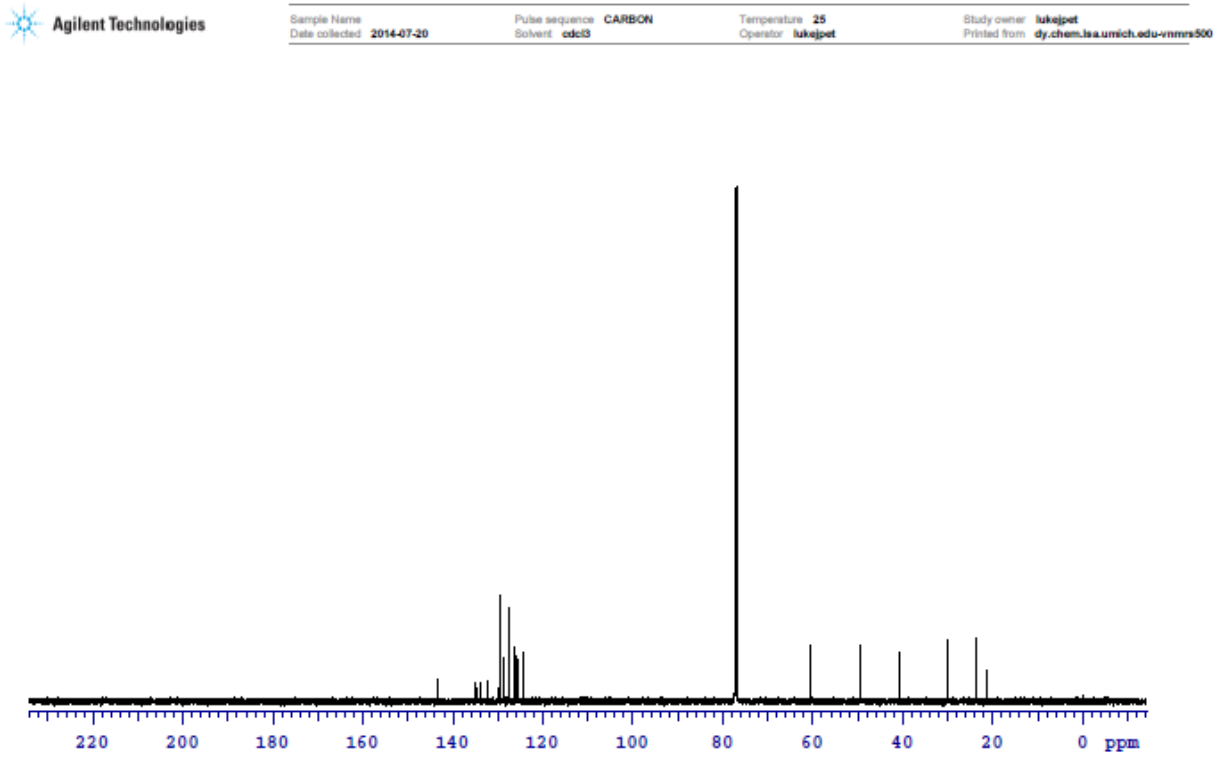
Sample Name		Pulse sequence	CARBON	Temperature	25	Study owner	lukejpet
Date collected	2014-08-01	Solvent	cdcl3	Operator	lukejpet	Printed from	dy.chem.lsa.umich.edu-vnmrs500

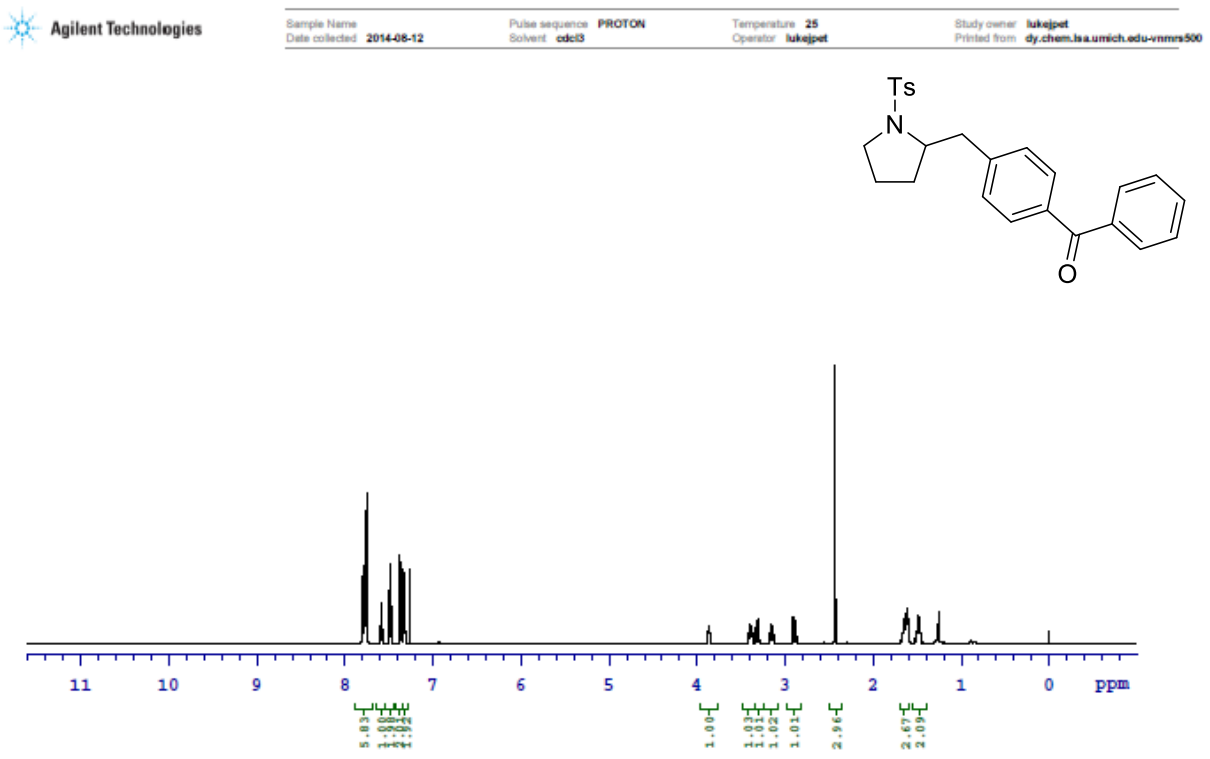


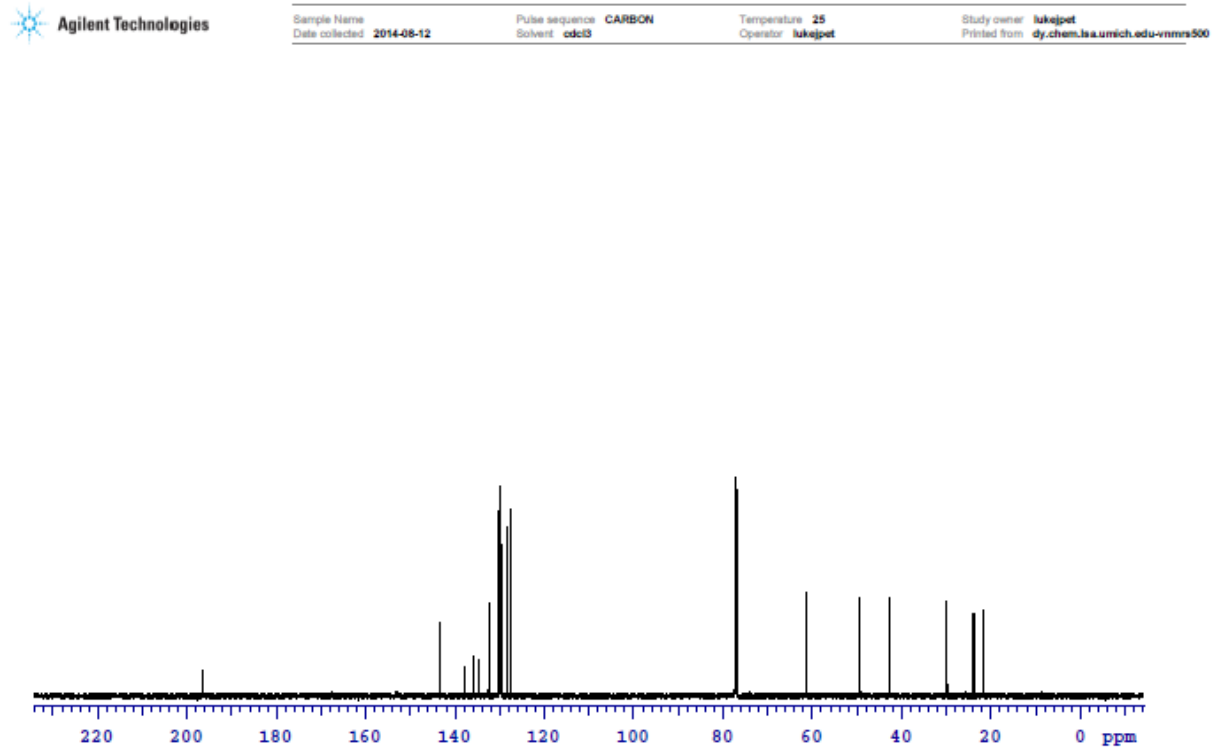

Agilent Technologies
Sample Name
Date collected 2014-11-02
Pulse sequence PROTON
Solvent cdcl3
Temperature 25
Operator lukejpet
Study owner lukejpet
Printed from dy.chem.lsa.umich.edu-vnmrs500
Ts
N
TMSO
OMe
11
10
9
8
7
6
5
4
3
2
1
0
ppm

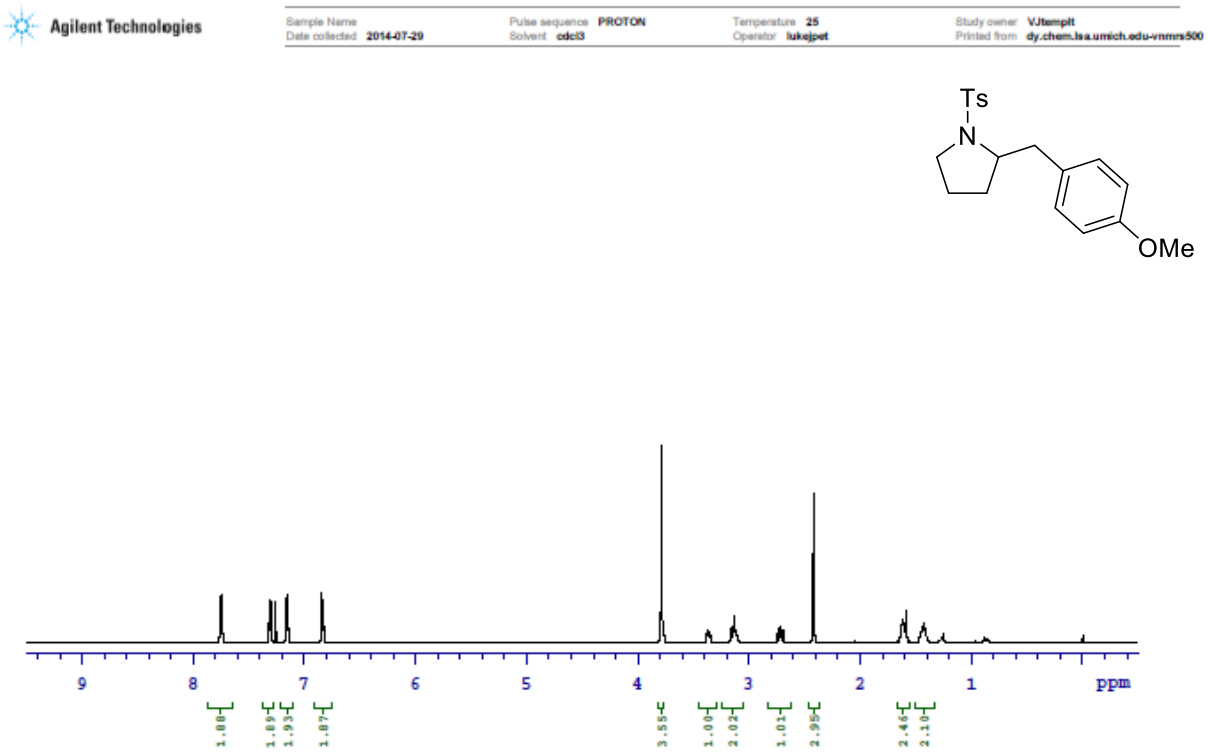

Agilent Technologies
Sample Name
Date collected 2014-11-02
Pulse sequence CARBON
Solvent cdcl3
Temperature 25
Operator lukejpet
Study owner lukejpet
Printed from dy.chem.lsa.umich.edu-vnmrs500
220
200
180
160
140
120
100
80
60
40
20
0
ppm

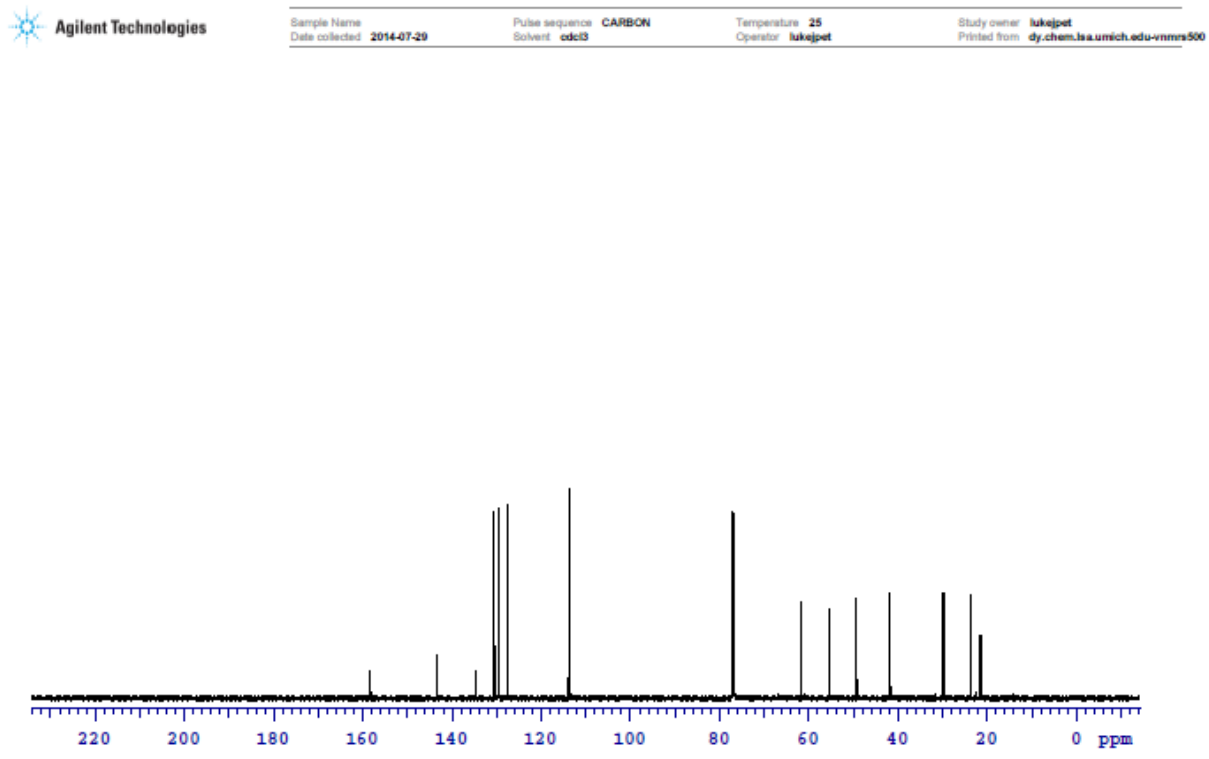

Agilent Technologies
Sample Name
Date collected 2014-07-20
Pulse sequence PROTON
Solvent cdcl3
Temperature 25
Operator lukejpet
Study owner lukejpet
Printed from dy.chem.lsa.umich.edu-vnmrs500
Ts
N
11 10 9 8 7 6 5 4 3 2 1 0 ppm
0.95
1.99
1.00
0.99
1.01
2.94
1.05
1.09
1.76
1.48

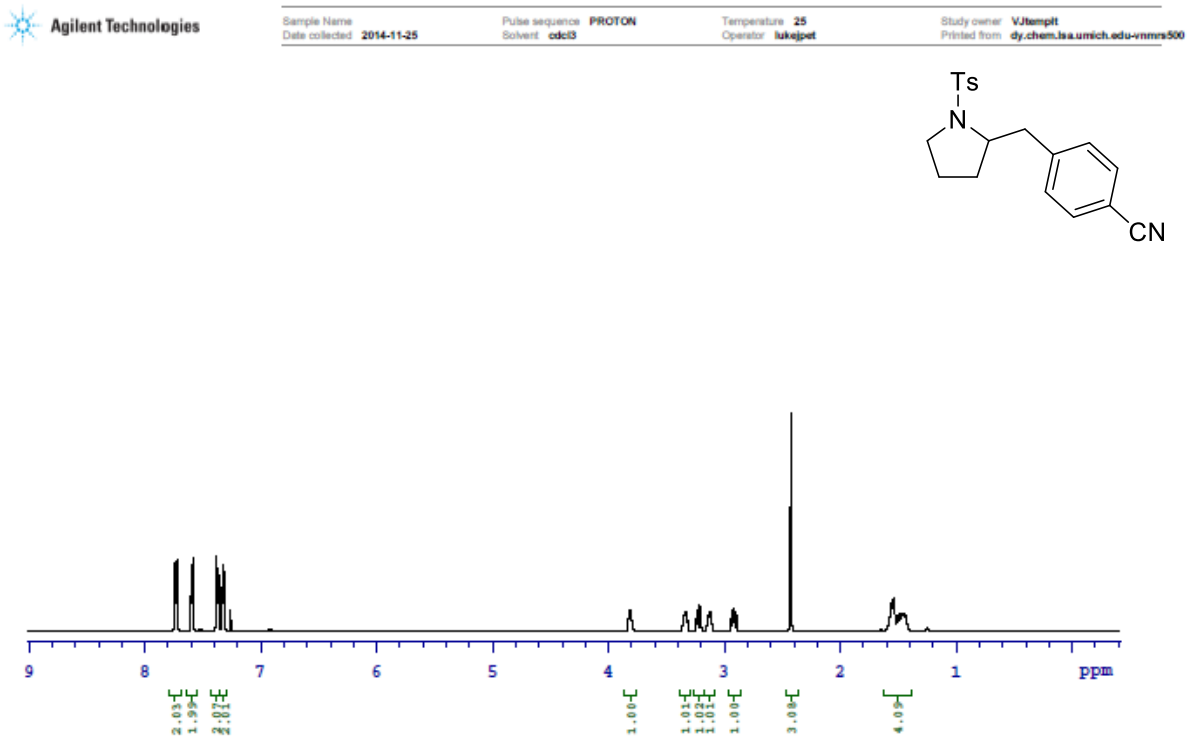

Agilent Technologies
Sample Name
Date collected 2014-07-20
Pulse sequence CARBON
Solvent cdcl3
Temperature 25
Operator lukejpet
Study owner lukejpet
Printed from dy.chem.lsa.umich.edu-vnmrs500
220 200 180 160 140 120 100 80 60 40 20 0 ppm

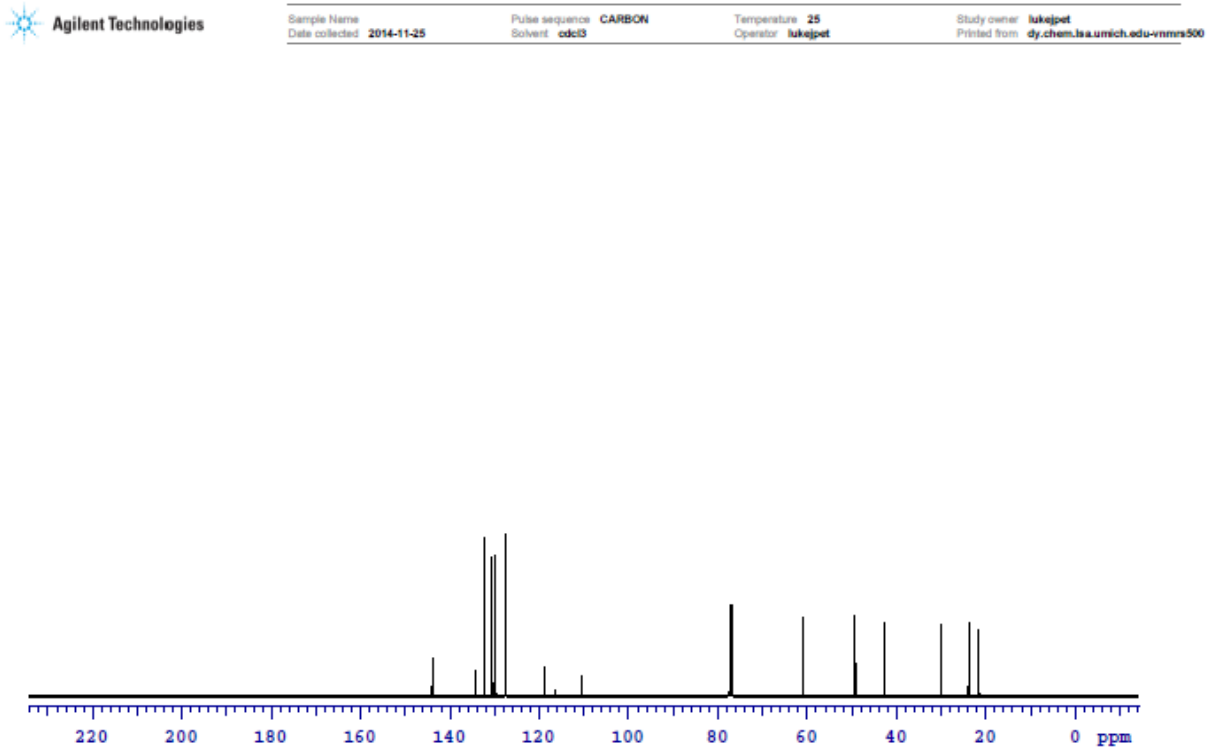

Agilent Technologies
Sample Name
Date collected 2014-08-12
Pulse sequence PROTON
Solvent cdcl3
Temperature 25
Operator lukejpet
Study owner lukejpet
Printed from dy.chem.lsa.umich.edu-vnmrs500
Ts
N
O
11 10 9 8 7 6 5 4 3 2 1 0 ppm
5.03
1.00
0.98
1.02
1.00
1.03
1.01
1.02
1.01
2.96
2.67
2.09

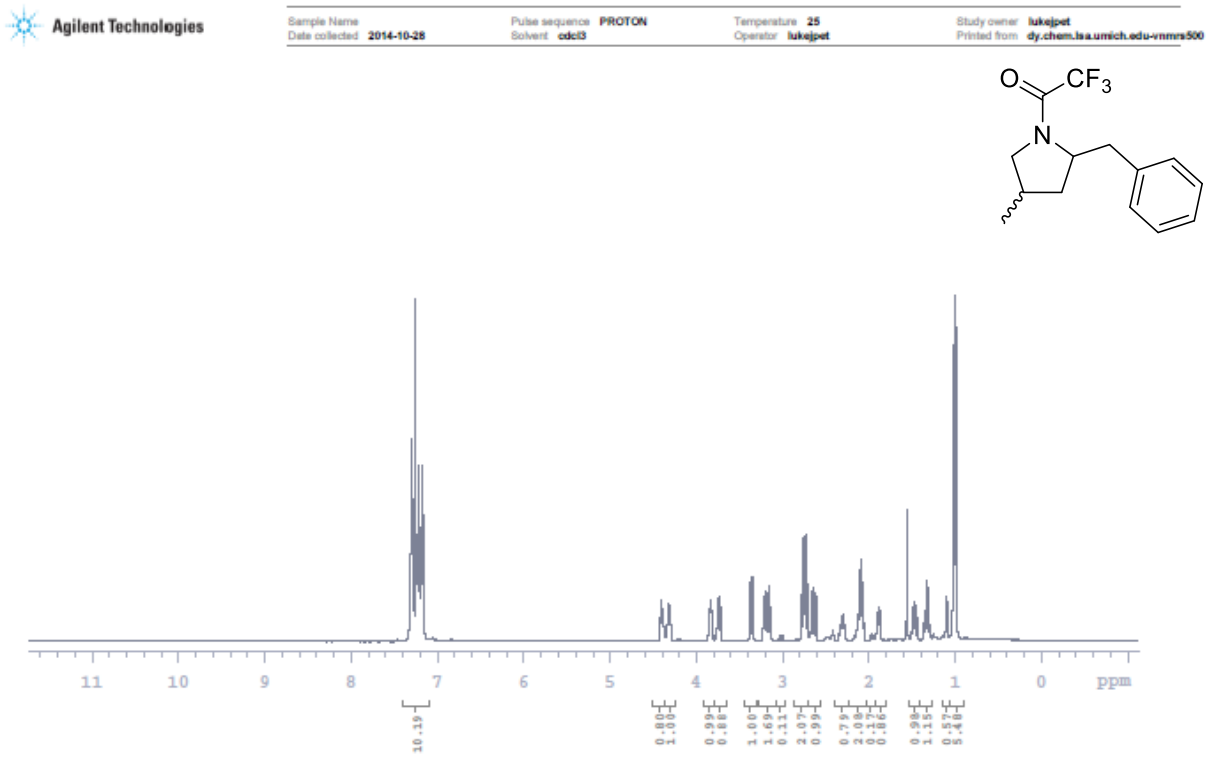

Agilent Technologies
Sample Name
Date collected 2014-08-12
Pulse sequence CARBON
Solvent cdcl3
Temperature 25
Operator lukejpet
Study owner lukejpet
Printed from dy.chem.lsa.umich.edu-vnmrs500
220 200 180 160 140 120 100 80 60 40 20 0 ppm

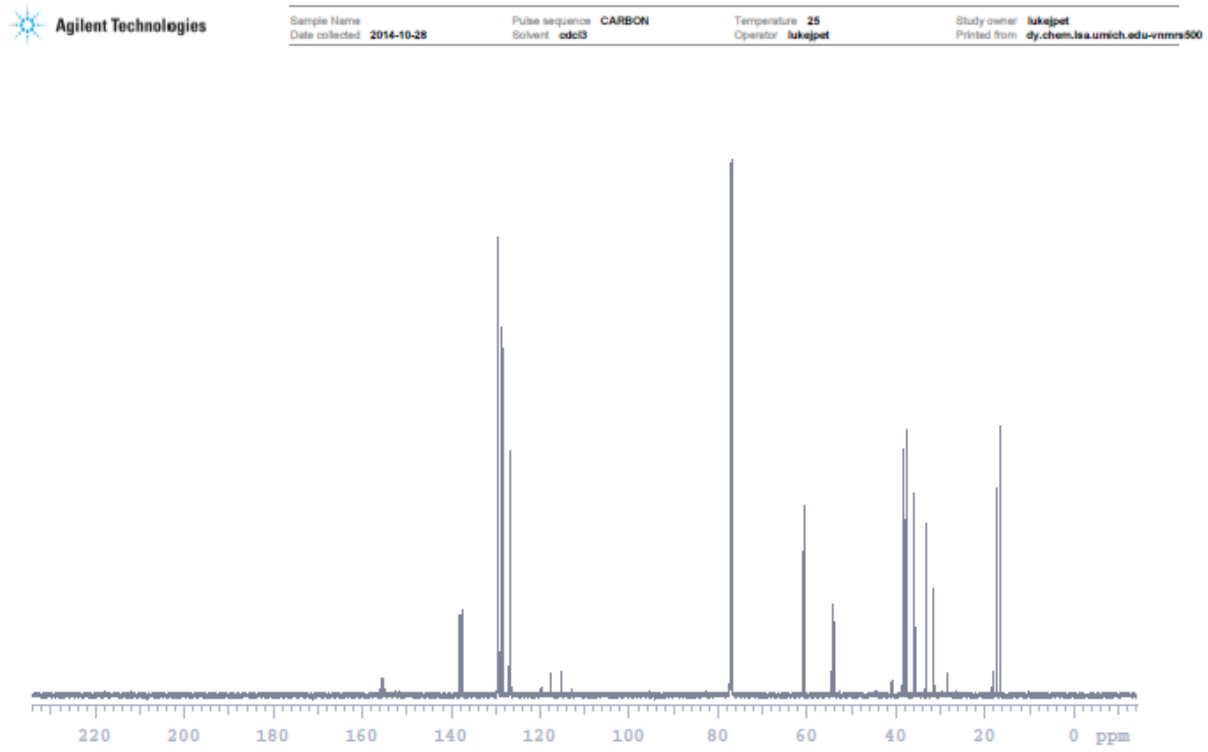

Agilent Technologies
Sample Name
Date collected 2014-07-29
Pulse sequence PROTON
Solvent cdcl3
Temperature 25
Operator lukejpet
Study owner VJtempIt
Printed from dy.chem.lsa.umich.edu-vnmrs500
Ts
N
OMe
9
8
7
6
5
4
3
2
1
ppm
1.00
1.89
1.93
1.87
3.55
1.00
2.02
1.01
2.95
2.46
2.10

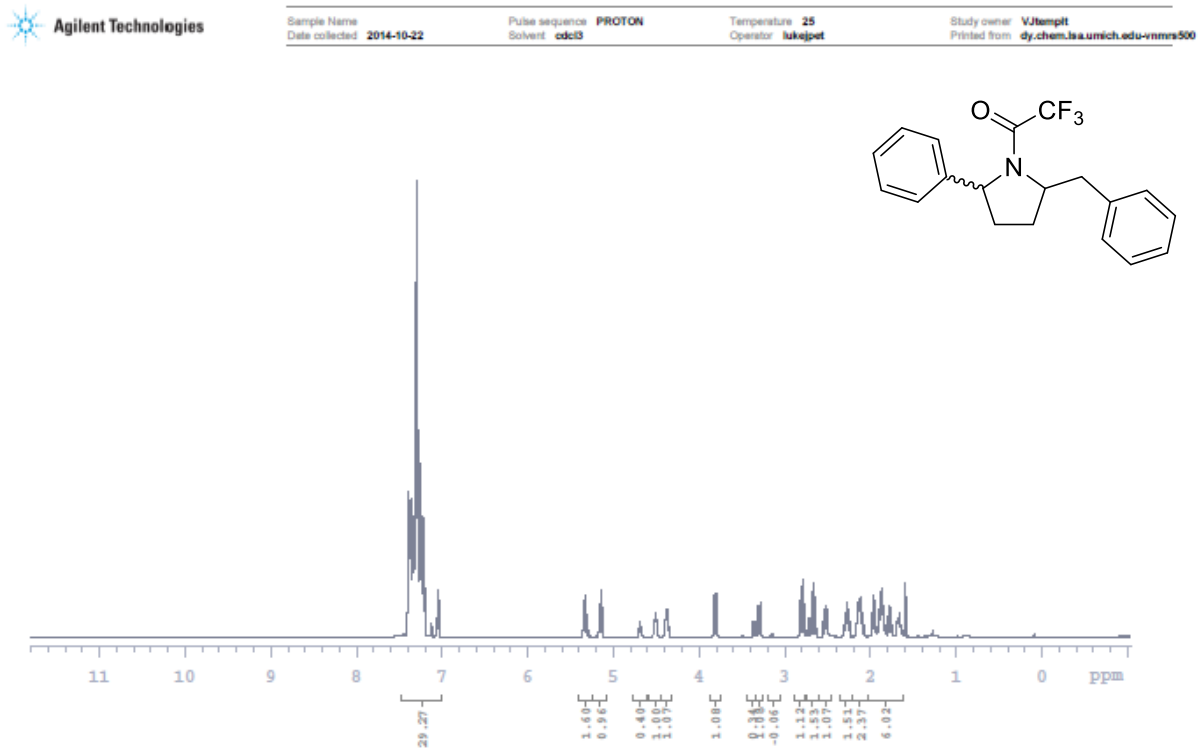

Agilent Technologies
Sample Name
Date collected 2014-07-29
Pulse sequence CARBON
Solvent cdcl3
Temperature 25
Operator lukejpet
Study owner lukejpet
Printed from dy.chem.lsa.umich.edu-vnmrs500
220
200
180
160
140
120
100
80
60
40
20
0
ppm

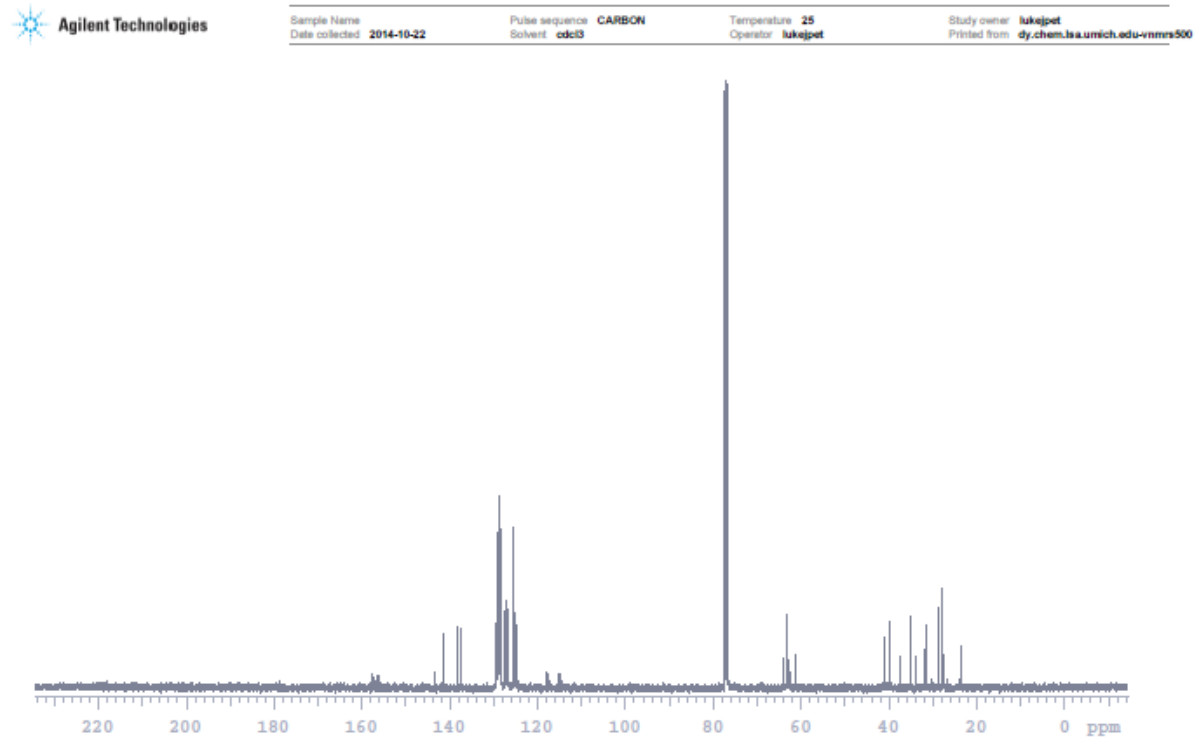

Agilent Technologies
Sample Name
Date collected 2014-11-25
Pulse sequence PROTON
Solvent cdcl3
Temperature 25
Operator lukejpet
Study owner VJtempIt
Printed from dy.chem.lsa.umich.edu-vnmrs500
Ts
N
CN
9
8
7
6
5
4
3
2
1
ppm
2.03
1.99
2.07
2.01
1.00
1.01
1.02
1.01
1.00
3.08
4.08

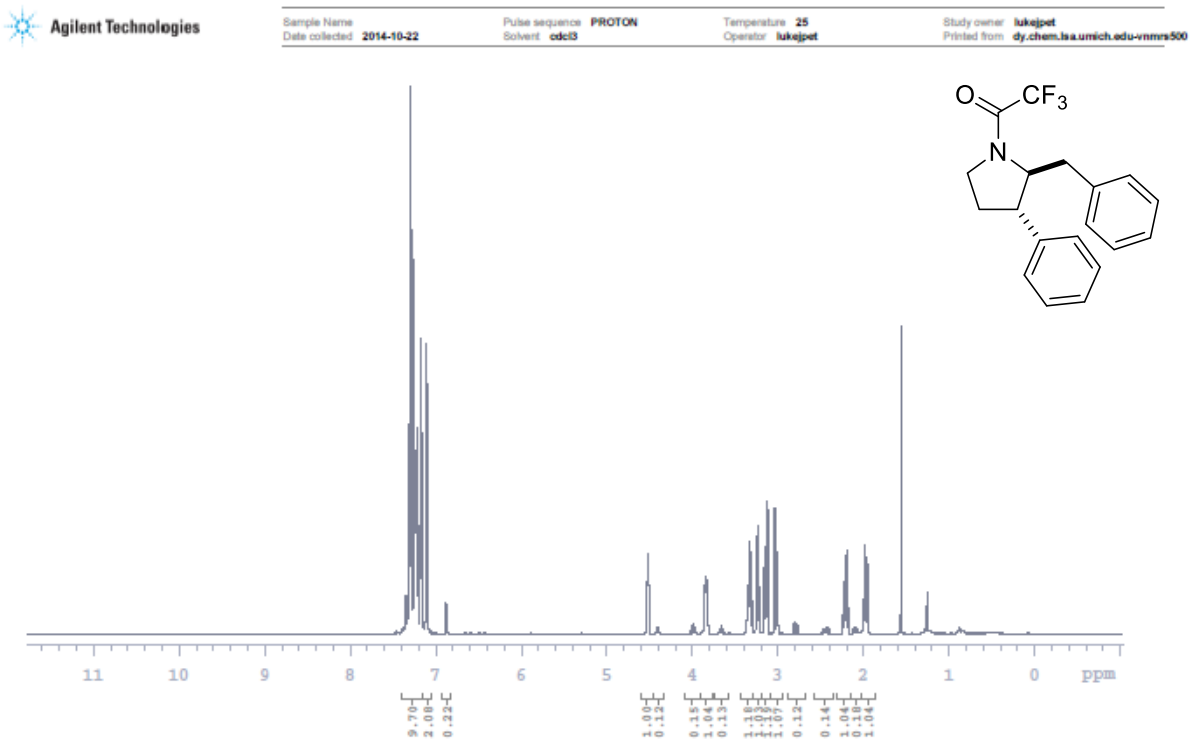

Agilent Technologies
Sample Name
Date collected 2014-11-25
Pulse sequence CARBON
Solvent cdcl3
Temperature 25
Operator lukejpet
Study owner lukejpet
Printed from dy.chem.lsa.umich.edu-vnmrs500
220
200
180
160
140
120
100
80
60
40
20
0
ppm

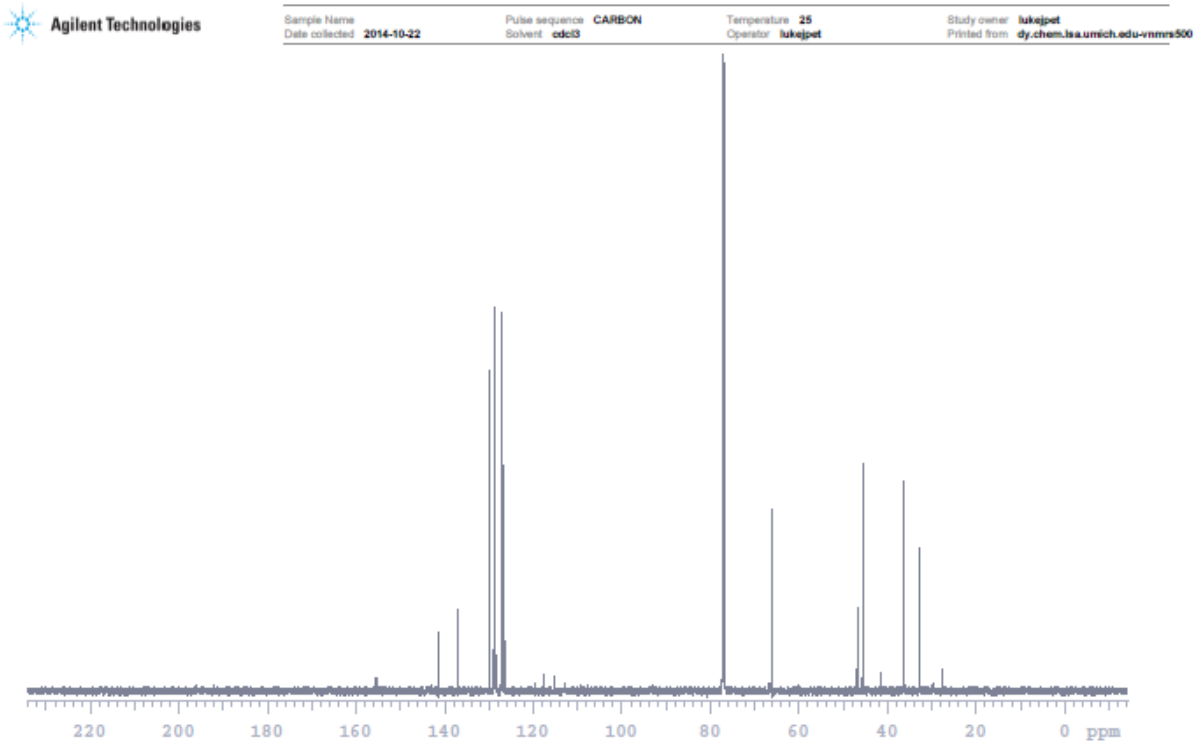

Agilent Technologies
Sample Name
Date collected 2014-10-28
Pulse sequence PROTON
Solvent cdcl3
Temperature 25
Operator lukejpet
Study owner lukejpet
Printed from dy.chem.lsa.umich.edu-vnmrs500
O
CF3
N
11 10 9 8 7 6 5 4 3 2 1 0 ppm
10.19
0.80
1.00
0.90
0.88
1.00
1.69
0.11
2.07
0.99
0.79
2.00
0.97
0.86
0.98
1.15
0.57
0.48

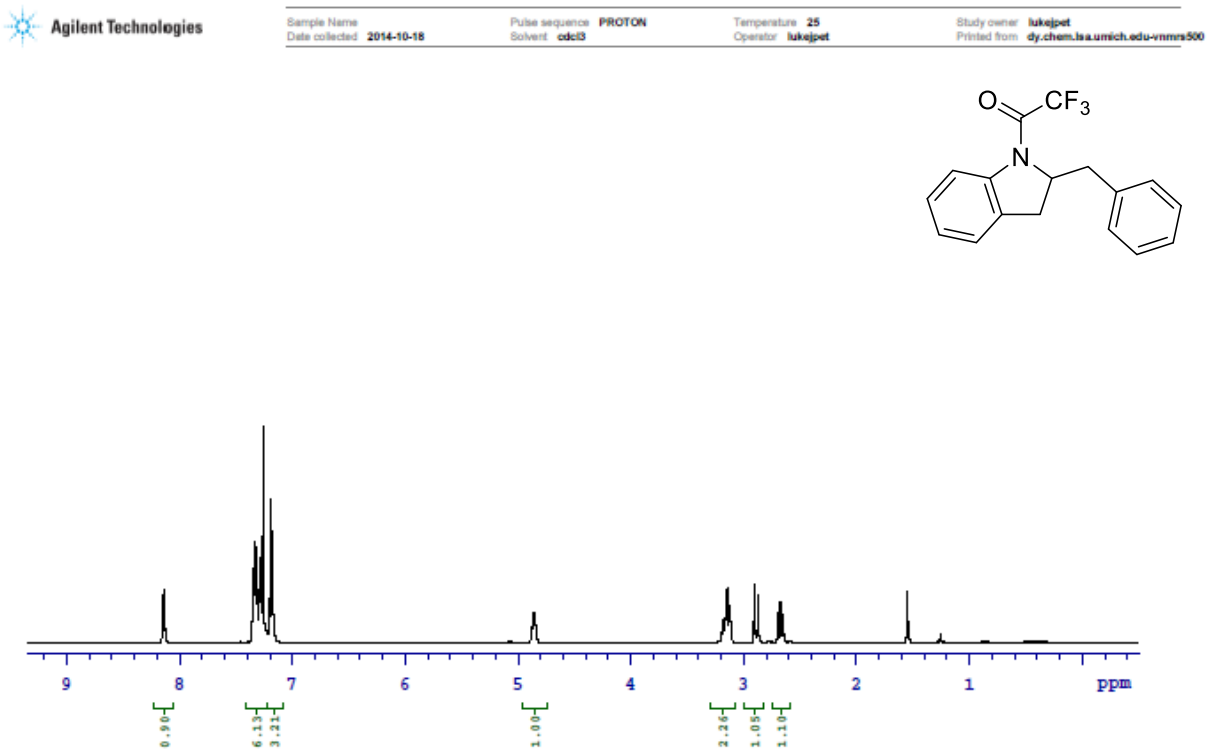

Agilent Technologies
Sample Name
Date collected 2014-10-28
Pulse sequence CARBON
Solvent cdcl3
Temperature 25
Operator lukejpet
Study owner lukejpet
Printed from dy.chem.lsa.umich.edu-vnmrs500
220 200 180 160 140 120 100 80 60 40 20 0 ppm

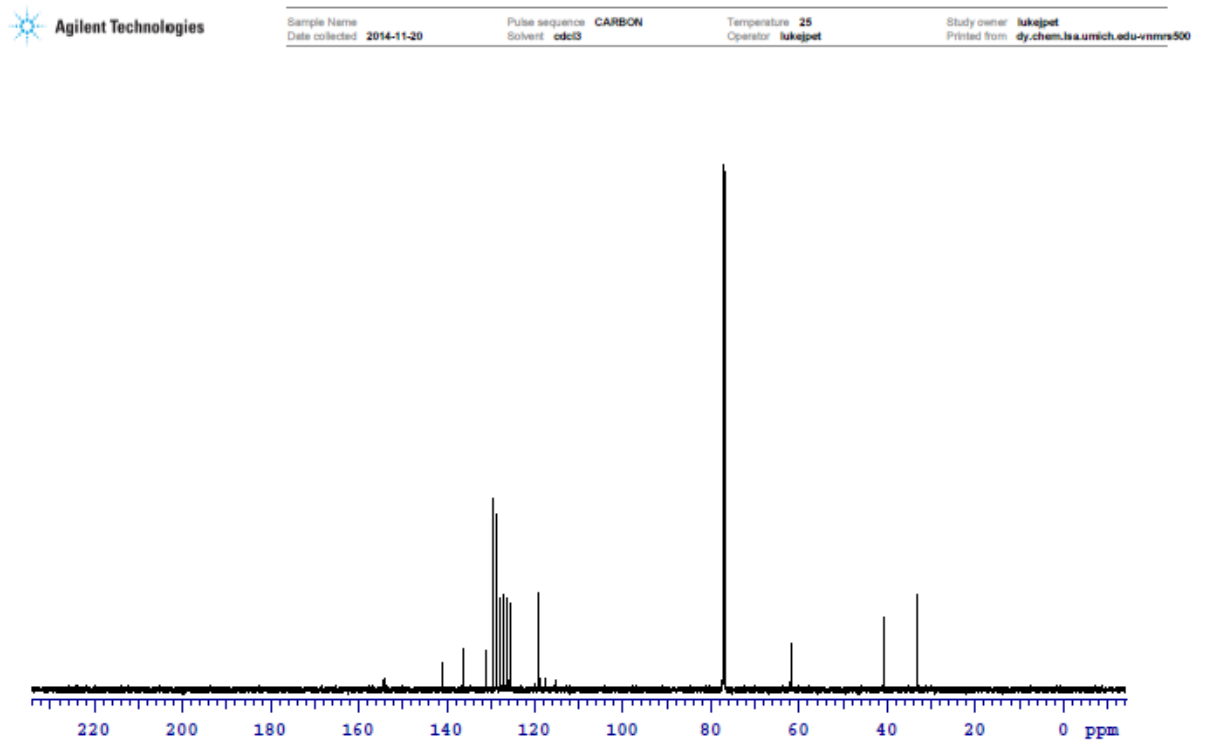

Agilent Technologies
Sample Name
Date collected 2014-10-22
Pulse sequence PROTON
Solvent cdcl3
Temperature 25
Operator lukejpet
Study owner VJtempIt
Printed from dy.chem.lsa.umich.edu-vnmrs500
O
CF3
N
11 10 9 8 7 6 5 4 3 2 1 0 ppm
29.27
1.60
0.96
0.40
1.00
1.07
1.08
0.35
2.08
0.06
1.12
1.53
1.07
1.51
2.57
6.02


Agilent Technologies
Sample Name
Date collected 2014-10-22
Pulse sequence CARBON
Solvent cdcl3
Temperature 25
Operator lukejpet
Study owner lukejpet
Printed from dy.chem.lsa.umich.edu-vnmrs500
220 200 180 160 140 120 100 80 60 40 20 0 ppm


Agilent Technologies
Sample Name
Date collected 2014-10-22
Pulse sequence PROTON
Solvent cdcl3
Temperature 25
Operator lukejpet
Study owner lukejpet
Printed from dy.chem.lsa.umich.edu-vnmrs500
O
CF3
N
11 10 9 8 7 6 5 4 3 2 1 0 ppm
9.70 2.08 0.22 1.00 0.12 0.15 1.04 0.13 1.18 1.01 1.07 0.12 0.14 1.04 0.10 1.04


Agilent Technologies
Sample Name
Date collected 2014-10-22
Pulse sequence CARBON
Solvent cdcl3
Temperature 25
Operator lukejpet
Study owner lukejpet
Printed from dy.chem.lsa.umich.edu-vnmrs500
220 200 180 160 140 120 100 80 60 40 20 0 ppm


Agilent Technologies
Sample Name
Date collected 2014-10-18
Pulse sequence PROTON
Solvent cdcl3
Temperature 25
Operator lukejpet
Study owner lukejpet
Printed from dy.chem.lsa.umich.edu-vnmrs500
O
CF3
N
9
8
7
6
5
4
3
2
1
ppm
0.90
6.13
3.21
1.00
2.26
1.05
1.10


Agilent Technologies
Sample Name
Date collected 2014-11-20
Pulse sequence CARBON
Solvent cdcl3
Temperature 25
Operator lukejpet
Study owner lukejpet
Printed from dy.chem.lsa.umich.edu-vnmrs500
220
200
180
160
140
120
100
80
60
40
20
0
ppm