

Supporting Information

Photo-induced benzannulation of 1,3-dicarbonyl compounds with alkynes under external-oxidant-free condition

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Table of contents

1. General Information	S1
2. Substrate's Preparation	S2
3. General Experimental Procedure	S8
4. Mechanism Study	S10
5. Characterization Data for Compounds	S18
6. Reference	S37
7. Copies of ^1H NMR, ^{13}C NMR and ^{19}F NMR	S38

1. General Information

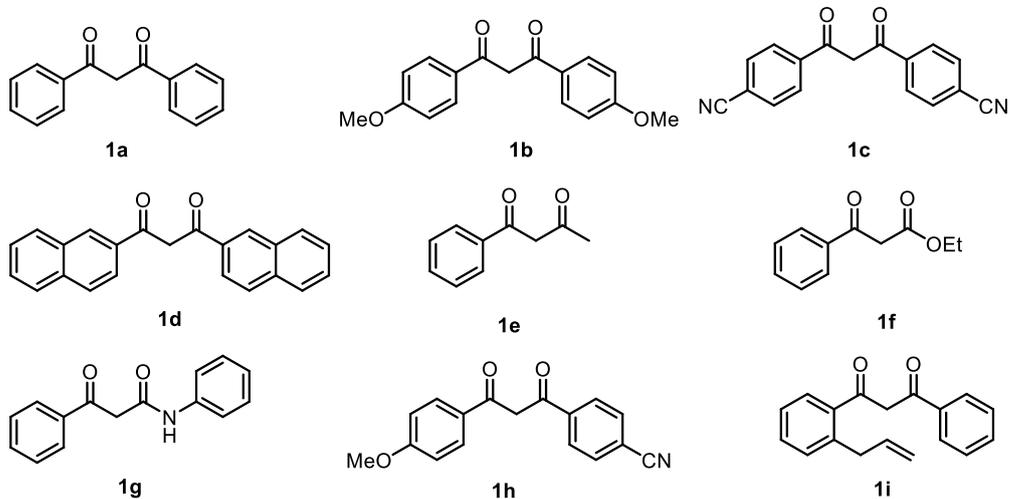
All reagents were purchased from commercial suppliers and used without further purification. Flash chromatography was performed using silica gel (200 - 300 mesh). Analytical thin-layer chromatography (TLC) was carried out on silica gel GF254 plates, and the products were visualized under UV light. ^1H NMR spectra were recorded at room temperature in 5 mm tubes with CDCl_3 as the solvent using a Bruker 400 MHz spectrometer (400 MHz) or a Bruker AVANCE III HD 600 (600 MHz). ^{13}C NMR spectra were recorded at room temperature in 5 mm tubes with CDCl_3 as the solvent using a Bruker 400 MHz spectrometer (101 MHz) or a Bruker AVANCE III HD 600 (150 MHz). ^{19}F NMR spectra were recorded at room temperature in 5 mm tubes with CDCl_3 as the solvent using a Bruker AVANCE III HD 600 (565 MHz). NMR spectra recorded in CDCl_3 were referenced to CHCl_3 at 7.26 ppm (^1H) or 77.16 ppm (^{13}C). The following abbreviations were used: m (multiplet), s (singlet), d (doublet), t (triplet), q (quartet), dd (doublet of doublets), etc. High-resolution mass spectrometry (HRMS) was performed on a Bruker Daltonics APEX II 47e mass spectrometer using electrospray ionization (ESI). Blue LED irradiation was carried out using Tao Yuan LEDs (3 W, $\lambda = 440$ nm, @1200 mA). For irradiation, the reaction vessels were made of ordinary glass and the distance between the light source and the vessel was approximately 0.5 cm.

2. Substrate's Preparation

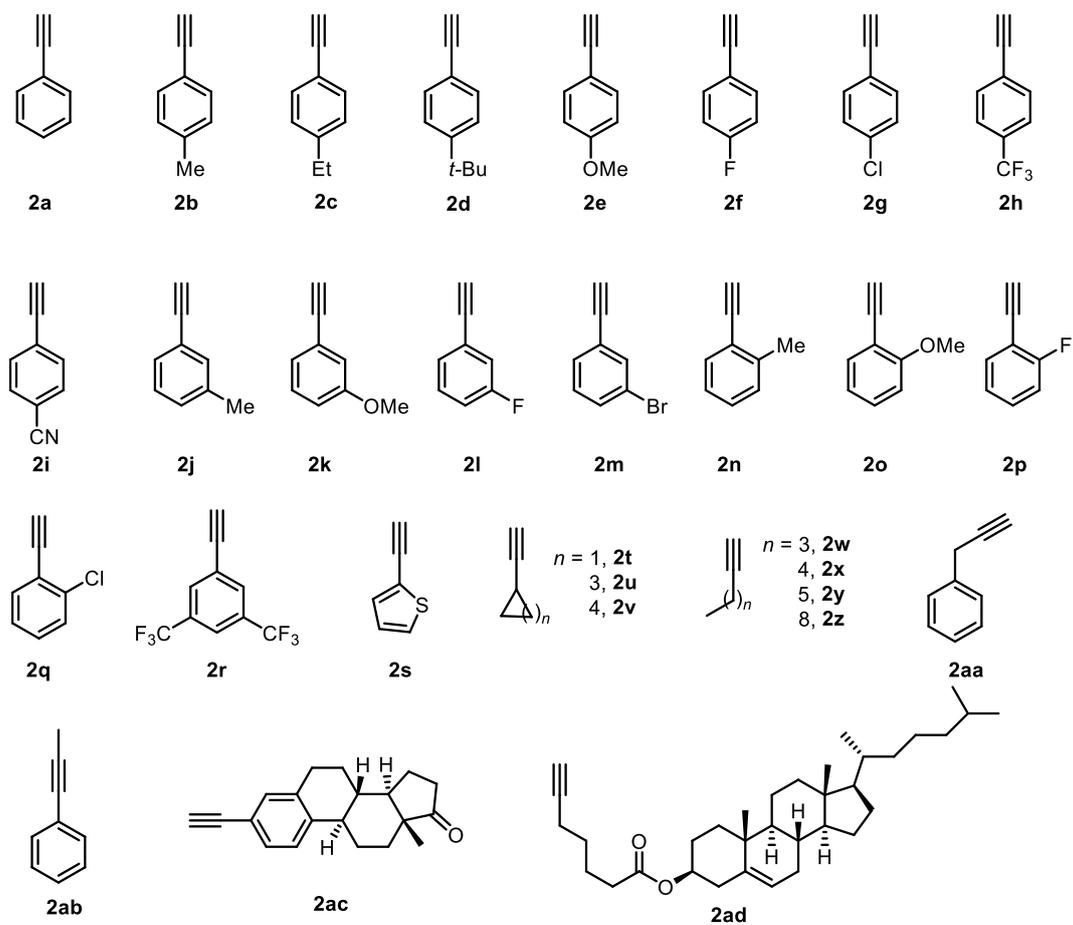
2.1 Involved Substrates

Scheme S1. Involved Substrates

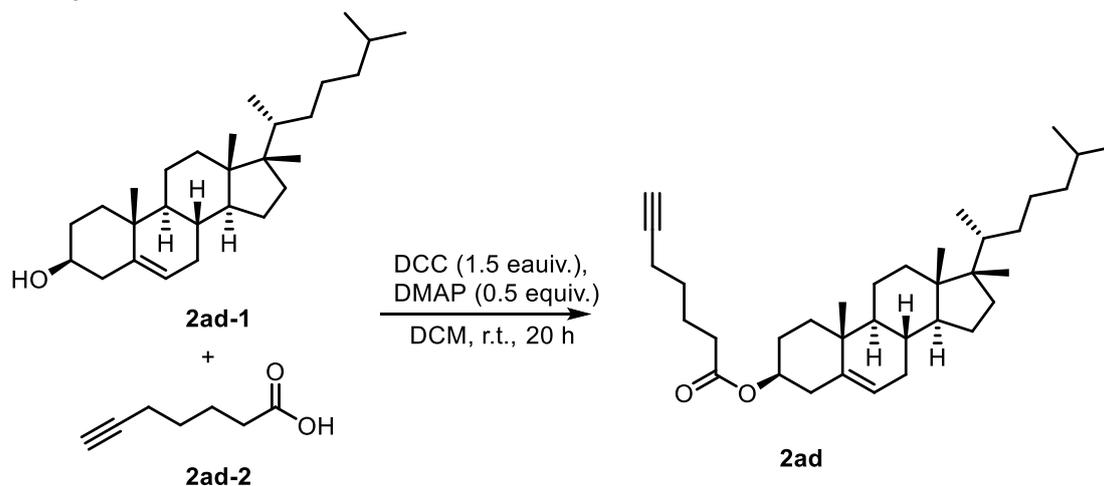
Involved 1,3-dicarbonyl compounds 1



Involved alkynes 2

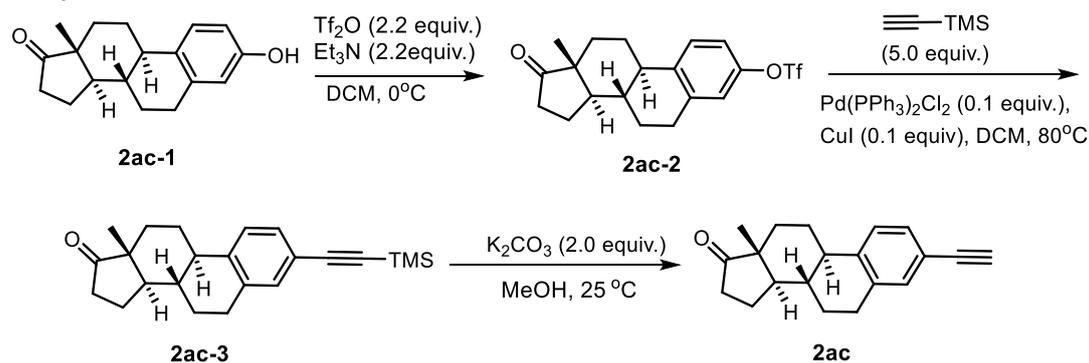


2.2 Synthesis of Substrates 2ad



According to previous report¹: At 0 °C, DCC (9 mmol, 1.5 equiv., 9 mL of a 1 M solution in DCM) and DMAP (3 mmol, 0.5 equiv.) were added successively to a solution of cholesterol (6 mmol, 1 equiv.) and 5-hexynoic acid (7.2 mmol, 1.2 equiv.) in DCM (20 mL). The mixture was warmed to room temperature and stirred for 20 h. The suspension was filtered and the solid washed with TBME (Methyl *tert*-butyl ether). The combined filtrates were concentrated under reduced pressure, and the residue was purified by column chromatography, affording **2ad** in 85% yield.

2.3 Synthesis of Substrates **2ac**

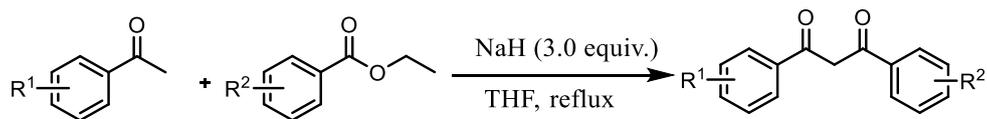


According to previous report²: To **2ac-1** (4 mmol, 1 equiv.) in dry DCM (15 mL) at 0°C , Et_3N (8.8 mmol, 2.2 equiv.) and Tf_2O (8.8 mmol, 2.2 equiv.) were added. The reaction mixture was stirred at 0°C for 20 min, then quenched with water. The mixture was extracted with DCM (2×20 mL), and the combined organic phases were washed with brine and dried over Na_2SO_4 . The filtrate was concentrated in vacuo and the residue was purified by column chromatography to afford **2ac-2** in 68% yield.

To a mixture of **2ac-2** (2.0 mmol, 1 equiv.), $\text{Pd}(\text{PPh}_3)_2\text{Cl}_2$ (0.2 mmol, 0.1 equiv.), and CuI (0.2 mmol, 0.1 equiv.) in DMF (40 mL), Et_3N (6.0 mmol, 3 equiv.) and TMSA (10.0 mmol, 5 equiv.) were added. The mixture was stirred at 80°C for 4 h. After the reaction was completed as monitored by TLC, the mixture was quenched with water and extracted with EtOAc (3×50 mL). The combined organic phases were washed with brine, dried over Na_2SO_4 , and concentrated in vacuo. The residue was purified by column chromatography, affording **2ac-3** with a 65% yield.

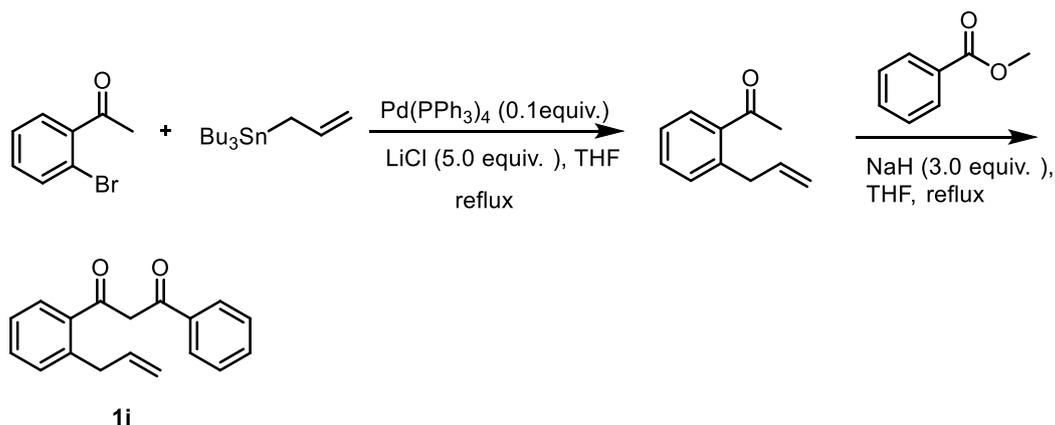
To a solution of **2ac-3** (1.0 mmol, 1 equiv.) in MeOH (10 mL), K_2CO_3 (2.0 mmol, 2 equiv.) was added. The reaction mixture was stirred at 25°C for 4 h. Once the reaction was completed as monitored by TLC, the mixture was quenched with water and extracted with EtOAc (3×20 mL). The combined organic phases were washed with brine, dried over Na_2SO_4 , and concentrated in vacuo. Evaporated under reduced pressure to give the residue, then purified by column chromatography (hexanes: ethyl acetate = 50:1), giving **2ac** with 60% yield.

2.4 Synthesis of Substrates 1b, 1c, 1d, 1h



According to reported method,³ ketone (7.5 mmol, 1.0 equiv.) was added dropwise to a dispersion of 60% NaH in mineral oil (906 mg, 22.6 mmol, 3 equiv.) in THF (20 mL) at 0 °C and under argon atmosphere. Then, a solution of the methyl benzoate (8.2 mmol, 1.1 equiv.) in anhydrous THF (5 mL) was added dropwise over 15 min. The mixture was refluxed for 16 h under argon atmosphere and quenched with ice. Then a solution of HCl (0.1M) was added until a precipitate was formed. The solid was recovered by filtration and washed with distilled H₂O. The filtrate was extracted with AcOEt (3 × 20 mL); the organic phases were washed with brine (3 × 10 mL) and dried over anhydrous MgSO₄. Evaporated under reduced pressure to give the residue, then purified by column chromatography (hexanes : ethyl acetate = 20:1) to afford the β -ketoester.

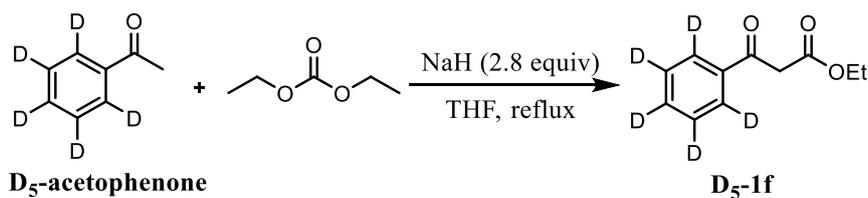
2.5 Synthesis of Substrates 1i



To an oven dried 100 mL round bottom flask charged with magnetic stir bar was added 1-(2-bromophenyl)ethan-1-one (0.500 g, 2.5 mmol, 1.0 equiv.), LiCl (0.53 g, 12.6 mmol, 5.0 equiv.), allyltributylstannane (0.915 g, 2.76 mmol, 1.1 equiv.), and anhydrous THF (25 mL, 0.10 M). The reaction vessel was rigorously degassed with Ar for 10 min. $\text{Pd}(\text{PPh}_3)_4$ (0.290 g, 2.5 mmol, 0.10 equiv.) was added and the reaction was heated to reflux under an atmosphere of Ar for 12 h. After, the reaction was cooled to room temperature and diluted with 50 mL H_2O . The aqueous layer was extracted 3×100 mL EtOAc, dried over anhydrous Na_2SO_4 and concentrated to dryness under reduced pressure on a rotary evaporator. The crude material was purified by column chromatography (gradient from 100% hexane to 10% EtOAc/hexane) to obtain the named product as a clear oil (0.300 g, 1.88 mmol, 75%).⁴

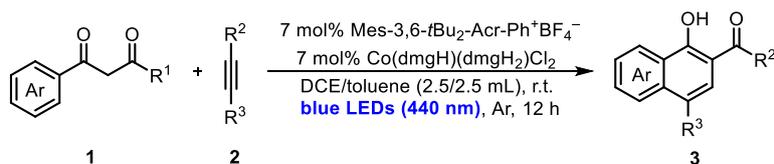
According to reported method, ketone (1.5 mmol) was added dropwise to a dispersion of 60% NaH in mineral oil (181 mg, 4.5 mmol) in THF 4 mL at 0 °C and under nitrogen atmosphere. Then, a solution of the methyl benzoate (1.6 mmol) in anhydrous THF (1 mL) was added dropwise over 15 min. The mixture was refluxed for 16 h under nitrogen and quenched with ice. Then a solution of HCl (0.1M) was added until a precipitate was formed. The solid was recovered by filtration and washed with distilled H_2O . The filtrate was extracted with AcOEt (3×20 mL); the organic phases were washed with brine (3×10 mL) and dried over anhydrous MgSO_4 . Evaporated under reduced pressure to give the residue, then purified by column chromatography (hexanes : ethyl acetate = 30:1).

2.6 Synthesis of D₅-1f



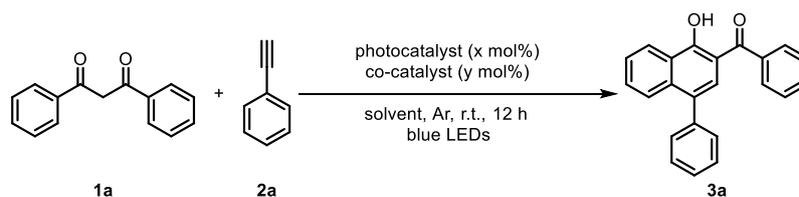
According to previous report⁵: To a dried three-necked flask equipped with a dropping funnel, a condenser, and a magnetic stirrer was added NaH (60% in mineral oil, 8.4 mmol, 2.8 equiv.), diethyl carbonate (6 mmol, 2 equiv.), and dry THF (20 mL). The mixture was heated to 80 °C in an oil bath under Ar. A solution of D₅-acetophenone (3 mmol, 1.0 equiv.) in dry THF (20 mL) was added dropwise from the dropping funnel over 20 min. After the addition, the mixture was heated to reflux until the ketone is completely consumed (12 h). When the reaction was cooled to room temperature, glacial acetic acid was added dropwise and a heavy, pasty solid appeared. Ice-water was added until the solid was dissolved completely. The THF layer was separated, and the water layer was extracted with EtOAc (3 × 30 mL). The combined organic solution was washed with water and brine. After evaporation of the solvent, the mixture was distilled under reduced pressure. The crude residue was purified by column chromatography to furnish the desired compound D₅-1f in 62% yield.

3. General Experimental Procedure



A 10 mL Pyrex tube equipped with a magnetic stir bar was charged with substrates **1** (0.1 mmol, 1.0 equiv.), **2** [0.2 mmol, 2.0 equiv. (5.0 equiv. in **2t-2aa**, **2ac-2ad**)], Mes-3,6-*t*Bu₂-Acr-Ph⁺BF₄⁻ (0.007 mmol, 7 mol%), Co(dmgh)(dmgh₂)Cl₂ (0.007 mmol, 7 mol%) in DCE/toluene (2.5/2.5 mL). After sealing the reaction tube, purged with argon for about 15 minutes, then stirred and irradiated the reaction at room temperature with a 3 W blue LED ($\lambda_{\text{max}} = 440 \text{ nm}$) for 12 hours. After the reaction was complete, concentrated under reduced pressure. The crude product was then purified by column chromatography on silica gel using a mixture of industrial hexane and ethyl acetate to obtain the target product **3**. The structure and purity of the product were confirmed by ¹H NMR, ¹³C NMR, or ¹⁹F NMR.

Table S1. Optimization of the Reaction Conditions ^a



entry	photocatalyst (x mol%)	co-catalyst (y mol%)	solvent (mL)	yield ^b (%)
1	Mes-Acr-Me ⁺ ClO ₄ ⁻ (5)	Co(dmgh)(dmgh ₂)Cl ₂ (10)	DCE/HFIP (2.5/2.5)	63
2	Mes-Acr-Me ⁺ ClO ₄ ⁻ (5)	Co(dmgh)(dmgh ₂)Cl ₂ (10)	DCM (5)	43
3	Mes-Acr-Me ⁺ ClO ₄ ⁻ (5)	Co(dmgh)(dmgh ₂)Cl ₂ (10)	CH ₃ CN (5)	48
4	Mes-Acr-Me ⁺ ClO ₄ ⁻ (7)	Co(dmgh)(dmgh ₂)Cl ₂ (8)	DCE (5)	54
5	Mes-Acr-Me ⁺ ClO ₄ ⁻ (5)	Co(dmgh)(dmgh ₂)Cl ₂ (2)	toluene (5)	53
6	Mes-Acr-Me ⁺ ClO ₄ ⁻ (7)	Co(dmgh)(dmgh ₂)Cl ₂ (5)	DMSO (5)	n.r.
7	Mes-Acr-Me ⁺ ClO ₄ ⁻ (7)	Co(dmgh)(dmgh ₂)pyCl (5)	DCE (5)	64
8	Mes-Acr-Me ⁺ ClO ₄ ⁻ (7)	Co(dmgh)(dmgh ₂)Br ₂ (10)	DCE (5)	68
9	Mes-3,6- <i>t</i> Bu ₂ -Acr-Ph ⁺ BF ₄ ⁻ (10)	Co(dmgh)(dmgh ₂)Cl ₂ (5)	DCE (5)	39
10	Mes-3,6- <i>t</i> Bu ₂ -Acr-Ph ⁺ BF ₄ ⁻ (10)	Co(dmgh)(dmgh ₂)Br ₂ (5)	DCE (5)	50
11	Mes-3,6- <i>t</i> Bu ₂ -Acr-Ph ⁺ BF ₄ ⁻ (10)	Co(dmgh)(dmgh ₂)Cl ₂ (10)	EtOH (5)	n.r.
12	(-)-Riboflavin (5)	Co(dmgh)(dmgh ₂)Cl ₂ (5)	CH ₃ CN (5)	n.r.
13	Mes-3,6- <i>t</i> Bu ₂ -Acr-Ph ⁺ BF ₄ ⁻ (7)	Co(dmgh) ₂ pyCl (7)	DCE/toluene (2.5/2.5)	62
14	Mes-3,6- <i>t</i> Bu ₂ -Acr-Ph ⁺ BF ₄ ⁻ (7)	Co(dmgh)(dmgh ₂)Cl ₂ (7)	DCE/toluene (2.5/2.5)	77
15	Mes-3,6- <i>t</i> Bu ₂ -Acr-Ph ⁺ BF ₄ ⁻ (7)	Co(dmgh)(dmgh ₂)Br ₂ (5)	DCE/toluene (2.5/2.5)	61
16	Mes-3,6- <i>t</i> Bu ₂ -Acr-Ph ⁺ BF ₄ ⁻ (7)	Co(dmgh)(dmgh ₂)Cl ₂ (7)	CH ₃ CN (5)	64
17	Mes-3,6- <i>t</i> Bu ₂ -Acr-Ph ⁺ BF ₄ ⁻ (7)	Co(dmgh)(dmgh ₂)Cl ₂ (7)	toluene (5)	73
18	Mes-3,6- <i>t</i> Bu ₂ -Acr-Ph ⁺ BF ₄ ⁻ (7)	Co(dmgh)(dmgh ₂)Br ₂ (7)	DCE/Toluene (2.5/2.5)	61
19	Mes-3,6- <i>t</i> Bu ₂ -Acr-Ph ⁺ BF ₄ ⁻ (7)	Co(dmgh) ₂ py ₂ PF ₆ (7)	DCE/Toluene (2.5/2.5)	57
20	Mes-3,6- <i>t</i> Bu ₂ -Acr-Ph ⁺ BF ₄ ⁻ (7)	Co(dmgh)(dmgh ₂)Cl ₂ (7)	DCE (5)	24
21	Mes-3,6- <i>t</i> Bu ₂ -Acr-Ph ⁺ BF ₄ ⁻ (7)	—	DCE/toluene (2.5/2.5)	36
22	Mes-3,6- <i>t</i> Bu ₂ -Acr-Ph ⁺ BF ₄ ⁻ (7)	CoCl ₂ ·6H ₂ O (10)	DCE/toluene (2.5/2.5)	34
23	—	Co(dmgh)(dmgh ₂)Cl ₂ (7)	DCE/toluene (2.5/2.5)	n.r.
24	Mes-3,6- <i>t</i> Bu ₂ -Acr-Ph ⁺ BF ₄ ⁻ (7)	Co(dmghBF ₂) ₂ (H ₂ O) ₂ (7)	DCE/toluene (2.5/2.5)	71
25	Mes-3,6- <i>t</i> Bu ₂ -Acr-Ph ⁺ BF ₄ ⁻ (7)	Co(dmgh)(dmgh ₂)Cl ₂ (7)	HOAc (5)	46
26	Mes-3,6- <i>t</i> Bu ₂ -Acr-Ph ⁺ BF ₄ ⁻ (7)	Co(dmgh)(dmgh ₂)pyCl (7)	DCE/toluene (2.5/2.5)	62
27 ^c	Mes-3,6- <i>t</i> Bu ₂ -Acr-Ph ⁺ BF ₄ ⁻ (7)	Co(dmgh)(dmgh ₂)Cl ₂ (7)	DCE/toluene (2.5/2.5)	75
28 ^d	Mes-3,6- <i>t</i> Bu ₂ -Acr-Ph ⁺ BF ₄ ⁻ (7)	Co(dmgh)(dmgh ₂)Cl ₂ (7)	DCE/toluene (2.5/2.5)	n.r.
29 ^e	Mes-3,6- <i>t</i> Bu ₂ -Acr-Ph ⁺ BF ₄ ⁻ (7)	Co(dmgh)(dmgh ₂)Cl ₂ (7)	DCE/toluene (2.5/2.5)	n.r.
30 ^f	Mes-3,6- <i>t</i> Bu ₂ -Acr-Ph ⁺ BF ₄ ⁻ (7)	Co(dmgh)(dmgh ₂)Cl ₂ (7)	DCE/toluene (2.5/2.5)	77

^aReaction conditions: **1a** (0.1 mmol), **2a** (0.2 mmol), photocatalyst (x mol%), co-catalyst (y mol%), solvent, under Ar, room temperature, 3 W blue LEDs ($\lambda_{\text{max}} = 440 \text{ nm}$) irradiation for 12 h. ^bIsolated yields. ^c24 h. ^dUnder dark. ^eUnder air. ^f**2a** (0.5 mmol). n.r. = no reaction.

4. Mechanism Study

4.1 Fluorescence quenching spectrum

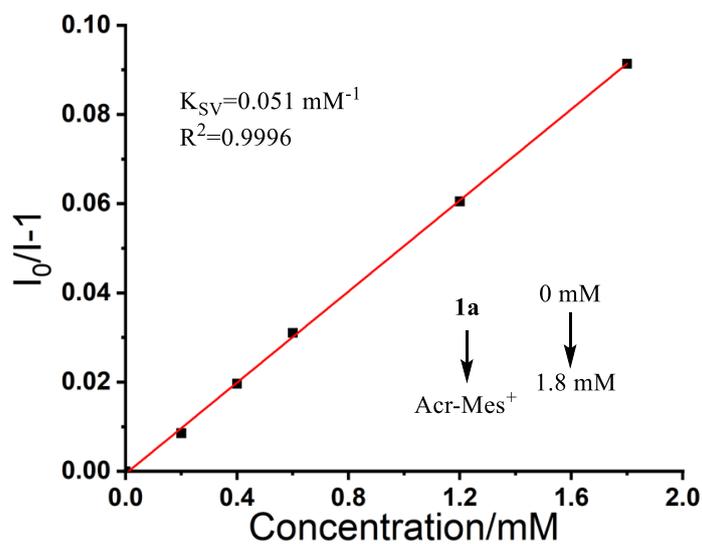


Figure S1. Emission-quenching experiment of Acr-Mes⁺ (1×10^{-5} M) as a function of concentration of **1a** in degassed DCE/toluene (1.5/1.5 mL) with excitation at 440nm

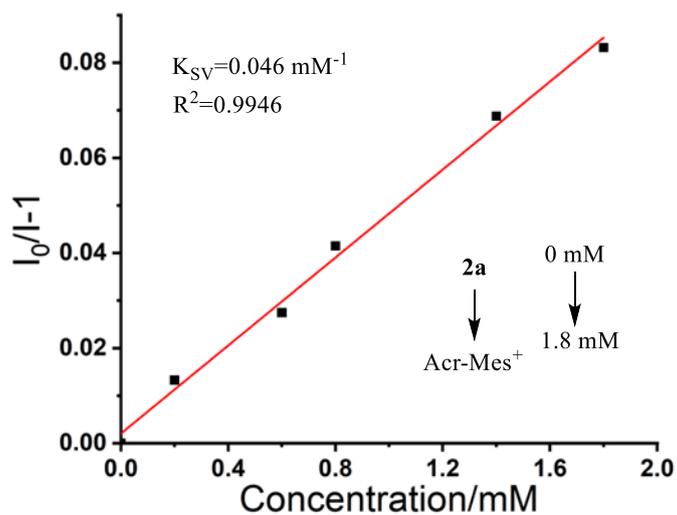


Figure S2. Emission-quenching experiment of Acr-Mes⁺ (1×10^{-5} M) as a function of concentration of **2a** in degassed DCE/toluene (1.5/1.5 mL) with excitation at 440nm

4.2 Radical capture

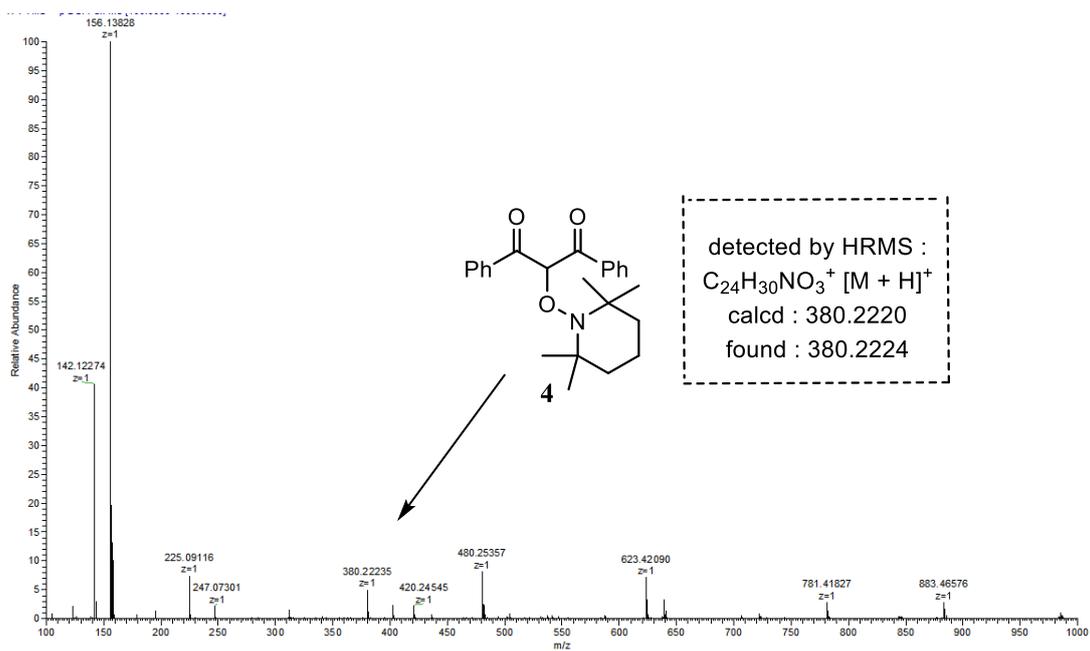


Figure S3. capture mass spectrum

4.3 GC data

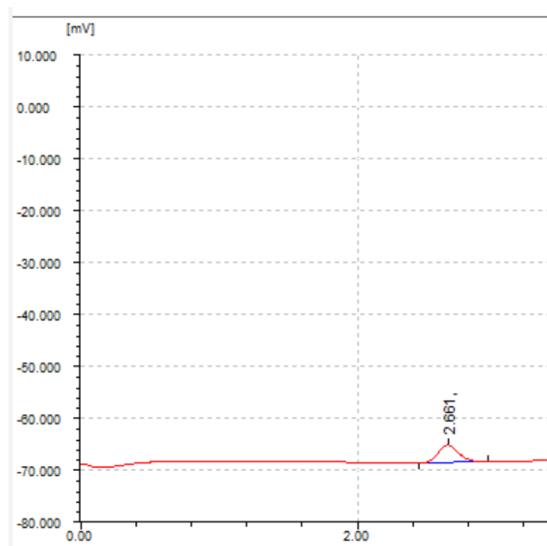


Figure S4. GC data with **1a** (0.1 mmol), **2a** (0.2 mmol), Mes-3,6-^tBu₂-Acr-Ph⁺BF₄⁻ (7 mol%), Co(dm^gH)(dm^gH₂)Cl₂ (7 mol%) in DCE/toluene (2.5/2.5 mL), under Ar, room temperature, 3 W LEDs ($\lambda = 440$ nm) irradiation for 12 h.

4.4 Cyclic Voltammetry (CV) Experiments

Cyclic voltammetry experiments were performed on an electrochemical workstation (CHI 660E, Chenhua Instruments, China) equipped with a glassy carbon working electrode (3 mm diameter, use polishing powder (Al_2O_3) to polish the electrode on suede before use), a platinum plate counter electrode (1 cm \times 1 cm) and a SCE reference electrode. The measurements were carried out at a concentration of 1 mM corresponding substrates in solvent (CH_3CN) with an electrolyte (0.01 M tetrabutylammonium hexafluorophosphate in solvent (CH_3CN), with positive scan (a scan rate of 25 mV/s) under nitrogen atmosphere at room temperature.

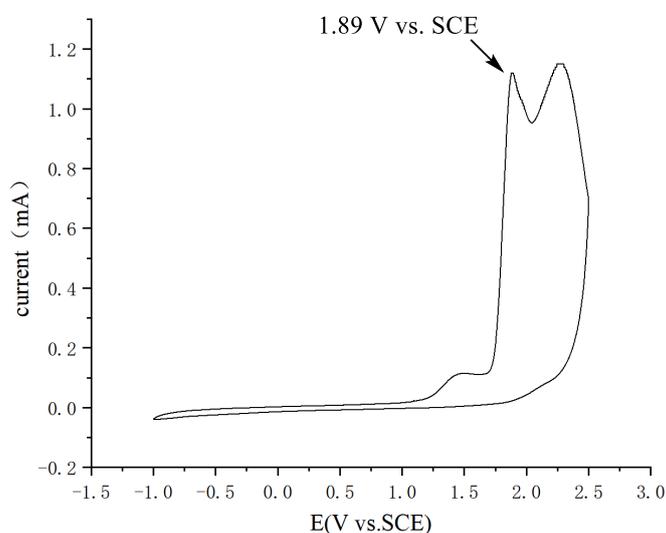


Figure S5. CV spectra of 1 mM **1a** and 0.01 M *n*-Bu₄PF₆ in degassed CH₃CN with scan rate 25 mV/s.

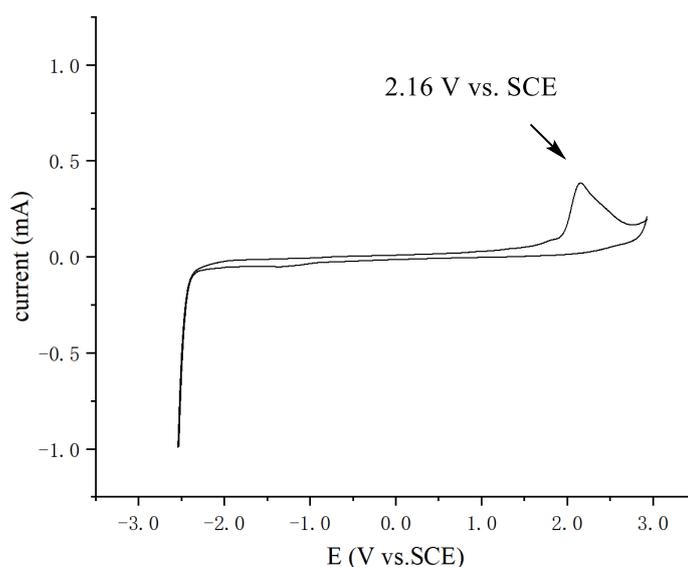


Figure S6. CV spectra of 1 mM **2a** and 0.01 M *n*-Bu₄PF₆ in degassed CH₃CN with scan rate 25 mV/s.

4.5 Competing Kinetic Isotope Effect (KIE) Experiments

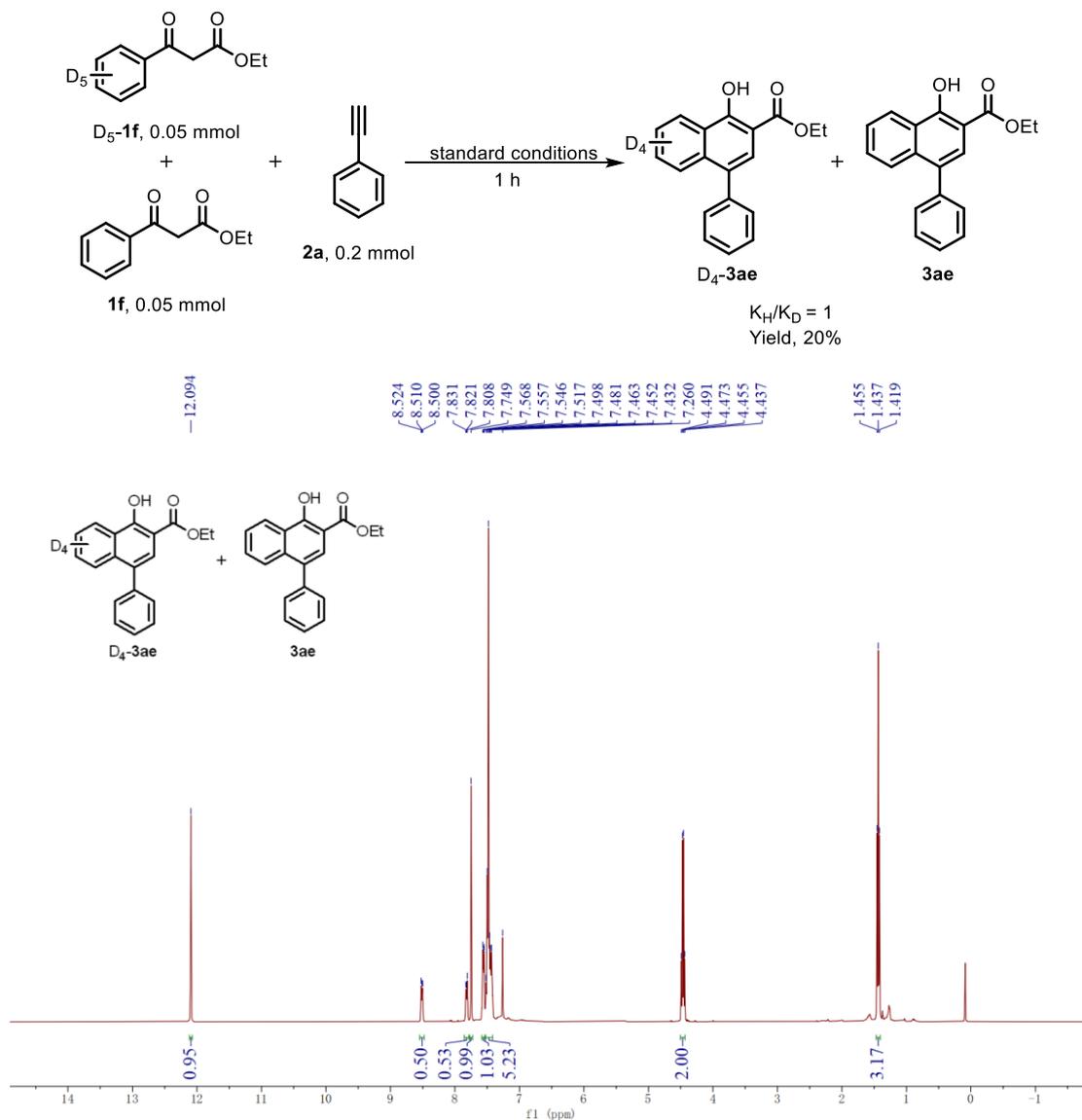


Figure S7. Intermolecular KIE with D₄-3ae and 3ae.

4.6 Intramolecular/Intermolecular competition

The products **3al** and **3am** from Competitive Experiment 1 are difficult to separate by column chromatography, so their individual yields are determined based on NMR spectra after calculating the total yield. The yields of products from Competitive Experiments 2 and 3 are calculated after separation by column chromatography.

Competition Experiment 1:

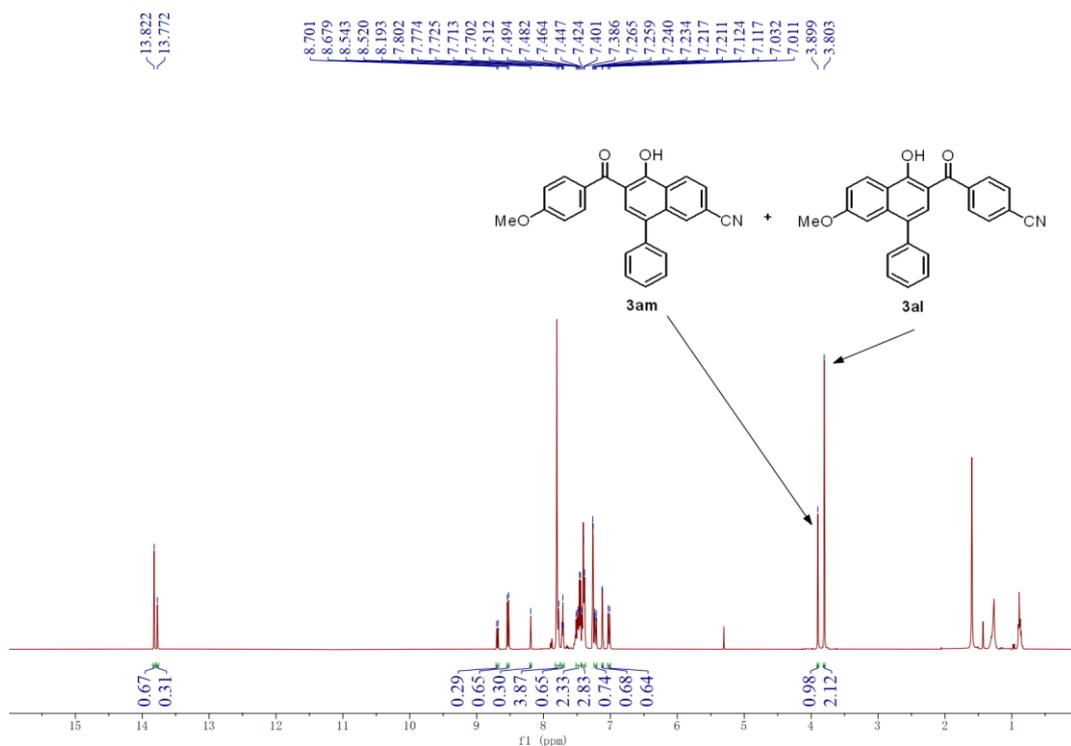
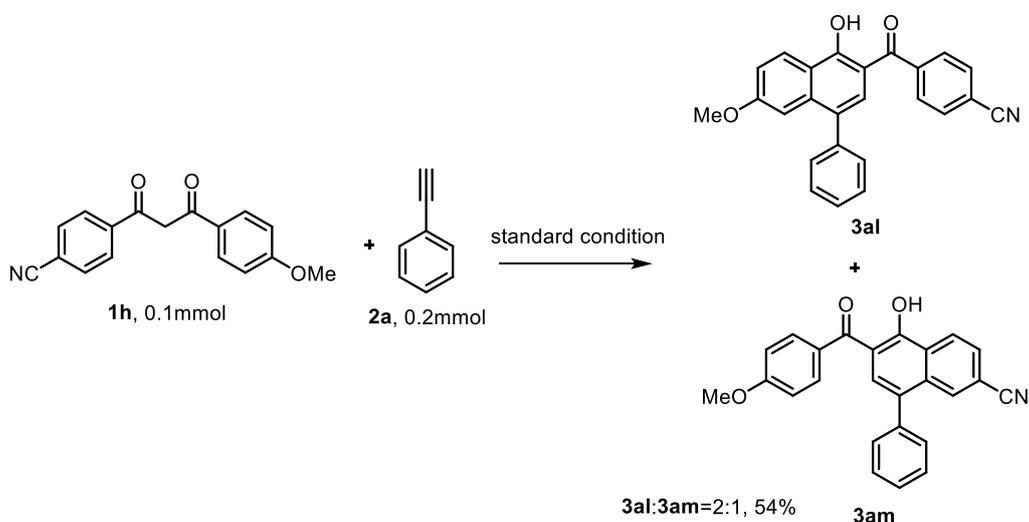
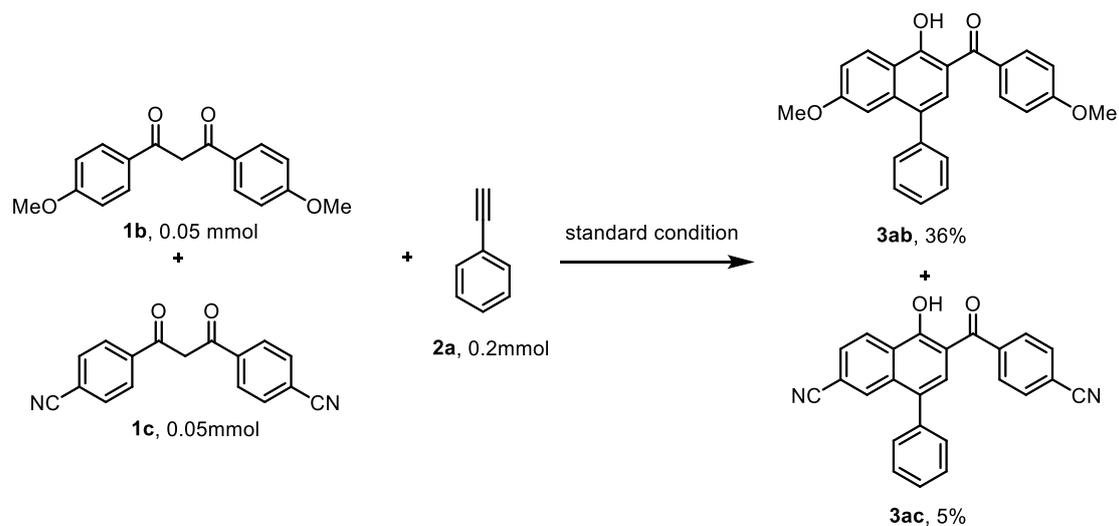
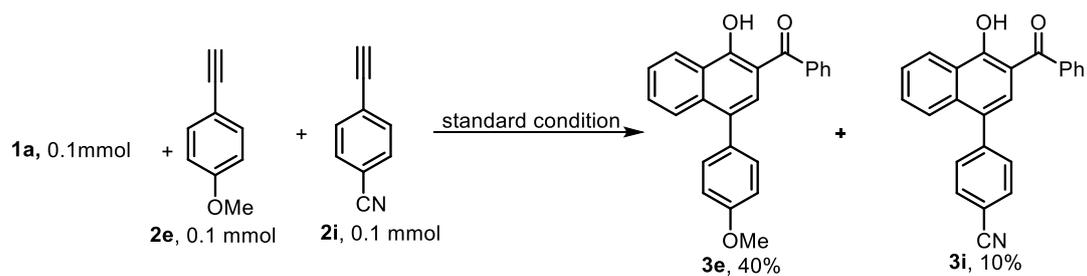


Figure S8. intermolecular competition experiment of **1h**

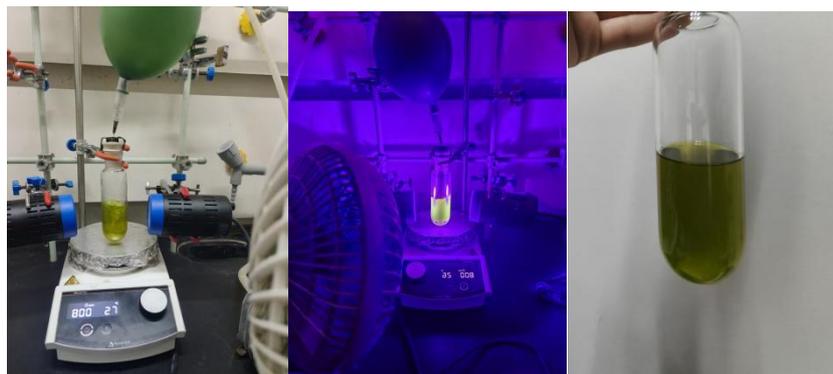
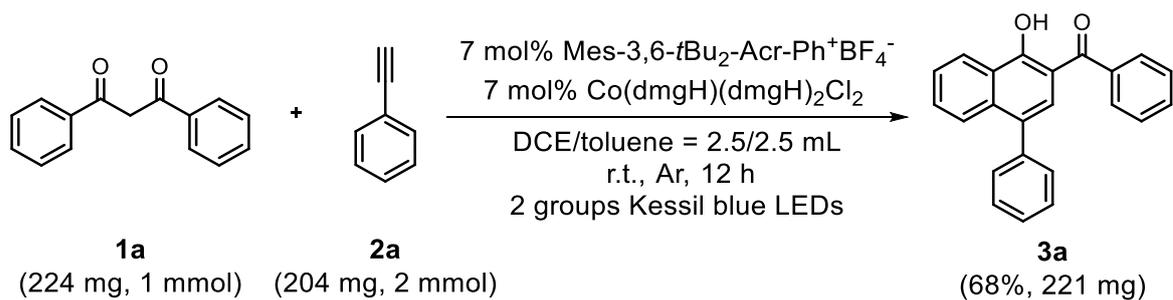
Competition Experiment 2:



Competition Experiment 3:



4.7 Gram-scale Reaction



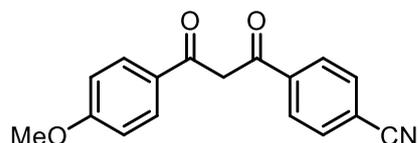
A 100 mL Pyrex tube equipped with a magnetic stir bar was charged with substrates **1a** (1 mmol, 1.0 equiv.), Mes-3,6-*t*Bu₂-Acr-Ph⁺BF₄⁻ (7 mol%), Co(dmgH)(dmgH)₂Cl₂ (7 mol%), **2a** (1 mmol, 2.0 equiv.) and mixed solvent (DCE/toluene = 25/25 mL). The reaction tube was sealed and the resulting mixture was bubbled with a stream of argon for about 15 minutes, then the sample was stirred and irradiated using two 40 W Kessil LED lamps (PR160L-440 nm, 75% intensity, 3 cm away) at room temperature for 12 h. After reaction, reaction system was concentrated under reduced pressure. Then the crude product was purified by silica gel column chromatography using industrial hexane and ethyl acetate as eluents to afford the desired product **3a** in 68% yield (221 mg).

5. Characterization Data for Compounds

1a, 2e, 1f, 1g, 2a-2ab purchased directly from commercial reagents.

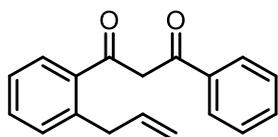
1b⁶, 1c⁷, 1d⁸, 2ac⁹, 2ad¹⁰ are reported in previous report.

4-(3-(4-methoxyphenyl)-3-oxopropanoyl)benzotrile (**1h**)



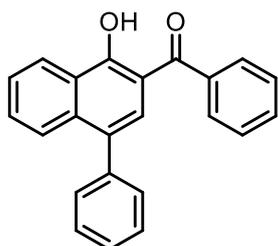
Yellow solid; $R_f = 0.21$ (PE/EtOAc = 20:1); m.p. 150.4 – 151.6 °C; $^1\text{H NMR}$ (400 MHz, CDCl_3) δ 8.00 (dd, $J = 24, 8.8$ Hz, 4H), 7.75 (d, $J = 8.6$ Hz, 2H), 6.97 (d, $J = 9.0$ Hz, 2H), 6.78 (s, 1H), 3.88 (s, 3H); $^{13}\text{C NMR}$ (101 MHz, CDCl_3) δ 187.7, 180.5, 163.8, 139.5, 132.5, 129.7, 127.8, 127.5, 118.3, 115.2, 114.2, 93.4, 55.7; **ESI-HRMS** Calcd for $\text{C}_{17}\text{H}_{14}\text{NO}_3^+$ $[\text{M} + \text{H}]^+$ 280.0968, found 280.0968.

1-(2-allylphenyl)-3-phenylpropane-1,3-dione (**1i**)



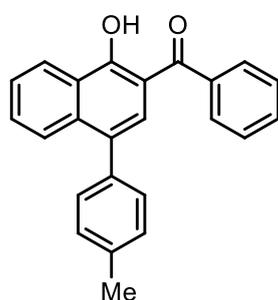
Brown viscous liquid; $R_f = 0.35$ (PE/EtOAc =20:1); $^1\text{H NMR}$ (400 MHz, CDCl_3) δ 7.96 (d, $J = 7.6$ Hz, 2H), 7.64 – 7.36 (m, 7H), 7.32 (t, $J = 7.6$ Hz, 1H), 6.88 (d, $J = 15.6$ Hz, 1H), 6.57 (s, 1H), 6.33 – 6.24 (m, 1H), 1.94 (d, $J = 6.8$ Hz, 2H). $^{13}\text{C NMR}$ (101 MHz, CDCl_3) δ 189.78, 184.59, 137.12, 135.24, 135.18, 132.59, 130.98, 129.30, 128.77, 128.59, 128.45, 127.21, 126.91, 126.84, 98.35, 18.88; **ESI-HRMS** Calcd for $\text{C}_{18}\text{H}_{15}\text{O}_2^-$ $[\text{M} - \text{H}]^-$ 263.1078, found 263.1076.

(1-hydroxy-4-phenyl)naphthalen-2-yl)(phenyl)methanone (**3a**)



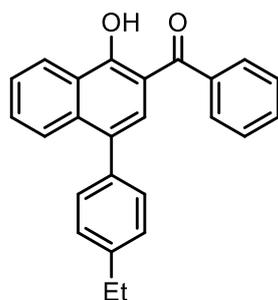
Yellow solid; yield 24.9 mg, 77% $R_f = 0.78$ (PE/EtOAc = 20:1); m.p. 166.3 – 167.1 °C; $^1\text{H NMR}$ (400 MHz, CDCl_3) δ 14.00 (s, 1H), 8.68 – 8.60 (m, 1H), 7.84 (d, $J = 8.8$ Hz, 1H), 7.76 (d, $J = 7.4$ Hz, 2H), 7.64 – 7.56 (m, 3H), 7.52 (d, $J = 6.4$ Hz, 3H), 7.47 – 7.40 (m, 5H). $^{13}\text{C NMR}$ (101 MHz, CDCl_3) δ 201.61, 163.45, 140.10, 138.25, 135.87, 131.82, 130.69, 130.56, 130.25, 129.19, 128.82, 128.56, 128.53, 127.83, 127.39, 126.06, 125.62, 124.87, 112.28. **ESI-HRMS** Calcd for $\text{C}_{23}\text{H}_{17}\text{O}_2^+$ $[\text{M} + \text{H}]^+$ 325.1223, found 325.1224.

(1-hydroxy-4-(*p*-tolyl)naphthalen-2-yl)(phenyl)methanone (3b)



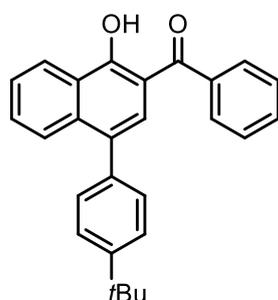
Yellow solid; yield 18.1 mg, 53%; $R_f = 0.34$ (PE/EtOAc = 20:1); m.p. 135.4 – 136.5 °C; $^1\text{H NMR}$ (400 MHz, CDCl_3) δ 13.88 (s, 1H), 8.52 (d, $J = 6.8$ Hz, 1H), 7.74 (d, $J = 7.0$ Hz, 1H), 7.64 (d, $J = 6.8$ Hz, 2H), 7.54 – 7.43 (m, 3H), 7.41 (d, $J = 4.4$ Hz, 3H), 7.22 (d, $J = 7.8$ Hz, 2H), 7.16 (d, $J = 7.8$ Hz, 2H), 2.33 (s, 3H); $^{13}\text{C NMR}$ (101 MHz, CDCl_3) δ 201.6, 163.3, 138.3, 137.1, 137.1, 135.9, 131.8, 130.6, 130.5, 130.1, 129.2, 129.2, 128.5, 127.8, 126.1, 126.0, 125.6, 124.8, 112.3, 21.3; **ESI-HRMS** Calcd for $\text{C}_{24}\text{H}_{19}\text{O}_2^+$ $[\text{M} + \text{H}]^+$ 339.1380, found 339.1378.

(4-(4-ethylphenyl)-1-hydroxynaphthalen-2-yl)(phenyl)methanone (3c)



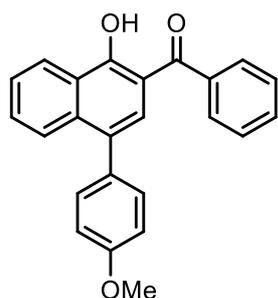
Yellow solid; yield 22.9 mg, 65%; $R_f = 0.71$ (PE/EtOAc = 20:1); m.p. 121.0 – 123.6 °C; $^1\text{H NMR}$ (400 MHz, CDCl_3) δ 13.97 (s, 1H), 8.62 (d, $J = 8.6$ Hz, 1H), 7.86 (d, $J = 8.8$ Hz, 1H), 7.75 (d, $J = 6.6$ Hz, 2H), 7.64 – 7.55 (m, 3H), 7.52 (d, $J = 4.8$ Hz, 3H), 7.35 (d, $J = 8.0$ Hz, 2H), 7.29 (d, $J = 7.8$ Hz, 2H), 2.73 (q, $J = 7.8$ Hz, 2H), 1.31 (t, $J = 7.6$ Hz, 3H); $^{13}\text{C NMR}$ (101 MHz, CDCl_3) δ 201.7, 163.3, 143.4, 138.3, 137.4, 136.0, 131.8, 130.7, 130.5, 130.2, 129.2, 128.6, 128.0, 127.8, 126.2, 126.0, 125.6, 124.8, 112.3, 28.7, 15.7; **ESI-HRMS** Calcd for $\text{C}_{24}\text{H}_{19}\text{O}_2^+$ $[\text{M} + \text{H}]^+$ 353.1536 found 353.1534.

(4-(4-(*tert*-butyl)phenyl)phenyl)-1-hydroxynaphthalen-2-yl(phenyl)methanone (3d)



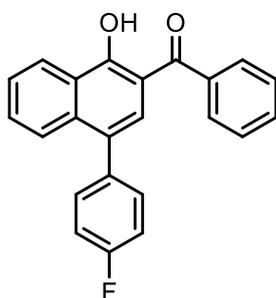
Yellow solid; yield 25.9 mg, 68%; $R_f = 0.52$ (PE/EtOAc = 20:1); m.p. 159.8 – 161.2 °C. $^1\text{H NMR}$ (400 MHz, CDCl_3) δ 13.96 (s, 1H), 8.62 (d, $J = 7.8$ Hz, 1H), 7.88 (d, $J = 8.0$ Hz, 1H), 7.75 (d, $J = 7.4$ Hz, 2H), 7.64 – 7.55 (m, 3H), 7.53 – 7.46 (m, 5H), 7.36 (d, $J = 7.8$ Hz, 2H), 1.39 (s, 9H). $^{13}\text{C NMR}$ (101 MHz, CDCl_3) δ 201.7, 163.3, 150.3, 138.3, 137.1, 136.0, 131.8, 130.7, 130.5, 129.9, 129.2, 128.6, 127.8, 126.2, 126.0, 125.6, 125.4, 124.8, 112.3, 77.5, 77.2, 76.8, 34.7, 31.6. **ESI-HRMS** Calcd for $\text{C}_{27}\text{H}_{25}\text{O}_2^+$ $[\text{M} + \text{H}]^+$ 381.1849, found 381.1847.

(1-hydroxy-4-(4-methoxyphenyl)naphthalen-2-yl(phenyl)methanone (3e)



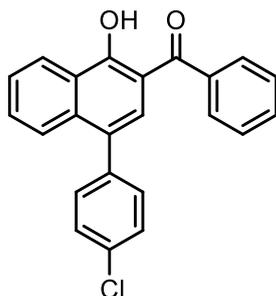
Yellow oily liquid; yield 23.0 mg, 65%; $R_f = 0.57$ (PE/EtOAc = 20:1); $^1\text{H NMR}$ (400 MHz, CDCl_3) δ 13.95 (s, 1H), 8.62 (d, $J = 7.2$ Hz, 1H), 7.84 (d, $J = 7.8$ Hz, 1H), 7.75 (d, $J = 5.2$ Hz, 2H), 7.64 – 7.55 (m, 3H), 7.54 – 7.47 (m, 3H), 7.34 (d, $J = 8.6$ Hz, 2H), 6.99 (d, $J = 8.4$ Hz, 2H), 3.87 (s, 3H); $^{13}\text{C NMR}$ (101 MHz, CDCl_3) δ 201.6, 163.2, 159.0, 138.3, 136.1, 132.4, 131.8, 131.3, 130.5, 130.3, 129.2, 128.6, 127.8, 127.3, 126.1, 126.0, 125.6, 124.9, 113.9, 112.3, 55.5; **ESI-HRMS** Calcd for $\text{C}_{24}\text{H}_{19}\text{O}_3^+$ [$\text{M} + \text{H}$] $^+$ 355.1329, found 355.1328.

(4-(4-fluorophenyl)-1-hydroxynaphthalen-2-yl)(phenyl)methanone (3f)



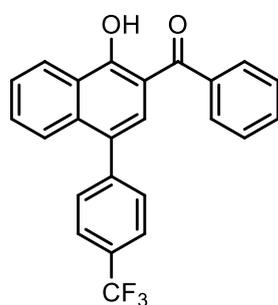
Yellow solid; yield 24.6 mg, 72%; $R_f = 0.61$ (PE/EtOAc = 20:1); m.p. 125.8 – 127.6 °C. $^1\text{H NMR}$ (400 MHz, CDCl_3) δ 14.00 (s, 1H), 8.63 (d, $J = 7.4$ Hz, 1H), 7.76 (t, $J = 8.0$ Hz, 3H), 7.66 – 7.56 (m, 3H), 7.55 – 7.48 (m, 3H), 7.38 (t, $J = 7.0$ Hz, 2H), 7.15 (t, $J = 8.6$ Hz, 2H). $^{13}\text{C NMR}$ (101 MHz, CDCl_3) δ 201.5, 163.5, 161.1, 138.1, 135.9 (d, $J_{\text{C,F}}=3.3$ Hz), 135.8, 131.9, 131.7, (d, $J_{\text{C,F}}=7.9$ Hz), 130.7, 129.5, 129.2, 128.6, 127.9, 126.1, 125.8, 125.6, 124.9, 115.5 (d, $J_{\text{C,F}}=21.4$ Hz), 112.2. $^{19}\text{F NMR}$ (565 MHz, CDCl_3) δ -115.15 (s, 1F). **ESI-HRMS** Calcd for $\text{C}_{23}\text{H}_{14}\text{O}_2^-$ [$\text{M} - \text{H}$] $^-$ 341.0983, found 341.0979.

(4-(4-chlorophenyl)-1-hydroxynaphthalen-2-yl)(phenyl)methanone (3g)



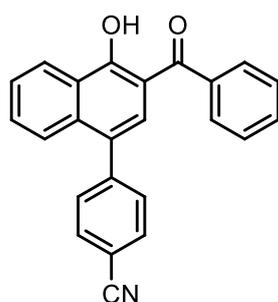
Yellow solid; yield 19.7 mg, 55%; $R_f = 0.77$ (PE/EtOAc = 20:1); m.p. 146.2 – 147.7 °C. $^1\text{H NMR}$ (400 MHz, CDCl_3) δ 14.00 (s, 1H), 8.63 (d, $J = 7.8$ Hz, 1H), 7.75 (dd, $J = 12.6, 7.6$ Hz, 3H), 7.65 – 7.57(m, 3H), 7.51 (dd, $J = 14.4, 7.0$ Hz, 3H), 7.43 (d, $J = 8.0$ Hz, 2H), 7.35 (d, $J = 8.0$ Hz, 2H). $^{13}\text{C NMR}$ (101 MHz, CDCl_3) δ 201.5, 163.6, 138.5, 138.1, 135.6, 133.4, 131.9, 131.5, 130.7, 129.3, 129.2, 128.7, 128.6, 127.9, 126.2, 125.7, 125.6, 125.0, 112.2. **ESI-HRMS** Calcd for $\text{C}_{23}\text{H}_{14}\text{O}_2^-$ [$\text{M} - \text{H}$] $^-$ 357.0688, found 357.0686.

(1-hydroxy-4-(*p*-tolyl)naphthalen-2-yl)(phenyl)methanone (3h)



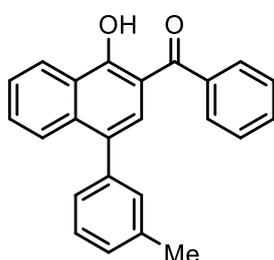
Yellow oily liquid; yield 26.3 mg, 67%; $R_f = 0.50$ (PE/EtOAc = 20:1); $^1\text{H NMR}$ (400 MHz, CDCl_3) δ 14.03 (s, 1H), 8.65 (d, $J = 9.0$ Hz, 1H), 7.73 (t, $J = 8.4$ Hz, 5H), 7.67 – 7.58 (m, 3H), 7.54 (dd, $J = 12.3, 4.4$ Hz, 6H). $^{13}\text{C NMR}$ (101 MHz, CDCl_3) δ 201.5, 169.9, 143.8, 138.1, 135.4, 132.3 (d, $J_{\text{C,F}}=59.1$ Hz), 132.0, 130.9, 130.6, 129.6 (d, $J_{\text{C,F}}=32.5$ Hz), 129.2, 128.8, 128.6, 128.2, 127.3, 126.3, 125.7, 125.5 (d, $J_{\text{C,F}}=3.9$ Hz), 125.1, 112.2. $^{19}\text{F NMR}$ (565 MHz, CDCl_3) δ -62.41 (s, 3F). **ESI-HRMS** Calcd for $\text{C}_{24}\text{H}_{14}\text{F}_3\text{O}_2^-$ [$\text{M} - \text{H}$] $^-$ 391.0951, found 391.0947.

4-(3-benzoyl-4-hydroxynaphthalen-1-yl)benzonitrile (3i)



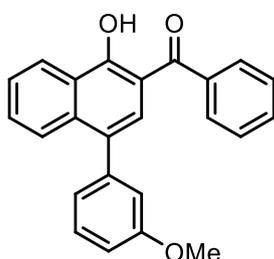
Yellow solid; yield 14.7 mg, 42%; $R_f = 0.19$ (PE/EtOAc = 20:1); m.p. 192.9 – 194.5 °C. $^1\text{H NMR}$ (400 MHz, CDCl_3) δ 14.04 (s, 1H), 8.64 (d, $J = 7.2$ Hz, 1H), 7.78 – 7.70 (m, 5H), 7.68 – 7.58 (m, 3H), 7.54 (d, $J = 7.8$ Hz, 4H), 7.50 (d, $J = 6.0$ Hz, 1H). $^{13}\text{C NMR}$ (101 MHz, CDCl_3) δ 201.4, 164.1, 145.0, 137.9, 135.0, 132.4, 132.1, 131.1, 130.9, 129.2, 128.7, 128.6, 128.3, 126.5, 125.7, 125.3, 125.2, 118.9, 112.2, 111.2. **ESI-HRMS** Calcd for $\text{C}_{24}\text{H}_{14}\text{NO}_2^-$ [$\text{M} - \text{H}$] $^-$ 348.1030, found 348.1027.

(1-hydroxy-4-(*m*-tolyl)naphthalen-2-yl)(phenyl) methanone (3j)



Yellow solid; yield 25.0 mg, 74%; m.p. 109.3 – 111.4 °C. $R_f = 0.79$ (PE/EtOAc = 20:1); $^1\text{H NMR}$ (400 MHz, CDCl_3) δ 14.01 (s, 1H), 8.64 (d, $J = 8.8$ Hz, 1H), 7.84 (d, $J = 7.4$ Hz, 1H), 7.76 (d, $J = 6.6$ Hz, 2H), 7.67 – 7.55 (m, 3H), 7.52 (t, $J = 7.4$ Hz, 3H), 7.36 (t, $J = 7.6$ Hz, 1H), 7.23 (d, $J = 7.8$ Hz, 3H), 2.43 (s, 3H). $^{13}\text{C NMR}$ (101 MHz, CDCl_3) δ 201.6, 163.4, 140.0, 138.2, 138.1, 135.9, 131.8, 130.9, 130.8, 130.5, 129.2, 128.6, 128.4, 128.1, 127.7, 127.3, 126.1, 126.0, 125.6, 124.8, 112.2, 21.6. **ESI-HRMS** Calcd for $\text{C}_{24}\text{H}_{17}\text{O}_2^-$ [$\text{M} - \text{H}$] $^-$ 337.1234, found 337.1232.

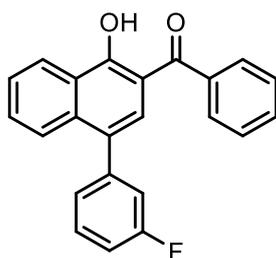
(1-hydroxy-4-(3-methoxyphenyl)naphthalen-2-yl)(phenyl)methanone (3k)



Yellow solid; yield 23.7 mg, 67%; $R_f = 0.28$ (PE/EtOAc = 20:1); m.p. 146.3 – 148.1 °C. $^1\text{H NMR}$ (400 MHz, CDCl_3) δ 13.99 (s, 1H), 8.63 (d, $J = 7.8$ Hz, 1H), 7.86 (d, $J = 7.8$ Hz, 1H), 7.75 (d, $J = 7.2$ Hz, 2H), 7.58 (q, $J = 5.8$ Hz, 3H), 7.52 (d, $J = 6.8$

Hz, 3H), 7.36 (d, $J = 7.4$ Hz, 1H), 7.02 (d, $J = 7.6$ Hz, 1H), 6.96 (d, $J = 10.0$ Hz, 2H), 3.85 (s, 3H). ^{13}C NMR (101 MHz, CDCl_3) δ 201.6, 163.5, 159.6, 141.5, 138.2, 135.8, 131.8, 130.6, 130.5, 129.5, 129.2, 128.6, 127.7, 127.3, 126.1, 125.6, 124.8, 122.7, 116.1, 112.6, 112.2, 55.4. **ESI-HRMS** Calcd for $\text{C}_{24}\text{H}_{17}\text{O}_3^-$ [$\text{M} - \text{H}$] $^-$ 352.1183, found 353.1181.

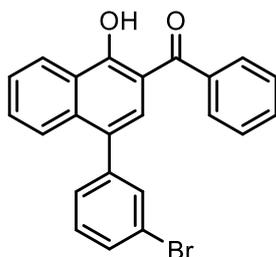
(4-(3-fluorophenyl)-1-hydroxynaphthalen-2-yl)(phenyl)methanone (3l)



Yellow solid; yield 24.6 mg, 72%; $R_f = 0.68$ (PE/EtOAc = 20:1); m.p. 141.7 – 144.7 °C

^1H NMR (400 MHz, CDCl_3) δ 14.03 (s, 1H), 8.64 (d, $J = 8.0$ Hz, 1H), 7.81 (d, $J = 9.0$ Hz, 1H), 7.75 (d, $J = 6.8$ Hz, 2H), 7.68 – 7.56 (m, 3H), 7.56 – 7.50 (m, 3H), 7.46 – 7.39 (m, 1H), 7.21 (d, $J = 8.0$ Hz, 1H), 7.19 – 7.07 (m, 2H). ^{13}C NMR (101 MHz, CDCl_3) δ 201.5, 163.7, 162.8 (d, $J_{\text{C,F}}=246.4$ Hz), 142.2 (d, $J_{\text{C,F}}=7.8$ Hz), 138.1, 135.5, 131.9, 130.8, 130.0 (d, $J_{\text{C,F}}=8.6$ Hz), 129.3 (d, $J_{\text{C,F}}=2.1$ Hz), 129.2, 128.6, 127.9, 126.2, 125.9 (d, $J_{\text{C,F}}=2.8$ Hz), 125.7, 125.6, 124.9, 117.2 (d, $J_{\text{C,F}}=21.2$ Hz), 114.3 (d, $J_{\text{C,F}}=21.0$ Hz), 112.14. ^{19}F NMR (565 MHz, CDCl_3) δ -113.14 (s, 1F) **ESI-HRMS** Calcd for $\text{C}_{23}\text{H}_{15}\text{FO}_2^-$ [$\text{M} - \text{H}$] $^-$ 341.0983, found 341.0979.

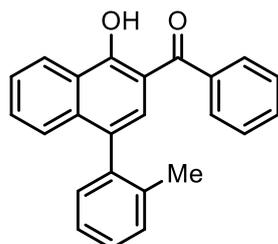
(4-(3-bromophenyl)-1-hydroxynaphthalen-2-yl)(phenyl)methanone (3m)



Yellow oily liquid; yield 25.3 mg, 63%; $R_f = 0.41$ (PE/EtOAc = 20:1); ^1H NMR (400 MHz, CDCl_3) δ 14.03 (s, 1H), 8.63 (d, $J = 9.4$ Hz, 1H), 7.75 (t, $J = 8.2$ Hz, 3H), 7.66

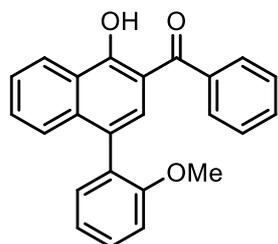
– 7.55 (m, 4H), 7.54 (d, $J = 8.0$ Hz, 3H), 7.49 (s, 1H), 7.33 (d, $J = 7.8$ Hz, 2H). ^{13}C NMR (101 MHz, CDCl_3) δ 201.5, 163.8, 142.2, 138.0, 135.5, 133.1, 132.0, 130.8, 130.5, 130.1, 129.2, 129.1, 128.9, 128.6, 128.0, 126.0, 125.7, 125.6, 125.0, 122.6, 112.1. **ESI-HRMS** Calcd for $\text{C}_{23}\text{H}_{14}\text{BrO}_2^-$ [$\text{M} - \text{H}$] $^-$ 401.0183, found 401.0182.

(1-hydroxy-4-(*o*-tolyl)naphthalen-2-yl)(phenyl)methanone (3n)



Yellow solid; yield 21.3 mg, 63%; $R_f = 0.48$ (PE/EtOAc = 20:1); m.p. 122.1 – 124.3 °C. ^1H NMR (400 MHz, CDCl_3) δ 13.89 (s, 1H), 8.57 – 8.49 (m, 1H), 7.62 (d, $J = 6.6$ Hz, 2H), 7.46 (dd, $J = 13.6, 6.6$ Hz, 3H), 7.42 – 7.36 (m, 2H), 7.33 (s, 1H), 7.32 – 7.27 (m, 1H), 7.23 (d, $J = 6.0$ Hz, 2H), 7.20 – 7.10 (m, 2H), 1.96 (s, 3H). ^{13}C NMR (101 MHz, CDCl_3) δ 201.6, 163.4, 139.4, 138.3, 137.3, 136.2, 131.8, 130.9, 130.6, 130.1, 129.9, 129.1, 128.5, 127.9, 127.5, 126.1, 126.0, 125.9, 125.4, 124.8, 112.2, 20.3. **ESI-HRMS** Calcd for $\text{C}_{24}\text{H}_{17}\text{O}_2^-$ [$\text{M} - \text{H}$] $^-$ 337.1234, found 337.1235.

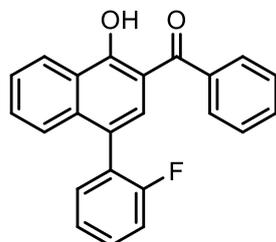
(1-hydroxy-4-(2-methoxyphenyl)naphthalen-2-yl)(phenyl)methanone (3o)



Yellow solid; yield 18.4 mg, 52%; $R_f = 0.41$ (PE/EtOAc = 20:1); m.p. 105.4 – 107.1 °C. ^1H NMR (400 MHz, CDCl_3) δ 13.97 (s, 1H), 8.60 (d, $J = 9.4$ Hz, 1H), 7.74 (s, 2H), 7.62 – 7.46 (m, 7H), 7.40 (t, $J = 7.9$ Hz, 1H), 7.25 (d, $J = 7.8$ Hz, 1H), 7.09 – 6.99 (m, 2H), 3.72 (s, 3H). ^{13}C NMR (101 MHz, CDCl_3) δ 201.55, 163.54, 157.51, 138.33, 136.34, 132.23, 131.73, 130.26, 129.31, 129.22, 128.69, 128.47, 128.43,

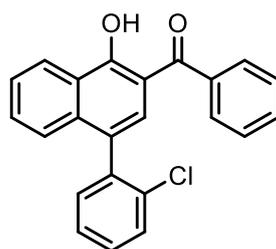
127.03, 126.41, 125.82, 125.38, 124.67, 120.76, 112.38, 111.02, 55.59. **ESI-HRMS**
Calcd for $C_{24}H_{17}O_2^-$ $[M - H]^-$ 353.1183, found 353.1181.

(4-(2-fluorophenyl)-1-hydroxynaphthalen-2-yl)(phenyl)methanone (3p)



Yellow solid; yield 23.9 mg, 70%; R_f = 0.28 (PE/EtOAc = 20:1); m.p. 146.3 – 148.1 °C. 1H NMR (400 MHz, $CDCl_3$) δ 13.93 (s, 1H), 8.51 (d, J = 7.4 Hz, 1H), 7.64 (d, J = 8.2 Hz, 2H), 7.55 – 7.33 (m, 7H), 7.33 – 7.19 (m, 2H), 7.15 – 7.03 (m, 2H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 201.5, 164.0, 160.5 (d, $J_{C,F}$ = 246.4 Hz), 138.12, 135.91, 132.6 (d, $J_{C,F}$ = 3.3 Hz), 131.90, 130.75, 129.63, (d, $J_{C,F}$ = 8.0 Hz), 129.29, 128.85 (d, $J_{C,F}$ = 4.7 Hz), 127.3(m), 126.16, 125.84, 125.33, 124.87, 124.31(d, $J_{C,F}$ = 3.6 Hz), 124.03, 116.05, 115.83, 111.25. ^{19}F NMR (565 MHz, $CDCl_3$) δ -113.89 (s, 1F). **ESI-HRMS** Calcd for $C_{23}H_{16}FO_2^+$ $[M + H]^+$ 343.1129, found 343.1130.

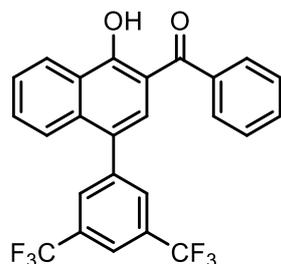
(4-(2-chlorophenyl)-1-hydroxynaphthalen-2-yl)(phenyl)methanone (3q)



Yellow solid; yield 22.9 mg, 64%; R_f = 0.55 (PE/EtOAc = 20:1); m.p. 170.1 – 172.5 °C. 1H NMR (400 MHz, $CDCl_3$) δ 14.04 (s, 1H), 8.64 (d, J = 9.4 Hz, 1H), 7.77 (d, J = 6.8 Hz, 2H), 7.65 – 7.58 (m, 2H), 7.58 – 7.48 (m, 5H), 7.44 (d, J = 9.2 Hz, 1H), 7.36 (d, J = 9.6 Hz, 3H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 201.4, 163.8, 138.4, 138.1, 135.8, 134.6, 132.5, 131.9, 130.7, 129.8, 129.3, 129.2, 128.5, 128.4, 127.6, 126.8,

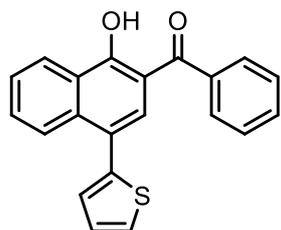
126.1, 125.9, 125.4, 124.8, 112.1. **ESI-HRMS** Calcd for $C_{23}H_{16}O_2^+$ $[M + H]^+$ 359.0833, found 359.0833.

(4-(3,5-bis(trifluoromethyl)phenyl)-1-hydroxynaphthalen-2-yl)(phenyl)methanone (3r)



Yellow solid; yield 30.8 mg, 67%; $R_f = 0.43$ (PE/EtOAc = 20:1); m.p. 140.2 – 142.5 °C. 1H NMR (400 MHz, $CDCl_3$) δ 14.10 (s, 1H), 8.66 (d, $J = 8.0$ Hz, 1H), 7.94 (s, 1H), 7.89 (s, 2H), 7.75 (d, $J = 7.4$ Hz, 2H), 7.72 – 7.57 (m, 4H), 7.55 (d, $J = 10.8$ Hz, 3H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 210.3, 164.4, 142.2, 137.8, 135.0, 132.5, 132.2 (d, $J_{C,F}=6.9$ Hz), 131.8, 131.4 (d, $J_{C,F}=10.6$ Hz), 130.3 (d, $J_{C,F}=3.8$ Hz), 129.2, 128.7 (d, $J_{C,F}=8.2$ Hz), 127.4 (d, $J_{C,F}=12.7$ Hz), 126.6, 125.8, 125.3, 124.9, 124.8 (d, $J_{C,F}=11.0$ Hz), 122.1, 121.4 (m), 112.1. ^{19}F NMR (565 MHz, $CDCl_3$) δ -62.75 (s, 6F). **ESI-HRMS** Calcd for $C_{25}H_{15}F_6O_2^+$ $[M + H]^+$ 461.0971, found 461.0970.

(1-hydroxy-4-(thiophen-2-yl)naphthalen-2-yl)(phenyl)methanone (3s)

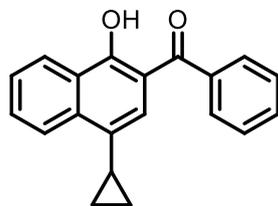


Yellow oily liquid; yield 20.8 mg, 63%; $R_f = 0.41$ (PE/EtOAc = 20:1); 1H NMR (400 MHz, $CDCl_3$) δ 14.00 (s, 1H), 8.62 (d, $J = 8.0$ Hz, 1H), 7.95 (d, $J = 8.2$ Hz, 1H), 7.75 (d, $J = 8.6$ Hz, 2H), 7.68 – 7.63 (m, 1H), 7.63 – 7.56 (m, 3H), 7.53 (t, $J = 7.4$ Hz, 2H), 7.46 – 7.40 (m, 1H), 7.31 (s, 1H), 7.22 (d, $J = 4.8$ Hz, 1H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 201.51, 163.50, 140.41, 138.16, 135.98, 131.87, 130.68, 129.63, 129.18,

129.18, 128.56, 127.88, 126.11, 125.87, 125.59, 125.32, 124.87, 123.56, 112.23.

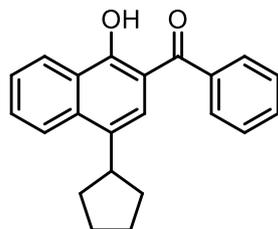
ESI-HRMS Calcd for $C_{21}H_{15}O_2S^+$ $[M + H]^+$ 331.0787, found 331.0787.

(4-cyclopropyl-1-hydroxynaphthalen-2-yl)(phenyl)methanone (3t)



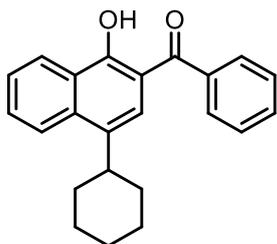
Yellow solid; yield 19.9 mg, 69%; R_f = 0.61 (PE/EtOAc = 20:1); m.p. 117.7 – 119.5 °C. 1H NMR (400 MHz, $CDCl_3$) δ 13.92 (s, 1H), 8.57 (d, J = 8.2 Hz, 1H), 8.36 (d, J = 8.4 Hz, 1H), 7.74 (d, J = 19.6 Hz, 3H), 7.61 (d, J = 8.6 Hz, 2H), 7.55 (t, J = 7.6 Hz, 2H), 7.38 (s, 1H), 2.20 – 2.10 (m, 1H), 0.98 (d, J = 8.2 Hz, 2H), 0.60 (d, J = 5.2 Hz, 2H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 201.3, 163.0, 138.3, 137.6, 131.8, 130.4, 129.2, 128.9, 128.4, 125.9, 125.4, 125.3, 125.0, 124.5, 112.0, 13.1, 6.1. **ESI-HRMS** Calcd for $C_{20}H_{17}O_2^+$ $[M + H]^+$ 289.1223, found 289.1222.

(4-cyclopentyl-1-hydroxynaphthalen-2-yl)(phenyl)methanone (3u)



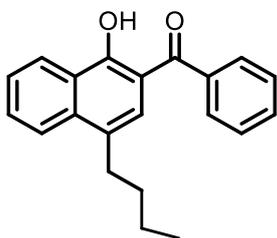
Yellow solid; yield 24.3 mg, 77%; R_f = 0.59 (PE/EtOAc = 20:1); m.p. 123.1 – 125.7 °C. 1H NMR (400 MHz, $CDCl_3$) δ 13.82 (s, 1H), 8.59 (d, J = 8.2 Hz, 1H), 8.07 (s, 1H), 7.77 – 7.66 (m, 3H), 7.66 – 7.45 (m, 5H), 3.62 (q, J = 7.8 Hz, 1H), 2.18 – 2.06 (m, 2H), 1.75 (s, 4H), 1.60 (t, J = 9.8 Hz, 2H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 201.4, 162.4, 138.5, 136.5, 131.8, 131.7, 130.2, 129.3, 128.4, 125.8, 125.6, 125.2, 124.1, 122.9, 112.1, 40.9, 33.3, 25.1. **ESI-HRMS** Calcd for $C_{22}H_{21}O_2^+$ $[M + H]^+$ 317.1536, found 317.1534.

(5-cyclohexyl-1-hydroxynaphthalen-2-yl)(phenyl)methanone (3v)



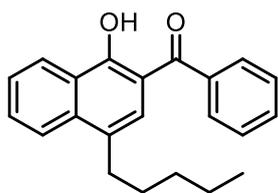
Yellow solid; yield 15.5 mg, 47%; $R_f = 0.46$ (PE/EtOAc = 20:1); m.p. 108.2 – 110.1 °C. $^1\text{H NMR}$ (400 MHz, CDCl_3) δ 13.80 (s, 1H), 8.60 (d, $J = 8.2$ Hz, 1H), 8.04 (d, $J = 8.4$ Hz, 1H), 7.75 (d, $J = 7.4$ Hz, 2H), 7.70 (t, $J = 7.4$ Hz, 1H), 7.62 (d, $J = 7.0$ Hz, 1H), 7.56 (t, $J = 7.4$ Hz, 3H), 7.45 (s, 1H), 3.21 – 3.09 (m, 1H), 1.98 (d, $J = 12.4$ Hz, 2H), 1.84 (dd, $J = 29.2, 12.8$ Hz, 3H), 1.59 – 1.45 (m, 2H), 1.41 – 1.21 (m, 3H). $^{13}\text{C NMR}$ (101 MHz, CDCl_3) δ 201.4, 162.3, 138.4, 135.7, 133.6, 131.8, 130.3, 129.4, 128.5, 125.7, 125.5, 125.3, 123.3, 123.2, 112.2, 38.8, 34.2, 27.3, 26.5. **ESI-HRMS** Calcd for $\text{C}_{23}\text{H}_{23}\text{O}_2^+$ $[\text{M} + \text{H}]^+$: 331.1693, found 331.1694.

(4-butyl-1-hydroxynaphthalen-2-yl)(phenyl)methanone (3w)



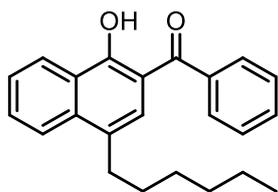
Yellow solid; yield 22.8 mg, 75%; $R_f = 0.43$ (PE/EtOAc = 20:1); m.p. 69.7 – 70.2 °C. $^1\text{H NMR}$ (400 MHz, CDCl_3) δ 13.81 (s, 1H), 8.59 (d, $J = 8.2$ Hz, 1H), 7.97 (d, $J = 8.4$ Hz, 1H), 7.74 (d, $J = 7.4$ Hz, 2H), 7.69 (d, $J = 7.6$ Hz, 1H), 7.59 (dd, $J = 19.8, 7.0$ Hz, 4H), 7.38 (s, 1H), 2.91 (t, $J = 7.6$ Hz, 2H), 1.69 – 1.61 (m, 2H), 1.37 – 1.47 (m 2H), 0.95 (t, $J = 7.4$ Hz, 3H). $^{13}\text{C NMR}$ (101 MHz, CDCl_3) δ 201.38, 162.59, 138.41, 136.13, 131.74, 130.29, 129.27, 128.52, 128.44, 126.36, 125.72, 125.62, 125.20, 123.99, 112.18, 32.74, 32.37, 22.77, 14.08. **ESI-HRMS** Calcd for $\text{C}_{21}\text{H}_{21}\text{O}_2^+$ $[\text{M} + \text{H}]^+$ 305.1536, found 305.1535.

(1-hydroxy-4-pentyl-naphthalen-2-yl)(phenyl)methanone (3x)



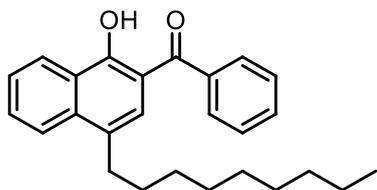
Yellow oily liquid; yield 20.4 mg, 64%; $R_f = 0.43$ (PE/EtOAc = 20:1); $^1\text{H NMR}$ (400 MHz, CDCl_3) δ 13.77 (s, 1H), 8.58 (d, $J = 8.3$ Hz, 1H), 7.96 (d, $J = 8.4$ Hz, 1H), 7.79 – 7.66 (m, 3H), 7.66 – 7.50 (m, 4H), 7.37 (s, 1H), 2.89 (t, $J = 7.6$ Hz, 2H), 1.66 (t, $J = 7.5$ Hz, 2H), 1.36 (d, $J = 5.2$ Hz, 4H), 0.90 (t, $J = 6.8$ Hz, 3H). $^{13}\text{C NMR}$ (101 MHz, CDCl_3) δ 201.4, 162.6, 138.5, 136.2, 131.8, 130.9, 129.3, 128.6, 128.5, 126.4, 125.8, 125.7, 125.2, 124.0, 112.2, 32.7, 32.0, 30.3, 22.67, 14.24. **ESI-HRMS** Calcd for $\text{C}_{21}\text{H}_{21}\text{O}_2^+$ $[\text{M} + \text{H}]^+$ 305.1536, found 305.1535.

(4-hexyl-1-hydroxynaphthalen-2-yl)(phenyl)methanone (3y)



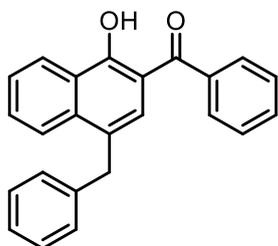
Yellow solid; yield 20.4 mg, 64%; $R_f = 0.50$ (PE/EtOAc = 20:1); m.p. 63.7 – 63.8 °C. $^1\text{H NMR}$ (400 MHz, CDCl_3) δ 13.76 (s, 1H), 8.58 (d, $J = 8.4$ Hz, 1H), 7.96 (d, $J = 8.4$ Hz, 1H), 7.75 – 7.67 (m, 3H), 7.64 – 7.51 (m, 4H), 7.36 (s, 1H), 2.93 – 2.85 (m, 2H), 1.69 – 1.61 (m, 2H), 1.43 – 1.34 (m, 2H), 1.31 (d, $J = 4.2$ Hz, 2H), 1.29 (s, 2H), 0.93 – 0.84 (m, 3H). $^{13}\text{C NMR}$ (101 MHz, CDCl_3) δ 201.4, 162.6, 138.5, 136.2, 131.7, 130.3, 129.3, 128.6, 128.5, 126.4, 125.8, 125.7, 125.3, 124.0, 112.3, 32.7, 31.8, 30.6, 29.5, 22.8, 14.2. **ESI-HRMS** Calcd for $\text{C}_{22}\text{H}_{23}\text{O}_2^+$ $[\text{M} + \text{H}]^+$ 319.1693, found 319.1693.

(1-hydroxy-4-nonylnaphthalen-2-yl)(phenyl)methanone (3z)



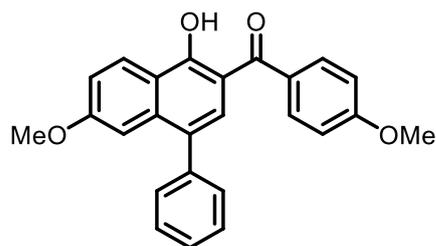
Yellow oily liquid; yield 28.0mg, 75%; $R_f = 0.53$ (PE/EtOAc = 20:1); $^1\text{H NMR}$ (400 MHz, CDCl_3) δ 13.80 (s, 1H), 8.59 (d, $J = 8.2$ Hz, 1H), 7.96 (d, $J = 8.4$ Hz, 1H), 7.75 (s, 1H), 7.72 (d, $J = 13.6$ Hz, 2H), 7.58 (dd, $J = 21.0, 7.4$ Hz, 4H), 7.37 (s, 1H), 2.90 (t, $J = 7.4$ Hz, 2H), 1.65 (p, $J = 7.8, 6.6$ Hz, 2H), 1.33 (d, $J = 46.8$ Hz, 12H), 0.89 (t, $J = 6.4$ Hz, 3H). $^{13}\text{C NMR}$ (101 MHz, CDCl_3) δ 201.4, 162.6, 138.4, 136.1, 131.7, 130.3, 129.3, 128.6, 128.4, 126.4, 125.7, 125.6, 125.2, 124.0, 112.2, 32.7, 32.0, 30.6, 29.8 (2C), 29.6, 29.5, 22.8, 14.3. **ESI-HRMS** Calcd for $\text{C}_{26}\text{H}_{31}\text{O}_2^+$ $[\text{M} + \text{H}]^+$ 375.2319, found 375.2319.

(4-benzyl-1-hydroxynaphthalen-2-yl)(phenyl)methanone (3aa)



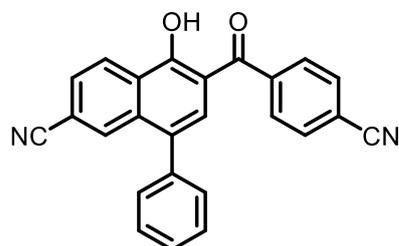
Yellow solid; yield 20.3 mg, 60%; $R_f = 0.50$ (PE/EtOAc = 20:1); m.p. 111.1 – 113.7°C. $^1\text{H NMR}$ (400 MHz, CDCl_3) δ 13.85 (s, 1H), 8.50 (d, $J = 8.2$ Hz, 1H), 7.79 (d, $J = 8.2$ Hz, 1H), 7.60 (d, $J = 6.4$ Hz, 2H), 7.54 (t, $J = 7.6$ Hz, 1H), 7.47 (t, $J = 7.4$ Hz, 2H), 7.40 (t, $J = 7.6$ Hz, 2H), 7.29 (s, 1H), 7.16 (d, $J = 8.2$ Hz, 2H), 7.06 (d, $J = 7.6$ Hz, 3H), 4.20 (s, 2H). $^{13}\text{C NMR}$ (101 MHz, CDCl_3) δ 201.3, 163.3, 140.4, 138.2, 136.3, 131.8, 130.6, 129.3, 128.6, 128.4, 128.3, 126.4, 126.3, 125.9, 125.9, 125.2, 124.5, 112.2, 38.7. **ESI-HRMS** Calcd for $\text{C}_{24}\text{H}_{19}\text{O}_2^+$ $[\text{M} + \text{H}]^+$ 339.1380, found 339.1380.

(1-hydroxy-6-methoxy-4-phenylnaphthalen-2-yl)(4-methoxyphenyl)methanone (3ab)



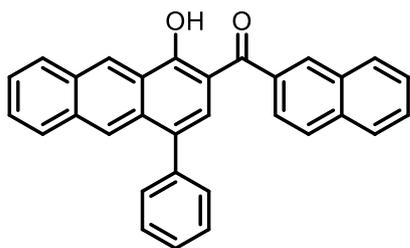
Yellow solid; yield 20.0 mg, 52%; R_f = 0.40 (PE/EtOAc = 20:1); m.p. 135.6 – 137.5 °C. $^1\text{H NMR}$ (400 MHz, CDCl_3) δ 14.08 (s, 1H), 8.52 (d, J = 9.0 Hz, 1H), 7.76 (d, J = 8.8 Hz, 2H), 7.54 (d, J = 2.0 Hz, 1H), 7.46 (d, J = 5.8 Hz, 4H), 7.41 (d, J = 3.8 Hz, 1H), 7.20 (d, J = 11.4 Hz, 1H), 7.16 (s, 1H), 6.99 (d, J = 8.8 Hz, 2H), 3.88 (s, 3H), 3.80 (s, 3H). $^{13}\text{C NMR}$ (101 MHz, CDCl_3) δ 199.8, 163.3, 162.6, 161.4, 140.4, 137.8, 131.6, 130.8, 130.1, 129.4, 129.0, 128.6, 127.3, 126.8, 120.3, 117.4, 113.8, 111.3, 105.5, 55.6, 55.4. **ESI-HRMS** Calcd for $\text{C}_{25}\text{H}_{21}\text{O}_2^+$ $[\text{M} + \text{H}]^+$ 385.1434, found 385.1434.

6-(4-cyanobenzoyl)-5-hydroxy-8-phenyl-2-naphthonitrile (3ac)



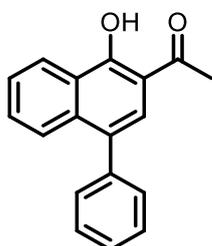
Yellow solid; yield 8.6 mg, 23%; R_f = 0.40 (PE/EtOAc = 20:1); m.p. 156.6 – 157.5 °C. $^1\text{H NMR}$ (400 MHz, CDCl_3) δ 13.58 (d, J = 2.1 Hz, 1H), 8.71 (d, J = 8.6 Hz, 1H), 8.17 (s, 1H), 7.83 (s, 4H), 7.75 (d, J = 10.3 Hz, 1H), 7.47 (d, J = 11.9 Hz, 4H), 7.34 (d, J = 7.8 Hz, 2H). $^{13}\text{C NMR}$ (101 MHz, CDCl_3) δ 199.78, 162.66, 141.25, 138.18, 135.14, 132.60, 132.00, 131.56, 129.99, 129.52, 129.07, 128.46, 128.37, 127.24, 127.08, 126.33, 118.74, 117.86, 115.77, 114.19, 113.54. **ESI-HRMS** Calcd for $\text{C}_{25}\text{H}_{15}\text{N}_2\text{O}_2^+$ $[\text{M} + \text{H}]^+$ 375.1128, found 375.1128.

ethyl 1-hydroxy-4-phenyl-2-naphthoate (3ad)



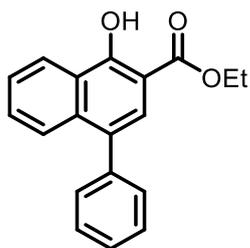
Yellow solid; yield 27.1 mg, 64%; $R_f = 0.50$ (PE/EtOAc = 20:1); m.p. 188.1 – 190.3 °C. $^1\text{H NMR}$ (400 MHz, CDCl_3) δ 13.58 (s, 1H), 8.56 (d, $J = 9.0$ Hz, 1H), 8.33 (s, 1H), 7.99 (d, $J = 8.4$ Hz, 2H), 7.95 – 7.86 (m, 4H), 7.76 (d, $J = 8.8$ Hz, 1H), 7.68 (s, 1H), 7.61 (p, $J = 6.6$ Hz, 2H), 7.52 (t, $J = 7.4$ Hz, 1H), 7.37 (q, $J = 7.4, 6.8$ Hz, 5H), 7.14 (t, $J = 7.8$ Hz, 1H). $^{13}\text{C NMR}$ (101 MHz, CDCl_3) δ 201.3, 161.8, 144.7, 135.3, 135.3, 135.0, 134.4, 132.5, 132.5, 130.9, 130.8, 129.8, 129.4, 129.2, 129.2, 129.0, 128.7, 128.5, 128.4, 128.0, 127.8, 127.7, 127.2, 125.5, 125.2, 124.6, 121.1, 113.7. **ESI-HRMS** Calcd for $\text{C}_{31}\text{H}_{19}\text{O}_2^-$ $[\text{M} + \text{H}]^+$ 423.1391, found 423.1389.

1-(1-hydroxy-4-phenyl-naphthalen-2-yl)ethan-1-one (3ae)



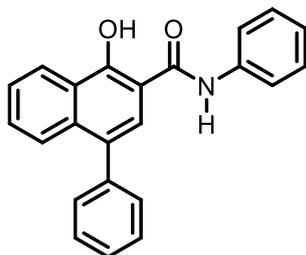
Yellow solid; yield 15.5 mg, 59%; $R_f = 0.65$ (PE/EtOAc = 20:1); m.p. 178.6 – 181.4 °C. $^1\text{H NMR}$ (400 MHz, CDCl_3) δ 14.01 (s, 1H), 8.55 (d, $J = 9.4$ Hz, 1H), 7.79 (d, $J = 7.6$ Hz, 1H), 7.63 – 7.54 (m, 3H), 7.48 (q, $J = 7.0$ Hz, 5H), 2.71 (s, 3H). $^{13}\text{C NMR}$ (101 MHz, CDCl_3) δ 204.6, 162.0, 140.2, 136.0, 131.1, 130.3, 128.6, 127.5, 126.0, 125.7, 125.5, 124.8, 112.9, 27.1. **ESI-HRMS** Calcd for $\text{C}_{18}\text{H}_{13}\text{O}_2^-$ $[\text{M} - \text{H}]^-$ 261.0916, found 261.0918.

ethyl 1-hydroxy-4-phenyl-2-naphthoate (3af)



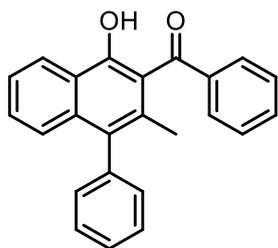
Yellow solid; yield 11.9 mg, 58%; $R_f = 0.47$ (PE/EtOAc = 20:1); m.p. 112.5 – 114.5 °C. $^1\text{H NMR}$ (400 MHz, CDCl_3) δ 12.11 (d, $J = 1.6$ Hz, 1H), 8.55 – 8.47 (m, 1H), 7.86 – 7.79 (m, 1H), 7.76 (d, $J = 1.4$ Hz, 1H), 7.61 – 7.54 (m, 2H), 7.53 – 7.41 (m, 5H), 4.44–4.49 (m, 2H), 1.44 (td, $J = 7.0, 1.4$ Hz, 3H). $^{13}\text{C NMR}$ (101 MHz, CDCl_3) δ 171.2, 160.5, 140.3, 135.6, 131.2, 130.3, 129.5, 128.5, 127.3, 126.0, 125.8, 125.1, 125.0, 124.2, 105.5, 61.6, 14.4. **ESI-HRMS** Calcd for $\text{C}_{19}\text{H}_{15}\text{O}_3^-$ $[\text{M} + \text{H}]^+$ 291.1021, found 291.1022.

1-hydroxy-N,4-diphenyl-2-naphthamide (3ag)



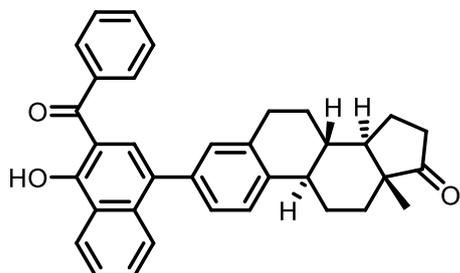
Yellow solid; yield 10.5 mg, 31%; $R_f = 0.30$ (PE/EtOAc = 20:1); m.p. 207.8 – 209.5 °C. $^1\text{H NMR}$ (400 MHz, CDCl_3) δ 13.60 (s, 1H), 8.60 – 8.52 (m, 1H), 8.02 (s, 1H), 7.85 – 7.78 (m, 1H), 7.63 – 7.56 (m, 4H), 7.54 (s, 4H), 7.46 (q, $J = 5.4, 4.0$ Hz, 1H), 7.42 – 7.36 (m, 3H), 7.20 (t, $J = 7.4$ Hz, 1H). $^{13}\text{C NMR}$ (101 MHz, CDCl_3) δ 169.2, 160.9, 140.1, 136.7, 134.9, 131.2, 130.2, 129.4, 129.3, 128.6, 127.5, 126.1, 125.9, 125.4, 124.3, 121.5, 121.4, 106.4. **ESI-HRMS** Calcd for $\text{C}_{23}\text{H}_{18}\text{NO}_2^+$ $[\text{M} + \text{H}]^+$ 340.1332, found 340.1332.

(1-hydroxy-3-methyl-4-phenyl-naphthalen-2-yl)(phenyl)methanone (3ah)



Yellow solid; yield 10.5 mg, 31%; $R_f = 0.56$ (PE/EtOAc = 20:1); m.p. 195.6 – 203.7 °C. $^1\text{H NMR}$ (400 MHz, CDCl_3) δ 11.02 (s, 1H), 8.52 – 8.45 (m, 1H), 7.76 (d, $J = 7.1$ Hz, 2H), 7.57 (d, $J = 7.6$ Hz, 1H), 7.50 (d, $J = 7.0$ Hz, 6H), 7.35 – 7.31 (m, 1H), 7.29 – 7.24 (m, 3H), 1.80 (s, 3H). $^{13}\text{C NMR}$ (101 MHz, CDCl_3) δ 201.64, 157.85, 140.84, 139.44, 136.07, 132.74, 131.89, 130.87, 130.80, 129.40, 129.15, 128.78, 128.74, 127.33, 126.27, 125.24, 123.90, 123.68, 117.13, 22.65. **ESI-HRMS** Calcd for $\text{C}_{24}\text{H}_{17}\text{O}_2^-$ $[\text{M} - \text{H}]^-$ 337.1234, found 337.1233.

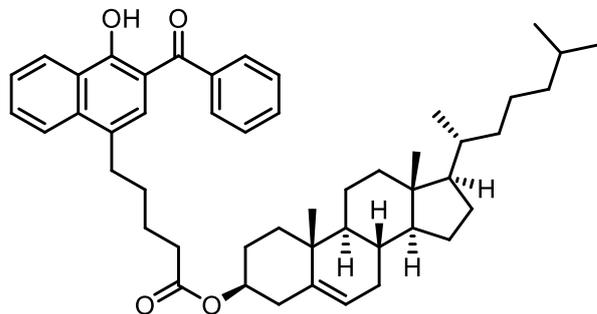
(8*S*,9*R*,13*R*,14*R*)-3-(3-benzoyl-4-hydroxynaphthalen-1-yl)-13-methyl-6,7,8,9,11,12,13,14,15,16-decahydro-17*H*-cyclopenta[*a*]phenanthren-17-one (3ai)



Yellow oily liquid, yield 34.0 mg, 68%; $R_f = 0.10$ (PE/EtOAc = 20:1); $^1\text{H NMR}$ (400 MHz, CDCl_3) δ 14.00 (s, 1H), 8.65 (d, $J = 7.8$ Hz, 1H), 7.89 (d, $J = 7.8$ Hz, 1H), 7.77 (d, $J = 7.4$ Hz, 2H), 7.69 – 7.49 (m, 6H), 7.41 (d, $J = 8.0$ Hz, 1H), 7.25 (d, $J = 8.0$ Hz, 1H), 7.18 (s, 1H), 2.99 (d, $J = 9.2$ Hz, 2H), 2.55 (dt, $J = 18.3, 9.4$ Hz, 2H), 2.42 (t, $J = 10.4$ Hz, 1H), 2.25 – 2.00 (m, 4H), 1.78 – 1.64 (m, 4H), 1.55 (d, $J = 12.2$ Hz, 2H), 0.98 (s, 3H). $^{13}\text{C NMR}$ (101 MHz, CDCl_3) δ 221.0, 201.7, 163.3, 138.9, 138.3, 137.6, 136.7, 136.0, 131.7, 130.8, 130.6, 130.5, 129.1, 128.6, 127.7, 127.7, 126.2, 126.0, 125.6, 125.5, 124.9, 112.3, 50.7, 48.1, 45.0, 38.3, 36.0, 31.8, 29.6, 26.7, 25.9, 21.7, 14.0. **ESI-HRMS** Calcd for $\text{C}_{35}\text{H}_{33}\text{O}_3^+$ $[\text{M} + \text{H}]^+$ 501.2424, found 501.2424.

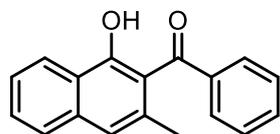
(3*S*,8*S*,9*S*,10*R*,13*R*,14*S*,17*R*)-10,13-dimethyl-17-((*R*)-6-methylheptan-2-yl)-2,3,4,7,

**8,9,10,11,12,13,14,15,16,17-tetradecahydro-1H-cyclopenta[*a*]phenanthren-3-yl
5-(3-benzoyl-4-hydroxynaphthalen-1-yl)pentanoate (3aj)**



Yellow solid; yield 30.8 mg, 43%; $R_f = 0.18$ (PE/EtOAc = 20:1); m.p. 154.3 – 156.5 °C. $^1\text{H NMR}$ (400 MHz, Chloroform-*d*) δ 13.81 (s, 1H), 8.58 (d, $J = 8.4$ Hz, 1H), 8.00 (d, $J = 8.0$ Hz, 1H), 7.73 (d, $J = 7.5$ Hz, 3H), 7.63 – 7.52 (m, 4H), 7.37 (s, 1H), 5.35 (s, 1H), 4.60 (s, 1H), 2.95 (s, 2H), 2.34 (s, 2H), 2.26 (d, $J = 6.5$ Hz, 2H), 2.01 (d, $J = 12.4$ Hz, 3H), 1.56 (s, 10H), 1.50 (s, 3H), 1.33 (s, 2H), 1.26 (s, 5H), 1.12 (s, 3H), 1.00 (s, 5H), 0.91 (d, $J = 5.8$ Hz, 4H), 0.86 (d, $J = 4.8$ Hz, 7H), 0.68 (s, 3H). $^{13}\text{C NMR}$ (101 MHz, CDCl_3) δ 201.4, 172.9, 162.9, 139.7, 138.3, 136.0, 131.8, 130.5, 129.3, 128.5, 127.4, 126.9, 125.8, 125.3, 124.0, 122.9, 112.2, 74.1, 56.8, 56.2, 50.1, 42.4, 39.8, 39.6, 38.3, 37.1, 36.7, 36.3, 35.9, 34.3, 32.1, 32.0, 32.0, 28.4, 28.2, 27.9, 25.9, 24.4, 24.0, 23.0, 22.7, 21.2, 19.5, 18.8, 12.0. **ESI-HRMS** Calcd for $\text{C}_{49}\text{H}_{65}\text{O}_4^+$ $[\text{M} + \text{H}]^+$ 717.4877, found 717.4877.

(1-hydroxy-3-methylnaphthalen-2-yl)(phenyl)methanone (3ak)



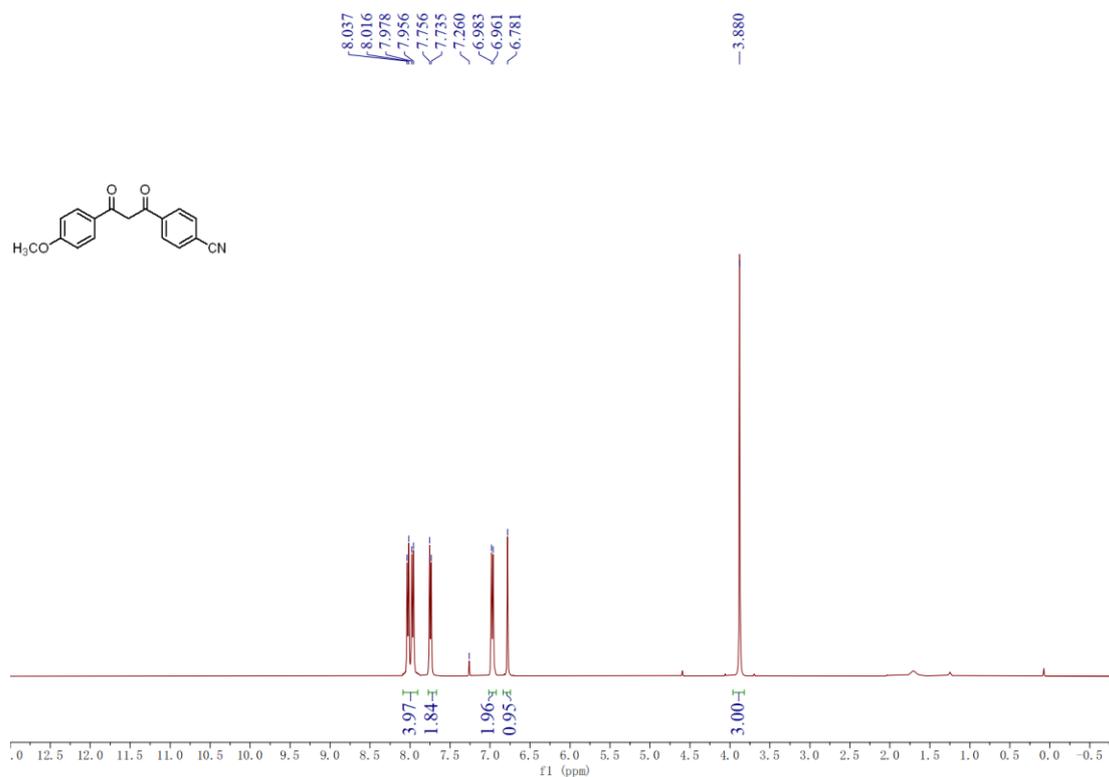
Yellow oily liquid; yield 9.1 mg, 35%; $R_f = 0.69$ (PE/EtOAc = 20:1); $^1\text{H NMR}$ (400 MHz, CDCl_3) δ 11.57 (s, 1H), 8.39 (d, $J = 8.4$ Hz, 1H), 7.66 (dd, $J = 15.5, 7.6$ Hz, 3H), 7.58 (q, $J = 8.4$ Hz, 2H), 7.47 (q, $J = 8.4, 7.7$ Hz, 3H), 7.12 (s, 1H), 2.05 (s, 3H). $^{13}\text{C NMR}$ (101 MHz, CDCl_3) δ 202.09, 159.82, 141.02, 136.44, 133.57, 132.51, 129.81, 128.83, 128.73, 127.30, 126.80, 125.40, 124.21, 123.77, 120.94, 116.51, 23.77. **ESI-HRMS** Calcd for $\text{C}_{18}\text{H}_{13}\text{O}_2^-$ $[\text{M} - \text{H}]^-$ 261.0921, found 261.0920.

6. Reference

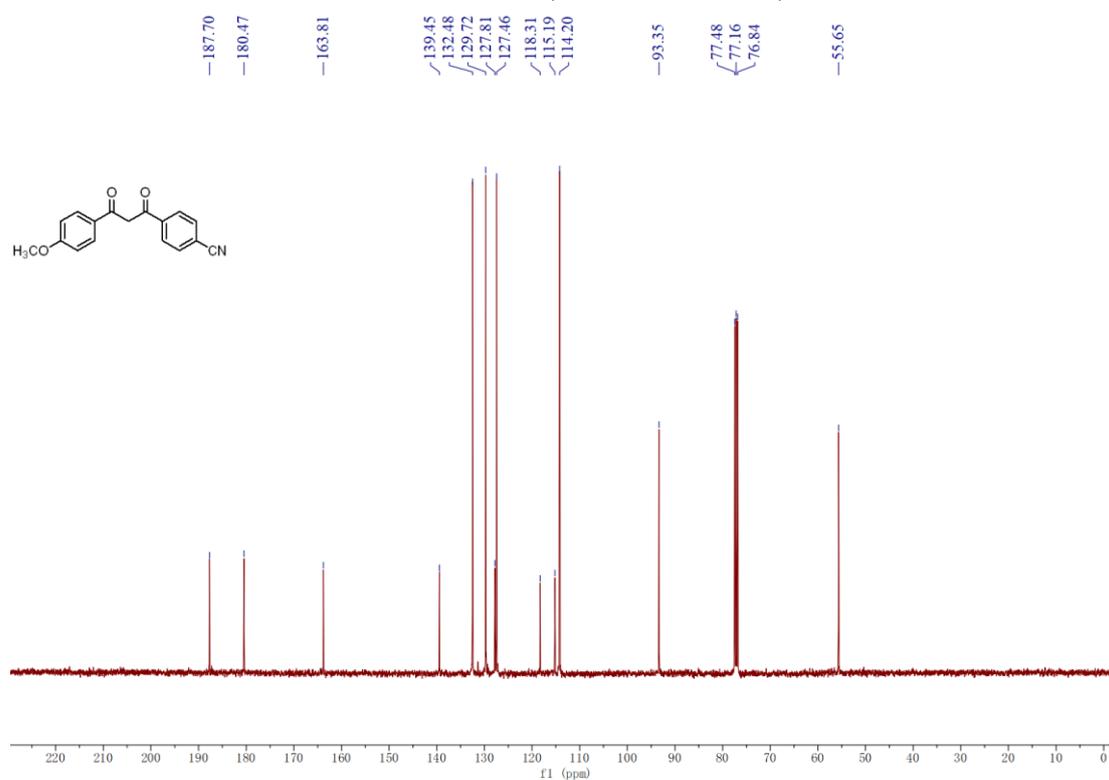
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2. Z. Zhang and X. Jiang, *Org. Lett.*, 2014, **16**, 4400-4403.
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6. L.-H. Zou, D. L. Priebbenow, L. Wang, J. Mottweiler and C. Bolm, *Adv. Synth. Catal.*, 2013, **355**, 2558-2563.
7. R. Martinez-Haya, L. Marzo and B. König, *Chem. Commun.*, 2018, **54**, 11602-11605.
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9. Z.-F. Xu, H. Dai, L. Shan and C.-Y. Li, *Org. Lett.*, 2018, **20**, 1054-1057.
10. Y. Xi, B. Dong, E. J. McClain, Q. Wang, T. L. Gregg, N. G. Akhmedov, J. L. Petersen and X. Shi, *Angew. Chem. Int. Ed.*, 2014, **53**, 4657-4661.

7. Copies of ^1H NMR, ^{13}C NMR and ^{19}F NMR

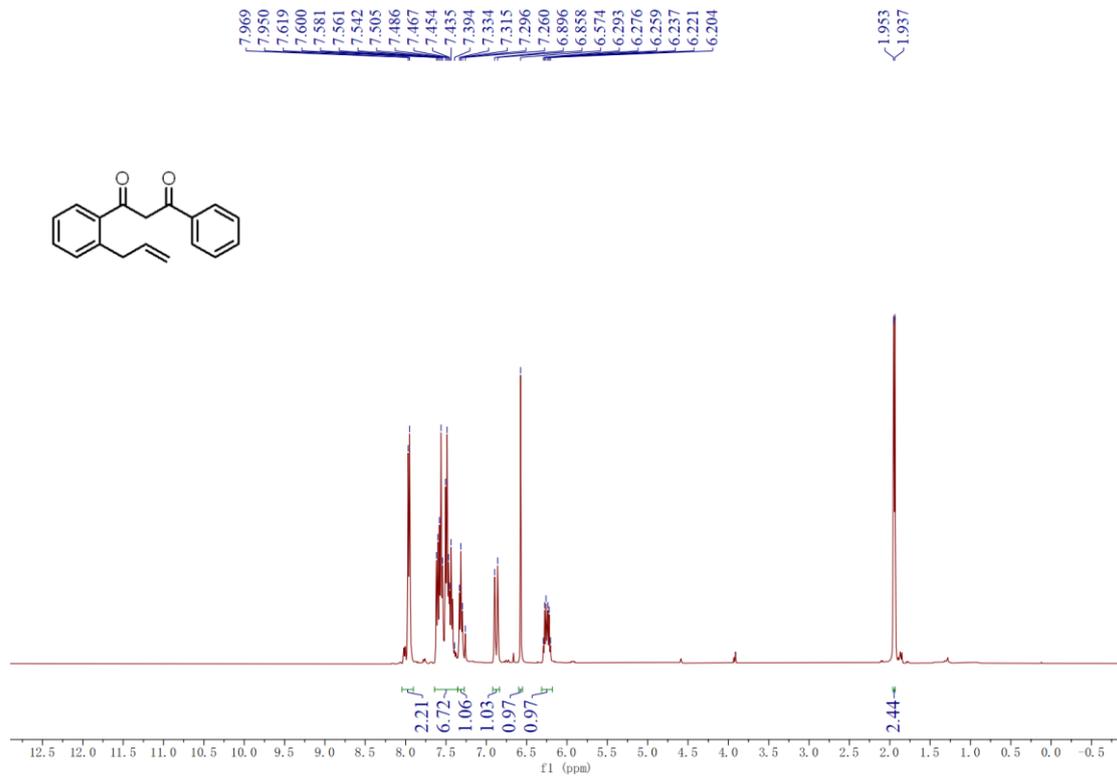
1h – ^1H NMR (400 MHz, CDCl_3)



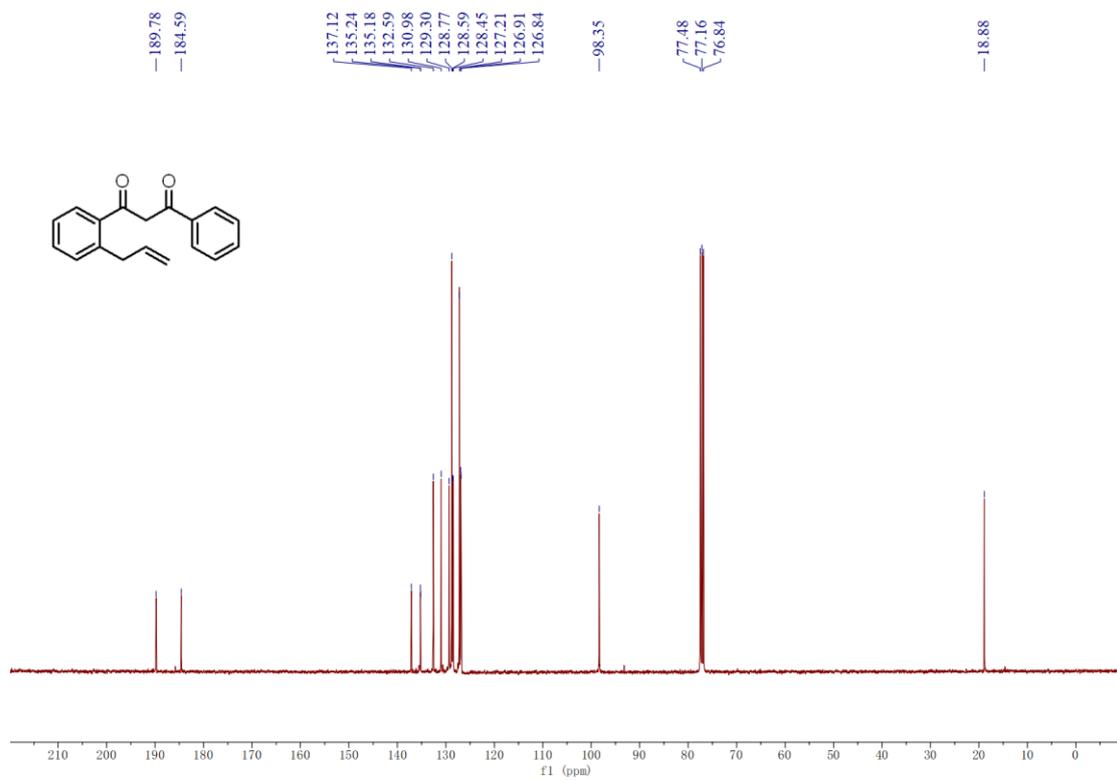
1h – ^{13}C NMR (101 MHz, CDCl_3)



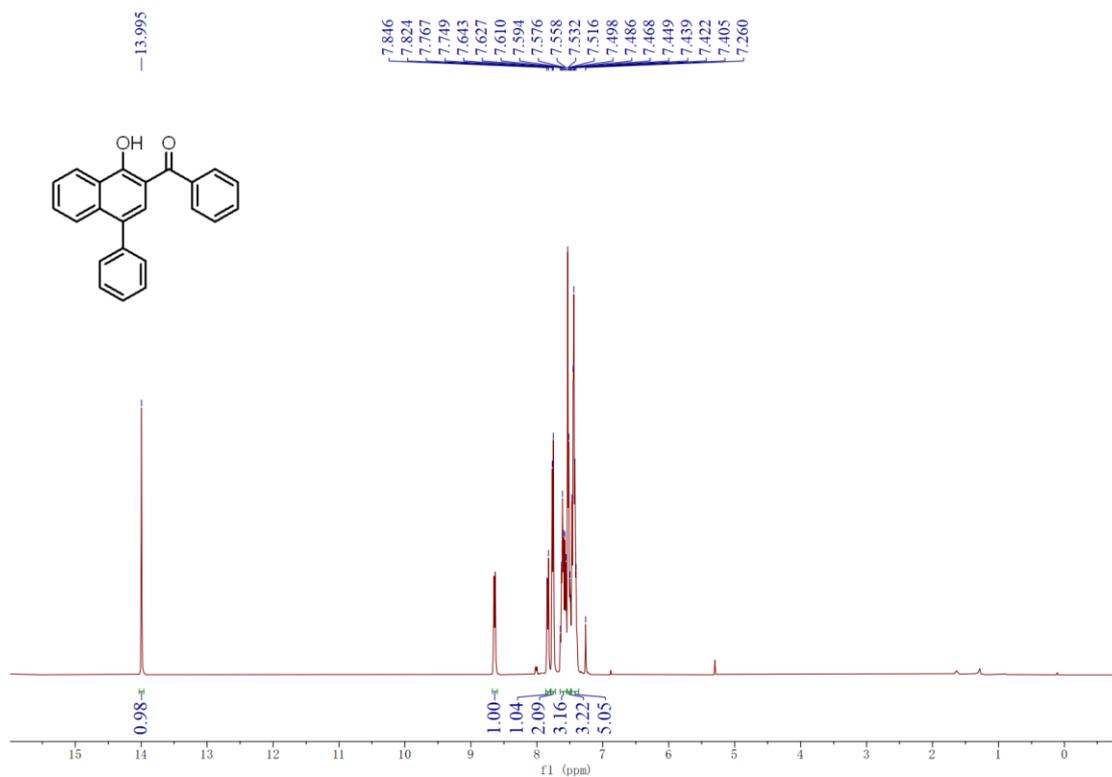
1i – ^1H NMR (400 MHz, CDCl_3)



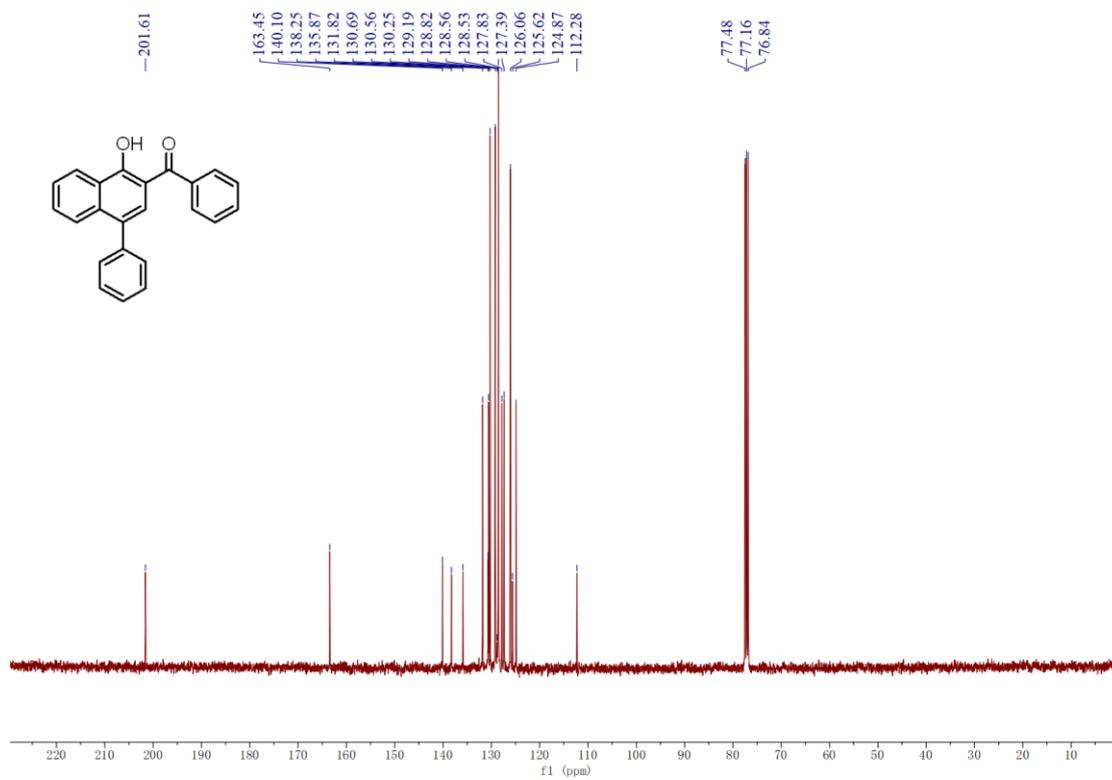
1i – ^{13}C NMR (101 MHz, CDCl_3)



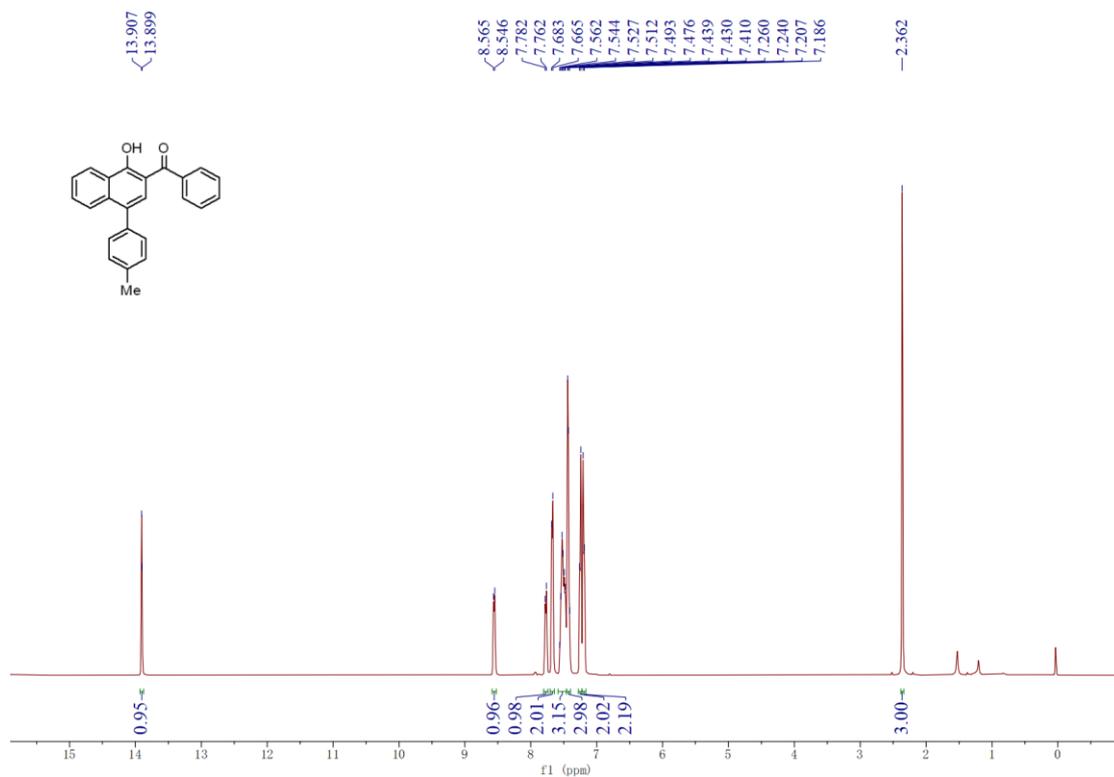
3a – ^1H NMR (400 MHz, CDCl_3)



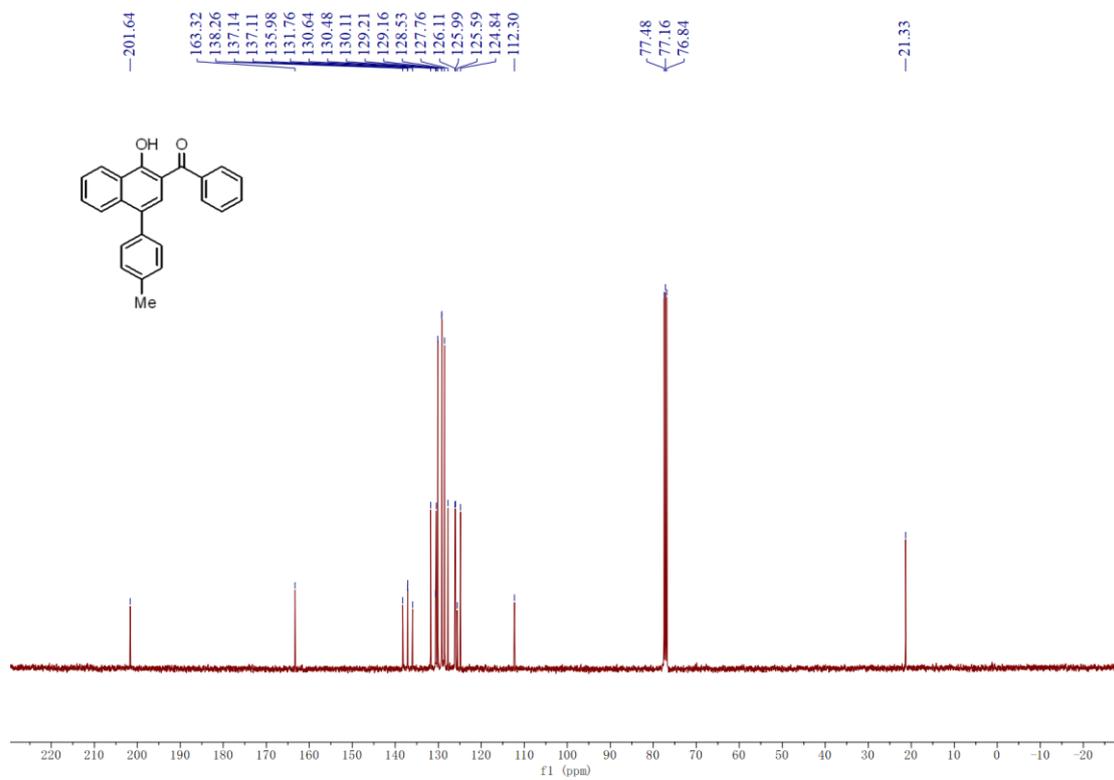
3b – ^{13}C NMR (101 MHz, CDCl_3)



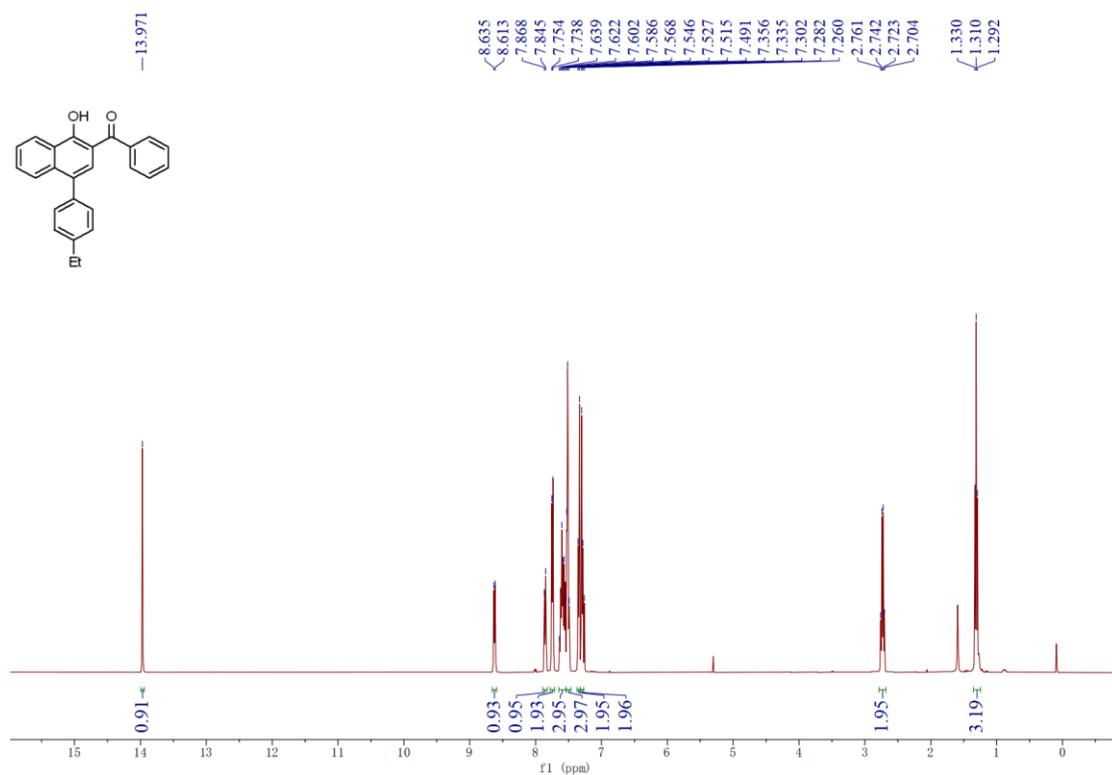
3b – ^1H NMR (400 MHz, CDCl_3)



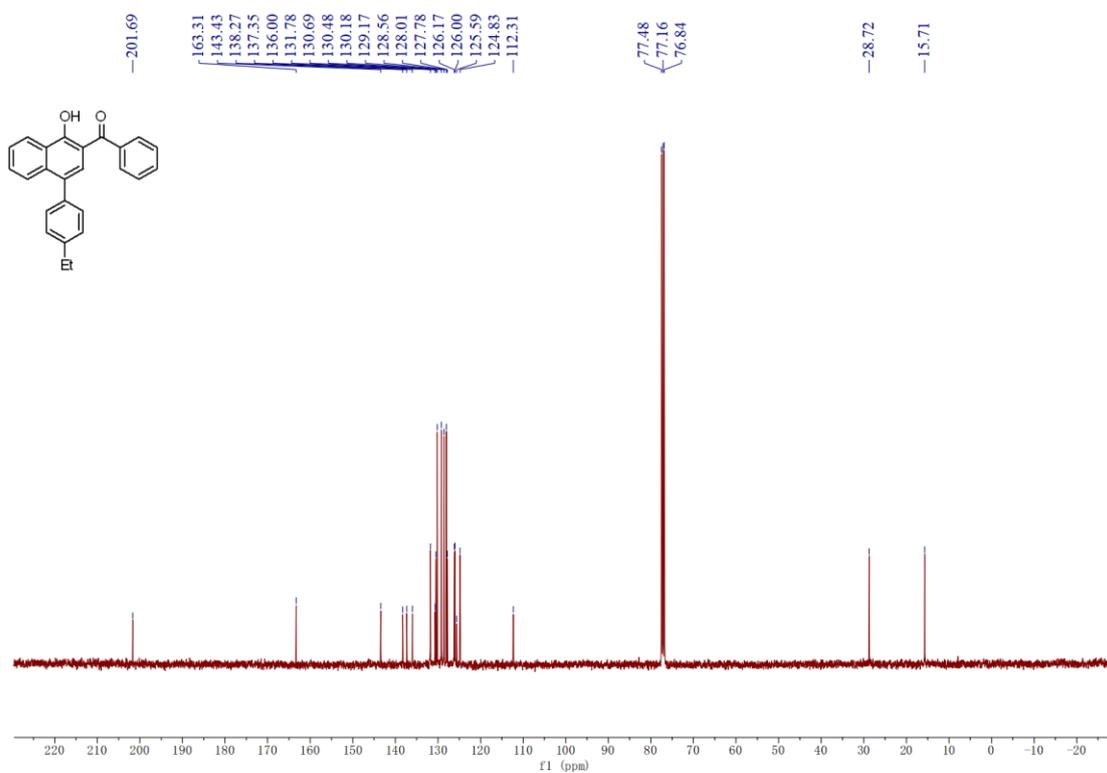
3b – ^{13}C NMR (101 MHz, CDCl_3)



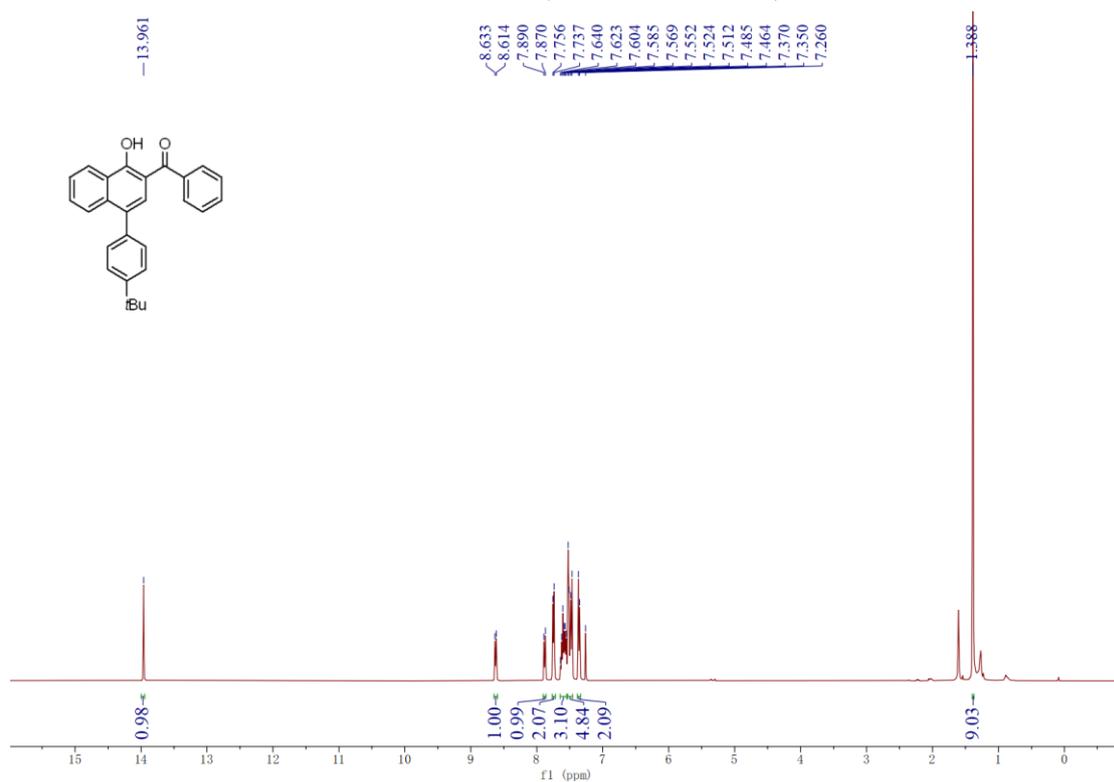
3c – ^1H NMR (400 MHz, CDCl_3)



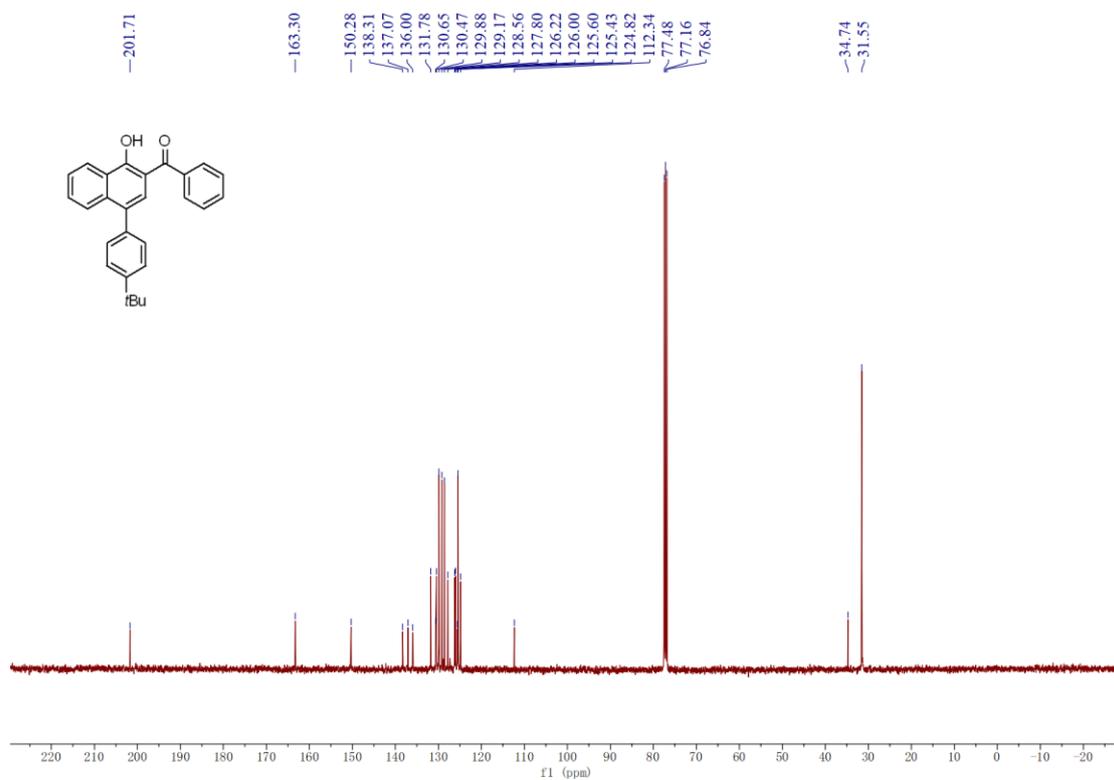
3c – ^{13}C NMR (101 MHz, CDCl_3)



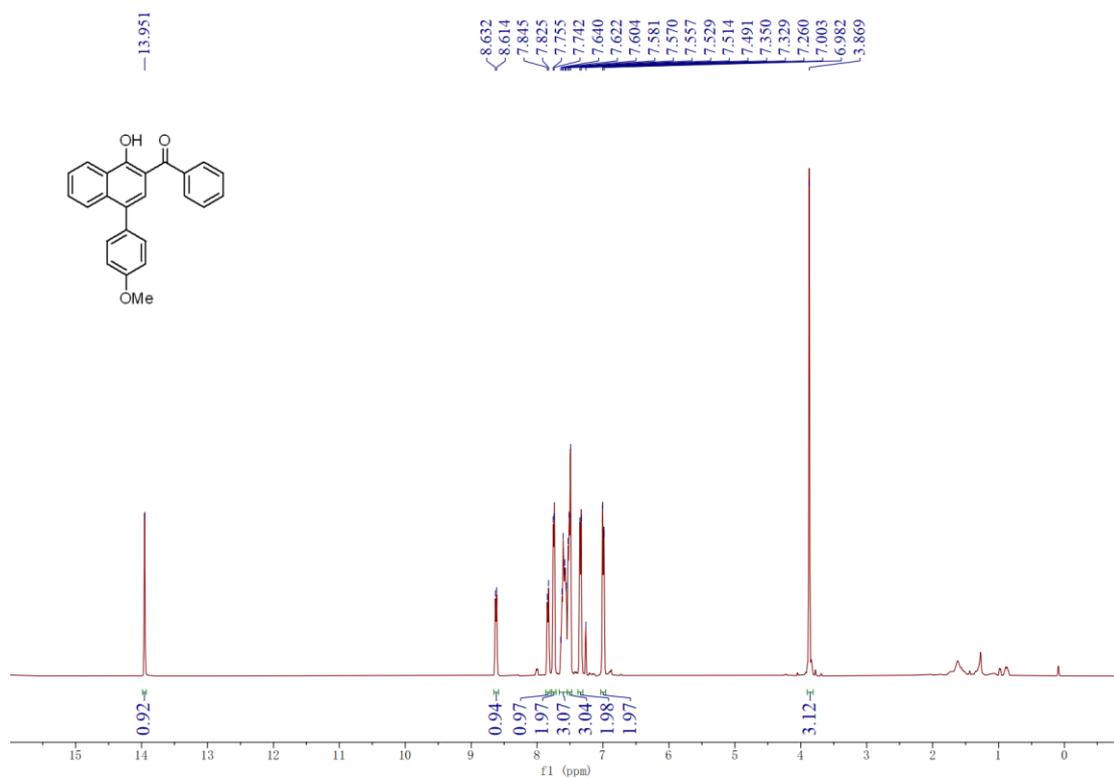
3d – ^1H NMR (400 MHz, CDCl_3)



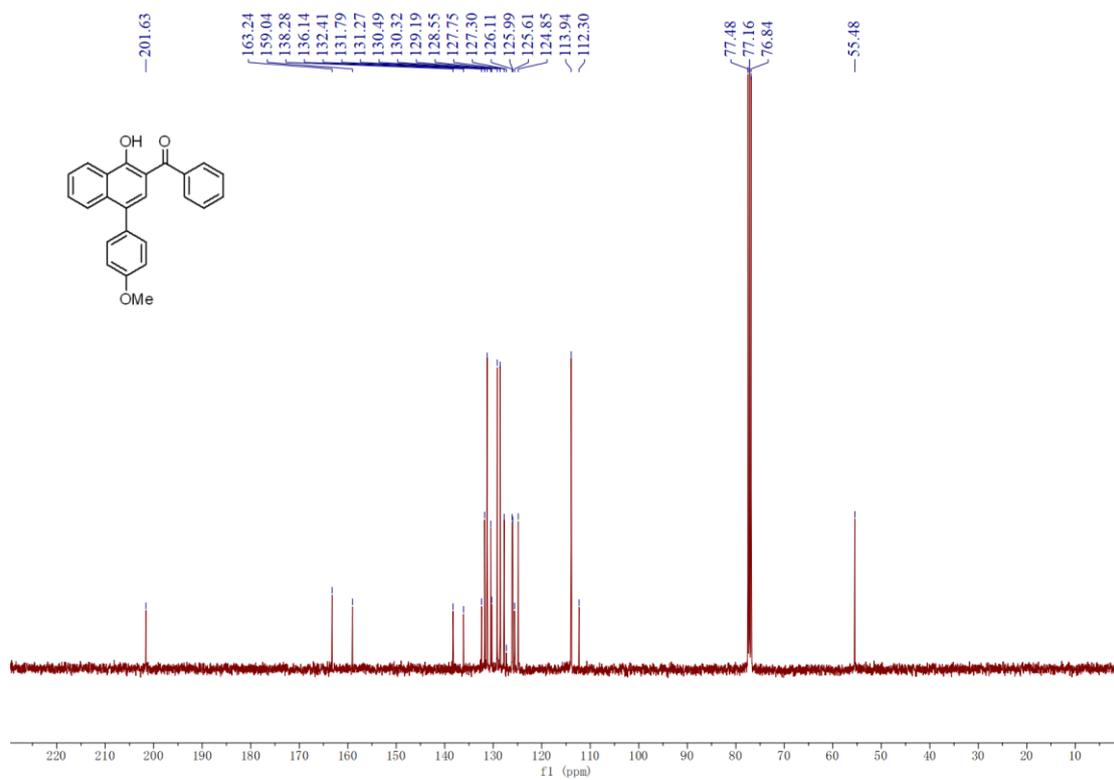
3d – ^{13}C NMR (101 MHz, CDCl_3)



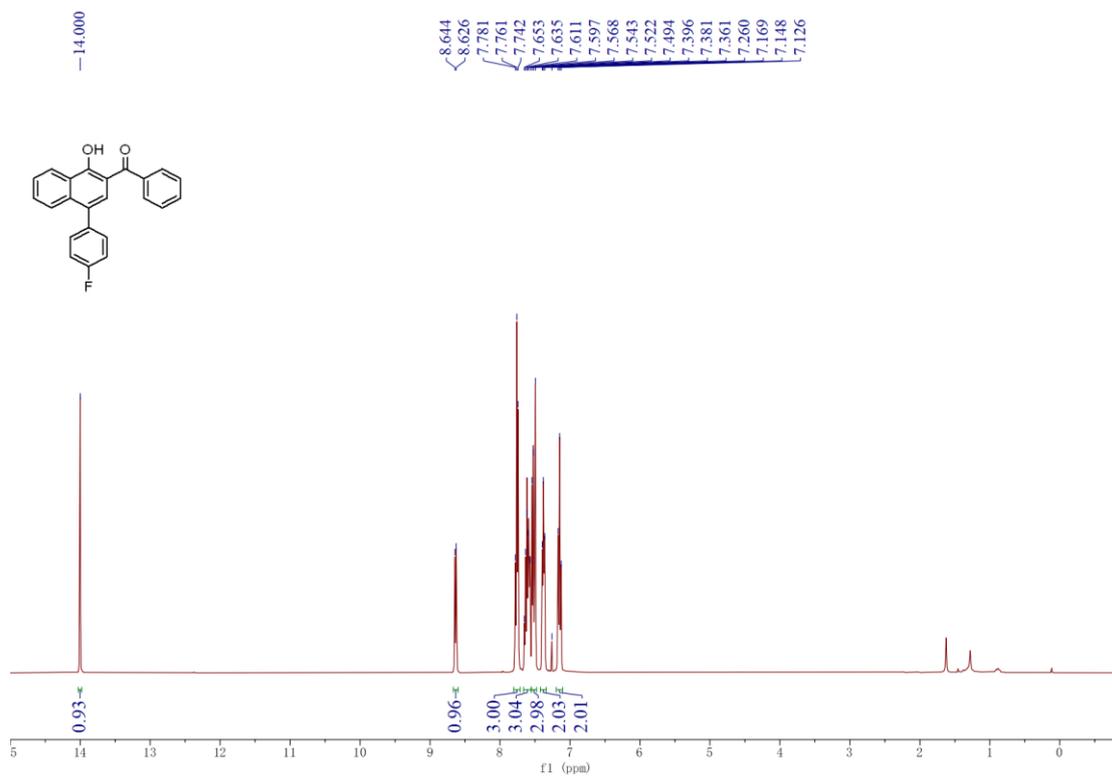
3e – ^1H NMR (400 MHz, CDCl_3)



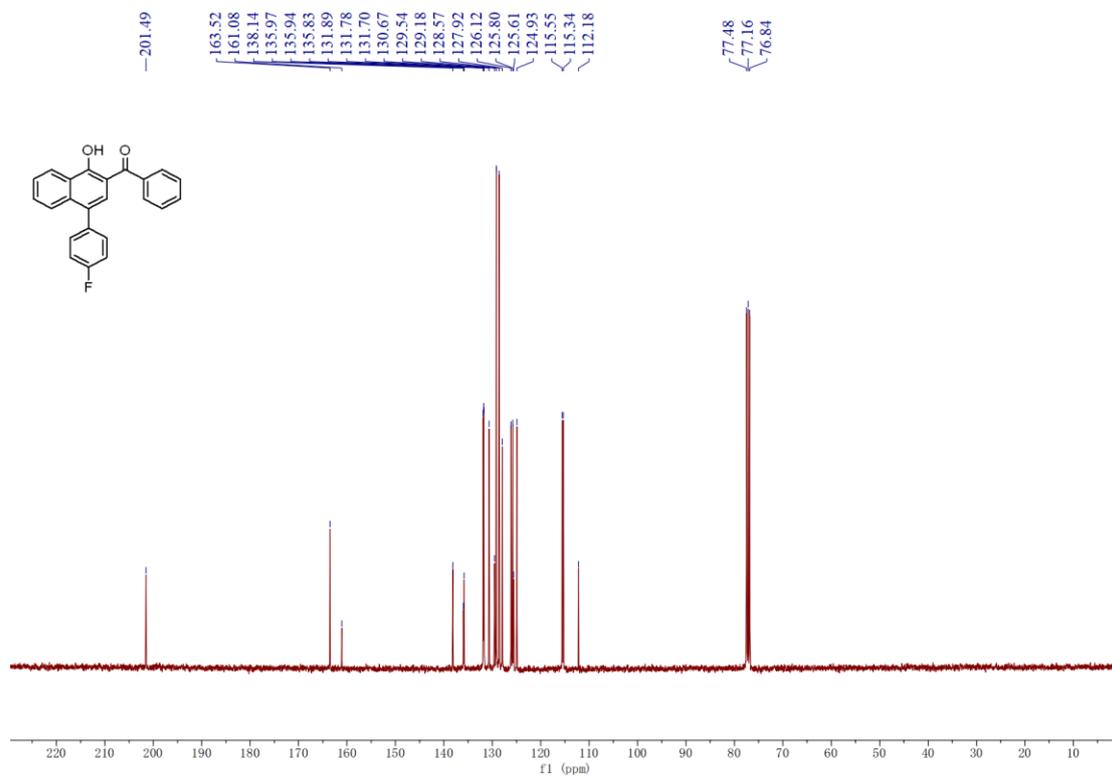
3e – ^{13}C NMR (101 MHz, CDCl_3)



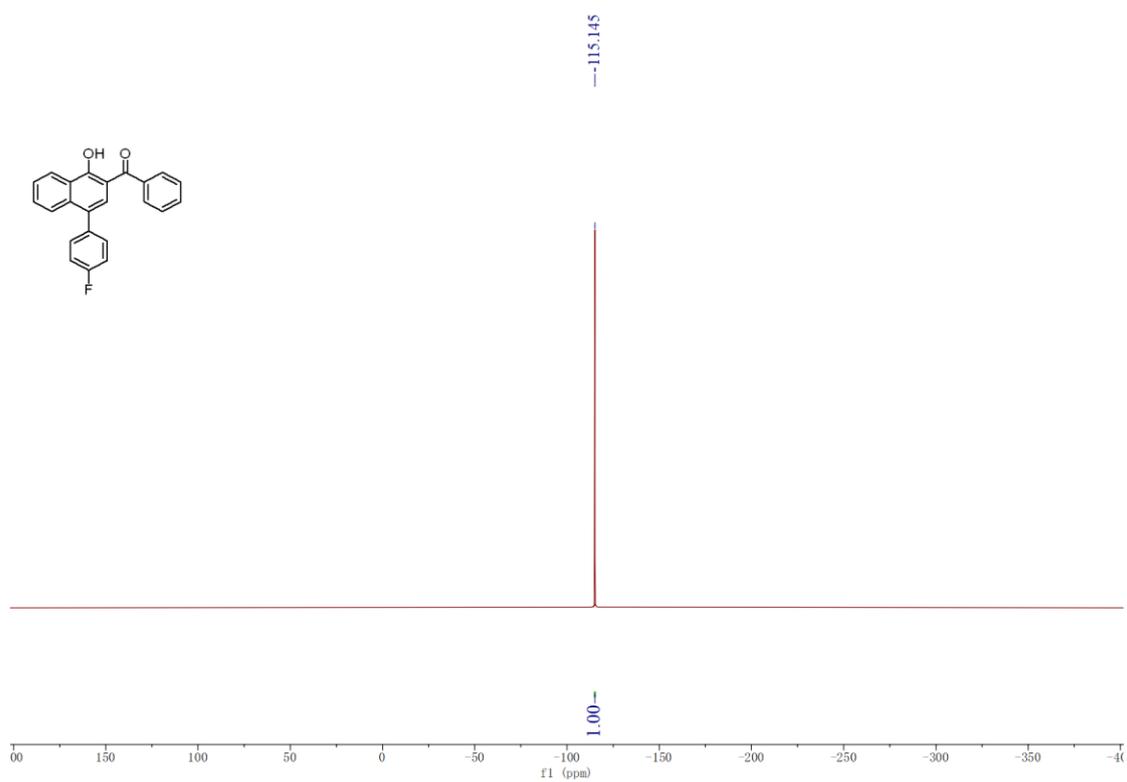
3f – ^1H NMR (400 MHz, CDCl_3)



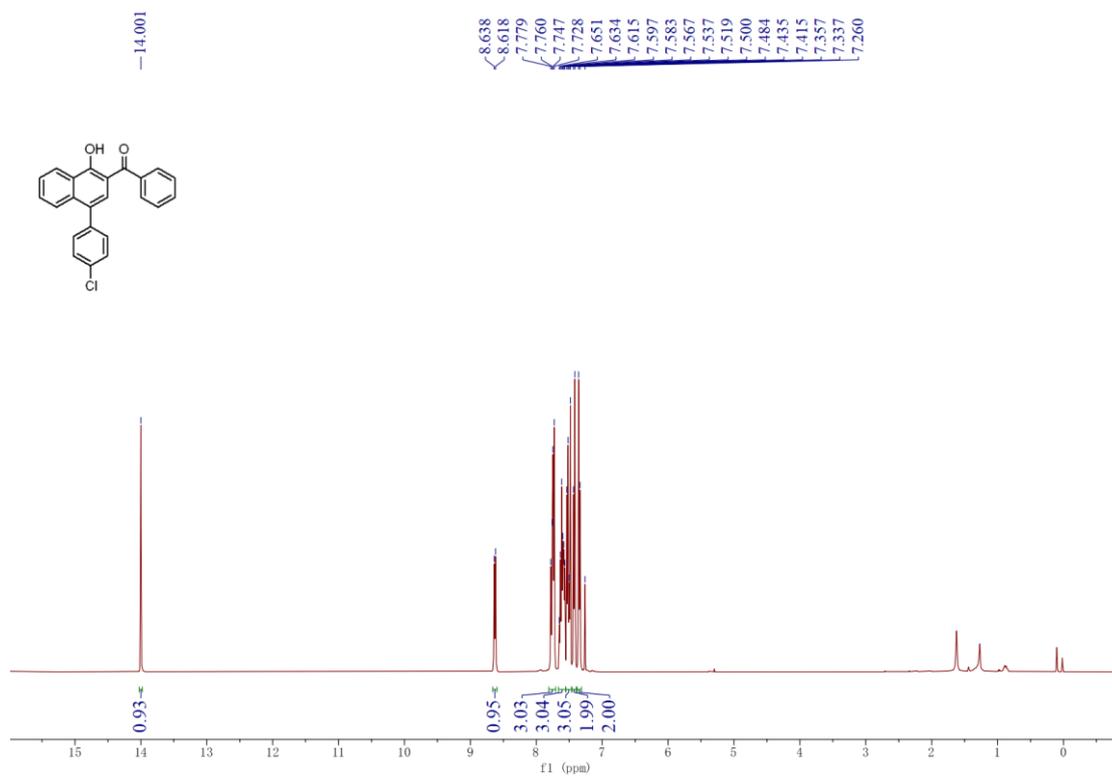
3f – ^{13}C NMR (101 MHz, CDCl_3)



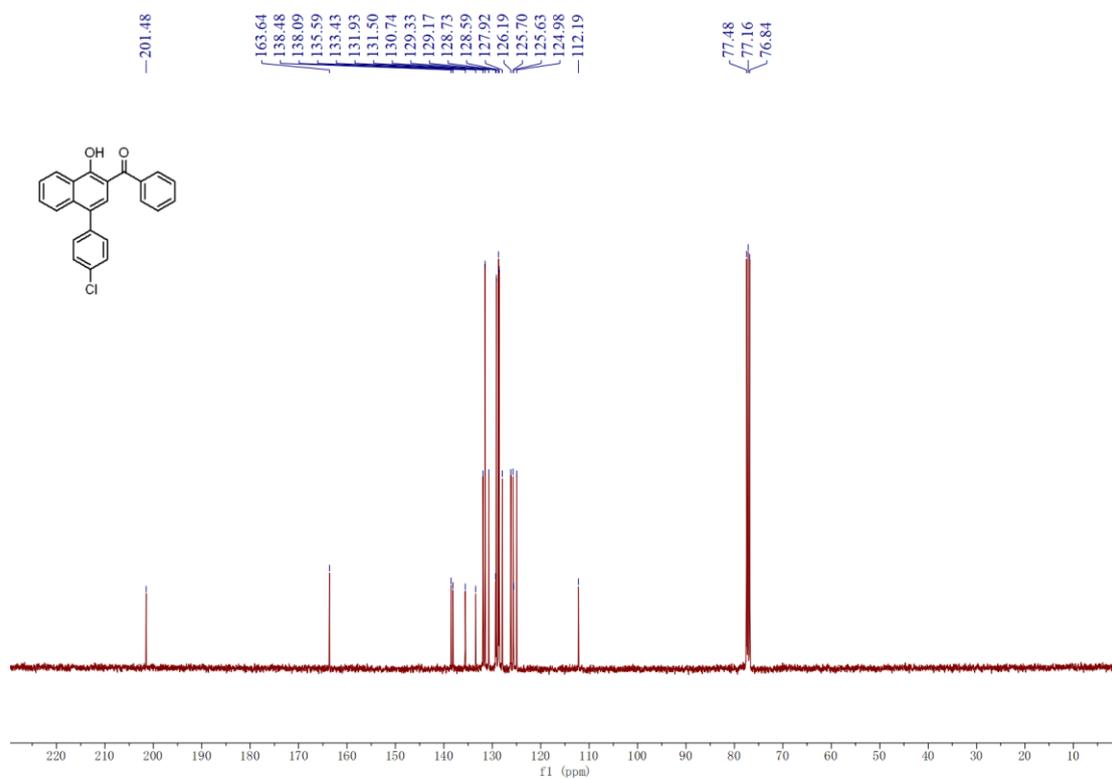
3f – ^{19}F NMR (565 MHz, CDCl_3)



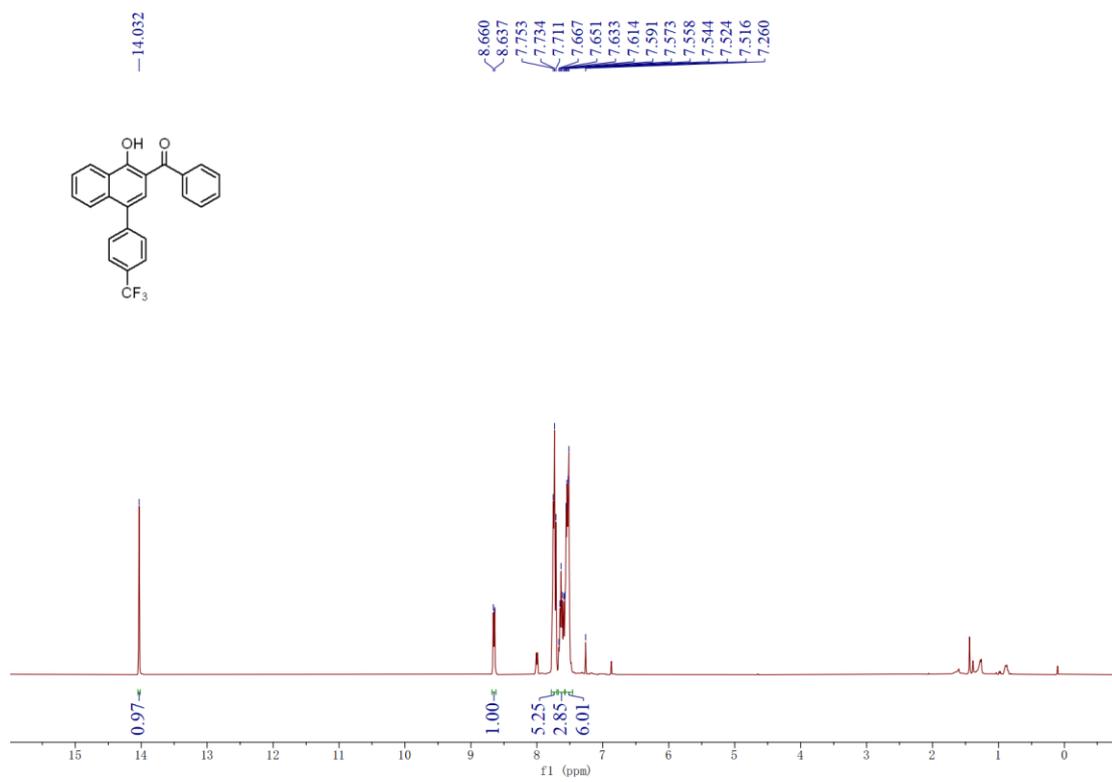
3g – ^1H NMR (400 MHz, CDCl_3)



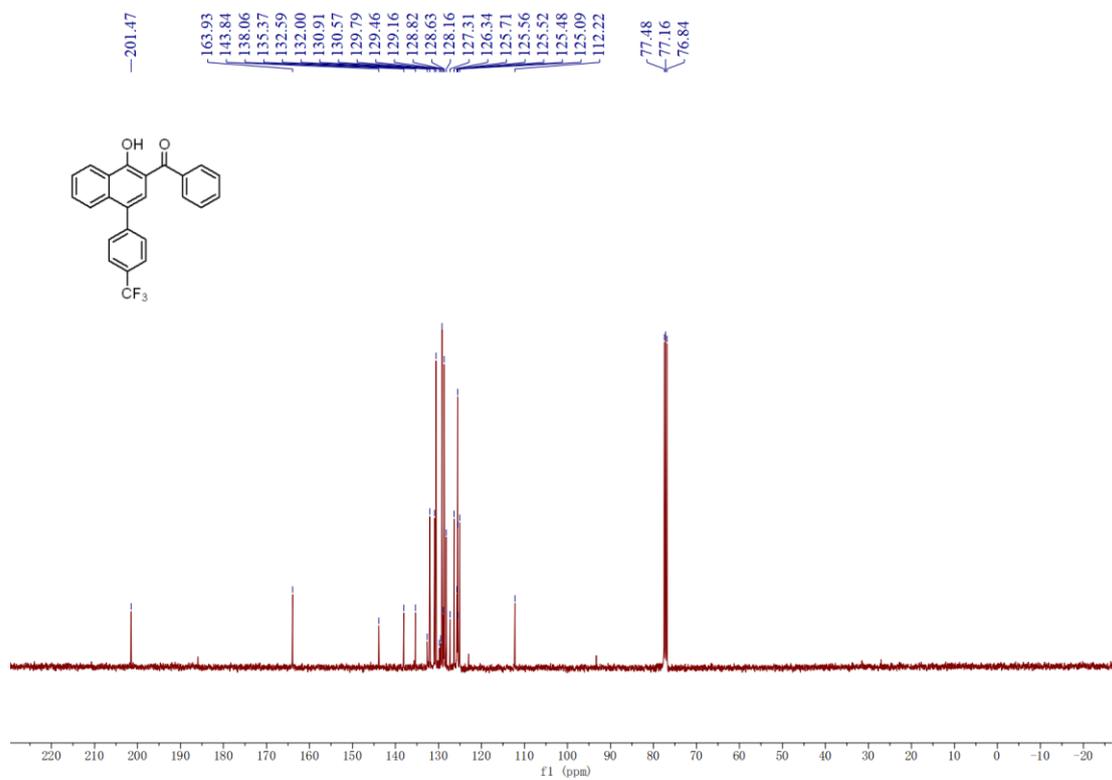
3g – ^{13}C NMR (101 MHz, CDCl_3)



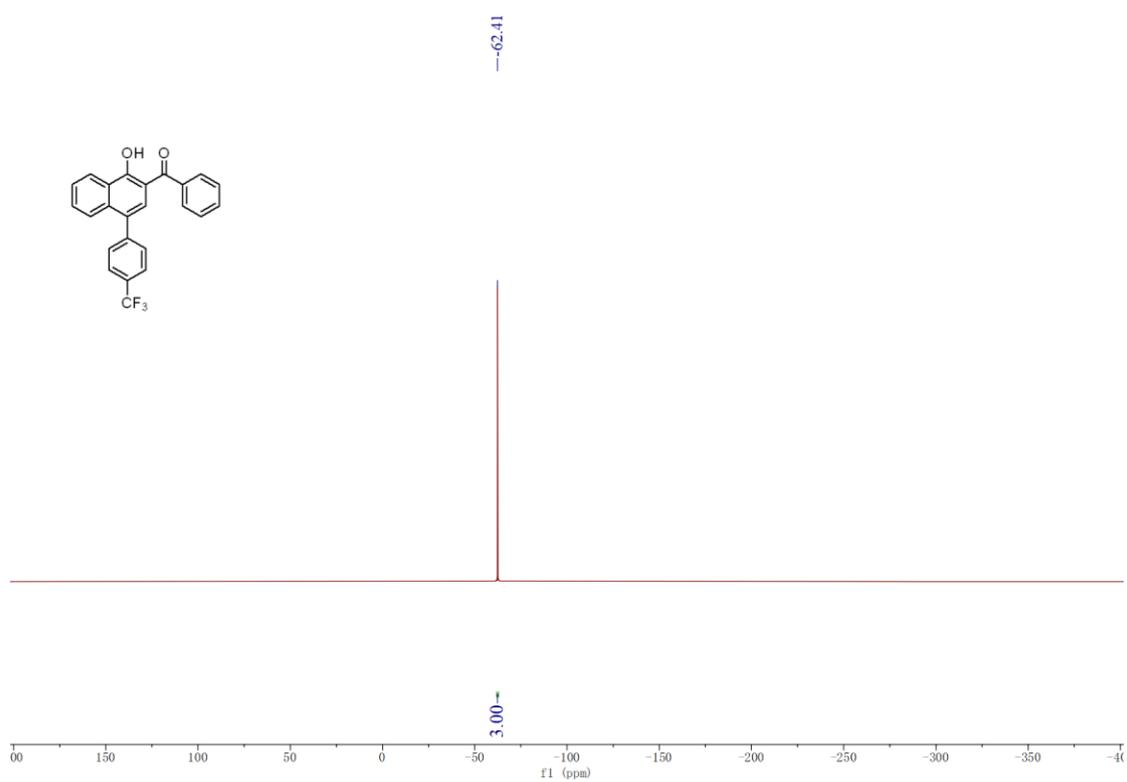
3h – ¹H NMR (400 MHz, CDCl₃)



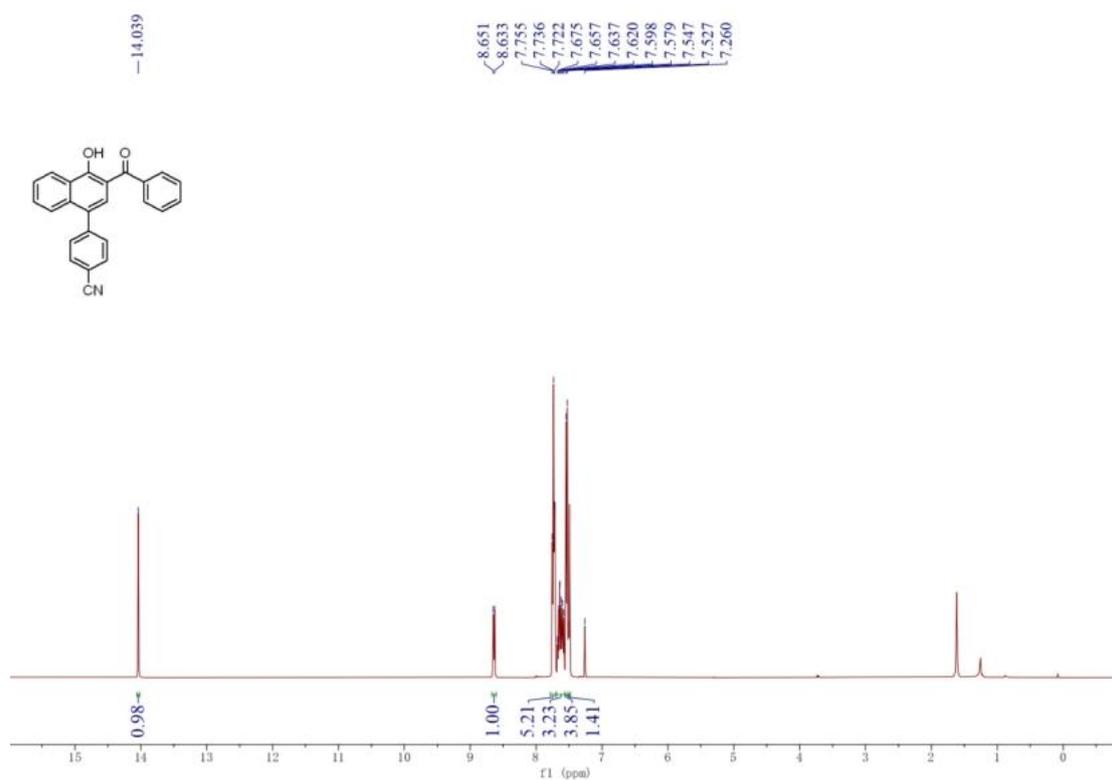
3h – ¹³C NMR (101 MHz, CDCl₃)



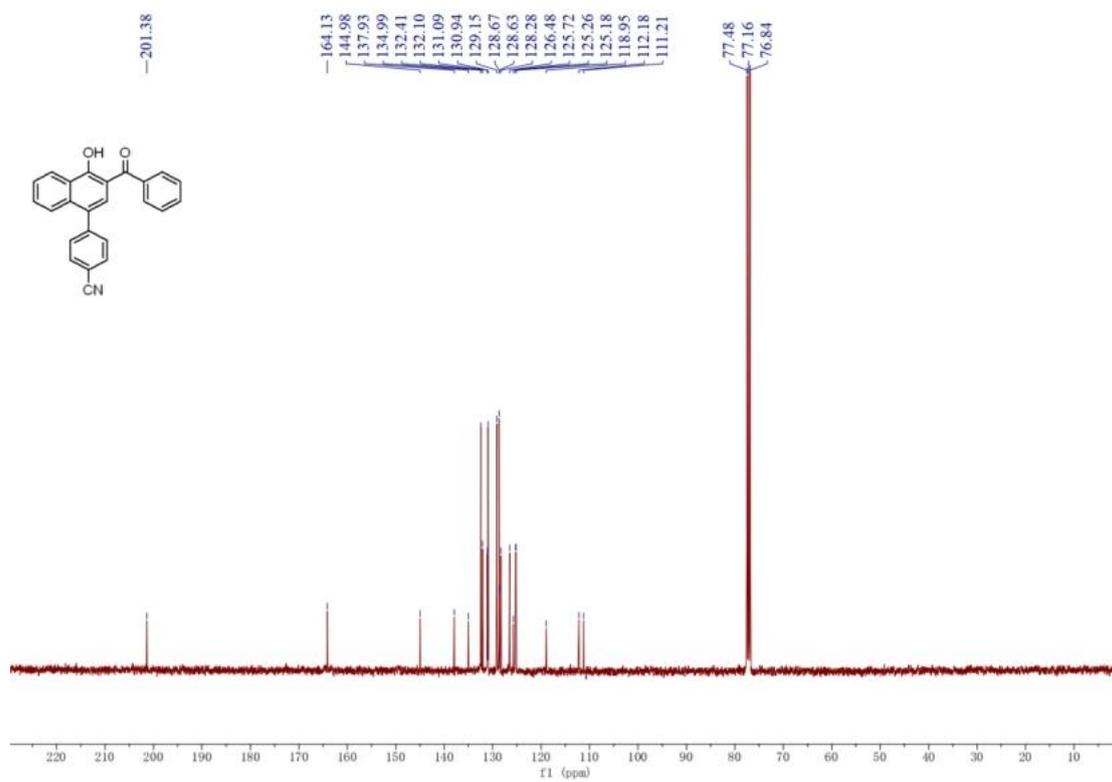
3h – ^{19}F NMR (565 MHz, CDCl_3)



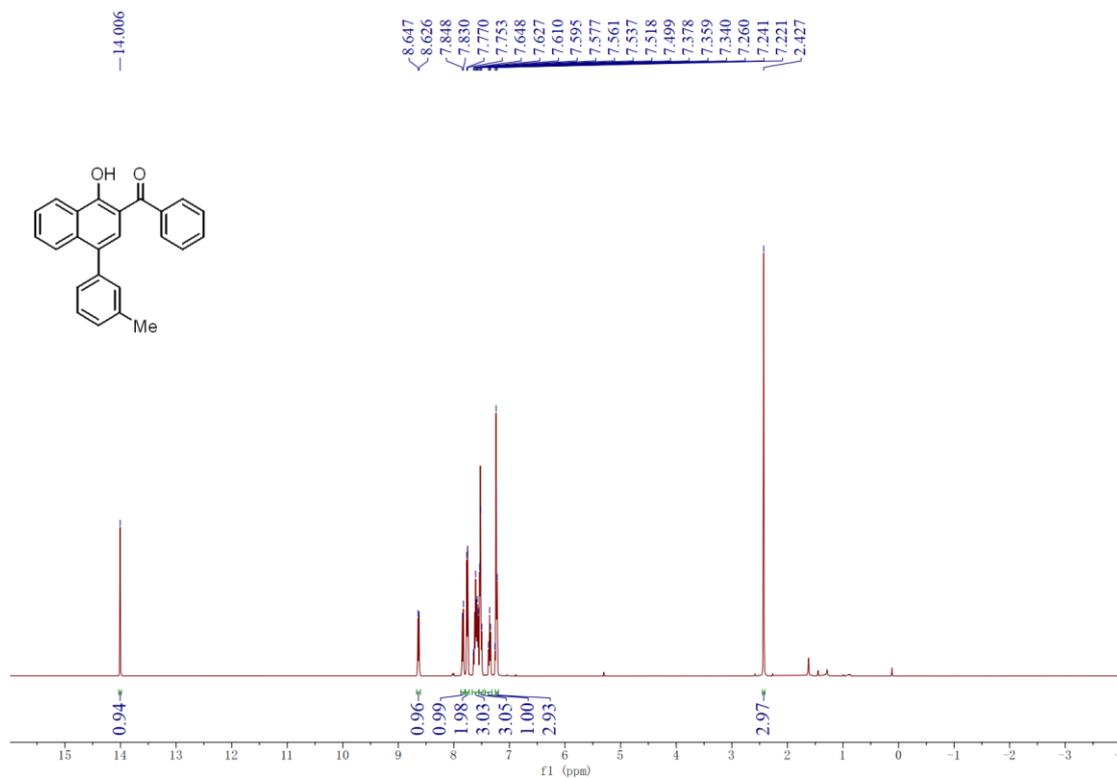
3i – ^1H NMR (400 MHz, CDCl_3)



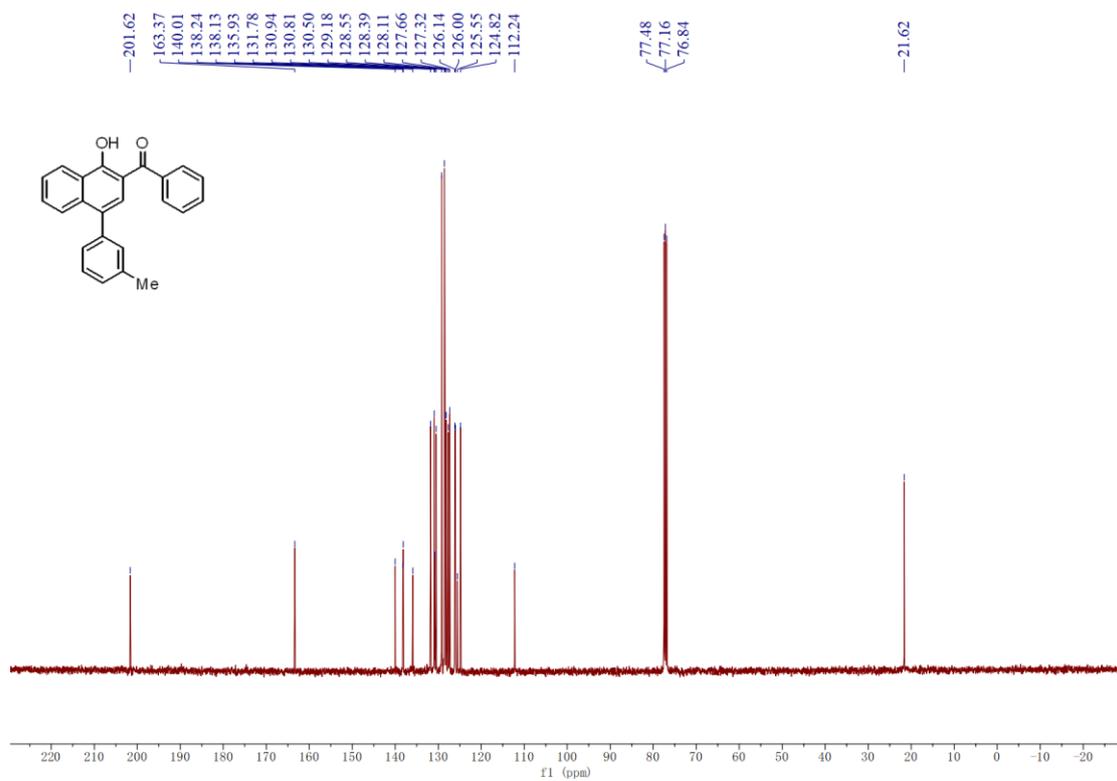
3i – ^{13}C NMR (101 MHz, CDCl_3)



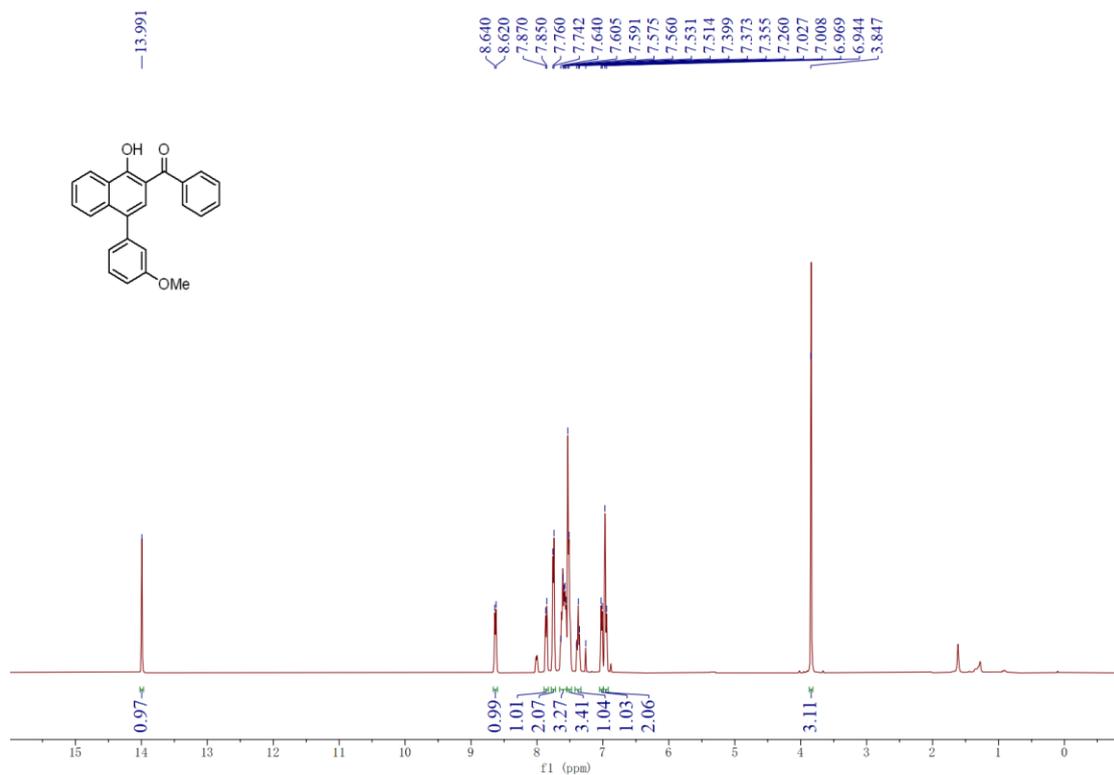
3j – ^1H NMR (400 MHz, CDCl_3)



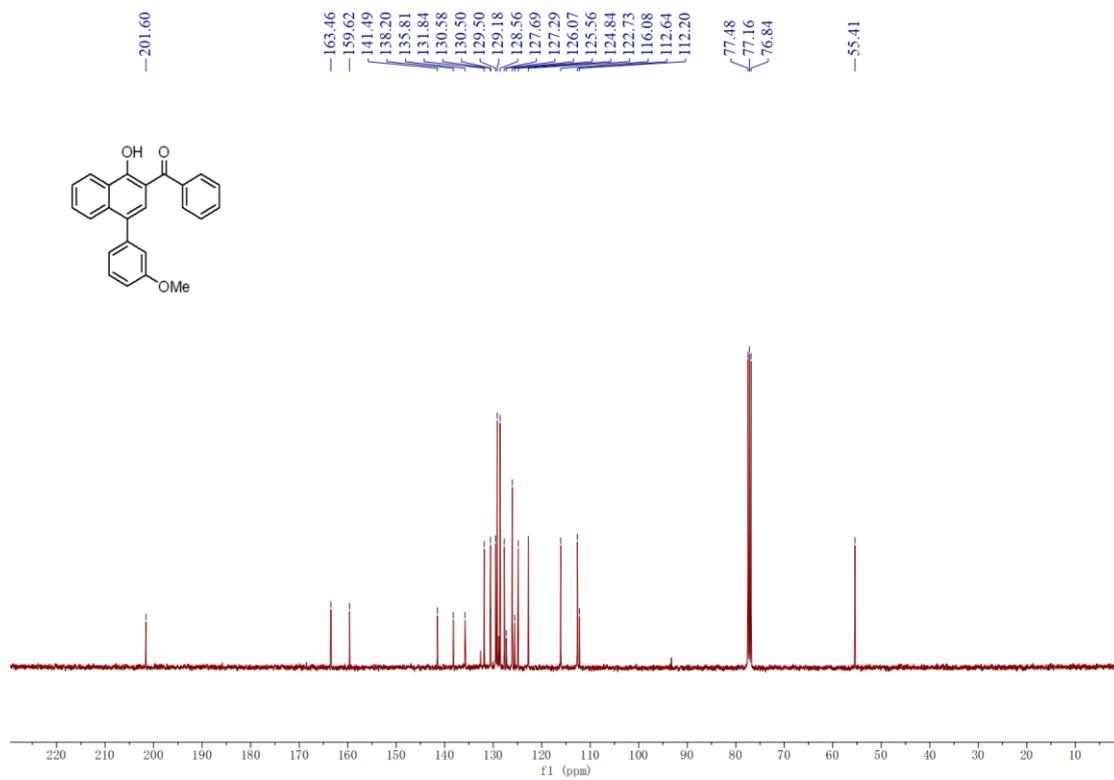
3j – ^{13}C NMR (101 MHz, CDCl_3)



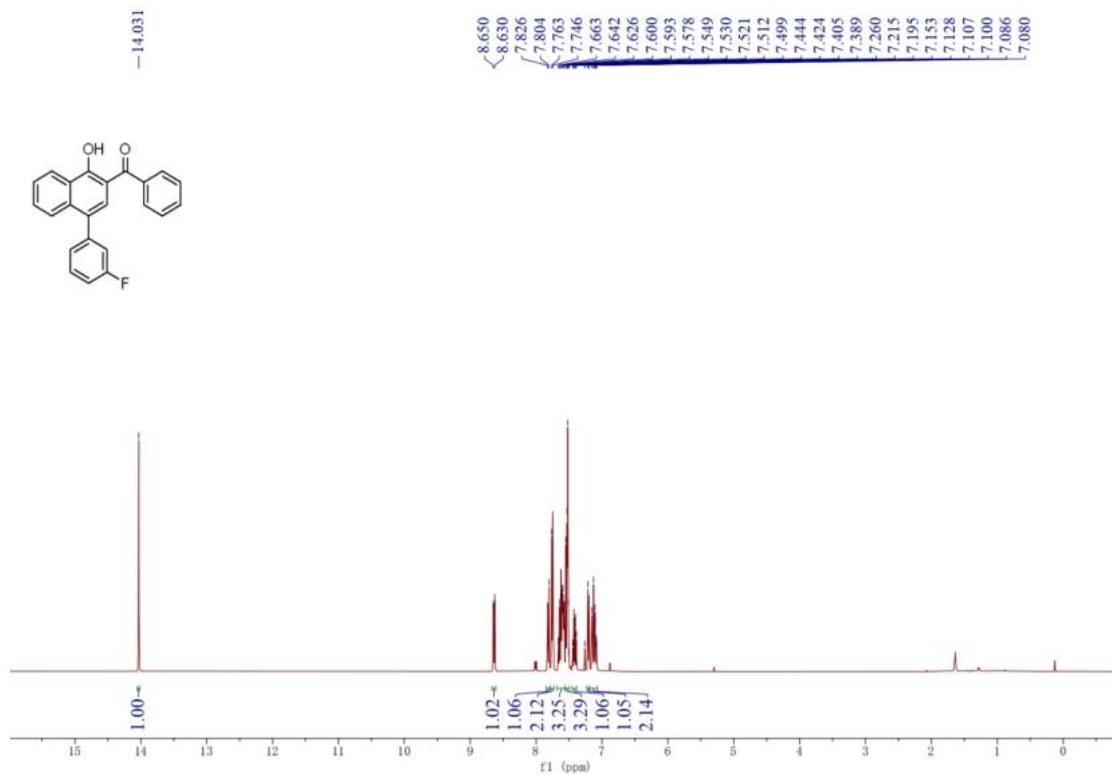
3k – ^1H NMR (400 MHz, CDCl_3)



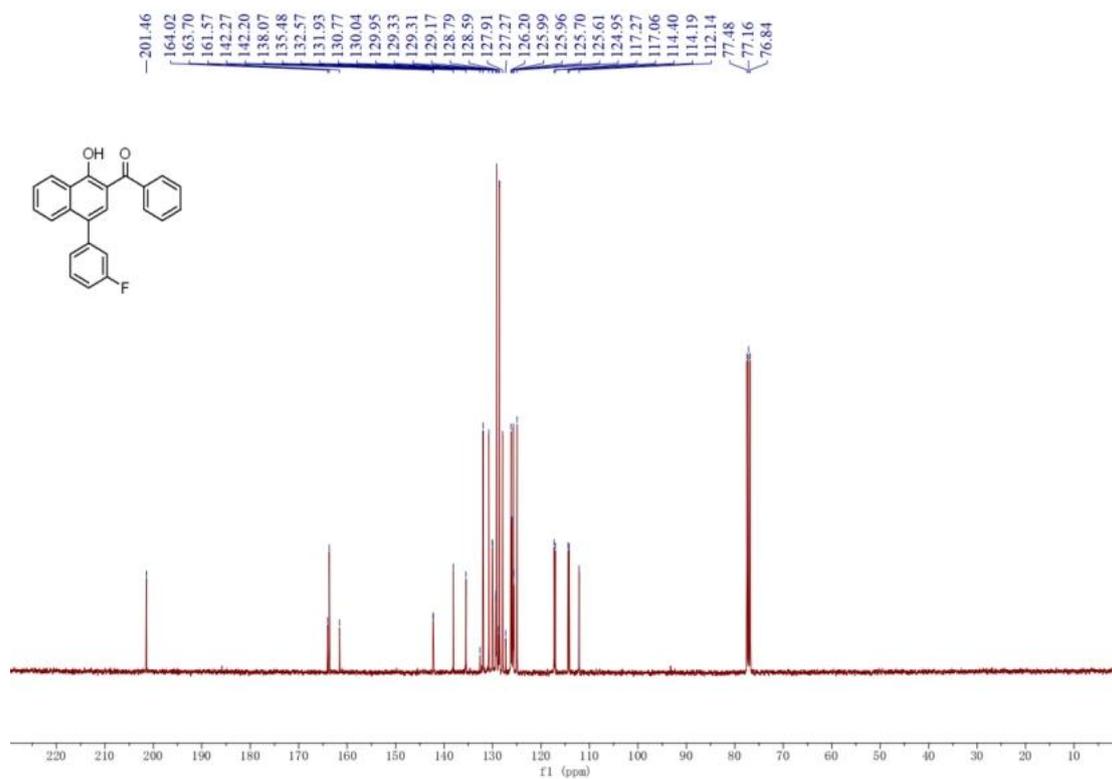
3k – ^{13}C NMR (101 MHz, CDCl_3)



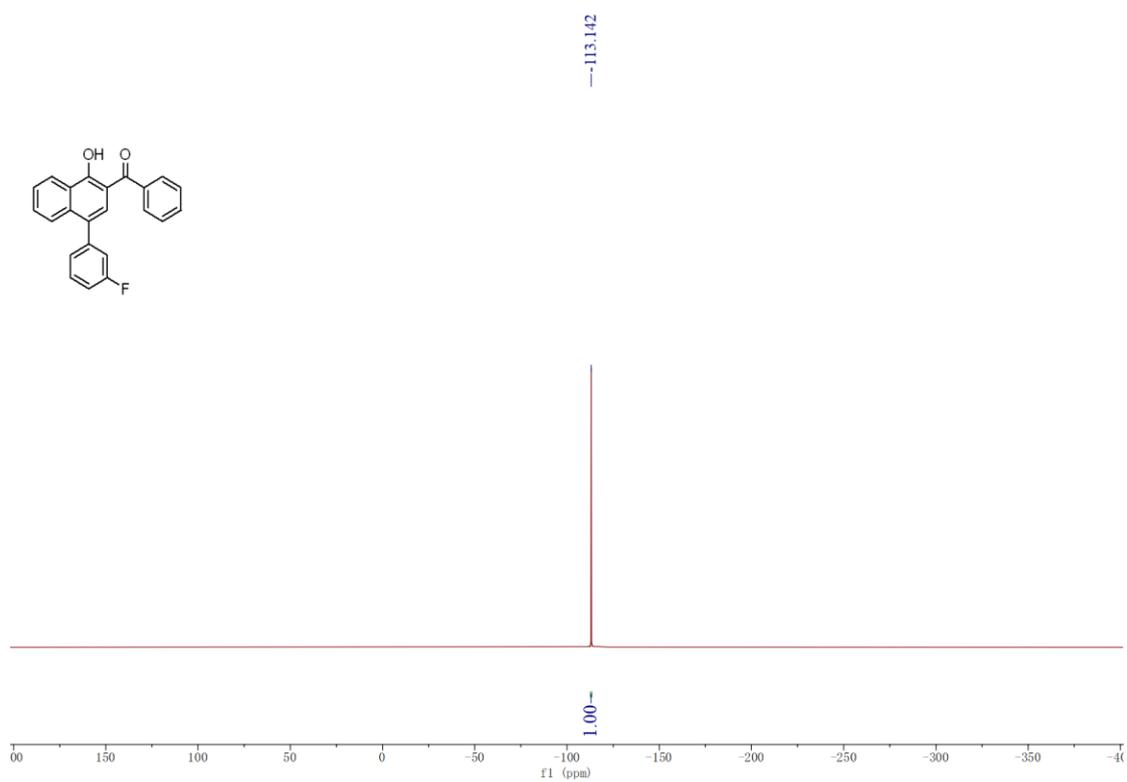
31 – ^1H NMR (400 MHz, CDCl_3)



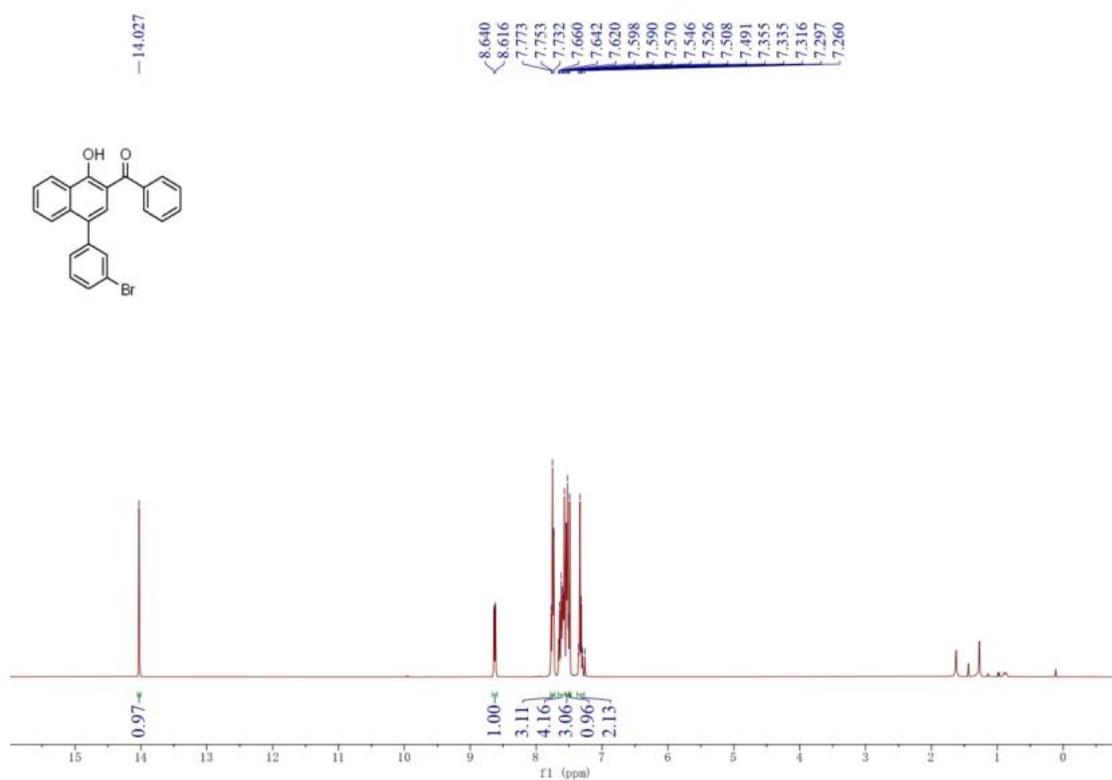
31 – ^{13}C NMR (101 MHz, CDCl_3)



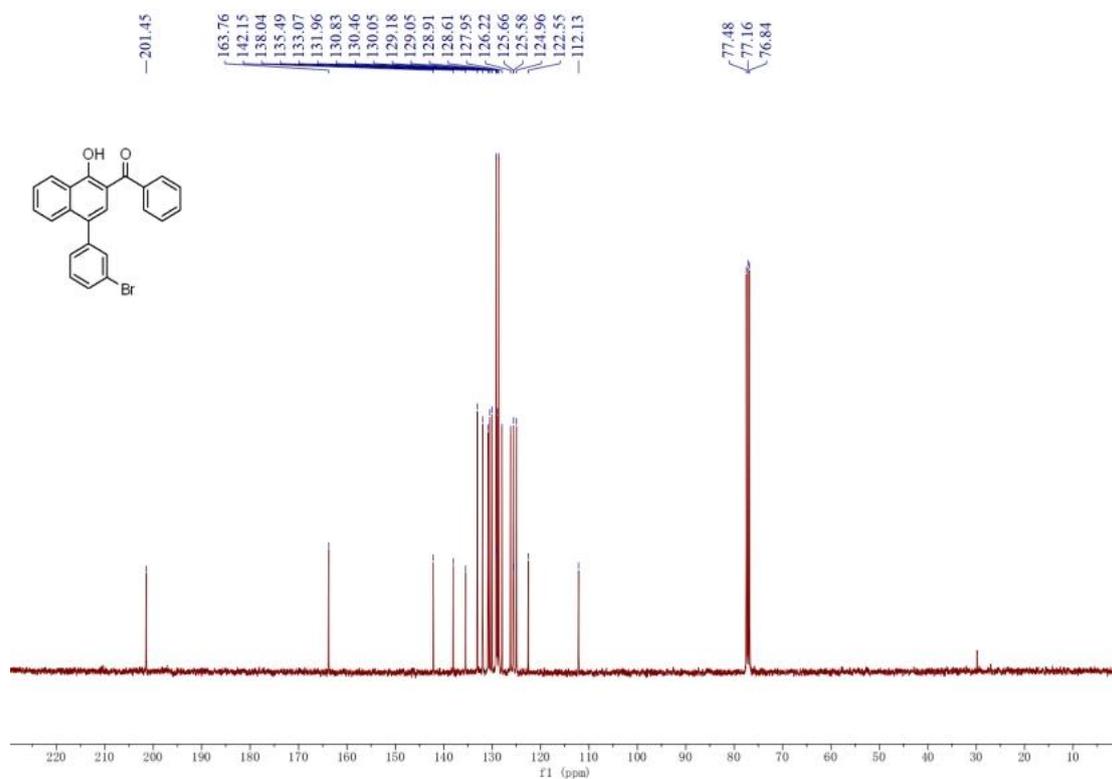
31 – ^{19}F NMR (565 MHz, CDCl_3)



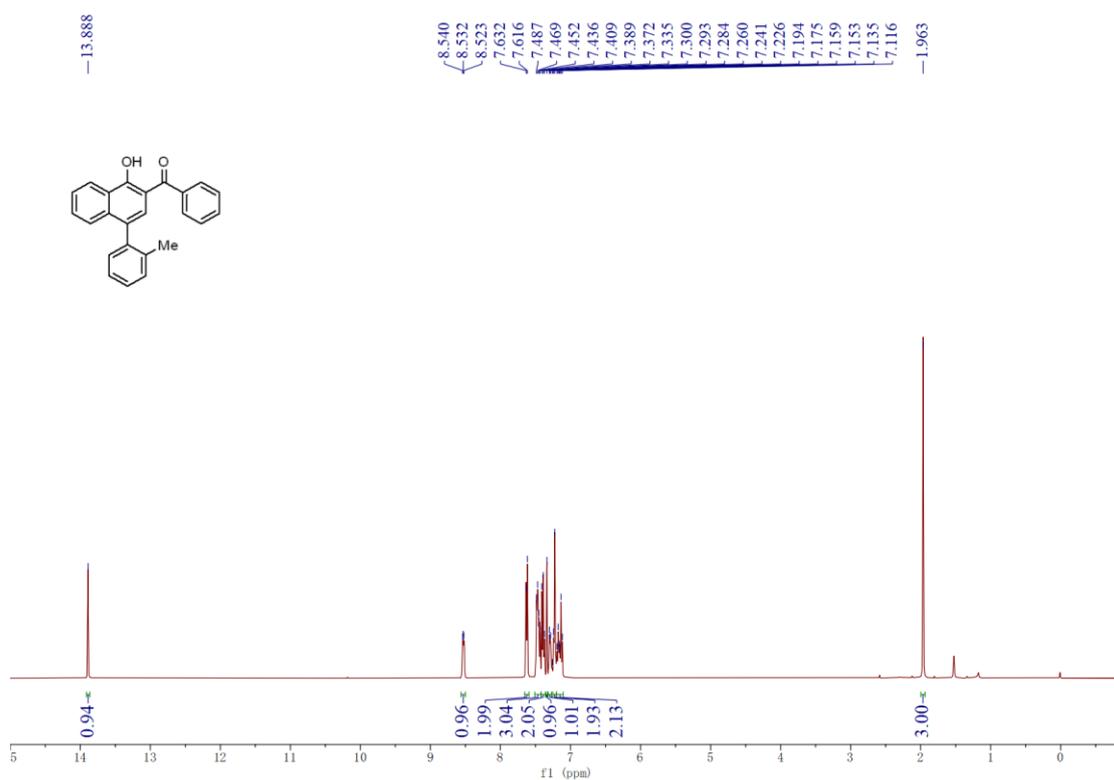
3m – ^1H NMR (400 MHz, CDCl_3)



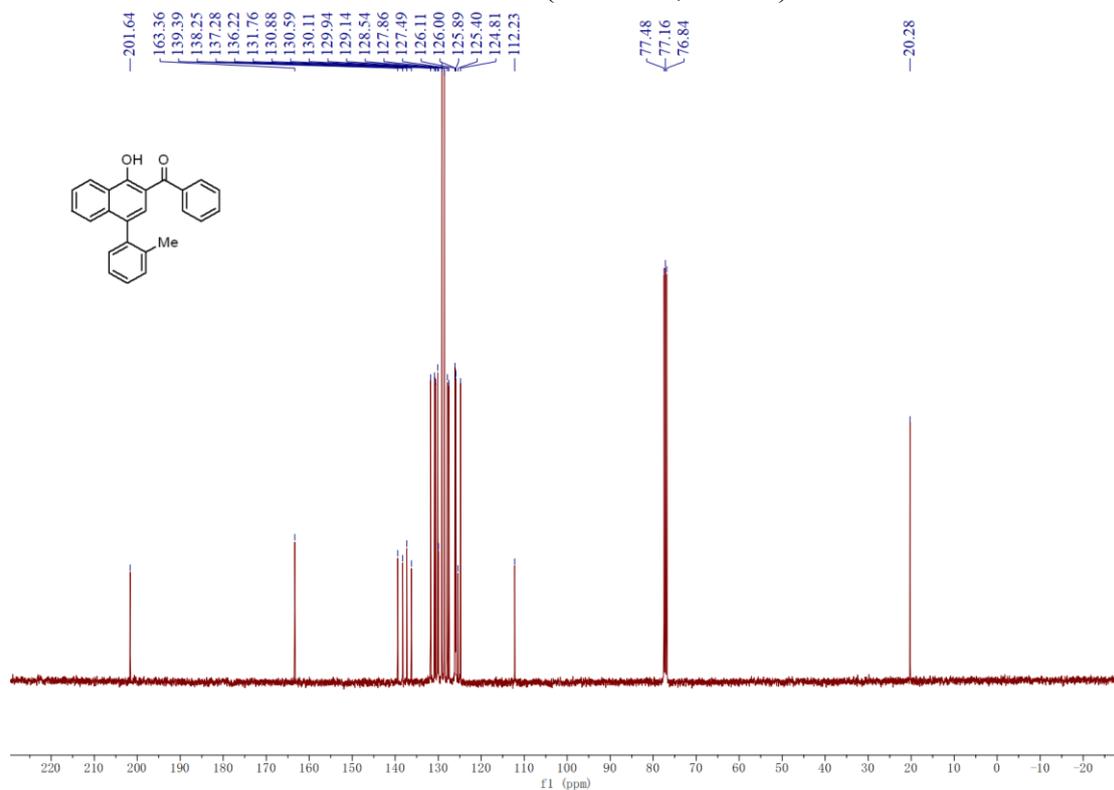
3m – ^{13}C NMR (101 MHz, CDCl_3)



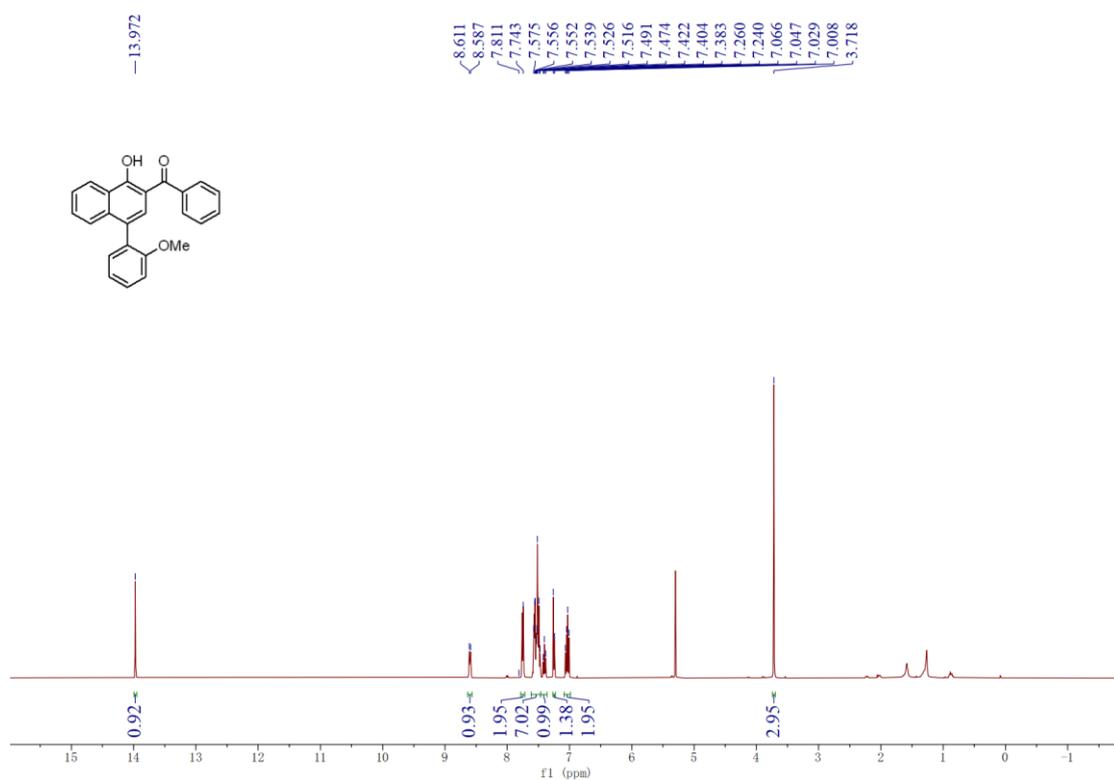
3n – ¹H NMR (400 MHz, CDCl₃)



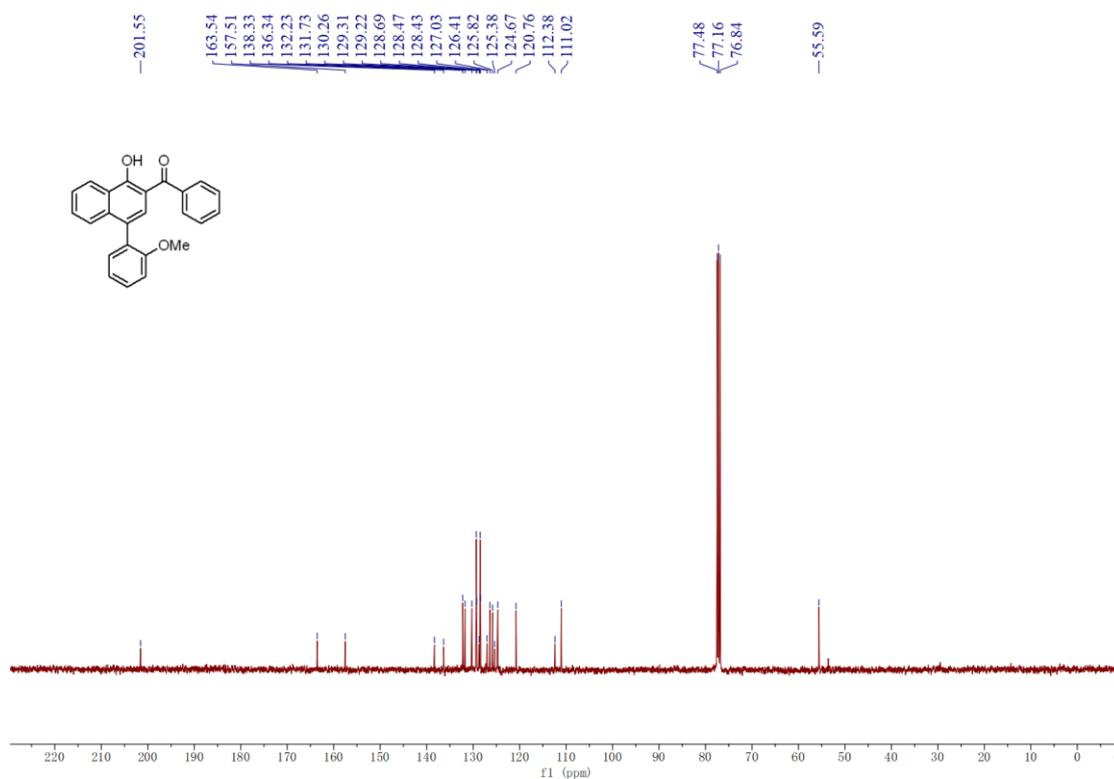
3n – ¹³C NMR (101 MHz, CDCl₃)



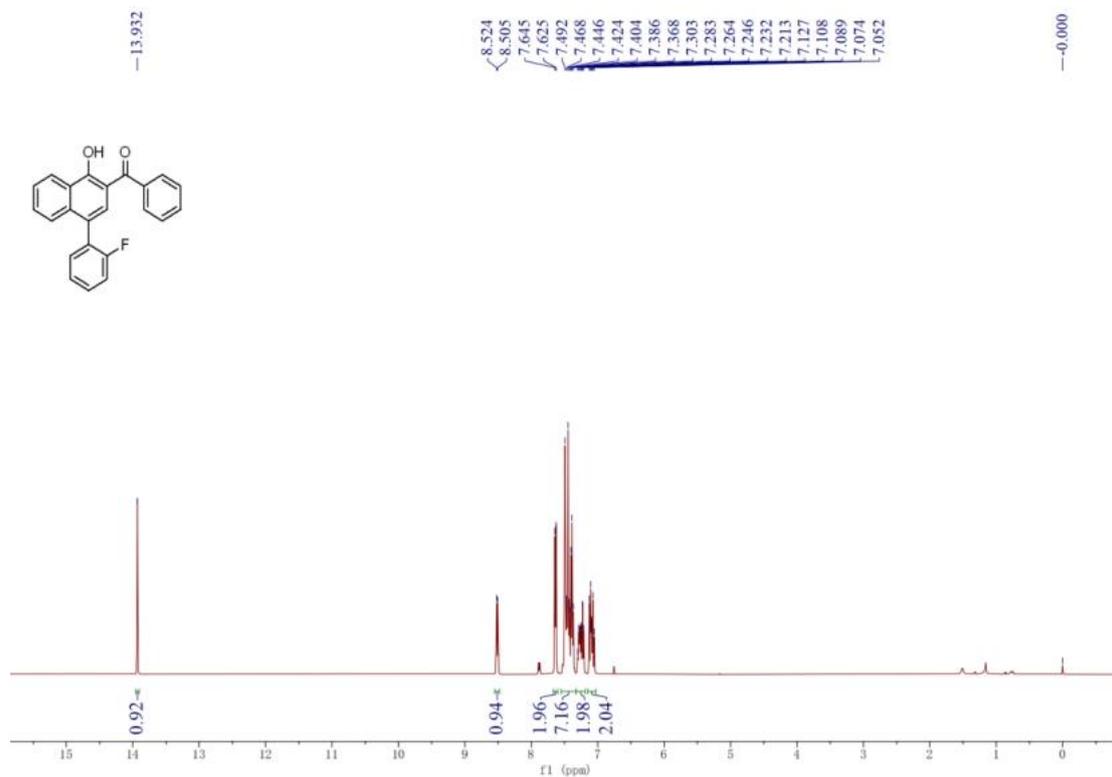
30 – ^1H NMR (400 MHz, CDCl_3)



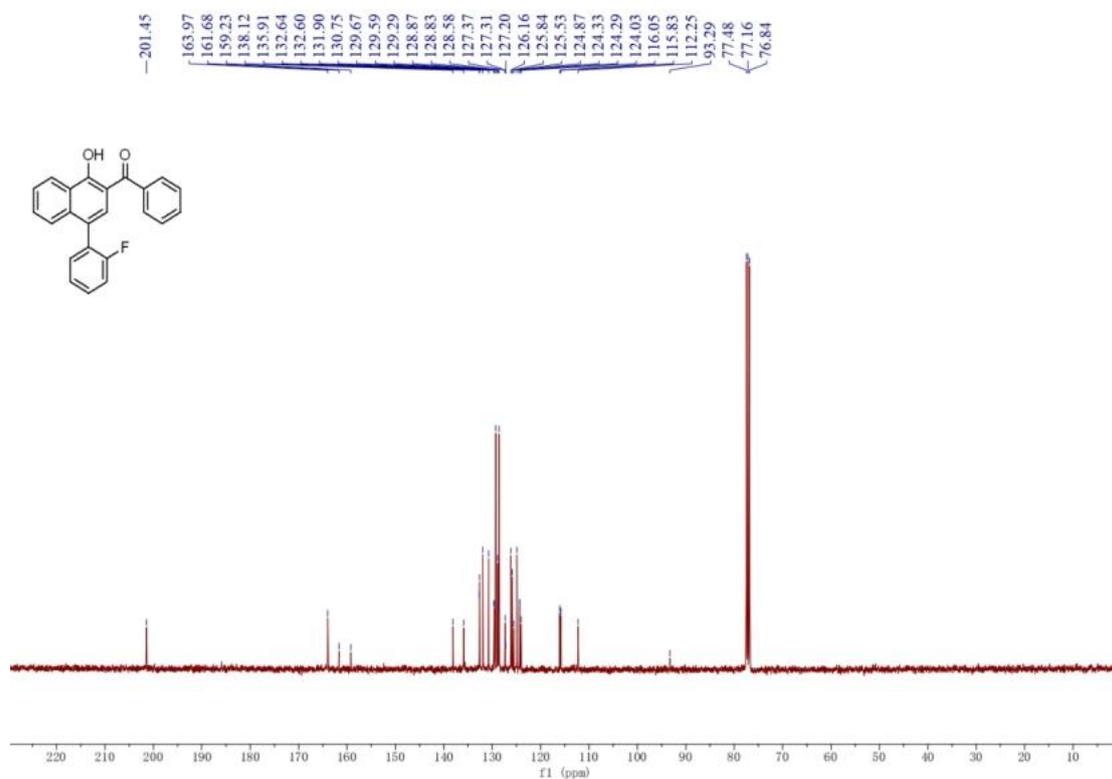
30 – ^{13}C NMR (101 MHz, CDCl_3)



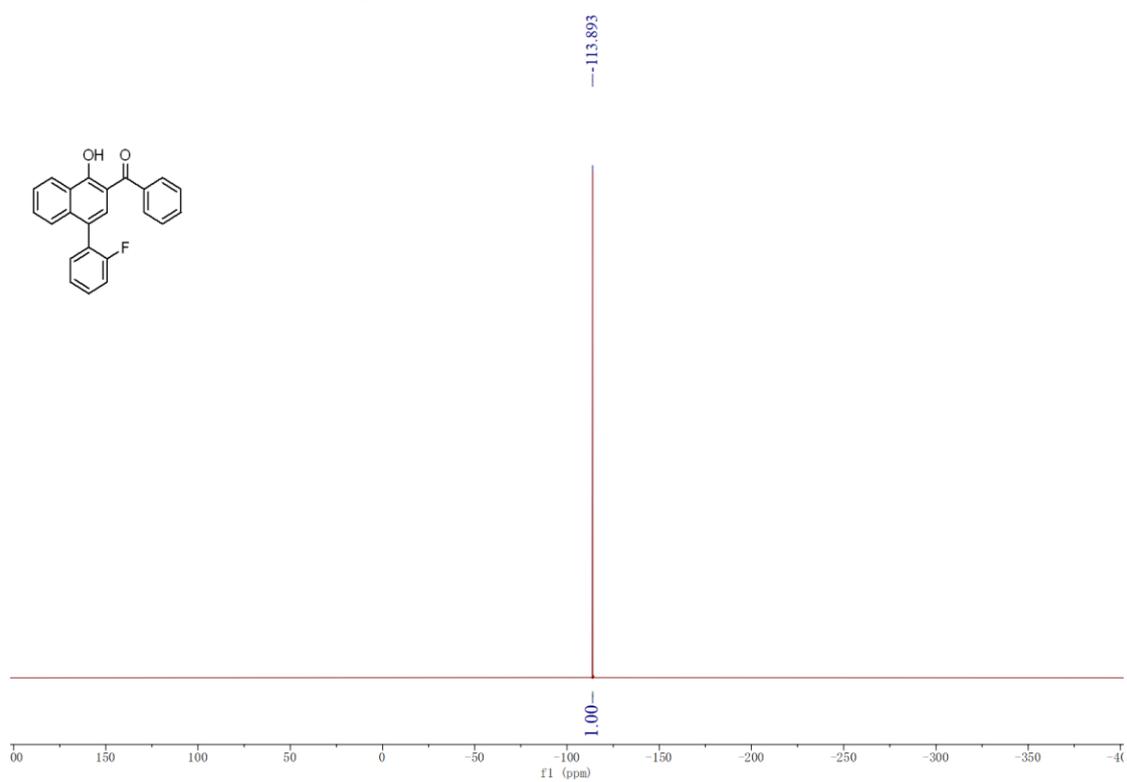
3p – ^1H NMR (400 MHz, CDCl_3)



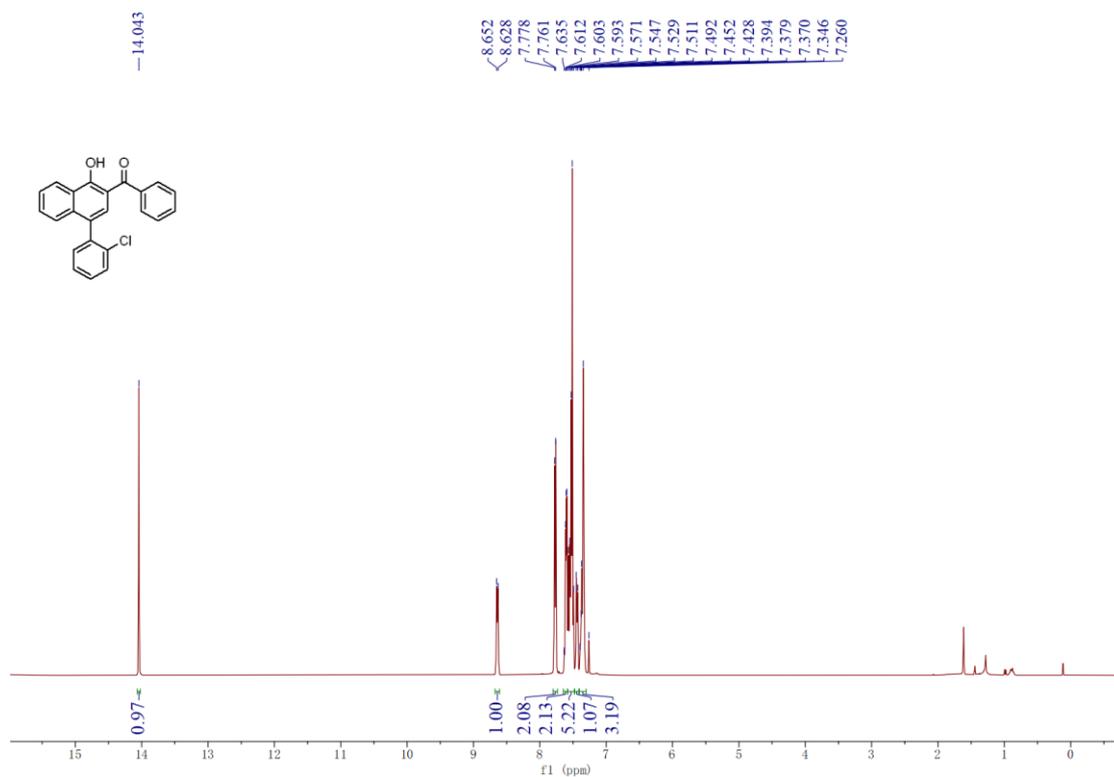
3p – ^{13}C NMR (101 MHz, CDCl_3)



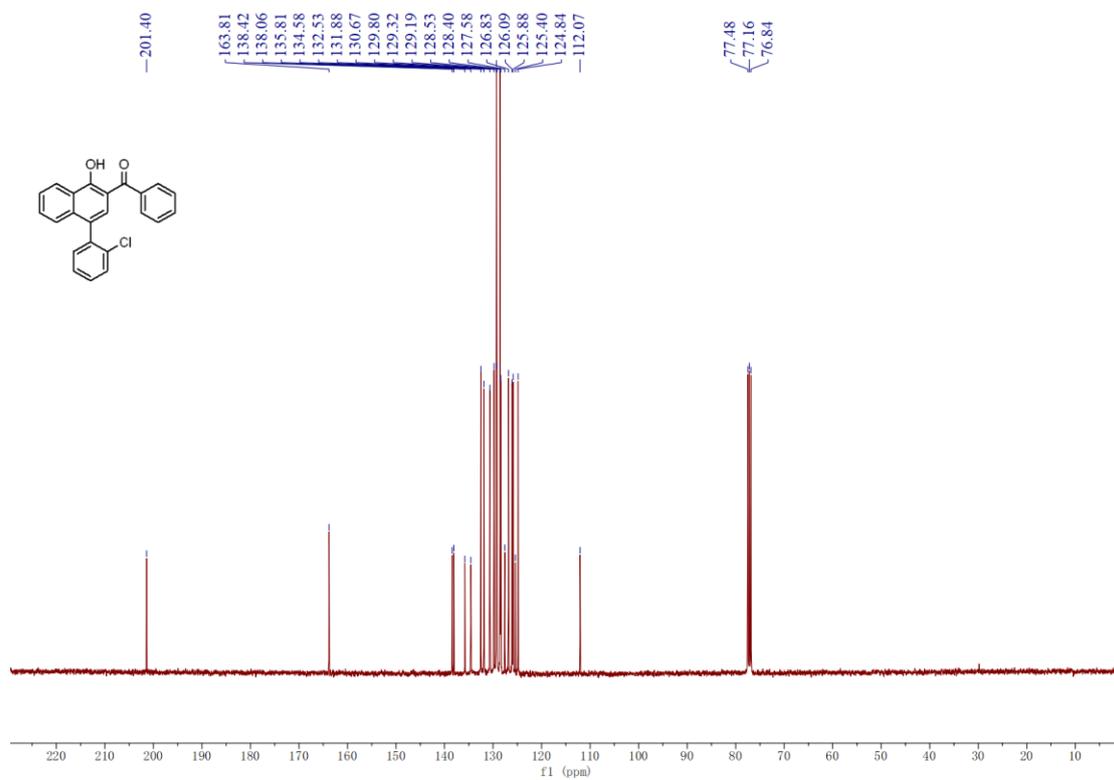
3p – ^{19}F NMR (565 MHz, CDCl_3)



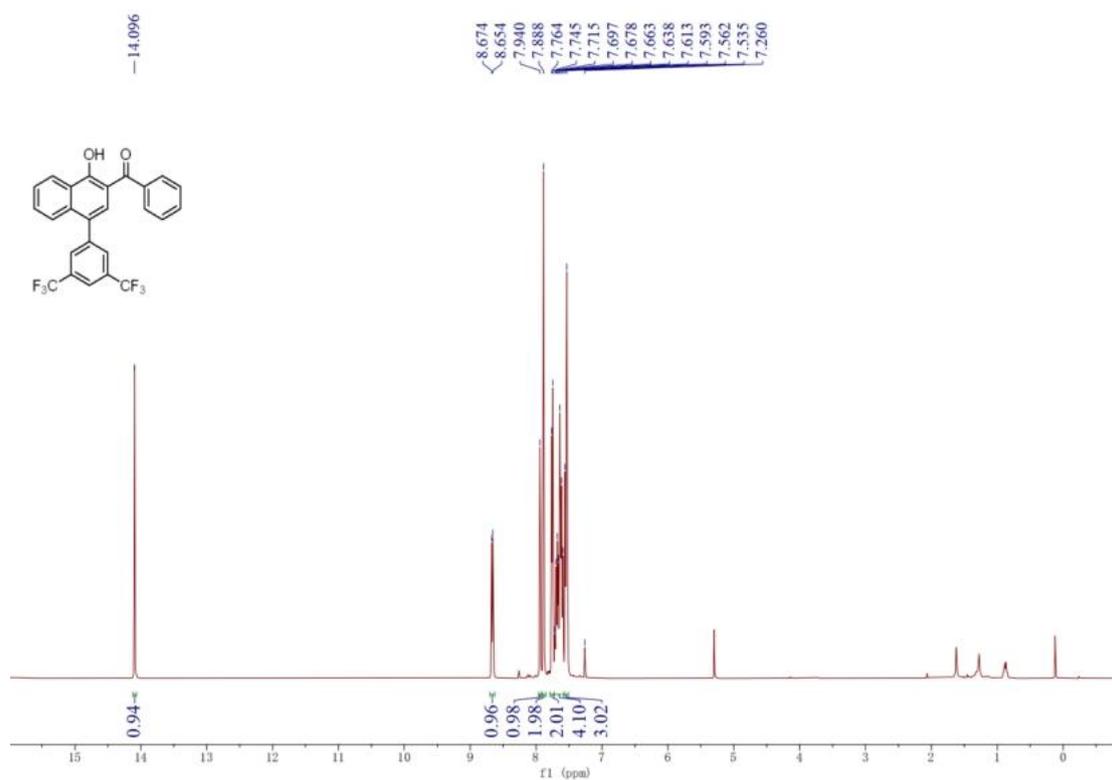
3q – ^1H NMR (400 MHz, CDCl_3)



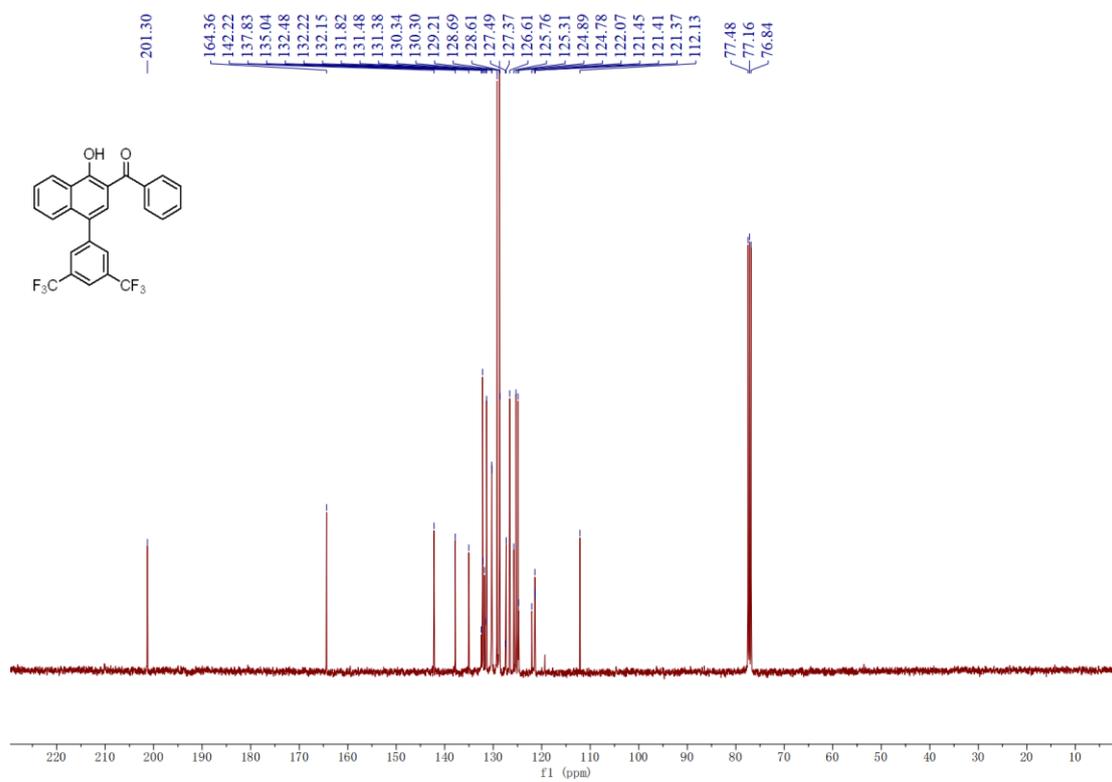
3q – ^{13}C NMR (101 MHz, CDCl_3)



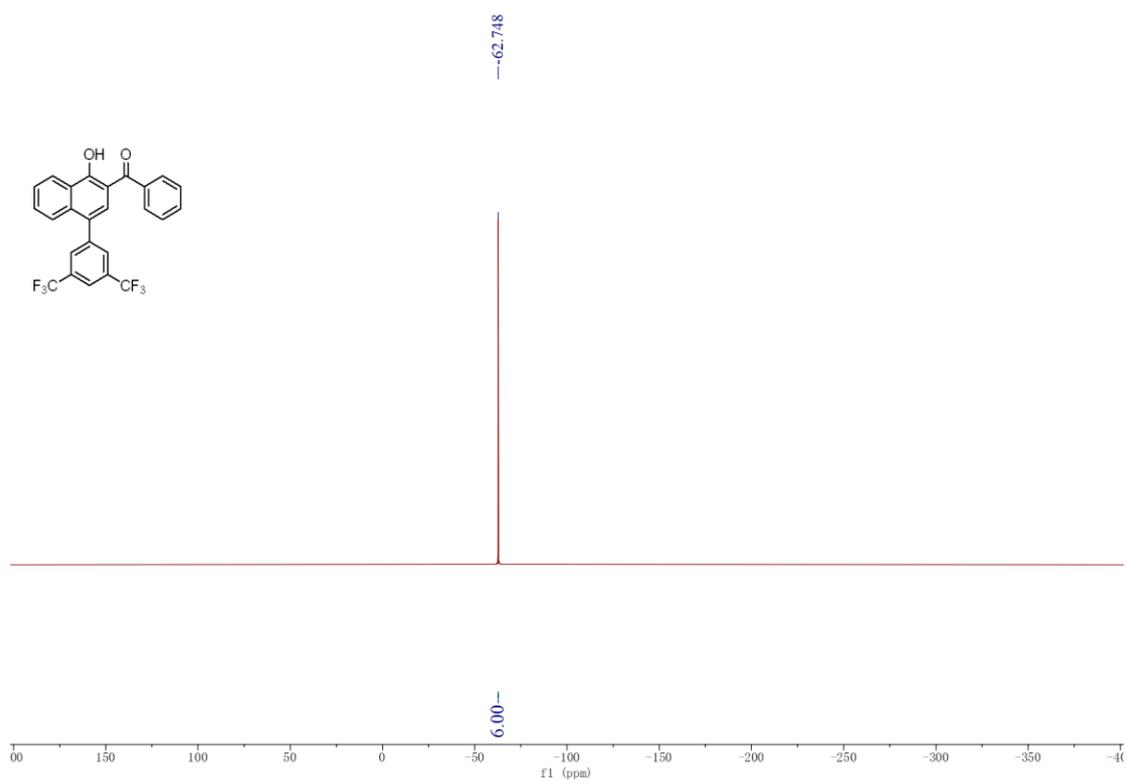
3r – ^1H NMR (400 MHz, CDCl_3)



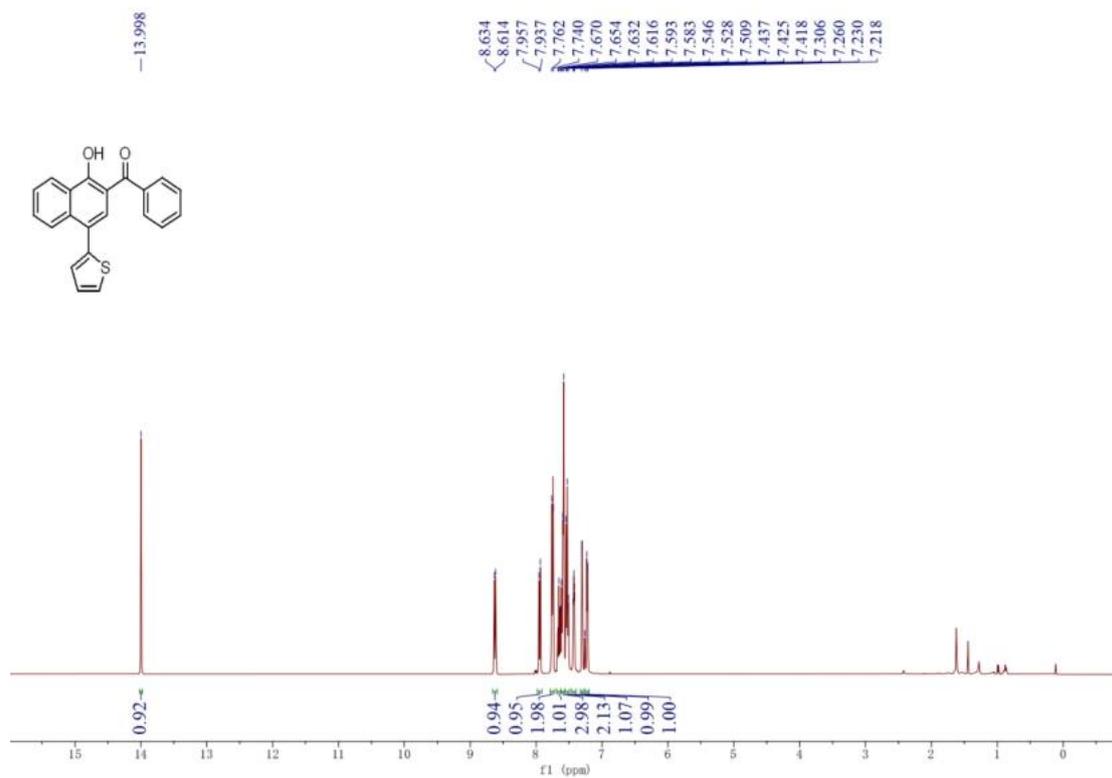
3r – ^{13}C NMR (101 MHz, CDCl_3)



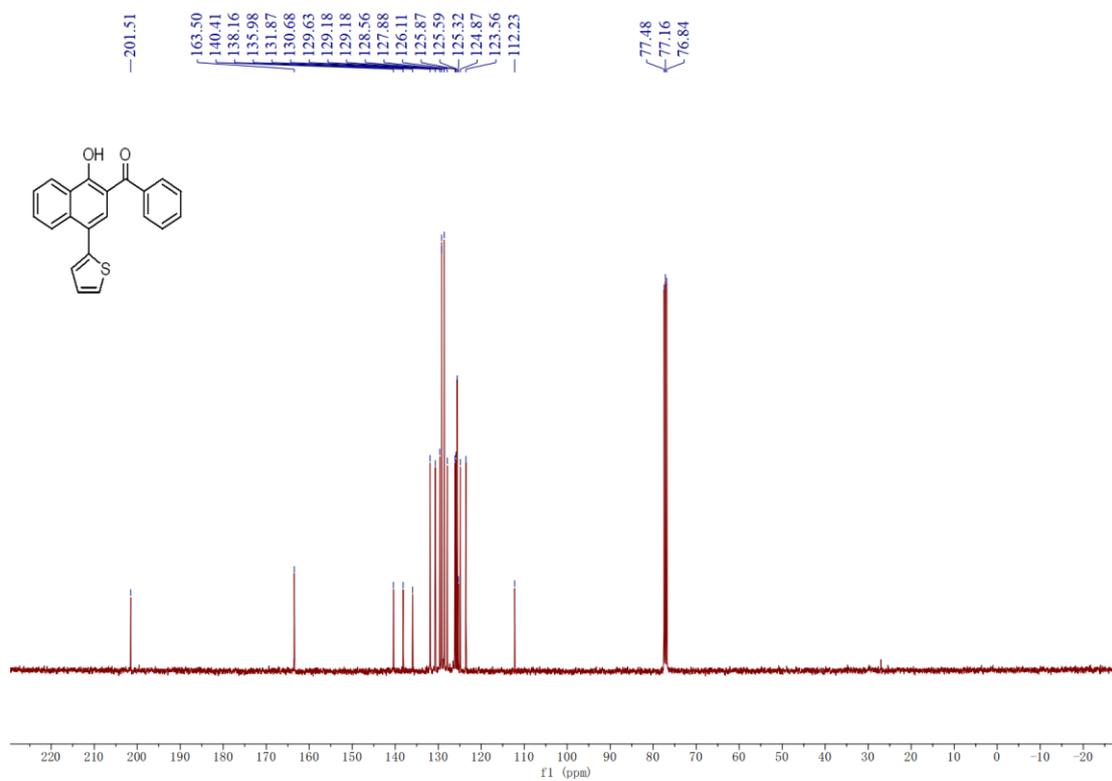
3r – ^{19}F NMR (565 MHz, CDCl_3)



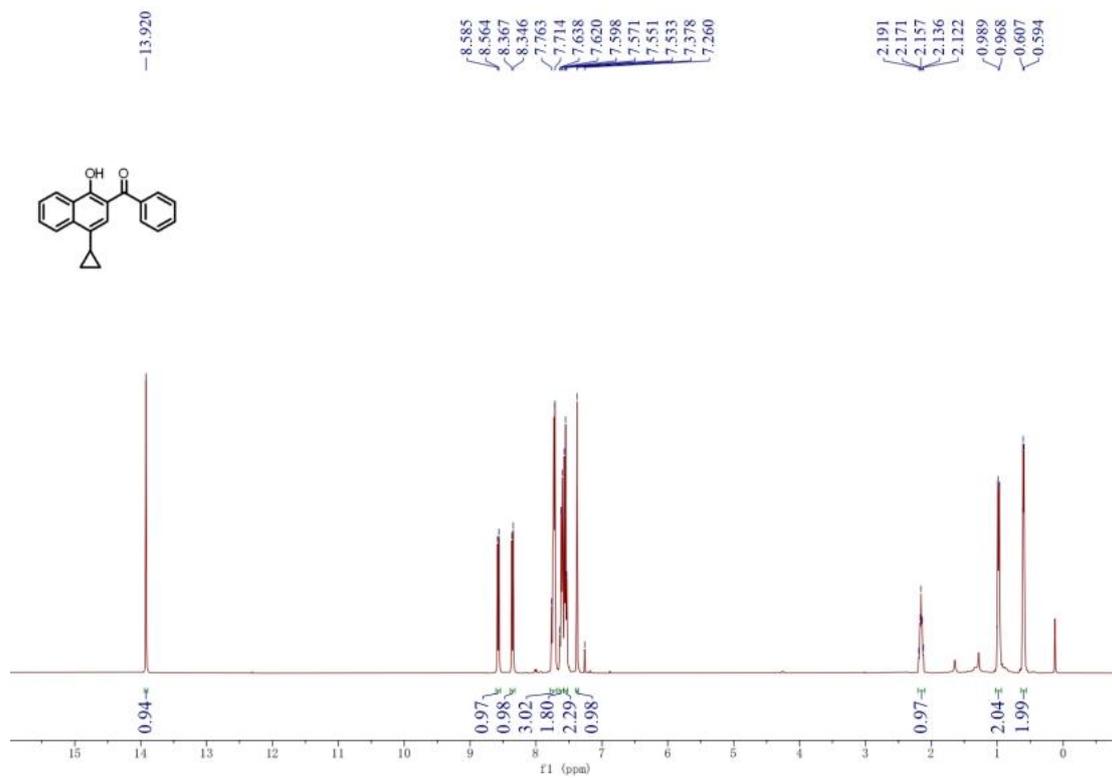
3s – ^1H NMR (400 MHz, CDCl_3)



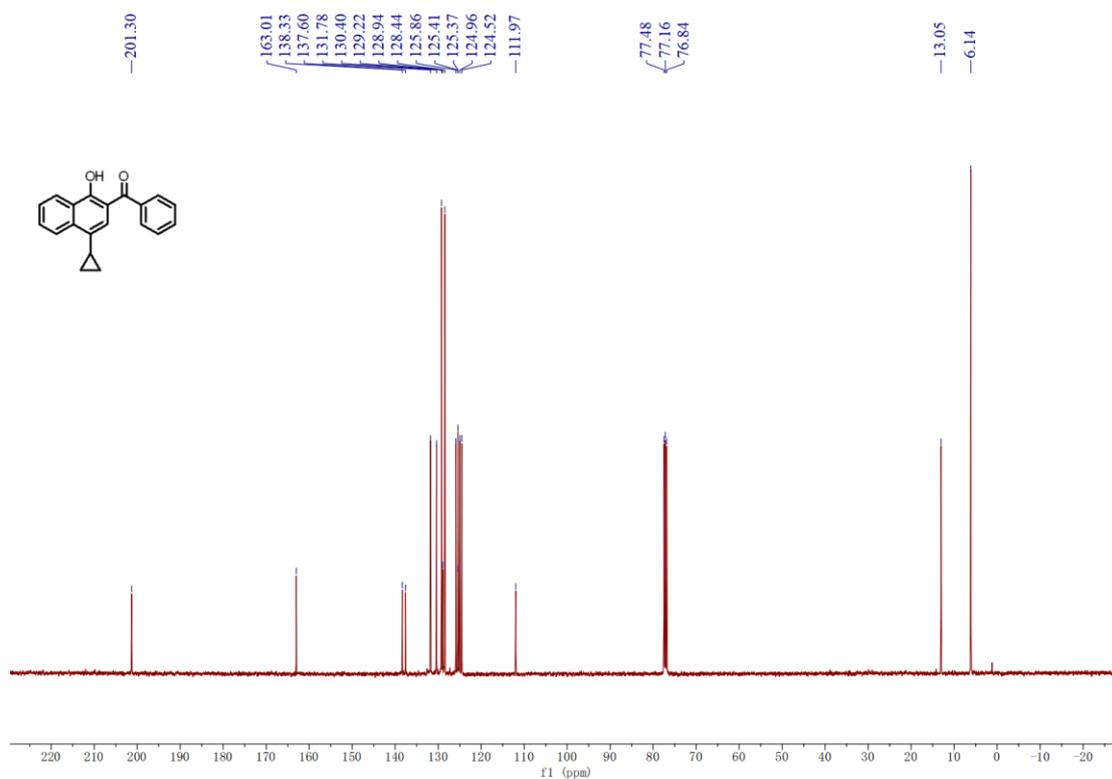
3s – ^{13}C NMR (101 MHz, CDCl_3)



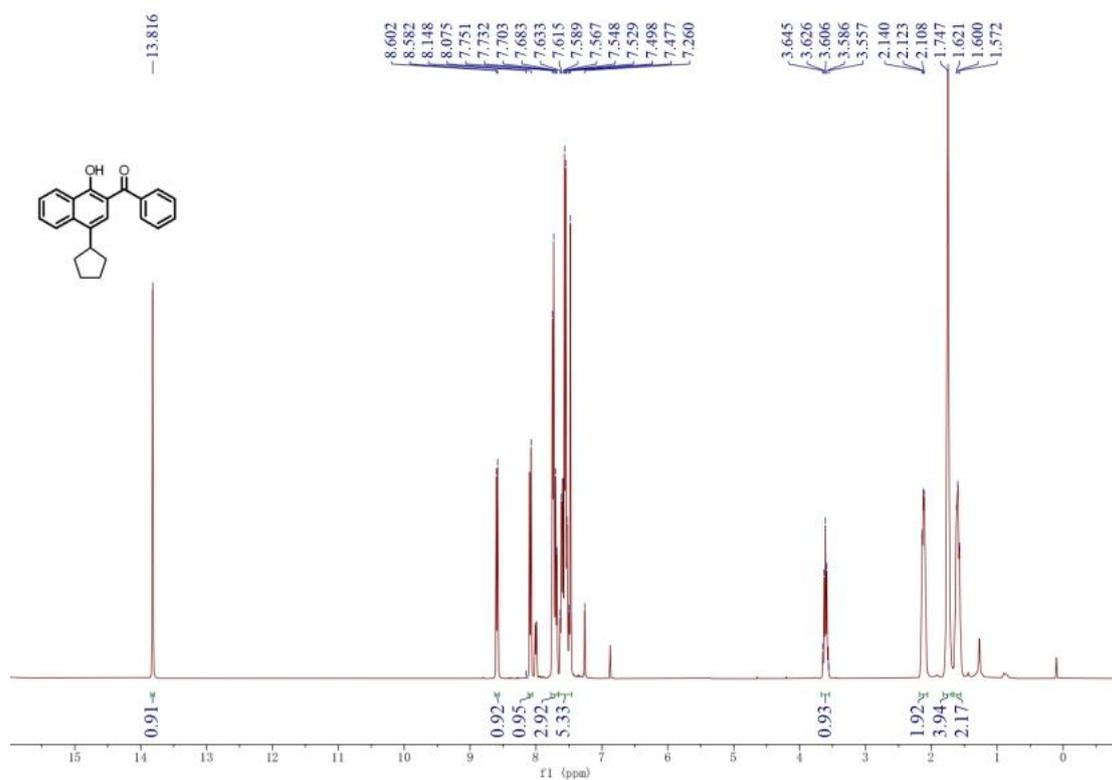
3t – ^1H NMR (400 MHz, CDCl_3)



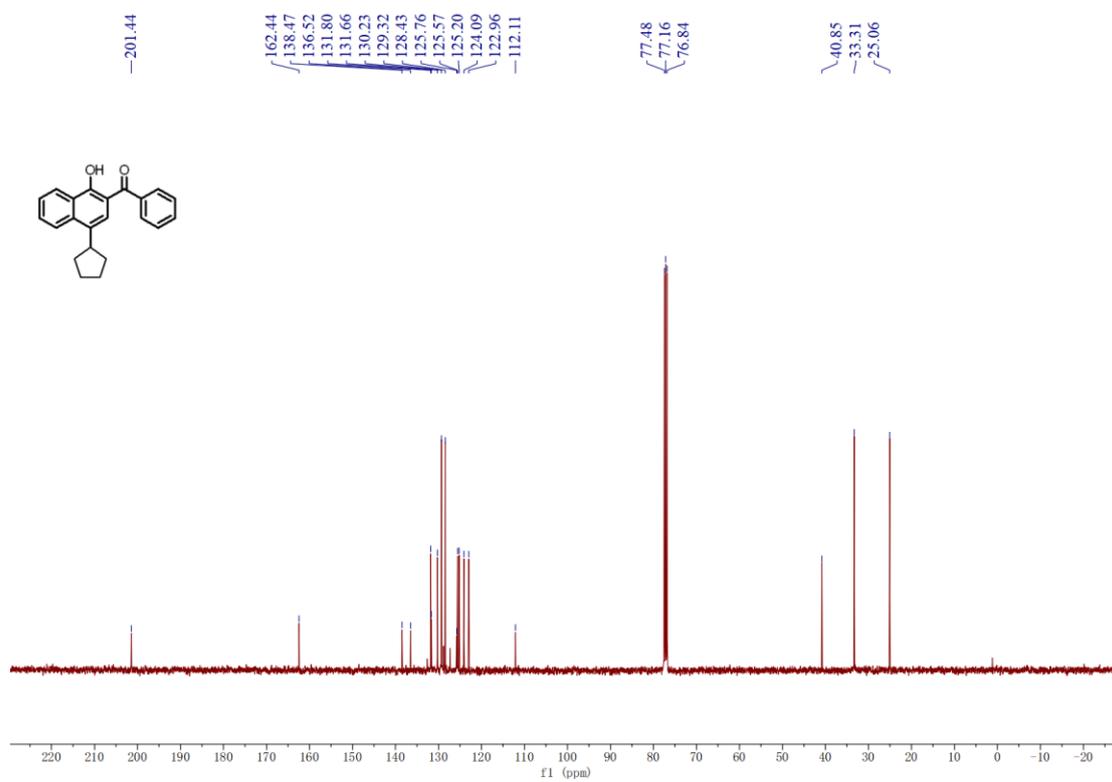
3t – ^{13}C NMR (101 MHz, CDCl_3)



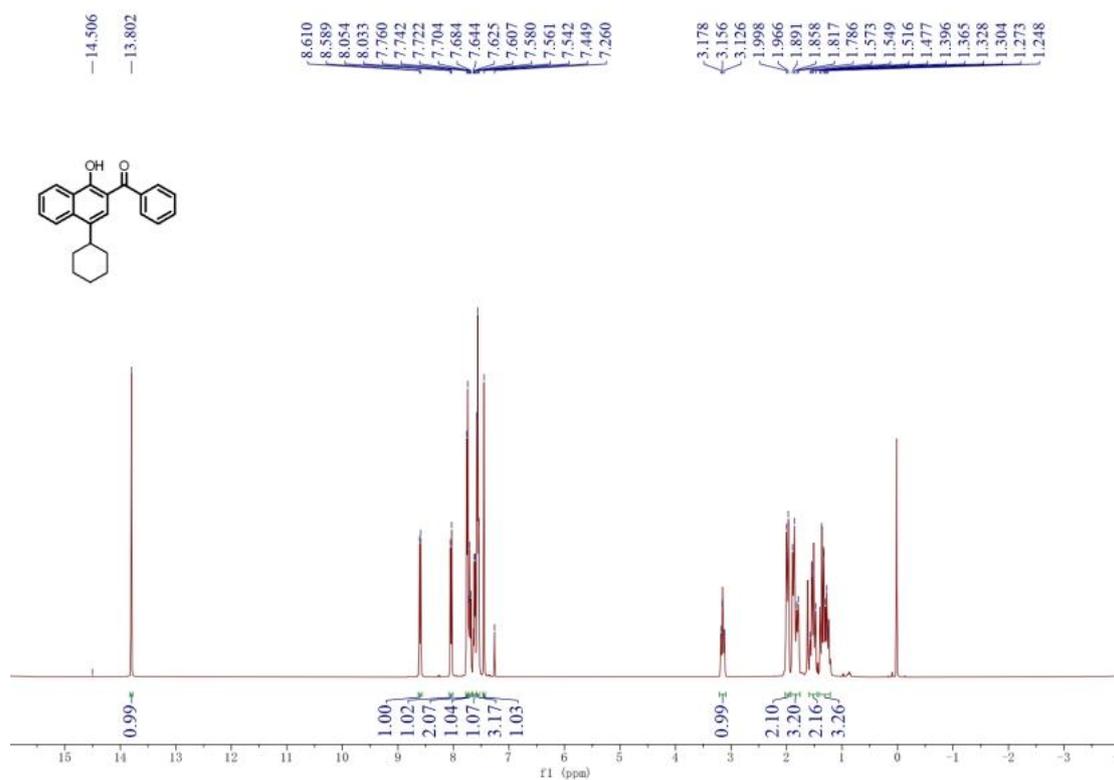
3u – ^1H NMR (400 MHz, CDCl_3)



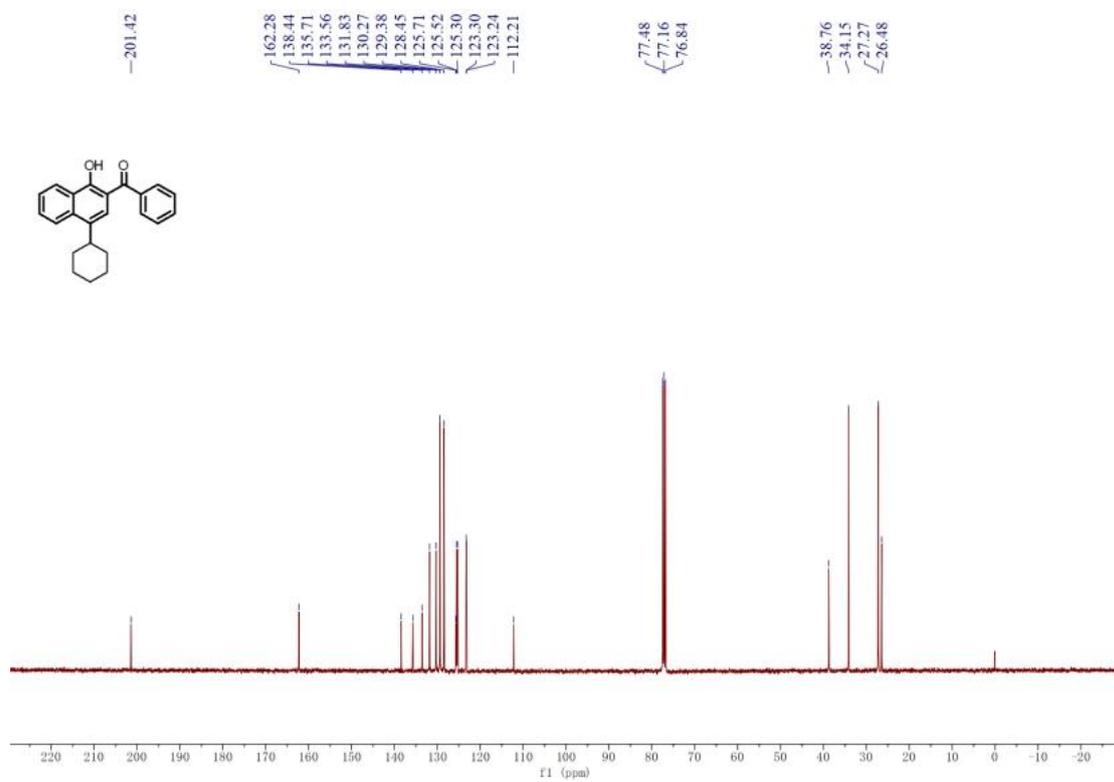
3u – ^{13}C NMR (101 MHz, CDCl_3)



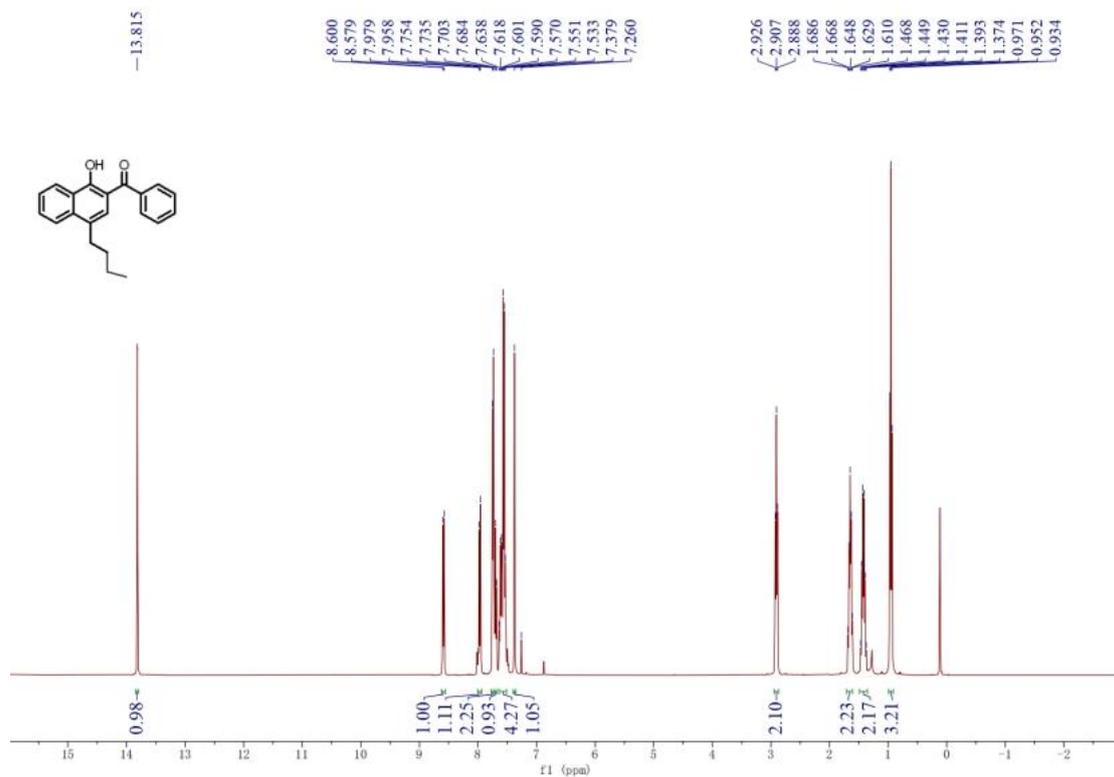
3v – ^1H NMR (400 MHz, CDCl_3)



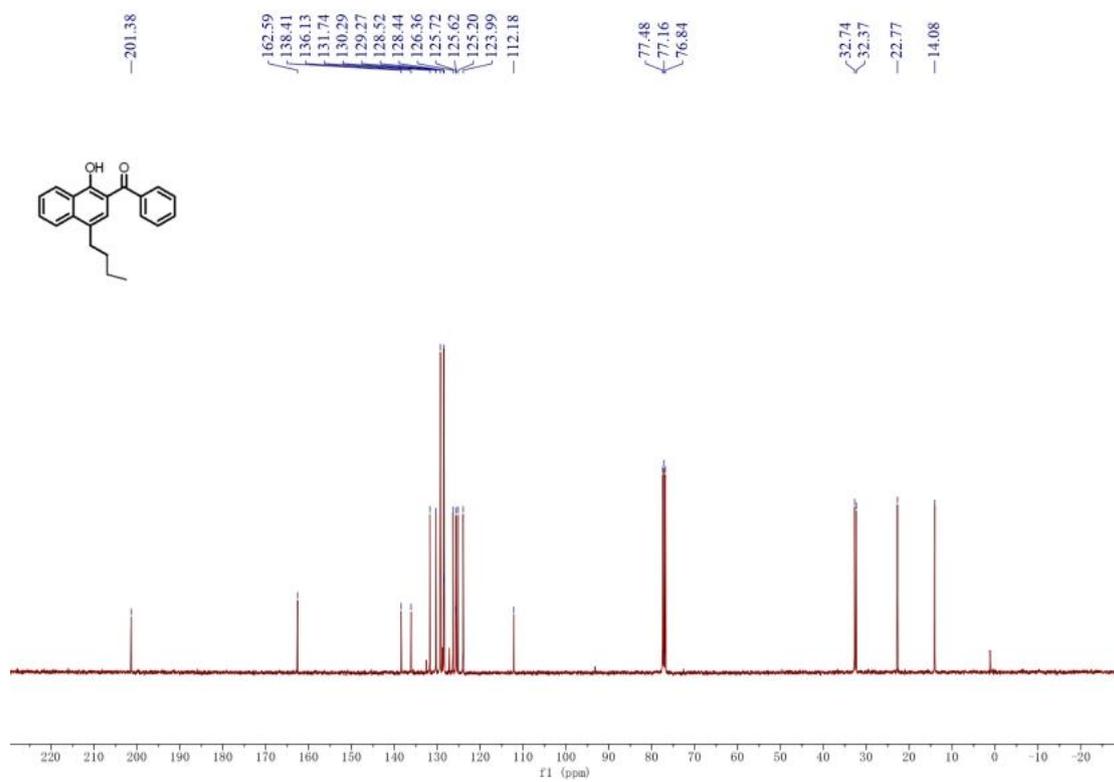
3v – ^{13}C NMR (101 MHz, CDCl_3)



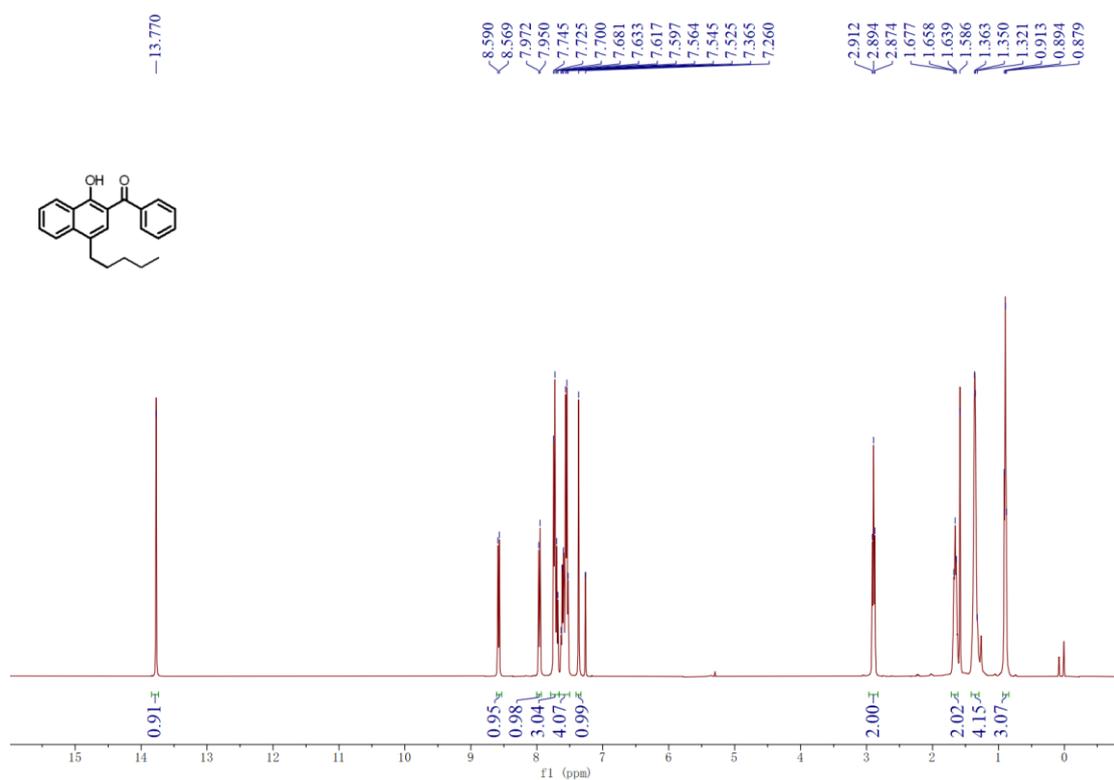
3w – ^1H NMR (400 MHz, CDCl_3)



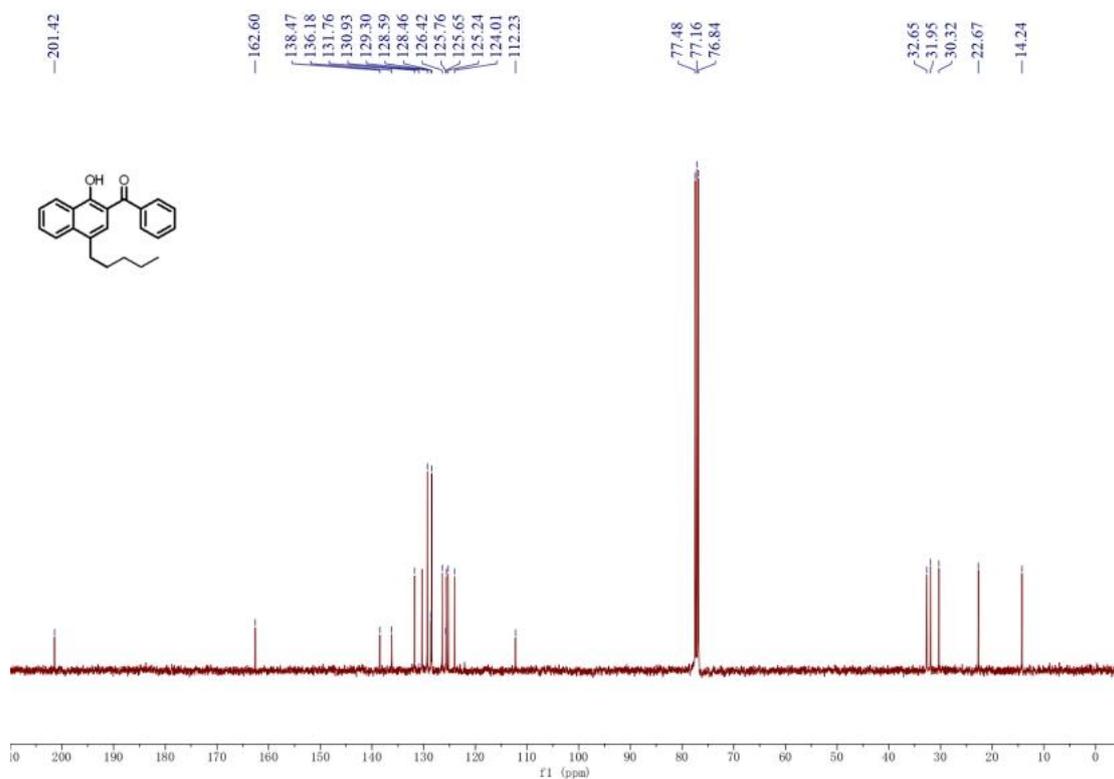
3w – ^{13}C NMR (101 MHz, CDCl_3)



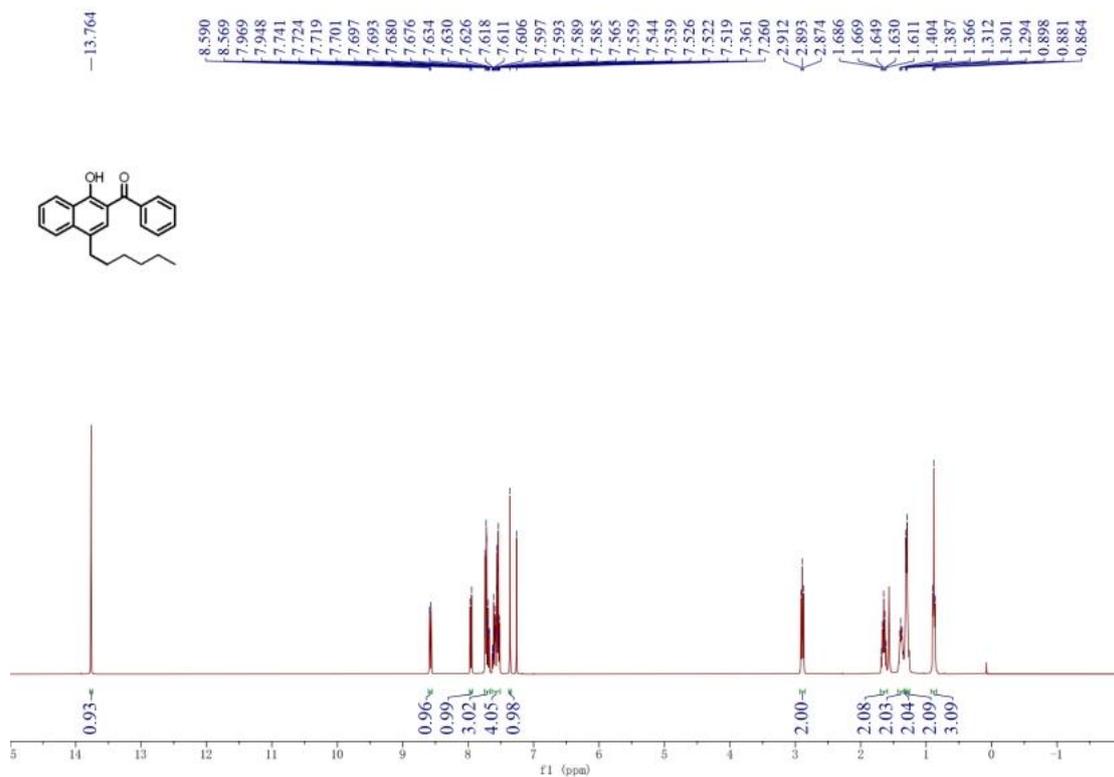
3x – ¹H NMR (400 MHz, CDCl₃)



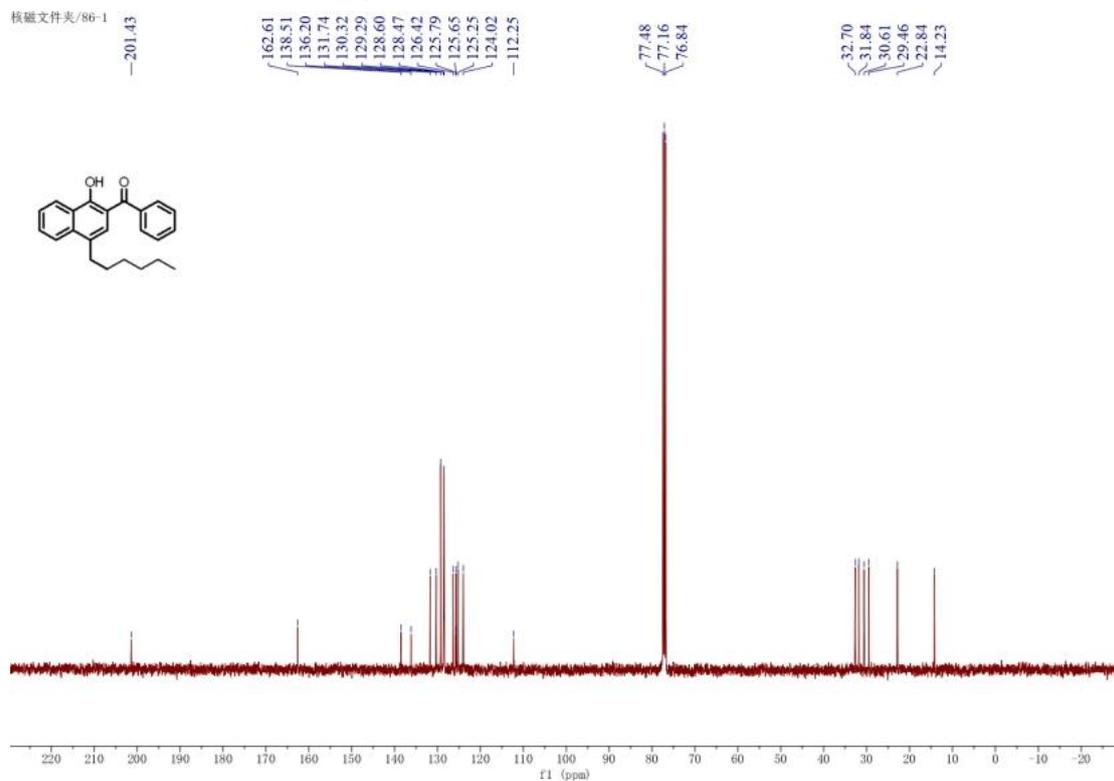
3x – ¹³C NMR (101 MHz, CDCl₃)



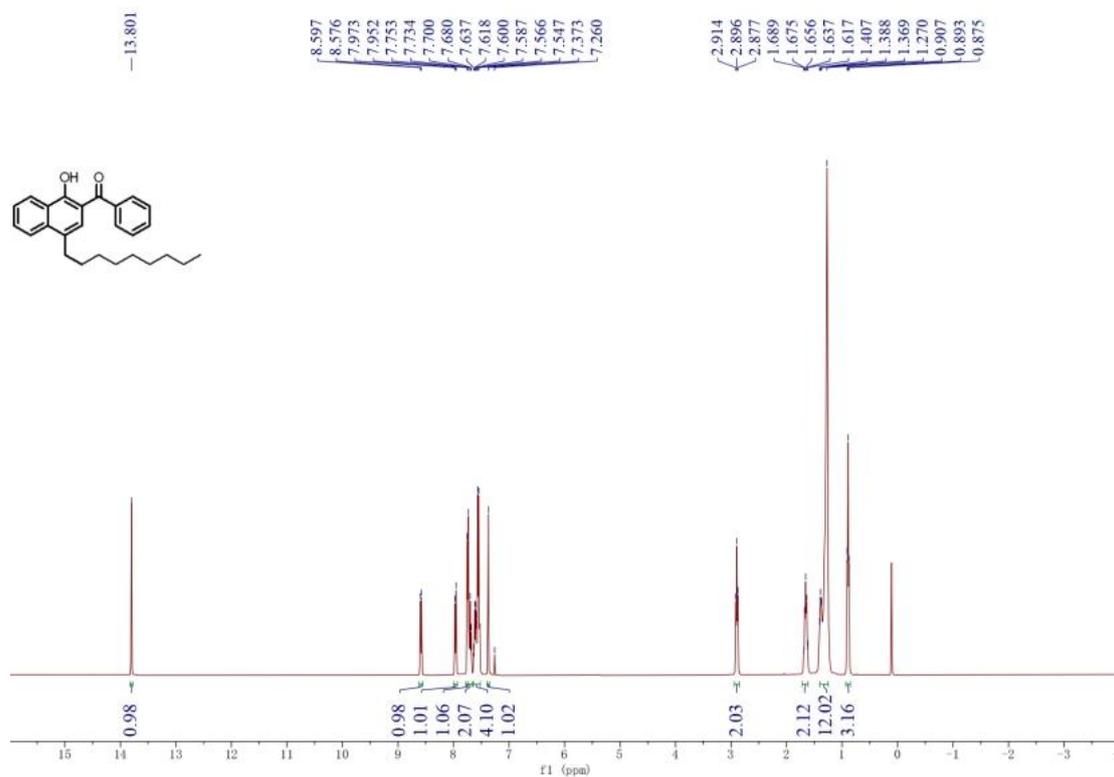
3y – ^1H NMR (400 MHz, CDCl_3)



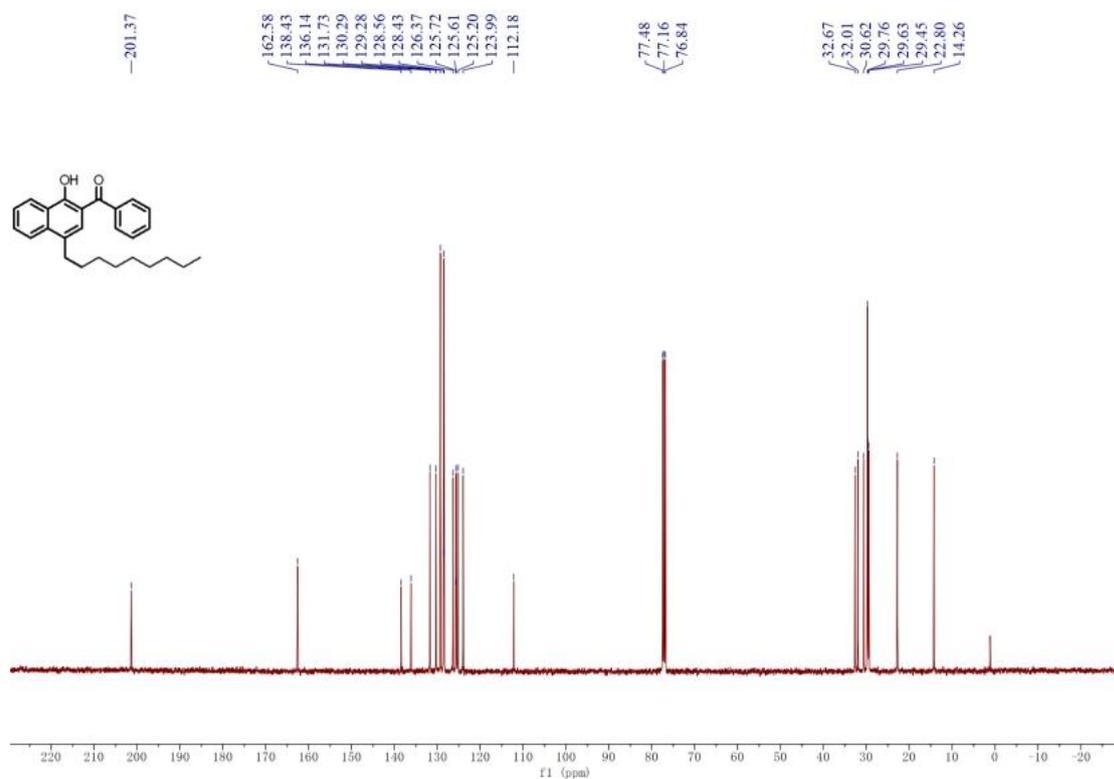
3y – ^{13}C NMR (101 MHz, CDCl_3)



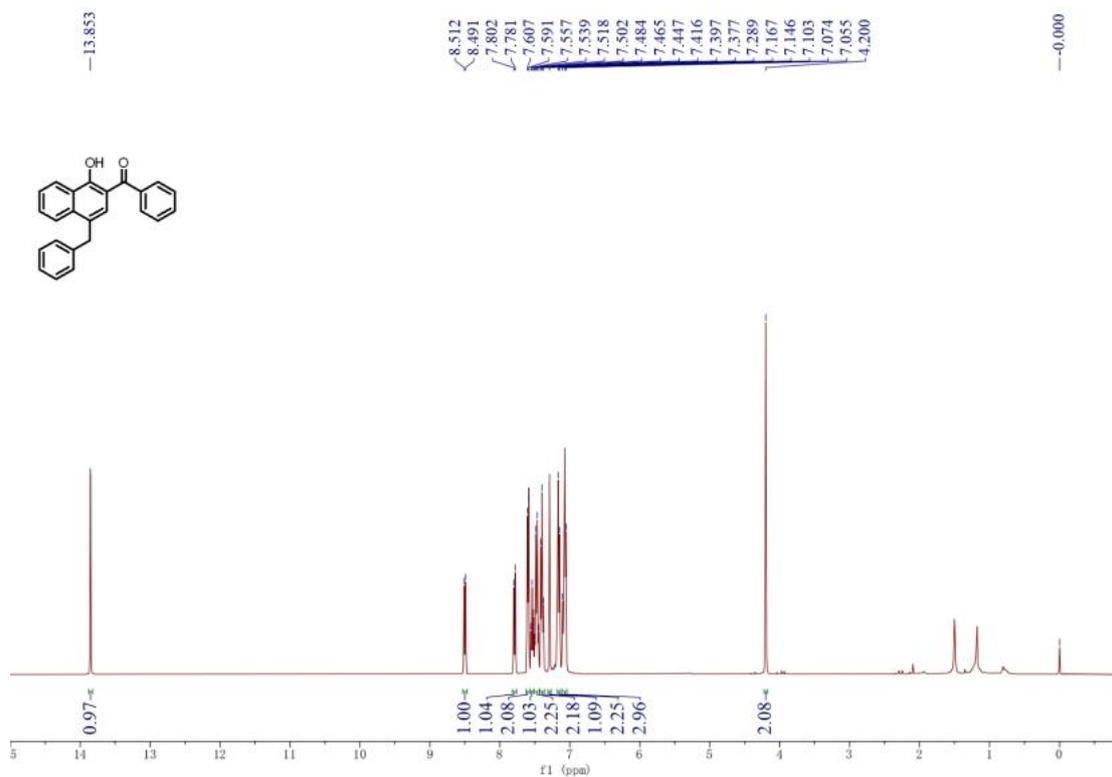
3z – ^1H NMR (400 MHz, CDCl_3)



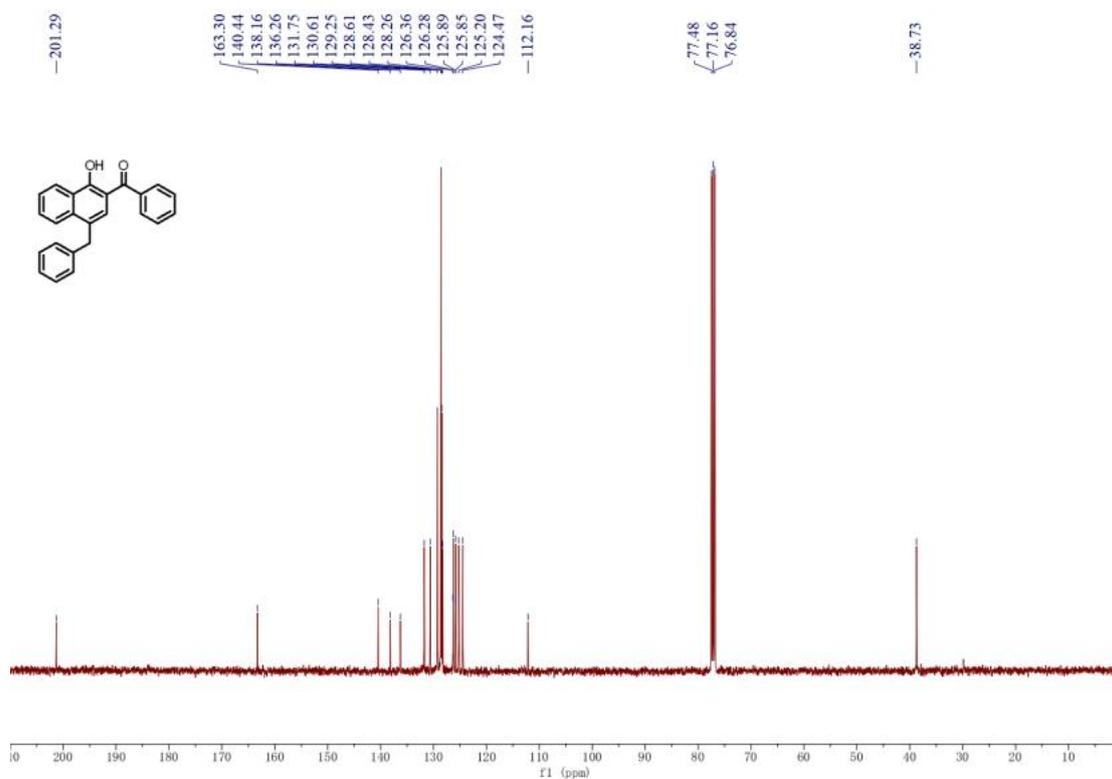
3z – ^{13}C NMR (101 MHz, CDCl_3)



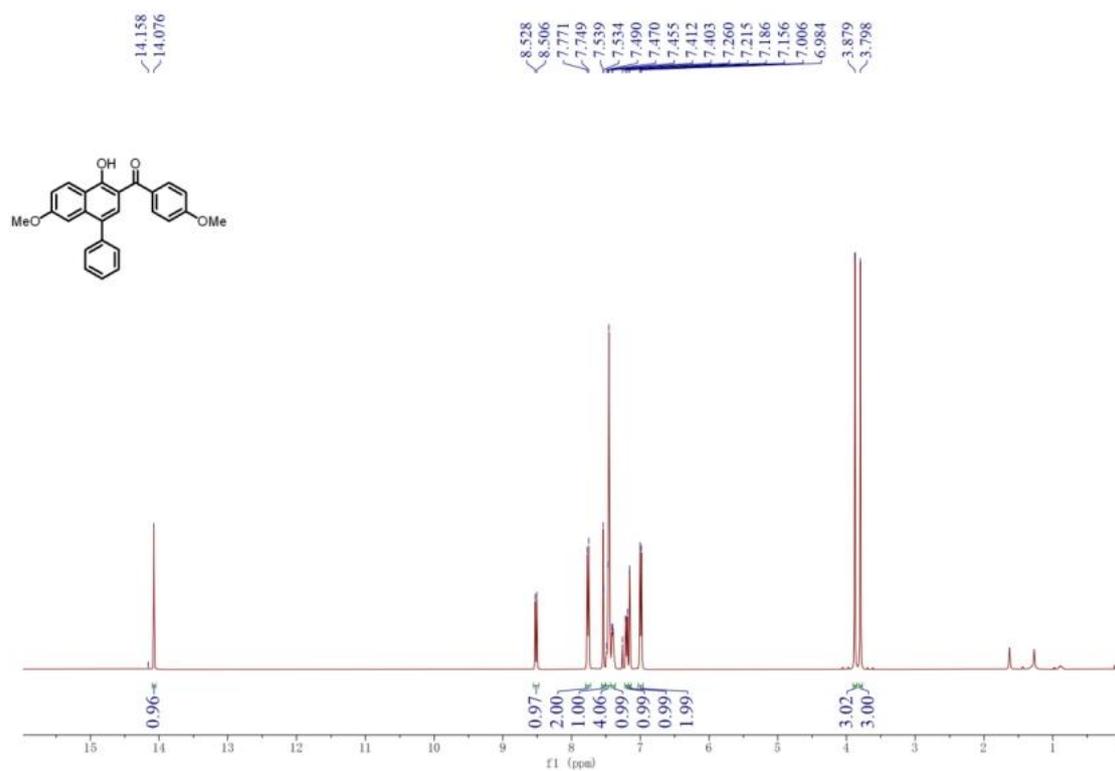
3aa – ^1H NMR (400 MHz, CDCl_3)



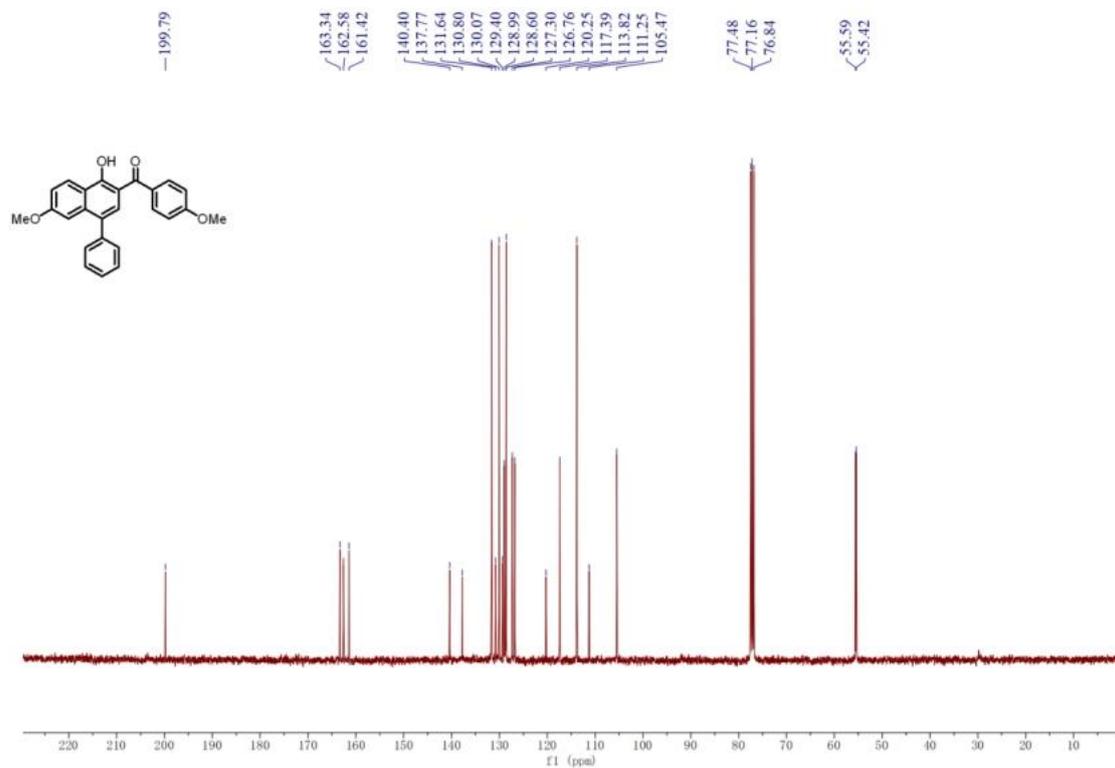
3aa – ^{13}C NMR (101 MHz, CDCl_3)



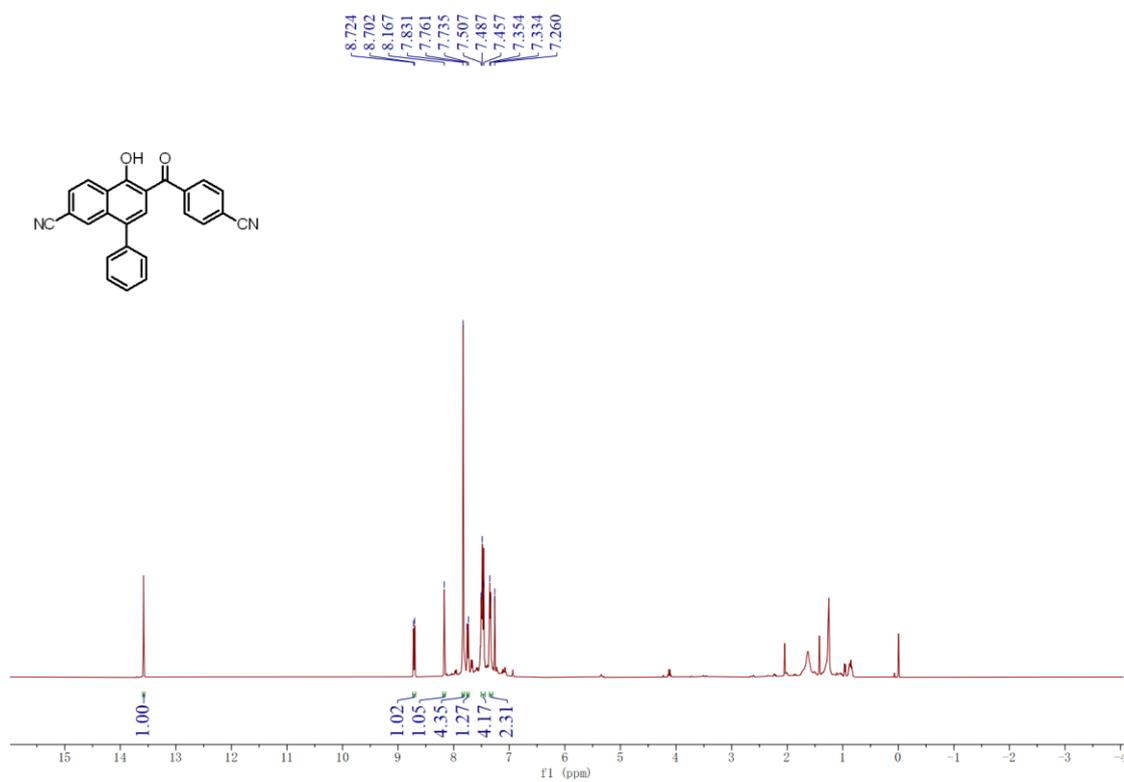
3ab – ^1H NMR (400 MHz, CDCl_3)



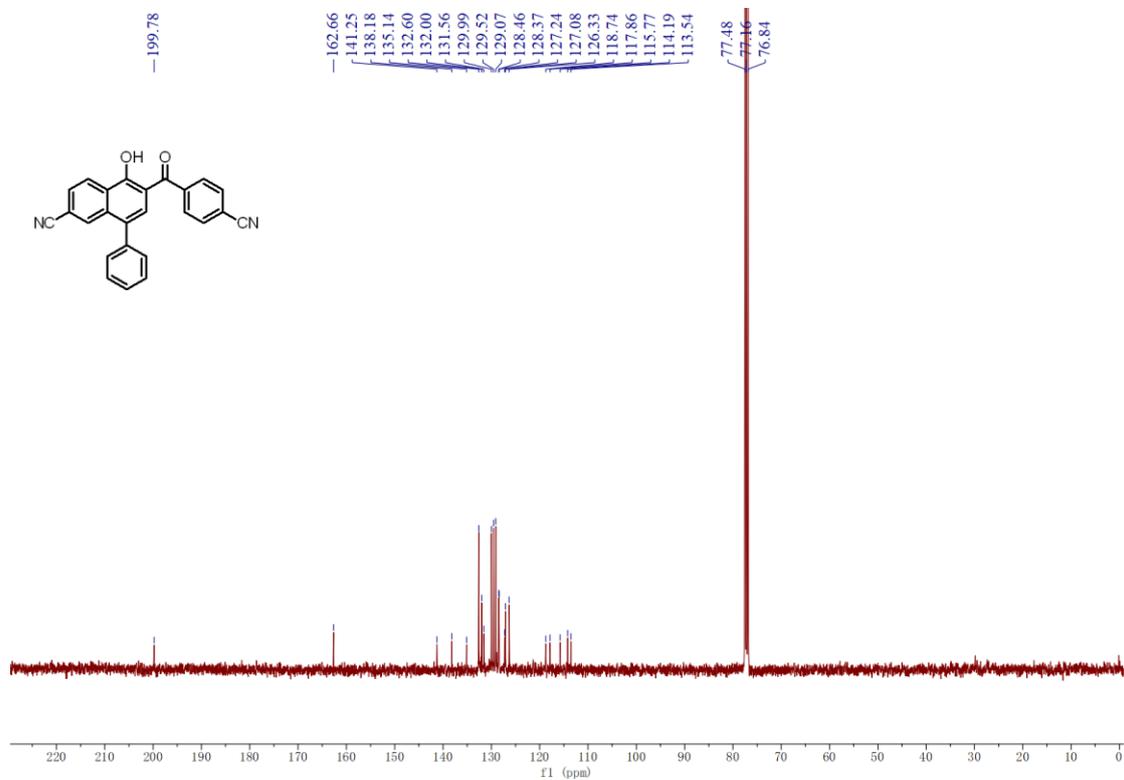
3ab – ^{13}C NMR (101 MHz, CDCl_3)



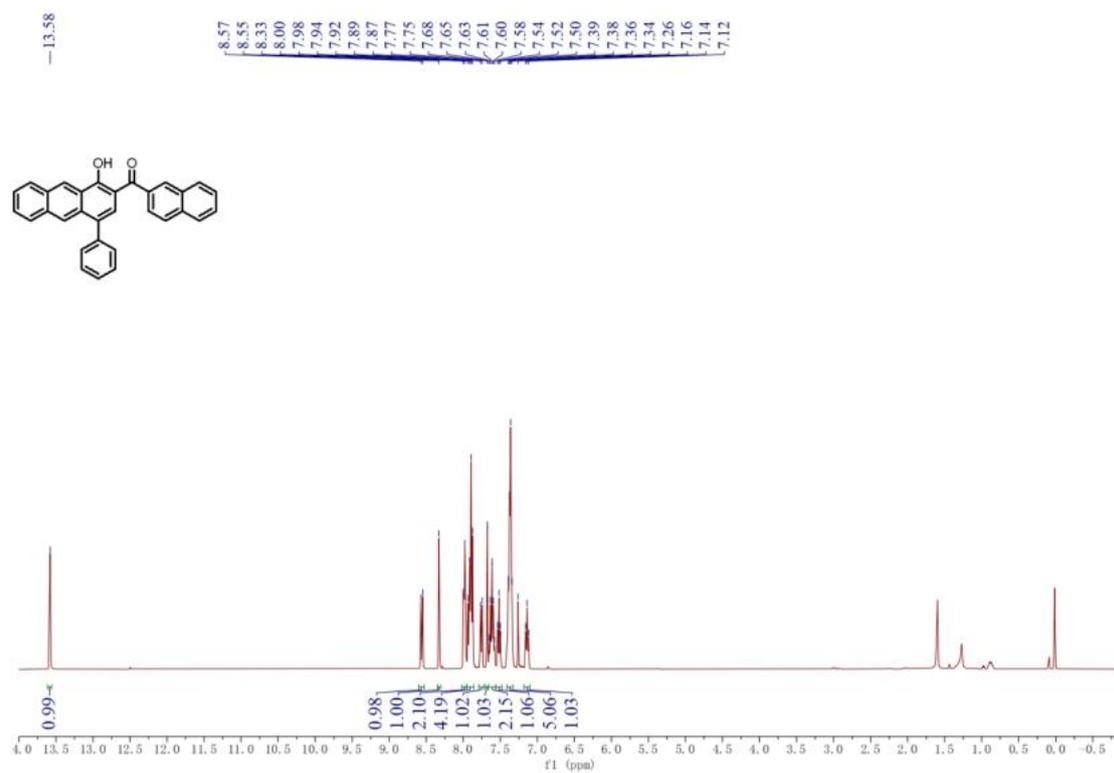
3ac – ^1H NMR (400 MHz, CDCl_3)



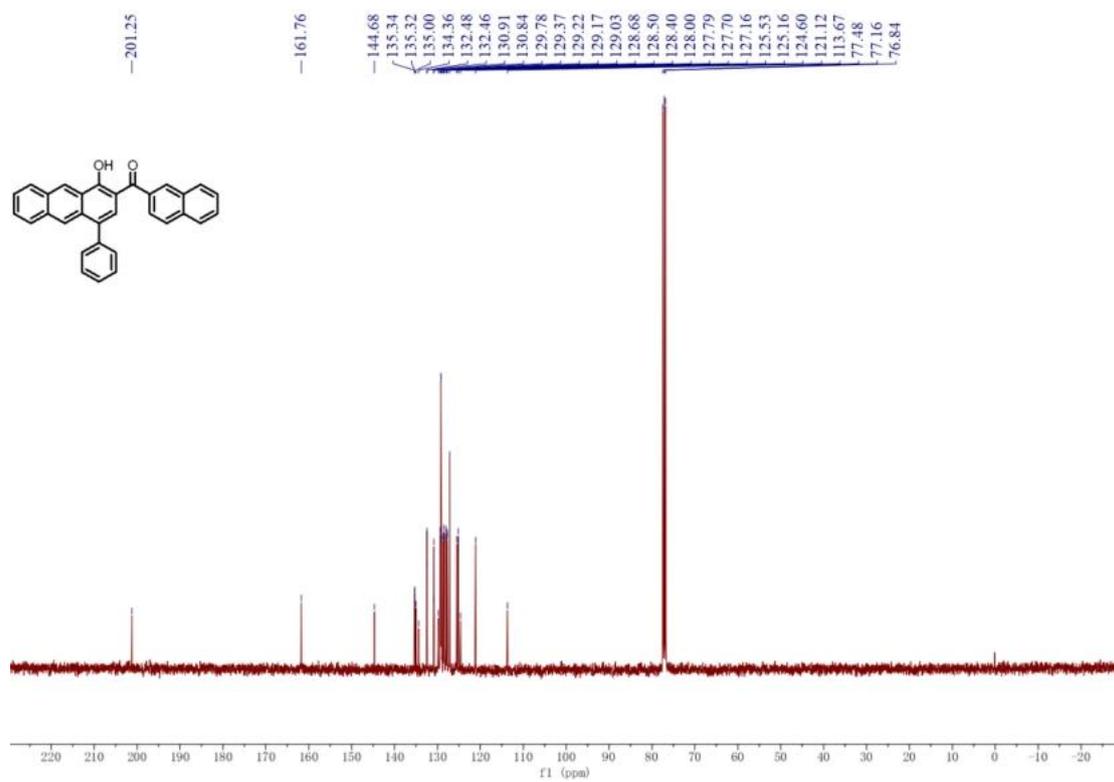
3ac – ^{13}C NMR (101 MHz, CDCl_3)



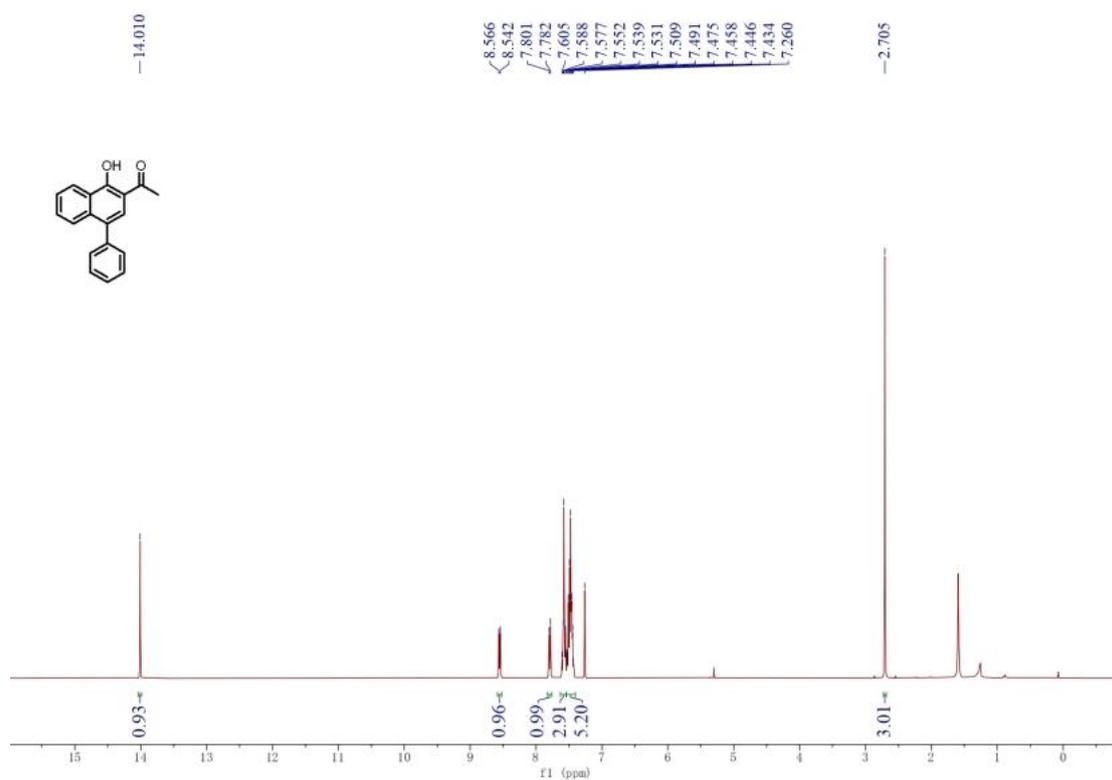
3ad – ^1H NMR (400 MHz, CDCl_3)



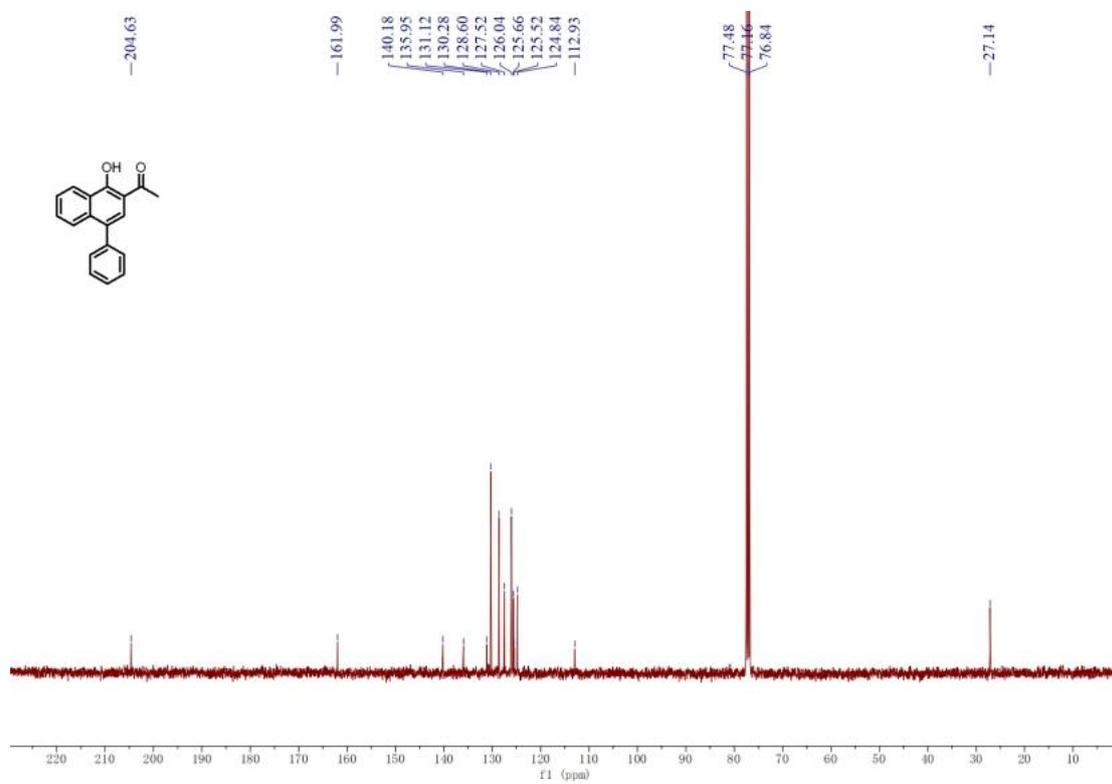
3ad – ^{13}C NMR (101 MHz, CDCl_3)



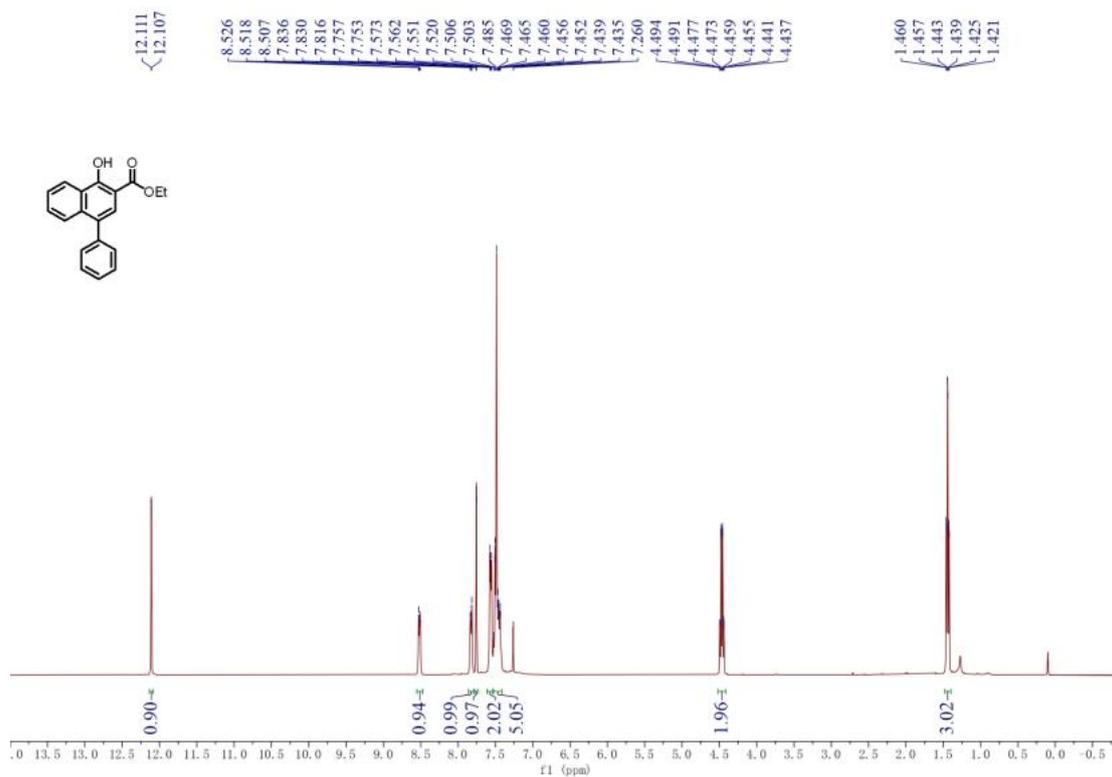
3ae – ^1H NMR (400 MHz, CDCl_3)



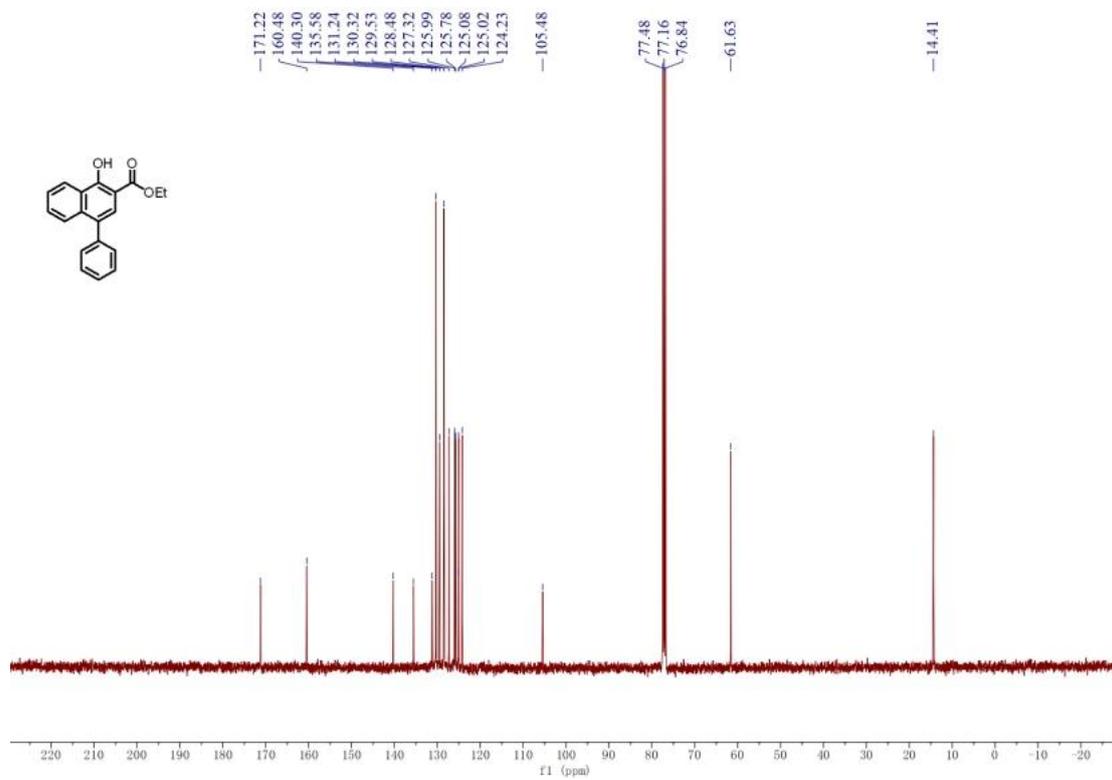
3ae – ^{13}C NMR (101 MHz, CDCl_3)



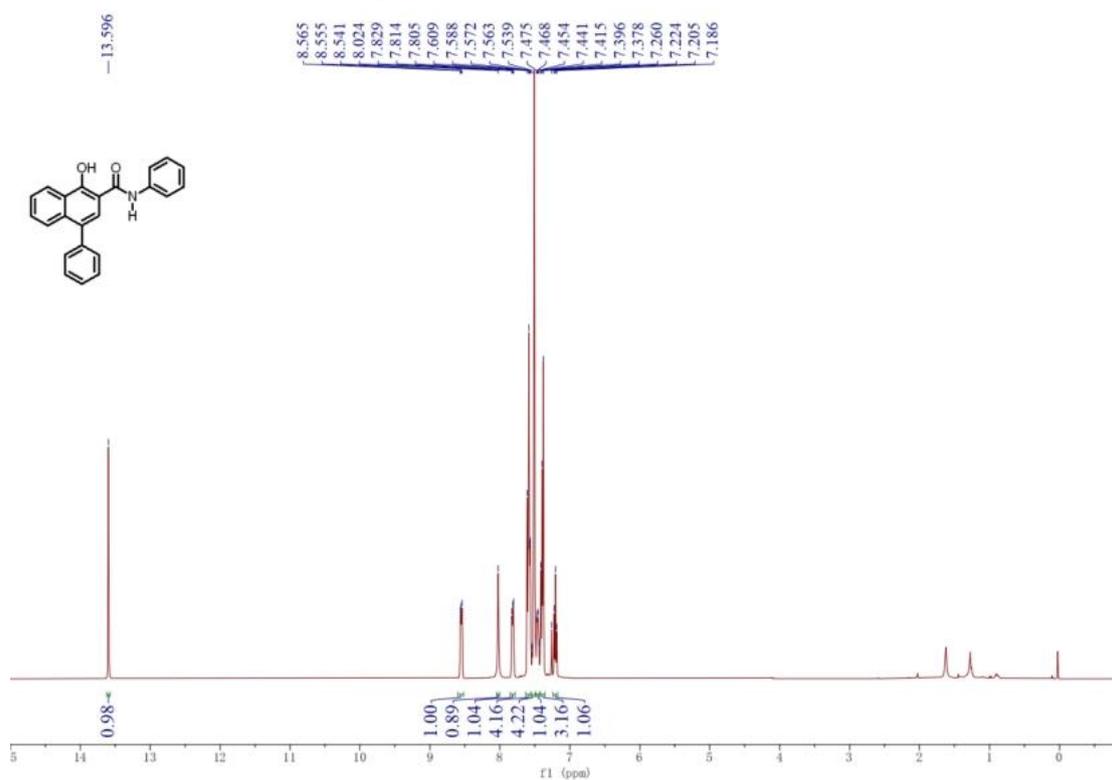
3af – ^1H NMR (400 MHz, CDCl_3)



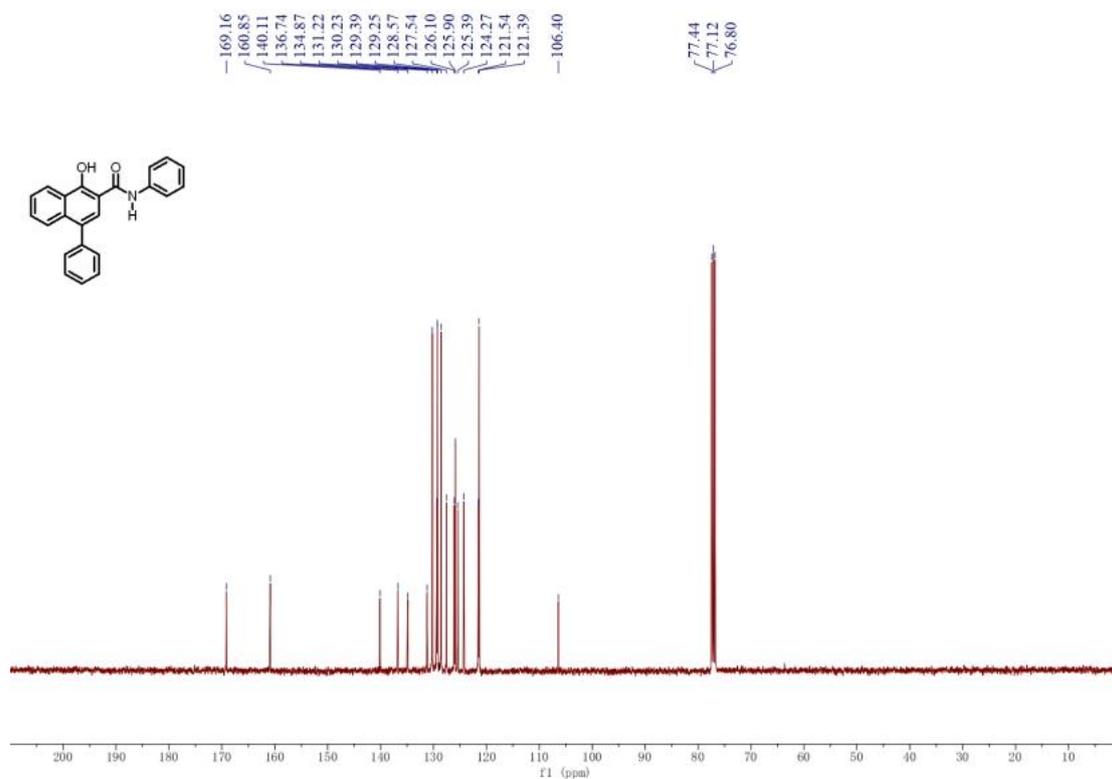
3af – ^{13}C NMR (101 MHz, CDCl_3)



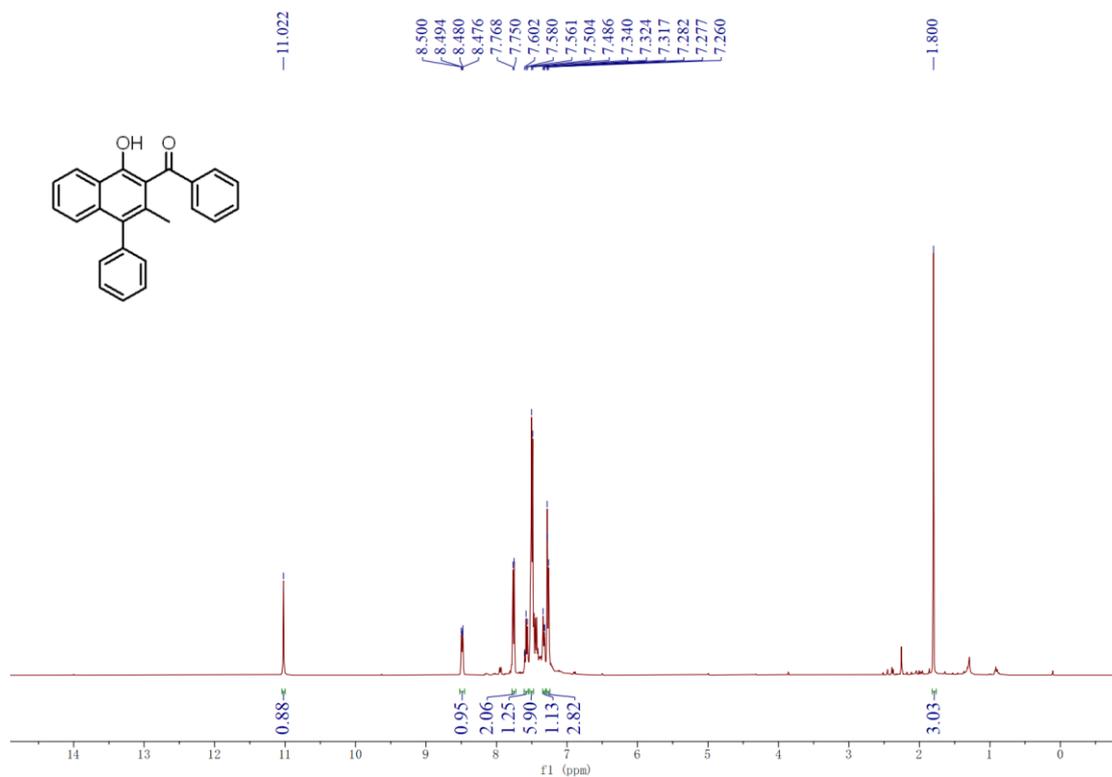
3ag – ^1H NMR (400 MHz, CDCl_3)



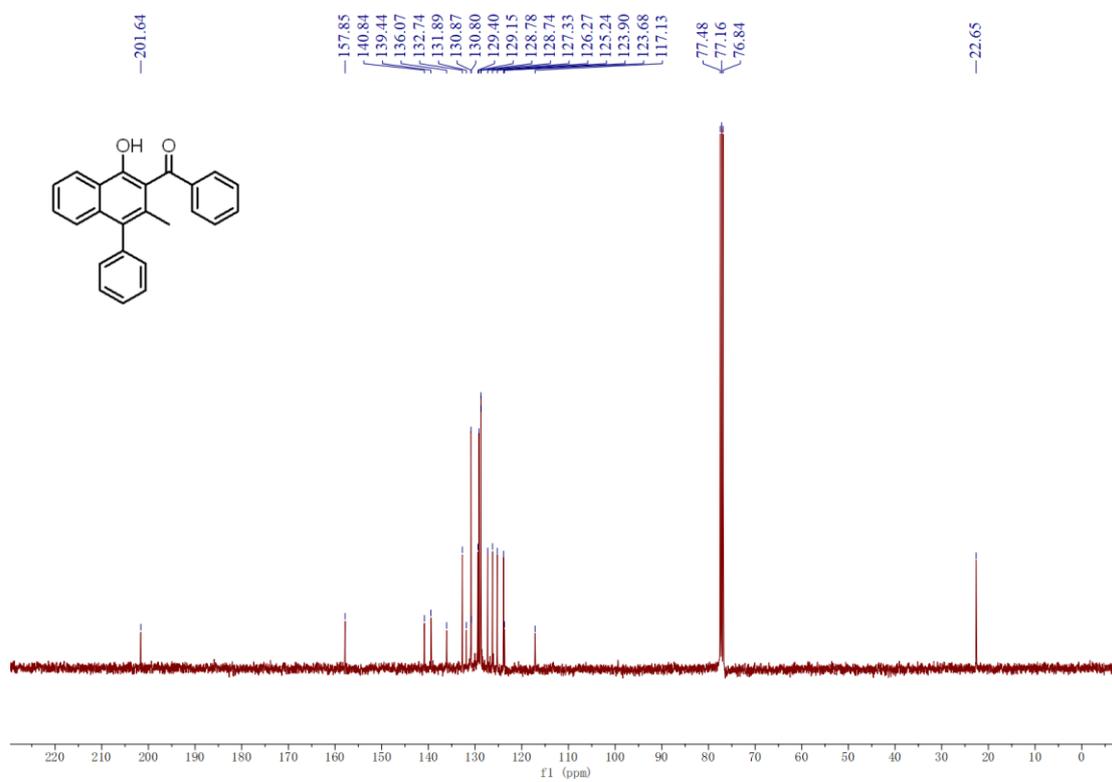
3ag – ^{13}C NMR (101 MHz, CDCl_3)



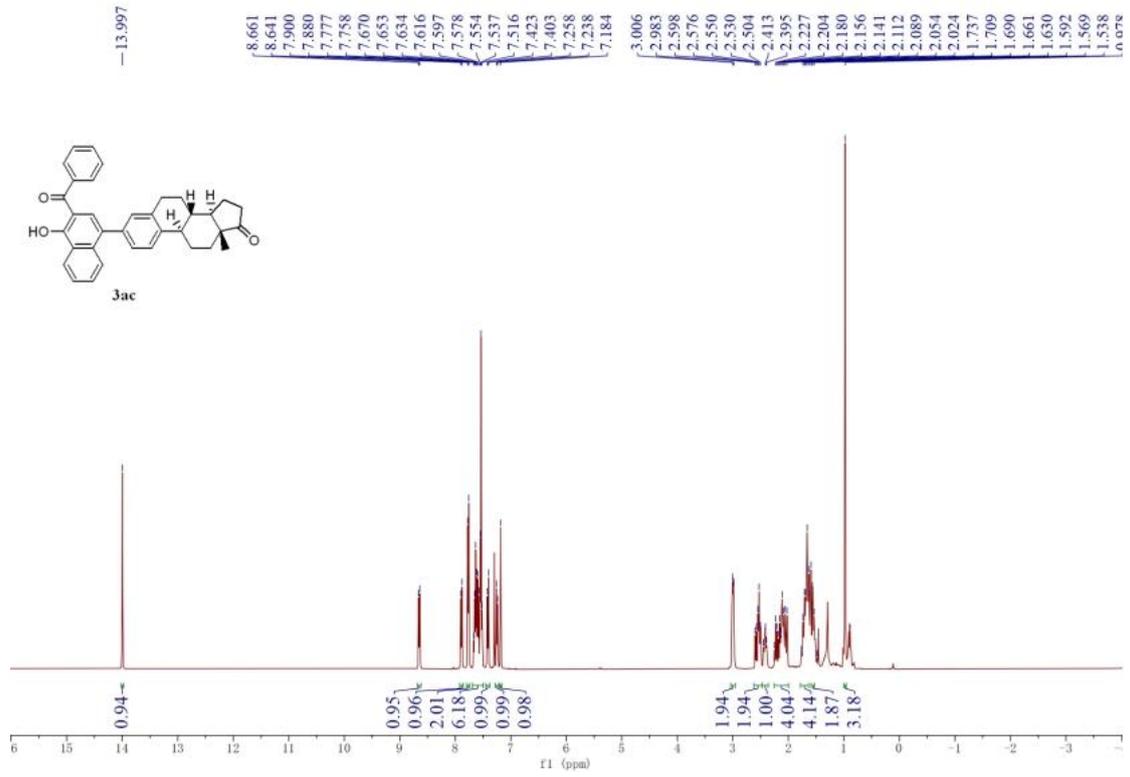
3ah – ^1H NMR (400 MHz, CDCl_3)



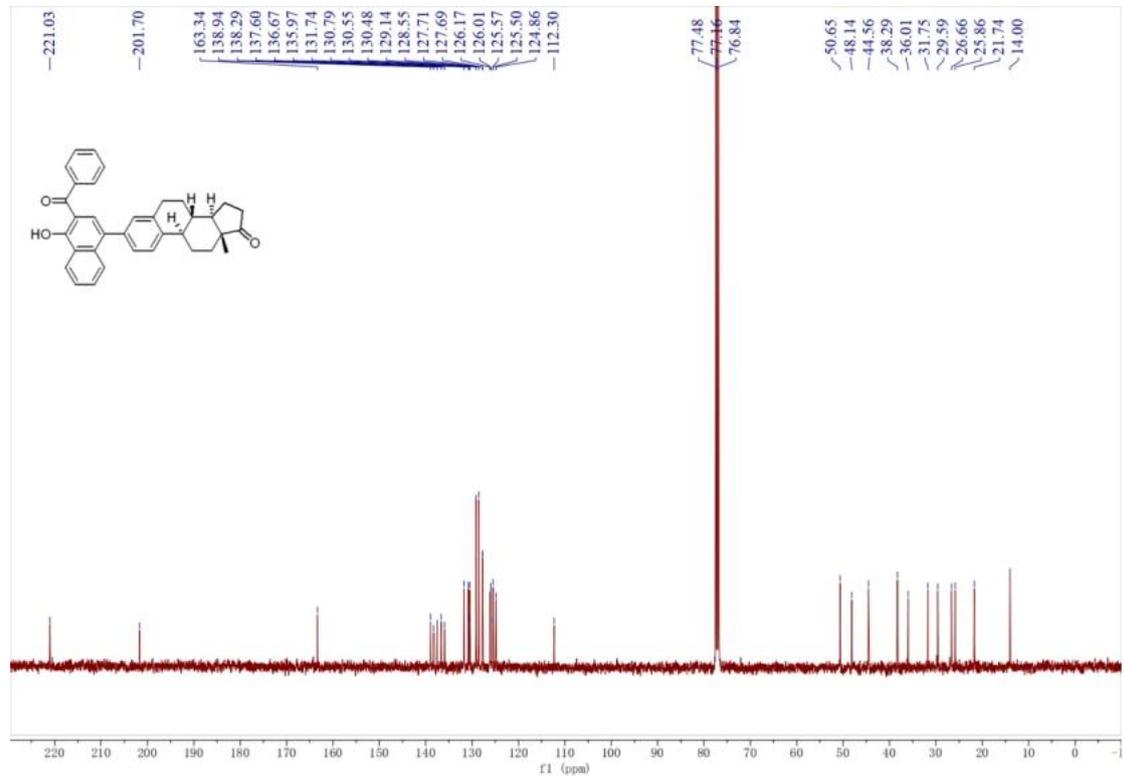
3ah – ^{13}C NMR (101 MHz, CDCl_3)



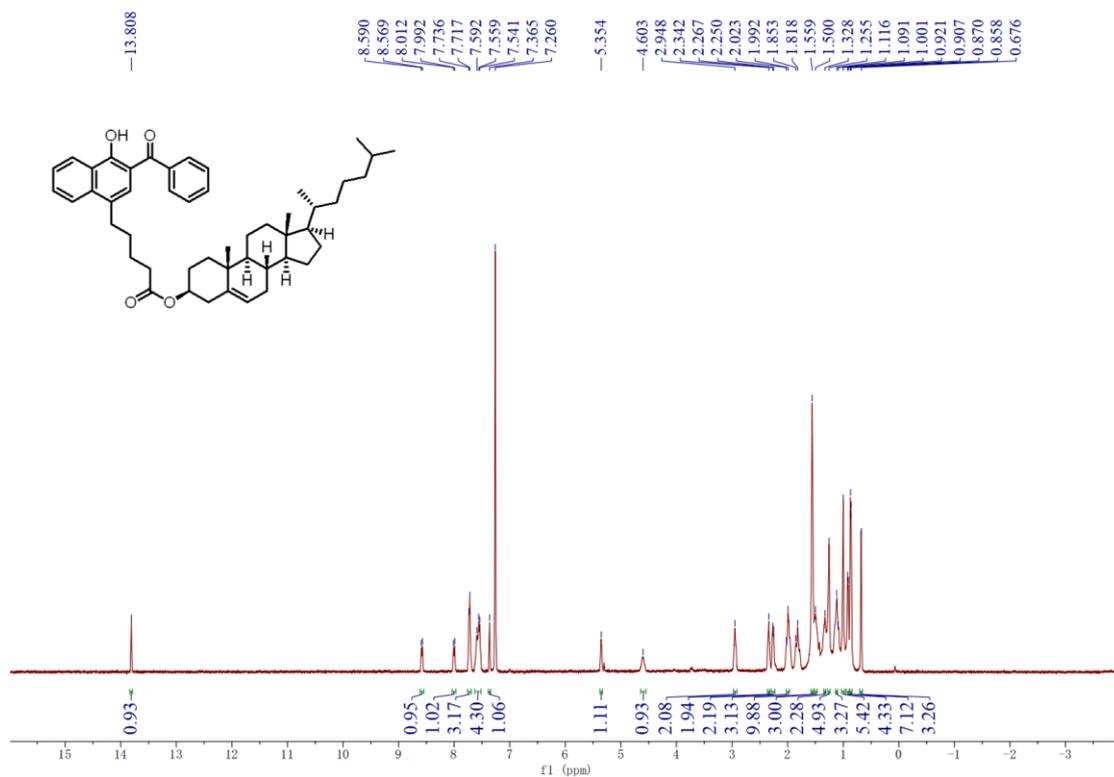
3ai – ^1H NMR (400 MHz, CDCl_3)



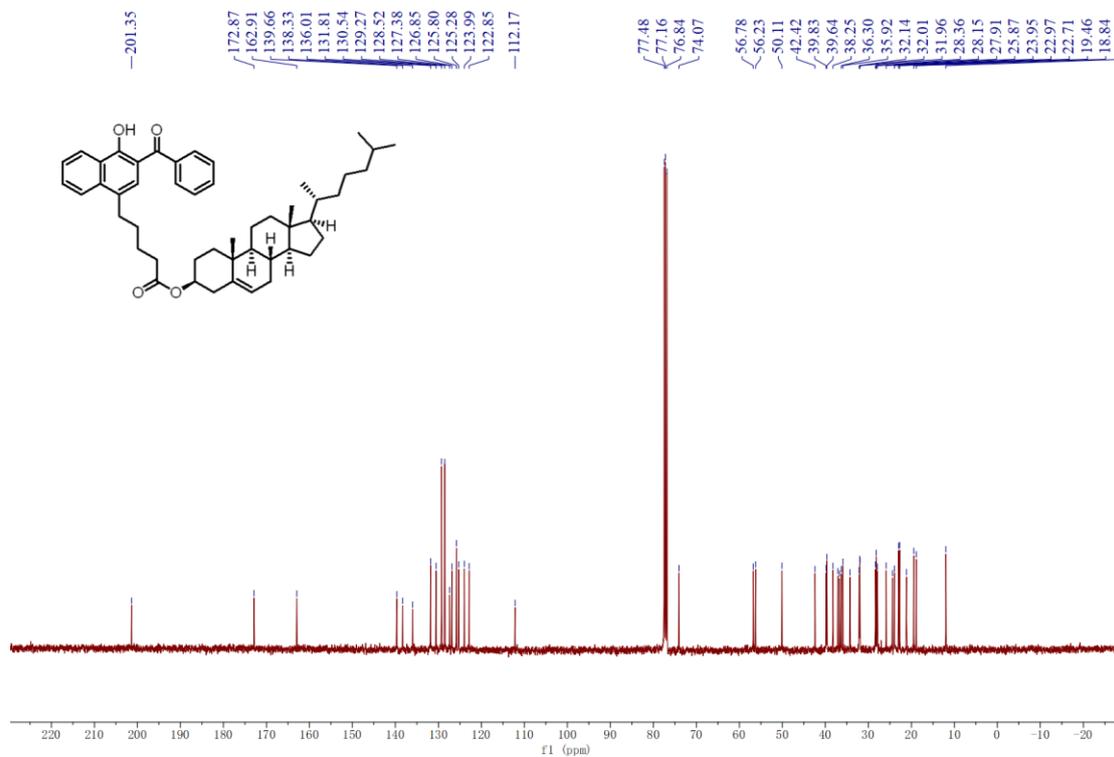
3ai – ^{13}C NMR (101 MHz, CDCl_3)



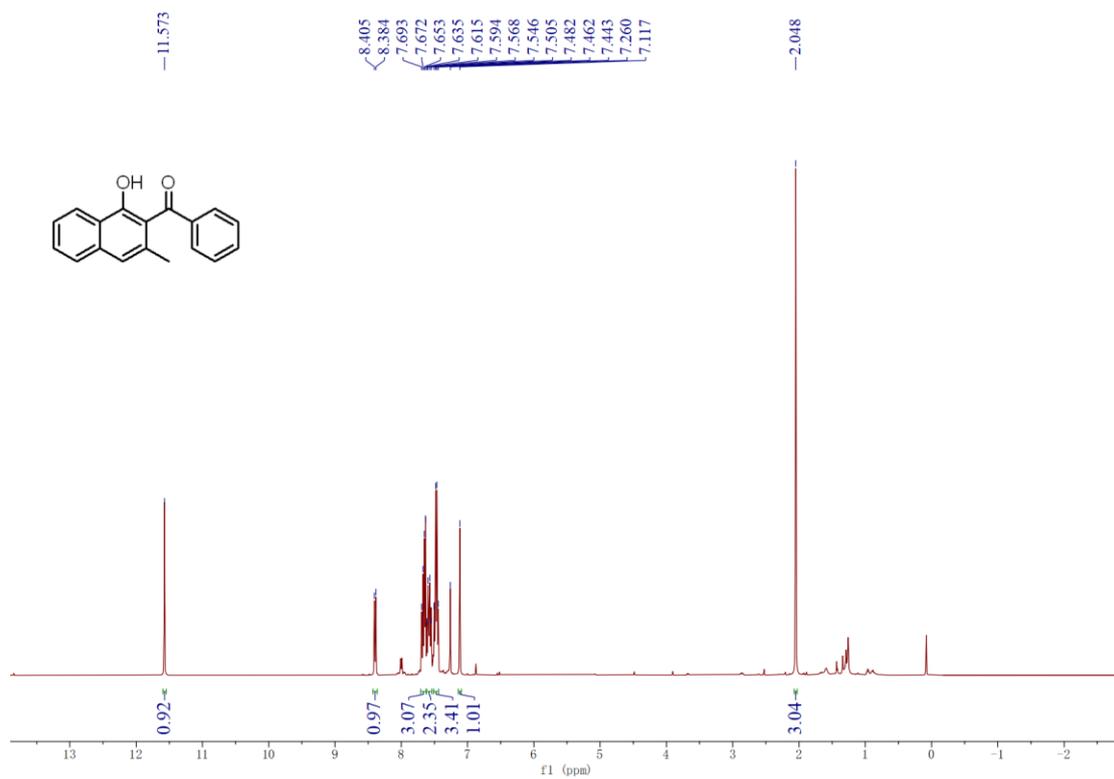
3aj – ^1H NMR (400 MHz, CDCl_3)



3aj – ^{13}C NMR (101 MHz, CDCl_3)



3ak – ^1H NMR (400 MHz, CDCl_3)



3ak – ^{13}C NMR (101 MHz, CDCl_3)

