Supporting Information

I_2-DMSO mediated multi-component cascade cyclization to construct pyrazolo[3,4-*b*]pyrrolo[3,4-*d*]pyridine-6-one skeleton

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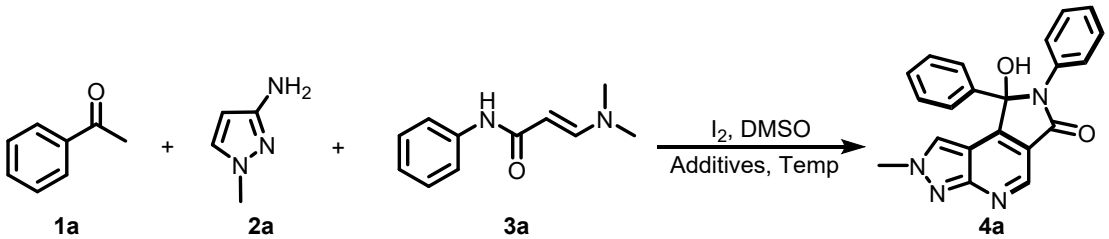
Table of Contents page

1. General.

All substrates and reagents were commercially available and used without further purification. TLC analysis was performed using pre-coated glass plates. Column chromatography was performed using silica gel (200–300 mesh). IR spectra were recorded on an Agilent 8700 LDIR infrared spectrometer with absorption in cm^{-1}. ^{1}H, ^{13}C, ^{19}F spectra were recorded in $CDCl_3$ or DMSO-d_6 on 400 MHz NMR spectrometers and chemical shifts of ^{1}H NMR are reported in ppm, relative to the internal standard of tetramethylsilane (TMS, δ = 0.00 ppm). Chemical shifts of ^{13}C NMR were reported in ppm with the solvent as the internal standard ($CDCl_3$, δ = 77.0 ppm; DMSO-d_6, δ = 77.0 ppm). Data are reported as follows: chemical shift, multiplicity (s = singlet, d = doublet, t = triplet, q = quartet, m = multiplet), coupling constants (Hz) and integration. ^{13}C spectra were recorded in $CDCl_3$ or DMSO-d_6 on 100 MHz NMR spectrometers and resonances (δ) are given in ppm. ^{19}F spectra were recorded in $CDCl_3$ or DMSO-d_6 on 376 MHz NMR spectrometers and resonances (δ) are given in ppm. High-resolution mass spectra (HRMS) were obtained by electrospray ionization (ESI) on a TOF mass analyzer. The *X-ray* crystal-structure determinations of **4a** was obtained on a Bruker SMART APEX CCD system. Melting points were determined using XT-4 apparatus and not corrected.

2. Screening of the reaction conditions[a]



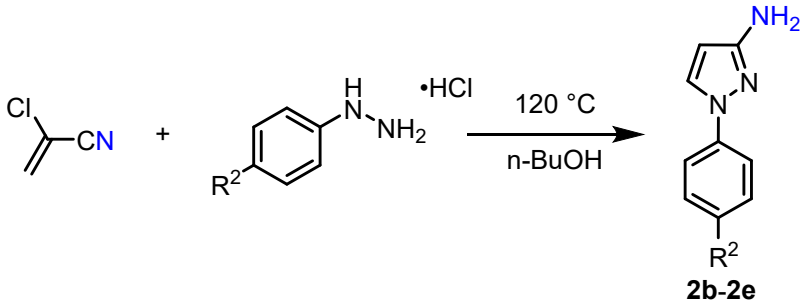
1a **2a** **3a** **4a**

Entry	I_2(x eq.)	Additives(x eq.)	Temp(°C)	Yield (%)[b]
1	1.6	-	100	48
2	1.6	50% HI (1.0)	100	55
3	1.6	CH_3CO_2H (1.0)	100	53
4	1.6	CF_3CO_2H (1.0)	100	32
5	1.6	CF_3SO_3H (1.0)	100	51
6	1.6	TsOH (1.0)	100	68
7	1.6	$ZnCl_2$ (1.0)	100	61
8	1.6	$CuBr_2$ (1.0)	100	57
9	1.6	$Cu(OTf)_2$ (1.0)	100	44
10	1.6	$FeCl_3$ (1.0)	100	59
11	1.6	$Fe(OTf)_3$ (1.0)	100	52
12	1.6	TsOH (0.5)	100	60
13	**1.6**	**TsOH (1.5)**	**100**	**75**
14	1.6	TsOH (2.0)	100	69
15	0.8	TsOH (1.5)	100	51
16	1.2	TsOH (1.5)	100	62
17	2.0	TsOH (1.5)	100	67
18	1.6	TsOH (1.5)	80	47
19	1.6	TsOH (1.5)	120	70

[a]Reaction conditions: **1a** (1.0 mmol), **2a** (1.0 mmol), **3a** (1.0 mmol), I_2 (x equiv), additive (x equiv), 6 h, DMSO (6.0 mL), indicated temperature, unless otherwise noted. [b]Isolated yields.

3. Operation methods for synthesis of target products.

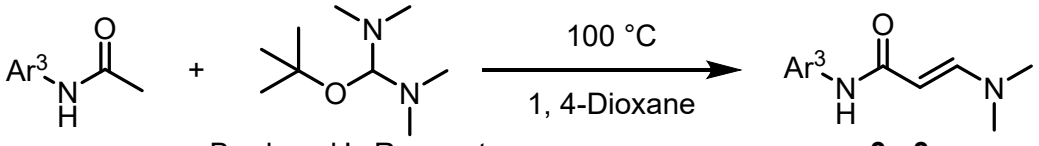
General procedure for the synthesis of 2.[1]



2b-2e

The substituted phenylhydrazine hydrochloride (5.0 mmol) was placed in a 38 mL glass reaction tube, and then Na_2CO_3 (529.9 mg, 5.0 mmol) was added separately, followed by 15 mL of *n*-Butanol as solvent, so that the mixture was stirred well on the reaction pot, and then 2-chloroacrylonitrile (437.6 mg, 5.0 mmol) was added, and finally the reaction was carried out at 120 ℃ for 10 h. The target product in the reaction solution could be detected by TLC, and after the reaction was completed, the fraction was extracted with saline and ethyl acetate, and the combined organic phases were spun dry, and finally the pure target product was obtained by column chromatography (eluent polarity, EA:PE = 5:1, yield above 80%).

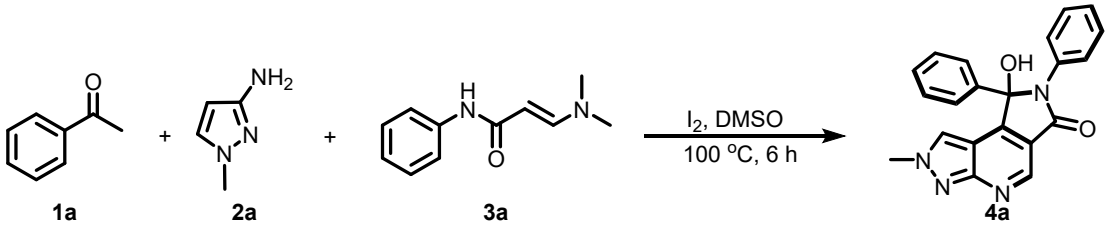
General procedure for the synthesis of 3.[2]



Bredereck's Reagent **3a-3g**

To a solution of acetanilide (5.0 mmol, 1.0 eq.) in 1,4-dioxane (12 mL), Bredereck's Reagent (20.0 mmol, 4.0 eq.) was added and stirred at 100 ℃. After 8 hours, the reaction solution can be transferred to a flask using ethyl acetate, concentrated under reduced pressure and filtered under reduced pressure, and finally washed with petroleum ether to obtain the target product. It can be used without column chromatographic separation and purification.

General procedure for the synthesis of 4, 7 and 9(4a as an example).



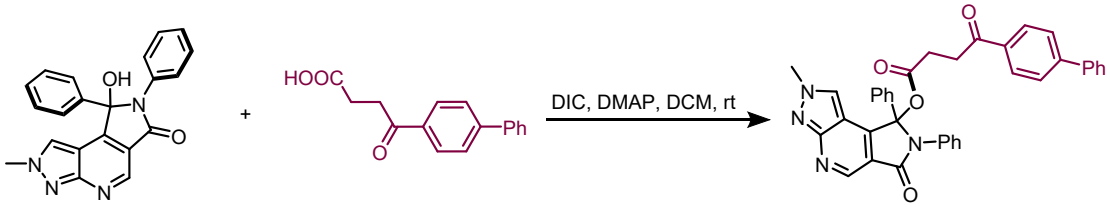
1a **2a** **3a** **4a**

1.0 mmol scale: The reactions did not require the protection of inert gases. In a 35 mL sealed tube were added acetophenone (**1a**) (120.1 mg, 1.0 mmol), iodine (406.1 mg, 1.6 mmol) and dimethyl sulfoxide (6.0 mL) and the resulting mixture was stirred at 100 ℃ (heating block), the reaction tube was removed after about 1 hour.

Then additional **2a** (97.1 mg, 1.0 mmol), **3a** (190.1 mg, 1.0 mmol), $TsOH \cdot H_2O$ (285.3 mg, 1.5 mmol) were added at room temperature, followed by reaction at 100 ℃ for 6 hours until substrate conversion was almost complete by TLC analysis. The reaction mixture was quenched with saturated $Na_2S_2O_3$ solution (50 mL) and NaCl solution (150 mL), then the mixture was extracted with EtOAc (150 mL x 2), the organic layers were separated and combined, dried over anhydrous Na_2SO_4 and concentrated under reduced pressure. The crude product was purified by column chromatography on silica gel (eluent polarity, EA:PE = 3:1) to afford the product **4a** (267.1 mg, 75% yield).

5.0 mmol scale: The reactions did not require the protection of inert gases. In a 100 mL round flask were added acetophenone (**1a**) (600.8 mg, 5.0 mmol), iodine (2030.5 mg, 8.0 mmol) and dimethyl sulfoxide (30 mL) and the resulting mixture was stirred in oil bath heating at 100 ℃, the round flask was removed after about 1.5 hours. Then additional **2a** (485.6 mg, 5.0 mmol), **3a** (950.6 mg, 5.0 mmol), $TsOH \cdot H_2O$ (1426.7 mg, 7.5 mmol) were added at room temperature, followed by reaction at 100 ℃ for 6 hours until substrate conversion was almost complete by TLC analysis. The reaction mixture was quenched with saturated $Na_2S_2O_3$ solution (150 mL) and NaCl solution (300 mL), then the mixture was extracted with EtOAc (300 mL x 2), the organic layers were separated and combined, dried over anhydrous Na_2SO_4 and concentrated under reduced pressure. The crude product was purified by column chromatography on silica gel (eluent: petroleum ether/EtOAc = 3:1) to afford the product **4a** (1.07 g, 60% yield).

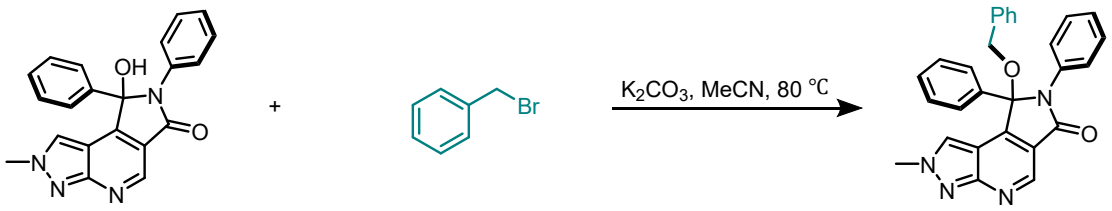
Synthesis of derivative 7.



4a **6** **7, 62%**

A mixture of **4a** (71.2 mg, 0.2 mmol), fenbufen **6** (55.9 mg, 0.22 mmol), 4-dimethylaminopyridine (DMAP, 0.06 mmol, 7.3 mg) were added to a 30 mL round-bottomed flask, then 5 mL of dichloromethane was added and mixed well to form a solution, and add the condensation reagent N, N-diisopropylcarbodiimide (DIC, 0.3 mmol, 37.8 mg) while stirring the solution. Keep the mixture stirred at room temperature for 6 hours using a magnetic stirrer to complete the reaction. At the end of the reaction, the organic phase was extracted and partitioned with ethyl acetate and NaCl aqueous solution, and the crude product mixture was obtained after rotary evaporation under reduced pressure. Finally, the pure target product was obtained by column chromatography separation.

Synthesis of derivative 9.



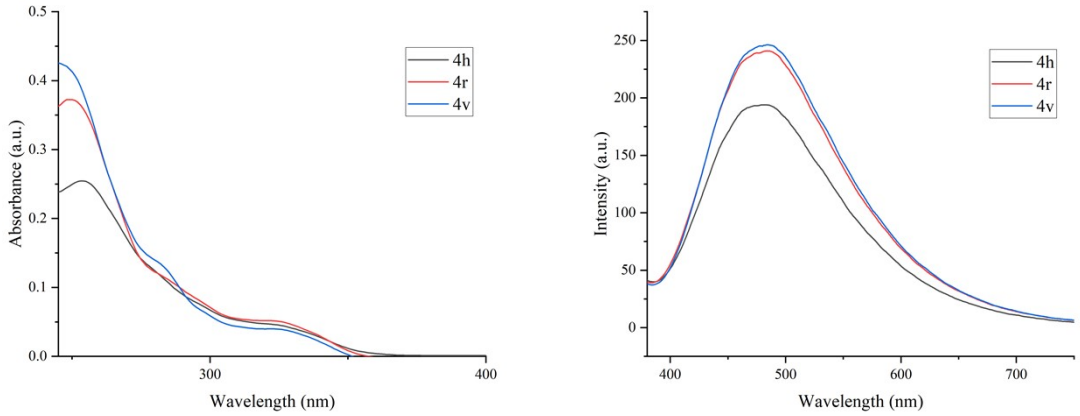
4a **8** **9, 65%**

A mixture of **4a** (126.4 mg, 0.2 mmol), benzyl bromide **7** (101.4 mg, 0.6 mmol), K_2CO_3 (0.4 mmol, 55.2 mg) were added to a 30 mL round-bottomed flask, then 5 mL of MeCN was added and mixed well to form a solution. The resulting mixture was stirred at 80 ºC (heating block) about 6 h till almost completed conversion of the substrates by TLC analysis. At the end of the reaction, the organic phase was extracted and partitioned with ethyl acetate and NaCl aqueous solution, and the crude product mixture was obtained after rotary evaporation under reduced pressure. Finally, the pure target product was obtained by column chromatography separation.

1.(a) H. Bredereck, G. Simchen, S. Rebsdat, W. Kantlehner, P. Horn, R. Wahl, H. Hoffmann and P. Grieshaber, *Chem. Ber.*, 1968, **101**, 41-50; (b) P. F. Schuda, C. B. Ebner and T. M. Morgan, *Tetrahedron Lett.*, 1986, **27**, 2567-2570; (c) E. Morera, F. Pinnen and G. Lucente, *Org. Lett.*, 2002, **4**, 1139-1142; (d) Y. Zhou, L. S. Wang, S. G. Lei, Y. X. Gao, J. T. Ma, Z. C. Yu, Y. D. Wu and A. X. Wu, *Org. Chem. Front.*, 2022, **9**, 4416-4420; (e) X. Shen, Z. Yu, Y. Zhou, Y. Wu and A. Wu, *Adv Synth Catal*, 2024, **366**, 4399-4403.

2. M. C. Bagley, M. Baashen, V. L. Paddock, D. Kipling and T. Davis, *Tetrahedron*, 2013, **69**, 8429-8438.

4. Study on the practicability of the reaction[3]



Absorption and emission spectra of compound 4h, 4r, 4v in THF; c = 10^{-5} mol L^{-1}

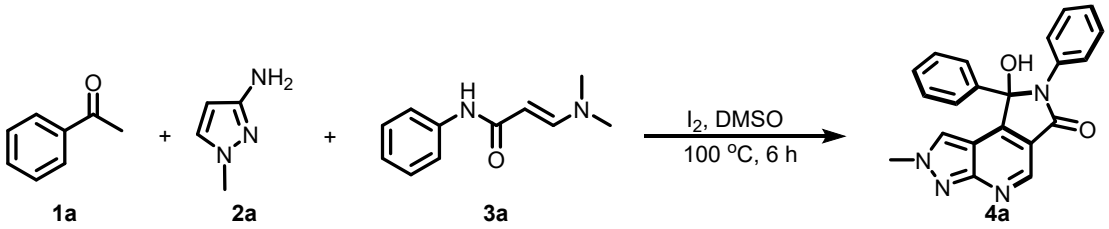
In the absorption spectrum, these compounds exhibit two highly intense absorption maxima peaks. Among these two, the first one was a high energy absorption between 250 nm and 260 nm, probably due to the π-π transition of the aryl core while the low energy band between 320 nm and 330 nm is attributed to the intramolecular charge transfer transition (ICT).

In the emission spectrum, these compounds provided the weak fluorescence intensity, so that they were the inappropriate photoluminescent substrates.

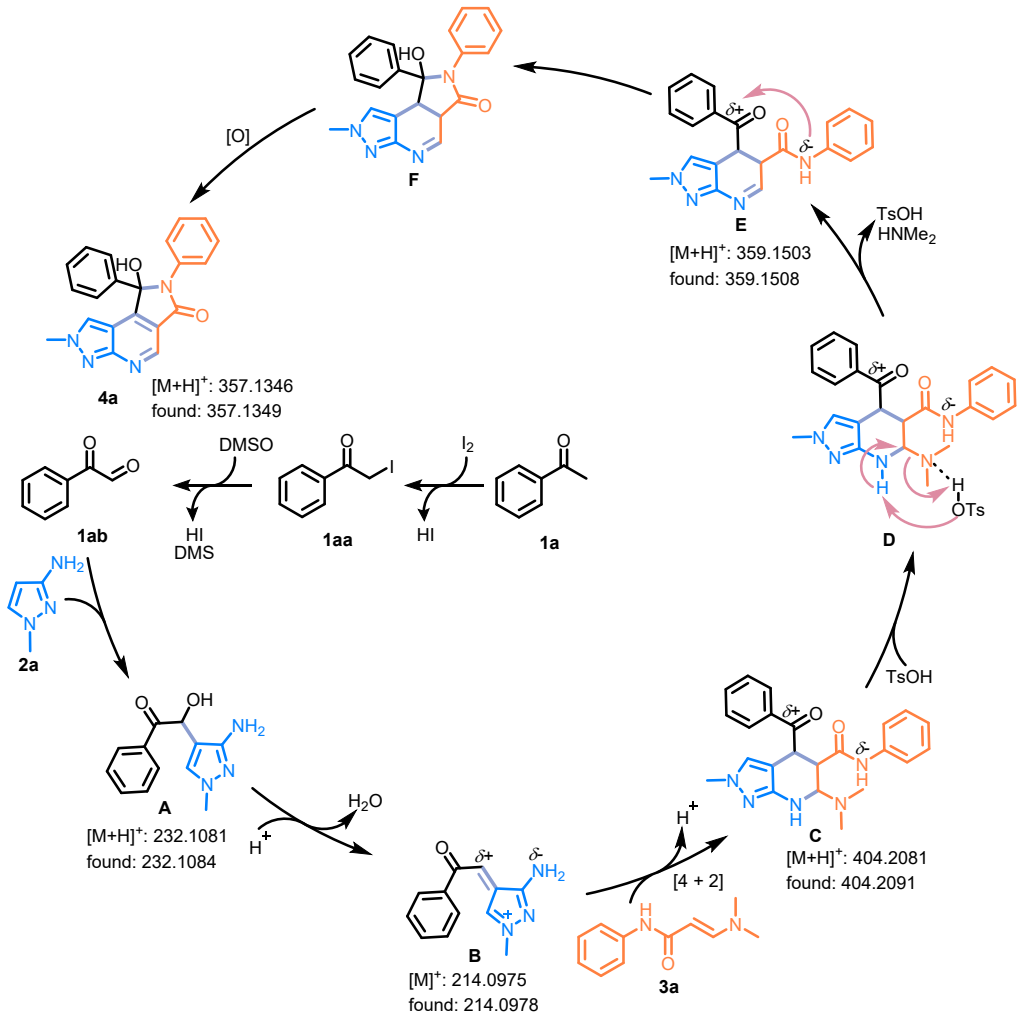
3. C. C. Tseng, C. Y. Chung, S. E. Tsai, H. Takayama, N. Uramaru, C. Y. Lin and F. F. Wong, *Molecules*, 2020, **25**, 2409.

5. Mechanistic study

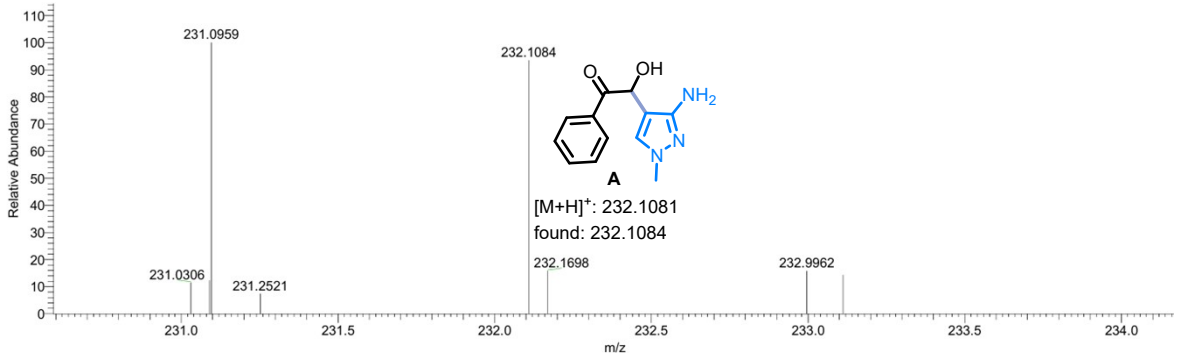
The mechanism of HRMS.

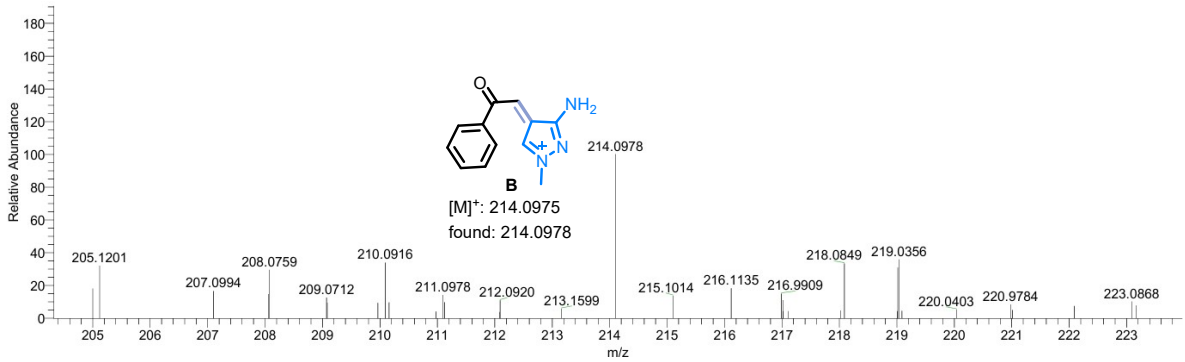


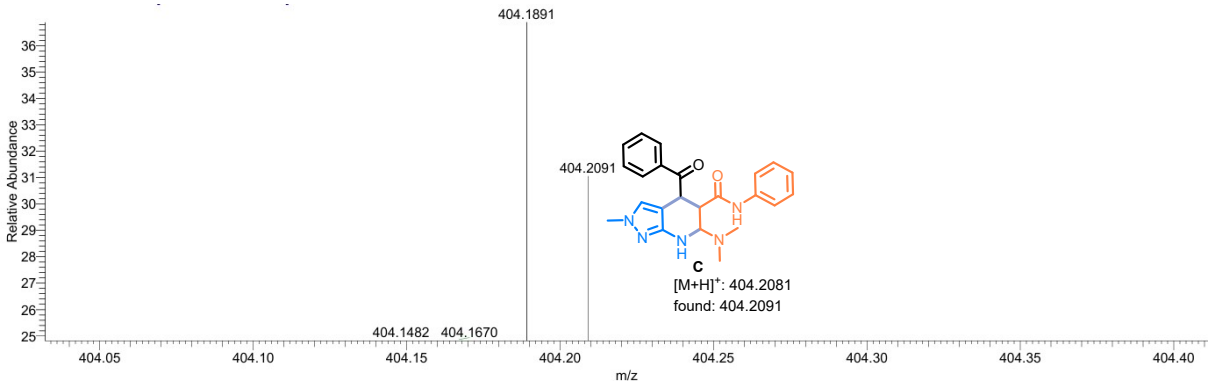
The reactions did not require the protection of inert gases. In a 35 mL sealed tube were added acetophenone (**1a**) (120.1 mg, 1.0 mmol), iodine (406.1 mg, 1.6 mmol) and dimethyl sulfoxide (4 mL) and the resulting mixture was stirred at 100 ℃ (heating block), the reaction tube was removed after about 1 hour. Then additional **2a** (97.1 mg, 1.0 mmol), **3a** (190.1 mg, 1.0 mmol) and TsOH·H_2O (285.3 mg, 1.5 mmol) were added at room temperature, followed by reaction at 100 ℃ for 0.5 hours, then wait for the reaction to cool to room temperature. Take 0.5 mL of reaction solution and dilute it with 4 mL of CH_2Cl_2. Then 1.5 mL of the extraction solution was added into the test bottle, the samples were immediately monitored by Agilent LC1290-TOF 6224 high resolution mass spectrometers.

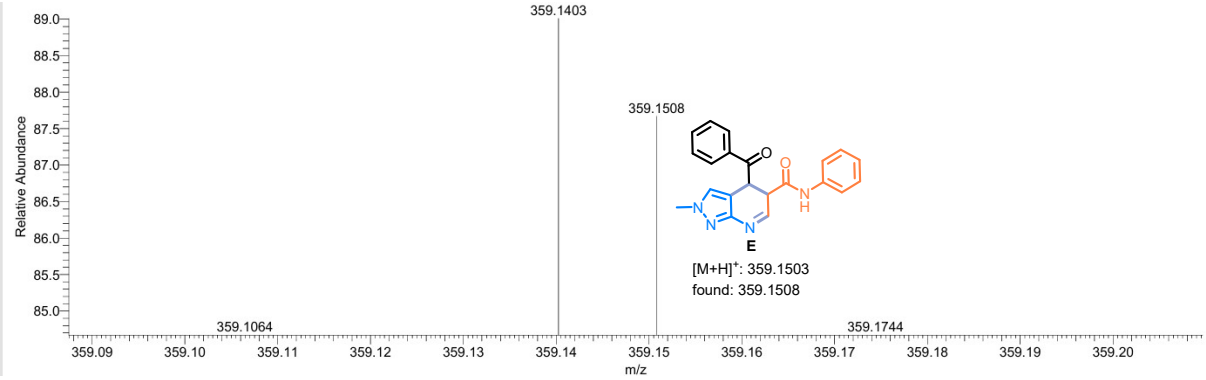


Spectrum of HRMS:

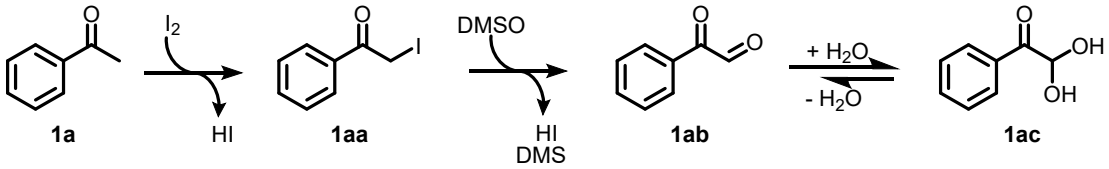






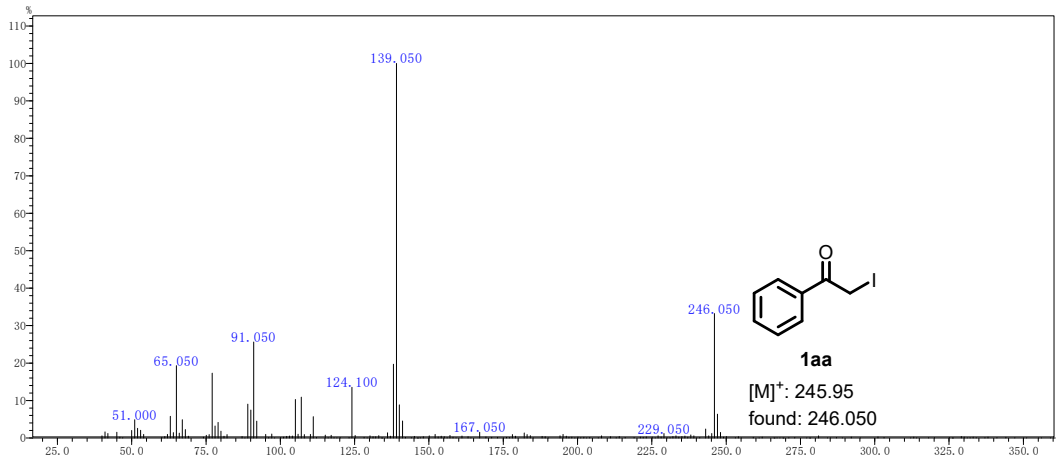


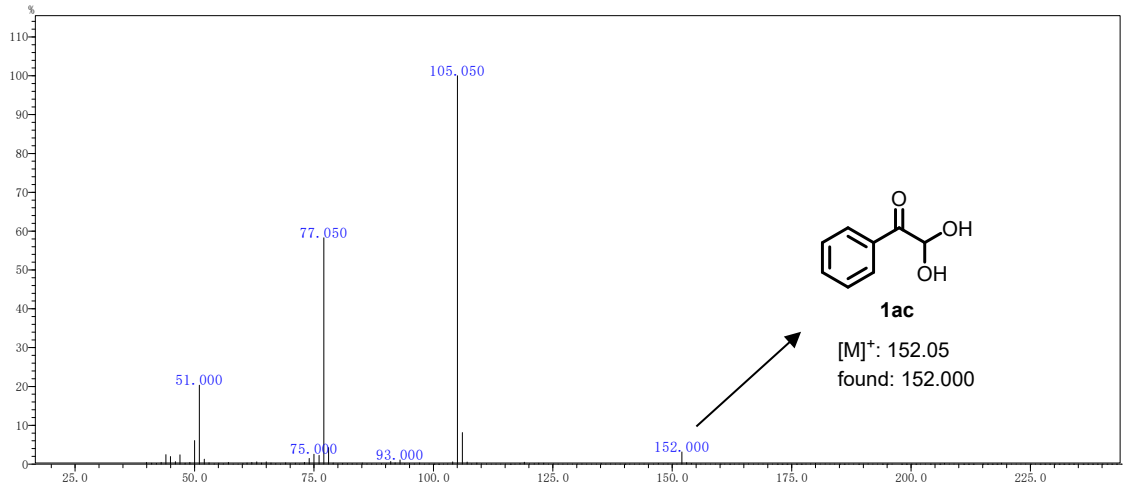
The mechanism of GC-MS.



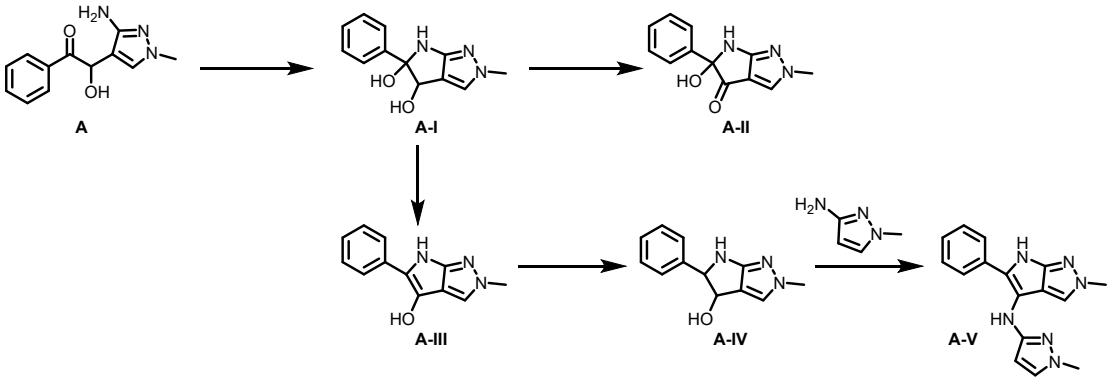
The reactions did not require the protection of inert gases. In a 35 mL sealed tube were added acetophenone (**1a**) (120.1 mg, 1.0 mmol), iodine (406.1 mg, 1.6 mmol) and dimethyl sulfoxide (4 mL) and the resulting mixture was stirred at 100 ℃ (heating block), the reaction tube was removed after about 1 hour. Then additional **2a** (97.1 mg, 1.0 mmol), **3a** (190.1 mg, 1.0 mmol) and TsOH·H_2O (285.3 mg, 1.5 mmol) were added at room temperature, followed by reaction at 100 ℃ for 1.0 hours, then wait for the reaction to cool to room temperature. Take 1.0 mL of reaction solution and dilute it with 4 mL of CH_2Cl_2. Then 1.5 mL of the extraction solution was added into the test bottle, the samples were immediately monitored by GCMS-QP2020.

Spectrum of GC-MS:

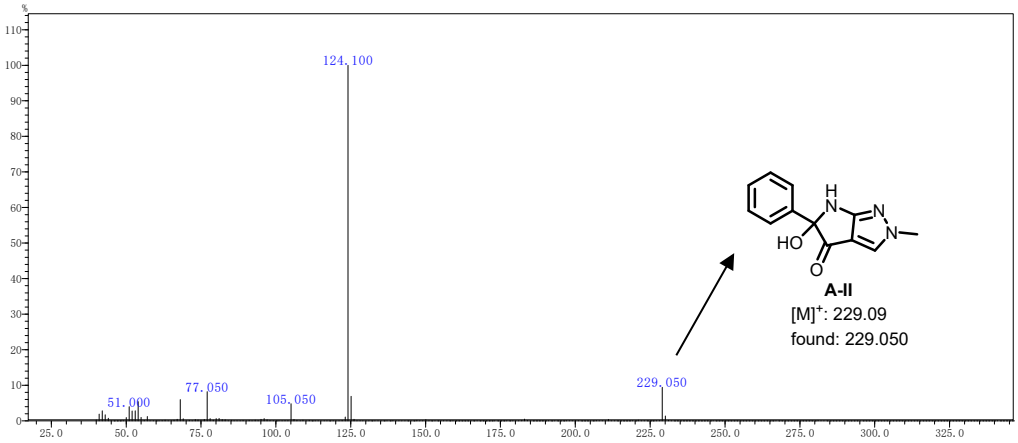


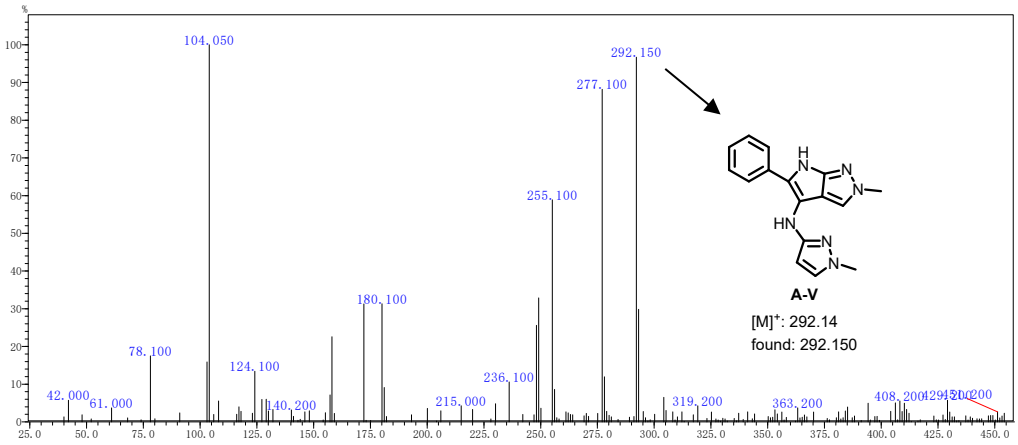


side reaction

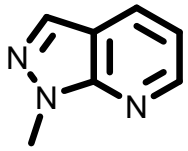


Spectrum of GC-MS:





6. DFT calculations.



1-methyl-1*H*-pyrazolo[3,4-*b*]pyridine

Zero-point correction=	0.135984 (Hartree/Particle)
Thermal correction to Energy=	0.142718
Thermal correction to Enthalpy=	0.143662
Thermal correction to Gibbs Free Energy=	0.104560
Sum of electronic and zero-point Energies=	-434.560767
Sum of electronic and thermal Energies=	-434.554034
Sum of electronic and thermal Enthalpies=	-434.553090
Sum of electronic and thermal Free Energies=	-434.592192

Cartesian coordinates

C	0	-0.768840	2.531075	0.000000
C	0	-2.253912	2.531075	0.000000
C	0	-2.233028	4.944471	0.000000
C	0	-0.789724	4.944471	0.000000
C	0	-0.079580	3.789357	0.000000
C	0	-0.325963	1.239537	0.000000
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H	0	1.019998	3.781779	0.000000
H	0	0.699117	0.876948	0.000000
N	0	-2.943172	3.789357	0.000000
N	0	-2.696789	1.239537	0.000000
N	0	-1.511376	0.310026	0.000000
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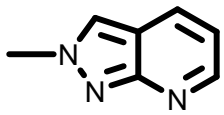


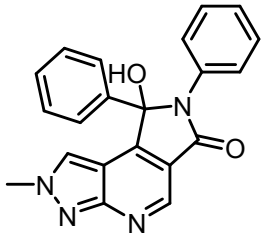
2-methyl-2*H*-pyrazolo[3,4-*b*]pyridine

Zero-point correction=	0.135900 (Hartree/Particle)
Thermal correction to Energy=	0.142561
Thermal correction to Enthalpy=	0.143505
Thermal correction to Gibbs Free Energy=	0.104592
Sum of electronic and zero-point Energies=	-434.546622
Sum of electronic and thermal Energies=	-434.539961
Sum of electronic and thermal Enthalpies=	-434.539017
Sum of electronic and thermal Free Energies=	-434.577930

Cartesian coordinates

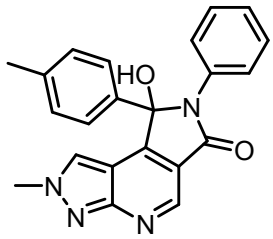
C	0	-0.768840	2.531075	0.000000
C	0	-2.253912	2.531075	0.000000
C	0	-2.233028	4.944471	0.000000
C	0	-0.789724	4.944471	0.000000
C	0	-0.079580	3.789357	0.000000
C	0	-0.325963	1.239537	0.000000
H	0	-2.739177	5.921461	0.000000
H	0	-0.283575	5.921461	0.000000
H	0	1.019998	3.781779	0.000000
H	0	0.699117	0.876948	0.000000
N	0	-2.943172	3.789357	0.000000
N	0	-2.696789	1.239537	0.000000
N	0	-1.511376	0.310026	0.000000
C	0	-1.511376	-1.159974	0.000000
H	0	-1.008668	-1.516640	-0.874628
H	0	-1.005280	-1.516640	0.872672
H	0	-2.520180	-1.516641	0.001956

7. Characterization data for compounds.



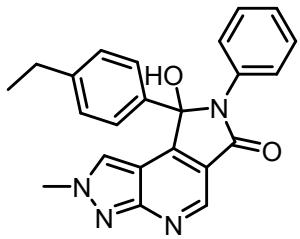
8-hydroxy-2-methyl-7,8-diphenyl-7,8-dihydropyrazolo[3,4-*b*]pyrrolo[3,4-*d*]pyridin-6(2*H*)-one (4a):

Yield 75%; 267.1 mg; yellow solid; column chromatography, silica gel (PE:EA, 3:1); mp 270-272 ℃. IR: 3655, 3116, 2922, 1707, 1632, 1453, 1364, 1207, 1140, 1051, 916 cm^{-1}. ^1H NMR (400 MHz, DMSO-d_6) δ 9.03 (s, 1H), 8.44 (s, 1H), 8.04 (s, 1H), 7.60–7.47 (m, 4H), 7.34–7.21 (m, 5H), 7.14 (s, 1H), 4.19 (s, 3H). ^{13}C NMR (100 MHz, DMSO-d_6) δ 165.9, 160.2, 153.5, 145.2, 138.3, 136.3, 128.7, 128.4, 126.0, 125.6, 125.1, 124.4, 118.1, 106.3, 91.4, 40.9. HRMS (ESI): m/z $[M+H]^+$ calcd for $C_{21}H_{17}N_4O_2^+$: 357.1346; found: 357.1338.



8-hydroxy-2-methyl-7-phenyl-8-(p-tolyl)-7,8-dihydropyrazolo[3,4-*b*]pyrrolo[3,4-*d*]pyridin-6(2*H*)-one (4b):

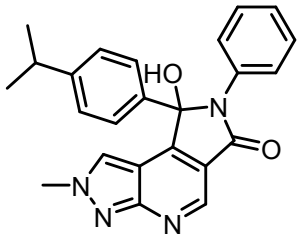
Yield 73%; 270.2 mg; white solid; column chromatography, silica gel (PE:EA, 3:1); mp 264-266 ℃. IR: 3653, 3093, 2959, 1702, 1632, 1492, 1364, 1323, 1177, 1088, 920 cm^{-1}. ^1H NMR (400 MHz, DMSO-d_6) δ 9.04 (s, 1H), 8.45 (s, 1H), 8.01 (s, 1H), 7.60 (d, J = 7.6 Hz, 2H), 7.41 (d, J = 8.0 Hz, 2H), 7.30 (t, J = 8.0 Hz, 2H), 7.16–7.08 (m, 3H), 4.19 (s, 3H), 2.20 (s, 3H). ^{13}C NMR (100 MHz, DMSO-d_6) δ 165.9, 160.2, 153.7, 145.3, 137.7, 136.5, 135.4, 129.3, 128.4, 125.9, 125.6, 125.0, 124.4, 118.0, 106.3, 91.5, 40.9, 20.6. HRMS (ESI): m/z $[M+H]^+$ calcd for $C_{22}H_{19}N_4O_2^+$: 371.1503; found: 371.1501.



8-(4-ethylphenyl)-8-hydroxy-2-methyl-7-phenyl-7,8-dihydropyrazolo[3,4-*b*]pyrrolo[3,4-*d*]pyridin-6(2*H*)-one (4c):

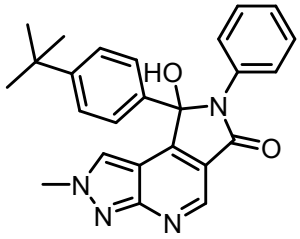
Yield 70%; 268.9 mg; white solid; column chromatography, silica gel (PE:EA, 3:1); mp 235-237 ℃. IR: 3658, 3190, 2959, 1699, 1632, 1498, 1408, 1352, 1312, 1200, 916 cm^{-1}. ^1H NMR (400 MHz, DMSO-d_6) δ 9.02 (s, 1H), 8.46 (s, 1H), 8.00 (s, 1H), 7.60 (d, J = 8.0 Hz, 2H), 7.43 (d, J = 8.0 Hz, 2H), 7.29 (t, J = 8.0 Hz, 2H), 7.16–7.11 (m, 3H), 4.19 (s, 3H), 2.51 (d, J = 7.6

Hz, 2H), 1.08 (t, *J* = 7.6 Hz, 3H). ^{13}C NMR (100 MHz, DMSO-d_6) δ 165.9, 160.2, 153.6, 145.2, 143.8, 136.5, 135.6, 128.4, 128.1, 126.0, 125.5, 125.0, 124.4, 118.0, 106.3, 91.5, 40.9, 27.6, 14.9. HRMS (ESI): m/z $[M+H]^+$ calcd for $C_{23}H_{21}N_4O_2^+$: 385.1659; found: 385.1656.



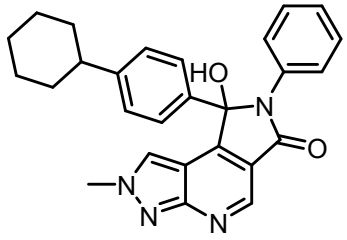
8-hydroxy-8-(4-isopropylphenyl)-2-methyl-7-phenyl-7,8-dihydropyrazolo[3,4-*b*]pyrrolo[3,4-*d*]pyridin-6(2*H*)-one (4d):

Yield 71%; 282.7 mg; white solid; column chromatography, silica gel (PE:EA, 3:1); mp 218-220 ℃. IR: 3646, 3190, 2646, 1699, 1632, 1490, 1356, 1328, 1140, 1051, 924 cm^{-1}. ^{1}H NMR (400 MHz, DMSO-d_6) δ 9.02 (s, 1H), 8.48 (s, 1H), 8.00 (s, 1H), 7.62 (d, *J* = 7.6 Hz, 2H), 7.45 (d, *J* = 8.4 Hz, 2H), 7.30 (t, *J* = 8.0 Hz, 2H), 7.19–7.13 (m, 3H), 4.19 (s, 3H), 2.83–2.76 (m, 1H), 1.11 (s, 3H), 1.09 (s, 3H). ^{13}C NMR (100 MHz, DMSO-d_6) δ 165.9, 160.2, 153.6, 148.3, 145.2, 136.5, 135.7, 128.4, 126.7, 126.0, 125.5, 125.0, 124.5, 117.9, 106.3, 91.6, 40.9, 32.8, 23.7, 23.4. HRMS (ESI): m/z $[M+H]^+$ calcd for $C_{24}H_{23}N_4O_2^+$: 399.1816; found: 399.1814.



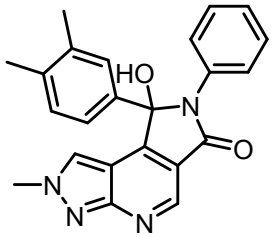
8-(4-(tert-butyl)phenyl)-8-hydroxy-2-methyl-7-phenyl-7,8-dihydropyrazolo[3,4-*b*]pyrrolo[3,4-*d*]pyridin-6(2*H*)-one (4e):

Yield 68%; 280.3 mg; white solid; column chromatography, silica gel (PE:EA, 3:1); mp 214-216 ℃. IR: 3652, 3183, 2967, 1702, 1498, 1416, 1394, 1036, 924, 805 cm^{-1}. ^{1}H NMR (400 MHz, DMSO-d_6) δ 9.02 (s, 1H), 8.49 (s, 1H), 8.00 (s, 1H), 7.62 (d, *J* = 8.0 Hz, 2H), 7.47 (d, *J* = 8.4 Hz, 2H), 7.32 (d, *J* = 8.4 Hz, 2H), 7.29 (d, *J* = 8.0 Hz, 2H), 7.13 (t, *J* = 7.6 Hz, 1H), 4.20 (s, 3H), 1.18 (s, 9H). ^{13}C NMR (100 MHz, DMSO-d_6) δ 165.9, 160.2, 153.6, 150.7, 145.3, 136.5, 135.4, 128.4, 125.7, 125.5, 125.0, 124.5, 117.9, 106.3, 91.6, 40.9, 34.2, 31.0. HRMS (ESI): m/z $[M+H]^+$ calcd for $C_{25}H_{25}N_4O_2^+$: 413.1972; found: 413.1969.



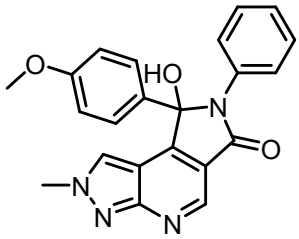
8-(4-cyclohexylphenyl)-8-hydroxy-2-methyl-7-phenyl-7,8-dihydropyrazolo[3,4-*b*]pyrrolo[3,4-*d*]pyridin-6(2*H*)-one (4f):

Yield 65%; 284.8 mg; white solid; column chromatography, silica gel (PE:EA, 3:1); mp 228-230℃. IR: 3655, 2922, 2847, 1714, 1490, 1416, 1352, 1319, 1136, 1043, 916 cm^{-1}. ^1H NMR (400 MHz, DMSO-d_6) δ 9.02 (s, 1H), 8.48 (s, 1H), 8.00 (s, 1H), 7.61 (d, J = 8.0 Hz, 2H), 7.45 (d, J = 8.4 Hz, 2H), 7.29 (t, J = 8.0 Hz, 2H), 7.17–7.11 (m, 3H), 4.18 (s, 3H), 2.40 (s, 1H), 1.75–1.62 (m, 5H), 1.33–1.20 (m, 5H). ^{13}C NMR (100 MHz, DMSO-d_6) δ 165.9, 160.2, 153.6, 147.6, 145.2, 136.5, 135.7, 128.4, 127.0, 125.9, 125.5, 125.0, 124.5, 117.9, 106.3, 91.6, 43.1, 40.9, 33.9, 33.5, 26.3, 26.2, 25.5. HRMS (ESI): m/z $[M+H]^+$ calcd for $C_{27}H_{27}N_4O_2^+$: 439.2129; found: 439.2125.



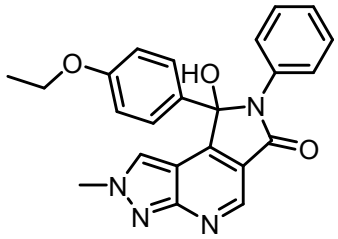
8-(3,4-dimethylphenyl)-8-hydroxy-2-methyl-7-phenyl-7,8-dihydropyrazolo[3,4-*b*]pyrrolo[3,4-*d*]pyridin-6(2*H*)-one (4g):

Yield 60%; 230.5 mg; yellow solid; column chromatography, silica gel (PE:EA, 3:1); mp 265-267 ℃. IR: 3655, 3235, 2922, 1693, 1632, 1498, 1352, 1312, 1133, 1058, 857 cm^{-1}. ^1H NMR (400 MHz, DMSO-d_6) δ 9.00 (s, 1H), 8.42 (s, 1H), 7.92 (s, 1H), 7.58 (d, J = 8.0 Hz, 2H), 7.31–7.24 (m, 4H), 7.13 (t, J = 7.6 Hz, 1H), 7.06 (d, J = 8.4 Hz, 1H), 4.19 (s, 3H), 2.11 (d, J = 4.0 Hz, 6H). ^{13}C NMR (100 MHz, DMSO-d_6) δ 165.8, 160.1, 153.7, 145.2, 136.5, 136.4, 135.7, 129.8, 128.4, 126.7, 125.5, 124.9, 124.4, 123.4, 117.9, 106.2, 91.5, 40.9, 19.5, 19.0. HRMS (ESI): m/z $[M+H]^+$ calcd for $C_{23}H_{21}N_4O_2^+$: 385.1659; found: 385.1656.



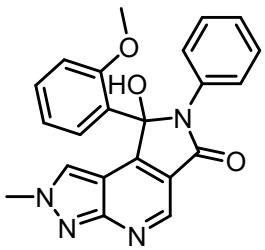
8-hydroxy-8-(4-methoxyphenyl)-2-methyl-7-phenyl-7,8-dihydropyrazolo[3,4-*b*]pyrrolo[3,4-*d*]pyridin-6(2*H*)-one (4h):

Yield 76%; 293.5 mg; white solid; column chromatography, silica gel (PE:EA, 3:1); mp 236-238 ℃. IR: 3655, 3168, 2922, 1702, 1638, 1364, 1244, 1177, 1028, 924 cm^{-1}. ^1H NMR (400 MHz, DMSO-d_6) δ 9.00 (s, 1H), 8.41 (s, 1H), 7.93 (s, 1H), 7.56 (d, J = 7.6 Hz, 2H), 7.40 (d, J = 7.2 Hz, 2H), 7.30 (t, J = 7.6 Hz, 2H), 7.14 (t, J = 7.2 Hz, 1H), 6.83 (d, J = 8.8 Hz, 2H), 4.19 (s, 3H), 3.67 (s, 3H). ^{13}C NMR (100 MHz, DMSO-d_6) δ 165.8, 160.2, 159.0, 153.7, 145.2, 136.4, 130.0, 128.4, 127.4, 125.6, 125.1, 124.4, 117.9, 114.0, 106.3, 91.4, 55.0, 40.9. HRMS (ESI): m/z $[M+H]^+$ calcd for $C_{22}H_{19}N_4O_3^+$: 387.1452; found: 387.1442.



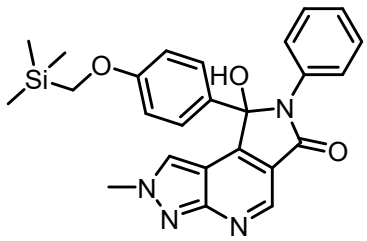
8-(4-ethoxyphenyl)-8-hydroxy-2-methyl-7-phenyl-7,8-dihydropyrazolo[3,4-*b*]pyrrolo[3,4-*d*]pyridin-6(2*H*)-one (4i):

Yield 73%; 292.1 mg; white solid; column chromatography, silica gel (PE:EA, 3:1); mp 231-233 °C. IR: 3652, 3116, 2946, 1690, 1640, 1504, 1431, 1351, 1140, 1043, 916 cm^{-1}. ^1H NMR (400 MHz, DMSO-d_6) δ 9.04 (s, 1H), 8.44 (s, 1H), 7.97 (s, 1H), 7.60 (d, J = 8.0 Hz, 2H), 7.43 (d, J = 8.8 Hz, 2H), 7.31 (t, J = 8.0 Hz, 2H), 7.14 (t, J = 7.6 Hz, 1H), 6.83 (d, J = 8.8 Hz, 2H), 4.21 (s, 3H), 3.91 (m, J = 6.8, 3.2 Hz, 2H), 1.24 (t, J = 6.8 Hz, 3H). ^{13}C NMR (100 MHz, DMSO-d_6) δ 165.8, 160.2, 158.4, 153.8, 145.3, 136.5, 129.9, 128.4, 127.4, 125.6, 125.1, 124.4, 118.0, 114.4, 106.3, 91.5, 63.0, 40.9, 14.6. HRMS (ESI): m/z $[M+H]^+$ calcd for $C_{23}H_{21}N_4O_3^+$: 401.1608; found: 401.1605.



8-hydroxy-8-(2-methoxyphenyl)-2-methyl-7-phenyl-7,8-dihydropyrazolo[3,4-*b*]pyrrolo[3,4-*d*]pyridin-6(2*H*)-one (4j):

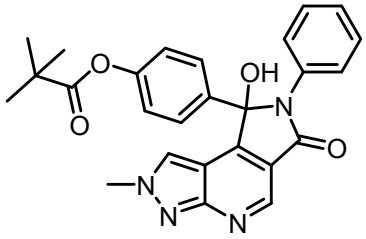
Yield 68%; 262.6 mg; white solid; column chromatography, silica gel (PE:EA, 3:1); mp 253-255 °C. IR: 3652, 3011, 2773, 1690, 1595, 1490, 1312, 1028, 908, 785, 750 cm^{-1}. ^1H NMR (400 MHz, DMSO-d_6) δ 9.02 (s, 1H), 8.20 (s, 1H), 8.06 (d, J = 6.8 Hz, 1H), 7.87 (s, 1H), 7.51 (d, J = 8.0 Hz, 2H), 7.28–7.22 (m, 3H), 7.09 (t, J = 7.6 Hz, 1H), 7.02 (t, J = 7.6 Hz, 1H), 6.74 (d, J = 8.4 Hz, 1H), 4.16 (s, 3H), 3.30 (s, 3H). ^{13}C NMR (100 MHz, DMSO-d_6) δ 166.3, 160.2, 155.9, 152.9, 144.9, 136.7, 130.4, 128.6, 128.2, 125.5, 125.4, 124.9, 123.8, 120.4, 120.1, 111.6, 106.6, 89.3, 55.3, 40.8. HRMS (ESI): m/z $[M+H]^+$ calcd for $C_{22}H_{19}N_4O_3^+$: 387.1452; found: 387.1449.



8-hydroxy-2-methyl-7-phenyl-8-(4-((trimethylsilyl)methoxy)phenyl)-7,8-dihydropyrazolo[3,4-*b*]pyrrolo[3,4-*d*]pyridin-6(2*H*)-one (4k):

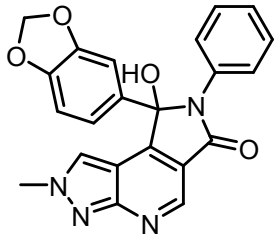
Yield 60%; 274.9 mg; white solid; column chromatography, silica gel (PE:EA, 3:1); mp 227-229 °C. IR: 3658, 3220, 2952, 1708, 1640, 1513, 1423, 1356, 1222, 1021, 924 cm^{-1}. ^1H NMR

(400 MHz, DMSO-d_6) δ 9.01 (s, 1H), 8.41 (s, 1H), 7.93 (s, 1H), 7.57 (d, J = 8.0 Hz, 2H), 7.39 (d, J = 8.8 Hz, 2H), 7.30 (t, J = 8.0 Hz, 2H), 7.14 (t, J = 7.6 Hz, 1H), 6.87 (d, J = 8.8 Hz, 2H), 4.19 (s, 3H), 3.51 (d, J = 5.2 Hz, 2H), 0.06 (s, 9H). ^{13}C NMR (100 MHz, DMSO-d_6) δ 165.8, 160.9, 160.2, 153.8, 145.2, 136.5, 129.8, 128.4, 127.2, 125.5, 125.1, 124.4, 117.9, 114.1, 106.3, 91.4, 60.5, 40.9, -3.17. HRMS (ESI): m/z $[M+H]^+$ calcd for $C_{25}H_{27}N_4O_3Si^+$: 459.1847; found: 459.1843.



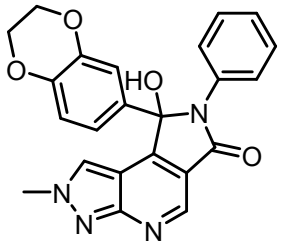
4-(8-hydroxy-2-methyl-6-oxo-7-phenyl-2,6,7,8-tetrahydropyrazolo[3,4-*b*]pyrrolo[3,4-*d*]pyridin-8-yl)phenyl pivalate (4l):

Yield 58%; 264.6 mg; white solid; column chromatography, silica gel (PE:EA, 3:1); mp 233-235℃. IR: 3646, 3063, 2967, 1743, 1692, 1632, 1498, 1416, 1356, 1274, 1118, 916 cm^{-1}. ^{1}H NMR (400 MHz, DMSO-d_6) δ 9.04 (s, 1H), 8.47 (s, 1H), 8.10 (s, 1H), 7.58–7.54 (m, 4H), 7.31 (t, J = 8.0 Hz, 2H), 7.16 (t, J = 7.2 Hz, 1H), 7.04 (d, J = 8.8 Hz, 2H), 4.21 (s, 3H), 1.24 (s, 9H). ^{13}C NMR (100 MHz, DMSO-d_6) δ 176.0, 165.8, 160.2, 153.3, 150.5, 145.2, 136.2, 135.6, 128.5, 127.3, 125.8, 125.3, 124.3, 121.8, 118.1, 106.2, 91.2, 40.9, 38.5, 26.6. HRMS (ESI): m/z $[M+H]^+$ calcd for $C_{26}H_{25}N_4O_4^+$: 457.1870; found: 457.1866.



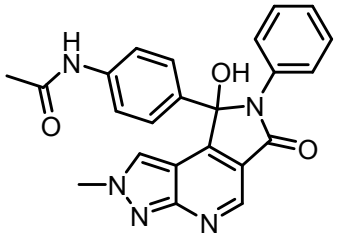
8-(benzo[d][1,3]dioxol-5-yl)-8-hydroxy-2-methyl-7-phenyl-7,8-dihydropyrazolo[3,4-*b*]pyrrolo[3,4-*d*]pyridin-6(2*H*)-one (4m):

Yield 64%; 256.1 mg; yellow solid; column chromatography, silica gel (PE:EA, 3:1); mp 243-245 ℃. IR: 3652, 2899, 2773, 1714, 1632, 1349, 1252, 1088, 1031, 925, 790 cm^{-1}. ^{1}H NMR (400 MHz, DMSO-d_6) δ 9.01 (s, 1H), 8.48 (s, 1H), 8.00 (s, 1H), 7.60 (d, J = 8.0 Hz, 2H), 7.32 (t, J = 8.0 Hz, 2H), 7.16 (t, J = 7.6 Hz, 1H), 7.04–6.99 (m, 2H), 6.81 (d, J = 8.0 Hz, 1H), 5.99 (s, 1H), 5.95 (s, 1H), 4.21 (s, 3H). ^{13}C NMR (100 MHz, DMSO-d_6) δ 165.8, 160.2, 153.5, 147.6, 147.3, 145.3, 136.4, 132.1, 128.5, 125.6, 125.0, 124.5, 119.9, 118.0, 108.3, 106.5, 106.2, 101.3, 91.3, 40.9. HRMS (ESI): m/z $[M+H]^+$ calcd for $C_{22}H_{17}N_4O_4^+$: 401.1244; found: 401.1248.



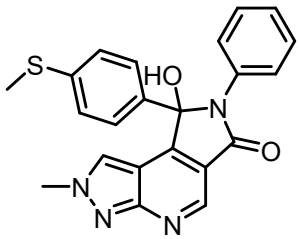
8-(2,3-dihydrobenzo[b][1,4]dioxin-6-yl)-8-hydroxy-2-methyl-7-phenyl-7,8-dihydropyrazolo[3,4-*b*]pyrrolo[3,4-*d*]pyridin-6(2*H*)-one (4n):

Yield 63%; 260.9 mg; white solid; column chromatography, silica gel (PE:EA, 3:1); mp 171-173 ℃. IR: 3652, 3063, 2870, 1690, 1632, 1498, 1356, 1317, 1140, 1051, 857 cm^{-1}. ^1H NMR (400 MHz, DMSO-d_6) δ 9.01 (s, 1H), 8.47 (s, 1H), 7.95 (s, 1H), 7.60 (d, J = 7.6 Hz, 2H), 7.32 (t, J = 8.0 Hz, 2H), 7.16 (t, J = 7.6 Hz, 1H), 7.00 (d, J = 2.0 Hz, 1H), 6.94–6.90 (m, 1H), 6.76 (d, J = 8.4 Hz, 1H), 4.22 (s, 3H), 4.16 (s, 4H). ^{13}C NMR (100 MHz, DMSO-d_6) δ 165.8, 160.2, 153.5, 145.2, 143.3, 143.2, 136.4, 131.2, 128.4, 125.5, 124.9, 124.4, 118.9, 117.9, 117.3, 114.8, 106.2, 91.1, 63.93, 63.90, 40.9. HRMS (ESI): m/z $[M+H]^+$ calcd for $C_{23}H_{19}N_4O_4^+$: 415.1401; found: 415.1397.



N-(4-(8-hydroxy-2-methyl-6-oxo-7-phenyl-2,6,7,8-tetrahydropyrazolo[3,4-*b*]pyrrolo[3,4-*d*]pyridin-8-yl)phenyl)acetamide (4o):

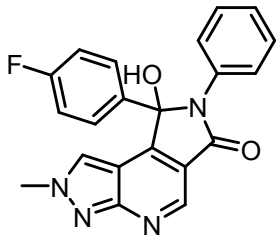
Yield 55%; 227.2 mg; white solid; column chromatography, silica gel (PE:EA, 3:1); mp 184-186 ℃. IR: 3655, 3101, 2922, 1702, 1600, 1505, 1356, 1259, 1148, 1051, 924 cm^{-1}. ^1H NMR (400 MHz, DMSO-d_6) δ 9.94 (s, 1H), 9.00 (s, 1H), 8.44 (s, 1H), 7.95 (s, 1H), 7.57 (d, J = 7.2 Hz, 2H), 7.50 (d, J = 7.6 Hz, 2H), 7.43 (s, 2H), 7.30 (s, 2H), 7.14 (s, 1H), 4.19 (s, 3H), 1.98 (s, 3H). ^{13}C NMR (100 MHz, DMSO-d_6) δ 168.4, 165.8, 160.2, 153.6, 145.2, 139.3, 136.4, 132.5, 128.4, 126.5, 125.6, 125.1, 124.4, 119.0, 118.0, 106.3, 91.4, 40.9, 23.9. HRMS (ESI): m/z [M+H]+ calcd for $C_{23}H_{20}N_5O_3^+$: 414.1561; found: 414.1556.



8-hydroxy-2-methyl-8-(4-(methylthio)phenyl)-7-phenyl-7,8-dihydropyrazolo[3,4-*b*]pyrrolo[3,4-*d*]pyridin-6(2*H*)-one (4p)：

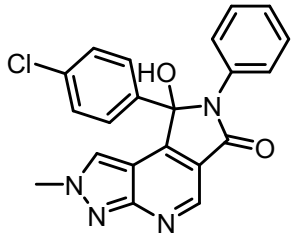
Yield 72%; 289.5 mg; yellow solid; column chromatography, silica gel (PE:EA, 3:1); mp 170-172 ℃. IR: 3652, 3108, 2825, 1690, 1632, 1490, 1431, 1319, 1140, 1051, 916 cm^{-1}. ^1H NMR (400 MHz, DMSO-d_6) δ 9.03 (s, 1H), 8.45 (s, 1H), 8.05 (s, 1H), 7.60–7.57 (m, 2H),

7.44 (d, J = 8.4 Hz, 2H), 7.30 (d, J = 8.4 Hz, 2H), 7.17–7.14 (m, 3H), 4.20 (s, 3H), 2.38 (s, 3H). ^{13}C NMR (100 MHz, DMSO-d_6) δ 165.9, 160.2, 153.4, 145.3, 138.7, 136.4, 134.6, 128.5, 126.6, 125.7, 125.5, 125.1, 124.4, 118.0, 106.3, 91.3, 40.9, 14.0. HRMS (ESI): m/z $[M+H]^+$ calcd for $C_{22}H_{19}N_4O_2S^+$: 403.1223; found: 403.1220.



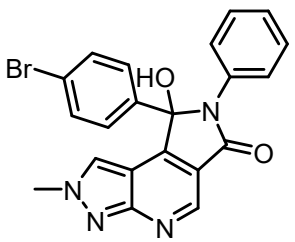
8-(4-fluorophenyl)-8-hydroxy-2-methyl-7-phenyl-7,8-dihydropyrazolo[3,4-*b*]pyrrolo[3,4-*d*]pyridin-6(2*H*)-one (4q):

Yield 73%; 273.1 mg; white solid; column chromatography, silica gel (PE:EA, 3:1); mp 285-287 °C. IR: 3655, 3071, 2922, 1707, 1595, 1431, 1351, 1312, 1133, 1043, 924 cm^{-1}. ^{1}H NMR (400 MHz, DMSO-d_6) δ 9.03 (s, 1H), 8.45 (s, 1H), 8.10 (s, 1H), 7.59–7.51 (m, 4H), 7.34–7.27 (m, 2H), 7.19–7.08 (m, 3H), 4.20 (s, 3H). ^{13}C NMR (100 MHz, DMSO-d_6) δ 165.8, 161.9 (d, J = 243.0 Hz, $^1J_{CF}$), 160.2, 153.2, 145.3, 136.2, 134.5 (d, J = 2.0 Hz, $^3J_{CF}$), 128.5, 128.4, 125.9, 125.4, 124.4, 118.2, 115.5 (d, J = 22.0 Hz, $^2J_{CF}$), 106.3, 91.0, 40.9. ^{19}F NMR (376 MHz, $CDCl_3$) δ -113.73. HRMS (ESI): m/z $[M+H]^+$ calcd for $C_{21}H_{16}FN_4O_2^+$: 375.1252; found: 375.1243.



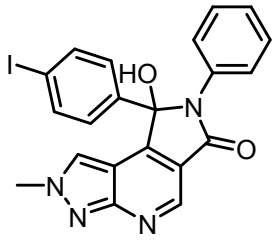
8-(4-chlorophenyl)-8-hydroxy-2-methyl-7-phenyl-7,8-dihydropyrazolo[3,4-*b*]pyrrolo[3,4-*d*]pyridin-6(2*H*)-one (4r):

Yield 69%; 269.2 mg; white solid; column chromatography, silica gel (PE:EA, 3:1); mp 278-280 °C. IR: 3652, 3123, 1702, 1692, 1623, 1568, 1492, 1371, 1177, 1088, 916 cm^{-1}. ^{1}H NMR (400 MHz, DMSO-d_6) δ 9.03 (s, 1H), 8.45 (s, 1H), 8.15 (s, 1H), 7.55–7.50 (m, 4H), 7.36–7.29 (m, 4H), 7.16 (t, J = 7.6 Hz, 1H), 4.20 (s, 3H). ^{13}C NMR (100 MHz, DMSO-d_6) δ 165.8, 160.2, 153.0, 145.3, 137.4, 136.1, 133.2, 128.7, 128.6, 128.1, 125.9, 125.3, 124.4, 118.2, 106.2, 91.0, 40.9. HRMS (ESI): m/z $[M+H]^+$ calcd for $C_{21}H_{16}ClN_4O_2^+$: 391.0956; found: 391.0950.



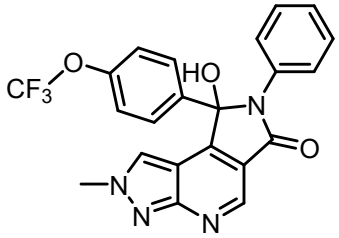
8-(4-bromophenyl)-8-hydroxy-2-methyl-7-phenyl-7,8-dihydropyrazolo[3,4-*b*]pyrrolo[3,4-*d*]pyridin-6(2*H*)-one (4s):

Yield 66%; 286.5 mg; white solid; column chromatography, silica gel (PE:EA, 3:1); mp 280-282 ℃. IR: 3652, 3123, 2922, 1696, 1626, 1565, 1485, 1371, 1177, 1141, 916 cm^{-1}. ^1H NMR (400 MHz, DMSO-d_6) δ 9.02 (s, 1H), 8.44 (s, 1H), 8.14 (s, 1H), 7.53 (d, J = 7.6 Hz, 2H), 7.49–7.43 (m, 4H), 7.34–7.28 (m, 2H), 7.17 (d, J = 6.8 Hz, 1H), 4.20 (s, 3H). ^{13}C NMR (100 MHz, DMSO-d_6) δ 165.8, 160.1, 152.9, 145.2, 137.8, 136.1, 131.7, 128.6, 128.4, 125.9, 125.3, 124.3, 121.9, 118.1, 106.2, 91.0, 40.9. HRMS (ESI): m/z $[M+H]^+$ calcd for $C_{21}H_{16}BrN_4O_2^+$: 435.0451; found: 435.0448.



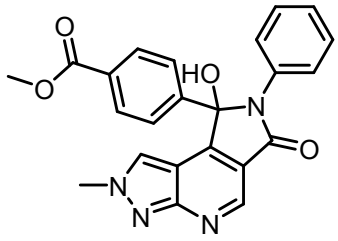
8-hydroxy-8-(4-iodophenyl)-2-methyl-7-phenyl-7,8-dihydropyrazolo[3,4-*b*]pyrrolo[3,4-*d*]pyridin-6(2*H*)-one (4t):

Yield 71%; 342.2 mg; white solid; column chromatography, silica gel (PE:EA, 3:1); mp 293-295 ℃. IR: 3655, 3123, 1693, 1622, 1565, 1483, 1364, 1325, 1140, 998, 904 cm^{-1}. ^1H NMR (400 MHz, DMSO-d_6) δ 9.03 (s, 1H), 8.45 (s, 1H), 8.12 (s, 1H), 7.66 (d, J = 8.0 Hz, 2H), 7.55 (d, J = 7.6 Hz, 2H), 7.34–7.28 (m, 4H), 7.16 (t, J = 6.8 Hz, 1H), 4.20 (s, 3H). ^{13}C NMR (100 MHz, DMSO-d_6) δ 165.8, 160.1, 153.0, 145.2, 138.2, 137.5, 136.1, 128.5, 128.4, 125.9, 125.2, 124.4, 118.1, 106.2, 95.3, 91.1, 40.9. HRMS (ESI): m/z $[M+H]^+$ calcd for $C_{21}H_{16}IN_4O_2^+$: 483.0312; found: 483.0310.



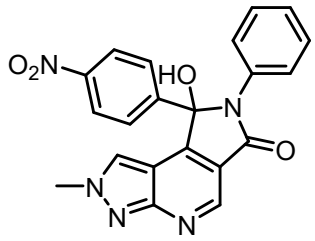
8-hydroxy-2-methyl-7-phenyl-8-(4-(trifluoromethoxy)phenyl)-7,8-dihydropyrazolo[3,4-*b*]pyrrolo[3,4-*d*]pyridin-6(2*H*)-one (4u):

Yield 68%; 299.3 mg; white solid; column chromatography, silica gel (PE:EA, 3:1); mp 232-234 ℃. IR: 3652, 3071, 2810, 1702, 1632, 1490, 1423, 1352, 1311, 1259, 916 cm^{-1}. ^1H NMR (400 MHz, DMSO-d_6) δ 9.04 (s, 1H), 8.48 (s, 1H), 8.18 (s, 1H), 7.66–7.62 (m, 2H), 7.55–7.52 (m, 2H), 7.33–7.26 (m, 4H), 7.16 (t, J = 7.6 Hz, 1H), 4.20 (s, 3H). ^{13}C NMR (100 MHz, DMSO-d_6) δ 165.8, 160.2, 152.9, 148.2, 145.3, 137.6, 136.1, 128.6, 128.3, 126.0, 125.5, 124.3, 120.9, 119.9 (q, J = 256.0 Hz, $^1J_{CF}$), 118.2, 106.2, 90.9, 40.9. ^{19}F NMR (376 MHz, $CDCl_3$) δ -56.84. HRMS (ESI): m/z $[M+H]^+$ calcd for $C_{22}H_{16}F_3N_4O_3^+$: 441.1169; found: 441.1165.



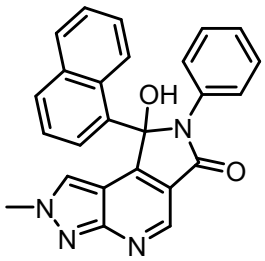
Methyl 4-(8-hydroxy-2-methyl-6-oxo-7-phenyl-2,6,7,8-tetrahydropyrazolo[3,4-b]pyrrolo[3,4-d]pyridin-8-yl)benzoate (4v):

Yield 58%; 240.2 mg; white solid; column chromatography, silica gel (PE:EA, 2:1); mp 259-261 ℃. IR: 3655, 3190, 2944, 1714, 1492, 1408, 1282, 1200, 1043, 827, 760 cm^{-1}. ^1H NMR (400 MHz, DMSO-d_6) δ 9.06 (s, 1H), 8.44 (s, 1H), 8.22 (s, 1H), 7.91–7.85 (m, 2H), 7.70–7.64 (m, 2H), 7.56–7.52 (m, 2H), 7.30 (s, 2H), 7.15 (s, 1H), 4.19 (s, 3H), 3.79 (s, 3H). ^{13}C NMR (100 MHz, DMSO-d_6) δ 165.8, 165.7, 160.1, 152.8, 145.3, 143.5, 136.1, 129.7, 129.6, 128.6, 126.6, 125.9, 125.3, 124.3, 118.2, 106.2, 91.1, 52.2, 40.9. HRMS (ESI): m/z $[M+H]^+$ calcd for $C_{23}H_{19}N_4O_4^+$: 415.1401; found: 415.1397.



8-hydroxy-2-methyl-8-(4-nitrophenyl)-7-phenyl-7,8-dihydropyrazolo[3,4-*b*]pyrrolo[3,4-*d*]pyridin-6(2*H*)-one (4w):

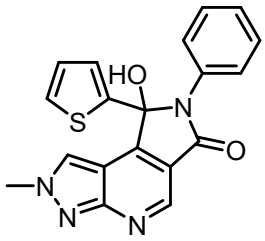
Yield 47%; 188.5 mg; yellow solid; column chromatography, silica gel (PE:EA, 2:1); mp 324-326 ℃. IR: 3652, 3063, 2922, 1708, 1632, 1513, 1446, 1341, 1148, 1051, 991 cm^{-1}. ^1H NMR (400 MHz, DMSO-d_6) δ 9.06 (s, 1H), 8.47 (s, 1H), 8.37 (s, 1H), 8.13 (d, J = 8.8 Hz, 2H), 7.81 (d, J = 8.8 Hz, 2H), 7.53 (d, J = 8.0 Hz, 2H), 7.32 (t, J = 7.6 Hz, 2H), 7.17 (t, J = 7.2 Hz, 1H), 4.19 (s, 3H). ^{13}C NMR (100 MHz, DMSO-d_6) δ 165.8, 160.1, 152.3, 147.5, 145.6, 145.3, 135.8, 128.7, 127.8, 126.2, 125.5, 124.3, 123.9, 118.3, 106.1, 90.8, 41.0. HRMS (ESI): m/z $[M+H]^+$ calcd for $C_{21}H_{16}N_5O_4^+$: 402.1197; found: 402.1195.



8-hydroxy-2-methyl-8-(naphthalen-1-yl)-7-phenyl-7,8-dihydropyrazolo[3,4-*b*]pyrrolo[3,4-*d*]pyridin-6(2*H*)-one (4x):

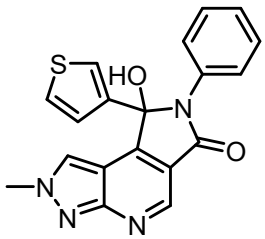
Yield 43%; 174.6 mg; yellow solid; column chromatography, silica gel (PE:EA, 3:1); mp 209-211 ℃. IR: 3655, 3175, 2847, 1702, 1346, 1312, 1222, 1058, 909, 834, 752 cm^{-1}. ^1H NMR (400 MHz, DMSO-d_6) δ 9.15 (s, 1H), 8.51 (d, J = 6.8 Hz, 1H), 8.02 (d, J = 14.0 Hz,

2H), 7.94 (d, *J* = 7.6 Hz, 1H), 7.85 (d, *J* = 7.2 Hz, 1H), 7.65 (s, 1H), 7.45 (d, *J* = 8.0 Hz, 1H), 7.39–7.30 (m, 3H), 7.26 (s, 1H), 7.16 (s, 2H), 7.03 (s, 1H), 4.07 (s, 3H). ^{13}C NMR (100 MHz, DMSO-d_6) δ 166.2, 160.2, 154.0, 145.5, 136.1, 133.6, 131.8, 130.5, 129.3, 128.4, 128.2, 127.5, 126.7, 125.8, 125.4, 124.8, 124.0, 122.0, 120.9, 119.0, 106.4, 90.4, 40.8. HRMS (ESI): m/z $[M+H]^+$ calcd for $C_{25}H_{19}N_4O_2^+$: 407.1503; found: 407.1501.



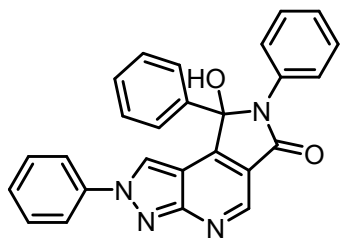
8-hydroxy-2-methyl-7-phenyl-8-(thiophen-2-yl)-7,8-dihydropyrazolo[3,4-*b*]pyrrolo[3,4-*d*]pyridin-6(2*H*)-one (4y):

Yield 64%; 231.7 mg; white solid; column chromatography, silica gel (PE:EA, 3:1); mp 293-295 ℃. IR: 3652, 3116, 2758, 1702, 1632, 1490, 1356, 1320, 1177, 1136, 894 cm^{-1}. ^{1}H NMR (400 MHz, DMSO-d_6) δ 9.03 (s, 1H), 8.55 (s, 1H), 8.25 (s, 1H), 7.59 (d, *J* = 7.6 Hz, 2H), 7.47–7.44 (m, 1H), 7.36 (t, *J* = 8.0 Hz, 2H), 7.21 (t, *J* = 7.6 Hz, 1H), 7.03 (d, *J* = 2.8 Hz, 1H), 6.92–6.88 (m, 1H), 4.25 (s, 3H). ^{13}C NMR (100 MHz, DMSO-d_6) δ 165.3, 160.3, 152.9, 145.2, 142.5, 136.0, 128.5, 127.5, 127.0, 126.2, 125.99, 125.96, 124.5, 117.5, 106.2, 90.1, 41.0. HRMS (ESI): m/z $[M+H]^+$ calcd for $C_{19}H_{15}N_4O_2S^+$: 363.0910; found: 363.0908.



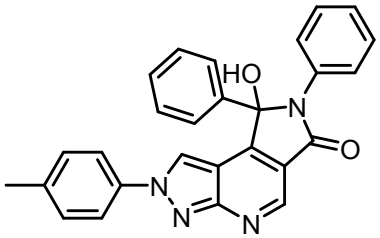
8-hydroxy-2-methyl-7-phenyl-8-(thiophen-3-yl)-7,8-dihydropyrazolo[3,4-*b*]pyrrolo[3,4-*d*]pyridin-6(2*H*)-one (4z):

Yield 62%; 224.5 mg; white solid; column chromatography, silica gel (PE:EA, 3:1); mp 268-270℃. IR: 3655, 3108, 2862, 1702, 1632, 1490, 1356, 1325, 1131, 1058, 842 cm^{-1}. ^{1}H NMR (400 MHz, DMSO-d_6) δ 9.00 (s, 1H), 8.53 (s, 1H), 7.90 (s, 1H), 7.74 (d, *J* = 2.0 Hz, 1H), 7.56 (d, *J* = 7.6 Hz, 2H), 7.40–7.38 (m, 1H), 7.33 (t, *J* = 8.0 Hz, 2H), 7.18 (t, *J* = 7.6 Hz, 1H), 6.90–6.87 (m, 1H), 4.22 (s, 3H). ^{13}C NMR (100 MHz, DMSO-d_6) δ 165.5, 160.2, 152.8, 145.2, 140.3, 136.3, 128.4, 127.2, 125.9, 125.7, 125.5, 124.5, 124.4, 118.0, 106.4, 90.1, 40.9. HRMS (ESI): m/z $[M+H]^+$ calcd for $C_{19}H_{15}N_4O_2S^+$: 363.0910; found: 363.0906.



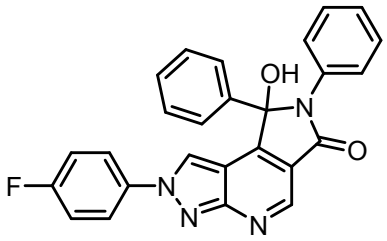
8-hydroxy-2,7,8-triphenyl-7,8-dihydropyrazolo[3,4-*b*]pyrrolo[3,4-*d*]pyridin-6(2*H*)-one (5a):

Yield 75%; 313.6 mg; white solid; column chromatography, silica gel (PE:EA, 5:1); mp 217-219 ℃. IR: 3652, 3056, 2922, 1685, 1595, 1356, 1192, 1125, 1043, 834 cm^{-1}. ^1H NMR (400 MHz, DMSO-d_6) δ 9.15 (s, 1H), 8.33 (s, 1H), 8.23 (s, 1H), 8.17 (d, J = 8.0 Hz, 2H), 7.62–7.57 (m, 6H), 7.42 (t, J = 7.2 Hz, 1H), 7.35–7.30 (m, 4H), 7.29–7.25 (m, 1H), 7.17 (t, J = 7.2 Hz, 1H). ^{13}C NMR (100 MHz, DMSO-d_6) δ 165.2, 152.8, 151.5, 144.9, 138.4, 138.2, 136.1, 132.7, 129.2, 128.7, 128.6, 128.5, 127.0, 126.1, 125.9, 125.3, 121.7, 119.5, 109.7, 91.5. HRMS (ESI): m/z $[M+H]^+$ calcd for $C_{26}H_{19}N_4O_2^+$: 419.1503; found: 419.1495.



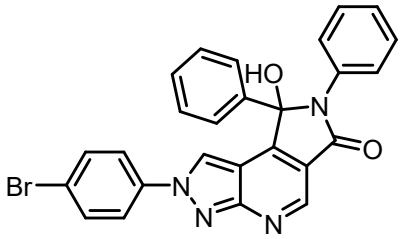
8-hydroxy-7,8-diphenyl-2-(p-tolyl)-7,8-dihydropyrazolo[3,4-*b*]pyrrolo[3,4-*d*]pyridin-6(2*H*)-one (5b):

Yield 67%; 289.5 mg; yellow solid; column chromatography, silica gel (PE:EA, 5:1); mp 245-247 ℃. IR: 3652, 3056, 2922, 1670, 1625, 1513, 1431, 1356, 1207, 1028, 760 cm^{-1}. ^1H NMR (400 MHz, DMSO-d_6) δ 9.14 (s, 1H), 8.30 (s, 1H), 8.23 (s, 1H), 8.03 (d, J = 8.4 Hz, 2H), 7.59 (d, J = 8.0 Hz, 4H), 7.39 (d, J = 8.4 Hz, 2H), 7.32 (t, J = 7.6 Hz, 4H), 7.27 (d, J = 7.2 Hz, 1H), 7.17 (t, J = 7.2 Hz, 1H), 2.38 (s, 3H). ^{13}C NMR (100 MHz, DMSO-d_6) δ 165.2, 152.8, 151.4, 144.9, 138.2, 136.5, 136.1, 136.0, 132.4, 129.7, 128.8, 128.6, 128.5, 126.1, 126.0, 125.3, 121.7, 119.4, 109.5, 91.5, 20.6. HRMS (ESI): m/z $[M+H]^+$ calcd for $C_{27}H_{21}N_4O_2^+$: 433.1659; found: 433.1658.



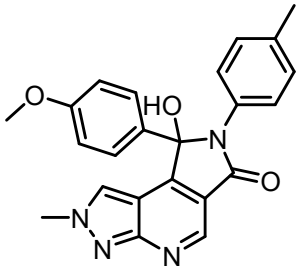
2-(4-fluorophenyl)-8-hydroxy-7,8-diphenyl-7,8-dihydropyrazolo[3,4-*b*]pyrrolo[3,4-*d*]pyridin-6(2*H*)-one (5c):

Yield 58%; 252.9 mg; white solid; column chromatography, silica gel (PE:EA, 5:1); mp 238-240 ℃, IR: 3658, 3063, 1673, 1629, 1492, 1379, 1328, 1207, 1133, 1071, 954 cm^{-1}. ^1H NMR (400 MHz, DMSO-d_6) δ 9.14 (s, 1H), 8.33 (s, 1H), 8.23 (s, 1H), 8.21–8.16 (m, 2H), 7.59 (d, J = 6.8 Hz, 4H), 7.45 (t, J = 8.4 Hz, 2H), 7.35–7.28 (m, 5H), 7.17 (t, J = 7.2 Hz, 1H). ^{13}C NMR (100 MHz, DMSO-d_6) δ 165.2, 160.6 (d, J = 242.0 Hz, $^1J_{CF}$), 152.9, 151.4, 145.1, 138.1, 136.1, 134.75, 132.8, 128.8, 128.6, 128.5, 126.1, 126.0, 125.3, 123.86 (d, J = 8.0 Hz, $^3J_{CF}$), 119.6, 116.15 (d, J = 23.0 Hz, $^2J_{CF}$), 109.6, 91.5. ^{19}F NMR (376 MHz, $CDCl_3$) δ -114.89. HRMS (ESI): m/z $[M+H]^+$ calcd for $C_{26}H_{18}FN_4O_2^+$: 437.1408; found: 437.1407.



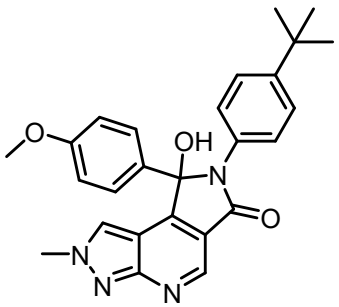
2-(4-bromophenyl)-8-hydroxy-7,8-diphenyl-7,8-dihydropyrazolo[3,4-*b*]pyrrolo[3,4-*d*]pyridin-6(2*H*)-one (5d):

Yield 65%; 322.4 mg; yellow solid; column chromatography, silica gel (PE:EA, 5:1); mp 250-252 ℃. IR: 3664, 3265, 2639, 1679, 1587, 1492, 1356, 1207, 1028, 954 cm^{-1}. ^1H NMR (400 MHz, DMSO-d_6) δ 9.17 (s, 1H), 8.35 (s, 1H), 8.25 (s, 1H), 8.19 (d, J = 8.8 Hz, 2H), 7.78 (d, J = 8.8 Hz, 2H), 7.60 (d, J = 8.0 Hz, 4H), 7.32 (t, J = 7.6 Hz, 4H), 7.27 (d, J = 7.2 Hz, 1H), 7.17 (t, J = 7.6 Hz, 1H). ^{13}C NMR (100 MHz, DMSO-d_6) δ 165.1, 152.9, 151.5, 145.1, 138.1, 137.7, 136.0, 133.2, 132.2, 128.8, 128.6, 128.5, 126.1, 126.0, 125.4, 123.1, 119.7, 119.3, 110.0, 91.5. HRMS (ESI): m/z $[M+H]^+$ calcd for $C_{26}H_{18}BrN_4O_2^+$: 497.0608; found: 497.0604.



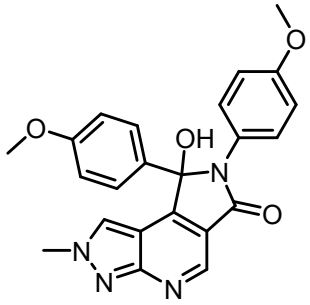
8-hydroxy-8-(4-methoxyphenyl)-2-methyl-7-(p-tolyl)-7,8-dihydropyrazolo[3,4-*b*]pyrrolo[3,4-*d*]pyridin-6(2*H*)-one (5e):

Yield 76%; 304.1 mg; white solid; column chromatography, silica gel (PE:EA, 2:1); mp 238-240 ℃. IR: 3661, 3123, 2937, 1692, 1518, 1371, 1326, 1252, 1170, 1043, 805 cm^{-1}. ^1H NMR (400 MHz, DMSO-d_6) δ 9.02 (s, 1H), 8.42 (s, 1H), 7.91 (s, 1H), 7.43 (t, J = 9.2 Hz, 4H), 7.10 (d, J = 8.4 Hz, 2H), 6.84 (d, J = 8.8 Hz, 2H), 4.20 (s, 3H), 3.67 (s, 3H), 2.22 (s, 3H). ^{13}C NMR (100 MHz, DMSO-d_6) δ 165.8, 160.2, 159.1, 153.7, 145.2, 135.0, 133.7, 130.1, 128.9, 127.5, 125.4, 124.4, 118.2, 113.9, 106.4, 91.3, 55.0, 40.9, 20.5. HRMS (ESI): m/z $[M+H]^+$ calcd for $C_{23}H_{21}N_4O_3^+$: 401.1608; found: 401.1606.



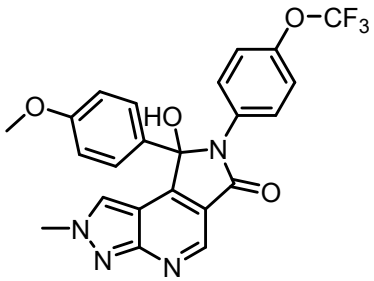
7-(4-(tert-butyl)phenyl)-8-hydroxy-8-(4-methoxyphenyl)-2-methyl-7,8-dihydropyrazolo[3,4-*b*]pyrrolo[3,4-*d*]pyridin-6(2*H*)-one (5f):

Yield 54%; 238.8 mg; white solid; column chromatography, silica gel (PE:EA, 2:1); mp 258-260 ℃. IR: 3658, 3108, 2967, 1702, 1632, 1509, 1401, 1358, 1103, 1021, 924 cm^{-1}. ^1H NMR (400 MHz, DMSO-d_6) δ 8.98 (s, 1H), 8.41 (s, 1H), 7.87 (s, 1H), 7.44 (t, J = 8.8 Hz, 4H), 7.32 (d, J = 8.4 Hz, 2H), 6.85 (d, J = 8.8 Hz, 2H), 4.19 (s, 3H), 3.68 (s, 3H), 1.24 (s, 9H). ^{13}C NMR (100 MHz, DMSO-d_6) δ 165.8, 160.1, 159.1, 153.8, 147.9, 145.2, 133.7, 130.2, 127.4, 125.2, 125.0, 124.3, 117.9, 114.0, 106.2, 91.3, 55.0, 40.9, 34.2, 31.1. HRMS (ESI): m/z $[M+H]^+$ calcd for $C_{26}H_{27}N_4O_3^+$: 443.2078; found: 443.2075.



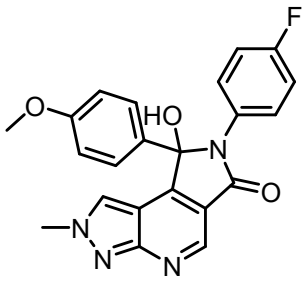
8-hydroxy-7,8-bis(4-methoxyphenyl)-2-methyl-7,8-dihydropyrazolo[3,4-*b*]pyrrolo[3,4-*d*]pyridin-6(2*H*)-one (5g):

Yield 78%; 324.6 mg; white solid; column chromatography, silica gel (PE:EA, 2:1); mp 263-265 ℃. IR: 3658, 2959, 2832, 1693, 1504, 1371, 1244, 1170, 1028, 924, 805 cm^{-1}. ^1H NMR (400 MHz, DMSO-d_6) δ 9.03 (s, 1H), 8.41 (s, 1H), 7.85 (s, 1H), 7.40–7.34 (m, 4H), 6.88–6.80 (m, 4H), 4.21 (s, 3H), 3.69 (d, J = 10.8 Hz, 6H). ^{13}C NMR (100 MHz, DMSO-d_6) δ 165.8, 160.2, 159.1, 157.3, 153.7, 145.2, 130.1, 128.8, 127.7, 127.5, 124.3, 118.3, 113.9, 113.7, 106.5, 91.2, 55.1, 55.0, 40.9. HRMS (ESI): m/z $[M+H]^+$ calcd for $C_{23}H_{21}N_4O_4^+$: 417.1557; found: 417.1552.



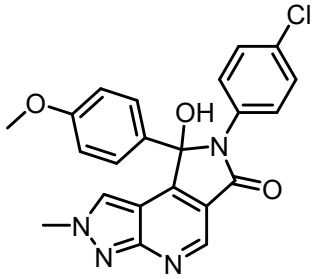
8-hydroxy-8-(4-methoxyphenyl)-2-methyl-7-(4-(trifluoromethoxy)phenyl)-7,8-dihydropyrazolo[3,4-*b*]pyrrolo[3,4-*d*]pyridin-6(2*H*)-one (5h):

Yield 64%; 300.9 mg; white solid; column chromatography, silica gel (PE:EA, 2:1); mp 241-243 ℃. IR: 3652, 3257, 2922, 1702, 1632, 1505, 1356, 1244, 991, 790 cm^{-1}. ^1H NMR (400 MHz, DMSO-d_6) δ 9.02 (s, 1H), 8.46 (s, 1H), 8.07 (s, 1H), 7.74 (d, J = 9.2 Hz, 2H), 7.44 (d, J = 8.8 Hz, 2H), 7.34 (d, J = 8.8 Hz, 2H), 6.85 (d, J = 8.8 Hz, 2H), 4.20 (s, 3H), 3.68 (s, 3H). ^{13}C NMR (100 MHz, DMSO-d_6) δ 165.9, 160.2, 159.2, 153.7, 145.3, 135.7, 129.7, 127.4, 126.0, 124.5, 121.2, 120.1(q, J = 255.0 Hz, $^1J_{CF}$), 117.6, 114.1, 106.2, 91.5, 55.0, 40.9. ^{19}F NMR (376 MHz, $CDCl_3$) δ -56.85. HRMS (ESI): m/z $[M+H]^+$ calcd for $C_{23}H_{18}F_3N_4O_4^+$: 471.1275; found: 471.1267.



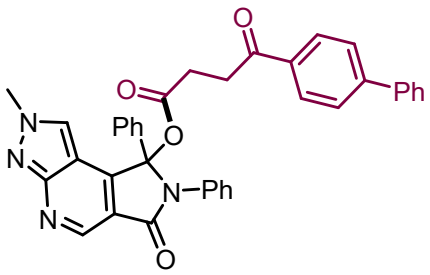
7-(4-fluorophenyl)-8-hydroxy-8-(4-methoxyphenyl)-2-methyl-7,8-dihydropyrazolo[3,4-*b*]pyrrolo[3,4-*d*]pyridin-6(2*H*)-one (5i):

Yield 53%; 214.2 mg; white solid; column chromatography, silica gel (PE:EA, 2:1); mp 200-202 °C. IR: 3659, 3004, 2922, 1705, 1506, 1356, 1304, 1253, 1177, 1088, 916 cm^{-1}. ^1H NMR (400 MHz, DMSO-d_6) δ 9.00 (s, 1H), 8.41 (s, 1H), 7.95 (s, 1H), 7.56–7.51 (m, 2H), 7.39 (d, J = 8.8 Hz, 2H), 7.16 (t, J = 8.8 Hz, 2H), 6.83 (d, J = 8.8 Hz, 2H), 4.20 (s, 3H), 3.68 (s, 3H). ^{13}C NMR (100 MHz, DMSO-d_6) δ 165.8, 160.2, 159.8 (d, J = 243.0 Hz, $^1J_{CF}$), 159.1, 153.6, 145.2, 132.5, 129.8, 127.5, 127.4, 124.4, 117.9, 115.3 (d, J = 22.0 Hz, $^2J_{CF}$), 114.0, 106.3, 91.3, 55.0, 40.9. ^{19}F NMR (376 MHz, $CDCl_3$) δ -116.16. HRMS (ESI): m/z $[M+H]^+$ calcd for $C_{22}H_{18}FN_4O_3^+$: 405.1357; found: 405.1355.



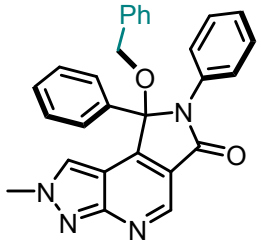
7-(4-chlorophenyl)-8-hydroxy-8-(4-methoxyphenyl)-2-methyl-7,8-dihydropyrazolo[3,4-*b*]pyrrolo[3,4-*d*]pyridin-6(2*H*)-one (5j):

Yield 50%; 210.0 mg; white solid; column chromatography, silica gel (PE:EA, 2:1); mp 250-252 °C. IR: 3568, 2922, 2847, 1696, 1632, 1490, 1423, 1356, 1170, 1028, 924 cm^{-1}. ^1H NMR (400 MHz, DMSO-d_6) δ 9.00 (s, 1H), 8.44 (s, 1H), 8.04 (s, 1H), 7.64 (d, J = 8.8 Hz, 2H), 7.39 (m, J = 14.0, 8.8 Hz, 4H), 6.84 (d, J = 8.8 Hz, 2H), 4.20 (s, 3H), 3.68 (s, 3H). ^{13}C NMR (100 MHz, DMSO-d_6) δ 165.8, 160.2, 159.1, 153.6, 145.2, 135.5, 129.7, 129.5, 128.4, 127.4, 126.0, 124.5, 117.7, 114.1, 106.2, 91.5, 55.0, 40.9. HRMS (ESI): m/z $[M+H]^+$ calcd for $C_{22}H_{18}ClN_4O_3^+$: 421.1062; found: 421.1058.



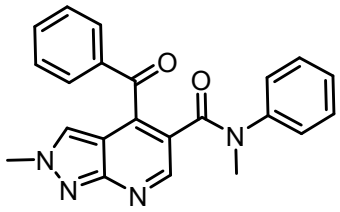
2-methyl-6-oxo-7,8-diphenyl-2,6,7,8-tetrahydropyrazolo[3,4-*b*]pyrrolo[3,4-*d*]pyridin-8-yl 4-([1,1'-biphenyl]-4-yl)-4-oxobutanoate (7):

Yield 62%; 73.4 mg; white solid; column chromatography, silica gel (PE:EA, 1:1); mp 155-157 ℃. IR: 3183, 3056, 2922, 1760, 1705, 1679, 1629, 1486, 1200, 1110, 991 cm^{-1}. ^1H NMR (400 MHz, $CDCl_3$) δ 9.20 (s, 1H), 7.97 (s, 1H), 7.91 (s, 1H), 7.89 (s, 1H), 7.65 (s, 1H), 7.63 (s, 1H), 7.60 (s, 1H), 7.58 (s, 1H), 7.48–7.44 (m, 4H), 7.41–7.38 (m, 1H), 7.34–7.32 (m, 3H), 7.28 (s, 1H), 7.27 (s, 1H), 7.22–7.20 (m, 2H), 7.19 (s, 1H), 4.18 (s, 3H), 3.20–3.14 (m, 2H), 2.89–2.84 (m, 1H), 2.76–2.69 (m, 1H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 196.8, 169.8, 167.1, 160.5, 150.2, 146.4, 146.0, 139.4, 136.1, 134.7, 134.6, 129.3, 129.0, 128.9, 128.8, 128.3, 128.2, 127.12, 127.08, 127.0, 126.0, 125.5, 123.5, 119.8, 106.7, 93.7, 41.2, 33.0, 28.4. HRMS (ESI): m/z $[M+H]^+$ calcd for $C_{37}H_{29}N_4O_4^+$: 593.2183; found: 593.2176.



8-(benzyloxy)-2-methyl-7,8-diphenyl-7,8-dihydropyrazolo[3,4-*b*]pyrrolo[3,4-*d*]pyridin-6(2*H*)-one (9):

Yield 65%; 58.0 mg; white solid; column chromatography, silica gel (PE:EA, 4:1); mp 231-233 ℃. IR: 2922, 1749, 1693, 1632, 1493, 1379, 1177, 1145, 1104, 954, 689 cm^{-1}. ^1H NMR (400 MHz, $CDCl_3$) δ 7.68 (s, 1H), 7.59 (s, 1H), 7.51 (d, J = 7.6 Hz, 2H), 7.39 (t, J = 7.6 Hz, 2H), 7.32–7.28 (m, 7H), 7.26–7.23 (m, 4H), 5.09 (d, J = 15.2 Hz, 1H), 4.79 (d, J = 15.2 Hz, 1H), 3.80 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 175.9, 167.9, 148.9, 142.8, 137.0, 136.1, 132.3, 128.8, 128.0, 127.9, 127.8, 127.6, 126.6, 125.5, 104.7, 102.1, 52.9, 39.4. HRMS (ESI): m/z $[M+H]^+$ calcd for $C_{28}H_{23}N_4O_2^+$: 447.1816; found: 447.1810.



4-benzoyl-*N*,2-dimethyl-*N*-phenyl-2*H*-pyrazolo[3,4-*b*]pyridine-5-carboxamide (10):

Yield 76%; 281.3 mg; yellow solid; column chromatography, silica gel (PE:EA, 3:1); mp 174-176 ℃. IR: 3123, 3041, 2922, 1658, 1626, 1588, 1490, 1356, 1267, 1155, 998 cm^{-1}. ^1H NMR (400 MHz, $CDCl_3$) δ 7.98 (s, 1H), 7.97 (s, 1H), 7.88 (s, 1H), 7.84 (s, 1H), 7.54 (t, J = 7.6 Hz, 1H), 7.40 (t, J = 7.6 Hz, 2H), 7.30–7.27 (m, 2H), 7.13–7.09 (m, 2H), 7.06–7.03 (m, 1H), 4.17 (s, 3H), 3.48 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 193.9, 168.8, 155.7, 155.5, 144.1, 135.5, 133.0, 131.0, 130.9, 129.1, 127.9, 127.8, 126.8, 126.5, 124.8, 112.8, 41.2, 37.6. HRMS (ESI): m/z $[M+H]^+$ calcd for $C_{22}H_{19}N_4O_2^+$: 371.1503; found: 371.1499.

8. Crystallographic data and molecular structure of 3a.

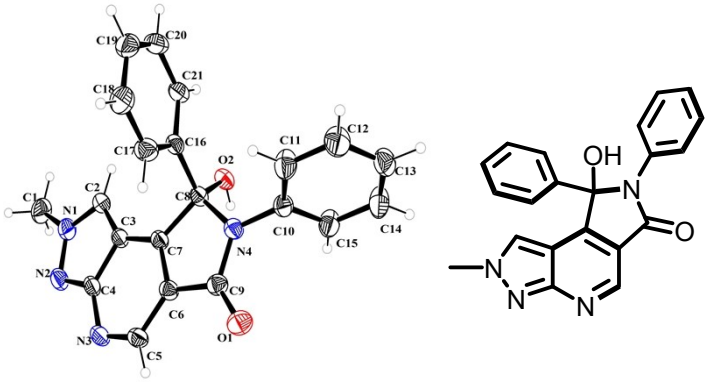


Figure 1. Molecular structure of **4a** with 30% probability ellipsoids

Crystal Data for Compound **4a**: CCDC 2423210 contains the supplementary crystallographic data for this paper. These data can be obtained free of charge from The Cambridge Crystallographic.

Sample preparation: In a 10 mL glass bottle, 15 mg of pure **4a** was completely dissolved in the mixed solvent of 3 mL $CHCl_3$, and then 2 mL of n-hexane was added slowly. After a week of solvent evaporation, some white transparent crystals were obtained. The crystals were mounted on a glass fiber for diffraction experiments. Intensity data were collected on a Bruker SMART APEX CCD diffractometer with Mo Kα radiation (0.71073 Å) at room temperature.

Bond precision: C-C = 0.0025 A Wavelength=0.71073

Cell: a=14.613(3) b=10.293(2) c=11.665(3)
alpha=90 beta=94.435(4) gamma=90
Temperature: 296 K

	Calculated	Reported
Volume	1749.3(7)	1749.2(6)
Space group	P 21/c	P 1 21/c 1
Hall group	-P 2ybc	-P 2ybc
Moiety formula	C21 H16 N4 O2	C21 H16 N4 O2
Sum formula	C21 H16 N4 O2	C21 H16 N4 O2
Mr	356.38	356.38
Dx,g cm-3	1.353	1.353
Z	4	4
Mu (mm-1)	0.090	0.090
F000	744.0	744.0
F000'	744.30	
h,k,lmax	19,13,15	19,13,15
Nref	4164	4127
Tmin,Tmax	0.988,0.991	0.661,0.746
Tmin'	0.988	

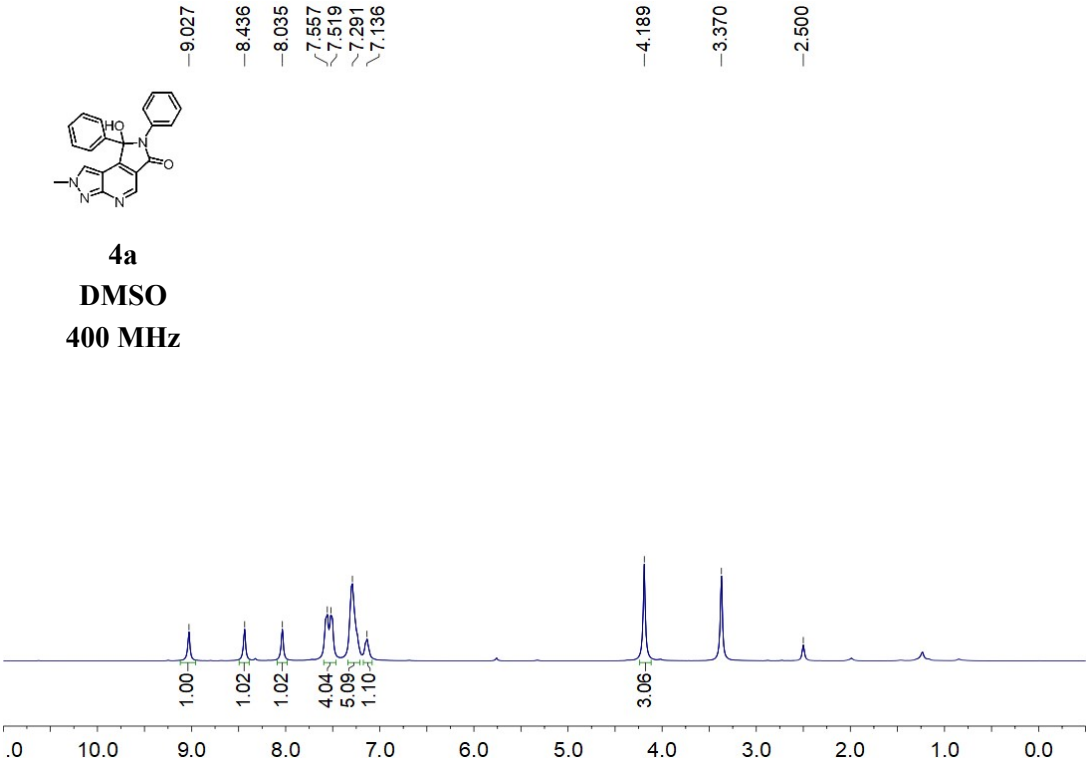
Correction method= # Reported T Limits: Tmin=0.661 Tmax=0.746
AbsCorr = MULTI-SCAN

Data completeness= 0.991 Theta(max)= 27.840

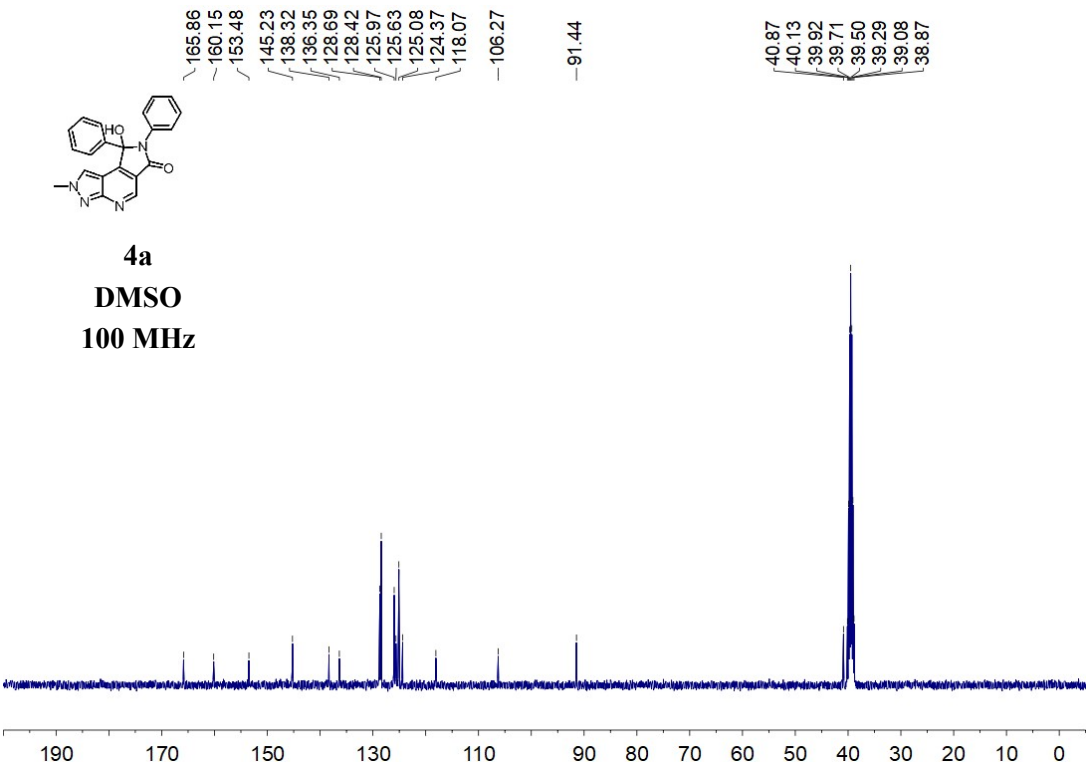
R(reflections)= 0.0459(2889) wR2(reflections)= 0.1441(4127)

S = 1.023 Npar= 246

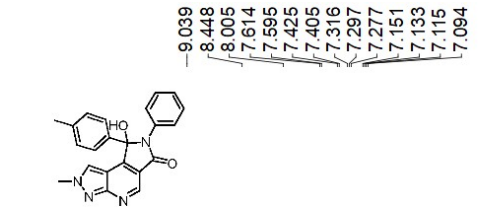
9.^{1}H, ^{13}C and ^{19}F NMR spectra of compounds



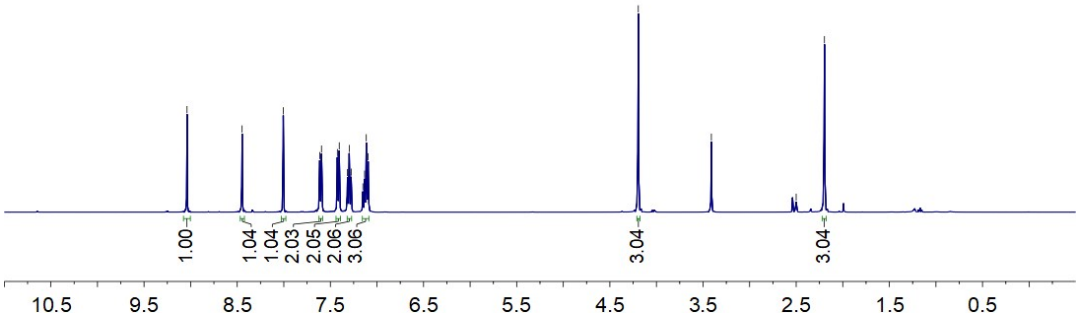
4a
DMSO
400 MHz

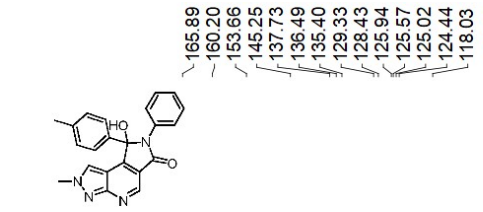


4a
DMSO
100 MHz

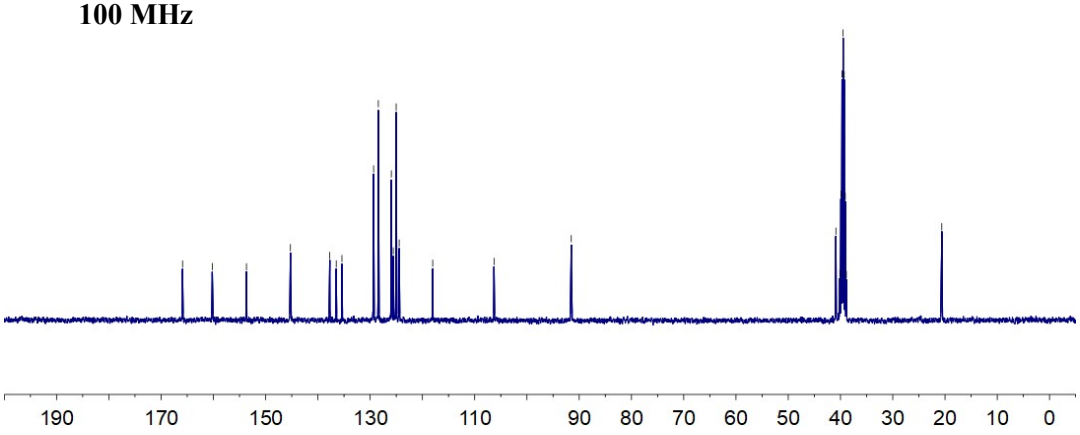


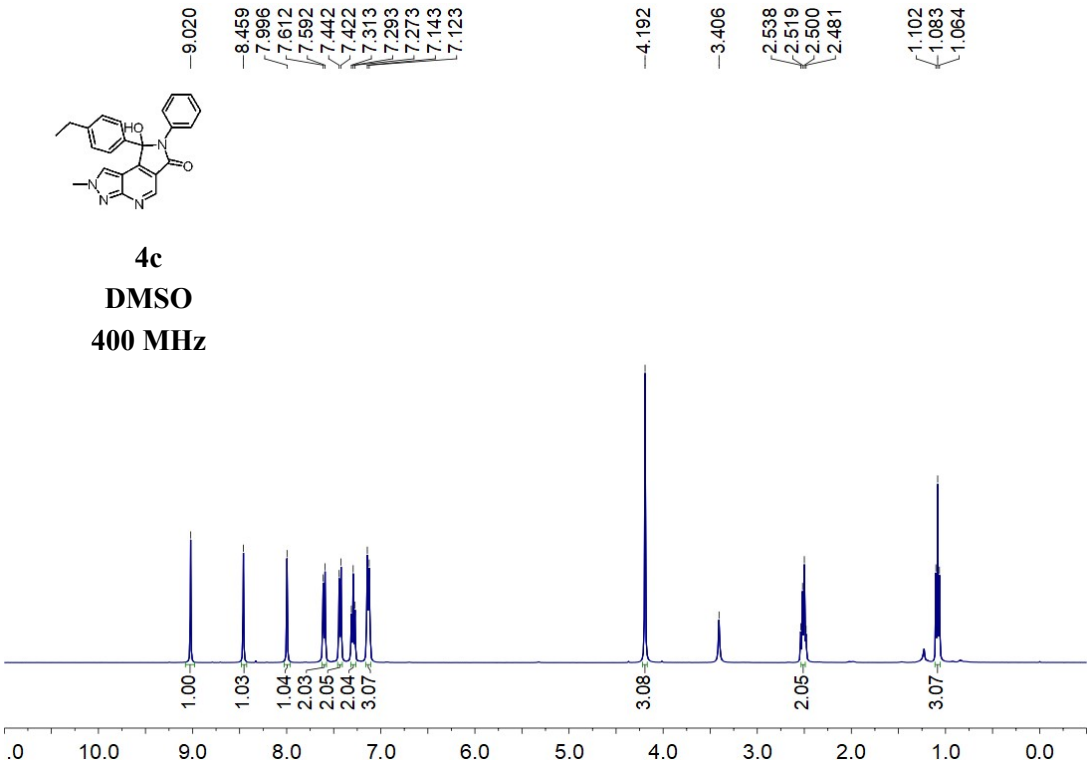
4b
DMSO
400 MHz



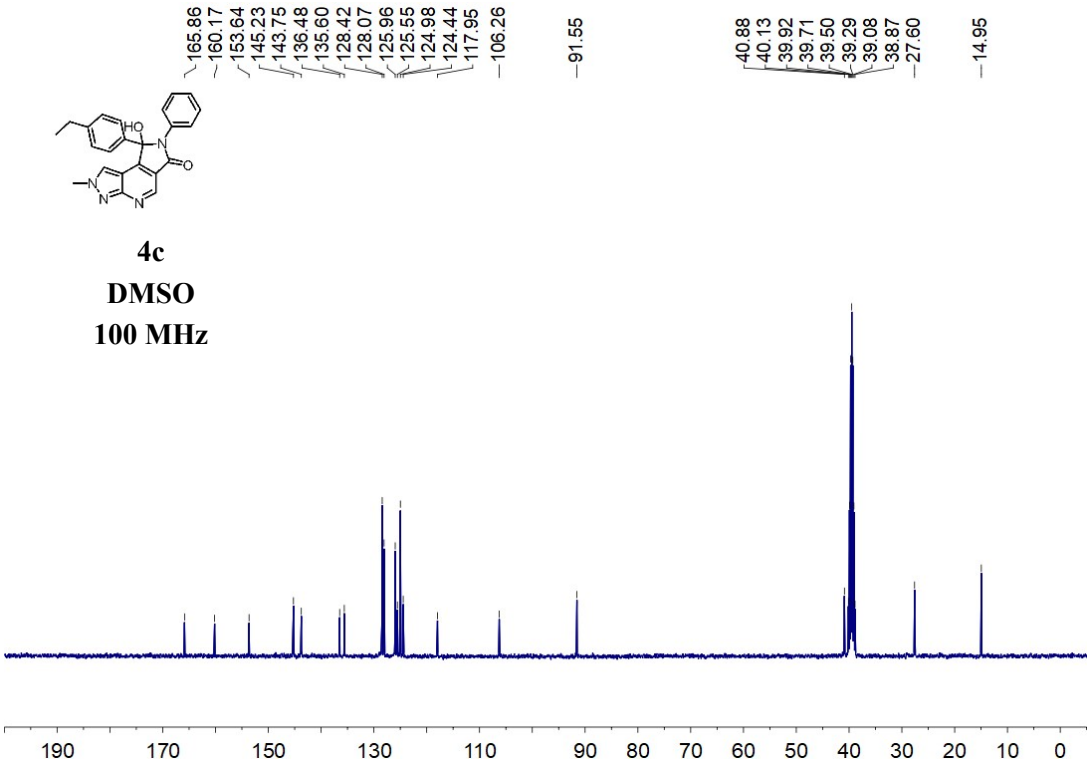


4b
DMSO
100 MHz

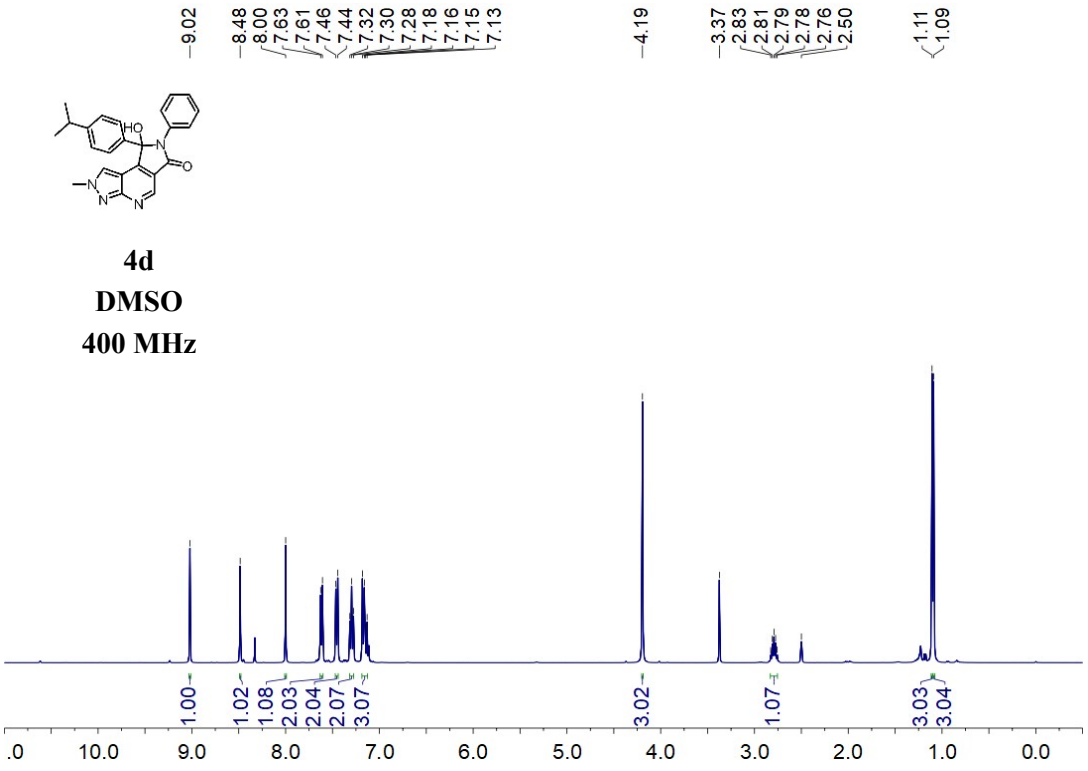




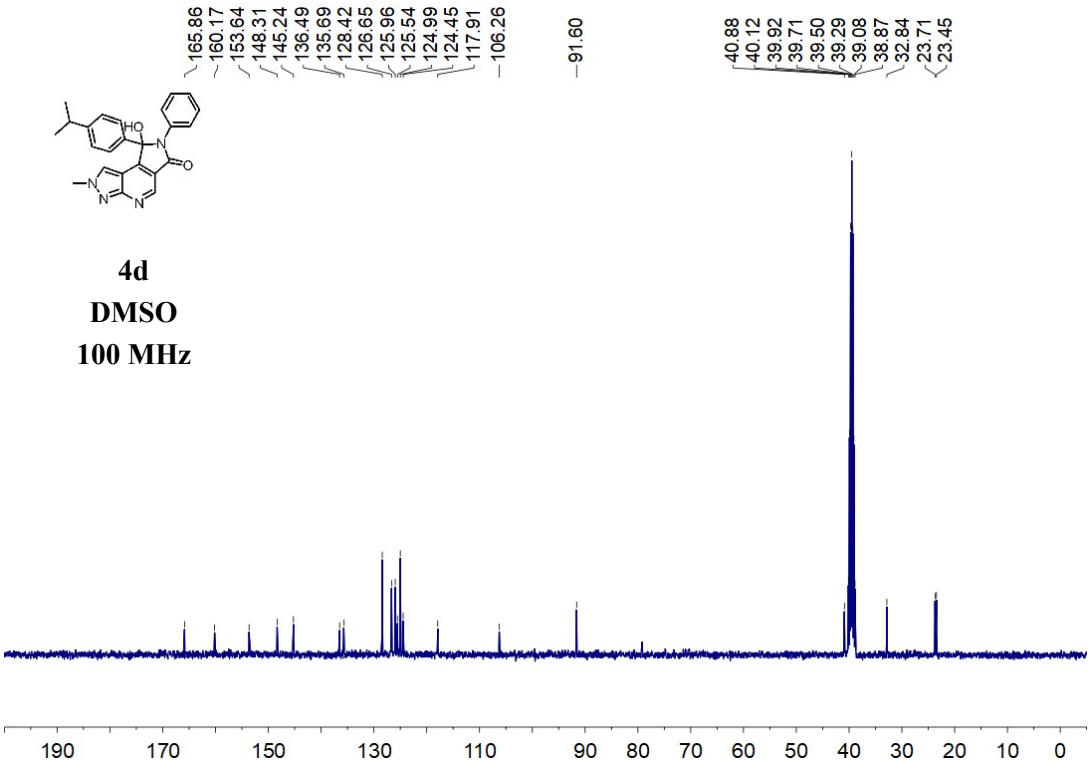
4c
DMSO
400 MHz



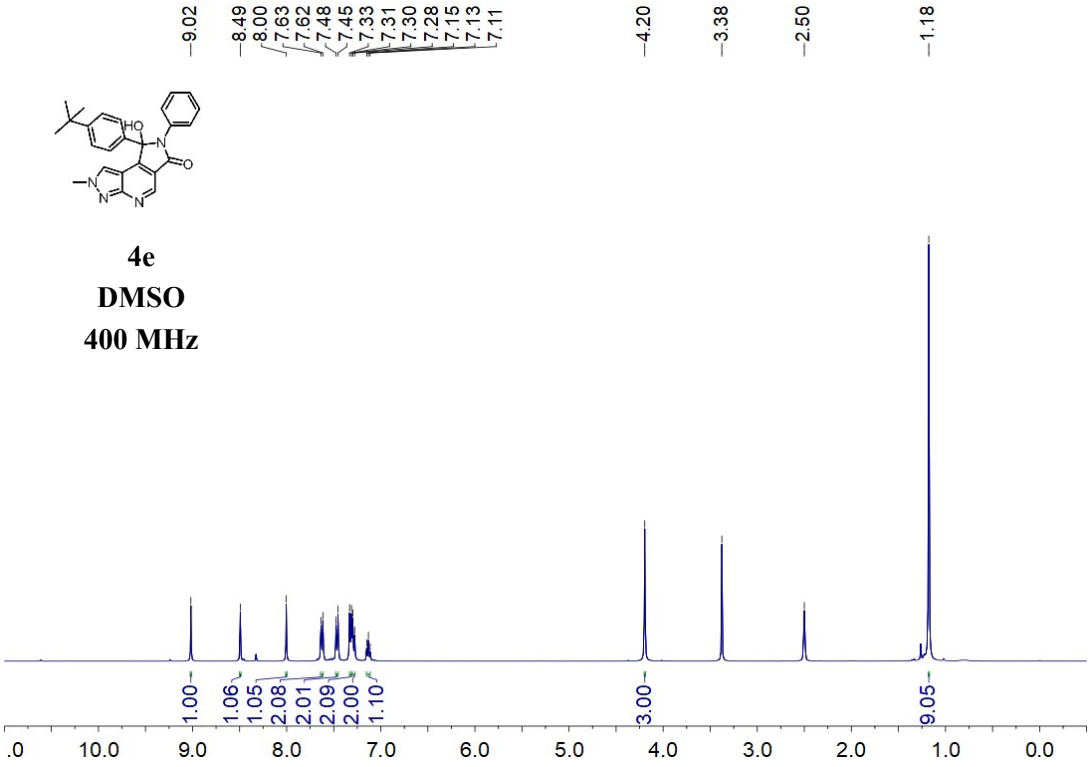
4c
DMSO
100 MHz



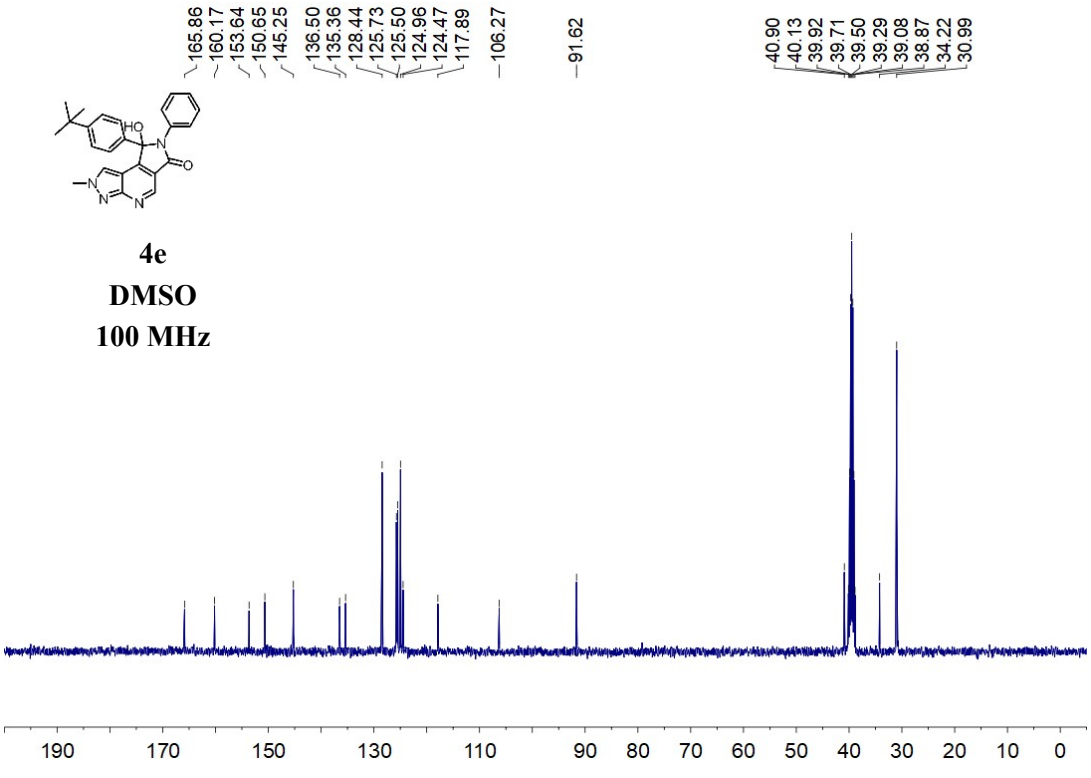
4d
DMSO
400 MHz



4d
DMSO
100 MHz



4e
DMSO
400 MHz



4e
DMSO
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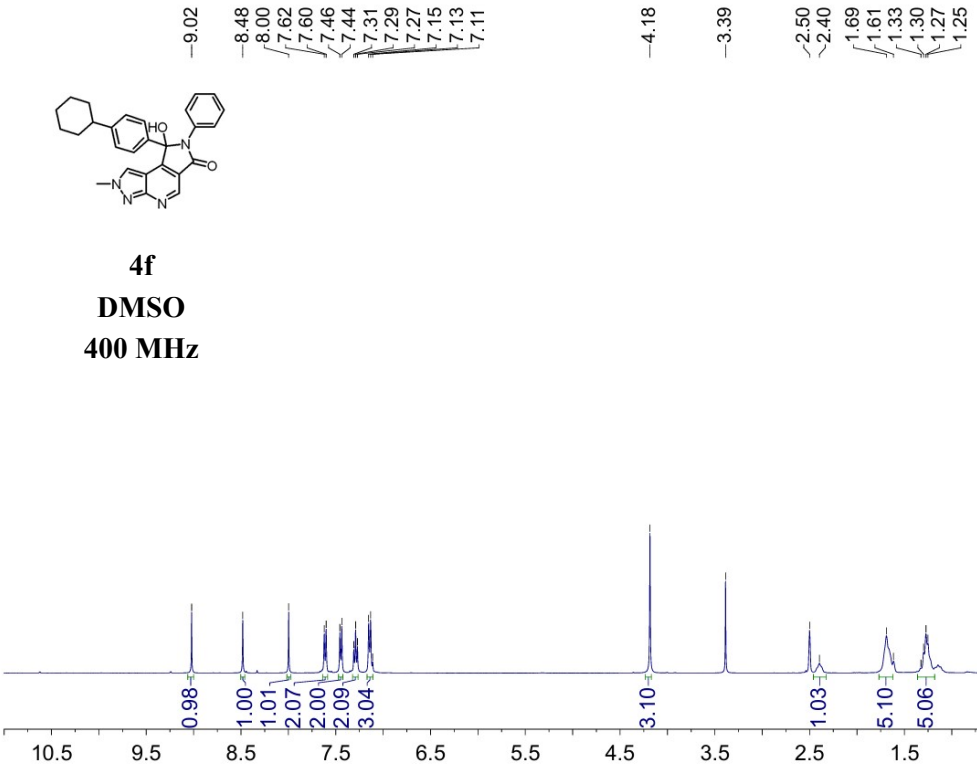
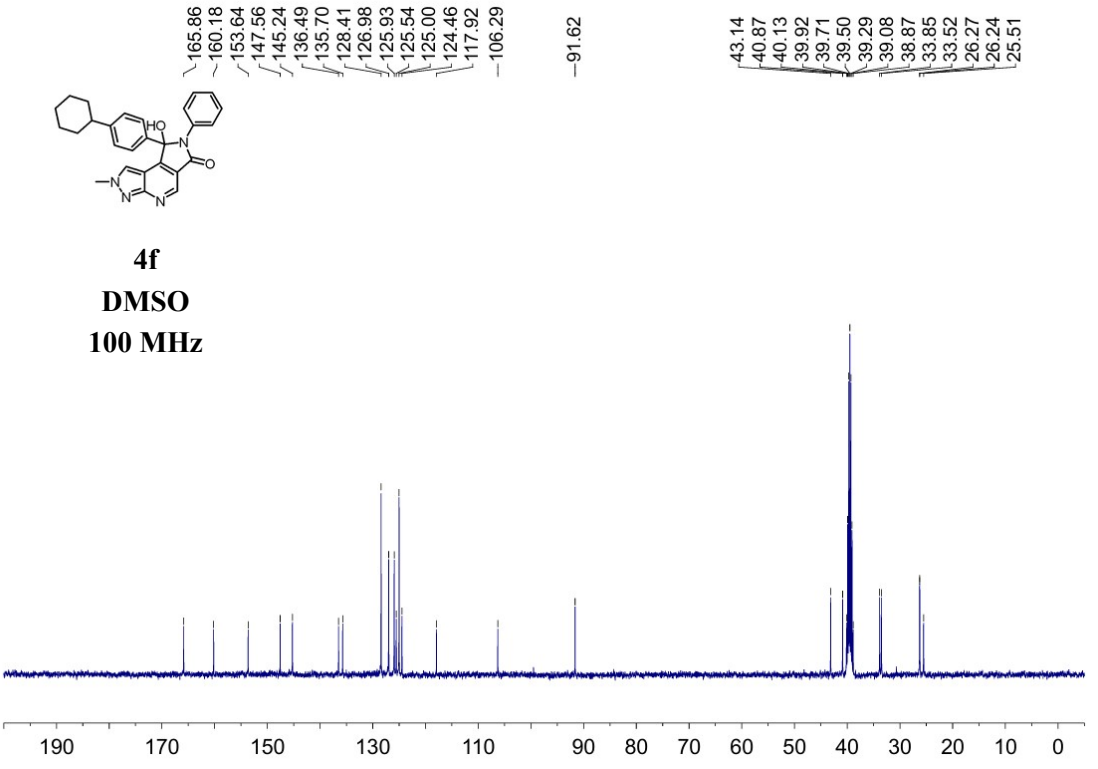
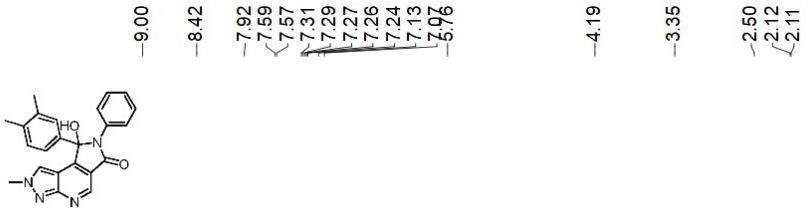


4f
DMSO
400 MHz



4f
DMSO
100 MHz



4g
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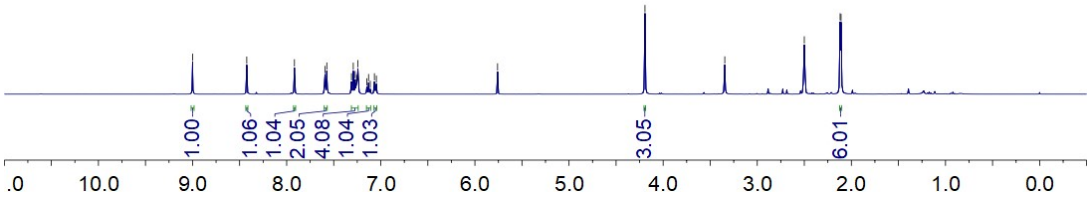

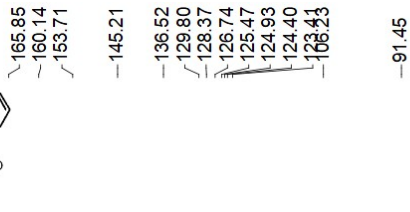

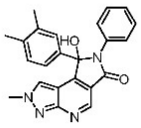

4g
DMSO
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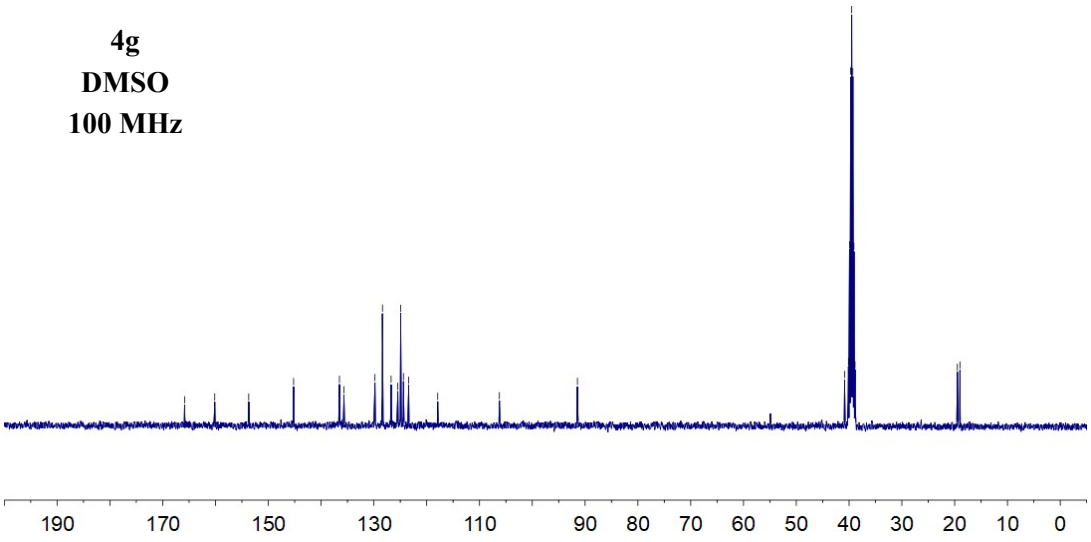

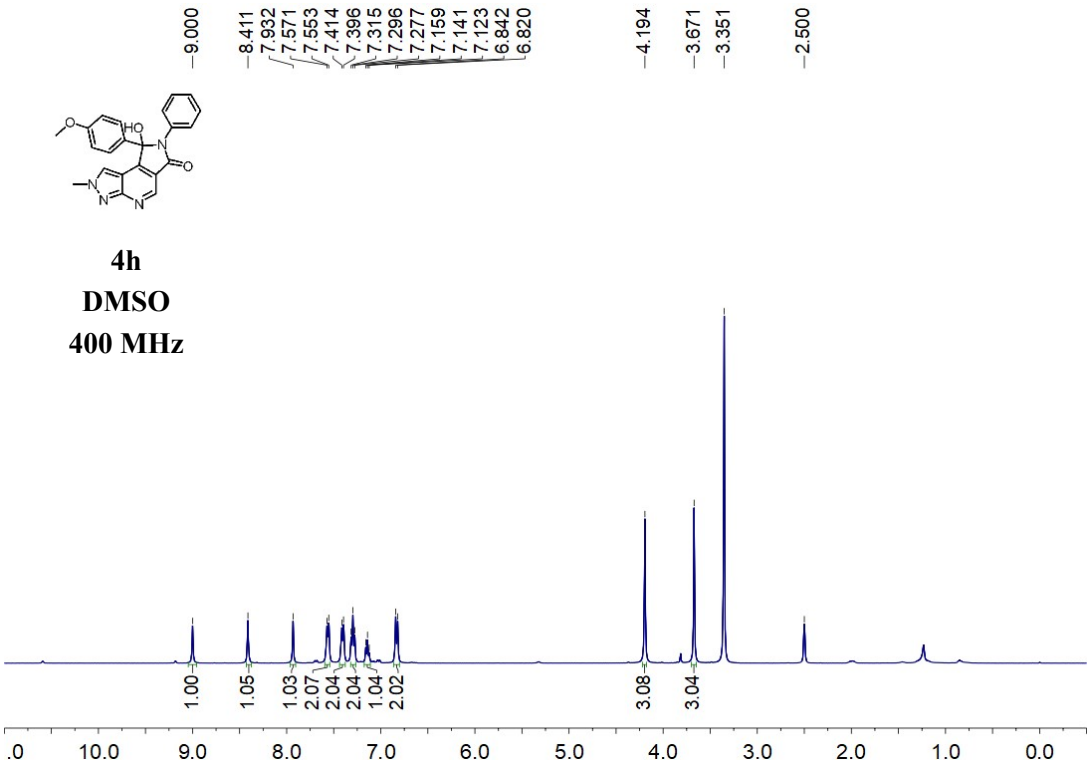

4h
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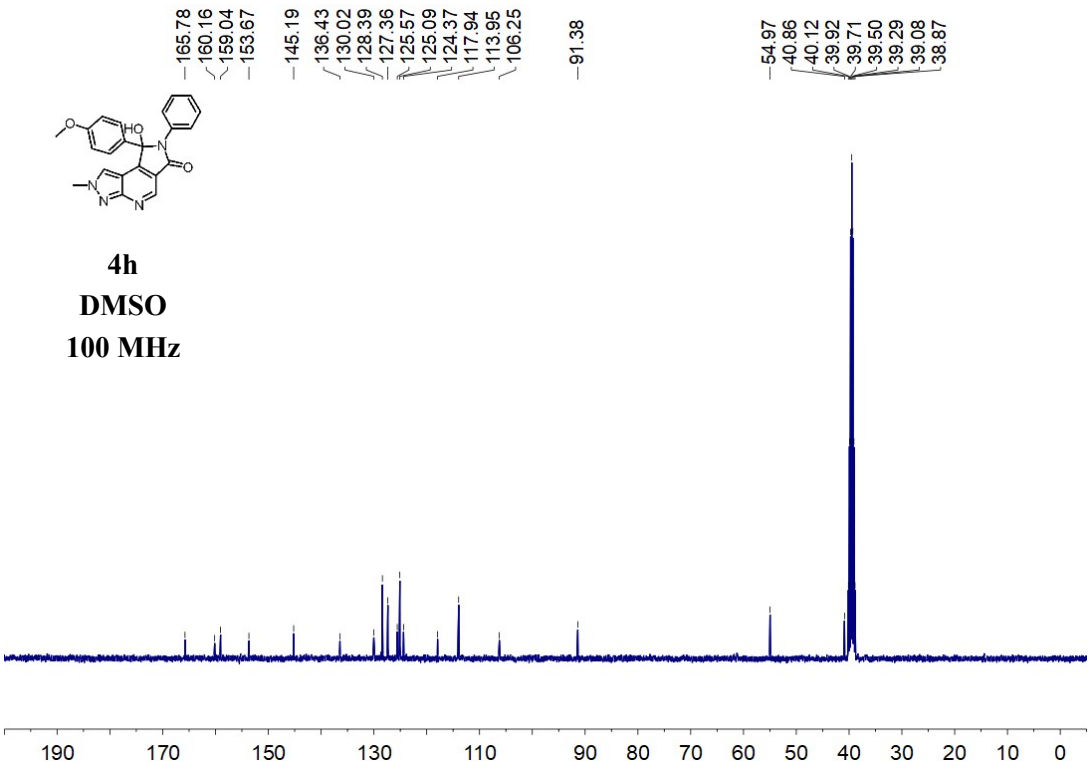

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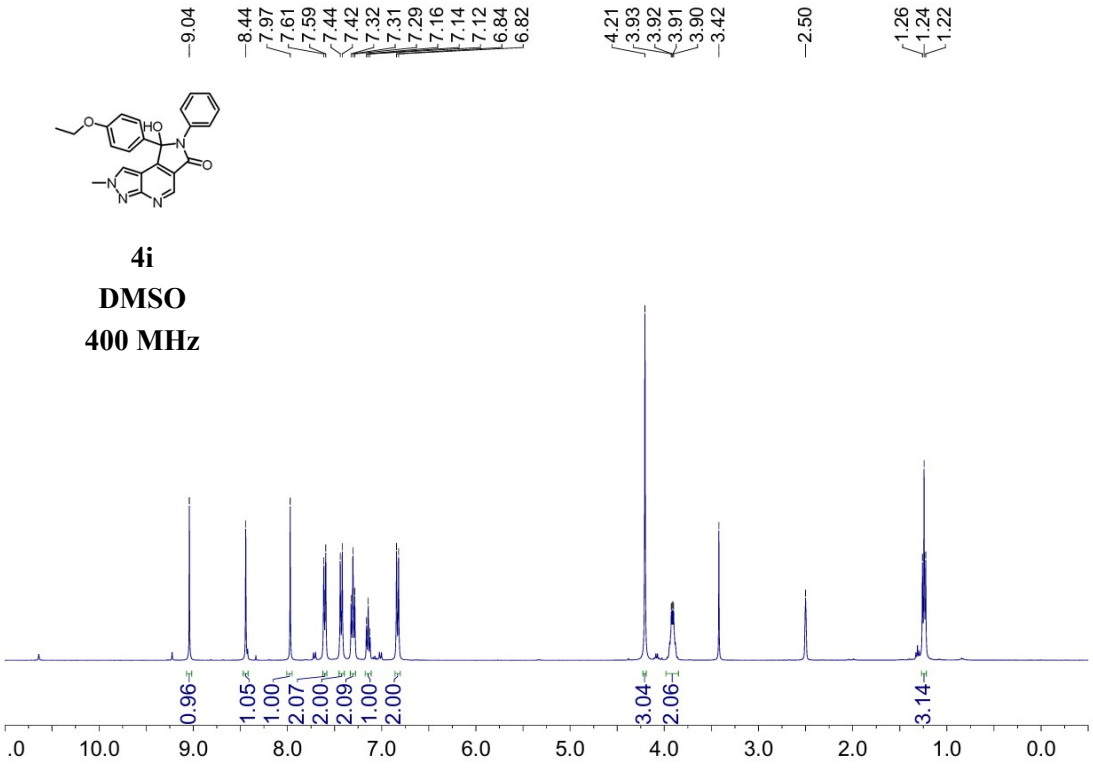

4i
DMSO
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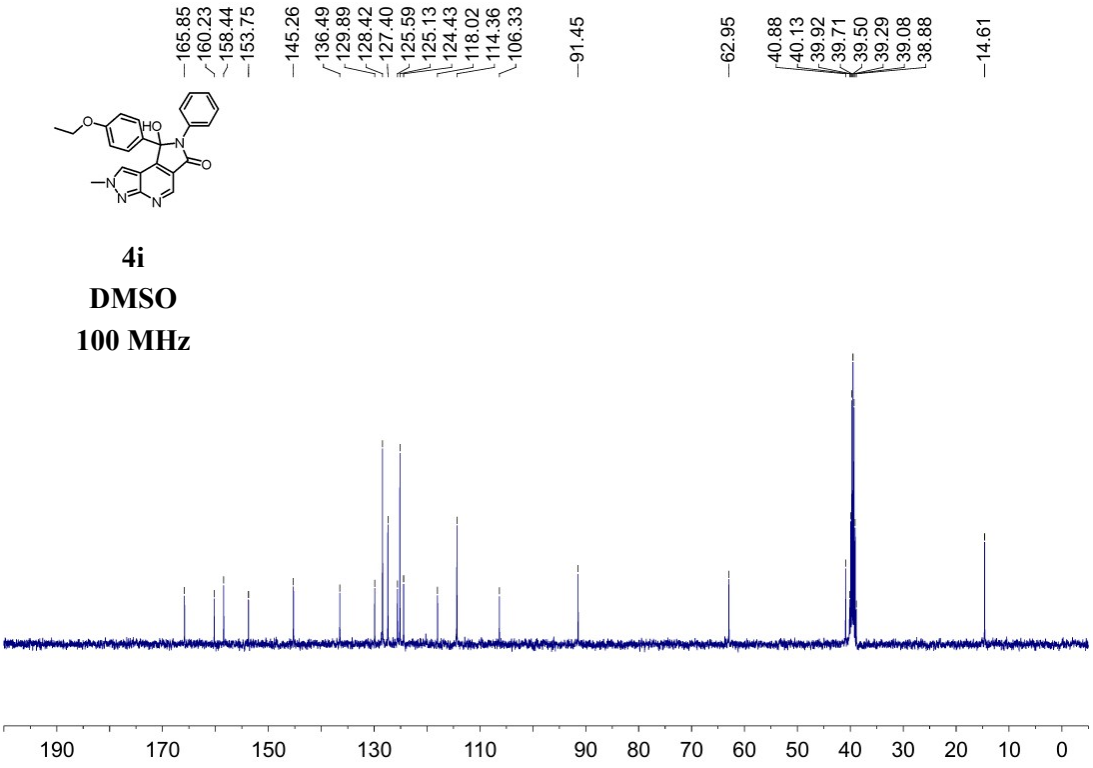

4i
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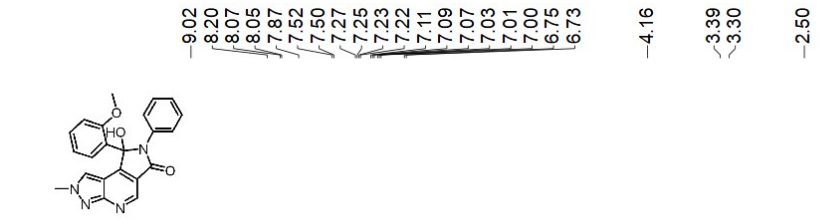

4j
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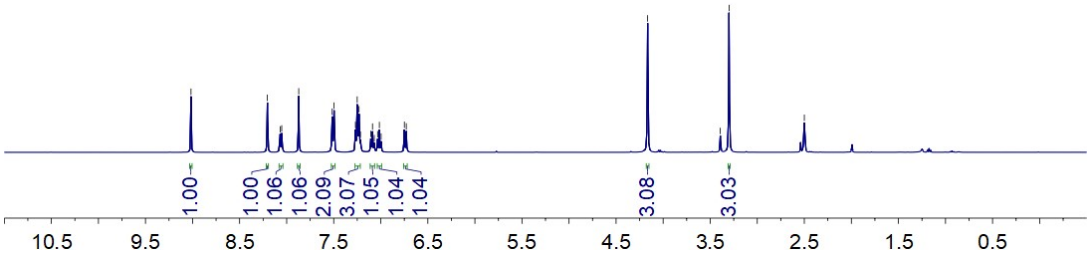

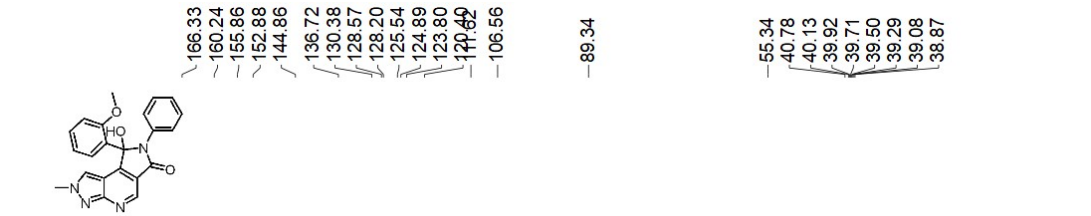

4j
DMSO
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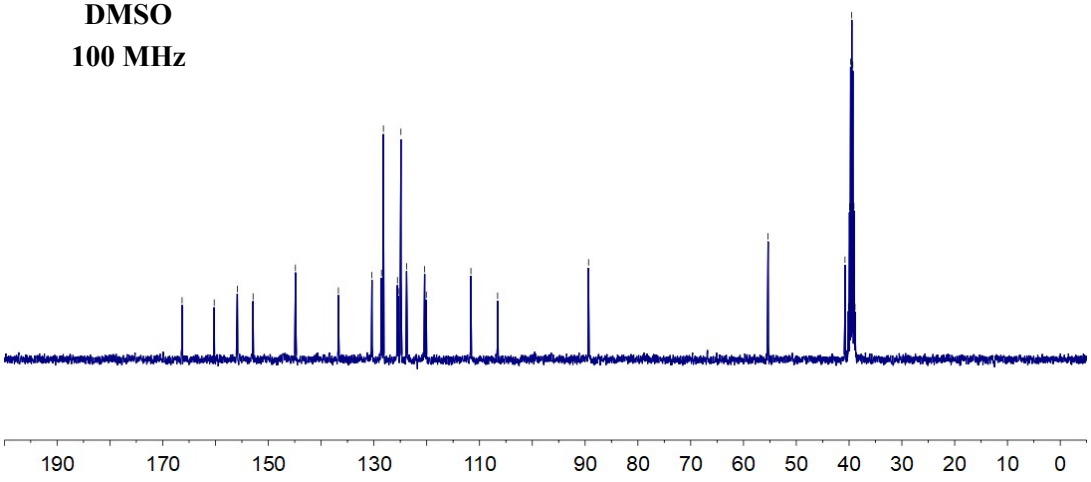

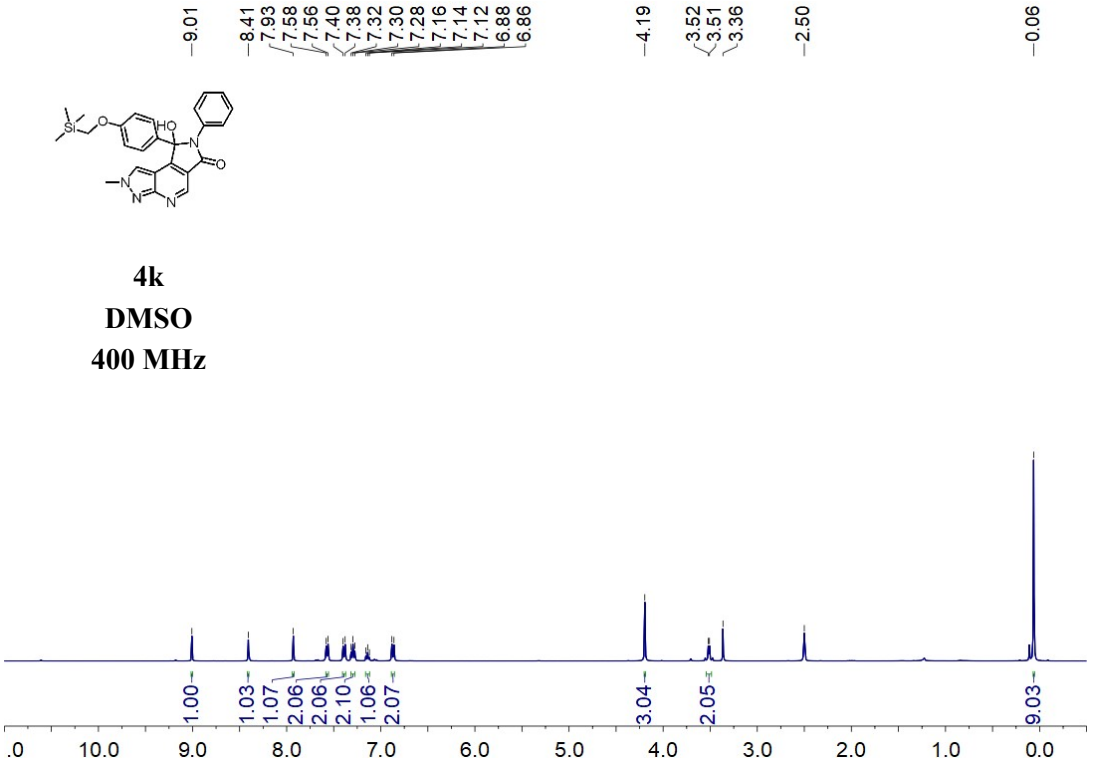

4k
DMSO
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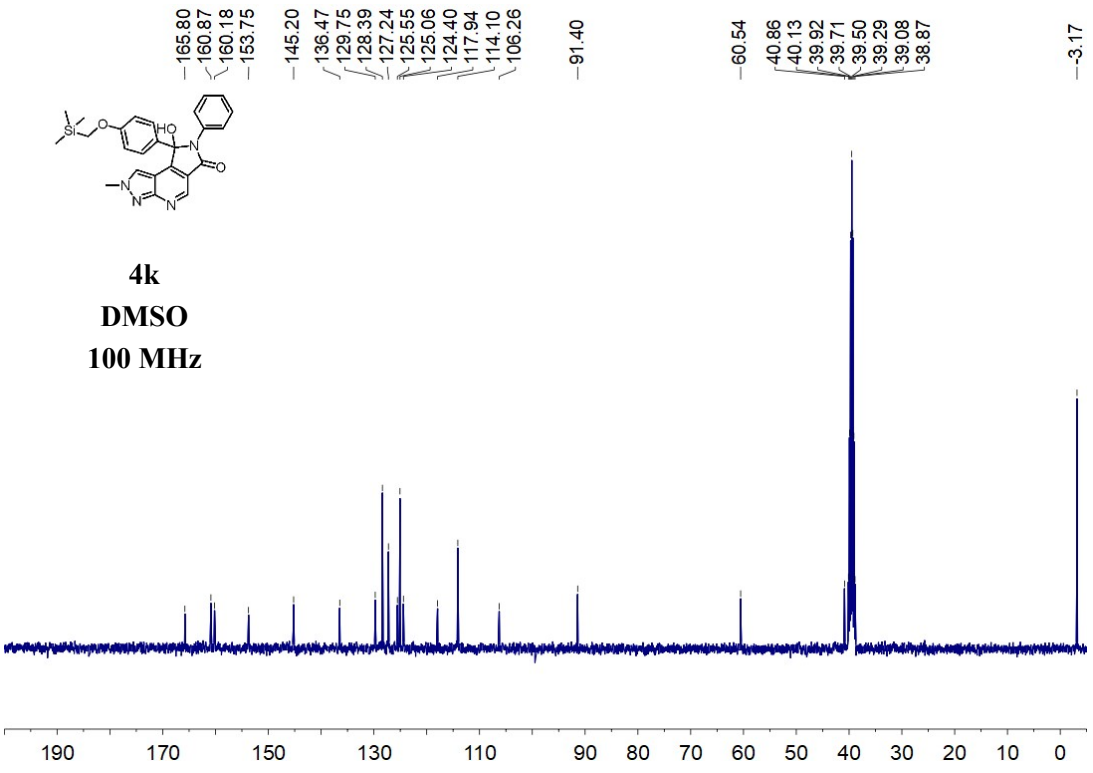

4k
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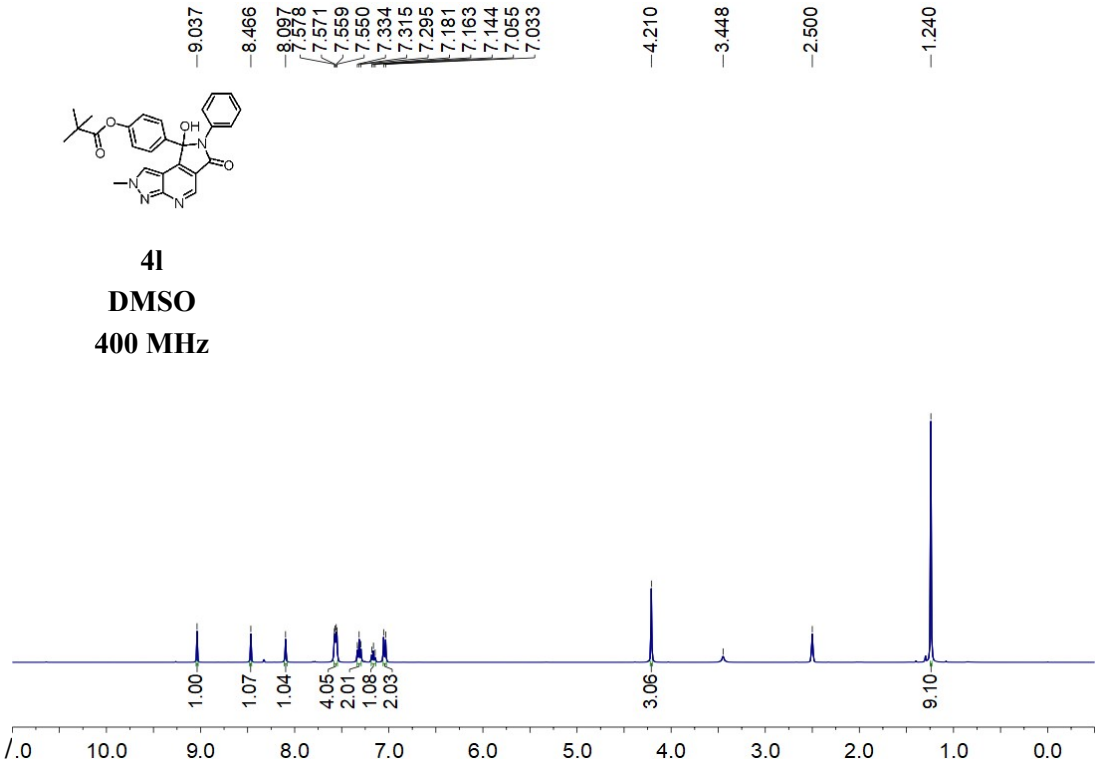

4l
DMSO
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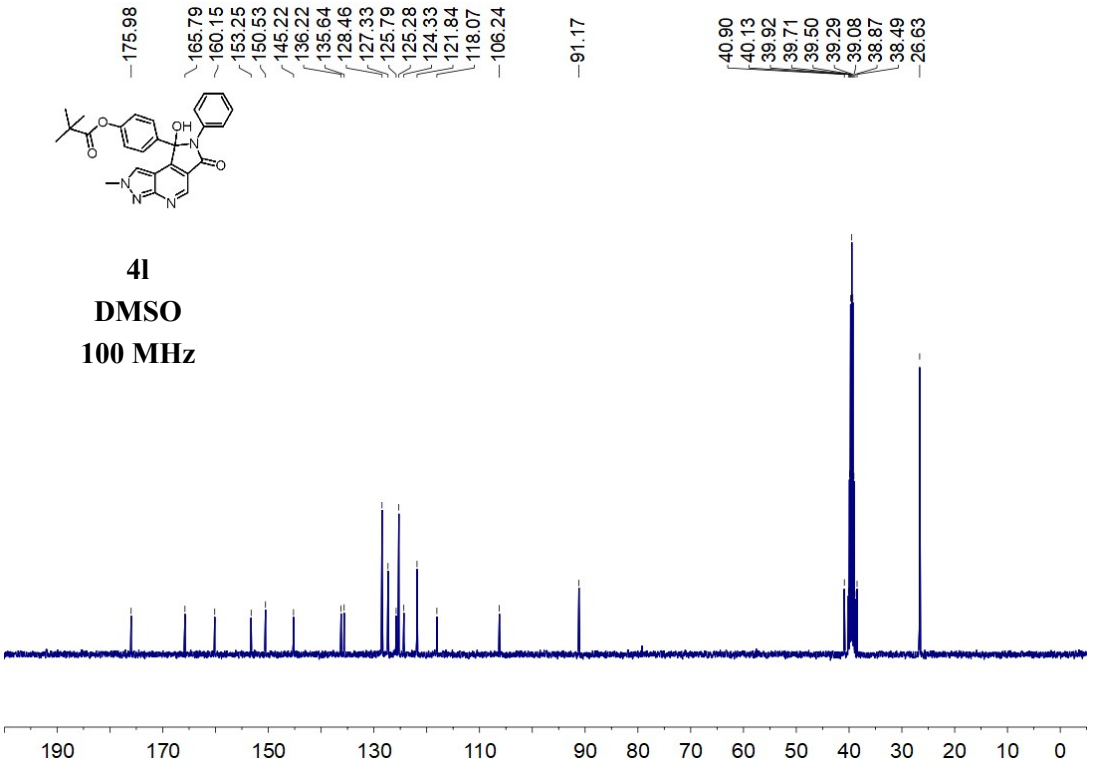

4l
DMSO
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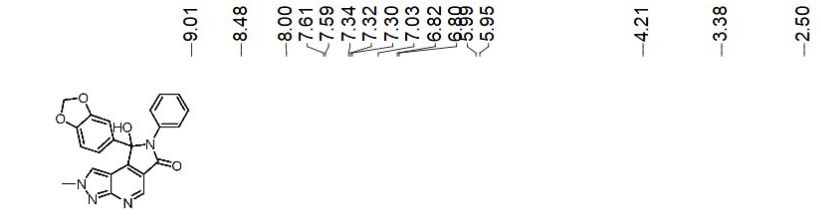
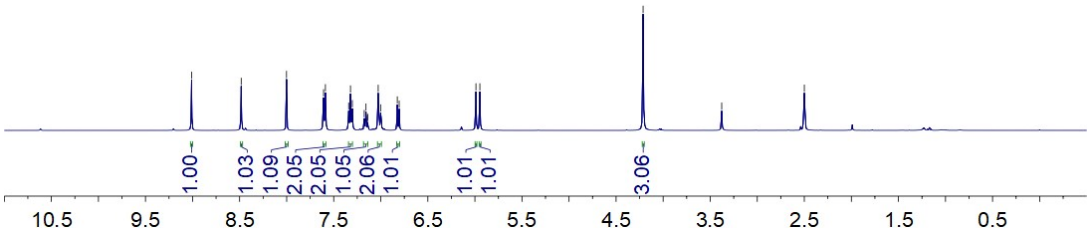
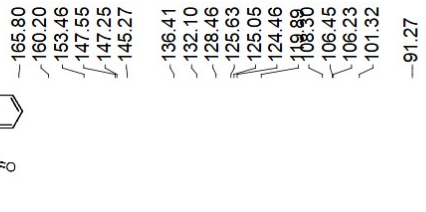
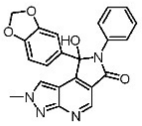


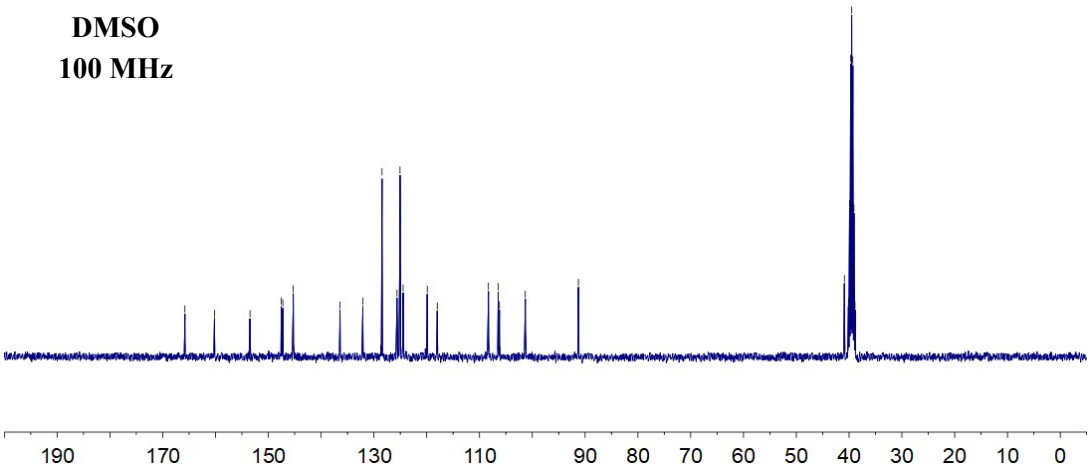
4m
DMSO
400 MHz

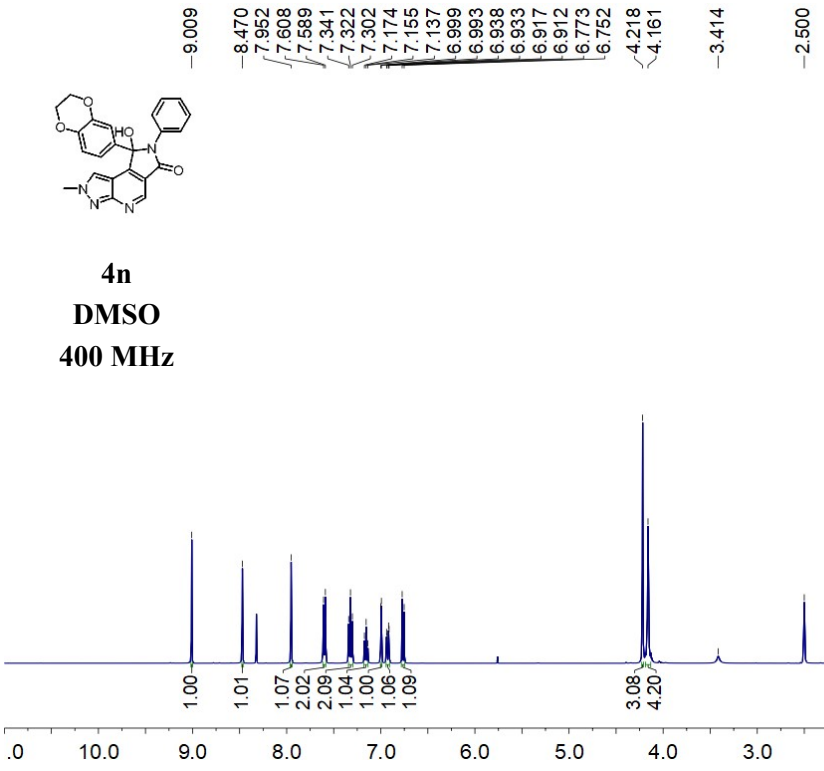




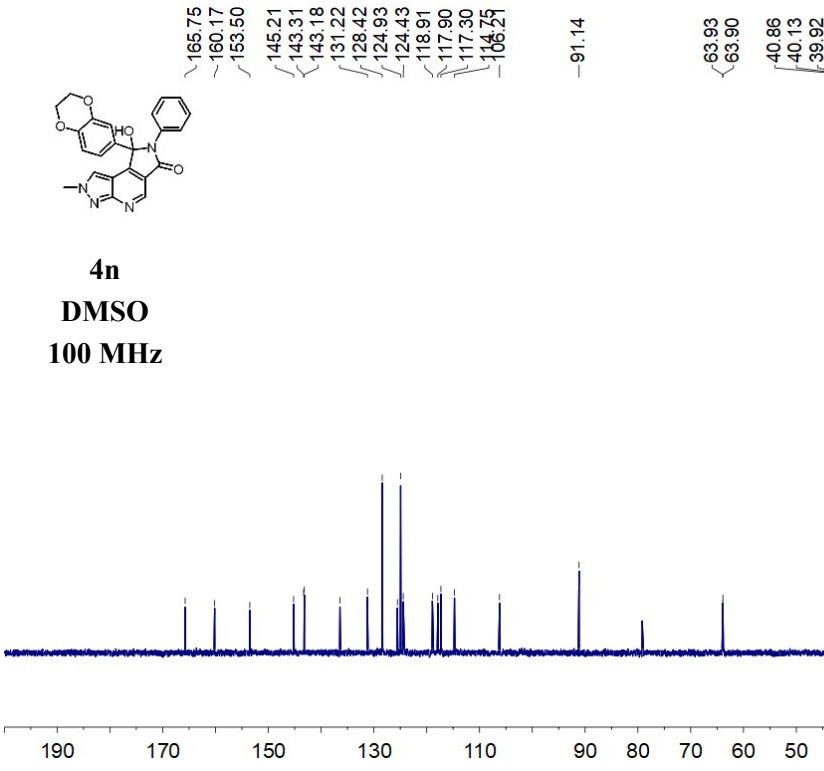


4m
DMSO
100 MHz





4n
DMSO
400 MHz



4n
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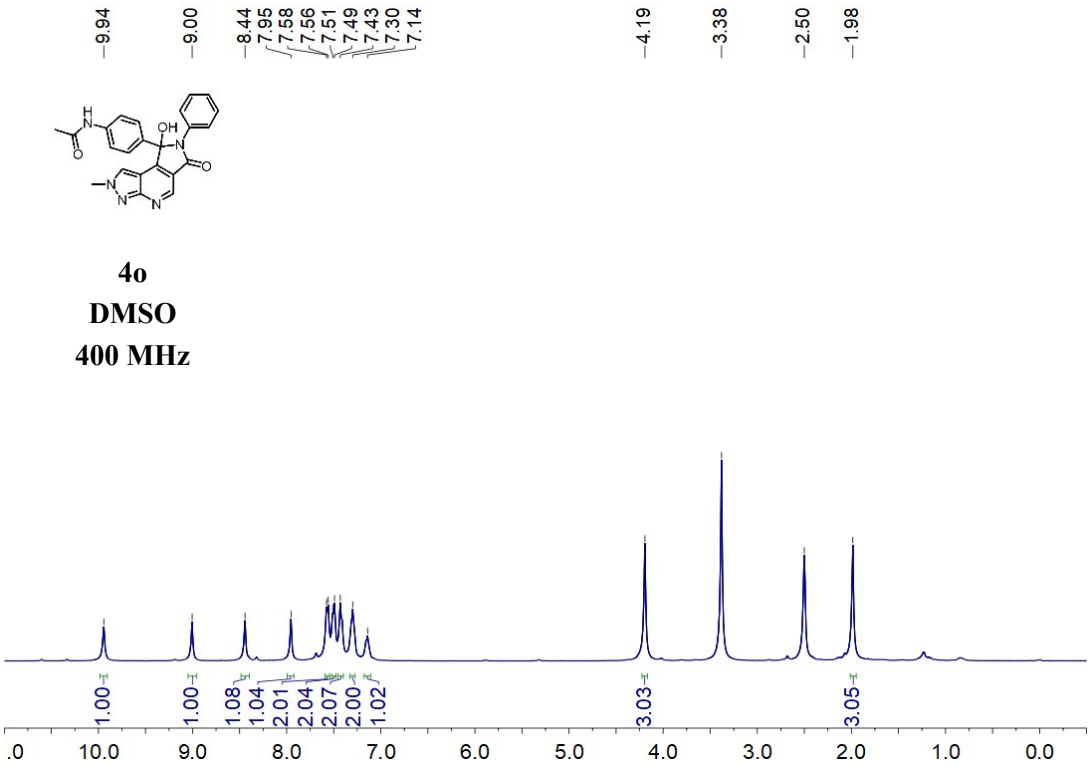

4o
DMSO
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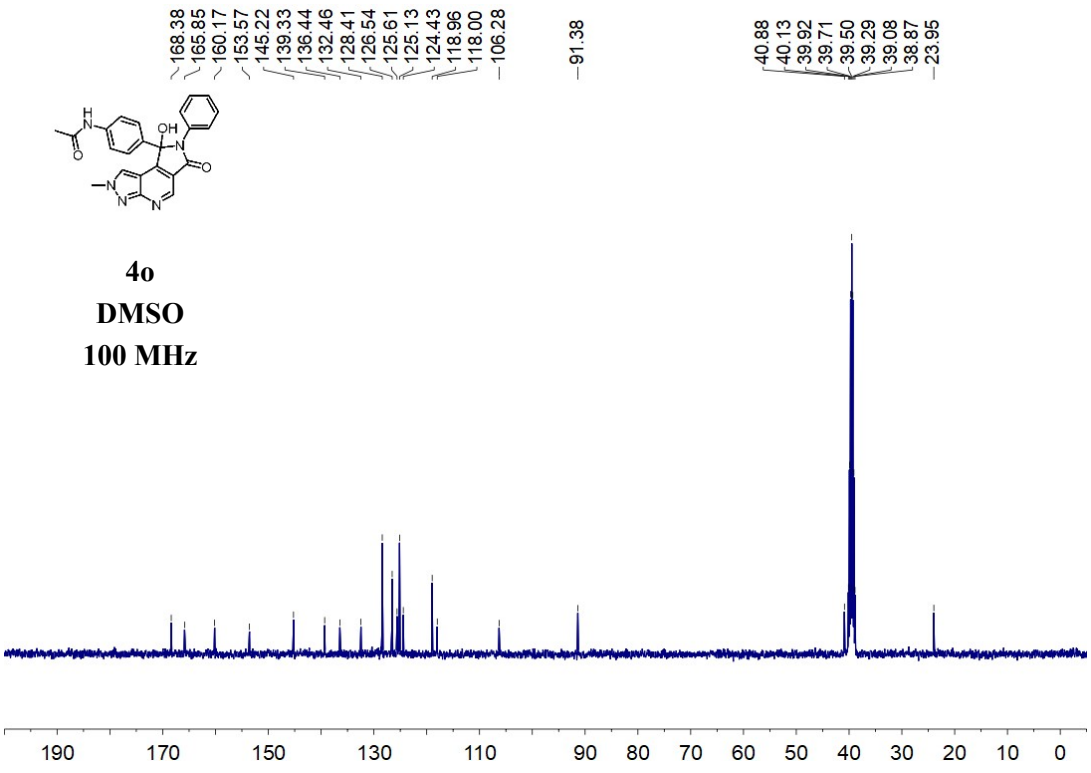

4o
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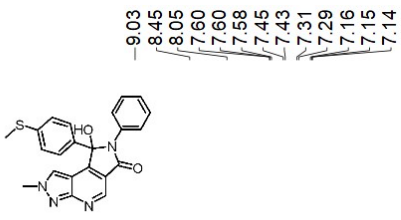
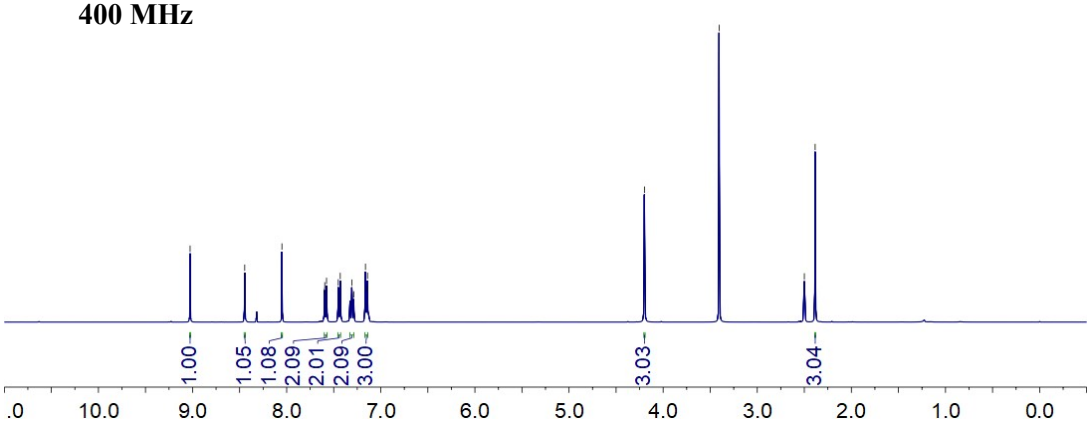
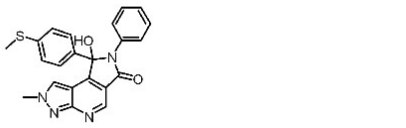


4p
DMSO
400 MHz





4p
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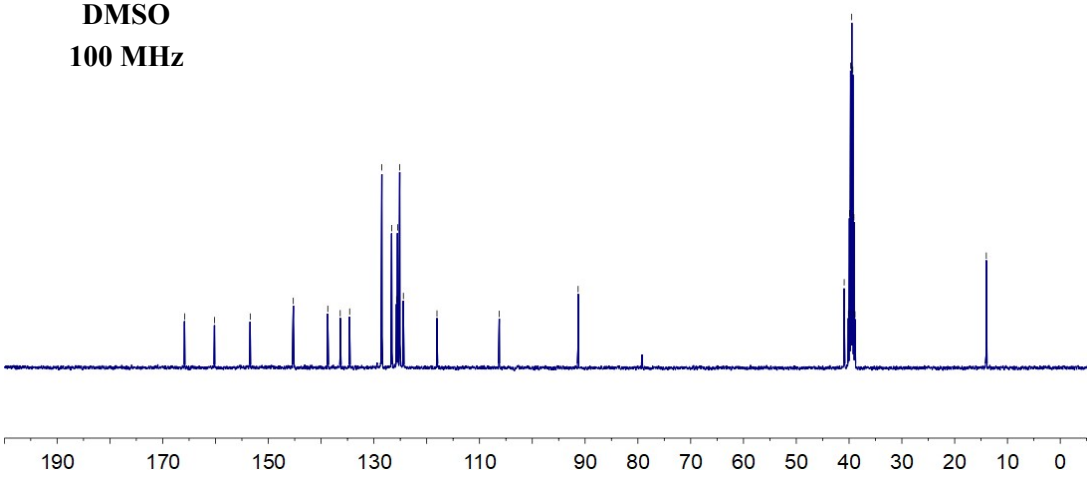
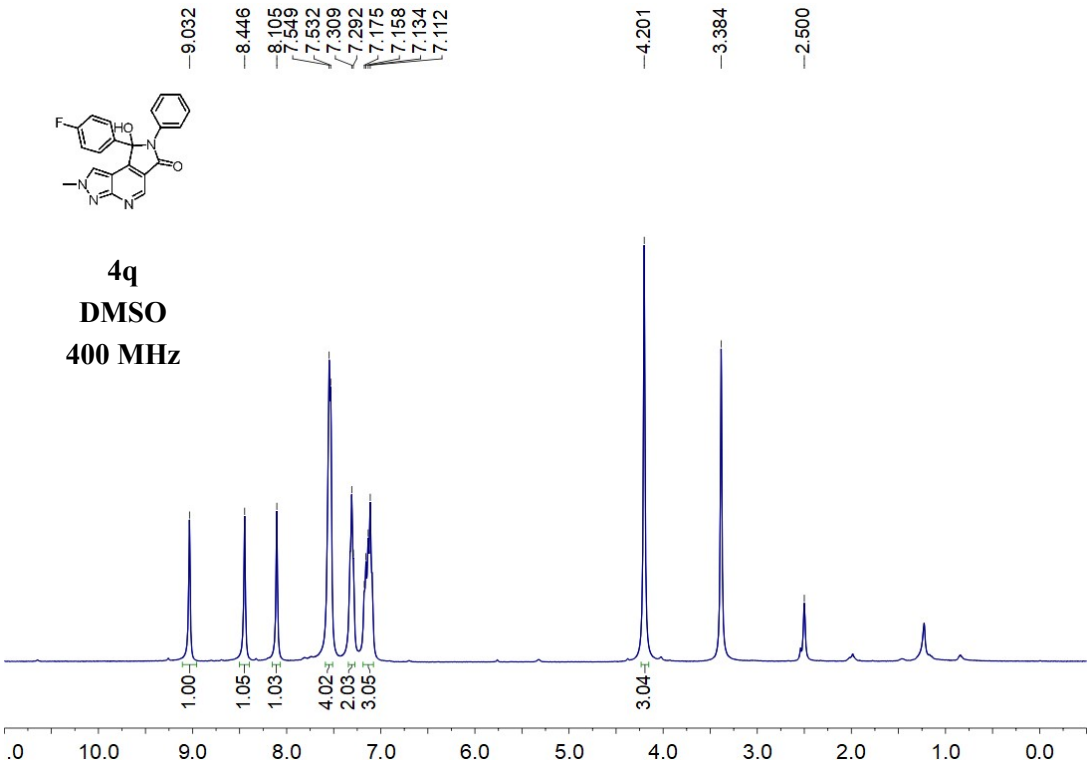
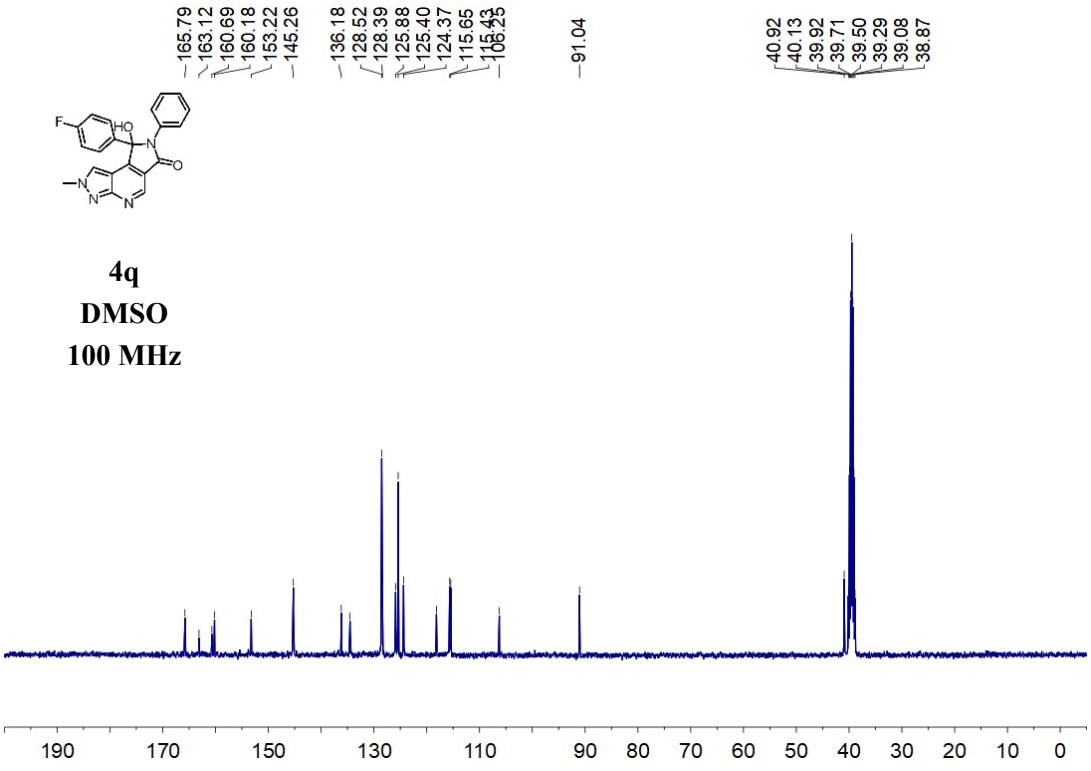
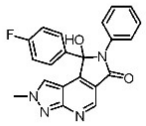




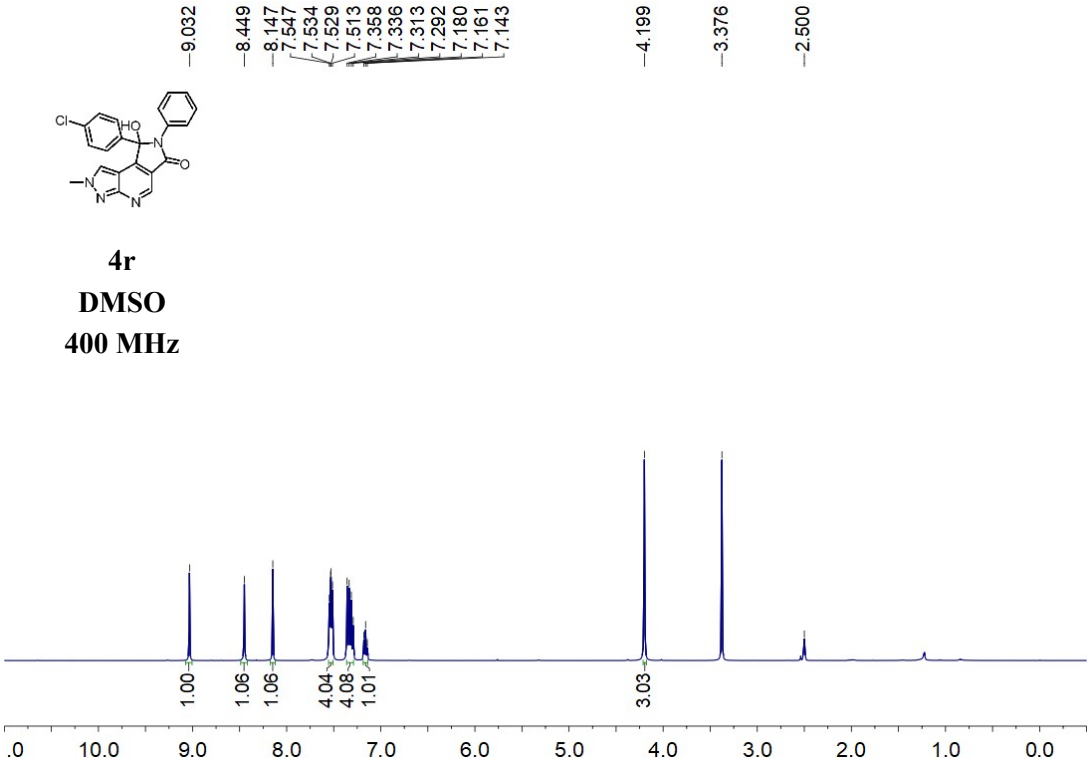
4q
DMSO
400 MHz



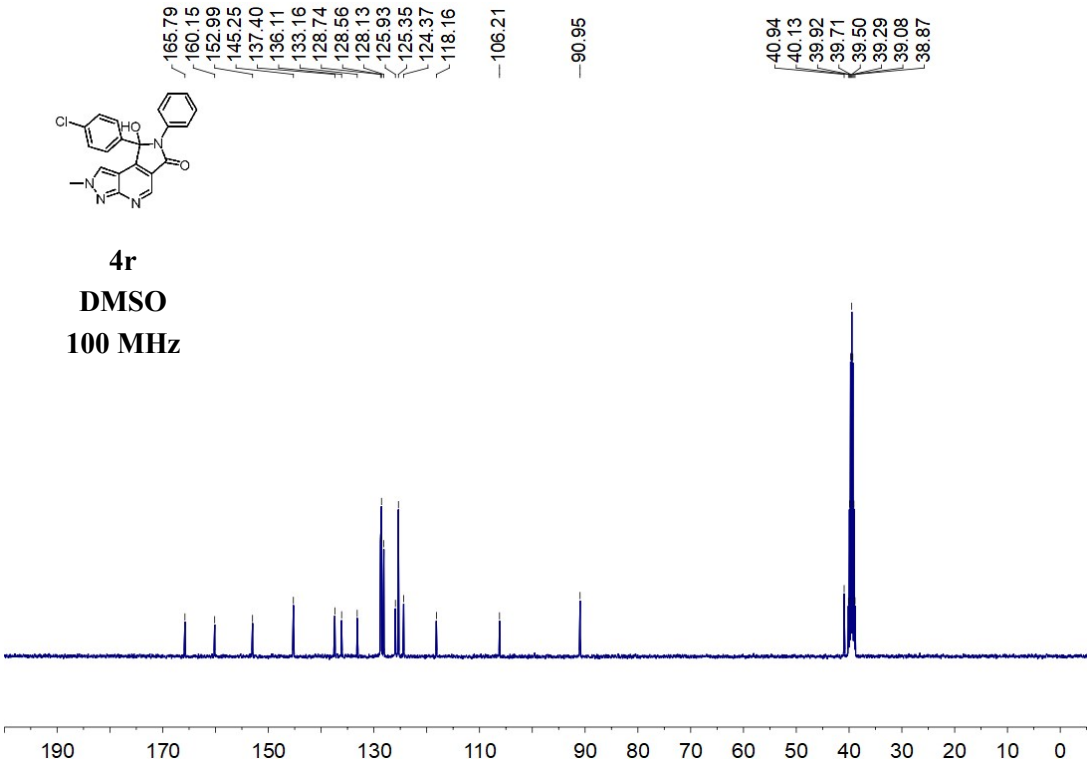
4q
DMSO
100 MHz



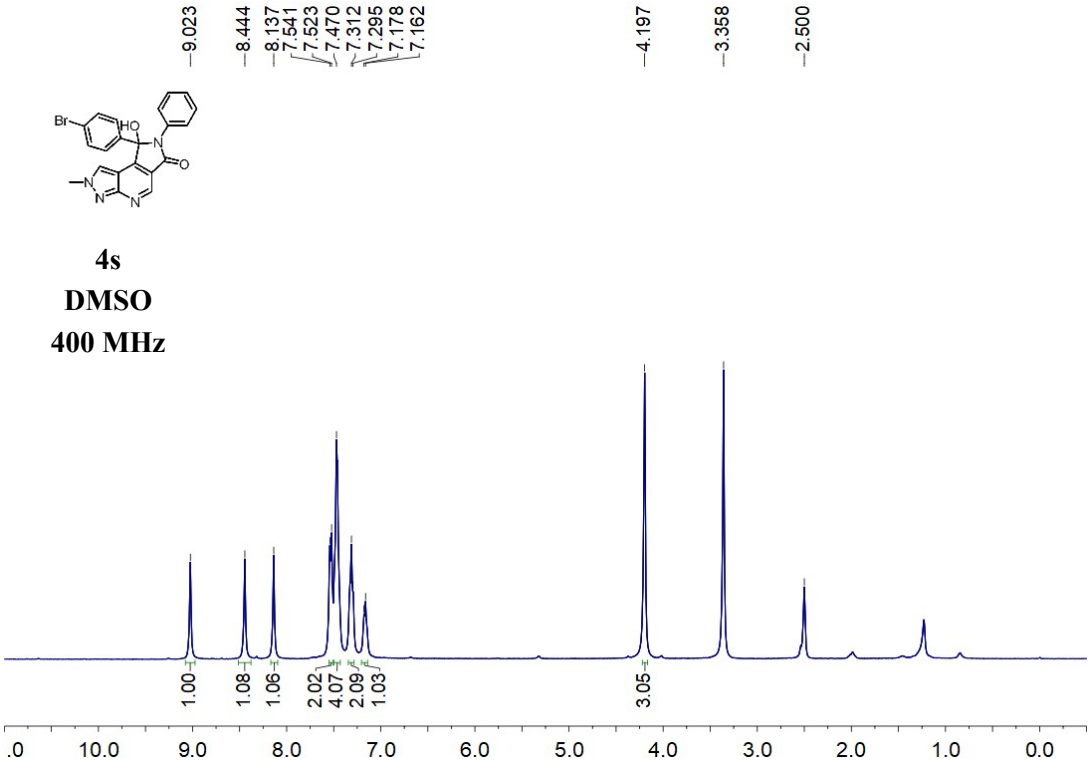
4q
$CDCl_3$
376 MHz



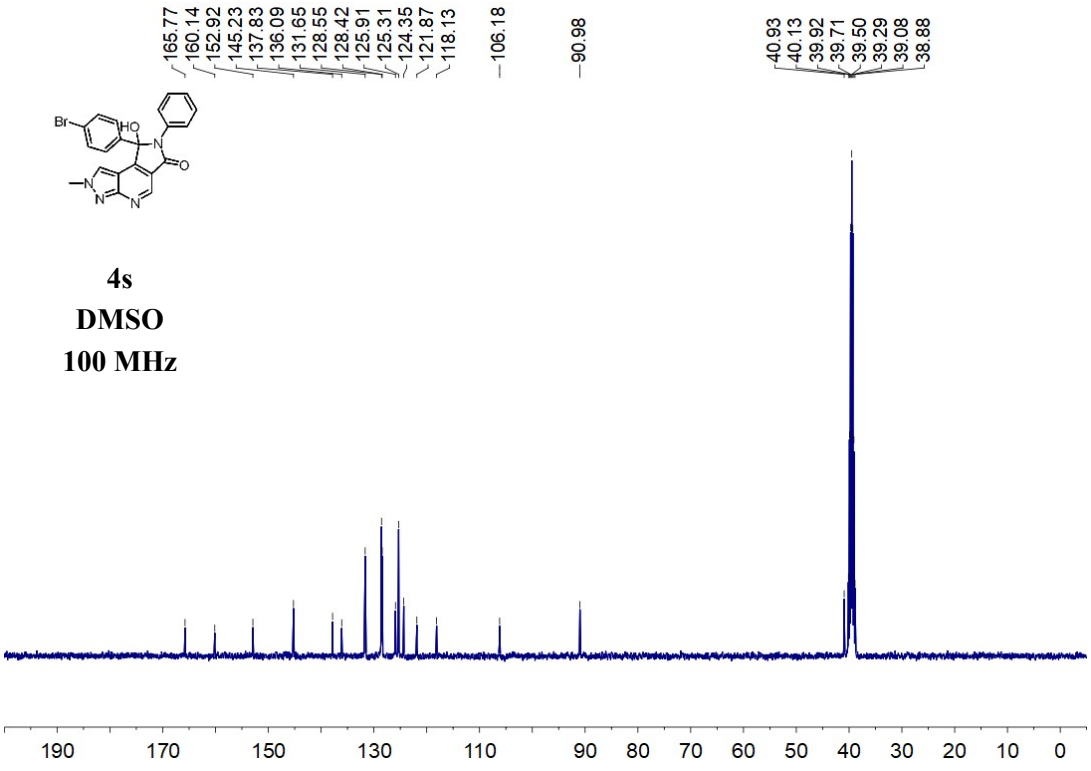
4r
DMSO
400 MHz



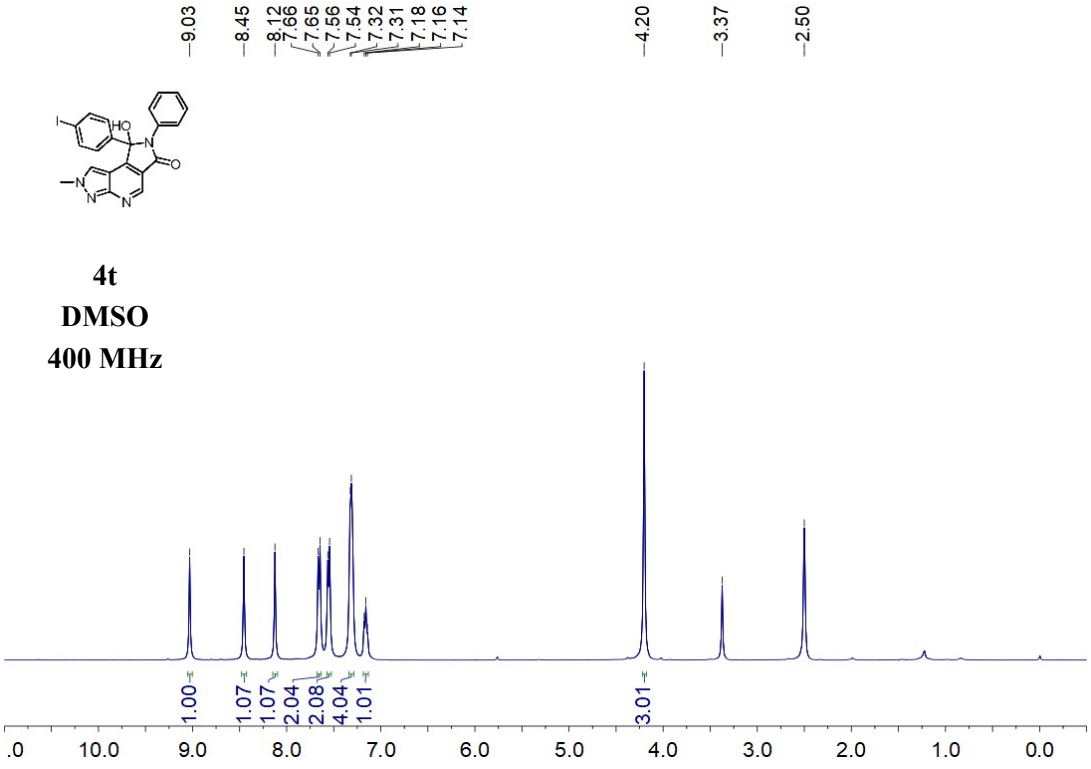
4r
DMSO
100 MHz



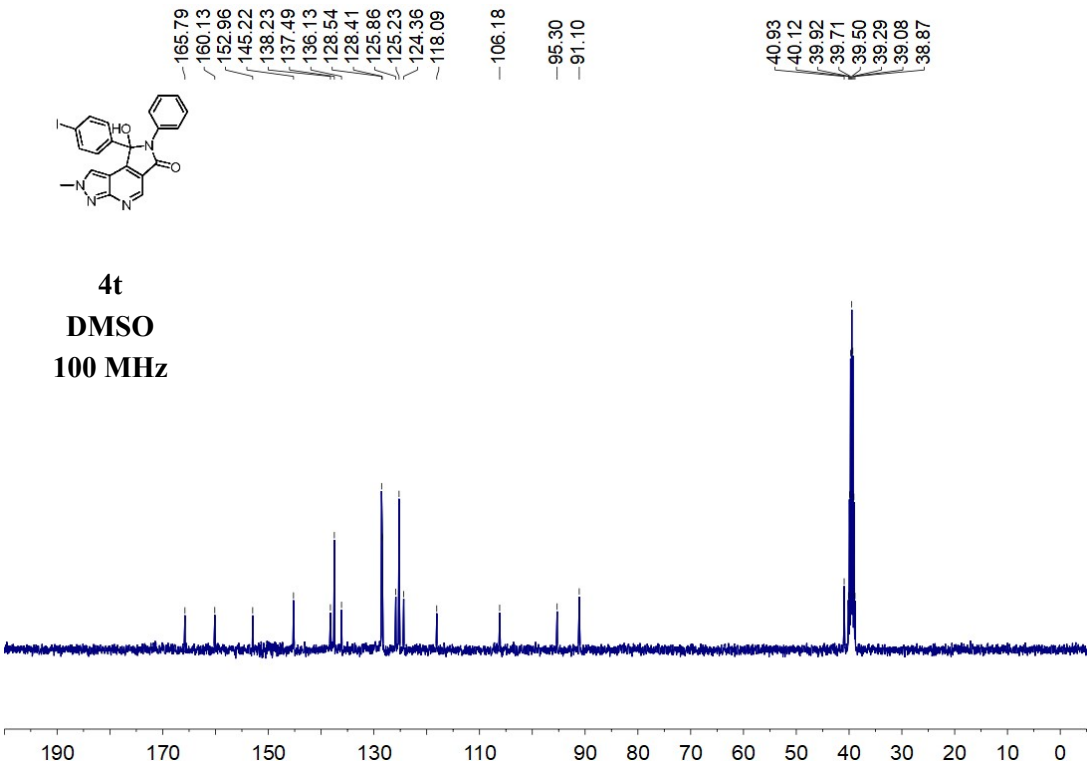
4s
DMSO
400 MHz



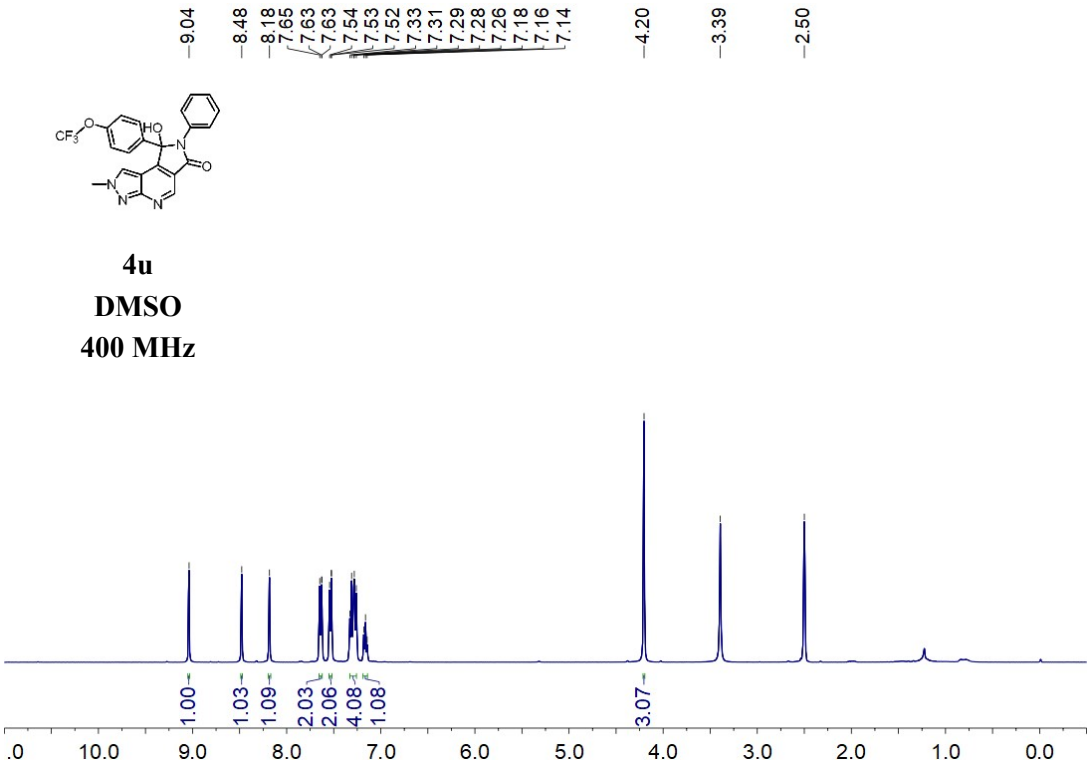
4s
DMSO
100 MHz



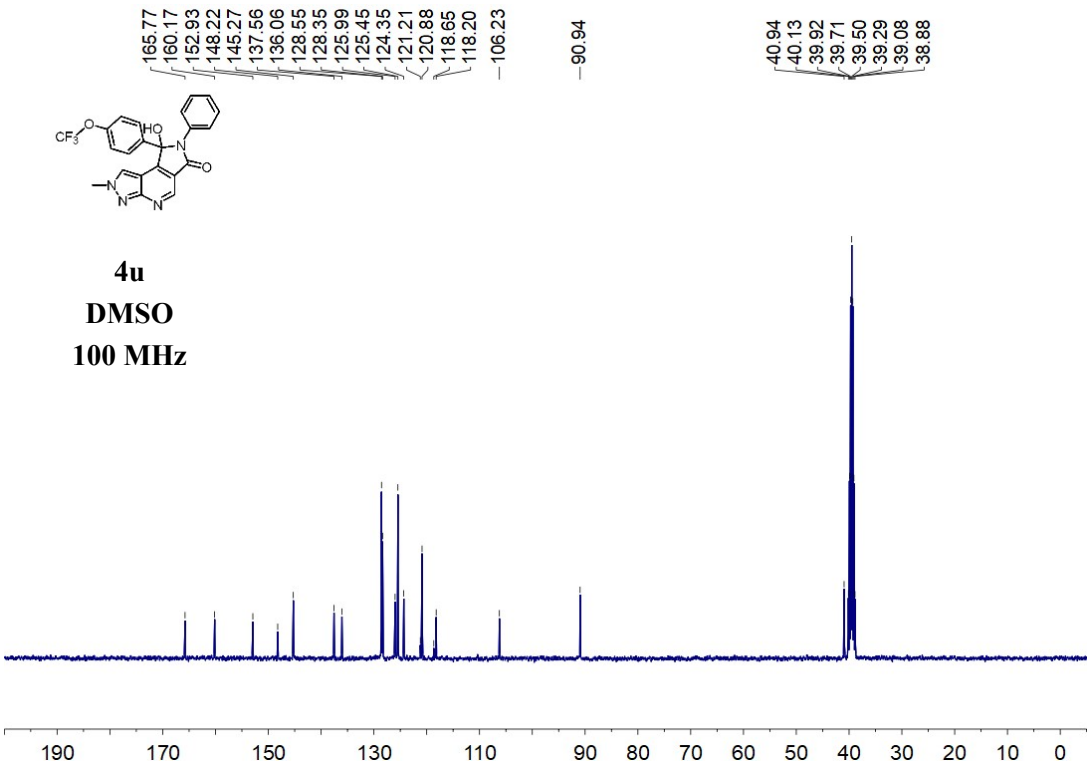
4t
DMSO
400 MHz



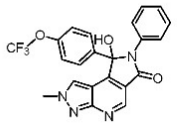
4t
DMSO
100 MHz



4u
DMSO
400 MHz



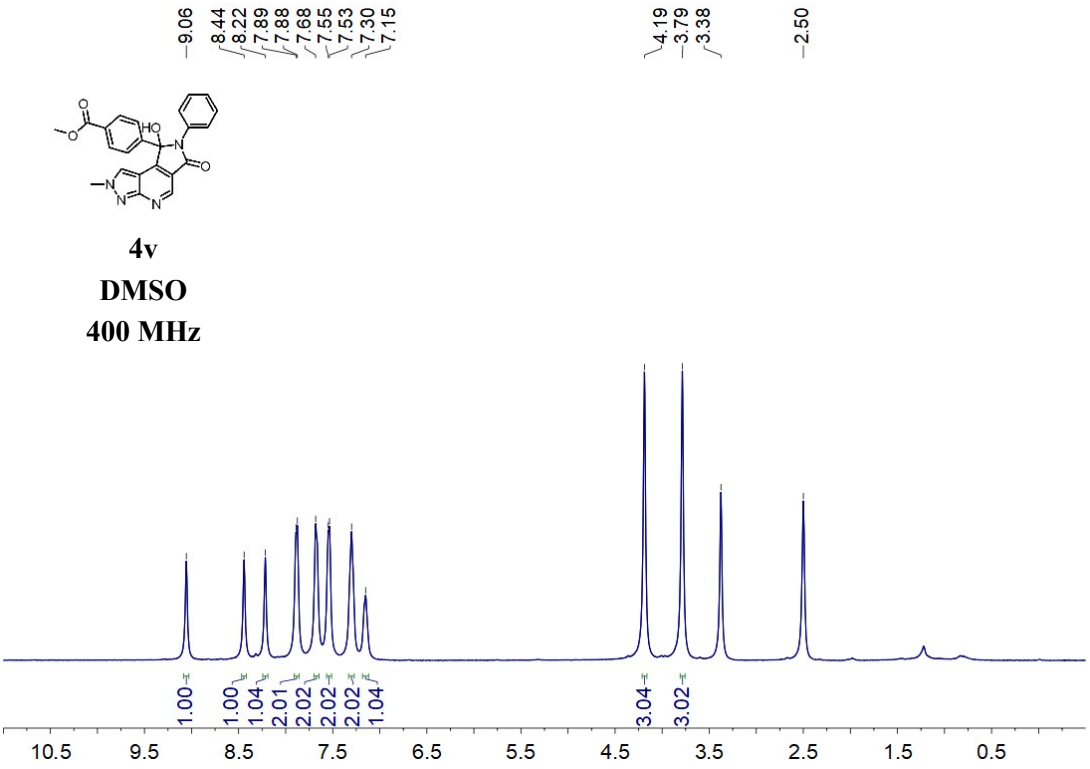
4u
DMSO
100 MHz



4u

$CDCl_3$

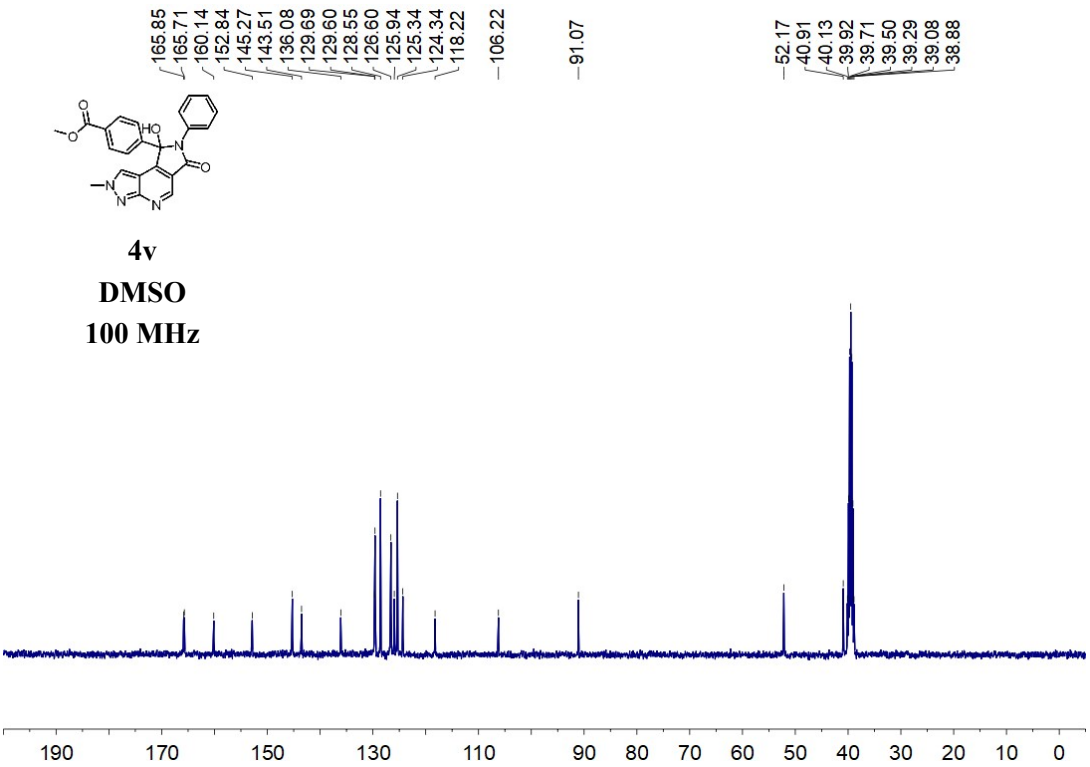
376 MHz



4v

DMSO

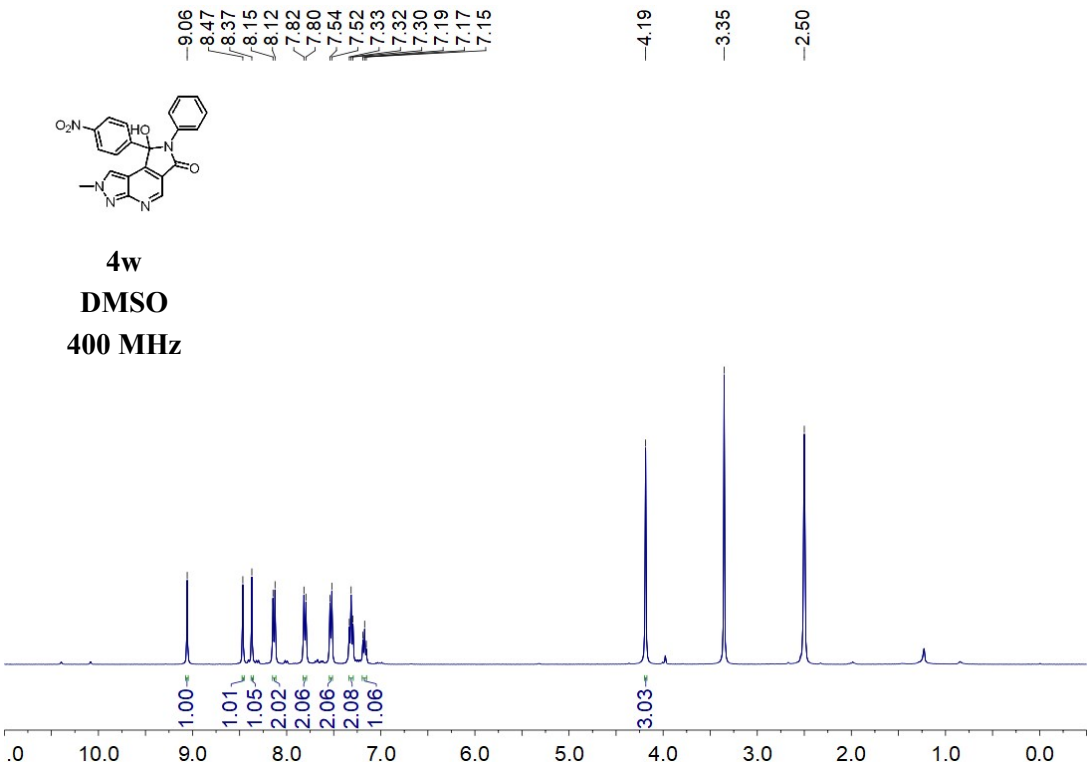
400 MHz



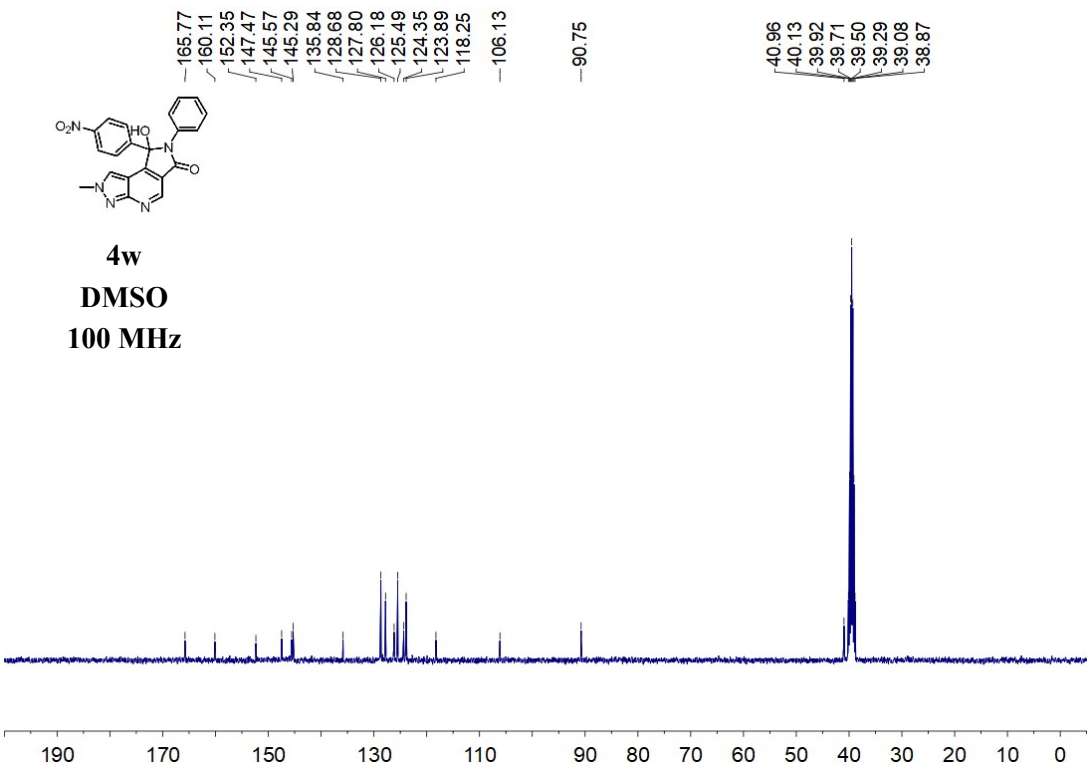
4v

DMSO

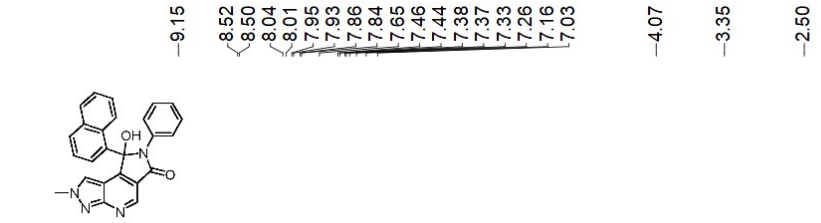
100 MHz



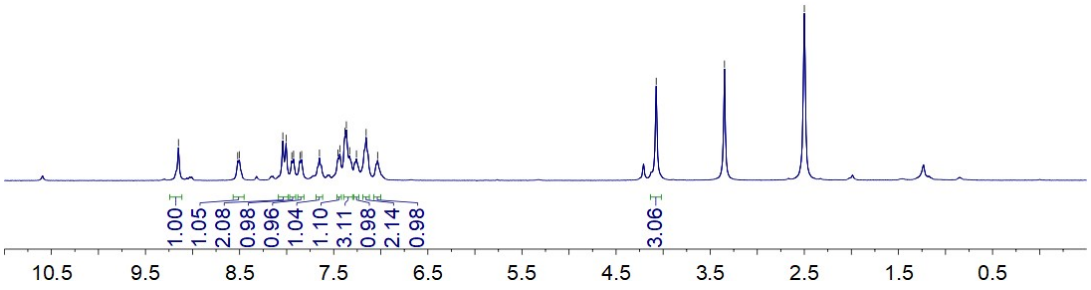
4w
DMSO
400 MHz

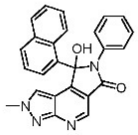


4w
DMSO
100 MHz



4x
DMSO
400 MHz





4x
DMSO
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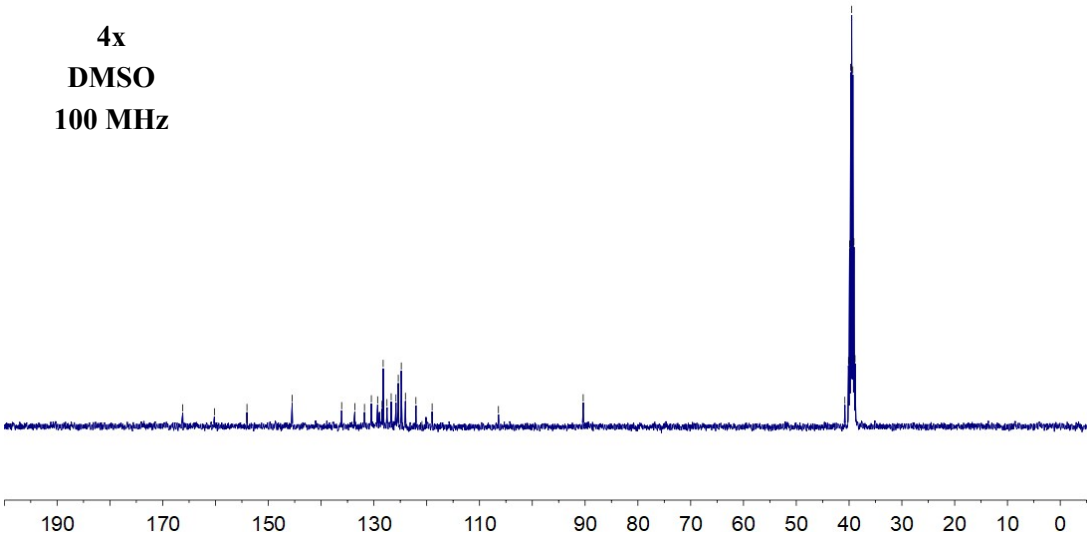
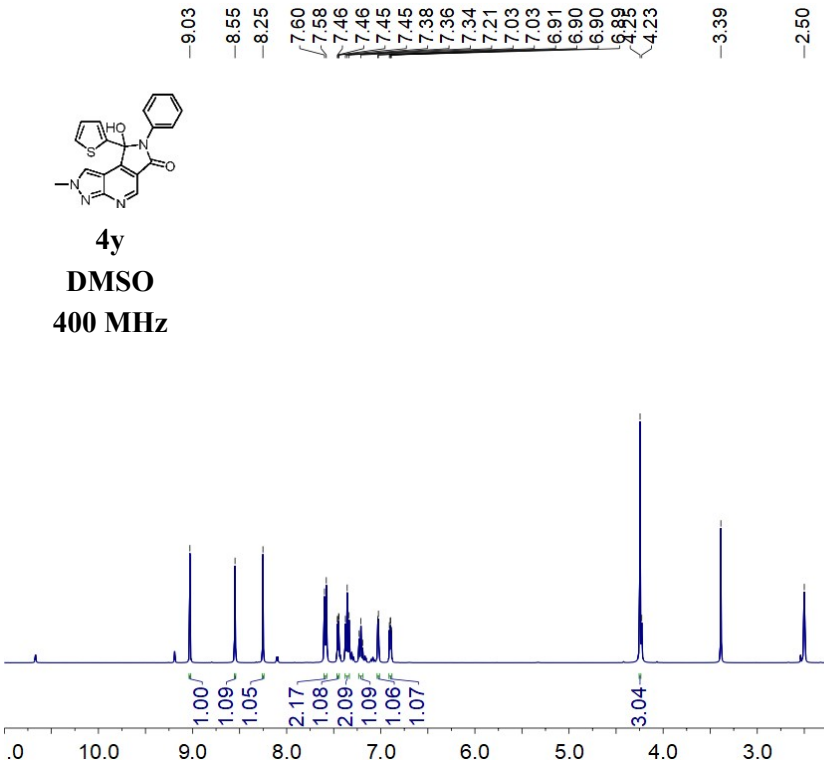
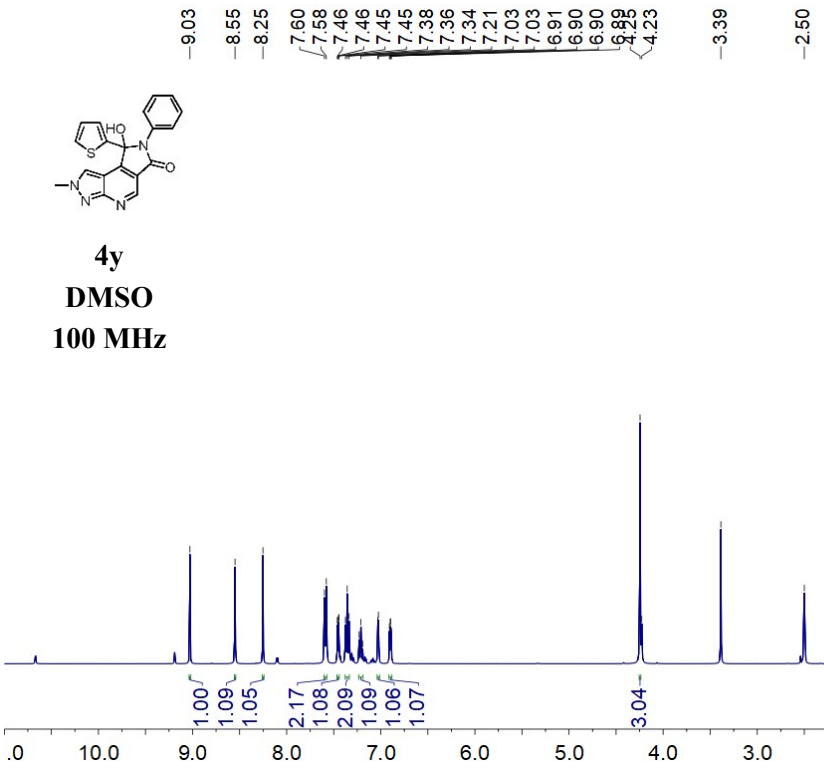
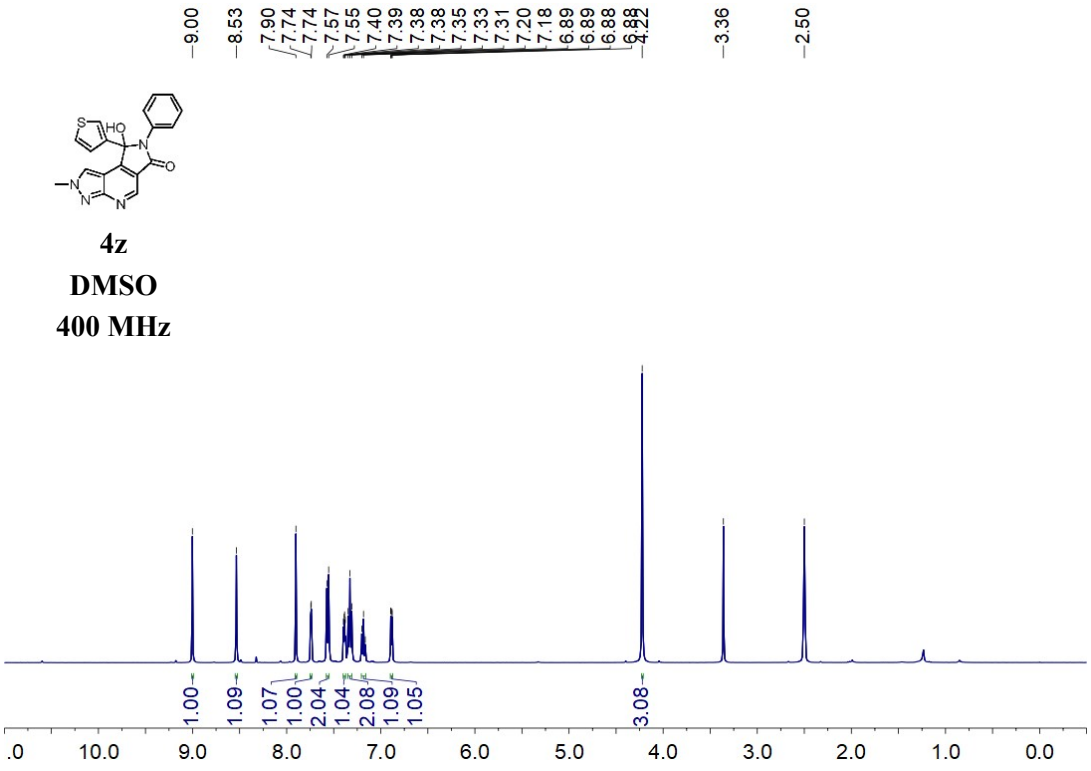




4y
DMSO
400 MHz



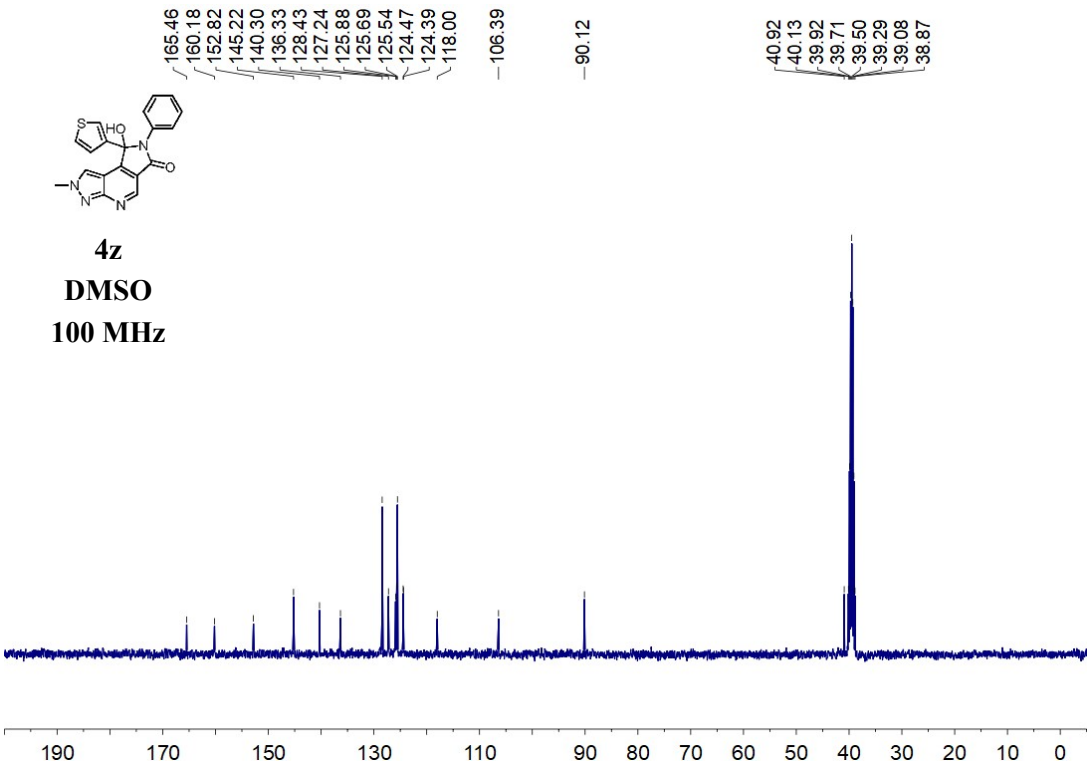
4y
DMSO
100 MHz



4z

DMSO

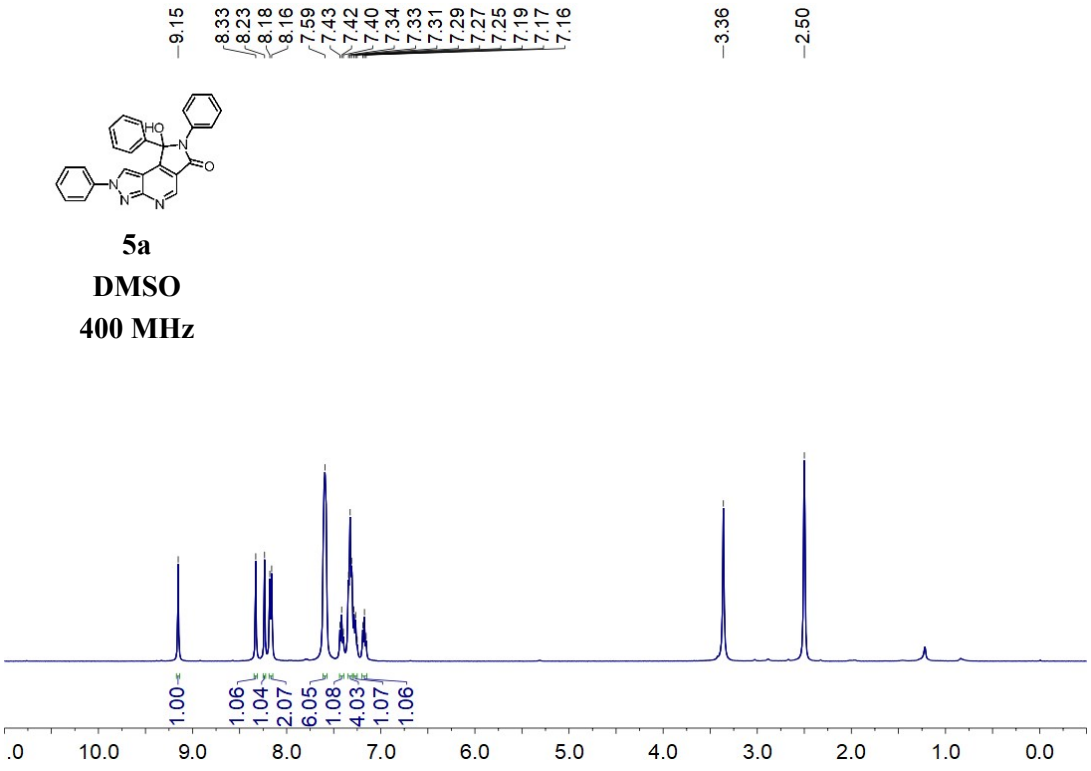
400 MHz



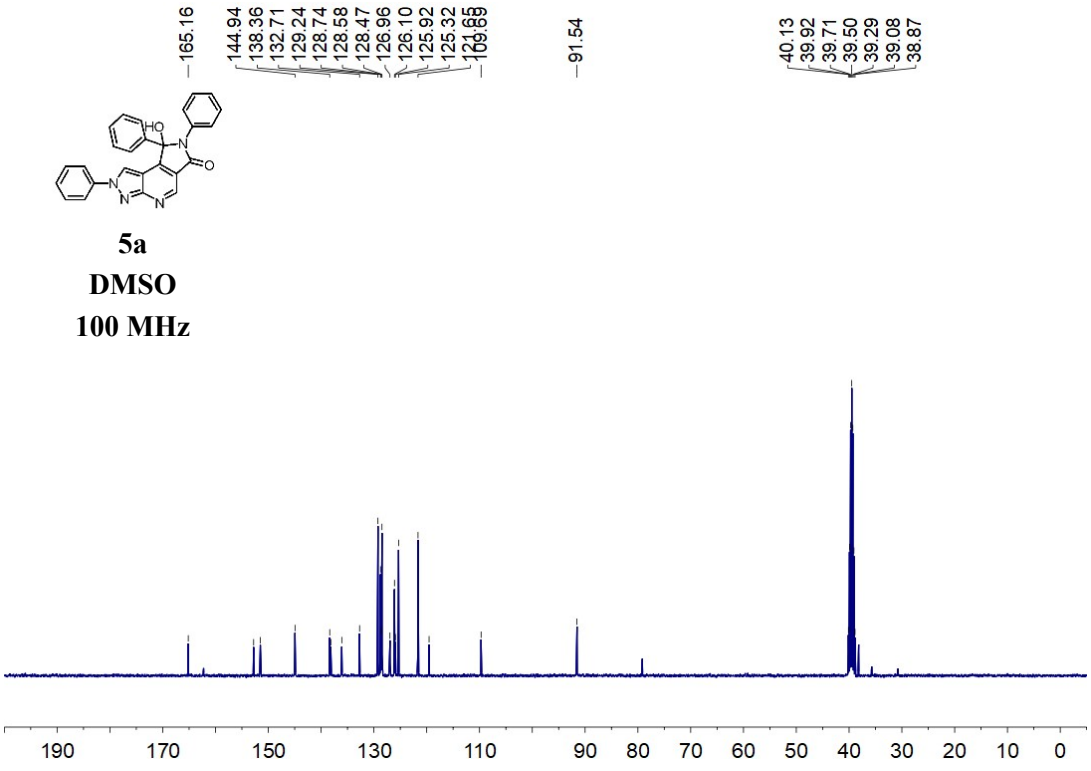
4z

DMSO

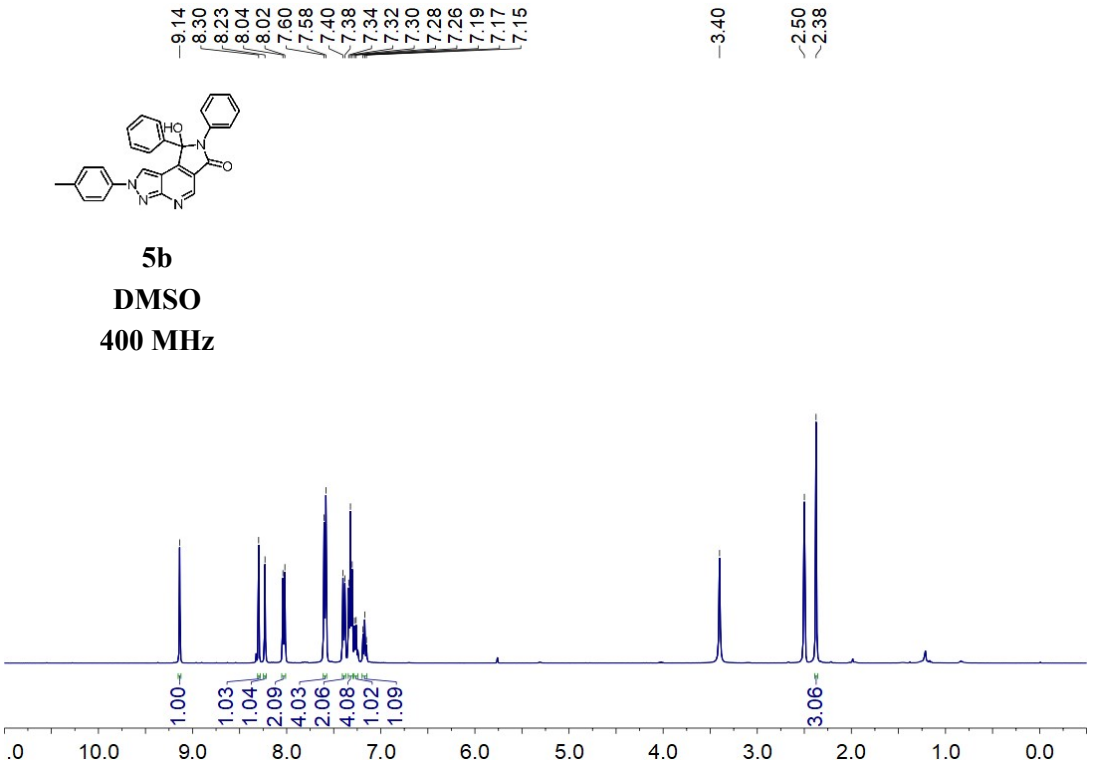
100 MHz



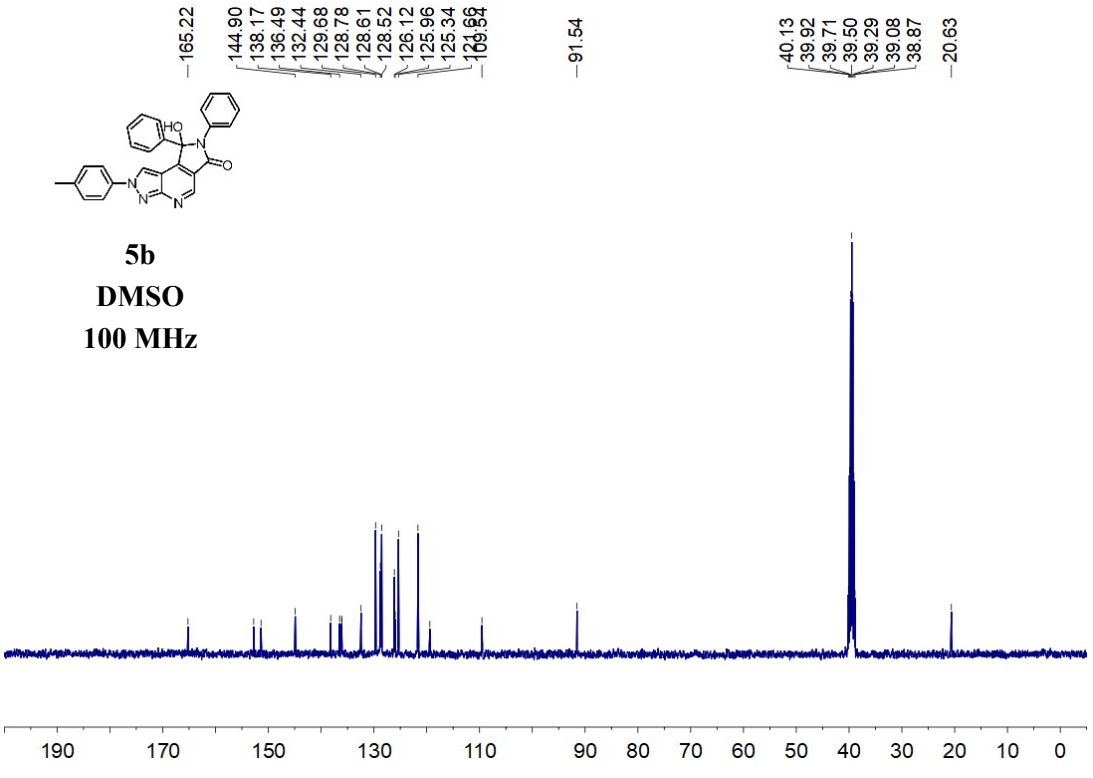
5a
DMSO
400 MHz



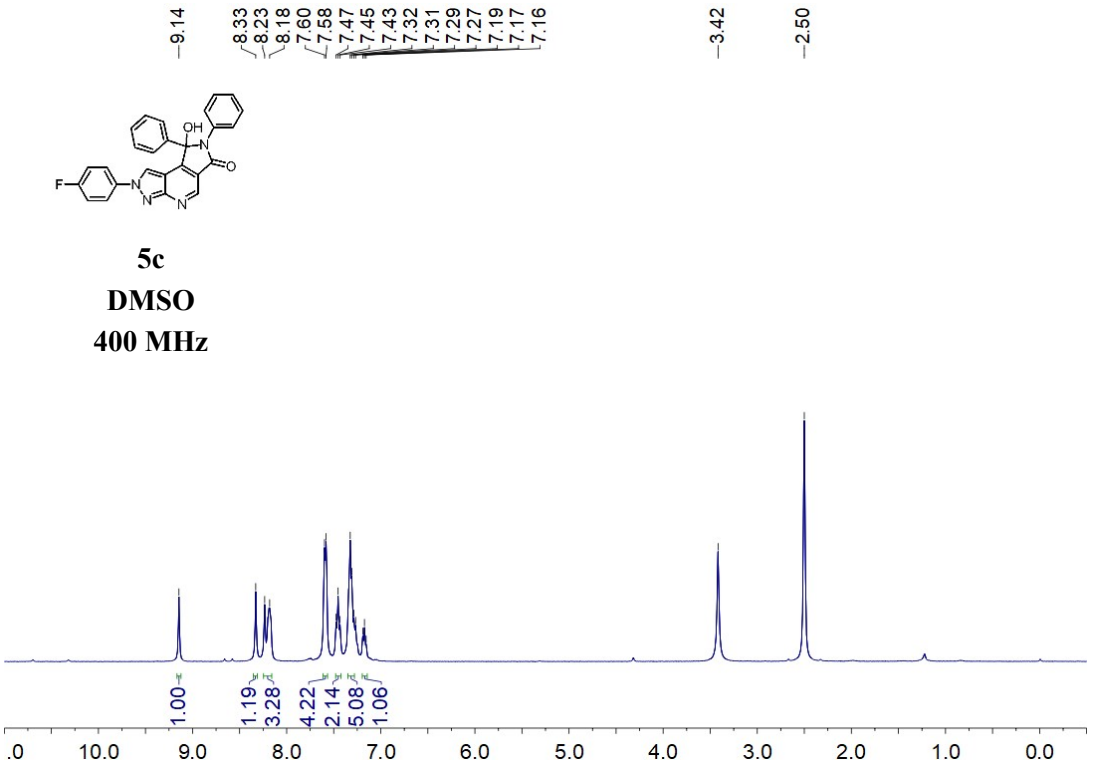
5a
DMSO
100 MHz



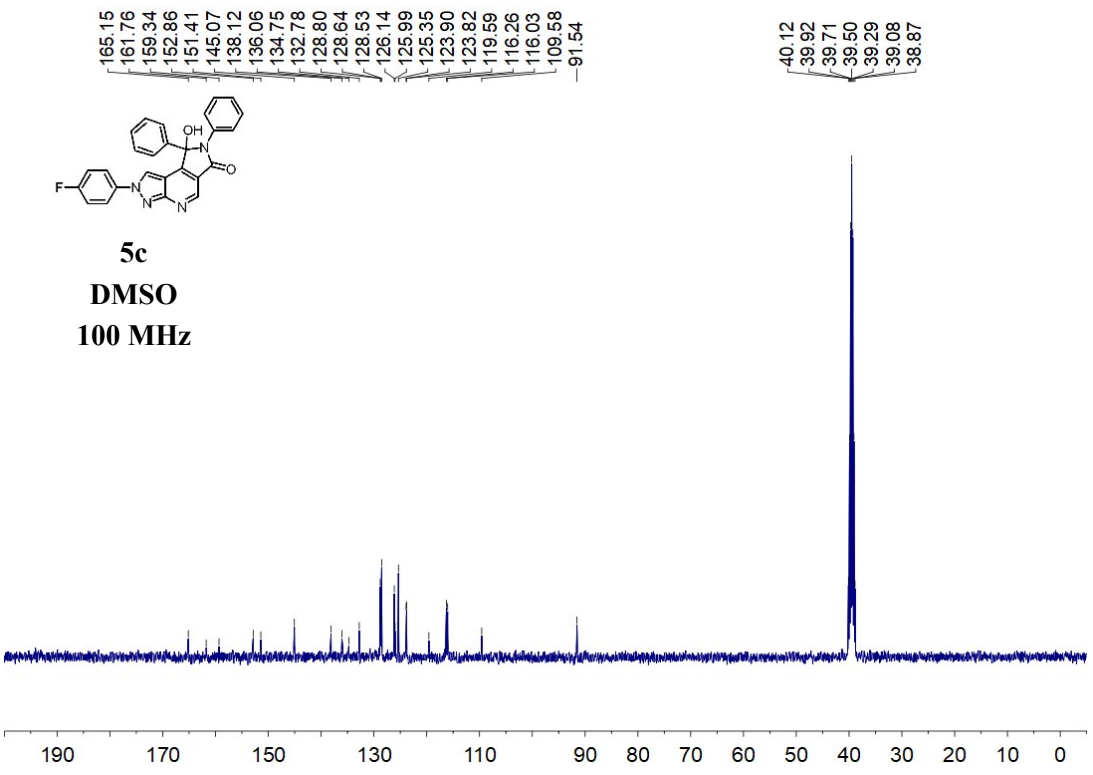
5b
DMSO
400 MHz



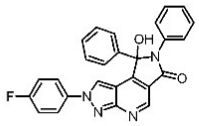
5b
DMSO
100 MHz



5c
DMSO
400 MHz



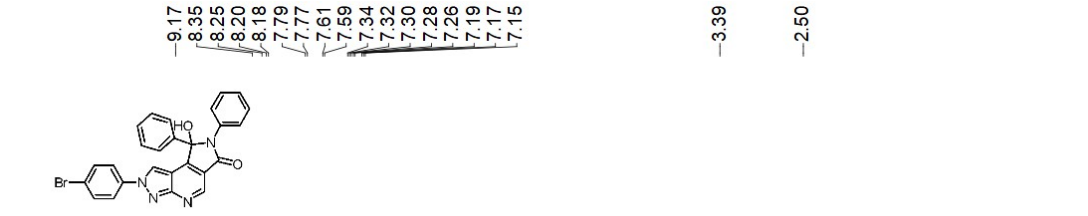
5c
DMSO
100 MHz



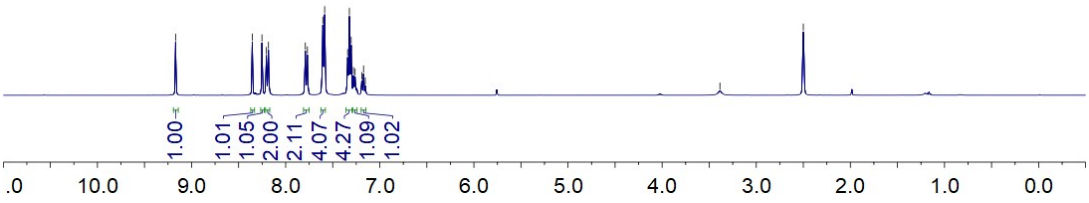
5c

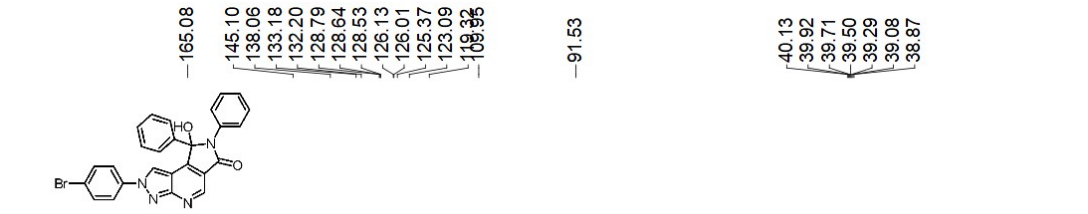
$CDCl_3$

376 MHz

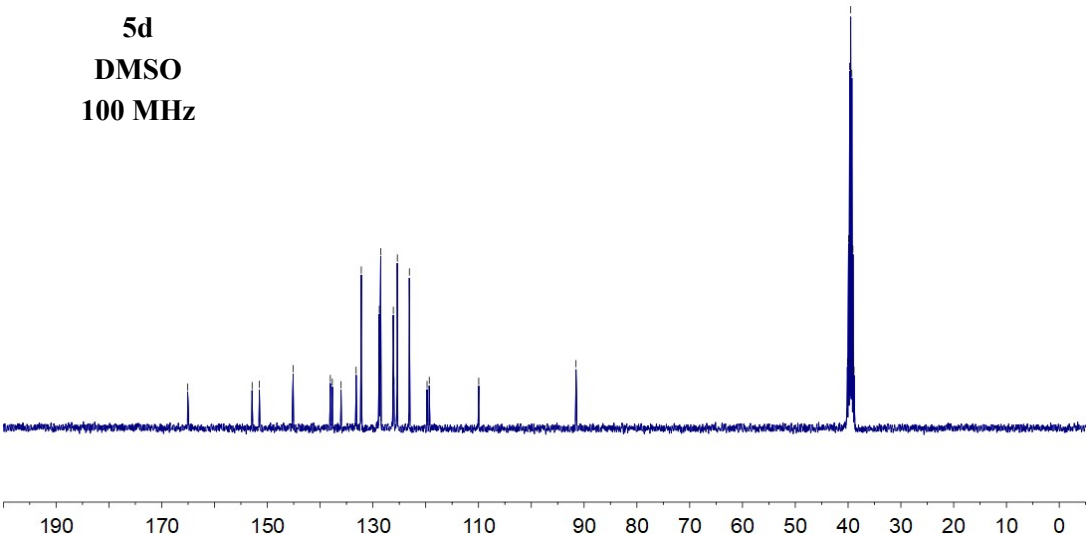


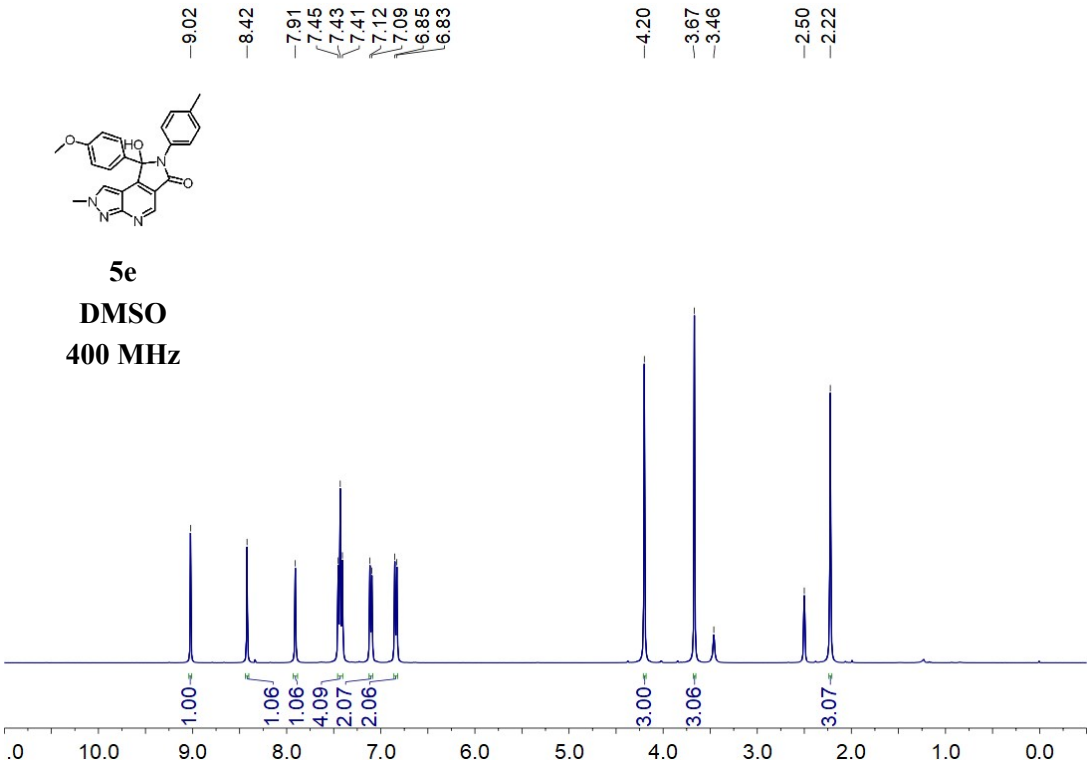
5d
DMSO
400 MHz



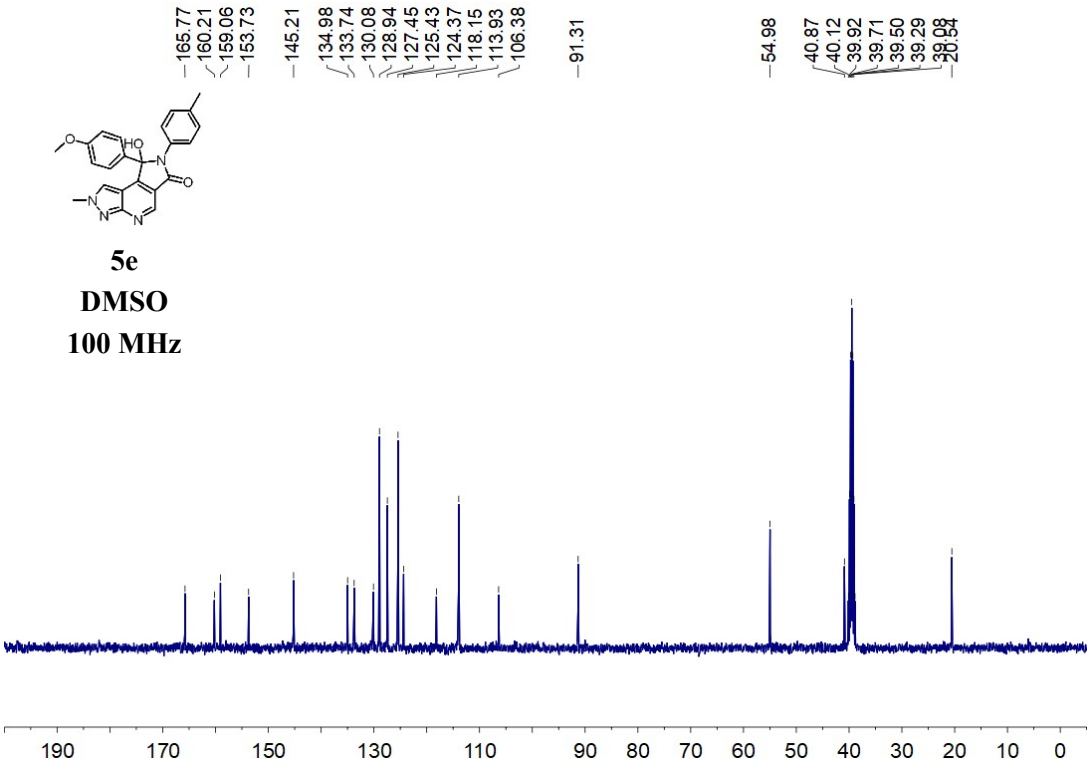


5d
DMSO
100 MHz

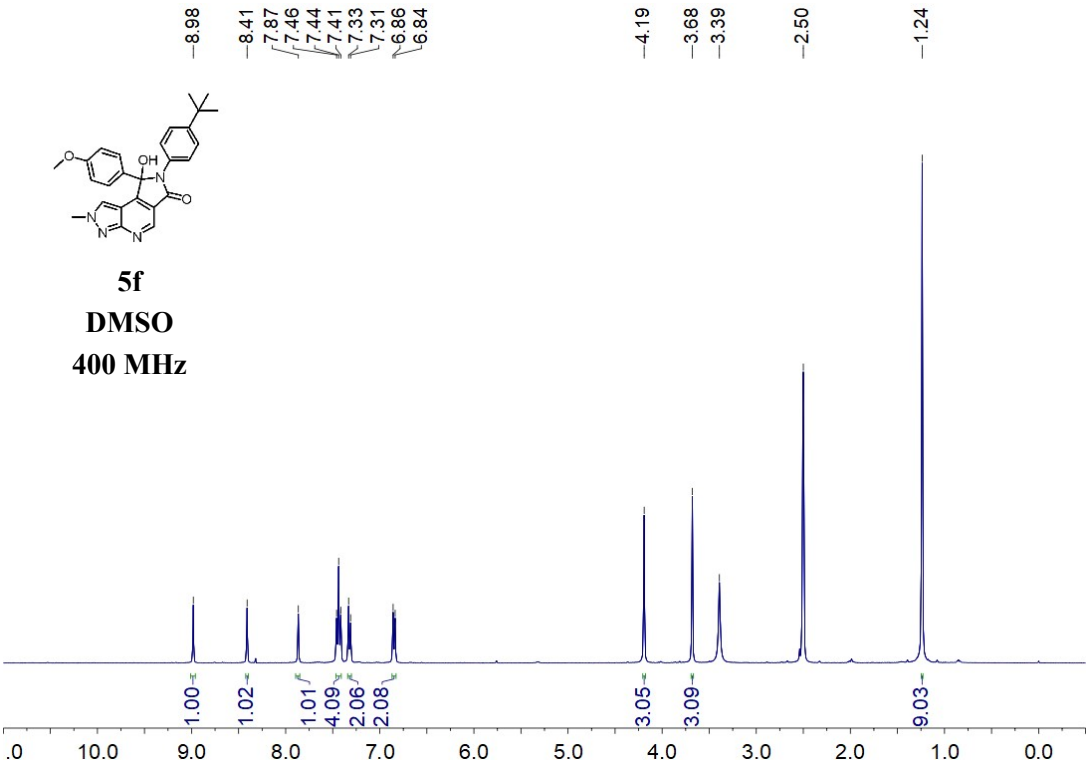




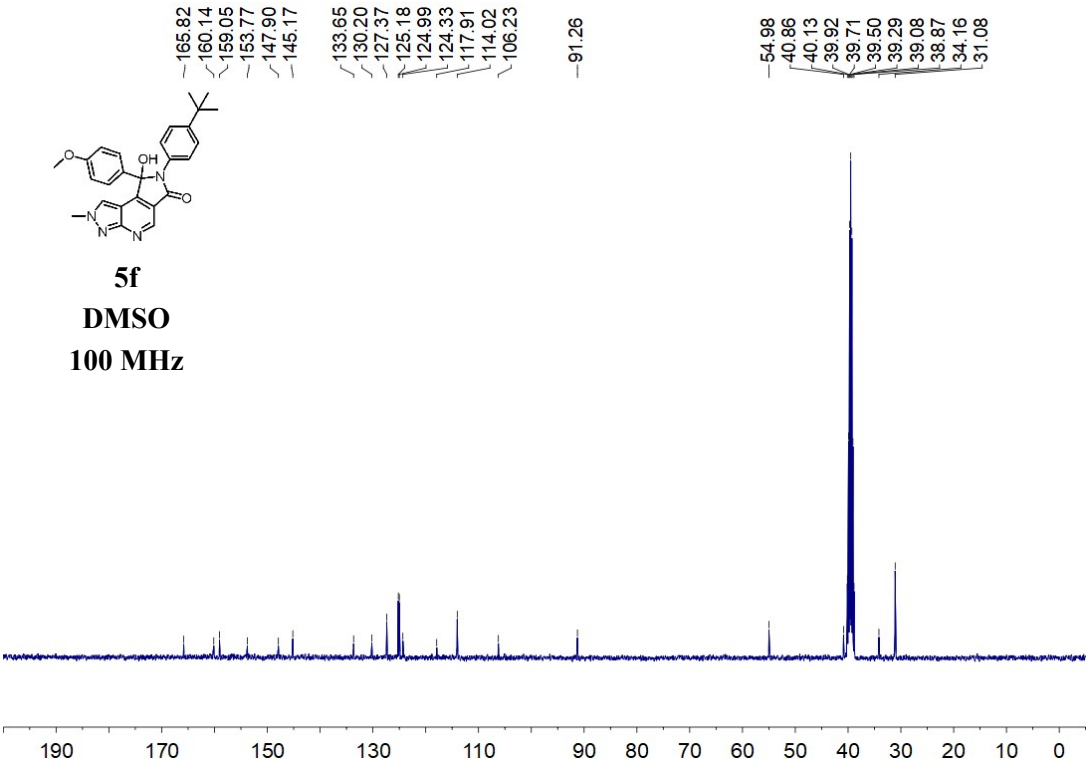
5e
DMSO
400 MHz



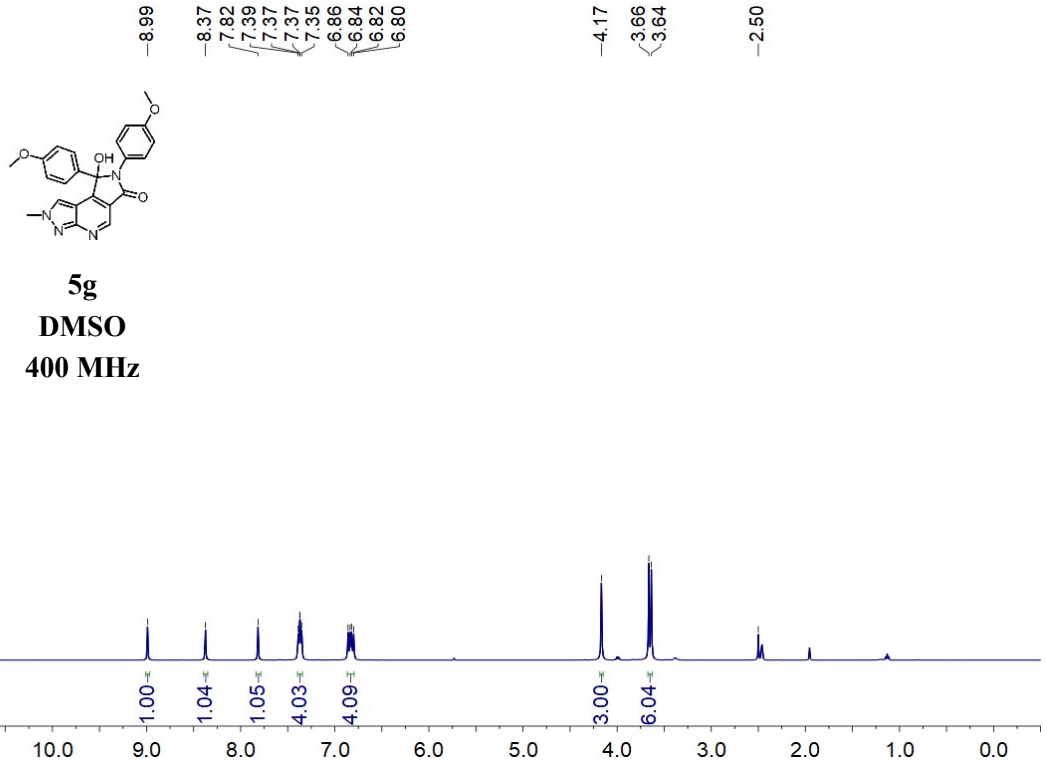
5e
DMSO
100 MHz



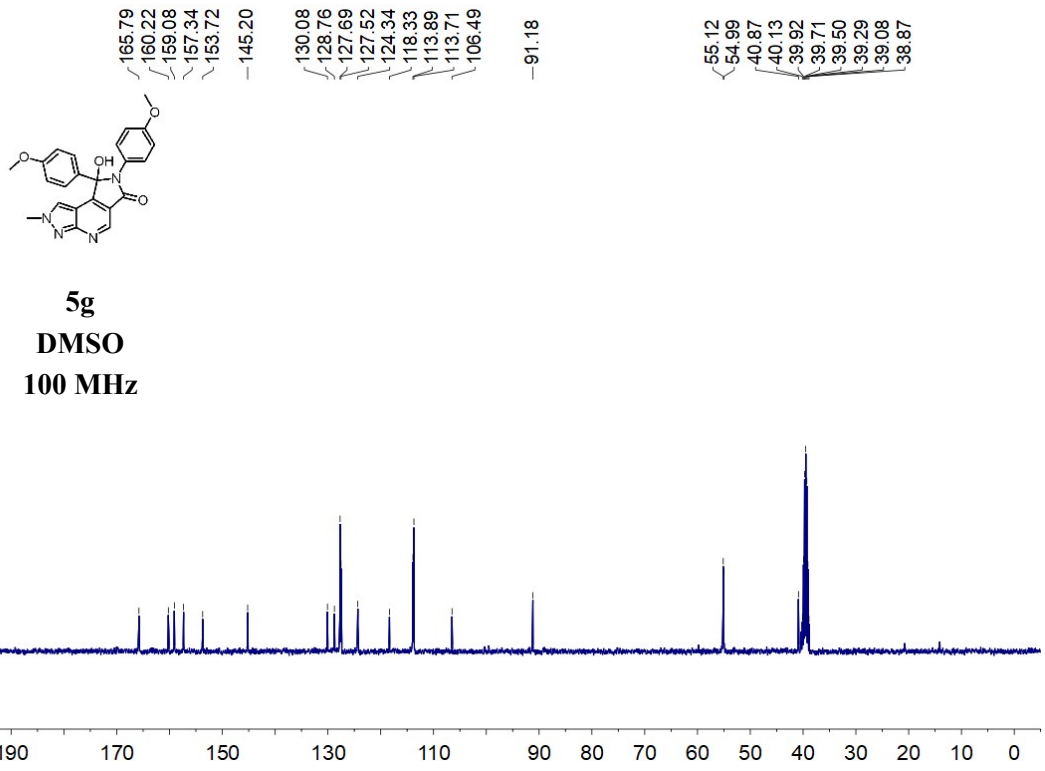
5f
DMSO
400 MHz



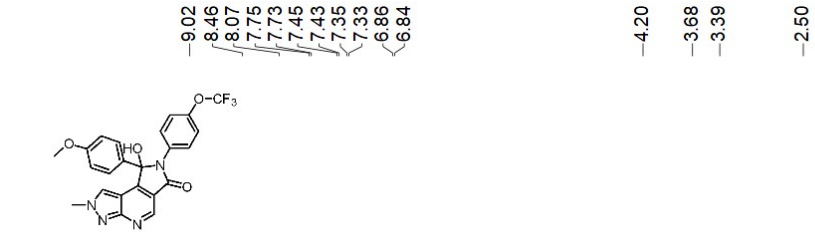
5f
DMSO
100 MHz



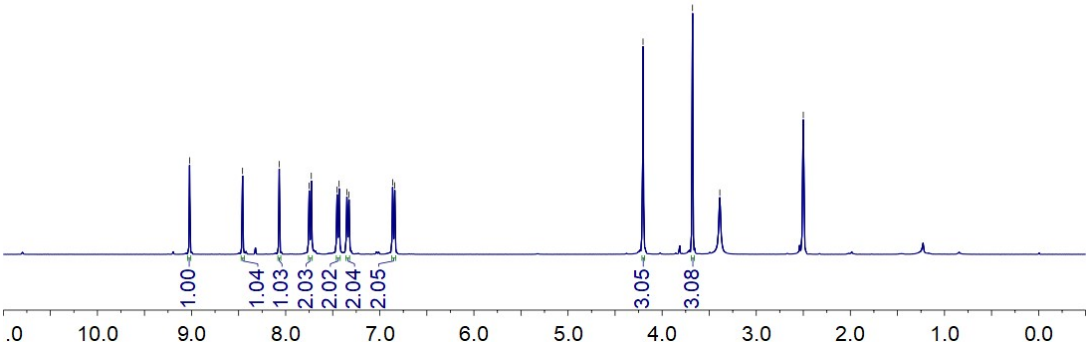
5g
DMSO
400 MHz

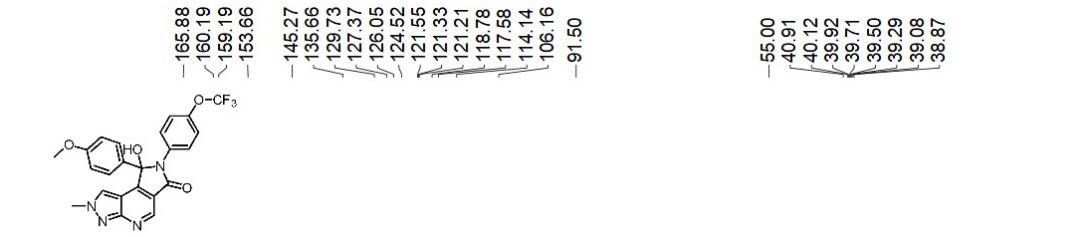


5g
DMSO
100 MHz

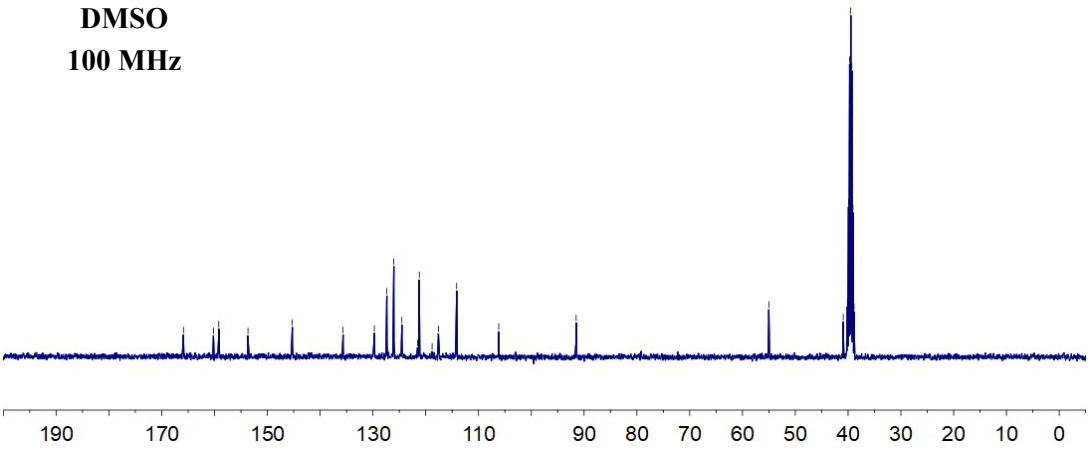


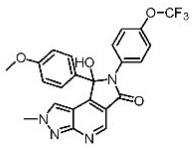
5h
DMSO
400 MHz





5h
DMSO
100 MHz

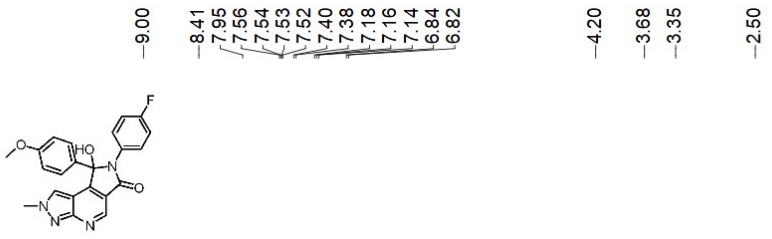




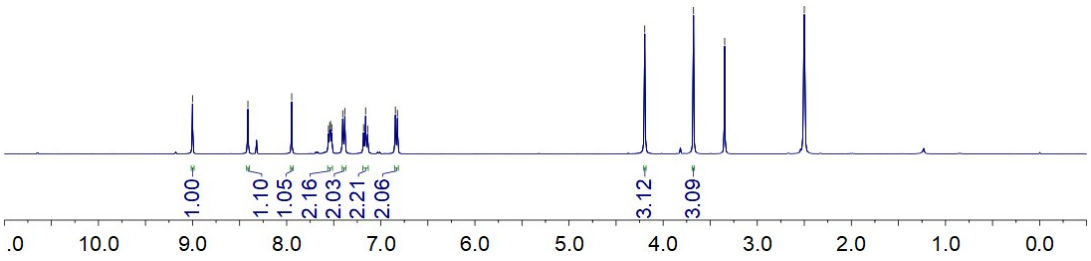
5h

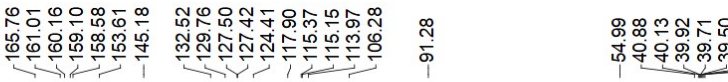
$CDCl_3$

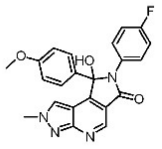
376 MHz



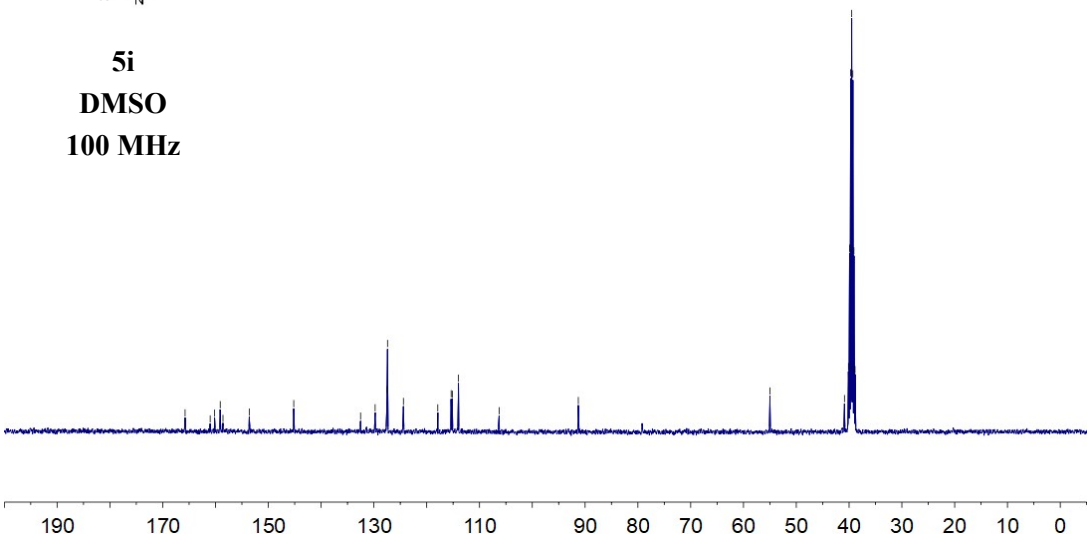
5i
DMSO
400 MHz

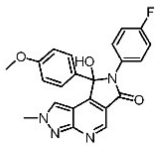






5i
DMSO
100 MHz

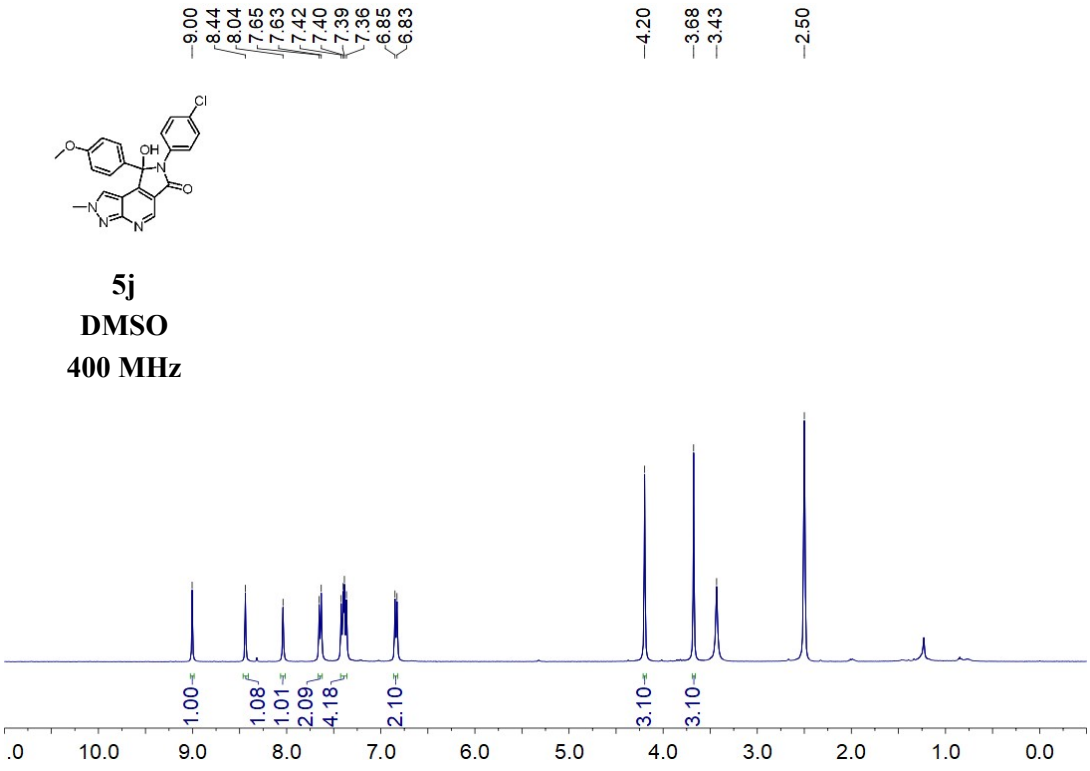




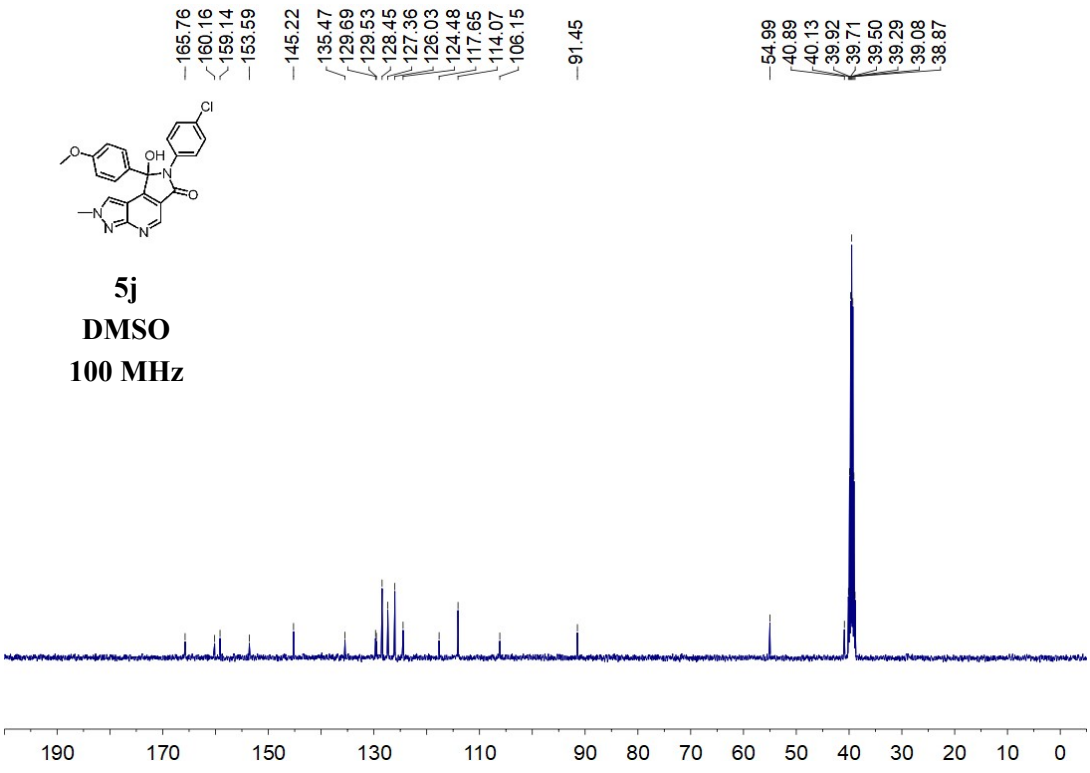
5i

$CDCl_3$

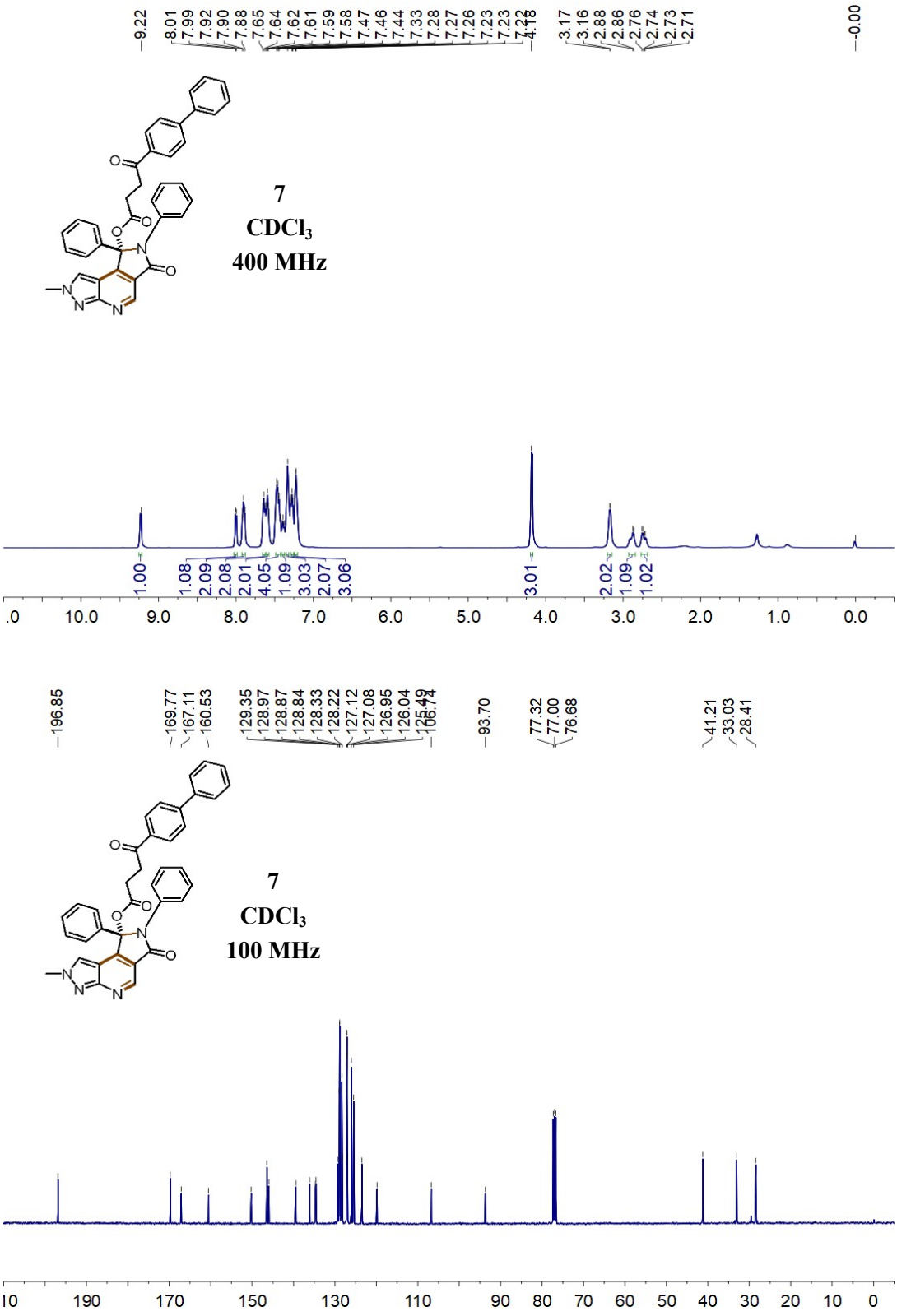
376 MHz



5j
DMSO
400 MHz



5j
DMSO
100 MHz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8.01
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7.61
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7.47
7.46
7.44
7.33
7.28
7.27
7.26
7.23
7.23
7.22
4.18
3.17
3.16
2.88
2.86
2.76
2.74
2.73
2.71
0.00
7
CDCl3
400 MHz
1.00
1.08
2.09
2.08
2.01
4.05
1.09
3.03
2.07
3.06
3.01
2.02
1.09
1.02
.0
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
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167.11
160.53
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128.87
128.84
128.33
128.22
127.12
127.08
126.95
126.04
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125.44
93.70
77.32
77.00
76.68
41.21
33.03
28.41
7
CDCl3
100 MHz
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150
130
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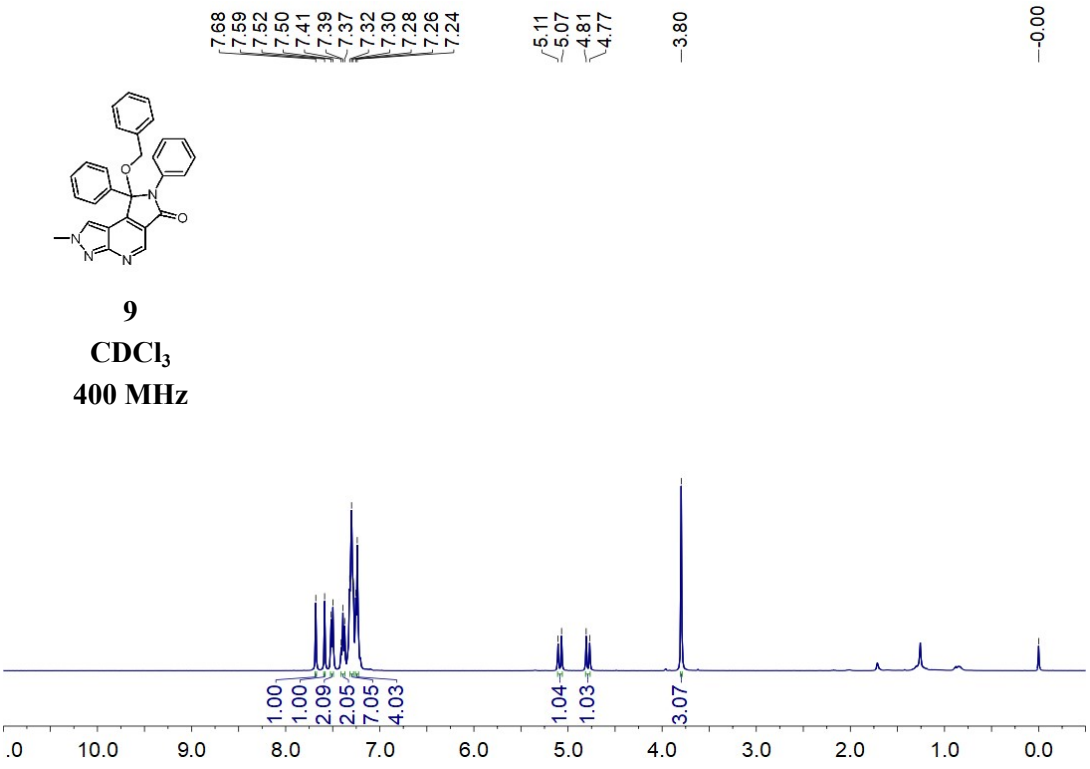
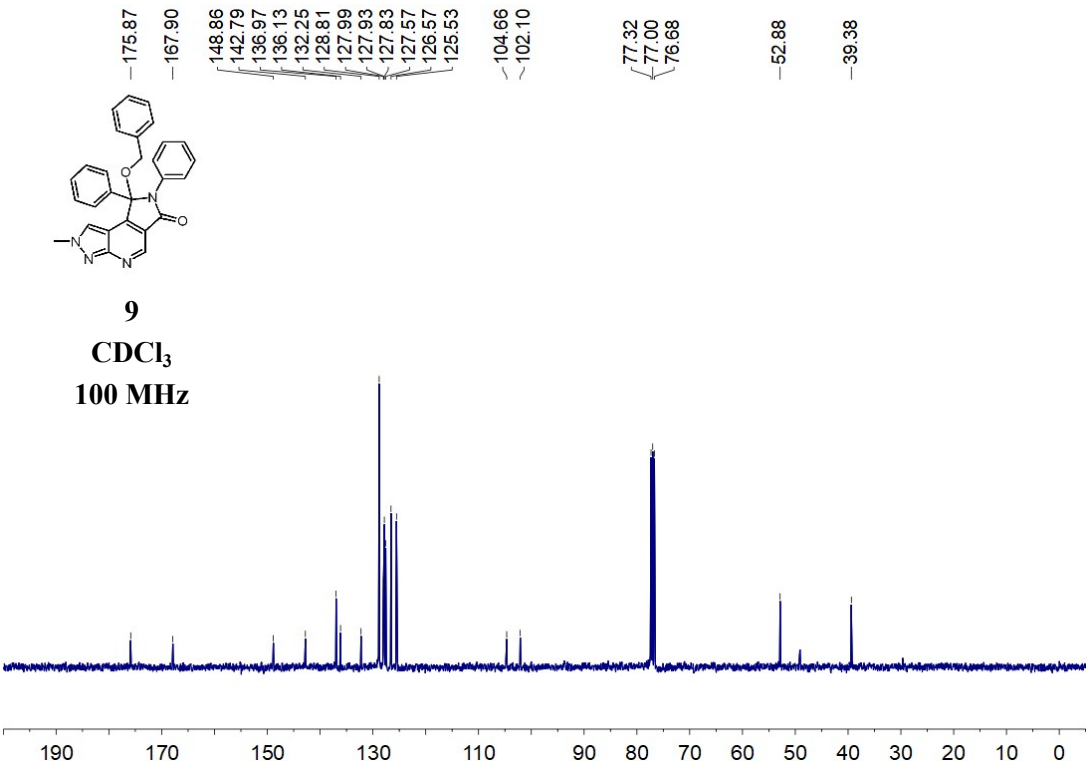
30
20
10
0



9

$CDCl_3$

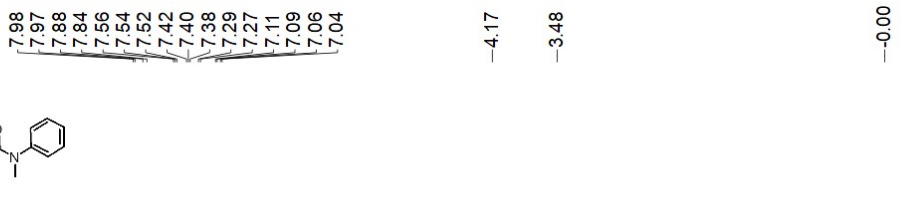
400 MHz

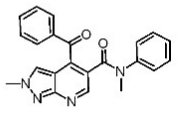


9

$CDCl_3$

100 MHz

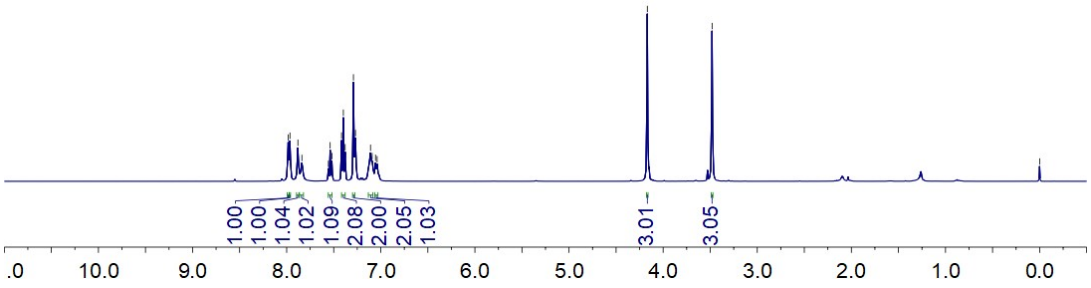


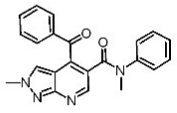


10

$CDCl_3$

400 MHz





10

$CDCl_3$

100 MHz