Electronic Supplementary Material (ESI) for Organic Chemistry Frontiers.

Supporting Information

Synthesis of Mono-fluorinated Fused Heterocylces with a Ring-Junction Nitrogen Atom via Rh(III)-Catalyzed CF_3-Carbenoid C−H Functionalization and Defluorinative Annulation

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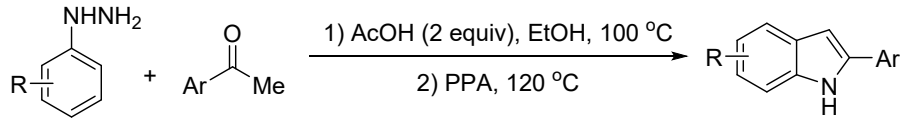
1. General information

Unless otherwise noted, all commercially available compounds and solvents were used as provided without further purification. Thin-layer chromatography (TLC) was performed using E. Merck silica gel 60 F254 precoated plates (0.5 mm) or Sorbent Silica Gel 60 F254 plates. For column chromatography, 200-300 mesh silica gel (Qingdao, China) was used. High-resolution mass spectra (HRMS) were performed on ThermoFisher Q Exactive using orbitrap as the mass analyzer with an ESI source. ^{1}H NMR and ^{13}C NMR spectra were measured recorded on Brucker ARX 400 or Brucker ARX 600 spectrometer at ambient temperature. Chemical shifts for ^{1}H NMR spectra are reported in parts per million (ppm) from tetramethylsilane with the solvent resonance as the internal standard (chloroform: δ 7.26 ppm, DMSO-d_6: δ 2.50 ppm). Chemical shifts for ^{13}C NMR spectra are reported in parts per million (ppm) from tetramethylsilane with the solvent as the internal standard ($CDCl_3$: δ 77.16 ppm). Data are reported as following: chemical shift, multiplicity (s = singlet, d = doublet, dd = doublet of doublets, t = triplet, q = quartet, m = multiplet, br = broad signal), coupling constant (Hz), and integration.

2-Phenyl-1H-imidazole (**4j**), 4,5-diphenyl-1H-imidazole (**4l**), and 3,5-diphenyl-1H-pyrazole (**4n**) are commercially available. 2-Arylindoles **1a-m**, 2-arylbenzimidazoles **4a-i**, (*E*)-2-(1-phenyl-1-propen-2-yl)-1H-imidazole (**4k**), 5-methyl-3-phenyl-1H-pyrazole (*4m*), 3,5-diphenyl-1H-1,2,4-triazole (**4o**), and ethyl 3,3,3-trifluoro-2-diazo propionate **2** were prepared according to the known procedures, see Section 2: Preparation of substrates.

2. Preparation of substrates

2.1 Preparation of 2-arylindoles[1]

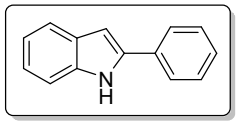


A mixture of acetophenone (20 mmol, 1.0 equiv), aryl hydrazine (24 mmol, 1.2 equiv), HOAc (40 mmol, 2.0 equiv) and EtOH (12.0 mL) were taken in a 100 mL round bottom flask. The resultant solution was refluxed at 100 °C. After the reaction was completed (monitored by TLC), the solution was cooled to 0 °C gradually. The precipitate was collected by suction filtration and washed by hexane. The obtained aryl hydrazine can be used for next step directly.

The freshly prepared aryl hydrazone (10 mmol, 1.0 equiv) and polyphosphoric acid (PPA, 15 mmol, 1.5 equiv) were taken in a 100 mL round bottom flask, and the sticky solution was refluxed at 120 °C. After aryl hydrazine was consumed as monitored by TLC, the solution was cooled to room temperature, quenched with cold H_2O (10 mL) and extracted with EtOAc (3×10mL). The combined organic layers were dried over anhydrous Na_2SO_4. The crude product was purified by column chromatography on silica gel with ethyl acetate/hexane as eluent to afford the corresponding 2-arylindole.

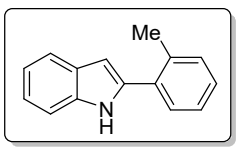
All 2-arylindoles are known compounds. Their structures were confirmed by ^{1}H-NMR as compared with the literature reports.

2-phenyl-1H-indole (**1a**)[1]



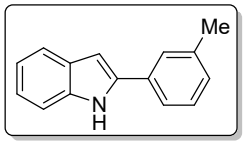
(**Yield**: 85%, 1.6 g). **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.34 (s, 1H), 7.69 – 7.60 (m, 3H), 7.48 – 7.36 (m, 3H), 7.36 – 7.28 (m, 1H), 7.23 – 7.15 (m, 1H), 7.15 – 7.08 (m, 1H), 6.85 – 6.80 (m, 1H).

2-(*o*-tolyl)-1H-indole (**1b**)[1]



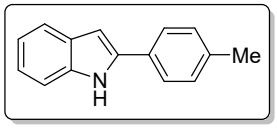
(**Yield**: 69%, 1.4 g). **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.12 (s, 1H), 7.68 – 7.62 (m, 1H), 7.50 – 7.45 (m, 1H), 7.43 – 7.38 (m, 1H), 7.35 – 7.25 (m, 3H), 7.24 – 7.18 (m, 1H), 7.17 – 7.11 (m, 1H), 6.64 – 6.59 (m, 1H), 2.50 (s, 3H).

2-(m-tolyl)-1H-indole (**1c**)[1]



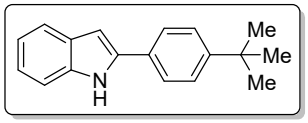
(**Yield**: 73%, 1.5 g). **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.27 (s, 1H), 7.66 – 7.60 (m, 1H), 7.49 – 7.40 (m, 2H), 7.40 – 7.34 (m, 1H), 7.34 – 7.27 (m, 1H), 7.24 – 7.16 (m, 1H), 7.15 – 7.10 (m, 2H), 6.83 – 6.78 (m, 1H), 2.41 (s, 3H).

2-(p-tolyl)-1H-indole (**1d**)[1]



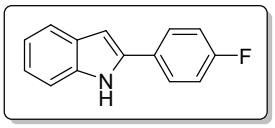
(**Yield**: 90%, 1.9 g). **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.29 (s, 1H), 7.65 – 7.60 (m, 1H), 7.59 – 7.52 (m, 2H), 7.43 – 7.37 (m, 1H), 7.27 – 7.23 (m, 3H), 7.20 – 7.15 (m, 1H), 7.14 – 7.08 (m, 1H), 6.81 – 6.76 (m, 1H), 2.39 (s, 3H).

2-(4-(tert-butyl)phenyl)-1H-indole (**1e**)[1]



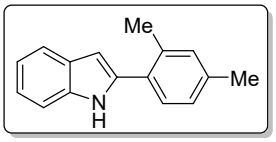
(**Yield**: 76%, 1.9 g). **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.30 (s, 1H), 7.65 – 7.56 (m, 3H), 7.49 – 7.43 (m, 2H), 7.42 – 7.35 (m, 1H), 7.21 – 7.15 (m, 1H), 7.14 – 7.08 (m, 1H), 6.81 – 6.76 (m, 1H), 1.36 (s, 9H).

2-(4-fluorophenyl)-1H-indole (**1f**)[1]



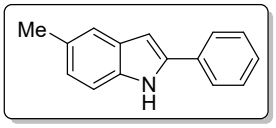
(**Yield**: 76%, 1.6 g). **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.24 (s, 1H), 7.66 – 7.57 (m, 3H), 7.43 – 7.36 (m, 1H), 7.22 – 7.17 (m, 1H), 7.17 – 7.10 (m, 3H), 6.78 – 6.73 (m, 1H).

2-(2,4-dimethylphenyl)-1H-indole (**1g**)[2]



(**Yield**: 76%, 1.7 g). **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.09 (s, 1H), 7.67 – 7.60 (m, 1H), 7.42 – 7.30 (m, 2H), 7.23 – 7.16 (m, 1H), 7.16 – 7.07 (m, 3H), 6.60 – 6.55 (m, 1H), 2.47 (s, 3H), 2.37 (s, 3H).

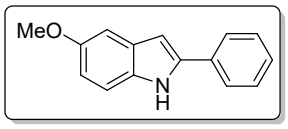
5-methyl-2-phenyl-1H-indole (**1h**)[1]



(**Yield**: 90%, 1.9 g). **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.22 (s,

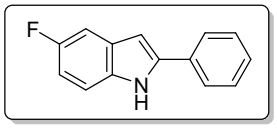
1H), 7.67 – 7.63 (m, 2H), 7.46 – 7.40 (m, 3H), 7.33 – 7.27 (m, 2H), 7.05 – 6.98 (m, 1H), 6.76 – 6.73 (m, 1H), 2.45 (s, 3H).

5-methoxy-2-phenyl-1H-indole (**1i**)[3]



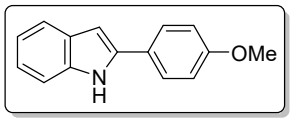
(**Yield**: 80%, 1.8g). **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.21 (s, 1H), 7.66 – 7.60 (m, 2H), 7.46 – 7.38 (m, 2H), 7.33 – 7.25 (m, 2H), 7.11 – 7.06 (m, 1H), 6.89 – 6.82 (m, 1H), 6.78 – 6.73 (m, 1H), 3.86 (s, 3H).

5-fluoro-2-phenyl-1H-indole (**1j**)[1]



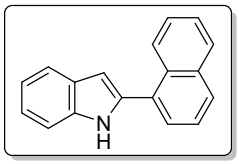
(**Yield**: 79%, 1.7 g). **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.30 (s, 1H), 7.69 – 7.62 (m, 2H), 7.49 – 7.41 (m, 2H), 7.38 – 7.27 (m, 3H), 6.98 – 6.89 (m, 1H), 6.81 – 6.76 (m, 1H).

2-(4-methoxyphenyl)-1H-indole (**1k**)[3]



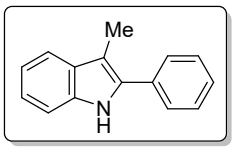
(**Yield**: 73%, 1.6 g). **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.24 (s, 1H), 7.62 – 7.57 (m, 3H), 7.40 – 7.36 (m, 1H), 7.19 – 7.14 (m, 1H), 7.13 – 7.08 (m, 1H), 7.02 – 6.94 (m, 2H), 6.74 – 6.69 (m, 1H), 3.86 (s, 3H).

2-(naphthalen-1-yl)-1H-indole (**1l**)[2]



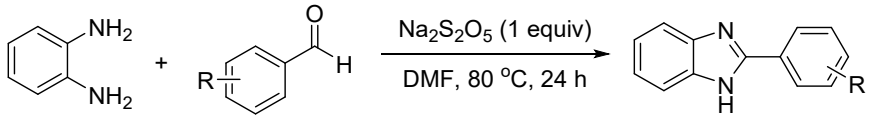
(**Yield**: 52%, 1.3 g). **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.36 – 8.29 (m, 1H), 8.26 (s, 1H), 7.97 – 7.86 (m, 2H), 7.75 – 7.69 (m, 1H), 7.67 – 7.60 (m, 1H), 7.58 – 7.46 (m, 3H), 7.46 – 7.40 (m, 1H), 7.29 – 7.25 (m, 1H), 7.23 – 7.18 (m, 1H), 6.83 – 6.80 (m, 1H).

3-methyl-2-phenyl-1H-indole (**1m**)[1]



(**Yield**: 73%, 1.5 g). **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.01 (s, 1H), 7.64 – 7.55 (m, 3H), 7.52 – 7.43 (m, 2H), 7.40 – 7.31 (m, 2H), 7.24 – 7.18 (m, 1H), 7.17 – 7.12 (m, 1H), 2.47 (s, 3H).

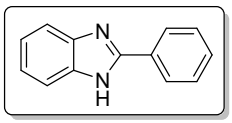
2.2 Preparation of 2-arylbenzimidazole[4]



In a 100-mL flask, 1,2-phenylenediamine (10 mmol, 1.0 equiv), $Na_2S_2O_5$ (10 mmol, 1.0 equiv), and the corresponding aldehyde (10 mmol, 1.0 equiv) were dissolved in 50 mL of DMF. After refluxing for 24 h, the reaction mixture was poured onto ice water and extracted with $CHCl_3$ (3×50 mL). The organic layer was dried with anhydrous Na_2SO_4 and evaporated under reduced pressure. The crude product was purified by chromatography to obtain the desired benzimidazole.

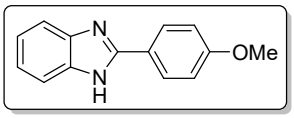
All 2-arylbenzimidazoles are known compounds. Their structures were confirmed by 1H-NMR as compared with the literature reports.

2-phenyl-1H-benzo[d]imidazole (**4a**)[4]



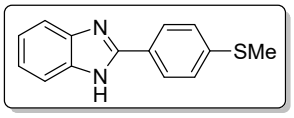
(**Yield**: 75%, 1.5 g). **^{1}H NMR** (400 MHz, DMSO-d_6) δ 12.97 (s, 1H), 8.26 – 8.18 (m, 2H), 7.66 – 7.60 (m, 2H), 7.58 – 7.52 (m, 2H), 7.51 – 7.46 (m, 1H), 7.26 – 7.17 (m, 2H).

2-(4-methoxyphenyl)-1H-benzo[d]imidazole (**4b**)[4]



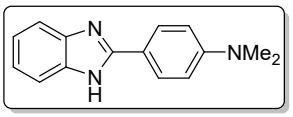
(**Yield**: 47%, 1.1 g). **^{1}H NMR** (400 MHz, DMSO-d_6) δ 12.75 (s, 1H), 8.16 – 8.10 (m, 2H), 7.71 – 7.60 (m, 1H), 7.53 – 7.47 (m, 1H), 7.20 – 7.15 (m, 2H), 7.13 – 7.09 (m, 2H), 3.83 (s, 3H).

2-(4-(methylthio)phenyl)-1H-benzo[d]imidazole (**4c**)[4]



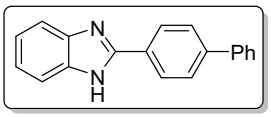
(**Yield**: 80%, 1.9 g). **^{1}H NMR** (400 MHz, DMSO-d_6) δ 12.86 (s, 1H), 8.14 – 8.07 (m, 2H), 7.66 – 7.54 (m, 2H), 7.45 – 7.39 (m, 2H), 7.27 – 7.15 (m, 2H), 2.55 (s, 3H).

4-(1H-benzo[d]imidazol-2-yl)-N,N-dimethylaniline (**4d**)[4]



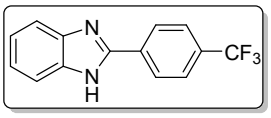
(**Yield**: 80%, 1.9 g). **^{1}H NMR** (400 MHz, DMSO-d_6) δ 12.78 (s, 1H), 8.07 – 8.00 (m, 2H), 7.60 – 7.53 (m, 2H), 7.22 – 7.21 (m, 2H), 6.89 – 6.82 (m, 2H), 3.01 (s, 6H).

2-([1,1'-biphenyl]-4-yl)-1H-benzo[d]imidazole (**4e**)[5]



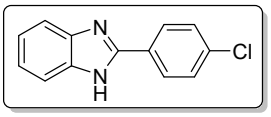
(**Yield**: 75%, 2.0 g). **^{1}H NMR** (400 MHz, DMSO-d_6) δ 12.98 (s, 1H), 8.32 – 8.25 (m, 2H), 7.91 – 7.84 (m, 2H), 7.80 – 7.75 (m, 2H), 7.71 – 7.67 (m, 1H), 7.57 – 7.54 (m, 1H), 7.52 – 7.48 (m, 2H), 7.43 – 7.37 (m, 1H), 7.25 – 7.19 (m, 2H).

2-(4-(trifluoromethyl)phenyl)-1H-benzo[d]imidazole (**4f**)[4]



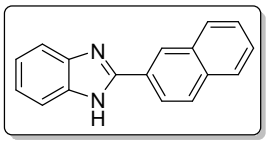
(**Yield**: 47%, 1.2 g). **^{1}H NMR** (400 MHz, DMSO-d_6) δ 13.17 (s, 1H), 8.42 – 8.35 (m, 2H), 7.97 – 7.90 (m, 2H), 7.77 – 7.53 (m, 2H), 7.28 – 7.22 (m, 2H).

2-(4-chlorophenyl)-1H-benzo[d]imidazole (**4g**)[4]



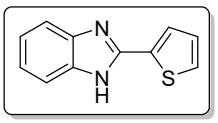
(**Yield**: 85%, 1.9 g). **^{1}H NMR** (400 MHz, DMSO-d_6) δ 12.98 (s, 1H), 8.21 – 8.17 (m, 2H), 7.65 – 7.56 (m, 4H), 7.25 – 7.19 (m, 2H).

2-(naphthalen-2-yl)-1H-benzo[d]imidazole (**4h**)[6]



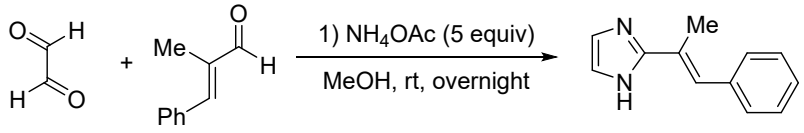
(**Yield**: 61%, 1.5 g). **^{1}H NMR** (400 MHz, DMSO-d_6) δ 13.07 (s, 1H), 8.74 (s, 1H), 8.34 – 8.30 (m, 1H), 8.10 – 8.07 (m, 1H), 8.06 – 8.03 (m, 1H), 8.02 – 7.97 (m, 1H), 7.73 – 7.67 (m, 1H), 7.63 – 7.55 (m, 3H), 7.25 – 7.21 (m, 2H).

2-(thiophen-2-yl)-1H-benzo[d]imidazole (**4i**)[4]



(**Yield**: 70%, 1.4 g). **^{1}H NMR** (400 MHz, DMSO-d_6) δ 12.98 (s, 1H), 7.86 – 7.82 (m, 1H), 7.75 – 7.72 (m, 1H), 7.59 – 7.53 (m, 2H), 7.27 – 7.17 (m, 3H).

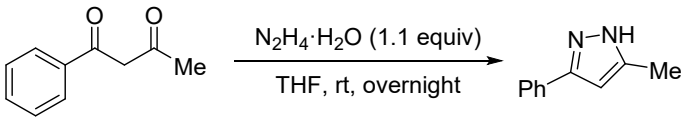
2.3 Synthesis of (*E*)-2-(1-phenyl-1-propen-2-yl)-1H-imidazole (4k)[7]



To a round-bottom flask, NH_4OAc (3.85 g, 50 mmol, 5.0 equiv) and MeOH (20 mL, 0.5 M) were added. α-Methyl-*trans*-cinnamaldehyde (4.2 mL, 30 mmol, 3.0 equiv) was added dropwise to the stirred solution, followed by the dropwise addition of the glyoxal (40% w/w in H_2O, 1.2 mL, 10 mmol, 1.0 equiv). The resultant solution was stirred at room temperature overnight. After the removal of volatile components in vacuo, the crude residue was basified (pH > 14) by the addition of 2 M NaOH and extracted with CH_2Cl_2 (3 times). The combined organic layers were dried over $MgSO_4$, filtered, and concentrated. Purification by silica gel column chromatography (50%, then 60% EtOAc/hexane) gave the desired product **4k** (616 mg, 33%) as a yellow solid.

^{1}H NMR (400 MHz, DMSO-d_6) δ 12.25 (s, 1H), 7.43 – 7.37 (m, 4H), 7.31 – 7.21 (m, 2H), 7.18 – 6.97 (m, 2H), 2.27 (s, 3H).

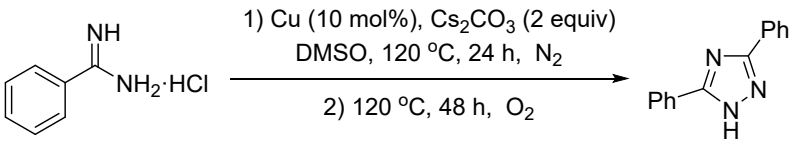
2.4 Preparation of 5-methyl-3-phenyl-1H-pyrazole (4m)[8]



Hydrazine monohydrate (1.1 equiv, 11 mmol, 551 mg) in THF (22 mL) was added via a syringe to a stirred solution of 1-phenylbutane-1,3-dione (10 mmol, 1.6 g) in THF (20 mL) over a period of 30 min. After stirring overnight, the reaction mixture was concentrated in vacuo prior to the addition of water (50 mL), and the reaction products were extracted into ethyl acetate (3×50 mL). The combined extracts were dried ($MgSO_4$) and concentrated in vacuo, whereby purification by silica gel chromatography (7-10% ethyl acetate in hexane) afforded the desired pyrazole **4m** (981 mg, 62%) as a pale yellow solid.

^{1}H NMR (400 MHz, DMSO-d_6) δ 12.55 (s, 1H), 7.77 – 7.70 (m, 2H), 7.42 – 7.34 (m, 2H), 7.31 – 7.22 (m, 1H), 6.43 (s, 1H), 2.24 (s, 3H).

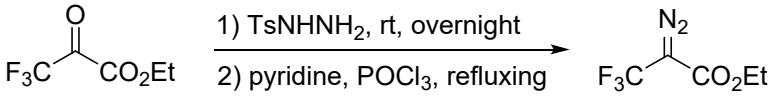
2.5 Preparation of 3,5-diphenyl-1H-1,2,4-triazole (4o)[9]



To a 10 mL Schlenk tube charged with a magnetic stirrer, DMSO (2 mL), benzamidine hydrochloride (1 mmol, 156 mg), Cu powder (0.1 mmol, 6.4 mg, 10 mol%), and Cs_2CO_3 (2 mmol, 489 mg, 2.0 equiv) were added. The mixture was stirred at 120 °C for 24 h under nitrogen atmosphere. Then the nitrogen atmosphere was changed into oxygen atmosphere (other conditions were kept). The following aerobic oxidative intramolecular formation of N–N bond was carried out at 120 °C for 48 h. The resulting mixture was cooled to r.t. and filtered, and the solid was washed with EtOAc (3×3 mL). The combined filtrate was concentrated by a rotary evaporator, and the residue was purified by column chromatography on silica gel using petroleum ether/EtOAc = 6/1 as eluent to give **4o** (137 mg, 62%) as a white solid.

^{1}H NMR (400 MHz, $CDCl_3$) δ 12.09 (s, 1H), 8.07 – 8.00 (m, 4H), 7.45 – 7.39 (m, 6H).

2.6 Preparation of ethyl 3,3,3-trifluoro-2-diazopropionate (2)[10]

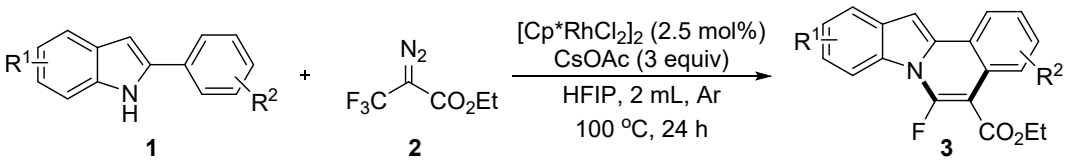


Ethyl 3,3,3-trifluoro-2-oxopropionate (20 g, 0.1 mol, 1.0 equiv) and tosyl hydrazide (18.6 g, 0.1 mol, 1.0 equiv) were mixed in CH_2Cl_2 (120 mL). The mixture was briefly refluxed and then stirred at room temperature overnight. Then pyridine (50 mL) and $POCl_3$ (9.4 mL, 0.1 mol, 1.0 equiv) were added. After addition, the reaction mixture was refluxed for 40 min and then quenched by water (200 mL). The organic layer was separated while the water layer was extracted with ether (80 mL×3). The combined organic layers were washed with 1 N HCl solution to remove the pyridine and then washed with saturated $NaHCO_3$ solution and brine, dried over Na_2SO_4. The bulk of the solvent was removed in a rotary evaporator, and the remaining solvent was

carefully distilled off under atmospheric pressure. Further distillation under reduced pressure gave 14 g (77%) of **2** as a yellow liquid: bp 60-62 °C (100 mmHg).

^{1}H NMR (400 MHz, $CDCl_3$) δ 4.32 (q, *J* = 7.1 Hz, 2H), 1.32 (t, *J* = 7.2 Hz, 3H).

3. General experimental procedures for [4+2] annulation

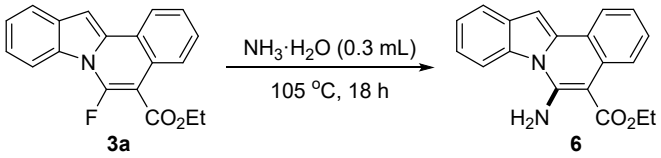


A sealed tube equipped with a magnetic stirring bar was charged with 2-arylindole **1** (0.2 mmol, 1.0 equiv), EtDTP **2** (80.1 mg, 0.44 mmol, 2.2 equiv), $[Cp^*RhCl_2]_2$ (3.1 mg, 0.005 mmol, 2.5 mol%), CsOAc (115.2 mg, 0.6 mmol, 3 equiv), and dry HFIP (2 mL). The reaction mixture was stirred at 100 °C under argon atmosphere for 24 h. After the reaction was completed, the solvent was evaporated and the organic product purified by column chromatography.

For the Rh(III)-catalyzed defluorinative [4+2] annulation of EtDTP **2** with other aryl N-heterocycles **4a-4o**, the reactions were carried out at 50 °C for 4 h. The reaction scale and other conditions were same as described above.

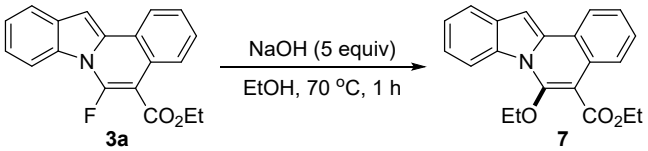
4. Experimental procedures for S_NAr reaction of 3a

4.1 Aqueous ammonia as the nucleophile: Synthesis of 6[11]



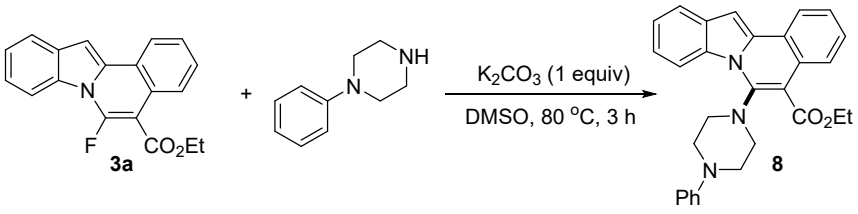
To an oven-dried microwave tube were added **3a** (0.1 mmol, 30.7 mg, 1.0 equiv) and excess of NH_3 (0.3 ml, 28% aqueous solution). The reaction mixture was stirred at 105 ºC for 18 h. After cooling, the mixture was diluted with water (3 mL) and extracted with diethyl ether (3×3 mL). The combined organic layers were dried over anhydrous $MgSO_4$, filtered, and solvent was evaporated. The residue was purified by flash column chromatography to afford product **6** in 69% yield (21.0 mg) as a colorless oil.

4.2 EtOH as the nucleophile: Synthesis of 7[12]



To a solution of **3a** (0.1 mmol, 30.7 mg, 1.0 equiv) in EtOH (3.0 mL) was added NaOH (0.5 mmol, 20.0 mg, 5 equiv) at 70 °C. After stirring for 1 h, the solvent was evaporated and DCM was added to the residue. The solution was washed with water, dried over $MgSO_4$. After the removal of solvent, the residue was purified by flash column chromatography to afford **7** in 78% yield (26.0 mg) as a colorless oil.

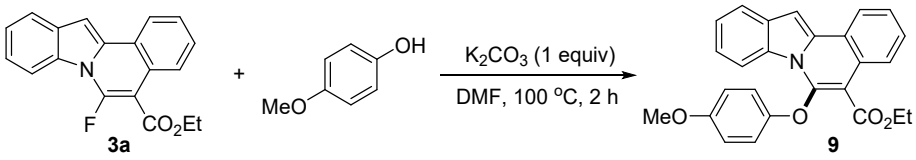
4.3 1-Phenylpiperazine as the nucleophile: Synthesis of 8[11]



To an oven-dried microwave tube were added **3a** (0.1 mmol, 30.7 mg, 1.0 equiv), K_2CO_3 (0.1 mmol, 13.8 mg, 1.0 equiv), 1-phenylpiperazine (0.12 mmol, 19.5 mg, 1.2 equiv) and DMSO (1.0 mL). The reaction mixture was stirred at 80 °C for 3 h. Then the reaction mixture was diluted with diethyl ether, washed with brine, dried over

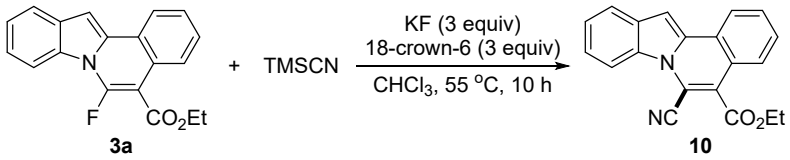
Na_2SO_4. After concentration in vacuo, the residue was purified by flash column chromatography to afford product **8** in 72% yield (32.5 mg) as a white solid.

4.4 4-Methoxyphenol as the nucleophile: Synthesis of 9[12]



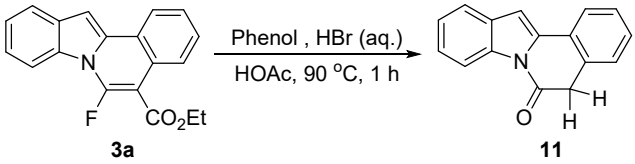
To an oven-dried microwave tube were added **3a** (0.1 mmol, 30.7 mg, 1.0 equiv), K_2CO_3 (0.1 mmol, 13.8 mg, 1.0 equiv), 4-methoxyphenol (0.2 mmol, 24.8 mg, 2.0 equiv) and DMF (1.0 mL). The reaction mixture was stirred at 100 °C for 2 h. Then the solution was diluted with diethyl ether, washed with brine, dried over Na_2SO_4. After concentration in vacuo, the residue was purified by flash column chromatography to afford product **9** in 90% yield (37.1 mg) as a white solid.

4.5 TMSCN as the nucleophile: Synthesis of 10[11]



To an oven-dried microwave tube were added **3a** (0.1 mmol, 30.7 mg, 1.0 equiv) and 18-crown-6 (0.3 mmol, 79.3 mg, 3.0 equiv) and anhydrous $CHCl_3$ (1 mL). KF (17.4 mg, 0.3 mmol, 3.0 equiv) and TMSCN (29.8 mg, 0.3 mmol, 3.0 equiv) were added under argon atmosphere. The solution was stirred at 55 °C for 10 h, then quenched with 3 mL of NaOH (1 N) solution. Aqueous layer was extracted with diethyl ether (3×3 mL). The combined extracts were washed with brine, dried over anhydrous $MgSO_4$, filtered. After the removal of solvent, the residue was purified by flash column chromatography to afford **10** in 82% yield (25.7 mg) as a yellow oil.

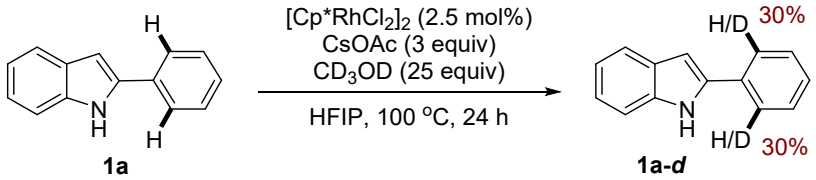
4.6 Removal of ester group[12]



Under argon atmosphere, **3a** (0.1 mmol, 30.7 mg, 1.0 equiv), phenol (1.06 mmol, 100 mg, 10.6 equiv), HBr (40% aqueous solution, 1.2 mL) and CH_3COOH (0.4 mL) were added to a sealed tube equipped with a magnetic stir bar. After stirring for 1 h at 90 °C, acetic acid was evaporated under reduced pressure. The residue was diluted with H_2O (3.0 mL), then extracted with ethyl acetate (3×3.0 mL). The organic layer was washed with brine, dried over $MgSO_4$ and concentrated, purified by flash column chromatography to afford the desired product **11** in 59% yield (13.8 mg) as a colorless oil.

5. Mechanism studies

5.1 H/D Exchange experiments of 1a with CD_3OD



A sealed tube equipped with a magnetic stirring bar were charged with 2-phenyl-1H-indole **1a** (38.7 mg, 0.2 mmol, 1.0 equiv), $[Cp^*RhCl_2]_2$ (3.1 mg, 0.005 mmol, 0.025 equiv), CsOAc (115.2 mg, 0.6 mmol, 3 equiv), CD_3OD (0.2 mL, 5 mmol, 25 equiv), and dry HFIP (2 mL). The reaction mixture was stirred at 100 °C under argon atmosphere for 24 h. After the reaction was completed, the solvent was evaporated and the organic product purified by column chromatography (petroleum ether/EtOAc = 20/1). 89% yield of **1a** was recycled and the deuterium incorporation was determined to be 30% by ^{1}H-NMR (Figure S1).

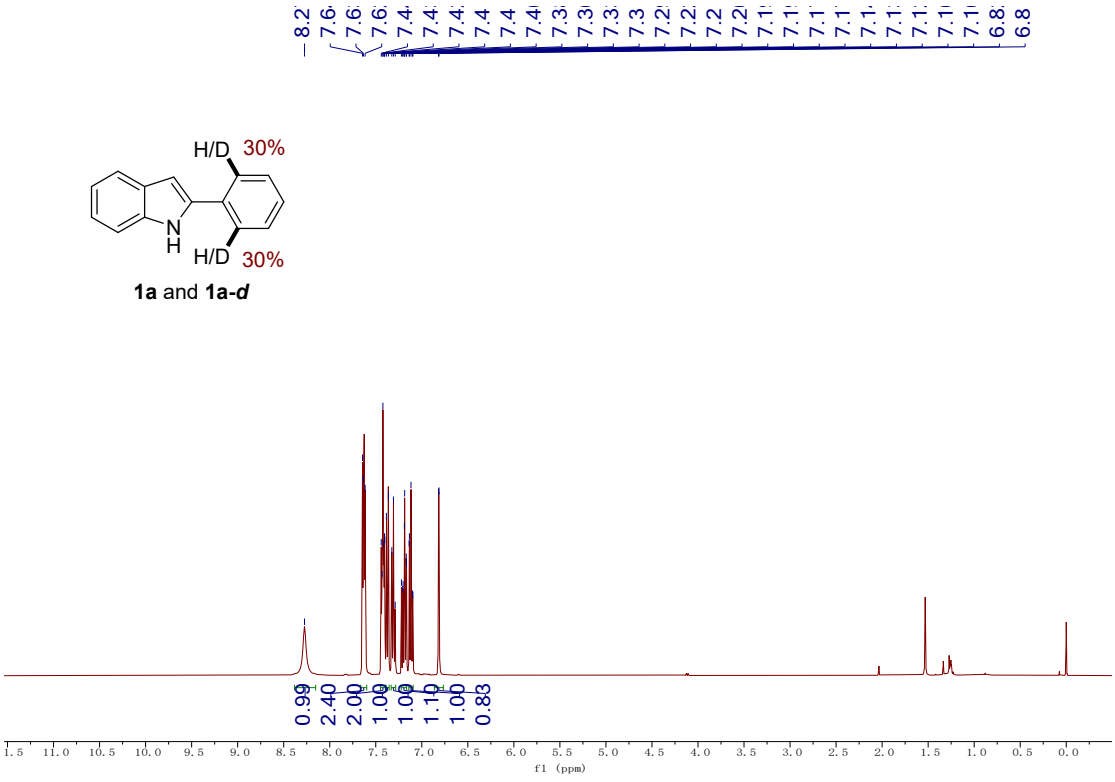
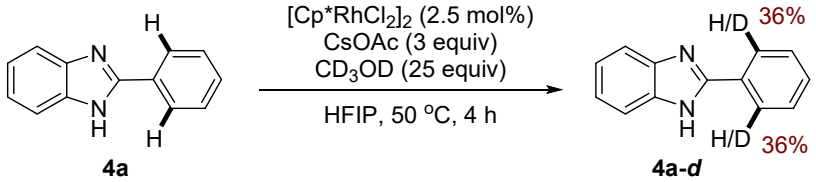


Figure S1 ^{1}H-NMR of **1a** and **1a-*d*.**

5.2 H/D Exchange experiments of 4a with CD_3OD



A sealed tube equipped with a magnetic stirring bar was charged with 2-phenyl-1H-benzoimidazole **4a** (38.8 mg,0.2 mmol, 1.0 equiv), $[Cp^*RhCl_2]_2$ (3.1 mg, 0.005 mmol, 0.025 equiv), CsOAc (115.2 mg, 0.6 mmol, 3 equiv), CD_3OD (0.2 mL, 5 mmol, 25 equiv), and dry HFIP (2 mL). The reaction mixture was stirred at 50 °C under argon atmosphere for 4 h. After the reaction was completed, the solvent was evaporated and the organic product purified by column chromatography (petroleum ether/EtOAc = 5/1). 92% yield of **4a** was recycled and the deuterium incorporation was determined to be 36% by ^{1}H-NMR (Figure S2).

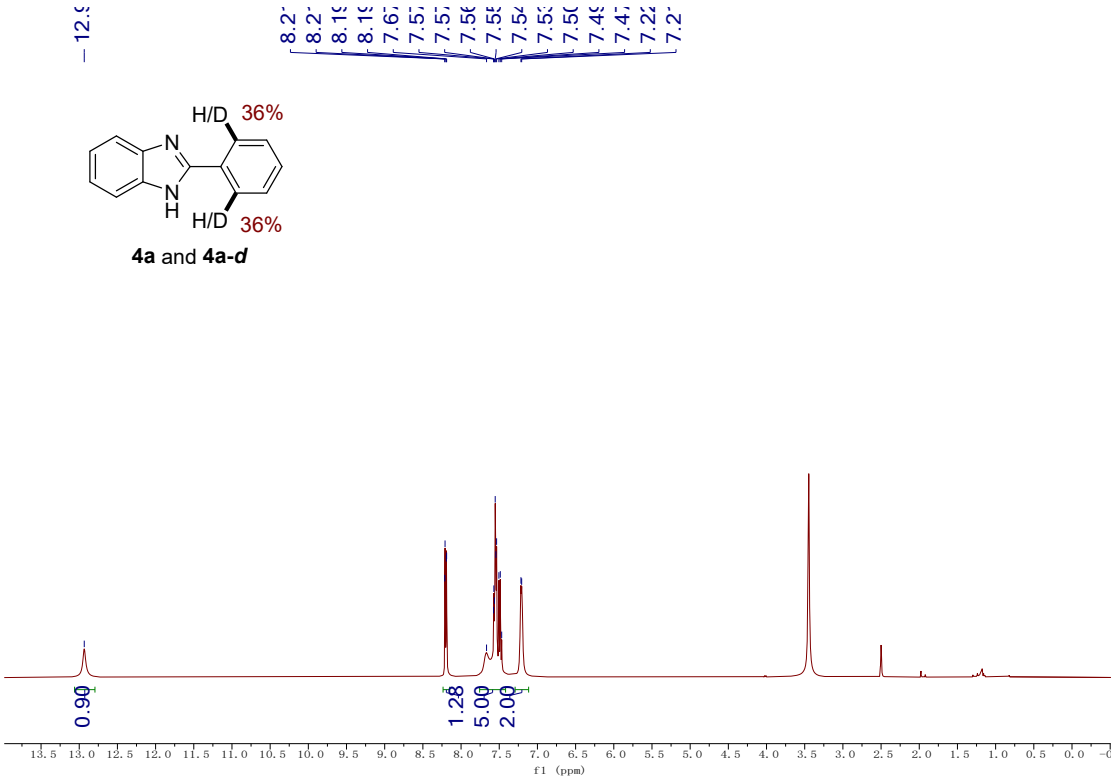
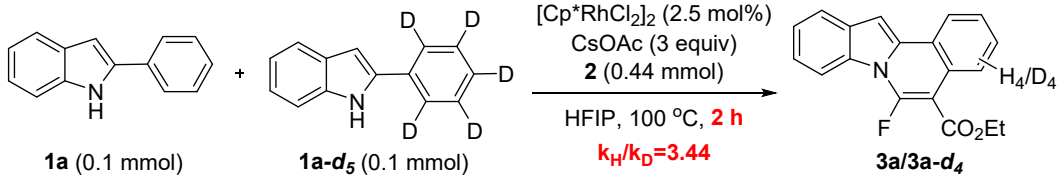
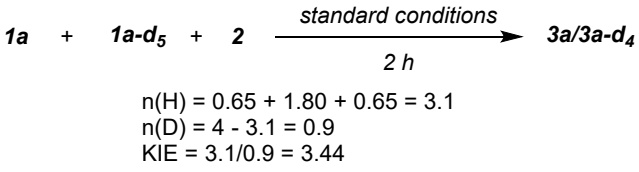


Figure S2 ^{1}H-NMR of **4a** and **4a-*d*.**

5.3 Kinetic isotope effect determination



A sealed tube equipped with a magnetic stirring bar was charged with **1a** (0.1 mmol, 27.4 mg, 0.5 equiv), **1a-*d*$_5$** (0.1 mmol, 28.0 mg, 0.5 equiv), EtDTP **2** (80.1 mg, 0.44 mmol, 2.2 equiv), [Cp*RhCl$_2$]$_2$ (3.1 mg, 0.005 mmol, 0.025 equiv), CsOAc (115.2 mg, 0.6 mmol, 3.0 equiv), and dry HFIP (2 mL). The reaction mixture was stirred at 100 °C under argon atmosphere for 2 h. Then, the solvent was evaporated and the organic product purified by column chromatography (petroleum ether/EtOAc = 20/1), giving the expected product **3a and 3a-*d*$_4$** (12.9 mg, 21%) as a white solid. The ratio of **3a** and **3a-*d*$_4$** was determined to be 3.44 by ^{1}H-NMR (Figure S3), suggesting that the C-H bond cleavage of benzoic acid might not be involved in the rate-determining step.



n(H) = 0.65 + 1.80 + 0.65 = 3.1
n(D) = 4 - 3.1 = 0.9
KIE = 3.1/0.9 = 3.44

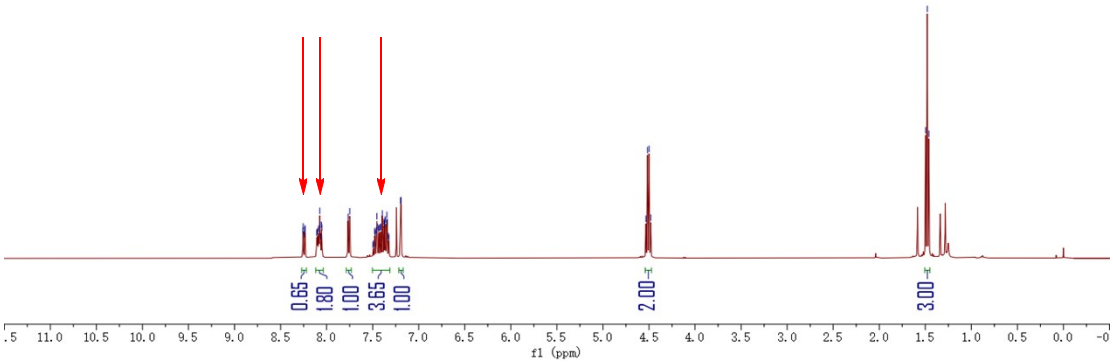
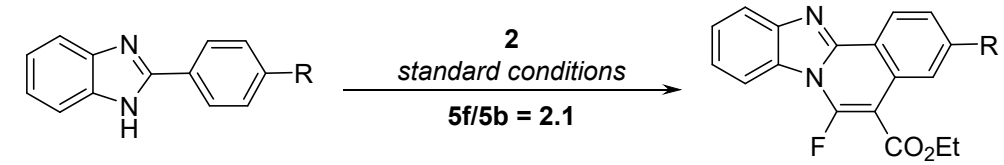


Figure S3. The ^{1}H NMR of **3a** and **3a-*d*$_4$**.

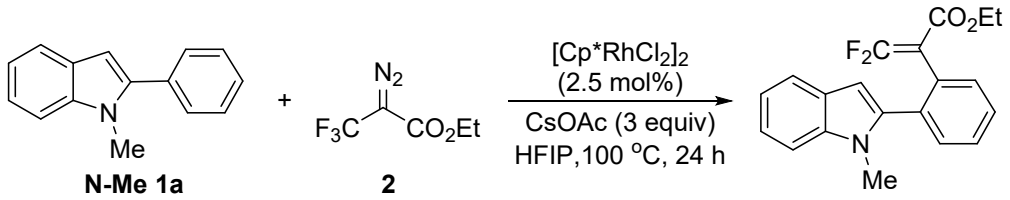
5.4 Intermolecular competition experiment



4b (R = OMe)/**4f** (R = CF_3) = 1:1 **5f/5b**

A sealed tube equipped with a magnetic stirring bar was charged with 2-(4-methoxyphenyl)-1H-benzoimidazole **4b** (44.9 mg, 0.2 mmol, 1.0 equiv), and 2-(4-(trifluoromethyl)phenyl)-1H-benzoimidazole **4f** (52.5 mg, 0.2 mmol, 1.0 equiv), EtDTP **2** (80.1 mg, 0.44 mmol), $[Cp^*RhCl_2]_2$ (3.1 mg, 0.005 mmol, 0.025 equiv), CsOAc (115.2 mg, 0.6 mmol, 3.0 equiv), and dry HFIP (2 mL). The reaction mixture was stirred at 50 °C under argon atmosphere for 4 h. After the reaction was completed, the solvent was evaporated and the residues were purified by column chromatography (petroleum ether/EtOAc = 5/1), giving the expected products **5b** (19.6 mg, 29%) and **5f** (45.9 mg, 61%) as white solids.

5.5 Reaction of N-Me 1a and 2 under standard conditions



N-Me 1a **2**

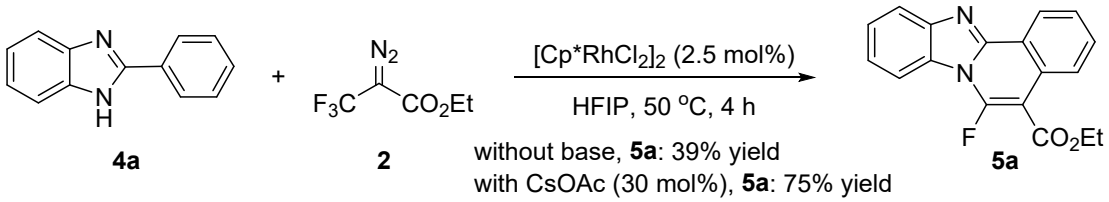
not detected

95% of N-Me **1a** was recovered

A sealed tube equipped with a magnetic stirring bar was charged with N-methyl-2-phenylindole (41.5 mg, 0.2 mmol, 1.0 equiv), EtDTP **2** (80.1 mg, 0.44 mmol, 2.2 equiv.), $[Cp^*RhCl_2]_2$ (3.1 mg, 0.005 mmol, 0.025 equiv), CsOAc (115.2 mg, 0.6 mmol, 3.0 equiv), and dry HFIP (2 mL). The reaction mixture was stirred at 100 °C under argon atmosphere for 24 h. No vinylic Csp^2-F signal was detected by ^{19}F-NMR. After removal of the solvent, the residues were purified by column chromatography (petroleum ether/EtOAc = 20/1), and **N-Me 1a** (39.4 mg, 95%) was recovered. This

result indicated that the unprotected N-H bond of indole is essentially important for the C-H bond functionalization.

5.6 The reactions of 4a and 2 without base or with catalytic amounts of base

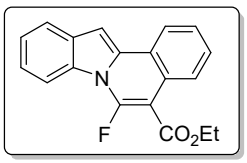


A sealed tube equipped with a magnetic stirring bar was charged with 2-phenyl-1H-benzoimidazole **4a** (38.8 mg, 0.2 mmol, 1.0 equiv), EtDTP **2** (80.1 mg, 0.44 mmol, 2.2 equiv), $[Cp^*RhCl_2]_2$ (3.1 mg, 0.005 mmol, 0.025 equiv), and dry HFIP (2 mL). The reaction mixture was stirred at 50 °C under argon atmosphere for 4 h. After the reaction was completed, the solvent was evaporated and the organic product purified by column chromatography (petroleum ether/EtOAc:5/1), giving the expected product **5a** (24.1 mg, 39%) as a white solid.

When CsOAc (30 mol%, 11.5 mg) was added, the reaction afforded **5a** in 75% yield (46.3 mg).

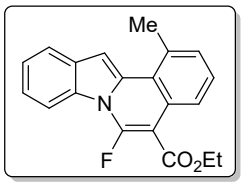
6. Characterization data

ethyl 6-fluoroindolo[2,1-a]isoquinoline-5-carboxylate (**3a**)



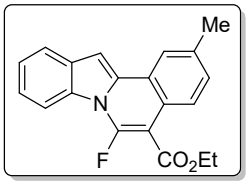
This compound was prepared according to the general procedure at 100 °C using **1a** (0.2 mmol, 38.7 mg), **2** (0.44 mmol, 80.1 mg), $[Cp^*RhCl_2]_2$ (2.5 mol%, 3.1 mg), CsOAc (0.6 mmol, 115.2 mg), HFIP (2.0 mL) and purified by column chromatography on silica gel (R_f = 0.5, eluent: petroleum ether: ethyl acetate = 20:1) to give the product **3a** as a white solid (**Yield**: 79%, 48.6 mg). **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.25 – 8.23 (m, 1H), 8.09 – 8.03 (m, 2H), 7.75 – 7.73 (m, 1H), 7.48 – 7.32 (m, 4H), 7.18 – 7.17 (m, 1H), 4.50 (q, *J* = 7.1 Hz, 2H), 1.48 (t, *J* = 7.1 Hz, 3H). **^{19}F NMR** (376 MHz, $CDCl_3$) δ -100.5. **^{13}C NMR** (100 MHz, $CDCl_3$) δ 164.5 (d, *J* = 3.3 Hz), 153.0 (d, *J* = 271.3 Hz), 135.5, 130.9, 130.0, 128.5, 127.0 (d, *J* = 4.0 Hz), 126.8, 125.6 (d, *J* = 6.4 Hz), 123.9, 123.5, 122.75, 122.66, 120.7, 115.1 (d, *J* = 14.4 Hz), 97.1, 93.2 (d, *J* = 10.1 Hz), 61.5, 14.5. HRMS (ESI) m/z: $[M + H]^+$ Calcd for $C_{19}H_{15}FNO_2$ 308.1081, Found: 308.1075.

ethyl 6-fluoro-1-methylindolo[2,1-a]isoquinoline-5-carboxylate (**3b**)



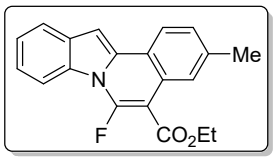
This compound was prepared according to the general procedure at 100 °C using **1b** (0.2 mmol, 41.5 mg), **2** (0.44 mmol, 80.1 mg), $[Cp^*RhCl_2]_2$ (2.5 mol%, 3.1 mg), CsOAc (0.6 mmol, 115.2 mg), HFIP (2.0 mL) and purified by column chromatography on silica gel (R_f = 0.6, eluent: petroleum ether: ethyl acetate = 20:1) to give the product **3b** as a white solid (**Yield**: 88%, 56.3 mg). **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.13 – 8.05 (m, 1H), 8.03 – 7.96 (m, 1H), 7.84 – 7.75 (m, 1H), 7.42 – 7.31 (m, 4H), 7.30 – 7.27 (m, 1H), 4.51 (q, *J* = 7.1 Hz, 2H), 2.81 (s, 3H), 1.48 (t, *J* = 7.1 Hz, 3H). **^{19}F NMR** (376 MHz, $CDCl_3$) δ -102.2. **^{13}C NMR** (100 MHz, $CDCl_3$) δ 164.8 (d, *J* = 2.7 Hz), 152.1 (d, *J* = 269.2 Hz), 135.4, 135.0, 129.9, 128.3 (d, *J* = 4.1 Hz), 127.6, 123.7, 123.2 (d, *J* = 6.3 Hz), 123.0 (d, *J* = 2.8 Hz), 122.5, 120.9, 115.0 (d, *J* = 16.1 Hz), 103.3, 94.0 (d, *J* = 11.1 Hz), 61.6, 25.1, 14.5. **HRMS** (ESI) m/z: $[M + H]^+$ Calcd for $C_{20}H_{17}FNO_2$ 322.1238, Found: 322.1230.

ethyl 6-fluoro-2-methylindolo[2,1-a]isoquinoline-5-carboxylate (**3c**)



This compound was prepared according to the general procedure at 100 °C using **1c** (0.2 mmol, 41.5 mg), **2** (0.44 mmol, 80.1 mg), $[Cp^*RhCl_2]_2$ (2.5 mol%, 3.1 mg), CsOAc (0.6 mmol, 115.2 mg), HFIP (2.0 mL) and purified by column chromatography on silica gel (R_f = 0.5, eluent: petroleum ether: ethyl acetate = 20:1) to give the product **3c** as a white solid (**Yield**: 73%, 46.7 mg). **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.14 – 8.07 (m, 1H), 8.07 – 8.00 (m, 1H), 7.79 (s, 1H), 7.75 – 7.68 (m, 1H), 7.39 – 7.28 (m, 2H), 7.26 – 7.22 (m, 1H), 7.12 – 7.07 (m, 1H), 4.49 (q, *J* = 7.1 Hz, 2H), 2.43 (s, 3H), 1.47 (t, *J* = 7.1 Hz, 3H). **^{19}F NMR** (376 MHz, $CDCl_3$) δ -101.4. **^{13}C NMR** (150 MHz, $CDCl_3$) δ 164.6 (d, *J* = 3.3 Hz), 152.7 (d, *J* = 271.0 Hz), 135.4, 130.8 (d, *J* = 2.3 Hz), 130.0, 129.8, 125.5 (d, *J* = 6.3 Hz), 124.4 (d, *J* = 3.5 Hz), 123.8, 123.4, 122.6, 122.4 (d, *J* = 2.5 Hz), 120.6, 115.0 (d, *J* = 14.4 Hz), 96.7, 93.0 (d, *J* = 10.0 Hz), 61.4, 21.4, 14.5. **HRMS** (ESI) m/z: $[M + H]^+$ Calcd for $C_{20}H_{17}FNO_2$ 322.1238, Found: 322.1231.

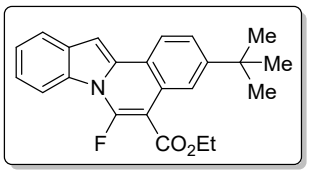
ethyl 6-fluoro-3-methylindolo[2,1-a]isoquinoline-5-carboxylate (**3d**)



This compound was prepared according to the general procedure at 90 °C using **1d** (0.2 mmol, 41.5 mg), **2** (0.44 mmol, 80.1 mg), $[Cp^*RhCl_2]_2$ (2.5 mol%, 3.1 mg), CsOAc (0.6 mmol, 115.2 mg), HFIP (2.0 mL) and purified by column chromatography on silica gel (R_f = 0.5, eluent: petroleum ether: ethyl acetate = 20:1) to give the product **3d** as a white solid (**Yield**: 57%, 36.6 mg). **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.11 – 8.04 (m, 1H), 8.02 (s, 1H), 7.96 – 7.92 (m, 1H), 7.77 – 7.70 (m, 1H), 7.42 – 7.28 (m, 2H), 7.27 – 7.20 (m, 1H), 7.14 – 7.09 (m, 1H), 4.51 (q, *J* = 7.2 Hz, 2H), 2.45 (s, 3H), 1.48 (t, *J* = 7.1 Hz, 3H). **^{19}F NMR** (376 MHz, $CDCl_3$) δ -100.6. **^{13}C NMR** (100 MHz, $CDCl_3$) δ 164.6 (d, *J* = 3.2 Hz), 153.0 (d, *J* = 271.0 Hz), 138.6 (d, *J* = 2.3 Hz), 135.7, 130.8, 130.2, 128.1, 127.0 (d, *J* = 4.0 Hz), 125.5 (d, *J* = 6.3 Hz), 123.8, 123.4, 122.3 (d, *J* = 2.5 Hz), 120.6, 120.3, 115.0 (d, *J* = 14.3 Hz), 96.3, 93.0 (d, *J* = 10.5 Hz), 61.5,

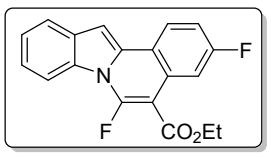
22.0, 14.5. **HRMS** (ESI) m/z: $[M + H]^+$ Calcd for $C_{20}H_{17}FNO_2$ 322.1238, Found: 322.1231.

ethyl 3-(tert-butyl)-6-fluoroindolo[2,1-a]isoquinoline-5-carboxylate (**3e**)



This compound was prepared according to the general procedure at 100 °C using **1e** (0.2 mmol, 49.9 mg), **2** (0.44 mmol, 80.1 mg), $[Cp^*RhCl_2]_2$ (2.5 mol%, 3.1 mg), CsOAc (0.6 mmol, 115.2 mg), HFIP (2.0 mL) and purified by column chromatography on silica gel (R_f = 0.7, eluent: petroleum ether: ethyl acetate = 20:1) to give the product **3e** as a white solid (**Yield**: 83%, 60.0 mg). **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.33 – 8.28 (m, 1H), 8.15 – 8.08 (m, 1H), 8.06 – 8.00 (m, 1H), 7.80 – 7.73 (m, 1H), 7.60 – 7.49 (m, 1H), 7.44 – 7.30 (m, 2H), 7.21 – 7.16 (m, 1H), 4.52 (q, *J* = 7.1 Hz, 2H), 1.49 (t, *J* = 7.1 Hz, 3H), 1.41 (s, 9H). **^{19}F NMR** (376 MHz, $CDCl_3$) δ -100.8. **^{13}C NMR** (150 MHz, $CDCl_3$) 164.7 (d, *J* = 3.1 Hz), 153.2 (d, *J* = 271.3 Hz), 151.7, 135.7, 130.9 (d, *J* = 2.3 Hz), 130.2, 126.8 (d, *J* = 3.8 Hz), 124.7, 123.9, 123.4, 122.4 (d, *J* = 2.6 Hz), 122.1 (d, *J* = 6.3 Hz), 120.7, 120.4, 115.1 (d, *J* = 14.2 Hz), 96.5, 93.5 (d, *J* = 9.8 Hz), 61.5, 35.3, 31.4, 14.6. **HRMS** (ESI) m/z: $[M + H]^+$ Calcd for $C_{23}H_{23}FNO_2$ 364.1707, Found: 364.1697.

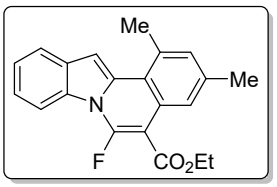
ethyl 3,6-difluoroindolo[2,1-a]isoquinoline-5-carboxylate (**3f**)



This compound was prepared according to the general procedure at 100 °C using **1f** (0.2 mmol, 42.3 mg), **2** (0.44 mmol, 80.1 mg), $[Cp^*RhCl_2]_2$ (2.5 mol%, 3.1 mg), CsOAc (0.6 mmol, 115.2 mg), HFIP (2.0 mL) and purified by column chromatography on silica gel (R_f = 0.7, eluent: petroleum ether: ethyl acetate = 20:1) to give the product **3f** as a white solid (**Yield**: 63%, 41.3 mg). **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.10 – 8.00 (m, 2H), 8.00 – 7.92 (m, 1H), 7.75 – 7.69 (m, 1H), 7.43 – 7.29 (m, 2H), 7.17 – 7.07 (m, 1H), 7.07 – 7.03 (m, 1H), 4.49 (q, *J* = 7.1 Hz, 2H), 1.48 (t, *J* = 7.1 Hz, 3H). **^{19}F NMR** (376 MHz, $CDCl_3$) δ -97.6, -110.8. **^{13}C NMR** (150 MHz, $CDCl_3$) δ 164.2 (d, *J*

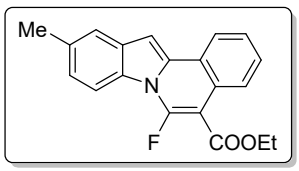
= 3.5 Hz), 162.7 (d, *J* = 246.8 Hz), 154.1 (d, *J* = 273.5 Hz), 134.8, 130.8, 130.1, 129.2 (dd, *J* = 10.1, 4.6 Hz), 125.4 (d, *J* = 9.1 Hz), 124.2, 122.8, 120.7, 119.1, 115.1 (d, *J* = 14.6 Hz), 114.9 (d, *J* = 23.7 Hz), 112.0 (dd, *J* = 25.8, 6.5 Hz), 96.9, 92.4 (d, *J* = 8.5 Hz), 61.6, 14.5. **HRMS** (ESI) m/z: $[M + H]^+$ Calcd for $C_{19}H_{14}F_2NO_2$ 326.0987, Found: 326.0981.

ethyl 6-fluoro-1,3-dimethylindolo[2,1-a]isoquinoline-5-carboxylate (**3g**)



This compound was prepared according to the general procedure at 90 °C using **1g** (0.2 mmol, 44.3 mg), **2** (0.44 mmol, 80.1 mg), $[Cp^*RhCl_2]_2$ (2.5 mol%, 3.1 mg), CsOAc (0.6 mmol, 115.2 mg), HFIP (2.0 mL) and purified by column chromatography on silica gel (R_f = 0.7, eluent: petroleum ether: ethyl acetate = 20:1) to give the product **3g** as a white solid (**Yield**: 72%, 48.3 mg). **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.08 – 8.00 (m, 1H), 7.78 – 7.71 (m, 2H), 7.39 – 7.28 (m, 2H), 7.20 (s, 1H), 7.07 (s, 1H), 4.51 (q, *J* = 7.1 Hz, 2H), 2.73 (s, 3H), 2.39 (s, 3H), 1.48 (t, *J* = 7.1 Hz, 3H). **^{19}F NMR** (376 MHz, $CDCl_3$) δ -102.2. **^{13}C NMR** (100 MHz, $CDCl_3$) δ 164.5 (d, *J* = 2.6 Hz), 151.8 (d, *J* = 268.8 Hz), 137.1, 134.8, 134.7, 130.7 (d, *J* = 2.0 Hz), 129.6, 129.4 (d, *J* = 2.4 Hz), 127.9 (d, *J* = 4.2 Hz), 123.2, 122.9 (d, *J* = 6.3 Hz), 122.2 (d, *J* = 2.9 Hz), 120.3, 119.5, 114.5 (d, *J* = 16.0 Hz), 102.0, 93.4 (d, *J* = 10.9 Hz), 61.2, 24.5, 21.3, 14.2. **HRMS** (ESI) m/z: $[M + H]^+$ Calcd for $C_{21}H_{19}FNO_2$ 336.1394, Found: 336.1386.

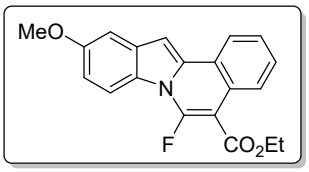
ethyl 6-fluoro-10-methylindolo[2,1-a]isoquinoline-5-carboxylate (**3h**)



This compound was prepared according to the general procedure at 100 °C using **1h** (0.2 mmol, 41.5 mg), **2** (0.44 mmol, 80.1 mg), $[Cp^*RhCl_2]_2$ (2.5 mol%, 3.1 mg), CsOAc (0.6 mmol, 115.2 mg), HFIP (2.0 mL) and purified by column chromatography on silica gel (R_f = 0.6, eluent: petroleum ether: ethyl acetate = 20:1) to give the product **3h** as a white solid (**Yield**: 68%, 43.7 mg). **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.30 – 8.23 (m, 1H), 8.11 – 8.01 (m, 1H), 8.00 – 7.93 (m, 1H), 7.53 (s, 1H), 7.50 – 7.40 (m, 2H),

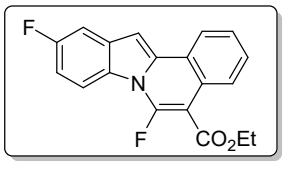
7.20 – 7.14 (m, 1H), 7.14 – 7.11 (m, 1H), 4.50 (q, *J* = 7.1 Hz, 2H), 2.51 (s, 3H), 1.48 (t, *J* = 7.1 Hz, 3H). **^{19}F NMR** (376 MHz, $CDCl_3$) δ -100.2. **^{13}C NMR** (100 MHz, $CDCl_3$) δ 164.6 (d, *J* = 3.3 Hz), 153.1 (d, *J* = 271.3 Hz), 135.6, 133.7, 130.3, 129.2 (d, *J* = 2.4 Hz), 128.4, 127.1 (d, *J* = 3.9 Hz), 126.7 (d, *J* = 1.9 Hz), 125.6 (d, *J* = 6.3 Hz), 124.4 (d, *J* = 2.5 Hz), 123.5, 122.8, 120.4, 114.7 (d, *J* = 14.0 Hz), 96.8, 92.8 (d, *J* = 10.1 Hz), 61.5, 21.8, 14.5. **HRMS** (ESI) m/z: $[M + H]^+$ Calcd for $C_{20}H_{17}FNO_2$ 322.1238, Found: 322.1231.

ethyl 6-fluoro-10-methoxyindolo[2,1-a]isoquinoline-5-carboxylate (**3i**)



This compound was prepared according to the general procedure at 100 °C using **1i** (0.2 mmol, 44.7 mg), **2** (0.44 mmol, 80.1 mg), $[Cp^*RhCl_2]_2$ (2.5 mol%, 3.1 mg), CsOAc (0.6 mmol, 115.2 mg), HFIP (2.0 mL) and purified by column chromatography on silica gel (R_f = 0.4, eluent: petroleum ether: ethyl acetate = 20:1) to give the product **3i** as a white solid (**Yield**: 85%, 57.4 mg). **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.29 – 8.23 (m, 1H), 8.03 – 7.97 (m, 1H), 7.96 – 7.89 (m, 1H), 7.49 – 7.36 (m, 2H), 7.13 – 7.04 (m, 2H), 7.00 – 6.90 (m, 1H), 4.49 (q, *J* = 7.1 Hz, 2H), 3.88 (s, 3H), 1.47 (t, *J* = 7.1 Hz, 3H). **^{19}F NMR** (376 MHz, $CDCl_3$) δ -100.7. **^{13}C NMR** (100 MHz, $CDCl_3$) δ 164.6 (d, *J* = 3.4 Hz), 156.8, 152.8 (d, *J* = 270.8 Hz), 136.1, 131.1, 128.3, 127.0 (d, *J* = 4.0 Hz), 126.6 (d, *J* = 1.9 Hz), 125.7 (d, *J* = 2.2 Hz), 125.6 (d, *J* = 6.3 Hz), 123.4, 122.4, 115.9 (d, *J* = 14.2 Hz), 112.7 (d, *J* = 2.8 Hz), 101.8, 96.9, 92.7 (d, *J* = 10.2 Hz), 61.5, 55.7, 14.5. **HRMS** (ESI) m/z: $[M + H]^+$ Calcd for $C_{20}H_{17}FNO_3$ 338.1187, Found: 338.1184.

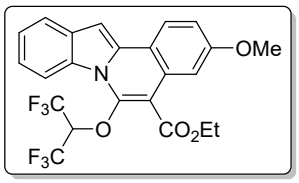
ethyl 6,10-difluoroindolo[2,1-a]isoquinoline-5-carboxylate (**3j**)



This compound was prepared according to the general procedure at 90 °C using **1j** (0.2 mmol, 42.3 mg), **2** (0.44 mmol, 80.1 mg), $[Cp^*RhCl_2]_2$ (2.5 mol%, 3.1 mg), CsOAc (0.6 mmol, 115.2 mg), HFIP (2.0 mL) and purified by column chromatography on

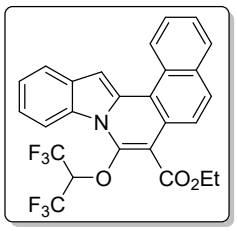
silica gel (R_f = 0.4, eluent: petroleum ether: ethyl acetate = 20:1) to give the product **3j** as a white solid (**Yield**: 60%, 39.1 mg). **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.28 – 8.21 (m, 1H), 8.06 – 7.95 (m, 2H), 7.52 – 7.41 (m, 2H), 7.39 – 7.33 (m, 1H), 7.16 – 7.01 (m, 2H), 4.51 (q, *J* = 7.1 Hz, 2H), 1.48 (t, *J* = 7.1 Hz, 3H). **^{19}F NMR** (376 MHz, $CDCl_3$) δ -101.2, -118.3. **^{13}C NMR** (100 MHz, $CDCl_3$) δ 164.3 (d, *J* = 3.4 Hz), 159.9 (d, *J* = 241.1 Hz), 152.5 (d, *J* = 271.0 Hz), 136.9, 130.9 (d, *J* = 10.6 Hz), 128.7, 127.2, 127.0 (d, *J* = 3.9 Hz), 126.8, 125.6 (d, *J* = 6.4 Hz), 123.5, 122.2, 116.1 (dd, *J* = 14.9, 9.8 Hz), 111.0 (dd, *J* = 26.1, 2.8 Hz), 105.5 (d, *J* = 23.9 Hz), 96.8 (d, *J* = 4.5 Hz), 93.3 (d, *J* = 10.2 Hz), 61.6, 14.5. **HRMS** (ESI) m/z: $[M + H]^+$ Calcd for $C_{19}H_{14}F_2NO_2$ 326.0987, Found: 326.0978.

ethyl 6-((1,1,1,3,3,3-hexafluoropropan-2-yl)oxy)-3-methoxyindolo[2,1-a]isoquinoline -5-carboxylate (**3k**)



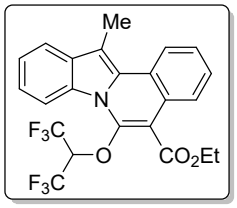
This compound was prepared according to the general procedure at 100 °C using **1k** (0.2 mmol, 44.7 mg), **2** (0.44 mmol, 80.1 mg), $[Cp^*RhCl_2]_2$ (2.5 mol%, 3.1 mg), CsOAc (0.6 mmol, 115.2 mg), HFIP (2.0 mL) and purified by column chromatography on silica gel (R_f = 0.4, eluent: petroleum ether: ethyl acetate = 20:1) to give the product **3k** as a yellow solid (**Yield**: 70%, 68.1 mg). **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.24 – 8.18 (m, 1H), 8.08 – 8.01 (m, 1H), 7.78 – 7.71 (m, 1H), 7.42 – 7.33 (m, 1H), 7.35 – 7.26 (m, 1H), 7.15 – 7.11 (m, 1H), 7.13 – 7.06 (m, 2H), 5.92 – 5.79 (m, 1H), 4.52 (q, *J* = 7.1 Hz, 2H), 3.89 (s, 3H), 1.46 (t, *J* = 7.2 Hz, 3H). **^{19}F NMR** (376 MHz, $CDCl_3$) δ -72.2. **^{13}C NMR** (150 MHz, $CDCl_3$) δ 166.6, 159.7, 148.3, 135.7, 131.7, 130.3, 128.3, 125.2, 123.5, 121.8, 120.2, 119.8 (q, *J* = 285.4 Hz), 117.3, 116.0, 115.7, 107.5, 100.6, 95.3, 78.9 (p, *J* = 33.6 Hz), 62.7, 55.5, 14.2. **HRMS** (ESI) m/z: $[M + H]^+$ Calcd for $C_{23}H_{18}F_6NO_4$ 486.1134, Found: 485.1121.

ethyl 8-((1,1,1,3,3,3-hexafluoropropan-2-yl)oxy)benzo[h]indolo[2,1-a]isoquinoline -7-carboxylate (**3l**)



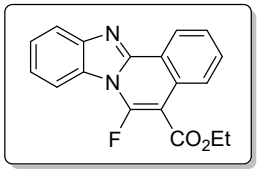
This compound was prepared according to the general procedure at 100 °C using **1l** (0.2 mmol, 48.7 mg), **2** (0.44 mmol, 80.1 mg), $[Cp^*RhCl_2]_2$ (2.5 mol%, 3.1 mg), CsOAc (0.6 mmol, 115.2 mg), HFIP (2.0 mL) and purified by column chromatography on silica gel (R_f = 0.5, eluent: petroleum ether: ethyl acetate = 20:1) to give the product **3l** as a yellow solid (**Yield**: 59%, 59.7 mg). **^{1}H NMR** (400 MHz, $CDCl_3$) δ 9.13 – 9.06 (m, 1H), 8.38 – 8.32 (m, 1H), 7.97 – 7.91 (m, 1H), 7.90 – 7.84 (m, 3H), 7.78 – 7.70 (m, 1H), 7.65 – 7.58 (m, 1H), 7.58 – 7.51 (m, 1H), 7.49 – 7.35 (m, 2H), 6.04 – 5.97 (m, 1H), 4.56 (q, *J* = 7.2 Hz, 2H), 1.47 (t, *J* = 8.4 Hz, 3H). **^{19}F NMR** (376 MHz, $CDCl_3$) δ -72.2. **^{13}C NMR** (150 MHz, $CDCl_3$) δ 167.0, 147.0, 134.7, 133.0, 130.9, 130.5, 129.3, 129.2, 129.1, 127.8, 126.5, 126.4, 125.4, 123.7, δ 122.7 (q, *J* = 285.6 Hz), 122.5, 121.9, 120.6, 119.9, 116.1, 102.8, 102.0, 79.5 (p, *J* = 33.5 Hz), 63.0, 14.2. **HRMS** (ESI) m/z: $[M + H]^+$ Calcd for $C_{26}H_{18}F_6NO_3$ 506.1185, Found: 506.1176.

ethyl 6-((1,1,1,3,3,3-hexafluoropropan-2-yl)oxy)-12-methylindolo[2,1-a]isoquinoline -5-carboxylate (**3m**)



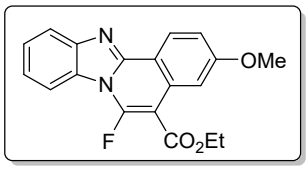
This compound was prepared according to the general procedure at 100 °C using **1m** (0.2 mmol, 41.5 mg), **2** (0.44 mmol, 80.1 mg), $[Cp^*RhCl_2]_2$ (2.5 mol%, 3.1 mg), CsOAc (0.6 mmol, 115.2 mg), HFIP (2.0 mL) and purified by column chromatography on silica gel (R_f = 0.5, eluent: petroleum ether: ethyl acetate = 20:1) to give the product **3m** as a yellow solid (**Yield**: 30%, 28.2 mg). **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.39 – 8.33 (m, 1H), 8.27 – 8.21 (m, 1H), 7.84 – 7.77 (m, 1H), 7.59 – 7.50 (m, 2H), 7.48 – 7.41 (m, 2H), 7.40 – 7.34 (m, 1H), 5.97 – 5.85 (m, 1H), 4.51 (q, *J* = 7.1 Hz, 2H), 2.82 (s, 3H), 1.45 (t, *J* = 7.2 Hz, 3H). **^{19}F NMR** (376 MHz, $CDCl_3$) δ -72.2. **^{13}C NMR** (150 MHz, $CDCl_3$) δ 166.8, 147.7, 130.9, 130.6, 127.6, 127.3, 127.2, 125.6, 124.7, 124.2, 122.9, 122.7, 120.8 (q, *J* = 285.3 Hz), 118.4, 115.9, 108.2, 100.7, 79.1 (p, *J* = 33.6 Hz), 62.7, 14.2, 11.8. **HRMS** (ESI) m/z: $[M + H]^+$ Calcd for $C_{23}H_{18}F_6NO_3$ 470.1185, Found: 470.1181.

ethyl 6-fluorobenzo[4,5]imidazo[2,1-a]isoquinoline-5-carboxylate (**5a**)



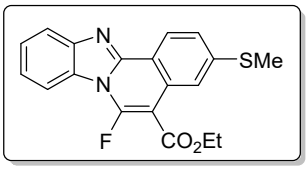
This compound was prepared according to the general procedure at 50 °C using **4a** (0.2 mmol, 38.8 mg), **2** (0.44 mmol, 80.1 mg), $[Cp^*RhCl_2]_2$ (2.5 mol%, 3.1 mg), CsOAc (0.6 mmol, 115.2 mg), HFIP (2.0 mL) and purified by column chromatography on silica gel (R_f = 0.5, eluent: petroleum ether: ethyl acetate = 5:1) to give the product **5a** as a white solid (**Yield**: 83%, 51.2 mg). **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.73 – 8.66 (m, 1H), 8.36 – 8.29 (m, 1H), 8.02 – 7.96 (m, 1H), 7.94 – 7.88 (m, 1H), 7.71 – 7.61 (m, 1H), 7.60 – 7.53 (m, 1H), 7.52 – 7.45 (m, 1H), 7.40 – 7.33 (m, 1H), 4.53 (q, *J* = 7.2 Hz, 2H), 1.49 (t, *J* = 7.2 Hz, 3H). **^{19}F NMR** (376 MHz, $CDCl_3$) δ -101.6. **^{13}C NMR** (100 MHz, $CDCl_3$) δ 163.4 (d, *J* = 3.5 Hz), 150.7 (d, *J* = 274.6 Hz), 147.2, 143.8, 130.8, 129.3 (d, *J* = 3.6 Hz), 128.6 (d, *J* = 3.6 Hz), 127.2, 125.7, 125.4 (d, *J* = 6.6 Hz), 125.0, 123.2, 120.2, 119.9, 114.0 (d, *J* = 10.6 Hz), 95.7 (d, *J* = 9.5 Hz), 61.8, 14.4. **HRMS** (ESI) m/z: $[M + H]^+$ Calcd for $C_{18}H_{14}FN_2O_2$ 309.1034, Found: 309.1028.

ethyl 6-fluoro-3-methoxybenzo[4,5]imidazo[2,1-a]isoquinoline-5-carboxylate (**5b**)



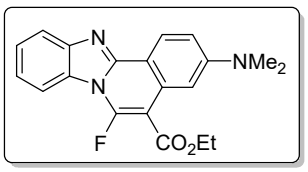
This compound was prepared according to the general procedure at 50 °C using **4b** (0.2 mmol, 44.9 mg), **2** (0.44 mmol, 80.1 mg), $[Cp^*RhCl_2]_2$ (2.5 mol%, 3.1 mg), CsOAc (0.6 mmol, 115.2 mg), HFIP (2.0 mL) and purified by column chromatography on silica gel (R_f = 0.4, eluent: petroleum ether: ethyl acetate = 5:1) to give the product **5b** as a white solid (**Yield**: 77%, 52.2 mg). **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.62 – 8.54 (m, 1H), 8.01 – 7.95 (m, 1H), 7.91 – 7.82 (m, 2H), 7.52 – 7.44 (m, 1H), 7.39 – 7.30 (m, 1H), 7.18 – 7.10 (m, 1H), 4.52 (q, *J* = 7.1 Hz, 2H), 3.89 (s, 3H), 1.49 (t, *J* = 7.1 Hz, 3H). **^{19}F NMR** (376 MHz, $CDCl_3$) δ -100.1. **^{13}C NMR** (100 MHz, $CDCl_3$) δ 163.8 (d, *J* = 3.8 Hz), 161.9, 151.6 (d, *J* = 275.0 Hz), 147.5, 144.2, 131.5 (d, *J* = 3.9 Hz), 128.8 (d, *J* = 3.8 Hz), 126.8, 125.9, 122.8, 119.7, 116.8, 114.1, 114.0, 107.6 (d, *J* = 6.6 Hz), 95.3 (d, *J* = 9.4 Hz), 61.9, 55.5, 14.4. **HRMS** (ESI) m/z: $[M + H]^+$ Calcd for $C_{19}H_{16}FN_2O_3$ 339.1140, Found: 339.1134.

ethyl 6-fluoro-3-(methylthio)benzo[4,5]imidazo[2,1-a]isoquinoline-5-carboxylate (**5c**)



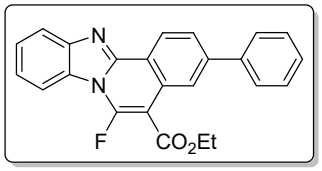
This compound was prepared according to the general procedure at 50 °C using **4c** (0.2 mmol, 48.1 mg), **2** (0.44 mmol, 80.1 mg), $[Cp^*RhCl_2]_2$ (2.5 mol%, 3.1 mg), CsOAc (0.6 mmol, 115.2 mg), HFIP (2.0 mL) and purified by column chromatography on silica gel (R_f = 0.4, eluent: petroleum ether: ethyl acetate = 5:1) to give the product **5c** as a white solid (**Yield**: 72%, 51.1 mg). **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.56 – 8.46 (m, 1H), 8.18 – 8.12 (m, 1H), 8.01 – 7.94 (m, 1H), 7.92 – 7.84 (m, 1H), 7.53 – 7.44 (m, 1H), 7.41 – 7.32 (m, 2H), 4.52 (q, *J* = 7.1 Hz, 2H), 2.55 (s, 3H), 1.50 (t, *J* = 7.1 Hz, 3H). **^{19}F NMR** (376 MHz, $CDCl_3$) δ -99.7. **^{13}C NMR** (100 MHz, $CDCl_3$) δ 163.5 (d, *J* = 3.8 Hz), 151.5 (d, *J* = 275.5 Hz), 147.3, 144.1, 143.7, 129.9 (d, *J* = 3.6 Hz), 128.7 (d, *J* = 3.4 Hz), 126.0, 125.2, 125.1, 123.2, 120.7 (d, *J* = 6.5 Hz), 119.8, 117.0, 114.1 (d, *J* = 10.6 Hz), 95.1 (d, *J* = 9.6 Hz), 61.9, 15.0, 14.5. **HRMS** (ESI) m/z: $[M + H]^+$ Calcd for $C_{19}H_{16}FN_2O_2S$ 355.0911, Found: 355.0904.

ethyl 3-(dimethylamino)-6-fluorobenzo[4,5]imidazo[2,1-a]isoquinoline-5-carboxylate (**5d**)



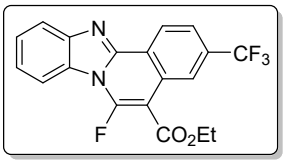
This compound was prepared according to the general procedure at 50 °C using **4d** (0.2 mmol, 47.5 mg), **2** (0.44 mmol, 80.1 mg), $[Cp^*RhCl_2]_2$ (2.5 mol%, 3.1 mg), CsOAc (0.6 mmol, 115.2 mg), HFIP (2.0 mL) and purified by column chromatography on silica gel (R_f = 0.2, eluent: petroleum ether: ethyl acetate = 5:1) to give the product **5d** as a white solid (**Yield**: 50%, 35.2 mg). **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.56 – 8.49 (m, 1H), 8.02 – 7.95 (m, 1H), 7.93 – 7.84 (m, 1H), 7.51 – 7.43 (m, 2H), 7.35 – 7.28 (m, 1H), 7.02 – 6.94 (m, 1H), 4.52 (q, *J* = 7.1 Hz, 2H), 3.07 (s, 6H), 1.49 (t, *J* = 7.1 Hz, 3H). **^{19}F NMR** (376 MHz, $CDCl_3$) δ -101.4. **^{13}C NMR** (100 MHz, $CDCl_3$) δ 164.2 (d, *J* = 3.6 Hz), 152.0, 148.4, 144.5, 131.3 (d, *J* = 4.0 Hz), 129.0 (d, *J* = 3.6 Hz), 126.5, 125.6, 122.2, 119.2, 113.9 (d, *J* = 10.6 Hz), 113.2 (d, *J* = 2.0 Hz), 109.7, 105.6 (d, *J* = 6.6 Hz), 95.5 (d, *J* = 9.2 Hz), 61.7, 40.3, 14.5. **HRMS** (ESI) m/z: $[M + H]^+$ Calcd for $C_{20}H_{19}FN_3O_2$ 352.1456, Found: 352.1448.

ethyl 6-fluoro-3-phenylbenzo[4,5]imidazo[2,1-a]isoquinoline-5-carboxylate (**5e**)



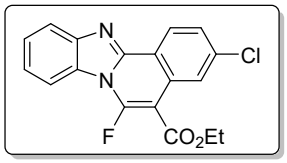
This compound was prepared according to the general procedure at 50 °C using **4e** (0.2 mmol, 54.1 mg), **2** (0.44 mmol, 80.1 mg), $[Cp^*RhCl_2]_2$ (2.5 mol%, 3.1 mg), CsOAc (0.6 mmol, 115.2 mg), HFIP (2.0 mL) and purified by column chromatography on silica gel (R_f = 0.5, eluent: petroleum ether: ethyl acetate = 5:1) to give the product **5e** as a white solid (**Yield**: 63%, 48.5 mg). **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.81 – 8.73 (m, 1H), 8.63 – 8.58 (m, 1H), 8.07 – 8.00 (m, 1H), 7.98 – 7.92 (m, 1H), 7.87 – 7.80 (m, 1H), 7.73 – 7.67 (m, 2H), 7.56 – 7.44 (m, 3H), 7.43 – 7.36 (m, 2H), 4.55 (q, *J* = 7.1 Hz, 2H), 1.50 (t, *J* = 7.1 Hz, 3H). **^{19}F NMR** (376 MHz, $CDCl_3$) δ -100.9. **^{13}C NMR** (100 MHz, $CDCl_3$) δ 163.7 (d, *J* = 3.6 Hz), 151.2 (d, *J* = 274.8 Hz), 147.4, 144.2, 143.8, 140.1, 129.9 (d, *J* = 3.6 Hz), 129.1, 128.9 (d, *J* = 3.8 Hz), 128.3, 127.6, 126.6, 126.0, 125.7, 124.0 (d, *J* = 6.6 Hz), 123.5, 120.1, 119.4, 114.2 (d, *J* = 10.4 Hz), 96.0 (d, *J* = 9.7 Hz), 62.0, 14.5. **HRMS** (ESI) m/z: $[M + H]^+$ Calcd for $C_{24}H_{18}FN_2O_2$ 385.1347, Found: 385.1336.

ethyl 6-fluoro-3-(trifluoromethyl)benzo[4,5]imidazo[2,1-a]isoquinoline-5-carboxylate (**5f**)



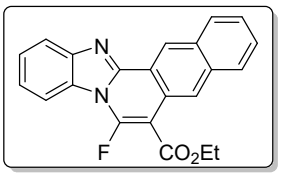
This compound was prepared according to the general procedure at 50 °C using **4f** (0.2 mmol, 52.5 mg), **2** (0.44 mmol, 80.1 mg), $[Cp^*RhCl_2]_2$ (2.5 mol%, 3.1 mg), CsOAc (0.6 mmol, 115.2 mg), HFIP (2.0 mL) and purified by column chromatography on silica gel (R_f = 0.7, eluent: petroleum ether: ethyl acetate = 5:1) to give the product **5f** as a white solid (**Yield**: 95%, 71.5 mg). **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.77 – 8.69 (m, 2H), 8.04 – 7.96 (m, 1H), 7.94 – 7.87 (m, 1H), 7.80 – 7.72 (m, 1H), 7.58 – 7.48 (m, 1H), 7.47 – 7.38 (m, 1H), 4.55 (q, *J* = 7.2 Hz, 2H), 1.51 (t, *J* = 7.1 Hz, 3H). **^{19}F NMR** (376 MHz, $CDCl_3$) δ -62.7, -98.4. **^{13}C NMR** (100 MHz, $CDCl_3$) δ 163.0 (d, *J* = 4.0 Hz), 151.9 (d, *J* = 277.2 Hz), 146.1, 143.9, 132.6 (q, *J* = 32.8 Hz), 129.5 (d, *J* = 3.9 Hz), 128.7 (d, *J* = 3.3 Hz), 126.5, 125.9, 124.2, 123.8, (q, *J* = 272.9 Hz), 123.7, 123.4 – 123.2 (m), 122.7, 120.4, 114.3 (d, *J* = 10.9 Hz), 95.4 (d, *J* = 9.6 Hz), 62.3, 14.4. **HRMS** (ESI) m/z: $[M + H]^+$ Calcd for $C_{19}H_{13}F_4N_2O_2$ 377.0908, Found: 377.0900.

ethyl 3-chloro-6-fluorobenzo[4,5]imidazo[2,1-a]isoquinoline-5-carboxylate (**5g**)



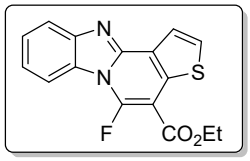
This compound was prepared according to the general procedure at 50 °C using **4g** (0.2 mmol, 45.7 mg), **2** (0.44 mmol, 80.1 mg), $[Cp^*RhCl_2]_2$ (2.5 mol%, 3.1 mg), CsOAc (0.6 mmol, 115.2 mg), HFIP (2.0 mL) and purified by column chromatography on silica gel (R_f = 0.6, eluent: petroleum ether: ethyl acetate = 5:1) to give the product **5g** as a white solid (**Yield**: 90%, 62.0 mg). **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.62 – 8.55 (m, 1H), 8.45 – 8.40 (m, 1H), 8.03 – 7.95 (m, 1H), 7.93 – 7.86 (m, 1H), 7.58 – 7.48 (m, 2H), 7.44 – 7.36 (m, 1H), 4.54 (q, *J* = 7.2 Hz, 2H), 1.50 (t, *J* = 7.1 Hz, 3H). **^{19}F NMR** (376 MHz, $CDCl_3$) δ -98.8. **^{13}C NMR** (150 MHz, $CDCl_3$) δ 163.1 (d, *J* = 3.9 Hz), 151.6 (d, *J* = 276.4 Hz), 146.6, 143.9, 137.6, 130.7 (d, *J* = 4.0 Hz), 128.7 (d, *J* = 3.7 Hz), 128.0 (d, *J* = 2.3 Hz), 126.4, 126.2, 125.4 (d, *J* = 6.7 Hz), 123.7, 120.1, 118.7, 114.2 (d, *J* = 10.5 Hz), 94.9 (d, *J* = 10.1 Hz), 62.1, 14.4. **HRMS** (ESI) m/z: $[M + H]^+$ Calcd for $C_{18}H_{13}ClFN_2O_2$ 343.0644, Found: 343.0638.

ethyl 8-fluorobenzo[f]benzo[4,5]imidazo[2,1-a]isoquinoline-7-carboxylate (**5h**)



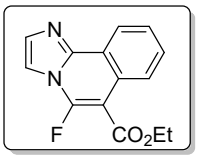
This compound was prepared according to the general procedure at 50 °C using **4h** (0.2 mmol, 48.9 mg), **2** (0.44 mmol, 80.1 mg), $[Cp^*RhCl_2]_2$ (2.5 mol%, 3.1 mg), CsOAc (0.6 mmol, 115.2 mg), HFIP (2.0 mL) and purified by column chromatography on silica gel (R_f = 0.7, eluent: petroleum ether: ethyl acetate = 5:1) to give the product **5h** as a white solid (**Yield**: 48%, 34.5 mg). **^{1}H NMR** (600 MHz, $CDCl_3$) δ 9.31 (s, 1H), 8.88 (s, 1H), 8.09 – 8.03 (m, 2H), 8.02 – 7.98 (m, 2H), 7.62 – 7.52 (m, 3H), 7.49 – 7.43 (m, 1H), 4.61 (q, *J* = 7.1 Hz, 2H), 1.54 (t, *J* = 7.1 Hz, 3H). **^{19}F NMR** (376 MHz, $CDCl_3$) δ -102.3. **^{13}C NMR** (150 MHz, $CDCl_3$) δ 163.9 (d, *J* = 3.0 Hz), 151.0 (d, *J* = 274.2 Hz), 147.9, 144.0, 134.5, 131.8, 129.6, 128.63, 128.57, 128.0, 127.1, 125.9 (d, *J* = 3.6 Hz), 125.8, 125.5, 125.2 (d, *J* = 8.4 Hz), 124.0, 120.3, 118.9, 114.0 (d, *J* = 10.4 Hz), 95.8 (d, *J* = 9.8 Hz), 62.1, 14.5. **HRMS** (ESI) m/z: $[M + H]^+$ Calcd for $C_{22}H_{16}FN_2O_2$ 359.1190, Found: 359.1180.

ethyl 5-fluorobenzo[4,5]imidazo[1,2-a]thieno[3,2-c]pyridine-4-carboxylate (**5i**)



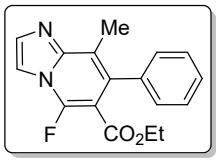
This compound was prepared according to the general procedure at 50 °C using **4i** (0.2 mmol, 40.1 mg), **2** (0.44 mmol, 80.1 mg), $[Cp^*RhCl_2]_2$ (2.5 mol%, 3.1 mg), CsOAc (0.6 mmol, 115.2 mg), HFIP (2.0 mL) and purified by column chromatography on silica gel (R_f = 0.5, eluent: petroleum ether: ethyl acetate = 5:1) to give the product **5i** as a white solid (**Yield**: 62%, 39.1 mg). **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.14 – 8.06 (m, 2H), 7.94 – 7.88 (m, 1H), 7.76 – 7.70 (m, 1H), 7.58 – 7.50 (m, 1H), 7.43 – 7.35 (m, 1H), 4.51 (q, *J* = 7.1 Hz, 2H), 1.49 (t, *J* = 7.1 Hz, 3H). **^{19}F NMR** (376 MHz, $CDCl_3$) δ -100.3. **^{13}C NMR** (100 MHz, $CDCl_3$) 163.3 (d, *J* = 5.4 Hz), 152.9 (d, *J* = 278.7 Hz), 144.6, 144.2, 137.2 (d, *J* = 3.2 Hz), 131.0, 128.5 (d, *J* = 3.7 Hz), 126.6, 126.3 (d, *J* = 5.4 Hz), 123.0 (d, *J* = 2.1 Hz), 122.8 (d, *J* = 2.3 Hz), 119.9, 114.5 (d, *J* = 11.2 Hz), 94.7 (d, *J* = 8.8 Hz), 61.9, 14.5. **HRMS** (ESI) m/z: $[M + H]^+$ Calcd for $C_{16}H_{12}FN_2O_2S$ 315.0598, Found: 315.0588.

ethyl 5-fluoroimidazo[2,1-a]isoquinoline-6-carboxylate (**5j**)



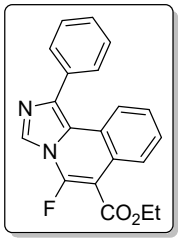
This compound was prepared according to the general procedure at 50 °C using **4j** (0.2 mmol, 28.8 mg), **2** (0.44 mmol, 80.1 mg), $[Cp^*RhCl_2]_2$ (2.5 mol%, 3.1 mg), CsOAc (0.6 mmol, 115.2 mg), HFIP (2.0 mL) and purified by column chromatography on silica gel (R_f = 0.2, eluent: petroleum ether: ethyl acetate = 5:1) to give the product **5j** as a white solid (**Yield**: 84%, 43.3 mg). **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.69 – 8.58 (m, 1H), 8.36 – 8.26 (m, 1H), 7.75 – 7.70 (m, 1H), 7.69 – 7.59 (m, 3H), 4.53 (q, *J* = 7.1 Hz, 2H), 1.47 (t, *J* = 7.2 Hz, 3H). **^{19}F NMR** (376 MHz, $CDCl_3$) δ -102.9. **^{13}C NMR** (100 MHz, $CDCl_3$) δ 163.6 (d, *J* = 3.4 Hz), 148.1 (d, *J* = 273.3 Hz), 144.6 (d, *J* = 2.5 Hz), 133.2, 129.6, 127.7 (d, *J* = 2.2 Hz), 127.4 (d, *J* = 2.9 Hz), 125.6 (d, *J* = 6.6 Hz), 123.7, 121.1 (d, *J* = 1.7 Hz), 110.3, 97.9 (d, *J* = 9.4 Hz), 62.1, 14.4. **HRMS** (ESI) m/z: $[M + H]^+$ Calcd for $C_{14}H_{12}FN_2O_2$ 259.0877, Found: 259.0873.

ethyl 5-fluoro-8-methyl-7-phenylimidazo[1,2-a]pyridine-6-carboxylate (**5k**)



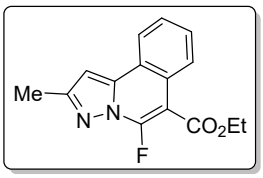
This compound was prepared according to the general procedure at 50 °C using **4k** (0.2 mmol, 36.9 mg), **2** (0.44 mmol, 80.1 mg), $[Cp^*RhCl_2]_2$ (2.5 mol%, 3.1 mg), CsOAc (0.6 mmol, 115.2 mg), HFIP (2.0 mL) and purified by column chromatography on silica gel (R_f = 0.2, eluent: petroleum ether: ethyl acetate = 5:1) to give the product **5k** as a white solid (**Yield**: 59%, 35.3 mg). **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.76 – 7.71 (m, 2H), 7.47 – 7.38 (m, 3H), 7.28 – 7.22 (m, 2H), 4.02 (q, *J* = 7.1 Hz, 2H), 2.41 (s, 3H), 0.93 (t, *J* = 7.1 Hz, 3H). **^{19}F NMR** (376 MHz, $CDCl_3$) δ -107.4. **^{13}C NMR** (100 MHz, $CDCl_3$) δ 163.6 (d, *J* = 2.5 Hz), 146.8, 146.3 (d, *J* = 271.8 Hz), 137.3 (d, *J* = 2.5 Hz), 135.3, 134.9, 129.2, 128.3, 127.9, 121.3 (d, *J* = 4.9 Hz), 108.6, 103.1 (d, *J* = 9.2 Hz), 61.8, 14.4, 13.6. **HRMS** (ESI) m/z: $[M + H]^+$ Calcd for $C_{17}H_{16}FN_2O_2$ 299.1190, Found: 299.1185.

ethyl 5-fluoro-1-phenylimidazo[5,1-a]isoquinoline-6-carboxylate (**5l**)



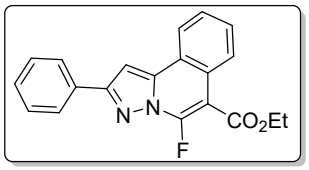
This compound was prepared according to the general procedure at 50 °C using **4l** (0.2 mmol, 44.1 mg), **2** (0.44 mmol, 80.1 mg), $[Cp^*RhCl_2]_2$ (2.5 mol%, 3.1 mg), CsOAc (0.6 mmol, 115.2 mg), HFIP (2.0 mL) and purified by column chromatography on silica gel (R_f = 0.4, eluent: petroleum ether: ethyl acetate = 5:1) to give the product **5l** as a white solid (**Yield**: 81%, 54.2 mg). **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.33 (s, 1H), 8.14 – 8.05 (m, 2H), 7.74 – 7.66 (m, 2H), 7.55 – 7.48 (m, 2H), 7.48 – 7.41 (m, 2H), 7.33 – 7.27 (m, 1H), 4.52 (q, *J* = 7.1 Hz, 2H), 1.47 (t, *J* = 7.1 Hz, 3H). **^{19}F NMR** (376 MHz, $CDCl_3$) δ -107.9. **^{13}C NMR** (100 MHz, $CDCl_3$) δ 163.5 (d, *J* = 2.9 Hz), 146.6 (d, *J* = 270.4 Hz), 136.9, 135.1, 129.7, 128.8, 128.5, 127.9, 127.5 (d, *J* = 2.2 Hz), 126.2 (d, *J* = 3.4 Hz), 125.9 (d, *J* = 6.4 Hz), 125.8 (d, *J* = 2.7 Hz), 124.1, 122.8, 122.6, 97.9 (d, *J* = 9.3 Hz), 62.2, 14.4. **HRMS** (ESI) m/z: $[M + H]^+$ Calcd for $C_{20}H_{16}FN_2O_2$ 335.1190, Found: 335.1183.

ethyl 5-fluoro-2-methylpyrazolo[5,1-a]isoquinoline-6-carboxylate (**5m**)



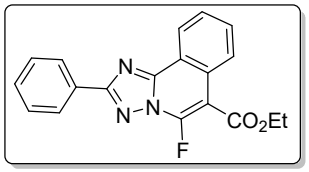
This compound was prepared according to the general procedure at 50 °C using **4m** (0.2 mmol, 31.6 mg), **2** (0.44 mmol, 80.1 mg), $[Cp^*RhCl_2]_2$ (2.5 mol%, 3.1 mg), CsOAc (0.6 mmol, 115.2 mg), HFIP (2.0 mL) and purified by column chromatography on silica gel (R_f = 0.5, eluent: petroleum ether: ethyl acetate = 5:1) to give the product **5m** as a white solid (**Yield**: 81%, 44.2 mg). **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.34 – 8.28 (m, 1H), 7.99 – 7.92 (m, 1H), 7.60 – 7.45 (m, 2H), 6.82 – 6.77 (m, 1H), 4.51 (q, *J* = 7.1 Hz, 2H), 2.55 (s, 3H), 1.46 (t, *J* = 7.1 Hz, 3H). **^{19}F NMR** (377 MHz, $CDCl_3$) δ -106.9. **^{13}C NMR** (100 MHz, $CDCl_3$) δ 163.9 (d, *J* = 3.5 Hz), 154.6, 149.3 (d, *J* = 273.8 Hz), 141.7, 129.0, 127.1 (d, *J* = 2.9 Hz), 127.0 (d, *J* = 2.1 Hz), 125.7 (d, *J* = 6.3 Hz), 123.7, 120.9, 99.5 (d, *J* = 2.2 Hz), 96.1 (d, *J* = 9.2 Hz), 61.9, 14.3, 14.2. **HRMS** (ESI) m/z: $[M + H]^+$ Calcd for $C_{15}H_{14}FN_2O_2$ 273.1034, Found: 273.1029.

ethyl 5-fluoro-2-phenylpyrazolo[5,1-a]isoquinoline-6-carboxylate (**5n**)



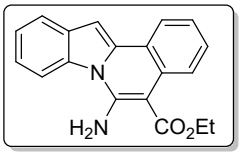
This compound was prepared according to the general procedure at 50 °C using **4n** (0.2 mmol, 44.1 mg), **2** (0.44 mmol, 80.1 mg), $[Cp^*RhCl_2]_2$ (2.5 mol%, 3.1 mg), CsOAc (0.6 mmol, 115.2 mg), HFIP (2.0 mL) and purified by column chromatography on silica gel (R_f = 0.7, eluent: petroleum ether: ethyl acetate = 5:1) to give the product **5n** as a white solid (**Yield**: 75%, 50.2 mg). **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.37 – 8.30 (m, 1H), 8.11 – 8.05 (m, 1H), 8.04 – 7.99 (m, 2H), 7.65 – 7.51 (m, 2H), 7.51 – 7.44 (m, 2H), 7.44 – 7.38 (m, 1H), 7.33 – 7.28 (m, 1H), 4.52 (q, *J* = 7.1 Hz, 2H), 1.47 (t, *J* = 7.1 Hz, 3H). **^{19}F NMR** (376 MHz, $CDCl_3$) δ -106.7. **^{13}C NMR** (100 MHz, $CDCl_3$) δ 163.9 (d, *J* = 3.5 Hz), 156.1, 149.5 (d, *J* = 274.5 Hz), 142.3, 132.1, 129.34, 129.31, 129.0, 127.3 (d, *J* = 2.0 Hz), 127.2, 126.8, 125.9 (d, *J* = 6.4 Hz), 123.9, 121.3, 97.1 (d, *J* = 9.1 Hz), 96.8 (d, *J* = 2.3 Hz), 62.0, 14.4. **HRMS** (ESI) m/z: $[M + H]^+$ Calcd for $C_{20}H_{16}FN_2O_2$ 335.1190, Found: 335.1184.

ethyl 5-fluoro-2-phenyl-[1,2,4]triazolo[5,1-a]isoquinoline-6-carboxylate (**5o**)



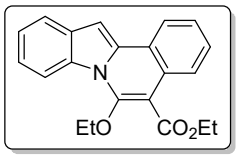
This compound was prepared according to the general procedure at 50 °C using **4o** (0.2 mmol, 44.3 mg), **2** (0.44 mmol, 80.1 mg), $[Cp^*RhCl_2]_2$ (2.5 mol%, 3.1 mg), CsOAc (0.6 mmol, 115.2 mg), HFIP (2.0 mL) and purified by column chromatography on silica gel (R_f = 0.8, eluent: petroleum ether: ethyl acetate = 5:1) to give the product **5o** as a white solid (**Yield**: 32%, 21.4 mg). **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.76 – 8.70 (m, 1H), 8.48 – 8.41 (m, 1H), 8.42 – 8.35 (m, 2H), 7.84 – 7.76 (m, 1H), 7.76 – 7.68 (m, 1H), 7.58 – 7.46 (m, 3H), 4.57 (q, *J* = 7.1 Hz, 2H), 1.49 (t, *J* = 7.1 Hz, 3H). **^{19}F NMR** (376 MHz, $CDCl_3$) δ -105.4. **^{13}C NMR** (150 MHz, $CDCl_3$) δ 165.5, 163.2 (d, *J* = 3.6 Hz), 152.5 (d, *J* = 3.8 Hz), 148.1 (d, *J* = 279.0 Hz), 131.6, 130.8, 130.1, 129.7 (d, *J* = 2.7 Hz), 128.9, 128.0 (d, *J* = 2.2 Hz), 127.8, 125.9 (d, *J* = 6.4 Hz), 125.0, 119.4, 99.5 (d, *J* = 9.1 Hz), 62.5, 14.4. **HRMS** (ESI) m/z: $[M + H]^+$ Calcd for $C_{19}H_{15}FN_3O_2$ 336.1143, Found: 336.1137.

ethyl 6-aminoindolo[2,1-a]isoquinoline-5-carboxylate (**6**)



R_f = 0.3 (petroleum ether: DCM = 3:1); Colorless oil. (**Yield**: 69%, 21.0 mg). **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.45 – 8.38 (m, 1H), 8.19 – 8.13 (m, 1H), 8.07 – 8.00 (m, 1H), 7.83 – 7.77 (m, 1H), 7.58 (s, 2H), 7.45 – 7.36 (m, 2H), 7.34 – 7.27 (m, 2H), 7.20 (s, 1H), 4.47 (q, *J* = 7.1 Hz, 2H), 1.48 (t, *J* = 7.1 Hz, 3H). **^{13}C NMR** (100 MHz, $CDCl_3$) δ 170.2, 151.4, 136.6, 132.5, 131.6, 128.5, 128.1, 125.8, 124.0, 123.61, 123.55, 121.8, 121.3, 121.2, 114.3, 96.6, 87.1, 60.7, 14.7. **HRMS** (ESI) m/z: $[M + H]^+$ Calcd for $C_{19}H_{17}N_2O_2$, 305.1284 Found: 305.1274.

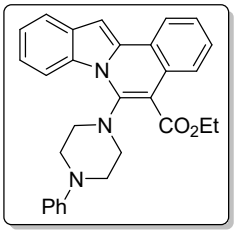
ethyl 6-ethoxyindolo[2,1-a]isoquinoline-5-carboxylate (**7**)



R_f = 0.5 (petroleum ether: ethyl acetate = 10:1); Colorless oil. (**Yield**: 78%, 26.0 mg). **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.31 – 8.25 (m, 1H), 8.17 – 8.10 (m, 1H), 7.86 – 7.76 (m, 2H), 7.48 –

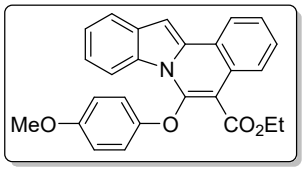
7.41 (m, 2H), 7.40 – 7.30 (m, 2H), 7.27 – 7.25 (m, 1H), 4.52 (q, *J* = 7.1 Hz, 2H), 4.41 (q, *J* = 7.0 Hz, 2H), 1.60 (t, *J* = 7.1 Hz, 3H), 1.48 (t, *J* = 7.1 Hz, 3H). **^{13}C NMR** (100 MHz, $CDCl_3$) δ 166.8, 150.9, 136.1, 131.7, 130.0, 128.1, 127.8, 126.5, 124.4, 123.6, 123.3, 123.1, 121.9, 120.5, 115.5, 101.5, 96.0, 72.2, 61.6, 15.3, 14.5. **HRMS** (ESI) m/z: $[M + H]^+$ Calcd for $C_{21}H_{20}NO_3$, 334.1438 Found: 334.1428.

ethyl 6-(4-phenylpiperazin-1-yl)indolo[2,1-a]isoquinoline-5-carboxylate (**8**)



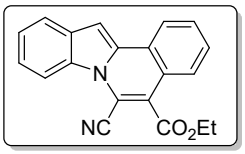
R_f = 0.5 (petroleum ether: ethyl acetate = 10:1); White solid. (**Yield**: 72%, 32.5 mg). **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.97 – 8.91 (m, 1H), 8.19 – 8.12 (m, 1H), 7.84 – 7.77 (m, 1H), 7.59 – 7.52 (m, 1H), 7.50 – 7.39 (m, 2H), 7.39 – 7.28 (m, 4H), 7.28 – 7.23 (m, 2H), 7.07 – 7.00 (m, 2H), 6.97 – 6.89 (m, 1H), 4.50 (q, *J* = 7.1 Hz, 2H), 3.68 (d, *J* = 12.5 Hz, 2H), 3.59 – 3.37 (m, 6H), 1.44 (t, *J* = 7.1 Hz, 3H). **^{13}C NMR** (100 MHz, $CDCl_3$) δ 168.3, 151.3, 144.4, 136.6, 133.0, 130.2, 129.5, 129.4, 128.0, 127.5, 127.1, 124.4, 123.5, 123.3, 122.6, 120.9, 120.5, 120.3, 116.4, 109.3, 95.8, 62.0, 49.7, 49.0, 14.4. **HRMS** (ESI) m/z: $[M + H]^+$ Calcd for $C_{29}H_{28}N_3O_2$, 450.2176 Found: 450.2166.

ethyl 6-(4-methoxyphenoxy)indolo[2,1-a]isoquinoline-5-carboxylate (**9**)



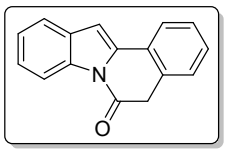
R_f = 0.4 (petroleum ether: ethyl acetate = 10:1); White solid. (**Yield**: 90%, 37.1 mg). **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.22 – 8.13 (m, 1H), 8.12 – 8.06 (m, 1H), 7.94 – 7.85 (m, 1H), 7.80 – 7.74 (m, 1H), 7.51 – 7.42 (m, 2H), 7.36 – 7.28 (m, 2H), 7.25 – 7.15 (m, 1H), 7.02 – 6.93 (m, 2H), 6.85 – 6.77 (m, 2H), 4.13 (q, *J* = 7.2 Hz, 2H), 3.72 (s, 3H), 1.15 (t, *J* = 7.2 Hz, 3H). **^{13}C NMR** (100 MHz, $CDCl_3$) δ 165.6, 155.8, 150.4, 147.3, 135.8, 131.4, 130.0, 128.2, 127.3, 127.0, 124.8, 123.59, 123.56, 123.3, 122.2, 120.4, 116.6, 115.8, 115.1, 102.2, 96.6, 61.4, 55.7, 14.1. **HRMS** (ESI) m/z: $[M + H]^+$ Calcd for $C_{26}H_{22}NO_4$, 412.1543 Found: 412.1527.

ethyl 6-cyanoindolo[2,1-a]isoquinoline-5-carboxylate (**10**)



R_f = 0.5 (petroleum ether: ethyl acetate = 10:1); Yellow oil. (**Yield**: 82%, 25.7 mg). **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.73 – 8.66 (m, 1H), 8.13 – 8.06 (m, 1H), 7.87 – 7.77 (m, 2H), 7.63 – 7.55 (m, 1H), 7.52 – 7.46 (m, 1H), 7.44 – 7.35 (m, 2H), 7.29 – 7.23 (m, 1H), 4.61 (q, *J* = 7.2 Hz, 2H), 1.54 (t, *J* = 7.1 Hz, 3H). **^{13}C NMR** (100 MHz, $CDCl_3$) δ 164.8, 133.9, 132.4, 130.9, 129.8, 128.4, 127.1, 126.3, 125.3, 123.9, 123.8, 123.7, 122.8, 121.1, 113.8, 110.2, 96.7, 63.1, 14.1. **HRMS** (ESI) m/z: $[M + H]^+$ Calcd for $C_{20}H_{15}N_2O_2$, 315.1128 Found: 315.1121.

indolo[2,1-a]isoquinolin-6(5H)-one (**11**)



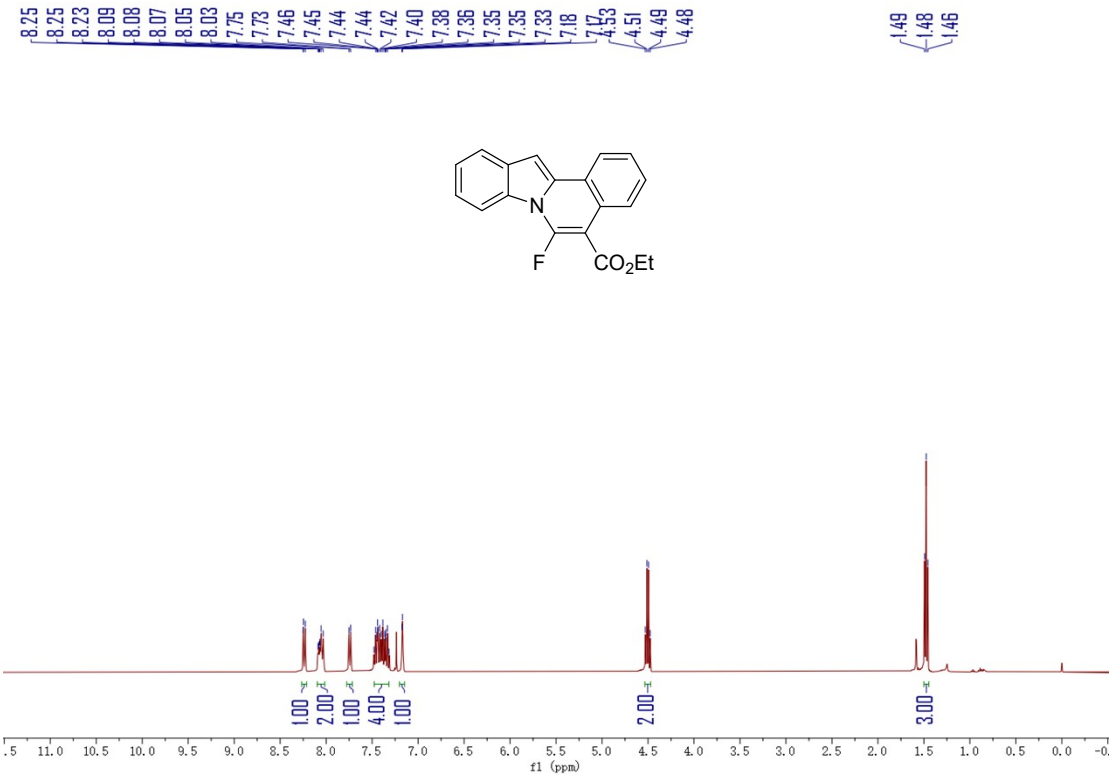
R_f = 0.5 (petroleum ether: ethyl acetate = 3:1); Colorless oil. (**Yield**: 59%, 13.8 mg). **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.58 – 8.51 (m, 1H), 7.87 – 7.81 (m, 1H), 7.62 – 7.56 (m, 1H), 7.41 – 7.28 (m, 4H), 7.27 – 7.24 (m, 1H), 7.04 (s, 1H), 4.11 (s, 2H). **^{13}C NMR** (100 MHz, $CDCl_3$) δ 167.0, 136.7, 135.3, 130.6, 129.7, 128.6, 128.1, 127.7, 125.4, 125.3, 124.7, 124.0, 120.6, 116.7, 103.5, 37.8. **HRMS** (ESI) m/z: $[M + H]^+$ Calcd for $C_{16}H_{12}NO$, 234.0913 Found: 234.0912.

7. References

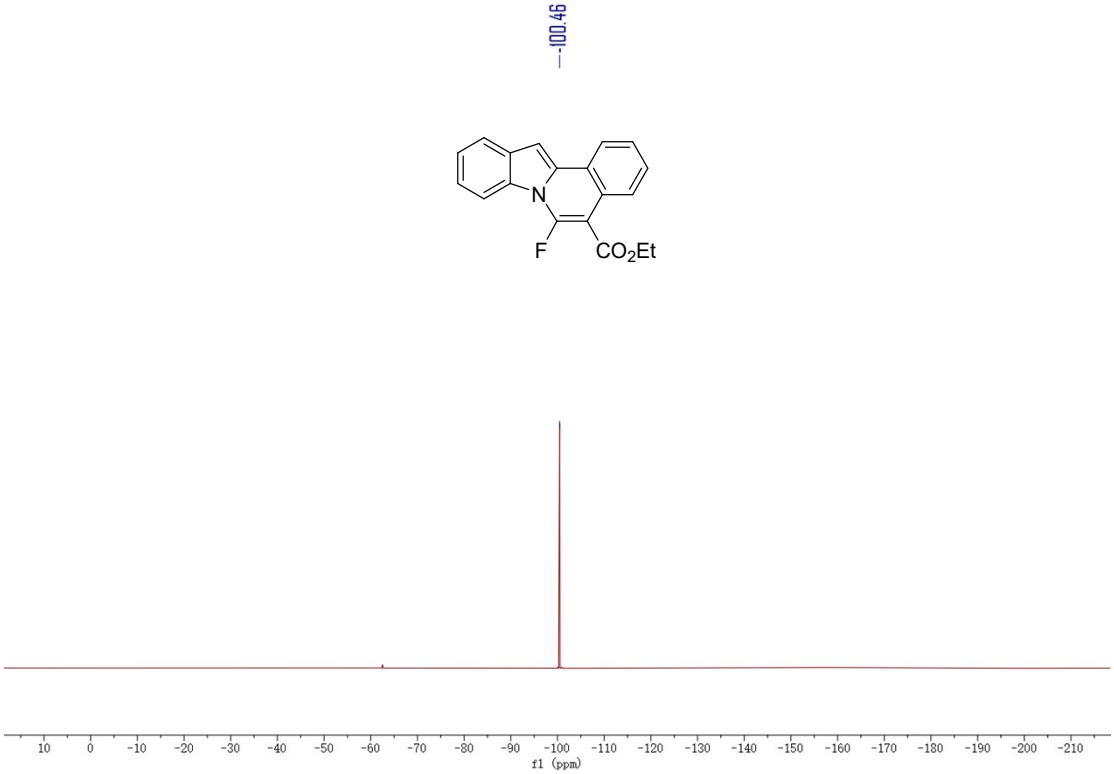
1. Bhunia, S. K.; Polley, A.; Natarajan, R.; Jana, R. Through-Space 1,4-Palladium Migration and 1,2-Aryl Shift: Direct Access to Dibenzo[a,c]carbazoles through a Triple C-H Functionalization Cascade. *Chem. Eur. J.* **2015**, *21*, 16786 – 16791.
2. Huang, J.-R.; Qin, L.; Zhu, Y.-Q.; Song Q.; Dong L. Multi-site cyclization via initial C–H activation using a rhodium(iii) catalyst: rapid assembly of frameworks containing indoles and indolines. *Chem. Commun.*, **2015**, *51*, 2844 – 2847.
3. Yang, S.-D.; Sun, C.-L.; Fang, Z.; Li, B.-J.; Li, Y.-Z.; Shi. Z.-J. Palladium-Catalyzed Direct Arylation of (Hetero)Arenes with Aryl Boronic Acids. *Angew. Chem. Int. Ed.* **2008**, *47*, 1473 – 1476.
4. Secci, D.; Bolasco, A.; D'Ascenzio, M.; Sala, F.; Yáñez, M.; Carradori. S. Conventional and Microwave-Assisted Synthesis of Benzimidazole Derivatives and Their In Vitro Inhibition of Human Cyclooxygenase. *J. Heterocyclic Chem.* **2012**, *49*, 1187 – 1195.
5. Kumar, C. K.; Sathiyashivan, S. D.; Masram, D. T.; Jose K. V. J.; Sathiyendiran. M. Experimental and theoretical investigation of intramolecular cooperativity in cyclic benzene trimer motif. *RSC Adv.*, **2019**, *9*, 753 – 760.
6. Chari, M. A.; Sadanandam, P.; Shobha, D.; Mukkanti. K. A Simple, Mild, and Efficient Procedure for High-Yield Synthesis of Benzimidazoles Using Coppertriflate as Catalyst. *J. Heterocyclic Chem.*, **2010**, *47*, 153 – 155.
7. Halskov, K. S.; Roth, H. S.; Ellman. J. A. Synthesis of [5,6]-Bicyclic Heterocycles with a Ring-Junction Nitrogen Atom: Rhodium(III)-Catalyzed C−H Functionalization of Alkenyl Azoles. *Angew. Chem. Int. Ed.* **2017**, *56*, 9183 – 9187.
8. Wiles, C.; Watts, P.; Haswell, S. J. The Application of Microreactor Technology for the Synthesis of 1,2-Azoles. *Org. Process Res. Dev.* **2004**, *8*, 28 – 32.

9. Xu, H.; Jiang, Y.; Fu. H. Copper-Catalyzed Synthesis of 1,2,4-Triazoles via Sequential Coupling and Aerobic Oxidative Dehydrogenation of Amidines. *Synlett* **2013**, *24*, 125 –129.
10. Shi, G.; Xu, Y. Trifluoromethyl-substituted carbethoxy carbene as a novel CF_3-containing a^2 synthon equivalent for the preparation of 2-(trifluoromethyl)-4-oxo carboxylic ester derivatives: highly functionalized synthetic building blocks bearing a CF_3 group. *J. Org. Chem.* **1990**, *55*, 3383 –3386.
11. Kosobokov, M.; Cui, B.; Balia, A.; Matsuzaki, K.; Tokunaga, E.; Saito, N.; Shibata, N. Importance of a Fluorine Substituent for the Preparation of meta- and para-Pentafluoro-λ^6-sulfanyl-Substituted Pyridines. *Angew. Chem. Int. Ed.* **2016**, *55*, 10781 – 10785.
12. Yang, J.; Zhou, X.; Zeng, Y.; Huang, C.; Xiao, Y.; Zhang, J. Synthesis of 2-fluoro-2-pyrrolines via tandem reaction of α-trifluoromethyl-α,β-unsaturated carbonyl compounds with N-tosylated 2-aminomalonates. *Chem. Commun.,* **2016**, *52*, 4922 – 4925.

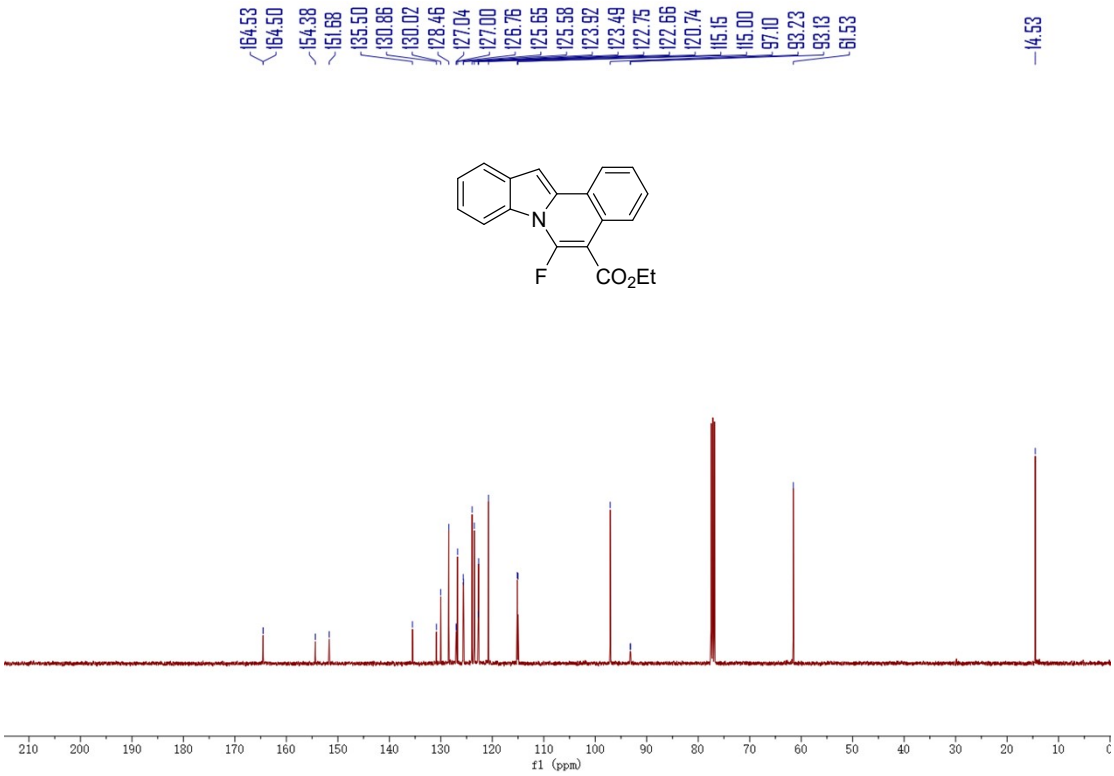
8. Copies of ^{1}H, ^{13}C NMR spectra of products



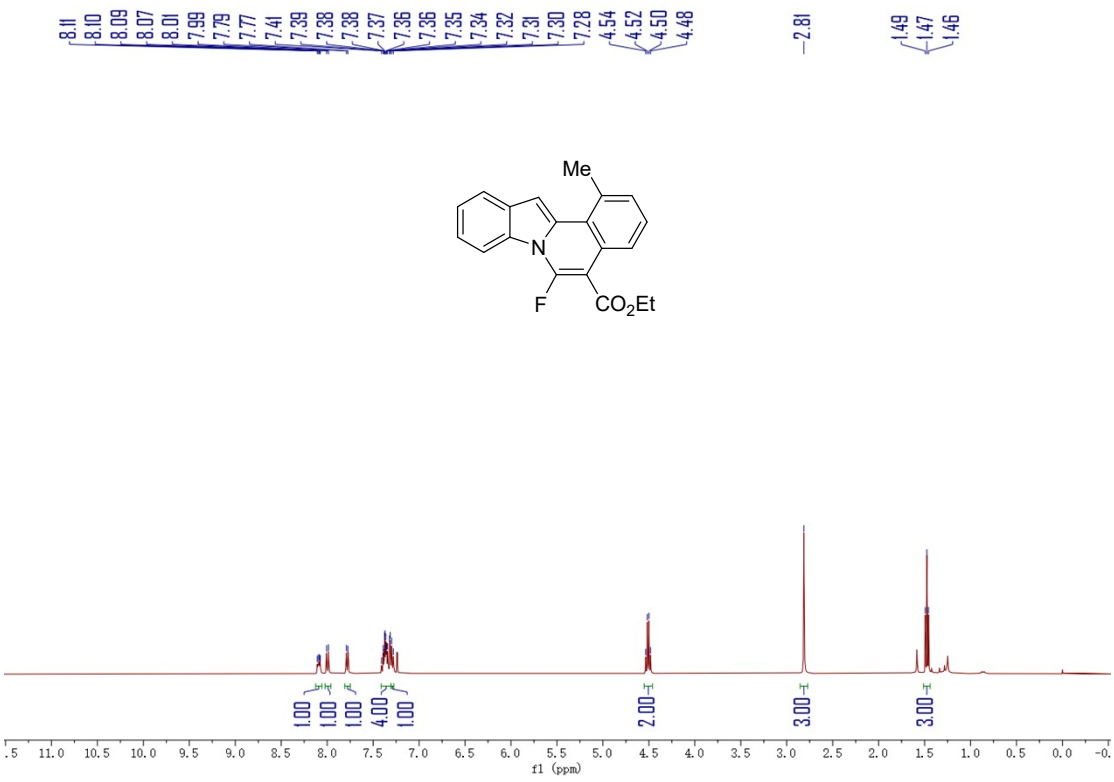
^{1}H NMR of **3a** (400 MHz, $CDCl_3$)



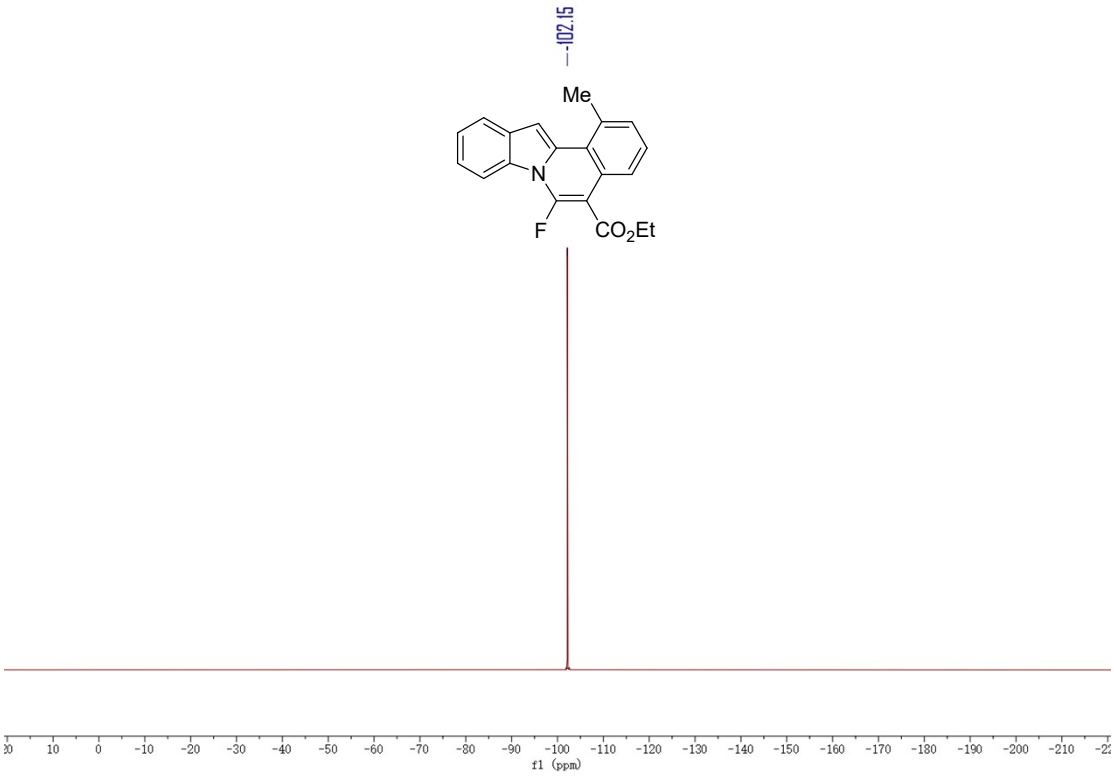
^{19}F NMR of **3a** (376 MHz, $CDCl_3$)



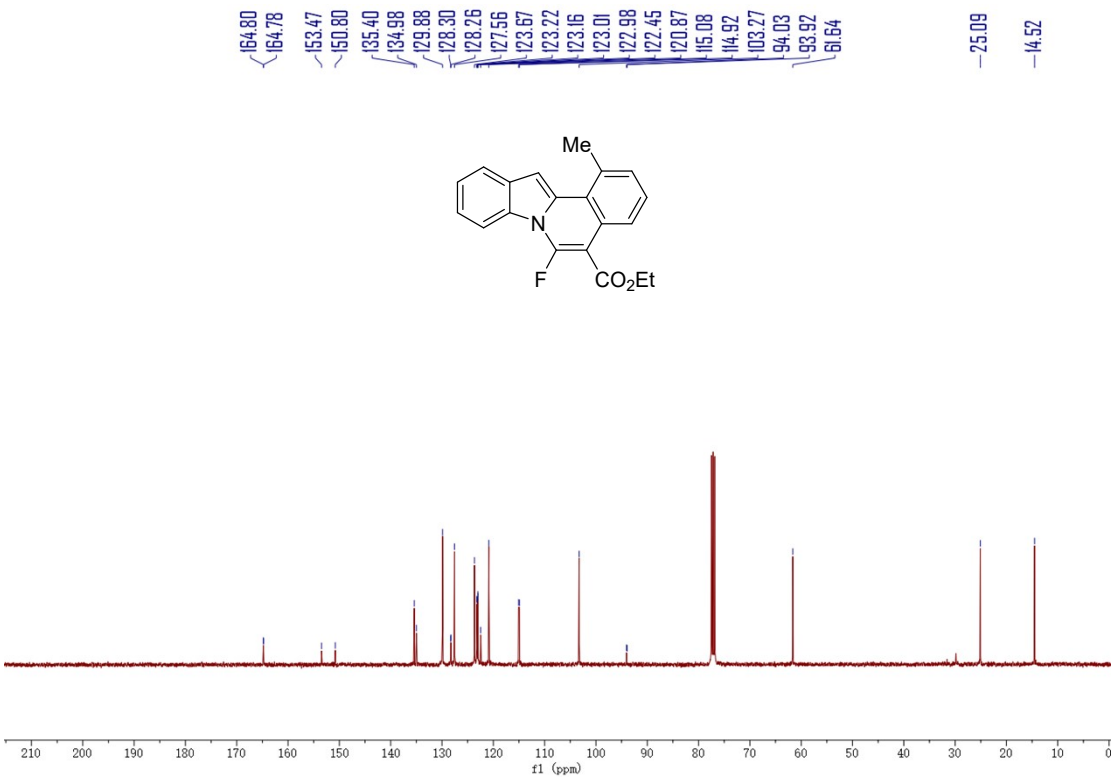
^{13}C NMR of **3a** (100 MHz, $CDCl_3$)



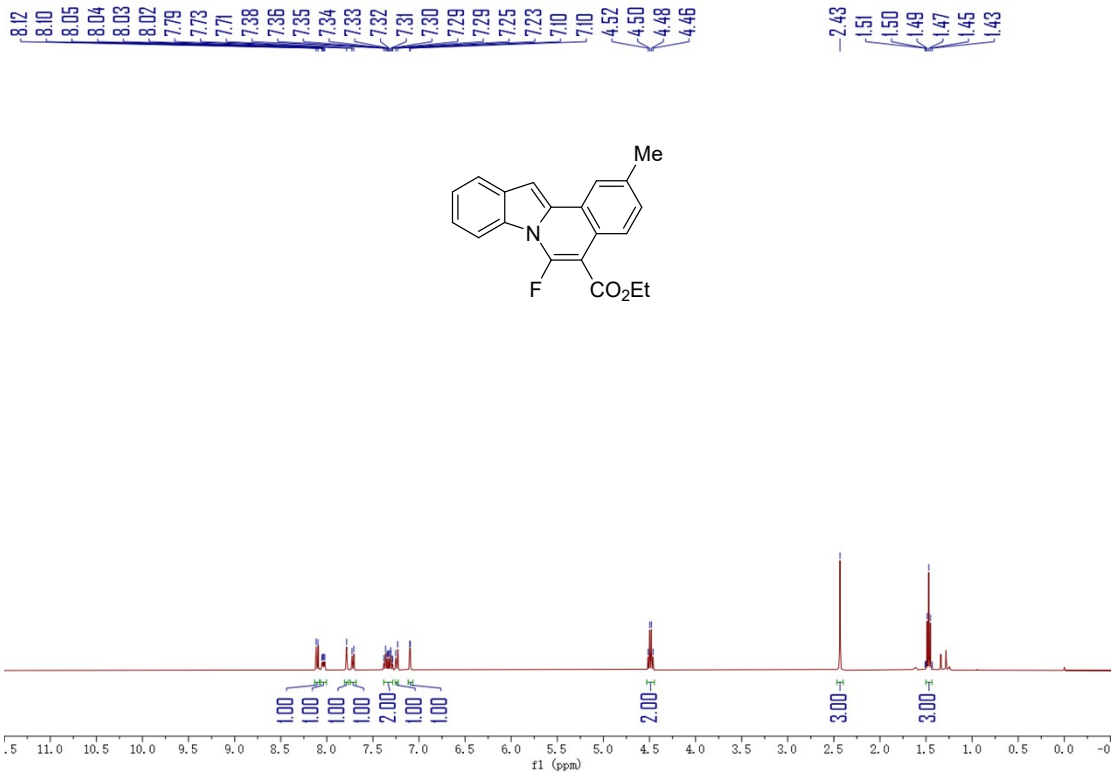
^{1}H NMR of **3b** (400 MHz, $CDCl_3$)



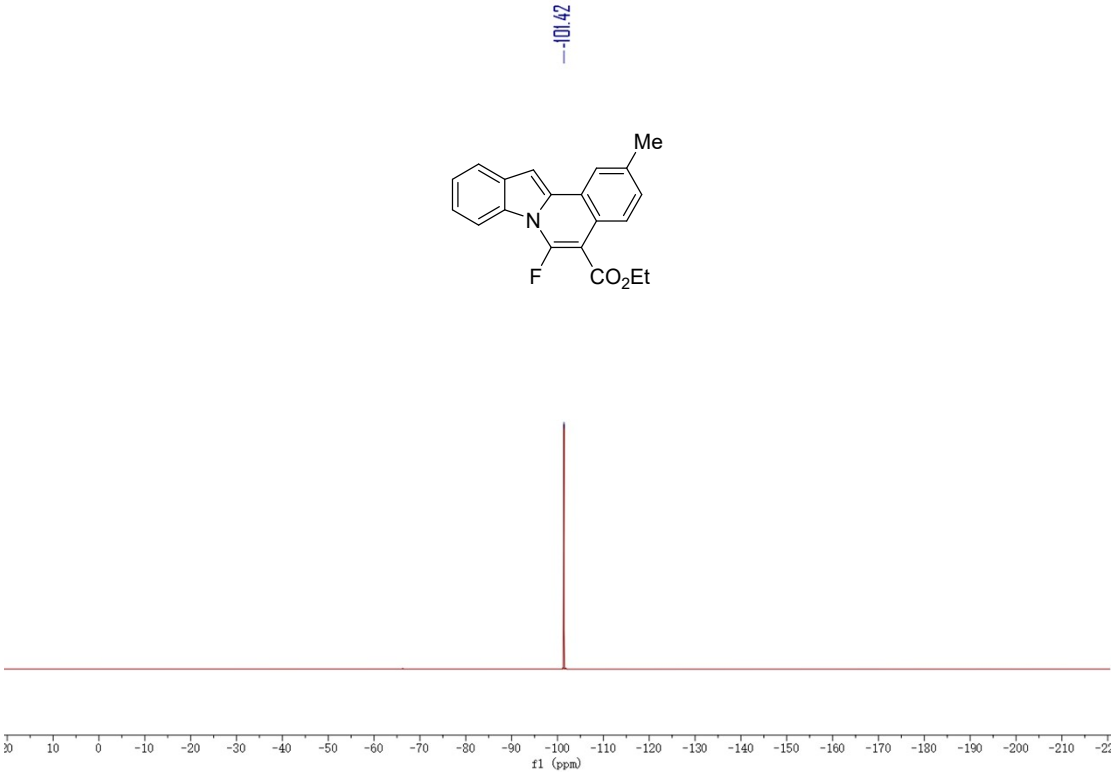
^{19}F NMR of **3b** (376 MHz, $CDCl_3$)



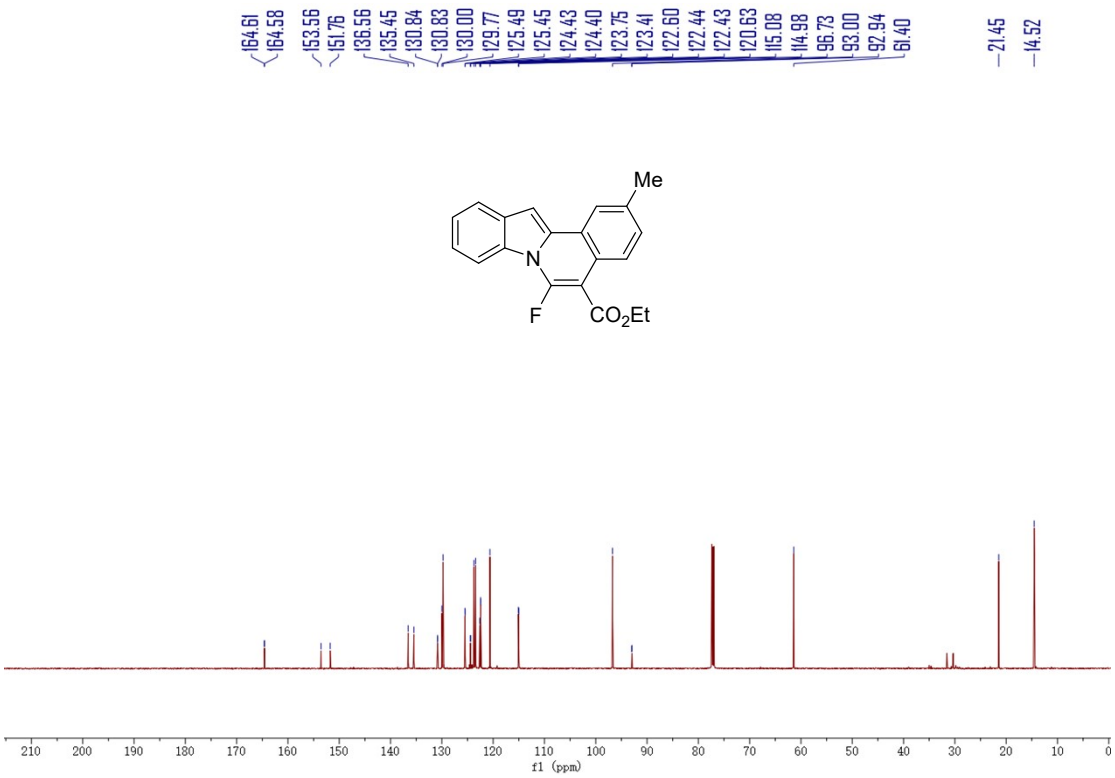
^{13}C NMR of **3b** (100 MHz, $CDCl_3$)



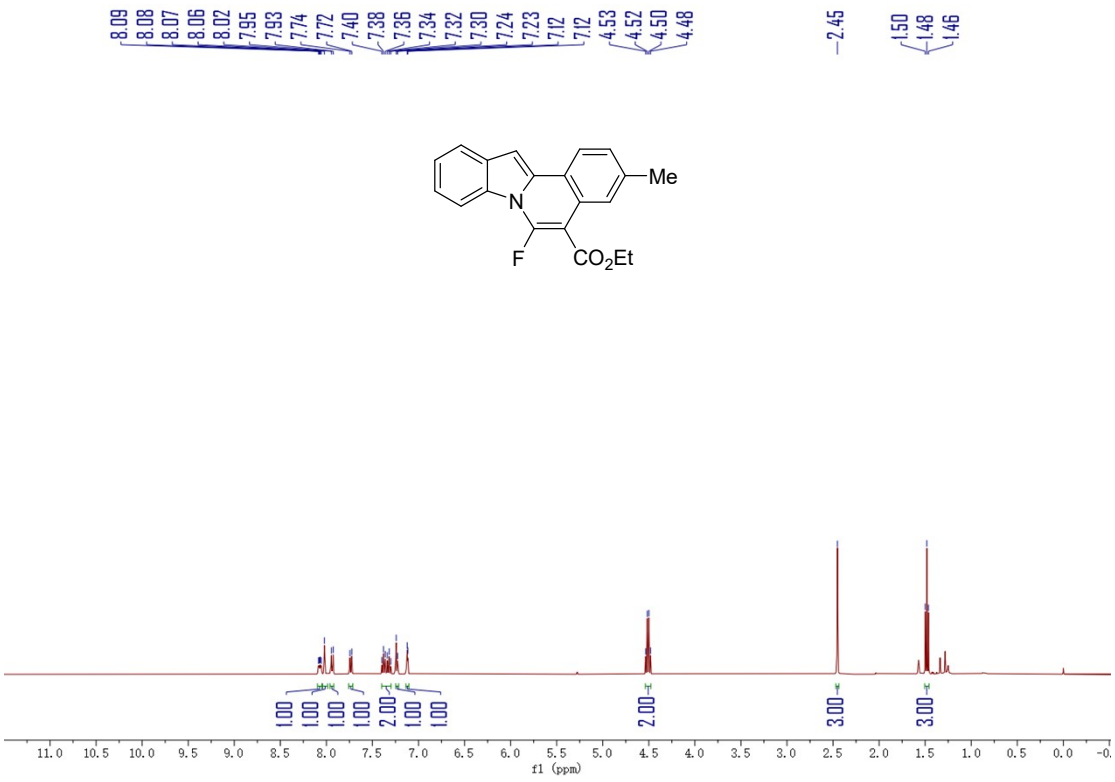
^{1}H NMR of **3c** (400 MHz, $CDCl_3$)



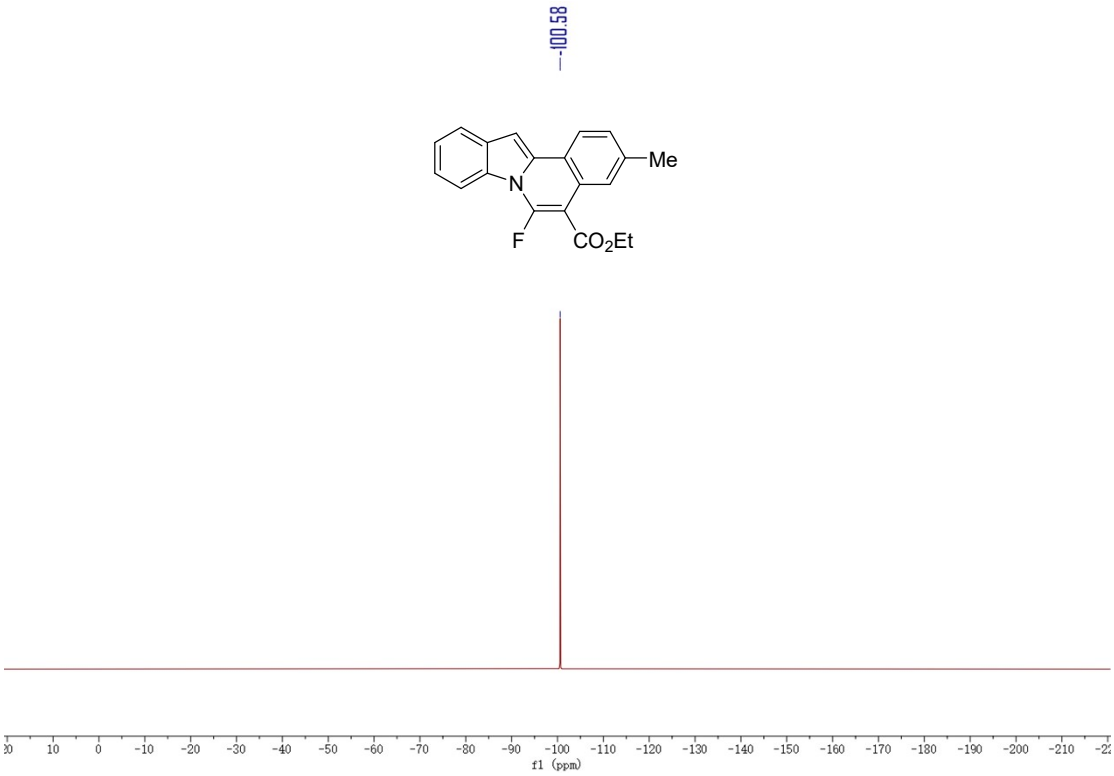
^{19}F NMR of **3c** (376 MHz, $CDCl_3$)



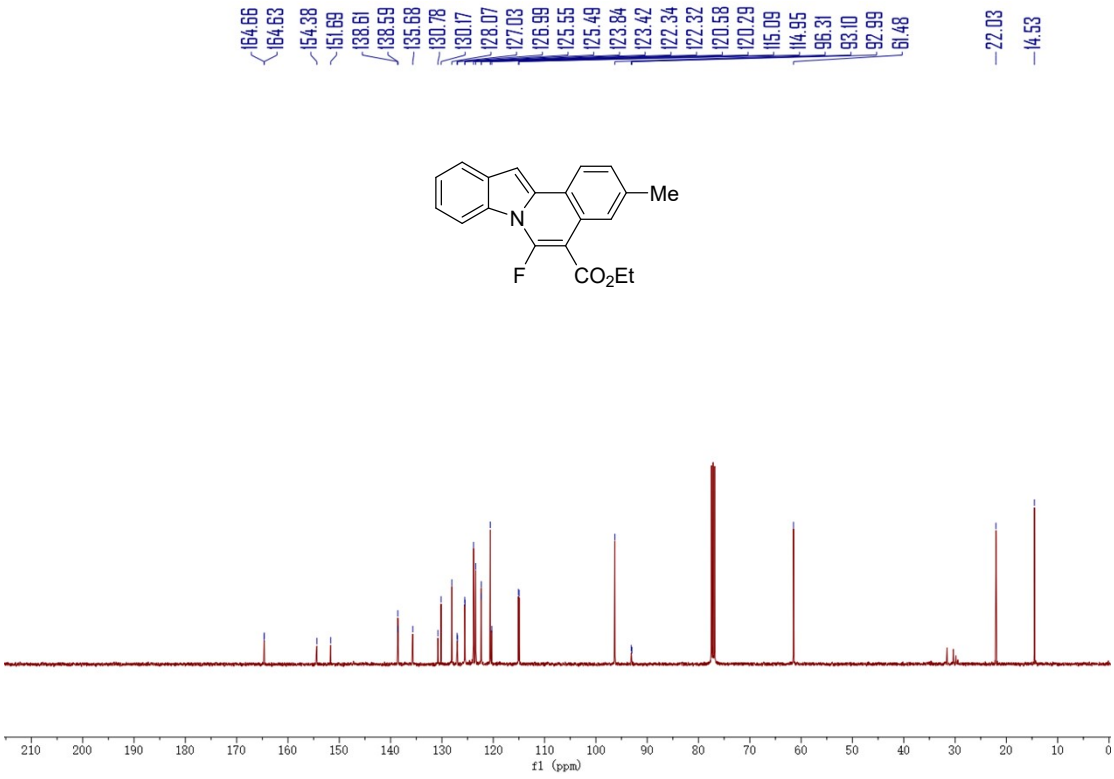
^{13}C NMR of **3c** (150 MHz, $CDCl_3$)



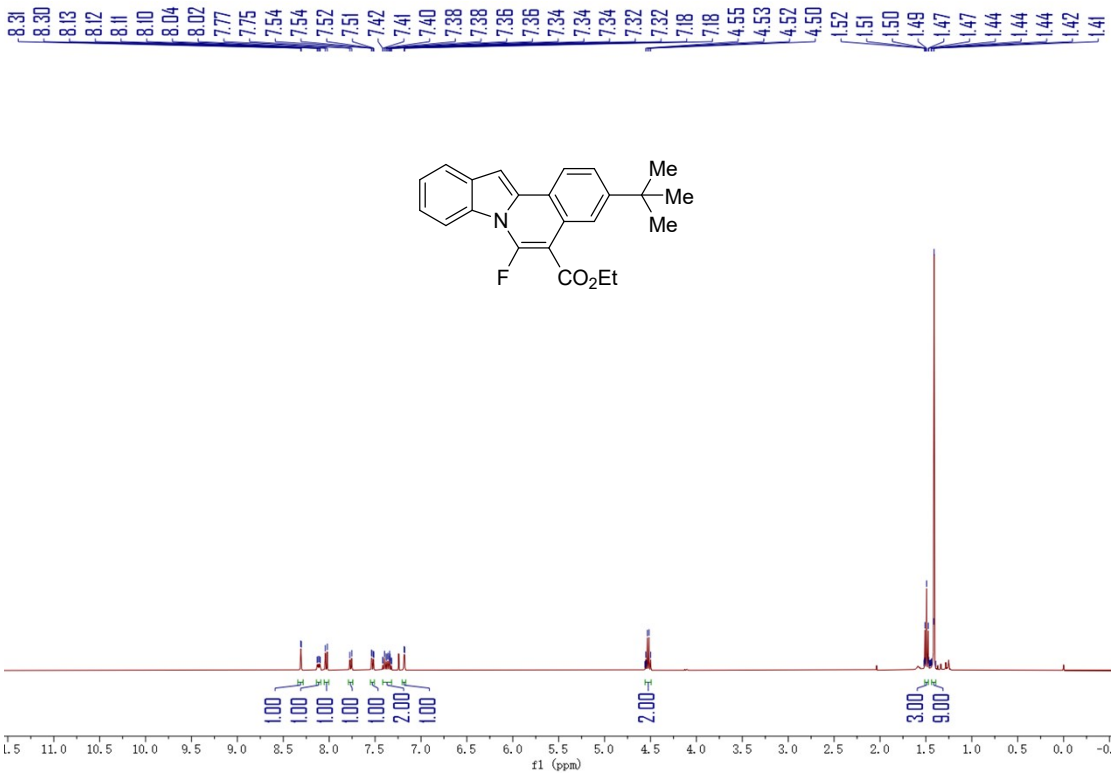
^{1}H NMR of **3d** (400 MHz, $CDCl_3$)



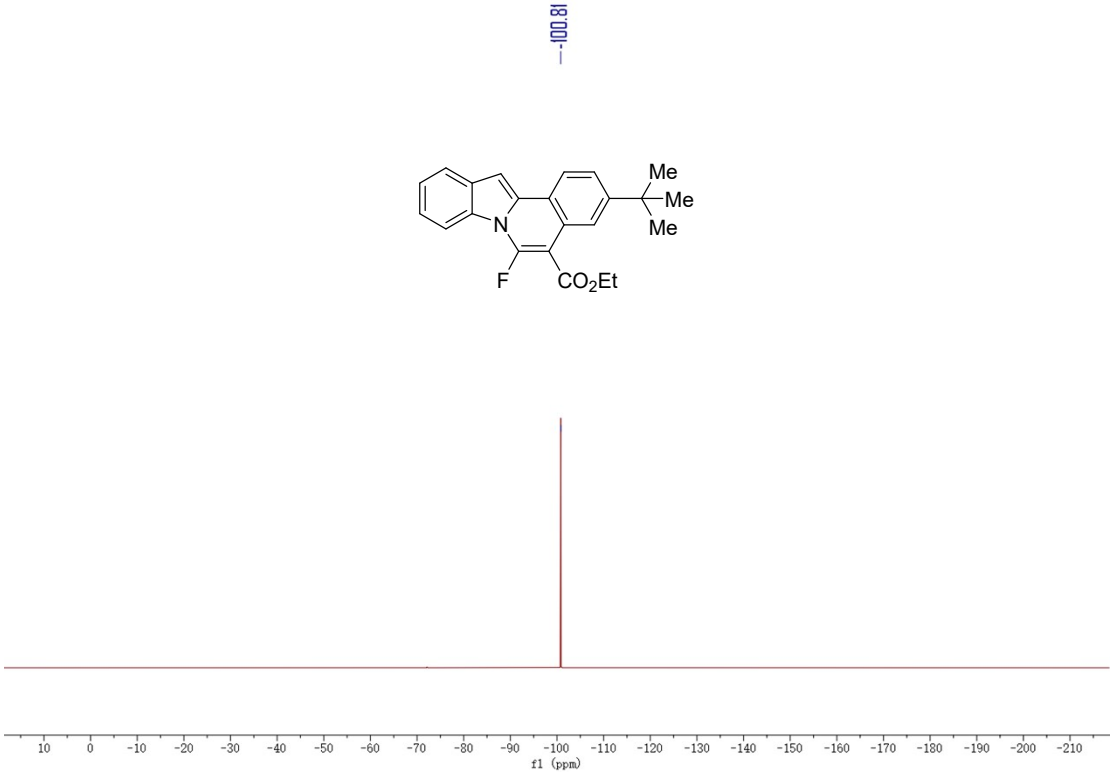
^{19}F NMR of **3d** (376 MHz, $CDCl_3$)



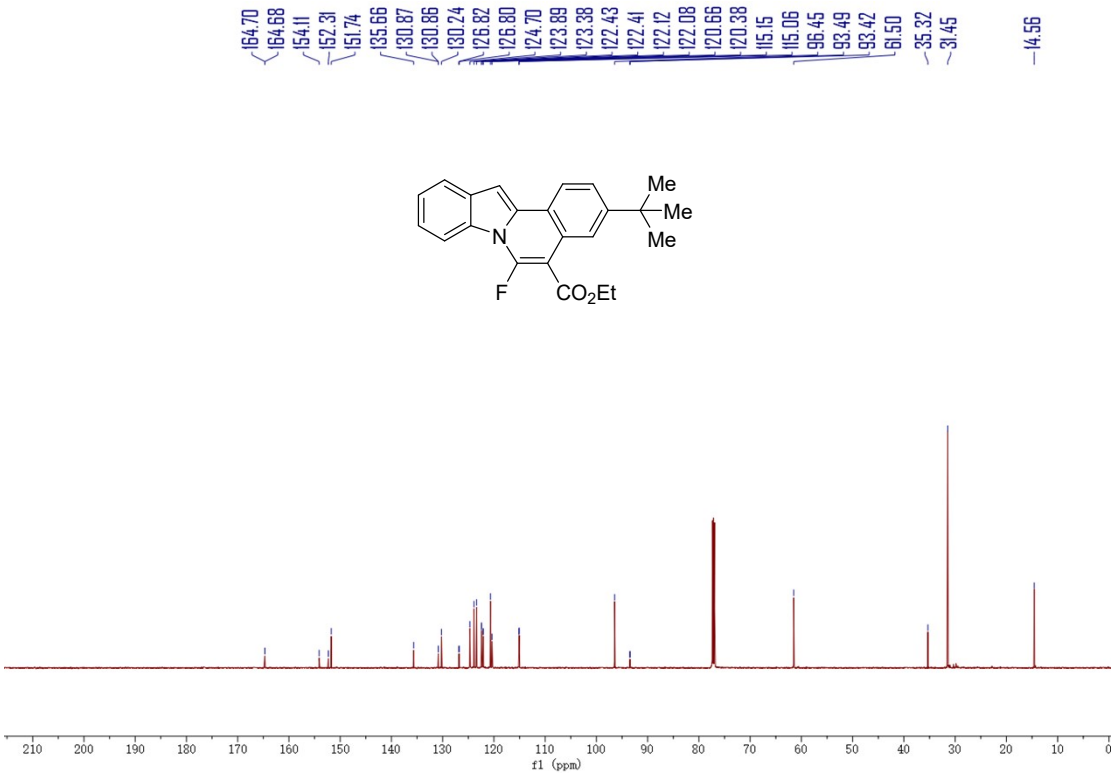
^{13}C NMR of **3d** (100 MHz, $CDCl_3$)



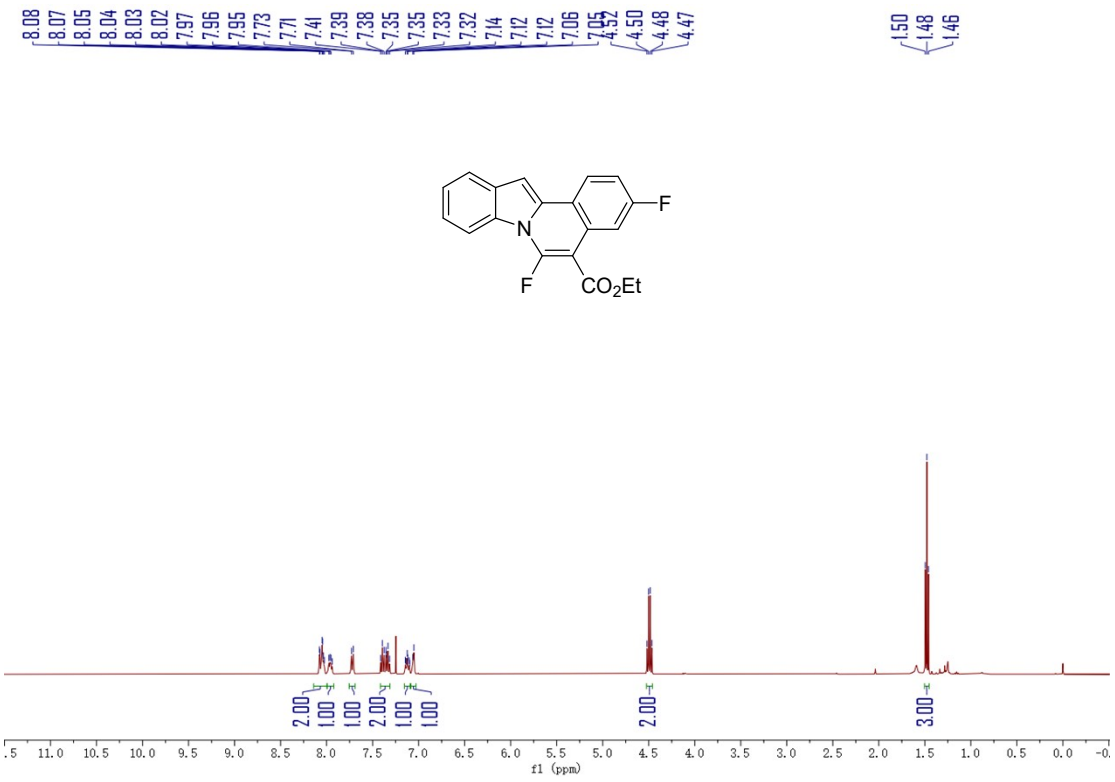
^{1}H NMR of **3e** (400 MHz, $CDCl_3$)



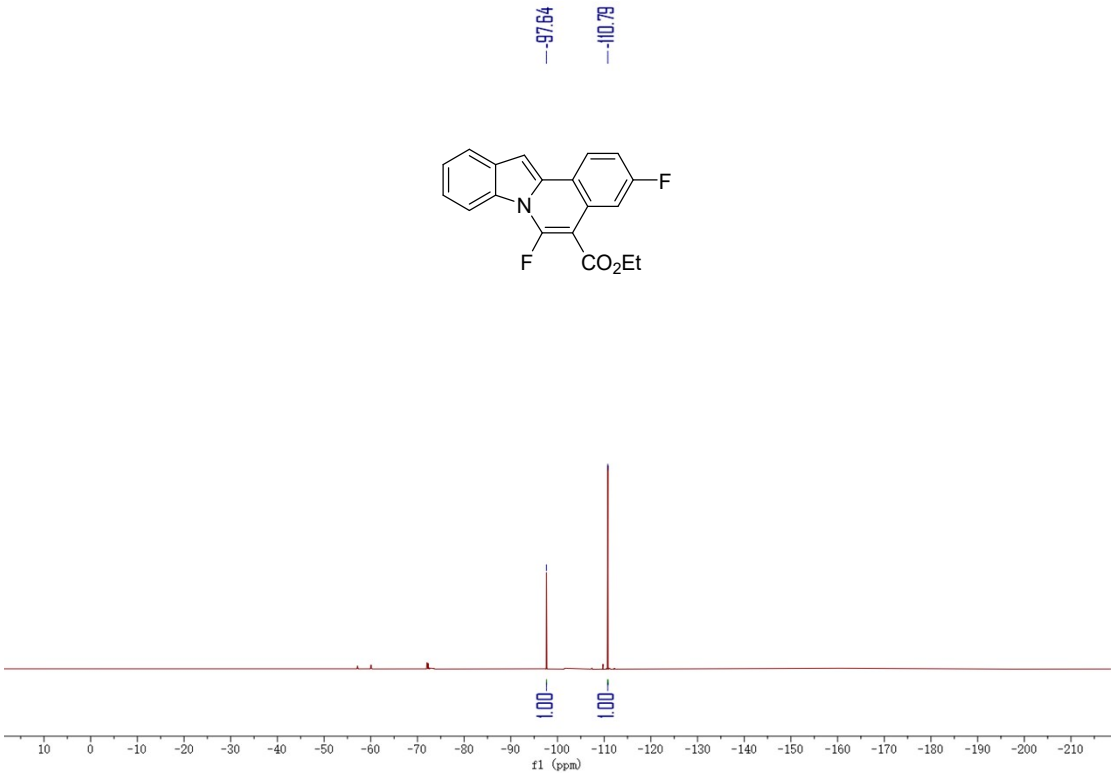
^{19}F NMR of **3e** (376 MHz, $CDCl_3$)



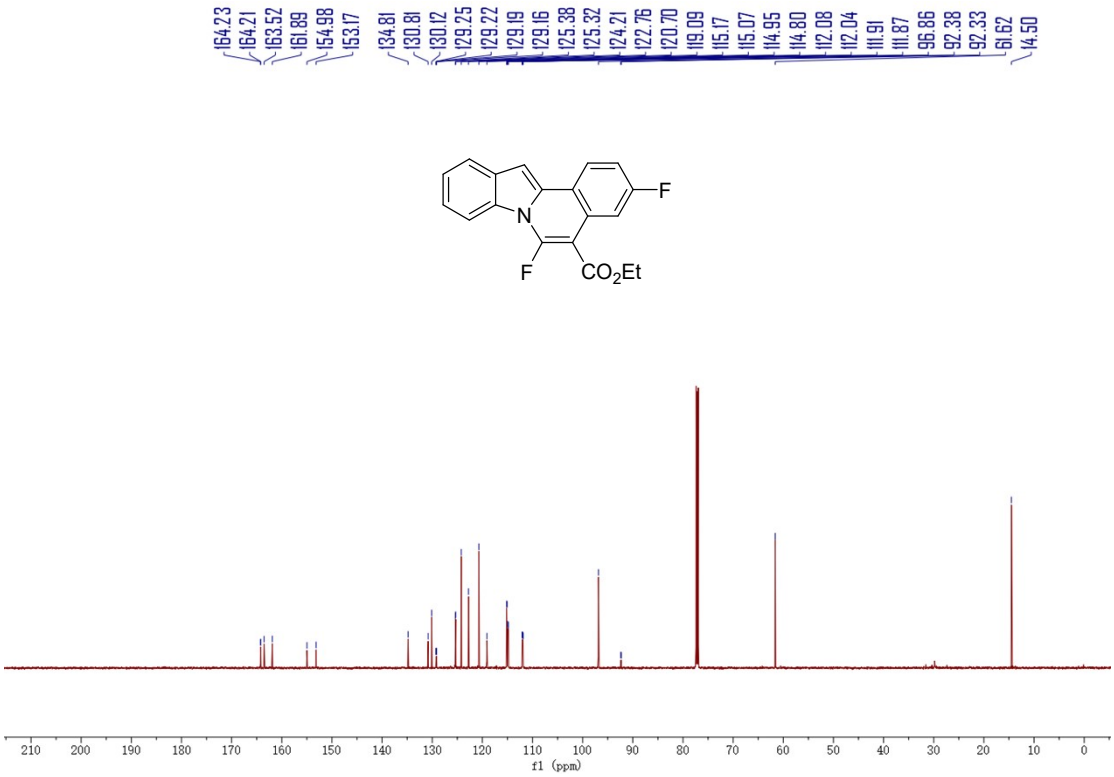
^{13}C NMR of **3e** (150 MHz, $CDCl_3$)



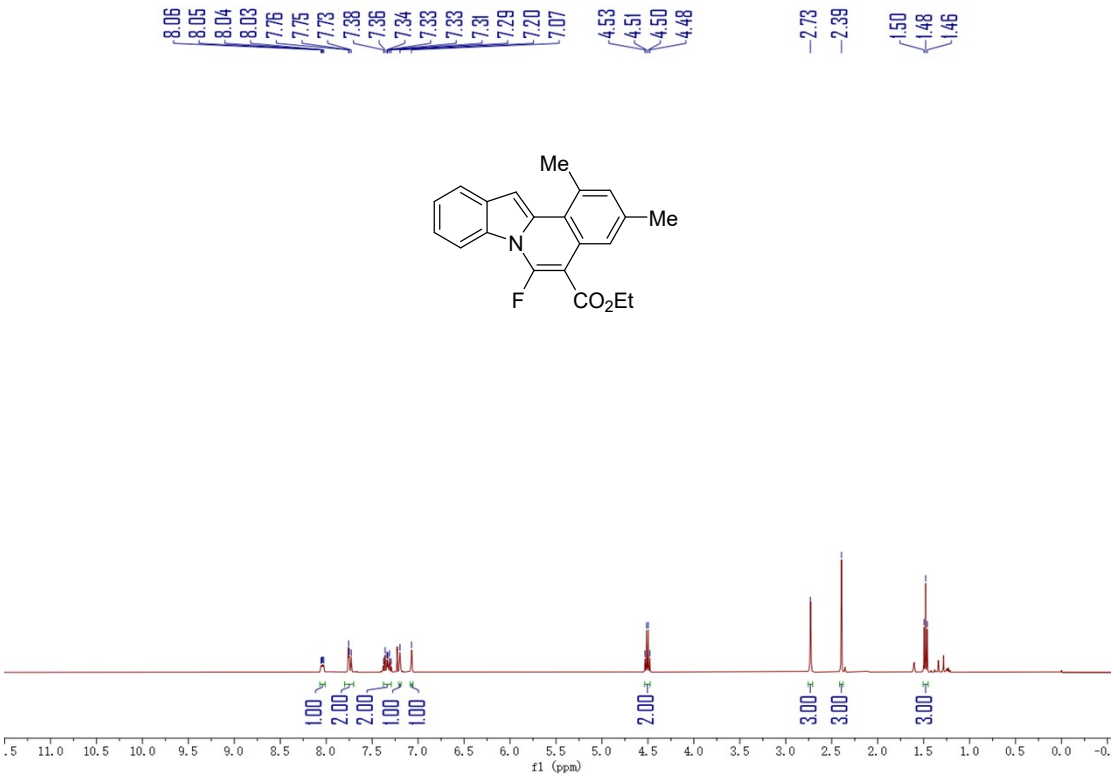
^{1}H NMR of **3f** (400 MHz, $CDCl_3$)



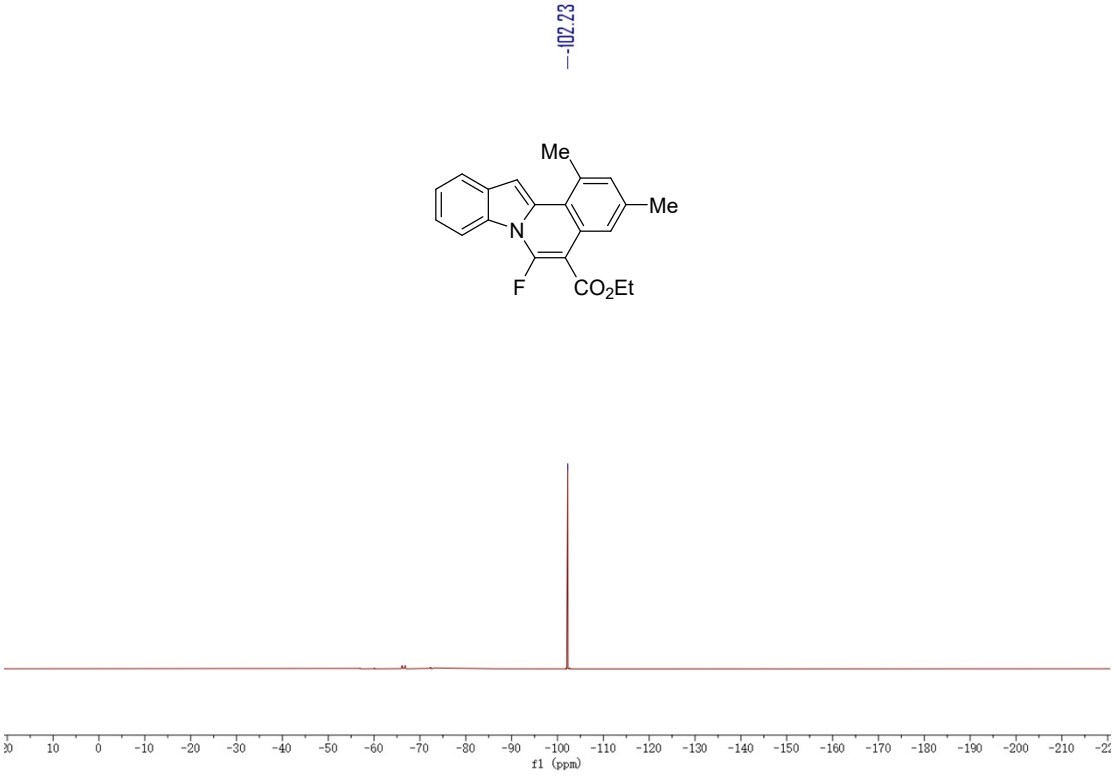
^{19}F NMR of **3f** (376 MHz, $CDCl_3$)



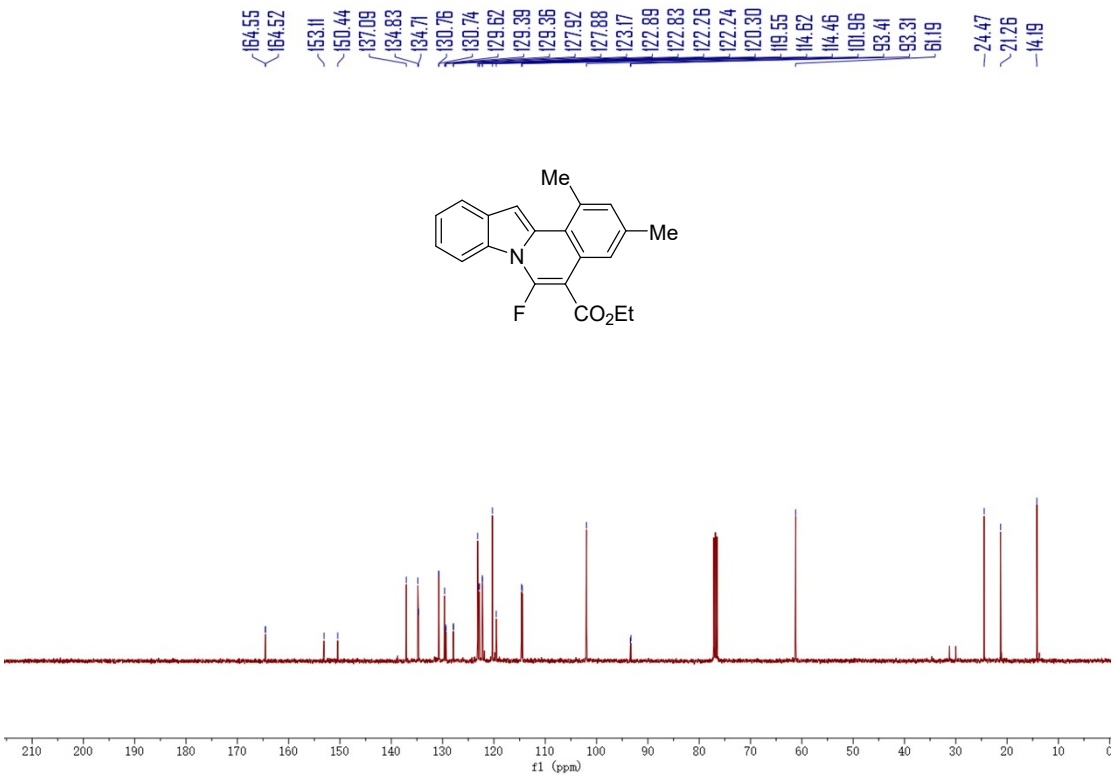
^{13}C NMR of **3f** (150 MHz, $CDCl_3$)



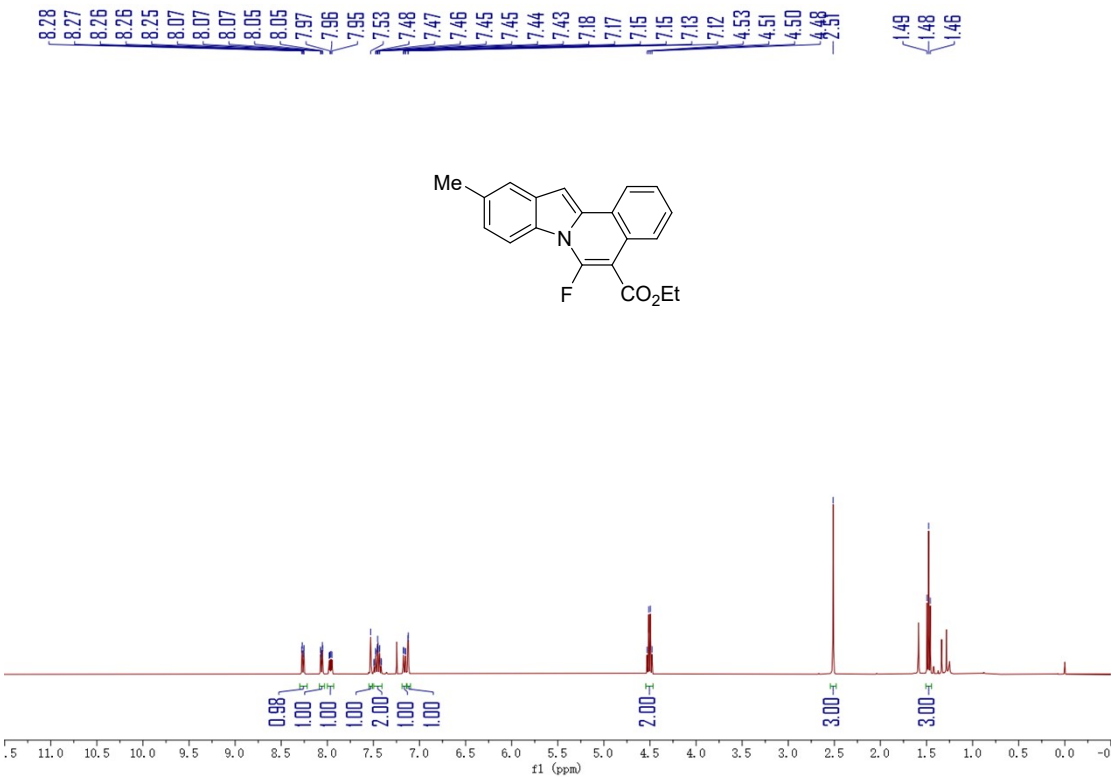
^{1}H NMR of **3g** (400 MHz, $CDCl_3$)



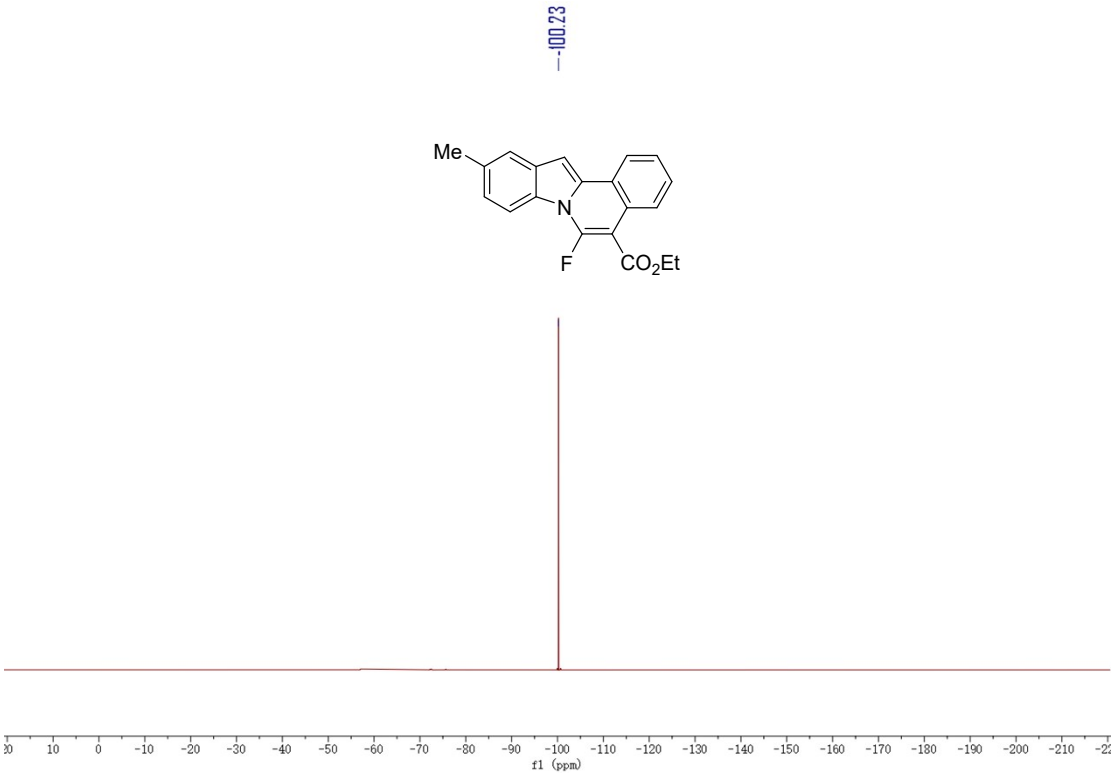
^{19}F NMR of **3g** (376 MHz, $CDCl_3$)



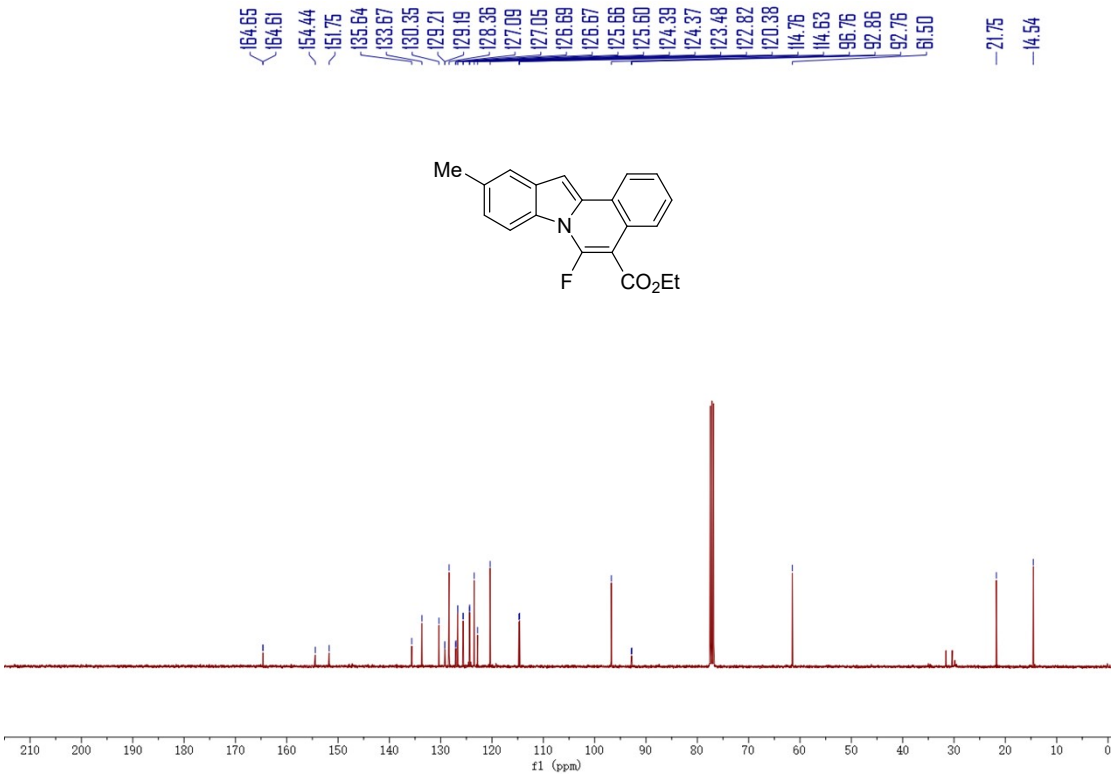
^{13}C NMR of **3g** (100 MHz, $CDCl_3$)



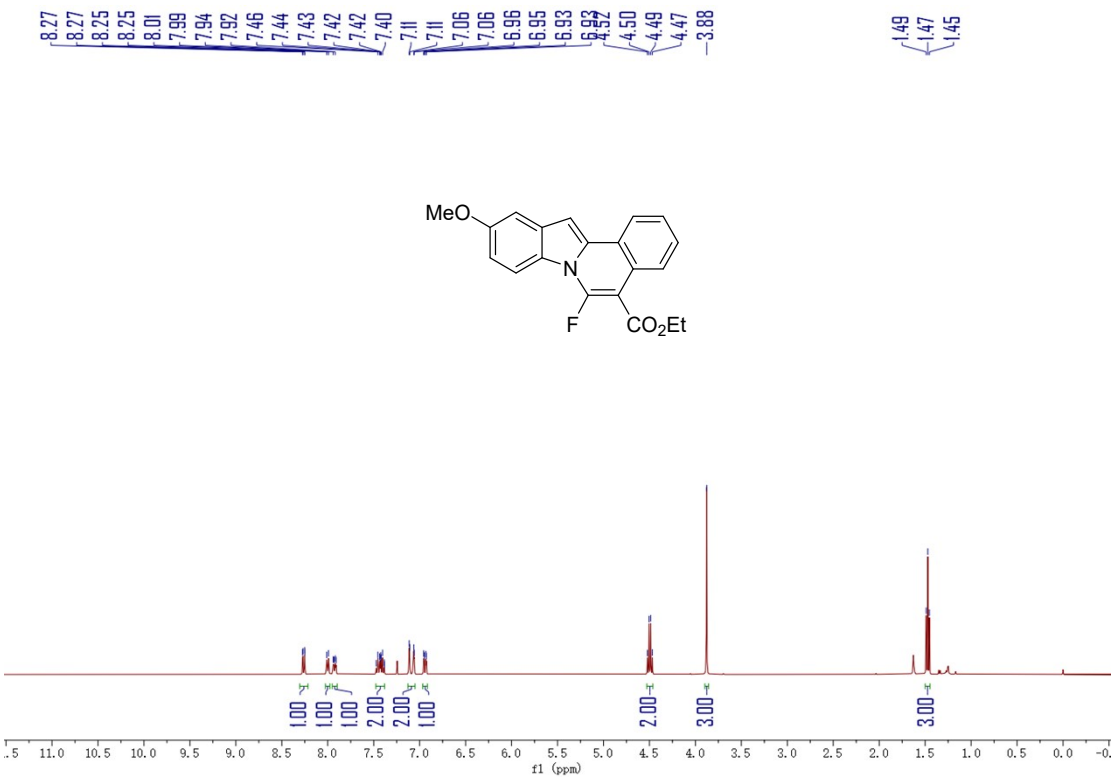
^{1}H NMR of **3h** (400 MHz, $CDCl_3$)



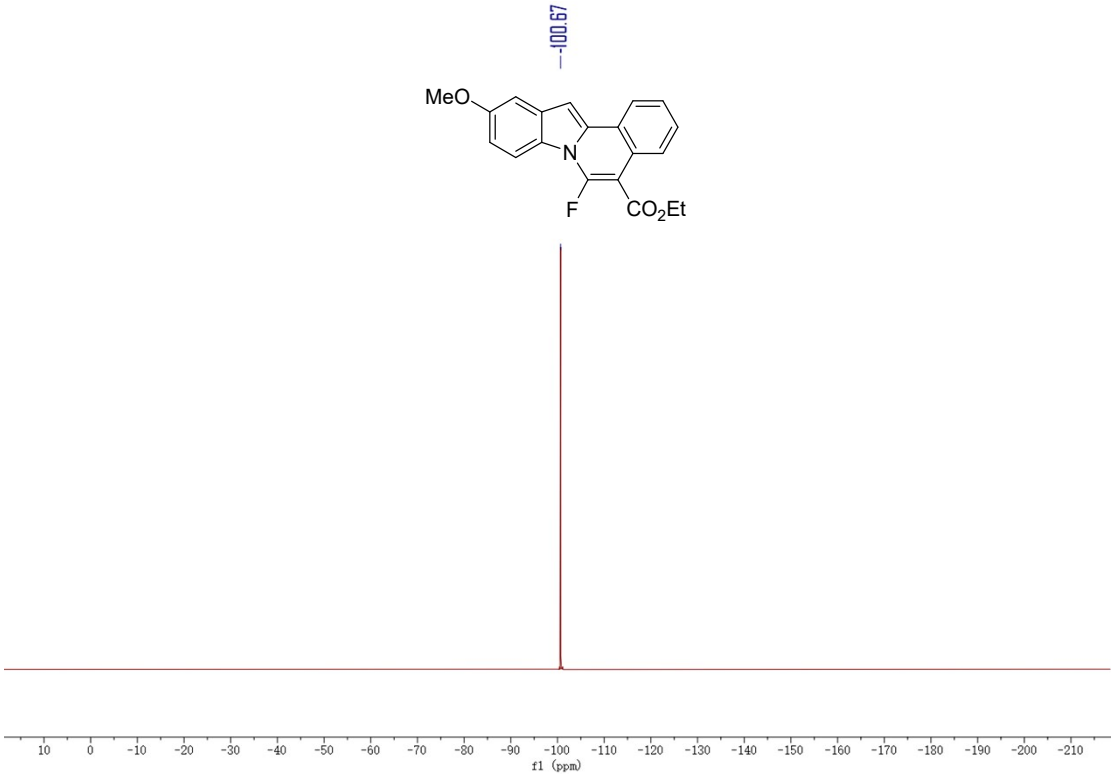
^{19}F NMR of **3h** (376 MHz, $CDCl_3$)



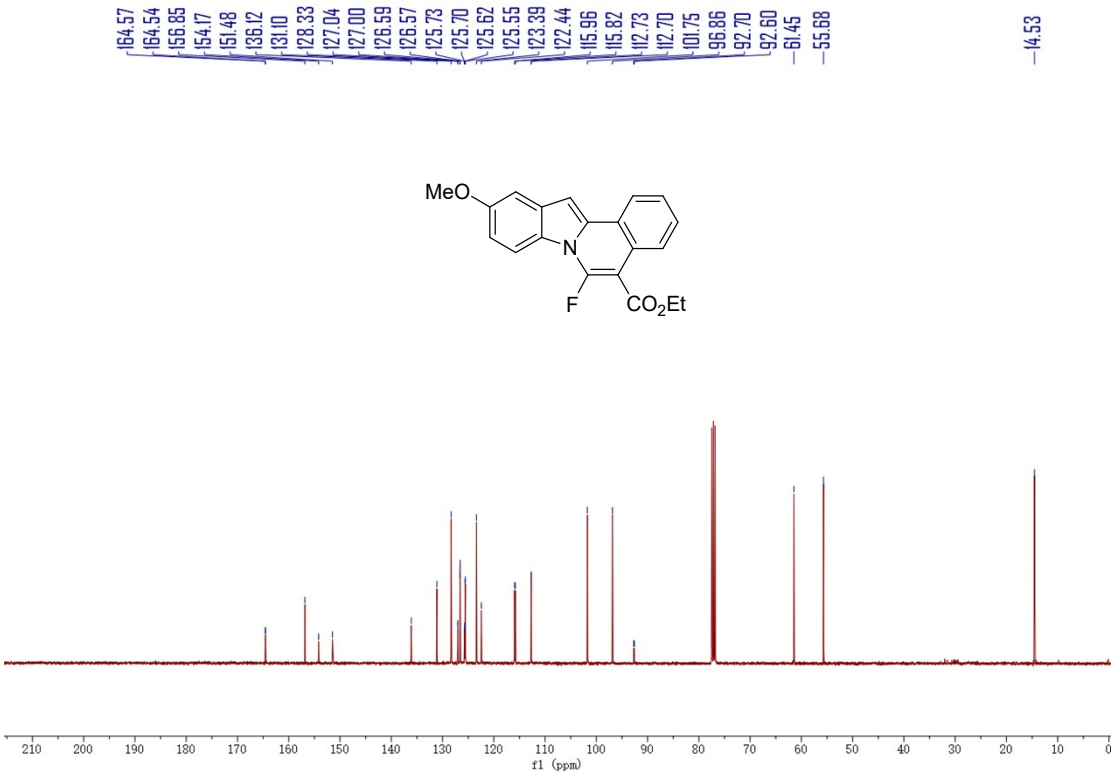
^{13}C NMR of **3h** (100 MHz, $CDCl_3$)



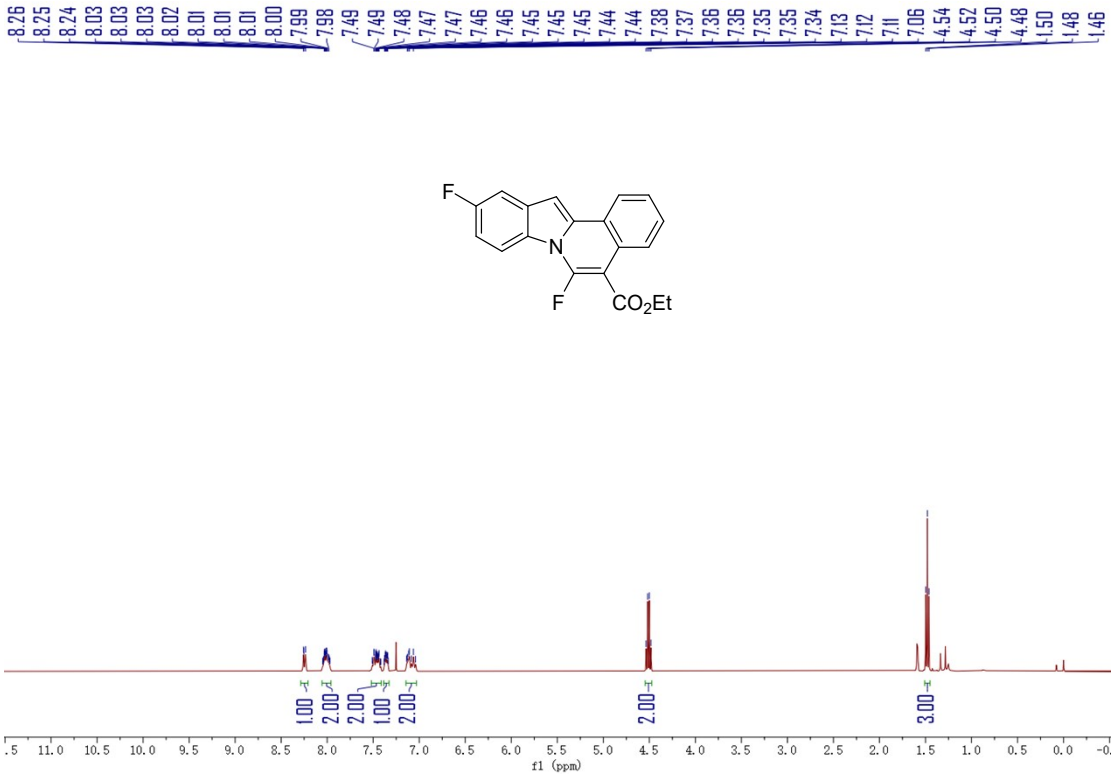
^{1}H NMR of **3i** (400 MHz, $CDCl_3$)



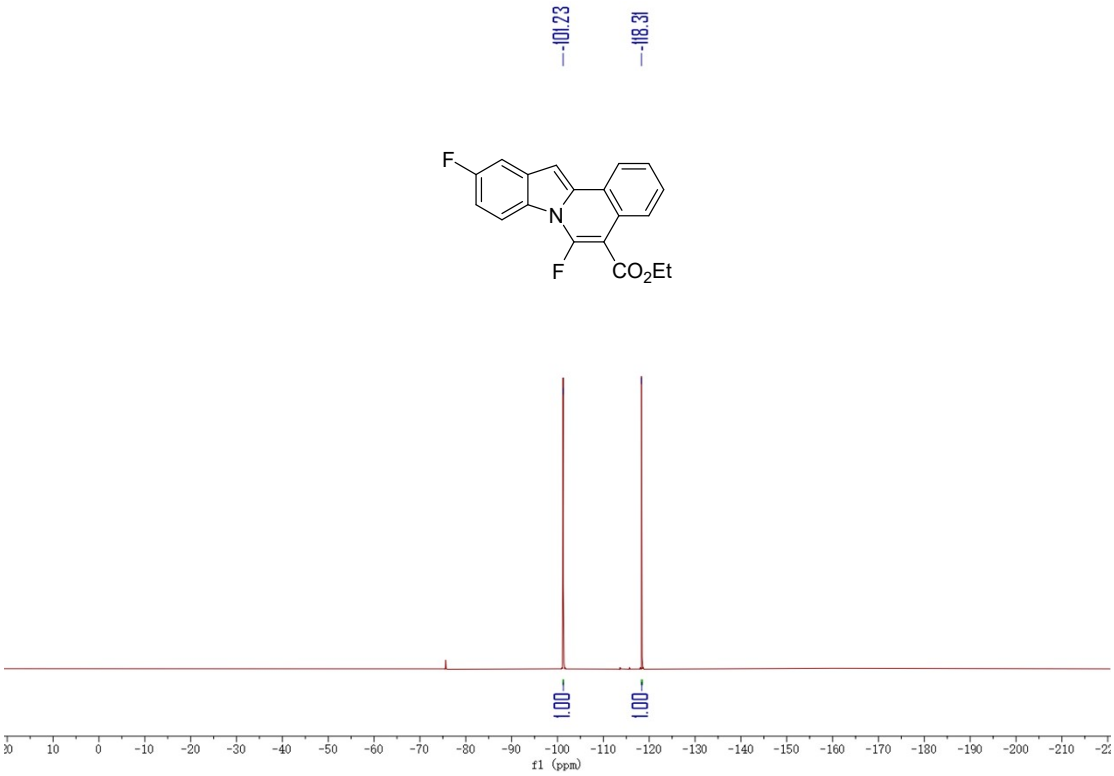
^{19}F NMR of **3i** (376 MHz, $CDCl_3$)



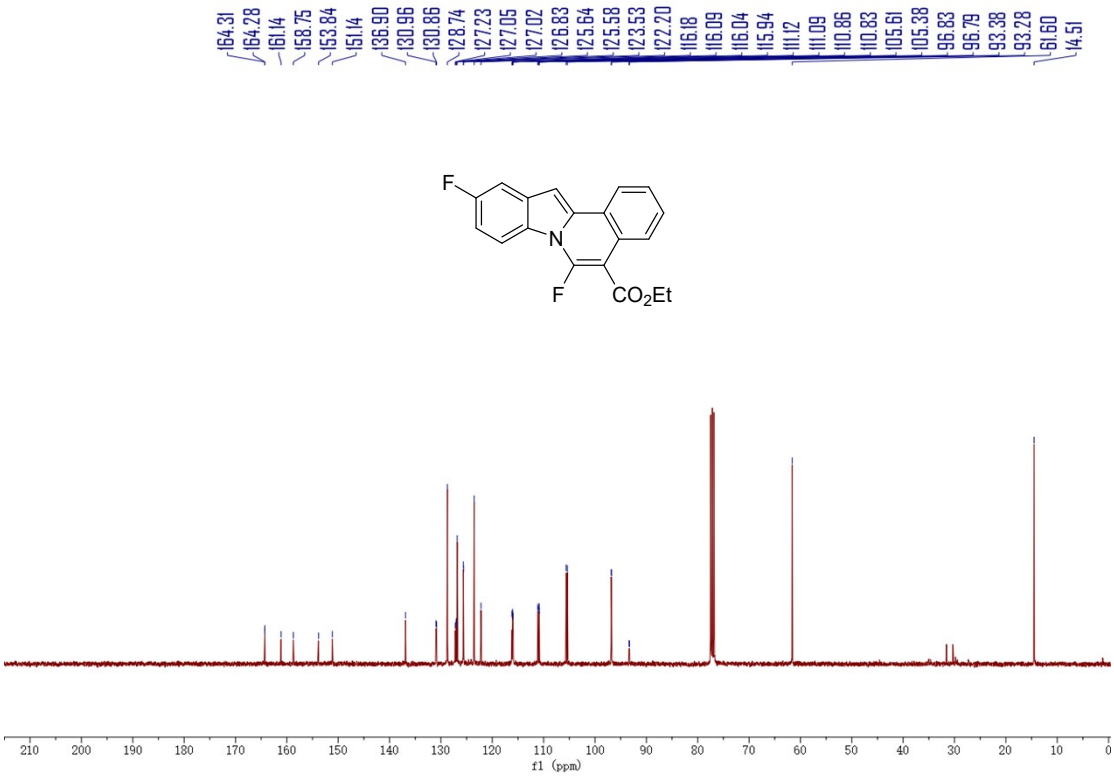
^{13}C NMR of **3i** (100 MHz, $CDCl_3$)



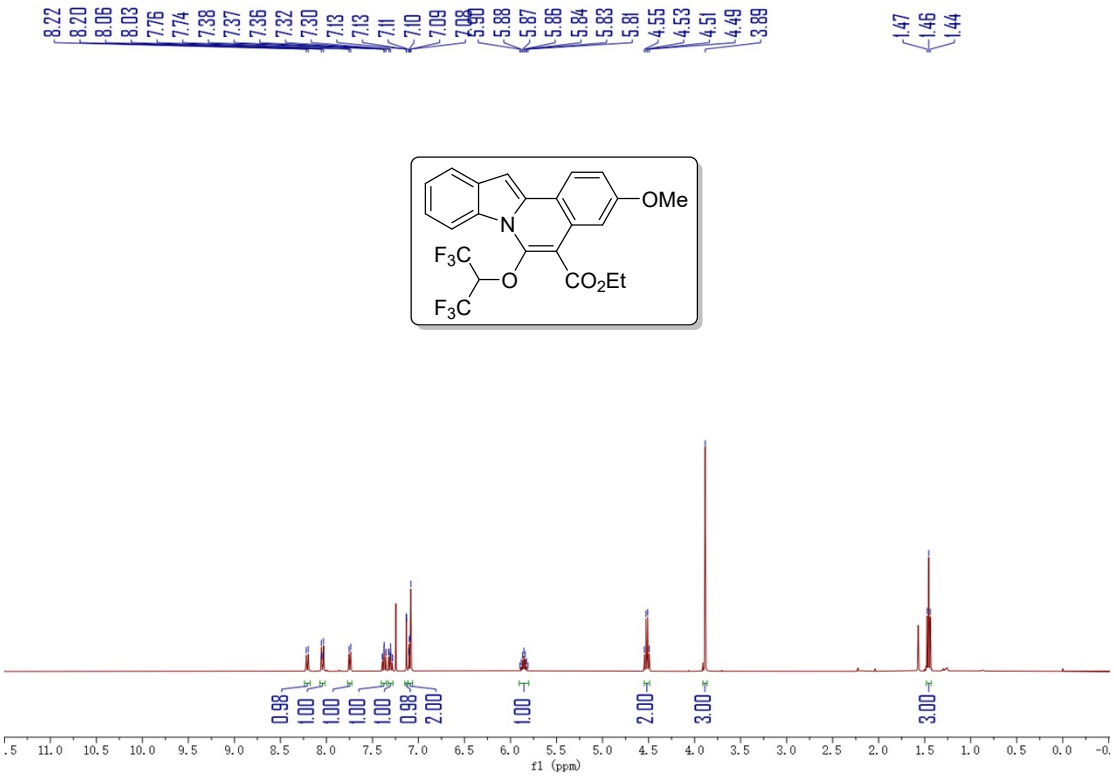
^{1}H NMR of **3j** (400 MHz, $CDCl_3$)



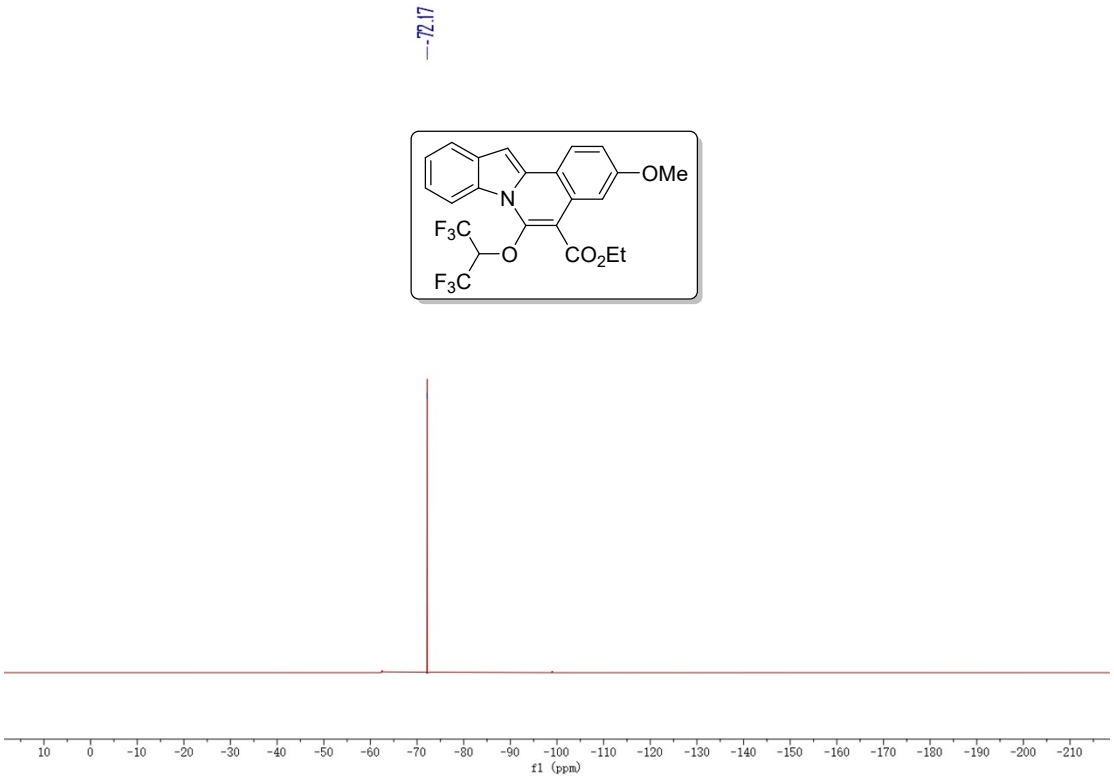
^{19}F NMR of **3j** (376 MHz, $CDCl_3$)



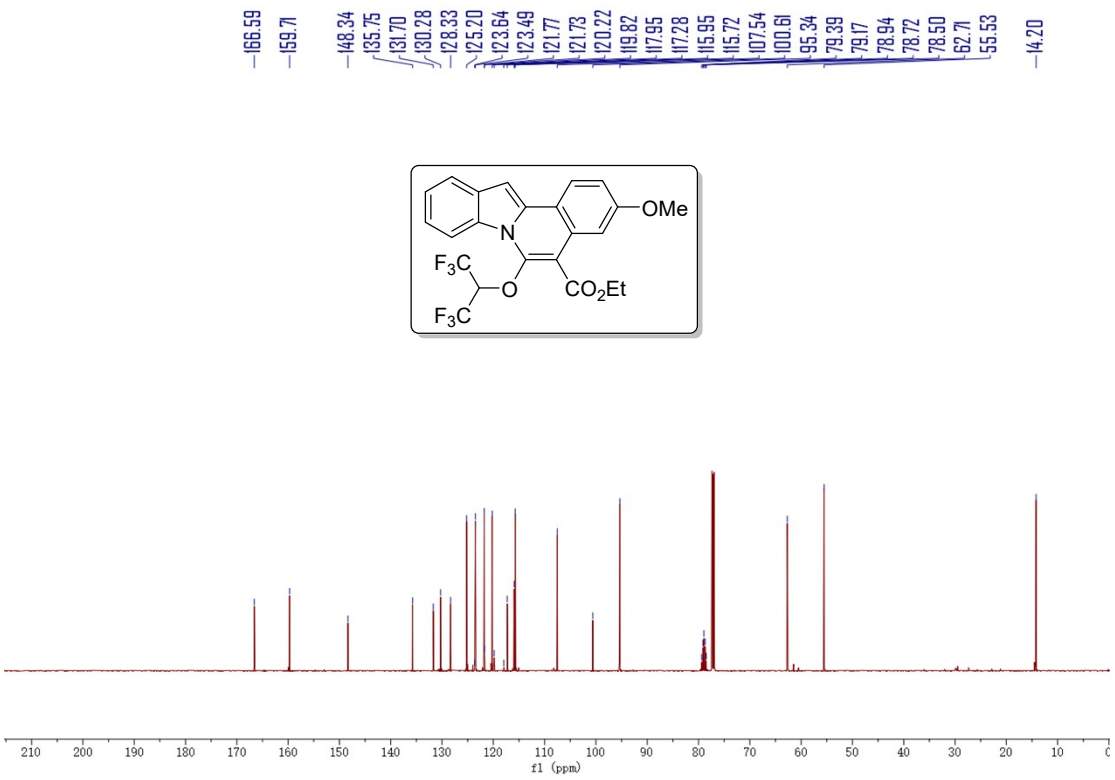
^{13}C NMR of **3j** (100 MHz, $CDCl_3$)



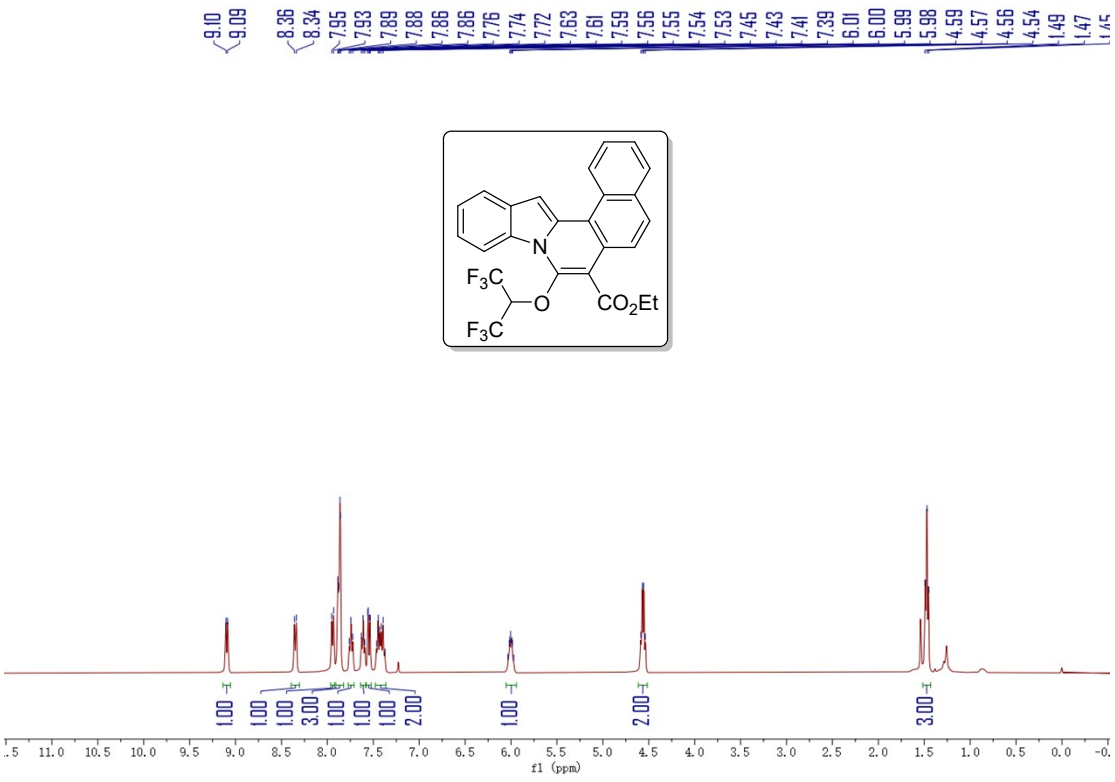
^{1}H NMR of **3k** (400 MHz, $CDCl_3$)



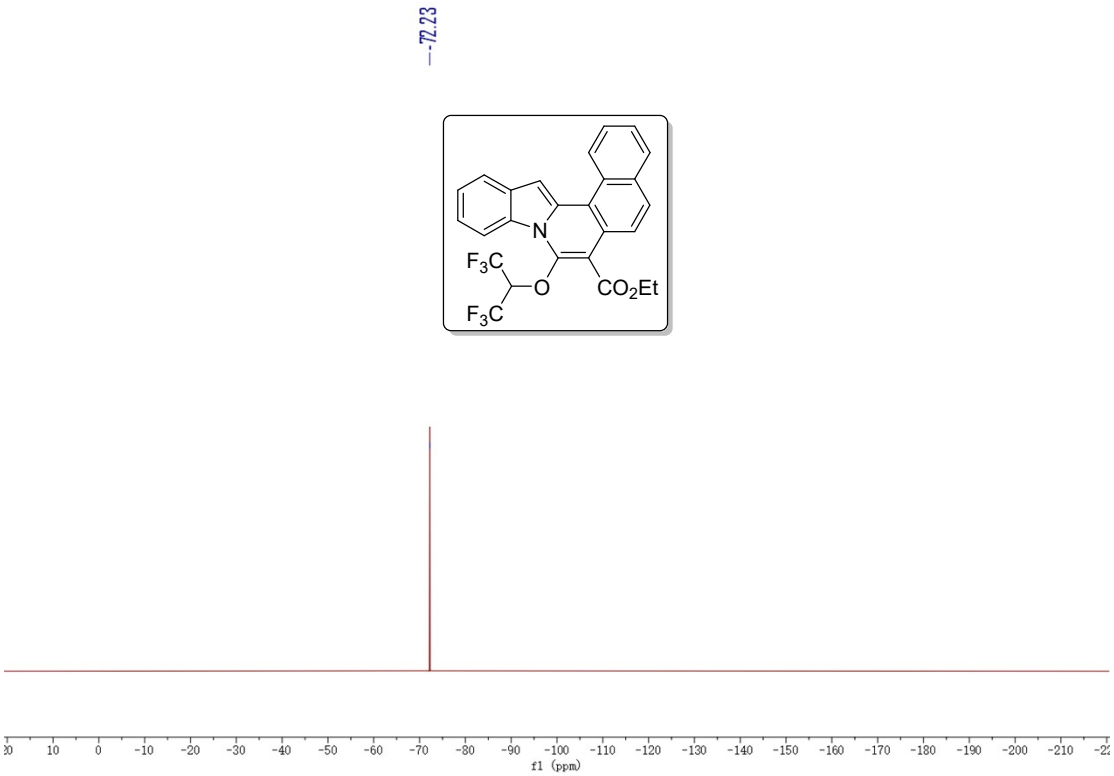
^{19}F NMR of **3k** (376 MHz, $CDCl_3$)



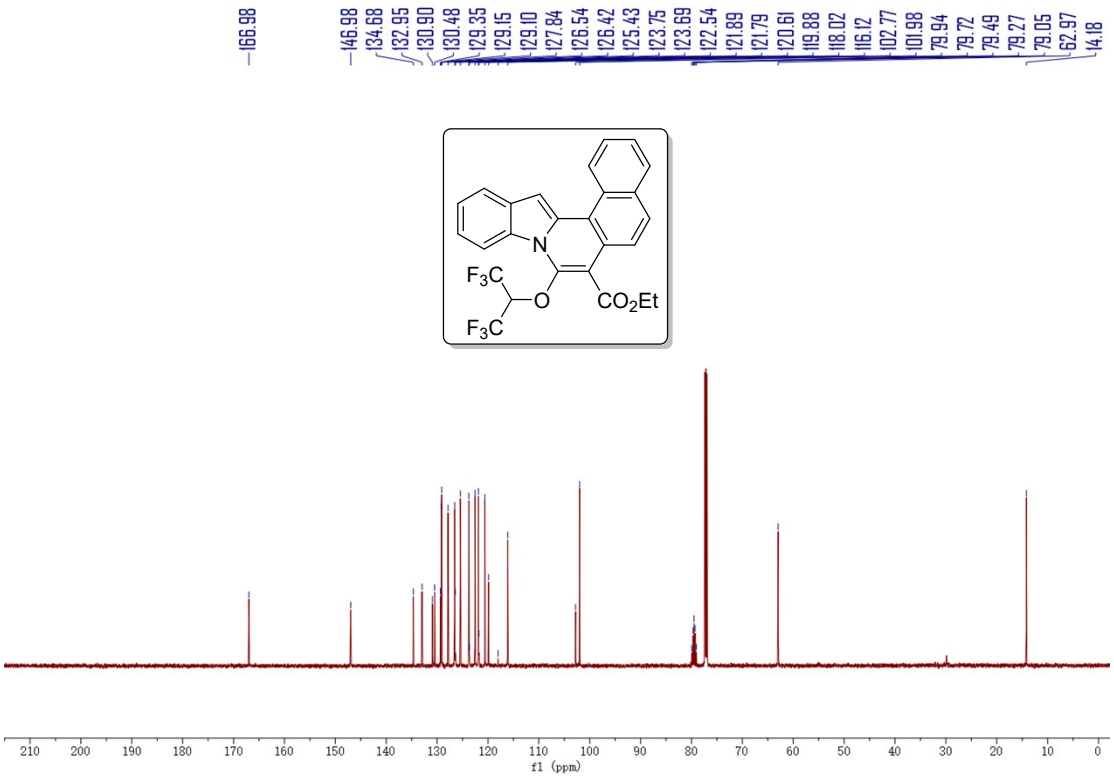
^{13}C NMR of **3k** (150 MHz, $CDCl_3$)



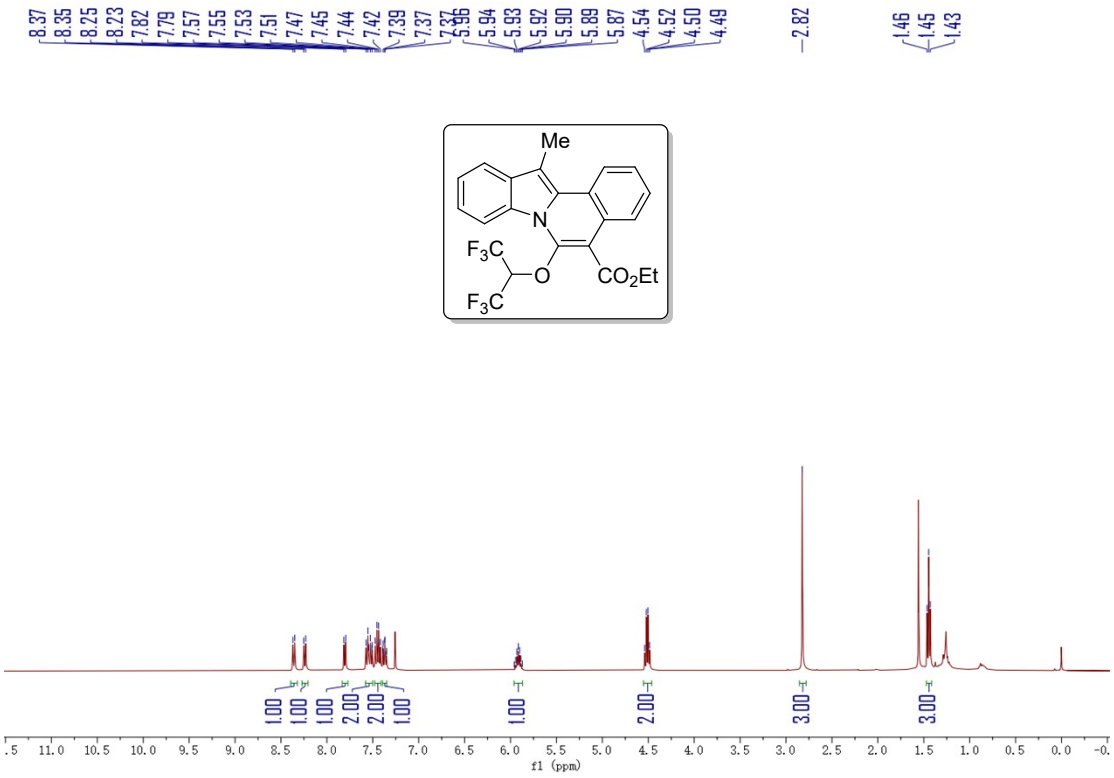
^{1}H NMR of **3l** (400 MHz, $CDCl_3$)



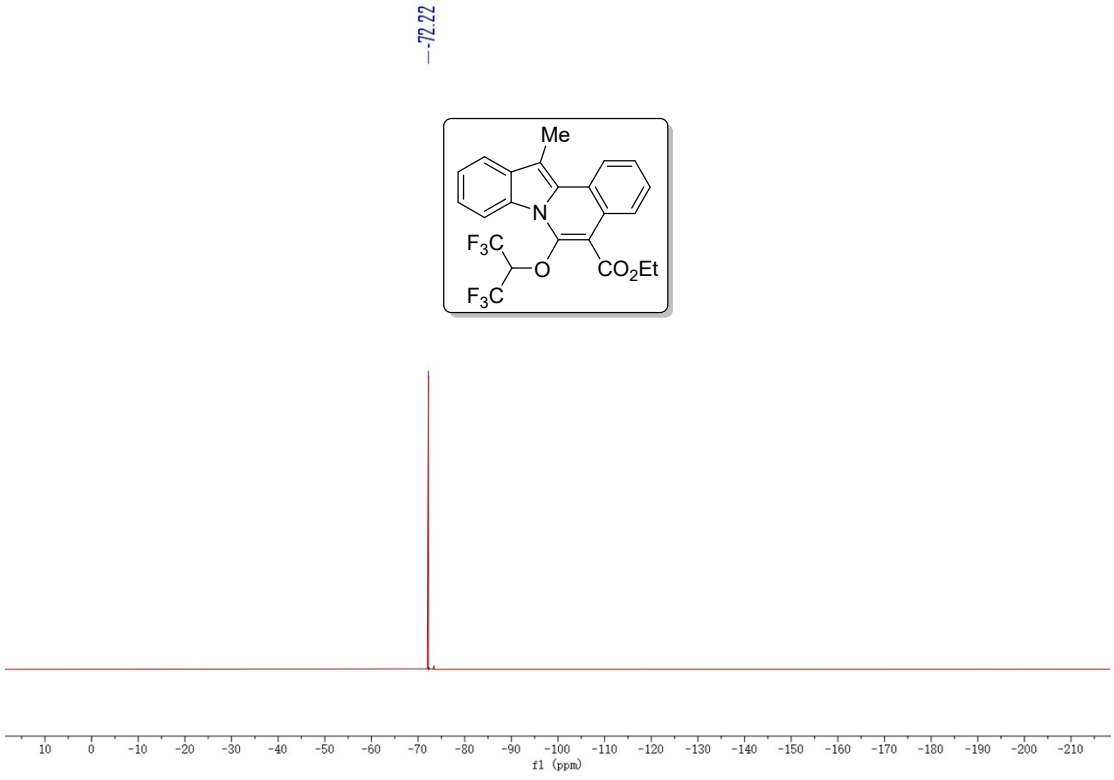
^{19}F NMR of **3l** (376 MHz, $CDCl_3$)



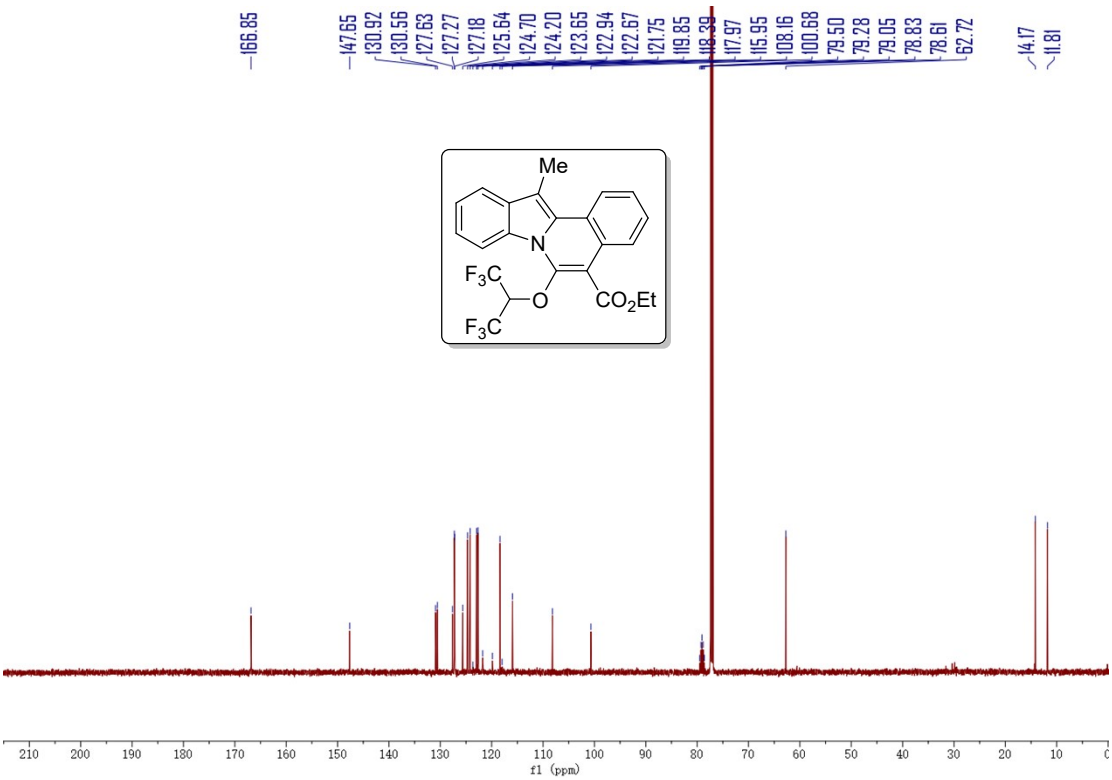
^{13}C NMR of **3l** (150 MHz, $CDCl_3$)



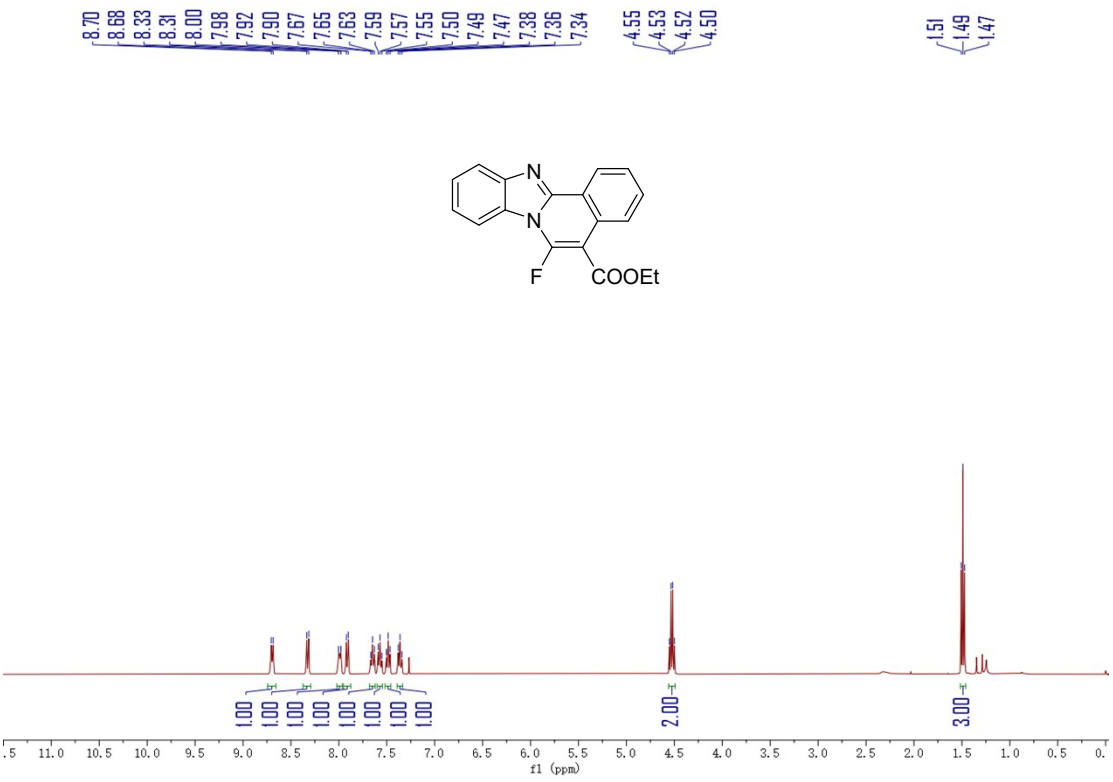
^{1}H NMR of **3m** (400 MHz, $CDCl_3$)



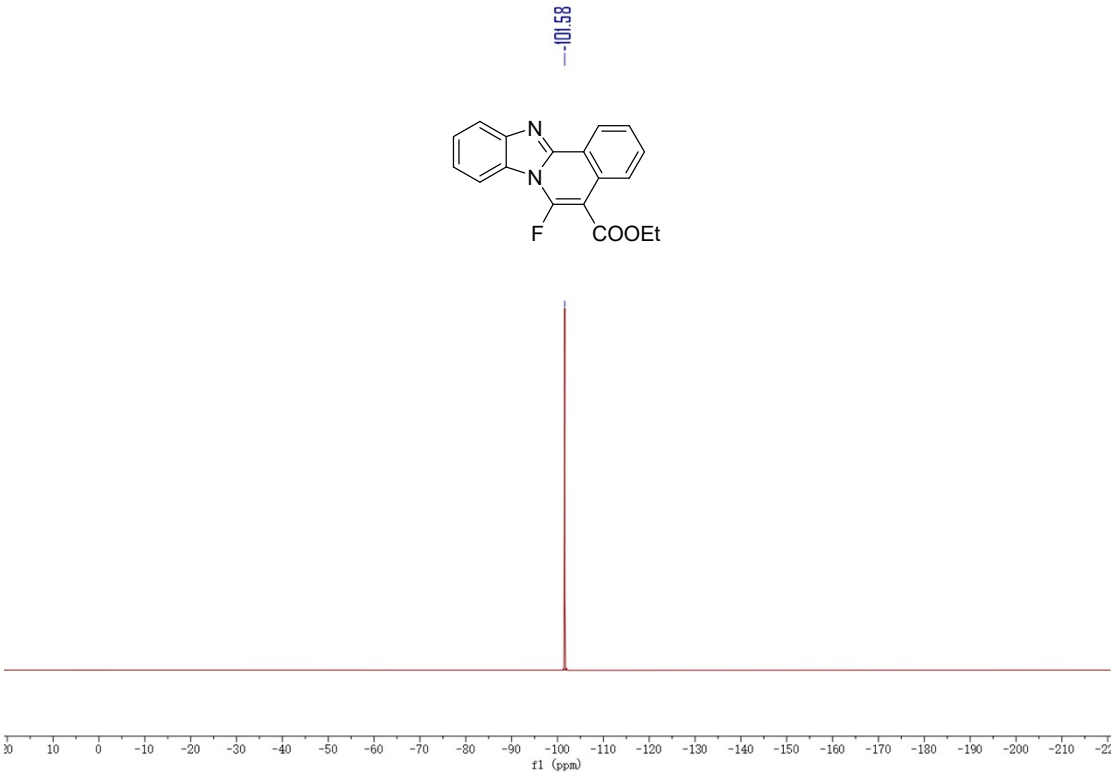
^{19}F NMR of **3m** (376 MHz, $CDCl_3$)



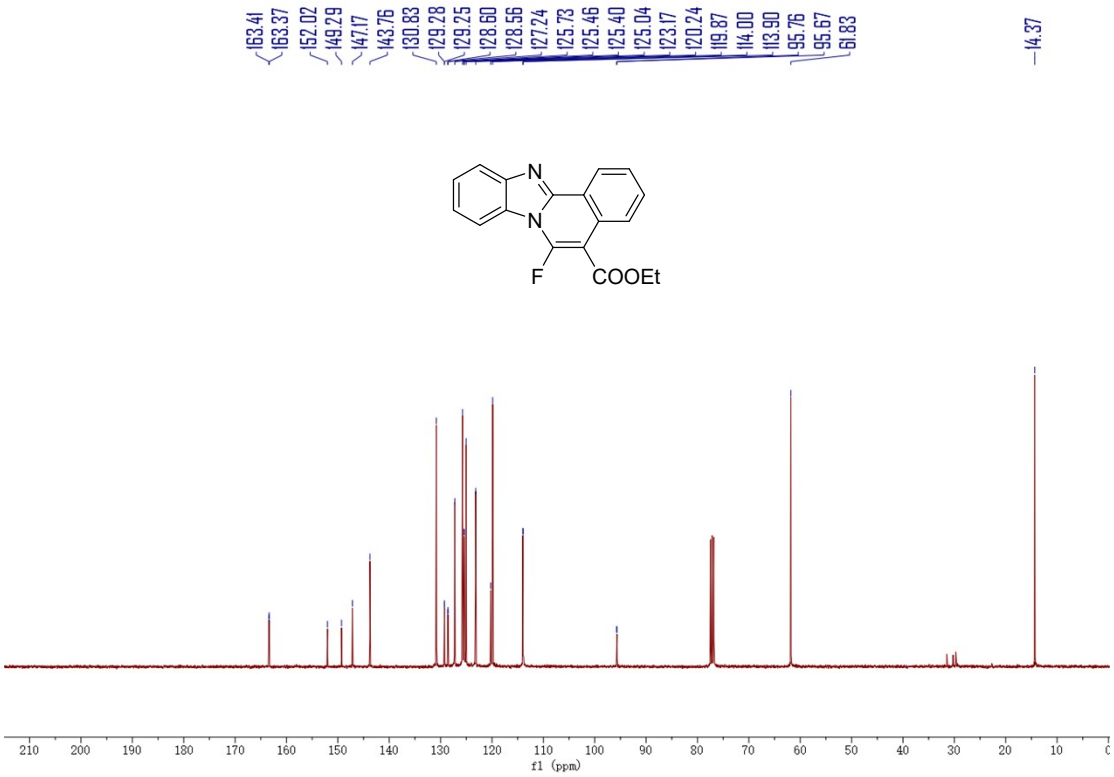
^{13}C NMR of **3m** (150 MHz, $CDCl_3$)



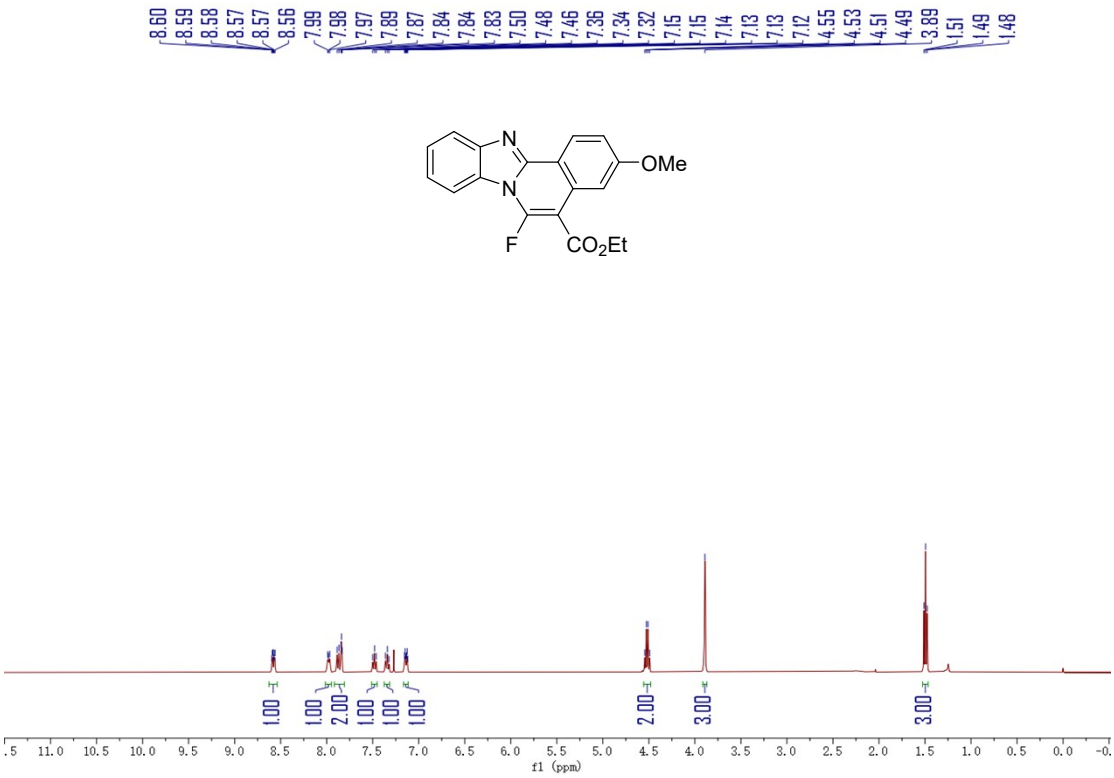
^{1}H NMR of **5a** (400 MHz, $CDCl_3$)



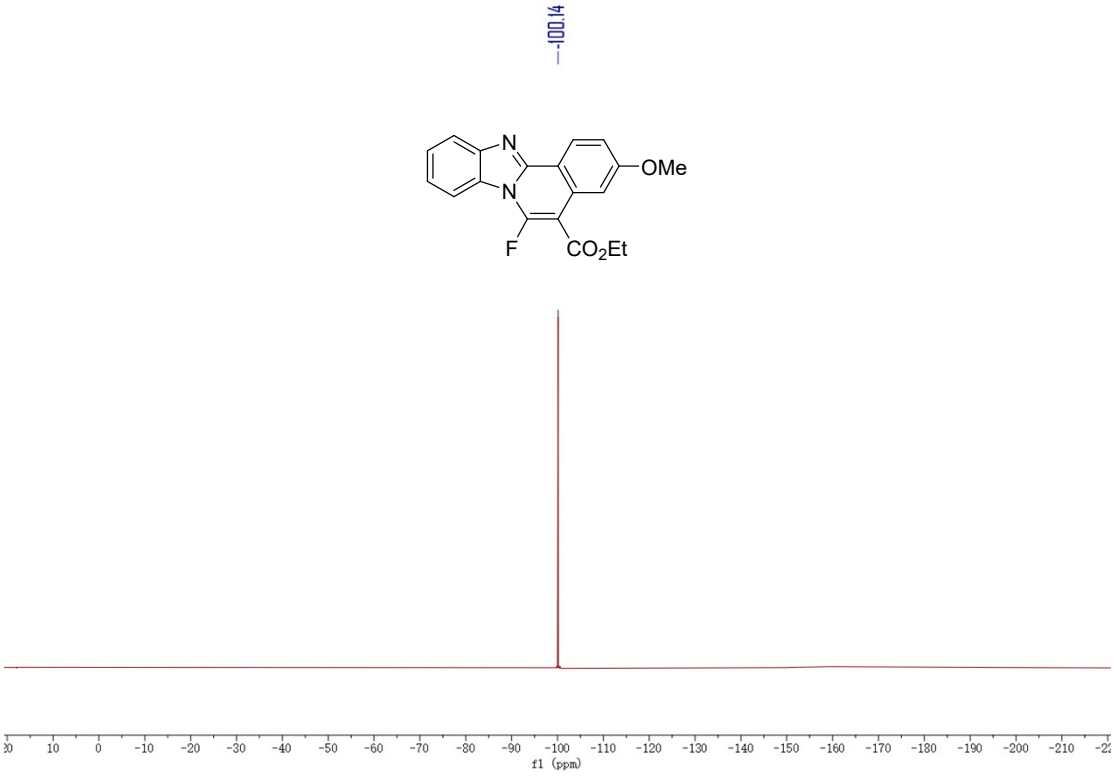
^{19}F NMR of **5a** (376 MHz, $CDCl_3$)



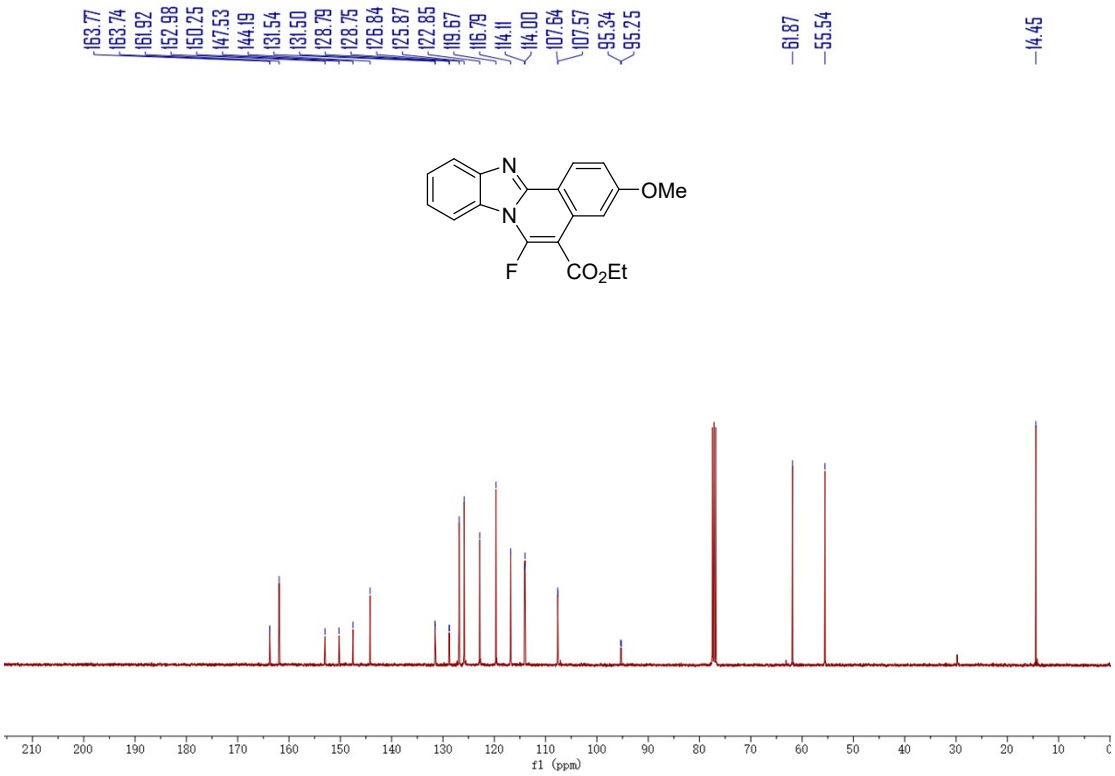
^{13}C NMR of **5a** (100 MHz, $CDCl_3$)



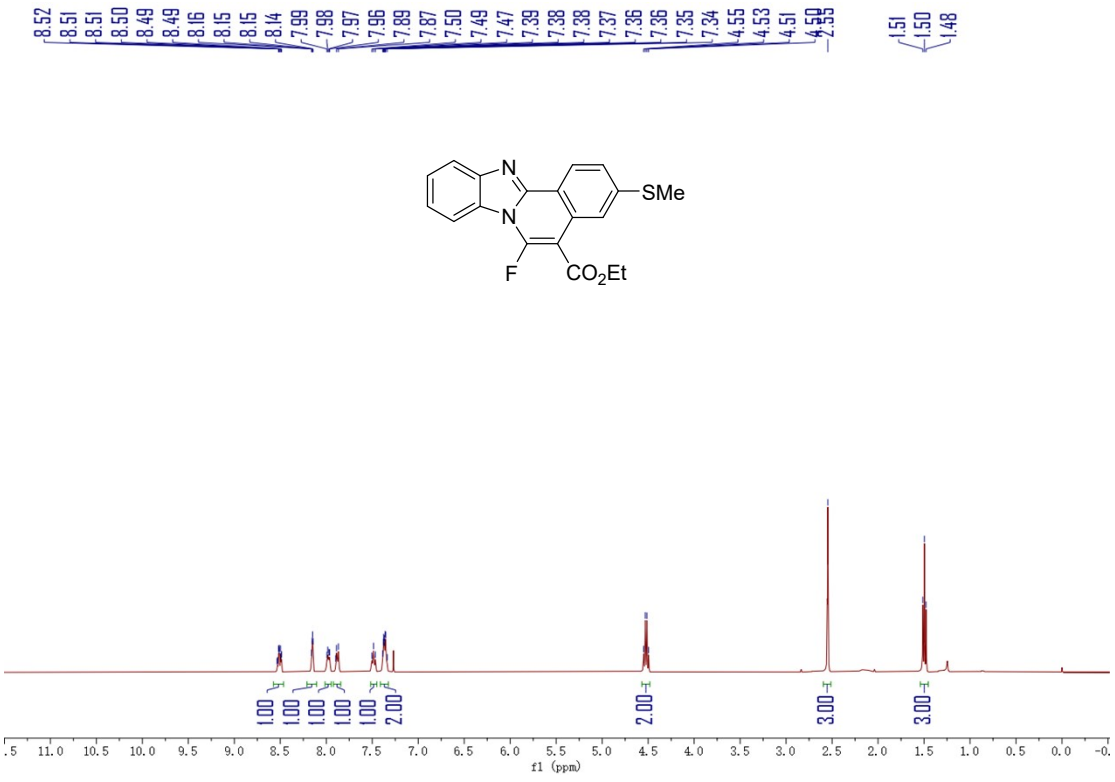
^{1}H NMR of **5b** (400 MHz, $CDCl_3$)



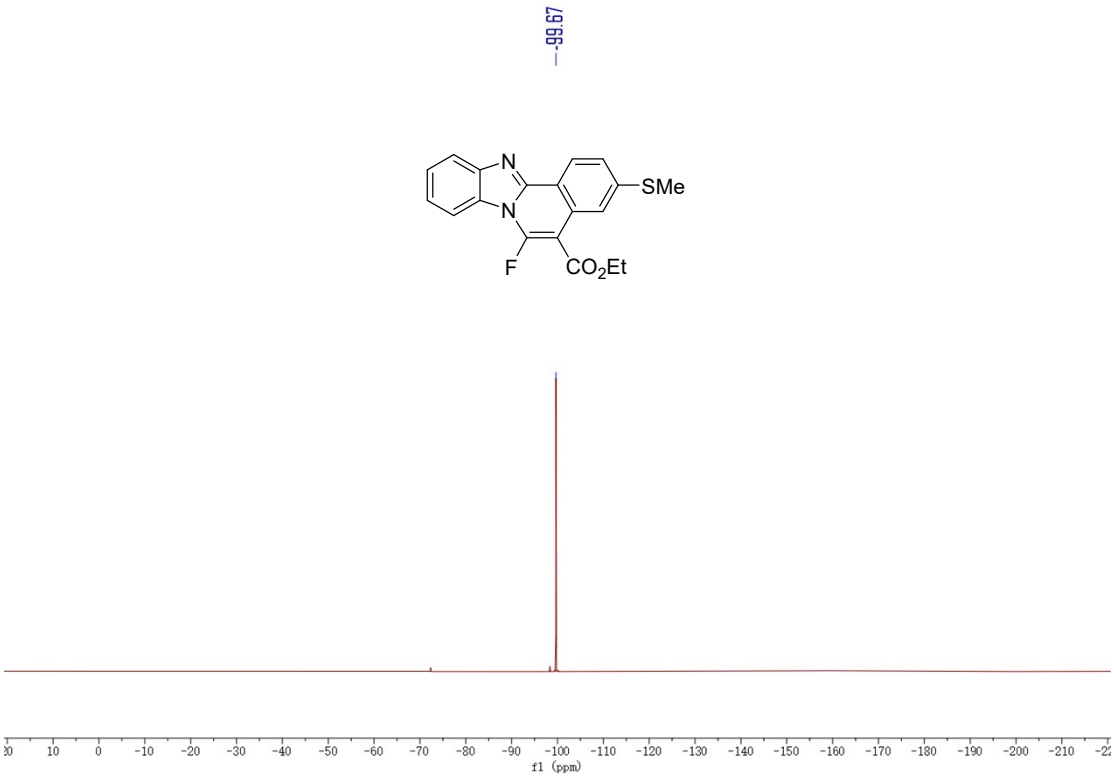
^{19}F NMR of **5b** (376 MHz, $CDCl_3$)



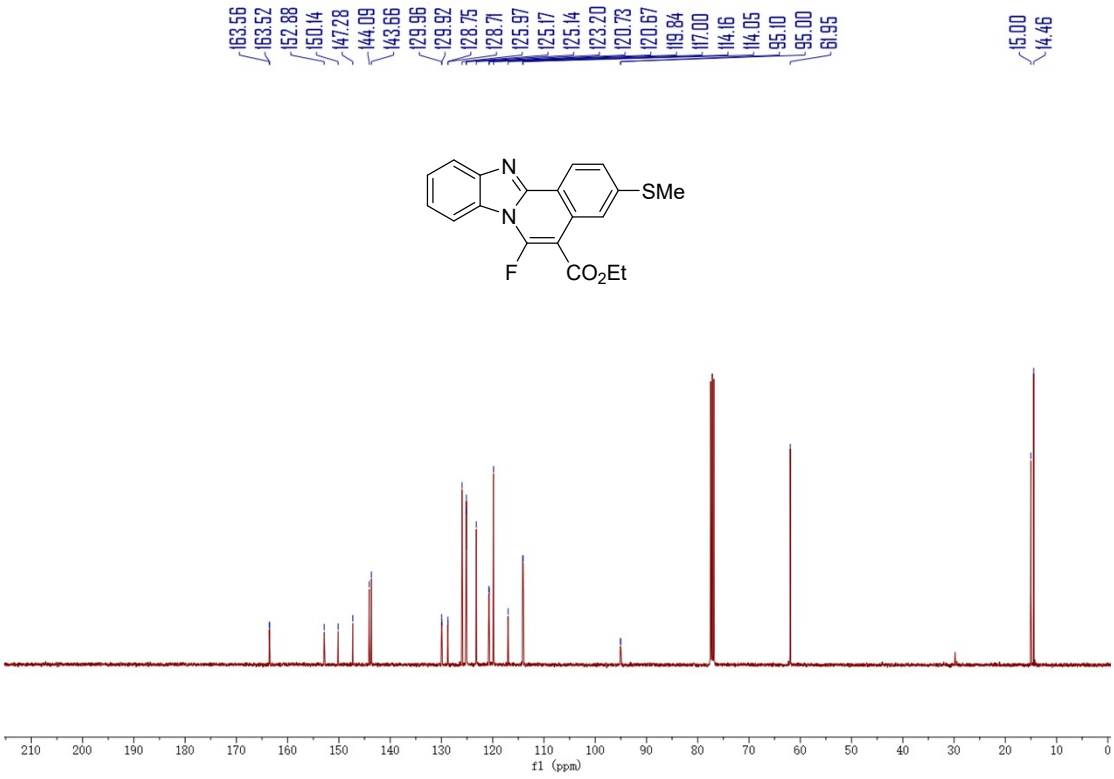
^{13}C NMR of **5b** (100 MHz, $CDCl_3$)



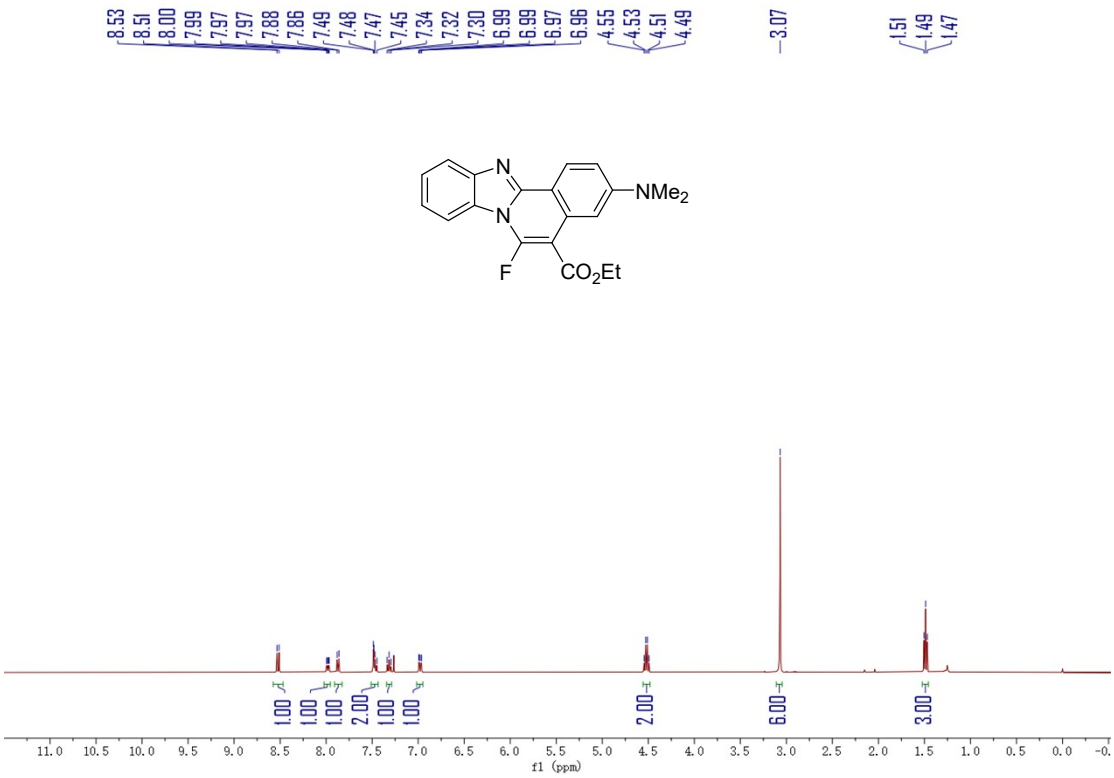
^{1}H NMR of **5c** (400 MHz, $CDCl_3$)



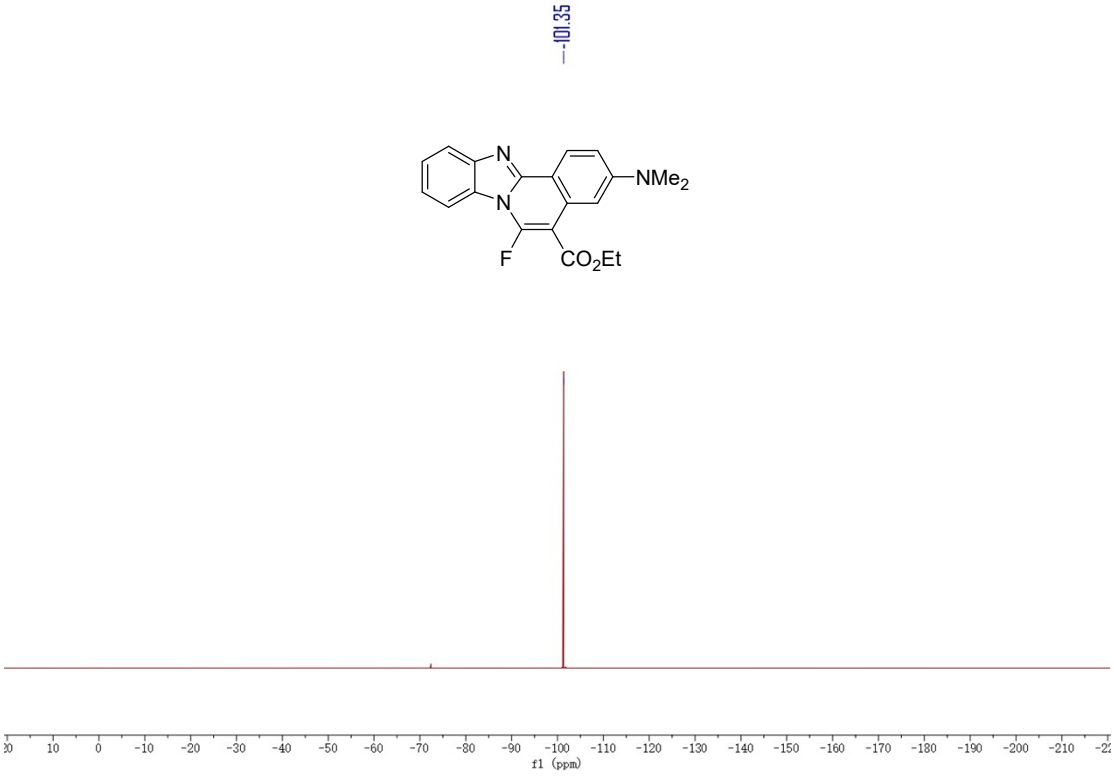
^{19}F NMR of **5c** (376 MHz, $CDCl_3$)



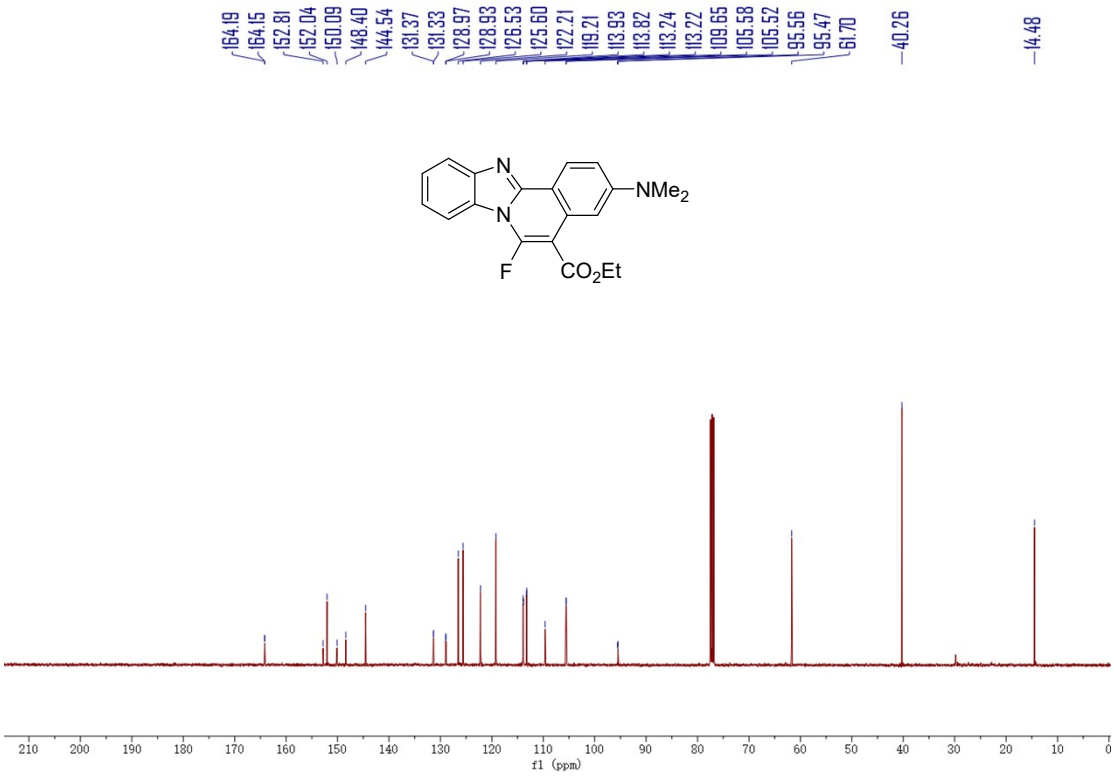
^{13}C NMR of **5c** (100 MHz, $CDCl_3$)



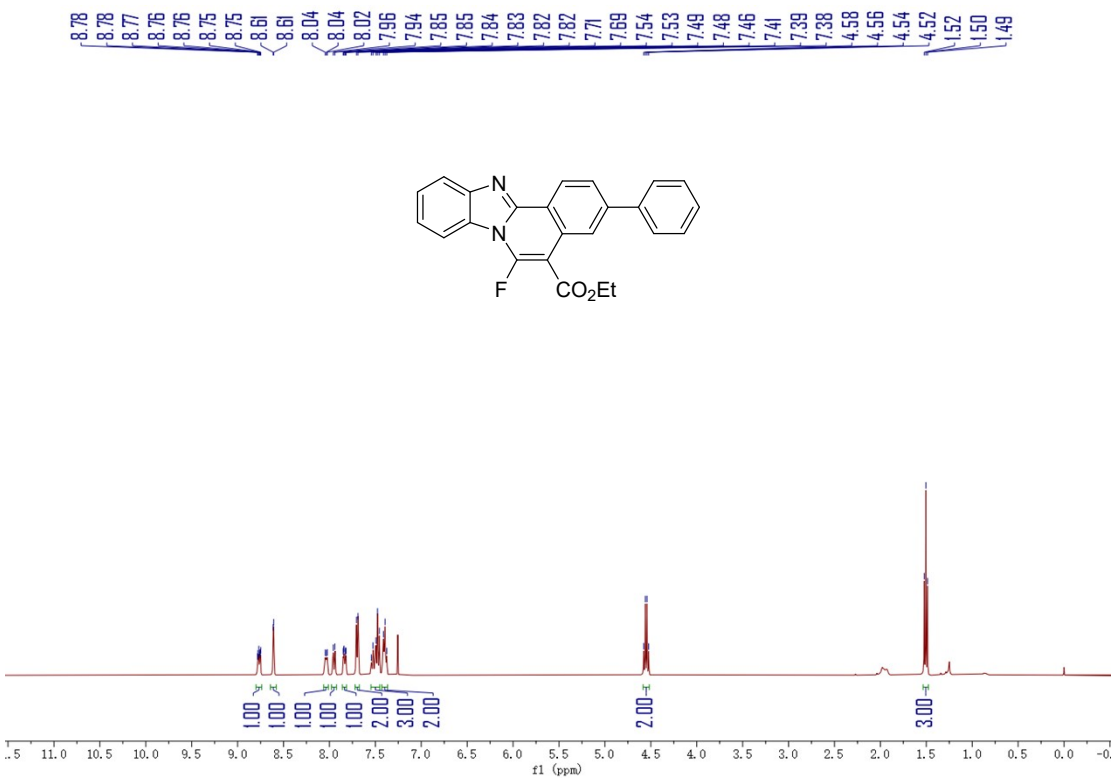
^{1}H NMR of **5d** (400 MHz, $CDCl_3$)



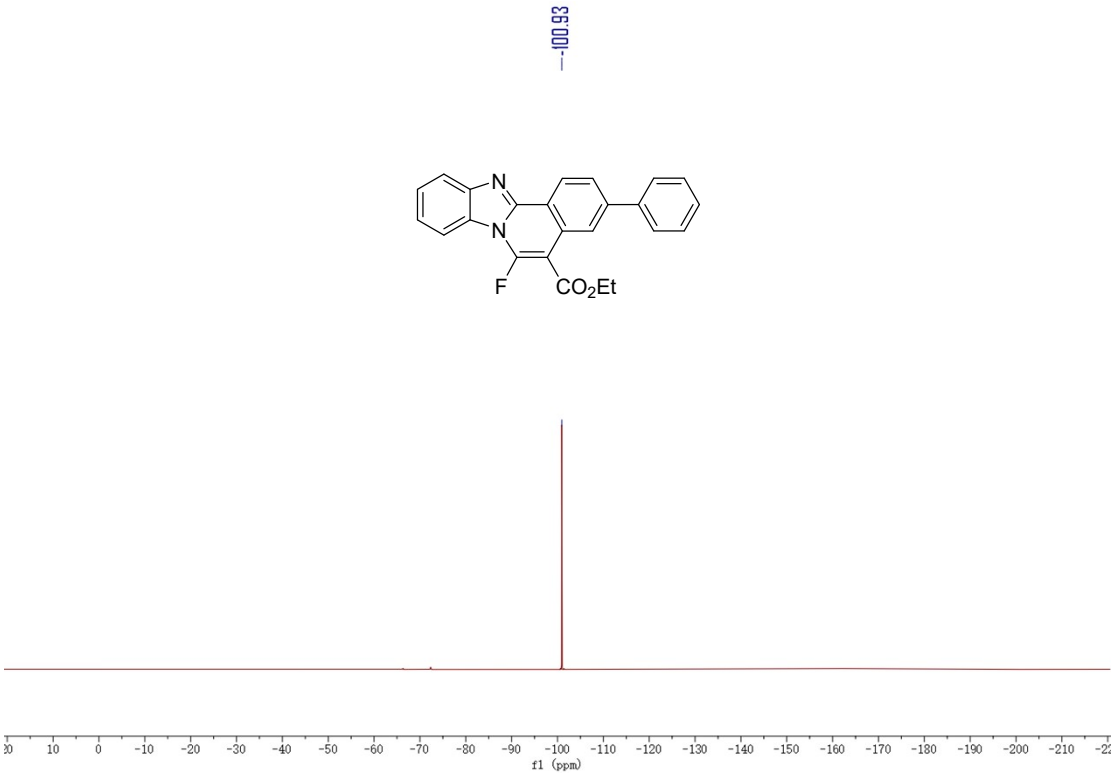
^{19}F NMR of **5d** (376 MHz, $CDCl_3$)



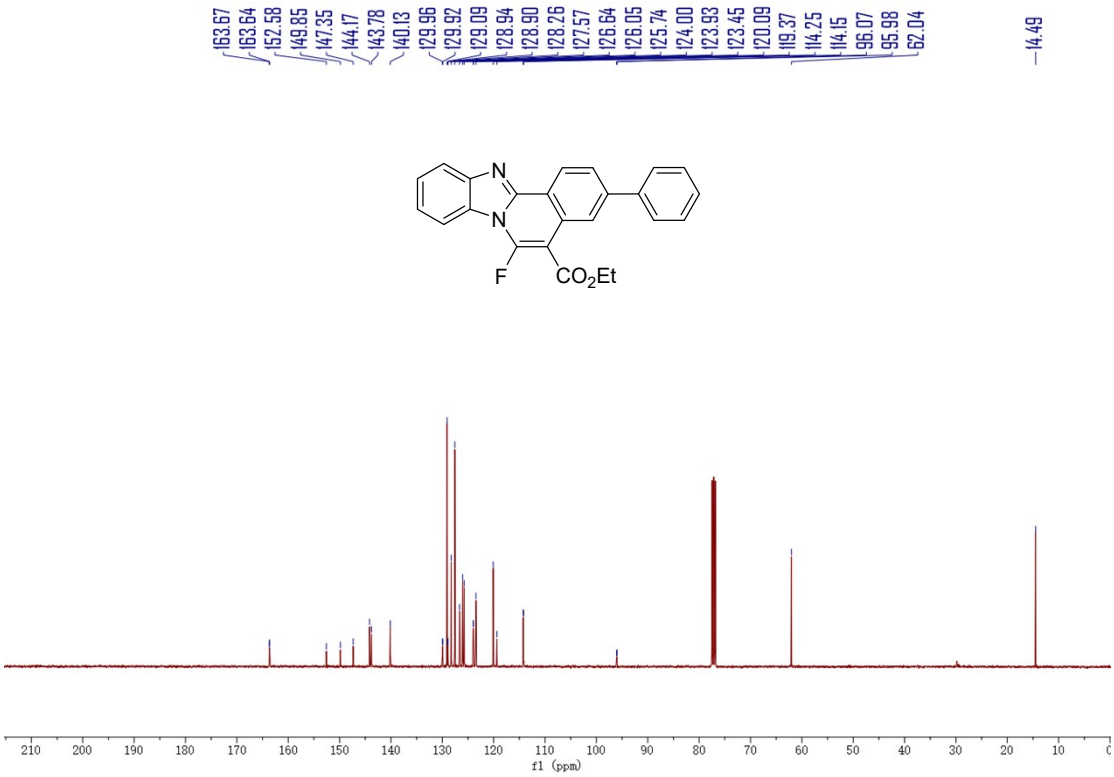
^{13}C NMR of **5d** (100 MHz, $CDCl_3$)



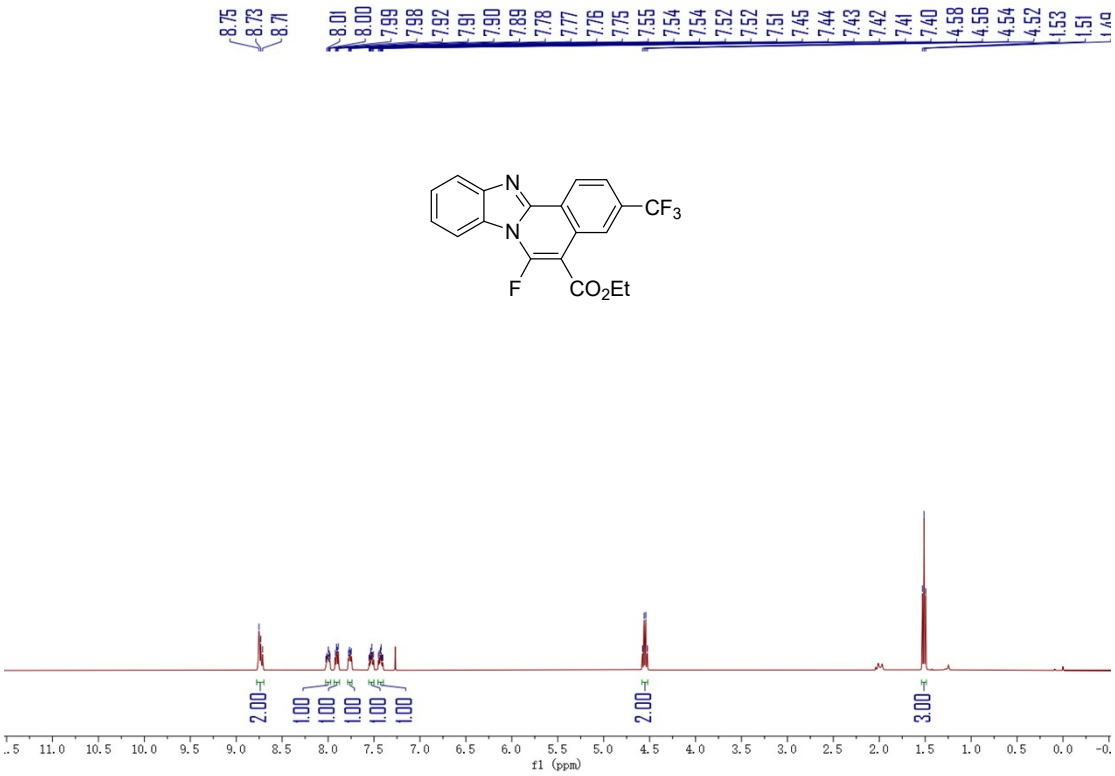
^{1}H NMR of **5e** (400 MHz, $CDCl_3$)



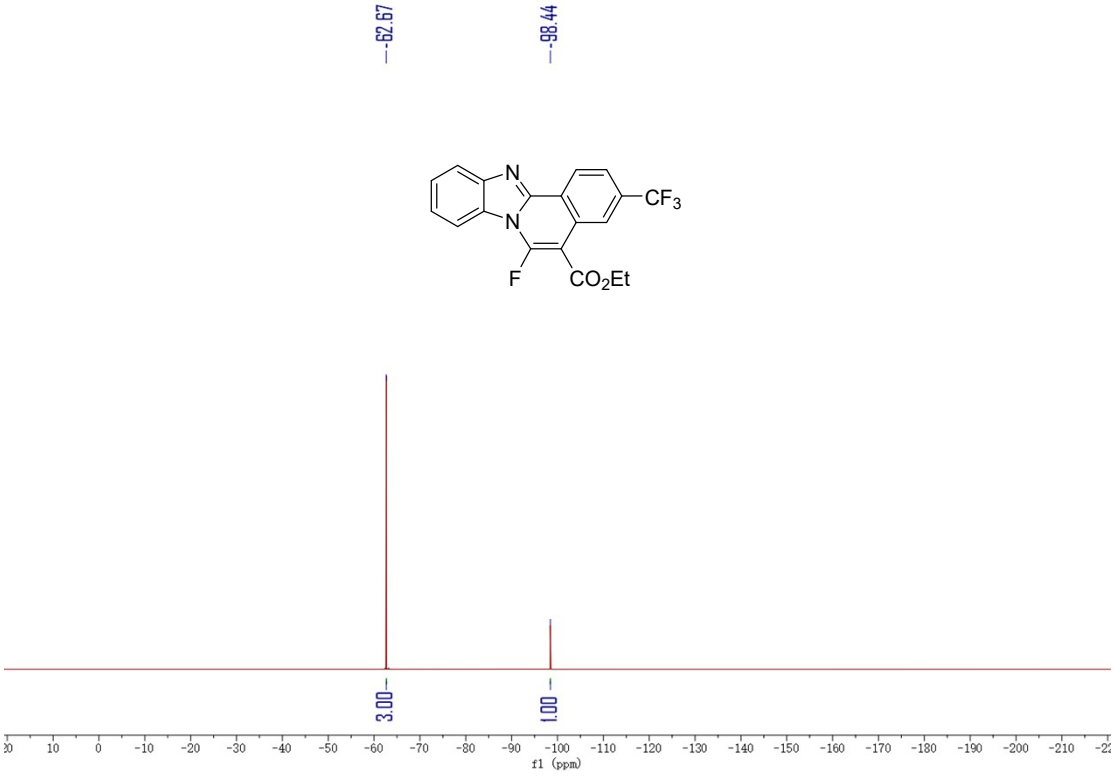
^{19}F NMR of **5e** (376 MHz, $CDCl_3$)



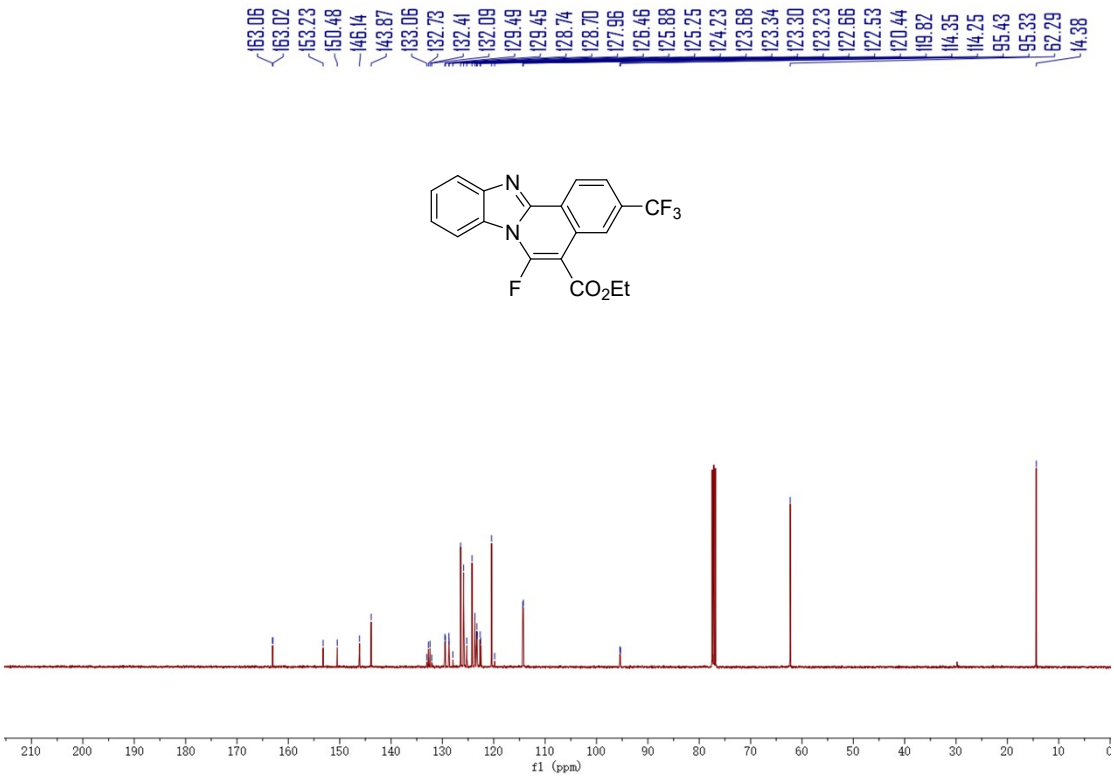
^{13}C NMR of **5e** (100 MHz, $CDCl_3$)



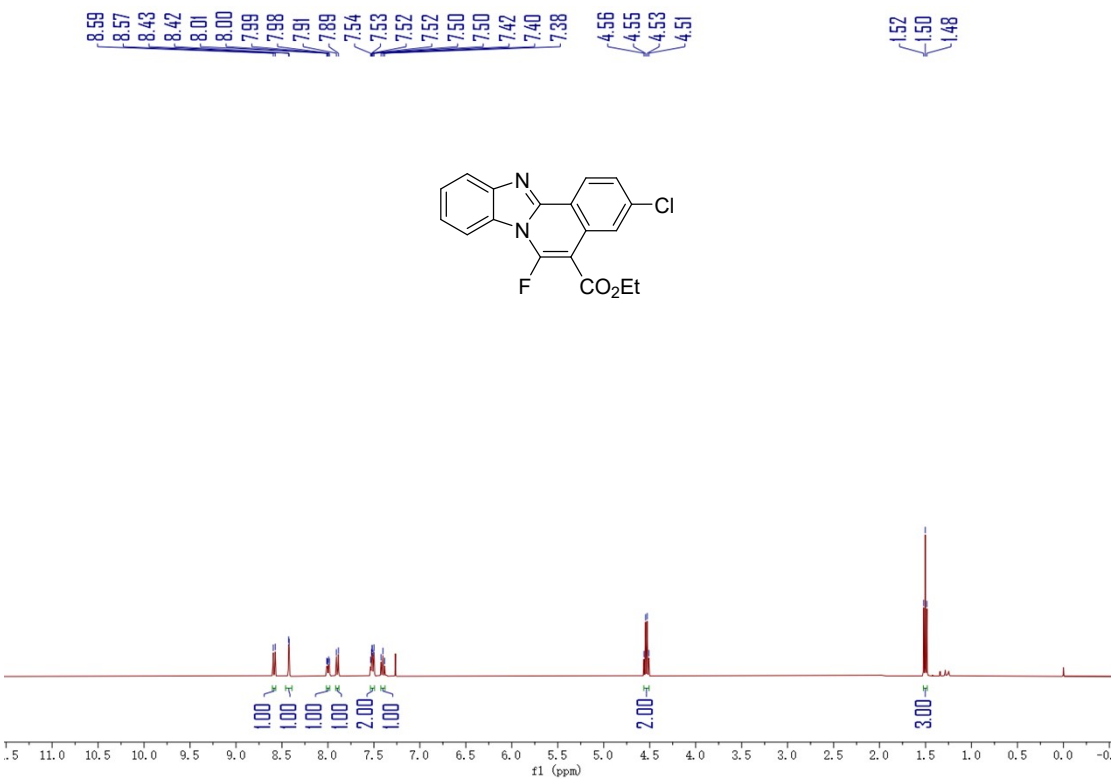
^{1}H NMR of **5f** (400 MHz, $CDCl_3$)



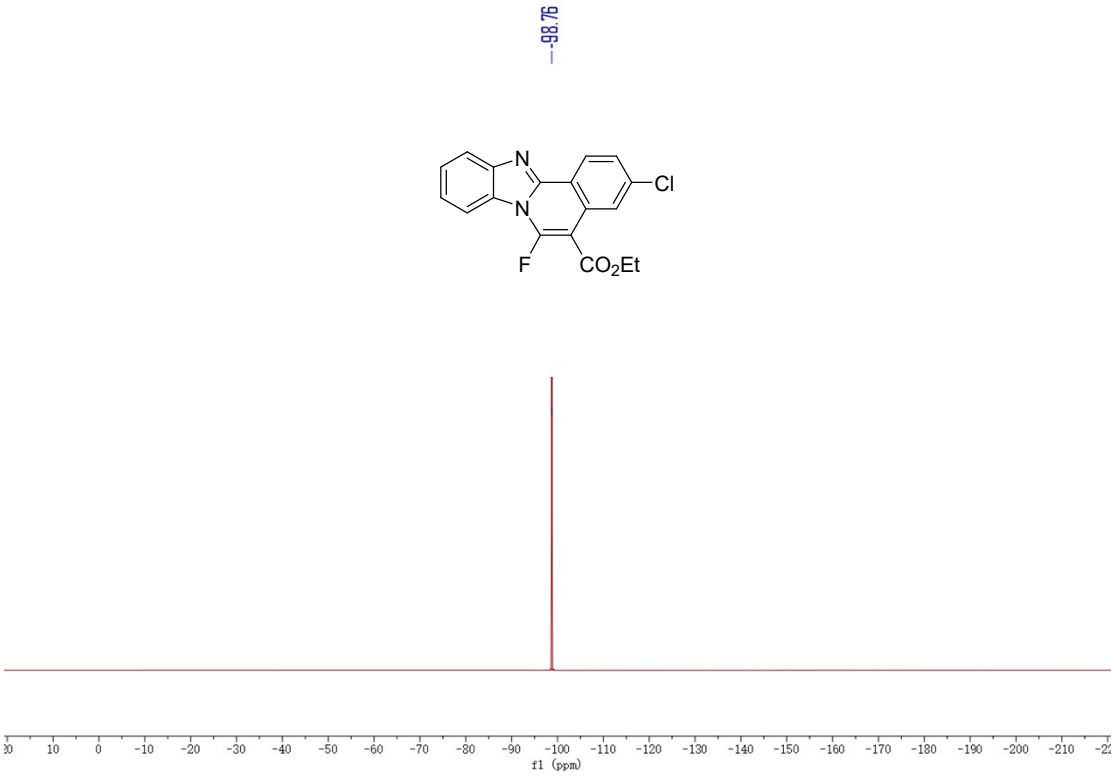
^{19}F NMR of **5f** (376 MHz, $CDCl_3$)



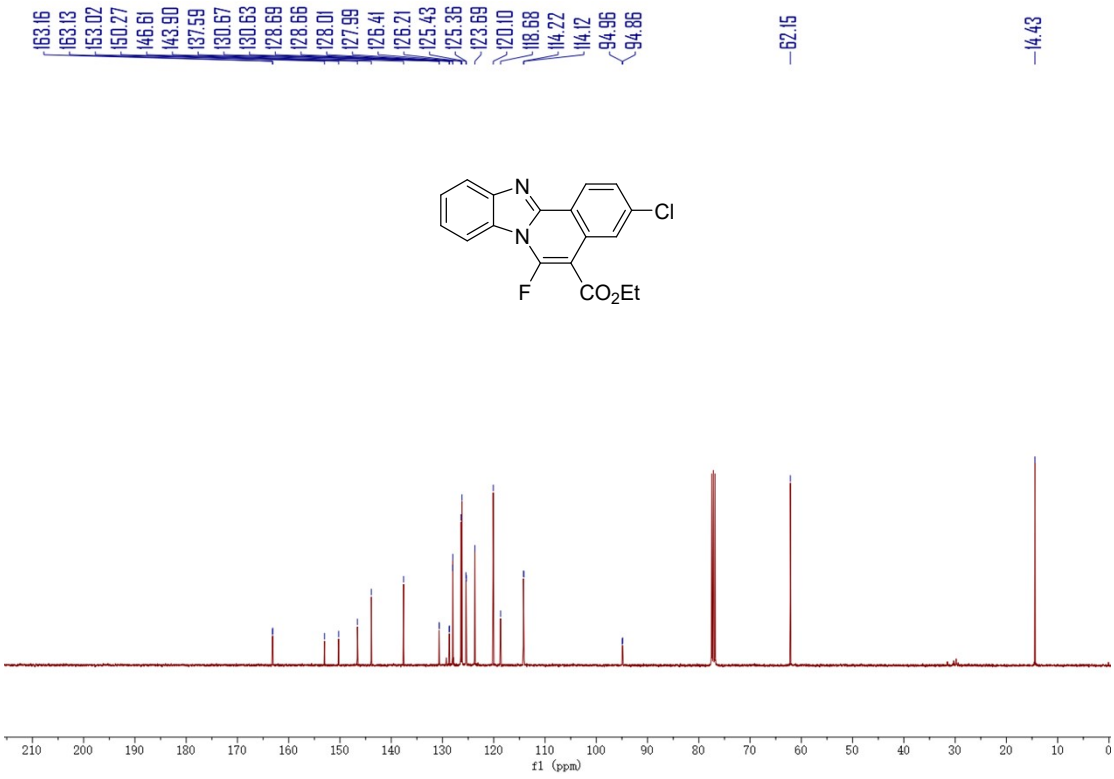
^{13}C NMR of **5f** (100 MHz, $CDCl_3$)



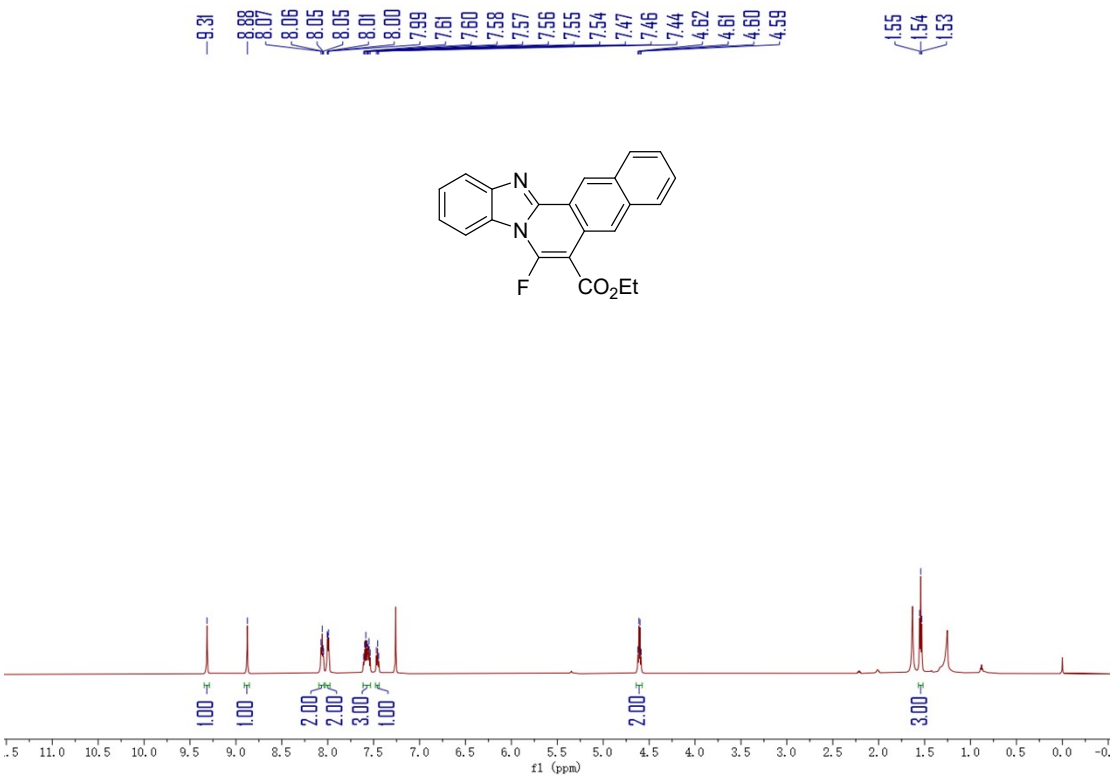
^{1}H NMR of **5g** (400 MHz, $CDCl_3$)



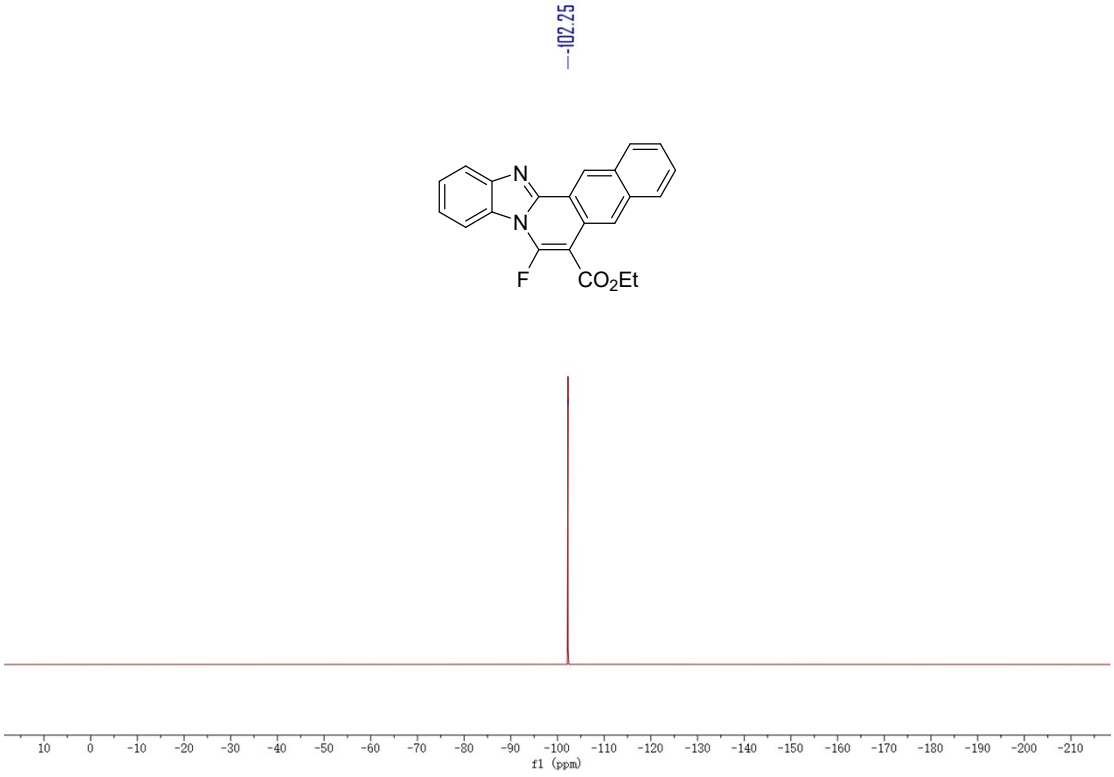
^{19}F NMR of **5g** (376 MHz, $CDCl_3$)



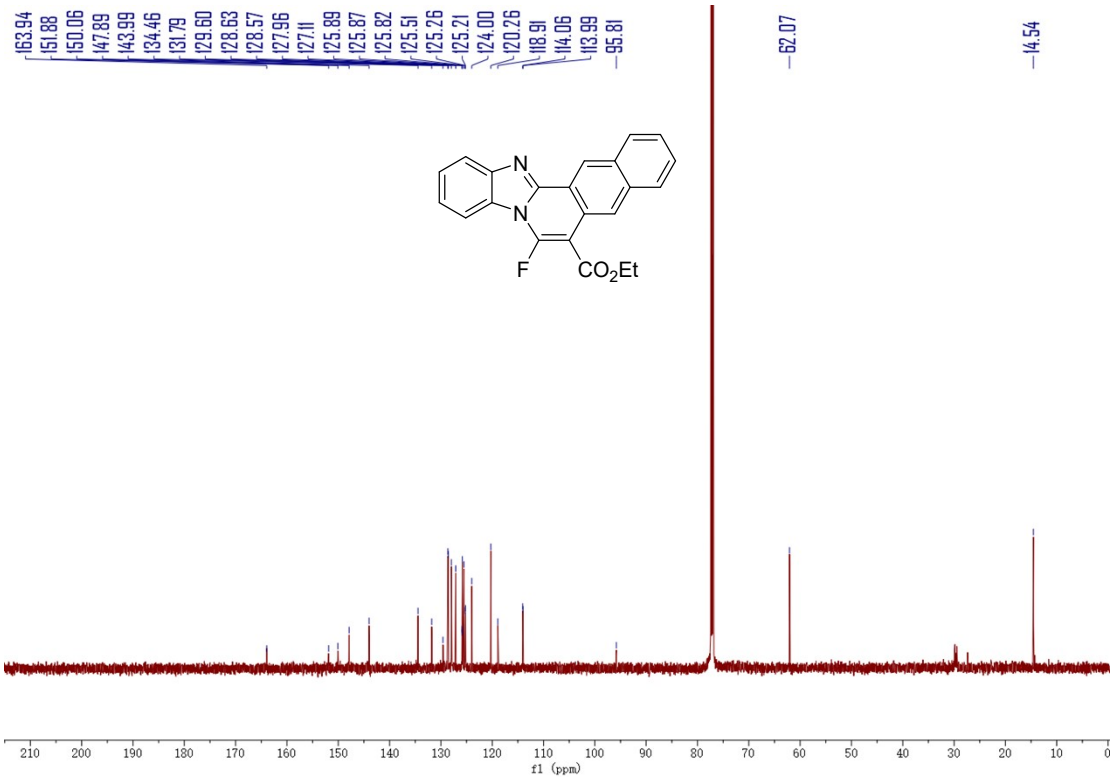
^{13}C NMR of **5g** (150 MHz, $CDCl_3$)



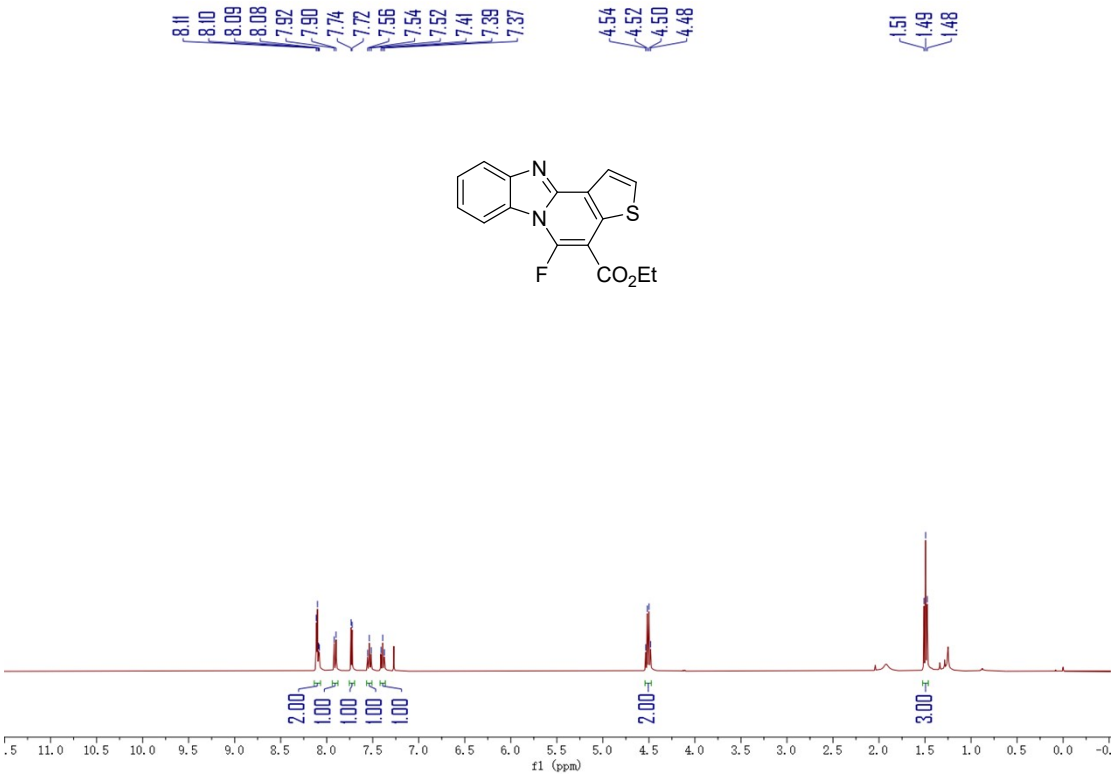
^{1}H NMR of **5h** (600 MHz, $CDCl_3$)



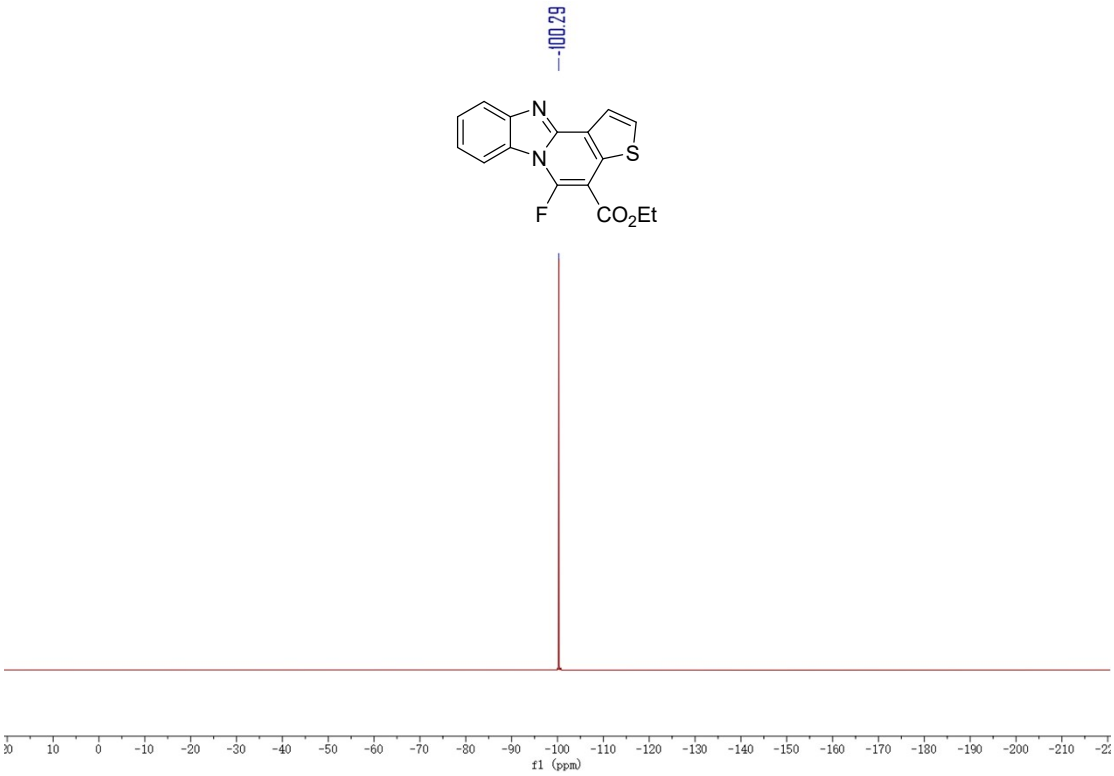
^{19}F NMR of **5h** (376 MHz, $CDCl_3$)



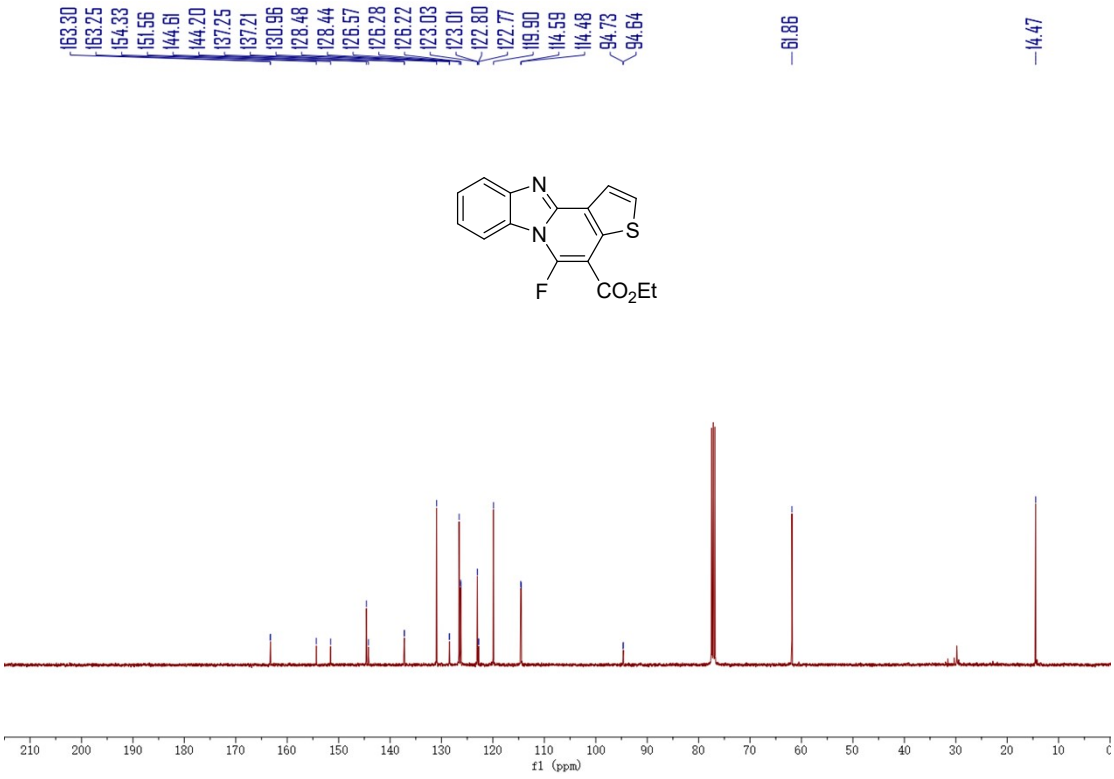
^{13}C NMR of **5h** (150 MHz, $CDCl_3$)



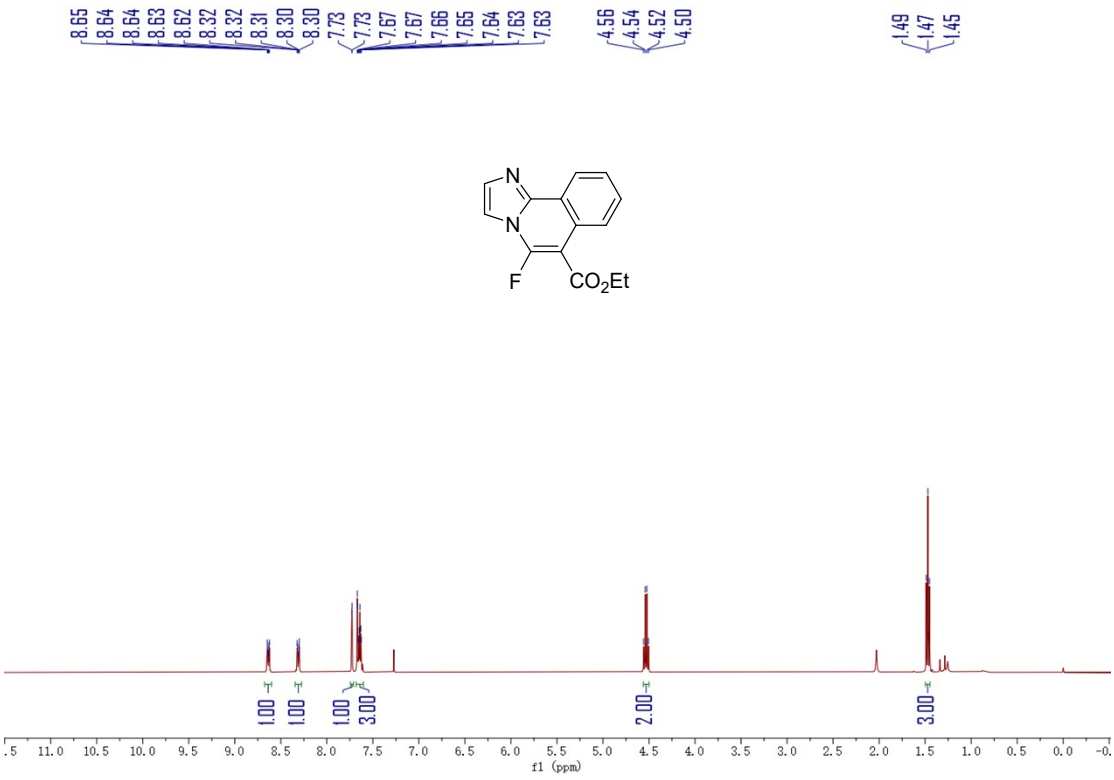
^{1}H NMR of **5i** (400 MHz, $CDCl_3$)



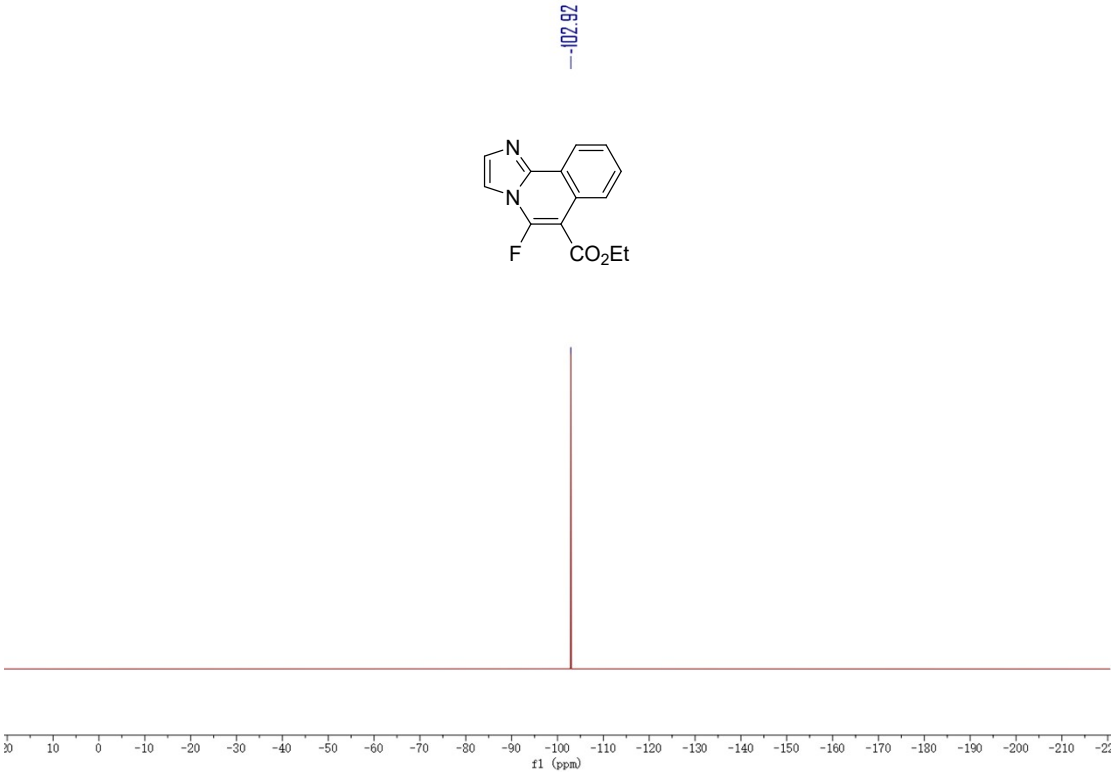
^{19}F NMR of **5i** (376 MHz, $CDCl_3$)



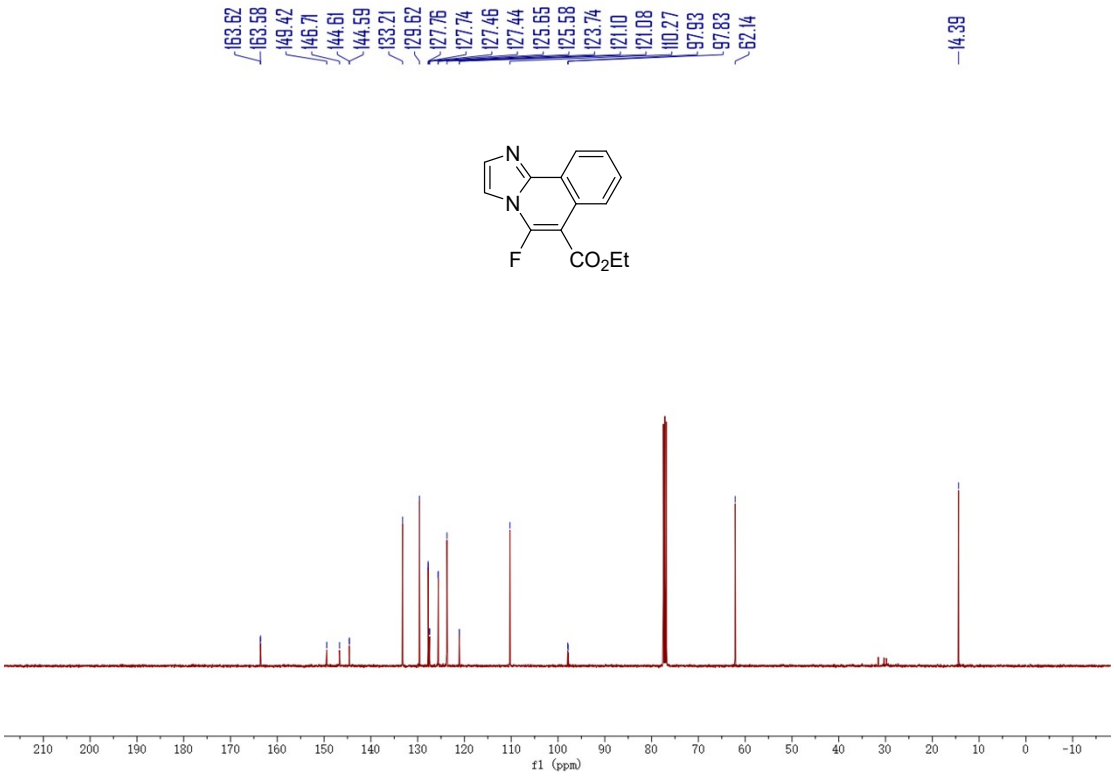
^{13}C NMR of **5i** (100 MHz, $CDCl_3$)



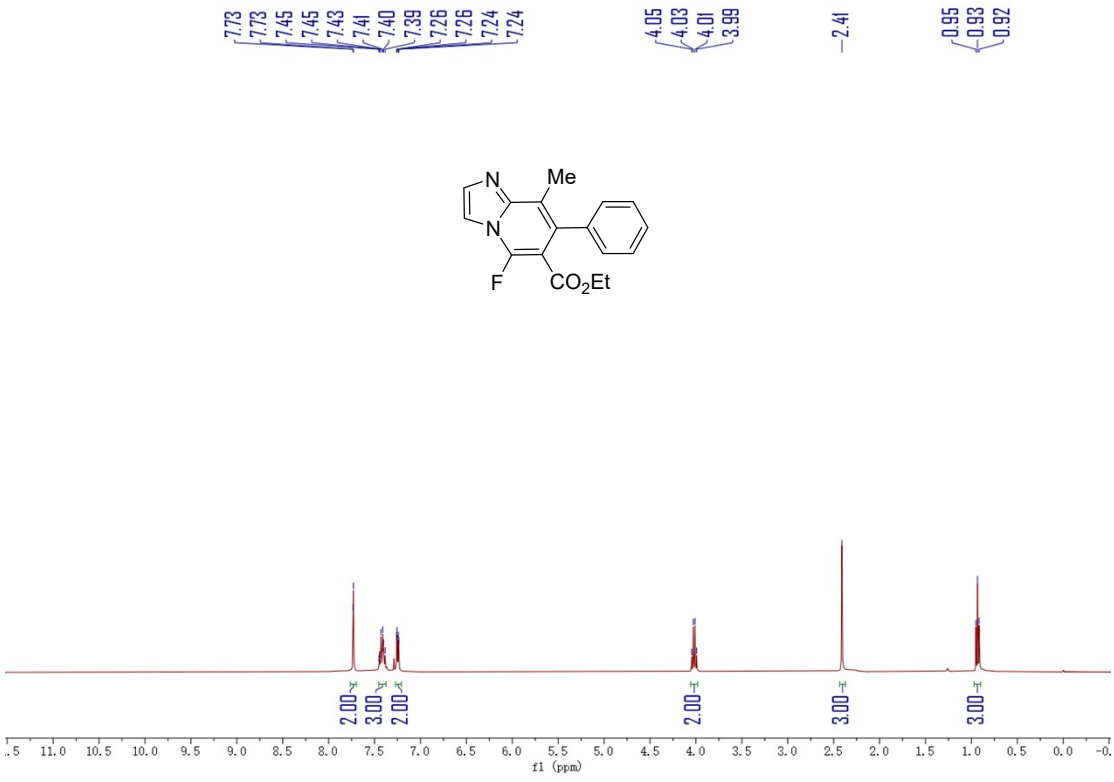
^{1}H NMR of **5j** (400 MHz, $CDCl_3$)



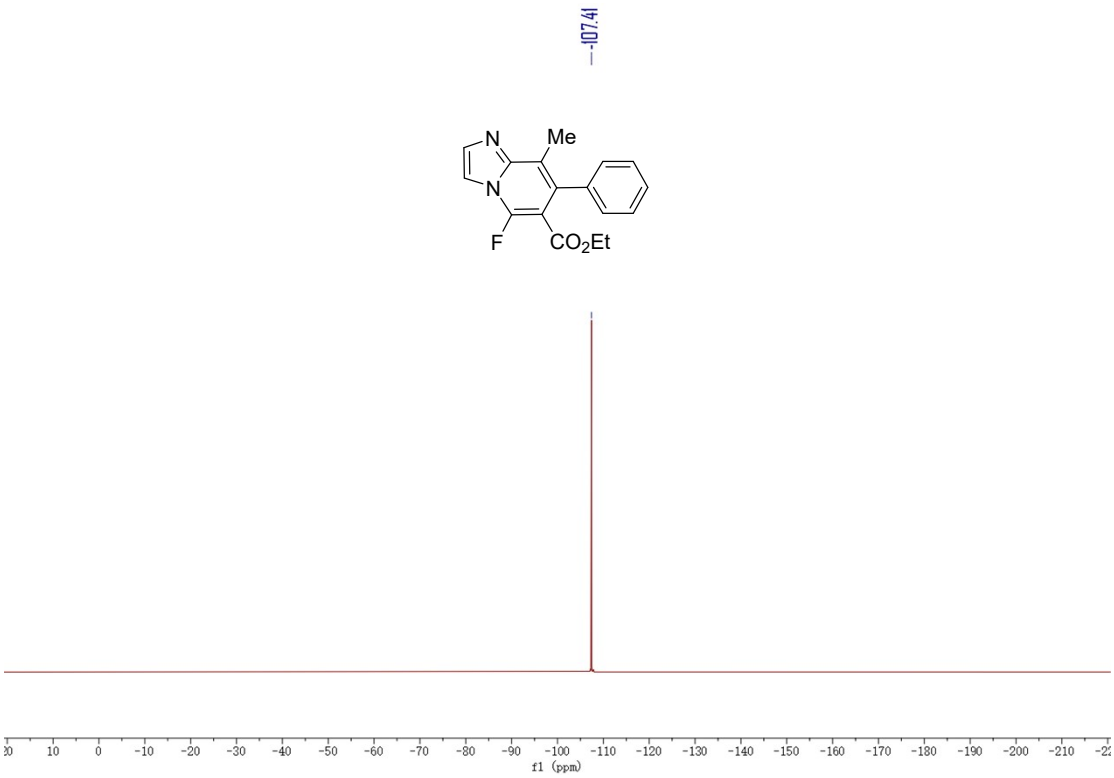
^{19}F NMR of **5j** (376 MHz, $CDCl_3$)



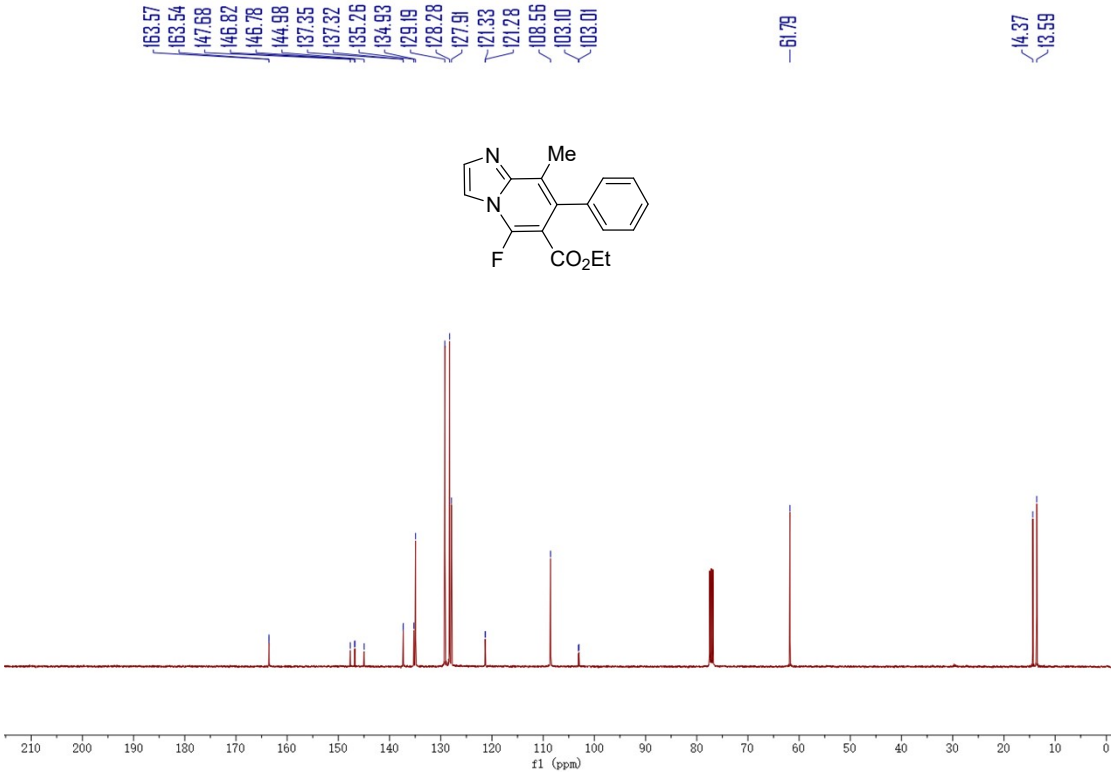
^{13}C NMR of **5j** (100 MHz, $CDCl_3$)



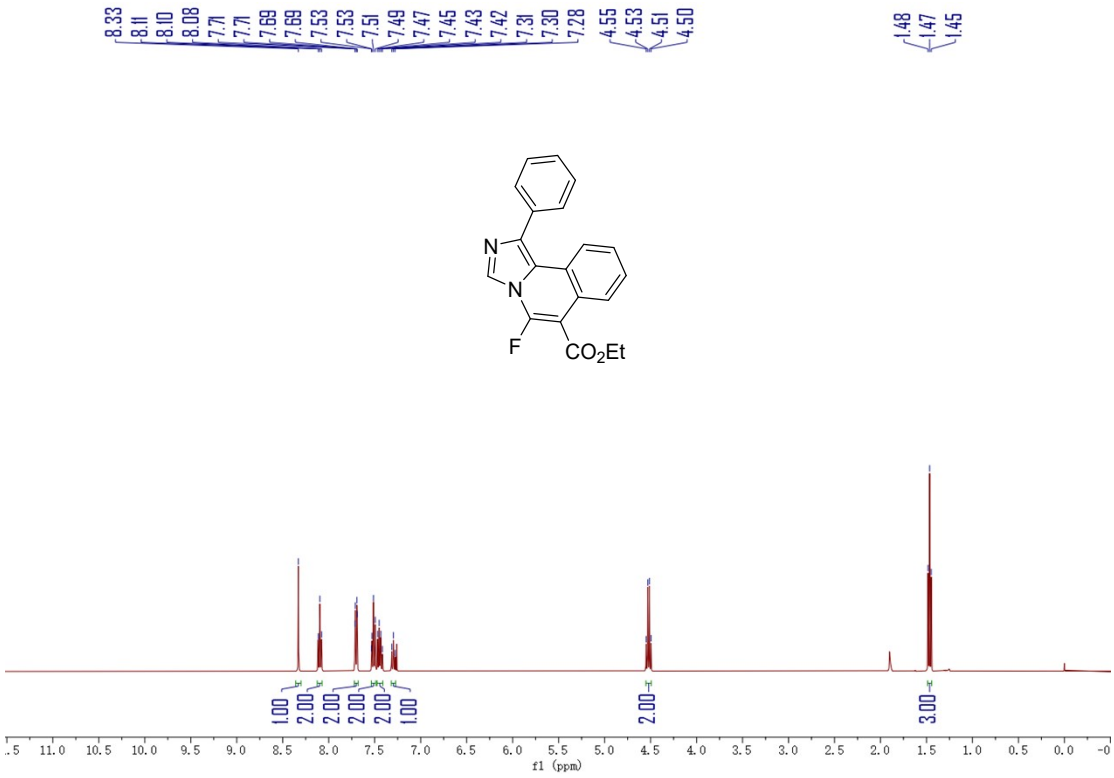
^{1}H NMR of **5k** (400 MHz, $CDCl_3$)



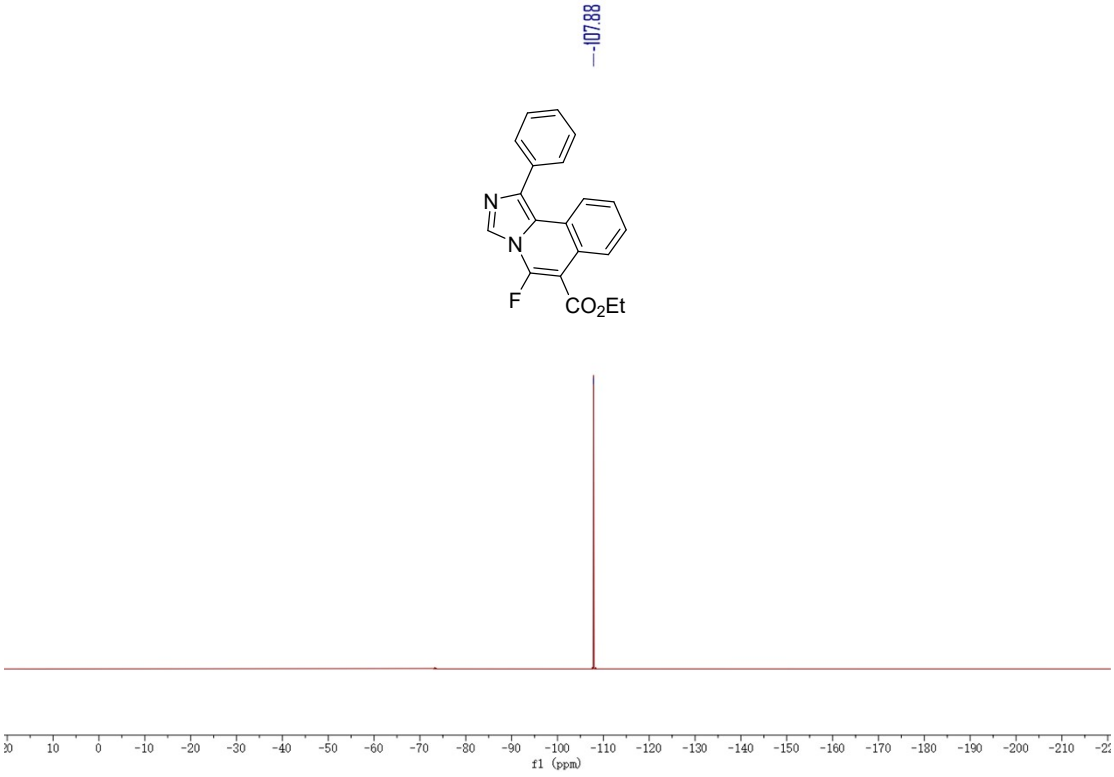
^{19}F NMR of **5k** (376 MHz, $CDCl_3$)



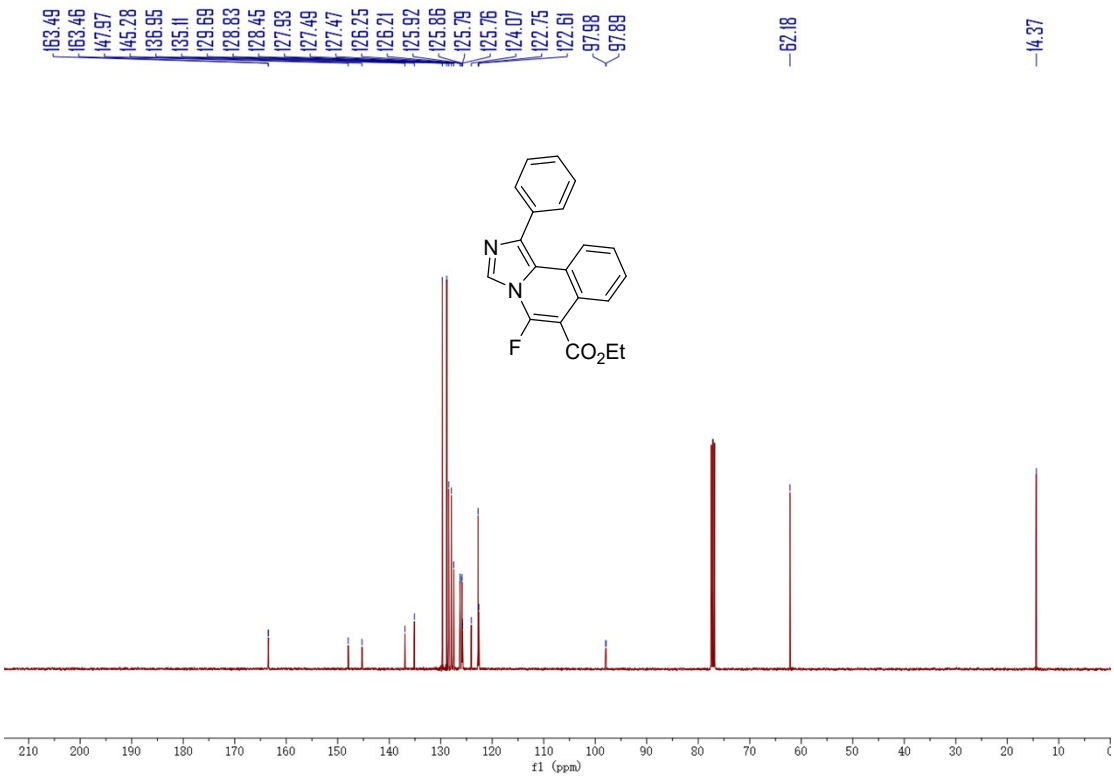
^{13}C NMR of **5k** (100 MHz, $CDCl_3$)



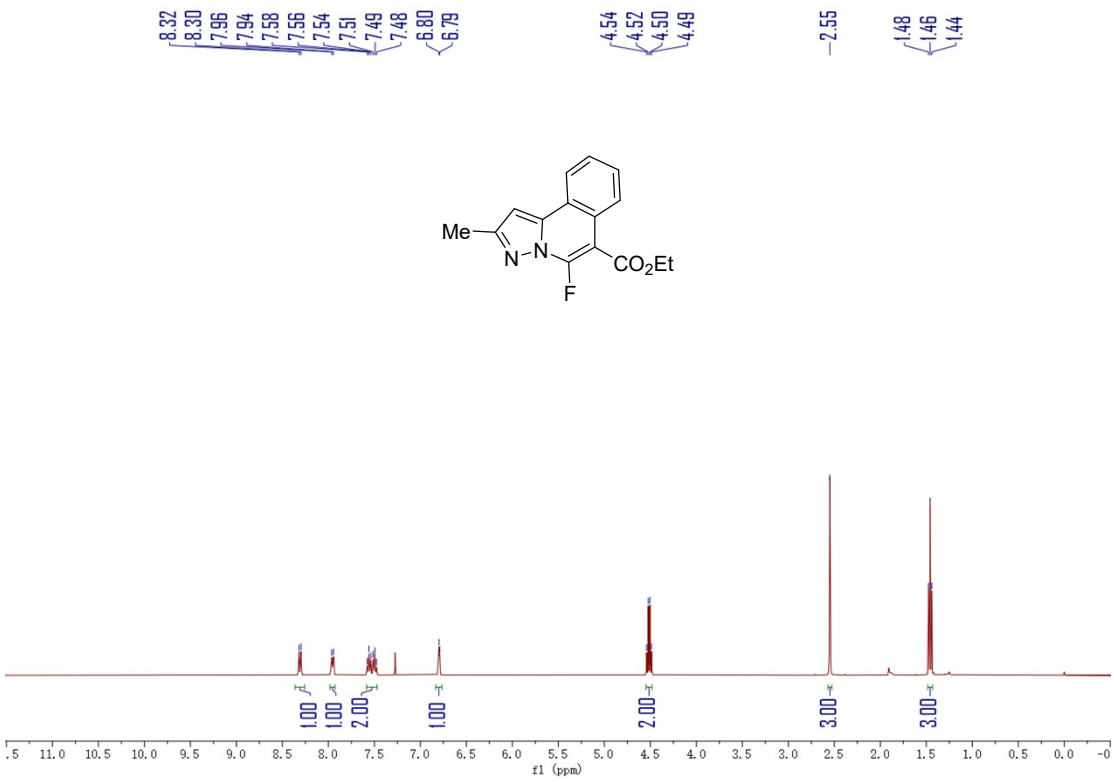
^{1}H NMR of **5l** (400 MHz, $CDCl_3$)



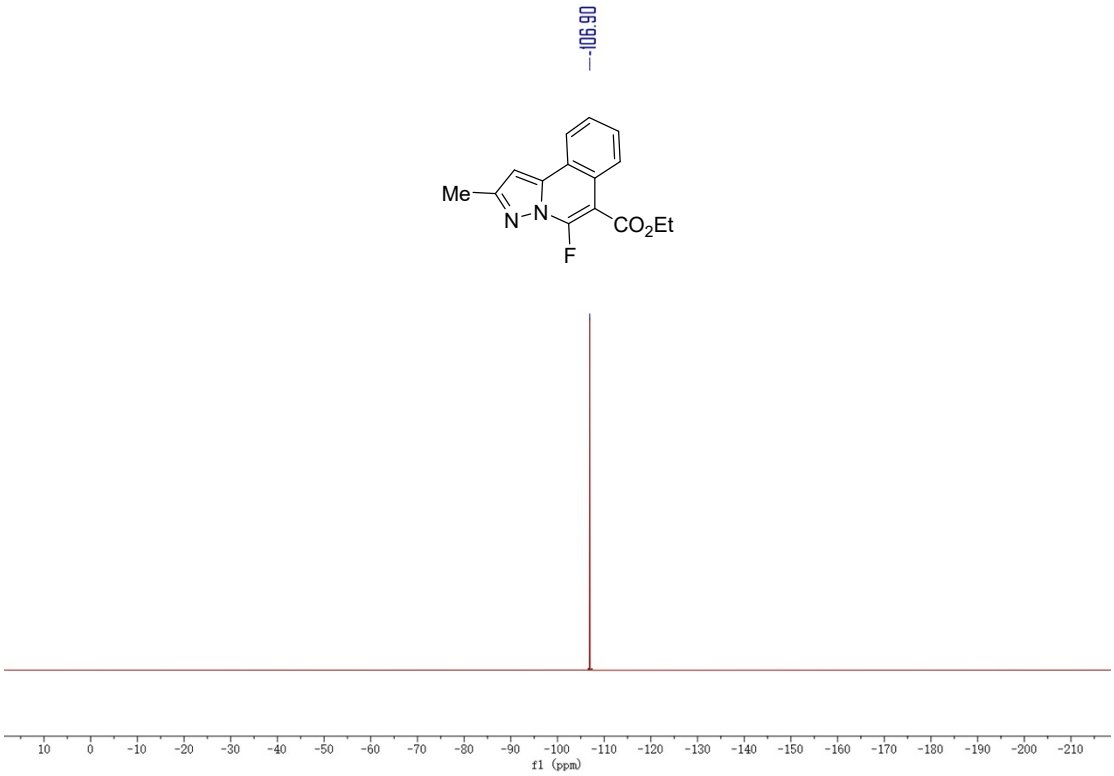
^{19}F NMR of **5l** (376 MHz, $CDCl_3$)



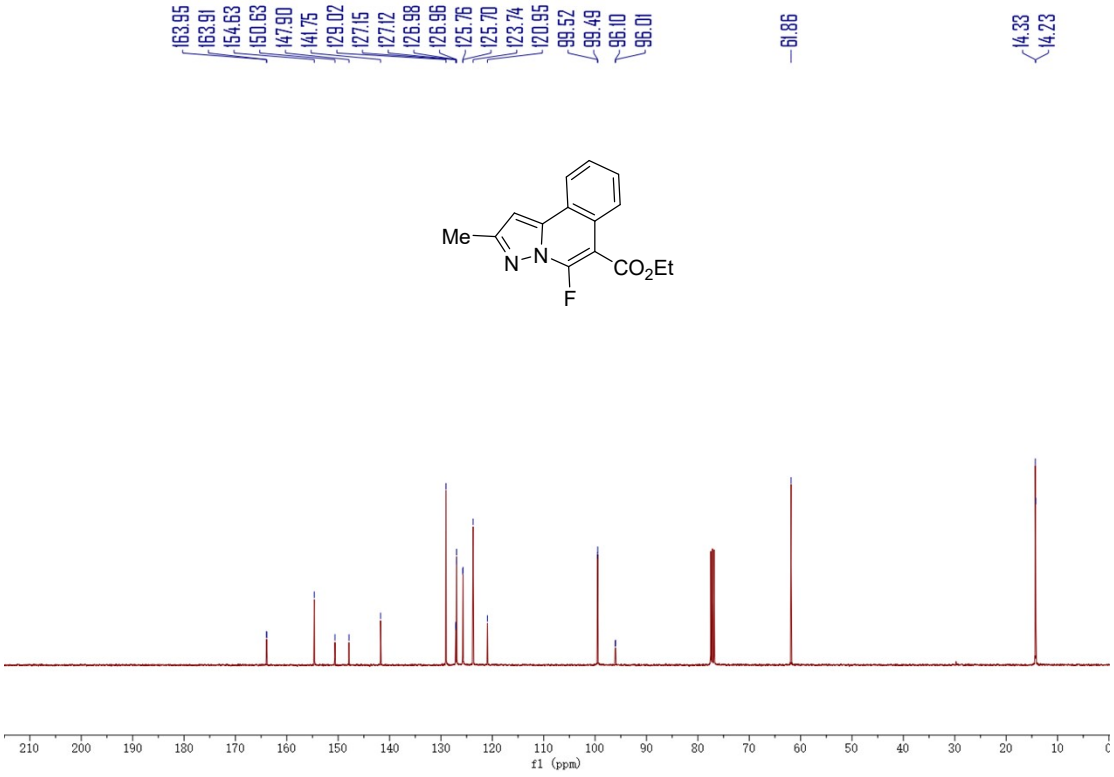
^{13}C NMR of **5l** (100 MHz, $CDCl_3$)



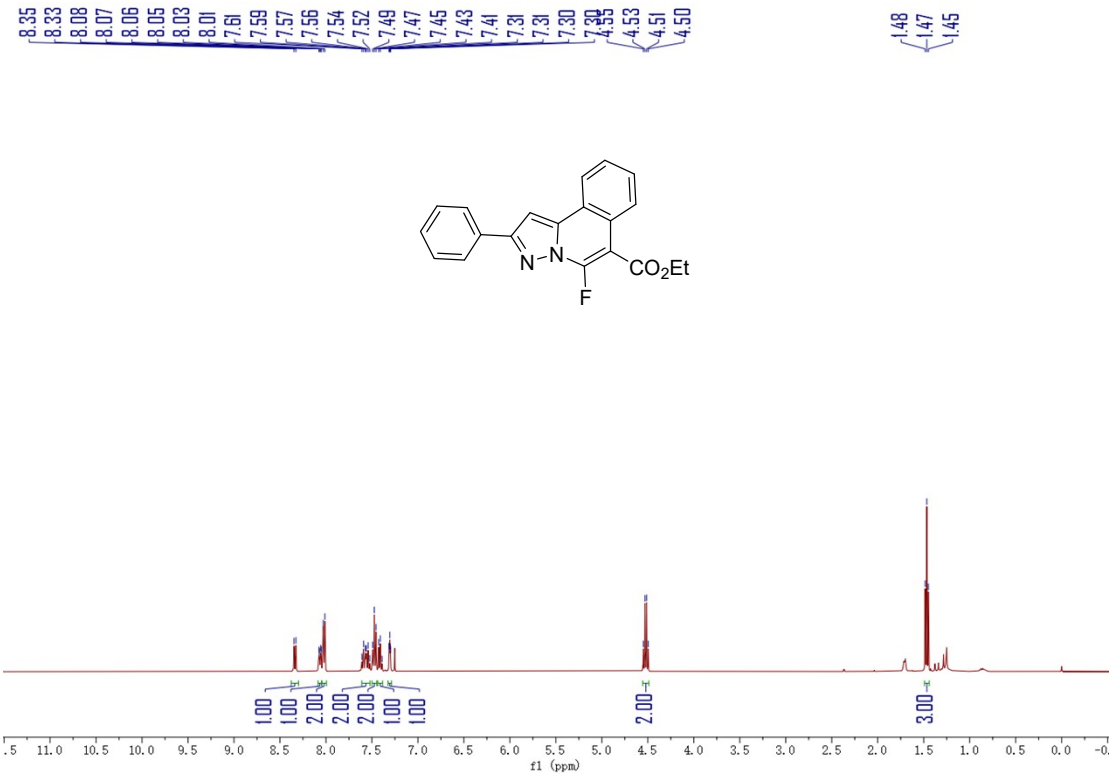
^{1}H NMR of **5m** (400 MHz, $CDCl_3$)



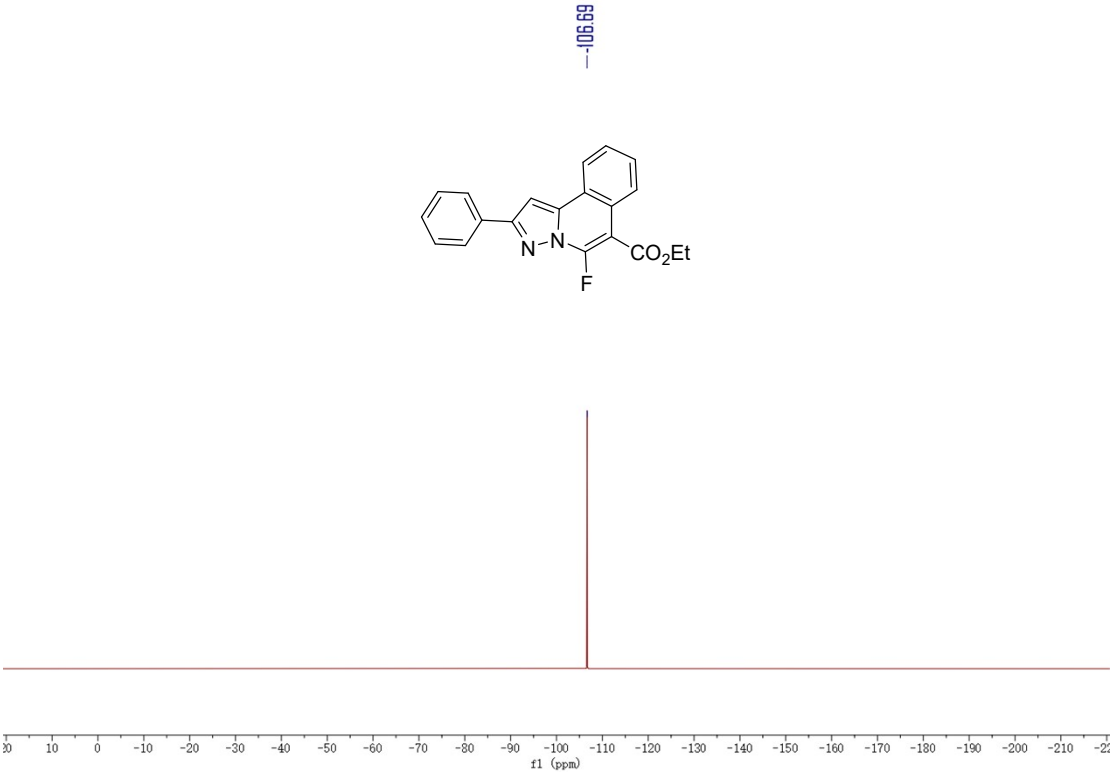
^{19}F NMR of **5m** (376 MHz, $CDCl_3$)



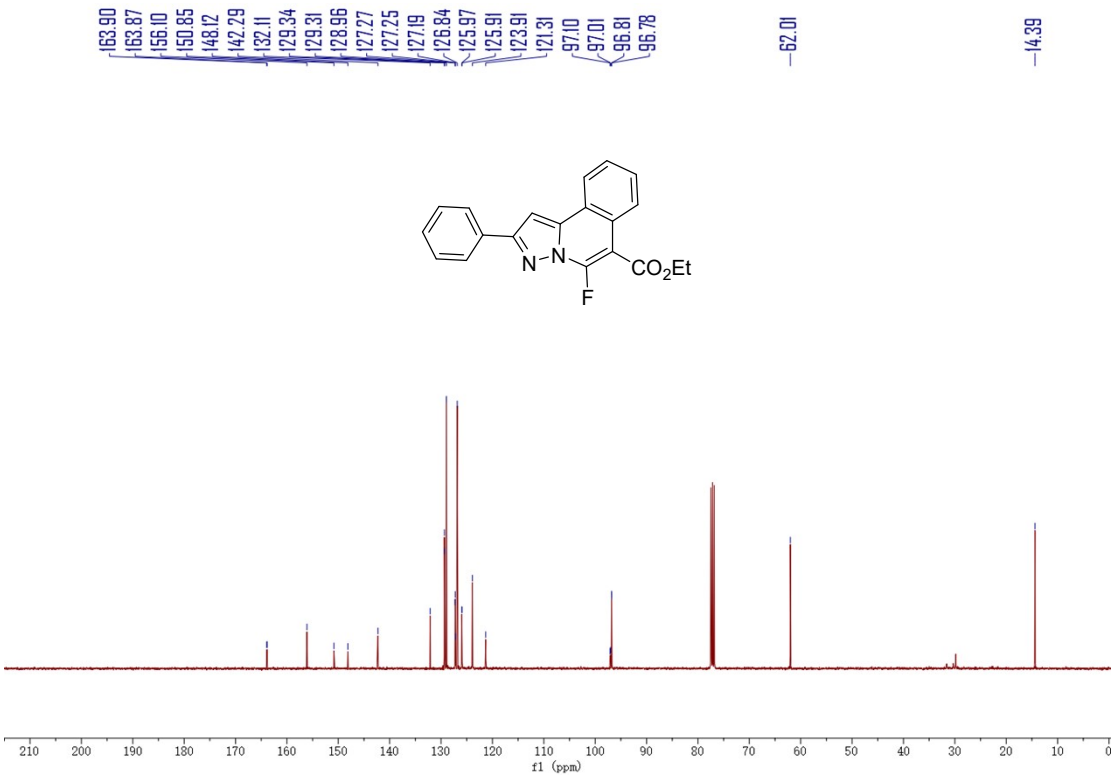
^{13}C NMR of **5m** (100 MHz, $CDCl_3$)



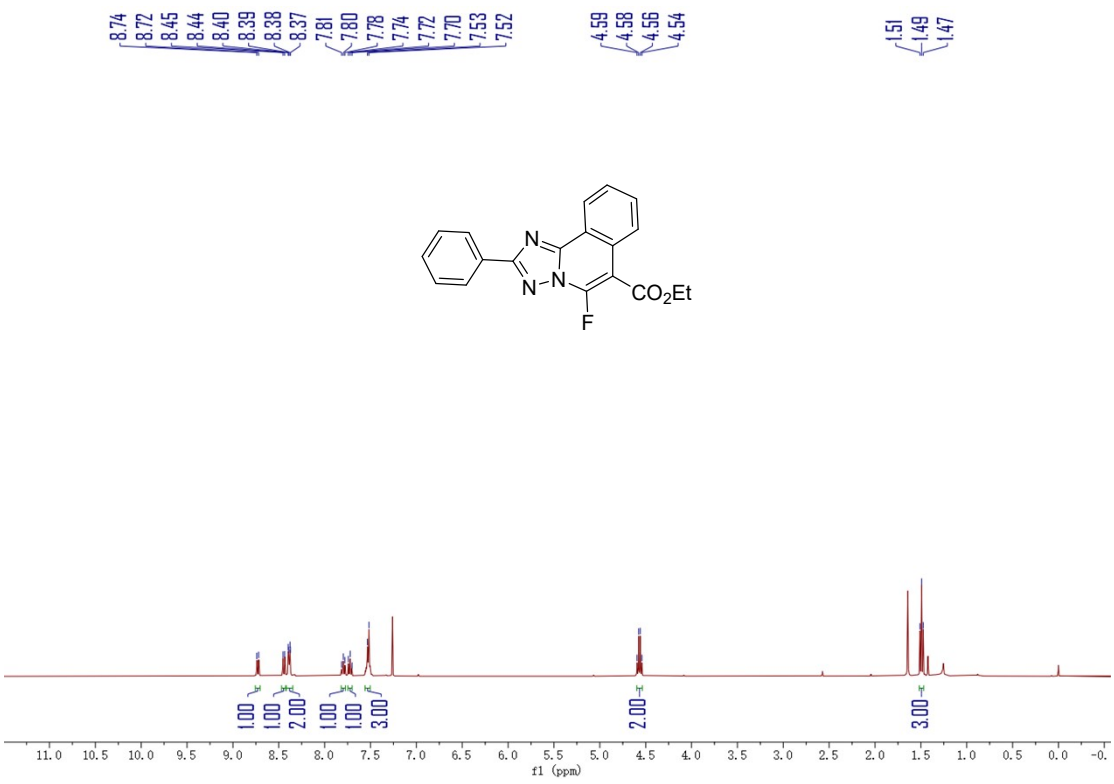
^{1}H NMR of **5n** (400 MHz, $CDCl_3$)



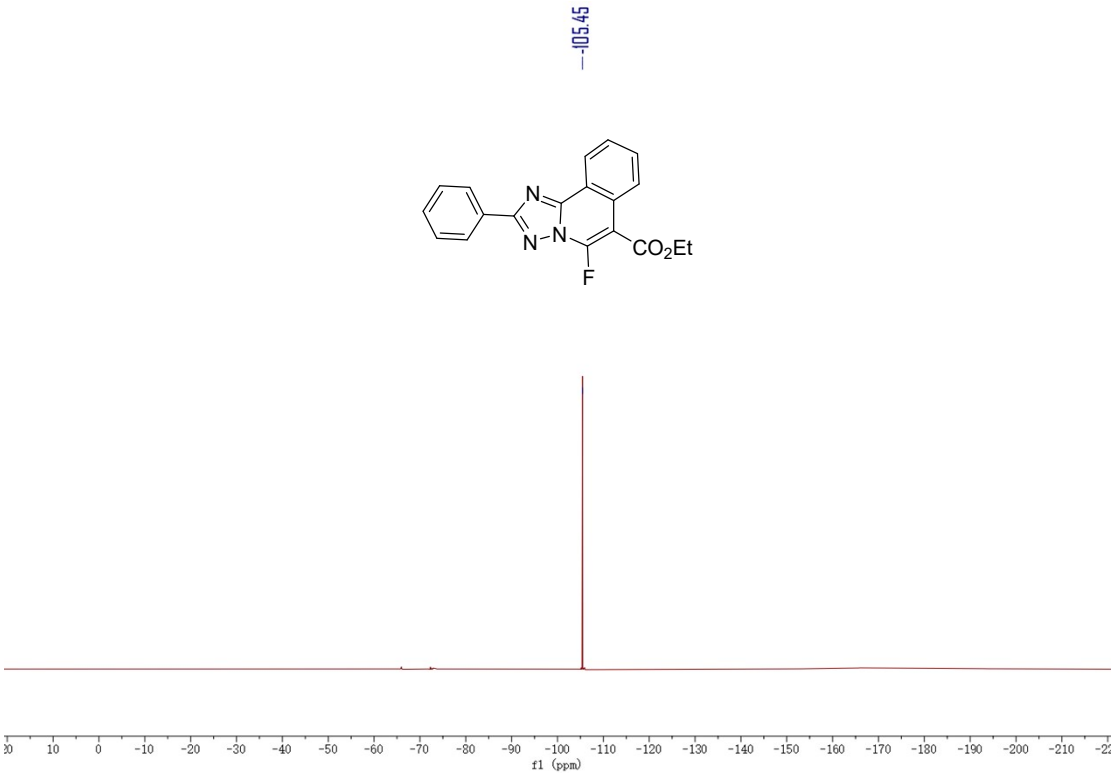
^{19}F NMR of **5n** (376 MHz, $CDCl_3$)



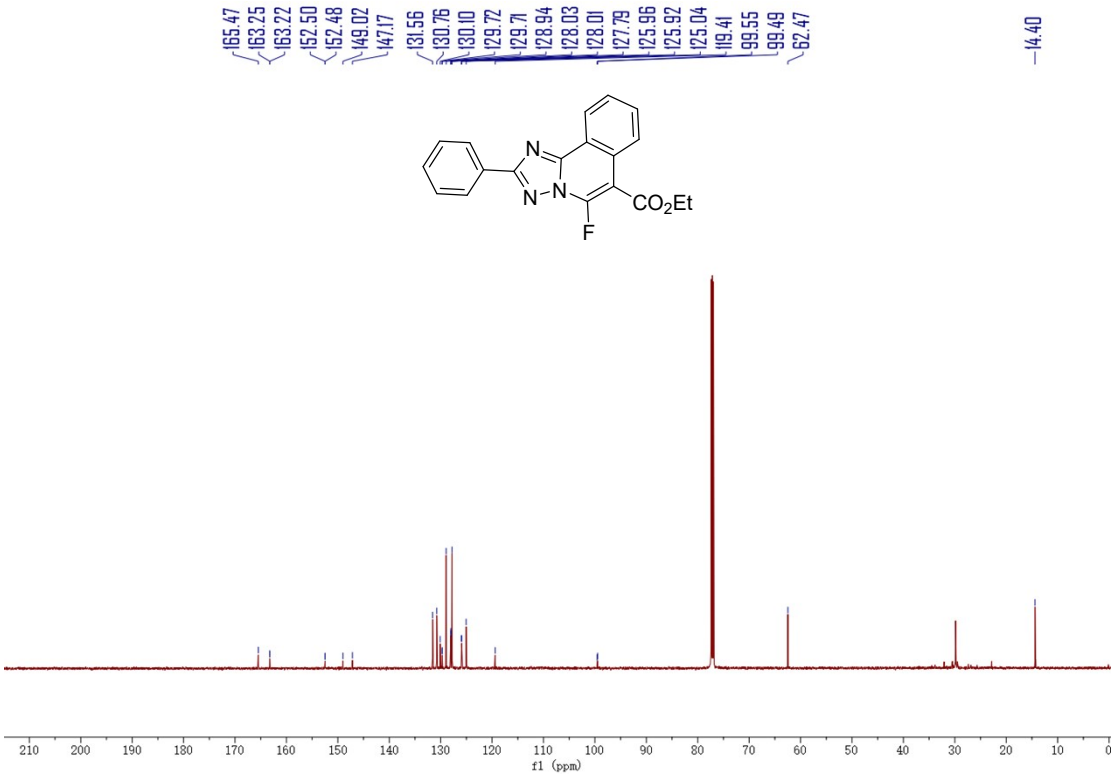
^{13}C NMR of **5n** (100 MHz, $CDCl_3$)



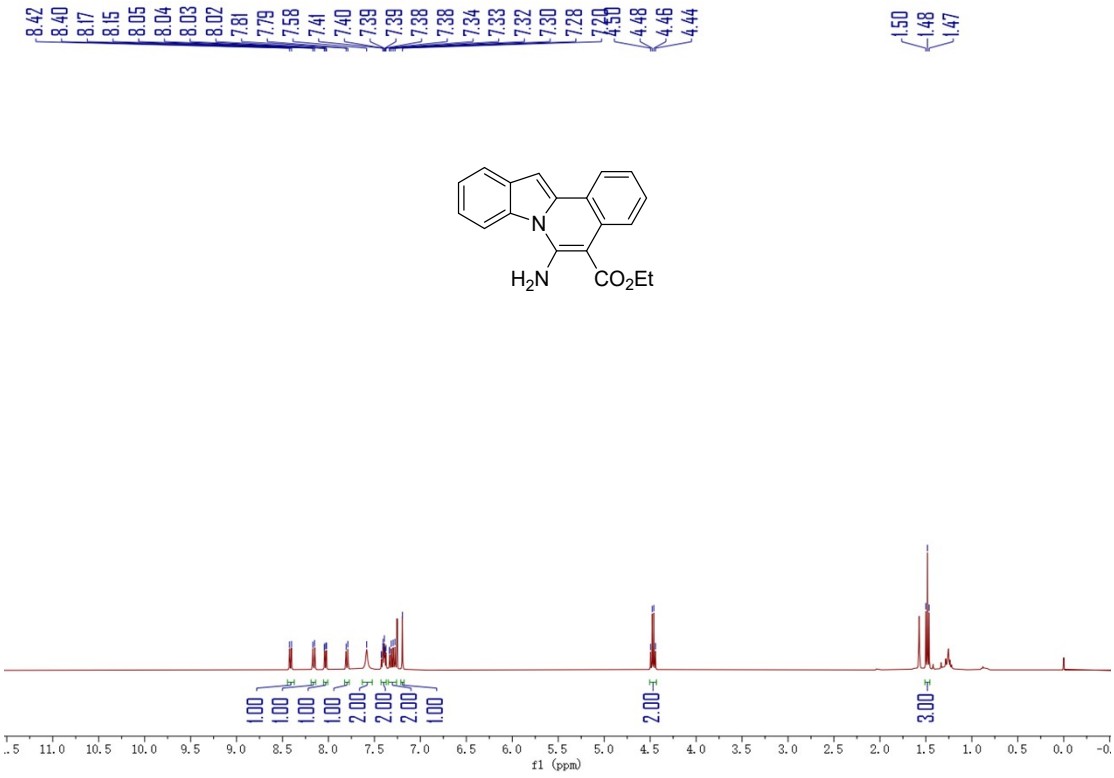
^{1}H NMR of **5o** (400 MHz, $CDCl_3$)



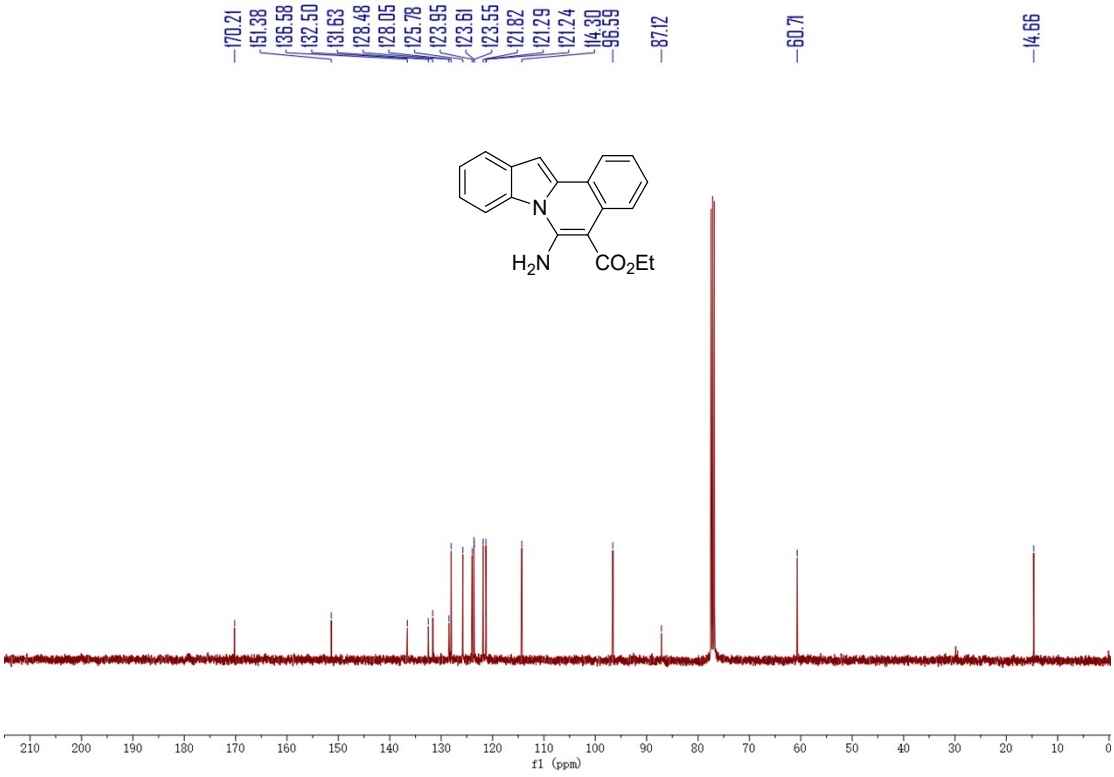
^{19}F NMR of **5o** (376 MHz, $CDCl_3$)



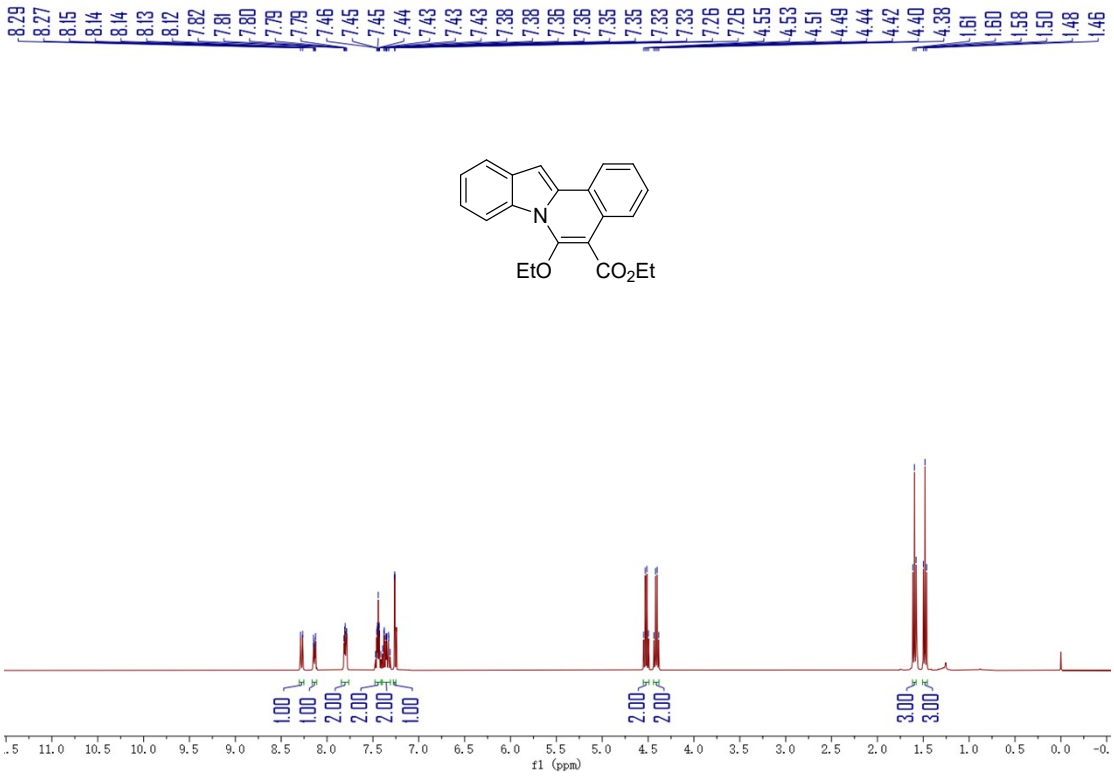
^{13}C NMR of **5o** (150 MHz, $CDCl_3$)



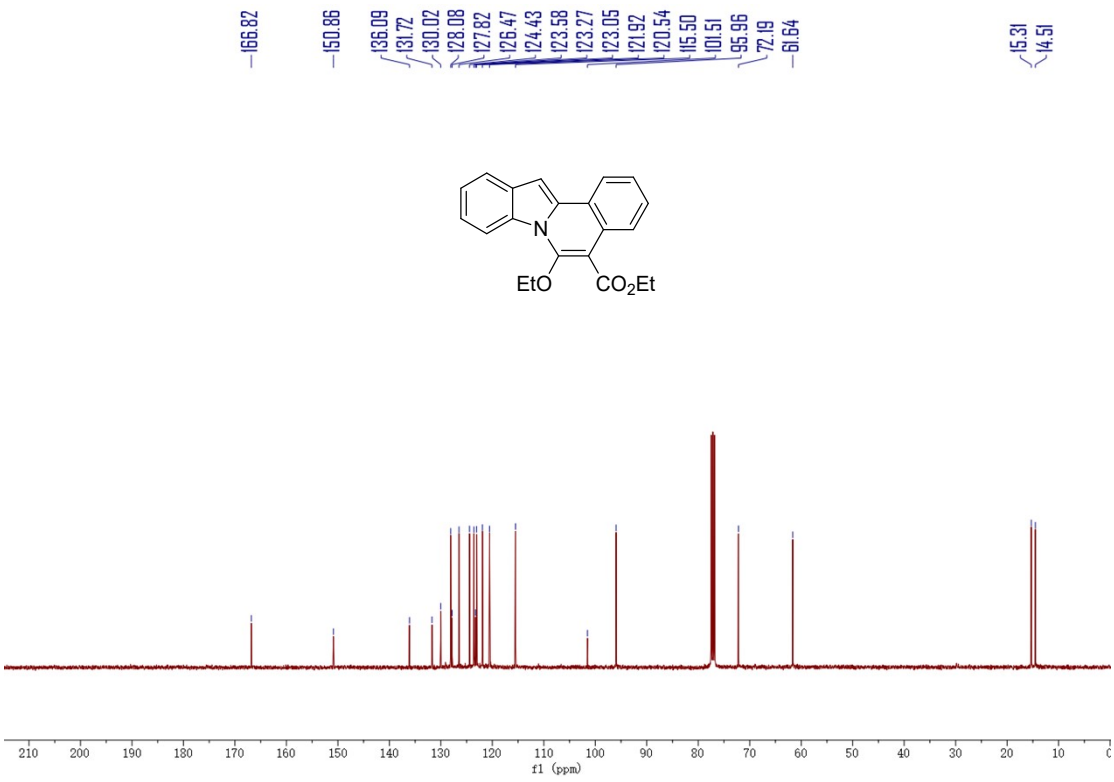
^{1}H NMR of **6** (400 MHz, $CDCl_3$)



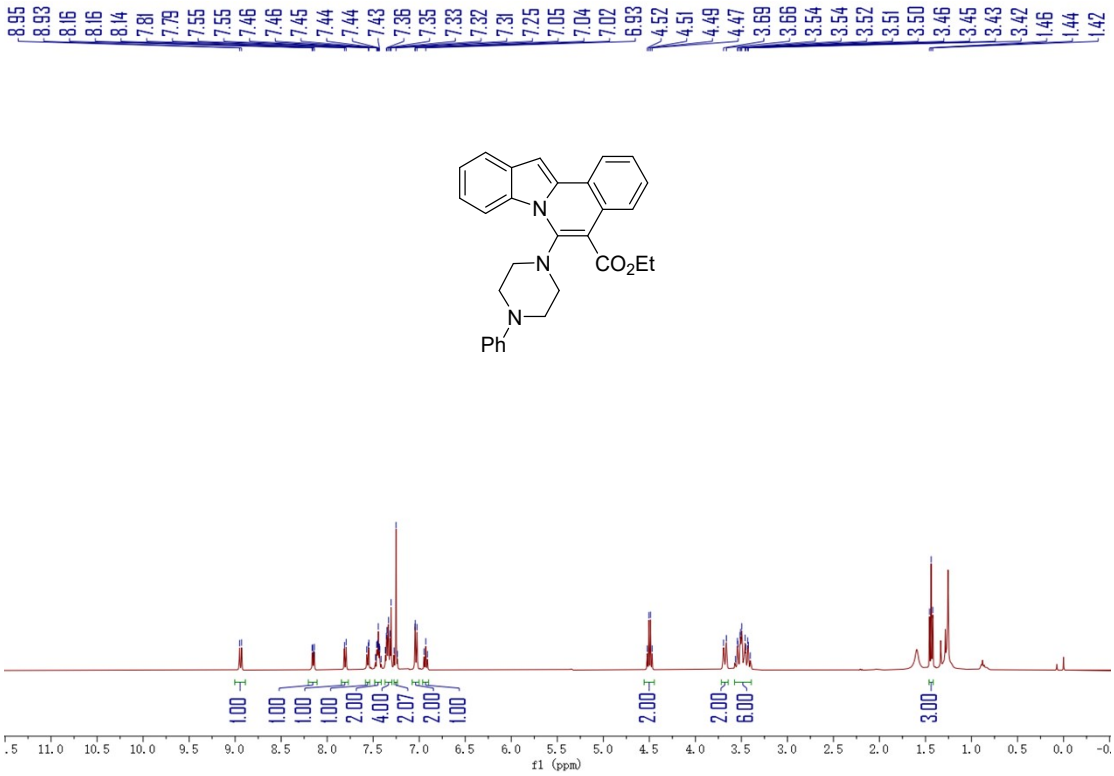
^{13}C NMR of **6** (100 MHz, $CDCl_3$)



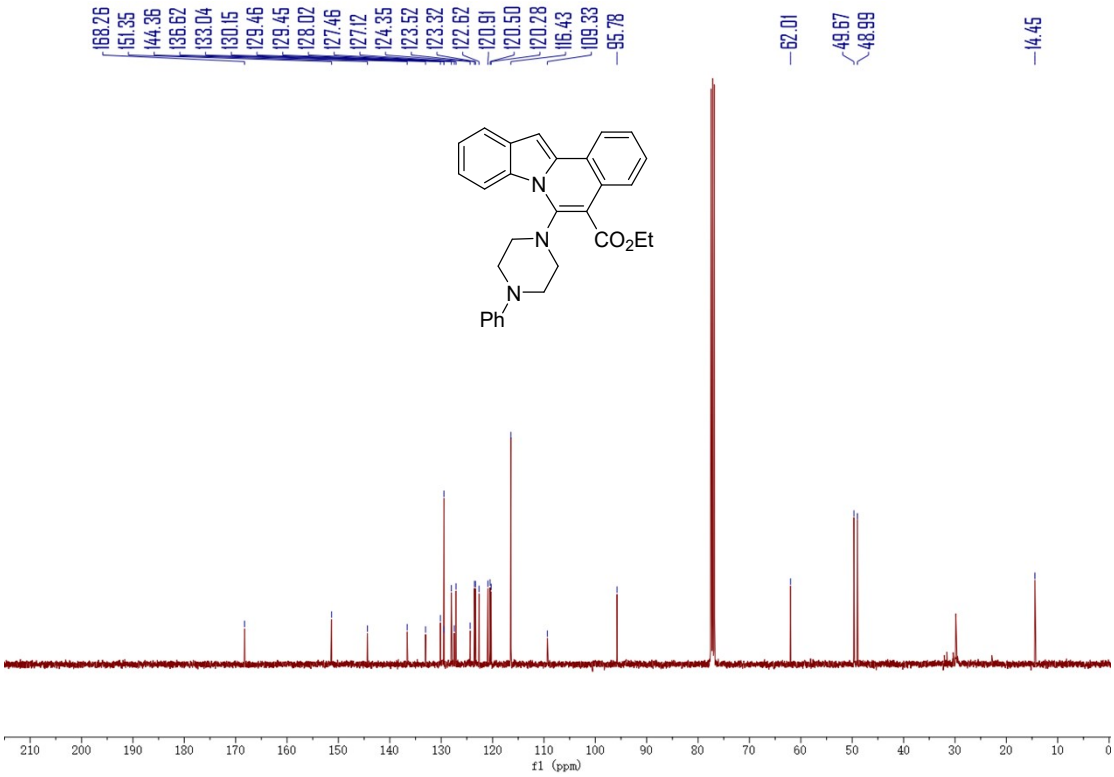
^{1}H NMR of **7** (400 MHz, $CDCl_3$)



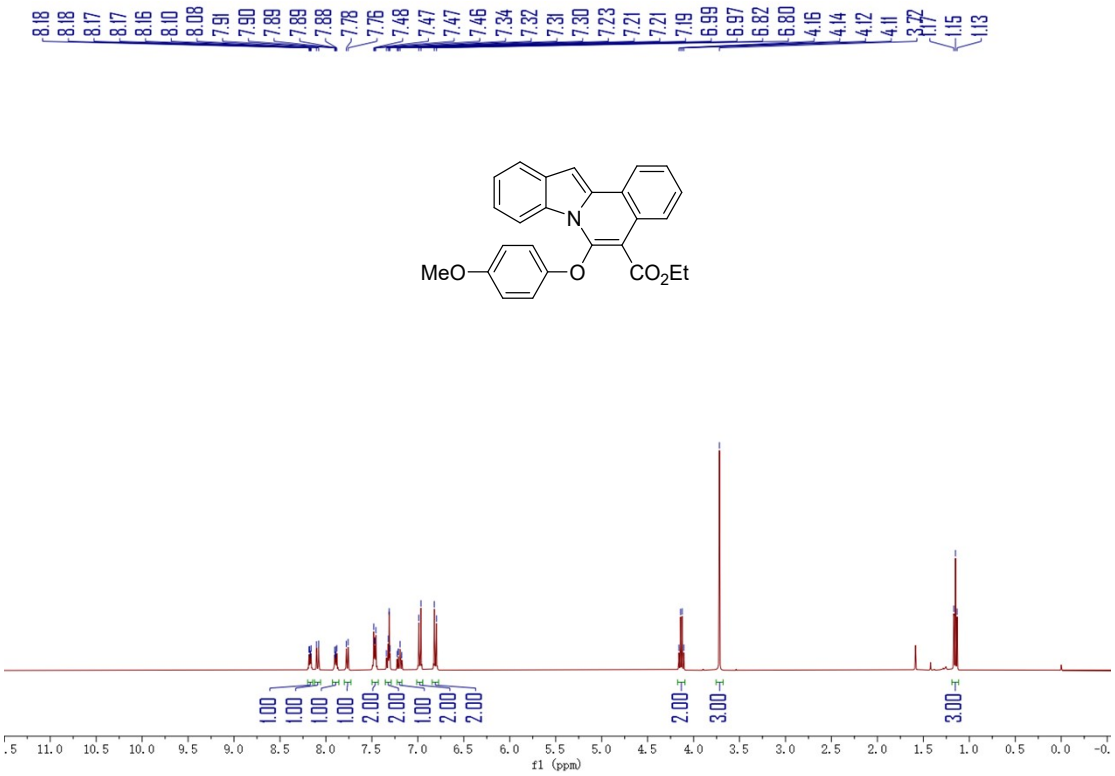
^{13}C NMR of **7** (100 MHz, $CDCl_3$)



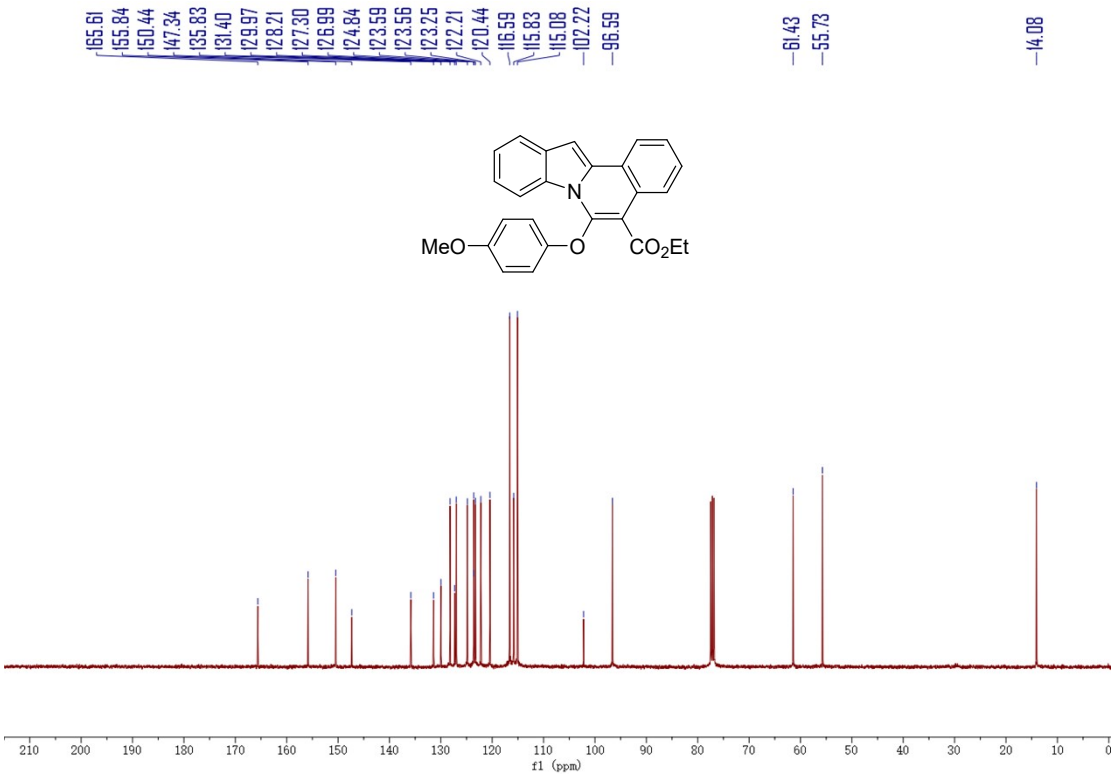
^{1}H NMR of **8** (400 MHz, $CDCl_3$)



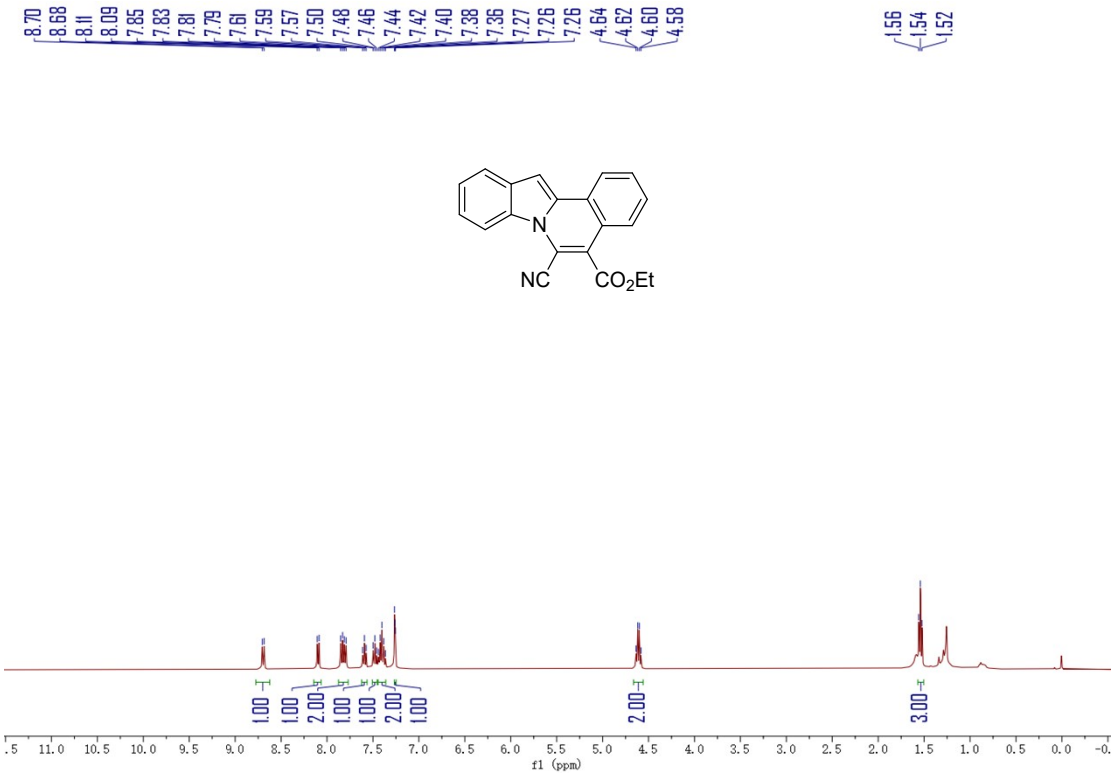
^{13}C NMR of **8** (100 MHz, $CDCl_3$)



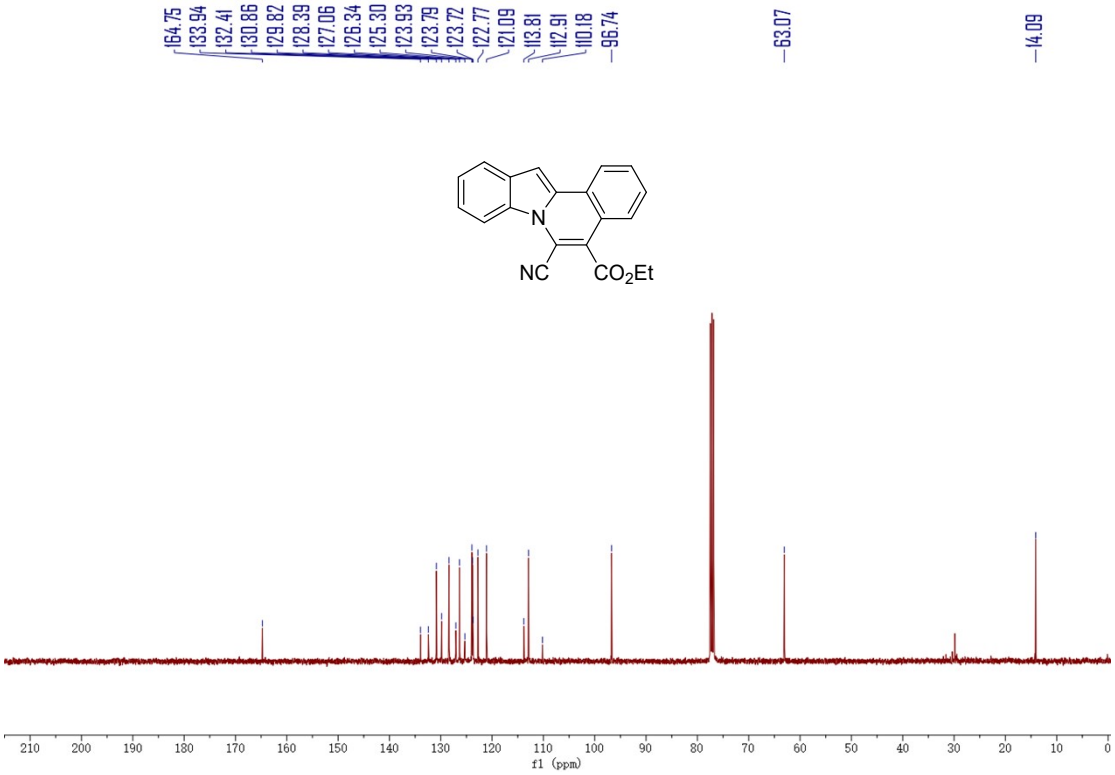
^{1}H NMR of **9** (400 MHz, $CDCl_3$)



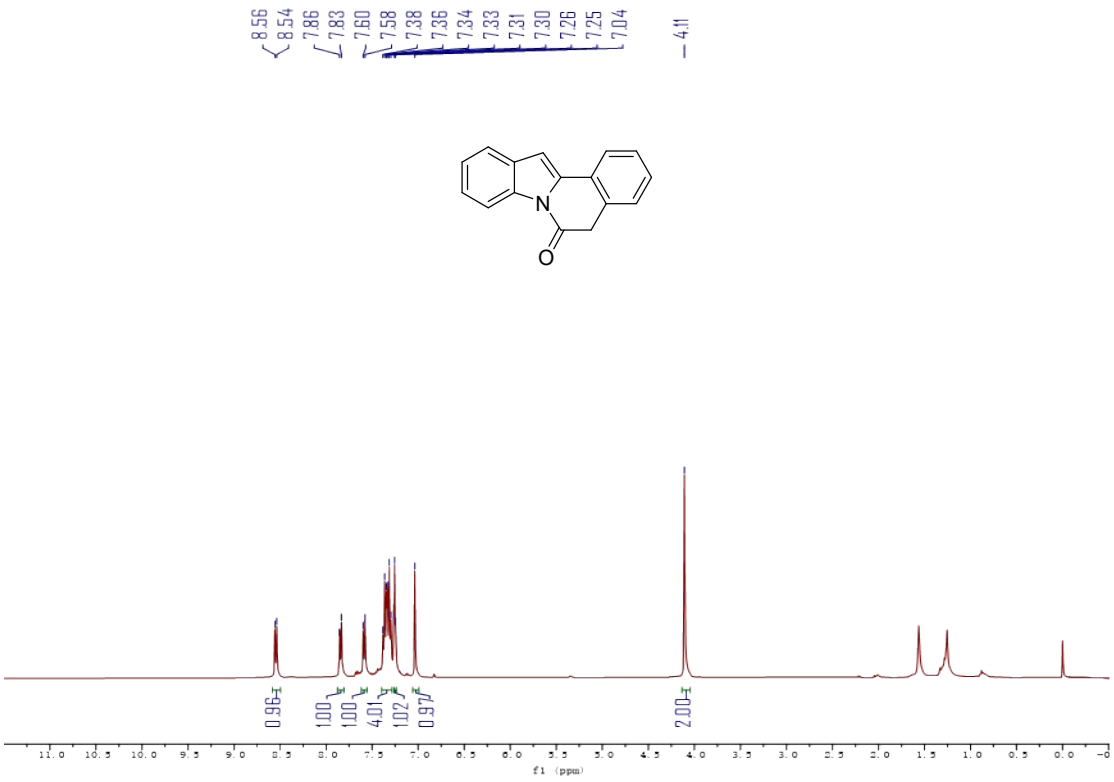
^{13}C NMR of **9** (100 MHz, $CDCl_3$)



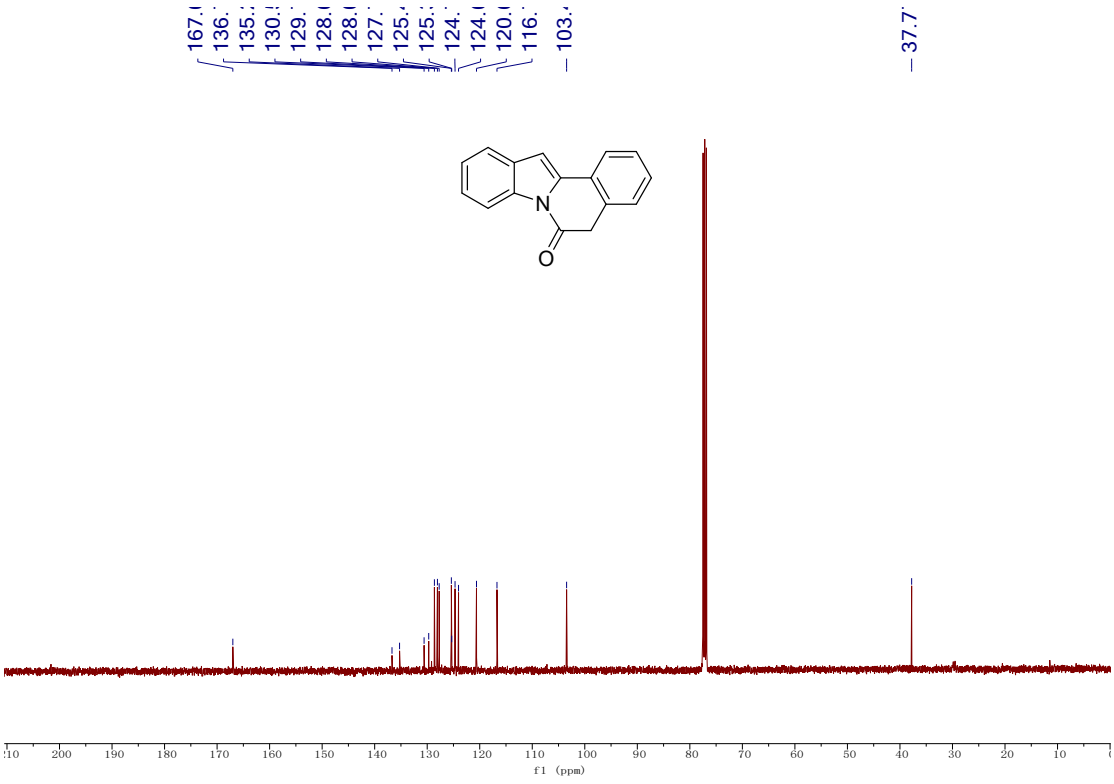
^{1}H NMR of **10** (400 MHz, $CDCl_3$)



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



^{1}H NMR of **11** (400 MHz, $CDCl_3$)



^{13}C NMR of **11** (100 MHz, $CDCl_3$)