Supporting Information

Copper-Catalyzed Aminophosphorothiolation of Maleimides with Diethylphosphorodithioate and Amines

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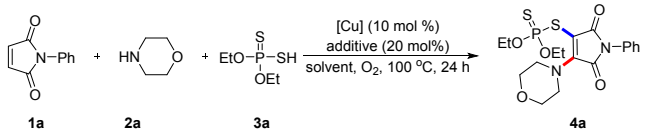
General Information

Maleimides[1] and $Cu(S_2P(OEt)_2)$[2] were prepared according to the reported procedures. ^1H and ^{13}C spectra of known compounds were in accordance with those described in the literatures. All other reagents were purchased from TCI, Sigma-Aldrich, Alfa Aesar, Acros, and Meryer and used without further purification. ^1H NMR (500 MHz), ^{13}C NMR (125 MHz) and ^{19}F NMR (470 MHz) spectra were recorded in $CDCl_3$ and DMSO-D6 solutions using a Burker AVANCE 500 spectrometer. High-resolution mass spectra were recorded on an ESI-Q-TOF mass spectrometer. Analysis of crude reaction mixture was done on the Varian 4000 GC/MS and 1200 LC. All reactions were conducted using standard Schlenk techniques. Column chromatography was performed using EM silica gel 60 (300−400 m).

Screening with different reaction conditions

Table 1. Reaction Optimization[a]



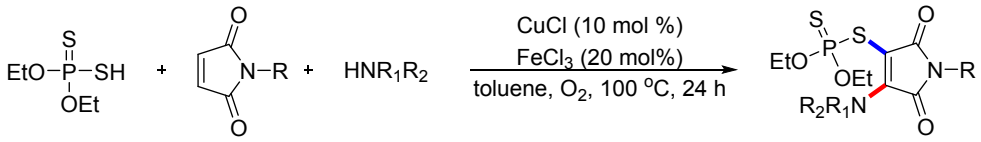
1a 2a 3a 4a

entry	[Cu]	additive	solvent	Yield (%)[b]
1	CuI		toluene	45
2	CuBr		toluene	55
3	CuCl		toluene	61
4	Cu(OAc)2		toluene	33
5	CuCl	$FeCl_3$	toluene	74
6	CuCl	$ZnCl_2$	toluene	51
7	CuCl	$AlCl_3$	toluene	50
8	CuCl	$BF_3.2H_2O$	toluene	25
9	CuCl	$FePO_4$	toluene	66
10	CuCl	TsOH	toluene	49
11	CuCl	$FeCl_3$	DMF	0
12	CuCl	$FeCl_3$	CH_3CN	0
13	CuCl	$FeCl_3$	DCE	70
14[c]	CuCl	$FeCl_3$	toluene	0
15[d]	CuCl	$FeCl_3$	toluene	65
16		$FeCl_3$	toluene	0

[a]Reaction conditions unless specified otherwise: **1a** (0.2 mmol), **2a** (0.6 mmol), **3a** (0.6 mmol), catalyst (0.02 mmol), additive (0.04 mmol), solvent (2.0 mL), under O_2, 100 °C, 24 h,. [b]Isolated yield. [c]Under N_2. [d]Under air atmosphere.

General Experimental Procedures

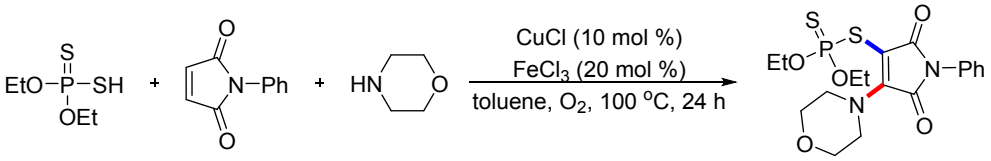
General Procedure of Copper-Catalyzed Direct Aminophosphorothiolation of Maleimides with Diethylphosphorodithioate and Amines:



1a **2** **3** **4-5**

A 25 mL Schlenk tube equipped with a stir bar was charged with maleimide (0.2 mmol), secondary amines (0.6 mmol), CuCl (0.02 mmol) $FeCl_3$ (0.04 mmol) and 2 mL toluene. Then, the addition of diethylphosphorodithioate (0.6 mmol) uses a pipette. The tube was fitted with a rubber septum, and then it was evacuated and refilled with dioxygen three times, then the septum was replaced by a Teflon screwcap under oxygen flow. The reaction mixture was stirred at 100 ℃ (aluminium block heating mantle) for 24 h. After cooling down, the reaction mixture was diluted with 10 mL of ethyl acetate, filtered through a pad of silica gel, followed by washing the pad of the silica gel with ethyl acetate (20 mL), concentrated under reduced pressure. The residue was then purified by flash chromatography on silica gel to provide the corresponding product.

1mmol scale-up reaction:

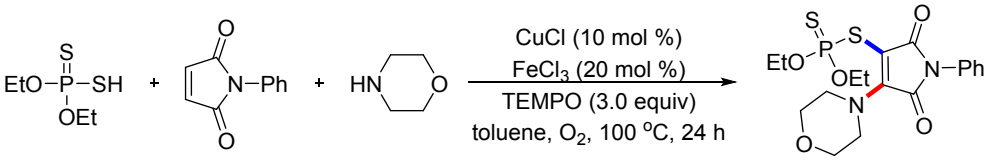


1a **2a** **3a** **4a**

A 35 mL Schlenk tube equipped with a stir bar was charged with *N*-phenyl maleimide (1.0 mmol), morpholine (3.0 mmol), CuCl (0.1 mmol), $FeCl_3$ (0.2 mmol) and 10 mL toluene. Then, the addition of diethylphosphorodithioate (3.0 mmol) uses a pipette. The tube was fitted with a rubber septum, and then it was evacuated and refilled with dioxygen three times, then the septum was replaced by a Teflon screwcap under oxygen flow. The reaction mixture was stirred at 100 ℃ (aluminium block heating mantle) for 24 h. After routine laboratory operations, the corresponding product was isolated in 61% yield.

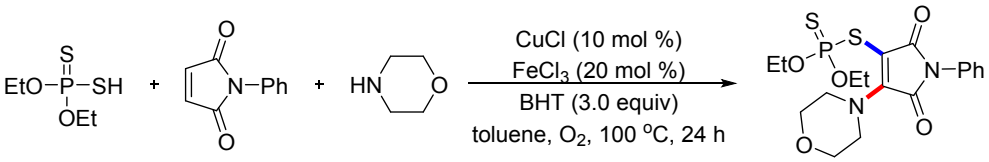
Mechanism investigation:

(a) Radical scavenger



1a **2a** **3a** **4a**

Three 25 mL Schlenk tubes equipped with a stir bar was charged with *N*-phenyl maleimide (0.2 mmol), morpholine (0.6 mmol), CuCl (0.02 mmol), $FeCl_3$ (0.04 mmol), TEMPO (0.6 mmol) and 2 mL toluene. Then, the addition of diethylphosphorodithioate (0.6 mmol) uses a pipette. The tube was fitted with a rubber septum, and then it was evacuated and refilled with dioxygen three times, then the septum was replaced by a Teflon screwcap under oxygen flow. The reaction mixture was stirred at 100 ℃ for 24 h. After cooling down, the reaction mixture was diluted with 10 mL of ethyl ether, filtered through a pad of silica gel, followed by washing the pad of the silica gel with the same solvent (20 mL), concentrated under reduced pressure. Each residue was then purified by flash chromatography on silica gel (petroleum ether : EtOAc = 9 : 1) to give **4a** product in 45% .

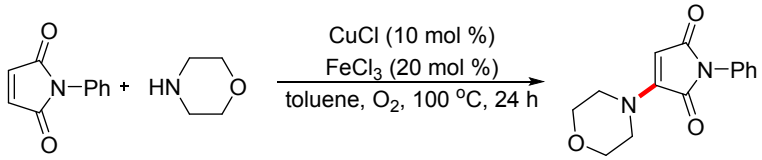


1a **2a** **3a** **4a**

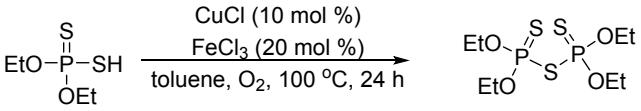
Three 25 mL Schlenk tubes equipped with a stir bar was charged with *N*-phenyl maleimide (0.2 mmol), morpholine (0.6 mmol), CuCl (0.02 mmol), $FeCl_3$ (0.04 mmol), BHT (0.6 mmol) and 2 mL toluene. Then, the addition of diethylphosphorodithioate (0.6 mmol) uses a pipette. The tube was fitted with a rubber septum, and then it was evacuated and refilled with dioxygen three times, then the septum was replaced by a Teflon screwcap under oxygen flow. The reaction mixture was stirred at 100 ℃ for 24 h. After cooling down, the reaction mixture was diluted with 10 mL of ethyl ether, filtered through a pad of silica gel, followed by washing the pad of the silica gel with the same solvent (20 mL), concentrated under reduced pressure. Each residue was then purified by flash chromatography on silica gel (petroleum ether : EtOAc = 9 : 1) to give **4a** product in 56% .

These results clearly indicated that the radical reaction process could be excluded in this multi-component reaction.

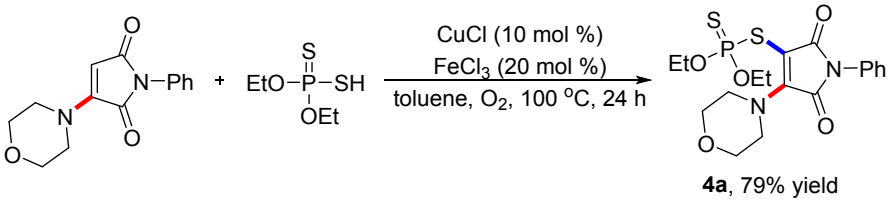
(b) Probing key intermediate



A 25 mL Schlenk tube equipped with a stir bar was charged with *N*-phenyl maleimide (0.2 mmol), morpholine (0.6 mmol), CuCl (0.02 mmol), $FeCl_3$ (0.04 mmol) and 2 mL toluene. The tube was fitted with a rubber septum, and then it was evacuated and refilled with dioxygen three times, then the septum was replaced by a Teflon screwcap under oxygen flow. The reaction mixture was stirred at 100 ℃ for 24 h. After cooling down, the reaction mixture was diluted with 10 mL of ethyl ether, filtered through a pad of silica gel, followed by washing the pad of the silica gel with the same solvent (20 mL), concentrated under reduced pressure. The residue was then purified by flash chromatography on silica gel (petroleum ether : EtOAc = 9 : 1) to give 3-morpholino-1-phenyl-1H-pyrrole-2,5-dione (isolated 83% yield).



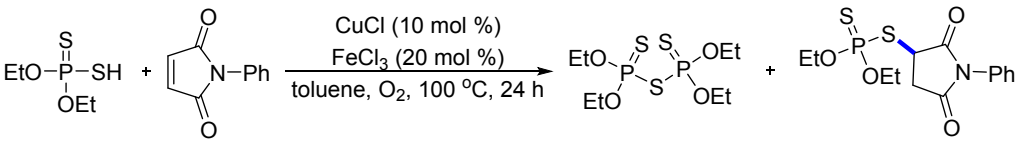
A 25 mL Schlenk tube equipped with a stir bar was charged with CuI (0.02 mmol), $FeCl_3$ (0.04 mmol) and 2 mL toluene, then, the addition of diethylphosphorodithioate (0.6 mmol) uses a pipette. The tube was fitted with a rubber septum, and then it was evacuated and refilled with dioxygen three times, then the septum was replaced by a Teflon screwcap under oxygen flow. The reaction mixture was stirred at 100 ℃ for 24 h. After cooling down, the reaction mixture was diluted with 10 mL of ethyl ether, filtered through a pad of silica gel, the oxidative homo-coupling bis(diethoxyphosphoryl)disulphide was not detected by TLC and GC-MS, in contrast, O,O,O,O-tetraethyl trithiopyrophosphate was isolated (95% yield).



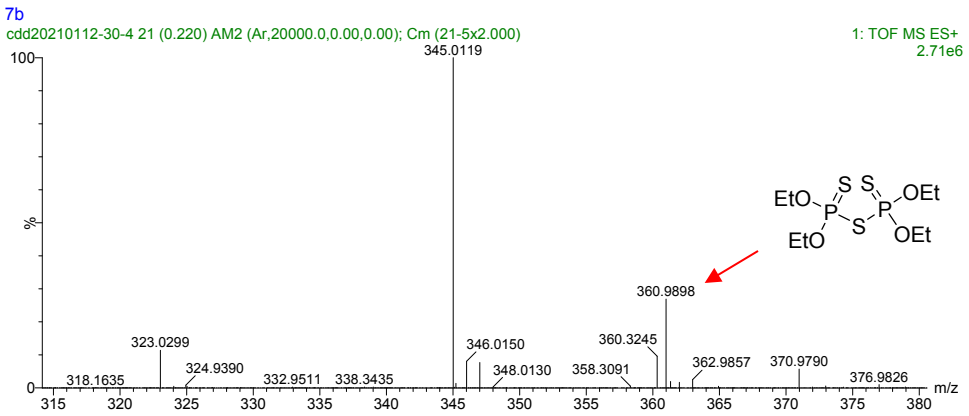
4a, 79% yield

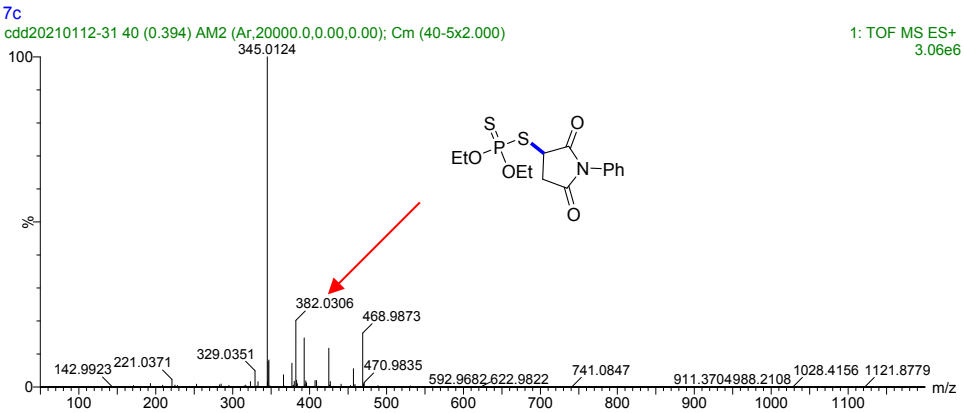
A 25 mL Schlenk tube equipped with a stir bar was charged with 3-morpholino-1-phenyl-1H-pyrrole-2,5-dione (0.2 mmol), CuCl (0.02 mmol), $FeCl_3$ (0.04 mmol) and 2 mL toluene, then, the

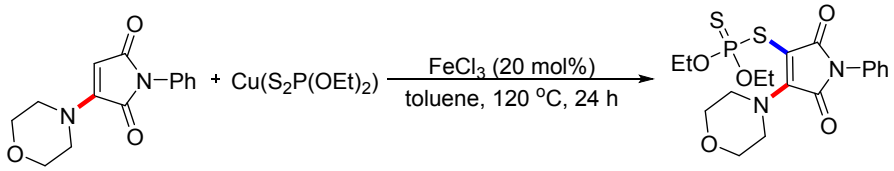
addition of diethylphosphorodithioate (0.6 mmol) uses a pipette. The tube was fitted with a rubber septum, and then it was evacuated and refilled with dioxygen three times, then the septum was replaced by a Teflon screwcap under oxygen flow. The reaction mixture was stirred at 100 ℃ for 24 h. After cooling down, the reaction mixture was diluted with 10 mL of ethyl ether, filtered through a pad of silica gel, the corresponding product **4a** was isolated in 79%.



A 25 mL Schlenk tube equipped with a stir bar was charged with *N*-phenyl maleimide (0.2 mmol), CuCl (0.02 mmol), $FeCl_3$ (0.04 mmol) and 2 mL toluene, then, the addition of diethylphosphorodithioate (0.6 mmol) uses a pipette. The tube was fitted with a rubber septum, and then it was evacuated and refilled with dioxygen three times, then the septum was replaced by a Teflon screwcap under oxygen flow. The reaction mixture was stirred at 100 ℃ for 24 h. After cooling down, the reaction mixture was diluted with 10 mL of ethyl ether, there are two new points by judging by the TLC, however, these two new points were close, and could not be isolated by flash chromatography on silica gel. The unexpected byproduct O,O,O,O-tetraethyl trithiopyrophosphate and S-Michael-addition products were detected by GC-MS and HRMS.

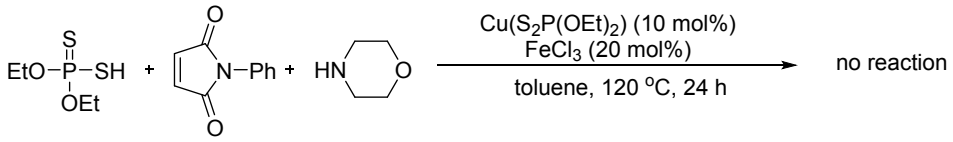






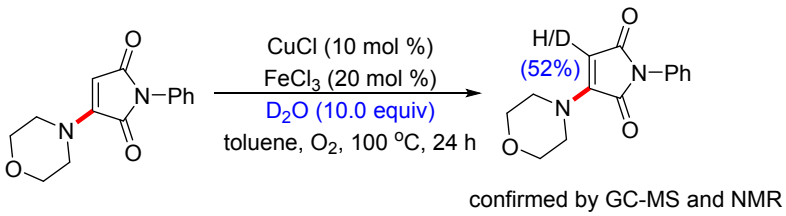
4a, 12% yield

A 25 mL Schlenk tube equipped with a stir bar was charged with 3-morpholino-1-phenyl-1H-pyrrole-2,5-dione (0.2 mmol), $FeCl_3$ (0.04 mmol), $Cu(S_2P(OEt)_2)$ (0.2 mmol) (light grey solid), and 2 mL toluene. The tube was fitted with a rubber septum, and then it was evacuated and refilled with dioxygen three times, then the septum was replaced by a Teflon screwcap under oxygen flow. The reaction mixture was stirred at 100 ℃ for 24 h. After cooling down, the reaction mixture was diluted with 10 mL of ethyl ether, filtered through a pad of silica gel, the corresponding product 4a was isolated in 12% yield.

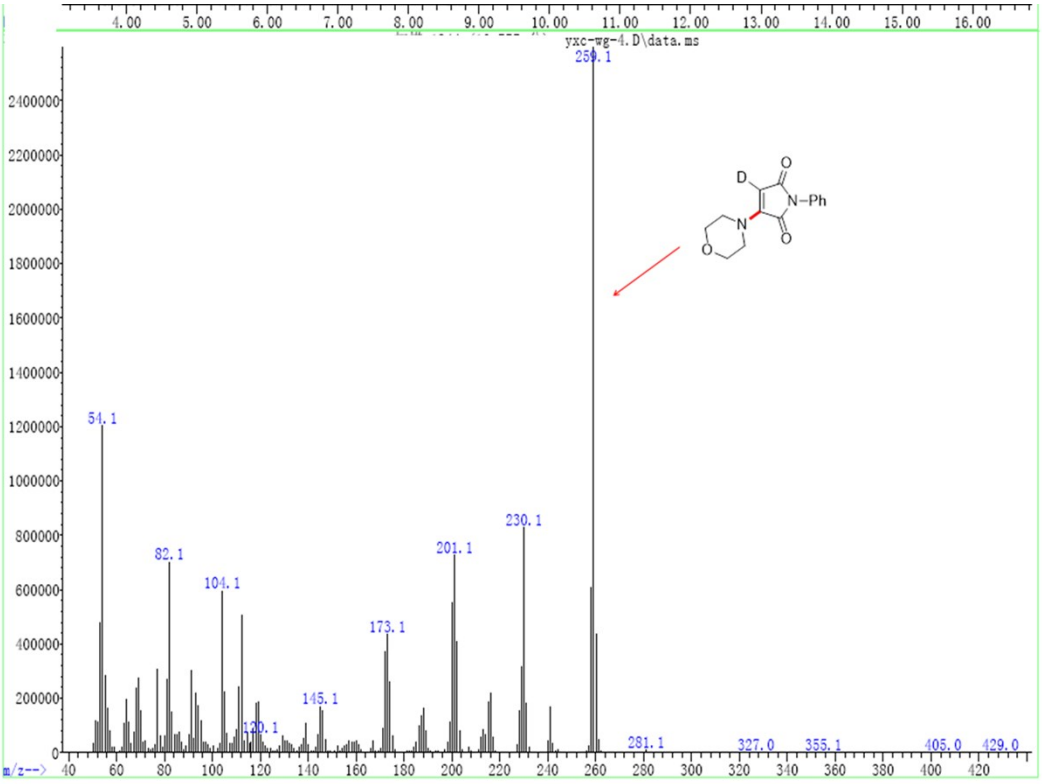


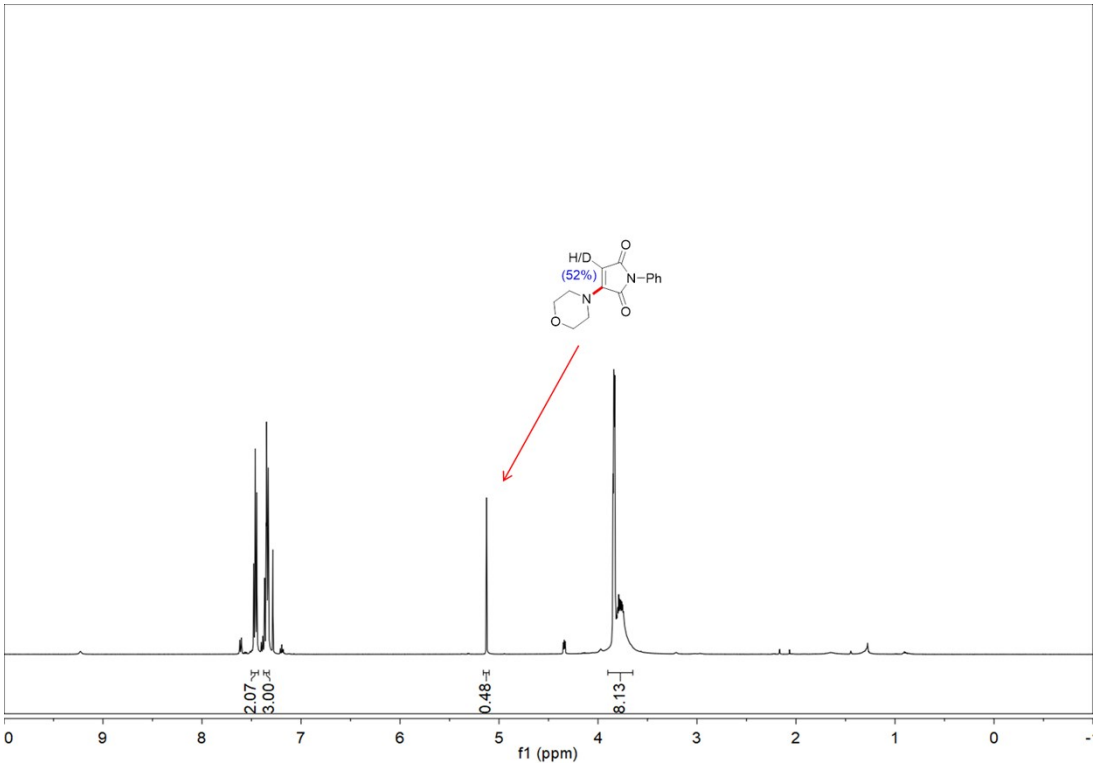
A 25 mL Schlenk tube equipped with a stir bar was charged with *N*-phenyl maleimide (0.2 mmol), morpholine (0.6 mmol), $Cu(S_2P(OEt)_2)$ (0.02 mmol), $FeCl_3$ (0.04 mmol) and 2 mL toluene. Then, the addition of diethylphosphorodithioate (0.6 mmol) uses a pipette. The tube was fitted with a rubber septum, and then it was evacuated and refilled with dioxygen three times, then the septum was replaced by a Teflon screwcap under oxygen flow. The reaction mixture was stirred at 100 ℃ for 24 h. After cooling down, the reaction mixture was diluted with 10 mL of ethyl ether, filtered through a pad of silica gel, the corresponding product was not detected by TLC and GC-MS.

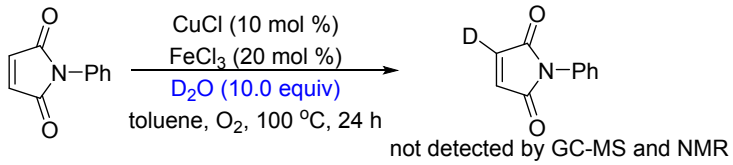
(c) H/D exchange



A 25 mL Schlenk tube equipped with a stir bar was charged with 3-morpholino-1-phenyl-1H-pyrrole-2,5-dione (0.2 mmol), D_2O (2.0 mmol), CuCl (0.02 mmol), $FeCl_3$ (0.04 mmol) and 2 mL toluene. The tube was fitted with a rubber septum, and then it was evacuated and refilled with dioxygen three times, then the septum was replaced by a Teflon screwcap under oxygen flow. The reaction mixture was stirred at 100 ℃. After stirring for 24 h, the reaction mixture was cooled to room temperature and the reaction was filtered through a pad of Celite and diluted with ethyl acetate (10 mL), deuterium-hydrogen exchange was observed in 3-morpholino-1-phenyl-1H-pyrrole-2,5-dione, which suggest the C-H activation was occurred under the current reaction condition.





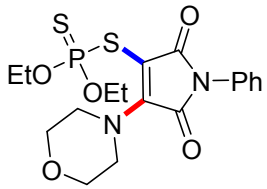


not detected by GC-MS and NMR

A 25 mL Schlenk tube equipped with a stir bar was charged with *N*-phenyl maleimide (0.2 mmol), D_2O (2.0 mmol), CuCl (0.02 mmol), $FeCl_3$ (0.04 mmol) and 2 mL toluene. The tube was fitted with a rubber septum, and then it was evacuated and refilled with dioxygen three times, then the septum was replaced by a Teflon screwcap under oxygen flow. The reaction mixture was stirred at 100 ℃. After stirring for 18 h, the reaction mixture was cooled to room temperature and the reaction was filtered through a pad of Celite and diluted with ethyl acetate (10 mL), the deuterated product was not detected by GC-MS and NMR.

Characterization of Products in Details :

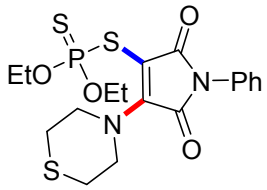
O,O-diethyl S-(4-morpholino-2,5-dioxo-1-phenyl-2,5-dihydro-1H-pyrrol-3-yl) phosphorodithioate



4a

Following the general procedure, using (petroleum ether : EtOAc = 9 : 1) as the eluant afforded a yellow solid (65.4 mg, 74% yield), Mp = 112-113℃. **^{1}H NMR** (500 MHz, $CDCl_3$): δ 7.45 (t, *J* = 7.7 Hz, 2H), 7.36-7.32(m, 3H), 4.31-4.24 (m, 8H), 3.88-3.86 (m, 4H), 1.35 (t, *J* = 7.0 Hz, 6H); **^{13}C NMR** (125MHz, $CDCl_3$): δ 168.3, 164.9, 149.9, 131.7, 128.9, 127.8, 126.4, 86.3, 66.9, 65.0, 64.9, 49.2, 15.9, 15.9; **^{31}P NMR** (162 MHz, $CDCl_3$): δ 89.0; **HRMS** (ESI): calcd for $C_{18}H_{23}N_2O_5NaPS_2$ $[M + Na]^+$ 465.0684, found 465.0686.

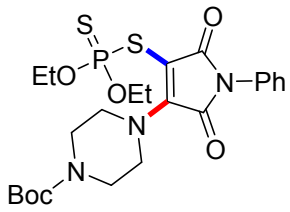
S-(2,5-dioxo-1-phenyl-4-thiomorpholino-2,5-dihydro-1H-pyrrol-3-yl) O,O-diethyl phosphorodithioate



4b

Following the general procedure, using (petroleum ether : EtOAc = 9 : 1) as the eluant afforded a yellow liquid (62.3 mg, 68% yield). **^{1}H NMR** (400 MHz, $CDCl_3$): δ 7.47-7.42 (m, 2H), 7.37-7.31 (m, 3H), 4.46 (dt, *J* = 4.9, 2.4 Hz, 4H), 4.27 (dq, *J* = 9.4, 7.1 Hz, 4H), 2.87-2.84 (m, 4H), 1.35 (t, *J* = 7.1 Hz, 6H); **^{13}C NMR** (100 MHz, $CDCl_3$): δ 168.3, 164.9, 150.0, 131.6, 128.9, 127.9, 126.3, 87.0, 65.0, 64.9, 51.9, 28.1, 15.9, 15.9; **^{31}P NMR** (162 MHz, $CDCl_3$): δ 89.1; **HRMS** (ESI): calcd for $C_{18}H_{23}N_2O_4NaPS_3$ $[M + Na]^+$ 481.0455, found 481.0457.

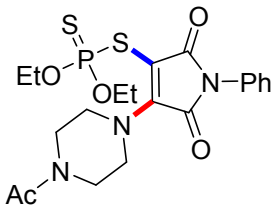
tert-butyl 4-(4-((diethoxyphosphorothioyl)thio)-2,5-dioxo-1-phenyl-2,5-dihydro-1H-pyrrol-3-yl)piperazine-1-carboxylate



4c

Following the general procedure, using (petroleum ether : EtOAc = 9 : 1) as the eluant afforded a yellow liquid (83.3 mg, 77% yield). **^{1}H NMR** (400 MHz, $CDCl_3$): δ 7.51-7.46 (m, 2H), 7.41-7.34 (m, 3H), 4.35-4.27 (m, 4H), 4.00 (t, *J* = 5.0 Hz, 1H), 3.64 (dt, *J* = 18.4, 5.2 Hz, 4H), 1.68-1.67 (m, 1H), 1.53 (s, 9H), 1.46-1.45 (m, 1H), 1.39 (t, *J* = 7.1 Hz, 4H), 1.29 (s, 2H); **^{13}C NMR** (125 MHz, $CDCl_3$): δ 168.3, 165.2, 154.4, 131.6, 129.0, 129.0, 127.9, 126.4, 126.2, 80.6, 65.1, 65.0, 48.6, 48.0, 29.7, 28.4, 15.9, 15.9; **^{31}P NMR** (162 MHz, $CDCl_3$): δ 89.2; **HRMS** (ESI): calcd for $C_{23}H_{32}N_3O_6NaPS_2$ $[M + Na]^+$ 564.1368, found 564.1369.

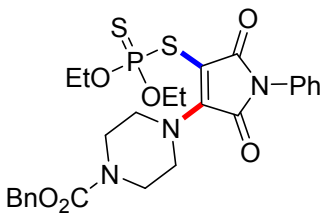
S-(4-(4-acetylpiperazin-1-yl)-2,5-dioxo-1-phenyl-2,5-dihydro-1H-pyrrol-3-yl) O,O-diethyl phosphorodithioate



4d

Following the general procedure, using (petroleum ether : EtOAc = 9 : 1) as the eluant afforded a yellow liquid (67.6 mg, 70% yield). **^{1}H NMR** (500 MHz, $CDCl_3$): δ 7.47-7.44 (m, 2H), 7.38-7.32 (m, 3H), 4.31-4.24 (m, 8H), 3.83 (t, *J* = 5.3 Hz, 2H), 3.68 (t, *J* = 5.2 Hz, 2H), 2.15 (s, 3H), 1.36 (t, *J* = 7.1 Hz, 6H); **^{13}C NMR** (125 MHz, $CDCl_3$): δ 169.2, 168.2, 164.9, 150.2, 131.6, 129.0, 127.9, 126.4, 87.3, 65.2, 65.1, 48.6, 48.4, 46.0, 41.2, 21.3, 16.0, 15.9; **^{31}P NMR** (162 MHz, $CDCl_3$): δ 89.0; **HRMS** (ESI): calcd for $C_{20}H_{26}N_3O_5NaPS_2$ $[M + Na]^+$ 506.0949, found 506.0956.

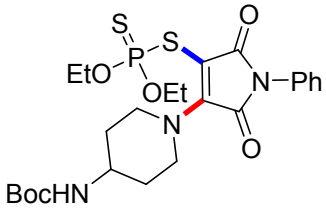
benzyl 4-(4-((diethoxyphosphorothioyl)thio)-2,5-dioxo-1-phenyl-2,5-dihydro-1H-pyrrol-3-yl)piperazine-1-carboxylate



4e

Following the general procedure, using (petroleum ether : EtOAc = 9 : 1) as the eluant afforded a yellow liquid (75.9 mg, 66% yield). **^{1}H NMR** (500 MHz, $CDCl_3$): δ 7.44 (t, *J* = 7.8 Hz, 2H), 7.38-7.31 (m, 8H), 5.17 (s, 2H), 4.26-4.23 (m, 8H), 3.71 (t, *J* = 5.3 Hz, 4H), 1.34 (t, *J* = 7.0 Hz, 6H); **^{13}C NMR** (125 MHz, $CDCl_3$): δ 168.3, 164.9, 155.0, 150.2, 136.3, 131.6, 129.0, 128.6, 128.3, 128.1, 127.9, 126.4, 87.0, 67.6, 65.1, 65.1, 48.5, 43.8, 16.0, 15.9; **^{31}P NMR** (162 MHz, $CDCl_3$): δ 89.1; **HRMS** (ESI): calcd for $C_{26}H_{30}N_3O_6NaPS_2$ $[M + Na]^+$ 598.1211, found 598.1218.

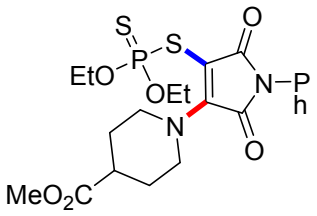
tert-butyl (1-(4-((diethoxyphosphorothioyl)thio)-2,5-dioxo-1-phenyl-2,5-dihydro-1H-pyrrol-3-yl)piperidin-4-yl)carbamate



4f

Following the general procedure, using (petroleum ether : EtOAc = 9 : 1) as the eluant afforded a yellow solid (61.1 mg, 55% yield), Mp = 111-112℃. **^{1}H NMR** (500 MHz, $CDCl_3$): δ 7.44 (t, *J* = 7.8 Hz, 2H), 7.35-7.31 (m, 3H), 5.07 (d, *J* = 13.5 Hz, 2H), 4.53 (brs, 1H), 4.29-4.23 (m, 4H), 3.77 (brs, 1H), 3.36 (t, *J* = 12.7 Hz, 2H), 2.13-2.09 (m, 2H), 1.65-1.57 (m, 2H), 1.45 (s, 9H), 1.35 (t, *J* = 7.0 Hz, 6H); **^{13}C NMR** (125 MHz, $CDCl_3$): δ 168.5, 164.9, 155.0, 150.4, 131.7, 129.2, 128.9, 127.8, 126.4, 126.4, 86.1, 79.7, 64.9, 64.9, 48.2, 47.2, 32.9, 28.4, 16.0, 15.9; **^{31}P NMR** (162 MHz, $CDCl_3$): δ 89.8; **HRMS** (ESI): calcd for $C_{24}H_{34}N_3O_6NaPS_2$ $[M + Na]^+$ 578.1524, found 578.1531.

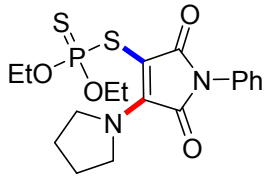
methyl 1-(4-((diethoxyphosphorothioyl)thio)-2,5-dioxo-1-phenyl-2,5-dihydro-1H-pyrrol-3-yl)piperidine-4-carboxylate



4g

Following the general procedure, using (petroleum ether : EtOAc = 9 : 1) as the eluant afforded a yellow liquid (67.7 mg, 68% yield). **^{1}H NMR** (500 MHz, $CDCl_3$): δ 7.44 (t, *J* = 7.8 Hz, 2H), 7.36-7.32 (m, 3H), 4.92 (dt, *J* = 13.7, 4.3 Hz, 2H), 4.27 (dq, *J* = 9.3, 7.1 Hz, 4H), 3.72 (s, 3H), 3.57-3.52 (m, 2H), 2.68 (tt, *J* = 10.3, 4.3 Hz, 1H), 2.11-2.07 (m, 2H), 1.96 (dtd, *J* = 14.2, 10.5, 3.8 Hz, 2H), 1.35 (t, *J* = 7.0 Hz, 6H); **^{13}C NMR** (125 MHz, $CDCl_3$): δ 174.2, 168.4, 164.9, 150.4, 131.8, 128.9, 127.7, 126.4, 86.0, 64.9, 64.9, 51.9, 48.5, 40.0, 28.5, 155.9, 15.9; **^{31}P NMR** (162 MHz, $CDCl_3$): δ 89.4; **HRMS** (ESI): calcd for $C_{21}H_{27}N_2O_6NaPS_2$ $[M + Na]^+$ 521.0946, found 521.0953.

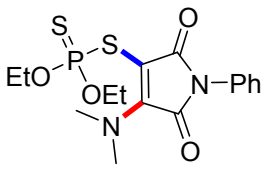
S-(2,5-dioxo-1-phenyl-4-(pyrrolidin-1-yl)-2,5-dihydro-1H-pyrrol-3-yl) O,O-diethyl phosphorodithioate



4h

Following the general procedure, using (petroleum ether : EtOAc = 9 : 1) as the eluant afforded a yellow solid (63.9 mg, 75% yield), Mp = 135-136℃. **^{1}H NMR** (500 MHz, $CDCl_3$): δ 7.43 (t, *J* = 7.8 Hz, 2H), 7.35-7.31 (m, 3H), 4.29-4.07 (m, 8H), 1.99-1.96 (m, 4H), 1.33 (t, *J* = 7.4 Hz, 6H); **^{13}C NMR** (125 MHz, $CDCl_3$): δ 169.1, 164.3, 148.9, 132.0, 128.9, 127.6, 126.3, 81.3, 64.8, 64.7, 51.9, 25.4, 24.9, 15.9, 15.9; **^{31}P NMR** (162 MHz, $CDCl_3$): δ 90.9; **HRMS** (ESI): calcd for $C_{18}H_{23}N_2O_4NaPS_2$ $[M + Na]^+$ 449.0735, found 449.0739.

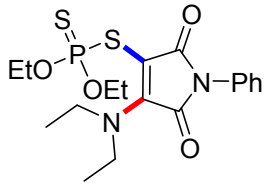
S-(4-(dimethylamino)-2,5-dioxo-1-phenyl-2,5-dihydro-1H-pyrrol-3-yl) O,O-diethyl phosphorodithioate



4i

Following the general procedure, using (petroleum ether : EtOAc = 9 : 1) as the eluant afforded a yellow solid (63.2 mg, 79% yield), Mp = 133-134℃. **^{1}H NMR** (500 MHz, $CDCl_3$): δ 7.44 (dd, *J* = 8.8, 6.8 Hz, 2H), 7.35-7.32 (m, 3H), 4.27 (dq, *J* = 9.2, 7.0 Hz, 4H), 3.60 (d, *J* = 3.3 Hz, 6H), 1.34 (t, *J* = 7.0 Hz, 6H); **^{13}C NMR** (125 MHz, $CDCl_3$): δ 168.7, 164.7, 151.0, 150.9, 131.9, 128.9, 127.7, 126.4, 83.9, 64.8, 64.8, 43.2, 15.9, 15.9; **^{31}P NMR** (162 MHz, $CDCl_3$): δ 90.2; **HRMS** (ESI): calcd for $C_{16}H_{21}N_2O_4NaPS_2$ $[M + Na]^+$ 423.0578, found 423.0576.

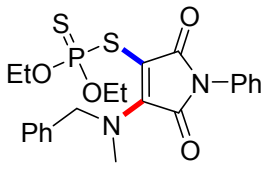
S-(4-(diethylamino)-2,5-dioxo-1-phenyl-2,5-dihydro-1H-pyrrol-3-yl) O,O-diethyl phosphorodithioate



4j

Following the general procedure, using (petroleum ether : EtOAc = 9 : 1) as the eluant afforded a yellow solid (66.8 mg, 78% yield), Mp = 57-58℃. **^{1}H NMR** (500 MHz, $CDCl_3$): δ 7.44 (t, *J* = 7.7 Hz, 2H), 7.35-7.30 (m, 3H), 4.27 (p, *J* = 7.1 Hz, 4H), 4.01 (q, *J* = 7.2 Hz, 4H), 1.32 (dt, *J* = 20.0, 7.2 Hz, 12H); **^{13}C NMR** (125 MHz, $CDCl_3$): δ 168.8, 164.5, 149.1, 149.0, 131.9, 128.9, 127.6, 126.5, 126.4, 82.4, 64.8, 64.7, 47.2, 15.9, 15.9, 13.9; **^{31}P NMR** (162 MHz, $CDCl_3$): δ 90.6; **HRMS** (ESI): calcd for $C_{18}H_{25}N_2O_4NaPS_2$ $[M + Na]^+$ 451.0891, found 451.0897.

S-(4-(benzyl(methyl)amino)-2,5-dioxo-1-phenyl-2,5-dihydro-1H-pyrrol-3-yl) O,O-diethyl phosphorodithioate

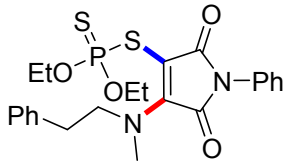


4k

Following the general procedure, using (petroleum ether : EtOAc = 9 : 1) as the eluant afforded a yellow solid (48.5 mg, 51% yield), Mp = 76-77℃. **^{1}H NMR** (400 MHz, $CDCl_3$): δ 7.50 (dd, *J* =

8.4, 7.1 Hz, 2H), 7.44-7.33 (m, 8H), 5.33-5.32 (m, 2H), 4.29 (dqd, *J* = 9.4, 7.1, 4.2 Hz, 4H), 3.57 (d, *J* = 3.3 Hz, 3H), 1.37 (t, *J* = 7.1 Hz, 6H); **^{13}C NMR** (125 MHz, $CDCl_3$): δ 168.6, 164.8, 150.7, 150.7, 135.8, 135.8, 131.8, 128.9, 128.9, 128.0, 127.8, 127.6, 126.4, 85.1, 64.9, 64.9, 57.1, 41.1, 15.9, 15.9; **^{31}P NMR** (162 MHz, $CDCl_3$): δ 90.4; **HRMS** (ESI): calcd for $C_{22}H_{25}N_2O_4NaPS_2$ $[M + Na]^+$ 499.0891, found 499.0894.

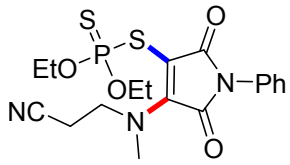
O,O-diethyl S-(4-(methyl(phenethyl)amino)-2,5-dioxo-1-phenyl-2,5-dihydro-1H-pyrrol-3-yl) phosphorodithioate



4l

Following the general procedure, using (petroleum ether : EtOAc = 9 : 1) as the eluant afforded a yellow solid (51.9 mg, 53% yield), Mp = 80-81℃. **^{1}H NMR** (500 MHz, $CDCl_3$): δ 7.45 (t, *J* = 7.8 Hz, 2H), 7.36-7.28 (m, 7H), 7.24-7.22 (m, 1H), 4.28-4.17 (m, 6H), 3.59 (d, *J* = 3.4 Hz, 3H), 3.02 (t, *J* = 7.9 Hz, 2H), 1.32 (t, *J* = 7.0 Hz, 6H); **^{13}C NMR** (125 MHz, $CDCl_3$): δ 168.6, 164.6, 137.7, 131.8, 129.0, 128.9, 128.7, 127.8, 126.8, 126.5, 84.1, 64.9, 64.8, 56.2, 42.1, 34.8, 15.9, 15.9; **^{31}P NMR** (162 MHz, $CDCl_3$): δ 90.5; **HRMS** (ESI): calcd for $C_{23}H_{27}N_2O_4NaPS_2$ $[M + Na]^+$ 513.1048, found 513.1045.

S-(4-((2-cyanoethyl)(methyl)amino)-2,5-dioxo-1-phenyl-2,5-dihydro-1H-pyrrol-3-yl) O,O-diethyl phosphorodithioate

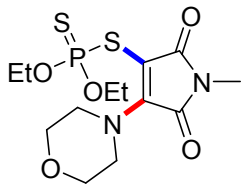


4m

Following the general procedure, using (petroleum ether : EtOAc = 9 : 1) as the eluant afforded a yellow liquid (57.1 mg, 65% yield). **^{1}H NMR** (500 MHz, $CDCl_3$): δ 7.46 (t, *J* = 7.8 Hz, 2H), 7.38-7.31 (m, 3H), 4.30-4.22 (m, 6H), 3.71 (d, *J* = 3.3 Hz, 3H), 2.81 (t, *J* = 6.7 Hz, 2H), 1.35 (t, *J* = 7.0 Hz, 6H); **^{13}C NMR** (125 MHz, $CDCl_3$): δ 168.3, 164.7, 149.8, 131.5, 129.1, 128.0, 126.4, 117.3, 87.4, 65.3, 65.2, 50.3, 42.6, 17.4, 15.9, 15.9; **^{31}P NMR** (162 MHz, $CDCl_3$): δ 90.0; **HRMS** (ESI):

calcd for $C_{18}H_{22}N_3O_4NaPS_2$ [M + Na]$^+$ 462.0687, found 462.0688.

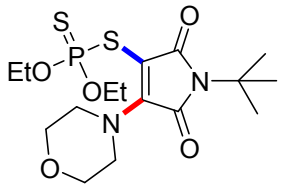
O,O-diethyl S-(1-methyl-4-morpholino-2,5-dioxo-2,5-dihydro-1H-pyrrol-3-yl) phosphorodithioate



5a

Following the general procedure, using (petroleum ether : EtOAc = 9 : 1) as the eluant afforded a yellow solid (54.7 mg, 72% yield), Mp = 88-89℃. **^{1}H NMR** (500 MHz, $CDCl_3$): δ 4.26-4.25 (m, 8H), 3.84-3.82 (m, 4H), 3.02 (s, 3H), 1.35 (t, *J* = 6.8 Hz, 6H); **^{13}C NMR** (125 MHz, $CDCl_3$): δ 169.4, 166.1, 150.4, 85.1, 66.9, 64.9, 64.8, 48.9, 24.3, 15.9, 15.8; **^{31}P NMR** (162 MHz, $CDCl_3$): δ 89.1; **HRMS** (ESI): calcd for $C_{13}H_{21}N_2O_5NaPS_2$ [M + Na]$^+$ 403.0527, found 403.0527.

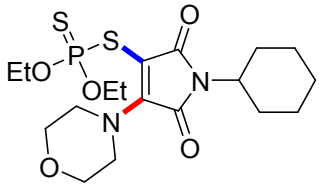
S-(1-(tert-butyl)-4-morpholino-2,5-dioxo-2,5-dihydro-1H-pyrrol-3-yl) O,O-diethyl phosphorodithioate



5b

Following the general procedure, using (petroleum ether : EtOAc = 9 : 1) as the eluant afforded a yellow solid (61.6 mg, 73% yield), Mp = 57-58℃. **^{1}H NMR** (500 MHz, $CDCl_3$): δ 4.24 (dq, *J* = 9.4, 7.1 Hz, 4H), 4.15 (dq, *J* = 5.4, 2.3 Hz, 4H), 3.82 (t, *J* = 4.8 Hz, 4H), 1.58 (s, 9H), 1.34 (t, *J* = 7.1 Hz, 6H); **^{13}C NMR** (125 MHz, $CDCl_3$): δ 170.4, 166.7, 150.0, 86.6, 66.9, 64.9, 64.8, 58.1, 48.9, 29.1, 15.9, 15.9; **^{31}P NMR** (162 MHz, $CDCl_3$): δ 89.1; **HRMS** (ESI): calcd for $C_{16}H_{27}N_2O_5NaPS_2$ [M + Na]$^+$ 445.0997, found 445.0992.

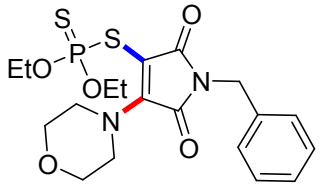
S-(1-cyclohexyl-4-morpholino-2,5-dioxo-2,5-dihydro-1H-pyrrol-3-yl) O,O-diethyl phosphorodithioate



5c

Following the general procedure, using (petroleum ether : EtOAc = 9 : 1) as the eluant afforded a yellow liquid (66.3 mg, 74% yield). **^{1}H NMR** (500 MHz, $CDCl_3$): δ 4.23 (d, *J* = 7.5 Hz, 8H), 3.94 (t, *J* = 12.9 Hz, 1H), 3.84-3.82 (m, 4H), 2.05 (q, *J* = 12.7 Hz, 2H), 1.82 (d, *J* = 13.0 Hz, 2H), 1.65 (d, *J* = 12.3 Hz, 2H), 1.39-1.18 (m, 9H); **^{13}C NMR** (125 MHz, $CDCl_3$): δ 169.3, 165.9, 150.0, 85.4, 66.9, 64.8, 64.8, 51.4, 48.8, 29.9, 26.0, 25.1, 15.9, 15.9; **^{31}P NMR** (162 MHz, $CDCl_3$): δ 89.4; **HRMS** (ESI): calcd for $C_{18}H_{29}N_2O_5NaPS_2$ $[M + Na]^+$ 471.1153, found 471.1157.

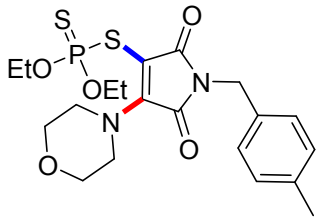
S-(1-benzyl-4-morpholino-2,5-dioxo-2,5-dihydro-1H-pyrrol-3-yl) O,O-diethyl phosphorodithioate



5d

Following the general procedure, using (petroleum ether : EtOAc = 9 : 1) as the eluant afforded a yellow liquid (64.8 mg, 71% yield). **^{1}H NMR** (500 MHz, $CDCl_3$): δ 7.35-7.27 (m, 5H), 4.67 (s, 2H), 4.25-4.21 (m, 8H), 3.81 (t, *J* = 4.8 Hz, 4H), 1.32 (t, *J* = 7.0 Hz, 6H); **^{13}C NMR** (125 MHz, $CDCl_3$): δ 169.1, 165.7, 150.2, 136.3, 128.6, 128.4, 127.7, 85.2, 66.9, 64.9, 64.9, 48.9, 41.9, 15.9, 15.8; **^{31}P NMR** (162 MHz, $CDCl_3$): δ 89.1; **HRMS** (ESI): calcd for $C_{19}H_{25}N_2O_5NaPS_2$ $[M + Na]^+$ 479.0840, found 479.0843.

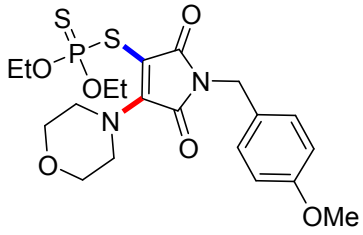
O,O-diethyl S-(1-(4-methylbenzyl)-4-morpholino-2,5-dioxo-2,5-dihydro-1H-pyrrol-3-yl) phosphorodithioate



5e

Following the general procedure, using (petroleum ether : EtOAc = 9 : 1) as the eluant afforded a yellow solid (65.8 mg, 70% yield), Mp = 61-62℃. **^{1}H NMR** (500 MHz, $CDCl_3$): δ 7.24 (d, *J* = 7.6 Hz, 2H), 7.11 (d, *J* = 7.7 Hz, 2H), 4.63 (s, 2H), 4.24-4.23 (m, 8H), 3.80 (t, *J* = 4.7 Hz, 4H), 2.31 (s, 3H), 1.32 (t, *J* = 7.1 Hz, 6H); **^{13}C NMR** (125 MHz, $CDCl_3$): δ 169.1, 165.7, 150.3, 137.4, 133.3, 129.3, 128.4, 85.1, 66.9, 64.9, 64.8, 48.8, 41.7, 21.1, 15.9, 15.8; **^{31}P NMR** (162 MHz, $CDCl_3$): δ 89.0; **HRMS** (ESI): calcd for $C_{20}H_{27}N_2O_5NaPS_2$ $[M + Na]^+$ 493.0997, found 493.0995.

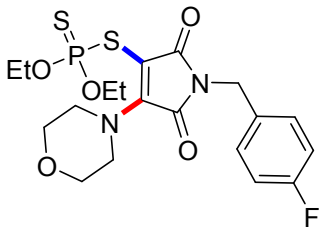
O,O-diethyl S-(1-(4-methoxybenzyl)-4-morpholino-2,5-dioxo-2,5-dihydro-1H-pyrrol-3-yl) phosphorodithioate



5f

Following the general procedure, using (petroleum ether : EtOAc = 9 : 1) as the eluant afforded a yellow liquid (71.9 mg, 74% yield). **^{1}H NMR** (500 MHz, $CDCl_3$): δ 7.29 (d, *J* = 8.2 Hz, 2H), 6.82 (d, *J* = 8.1 Hz, 2H), 4.61 (s, 2H), 4.24-4.21 (m, 8H), 3.82-3.77 (m, 7H), 1.32 (t, *J* = 7.1 Hz, 6H); **^{13}C NMR** (125 MHz, $CDCl_3$): δ 169.1, 165.7, 159.2, 150.3, 130.1, 129.9, 128.6, 113.9, 85.1, 66.9, 64.9, 64.8, 55.2, 48.8, 41.4, 15.9, 15.8; **^{31}P NMR** (162 MHz, $CDCl_3$): δ 89.0; **HRMS** (ESI): calcd for $C_{20}H_{27}N_2O_6NaPS_2$ $[M + Na]^+$ 509.0946, found 509.0950.

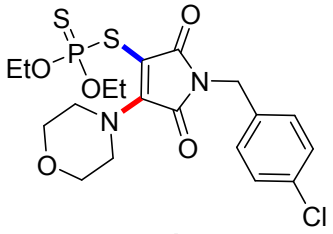
O,O-diethyl S-(1-(4-fluorobenzyl)-4-morpholino-2,5-dioxo-2,5-dihydro-1H-pyrrol-3-yl) phosphorodithioate



5g

Following the general procedure, using (petroleum ether : EtOAc = 9 : 1) as the eluant afforded a yellow liquid (56.9 mg, 60% yield). **^{1}H NMR** (500 MHz, $CDCl_3$): δ 7.34-7.32 (m, 2H), 7.00-6.97 (m, 2H), 4.64 (s, 2H), 4.26-4.21 (m, 8H), 3.83-3.81 (m, 4H), 1.32 (t, *J* = 7.1 Hz, 6H); **^{13}C NMR** (125 MHz, $CDCl_3$): δ 169.0, 165.6, 163.3, 161.4, 150.3, 132.1, 130.3, 130.2, 115.5, 115.4, 115.3, 85.3, 66.8, 64.9, 64.8, 48.9, 41.2, 15.9, 15.8; **^{31}P NMR** (162 MHz, $CDCl_3$): δ 89.3; **^{19}F NMR** (375 MHz, $CDCl_3$): δ -114.3 (s, 1F); **HRMS** (ESI): calcd for $C_{19}H_{24}FN_2O_5NaPS_2$ $[M + Na]^+$ 497.0746, found 497.0743.

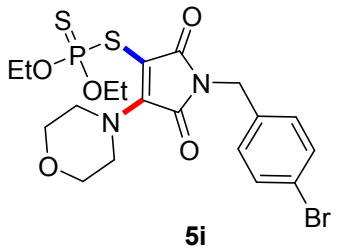
S-(1-(4-chlorobenzyl)-4-morpholino-2,5-dioxo-2,5-dihydro-1H-pyrrol-3-yl) O,O-diethyl phosphorodithioate



5h

Following the general procedure, using (petroleum ether : EtOAc = 9 : 1) as the eluant afforded a yellow liquid (63.7 mg, 65% yield). **^{1}H NMR** (500 MHz, $CDCl_3$): δ 7.28-7.26 (m, 4H), 4.63 (s, 2H), 4.25-4.21 (m, 8H), 3.82 (t, *J* = 4.8 Hz, 4H), 1.32 (t, *J* = 7.1 Hz, 6H); **^{13}C NMR** (125 MHz, $CDCl_3$): δ 168.9, 165.6, 150.2, 134.7, 133.7, 129.8, 128.8, 128.7, 85.3, 66.8, 64.9, 64.9, 48.9, 41.3, 15.9, 15.9; **^{31}P NMR** (162 MHz, $CDCl_3$): δ 89.3; **HRMS** (ESI): calcd for $C_{19}H_{24}ClN_2O_5NaPS_2$ $[M + Na]^+$ 513.0450, found 513.0453.

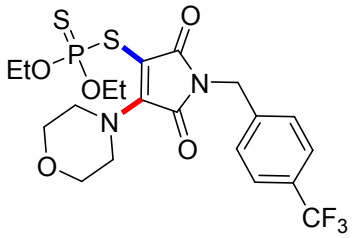
S-(1-(4-bromobenzyl)-4-morpholino-2,5-dioxo-2,5-dihydro-1H-pyrrol-3-yl) O,O-diethyl phosphorodithioate



5i

Following the general procedure, using (petroleum ether : EtOAc = 9 : 1) as the eluant afforded a yellow liquid (66.2 mg, 62% yield). **^{1}H NMR** (500 MHz, $CDCl_3$): δ7.43 (d, *J* = 8.0 Hz, 2H), 7.22 (d, *J* = 8.0 Hz, 2H), 4.62 (s, 2H), 4.24-4.20 (m, 8H), 3.82 (t, *J* = 4.8 Hz, 4H), 1.32 (t, *J* = 7.1 Hz, 6H); **^{13}C NMR** (125 MHz, $CDCl_3$): δ 168.9, 165.6, 150.2, 135.3, 131.7, 130.2, 121.8, 85.4, 66.8, 64.9, 64.9, 48.9, 41.3, 15.9, 15.9; **^{31}P NMR** (162 MHz, $CDCl_3$): δ 89.3; **HRMS** (ESI): calcd for $C_{19}H_{24}BrN_2O_5NaPS_2$ $[M + Na]^+$ 556.9945, found 556.9945.

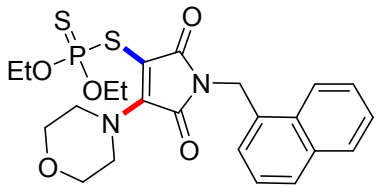
O,O-diethyl S-(4-morpholino-2,5-dioxo-1-(4-(trifluoromethyl)benzyl)-2,5-dihydro-1H-pyrrol-3-yl) phosphorodithioate



5j

Following the general procedure, using (petroleum ether : EtOAc = 9 : 1) as the eluant afforded a yellow solid (57.6 mg, 55% yield), Mp = 86-87℃. **^{1}H NMR** (500 MHz, $CDCl_3$): δ 7.57 (d, J = 7.9 Hz, 2H), 7.45 (d, J = 8.0 Hz, 2H), 4.73 (s, 2H), 4.24 (dt, J = 10.1, 5.1 Hz, 8H), 3.82 (t, J = 4.7 Hz, 4H), 1.32 (t, J = 7.1 Hz, 6H); **^{13}C NMR** (125 MHz, $CDCl_3$): δ 168.9, 165.6, 150.2, 140.1, 130.2, 128.8, 128.6, 125.6, 125.5, 125.1, 122.9, 85.4, 66.8, 64.9, 64.9, 48.9, 41.4, 15.9, 15.8; **^{31}P NMR** (162 MHz, $CDCl_3$): δ 89.4; **^{19}F NMR** (375 MHz, $CDCl_3$): δ -62.5 (s, 3F); **HRMS** (ESI): calcd for $C_{20}H_{24}F_3N_2O_5NaPS_2$ $[M + Na]^+$ 547.0714, found 547.0720.

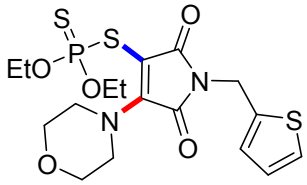
O,O-diethyl S-(4-morpholino-1-(naphthalen-1-ylmethyl)-2,5-dioxo-2,5-dihydro-1H-pyrrol-3-yl) phosphorodithioate



5k

Following the general procedure, using (petroleum ether : EtOAc = 9 : 1) as the eluant afforded a yellow liquid (73.9 mg, 73% yield). **^{1}H NMR** (500 MHz, $CDCl_3$): δ 8.26 (d, *J* = 8.5 Hz, 1H), 7.85 (d, *J* = 8.1 Hz, 1H), 7.79 (d, *J* = 8.1 Hz, 1H), 7.53 (td, *J* = 14.6, 13.2, 7.4 Hz, 3H), 7.42 (t, *J* = 7.6 Hz, 1H), 5.15 (s, 2H), 4.24-4.21 (m, 8H), 3.80 (t, *J* = 4.7 Hz, 4H), 1.30 (t, *J* = 7.1 Hz, 6H); **^{13}C NMR** (125 MHz, $CDCl_3$): δ 169.2, 165.9, 150.2, 133.8, 131.4, 131.2, 128.7, 128.5, 127.1, 126.5, 125.8, 125.2, 123.5, 85.4, 66.8, 64.9, 64.9, 48.9, 39.9, 15.9, 15.9; **^{31}P NMR** (162 MHz, $CDCl_3$): δ 89.2; **HRMS** (ESI): calcd for $C_{23}H_{27}N_2O_5NaPS_2$ $[M + Na]^+$ 529.0997, found 529.0995.

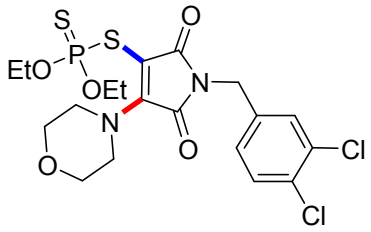
O,O-diethyl S-(4-morpholino-2,5-dioxo-1-(thiophen-2-ylmethyl)-2,5-dihydro-1H-pyrrol-3-yl) phosphorodithioate



5l

Following the general procedure, using (petroleum ether : EtOAc = 9 : 1) as the eluant afforded a yellow liquid (62.8 mg, 68% yield). **^{1}H NMR** (500 MHz, $CDCl_3$): δ 7.21 (d, *J* = 5.2 Hz, 1H), 7.06 (d, *J* = 3.3 Hz, 1H), 6.93-6.91 (m, 1H), 4.84 (s, 2H), 4.26-4.22 (m, 8H), 3.83-3.81 (m, 4H), 1.33 (t, *J* = 6.9 Hz, 6H); **^{13}C NMR** (125 MHz, $CDCl_3$): δ 168.5, 165.3, 150.3, 138.1, 127.5, 126.8, 125.7, 85.3, 66.8, 64.9, 64.9, 48.9, 36.2, 15.9, 15.8; **^{31}P NMR** (162 MHz, $CDCl_3$): δ 88.8; **HRMS** (ESI): calcd for $C_{17}H_{23}N_2O_5NaPS_3$ $[M + Na]^+$ 485.0404, found 485.0404.

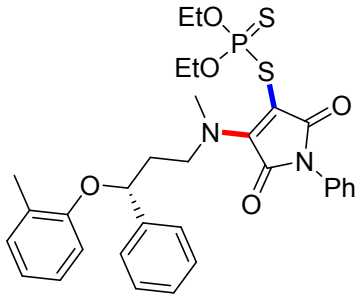
S-(1-(3,4-dichlorobenzyl)-4-morpholino-2,5-dioxo-2,5-dihydro-1H-pyrrol-3-yl) O,O-diethyl phosphorodithioate



5m

Following the general procedure, using (petroleum ether : EtOAc = 9 : 1) as the eluant afforded a yellow liquid (63.9 mg, 61% yield). **^{1}H NMR** (500 MHz, $CDCl_3$): δ 7.43 (s, 1H), 7.38 (d, *J* = 8.2 Hz, 1H), 7.19 (d, *J* = 10.0 Hz, 1H), 4.62 (s, 2H), 4.26-4.20 (m, 8H), 3.83 (t, *J* = 4.9 Hz, 4H), 1.33 (t, *J* = 7.1 Hz, 6H); **^{13}C NMR** (125 MHz, $CDCl_3$): δ 168.9, 165.5, 150.2, 136.3, 132.7, 132.0, 130.6, 130.4, 127.8, 85.2, 66.8, 65.0, 64.9, 48.9, 40.8, 15.9, 15.9; **^{31}P NMR** (162 MHz, $CDCl_3$): δ 89.3; **HRMS** (ESI): calcd for $C_{19}H_{23}Cl_2N_2O_5NaPS_2$ $[M + Na]^+$ 547.0061, found 547.0058.

(R)-O,O-diethyl S-(4-(methyl(3-phenyl-3-(o-tolyloxy)propyl)amino)-2,5-dioxo-1-phenyl-2,5-dihydro-1H-pyrrol-3-yl) phosphorodithioate

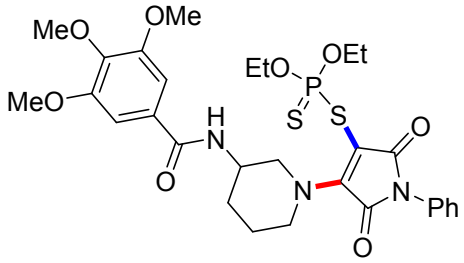


6a

Following the general procedure, using (petroleum ether : EtOAc = 9 : 1) as the eluant afforded a yellow liquid (86.6 mg, 71% yield). **^{1}H NMR** (500 MHz, $CDCl_3$): δ 7.42 (t, *J* = 7.7 Hz, 2H), 7.36-7.30 (m, 5H), 7.25-7.24 (m, 3H), 7.12 (d, *J* = 7.4 Hz, 1H), 6.94 (t, *J* = 7.8 Hz, 1H), 6.78 (t, *J* = 7.4 Hz, 1H), 6.60 (d, *J* = 8.2 Hz, 1H), 5.32 (dd, *J* = 9.3, 3.7 Hz, 1H), 4.35-4.13 (m, 6H), 3.60 (d, *J* = 3.6 Hz, 3H), 2.40-2.30 (m, 4H), 2.30-2.23 (m, 1H), 1.32-1.29 (m, 6H); **^{13}C NMR** (125 MHz, $CDCl_3$): δ 168.6, 164.5, 155.5, 141.1, 131.8, 130.8, 128.9, 127.8, 127.7, 126.8, 126.7, 126.4, 125.7, 120.5, 112.6, 101.9, 84.1, 64.9, 64.9, 51.9, 42.0, 38.6, 37.3, 16.6, 15.9, 15.9; **^{31}P NMR** (162 MHz, $CDCl_3$): δ 90.7; **HRMS** (ESI): calcd for $C_{31}H_{35}N_2O_5NaPS_2$ $[M + Na]^+$ 633.1623, found 633.1629.

S-(2,5-dioxo-1-phenyl-4-(3-(3,4,5-trimethoxybenzamido)piperidin-1-yl)-2,5-dihydro-1H-pyrrol-3-

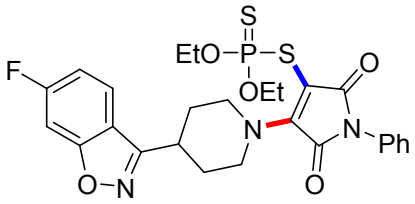
yl) O,O-diethyl phosphorodithioate



6b

Following the general procedure, using (petroleum ether : EtOAc = 9 : 1) as the eluant afforded a yellow solid (81.8 mg, 63% yield), Mp = 146-147℃. **^{1}H NMR** (500 MHz, $CDCl_3$): δ 7.45 (t, J = 7.8 Hz, 2H), 7.37 (t, J = 7.4 Hz, 1H), 7.31-7.28 (m, 1H), 7.22 (brs, 1H), 7.06 (s, 2H), 4.58 (d, J = 13.5 Hz, 1H), 4.39 (d, J = 13.0 Hz, 1H), 4.40-4.24 (m, 5H), 4.15-4.10 (m, 1H), 3.83 (s, 3H), 3.68 (s, 6H), 2.35 (d, J = 10.6 Hz, 1H), 2.05 (s, 1H), 1.97-1.86 (m, 2H), 1.83-1.78 (m, 1H), 1.36 (t, J = 7.1 Hz, 6H), 1.26 (t, J = 6.8 Hz, 1H); **^{13}C NMR** (125 MHz, $CDCl_3$): δ 171.1, 168.1, 167.1, 166.2, 153.1, 152.5, 140.7, 131.5, 129.6, 129.0, 128.0, 126.2, 104.3, 89.8, 65.2, 60.8, 60.4, 56.0, 53.6, 50.6, 46.9, 27.8, 22.0, 21.0, 15.9, 14.2; **^{31}P NMR** (162 MHz, $CDCl_3$): δ 88.7; **HRMS** (ESI): calcd for $C_{29}H_{36}N_3O_8NaPS_2$ $[M + Na]^+$ 672.1579, found 672.1586.

O,O-diethyl S-(4-(4-(6-fluorobenzo[d]isoxazol-3-yl)piperidin-1-yl)-2,5-dioxo-1-phenyl-2,5-dihydro-1H-pyrrol-3-yl) phosphorodithioate

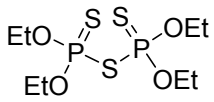


6c

Following the general procedure, using (petroleum ether : EtOAc = 9 : 1) as the eluant afforded a yellow liquid (70.2 mg, 61% yield). **^{1}H NMR** (500 MHz, $CDCl_3$): δ 7.70 (dd, *J* = 8.7, 5.0 Hz, 1H), 7.45 (dd, *J* = 8.5, 7.2 Hz, 2H), 7.37-7.34 (m, 3H), 7.28 (d, *J* = 2.1 Hz, 1H), 7.09 (td, *J* = 8.8, 2.1 Hz, 1H), 5.18 (d, *J* = 13.6 Hz, 2H), 4.31-4.25 (m, 4H), 3.64 (qd, *J* = 7.7, 6.6, 3.4 Hz, 2H), 3.51-3.43 (m, 1H), 2.28 (dt, *J* = 9.6, 4.7 Hz, 4H), 1.35 (t, *J* = 7.1 Hz, 6H); **^{13}C NMR** (125 MHz, $CDCl_3$): δ 168.5, 165.3, 165.0, 164.1, 163.9, 159.8, 150.5, 131.7, 128.9, 127.8, 126.4, 122.3, 122.2, 116.9, 112.8, 112.6, 97.7, 97.5, 86.3, 65.0, 65.0, 48.9, 33.5, 30.6, 16.0, 15.9; **^{19}F NMR** (375 MHz,

$CDCl_3$): δ -108.8 (s, 1F); **^{31}P NMR** (162 MHz, $CDCl_3$): δ 89.7; **HRMS** (ESI): calcd for $C_{26}H_{27}FN_3O_5NaPS_2$ $[M + Na]^+$ 598.1011, found 598.1014.

O,O,O,O-tetraethyl trithiopyrophosphate



7b

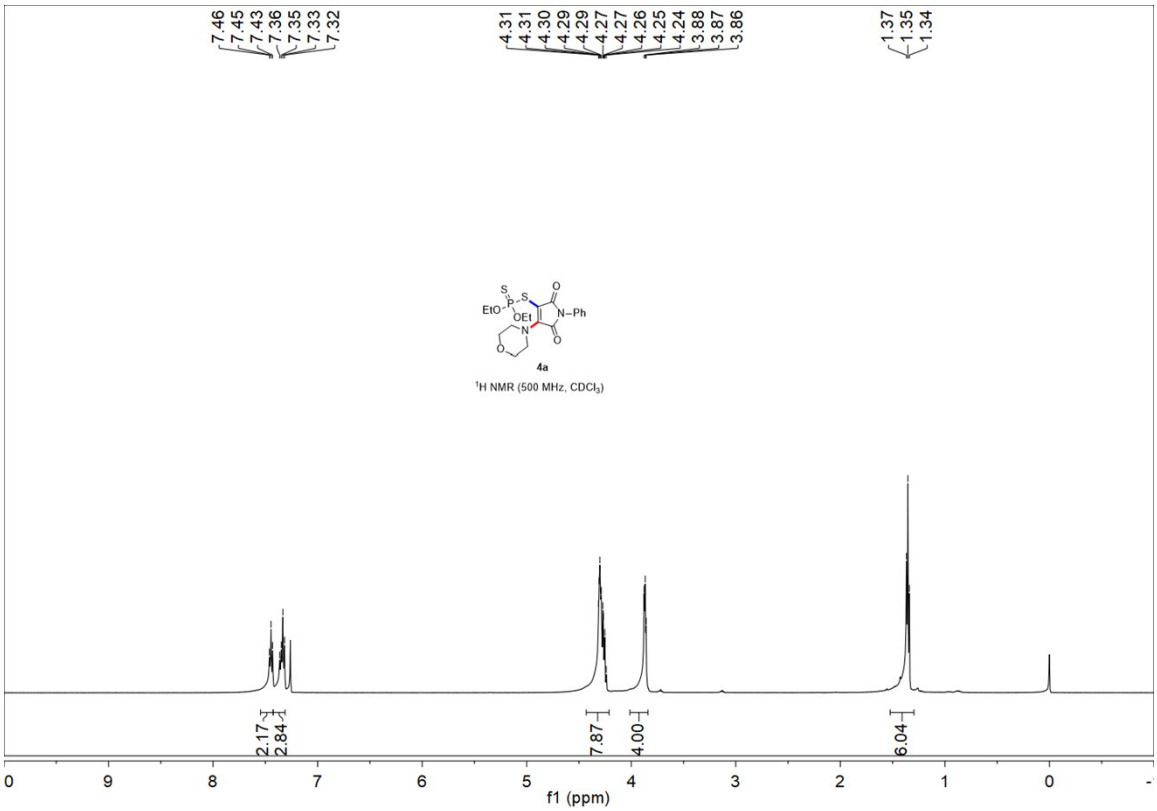
Using petroleum ether as the eluant afforded a green solid (64.2 mg, 95 % yield), Mp = 56-57℃. **^{1}H NMR** (400 MHz, $CDCl_3$): δ 4.37-4.27 (m, 4H), 4.25-4.14 (m, 4H), 1.46-1.41 (12H); **^{31}P NMR** (162 MHz, $CDCl_3$): δ 84.7, 83.9; **HRMS** (ESI): calcd for $C_8H_{20}O_4NaP_2S_3$ $[M + Na]^+$ 360.9897, found 360.9898.

References:

(1) C. E. P. Galvis, V. V. Kouznetsov, *Org. Biomol. Chem.* **2013**, *11*, 407-411.

(2) L. M. Nguyen, M. E. Dellinger, J. T. Lee, R. A. Quinlan, A. L. Rheingold, R. D. Pike a, *Inorg. Chim. Acta.* **2005**, *358*, 1331-1336.

^{1}H, ^{13}C, ^{19}F and ^{31}P NMR spectra of product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4.27
4.26
4.25
4.24
3.88
3.87
3.86
1.37
1.35
1.34
4a
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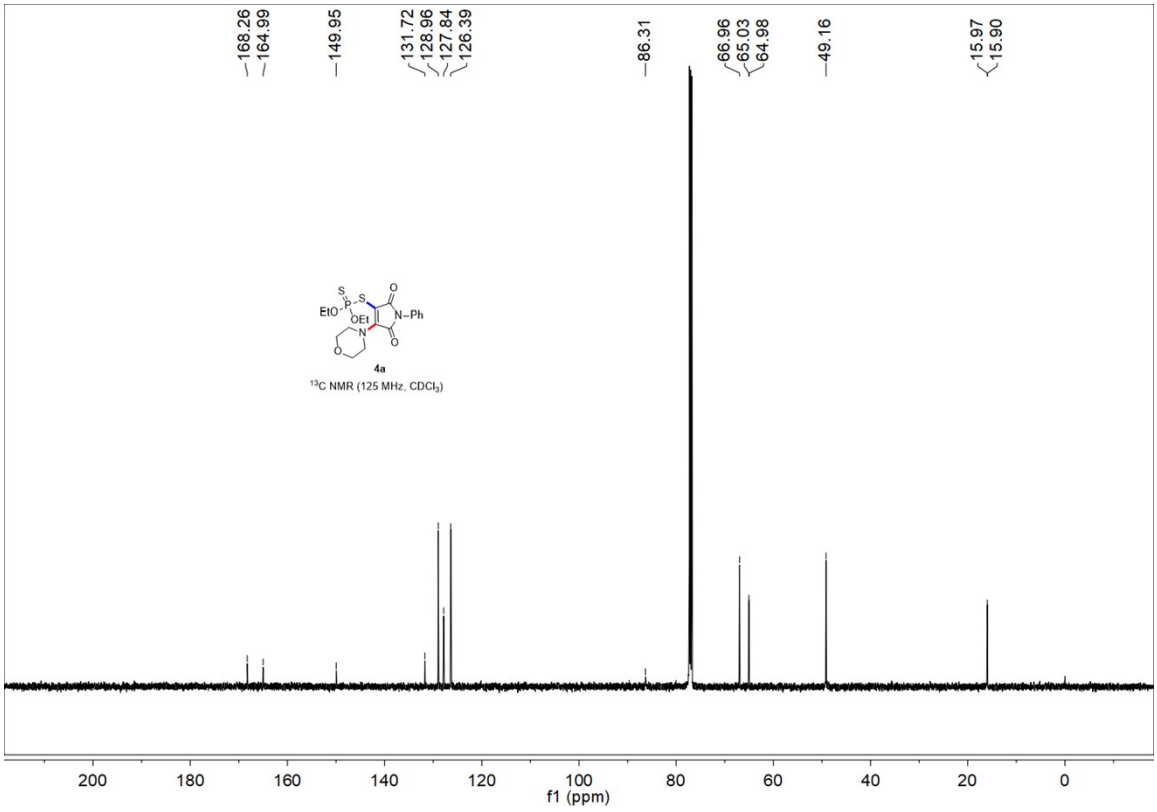
7.87
4.00
6.04
f1 (ppm)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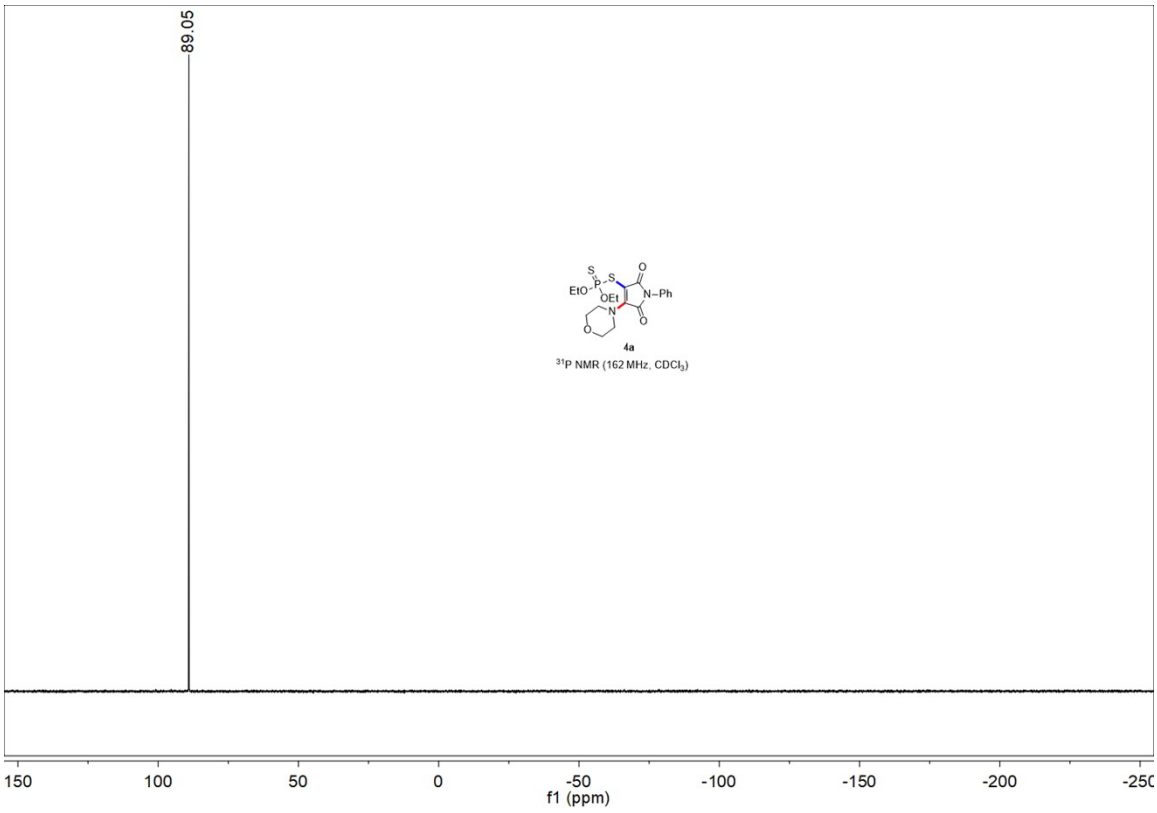
4a
13C NMR (125 MHz, CDCl3)
f1 (ppm)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4a
31P NMR (162 MHz, CDCl3)
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100
50
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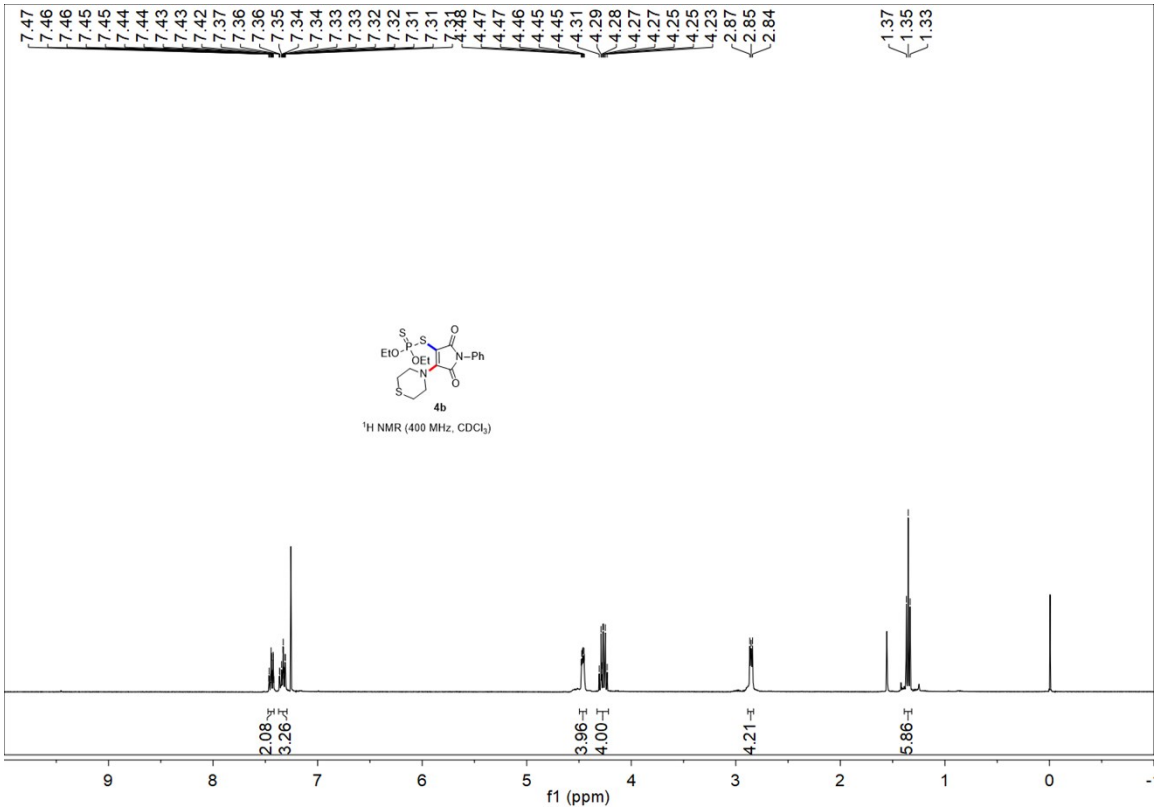
-50
-100
-150
-200
-250
f1 (ppm)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4.27
4.25
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4.23
2.87
2.85
2.84
1.37
1.35
1.33
4b
1H NMR (400 MHz, CDCl3)
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5
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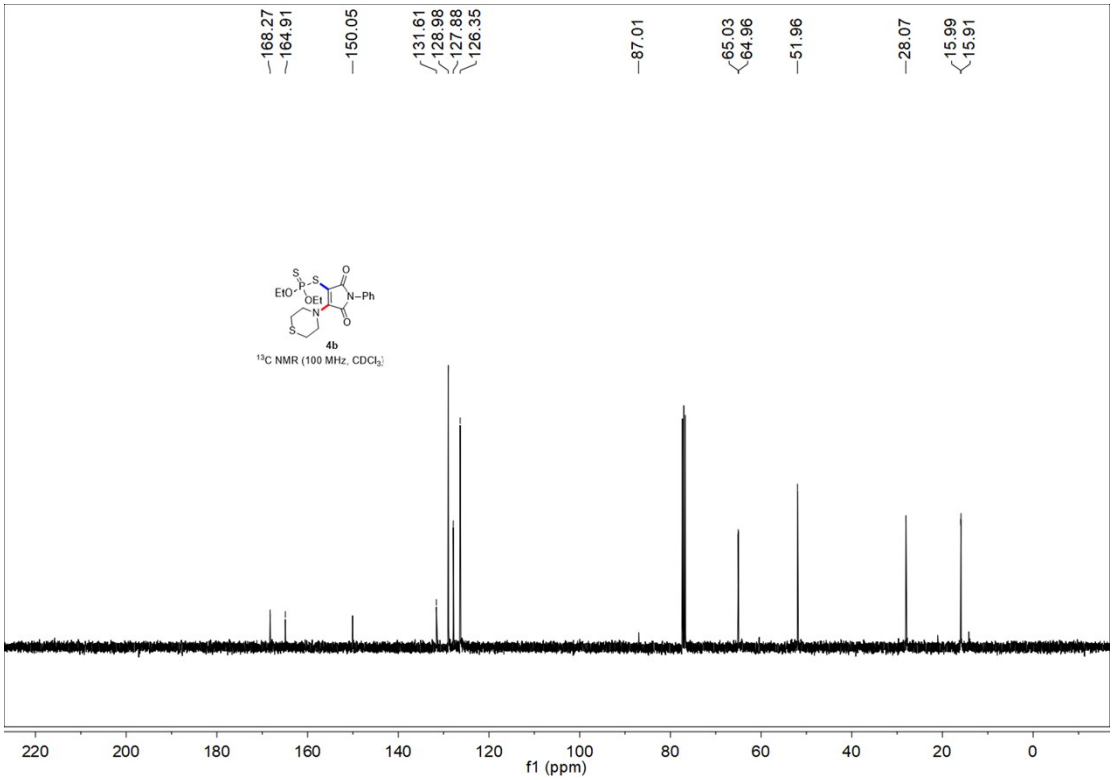
f1 (ppm)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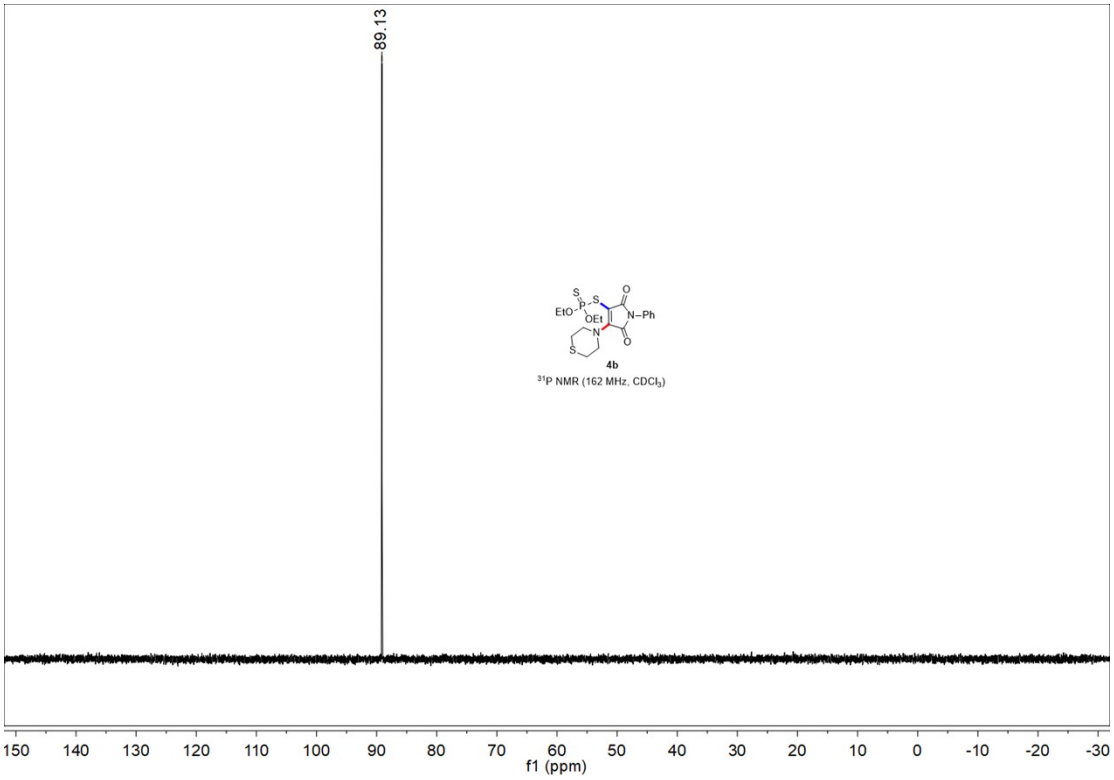
15.91
4b
13C NMR (100 MHz, CDCl3)
f1 (ppm)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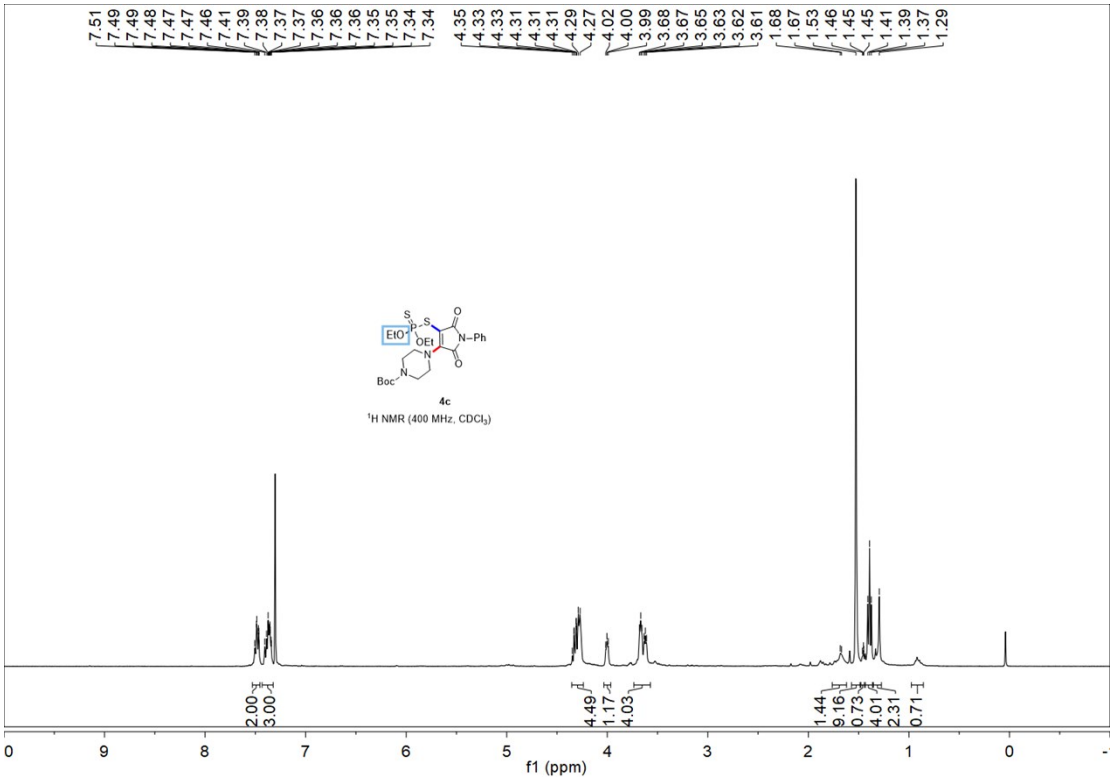
4b
31P NMR (162 MHz, CDCl3)
f1 (ppm)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1.68 1.67 1.53 1.46 1.45 1.45 1.41 1.39 1.37 1.29
EtO
OEt
N–Ph
Boc
4c
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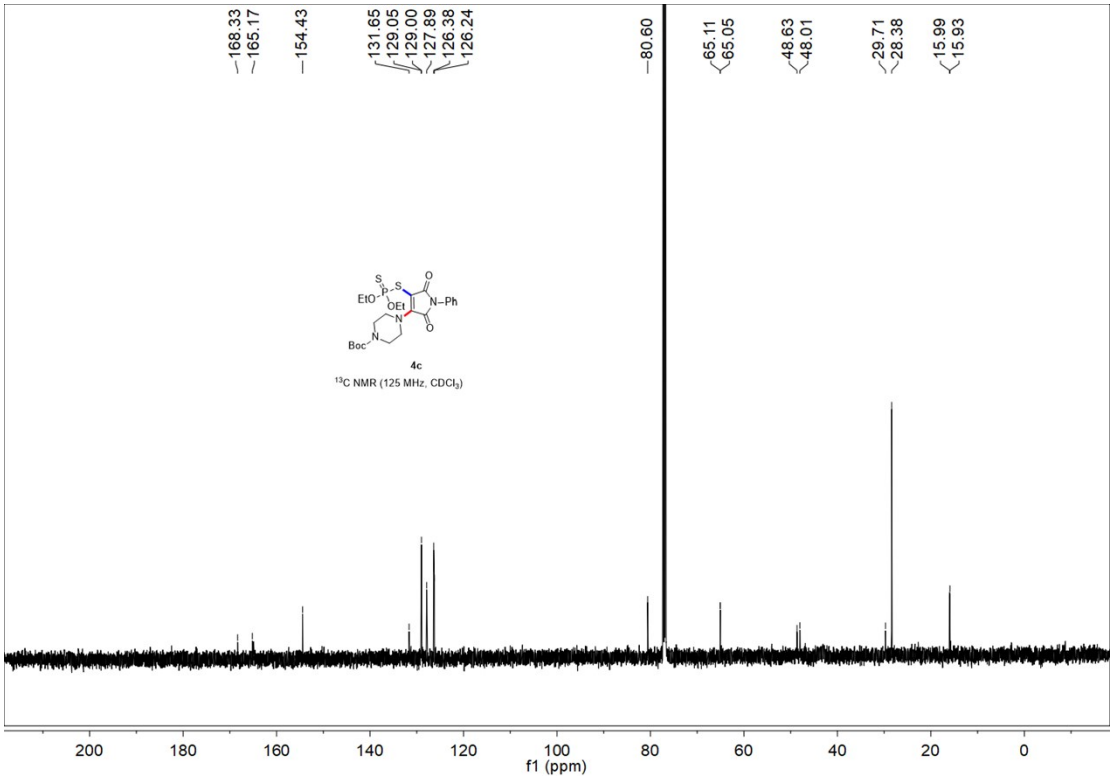
f1 (ppm)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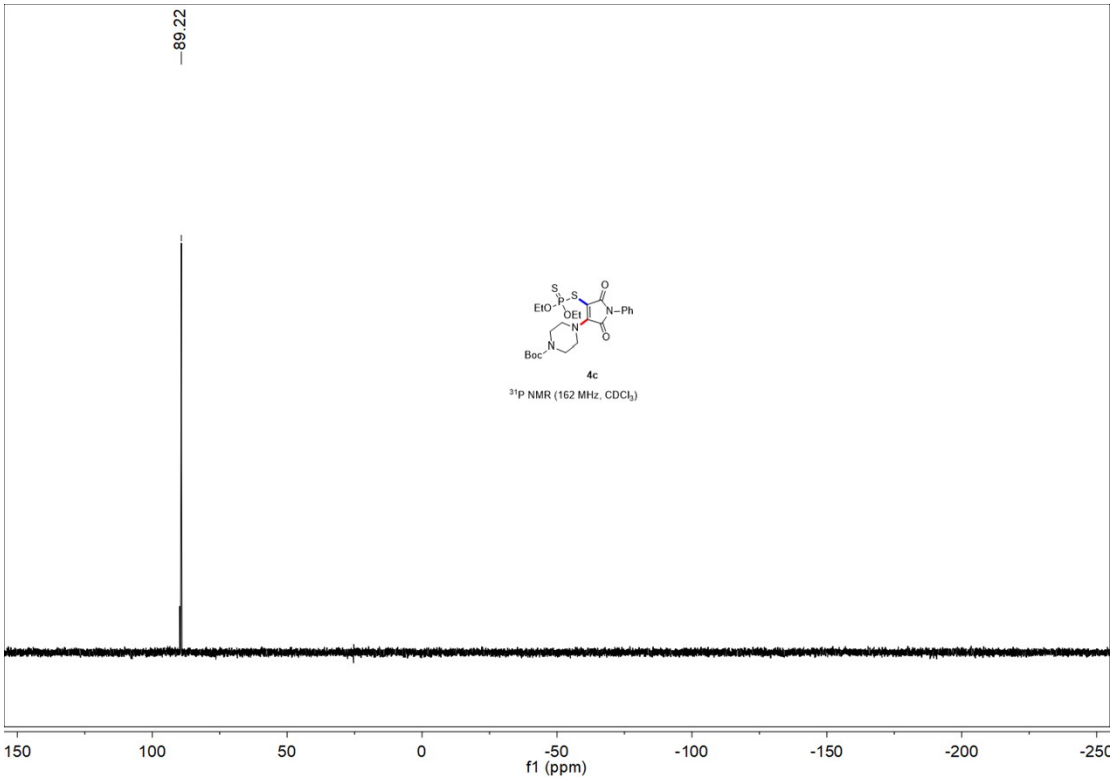
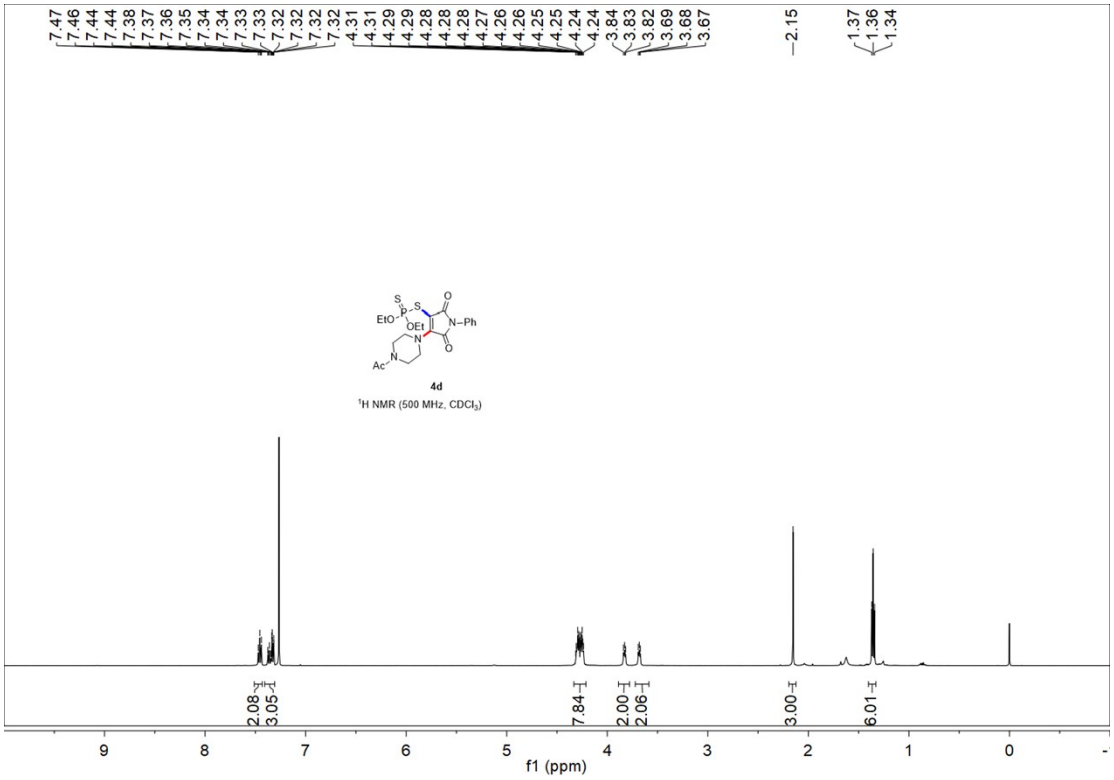
EtO
OEt
N–Ph
Boc
4c
¹³C NMR (125 MHz, CDCl3)
f1 (ppm)


89.22
4c
31P NMR (162 MHz, CDCl3)
150
100
50
0
-50
-100
-150
-200
-250
f1 (ppm)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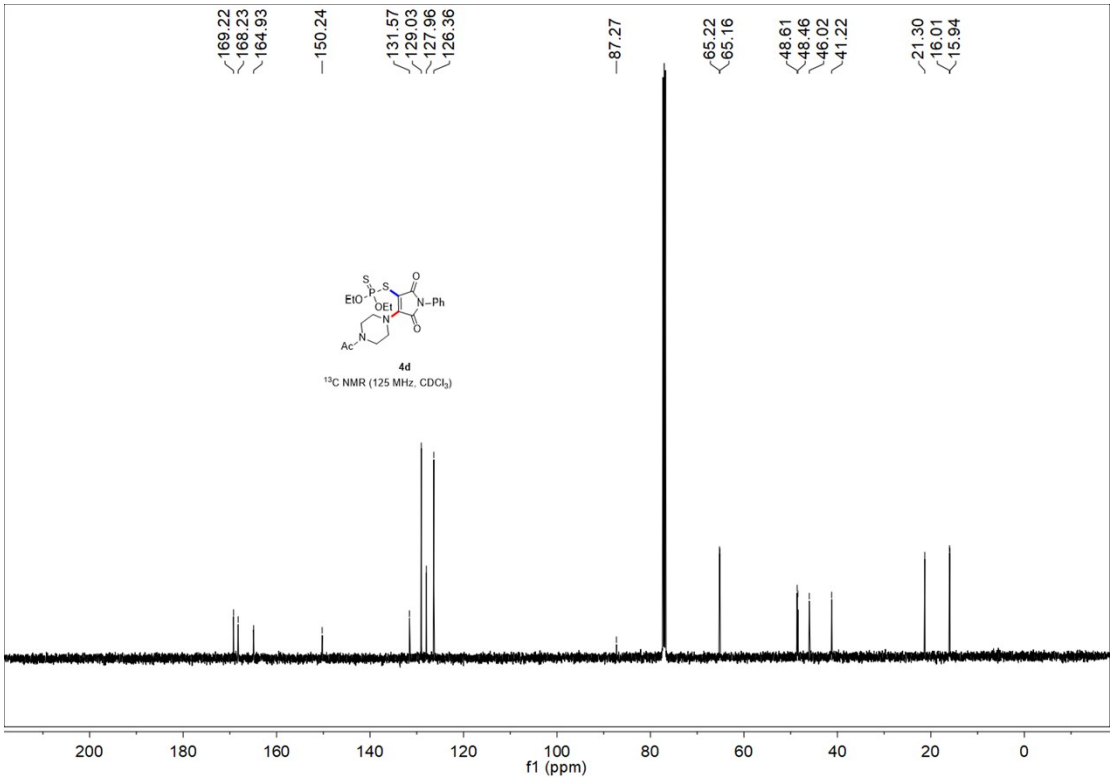
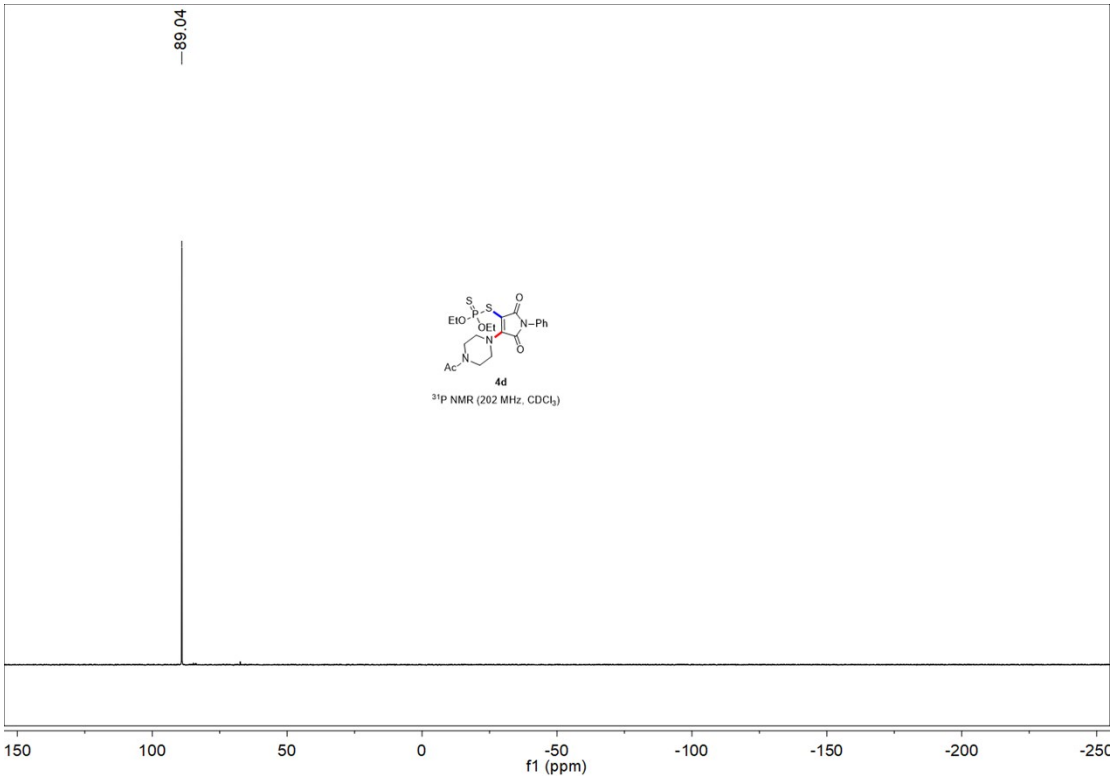
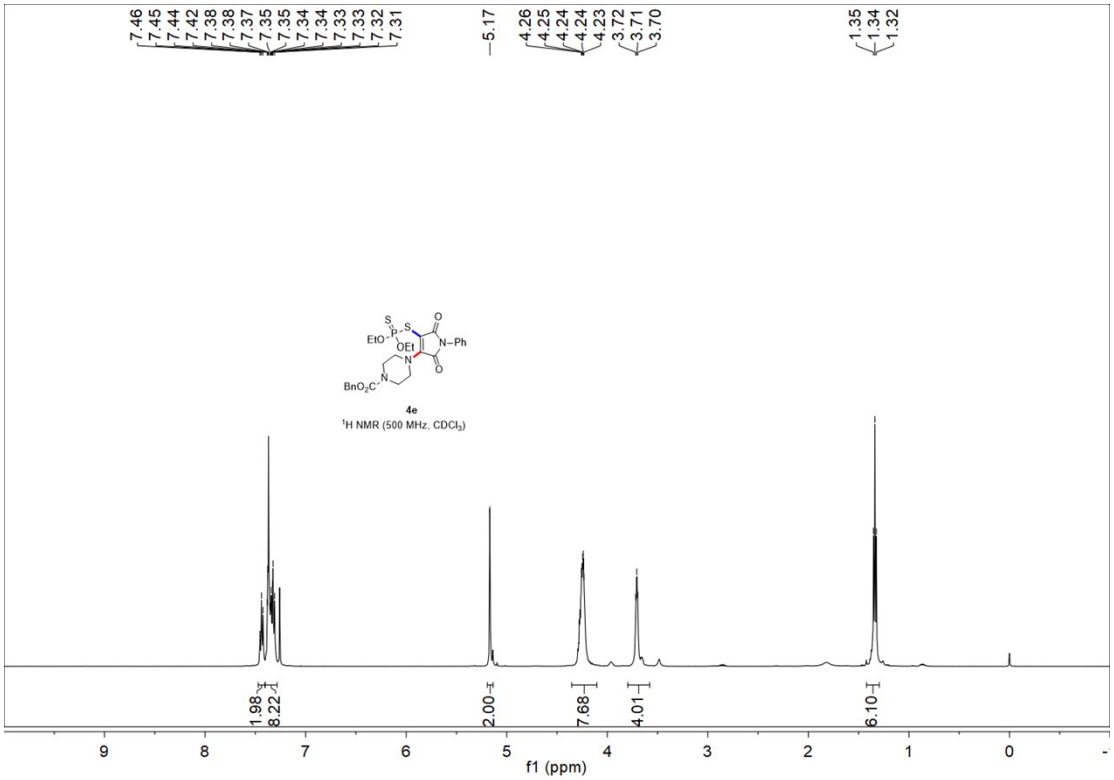
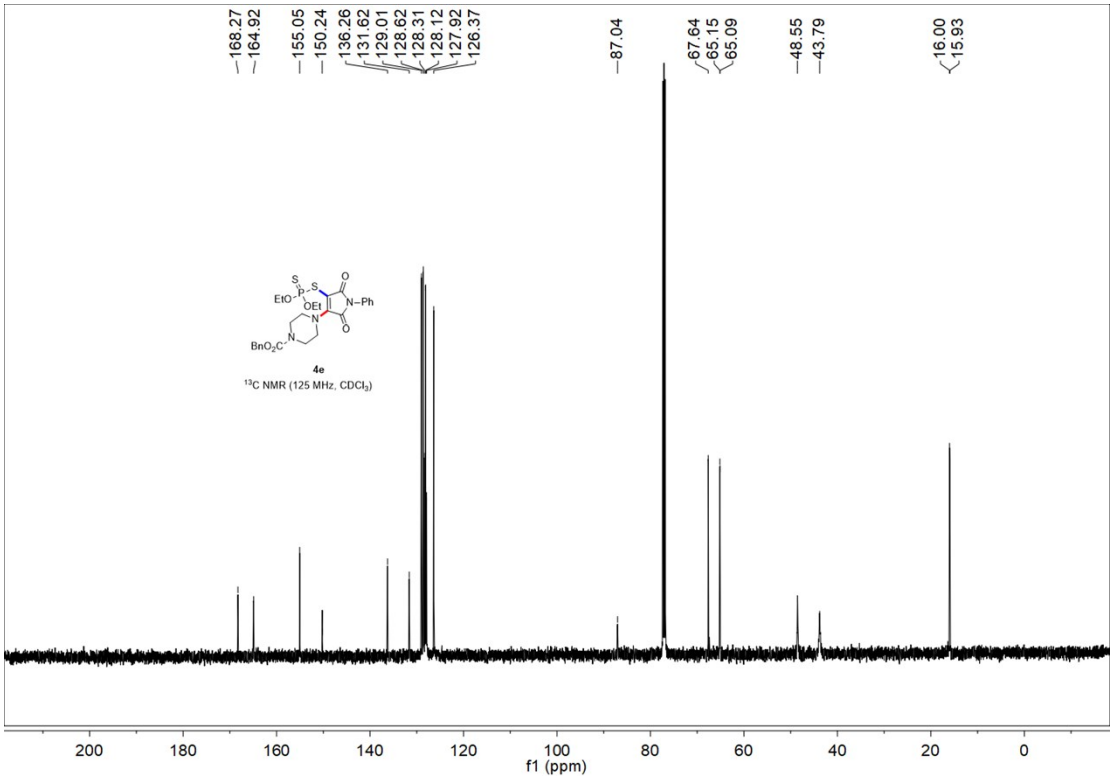
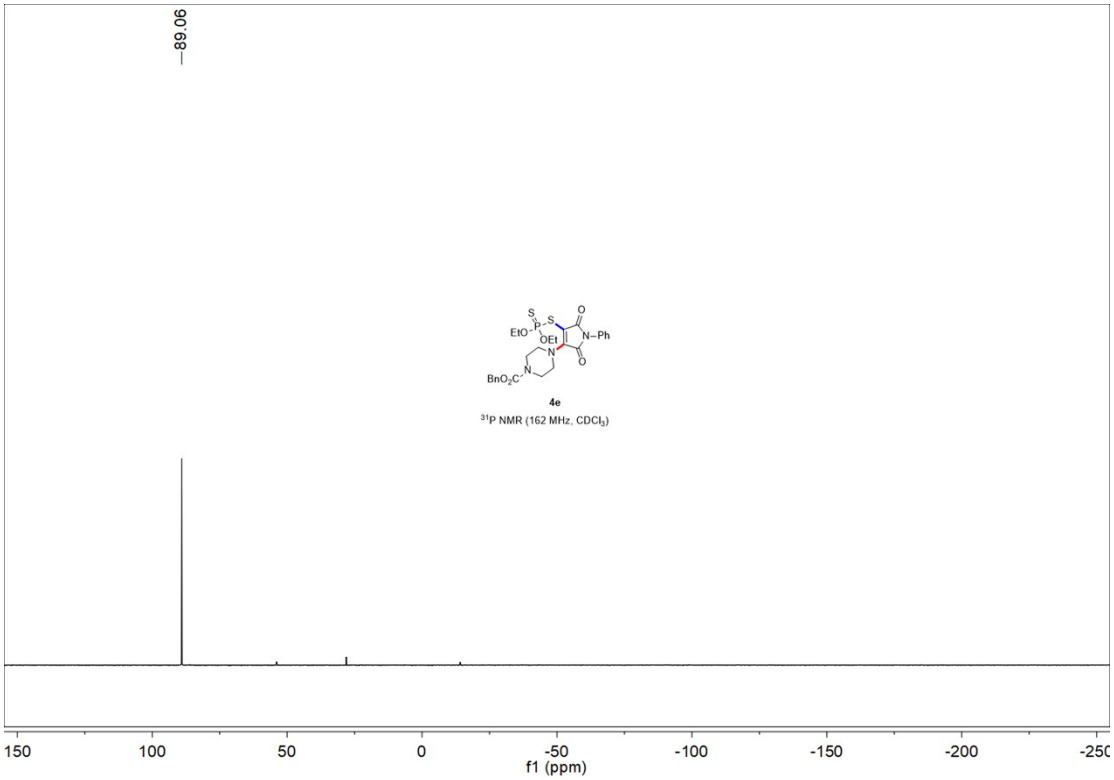
7.46
7.44
7.44
7.38
7.37
7.36
7.35
7.34
7.34
7.33
7.33
7.32
7.32
7.32
7.32
4.31
4.31
4.29
4.29
4.28
4.28
4.28
4.27
4.26
4.26
4.25
4.25
4.24
4.24
3.84
3.83
3.82
3.69
3.68
3.67
2.15
1.37
1.36
1.34
4d
1H NMR (500 MHz, CDCl3)
2.08
3.05
7.84
2.00
2.06
3.00
6.01
9
8
7
6
5
4
3
2
1
0
f1 (ppm)

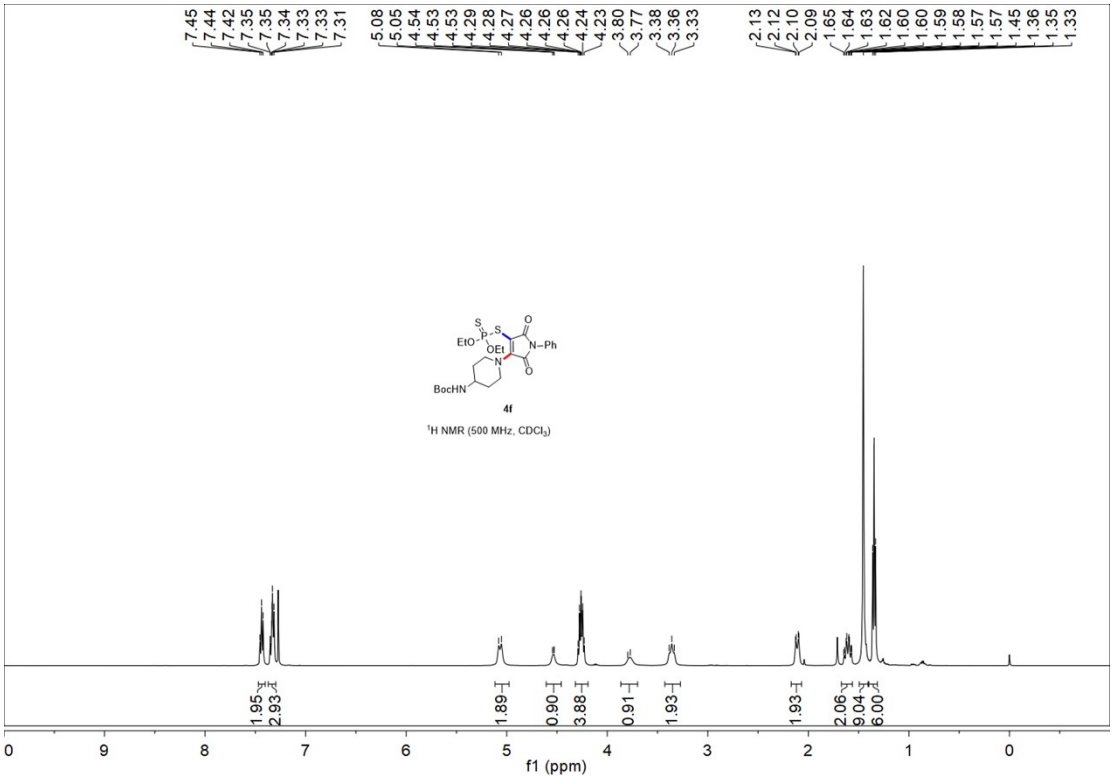

169.22
168.23
164.93
150.24
131.57
129.03
127.96
126.36
87.27
65.22
65.16
48.61
48.46
46.02
41.22
21.30
16.01
15.94
EtO
OEt
N–Ph
Ac
4d
13C NMR (125 MHz, CDCl3)
200
180
160
140
120
100
80
60
40
20
0
f1 (ppm)

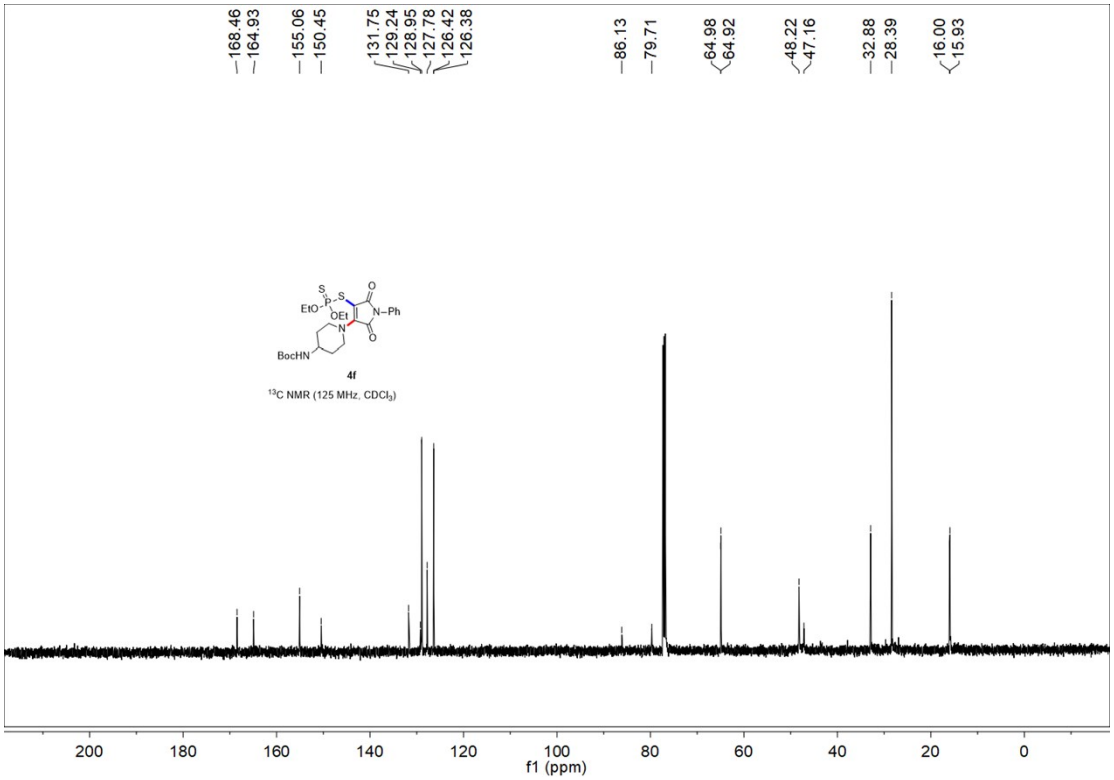

89.04
EtO
OEt
N–Ph
Ac
4d
31P NMR (202 MHz, CDCl3)
150
100
50
0
-50
-100
-150
-200
-250
f1 (ppm)

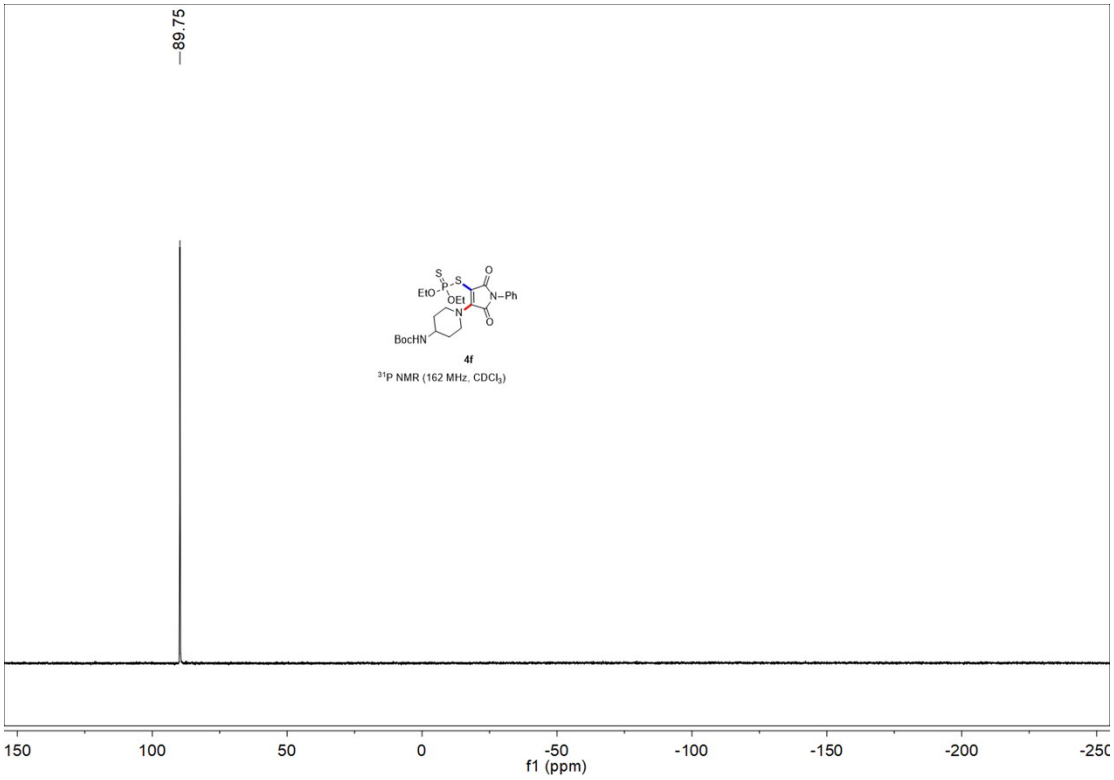

7.46
7.45
7.44
7.42
7.38
7.38
7.37
7.35
7.35
7.34
7.34
7.33
7.33
7.32
7.31
5.17
4.26
4.25
4.24
4.24
4.23
3.72
3.71
3.70
1.35
1.34
1.32
4e
1H NMR (500 MHz, CDCl3)
1.98
8.22
2.00
7.68
4.01
6.10
f1 (ppm)

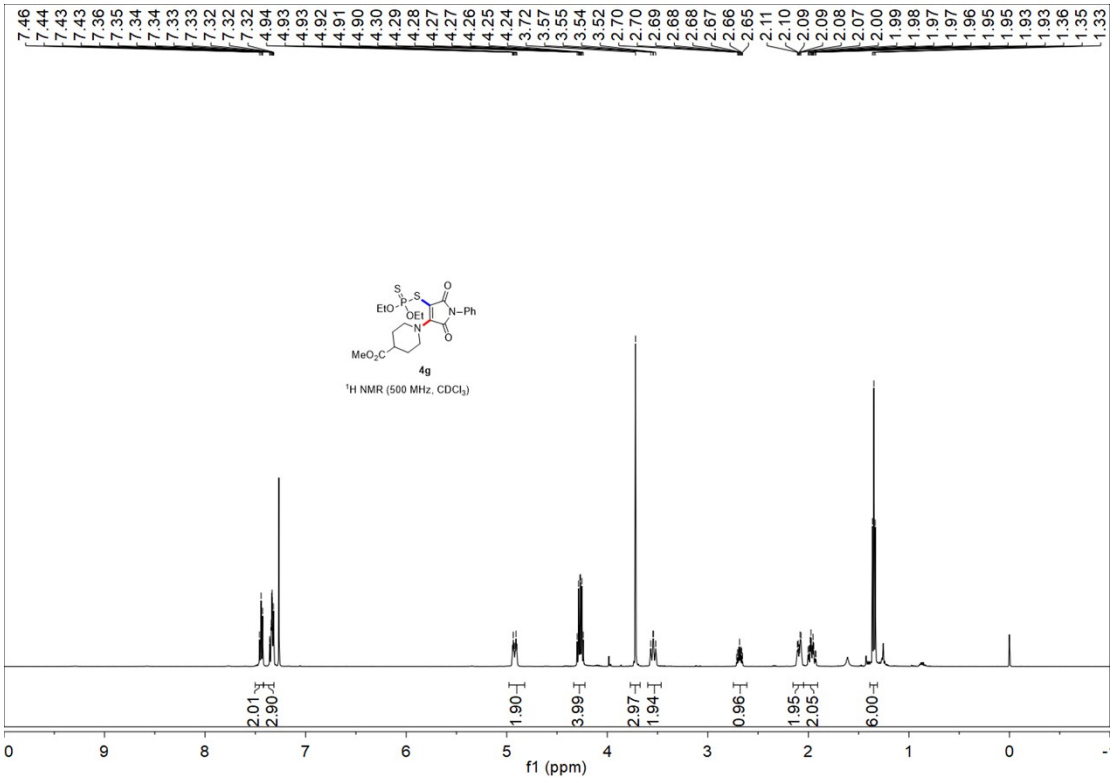

168.27
164.92
155.05
150.24
136.26
131.62
129.01
128.62
128.31
128.12
127.92
126.37
87.04
67.64
65.15
65.09
48.55
43.79
16.00
15.93
4e
13C NMR (125 MHz, CDCl3)
f1 (ppm)

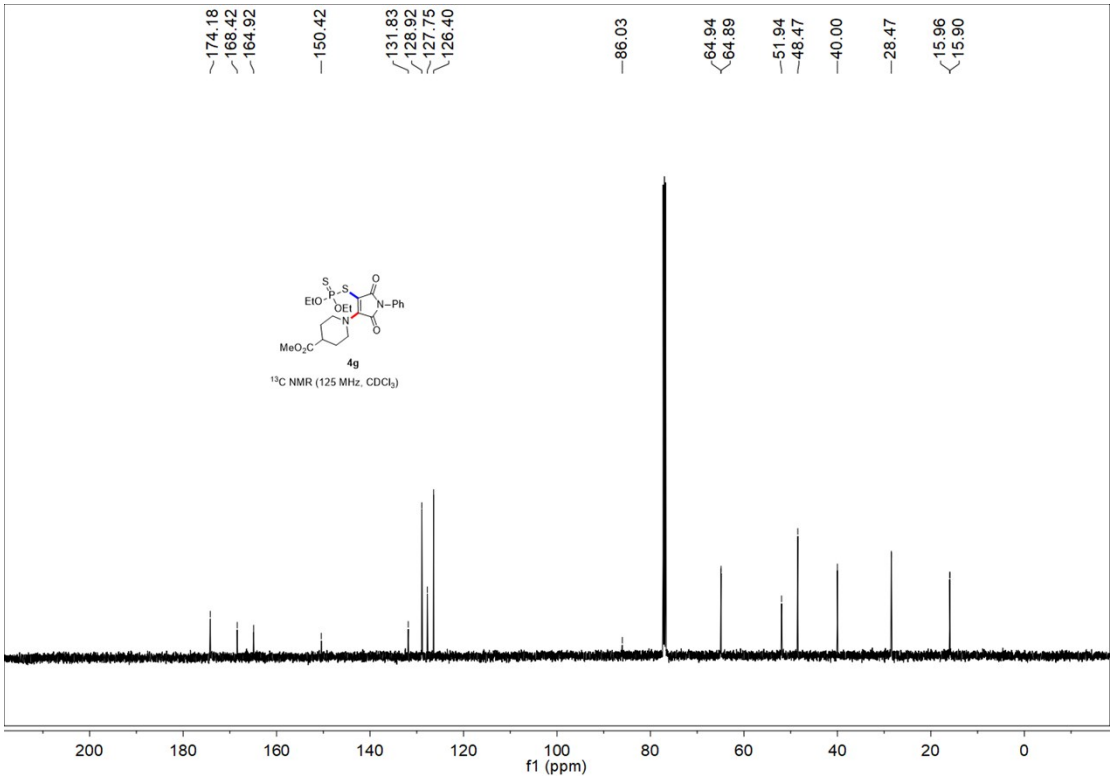

89.06
4e
31P NMR (162 MHz, CDCl3)
150
100
50
0
-50
-100
-150
-200
-250
f1 (ppm)

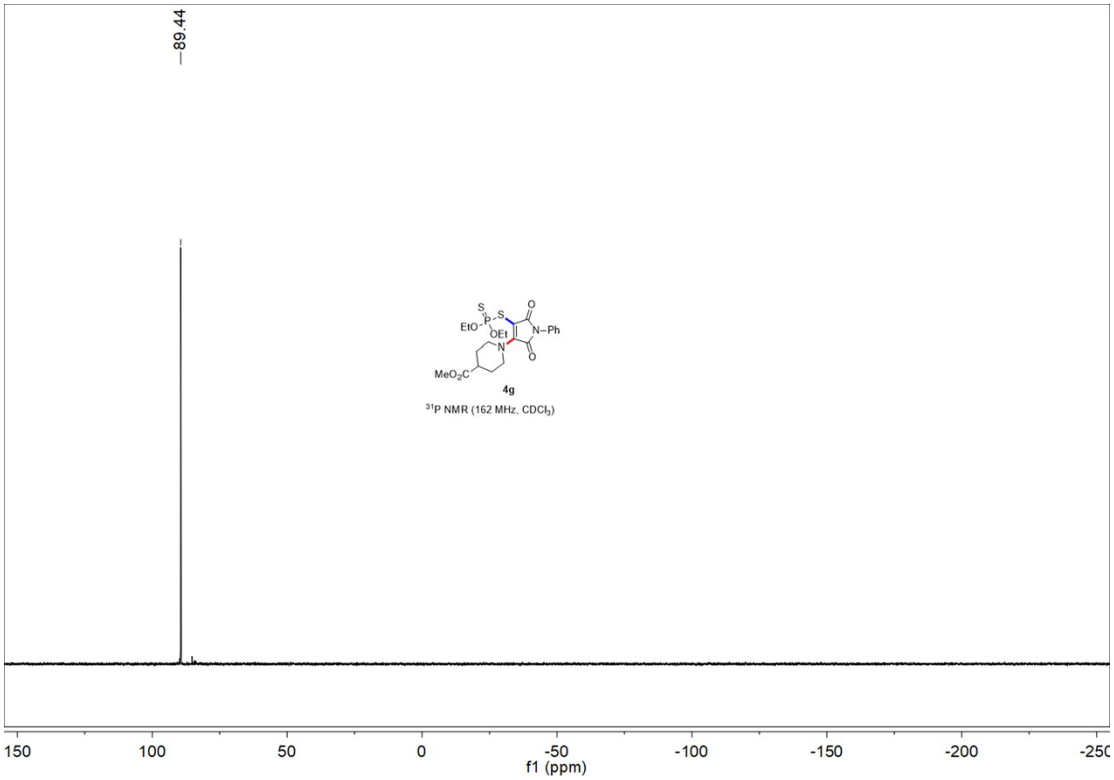

7.45
7.44
7.42
7.35
7.35
7.34
7.33
7.33
7.31
5.08
5.05
4.54
4.53
4.53
4.29
4.28
4.27
4.26
4.26
4.26
4.24
4.23
3.80
3.77
3.38
3.36
3.33
2.13
2.12
2.10
2.09
1.65
1.64
1.63
1.62
1.60
1.60
1.60
1.59
1.58
1.57
1.57
1.45
1.36
1.35
1.33
4f
1H NMR (500 MHz, CDCl3)
1.95
2.93
1.89
0.90
3.88
0.91
1.93
1.93
2.06
9.04
6.00
0
9
8
7
6
5
4
3
2
1
0
f1 (ppm)

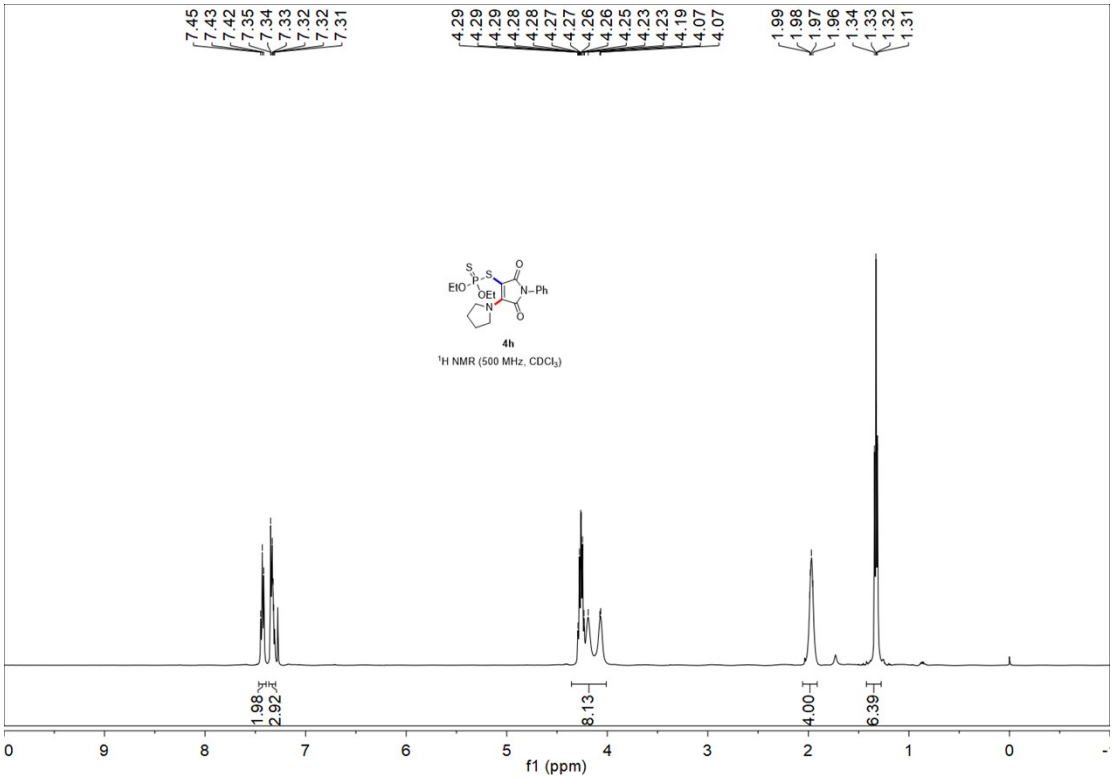

168.46
164.93
155.06
150.45
131.75
129.24
128.95
127.78
126.42
126.38
86.13
79.71
64.98
64.92
48.22
47.16
32.88
28.39
16.00
15.93
4f
13C NMR (125 MHz, CDCl3)
200
180
160
140
120
100
80
60
40
20
0
f1 (ppm)

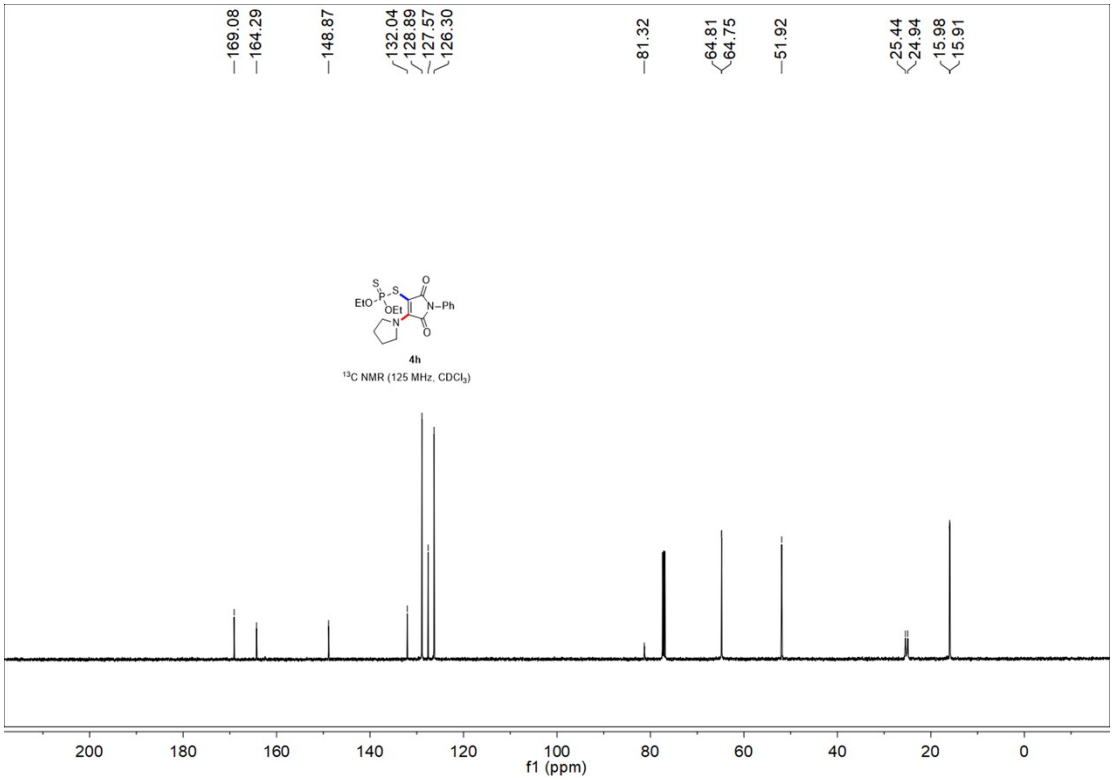

89.75
4f
31P NMR (162 MHz, CDCl3)
150
100
50
0
-50
-100
-150
-200
f1 (ppm)

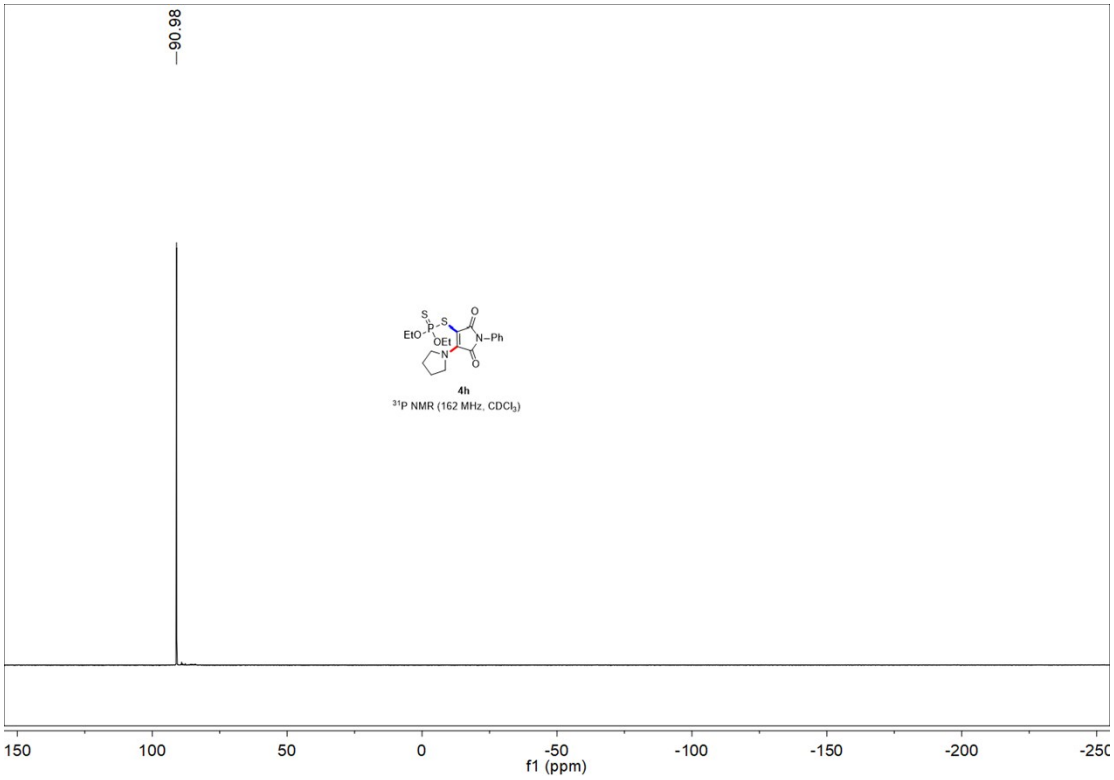

4g
^{1}H NMR (500 MHz, CDCl$_3$)
f1 (ppm)

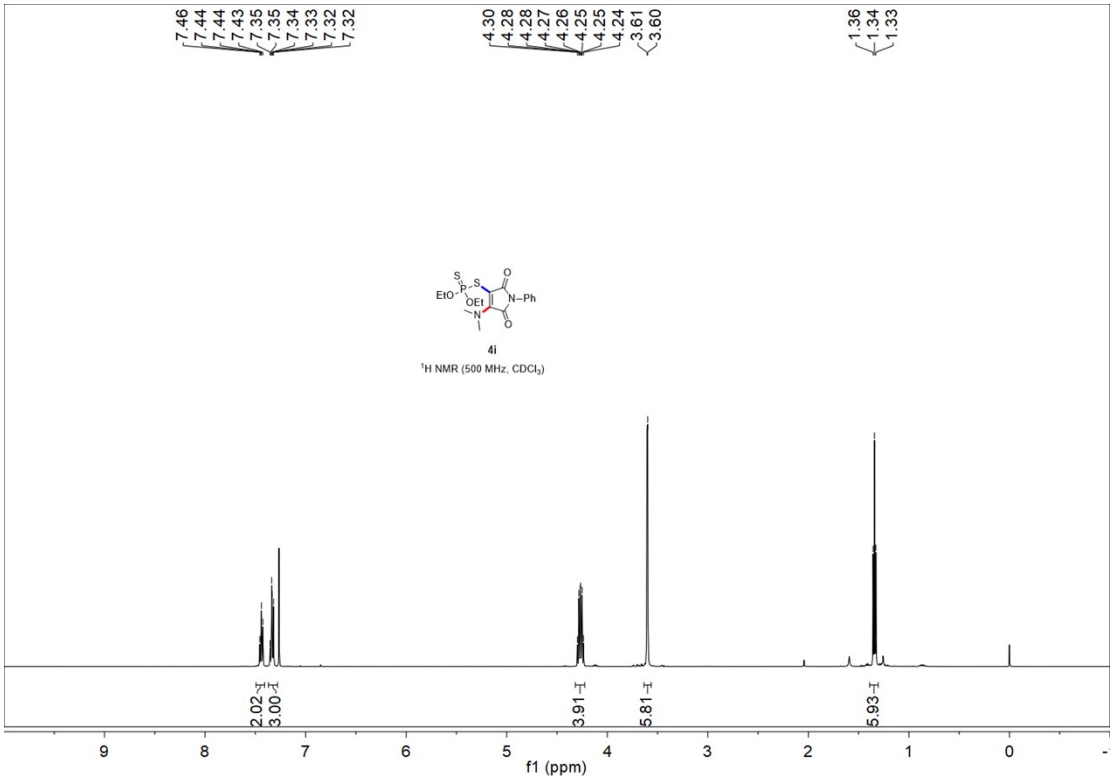

4g
^{13}C NMR (125 MHz, CDCl$_3$)
f1 (ppm)

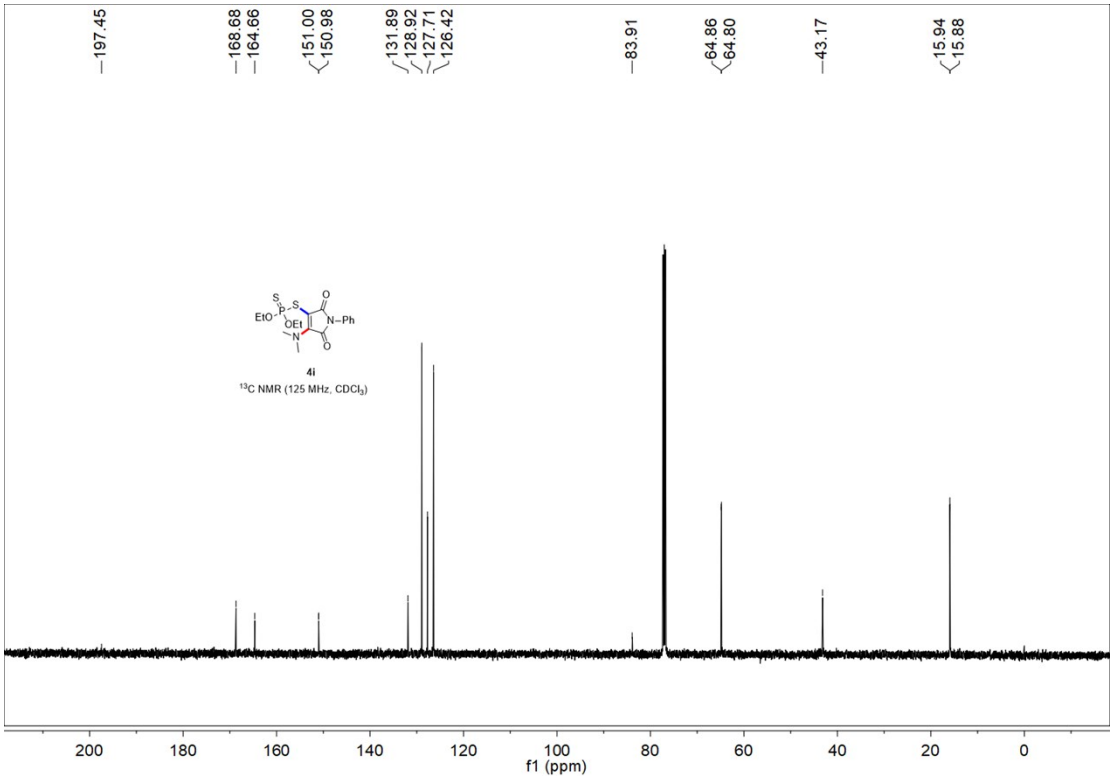

89.44
4g
31P NMR (162 MHz, CDCl3)
150
100
50
0
-50
-100
-150
-200
-250
f1 (ppm)

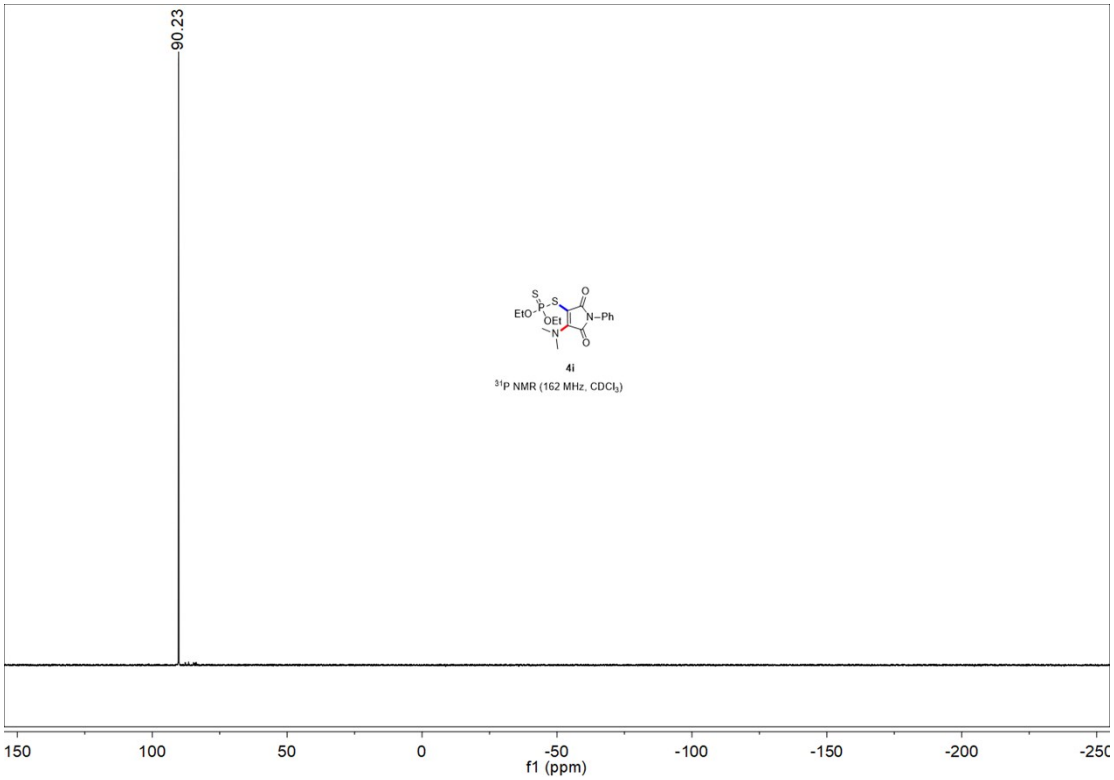

7.45
7.43
7.42
7.35
7.34
7.33
7.32
7.32
7.31
4.29
4.29
4.29
4.28
4.28
4.27
4.27
4.26
4.26
4.25
4.23
4.19
4.07
4.07
1.99
1.98
1.97
1.96
1.34
1.33
1.32
1.31
4h
1H NMR (500 MHz, CDCl3)
1.98
2.92
8.13
4.00
6.39
0
9
8
7
6
5
4
3
2
1
0
f1 (ppm)

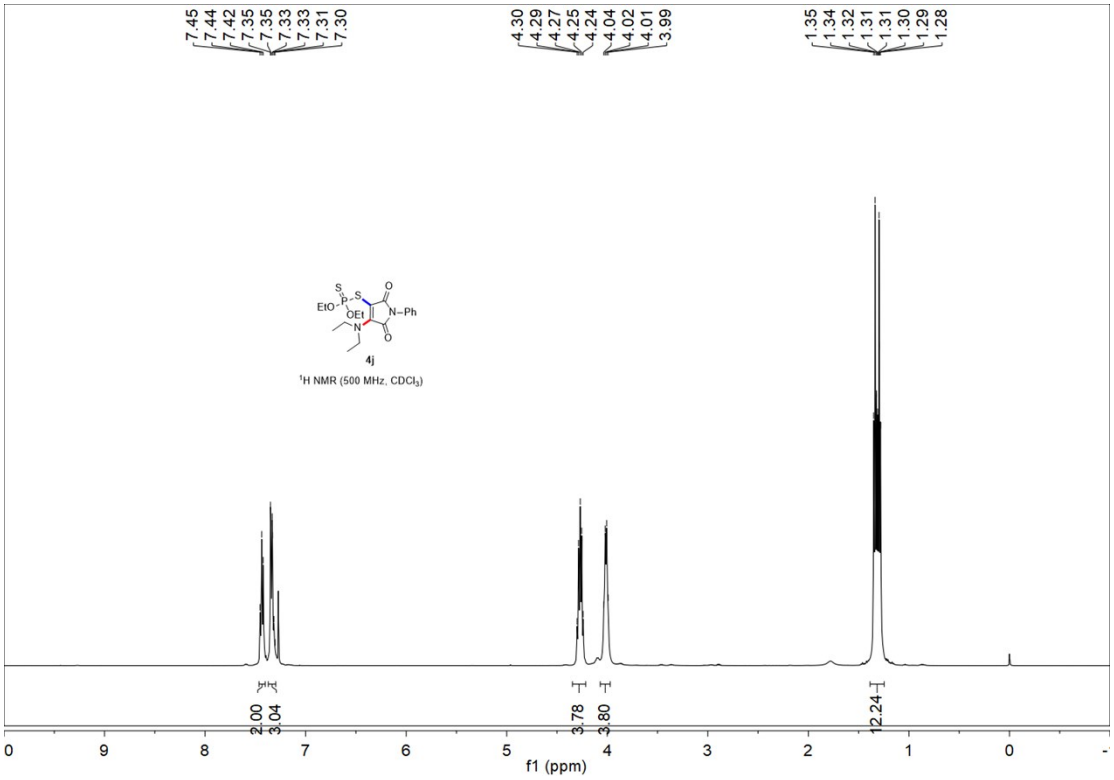

169.08
164.29
148.87
132.04
128.89
127.57
126.30
81.32
64.81
64.75
51.92
25.44
24.94
15.98
15.91
4h
13C NMR (125 MHz, CDCl3)
200
180
160
140
120
100
80
60
40
20
0
f1 (ppm)

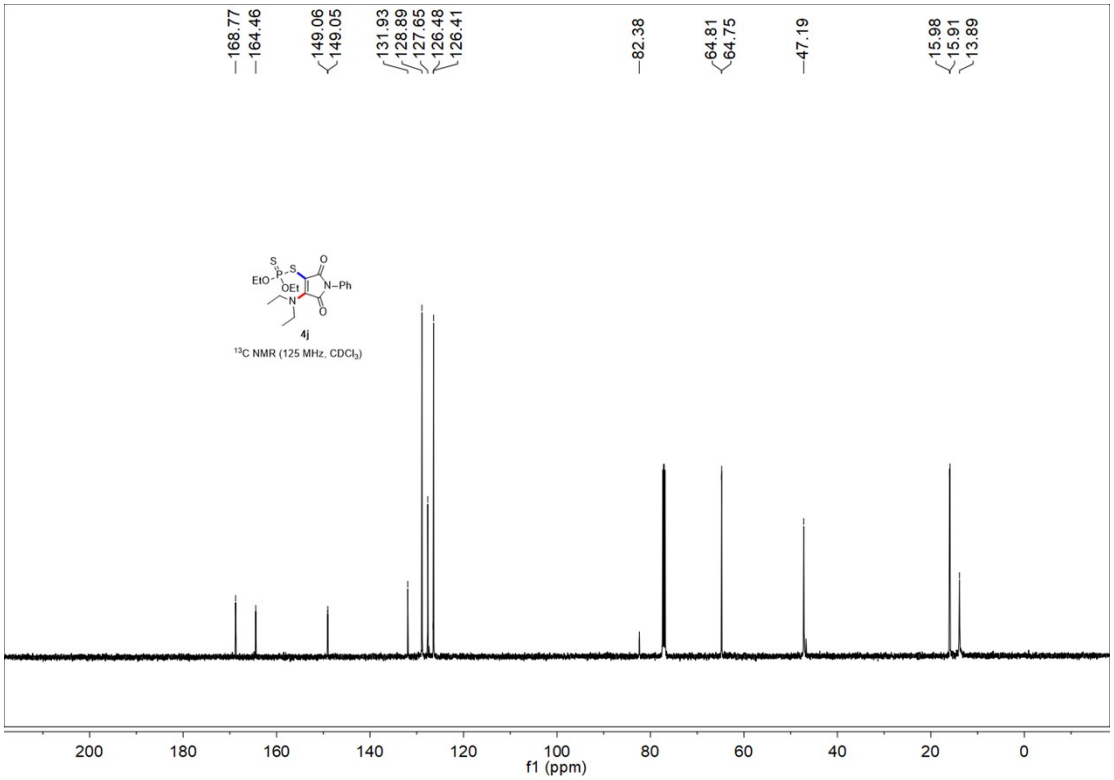

90.98
4h
31P NMR (162 MHz, CDCl3)
150
100
50
0
-50
-100
-150
-200
-250
f1 (ppm)


7.46
7.44
7.44
7.43
7.35
7.35
7.34
7.33
7.32
7.32
4.30
4.28
4.28
4.27
4.26
4.25
4.25
4.24
3.61
3.60
1.36
1.34
1.33
4i
1H NMR (500 MHz, CDCl3)
2.02
3.00
3.91
5.81
5.93
f1 (ppm)


197.45
168.68
164.66
151.00
150.98
131.89
128.92
127.71
126.42
83.91
64.86
64.80
43.17
15.94
15.88
4i
13C NMR (125 MHz, CDCl3)
f1 (ppm)


90.23
4i
31P NMR (162 MHz, CDCl3)
150
100
50
0
-50
-100
-150
-200
-250
f1 (ppm)


7.45
7.44
7.42
7.35
7.35
7.33
7.33
7.31
7.30
4.30
4.29
4.27
4.25
4.24
4.04
4.02
4.01
3.99
1.35
1.34
1.32
1.31
1.31
1.30
1.29
1.28
4j
1H NMR (500 MHz, CDCl3)
2.00
3.04
3.78
3.80
12.24
0
9
8
7
6
5
4
3
2
1
0
f1 (ppm)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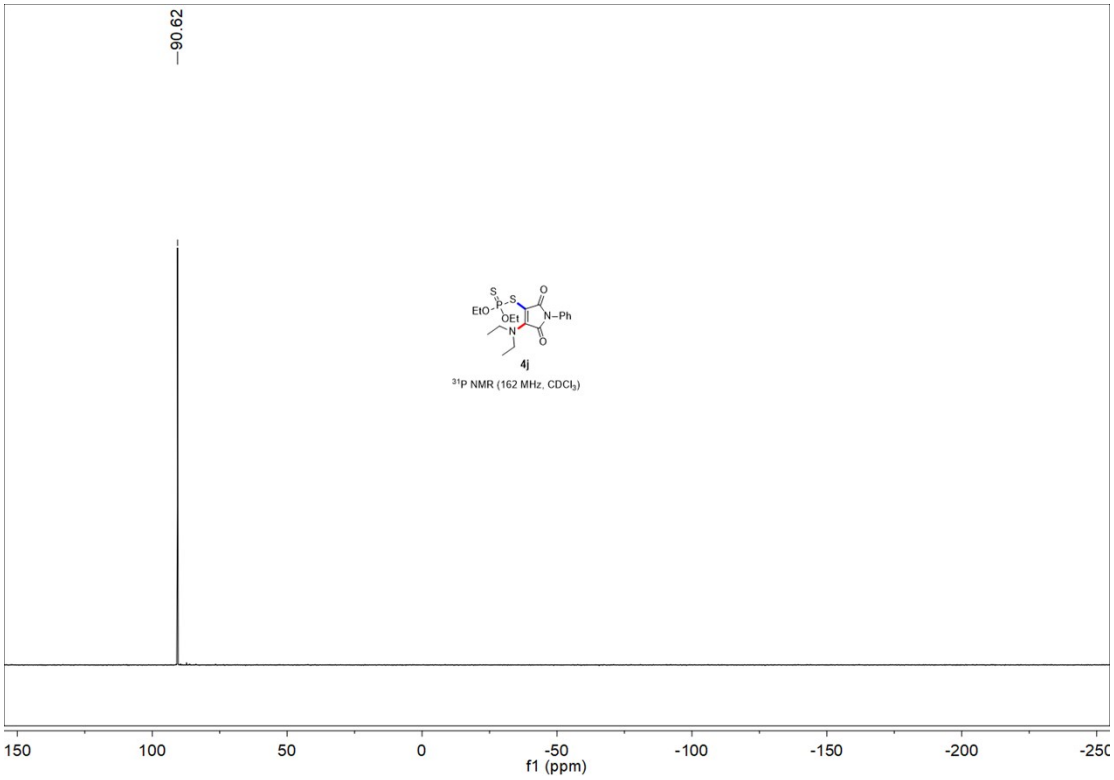
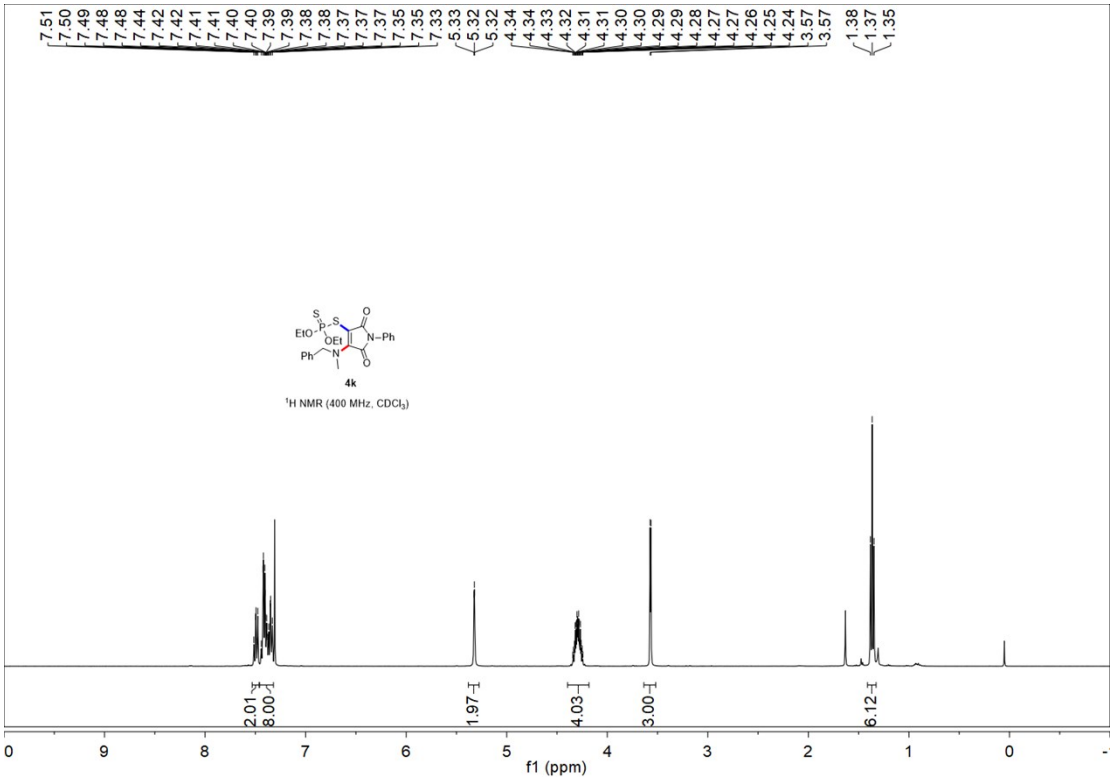
149.05
131.93
128.89
127.65
126.48
126.41
82.38
64.81
64.75
47.19
15.98
15.91
13.89
4j
13C NMR (125 MHz, CDCl3)
200
180
160
140
120
100
80
60
40
20
0
f1 (ppm)


90.62
4j
31P NMR (162 MHz, CDCl3)
150
100
50
0
-50
-100
-150
-200
-250
f1 (ppm)


7.51
7.50
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7.48
7.48
7.44
7.42
7.42
7.41
7.41
7.40
7.40
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7.39
7.38
7.38
7.37
7.37
7.37
7.35
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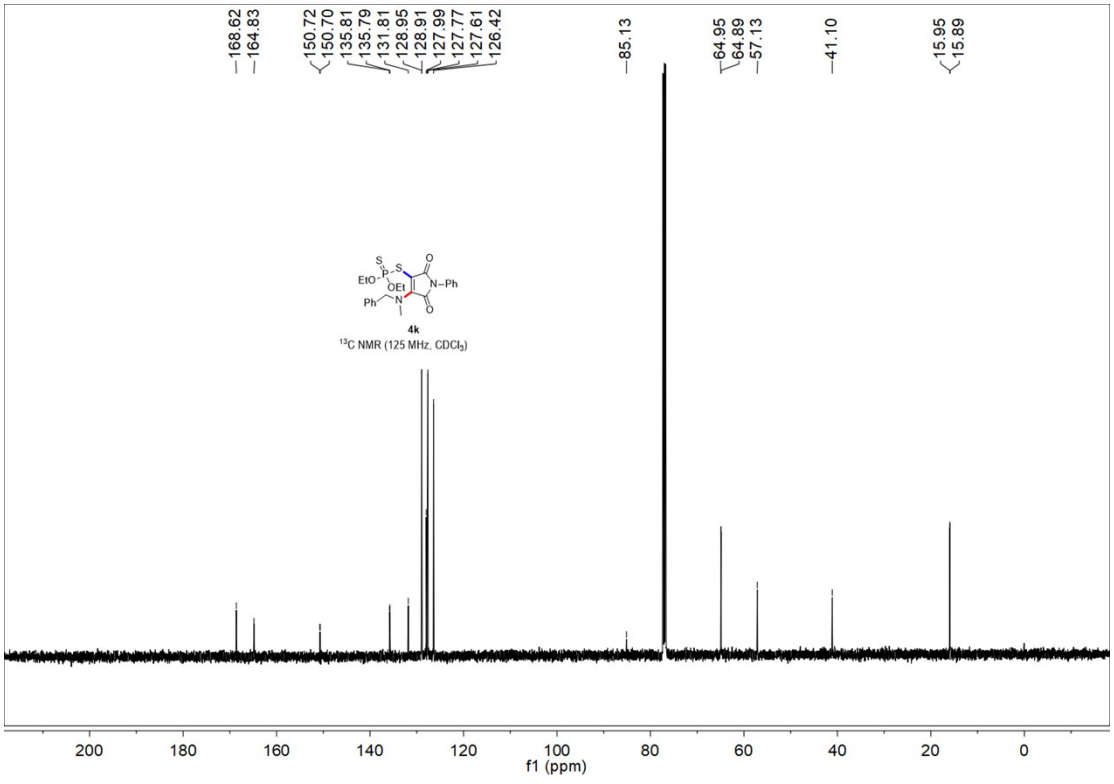
7.33
5.33
5.32
5.32
4.34
4.34
4.33
4.32
4.31
4.31
4.30
4.30
4.29
4.29
4.28
4.27
4.27
4.26
4.25
4.24
3.57
3.57
1.38
1.37
1.35
4k
1H NMR (400 MHz, CDCl3)
2.01
8.00
1.97
4.03
3.00
6.12
f1 (ppm)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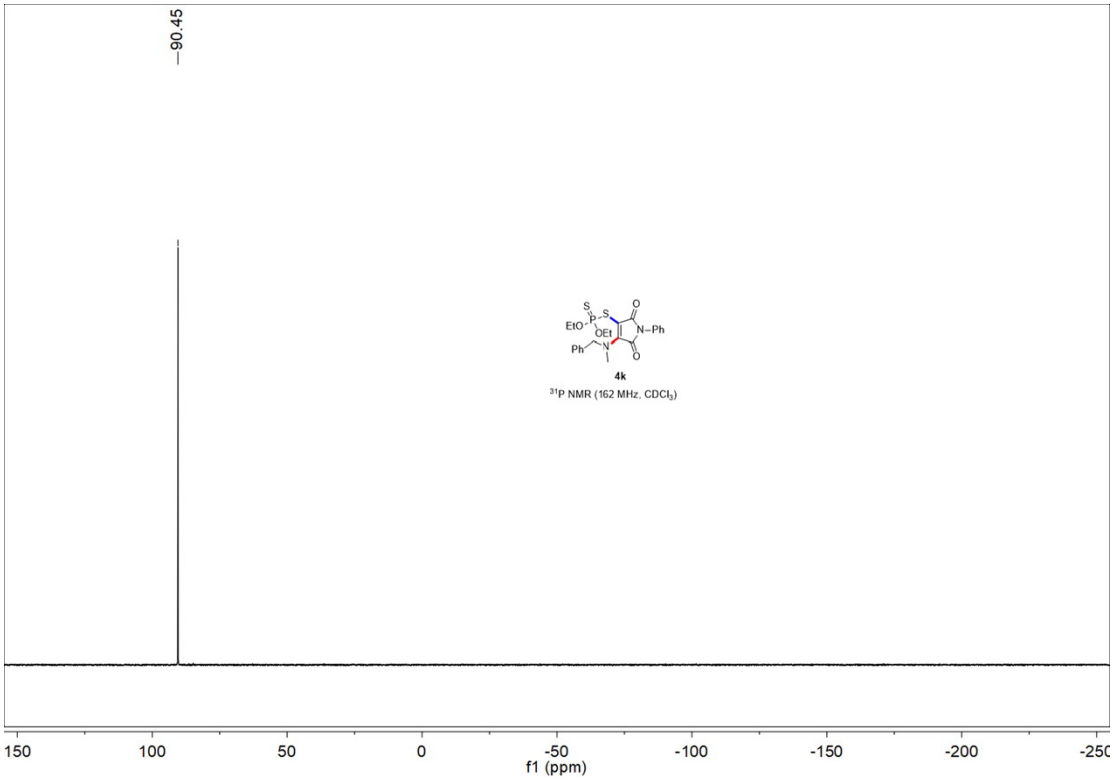
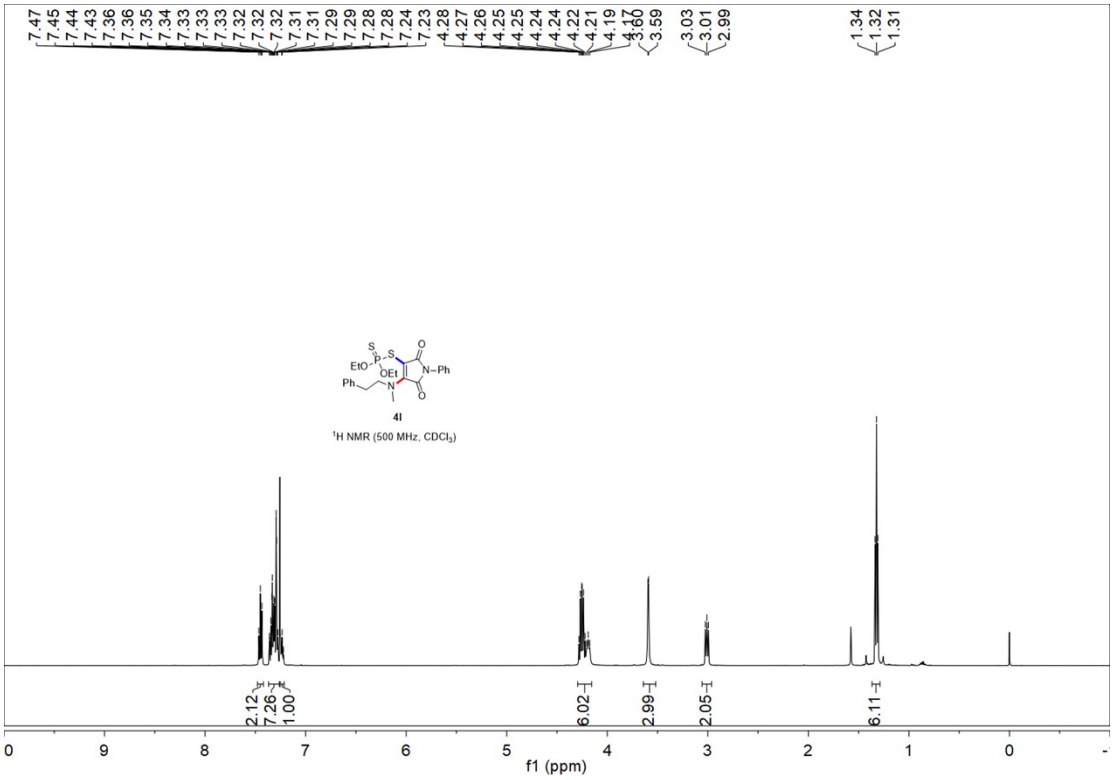
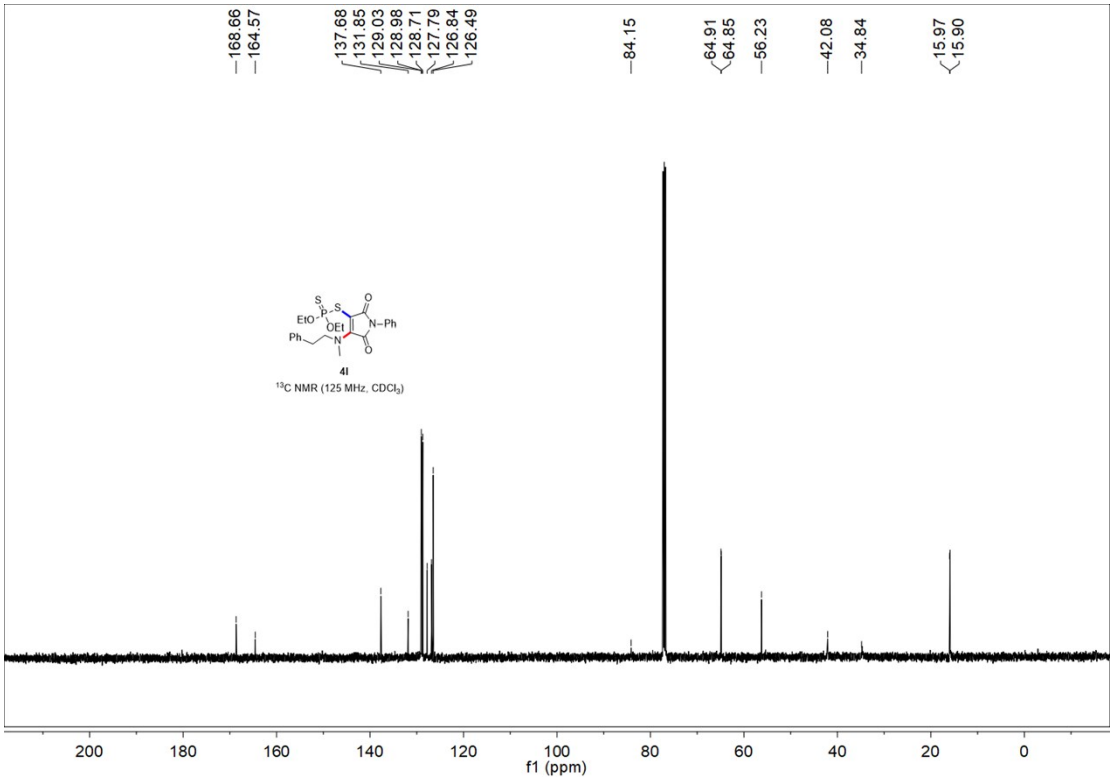
164.83
150.72
150.70
135.81
135.79
131.81
128.95
128.91
127.99
127.77
127.61
126.42
85.13
64.95
64.89
57.13
41.10
15.95
15.89
4k
13C NMR (125 MHz, CDCl3)
f1 (ppm)


90.45
4k
31P NMR (162 MHz, CDCl3)
150
100
50
0
-50
-100
-150
-200
f1 (ppm)


7.47
7.45
7.44
7.43
7.36
7.35
7.34
7.33
7.33
7.32
7.32
7.32
7.31
7.31
7.29
7.29
7.28
7.28
7.24
7.23
4.28
4.27
4.26
4.25
4.25
4.24
4.24
4.22
4.21
4.19
4.17
3.60
3.59
3.03
3.01
2.99
1.34
1.32
1.31
4l
1H NMR (500 MHz, CDCl3)
2.12
7.26
1.00
6.02
2.99
2.05
6.11
0
9
8
7
6
5
4
3
2
1
0
f1 (ppm)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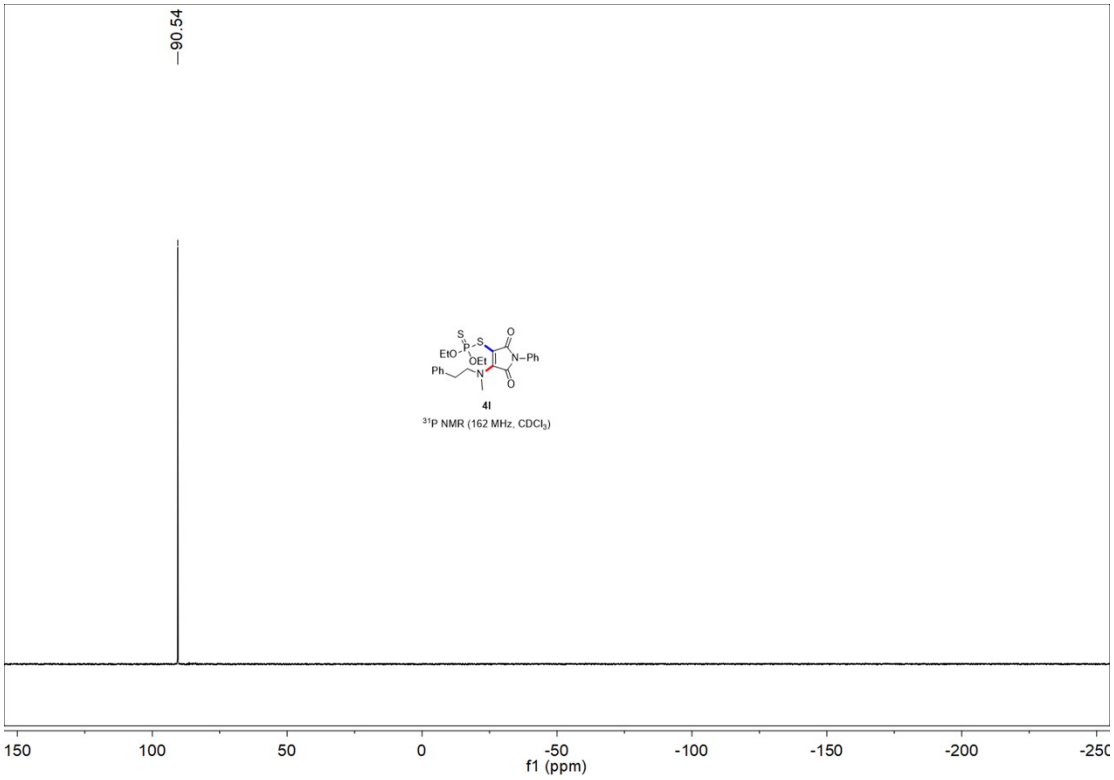
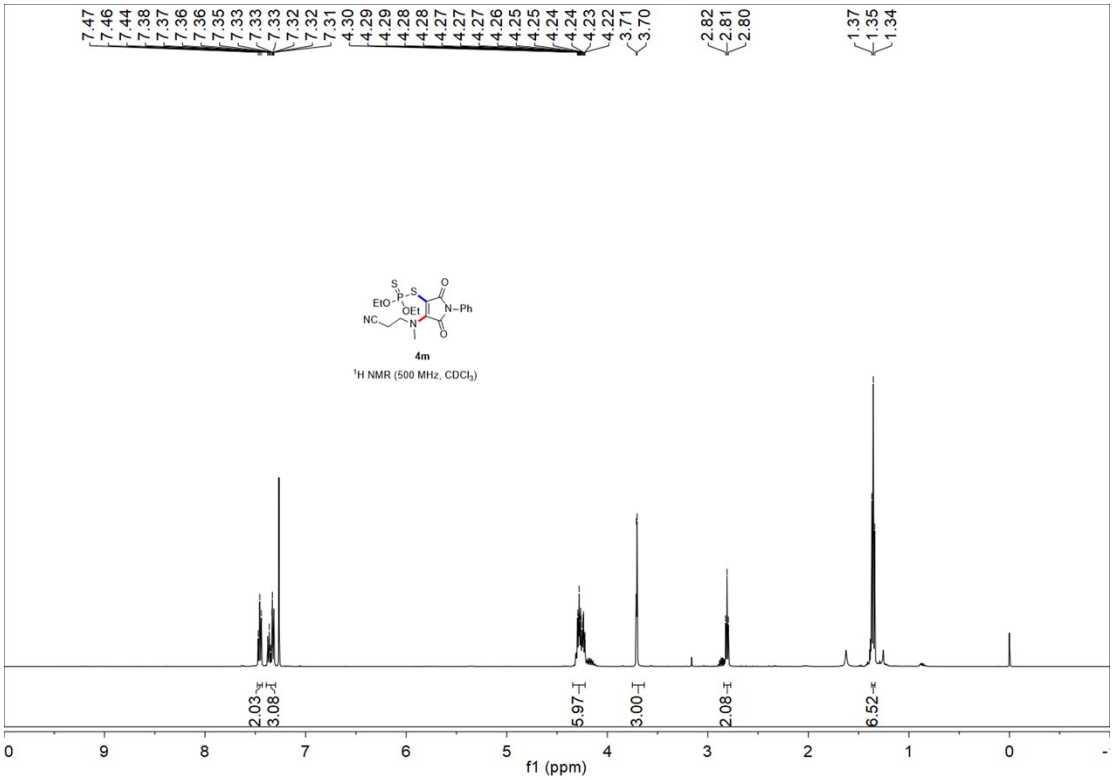
164.57
137.68
131.85
129.03
128.98
128.71
127.79
126.84
126.49
84.15
64.91
64.85
56.23
42.08
34.84
15.97
15.90
4l
13C NMR (125 MHz, CDCl3)
200
180
160
140
120
100
80
60
40
20
0
f1 (ppm)


90.54
4l
31P NMR (162 MHz, CDCl3)
150
100
50
0
-50
-100
-150
-200
-250
f1 (ppm)


7.47
7.46
7.44
7.38
7.37
7.36
7.36
7.35
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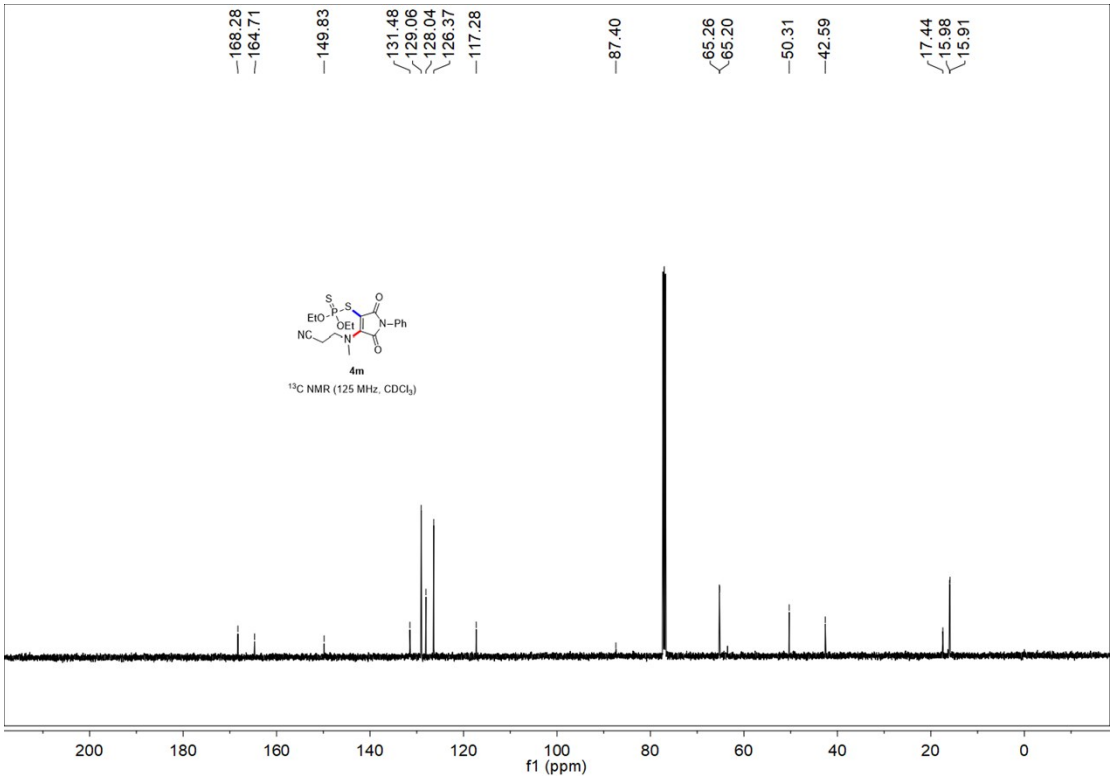
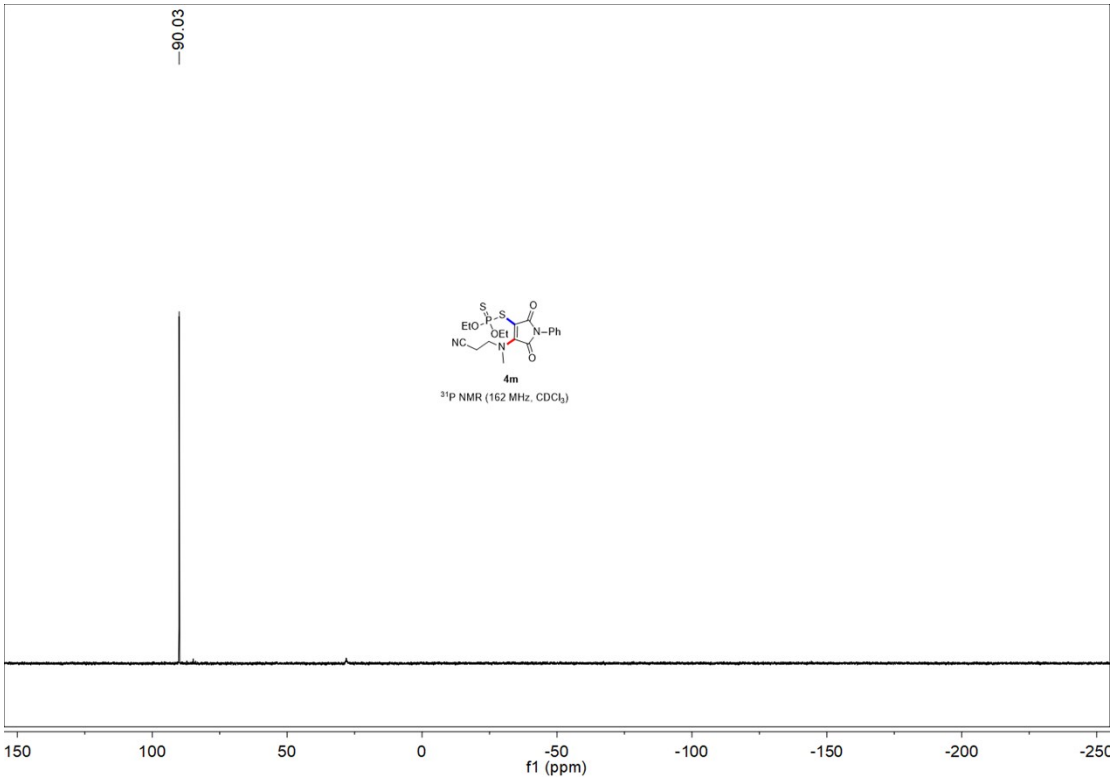
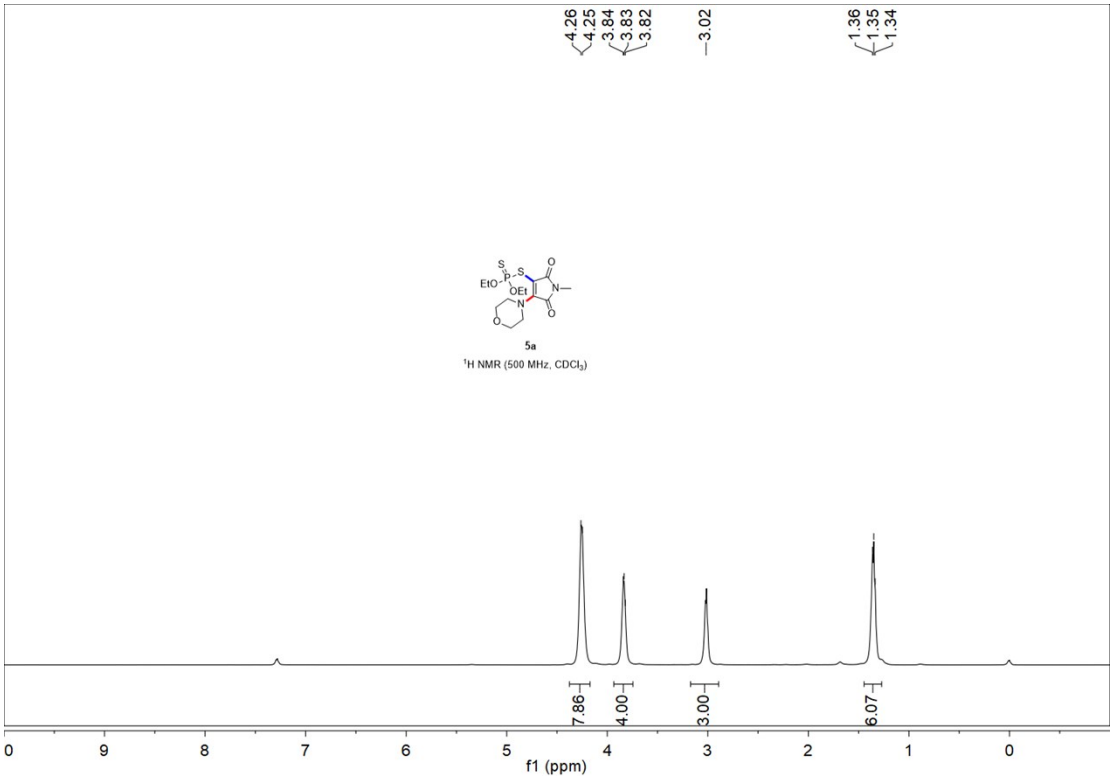
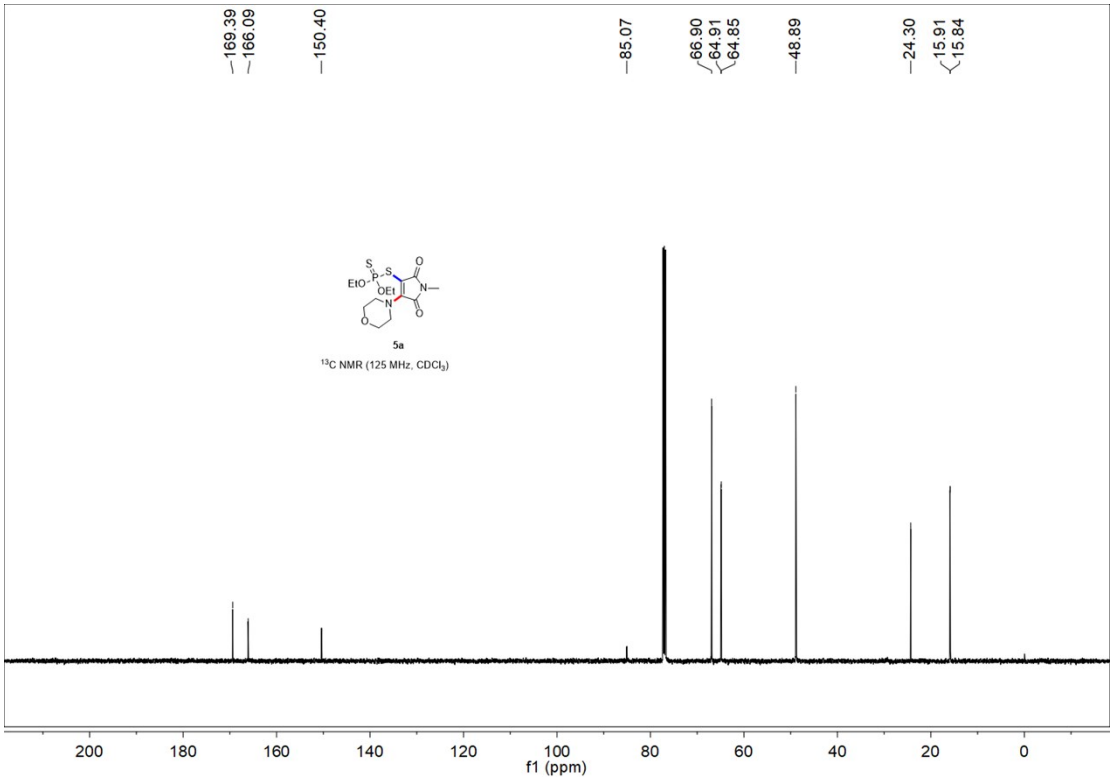
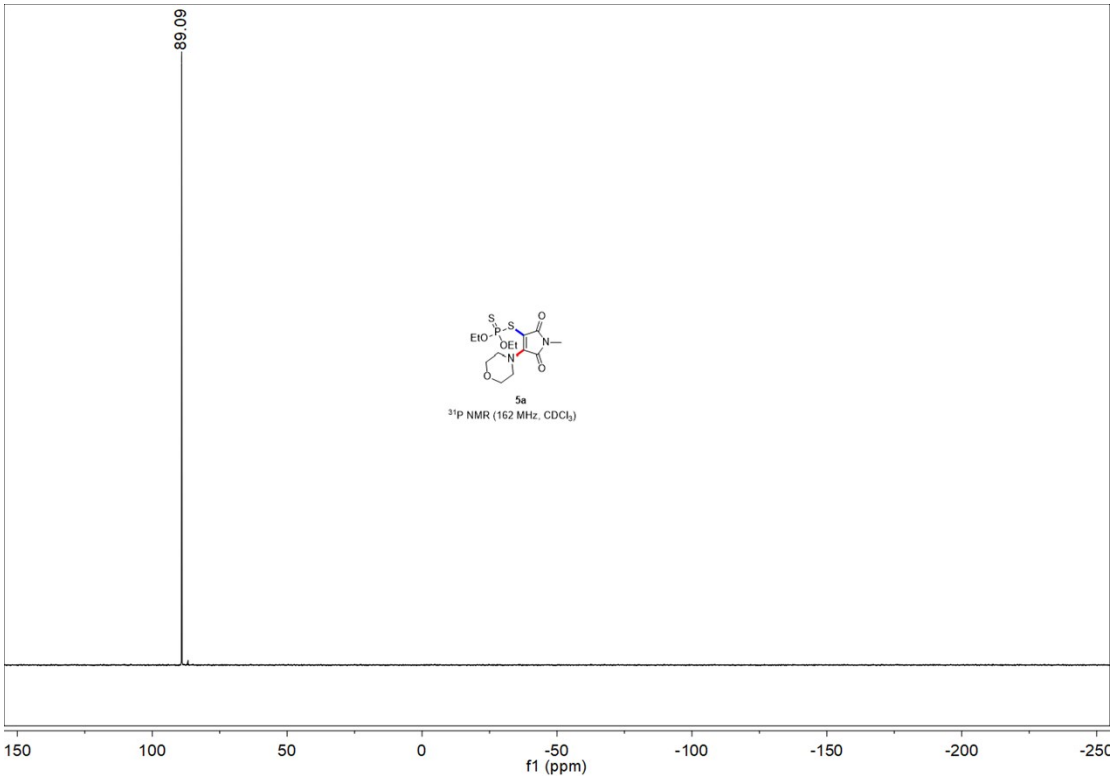
7.33
7.33
7.32
7.32
7.31
4.30
4.29
4.29
4.28
4.28
4.27
4.27
4.27
4.26
4.25
4.25
4.24
4.24
4.23
4.22
3.71
3.70
2.82
2.81
2.80
1.37
1.35
1.34
4m
1H NMR (500 MHz, CDCl3)
2.03
3.08
5.97
3.00
2.08
6.52
f1 (ppm)

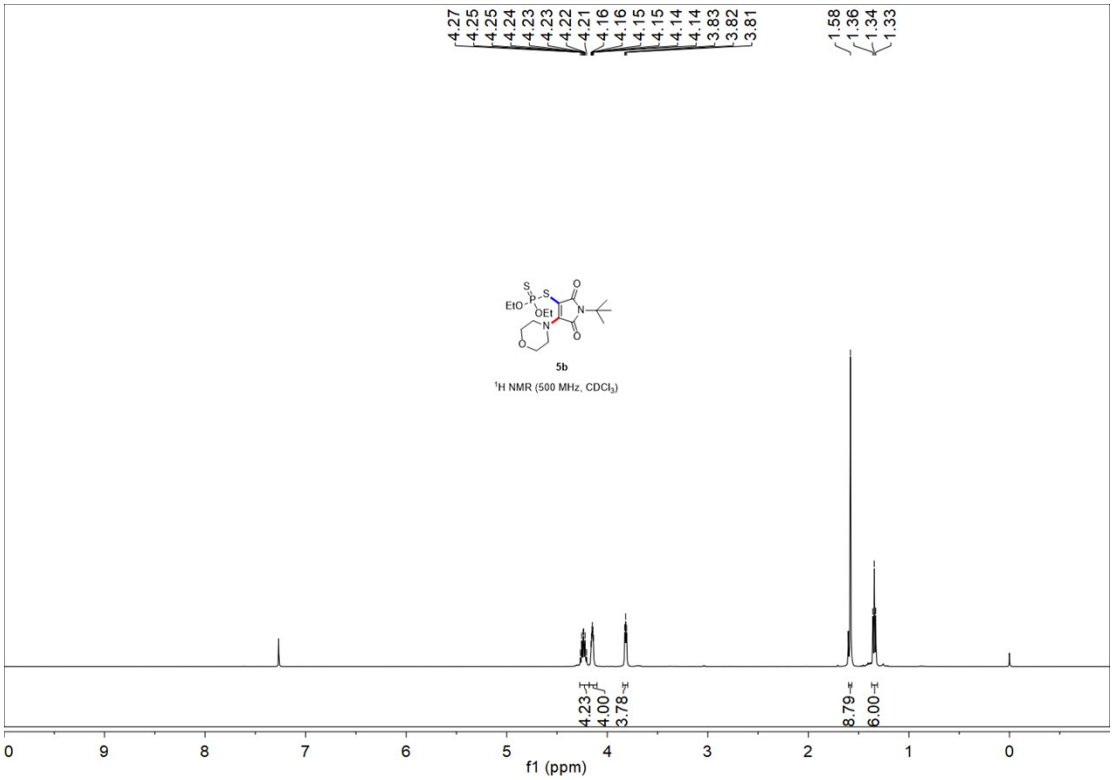

168.28
164.71
149.83
131.48
129.06
128.04
126.37
117.28
87.40
65.26
65.20
50.31
42.59
17.44
15.98
15.91
4m
13C NMR (125 MHz, CDCl3)
f1 (ppm)

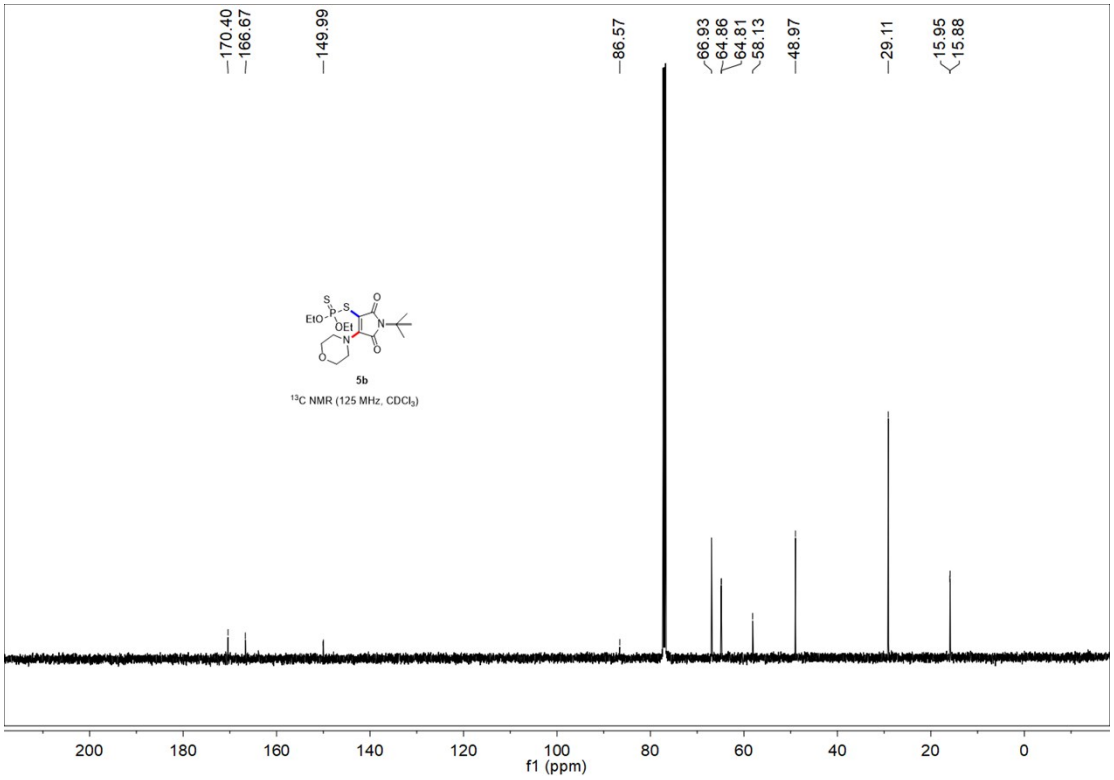

90.03
4m
31P NMR (162 MHz, CDCl3)
150
100
50
0
-50
-100
-150
-200
-250
f1 (ppm)

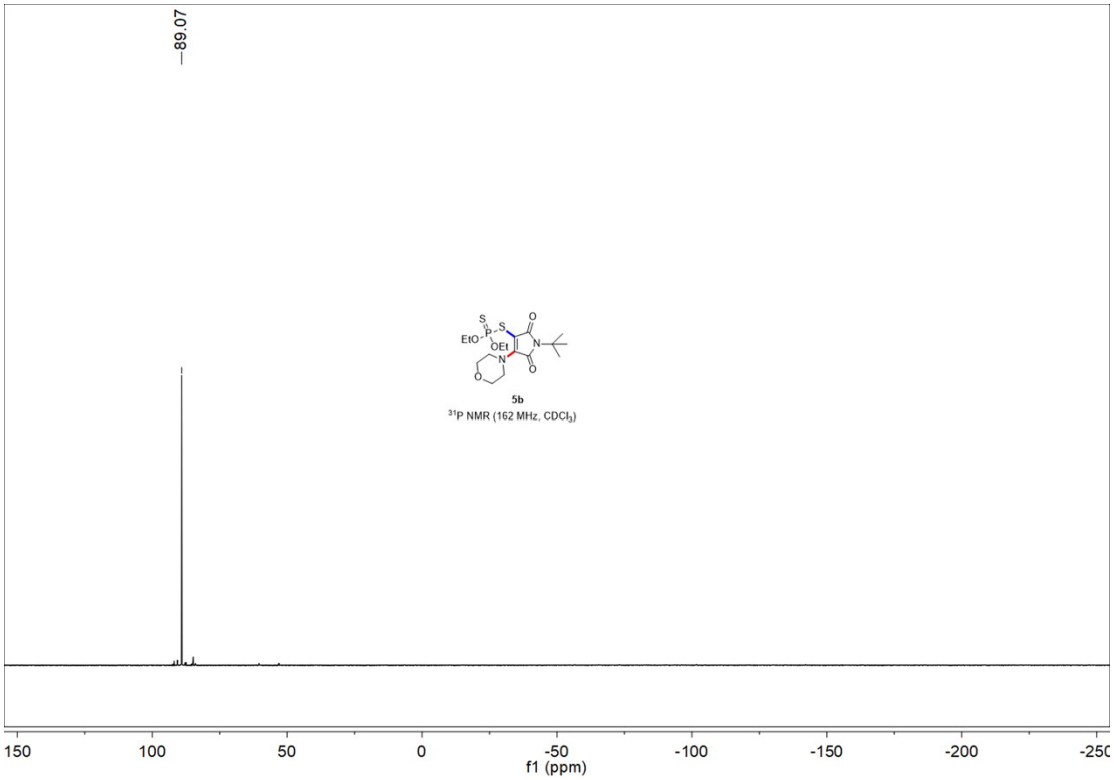

4.26
4.25
3.84
3.83
3.82
3.02
1.36
1.35
1.34
5a
1H NMR (500 MHz, CDCl3)
7.86
4.00
3.00
6.07
0
9
8
7
6
5
4
3
2
1
0
f1 (ppm)

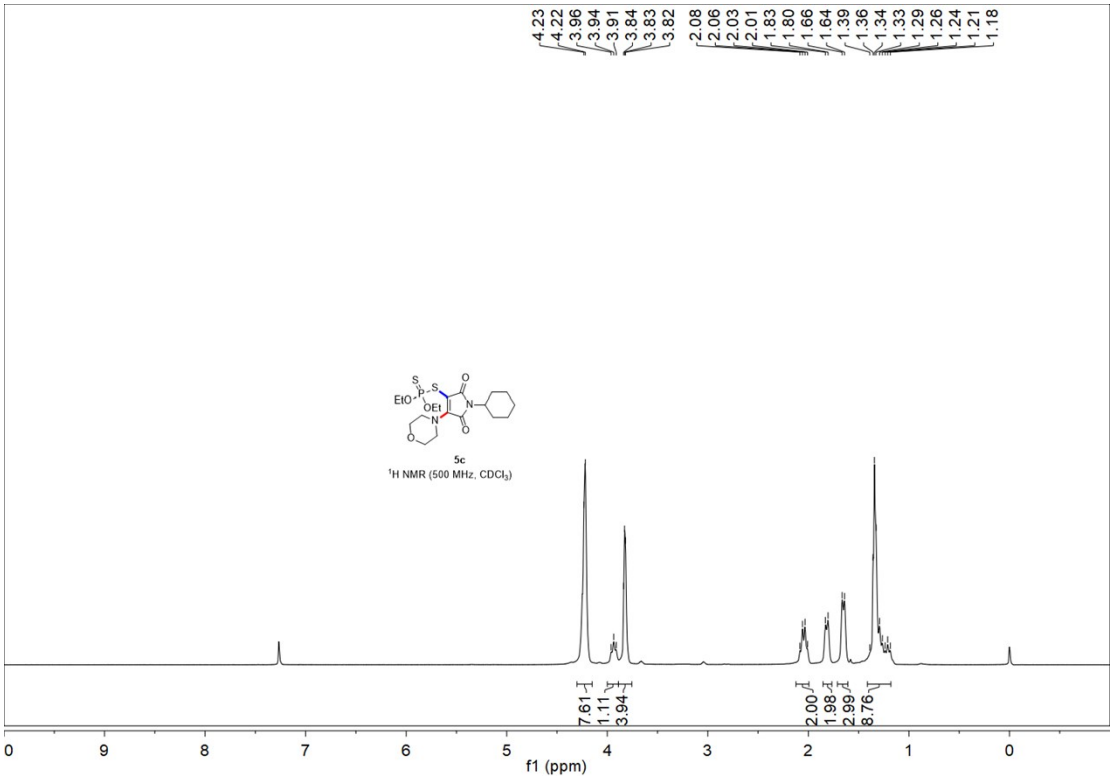

169.39
166.09
150.40
85.07
66.90
64.91
64.85
48.89
24.30
15.91
15.84
EtO
OEt
N
O
S
P
5a
13C NMR (125 MHz, CDCl3)
200
180
160
140
120
100
80
60
40
20
0
f1 (ppm)

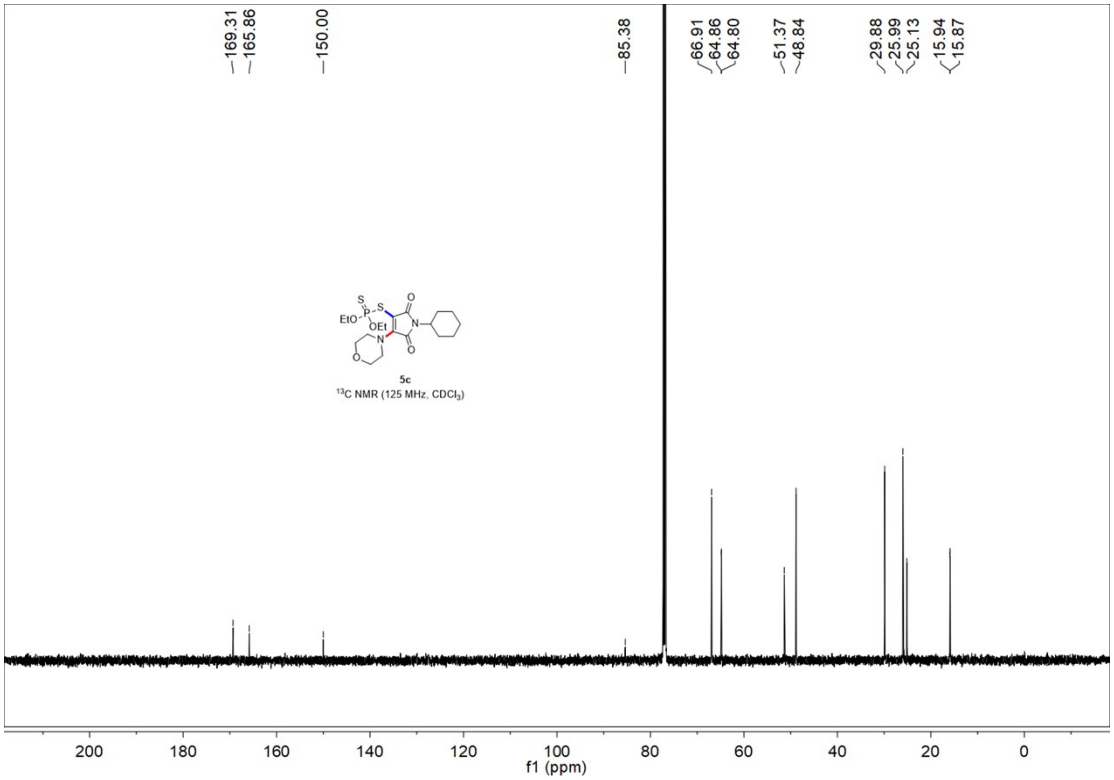

89.09
EtO
OEt
N
O
S
P
5a
31P NMR (162 MHz, CDCl3)
150
100
50
0
-50
-100
-150
-200
-250
f1 (ppm)

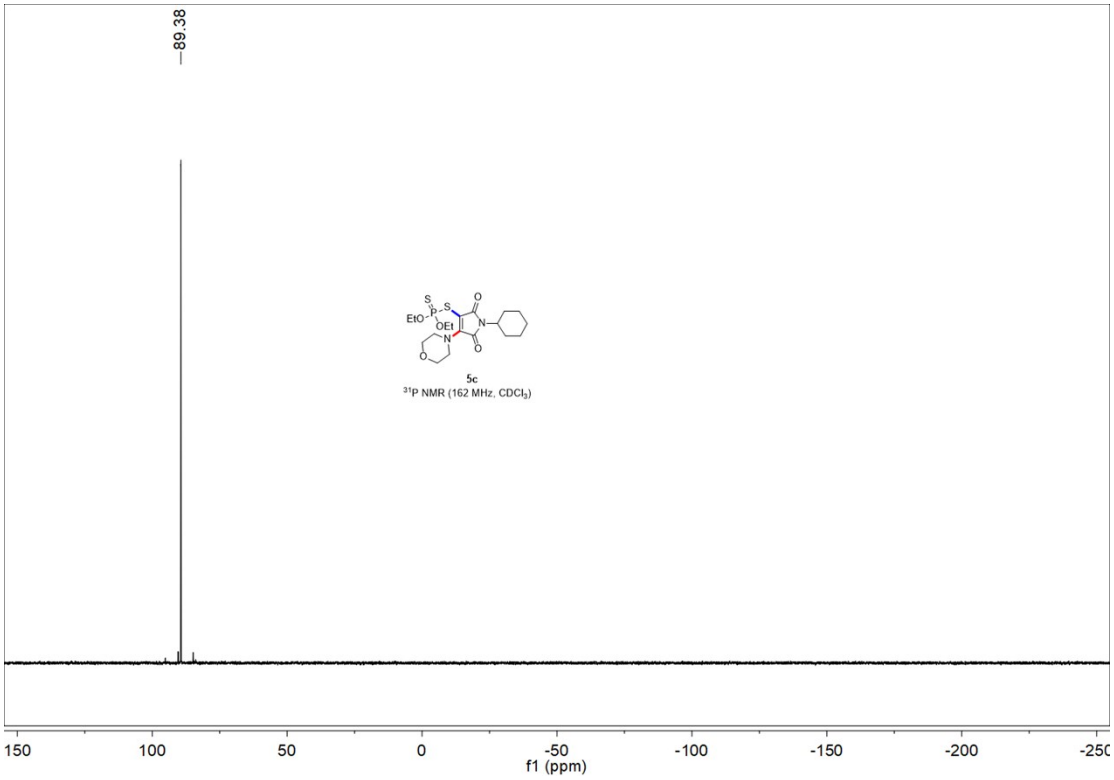

4.27
4.25
4.25
4.24
4.23
4.23
4.22
4.21
4.16
4.16
4.15
4.15
4.14
4.14
3.83
3.82
3.81
1.58
1.36
1.34
1.33
5b
1H NMR (500 MHz, CDCl3)
4.23
4.00
3.78
8.79
6.00
f1 (ppm)

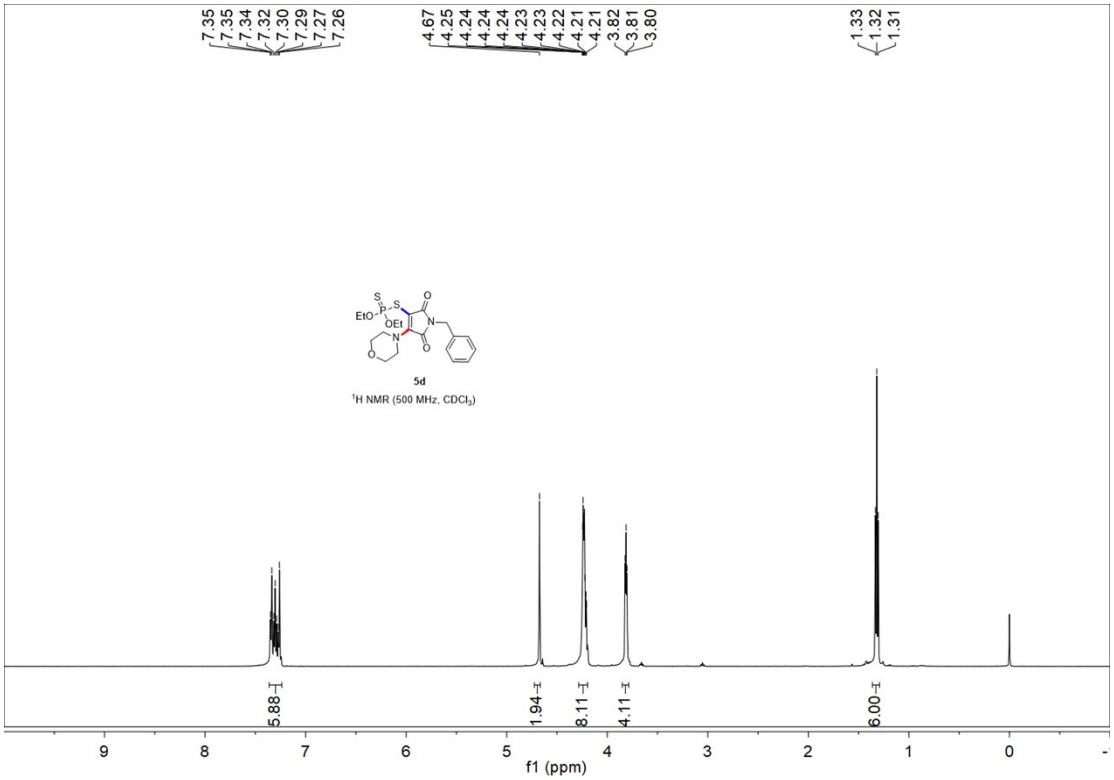

170.40
166.67
149.99
86.57
66.93
64.86
64.81
58.13
48.97
29.11
15.95
15.88
5b
13C NMR (125 MHz, CDCl3)
f1 (ppm)

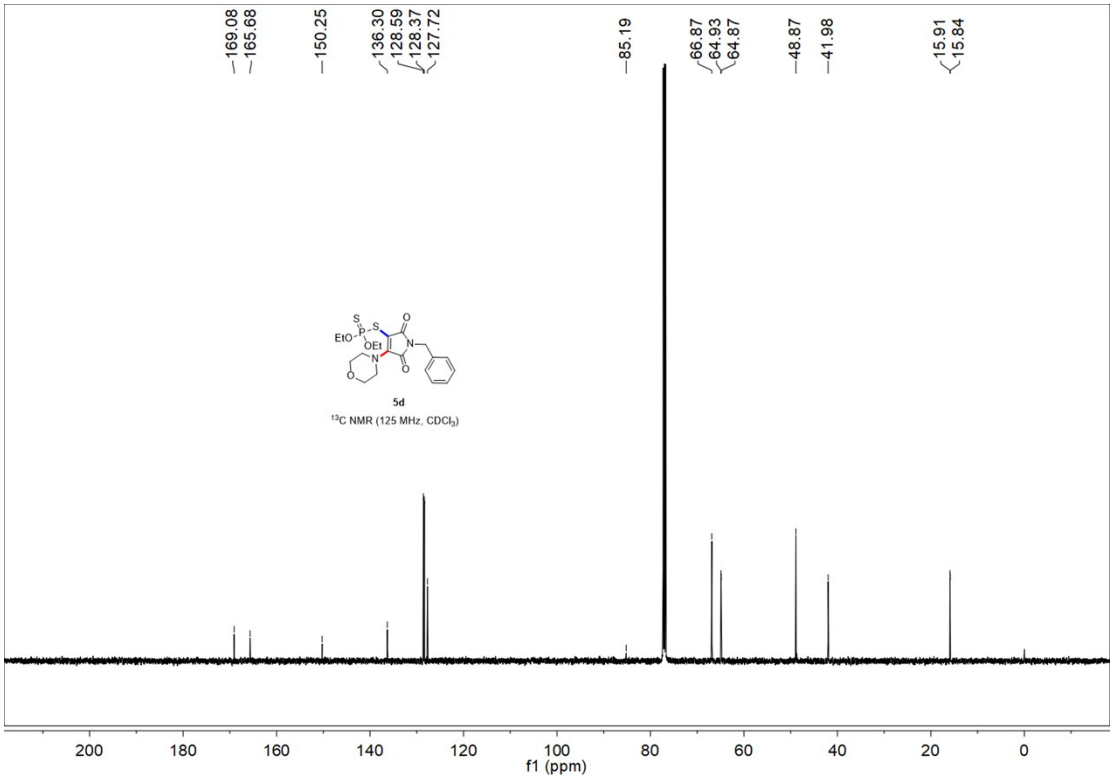

89.07
5b
31P NMR (162 MHz, CDCl3)
150
100
50
0
-50
-100
-150
-200
-250
f1 (ppm)

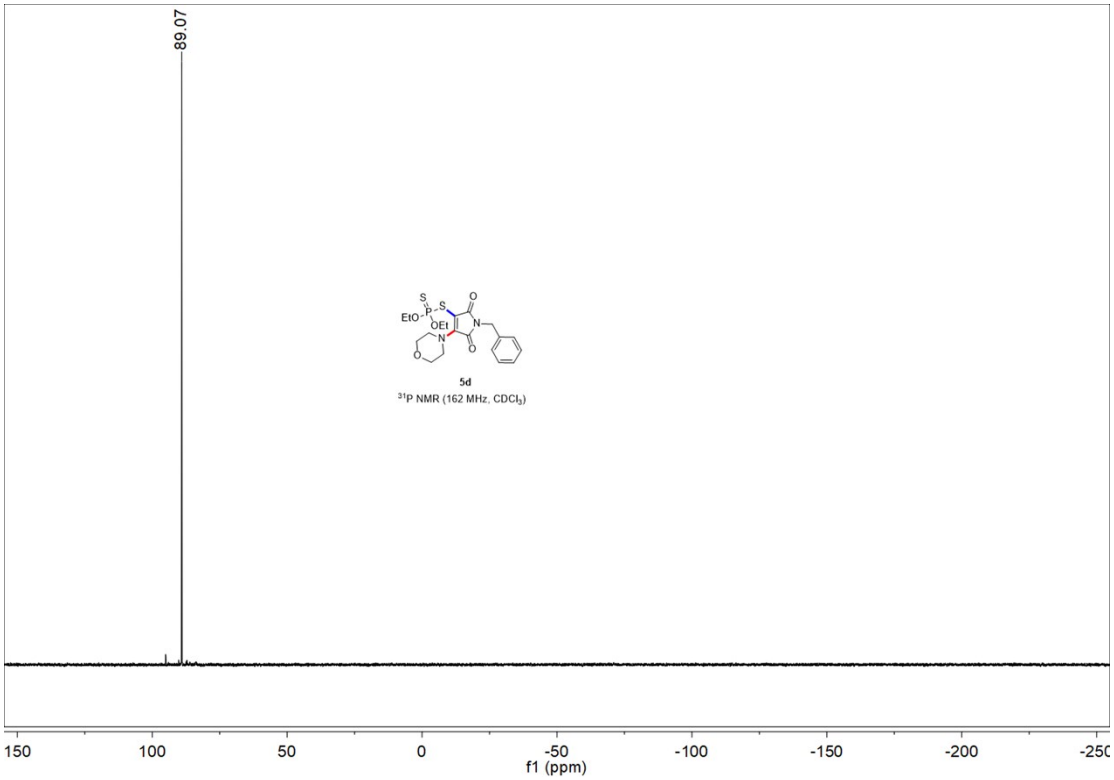

4.23
4.22
3.96
3.94
3.91
3.84
3.83
3.82
2.08
2.06
2.03
2.01
1.83
1.80
1.66
1.64
1.39
1.36
1.34
1.33
1.29
1.26
1.24
1.21
1.18
5c
1H NMR (500 MHz, CDCl3)
7.61
1.11
3.94
2.00
1.98
2.99
8.76
0
9
8
7
6
5
4
3
2
1
0
f1 (ppm)

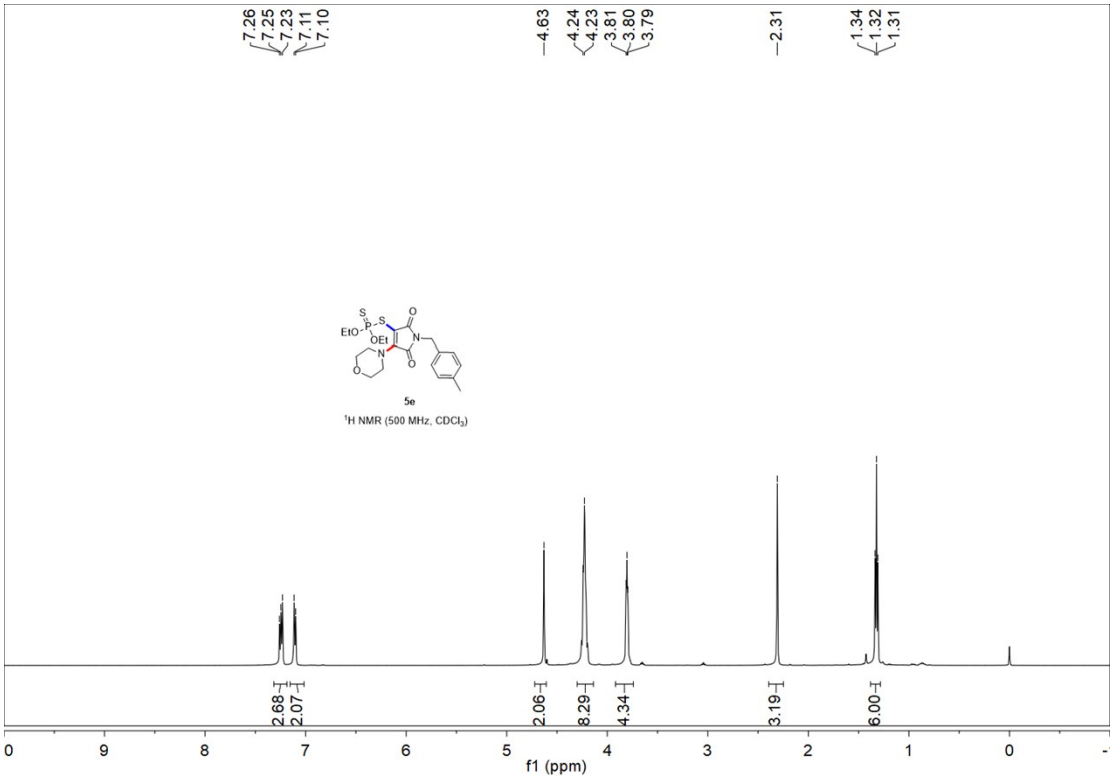

169.31
165.86
150.00
85.38
66.91
64.86
64.80
51.37
48.84
29.88
25.99
25.13
15.94
15.87
5c
13C NMR (125 MHz, CDCl3)
200
180
160
140
120
100
80
60
40
20
0
f1 (ppm)

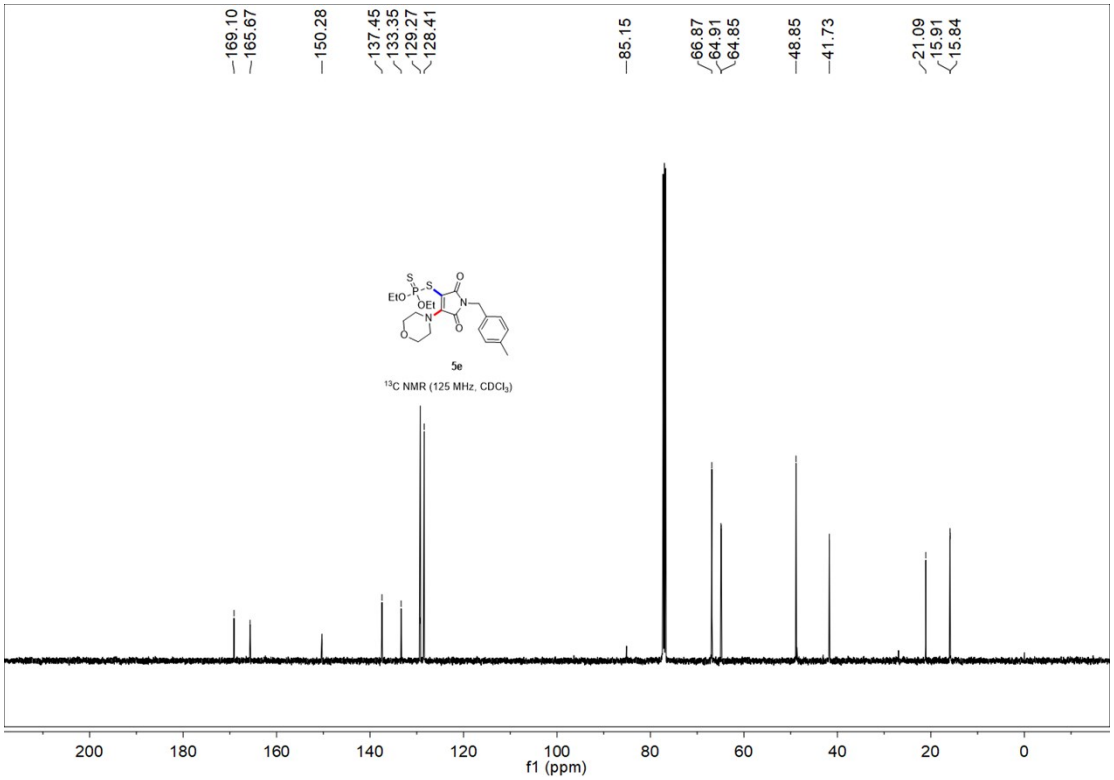

89.38
5c
31P NMR (162 MHz, CDCl3)
150
100
50
0
-50
-100
-150
-200
-250
f1 (ppm)

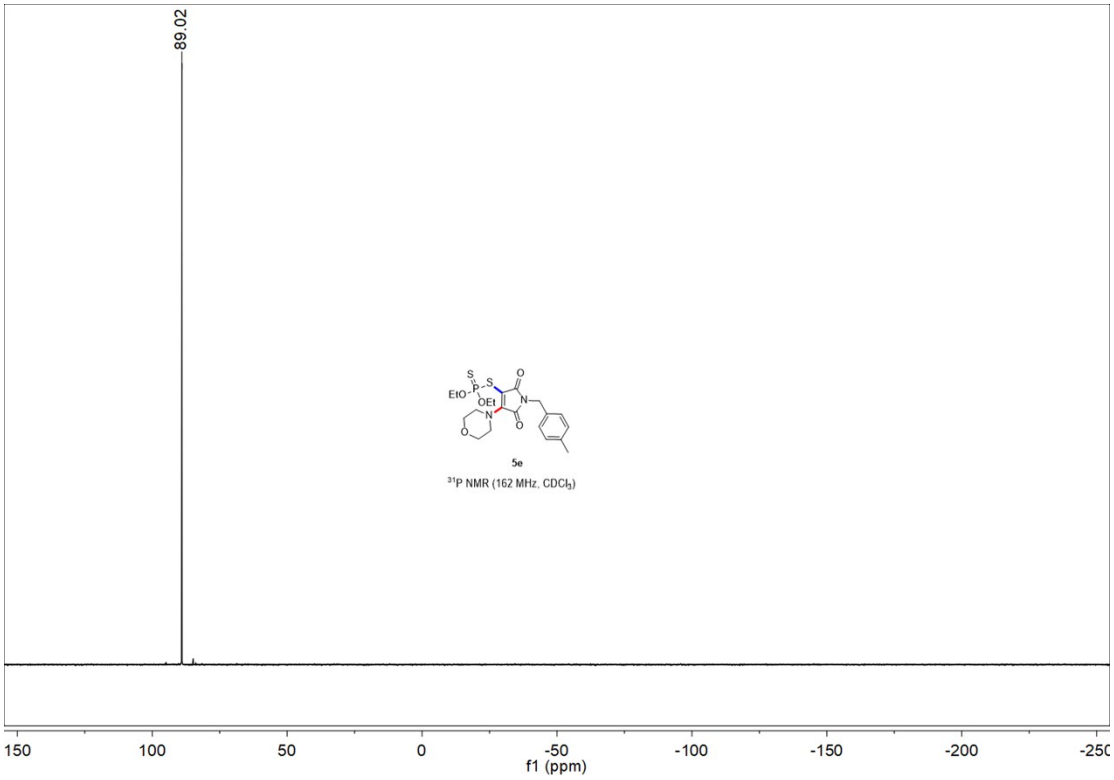

7.35
7.35
7.34
7.32
7.30
7.29
7.27
7.26
4.67
4.25
4.24
4.24
4.24
4.23
4.23
4.22
4.21
4.21
3.82
3.81
3.80
1.33
1.32
1.31
5d
1H NMR (500 MHz, CDCl3)
5.88
1.94
8.11
4.11
6.00
f1 (ppm)

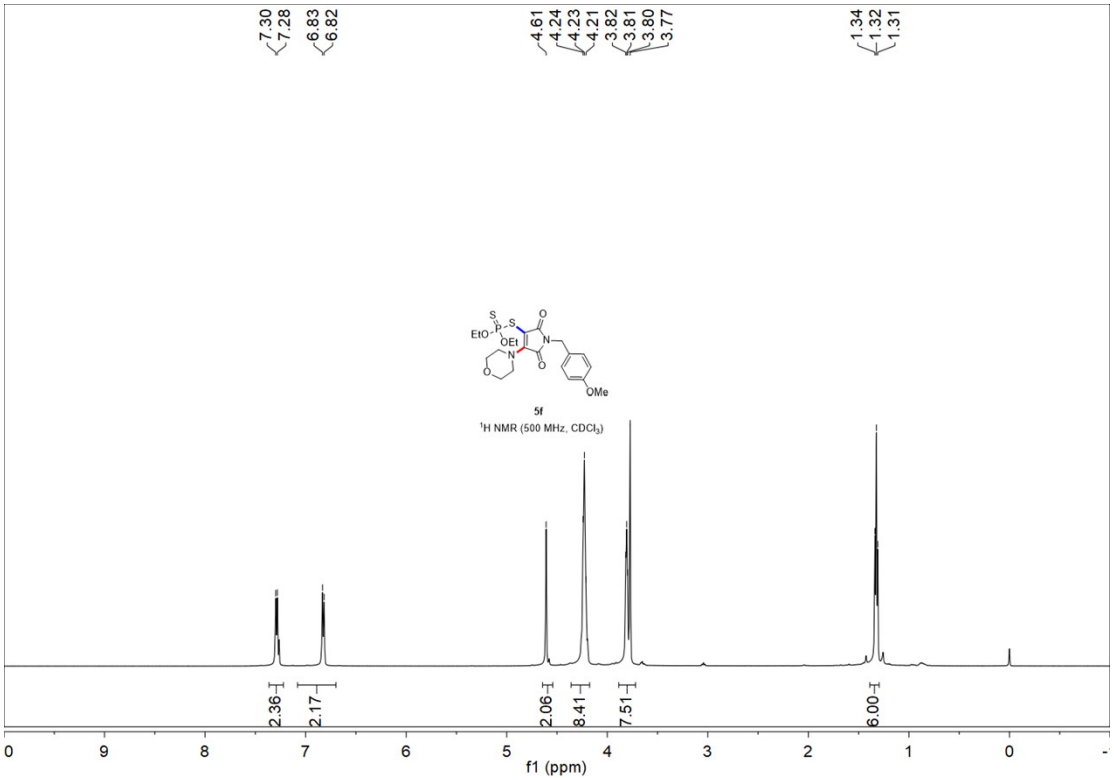

169.08
165.68
150.25
136.30
128.59
128.37
127.72
85.19
66.87
64.93
64.87
48.87
41.98
15.91
15.84
5d
13C NMR (125 MHz, CDCl3)
f1 (ppm)

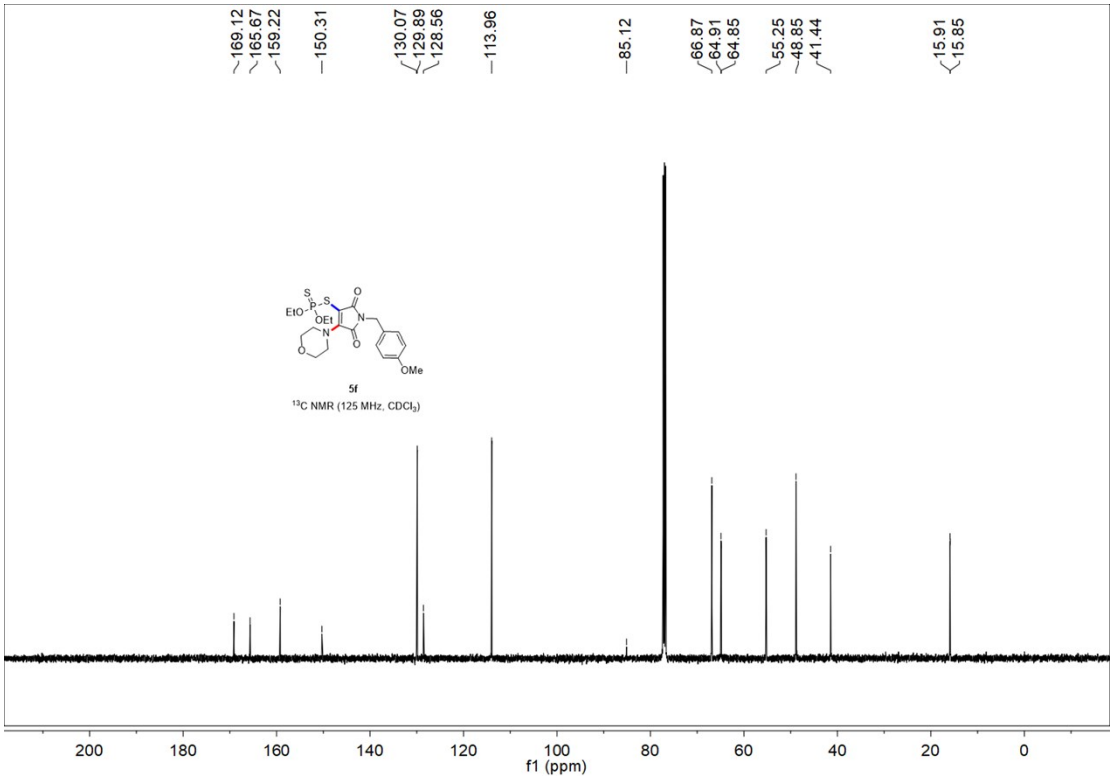

89.07
5d
31P NMR (162 MHz, CDCl3)
150
100
50
0
-50
-100
-150
-200
-250
f1 (ppm)

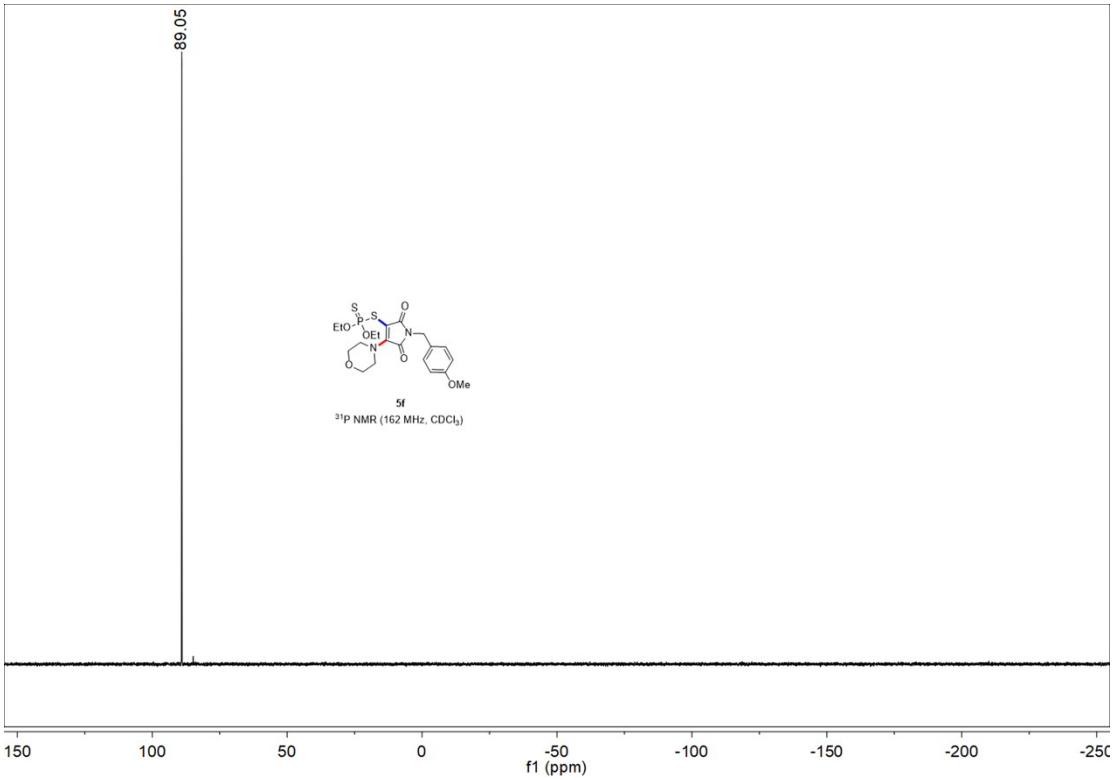

7.26
7.25
7.23
7.11
7.10
4.63
4.24
4.23
3.81
3.80
3.79
2.31
1.34
1.32
1.31
5e
1H NMR (500 MHz, CDCl3)
2.68
2.07
2.06
8.29
4.34
3.19
6.00
0
9
8
7
6
5
4
3
2
1
0
f1 (ppm)

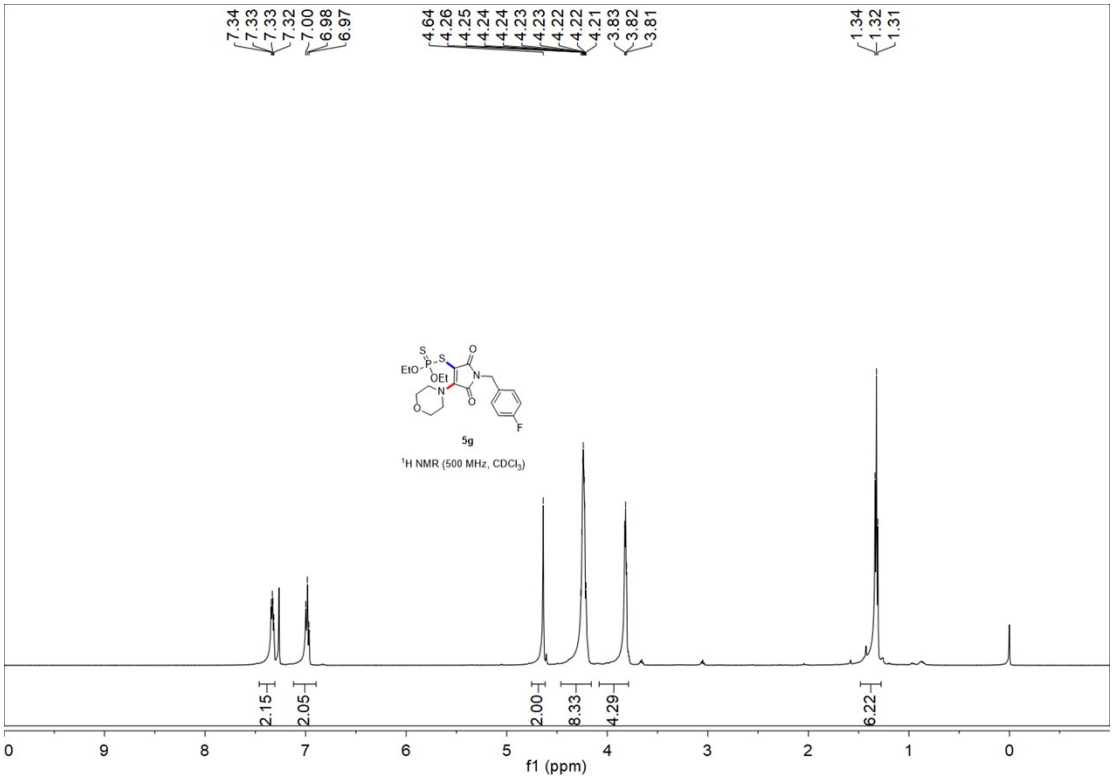

169.10
165.67
150.28
137.45
133.35
129.27
128.41
85.15
66.87
64.91
64.85
48.85
41.73
21.09
15.91
15.84
5e
13C NMR (125 MHz, CDCl3)
200
180
160
140
120
100
80
60
40
20
0
f1 (ppm)

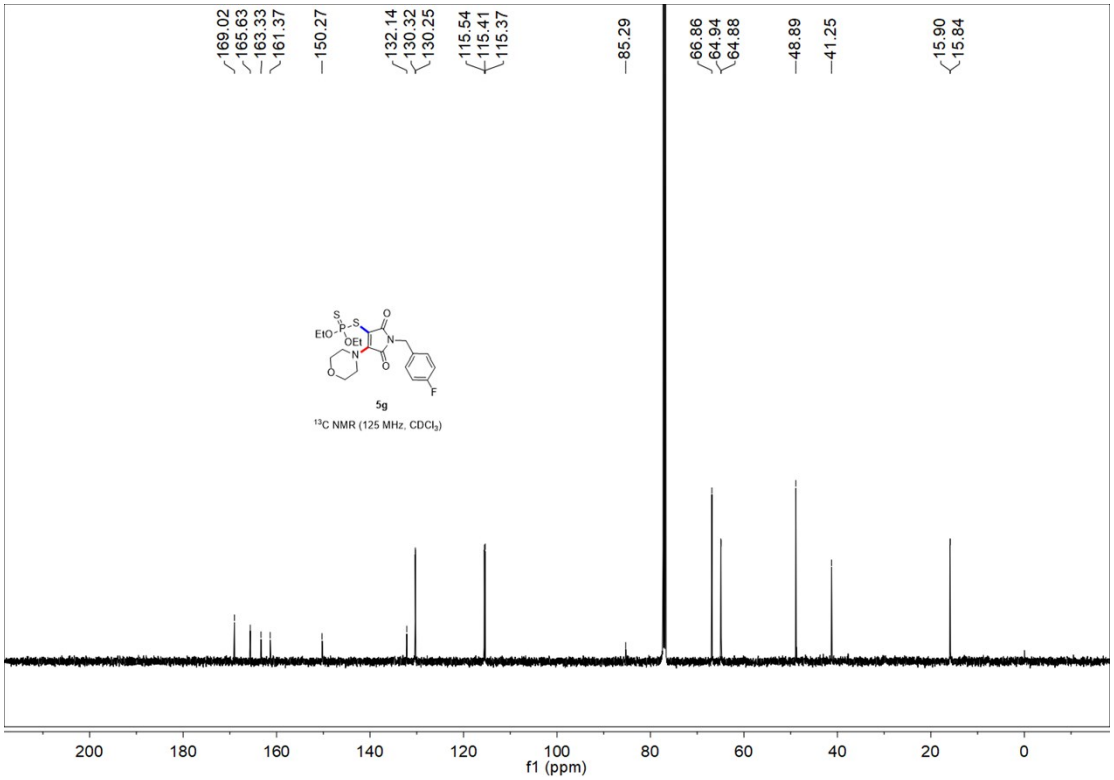

89.02
5e
31P NMR (162 MHz, CDCl3)
150
100
50
0
-50
-100
-150
-200
f1 (ppm)

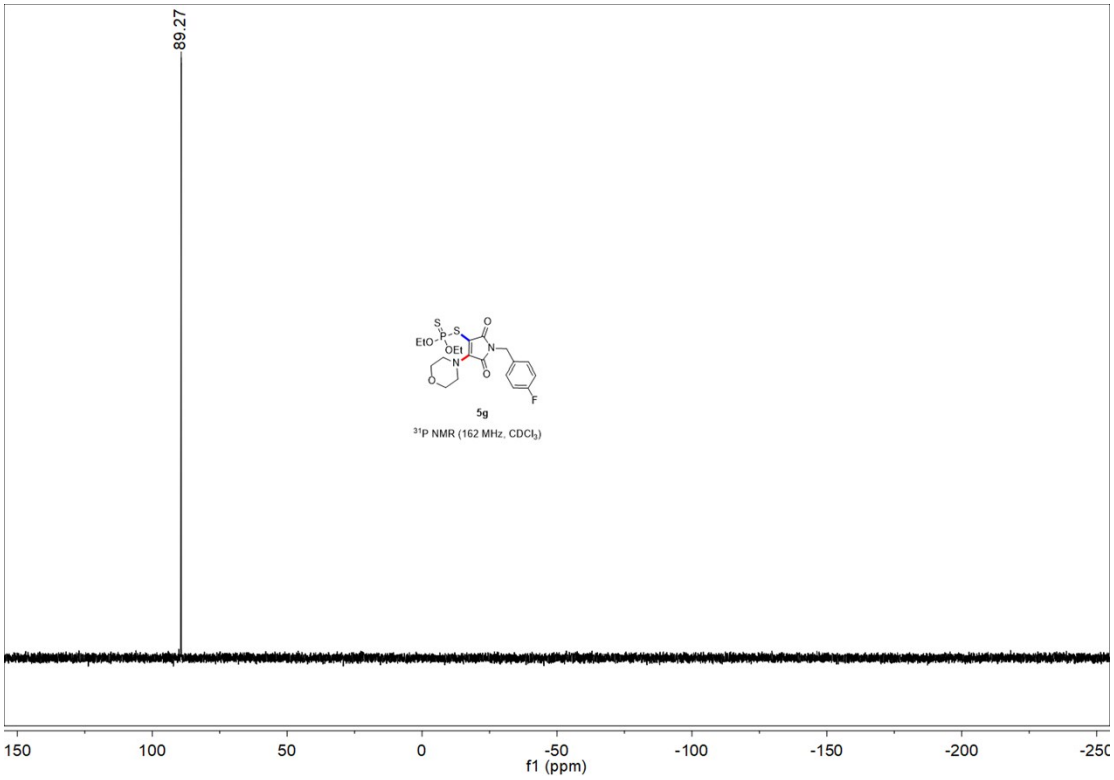

7.30
7.28
6.83
6.82
4.61
4.24
4.23
4.21
3.82
3.81
3.80
3.77
1.34
1.32
1.31
5f
¹H NMR (500 MHz, CDCl₃)
2.36
2.17
2.06
8.41
7.51
6.00
f1 (ppm)

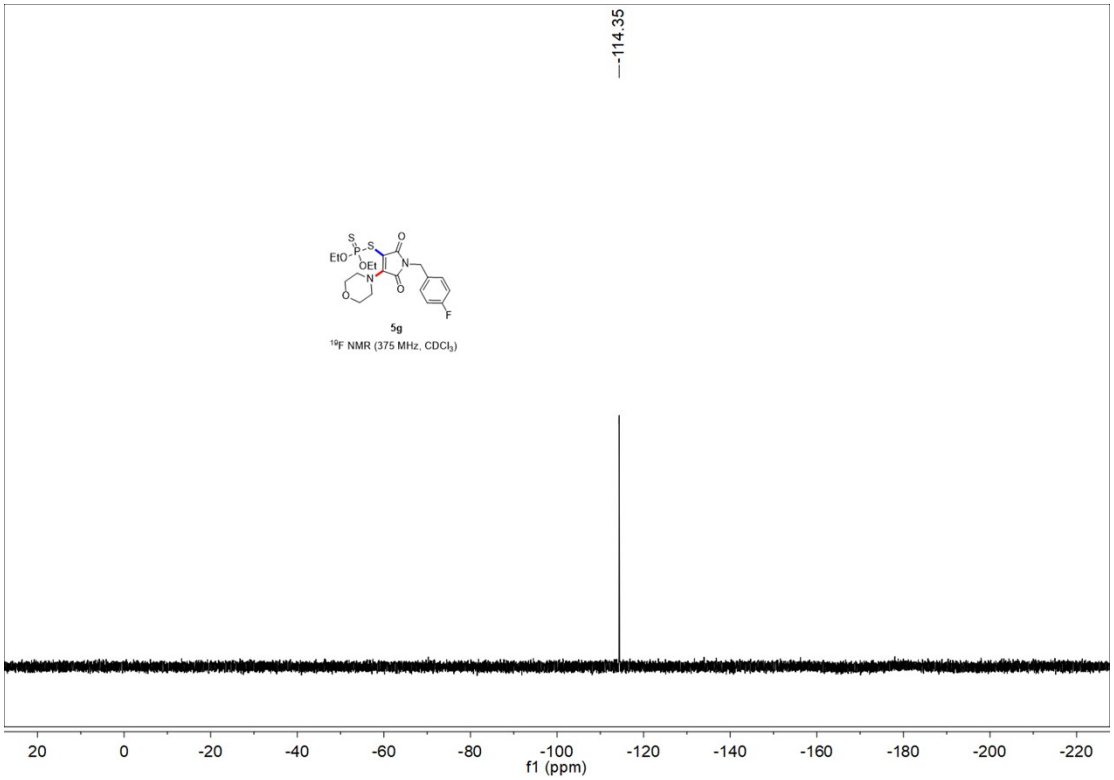

169.12
165.67
159.22
150.31
130.07
129.89
128.56
113.96
85.12
66.87
64.91
64.85
55.25
48.85
41.44
15.91
15.85
5f
¹³C NMR (125 MHz, CDCl₃)
f1 (ppm)

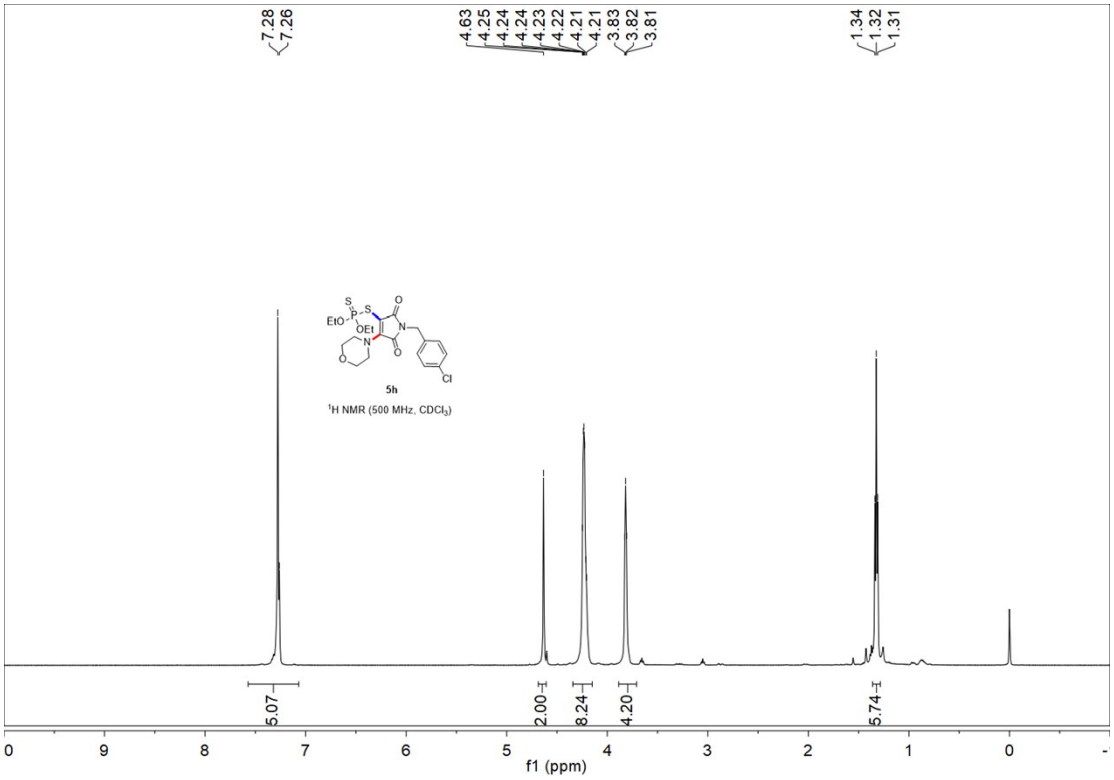

89.05
OMe
5f
31P NMR (162 MHz, CDCl3)
150
100
50
0
-50
-100
-150
-200
-250
f1 (ppm)

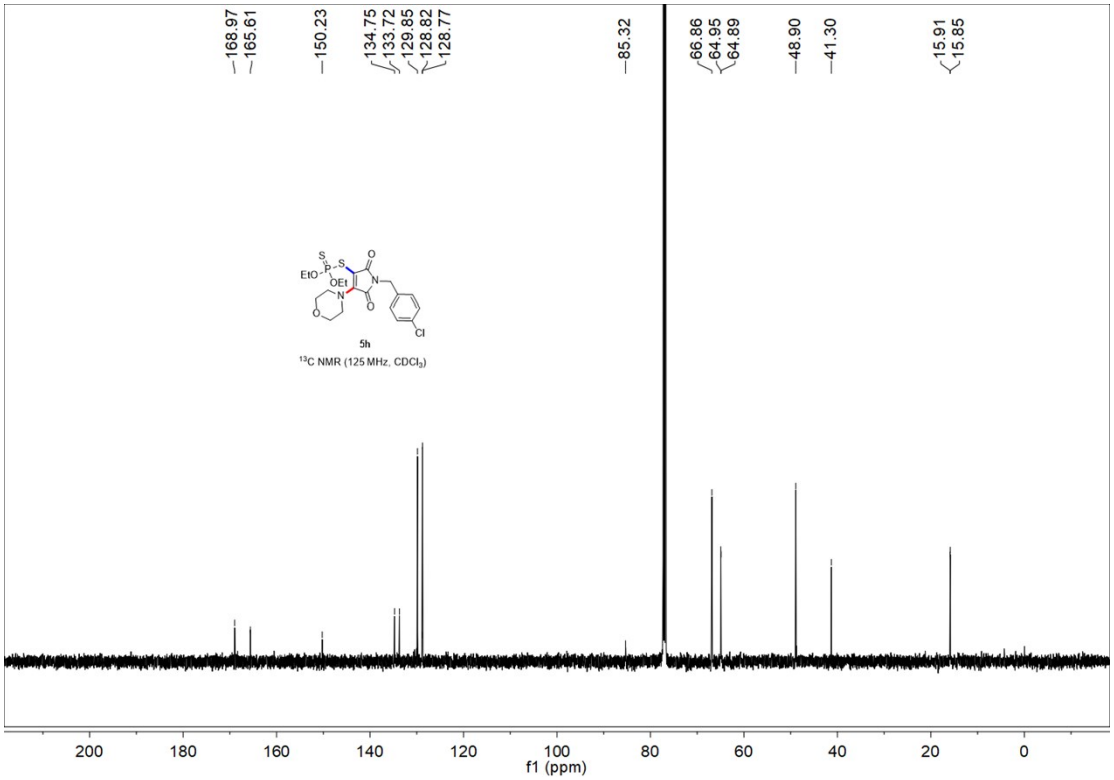

7.34
7.33
7.33
7.32
7.00
6.98
6.97
4.64
4.26
4.25
4.24
4.24
4.23
4.23
4.22
4.22
4.21
3.83
3.82
3.81
1.34
1.32
1.31
F
5g
1H NMR (500 MHz, CDCl3)
2.15
2.05
2.00
8.33
4.29
6.22
0
9
8
7
6
5
4
3
2
1
0
f1 (ppm)

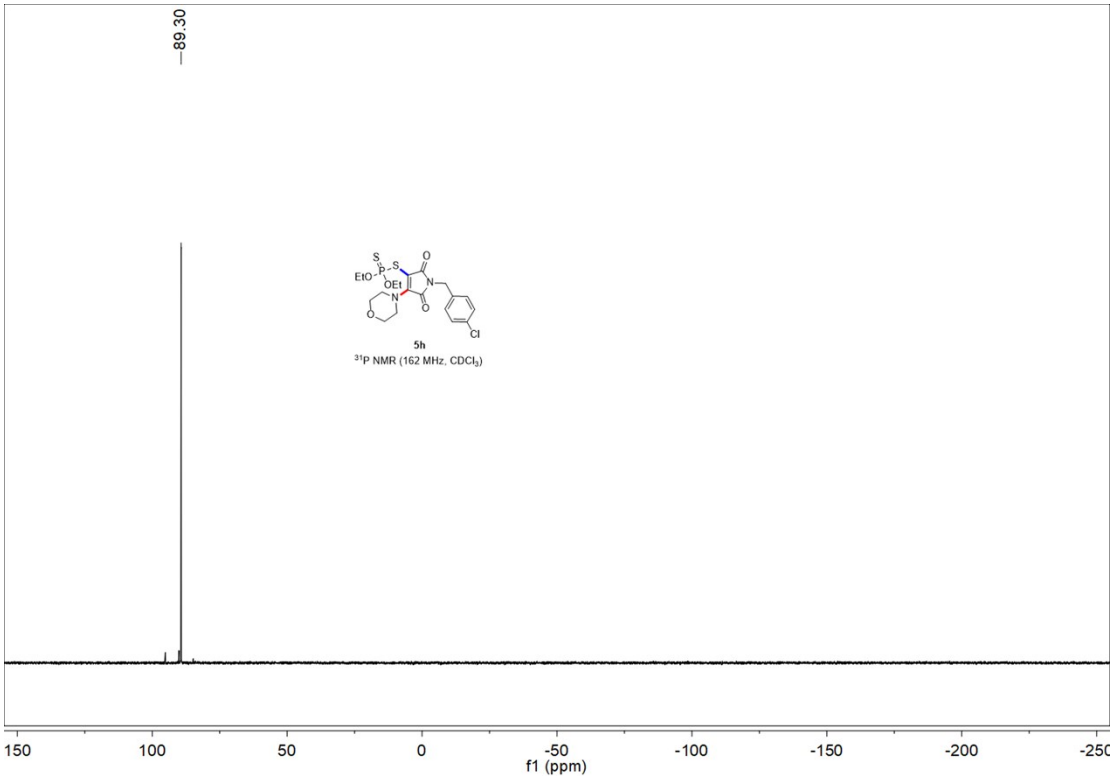

169.02
165.63
163.33
161.37
150.27
132.14
130.32
130.25
115.54
115.41
115.37
85.29
66.86
64.94
64.88
48.89
41.25
15.90
15.84
5g
13C NMR (125 MHz, CDCl3)
f1 (ppm)

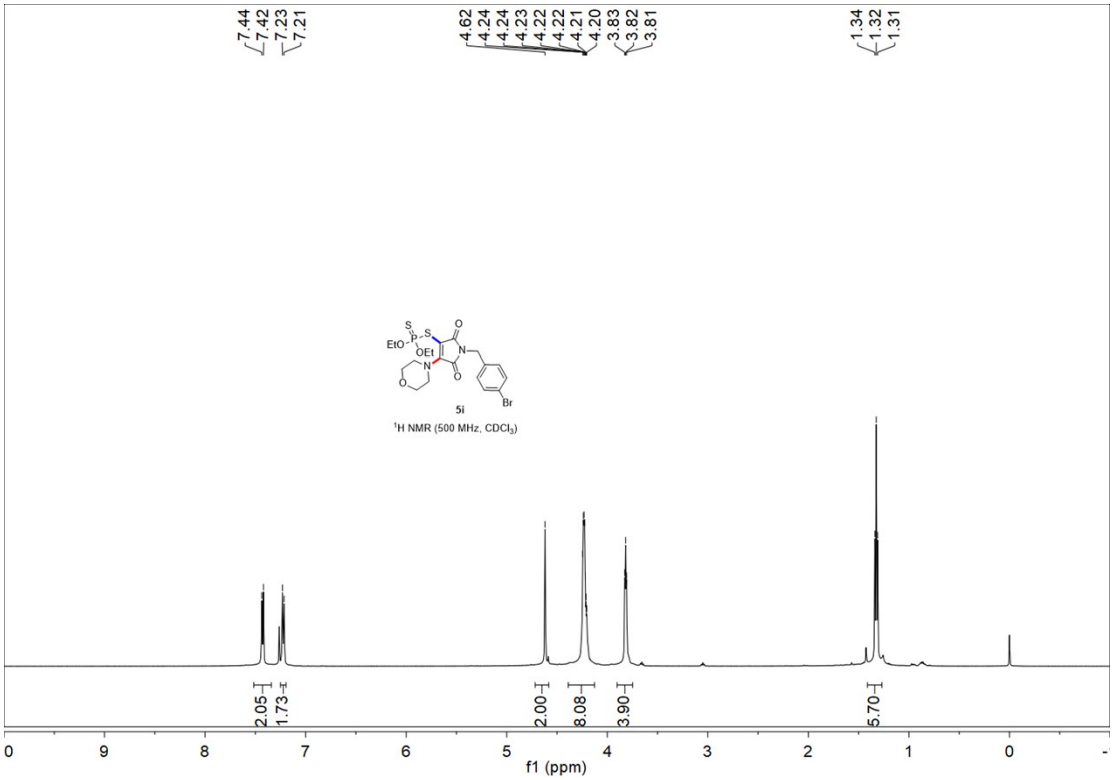

89.27
5g
31P NMR (162 MHz, CDCl3)
f1 (ppm)

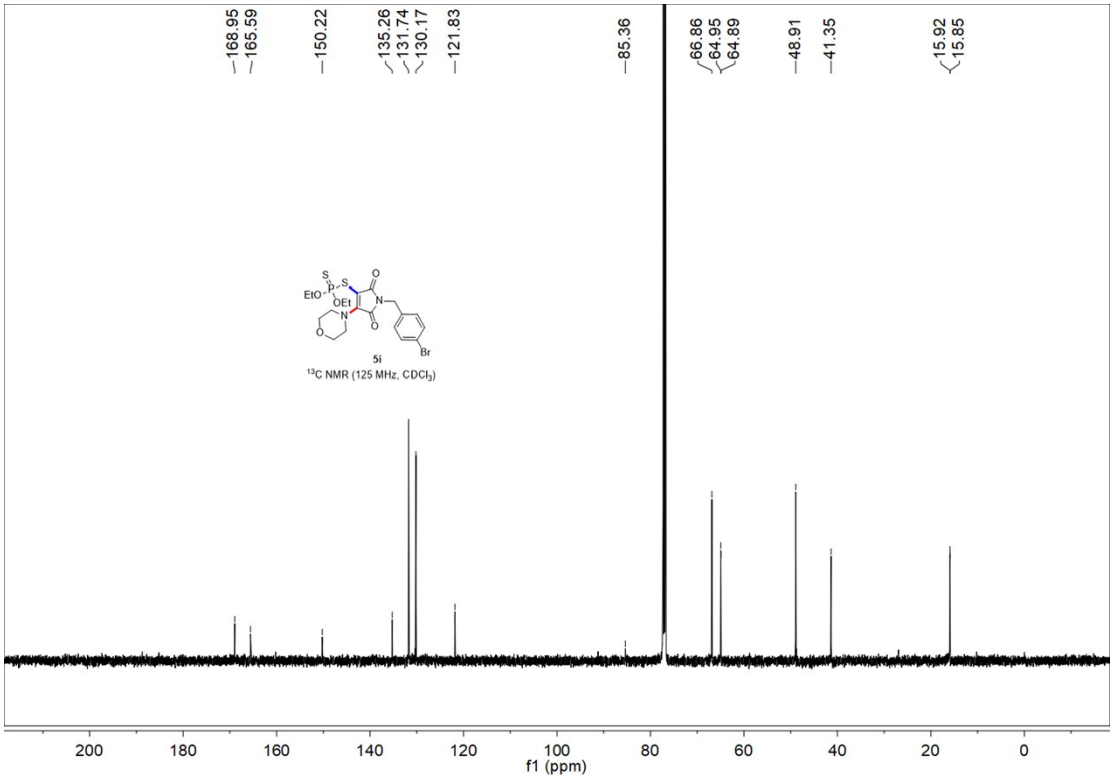

-114.35
5g
19F NMR (375 MHz, CDCl3)
20
0
-20
-40
-60
-80
-100
-120
-140
-160
-180
-200
-220
f1 (ppm)

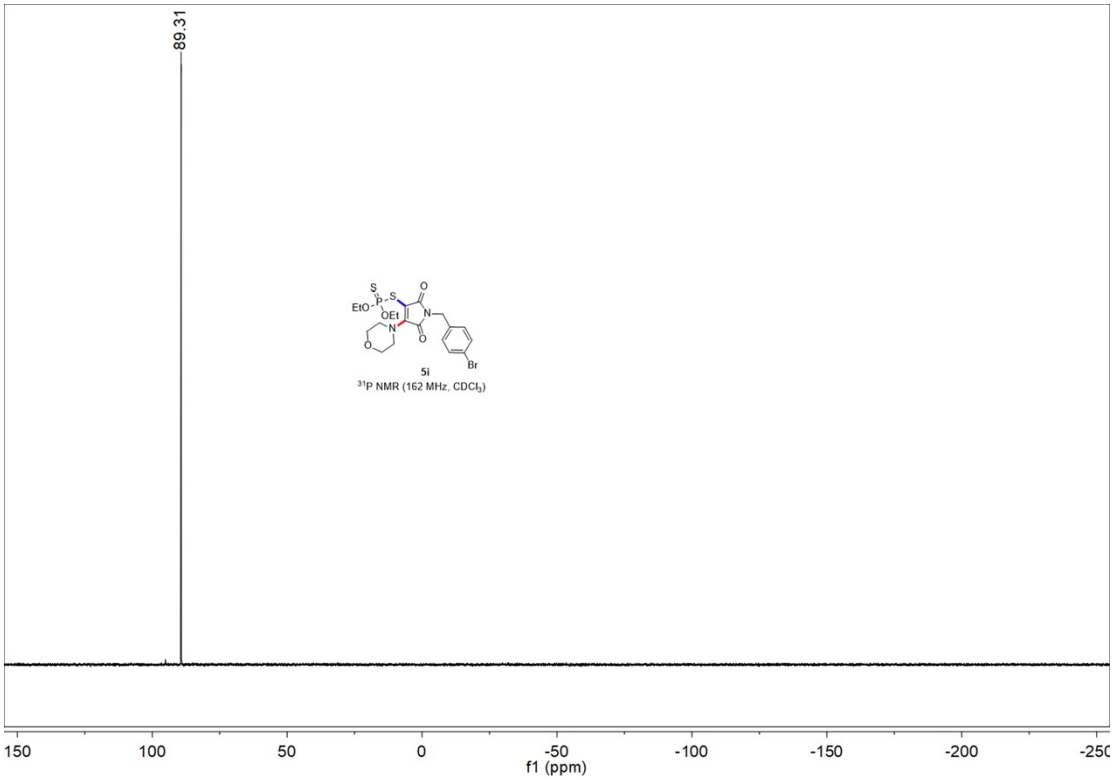

7.28
7.26
4.63
4.25
4.24
4.24
4.23
4.22
4.21
4.21
3.83
3.82
3.81
1.34
1.32
1.31
5h
1H NMR (500 MHz, CDCl3)
5.07
2.00
8.24
4.20
5.74
0
9
8
7
6
5
4
3
2
1
0
f1 (ppm)

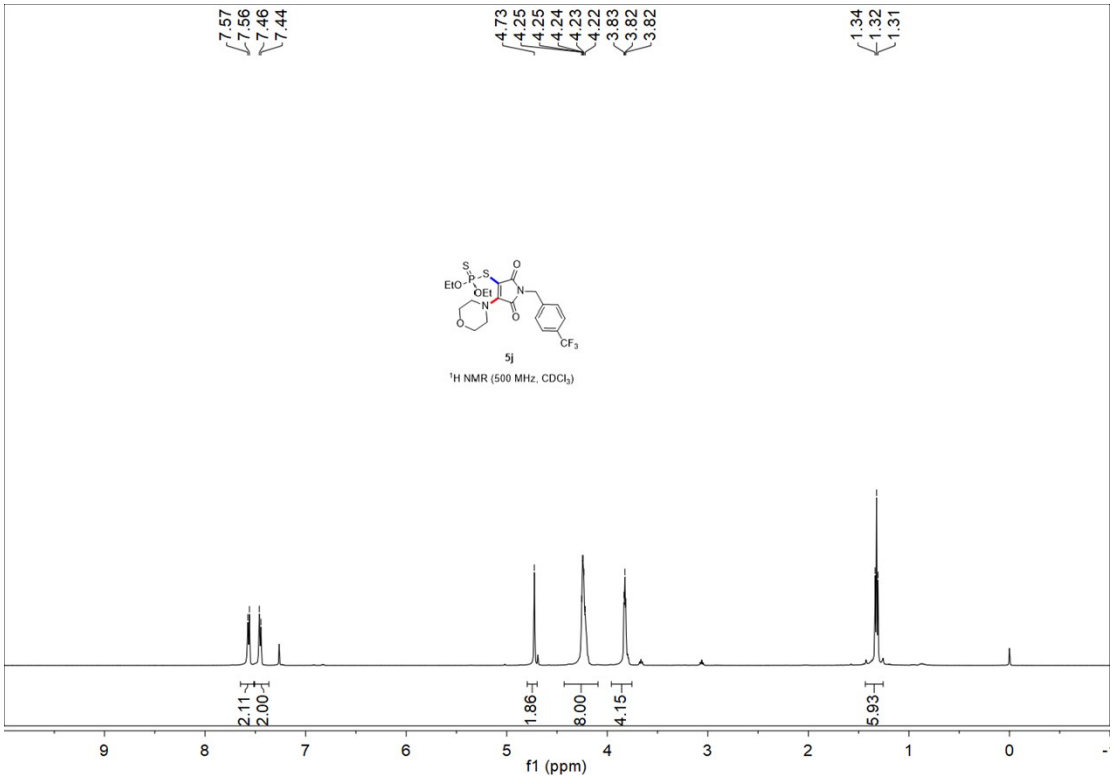

168.97
165.61
150.23
134.75
133.72
129.85
128.82
128.77
85.32
66.86
64.95
64.89
48.90
41.30
15.91
15.85
5h
13C NMR (125 MHz, CDCl3)
200
180
160
140
120
100
80
60
40
20
0
f1 (ppm)

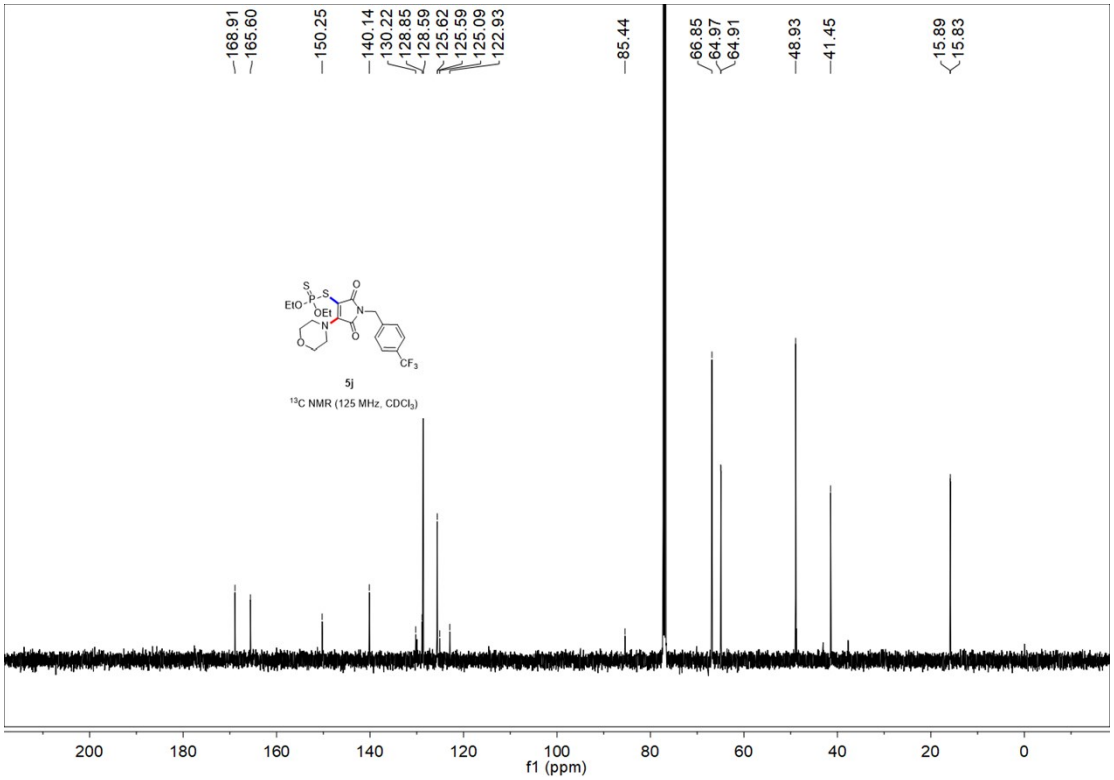

89.30
5h
31P NMR (162 MHz, CDCl3)
150
100
50
0
-50
-100
-150
-200
-250
f1 (ppm)

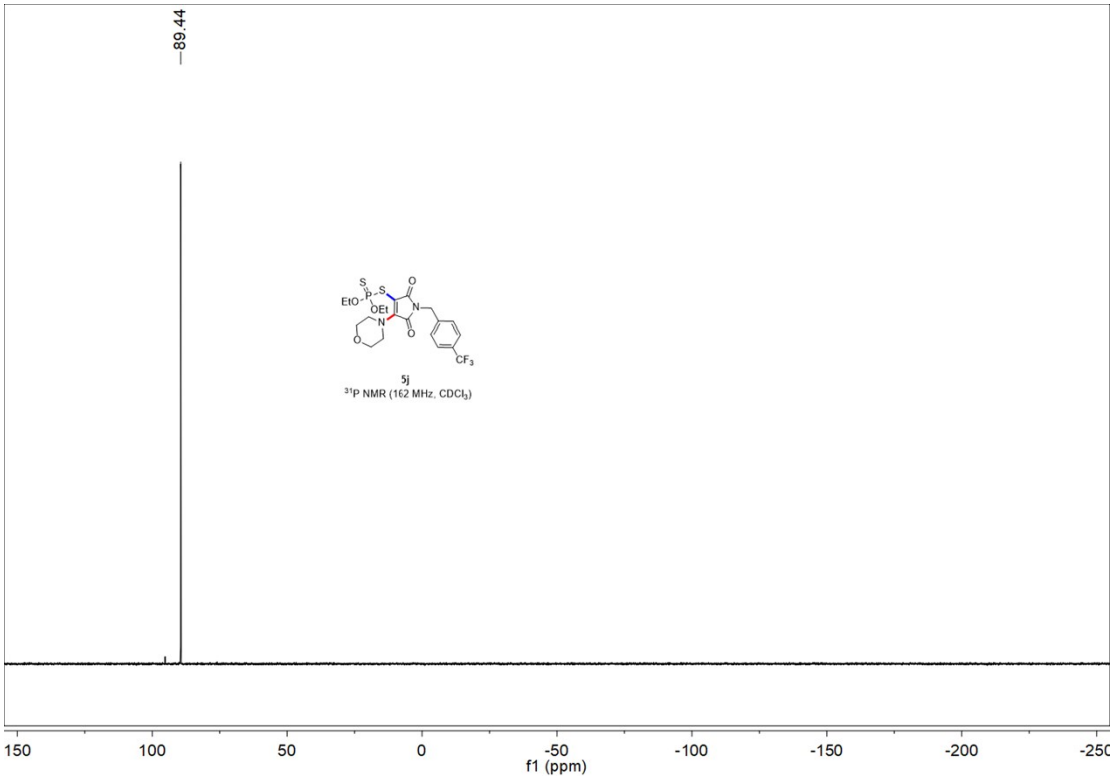

7.44
7.42
7.23
7.21
4.62
4.24
4.24
4.23
4.22
4.22
4.21
4.20
3.83
3.82
3.81
1.34
1.32
1.31
5i
1H NMR (500 MHz, CDCl3)
2.05
1.73
2.00
8.08
3.90
5.70
f1 (ppm)

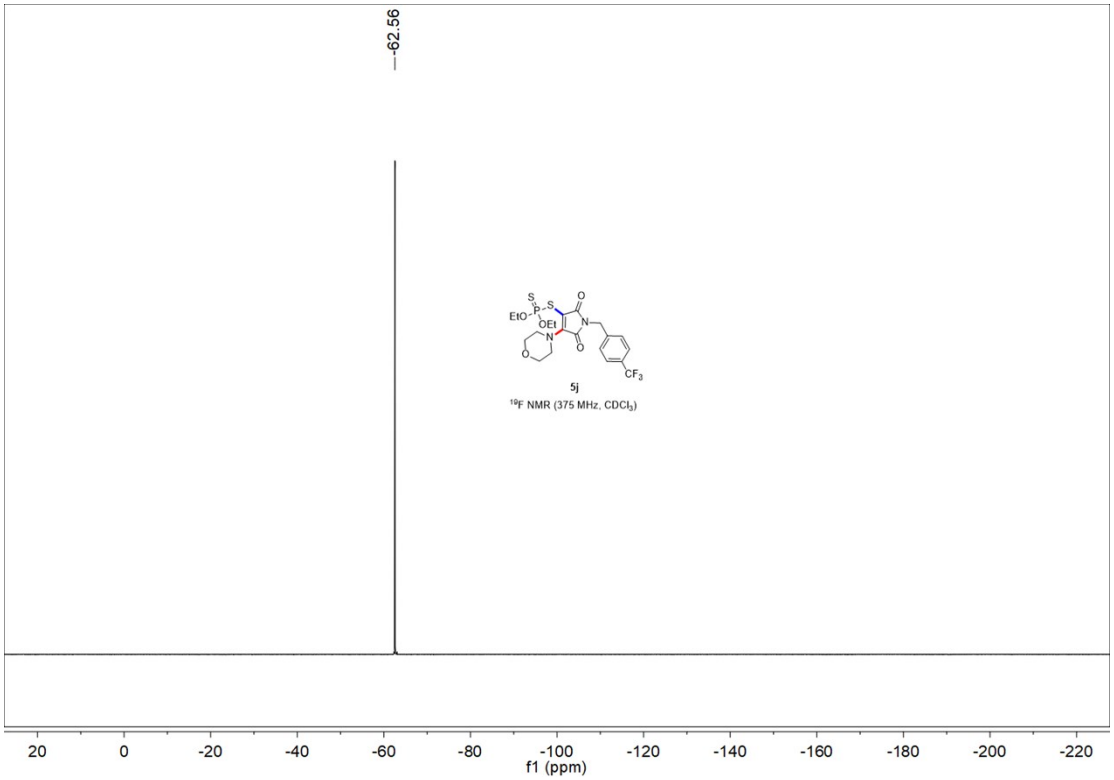

168.95
165.59
150.22
135.26
131.74
130.17
121.83
85.36
66.86
64.95
64.89
48.91
41.35
15.92
15.85
5i
13C NMR (125 MHz, CDCl3)
f1 (ppm)

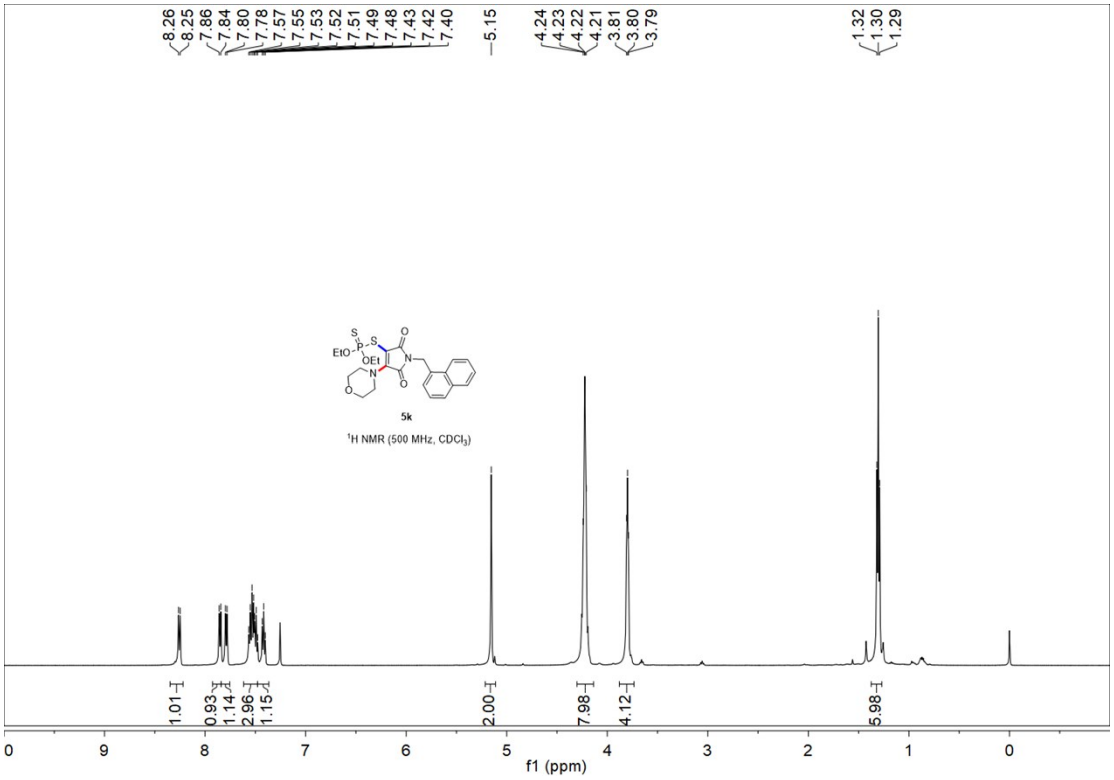

89.31
5i
31P NMR (162 MHz, CDCl3)
150
100
50
0
-50
-100
-150
-200
-250
f1 (ppm)

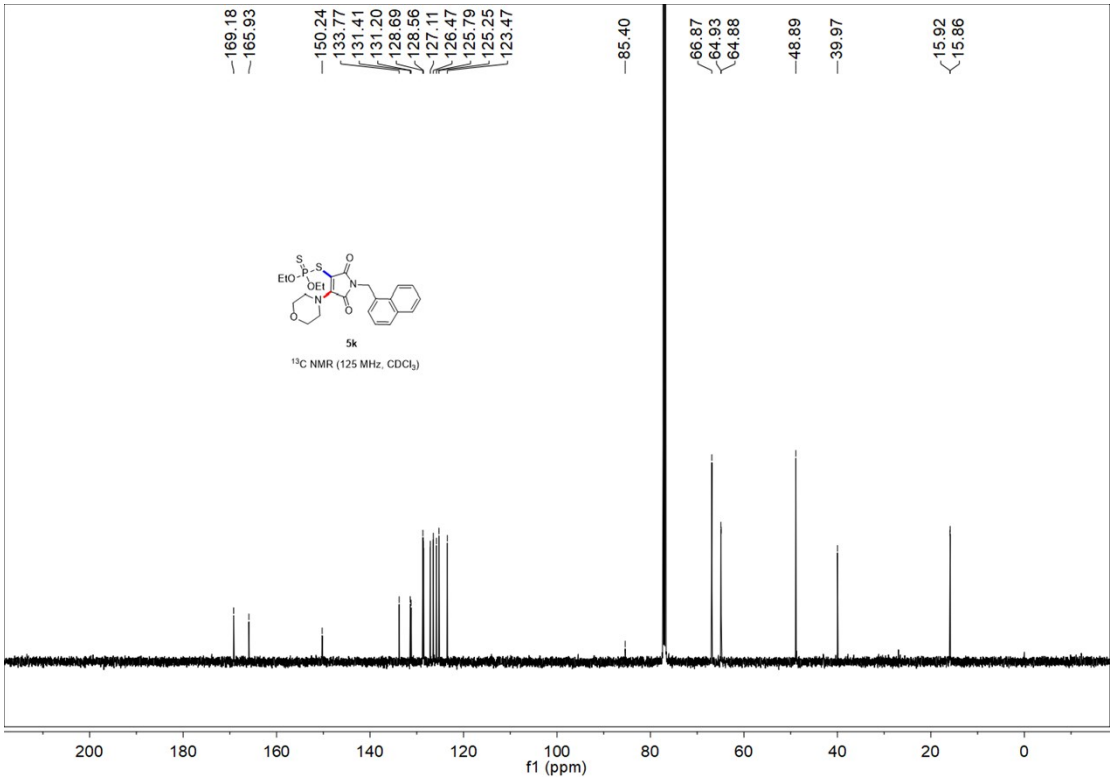

7.57
7.56
7.46
7.44
4.73
4.25
4.25
4.24
4.23
4.22
3.83
3.82
3.82
1.34
1.32
1.31
5j
1H NMR (500 MHz, CDCl3)
2.11
2.00
1.86
8.00
4.15
5.93
9
8
7
6
5
4
3
2
1
0
f1 (ppm)

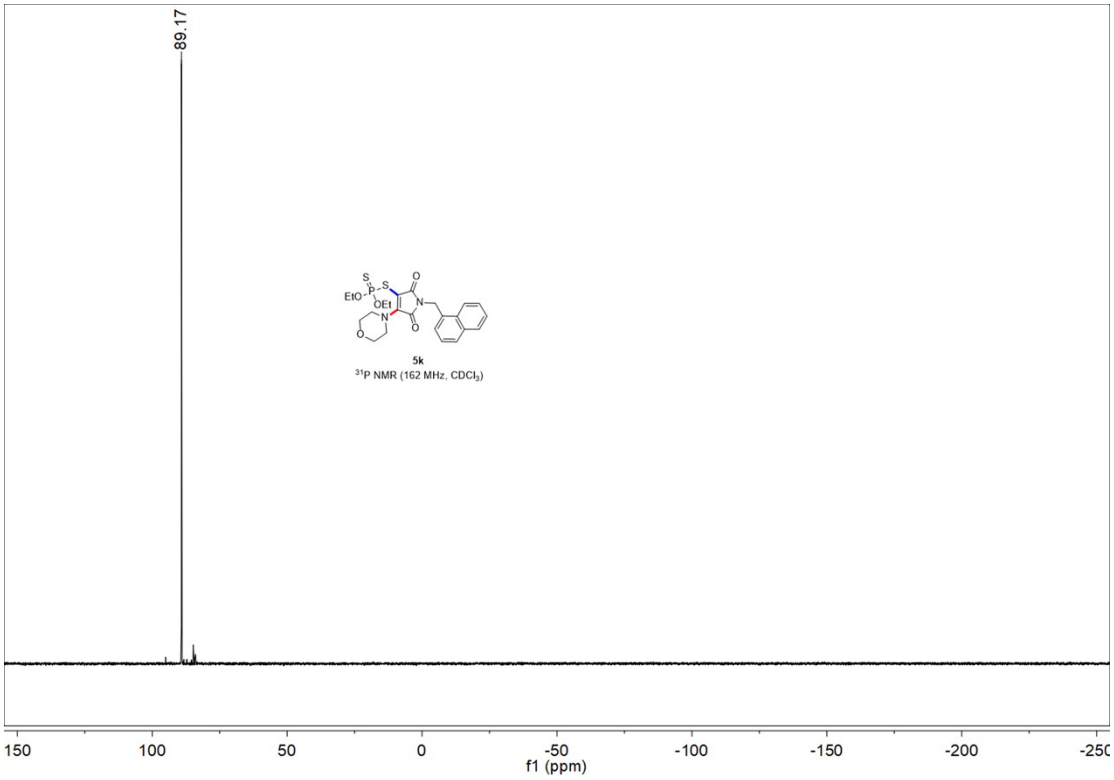

168.91
165.60
150.25
140.14
130.22
128.85
128.59
125.62
125.59
125.09
122.93
85.44
66.85
64.97
64.91
48.93
41.45
15.89
15.83
5j
13C NMR (125 MHz, CDCl3)
200
180
160
140
120
100
80
60
40
20
0
f1 (ppm)

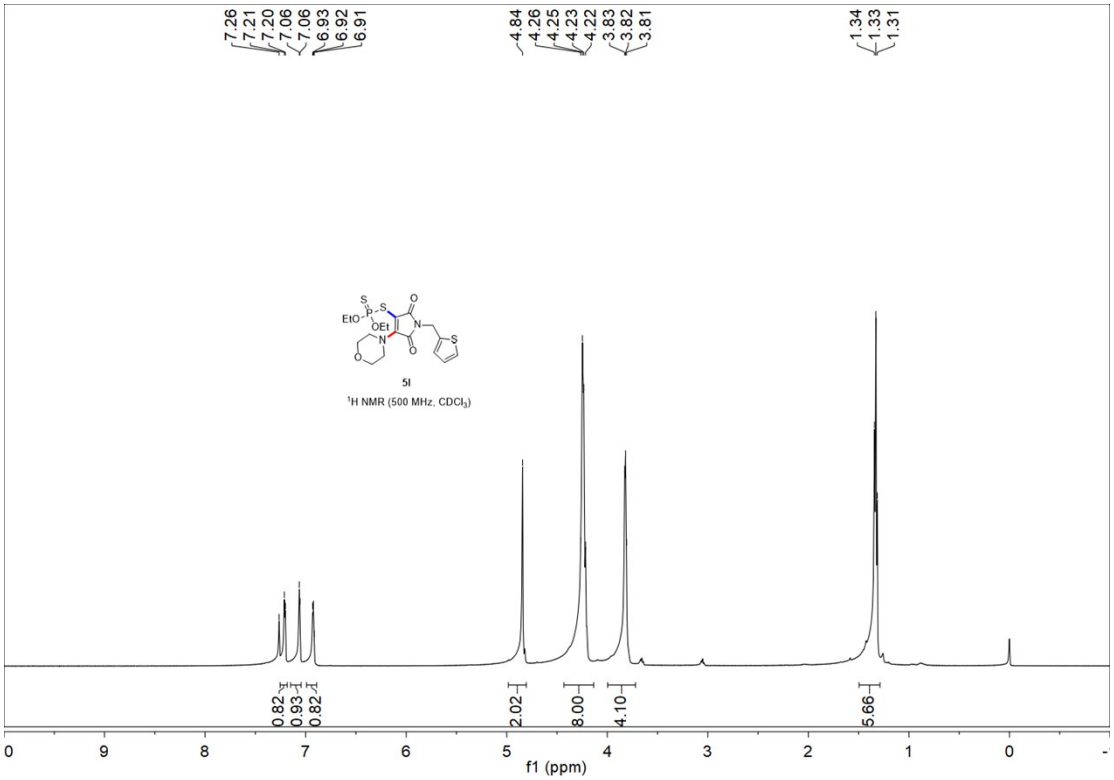

89.44
5j
31P NMR (162 MHz, CDCl3)
150
100
50
0
-50
-100
-150
-200
f1 (ppm)

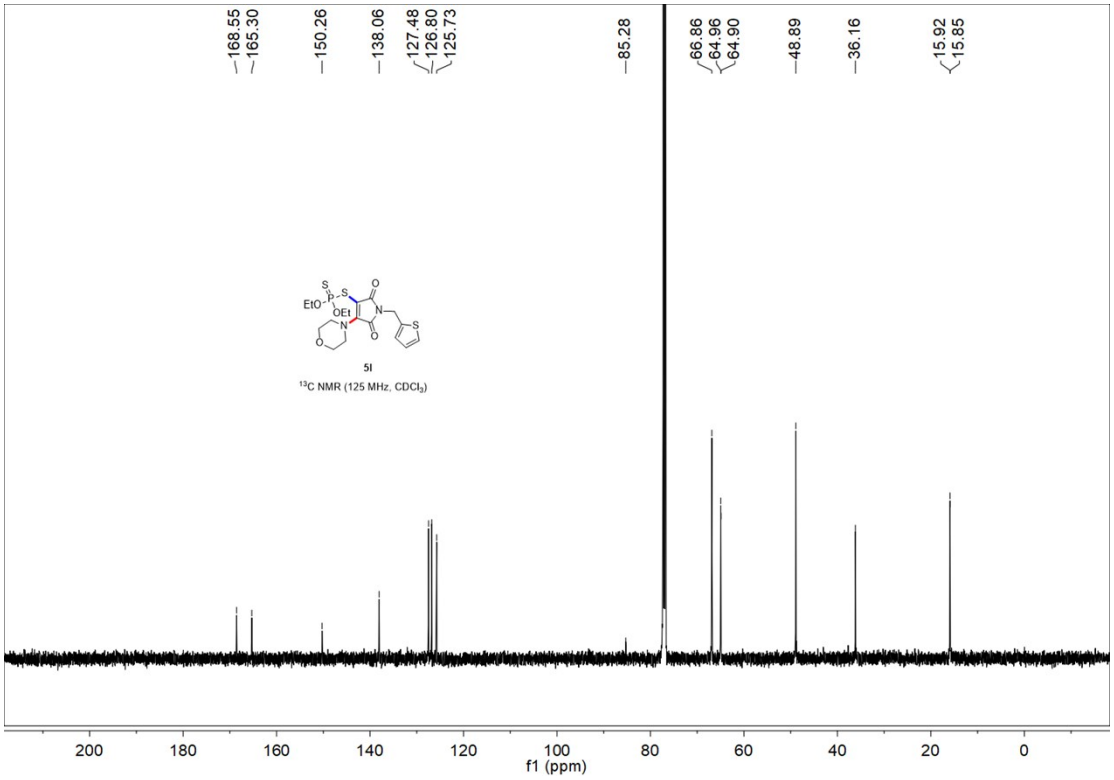

-62.56
5j
^{19}F NMR (375 MHz, CDCl$_3$)
f1 (ppm)

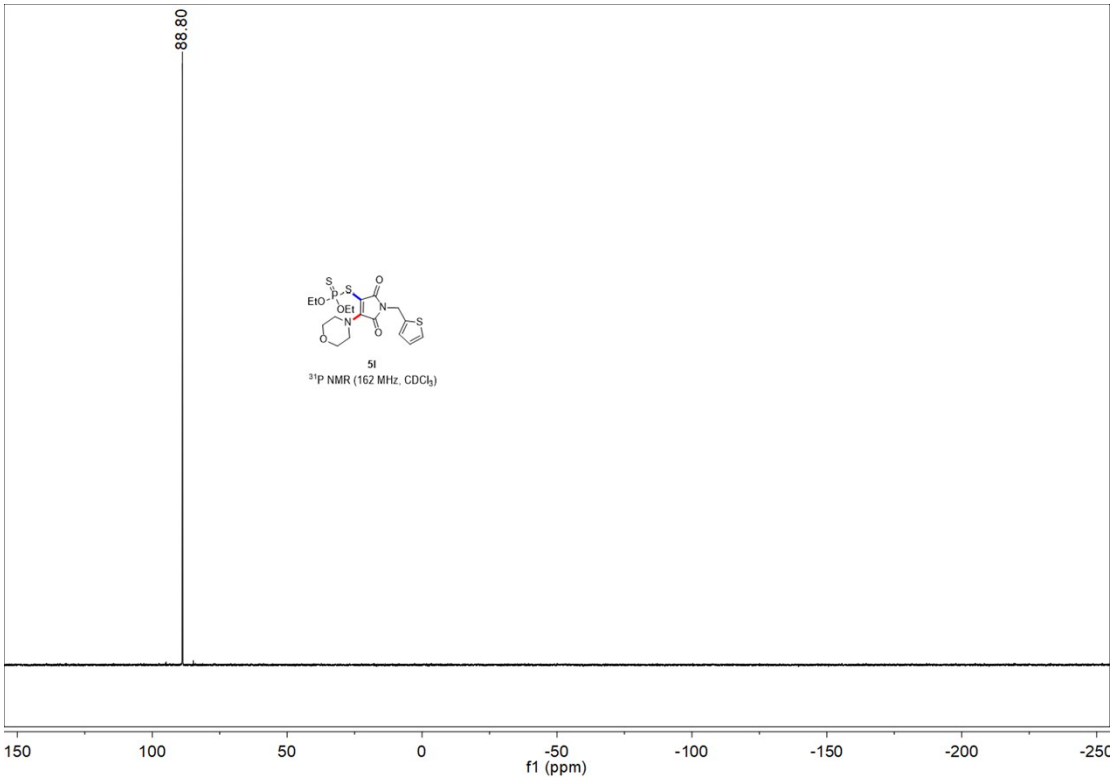

8.26
8.25
7.86
7.84
7.80
7.78
7.57
7.55
7.53
7.52
7.51
7.49
7.48
7.43
7.42
7.40
5.15
4.24
4.23
4.22
4.21
3.81
3.80
3.79
1.32
1.30
1.29
5k
^{1}H NMR (500 MHz, CDCl$_3$)
1.01
0.93
1.14
2.96
1.15
2.00
7.98
4.12
5.98
f1 (ppm)

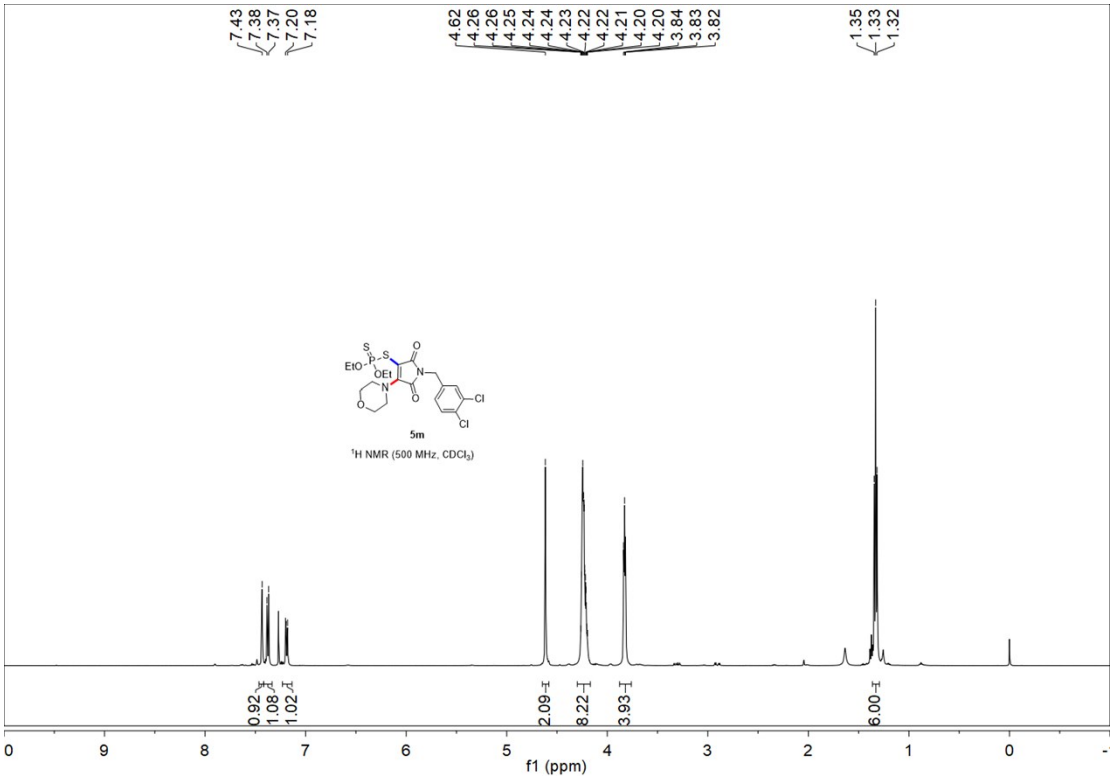

169.18
165.93
150.24
133.77
131.41
131.20
128.69
128.56
127.11
126.47
125.79
125.25
123.47
85.40
66.87
64.93
64.88
48.89
39.97
15.92
15.86
5k
13C NMR (125 MHz, CDCl3)
200
180
160
140
120
100
80
60
40
20
0
f1 (ppm)

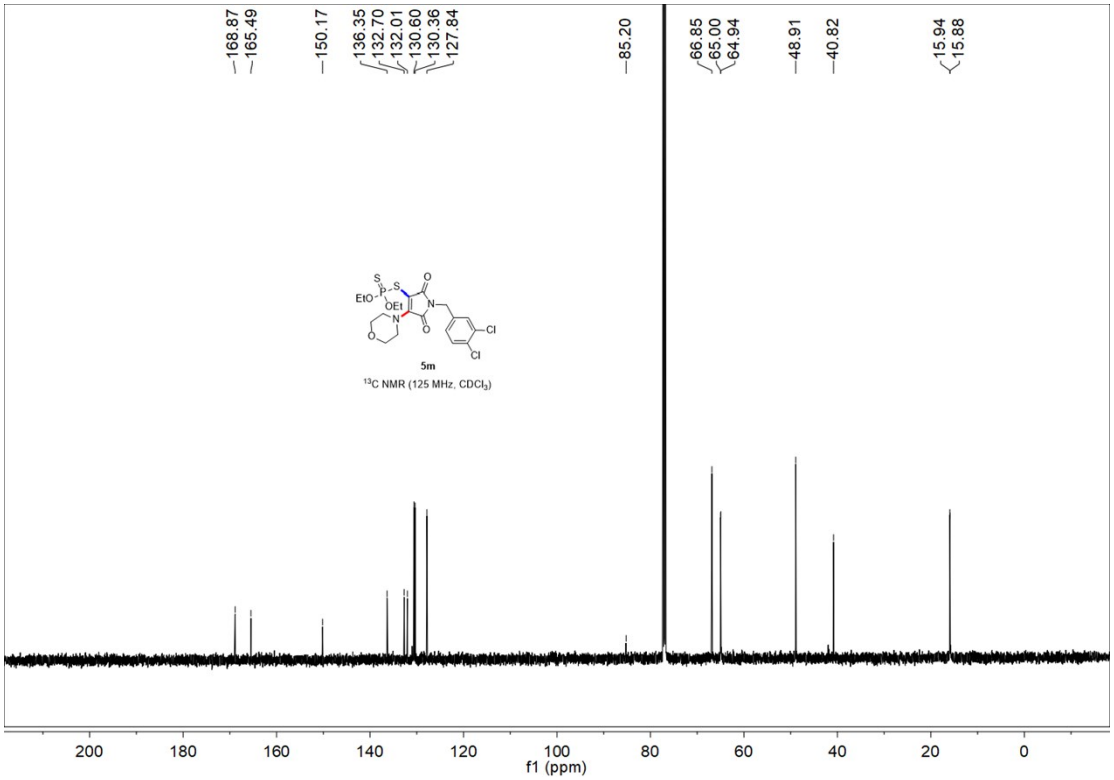

89.17
5k
31P NMR (162 MHz, CDCl3)
150
100
50
0
-50
-100
-150
-200
-250
f1 (ppm)

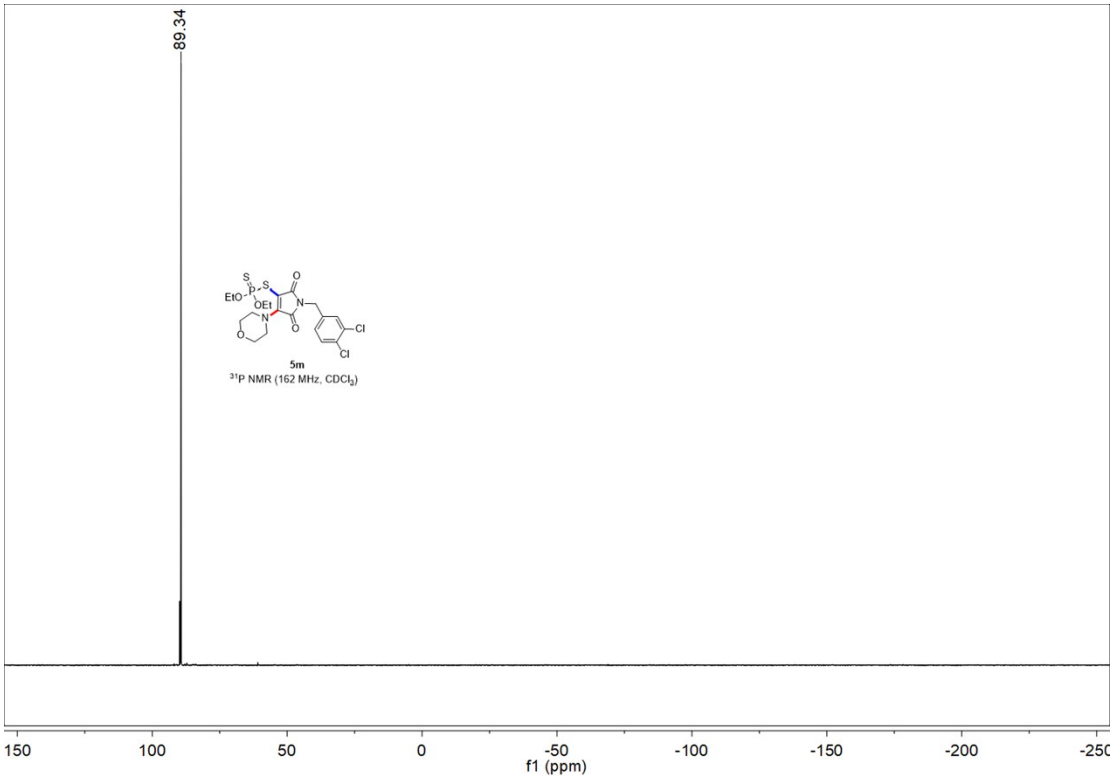

7.26
7.21
7.20
7.06
7.06
6.93
6.92
6.91
4.84
4.26
4.25
4.23
4.22
3.83
3.82
3.81
1.34
1.33
1.31
5l
¹H NMR (500 MHz, CDCl3)
0.82
0.93
0.82
2.02
8.00
4.10
5.66
f1 (ppm)

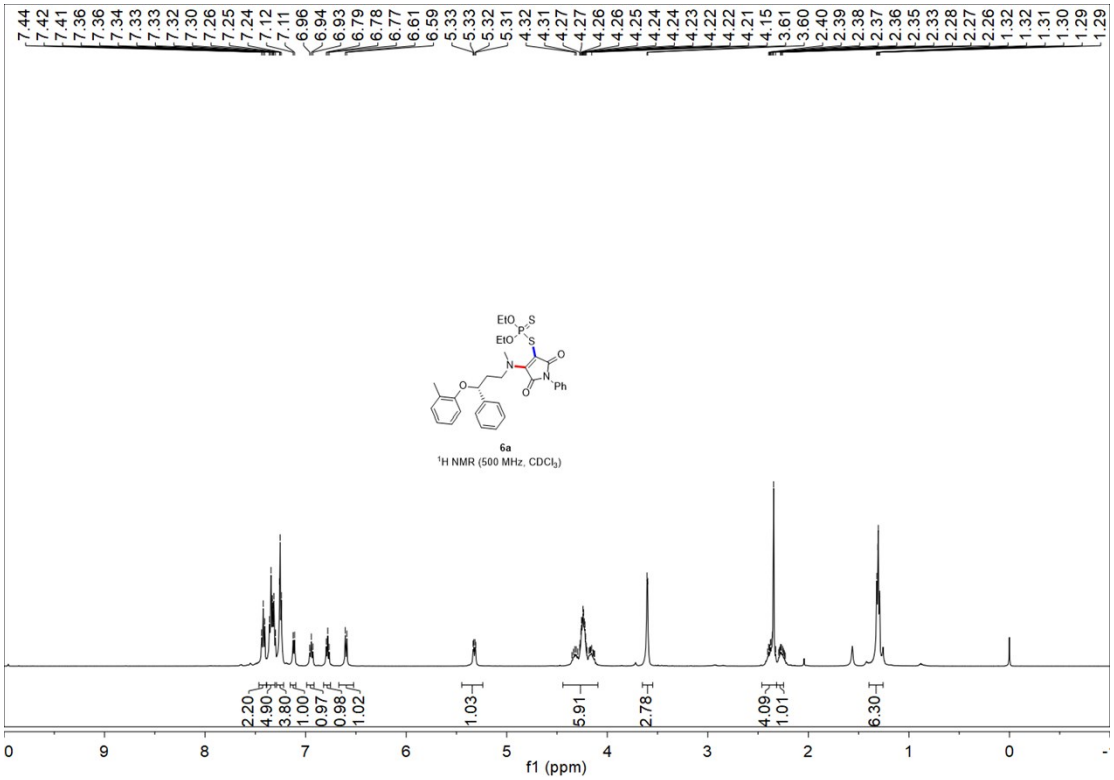

168.55
165.30
150.26
138.06
127.48
126.80
125.73
85.28
66.86
64.96
64.90
48.89
36.16
15.92
15.85
5l
¹³C NMR (125 MHz, CDCl3)
f1 (ppm)

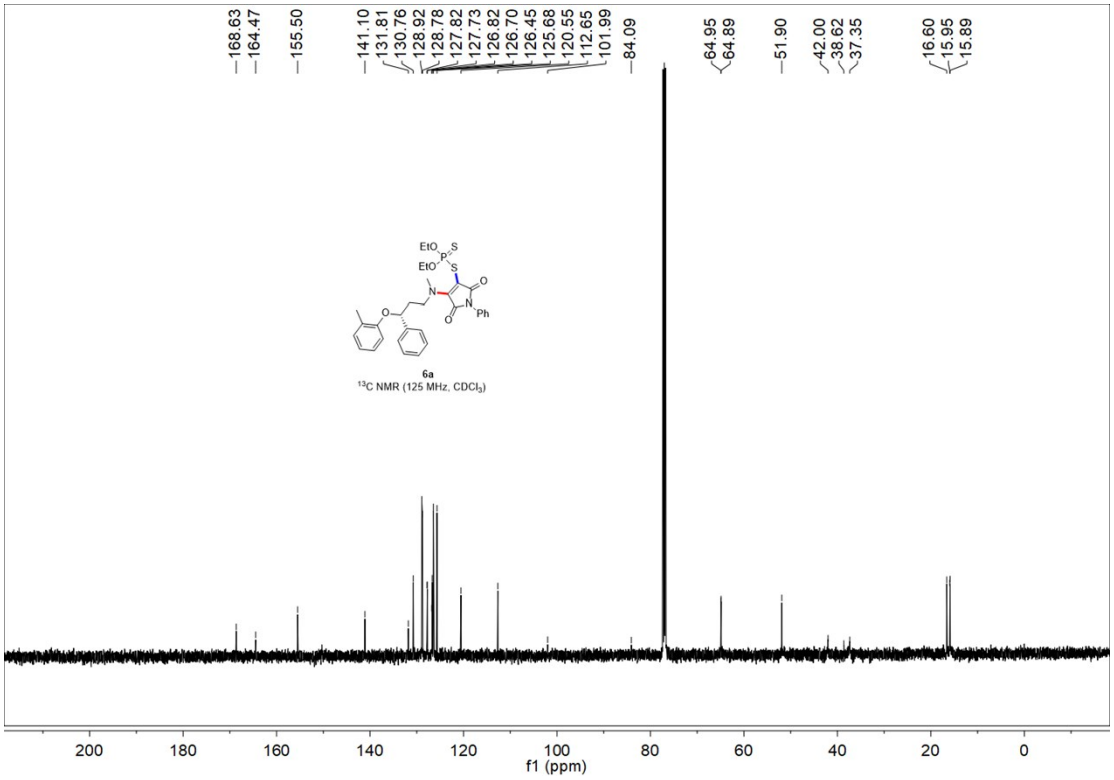

88.80
5l
31P NMR (162 MHz, CDCl3)
150
100
50
0
-50
-100
-150
-200
-250
f1 (ppm)

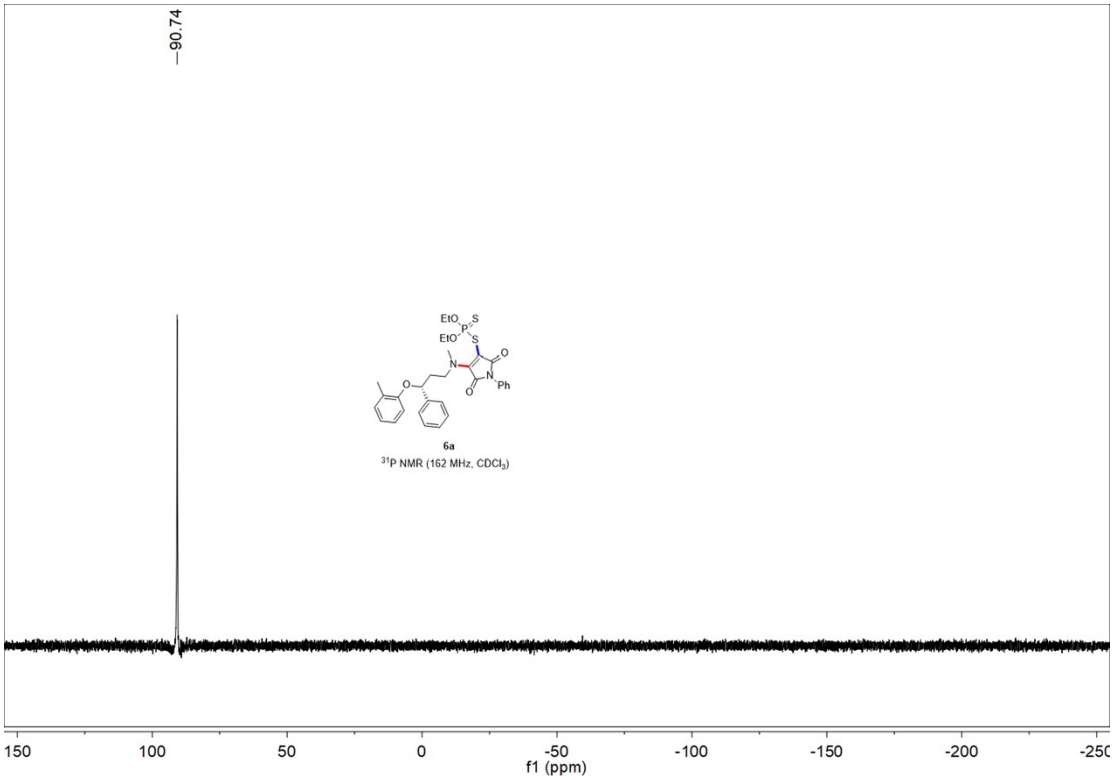

7.43
7.38
7.37
7.20
7.18
4.62
4.26
4.26
4.25
4.24
4.24
4.23
4.22
4.22
4.21
4.20
4.20
3.84
3.83
3.82
1.35
1.33
1.32
5m
1H NMR (500 MHz, CDCl3)
0.92
1.08
1.02
2.09
8.22
3.93
6.00
0
9
8
7
6
5
4
3
2
1
0
f1 (ppm)

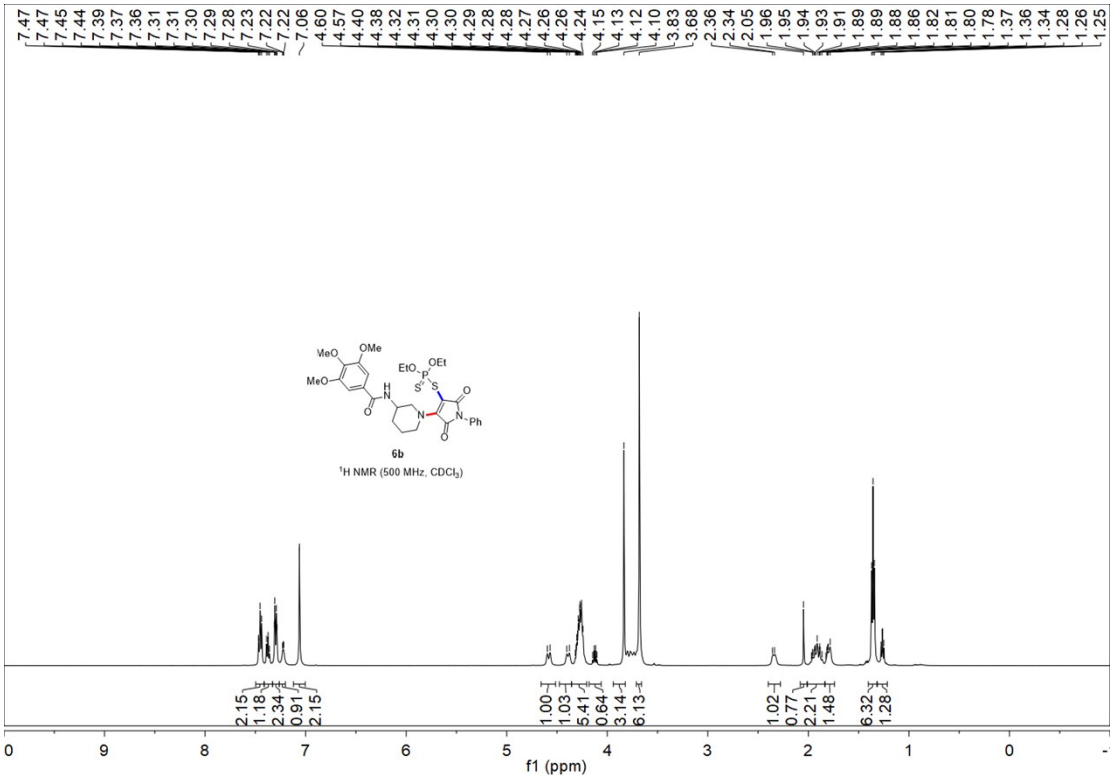

168.87
165.49
150.17
136.35
132.70
132.01
130.60
130.36
127.84
85.20
66.85
65.00
64.94
48.91
40.82
15.94
15.88
5m
13C NMR (125 MHz, CDCl3)
f1 (ppm)

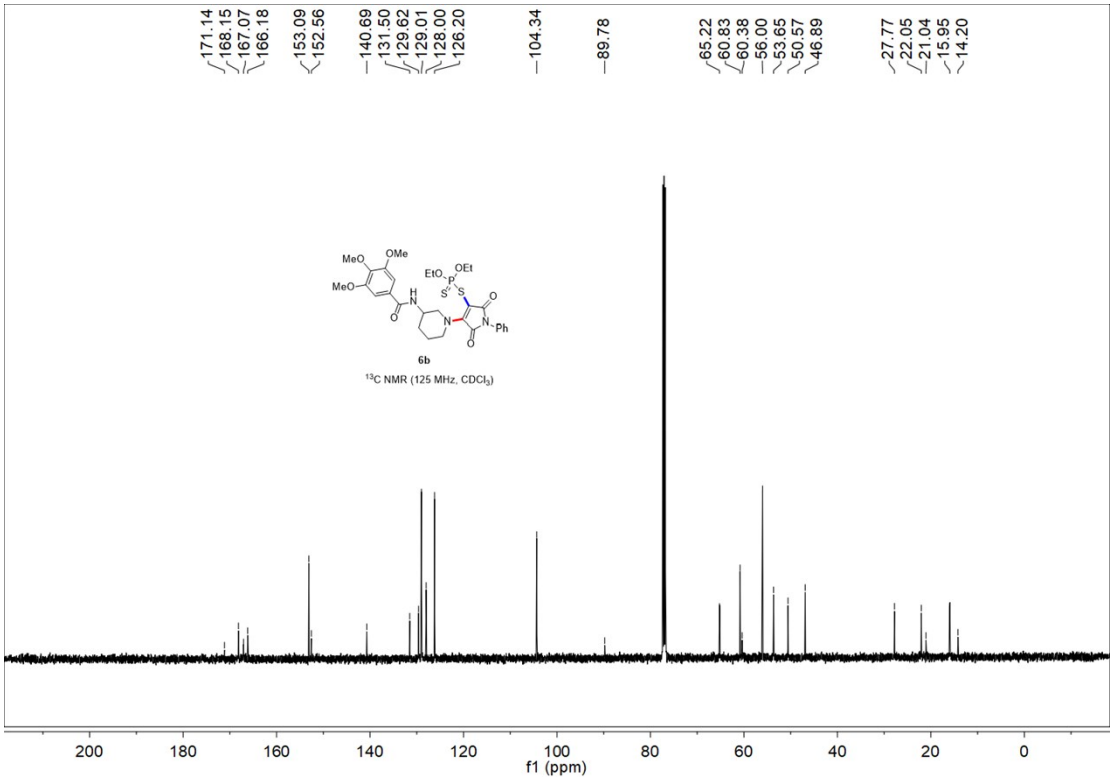

89.34
5m
31P NMR (162 MHz, CDCl3)
f1 (ppm)

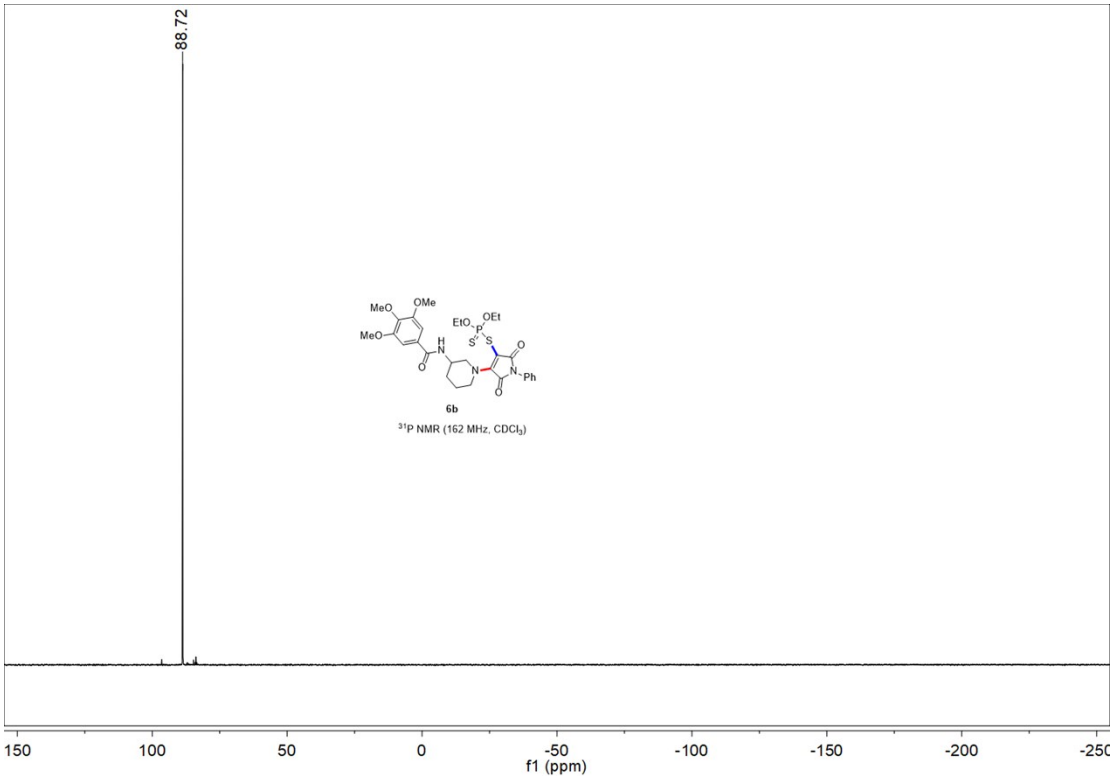

7.44
7.42
7.41
7.36
7.36
7.34
7.33
7.33
7.32
7.30
7.26
7.25
7.24
7.12
7.11
6.96
6.94
6.93
6.79
6.78
6.77
6.61
6.59
5.33
5.33
5.32
5.31
4.32
4.31
4.27
4.27
4.26
4.26
4.25
4.24
4.24
4.23
4.22
4.22
4.21
4.15
3.61
3.60
2.40
2.39
2.38
2.37
2.36
2.35
2.33
2.28
2.27
2.26
1.32
1.32
1.31
1.30
1.29
1.29
EtO
EtO
P
S
S
N
O
O
N
Ph
O
6a
1H NMR (500 MHz, CDCl3)
2.20
4.90
3.80
1.00
0.97
0.98
1.02
1.03
5.91
2.78
4.09
1.01
6.30
0
9
8
7
6
5
4
3
2
1
0
f1 (ppm)

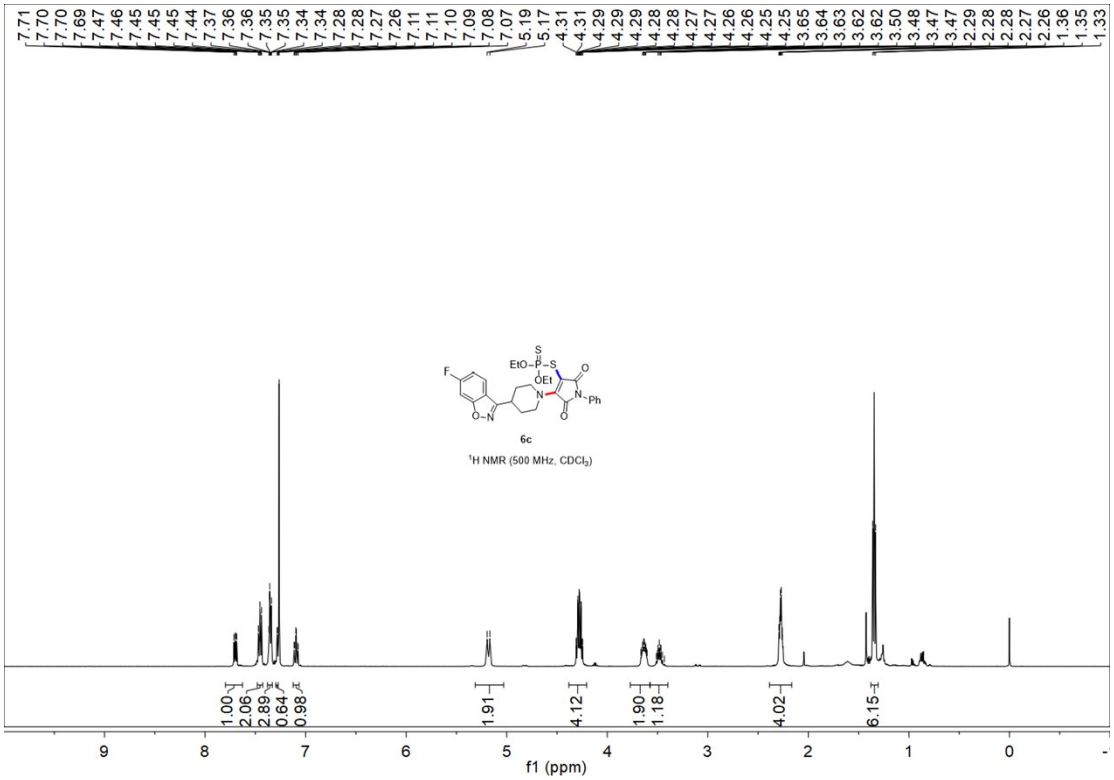

168.63
164.47
155.50
141.10
131.81
130.76
128.92
128.78
127.82
127.73
126.82
126.70
126.45
125.68
120.55
112.65
101.99
84.09
64.95
64.89
51.90
42.00
38.62
37.35
16.60
15.95
15.89
EtO
EtO
P
S
S
N
O
O
N
Ph
O
6a
13C NMR (125 MHz, CDCl3)
200
180
160
140
120
100
80
60
40
20
0
f1 (ppm)

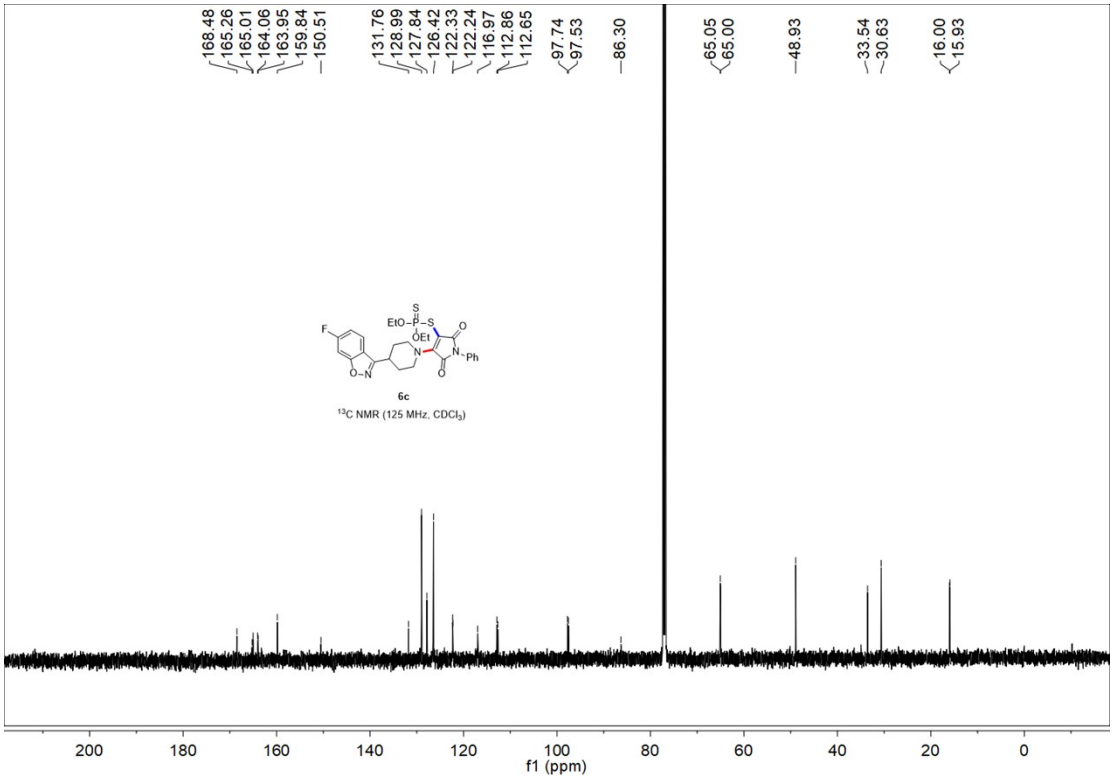

90.74
6a
31P NMR (162 MHz, CDCl3)
150
100
50
0
-50
-100
-150
-200
f1 (ppm)

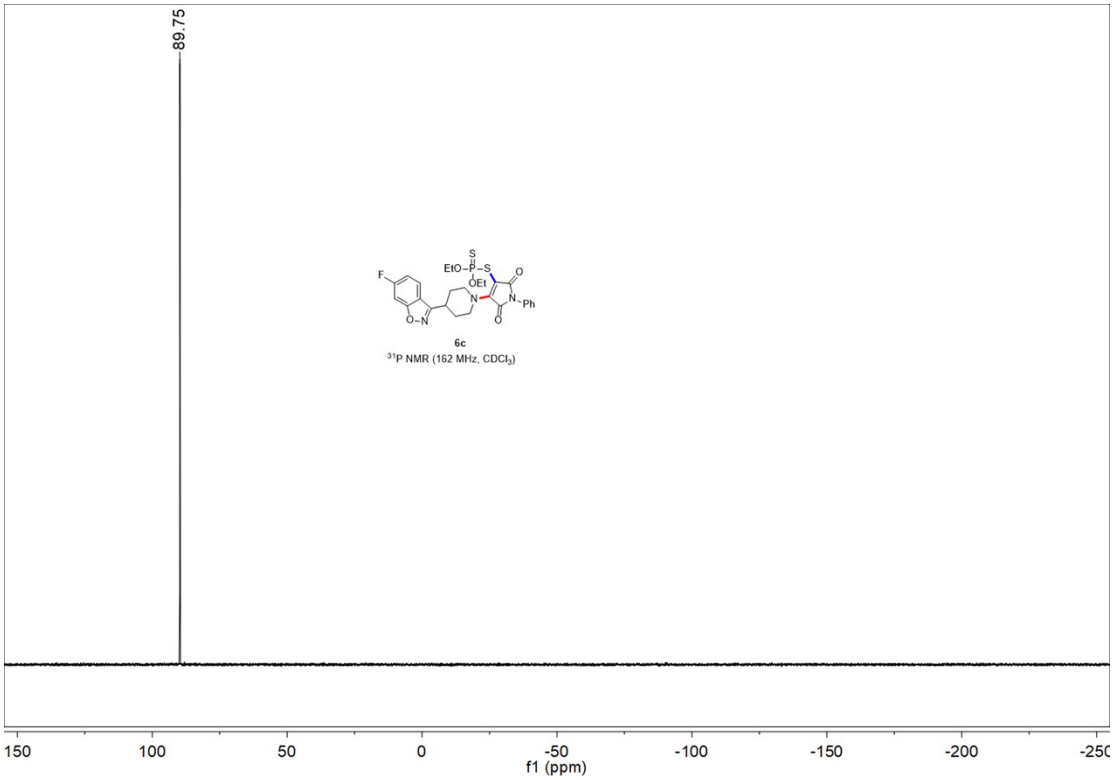

6b
1H NMR (500 MHz, CDCl3)
2.15
1.18
2.34
0.91
2.15
1.00
1.03
5.41
0.64
3.14
6.13
1.02
0.77
2.21
1.48
6.32
1.28
f1 (ppm)


171.14
168.15
167.07
166.18
153.09
152.56
140.69
131.50
129.62
129.01
128.00
126.20
104.34
89.78
65.22
60.83
60.38
56.00
53.65
50.57
46.89
27.77
22.05
21.04
15.95
14.20
MeO
OMe
MeO
EtO
OEt
P
S
S
O
N
Ph
6b
13C NMR (125 MHz, CDCl3)
200
180
160
140
120
100
80
60
40
20
0
f1 (ppm)


88.72
MeO
OMe
MeO
EtO
OEt
P
S
S
O
N
Ph
6b
31P NMR (162 MHz, CDCl3)
150
100
50
0
-50
-100
-150
-200
-250
f1 (ppm)

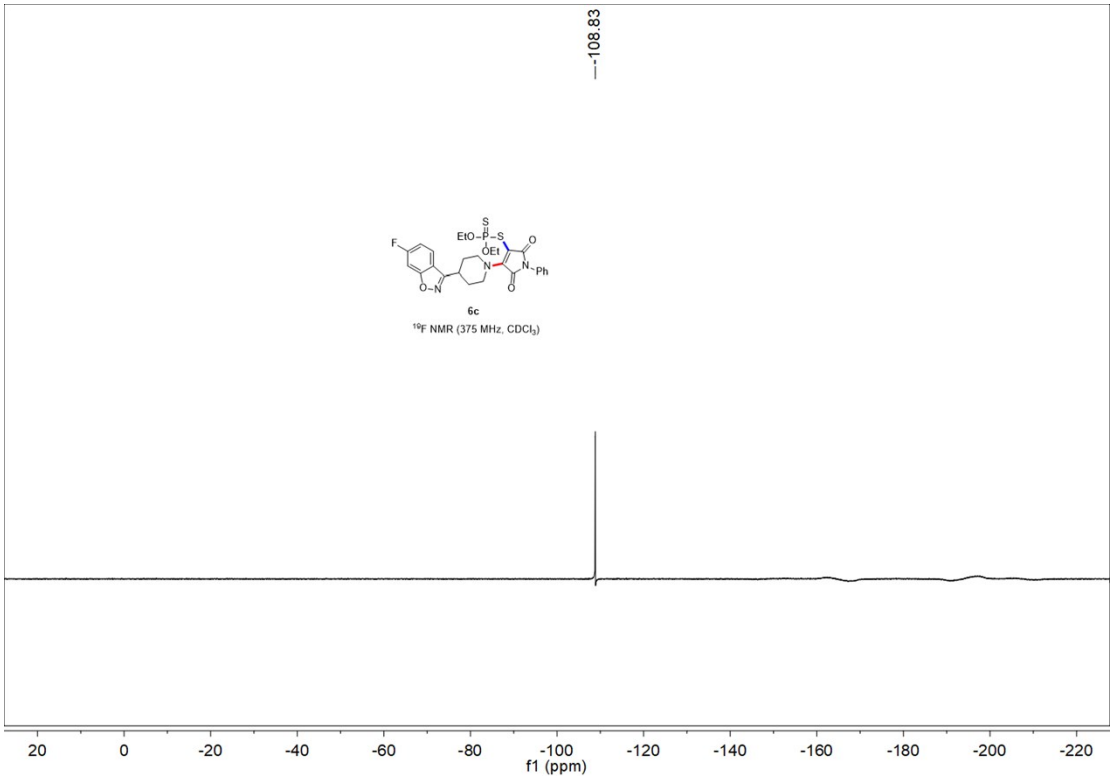

7.71 7.70 7.70 7.69 7.47 7.46 7.45 7.45 7.45 7.44 7.37 7.36 7.36 7.35 7.35 7.34 7.34 7.28 7.28 7.27 7.26 7.11 7.11 7.10 7.09 7.08 7.07 5.19 5.17 4.31 4.31 4.29 4.29 4.29 4.28 4.28 4.27 4.27 4.26 4.26 4.25 4.25 3.65 3.64 3.63 3.62 3.62 3.50 3.48 3.47 3.47 2.29 2.28 2.28 2.27 2.26 1.36 1.35 1.33
6c
1H NMR (500 MHz, CDCl3)
1.00 2.06 2.89 0.64 0.98 1.91 4.12 1.90 1.18 4.02 6.15
f1 (ppm)


168.48 165.26 165.01 164.06 163.95 159.84 150.51 131.76 128.99 127.84 126.42 122.33 122.24 116.97 112.86 112.65 97.74 97.53 86.30 65.05 65.00 48.93 33.54 30.63 16.00 15.93
6c
13C NMR (125 MHz, CDCl3)
f1 (ppm)



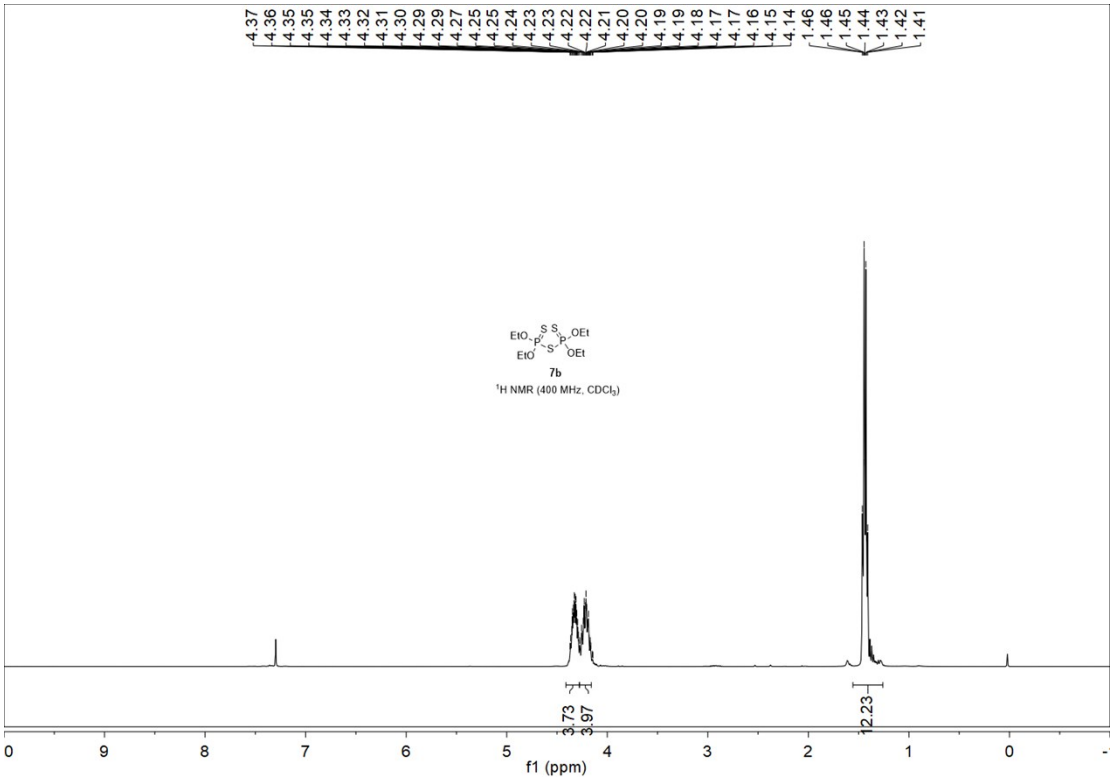
6c

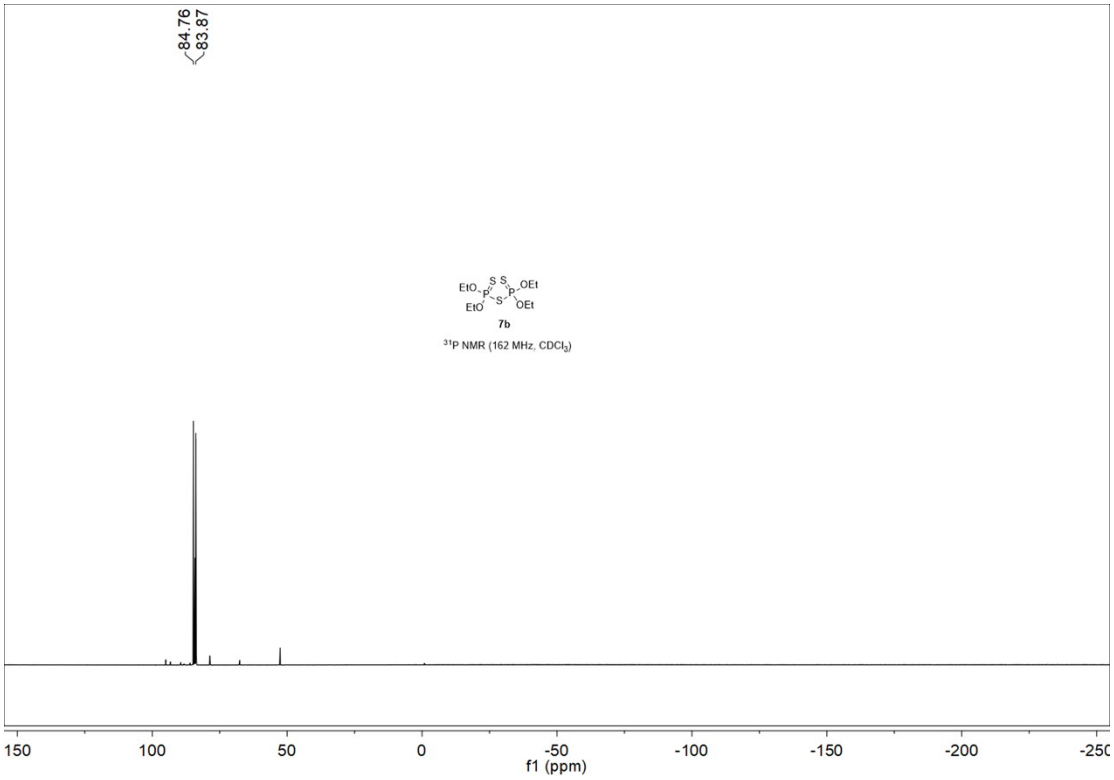
^{31}P NMR (162 MHz, $CDCl_3$)



6c

^{19}F NMR (375 MHz, $CDCl_3$)


4.37 4.36 4.35 4.35 4.34 4.33 4.32 4.31 4.30 4.29 4.29 4.27 4.25 4.25 4.24 4.23 4.23 4.22 4.22 4.21 4.20 4.20 4.19 4.19 4.18 4.17 4.17 4.16 4.15 4.14 1.46 1.46 1.45 1.44 1.43 1.42 1.41
7b
1H NMR (400 MHz, CDCl3)
3.73
3.97
12.23
f1 (ppm)


84.76
83.87
7b
31P NMR (162 MHz, CDCl3)
f1 (ppm)