Electronic Supplementary Material (ESI) for New Journal of Chemistry.

Electronic Supporting Information

Copper-catalyzed oxidative cleavage of Passerini and Ugi adducts in basic medium yielding α-ketoamides

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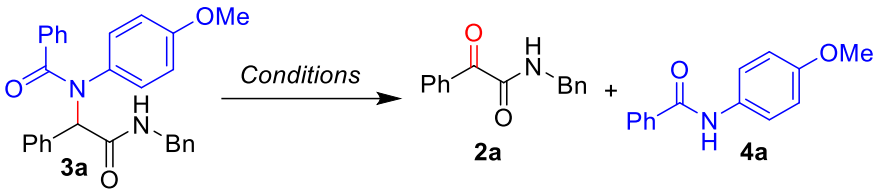
1. Optimization studies for oxidative cleavage of Ugi adducts

Table S1. Optimization of the reaction conditions[a]

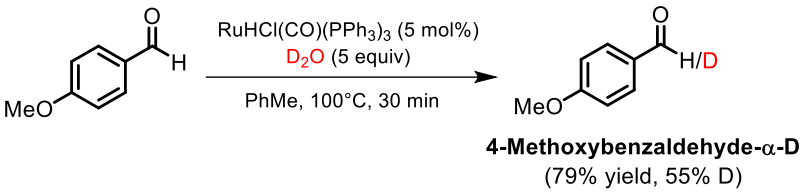


Entry	Base	Additive (mol %)	Solvent	Time (h)	Conversion (%)	**2a**; yield (%)[c]	**4a**; yield (%)[c]
1	NaH	----	THF	12	5	trace	trace
2	NaH	CuI (5)	THF	2	11	trace	trace
3	NaH	CuI (10)	THF	2	50	35	60
4	NaH	CuI (20)	THF	2	15	5	20
5	NaH	CuI (20)	CH_3CN	2	20	15	38
6	NaH	CuI (20)	DMF	4	90	50	30
7	KO^{t}Bu	----	THF	12	75	41	52
8	KO^{t}Bu	CuI (5)	THF	2	11	trace	trace
9	KO^{t}Bu	CuI (10)	THF	2	81	50	67
10	KO^{t}Bu	CuI (20)	THF	2	83	65	50
11	**KO^{t}Bu**	**CuI (20)**	**CH_3CN**	**0.5**	**100**	**81**	**53**
12	KO^{t}Bu	CuI (20)	DMSO	4	30	15	35
13	KO^{t}Bu	CuI (20)	DMF	4	93	55	45
14[b]	KO^{t}Bu	CuI (20)	THF	0.5	5	trace	trace

[a]Reaction Conditions: **1a** (0.1 mmol), base (0.3 mmol), CuI in solvent (2.0 mL) at rt under oxygen balloon. [b]Under argon. [c]Isolated yields.

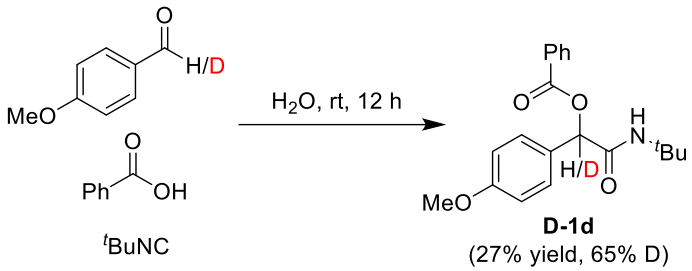
2. Labeling Experiments

a) Preparation of 4-Methoxybenzaldehyde-α-D



4-Methoxybenzaldehyde-α-D was synthesized according to reported procedure.[1] 4-Methoxybenzaldehyde (100.0 mg, 0.734 mmol) and $RuHCl(CO)(PPh_3)_3$ (34.9 mg, 0.036 mmol, 5 mol %) were dissolved in toluene (3.0 ml) in an oven-dried screw-cap vial. D_2O (0.07 ml, 3.670 mmol) was then added and the vial was sparged with argon and capped. The resulting solution was heated to 100 °C and stirred for 30 minutes. On completion of the reaction, the solvent was removed *in vacuo* and crude was purified by column chromatography to afford **4-Methoxybenzaldehyde-α-D** as colourless oil (80.0 mg, 79% yield, 55% D); ^{1}H NMR (400 MHz, $CDCl_3$): 7.89 – 7.80 (m, 2H), 7.04 – 6.98 (m, 2H), 3.89 (s, 3H); residual formyl proton: δ 9.89.

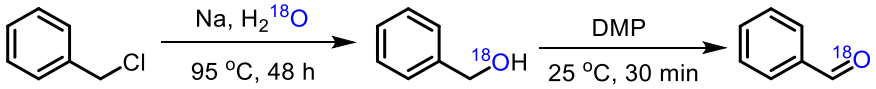
b) Preparation of the deuterated Passerini adduct D-1d



Equimolar mixture of 4-Methoxybenzaldehyde-α-D (200.0 mg, 1.45 mmol), benzoic acid (194.5 mg, 1.59 mmol) and *tert*-butyl isocyanide (0.16 ml, 1.45 mmol) in water was stirred at room temperature for 12 h. After completion of the reaction (based on TLC), reaction mixture was diluted with ethyl acetate and washed with saturated sodium bicarbonate solution. Aqueous layer was extracted with ethyl acetate and the combined organic layers were dried over anhydrous sodium sulfate followed by evaporation of solvent *in vacuo*. The crude was

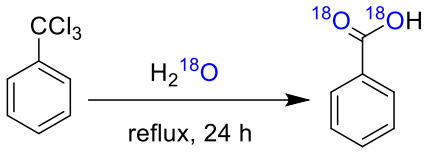
purified by silica gel column chromatography to afford the deuterium-labeled Passerini adduct **D-1d** as a white sticky solid (134.0 mg, 27% yield, 65% D); ^{1}H NMR (300 MHz, $CDCl_3$): δ 8.07 (dt, J = 8.5, 1.6 Hz, 2H), 7.63 – 7.56 (m, 1H), 7.50 – 7.41 (m, 4H), 6.95 – 6.87 (m, 2H), 5.96 (s, 1H), 3.80 (s, 3H), 1.37 (s, 9H); Residual formyl proton: δ 6.17.

c) Preparation of ^{18}O-labeled benzaldehyde



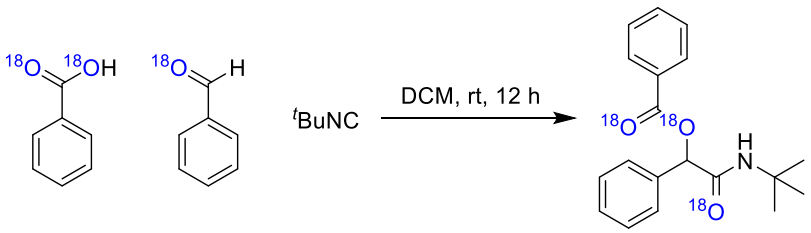
^{18}O-labeled benzaldehyde was synthesized according to reported procedure.[2] Sodium (0.05 g, 2.17 mmol) was added to ^{18}O-labeled water (98% $H_2{}^{18}O$, 0.75 mL) in a flask followed by the addition of benzyl chloride (0.5 mL, 4.34 mmol). The mixture was heated to 95 °C and then heated at reflux for 48 h with continuous stirring. The product was purified by column chromatography to yield the ^{18}O-labeled benzyl alcohol (0.2 g, 1.8 mmol, 83% yield). To a solution of the ^{18}O-labeled benzyl alcohol (0.2 g, 1.8 mmol) in anhydrous dichloromethane (20.0 mL) under nitrogen, Dess-Martin periodinane (0.99 g, 2.34 mmol) was added at 0 °C, and the resulting mixture was stirred at room temperature for 30 minutes. On completion of the reaction (progress monitored by TLC analysis), the reaction was quenched by the slow addition of $NaHCO_3/Na_2S_2O_3$ solution, and the mixture was vigorously stirred for 30 minutes. The aqueous layer was extracted with dichloromethane and the combined organic layers were washed with brine and dried with anhydrous Na_2SO_4. The solvent was removed under reduced pressure to afford the ^{18}O-labeled benzaldehyde in quantitative yield.

d) Preparation of ^{18}O-labeled benzoic acid



^{18}O-labeled benzoic acid was synthesized according to reported procedure.[3] α,α,α-trichlorotoluene (2.5 g, 12.5 mmol) and $H_2{}^{18}O$ (1.0 g, 50.0 mmol) were heated at 120 °C in a sealed tube for 24 h. The reaction mixture was concentrated *in vacuo* to remove excess water and HCl, then a solution of NaOH (0.15 M, 75 mL) was added to the crude mixture. The aqueous phase was washed with ethyl acetate, acidified with an aqueous HCl (1 N) solution and extracted with dichloromethane. The combined organic layers were dried upon anhydrous Na_2SO_4, filtered, concentrated *in vacuo* to afford ^{18}O-enriched benzoic acid (1.5 g, yield: 99%) as white solid.

e) Procedure for the synthesis of ^{18}O-labeled Passerini adduct ^{18}O-1b.

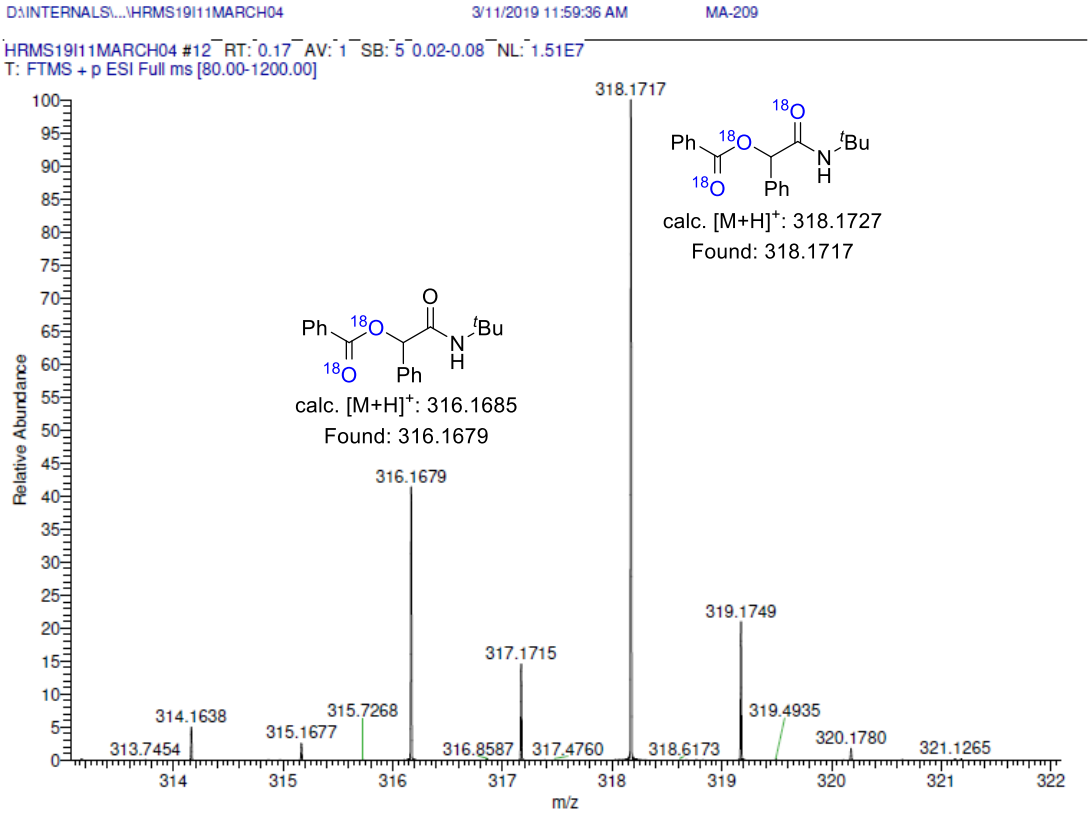


Equimolar mixture of ^{18}O-labeled benzaldehyde (200.00 mg, 1.85 mmol), ^{18}O-labeled benzoic acid (233.29 mg, 1.85 mmol) and *tert*-butyl isocyanide (0.21 mL, 1.85 mmol) in anhydrous dichloromethane was stirred at room temperature for 12 h under nitrogen. After completion of the reaction (based on TLC), reaction mixture was diluted with dichloromethane and washed with saturated sodium bicarbonate solution. Aqueous layer was extracted with dichloromethane and the combined organic layers were dried over anhydrous sodium sulfate followed by evaporation of solvent *in vacuo*. The crude was purified by silica

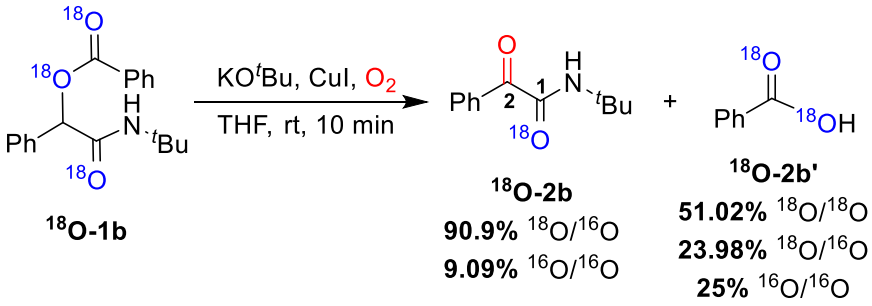
gel column chromatography to afford the ^{18}O-labeled Passerini adduct **^{18}O-1b** (240.00 mg, 40.8%). Isotopic distribution amounted to 70.92% ^{18}O/^{18}O/^{18}O and 29.08% ^{18}O/^{18}O/^{16}O respectively (Figure S1).

2-(*tert*-butylamino)-2-(oxo-^{18}*O*)-1-phenylethyl benzoate-^{18}*O*$_2$ (^{18}O-1b): White solid (240.0 mg, 41%); m.p : 140 °C; R_f = 0.32 (30% EtOAc in hexane); ^{1}H NMR (300 MHz, $CDCl_3$): δ 8.12 – 8.06 (m, 2H), 7.64 – 7.57 (m, 1H), 7.55 – 7.44 (m, 4H), 7.43 – 7.34 (m, 3H), 6.22 (s, 1H), 5.99 (s, 1H), 1.37 (s, 9H); ^{13}C NMR (75 MHz, $CDCl_3$): δ 167.3, 164.8, 135.9, 133.5, 129.7, 129.4, 128.9, 128.7, 128.6, 127.4, 76.0, 51.6, 28.7; HRMS (ESI): calcd. for $C_{19}H_{22}N^{18}O_3$ $[M+H]^+$: 318.1727, found: 318.1717.

Figure S1: HRMS Spectrum of **^{18}O-1b**



f) Procedure for the oxidative cleavage of ^{18}O-1b.



To the solution of **^{18}O-1b** (193.0 mg, 0.608 mmol) in dry THF was added KO^{t}Bu (204.7 mg, 1.82 mmol) and CuI (23.1 mg, 20 mol %) at room temperature and the reaction vessel was flushed with O_2. The resulting reaction mixture was stirred at room temperature. After completion of the reaction (based on TLC) in 10 minutes, the reaction mixture was quenched with water and the crude product was extracted with ethyl acetate. The organic layer was dried over anhydrous sodium sulfate, concentrated *in vacuo* and the crude was purified by silica gel column chromatography to afford α-ketoamide **^{18}O-2b** (34.0 mg, 27%). The aqueous layer was acidified with HCl solution up to pH 2-3, followed by extraction with dichloromethane. The organic layer was dried over anhydrous sodium sulfate, concentrated *in vacuo* to afford the ^{18}O-labeled benzoic acid **^{18}O-2b'** (29.0 mg, 38%). HRMS analysis revealed that the α-ketoamide **^{18}O-2b** (having only C-1 oxygen labeled) has m/z = 208.1217, while the ^{18}O-labeled benzoic acid has m/z = 127.9792. This indicates that the oxygen at C-2 position of the α-ketoamide **^{18}O-2b** is coming from molecular oxygen. On the contrary, this experiment also confirmed the incorporation of only one ^{16}O oxygen atom in the α-ketoamide **^{18}O-2b**. For α-ketoamide **^{18}O-2b**, isotopic distribution amounted to 90.9% ^{16}O/^{18}O and 9.09% ^{16}O/^{16}O (Figure S2). For the acid **^{18}O-2b'**, isotopic distribution amounted to 51.02% ^{18}O/^{18}O, 23.98% ^{18}O/^{16}O and 25% ^{16}O/^{16}O (Figure S3).

Figure S2: HRMS Spectrum of ^{18}**O-2b**

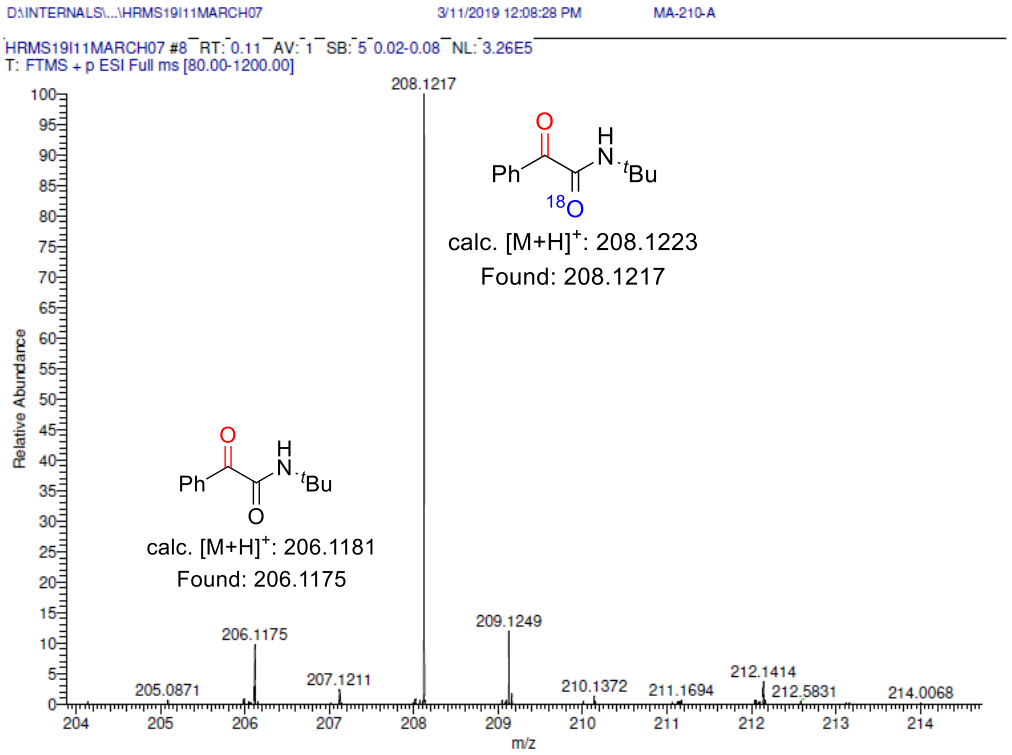
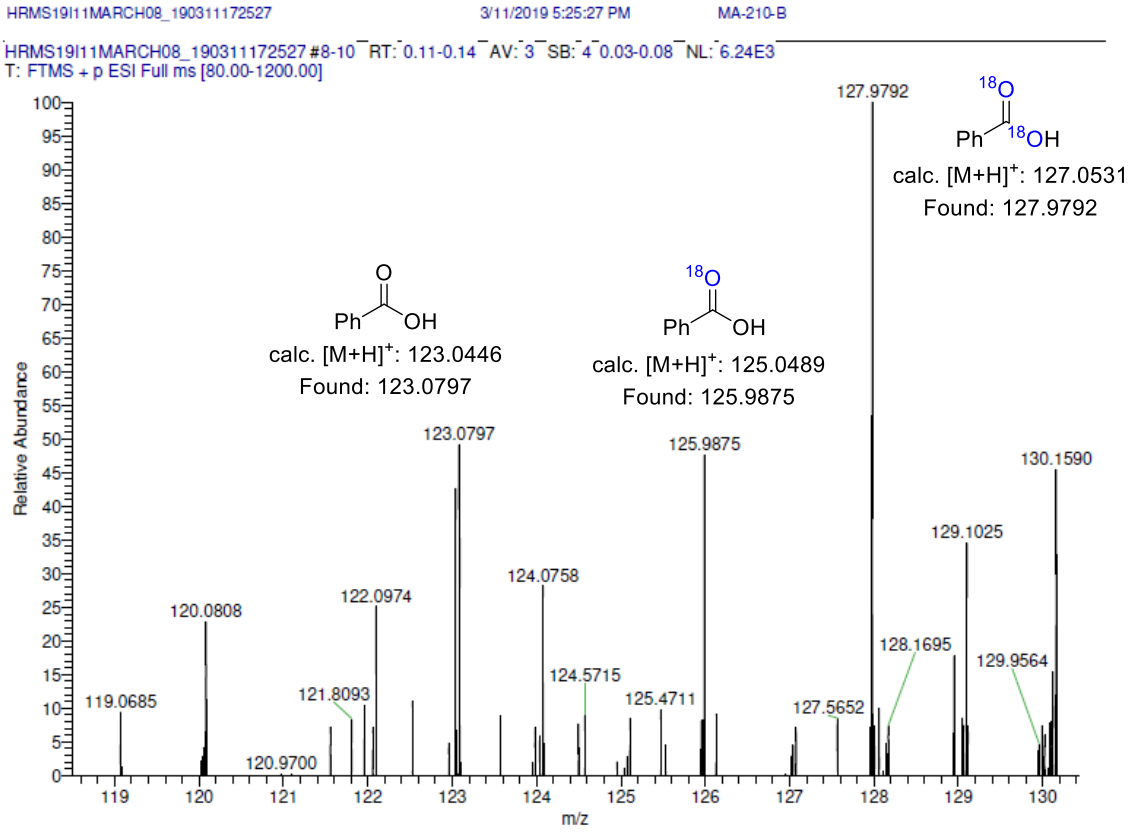
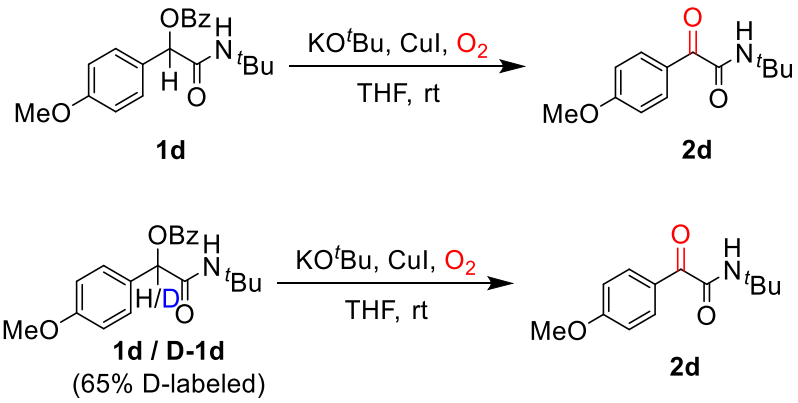


Figure S3: HRMS Spectrum of ^{18}**O-2b'**



3. Kinetic Isotope Effect (KIE) measurement by independent reactions



The aerobic oxidative cleavage of substrate **1d** and **D-1d** (65% D-enriched) were carried out in parallel under the standard reaction conditions to study the kinetic isotopic effect (KIE). To the solutions of **1d** (100.0 mg, 0.29 mmol) and **D-1d** (100.0 mg, 0.29 mmol) in dry THF, KO^{t}Bu (98.6 mg, 0.87 mmol) and CuI (11.1 mg, 0.058 mmol) were added at room temperature and the reaction vessel was flushed with O_2. The resulting reaction mixtures were stirred at room temperature. KIE value was determined by comparison of rates of formation of α-ketoamide by LCMS analysis. Aliquots (25 μL) were periodically removed to provide the following conversions as determined by LCMS analysis. K_H/K_D was calculated to be 3.14.

Table S2. % Formation *vs* time table.

t (min)	**1**	**3**	**5**	**10**
1d (%)	13.67	14.09	15.79	18.93
D-1d[#] (%)	3.71	4.52	5.08	5.58

[#]The product formation was calibrated by multiplying with 0.65 taking into the account that only 65% substrate was D-labeled.

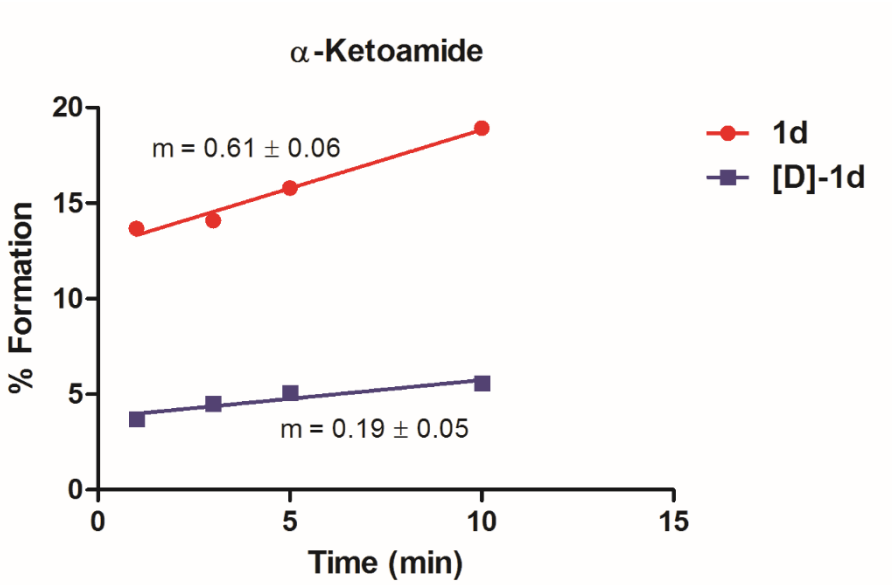


Figure S4. Kinetic Isotope Effect

4. References:

1. E. S. Isbrandt, J. K. Vandavasi, W. Zhang, M. P. Jamshidi and S. G Newman, *Synlett.* 2017, **28**, 2851.
2. C. Du, X. Wang, S. Jin, H. Shi, Y. Li, Y. Pang, Y. Liu, M. Cheng, C. Guo and Y. Liu, *Asian J. Org. Chem.* 2016, **5**, 755.
3. C.-H. Lei, L. Zhao, D.-X. Wang, J. Zhu and M.-X Wang, *Org. Chem. Front*. 2014, **1**, 909.

5. Copies of ^{1}H and ^{13}C NMR Spectra

Figure S5: ^{1}H NMR of compound **1a**

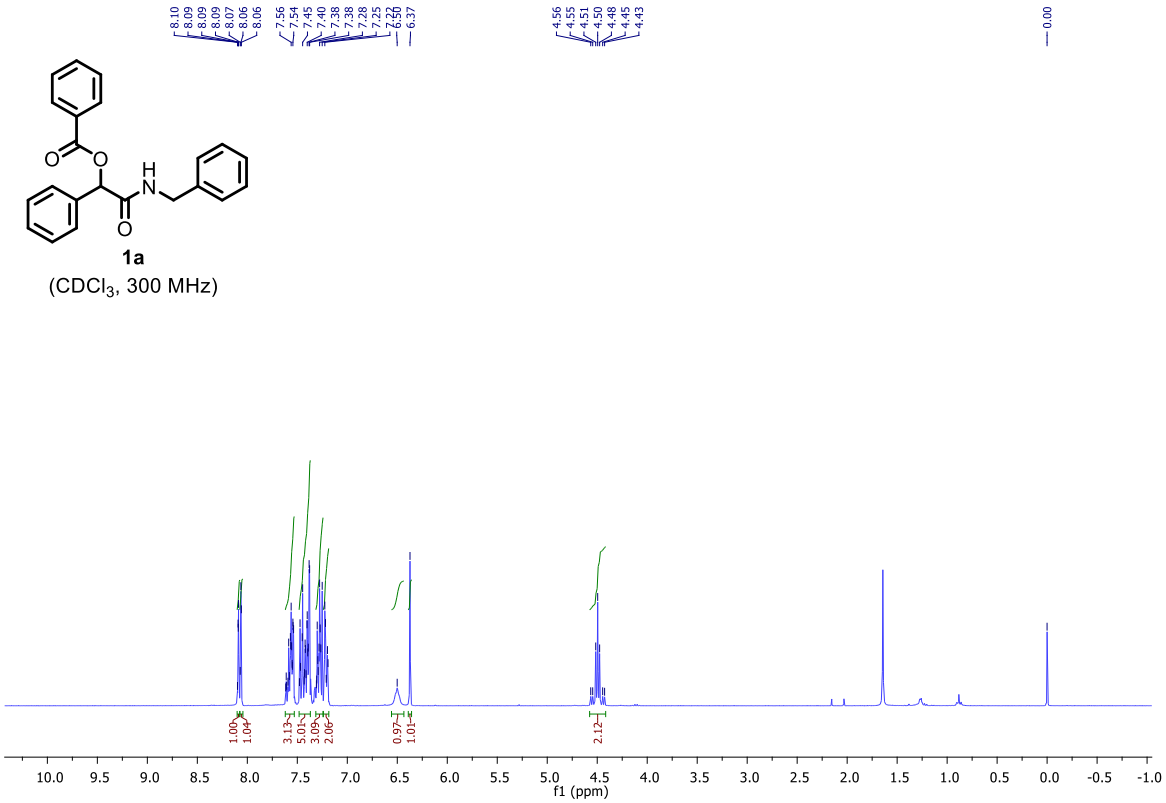


Figure S6: ^{13}C NMR of compound **1a**

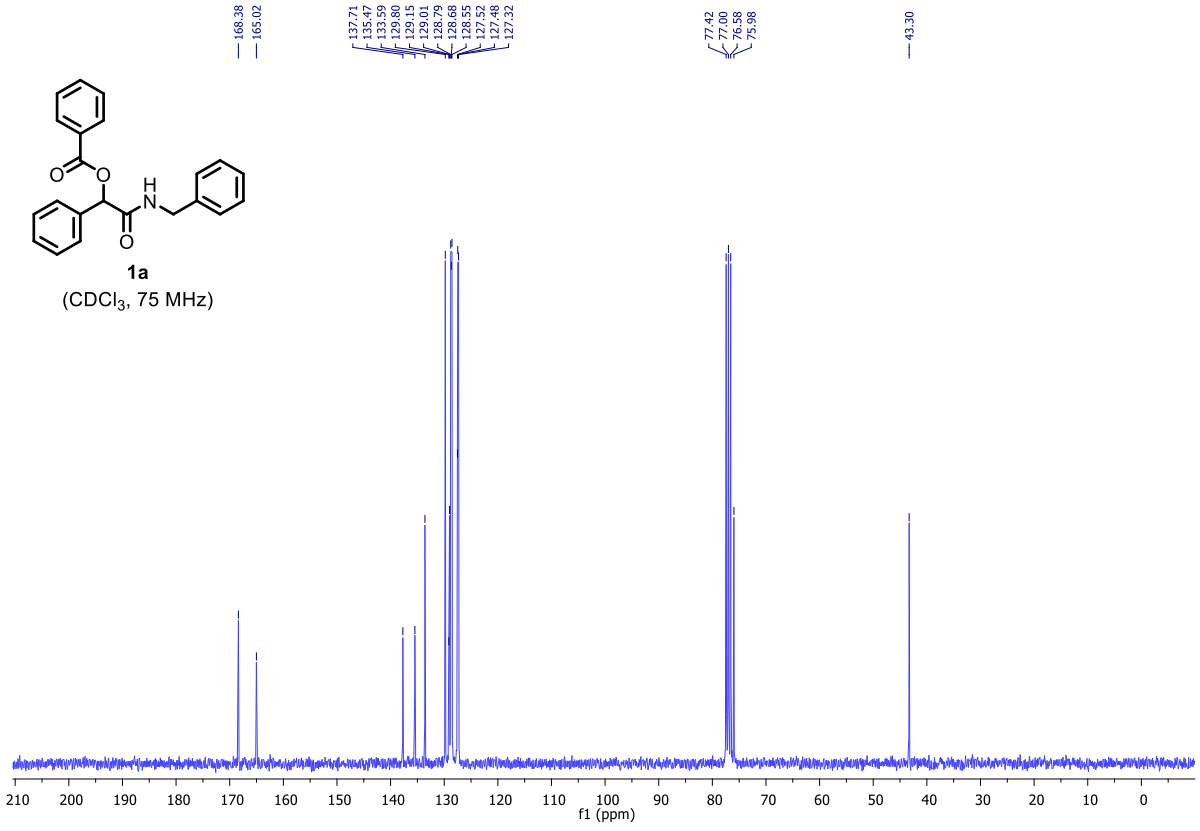


Figure S7: ^{1}H NMR of compound **1b**

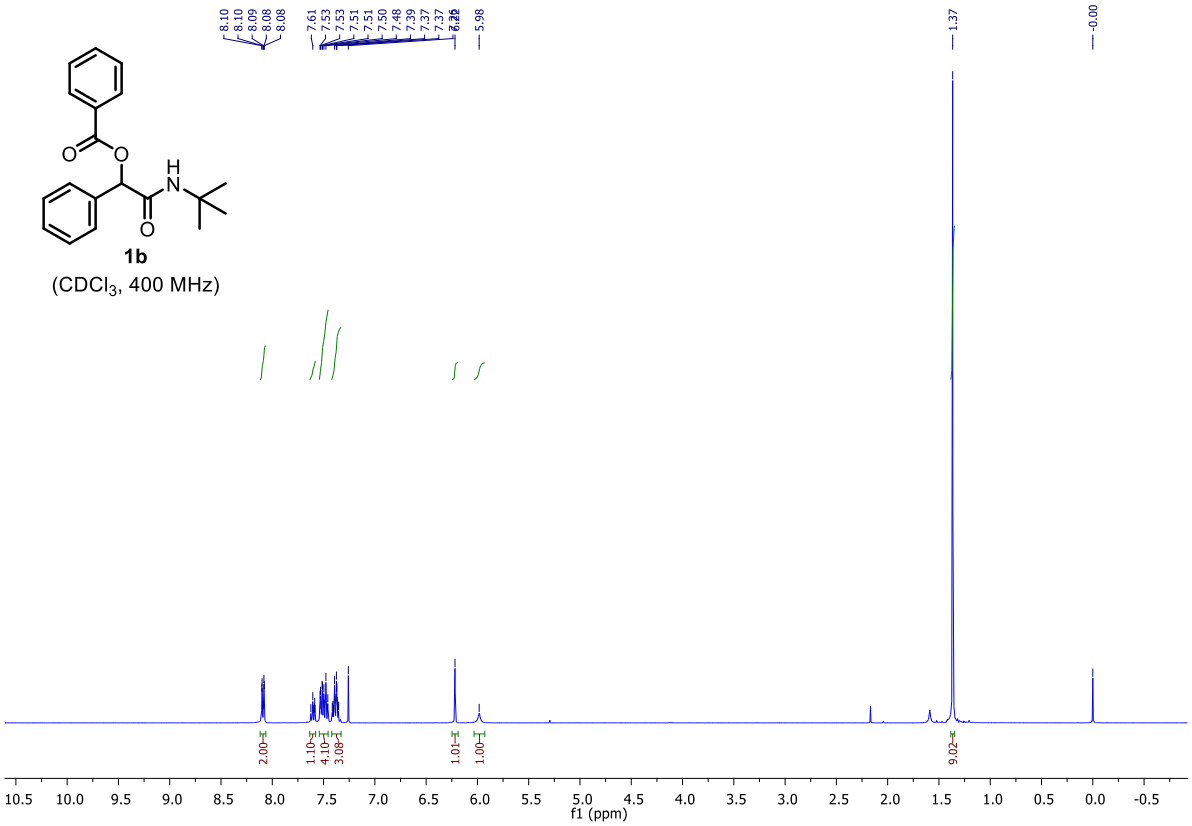


Figure S8: ^{13}C NMR of compound **1b**

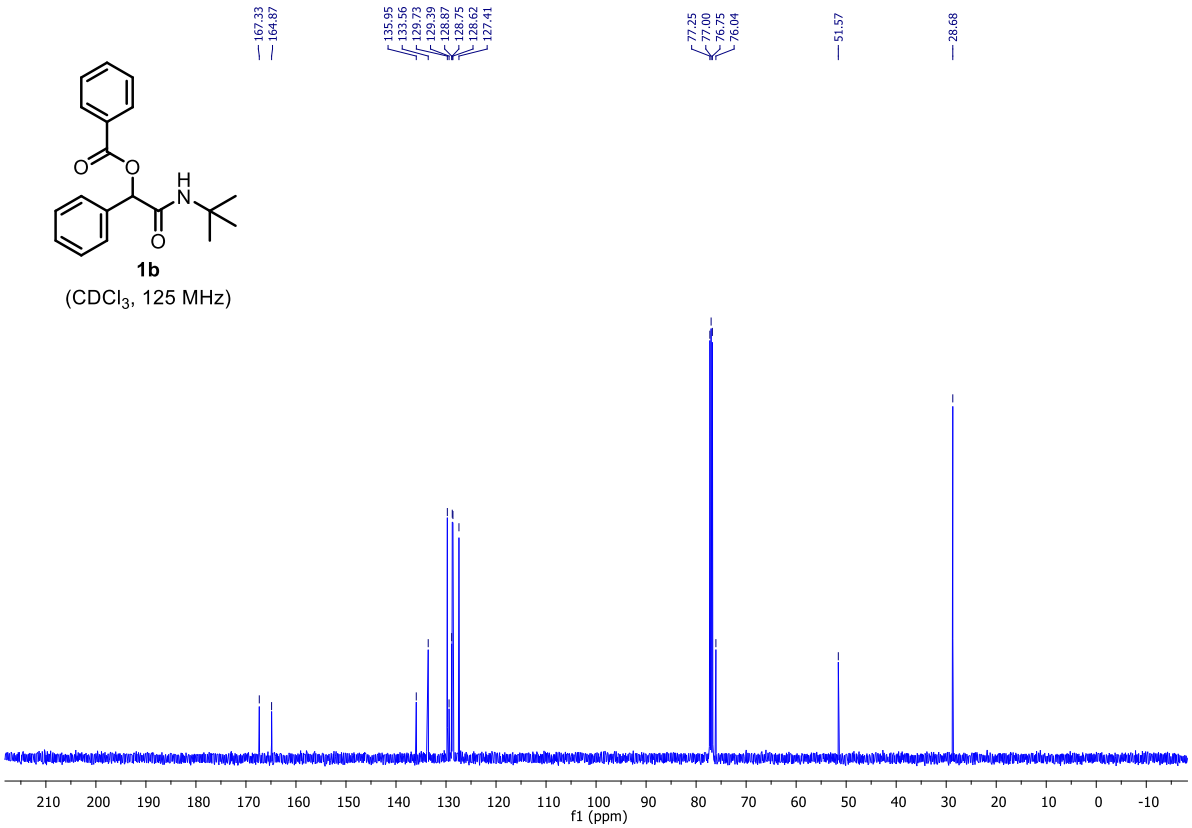


Figure S9: ^{1}H NMR of compound **1c**

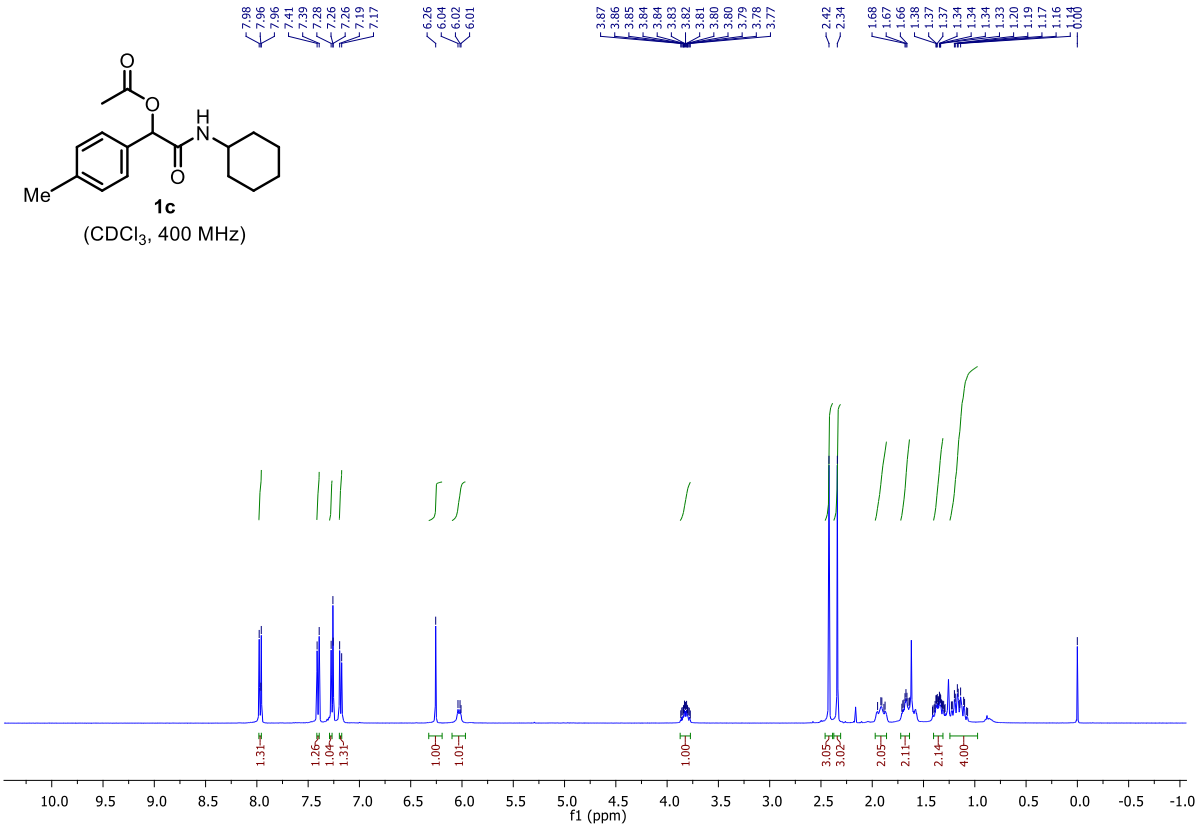


Figure S10: ^{13}C NMR of compound **1c**

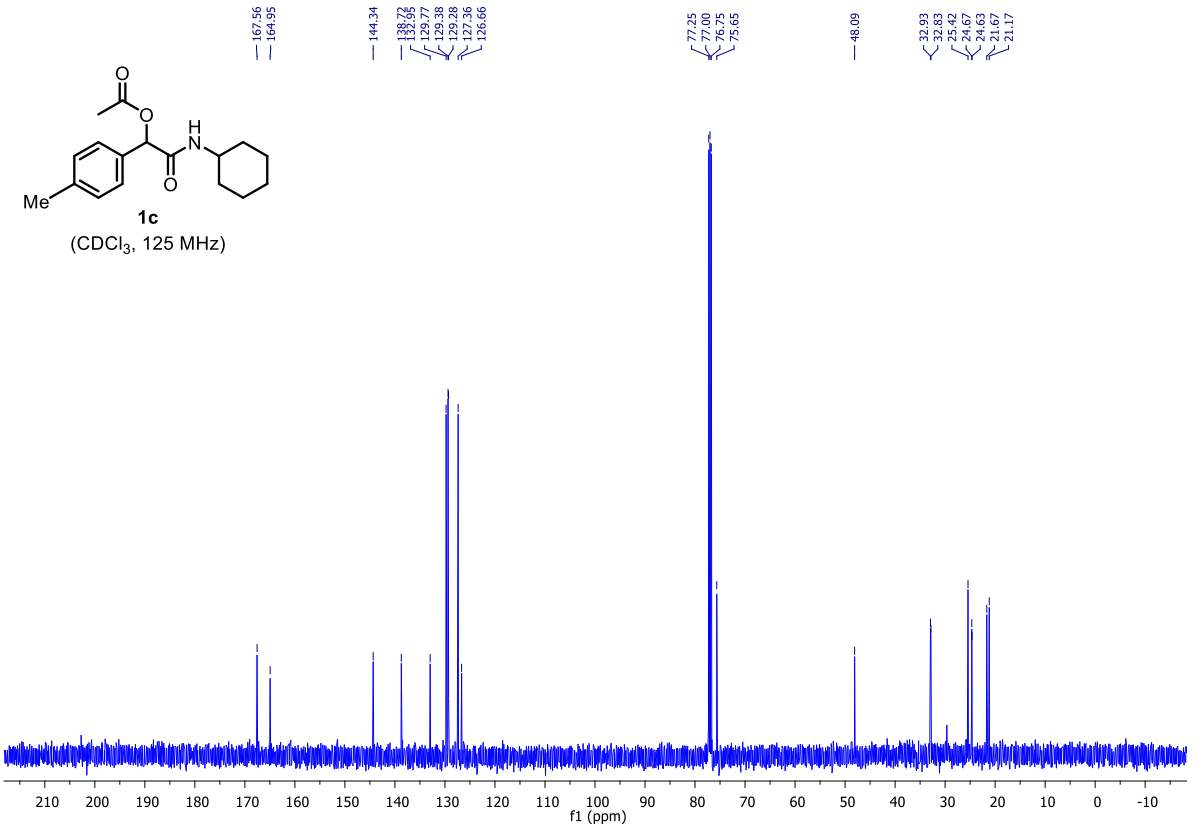


Figure S11: ^{1}H NMR of compound **1d**

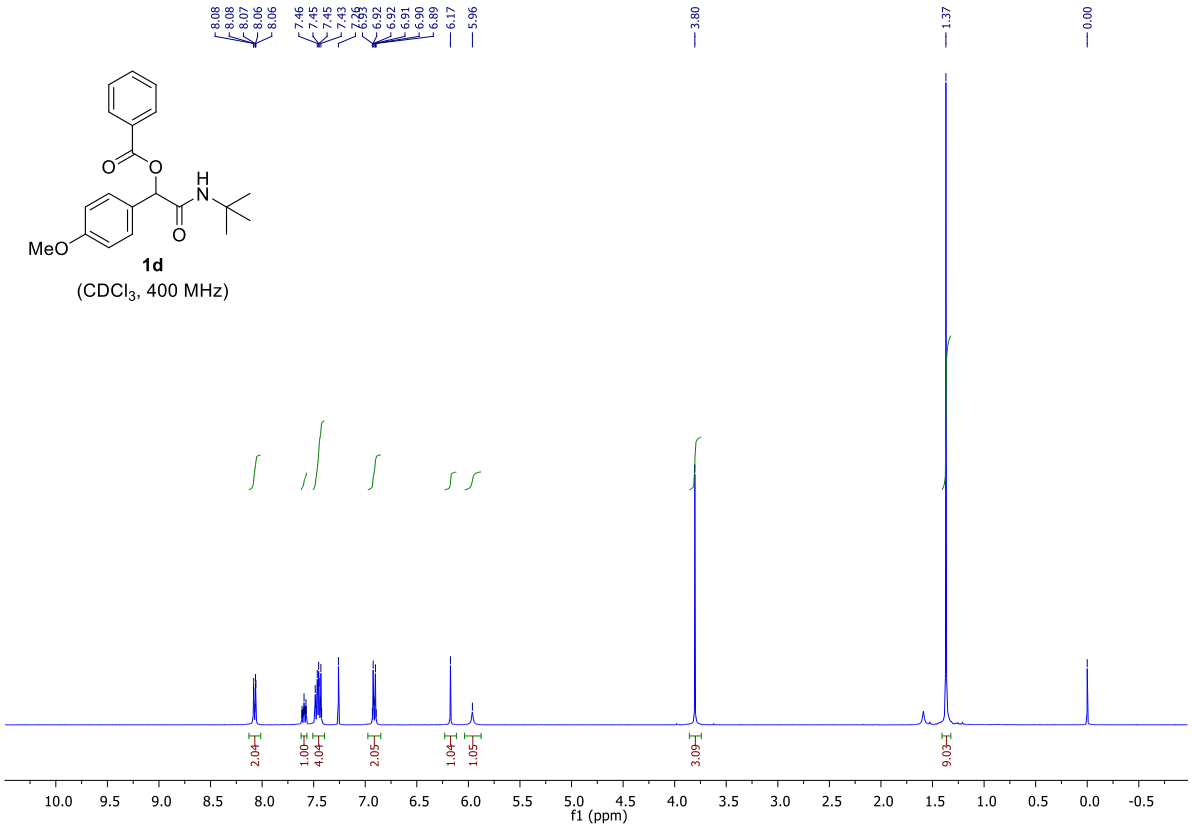


Figure S12: ^{13}C NMR of compound **1d**

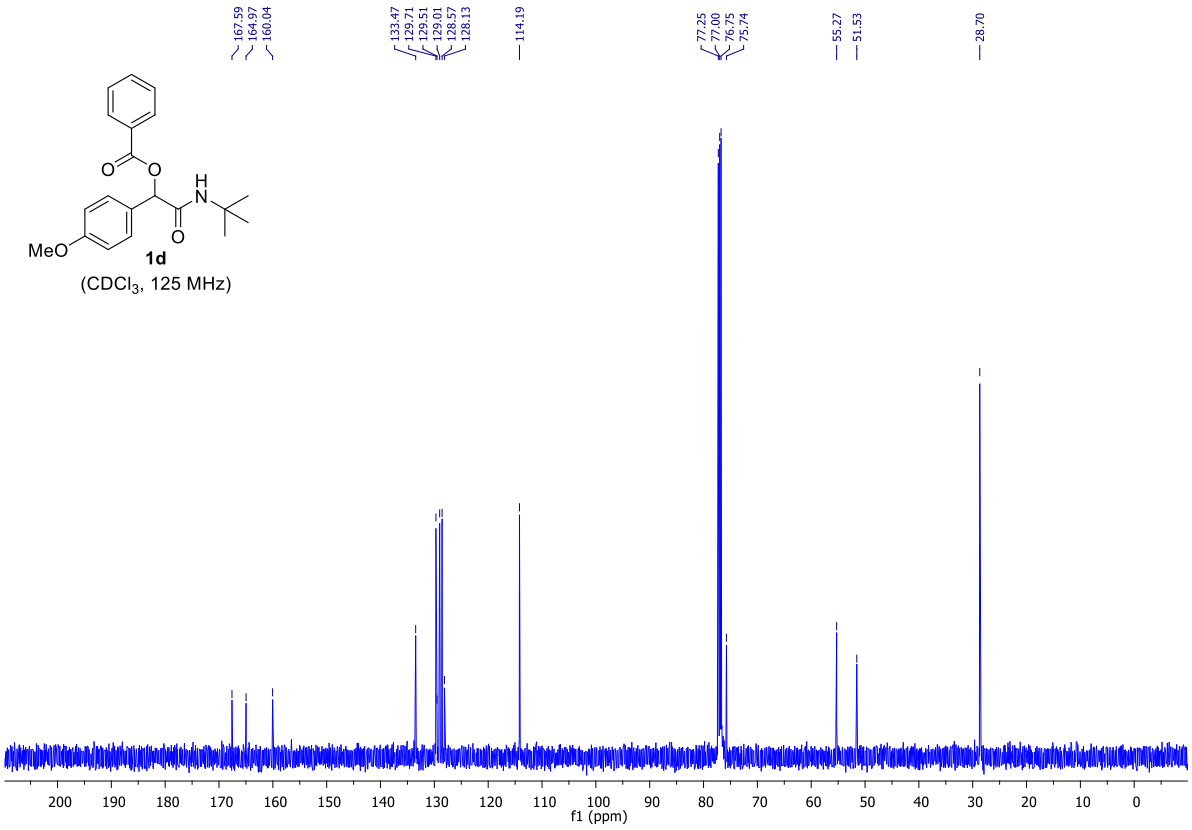


Figure S13: ^{1}H NMR of compound **1e**

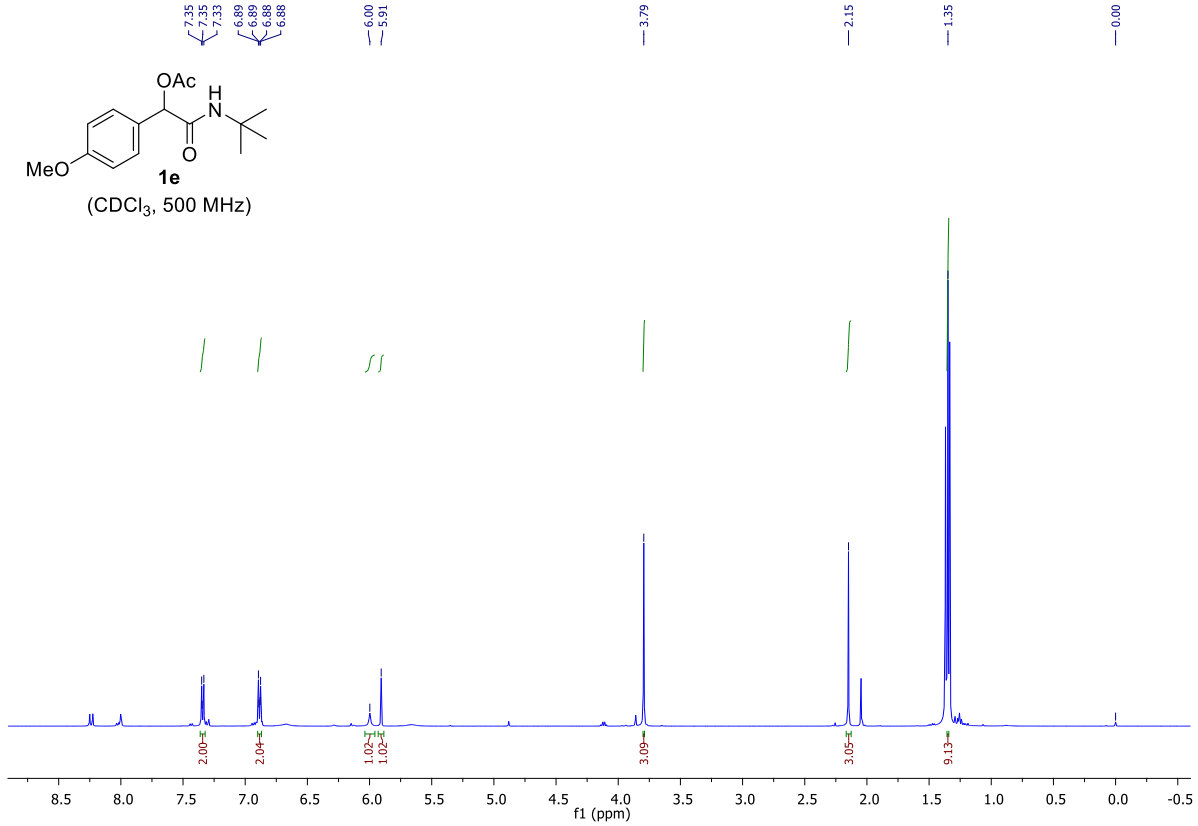


Figure S14: ^{13}C NMR of compound **1e**

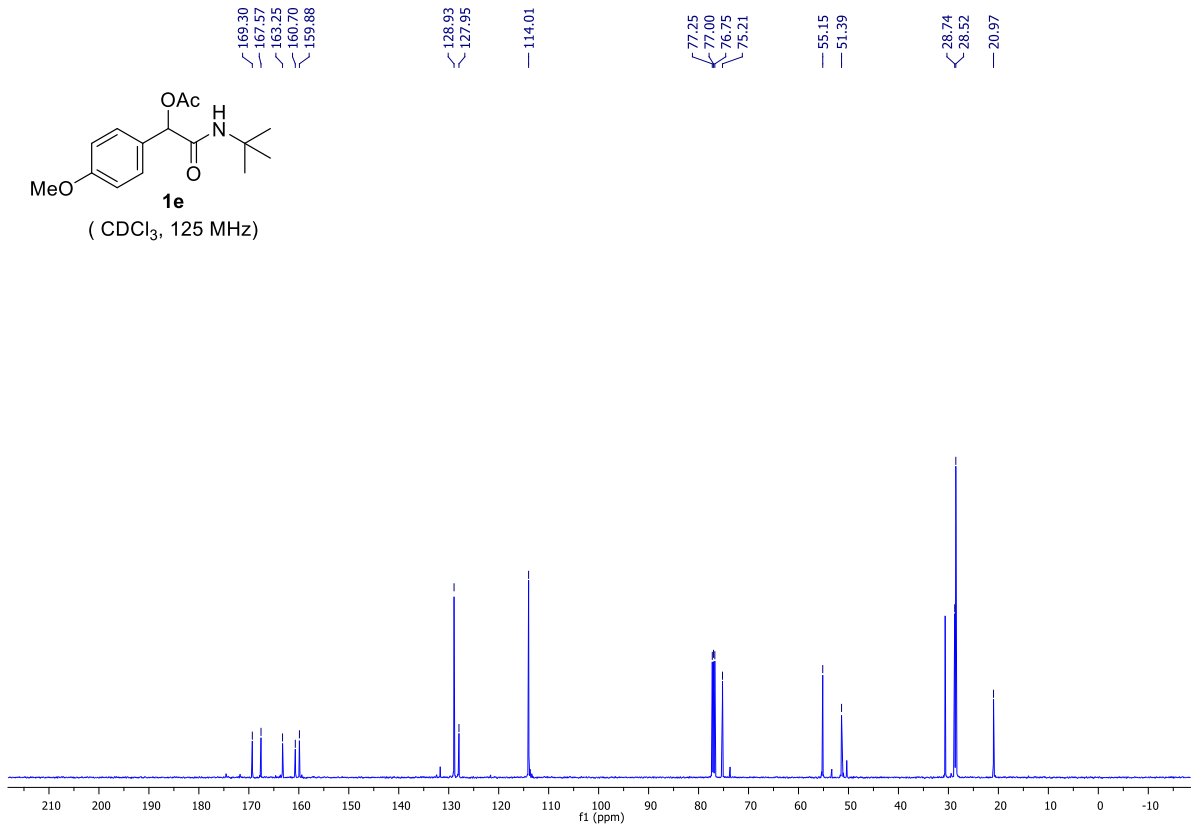


Figure S15: ^{1}H NMR of compound **1f**

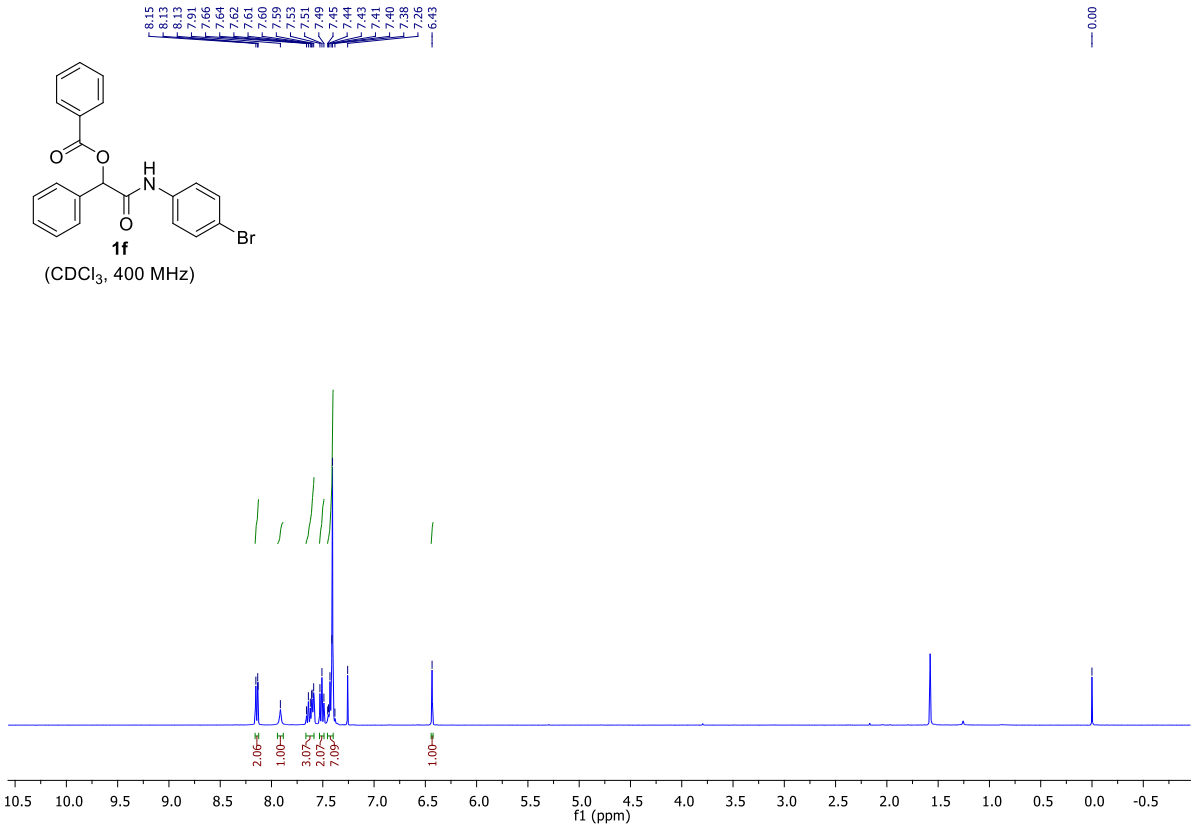


Figure S16: ^{13}C NMR of compound **1f**

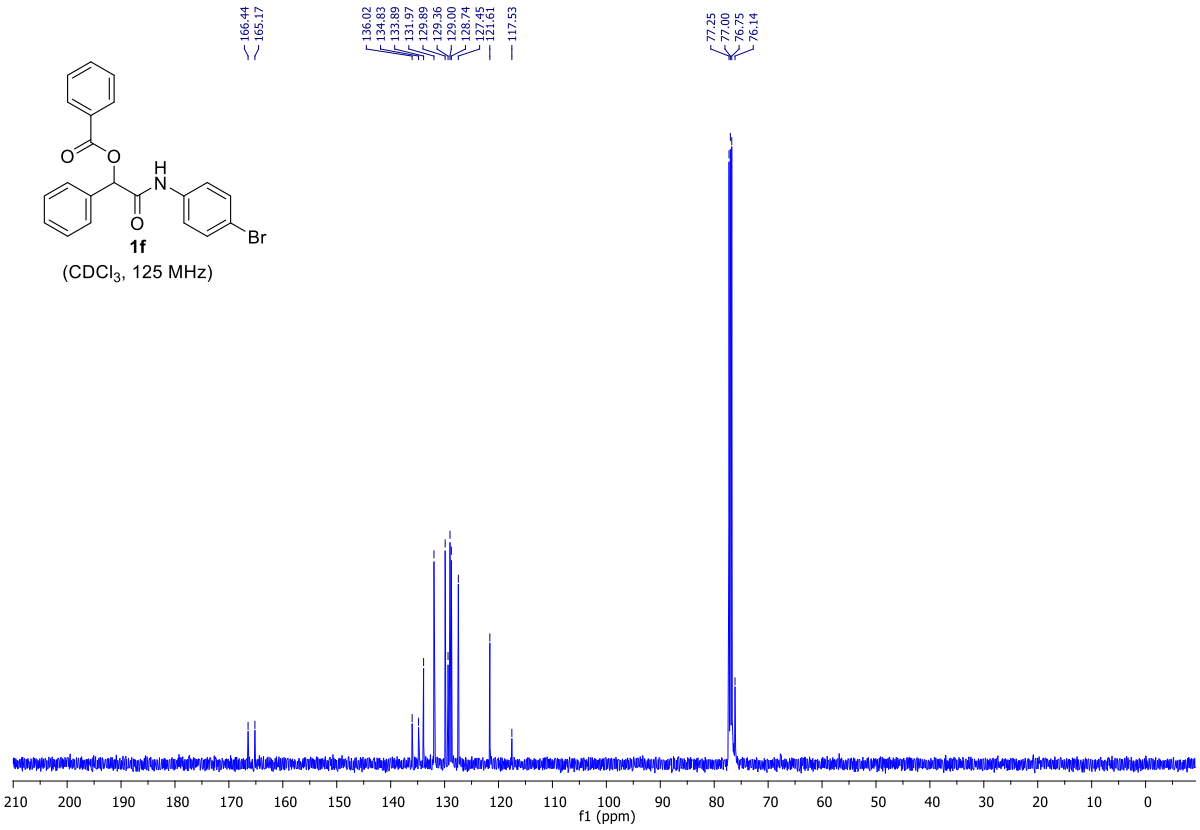


Figure S17: ^{1}H NMR of compound **1g**

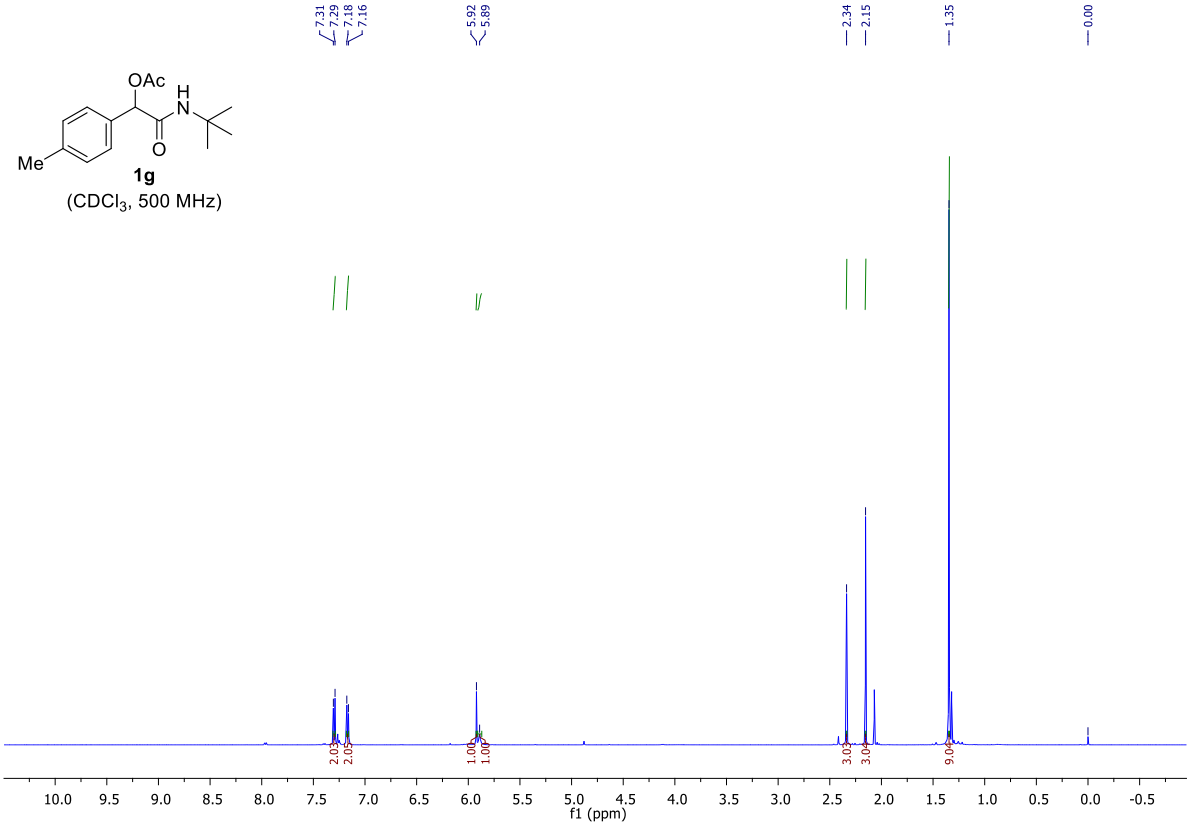


Figure S18: ^{13}C NMR of compound **1g**

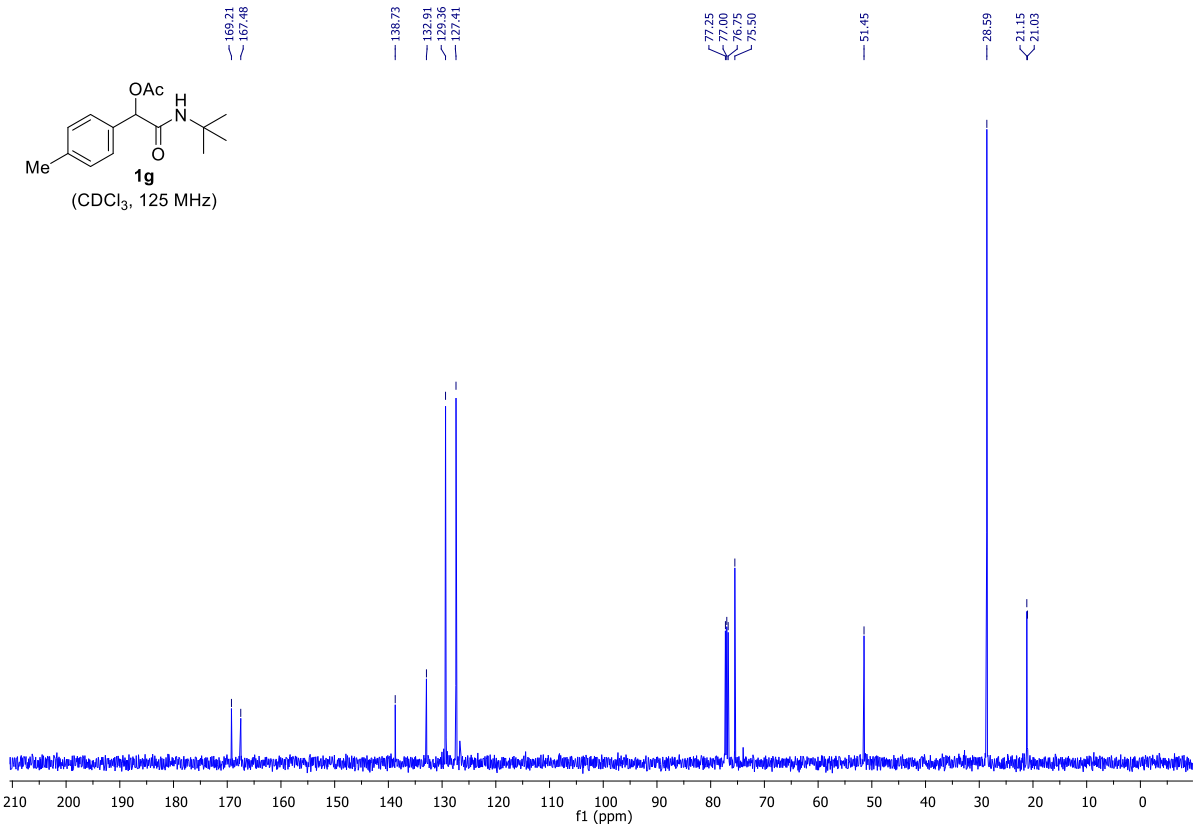


Figure S19: ^{1}H NMR of compound **1h**

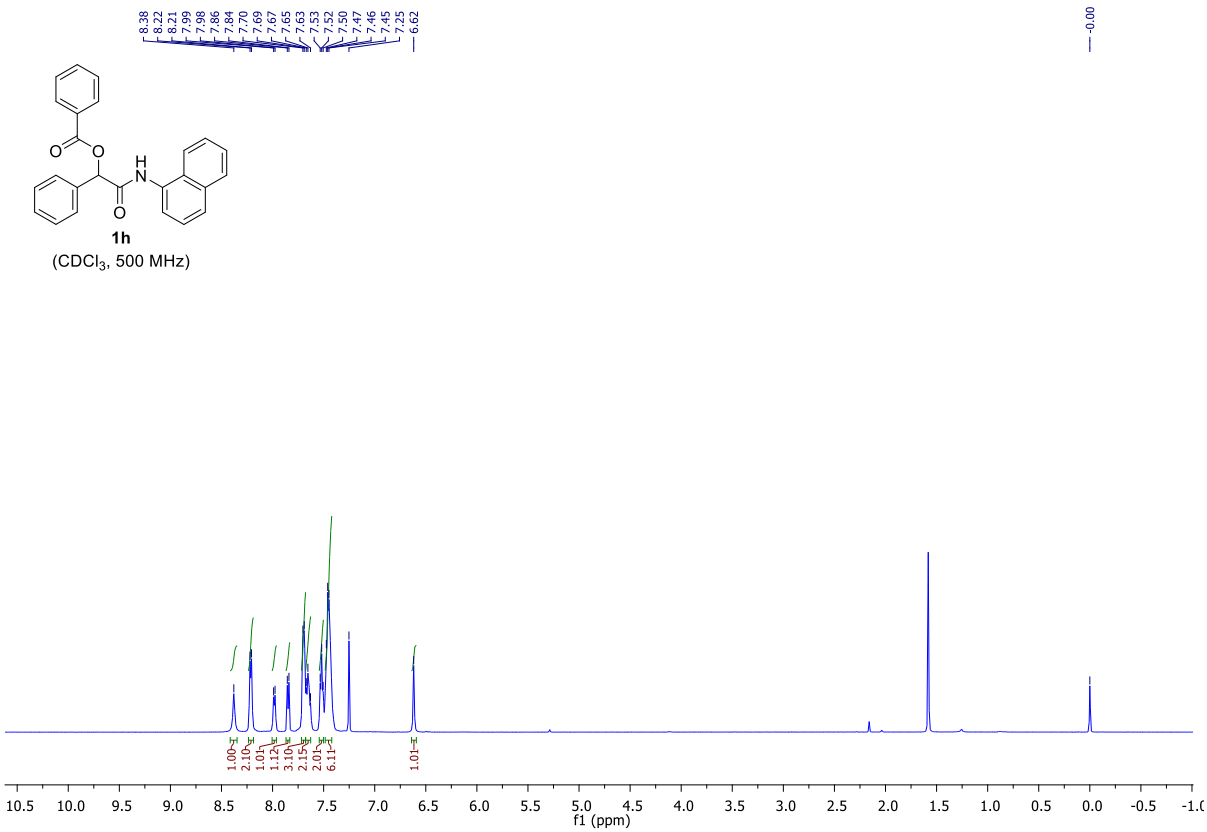


Figure S20: ^{13}C NMR of compound **1h**

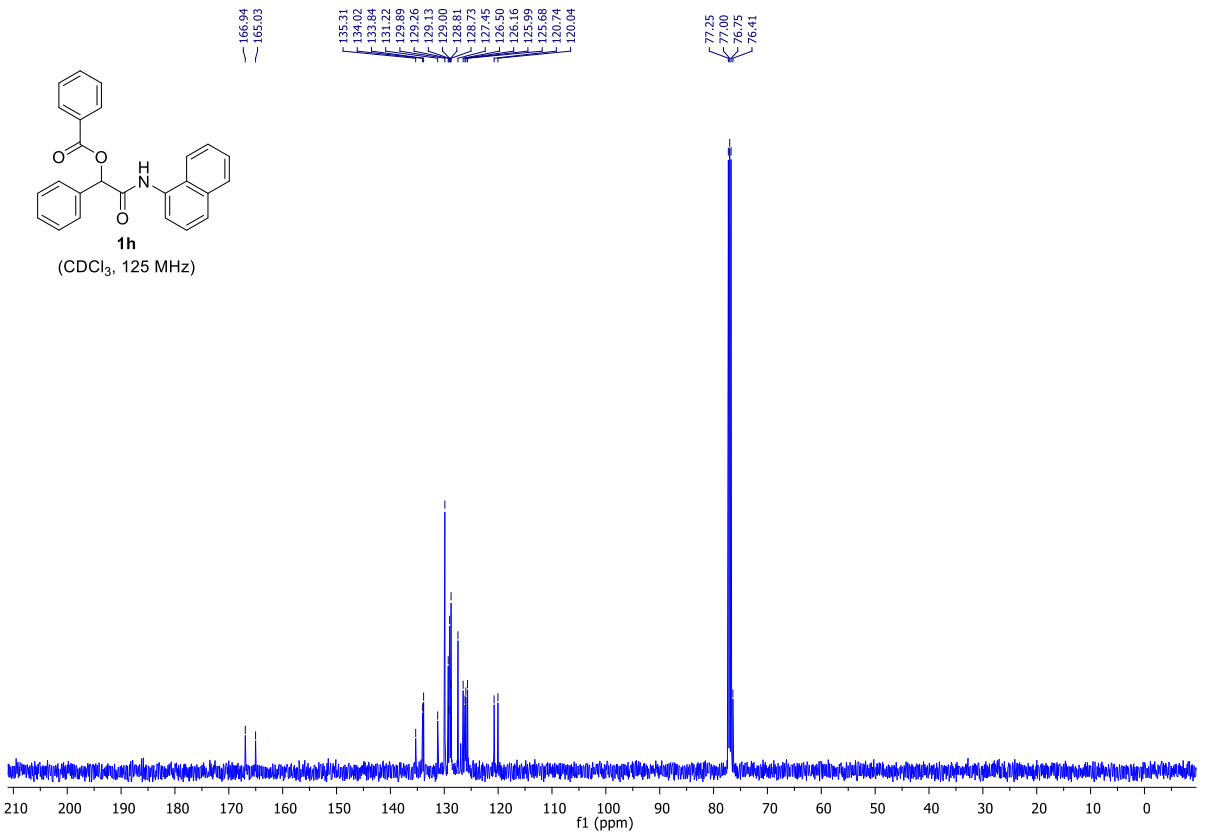


Figure S21: ^{1}H NMR of compound **1i**

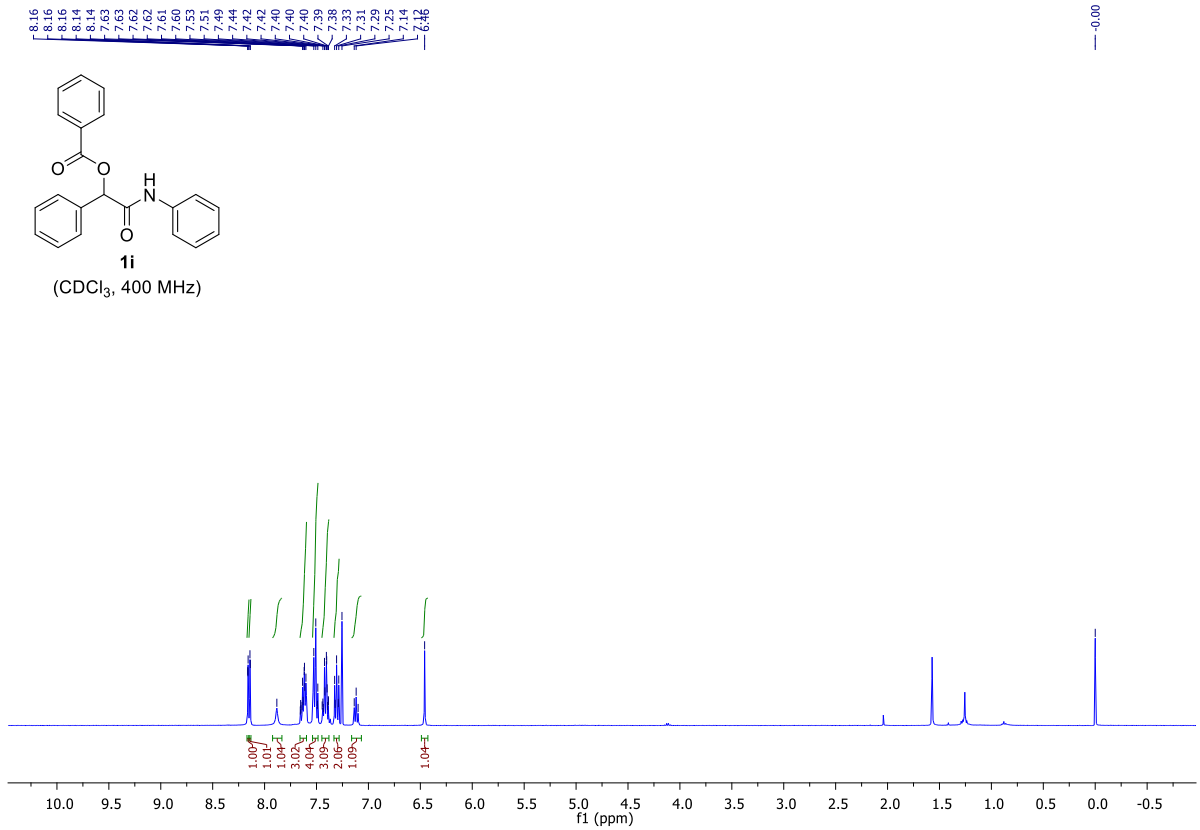


Figure S22: ^{13}C NMR of compound **1i**

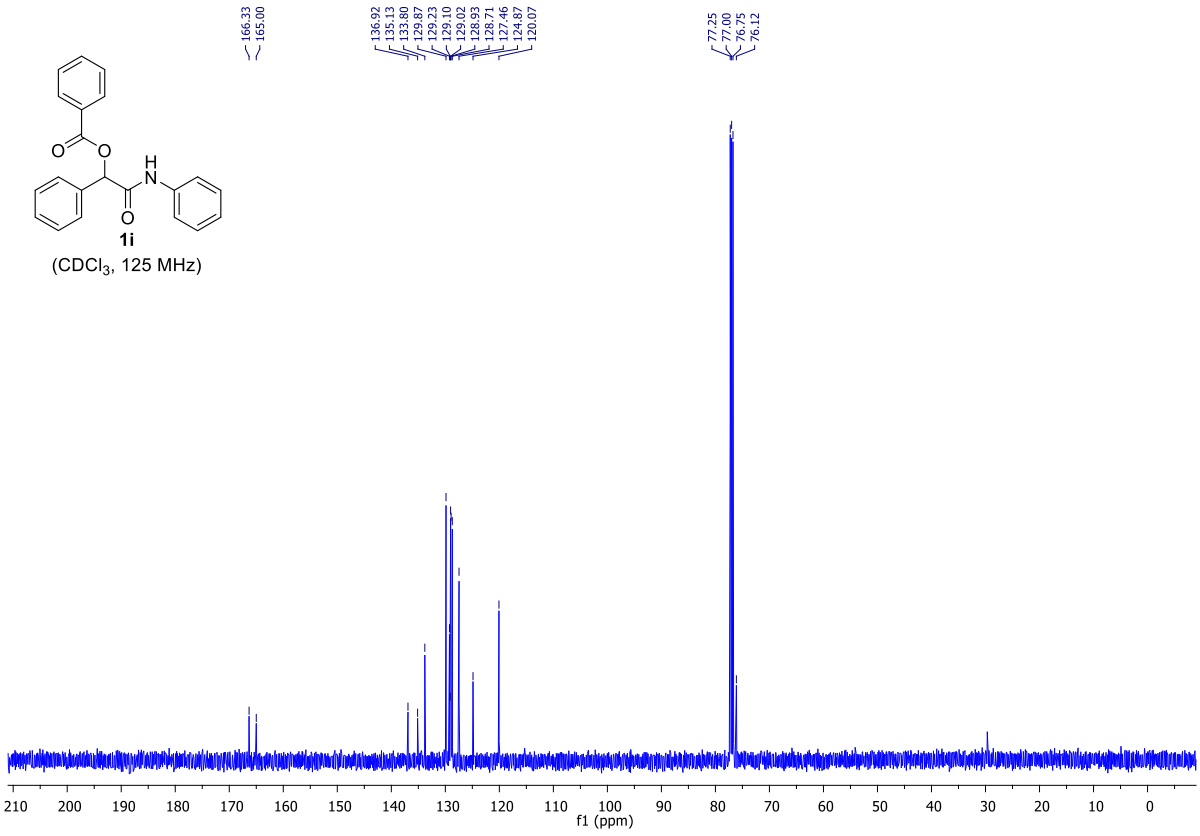


Figure S23: ^{1}H NMR of compound **1j**

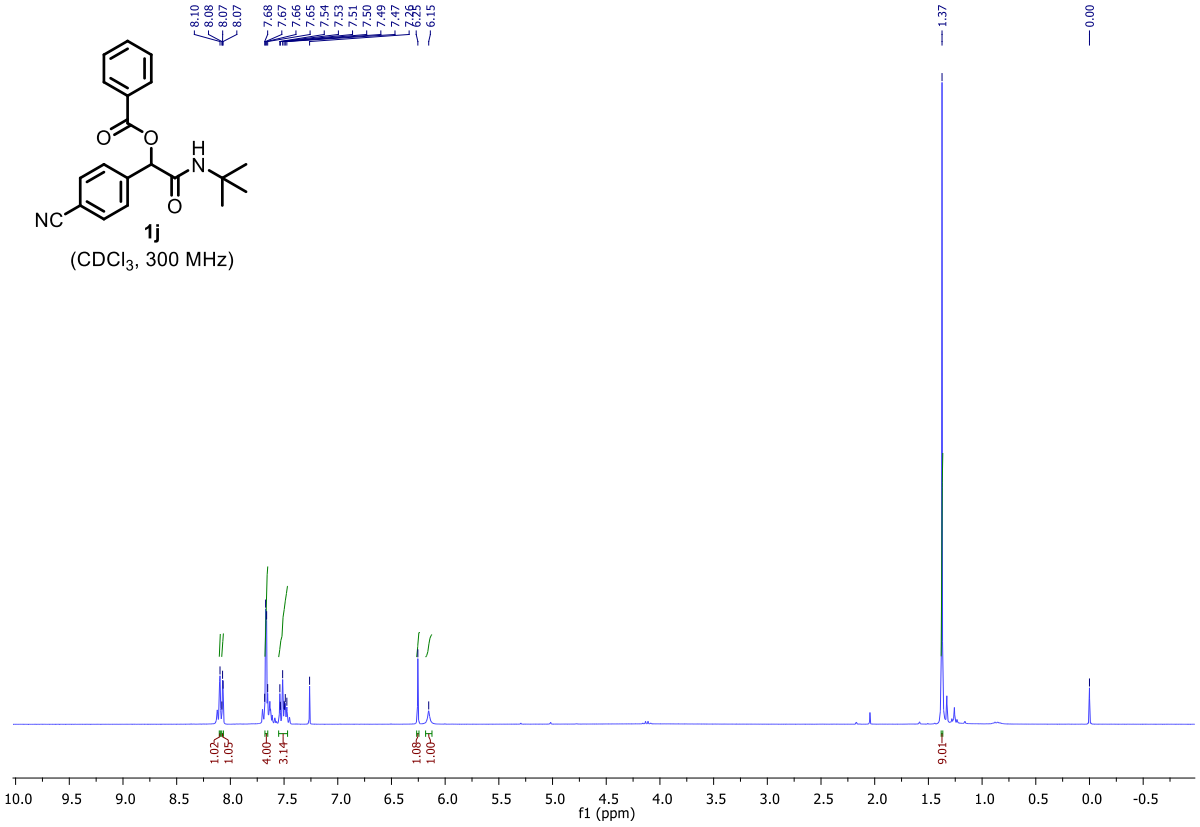


Figure S24: ^{13}C NMR of compound **1j**

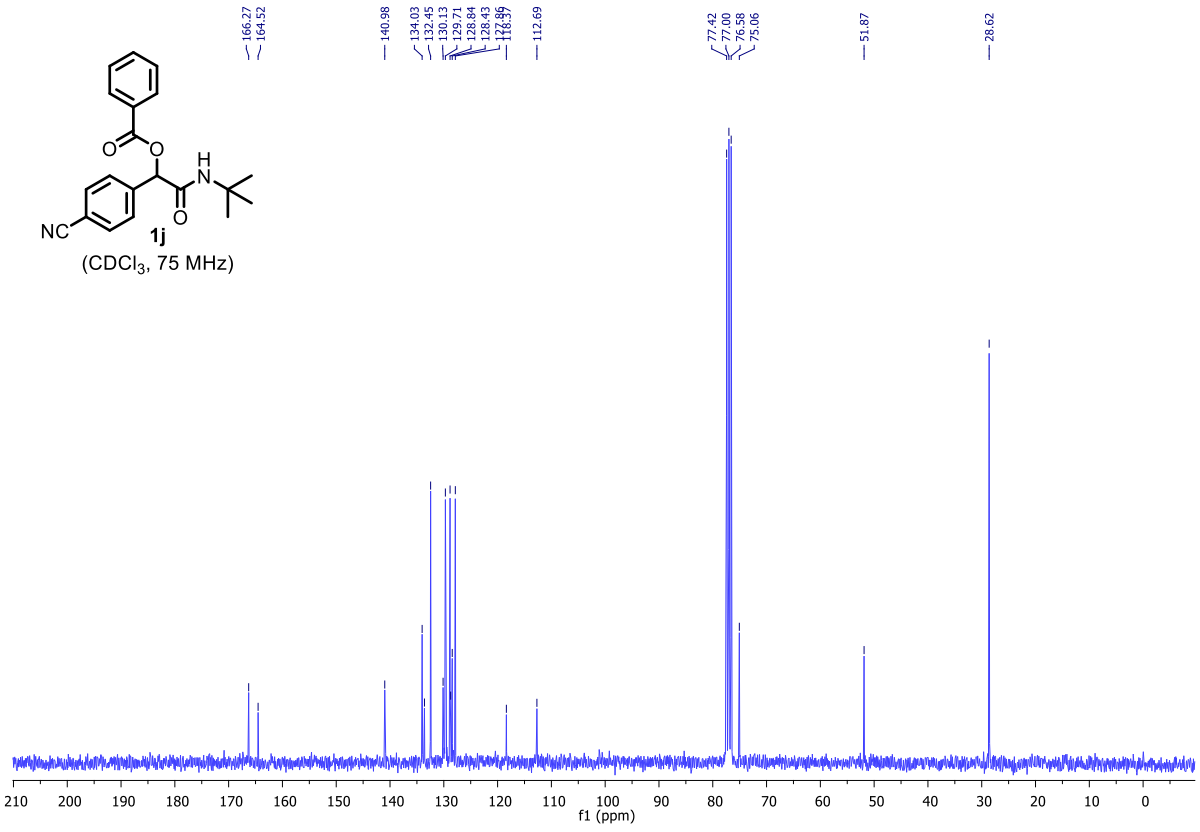


Figure S25: ^{1}H NMR of compound **1k**

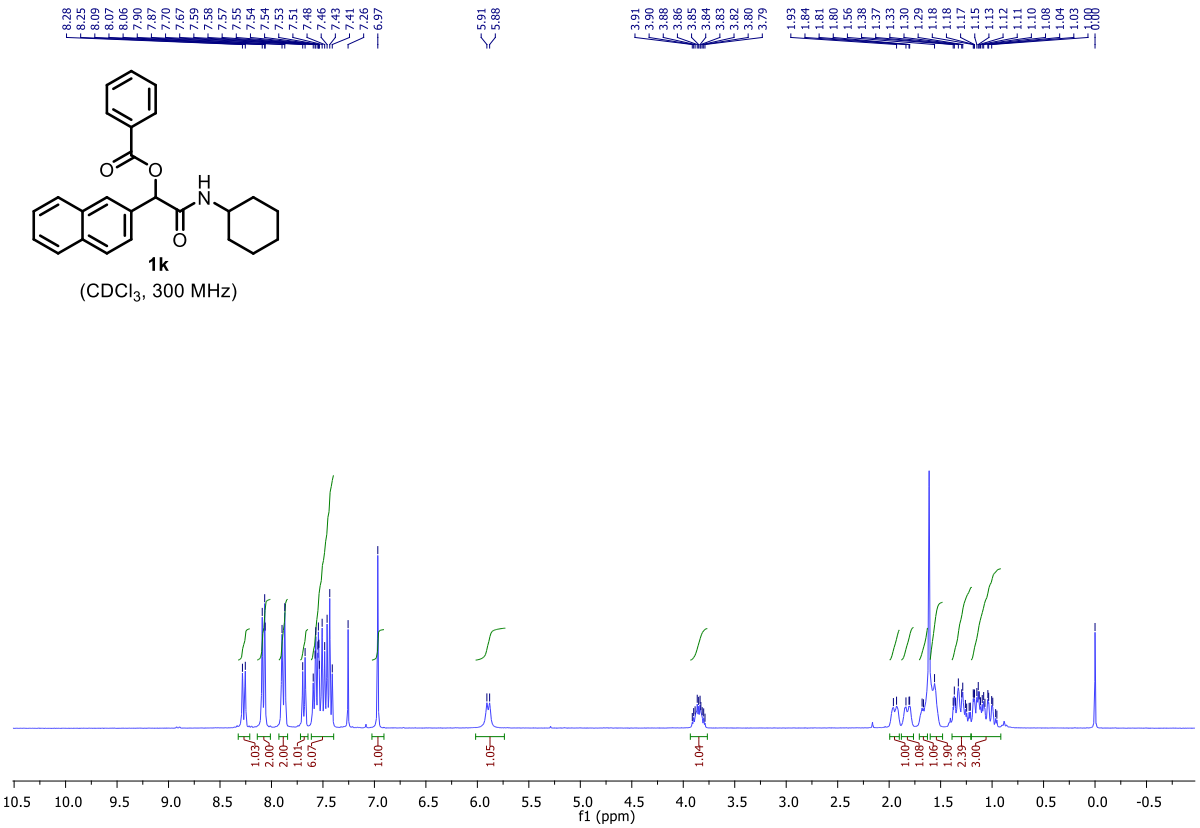


Figure S26: ^{13}C NMR of compound **1k**

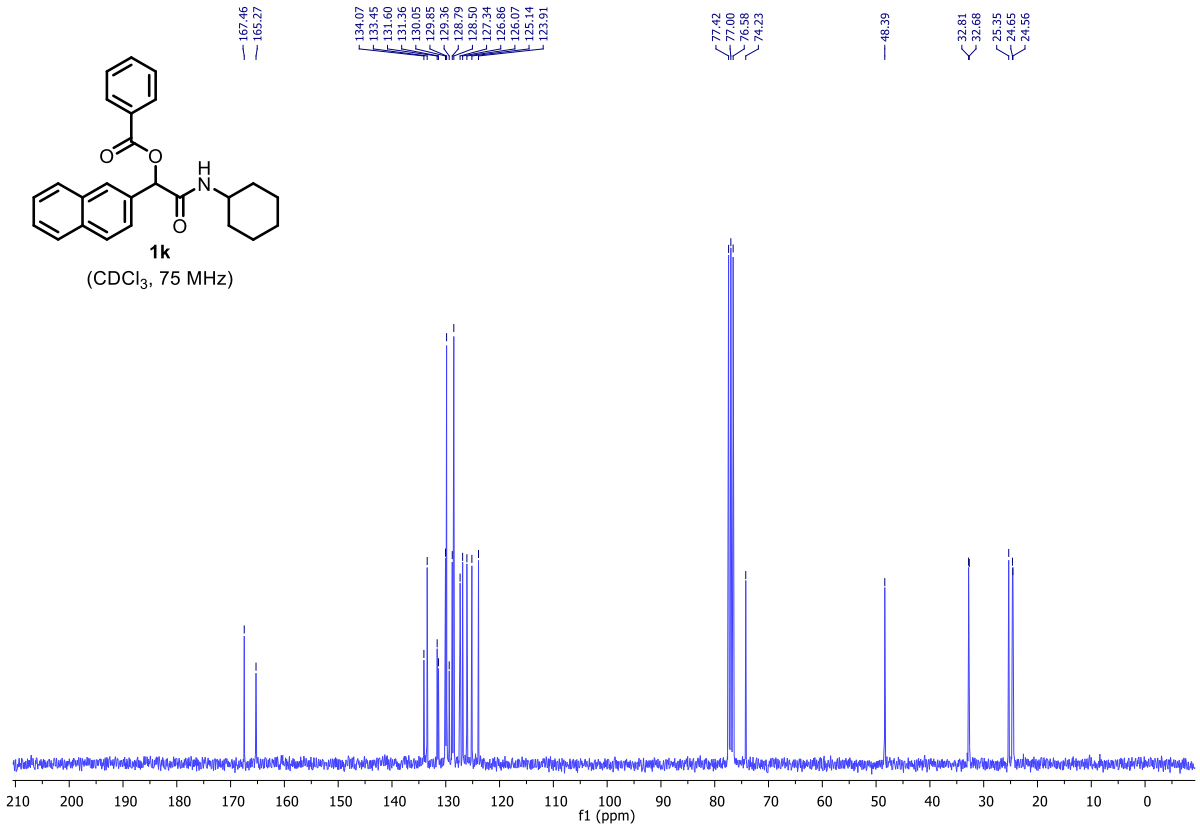


Figure S27: ^{1}H NMR of compound 1l

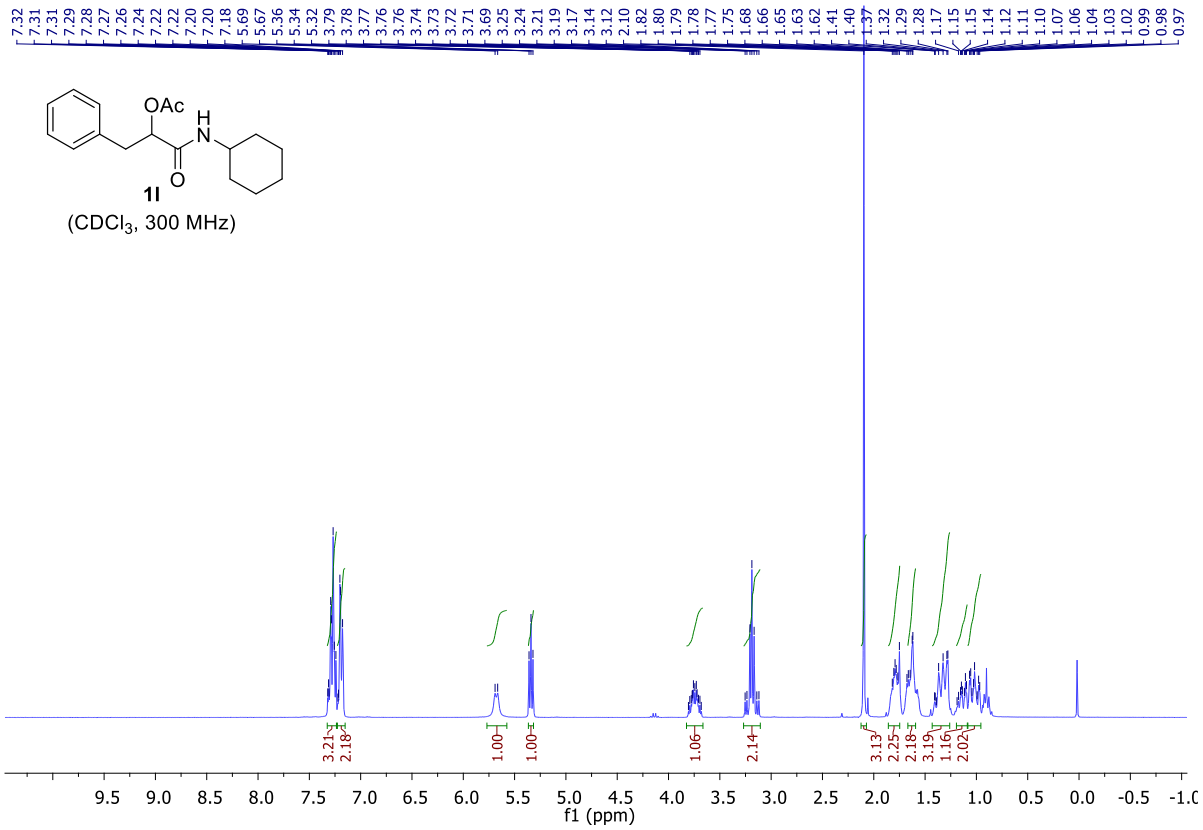


Figure S28: ^{13}C NMR of compound 1l

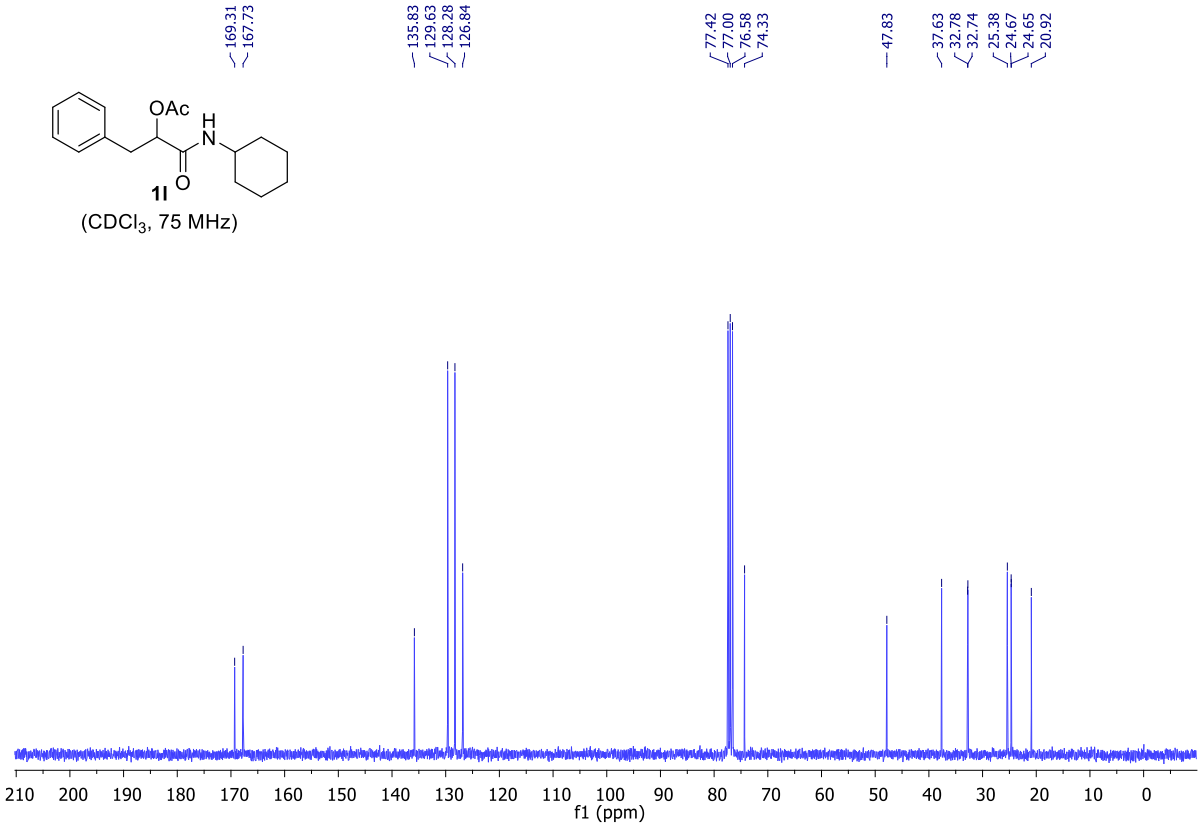


Figure S29: ^{1}H NMR of compound **1m**

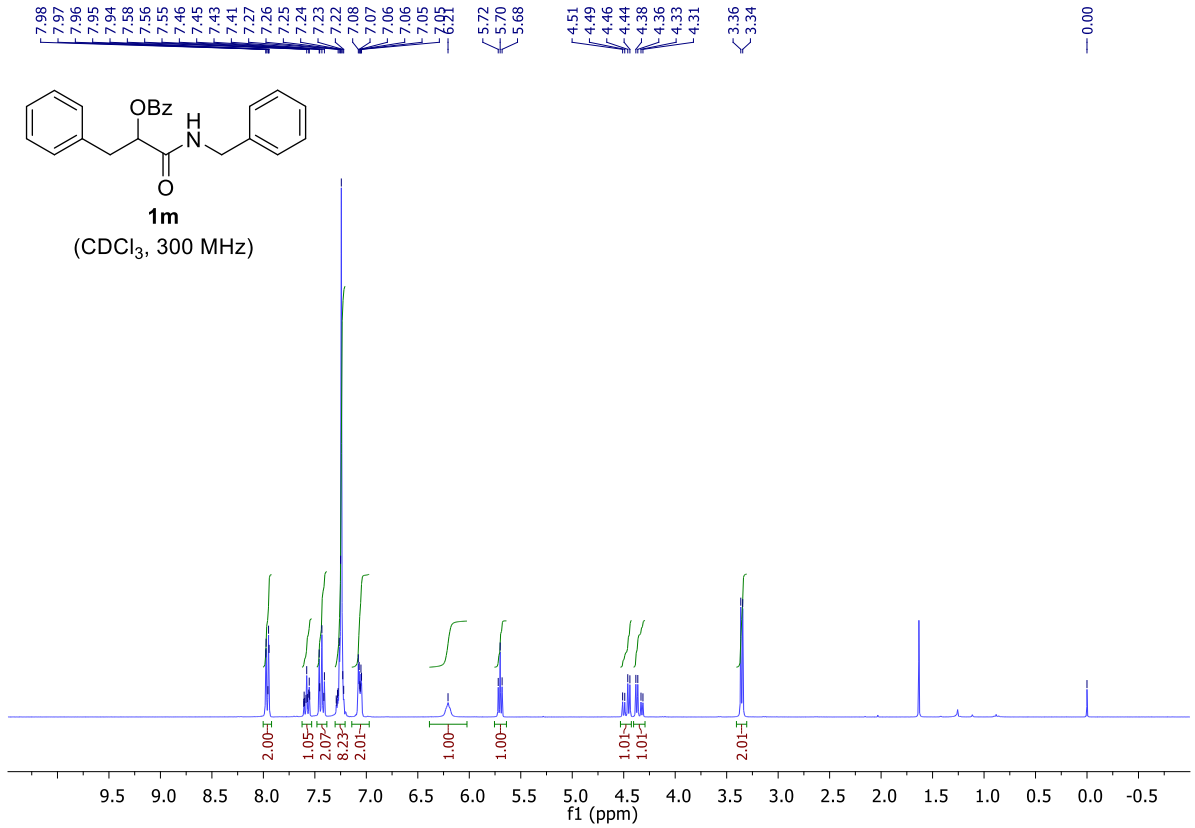


Figure S30: ^{13}C NMR of compound **1m**

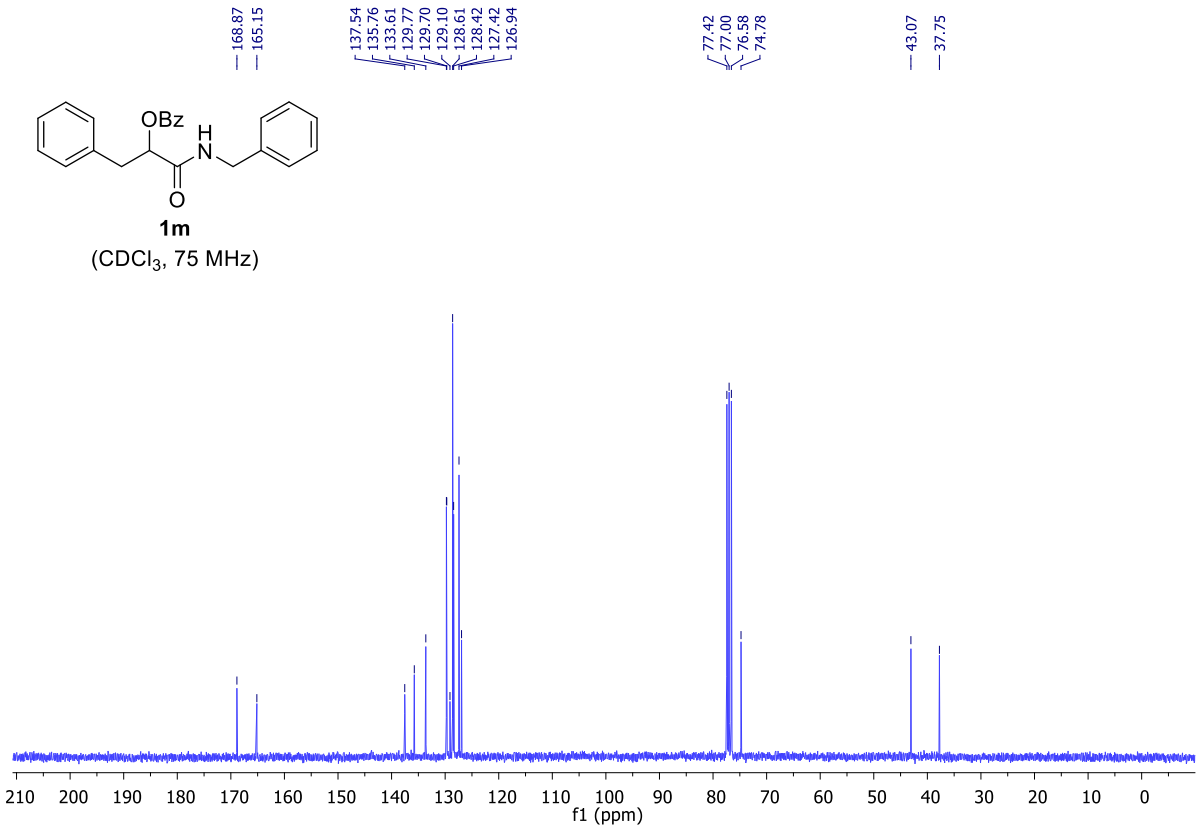


Figure S31: ^{1}H NMR of compound **1n**

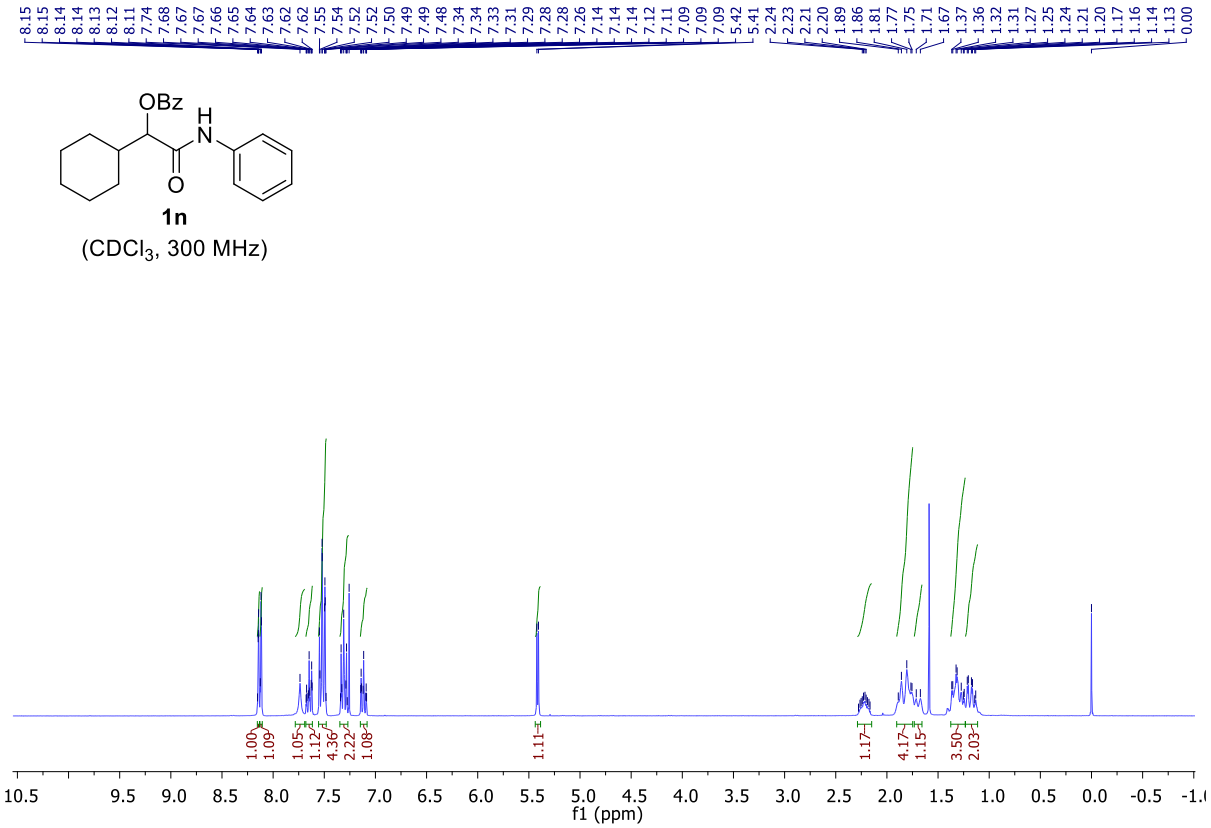


Figure S32: ^{13}C NMR of compound **1n**

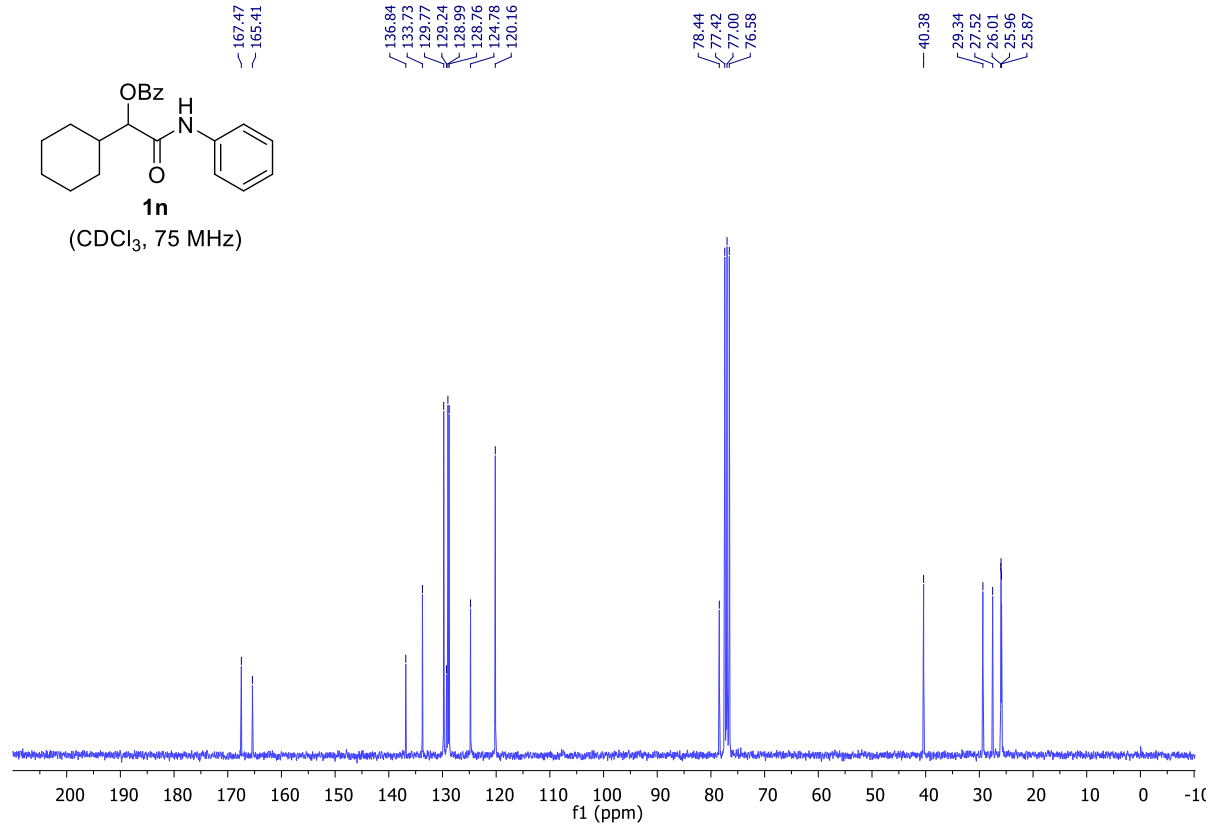


Figure S33: ^{1}H NMR of compound **2a**

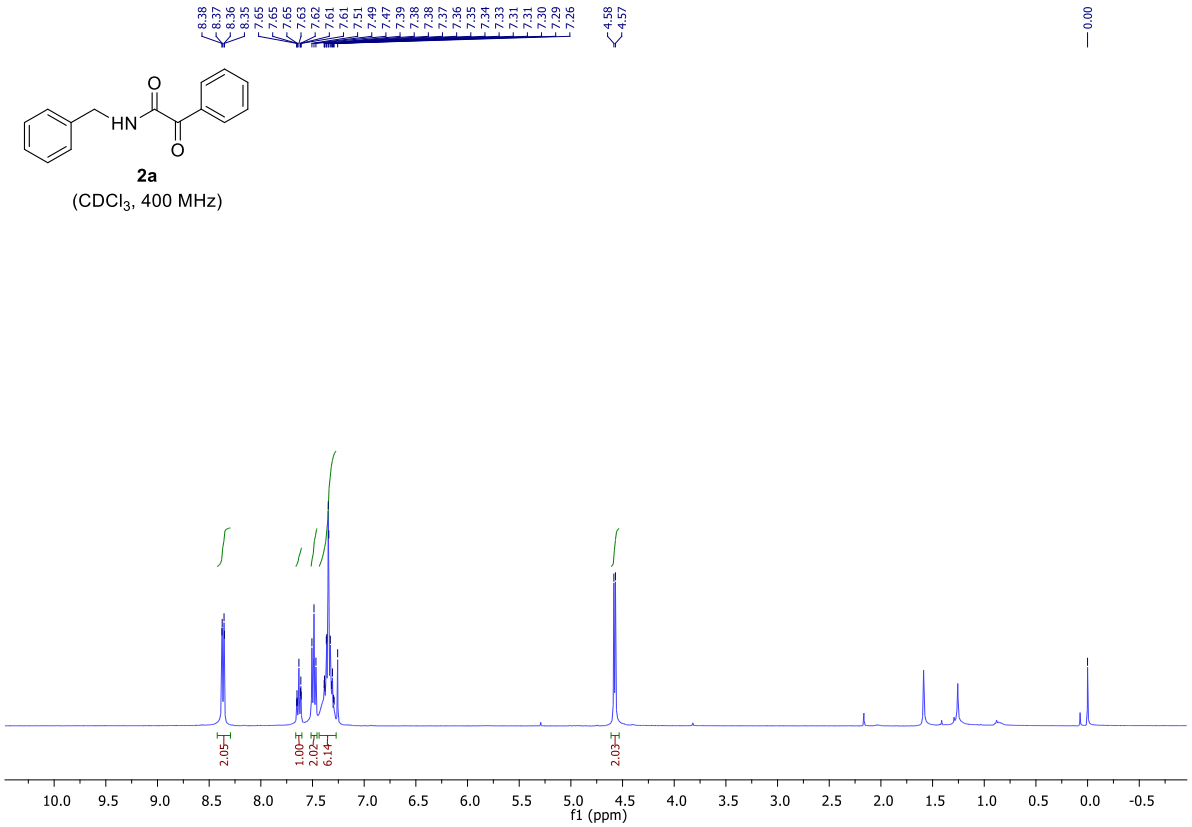


Figure S34: ^{13}C NMR of compound **2a**

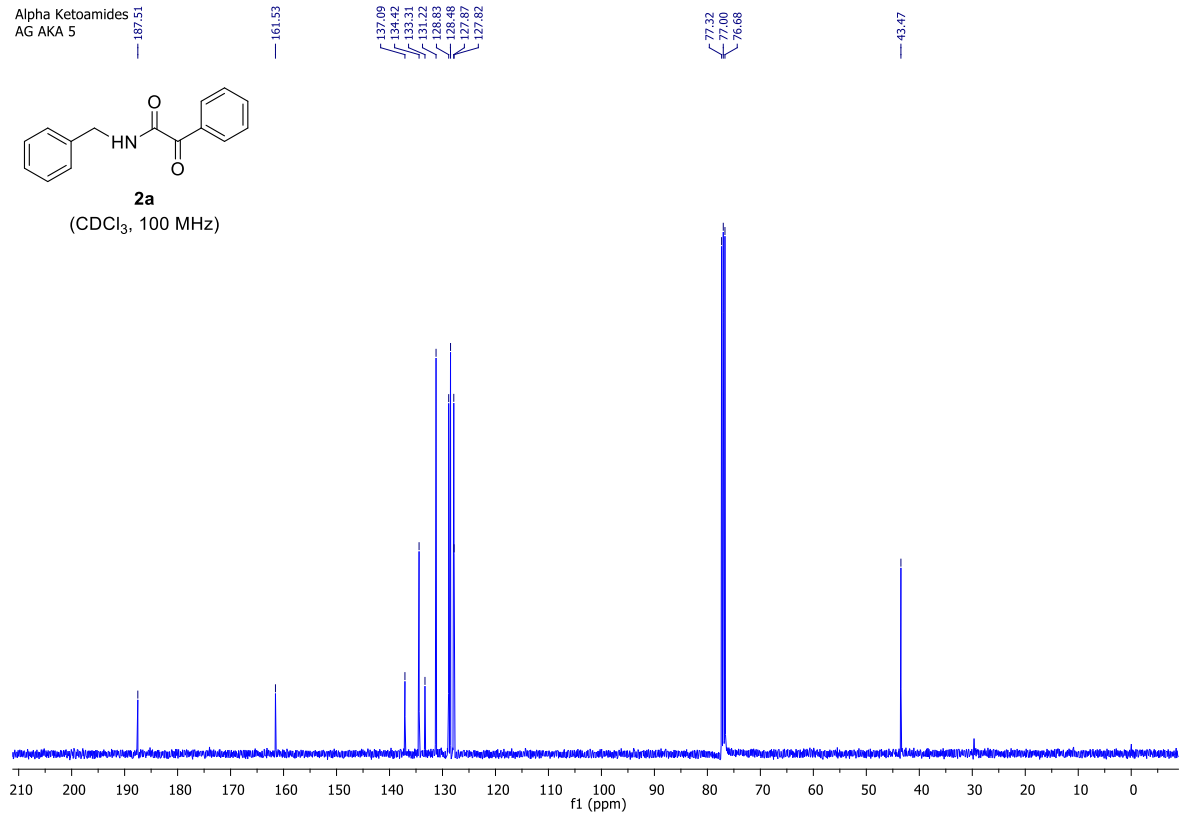


Figure S35: ^{1}H NMR of compound **2b**

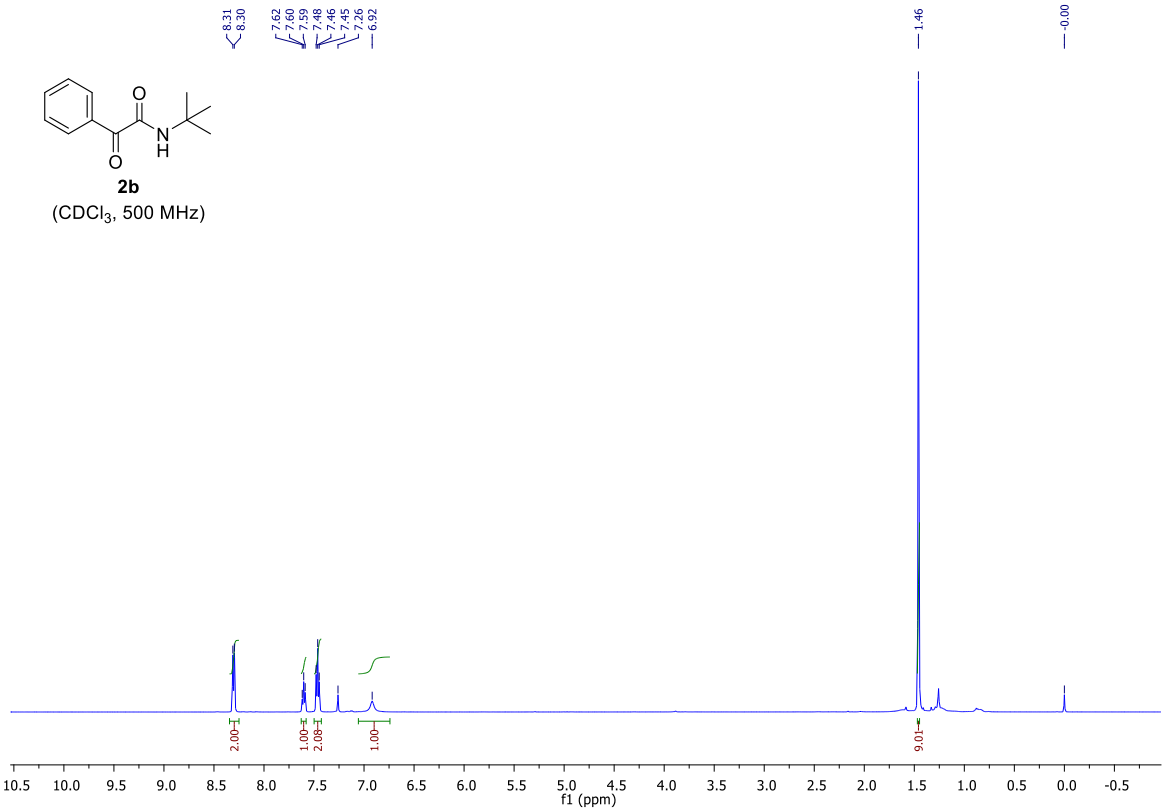


Figure S36: ^{13}C NMR of compound **2b**

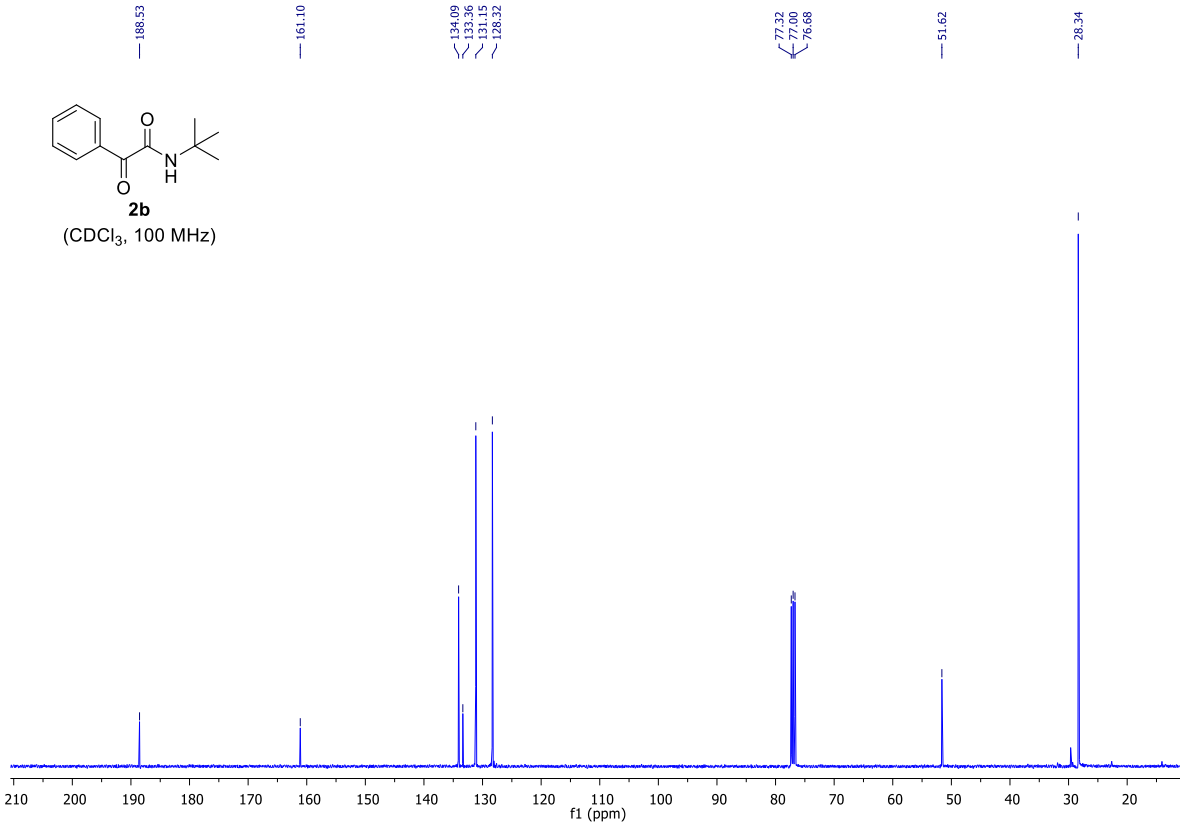


Figure S37: ^{1}H NMR of compound **2c**

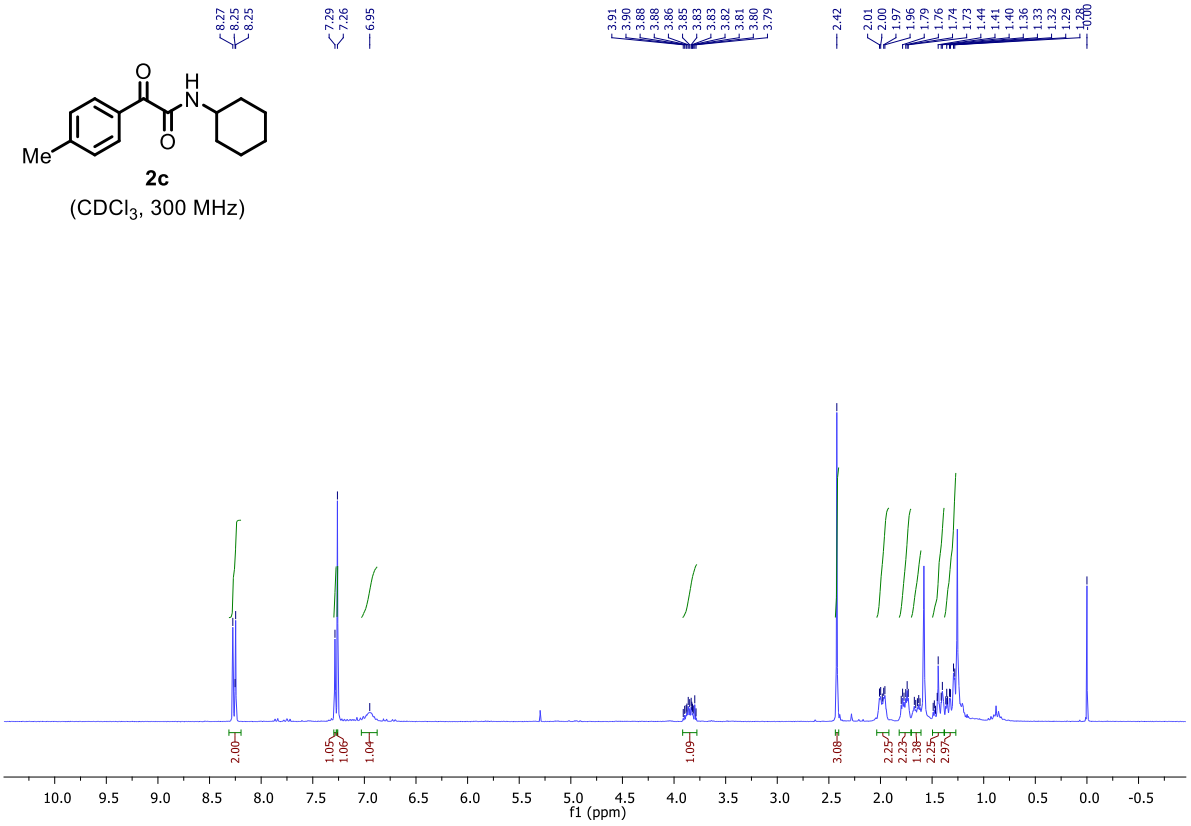


Figure S38: ^{13}C NMR of compound **2c**

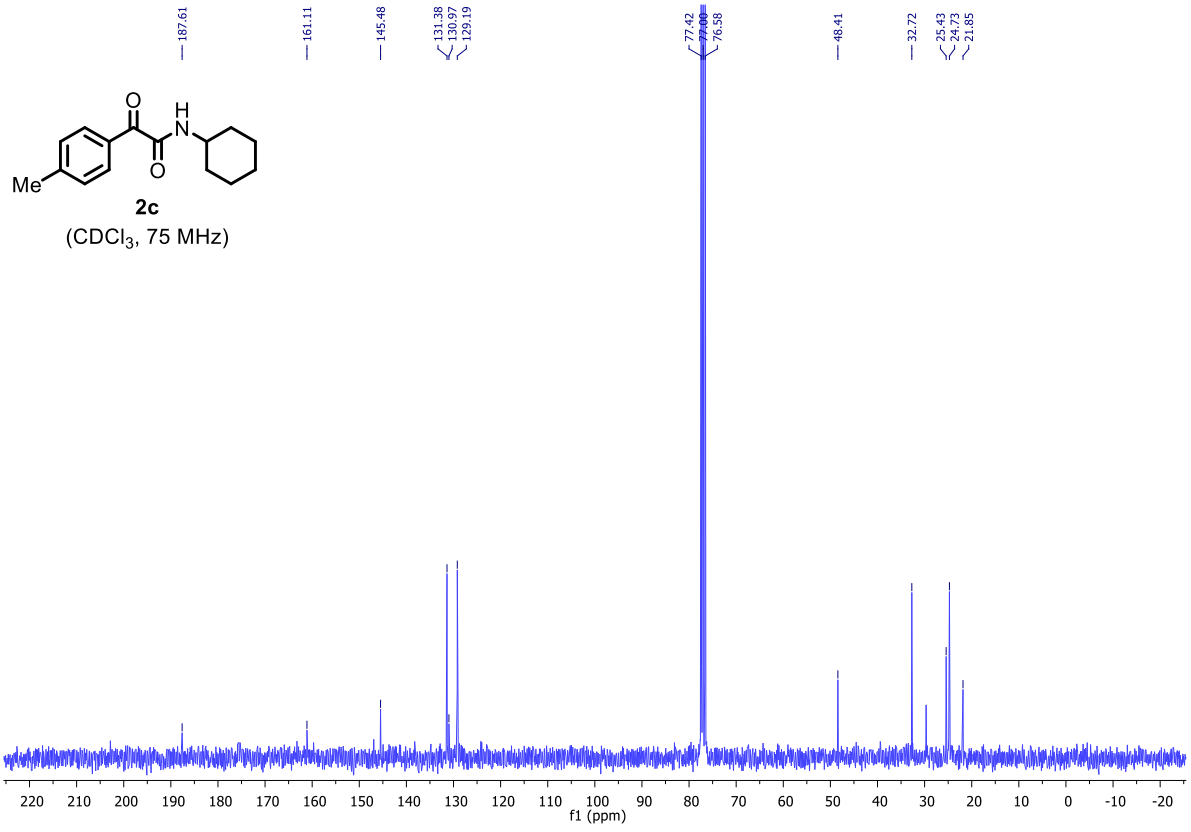


Figure S39: ^{1}H NMR of compound **2d**

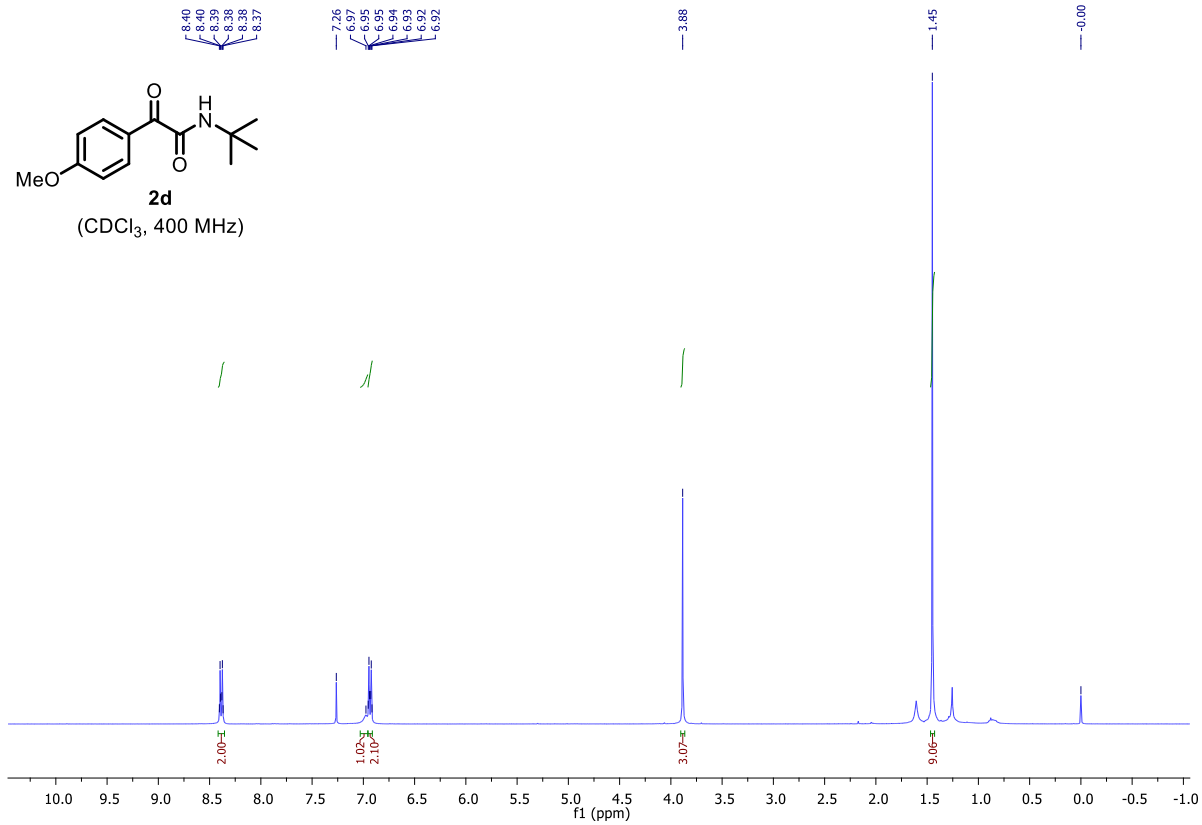


Figure S40: ^{13}C NMR of compound **2d**

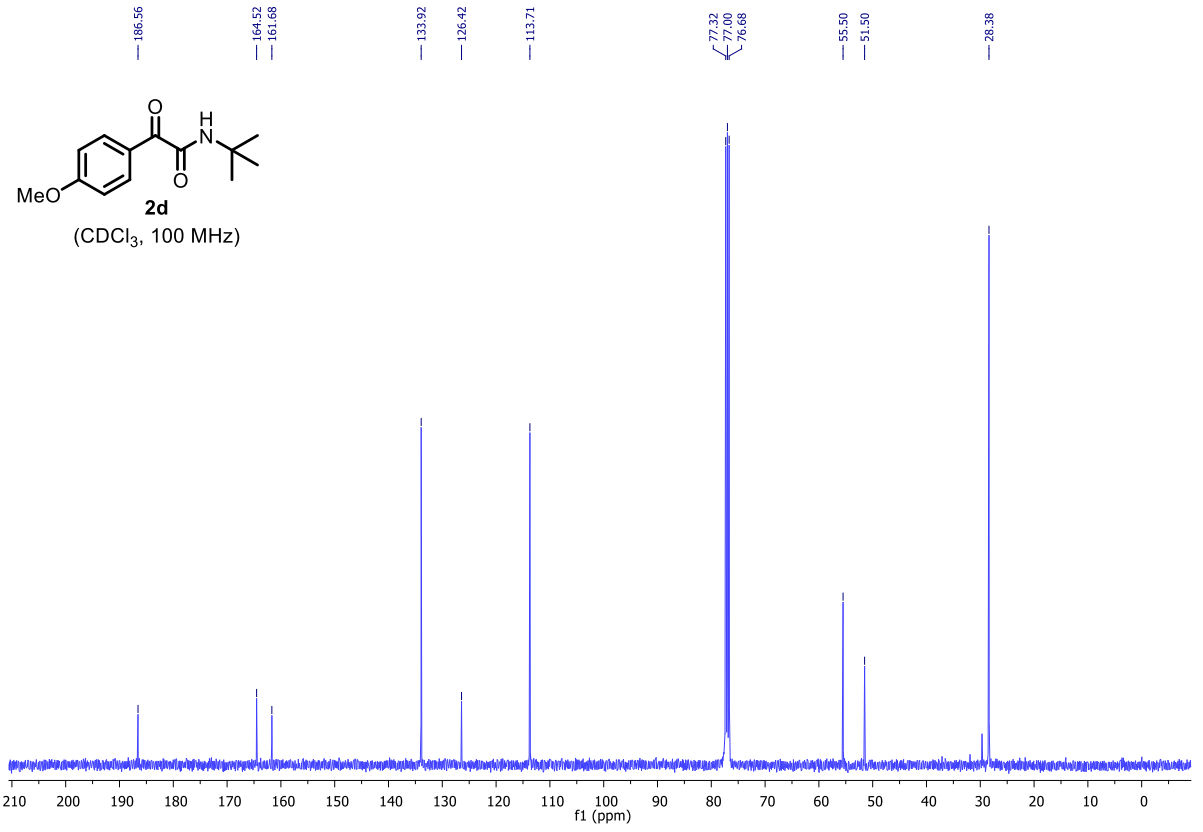


Figure S41: ^{1}H NMR of compound **2e**

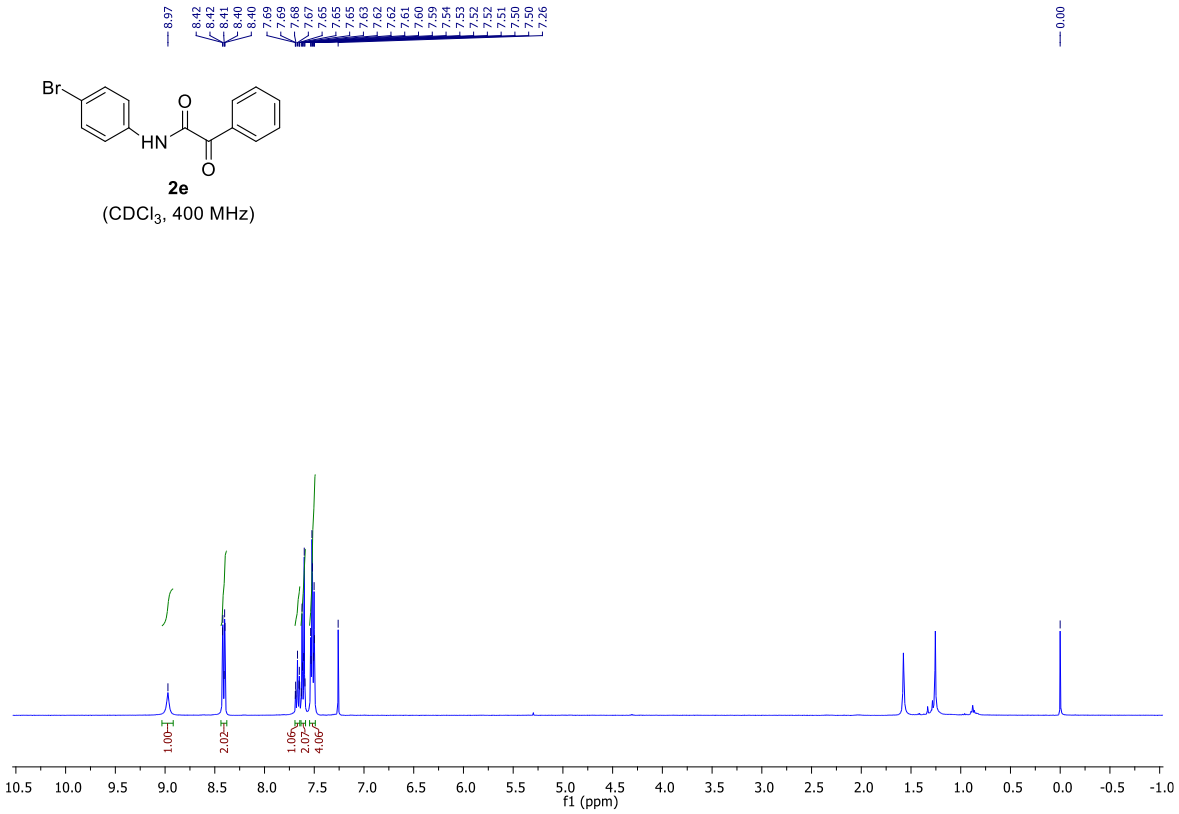


Figure S42: ^{13}C NMR of compound **2e**

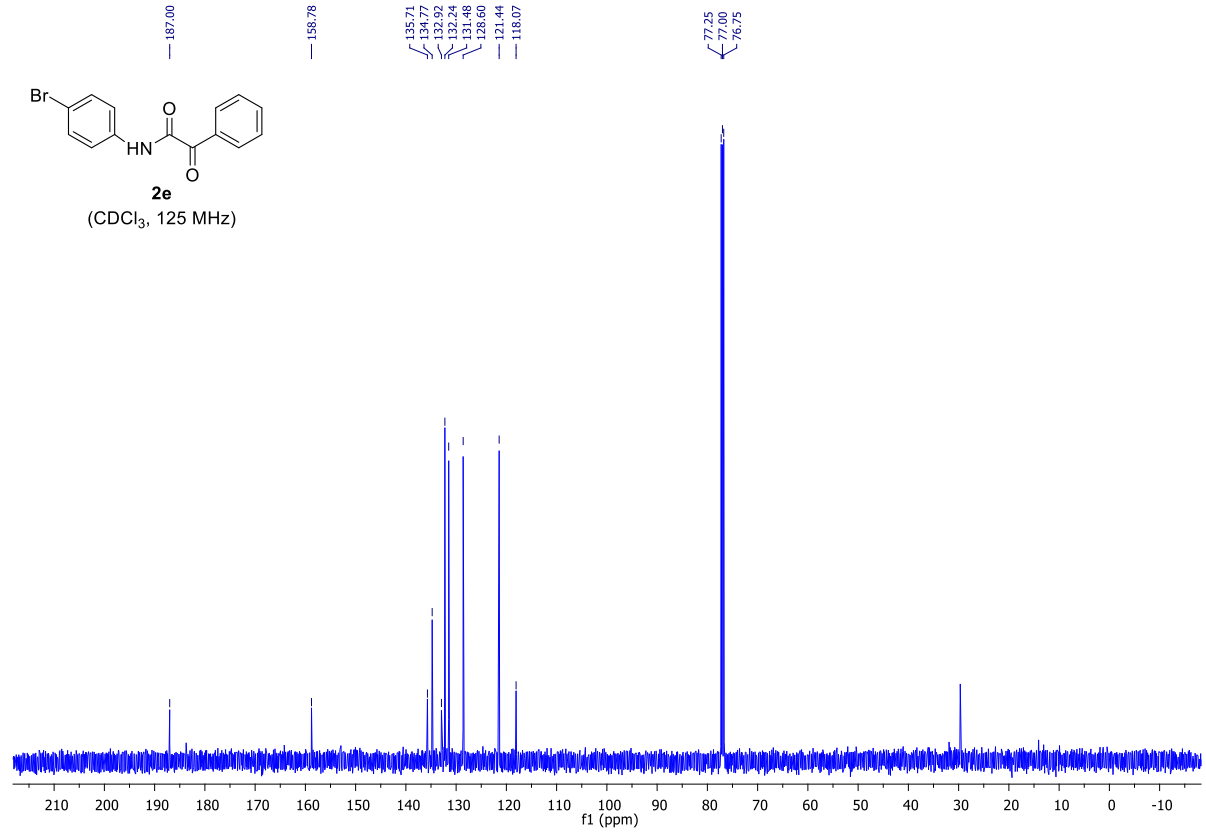


Figure S43: ^{1}H NMR of compound **2f**

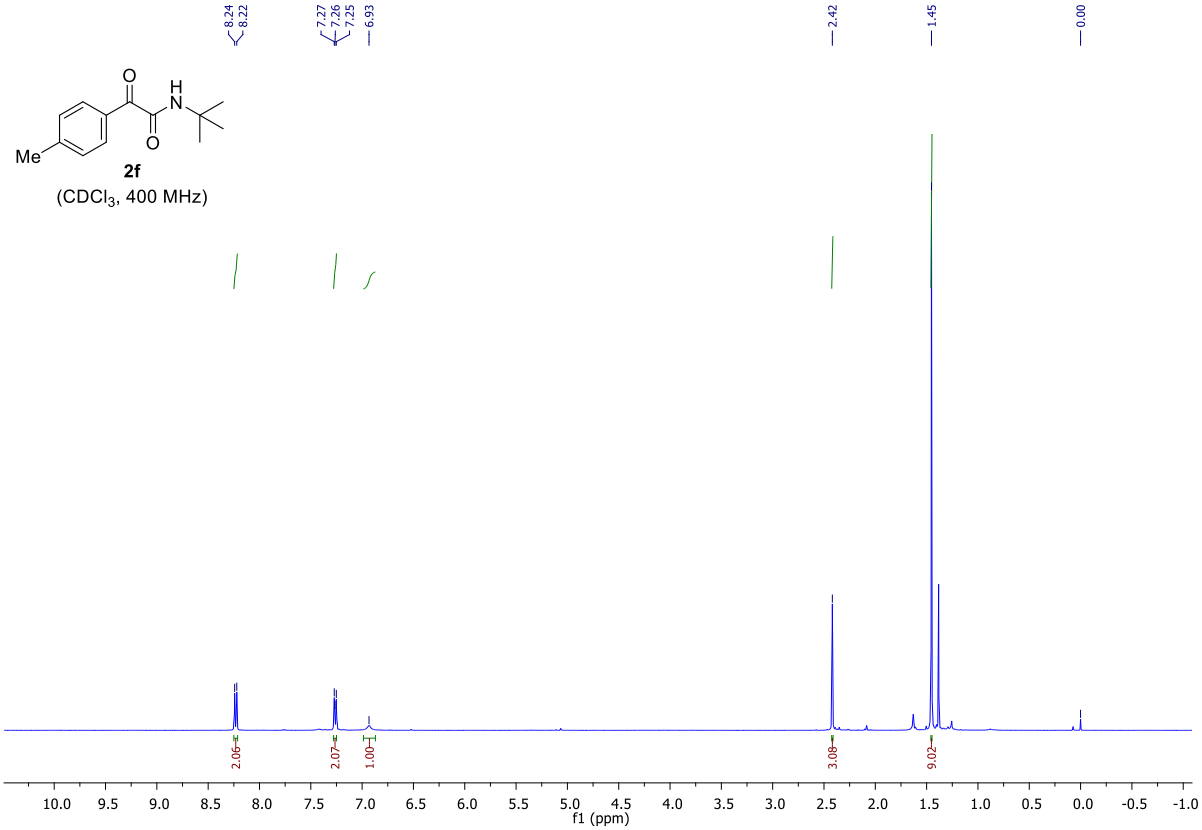


Figure S44: ^{13}C NMR of compound **2f**

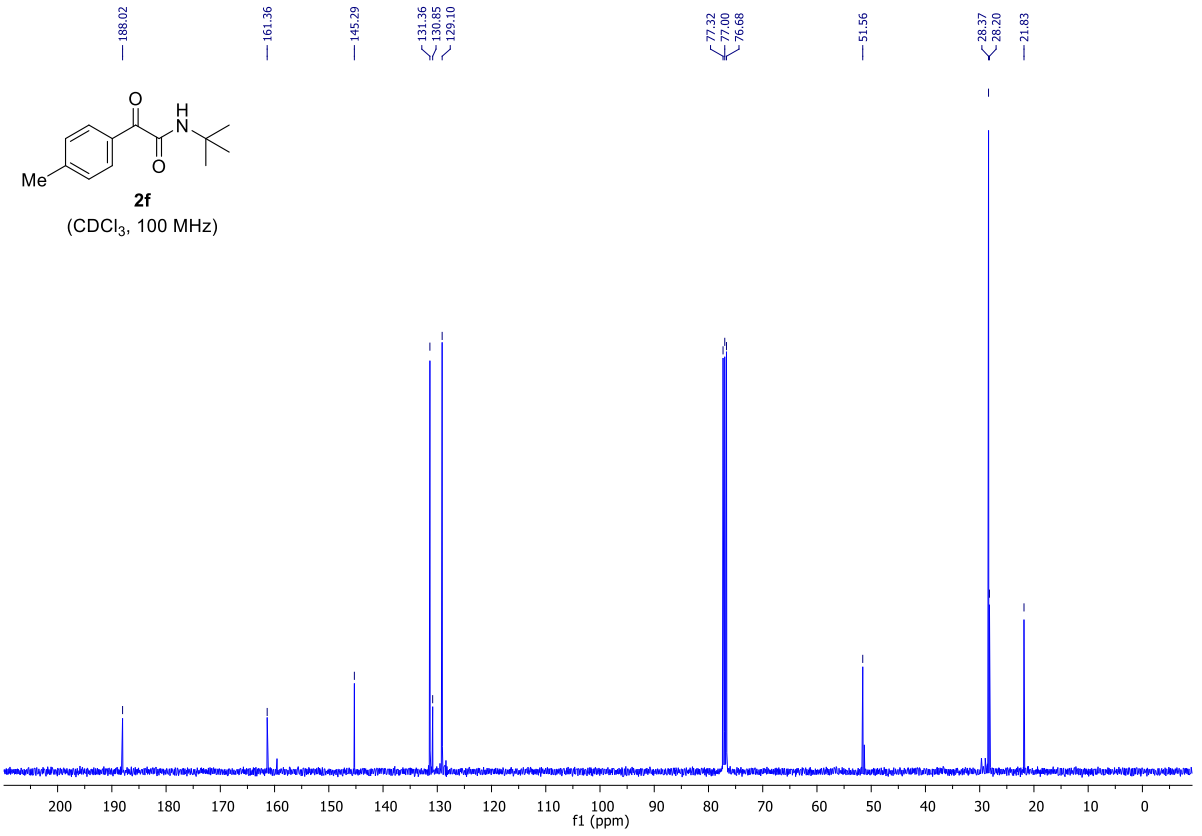


Figure S45: ^{1}H NMR of compound **2g**

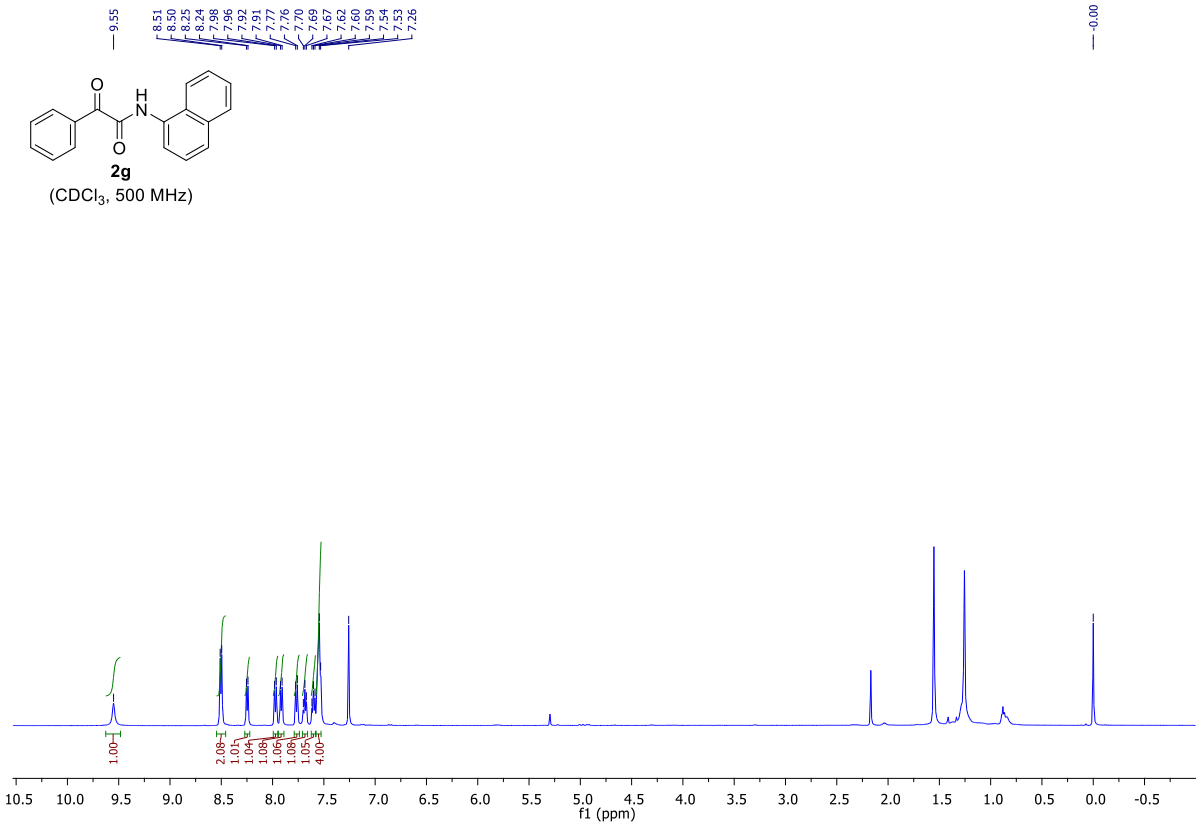


Figure S46: ^{13}C NMR of compound **2g**

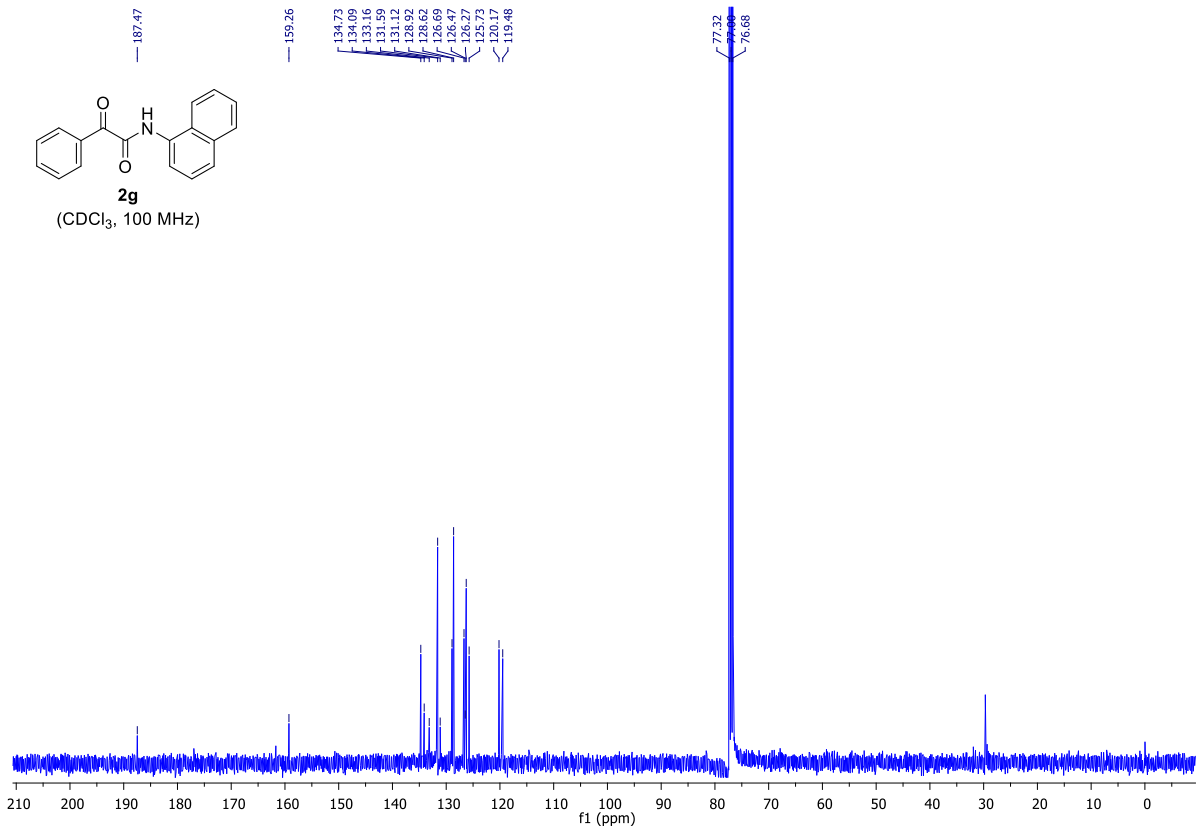


Figure S47: ^{1}H NMR of compound **2h**

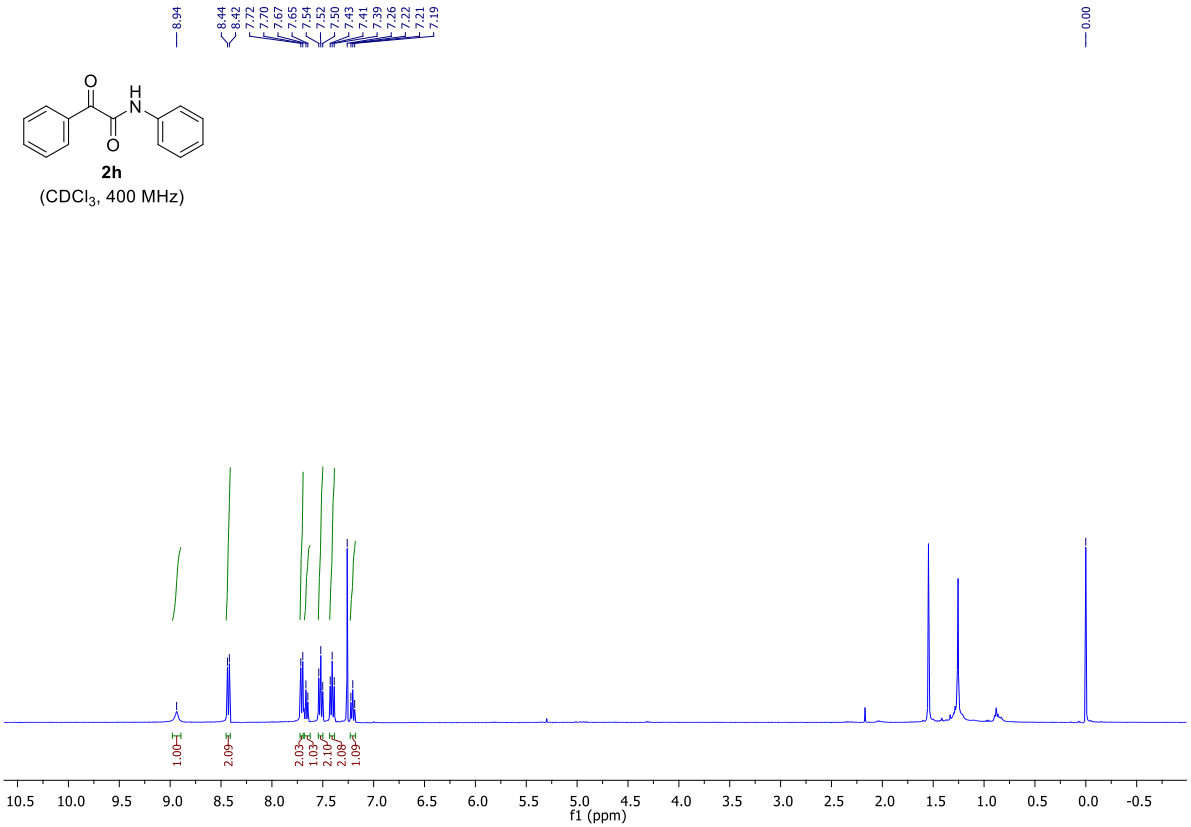


Figure S48: ^{13}C NMR of compound **2h**

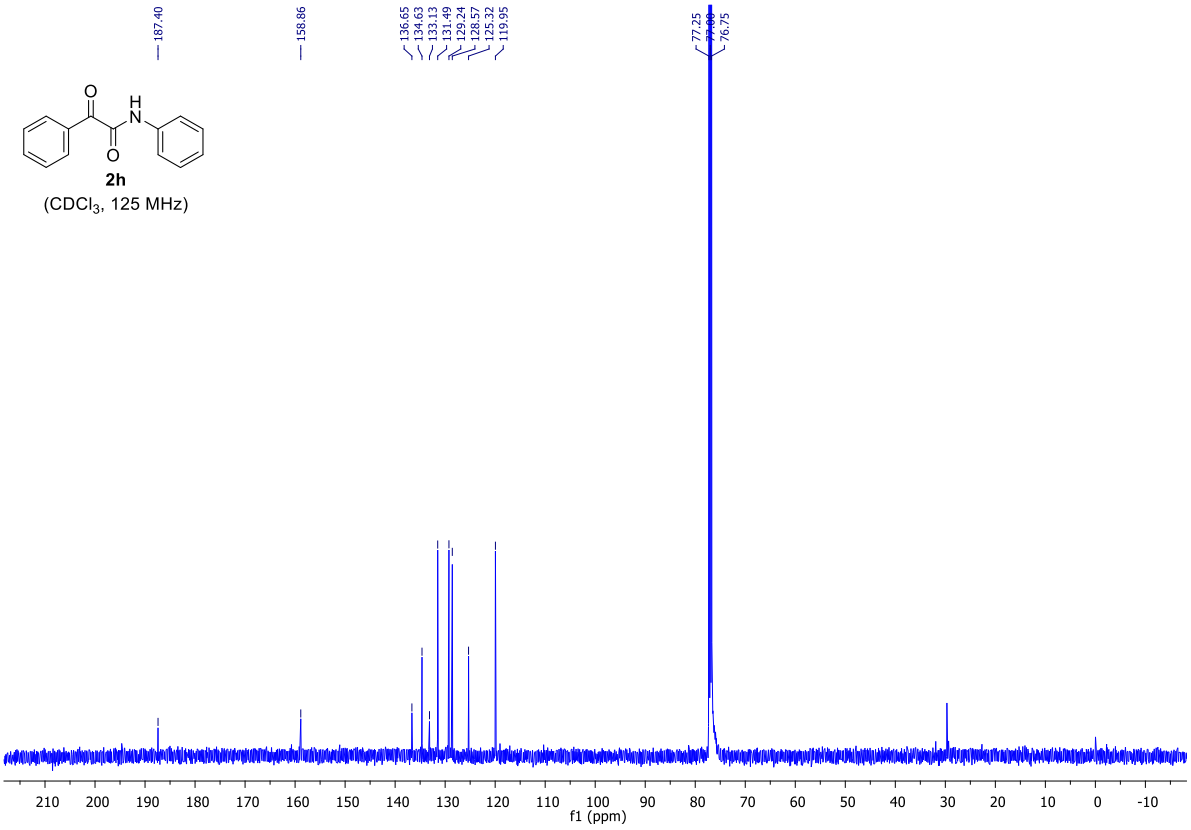


Figure S49: ^{1}H NMR of compound **2i**

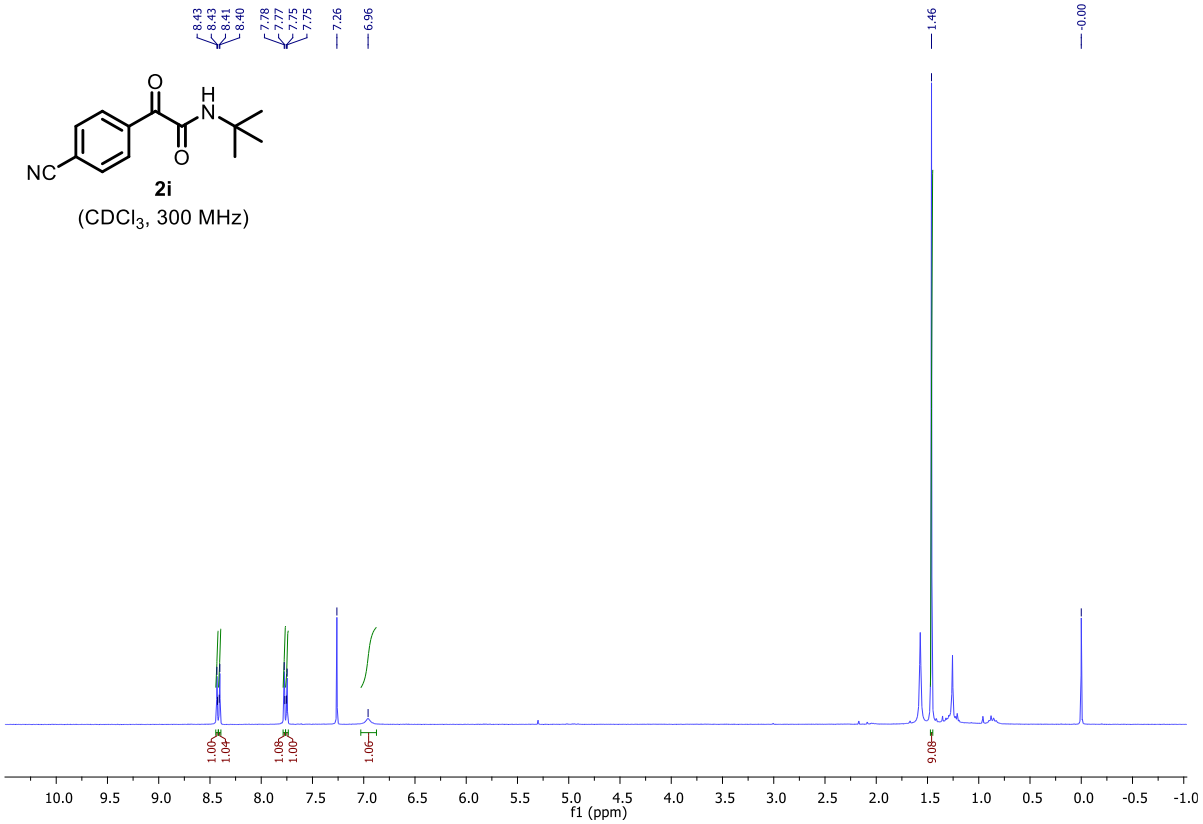


Figure S50: ^{13}C NMR of compound **2i**

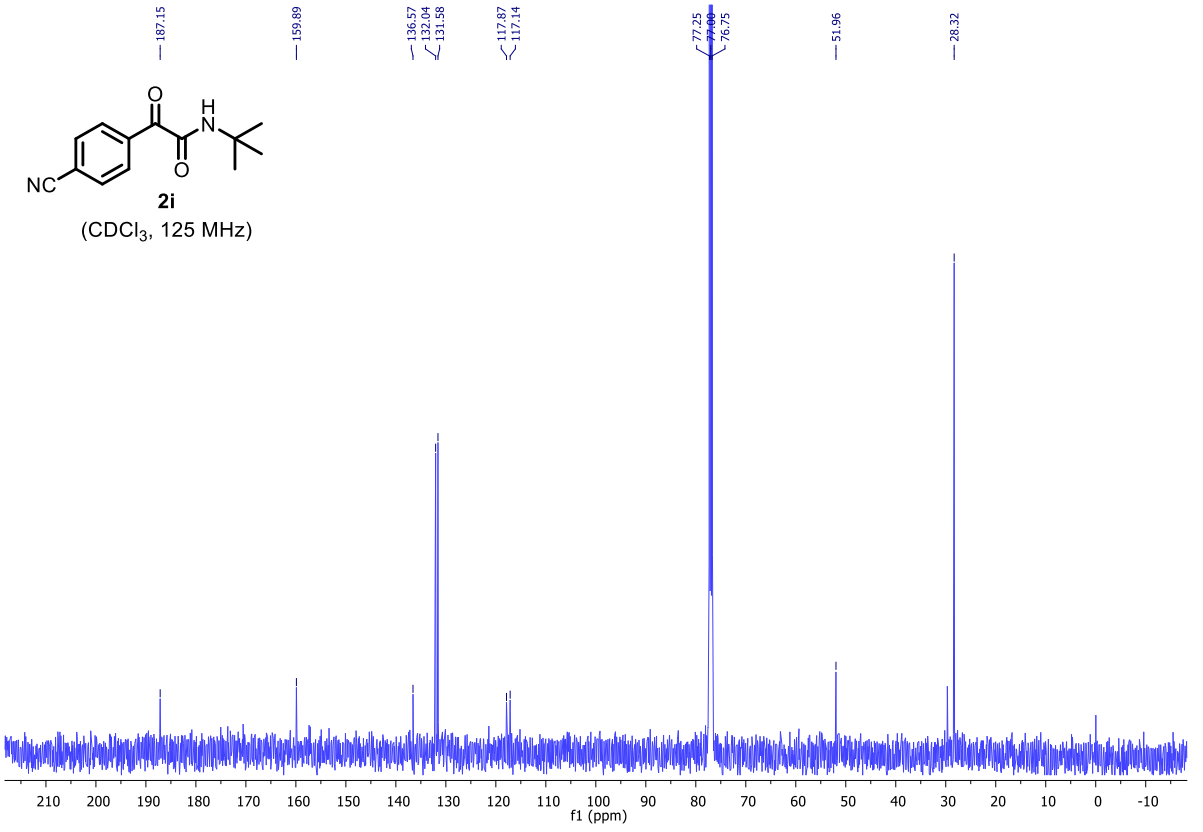


Figure S51: ^{1}H NMR of compound **2j**

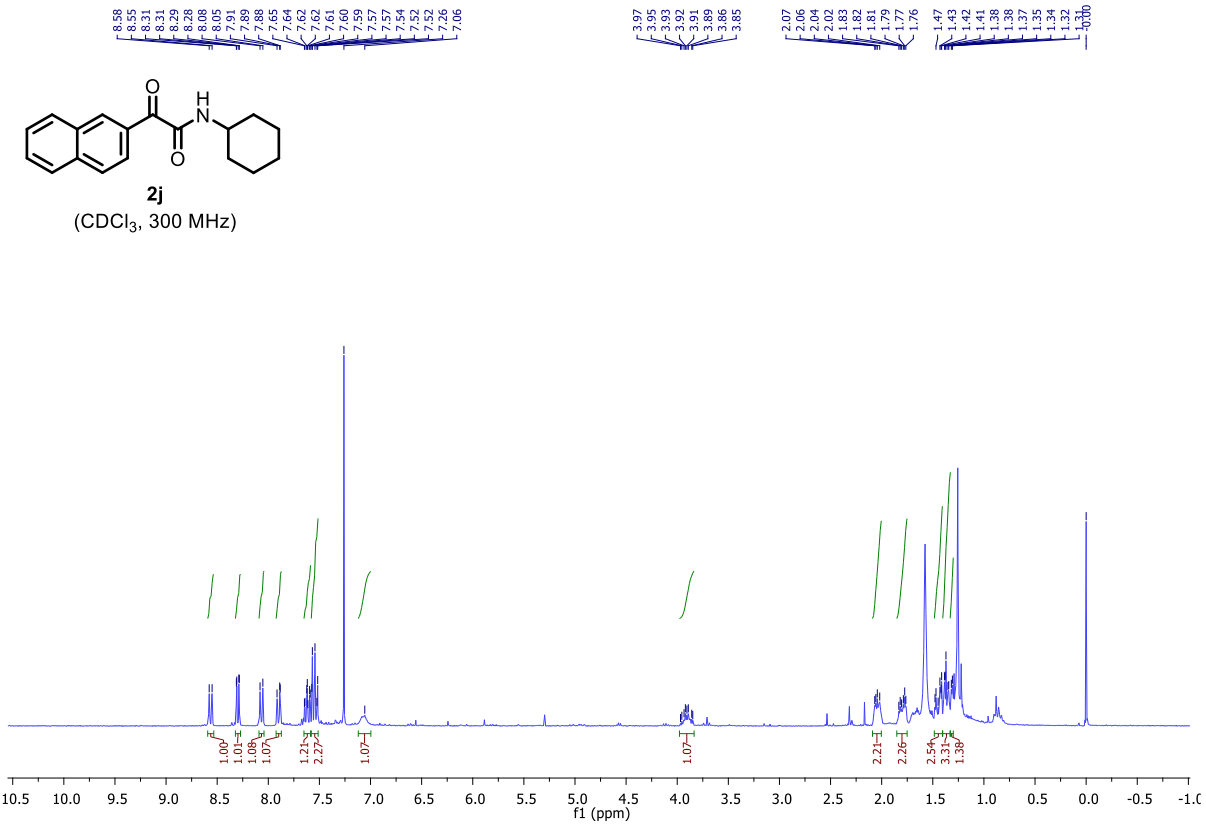


Figure S52: ^{13}C NMR of compound **2j**

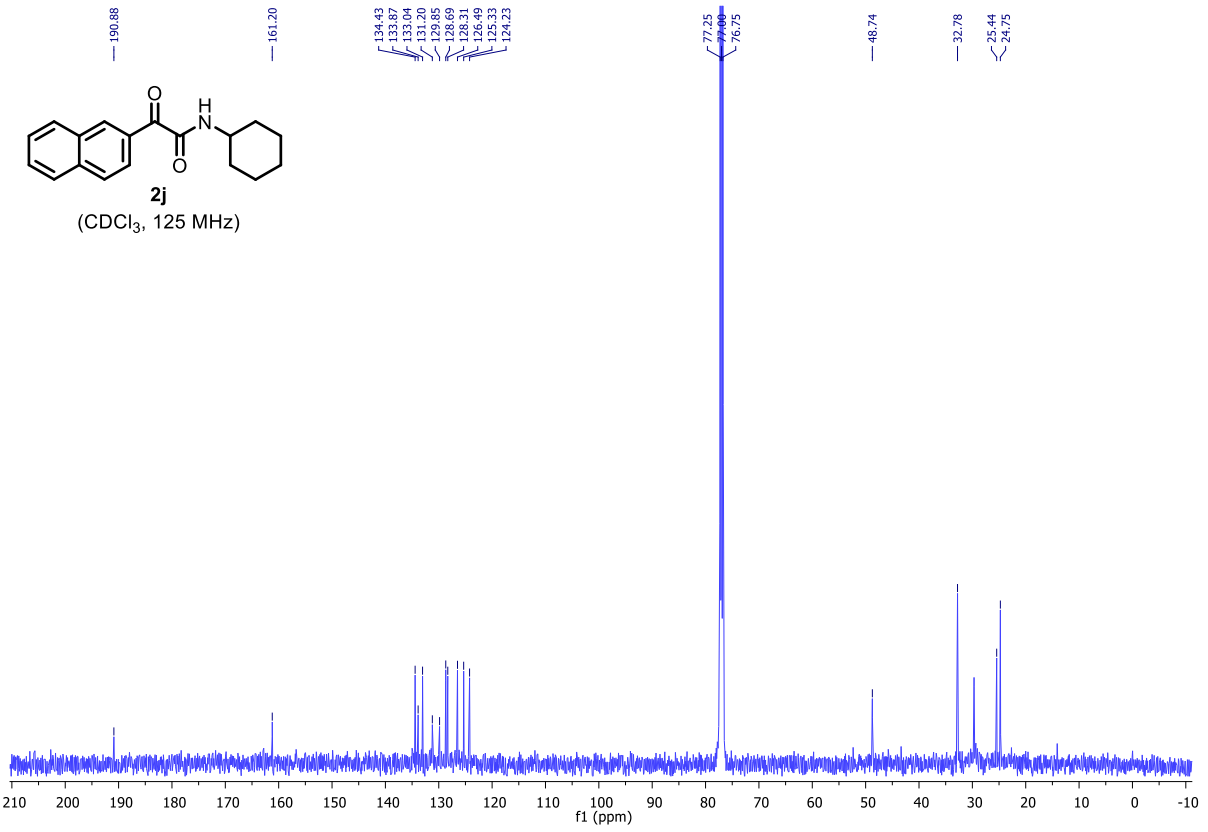


Figure S53: ^{1}H NMR of compound **2k**

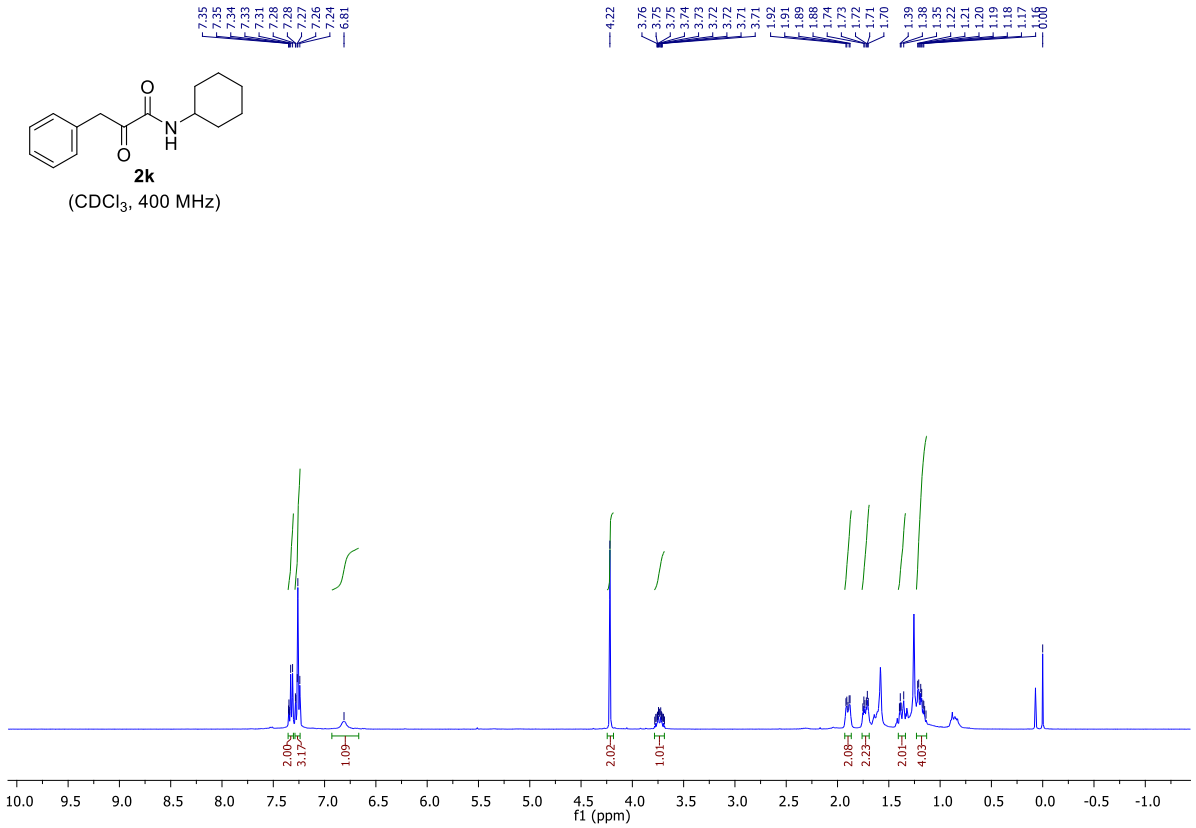


Figure S54: ^{13}C NMR of compound **2k**

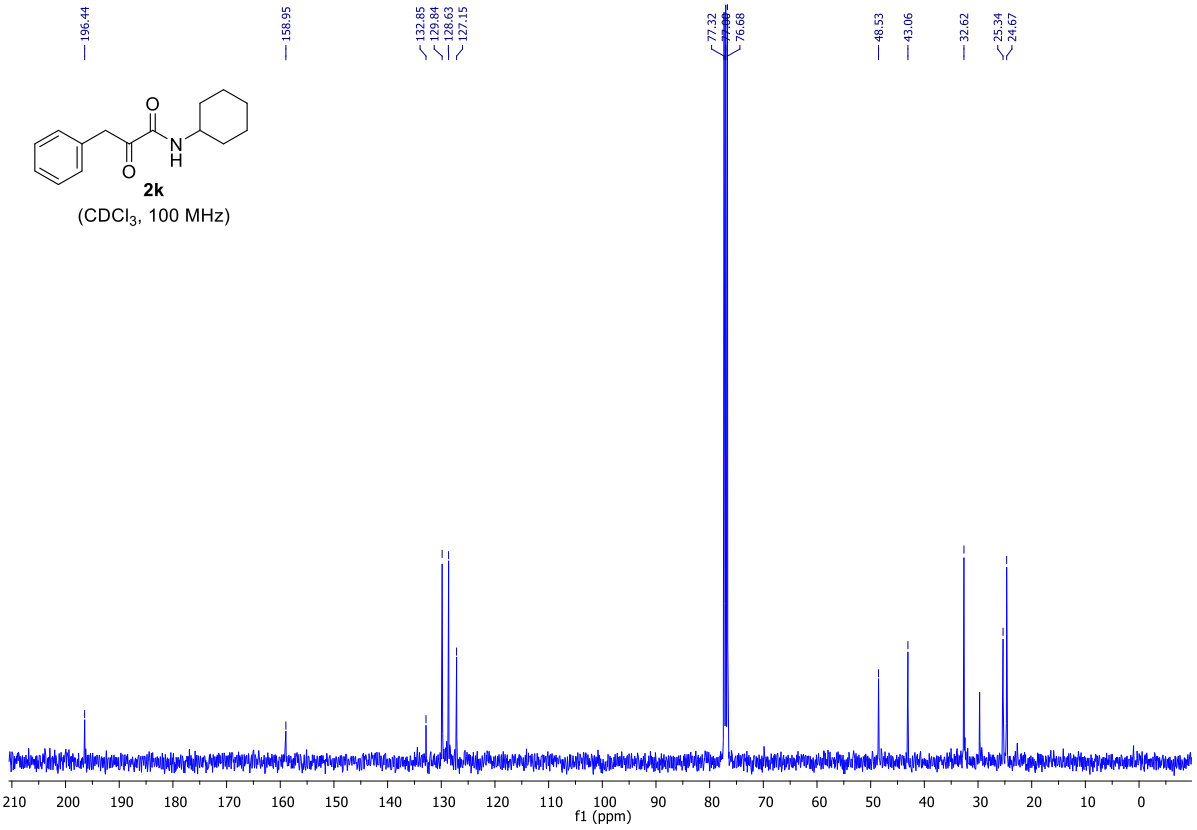


Figure S55: ^{1}H NMR of compound **2k'**

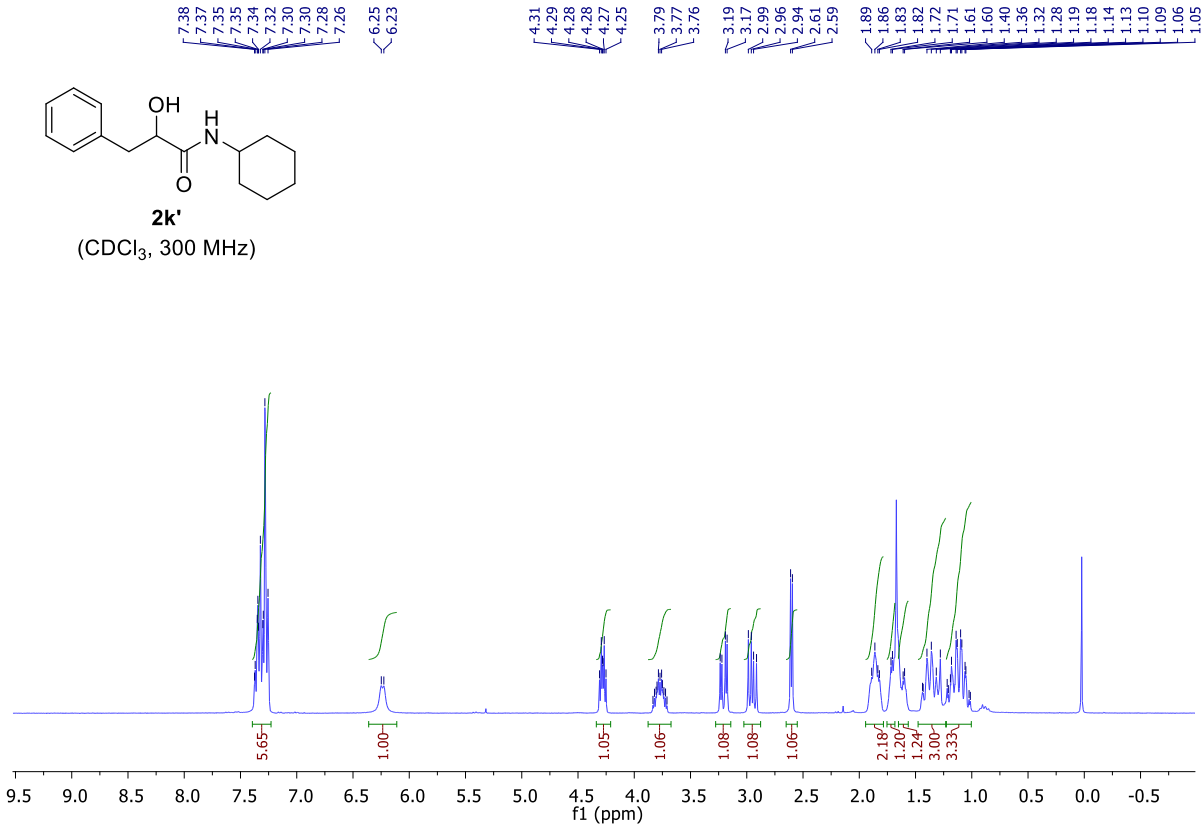


Figure S56: ^{13}C NMR of compound **2k'**

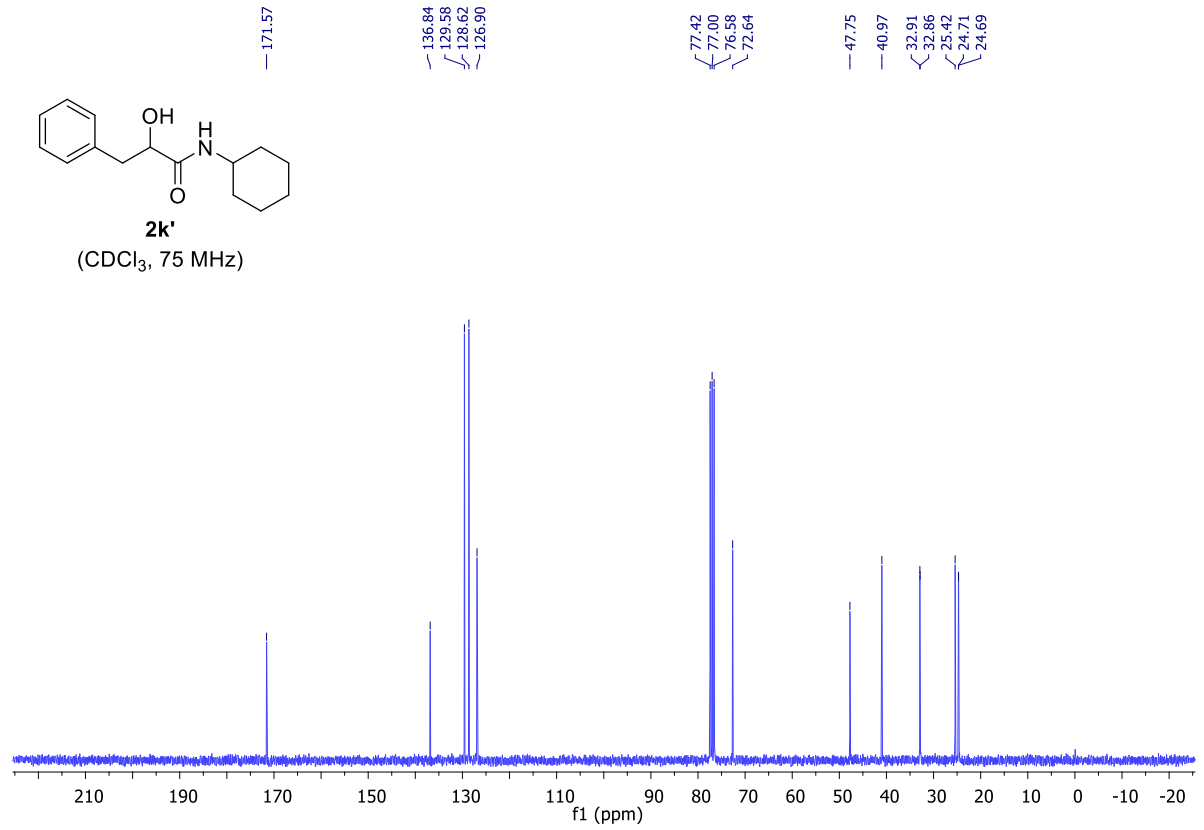


Figure S57: ^{1}H NMR of compound **2l'**

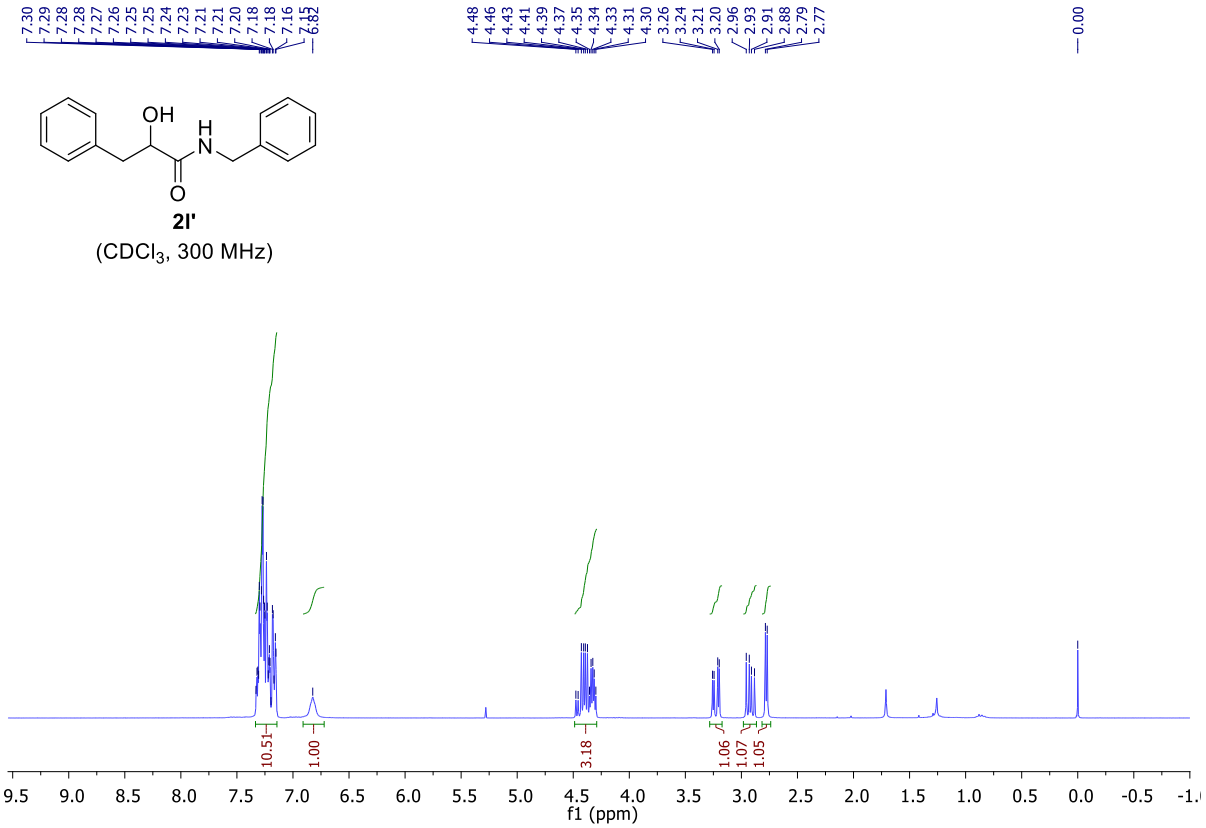


Figure S58: ^{13}C NMR of compound **2l'**

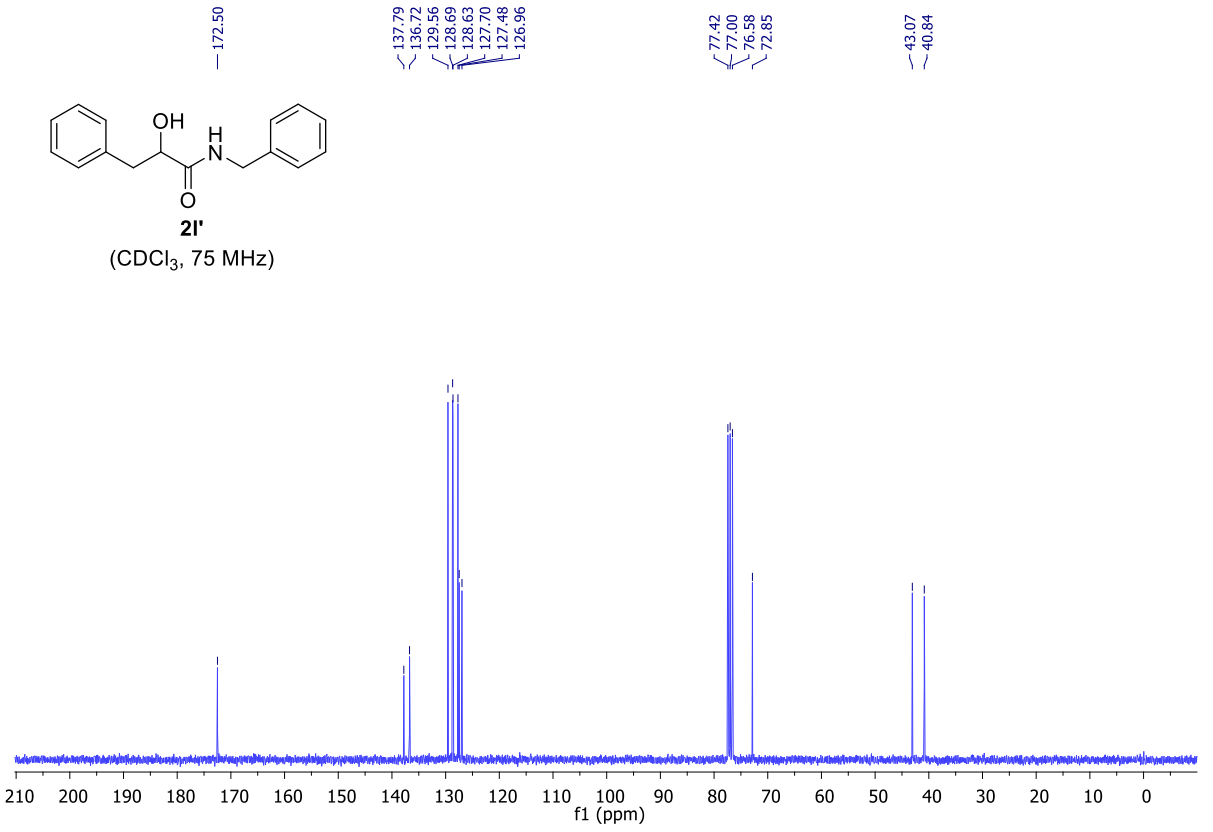


Figure S59: ^{1}H NMR of compound **2m'**

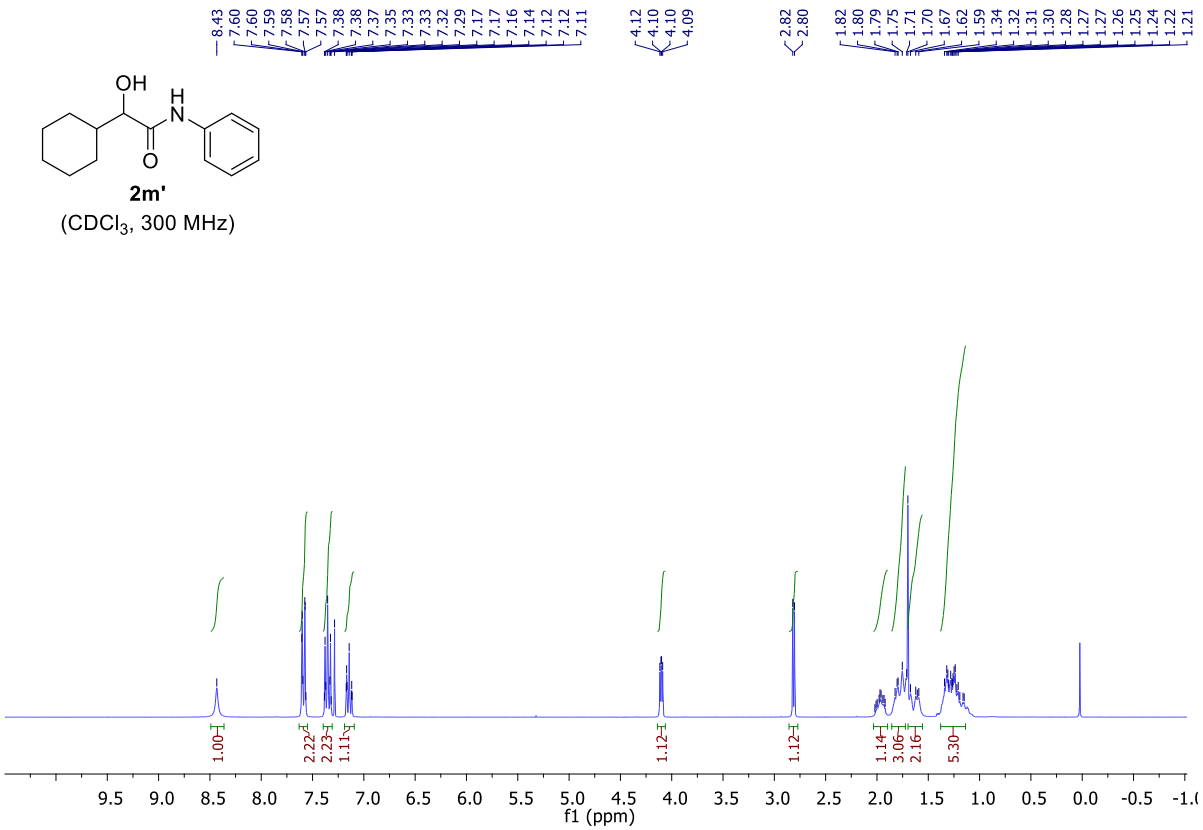


Figure S60: ^{13}C NMR of compound **2m'**

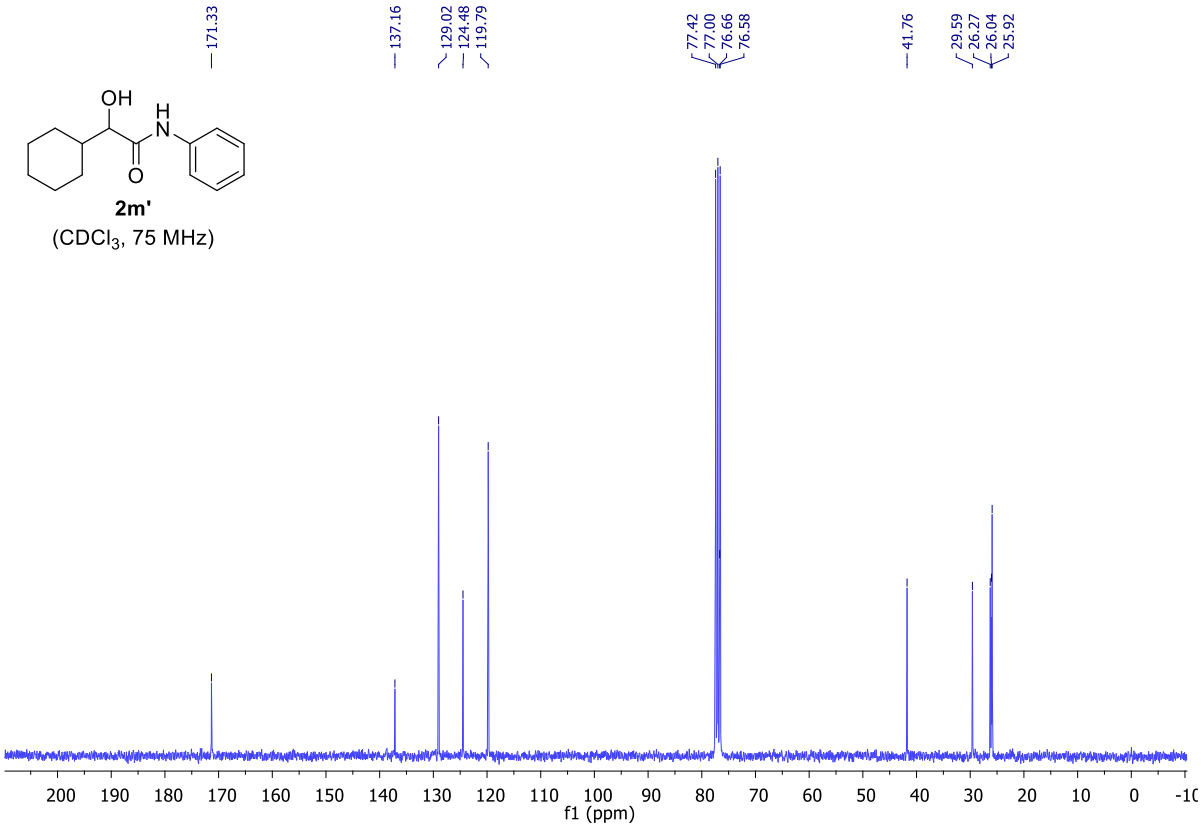


Figure S61: ^{1}H NMR of compound **2n**

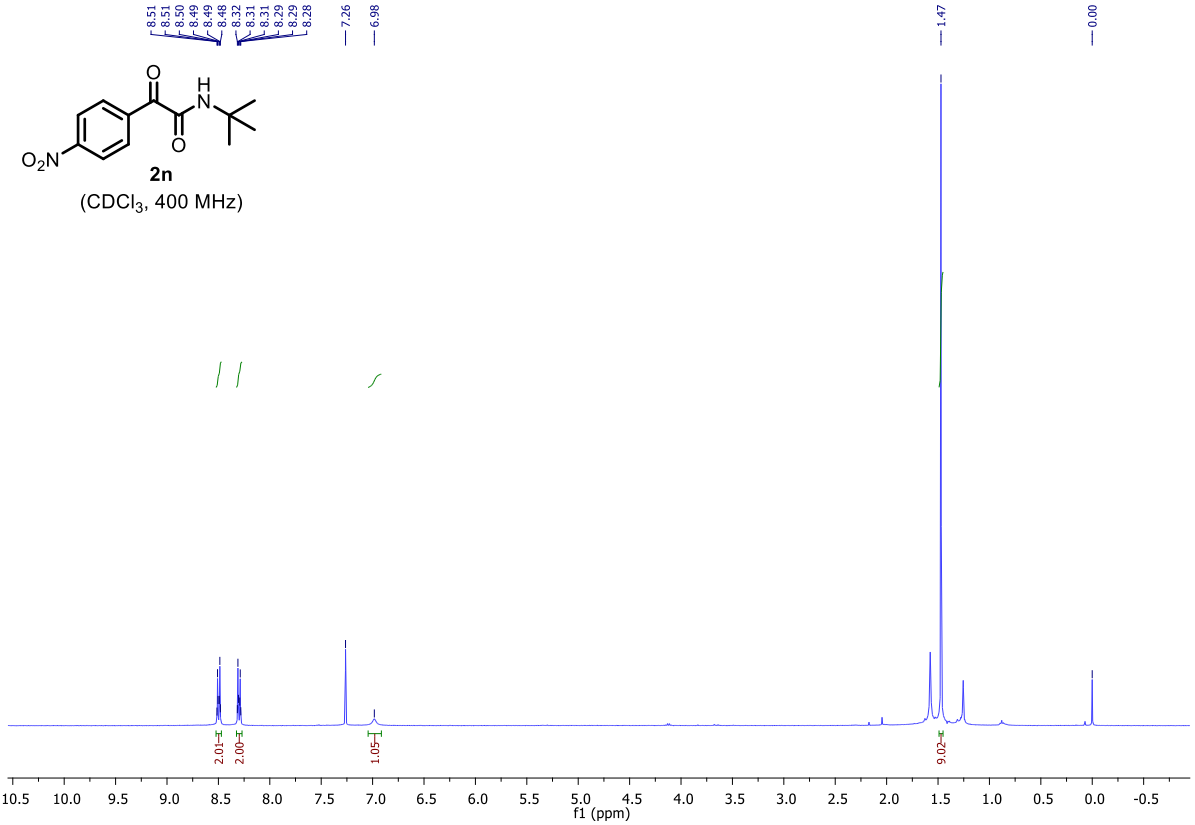


Figure S62: ^{13}C NMR of compound **2n**

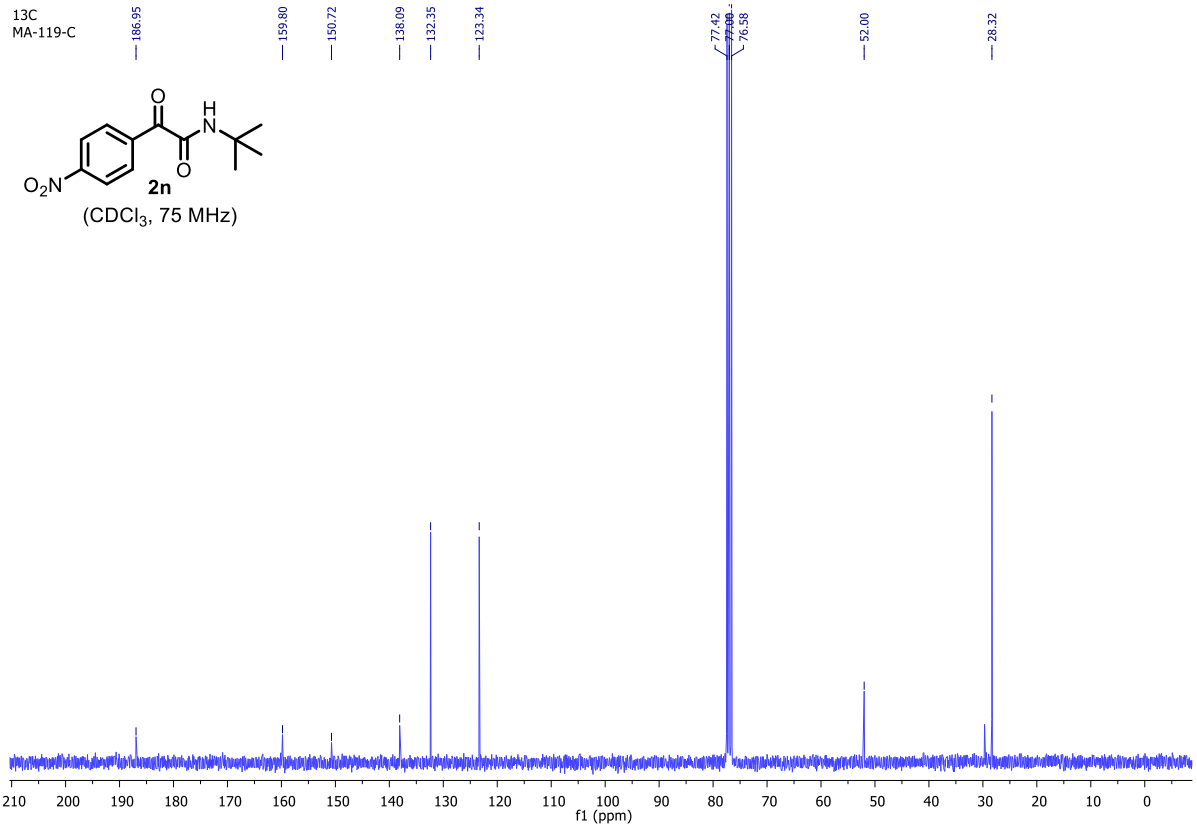


Figure S63: ^{1}H NMR of compound **2o**

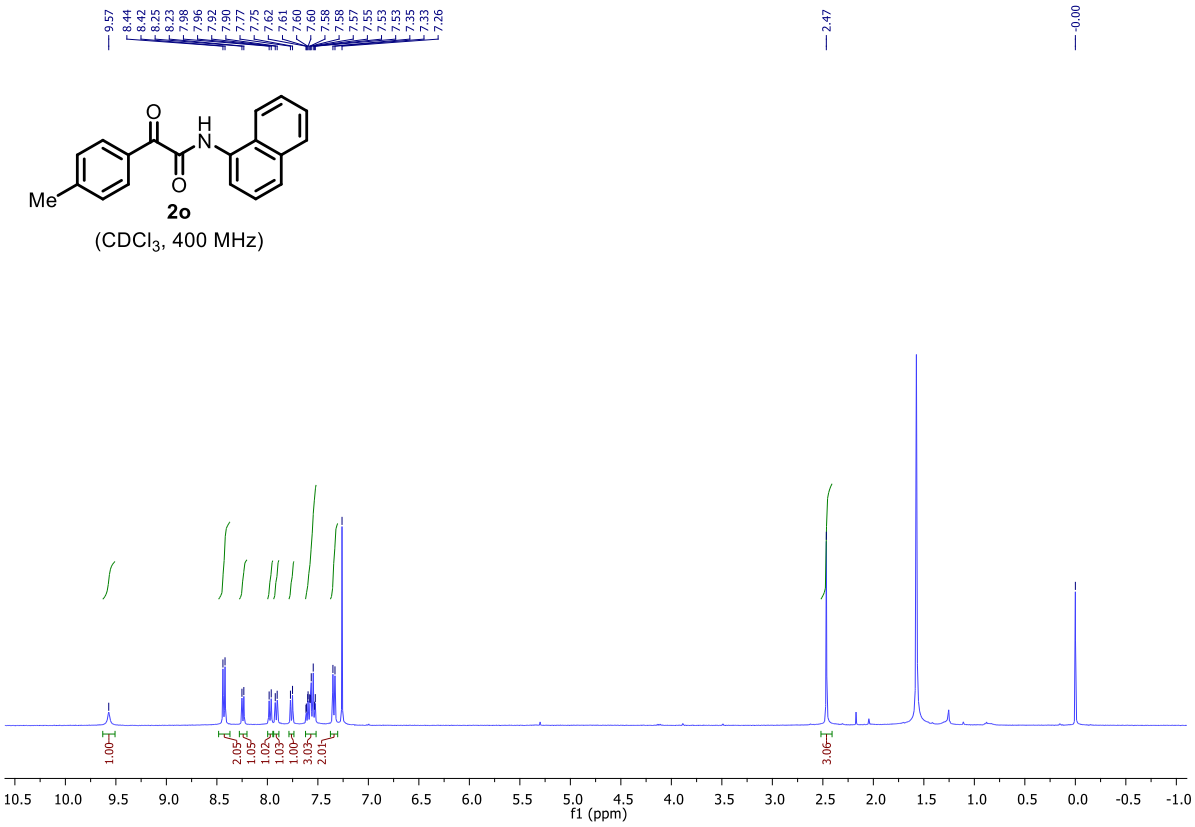


Figure S64: ^{13}C NMR of compound **2o**

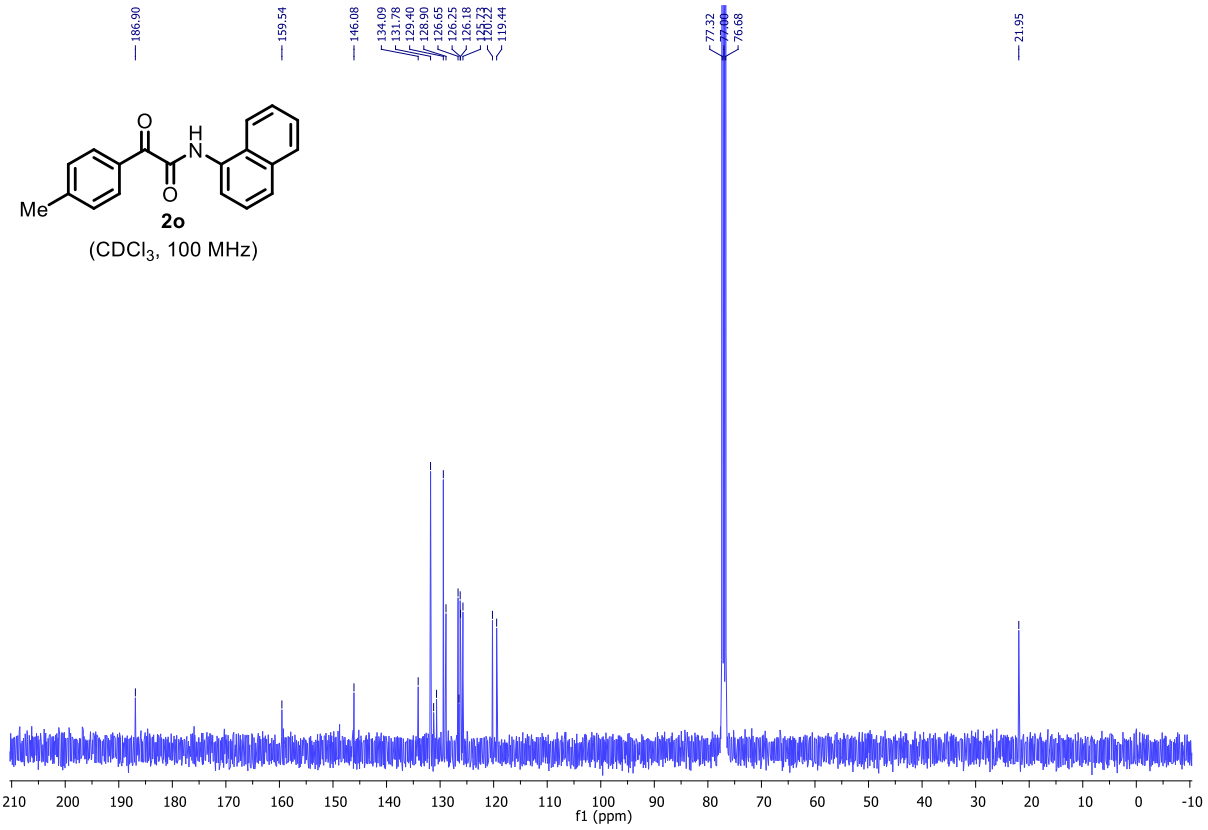


Figure S65: ^{1}H NMR of compound **2p**

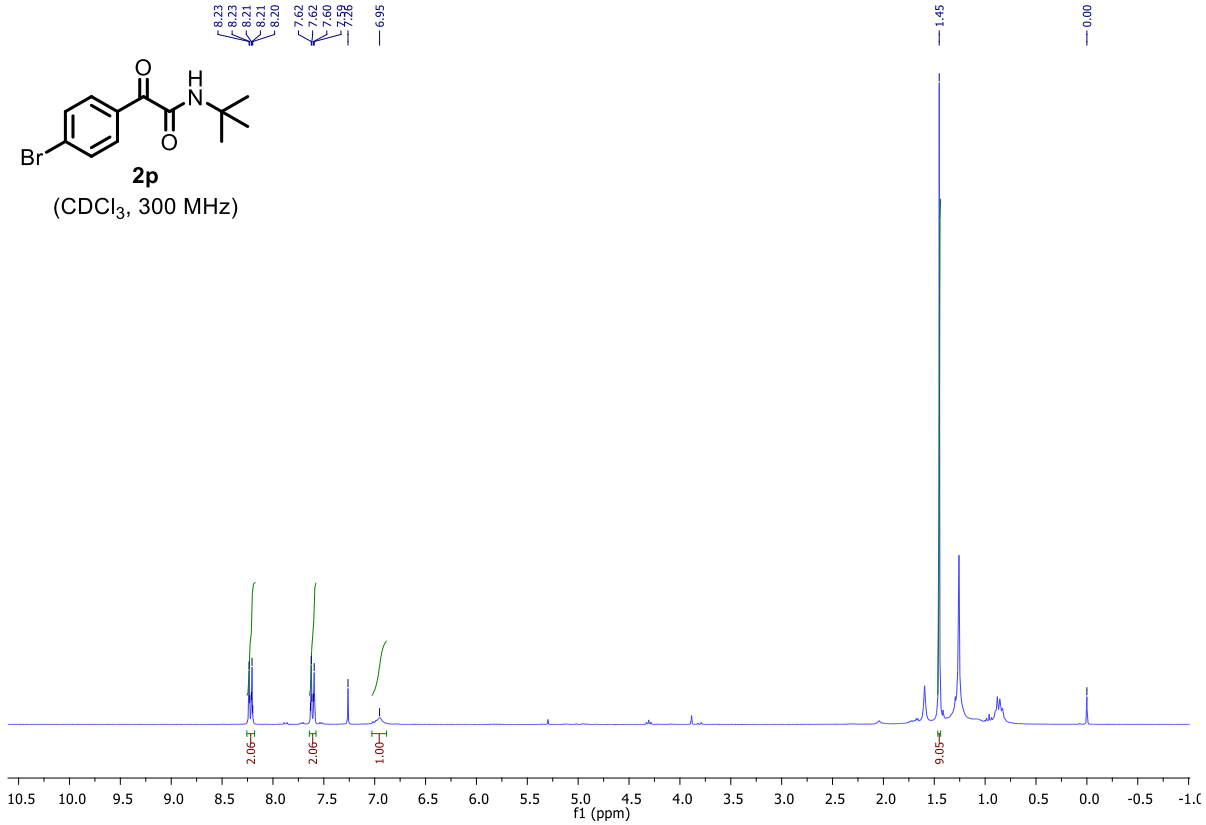


Figure S66: ^{13}C NMR of compound **2p**

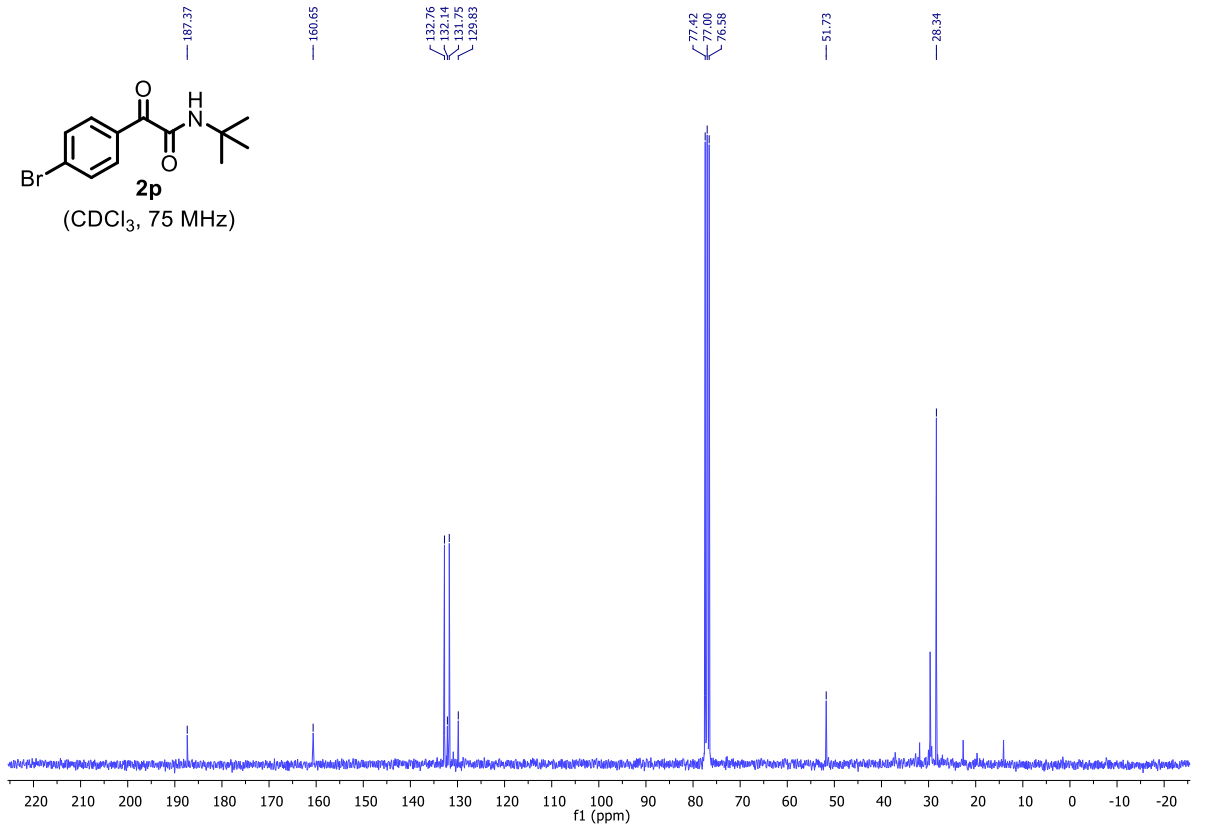


Figure S67: ^{1}H NMR of compound **2q**

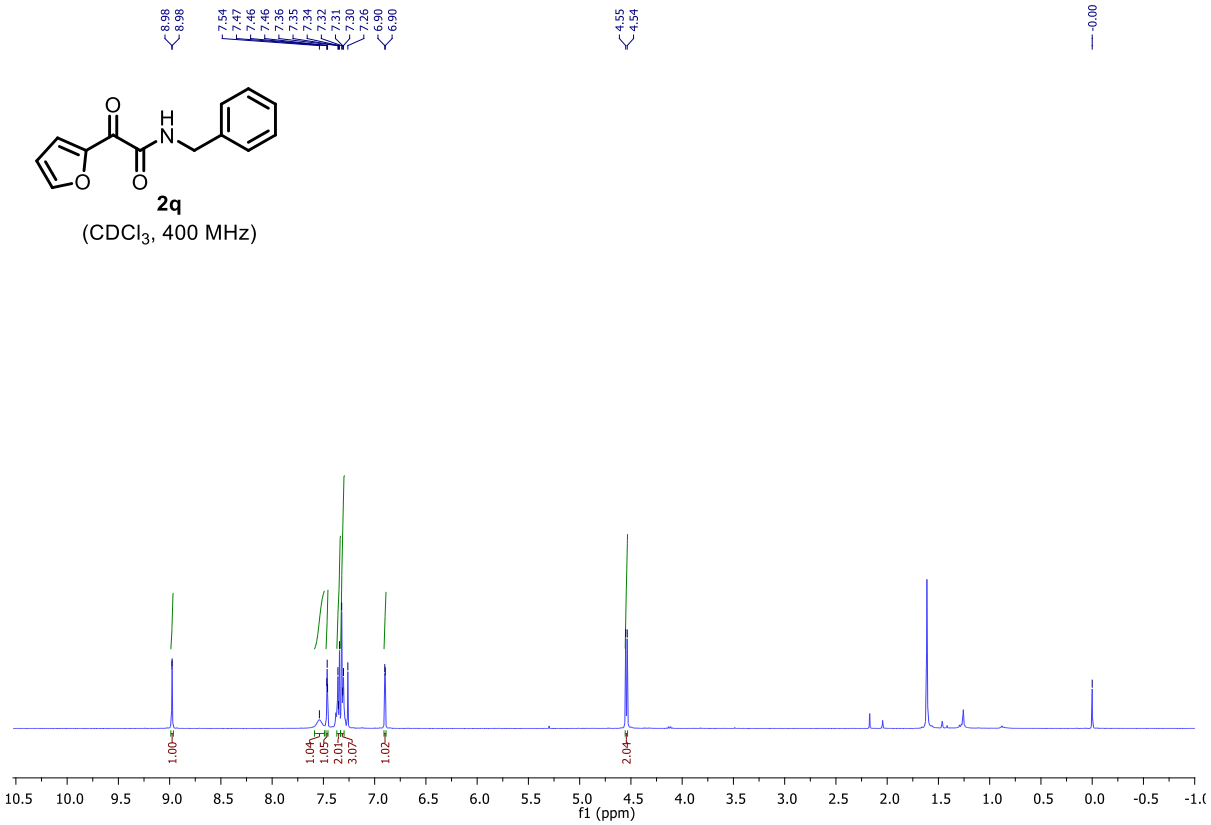


Figure S68: ^{13}C NMR of compound **2q**

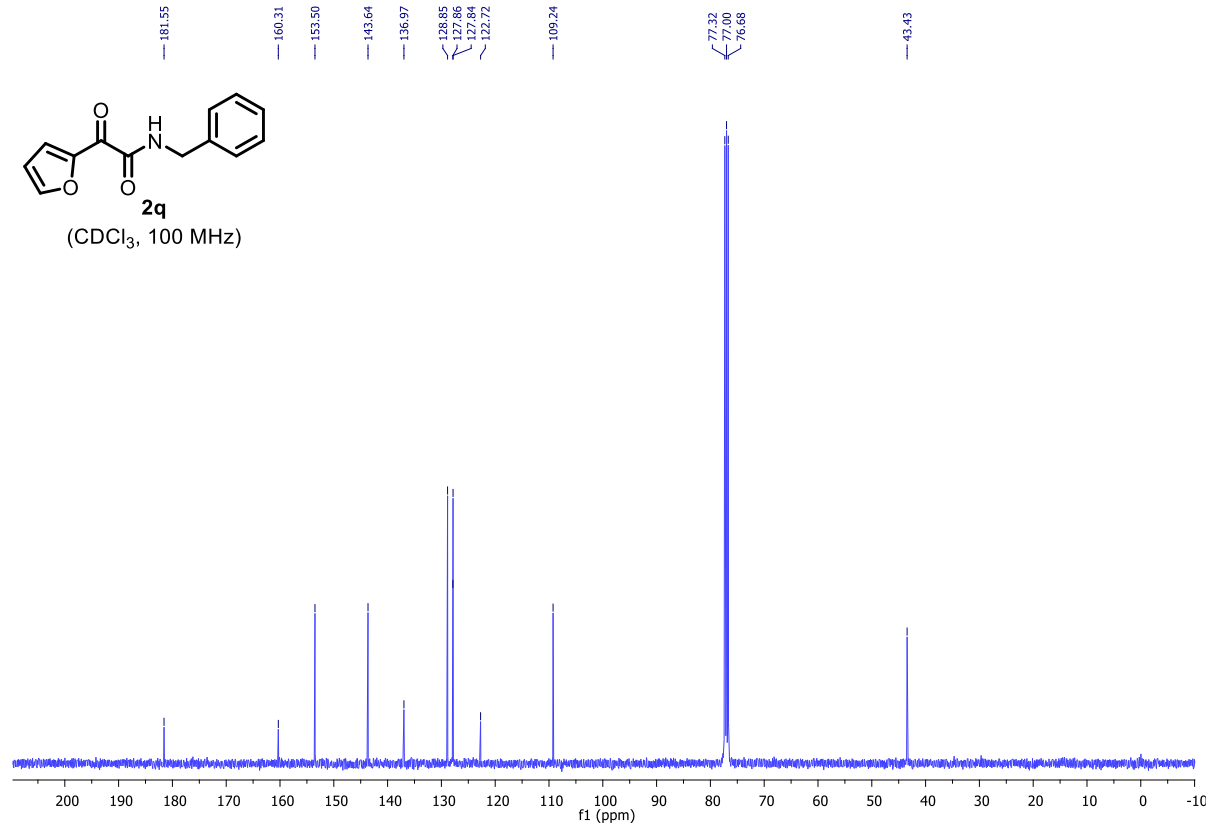


Figure S69: ^{1}H NMR of compound **2r**

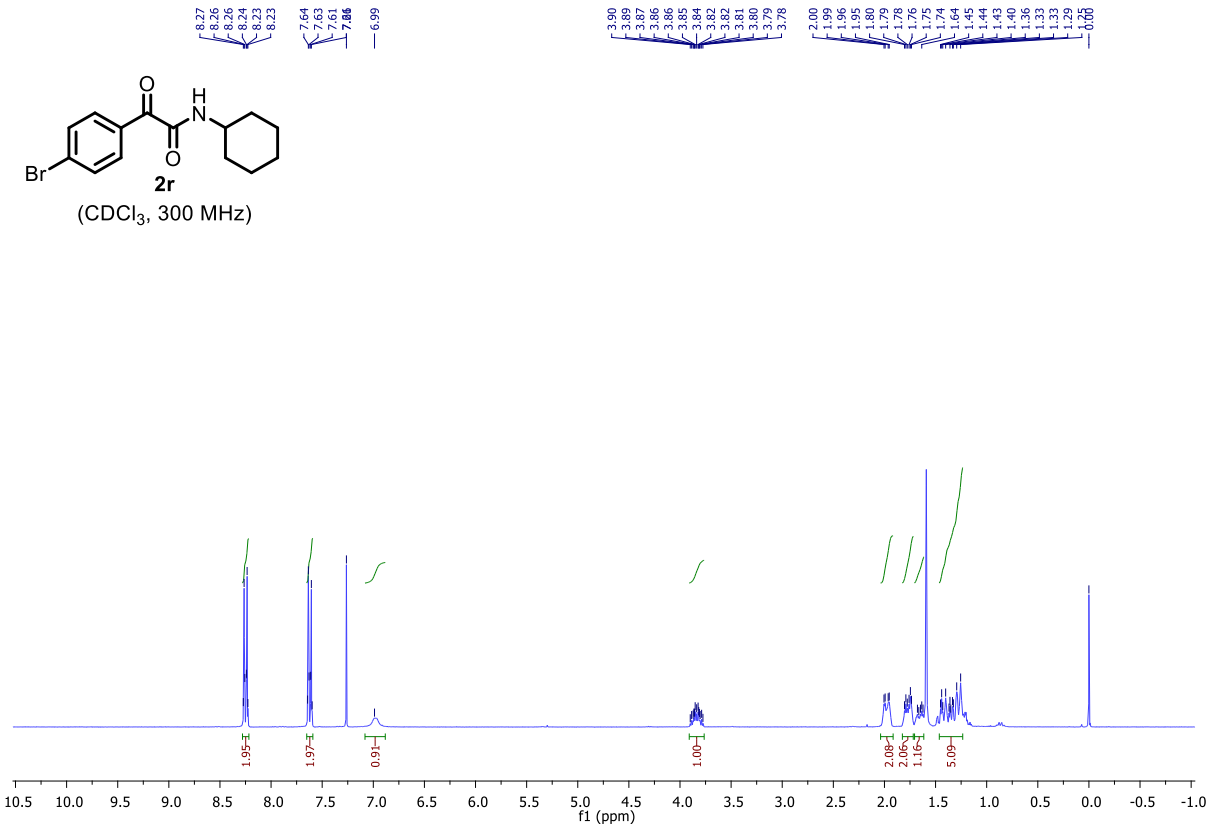


Figure S70: ^{13}C NMR of compound **2r**

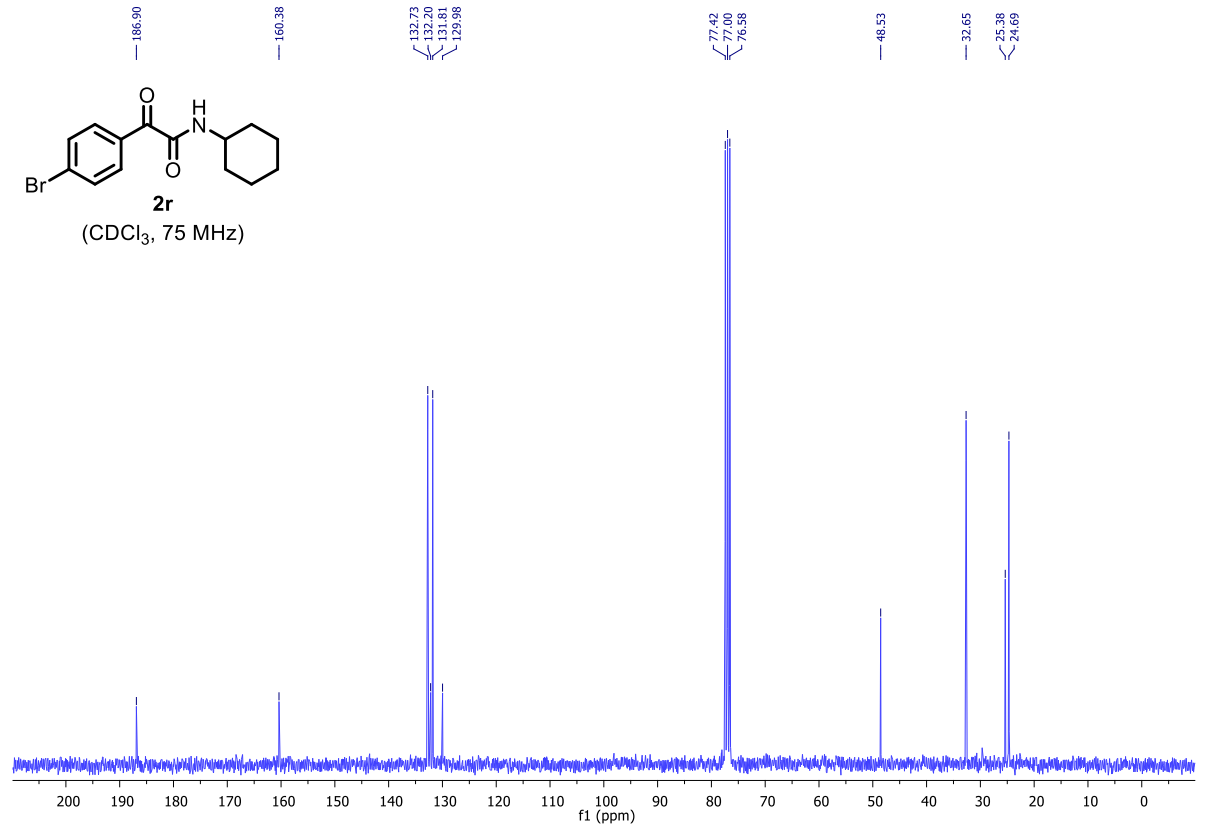


Figure S71: ^{1}H NMR of compound **2s**

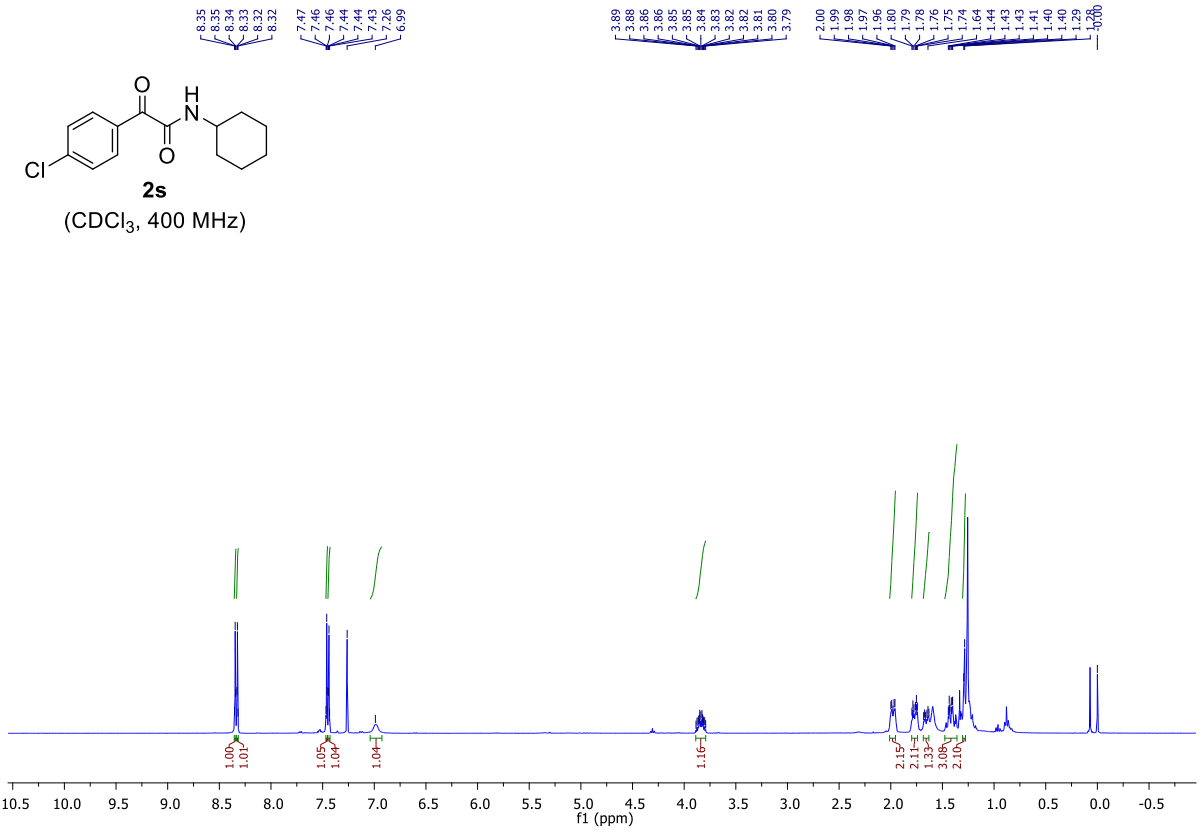


Figure S72: ^{13}C NMR of compound **2s**

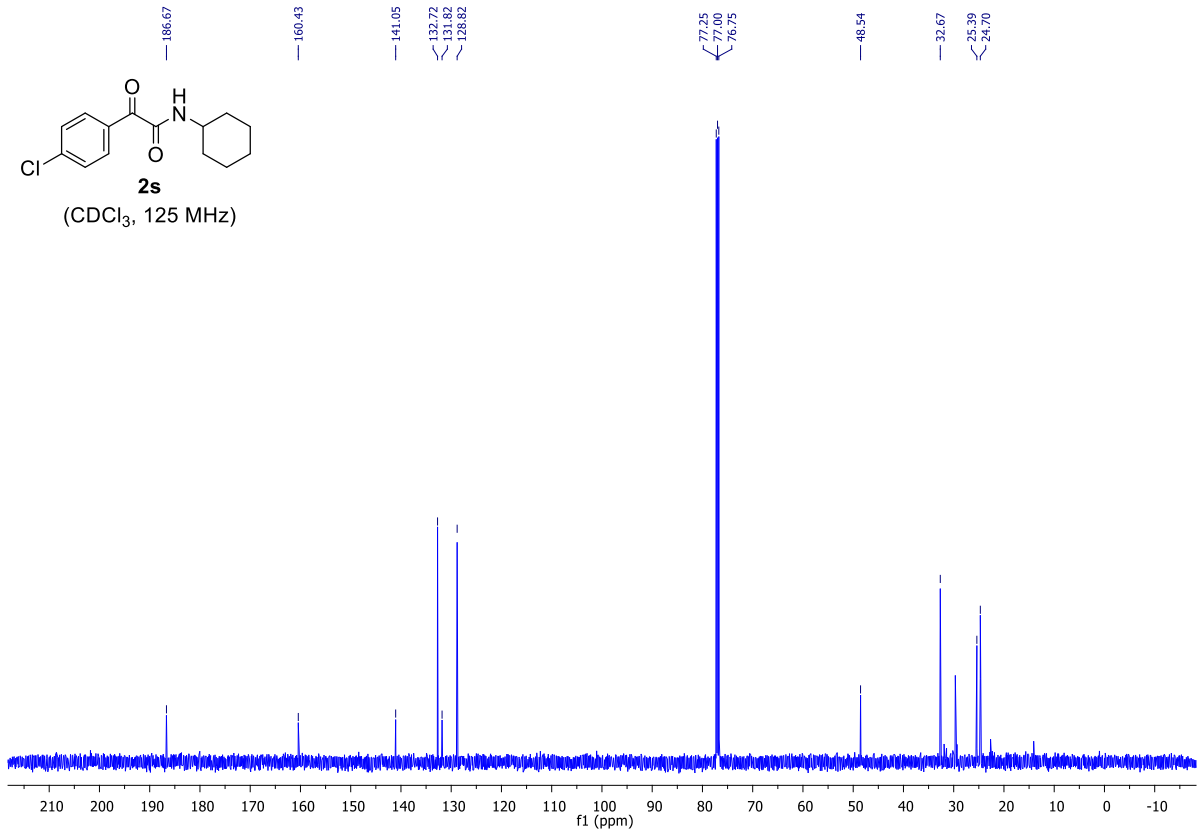


Figure S73: ^{1}H NMR of compound **2t**

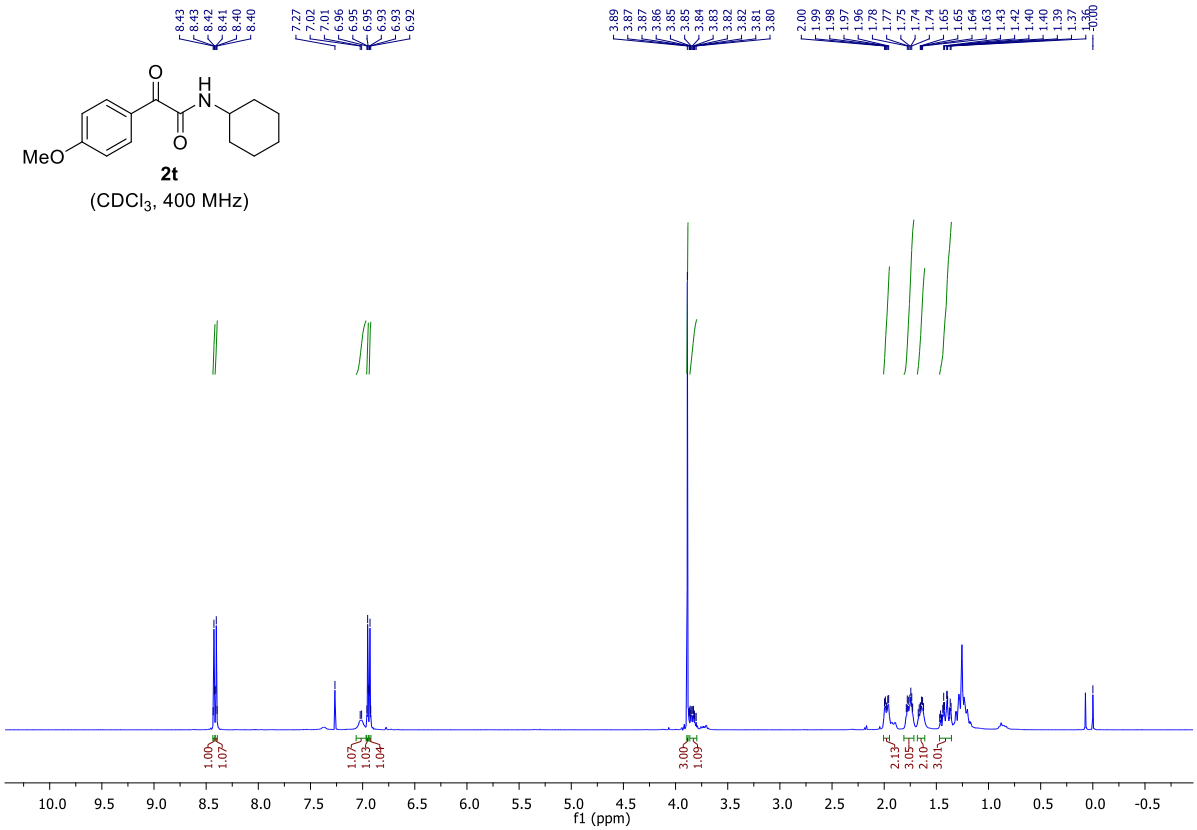


Figure S74: ^{13}C NMR of compound **2t**

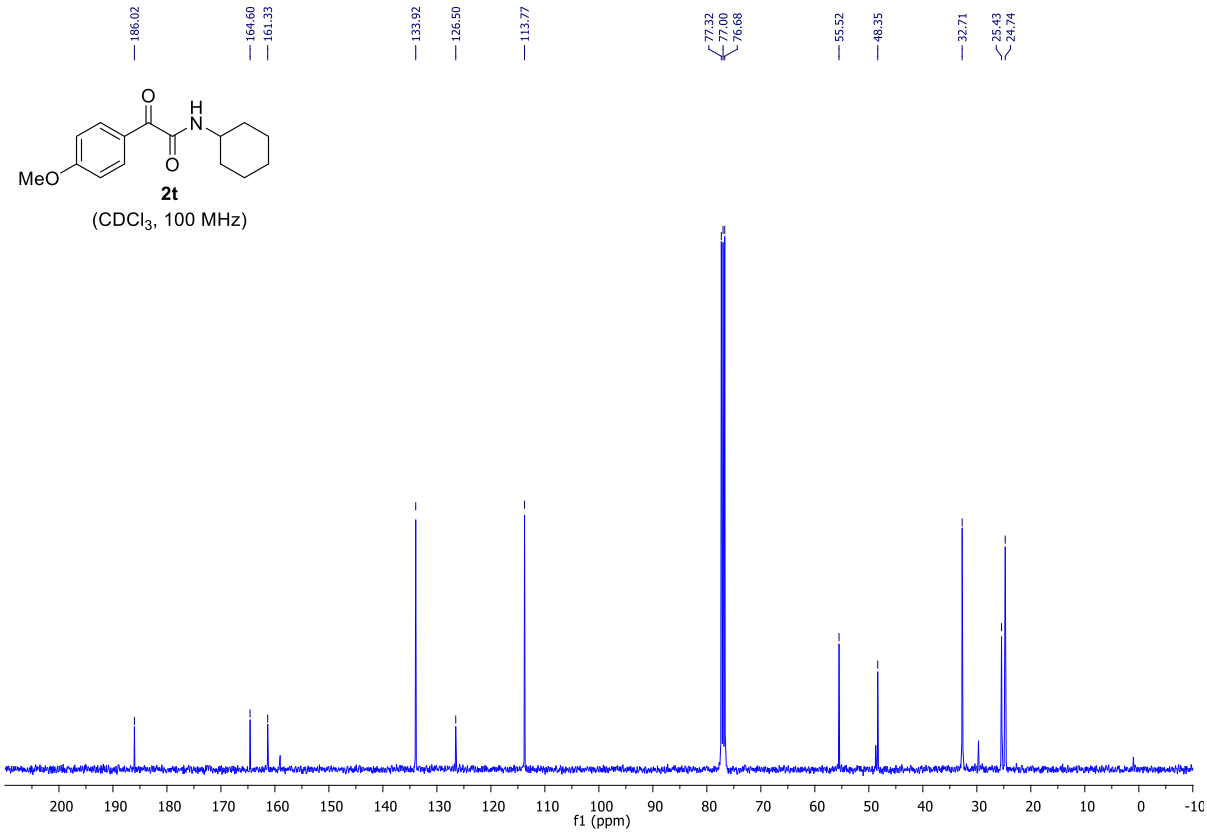


Figure S75: ^{1}H NMR of compound **2u**

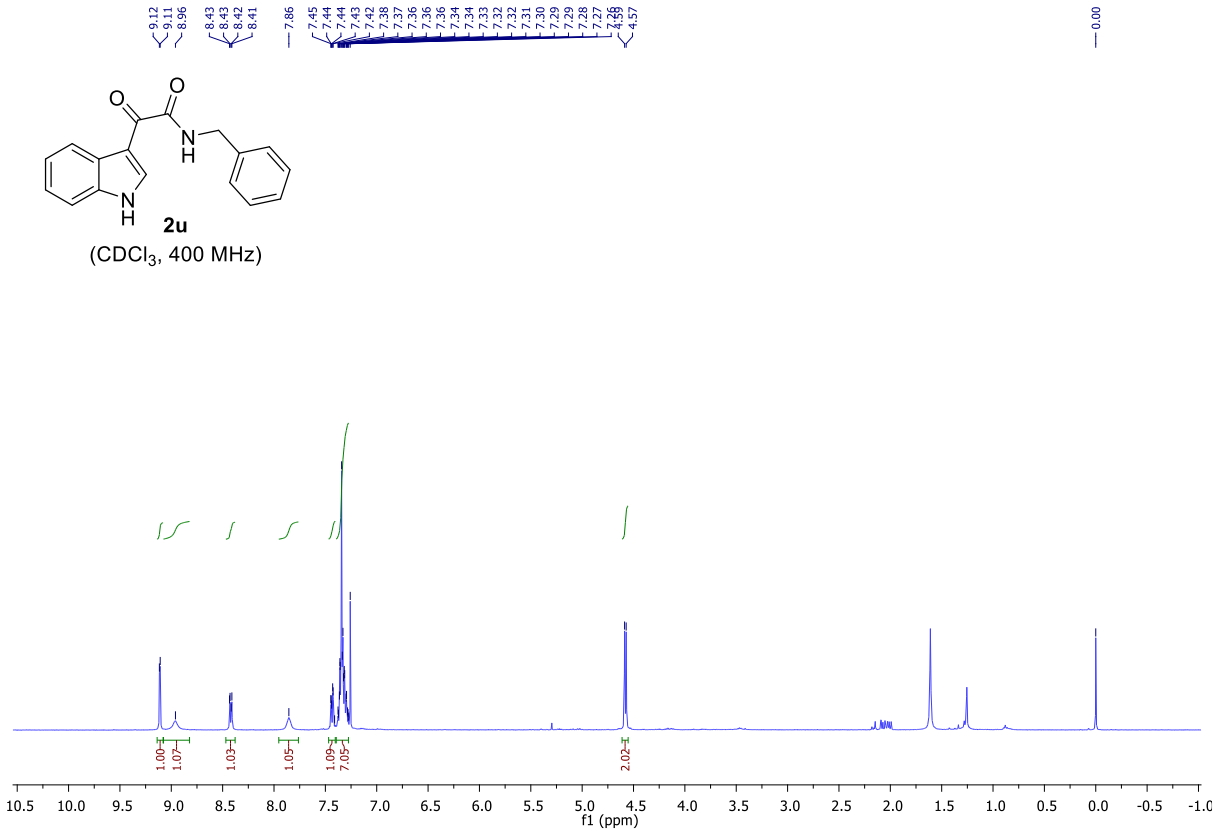


Figure S76: ^{13}C NMR of compound **2u**

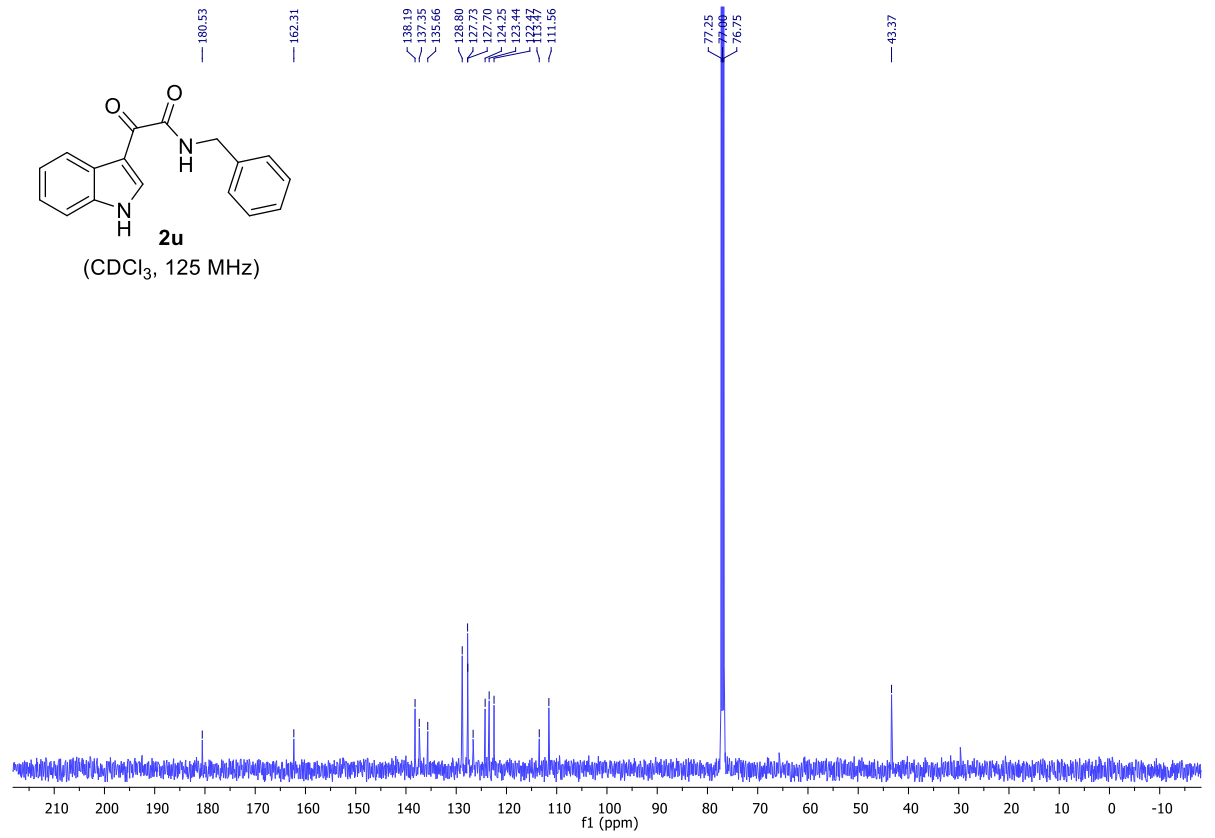


Figure S77: ^{1}H NMR of compound **2v**

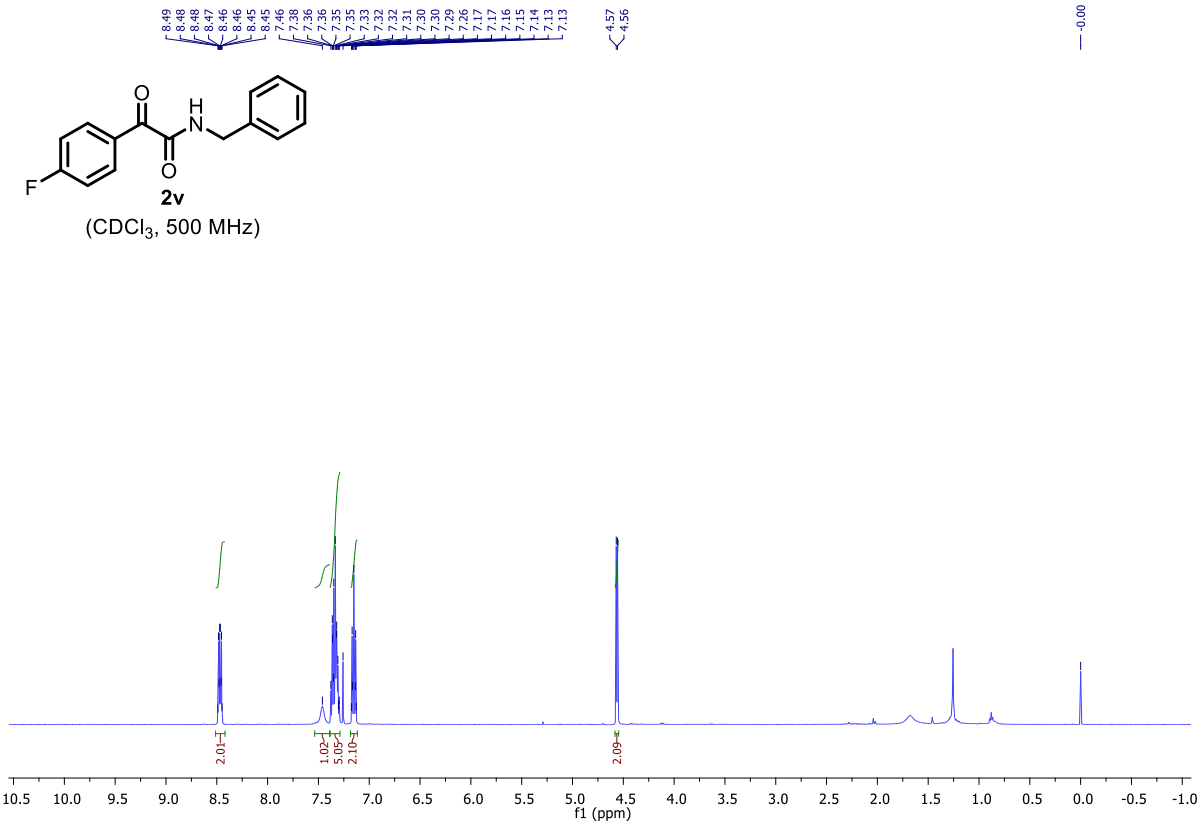


Figure S78: ^{13}C NMR of compound **2v**

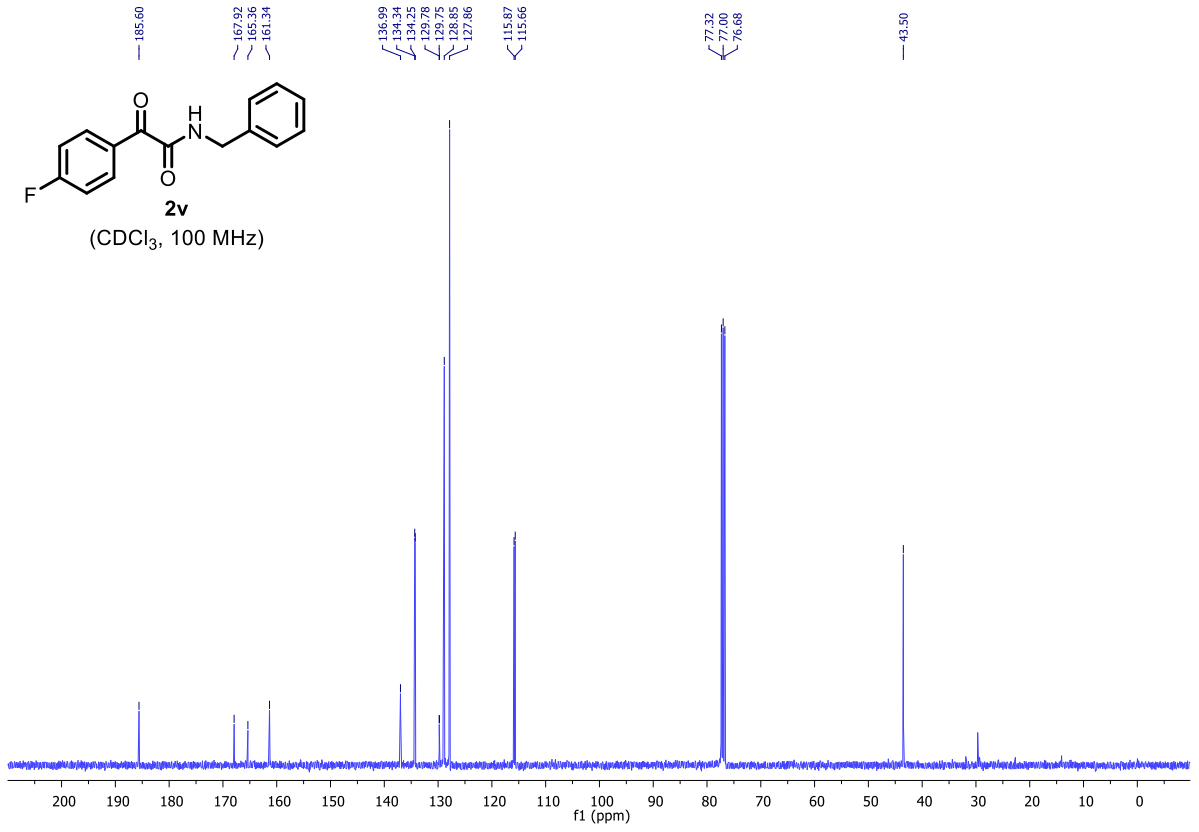


Figure S79: ^{1}H NMR of compound **2w**

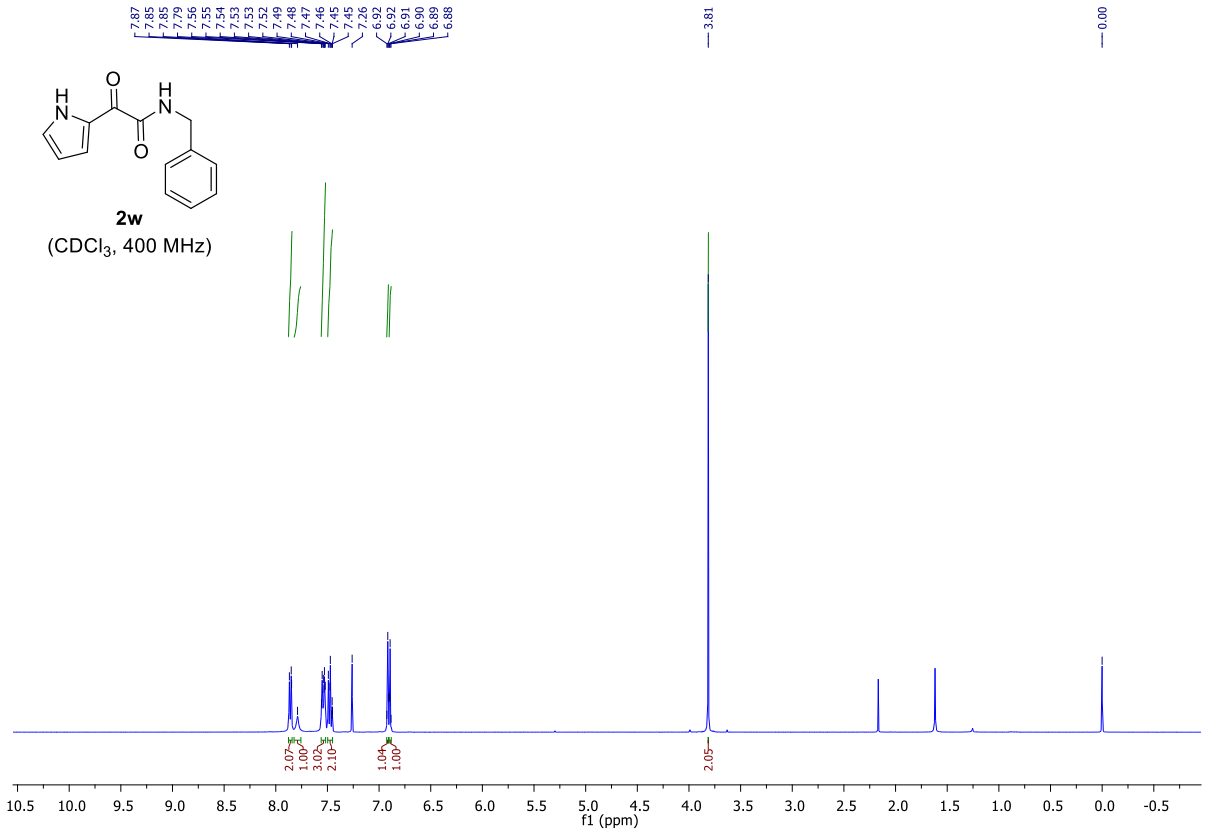


Figure S80: ^{13}C NMR of compound **2w**

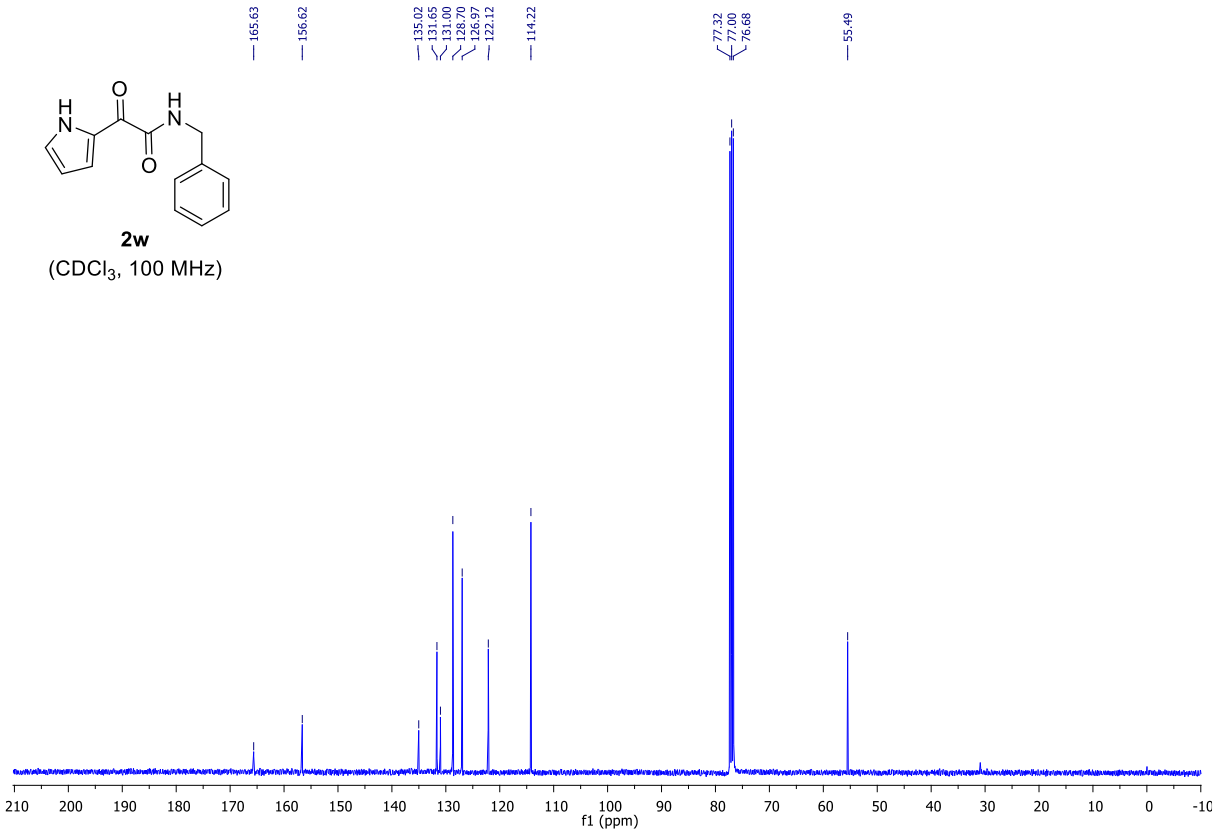


Figure S81: ^{1}H NMR of compound **2x**

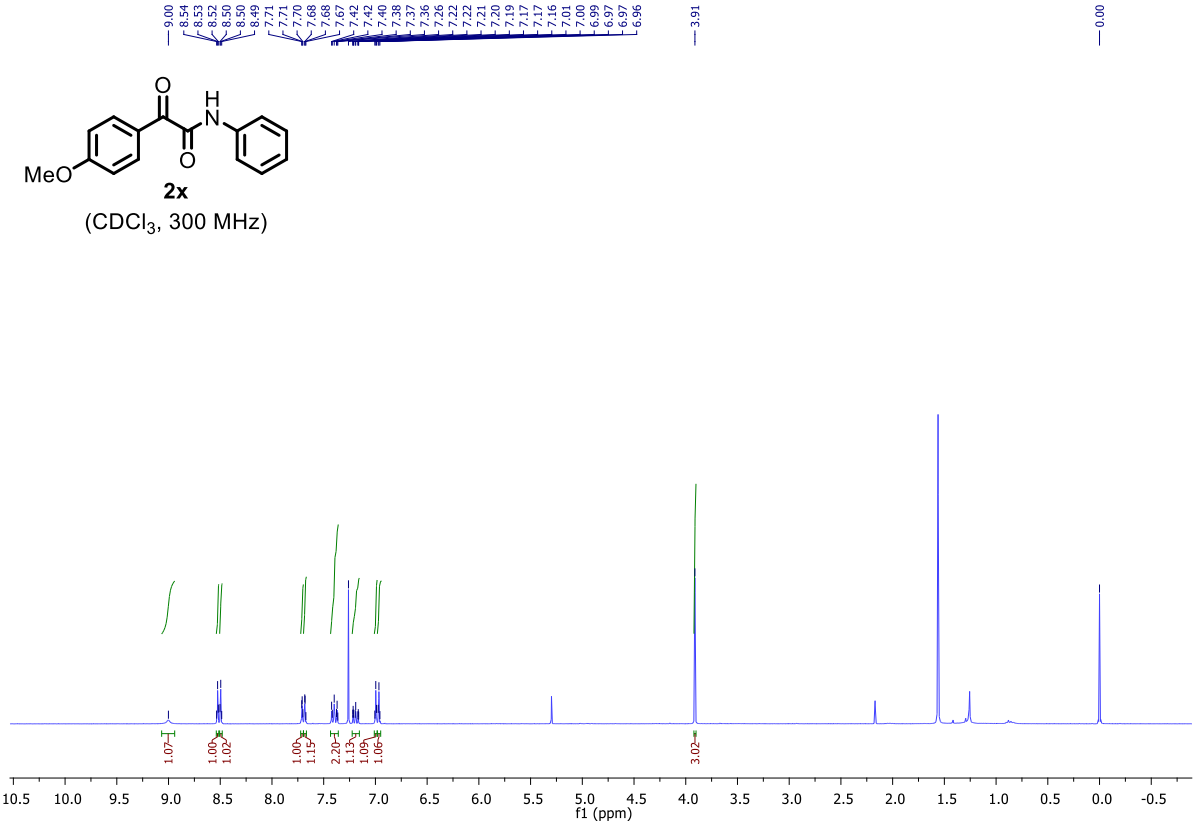


Figure S82: ^{13}C NMR of compound **2x**

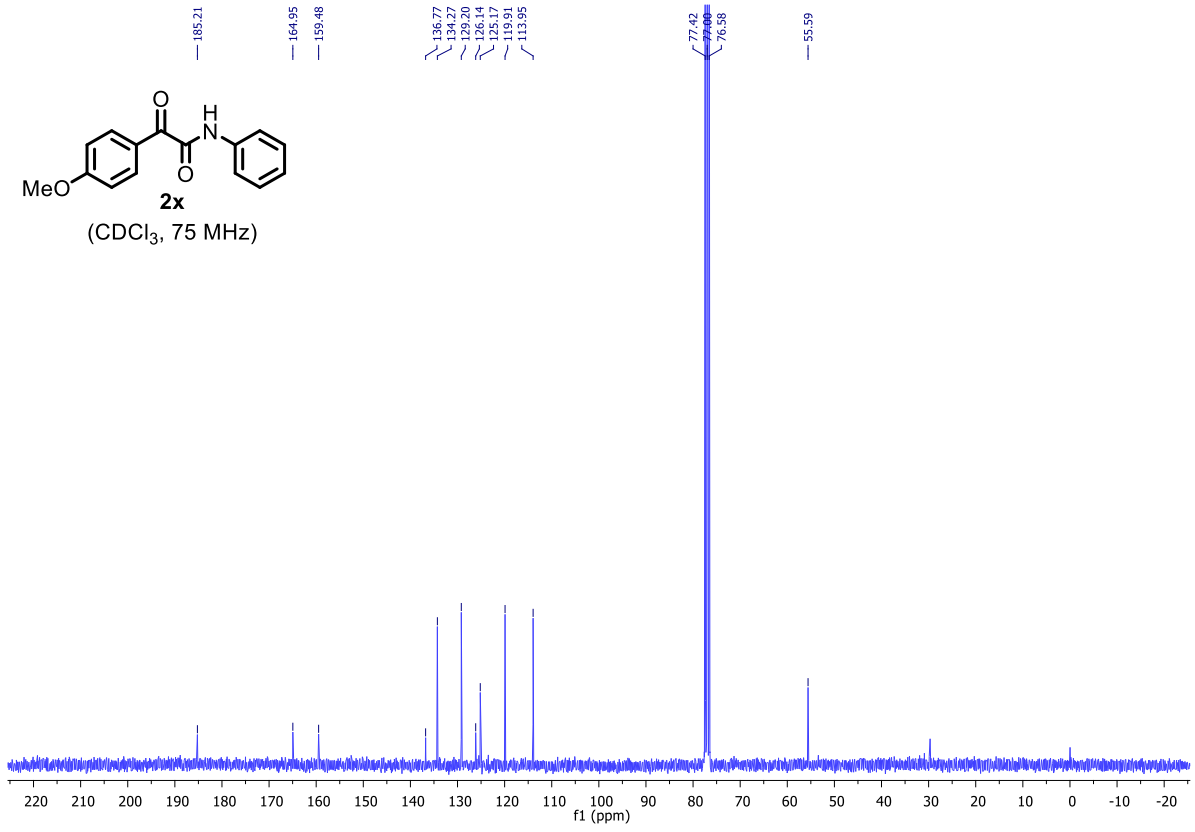


Figure S83: ^{1}H NMR of compound **2y**

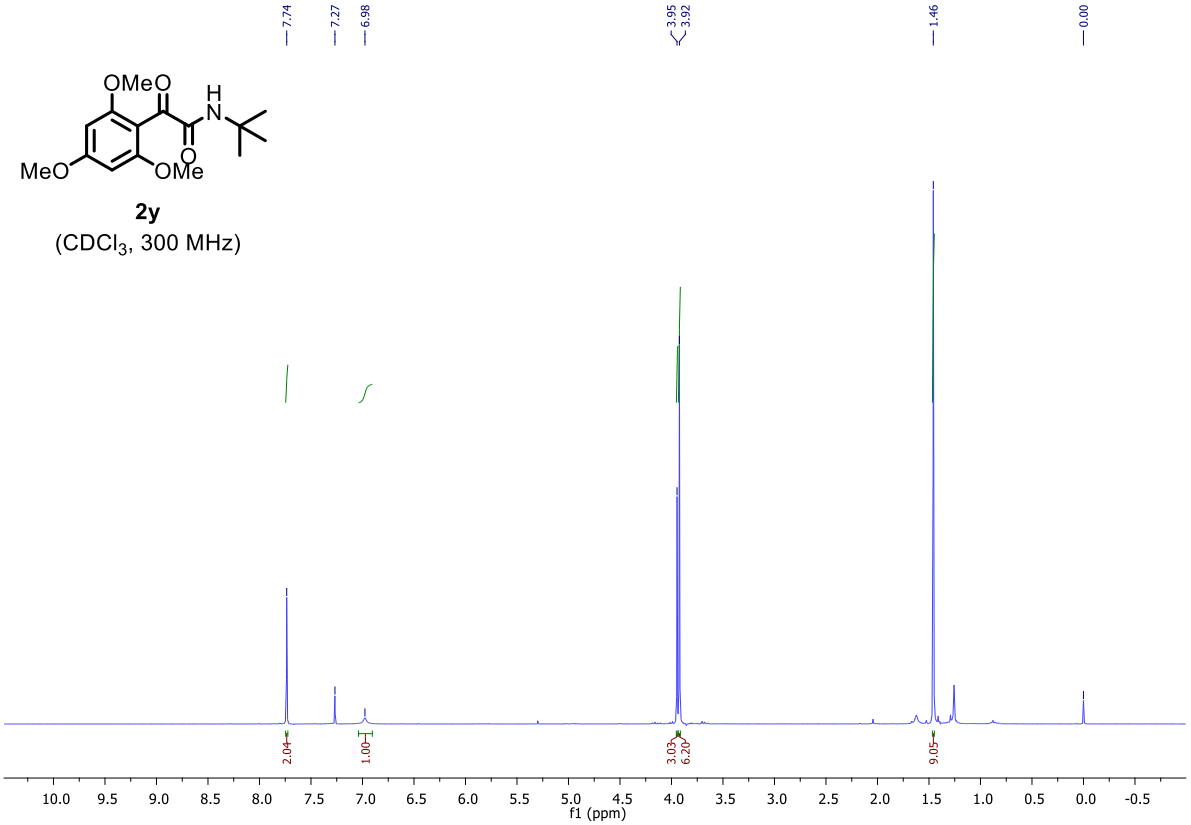


Figure S84: ^{13}C NMR of compound **2y**

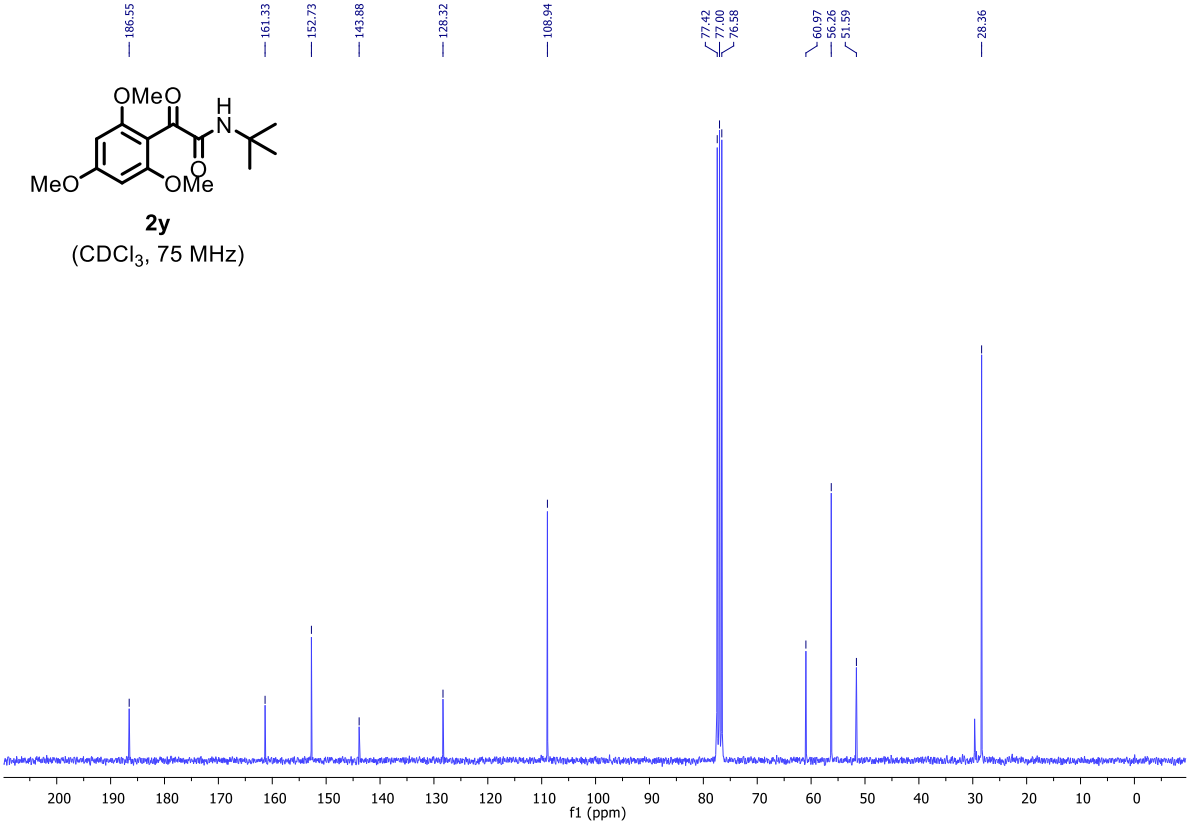


Figure S85: ^{1}H NMR of compound **2z**

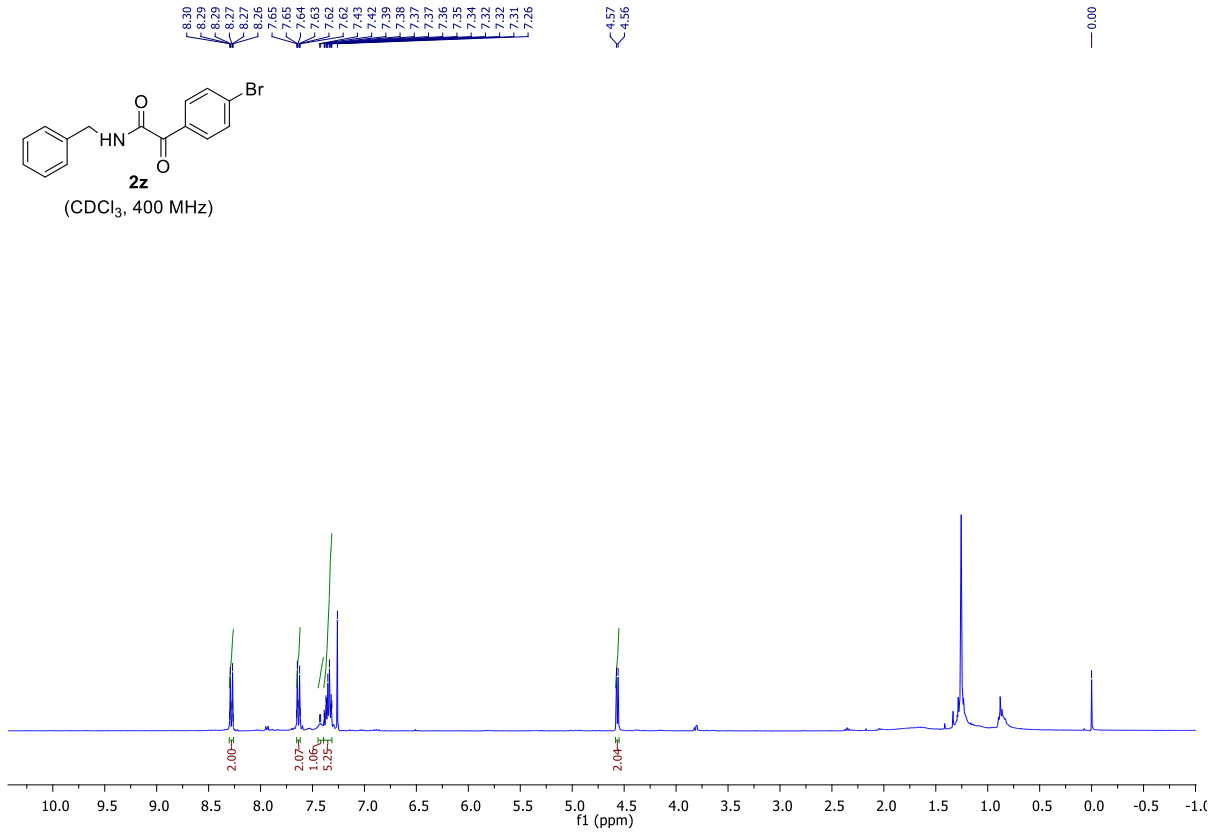


Figure S86: ^{13}C NMR of compound **2z**

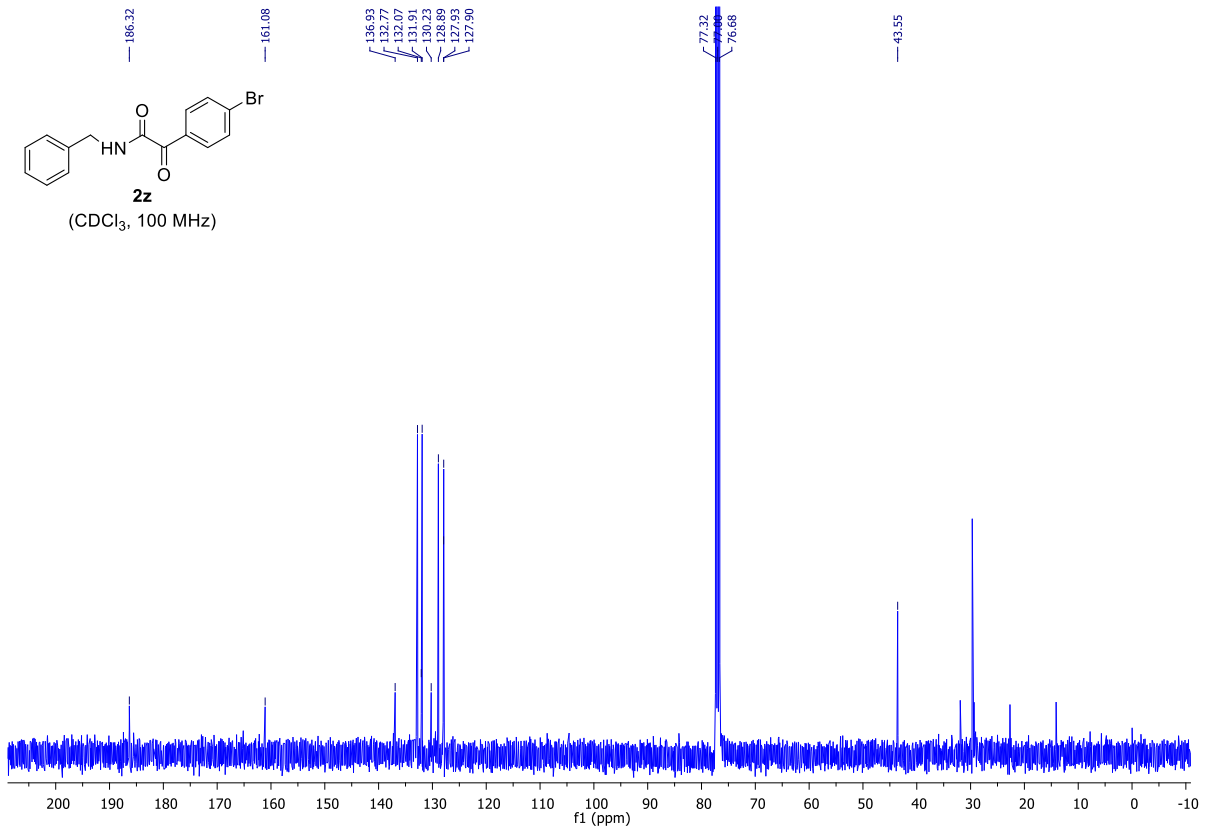


Figure S87: ^{1}H NMR of compound **2aa**

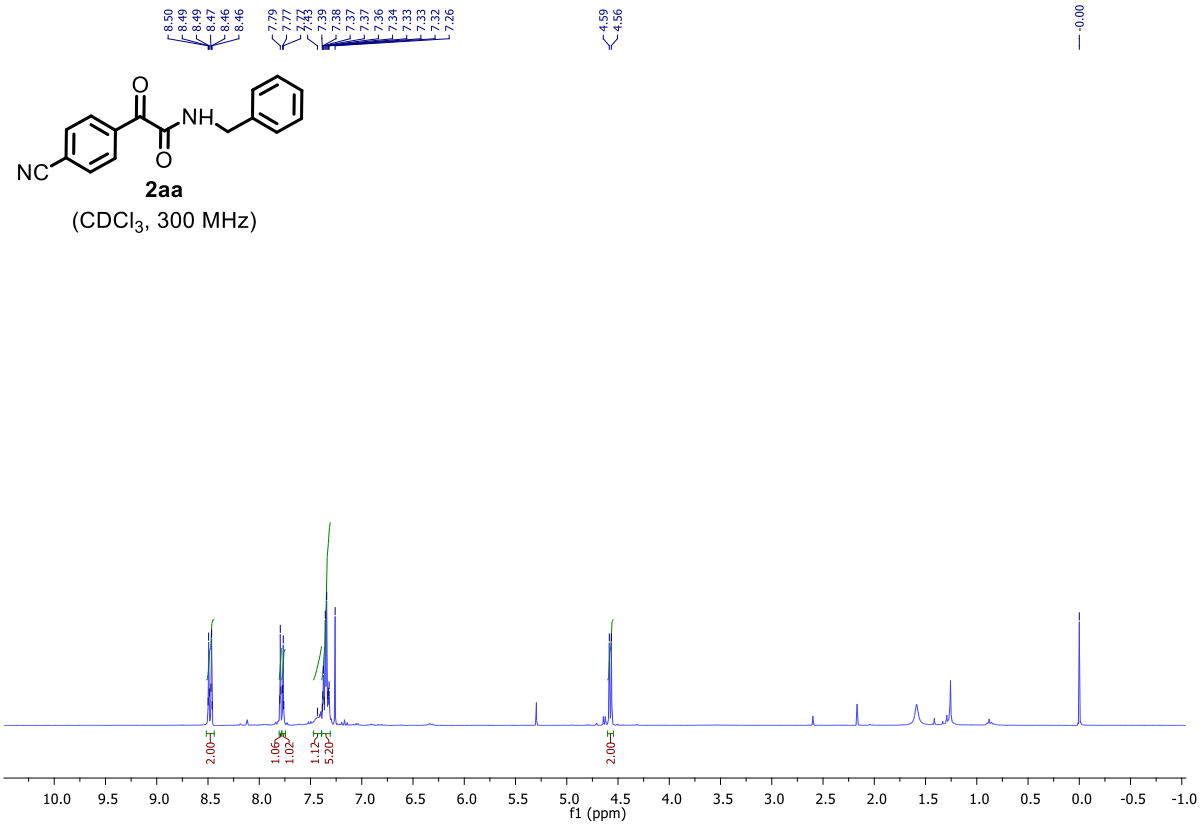


Figure S88: ^{13}C NMR of compound **2aa**

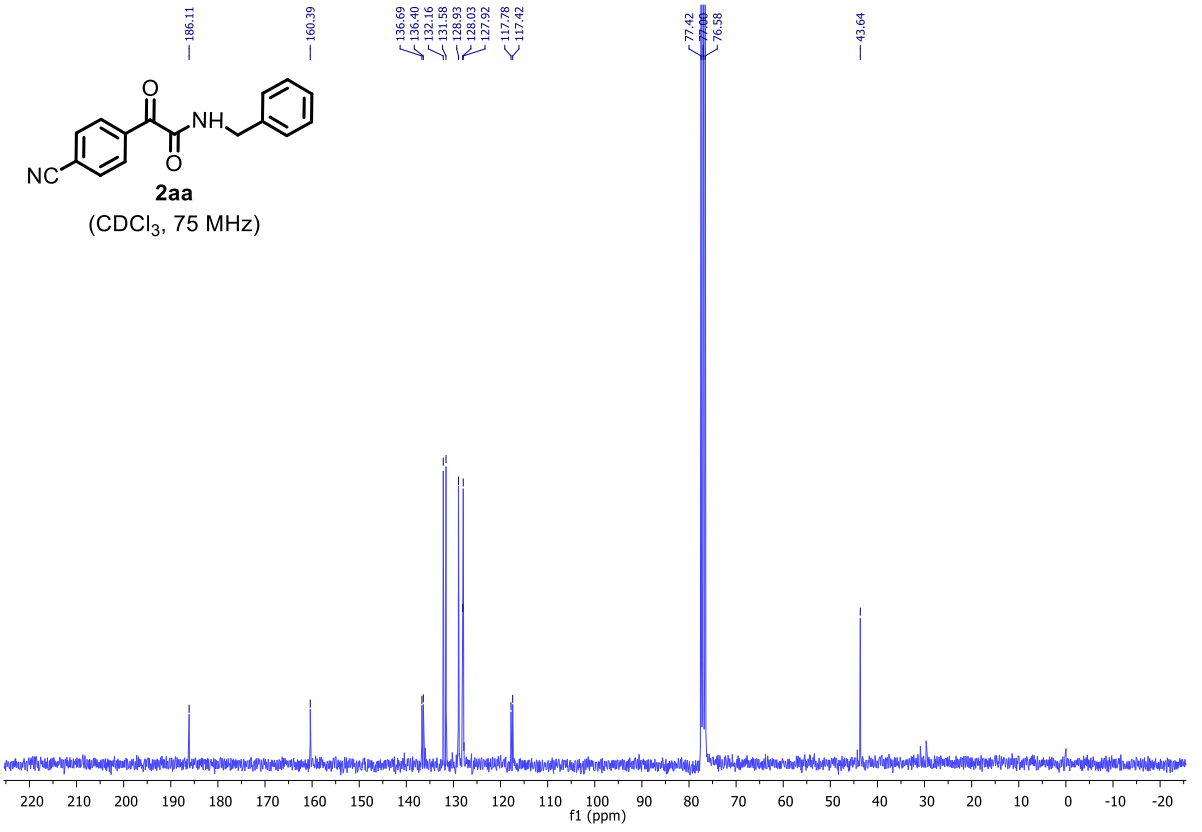


Figure S89: ^{1}H NMR of compound **2ab**

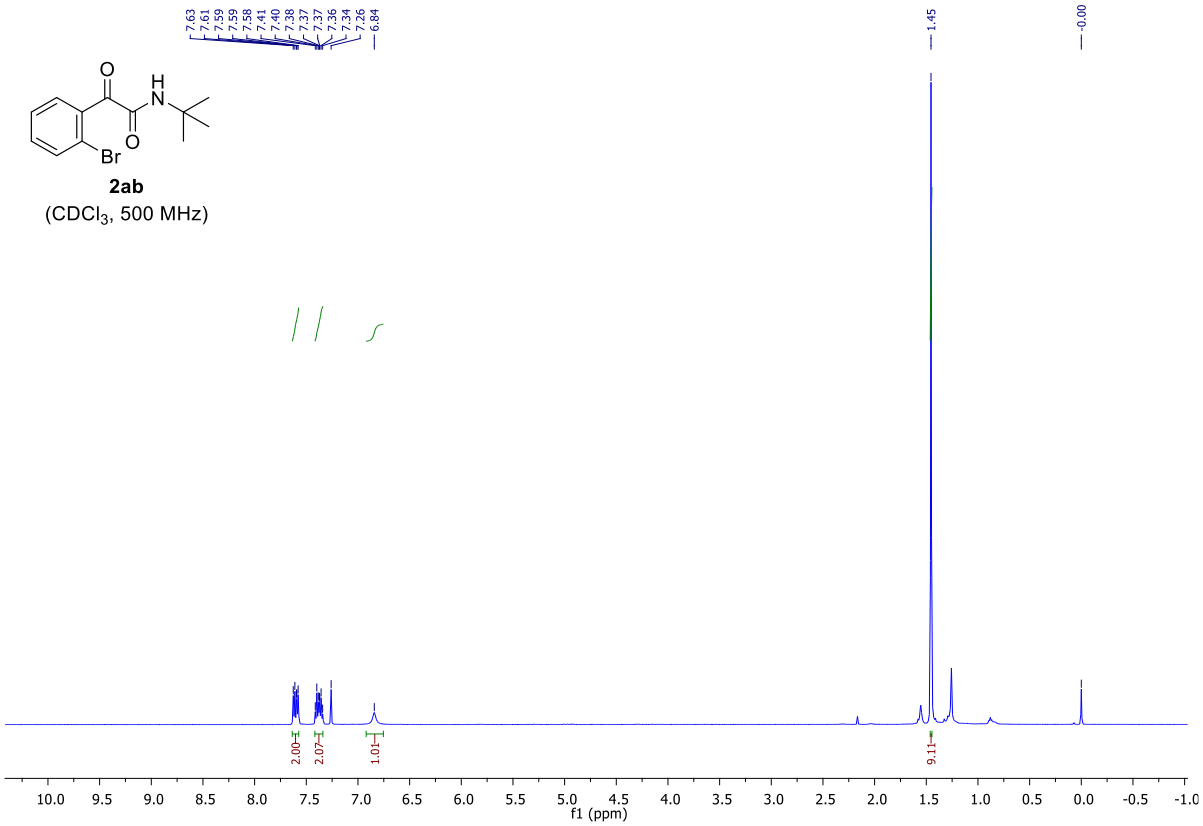


Figure S90: ^{13}C NMR of compound **2ab**

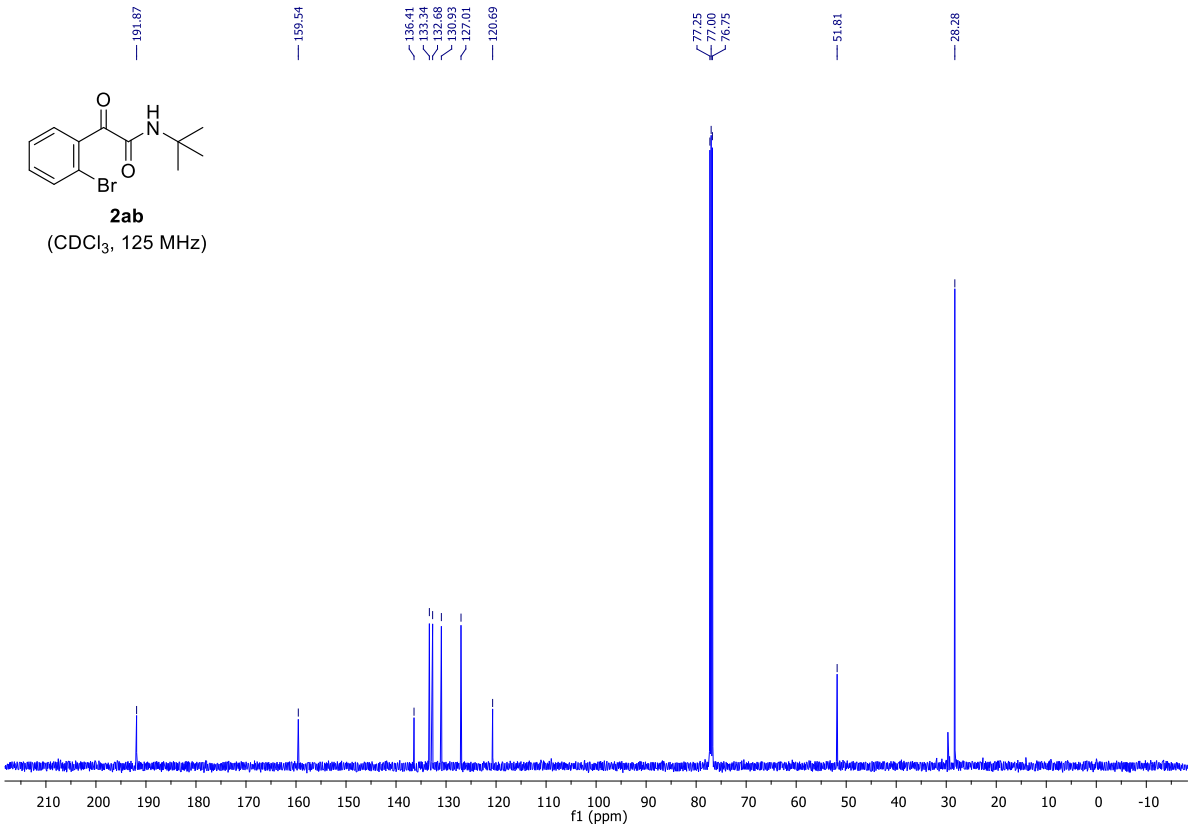


Figure S91: ^{1}H NMR of compound **2ac**

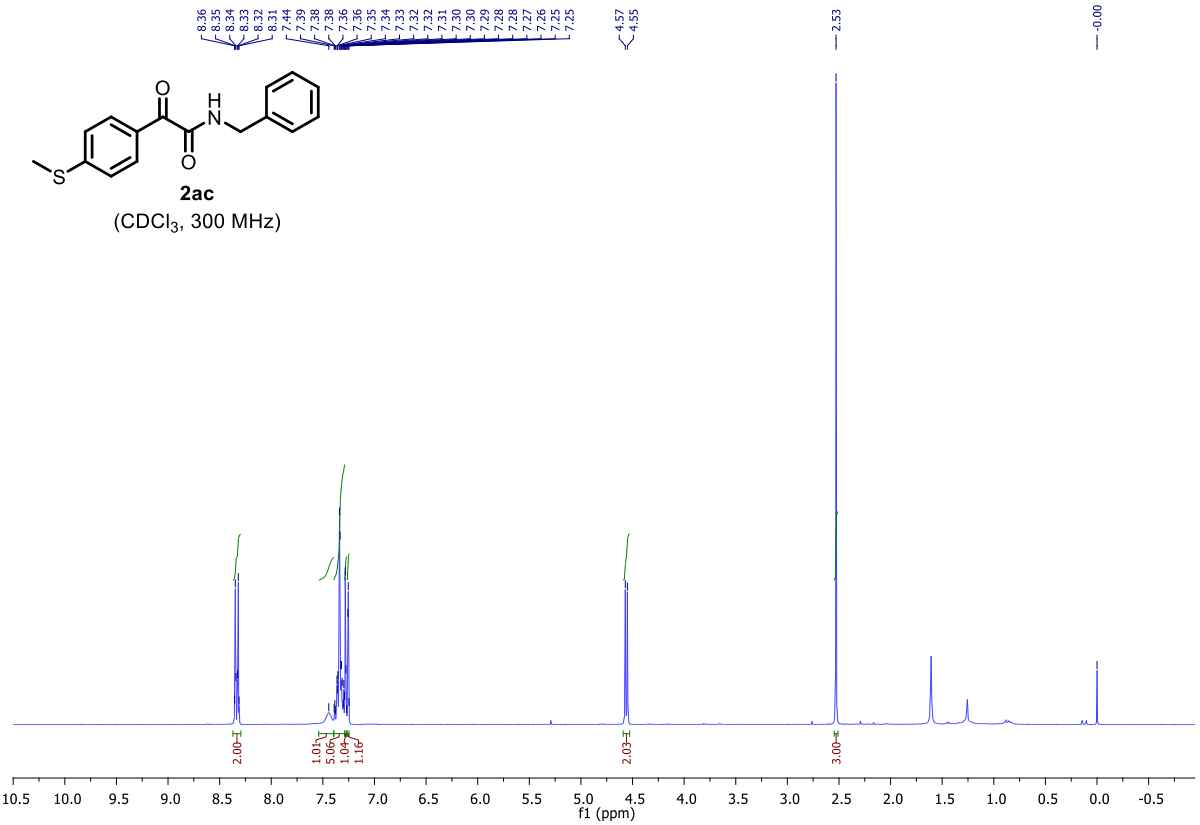


Figure S92: ^{13}C NMR of compound **2ac**

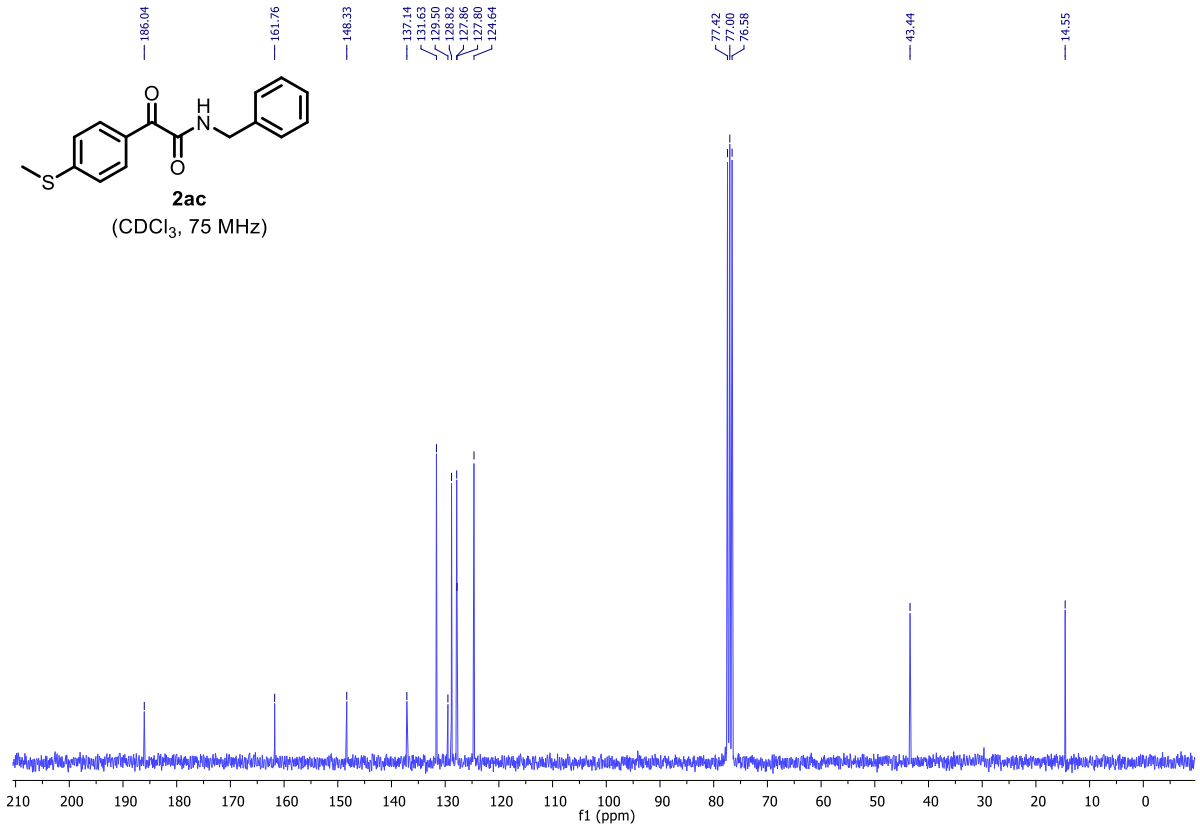


Figure S93: ^{1}H NMR of compound **2ad**

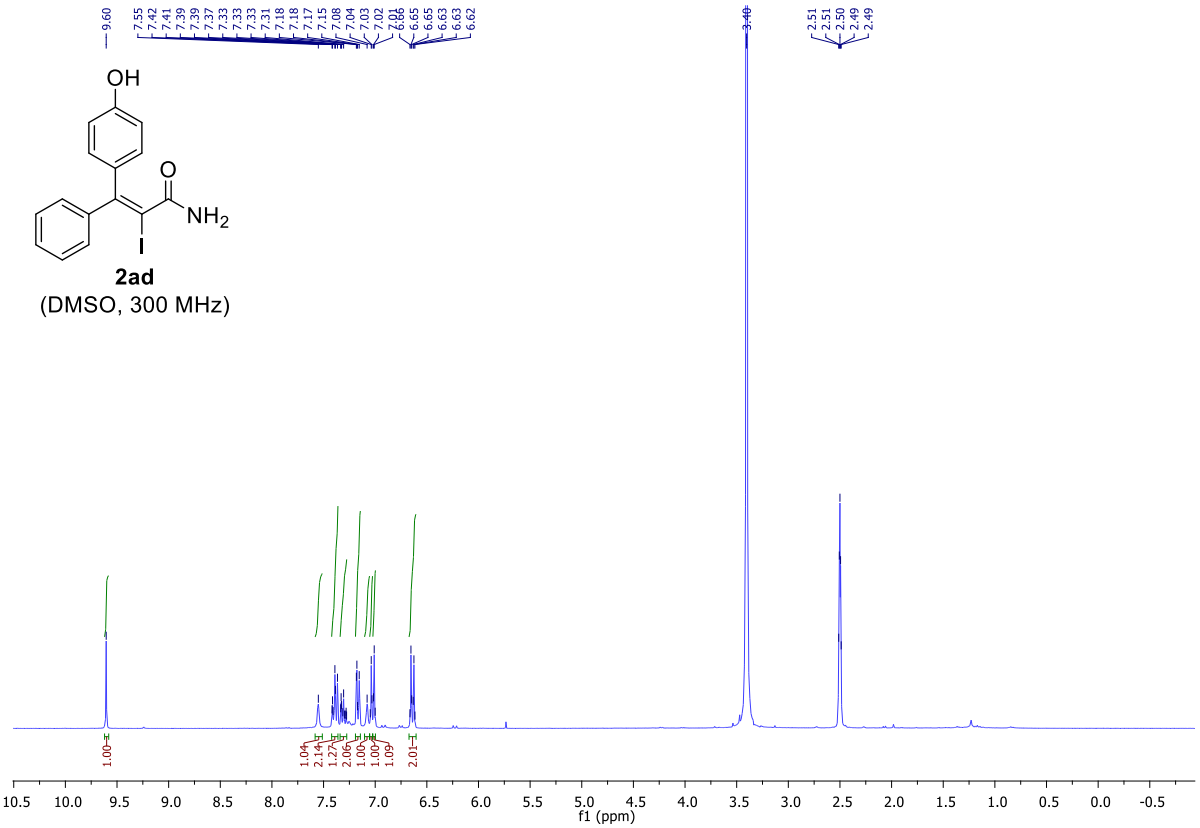


Figure S94: ^{13}C NMR of compound **2ad**

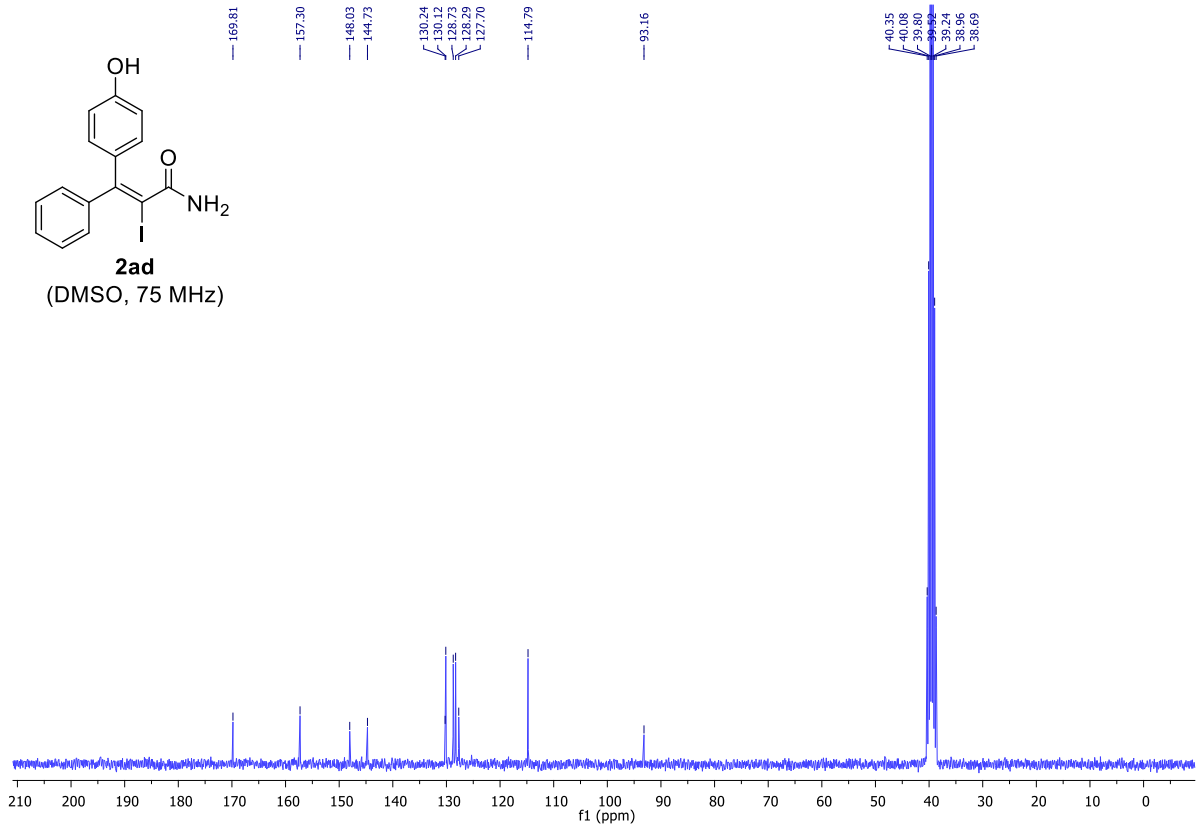


Figure S95: ^{1}H NMR of compound **2ae**

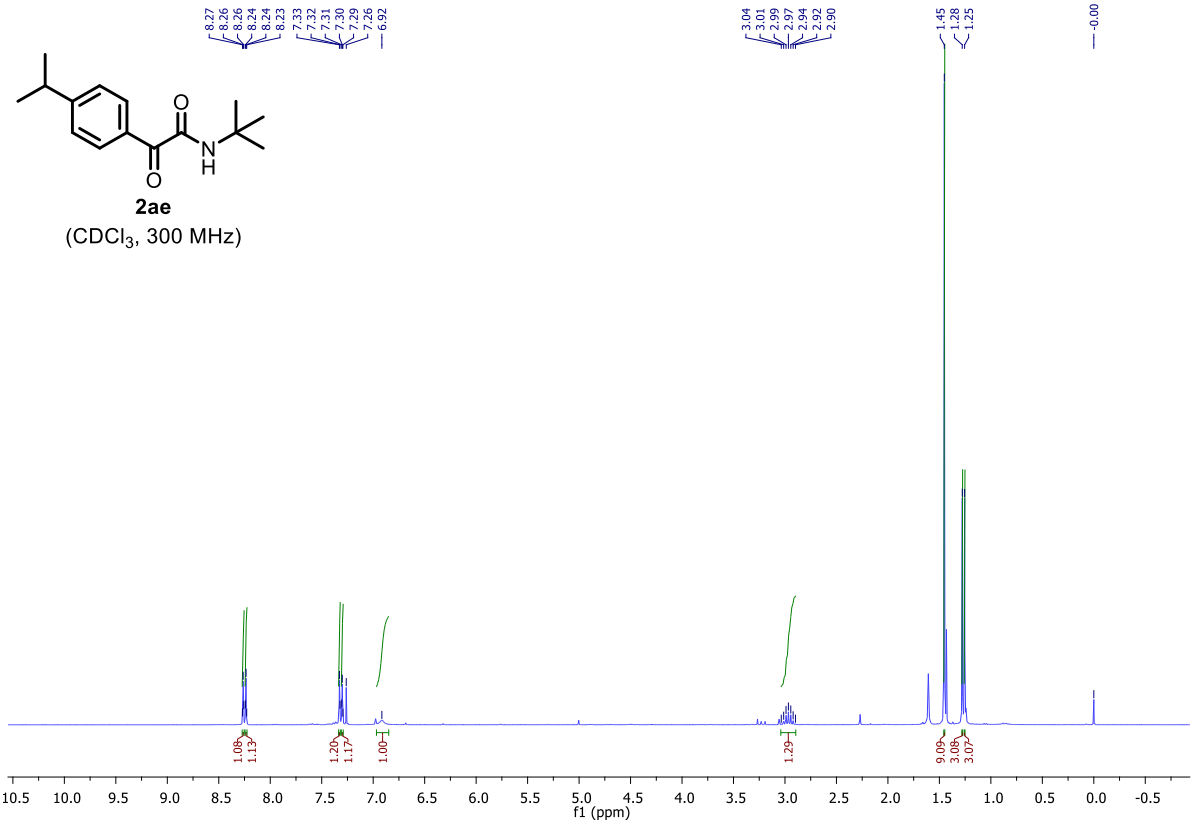


Figure S96: ^{13}C NMR of compound **2ae**

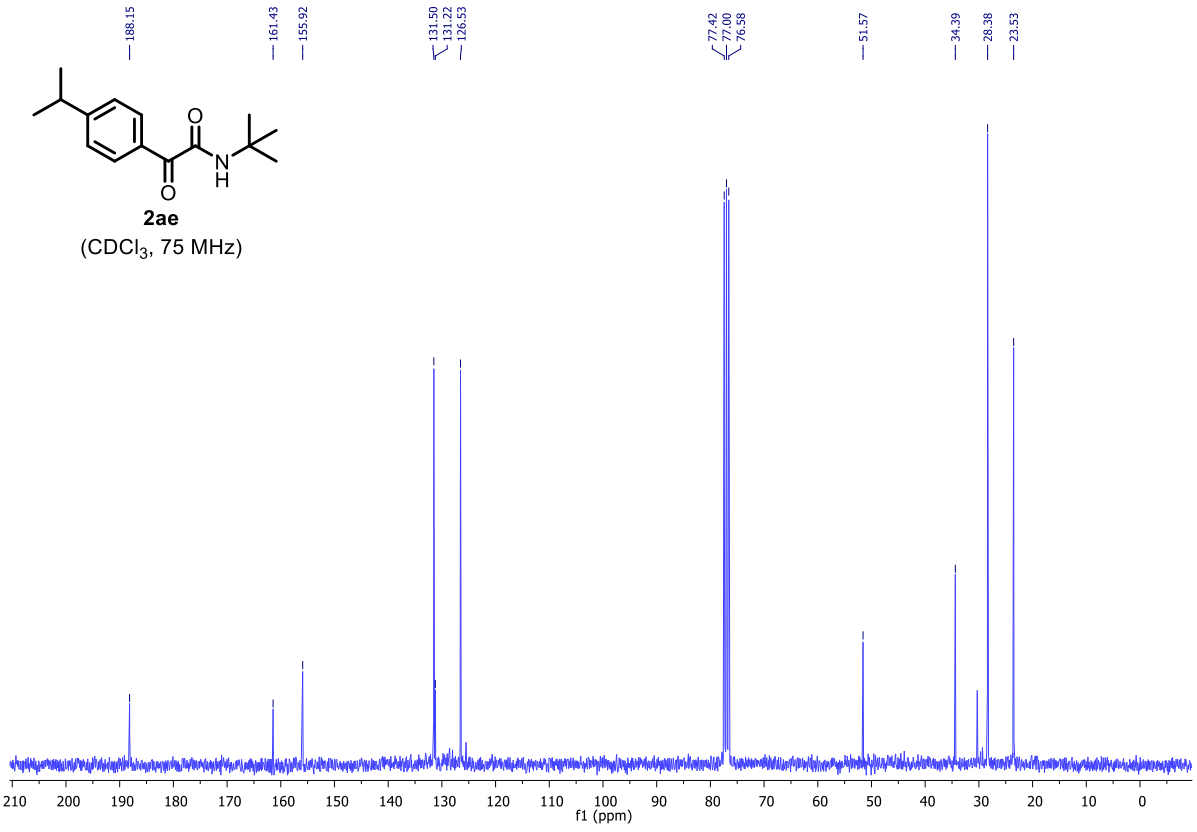


Figure S97: ^{1}H NMR of compound **3a**

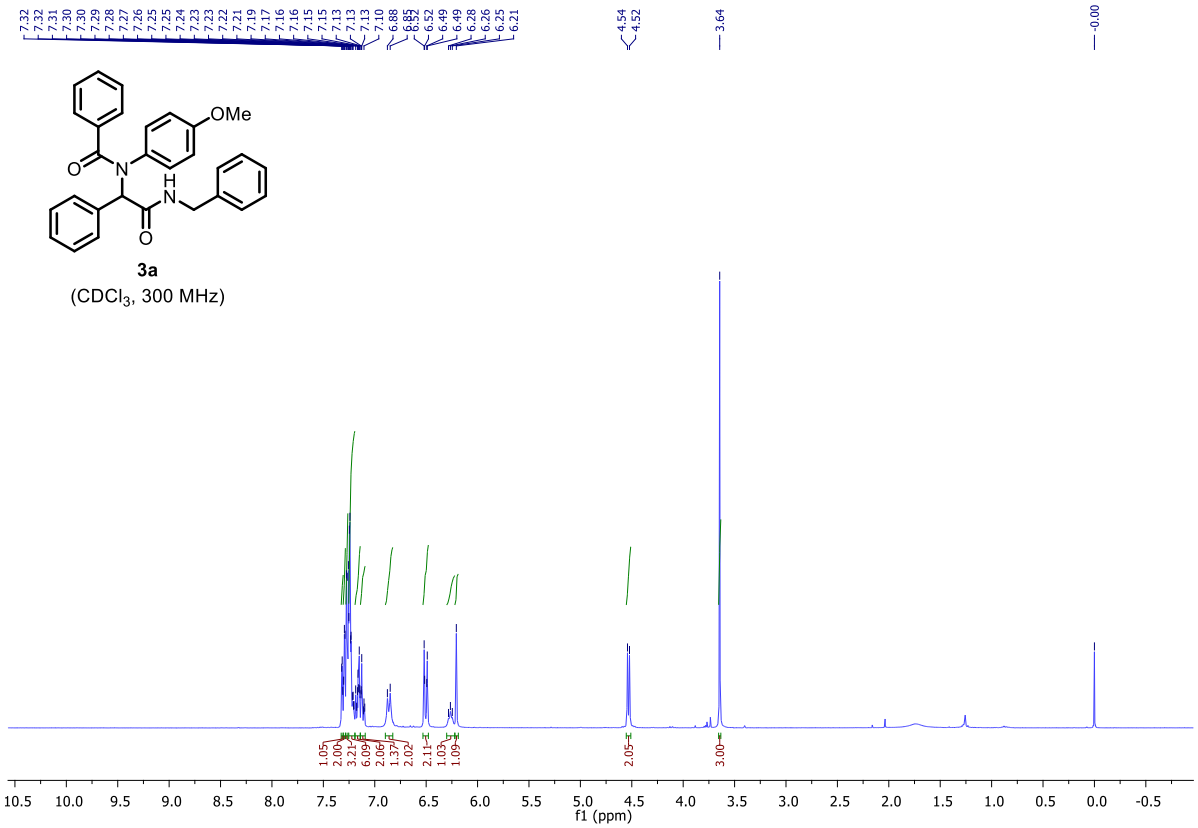


Figure S98: ^{13}C NMR of compound **3a**

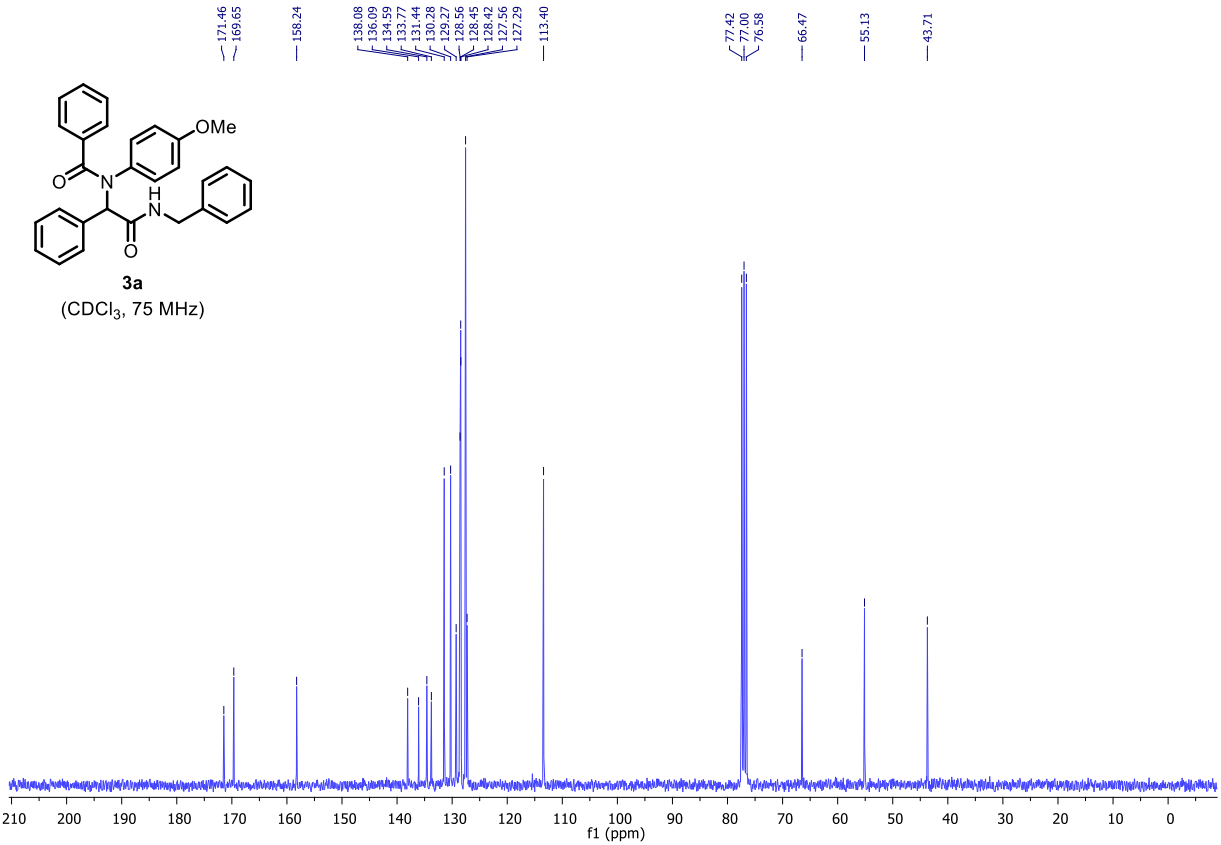


Figure S99: ^{1}H NMR of compound **3b**

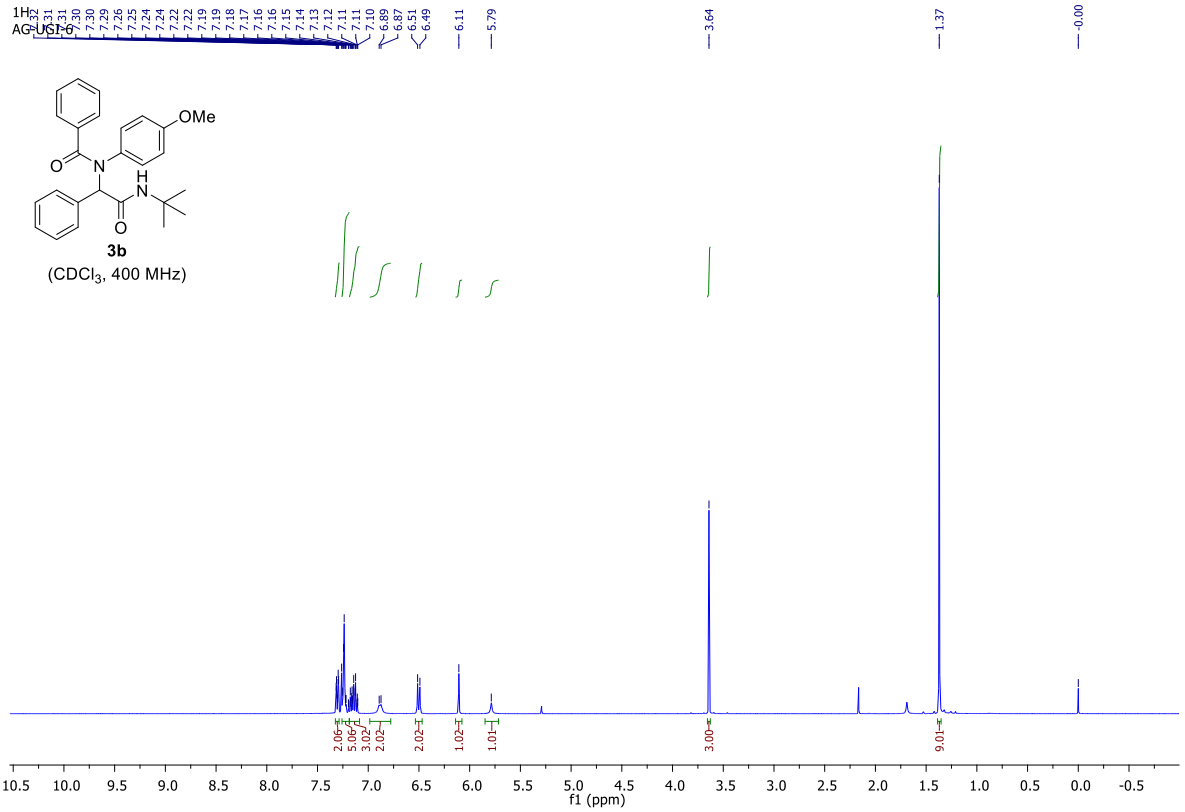


Figure S100: ^{13}C NMR of compound **3b**

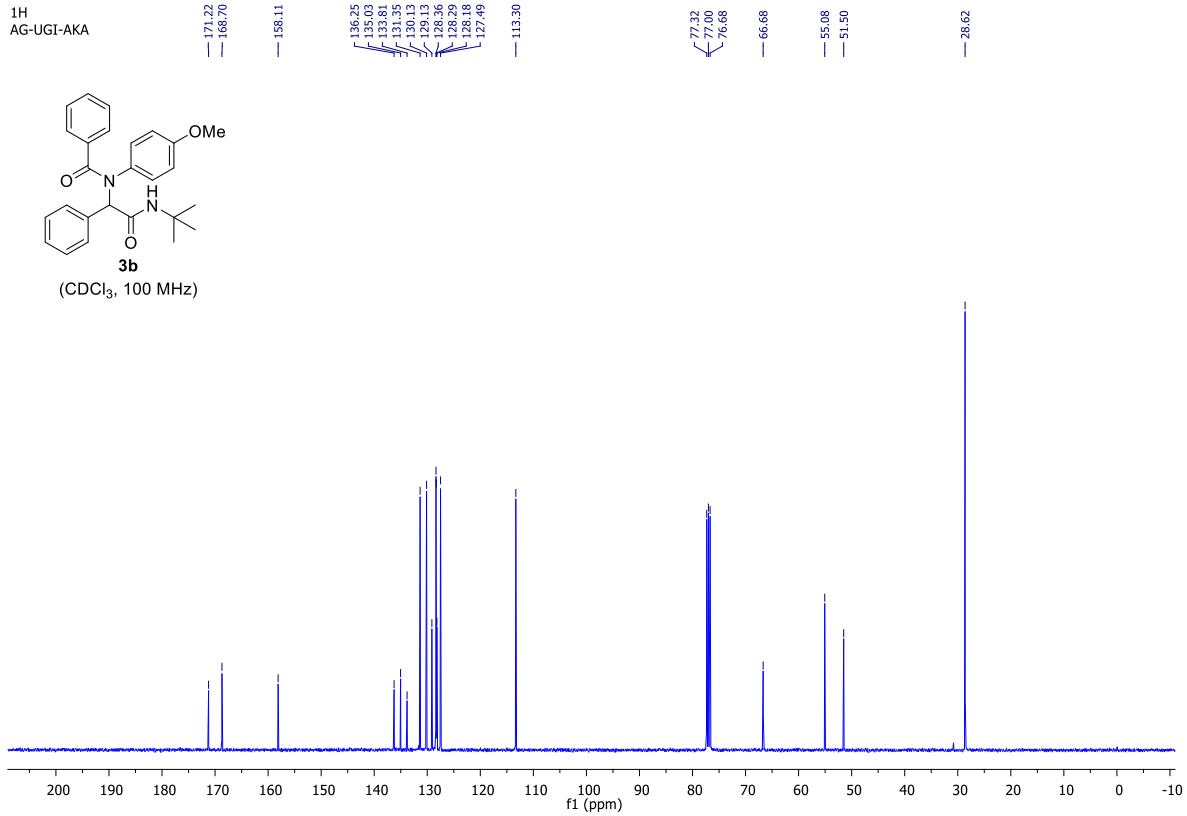


Figure S101: ^{1}H NMR of compound **3c**

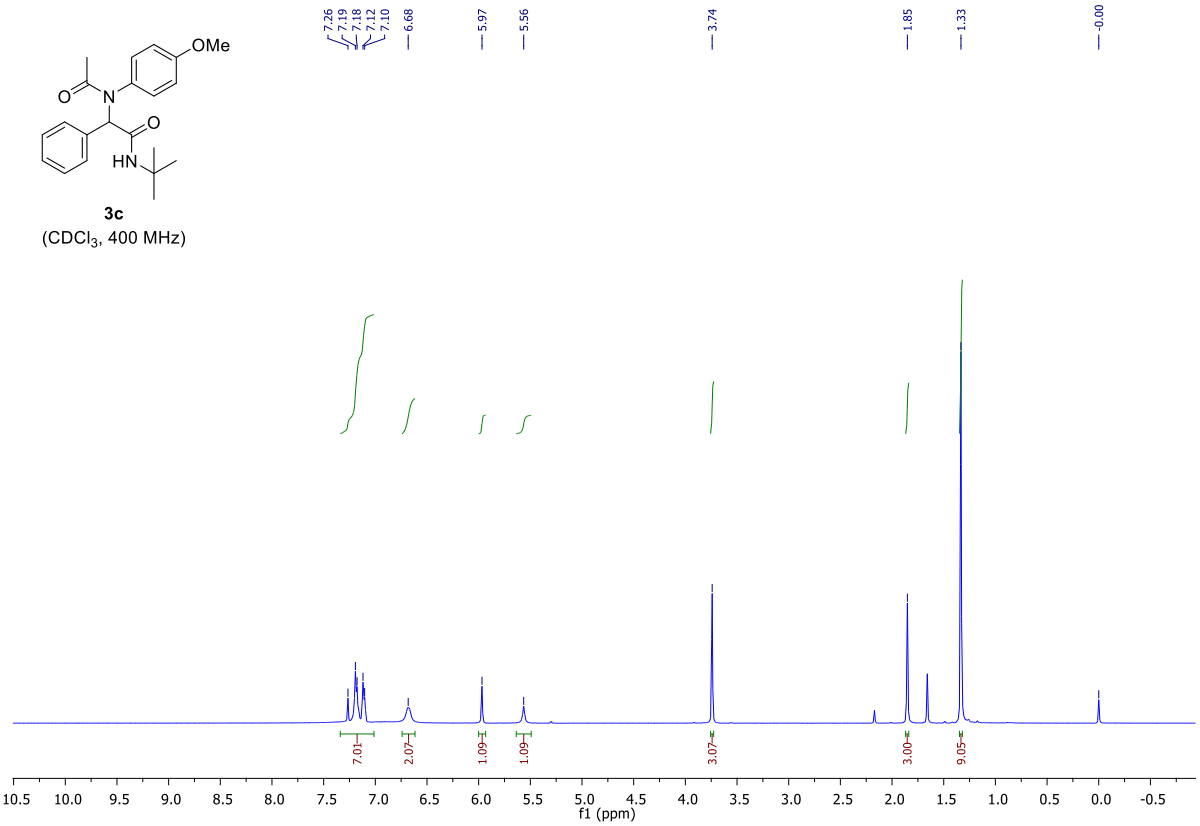


Figure S102: ^{13}C NMR of compound **3c**

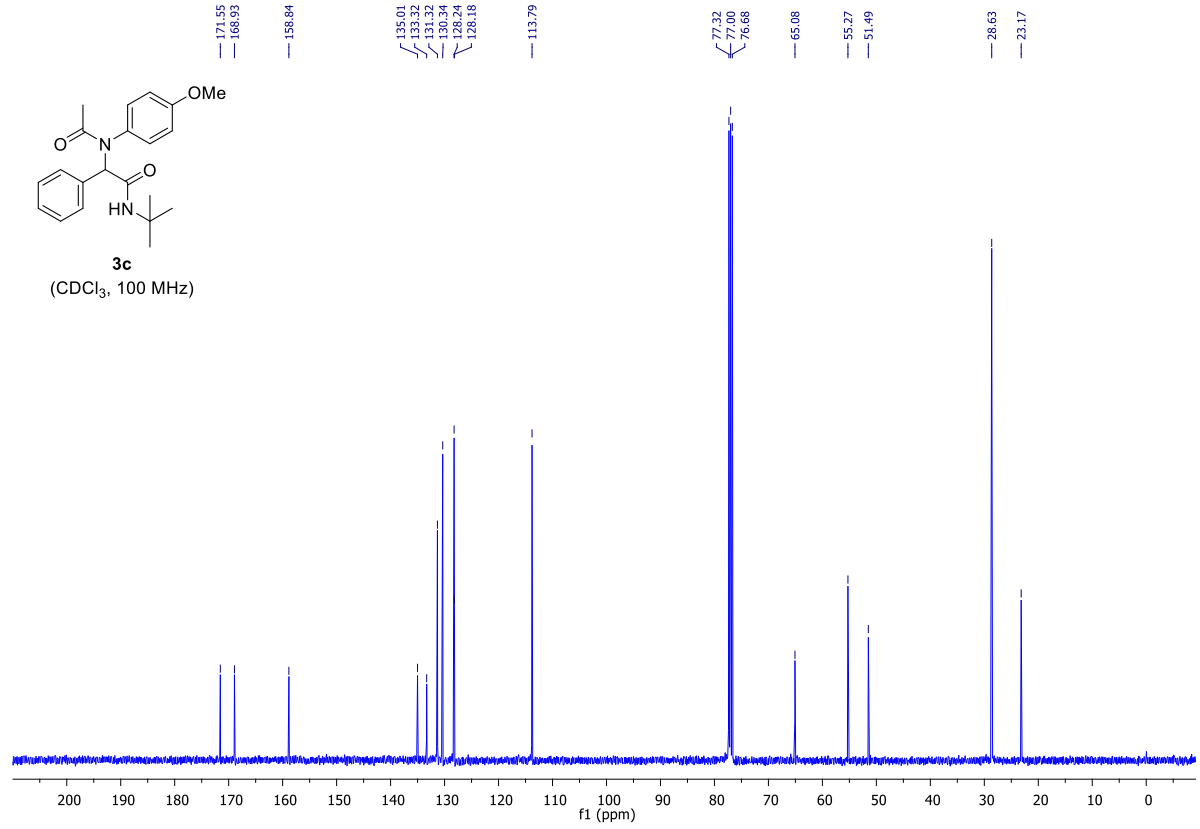


Figure S103: ^{1}H NMR of compound **3d**

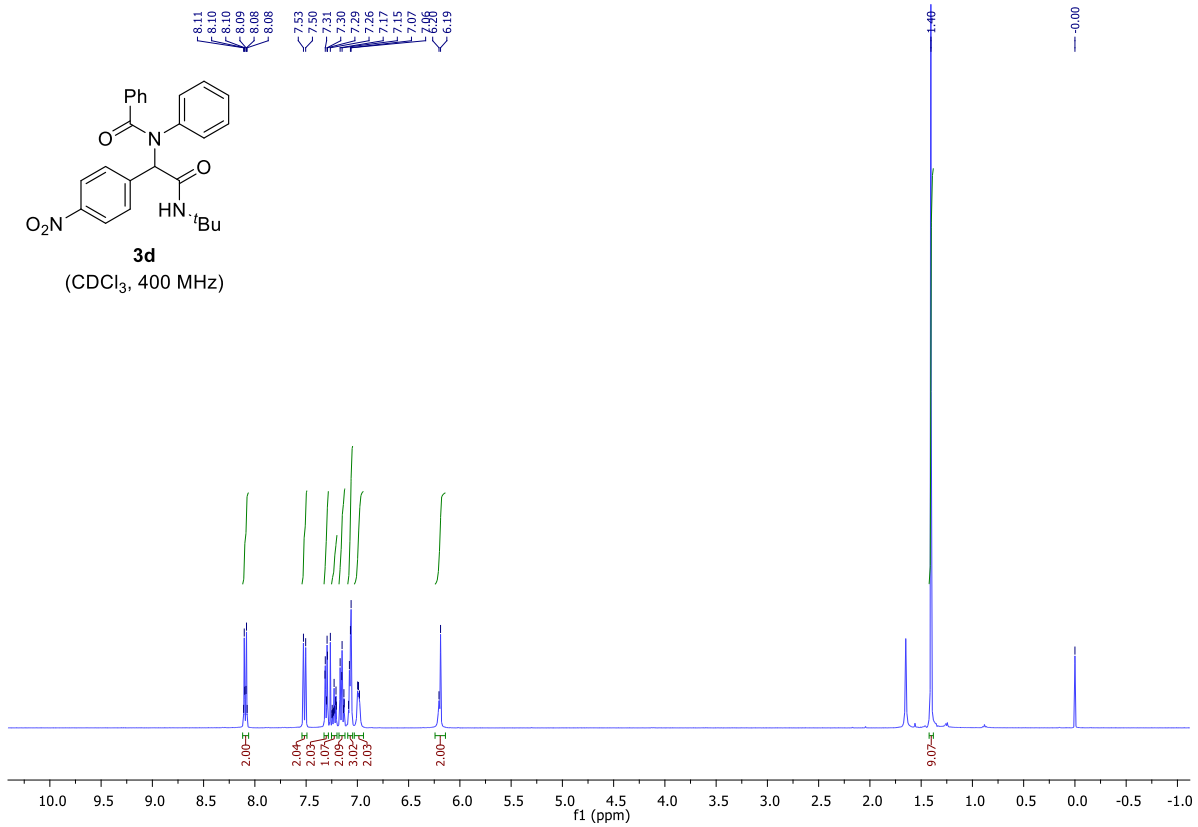


Figure S104: ^{13}C NMR of compound **3d**

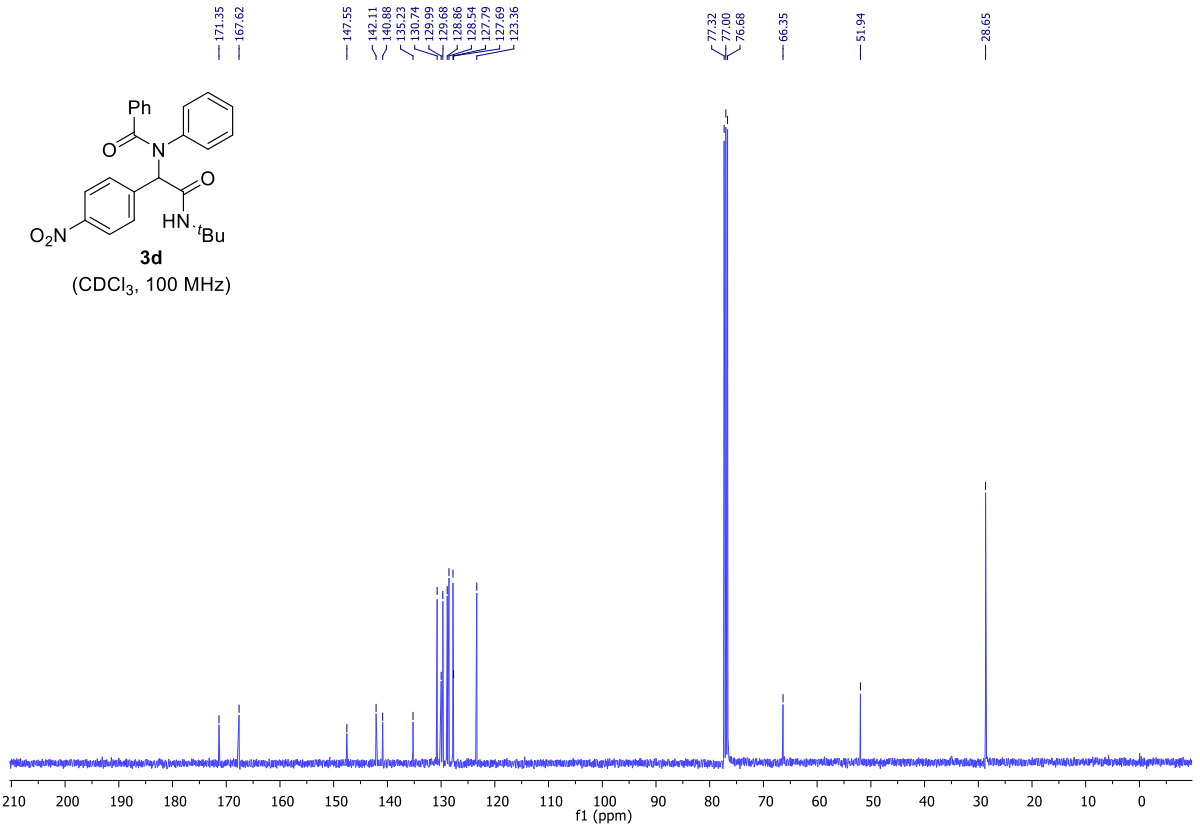


Figure S105: ^{1}H NMR of compound **3e**

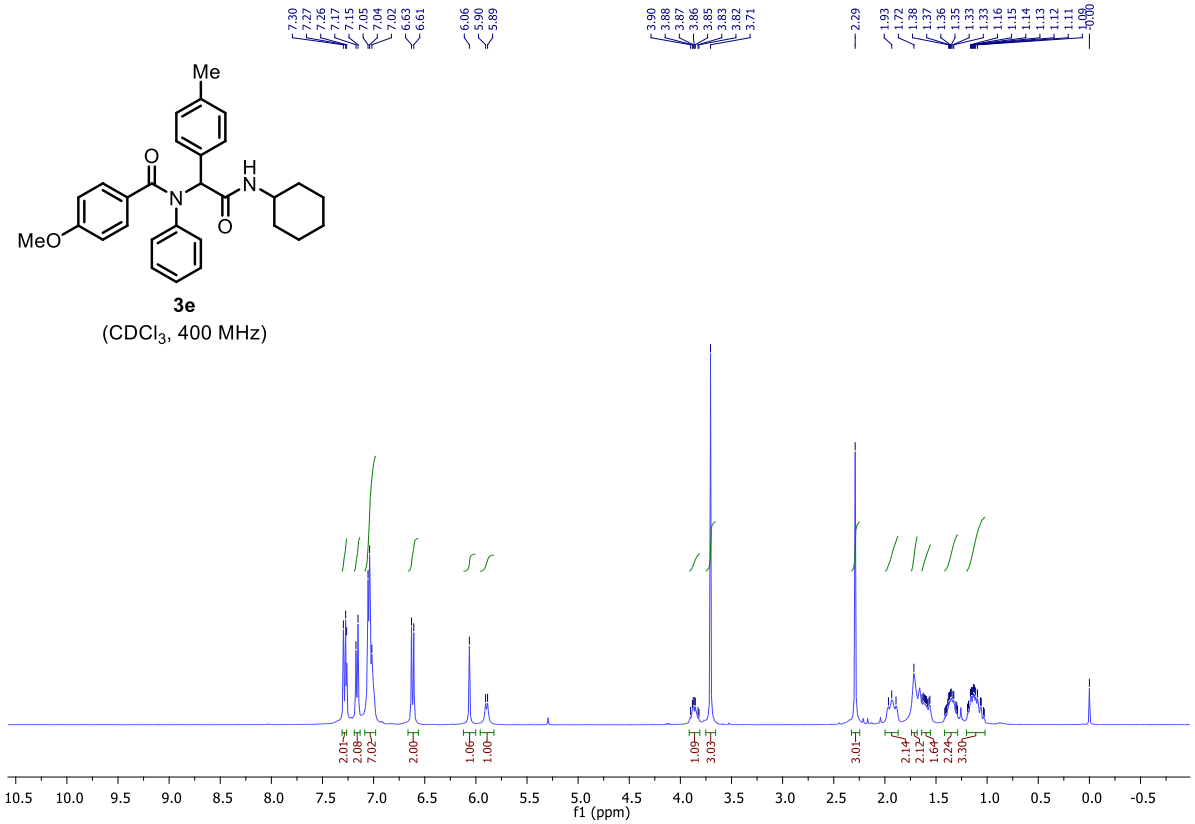


Figure S106: ^{13}C NMR of compound **3e**

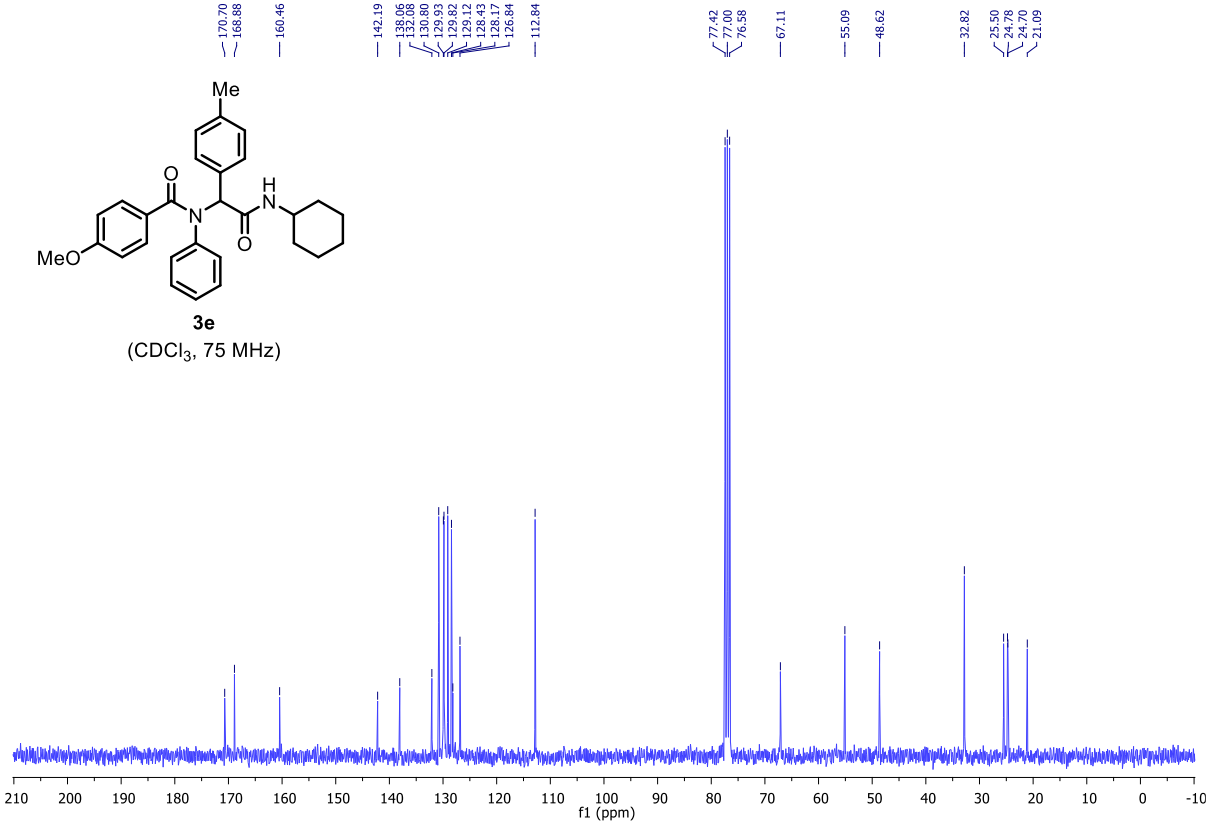


Figure S107: ^{1}H NMR of compound **3f**

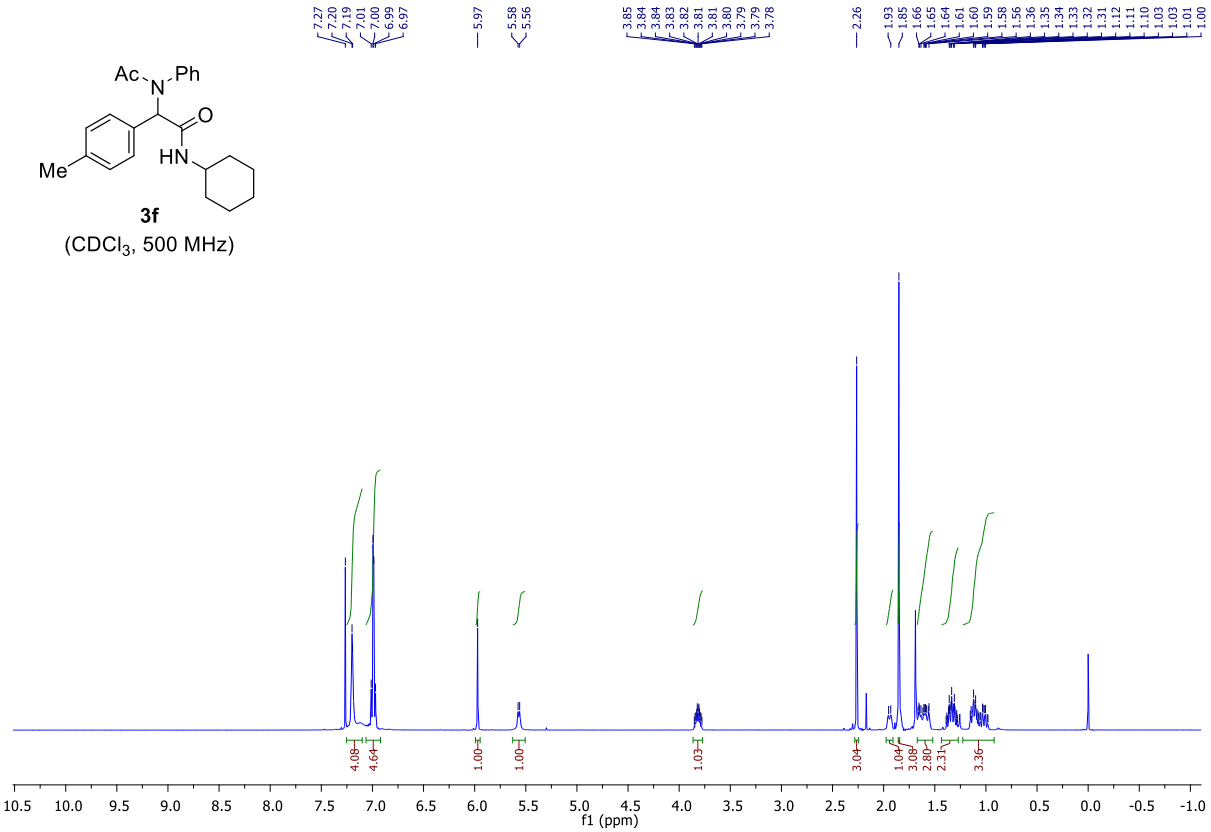


Figure S108: ^{13}C NMR of compound **3f**

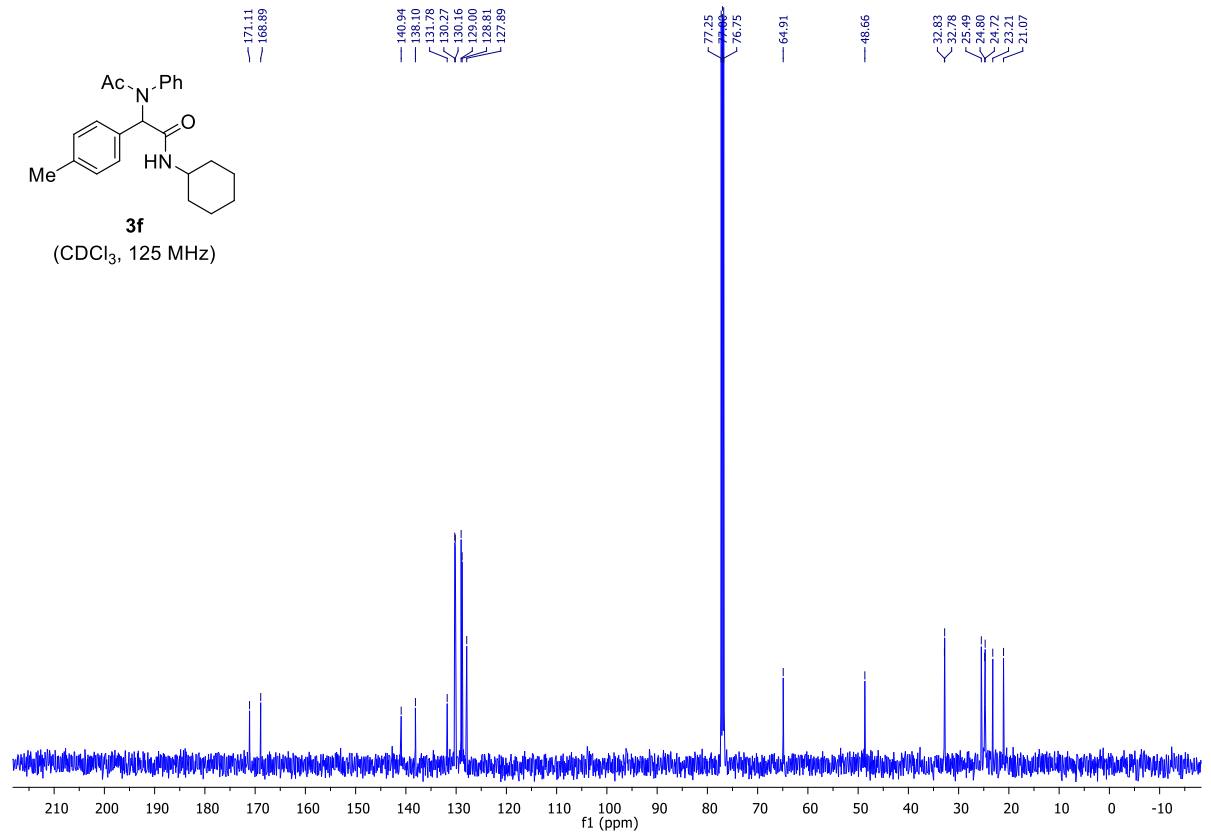


Figure S109: ^{1}H NMR of compound **3g**

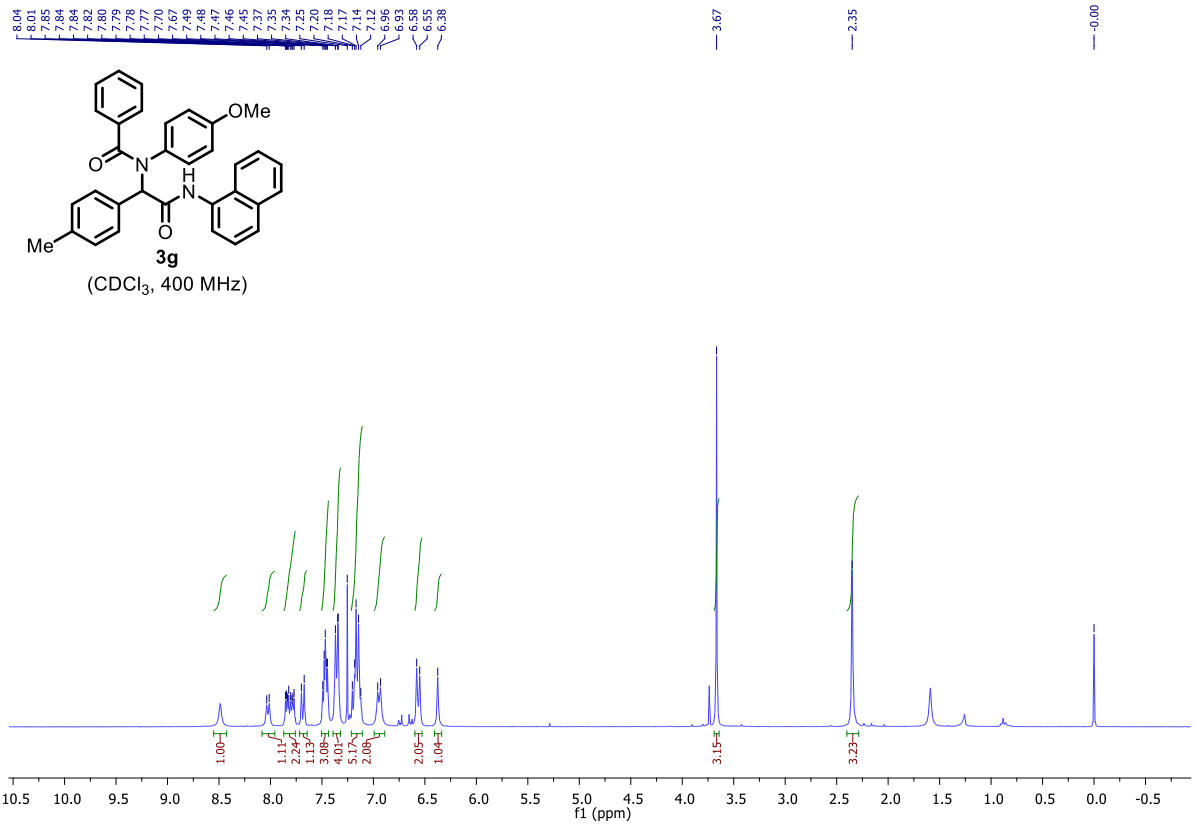


Figure S110: ^{13}C NMR of compound **3g**

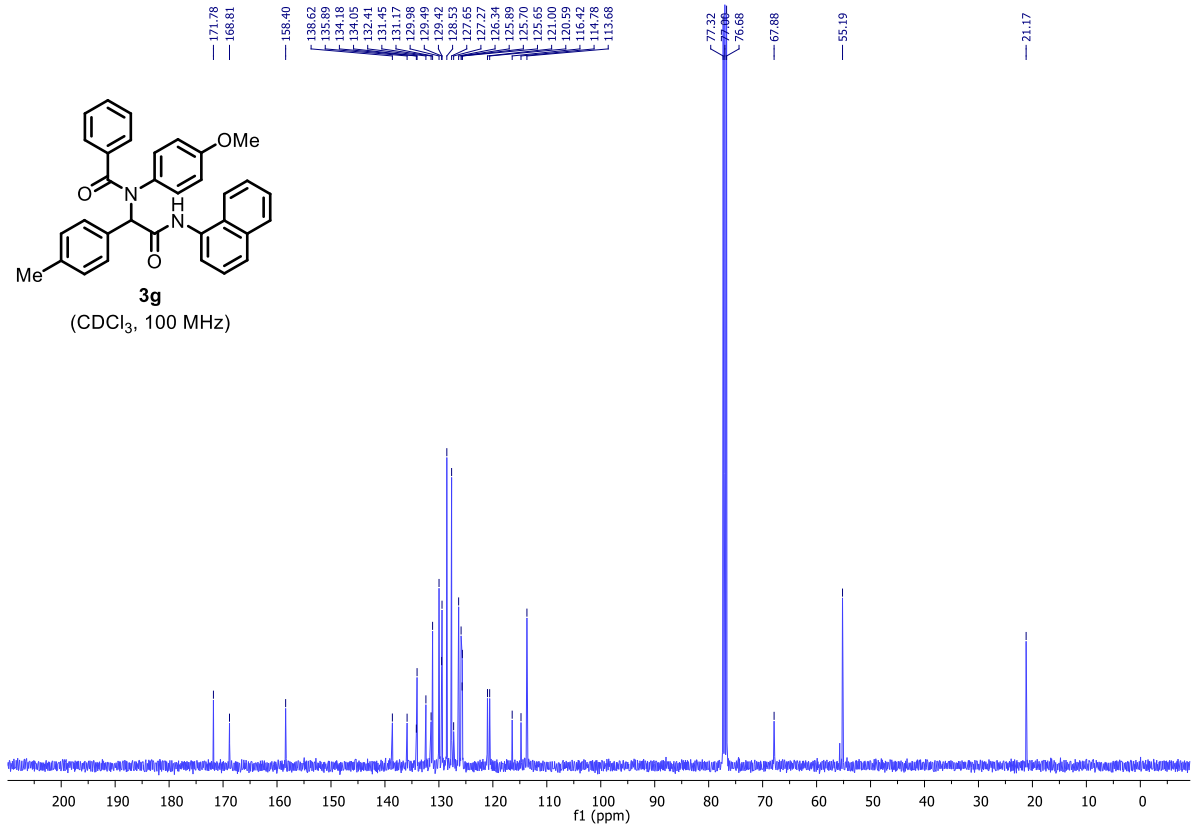


Figure S111: ^{1}H NMR of compound **3h**

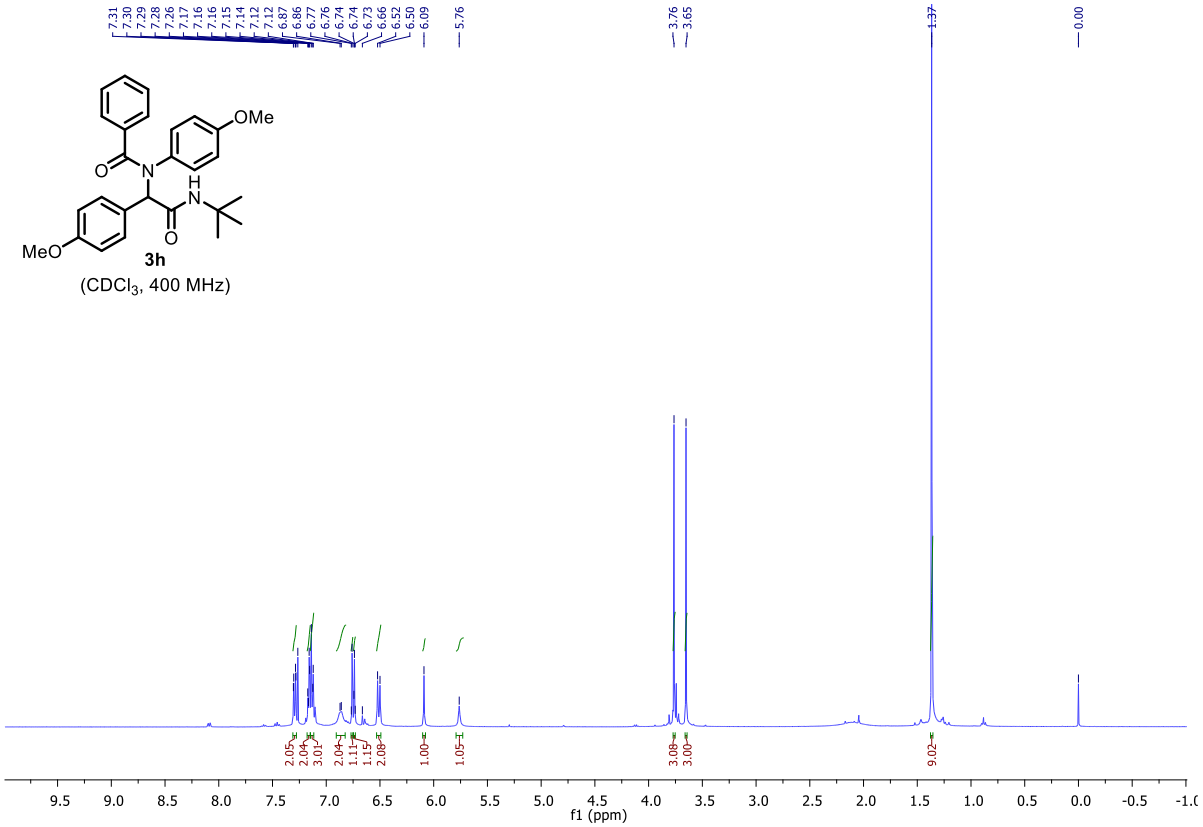


Figure S112: ^{13}C NMR of compound **3h**

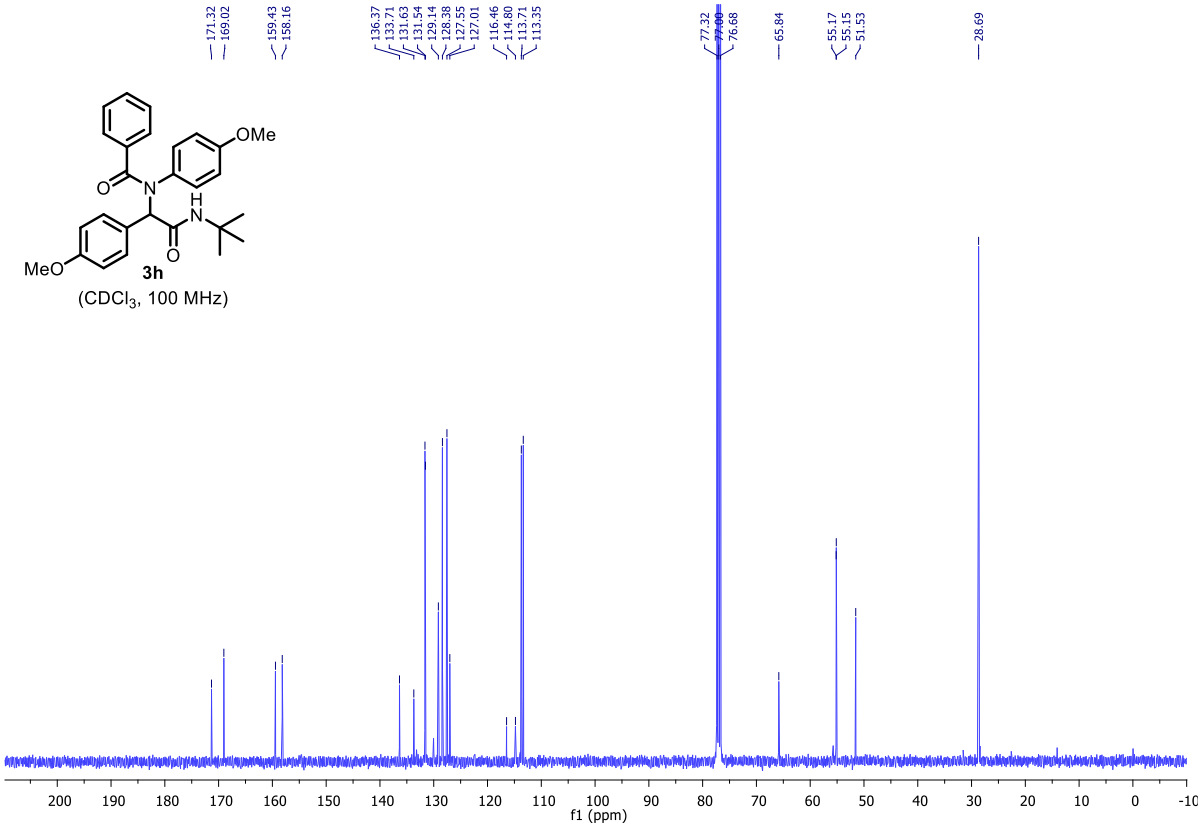


Figure S113: ^{1}H NMR of compound **3i**

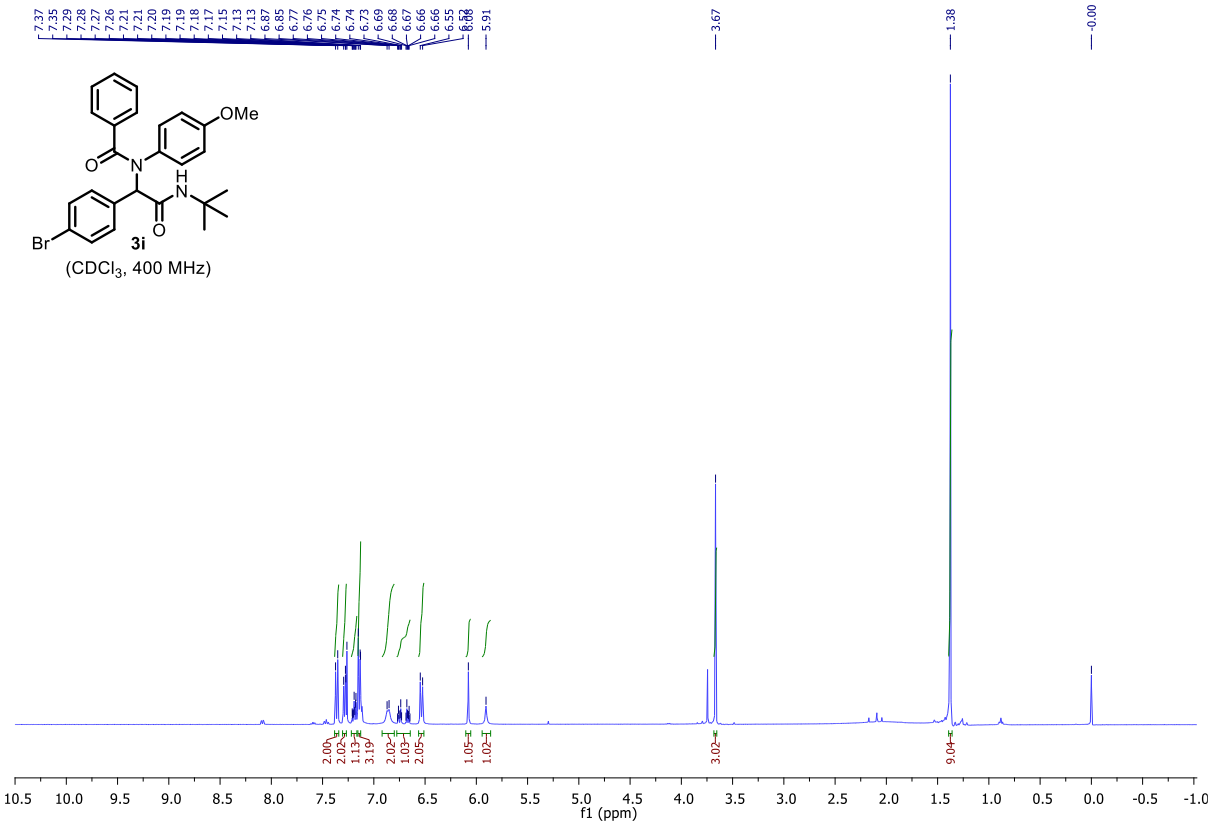


Figure S114: ^{13}C NMR of compound **3i**

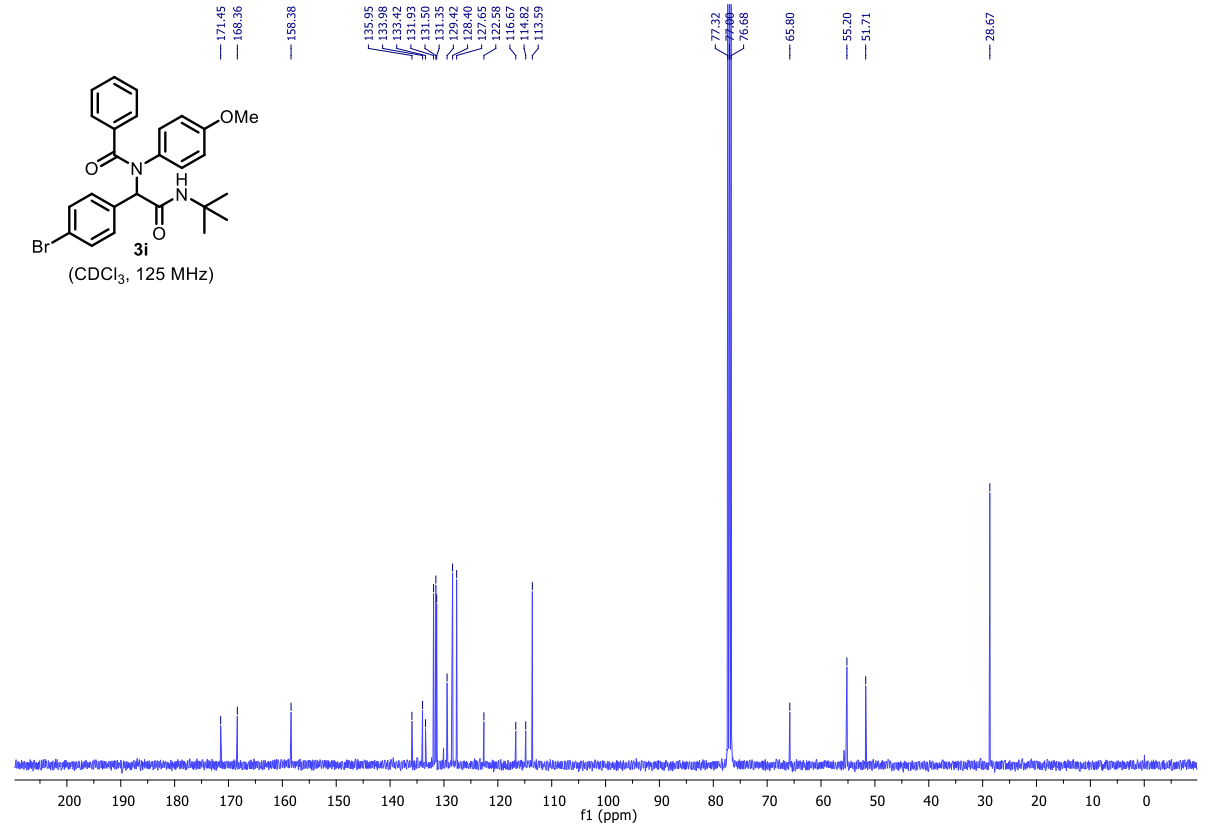


Figure S115: ^{1}H NMR of compound **3j**

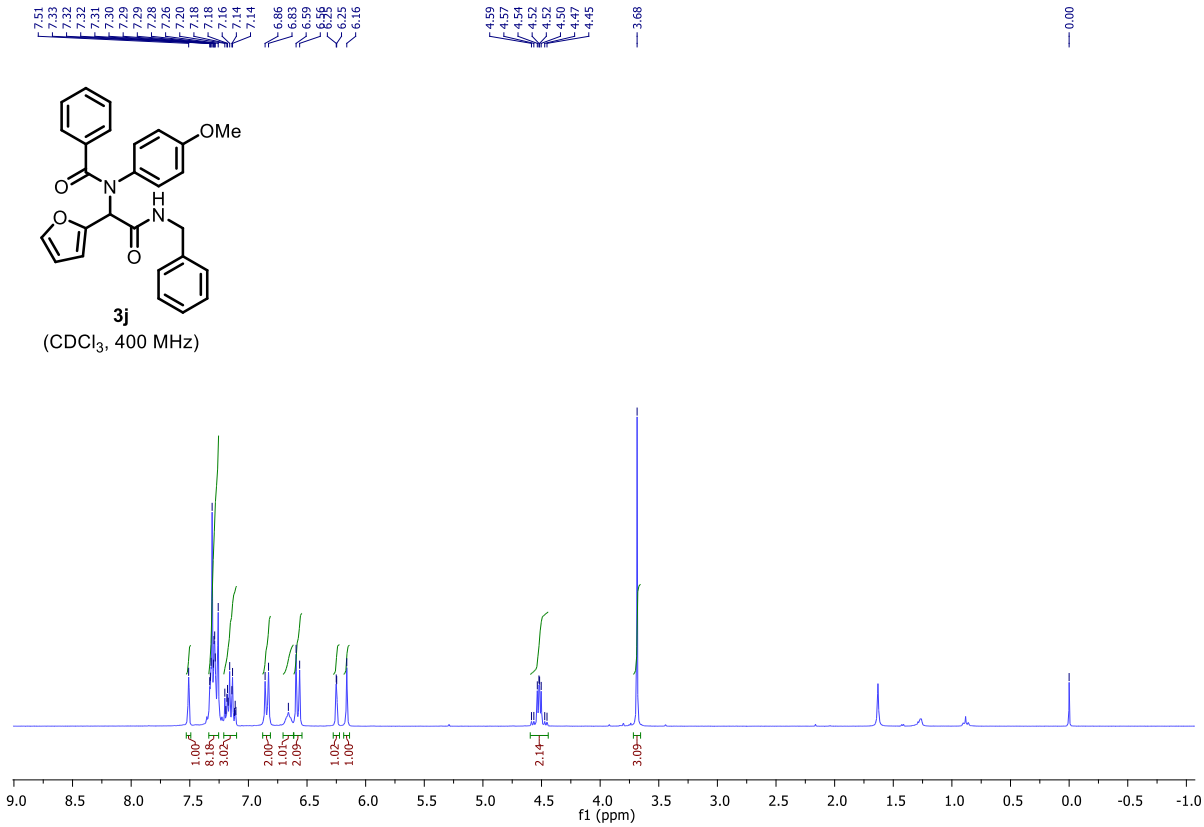


Figure S116: ^{13}C NMR of compound **3j**

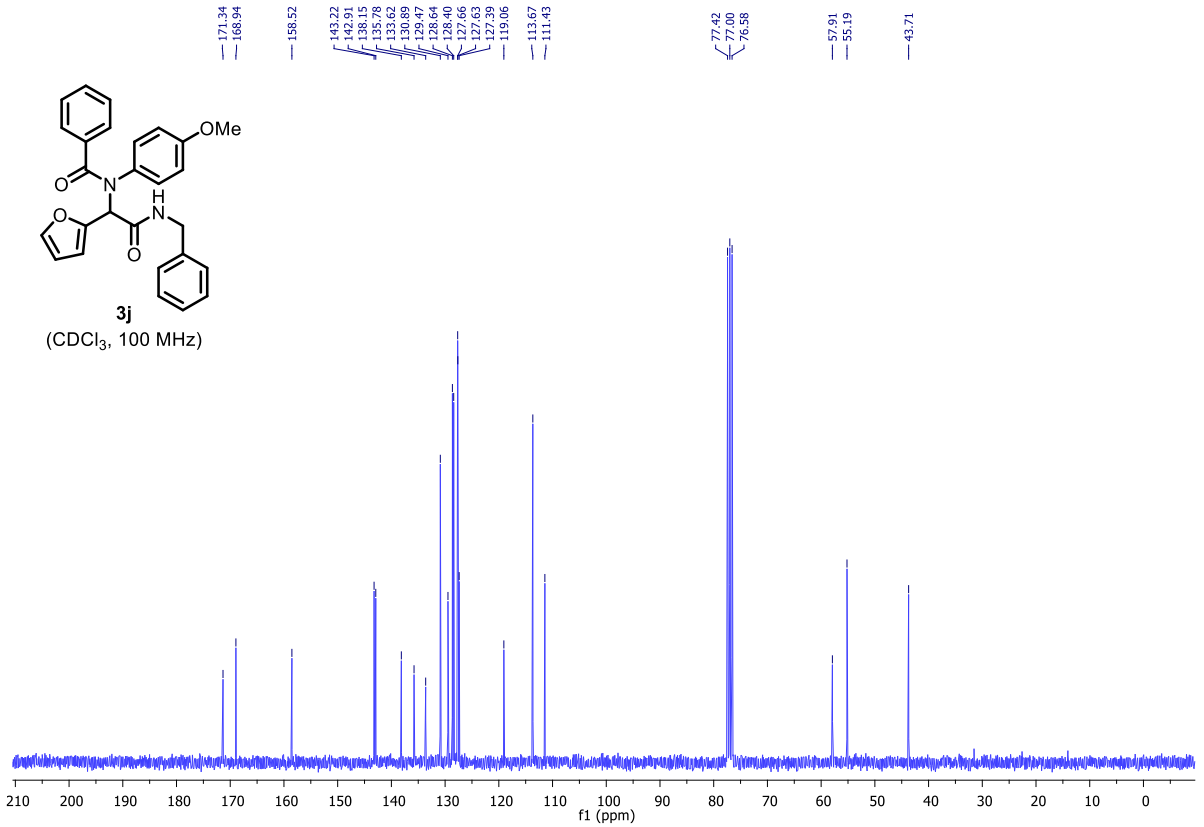


Figure S117: ^{1}H NMR of compound **3k**

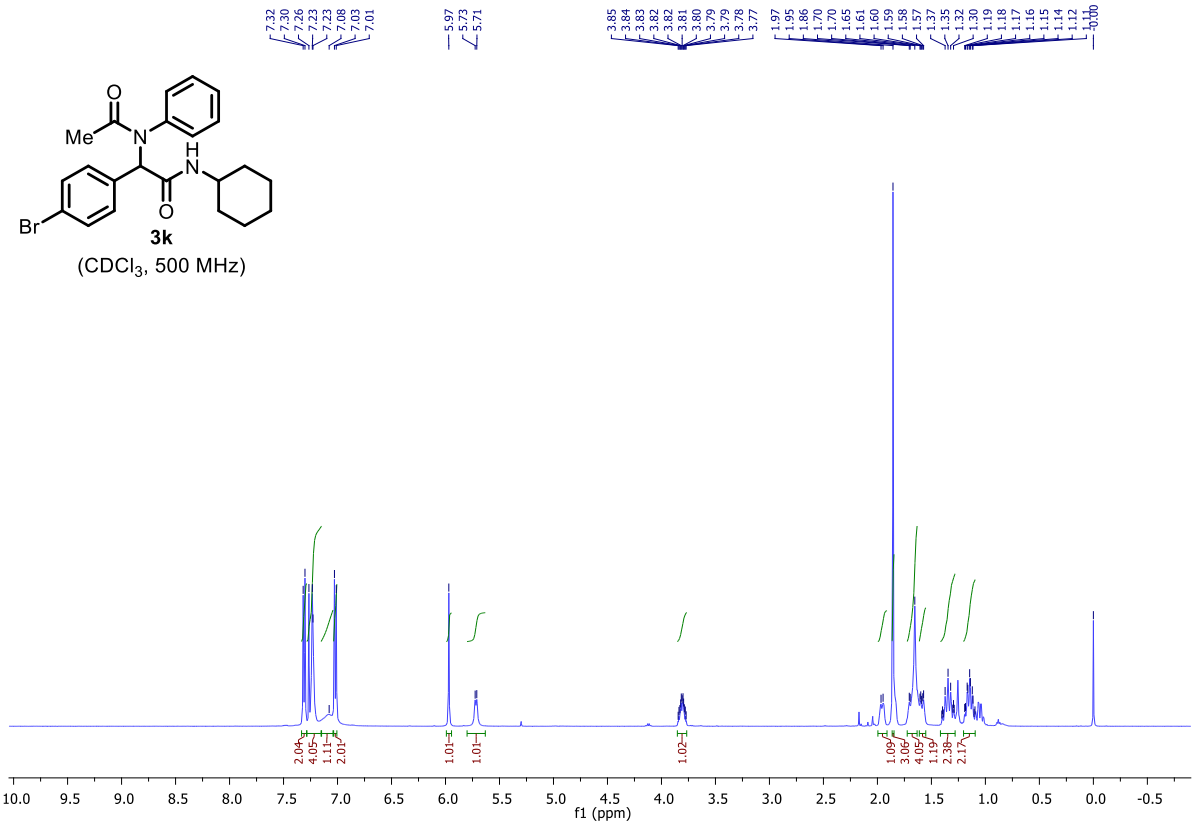


Figure S118: ^{13}C NMR of compound **3k**

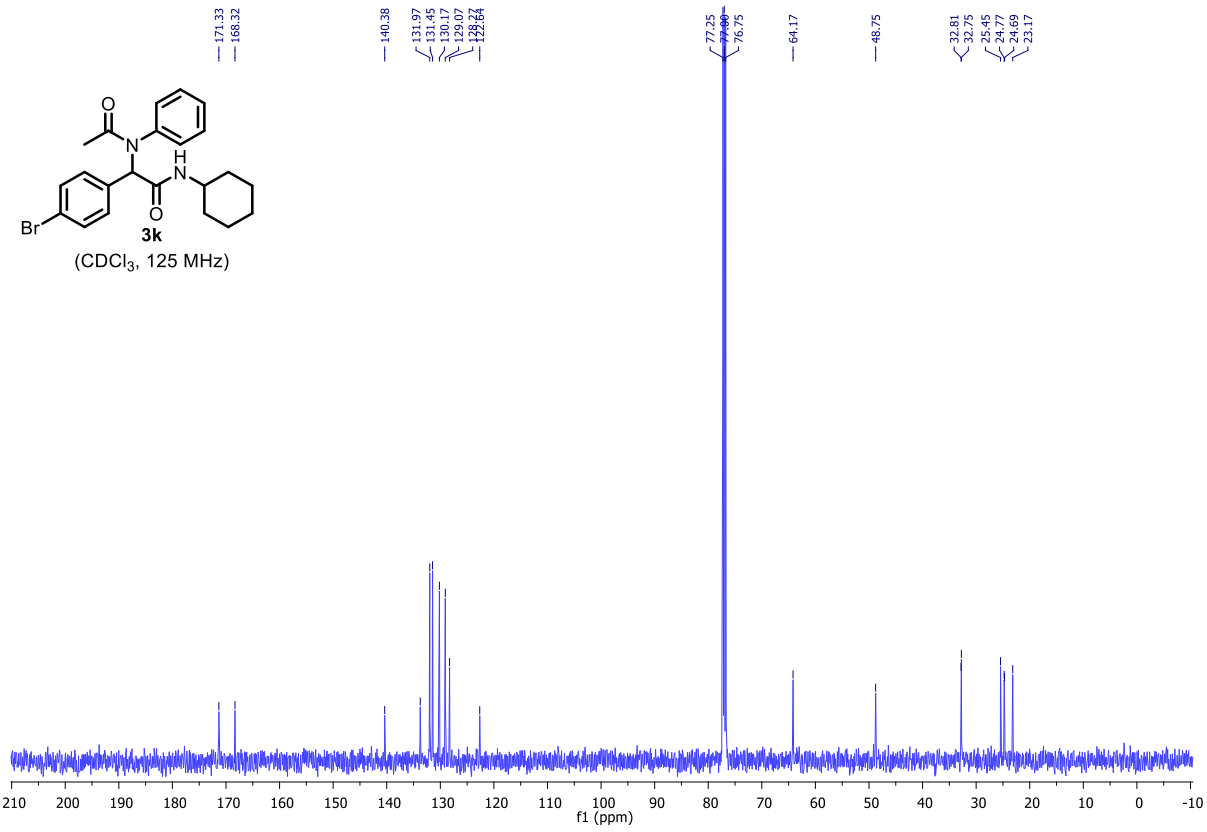


Figure S119: ^{1}H NMR of compound **3l**

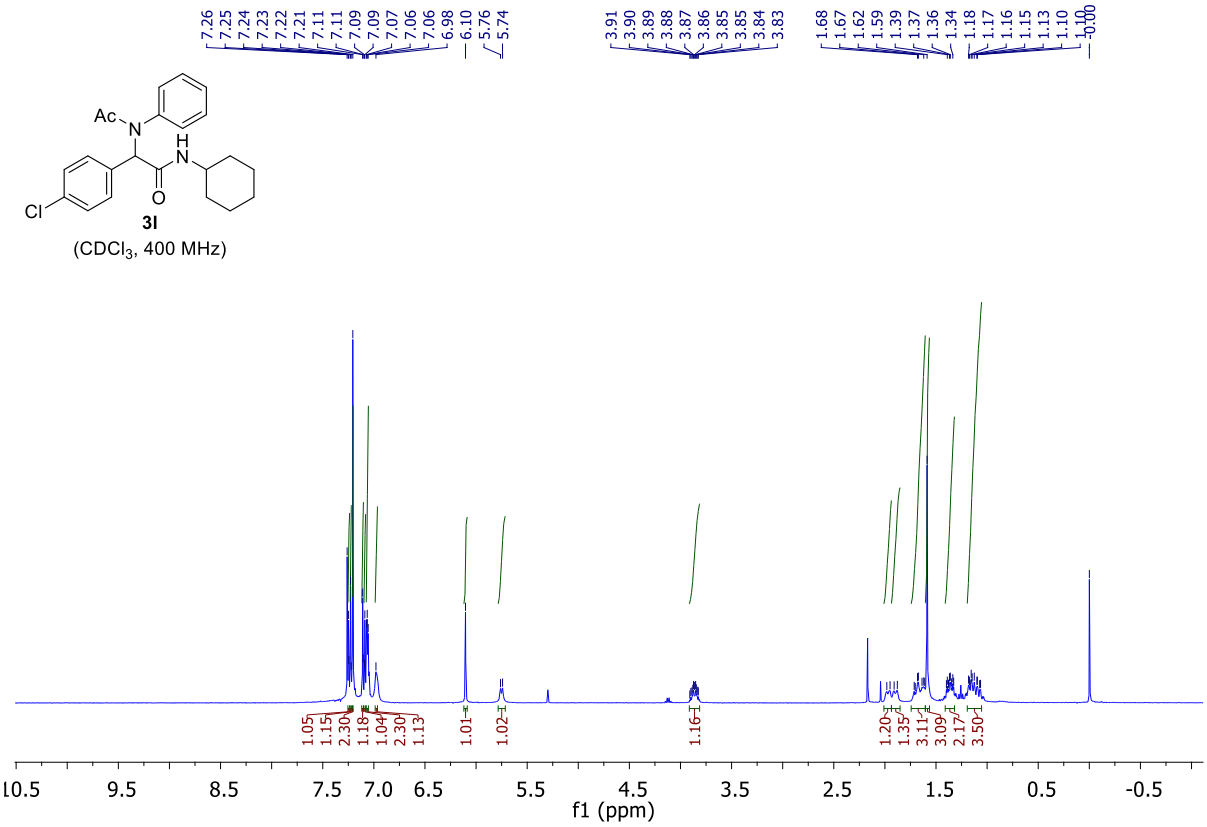


Figure S120: ^{13}C NMR of compound **3l**

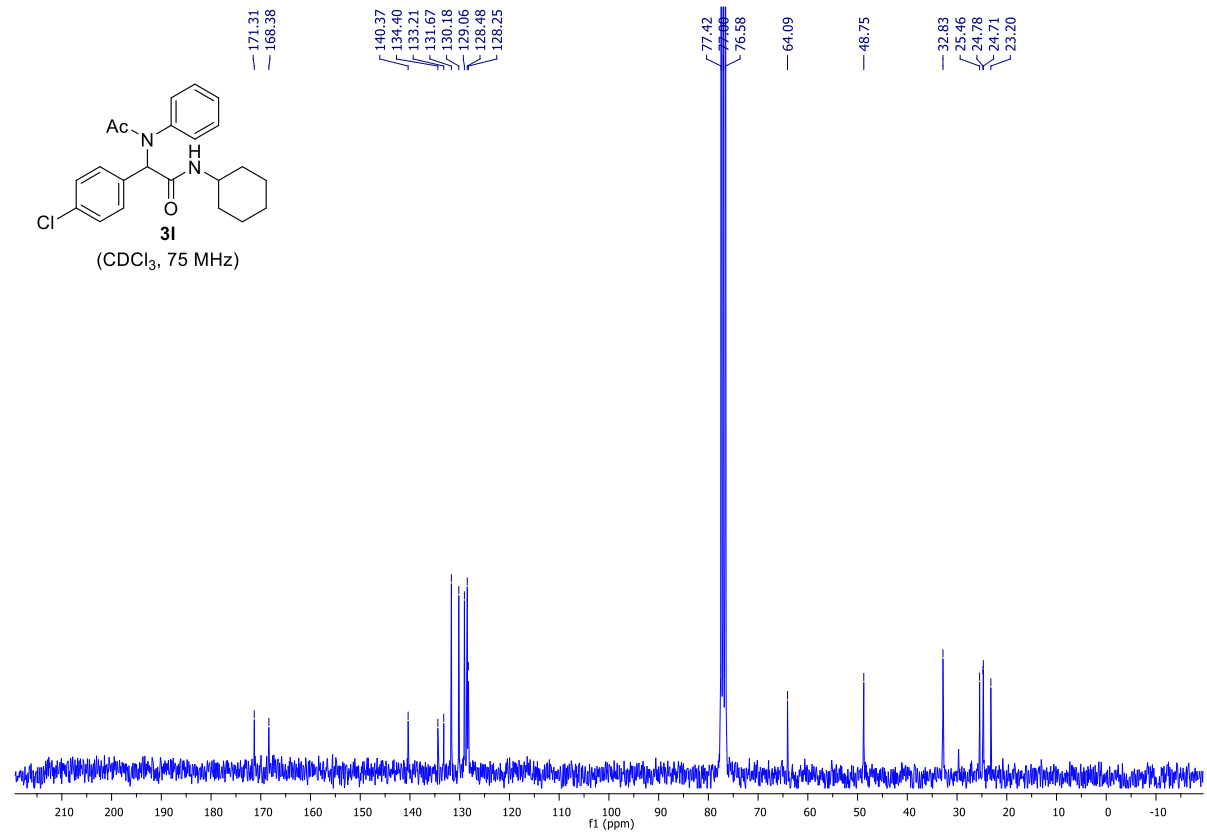


Figure S121: ^{1}H NMR of compound **3m**

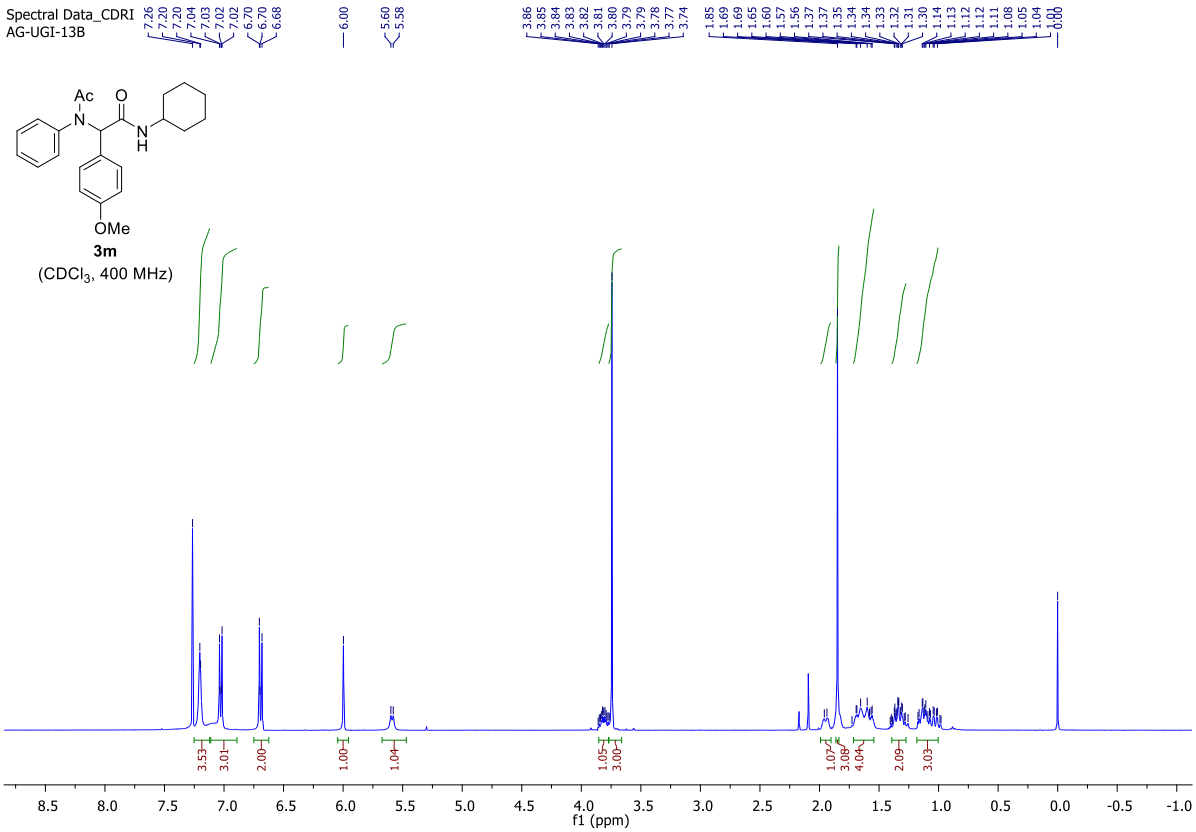


Figure S122: ^{13}C NMR of compound **3m**

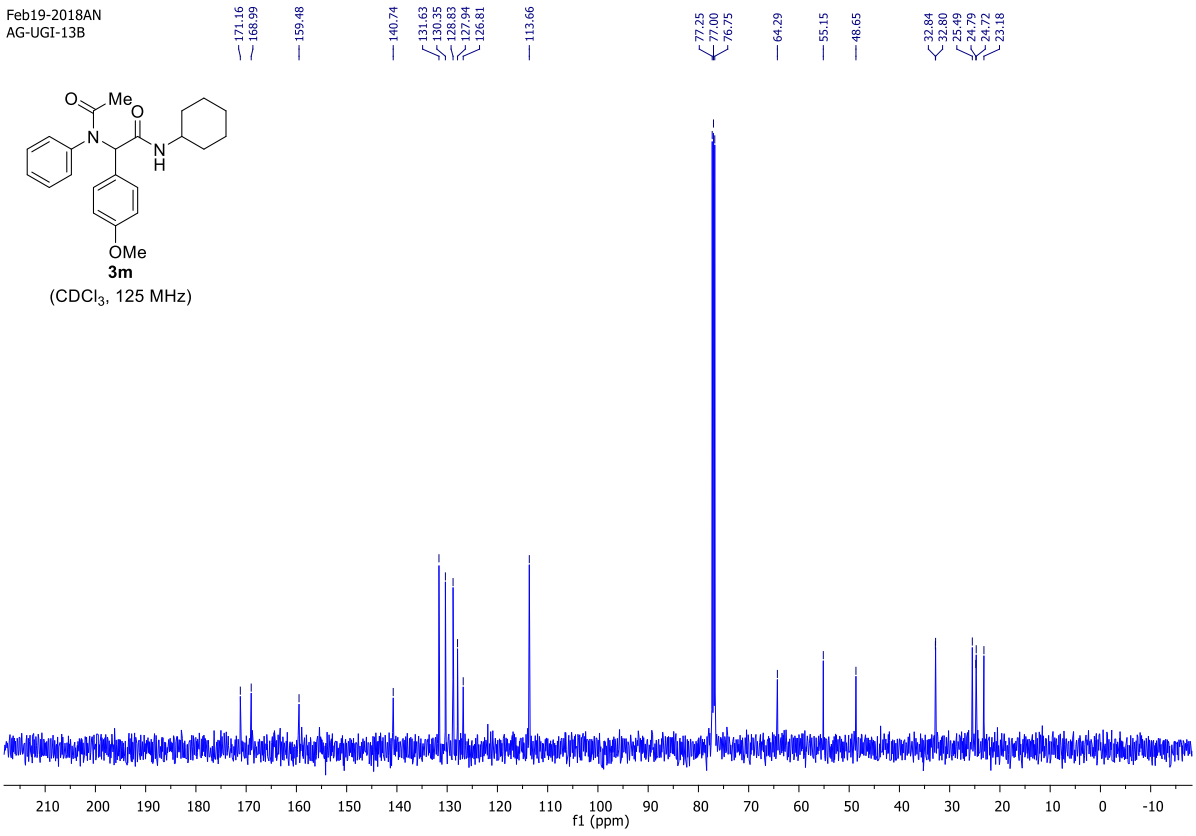


Figure S123: ^{1}H NMR of compound **3n**

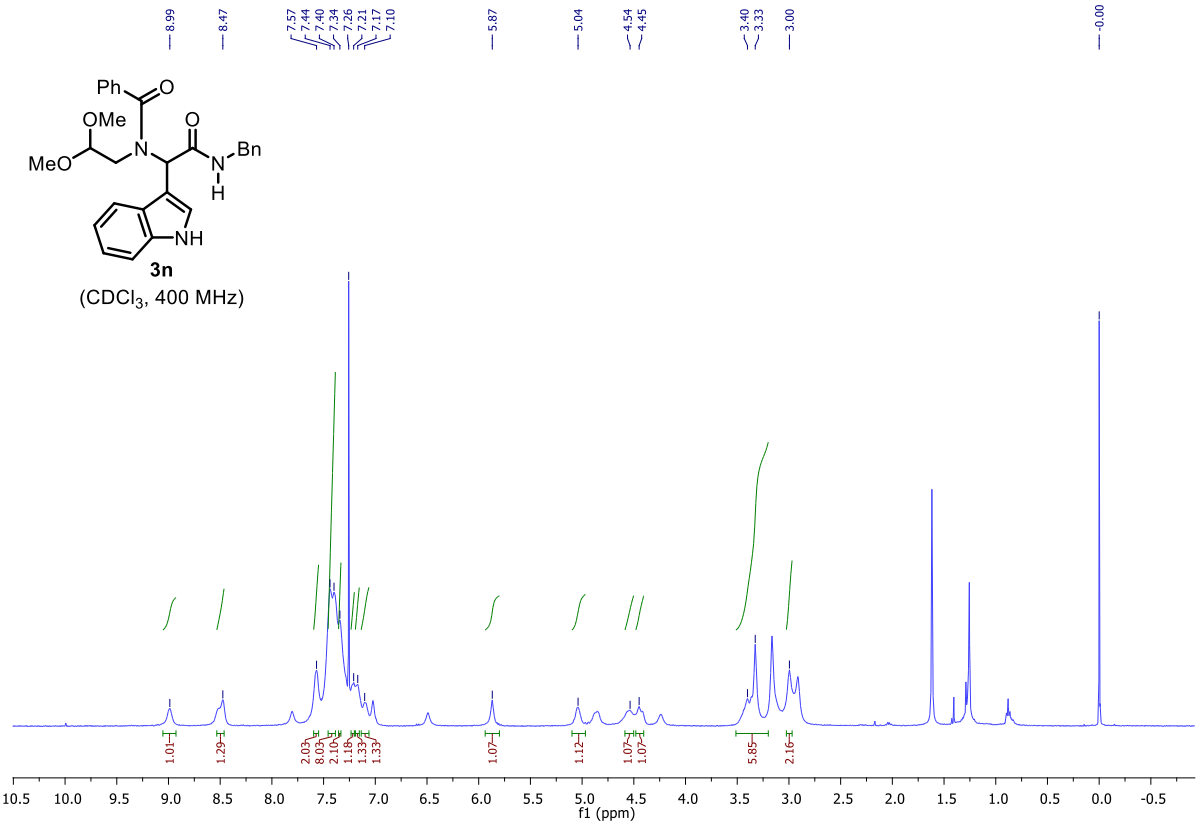


Figure S124: ^{13}C NMR of compound **3n**

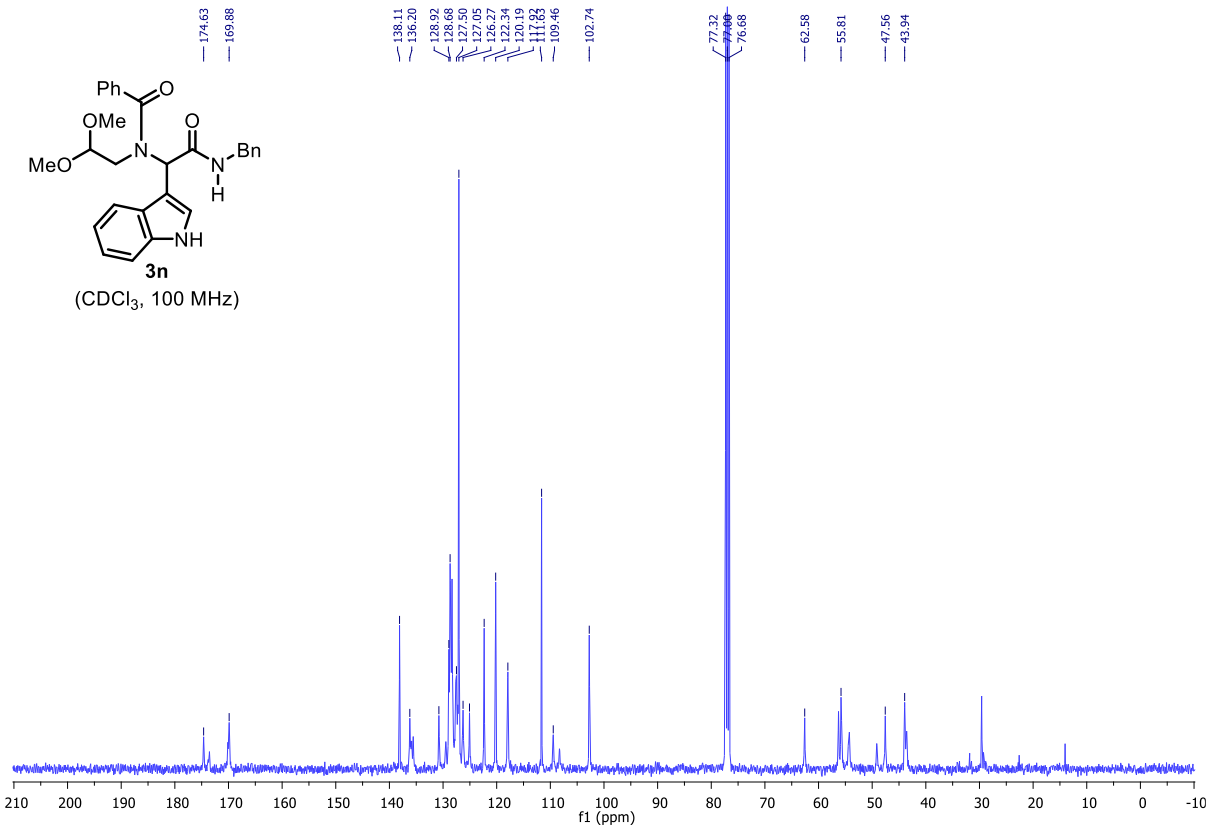


Figure S125: ^{1}H NMR of compound **3o**

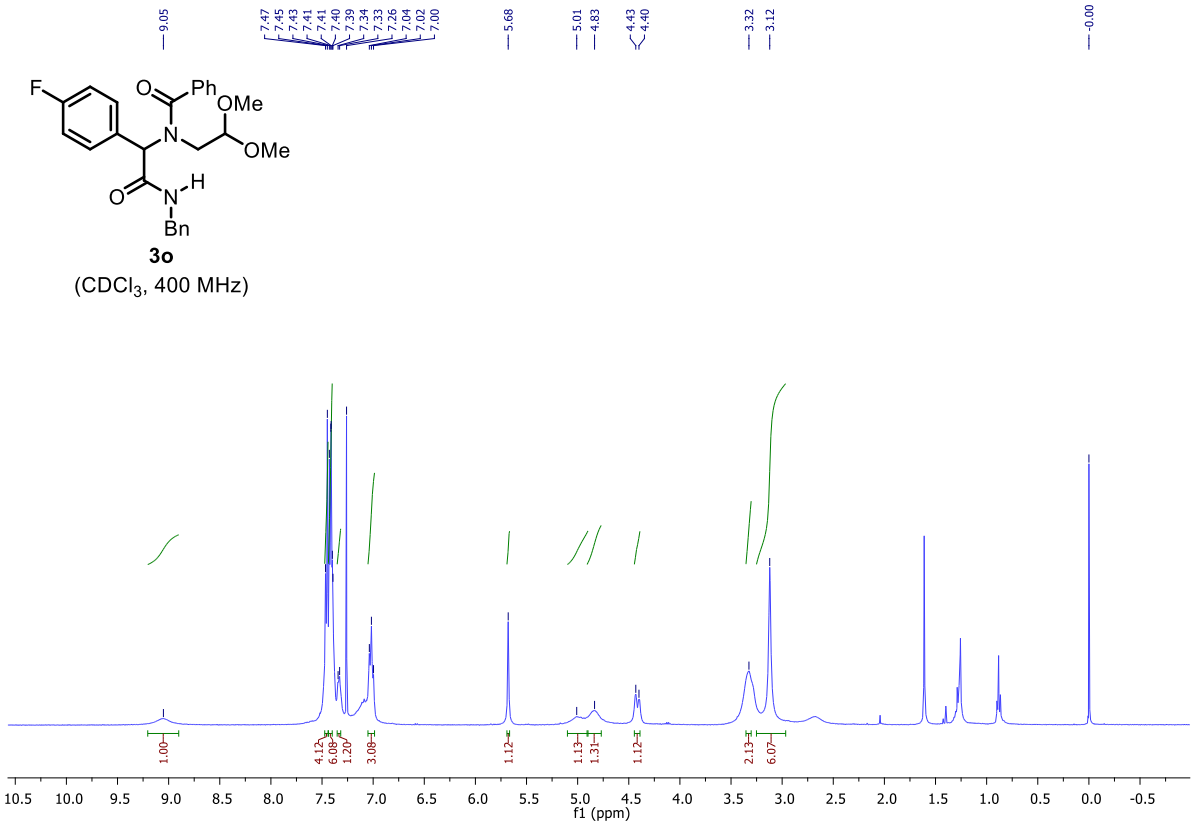


Figure S126: ^{13}C NMR of compound **3o**

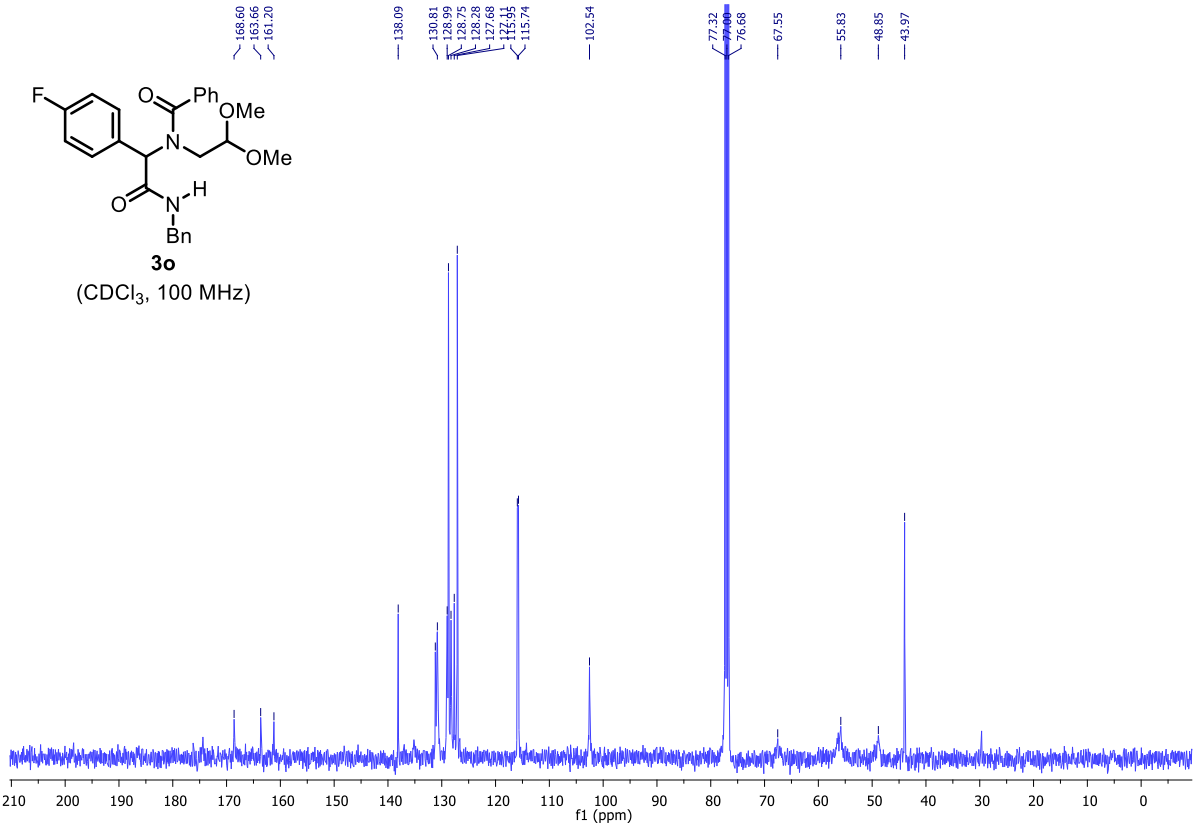


Figure S127: ^{1}H NMR of compound **3p**

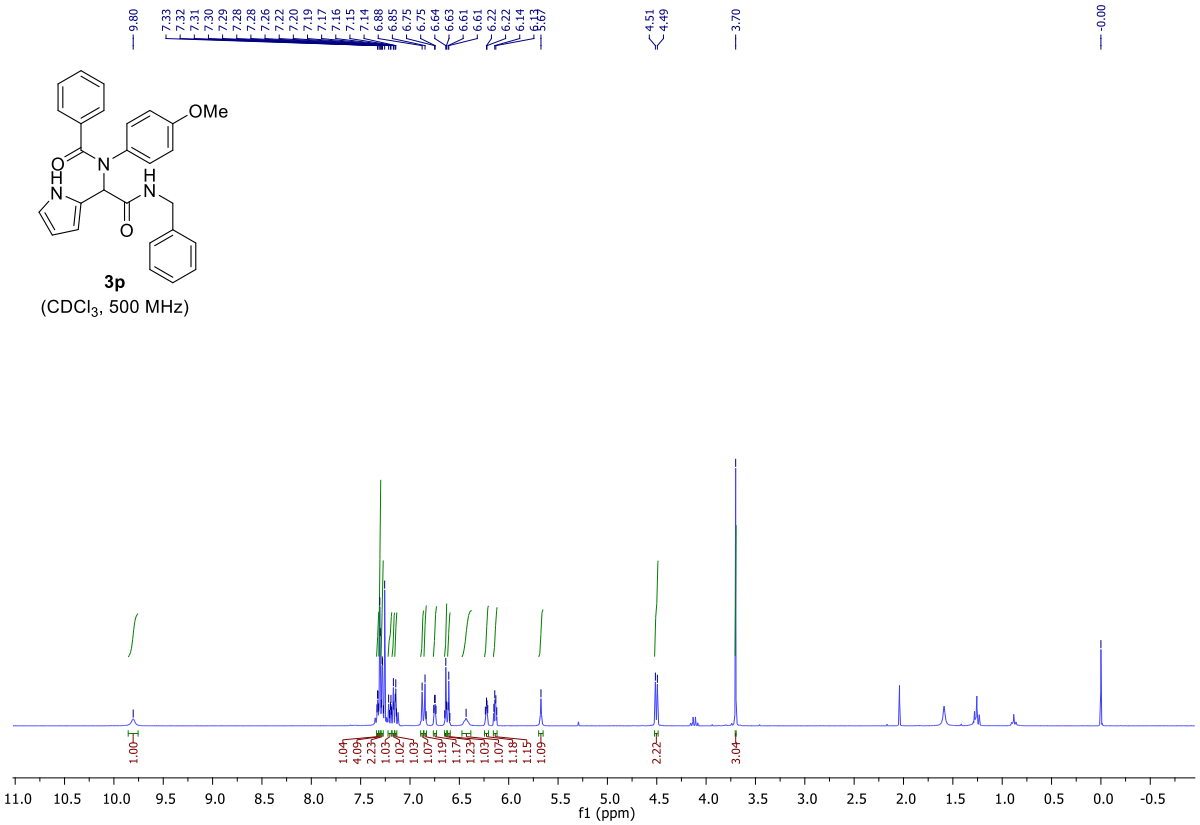


Figure S128: ^{13}C NMR of compound **3p**

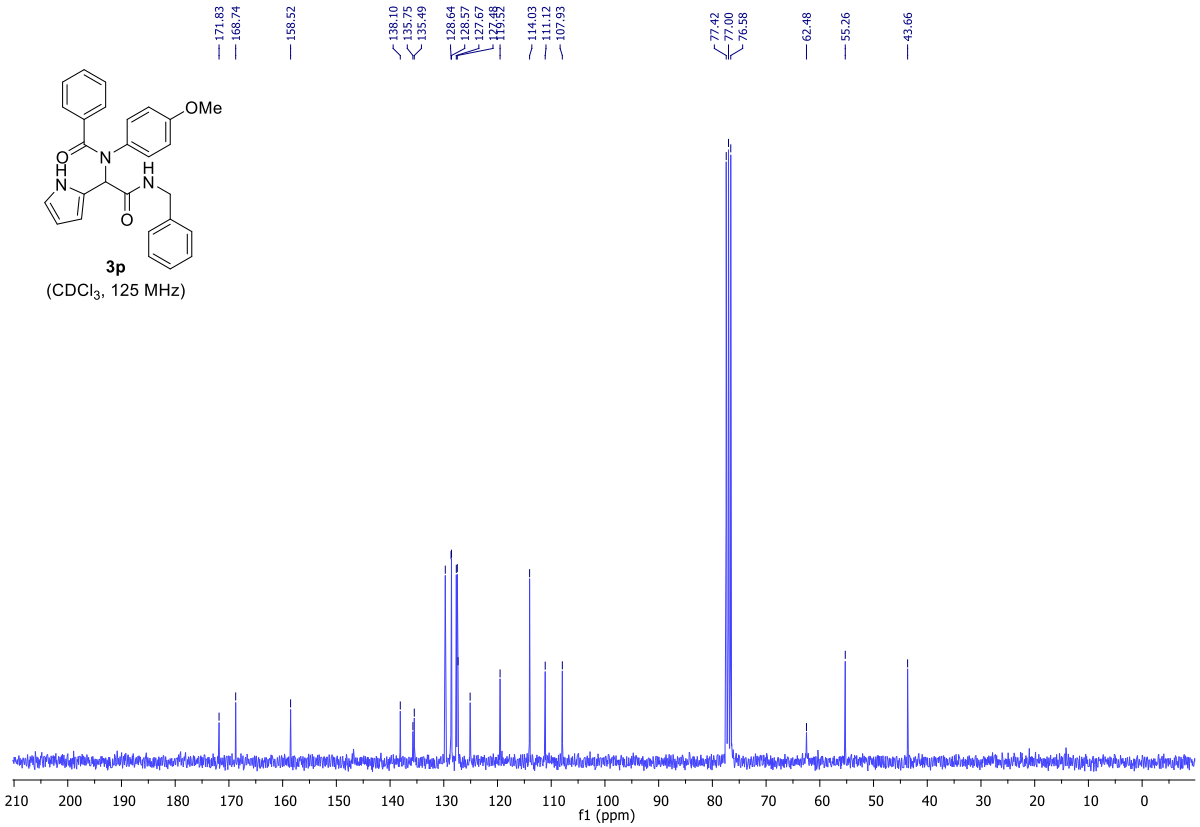


Figure S129: ^{1}H NMR of compound **3q**

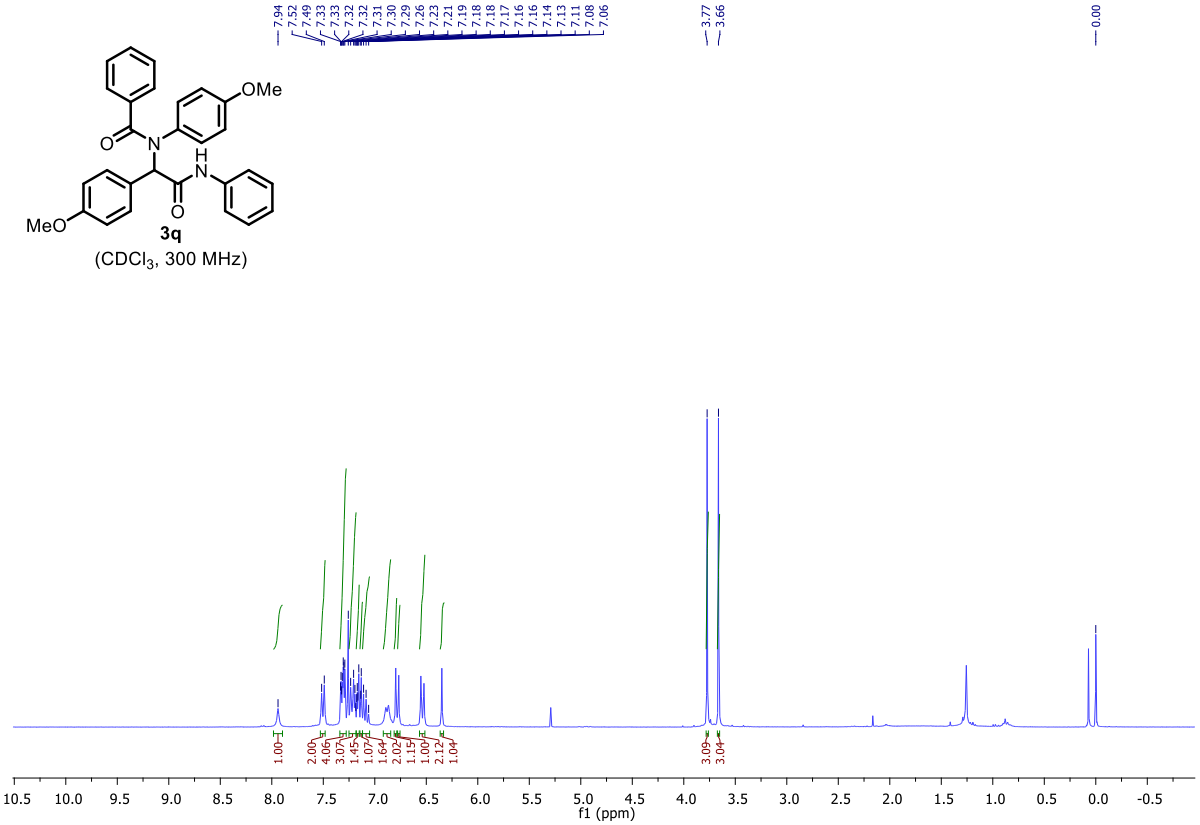


Figure S130: ^{13}C NMR of compound **3q**

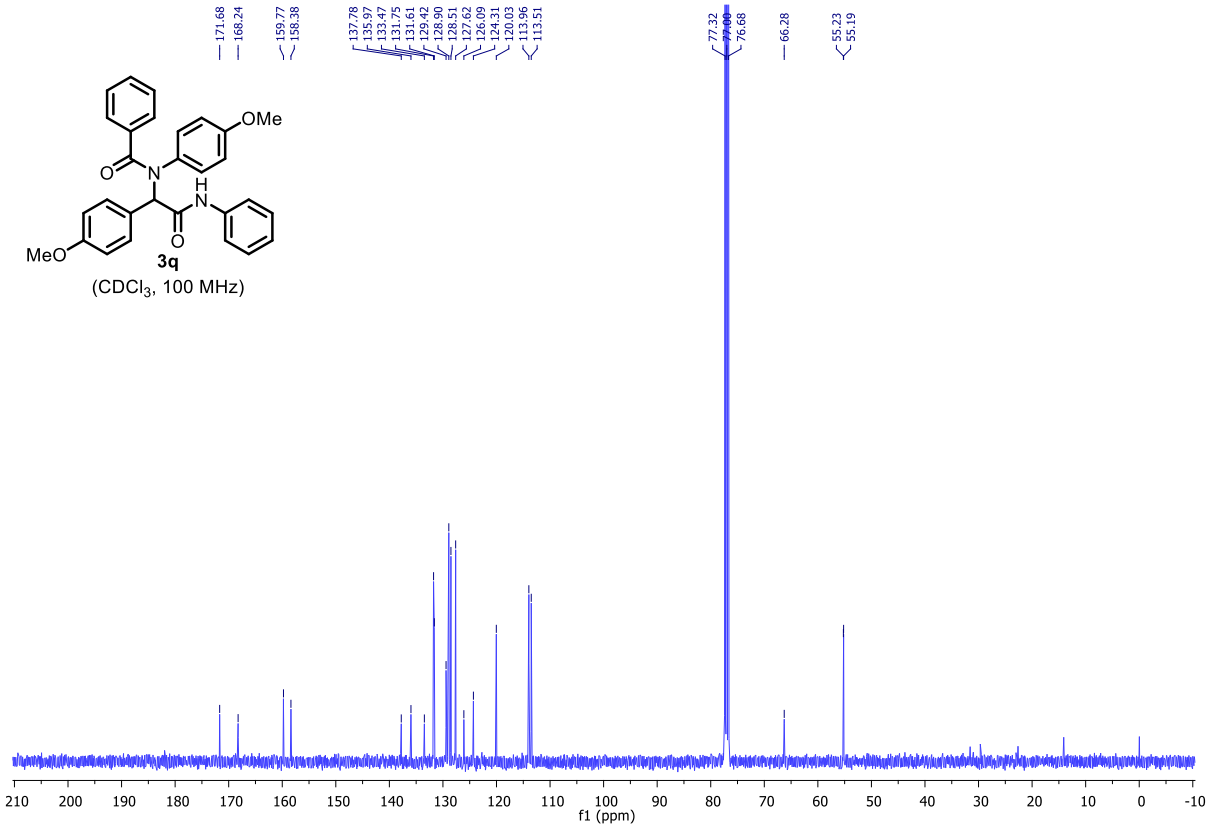


Figure S131: ^{1}H NMR of compound **3r**

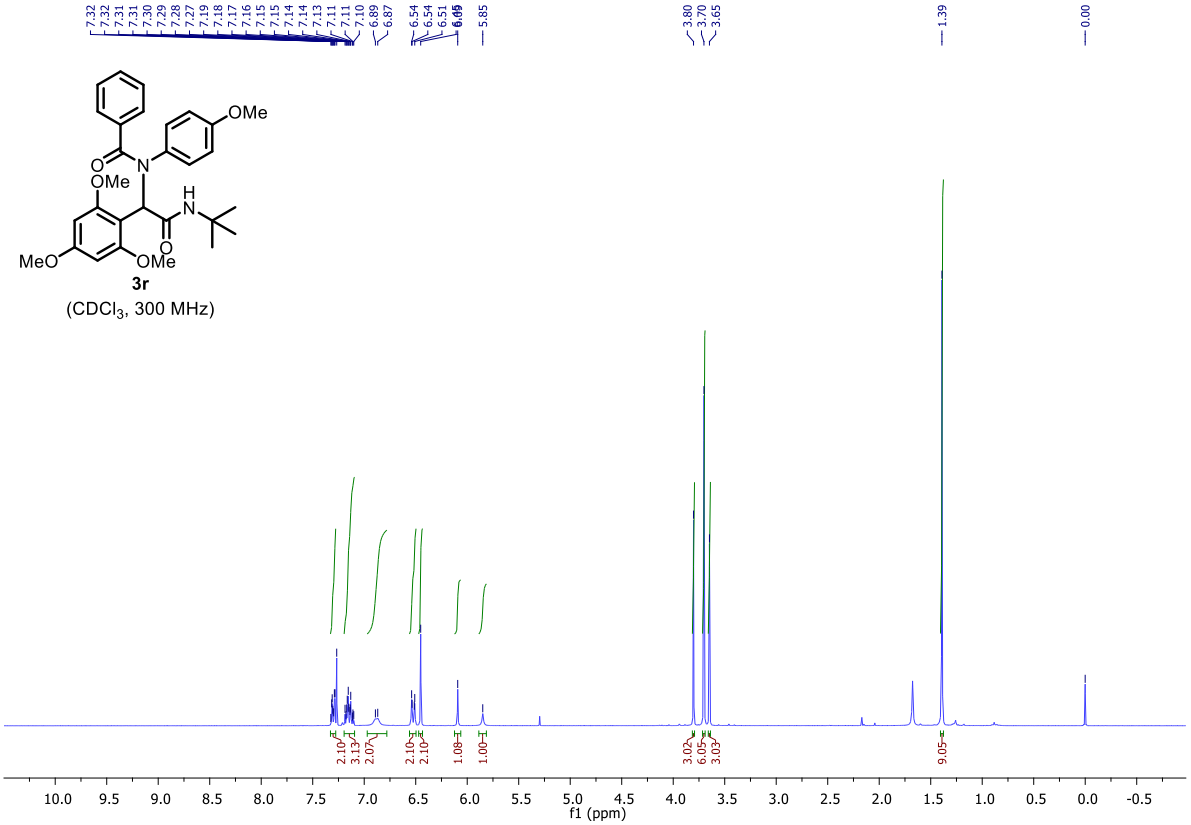


Figure S132: ^{13}C NMR of compound **3r**

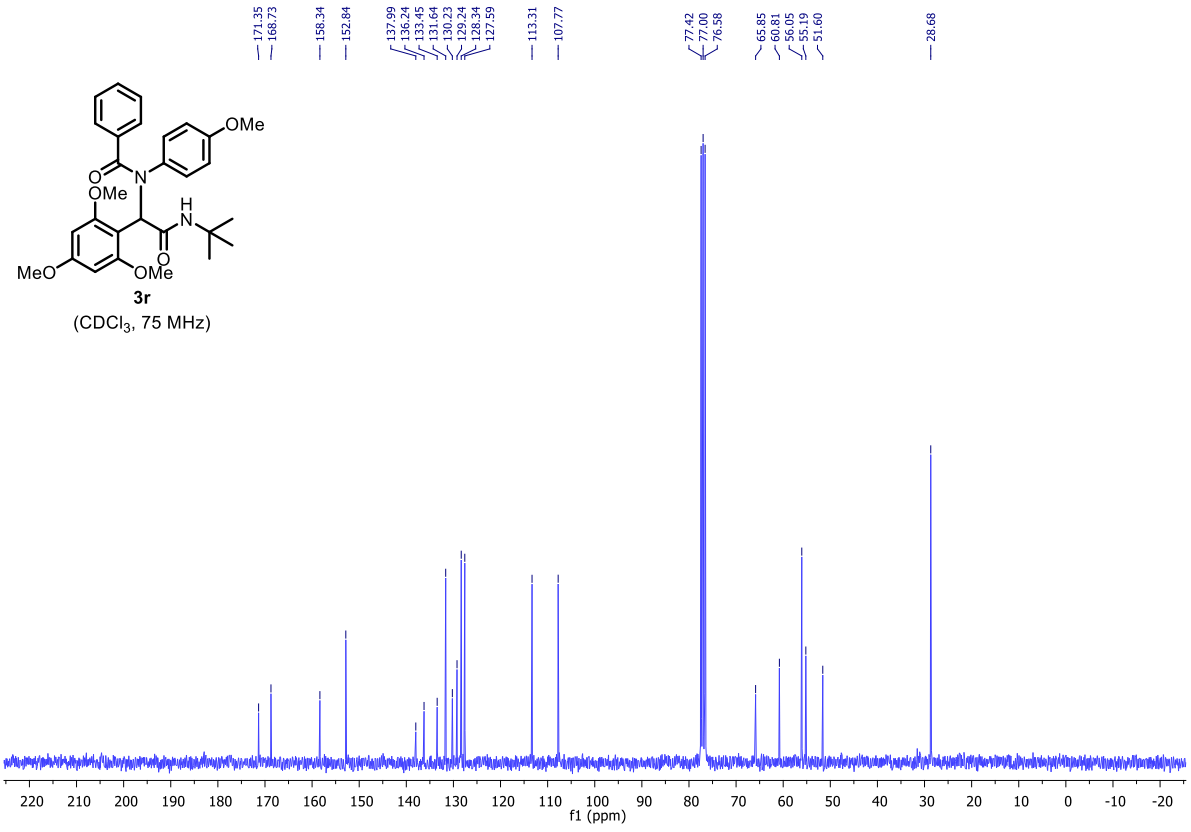


Figure S133: ^{1}H NMR of compound **3s**

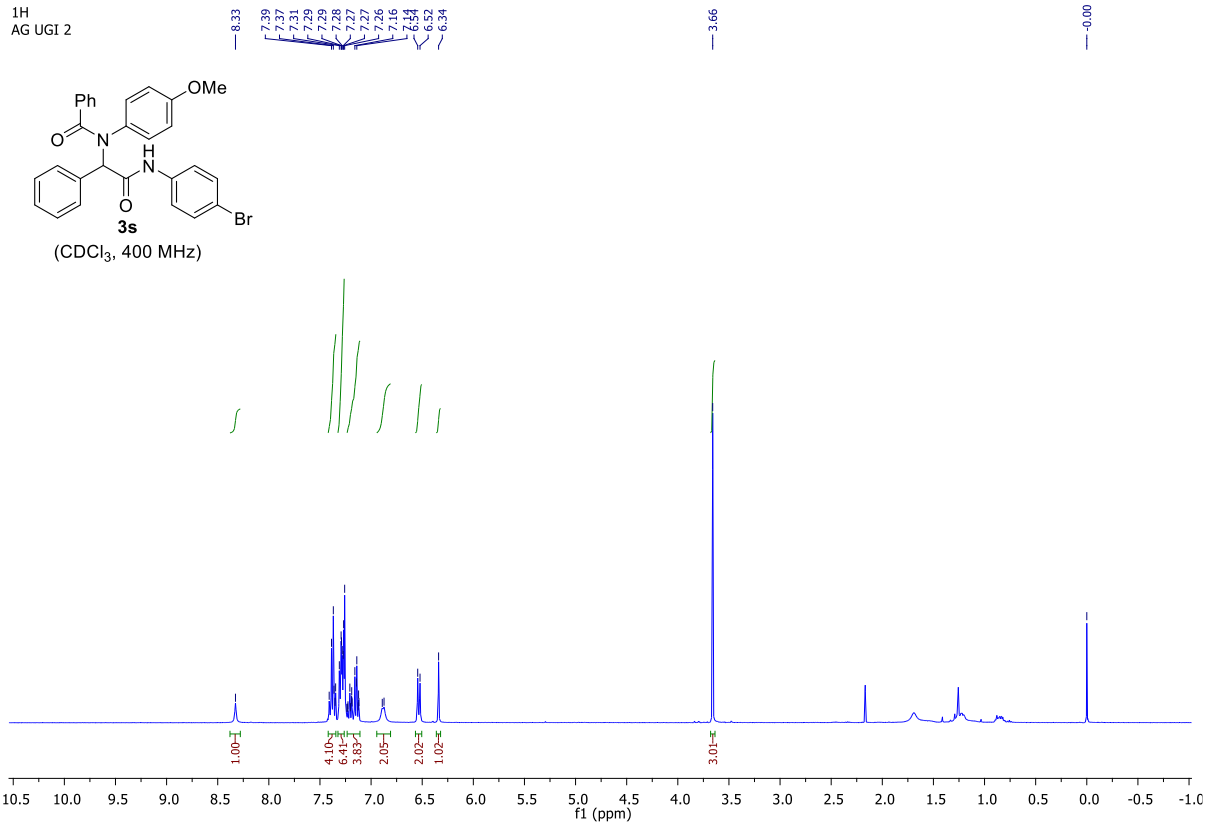


Figure S134: ^{13}C NMR of compound **3s**

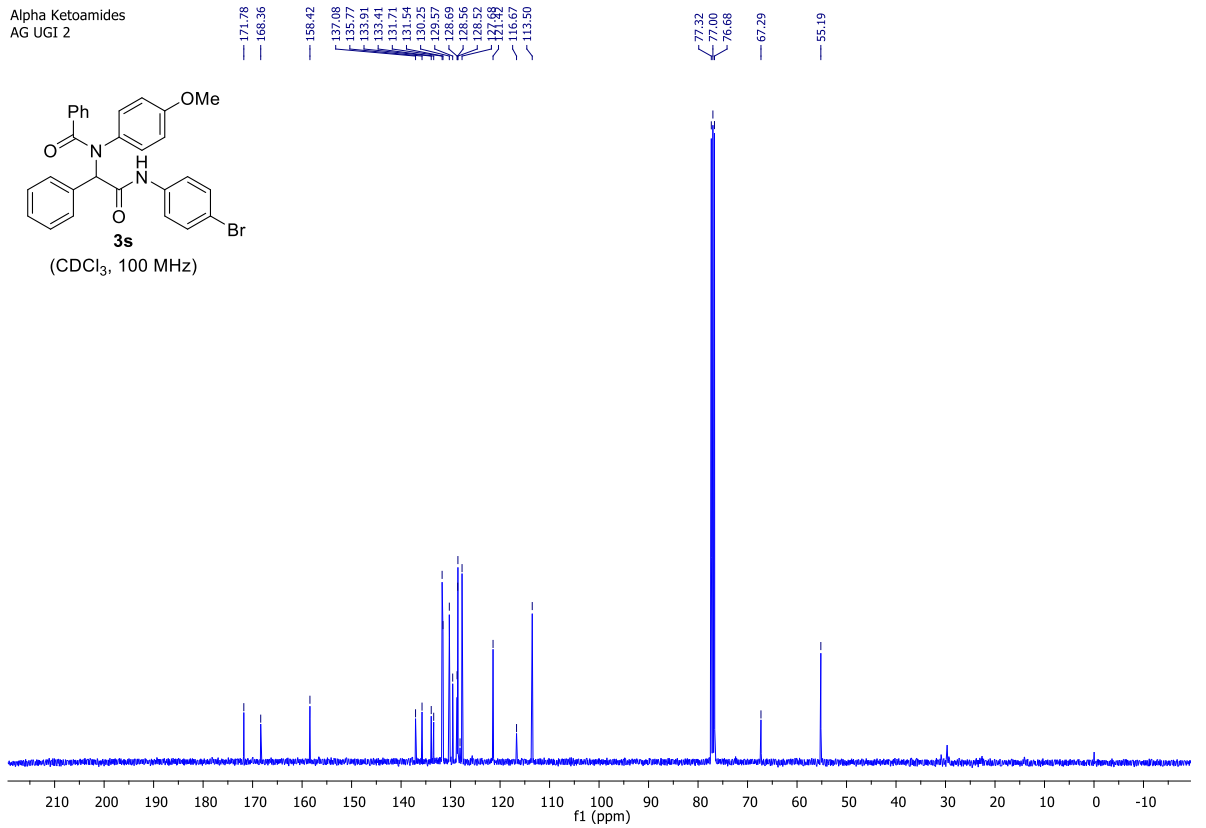


Figure S135: ^{1}H NMR of compound **3t**

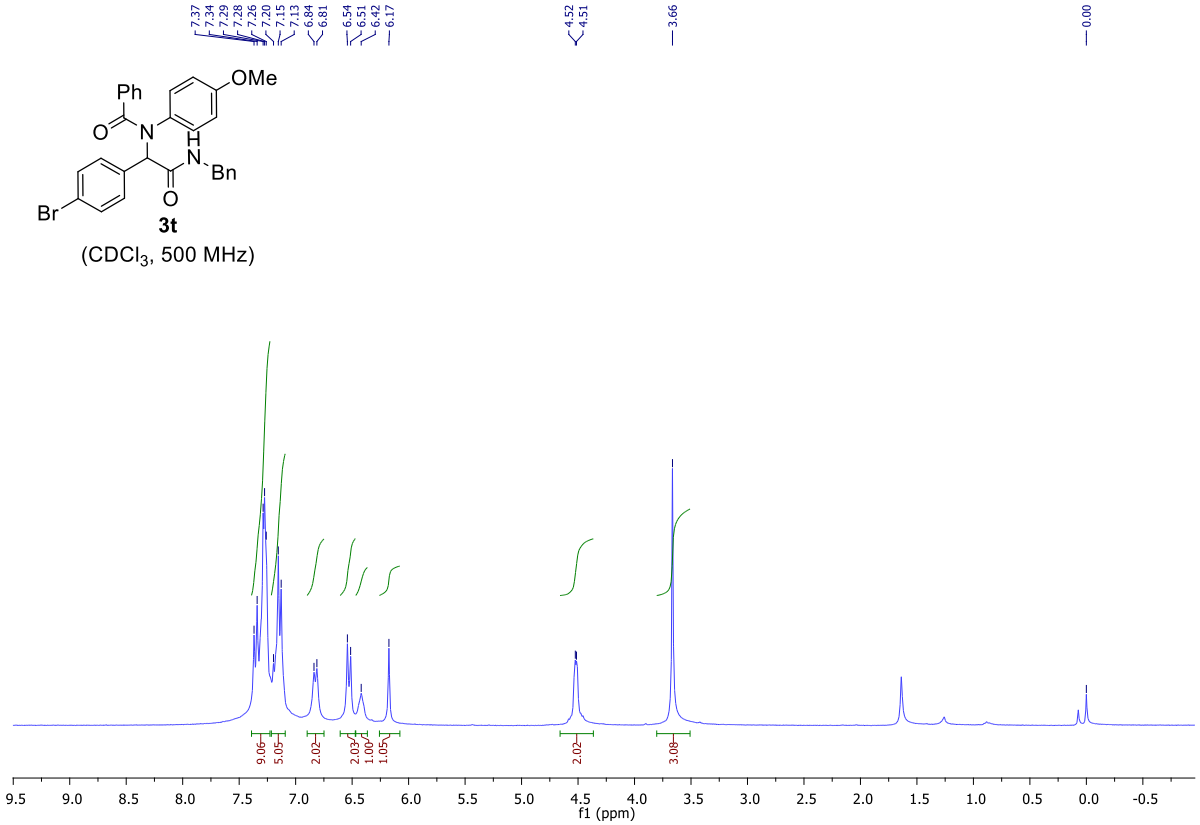


Figure S136: ^{13}C NMR of compound **3t**

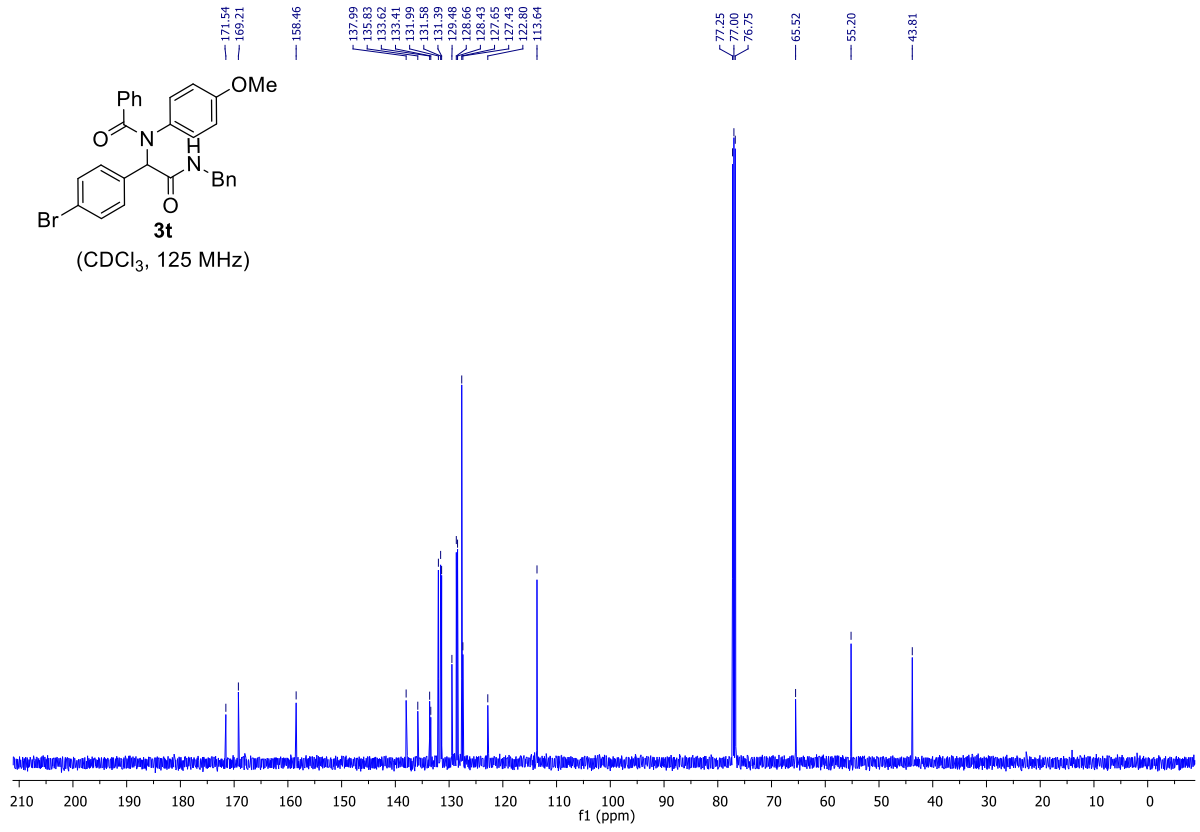


Figure S137: ^{1}H NMR of compound **3u**

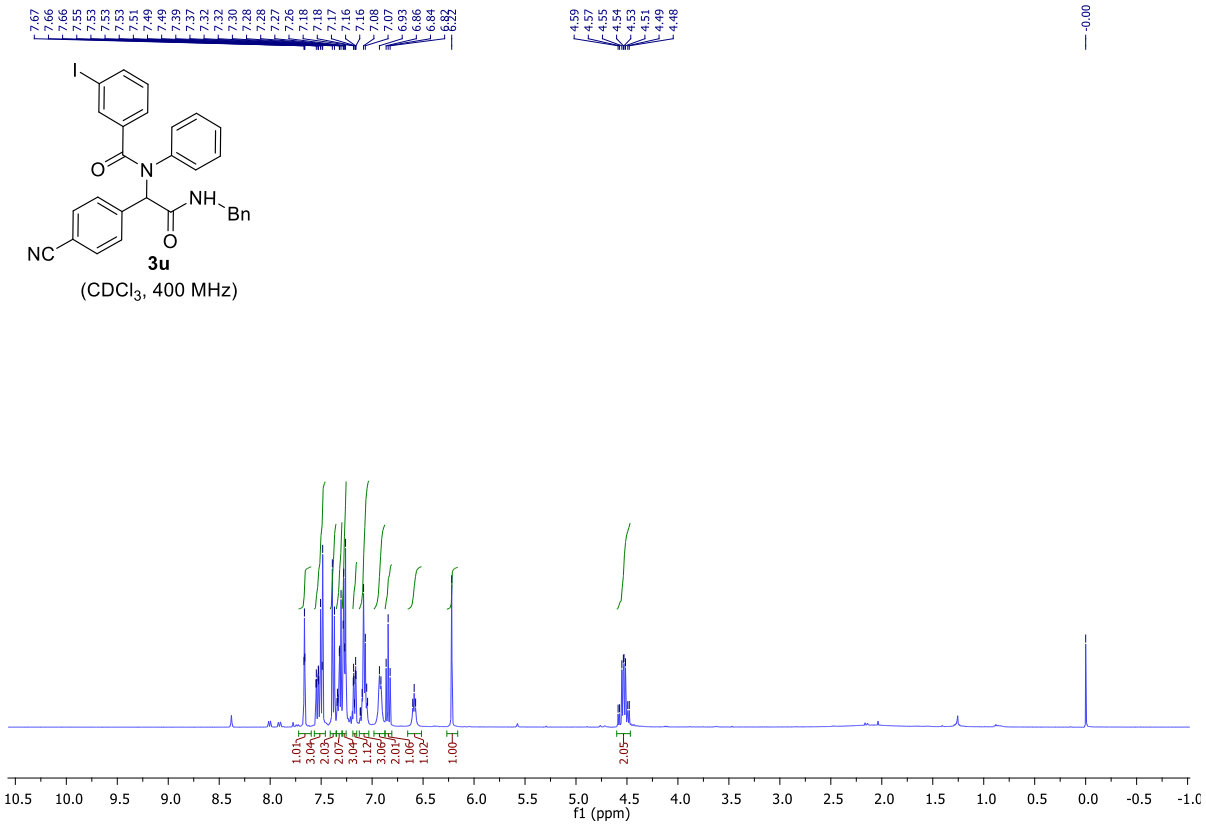


Figure S138: ^{13}C NMR of compound **3u**

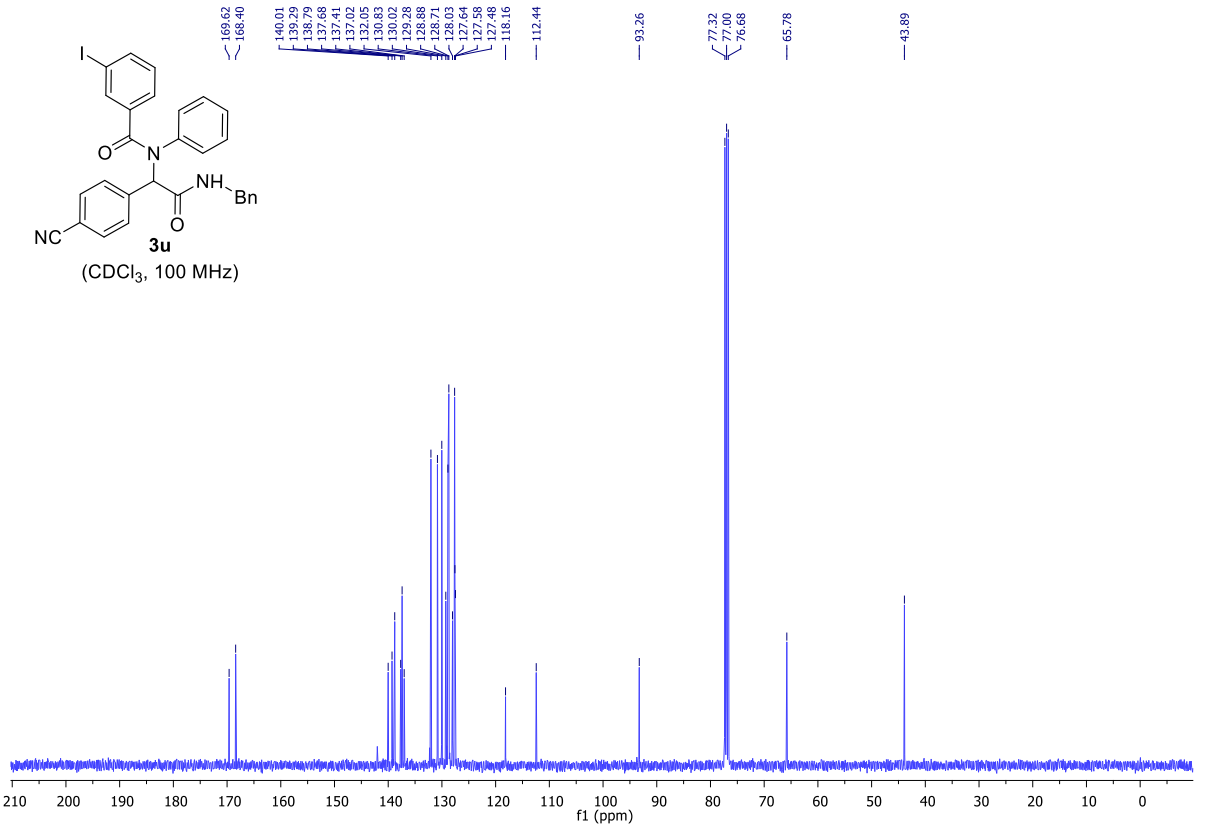


Figure S139: ^{1}H NMR of compound **4a**

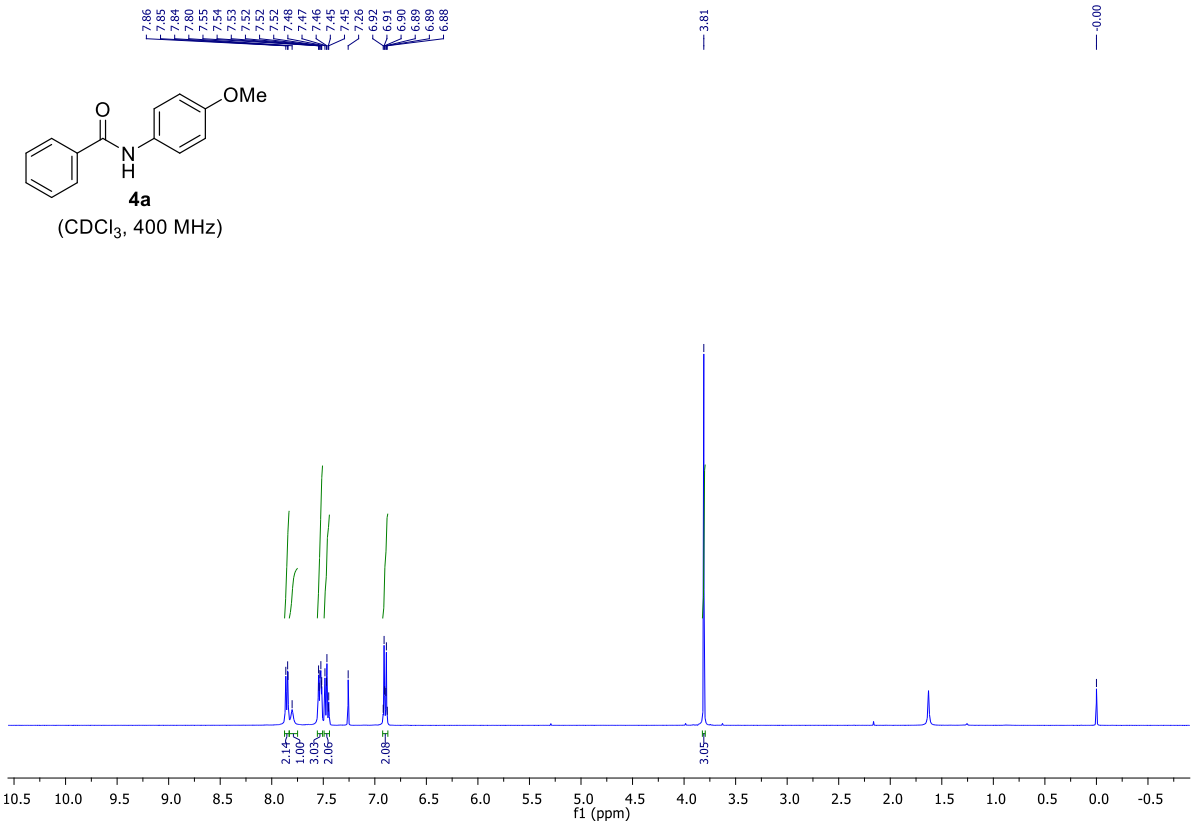


Figure S140: ^{13}C NMR of compound **4a**

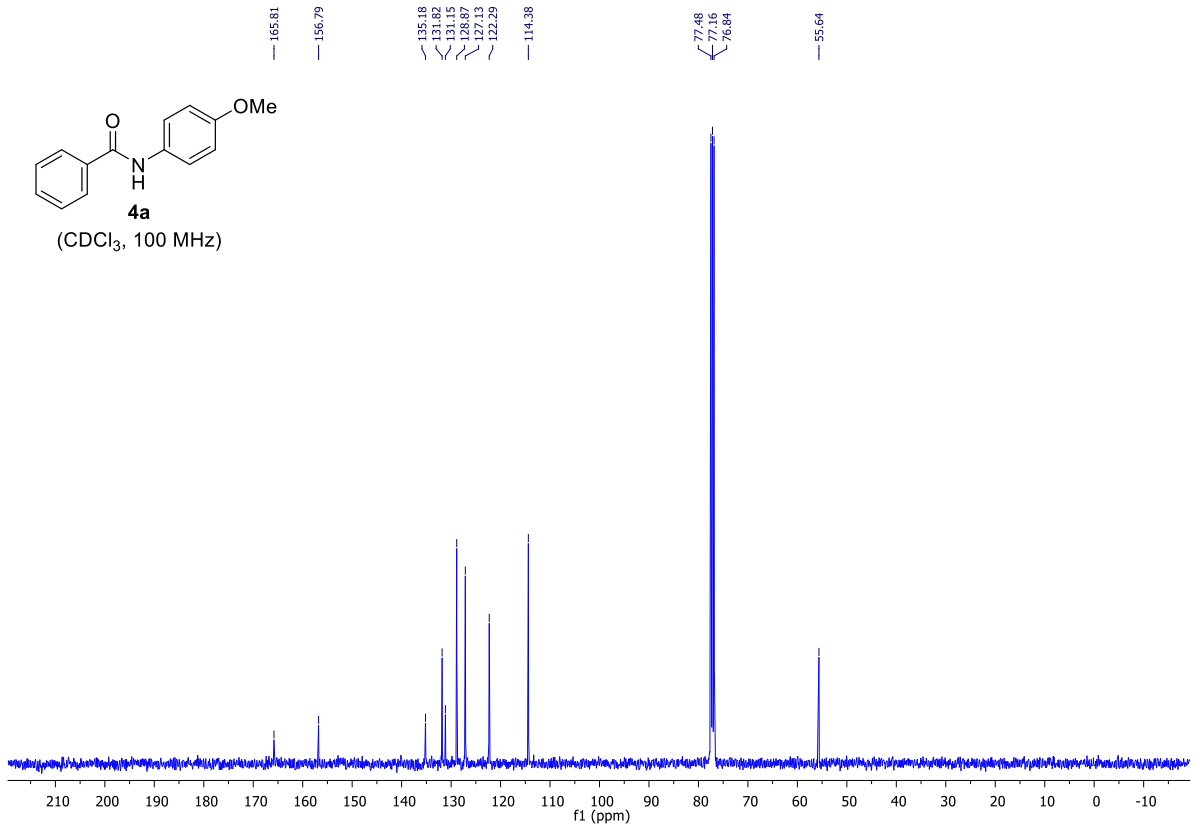


Figure S141: ^{1}H NMR of compound **4b**

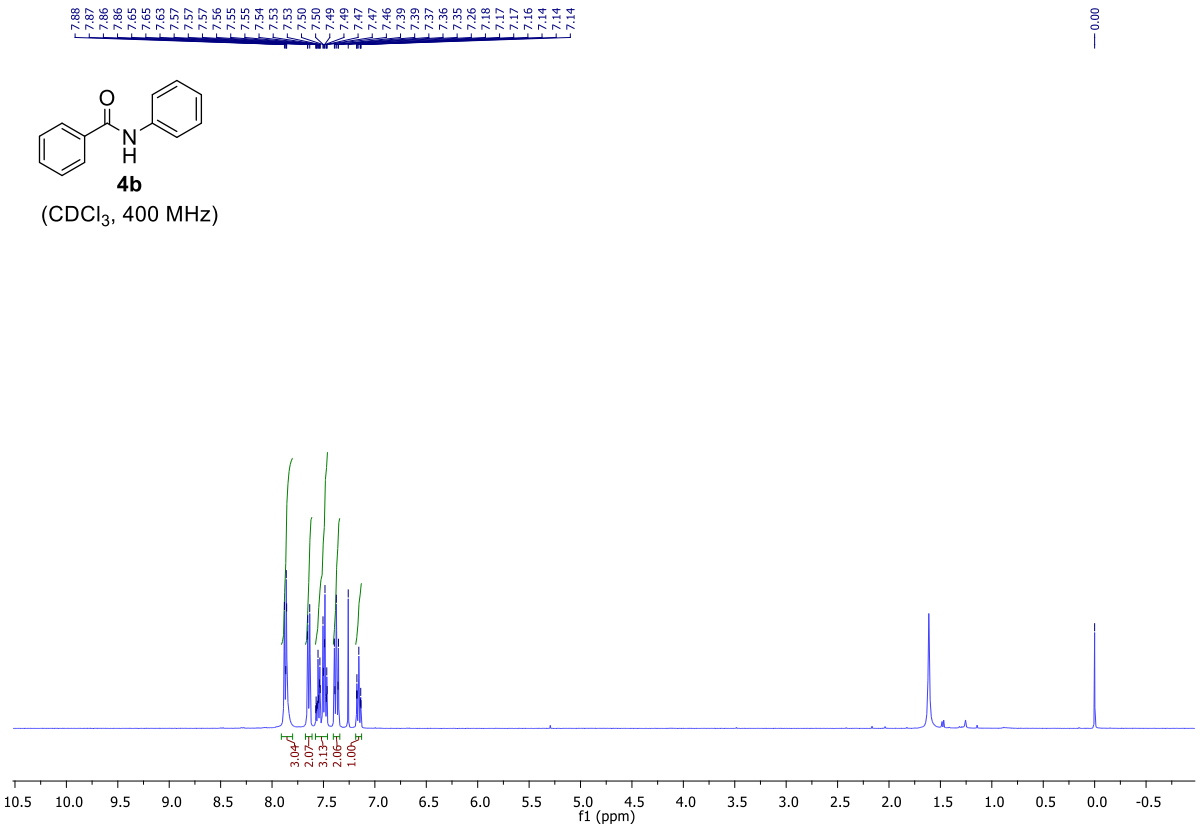


Figure S142: ^{13}C NMR of compound **4b**

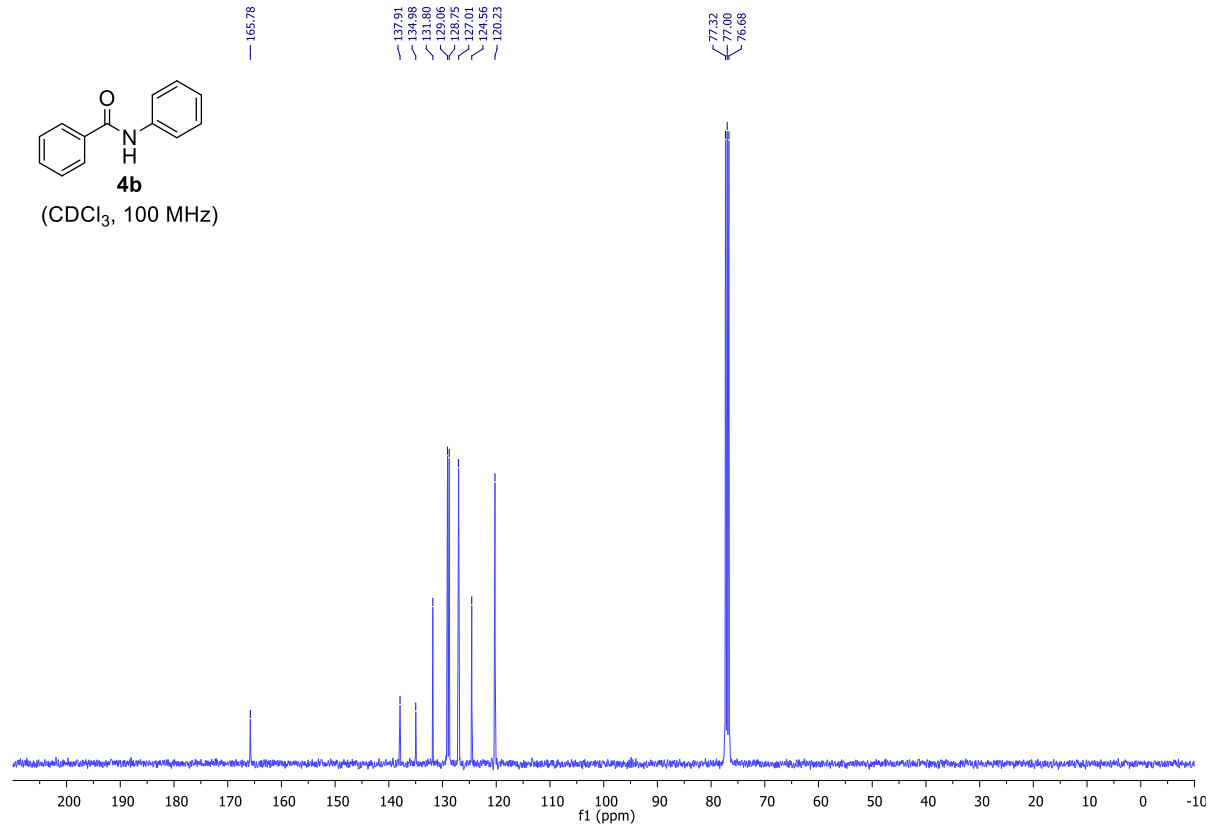


Figure S143: ^{1}H NMR of compound **4c**

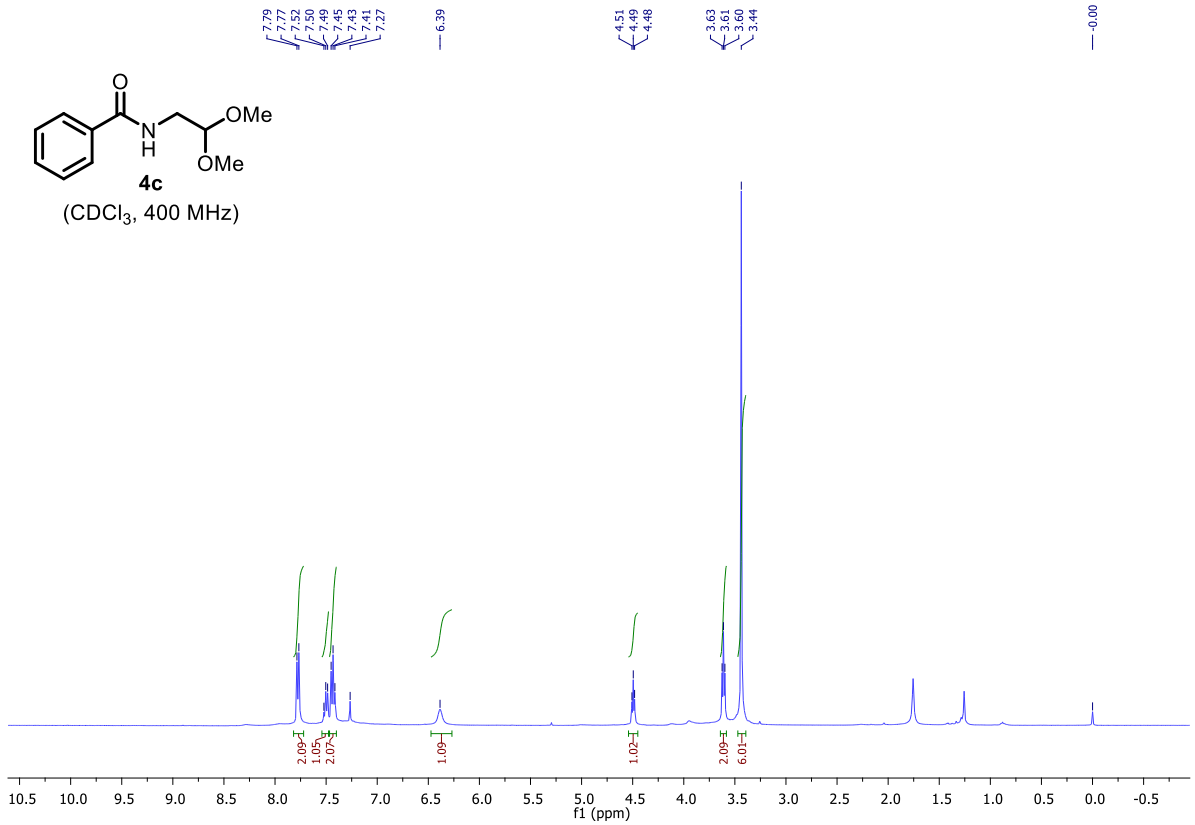


Figure S144: ^{13}C NMR of compound **4c**

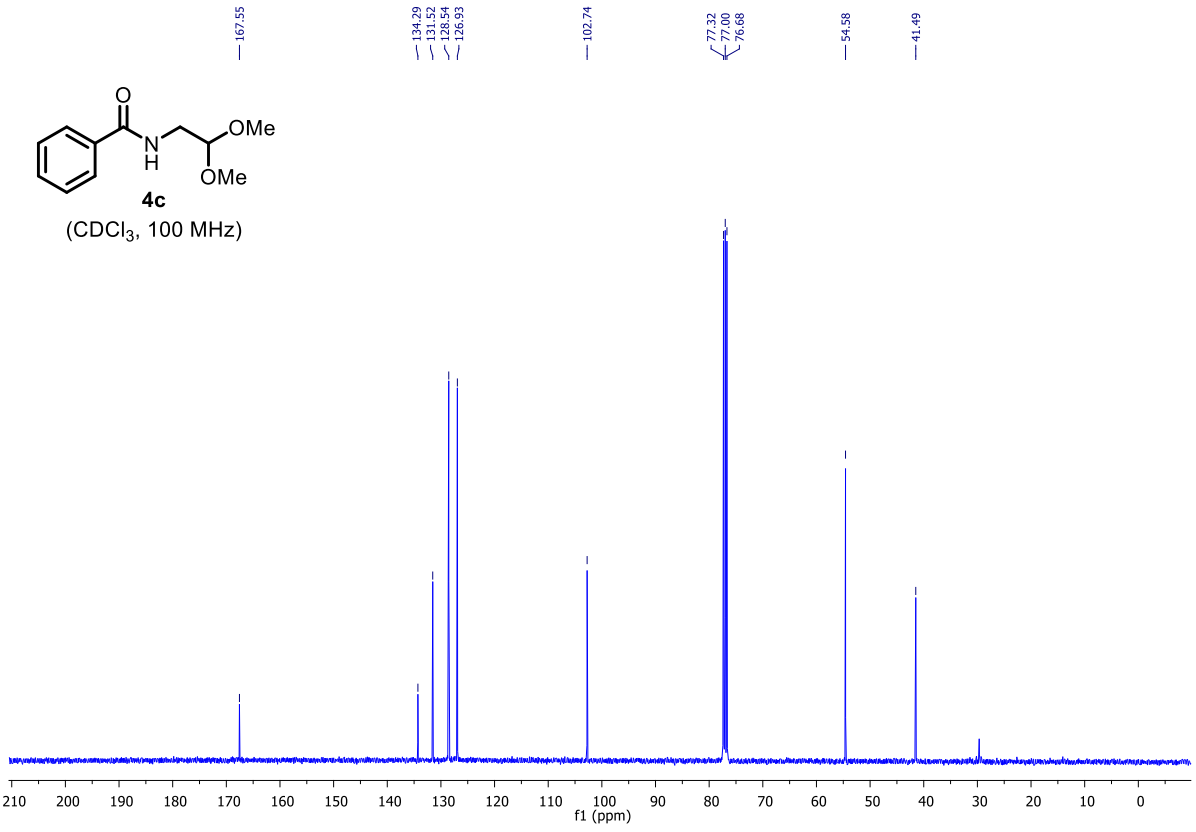


Figure S145: ^{1}H NMR of compound **4d**

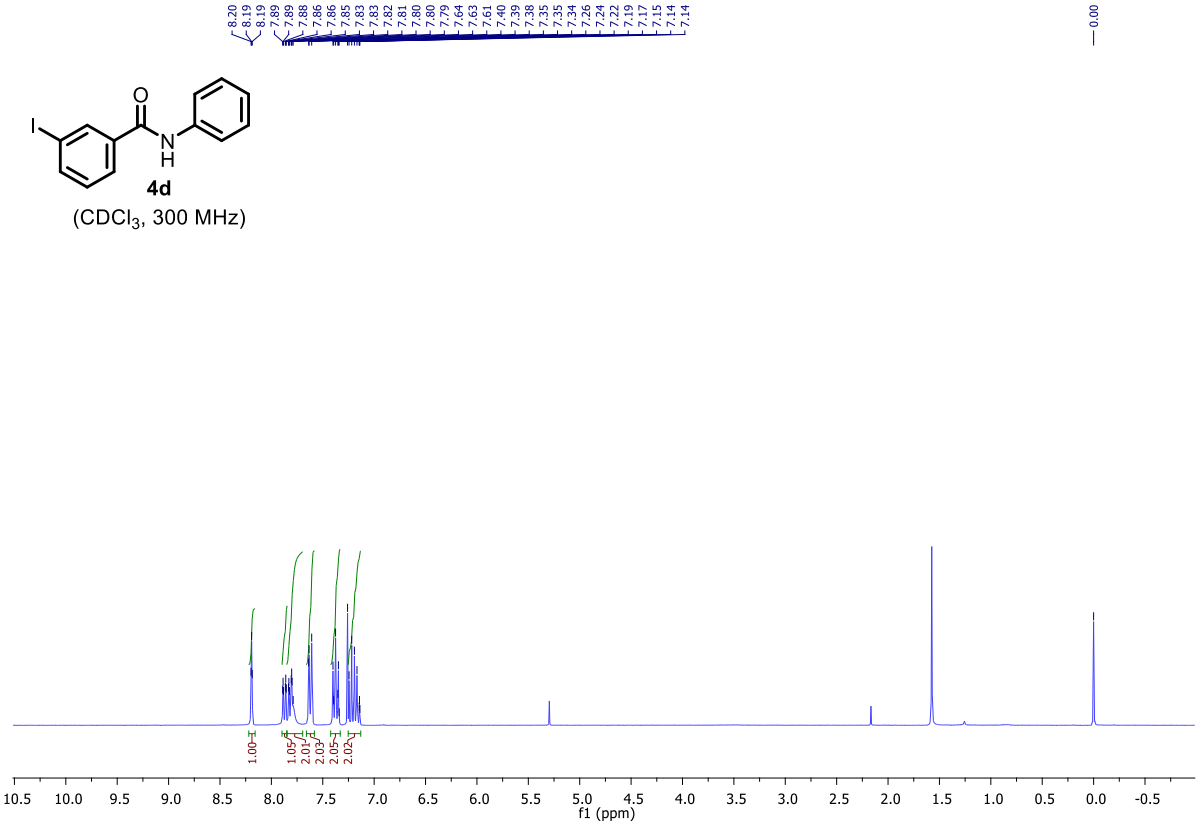


Figure S146: ^{13}C NMR of compound **4d**

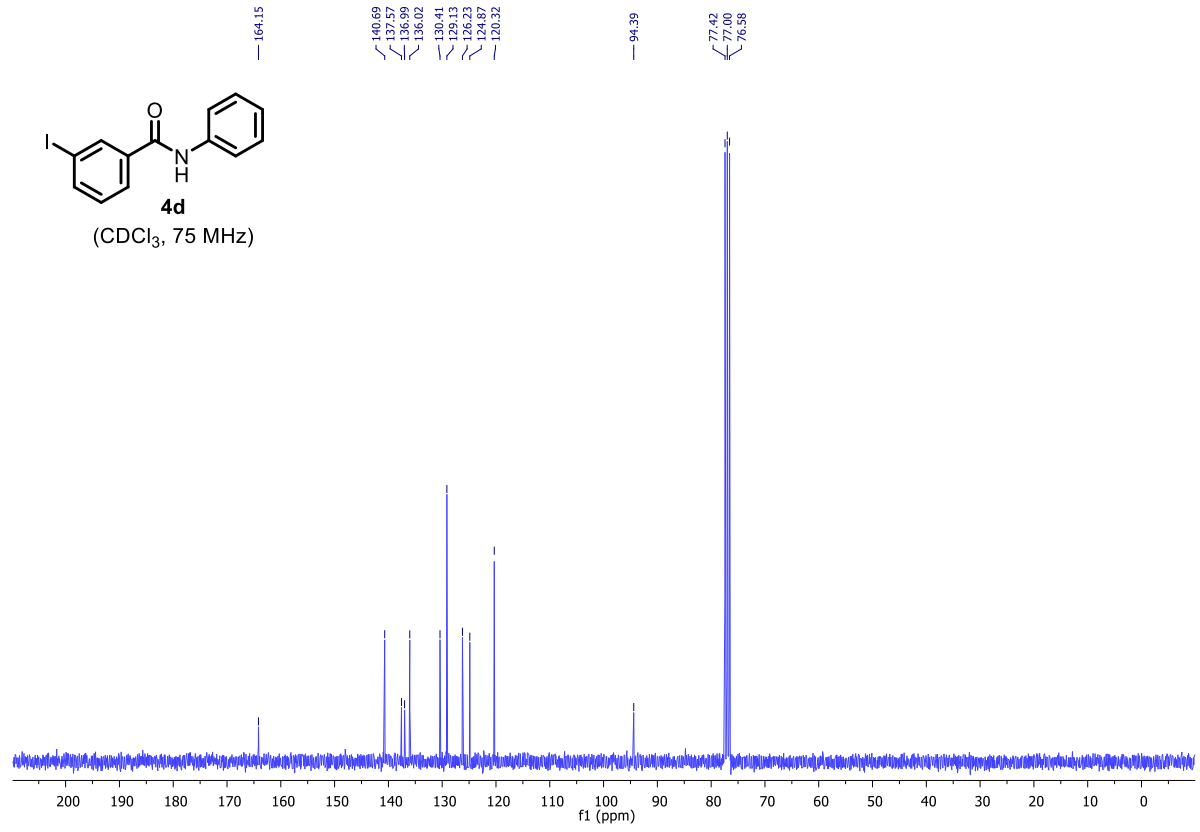


Figure S147: ^{1}H NMR of compound **5a**

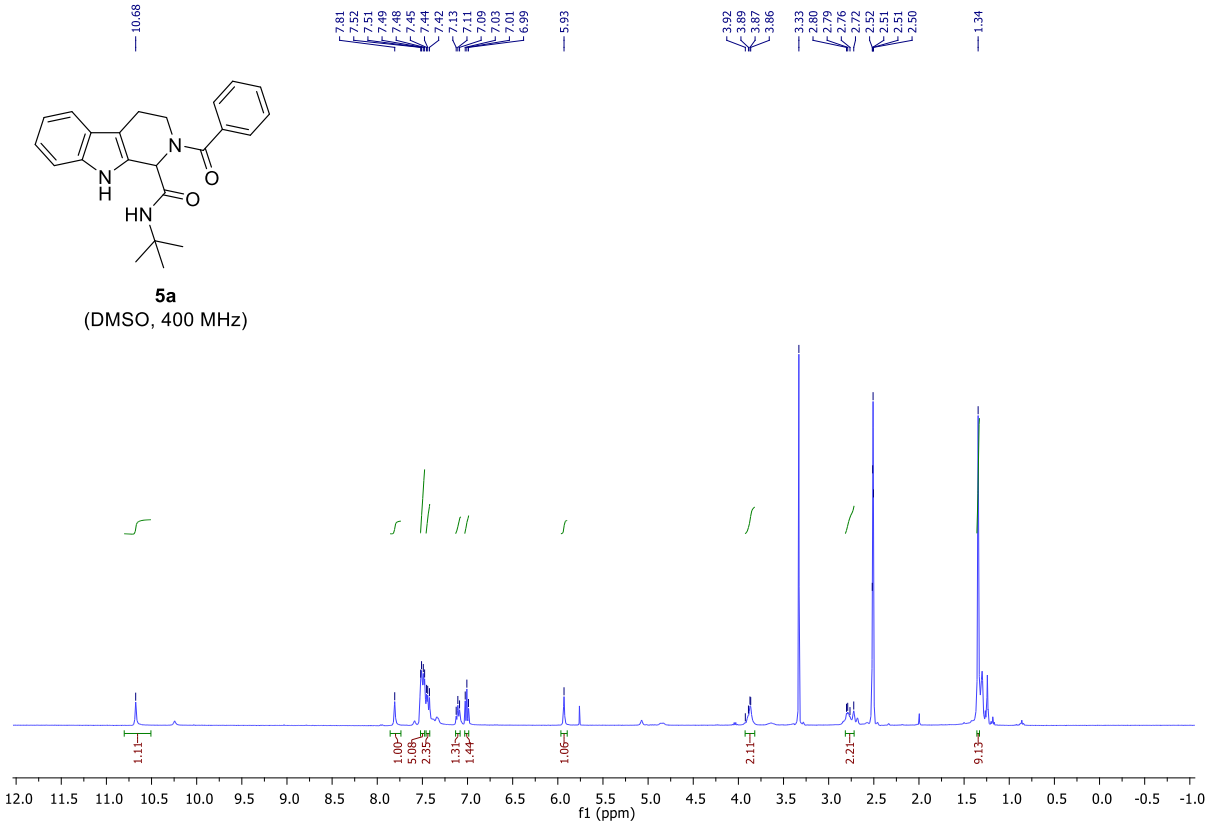


Figure S148: ^{13}C NMR of compound **5a**

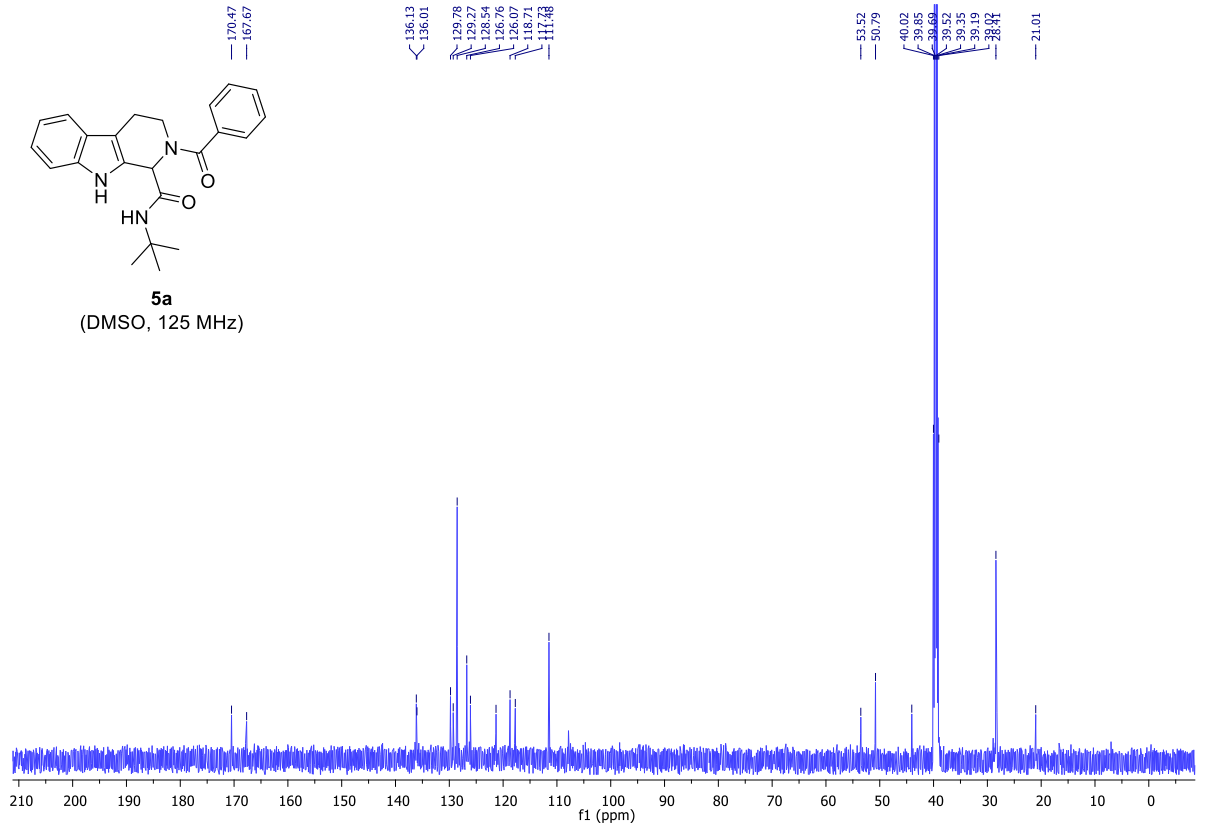


Figure S149: ^{1}H NMR of compound **5b**

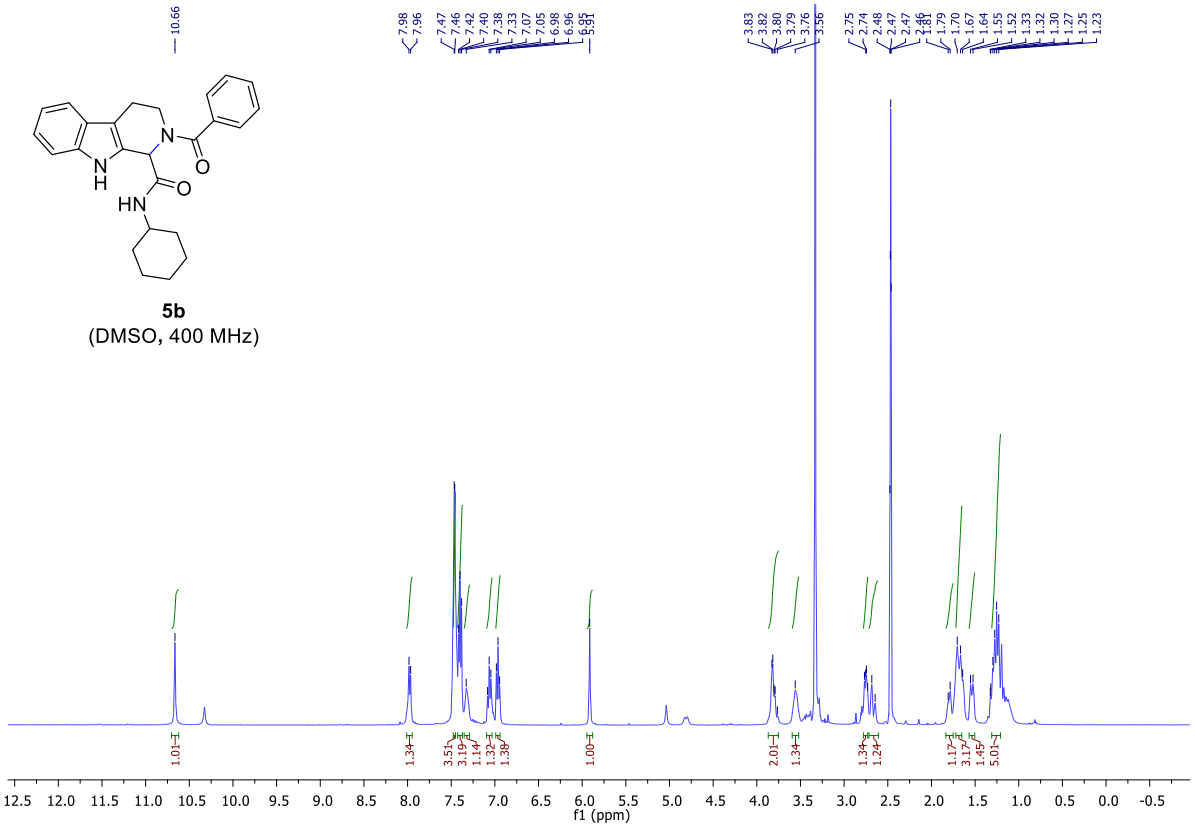


Figure S150: ^{13}C NMR of compound **5b**

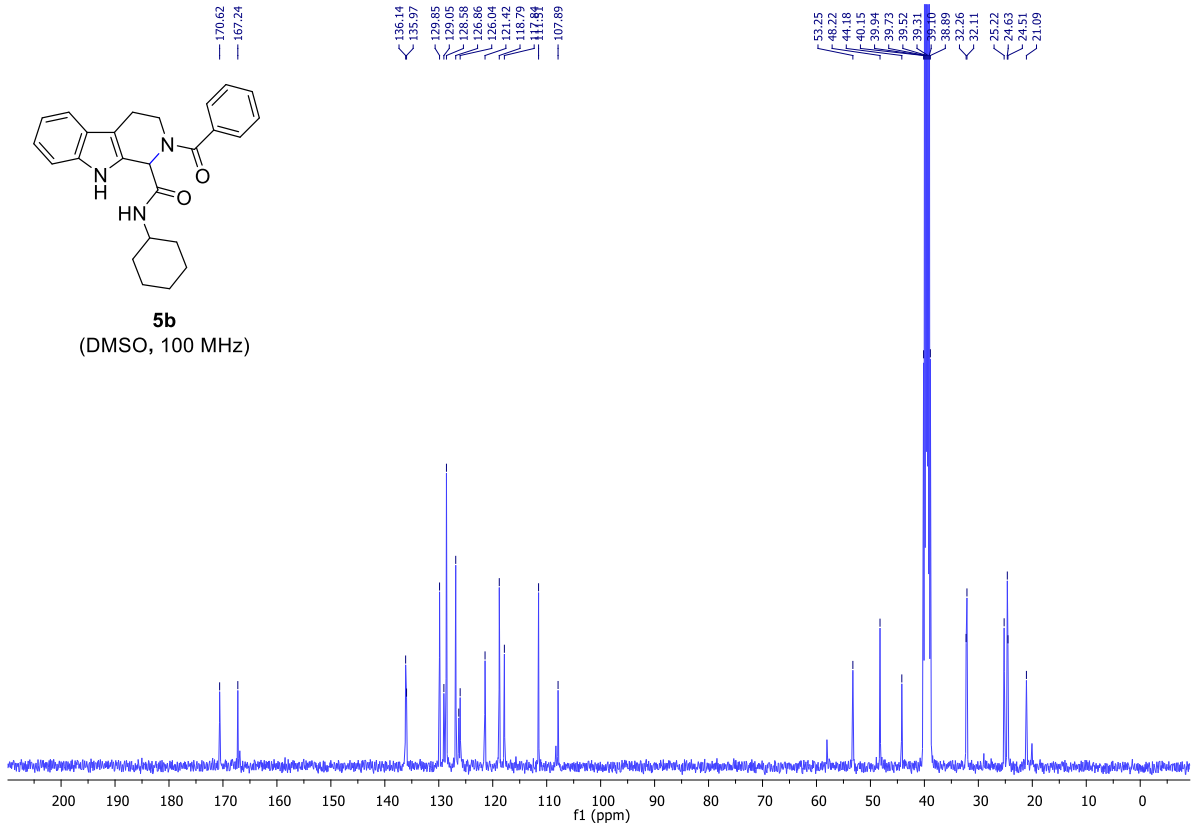


Figure S151: ^{1}H NMR of compound **5c**

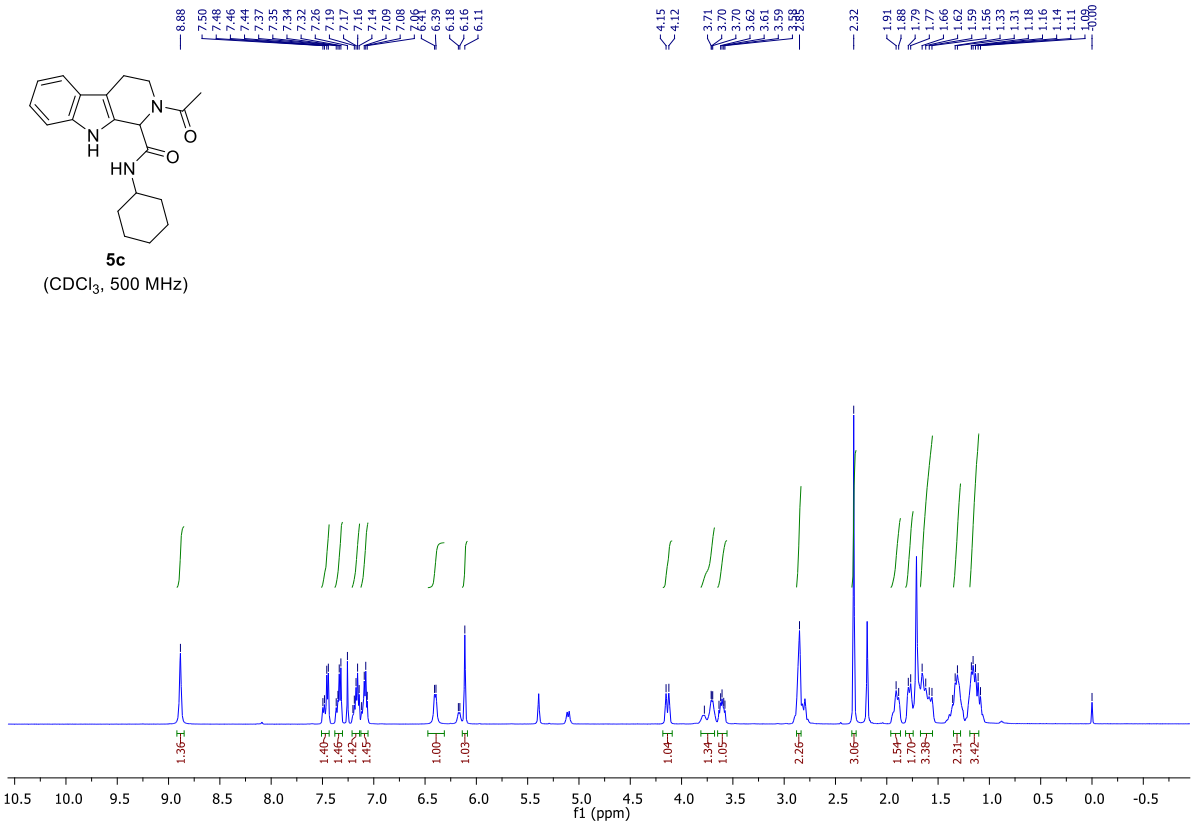


Figure S152: ^{13}C NMR of compound **5c**

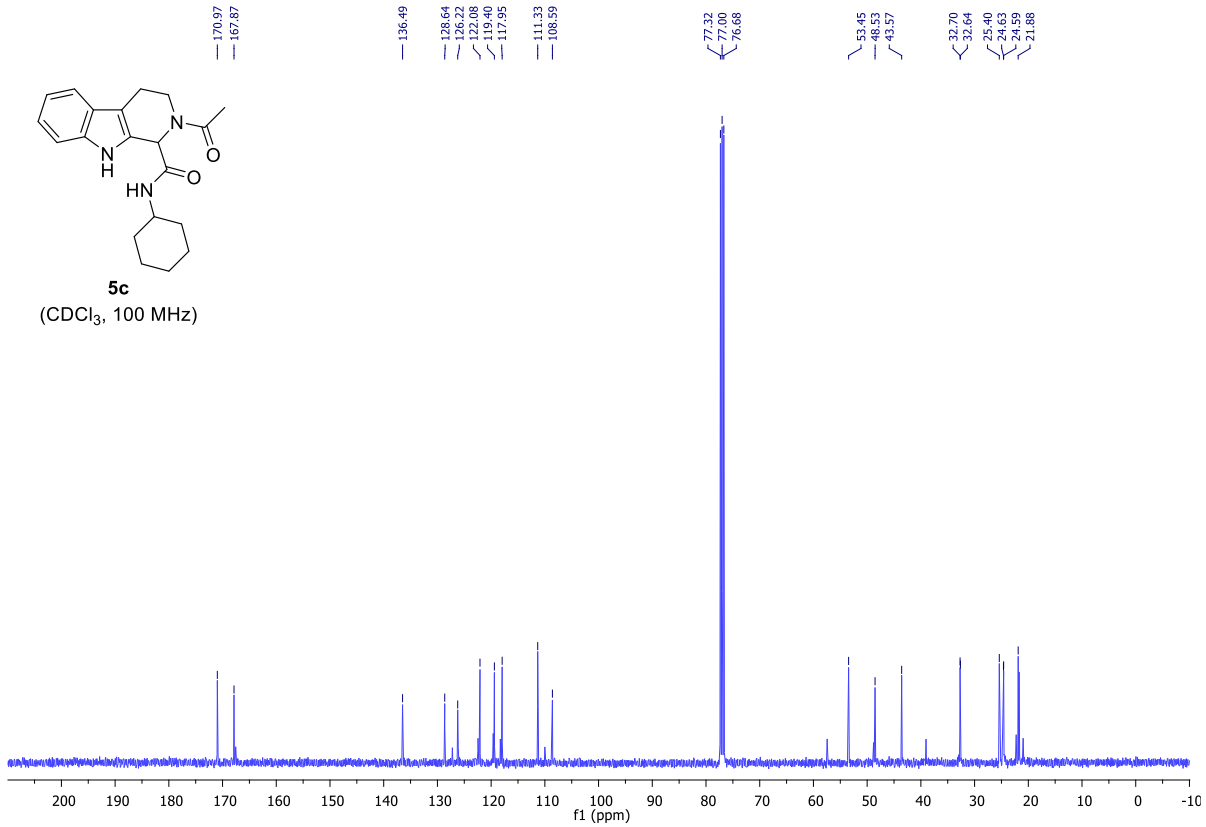


Figure S153: ^{1}H NMR of compound **6a**

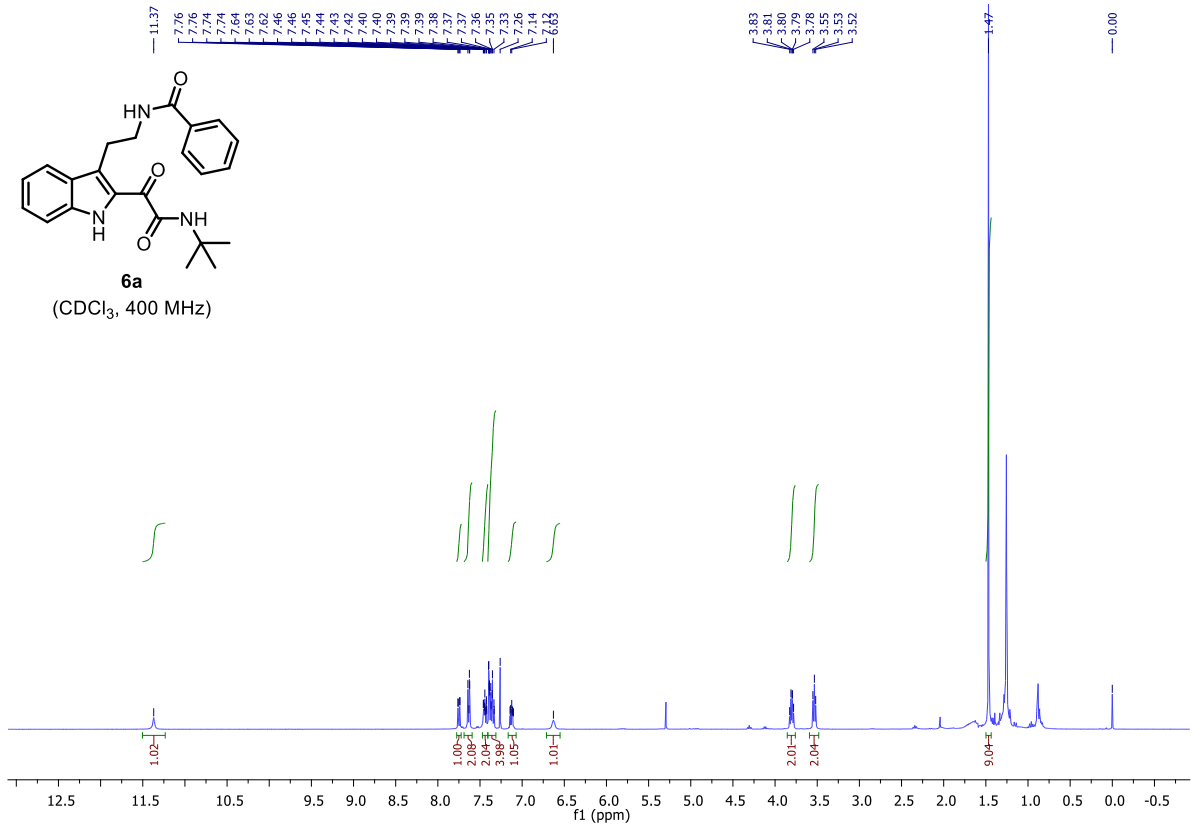


Figure S154: ^{13}C NMR of compound **6a**

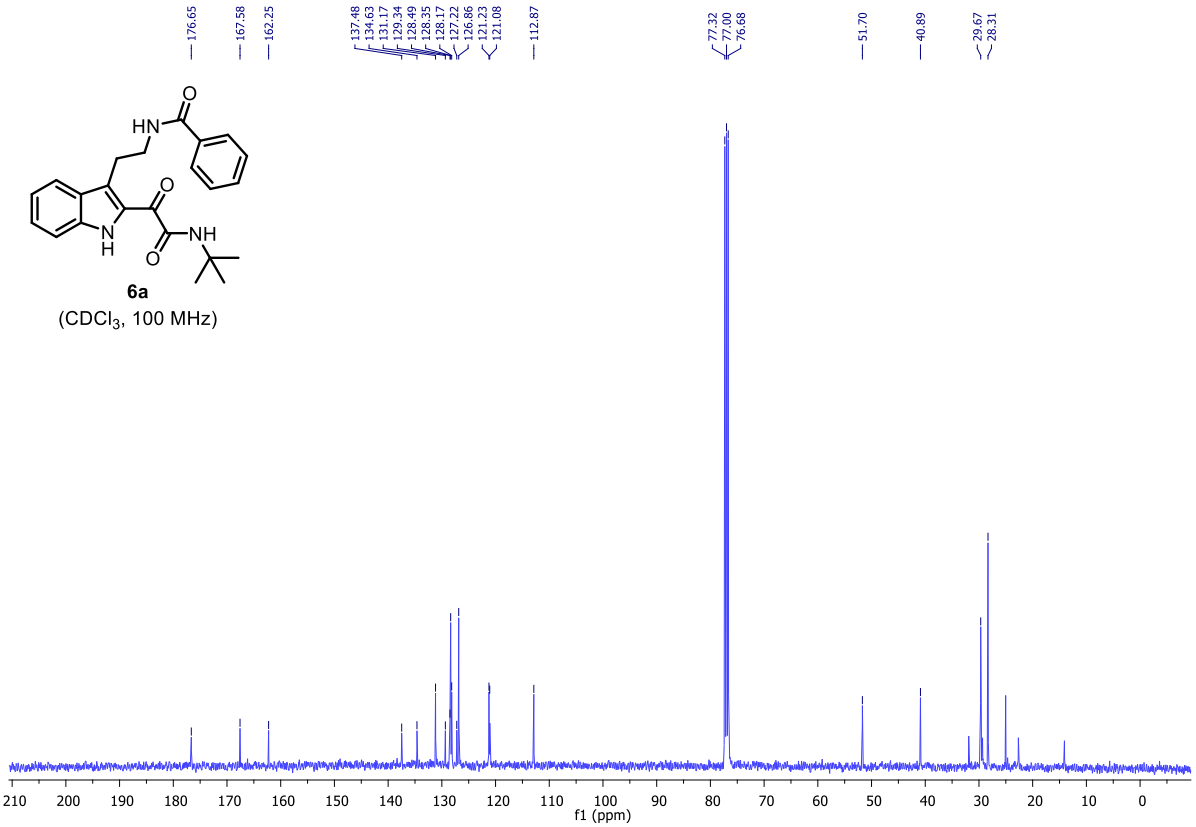


Figure S155: ^{1}H NMR of compound **6b**

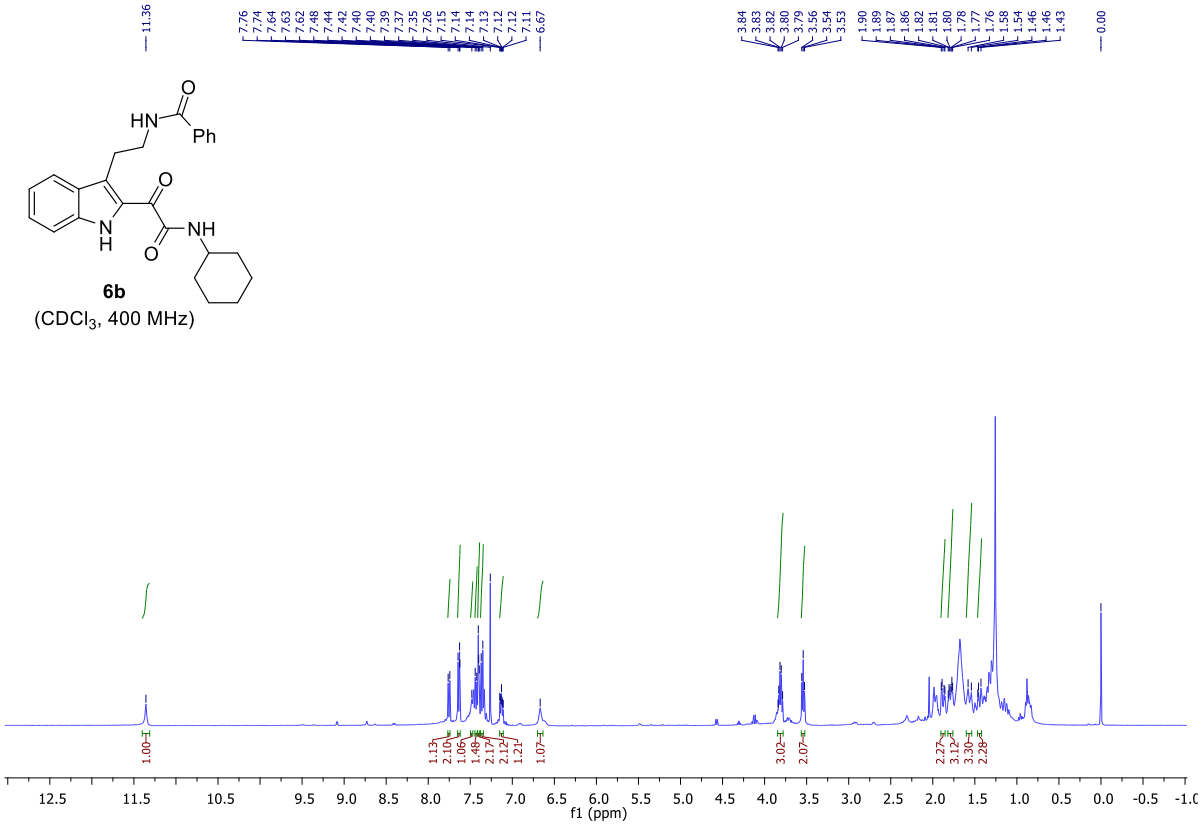


Figure S156: ^{13}C NMR of compound **6b**

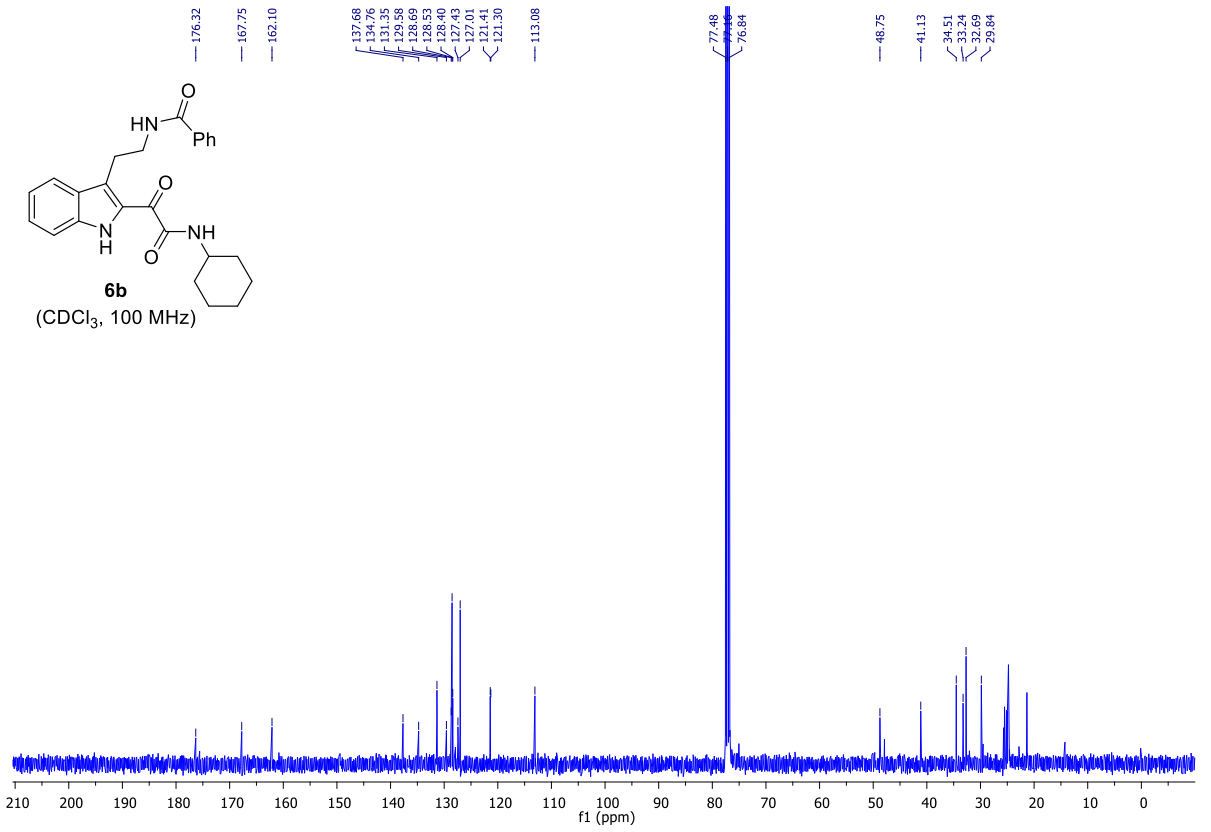


Figure S157: ^{1}H NMR of compound **6c**

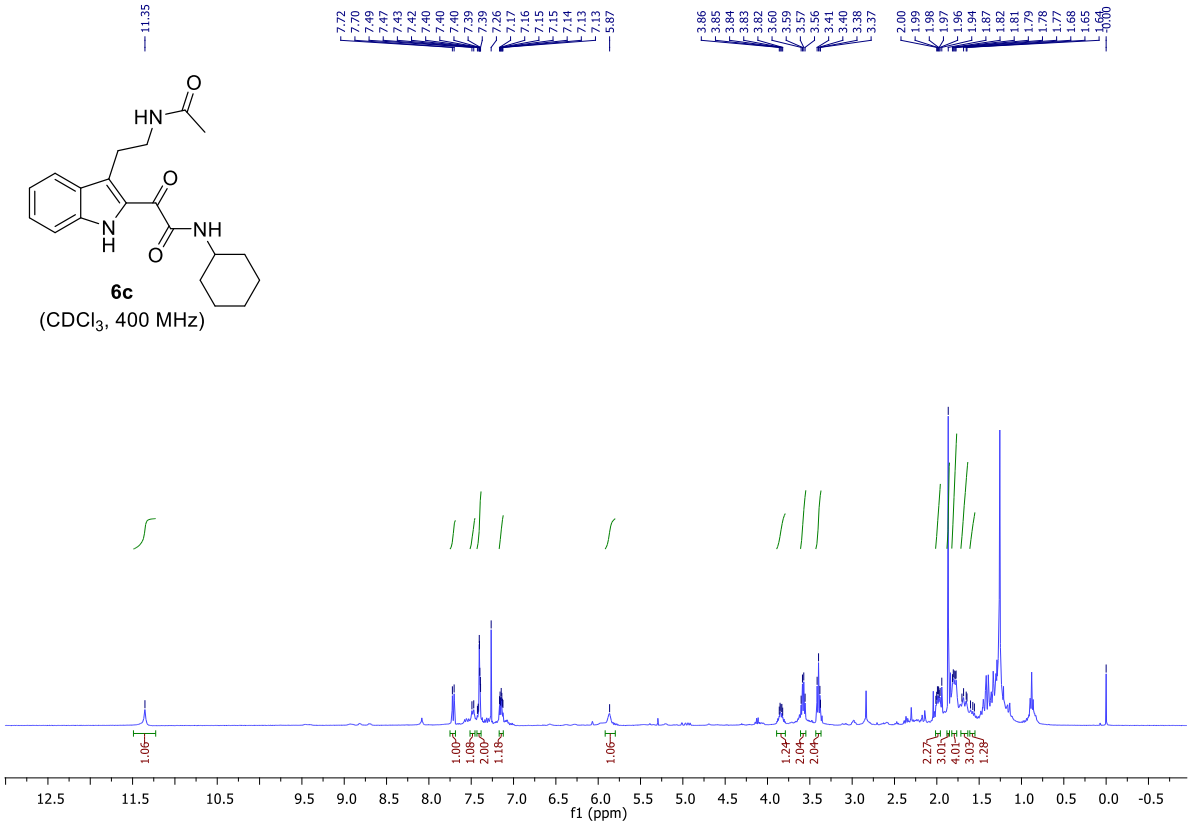


Figure S158: ^{13}C NMR of compound **6c**

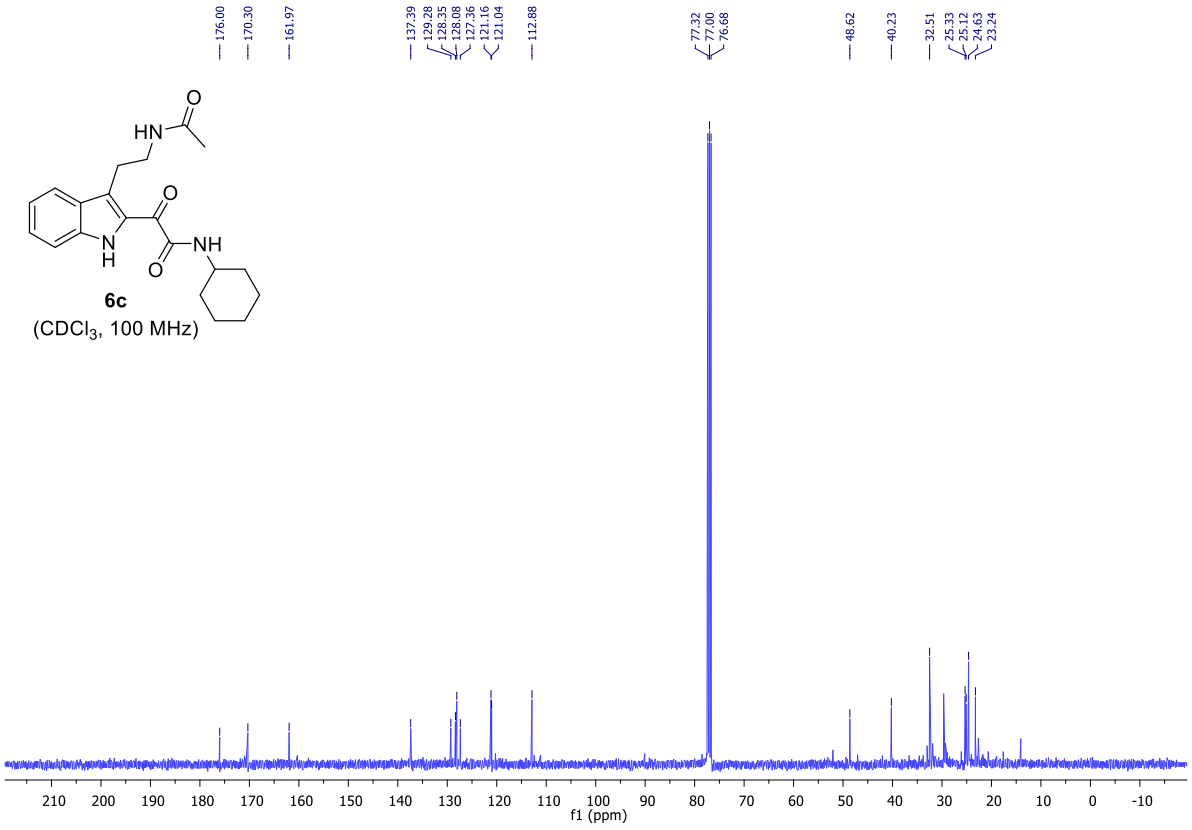


Figure S159: ^{1}H NMR of compound **8a**

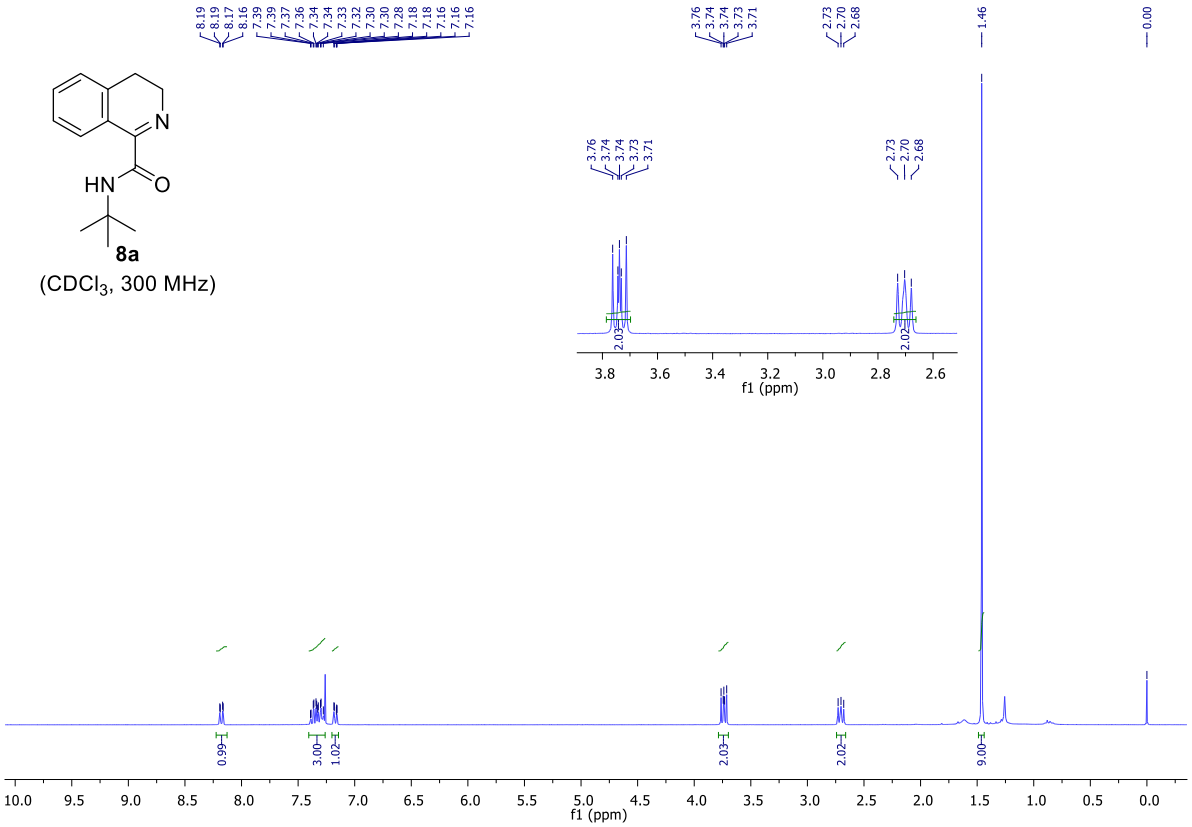


Figure S160: ^{13}C NMR of compound **8a**

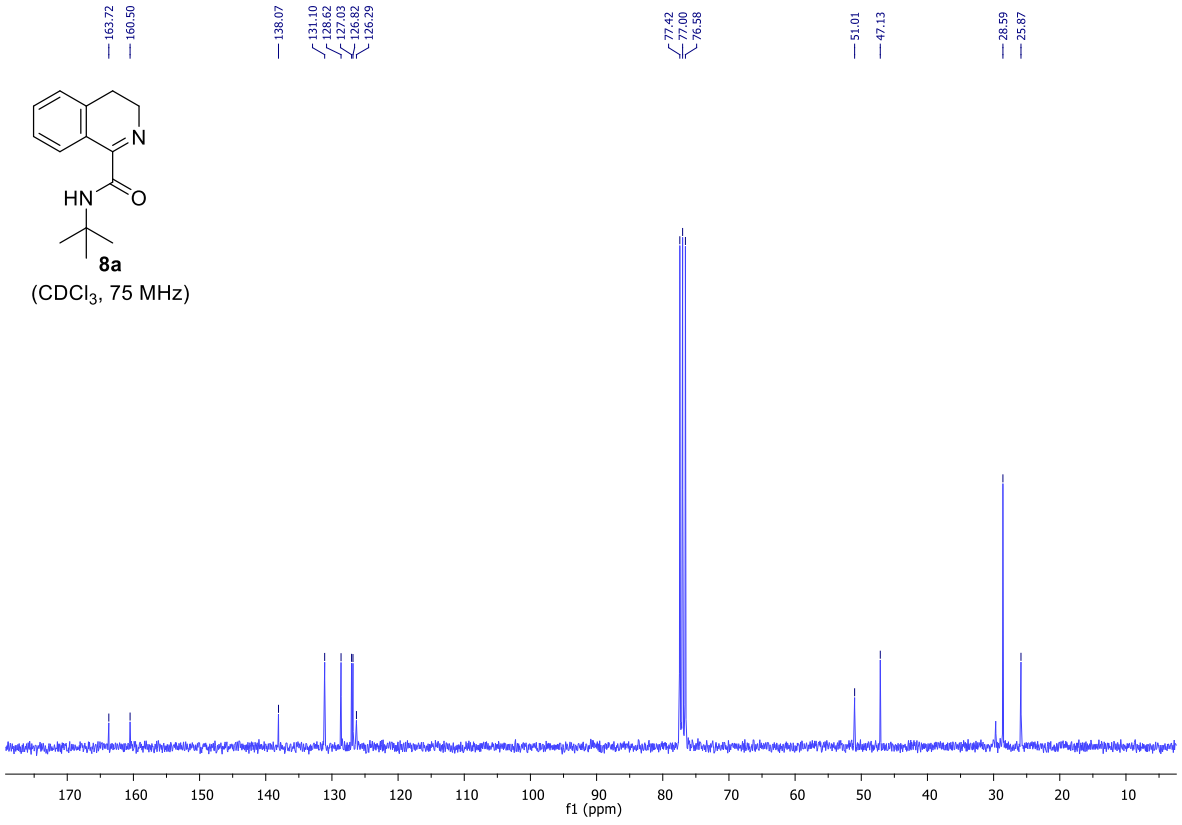


Figure S161: ^{1}H NMR of compound **9b**

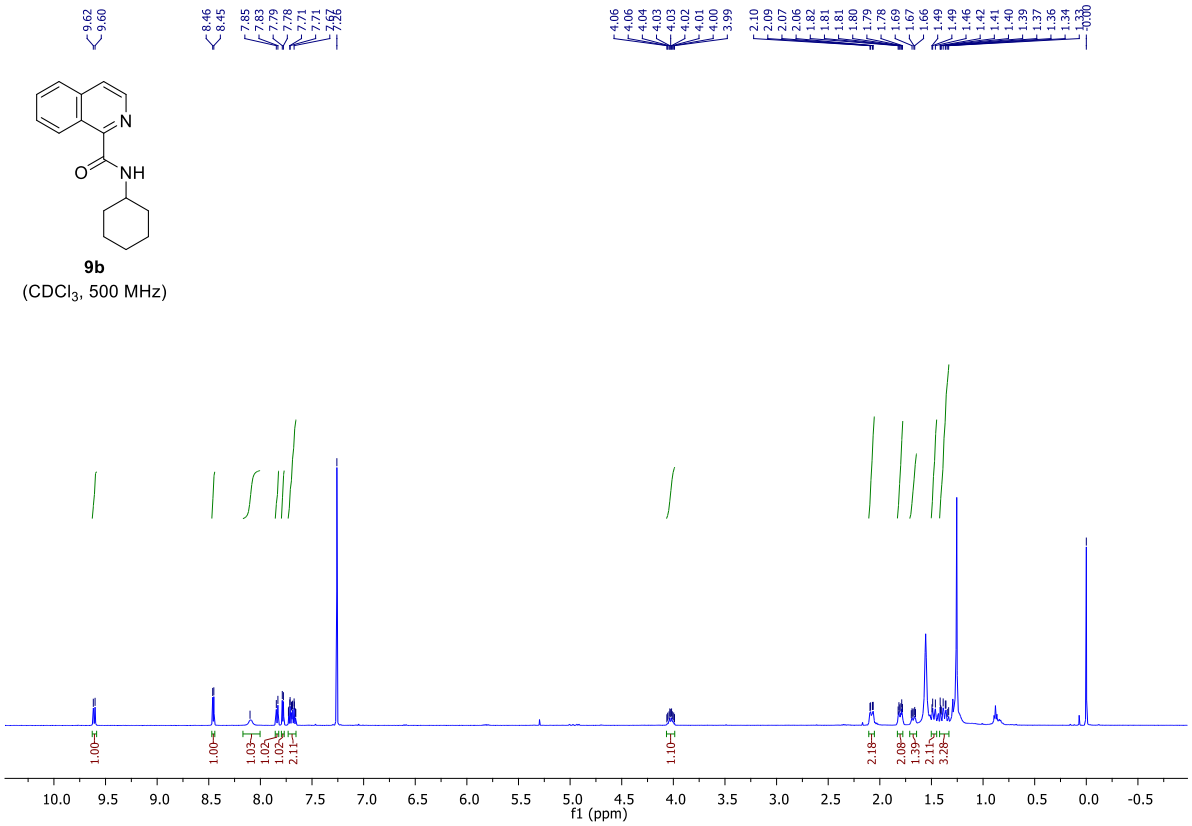


Figure S162: ^{13}C NMR of compound **9b**

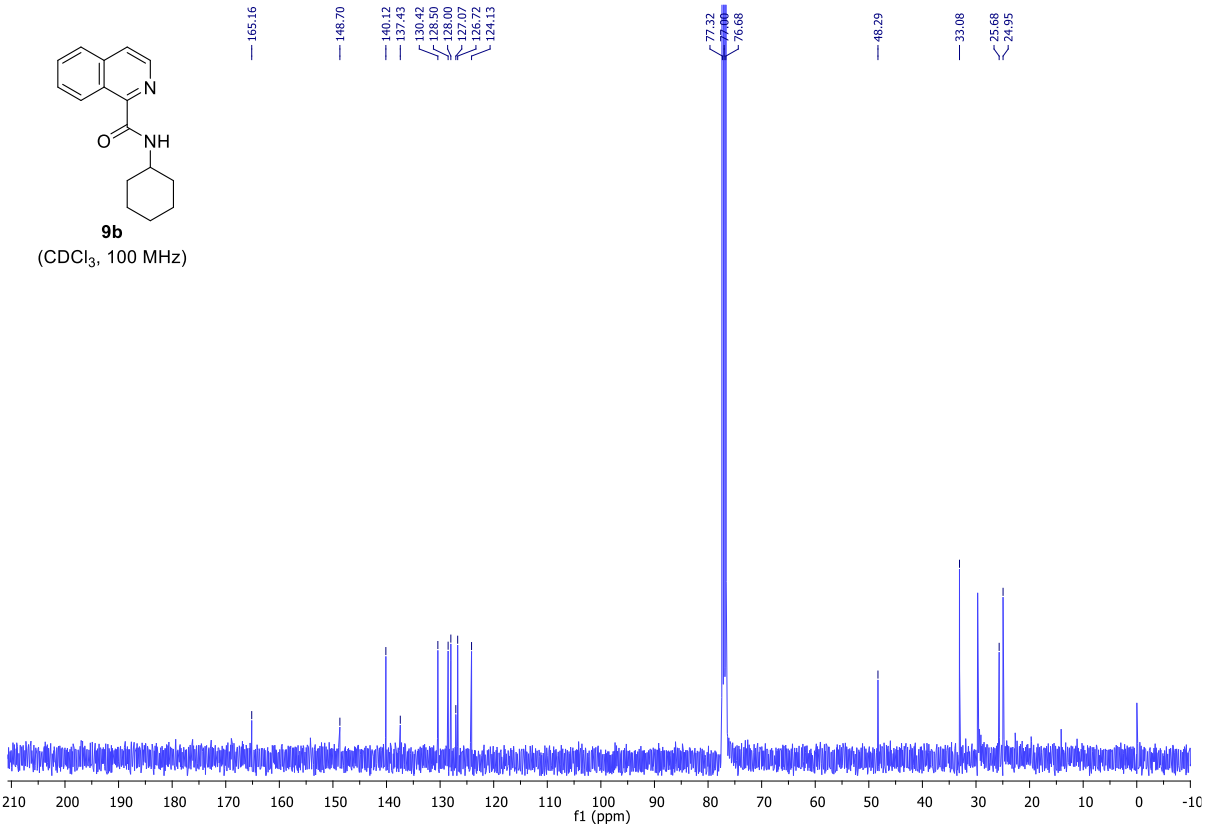


Figure S163: ^{1}H NMR of compound **10**

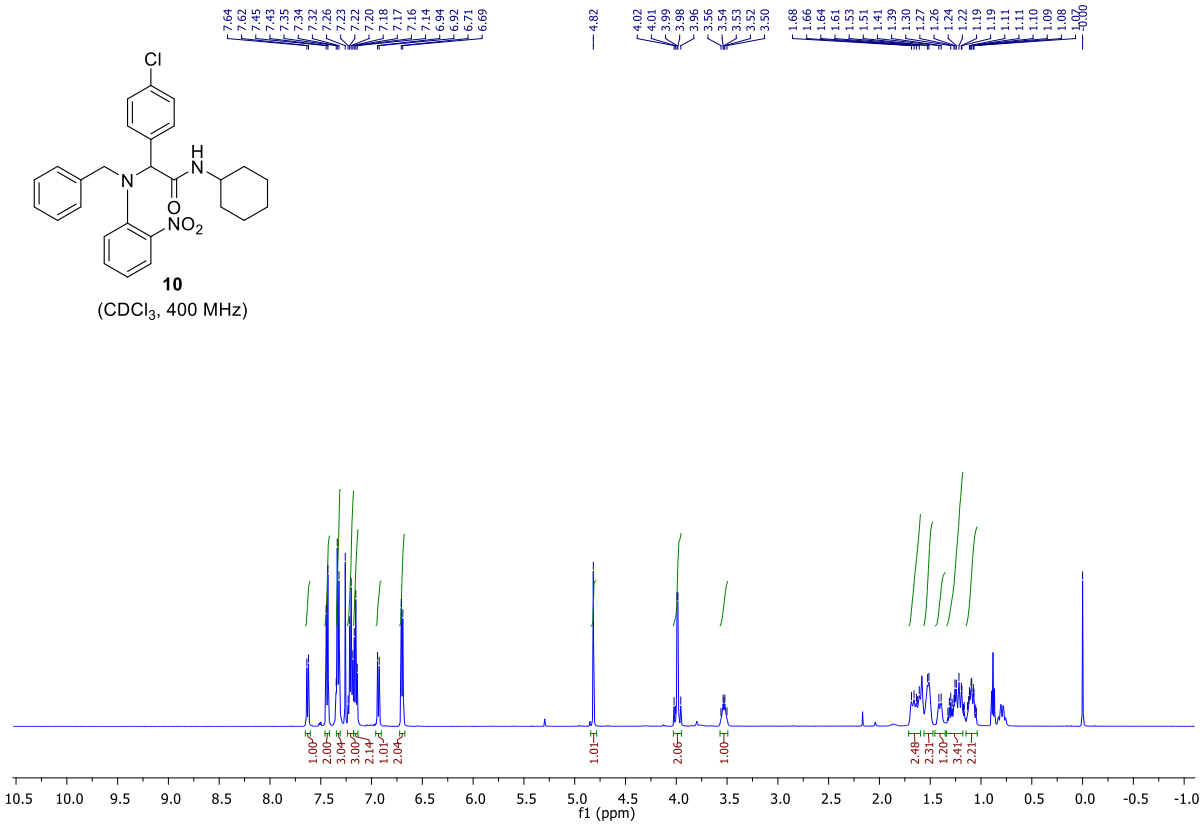


Figure S164: ^{13}C NMR of compound **10**

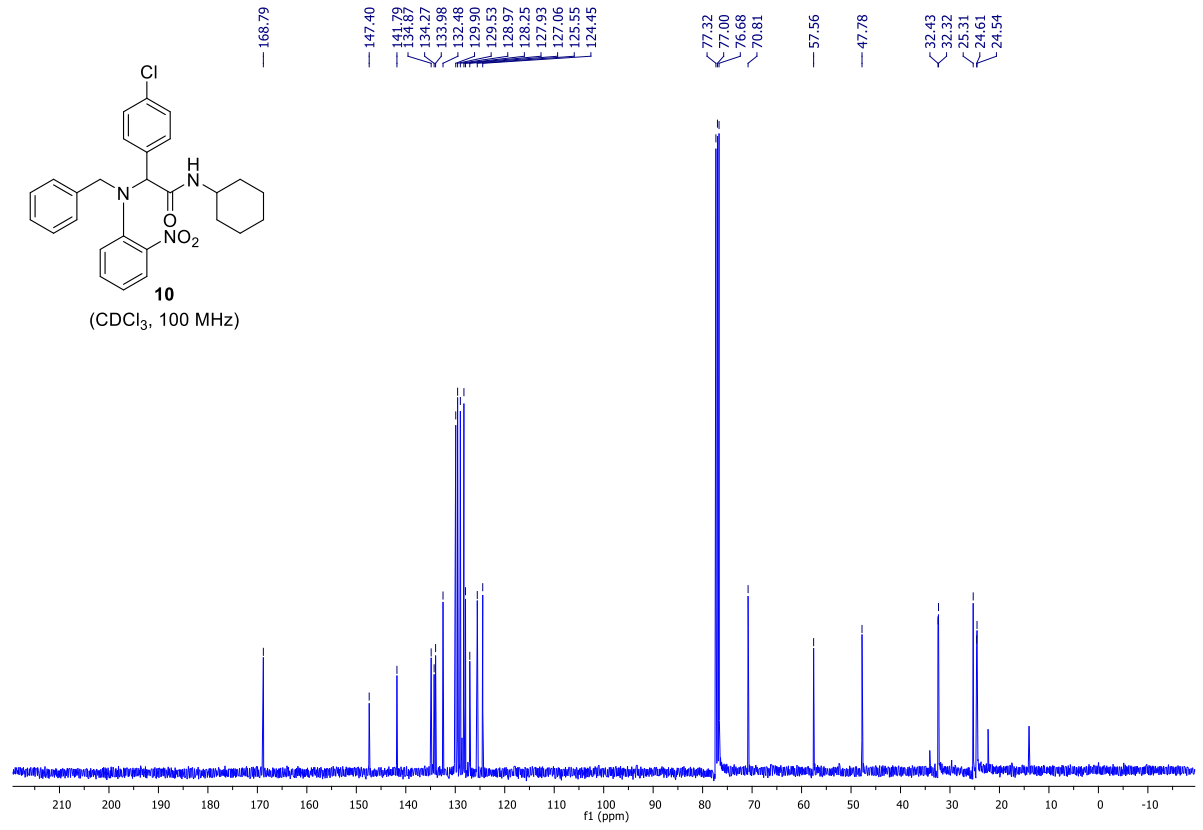


Figure S165: ^{1}H NMR of compound **11a**

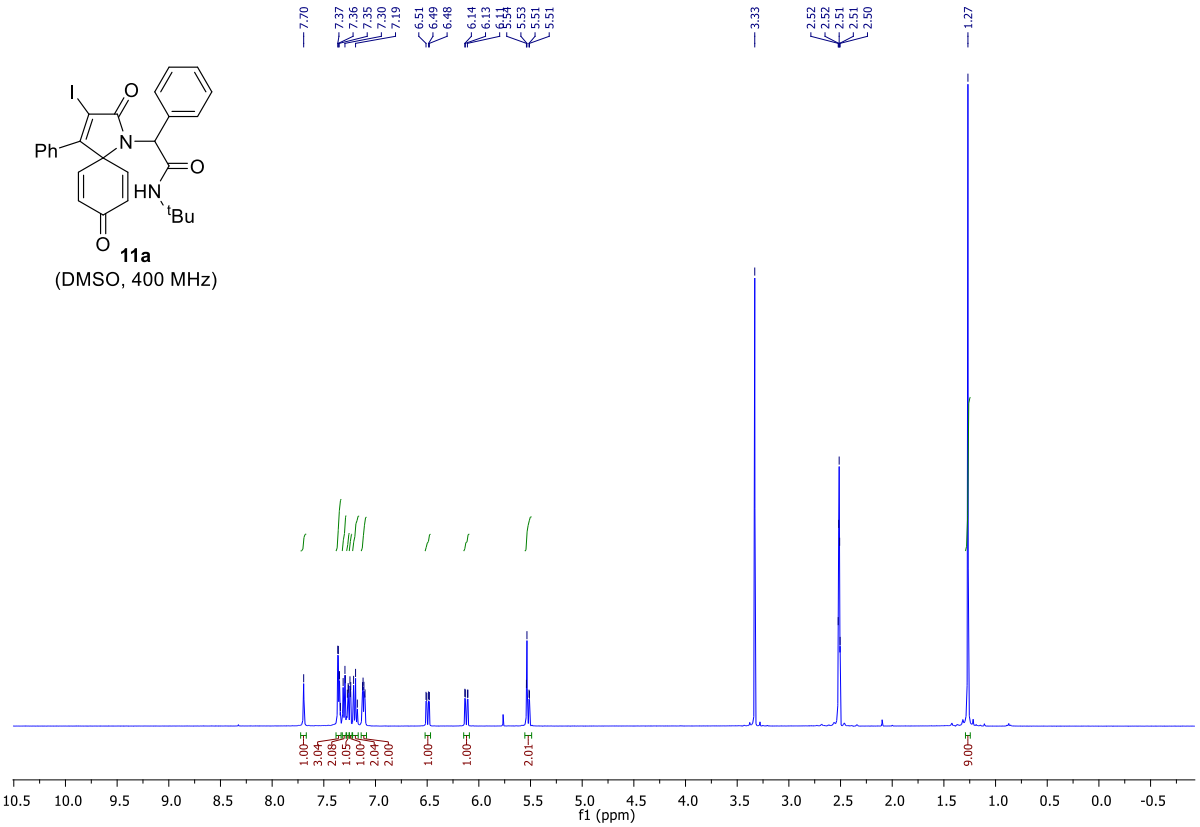


Figure S166: ^{13}C NMR of compound **11a**

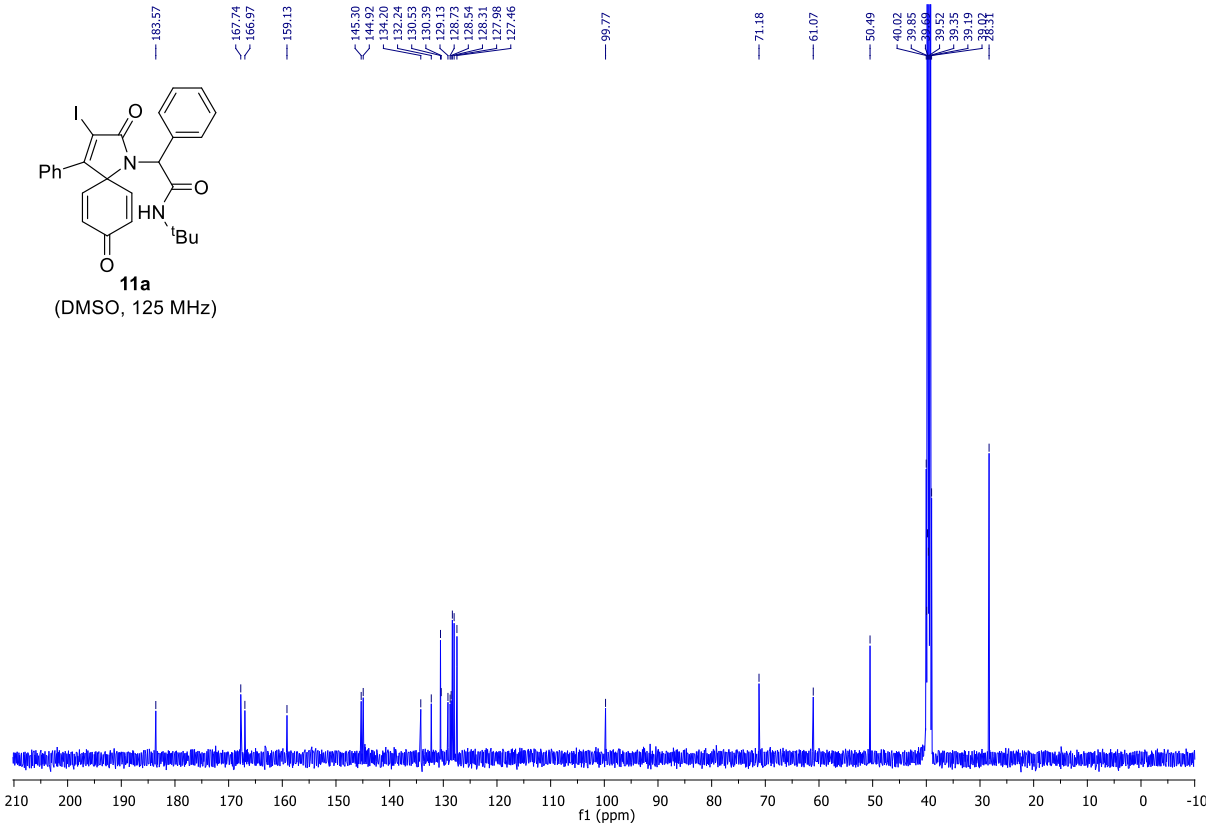


Figure S167: ^{1}H NMR of compound **11b**

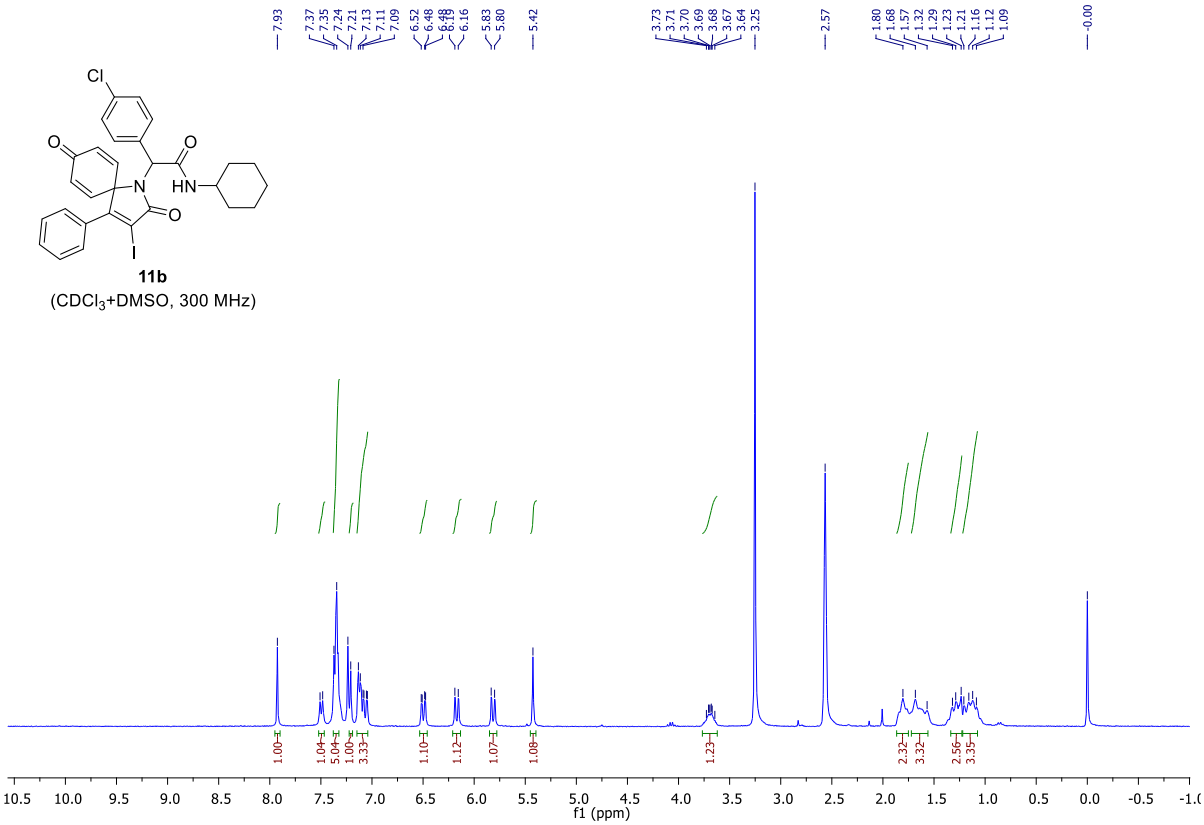


Figure S168: ^{13}C NMR of compound **11b**

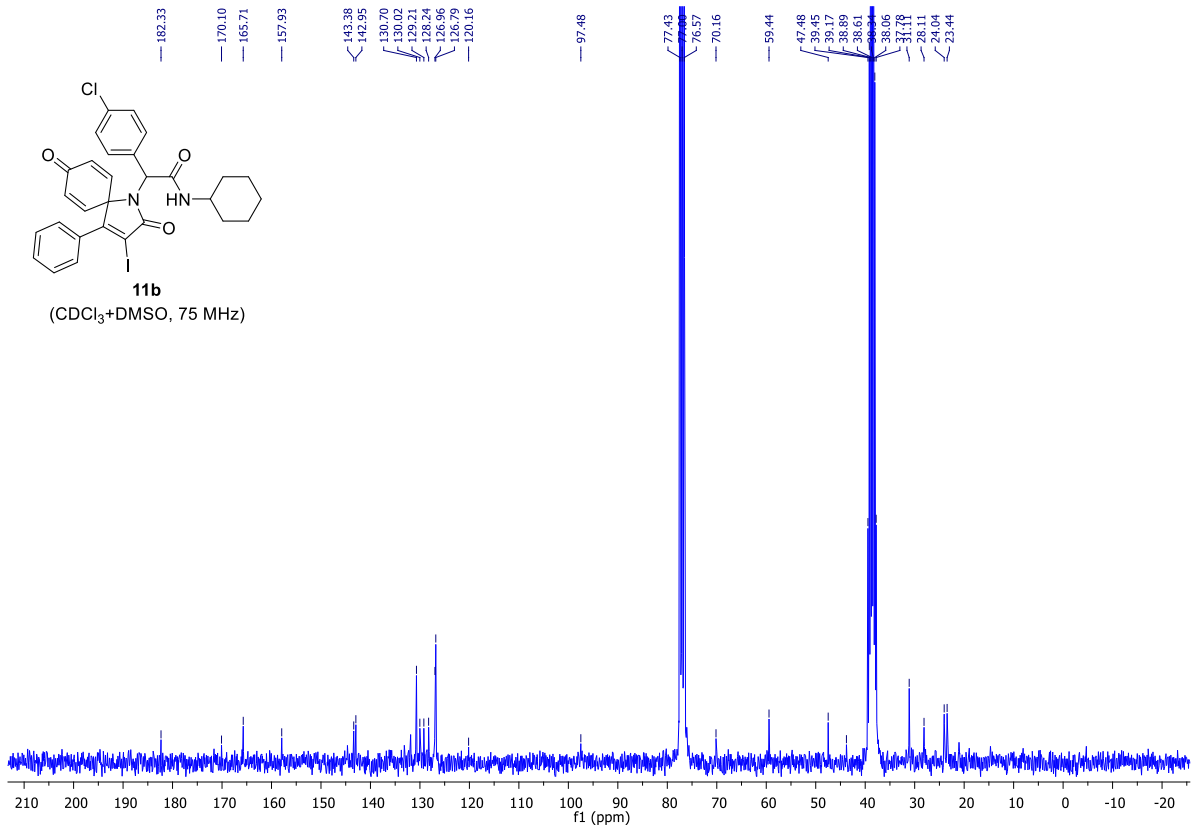


Figure S169: ^{1}H NMR of compound **11c**

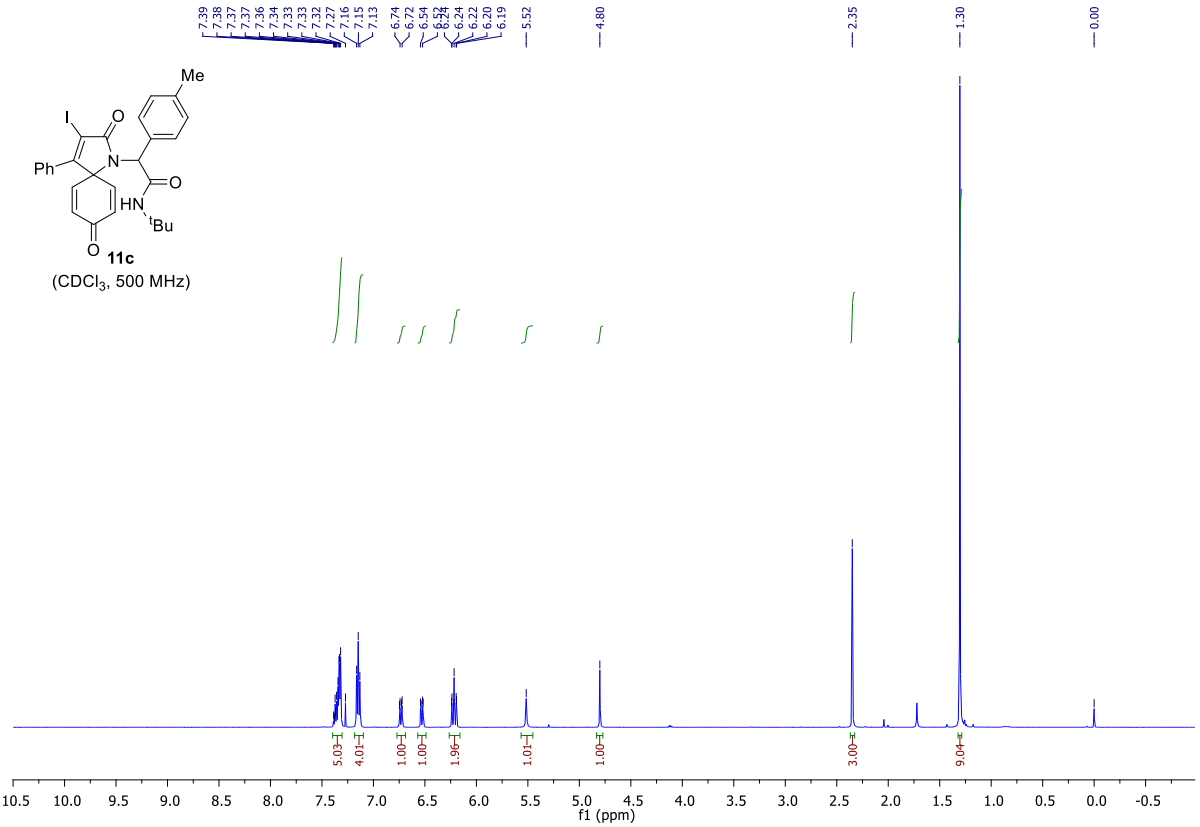


Figure S170: ^{13}C NMR of compound **11c**

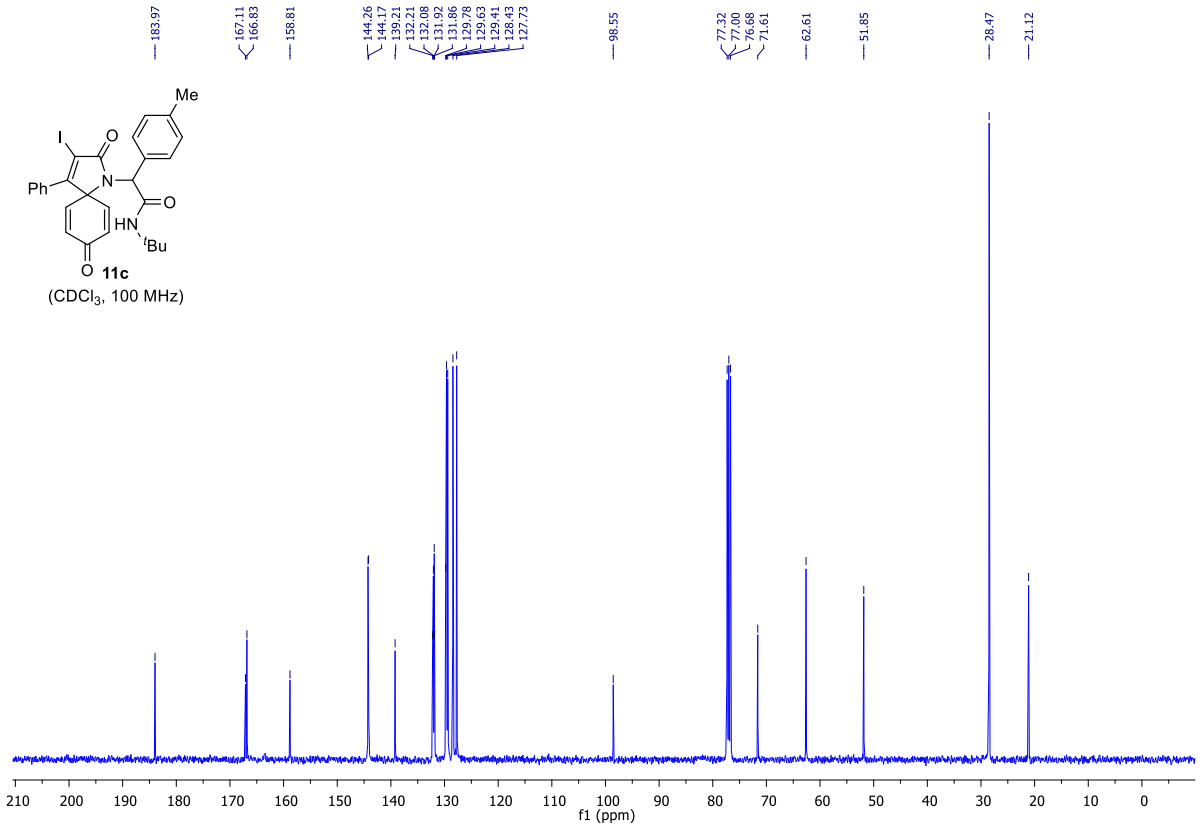


Figure S171: ^{1}H NMR of compound **11d**

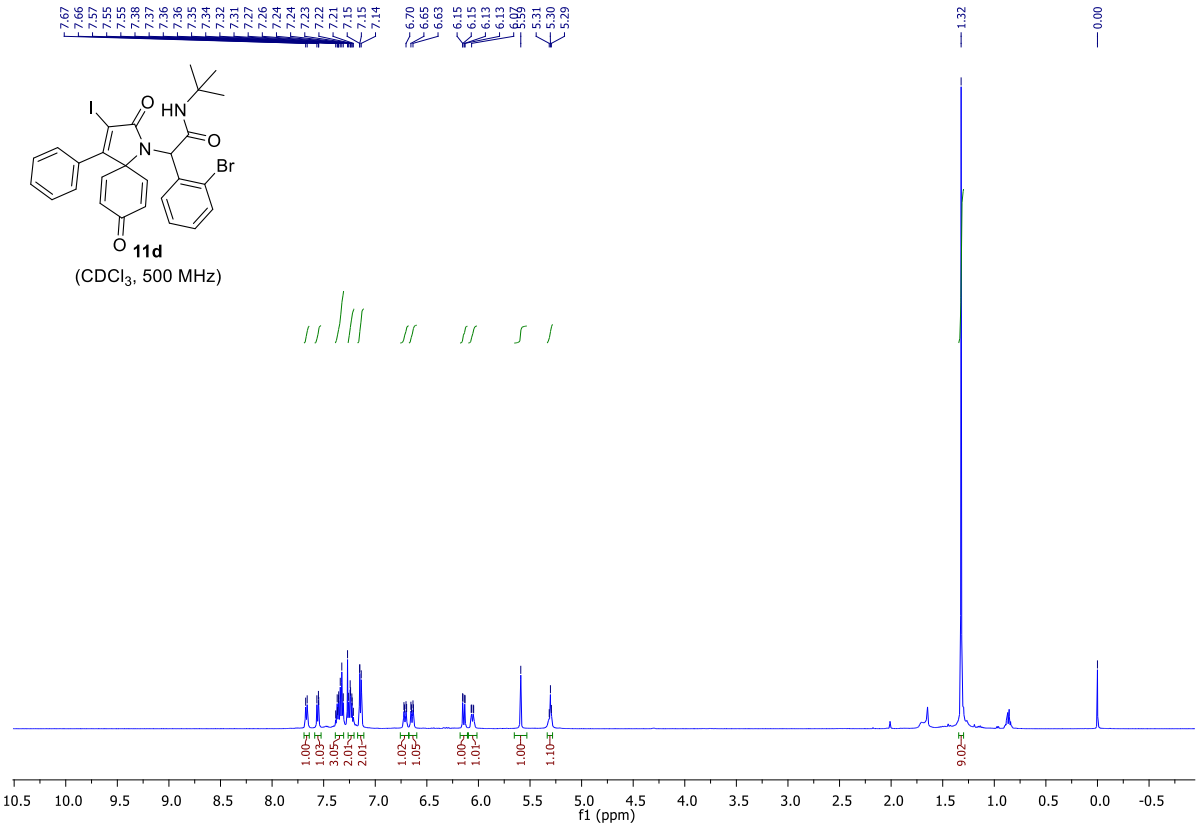


Figure S172: ^{13}C NMR of compound **11d**

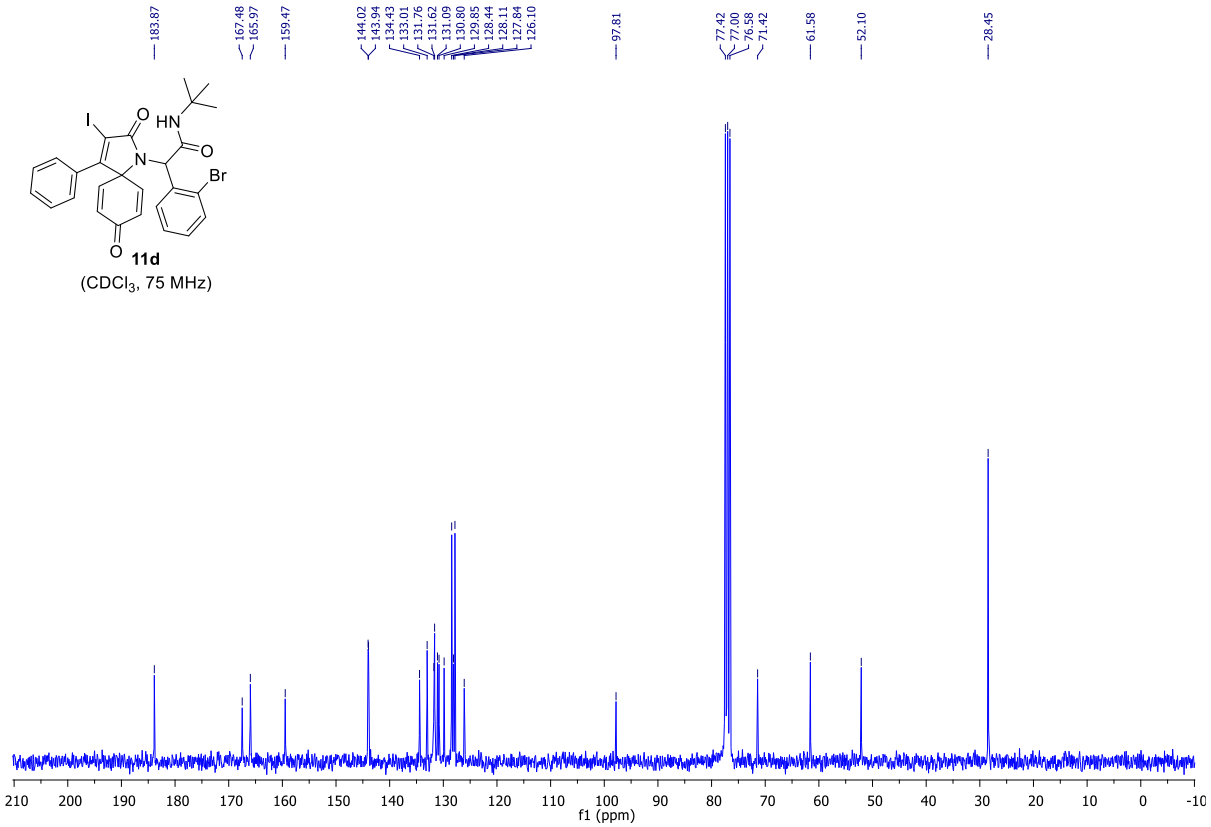


Figure S173: ^{1}H NMR of compound **11e**

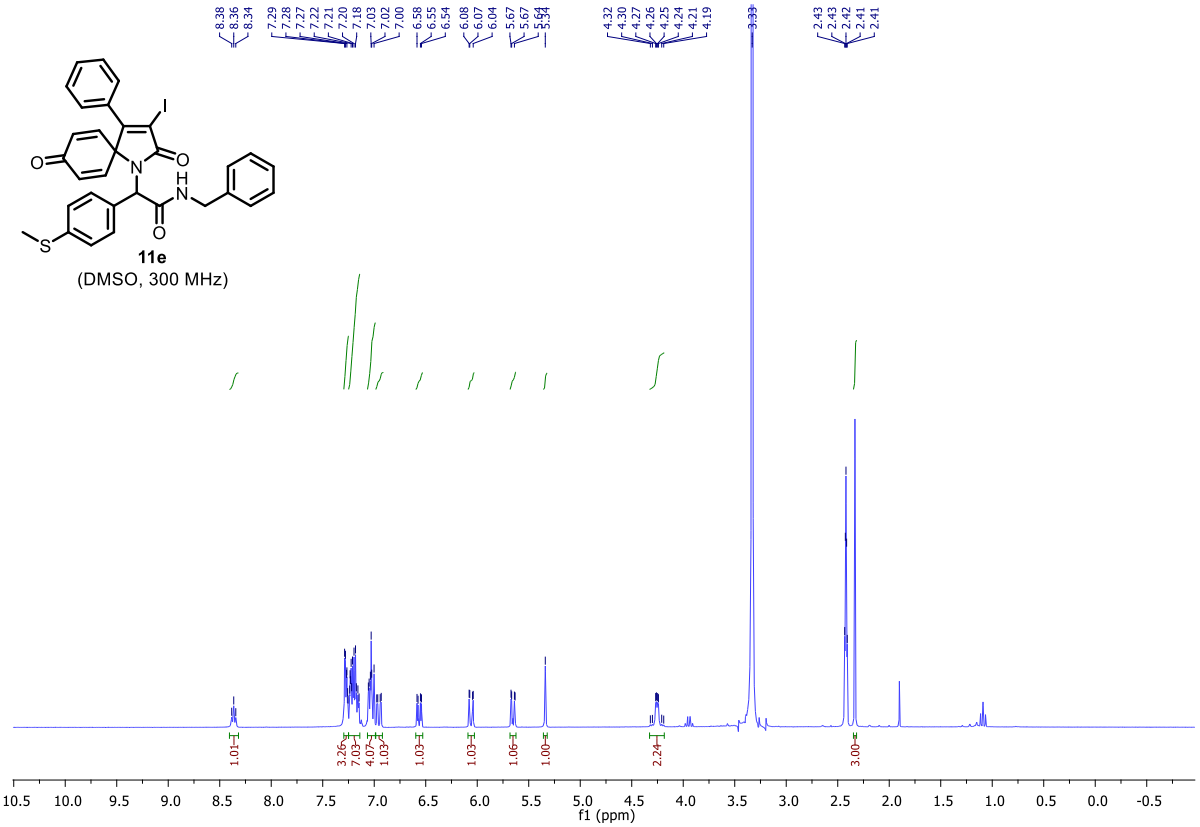


Figure S174: ^{13}C NMR of compound **11e**

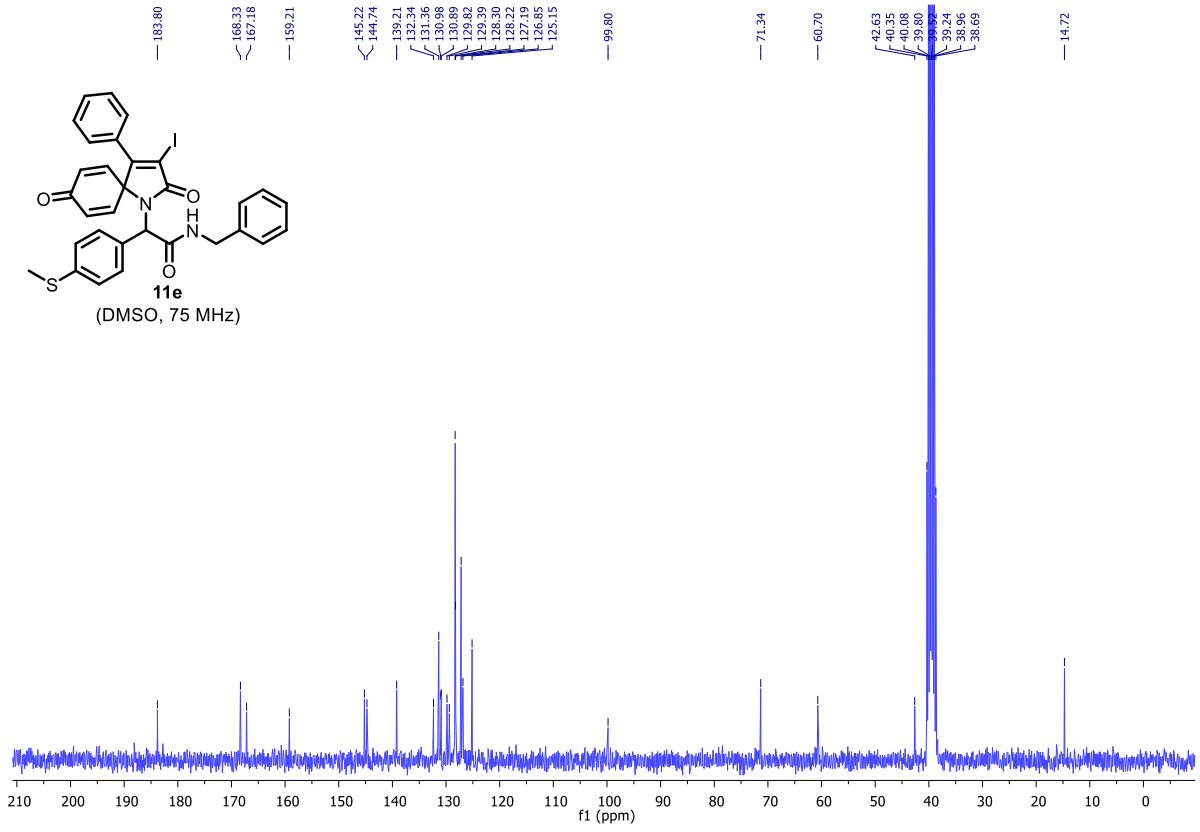


Figure S175: ^{1}H NMR of compound **11f**

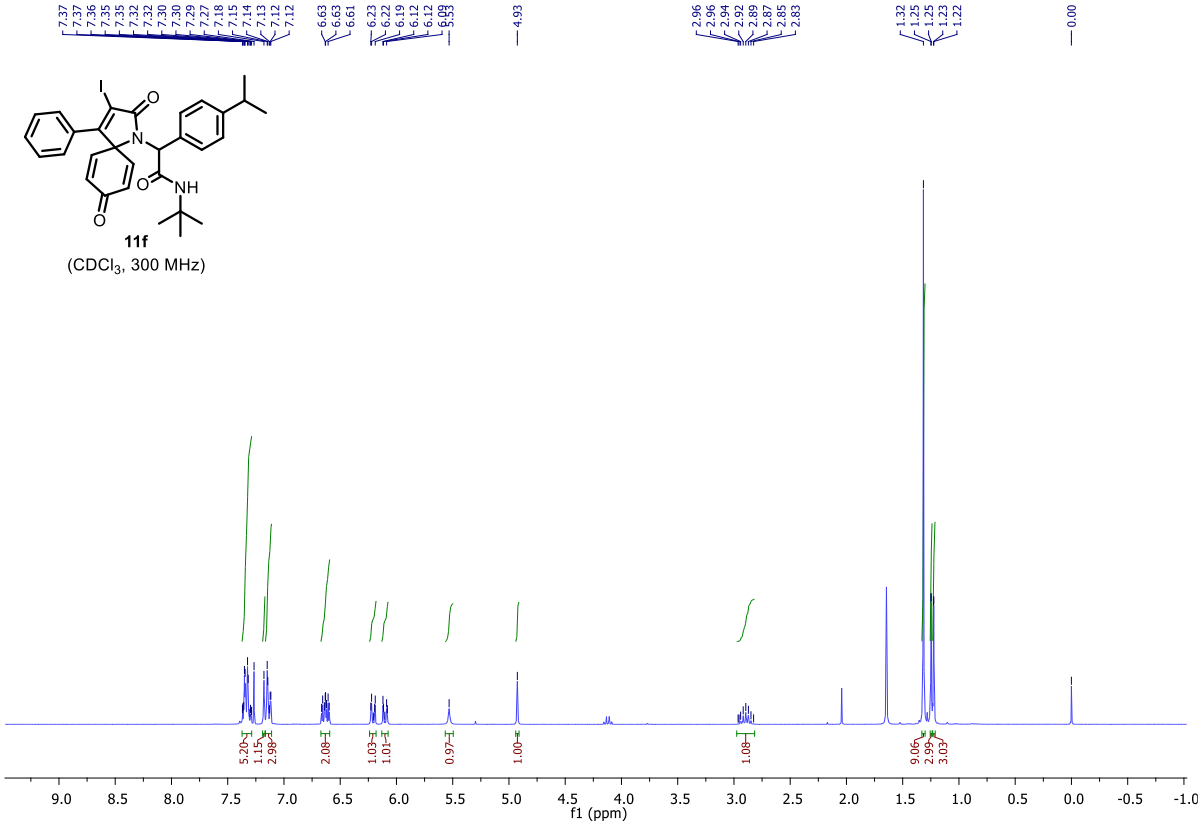


Figure S176: ^{13}C NMR of compound **11f**

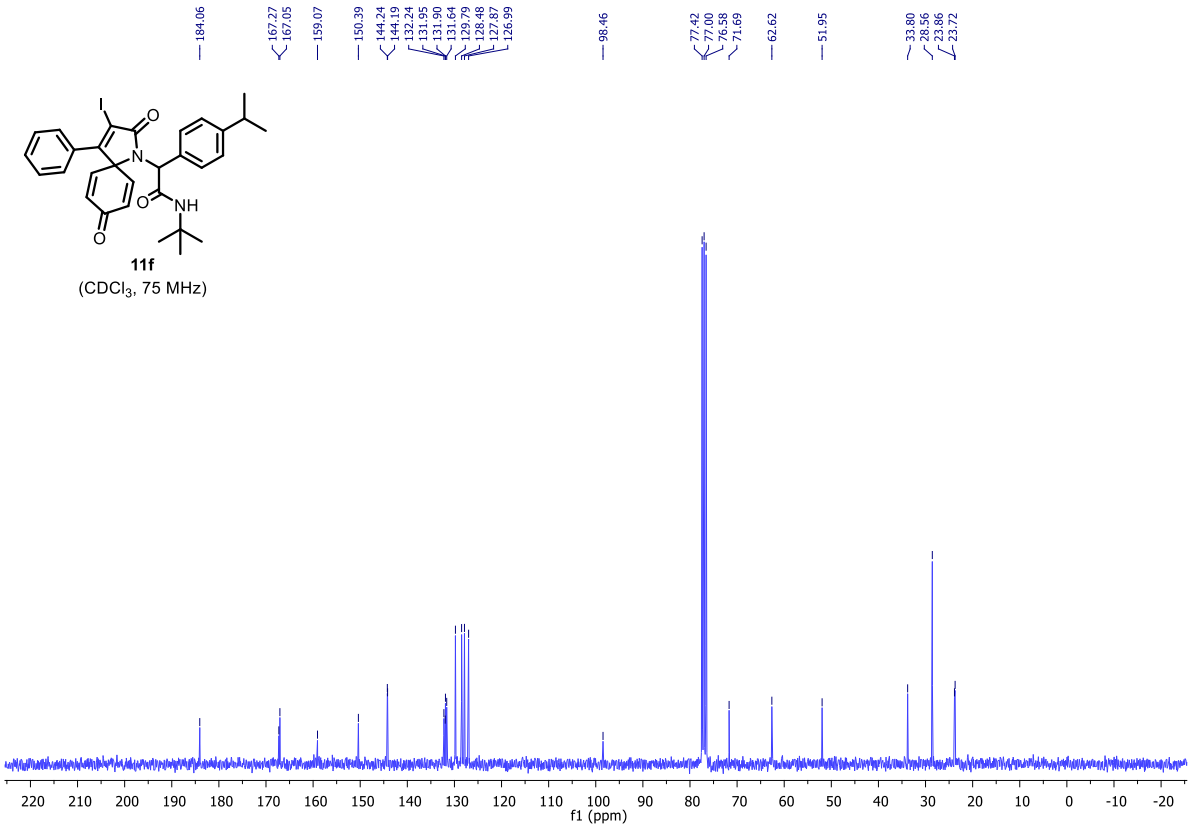


Figure S177: ^{1}H NMR of **4-Methoxybenzaldehyde-α-D**

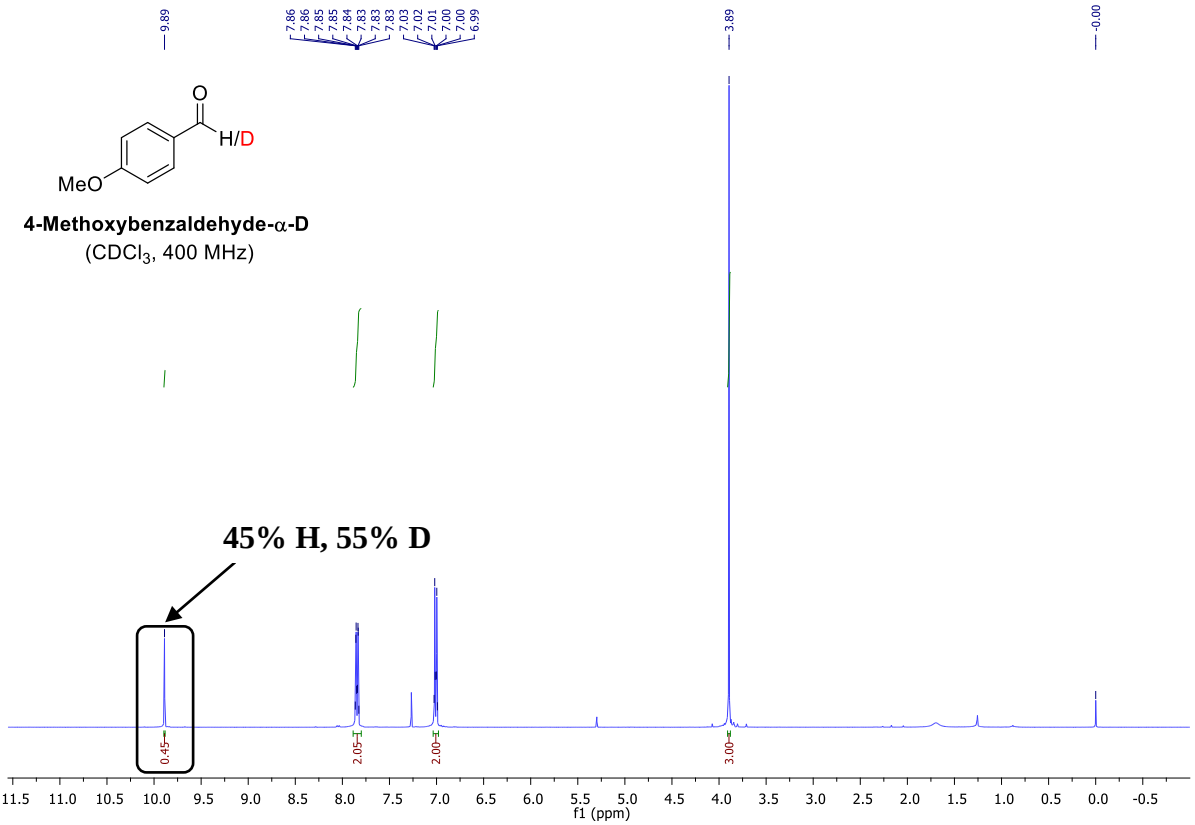


Figure S178: ^{1}H NMR of compound **D-1d**

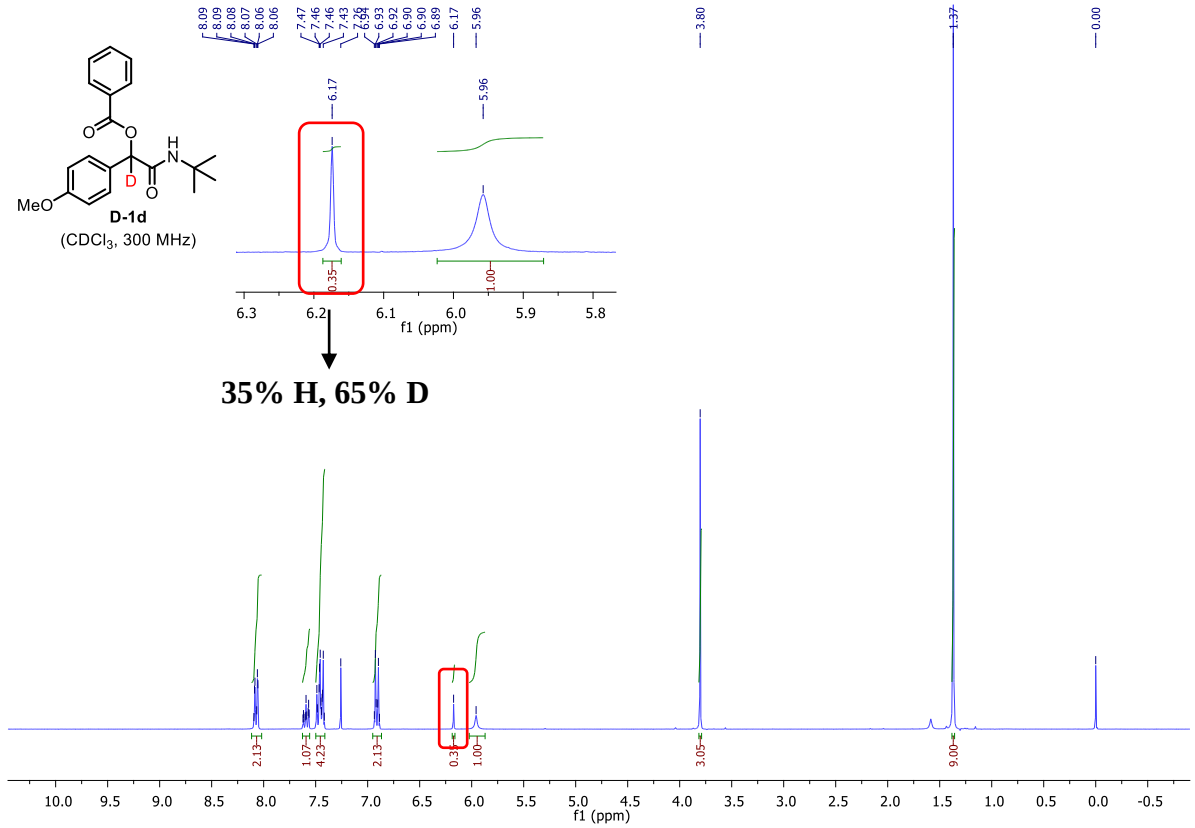


Figure S179: ^{1}H NMR of compound **^{18}O-1b**

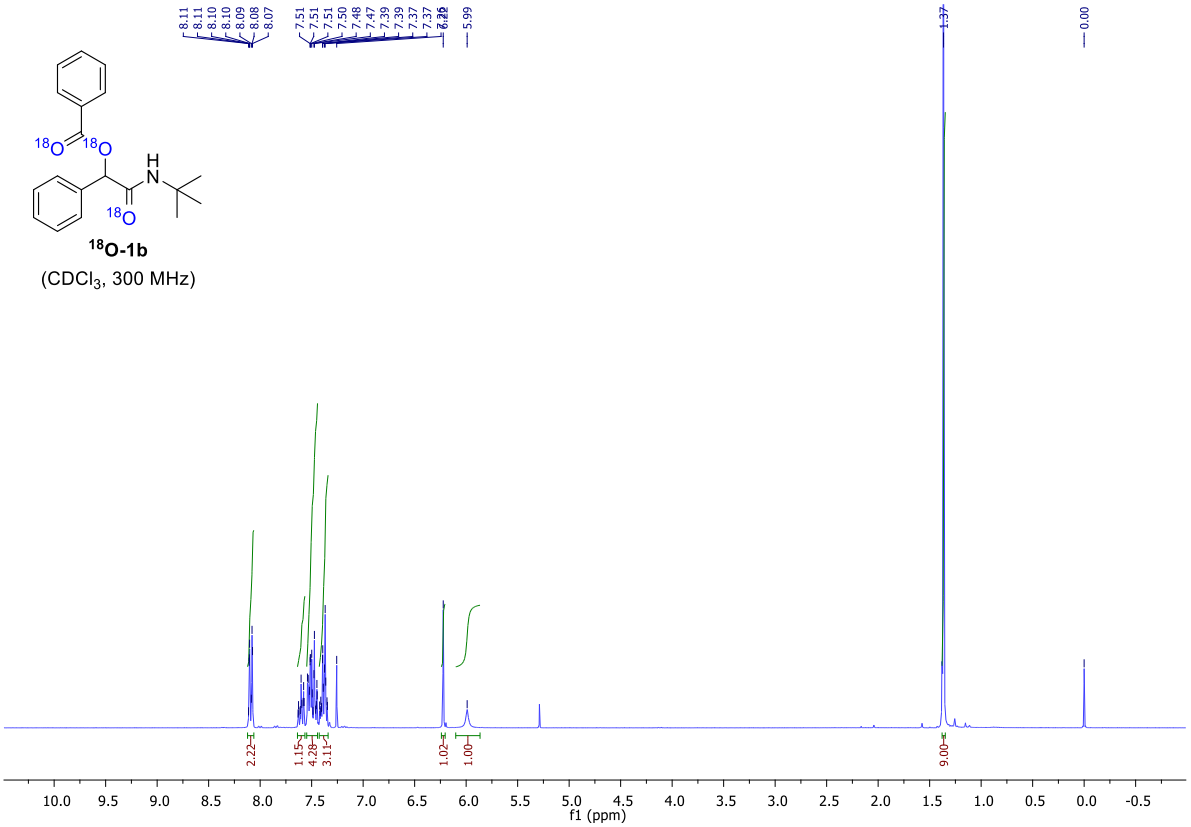


Figure S180: ^{13}C NMR of compound **^{18}O-1b**