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Access to high value sp^3-rich frameworks using photocatalyzed [2+2]-cycloadditions of γ-alkylidene-γ-lactams

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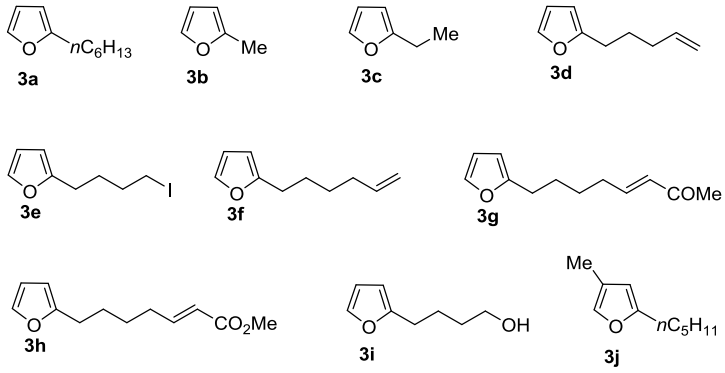
Part A: Experimental procedures

General methods

NMR data were obtained for ^{1}H at 500 MHz and for ^{13}C at 125 MHz. HRMS data was recorded on the Orbitrap analyzer of an LTQ Orbitrap XL and on a Q-Exactive Plus Orbitrap MS, using ESI ionization source.

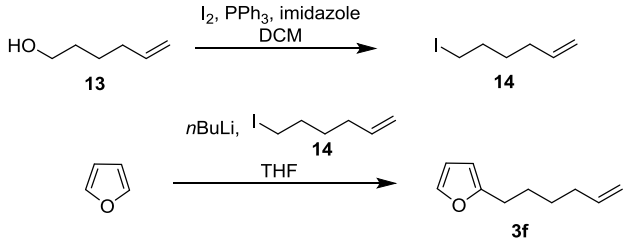
Furan substrates



Compounds **3b** and **3c** are commercially available. The following compounds were prepared as previously reported: **3a**,[1] **3d**,[2] **3e**,[2] **3g** and **3h**,[3] **3i**,[2] **3j**.[4]

[1] G. I. Ioannou, D. Kalaitzakis, G. Vassilikogiannakis, *Eur. J. Org. Chem.* **2016**, 3304.
[2] D. Kalaitzakis, E. Antonatou, G. Vassilikogiannakis, *Chem. Commun.* **2014**, *50*, 400.
[3] S. Hoxha, D. Kalaitzakis, A. Bosveli, T. Montagnon, G. Vassilikogiannakis, *Org. Lett.* **2021**, *23*, 5354.
[4] D. Kalaitzakis, T. Montagnon, I. Alexopoulou, G. Vassilikogiannakis, *Angew. Chem. Int. Ed.* **2012**, *51*, 8868.

Experimental procedure for the synthesis of 2-(hex-5-en-1-yl)furan (3f)



To a solution of alcohol **13** (240 μL, 2.0 mmol) in anhydrous CH_2Cl_2 (10 mL), under anargon atmosphere at 0 ^oC, PPh_3 (630 mg, 2.4 mmol) and I_2 (610 mg, 2.4 mmol) were added. The mixture was stirred for 5 min. Imidazole (340 mg, 5 mmol) was added at the same temperature. The resulting mixture was warmed to room temperature and stirred for a further 1.5 h. After completion of the reaction, as indicated by tlc analysis, a saturated aqueous solution of $Na_2S_2O_3$ (10 mL) was added and the solution stirred for 30 min. The layers were separated and the organic phase was dried over Na_2SO_4, filtered and concentrated *in vacuo*. The residue was purified by flash column chromatography (silica gel, petroleum ether) to afford the iodide **14** as a slightly yellow oil. Yield 327.6 mg (78%).

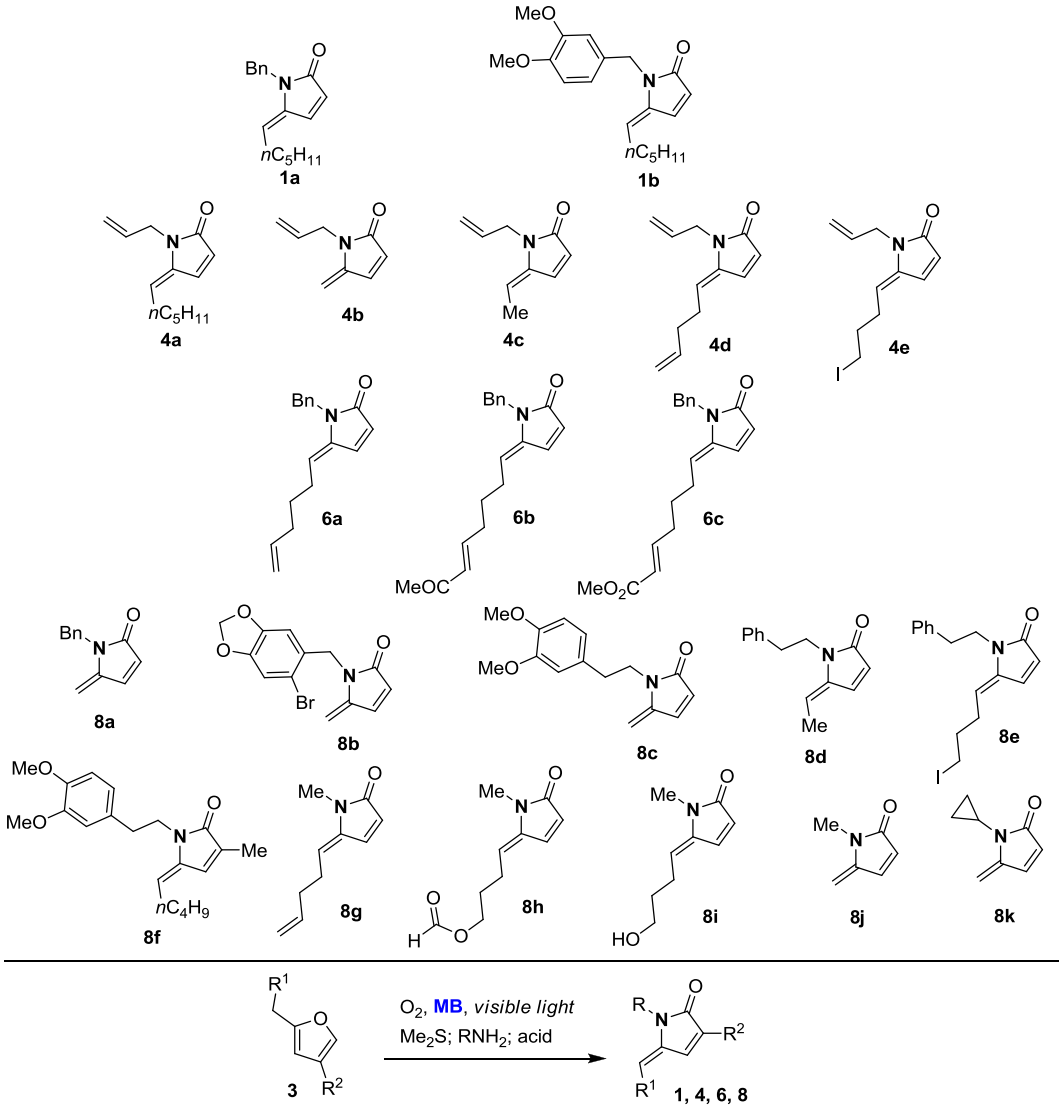
6-iodohex-1-ene (14)

^1H NMR (500 MHz, $CDCl_3$): 5.79 (ddt, J_1=17.0 Hz, J_2=10.3 Hz, J_3=6.7 Hz, 1H), 5.02 (dq, J_1=17.0 Hz, J_2=1.7 Hz, 1H), 4.97 (m, 1H), 3.19 (t, J=7.0 Hz, 2H), 2.08 (m, 2H), 1.84 (m, 2H), 1.50 (m, 2H) ppm; ^{13}C NMR (125 MHz, $CDCl_3$): 138.1, 115.0, 32.9, 32.6, 29.7, 6.8 ppm.

To a solution of furan (342 μL, 4.7 mmol) in anhydrous THF (4.5 mL), under an argon atmosphere and at 0 ^oC, was added dropwise a solution of *n*-BuLi (2.44 mL, 1.6 M in hexane, 3.9 mmol). The solution was stirred for a further 30 min at the same temperature. Afterwards, a solution of the iodide **14** (327.6 g, 1.56 mmol) in anhydrous THF (1.5 mL) was added slowly. The resulting solution was then warmed to room temperature and stirred for 1 h. After completion of the reaction, as indicated by tlc analysis, the reaction was quenched with a saturated aqueous solution of NH_4Cl (4 mL) and the resulting mixture was extracted with Et_2O (10 mL). The layers were separated and the organic layer was dried over Na_2SO_4 and then concentrated *in vacuo*. The product was purified by flash column chromatography (silica gel, petroleum ether) to afford **3f** as a slightly yellow oil. Yield 163.8 mg (70%).

^1H NMR (500 MHz, $CDCl_3$): 7.29 (dd, J_1=1.8 Hz, J_2=0.8 Hz, 1H), 6.27 (dd, J_1=3.0 Hz, J_2=1.8 Hz, 1H), 5.97 (dd, J_1=3.0 Hz, J_2=0.8 Hz, 1H), 5.80 (ddt, J_1=17.0 Hz, J_2=10.3 Hz, J_3=6.7 Hz, 1H), 5.00 (dq, J_1=17.0 Hz, J_2=1.7 Hz, 1H), 4.95 (m, 1H), 2.63 (t, J=7.5 Hz, 2H), 2.08 (m, 2H), 1.66 (m, 2H), 1.45 (m, 2H) ppm; ^{13}C NMR (125 MHz, $CDCl_3$): 156.3, 140.7, 138.7, 114.5, 110.0, 104.6, 33.5, 28.4, 27.8, 27.5 ppm.

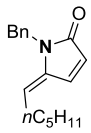
General experimental for the synthesis of substrates of type 1, 4, 6 and 8.



The corresponding substituted furan of type **3** (2 mmol, 304 mg for **3a**, 180 μL for **3b**, 210 μL for **3c**, 272 mg for **3d**, 500 mg for **3e**, 300 mg for **3f**, 384 mg for **3g**, 416 mg for **3h**, and 280 mg for **3i**, 304 mg for **3j**) was dissolved in methanol (25 mL, 80 mM) containing catalytic amounts of methylene blue as photosensitizer (1.3 mg, 0.004 mmol). The solution was then cooled using an ice bath. Oxygen was gently bubbled through the solution while it was irradiated by a xenon Variac Eimac Cermax 300 W lamp. The reaction was monitored by tlc. After completion of the reaction (10 min), the solution was warmed to room temperature and Et_3N (16.7 μL, 0.12 mmol) was added followed by Me_2S (580 μL, 8 mmol). After completion of the reduction (40 min), an additional amount of methylene blue was added (12.8 mg, 0.04 mmol) followed by the corresponding amine (2.2 mmol, 240 μL of benzylamine towards **1a**, **6a**–**6c** and **8a**, 330 μL of 3,4-dimethoxybenzylamine towards **1b**, 164 μL of allylamine towards **4a**–**4e**, 460 mg of (6-bromobenzo[d][1,3]dioxol-5-yl)methanamine towards **8b**, 337 μL of 3,4-dimethoxyphenethylamine towards **8c** and **8f**, 277 μL of phenethylamine towards **8d** and **8e**, 260 μL of a 11.6 M aqueous

solution of methylamine towards **8g**, **8h**, **8j**, 138 μL of cyclopropylamine towards **8k**). The reaction was then stirred at the same temperature for 3 h. After completion of the reaction (tlc analysis and ^{1}H-NMR), the solvent was removed under reduced pressure and DCM (8 mL) was added followed by PTSA.H_2O (114 mg, 0.6 mmol). Only in case of the reaction towards **8h**, HCOOH was added (2 mL) instead of PTSA. The reaction was stirred at rt until full consumption of the starting material was indicated by tlc analysis (1 h or 2 h in case of product **8h**). Then the solution was concentrated under reduced pressure and the products were purified by flash column chromatography (silica gel, petroleum ether : EtOAc).

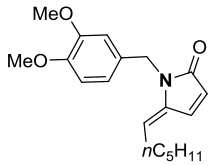
(E)-1-benzyl-5-hexylidene-1,5-dihydro-2H-pyrrol-2-one (1a)



Product **1a** was synthesized according to the general experimental procedure described above. The crude product was purified by flash column chromatography (silica gel, petroleum ether : EtOAc = 5:1) to furnish **1a** as a yellow oil (yield = 331.5 mg, 65%).

^{1}H NMR (500 MHz, $CDCl_3$) δ 7.29 (m, 3H), 7.22 (m, 1H), 7.16 (d, *J*=7.1 Hz, 2H), 6.25 (dd, J_1=5.9 Hz, J_2=1.6 Hz, 1H), 5.32 (td, J_1=8.2 Hz, J_2=1.2 Hz, 1H), 4.84 (s, 2H), 2.25 (q, *J*=7.6 Hz, 2H), 1.36 (quin, *J*=7.4 Hz, 2H), 1.26 (m, 2H), 1.18 (m, 2H), 0.84 (t, *J*=7.2 Hz, 3H) ppm; ^{13}C NMR (125 MHz, $CDCl_3$): δ = 170.0, 139.1, 137.3, 132.5, 128.4 (2C), 127.0, 126.6 (2C), 123.8, 116.7, 42.4, 30.9, 29.6, 27.4, 22.2, 13.8 ppm.

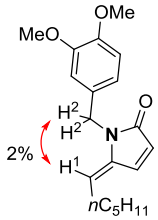
(E)-1-(3,4-dimethoxybenzyl)-5-hexylidene-1,5-dihydro-2H-pyrrol-2-one (1b)



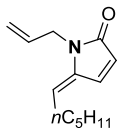
Product **1b** was synthesized according to the general experimental procedure described above. The crude product was purified by flash column chromatography (silica gel, petroleum ether : EtOAc = 5:1) to furnish **1b** as a brown oil (yield = 378 mg, 60%).

^{1}H NMR (500 MHz, $CDCl_3$) δ 7.25 (d, *J*=5.8 Hz, 1H), 6.77 (d, *J*=7.8 Hz, 1H), 6.71 (s, 1H), 6.71 (d, *J*=7.8 Hz, 1H), 6.22 (dd, J_1=5.8 Hz, J_2=1.6 Hz, 1H), 5.37 (td, J_1=8.2 Hz, J_2=1.1 Hz, 1H), 4.75 (s, 2H), 3.83 (s, 3H), 3.81 (s, 3H), 2.25 (q, *J*=7.6 Hz, 2H), 1.37 (quin, *J*=7.4 Hz, 2H), 1.27-1.17 (m, 4H), 0.84 (t, *J*=7.2 Hz, 3H) ppm; ^{13}C NMR (125 MHz, $CDCl_3$): δ = 170.1, 149.2, 148.2, 139.3, 132.6, 130.1, 123.9, 119.1, 116.7, 111.0, 110.2, 55.8 (2C), 42.3, 31.1, 29.7, 27.5, 22.3, 13.9 ppm.

Representative NOE of compound **1b**



(E)-1-allyl-5-hexylidene-1,5-dihydro-2H-pyrrol-2-one (4a)

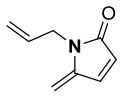


Product **4a** was synthesized according to the general experimental procedure described above. The crude product was purified by flash

column chromatography (silica gel, petroleum ether : EtOAc = 5:1 → 3:1) to furnish **4a** as a brown oil (yield = 258.3 mg, 63%).

^{1}H NMR (500 MHz, $CDCl_3$) δ 7.25 (d, *J*=6.0 Hz, 1H), 6.18 (dd, J_1=6.0 Hz, J_2=1.6 Hz, 1H), 5.77 (ddt, J_1=17.1 Hz, J_2=10.4 Hz, J_3=5.2 Hz, 1H), 5.40 (td, J_1=8.2 Hz, J_2=1.1 Hz, 1H), 5.12 (m, 1H), 5.03 (m, 1H), 4.24 (dt, J_1=5.0 Hz, J_2=1.7 Hz, 1H), 2.31 (q, *J*=7.6 Hz, 2H), 1.45 (m, 2H), 1.33-1.26 (m, 4H), 0.88 (t, *J*=7.0 Hz, 3H) ppm; ^{13}C NMR (125 MHz, $CDCl_3$) δ 169.7, 139.3, 133.1, 132.4, 123.9, 116.3, 116.1, 41.1, 31.2, 29.8, 27.5, 22.4, 14.0 ppm.

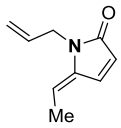
1-allyl-5-methylene-1,5-dihydro-2H-pyrrol-2-one (4b)



Product **4b** was synthesized according to the general experimental procedure described above. The crude product was purified by flash column chromatography (silica gel, petroleum ether : EtOAc = 3:1) to furnish **4b** as a yellow oil (yield = 135 mg, 50%).

^{1}H NMR (500 MHz, $CDCl_3$) δ 6.98 (d, *J*=5.8 Hz, 1H), 6.21 (dd, J_1=5.8 Hz, J_2=1.2 Hz, 1H), 5.78 (ddt, J_1=17.2 Hz, J_2=10.4 Hz, J_3=5.1 Hz, 1H), 5.14 (m, 1H), 5.08 (m, 1H), 4.89 (s, 1H), 4.83 (d, *J*=1.3 Hz, 1H), 4.24 (dt, J_1=5.1 Hz, J_2=1.6 Hz, 1H) ppm; ^{13}C NMR (125 MHz, $CDCl_3$) δ 170.0, 145.2, 137.2, 132.7, 124.9, 116.4, 97.2, 41.2 ppm.

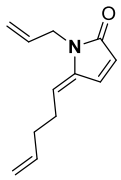
(E)-1-allyl-5-ethylidene-1,5-dihydro-2H-pyrrol-2-one (4c)



Product **4c** was synthesized according to the general experimental procedure described above. The crude product was purified by flash column chromatography (silica gel, petroleum ether : EtOAc = 3:1) to furnish a 17:1 mixture of E/Z isomers of **4c** as a yellow oil (yield = 158 mg, 53%).

^{1}H NMR (500 MHz, $CDCl_3$) δ 7.29 (dd, J_1=5.9 Hz, J_2=0.4 Hz, 1H), 6.19 (dd, J_1=5.9 Hz, J_2=1.3 Hz, 1H), 5.77 (ddt, J_1=17.2 Hz, J_2=10.4 Hz, J_3=5.1 Hz, 1H), 5.45 (qd, J_1=7.5 Hz, J_2=1.1 Hz, 1H), 5.12 (dq, J_1=10.4 Hz, J_2=1.6 Hz, 1H), 5.05 (dq, J_1=17.2 Hz, J_2=1.6 Hz, 1H), 4.24 (dt, J_1=5.1 Hz, J_2=1.6 Hz, 1H), 1.95 (d, *J*=7.5 Hz, 3H) ppm; ^{13}C NMR (125 MHz, $CDCl_3$) δ 169.7, 140.0, 133.2, 132.1, 123.9, 116.1, 110.5, 41.2, 13.1 ppm.

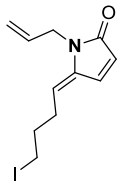
(E)-1-allyl-5-(pent-4-en-1-ylidene)-1,5-dihydro-2H-pyrrol-2-one (4d)



Product **4d** was synthesized according to the general experimental procedure described above. The crude product was purified by flash column chromatography (silica gel, petroleum ether : EtOAc = 5:1 → 3:1) to furnish **4d** as a brown oil (yield = 223 mg, 59%).

^{1}H NMR (500 MHz, $CDCl_3$) δ 7.25 (d, *J*=5.9 Hz, 1H), 6.20 (dd, J_1=5.9 Hz, J_2=1.4 Hz, 1H), 5.78 (m, 2H), 5.40 (t, *J*=8.2 Hz, 1H), 5.13 (dd, J_1=10.2 Hz, J_2=1.2 Hz, 1H), 5.03 (m, 3H), 4.24 (m, 2H), 2.43 (q, *J*=7.5 Hz, 2H), 2.22 (q, *J*=7.1 Hz, 2H) ppm; ^{13}C NMR (125 MHz, $CDCl_3$) δ 169.7, 139.6, 136.9, 133.0, 132.4, 124.2, 116.2, 115.9, 114.9, 41.2, 34.2, 27.1 ppm.

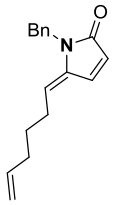
((E)-1-allyl-5-(4-iodobutylidene)-1,5-dihydro-2H-pyrrol-2-one (4e)



Product **4e** was synthesized according to the general experimental procedure described above. The crude product was purified by flash column chromatography (silica gel, petroleum ether : EtOAc = 5:1) to furnish **4e** as a brown oil (yield = 351.5 mg, 58%).

^{1}H NMR (500 MHz, $CDCl_3$) δ 7.33 (dd, J_1=5.9 Hz, J_2=0.6 Hz, 1H), 6.21 (dd, J_1=5.8 Hz, J_2=1.6 Hz, 1H), 5.75 (ddt, J_1=17.1 Hz, J_2=10.3 Hz, J_3=5.0 Hz, 1H), 5.29 (td, J_1=8.2 Hz, J_2=1.1 Hz, 1H), 5.12 (dq, J_1=10.3 Hz, J_2=1.6 Hz, 1H), 5.02 (dq, J_1=17.1 Hz, J_2=1.6 Hz, 1H), 4.23 (dt, J_1=5.0 Hz, J_2=1.8 Hz, 1H), 3.16 (t, J=6.6 Hz, 2H), 2.45 (q, J=7.3 Hz, 2H), 1.96 (quin, J=6.9 Hz, 2H) ppm; ^{13}C NMR (125 MHz, $CDCl_3$) δ 169.6, 140.4, 133.0, 132.6, 124.4, 116.1, 112.8, 41.2, 33.0, 28.0, 5.7 ppm.

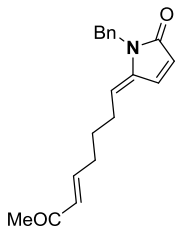
(E)-1-benzyl-5-(hex-5-en-1-ylidene)-1,5-dihydro-2H-pyrrol-2-one (6a)



Product **6a** was synthesized according to the general experimental procedure described above. The crude product was purified by flash column chromatography (silica gel, petroleum ether : EtOAc = 5:1) to furnish **6a** as a brown oil (yield = 313.7 mg, 62%).

^{1}H NMR (500 MHz, $CDCl_3$) δ 7.31-7.27 (m, 3H), 7.23 (m, 1H), 7.16 (d, J=7.7 Hz, 2H), 6.25 (dd, J_1=5.9 Hz, J_2=1.6 Hz, 1H), 5.71 (m, 1H), 5.30 (td, J_1=8.2 Hz, J_2=1.2 Hz, 1H), 4.96-4.92 (m, 2H), 4.84 (s, 2H), 2.27 (q, J=7.6 Hz, 2H), 1.96 (m, 2H), 1.46 (quin, J=7.3 Hz, 2H) ppm; ^{13}C NMR (125 MHz, $CDCl_3$) δ 170.1, 139.5, 137.9, 137.4, 132.6, 128.5 (2C), 127.1, 126.7 (2C), 124.0, 116.1, 115.1, 42.5, 32.8, 29.1, 26.8 ppm.

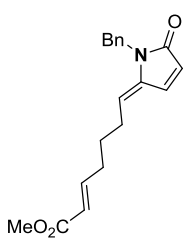
(E)-1-benzyl-5-((E)-7-oxooct-5-en-1-ylidene)-1,5-dihydro-2H-pyrrol-2-one (6b)



Product **6b** was synthesized according to the general experimental procedure described above. The crude product was purified by flash column chromatography (silica gel, petroleum ether : EtOAc = 5:1) to furnish **6b** as a brown oil (yield = 324.5 mg, 55%).

^{1}H NMR (500 MHz, $CDCl_3$) δ 7.28-7.19 (m, 4H), 7.12 (d, J=7.4 Hz, 1H), 6.67 (m, 1H), 6.23 (dd, J_1=5.8 Hz, J_2=1.5 Hz, 1H), 5.96 (d, J=16.0 Hz, 1H), 5.23 (t, J=8.2 Hz, 1H), 4.80 (s, 2H), 2.26 (q, J=7.5 Hz, 2H), 2.18 (s, 3H), 2.07 (m, 2H), 1.51 (quin, J=7.3 Hz, 2H) ppm; ^{13}C NMR (125 MHz, $CDCl_3$) δ 198.3, 170.0, 147.0, 139.7, 137.2, 132.5, 131.6, 128.6 (2C), 127.2, 126.7 (2C), 124.3, 115.1, 42.5, 31.4, 28.3, 27.0, 26.8 ppm.

methyl (2E,7E)-7-(1-benzyl-5-oxo-1,5-dihydro-2H-pyrrol-2-ylidene)hept-2-enoate (6c)



Product **6c** was synthesized according to the general experimental procedure described above. The crude product was purified by flash column chromatography (silica gel, petroleum ether : EtOAc = 5:1 → 3:1) to furnish **6c** as a brown oil (yield = 367 mg, 59%).

^{1}H NMR (500 MHz, $CDCl_3$) δ 7.28 (m, 2H), 7.23 (m, 2H), 7.14 (d,

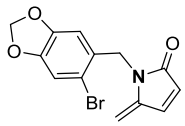
J=7.7 Hz, 1H), 6.85 (dt, J_1=15.7 Hz, J_2=7.0 Hz, 1H), 6.24 (dd, J_1=5.9 Hz, J_2=1.6 Hz, 1H), 5.73 (dt, J_1=15.7 Hz, J_2=1.5 Hz, 1H), 5.24 (td, J_1=8.2 Hz, J_2=1.0 Hz, 1H), 4.82 (s, 2H), 3.70 (s, 3H), 2.27 (q, *J*=7.6 Hz, 2H), 2.06 (m, 2H), 1.51 (quin, *J*=7.3 Hz, 2H) ppm; ^{13}C NMR (125 MHz, $CDCl_3$) δ 170.0, 166.8, 148.2, 139.6, 137.2, 132.5, 128.5 (2C), 127.2, 126.6 (2C), 124.2, 121.5, 115.0, 51.4, 42.5, 31.1, 28.2, 26.7 ppm.

1-benzyl-5-methylene-1,5-dihydro-2H-pyrrol-2-one (8a)

Product **8a** was synthesized according to the general experimental procedure described above. The crude product was purified by flash column chromatography (silica gel, petroleum ether : EtOAc = 8:1) to furnish **8a** as a yellow oil (yield = 185 mg, 50%).

^{1}H NMR (500 MHz, $CDCl_3$) δ 7.30 (m, 2H), 7.23 (m, 1H), 7.19 (d, *J*=7.5 Hz, 2H), 6.99 (d, *J*=5.8 Hz, 1H), 6.26 (dd, J_1=5.8 Hz, J_2=1.1 Hz, 1H), 4.82 (s, 2H), 4.82 (d, *J*=1.6 Hz, 1H), 4.78 (d, *J*=1.6 Hz, 1H) ppm; ^{13}C NMR (125 MHz, $CDCl_3$) δ 170.3, 145.1, 137.4, 137.0, 128.5 (2C), 127.2, 126.9 (2C), 124.8, 97.6, 42.5 ppm.

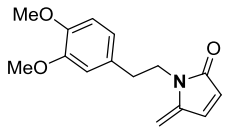
1-((6-bromobenzo[d][1,3]dioxol-5-yl)methyl)-5-methylene-1,5-dihydro-2H-pyrrol-2-one (8b)



Product **8b** was synthesized according to the general experimental procedure described above. The crude product was purified by flash column chromatography (silica gel, petroleum ether : EtOAc = 8:1) to furnish **8b** as a yellow oil (yield = 325.4 mg, 53%).

^{1}H NMR (500 MHz, $CDCl_3$) δ 7.04 (d, *J*=5.8 Hz, 1H), 6.99 (s, 1H), 6.44 (s, 1H), 6.30 (dd, J_1=5.8 Hz, J_2=0.7 Hz, 1H), 5.93 (s, 2H), 4.83 (m, 2H), 4.81 (s, 2H) ppm; ^{13}C NMR (125 MHz, $CDCl_3$) δ 170.3, 147.8, 147.5, 144.8, 137.6, 129.1, 124.9, 112.5, 112.4, 107.7, 101.7, 98.0, 42.5 ppm.

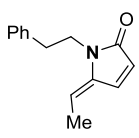
1-(3,4-dimethoxyphenethyl)-5-methylene-1,5-dihydro-2H-pyrrol-2-one (8c)



Product **8c** was synthesized according to the general experimental procedure described above. The crude product was purified by flash column chromatography (silica gel, petroleum ether : EtOAc = 4:1) to furnish **8c** as a white solid (yield = 290 mg, 56%).

^{1}H NMR (500 MHz, $CDCl_3$) δ 6.93 (d, *J*=5.8 Hz, 1H), 6.77 (d, *J*=8.0 Hz, 1H), 6.72 (d, *J*=8.0 Hz, 1H), 6.68 (s, 1H), 6.17 (d, *J*=5.8 Hz, 1H), 4.78 (s, 1H), 4.77 (s, 1H), 3.83 (s, 6H), 3.79 (t, *J*=7.5 Hz, 2H), 2.81 (t, *J*=7.5 Hz, 2H) ppm; ^{13}C NMR (125 MHz, $CDCl_3$) δ 170.1, 148.8, 147.6, 145.3, 137.1, 131.0, 125.0, 120.6, 112.0, 111.2, 96.4, 55.8 (2C), 40.7, 34.3 ppm.

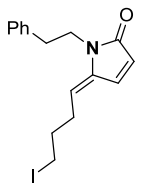
(E)-5-ethylidene-1-phenethyl-1,5-dihydro-2H-pyrrol-2-one (8d)



Product **8d** was synthesized according to the general experimental procedure described above. The crude product was purified by flash column chromatography (silica gel, petroleum ether : EtOAc = 6:1) to furnish a 20:1 mixture of E/Z isomers of **8d** as a yellow oil (yield = 260 mg, 61%).

^{1}H NMR (500 MHz, $CDCl_3$) δ 7.27 (t, *J*=7.3 Hz, 2H), 7.25 (d, *J*=5.8 Hz, 1H), 7.20 (m, 3H), 6.16 (dd, J_1=5.8 Hz, J_2=1.0 Hz, 1H), 5.34 (qd, J_1=7.5 Hz, J_2=1.2 Hz, 1H), 3.80 (t, *J*=7.7 Hz, 2H), 2.84 (t, *J*=7.7 Hz, 2H) ppm; ^{13}C NMR (125 MHz, $CDCl_3$) δ 169.8, 139.9, 138.6, 131.8, 128.7 (2C), 128.4 (2C), 126.4, 124.0, 109.6, 40.4, 35.1, 13.0 ppm.

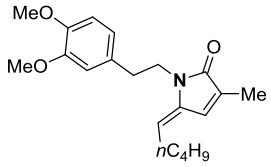
(E)-5-(4-iodobutylidene)-1-phenethyl-1,5-dihydro-2H-pyrrol-2-one (8e)



Product **8e** was synthesized according to the general experimental procedure described above. The crude product was purified by flash column chromatography (silica gel, petroleum ether : EtOAc = 5:1) to furnish **8e** as a brown oil (yield = 425.7 mg, 58%).

^{1}H NMR (500 MHz, $CDCl_3$) δ 7.26 (m, 3H), 7.20 (m, 1H), 7.15 (m, 2H), 6.18 (dd, J_1=5.9 Hz, J_2=1.6 Hz, 1H), 5.07 (td, J_1=8.3 Hz, J_2=1.0 Hz, 1H), 3.80 (t, *J* = 7.3 Hz, 2H), 3.06 (t, *J* = 6.6 Hz, 2H), 2.86 (t, *J*=7.3 Hz, 2H), 2.36 (q, *J*=7.4 Hz, 2H), 1.84 (quin, *J*=6.9 Hz, 2H) ppm; ^{13}C NMR (125 MHz, $CDCl_3$) δ 169.8, 140.5, 138.7, 132.3, 128.8 (2C), 128.4 (2C), 126.4, 124.4, 112.1, 40.6, 35.1, 33.0, 27.9, 5.8 ppm.

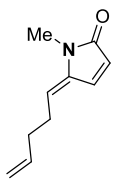
(E)-1-(3,4-dimethoxyphenethyl)-3-methyl-5-pentylidene-1,5-dihydro-2H-pyrrol-2-one (8f)



Product **8f** was synthesized according to the general experimental procedure described above. The crude product was purified by flash column chromatography (silica gel, petroleum ether : EtOAc = 5:1) to furnish **8f** as a brown oil (yield = 362 mg, 55%).

^{1}H NMR (500 MHz, $CDCl_3$) δ 6.88 (m, 1H), 6.78 (d, *J*=8.1 Hz, 1H), 6.73 (dd, J_1=8.1 Hz, J_2=1.7 Hz, 1H), 6.69 (d, *J*=1.7 Hz, 1H), 5.17 (t, *J*=8.2 Hz, 1H), 3.85 (s, 6H), 3.78 (t, *J*=7.6 Hz, 2H), 2.80 (t, *J*=7.6 Hz, 2H), 2.25 (q, *J*=7.4 Hz, 2H), 1.98 (s, 3H), 1.40-1.28 (m, 4H), 0.91 (t, *J*=7.1 Hz, 3H) ppm; ^{13}C NMR (125 MHz, $CDCl_3$) δ 170.3, 148.9, 147.6, 138.3, 133.4, 131.5, 126.5, 120.7, 112.6, 112.1, 111.2, 55.9, 55.8, 40.9, 34.8, 32.5, 27.1, 22.2, 13.8, 11.0 ppm.

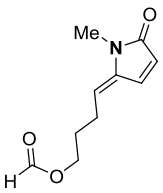
(E)-1-methyl-5-(pent-4-en-1-ylidene)-1,5-dihydro-2H-pyrrol-2-one (8g)



Product **8g** was synthesized according to the general experimental procedure described above. The crude product was purified by flash column chromatography (silica gel, petroleum ether : EtOAc = 7:1) to furnish **8g** as a brown oil (yield = 169.5 mg, 52%).

^{1}H NMR (500 MHz, $CDCl_3$) δ 7.19 (dd, J_1=5.9 Hz, J_2=0.6 Hz, 1H), 6.14 (dd, J_1=5.9 Hz, J_2=1.6 Hz, 1H), 5.77 (ddt, J_1=17.1 Hz, J_2=10.3, J_3=6.6 Hz, 1H), 5.36 (td, J_1=8.2 Hz, J_2=1.2 Hz, 1H), 5.03 (dq, J_1=17.1 Hz, J_2=1.6 Hz, 1H), 4.99 (m, 1H), 3.06 (s, 3H), 2.41 (q, *J*=7.5 Hz, 2H), 2.21 (m, 2H) ppm; ^{13}C NMR (125 MHz, $CDCl_3$) δ 169.9, 140.8, 136.9, 132.0, 124.5, 115.7, 113.8, 34.1, 26.9, 25.2 ppm.

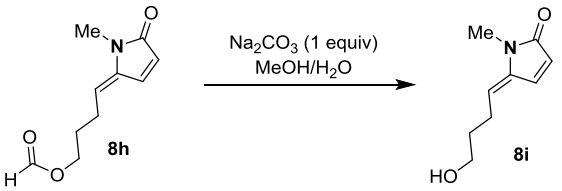
(E)-4-(1-methyl-5-oxo-1,5-dihydro-2H-pyrrol-2-ylidene)butyl formate (8h)



Product **8h** was synthesized according to the general experimental procedure described above. The crude product was purified by flash column chromatography (silica gel, petroleum ether : EtOAc = 3:1) to furnish **8h** as a brown oil (yield = 218.4 mg, 56%).

^{1}H NMR (500 MHz, $CDCl_3$) δ 8.07 (s, 1H), 7.22 (dd, J_1=5.9 Hz, J_2=0.6 Hz, 1H), 6.20 (dd, J_1=5.9 Hz, J_2=1.6 Hz, 1H), 5.36 (td, J_1=8.2 Hz, J_2=1.1 Hz, 1H), 4.21 (td, J_1=6.4 Hz, J_2=0.6 Hz, 1H), 3.10 (s, 3H), 2.45 (q, J=7.5 Hz, 2H), 1.86 (quin, J=7.2 Hz, 2H) ppm; ^{13}C NMR (125 MHz, $CDCl_3$) δ 170.0, 160.9, 141.5, 131.8, 125.0, 112.5, 62.7, 29.0, 25.3, 23.9 ppm.

(E)-5-(4-hydroxybutylidene)-1-methyl-1,5-dihydro-2H-pyrrol-2-one (8i)



Compound **8h** (218.4 mg, 1.12 mmol) was dissolved in MeOH (5.6 mL). Na_2CO_3 (119 mg, 1.12 mmol) dissolved in water (1 mL) was added and the solution was stirred at rt until full consumption of the starting material was indicated by tlc analysis. After completion of the reaction (1 h), water was added (4 mL) and the solution was extracted with DCM (2× 6 mL). The combined organic layers were dried over Na_2SO_4 and concentrated under reduced pressure. Product **8i** was utilized without further purification (yield = 159 mg, 85%).

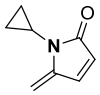
^{1}H NMR (500 MHz, $CDCl_3$) δ 7.27 (dd, J_1=5.9 Hz, J_2=0.6 Hz, 1H), 6.17 (dd, J_1=5.9 Hz, J_2=1.6 Hz, 1H), 5.41 (td, J_1=8.3 Hz, J_2=1.2 Hz, 1H), 3.69 (t, J=6.2 Hz, 1H), 3.10 (s, 3H), 2.47 (q, J=7.5 Hz, 2H), 1.75 (m, 2H) ppm; ^{13}C NMR (125 MHz, $CDCl_3$) δ 170.1, 141.1, 132.1, 124.6, 113.9, 61.6, 32.8, 25.3, 23.8 ppm.

1-methyl-5-methylene-1,5-dihydro-2H-pyrrol-2-one (8j)

Product **8j** was synthesized according to the general experimental procedure described above. The crude product was purified by flash column chromatography (silica gel, petroleum ether : EtOAc = 3:1 → 1:1) to furnish **8j** as a white solid (yield = 104.6 mg, 48%).

^{1}H NMR (500 MHz, $CDCl_3$) δ 6.97 (d, J=5.8 Hz, 1H), 6.20 (m, 1H), 4.89 (t, J=1.6 Hz, 1H), 4.82 (d, J=1.6 Hz, 1H), 3.12 (s, 3H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 170.4, 146.4, 136.7, 125.4, 96.1, 25.2.

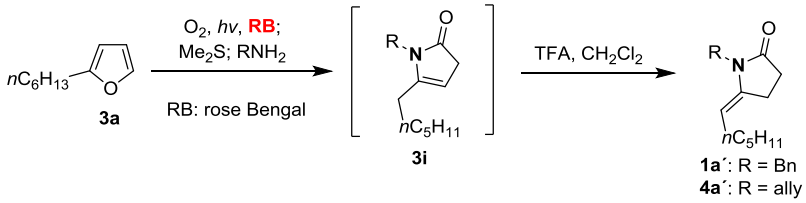
1-cyclopropyl-5-methylene-1,5-dihydro-2H-pyrrol-2-one (8k)



Product **8k** was synthesized according to the general experimental procedure described above. The crude product was purified by flash column chromatography (silica gel, petroleum ether : EtOAc = 3:1 → 1:1) to furnish **8k** as a yellow oil (yield = 135 mg, 50%).

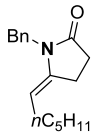
^{1}H NMR (500 MHz, $CDCl_3$) δ 6.90 (d, J=5.8 Hz, 1H), 6.07 (ddd, J_1=5.8, J_2=1.6, J_3=0.6 Hz, 1H), 5.20 (m, 1H), 4.81 (s, 1H), 2.50 (m, 1H), 0.95 (m, 2H), 0.86 (m, 2H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 171.0, 146.6, 136.7, 124.7, 97.5, 20.9, 5.7 (2C).

Synthesis of substrates 1a´ and 4a´



2-Substituted furan **3a** (76 mg, 0.5 mmol) was dissolved in MeOH (6.3 mL, 80 mM) containing catalytic amounts (0.1 mM) of rose Bengal as photosensitizer. The solution was cooled using an ice bath. Oxygen was gently bubbled through the solutions while they were irradiated with a xenon Variac Eimac Cermax 300 W lamp. After completion of the reactions (4 min) they were warmed to rt and Me_2S (146 µL, 2.0 mmol) was added. The solution was stirred at the same temperature. After completion of the reduction, as indicated by tlc analysis (45 min), the corresponding amine (0.55 mmol, 60 µL for benzylamine, or 41 µL for allylamine) was added and the reactions were stirred at the same temperature. After the formation of 2-pyrrolidinone of type **3i** (45 min, tlc analysis), the MeOH was replaced with CH_2Cl_2 (6 mL) and TFA (38 µL, 0.5 mmol) was added. The reaction was stirred at the same temperature for 0.5 h. After completion of the reactions, the solvent was removed under reduced pressure and the residues were purified by flash column chromatography (silica gel, petroleum ether : EtOAc = 4:1) to afford the corresponding pyrrolidin-2-ones **1a´** and **4a´**.

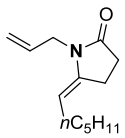
(E)-1-benzyl-5-hexylidenepyrrolidin-2-one (1a´)



Product **1a´** was synthesized according to the general experimental procedure described above. Yield of **1a´** (yellow oil) = 83,5 mg, 65%.

^{1}H NMR (500 MHz, $CDCl_3$) δ 7.27 (m, 2H), 7.20 (m, 3H), 4.65 (s, 2H), 4.59 (t, J=7.3 Hz, 1H), 2.62 (m, 2H), 2.56 (m, 2H), 1.91 (q, J=7.3 Hz, 2H), 1.29-1.20 (m, 4H), 1.18-1.12 (m, 2H), 0.83 (t, J=7.2 Hz, 3H) ppm; ^{13}C NMR (125 MHz, $CDCl_3$): δ = 175.4, 138.4, 136.2, 128.3 (2C), 127.0 (3C), 102.1, 43.4, 31.1, 29.5, 28.8, 26.4, 22.3, 21.1, 13.9 ppm.

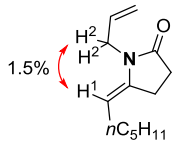
(E)-1-allyl-5-hexylidenepyrrolidin-2-one (4a´)



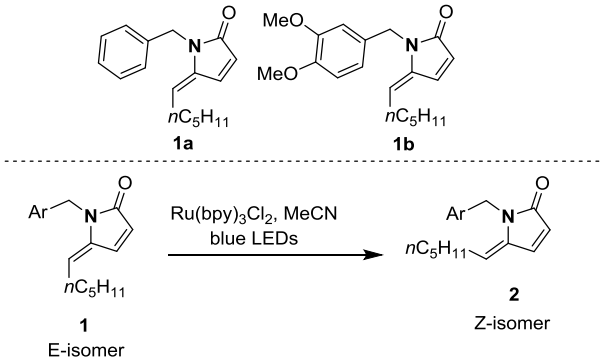
Product **4a´** was synthesized according to the general experimental procedure described. Yield **4a´** (yellow oil) = 64,2 mg, 62%.

^{1}H NMR (500 MHz, $CDCl_3$) δ 5.71 (m, 1H), 5.14 (m, 2H), 4.66 (t, J=7.4 Hz, 1H), 4.09 (d, J=5.3 Hz, 2H), 2.64 (m, 2H), 2.52 (m, 2H), 1.98 (q, J=7.4 Hz, 2H), 1.39-1.25 (m, 6H), 0.89 (t, J=6.9 Hz, 3H) ppm; ^{13}C NMR (125 MHz, $CDCl_3$) δ 176.0, 138.4, 131.3, 117.1, 102.6, 42.4, 31.4, 29.7, 28.8, 26.7, 22.5, 21.3, 14.0 ppm.

Representative NOE of compound **4a´**



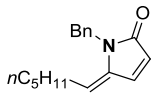
General procedure for the photocatalytic E → Z isomerization of compounds of type 1.



To a solution of compounds of type **1** (0.1 mmol, 25.5 mg for **1a**, 31.5 mg for **1b**) in dry CH_3CN (1 mL, 100 mM) at rt, the photocatalyst $Ru(bpy)_3Cl_2$ (0.5%, 0.3 mg, 0.0005 mmol) was added and argon (balloon) was gently bubbled through the solution for 10 min. Afterwards, the solution was irradiated using blue LED light strips (60 LEDs/m, 10.8 w/m, 1000 lm/m, λ_{max} = 420 nm) at rt for 4 h. Another time, the reaction was left for 24 h, but the isomerization results were identical. The reaction was monitored by ^{1}H-NMR. The solution was concentrated *in vacuo*. The Z/E ratio was calculated by ^{1}H-NMR without further purification. For **2a**: Z/E = 5.5/1, for **2b**: Z/E = 6.5/1.

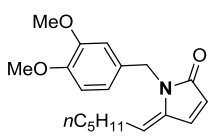
The same experiment for **1a** and **1b** was performed this time using $Ir(ppy)_3$ instead of the ruthenium catalyst and the Z/E ratio after 1 h irradiation was calculated as being 1.1/1 for **2a** and **2b**, respectively The reaction was also left for 24 h, but the isomerization results were identical.

(Z)-1-benzyl-5-hexylidene-1,5-dihydro-2H-pyrrol-2-one (2a)



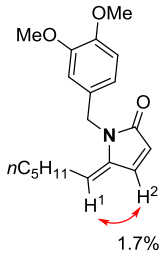
^{1}H NMR (500 MHz, $CDCl_3$) δ 7.30 (m, 2H), 7.22 (m, 1H), 7.07 (d, *J*=7.1 Hz, 2H), 6.92 (d, J_1=5.7 Hz, 1H), 6.19 (d, J_1=5.7 Hz, 1H), 5.13 (t, *J*=8.1 Hz, 1H), 5.05 (s, 2H), 2.17 (q, *J*=7.6 Hz, 2H), 1.24-1.04 (m, 6H), 0.80 (t, *J*=7.1 Hz, 3H) ppm; ^{13}C NMR (125 MHz, $CDCl_3$): δ = 170.1, 139.3, 137.4, 132.6, 128.5 (2C), 127.1, 126.8 (2C), 124.0, 116.7, 42.5, 31.1, 29.7, 27.5, 22.3, 13.9 ppm.

(Z)-1-(3,4-dimethoxybenzyl)-5-hexylidene-1,5-dihydro-2H-pyrrol-2-one (2b)

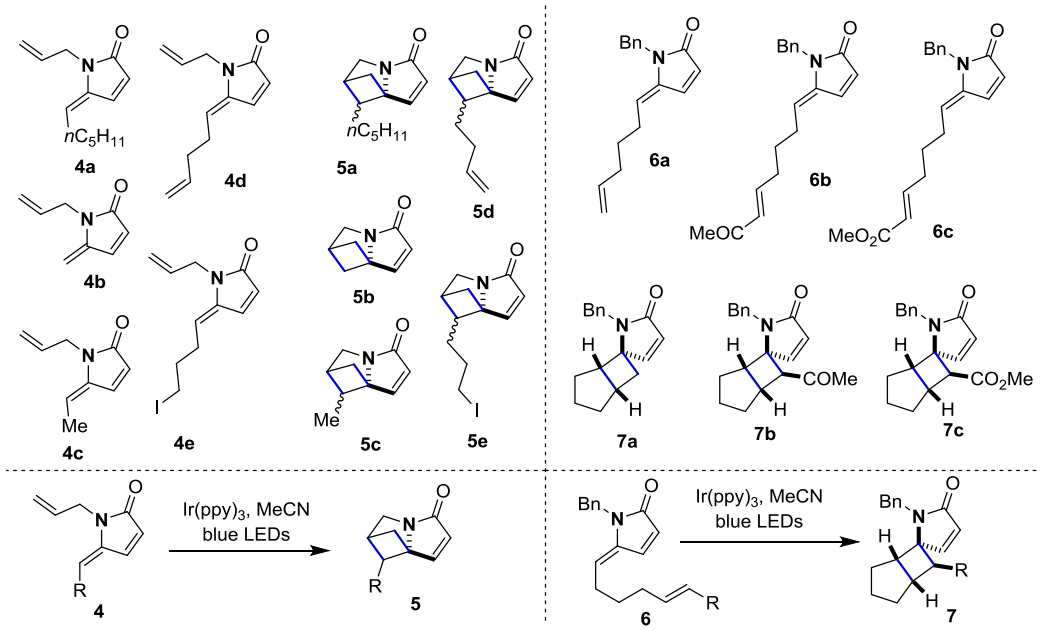


^{1}H NMR (500 MHz, $CDCl_3$) δ 6.91 (d, *J*=5.7 Hz, 1H), 6.78 (d, *J*=8.0 Hz, 1H), 6.61 (s, 1H), 6.60 (d, *J*=8.0 Hz, 1H), 6.17 (d, *J*=5.7 Hz, 1H), 5.14 (t, *J*=8.1 Hz, 1H), 4.97 (s, 2H), 3.83 (s, 3H), 3.81 (s, 3H), 2.21 (q, *J*=7.6 Hz, 2H), 1.27-1.09 (m, 6H), 0.81 (t, *J*=7.1 Hz,

3H) ppm; ^{13}C NMR (125 MHz, $CDCl_3$): δ = 172.0, 149.2, 148.0, 140.5, 138.6, 130.6, 121.3, 119.6, 117.8, 111.3, 109.1, 55.9, 55.8, 43.9, 31.3, 29.5, 27.0, 22.2, 13.8 ppm.
Representative NOE of compound **2b**

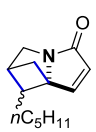


General procedure for the photocatalytic transformation of compounds of type 4 and 6 into compounds of type 5 and 7, respectively. Intramolecular [2+2] cycloaddition.



To a solution of compounds of type **4** or **6** (0.1 mmol, 20.5 mg for **4a**, 13.5 mg for **4b**, 14.9 mg for **4c**, 18.9 mg for **4d**, 30.3 mg for **4e**, 25.3 mg for **6a**, 29.5 mg for **6b**, 31.1 mg for **6c**) in dry CH_3CN (1 mL, 100 mM) at rt, the photocatalyst $Ir(ppy)_3$ (0.5%, 0.3 mg, 0.0005 mmol) was added and argon (balloon) was gently bubbled through the solution for 10 min. Afterwards, the solution was irradiated using blue LED light strips (60 LEDs/m, 10.8 w/m, 1000 lm/m, λ_{max} = 420 nm) at the same temperature. After completion of the reaction, as indicated by tlc analysis (8 h towards **5** or 4 h towards **7**), the solution was concentrated *in vacuo* and the product of type **5** or **7** was purified by flash column chromatography. Use of white LED light results to higher reaction times.

1-pentyl-2,3-dihydro-1H,5H-2,7a-methanopyrrolizin-5-one (5a)



Product **5a** was synthesized according to the general experimental procedure described above. The crude product was purified by flash column chromatography (silica gel, petroleum ether : EtOAc = 1:1 → 1:5) to afford

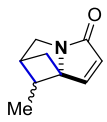
a 1.6/1 mixture of diastereoisomers of **5a** as a yellow solid (yield = 19.3 mg, 94%). ^{1}H NMR (500 MHz, $CDCl_3$) δ 6.90 (d, *J*=5.8 Hz, 1H for major isomer), 6.88 (d, *J*=5.8 Hz, 1H for minor isomer), 6.32 (dd, J_1=5.8 Hz, J_2=1.3 Hz, 1H for major isomer), 6.29 (dd, J_1=5.8 Hz, J_2=1.3 Hz, 1H for minor isomer), 3.50 (d, *J*=9.3 Hz, 1H for major isomer), 3.46 (d, *J*=9.3 Hz, 1H for major isomer), 3.38 (d, *J*=9.8 Hz, 1H for minor isomer), 3.33 (d, *J*=9.8 Hz, 1H for minor isomer), 2.90 (m, 1H for minor isomer), 2.81 (m, 1H for major isomer), 2.77 (ddd, J_1=7.5 Hz, J_2=3.6 Hz, J_3=0.6 Hz, 1H for major isomer), 2.31 (td, J_1=6.9 Hz, J_2=2.8 Hz, 1H for minor isomer), 2.07 (ddd, J_1=6.9 Hz, J_2=3.0 Hz, J_3=0.8 Hz, 1H for minor isomer), 1.99 (q, *J*=7.5 Hz, 1H for major isomer), 1.70 (m, 2H for major isomer), 1.60 (t, *J*=7.4 Hz, 1H for major isomer), 1.49 (d, *J*=7.0 Hz, 1H for minor isomer), 1.33-1.08 (m, 6H for major plus 6H for minor isomer), 0.94 (m, 2H for minor isomer), 0.88 (t, *J* = 6.9 Hz, 3H for major isomer), 0.83 (t, *J* = 7.1 Hz, 3H for minor isomer); ^{13}C NMR (125 MHz, $CDCl_3$) δ 164.6 (minor), 163.8 (major), 140.7 (major), 140.6 (minor), 135.8 (minor), 135.6 (major), 80.5 (minor), 80.3 (major), 59.8 (major), 54.1 (minor), 46.4 (major), 42.9 (major), 42.8 (minor), 41.9 (minor), 41.8 (minor plus major), 31.7 (major), 31.6 (minor), 28.5 (major), 26.9 (minor), 26.7 (major), 24.1 (minor), 22.5 (major), 22.4 (minor), 14.0 (major), 13.9 (minor); HRMS (TOF ESI): $[M+H]^+$ calcd for $C_{13}H_{20}NO$, 206.1539; found, 206.1541.

2,3-dihydro-1H,5H-2,7a-methanopyrrolizin-5-one (5b)

Product **5b** was synthesized according to the general experimental procedure described above. The crude product was purified by flash column chromatography (silica gel, EtOAc) to afford **5b** as a yellow oil (yield = 12.8 mg, 95%).

^{1}H NMR (500 MHz, $CDCl_3$) δ 6.95 (d, *J*=5.8 Hz, 1H), 6.32 (dd, J_1=5.8 Hz, J_2=1.4 Hz, 1H), 3.47 (s, 2H), 3.09 (m, 1H), 2.29 (m, 2H), 1.53 (m, 2H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 164.0, 141.2, 135.6, 79.0, 45.1, 44.9 (2C), 39.8; HRMS (TOF ESI): $[M+H]^+$ calcd for $C_8H_{10}NO$, 136.0757; found, 136.0755.

1-methyl-2,3-dihydro-1H,5H-2,7a-methanopyrrolizin-5-one (5c)

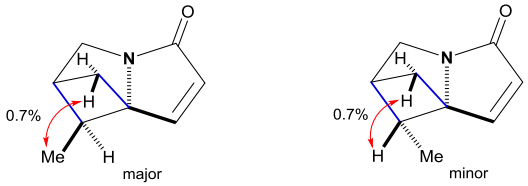


Product **5c** was synthesized according to the general experimental procedure described above. The crude product was purified by flash column chromatography (silica gel, EtOAc) to afford a 2/1 mixture of diastereoisomers of **5c** as a yellow solid (yield = 13.7 mg, 92%).

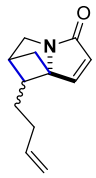
^{1}H NMR (500 MHz, $CDCl_3$) δ 6.88 (d, *J*=5.8 Hz, 1H for major isomer), 6.83 (d, *J*=5.8 Hz, 1H for minor isomer), 6.31 (dd, J_1=5.8 Hz, J_2=1.3 Hz, 1H for major isomer), 6.30 (dd, J_1=5.8 Hz, J_2=1.3 Hz, 1H for minor isomer), 3.48 (d, *J*=9.4 Hz, 1H for major isomer), 3.45 (d, *J*=9.4 Hz, 1H for major isomer), 3.37 (d, *J*=9.9 Hz, 1H for minor isomer), 3.33 (d, *J*=9.8 Hz, 1H for minor isomer), 2.85 (m, 1H for minor isomer), 2.80 (ddd, J_1=7.6 Hz, J_2=3.2 Hz, J_3=0.7 Hz, 1H for major isomer), 2.75 (m, 1H for major isomer), 2.43 (qd, J_1=6.4 Hz, J_2=3.0 Hz, 1H for minor isomer), 2.08 (m, 1H for major plus 1H for minor isomer), 1.60 (t, *J*=7.5 Hz, 1H for major isomer), 1.52 (d, *J*=7.0 Hz, 1H for minor isomer), 1.33 (d, *J* = 6.9 Hz, 3H for major isomer), 0.58 (d, *J* = 6.4 Hz,

3H for minor isomer); ^{13}C NMR (125 MHz, $CDCl_3$) δ 164.6 (minor), 163.8 (major), 140.2 (major), 140.0 (minor), 136.2 (minor), 135.9 (major), 80.6 (minor plus major), 53.5 (major), 48.2 (minor), 46.4 (major), 44.1 (major), 42.7 (minor), 42.6 (minor), 41.5 (minor), 41.3 (major), 11.8 (major), 8.7 (minor); HRMS (TOF ESI): $[M+H]^+$ calcd for $C_9H_{12}NO$, 150.0913; found, 150.0915.

Representative NOE of compound **5c**



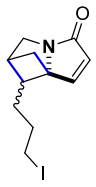
1-(but-3-en-1-yl)-2,3-dihydro-1H,5H-2,7a-methanopyrrolizin-5-one (5d)



Product **5d** was synthesized according to the general experimental procedure described above. The crude product was purified by flash column chromatography (silica gel, petroleum ether : EtOAc = 1:1 → 1:5) to afford a 1.7/1 mixture of diastereoisomers of **5d** as a yellow solid (yield = 16 mg, 85%).

^{1}H NMR (500 MHz, $CDCl_3$) δ 6.92 (d, *J*=5.8 Hz, 1H for major isomer), 6.88 (d, *J*=5.8 Hz, 1H for minor isomer), 6.33 (d, *J*=5.8 Hz, 1H for major isomer), 6.30 (d, *J*=5.8 Hz, 1H for minor isomer), 5.78 (m, 1H for major isomer), 5.68 (m, 1H for minor isomer), 5.03-4.93 (m, 2H for major plus 2H for minor isomer), 3.51 (d, *J*=9.5 Hz, 1H for major isomer), 3.47 (d, *J*=9.5 Hz, 1H for major isomer), 3.39 (d, *J*=9.8 Hz, 1H for minor isomer), 3.35 (d, *J*=9.8 Hz, 1H for minor isomer), 2.92 (m, 1H for minor isomer), 2.85 (m, 1H for major isomer), 2.79 (dd, J_1=7.5, J_2=3.0 Hz, 1H for major isomer), 2.34 (td, J_1=6.9 Hz, J_2=2.7 Hz, 1H for minor isomer), 2.09 (m, 2H for major plus 1H for minor isomer), 2.03 (q, *J*=7.5 Hz, 1H for major isomer), 1.90 (q, *J*=7.2 Hz, 1H for major isomer), 1.83 (m, 1H for major plus 2H for minor isomer), 1.63 (t, *J*=7.5 Hz, 1H for major isomer), 1.50 (d, *J*=7.0 Hz, 1H for minor isomer), 1.07 (q, *J*=7.4 Hz, 2H for minor isomer); ^{13}C NMR (125 MHz, $CDCl_3$) δ 164.6 (minor), 163.8 (major), 140.5 (minor plus major), 137.7 (minor), 137.4 (major), 135.9 (minor), 135.8 (major), 115.5 (major), 115.2 (minor), 80.4 (minor), 80.2 (major), 59.3 (major), 53.3 (minor), 46.4 (major), 42.9 (major), 42.8 (minor), 42.0 (minor), 41.9 (minor plus major), 32.8 (major), 31.3 (minor), 26.1 (major), 23.3 (minor); HRMS (TOF ESI): $[M+H]^+$ calcd for $C_{12}H_{16}NO$, 190.1226; found, 190.1228.

1-(3-iodopropyl)-2,3-dihydro-1H,5H-2,7a-methanopyrrolizin-5-one (5e)

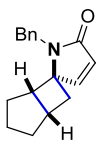


Product **5e** was synthesized according to the general experimental procedure described above. The crude product was purified by flash column chromatography (silica gel, petroleum ether : EtOAc = 1:1 → 1:5) to afford a 1.7/1 mixture of diastereoisomers of **5e** as a yellow solid (yield = 28.5 mg, 94%).

^{1}H NMR (500 MHz, $CDCl_3$) δ 6.90 (d, *J*=5.8 Hz, 1H for major isomer), 6.87 (d, *J*=5.8 Hz, 1H for minor isomer), 6.31 (dd, J_1=5.8 Hz, J_2=1.3 Hz, 1H for major isomer), 6.29

(dd, J_1=5.8 Hz, J_2=1.3 Hz, 1H for minor isomer), 3.49 (dd, J_1=9.5 Hz, J_2=0.9 Hz, 1H for major isomer), 3.45 (d, J=9.5 Hz, 1H for major isomer), 3.38 (dd, J_1=9.9 Hz, J_2=0.8 Hz, 1H for minor isomer), 3.34 (d, J=9.9 Hz, 1H for minor isomer), 3.18 (m, 2H for major isomer), 3.06 (m, 2H for minor isomer), 2.92 (m, 1H for minor isomer), 2.84 (m, 1H for major isomer), 2.78 (ddd, J_1=7.8 Hz, J_2=3.2 Hz, J_3=1.0 Hz, 1H for major isomer), 2.31 (td, J_1=6.9 Hz, J_2=2.8 Hz, 1H for minor isomer), 2.08 (ddd, J_1=7.0 Hz, J_2=3.2 Hz, J_3=1.0 Hz, 1H for minor isomer), 2.00 (m, 1H for major isomer), 1.87-1.78 (m, 3H for major plus 2H for minor isomer), 1.64 (m, 1H for major isomer), 1.63 (t, J=7.4 Hz, 1H for major isomer), 1.50 (d, J=7.0 Hz, 1H for minor isomer), 1.07 (m, 2H for minor isomer); ^{13}C NMR (125 MHz, $CDCl_3$) δ 164.4 (minor), 163.6 (major), 140.3 (minor), 140.2 (major), 136.1 (minor), 136.0 (major), 80.2 (minor), 80.1 (major), 58.6 (major), 52.6 (minor), 46.3 (major), 42.9 (major), 42.8 (minor), 41.9 (minor plus major), 41.8 (manor), 32.4 (major), 31.1 (minor), 27.7 (major), 25.2 (minor), 6.0 (major), 5.7 (minor); HRMS (TOF ESI): $[M+H]^+$ calcd for $C_{11}H_{15}INO$, 304.0193; found, 304.0193.

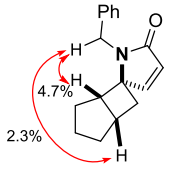
1'-benzylspiro[bicyclo[3.2.0]heptane-6,2'-pyrrol]-5'(1'H)-one (7a)



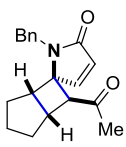
Product **7a** was synthesized according to the general experimental procedure described above. The crude product was purified by flash column chromatography (silica gel, petroleum ether : EtOAc = 3:1 → 1:1) to afford **7a** as a yellow oil (yield = 24.3 mg, 96%).

^{1}H NMR (500 MHz, $CDCl_3$) δ 7.36 (d, J=7.4 Hz, 2H), 7.31 (t, J=7.4 Hz, 2H), 7.24 (m, 1H), 7.09 (d, J=6.0 Hz, 1H), 6.10 (d, J=6.0 Hz, 1H), 4.83 (d, J=15.9 Hz, 1H), 4.76 (d, J=15.9 Hz, 1H), 2.86 (td, J_1=8.3 Hz, J_2=2.0 Hz, 1H), 2.77 (m, 1H), 2.25 (ddd, J_1=14.0 Hz, J_2=9.7 Hz, J_3=2.6 Hz, 1H), 1.91-1.81 (m, 3H), 1.71 (dd, J_1=14.0 Hz, J_2=6.0 Hz, 1H), 1.59 (dd, J_1=13.0 Hz, J_2=6.0 Hz, 1H), 1.47 (m, 2H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 170.3, 148.3, 139.1, 128.6 (2C), 127.3 (2C), 127.1, 125.4, 69.0, 46.2, 42.9, 32.6, 32.3, 31.6, 30.2, 25.6; HRMS (TOF ESI): $[M+H]^+$ calcd for $C_{17}H_{20}NO$, 254.1539; found, 254.1536.

Representative NOEs



7-acetyl-1'-benzylspiro[bicyclo[3.2.0]heptane-6,2'-pyrrol]-5'(1'H)-one (7b)

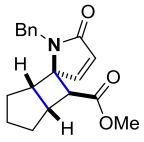


Product **7b** was synthesized according to the general experimental procedure described above. The crude product was purified by flash column chromatography (silica gel, petroleum ether : EtOAc = 3:1 → 1:1) to afford **7b** as a yellow oil (yield = 27.1 mg, 92%, dr = 20:1).

^{1}H NMR (500 MHz, $CDCl_3$) δ 7.28 (m, 2H), 7.21 (m, 4H), 6.30 (d, J=6.0 Hz, 1H), 5.05 (d, J=16.3 Hz, 1H), 4.16 (d, J=16.3 Hz, 1H), 3.41 (q, J=7.5 Hz, 1H), 3.12 (d, J=7.5 Hz, 1H), 2.71 (t, J=8.6 Hz, 1H), 1.92 (m, 1H), 1.85 (s, 3H), 1.76 (m, 2H), 1.60

(m, 1H), 1.50 (m, 2H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 204.5, 170.5, 147.9, 138.0, 128.6 (2C), 127.1, 126.9, 126.8 (2C), 72.0, 55.2, 43.9, 43.0, 34.9, 31.7, 29.4, 29.0, 25.9; HRMS (TOF ESI): $[M+H]^+$ calcd for $C_{19}H_{22}NO_2$, 296.1645; found, 296.1642.

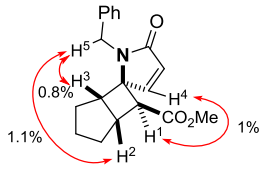
methyl 1'-benzyl-5'-oxo-1',5'-dihydrospiro[bicyclo[3.2.0]heptane-6,2'-pyrrole]-7-carboxylate (7c)



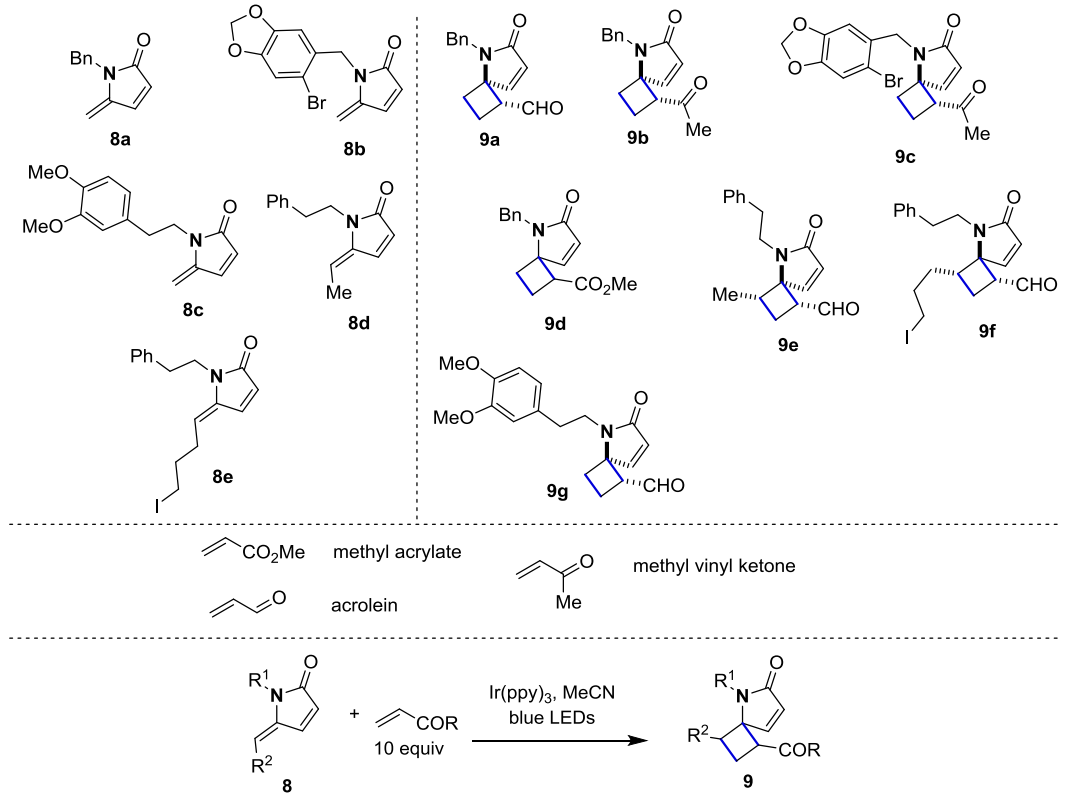
Product **7c** was synthesized according to the general experimental procedure described above. The crude product was purified by flash column chromatography (silica gel, petroleum ether : EtOAc = 3:1 → 1:1) to afford **7c** as a yellow oil (yield = 27.1 mg, 95%, dr = 20:1).

^{1}H NMR (500 MHz, $CDCl_3$) δ 7.28 (t, *J*=7.4 Hz, 2H), 7.22 (m, 3H), 7.07 (d, *J*=6.0 Hz, 1H), 6.20 (d, *J*=6.0 Hz, 1H), 5.05 (d, *J*=16.4 Hz, 1H), 4.31 (d, *J*=16.4 Hz, 1H), 3.61 (s, 3H), 3.34 (q, *J*=7.6 Hz, 1H), 3.09 (d, *J*=7.6 Hz, 1H), 2.78 (t, *J*=8.6 Hz, 1H), 1.92 (m, 1H), 1.81-1.67 (m, 3H), 1.49 (m, 2H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 170.9, 170.7, 147.1, 138.3, 128.5 (2C), 127.0, 126.8 (2C), 126.5, 71.3, 52.2, 47.3, 43.7, 43.2, 36.6, 31.7, 29.2, 25.7; HRMS (TOF ESI): $[M+H]^+$ calcd for $C_{19}H_{22}NO_3$, 312.1594; found, 312.1594.

Representative NOEs



General procedure for the photocatalytic transformation of compounds of type 8 into compounds of type 9. Intermolecular [2+2] cycloaddition.



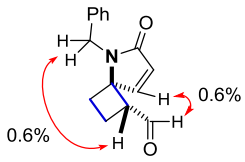
To a solution of compounds of type **8** (0.1 mmol, 18.5 mg for **8a**, 30.7 mg for **8b**, 25.9 mg for **8c**, 21.3 mg for **8d**, 36.7 mg for **8e**) in dry CH_3CN (1 mL, 100 mM) at rt, the photocatalyst $Ir(ppy)_3$ (0.5%, 0.3 mg, 0.0005 mmol) was added and argon (balloon) was gently bubbled through the solution for 10 min. Afterwards, the corresponding α,β-unsaturated carbonyl compound (1 mmol, 90.6 μL for methyl acrylate, 66.8 μL for acrolein, 83.3 μL for methyl vinyl ketone) was added and the solution was irradiated using blue LED light strips (60 LEDs/m, 10.8 w/m, 1000 lm/m, λ_{max} = 420 nm) at the same temperature. After completion of the reaction, as indicated by tlc analysis (20 h), the solution was concentrated *in vacuo* and the product of type **9** was purified by flash column chromatography. Use of white LED light results to higher reaction times.

5-benzyl-6-oxo-5-azaspiro[3.4]oct-7-ene-1-carbaldehyde (9a)

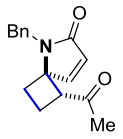
Product **9a** was synthesized according to the general experimental procedure described above. The reaction afforded a 1.6/1 mixture of diastereoisomers of **9a**. The crude product was purified by flash column chromatography (silica gel, petroleum ether : EtOAc = 2:1) to afford a single diastereoisomer (the major isomer of the reaction) of **9a** as a yellow oil. The isolation of a single diastereoisomer of **9a** was the outcome of an epimerization that occurred on silica. Yield = 19.8 mg, 82%. The reaction was tested also with PC4 (0.5%) and the result was exactly the same.

^{1}H NMR (500 MHz, $CDCl_3$) δ 9.25 (s, 1H), 7.33 (m, 2H), 7.27 (m, 3H), 7.26 (d, *J*=6.0 Hz, 1H), 6.25 (d, *J*=6.0 Hz, 1H), 4.99 (d, *J*=16.1 Hz, 1H), 4.58 (d, *J*=16.1 Hz, 1H), 3.46 (t, *J*=9.6 Hz, 1H), 2.46 (td, J_1=11.6 Hz, J_2=9.8 Hz, 1H), 2.23 (m, 1H), 1.93 (m, 1H), 1.83 (m, 1H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 198.5, 170.5, 147.5, 137.7, 128.9 (2C), 127.6, 126.9 (2C), 125.7, 70.1, 52.0, 42.4, 26.4, 13.9; HRMS (TOF ESI): $[M+H]^+$ calcd for $C_{15}H_{16}NO_2$, 242.1176; found, 242.1172.

Representative NOE



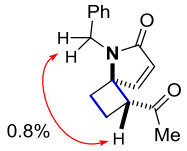
1-acetyl-5-benzyl-5-azaspiro[3.4]oct-7-en-6-one (9b)



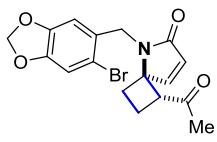
Product **9b** was synthesized according to the general experimental procedure described above. The reaction afforded a 1.6/1 mixture of diastereoisomers of **9b**. The crude product was purified by flash column chromatography (silica gel, petroleum ether : EtOAc = 4:1) to afford a single diastereoisomer (the major isomer of the reaction) of **9b** as a yellow oil. The isolation of a single diastereoisomer of **9b** was the outcome of an epimerization that occured on silica. Yield = 19.1 mg, 75%.

^{1}H NMR (500 MHz, $CDCl_3$) δ 7.39 (d, *J*=7.6 Hz, 2H), 7.34 (m, 2H), 7.29 (m, 1H), 7.16 (d, *J*=6.0 Hz, 1H), 6.21 (d, *J*=6.0 Hz, 1H), 5.03 (d, *J*=15.6 Hz, 1H), 4.50 (d, *J*=15.6 Hz, 1H), 3.49 (t, *J*=9.5 Hz, 1H), 2.44 (q, *J*=10.8 Hz, 1H), 2.25 (m, 1H), 1.89 (m, 1H), 1.76 (m, 1H), 1.47 (s, 3H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 204.4, 170.6, 148.0, 137.9, 128.8 (2C), 128.0 (2C), 127.7, 125.6, 70.6, 52.5, 42.7, 28.7, 25.4, 14.2; HRMS (TOF ESI): $[M+H]^+$ calcd for $C_{16}H_{18}NO_2$, 256.1332; found, 256.1330.

Representative NOE



1-acetyl-5-((6-bromobenzo[d][1,3]dioxol-5-yl)methyl)-5-azaspiro[3.4]oct-7-en-6-one (9c)

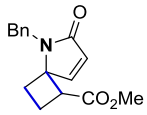


Product **9c** was synthesized according to the general experimental procedure described above. The reaction afforded a 1.6/1 mixture of diastereoisomers of **9c**. The crude product was purified by flash column chromatography (silica gel, petroleum ether : EtOAc = 3:1) to afford a single diastereoisomer (the major isomer of the reaction) of **9c** as a yellow oil. The isolation of a single diastereoisomer of **9c** was the outcome of an epimerization that occured on silica. Yield = 30.9 mg, 82%.

^{1}H NMR (500 MHz, $CDCl_3$) δ 7.19 (d, *J*=6.0 Hz, 1H), 7.00 (s, 1H), 6.92 (s, 1H), 6.21 (d, *J*=6.0 Hz, 1H), 5.95 (m, 2H), 4.88 (d, *J*=16.0 Hz, 1H), 4.76 (d, *J*=16.0 Hz, 1H), 3.62 (t, *J*=9.5 Hz, 1H), 2.48 (q, *J*=10.8 Hz, 1H), 2.29 (m, 1H), 1.90 (m, 1H), 1.83 (m,

1H), 1.60 (s, 3H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 204.3, 170.6, 148.3, 148.1, 148.0, 130.3, 125.5, 113.2, 112.4, 109.6, 101.9, 70.5, 52.6, 41.9, 28.8, 25.6, 14.3; HRMS (TOF ESI): $[M+H]^+$ calcd for $C_{17}H_{17}BrNO_4$, 378.0336; found, 378.0338.

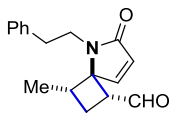
methyl 5-benzyl-6-oxo-5-azaspiro[3.4]oct-7-ene-1-carboxylate (9d)



Product **9d** was synthesized according to the general experimental procedure described above. The reaction afforded a 1/1 mixture of diastereoisomers of **9d**. The crude product was purified by flash column chromatography (silica gel, petroleum ether : EtOAc = 4:1) to afford a 1/1 mixture of diastereoisomers of **9d** as a yellow oil (yield = 19 mg, 70%).

^{1}H NMR (500 MHz, $CDCl_3$) δ 7.33 (d, *J*=6.0 Hz, 1H for one isomer), 7.32-7.19 (m, 5H for both isomers), 7.17 (d, *J*=6.0 Hz, 1H for one isomer), 6.20 (d, *J*=6.0 Hz, 1H for one isomer), 6.19 (d, *J*=6.0 Hz, 1H for one isomer), 5.09 (d, *J*=16.2 Hz, 1H for one isomer), 4.75 (d, *J*=16.1 Hz, 1H for one isomer), 4.70 (d, *J*=16.1 Hz, 1H for one isomer), 4.24 (d, *J*=16.2 Hz, 1H for one isomer), 3.58 (s, 3H for one isomer), 3.53 (s, 3H for one isomer), 3.51 (t, *J*=8.0 Hz, 1H for one isomer), 3.42 (t, *J*=9.4 Hz, 1H for one isomer), 2.46 (m, 1H for one isomer), 2.37-2.19 (m, 2H for both isomers), 2.04 (m, 1H for one isomer), 1.90 (m, 1H for both isomers); ^{13}C NMR (125 MHz, $CDCl_3$) δ 171.6 (one isomer), 171.2 (one isomer), 170.8 (both isomers), 151.0 (one isomer), 148.0 (one isomer), 138.1 (one isomer), 137.5 (one isomer), 128.6 (2C for one isomer), 128.5 (2C for one isomer), 127.3 (one isomer), 127.1 (2C for one isomer), 127.1 (one isomer), 126.8 (2C for one isomer), 125.4 (one isomer), 124.9 (one isomer), 70.0 (both isomers), 52.1 (one isomer), 51.7 (one isomer), 45.9 (one isomer), 44.6 (one isomer), 43.3 (one isomer), 42.5 (one isomer), 27.3 (one isomer), 26.4 (one isomer), 17.6 (one isomer), 16.0 (one isomer); HRMS (TOF ESI): $[M+H]^+$ calcd for $C_{16}H_{18}NO_3$, 272.1281; found, 272.1280.

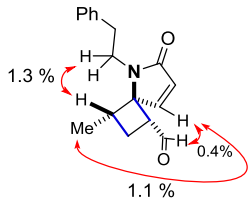
3-methyl-6-oxo-5-phenethyl-5-azaspiro[3.4]oct-7-ene-1-carbaldehyde (9e)



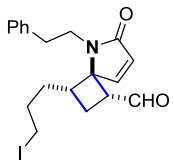
Product **9e** was synthesized according to the general experimental procedure described above. The reaction afforded a 1.6/1 mixture of diastereoisomers of **9e**. The crude product was purified by flash column chromatography (silica gel, petroleum ether : EtOAc = 2:1) to afford a single diastereoisomer (the major isomer of the reaction) of **9e** as a yellow oil. The isolation of a single diastereoisomer of **9e** was the outcome of an epimerization on silica. Yield = 19.8 mg, 68%.

^{1}H NMR (500 MHz, $CDCl_3$) δ 8.97 (d, *J*=1.0 Hz, 1H), 7.29 (t, *J*=7.4 Hz, 2H), 7.24 (d, *J*=7.4 Hz, 2H), 7.20 (m, 1H), 7.07 (d, *J*=6.0 Hz, 1H), 6.19 (d, *J*=6.0 Hz, 1H), 3.71 (ddd, J_1=13.9 Hz, J_2=7.8 Hz, J_3=5.4 Hz, 1H), 3.59 (dt, J_1=13.9 Hz, J_2=7.6 Hz, 1H), 3.19 (dt, J_1=13.6 Hz, J_2=7.8 Hz, 1H), 2.95 (m, 2H), 2.57 (m, 1H), 2.01 (dt, J_1=11.5 Hz, J_2=8.8 Hz, 1H), 1.86 (q, *J*=10.9 Hz, 1H) 0.78 (t, *J*=6.9 Hz, 3H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 198.7, 170.8, 144.7, 139.2, 129.1 (2C), 128.7 (2C), 127.6, 126.7, 73.5, 50.1, 41.9, 35.2, 34.4, 22.2, 15.4; HRMS (TOF ESI): $[M+H]^+$ calcd for $C_{17}H_{20}NO_2$, 270.1489; found, 270.1491.

Representative NOE



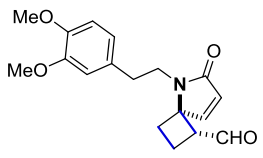
3-(3-iodopropyl)-6-oxo-5-phenethyl-5-azaspiro[3.4]oct-7-ene-1-carbaldehyde (9f)



Product **9f** was synthesized according to the general experimental procedure described above. The reaction afforded a 1.6/1 mixture of diastereoisomers of **9f**. The crude product was purified by flash column chromatography (silica gel, petroleum ether : EtOAc = 2:1) to afford a single diastereoisomer (the major isomer of the reaction) of **9f** as a yellow oil. The isolation of a single diastereoisomer The isolation of a single diastereoisomer of **9a** was the outcome of an epimerization on silica. Yield = 25.4 mg, 60%.

^{1}H NMR (500 MHz, $CDCl_3$) δ 8.93 (d, *J*=1.0 Hz, 1H), 7.30 (m, 2H), 7.25-7.19 (m, 3H), 7.10 (d, *J*=6.0 Hz, 1H), 6.21 (d, *J*=6.0 Hz, 1H), 3.74 (ddd, J_1=13.9 Hz, J_2=7.4 Hz, J_3=5.4 Hz, 1H), 3.57 (dt, J_1=13.9 Hz, J_2=7.6 Hz, 1H), 3.20 (dt, J_1=13.6 Hz, J_2=7.6 Hz, 1H), 3.02 (m, 3H), 2.90 (t, *J*=9.5 Hz, 1H), 2.45 (m, 1H), 1.99 (dt, J_1=11.5 Hz, J_2=8.8 Hz, 1H), 1.89 (q, *J*=10.9 Hz, 1H), 1.56 (m, 1H), 1.45 (m, 1H), 1.30 (m, 1H), 1.20 (m, 1H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 198.5, 170.7, 144.5, 139.2, 129.1 (2C), 128.7 (2C), 127.8, 126.7, 73.2, 49.7, 42.1, 39.2, 34.3, 32.2, 30.6, 20.7, 5.7; HRMS (TOF ESI): $[M+H]^+$ calcd for $C_{19}H_{23}INO_2$, 424.0768; found, 424.0771.

5-(3,4-dimethoxyphenethyl)-6-oxo-5-azaspiro[3.4]oct-7-ene-1-carbaldehyde (9g)

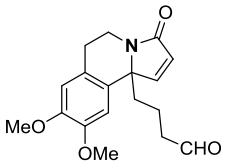


Product **9g** was synthesized according to the general experimental procedure described above. The reaction afforded a 1.6/1 mixture of diastereoisomers of **9g**. The crude product was purified by flash column chromatography (silica gel, petroleum ether : EtOAc = 2:1) to afford a single diastereoisomer (the major isomer of the reaction) of **9g** as a yellow oil. The isolation of a single diastereoisomer was the outcome of an epimerization on silica. Yield = 22 mg, 70%.

^{1}H NMR (500 MHz, $CDCl_3$) δ 9.10 (s, 1H), 7.16 (d, *J*=6.0 Hz, 1H), 6.79 (d, *J*=8.0 Hz, 1H), 6.76 (dd, J_1=8.0 Hz, J_2=1.6 Hz, 1H), 6.74 (d, *J*=1.6 Hz, 1H), 6.14 (d, *J*=6.0 Hz, 1H), 3.85 (s, 3H), 3.83 (s, 3H), 3.70 (ddd, J_1=13.9 Hz, J_2=7.6 Hz, J_3=5.8 Hz, 1H), 3.58 (dt, J_1=13.9 Hz, J_2=7.4 Hz, 1H), 3.18 (t, *J*=9.0 Hz, 1H), 3.08 (dt, J_1=13.7 Hz, J_2=7.6 Hz, 1H), 2.96 (ddd, J_1=13.7 Hz, J_2=7.4 Hz, J_3=5.8 Hz, 1H), 2.22 (m, 2H), 1.85 (m, 2H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 198.4, 170.7, 149.1, 147.9, 147.0, 131.8, 126.1, 120.9, 112.4, 111.5, 70.0, 56.0 (2C), 52.1, 42.1, 33.9, 26.4, 14.0; HRMS (TOF ESI): $[M+H]^+$ calcd for $C_{18}H_{22}NO_4$, 316.1543; found, 316.1547.

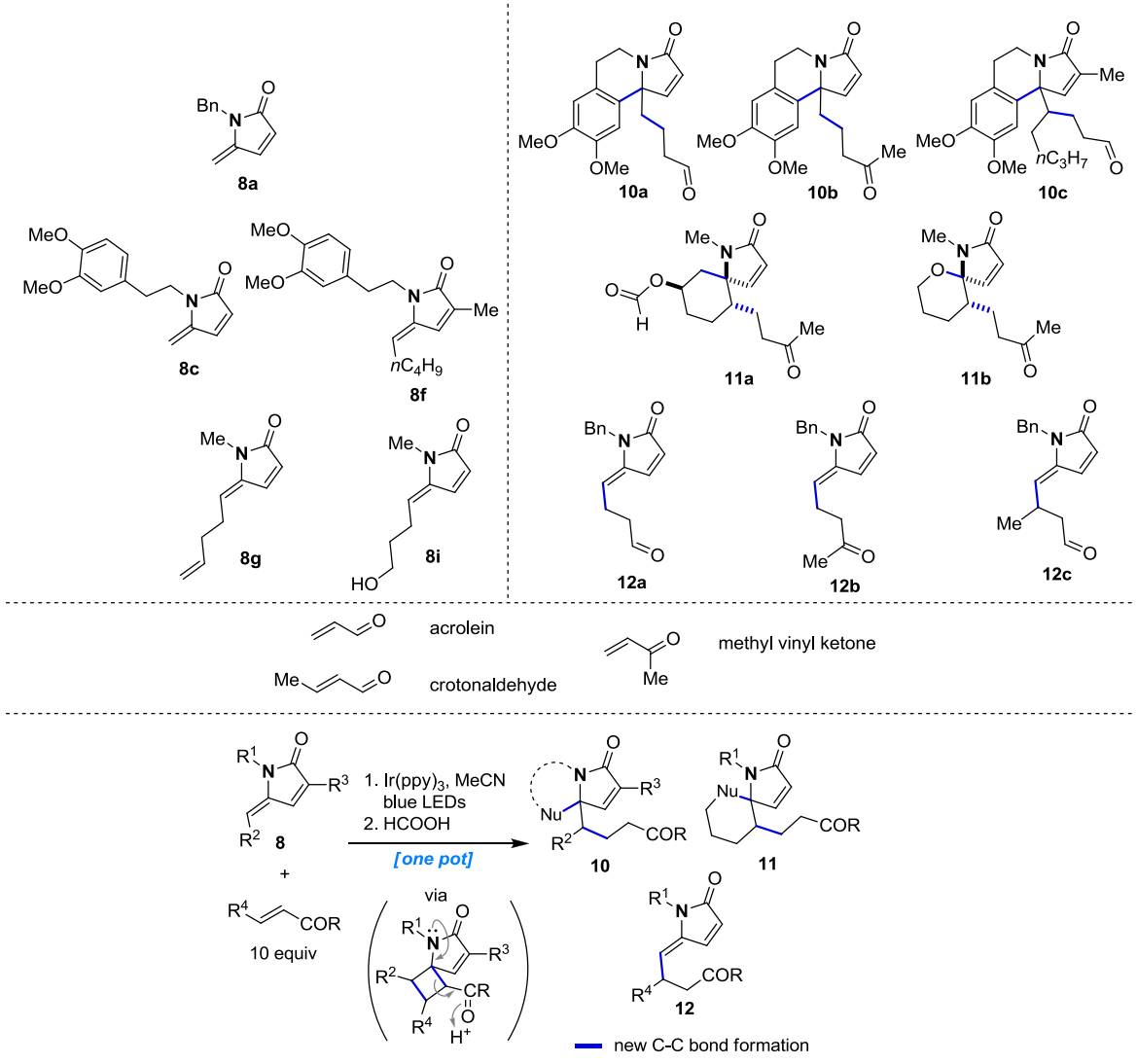
4-(8,9-dimethoxy-3-oxo-5,6-dihydropyrrolo[2,1-a]isoquinolin-10b(3H)-yl)butanal (10a)

The purified compound **9g** (20 mg, 0.063 mmol) was dissolved in HCOOH (300 μL) at rt and the solution was stirred for 3 h. After completion of the reaction, as indicated by tlc analysis, the solution was concentrated *in vacuo* and the crude product **10a** was purified by flash column chromatography (silica gel, petroleum ether : EtOAc = 1:2). Yield = 18.4 mg, 92%.



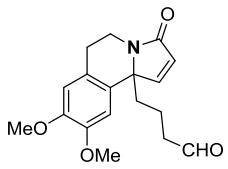
^{1}H NMR (500 MHz, $CDCl_3$) δ 9.72 (t, *J*=1.3 Hz, 1H), 7.25 (d, *J*=6.0 Hz, 1H), 6.67 (s, 1H), 6.60 (s, 1H), 6.16 (d, *J*=6.0 Hz, 1H), 4.43 (dd, J_1=13.3 Hz, J_2=6.5 Hz, 1H), 3.88 (s, 3H), 3.83 (s, 3H), 3.16 (ddd, J_1=13.3 Hz, J_2=11.8 Hz, J_3=4.5 Hz, 1H), 2.93 (ddd, J_1=16.1 Hz, J_2=11.8 Hz, J_3=6.5 Hz, 1H), 2.66 (dd, J_1=16.1 Hz, J_2=4.5 Hz, 1H), 2.43 (m, 2H), 1.98 (m, 2H), 1.47 (m, 2H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 201.4, 170.8, 151.5, 148.3, 147.7, 129.2, 126.5, 125.3, 112.2, 109.2, 68.2, 56.2, 55.9, 43.3, 37.9, 34.8, 28.9, 15.9; HRMS (TOF ESI): $[M+H]^+$ calcd for $C_{18}H_{22}NO_4$, 316.1543; found, 316.1548.

General procedure for the photocatalytic transformation of compounds of type 8 into compounds of type 10-12



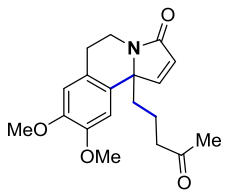
To a solution of compounds of type **8** (0.1 mmol, 18.5 mg for **8a**, 25.9 mg for **8c**, 32.9 mg for **8f**, 16.3 mg for **8g**, 16.7 mg for **8i**) in dry CH_3CN (1 mL, 100 mM) at rt, the photocatalyst $Ir(ppy)_3$ (0.5%, 0.3 mg, 0.0005 mmol) was added and argon (balloon) was gently bubbled through the solution for 10 min. Afterwards, the corresponding α,β-unsaturated carbonyl compound (1 mmol, 66.8 μL for acrolein, 83.3 μL for methyl vinyl ketone, 83.3 μL for crotonaldehyde) was added and the solution was irradiated using blue LED light strips (60 LEDs/m, 10.8 w/m, 1000 lm/m, λ_{max} = 420 nm) at the same temperature. After completion of the reaction as indicated by tlc analysis (20 h), the solution was concentrated *in vacuo* and HCOOH was added (0.5 mL). Only in the case of the reaction towards **11b** was the crude mixture dissolved in CH_2Cl_2 (0.5 mL) and PTSA.H_2O (38 mg, 0.2 mmol) added. After completion of the reaction as indicated by tlc analysis (3 h), the solution was concentrated *in vacuo* and the final products of type **10-12** were purified by flash column chromatography. In case of the reaction towards **11b**, after completion of the reaction (3 h), a saturated aqueous solution of $NaHCO_3$ (0.8 mL) was added and the mixture was extracted with CH_2Cl_2 (2× 1 mL). The combined organic layers were dried over Na_2SO_4, filtered and concentrated *in vacuo*.

4-(8,9-dimethoxy-3-oxo-5,6-dihydropyrrolo[2,1-a]isoquinolin-10b(3H)-yl)butanal (10a)



The data of **10a** were reported above. Yield = 19.5 mg, 62%.

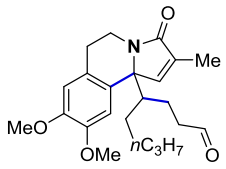
8,9-dimethoxy-10b-(4-oxopentyl)-6,10b-dihydropyrrolo[2,1-a]isoquinolin-3(5H)-one (10b)



Product **10b** was synthesized according to the general experimental procedure described above. The crude product was purified by flash column chromatography (silica gel, petroleum ether : EtOAc = 1:2) to afford **10b** as a yellow oil (yield = 22.7 mg, 69%).

^{1}H NMR (500 MHz, $CDCl_3$) δ 7.25 (d, *J*=5.8 Hz, 1H), 6.67 (s, 1H), 6.59 (s, 1H), 6.15 (d, *J*=5.8 Hz, 1H), 4.42 (dd, J_1=13.4 Hz, J_2=6.7 Hz, 1H), 3.88 (s, 3H), 3.83 (s, 3H), 3.17 (ddd, J_1=13.4 Hz, J_2=11.9 Hz, J_3=4.4 Hz, 1H), 2.93 (ddd, J_1=16.2 Hz, J_2=11.9 Hz, J_3=6.7 Hz, 1H), 2.65 (dd, J_1=16.2 Hz, J_2=4.4 Hz, 1H), 2.39 (m, 2H), 2.09 (s, 3H), 1.99 (ddd, J_1=14.2 Hz, J_2=11.2 Hz, J_3=5.5 Hz, 1H), 1.90 (ddd, J_1=14.2 Hz, J_2=11.4 Hz, J_3=5.1 Hz, 1H), 1.41 (m, 2H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 208.0, 170.8, 151.6, 148.2, 147.6, 129.3, 126.4, 125.2, 112.1, 109.1, 68.3, 56.2, 55.9, 42.8, 37.9, 34.7, 30.0, 29.0, 17.4; HRMS (TOF ESI): $[M+H]^+$ calcd for $C_{19}H_{24}NO_4$, 330.1700; found, 330.1698.

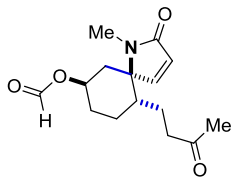
4-(8,9-dimethoxy-2-methyl-3-oxo-3,5,6,10b-tetrahydropyrrolo[2,1-a]isoquinolin-10b-yl)octanal (10c)



Product **10c** was synthesized according to the general experimental procedure described above. The crude product was purified by flash column chromatography (silica gel, petroleum ether : EtOAc = 1:1) to afford a 1/1 mixture of diastereoisomers of **10c** as a yellow oil (yield = 23.3 mg, 60%).

^{1}H NMR (500 MHz, $CDCl_3$) δ 9.66 (s, 1H for one isomer), 9.58 (s, 1H for one isomer), 6.87 (m, 1H for one isomer), 6.85 (m, 1H for one isomer), 6.69 (s, 1H for one isomer), 6.67 (s, 1H for one isomer), 6.62 (s, 1H for both isomers), 4.34 (m, 1H for both isomers), 3.89 (s, 3H for one isomer), 3.87 (s, 3H for one isomer), 3.85 (s, 3H for both isomers), 3.32 (m, 1H for both isomers), 2.89 (m, 1H for both isomers), 2.75 (m, 1H for both isomers), 2.41 (m, 1H for both isomers), 2.29 (m, 1H for both isomers), 1.89 (d, *J*=1.5 Hz, 3H for both isomers), 1.87 (m, 1H for one isomer), 1.77 (m, 1H for one isomer), 1.63 (m, 1H for one isomer), 1.55 (m, 1H for one isomer), 1.40 (m, 1H for both isomers), 1.28-1.02 (m, 6H for both isomers), 0.83 (t, *J*=7.1 Hz, 3H for one isomer), 0.77 (t, *J*=7.1 Hz, 3H for one isomer); ^{13}C NMR (125 MHz, $CDCl_3$) δ 201.8 (one isomer), 201.7 (one isomer), 172.9 (one isomer), 172.8 (one isomer), 148.2 (one isomer), 148.1 (one isomer), 147.5 (both isomers), 145.2 (one isomer), 145.0 (one isomer), 134.1 (both isomers), 128.7 (both isomers), 126.3 (one isomer), 126.2 (one isomer), 112.0 (both isomers), 109.8 (one isomer), 109.5 (one isomer), 69.4 (both isomers), 56.2 (both isomers), 55.8 (both isomers), 45.2 (one isomer), 45.0 (one isomer), 43.1 (both isomers), 37.2 (one isomer), 37.1 (one isomer), 31.7 (one isomer), 31.6 (one isomer), 30.5 (one isomer), 29.4 (one isomer), 28.3 (both isomers), 23.6 (one isomer), 23.0 (one isomer), 22.6 (one isomer), 21.9 (one isomer), 13.9 (one isomer), 13.8 (one isomer), 11.1 (one isomer), 10.9 (one isomer); HRMS (TOF ESI): $[M+H]^+$ calcd for $C_{23}H_{32}NO_4$, 386.2326; found, 386.2324.

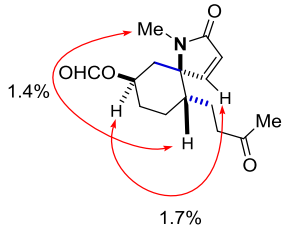
1-methyl-2-oxo-10-(3-oxobutyl)-1-azaspiro[4.5]dec-3-en-7-yl formate (11a)



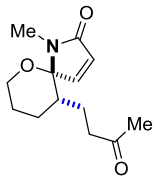
Product **11a** was synthesized according to the general experimental procedure described above. The crude product was purified by flash column chromatography (silica gel, petroleum ether : EtOAc = 1:2) to afford a single diastereoisomer of **11a** as a yellow oil (yield = 18.1 mg, 65%).

^{1}H NMR (500 MHz, $CDCl_3$) δ 8.00 (d, *J*=0.7 Hz, 1H), 7.13 (d, *J*=6.1 Hz, 1H), 6.25 (d, *J*=6.1 Hz, 1H), 5.09 (m, 1H), 2.88 (s, 3H), 2.39 (m, 2H), 2.22 (m, 1H), 2.10 (s, 3H), 2.01-1.92 (m, 2H), 1.74-1.64 (m, 2H), 1.49-1.34 (m, 2H), 1.27 (m, 1H), 0.89 (m, 1H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 207.7, 169.9, 160.1, 147.2, 128.5, 70.2, 69.8, 40.3, 39.2, 39.1, 31.0, 29.9, 25.8, 23.8, 22.4; HRMS (TOF ESI): $[M+H]^+$ calcd for $C_{15}H_{22}NO_4$, 280.1543; found, 280.1543.

Representative NOEs



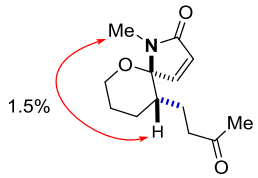
1-methyl-10-(3-oxobutyl)-6-oxa-1-azaspiro[4.5]dec-3-en-2-one (11b)



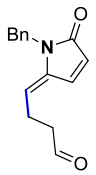
Product **11b** was synthesized according to the general experimental procedure described above. The crude product was purified by flash column chromatography (silica gel, petroleum ether : EtOAc = 1:1) to afford a single diastereoisomer of **11b** as a yellow oil (yield = 17.8 mg, 75%).

^{1}H NMR (500 MHz, $CDCl_3$) δ 7.30 (d, *J*=6.2 Hz, 1H), 6.24 (d, *J*=6.2 Hz, 1H), 3.97 (m, 1H), 3.71 (m, 1H), 2.84 (s, 3H), 2.38 (m, 2H), 2.09 (s, 3H), 1.98 (m, 1H), 1.84 (m, 1H), 1.70 (m, 2H), 1.36 (m, 2H), 1.05 (m, 1H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 207.7, 169.4, 142.9, 129.6, 95.0, 65.7, 40.2, 38.0, 29.9, 26.5, 25.6, 23.7, 23.5; HRMS (TOF ESI): $[M+H]^+$ calcd for $C_{13}H_{20}NO_3$, 238.1438; found, 238.1437.

Representative NOE



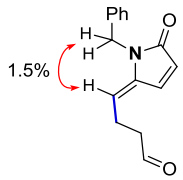
(E)-4-(1-benzyl-5-oxo-1,5-dihydro-2H-pyrrol-2-ylidene)butanal (12a)



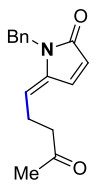
Product **12a** was synthesized according to the general experimental procedure described above. The crude product was purified by flash column chromatography (silica gel, petroleum ether : EtOAc = 5:1) to furnish a single isomer of **12a** as a brown oil (yield = 15.7 mg, 65%).

^{1}H NMR (500 MHz, $CDCl_3$) δ 9.72 (s, 1H), 7.32 (d, *J*=6.0 Hz, 1H), 7.29 (m, 2H), 7.23 (m, 1H), 7.14 (d, *J*=7.8 Hz, 2H), 6.28 (dd, J_1=6.0 Hz, J_2=1.7 Hz, 1H), 5.26 (m, 1H), 4.81 (s, 2H), 2.56 (m, 4H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 200.4, 170.0, 140.1, 137.1, 132.4, 128.6 (2C), 127.2, 126.7 (2C), 124.6, 113.1, 43.8, 42.6, 20.1; HRMS (TOF ESI): $[M+H]^+$ calcd for $C_{15}H_{16}NO_2$, 242.1176; found, 242.1175.

Representative NOE



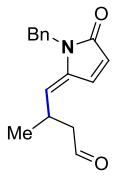
(E)-1-benzyl-5-(4-oxopentylidene)-1,5-dihydro-2H-pyrrol-2-one (12b)



Product **12b** was synthesized according to the general experimental procedure described above. The crude product was purified by flash column chromatography (silica gel, petroleum ether : EtOAc = 5:1) to furnish a single isomer of **12b** as a brown oil (yield = 18.4 mg, 72%).

^{1}H NMR (500 MHz, $CDCl_3$) δ 7.32 (d, *J*=6.0 Hz, 1H), 7.28 (m, 2H), 7.22 (m, 1H), 7.14 (d, *J*=7.8 Hz, 2H), 6.26 (dd, J_1=6.0 Hz, J_2=1.7 Hz, 1H), 5.25 (m, 1H), 4.80 (s, 2H), 2.50 (m, 4H), 2.05 (s, 3H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 207.0, 170.1, 139.9, 137.2, 132.6, 128.5 (2C), 127.2, 126.8 (2C), 124.4, 113.9, 43.2, 42.5, 30.1, 21.6; HRMS (TOF ESI): $[M+H]^+$ calcd for $C_{16}H_{18}NO_2$, 256.1332; found, 256.1331.

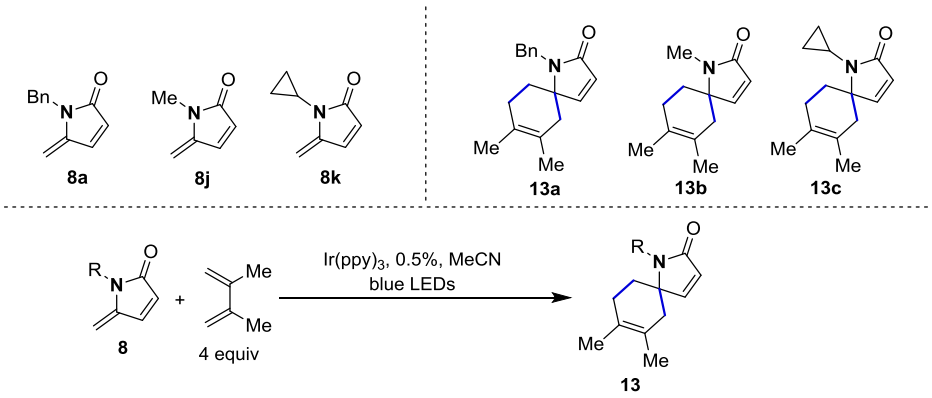
((E)-4-(1-benzyl-5-oxo-1,5-dihydro-2H-pyrrol-2-ylidene)-3-methylbutanal (12c)



Product **12c** was synthesized according to the general experimental procedure described above. The crude product was purified by flash column chromatography (silica gel, petroleum ether : EtOAc = 4:1) to furnish the E isomer of **12c** as a brown oil (yield = 15.6 mg, 61%).

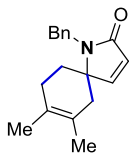
^{1}H NMR (500 MHz, $CDCl_3$) δ 9.59 (t, *J*=1.6 Hz, 1H), 7.35 (d, *J*=6.0 Hz, 1H), 7.29 (m, 2H), 7.22 (m, 1H), 7.13 (d, *J*=7.8 Hz, 2H), 6.28 (dd, J_1=6.0 Hz, J_2=1.7 Hz, 1H), 5.08 (dd, J_1=10.4 Hz, J_2=1.1 Hz, 1H), 4.86 (d, *J*=16.2 Hz, 1H), 4.77 (d, *J*=16.2 Hz, 1H), 3.20 (m, 1H), 2.45 (ddd, J_1=17.0 Hz, J_2=6.2 Hz, J_3=1.6 Hz, 1H), 2.39 (ddd, J_1=17.0 Hz, J_2=7.3 Hz, J_3=1.6 Hz, 1H), 1.07 (d, *J*=6.8 Hz, 3H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 200.5, 170.0, 140.1, 138.8, 137.1, 132.8, 128.6 (2C), 127.2, 126.6 (2C), 124.7, 119.0, 50.8, 42.5, 27.4, 21.8; HRMS (TOF ESI): $[M+H]^+$ calcd for $C_{16}H_{18}NO_2$, 256.1332; found, 256.1335.

General procedure for the photocatalytic transformation of compounds of type 8 into compounds of type 13



To a solution of compounds of type **8** (0.1 mmol, 18.5 mg for **8a**, 10.9 mg for **8j**, 13.5 mg for **8k**) in dry CH_3CN (1 mL, 100 mM) at rt, the photocatalyst $Ir(ppy)_3$ (0.5%, 0.3 mg, 0.0005 mmol) was added and argon (balloon) was gently bubbled through the solution for 10 min. Afterwards, 2,3-dimethylbutadiene (40.5 μL, 0.4 mmol) was added and the solution was irradiated using blue LED light strips (60 LEDs/m, 10.8 w/m, 1000 lm/m, λ_{max} = 420 nm) at the same temperature. After completion of the reaction as indicated by tlc analysis (20 h), the solution was concentrated *in vacuo* and the product of type **13** was purified by flash column chromatography.

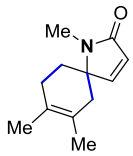
1-benzyl-7,8-dimethyl-1-azaspiro[4.5]deca-3,7-dien-2-one (13a)



Product **13a** was synthesized according to the general experimental procedure described above. The crude product was purified by flash column chromatography (silica gel, petroleum ether : EtOAc = 5:1) to furnish **13a** as a brown oil (yield = 19.8 mg, 74%).

^{1}H NMR (500 MHz, $CDCl_3$) δ 7.27 (m, 4H), 7.22 (m, 1H), 7.20 (d, *J*=6.0 Hz, 1H), 6.18 (d, *J*=6.0 Hz, 1H), 4.62 (d, *J*=15.9 Hz, 1H), 4.54 (d, *J*=15.9 Hz, 1H), 2.42 (d, *J*=16.7 Hz, 1H), 2.10 (m, 2H), 1.86 (td, J_1=12.1 Hz, J_2=6.6 Hz, 1H), 1.62 (s, 3H), 1.54 (s, 3H), 1.52 (d, *J*=16.7 Hz, 1H), 1.31 (m, 1H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 170.9, 152.1, 138.7, 128.4 (2C), 127.4 (2C), 127.0, 125.3, 124.7, 123.3, 67.4, 42.3, 38.2, 31.3, 31.1, 19.0, 18.5; HRMS (TOF ESI): $[M+H]^+$ calcd for $C_{18}H_{22}NO$, 268.1696; found, 268.1693.

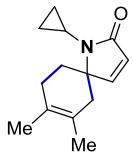
1,7,8-trimethyl-1-azaspiro[4.5]deca-3,7-dien-2-one (13b)



Product **13b** was synthesized according to the general experimental procedure described above. The crude product was purified by flash column chromatography (silica gel, petroleum ether : EtOAc = 4:1) to furnish **13b** as a brown oil (yield = 13.7 mg, 72%).

^{1}H NMR (500 MHz, $CDCl_3$) δ 7.17 (d, *J*=6.0 Hz, 1H), 6.10 (d, *J*=6.0 Hz, 1H), 2.86 (s, 3H), 2.51 (d, *J*=16.7 Hz, 1H), 2.20 (m, 2H), 2.00 (td, J_1=12.0 Hz, J_2=6.6 Hz, 1H), 1.67 (s, 3H), 1.64 (s, 3H), 1.58 (d, *J*=16.7 Hz, 1H), 1.39 (m, 1H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 170.3, 151.5, 125.7, 124.9, 123.2, 66.3, 37.0, 30.9, 30.0, 23.9, 19.1, 18.6; HRMS (TOF ESI): $[M+H]^+$ calcd for $C_{12}H_{18}NO$, 192.1383; found, 192.1381.

1-cyclopropyl-7,8-dimethyl-1-azaspiro[4.5]deca-3,7-dien-2-one (13c)



Product **13c** was synthesized according to the general experimental procedure described above. The crude product was purified by flash column chromatography (silica gel, petroleum ether : EtOAc = 4:1) to furnish **13c** as a brown oil (yield = 15.2 mg, 70%).

^{1}H NMR (500 MHz, $CDCl_3$) δ 7.14 (d, *J*=6.0 Hz, 1H), 6.03 (d, *J*=6.0 Hz, 1H), 2.84 (d, *J*=16.7 Hz, 1H), 2.27 (m, 2H), 2.19 (m, 2H), 1.67 (s, 3H), 1.64 (s, 3H), 1.56 (d, *J*=16.7 Hz, 1H), 1.42 (m, 1H), 0.93 (m, 2H), 0.82 (m, 2H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 171.8, 151.4, 126.0, 124.7, 123.6, 68.4, 38.3, 31.3 (2C), 21.3, 19.2, 18.5, 5.1, 5.0; HRMS (TOF ESI): $[M+H]^+$ calcd for $C_{14}H_{20}NO$, 218.1539; found, 218.1540.

Electrochemical data and Stern Volmer experiments

General Experimental Details

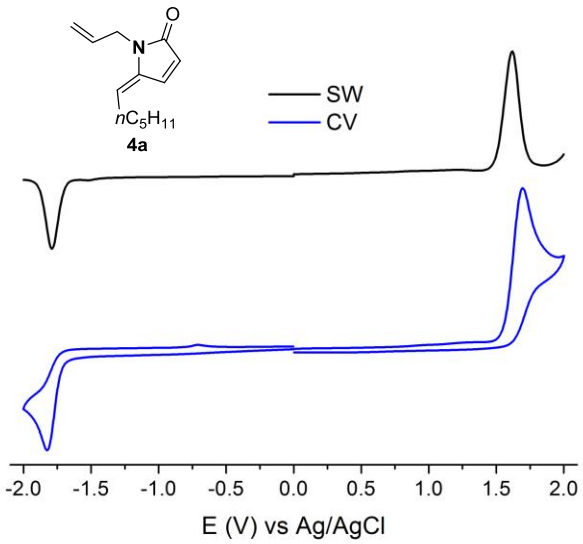
Cyclic and square wave voltammetry experiments were carried out at room temperature using an AutoLab PGSTAT20 potentiostat. All measurements were carried out in freshly distilled and deoxygenated (with N_2) acetonitrile in the presence of 0.1 M of tetrabutylammonium hexafluorophosphate (Bu_4NPF_6) as the supporting electrolyte, at a scan rate of 100 mV s^{-1}. Nitrogen was passed through the sample

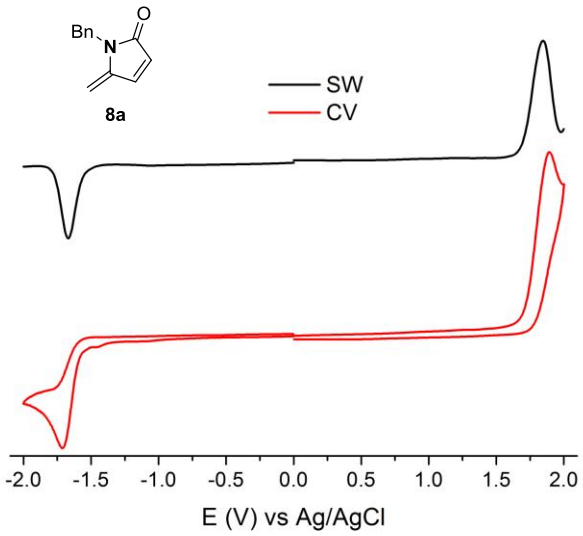
between measurements to avoid the deleterious influence of oxygen reduction. A three-electrode cell setup was used with a glassy carbon working electrode, a Ag/AgCl (3 M NaCl) reference electrode and a platinum wire as a counter electrode. In all measurements the ferrocene/ferrocenium couple was at 0.45 V versus Ag/AgCl under the aforementioned conditions.

Electrochemical Potential

$E_{1/2}^{red}$ of compound **4a** was measured +1.62 V and -1.79 V which was converted to SCE as reference electrode. $E_{1/2}^{red}$ = +1.58 V and -1.83 V versus SCE in CH_3CN.
$E_{1/2}^{red}$ of compound **8a** was measured +1.84 V and -1.67 V which was converted to SCE as reference electrode. $E_{1/2}^{red}$ = +1.80 and -1.71 V versus SCE in CH_3CN.

Voltammograms:





SW: square wave voltammetry
CV: cyclic voltammetry

The corresponding redox potentials for PC4 are +0.66 V and -0.96 V (versus SCE) and for PC5 +0.31 V and -1.73 V (versus SCE). Comparing these values with those of substrates **4a** and **8a**, it is obvious that neither PC4 nor PC5 are able to initiate a SET pathway with **4a**, while substrate **8a** can barely be reduced by PC5. Despite this fact, the reaction of substrate **8a** with PC4 gives exactly the same results as those obtained with PC5 (see, the footnotes of Scheme 4 and 6 of the manuscript). The combination of these observed results implies that the [2+2]-cycloaddition is not a SET-induced process. Furthermore, the reaction proceeds only with photocatalysts that have high triplet state energies. For instance, the reaction does not work with MB, rose Bengal and EY.Na_2 (E_T < 45 kcal/mol). The cyclization reaction of **4a** has a low reaction rate with $Ru(bpy)_3Cl_2$ (E_T = 46.5 kcal/mol), whereas all the reactions were efficiently implemented by the higher triplet energy catalysts, PC4 and PC5 (E_T > 49 kcal/mol).

The small degree of isomerization of compound **4a** upon irradiation in the absence of the catalyst and without affording any [2+2]-cyclization product (see, Entry 8, Scheme 2 of the manuscript), can be explained as being the outcome of the substrate's short lived singlet excitation state. The [2+2]-cyclization proceeds via its long lived triplet state, which is generated via energy transfer from the triplet state of the excited catalyst.

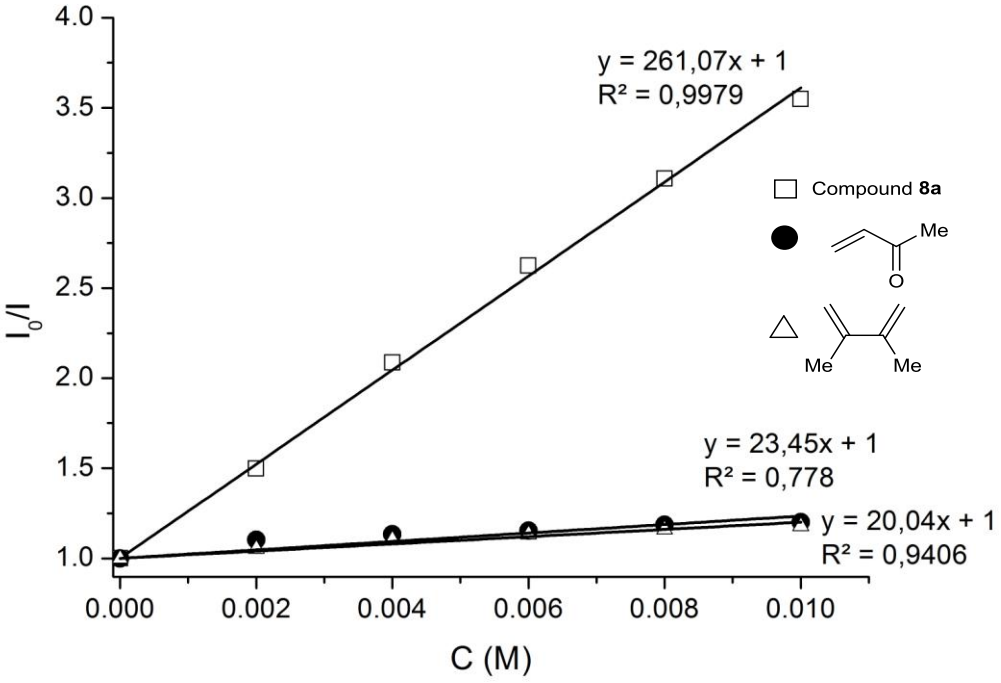
Emission Quenching Experiments - Stern-Volmer Plots

The emission spectra in solution were measured on a JASCO FP-6500 fluorescence spectrophotometer equipped with a red-sensitive WRE-343 photomultiplier tube (wavelength range: 200-850 nm). All the $Ir(ppy)_3$ solutions were excited at 385 nm and the emission intensity was collected at 515 nm.

Experimental procedure

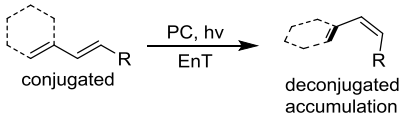
A screw-top quartz cuvette was charged with a 0.015 mM degassed solution of $Ir(ppy)_3$ in CH_3CN (2.0 mL) and the initial emission data was collected. Then the appropriate amount of the quencher as a 0.2 M degassed solution in CH_3CN was added. The sample was shaken for 30 sec and then the emission data for the sample was collected.

Combined Stern-Volmer plots

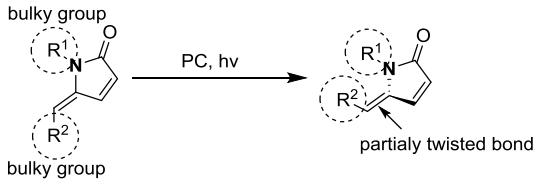


The Stern-Volmer quenching studies clearly illustrate that compound **8a** quenches the excited state of $Ir(ppy)_3$ (PC5) at a significantly higher rate than methylvinyl ketone (the intermolecular reaction is shown in Scheme 4 of the manuscript – product **9b**) or 2,3-dimethylbuta-1,3-diene (the intermolecular reaction is shown in Scheme 6 of the manuscript – product **13a**). This provides evidence that compounds of type **8** interact efficiently with the photocatalyst at the beginning of the reaction. In the case of the [2+2]-cycloaddition of compounds of type **8** with 2,3-dimethylbuta-1,3-diene, we observed the formation of intermediate **9h** (by ^{1}H-NMR) after 1.5 h reaction. This intermediate subsequently disappeared affording the final products of type **13**. This observation could be a consequence of a sequential photocatalytic event. However, we could not isolate the intermediate **9h** in a pure form, so the mechanism of the second step was not investigated.

In general, a significant structural feature of olefins that are amenable to photocatalytic E → Z isomerization is the existence of a cyclic system directly conjugated to the isomerizable C=C bond (see, scheme below). The Z-selectivity in this case is favored by the selective excitation of the E isomer (which is fully conjugated with all sp^2 carbons lying in the same plane). An intramolecular steric effect causes the Z isomer to twist out of the plane, thus, disrupting conjugation, and, consequently, affecting the olefin's ability to absorb energy and become excited.

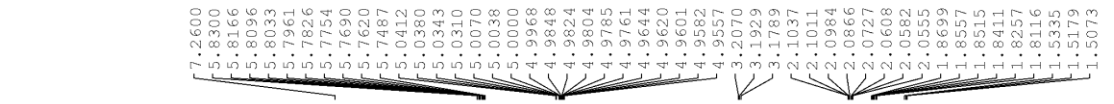


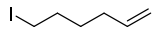
However in our case (compounds of type **1**), the isomerizable double bond shares an sp2 carbon with the cyclic system (it is exocyclic to that system) and therefore a twist of the type described above that leads to deconjugation is not feasible. We believe that a different source of intramolecular steric interaction is causing a partial twist in the Z isomer of exocyclic double bond leading to its partial deconjugation. This analysis could explain the selective excitation of the E isomer in this case which is responsible for the photocatalytic accumulation of the corresponding Z isomer of the γ-alkylidene-γ-lactam of type **1** (see, Scheme 1 of the manuscript).



Evidence supporting this assumption is currently being investigated and will be reported in due course.

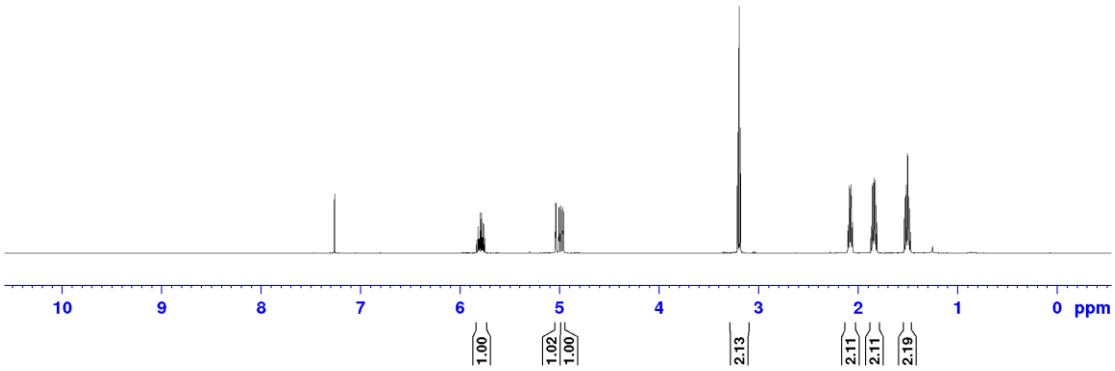
Part B: Copies of ^{1}H-NMR, ^{13}C-NMR, COSY, HMBC and NOE spectra

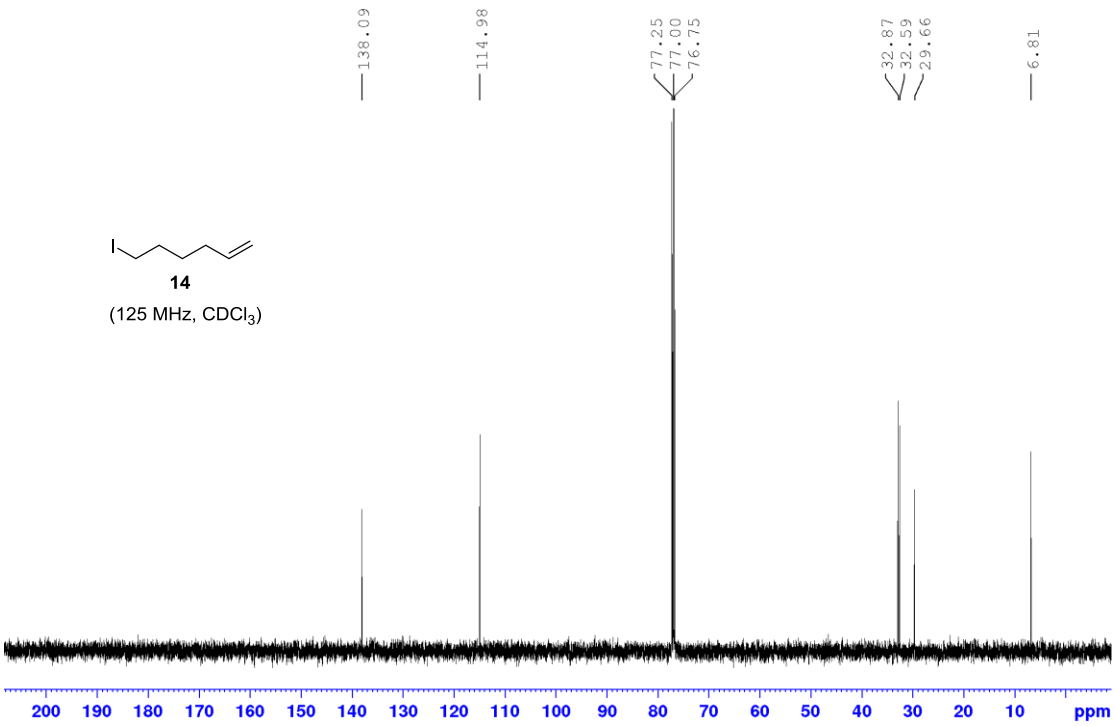




14

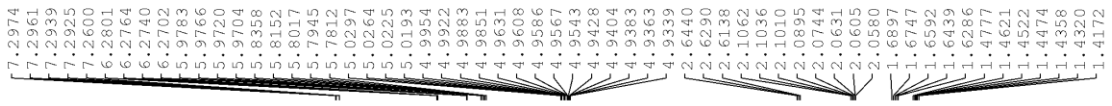
(500 MHz, $CDCl_3$)

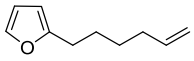




14

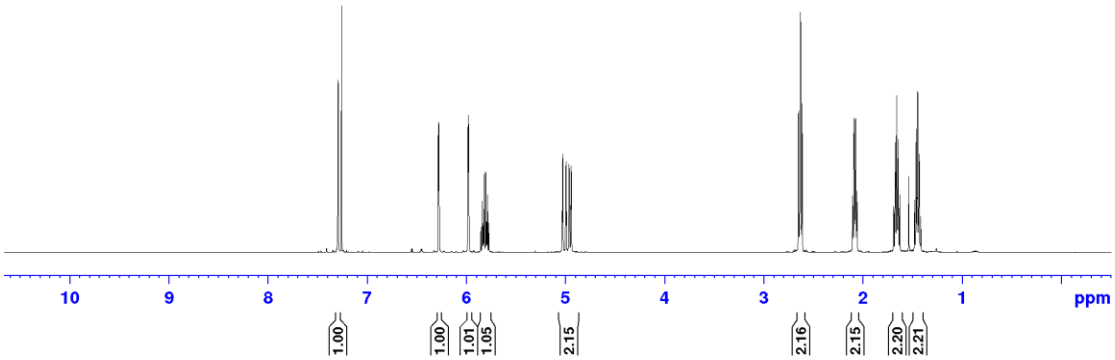
(125 MHz, $CDCl_3$)

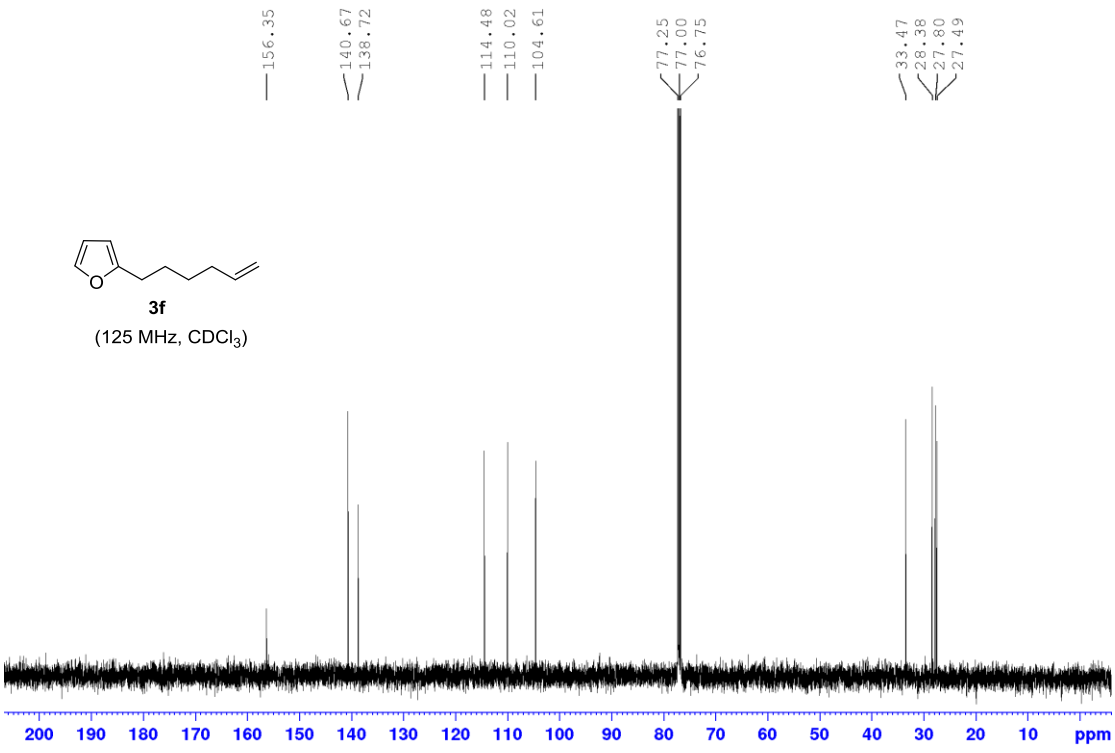




3f

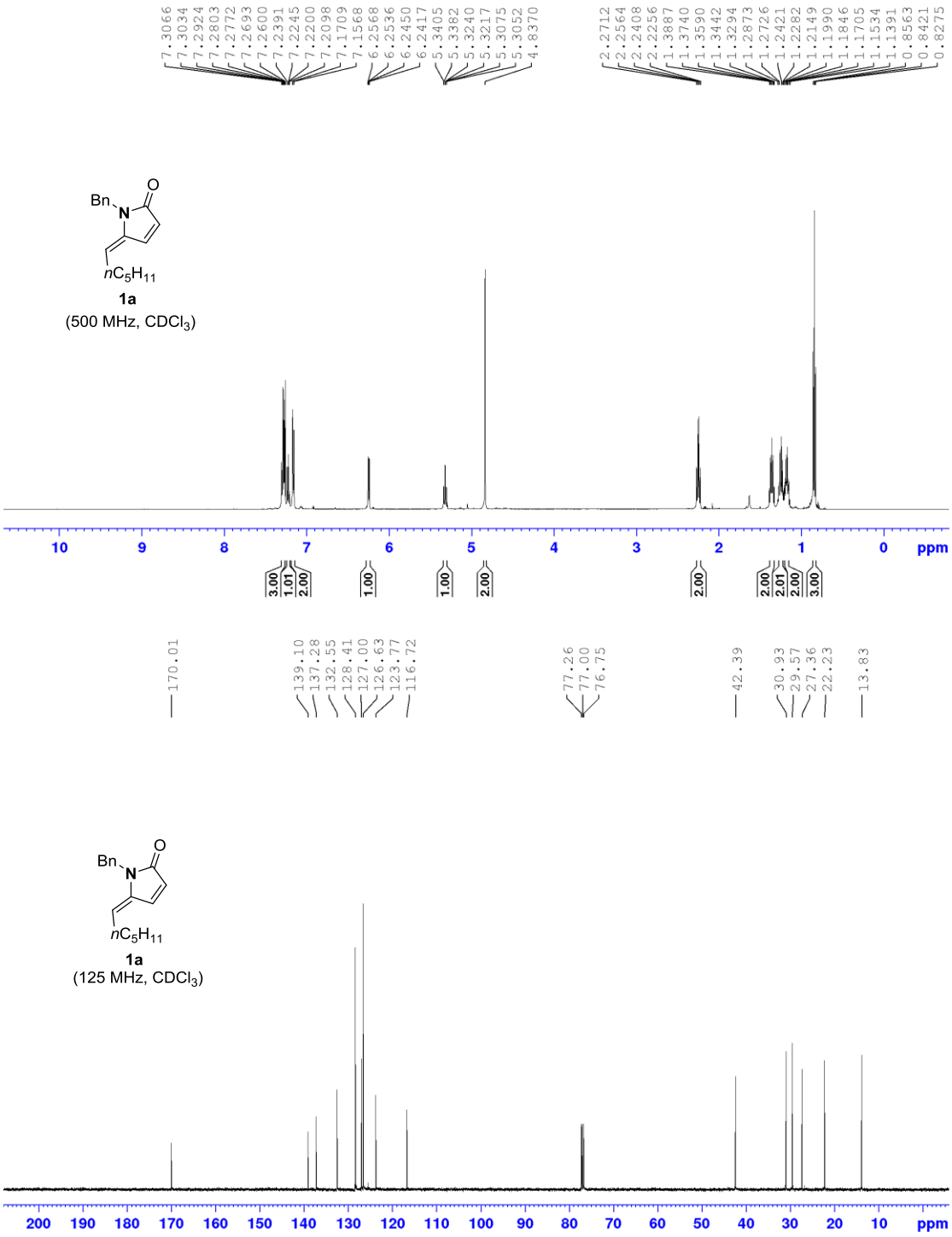
(500 MHz, $CDCl_3$)

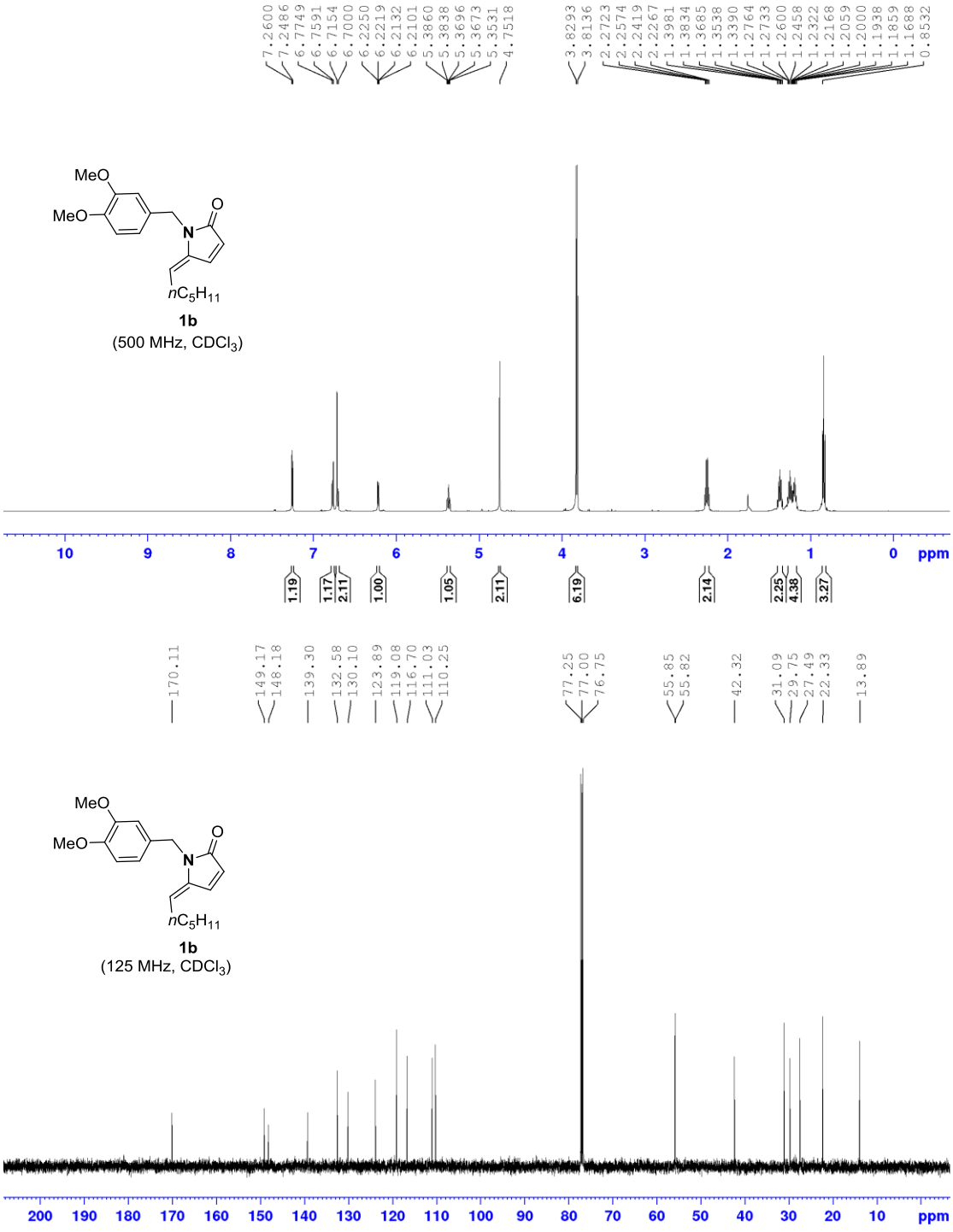




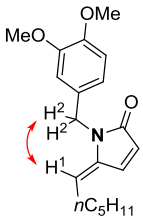
3f

(125 MHz, $CDCl_3$)

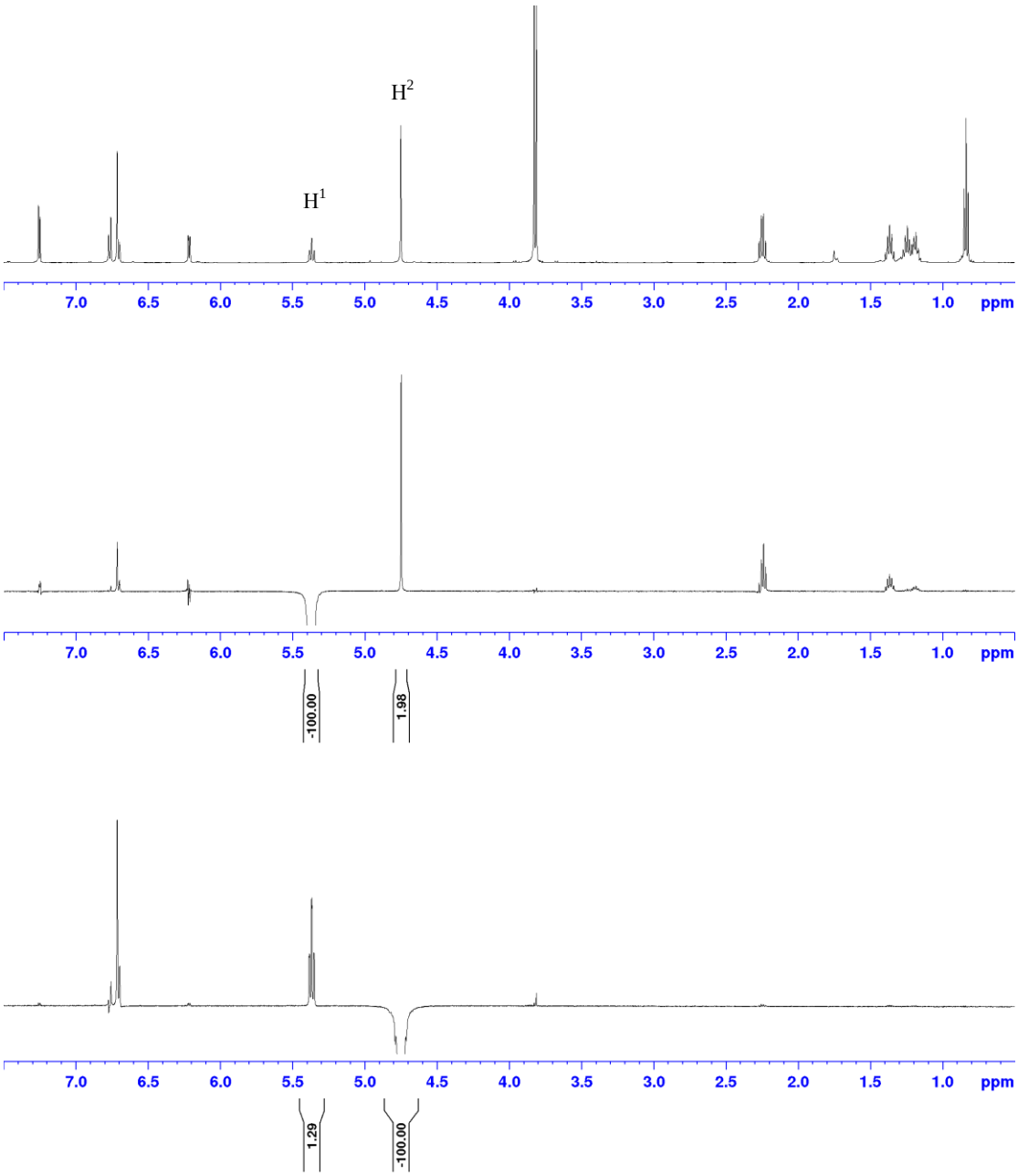


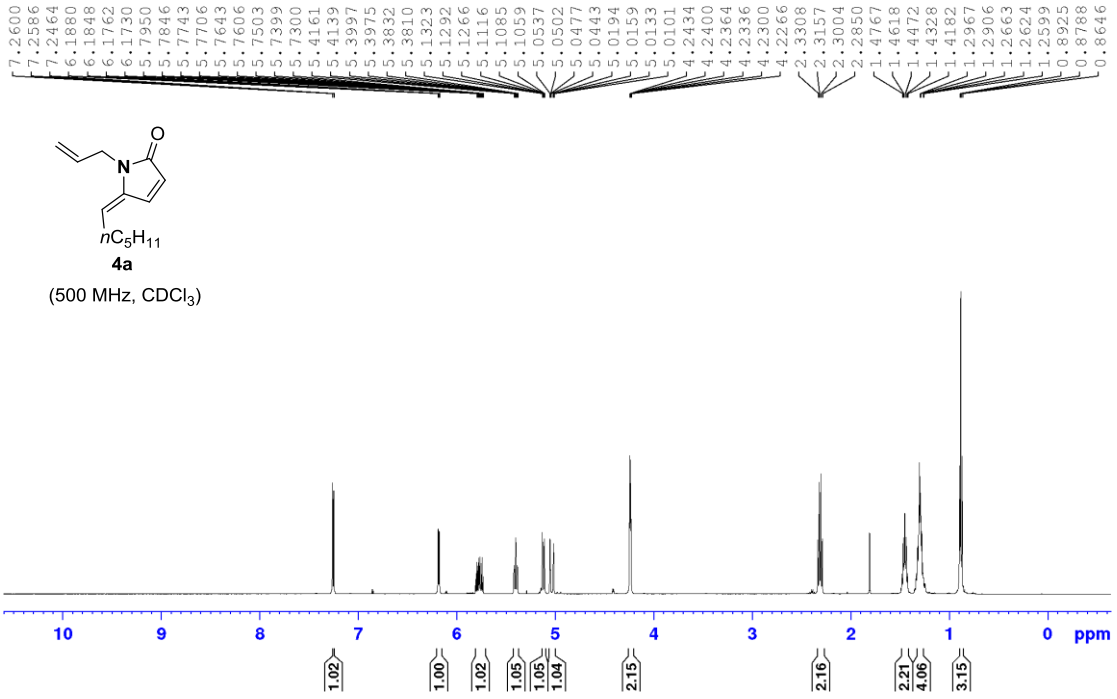


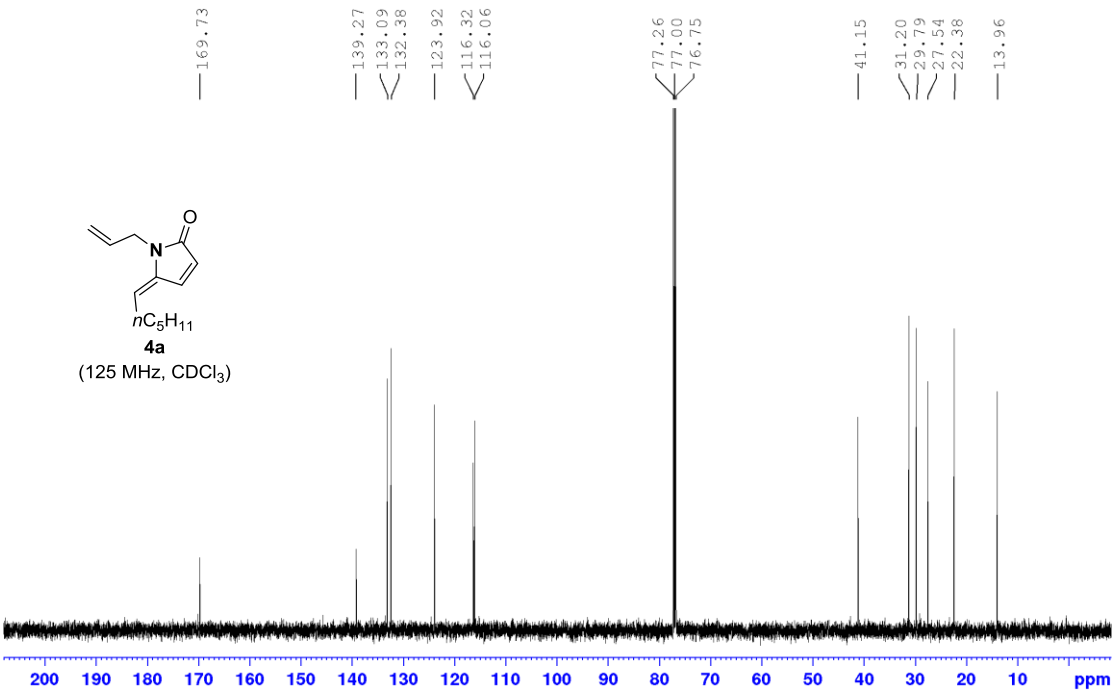
Representative NOE of compound 1b

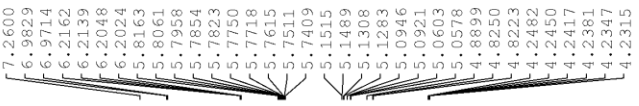


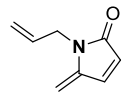
1b



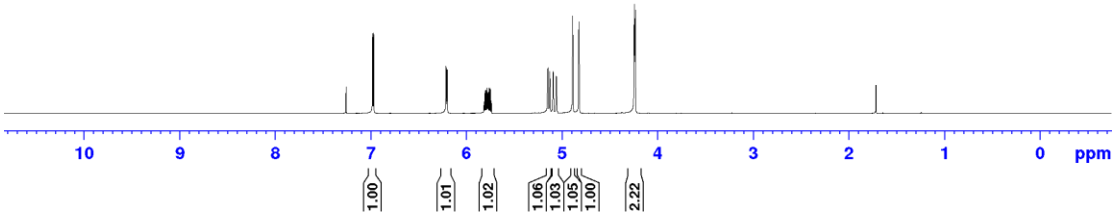


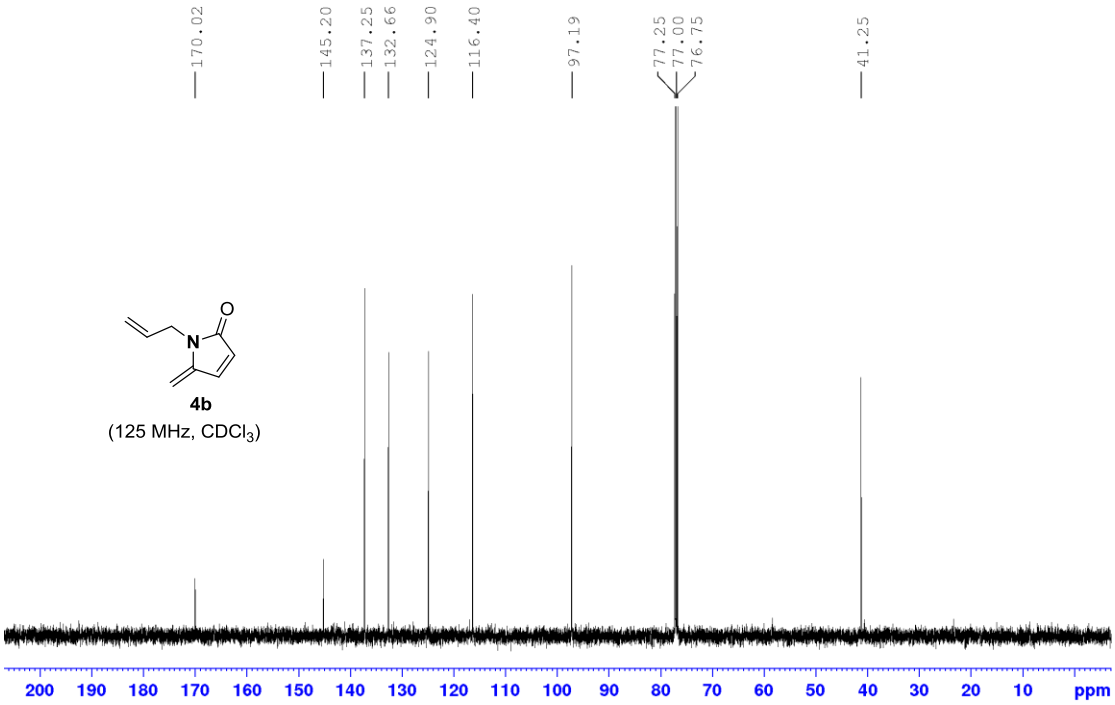




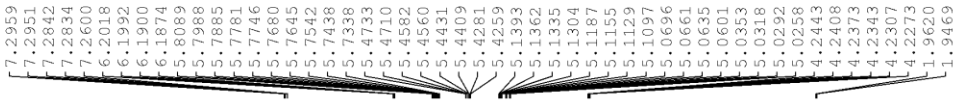


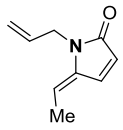
4b
(500 MHz, $CDCl_3$)





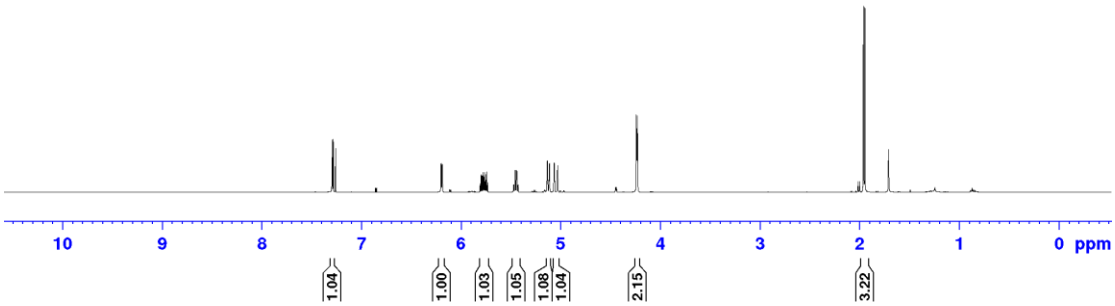
4b
(125 MHz, $CDCl_3$)

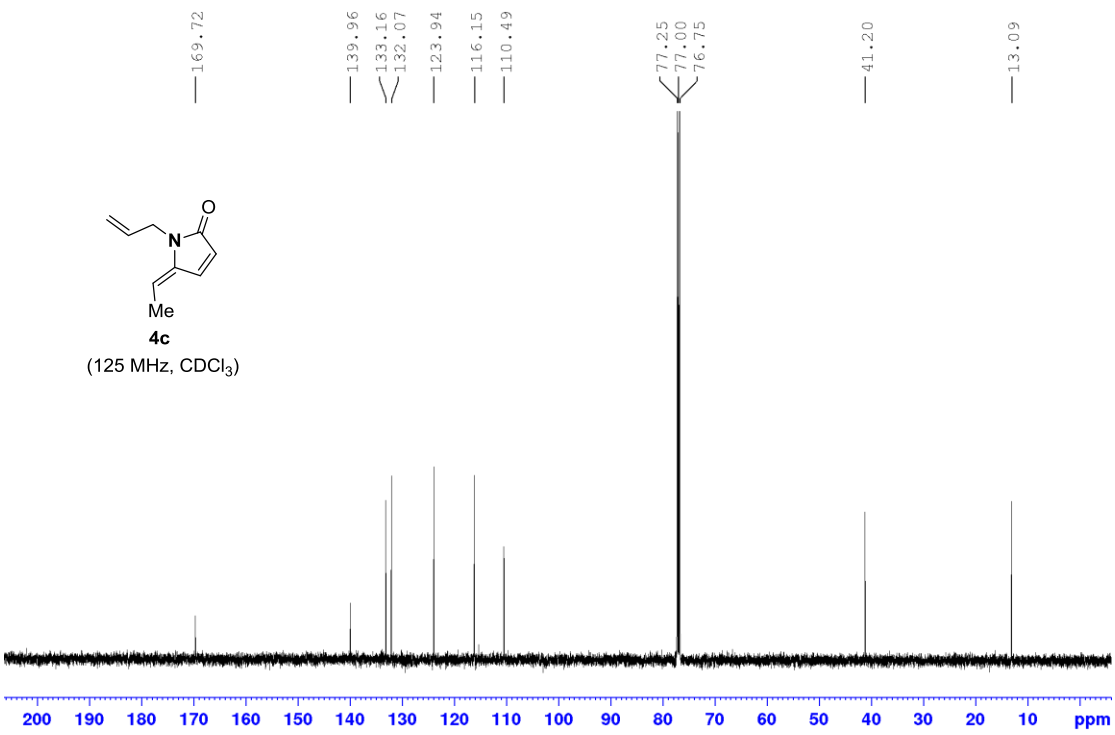




4c

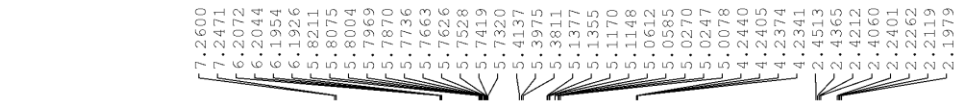
(500 MHz, $CDCl_3$)

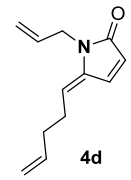




4c

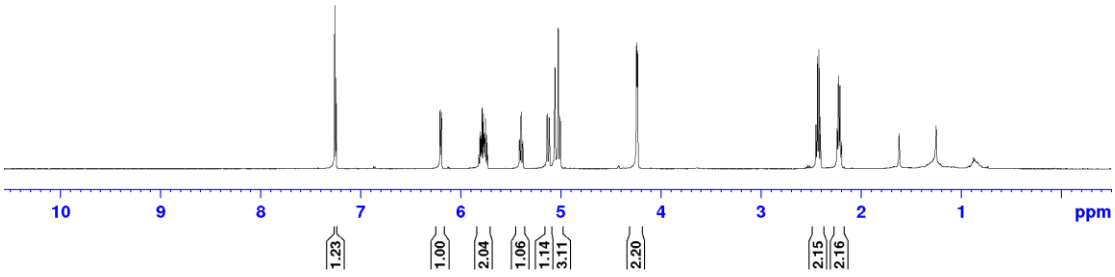
(125 MHz, $CDCl_3$)

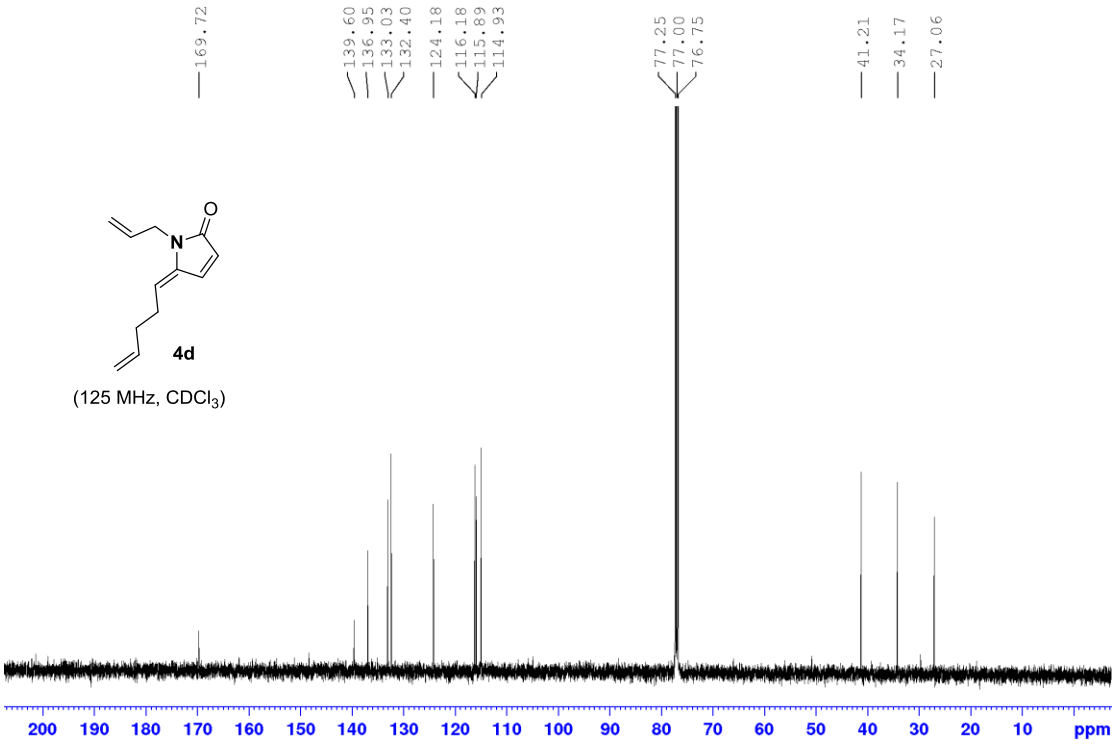




4d

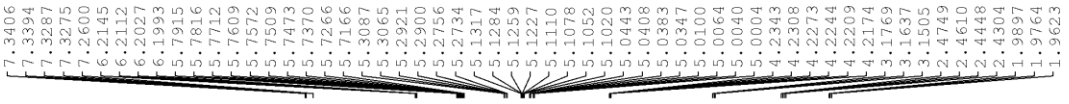
(500 MHz, $CDCl_3$)

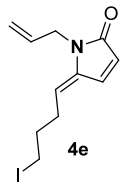




4d

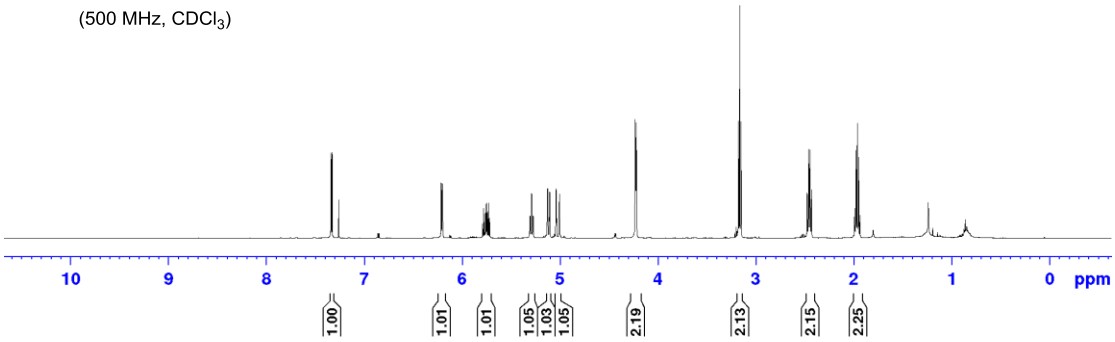
(125 MHz, $CDCl_3$)

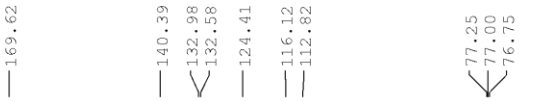


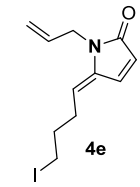


4e

(500 MHz, $CDCl_3$)

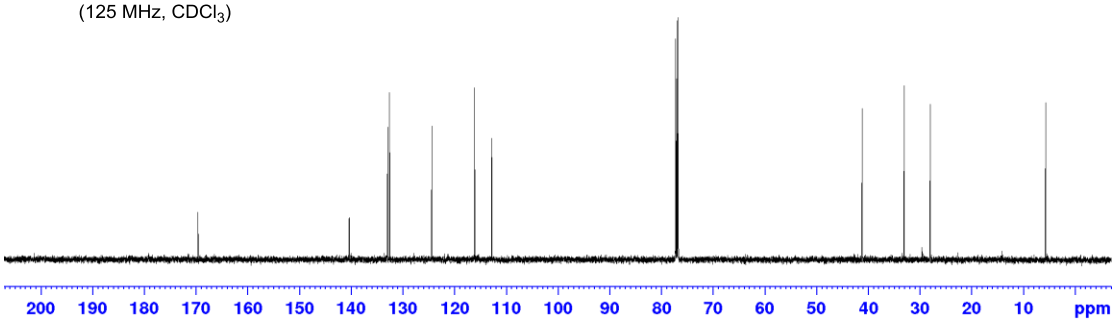


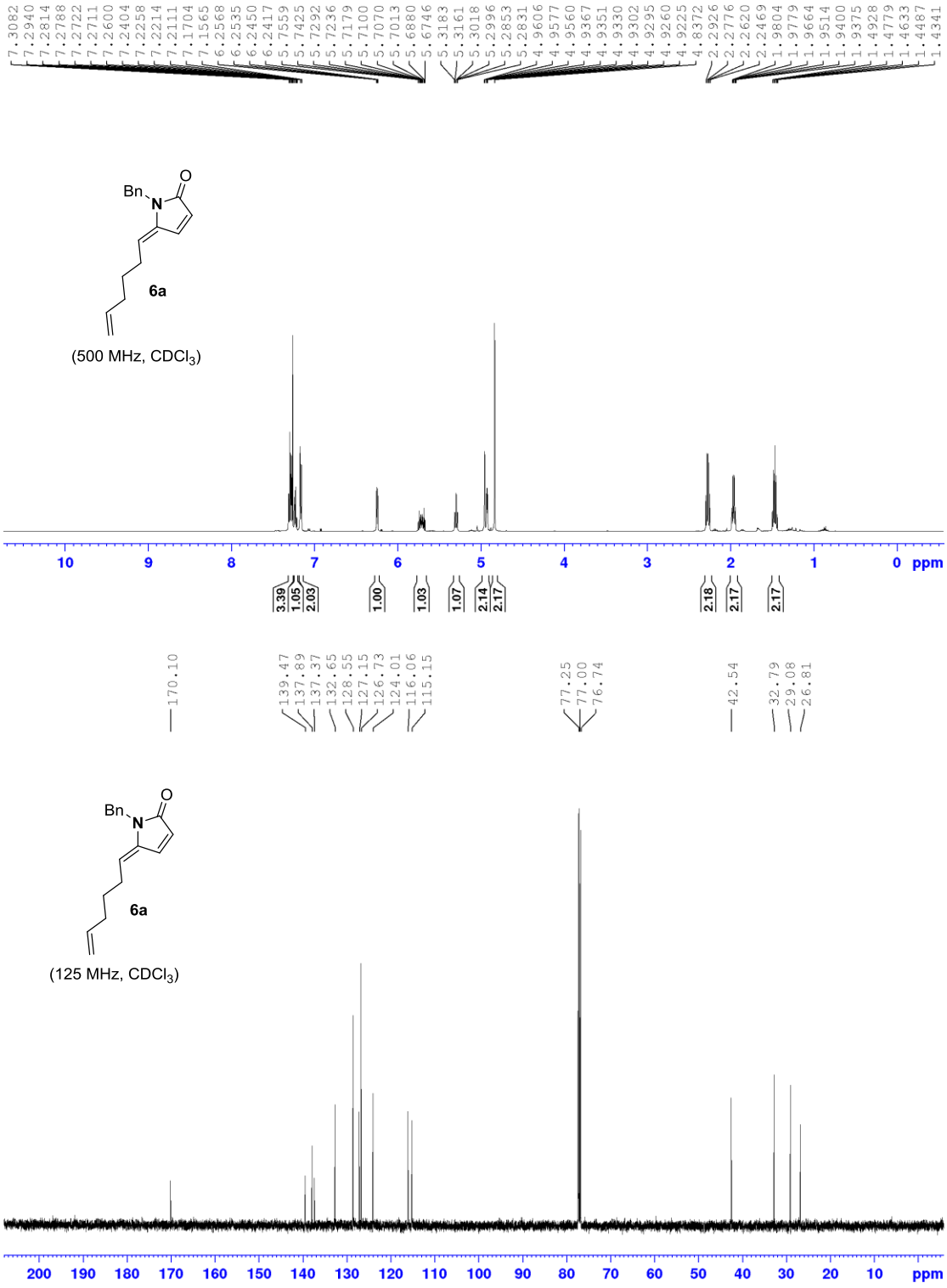


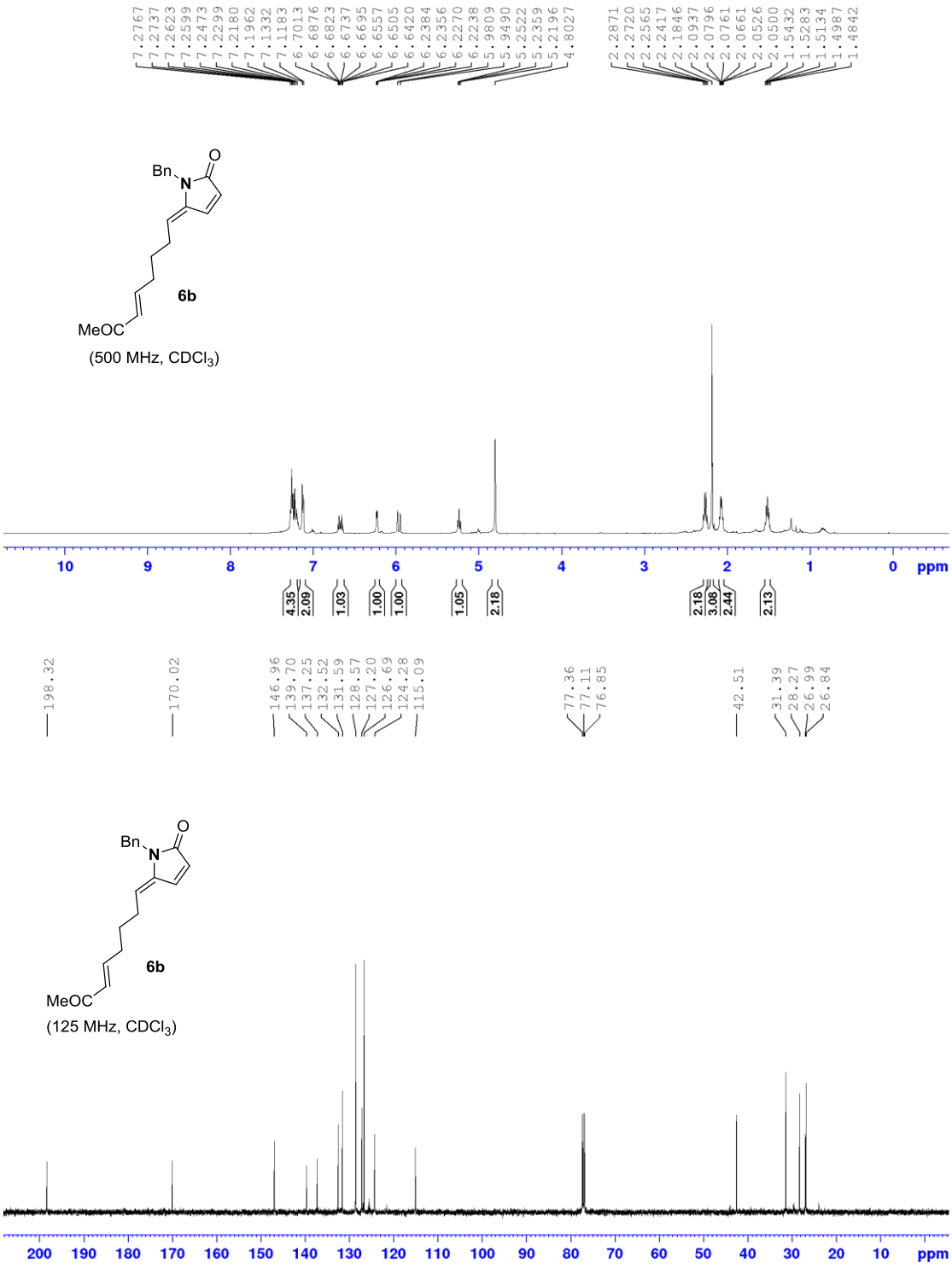


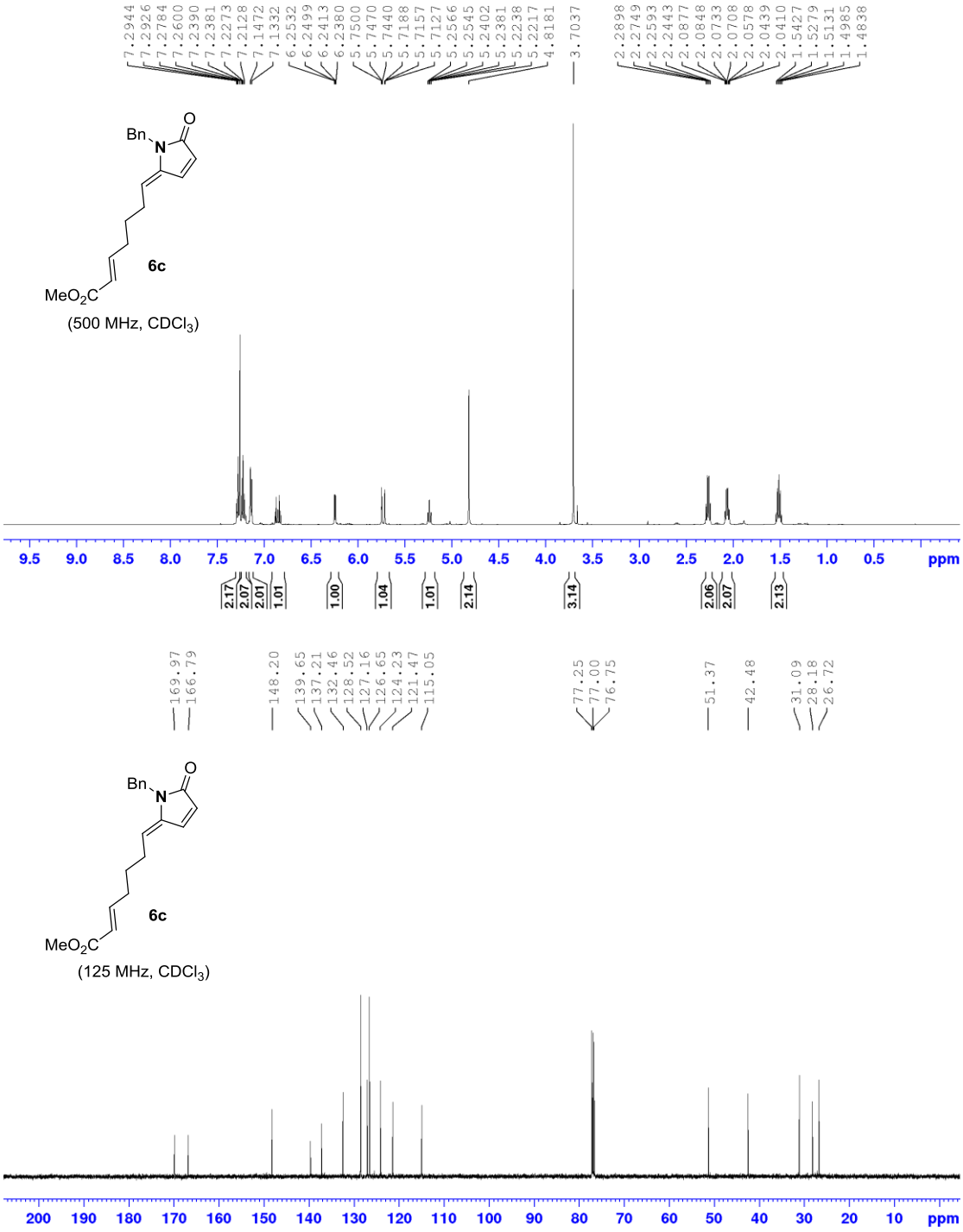
4e

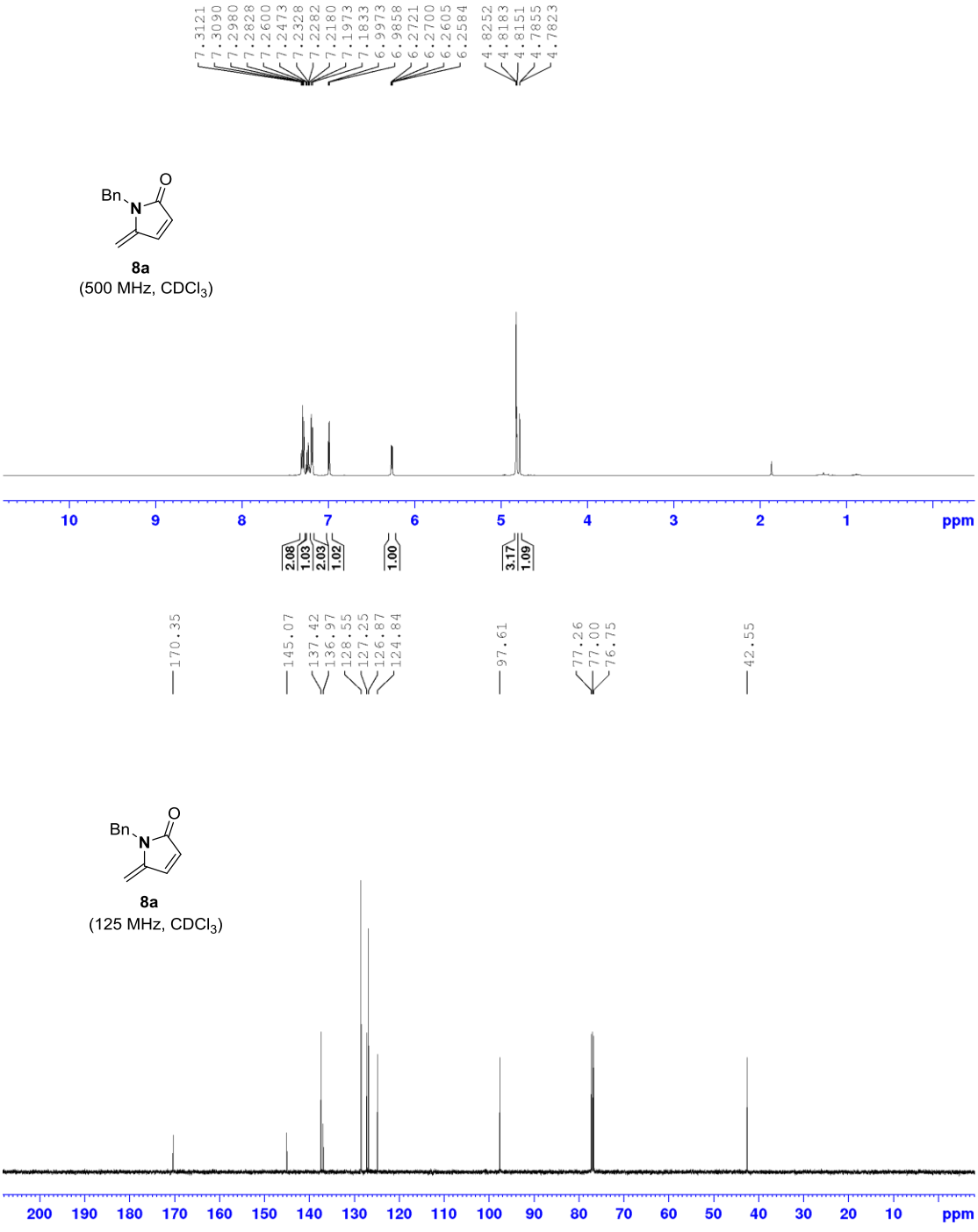
(125 MHz, $CDCl_3$)

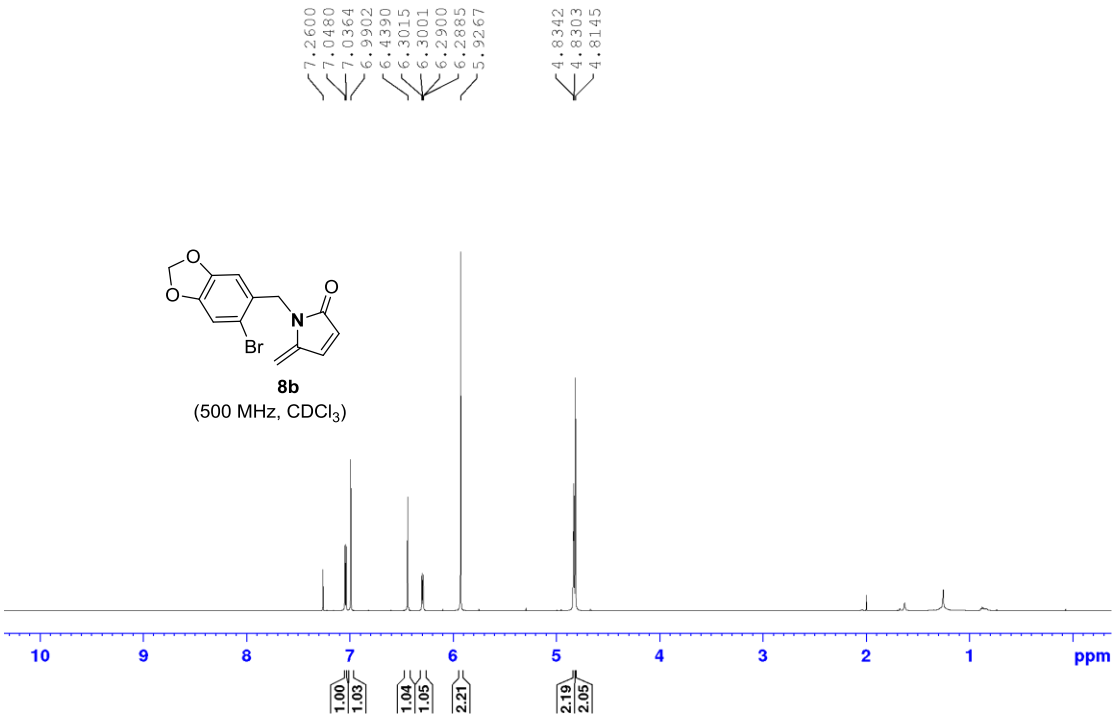




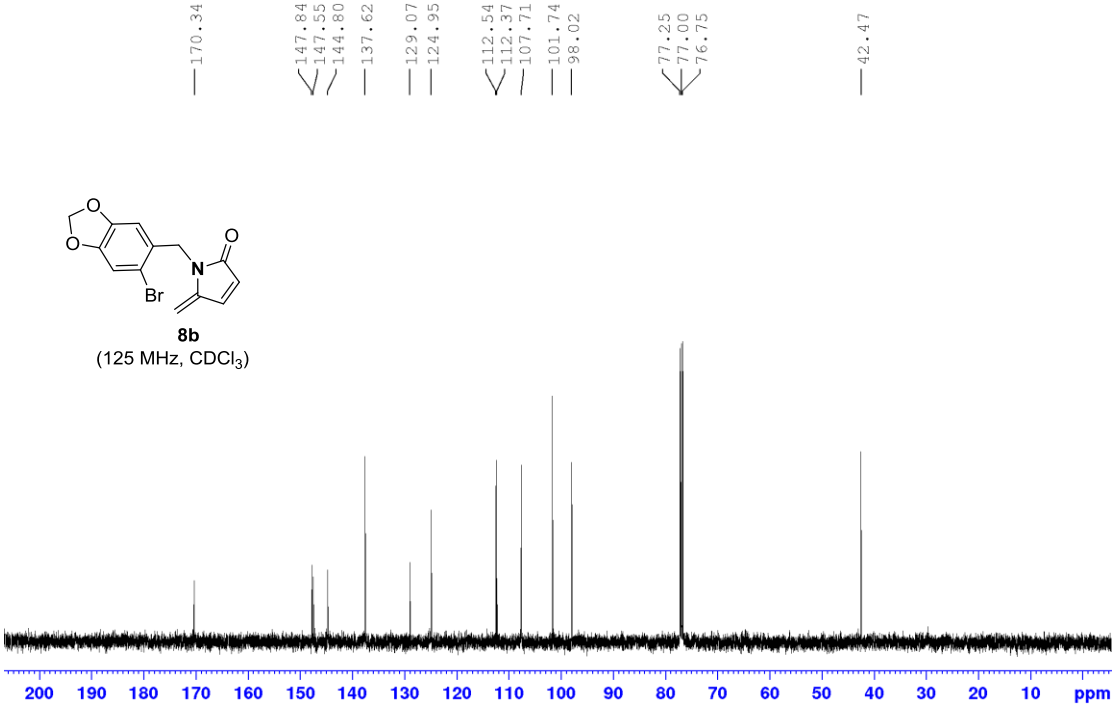




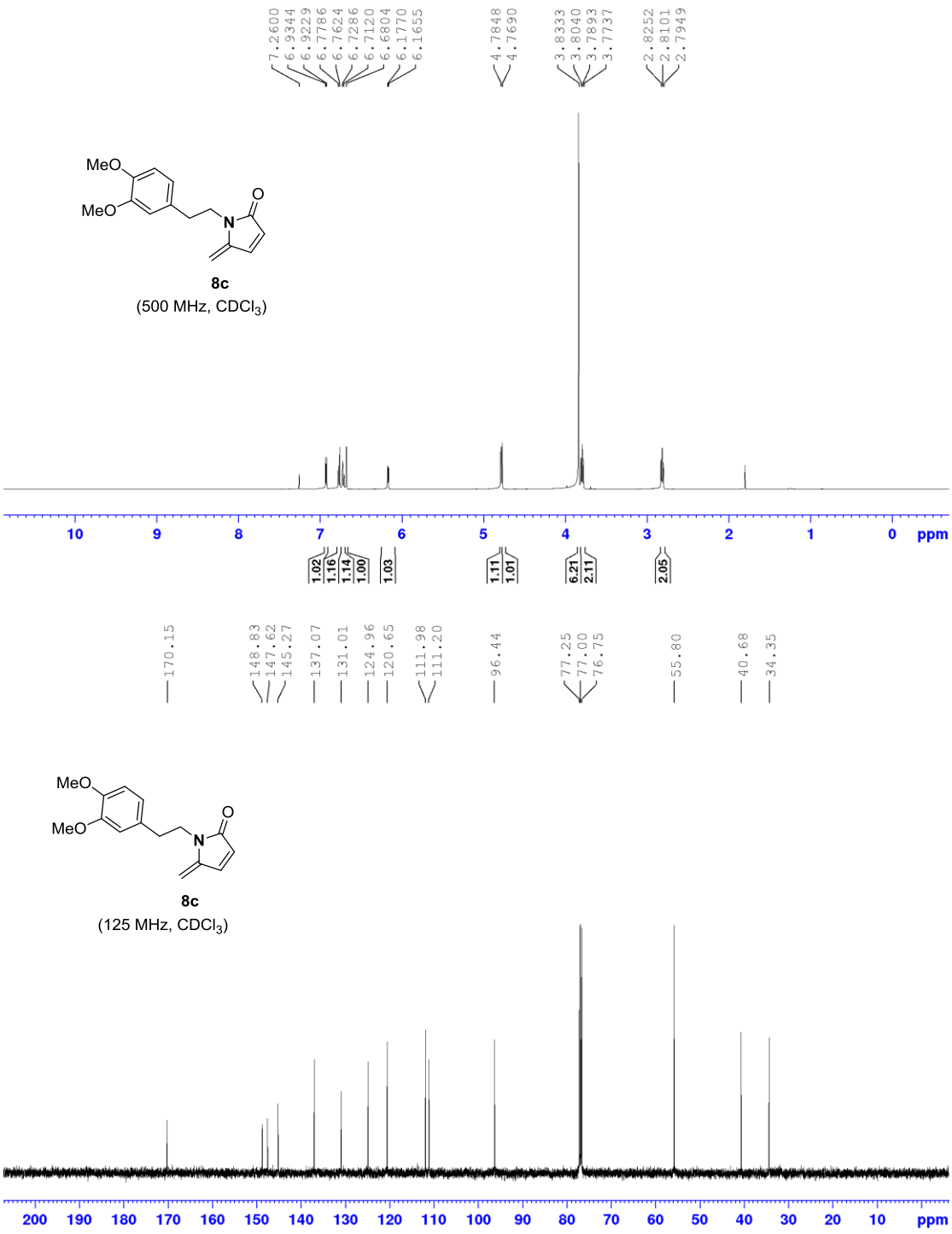




8b
(500 MHz, $CDCl_3$)



8b
(125 MHz, $CDCl_3$)

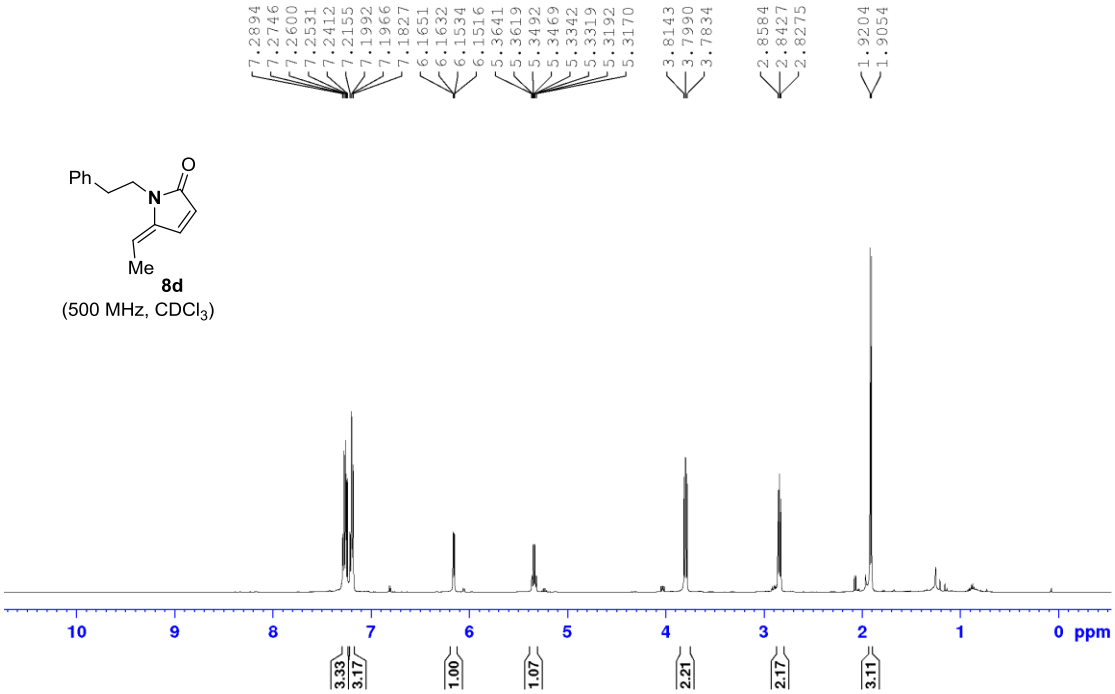


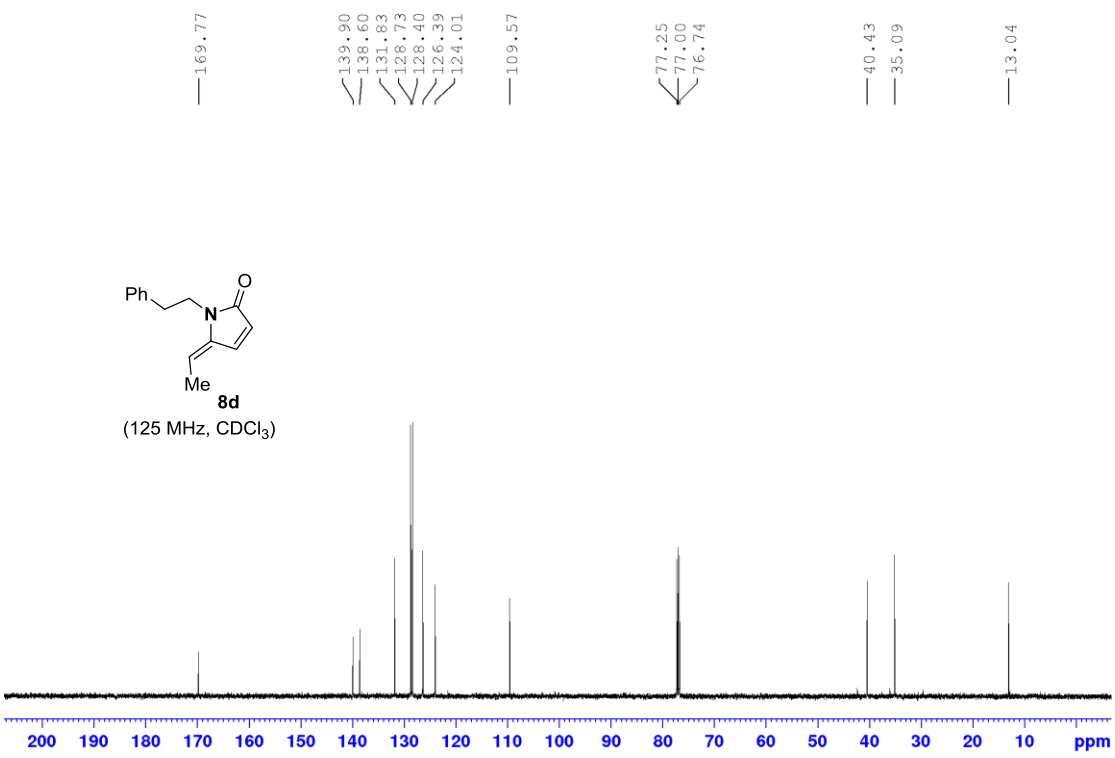
8c

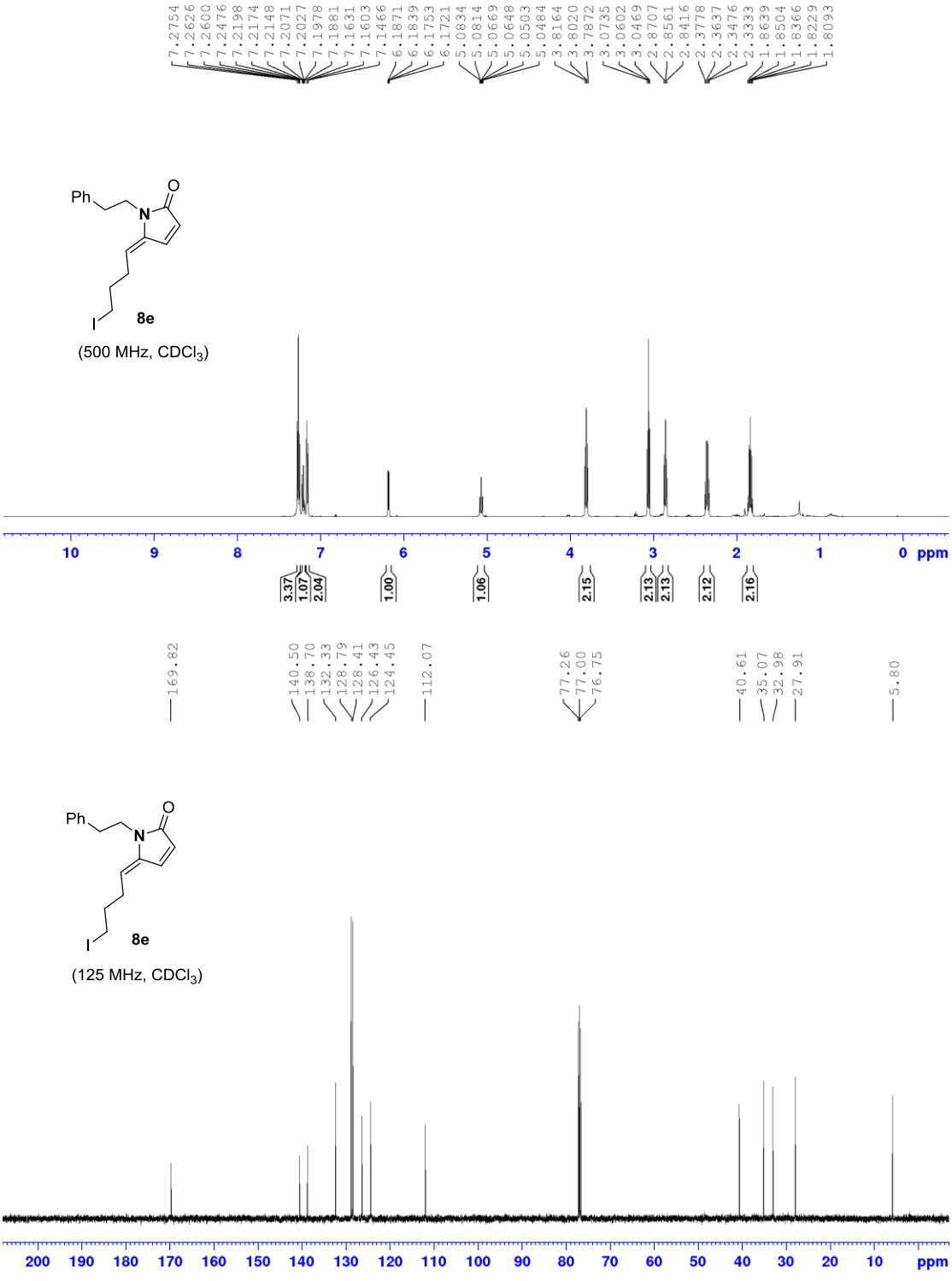
(500 MHz, $CDCl_3$)

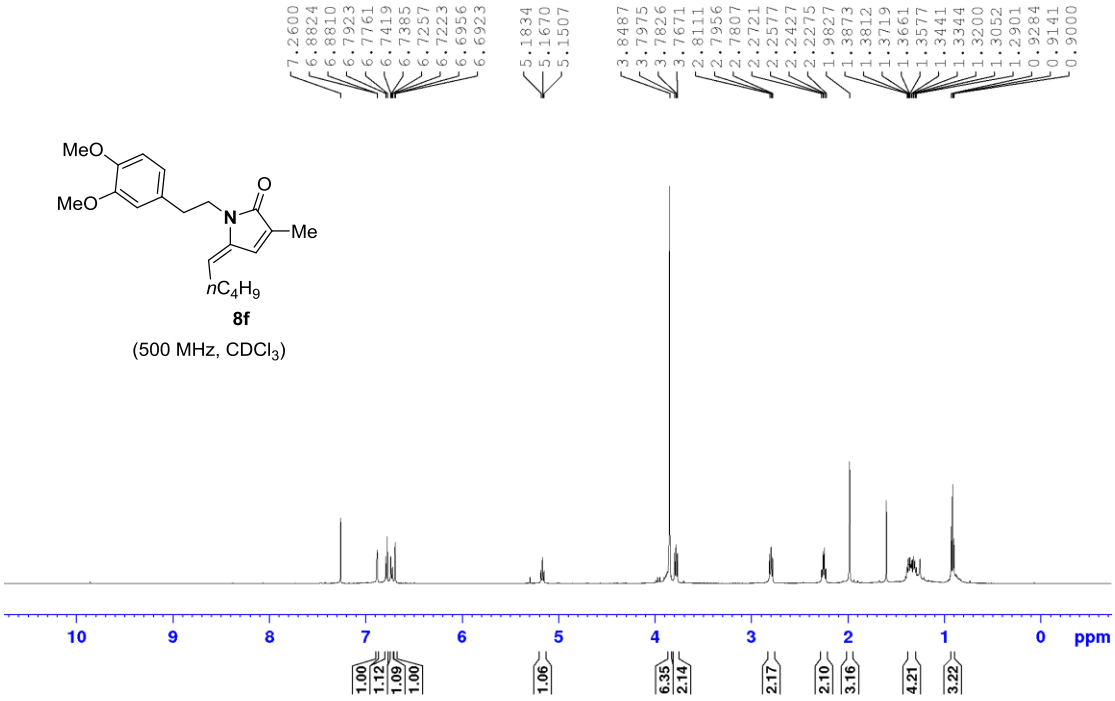
8c

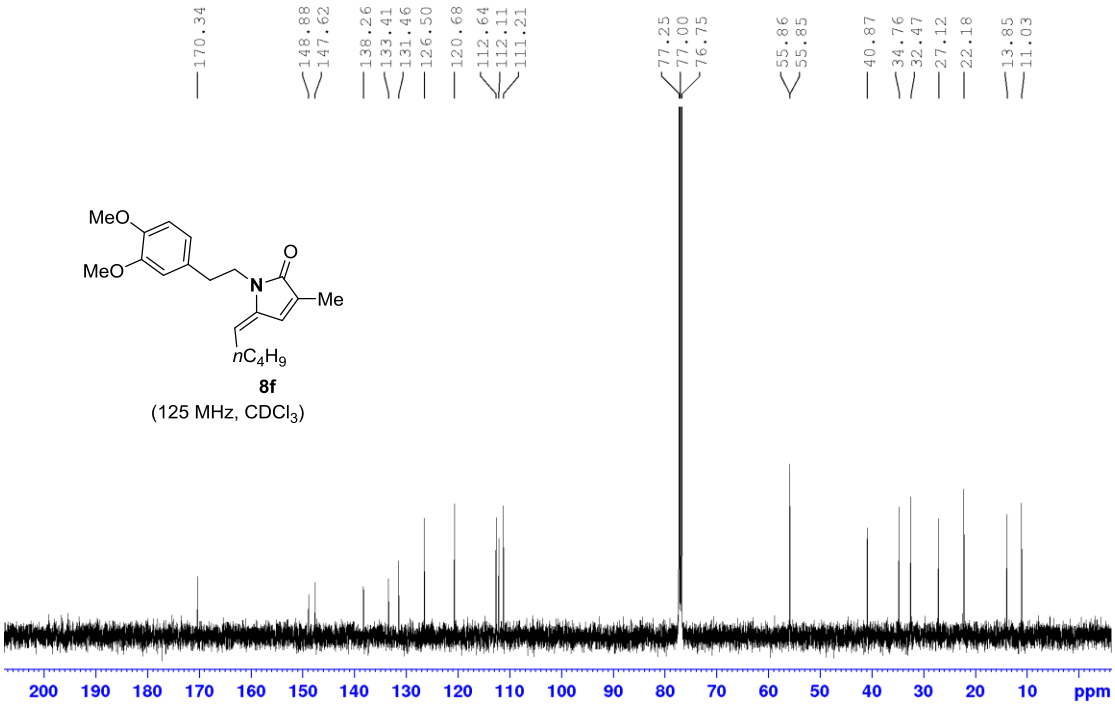
(125 MHz, $CDCl_3$)

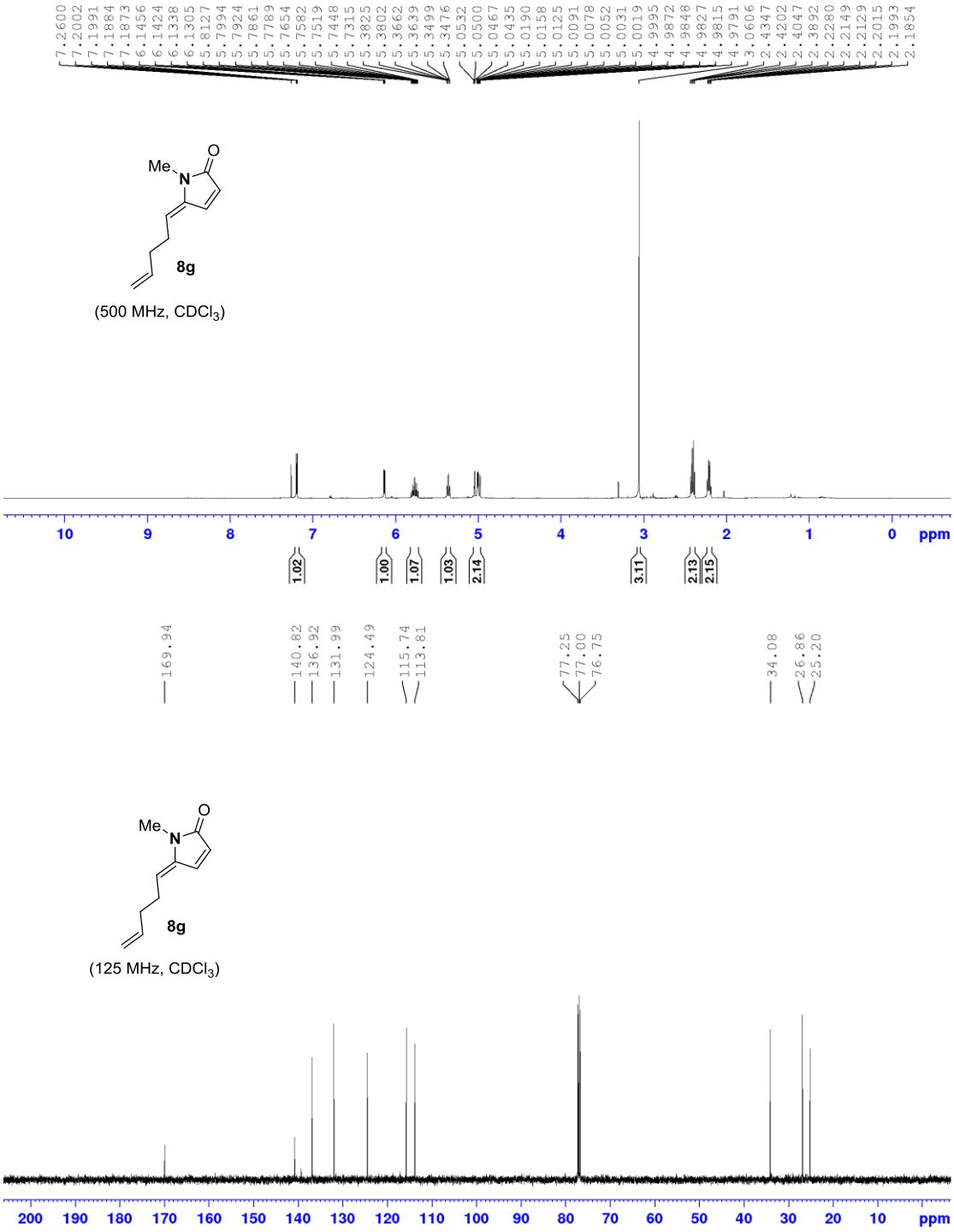


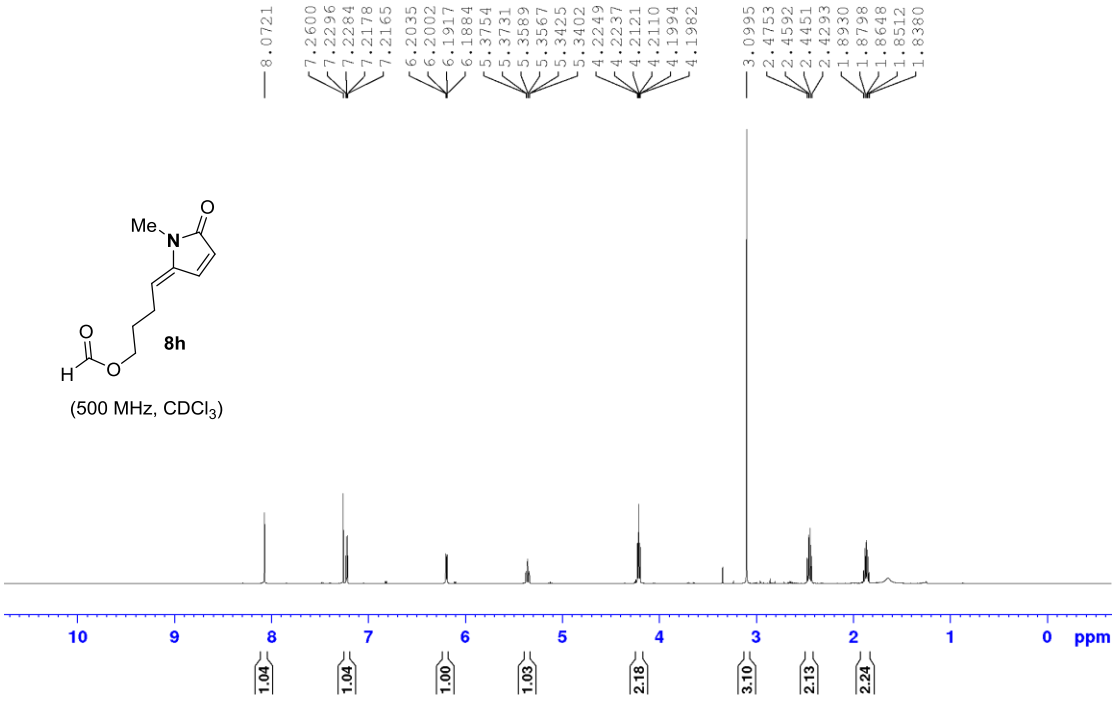


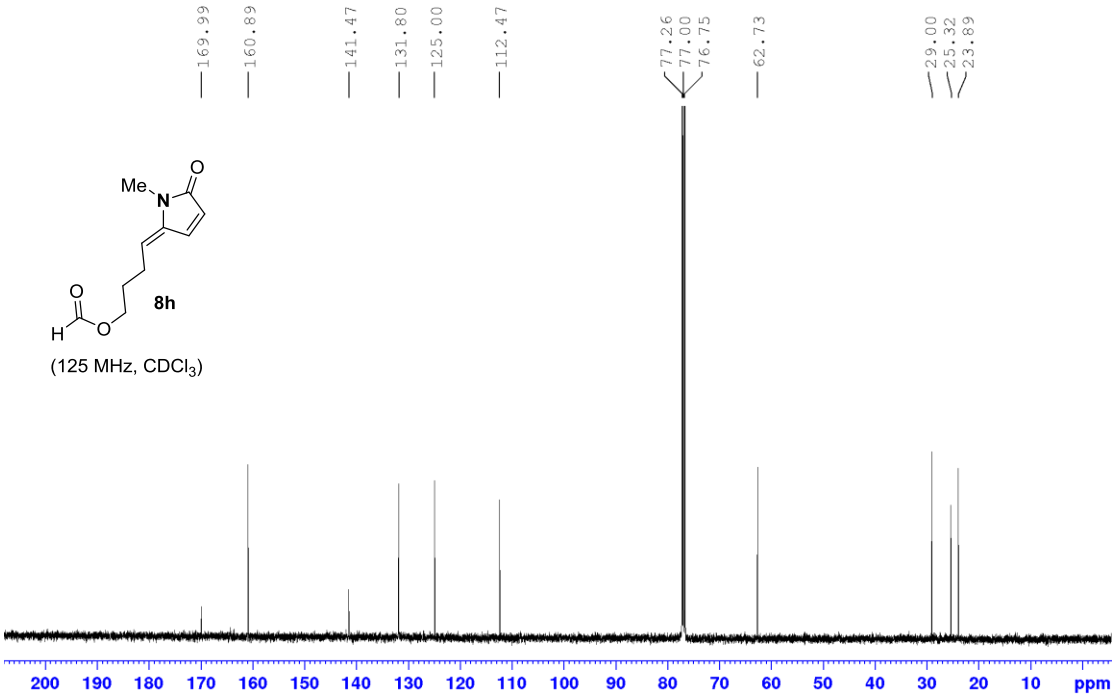


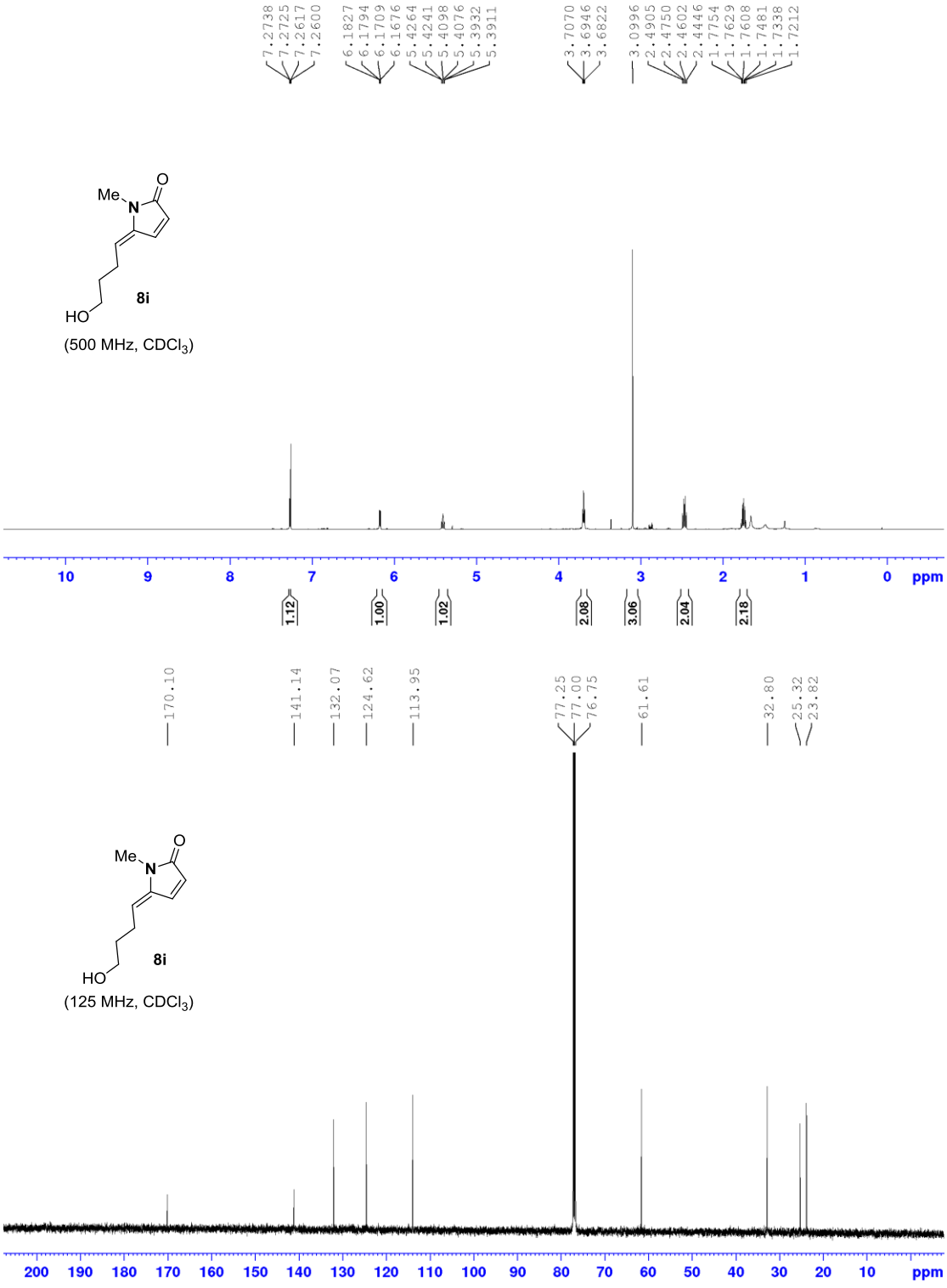


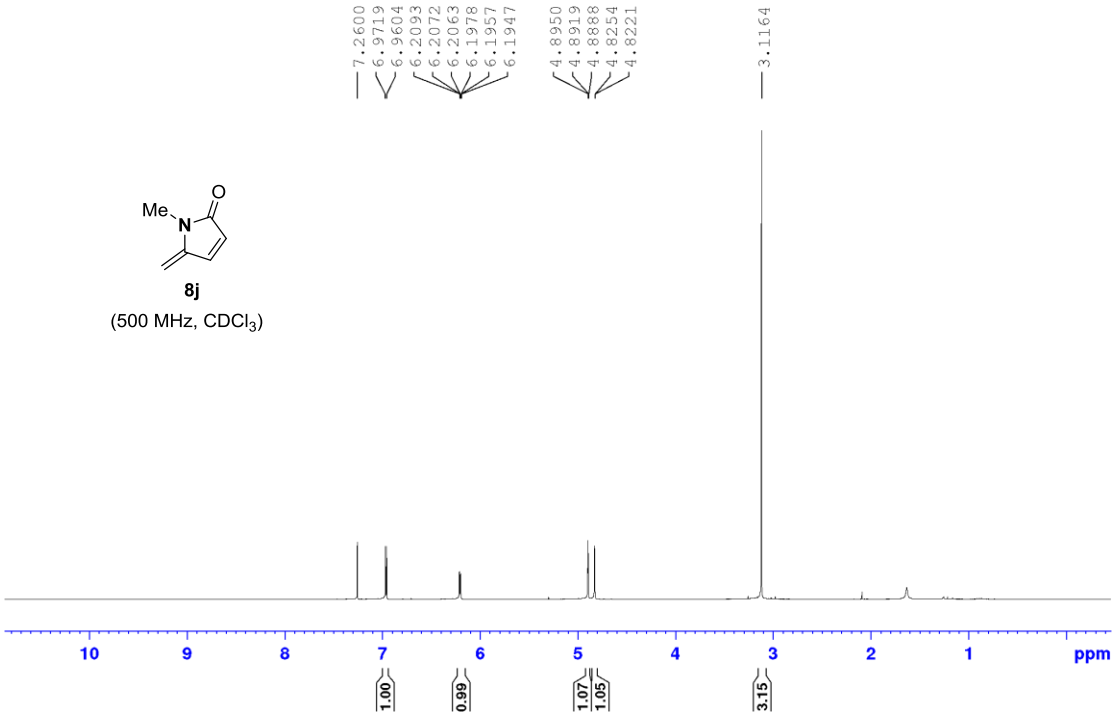






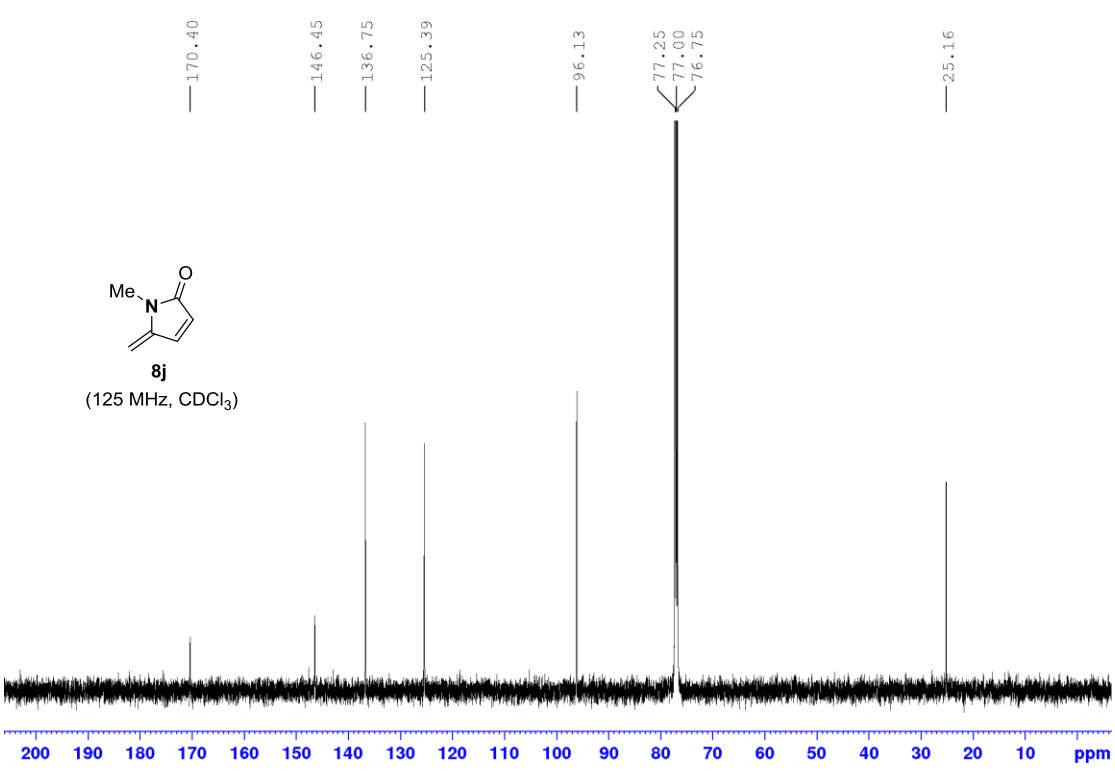






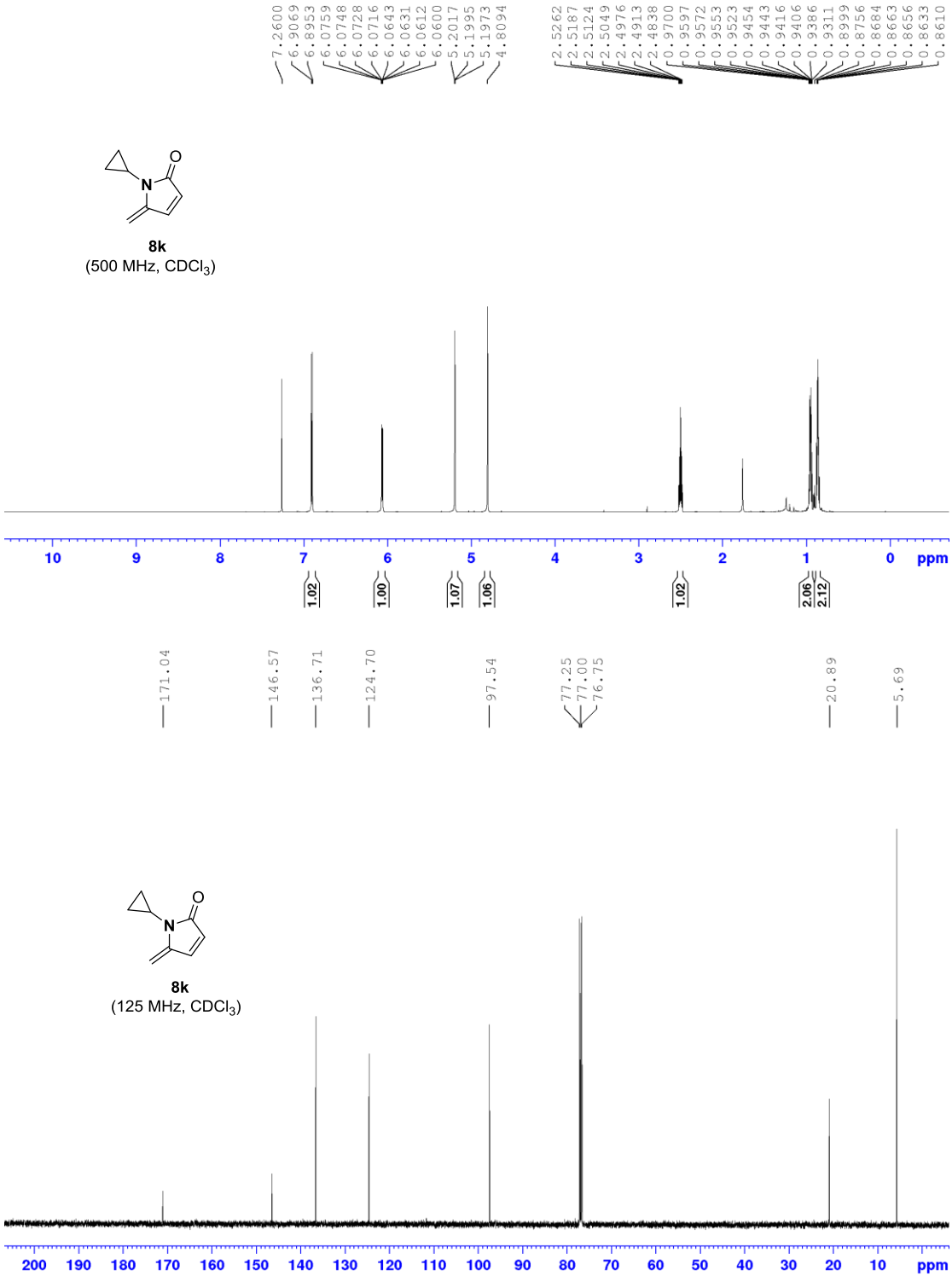
8j

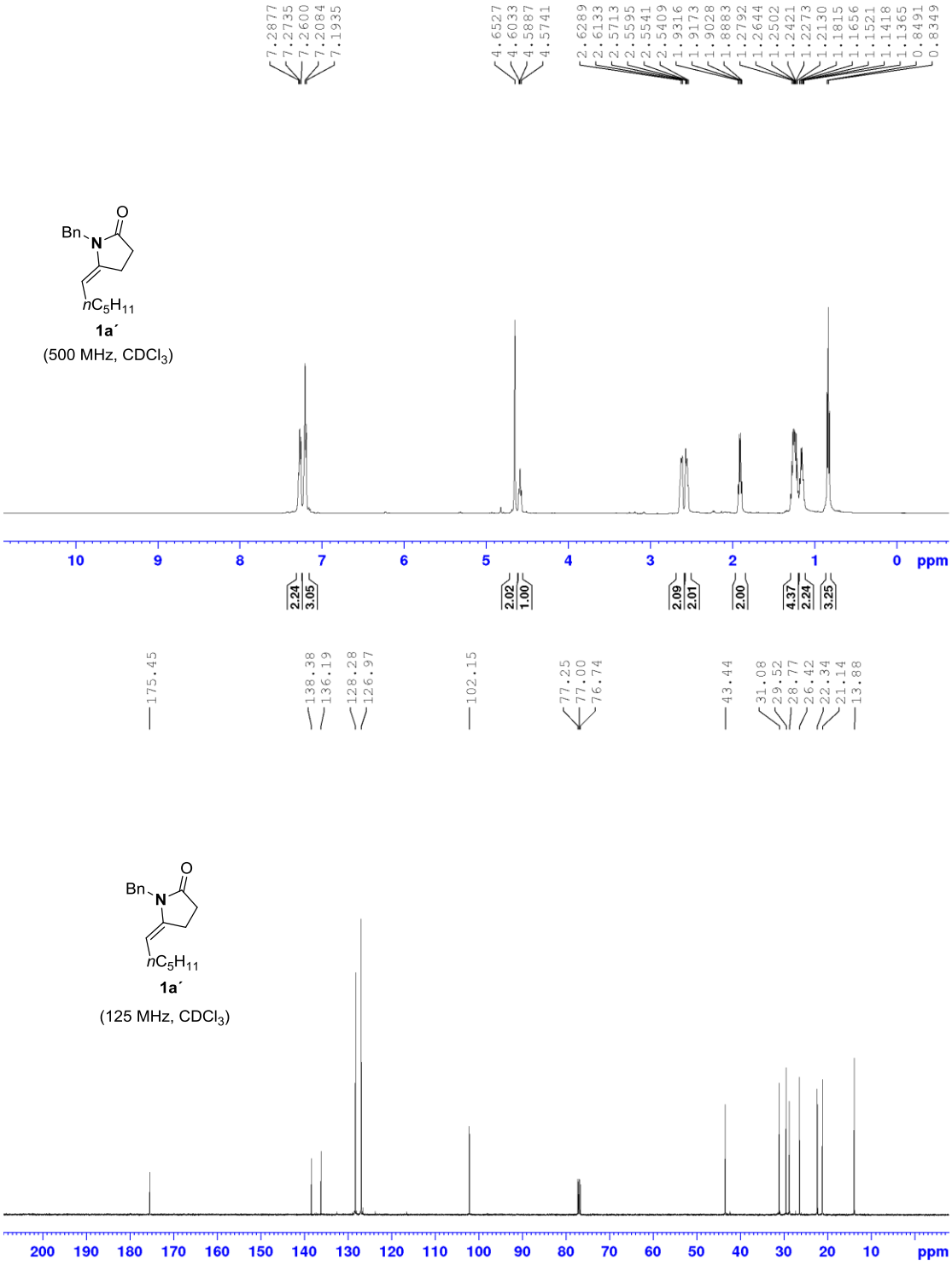
(500 MHz, $CDCl_3$)

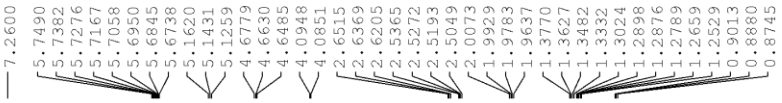


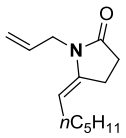
8j

(125 MHz, $CDCl_3$)



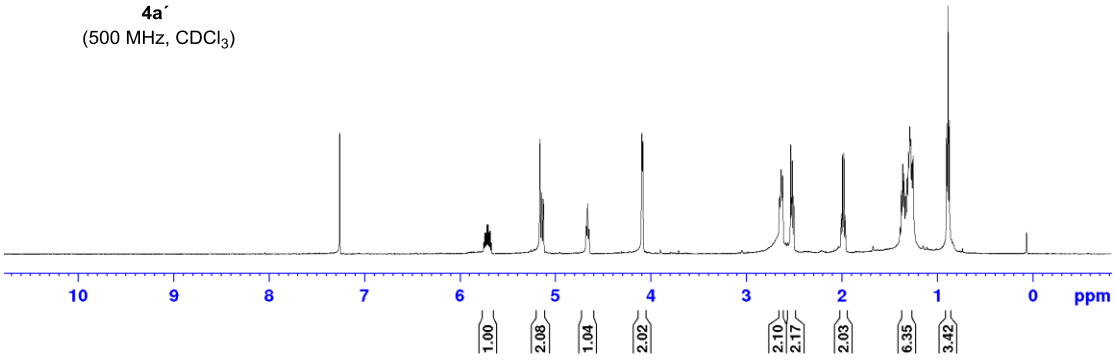


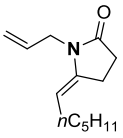




4a´

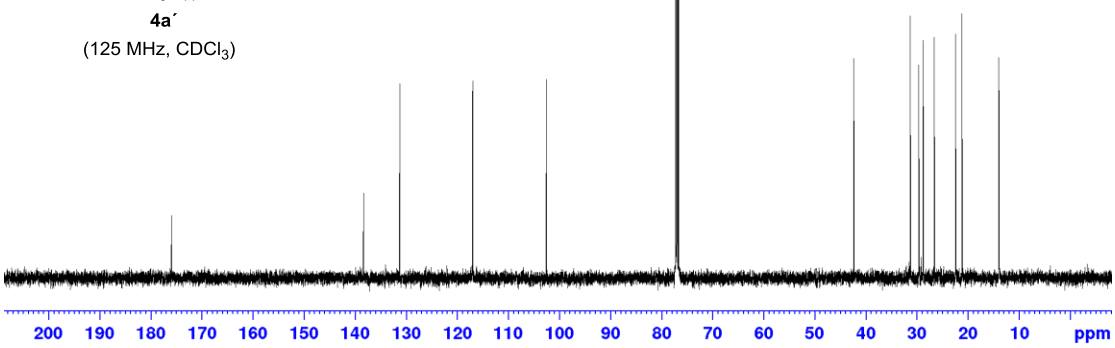
(500 MHz, $CDCl_3$)



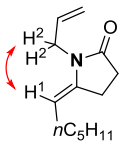


4a´

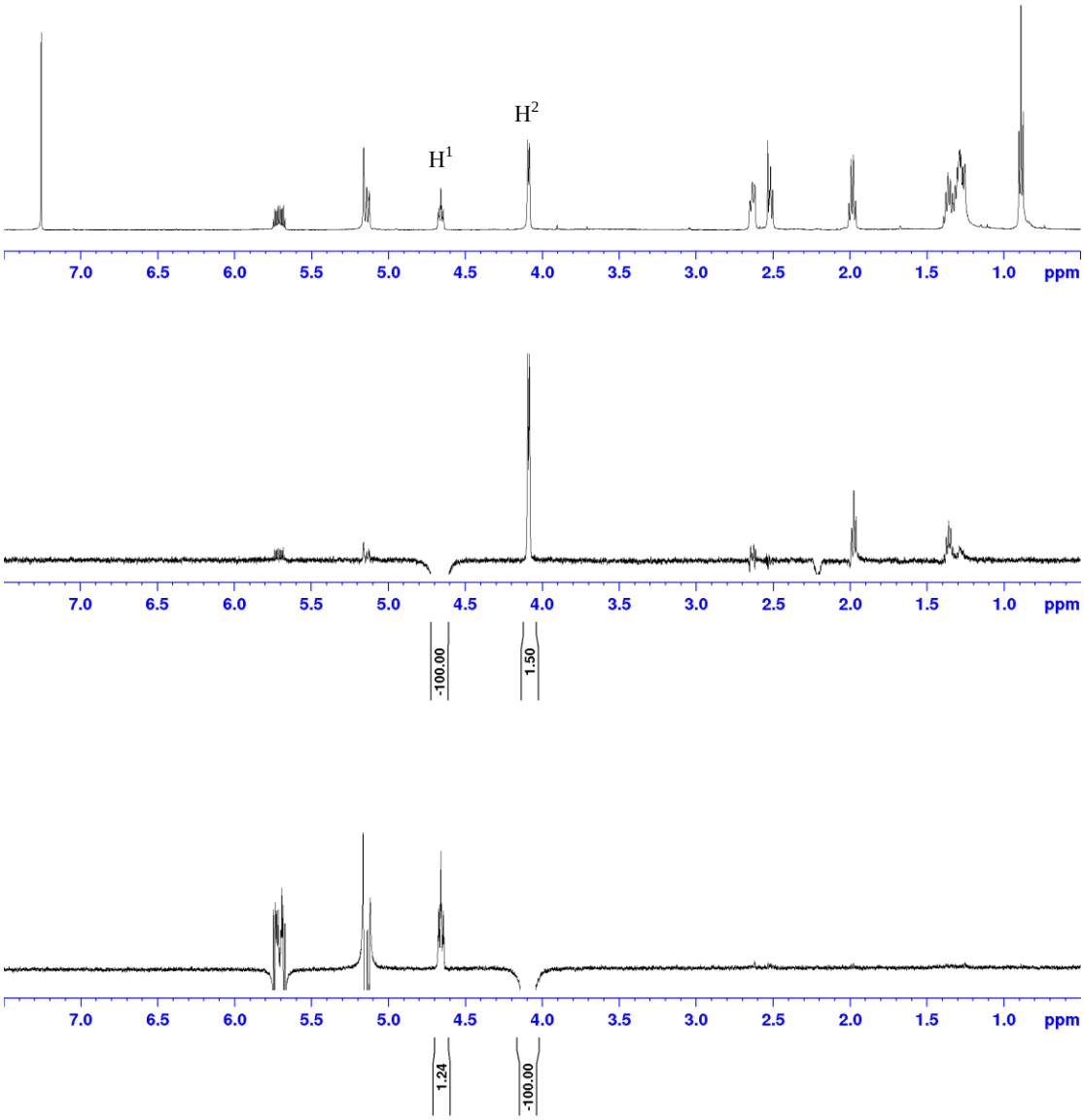
(125 MHz, $CDCl_3$)

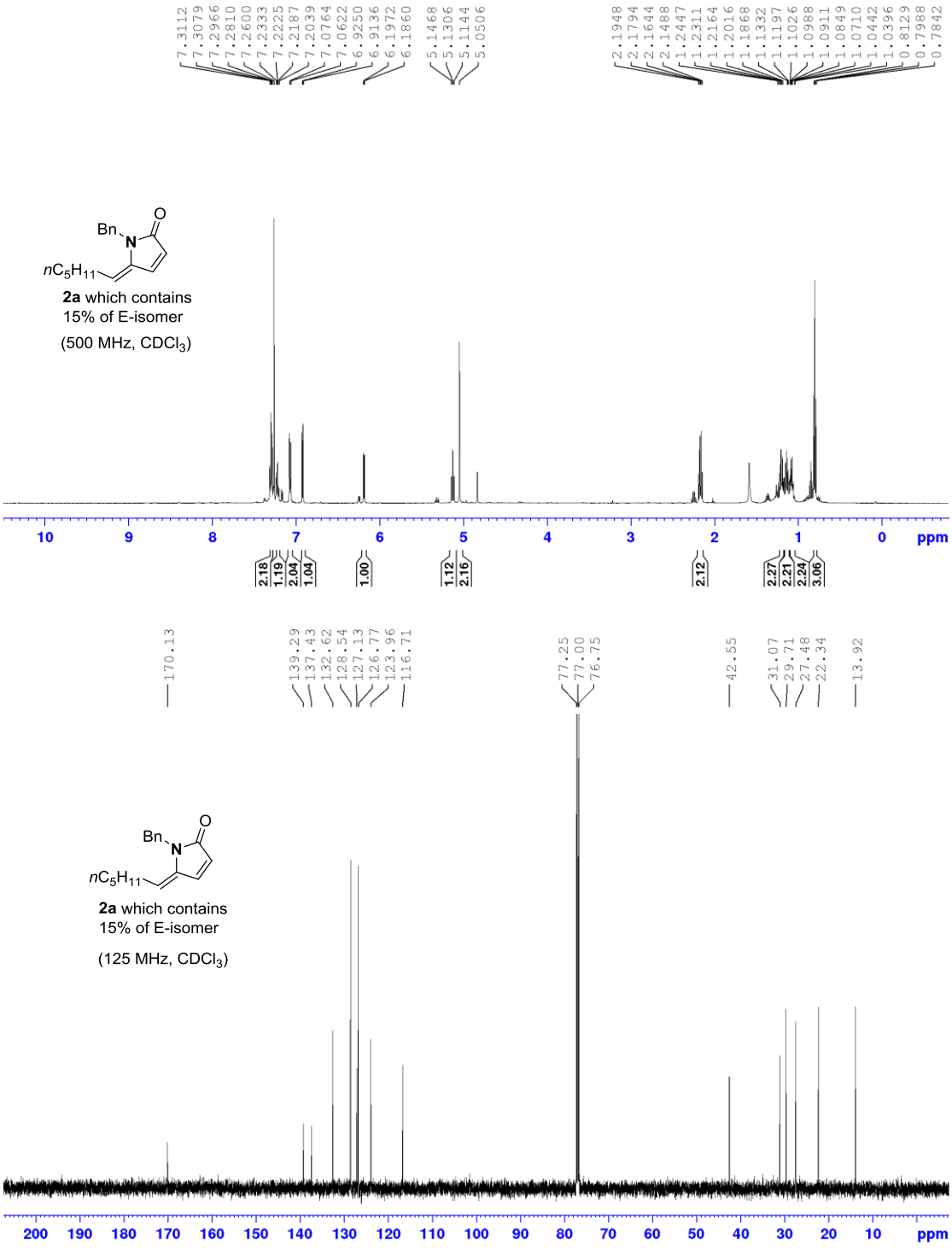


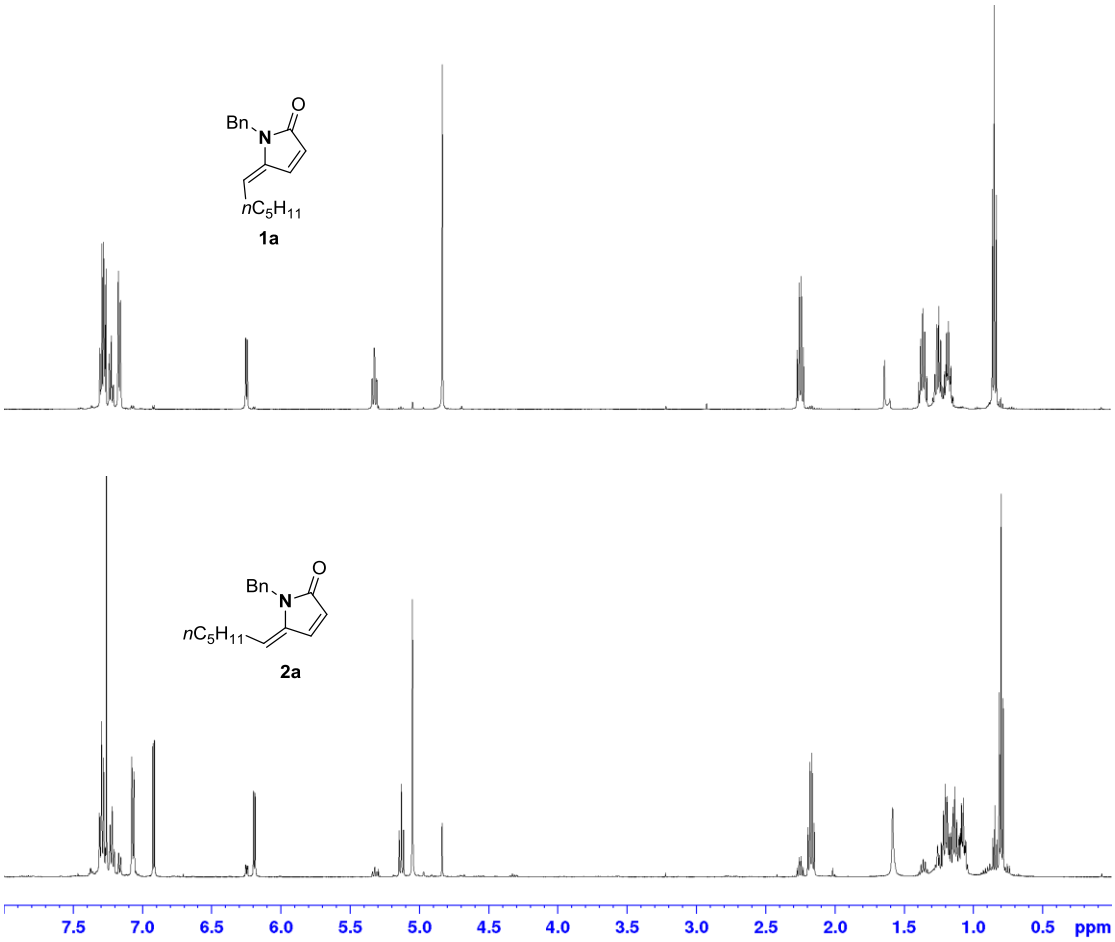
Representative NOE of compound 4a´

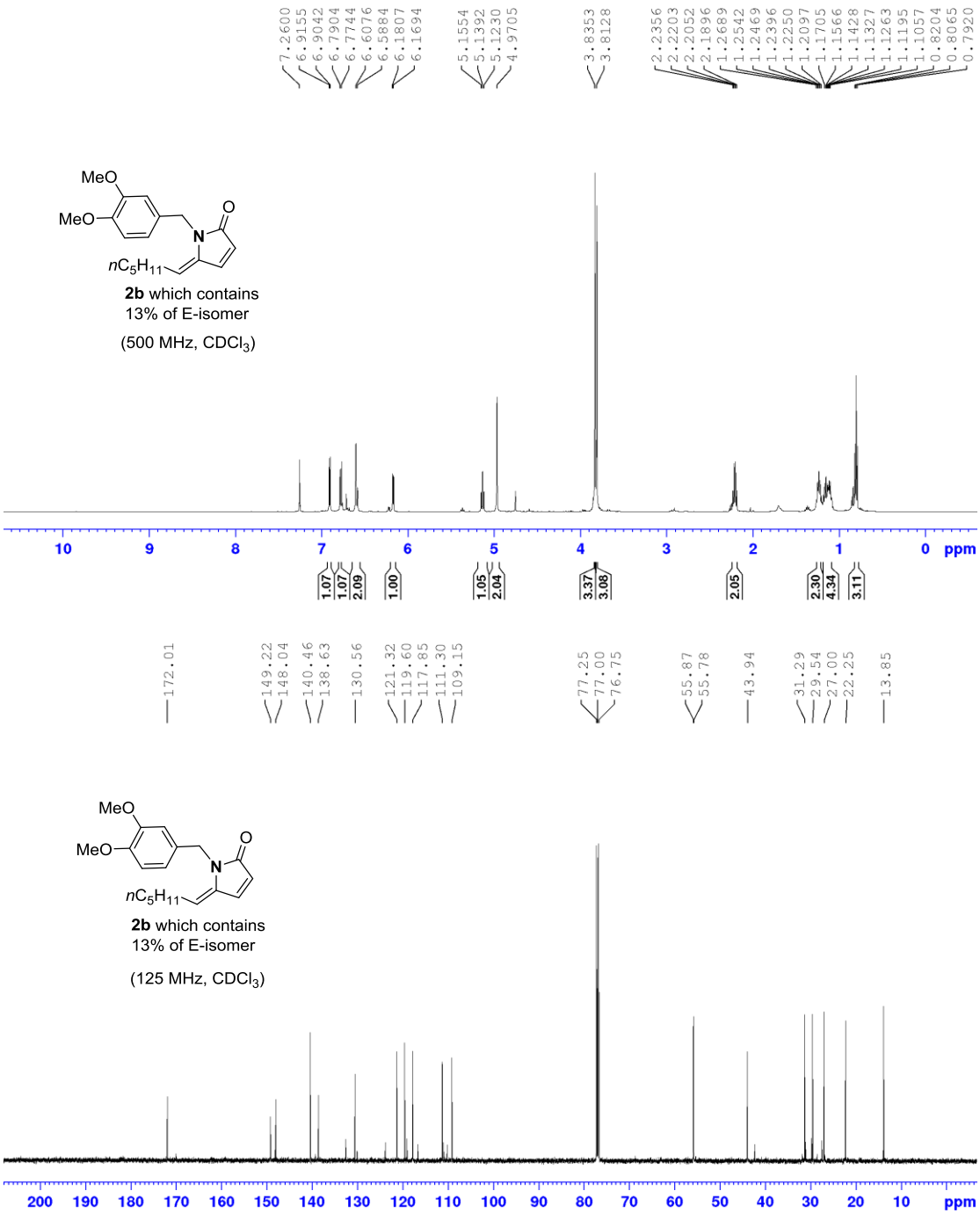


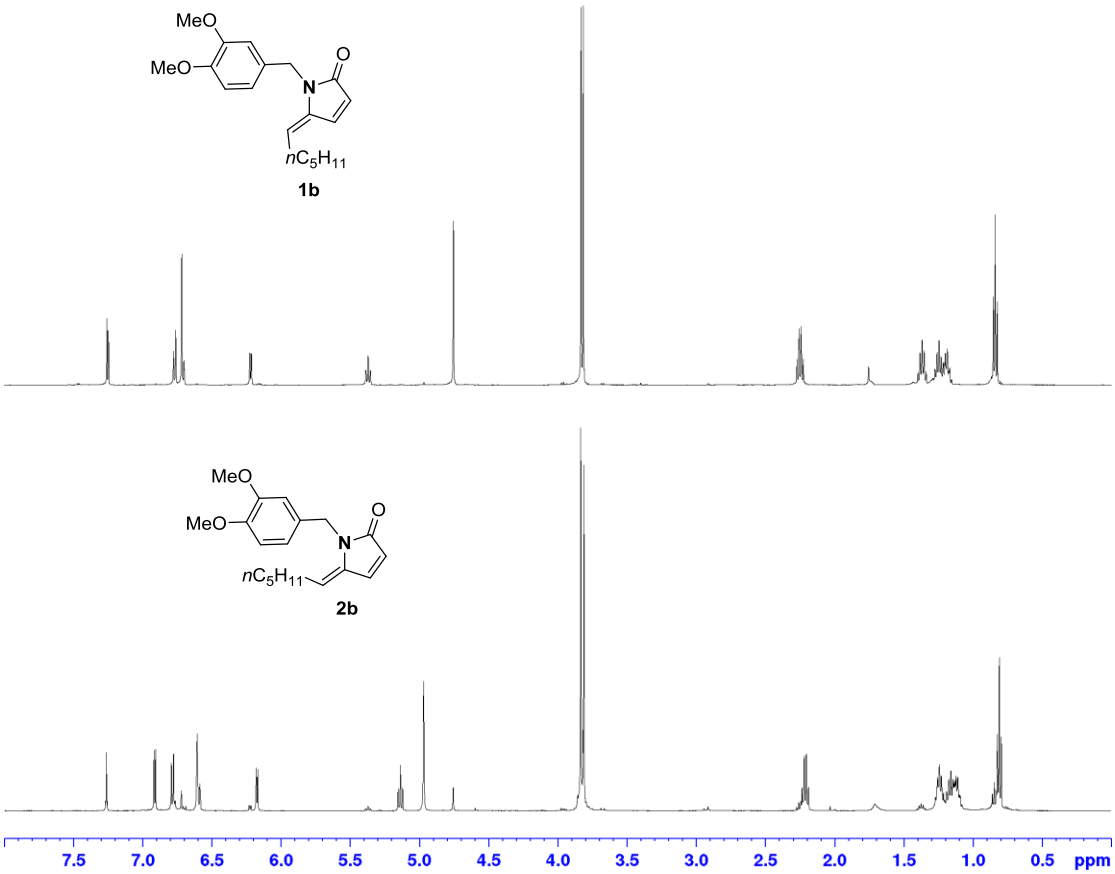
4a´



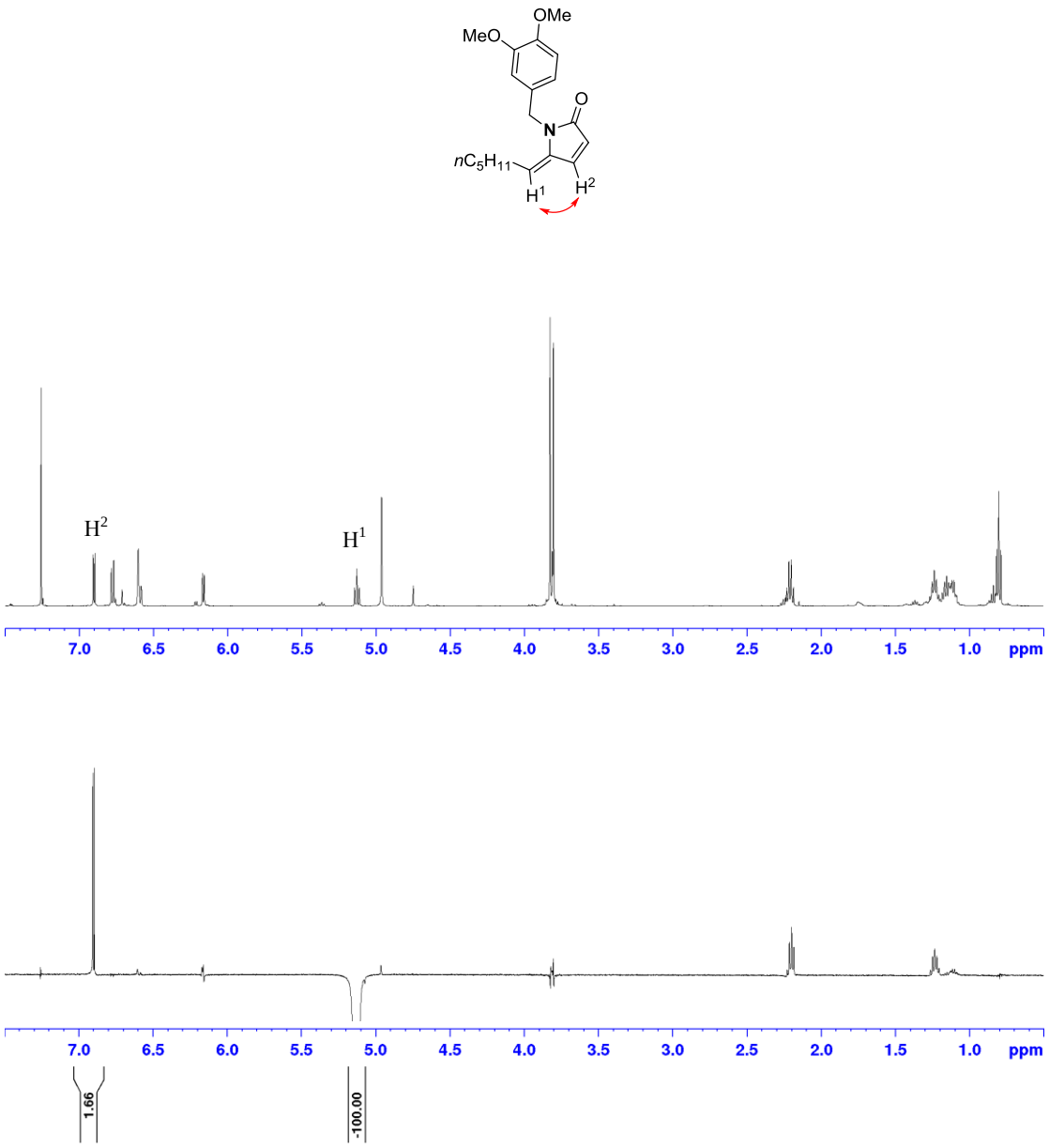


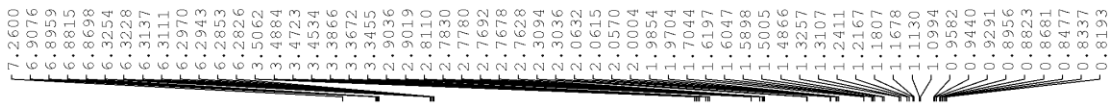


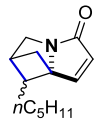




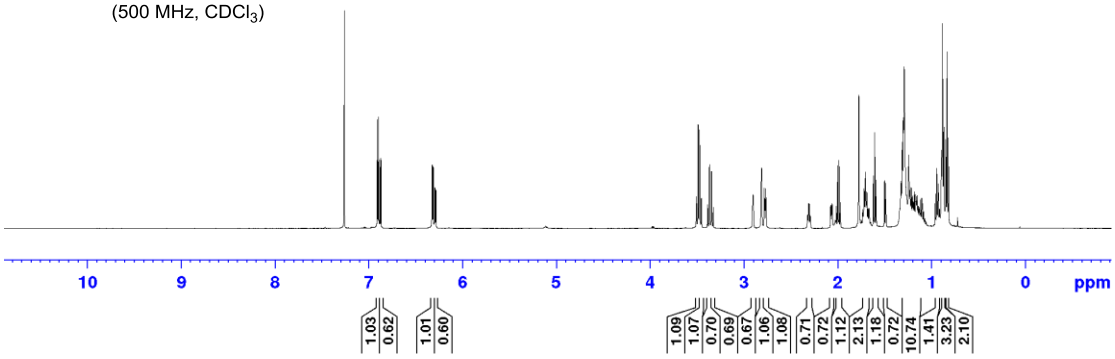
Representative NOE of compound 2b

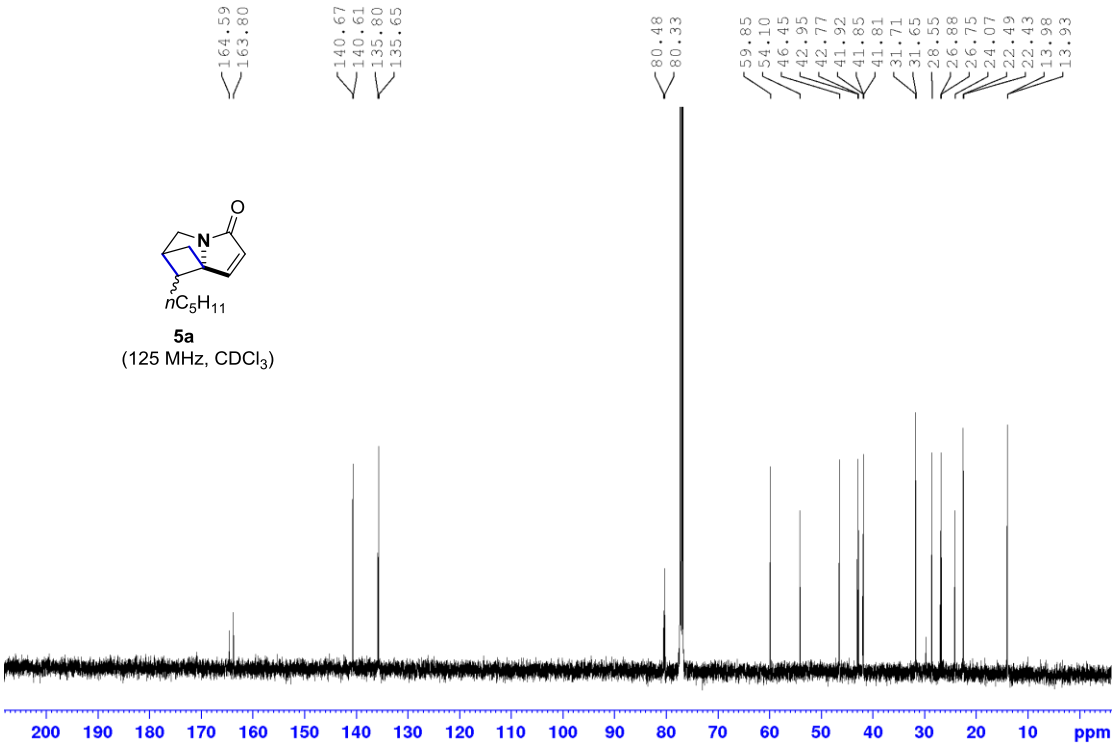




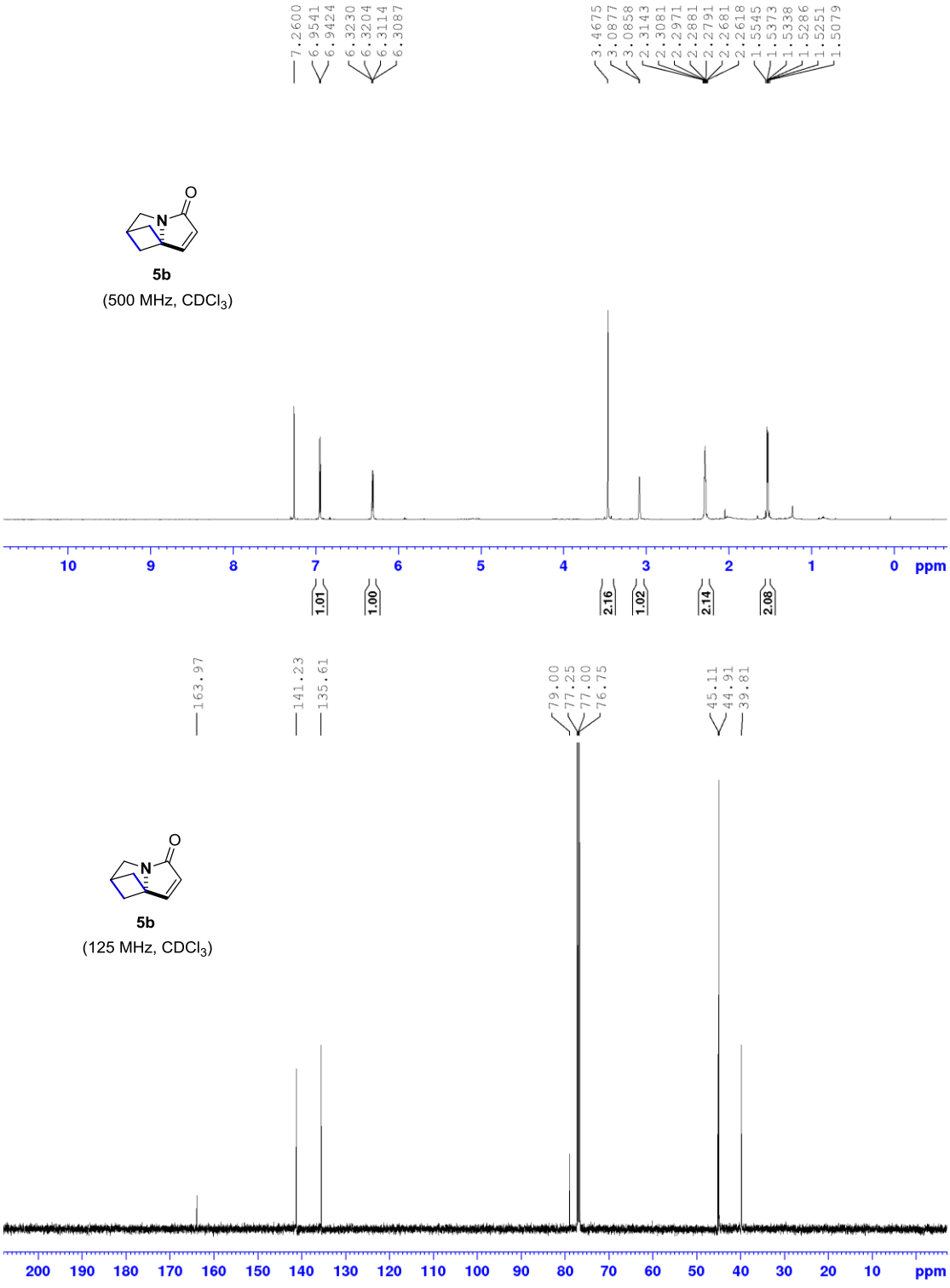


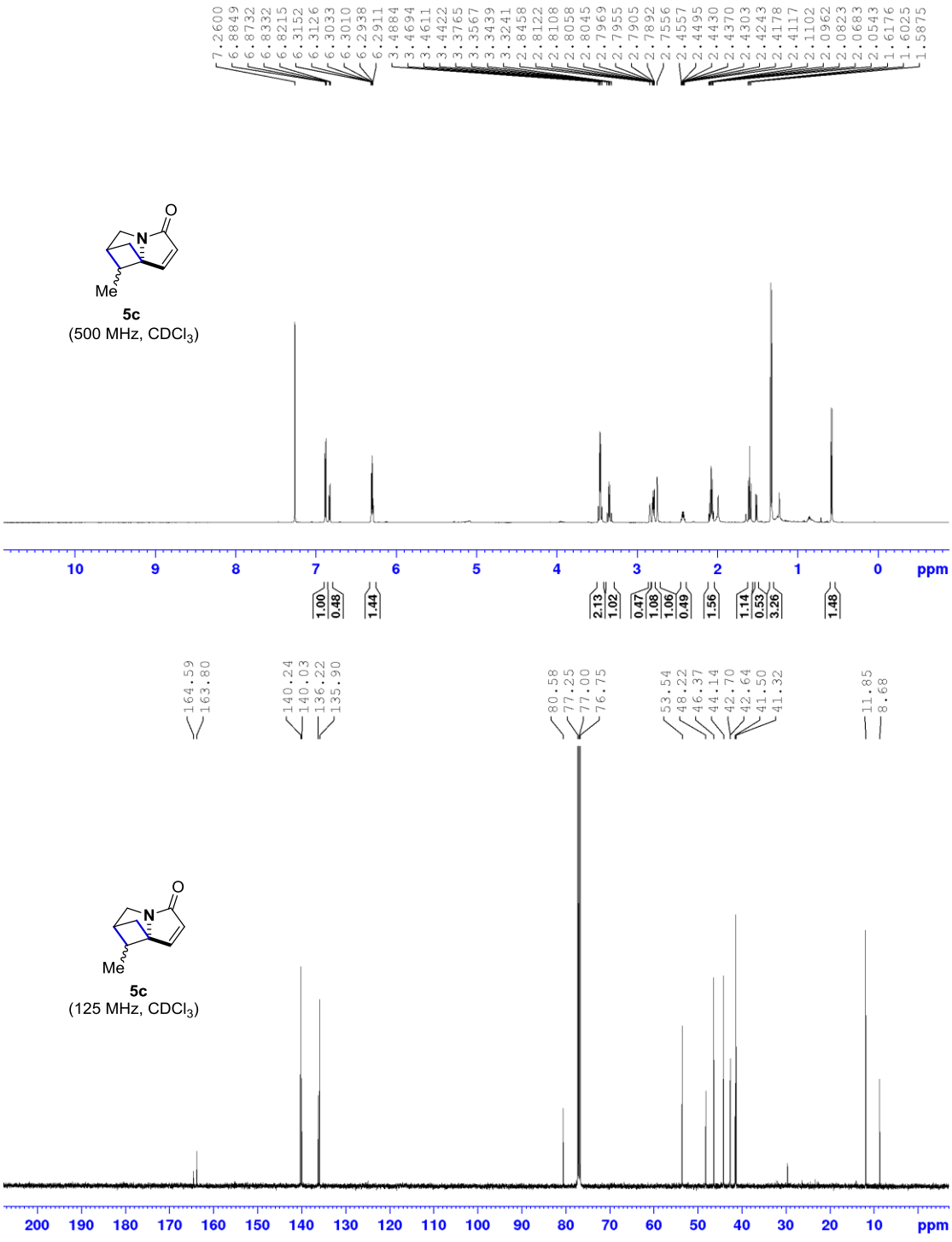
5a
(500 MHz, $CDCl_3$)



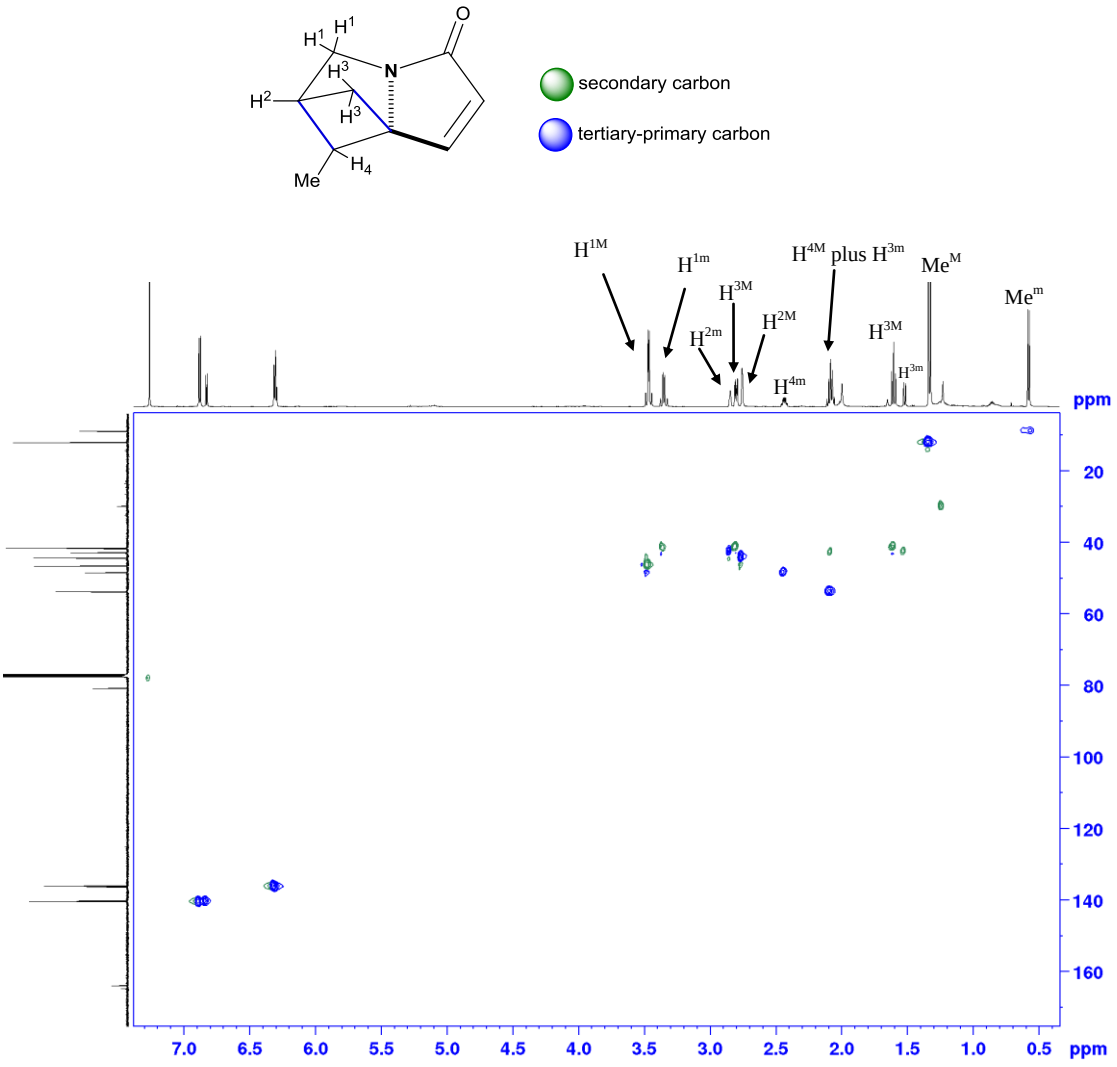


5a
(125 MHz, $CDCl_3$)

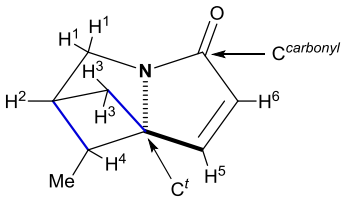


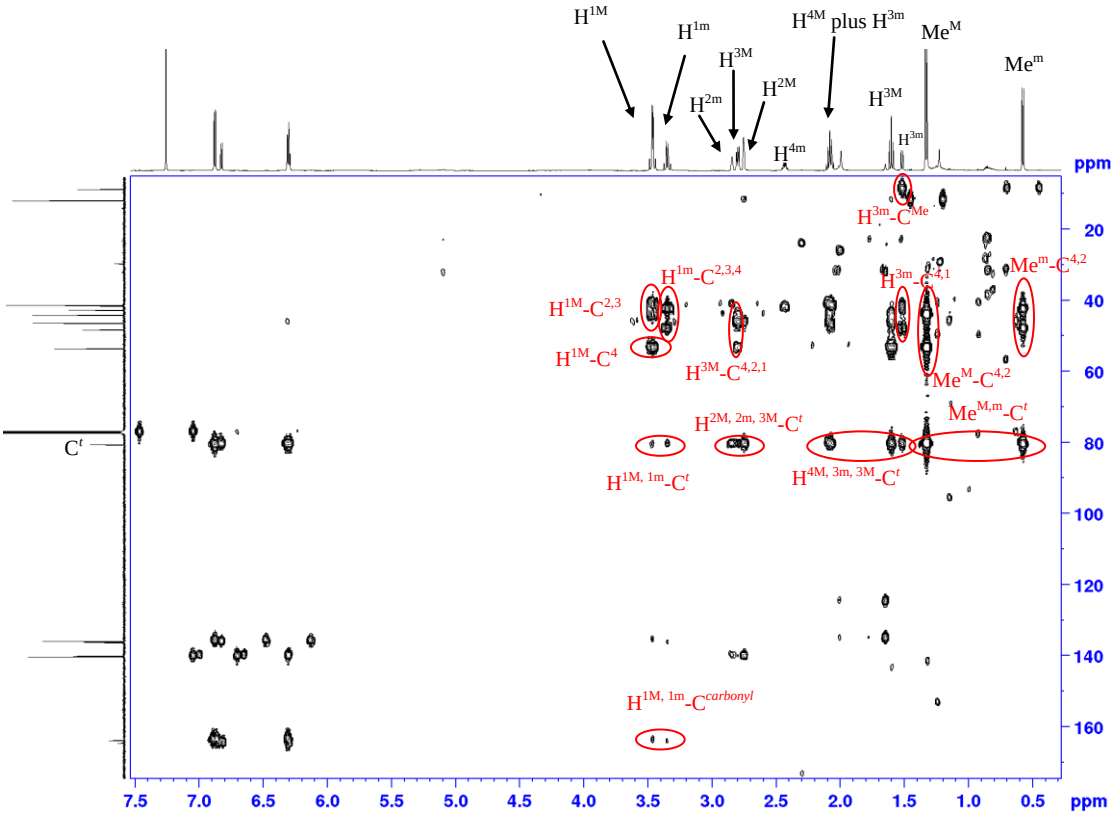


HSQC correlations of compound 5c

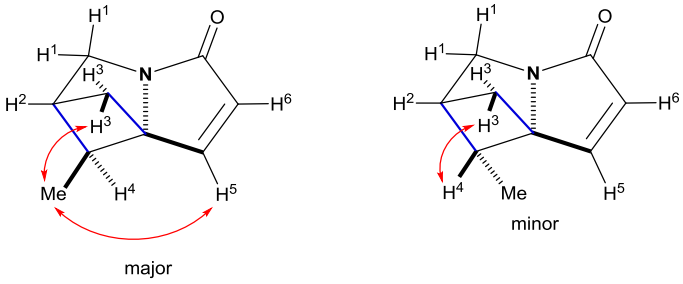


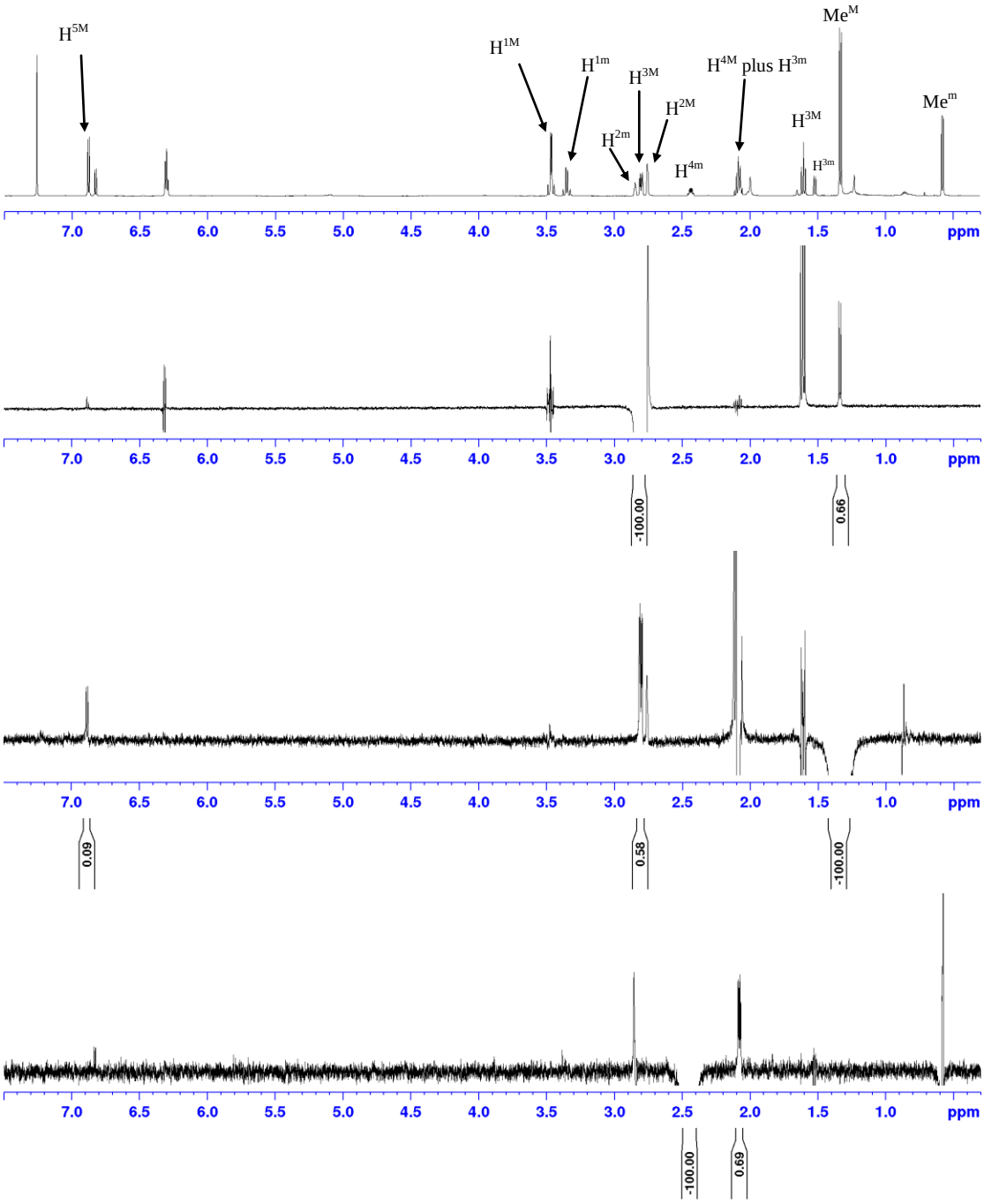
HMBC correlations of compound 5c

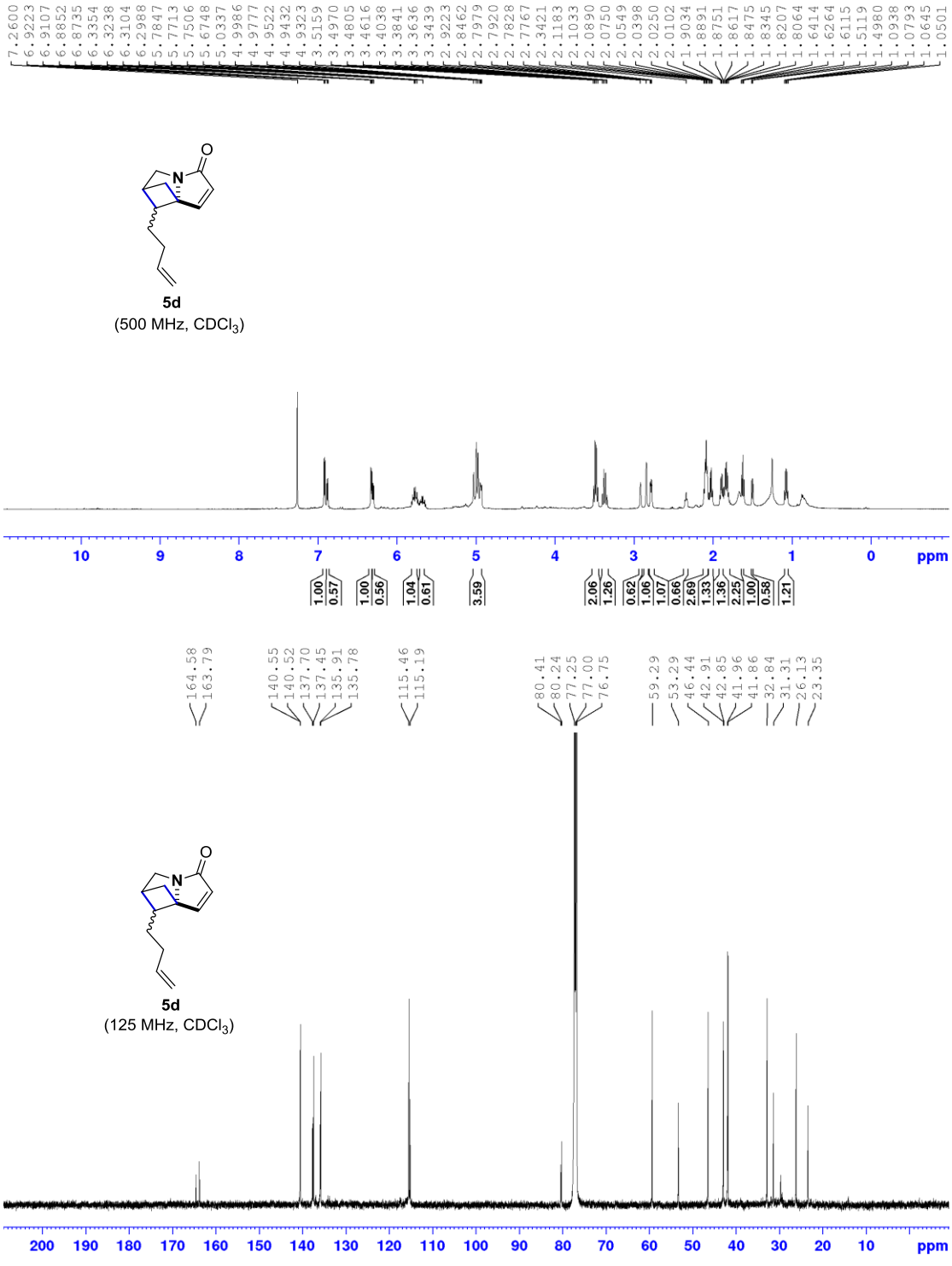


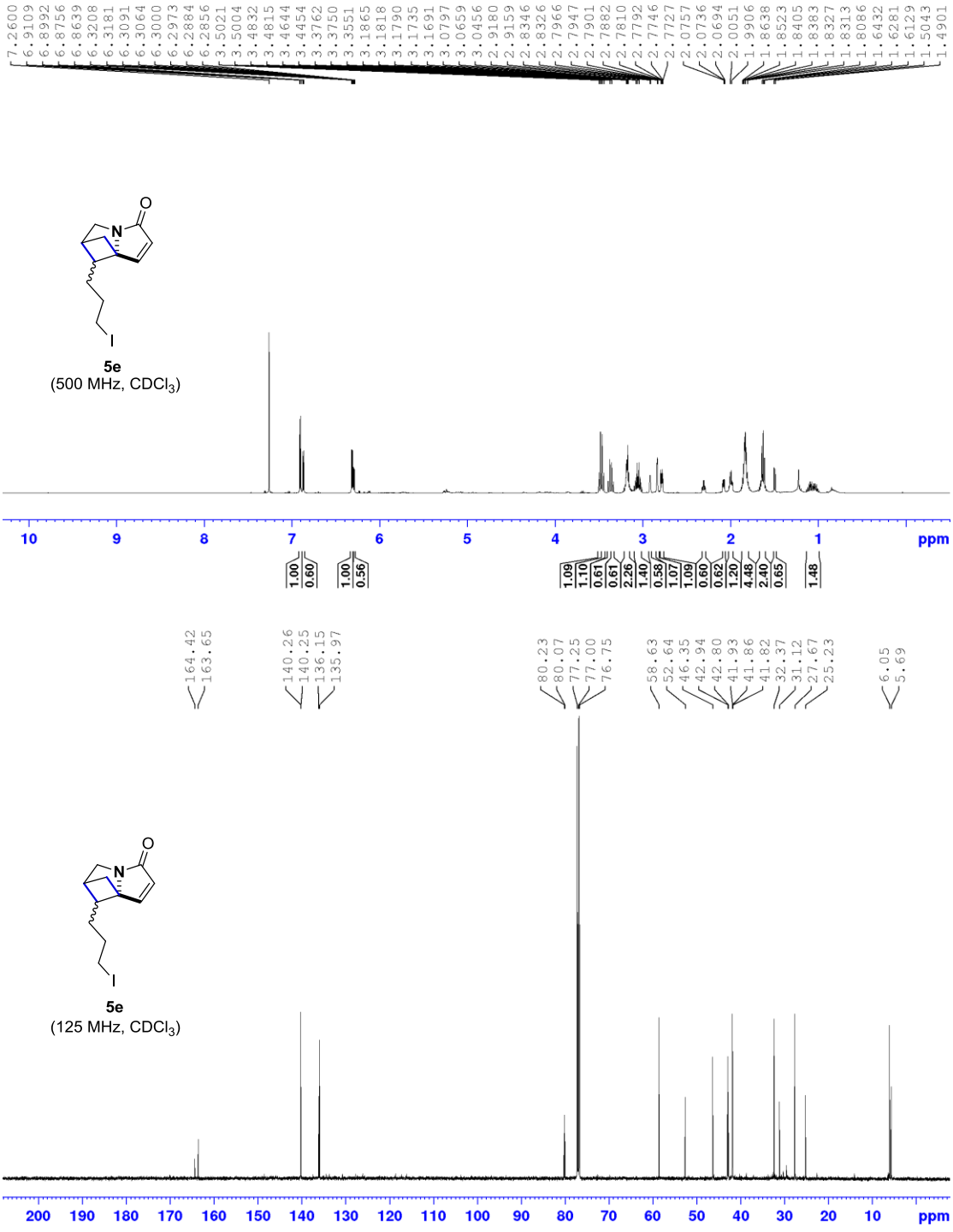


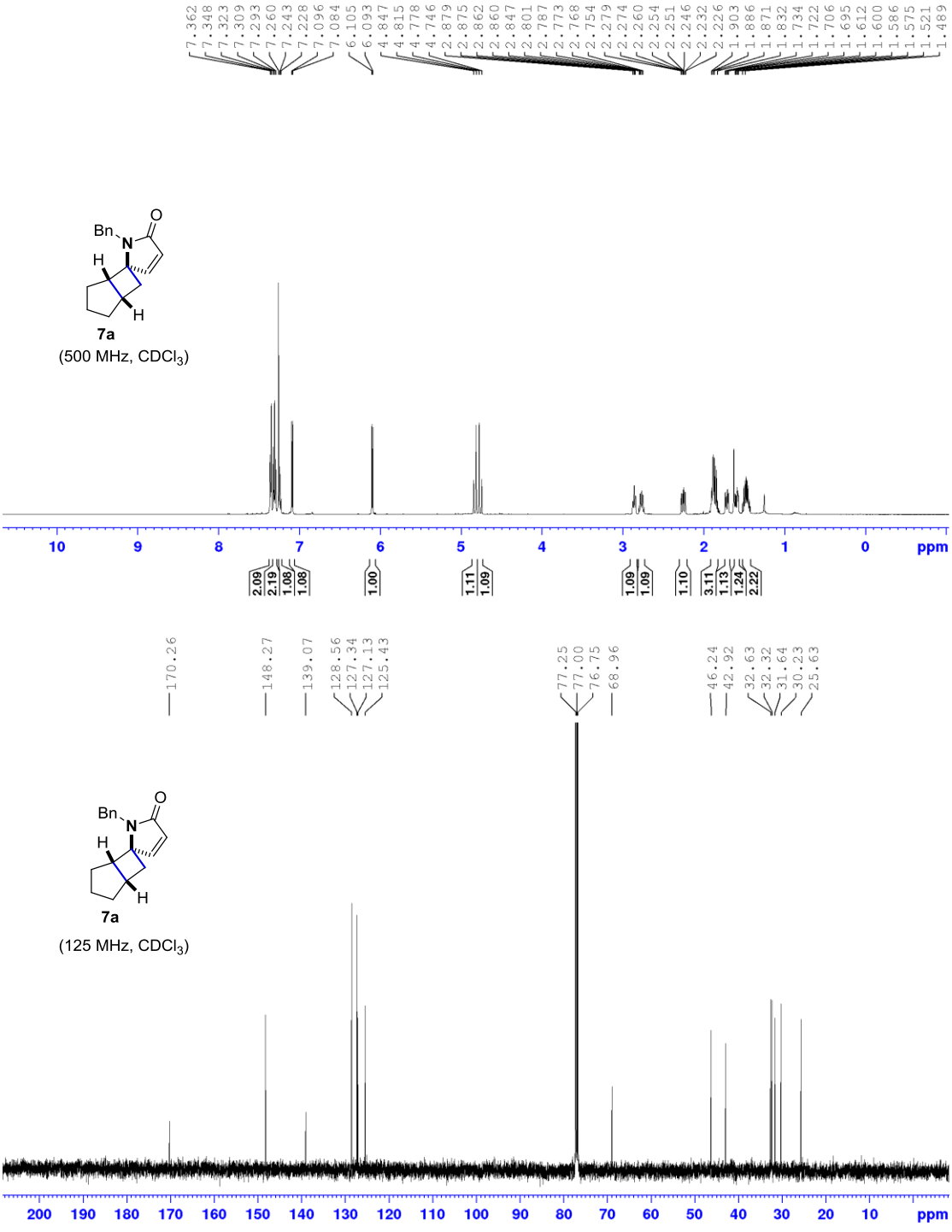
Representative NOE of compound 5c











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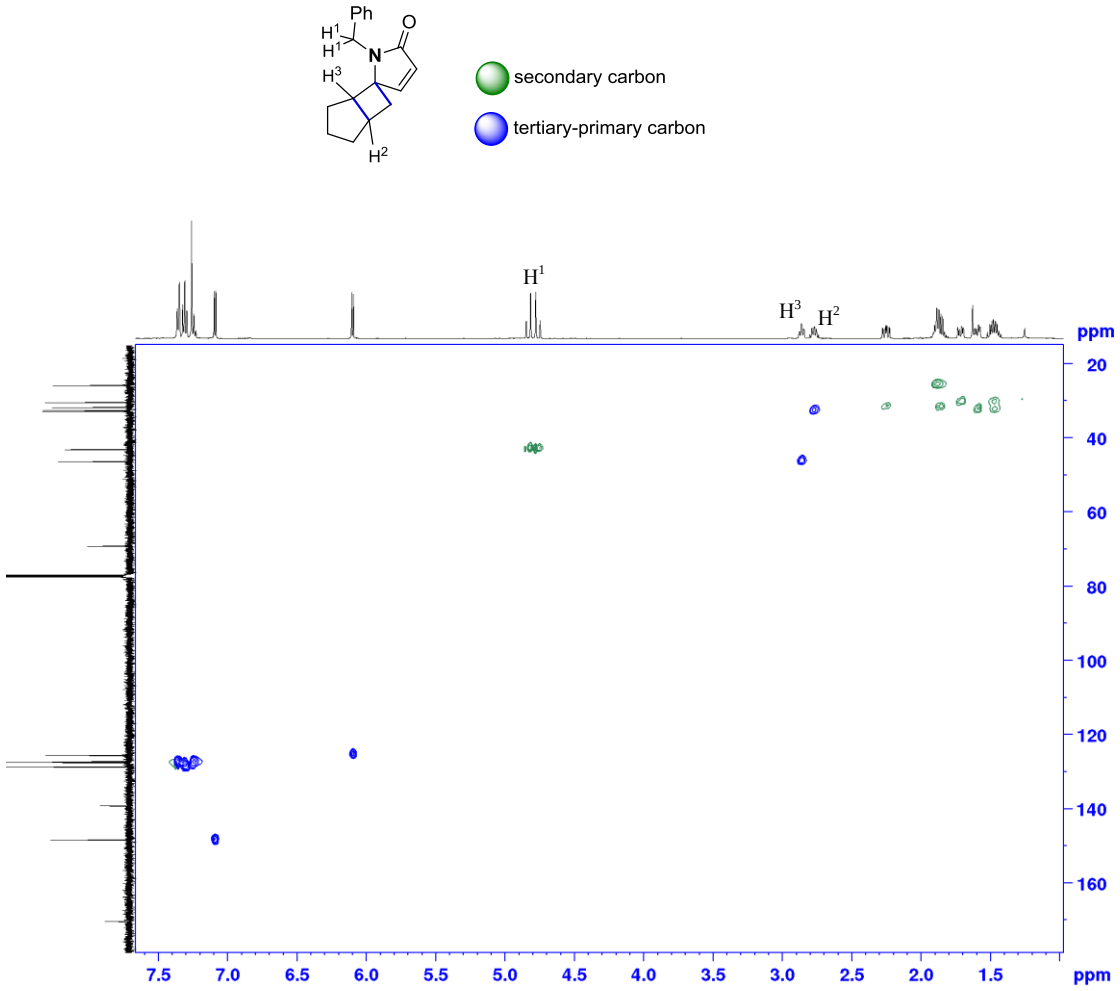
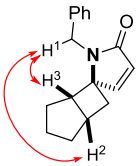
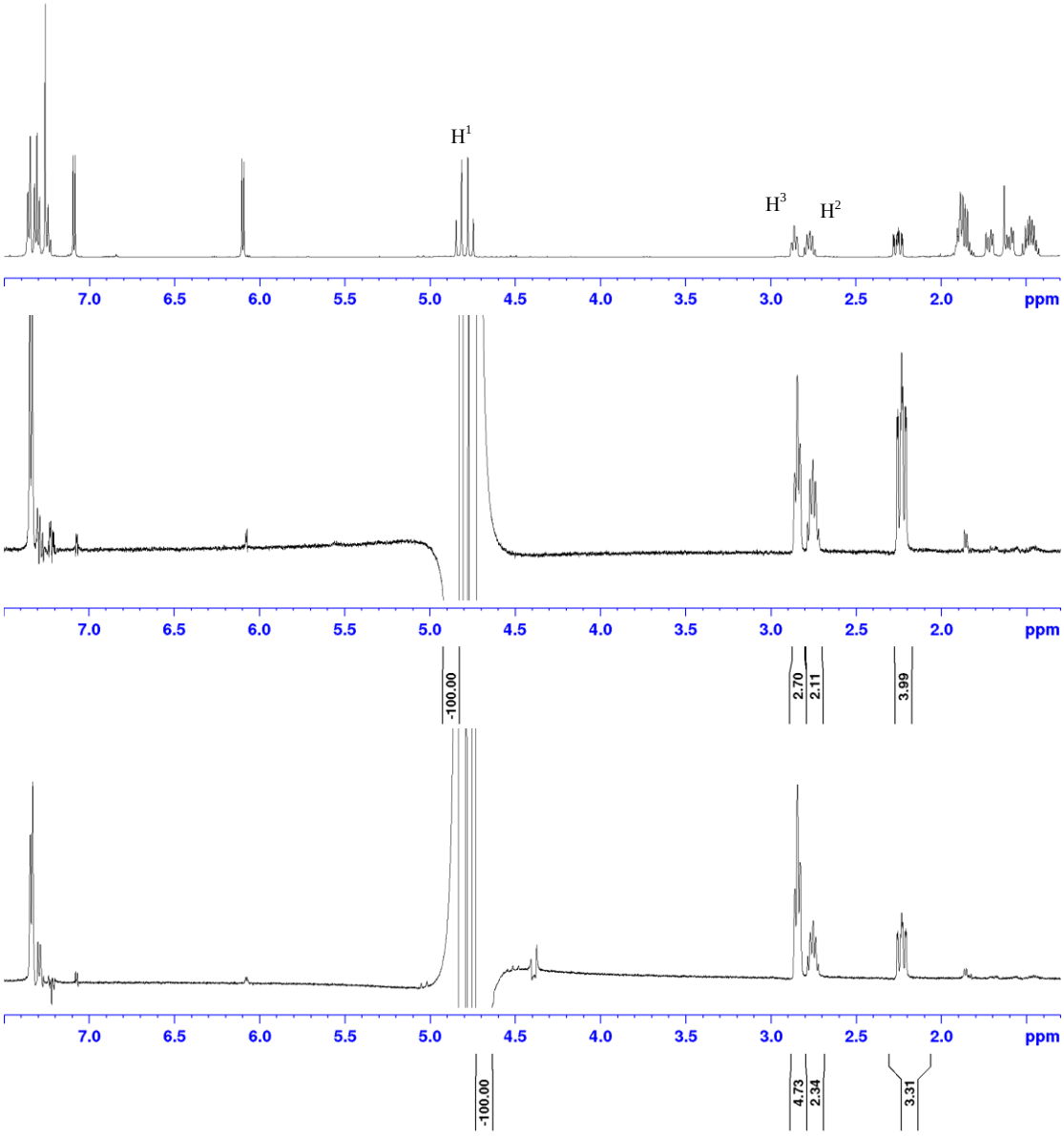
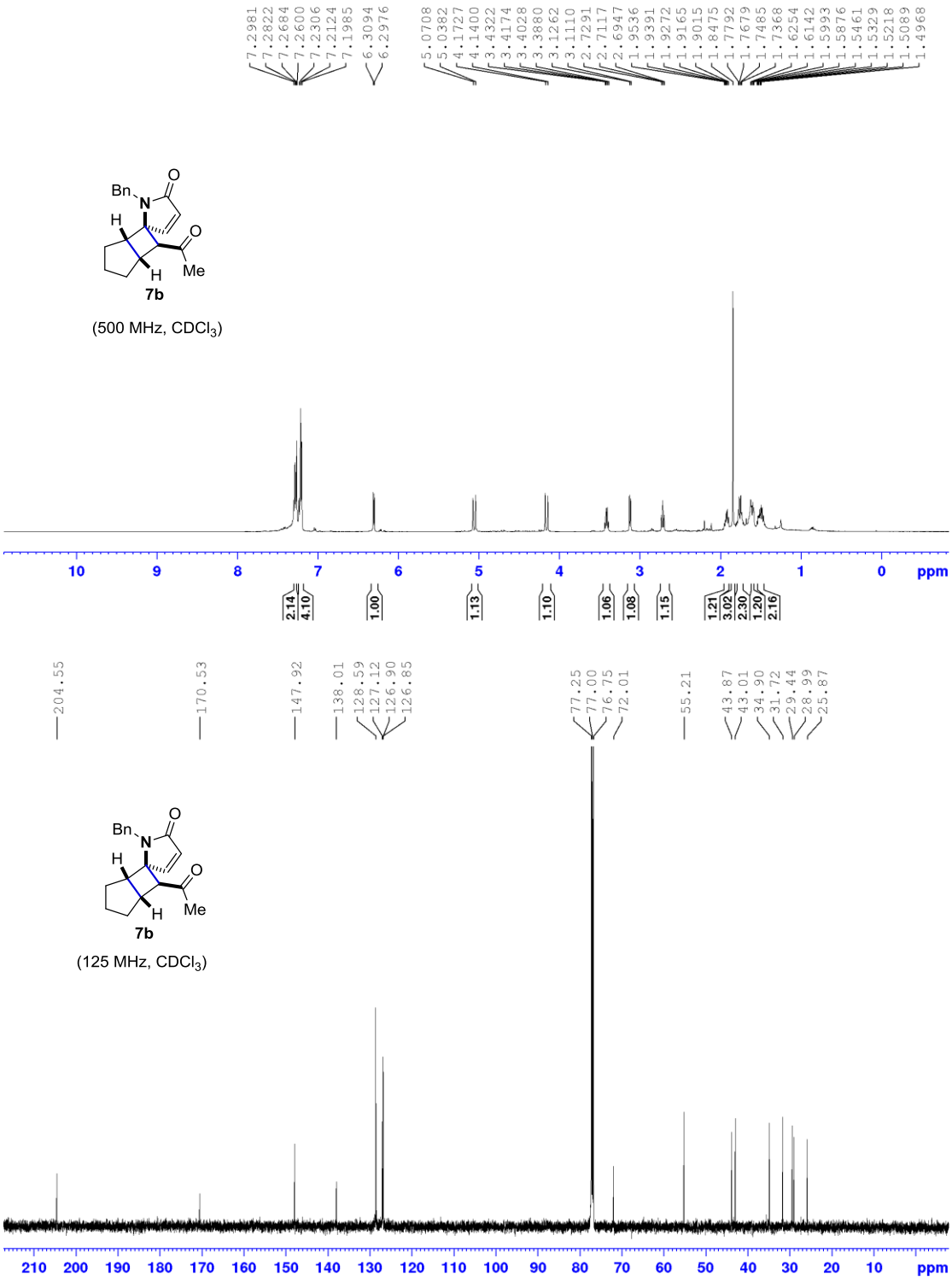
HSQC correlations of compound 7a

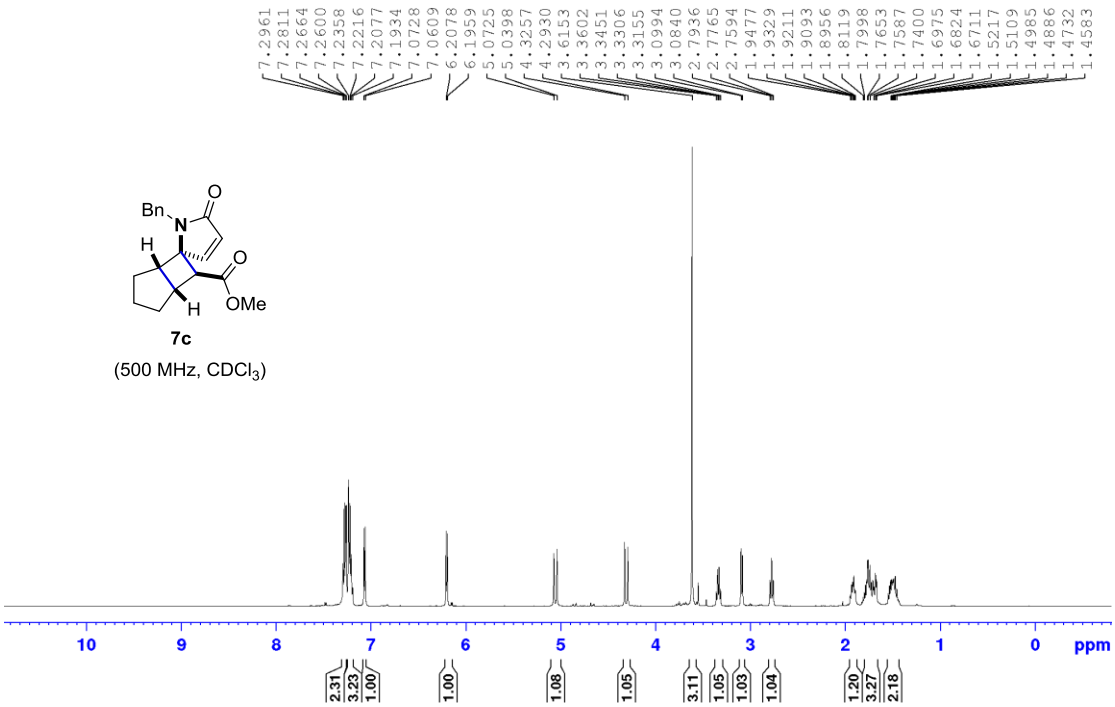


Representative NOE of compound 7a



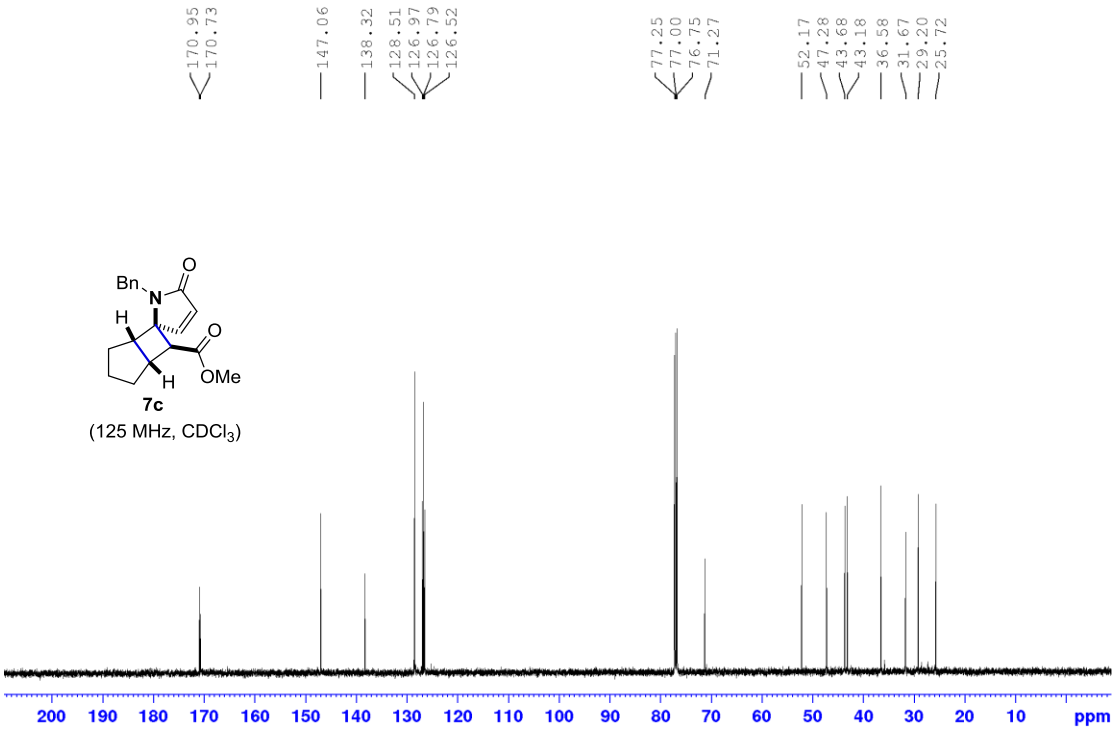






7c

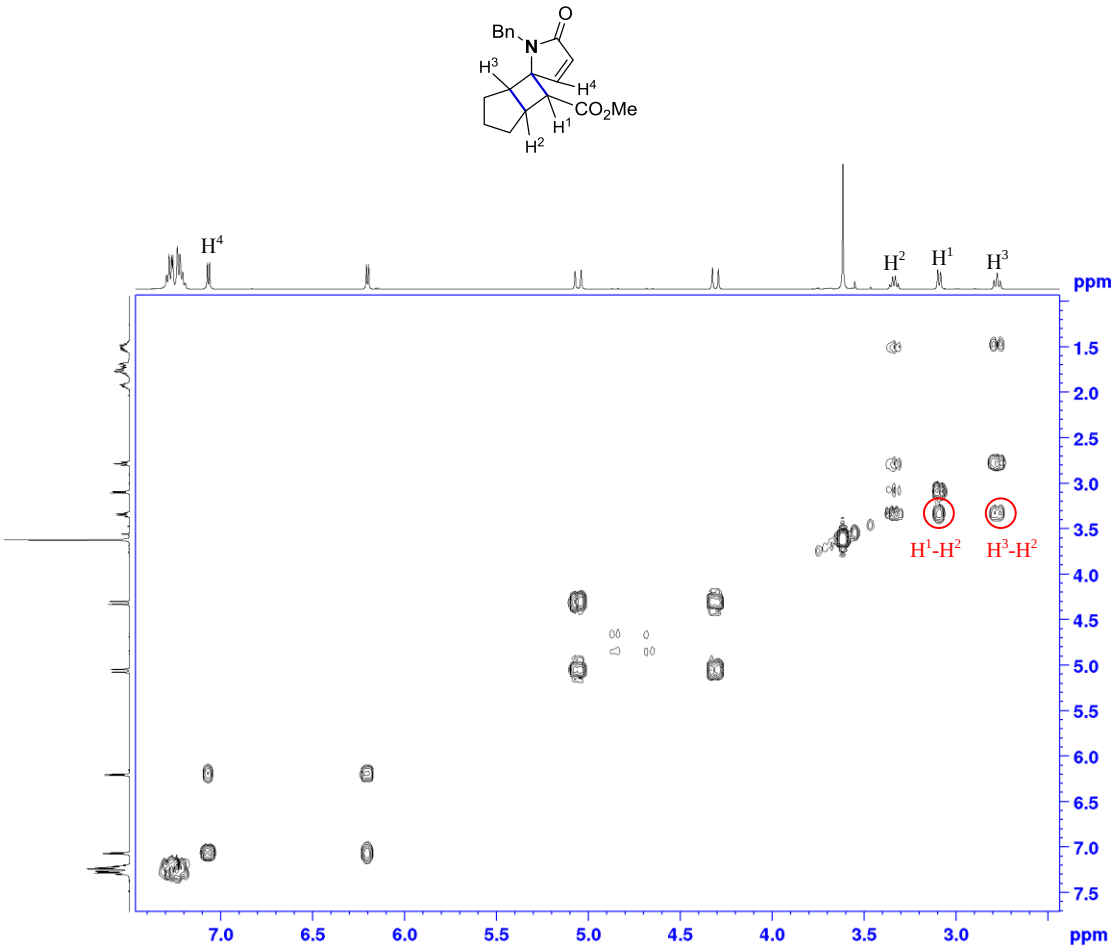
(500 MHz, $CDCl_3$)



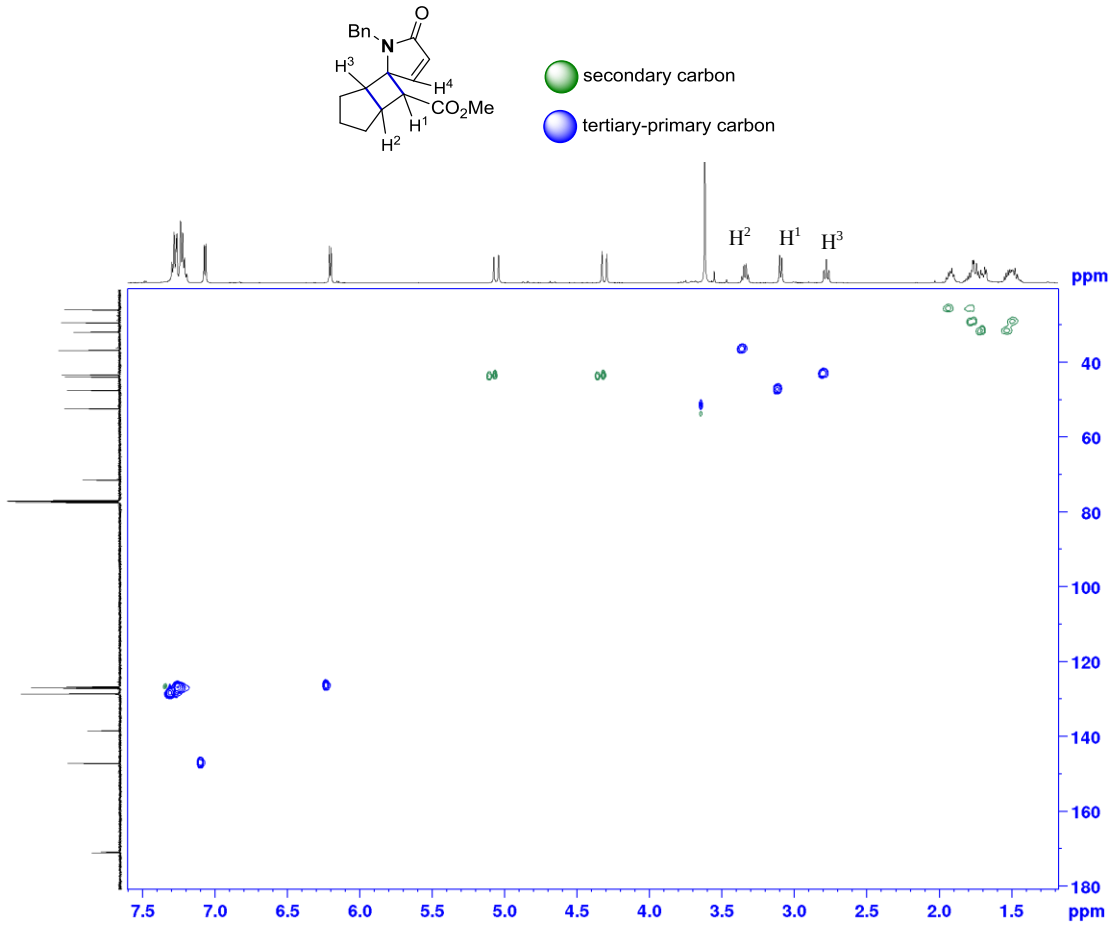
7c

(125 MHz, $CDCl_3$)

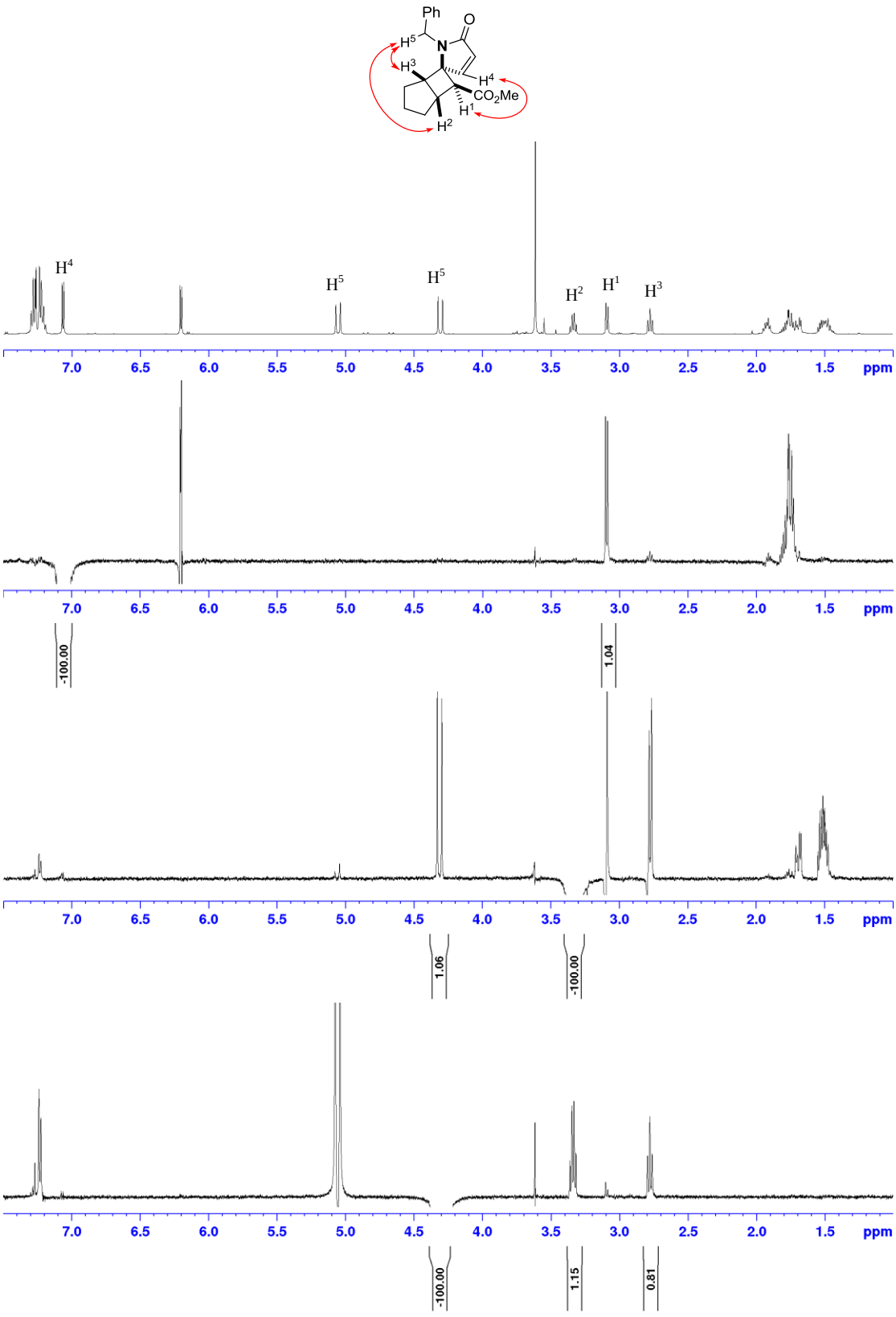
COSY correlations of compound 7c

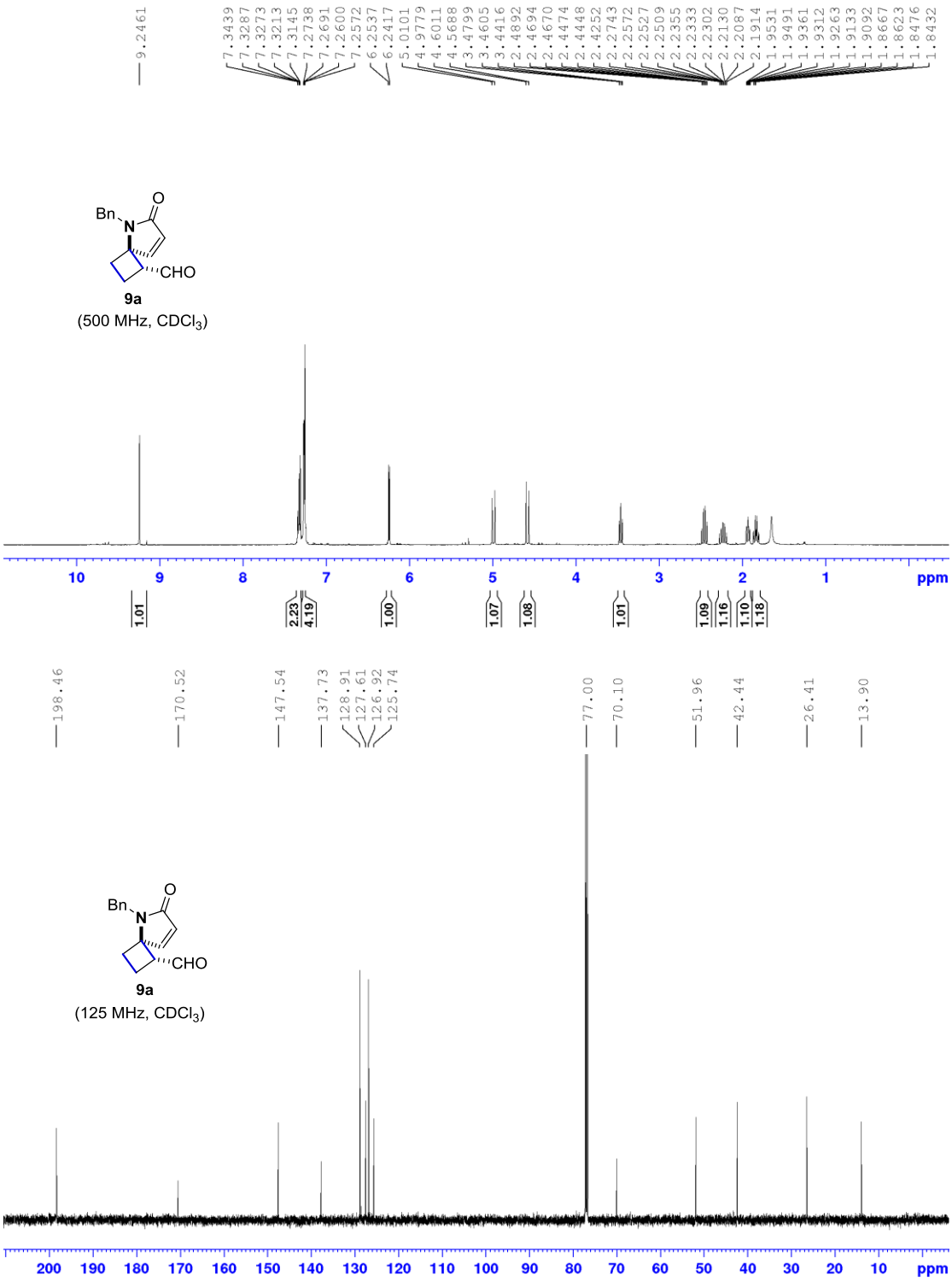


HSQC correlations of compound 7c

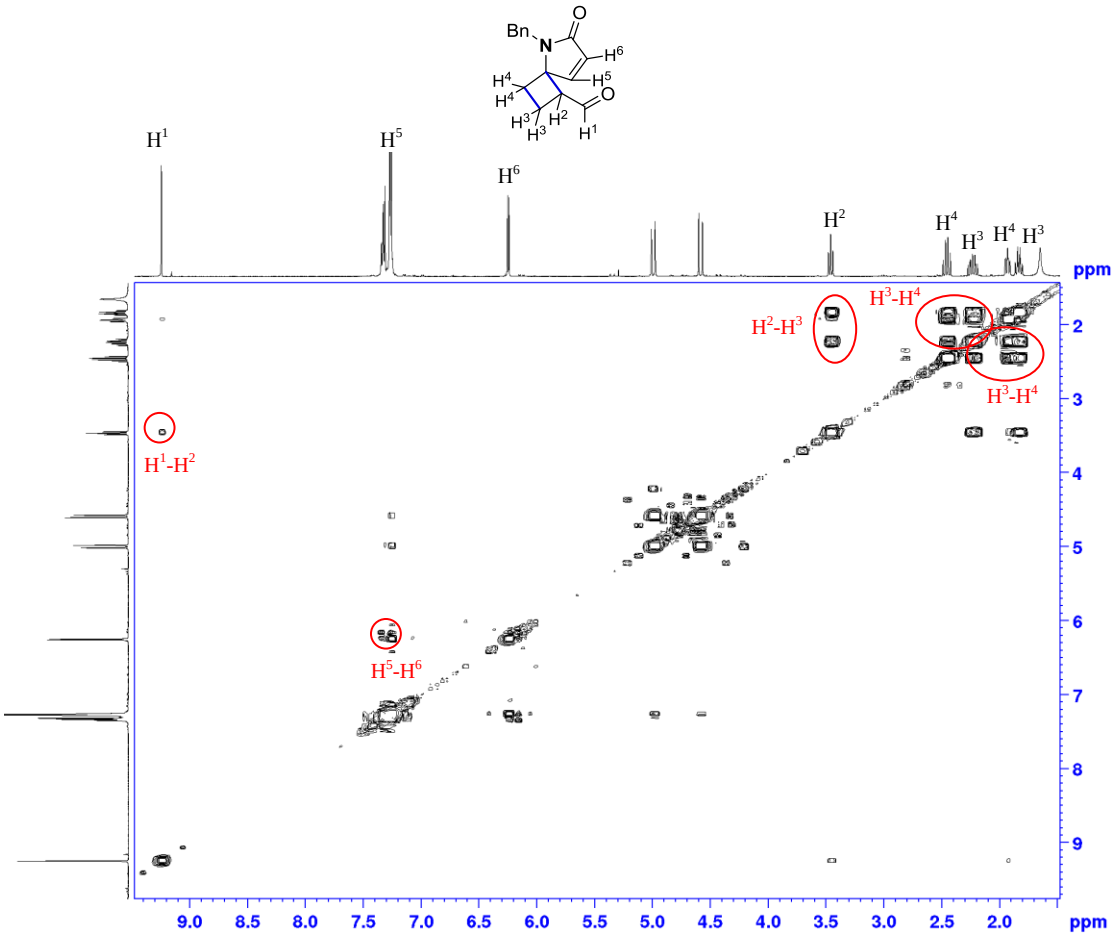


Representative NOE of compound 7c

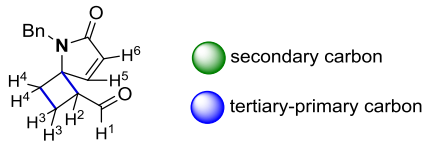


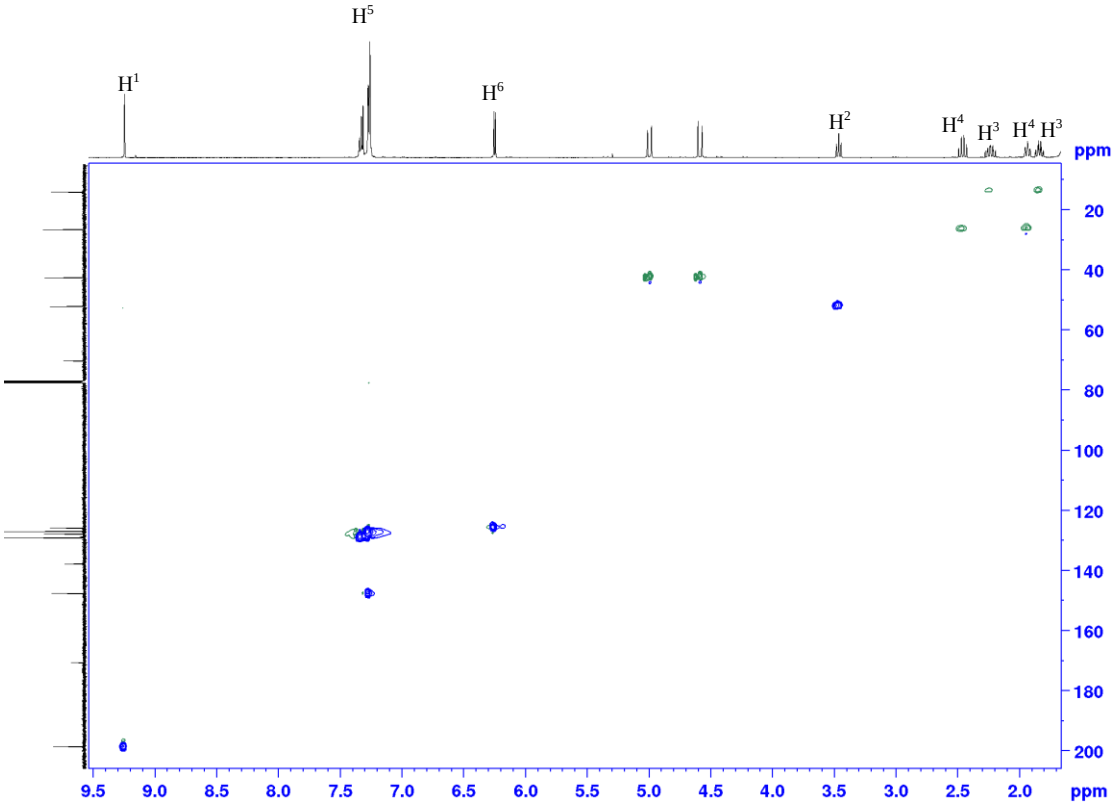


COSY correlations of compound 9a

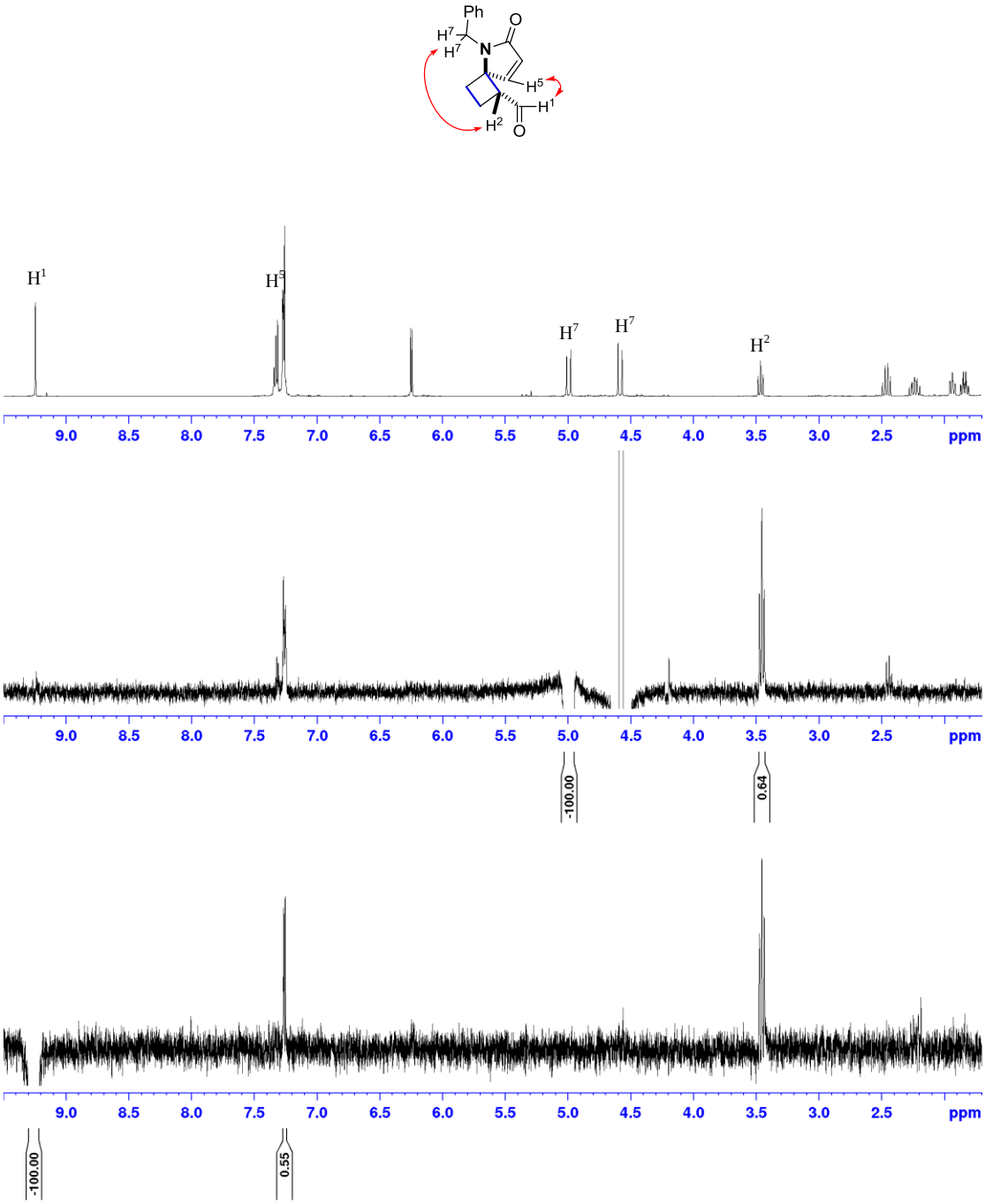


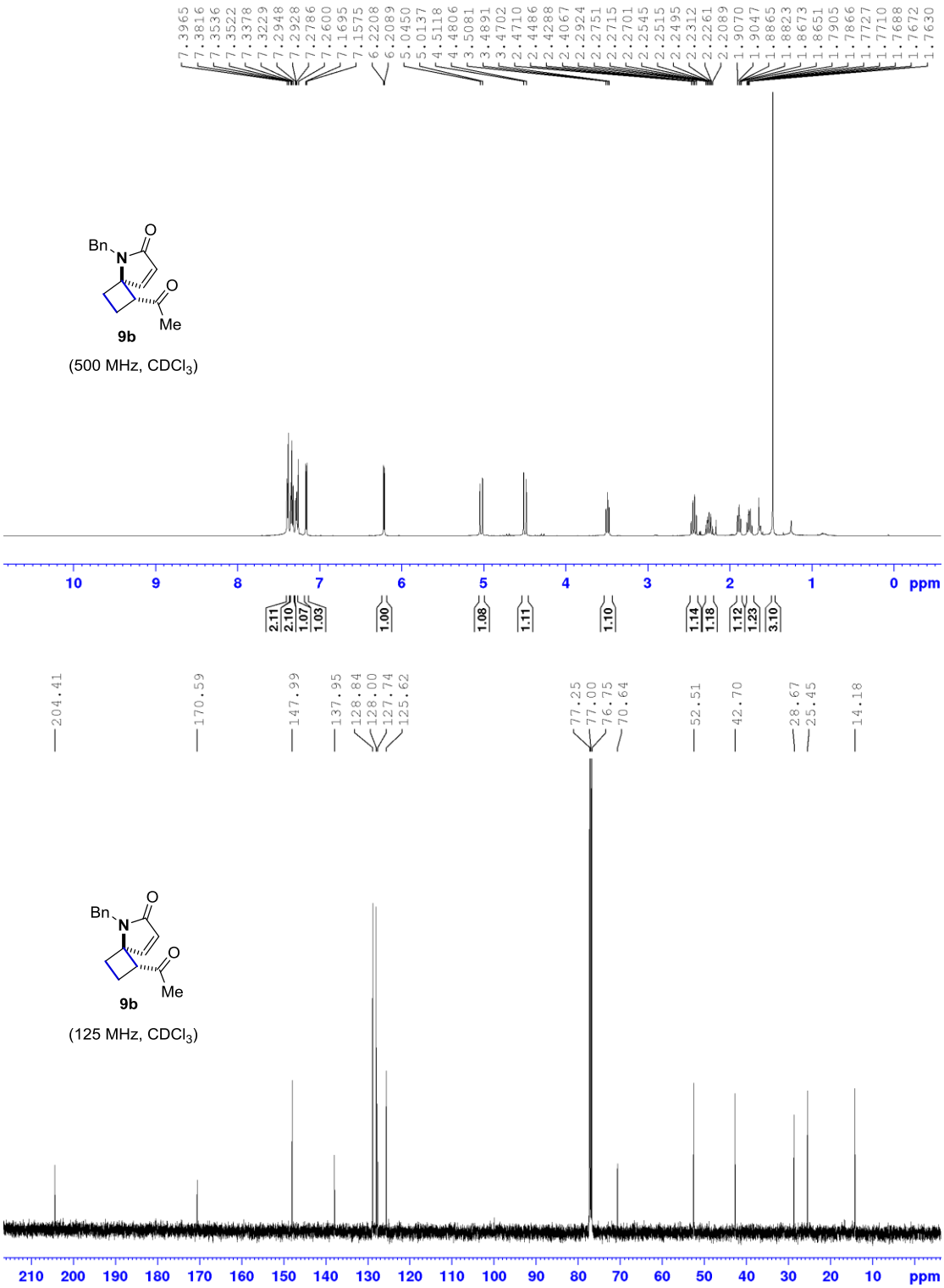
HSQC correlations of compound 9a



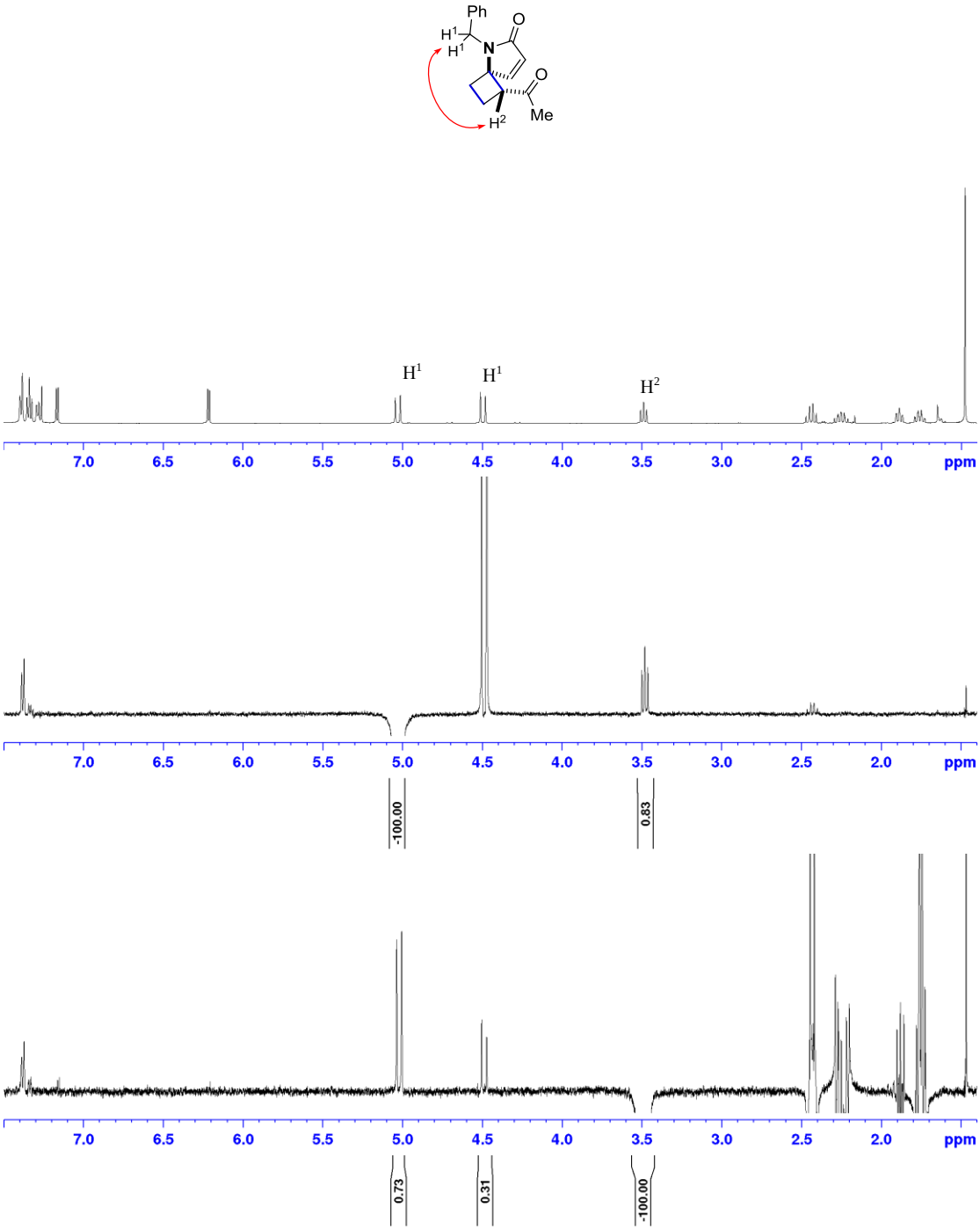


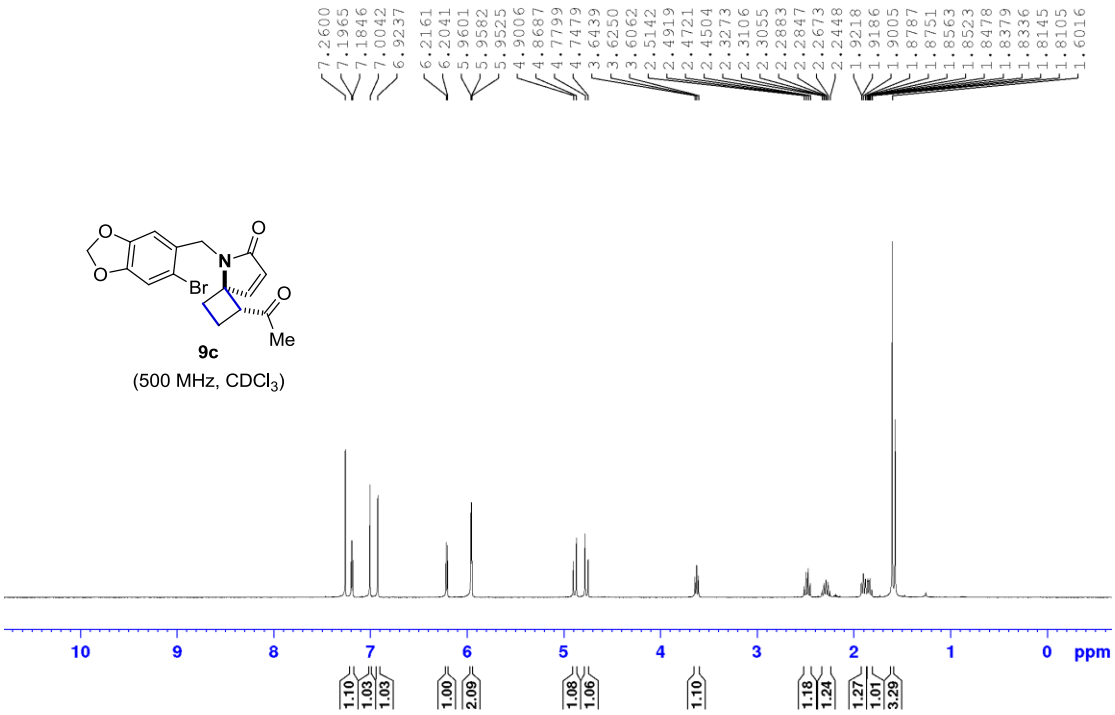
Representative NOE of compound 9a

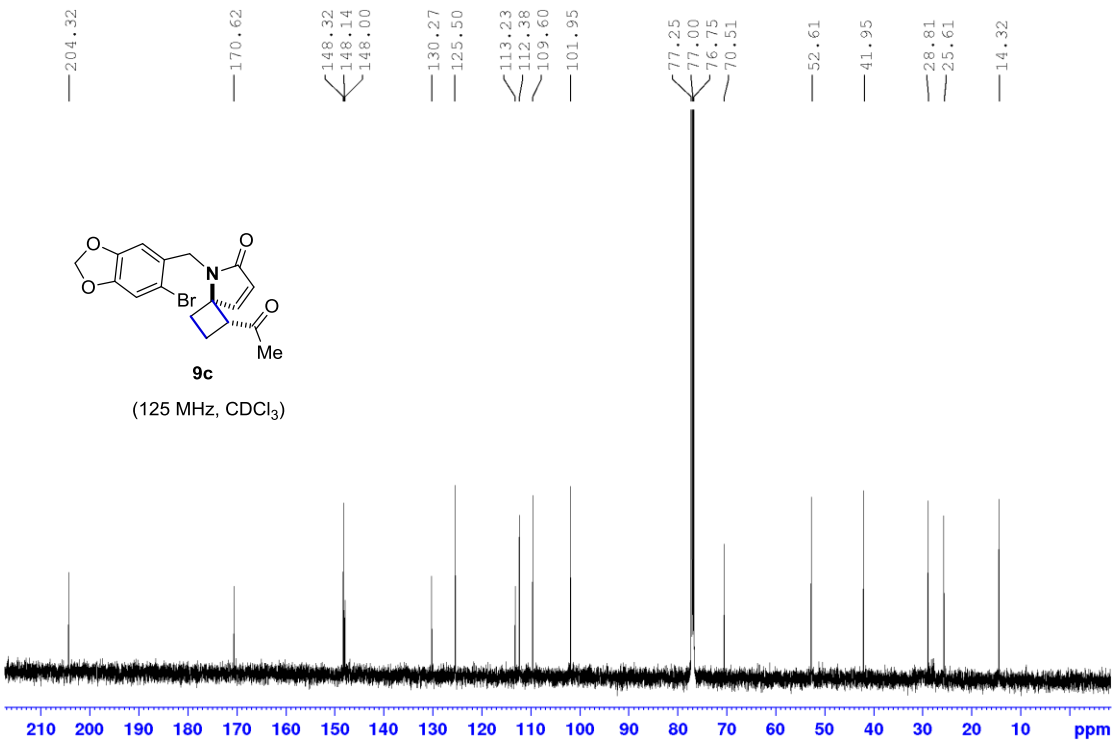


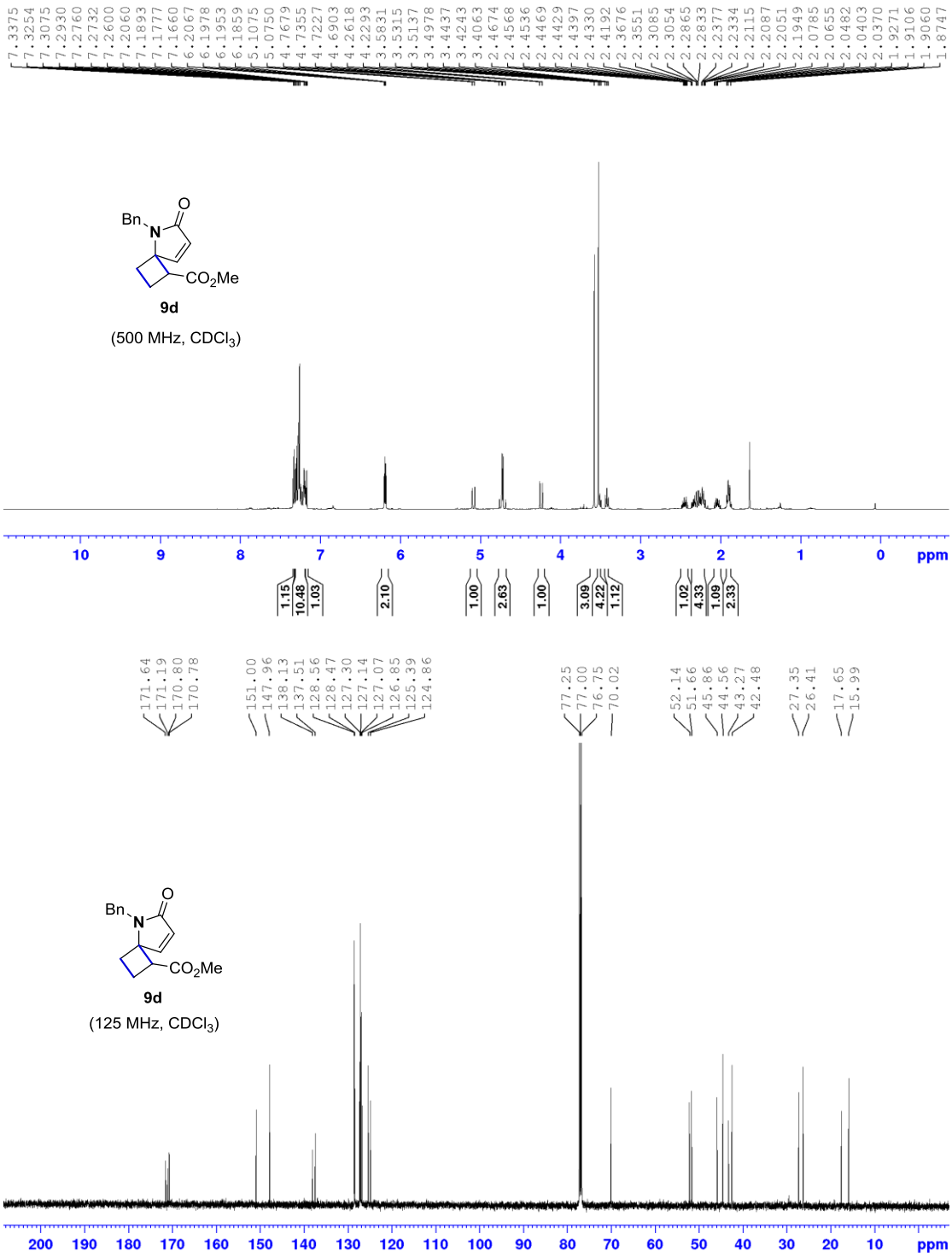


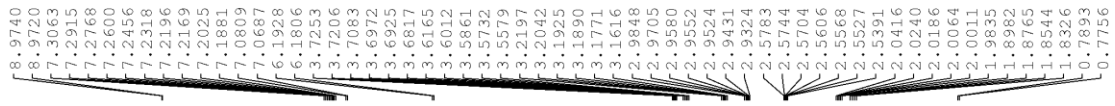
Representative NOE of compound 9b

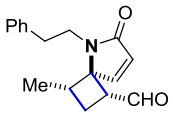






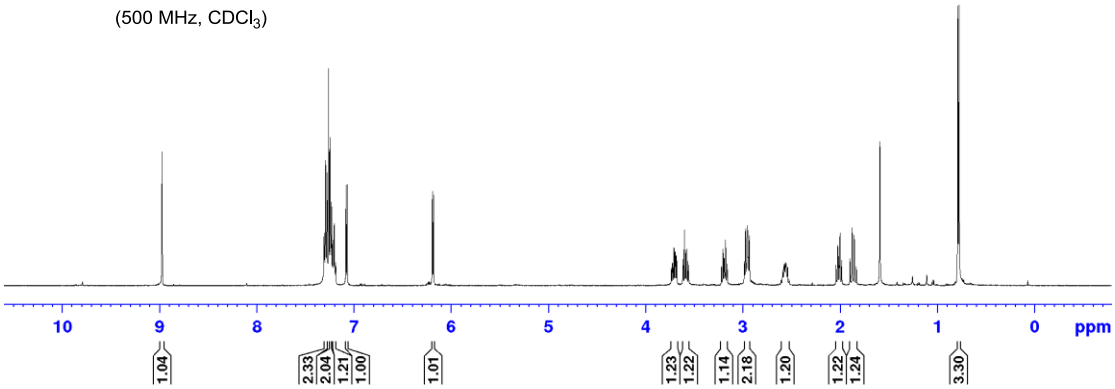


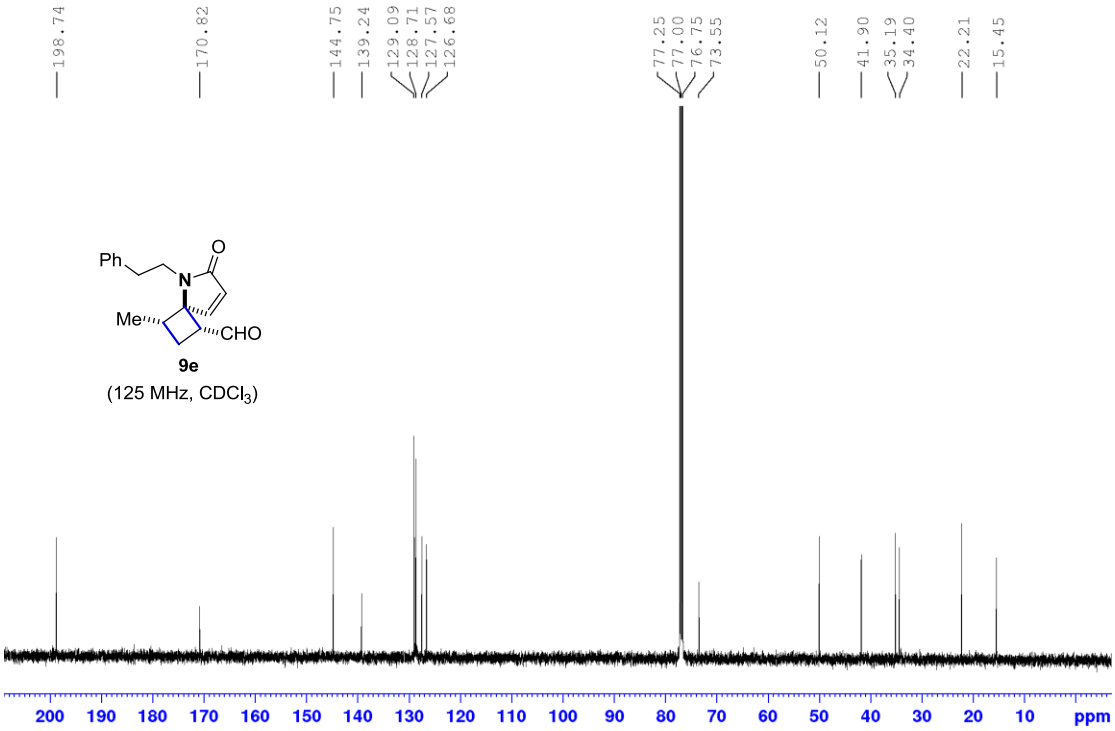




9e

(500 MHz, $CDCl_3$)

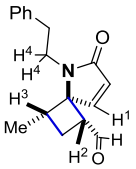




9e

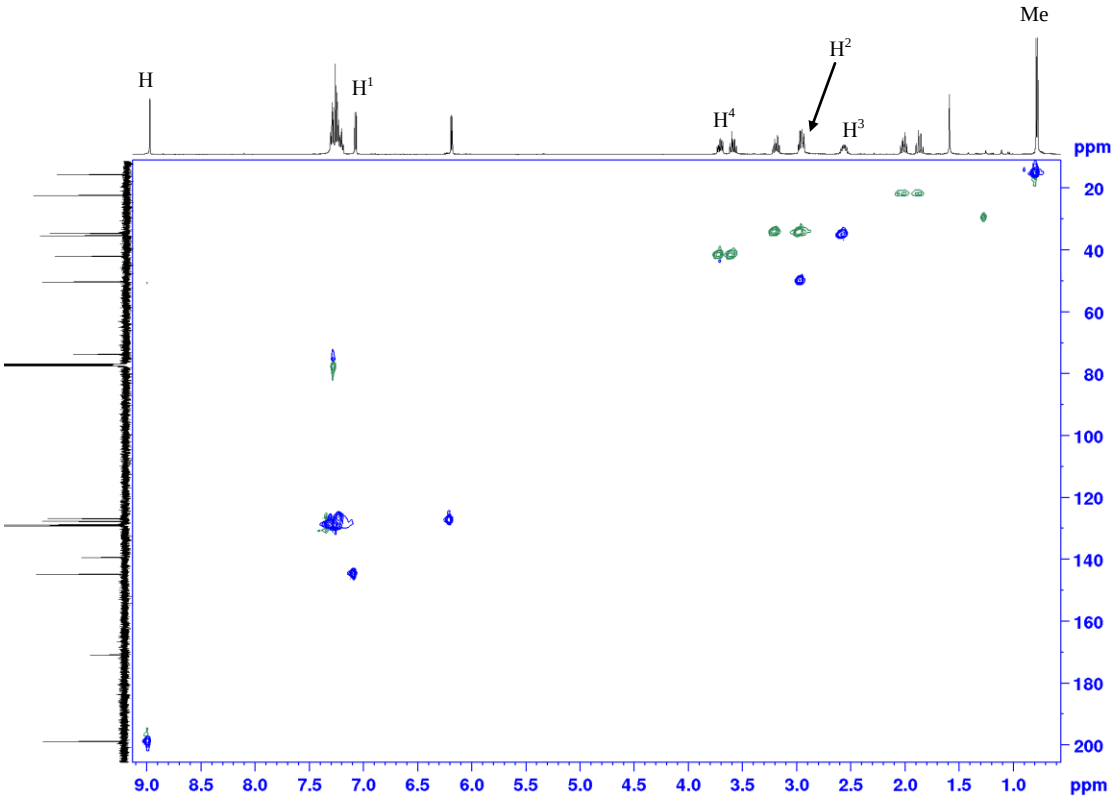
(125 MHz, $CDCl_3$)

HSQC correlations of compound 9e

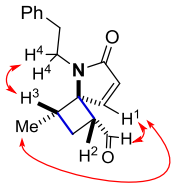


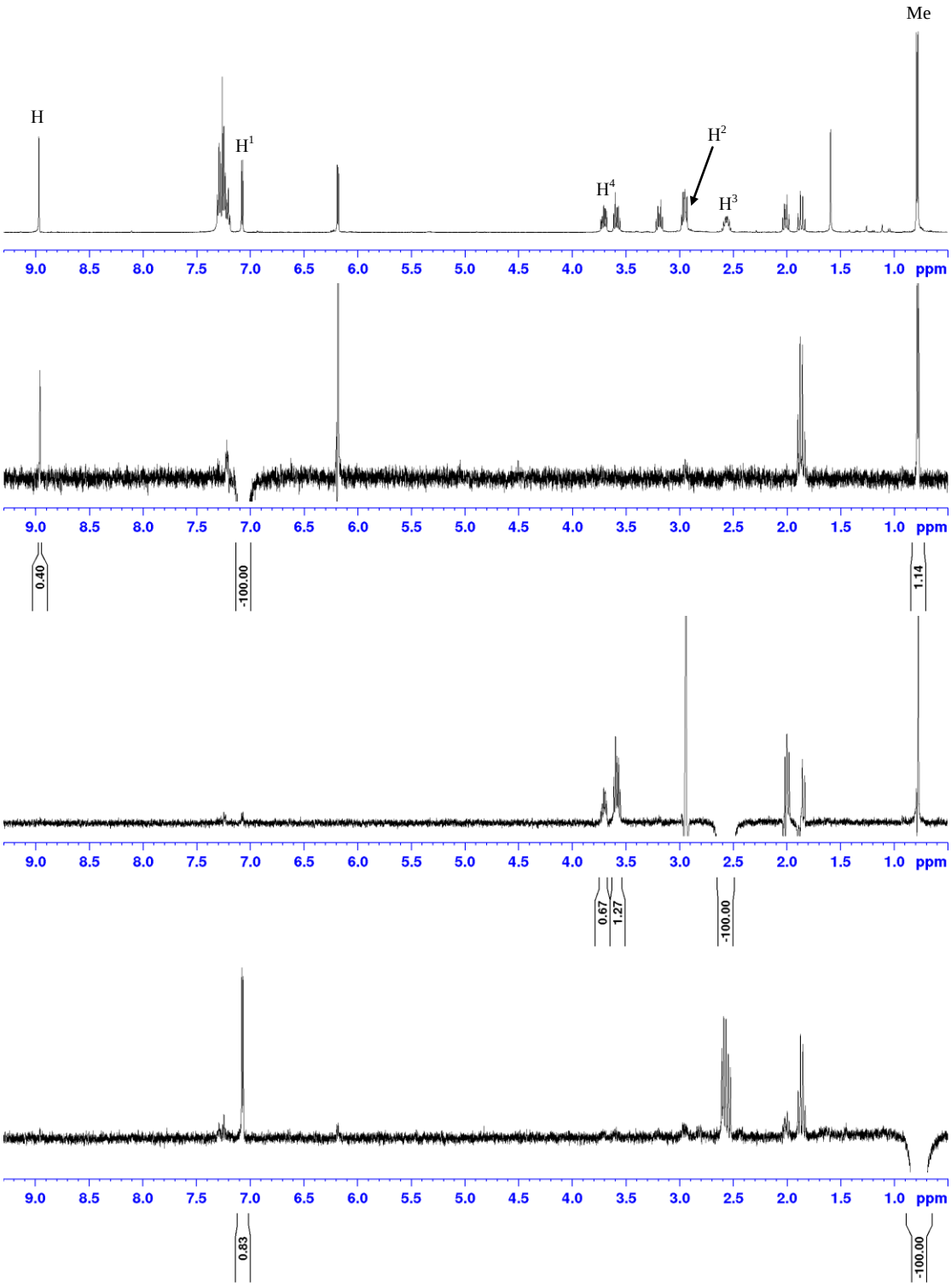
secondary carbon

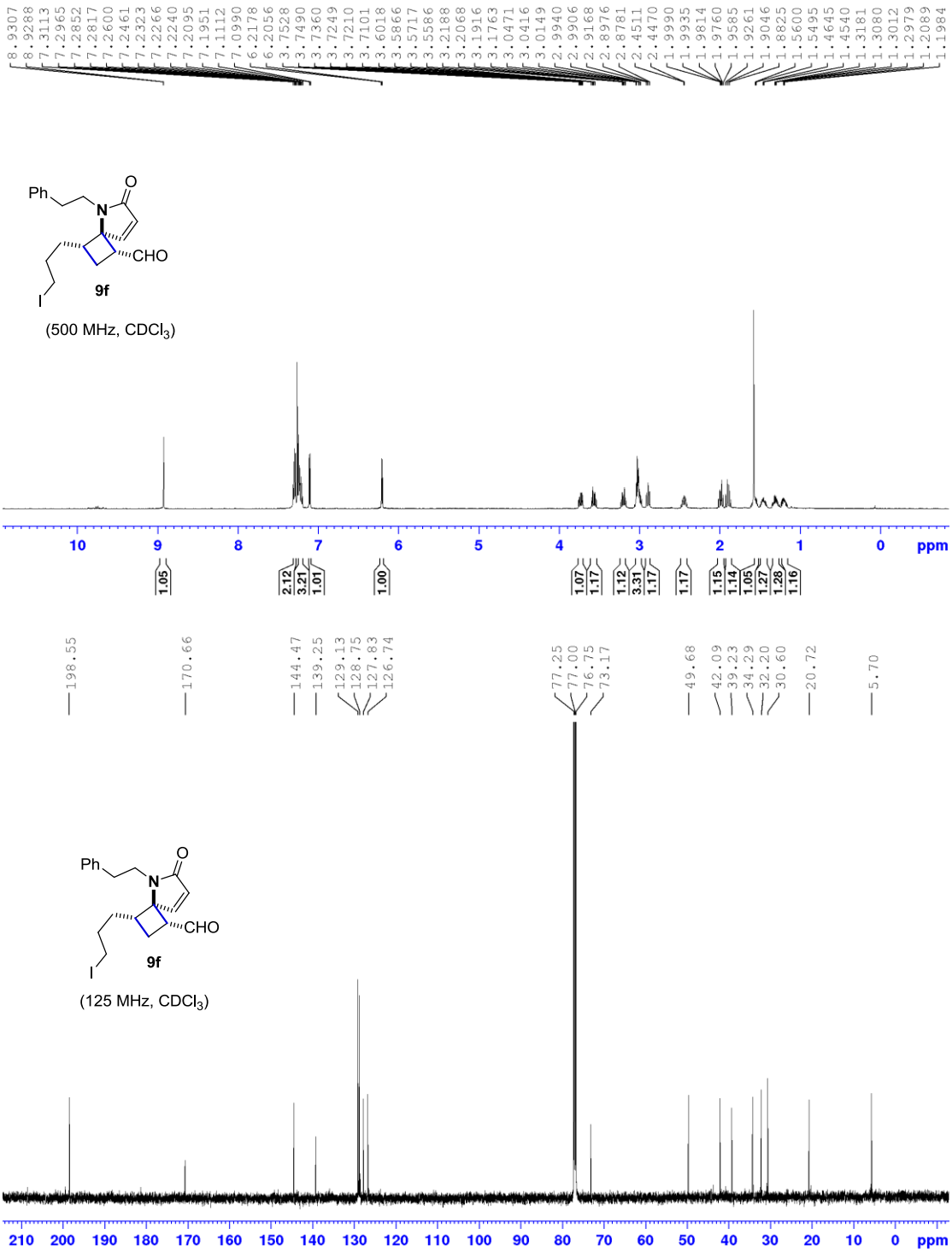
tertiary-primary carbon

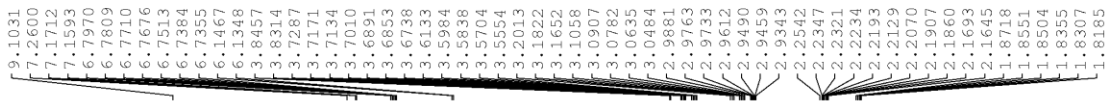


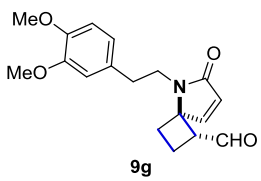
Representative NOE of compound 9e





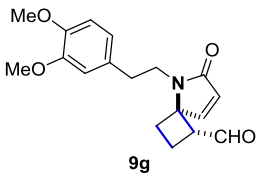






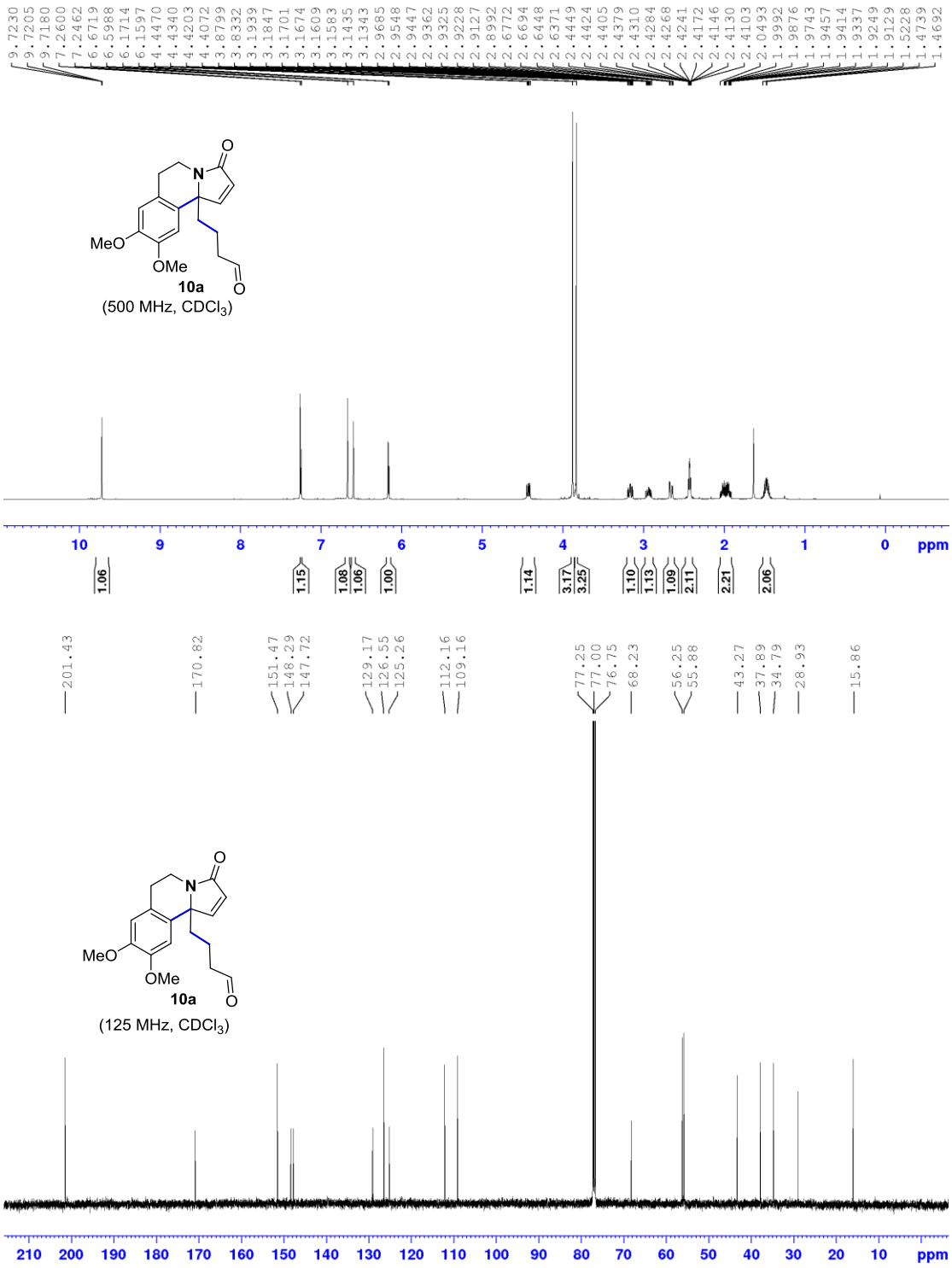
9g

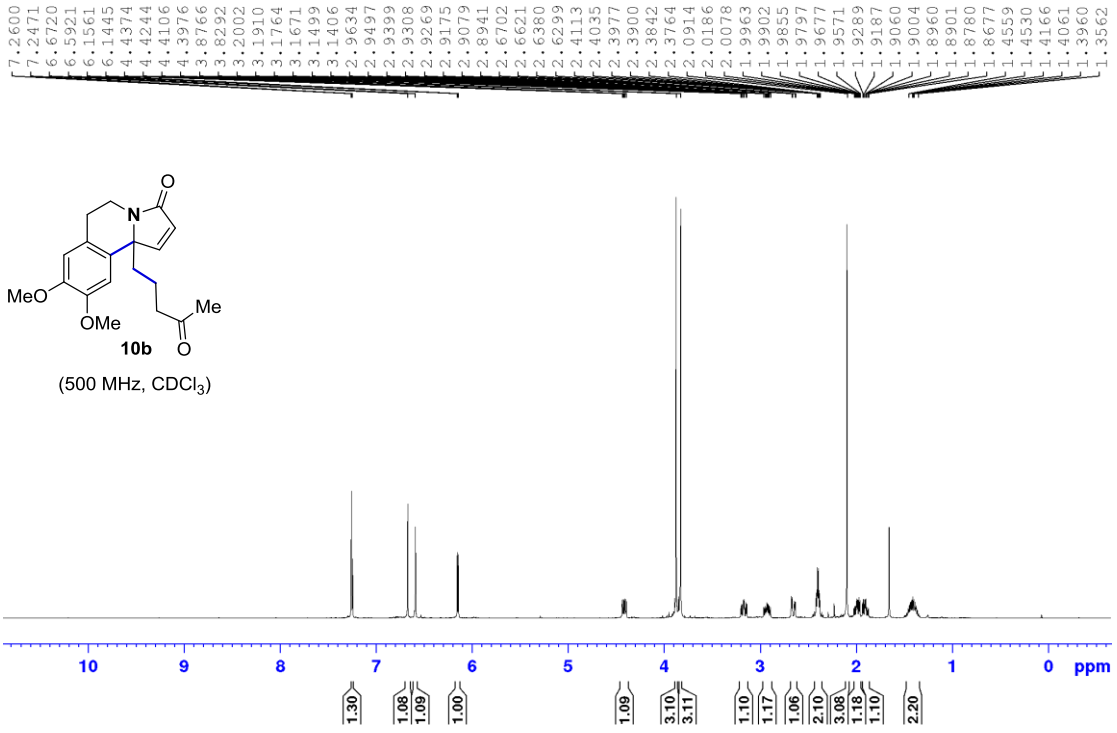
(500 MHz, $CDCl_3$)



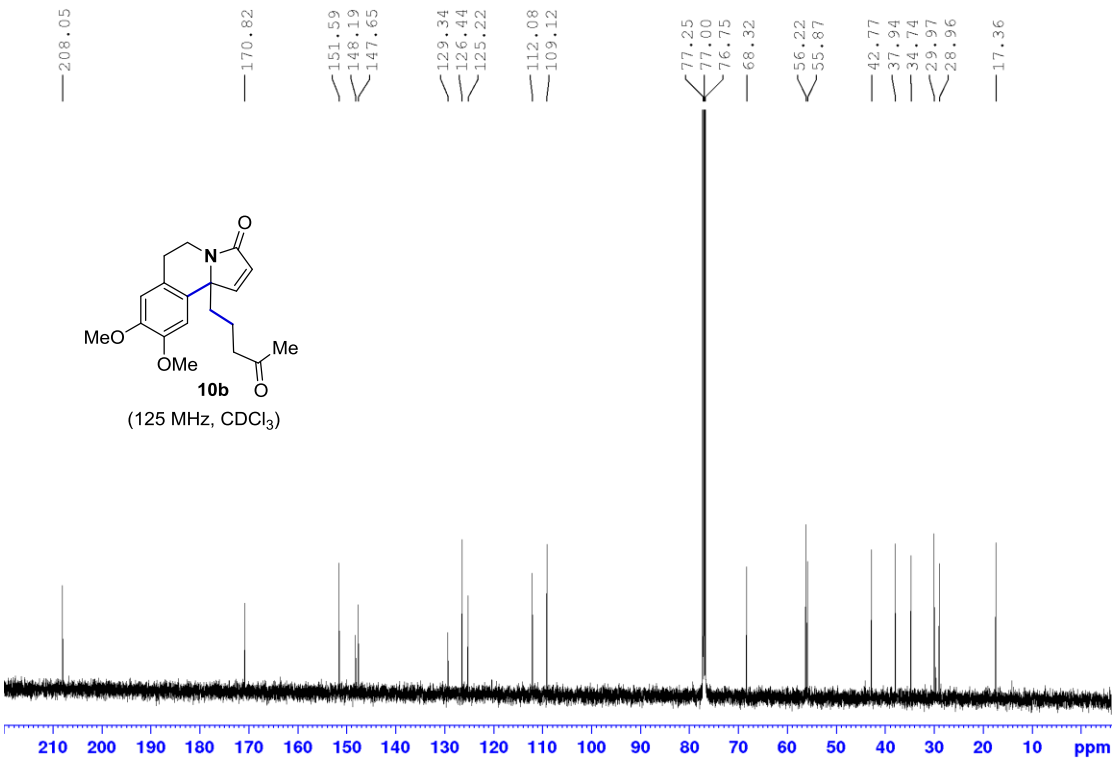
9g

(125 MHz, $CDCl_3$)

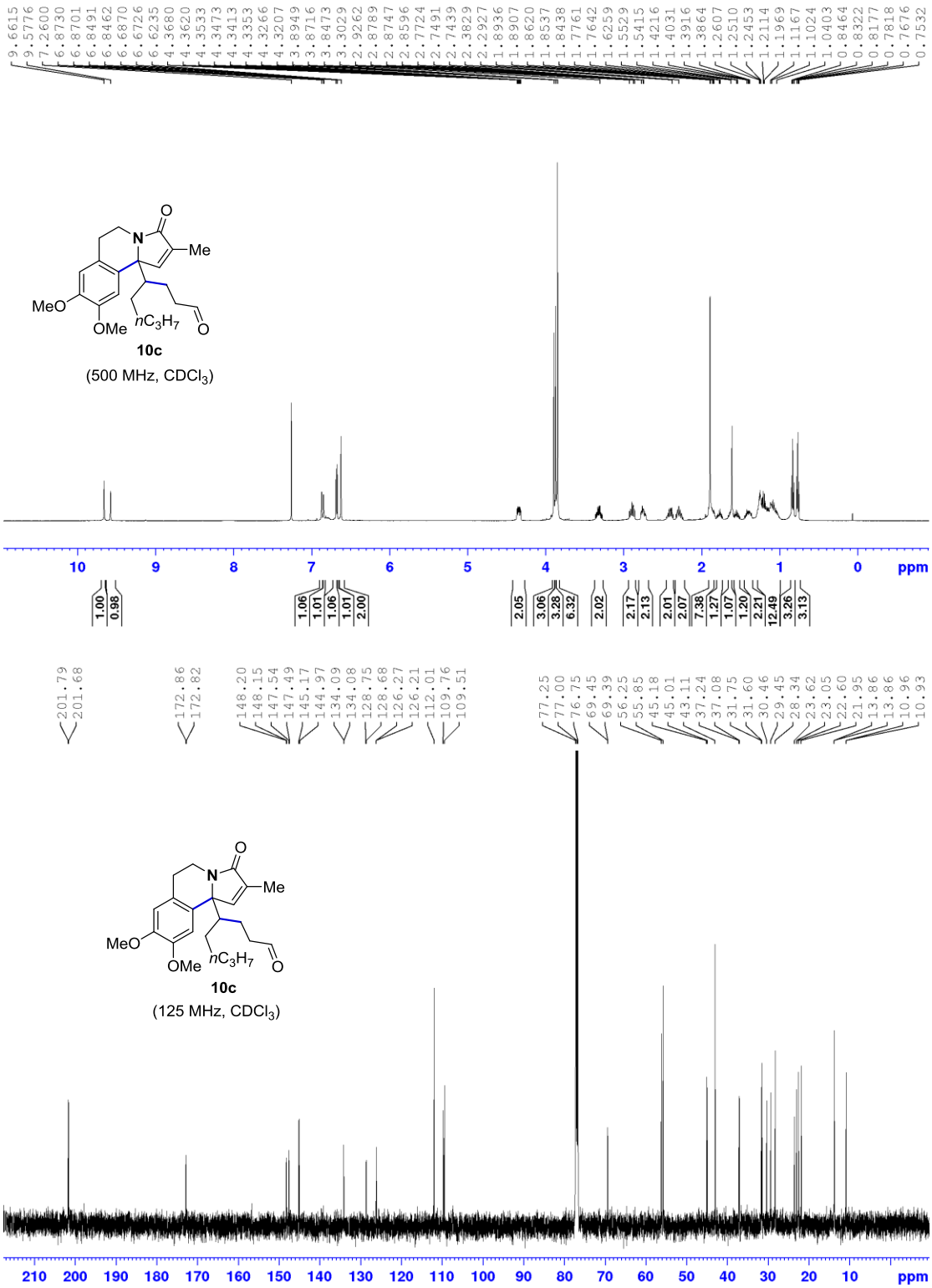


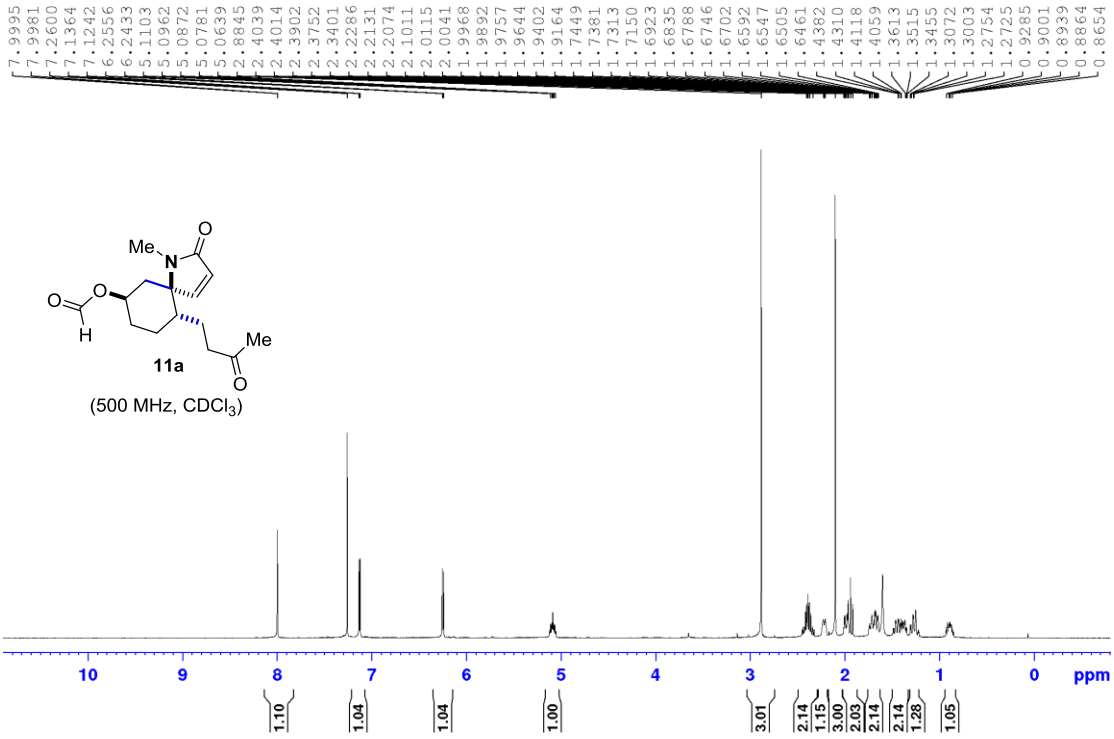


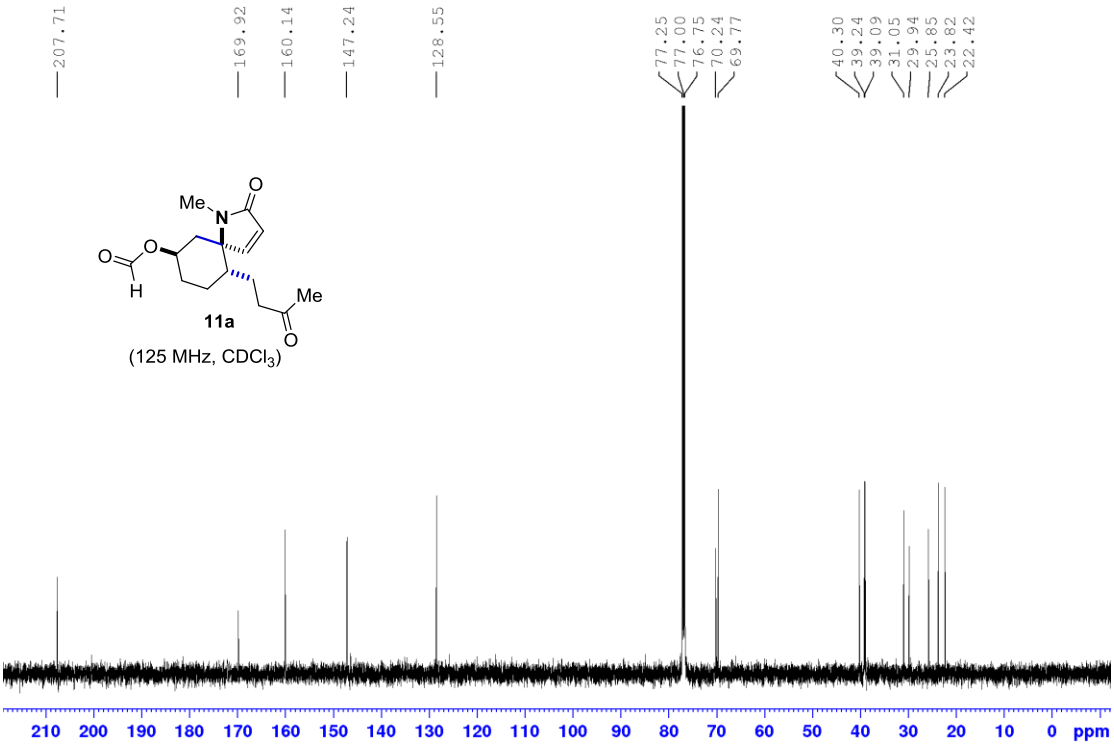
(500 MHz, $CDCl_3$)



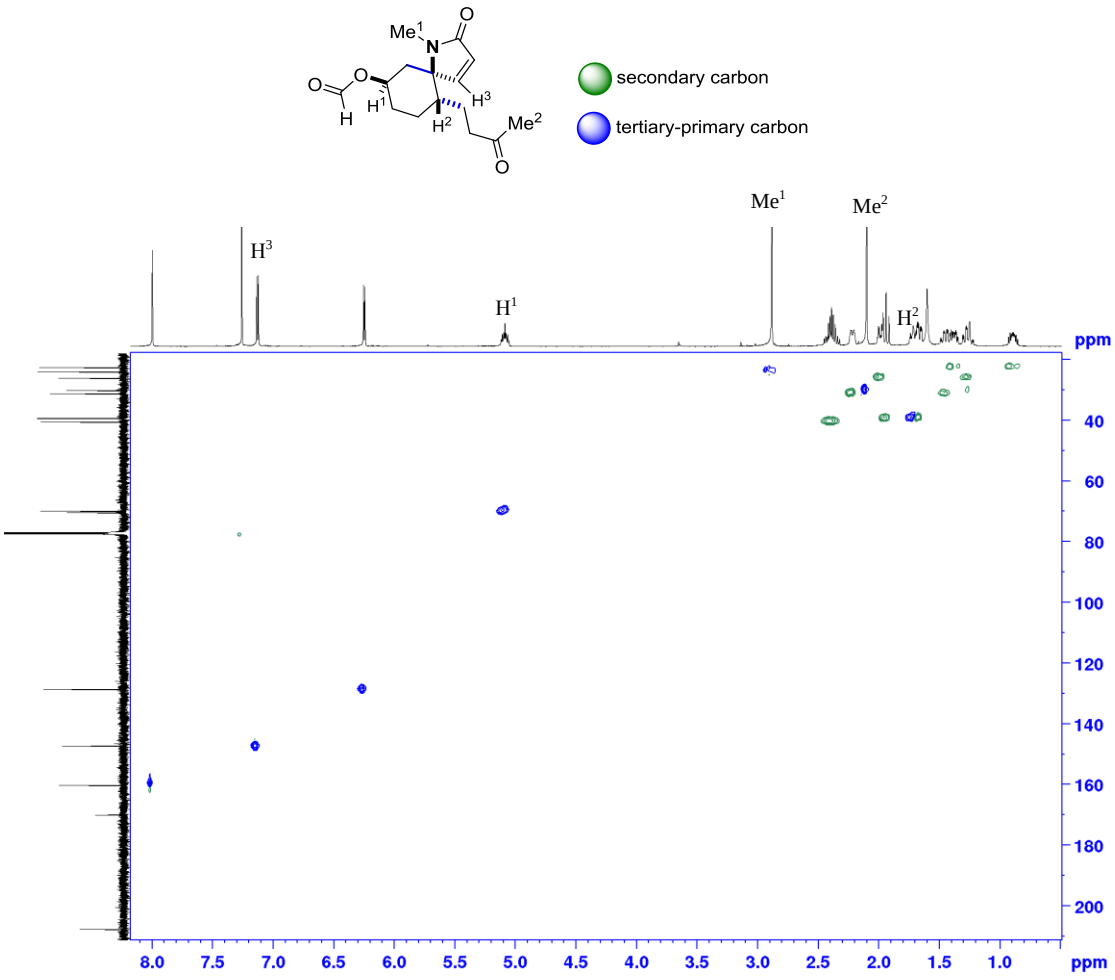
(125 MHz, $CDCl_3$)



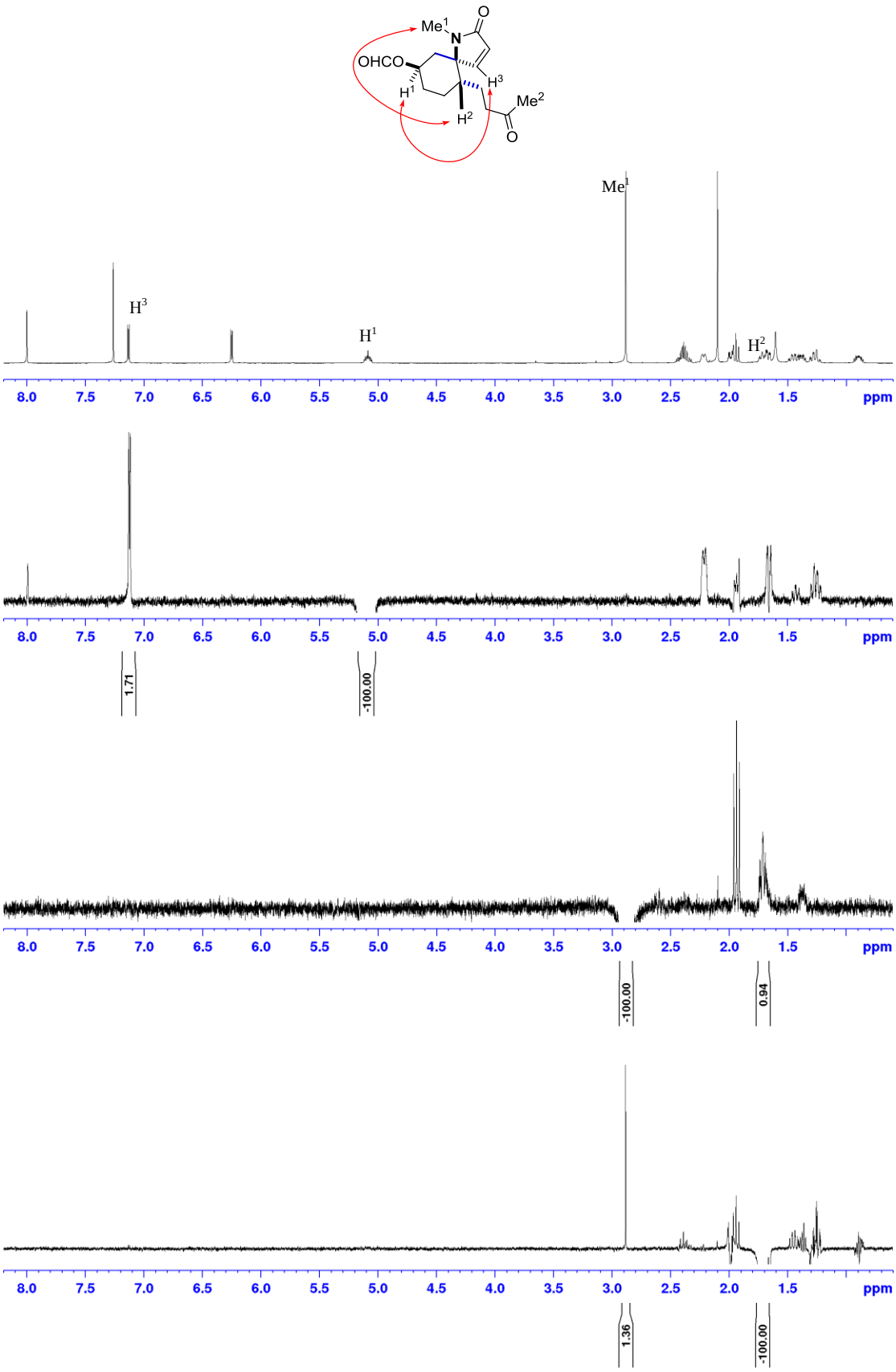


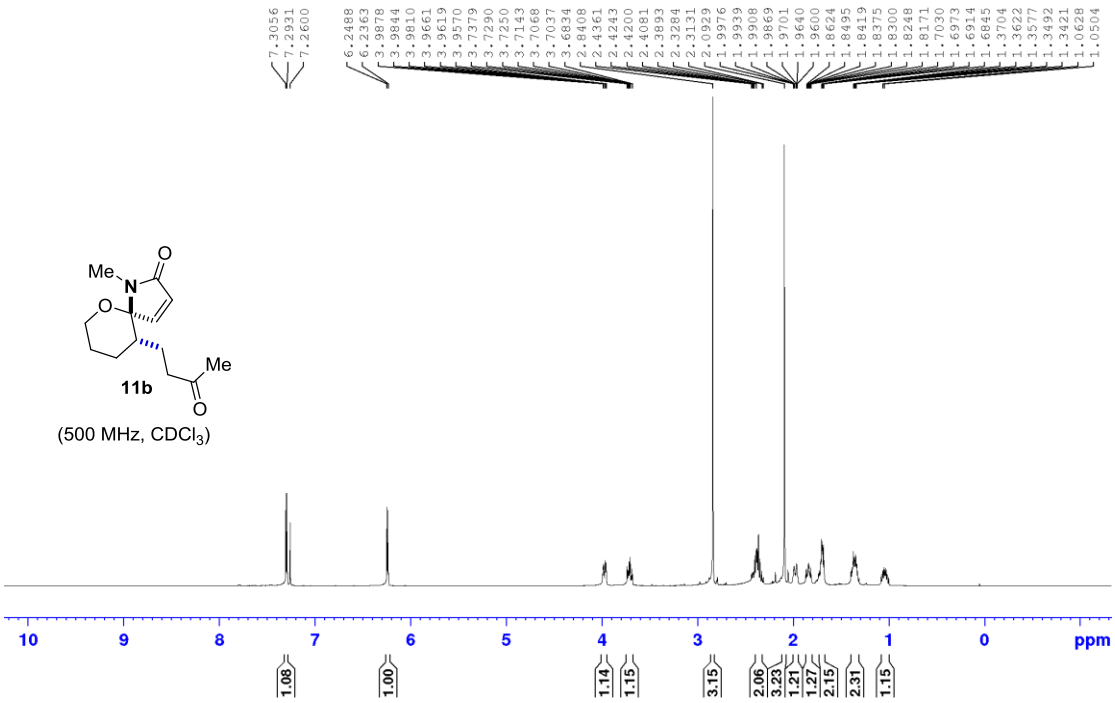


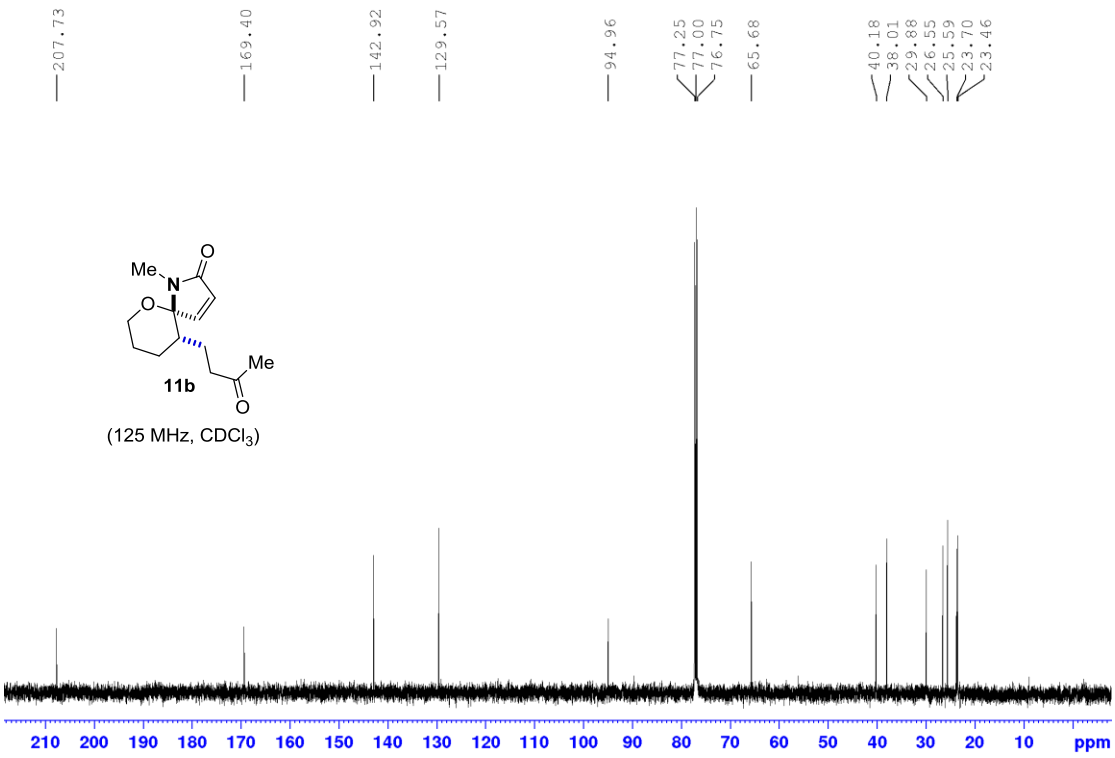
HSQC correlations of compound 11a



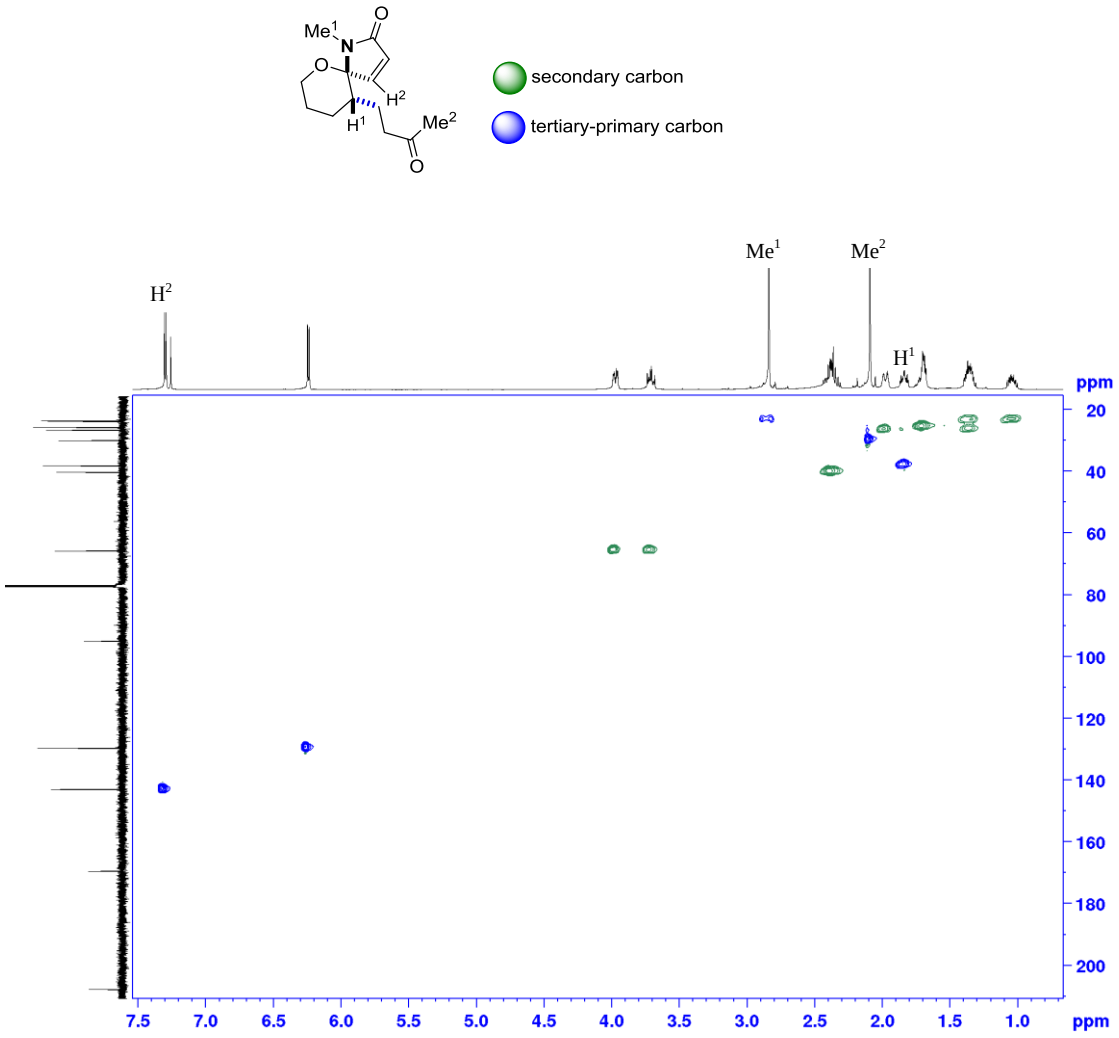
Representative NOE of compound 11a



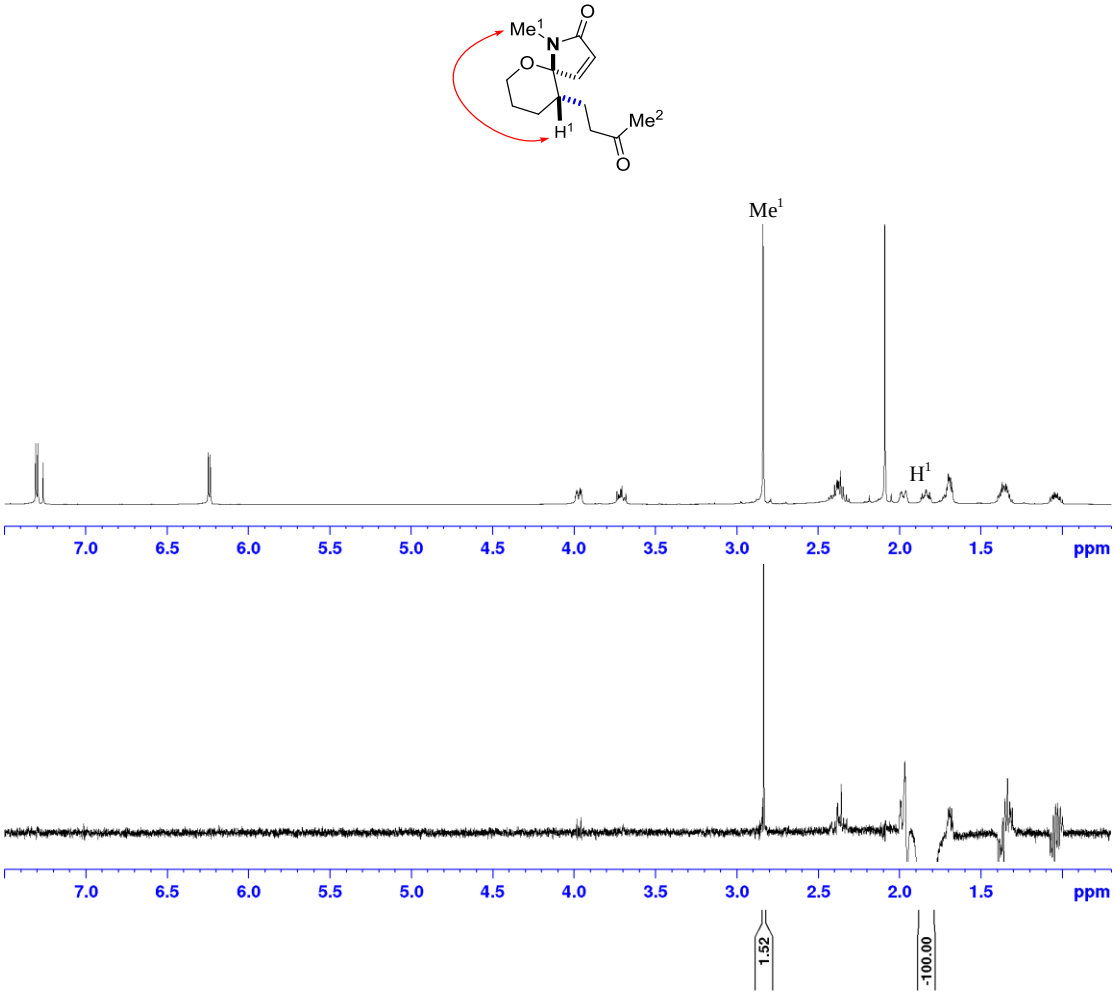


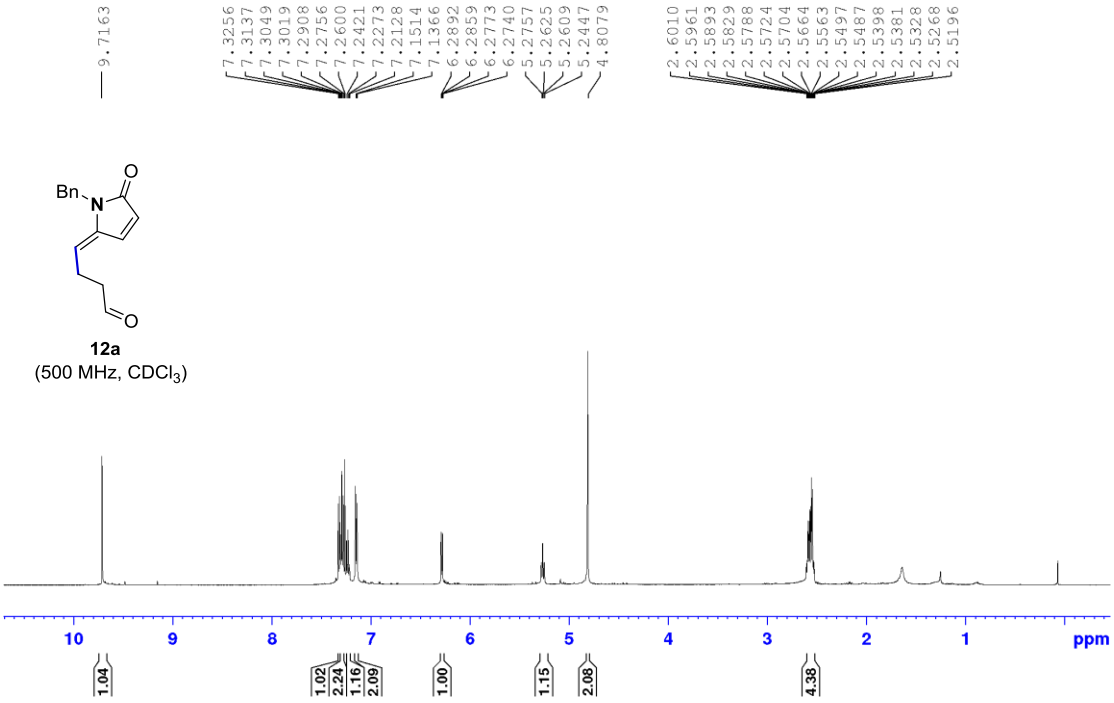


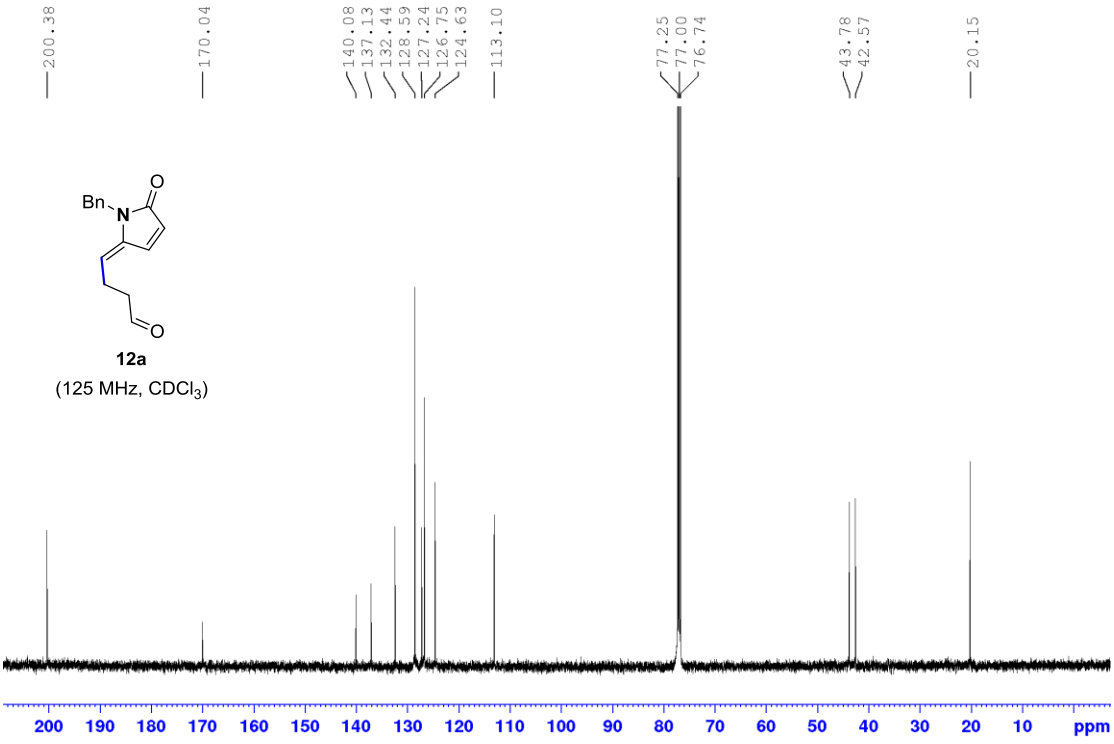
HSQC correlations of compound 11b



Representative NOE of compound 11a







Representative NOE of compound 12a