Electronic Supplementary Information

Construction of 1-Pyrroline Skeletons by Lewis Acid-Mediated Conjugate Addition of Vinyl Azides

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1. General

^{1}H NMR (400 MHz) spectra were recorded on a Bruker Avance 400 spectrometer in $CDCl_3$ [using $CDCl_3$ (for ^{1}H, $\delta = 7.26$) as the internal standard]. ^{13}C NMR (100 MHz) spectra on a Bruker Avance 400 spectrometer in $CDCl_3$ [using $CDCl_3$ (for ^{13}C, $\delta = 77.0$) as internal standard]. The following abbreviations were used to explain the multiplicities: s = singlet, d = doublet, t = triplet, q = quartet, dd = doublet of doublet, ddd = doublet of doublet of doublet, dddd = doublet of doublet of doublet of doublet, dt = doublet of triplet, sep = septet, m = multiplet, s br = singlet broadening. Melting points were uncorrected and were recorded on a Buchi B-54 melting point apparatus. IR spectra were recorded on a Shimazu IR Prestige-21 FT-IR Spectrometer. High-resolution mass spectra were obtained with a Q-Tof Premier LC HR mass spectrometer. X-ray crystallography analysis was performed on Bruker X8 APEX X-ray diffractionmeter. Flash column chromatography was performed using Merck silica gel 60 with distilled solvents. Anhydrous solvents were used in all cases. $TiCl_4$ (1.0 M in CH_2Cl_2) and $BF_3 \bullet OEt_2$ were purchased from Sigma-Aldrich Co., Inc.

2. The safety issues for handling of azido compounds[1,2]

2.1. Sodium azide (NaN_3): *Caution:* Sodium azide can be absorbed through skin and is toxic (LD_{50} oral = 27 mg/kg for rats). Wearing gloves are required when handling it. Sodium azide decomposes explosively upon heating to above 275 °C. It is relatively safe especially in aqueous solution, *unless acidified to form HN_3*, which is volatile and highly toxic.

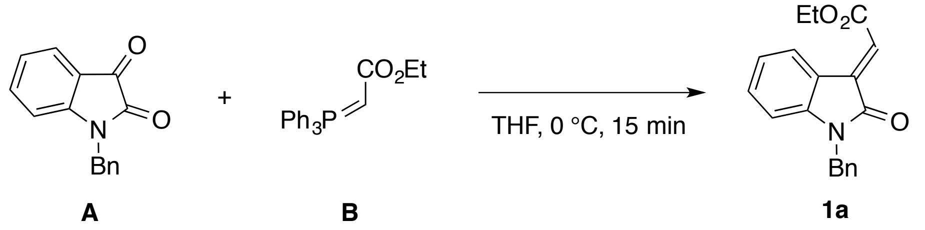
2.2. Organic azides: *Caution:* Organic azides are potentially explosive substances that can decompose with the slight input of energy from external sources (heat, light, pressure, etc). When designing the organic azides used for the project, please keep in mind the following equation.

$$\frac{N_C + N_O}{N_N} \geq 3 \quad \text{(N: number of the atom)}$$

It should be noted that this equation takes into account all nitrogen atoms in the organic azide molecule, not just those in the azido group. All organic azides prepared in this work are enough stable to be stored under –20 ºC at least for half a year. We have never experienced a safety problem with these compounds.

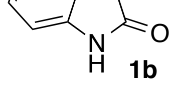
3. Synthesis of 3-alkylidene-2-oxindoles 1

Typical procedure for synthesis of 1a:

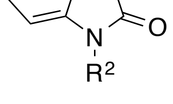


To a slution of isatin **A** (5.0 mmol, 1.19 g) in THF (5.0 mL) was added methyl 2-(triphenyl-λ^5-phosphanylidene)acetate (**B**) (5.00 mmol, 1.67 g) slowly at 0 °C. The reaction mixture was stirred for 15 min at the same temperature before evaporation to remove the solvent. The crude material obtained was filtered through celite with ether as eluent. The filtrate was concentrated and purified by flash column chromatography (silica gel; ethyl acetate: hexane = 20: 80) to give ethyl (*E*)-2-(1-benzyl-2-oxoindolin-3-ylidene)acetate[3] (**1a**) (1.39 g, 4.75 mmol, 95% yield) as a yellow solid. ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.37 (3H, t, *J* = 7.2 Hz), 4.33 (2H, q, *J* = 7.2 Hz), 4.92 (2H, s), 6.68 (1H, d, *J* = 8.0 Hz), 6.97 (1H, s), 6.99-7.04 (1H, m), 7.22-7.32 (6H, m), 8.56 (1H, d, *J* = 7.2 Hz); ^{13}C NMR (100 MHz, $CDCl_3$) δ 167.6, 165.6, 145.0, 137.6, 135.4, 132.3, 128.8, 127.7, 127.2, 122.8, 122.7, 119.9, 109.1, 61.2, 43.8, 14.1.

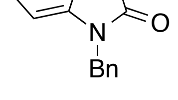
3-Alkylidene-2-oxindoles **1b**,[4] **1c**,[5] **1f**,[6] **1g**,[6] and **1h**[8] were known compounds and prepared as *E*-isomers by following the above procedure from the corresponding isatins and the Wittig reagents. 3-Alkylidene-2-oxindole **1e**[6] was prepared according to the reported literature.



1b



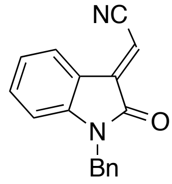
1c: R^1 = Bz, R^2 = Bn
1e: R^1 = H, R^2 = H



1f: R^3 = 5-OMe
1g: R^3 = 5-Cl
1h: R^3 = 7-CF_3

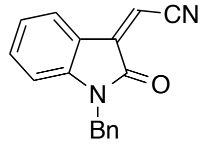
2-(1-Benzyl-2-oxoindolin-3-ylidene)acetonitrile (**1d**) was obtained as a mixture of the *E*- and *Z*-isomers by following the typical procedure using 2-(triphenyl-λ^5-phosphanylidene)acetonitrile.

(*E*)-2-(1-Benzyl-2-oxoindolin-3-ylidene)acetonitrile (*E*-1d):



75% yield as a wine red solid, mp 158-160 °C; IR (NaCl) 3028, 2976, 2866, 2212, 1713, 1606, 1467, 1383, 1352, 1188, 1126, 1078 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$) δ 4.91 (2H, s), 6.38 (1H, s), 6.73 (1H, d, *J* = 7.6 Hz), 7.08 (1H, dd, *J* = 7.6, 7.6 Hz), 7.25-7.35 (6H, m), 8.07 (1H, d, *J* = 7.6 Hz); ^{13}C NMR (100 MHz, $CDCl_3$) δ 165.4, 144.8, 143.3, 134.9, 133.6, 128.9, 128.0, 127.3, 125.0, 123.3, 119.3, 116.1, 109.8, 97.7, 43.9. ESIHRMS: Found: *m/z* 261.1025. Calcld for $C_{17}H_{13}N_2O$: $(M+H)^+$ 261.1028.

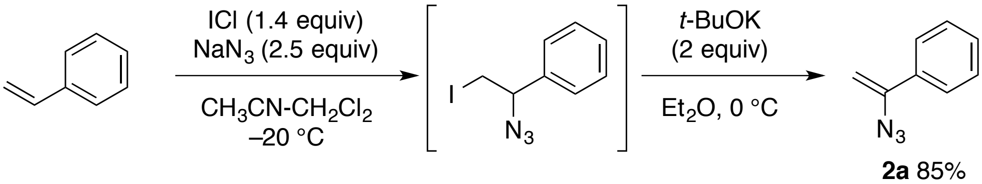
(*Z*)-2-(1-Benzyl-2-oxoindolin-3-ylidene)acetonitrile (*Z*-1d):



8% yield as an orange solid, mp 159-161 °C; IR (NaCl) 3415, 2976, 2933, 2864, 2218, 1711, 1612, 1470, 1383, 1350, 1288, 1122, 1078 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$) δ 4.93 (2H, s), 6.15 (1H, s), 6.73 (1H, d, *J* = 7.6 Hz), 7.02 (1H, dd, *J* = 7.6, 7.6 Hz), 7.28-7.34 (6H, m), 7.46 (1H, d, *J* = 7.2 Hz); ^{13}C NMR (100 MHz, $CDCl_3$) δ 163.7, 143.9, 143.6, 135.0, 133.7, 128.9, 127.9, 127.5, 122.8, 122.1, 120.1, 114.9, 109.9, 97.2, 43.8. ESIHRMS: Found: *m/z* 265.1026. Calcld for $C_{17}H_{13}N_2O$: $(M+H)^+$ 261.1028.

4. Synthesis of vinyl azides 2

Typical procedure for synthesis of 2a:

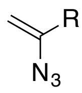


This procedure was slightly modified from the Hassner's method.[7]

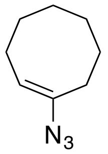
To a stirred suspension of NaN_3 (7.15 g, 110 mmol) in acetonitrile (30 mL) was added dropwise a solution of iodine monochloride (8.07 g, 49.7 mmol in 60 mL CH_2Cl_2) at −20 °C, and the mixture was stirred at the same temperature for 30 min. A solution of styrene (5.0 mL, 43.6 mmol) in CH_2Cl_2 (20 mL) was added slowly, and the mixture was kept stirring for 1 h. The reaction was quenched with saturated aqueous $Na_2S_2O_3$, and the reaction mixture was extracted twice with Et_2O. The combined extracts were washed with brine and dried over $MgSO_4$. After filtration and evaporation of solvents, the resulting crude materials were used immediately for the next step without any further purification.

The crude materials obtained above were dissolved in Et_2O (100 mL) and *t*-BuOK (5.92 g, 52.3 mmol) was added portion wise at 0 °C. The mixture was then stirred for 30 mins at the same temperature before quenching by adding pH 9 aqueous ammonium buffer, and the organic materials were extracted with Et_2O. The Et_2O solution was washed with brine and dried over $MgSO_4$. After filtration, the solvent was removed in *vacuo*, and the resulting crude materials were purified by flash column chromatography (silica gel; 100% hexane) to give vinyl azide **2a** (5.38 g, 37.1 mmol, 85% yield from styrene) as a pale yellow liquid. ^{1}H NMR (400 MHz, $CDCl_3$) δ 4.98 (1H, d, J = 2.4 Hz), 5.45 (1H, d, J = 2.4 Hz), 7.37-7.40 (3H, m), 7.57-7.59 (2H, m); ^{13}C NMR (100 MHz, $CDCl_3$) δ 145.1, 134.3, 129.1, 128.5, 125.6, 98.0.

Vinyl azides **2b**,[8] **2c**,[4] and **2d-2h**[9] were known compounds and prepared according to the reported procedures.



2b: R = 2-naphthyl
2c: R = 4-OMeC_6H_4
2d: R = 4-ClC_6H_4
2e: R = 3-BrC_6H_4
2f : R = 3-$NO_2C_6H_4$
2g: R = CH_2CH_2Ph

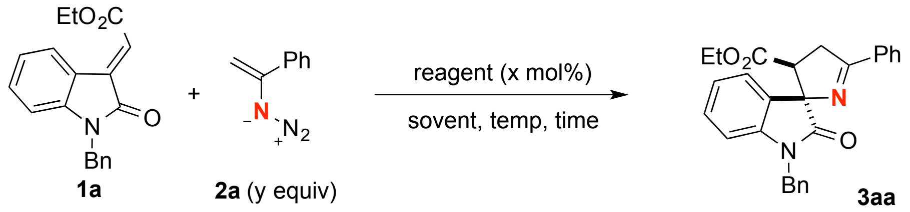


2h

5. BF₃•OEt₂-mediated/TiCl₄-catalyzed reactions of vinyl aizdes 2 with 3-alkylidene-2-oxindoles 1 (Schemes 2 and 3)

5.1 Optimization of the reaction conditions

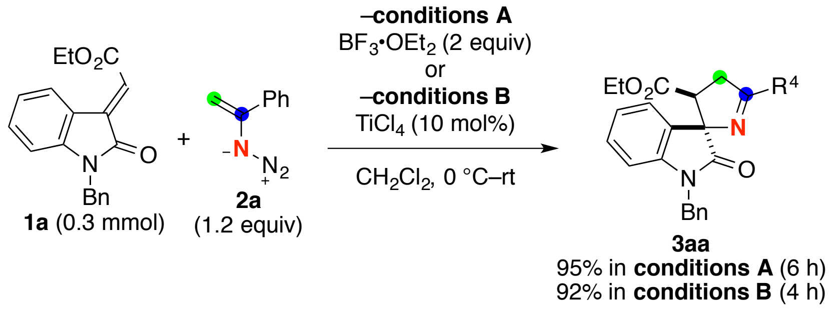
Table S1[a]

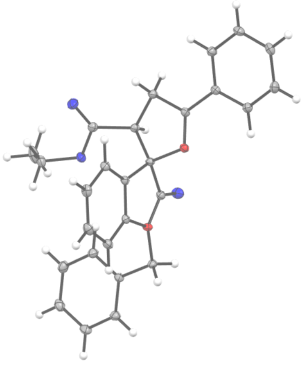


entry	reagent (x)	y	solvent	temp.	time	yield[b]
1	Tf_2NH (10)	1.0	$ClCH_2CH_2Cl$	40 °C	3 days	38% (36%[c])
2	$In(OTf)_3$ (20)	1.2	$ClCH_2CH_2Cl$	rt	19 h	0 (rsm: 91%[d])/(44%[e])
3	$Cu(MeCN)_4BF_4$ (20)	1.2	$ClCH_2CH_2Cl$	rt	68 h	12% (rsm: 74%[d])/(60%[f])
4	$Cu(MeCN)_4OTf$ (20)	1.2	$ClCH_2CH_2Cl$	rt	68 h	17% (rsm: 61%[d])/(58%[f])
5	$Cu(OTf)_2$ (20)	1.2	$ClCH_2CH_2Cl$	rt-60 °C	2 h	0 (rsm: 97%[d])/(50%[e])
6	BF_3•OEt_2 (20)	1.2	$ClCH_2CH_2Cl$	rt	25 h	16% (71%[c])
7	BF_3•OEt_2 (50)	1.2	$ClCH_2CH_2Cl$	rt	6 h	44%
8	BF_3•OEt_2 (50)	1.2	CH_2Cl_2	rt	5 h	57% (rsm: 39%[d])
9	BF_3•OEt_2 (120)	1.2	CH_2Cl_2	rt	6 h	80%
10	**BF_3•OEt_2 (200)**	**1.2**	**CH_2Cl_2**	**rt**	**6 h**	**95%[c]**
11	$TiCl_4$ (20)	1.2	CH_2Cl_2	rt	2 h	94%[c]
12	**$TiCl_4$ (10)**	**1.2**	**CH_2Cl_2**	**rt**	**4 h**	**92%[c]**
13	$TiCl_4$ (5)	1.2	CH_2Cl_2	rt	13 h	71%(rsm: 18%[d])

[a] All the reactions were conducted in 0.30 mmol scale. [b] Crude ^1H NMR yield. [c] Isolated yield. [d] Crude ^1H NMR yiled of recovery of **1a**. [e] Crude yield of *N*-phenylacetamide. [f] Crude ^1H NMR yield of recovery of vinyl azide **2a**.

5.2. Typical procedure: synthesis of 3aa



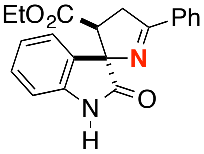


X-ray of 3aa

To a solution of alkylideneoxindole **1a** (0.30 mmol, 92.1 mg) and vinyl azide **2a** (0.36 mmol, 52.3 mg) in CH_2Cl_2 (3.0 mL) was added BF_3•OEt_2 (0.60 mmol, 74.0 μL, conditions **A**) or $TiCl_4$ (1.0 M in CH_2Cl_2, 0.030 mmol, 30.0 μL, conditions **B**) dropwise at 0 °C. The reaction was stirred at room temperature until **1a** was consumed before quenching with saturated aqueous $NaHCO_3$. The mixture was extracted trice with CH_2Cl_2 and the organic layers were combined and washed with brine. The solvent was removed in *vacuo*, and the resulting crude materials were purified by flash column chromatography (silica gel; ethylacetate:hexane = 20:80) to give ethyl (3*R**,3'*S**)-1-benzyl-2-oxo-5'-phenyl-3',4'-dihydrospiro[indoline-3,2'-pyrrole]-3'-carboxylate (**3aa**) in conditions **A**: 6 h, 95% yield as a single diastereomer and in conditions **B**: 4 h, 92% yield as a single diastereomer.

Pale yellow crystal (CCDC 1436809); mp 188-190 °C; IR (NaCl) 3053, 2986, 1724, 1635, 1612, 1576, 1487, 1369, 1265, 1199, 1177 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ 0.47 (3H, t, *J* = 7.2 Hz), 3.55 (1H, dd, *J* = 17.2, 9.6 Hz), 3.64 (1H, dq, *J* = 10.8, 7.2 Hz), 3.76 (1H, dq, *J* = 10.8, 7.2 Hz), 3.92 (1H, dd, *J* = 17.2, 9.6 Hz), 4.05 (1H, dd, *J* = 9.6, 9.6 Hz), 4.72 (1H, d, *J* = 15.6 Hz), 5.32 (1H, d, *J* = 15.6 Hz), 6.73 (1H, d, *J* = 8.0 Hz), 6.90-6.97 (2H, m), 7.16 (1H, dd, *J* = 7.6, 7.6 Hz), 7.29 (1H, d, *J* = 7.2 Hz), 7.34 (2H, dd, *J* = 8.0, 7.2 Hz), 7.41-7.45 (4H, m), 7.47-7.51 (1H, m), 7.92 (2H, d, *J* = 7.2 Hz); ^{13}C NMR (100 MHz, $CDCl_3$) δ 176.7, 175.9, 170.5, 142.9, 135.6, 133.2, 131.5, 129.6, 128.6, 128.5, 128.3, 127.8, 127.7, 127.4, 124.4, 122.8, 109.3, 82.9, 60.8, 49.8, 44.2, 38.5, 13.2. ESIHRMS: Found: *m/z* 425.1863. Calcld for $C_{27}H_{25}N_2O_3$: $(M+H)^+$ 425.1865.

Ethyl (3*R**,3'*S**)-2-oxo-5'-phenyl-3',4'-dihydrospiro[indoline-3,2'-pyrrole]-3'-carboxylate (3ba) :

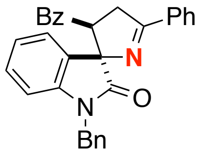


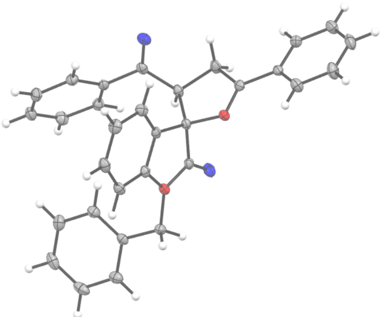
In conditions **A**: 1 h, 95% yield as a single diastereomer

In conditions **B**: 5 h, 95% yield as an inseparable mixture of two diastereomers with dr = 6:1

Yellow solid, mp 208-210 °C; IR (NaCl) 3426, 3053, 2928, 1732, 1645, 1620, 1472, 1344, 1265, 1199 cm^{-1}; ^{1}H NMR (400 MHz, CDCl$_3$) δ 0.73 (3H, t, *J* = 7.2 Hz), 3.54 (1H, dd, *J* = 17.2, 9.6 Hz), 3.78 (2H, q, *J* = 7.2 Hz), 3.89 (1H, dd, *J* = 17.2, 8.8 Hz), 3.98 (1H, dd, *J* = 9.6, 8.8 Hz), 6.92-6.97 (3H, m), 7.19-7.23 (1H, m), 7.41-7.51 (3H, m), 7.92 (2H, d, *J* = 7.2 Hz), 9.19 (1H, s br); ^{13}C NMR (100 MHz, CDCl$_3$) δ 179.1, 176.0, 170.5, 141.1, 133.1, 131.5, 129.7, 128.5, 128.2, 128.1, 124.6, 122.7, 110.2, 83.4, 60.9, 49.7, 38.4, 13.4. ESIHRMS: Found: *m/z* 335.1396. Calcld for $C_{20}H_{19}N_2O_3$: $(M+H)^+$ 335.1396.

(3*R**,3'*S**)-3'-Benzoyl-1-benzyl-5'-phenyl-3',4'-dihydrospiro[indoline-3,2'-pyrrol]-2-one (3ca) :





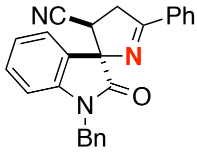
X-ray of **3ca**

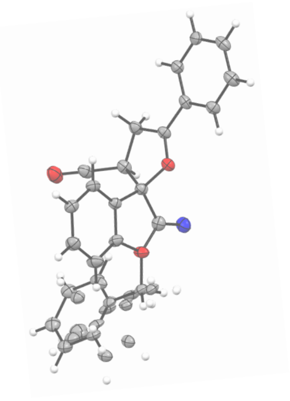
In conditions **A**: 5 h, 95% yield as a single diastereomer.

In conditions **B**: 2 h, 77% yield as a single diastereomer.

Pale yellow crystal (CCDC 1436810), mp 218-220 °C; IR (NaCl) 3421, 3053, 2986, 1716, 1682, 1611, 1487, 1346, 1265, 1182 cm^{-1}; ^{1}H NMR (400 MHz, CDCl$_3$) δ 3.56 (1H, dd, *J* = 17.2, 9.2 Hz), 4.31 (1H, dd, *J* = 17.2, 8.4 Hz), 4.56 (1H, d, *J* = 16.0 Hz), 4.88 (1H, d, *J* = 16.0 Hz), 4.95 (1H, dd, *J* = 9.2, 8.4 Hz), 6.35 (1H, d, *J* = 7.6 Hz), 6.83-6.9 (2H, m), 6.95-6.99 (1H, m), 7.14-7.18 (4H, m), 7.25-7.29 (3H, m), 7.37-7.51 (6H, m), 7.97 (2H, d, *J* = 8.4 Hz); ^{13}C NMR (100 MHz, CDCl$_3$) δ 197.2, 176.8, 176.3, 142.2, 136.9, 135.2, 133.3, 132.8, 131.4, 129.3, 128.7, 128.5, 128.3 (overlapped), 128.2, 127.8, 127.5, 127.0, 125.8, 122.9, 109.0, 83.3, 52.1, 44.3, 38.3. ESIHRMS: Found: *m/z* 457.1915. Calcld for C$_{31}$H$_{25}$N$_2$O$_2$: (M+H)$^+$ 457.1916.

(3R^*,3'S^*)-1-Benzyl-2-oxo-5'-phenyl-3',4'-dihydrospiro[indoline-3,2'-pyrrole]-3'-carbonitrile (3da) :



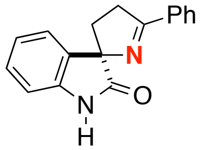


X-ray of **3da**

In conditions **A**: 24 h, 79% yield as a single diastereomer;
In conditions **B**: 24 h, 79% yield as a single diastereomer;
In these conditions, 2 equiv of vinyl azide **2a** was used.

Pale yellow crystal (CCDC 1436811), mp 214-216 °C; IR (NaCl) 3429, 3053, 2986, 2305, 1722, 1635, 1614, 1487, 1369, 1265, 1180 cm^{-1}; ^{1}H NMR (400 MHz, CDCl$_3$) δ 3.71 (1H, ddd, *J* = 14.8, 10.8, 4.0), 3.87-3.97 (2H, m), 4.94 (1H, d, *J* = 16.0 Hz), 5.00 (1H, d, *J* = 16.0 Hz), 6.81 (1H, d, *J* = 8.0 Hz), 7.10 (1H, dd, *J* = 7.6, 7.6 Hz), 7.24-7.35 (7H, m), 7.44 (2H, dd, *J* = 7.6, 7.2 Hz), 7.51 (1H, dd, *J* = 7.2, 7.2 Hz), 7.88 (2H, d, *J* = 7.2 Hz); ^{13}C NMR (100 MHz, CDCl$_3$) δ 174.9, 174.5, 142.7, 134.9, 132.2, 132.0, 130.6, 128.9, 128.7, 128.3, 127.8, 127.1, 126.5, 125.4, 123.5, 118.3, 110.0, 82.4, 44.3, 41.9, 34.6. ESIHRMS: Found: *m/z* 378.1609. Calcld for $C_{25}H_{20}N_3O$: $(M+H)^+$ 378.1606.

(*R**)-5'-Phenyl-3',4'-dihydrospiro[indoline-3,2'-pyrrol]-2-one (3ea) :

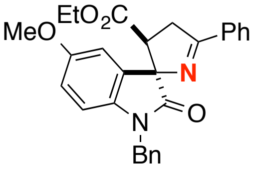


In conditions **A**: 3 h, 44% yield;

In conditions **B**: 3 h, 22% yield.

Yellow solid, mp 211-213 °C; IR (NaCl) 3426, 3053, 2986, 1716, 1620, 1470, 1422, 1265, 1203 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.30 (1H, ddd, *J* = 13.2, 9.6, 7.2 Hz), 2.65 (1H, ddd, *J* = 13.2, 9.6, 4.2 Hz), 3.36 (1H, ddd, *J* = 16.8, 9.6, 7.2 Hz), 3.48 (1H, ddd, *J* = 16.8, 9.6, 4.2), 6.91 (1H, d, *J* = 7.6 Hz), 7.02 (1H, dd, *J* = 7.6, 7.2 Hz), 7.11 (1H, d, *J* = 7.2 Hz), 7.20-7.24 (1H, dd, *J* = 7.6, 7.6 Hz), 7.39-7.49 (3H, m), 7.92 (2H, d, *J* = 8.0 Hz), 8.57 (1H, s br); ^{13}C NMR (100 MHz, $CDCl_3$) δ 179.5, 177.5, 140.7, 133.7, 132.7, 131.1, 128.4, 128.3 (overlapped), 123.9, 123.0, 110.1, 81.9, 36.7, 32.9. ESIHRMS: Found: *m/z* 263.1186. Calcld for $C_{17}H_{15}N_2O$: $(M+H)^+$ 263.1184.

Ethyl (3*R**,3'*S**)-1-benzyl-5-methoxy-2-oxo-5'-phenyl-3',4'-dihydrospiro[indoline-3,2'-pyrrole]-3'-carboxylate (3fa) :

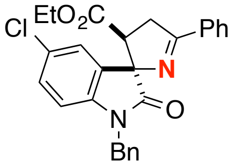


In conditions **A**: 3 h, 90% yield as a single diastereomer

In conditions **B**: 6 h, 76% yield as an inseparable mixture of two diastereomers with dr = 7: 1

White solid, mp 195-197 °C; IR (NaCl) 3421, 3053, 2984, 1715, 1609, 1608, 1576, 1495, 1371, 1265, 1202, 1180 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$) δ 0.54 (3H, t, *J* = 7.2 Hz), 3.55 (1H, dd, *J* = 17.6, 9.6 Hz), 3.65 (3H, s), 3.69 (1H, dq, *J* = 10.4, 7.2 Hz), 3.80 (1H, dq, *J* = 10.4, 7.2 Hz), 3.91 (1H, dd, *J* = 17.6, 9.2 Hz), 4.05 (1H, dd, *J* = 9.6, 9.2 Hz), 4.69 (1H, d, *J* = 15.6 Hz), 5.28 (1H, *J* = 15.6 Hz), 6.57 (1H, d, *J* = 2.4 Hz), 6.61 (1H, d, *J* = 8.4 Hz), 6.69 (1H, dd, *J* = 8.4, 2.4 Hz), 7.27 (1H, d, *J* = 7.2 Hz), 7.34 (2H, dd, *J* = 7.6, 6.8 Hz), 7.40-7.45 (4H, m), 7.47-7.51 (1H, m), 7.92 (2H, d, *J* = 7.2 Hz); ^{13}C NMR (100 MHz, $CDCl_3$) δ 176.4, 176.0, 170.5, 156.0, 136.3, 135.6, 133.1, 131.5, 129.0, 128.6, 128.5, 128.3, 127.6, 127.4, 114.4, 111.5, 109.8, 83.3, 60.9, 55.8, 49.7, 44.3, 38.6, 13.3. ESIHRMS: Found: *m/z* 455.1973. Calcld for $C_{28}H_{27}N_2O_4$: $(M+H)^+$ 455.1971.

Ethyl (3*R,3'*S**)-1-benzyl-5-chloro-2-oxo-5'-phenyl-3',4'-dihydrospiro[indoline-3,2'-pyrrole]-3'-carboxylate (3ga) :**

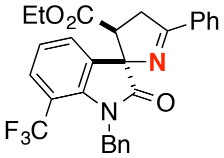


In conditions **A**: 3 h, 85% yield as a single diastereomer

In conditions **B**: 10 min, 91% yield as an inseparable mixture of two diastereomers with dr = 7:1

Pink solid, mp 243-245 °C; IR (NaCl) 3433, 3053, 2986, 1730, 1645, 1609, 1485, 1422, 1265, 1199, 1175 cm^{-1}; 0.57 (3H, t, *J* = 7.2 Hz), 3.56 (1H, dd, *J* = 17.6, 9.6 Hz), 3.70 (1H, dq, *J* = 10.8, 7.2 Hz), 3.83 (1H, dq, *J* = 10.8, 7.2 Hz), 3.90 (1H, dd, *J* = 17.6, 9.2 Hz), 4.04 (1H, dd, *J* = 9.6, 9.2 Hz), 4.70 (1H, d, *J* = 15.6 Hz), 5.29 (1H, d, *J* = 15.6 Hz), 6.63 (1H, d, *J* = 8.4 Hz), 6.95 (1H, d, *J* = 2.0 Hz), 7.13 (1H, dd, *J* = 8.0, 2.0 Hz), 7.26-7.52 (8H, m), 7.91 (2H, *J* = 7.2 Hz); ^{13}C NMR (100 MHz, $CDCl_3$) δ 176.5, 176.3, 170.2, 141.5, 135.1, 132.9, 131.7, 129.6, 129.5, 128.7, 128.6, 128.3, 128.2, 127.8, 127.4, 124.9, 110.3, 82.7, 61.0, 49.7, 44.3, 38.6, 13.3. ESIHRMS: Found: *m/z* 459.1476. Calcld for $C_{27}H_{24}ClN_2O_3$: $(M+H)^+$ 459.1475.

Ethyl (3*R**,3'*S**)-1-benzyl-2-oxo-5'-phenyl-7-(trifluoromethyl)-3',4'-dihydrospiro[indoline-3,2'-pyrrole]-3'-carboxylate (3ha) :



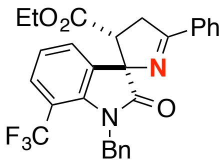
In conditions **A**: 4 h, 87% yield as a single diastereomer

In conditions **B**: 4 h, 80% yield, dr = 3:1, two diastereomers were isolated.

White solid, mp 142-145 °C; IR (NaCl) 3420, 3055, 2980, 1734, 1647, 1612, 1454, 1332, 1265, 1165, 1126 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$) δ 0.69 (3H, t, *J* = 7.2 Hz), 3.56 (1H, dd, *J* = 17.2, 9.6 Hz), 3.73-3.87 (2H, m), 3.90 (1H, dd, *J* = 17.2, 8.8 Hz), 4.04 (1H, dd, *J* = 9.6, 8.8 Hz), 5.21 (1H, d, *J* = 16.8 Hz), 5.29 (1H, d, *J* = 16.8 Hz), 7.04 (1H, dd, *J* = 7.6, 7.6 Hz), 7.16 (1H, d, *J* = 7.2 Hz), 7.21-7.24 (1H, m), 7.27-7.33 (4H, m), 7.40-7.50 (3H, m), 7.54 (1H, *J* = 8.0 Hz), 7.91 (2H, d, *J* = 7.2 Hz); ^{13}C NMR (100 MHz, $CDCl_3$) δ 178.0, 176.5, 170.1, 141.2, 135.9, 132.8, 131.7, 130.8, 128.5, 128.23, 128.21, 128.1, 127.6 (q, *J* = 3.1 Hz), 126.8, 125.6, 123.1 (q, *J* = 270.4 Hz), 122.3, 112.9 (q, *J* = 33.1 Hz), 80.9, 61.0, 50.0, 45.9 (d, *J* = 4.9 Hz), 38.7, 13.3. ESIHRMS: Found: *m/z* 4493.1739. Calcld for $C_{28}H_{24}F_3N_2O_3$: $(M+H)^+$ 493.1739.

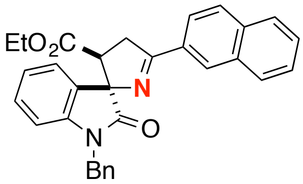
Minor isomer isolated from the conditions **B**:

Ethyl (3*R**,3'*R**)-1-benzyl-2-oxo-5'-phenyl-7-(trifluoromethyl)-3',4'-dihydrospiro[indoline-3,2'-pyrrole]-3'-carboxylate (3ha'):



White solid, mp 162-164 °C; IR (NaCl) 3421, 2978, 2868, 1740, 1647, 1613, 1597, 1491, 1446, 1381, 1350, 1296, 1126 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.11 (3H, t, *J* = 7.2 Hz), 3.61 (H, dd, *J* = 16.4, 9.6 Hz), 3.77 (1H, dd, *J* = 9.6, 9.6 Hz), 3.93 (1H, dd, *J* = 16.4, 9.6 Hz), 4.03 (1H, dq, *J* = 10.8, 7.2 Hz), 4.10 (1H, dq, *J* = 10.8, 7.2 Hz), 5.11 (1H, d, *J* = 16.8 Hz), 5.27 (1H, d, *J* = 16.8 Hz), 7.18-7.30 (6H, m), 7.41-7.51 (4H, m), 7.62 (1H, d, *J* = 7.2 Hz), 7.90 (2H, d, *J* = 6.8 Hz); ^{13}C NMR (100 MHz, $CDCl_3$) δ 177.2, 176.2, 169.9, 142.1, 136.1, 134.3, 133.3, 131.7, 128.6, 128.3, 128.2, 127.6 (q, *J* = 3.1 Hz), 127.4, 126.8, 125.9, 123.4 (q, *J* = 270.1 Hz), 122.7, 113.2 (q, *J* = 32.2 Hz), 80.4, 61.5, 52.0, 46.0 (q, *J* = 3.3 Hz), 38.7, 13.8. ESIHRMS: Found: *m/z* 493.1733. Calcld for $C_{28}H_{24}F_3N_2O_3$: $(M+H)^+$ 493.1739.

Ethyl (3*R,3'*S**)-1-benzyl-5'-(naphthalen-2-yl)-2-oxo-3',4'-dihydrospiro[indoline-3,2'-pyrrole]-3'-carboxylate (3ab) :**

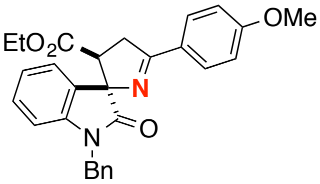


In cnditions **A**: 2 h, 91% yield as a single diastereomer

In conditions **B**: 0.5 h, 94% yield as an inseparable mixture of two diastereomers with dr = 10:1

Pale yellow solid, mp 195-197 °C; IR (NaCl) 3420, 3053, 2986, 1722, 1635, 1612, 1487, 1369, 1265, 1201, 1177 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$) δ 0.49 (3H, t, *J* = 7.2 Hz), 3.64 (1H, dq, *J* = 10.8, 7.2 Hz), 3.68 (1H, dd, *J* = 16.8, 8.8 Hz), 3.78 (1H, dq, *J* = 10.8, 7.2 Hz), 4.04 (1H, dd, *J* = 16.8, 9.2 Hz), 4.11 (1H, dd, *J* = 9.2, 8.8 Hz), 4.73 (1H, d, *J* = 15.6 Hz), 5.34 (1H, dd, *J* = 15.6 Hz), 6.74 (1H, d, *J* = 8.0 Hz), 6.92 (1H, dd, *J* = 7.6, 7.2 Hz), 6.99 (1H, d, *J* = 7.6 Hz), 7.16 (1H, dd, *J* = 8.0, 7.6 Hz), 7.29 (1H, dd, *J* = 7.2, 7.2 Hz), 7.35 (2H, dd, *J* = 7.2, 7.2 Hz), 7.44 (2H, d, *J* = 7.2 Hz), 7.51-7.57 (2H, m), 7.85 (2H, d, *J* = 8.4 Hz), 7.92 (1H, d, *J* = 7.2 Hz), 8.09 (1H, d, *J* = 8.4 Hz), 8.32 (1H, s); ^{13}C NMR (100 MHz, $CDCl_3$) δ 176.7, 175.8, 170.4, 142.9, 135.5, 134.7, 132.7, 130.6, 129.5, 129.1, 128.8, 128.6, 128.2, 127.8, 127.7, 127.6, 127.5, 127.4 (overlapped), 126.5, 124.6, 124.4, 122.8, 82.9, 60.7, 49.8, 44.2, 38.5, 13.1. ESIHRMS: Found: *m/z* 475.2021. Calcld for $C_{31}H_{27}N_2O_3$: $(M+H)^+$ 475.2022.

Ethyl (3*R**,3'*S**)-1-benzyl-5'-(4-methoxyphenyl)-2-oxo-3',4'-dihydrospiro[indoline-3,2'-pyrrole]-3'-carboxylate (3ac) :

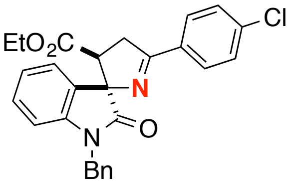


In conditions **A**: 22 h, 90% yield as a single diastereomer

In conditions **B**: 20 min, 96% yield as an inseparable mixture of two diastereomers with dr = 3:1

White solid, mp 163-165 °C; IR (NaCl) 3420, 3055, 2982, 1722, 1612, 1603, 1489, 1466, 1265, 1219, 1178 cm^{-1}; ^{1}H NMR (400 MHz, CDCl$_3$) δ 0.47 (3H, t, *J* = 7.2 Hz), 3.56-3.66 (2H, m), 3.78 (1H, dq, *J* = 10.8, 7.2 Hz), 3.92 (3H, s), 3.98-4.05 (2H, m), 4.71 (1H, d, *J* = 15.6 Hz), 5.30 (1H, d, *J* = 15.6 Hz), 6.70 (1H, d, *J* = 8.0 Hz), 6.90-6.97 (3H, m), 7.03 (1H, d, *J* = 7.2 Hz), 7.14 (1H, dd, *J* = 8.0, 7.6 Hz), 7.28 (1H, d, *J* = 7.2 Hz), 7.33 (2H, dd, *J* = 7.6, 7.2 Hz), 7.39-7.43 (3H, m), 7.93 (1H, d, *J* = 7.6 Hz); ^{13}C NMR (100 MHz, CDCl$_3$) δ 177.0, 176.2, 170.6, 158.4, 142.8, 135.6, 132.3, 130.7, 129.3, 128.5, 127.5, 127.4, 124.3, 122.6, 120.5, 111.1, 109.1, 81.1, 60.5, 55.3, 50.1, 44.1, 41.7, 13.1. ESIHRMS: Found: *m/z* 455.1969. Calcld for $C_{28}H_{27}N_2O_4$: $(M+H)^+$ 455.1971.

Ethyl (3*R**,3'*S**)-1-benzyl-5'-(4-chlorophenyl)-2-oxo-3',4'-dihydrospiro[indoline-3,2'-pyrrole]-3'-carboxylate (3ad) :

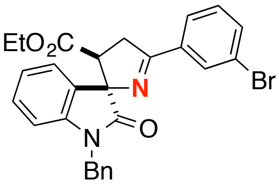


In conditions **A**: 5 h, 91% yield as a single diastereomer

In conditions **B**: 9 h, 94% yield as an inseparable mixture of two diastereomers with dr = 10:1

White solid, mp176-178 °C; IR (NaCl) 3429, 3053, 2984, 1722, 1645, 1612, 1489, 1369, 1265, 1200, 1091 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$) δ 0.48 (3H, t, *J* = 7.2 Hz), 3.51 (1H, dd, *J* = 17.6, 10.0 Hz), 3.64 (1H, dq, *J* = 10.8, 7.2 Hz), 3.75 (1H, dq, *J* = 10.8, 7.2 Hz), 3.88 (1H, d, *J* = 17.6, 9.2 Hz), 4.05 (1H, dd, *J* = 10.0, 9.2 Hz), 4.73 (1H, d, *J* = 15.6 Hz), 5.30 (1H, d, *J* = 15.6 Hz), 6.73 (1H, d, *J* = 7.6 Hz), 6.90-6.96 (2H, m), 7.16 (1H, dd, *J* = 8.0, 7.6 Hz), 7.29 (1H, d, *J* = 6.8 Hz), 7.34 (2H, dd, *J* = 7.6, 7.2 Hz), 7.39-7.42 (4H, m), 7.85 (1H, d, *J* = 8.8 Hz); ^{13}C NMR (100 MHz, $CDCl_3$) δ 176.6, 174.8, 170.4, 142.9, 137.6, 135.5, 131.6, 129.7, 129.6, 128.8, 128.7, 127.7, 127.6, 127.4, 124.4, 122.9, 109.4, 82.9, 60.9, 49.8, 44.3, 38.5, 13.2. ESIHRMS: Found: *m/z* 459.1476. Calcld for $C_{27}H_{24}ClN_2O_3$: $(M+H)^+$ 459.1475.

Ethyl (3*R,3'*S**)-1-benzyl-5'-(3-bromophenyl)-2-oxo-3',4'-dihydrospiro[indoline-3,2'-pyrrole]-3'-carboxylate (3ae) :**

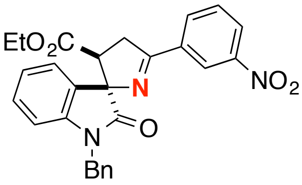


In conditions **A**: 11 h, 93% yield as a single diastereomer

In conditions **B**: 23 h, 72% yield as an inseparable mixture of two diastereomers with dr = 4:1

White solid, mp 150-152 °C; IR (NaCl) 3428, 3053, 2984, 1728, 1645, 1614, 1560, 1487, 1369, 1265, 1200, 1179 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$) δ 0.47 (3H, t, *J* = 7.2 Hz), 3.50 (1H, dd, *J* = 17.6, 9.6 Hz), 3.64 (1H, dq, *J* = 10.8, 7.2 Hz), 3.76 (1H, dq, *J* = 10.8, 7.2 Hz), 3.88 (1H, d, *J* = 17.6, 9.2 Hz), 4.05 (1H, dd, *J* = 9.6, 9.2 Hz), 4.72 (1H, d, *J* = 15.6 Hz), 5.30 (1H, d, *J* = 15.6 Hz), 6.73 (1H, d, *J* = 8.0 Hz), 6.90-6.96 (2H, m), 7.16 (1H, dd, *J* = 8.0, 8.0 Hz), 7.26-7.35 (4H, m), 7.41 (2H, d, *J* = 7.2 Hz), 7.59 (1H, d, *J* = 8.0 Hz), 7.80 (1H, d, *J* = 7.6 Hz), 8.11 (1H, s); ^{13}C NMR (100 MHz, $CDCl_3$) δ 176.4, 174.6, 170.2, 142.8, 135.4, 135.0, 134.3, 131.0, 130.0, 129.7, 128.6, 127.6, 127.5, 127.4, 126.8, 124.3, 122.8, 122.7, 109.3, 82.8, 60.8, 49.7, 44.2, 38.5, 13.1. ESIHRMS: Found: *m/z* 503.0975. Calcld for $C_{27}H_{24}{}^{79}BrN_2O_3$: $(M+H)^+$ 503.0970.

Ethyl (3*R**,3'*S**)-1-benzyl-5'-(3-nitrophenyl)-2-oxo-3',4'-dihydrospiro[indoline-3,2'-pyrrole]-3'-carboxylate (3af) :

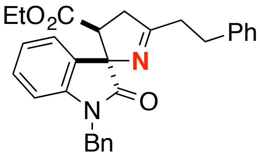


In conditions **A**: 23 h, 70% yield as a single diastereomer

In conditions **B**: 23 h, 38% yield as an inseparable mixture of two diastereomers with dr = 4:1

White solid, mp 163-165 °C; IR (NaCl) 3431, 3053, 2986, 1724, 1636, 1612, 1535, 1354, 1265, 1202 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$) δ 0.50 (3H, t, *J* = 7.2 Hz), 3.58 (1H, dd, *J* = 17.2, 10.0 Hz), 3.67 (1H, dq, *J* = 10.8, 7.2 Hz), 3.76 (1H, dq, *J* = 10.8, 7.2 Hz), 3.96 (1H, dd, *J* = 17.2, 8.8 Hz), 4.10 (1H, dd, *J* = 10.0, 8.8 Hz), 4.77 (1H, d, *J* = 15.6 Hz), 5.30 (1H, d, *J* = 15.6 Hz), 6.76 (1H, d, *J* = 7.6 Hz), 6.92-6.97 (2H, m), 7.17-7.7.22 (1H, m), 7.27-7.31 (1H, m), 7.35 (2H, dd, *J* = 7.6, 6.8 Hz), 7.42 (2H, d, *J* = 7.2 Hz), 7.63 (1H, dd, *J* = 8.0, 8.0 Hz), 8.26 (1H, d, *J* = 8.0 Hz), 8.34 (1H, d, *J* = 8.0 Hz), 8.74 (1H, s); ^{13}C NMR (100 MHz, $CDCl_3$) δ 176.2, 173.9, 170.1, 148.4, 142.9, 135.4, 134.8, 133.9, 129.9, 129.6, 128.7, 127.7, 127.4, 127.3, 125.9, 124.4, 123.2, 122.9, 109.5, 83.1, 61.0, 49.7, 44.3, 38.6, 13.2. ESIHRMS: Found: *m/z* 470.1716. Calcld for $C_{27}H_{24}N_3O_5$: $(M+H)^+$ 470.1716.

Ethyl (3*R**,3'*S**)-1-benzyl-2-oxo-5'-phenethyl-3',4'-dihydrospiro[indoline-3,2'-pyrrole]-3'-carboxylate (3ag) :

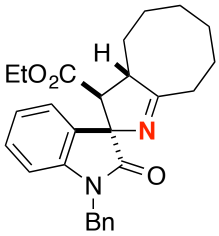


In conditions **A**: 19 h, 78% yield as a single diastereomer

In conditions **B**: no desired product was detected.

Pink solid, mp 121-123 °C; IR (NaCl) 3433, 3053, 2984, 1719, 1636, 1612, 1489, 1454, 1369, 1265, 1199 cm^{-1}; ^{1}H NMR (400 MHz, CDCl$_3$) δ 0.44 (3H, t, *J* = 7.2 Hz), 2.77-2.92 (2H, m), 2.94-3.10 (3H, m), 3.44 (1H, dd, *J* = 17.6, 9.2 Hz), 3.58 (1H, dq, *J* = 10.8, 7.2 Hz), 3.69 (1H, dq, *J* = 10.8, 7.2 Hz), 3.87 (1H, dd, *J* = 9.6, 9.2 Hz), 4.66 (1H, d, *J* = 15.6 Hz), 5.27 (1H, d, *J* = 15.6 Hz), 6.66-6.69 (2H, m), 6.87 (1H, dd, *J* = 7.6, 7.6 Hz), 7.13 (1H, dd, *J* = 8.0, 7.6 Hz), 7.19-7.33 (8H, m), 7.38 (2H, d, *J* = 7.2 Hz); ^{13}C NMR (100 MHz, CDCl$_3$) δ 181.3, 176.8, 170.4, 142.7, 140.6, 135.5, 129.4, 128.6, 128.5, 128.3, 127.6, 127.4 (overlapped), 126.2, 124.3, 122.7, 109.1, 82.5, 60.7, 49.7, 44.1, 41.1, 35.2, 32.3, 13.1. ESIHRMS: Found: *m/z* 453.2176. Calcld for $C_{29}H_{29}N_2O_3$: $(M+H)^+$ 453.2178.

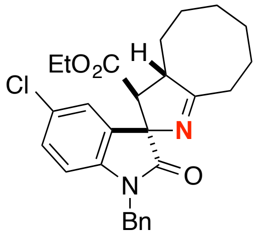
Ethyl (2*R,3*S**)-1'-benzyl-2'-oxo-3,3a,4,5,6,7,8,9-octahydrospiro[cycloocta[b]pyrrole-2,3'-indoline]-3-carboxylate (3ah):**

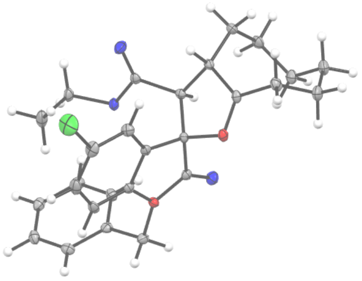


In conditions **A**: 8 h, 83% yield, dr = 14:1.3:1, the major isomer was isolated and charecterized. White solid, mp 166-168 °C; IR (NaCl) 3422, 3053, 2986, 1722, 1628, 1614, 1466, 1368, 1265, 1204, 1180 cm^{-1}; ^{1}H NMR (400 MHz, CDCl$_3$) δ 0.42 (3H, t, *J* = 7.2 Hz), 1.37-1.44 (1H, m), 1.53-1.64 (2H, m), 1.70-1.99 (6H, m), 2.24-2.31 (1H, m), 2.46 (1H, ddd, 12.8, 11.6, 3.6 Hz), 2.69-2.75 (1H, m), 3.57 (1H, dq, *J* = 10.8, 7.2 Hz), 3.75 (1H, dq, *J* = 10.8, 7.2 Hz), 3.79-3.83 (2H, m), 4.68 (1H, d, *J* = 15.6 Hz), 5.25 (1H, d, *J* = 15.6 Hz), 6.69 (1H, d, *J* = 7.6 Hz), 6.89-6.96 (2H, m), 7.13 (1H, dd, *J* = 7.6, 7.6 Hz), 7.24-7.27 (1H, m), 7.31 (2H, dd, *J* = 7.6, 6.8 Hz), 7.40 (2H, d, *J* = 7.2 Hz); ^{13}C NMR (100 MHz, CDCl$_3$) δ 187.8, 177.1, 170.3, 143.0, 135.7, 129.3, 128.6, 127.7, 127.6, 127.4, 124.0, 122.6, 109.1, 80.2, 60.5, 52.5, 52.1, 44.1, 31.1, 30.1,

25.6, 24.4, 24.2, 23.7, 13.1. ESIHRMS: Found: *m/z* 431.2335. Calcld for $C_{27}H_{31}N_2O_3$: $(M+H)^+$ 431.2335.

Ethyl (2*R**,3*S**)-1'-benzyl-5'-chloro-2'-oxo-3,3a,4,5,6,7,8,9-octahydrospiro[cycloocta[b]pyrr-ole-2,3'-indoline]-3-carboxylate (3gh):





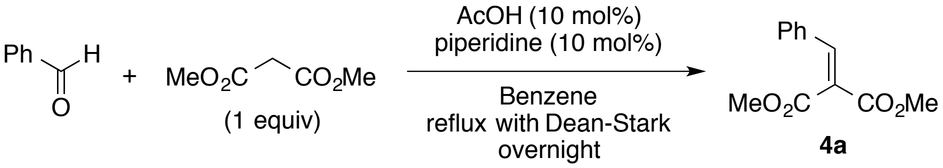
X-ray of **3gh**

In conditions **A**: 2 h, 78% yield, dr = 2.6:1.3:1, the major isomer was isolated and charecterized. The structure was further confirmed by X-ray analysis.

Colorless crystal (CCDC 1436812), mp 182-184 °C; IR (NaCl) 3412, 3062, 2930, 1712, 1655, 1608, 1483, 1342, 1265, 1182, 1098 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ 0.51 (3H, t, *J* = 7.2 Hz), 1.37-1.44 (1H, m), 1.51-1.64 (2H, m), 1.70-2.04 (6H, m), 2.26-2.32 (1H, m), 2.47 (1H, ddd, 12.8, 12.0, 3.6 Hz), 2.69-2.75 (1H, m), 3.63 (1H, dq, *J* = 10.8, 7.2 Hz), 3.74-3.87 (3H, m), 4.65 (1H, d, *J* = 15.6 Hz), 5.24 (1H, d, *J* = 15.6 Hz), 6.61 (1H, d, *J* = 8.4 Hz), 6.93 (1H, s), 7.11 (1H, d, *J* = 8.4 Hz), 7.25-7.28 (1H, m), 7.32 (2H, dd, *J* = 7.2, 7.2 Hz), 7.37 (2H, d, *J* = 7.2 Hz); ^{13}C NMR (100 MHz, $CDCl_3$) δ 188.6, 176.6, 169.9, 141.5, 135.1, 129.4, 129.2, 128.7, 127.9, 127.7, 127.4, 124.5, 110.0, 80.1, 60.7, 52.6, 51.9, 44.2, 31.1, 30.1, 25.5, 24.2, 24.1, 23.6, 13.2. ESIHRMS: Found: *m/z* 465.1948. Calcld for $C_{27}H_{30}ClN_2O_3$: $(M+H)^+$ 465.1945.

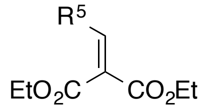
6. $TiCl_4$-catalyzed reactions of vinyl azides 2 with 2-alkylidenemalonates 4 (Shceme 4 and 5)

6.1 Synthesis of 2-alkylidenemalonates 4 (typical procedure: synthesis of 4a)

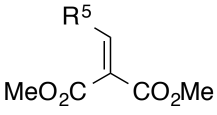


To a solution of benzaldehyde (5.0 mmol, 0.51 mL) and dimethyl malonate (5.0 mmol, 0.57 mL) in toluene was added AcOH (1.0 mmol, 57.2 μL) and piperidine (1.0 mmol, 98.8 μL) at room temperature. The reaction was then stirred under reflux conditions for 12 h until the starting materials were consumed. The mixture was cooled down to room temperature and evaporated to remove the solvent. The crude material was purified by flash column chromatography (silica gel; ethylacetate: hexane = 10: 90) to give dimethyl 2-benzylidenemalonate[10] (**4a**, 4.1 mmol, 0.903 g) in 82% yield as a pale yellow liquid. ^1H NMR (400 MHz, $CDCl_3$) δ 3.846 (3H, s), 3.852 (3H, s), 7.38-7.44 (5H, m), 7.78 (1H, s); ^{13}C NMR (100 MHz, $CDCl_3$) δ 167.1, 164.5, 142.9, 132.8, 130.7, 129.4, 128.9, 125.5, 52.7.

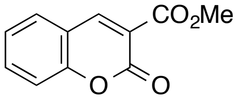
2-Alkylidenemalonate **4b**,[11] **4c-4f**,[10] **4h**,[12] and **4i**[11] were all known compounds and prepared following the reported procedures. Diethyl 2-ethylidenemalonate (**4g**) was purchased from Sigma-Aldrich Co., Inc.



4b: R^5 = 4-Me-C_6H_4
4g: R^5 = Me



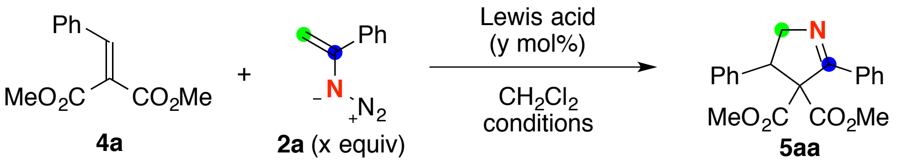
4c: R^5 = 4-OMe-C_6H_4
4d: R^5 = 2-Cl-C_6H_4
4e: R^5 = 4-CN-C_6H_4
4f : R^5 = CH=CHPh
4h: R^5 = CH_2CH_2Ph



4i

6.2 Optimization of the reaction conditions

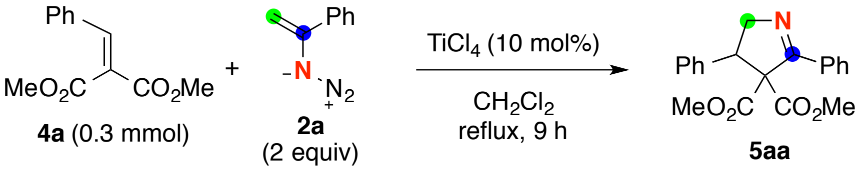
Table S2[a]



entry	Lewis acid	x	y	temp.	time	yield[b]
1	TiCl$_4$	1.2	10	rt	10 h	54%
2	TiCl$_4$	1.5	10	rt	9 h	63%
3	TiCl$_4$	1.5	10	reflux	9 h	71%
4	TiCl$_4$	1.5	20	reflux	9 h	72%
5	TiCl$_4$	2.0	10	reflux	9 h	76% (75%)[c]
6	TiCl$_4$	3.0	10	reflux	9 h	78% (76%)[c]
7	TiCl$_4$	1.5	20	reflux	9 h	76%
8	BF$_3$•OEt$_2$	2.0	200	rt-reflux	22 h[d]	0%[e]

[a] All the reactions were conducted in 0.30 mmol scale. [b] ^{1}H NMR yields of crude materials. [c] Isolated yields. [d] The reaction was stirred at rt for 15 h and then reflux for 7 h. [e] **4a** was recovered in 94% yield.

6.3. Typical procedure for synthesis of 5aa

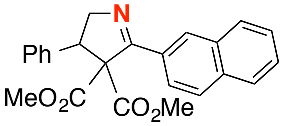


To a solution of 2-alkylidinemalonate **4a** (0.30 mmol, 66.1 mg) and vinyl azide **2a** (0.60 mmol, 87.1 mg) in CH$_2$Cl$_2$ was added TiCl$_4$ (1.0 M in CH$_2$Cl$_2$, 0.030 mmol, 30 μL) at room temperature. The reaction mixture was stirred under reflux (bath temp. at 40 °C) for 9 hours untill 2-alkylidinemalonate **4a** was consumed. The rection mixture was cooled down to room temperature, quencend with saturated aqueous NaHCO$_3$, and extracted trice with CH$_2$Cl$_2$. The combined organic layers was washed with brine and dried over MgSO$_4$. After filtration, the solvent was removed in *vacuo*, and the resulting crude materials were purified by flash column chromatography (silica gel; ethyl acetate: hexane = 20:80) to give dimethyl

2,4-diphenyl-4,5-dihydro-3*H*-pyrrole-3,3-dicarboxylate (**5aa**) (0.225 mmol, 75.9 mg) in 75% yield.

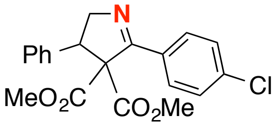
Pale yellow solid; mp: 96-98 °C; IR (NaCl) 3421, 3055, 2988, 1718, 1647, 1630, 1435, 1265 cm^{-1}; ^{1}H NMR (400 MHz, CDCl$_3$) δ 3.20 (3H, s), 3.72 (3H, s), 4.44 (1H, dd, *J* = 15.6, 5.2 Hz), 4.52 (1H, dd, *J* = 7.2, 5.2 Hz), 4.59 (1H, dd, *J* = 15.6, 7.2 Hz), 7.18-7.22 (2H, m), 7.23-7.30 (3H, m), 7.33-7.42 (3H, m), 7.82-7.85 (2H, m); ^{13}C NMR (100 MHz, CDCl$_3$) δ 168.6, 167.2, 167.0, 138.0, 133.3, 130.2, 128.5, 128.5, 128.2, 128.0, 127.7, 75.7, 65.6, 54.0, 53.1, 52.0. ESIHRMS: Found: *m/z* 338.1393. Calcld for $C_{20}H_{20}NO_4$: $(M+H)^+$ 338.1392.

Dimethyl 2-(naphthalen-2-yl)-4-phenyl-4,5-dihydro-3H-pyrrole-3,3-dicarboxylate (5ab):



23 h, 60% yield, brown stick oil; IR (NaCl) 3422, 3053, 2986, 1734, 1630, 1618, 1435, 1315, 1265, 1205, 1088 cm^{-1}; ^{1}H NMR (400 MHz, CDCl$_3$) δ 3.21 (3H, s), 3.73 (3H, s), 4.51 (1H, dd, *J* = 15.6, 4.8 Hz), 4.56 (1H, dd, *J* = 7.2, 4.8 Hz), 4.65 (1H, dd, *J* = 15.6, 7.2 Hz), 7.21-7.31 (5H, m), 7.46-7.53 (2H, m), 7.82 (2H, d, *J* = 8.4 Hz), 7.87 (1H, d, *J* = 7.6 Hz), 8.02 (1H, dd, *J* = 8.8, 2.0 Hz), 8.28 (1H, s); ^{13}C NMR (100 MHz, CDCl$_3$) δ 168.7, 167.2, 167.1, 138.1, 134.1, 132.6, 130.7, 129.0, 128.6 (overlapped), 128.3, 127.7, 127.6, 127.5, 127.2, 126.2, 125.5, 75.7, 65.7, 54.2, 53.2, 52.0. ESIHRMS: Found: *m/z* 388.1546. Calcld for $C_{24}H_{22}NO_4$: $(M+H)^+$ 388.1549.

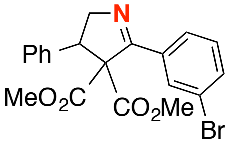
Dimethyl 2-(4-chlorophenyl)-4-phenyl-4,5-dihydro-3H-pyrrole-3,3-dicarboxylate (5ad):



24 h, 71% yield, yellow stick oil; IR (NaCl) 3419, 3055, 2953, 1728, 1622, 1493, 1435, 1317, 1265, 1232, 1093 cm^{-1}; ^{1}H NMR (400 MHz, CDCl$_3$) δ 3.19(3H, s), 3.74 (3H, s), 4.43 (1H, dd, *J* = 15.6, 4.4 Hz), 4.52 (1H, dd, *J* = 7.2, 4.4 Hz), 4.58 (1H, dd, *J* = 15.6, 7.2 Hz), 7.16-7.18 (2H,

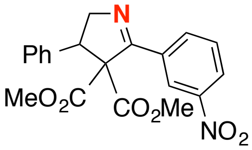
m), 7.22-7.30 (3H, m), 7.33 (2H, d, *J* = 8.8 Hz),7.80 (2H, d, *J* = 8.8 Hz); ^{13}C NMR (100 MHz, $CDCl_3$) δ 168.4, 167.0, 166.1, 138.1, 136.5, 131.8, 130.1, 128.6, 128.3, 128.3, 127.8, 75.8, 65.9, 54.0, 53.3, 52.2. ESIHRMS: Found: *m/z* 372.1002. Calcld for $C_{20}H_{19}ClNO_4$: $(M+H)^+$ 372.1003.

Dimethyl 2-(3-bromophenyl)-4-phenyl-4,5-dihydro-3H-pyrrole-3,3-dicarboxylate (5ae):



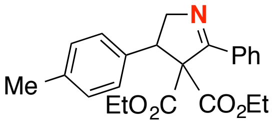
5 h, 67% yield, yellow stick oil; IR (NaCl) 3431, 3057, 2953, 1730, 1662, 1560, 1435, 1317, 1265, 1230, 1090 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$) δ 3.20 (3H, s), 3.75 (3H, s), 4.43 (1H, dd, *J* = 16.0, 4.4 Hz), 4.52 (1H, dd, *J* = 7.2, 4.4 Hz), 4.59 (1H, dd, *J* = 16.0, 7.2 Hz), 7.16-7.20 (2H, m), 7.22-7.30 (4H, m), 7.53 (1H, d, 8.0 Hz), 7.70 (1H, d, *J* = 8.0 Hz), 8.09 (1H, s); ^{13}C NMR (100 MHz, $CDCl_3$) δ 168.2, 166.8, 165.9, 137.9, 135.3, 133.1, 131.6, 129.4, 128.5, 128.3, 127.7, 127.2, 122.2, 75.8, 65.7, 53.9, 53.2, 52.1. ESIHRMS: Found: *m/z* 416.0479. Calcld for $C_{20}H_{19}{}^{79}BrNO_4$: $(M+H)^+$ 416.0497.

Dimethyl 2-(3-nitrophenyl)-4-phenyl-4,5-dihydro-3H-pyrrole-3,3-dicarboxylate (5af):



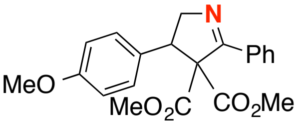
5 h, 61% yield, yellow stick oil; IR (NaCl) 3424, 3053, 2986, 1734, 1618, 1533, 1435, 1350, 1265, 1233, 1091 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$) δ 3.21 (3H, s), 3.79 (3H, s), 4.48 (1H, dd, *J* = 16.0, 4.0 Hz), 4.56 (1H, dd, *J* = 7.2, 4.0 Hz), 4.64 (1H, dd, *J* = 16.0, 7.2 Hz), 7.17-7.19 (2H, m), 7.23-7.33 (3H, m), 7.55 (1H, dd, *J* = 8.0, 8.0 Hz), 8.19 (1H, d, *J* = 8.0 Hz), 8.26 (1H, d, *J* = 8.0 Hz), 8.80 (1H, s); ^{13}C NMR (100 MHz, $CDCl_3$) δ 167.9, 166.8, 165.2, 148.0, 138.0, 135.1, 134.5, 128.9, 128.5, 128.3, 127.9, 124.7, 123.9, 76.0, 66.1, 53.7, 53.4, 52.3. ESIHRMS: Found: *m/z* 383.1241. Calcld for $C_{20}H_{19}N_2O_6$: $(M+H)^+$ 383.1243.

Diethyl 2-phenyl-4-(p-tolyl)-4,5-dihydro-3H-pyrrole-3,3-dicarboxylate (5ba):



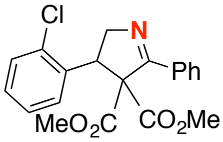
20 h, 75% yield, pale yellow stick oil; IR (NaCl) 3431, 3053, 2984, 1732, 1610, 1516, 1449, 1346, 1265, 1219, 1098 cm^{-1}; ^{1}H NMR (400 MHz, CDCl$_3$) δ 0.84 (3H, t, *J* = 7.2 Hz), 1.11 (3H, t, *J* = 7.2 Hz), 2.29 (3H, s), 3.64-3.76 (2H, m), 4.09-4.23 (2H, m), 4.39 (1H, dd, *J* = 14.4, 4.0 Hz), 4.49-4.58 (2H, m), 7.06-7.12 (4H, m), 7.31-7.40 (3H, m), 7.84 (2H, d, *J* = 8.0 Hz), (1H, dd, *J* = 7.2, 5.2 Hz), 4.59 (1H, dd, *J* = 15.6, 7.2 Hz), 7.18-7.22 (2H, m), 7.23-7.30 (3H, m), 7.33-7.42 (3H, m), 7.82-7.85 (2H, m); ^{13}C NMR (100 MHz, CDCl$_3$) δ 168.0, 167.8, 166.7, 137.2, 134.9, 133.7, 130.0, 128.8, 128.6, 128.4, 127.7, 75.6, 65.4, 62.1, 61.3, 53.4, 20.9, 13.6, 13.3. ESIHRMS: Found: *m/z* 380.1862. Calcld for $C_{23}H_{26}NO_4$: $(M+H)^+$ 380.1862.

Diethyl 4-(4-methoxyphenyl)-2-phenyl-4,5-dihydro-3H-pyrrole-3,3-dicarboxylate (5ca) :



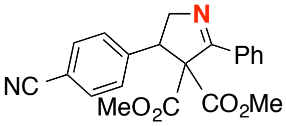
2 h, 63% yield, yellow solid, mp 100-102 °C; IR (NaCl) 3421, 3055, 2955, 1734, 1638, 1612, 1514, 1435, 1265, 1232, 1180 cm^{-1}; ^{1}H NMR (400 MHz, CDCl$_3$) δ 3.26 (3H, s), 3.71 (3H, s), 3.76 (3H, s), 4.39 (1H, dd, *J* = 16.0, 5.2 Hz), 4.47 (1H, dd, *J* = 7.2, 5.2 Hz), 4.57 (1H, dd, *J* = 16.0, 7.2 Hz), 6.81 (2H, d, *J* = 8.4 Hz), 7.12 (2H, d, *J* = 8.4 Hz), 7.33-7.41 (3H, m), 7.82 (2H, d, *J* = 8.4 Hz); ^{13}C NMR (100 MHz, CDCl$_3$) δ 168.6, 167.2, 167.1, 159.0, 133.3, 130.2, 129.8, 129.6, 128.4, 127.9, 113.6, 75.5, 65.7, 55.1, 53.4, 53.0, 52.0. ESIHRMS: Found: *m/z* 368.1497. Calcld for $C_{21}H_{22}NO_5$: $(M+H)^+$ 368.1498.

Diethyl 4-(2-chlorophenyl)-2-phenyl-4,5-dihydro-3H-pyrrole-3,3-dicarboxylate (5da) :



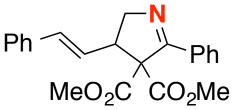
11 h, 60% yield, pale yellow solid, mp 116-118 °C; IR (NaCl) 3439, 3055, 2985, 2953, 1732, 1645, 1626, 1477, 1435, 1265, 1066 cm^{-1}; ^{1}H NMR (400 MHz, CDCl$_3$) δ 3.22 (3H, s), 3.75 (3H, s), 4.41 (1H, dd, *J* = 16.8, 4.8 Hz), 4.63 (1H, dd, *J* = 16.8, 8.0 Hz), 5.12 (1H, dd, *J* = 8.0, 4.8 Hz), 7.14-7.19 (3H, m), 7.34-7.43 (4H, m), 7.88 (2H, d, *J* = 7.2 Hz); ^{13}C NMR (100 MHz, CDCl$_3$) δ 168.4, 167.0, 166.9, 136.6, 134.9, 132.9, 130.4, 129.4, 129.0, 128.8, 128.5, 128.1, 126.8, 75.0, 66.5, 53.2, 51.9, 49.8. ESIHRMS: Found: *m/z* 372.1008. Calcld for $C_{20}H_{19}ClNO_4$: $(M+H)^+$ 372.1003.

Diethyl 4-(4-cyanophenyl)-2-phenyl-4,5-dihydro-3H-pyrrole-3,3-dicarboxylate (5ea) :



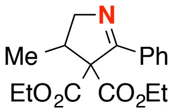
18 h, 67% yield, white solid, mp 142-144 °C; IR (NaCl) 3431, 3055, 2986, 2230, 1732, 1636, 1611, 1435, 1317, 1265, 1233, 1089 cm^{-1}; ^{1}H NMR (400 MHz, CDCl$_3$) δ 3.25 (3H, s), 3.74 (3H, s), 4.40 (1H, dd, *J* = 15.2, 4.0 Hz), 4.55-4.64 (2H, m), 7.32-7.45 (5H, m), 7.58 (2H, d, *J* = 8.4 Hz), 7.82 (2H, d, *J* = 7.2 Hz); ^{13}C NMR (100 MHz, CDCl$_3$) δ 168.1, 167.2, 166.7, 143.7, 132.9, 132.0, 130.5, 129.3, 128.6, 128.0, 118.4, 111.6, 75.6, 65.1, 53.6, 53.3, 52.2. ESIHRMS: Found: *m/z* 363.1345. Calcld for $C_{21}H_{19}N_2O_4$: $(M+H)^+$ 363.1345.

Dimethyl (E)-2-phenyl-4-styryl-4,5-dihydro-3H-pyrrole-3,3-dicarboxylate (5fa) :



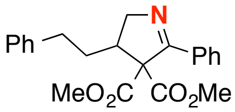
6 h, 58% yield, yellow stick oil; IR (NaCl) 3419, 3057, 2953, 1736, 1653, 1616, 1576, 1494, 1435, 1265, 1227, 1184 1065 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$) δ 3.68 (3H, s), 3.72 (3H, s), 3.98 (1H, ddd, *J* = 8.8, 7.2, 6.4 Hz), 4.08 (1H, dd, *J* = 16.4, 6.4 Hz), 4.42 (1H, dd, *J* = 16.4, 7.2 Hz), 6.15 (1H, dd, *J* = 15.6, 8.8 Hz), 6.55 (1H, d, *J* = 15.6 Hz), 7.22-7.44 (8H, m), 7.83 (2H, d, *J* = 7.6 Hz); ^{13}C NMR (100 MHz, $CDCl_3$) δ 168.5, 167.6, 167.4, 136.5, 133.6, 133.2, 130.3, 128.5, 128.3, 128.0, 127.8, 126.3, 125.7, 73.8, 64.8, 53.0, 52.6. ESIHRMS: Found: *m/z* 364.1548. Calcld for $C_{22}H_{22}NO_4$: $(M+H)^+$ 364.1549.

Diethyl 4-methyl-2-phenyl-4,5-dihydro-3H-pyrrole-3,3-dicarboxylate (5ga) :



10 min, 60% yield, pale yellow stick oil; IR (NaCl) 3431, 2980, 2937, 1730, 1662, 1614, 1576, 1447, 1368, 1252, 1190 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.09 (3H, t, *J* = 7.2 Hz), 1.17 (3H, d, *J* = 7.2 Hz), 1.22 (3H, t, *J* = 7.2 Hz), 3.21-3.28 (1H, m), 3.70 (1H, dd, *J* = 16.0, 7.2 Hz), 4.06-4.18 (2H, m), 4.20-4.33 (3H, m), 7.32-7.40 (3H, m), 7.74 (2H, d, *J* = 7.6 Hz); ^{13}C NMR (100 MHz, $CDCl_3$) δ 168.7, 168.4, 167.2, 133.9, 130.0, 128.2, 127.8, 72.8, 66.6, 61.8, 61.6, 43.6, 14.4, 14.0, 13.6. ESIHRMS: Found: *m/z* 304.1547. Calcld for $C_{17}H_{22}NO_4$: $(M+H)^+$ 304.1549.

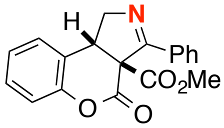
Dimethyl 4-phenethyl-2-phenyl-4,5-dihydro-3H-pyrrole-3,3-dicarboxylate (5ha) :

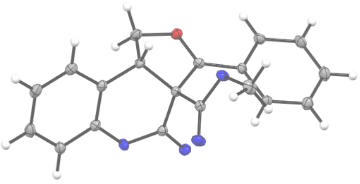


2 h, 61% yield, pale yellow stick oil; IR (NaCl) 3421, 3053, 2953, 1736, 1647, 1628, 1435, 1265, 1202, 1184 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.66-1.76 (1H, m), 1.99-2.07 (1H, m), 2.65-2.72 (2H, m), 3.09-3.17 (1H, m), 3.61 (3H, s), 3.74 (3H, s), 3.75 (1H, dd, *J* = 16.0, 8.8 Hz), 4.34 (1H, dd, *J* = 16.0, 7.6 Hz), 7.17-7.21 (3H, m), 7.28 (2H, dd, *J* = 8.0, 7.2 Hz), 7.32-7.41 (3H, m), 7.68 (2H, d, *J* = 7.6 Hz); ^{13}C NMR (100 MHz, $CDCl_3$) δ 169.1, 168.6, 167.5, 141.1, 133.5, 130.2,

128.4, 128.3, 128.1, 127.9, 126.1, 72.0, 64.7, 52.8, 52.5, 49.0, 34.2, 31.3. ESIHRMS: Found: *m/z* 366.1707. Calcld for $C_{22}H_{24}NO_4$: $(M+H)^+$ 366.1705.

Methyl (3a*R,9b*S**)-4-Oxo-3-phenyl-1,9b-dihydrochromeno[3,4-c]pyrrole-3a(4*H*)-carboxylate (5ia) :**





X-ray of **5ia**

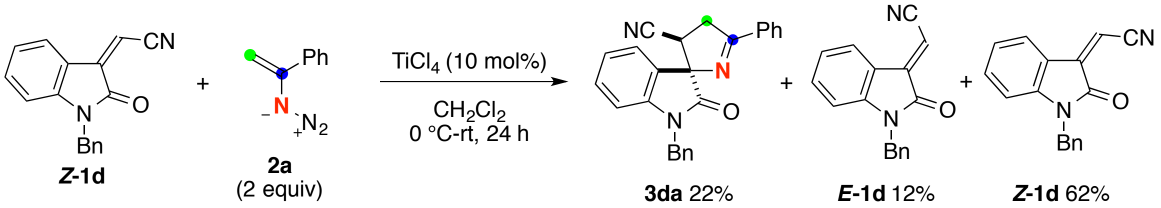
20 mol% of $TiCl_4$ was used. 20 h, 83% yield, colorless crystal (CCDC 1436813) ; mp 174-176 °C; IR (NaCl) 3421, 3053, 2986, 1763, 1742, 1607, 1576, 1607, 1490, 1308, 1265, 1184, 1111 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ 3.69 (3H, s), 3.80 (1H, dd, *J* = 16.0, 10.0 Hz), 4.16 (1H, dd, *J* = 10.0, 7.6 Hz), 4.57 (1H, d, *J* = 16.0, 7.6 Hz), 7.18 (2H, dd, *J* = 8.0, 7.2 Hz), 7.28 (1H, d, *J* = 7.6 Hz), 7.34 (1H, dd, *J* = 8.0, 7.6 Hz), 7.40-7.48 (3H, m), 7.97 (2H, d, *J* = 7.6 Hz); ^{13}C NMR (100 MHz, $CDCl_3$) δ 169.5, 168.7, 162.1, 150.0, 132.3, 131.0, 129.3, 128.9, 128.5, 128.4, 125.1, 118.7, 117.2, 66.3, 65.6, 53.8, 49.4. ESIHRMS: Found: *m/z* 322.1079. Calcld for $C_{19}H_{16}NO_4$: $(M+H)^+$ 322.1079.

7. Elucidation of the reaction mechanisms

7.1 The reaction of (*Z*)-2-(1-benzyl-2-oxoindolin-3-ylidene)acetonitrile (*Z*-1d) with vinyl azide 2a

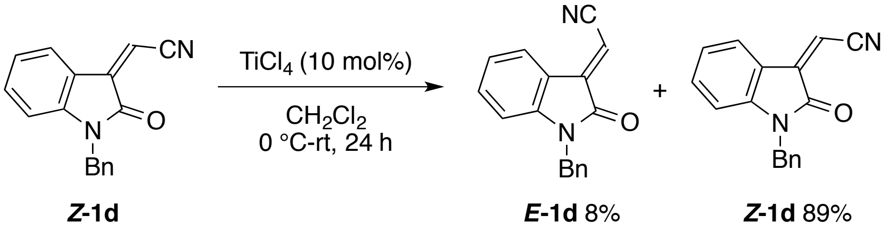
The reaction of (*Z*)-2-(1-benzyl-2-oxoindolin-3-ylidene)acetonitrile (*Z*-**1d**) with vinyl azide **2a** was conducted under the standard reaction conditions (Scheme S1). On the contarty to the reaction of *E*-isomer, that of *Z*-isomer proceeded very slowly, providing product **3da** in only 22% yield with the same diastereoselectivity even after 24 h of the reaction time. Interestingly, the *E*-isomer was isolated in 12% yield along with recovery of *Z*-**1d** in 62% yield.

Scheme S1.



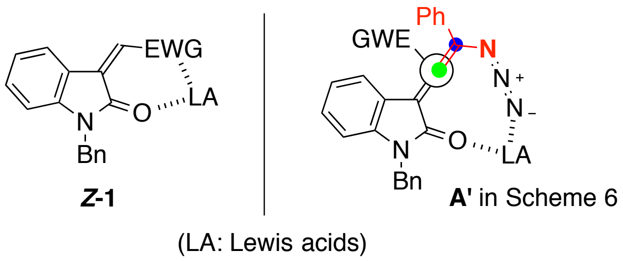
We wondered if the the *E*-*Z* isomerization takes place under the reaction conditions. Thus, *Z*-**1d** was solely treated under the standard reaction conditions (Scheme S2). As expected, isomerization could be observed albeit in the slow reaction rate (the *E*-**1d** was formed in 8% yield after 24 h).

Scheme S2.



Based on these results, it could be speculated that only *E*-isomers can react with vinyl azide **2a** under the standard reaction conditions. The *Z*-isomer could form internal chelation (Scheme S3) to prevent cooridnation of Lewis acids to both **1** and vinyl azides **2** in the state **A'** with the favoured bimolecular allignment described in Scheme 6.

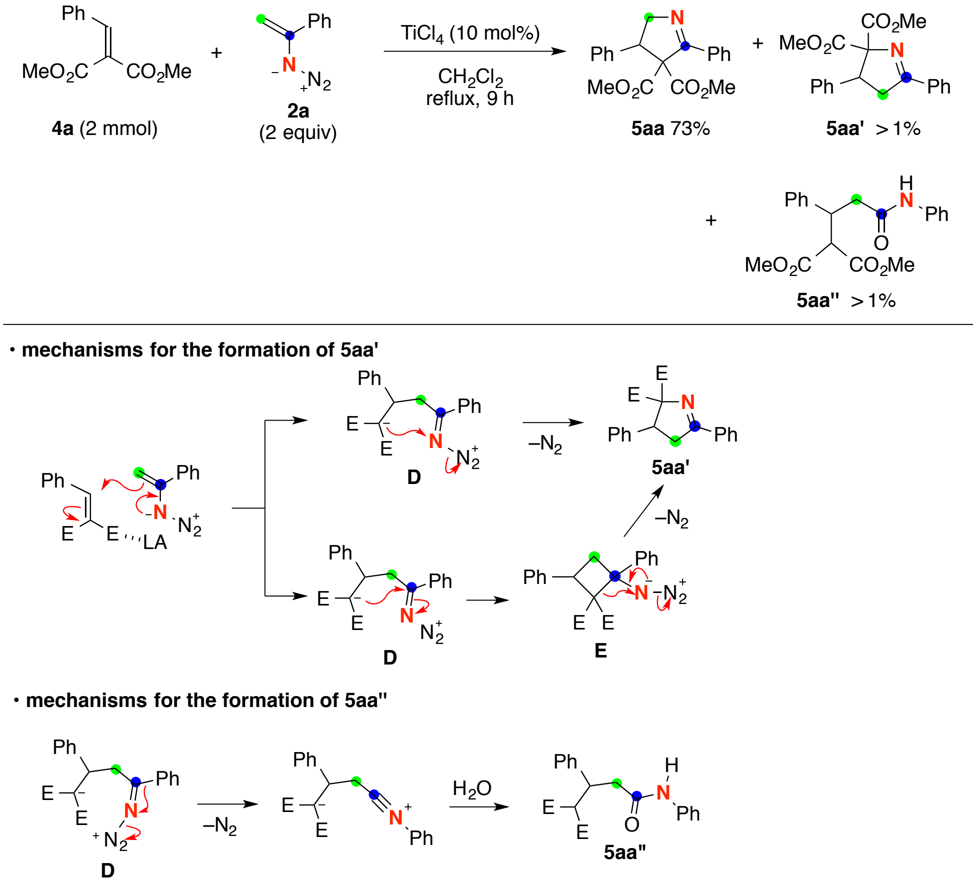
Scheme S3.



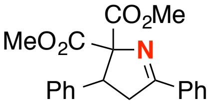
7.2 Formation of 5aa’ and 5aa’’ (reference 11)

In the reaction of **4a** and **2a** in 2 mmol scale, in addition to the formation of 1-pyrroline **5aa** (73% yield), a trace amount (>1% yield) of another 1-pyrroline **5aa’** and acyclic amide **5aa’’** were isolated (Scheme S4). There might be two mechanistic possibilities for the formation of **5aa’**: 1) nucleophilic substitution reaction of the active methine carbanion on the iminodiazonium ion **D** (Scheme 6-b); or 2) ring-expansion of azidocycloburane intermediate **E** (Scheme 6-b) by migration of the quaternary carbon having two methoxycarbonyl groups. The formation of **5aa’** should be enabled via the Schmidt type migration of the iminodiazonium intermedaite **D** (Schemd 6-b) followed by hydrolysis of the resulting nitririum ion.[13] Nonetheless, the formation of **5aa’** and **5aa”** supports the mechanistic proposal in Scheme 6 including stepwise sequence of conjugate addtion of vinyl azides, azidocyclobutane formation, and ring-expansion.

Scheme S4.

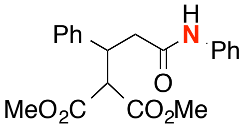


Dimethyl 3,5-diphenyl-3,4-dihydro-2*H*-pyrrole-2,2-dicarboxylate (5aa') :



Yellow stick oil including a small amout of inseparable impurity; IR (NaCl) 3053, 2983, 1730, 1618, 1516, 1445, 1265, 1227, 1093 cm^{-1}; ^{1}H NMR (400 MHz, CDCl$_3$) δ 3.26 (3H, s), 3.43 (1H, dd, *J* = 17.6, 5.6 Hz), 3.66 (1H, dd, *J* = 17.6, 9.2 Hz), 3.84 (3H, s), 4.54 (1H, dd, *J* = 9.2, 5.6), 7.21-7.28 (5H, m), 7.44-7.54 (3H, m), 7.99 (2H, d, *J* = 7.2 Hz); ^{13}C NMR (100 MHz, CDCl$_3$) δ 178.0, 169.5, 168.1, 139.4, 133.2, 131.7, 128.6, 128.5, 128.3, 128.2, 127.4, 91.8, 53.3, 52.0, 48.6, 43.5. ESIHRMS: Found: *m/z* 338.1392. Calcld for $C_{20}H_{20}NO_4$: $(M+H)^+$ 338.1392.

Dimethyl 2-(3-oxo-1-phenyl-3-(phenylamino)propyl)malonate (5aa'') :

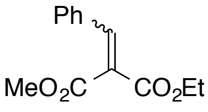


Yellow stick oil including a small amout of inseparable impurity; IR (NaCl) 3319, 3059, 2955, 1748, 1732, 1666, 1599, 1499, 1265, 1153 cm^{-1}; ^{1}H NMR (400 MHz, CDCl$_3$) δ 2.77 (1H, dd, *J* = 14.4, 8.0 Hz), 2.91 (1H, dd, *J* = 14.4, 5.2 Hz), 3.48 (3H, s), 3.75 (3H, s), 3.90 (1H, d, *J* = 9.2 Hz), 4.01 (1H, ddd, *J* = 9.2, 8.0, 5.2 Hz), 7.05 (1H, t, *J* = 7.2 Hz), 7.23-7.34 (10H, m); ^{13}C NMR (100 MHz, CDCl$_3$) δ 168.8, 168.6, 168.0, 140.0, 137.6, 128.8, 128.7, 127.9, 127.5, 124.2, 119.8, 56.7, 52.8, 52.5, 42.2, 41.7. ESIHRMS: Found: *m/z* 356.1496. Calcld for $C_{20}H_{22}NO_5$: $(M+H)^+$ 356.1498.

7.3 The reaction of 1-ethyl 3-methyl 2-benzylidenemalonate (4j and 4j', *E/Z* mixtures) with vinyl azide 2a

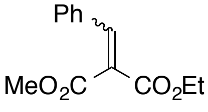
To confirm the stepwise nature of the present process, 1-ethyl-3-methyl 2-benzylidenemalonate was prepared from benzaldehyde and ethyl methyl malonate[14] by following the typical procedure (see Section 6.1). Purification of the crude materials by flash column chromatography gave two sets of *E/Z* mixtures having different E/Z ratio: **4j** (*E*:*Z* = 1:1.4) and **4j'** (*E*:*Z* = 2.5:1).[15]

1-Ethyl 3-methyl-2-benzylidenemalonate (4j) (*E/Z* = 1:1.4)



^{1}H NMR (400 MHz, $CDCl_3$) δ 1.27 (3H×1, t, *J* = 7.2 Hz), 1.33 (3H×1.4, t, *J* = 7.2 Hz), 3.84 (3H×1+3H×1.4, s), 4.28-4.36 (2H×1+2H×1.4, m), 7.34-7.46 (5H×1+5H×1.4, m), 7.75 (1H×1.4, s), 7.76 (1H×1, s); ^{13}C NMR (100 MHz, $CDCl_3$) δ 167.1, 166.5, 164.5, 163.9, 142.5, 142.4, 132.8 (overlapped), 130.5 (overlapped), 129.4, 129.3, 128.8, 128.7, 125.90, 125.88, 61.7, 61.6, 52.5 (overlapped), 14.1, 13.8.

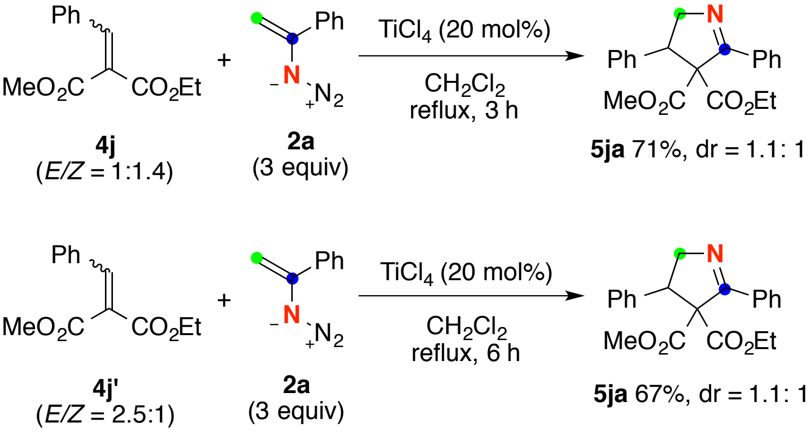
1-Ethyl 3-methyl-2-benzylidenemalonate (4j') (*E/Z* = 2.5:1)



A trace amount of inseparable impurity is contained. ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.27 (3H×2.5, t, *J* = 7.2 Hz), 1.33 (3H×1, t, *J* = 7.2 Hz), 3.84 (3H×2.5+3H×1, s), 4.28-4.36 (2H×2.5+2H×1, m), 7.34-7.46 (5H×2.5+5H×1, m), 7.75 (1H×1, s), 7.76 (1H×2.5, s); ^{13}C NMR (100 MHz, $CDCl_3$) δ 167.1, 166.6, 164.5, 164.0, 142.5, 142.4, 132.8 (overlapped), 130.5 (overlapped), 129.4, 129.3, 128.8, 128.7, 125.90, 125.88, 61.7, 61.6, 52.5 (overlapped), 14.1, 13.8.

4j and **4j'** were treated with 20 mol% of $TiCl_4$ in CH_2Cl_2 under reflux reaction conditions (Scheme S5). Both of the reactions provided product **5ja** with the same diastereoselectivity (dr = 1.1:1). These results further support the proposed stepwise mechanism including active methine enolate anion **D**.

Scheme S5.



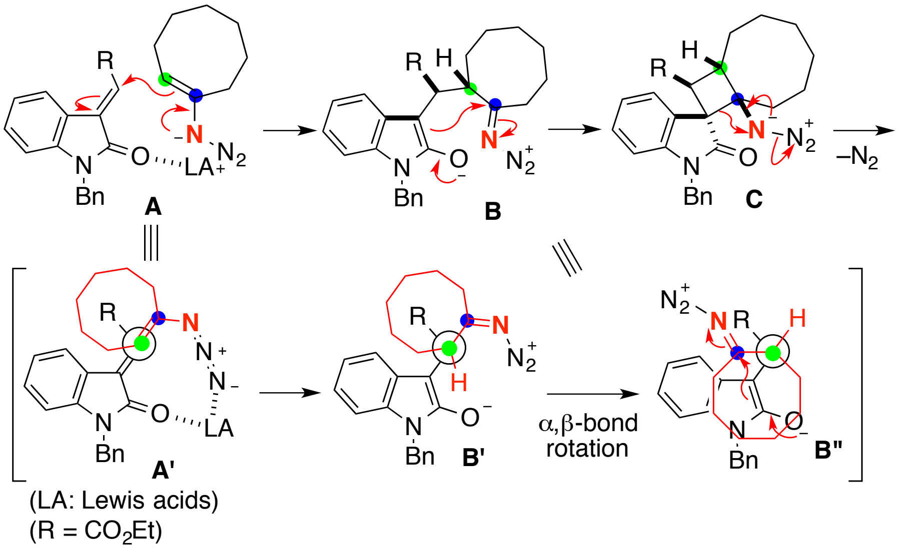
3-Ethyl 3-methyl 2,4-diphenyl-4,5-dihydro-3*H*-pyrrole-3,3-dicarboxylate (5ja) :

Yellow stick oil, IR (NaCl) as the mixture: 2976, 2934, 2866, 1732, 1616, 1605, 1576, 1494, 1444, 1369, 1118, 1028 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$) for the major isomer: δ 0.79 (3H, t, *J* = 7.2 Hz), 3.62-3.67 (2H, m), 3.72 (3H, s), 4.41-4.46 (1H, m), 4.51-4.61 (2H, m), 7.20-7.28 (5H, m), 7.33-7.41 (3H, m), 7.82-7.85 (2H, m); for the minor isomer: 1.10 (3H, t, *J* = 7.2 Hz), 3.21 (3H, s), 4.18 (2H, q, *J* = 7.2 Hz), 4.41-4.46 (1H, m), 4.51-4.61 (2H, m), 7.20-7.28 (5H, m), 7.33-7.41 (3H, m), 7.82-7.85 (2H, m); ^{13}C NMR (100 MHz, $CDCl_3$) as the mixture: δ 168.7, 167.9, 167. 5, 167.4, 167.1, 166.5, 138.2, 138.0, 133.5, 133.4, 130.1, 130.1, 128.6, 128.6, 128.5, 128.2, 128.2, 127.8, 127.8, 127.6, 127.5, 75.8, 75.5, 65.54, 65.46, 62.3, 61.4, 53.8, 53.7, 53.0, 51.9, 13.6, 13.2. ESIHRMS: Found: *m/z* 352.1547. Calcld for $C_{21}H_{22}NO_4$: $(M+H)^+$ 352.1549.

7.4. Origin of the diastereoselectivity in the reactions of cyclic vinyl azide 2h

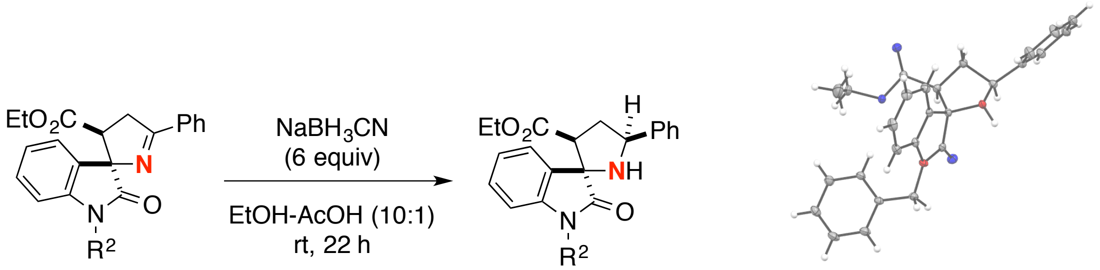
The diastereoselectivity for the reaction of cyclic vinyl azide **2h** (Scheme 3) could be rationalized as shown in Scheme S6.

Scheme S6



8. Further transformation of procuts 3aa, 3ea, and 5aa (Scheme 7)

8.1 Reduction of 3aa and 3ea



3aa (R^2 = Bn)
3ea (R^2 = H)

6a (R^2 = Bn) 93%, dr = 43:1
6e (R^2 = H) 92% as single diastereomer

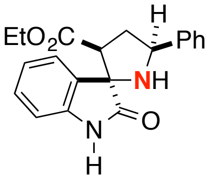
X-ray of **6a**

Typical procedure for reduction of 3aa:

To a solution of **3aa** (0.2 mmol, 84.9 mg) in the mixed solvent of EtOH and AcOH (10:1, 2 mL) was added $NaBH_3CN$ (1.2 mmol, 75.4 mg) at room temperature. The reaction mixture was stirred for 22 h at the same temperature and then quenched with saturated aqueous $NaHCO_3$. The mixture was extracted trice with CH_2Cl_2. The combined organic layers were washed with brine and dried over $MgSO_4$. The solvent was removed in *vacuo*, and the resulting crude materials were purified by flash column chromatography (silica gel; ethyl acetate: hexane = 20: 80) to give ethyl (3*R**,3'*S**,5'*S**)-1-benzyl-2-oxo-5'-phenylspiro[indoline-3,2'-pyrrolidine]-3'-carboxylate (**6a**, 0.186 mmol, 79.3 mg, dr = 43:1) in 93% yield.

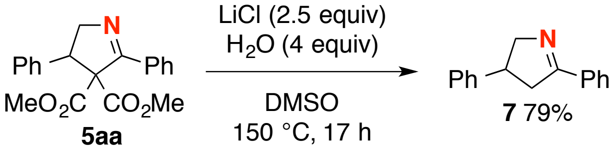
Colorless crystal (CCDC 1436814); mp 148-150 °C; IR (NaCl) 3352, 3055, 2982, 2936, 1732, 1614, 1487, 1468, 1371, 1178, 1028 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ 0.51 (3H, t, *J* = 7.2 Hz), 2.47 (1H, s br), 2.52-2.60 (2H, m), 3.57 (1H, dq, *J* = 10.4, 7.2 Hz), 3.65 (1H, dq, *J* = 10.4, 7.2 Hz), 3.75 (1H, dd, *J* = 11.6, 7.6 Hz), 4.71 (1H, d, *J* = 15.6 Hz), 4.87 (1H, dd, *J* = 10.4, 6.0 Hz), 5.13 (1H, d, *J* = 15.6 Hz), 6.68 (1H, d, *J* = 7.6 Hz), 7.00 (1H, dd, *J* = 7.6, 7.6 Hz), 7.14 (1H, dd, *J* = 8.0, 7.6 Hz), 7.26-7.38 (9H, m), 7.51 (2H, d, *J* = 7.6 Hz); ^{13}C NMR (100 MHz, $CDCl_3$) δ 180.1, 170.4, 142.7, 142.2, 135.6, 131.2, 129.0, 128.6, 128.4, 127.6, 127.5, 127.4, 126.7, 124.4, 122.9, 108.9, 68.5, 61.8, 60. 4, 53.8, 44.0, 37.7, 13.3. ESIHRMS: Found: *m/z* 427.2021. Calcld for $C_{27}H_{27}N_2O_3$: $(M+H)^+$ 427.2022.

Ethyl (3*R,3'*S**,5'*S**)-2-oxo-5'-phenylspiro[indoline-3,2'-pyrrolidine]-3'-carboxylate (6e) :**



Colourless stick oil, IR (NaCl) 3412, 3088, 2976, 2868, 1720, 1620, 1493, 1472, 1373, 1269, 1186, 1098 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ 0.76 (3H, t, *J* = 7.2 Hz), 2.46 (1H, s), 2.47-2.59 (2H, m), 3.64-3.73 (3H, m), 4.83 (1H, dd, *J* = 10.4, 5.6 Hz), 6.84 (1H, d, *J* = 7.6 Hz), 7.04 (1H, dd, *J* = 7.6, 7.6 Hz), 7.22 (1H, dd, *J* = 7.6, 7.6 Hz), 7.28-7.37 (3H, m), 7.50 (2H, d, *J* = 7.6 Hz), 7.59 (1H, s); ^{13}C NMR (100 MHz, $CDCl_3$) δ 182.4, 170.5, 142.2, 140.8, 131.5, 129.2, 128.5, 127.5, 126.7, 124.7, 122.8, 109.8, 69.1, 61.8, 60.5, 53.7, 37.5, 13.4. ESIHRMS: Found: *m/z* 337.1553. Calcld for $C_{20}H_{21}N_2O_3$: $(M+H)^+$ 337.1552.

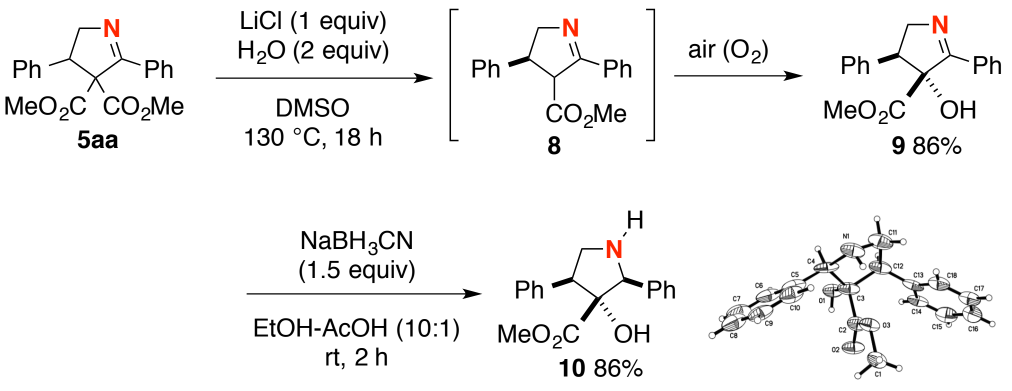
8.2 Decarboxylation of 5aa



To a solution of **5aa** (0.2 mmol, 67.5 mg) in DMSO (2 mL) was added LiCl (0.5 mmol, 21.2 mg) and H_2O (0.8 mmol, 14.4 µL) at room temperature. The reaction mixture was heated at 150 ºC and stirred for 17 h untill **5aa** was consumed. The reaction was cooled down to room temperature and diluted with water. The mixture was extracted trice with ethyl acetate. The combined organic layers were washed with water and brine and then dried over $MgSO_4$. After filtration, the solvent was removed in *vacuo*, and the resulting crude materials were purified by flash column chromatography (silica gel; ethyl acetate: hexane = 15:85) to give 3,5-diphenyl-3,4-dihydro-2*H*-pyrrole (**7**) (0.158 mmol, 35.0 mg) in 79% yield as a yellow sticky oil.

IR (NaCl) 3397, 3061, 1614, 1576, 1495, 1339, 1265, 1179 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ 3.08 (1H, dddd, *J* = 16.8, 6.4, 2.0, 1.6 Hz), 3.48 (1H, dddd, *J* = 16.8, 9.6, 2.0, 1.6 Hz), 3.68 (1H, dddd, *J* = 9.6, 8.8, 6.4, 6.0 Hz), 4.13 (1H, dddd, *J* = 16.4, 6.0, 2.0, 1.6 Hz), 4.54 (1H, dddd, *J* = 16.4, 8.8, 2.0, 1.6 Hz), 7.21-7.24 (3H, m), 7.30-7.34 (2H, m), 7.42-7.47 (3H, m), 7.88-7.90 (2H, m); ^{13}C NMR (100 MHz, $CDCl_3$) δ 172.3, 145.0, 134.3, 130.5, 128.7, 128.5, 127.6, 126.8, 126.4, 69.6, 44.0, 42.9. ESIHRMS: Found: *m/z* 222.1284. Calcld for $C_{16}H_{16}N$: $(M+H)^+$ 222.1283.

8.3 Decarboxylation and further transformation of 5aa



X-ray of **10**

To a solution of **5aa** (0.2 mmol, 67.5 mg) in DMSO (2 mL) was added LiCl (0.2 mmol, 8.5 mg) and H_2O (0.8 mmol, 7.2 µL) at room temperature. The reaction mixture was heated at 130 ºC and stirred for 18 h untill **5aa** was consumed. The reaction was cooled down to room temperature and diluted with water. The mixture was extracted trice with ethyl acetate. The combined organic layers were washed with water and brine and then dried over $MgSO_4$. The solvent was removed in *vacuo* and the crude material was purified by flash column chromatography (silica gel; ethyl acetate: hexane = 15:85) to give **8**. Auto-oxidation of **8** took place by exposure of **8** under air for overnight and then purification of the mixture by flash column chromatography (silica gel; ethyl acetate: hexane = 30:70) provided methyl (3*S**,4*R**)-4-hydroxy-3,5-diphenyl-3,4-dihydro-2*H*-pyrrole-4-carboxylate (**9**) (0.172 mmol, 50.8 mg, a single diastereomer) in 86% overall yield as a white solid.

Mp 160-163 °C; IR (NaCl) 3396, 3053, 1726, 1624, 1497, 1265, 1234, 1130 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ 3.48 (3H, s), 3.96 (1H, dd, *J* = 9.6, 8.0 Hz), 4.21 (1H, s), 4.40 (1H, dd, *J* = 15.6, 9.6 Hz), 4.48 (1H, dd, *J* = 15.6, 8.0 Hz), 7.26-7.36 (5H, m), 7.36-7.45 (3H, m), 7.83 (2H, d, *J* = 7.2 Hz); ^{13}C NMR (100 MHz, $CDCl_3$) δ 172.7, 170.4, 135.4, 132.3, 130.7, 128.5, 128.5, 127.8, 127.6, 90.4, 60.3, 57.7, 53.0. ESIHRMS: Found: *m/z* 296.1286. Calcld for $C_{18}H_{18}NO_3$: $(M+H)^+$ 296.1287.

To a solution of **9** (0.1 mmol, 29.5 mg) in the mixed solvent of EtOH and AcOH (10:1, 1 mL) was added $NaBH_3CN$ (0.15 mmol, 9.4 mg) at room temperature. The reaction mixture was stirred for 2 h at the same temperature and then quenched with saturated aqueous $NaHCO_3$. The mixture was extracted trice with CH_2Cl_2. The combined organic layers were washed with brine and dried over $MgSO_4$. After filtration, the solvent was removed in *vacuo*, and the resulting crude materials were purified by flash column chromatography (silica gel; ethyl acetate: hexane = 40:60) to give methyl (2*S**,3*R**,4*S**)-3-hydroxy-2,4-diphenylpyrrolidine-3-carboxylate (**10**) (0.085 mmol, 25.4 mg) as a single diastereomer in 86% yield.

Colorless crystal (CCDC 1436815, the solved crystal structure was disordered in two positions and the X-ray figure shown above is one component for clarity); mp 108-110 °C; IR (NaCl) 3397, 2978, 2868, 1718, 1491, 1229, 1381, 1134, 1072 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ 3.32 (3H, s), 3.71 (1H, dd, J = 10.8, 9.6 Hz), 3.82 (1H, J = 10.8, 10.0 Hz), 3.92 (1H, dd, J = 10.0, 9.6 Hz) 4.64 (1H, s), 7.22-7.32 (8H, m), 7.41 (2H, d, J = 7.2 Hz); ^{13}C NMR (100 MHz, $CDCl_3$) δ 172.8, 137.8, 136.9, 128.3, 128.2, 127.7, 127.6, 127.3, 126.0, 88.4, 70.8, 55.4, 52.0, 48.1. ESIHRMS: Found: *m/z* 298.1443. Calcld for $C_{18}H_{20}NO_3$: $(M+H)^+$ 298.1443.

9. References

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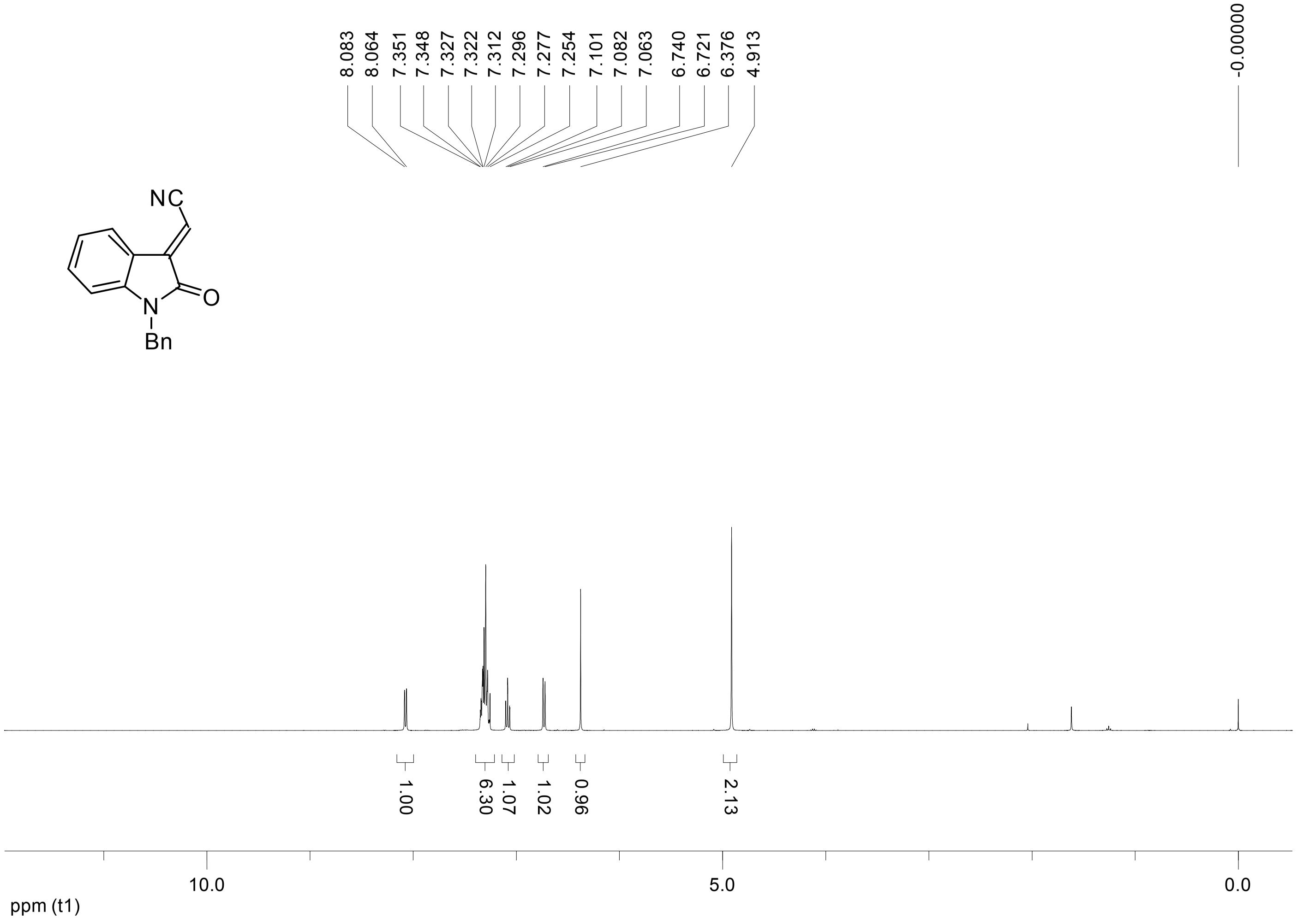
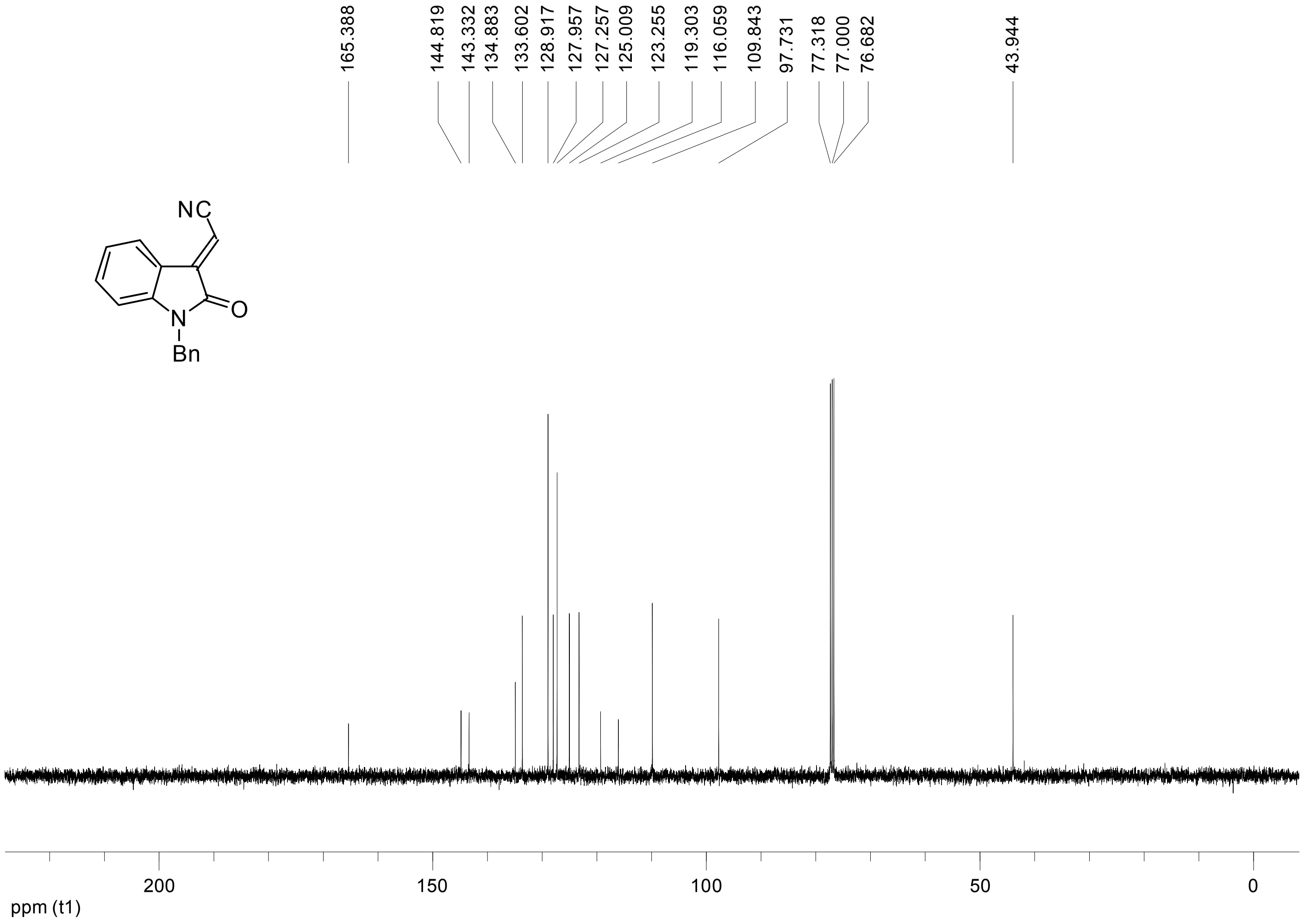
(15) For the compound data of (*Z*)-1-ethyl 3-methyl-2-benzylidenemalonate, see: J. Barluenga, L. riesgo, R. Vicente, L. López and M. Tomás, *J. Am. Chem. Soc*., 2007, **129**, 7772.

^{1}H NMR spectrum of ***E*-1d** (400 MHz, $CDCl_3$)



^{13}C NMR spectrum of ***E*-1d** (100 MHz, CDCl$_3$)



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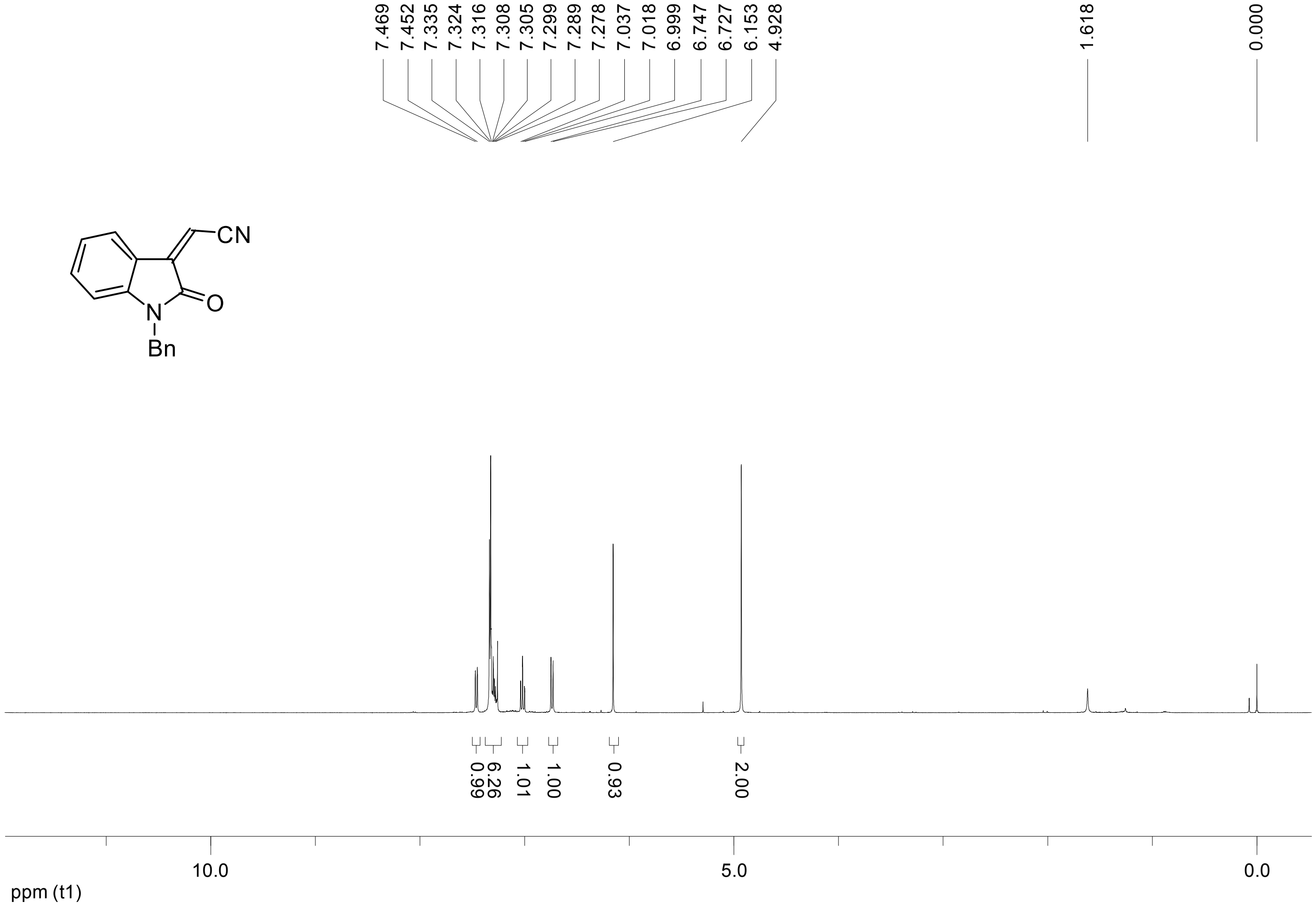

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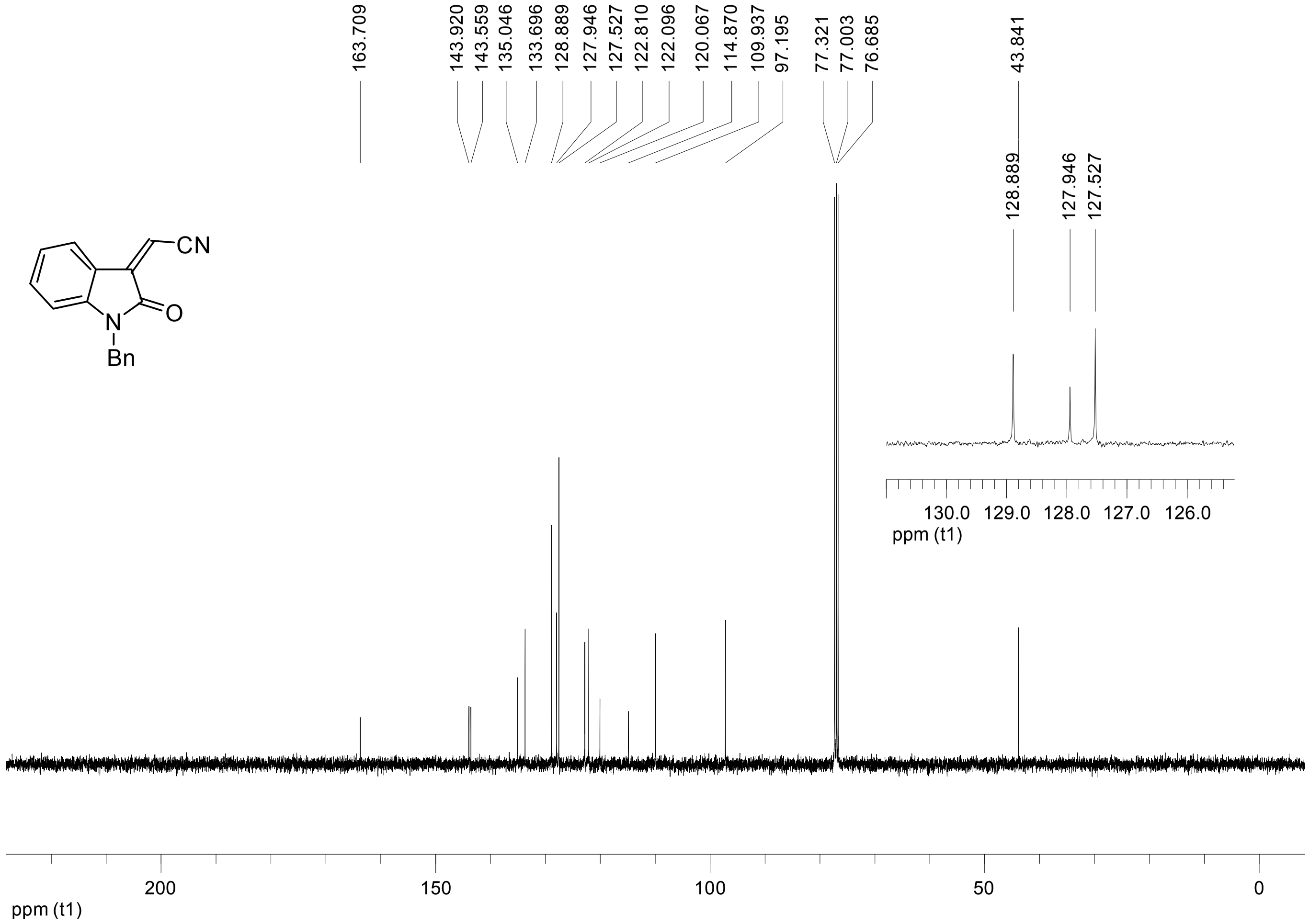
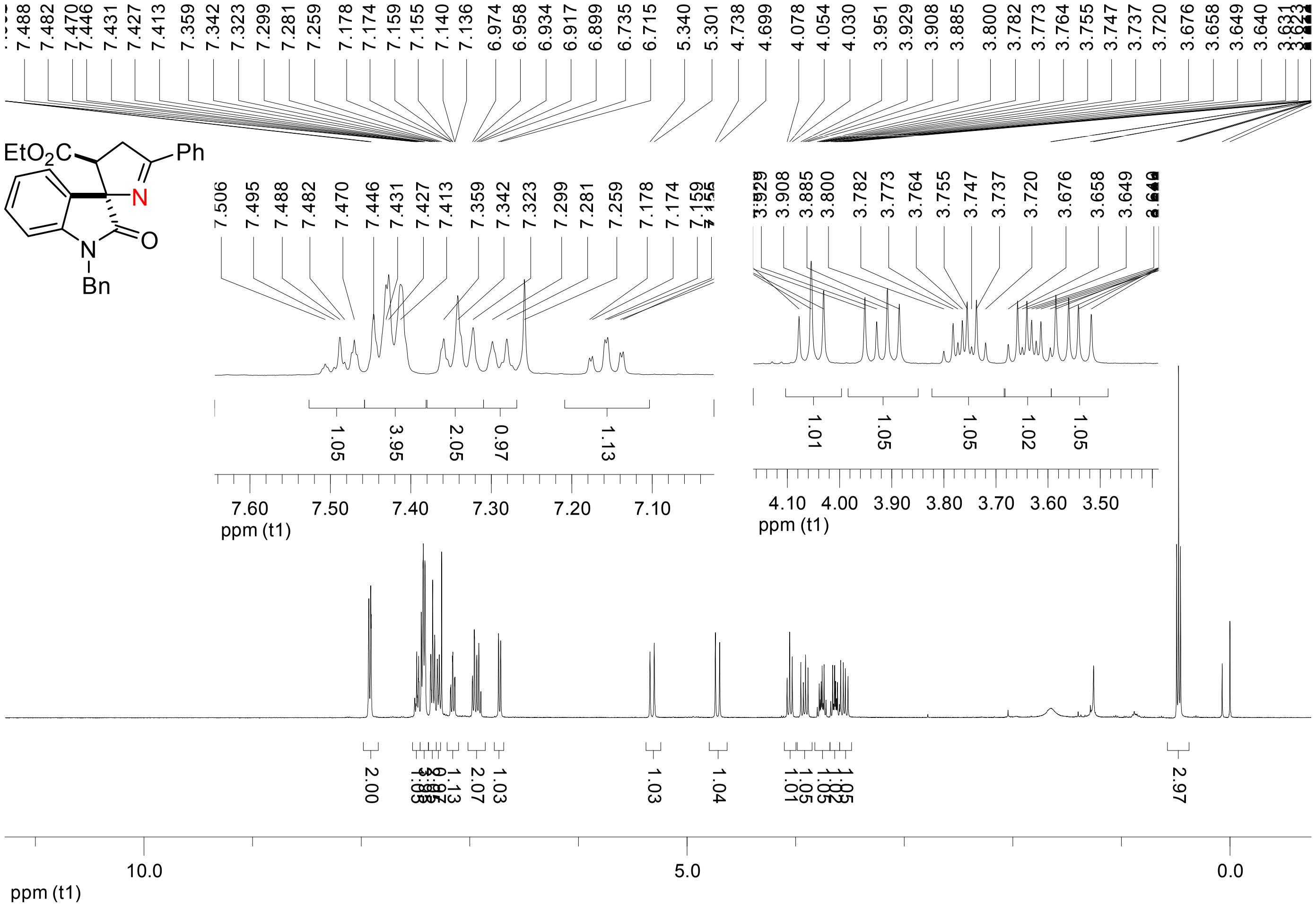


^{1}H NMR spectrum of **3aa**, single diastereomer (400 MHz, $CDCl_3$)



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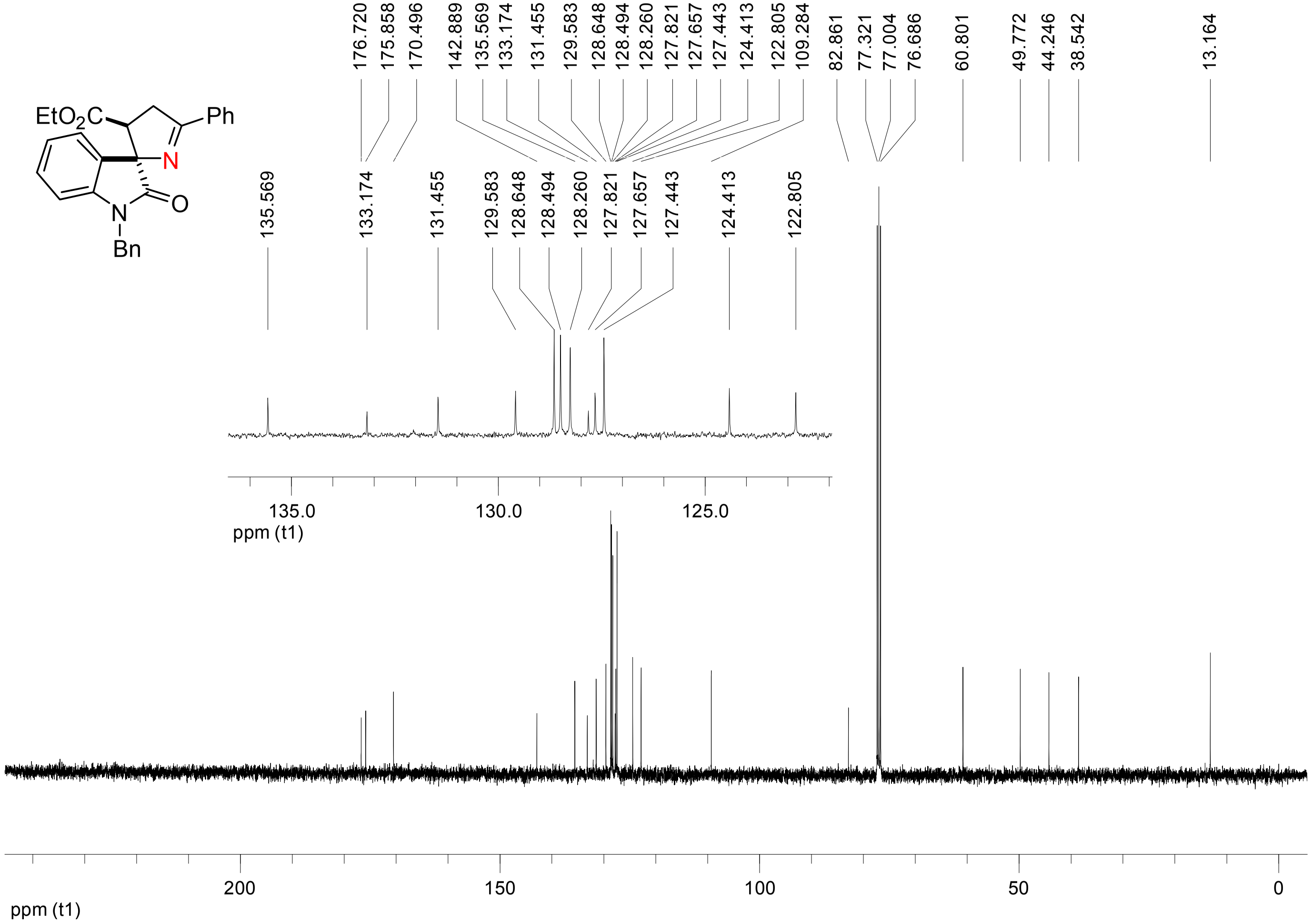

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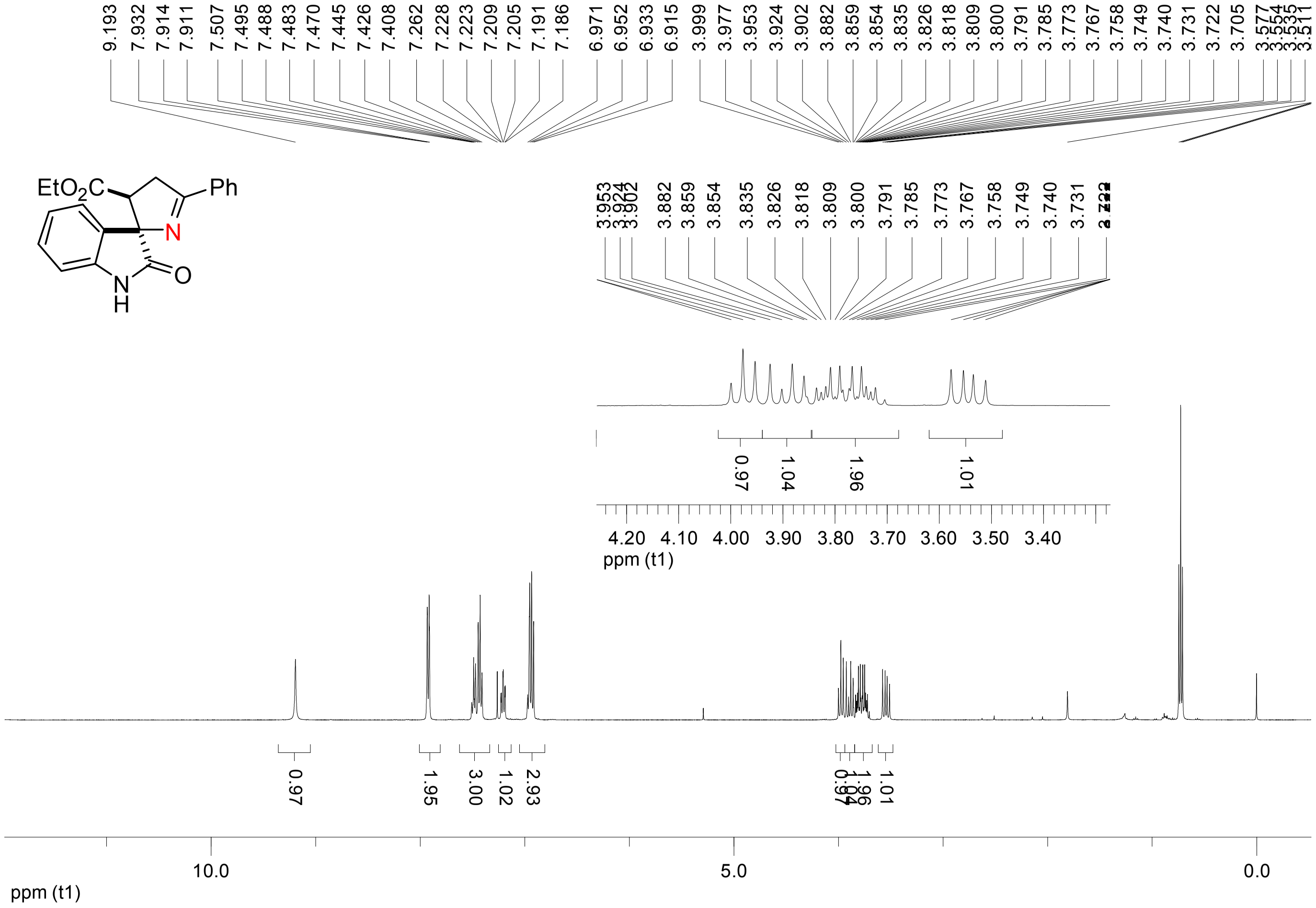

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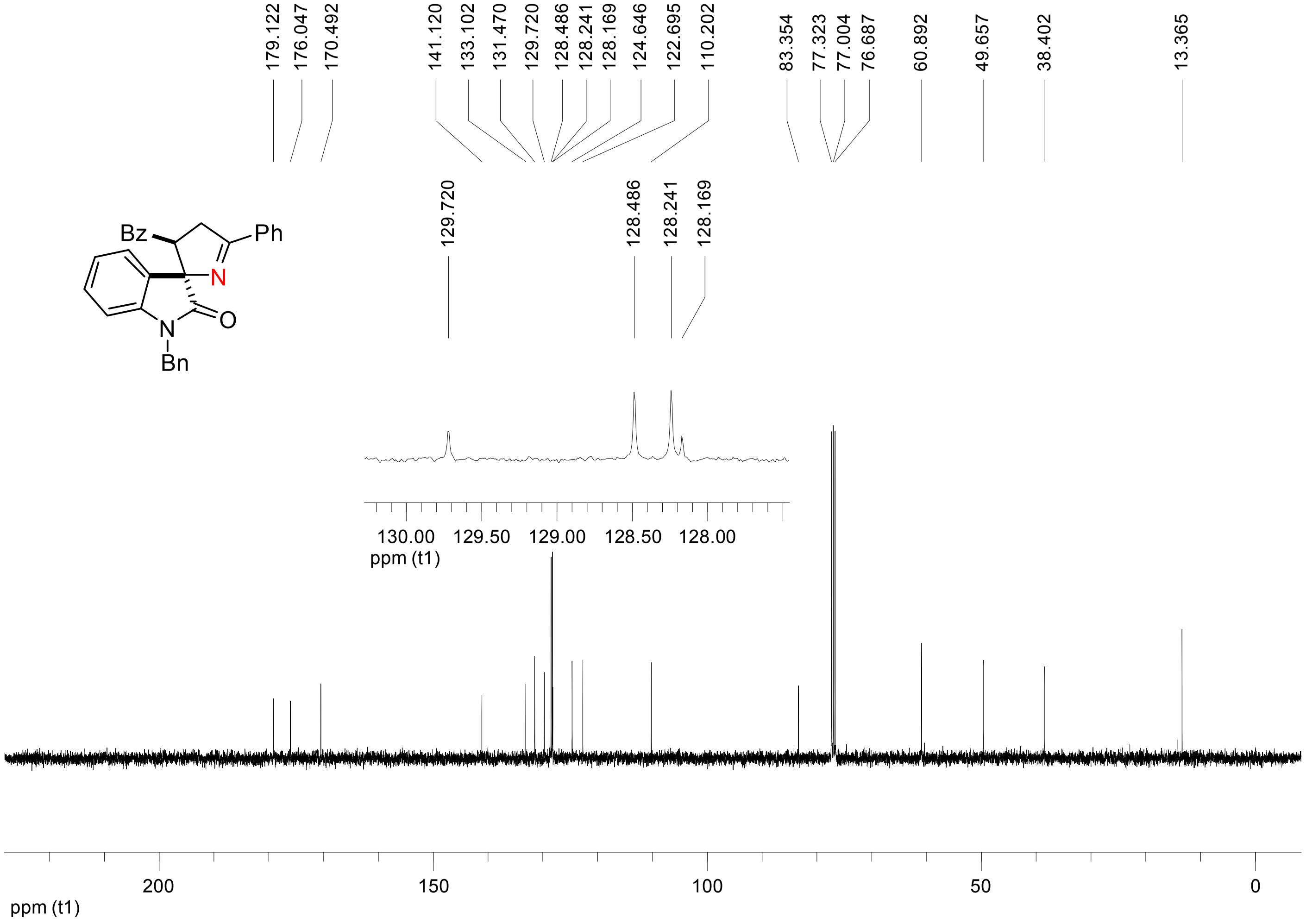

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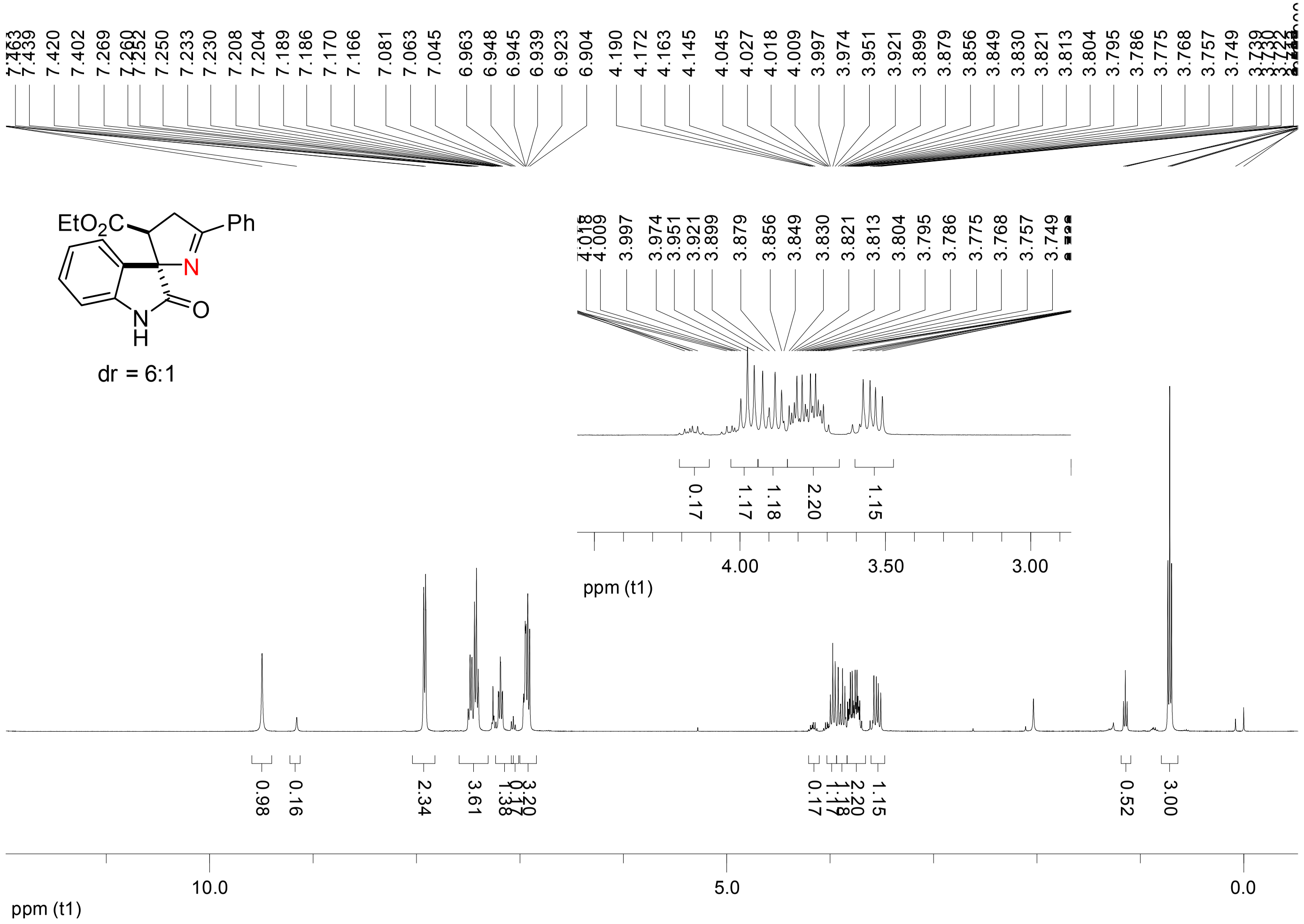

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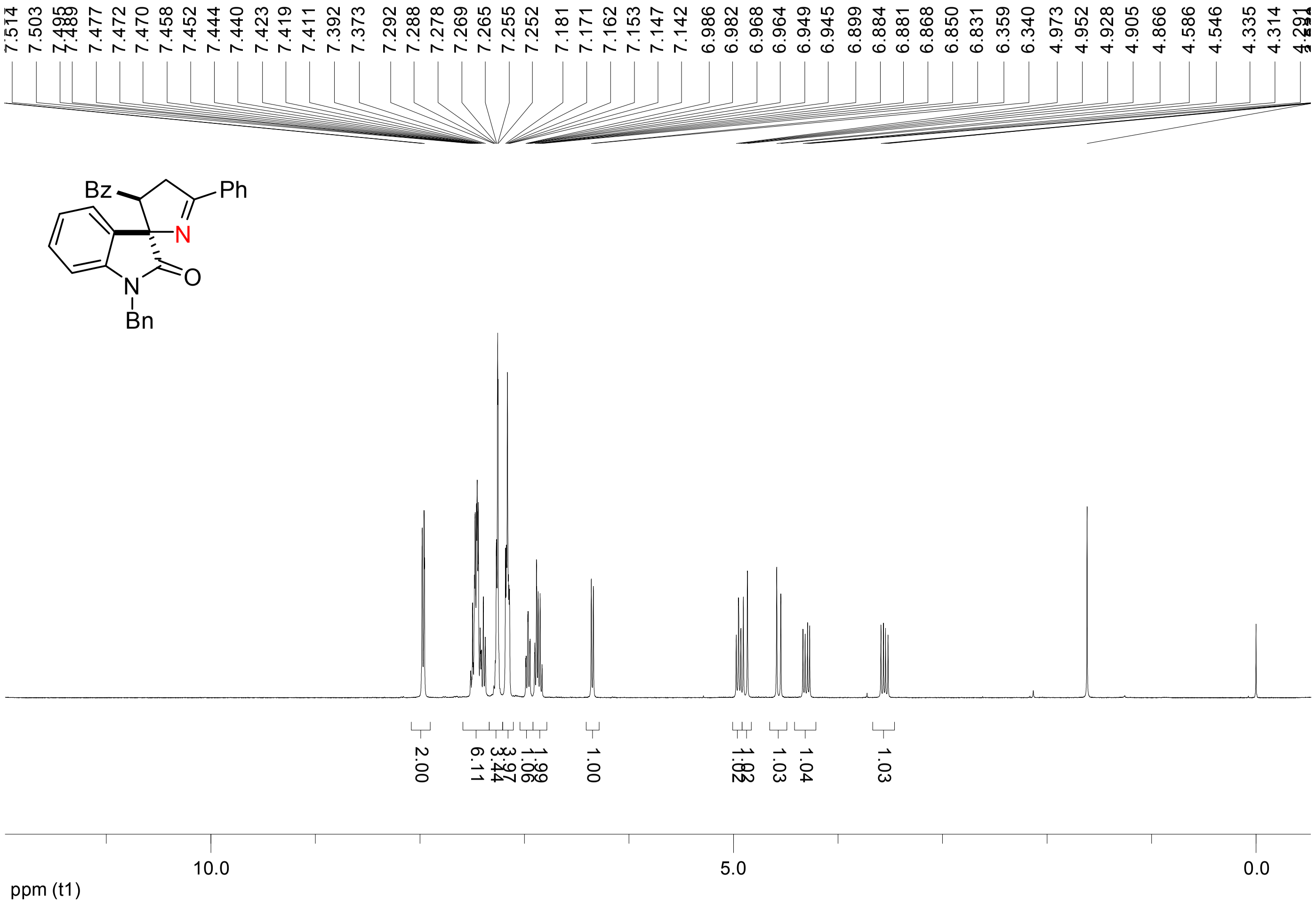

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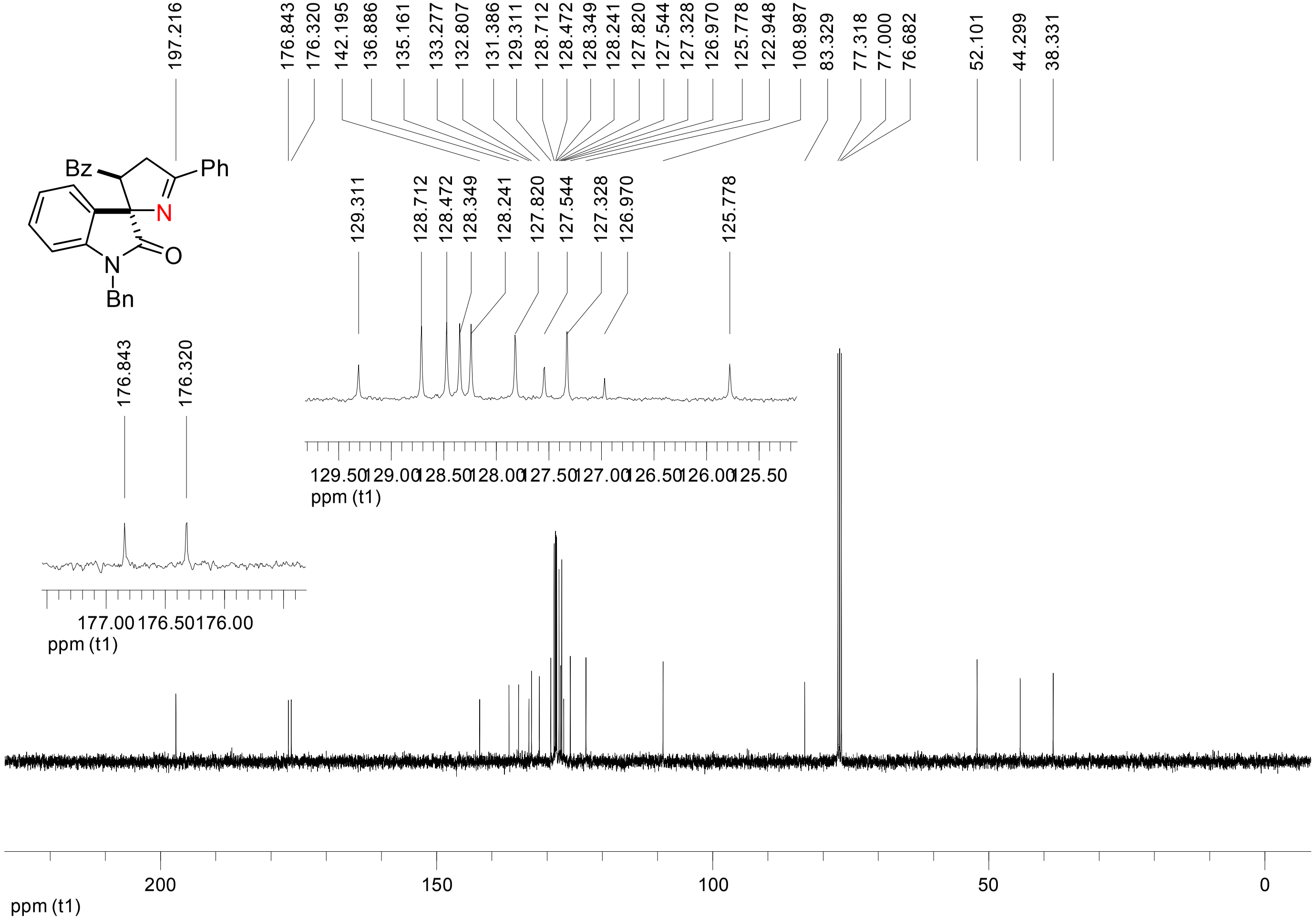

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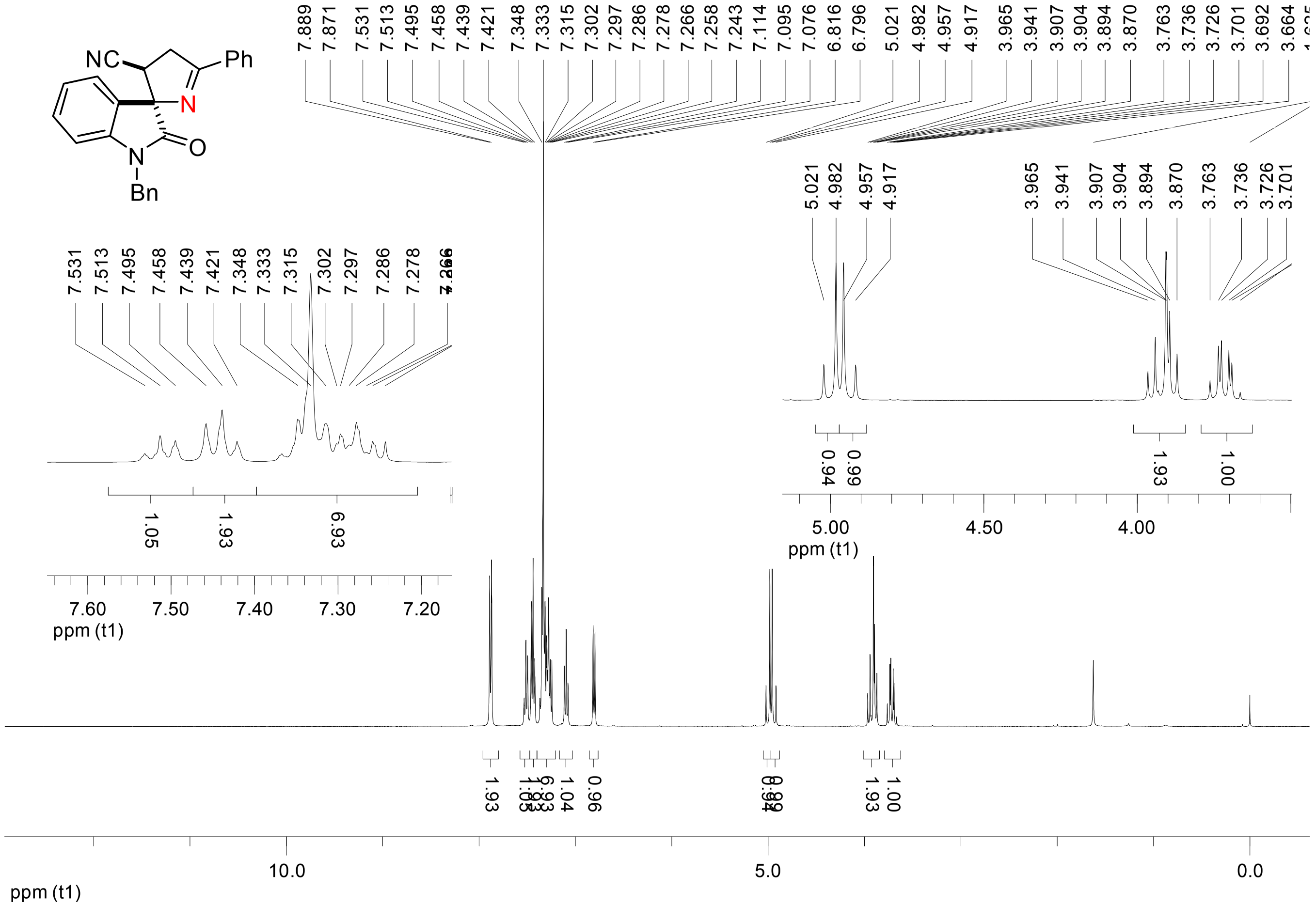

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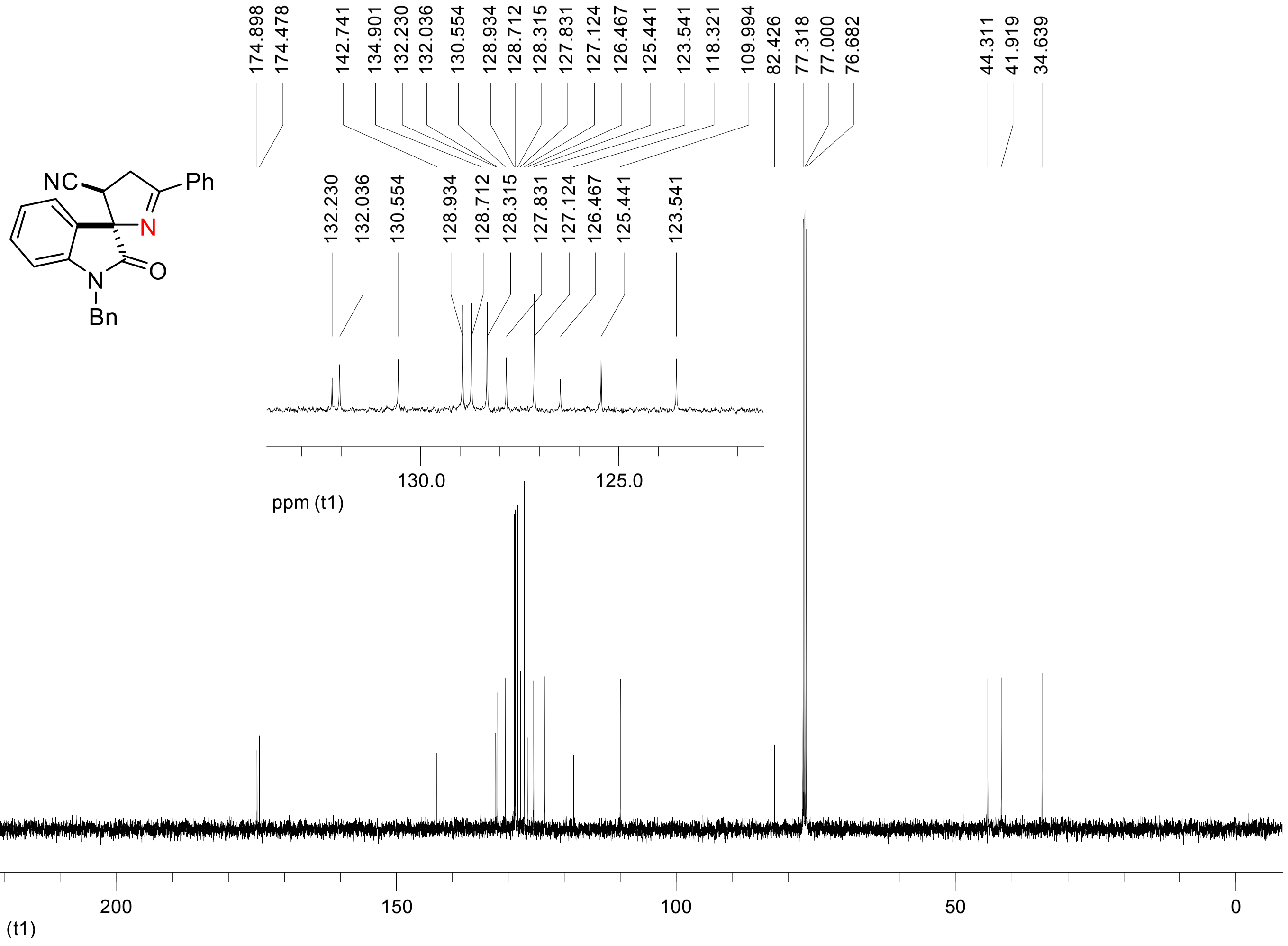

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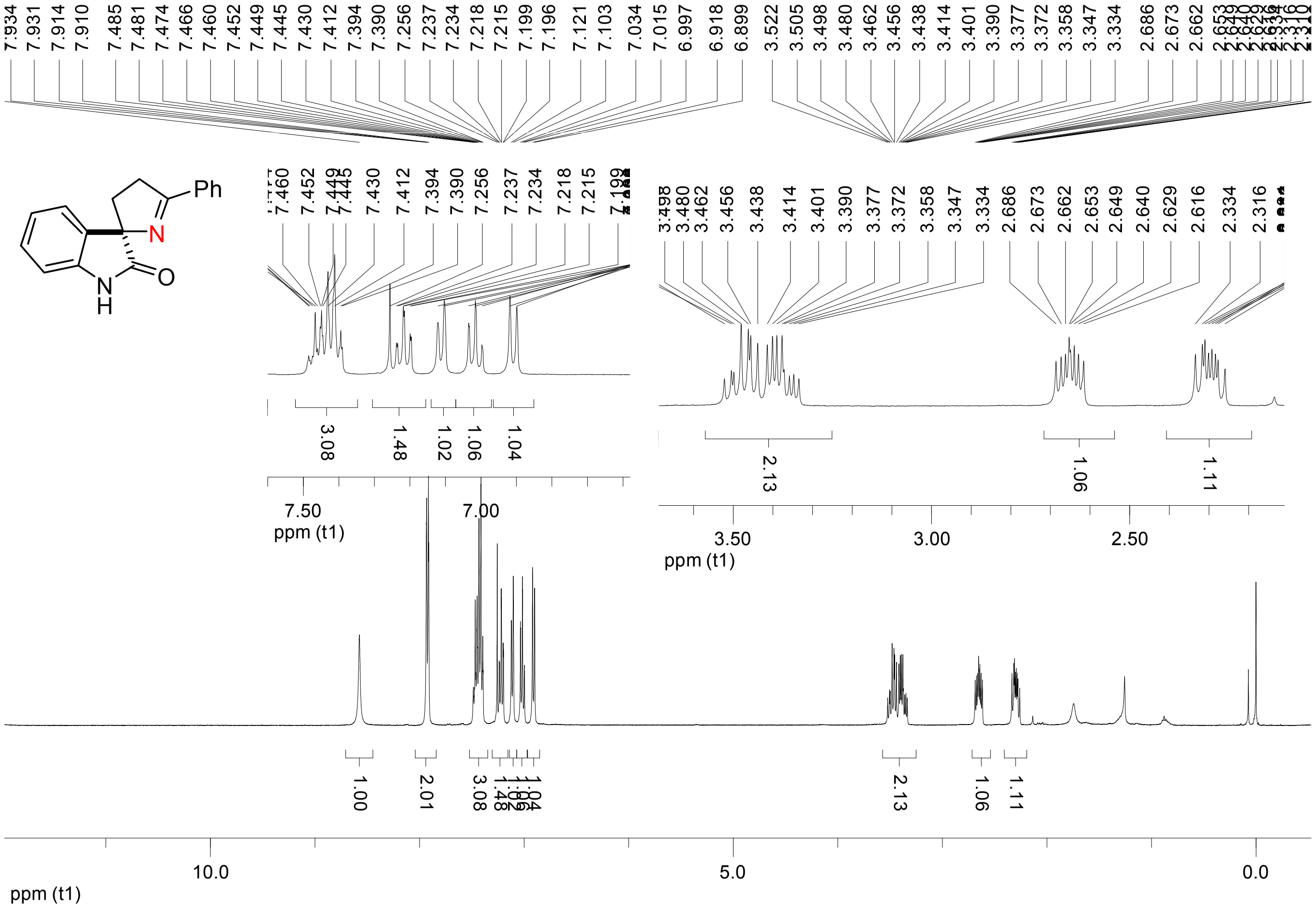

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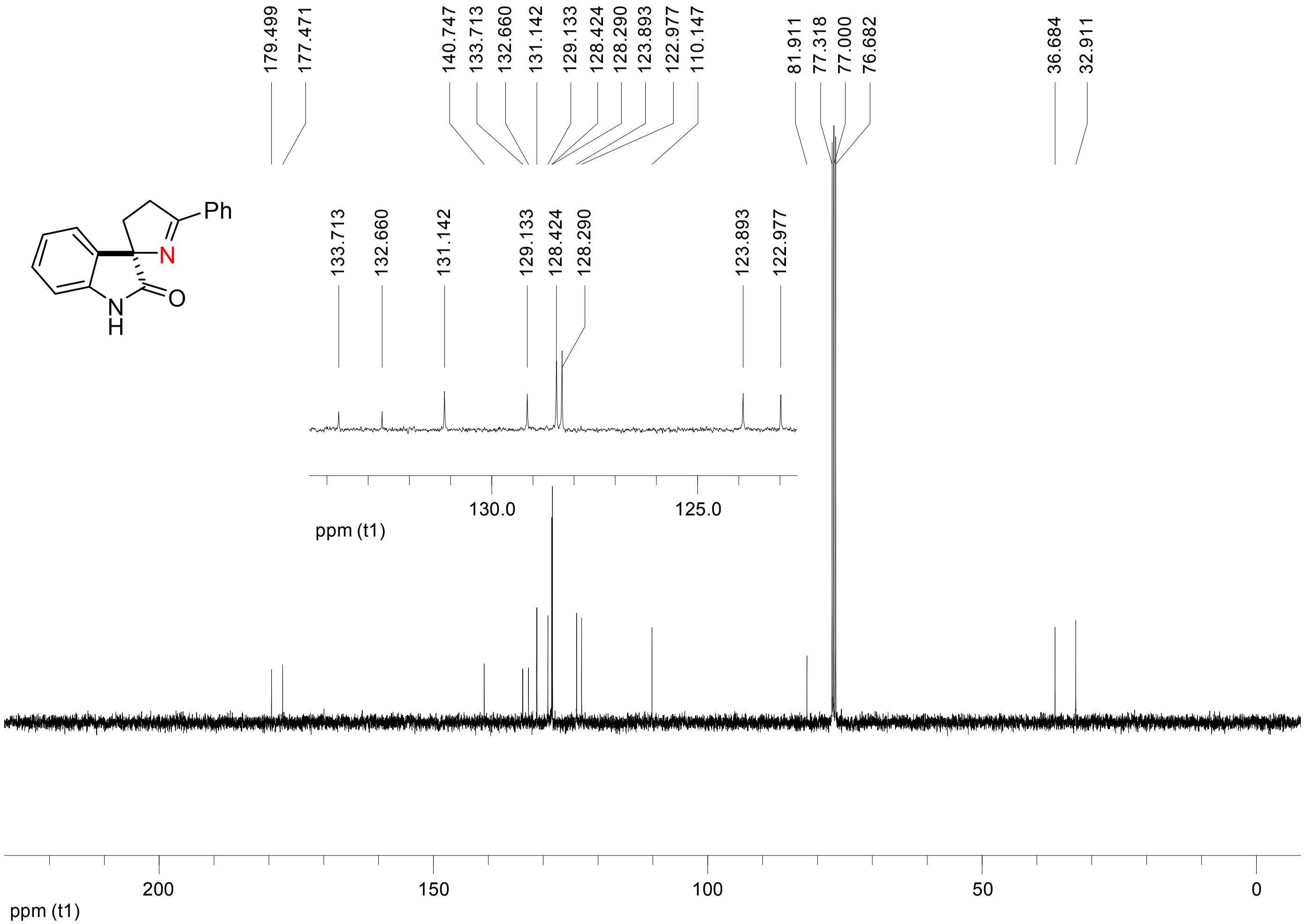

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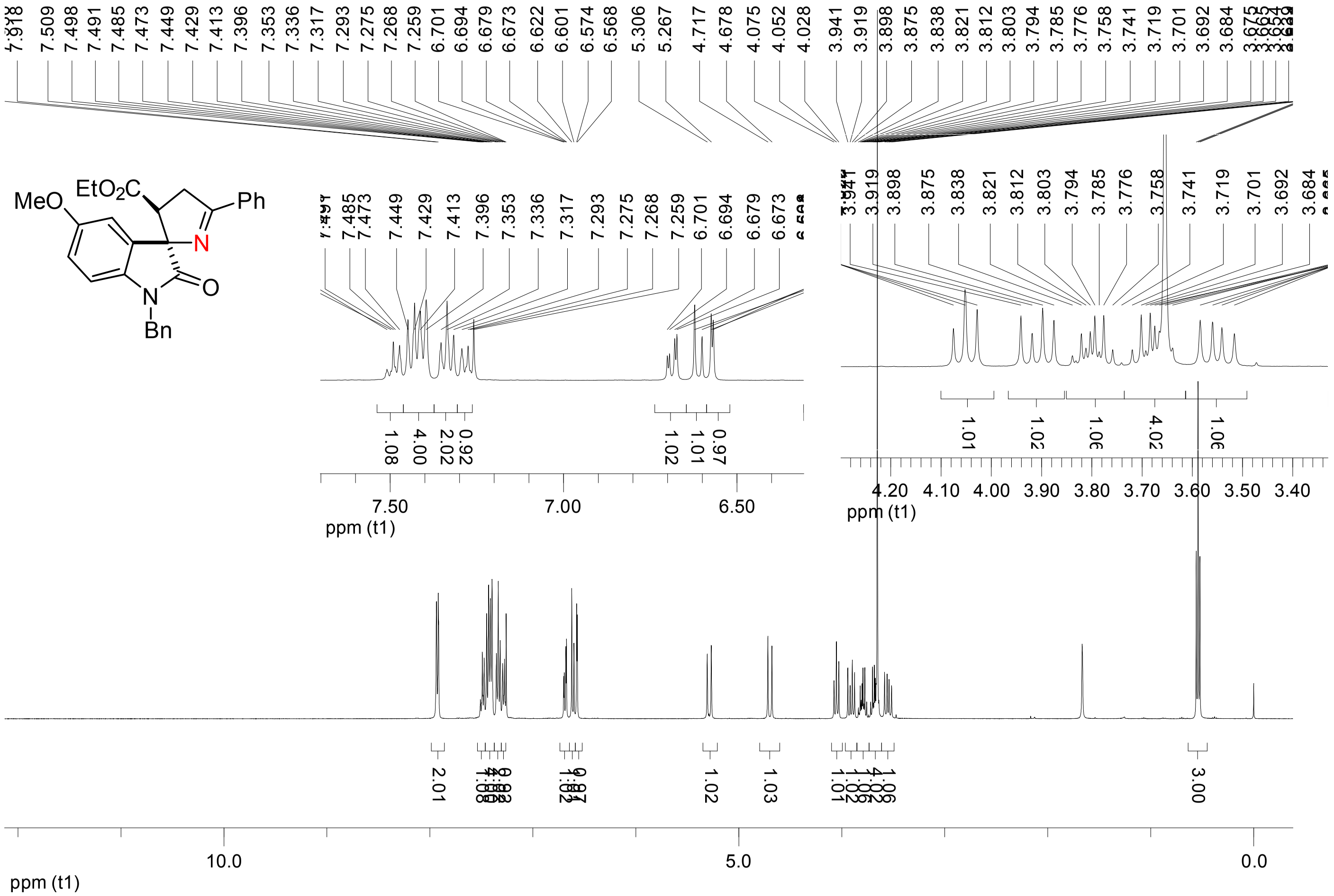

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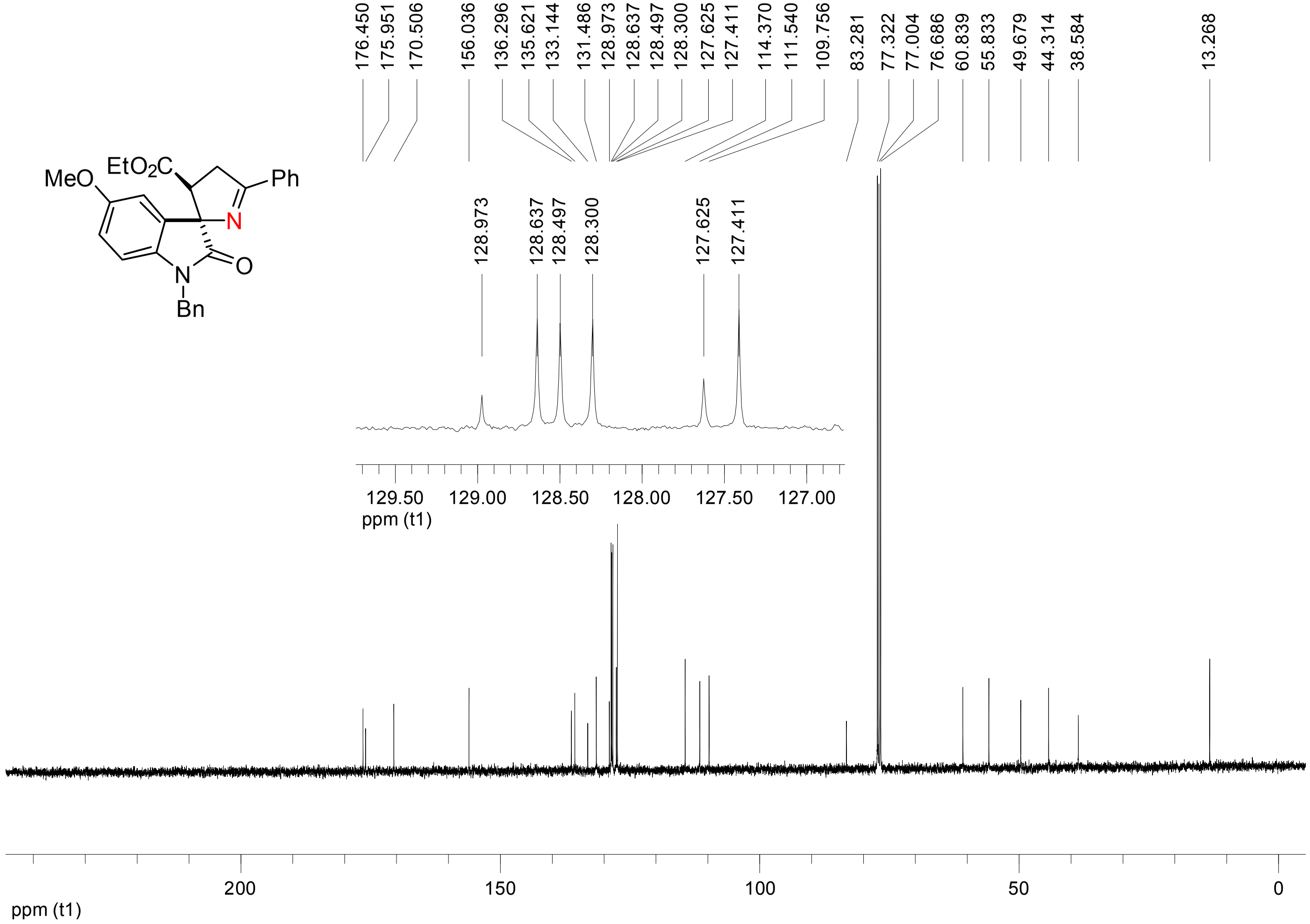

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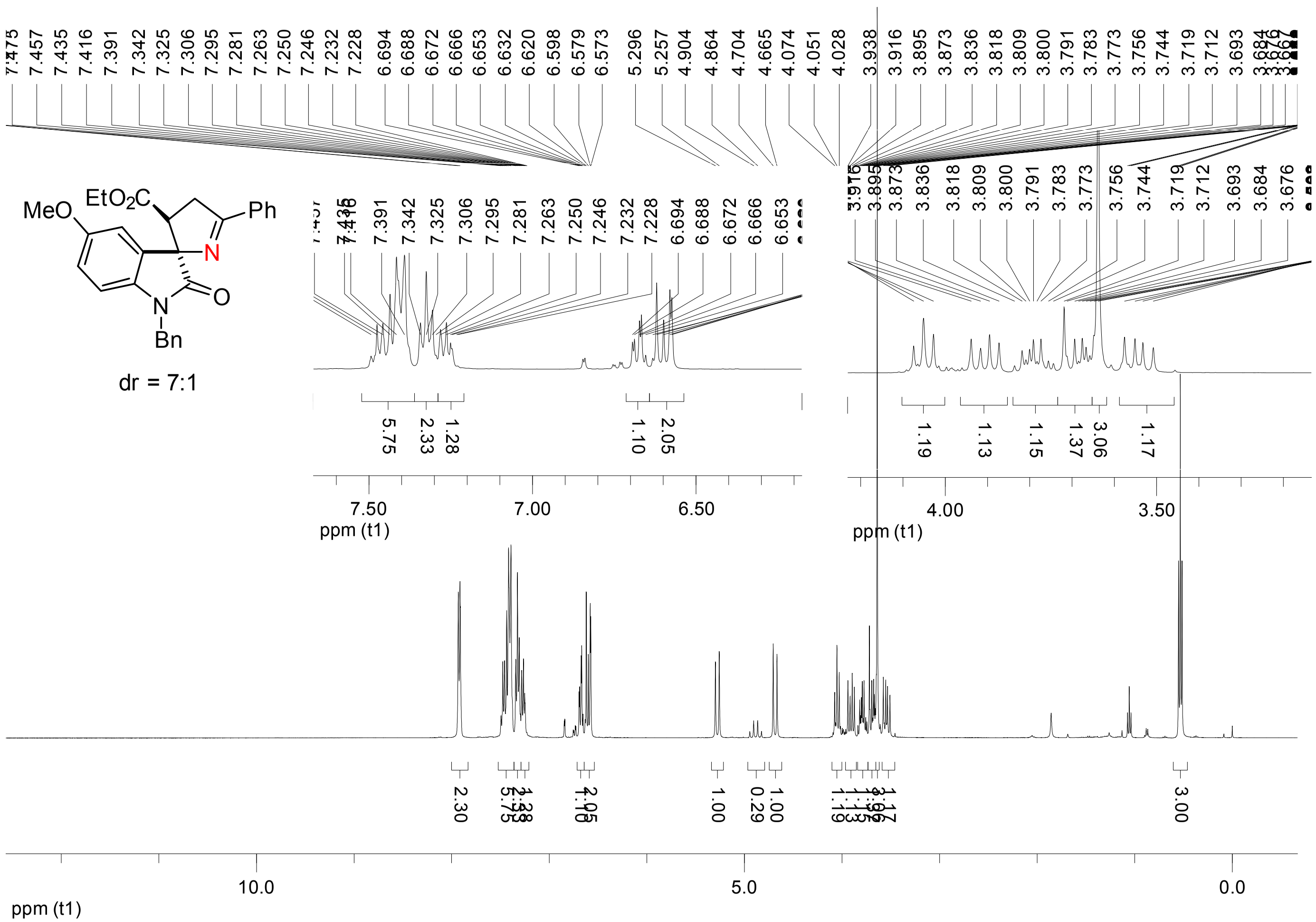

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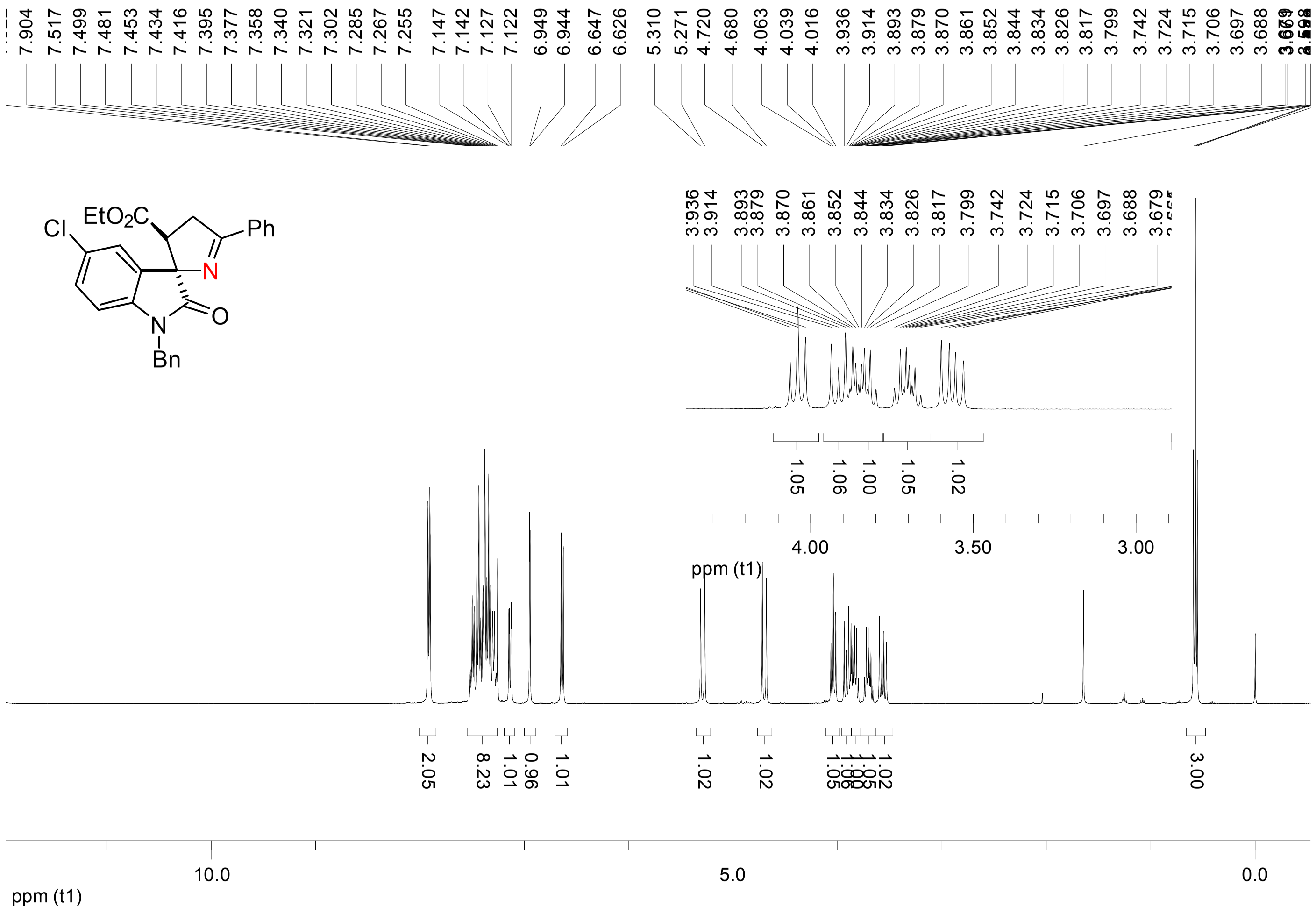

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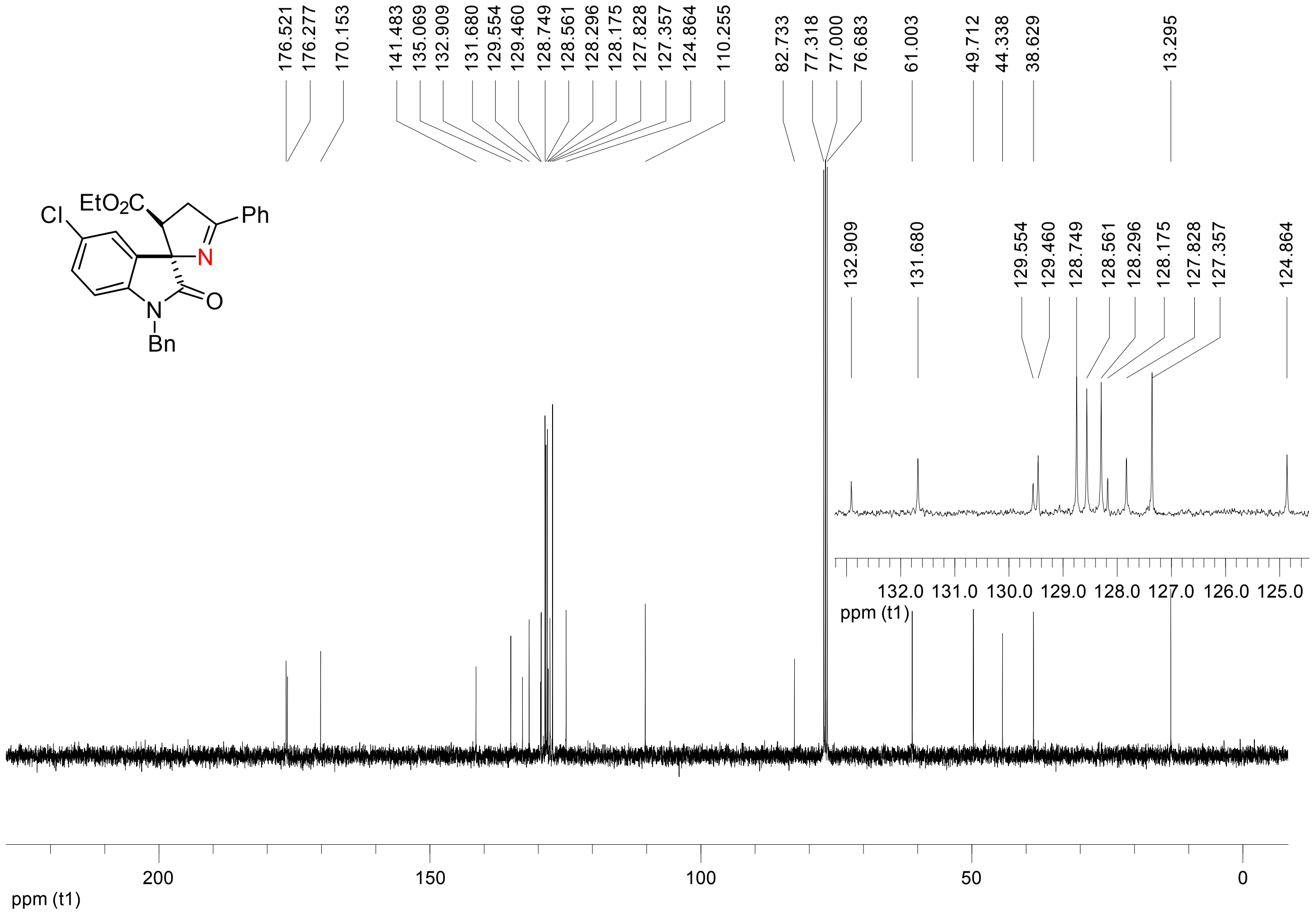

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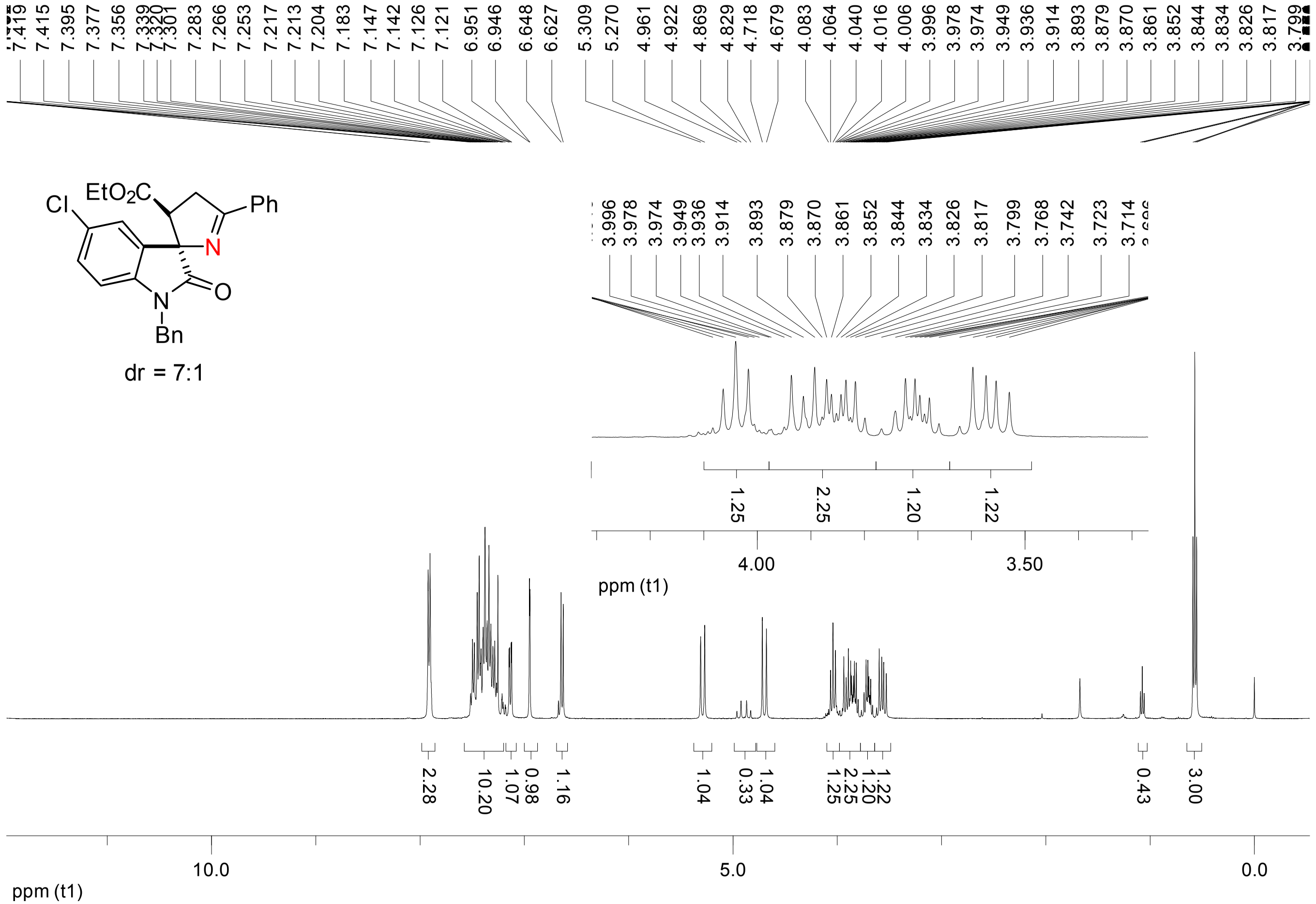

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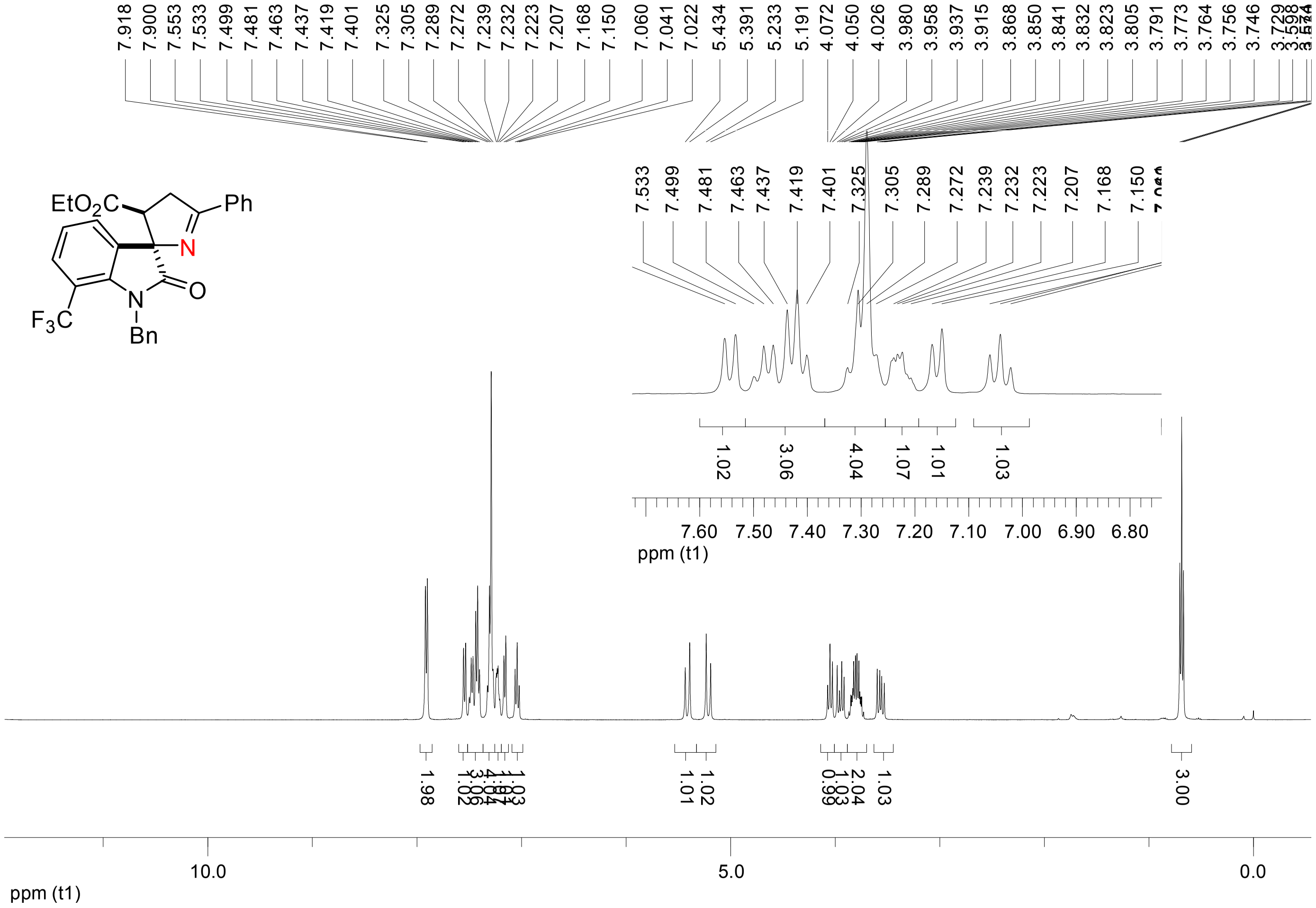

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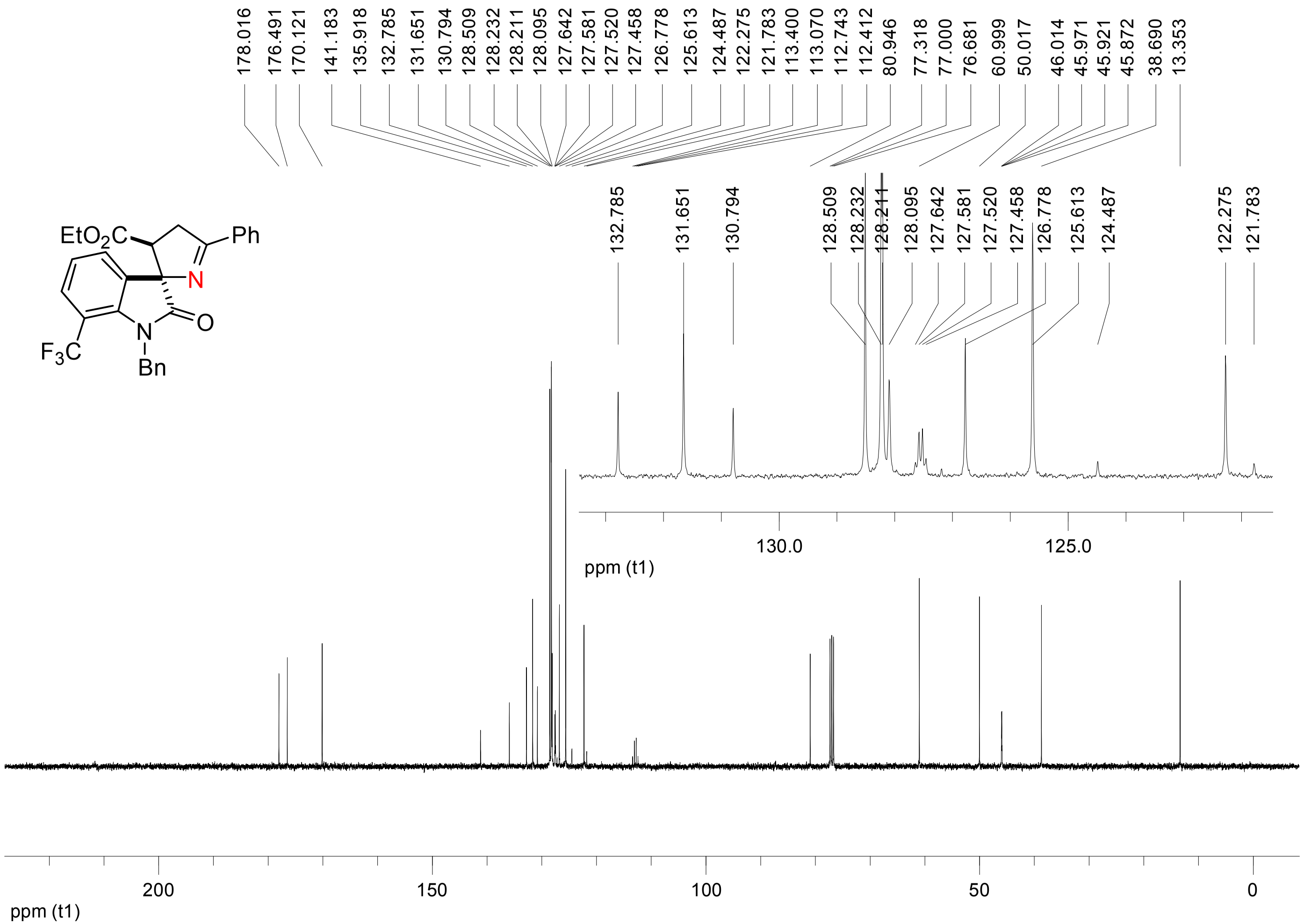
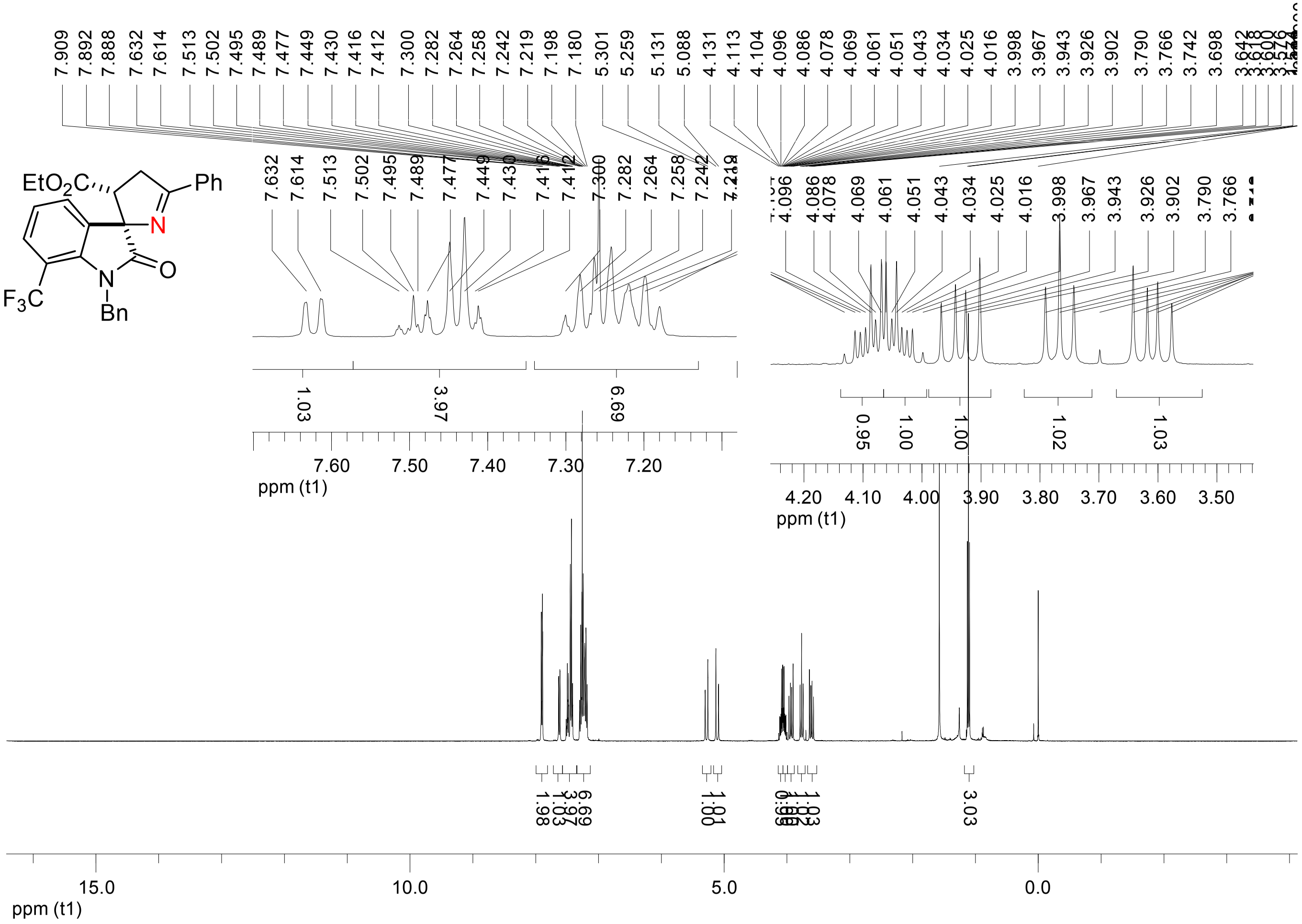


^{1}H NMR spectrum of **3ha’**, dr = 3:1, minor isomer (400 MHz, CDCl$_3$)



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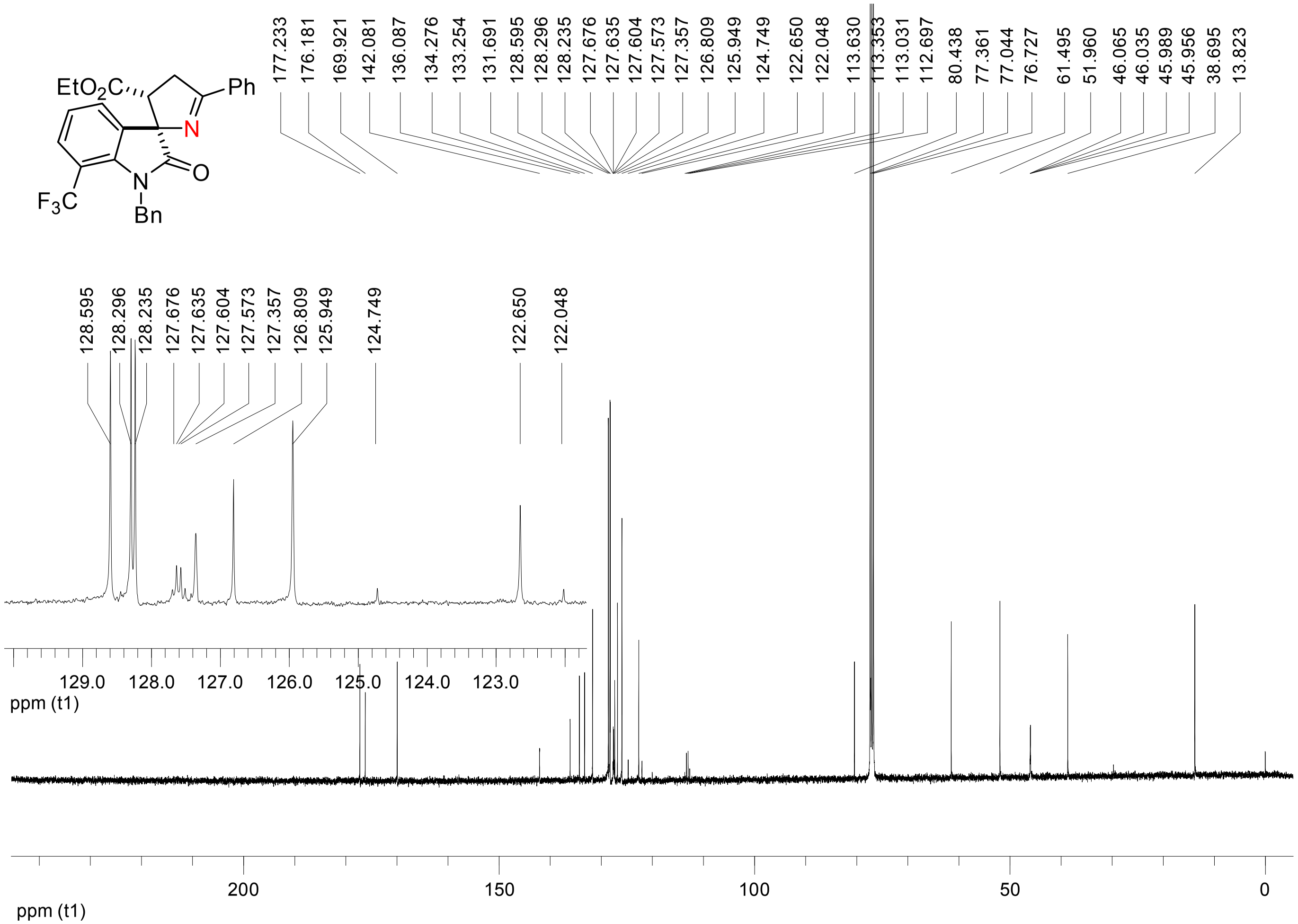
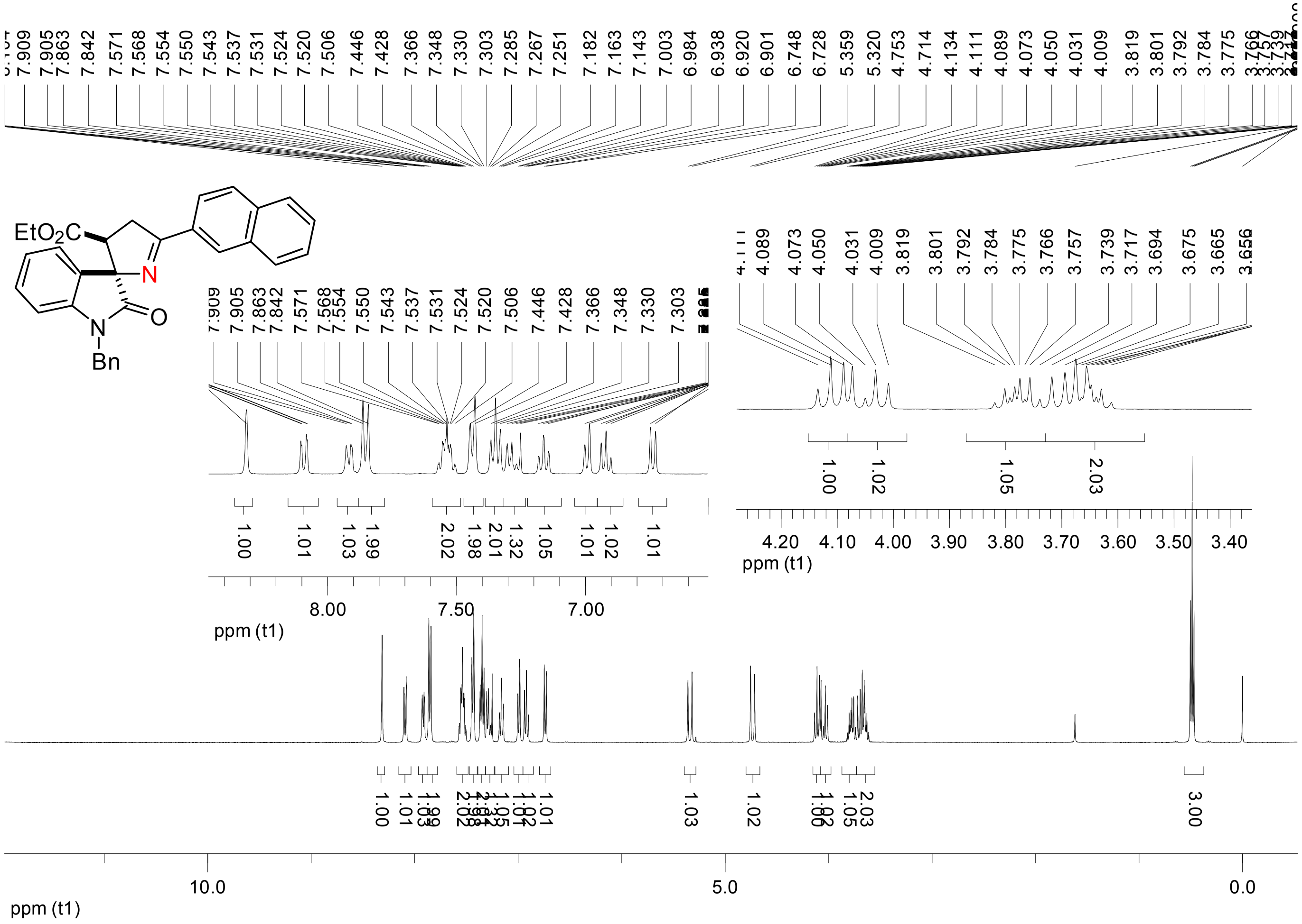
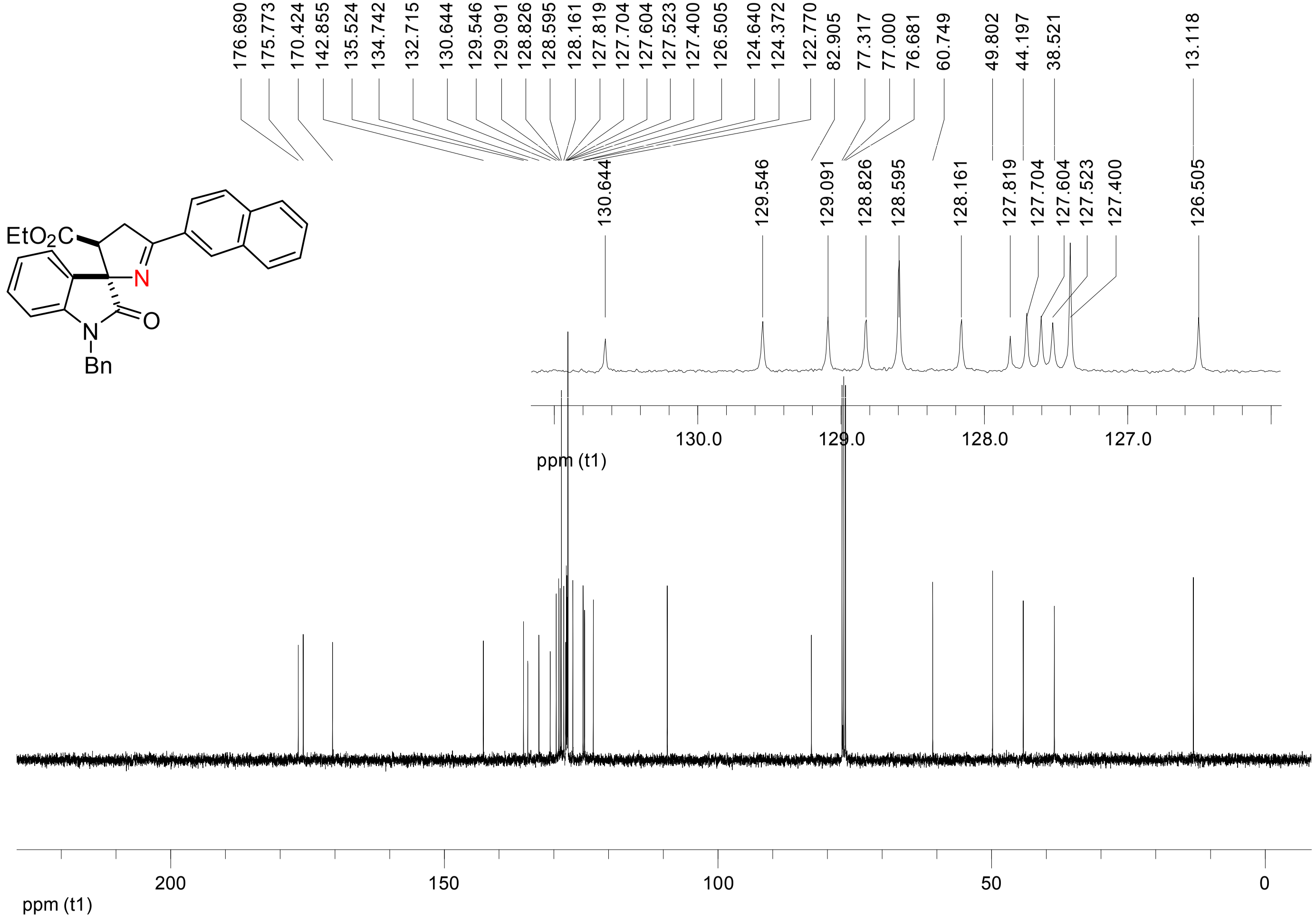


^{1}H NMR spectrum of **3ab**, single diastereomer (400 MHz, $CDCl_3$)



^{13}C NMR spectrum of **3ab**, single diastereomer (100 MHz, $CDCl_3$)



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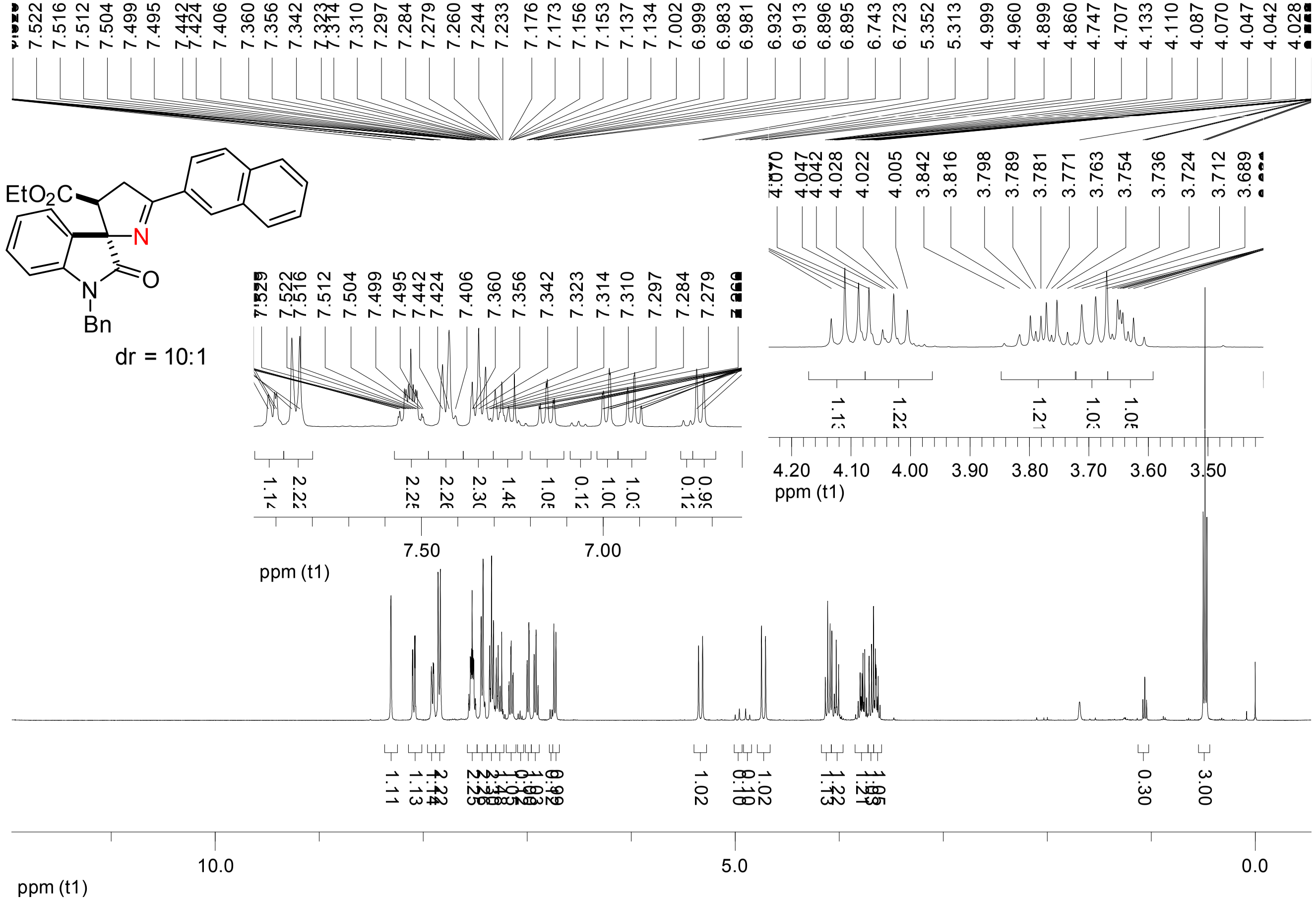
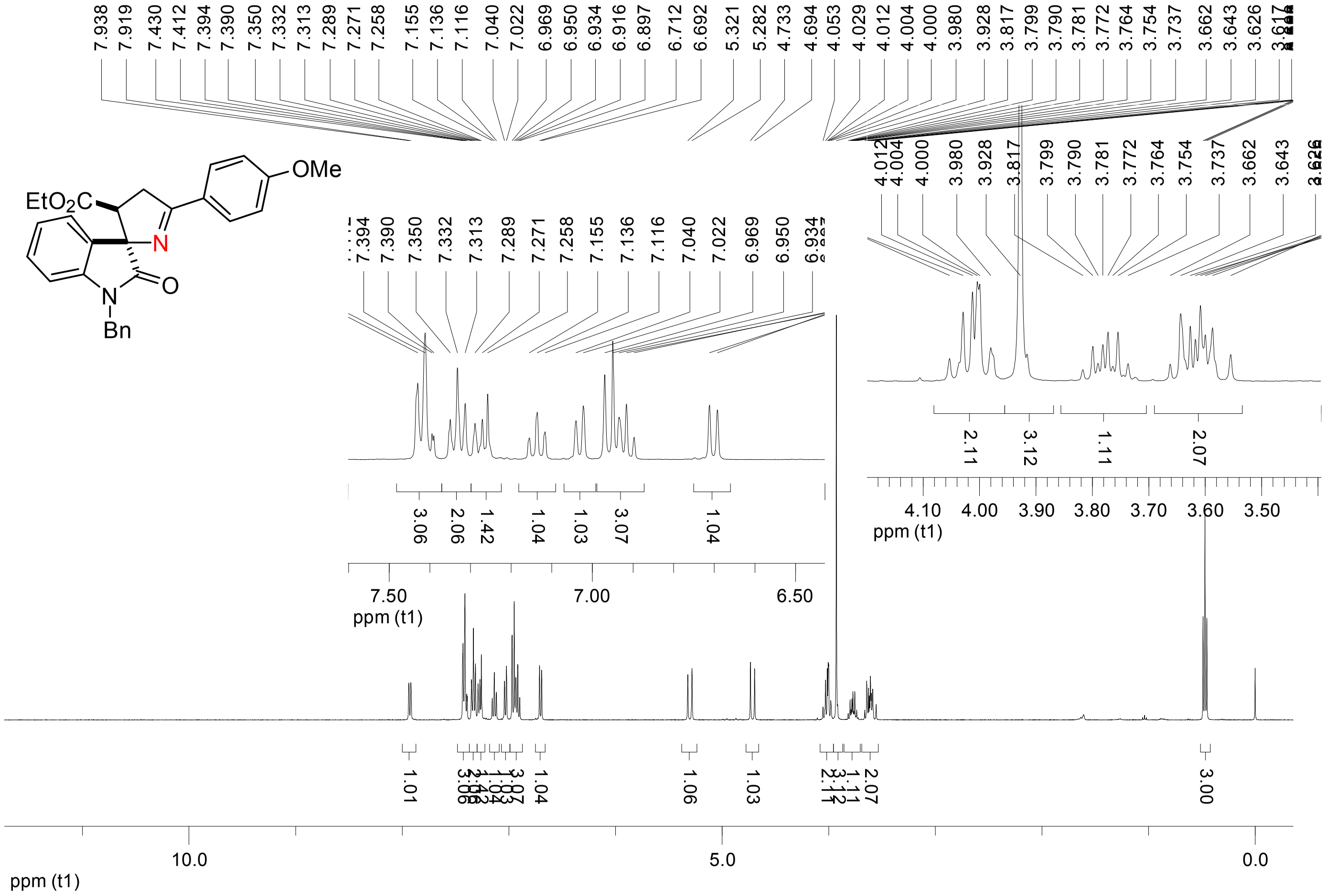
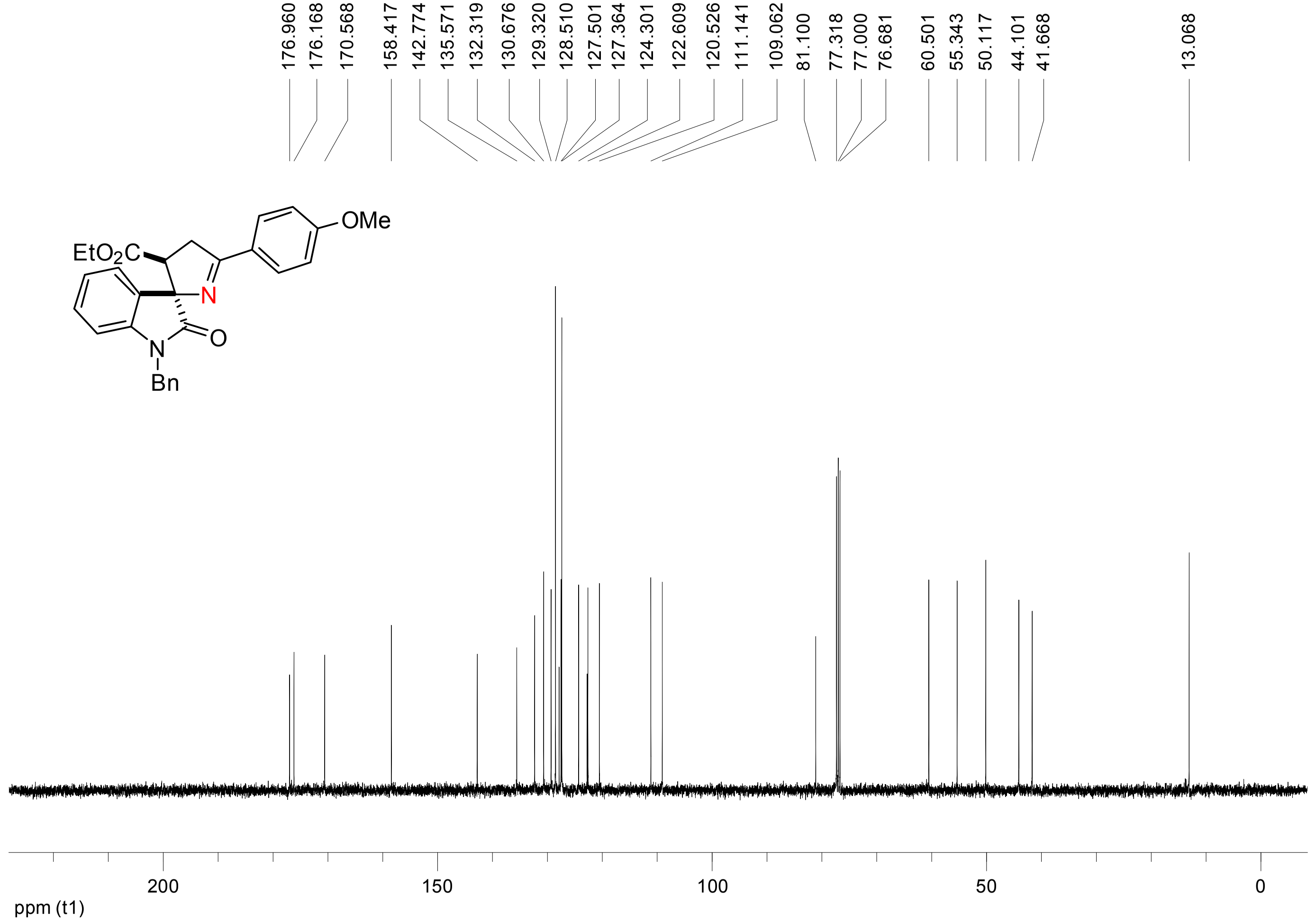


^{1}H NMR spectrum of **3ac**, single diastereomer (400 MHz, $CDCl_3$)



^{13}C NMR spectrum of **3ac**, single diastereomer (100 MHz, $CDCl_3$)



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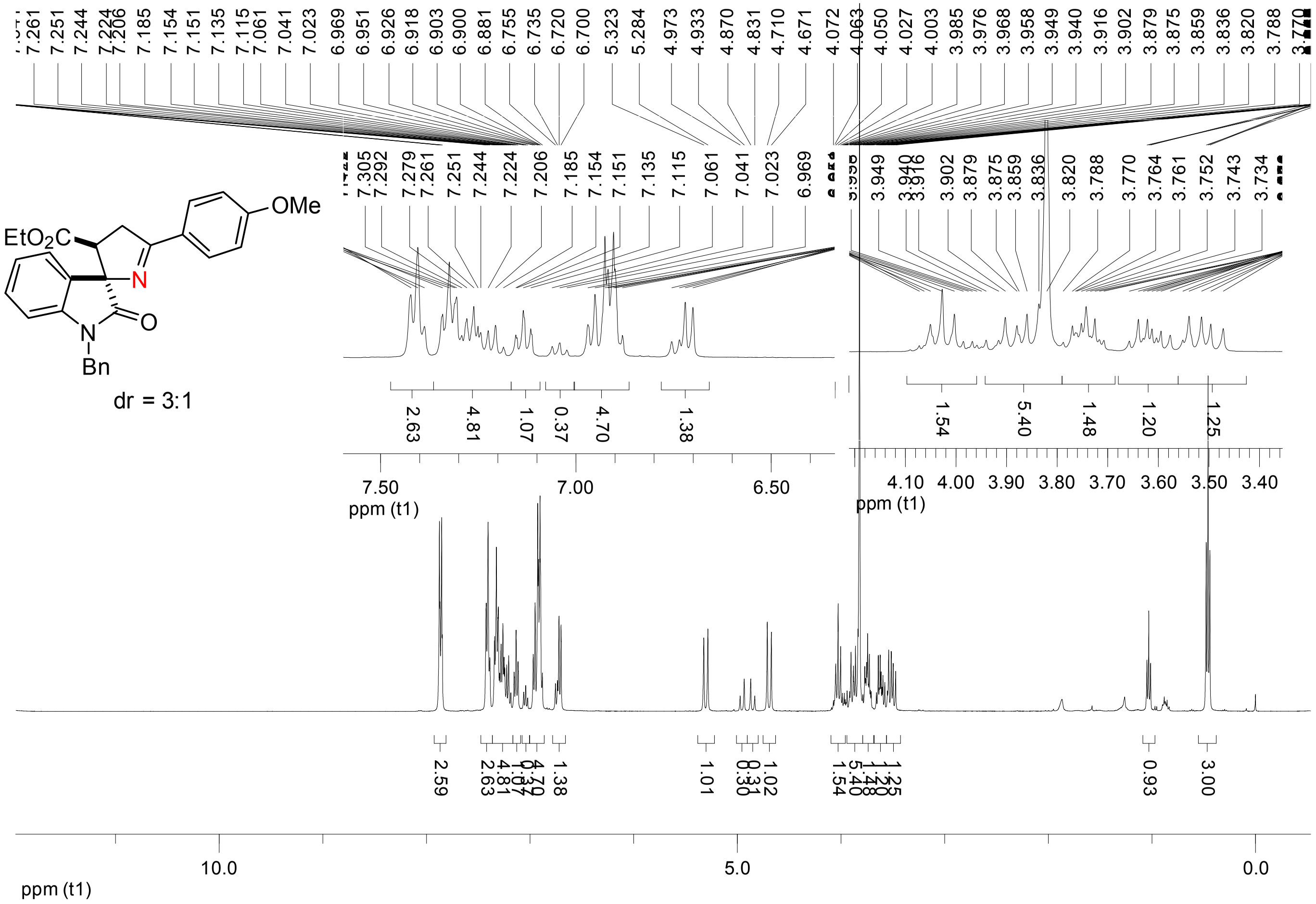
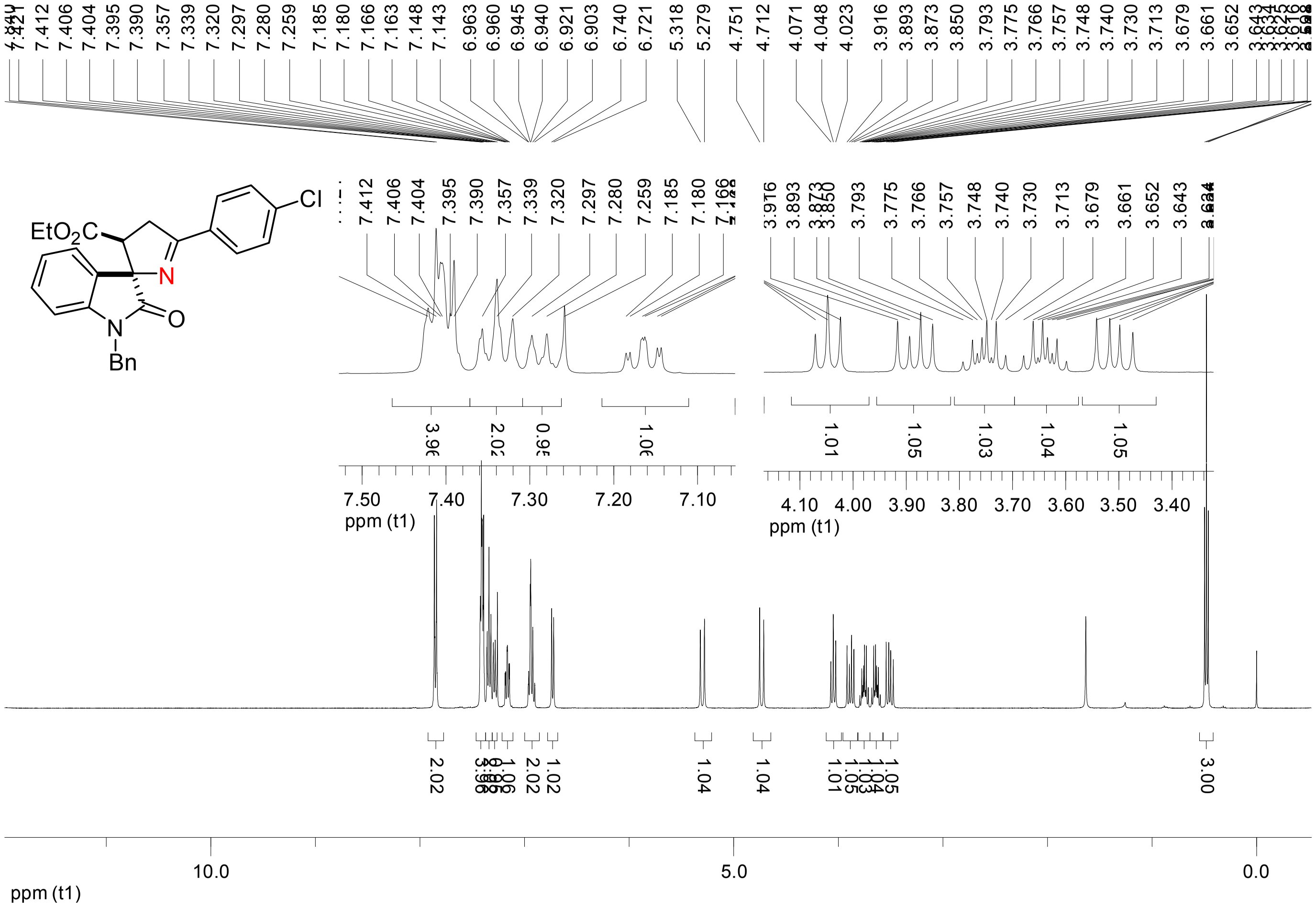


^{1}H NMR spectrum of **3ad**, single diastereomer (400 MHz, $CDCl_3$)



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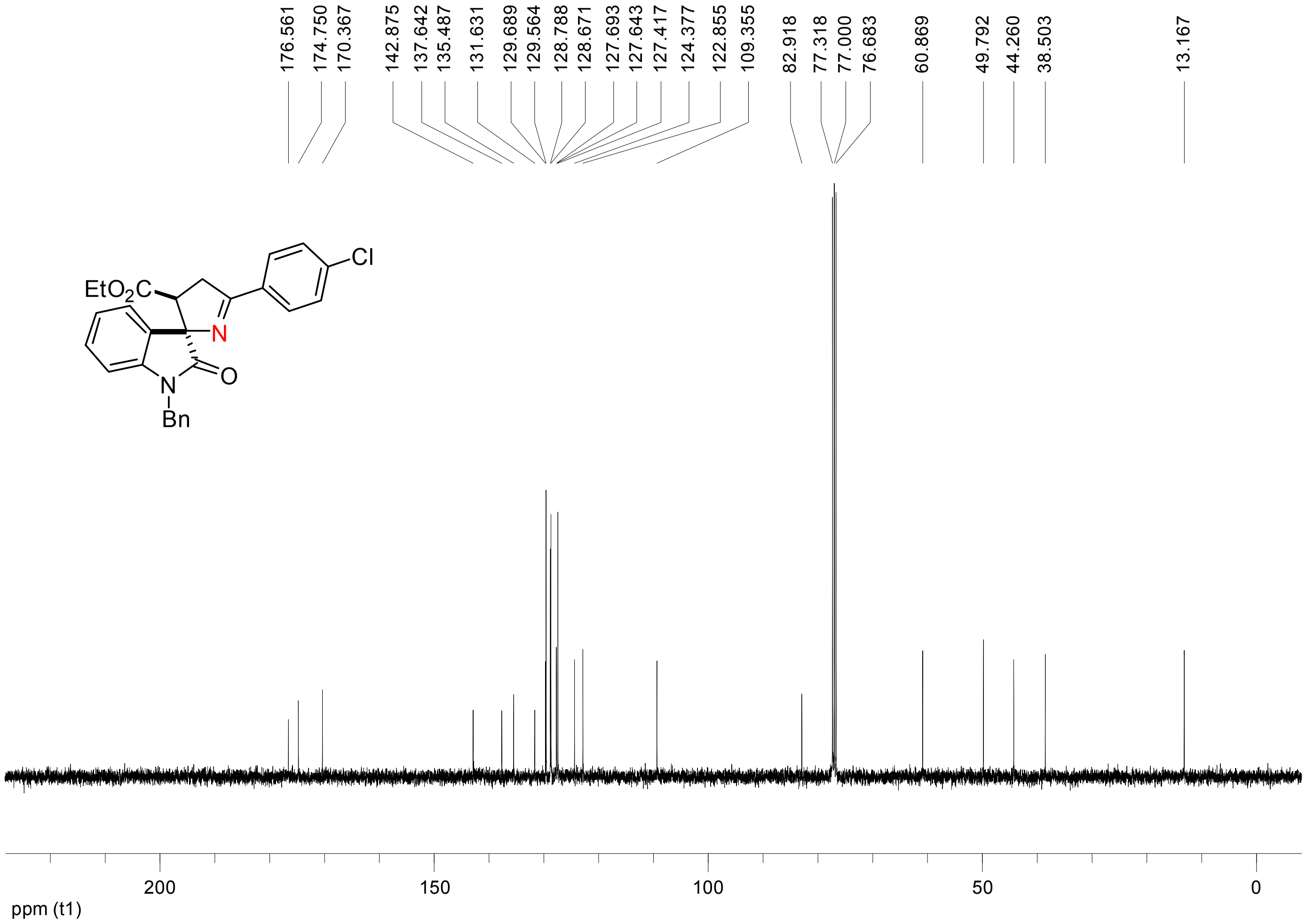

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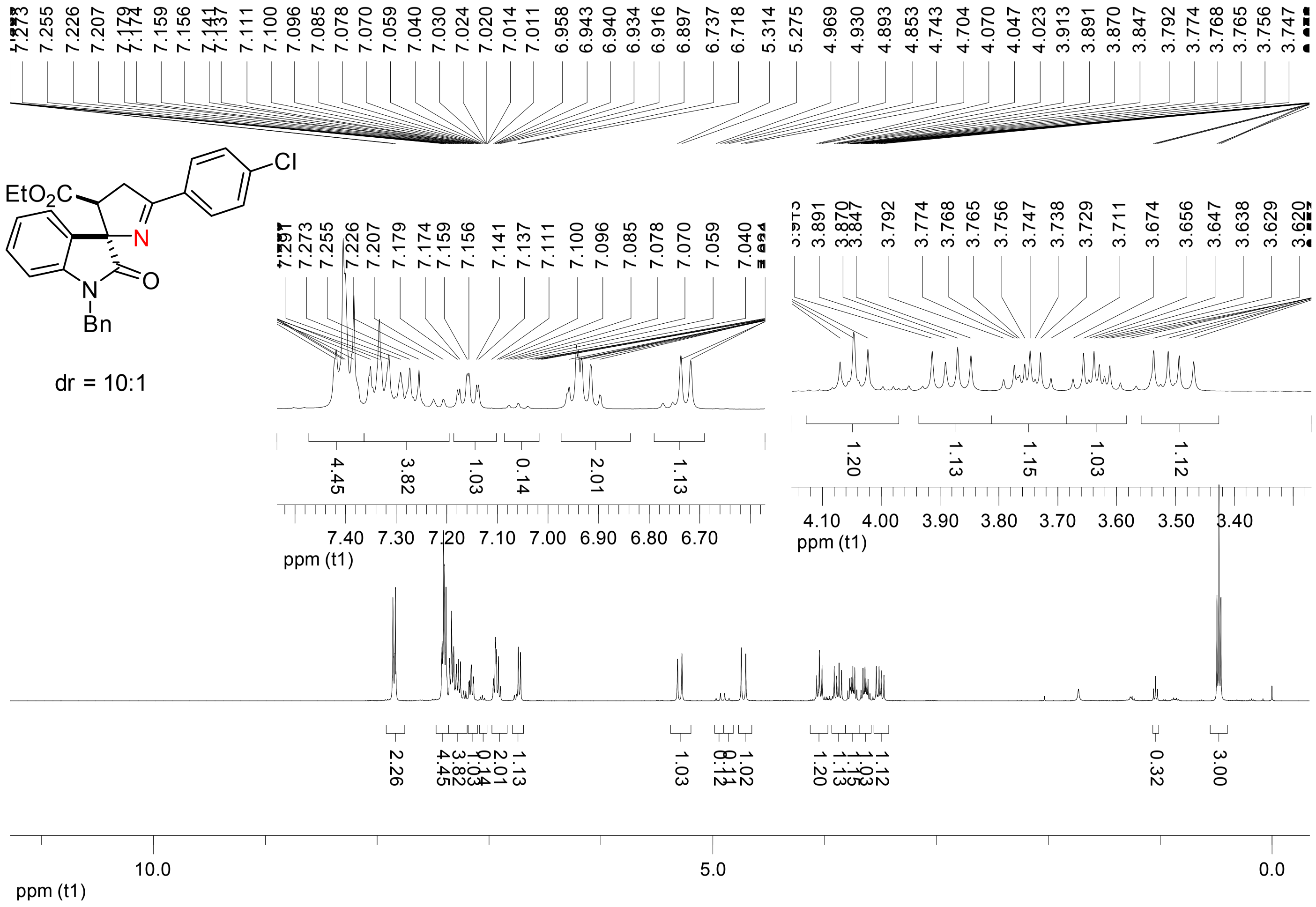
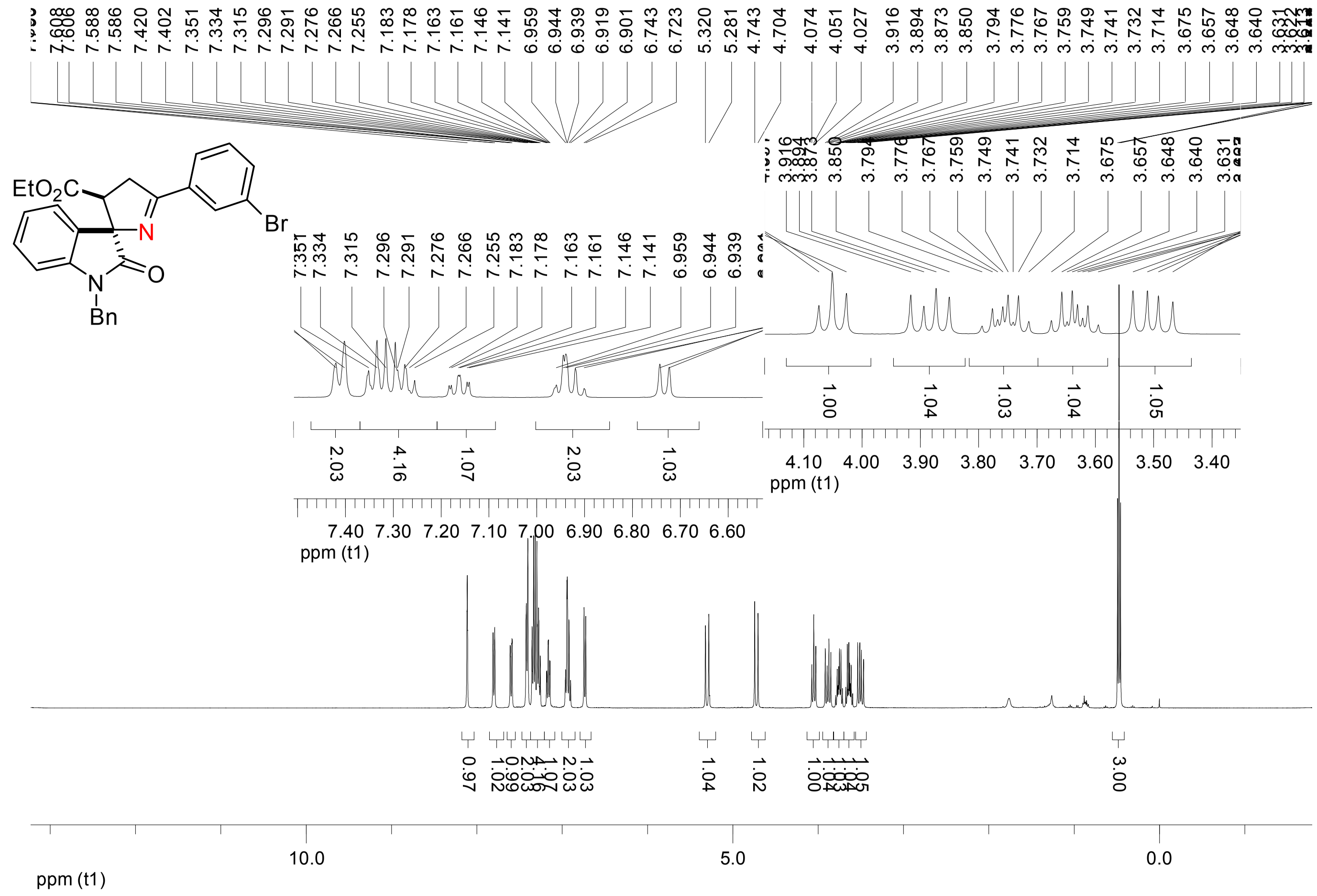
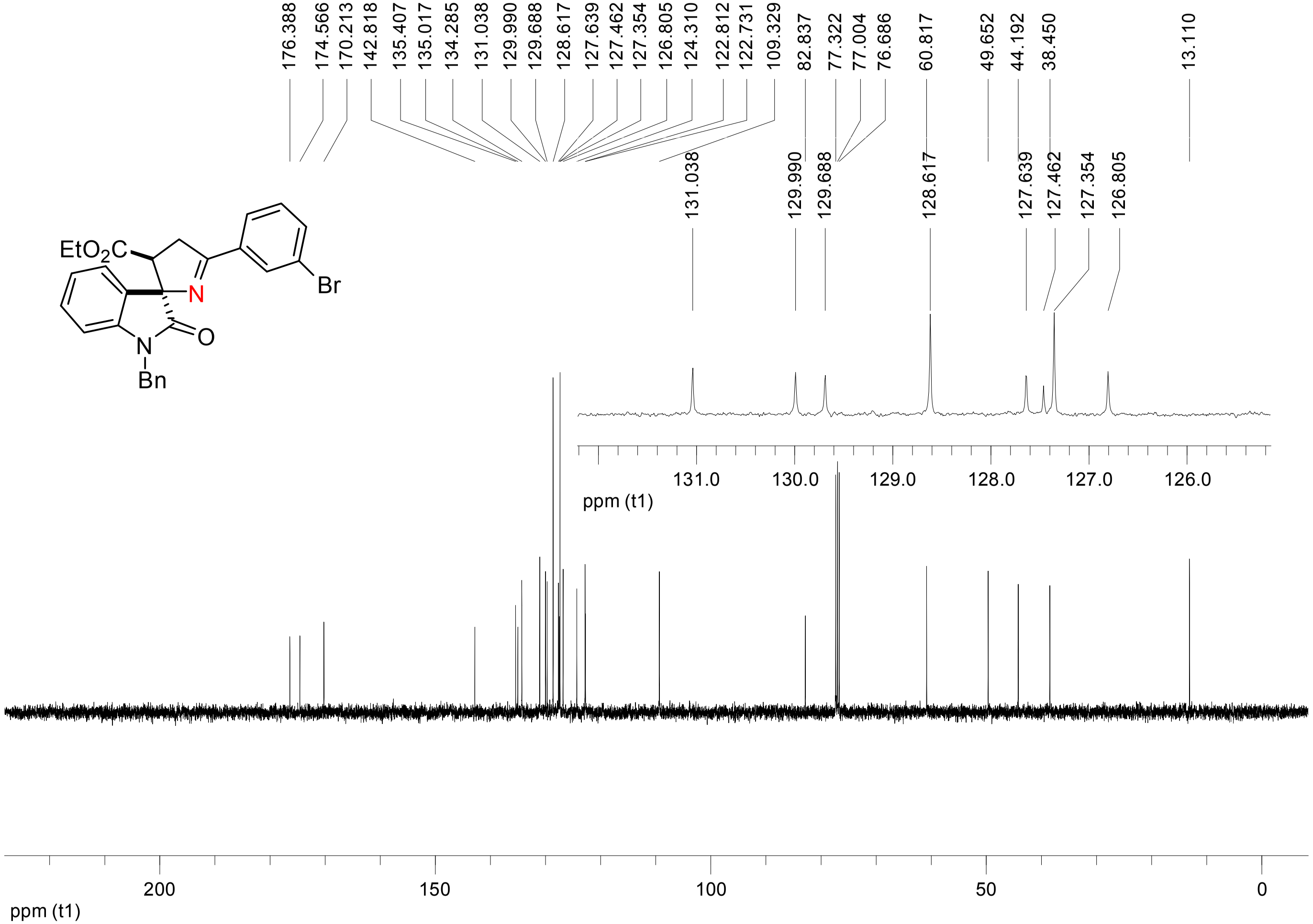


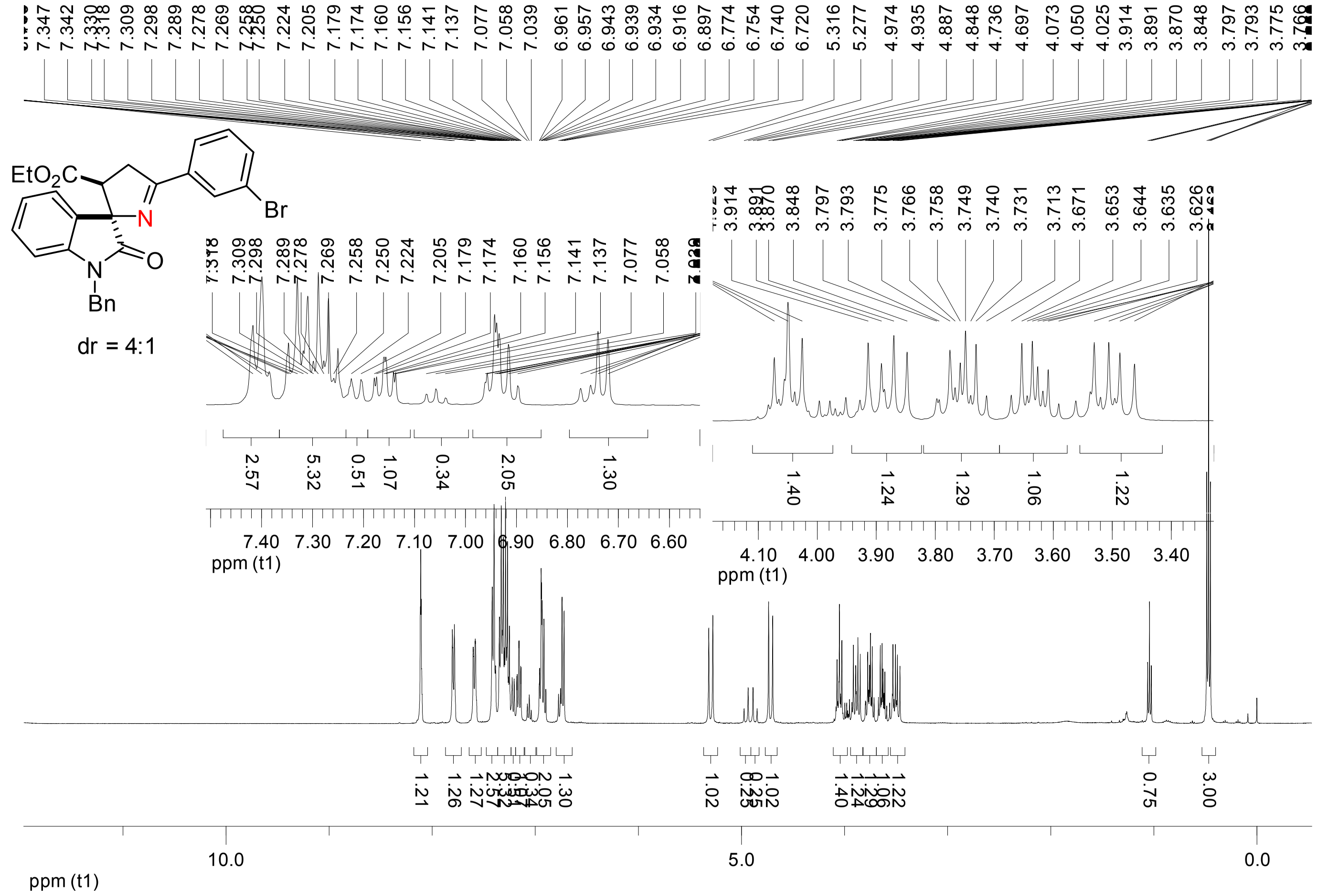
^{1}H NMR spectrum of **3ae**, single diastereomer (400 MHz, $CDCl_3$)



^{13}C NMR spectrum of **3ae**, single diastereomer (100 MHz, CDCl$_3$)



^{1}H NMR spectrum of **3ae**, dr = 4:1 (400 MHz, $CDCl_3$)



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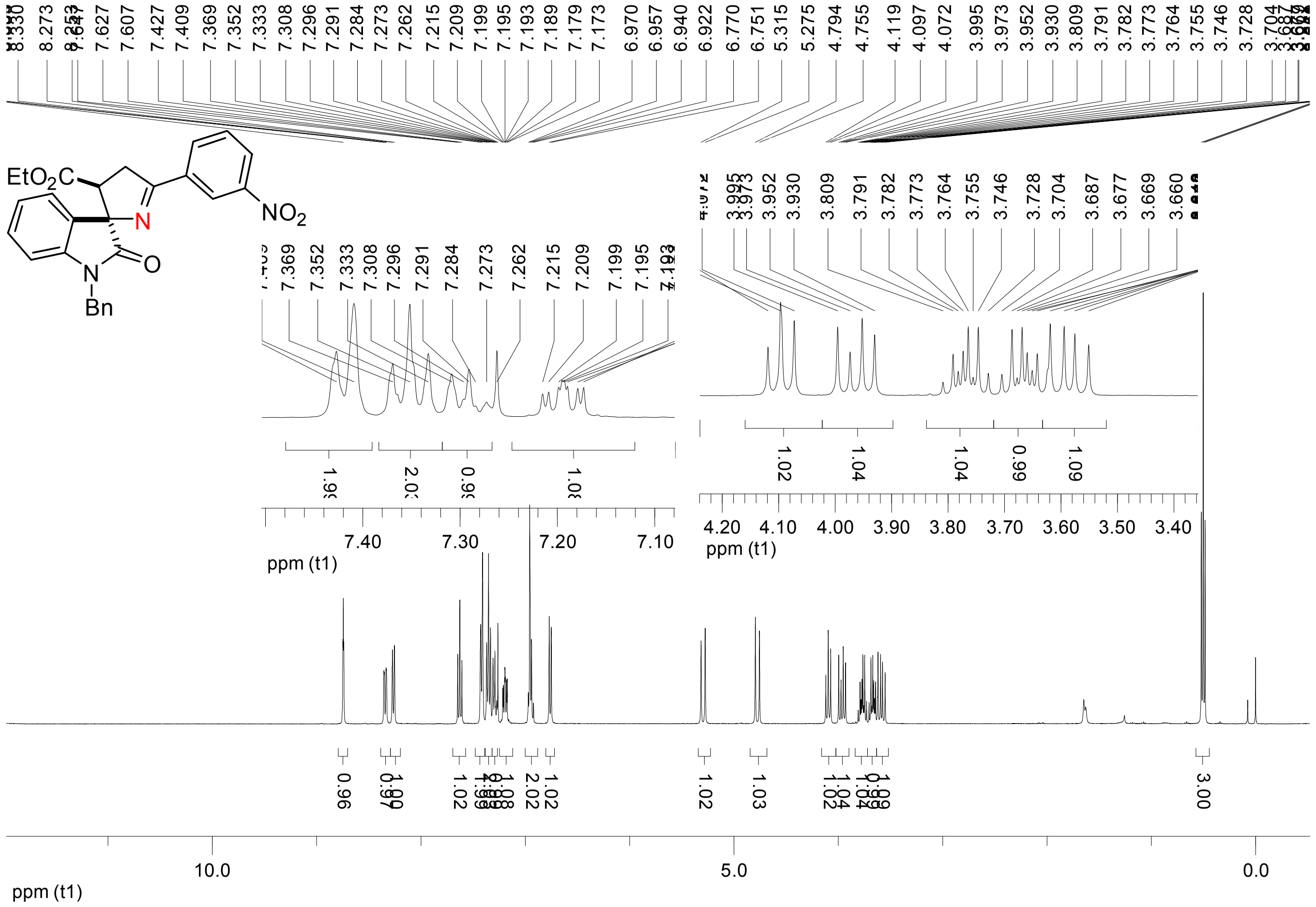

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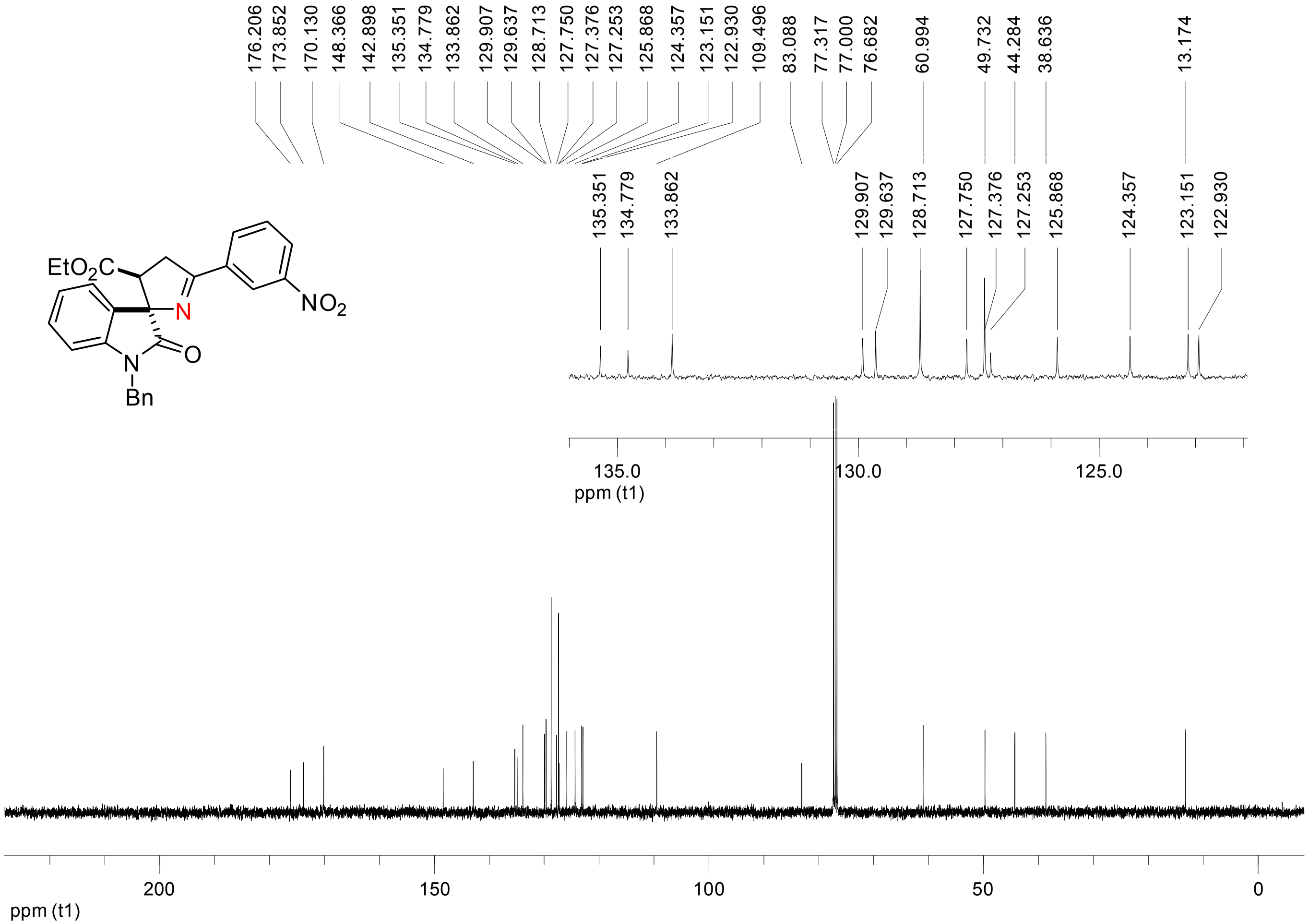

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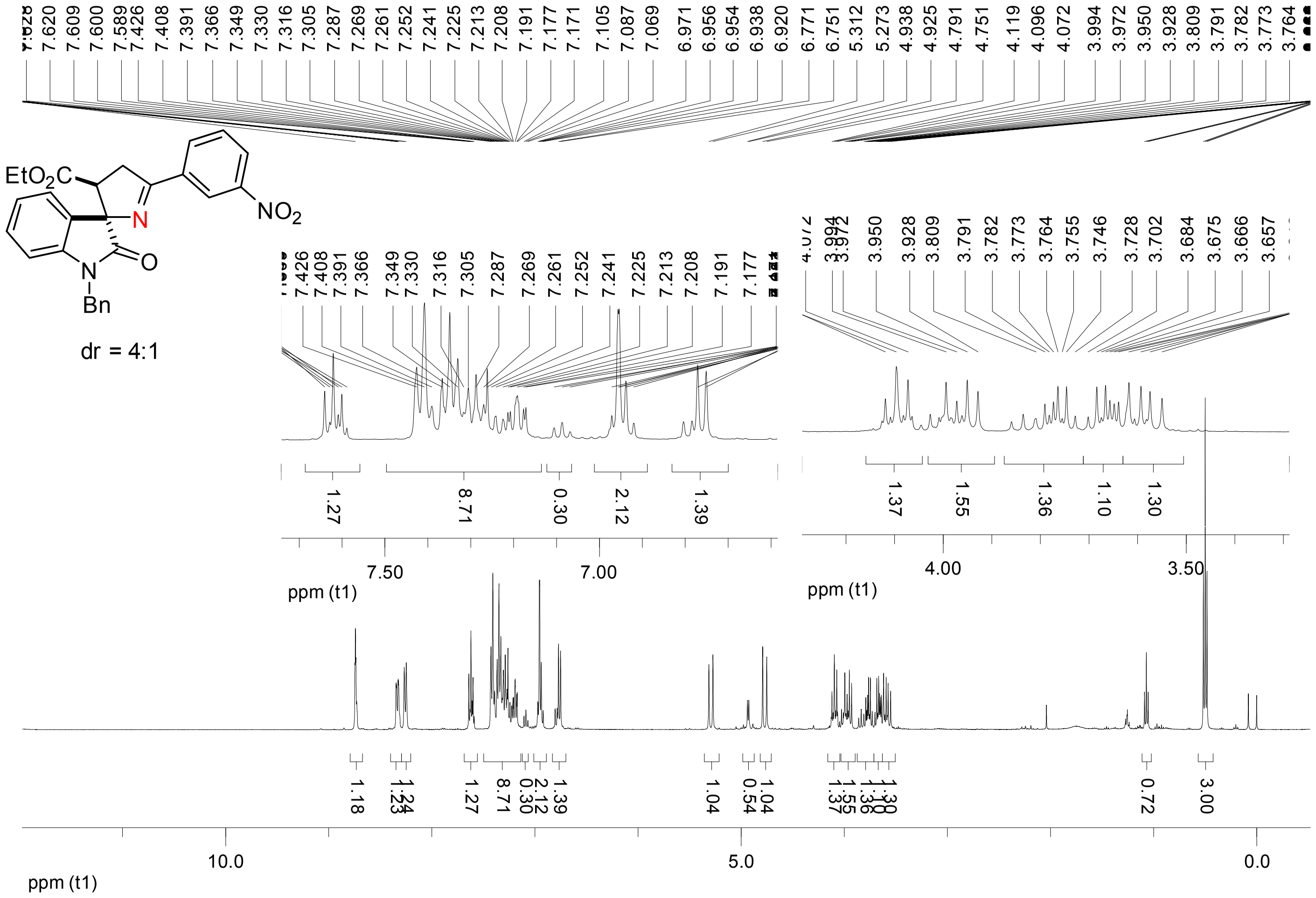

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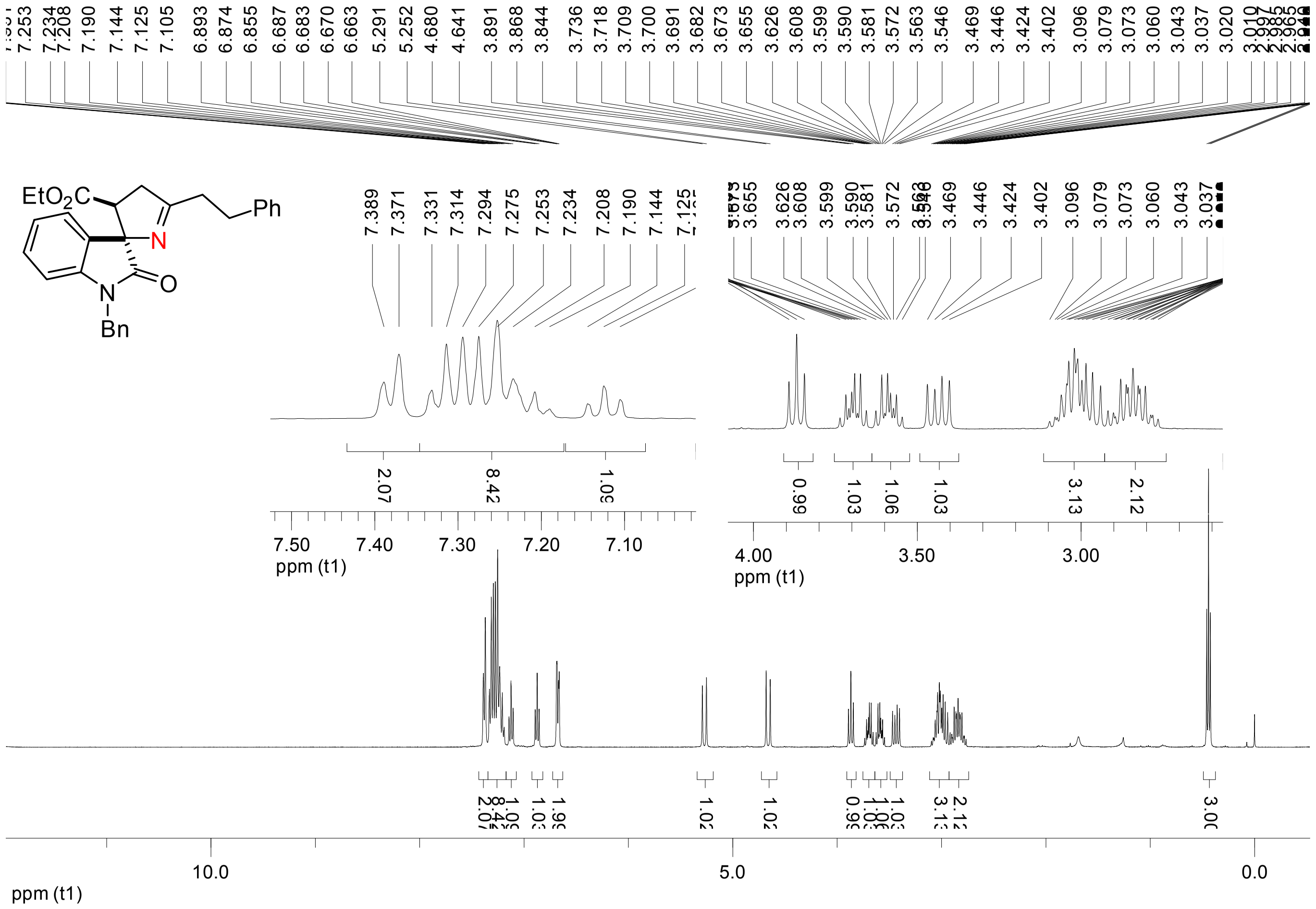
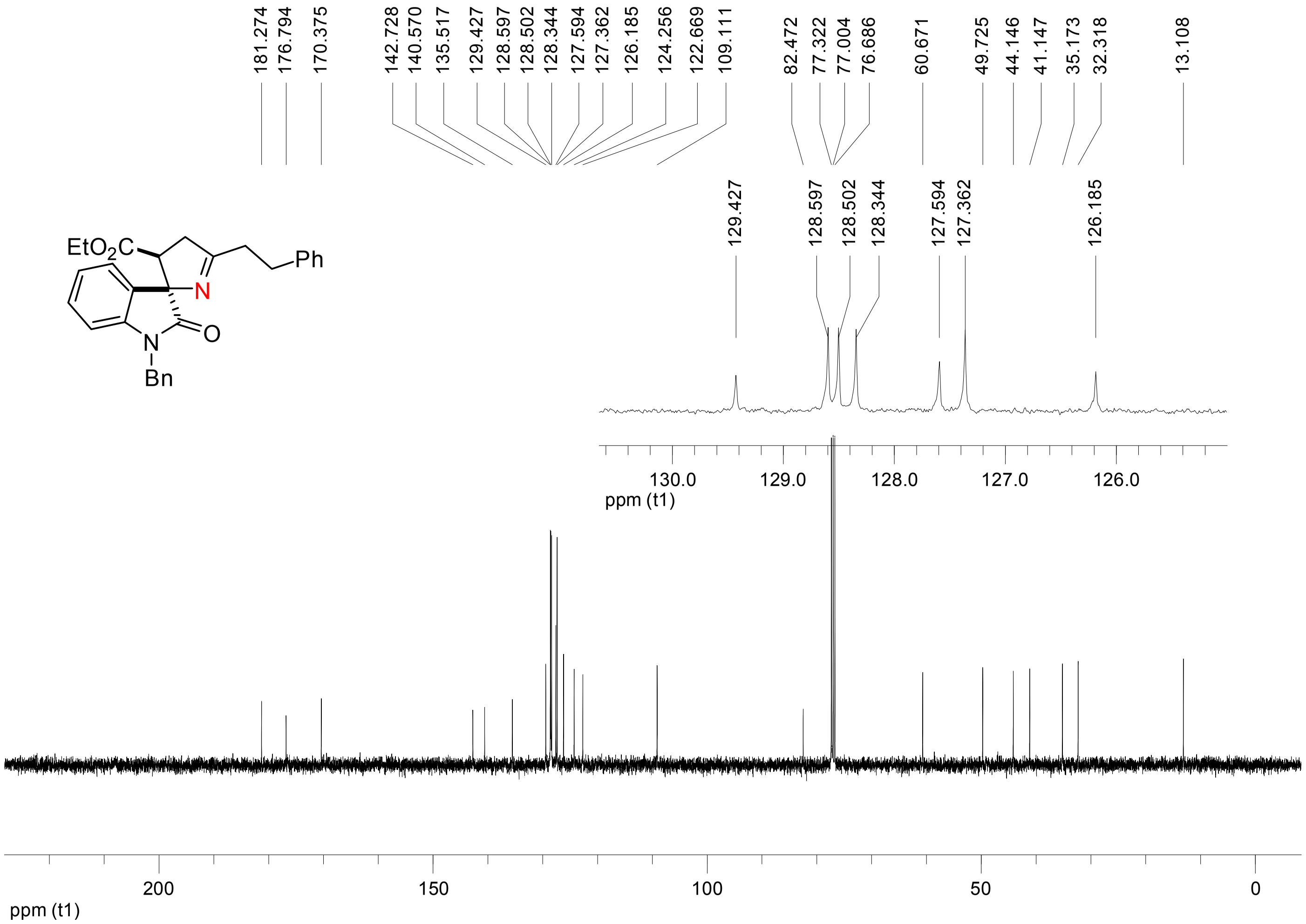
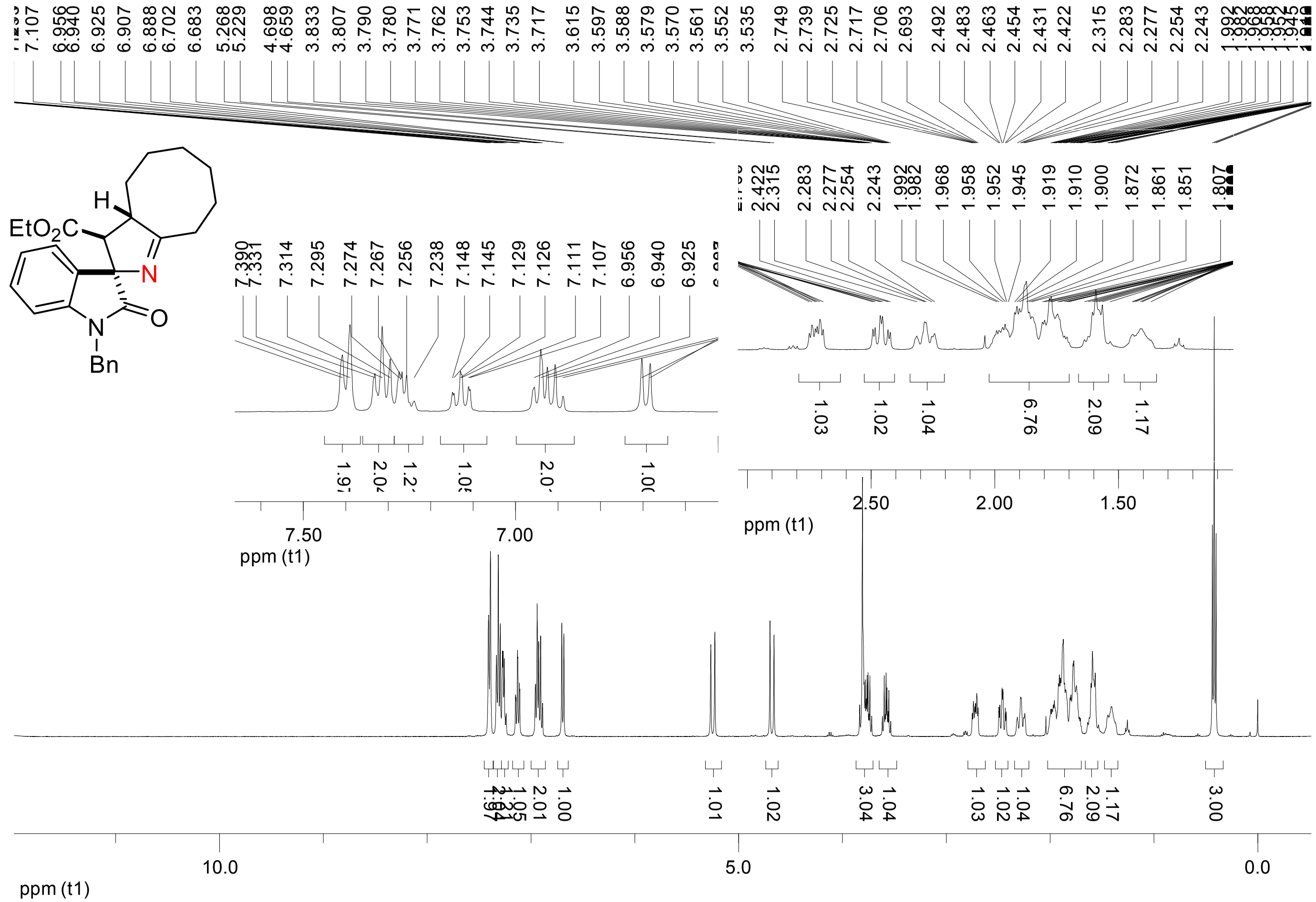


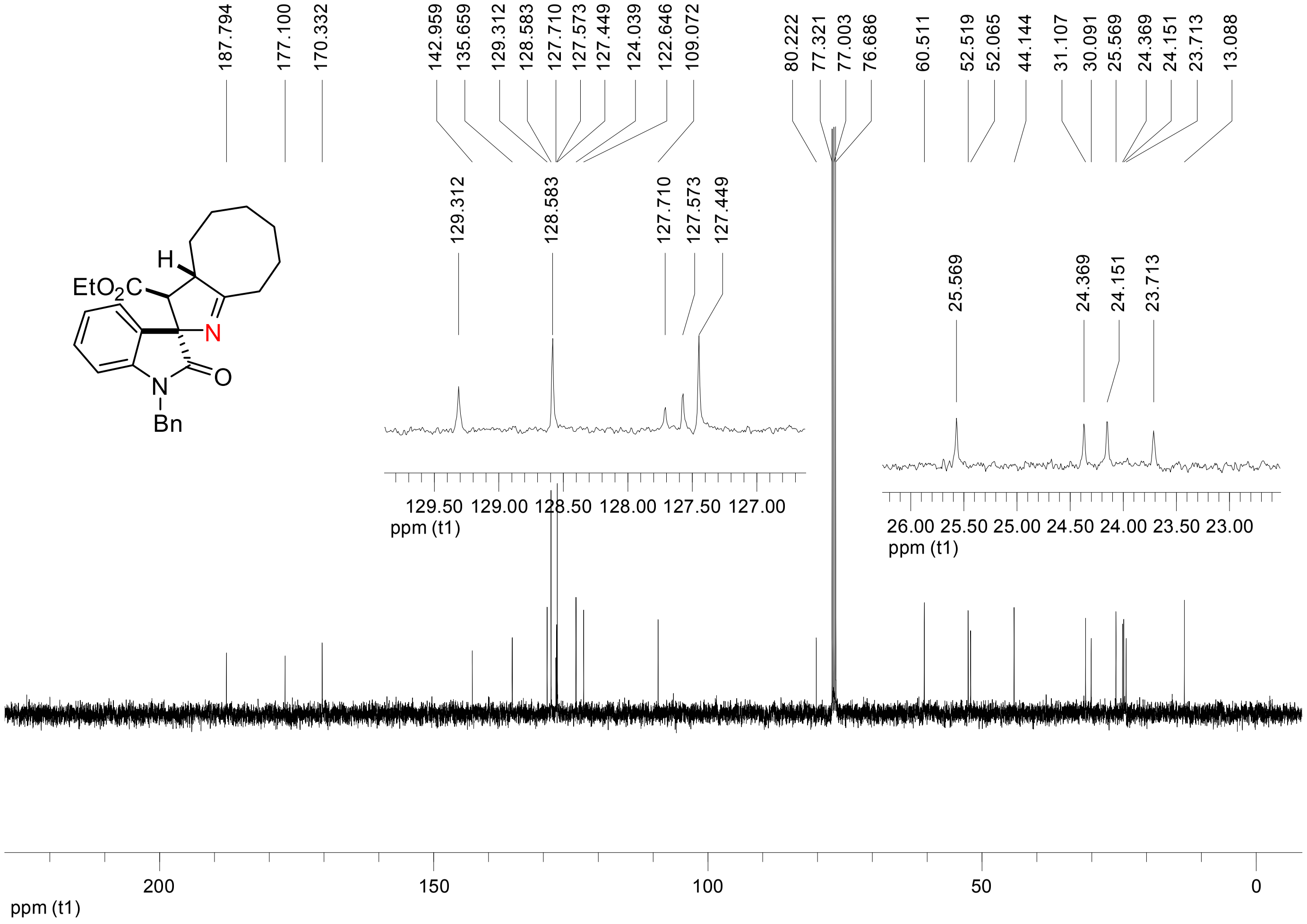
^{13}C NMR spectrum of **3ag**, single diastereomer (100 MHz, $CDCl_3$)



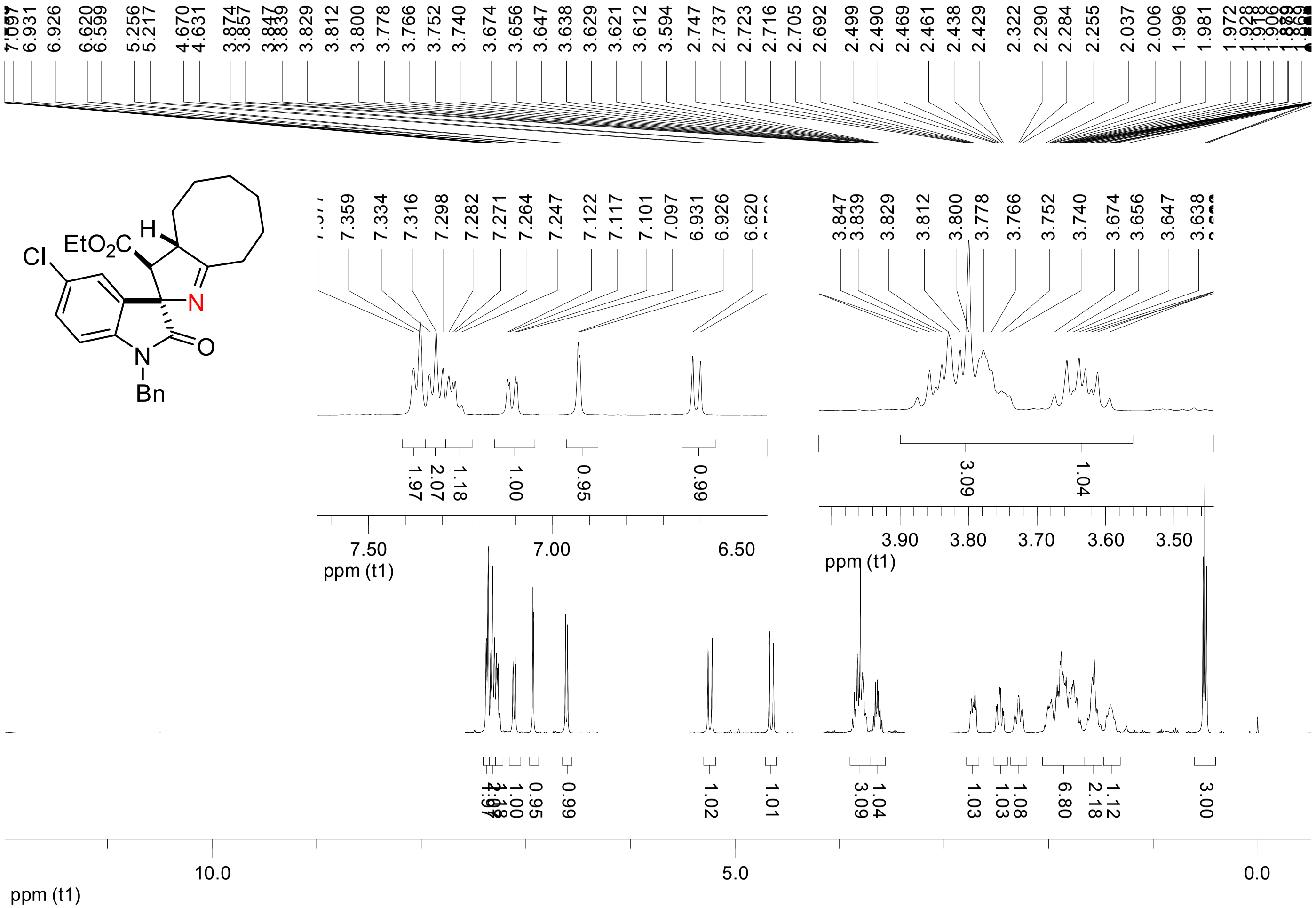
^{1}H NMR spectrum of **3ah**, major isomer (400 MHz, $CDCl_3$)



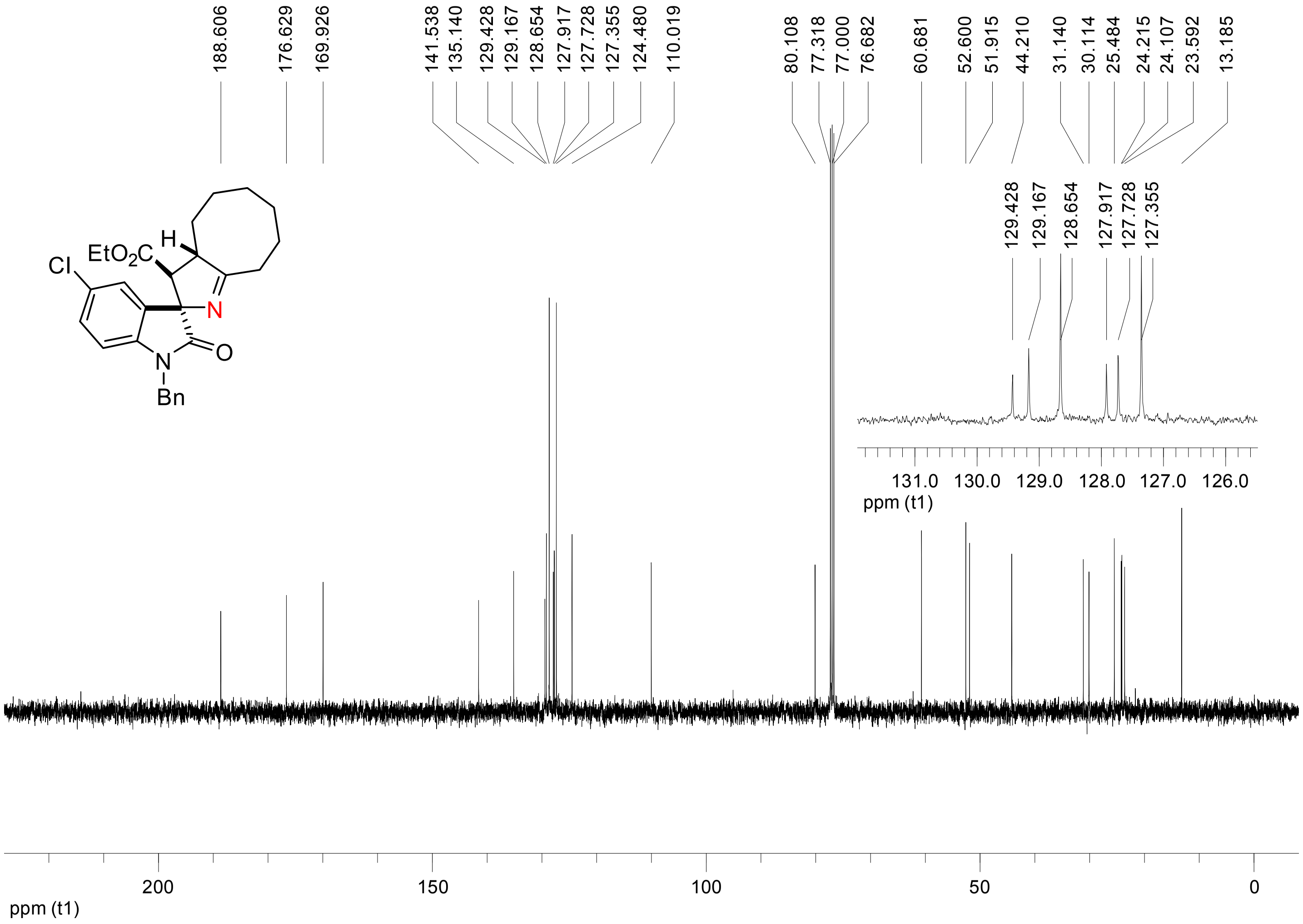
^{13}C NMR spectrum of **3ah**, major isomer (100 MHz, $CDCl_3$)



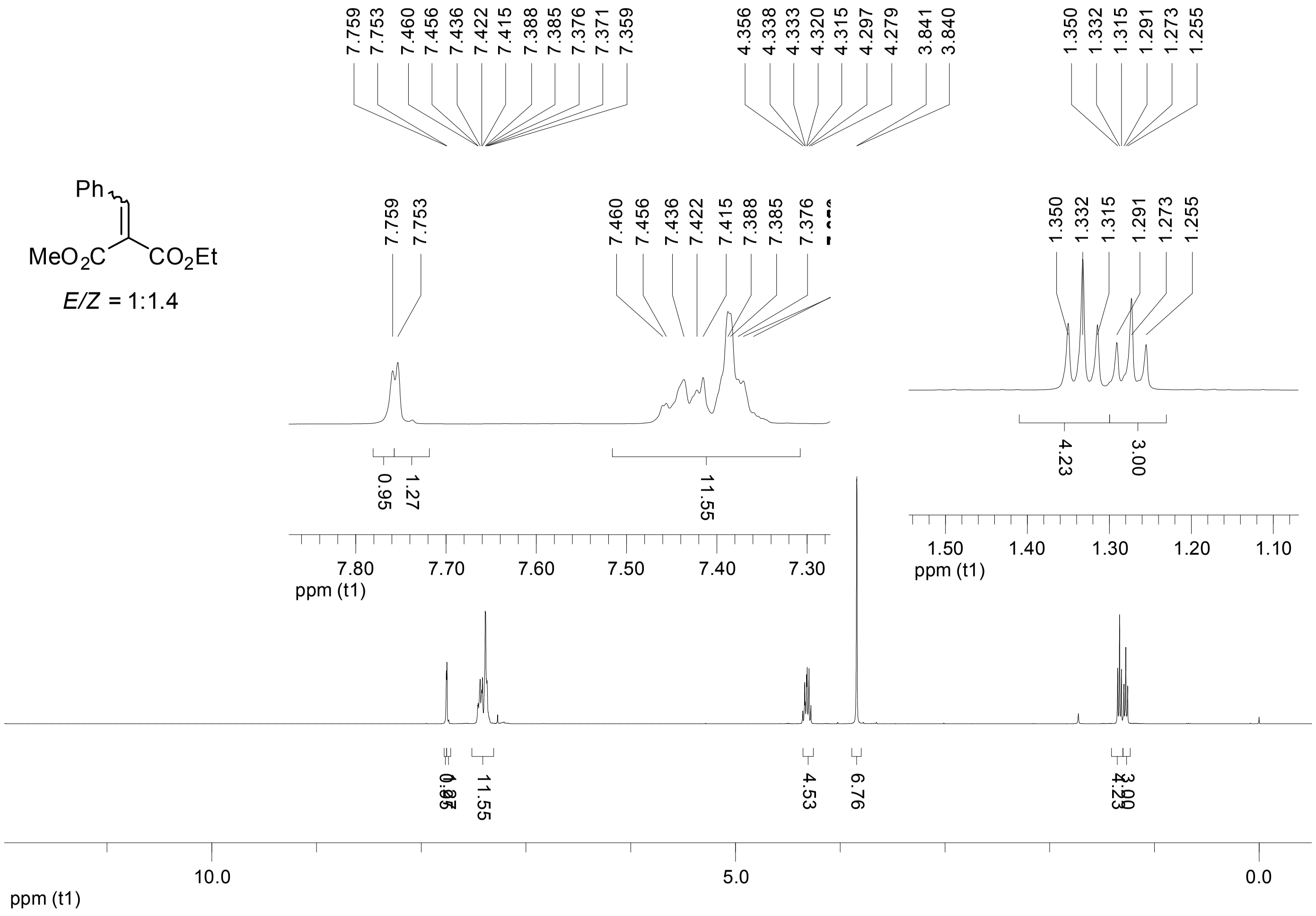
^{1}H NMR spectrum of **3gh**, major isomer (400 MHz, $CDCl_3$)



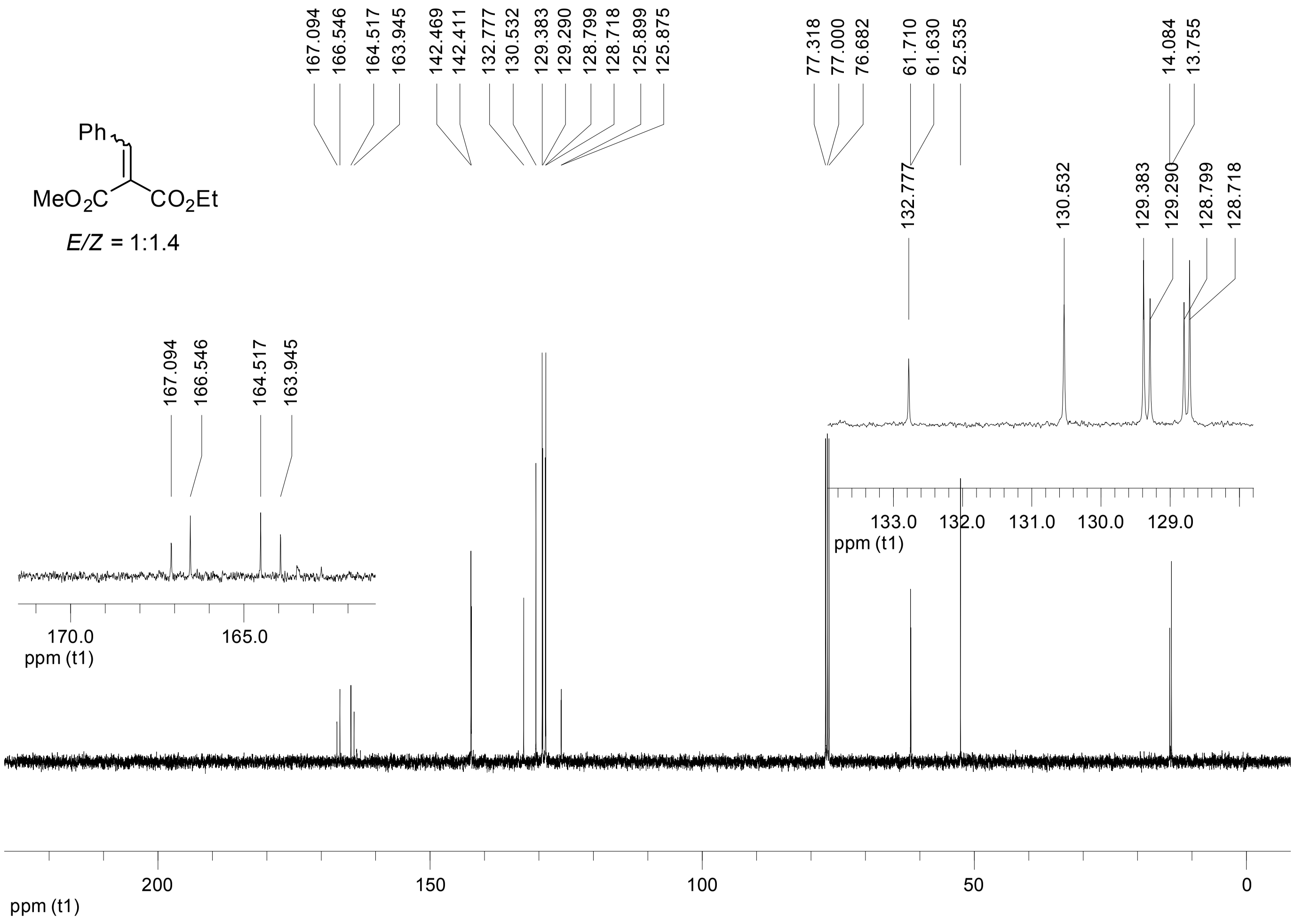
^{13}C NMR spectrum of **3gh**, major isomer (100 MHz, CDCl$_3$)



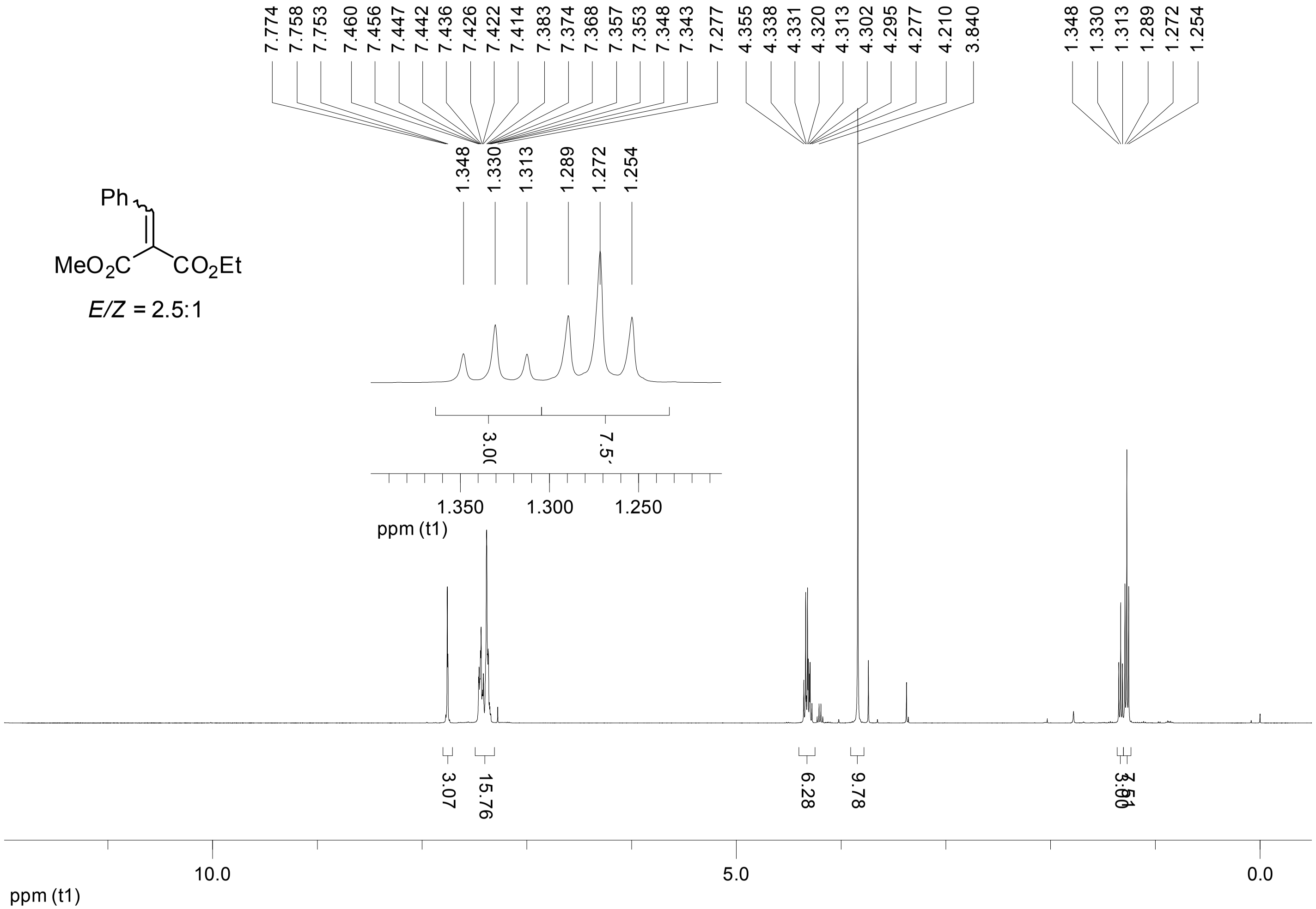
^{1}H NMR spectrum of **4j**, E/Z = 1:1.4 (400 MHz, $CDCl_3$)



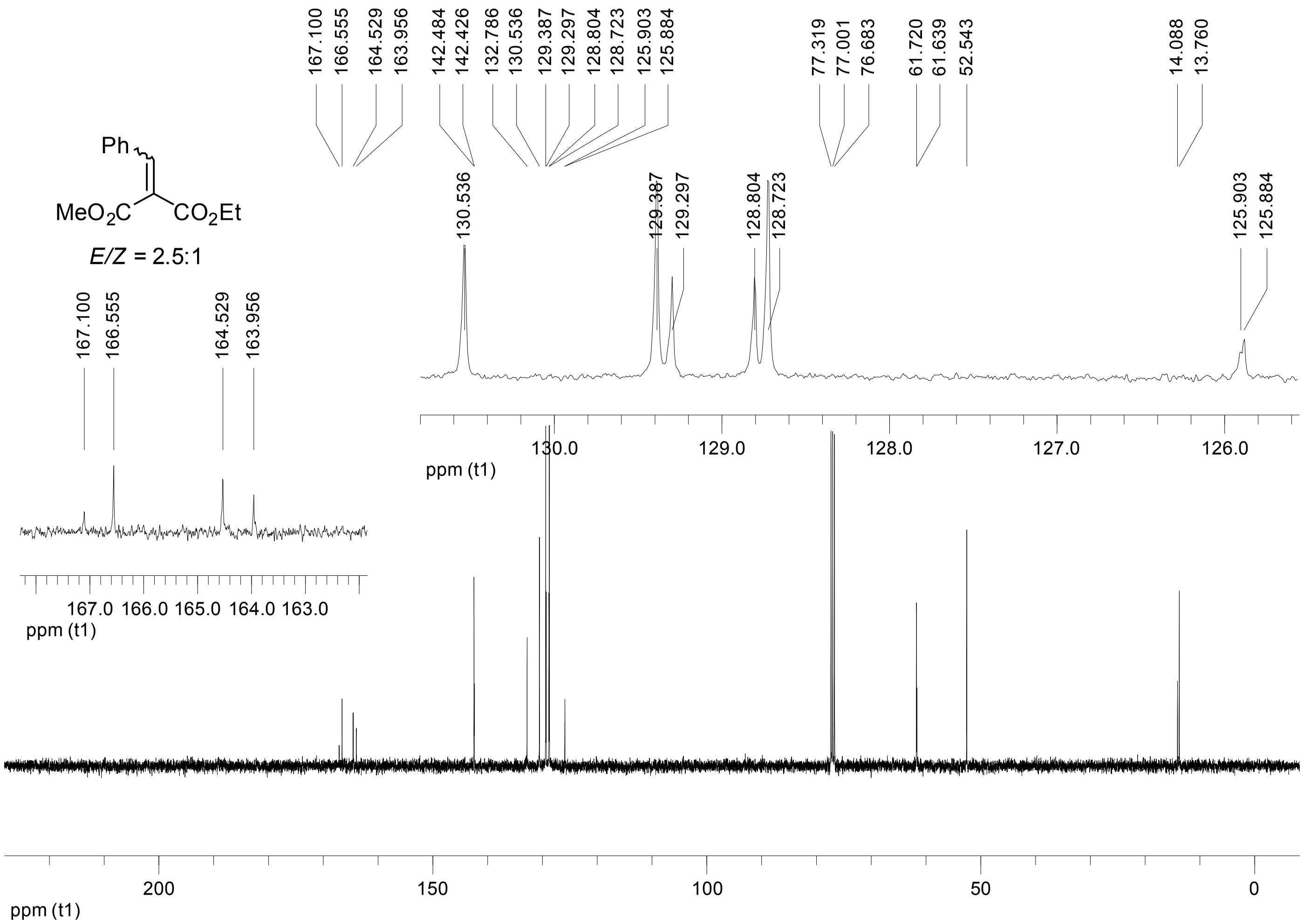
^{13}C NMR spectrum of **4j**, *E/Z* = 1:1.4 (100 MHz, $CDCl_3$)



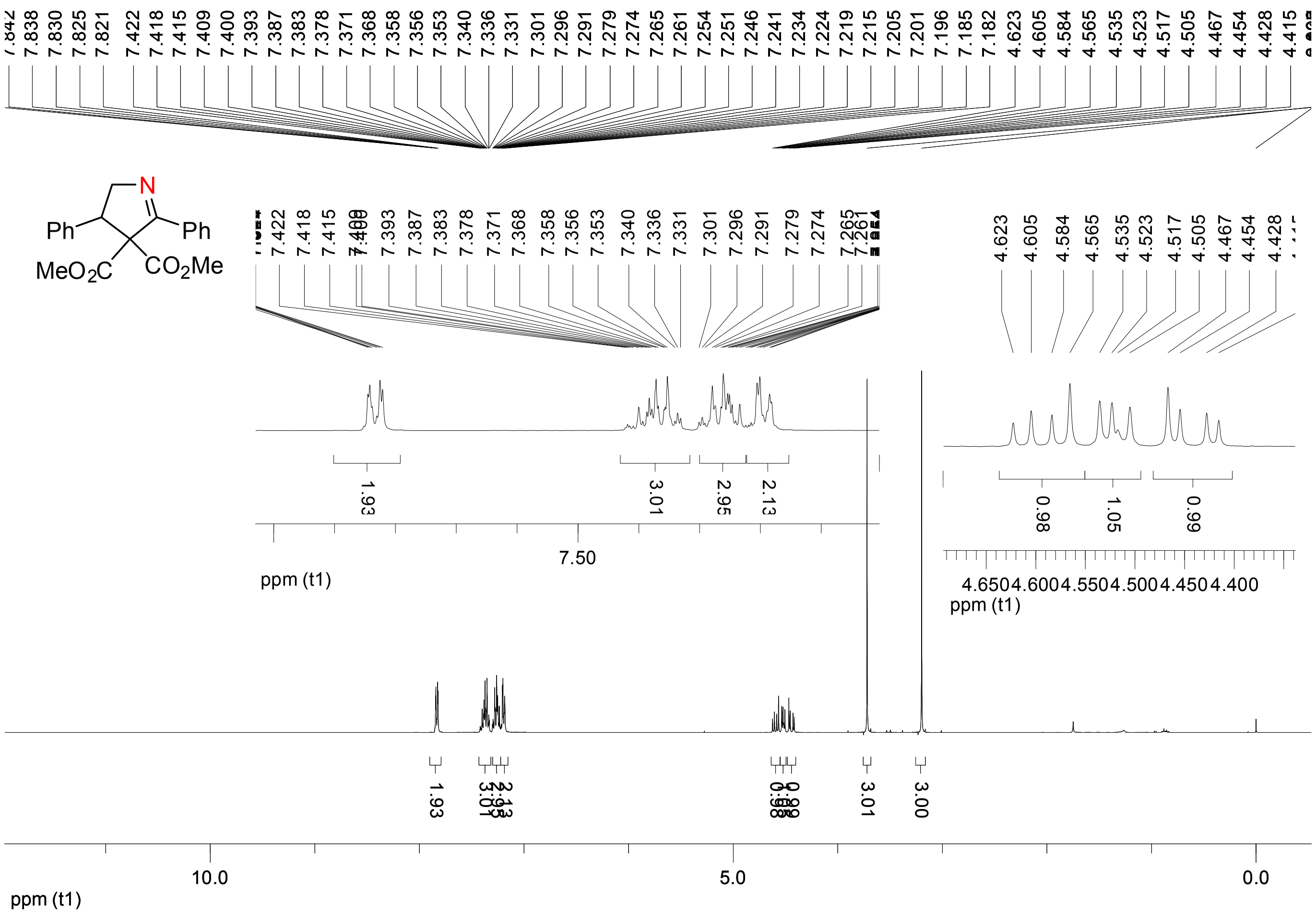
^{1}H NMR spectrum of **4j'**, E/Z = 2.5:1 (400 MHz, $CDCl_3$)



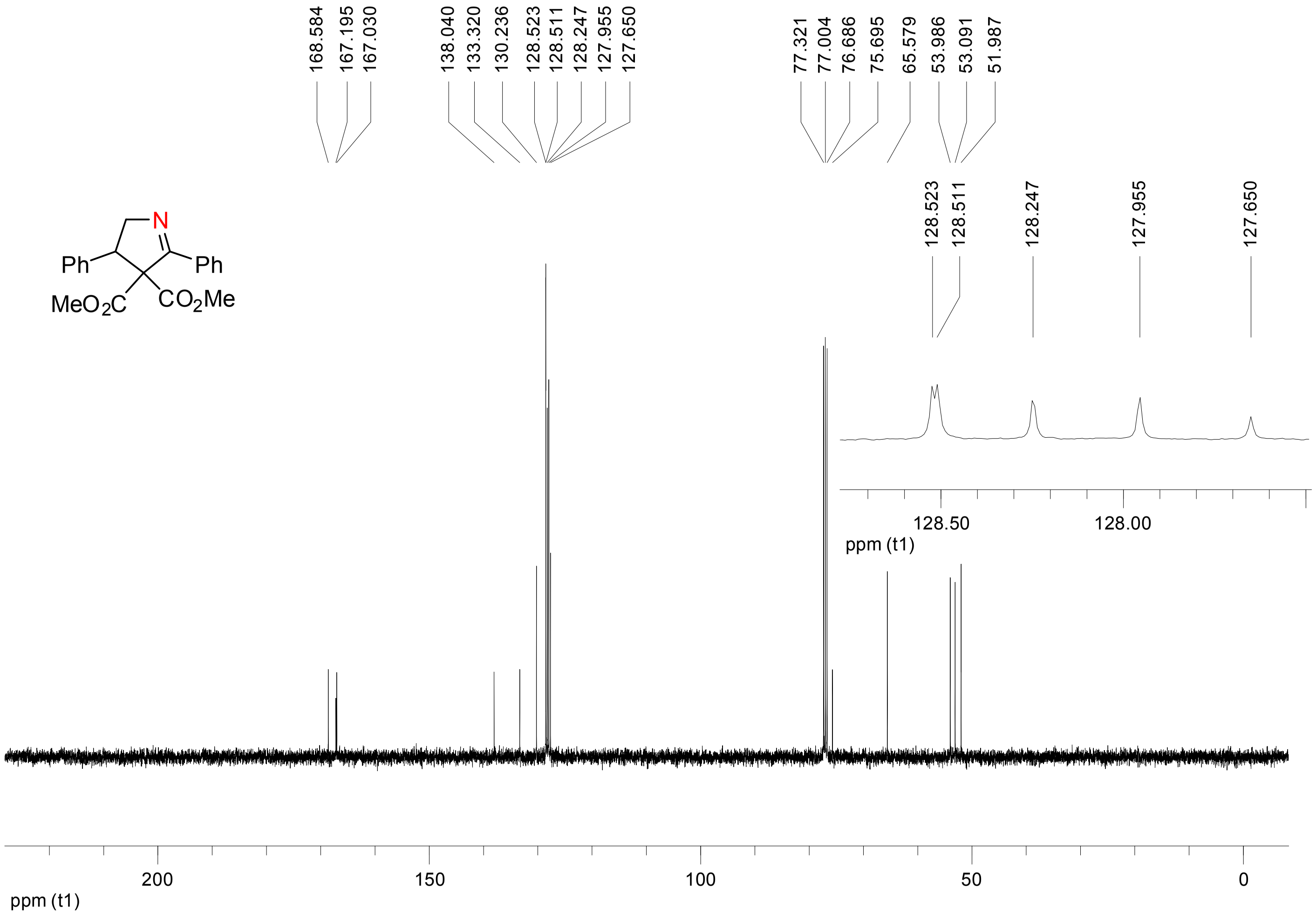
^{13}C NMR spectrum of **4j'**, *E/Z* = 2.5:1 (400 MHz, $CDCl_3$)



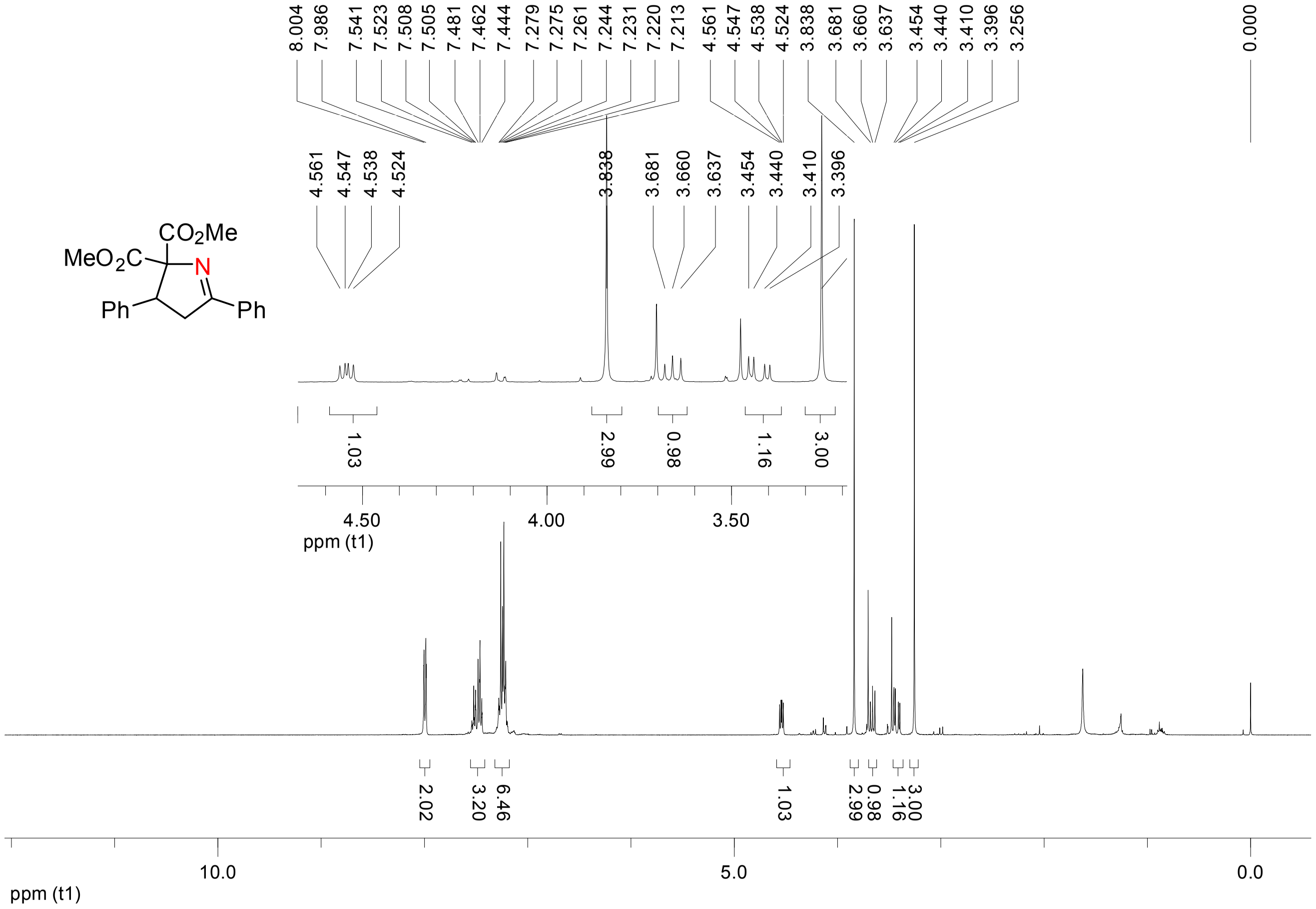
^{1}H NMR spectrum of **5aa** (400 MHz, CDCl$_3$)



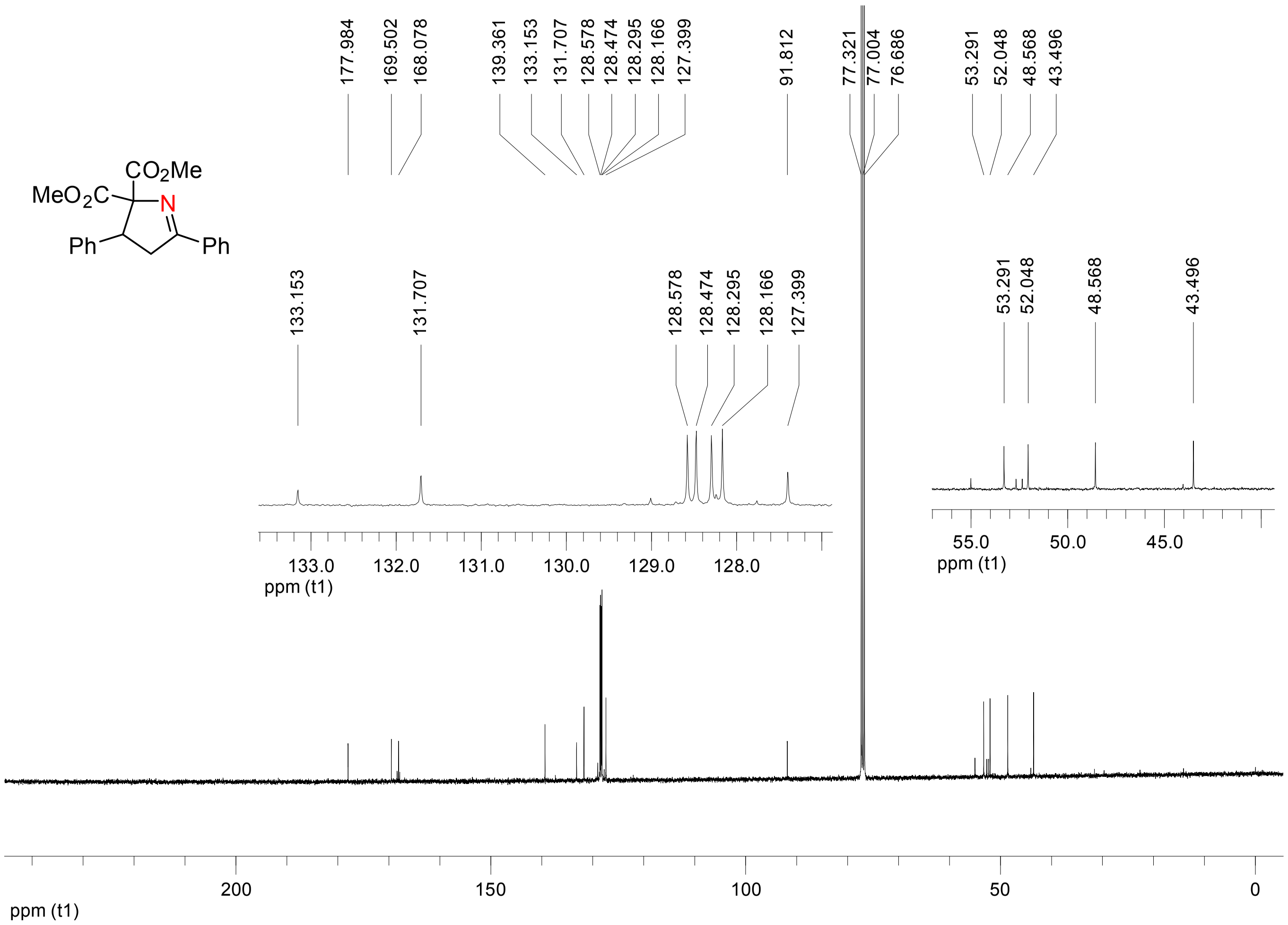
^{13}C NMR spectrum of **5aa** (100 MHz, CDCl$_3$)



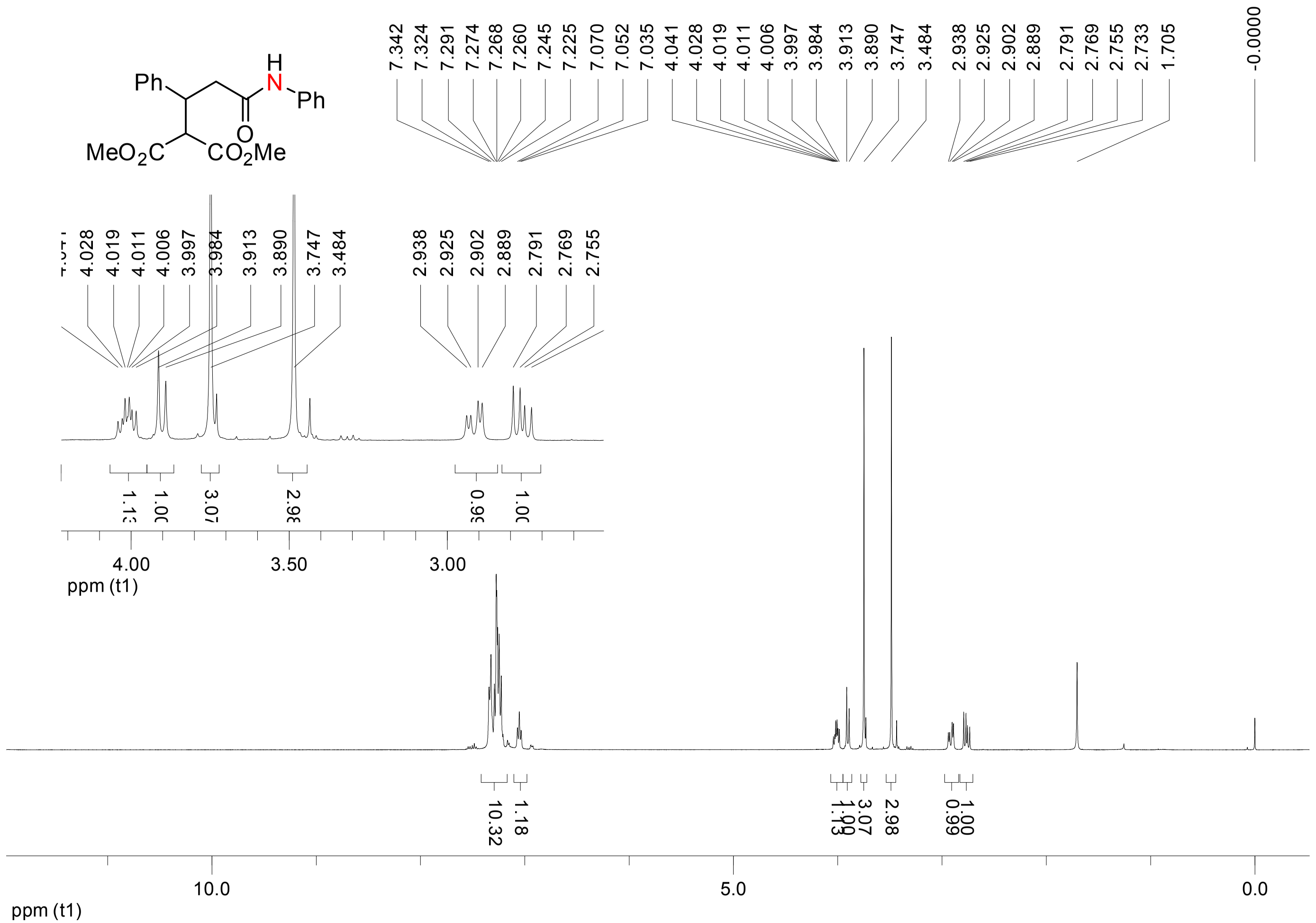
^{1}H NMR spectrum of **5aa’** (400 MHz, $CDCl_3$)



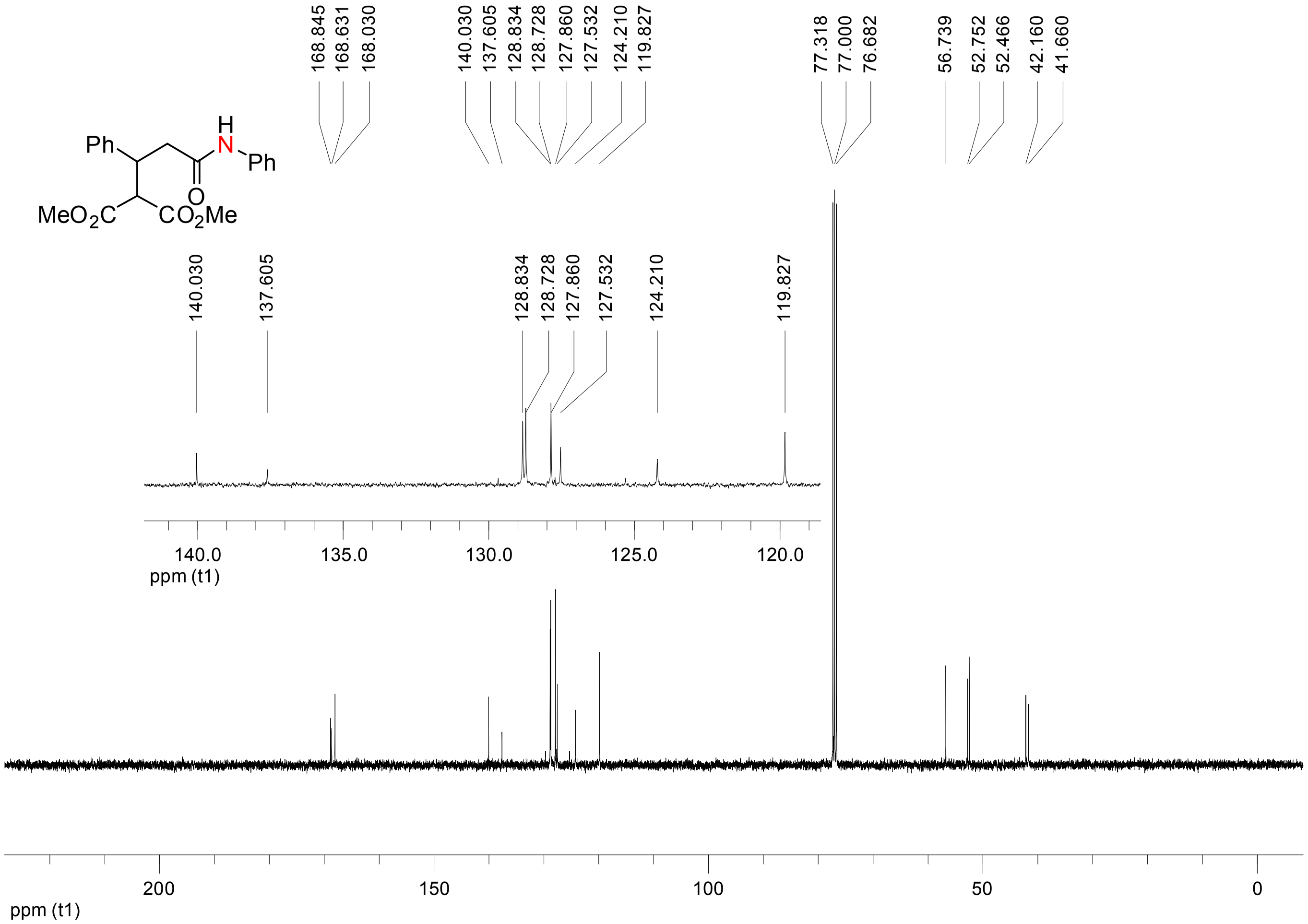
^{13}C NMR spectrum of **5aa’** (100 MHz, $CDCl_3$)



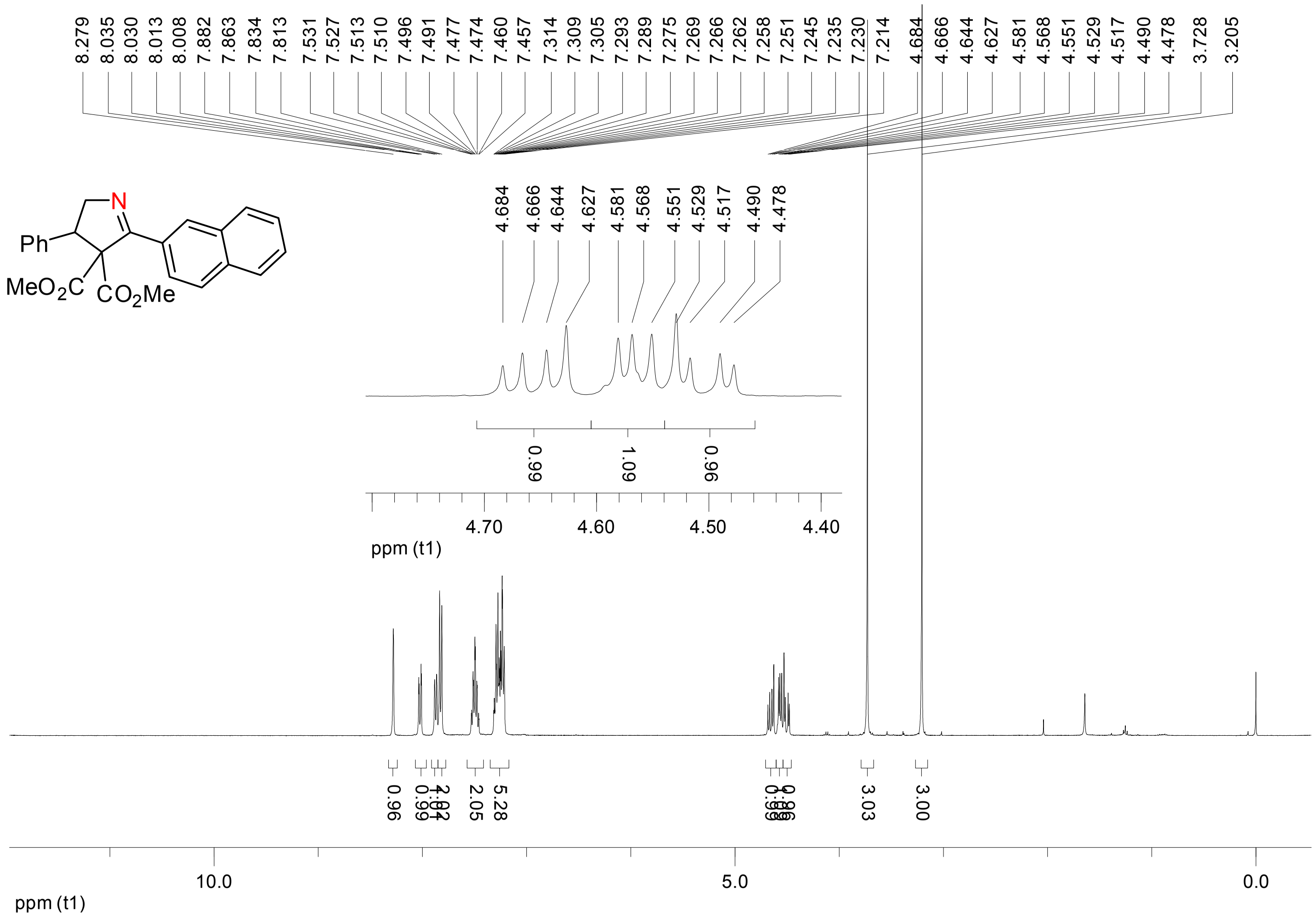
^{1}H NMR spectrum of **5aa”** (400 MHz, $CDCl_3$)



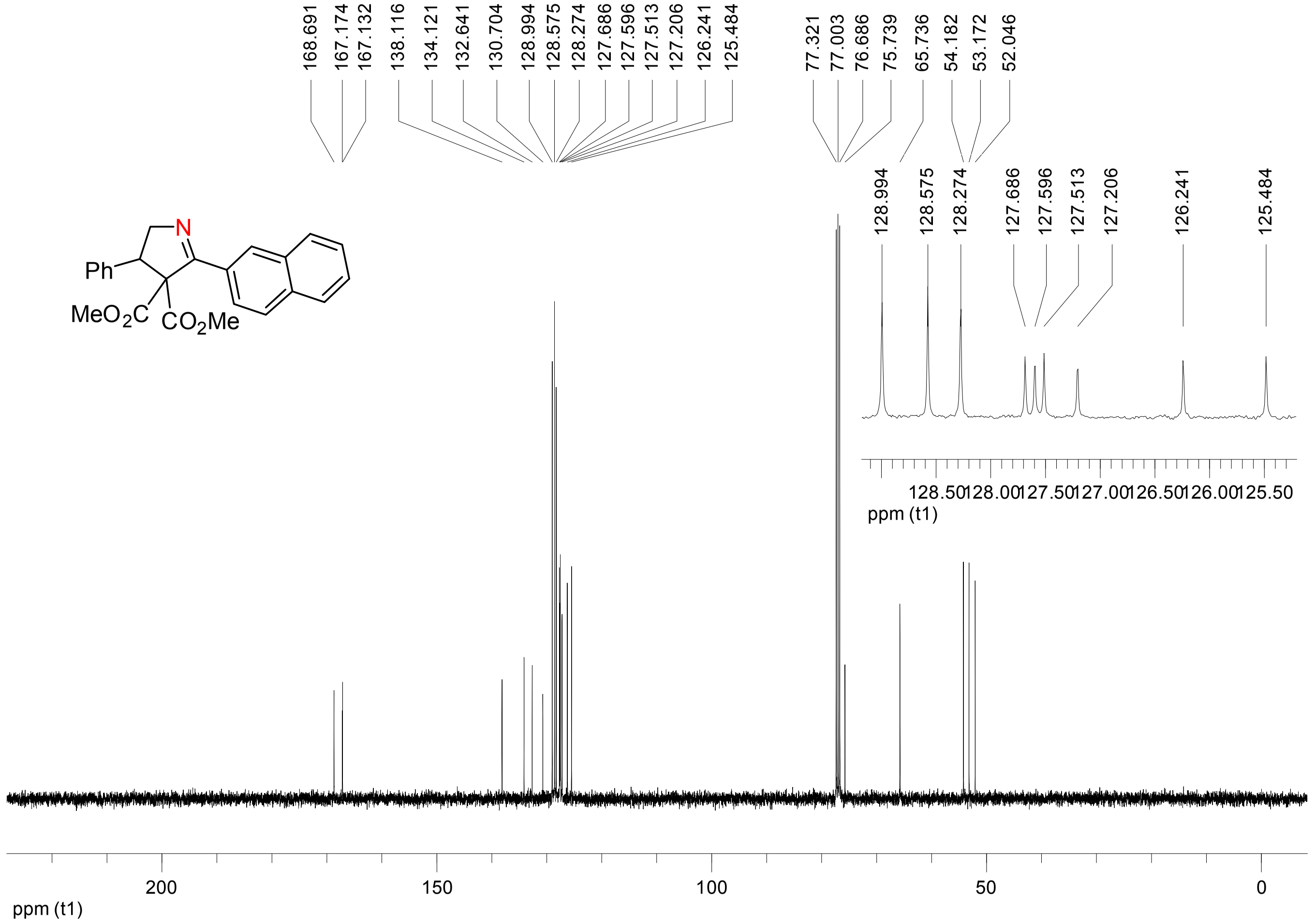
^{13}C NMR spectrum of **5aa”** (100 MHz, $CDCl_3$)



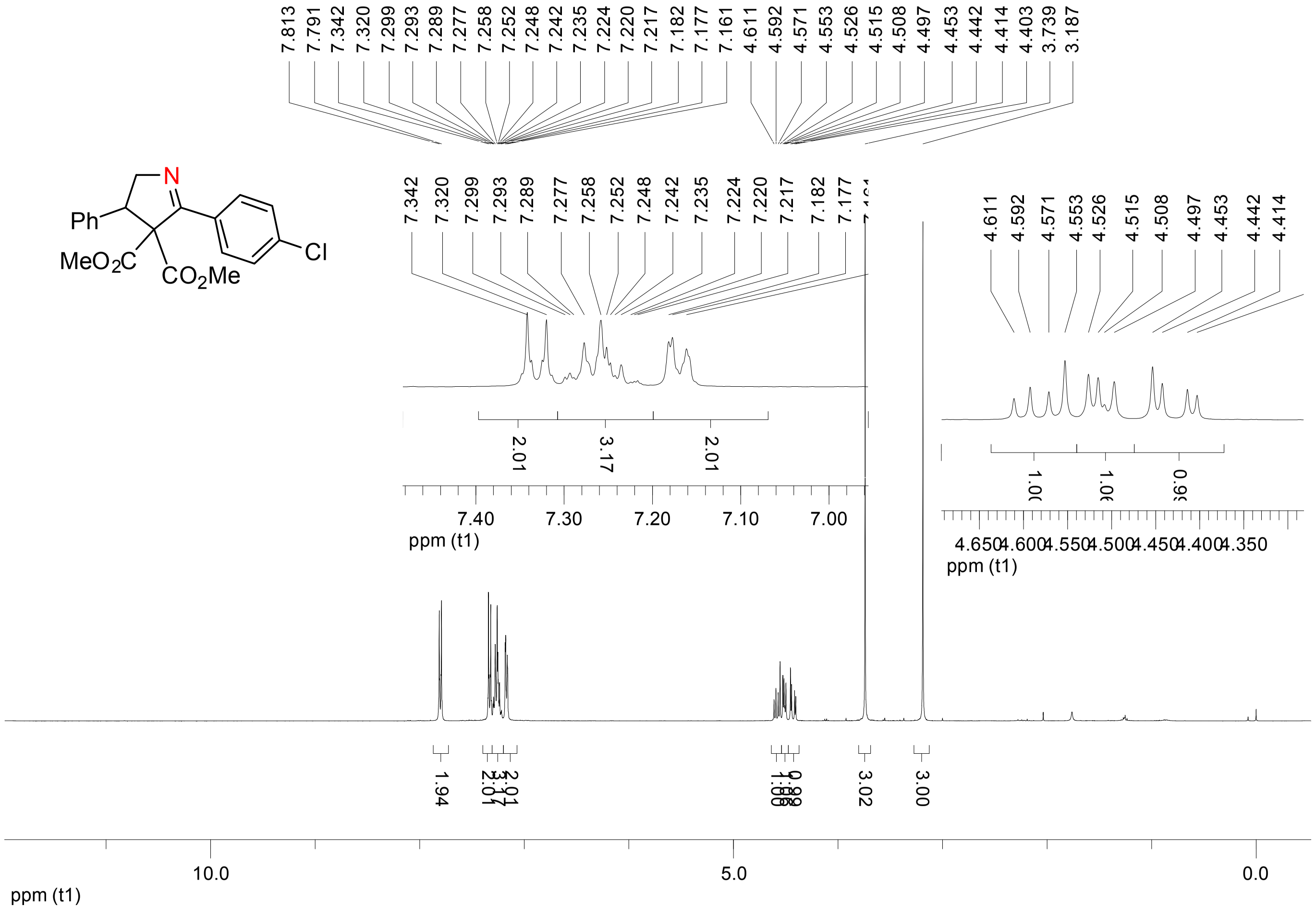
^{1}H NMR spectrum of **5ab** (400 MHz, CDCl$_3$)



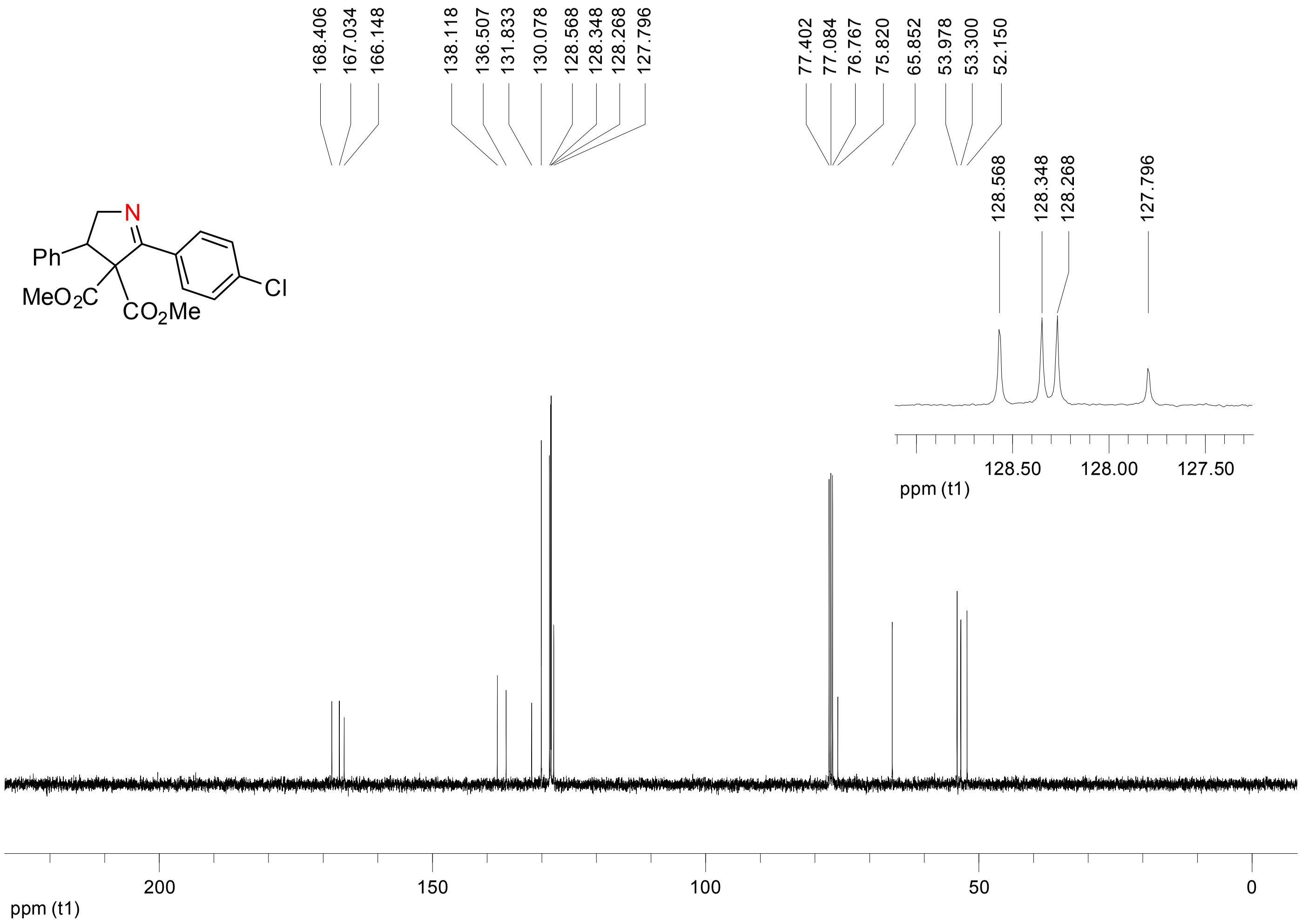
^{13}C NMR spectrum of **5ab** (100 MHz, $CDCl_3$)



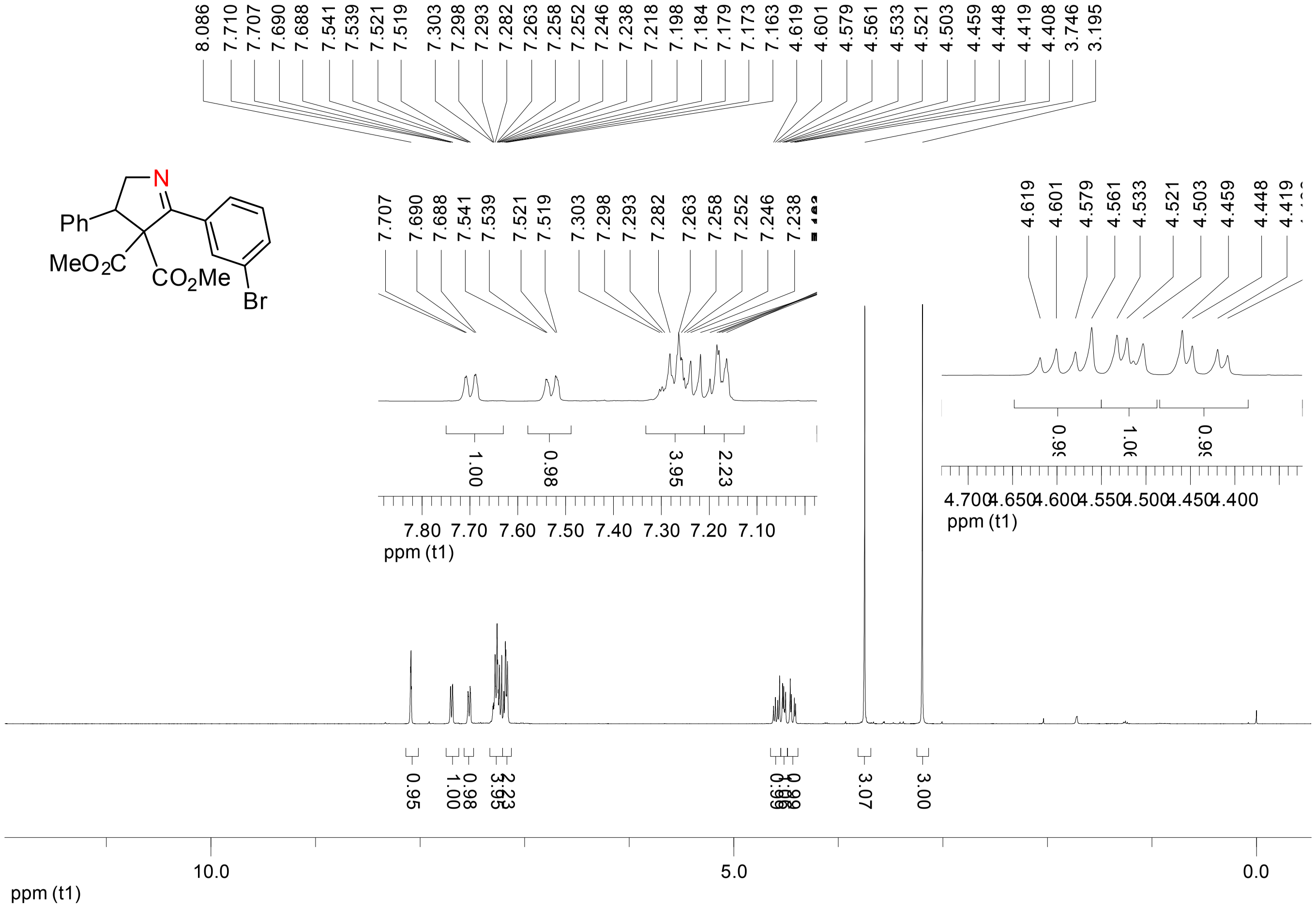
^{1}H NMR spectrum of **5ad** (400 MHz, $CDCl_3$)



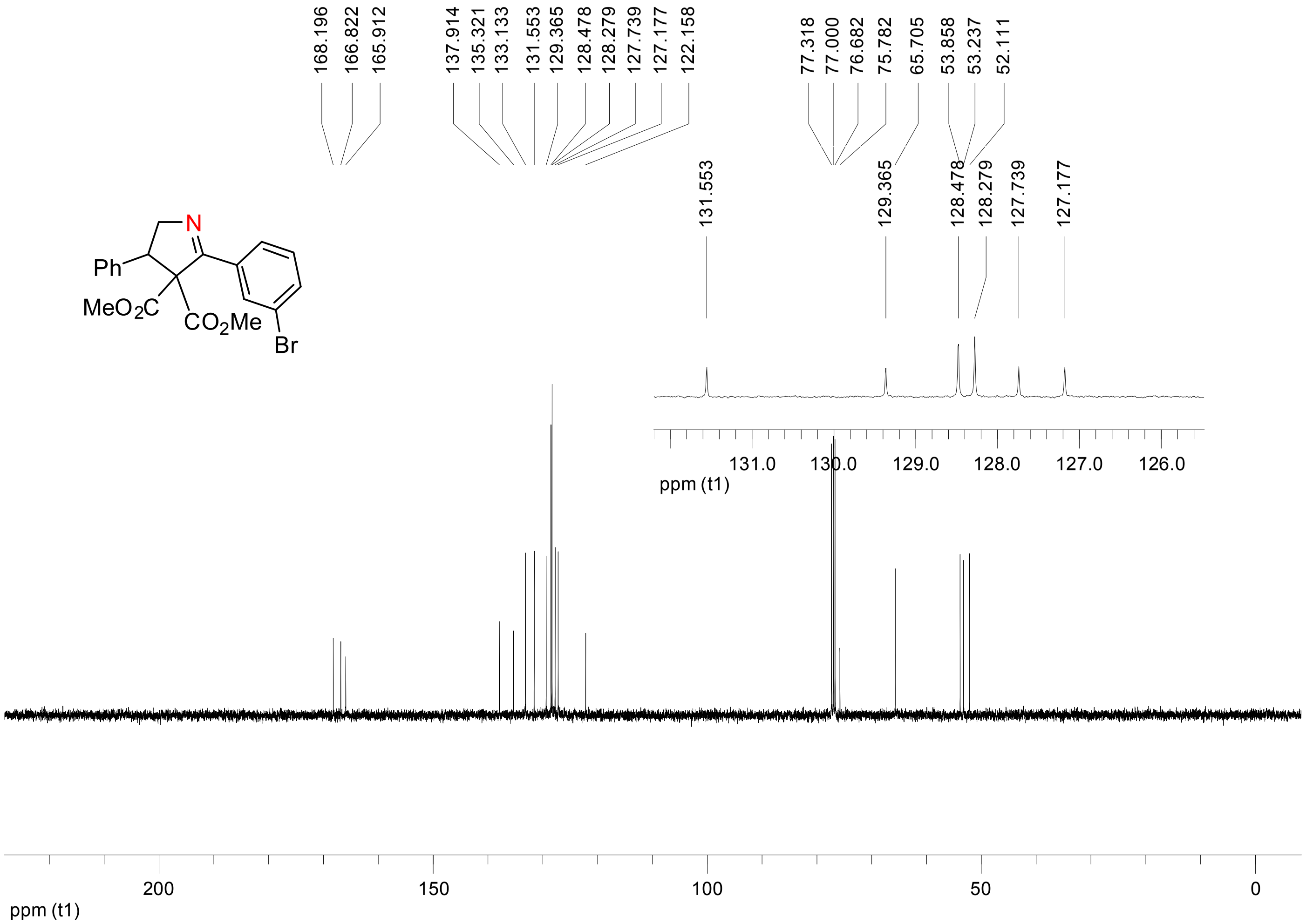
^{13}C NMR spectrum of **5ad** (100 MHz, $CDCl_3$)



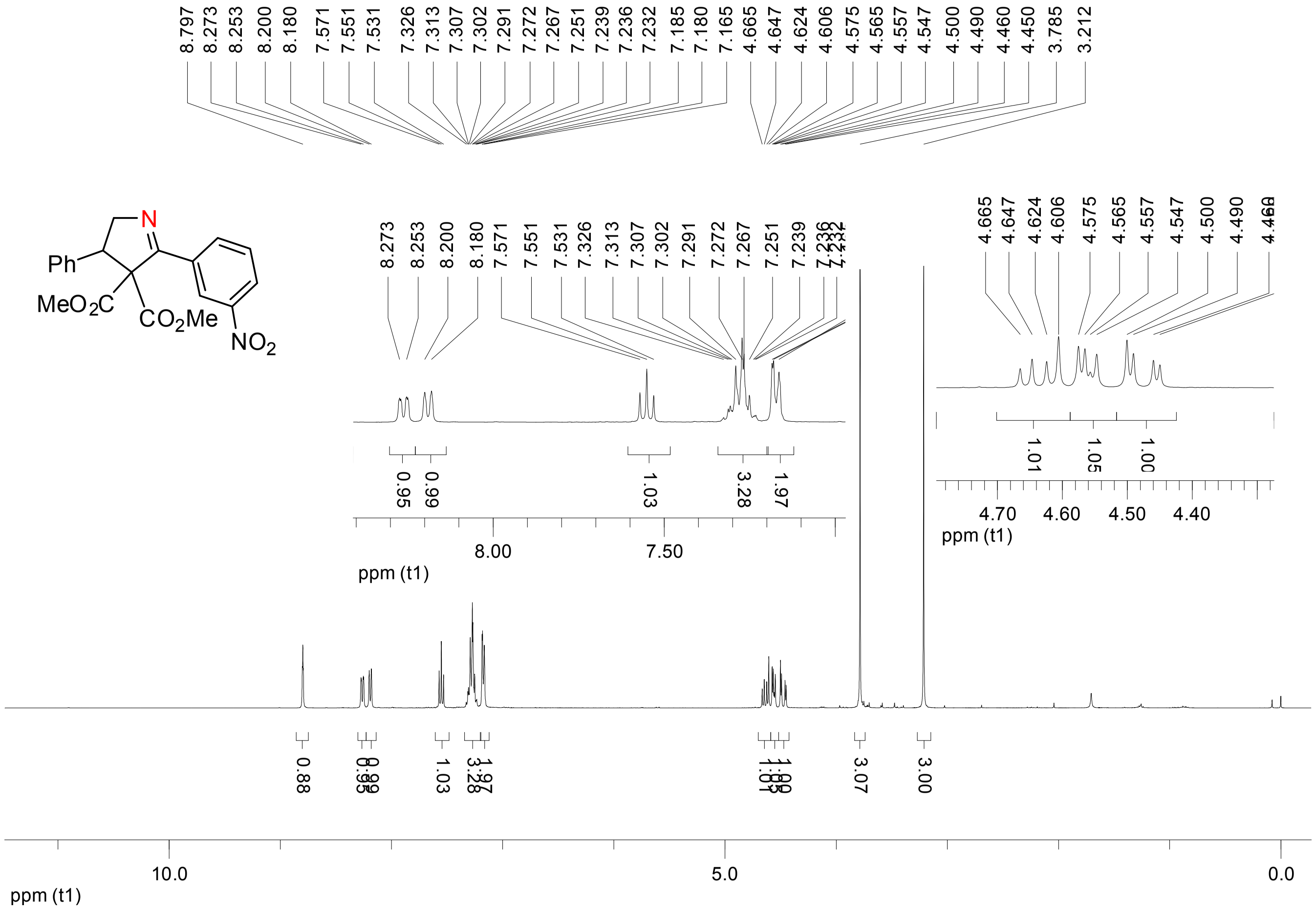
^{1}H NMR spectrum of **5ae** (400 MHz, $CDCl_3$)



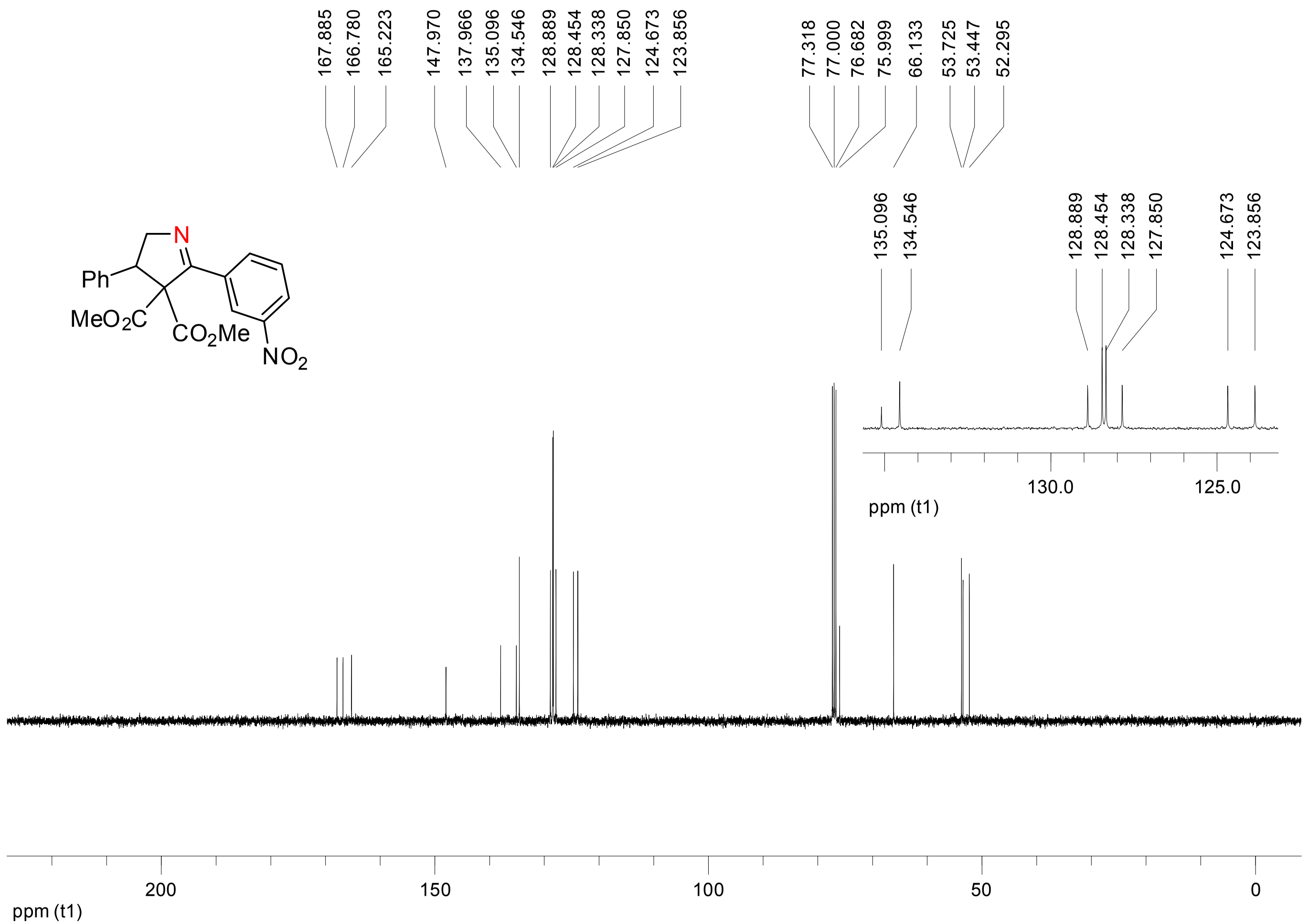
^{13}C NMR spectrum of **5ae** (100 MHz, $CDCl_3$)



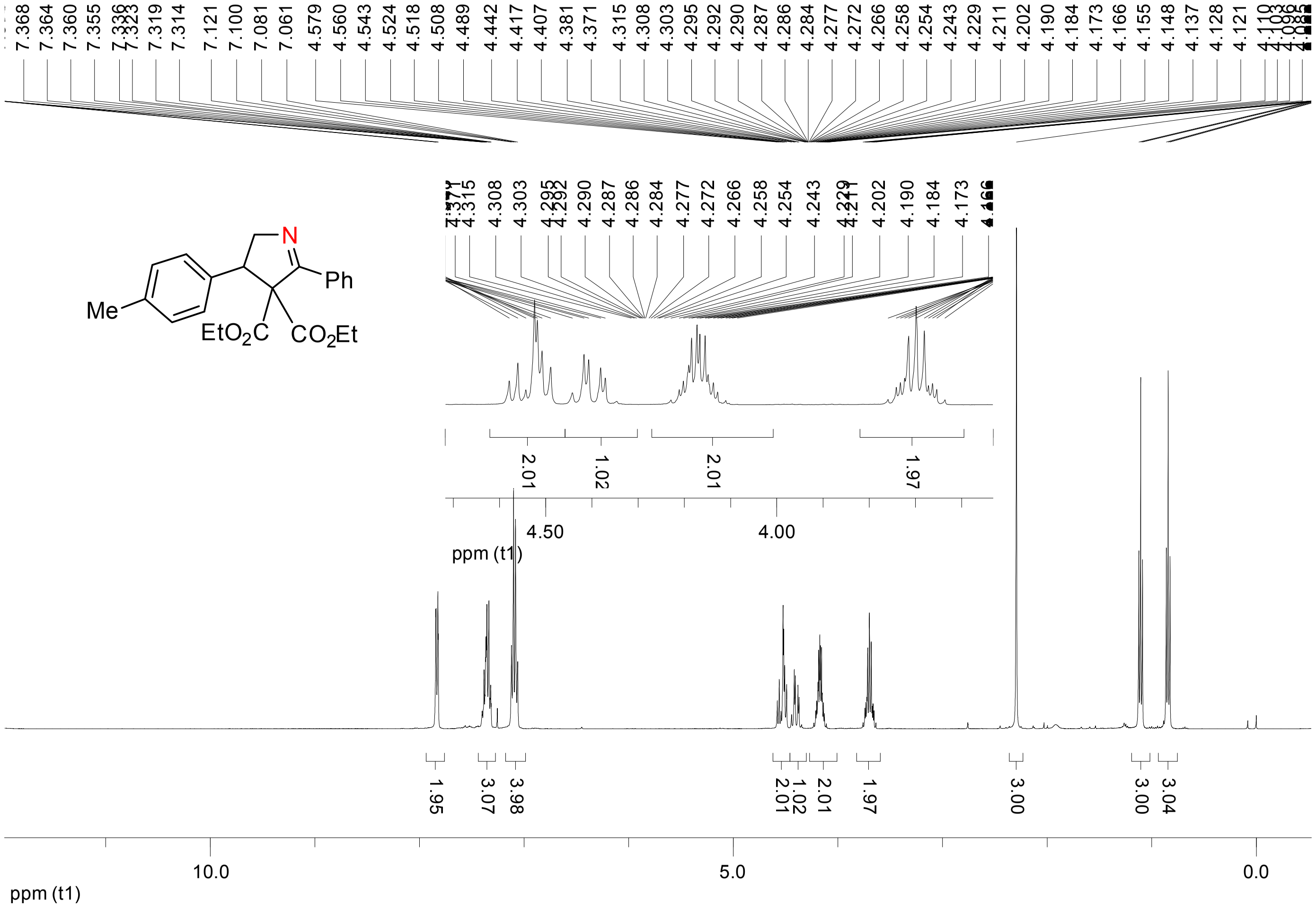
^{1}H NMR spectrum of **5af** (400 MHz, $CDCl_3$)



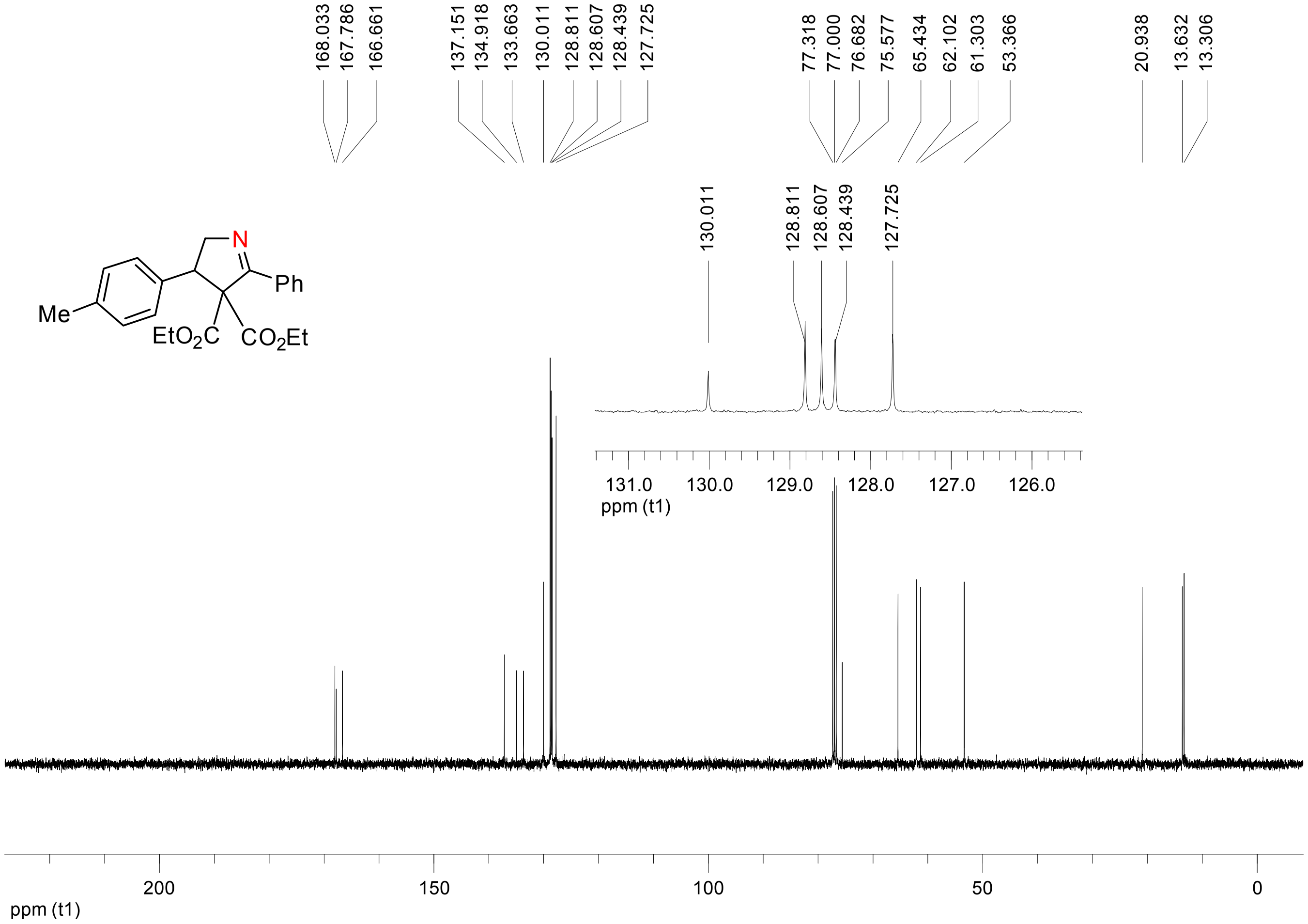
^{13}C NMR spectrum of **5af** (100 MHz, CDCl$_3$)



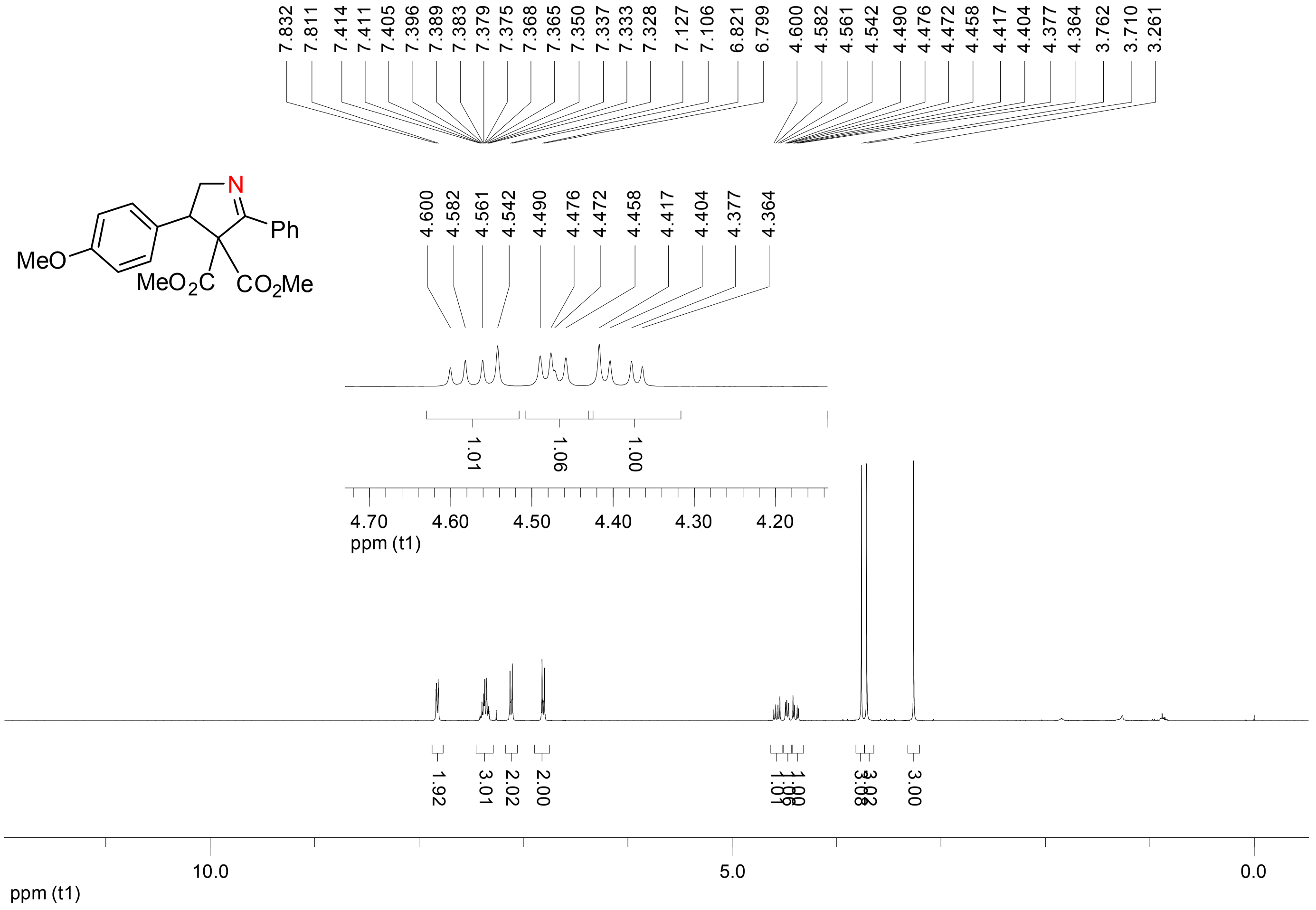
^{1}H NMR spectrum of **5ba** (400 MHz, $CDCl_3$)



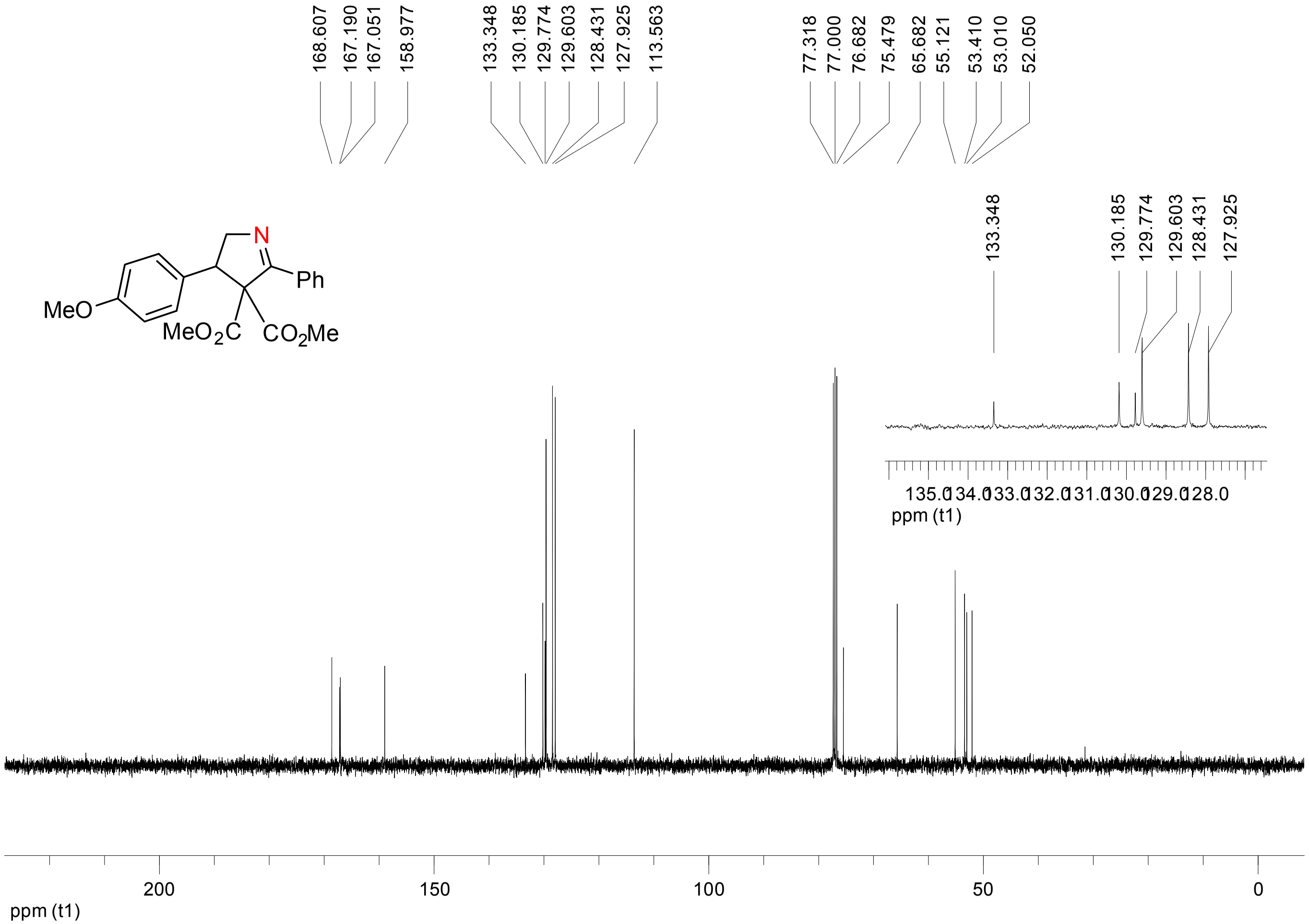
^{13}C NMR spectrum of **5ba** (100 MHz, $CDCl_3$)



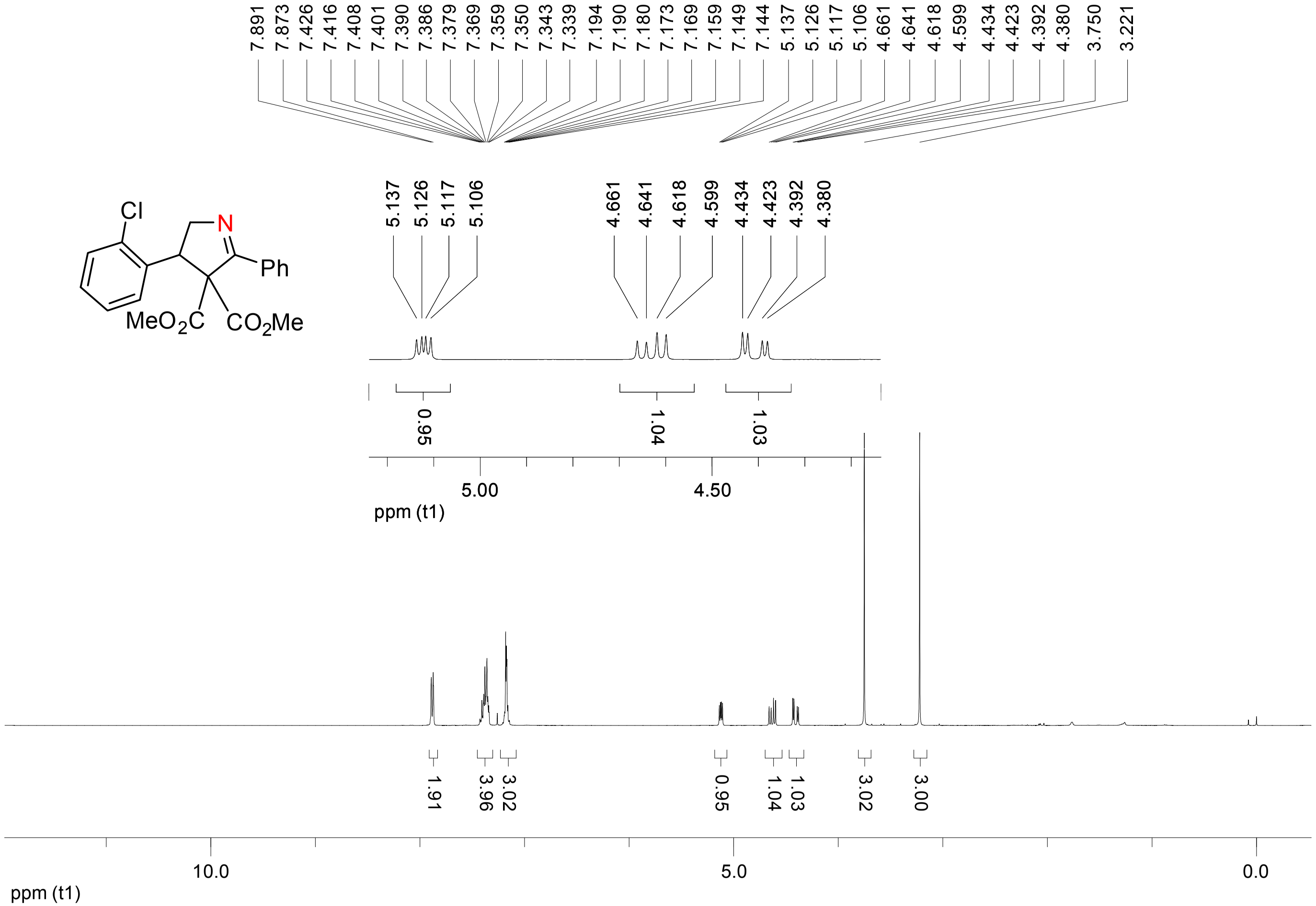
^{1}H NMR spectrum of **5ca** (400 MHz, $CDCl_3$)



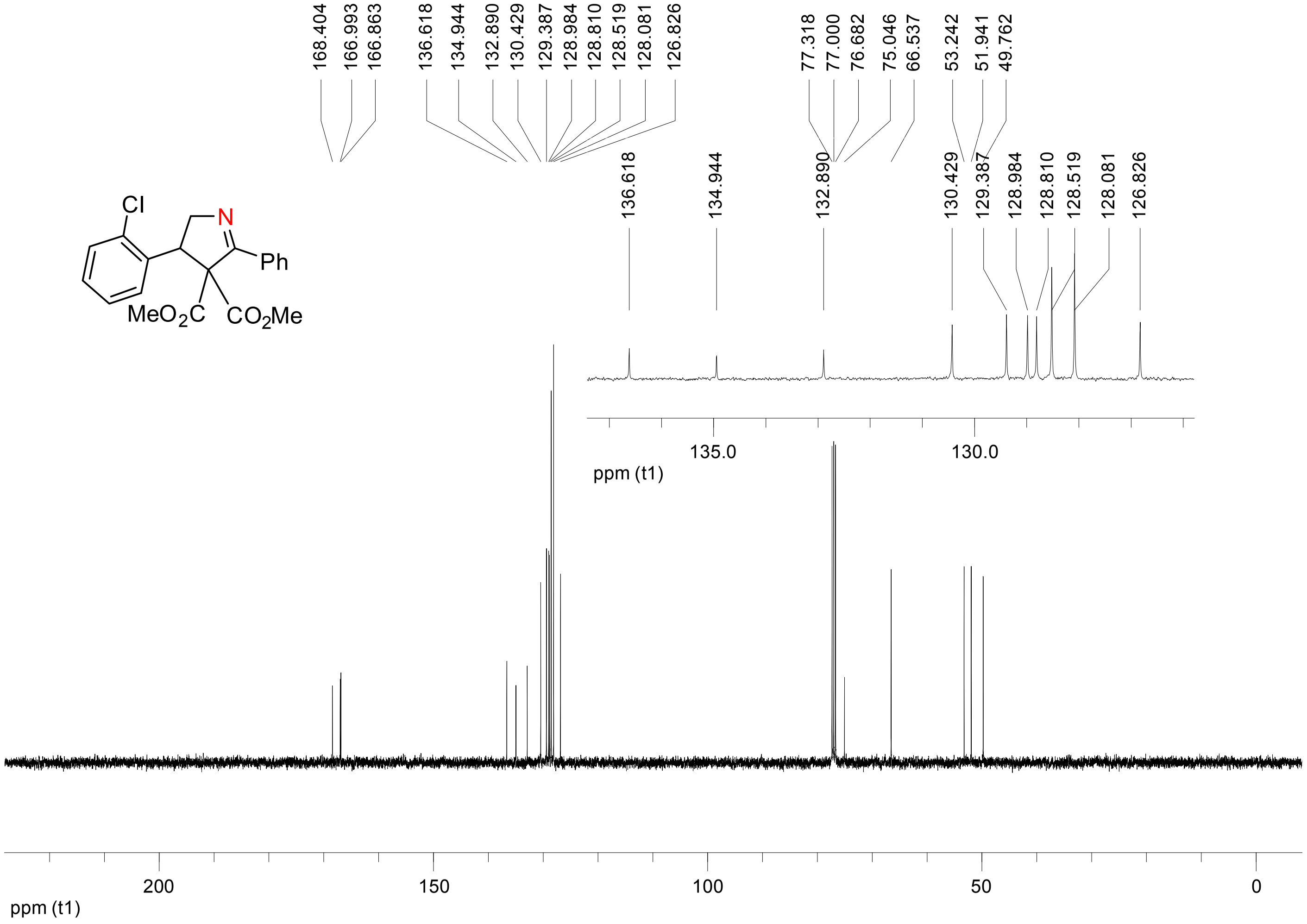
^{13}C NMR spectrum of **5ca** (100 MHz, CDCl$_3$)



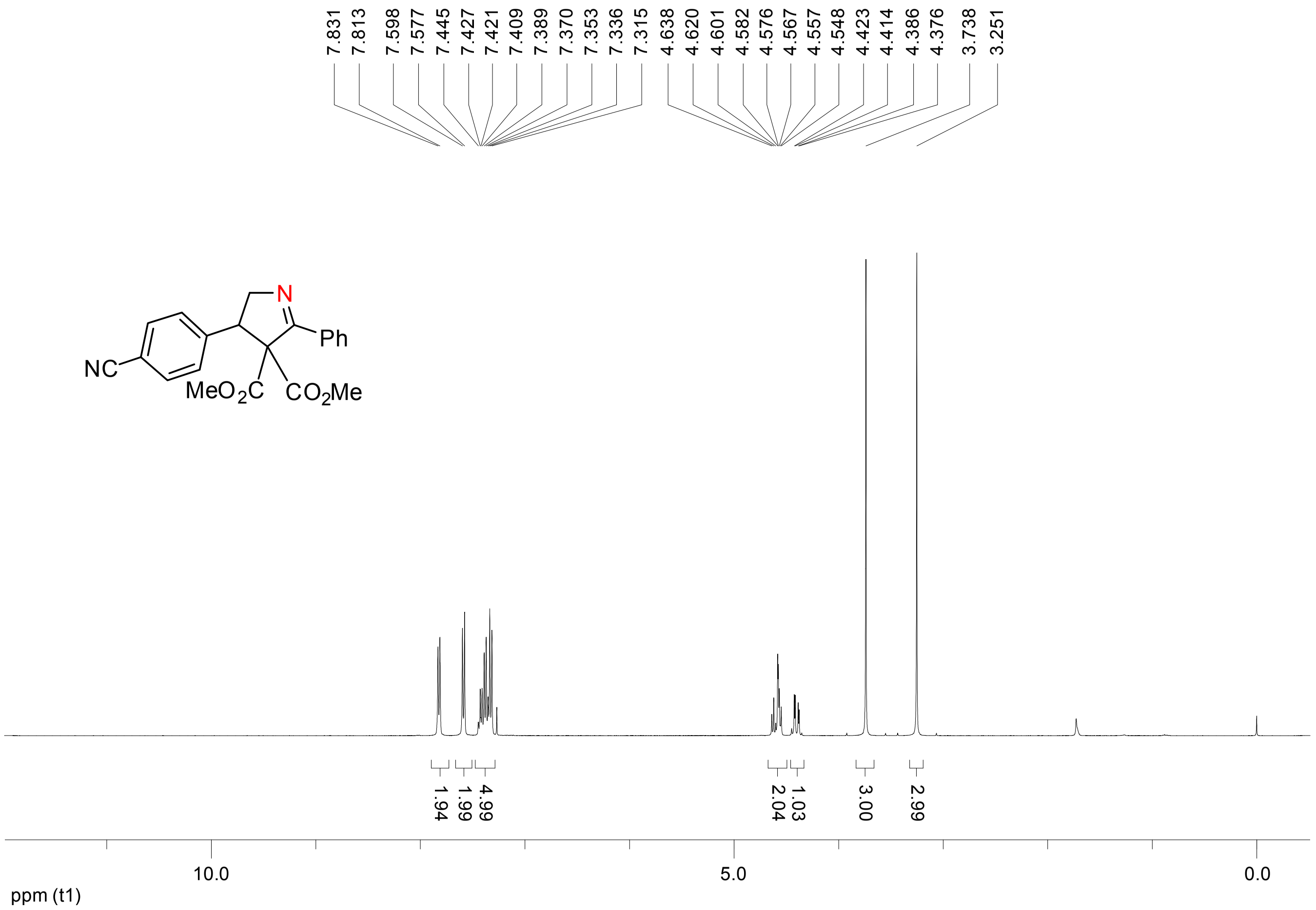
^{1}H NMR spectrum of **5da** (400 MHz, $CDCl_3$)



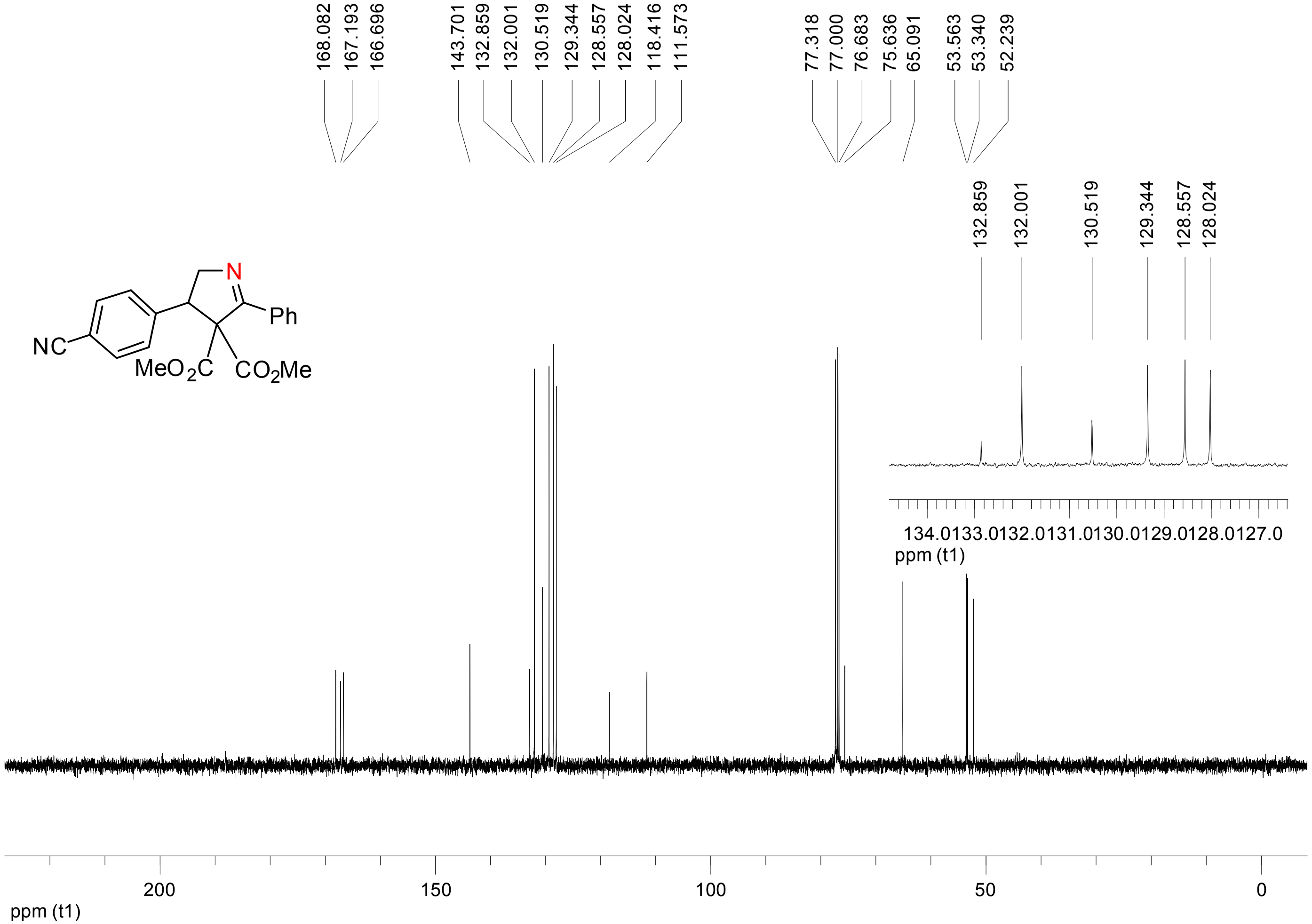
^{13}C NMR spectrum of **5da** (100 MHz, $CDCl_3$)



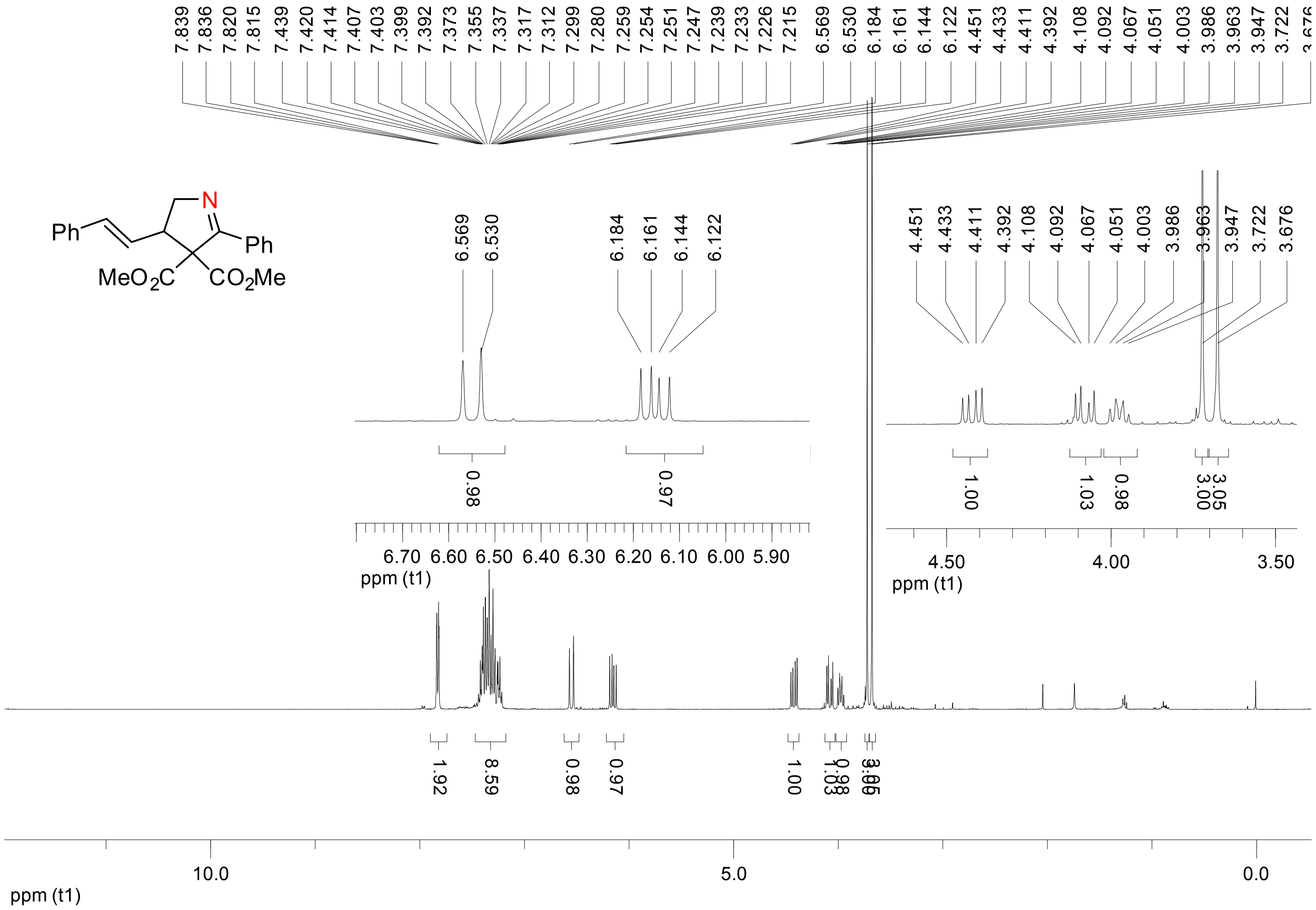
^{1}H NMR spectrum of **5ea** (400 MHz, $CDCl_3$)



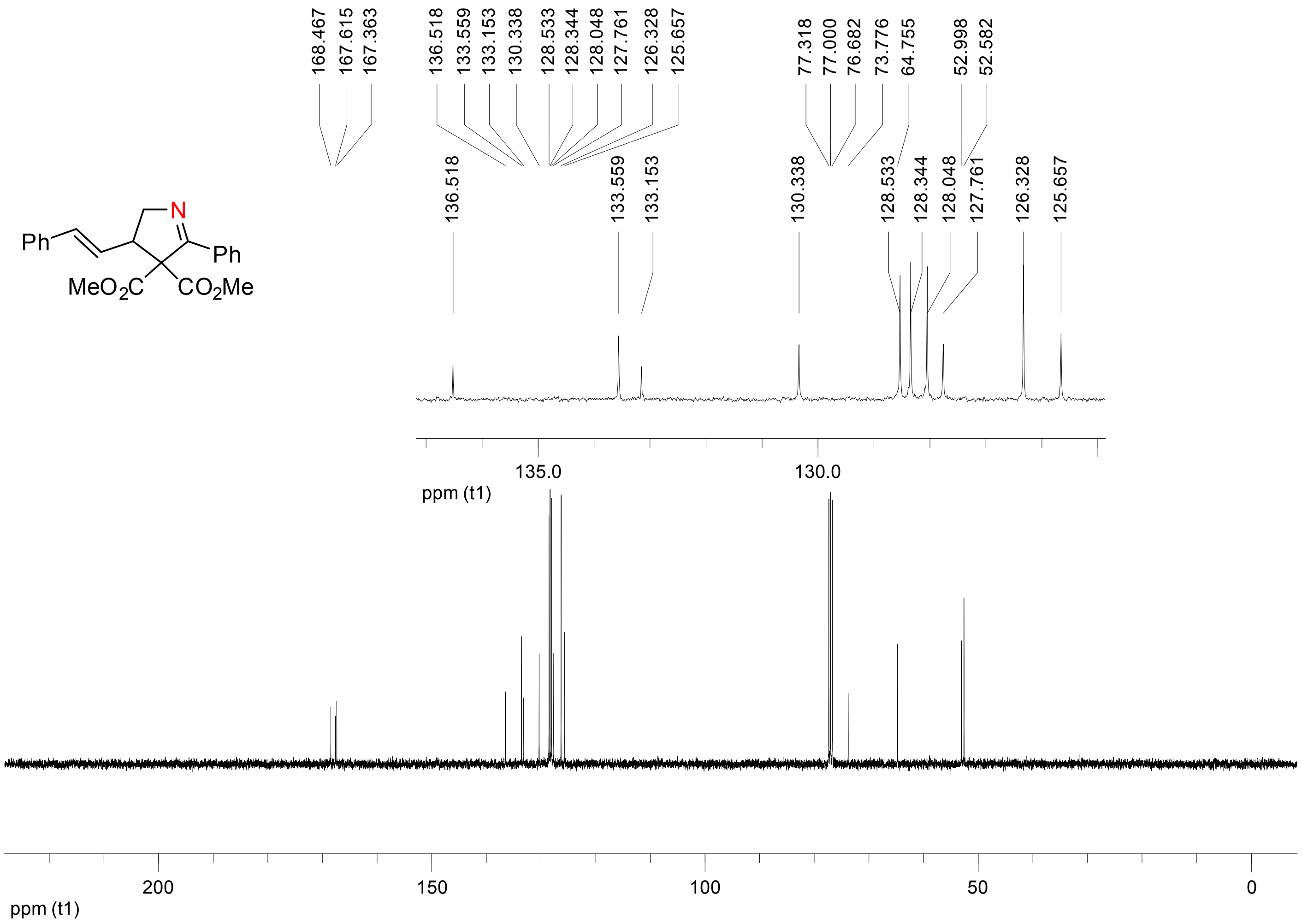
^{13}C NMR spectrum of **5ea** (100 MHz, $CDCl_3$)



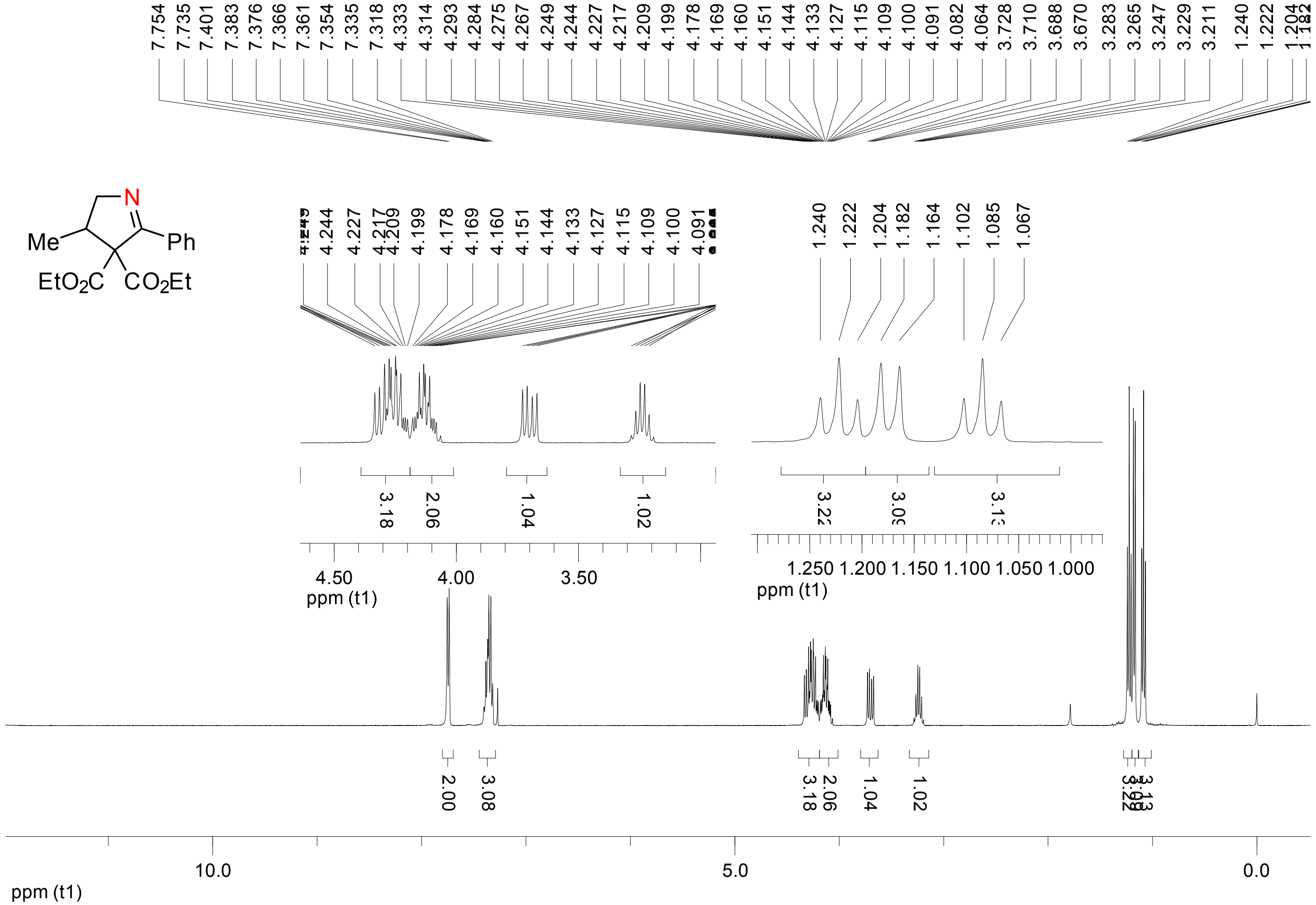
^{1}H NMR spectrum of **5fa** (400 MHz, $CDCl_3$)



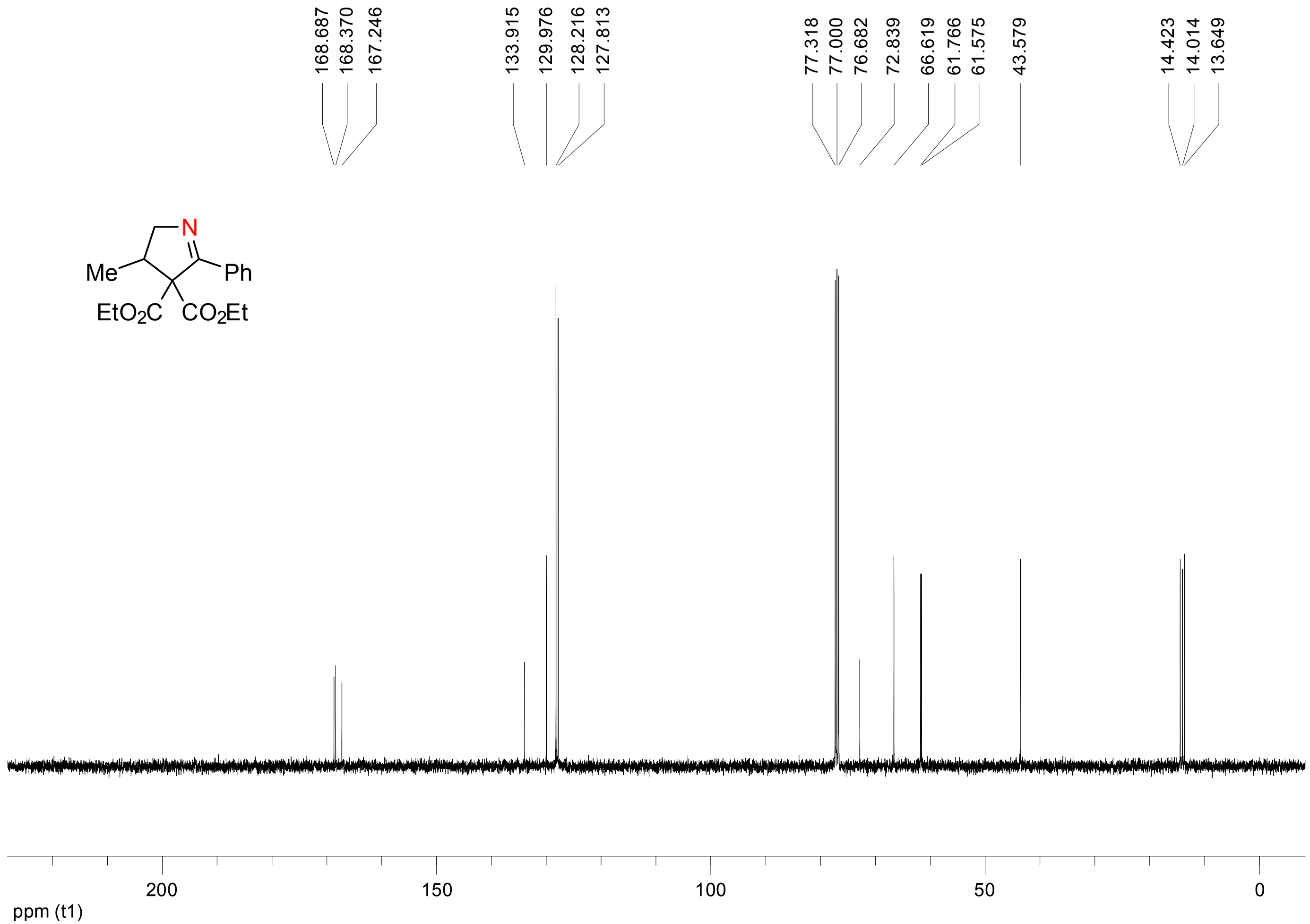
^{13}C NMR spectrum of **5fa** (100 MHz, CDCl$_3$)



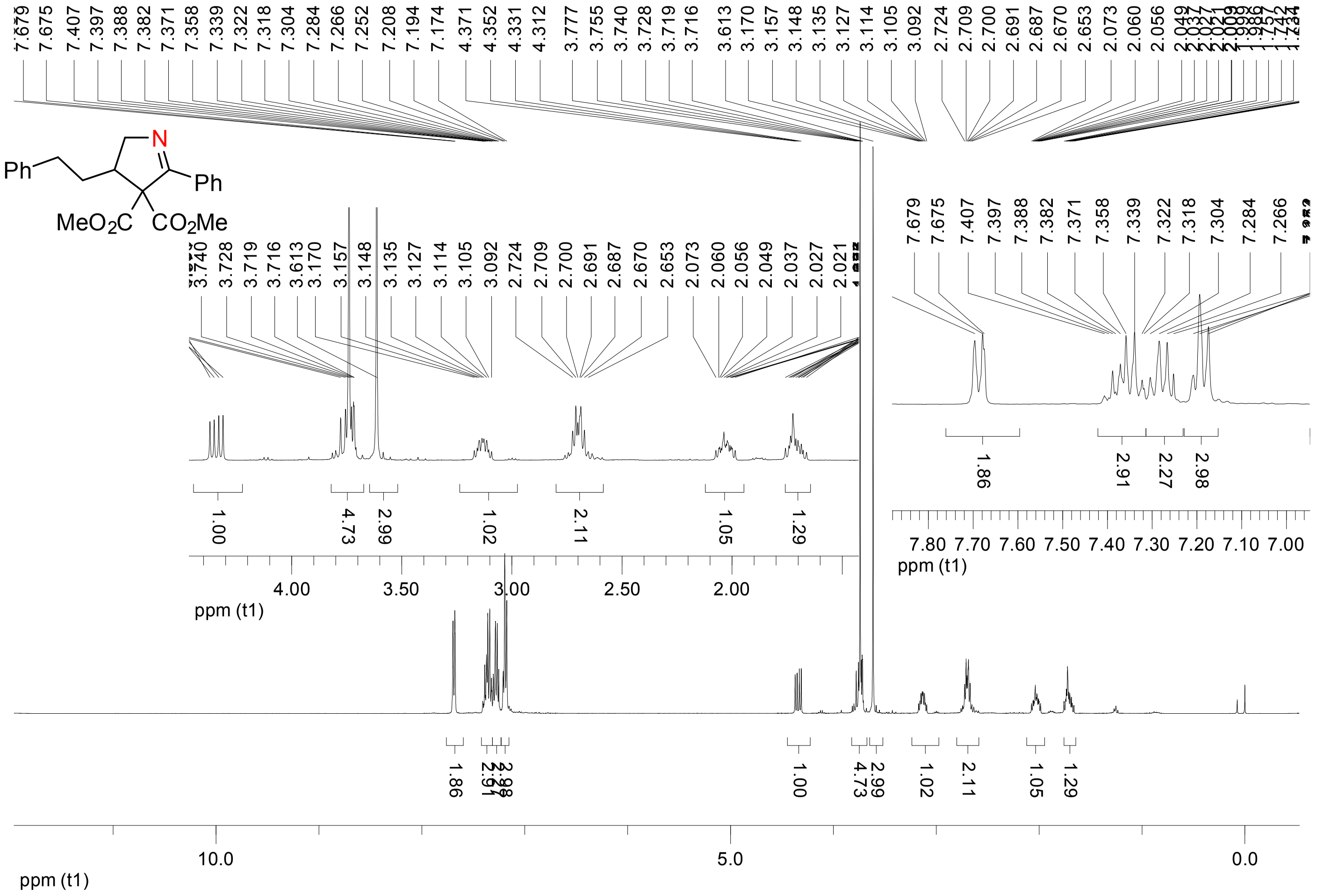
^{1}H NMR spectrum of **5ga** (400 MHz, $CDCl_3$)



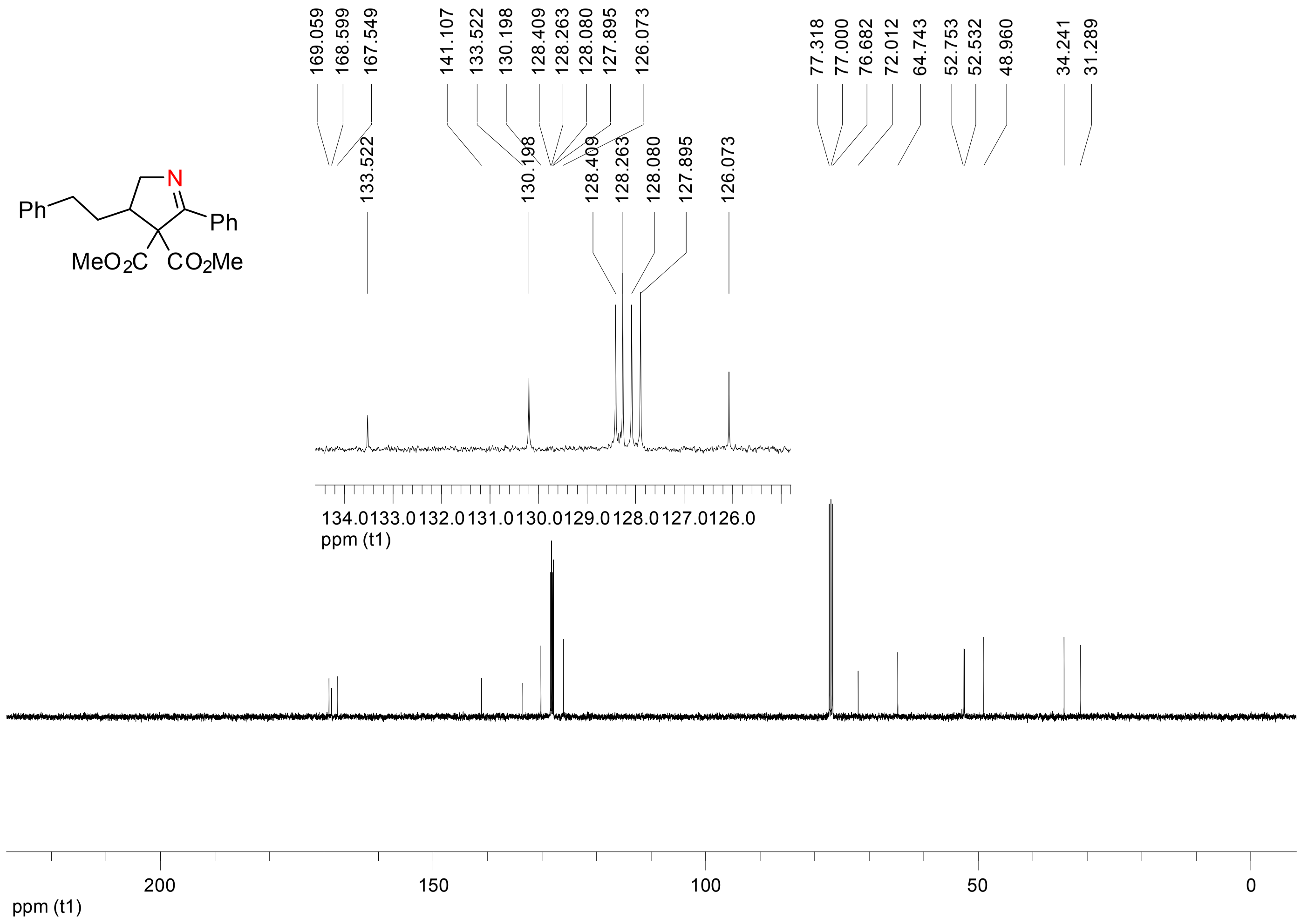
^{13}C NMR spectrum of **5ga** (100 MHz, $CDCl_3$)



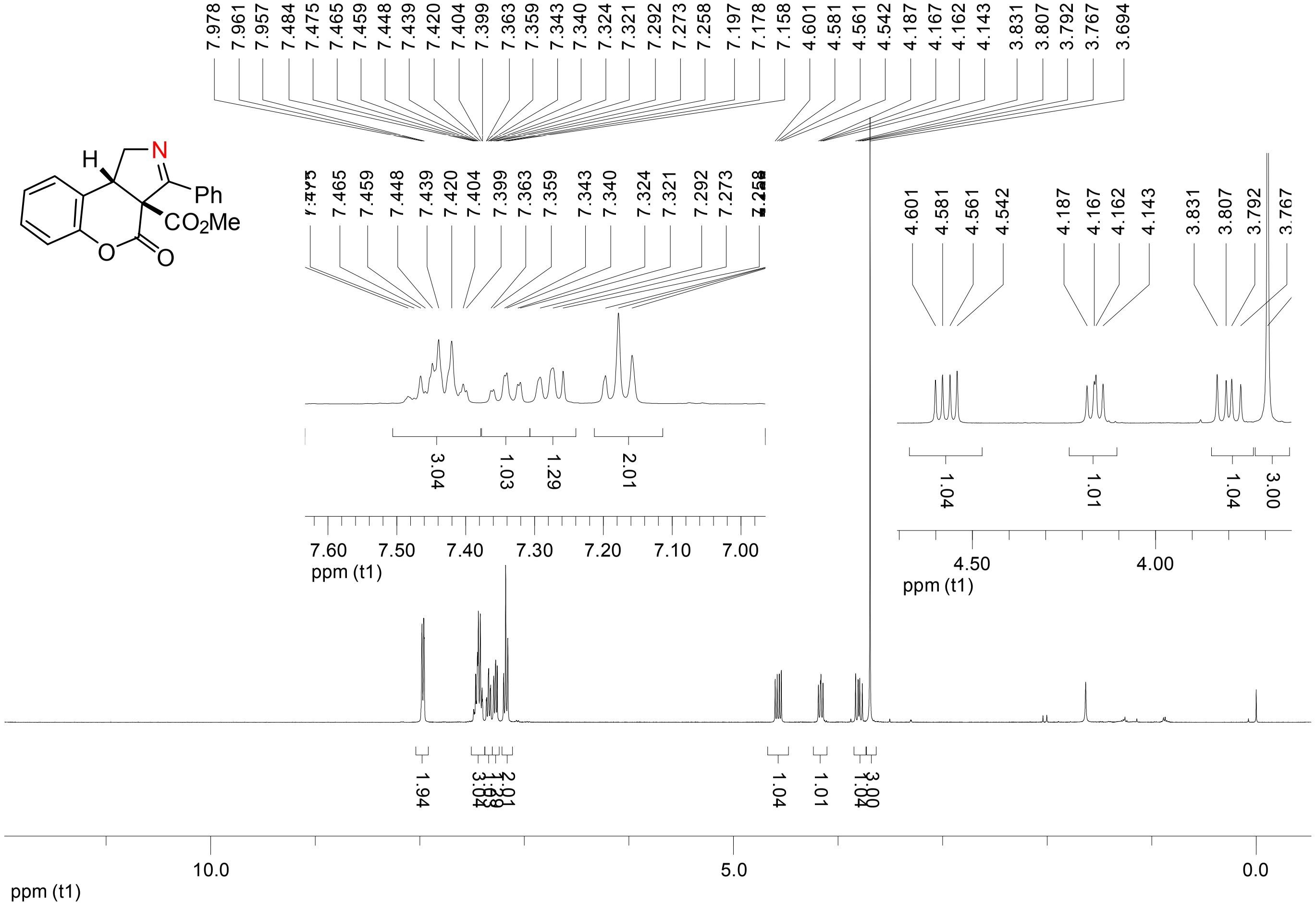
^{1}H NMR spectrum of **5ha** (400 MHz, $CDCl_3$)



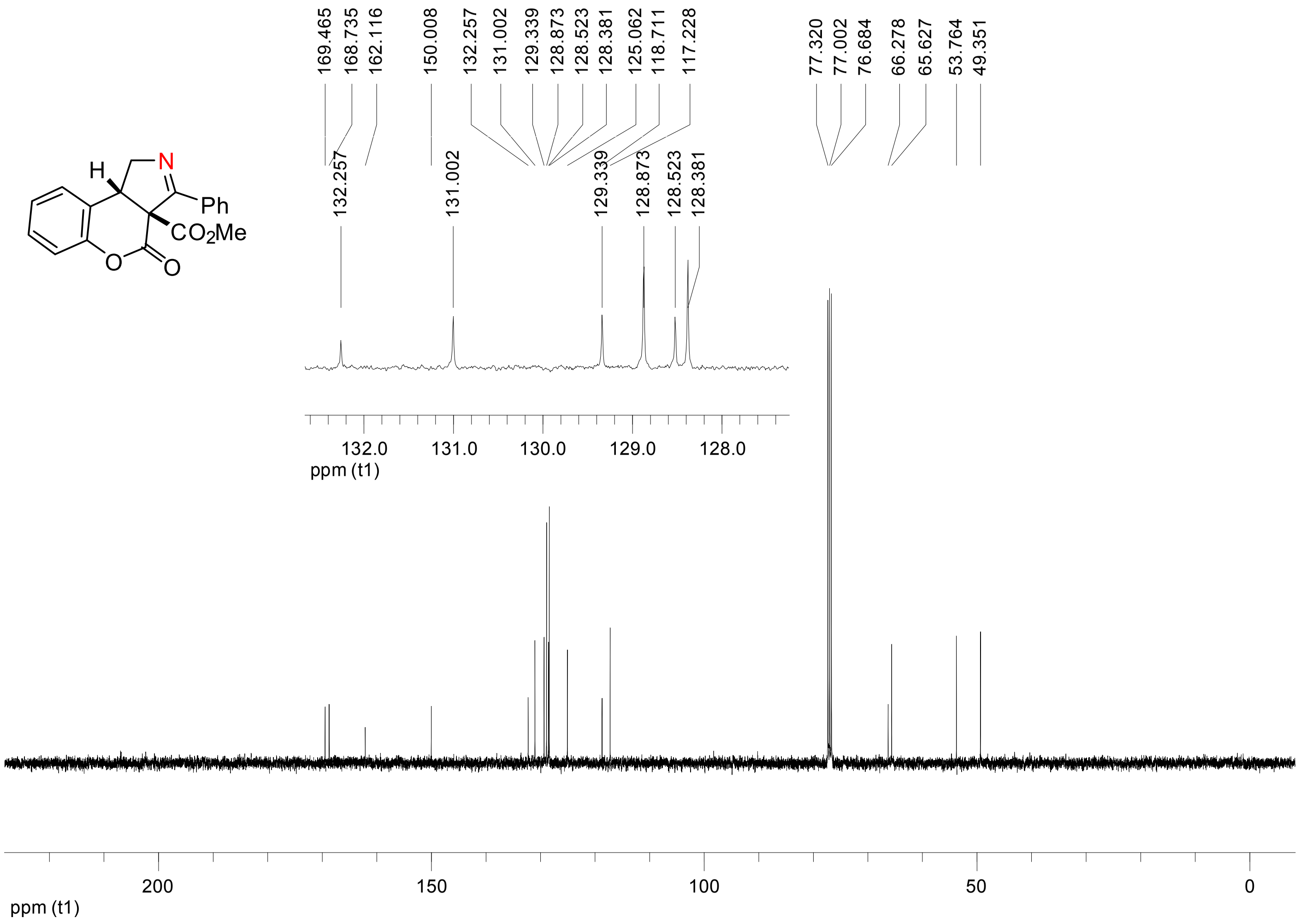
^{13}C NMR spectrum of **5ha** (100 MHz, $CDCl_3$)



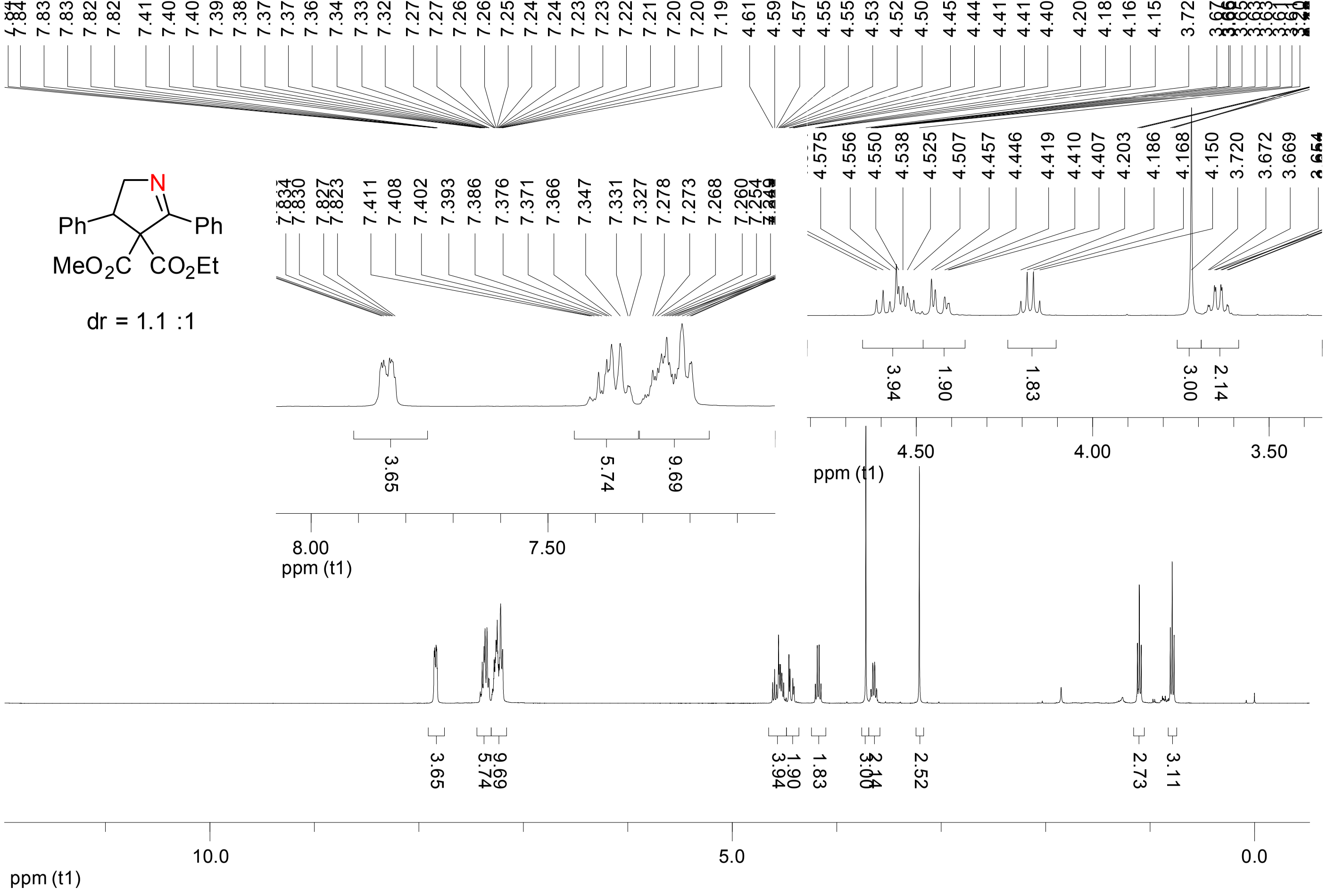
^{1}H NMR spectrum of **5ia** (400 MHz, $CDCl_3$)



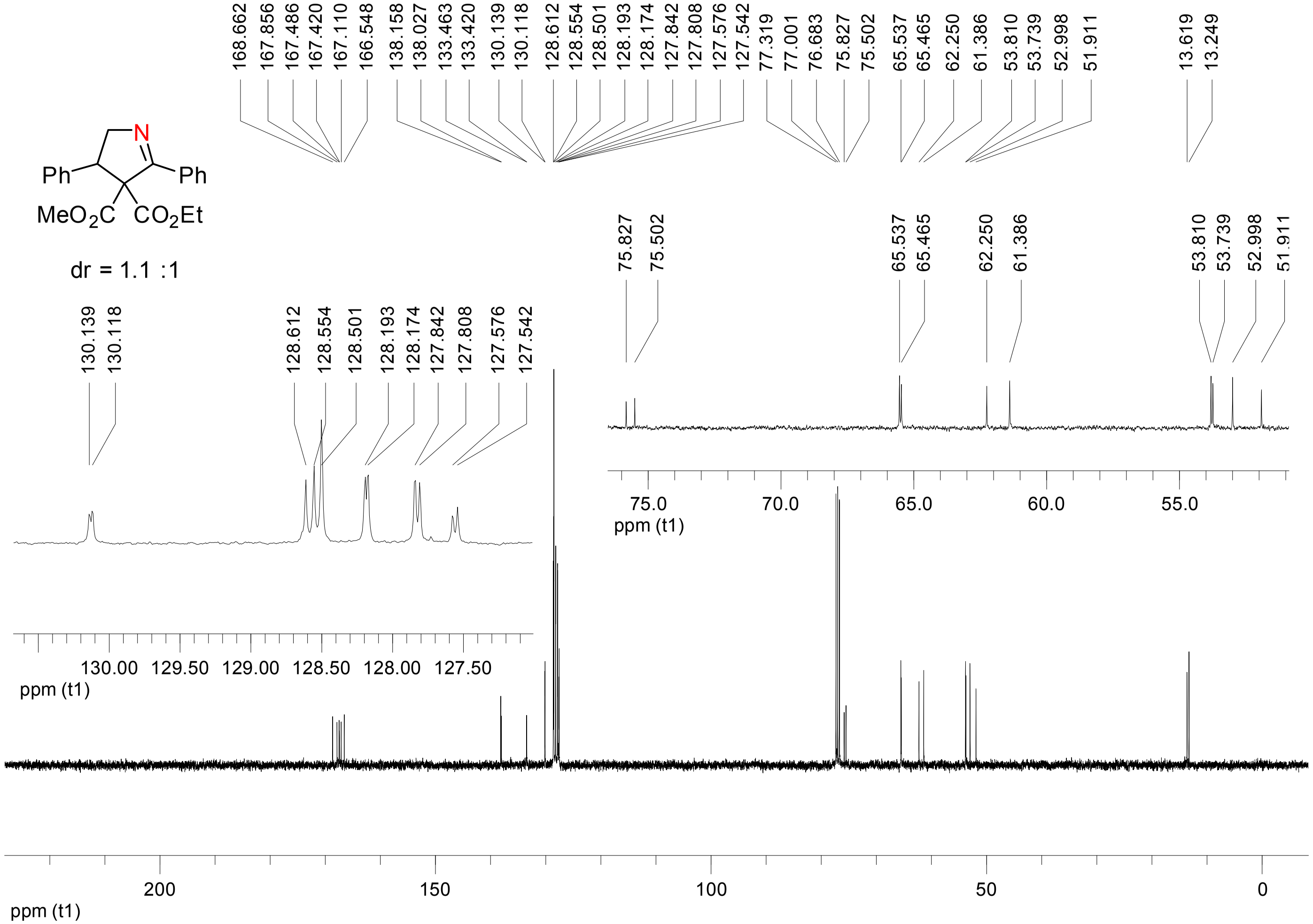
^{13}C NMR spectrum of **5ia** (100 MHz, CDCl$_3$)



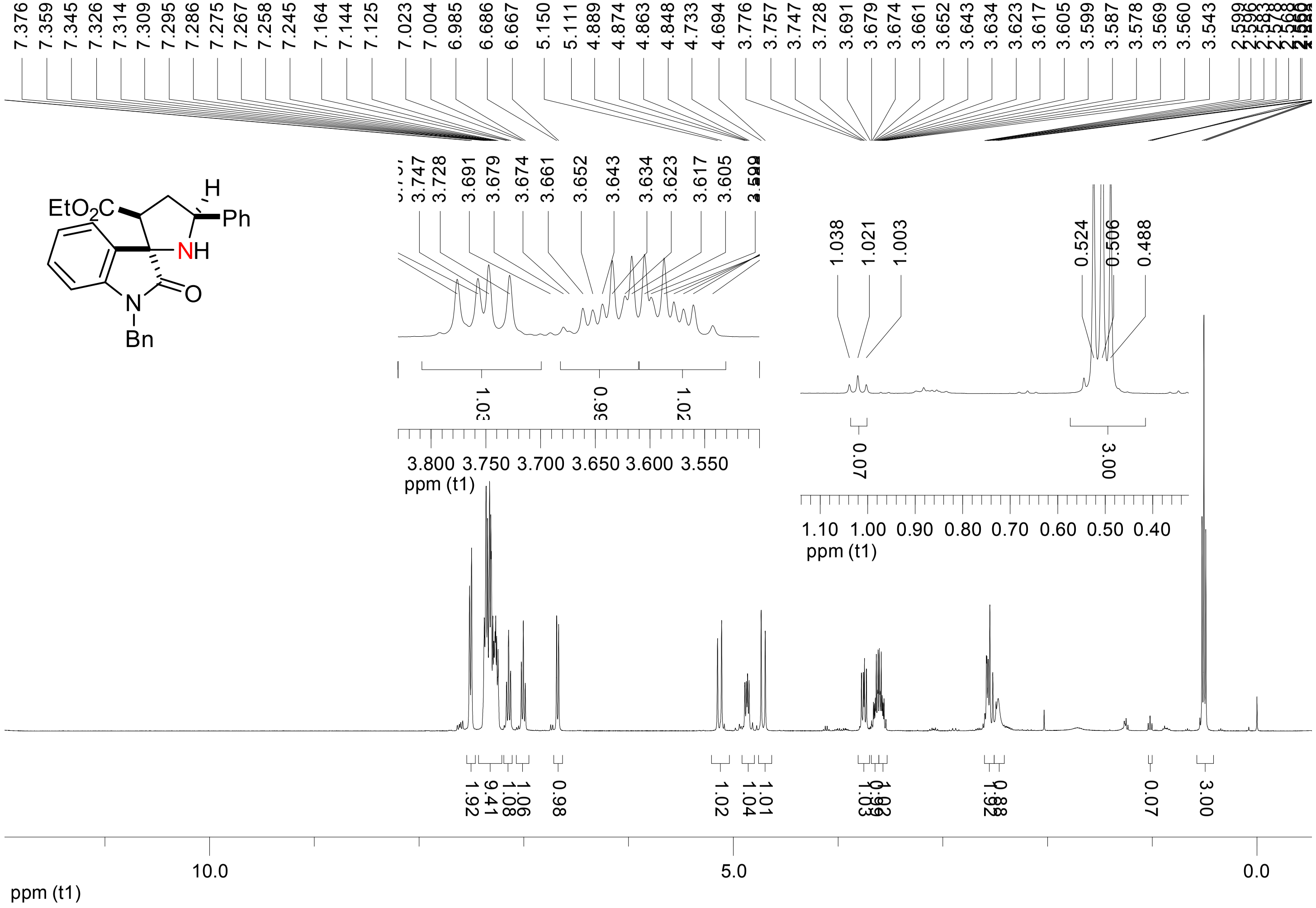
^{1}H NMR spectrum of **5ja**, dr = 1.1:1 (400 MHz, $CDCl_3$)



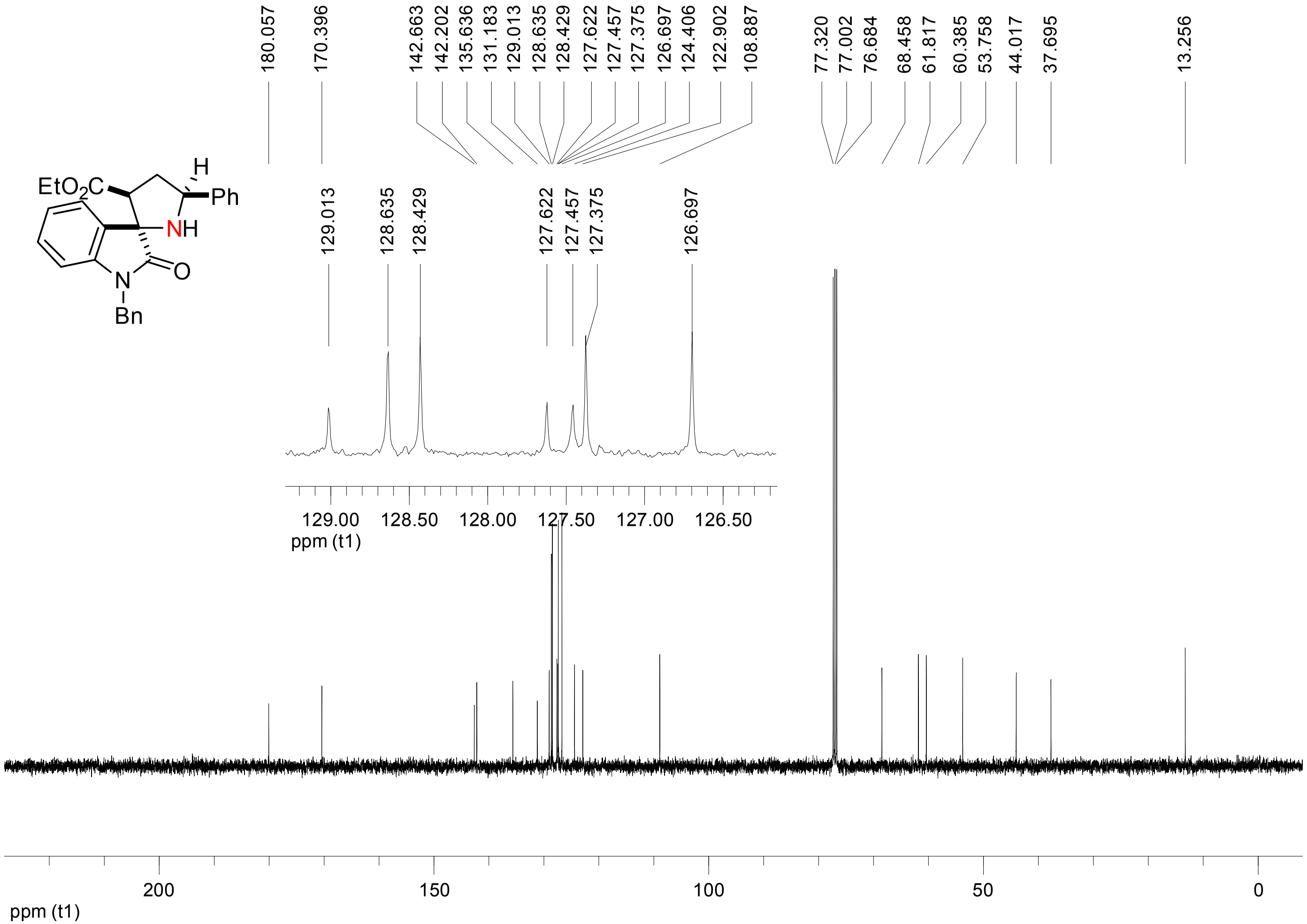
^{13}C NMR spectrum of **5ja**, dr = 1.1:1 (400 MHz, $CDCl_3$)



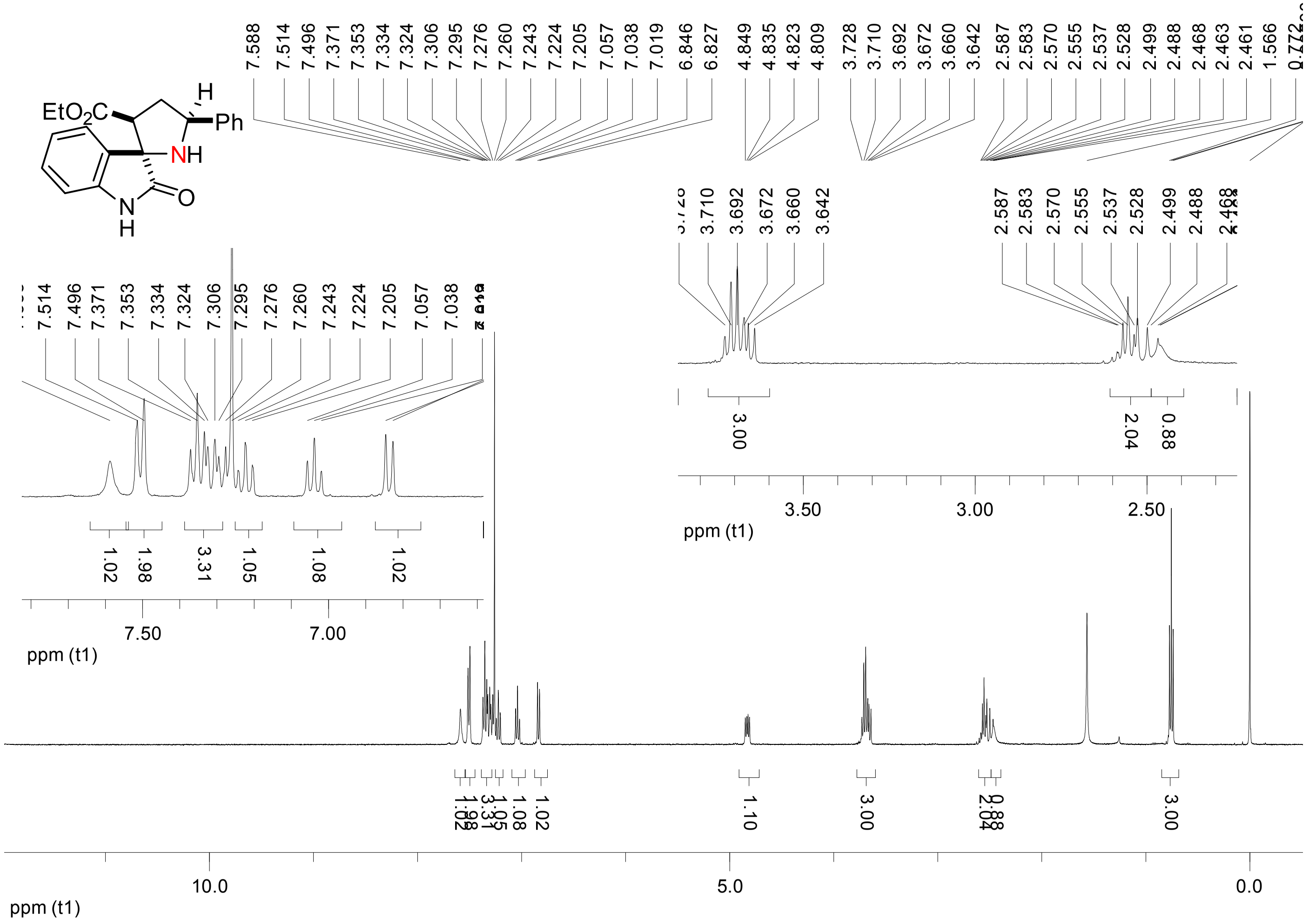
^{1}H NMR spectrum of **6a** (400 MHz, CDCl$_3$)



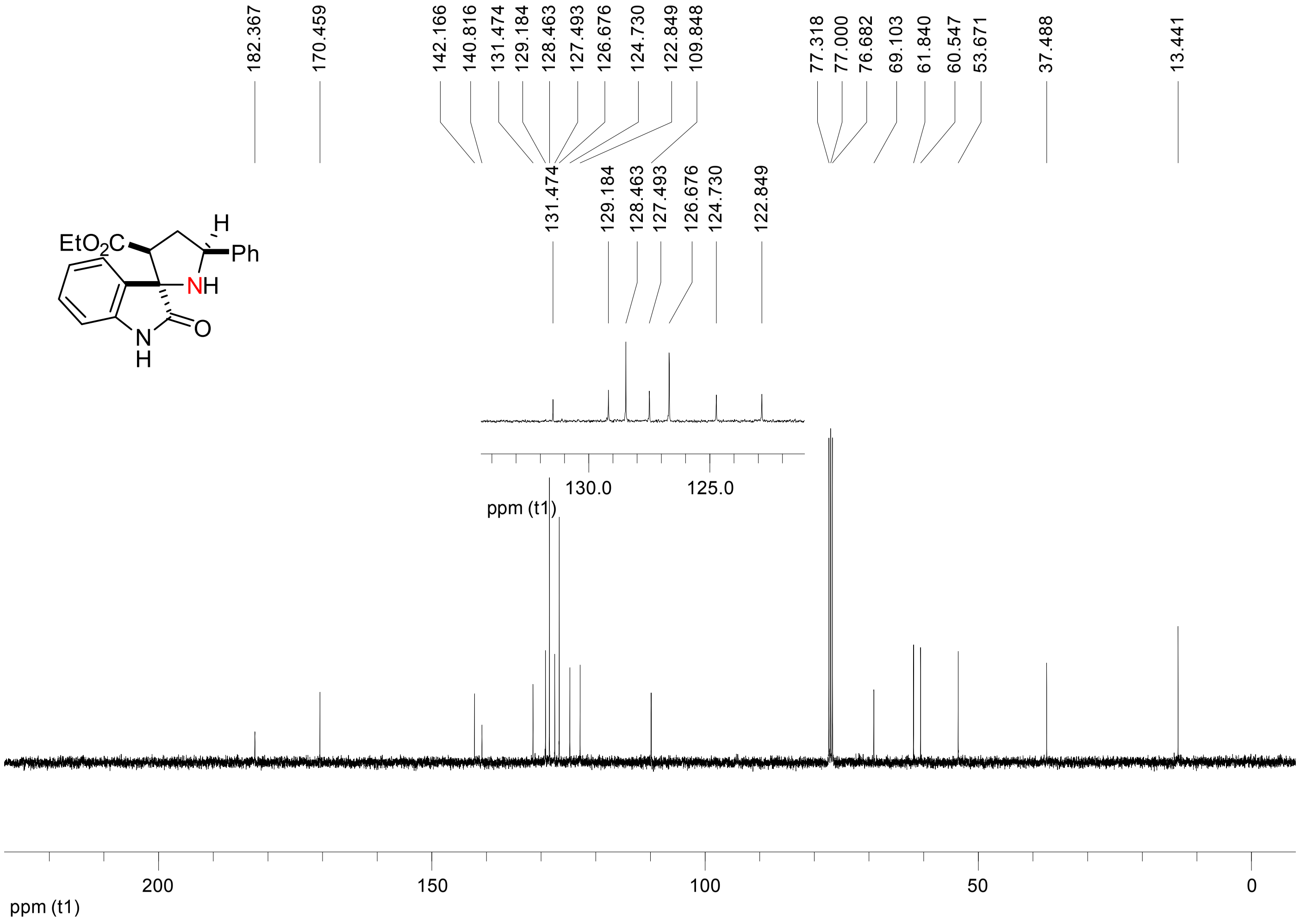
^{13}C NMR spectrum of **6a** (100 MHz, CDCl$_3$)



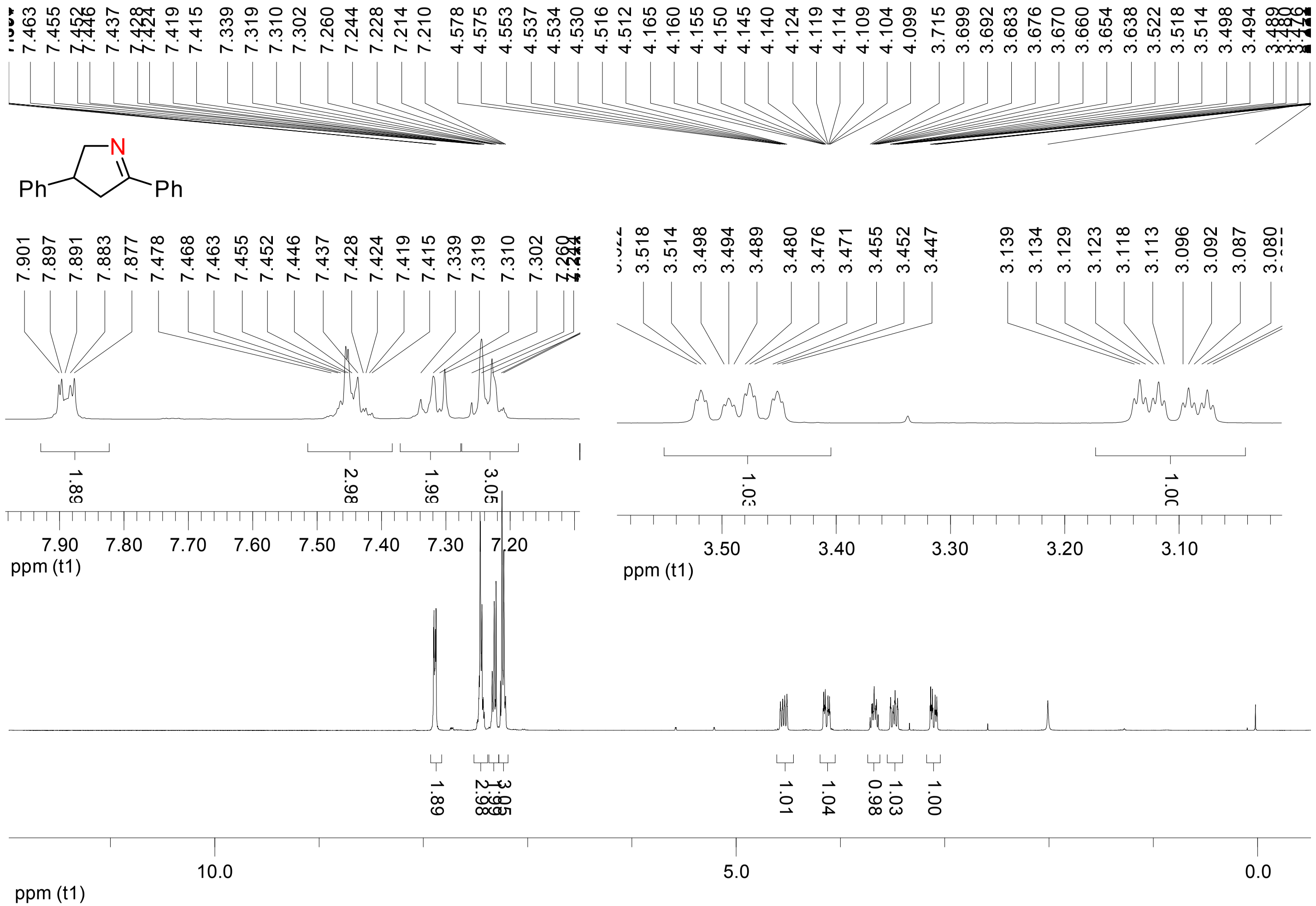
^{1}H NMR spectrum of **6e** (400 MHz, $CDCl_3$)



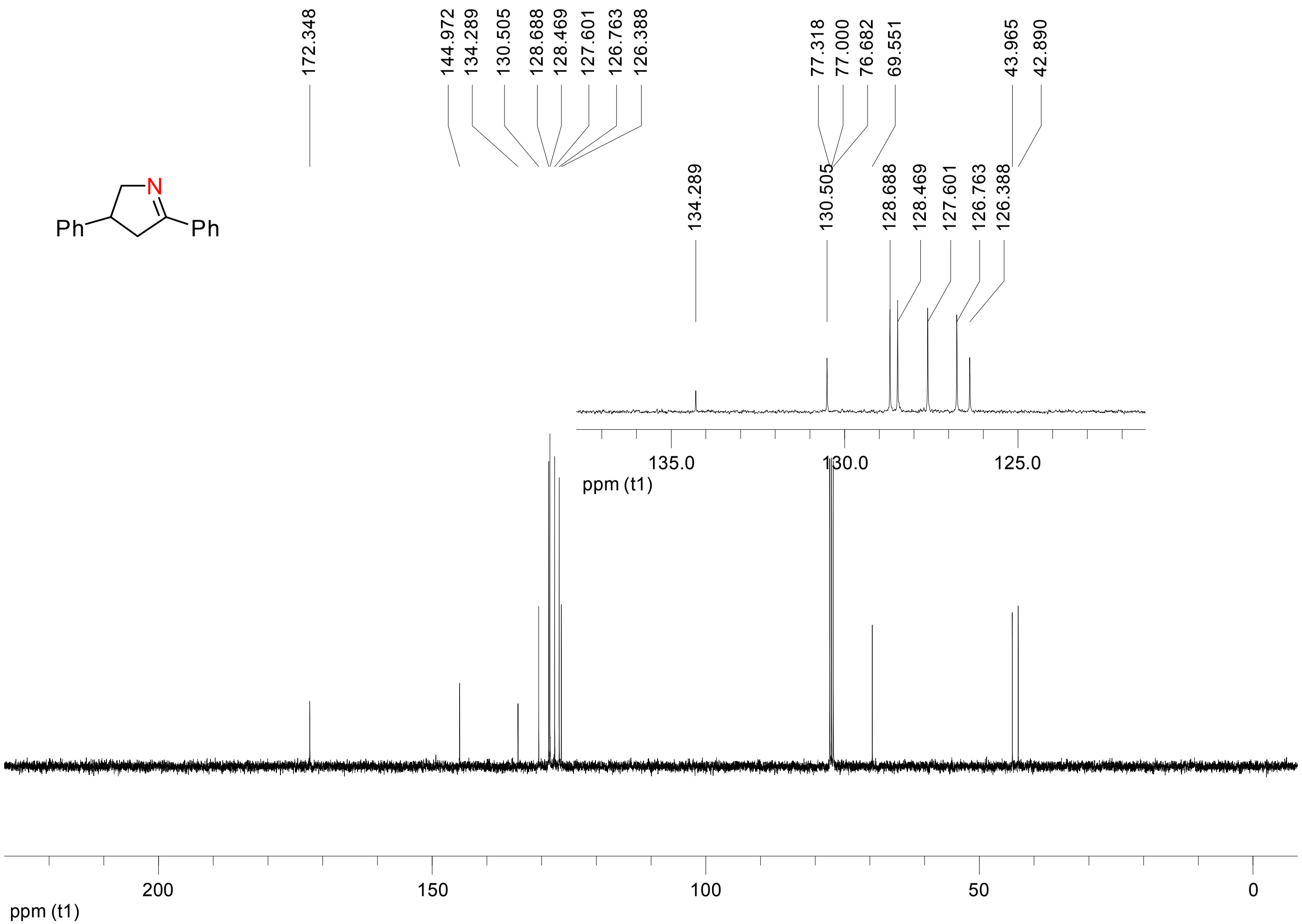
^{13}C NMR spectrum of **6e** (100 MHz, CDCl$_3$)



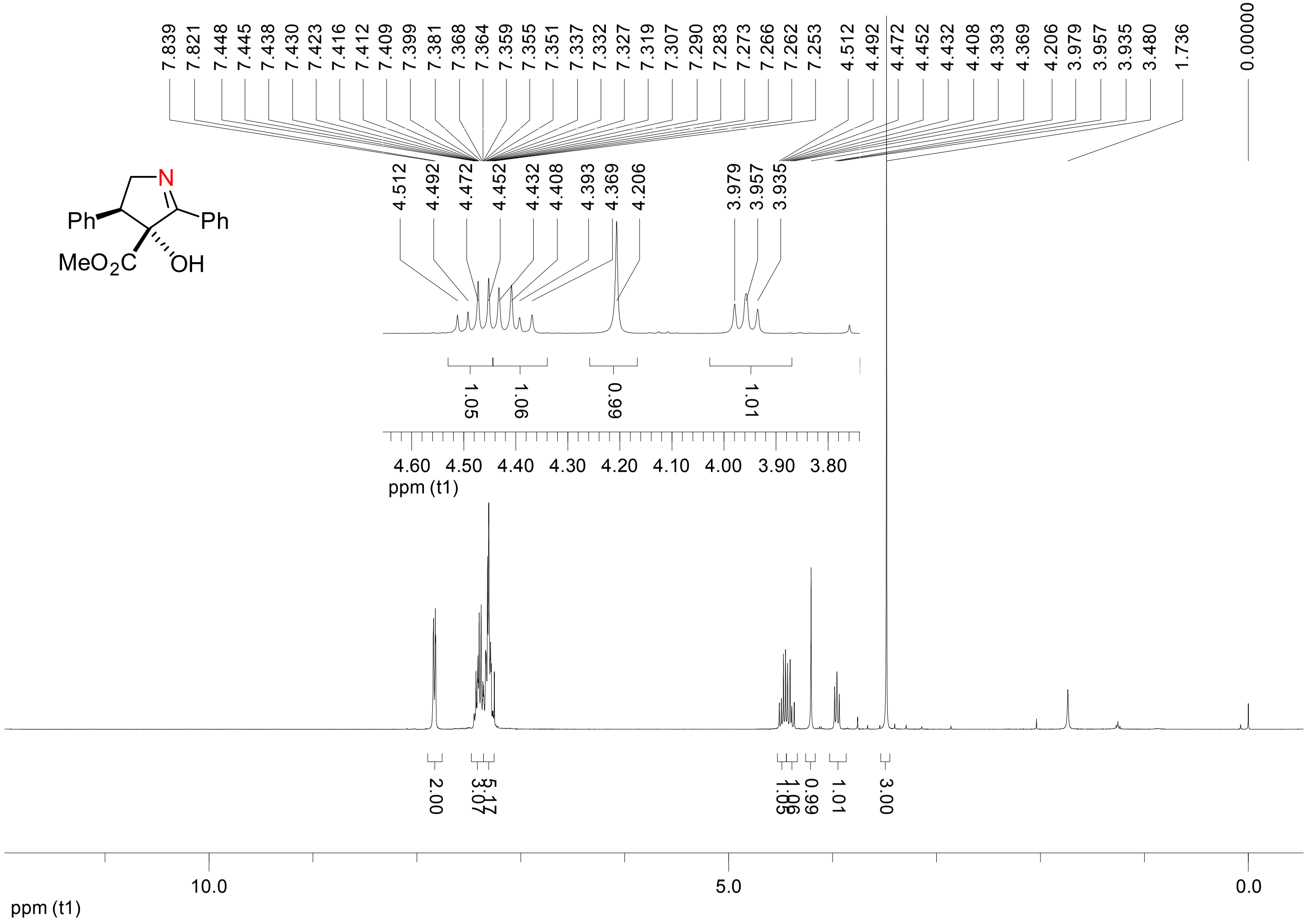
^{1}H NMR spectrum of **7** (400 MHz, $CDCl_3$)



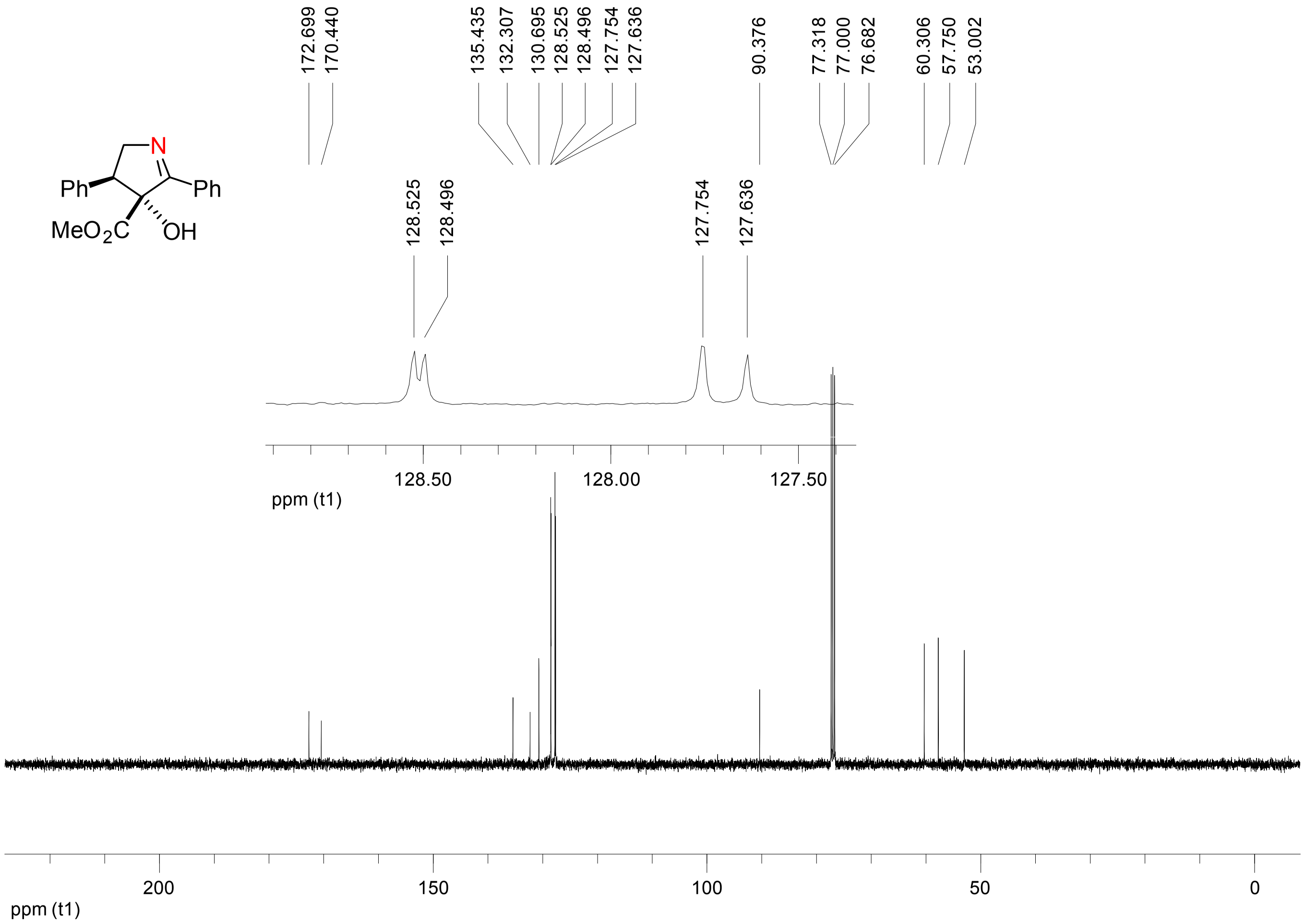
^{13}C NMR spectrum of **7** (100 MHz, $CDCl_3$)



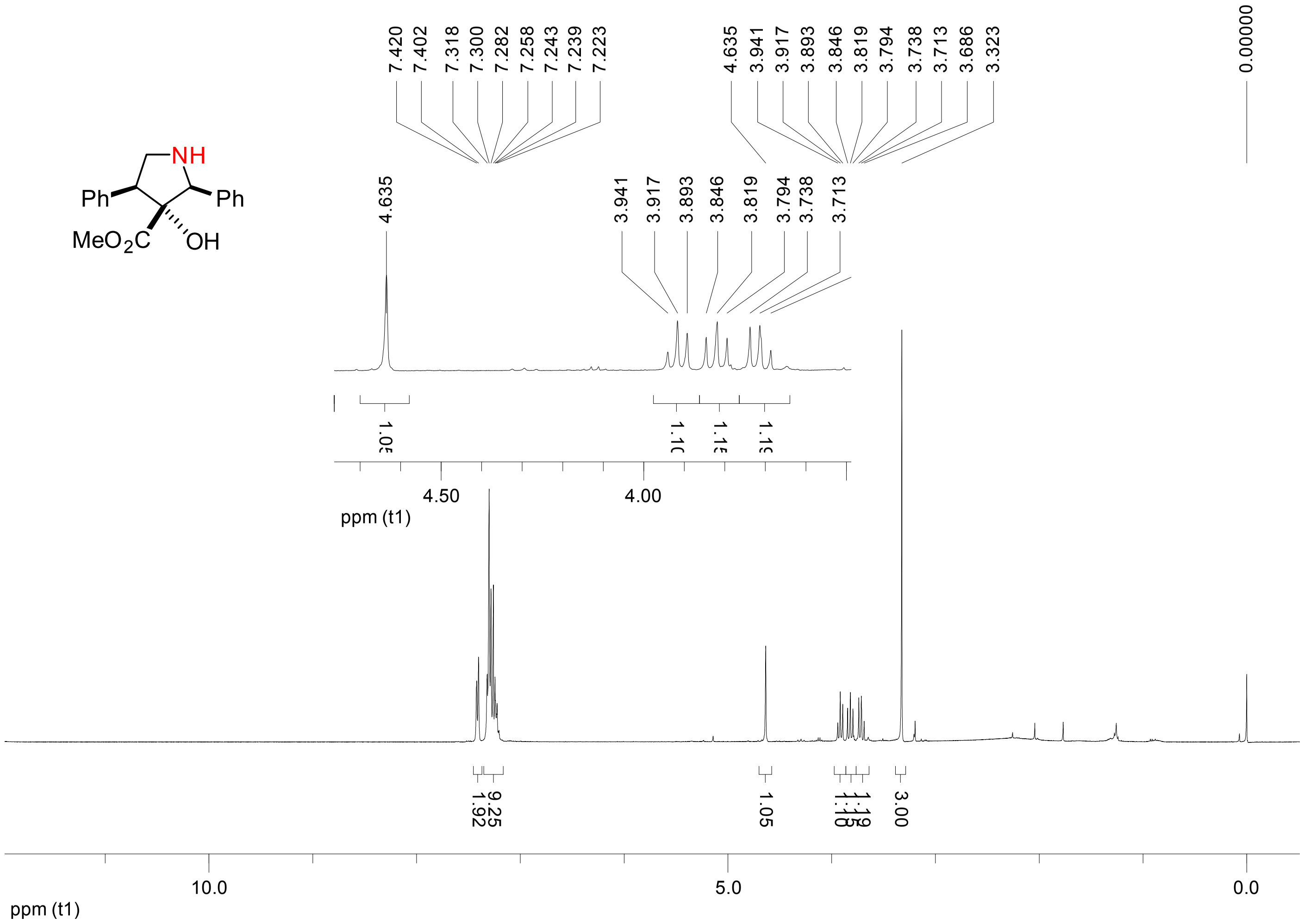
^{1}H NMR spectrum of **9** (400 MHz, $CDCl_3$)



^{13}C NMR spectrum of **9** (100 MHz, CDCl$_3$)



^{1}H NMR spectrum of **10** (400 MHz, CDCl$_3$)



^{13}C NMR spectrum of **10** (100 MHz, $CDCl_3$)