Supplementary Information (SI) for Chemical Science.
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Supplementary Information

Carbene-catalyzed enantioselective construction of quasi-symmetrical spirocyclic hydroquinone with minor chiral distinction

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1. General information

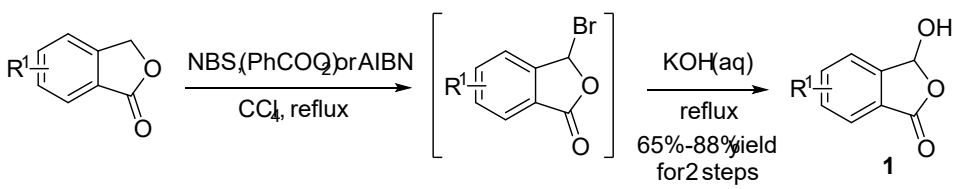
Commercial reagents were purchased from TCI, J&K, 3A Chemicals, Accela, Macklin, Energy, Bide, Meryer, CIL, or Adamas and used without further purification. The solvents used in the experiments were all purchased as anhydrous solvents and used directly. All reactions were carried out with oven-dried glassware. Analytical thin-layer chromatography was performed on 0.20 mm silica gel HSGF-254 plates (Huanghai, China), and visualized under 254 nm UV light. Column chromatography was performed on 200-300 mesh silica gel (General-Reagent, China).

^{1}H, ^{19}F, and ^{13}C NMR spectra were recorded on a Bruker Ascend 400 MHz or 600 MHz spectrometers. Chemical shifts were recorded in parts per million (ppm, δ) relative to solvent (Chloroform-*d*: for ^{1}H NMR, δ = 7.26 ppm, singlet, for ^{13}C NMR, δ = 77.16 ppm, triplet). ^{1}H NMR splitting patterns are designated as singlet (s), doublet (d), triplet (t), quartet (q), dd (doublet of doublets); m (multiplets), etc. All first-order splitting patterns were assigned on the basis of the appearance of the multiplet. Splitting patterns that could not be easily interpreted are designated as multiplet (m) or broad (br).

High-resolution mass spectra of new compounds were recorded on LTQ Orbitrap Elite LC/MS (ESI or APCI) (Thermofisher). Infrared (IR) spectra were recorded on the PerkinElmer Frontier spectrometer and reported in wave numbers (cm^{-1}). An Anton Paar MCP 500 polarimeter recorded optical rotations at room temperature. CD spectra were measured on an Applied Photophysics Chirascan spectropolarimeter. The determination of enantiomeric excesses was performed via chiral stationary phases analysis using Waters Acquity Ultra Performance Convergence Chromatography (UPCC) (Chiral stationary phases column: Chiralpak AD-3, OX-3, OD-3 columns from Daicel Chiral Technologies and Trefoil CEL-1, CEL-2 column from Waters). Its X-ray diffraction data were collected on an Agilent Gemini Ultra diffractometer (CuKα radiation, Agilent, Oxfordshire, UK).

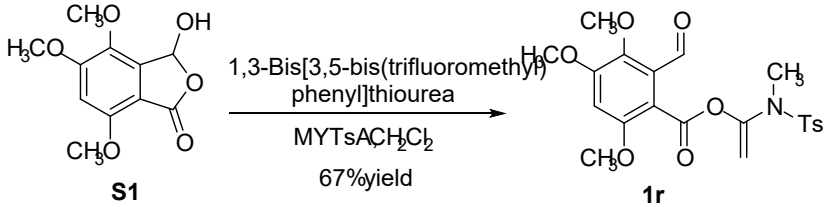
2. General procedure for the preparation of substrates

2.1 synthesis of phthalides



The substitute phthalide (2.0 mmol, 1.0 equiv.), NBS (0.39 g, 2.2 mmol, 1.1 equiv.), and benzoyl peroxide (48.4 mg, 0.2 mmol, 0.1 equiv.) or AIBN (32.8 mg, 0.2 mmol, 0.1 equiv.) were diluted in CCl_4 (10 mL) and heated to reflux overnight with stirring under a nitrogen atmosphere. The mixture was cooled to room temperature and filtered. The residue was washed with CCl_4 (2 × 5 mL), and the filtrate was concentrated in vacuo. H_2O (25 mL) and KOH (224.4 mg, 4.0 mmol, 2.0 equiv.) were added to the obtained yellow oil, and the mixture was heated to reflux with stirring for 2 h. The mixture was acidified with $NaHSO_4$ (240 mg, 2.0 mmol, 1.0 equiv.) and extracted with EtOAc (3 × 20 mL). The combined organic layers were dried over Na_2SO_4 and concentrated in vacuo, the residue was purified by column chromatography to provide the desired product as a white solid.[1,2]

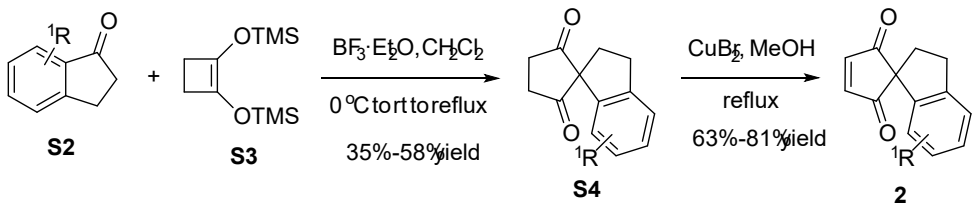
2.2 synthesis of 1r



A 10 mL round-bottomed flask was charged with **S1** (48.0 mg, 0.2 mmol, 1.0 equiv.), 1,3-Bis[3,5-bis(trifluoromethyl)-phenyl]thiourea (100 mg, 0.2 mmol, 1.0 equiv.), MYTsA (*N*-methylynetoluenesulfonamide) (41.8 mg, 0.2 mmol, 1.0 equiv.) and CH_2Cl_2 (4 mL). The reaction mixture was stirred at 25 °C for about 24 h under N_2. The mixture was concentrated under reduced pressure and purified by silica gel column chromatography to afford the product **1r**.[3]

2.3 synthesis of 1,3-diones

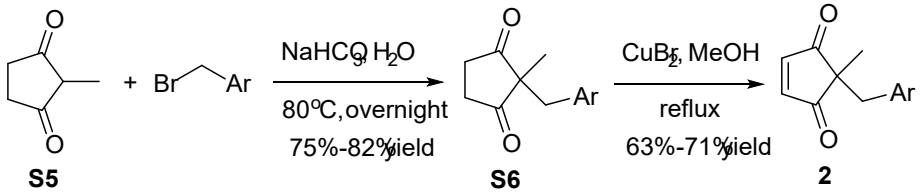
Procedure A:



The **S2** (500 mg, 4.46 mmol, 1.0 equiv.) was dissolved in dry dichloromethane (10 mL) at 0 °C under N_2. Then $BF_3.Et_2O$ (661 μL, 5.35 mmol, 1.2 equiv.) was added and followed by **S3** (1.7 mL, 7.14 mmol, 1.6 equiv.). The resulting mixture was stirred while the temperature increased to room

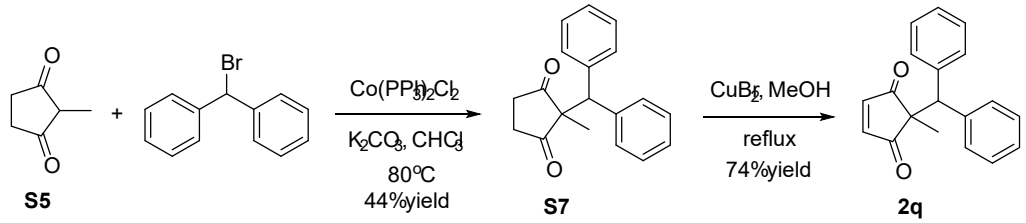
temperature for 2 h and then the mixture was heated to reflux with stirring for 2 h. It was quenched by sat. $NaHCO_3$ solution, diluted by dichloromethane, washed with brine, dried over Na_2SO_4, and the solvent was removed after filtration. The crude product was subject to column chromatography to give the **S4**.[4] $CuBr_2$ (315.6 mg, 2.2 mmol, 2.2 equiv.) was added to a solution of **S4** (200 mg, 1.0 mmol, 1.0 equiv.) in MeOH. The mixture was heated at reflux overnight under nitrogen. After cooling to room temperature, the solvent was evaporated under vacuum. The crude residue was directly subjected to column chromatography to afford **2**.[5] These compounds **2a** and **2i–2n** were prepared according to procedure A.

Procedure B:



To a stirred suspension of **S5** (224.3 mg, 2.0 mmol, 1.0 equiv.) in water (1M) was gradually added powdered $NaHCO_3$ (168 mg, 2.0 mmol, 1 equiv.). After the frothing had settled, benzyl bromide (4.0 mmol, 2 equiv.) was added and the reaction mixture was stirred at 80 °C overnight. Then the reaction mixture was cooled to room temperature and extracted with CH_2Cl_2 (3 × 20 mL). The combined organic solvent was dried over Na_2SO_4, after evaporation of the solvent, the crude mixture was purified by silica gel chromatography to give the desired **S6**. $CuBr_2$ (315.6 mg, 2.2 mmol,2.2 equiv.) was added to a solution of **S6** (1.0 mmol, 1.0 equiv.) in MeOH. The mixture was heated at reflux overnight under nitrogen. After cooling to room temperature, the solvent was evaporated under vacuum. The crude residue was directly subjected to column chromatography to afford **2**.[5] These compounds **2o–2p** were prepared according to procedure B.

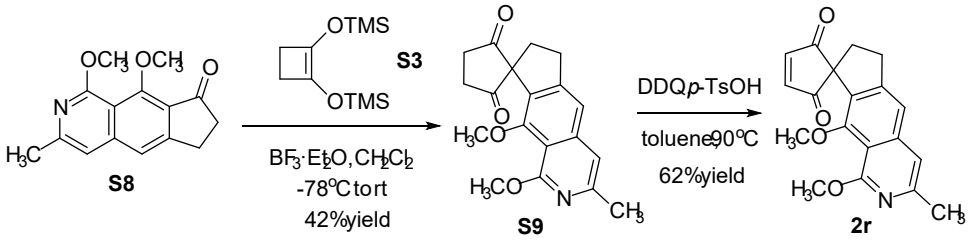
Procedure C:



To this was added **S5** (500 mg, 4.46 mmol, 1.0 equiv.), 4,4'-dibenzhydryl bromide (2.11 g, 6.68 mmol, 1.5 equiv.), $Co(PPh_3)_2Cl_2$ (584 mg, 0.892 mmol, 0.20 equiv.), K_2CO_3 (1.23 g, 8.91 mmol, 2.0

equiv.) followed by 21.0 mL of dry $CHCl_3$, and the resulting solution was stirred at 80 °C under argon. After being stirred for 48 h, the reaction mixture was cooled to room temperature, quenched with 20 mL of distilled water, and diluted with 20 mL of CH_2Cl_2. The organic phase was separated from the aqueous phase, aqueous phase was extracted with CH_2Cl_2 (2 × 10 mL). Combined organic phase was dried over Na_2SO_4 and concentrated under reduced pressure. The crude reaction mixture was purified by silica-gel column chromatography to obtain a colorless thick oil **S7**. $CuBr_2$ (315.6 mg, 2.2 mmol,2.2 equiv.) was added to a solution of **S7** (278 mg, 1.0 mmol, 1.0 equiv.) in MeOH. The mixture was heated at reflux overnight under nitrogen. After cooling to room temperature, the solvent was evaporated under a vacuum. The crude residue was directly subjected to column chromatography to afford **2q** as a yellow solid.[6]

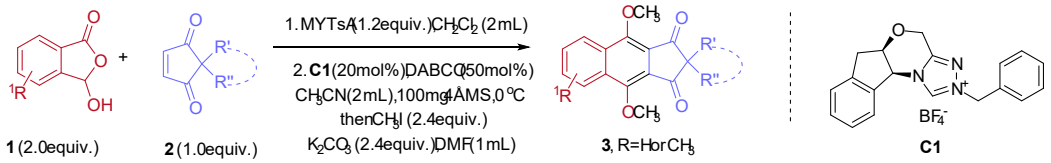
Procedure D:



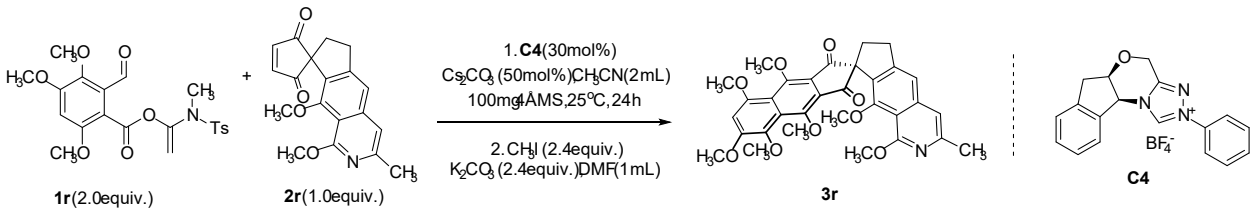
To a stirred solution of **S8** (3.00 g, 11.67 mmol, 1.0 equiv.) in CH_2Cl_2 (25 mL) was added freshly distilled $BF_3{\cdot}Et_2O$ (2.16 mL, 17.50 mmol, 1.5 equiv.) at -78 °C. 5 min later, compound **S3** (6.00 mL, 23.34 mmol, 2.0 equiv.) was added to the reaction mixture and the resulting mixture was stirred at the same temperature for 1 h. The mixture was warmed to ambient temperature for 10 min and stirred overnight. A saturated aqueous solution of $NaHCO_3$ (20 mL) was added to quench the reaction. The organic phase was separated, and the aqueous layer was extracted with CH_2Cl_2 (2 × 25 mL). The combined extracts were washed with brine (50 mL), dried over anhydrous Na_2SO_4, and concentrated under reduced pressure. The residue was purified by flash column chromatography on silica gel eluting with n-hexane/AcOEt (4:1) to afford the diketone **S9** as a yellow solid. To a stirred solution of **S9** (100 mg, 0.308 mmol, 1.0 equiv.) in toluene (3 mL) was sequentially added DDQ (167.8 mg, 0.739 mmol, 2.4 equiv.) and *p*-TsOH (29.3 mg, 0.154 mmol, 0.5 equiv.). The resulting mixture was stirred at 90 °C for 5 h. After cooling to rt, saturated aq. $NaHCO_3$ (2 mL) was added to the mixture. The organic phase was separated, and the aqueous layer was extracted with EtOAc (3 × 2 mL). The combined extracts were washed with brine (5 mL), dried over anhydrous Na_2SO_4, and

concentrated under reduced pressure. The residue was purified by flash column chromatography on silica gel eluting with n-hexane/AcOEt (4:1) to afford the diketone **2r** as a light yellow solid.[7]

3. General procedure for hydroquinone formation towards FDM-A analogs



Under nitrogen atmosphere, a 5 mL round-bottomed flask was charged with MYTsA (50.3 mg, 0.24 mmol, 1.2 equiv.), CH_2Cl_2 (1 mL) and **1** (0.2 mmol, 2.0 equiv.). The reaction mixture was stirred at room temperature until **1** was fully consumed and concentrated under reduced pressure. Next, **2** (0.1 mmol, 1.0 equiv.), **C1** (7.8 mg, 20 mol%), 4Å MS (100 mg), DABCO (5.6 mg, 50 mol%), and CH_3CN (2 mL) were added into the 5 mL round-bottomed, the mixture was stirred at 0 °C for about 24 h. AcOEt (20 mL) was added to the mixture after completion of the reaction monitored. The organic phase was separated, and the aqueous layer was extracted with AcOEt (2 × 10 mL). The combined extracts were washed with brine (20 mL), dried over anhydrous Na_2SO_4, and concentrated under reduced pressure. The residue was directly exposed to the next reaction without further purification. To the residue mentioned above in DMF (1 mL) was added K_2CO_3 (33.2 mg, 0.24 mmol, 2.4 equiv.) and CH_3I (14.9 μL, 0.24 mmol, 2.4 equiv.). The resulting mixture was stirred overnight at room temperature, a saturated aqueous solution of NH_4Cl (10 mL) and AcOEt (10 mL) were added to the mixture. The organic phase was separated and the aqueous layer was extracted with AcOEt (2 × 10 mL). The combined extracts were washed with brine (20 mL), dried over anhydrous Na_2SO_4 and concentrated under reduced pressure. The residue was purified by flash column chromatography on silica gel to afford **3**.

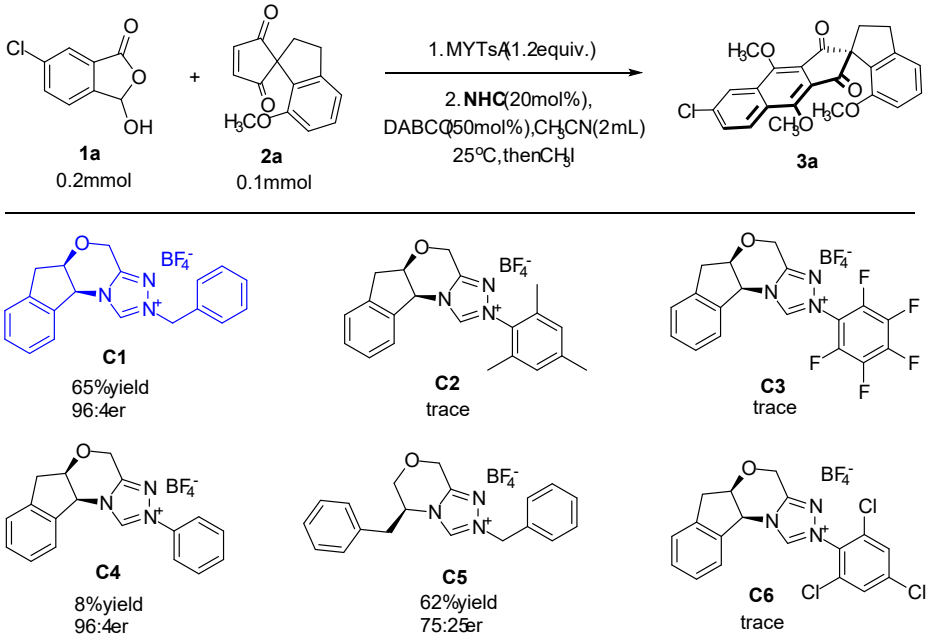


Under nitrogen atmosphere, **1r** (89.8 mg, 0.20 mmol, 2.0 equiv.), **2r** (32.3 mg, 0.10 mmol, 1.0 equiv.), **C4** (11.3 mg, 30 mol%), Cs_2CO_3 (16.3 mg, 50 mol%), 4Å MS (100 mg), and CH_3CN (2 mL) were added into the 5 mL round-bottomed, the mixture was stirred at 25 °C. AcOEt (20 mL) was

added to the mixture after completion of the reaction monitored. The organic phase was separated and the aqueous layer was extracted with AcOEt (2 × 10 mL). The combined extracts were washed with brine (20 mL), dried over anhydrous Na_2SO_4, and concentrated under reduced pressure. The residue was directly exposed to the next reaction without further purification. To the residue mentioned above in DMF (1 mL) was added K_2CO_3 (33.2 mg, 0.24 mmol, 2.4 equiv.) and CH_3I (14.9 μL, 0.24 mmol, 2.4 equiv.). The resulting mixture was stirred overnight at room temperature, a saturated aqueous solution of NH_4Cl (10 mL) and AcOEt (10 mL) were added to the mixture. The organic phase was separated and the aqueous layer was extracted with AcOEt (2 × 10 mL). The combined extracts were washed with brine (20 mL), dried over anhydrous Na_2SO_4 and concentrated under reduced pressure. The residue was purified by flash column chromatography on silica gel to afford **3r** as a yellow solid.

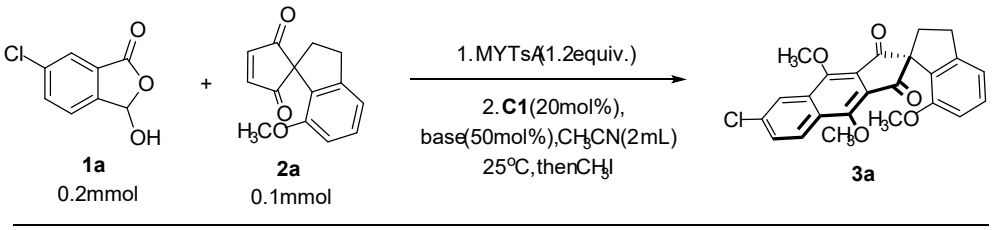
4. Details of the optimization of reaction conditions

Table S1. Screening of catalysts.



Result showed that the small steric hindrance of *N*-substituents in the NHC catalyst is essential in our reaction. The chiral *N*-benzyl triazolium **C4** or **C5** precatalysts can give the desired H-K annulation product **3a**. The **C1** gave the best results.

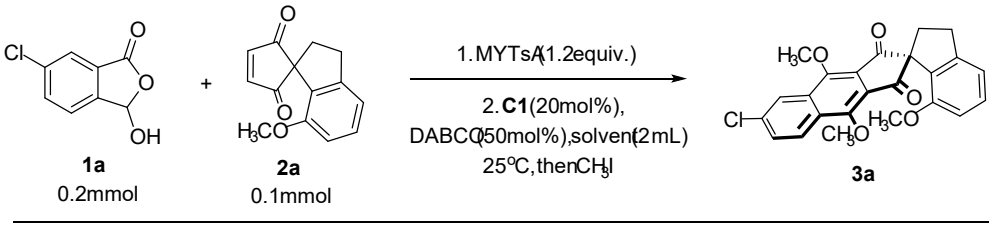
Table S2. Screening of bases.



Entry	Base	Yield	er
1	DABCO	65 %	96:4
2	DBU	58 %	93:7
3	NEt_3	24 %	91:9
4	*t*-BuOK	trace	—
5	Cs_2CO_3	63 %	95:5
6	NaOAc	trace	—

Choosing CH_3CN as the solvent, different bases were screened. Such as DBU and Cs_2CO_3 (these bases widely used in NHC organocatalysis) all gave products with decreased enantioselectivities. DABCO showed the best results.

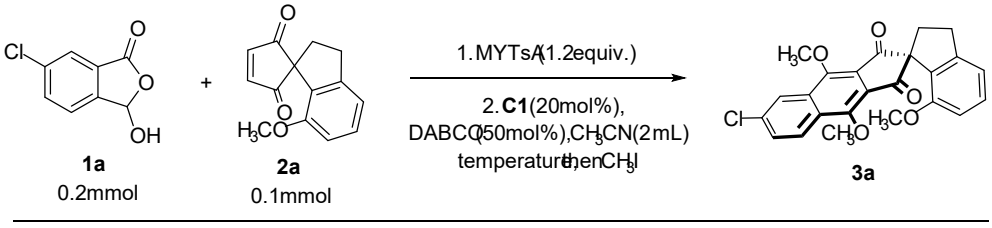
Table S3. Screening of solvents.



Entry	Solvent	Yield	er
1	CH_3CN	65 %	96:4
2	DMF	trace	—
3	CH_2Cl_2	54 %	91:9
4	$PhCH_3$	trace	—
5	THF	trace	—
6	EtOAc	trace	—

The reaction performed in CH_2Cl_2 furnished the product with a slightly reduced yield and enantioselectivity. CH_3CN showed the best results.

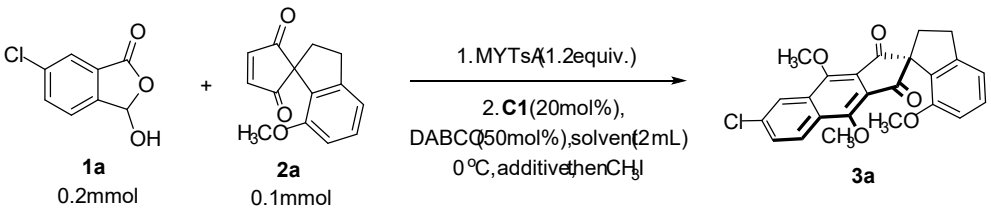
Table S4. Screening of temperature.



Entry	Temperature	Yield	er
1	-10 °C	31 %	97:3
2	0 °C	64 %	97:3
3	25 °C	65 %	96:4

Choosing CH_3CN and DABCO as solvent and base, decreased temperature to 0 °C slightly increased enantioselectivity.

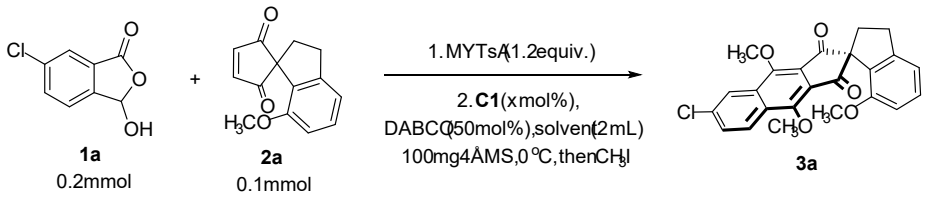
Table S5. Screening of additives.



Entry	Additive	Yield	er
1	no	64 %	97:3
2	4Å MS (100 mg)	73 %	97:3
3	$Sc(OTf)_3$ (0.02 mmol)	42 %	97:3

Choosing CH_3CN and DABCO as solvent and base, 4Å MS and $Sc(OTf)_3$ as additives were screened. The addition of 4Å MS further improved the yield to 73%.

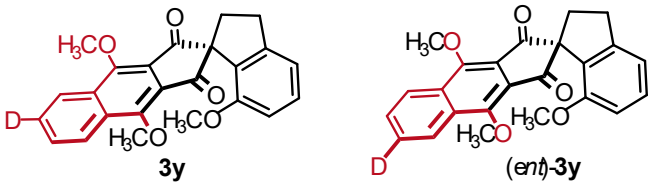
Table S6. Screening of the catalyst loading.



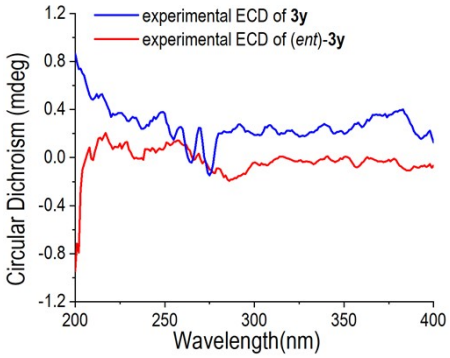
Entry	C1	Yield	er
1	0	0	—
2	5 mol %	11 %	—
3	10 mol %	45 %	97:3
4	20 mol %	73 %	97:3
5	30 mol %	82 %	97:3

Increased catalyst loading leads to obviously higher yield and the same er value. We selected 20 mol% as the optimal catalyst loading, under which the reaction gave the desired product in 73% yield with 97:3 er.

5. The ECD and OR of 3y and (*ent*)-3y



We tried a variety of chiral columns (Chiralpak AD-3, OX-3, OD-3, IC-3, ID; Trefoil CEL1, CEL2, AMY1; Viridis BEH-2EP; EnantioPak Y1, Y2, Y3, Y4, Y5, Y1-R, Y2-R, Y3-R, Y4-R, Y5-R, R-A, R-B, R-C, SACP, SCDP, SDMP, MCDP, MDMP, BAS), probably due to the differences between hydrogen and deuterium is too slight, the racemic of **3y** cannot be separated by chiral SFC.



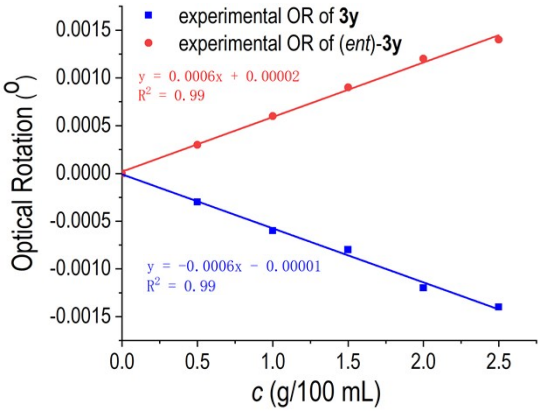
The experimental ECD spectra of the two enantiomers have been measured, no obvious signal can be observed in the ECD spectra of the two enantiomers.

Preparation of standard solutions of **3y** and (*ent*)-**3y** at various concentrations (0.5, 1.0, 1.5, 2.0, and 2.5 g/100 mL) was conducted using a 1.0 mL volumetric flask. A syringe was used to draw approximately 300 μL of each standard solution into sample cells with a 10 mm path length. The optical rotation of **3y** and its enantiomer was measured at a wavelength of 589 nm and a temperature of 25 °C. Each experiment was performed in duplicate.

Table S7. The optical rotation of **3y** and (*ent*)-**3y**

Entry	*C* (g/100 mL)	Optical rotation of **3y** (°)	Optical rotation of (*ent*)-**3y** (°)
1	0	0	0
2	0.5	-0.0003	0.0003
3	1.0	-0.0006	0.0006
4	1.5	-0.0008	0.0009

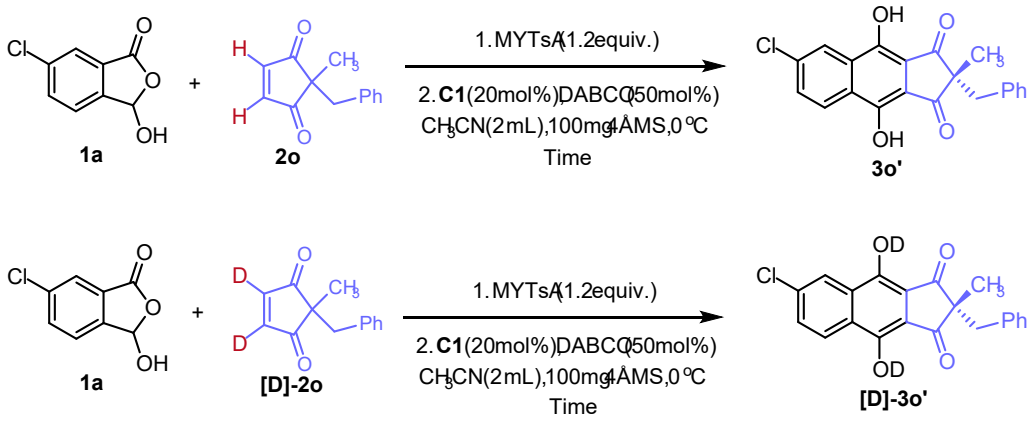
5	2.0	-0.0012	0.0012
6	2.5	-0.0014	0.0014



The optical rotation of **3y** and its enantiomer were measured in different concentrations, and the linear relationship is good ($R^2 > 0.99$), showing a reliable specific rotation with 0.6.

6. Mechanism studies

6.1 the parallel KIE experiment



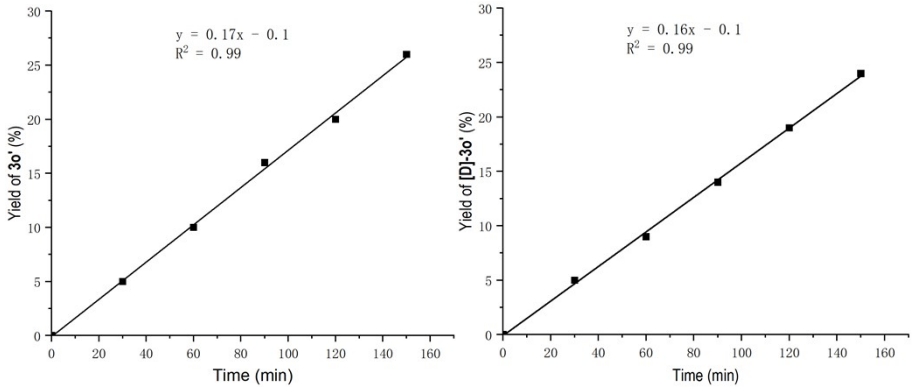
Scheme S1. The parallel KIE experiment of 1,3-cyclopentenediones

Individual reactions of **2o** and **[D]-2o** with **1a** were performed side by side according to the standard conditions in the presence of 1,3,5-trimethoxybenzene as an internal standard for ^{1}H NMR analysis. A KIE value was obtained using the initial rates method, each experiment was conducted in duplicate.

Table S8. The yield of **3o'** and **[D]-3o'**

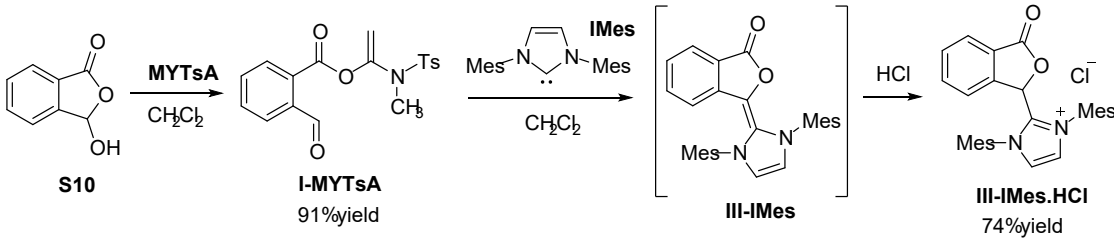
Entry	Time/min	Yield of **3o'** (%)	Yield of **[D]-3o'** (%)

1	0	0	0
2	30	5	5
3	60	10	9
4	90	16	14
5	120	20	19
6	150	26	24



KIE = k_H/k_D = 0.17/0.16 = **1.06**

6.2 synthesis of III-IMes.HCl



A 10 mL round-bottomed flask was charged with **MYTsA** (41.8 mg, 0.2 mmol, 1.0 equiv.), **S10** (48.0 mg, 0.2 mmol, 1.0 equiv.) and CH_2Cl_2 (4 mL). The reaction mixture was stirred at 25 ℃ for about 24 h under N_2. The mixture was concentrated under reduced pressure and purified by silica gel column chromatography to afford the product **I-MYTsA** with 91% yield. Under nitrogen atmosphere, CH_2Cl_2 (1 mL) was added to a mixture of **I-MYTsA** (53.9 mg, 0.15 mmol, 1.5 equiv.) and **IMes** (30.0 mg, 0.1 mmol, 1.0 equiv.), the mixture immediately took on an orange color which became deep red over time and the resulting mixture was stirred for 5 h. HCl (4 M HCl in dioxane, 50 μL, 0.2 mmol, 2.0 equiv.) dissolved in CH_2Cl_2 (1 mL) was added dropwise at 0 ℃ and the mixture was warmed to ambient temperature stirred for 1 h. The solvent removed in vacuo and purified by flash column chromatography on silica gel eluting to afford the **III-IMes.HCl** as a pale yellow solid (34.9 mg, 74% yield).

7. Supplementary references

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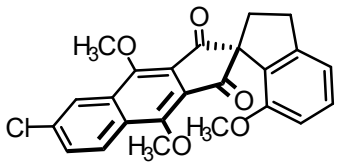
8. Characterization of products

(*R*)-6-chloro-4,7',9-trimethoxy-2',3'-dihydrospiro[cyclopenta[b]naphthalene-2,1'-indene]-1,3-dione (3a)



pale yellow solid; 73% yield, 30.8 mg.

^{1}H NMR (400 MHz, $CDCl_3$) δ 8.48 – 8.36 (m, 2H), 7.67 (d, J = 9.0 Hz, 1H), 7.21 (d, J = 7.9 Hz, 1H), 6.95 (d, J = 7.5 Hz, 1H), 6.58 (d, J = 8.2 Hz, 1H), 4.23 (s, 6H), 3.43 (s, 3H), 3.28 (t, J = 7.3 Hz, 2H), 2.51 (t, J = 7.3 Hz, 2H).

^{13}C NMR (100 MHz, $CDCl_3$) δ 200.3, 200.2, 154.8, 151.1, 150.0 148.3, 136.4, 134.0, 131.4, 130.4, 130.3, 129.9, 126.7, 125.5, 124.7, 123.9, 117.5, 108.4, 66.6, 63.5, 63.4, 55.1, 35.7, 32.58.

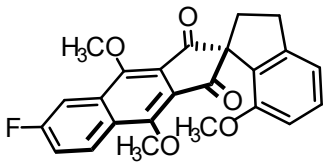
HRMS$^+$ (ESI): calcd for $C_{24}H_{20}ClO_5^+$ $[M+H]^+$ requires 423.0994, found 423.0996.

IR ν_{max} (film, cm^{-1}): 1698, 1603, 1452, 1335, 1265, 1079.

[α]$_D^{25}$ = -5.7 (c = 0.46 in $CHCl_3$).

UPCC: 97:3 er was determined by UPCC (Chiralpak OD-3, CO_2/CH_3OH = 50/50, 0.5 mL/min, detection wavelength: 254 nm), t_R (major) = 6.22 min, t_R(minor) = 6.38 min.

(*R*)-6-fluoro-4,7',9-trimethoxy-2',3'-dihydrospiro[cyclopenta[b]naphthalene-2,1'-indene]-1,3-dione (3b)



pale yellow solid; 70% yield, 28.4 mg.

^{1}H NMR (400 MHz, $CDCl_3$) δ 8.50 (dd, J = 9.3, 5.5 Hz, 1H), 8.06 (dd, J = 9.9, 2.5 Hz, 1H), 7.55 – 7.44 (m, 1H), 7.22 (t, J = 7.8 Hz, 1H), 6.95 (d, J = 7.6 Hz, 1H), 6.58 (d, J = 8.2 Hz, 1H), 4.24 (s, 3H), 4.22 (s, 3H), 3.44 (s, 3H), 3.28 (t, J = 7.3 Hz, 2H), 2.51 (t, J = 7.4 Hz, 2H).

^{13}C NMR (101 MHz, $CDCl_3$) δ 200.6, 200.2, 163.5 (d, J = 252.6 Hz), 155.0, 151.4, 150.3, 148.5, 135.1 (d, J = 9.2 Hz), 130.4, 130.2, 130.0, 128.1 (d, J = 9.1 Hz), 125.7, 124.1, 119.9 (d, J = 25.3 Hz), 117.7, 109.1 (d, J = 23.0 Hz), 108.6, 66.8, 63.6, 63.4, 55.2, 35.9, 32.7.

^{19}F NMR (376 MHz, $CDCl_3$) δ -107.83.

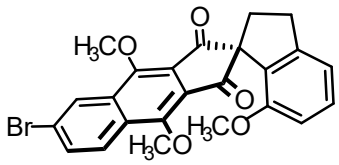
HRMS$^+$ (ESI): calcd for $C_{24}H_{20}FO_5^+$ $[M+H]^+$ requires 407.1289, found 407.1291.

IR ν_{max} (film, cm^{-1}): 1697, 1586, 1475, 1336, 1262, 1037.

$[\alpha]_D^{25}$ = -5.5 (c = 0.33 in $CHCl_3$).

UPCC: 97:3 er was determined by UPCC (Chiralpak CEL-1, CO_2/CH_3OH = 50/50, 0.5 mL/min, detection wavelength: 254 nm), t_R (major) = 7.06 min, t_R(minor) = 7.59 min.

(*R*)-6-bromo-4,7',9-trimethoxy-2',3'-dihydrospiro[cyclopenta[b]naphthalene-2,1'-indene]-1,3-dione (3c)



pale yellow solid; 67% yield, 31.2 mg.

^{1}H NMR (400 MHz, $CDCl_3$) δ 8.62 (d, J = 2.0 Hz, 1H), 8.34 (d, J = 9.0 Hz, 1H), 7.81 (dd, J = 8.9, 1.9 Hz, 1H), 7.22 (t, J = 7.8 Hz, 1H), 6.95 (d, J = 7.5 Hz, 1H), 6.58 (d, J = 8.2 Hz, 1H), 4.23 (s, 3H), 4.22 (s, 3H), 3.43 (s, 3H), 3.28 (t, J = 7.3 Hz, 2H), 2.51 (t, J = 7.3 Hz, 2H).

^{13}C NMR (101 MHz, $CDCl_3$) δ 200.4, 200.3, 154.9, 151.3, 150.0, 148.4, 134.4, 133.1, 131.8, 130.4, 130.0, 127.4, 126.7, 125.6, 125.0, 124.9, 117.7, 108.5, 66.8, 63.6, 55.2, 35.8, 32.7.

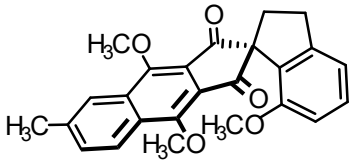
HRMS$^+$ (ESI): calcd for $C_{24}H_{20}BrO_5^+$ $[M+H]^+$ requires 467.0489, found 467.0495.

IR ν_{max} (film, cm^{-1}): 1698, 1586, 1454, 1334, 1262, 1035.

$[\alpha]_D^{25}$ = -5.4 (c = 0.71 in $CHCl_3$).

UPCC: 96:4 er was determined by UPCC (Chiralpak OD-3, CO_2/CH_3OH = 50/50, 0.5 mL/min, detection wavelength: 254 nm), t_R (major) = 7.69 min, t_R(minor) = 8.43 min.

(*R*)-4,7',9-trimethoxy-6-methyl-2',3'-dihydrospiro[cyclopenta[b]naphthalene-2,1'-indene]-1,3-dione (3d)



pale yellow solid; 68% yield, 27.3 mg.

^{1}H NMR (400 MHz, $CDCl_3$) δ 8.38 (d, J = 8.6 Hz, 1H), 8.24 (s, 1H), 7.58 (d, J = 8.6 Hz, 1H), 7.21 (t, J = 7.8 Hz, 1H), 6.94 (d, J = 7.5 Hz, 1H), 6.57 (d, J = 8.2 Hz, 1H), 4.22 (s, 6H), 3.43 (s, 3H), 3.28 (t, J = 7.3 Hz, 2H), 2.62 (s, 3H), 2.51 (t, J = 7.4 Hz, 2H).

^{13}C NMR (100 MHz, $CDCl_3$) δ 200.8, 200.5, 155.0, 151.5, 150.8, 148.5, 140.4, 133.6, 132.0, 131.5, 130.3, 130.2, 125.0, 125.0, 124.0, 124.0, 117.6, 108.6, 66.8, 63.3, 63.3, 55.2, 35.9, 32.7, 22.3.

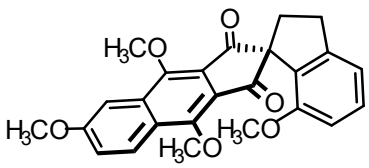
HRMS$^+$ (ESI): calcd for $C_{25}H_{23}O_5^+$ $[M+H]^+$ requires 403.1540, found 403.1542.

IR ν_{max} (film, cm^{-1}): 1695, 1588, 1423, 1348, 1263, 1159.

$[\alpha]_D^{25}$ = -5.1 (c = 0.67 in $CHCl_3$).

UPCC: 96:4 er was determined by UPCC (Chiralpak AD-3, CO_2/CH_3OH = 50/50, 0.5 mL/min, detection wavelength: 254 nm), t_R (major) = 6.27 min, t_R(minor) = 6.73 min.

(*R*)-4,6,7',9-tetramethoxy-2',3'-dihydrospiro[cyclopenta[b]naphthalene-2,1'-indene]-1,3-dione (3e)



pale yellow solid; 64% yield, 26.8 mg.

^{1}H NMR (400 MHz, $CDCl_3$) δ 8.38 (d, J = 9.2 Hz, 1H), 7.72 (d, J = 2.6 Hz, 1H), 7.37 (dd, J = 9.2, 2.6 Hz, 1H), 7.21 (t, J = 7.8 Hz, 1H), 6.94 (d, J = 7.6 Hz, 1H), 6.58 (d, J = 8.1 Hz, 1H), 4.21 (s, 3H),

4.21 (s, 3H), 4.02 (s, 3H), 3.44 (s, 3H), 3.28 (t, *J* = 7.4 Hz, 2H), 2.51 (t, *J* = 7.3 Hz, 2H).

^{13}C NMR (101 MHz, $CDCl_3$) δ 200.9, 200.2, 161.2, 155.1, 151.7, 149.8, 148.5, 135.4, 130.3, 130.2, 128.4, 126.9, 125.6, 123.1, 122.4, 117.6, 108.5, 102.9, 66.8, 63.4, 63.1, 55.9, 55.2, 35.9, 32.7.

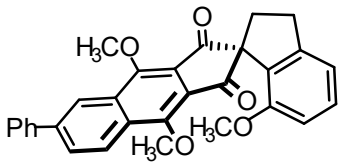
HRMS$^+$ (ESI): calcd for $C_{25}H_{23}O_6^+$ $[M+H]^+$ requires 419.1489, found 419.1491.

IR ν_{max} (film, cm^{-1}): 1696, 1594, 1454, 1350, 1272, 1120.

$[\alpha]_D^{25}$ = -5.9 (c = 0.41 in $CHCl_3$).

UPCC: 96:4 er was determined by UPCC (Chiralpak AD-3, CO_2/CH_3OH = 50/50, 0.5 mL/min, detection wavelength: 254 nm), t_R (major) = 6.89 min, t_R(minor) = 7.27 min.

(*R*)-4,7',9-trimethoxy-6-phenyl-2',3'-dihydrospiro[cyclopenta[b]naphthalene-2,1'-indene]-1,3-dione (3f)



pale yellow solid; 55% yield, 25.5 mg.

^{1}H NMR (400 MHz, $CDCl_3$) δ 8.69 (d, *J* = 1.8 Hz, 1H), 8.58 (d, *J* = 8.7 Hz, 1H), 8.04 (dd, *J* = 8.7, 1.9 Hz, 1H), 7.85 – 7.76 (m, 2H), 7.57 (t, *J* = 7.7 Hz, 2H), 7.53 – 7.44 (m, 1H), 7.25 (t, *J* = 7.8 Hz, 1H), 6.98 (d, *J* = 7.6 Hz, 1H), 6.61 (d, *J* = 8.1 Hz, 1H), 4.28 (s, 6H), 3.47 (s, 3H), 3.32 (t, *J* = 7.3 Hz, 2H), 2.56 (t, *J* = 7.3 Hz, 2H).

^{13}C NMR (101 MHz, $CDCl_3$) δ 200.7, 200.5, 155.0, 151.5, 151.3, 148.5, 142.6, 140.2, 133.8, 132.3, 130.6, 130.2, 129.8, 129.3, 129.3, 128.5, 128.0, 127.8, 125.7, 125.2, 124.7, 122.7, 117.6, 108.6, 66.9, 63.5, 55.2, 35.9, 32.8.

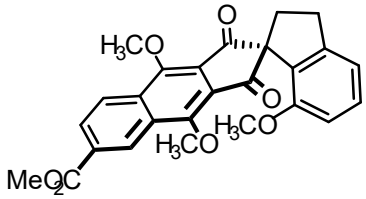
HRMS$^+$ (ESI): calcd for $C_{30}H_{25}O_5^+$ $[M+H]^+$ requires 465.1697, found 465.1700.

IR ν_{max} (film, cm^{-1}): 1696, 1593, 1458, 1350, 1270, 1158.

$[\alpha]_D^{25}$ = -7.4 (c = 0.95 in $CHCl_3$).

UPCC: 96:4 er was determined by UPCC (Chiralpak AD-3-1, CO_2/CH_3OH = 50/50, 0.5 mL/min, detection wavelength: 254 nm), t_R (major) = 6.85 min, t_R(minor) = 6.05 min.

Methyl-(*S*)-4,7',9-trimethoxy-1,3-dioxo-1,2',3,3'-tetrahydrospiro[cyclopenta[b]naphthalene-2,1'-indene]-6-carboxylate (3g)



pale yellow solid; 64% yield, 28.5 mg.

^{1}H NMR (400 MHz, $CDCl_3$) δ 9.17 (d, J = 1.8 Hz, 1H), 8.53 (d, J = 8.8 Hz, 1H), 8.31 (dd, J = 8.8, 1.7 Hz, 1H), 7.23 (t, J = 7.9 Hz, 1H), 6.95 (d, J = 7.5 Hz, 1H), 6.59 (d, J = 8.2 Hz, 1H), 4.28 (s, 3H), 4.24 (s, 3H), 4.04 (s, 3H), 3.44 (s, 3H), 3.29 (t, J = 7.3 Hz, 2H), 2.52 (t, J = 7.4 Hz, 2H).

^{13}C NMR (101 MHz, $CDCl_3$) δ 200.6, 200.2, 166.6, 155.0, 152.2, 150.7, 148.5, 135.4, 132.7, 131.0, 130.5, 130.0, 129.1, 127.7, 126.5, 125.4, 125.1, 117.7, 108.6, 66.8, 63.8, 63.6, 55.2, 52.8, 35.9, 32.7.

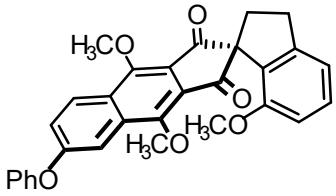
HRMS$^+$ (ESI): calcd for $C_{26}H_{23}O_7^+$ $[M+H]^+$ requires 447.1438, found 447.1443.

IR ν_{max} (film, cm^{-1}): 1703, 1589, 1436, 1344, 1256, 1121.

$[\alpha]_D^{25}$ = +7.4 (c = 0.98 in $CHCl_3$).

UPCC: 97:3 er was determined by UPCC (Chiralpak AD-3, CO_2/CH_3OH = 50/50, 0.5 mL/min, detection wavelength: 254 nm), t_R (major) = 9.07 min, t_R(minor) = 9.95 min.

(*S*)-4,7',9-trimethoxy-6-phenoxy-2',3'-dihydrospiro[cyclopenta[b]naphthalene-2,1'-indene]-1,3-dione (3h)



pale yellow solid; 51% yield, 24.5 mg.

^{1}H NMR (400 MHz, $CDCl_3$) δ 8.46 (d, J = 9.1 Hz, 1H), 7.86 (d, J = 2.5 Hz, 1H), 7.53 – 7.39 (m, 3H), 7.26 – 7.17 (m, 2H), 7.14 (d, J = 8.0 Hz, 2H), 6.94 (d, J = 7.5 Hz, 1H), 6.58 (d, J = 8.2 Hz, 1H), 4.23 (s, 3H), 4.12 (s, 3H), 3.45 (s, 3H), 3.27 (t, J = 7.3 Hz, 2H), 2.50 (t, J = 7.3 Hz, 2H).

^{13}C NMR (101 MHz, $CDCl_3$) δ 200.9, 200.1, 159.2, 155.9, 154.9, 151.4, 150.0, 148.4, 135.1, 130.2, 130.2, 130.0, 129.7, 129.3, 127.4, 127.3, 125.4, 124.6, 122.7, 119.9, 117.5, 110.3, 108.5, 66.7, 63.4, 63.1, 55.1, 35.8, 32.6.

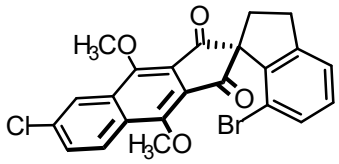
HRMS$^+$ (ESI): calcd for $C_{30}H_{25}O_6^+$ $[M+H]^+$ requires 481.1646, found 481.1650.

IR ν_{max} (film, cm^{-1}): 1698, 1588, 1487, 1337, 1267.

$[\alpha]_D^{25}$ = +7.9 (c = 0.94 in $CHCl_3$).

UPCC: 96:4 er was determined by UPCC (Chiralpak OD-3, CO_2/CH_3OH = 50/50, 0.5 mL/min, detection wavelength: 254 nm), t_R (major) = 6.94 min, t_R(minor) = 6.46 min.

(*R*)-7'-bromo-6-chloro-4,9-dimethoxy-2',3'-dihydrospiro[cyclopenta[b]naphthalene-2,1'-indene]-1,3-dione (3i)



pale yellow solid; 78% yield, 36.7 mg.

^{1}H NMR (400 MHz, $CDCl_3$) δ 8.43 – 8.33 (m, 2H), 7.63 (dd, J = 9.0, 2.1 Hz, 1H), 7.22 (dd, J = 10.9, 2.7 Hz, 2H), 7.11 (t, J = 7.7 Hz, 1H), 4.21 (s, 6H), 3.26 (t, J = 7.4 Hz, 2H), 2.47 (t, J = 7.4 Hz, 2H).

^{13}C NMR (101 MHz, $CDCl_3$) δ 198.9, 198.7, 151.7, 150.6, 149.6, 141.9, 136.9, 134.3, 131.7, 130.9, 130.6, 130.5, 126.9, 125.7, 124.9, 124.2, 124.1, 119.1, 69.7, 63.7, 63.7, 36.9, 32.6.

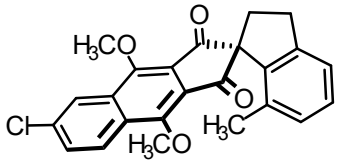
HRMS$^+$ (ESI): calcd for $C_{23}H_{17}BrClO_4^+$ $[M+H]^+$ requires 470.9993, found 470.9998.

IR ν_{max} (film, cm^{-1}): 1698, 1446, 1336, 1190, 1036.

$[\alpha]_D^{25}$ = -7.3 (c = 0.98 in $CHCl_3$).

UPCC: 98:2 er was determined by UPCC (Chiralpak OD-3, CO_2/CH_3OH = 50/50, 0.5 mL/min, detection wavelength: 254 nm), t_R (major) = 7.56 min, t_R(minor) = 8.00 min.

(*R*)-6-chloro-4,9-dimethoxy-7'-methyl-2',3'-dihydrospiro[cyclopenta[b]naphthalene-2,1'-indene]-1,3-dione (3j)



pale yellow solid; 66% yield, 26.8 mg.

^{1}H NMR (600 MHz, $CDCl_3$) δ 8.47 – 8.40 (m, 2H), 7.70 (dd, J = 8.9, 2.1 Hz, 1H), 7.21 – 7.16 (m, 2H), 6.93 (dd, J = 5.8, 2.8 Hz, 1H), 4.25 (s, 6H), 3.25 (t, J = 7.3 Hz, 2H), 2.51 (t, J = 7.3 Hz, 2H), 1.89 (s, 3H).

^{13}C NMR (100 MHz, $CDCl_3$) δ 200.1, 200.0, 151.7, 150.6, 147.1, 140.1, 137.0, 134.4, 133.6, 131.8,

131.0, 129.0, 128.6, 126.9, 125.1, 124.2, 124.2, 122.7, 69.0, 63.7, 63.7, 37.8, 32.1, 20.4.

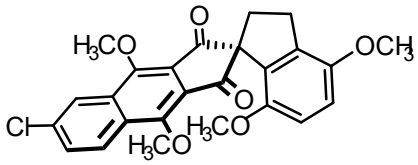
HRMS^{+} (ESI): calcd for $C_{24}H_{20}ClO_4^{+}$ $[M+H]^{+}$ requires 407.1045, found 407.1048.

IR ν_{max} (film, cm^{-1}): 1696, 1604, 1459, 1345, 1035.

$[\alpha]_D^{25}$ = -5.7 (c = 0.91 in $CHCl_3$).

UPCC: 97:3 er was determined by UPCC (Chiralpak CEL-1, CO_2/CH_3OH = 50/50, 0.5 mL/min, detection wavelength: 254 nm), t_R (major) = 7.55 min, t_R(minor) = 7.78 min.

(*R*)-6-chloro-4,4',7',9-tetramethoxy-2',3'-dihydrospiro[cyclopenta[b]naphthalene-2,1'-indene]-1,3-dione (3k)



pale yellow solid; 82% yield, 37.1 mg.

^{1}H NMR (400 MHz, $CDCl_3$) δ 8.50 – 8.36 (m, 2H), 7.67 (dd, *J* = 9.0, 2.1 Hz, 1H), 6.70 (d, *J* = 8.7 Hz, 1H), 6.53 (d, *J* = 8.7 Hz, 1H), 4.22 (s, 6H), 3.81 (s, 3H), 3.38 (s, 3H), 3.22 (t, *J* = 7.3 Hz, 2H), 2.51 (t, *J* = 7.3 Hz, 2H).

^{13}C NMR (101 MHz, $CDCl_3$) *δ* 200.2, 200.0, 151.3, 150.7, 150.1, 149.1, 136.6, 136.3, 134.2, 131.6, 131.5, 130.6, 126.8, 125.7, 124.8, 124.1, 111.3, 109.4, 67.3, 63.6, 63.6, 55.9, 55.6, 35.7, 29.8.

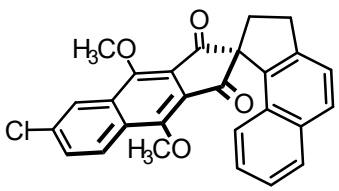
HRMS^{+} (ESI): calcd for $C_{25}H_{22}ClO_6^{+}$ $[M+H]^{+}$ requires 453.1099, found 453.1103.

IR ν_{max} (film, cm^{-1}): 1697, 1597, 1347, 1254, 1088.

$[\alpha]_D^{25}$ = -6.8 (c = 0.93 in $CHCl_3$).

UPCC: 96:4 er was determined by UPCC (Chiralpak CEL-1, CO_2/CH_3OH = 50/50, 0.5 mL/min, detection wavelength: 254 nm), t_R (major) = 6.81 min, t_R(minor) = 7.04 min.

(*R*)-6'-chloro-4',9'-dimethoxy-2,3-dihydrospiro[cyclopenta[a]naphthalene-1,2'-cyclopenta[b]naphthalene]-1',3'-dione (3l)



pale yellow solid; 71% yield, 31.4 mg.

^{1}H NMR (400 MHz, $CDCl_3$) δ 8.48 (d, J = 13.4 Hz, 2H), 7.83 (t, J = 8.5 Hz, 2H), 7.73 (dd, J = 9.0, 2.1 Hz, 1H), 7.50 (d, J = 8.4 Hz, 1H), 7.31 (t, J = 8.1 Hz, 1H), 7.16 (t, J = 8.3 Hz, 1H), 7.02 (d, J = 8.4 Hz, 1H), 4.26 (s, 6H), 3.44 (t, J = 7.3 Hz, 2H), 2.68 (t, J = 7.3 Hz, 2H).

^{13}C NMR (101 MHz, $CDCl_3$) δ 200.4, 200.2, 152.1, 151.0, 145.9, 137.1, 136.2, 134.5, 133.6, 131.9, 131.1, 129.9, 129.5, 129.4, 127.0, 126.9, 125.0, 124.8, 124.3, 123.9, 123.3, 123.3, 69.3, 63.9, 37.8, 33.0

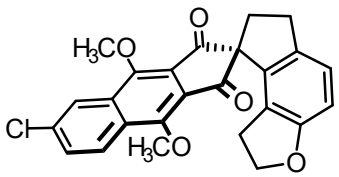
HRMS$^+$ (ESI): calcd for $C_{27}H_{20}ClO_4^+$ $[M+H]^+$ requires 443.1045, found 443.1049.

IR ν_{max} (film, cm^{-1}): 1697, 1334, 1256, 1160.

$[\alpha]_D^{25}$ = -4.8 (c = 0.99 in $CHCl_3$).

UPCC: 92:8 er was determined by UPCC (Chiralpak CEL-1, CO_2/CH_3OH = 50/50, 0.5 mL/min, detection wavelength: 254 nm), t_R (major) = 8.38 min, t_R(minor) = 8.84 min.

(*R*)-6-chloro-4,9-dimethoxy-1',2',6',7'-tetrahydrospiro[cyclopenta[b]naphthalene-2,8'-indeno[5,4-b]furan]-1,3-dione (3m)



pale yellow solid; 74% yield, 32.1 mg.

^{1}H NMR (400 MHz, $CDCl_3$) δ 8.51 – 8.35 (m, 2H), 7.70 (d, J = 9.0 Hz, 1H), 7.08 (d, J = 8.1 Hz, 1H), 6.68 (d, J = 8.1 Hz, 1H), 4.32 (t, J = 8.7 Hz, 2H), 4.25 (s, 6H), 3.23 (t, J = 7.3 Hz, 2H), 2.59 (t, J = 7.3 Hz, 2H), 2.53 (t, J = 8.6 Hz, 2H).

^{13}C NMR (101 MHz, $CDCl_3$) δ 199.2, 199.0, 159.8, 151.6, 150.5, 138.2, 138.1, 137.2, 134.3, 131.7, 131.1, 126.9, 125.4, 124.5, 124.3, 124.2, 121.8, 109.6, 70.9, 68.7, 63.8, 63.8, 36.1, 31.6, 28.3.

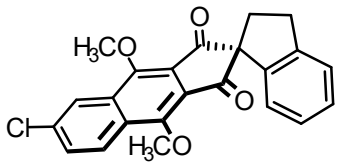
HRMS$^+$ (ESI): calcd for $C_{25}H_{20}ClO_5^+$ $[M+H]^+$ requires 435.0994, found 435.0996.

IR ν_{max} (film, cm^{-1}): 1696, 1457, 1333, 1195, 1034.

$[\alpha]_D^{25}$ = -6.1 (c = 0.83 in $CHCl_3$).

UPCC: 96:4 er was determined by UPCC (Chiralpak CEL-1, CO_2/CH_3OH = 50/50, 0.5 mL/min, detection wavelength: 254 nm), t_R (major) = 7.41 min, t_R(minor) = 7.69 min.

(*R*)-6-chloro-4,9-dimethoxy-2',3'-dihydrospiro[cyclopenta[b]naphthalene-2,1'-indene]-1,3-dione (3n)



pale yellow solid; 77% yield, 30.2 mg.

^{1}H NMR (400 MHz, $CDCl_3$) δ 8.51 – 8.39 (m, 2H), 7.70 (dd, J = 9.0, 2.1 Hz, 1H), 7.34 (d, J = 7.6 Hz, 1H), 7.22 (t, J = 7.5 Hz, 1H), 7.04 (t, J = 7.5 Hz, 1H), 6.69 (d, J = 7.7 Hz, 1H), 4.22 (s, 6H), 3.33 (t, J = 7.5 Hz, 2H), 2.64 (t, J = 7.5 Hz, 2H).

^{13}C NMR (100 MHz, $CDCl_3$) δ 198.5, 198.3, 152.1, 151.0, 145.3, 142.6, 137.0, 134.1, 131.4, 131.0 128.5, 127.0, 126.9, 125.6, 125.3, 124.4, 124.2, 122.6, 69.6, 63.7, 63.7, 32.2, 31.8.

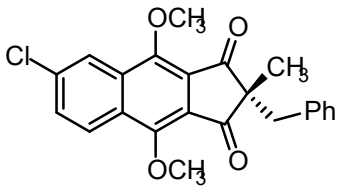
HRMS$^+$ (ESI): calcd for $C_{23}H_{18}ClO_4^+$ $[M]^+$ requires 393.0888, found 393.0888.

IR ν_{max} (film, cm^{-1}): 1693, 1579, 1456, 1341, 1203, 1042.

$[\alpha]_D^{25}$ = -0.7 (c = 0.83 in $CHCl_3$).

UPCC: 56:44 er was determined by UPCC (Chiralpak OX-3, CO_2/CH_3OH = 50/50, 0.5 mL/min, detection wavelength: 254 nm), t_R (major) = 7.00 min, t_R(minor) = 7.24 min.

(*R*)-2-benzyl-6-chloro-4,9-dimethoxy-2-methyl-1H-cyclopenta[b]naphthalene-1,3(2H)-dione (3o)



pale yellow solid; 75% yield, 29.6 mg.

^{1}H NMR (400 MHz, $CDCl_3$) δ 8.60 – 8.16 (m, 2H), 7.59 (dd, J = 8.9, 2.0 Hz, 1H), 7.16 – 6.74 (m, 5H), 4.10 (s, 6H), 3.19 (s, 2H), 1.41 (s, 3H).

^{13}C NMR (101 MHz, $CDCl_3$) δ 201.8, 201.6, 151.1, 145.0, 136.6, 136.1, 133.9, 131.3, 130.6, 129.8, 128.1, 126.9, 126.6, 125.1, 124.3, 123.9, 63.3, 63.3, 57.5, 42.5, 20.9.

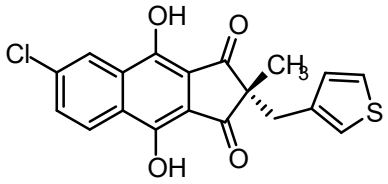
HRMS$^+$ (ESI): calcd for $C_{23}H_{20}ClO_4^+$ $[M]^+$ requires 395.1045, found 395.1046.

IR ν_{max} (film, cm^{-1}): 1698, 1452, 1338, 1200, 1024.

$[\alpha]_D^{25}$ = -3.3 (c = 0.66 in $CHCl_3$).

UPCC: 86:14 er was determined by UPCC (Chiralpak OX-3, CO_2/CH_3OH = 50/50, 0.5 mL/min, detection wavelength: 254 nm), t_R (major) = 4.89 min, t_R(minor) = 5.08 min.

(*R*)-6-chloro-4,9-dihydroxy-2-methyl-2-(thiophen-3-ylmethyl)-1H-cyclopenta[b]naphthalene-1,3(2H)-dione (3p)



yellow solid; 65% yield, 24.2 mg.

^{1}H NMR (400 MHz, $CDCl_3$) δ 8.84 (s, 2H), 8.30 (d, J = 2.1 Hz, 1H), 8.27 (d, J = 8.9 Hz, 1H), 7.64 (dd, J = 8.9, 2.1 Hz, 1H), 6.99 (dd, J = 5.0, 3.0 Hz, 1H), 6.89 (dd, J = 2.9, 1.3 Hz, 1H), 6.74 (dd, J = 5.0, 1.3 Hz, 1H), 3.21 (s, 2H), 1.42 (s, 3H).

^{13}C NMR (100 MHz, $CDCl_3$) δ 206.4, 206.2, 147.7, 146.64, 136.7, 135.9, 130.6, 130.4, 128.8, 127.6, 126.2, 125.7, 123.9, 123.5, 115.1, 114.4, 57.8, 35.6, 20.0.

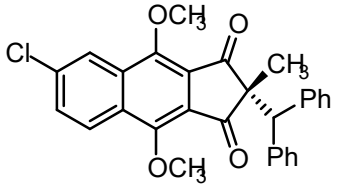
HRMS$^-$ (ESI): calcd for $C_{19}H_{12}ClO_4S^-$ $[M]^-$ requires 371.0150, found 371.0157.

IR ν_{max} (film, cm^{-1}): 3403, 1706, 1508, 1331, 1251, 1014.

$[\alpha]_D^{25}$ = -4.7 (c = 0.78 in $CHCl_3$).

UPCC: 92:8 er was determined by UPCC (Chiralpak AD-3, CO_2/CH_3OH = 50/50, 0.5 mL/min, detection wavelength: 254 nm), t_R (major) = 8.23 min, t_R(minor) = 7.83 min.

(*R*)-2-benzhydryl-6-chloro-4,9-dimethoxy-2-methyl-1H-cyclopenta[b]naphthalene-1,3(2H)-dione (3q)



pale yellow solid; 62% yield, 29.1 mg.

^{1}H NMR (400 MHz, $CDCl_3$) δ 8.37 – 8.24 (m, 2H), 7.61 (dd, J = 9.0, 1.9 Hz, 1H), 7.52 (d, J = 7.6 Hz, 4H), 7.17 (t, J = 7.5 Hz, 4H), 7.09 (d, J = 7.2 Hz, 2H), 4.62 (s, 1H), 4.11 (s, 6H), 1.33 (s, 3H).

^{13}C NMR (100 MHz, $CDCl_3$) δ 202.0, 201.8, 151.3, 150.2, 140.0, 136.7, 134.0, 131.4, 130.7, 130.0, 128.5, 128.4, 127.1, 126.7, 125.2, 124.4, 124.0, 63.3, 63.3, 59.6, 58.7, 20.8.

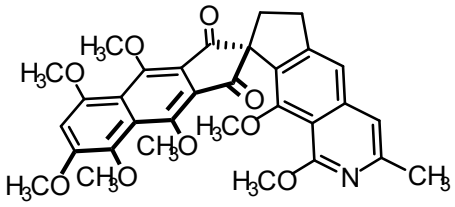
HRMS$^+$ (ESI): calcd for $C_{29}H_{23}ClO_4Na^+$ $[M]^+$ requires 493.1177, found 493.1177.

IR ν_{max} (film, cm^{-1}): 1698, 1451, 1336, 1025.

$[\alpha]_D^{25}$ = -3.6 (c = 0.83 in $CHCl_3$).

UPCC: 87:13 er was determined by UPCC (Chiralpak CEL1, CO_2/CH_3OH = 50/50, 0.5 mL/min, detection wavelength: 254 nm), t_R (major) = 8.06 min, t_R(minor) = 8.68 min.

(*S*)-1',4,5,6,8,9,9'-heptamethoxy-3'-methyl-6',7'-dihydrospiro[cyclopenta[b]naphthalene-2,8'-cyclopenta[g]isoquinoline]-1,3-dione (3r)



yellow solid; 31% yield, 17.8 mg.

^{1}H NMR (400 MHz, $CDCl_3$) δ 7.32 (s, 1H), 6.97 (s, 1H), 6.92 (s, 1H), 4.08 – 4.02 (m, 15H), 3.90 (s, 3H), 3.47 (s, 3H), 3.39 (td, *J* = 7.3, 2.8 Hz, 2H), 2.55 (t, *J* = 7.4 Hz, 2H), 2.50 (s, 3H).

^{13}C NMR (101 MHz, $CDCl_3$) δ 200.5, 199.3, 159.2, 157.0, 154.1, 153.8, 152.8, 151.1, 150.8, 148.2, 143.4, 139.6, 135.0, 131.3, 127.8, 124.7, 121.4, 117.4, 113.4, 111.3, 100.1, 66.4, 63.4, 63.3, 62.7, 62.4, 57.6, 56.8, 54.4, 36.4, 32.6, 23.5.

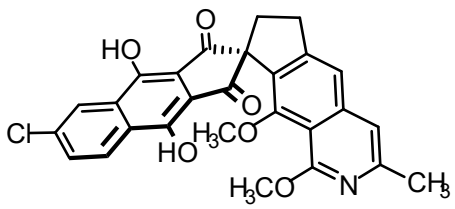
HRMS$^+$ (ESI): calcd for $C_{32}H_{32}NO_9^+$ $[M+H]^+$ requires 574.2072, found 574.2067.

IR ν_{max} (film, cm^{-1}): 1731, 1699, 1569, 1454, 1341, 1035.

$[\alpha]_D^{25}$ = +6.0 (c = 0.47 in $CHCl_3$).

UPCC: 92:8 er was determined by UPCC (Chiralpak CEL-1, CO_2/CH_3OH = 50/50, 0.5 mL/min, detection wavelength: 254 nm), t_R (major) = 7.03 min, t_R(minor) = 7.38 min.

(*R*)-6-chloro-4,9-dihydroxy-1',9'-dimethoxy-3'-methyl-6',7'-dihydrospiro[cyclopenta[b]naphthalene-2,8'-cyclopenta[g]isoquinoline]-1,3-dione (3s)



yellow solid; 53% yield, 25.9 mg.

^{1}H NMR (600 MHz, $CDCl_3$) δ 9.01 (s, 1H), 8.95 (s, 1H), 8.41 (d, *J* = 2.1 Hz, 1H), 8.38 (d, *J* = 8.9 Hz, 1H), 7.71 (dd, *J* = 8.9, 2.0 Hz, 1H), 7.34 (s, 1H), 6.98 (s, 1H), 4.02 (s, 3H), 3.48 (s, 3H), 3.41 (t,

J = 7.4 Hz, 2H), 2.60 (t, *J* = 7.4 Hz, 2H), 2.48 (s, 3H).

^{13}C NMR (151 MHz, $CDCl_3$) δ 204.7, 204.5, 159.0, 152.9, 149.7, 149.5, 148.1, 147.0, 143.6, 136.8, 133.2, 130.7, 130.6, 127.8, 126.3, 124.0, 117.6, 115.4, 114.7, 113.1, 111.2, 66.3, 62.7, 53.8, 35.3, 32.6, 23.9.

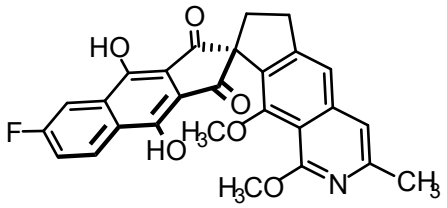
HRMS$^+$ (ESI): calcd for $C_{27}H_{21}ClNO_6^+$ $[M+H]^+$ requires 490.1052, found 490.1043.

IR ν_{max} (film, cm^{-1}): 3383, 1769, 1683, 1571, 1341, 1083, 1010.

$[\alpha]_D^{25}$ = -7.3 (c = 0.83 in $CHCl_3$).

UPCC: 98:2 er was determined by UPCC (Chiralpak CEL-2, CO_2/CH_3OH = 50/50, 0.5 mL/min, detection wavelength: 254 nm), t_R (major) = 11.39 min, t_R(minor) = 10.79 min.

(*R*)-6-fluoro-4,9-dihydroxy-1',9'-dimethoxy-3'-methyl-6',7'-dihydrospiro[cyclopenta[b]naphthalene-2,8'-cyclopenta[g]isoquinoline]-1,3-dione (3t)



yellow solid; 47% yield, 22.2 mg;

^{1}H NMR (400 MHz, $CDCl_3$) δ 8.95 (s, 2H), 8.46 (dd, *J* = 9.1, 5.3 Hz, 1H), 8.04 (d, *J* = 9.5 Hz, 1H), 7.58 – 7.47 (m, 1H), 7.35 (s, 1H), 6.98 (s, 1H), 4.02 (s, 3H), 3.49 (s, 3H), 3.41 (t, *J* = 7.4 Hz, 2H), 2.60 (t, *J* = 7.4 Hz, 2H), 2.48 (s, 3H).

^{13}C NMR (101 MHz, $CDCl_3$) δ 204.8, 204.4, 163.4 (d, *J* = 253.7 Hz), 159.0, 152.9, 149.8, 149.4, 148.3, 147.2, 143.6, 133.2, 131.6 (d, *J* = 9.5 Hz), 130.4, 127.6 (d, *J* = 9.3 Hz), 126.4, 119.8 (d, *J* = 24.8 Hz), 117.6, 115.3, 113.2, 111.2, 109.3 (d, *J* = 23.0 Hz), 66.3, 62.8, 53.9, 35.3, 32.6, 23.9.

^{19}F NMR (565 MHz, CDCl3) δ -106.53.

HRMS$^+$ (ESI): calcd for $C_{27}H_{21}FNO_6^+$ $[M+H]^+$ requires 474.1347, found 474.1347.

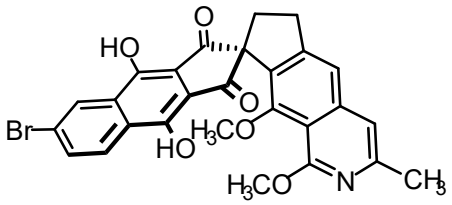
IR ν_{max} (film, cm^{-1}): 3390, 1711, 1679, 1571, 1339, 1098, 1014.

$[\alpha]_D^{25}$ = -7.2 (c = 0.69 in $CHCl_3$).

UPCC: 97:3 er was determined by UPCC (Chiralpak CEL-2, CO_2/CH_3OH = 50/50, 0.5 mL/min, detection wavelength: 254 nm), t_R (major) = 9.08 min, t_R(minor) = 8.75 min.

(*R*)-6-bromo-4,9-dihydroxy-1',9'-dimethoxy-3'-methyl-6',7'-

dihydrospiro[cyclopenta[b]naphthalene-2,8'-cyclopenta[g]isoquinoline]-1,3-dione (3u)



yellow solid; 47% yield, 25.1 mg.

^{1}H NMR (400 MHz, $CDCl_3$) δ 8.98 (s, 2H), 8.60 (s, 1H), 8.30 (d, J = 8.7 Hz, 1H), 7.85 (d, J = 8.8 Hz, 1H), 7.35 (s, 1H), 6.99 (s, 1H), 4.03 (s, 3H), 3.48 (s, 3H), 3.42 (t, J = 7.5 Hz, 2H), 2.60 (t, J = 7.5 Hz, 2H), 2.49 (s, 3H).

^{13}C NMR (101 MHz, $CDCl_3$) δ 204.7, 204.5, 159.1, 152.9, 149.9, 149.2, 148.2, 147.0, 143.7, 133.3, 130.8, 128.1, 127.3, 126.3, 125.2, 117.7, 115.4, 114.8, 113.2, 111.2, 66.3, 62.8, 54.0, 35.3, 32.6, 23.8;

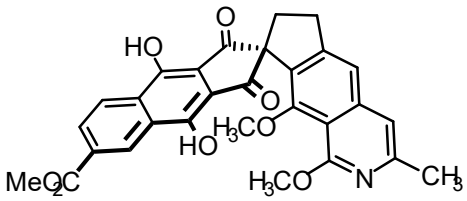
HRMS$^+$ (ESI): calcd for $C_{27}H_{21}BrNO_6^+$ $[M+H]^+$ requires 534.0547, found 534.0538.

IR ν_{max} (film, cm^{-1}): 3383, 1714, 1681, 1571, 1341, 1259, 1091, 1008.

$[\alpha]_D^{25}$ = -7.6 (c = 0.95 in $CHCl_3$).

UPCC: 98:2 er was determined by UPCC (Chiralpak OX-3, CO_2/CH_3OH = 50/50, 0.5 mL/min, detection wavelength: 254 nm), t_R (major) = 12.07 min, t_R(minor) = 11.62 min.

Methyl-(*S*)-4,9-dihydroxy-1',9'-dimethoxy-3'-methyl-1,3-dioxo-1,3,6',7'-tetrahydrospiro[cyclopenta[b]naphthalene-2,8'-cyclopenta[g]isoquinoline]-6-carboxylate (3v)



yellow solid; 50% yield, 25.7 mg.

^{1}H NMR (400 MHz, $CDCl_3$) δ 9.15 (s, 1H), 9.01 (s, 2H), 8.50 (d, J = 8.7 Hz, 1H), 8.35 (dd, J = 8.7, 1.7 Hz, 1H), 7.35 (s, 1H), 6.99 (s, 1H), 4.04 (s, 6H), 3.49 (s, 3H), 3.42 (t, J = 7.4 Hz, 2H), 2.61 (t, J = 7.4 Hz, 2H), 2.50 (s, 3H).

^{13}C NMR (101 MHz, $CDCl_3$) δ 204.8, 204.5, 166.3, 159.0, 152.9, 149.9, 149.3, 148.9, 147.6, 143.7, 133.3, 131.8, 131.1, 129.4, 129.1, 127.1, 125.1, 117.7, 116.1, 115.1, 113.23, 111.2, 66.3, 62.8, 54.1, 52.8, 35.3, 32.6, 23.9.

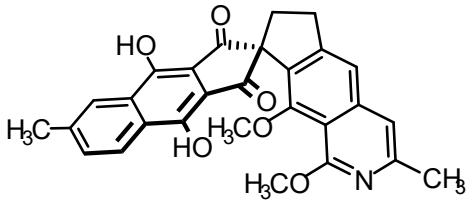
HRMS$^+$ (ESI): calcd for $C_{29}H_{24}NO_8^+$ $[M+H]^+$ requires 514.1496, found 514.1489.

IR ν_{max} (film, cm^{-1}): 3401, 1714, 1679, 1571, 1342, 1011.

$[\alpha]_D^{25}$ = +7.7 (c = 0.74 in $CHCl_3$).

UPCC: 98:2 er was determined by UPCC (Chiralpak OX-3, CO_2/CH_3OH = 50/50, 0.5 mL/min, detection wavelength: 254 nm), t_R (major) = 14.70 min, t_R(minor) = 15.35 min.

(*R*)-4,9-dihydroxy-1',9'-dimethoxy-3',6-dimethyl-6',7'-dihydrospiro[cyclopenta[b]naphthalene-2,8'-cyclopenta[g]isoquinoline]-1,3-dione (3w)



yellow solid; 42% yield, 19.7 mg.

^{1}H NMR (400 MHz, $CDCl_3$) δ 8.99 (s, 2H), 8.34 (d, J = 8.5 Hz, 1H), 8.23 (s, 1H), 7.62 (dd, J = 8.6, 1.7 Hz, 1H), 7.36 (s, 1H), 7.00 (s, 1H), 4.10 (s, 3H), 3.48 (s, 3H), 3.42 (t, J = 7.5 Hz, 2H), 2.63 (s, 3H), 2.60 (t, J = 7.5 Hz, 2H), 2.53 (s, 3H).

^{13}C NMR (101 MHz, $CDCl_3$) δ 204.7, 204.4, 159.2, 153.2, 150.7, 148.6, 148.0, 143.6, 140.9, 133.8, 132.1, 130.0, 127.8, 127.5, 124.6, 124.0, 117.7, 114.5, 113.7, 113.5, 111.3, 66.3, 62.8, 54.9, 35.3, 32.7, 23.5, 22.3.

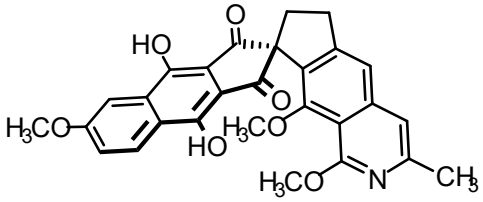
HRMS$^+$ (ESI): calcd for $C_{28}H_{24}NO_6^+$ $[M+H]^+$ requires 470.1598, found 470.1590.

IR ν_{max} (film, cm^{-1}): 3402, 1706, 1674, 1571, 1338, 1258, 1097, 1015.

$[\alpha]_D^{25}$ = -6.1 (c = 0.71 in $CHCl_3$).

UPCC: 98:2 er was determined by UPCC (Chiralpak OX-3, CO_2/CH_3OH = 50/50, 0.5 mL/min, detection wavelength: 254 nm), t_R (major) = 11.12 min, t_R(minor) = 10.74 min.

(*R*)-4,9-dihydroxy-1',6,9'-trimethoxy-3'-methyl-6',7'-dihydrospiro[cyclopenta[b]naphthalene-2,8'-cyclopenta[g]isoquinoline]-1,3-dione (3x)



yellow solid; 44% yield, 21.3 mg.

^{1}H NMR (600 MHz, $CDCl_3$) δ 8.99 (s, 1H), 8.94 (s, 1H), 8.34 (d, J = 9.1 Hz, 1H), 7.69 (d, J = 2.6

Hz, 1H), 7.38 (dd, *J* = 9.1, 2.6 Hz, 1H), 7.35 (s, 1H), 6.98 (s, 1H), 4.04 (s, 3H), 4.02 (s, 3H), 3.48 (s, 3H), 3.41 (td, *J* = 7.6, 3.2 Hz, 2H), 2.60 (t, *J* = 7.4 Hz, 2H), 2.50 (s, 3H).

^{13}C NMR (151 MHz, $CDCl_3$) δ 205.00, 204.0, 161.3, 159.1, 153.0, 150.0, 149.2, 148.8, 147.0, 143.6, 133.4, 131.9, 126.4, 124.3, 122.0, 117.6, 115.1, 113.2, 113.0, 111.3, 103.4, 66.4, 62.8, 55.9, 53.9, 35.3, 32.6, 23.8.

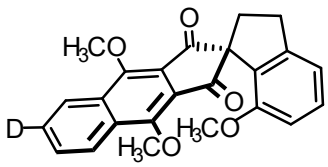
HRMS$^+$ (ESI): calcd for $C_{28}H_{24}NO_7^+$ $[M+H]^+$ requires 486.1547, found 486.1538.

IR ν_{max} (film, cm^{-1}): 3385, 1764, 1709, 1678, 1570, 1340, 1162, 1011.

$[\alpha]_D^{25}$ = -6.0 (c = 0.87 in $CHCl_3$).

UPCC: 99.5:0.5 er was determined by UPCC (Chiralpak CEL-2, CO_2/CH_3OH = 50/50, 0.5 mL/min, detection wavelength: 254 nm), t_R (major) = 10.02 min, t_R(minor) = 9.57 min.

(*R*)-4,7',9-trimethoxy-2',3'-dihydrospiro[cyclopenta[b]naphthalene-2,1'-indene]-1,3-dione-6-d (3y)



pale yellow solid; 65% yield, 25.3 mg.

^{1}H NMR (400 MHz, $CDCl_3$) δ 8.54 – 8.43 (m, 2H), 7.76 (d, *J* = 8.9 Hz, 1H), 7.22 (t, *J* = 7.9 Hz, 1H), 6.95 (d, *J* = 7.5 Hz, 1H), 6.58 (d, *J* = 8.2 Hz, 1H), 4.23 (s, 6H), 3.43 (s, 3H), 3.29 (t, *J* = 7.3 Hz, 2H), 2.52 (t, *J* = 7.4 Hz, 2H).

^{13}C NMR (101 MHz, $CDCl_3$) δ 200.6, 155.0, 151.3, 148.5, 133.4, 130.3, 130.2, 129.7, 129.6, 125.0, 124.9, 124.7, 117.6, 108.6, 66.8, 63.4, 55.2, 35.9, 32.7.

HRMS$^+$ (ESI): calcd for $C_{24}H_{20}O_5D^+$ $[M+H]^+$ requires 390.1446, found 390.1447.

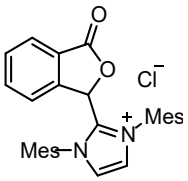
IR ν_{max} (film, cm^{-1}): 1696, 1455, 1342, 1263, 1158.

$[\alpha]_D^{25}$ = -0.6 (c = 0.5–2.5 in $CHCl_3$).

(*ent*)-3y: pale yellow solid; 63% yield, 24.5 mg.

$[\alpha]_D^{25}$ = +0.6 (c = 0.5–2.5 in $CHCl_3$).

1,3-dimesityl-2-(3-oxo-1,3-dihydroisobenzofuran-1-yl)-1H-imidazol-3-ium, chloride (1:1) (III-IMes.HCl)



pale yellow solid; 74% yield, 34.9 mg.

^{1}H NMR (600 MHz, $CDCl_3$) δ 8.48 (s, 2H), 7.76 (dd, J = 7.8, 3.5 Hz, 1H), 7.58 – 7.52 (m, 1H), 7.52 – 7.47 (m, 1H), 7.34 (dd, J = 8.0, 3.4 Hz, 1H), 7.06 (s, 2H), 6.79 (s, 2H), 6.17 (s, 1H), 2.30 (s, 6H), 2.26 (s, 6H), 1.89 (s, 6H).

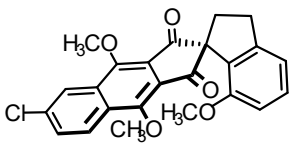
^{13}C NMR (151 MHz, $CDCl_3$) δ 166.4, 142.3, 140.5, 138.5, 135.1, 134.5, 134.0, 131.2, 130.4, 129.8, 128.5, 128.1, 125.9, 124.2, 122.5, 69.4, 21.0, 17.5, 17.5.

HRMS$^+$ (ESI): calcd for $C_{29}H_{29}N_2O_2^+$ $[M]^+$ requires 437.2224, found 437.2221.

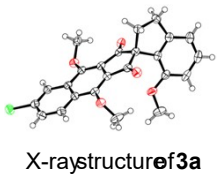
IR ν_{max} (film, cm^{-1}): 3305, 1792, 1601, 1539, 1459, 1379, 1232, 1036.

9. X-ray crystallographic data

Absolute configurations of products were assigned based on the crystal X-ray structures of **3a**. A colorless crystal of **3a** was obtained by vaporization of dichloromethane/n-hexane (2/8) solution. The absolute configuration of **3a** was determined by X-ray to be (*R*). CCDC 2394730 contains the Supplementary X-ray crystallographic data. Crystallographic data (excluding structure factor tables) have been deposited at the Cambridge Crystallographic Data Center as Supplementary publication (Table S9).



3a



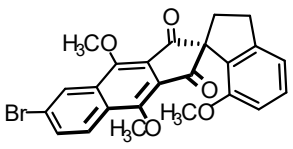
X-raystructureof**3a**
CCDC2394730

Table S9. Crystal data and structure refinement for **3a**.

Identification code	3a
Empirical formula	$C_{24}H_{19}ClO_5$
Formula weight	422.84
Temperature/K	99.9(5)
Crystal system	monoclinic
Space group	$P2_1$
a/Å	13.27670(10)
b/Å	7.84770(10)

c/Å	19.7078(2)
α/°	90
β/°	109.3060(10)
γ/°	90
Volume/Å^3	1937.92(4)
Z	2
ρ_{calc}g/cm^3	1.449
μ/mm^{-1}	2.050
F(000)	880.0
Crystal size/mm^3	0.12 × 0.1 × 0.09
Radiation	Cu Kα (λ = 1.54184)
2Θ range for data collection/°	4.75 to 148.044
Index ranges	-16 ≤ h ≤ 16, -9 ≤ k ≤ 9, -24 ≤ l ≤ 22
Reflections collected	11009
Independent reflections	5987 [R_{int} = 0.0255, R_{sigma} = 0.0371]
Data/restraints/parameters	5987/1/547
Goodness-of-fit on F^2	1.095
Final R indexes [I>=2σ (I)]	R_1 = 0.0297, wR_2 = 0.0814
Final R indexes [all data]	R_1 = 0.0310, wR_2 = 0.0819
Largest diff. peak/hole / e Å^{-3}	0.23/-0.20
Flack parameter	0.042(8)

Absolute configurations of products were assigned based on the crystal X-ray structures of **3c**. A colorless crystal of **3c** was obtained by vaporization of dichloromethane/n-hexane (2/8) solution. The absolute configuration of **3c** was determined by X-ray to be (*R*). CCDC 2394731 contains the Supplementary X-ray crystallographic data. Crystallographic data (excluding structure factor tables) have been deposited at the Cambridge Crystallographic Data Center as Supplementary publication (Table S10).



3c

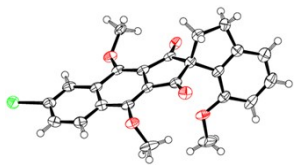
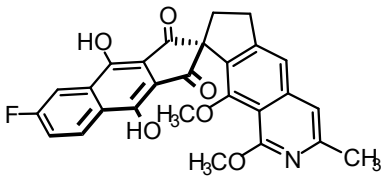

X-raystructureof**3c**
CCDC2394731

Table S10. Crystal data and structure refinement for **3c**.

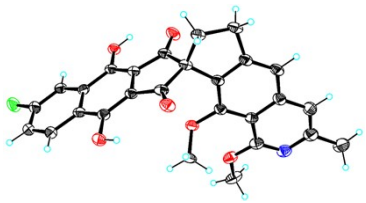
Identification code	3c
Empirical formula	$C_{24}H_{19}BrO_5$

Formula weight	468.30
Temperature/K	100.0(4)
Crystal system	monoclinic
Space group	$P2_1$
a/Å	13.3142(2)
b/Å	7.83960(10)
c/Å	19.8412(3)
α/°	90
β/°	108.449(2)
γ/°	90
Volume/Å^3	1964.55(5)
Z	2
ρ_{calc}g/cm^3	1.580
μ/mm^{-1}	3.154
F(000)	952.0
Crystal size/mm^3	0.25 × 0.1 × 0.08
Radiation	Cu Kα (λ = 1.54184)
2Θ range for data collection/°	4.694 to 147.418
Index ranges	-16 ≤ h ≤ 16, -9 ≤ k ≤ 9, -24 ≤ l ≤ 15
Reflections collected	11123
Independent reflections	6177 [R_{int} = 0.0231, R_{sigma} = 0.0303]
Data/restraints/parameters	6177/1/547
Goodness-of-fit on F^2	1.028
Final R indexes [I>=2σ (I)]	R_1 = 0.0356, wR_2 = 0.0943
Final R indexes [all data]	R_1 = 0.0362, wR_2 = 0.0947
Largest diff. peak/hole / e Å^{-3}	1.17/-0.69
Flack parameter	-0.013(11)

Absolute configurations of products were assigned based on the crystal X-ray structures of **3t**. A colorless crystal of **3t** was obtained by vaporization of acetone/ dichloromethane/n-hexane (2/1/7) solution. The absolute configuration of **3t** was determined by X-ray to be (*R*). CCDC 2294687 contains the Supplementary X-ray crystallographic data. Crystallographic data (excluding structure factor tables) have been deposited at the Cambridge Crystallographic Data Center as Supplementary publication (Table S11).



3t

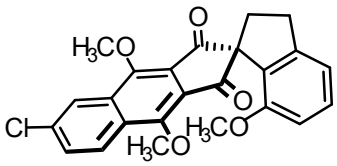


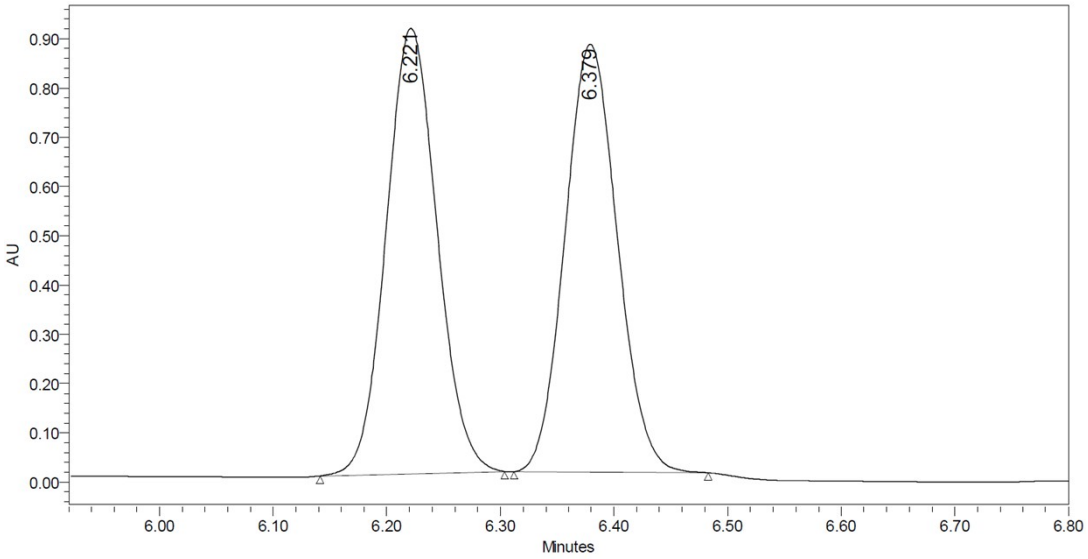
X-ray structure of **3t**
CCDC 2294687

Table S11. Crystal data and structure refinement for **3t**.

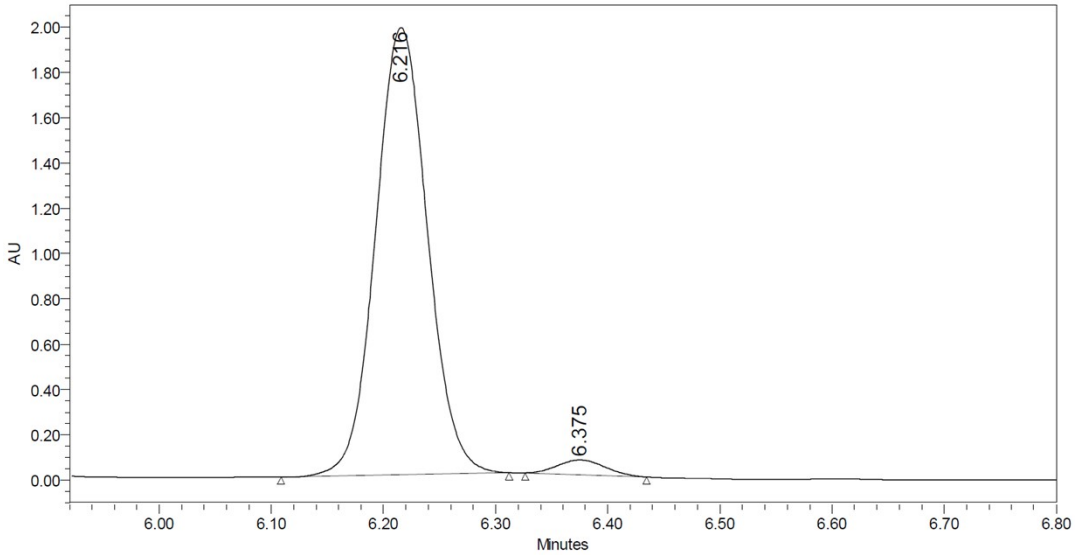
Identification code	3t
Empirical formula	$C_{27}H_{20}FNO_6$
Formula weight	473.44
Temperature/K	100.0(2)
Crystal system	triclinic
Space group	P1
a/Å	7.79410(10)
b/Å	15.0015(2)
c/Å	18.74620(10)
α/°	95.0280(10)
β/°	94.3680(10)
γ/°	92.2160(10)
Volume/Å^3	2174.82(4)
Z	4
ρ_{calc}g/cm^3	1.446
μ/mm^{-1}	0.908
F(000)	984.0
Crystal size/mm^3	0.45 × 0.06 × 0.05
Radiation	Cu Kα (λ = 1.54184)
2Θ range for data collection/°	5.92 to 148.822
Index ranges	-9 ≤ h ≤ 9, -18 ≤ k ≤ 18, -23 ≤ l ≤ 23
Reflections collected	51424
Independent reflections	16487 [R_{int} = 0.0453, R_{sigma} = 0.0431]
Data/restraints/parameters	16487/3/1280
Goodness-of-fit on F^2	1.060
Final R indexes [I>=2σ (I)]	R_1 = 0.0467, wR_2 = 0.1301
Final R indexes [all data]	R_1 = 0.0506, wR_2 = 0.1335
Largest diff. peak/hole / e Å^{-3}	0.77/-0.32
Flack parameter	-0.04(6)

10. Copies of chromatograms for er determination



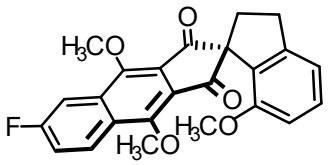


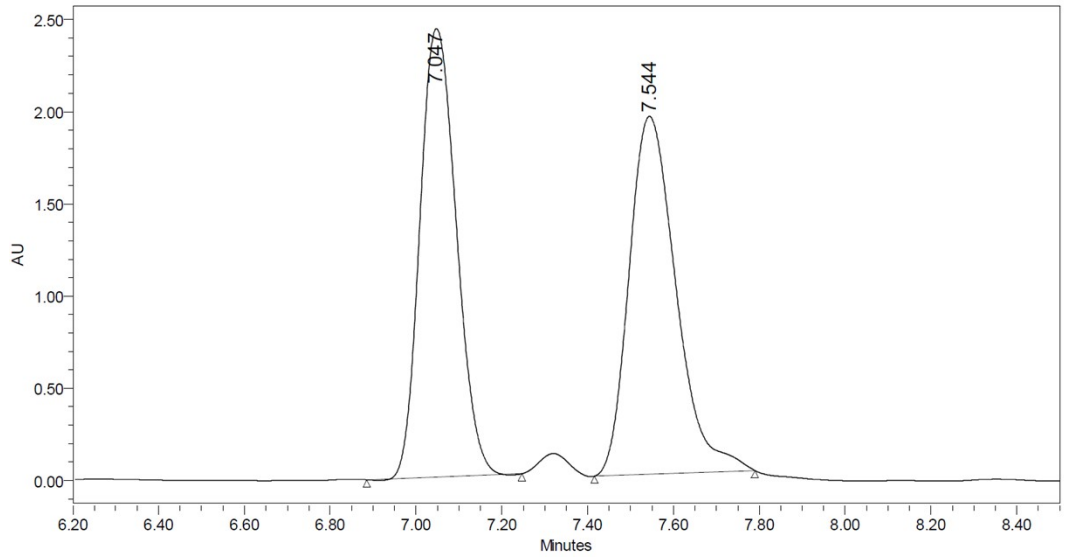
	RT	Area	% Area	Height	% Height
1	6.221	2812894	50.27	904240	51.02
2	6.379	2782162	49.73	868237	48.98



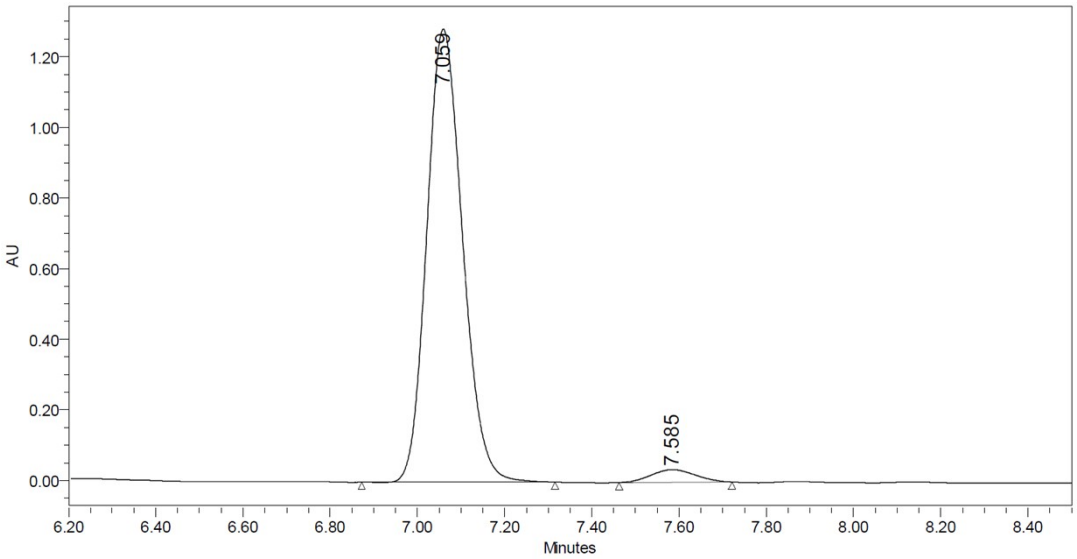
	RT	Area	% Area	Height	% Height
1	6.216	6334905	97.05	1973450	96.80
2	6.375	192713	2.95	65311	3.20

Fig. S1 The chiral SFC spectra of **3a**



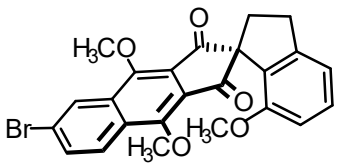


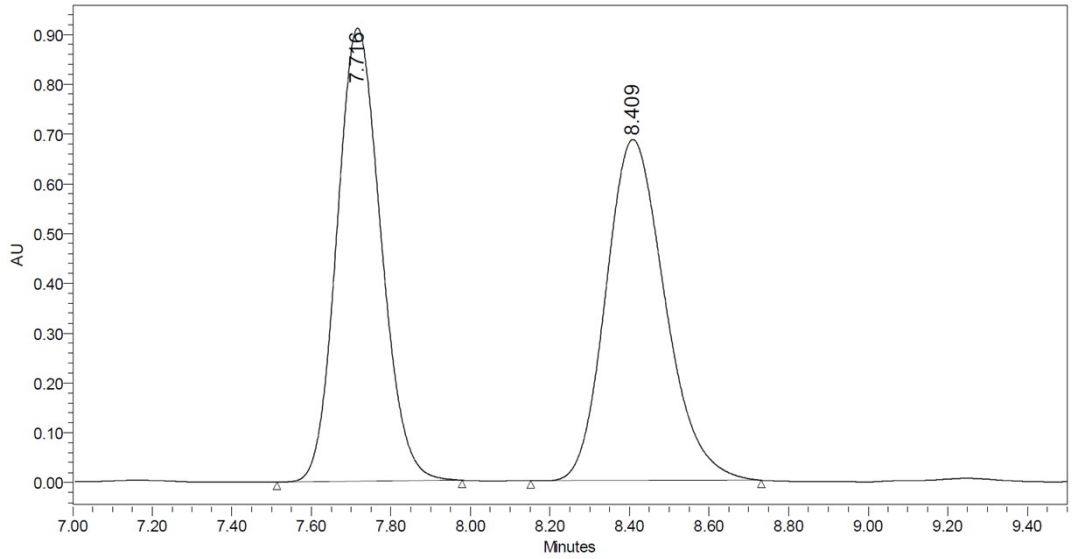
	RT	Area	% Area	Height	% Height
1	7.047	14338173	49.32	2431942	55.61
2	7.544	14730821	50.68	1941284	44.39



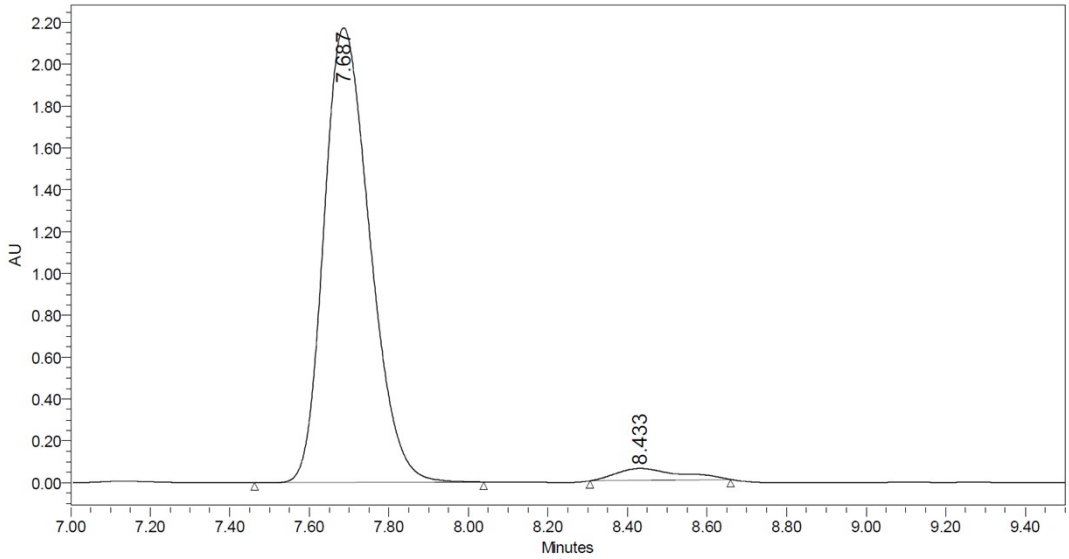
	RT	Area	% Area	Height	% Height
1	7.059	7293664	96.68	1282963	97.30
2	7.585	250096	3.32	35632	2.70

Fig. S2 The chiral SFC spectra of **3b**



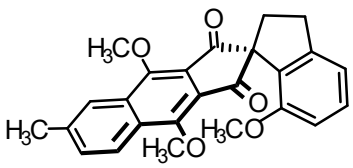


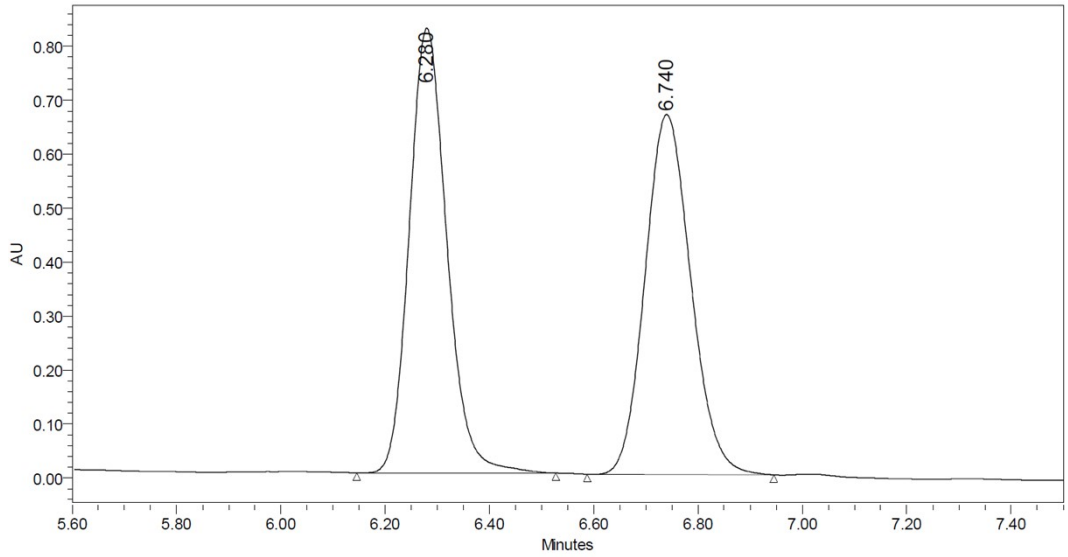
	RT	Area	% Area	Height	% Height
1	7.716	6989438	49.77	910405	57.07
2	8.409	7052730	50.23	684829	42.93



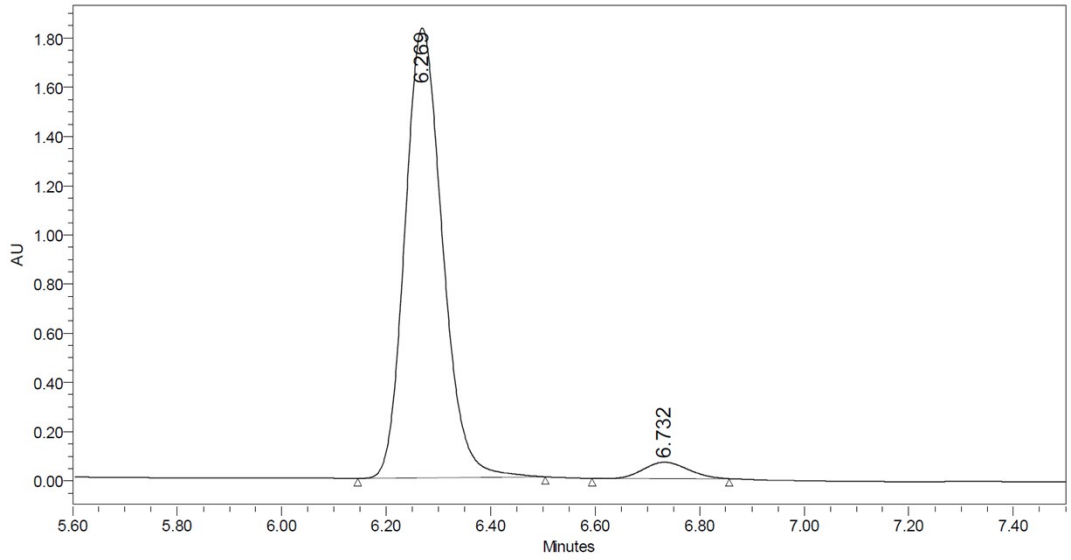
	RT	Area	% Area	Height	% Height
1	7.687	17395466	96.48	2172742	97.47
2	8.433	634067	3.52	56493	2.53

Fig. S3 The chiral SFC spectra of **3c**



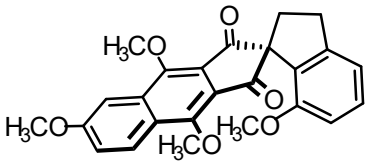


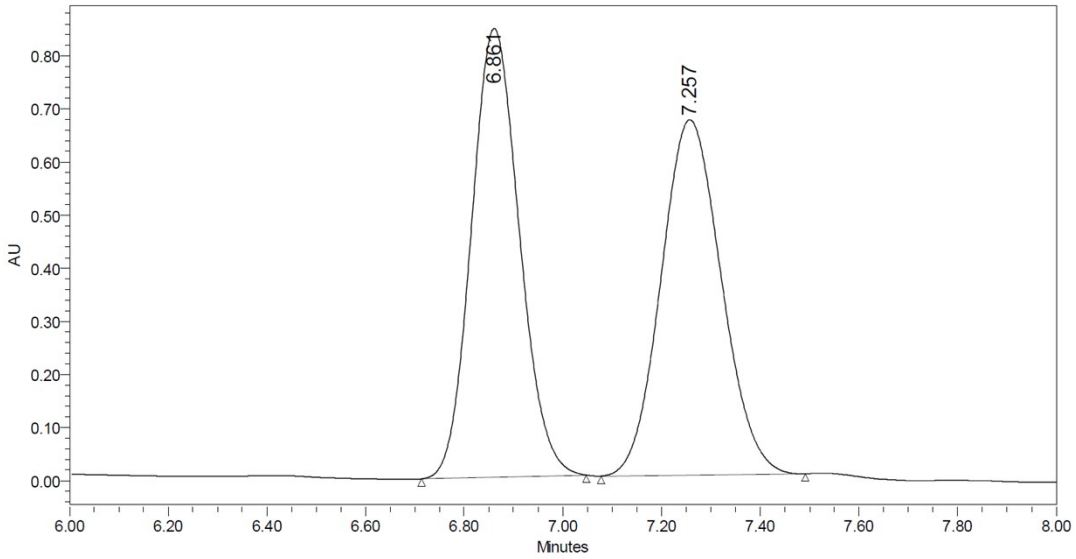
	RT	Area	% Area	Height	% Height
1	6.280	4115115	50.33	824308	55.27
2	6.740	4061252	49.67	667082	44.73



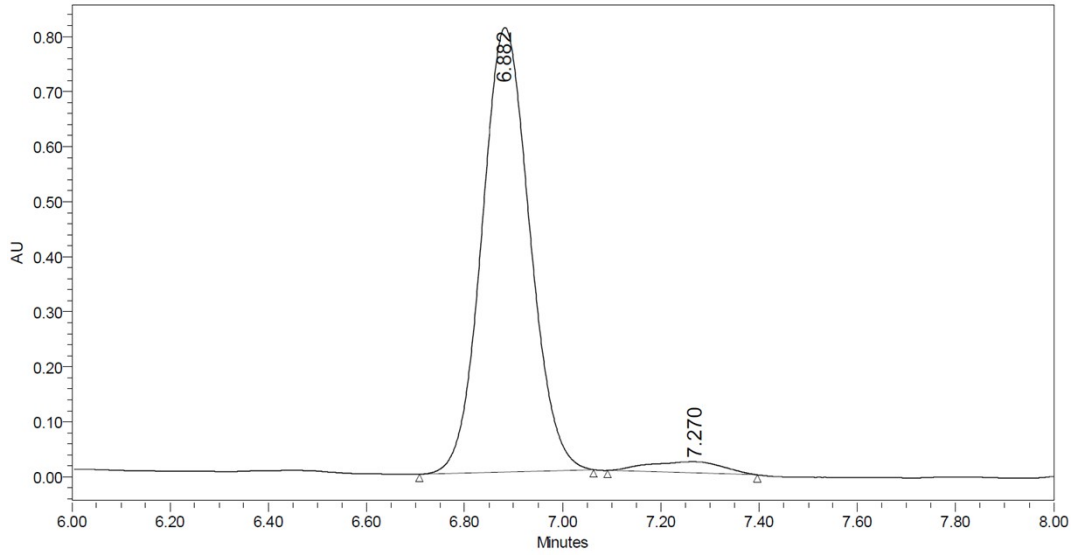
	RT	Area	% Area	Height	% Height
1	6.269	9113273	95.88	1829142	96.50
2	6.732	391610	4.12	66277	3.50

Fig. S4 The chiral SFC spectra of **3d**



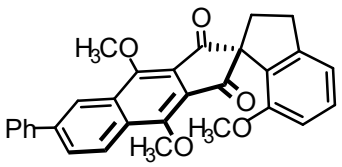


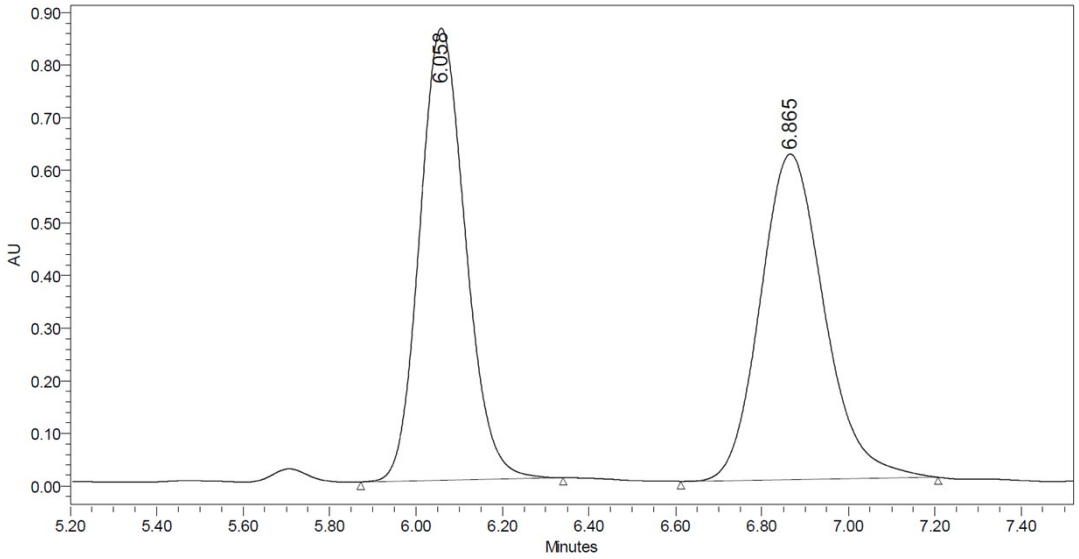
	RT	Area	% Area	Height	% Height
1	6.861	5703736	50.13	844952	55.81
2	7.257	5673895	49.87	668967	44.19



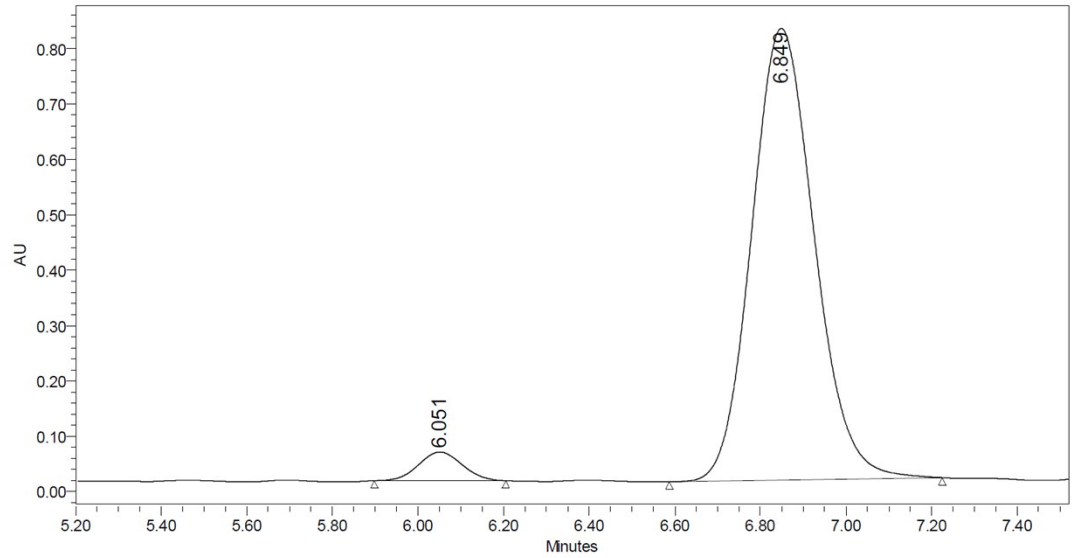
	RT	Area	% Area	Height	% Height
1	6.882	5457684	96.24	808243	97.51
2	7.270	213424	3.76	20618	2.49

Fig. S5 The chiral SFC spectra of **3e**



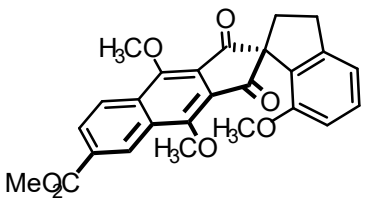


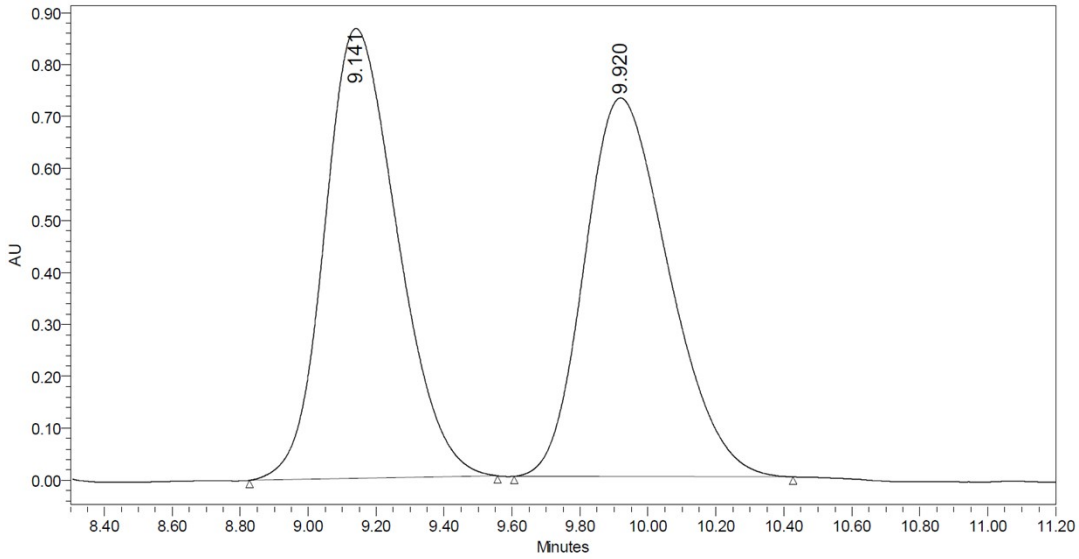
	RT	Area	% Area	Height	% Height
1	6.058	6298003	49.75	859499	58.13
2	6.865	6360668	50.25	618957	41.87



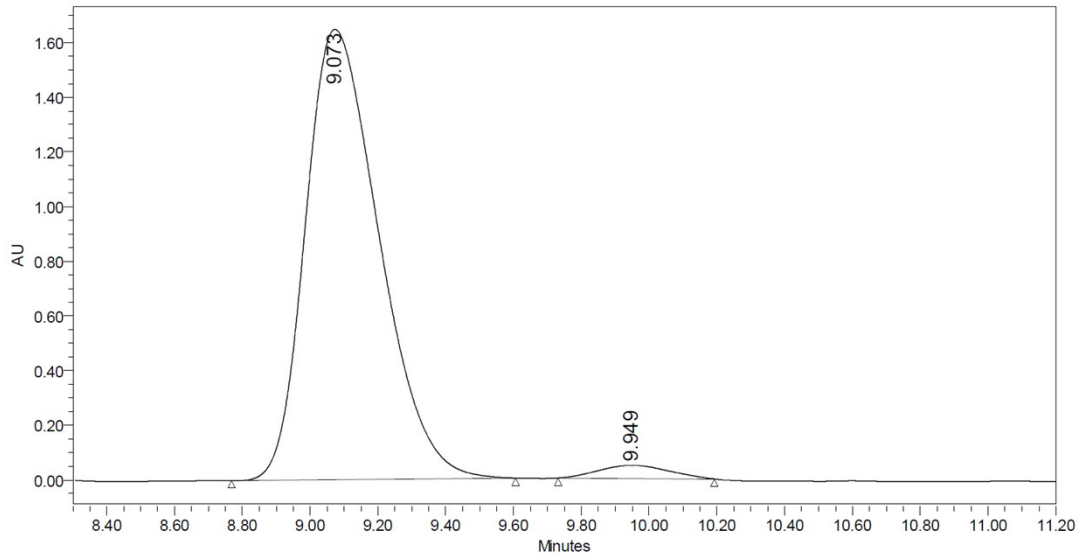
	RT	Area	% Area	Height	% Height
1	6.051	366643	4.24	51725	5.96
2	6.849	8287425	95.76	815820	94.04

Fig. S6 The chiral SFC spectra of **3f**



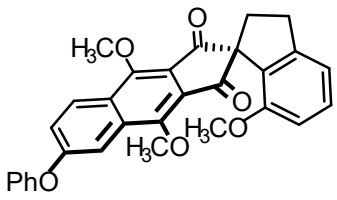


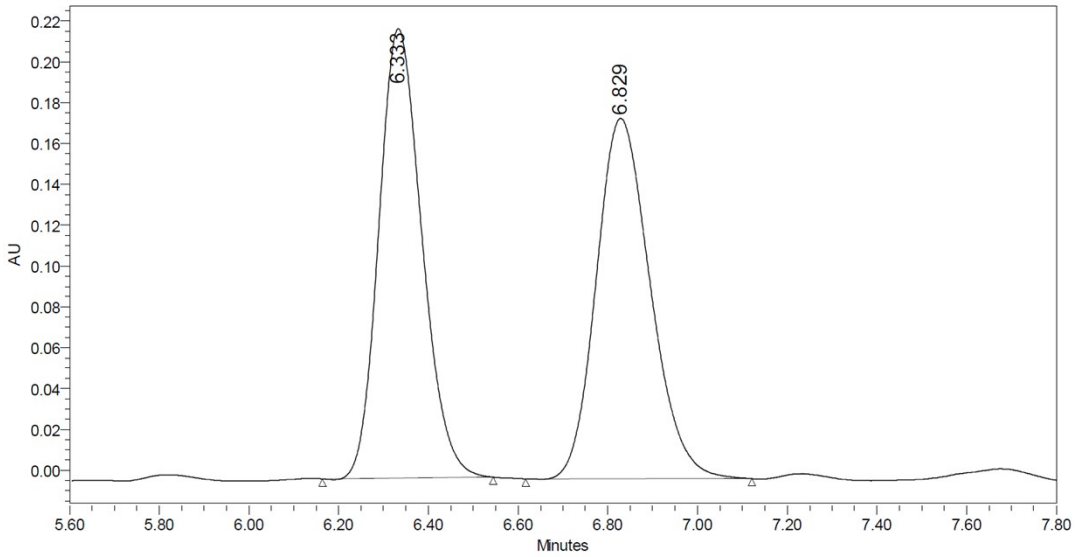
	RT	Area	% Area	Height	% Height
1	9.141	12881161	50.62	865939	54.30
2	9.920	12565801	49.38	728745	45.70



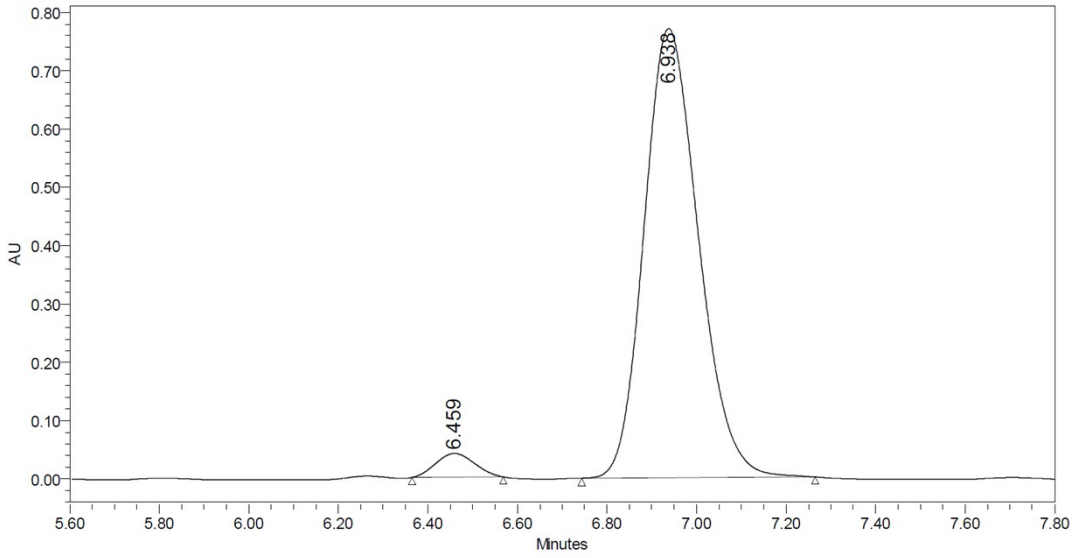
	RT	Area	% Area	Height	% Height
1	9.073	24830823	97.32	1647869	97.19
2	9.949	685092	2.68	47666	2.81

Fig. S7 The chiral SFC spectra of **3g**



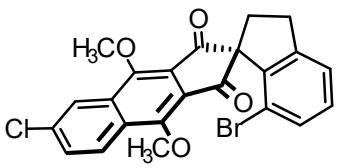


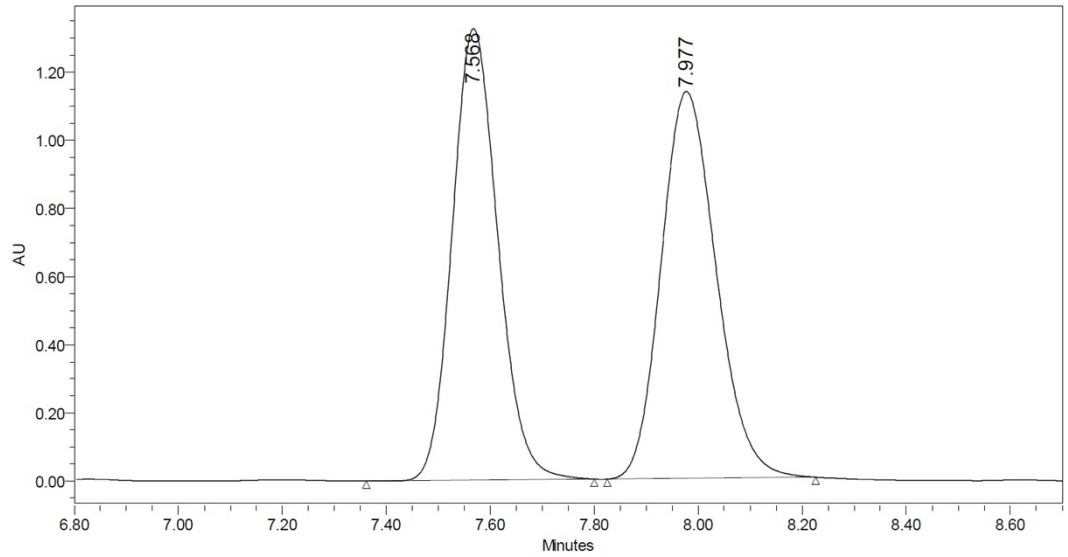
	RT	Area	% Area	Height	% Height
1	6.333	1465196	49.83	220132	55.50
2	6.829	1475259	50.17	176486	44.50



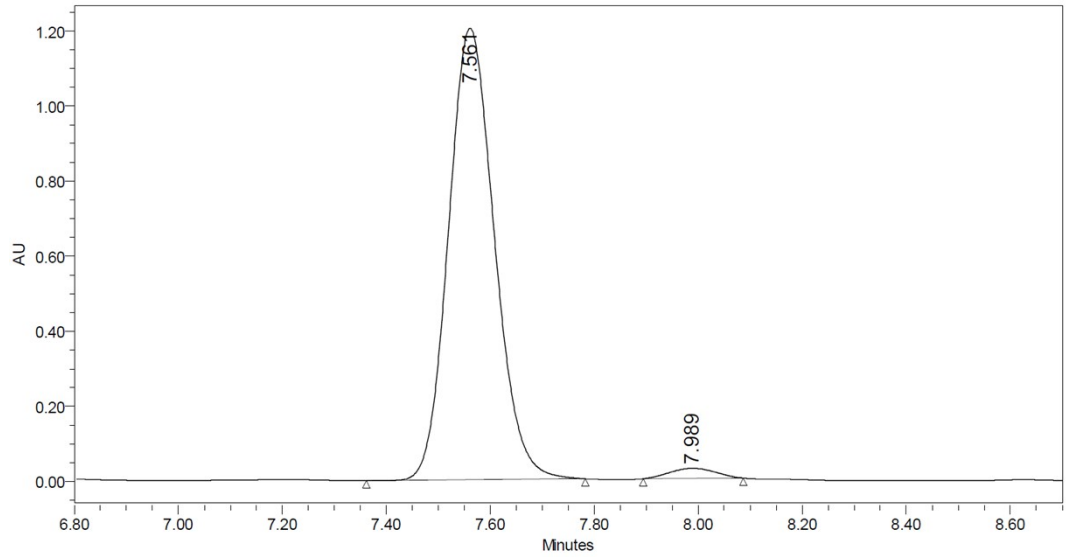
	RT	Area	% Area	Height	% Height
1	6.459	244811	3.64	40743	5.03
2	6.938	6482351	96.36	770051	94.97

Fig. S8 The chiral SFC spectra of **3h**



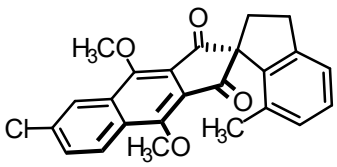


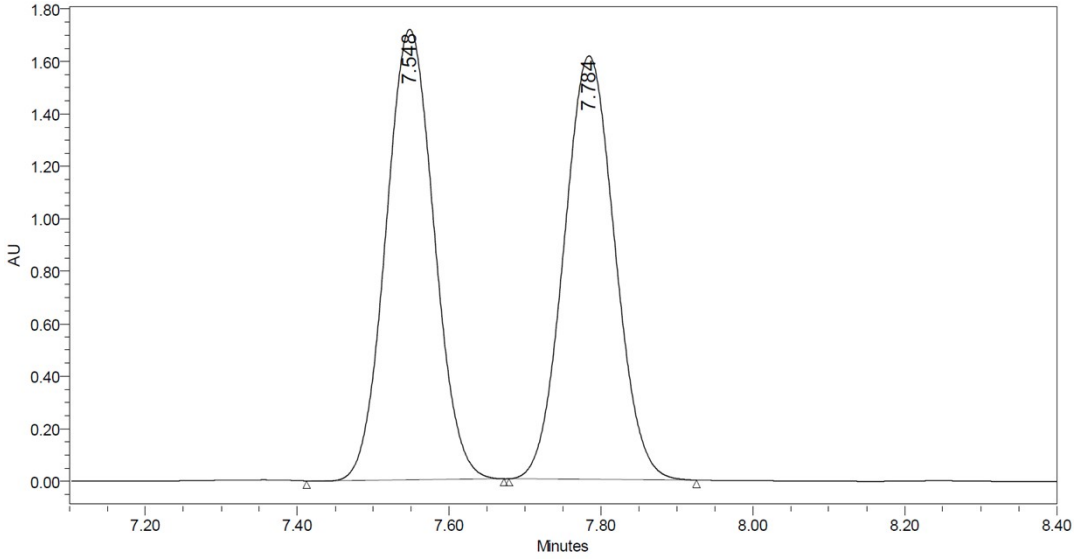
	RT	Area	% Area	Height	% Height
1	7.568	8080633	49.21	1325298	53.86
2	7.977	8341718	50.79	1135519	46.14



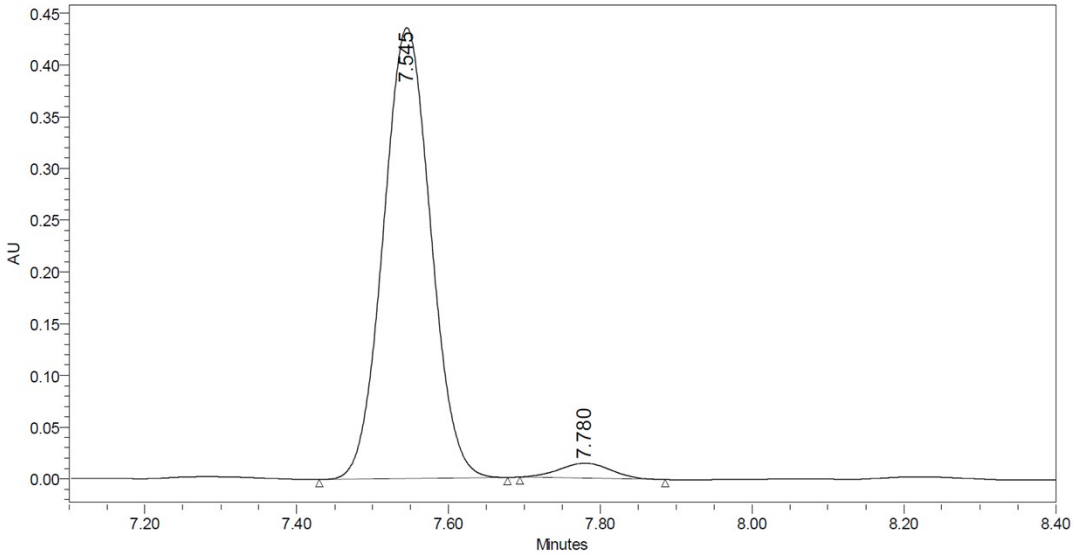
	RT	Area	% Area	Height	% Height
1	7.561	7364012	97.82	1202080	97.80
2	7.989	164190	2.18	27003	2.20

Fig. S9 The chiral SFC spectra of **3i**



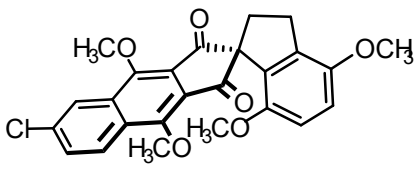


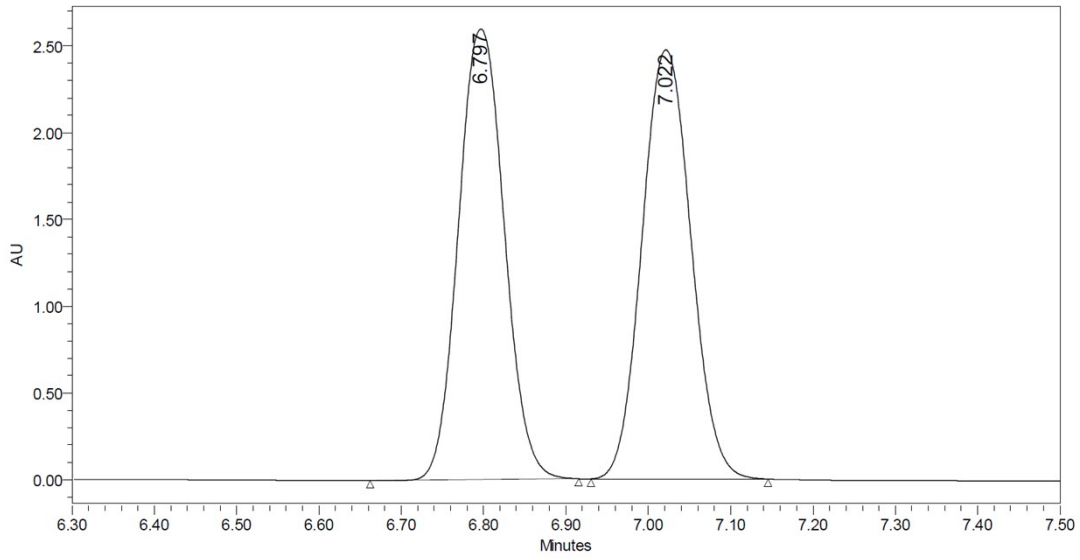
	RT	Area	% Area	Height	% Height
1	7.548	7550467	50.17	1717253	51.55
2	7.784	7499757	49.83	1614221	48.45



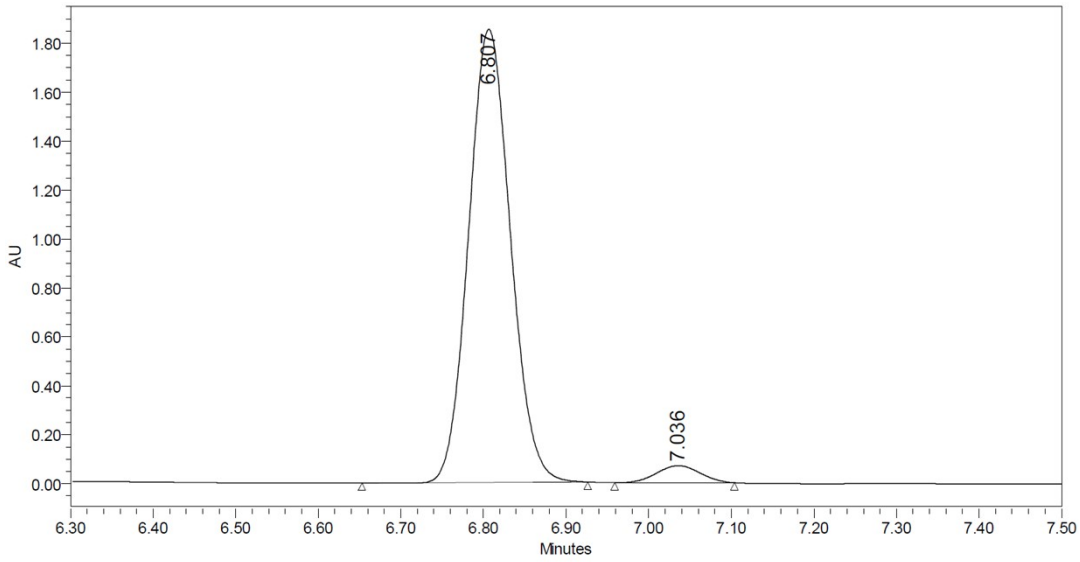
	RT	Area	% Area	Height	% Height
1	7.545	1886766	96.50	435817	96.78
2	7.780	68528	3.50	14505	3.22

Fig. S10 The chiral SFC spectra of **3j**



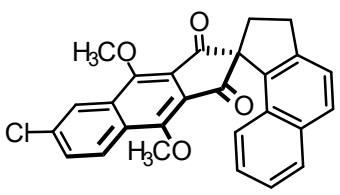


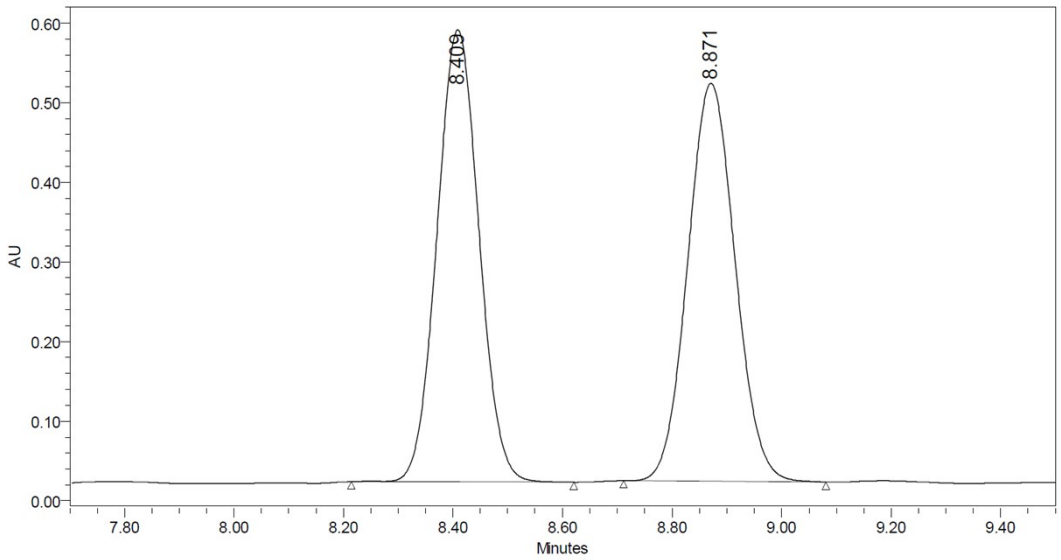
	RT	Area	% Area	Height	% Height
1	6.797	10044602	49.59	2596026	51.22
2	7.022	10210638	50.41	2472400	48.78



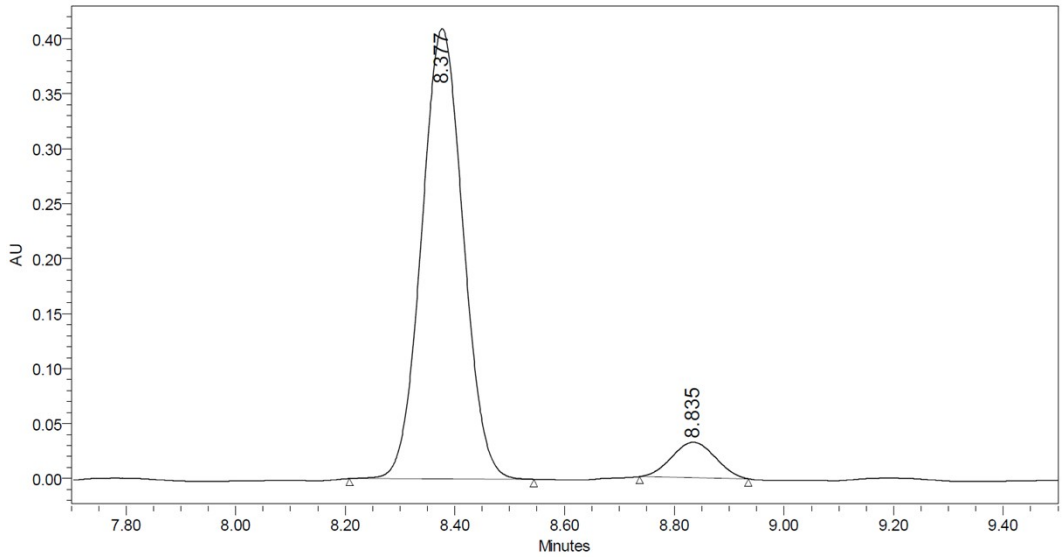
	RT	Area	% Area	Height	% Height
1	6.807	6519017	96.27	1853186	96.37
2	7.036	252662	3.73	69840	3.63

Fig. S11 The chiral SFC spectra of **3k**



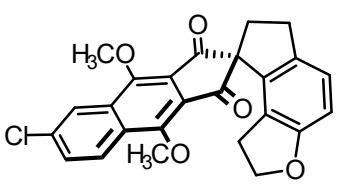


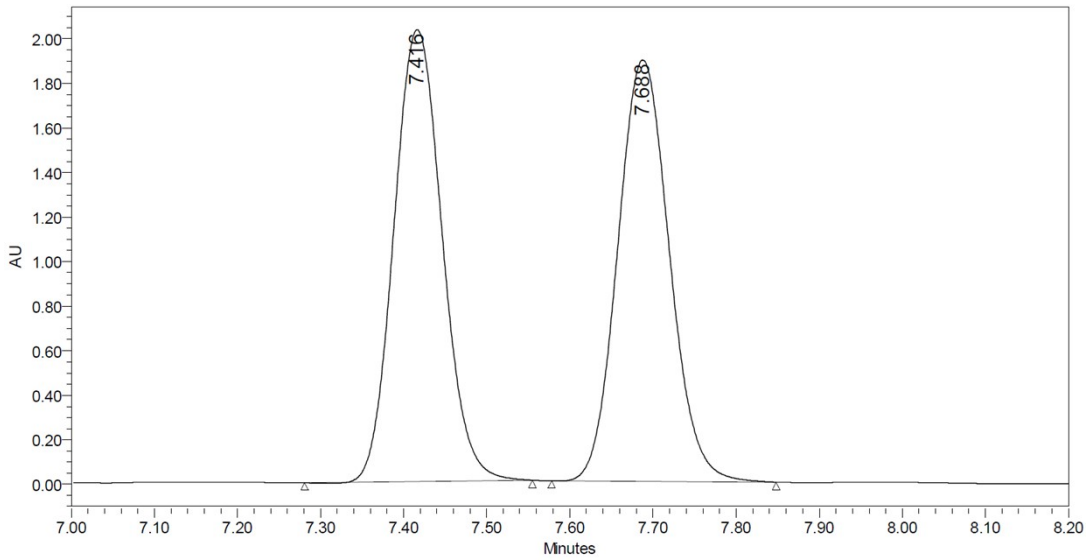
	RT	Area	% Area	Height	% Height
1	8.409	3024953	50.13	567925	53.19
2	8.871	3009348	49.87	499835	46.81



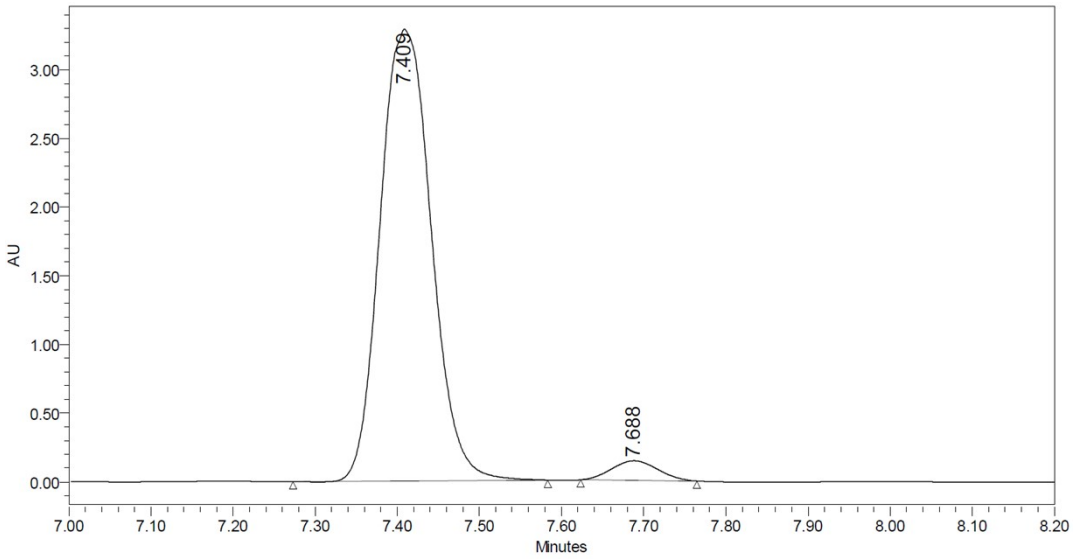
	RT	Area	% Area	Height	% Height
1	8.377	2147825	92.35	409172	92.70
2	8.835	177984	7.65	32213	7.30

Fig. S12 The chiral SFC spectra of **3l**



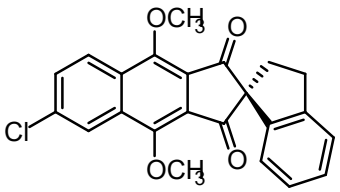


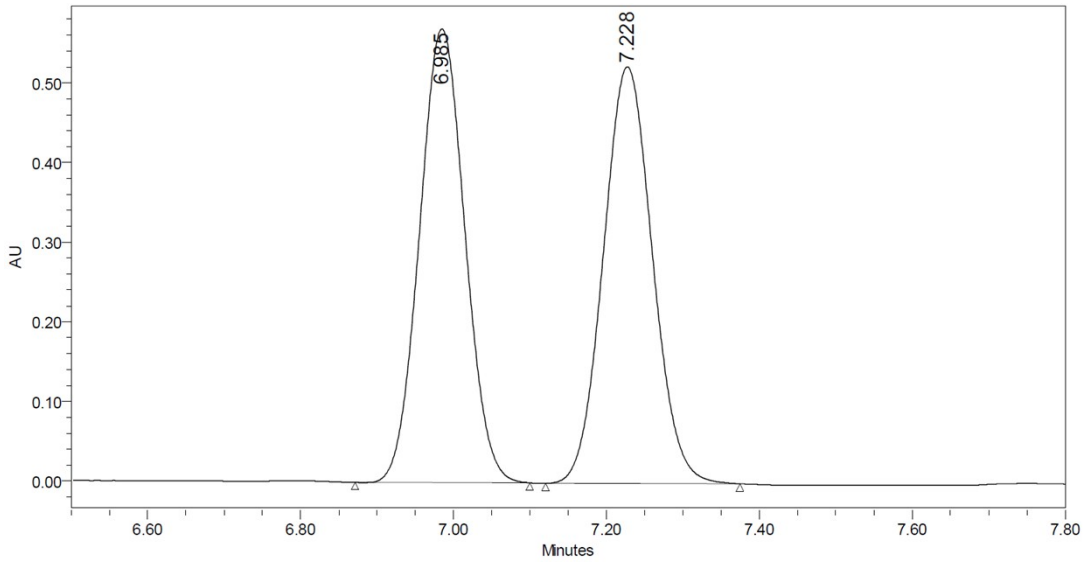
	RT	Area	% Area	Height	% Height
1	7.416	8181067	50.07	2028013	51.74
2	7.688	8159583	49.93	1891610	48.26



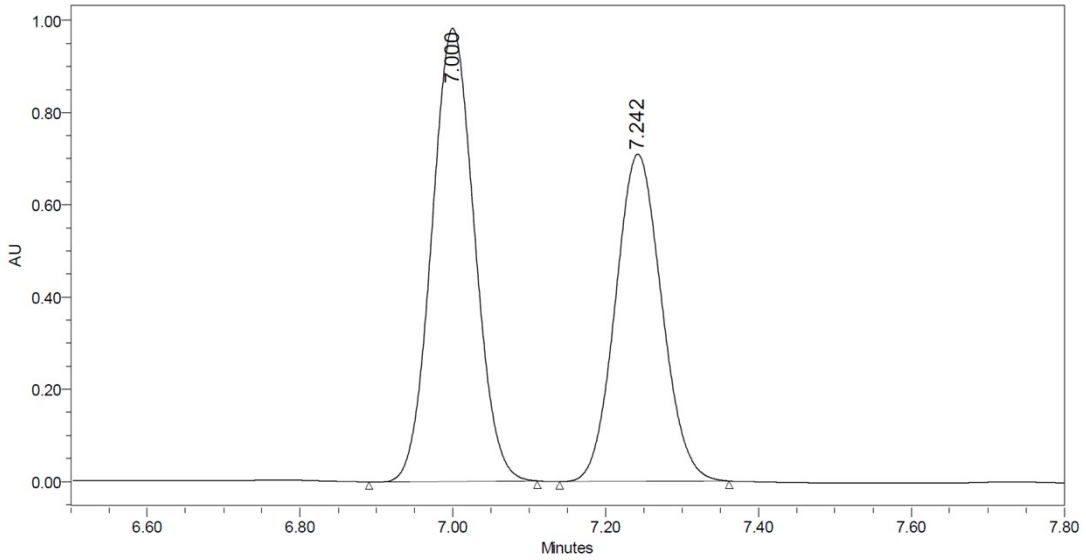
	RT	Area	% Area	Height	% Height
1	7.409	14242837	96.24	3288566	95.85
2	7.688	555726	3.76	142297	4.15

Fig. S13 The chiral SFC spectra of **3m**



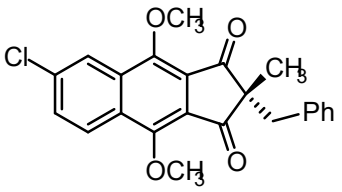


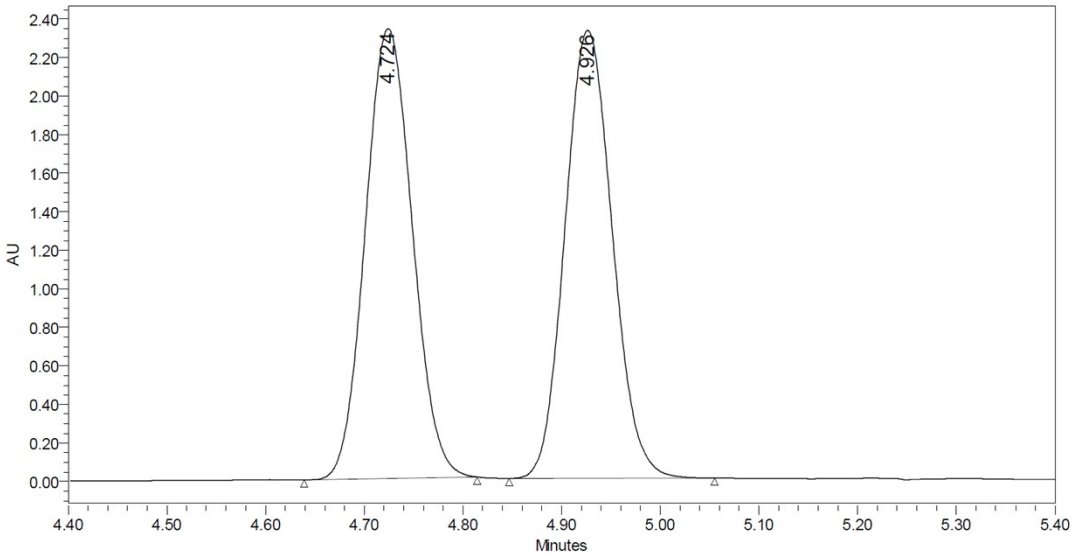
	RT	Area	% Area	Height	% Height
1	6.985	2349265	50.15	569778	52.13
2	7.228	2335162	49.85	523319	47.87



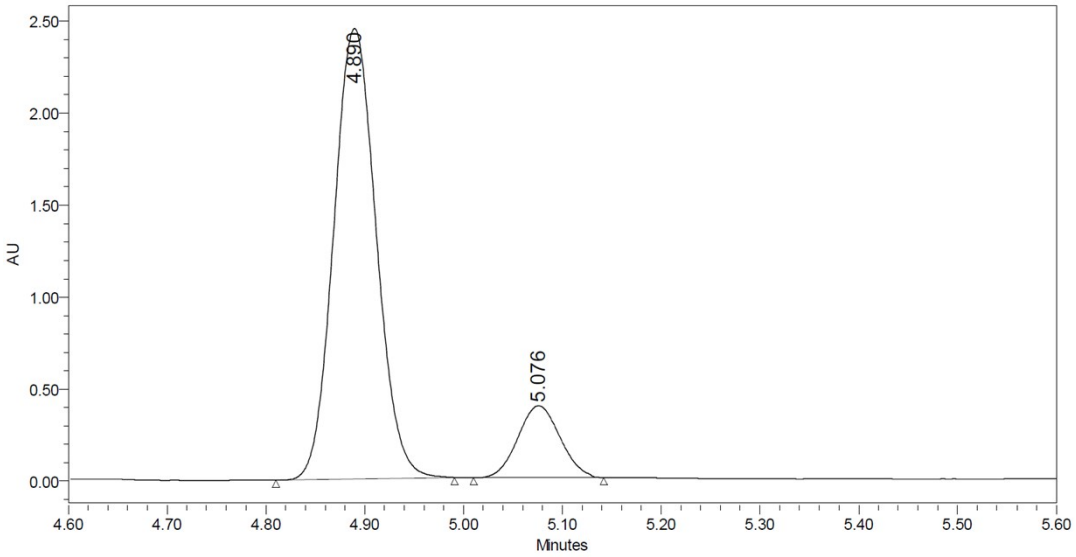
	RT	Area	% Area	Height	% Height
1	7.000	3799848	56.05	983236	58.07
2	7.242	2979434	43.95	709834	41.93

Fig. S14 The chiral SFC spectra of **3n**



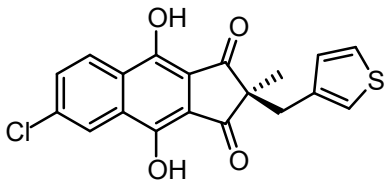


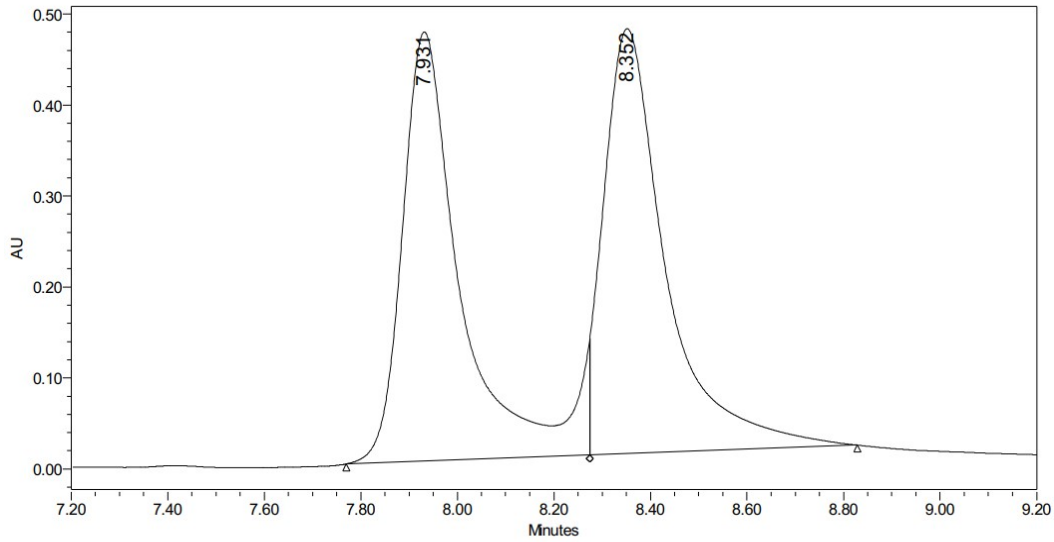
	RT	Area	% Area	Height	% Height
1	4.724	7734600	49.98	2334873	50.11
2	4.926	7741498	50.02	2325086	49.89



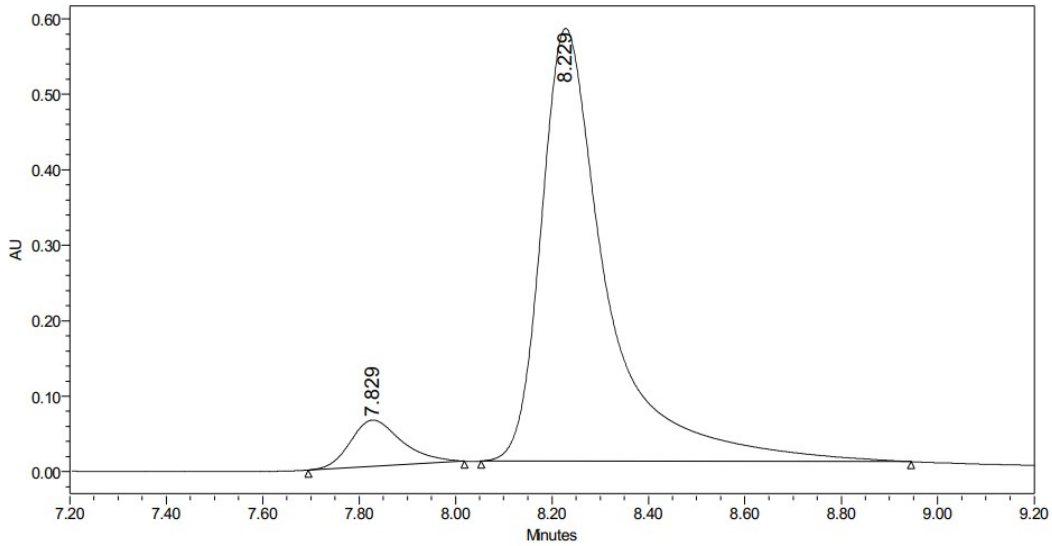
	RT	Area	% Area	Height	% Height
1	4.890	7310151	86.31	2447909	86.23
2	5.076	1159329	13.69	390879	13.77

Fig. S15 The chiral SFC spectra of **3o**



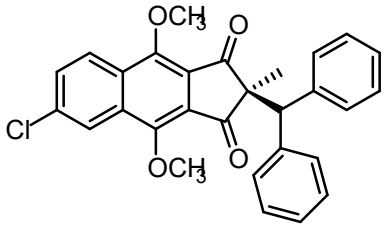


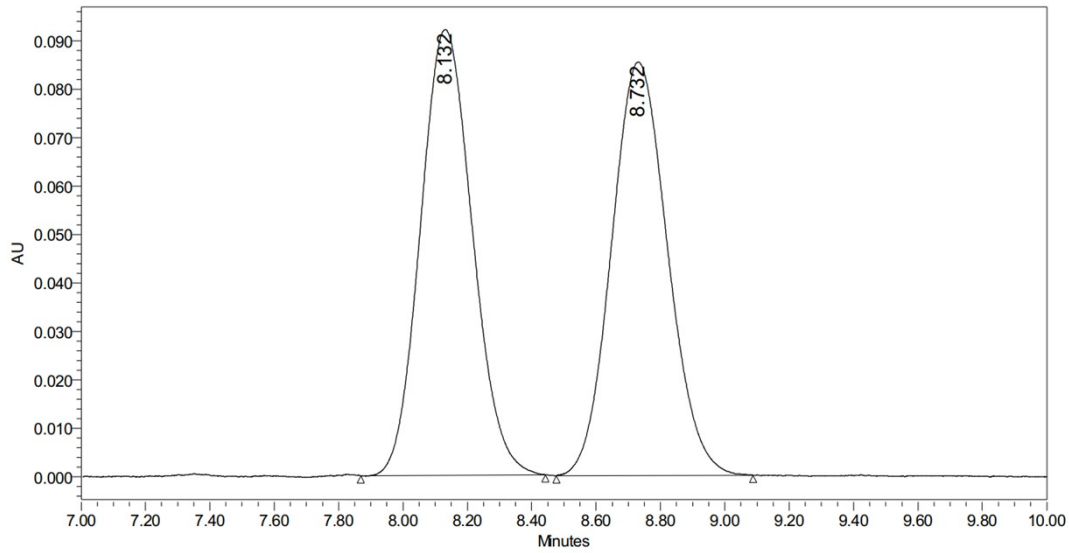
	RT	Area	% Area	Height	% Height
1	7.931	4024800	49.13	471641	50.25
2	8.352	4167096	50.87	467005	49.75



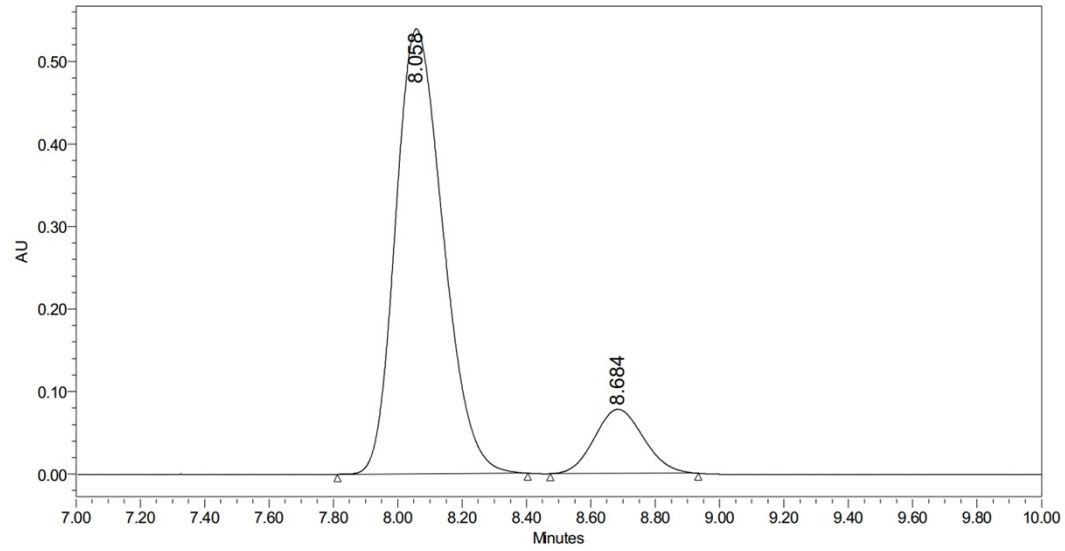
	RT	Area	% Area	Height	% Height
1	7.829	453517	7.66	61353	9.66
2	8.229	5468472	92.34	573473	90.34

Fig. S16 The chiral SFC spectra of **3p**



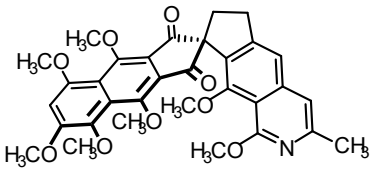


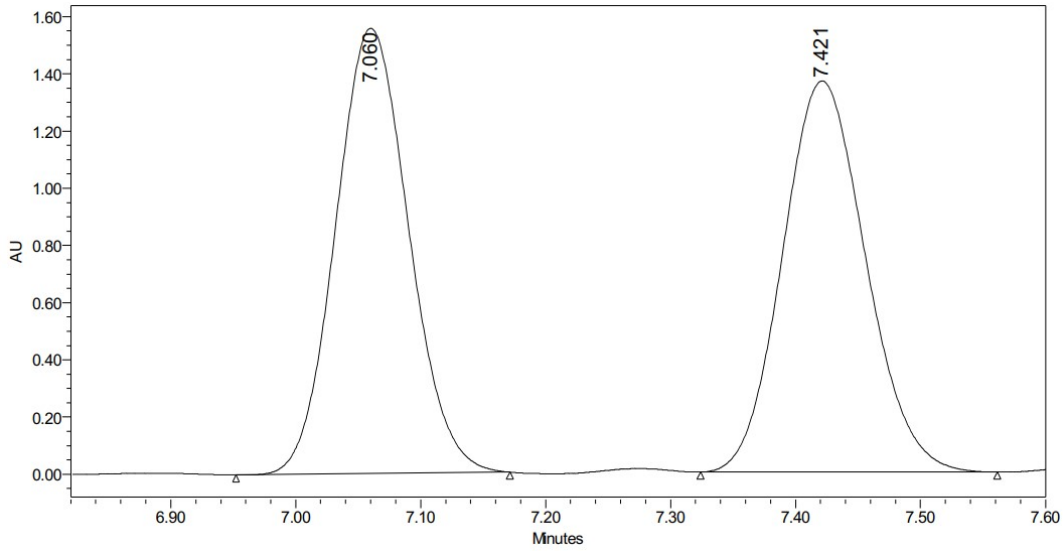
	RT	Area	% Area	Height	% Height
1	8.132	1030646	49.96	92015	51.89
2	8.732	1032443	50.04	85319	48.11



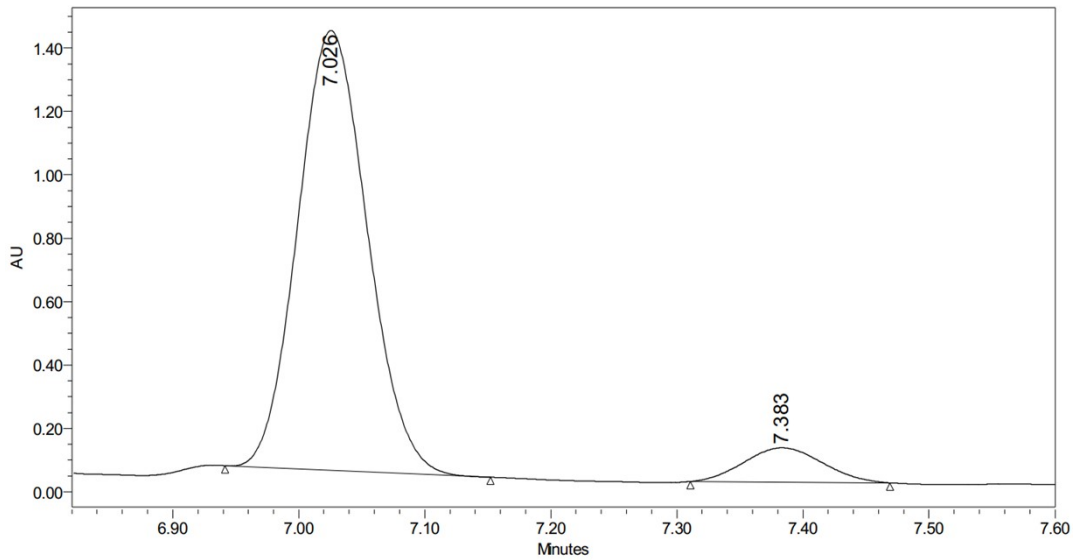
	RT	Area	% Area	Height	% Height
1	8.058	5525400	87.02	539244	87.39
2	8.684	824238	12.98	77816	12.61

Fig. S17 The chiral SFC spectra of **3q**



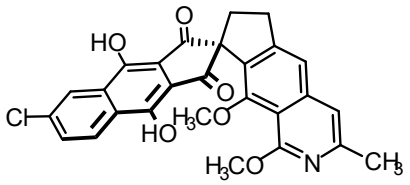


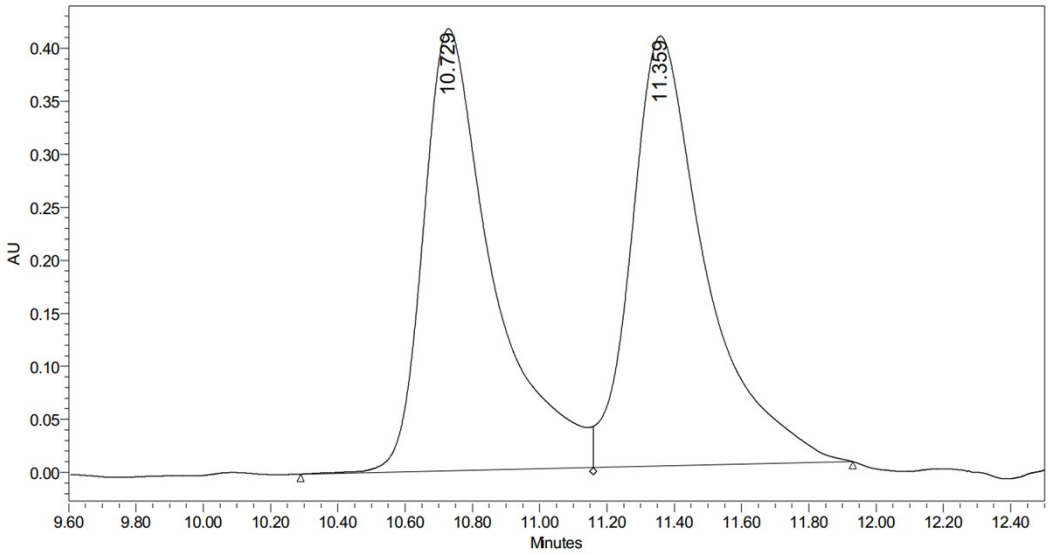
	RT	Area	% Area	Height	% Height
1	7.060	6329168	50.03	1557308	53.22
2	7.421	6322017	49.97	1368687	46.78



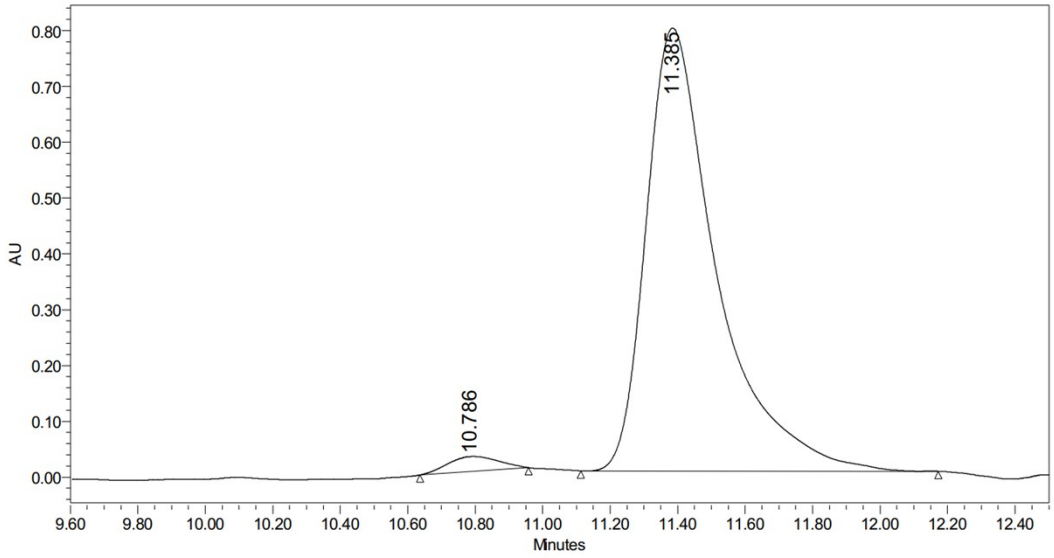
	RT	Area	% Area	Height	% Height
1	7.026	5321487	91.93	1387200	92.77
2	7.383	467377	8.07	108091	7.23

Fig. S18 The chiral SFC spectra of **3r**



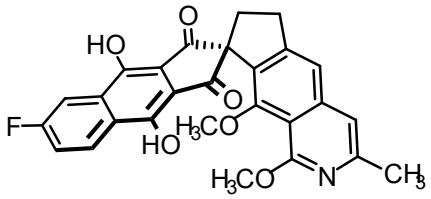


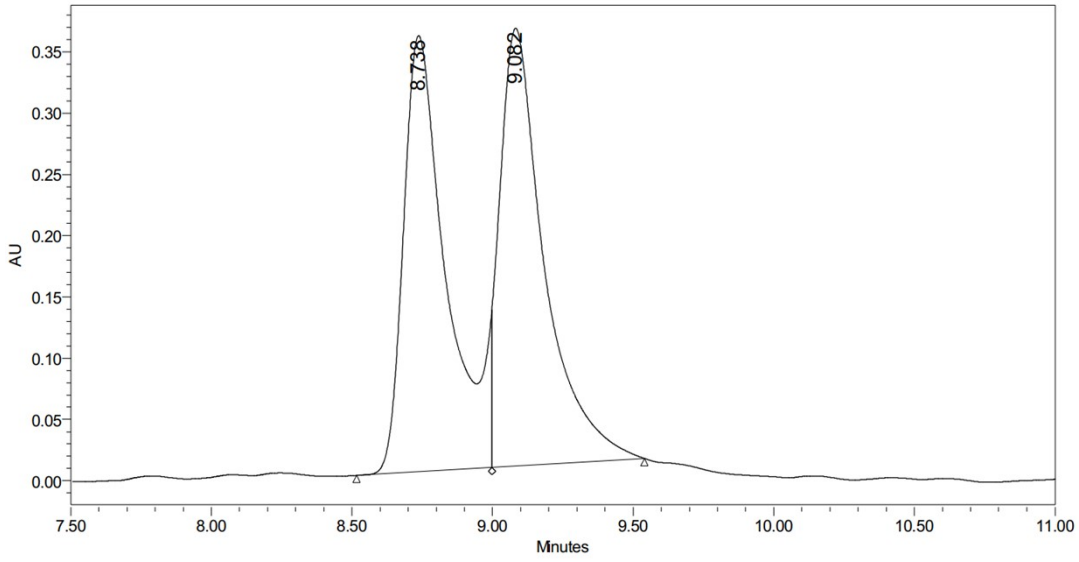
	RT	Area	% Area	Height	% Height
1	10.729	5976657	49.02	416781	50.70
2	11.359	6215394	50.98	405344	49.30



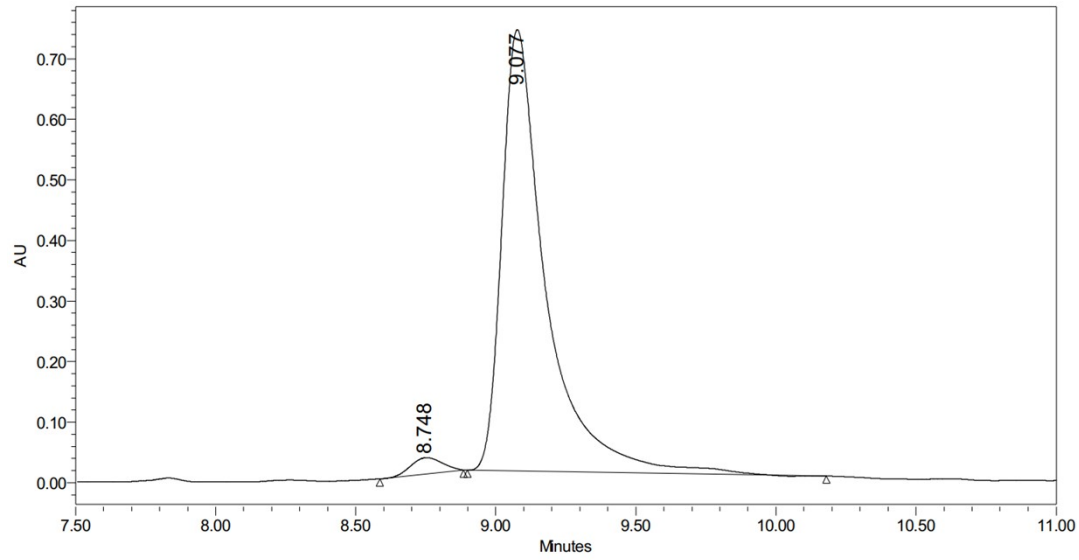
	RT	Area	% Area	Height	% Height
1	10.786	278823	2.37	26924	3.28
2	11.385	11479586	97.63	793436	96.72

Fig. S19 The chiral SFC spectra of **3s**



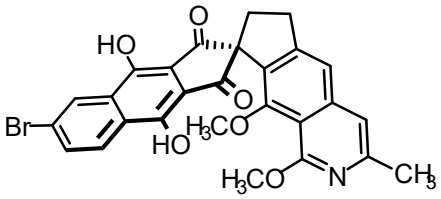


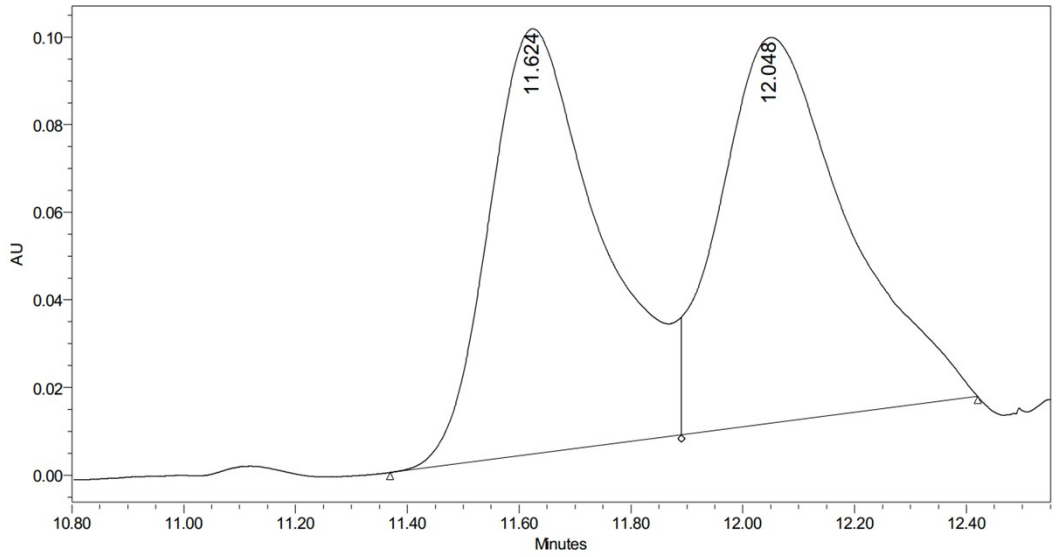
	RT	Area	% Area	Height	% Height
1	8.738	3763852	49.05	355998	49.91
2	9.082	3909023	50.95	357348	50.09



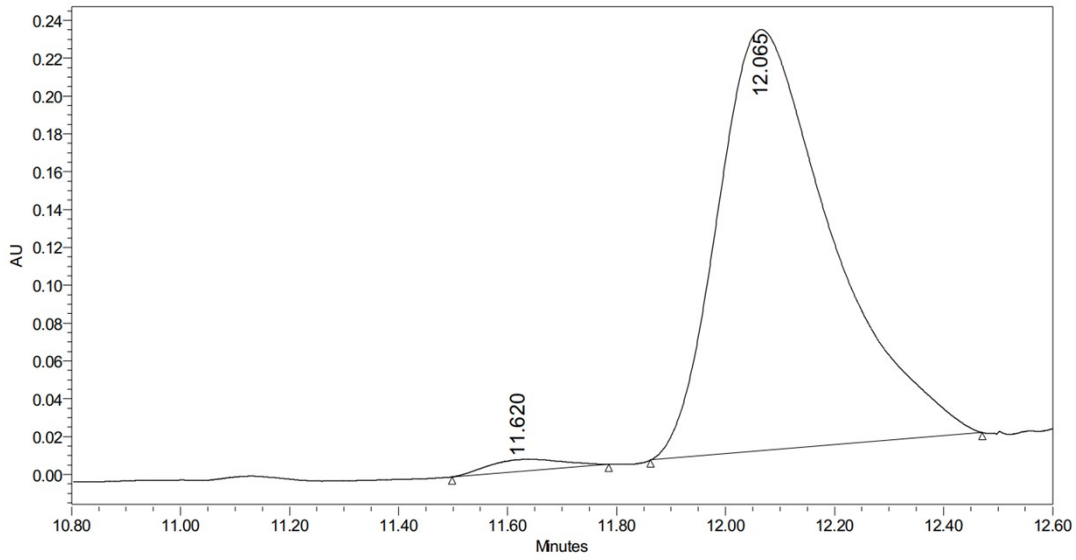
	RT	Area	% Area	Height	% Height
1	8.748	210295	2.56	27048	3.58
2	9.077	7988362	97.44	729232	96.42

Fig. S20 The chiral SFC spectra of **3t**



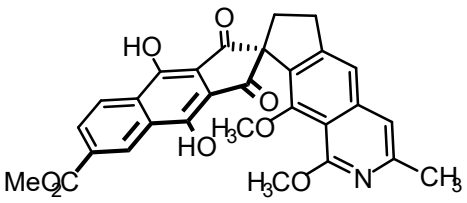


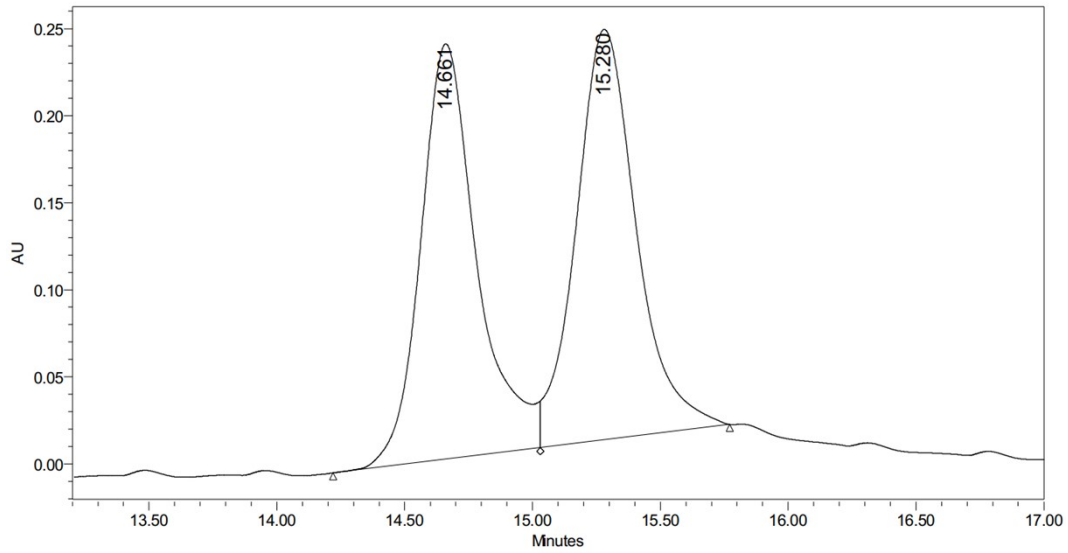
	RT	Area	% Area	Height	% Height
1	11.624	1351750	49.11	97067	52.43
2	12.048	1400585	50.89	88066	47.57



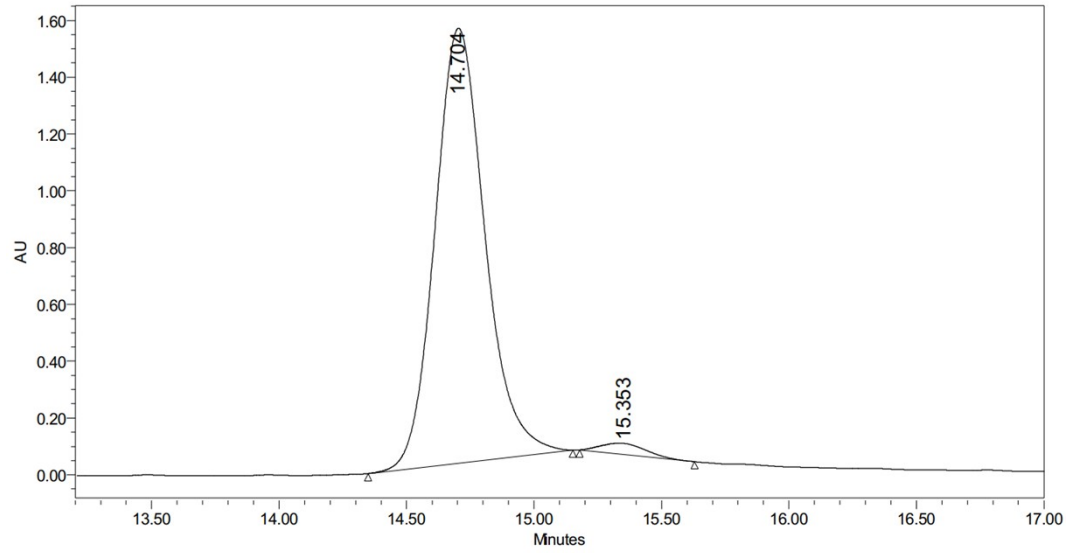
	RT	Area	% Area	Height	% Height
1	11.620	59061	1.79	6276	2.74
2	12.065	3231840	98.21	222646	97.26

Fig. S21 The chiral SFC spectra of **3u**



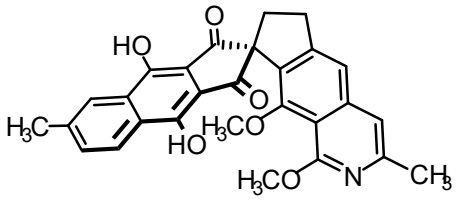


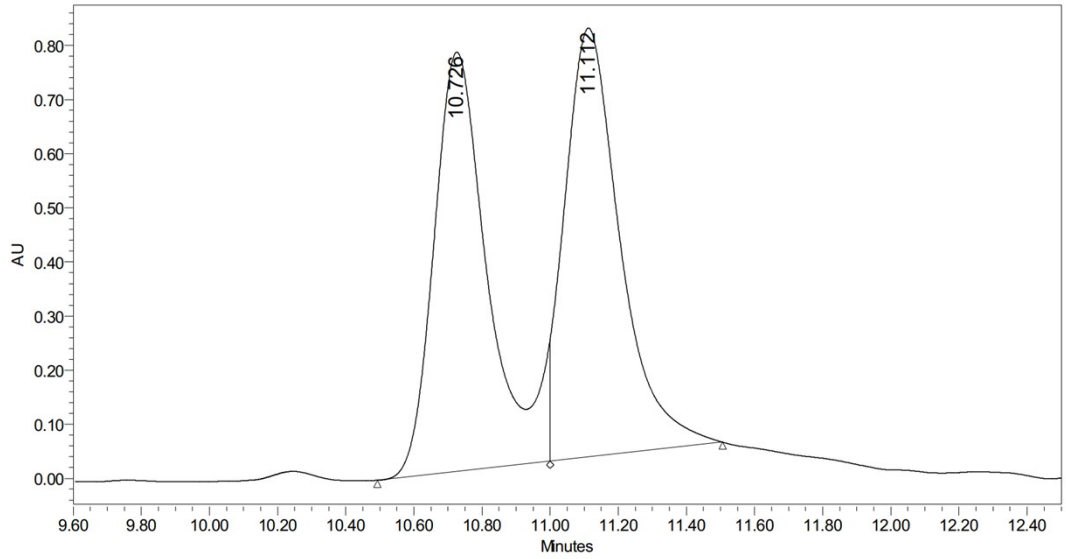
	RT	Area	% Area	Height	% Height
1	14.661	3647557	48.52	238544	50.30
2	15.280	3870153	51.48	235702	49.70



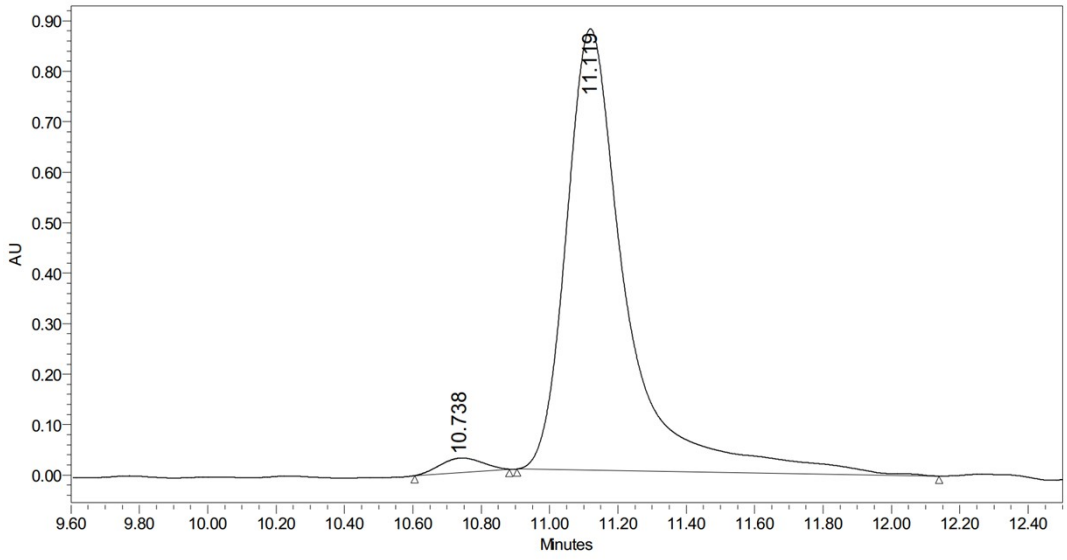
	RT	Area	% Area	Height	% Height
1	14.704	20926040	97.79	1531520	97.50
2	15.353	471891	2.21	39196	2.50

Fig. S22 The chiral SFC spectra of **3v**



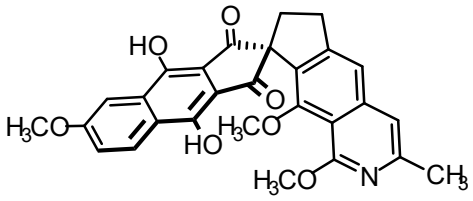


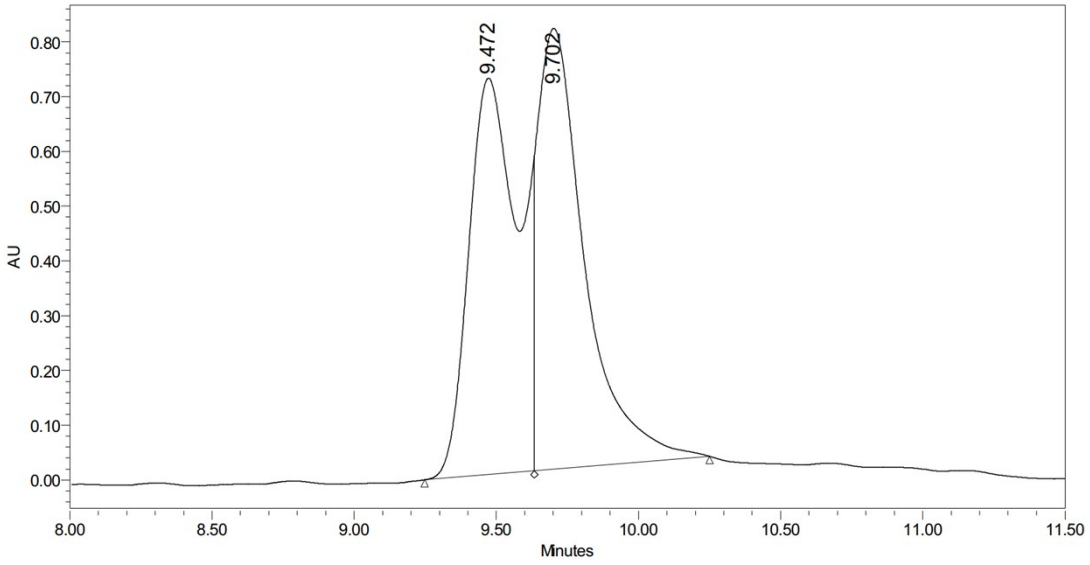
	RT	Area	% Area	Height	% Height
1	10.726	8575436	49.03	774806	49.44
2	11.112	8915562	50.97	792283	50.56



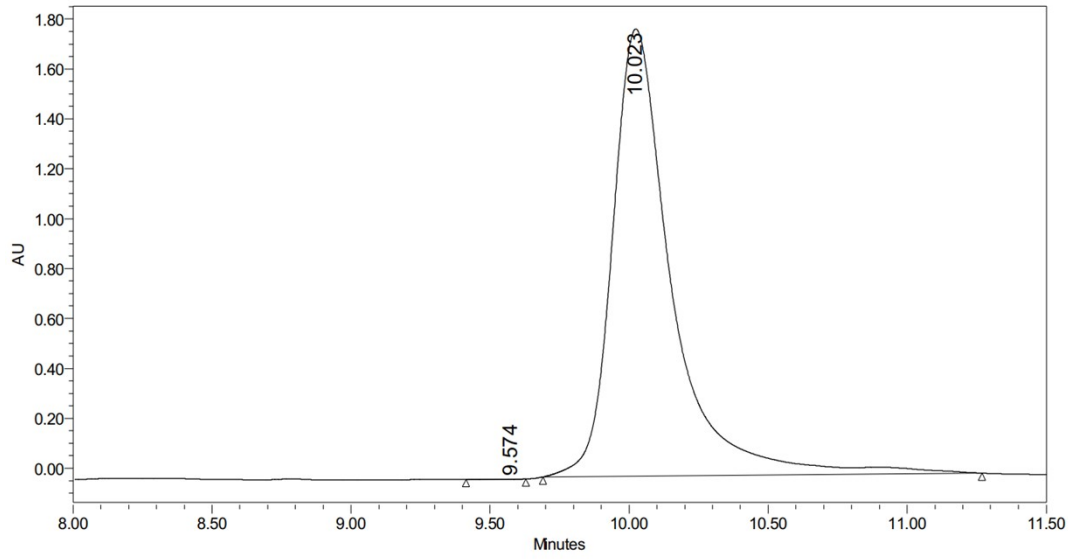
	RT	Area	% Area	Height	% Height
1	10.738	245768	2.25	28608	3.17
2	11.119	10694132	97.75	874824	96.83

Fig. S23 The chiral SFC spectra of **3w**





	RT	Area	% Area	Height	% Height
1	9.472	8791398	48.90	724168	47.35
2	9.702	9188554	51.10	805203	52.65



	RT	Area	% Area	Height	% Height
1	9.574	5860	0.02	-748	0.04
2	10.023	26661719	99.98	1791813	99.96

Fig. S24 The chiral SFC spectra of **3x**

11. Copies of ^{1}H NMR, ^{13}C NMR, ^{19}F NMR spectra of products

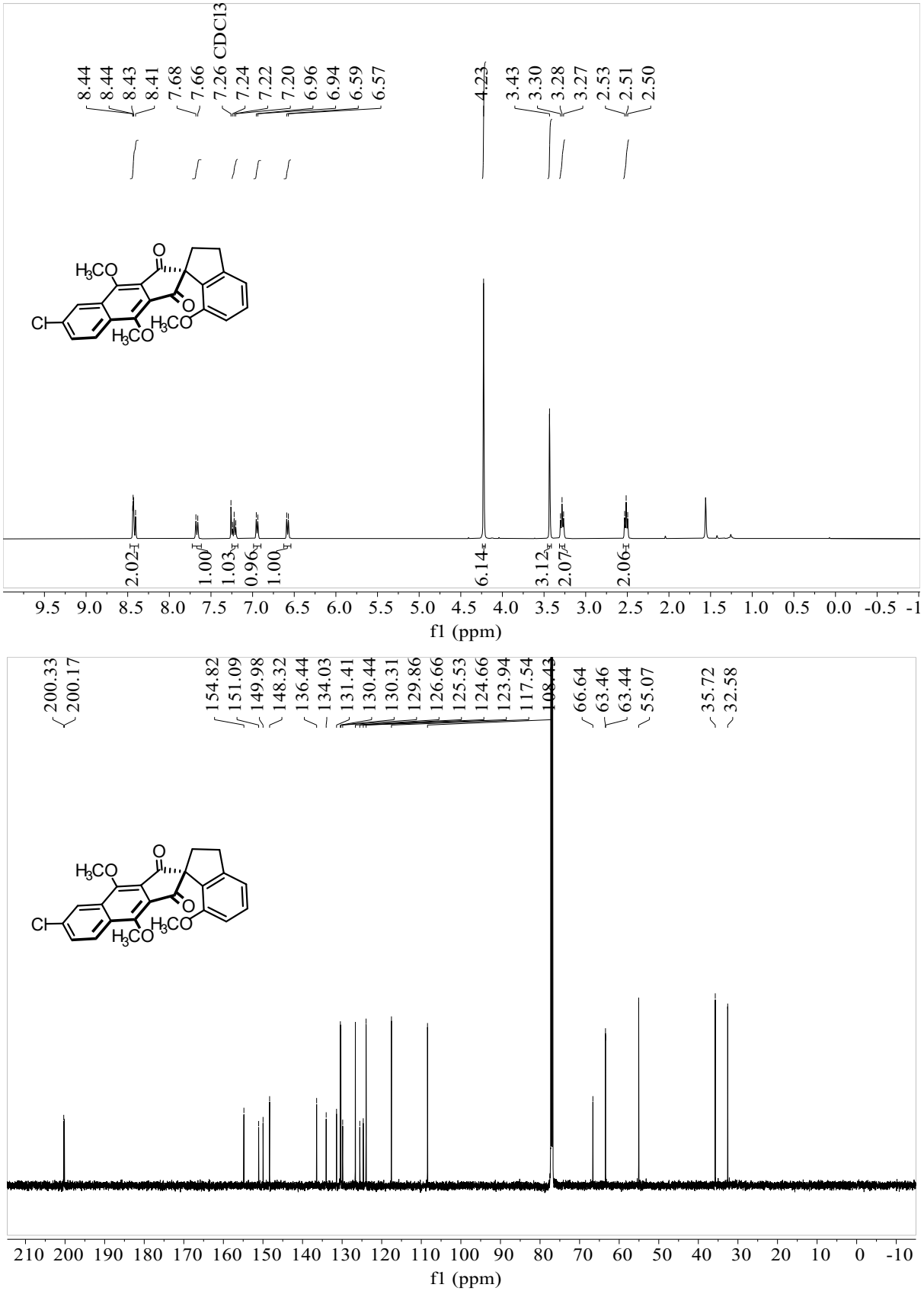


Fig. S25 ^{1}H NMR and ^{13}C NMR spectra of **3a**

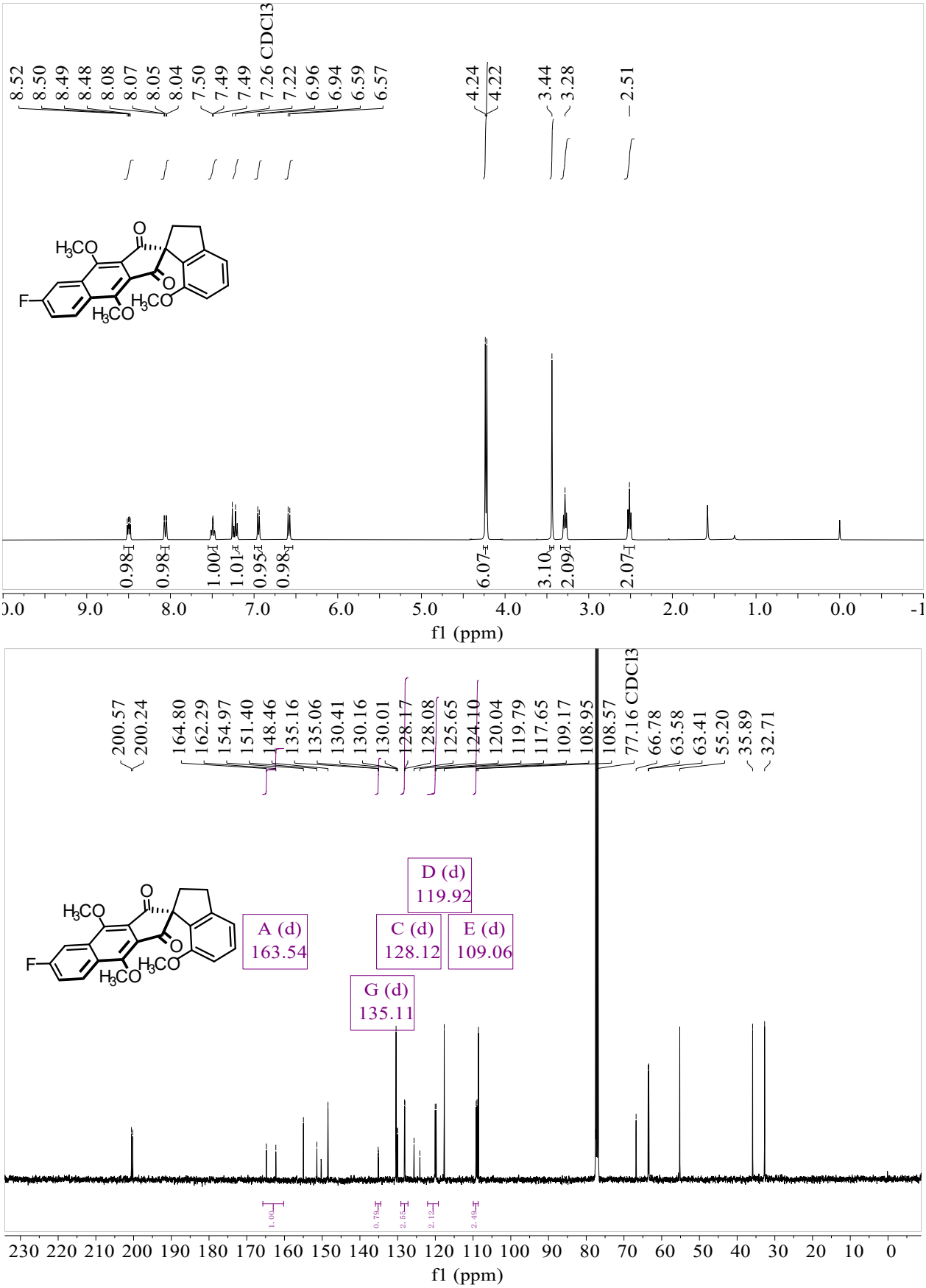


Fig. S26 ^{1}H NMR and ^{13}C NMR spectra of **3b**

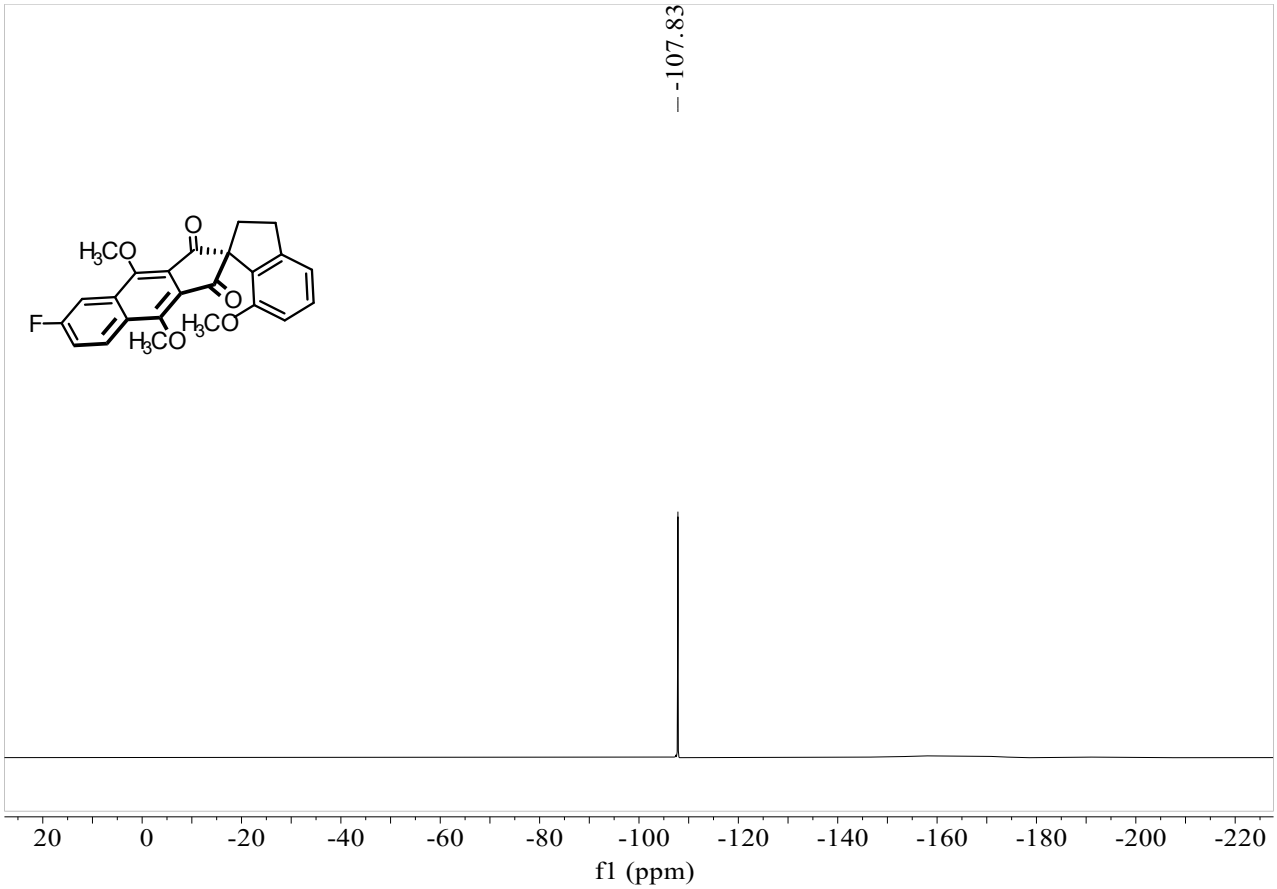
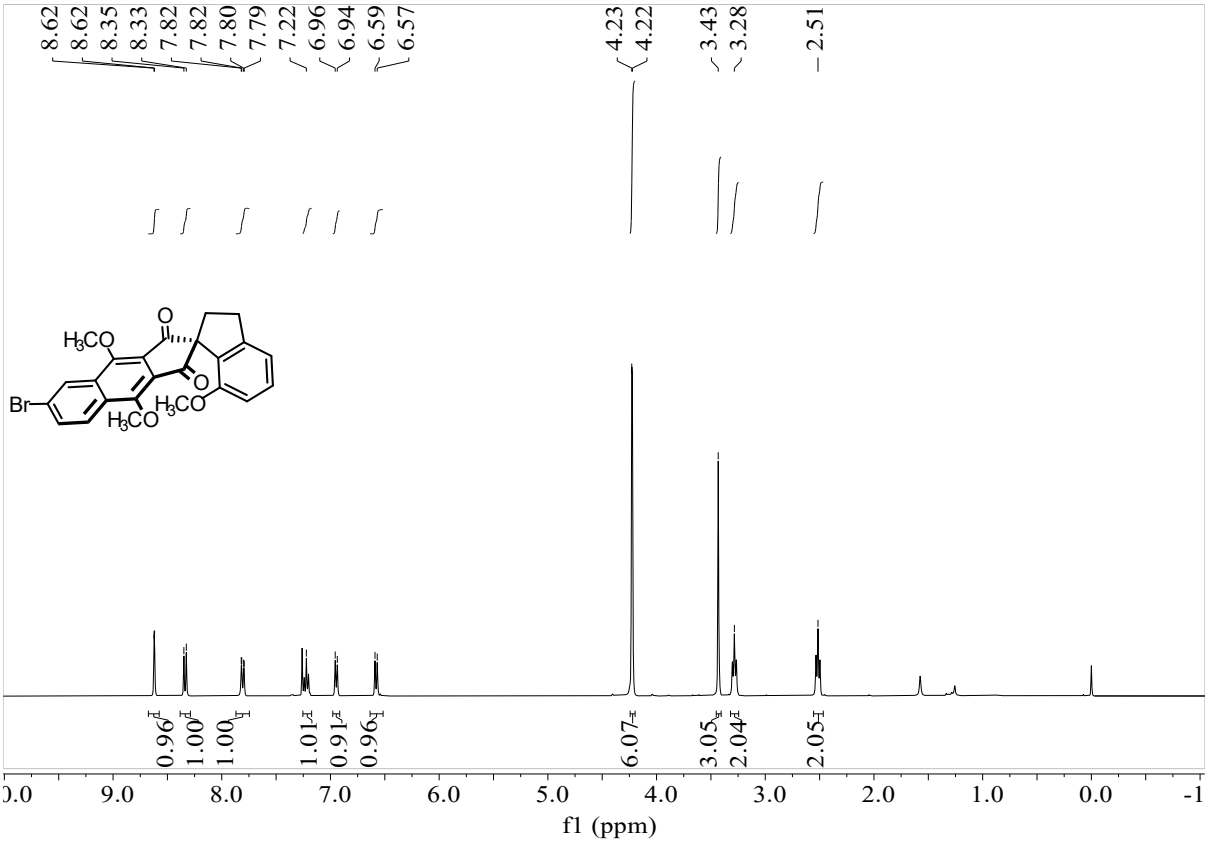


Fig. S27 ^{19}F NMR spectra of **3b**



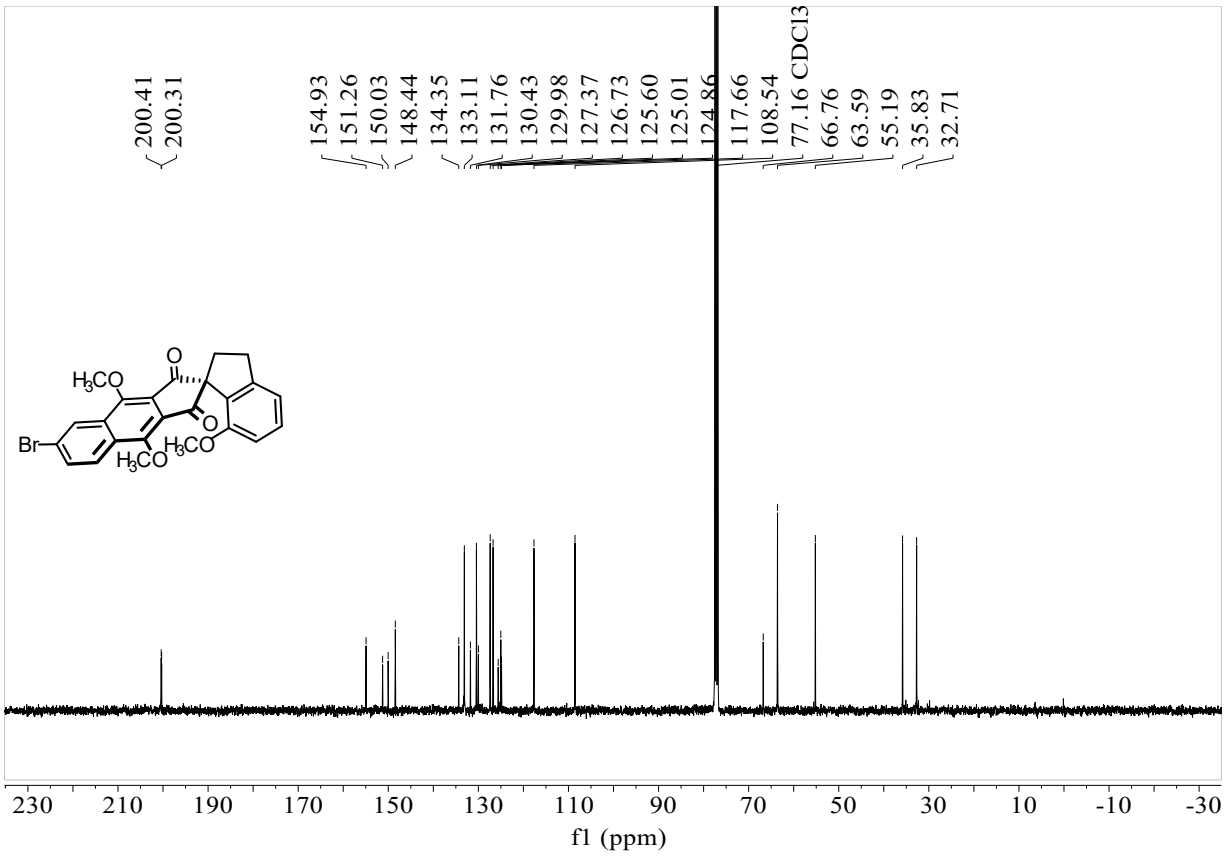
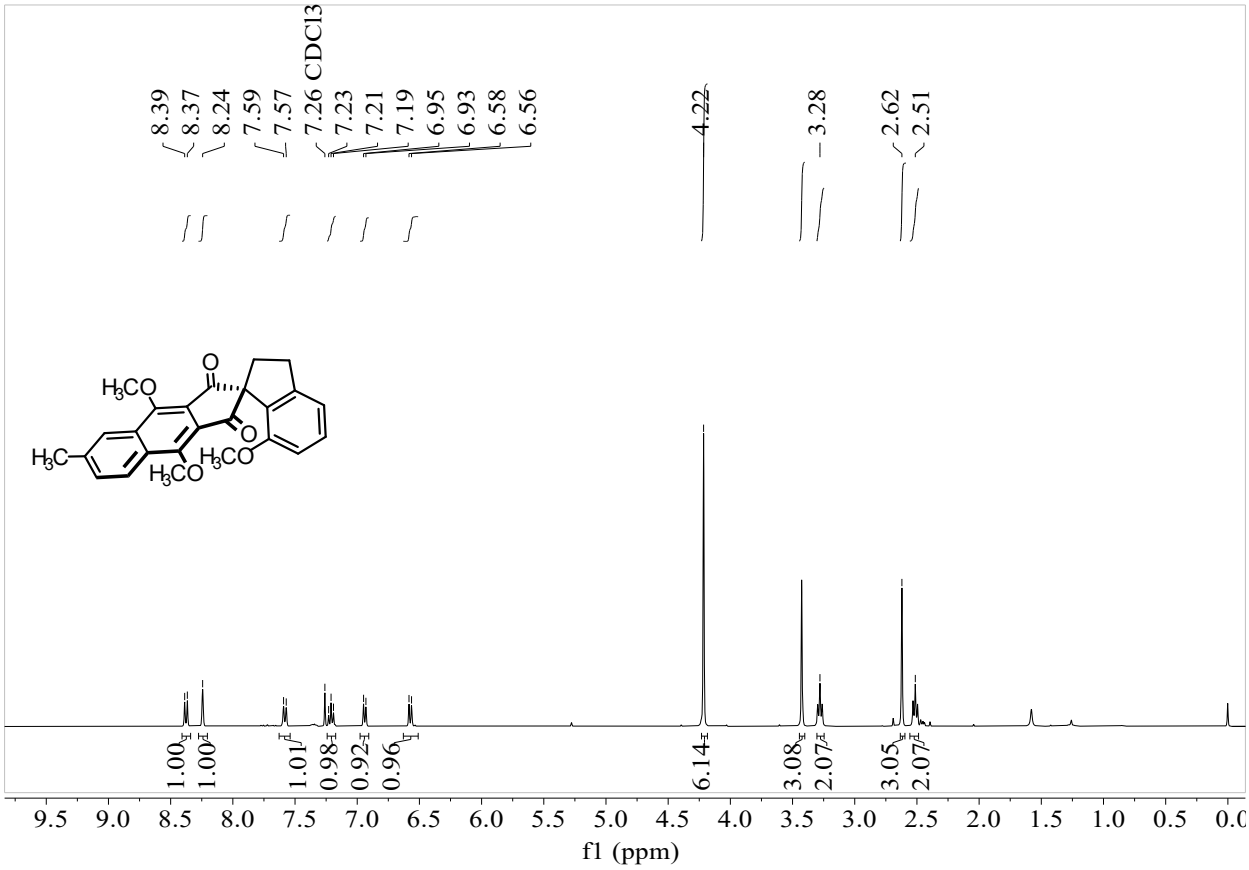


Fig. S28 ^{1}H NMR and ^{13}C NMR spectra of **3c**



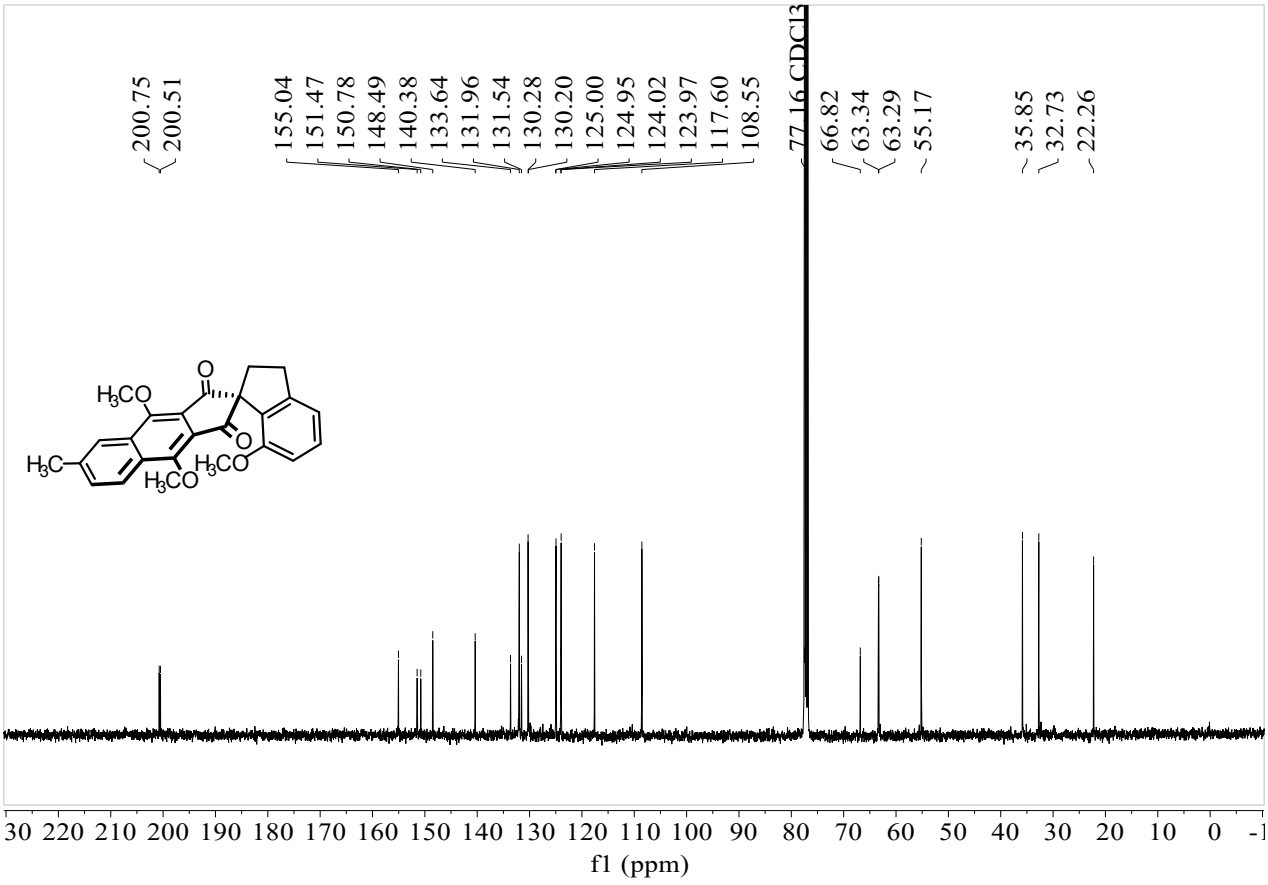
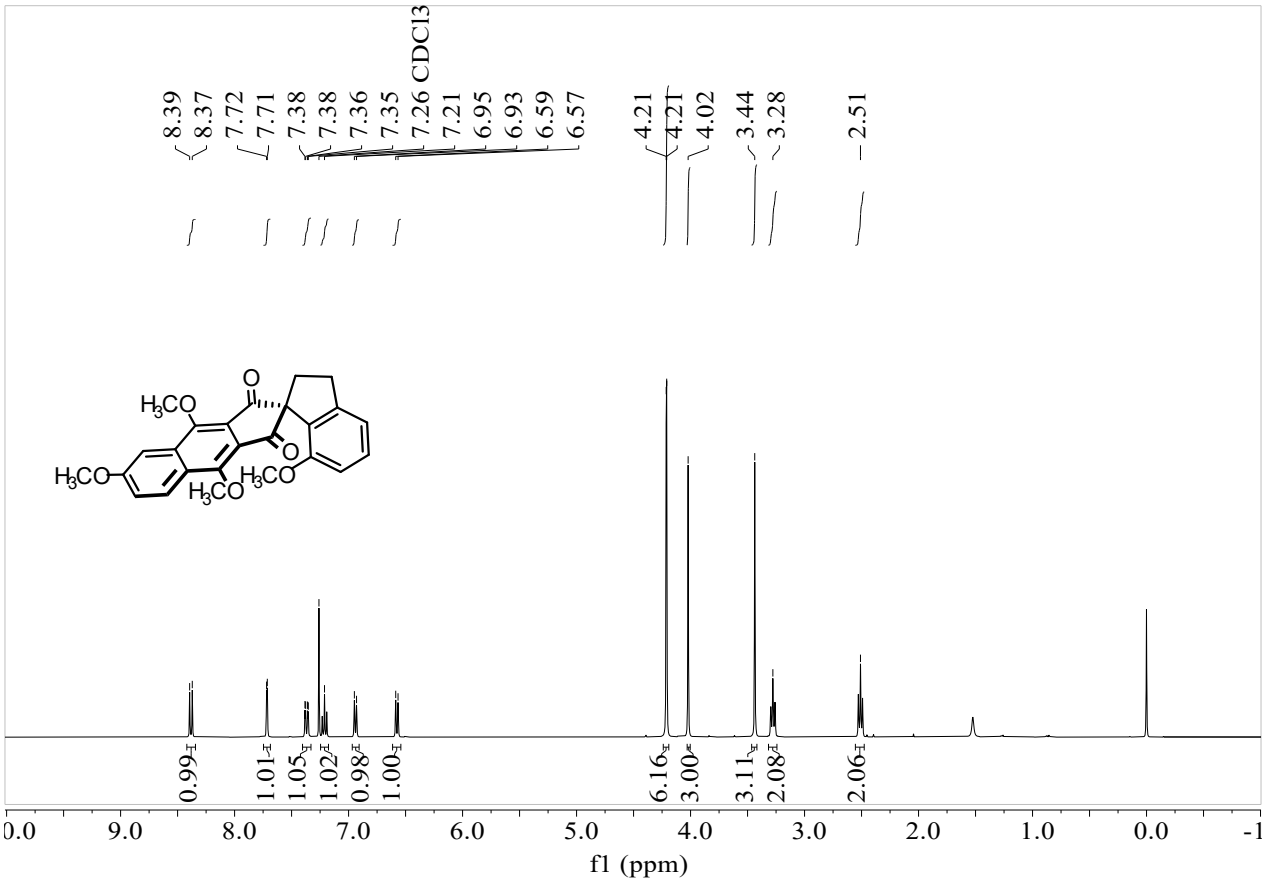


Fig. S29 ^{1}H NMR and ^{13}C NMR spectra of **3d**


8.39
8.37
7.72
7.71
7.38
7.38
7.36
7.35
7.26 CDCl3
7.21
6.95
6.93
6.59
6.57
4.21
4.21
4.02
3.44
3.28
2.51
H3CO
O
O
H3CO
H3CO
H3CO
0.99
1.01
1.05
1.02
0.98
1.00
6.16
3.00
3.11
2.08
2.06
f1 (ppm)

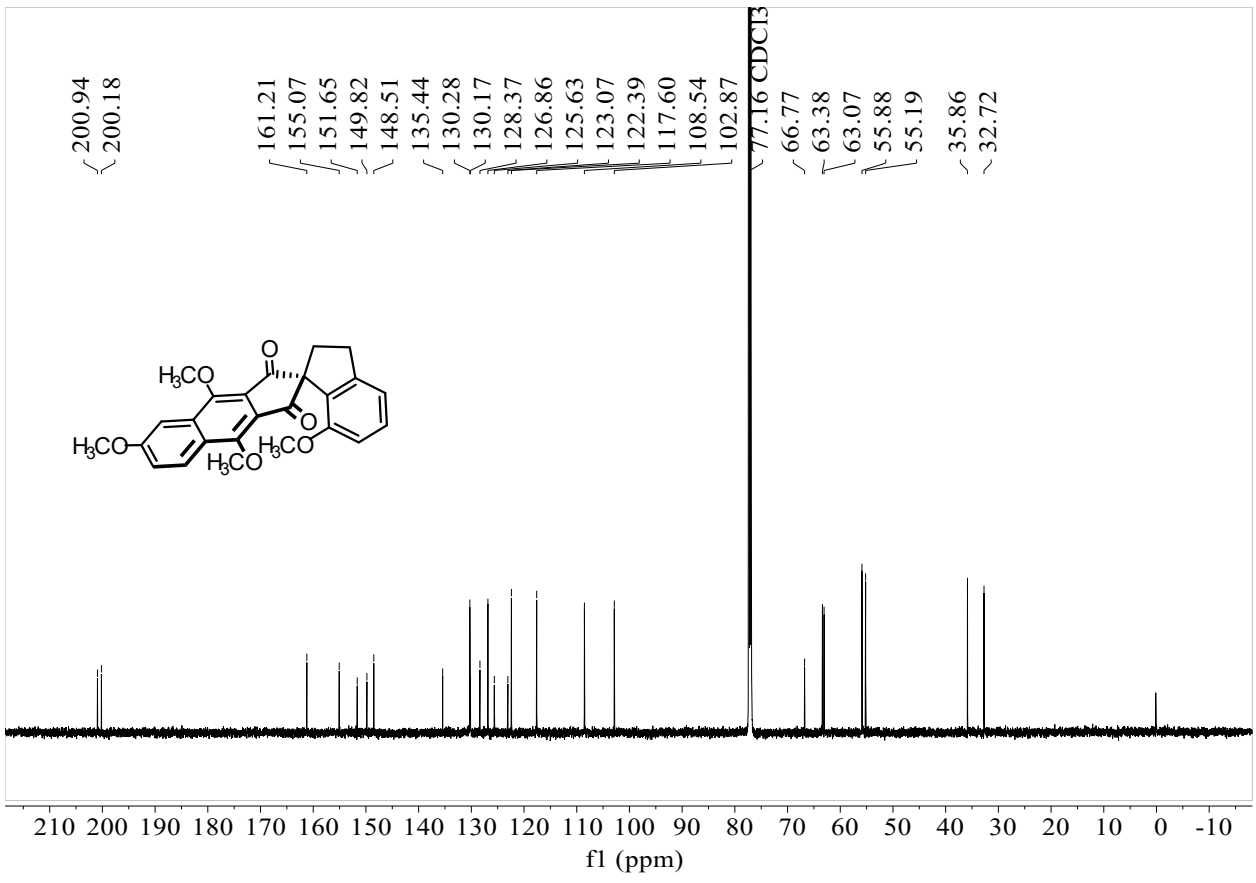
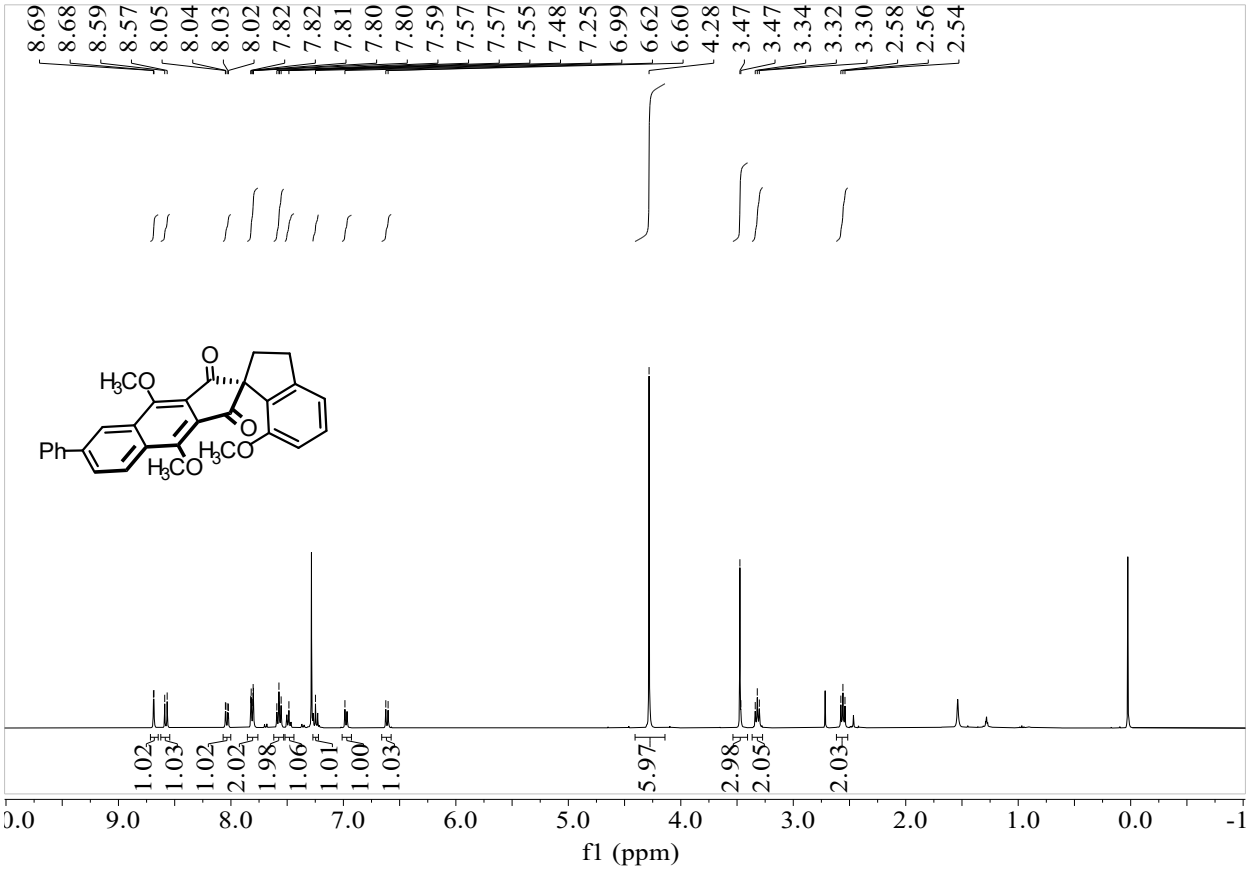

200.94
200.18
161.21
155.07
151.65
149.82
148.51
135.44
130.28
130.17
128.37
126.86
125.63
123.07
122.39
117.60
108.54
102.87
77.16 CDCl3
66.77
63.38
63.07
55.88
55.19
35.86
32.72
H3CO
O
O
H3CO
H3CO
H3CO
f1 (ppm)

Fig.

S30 ^{1}H NMR and ^{13}C NMR spectra of **3e**



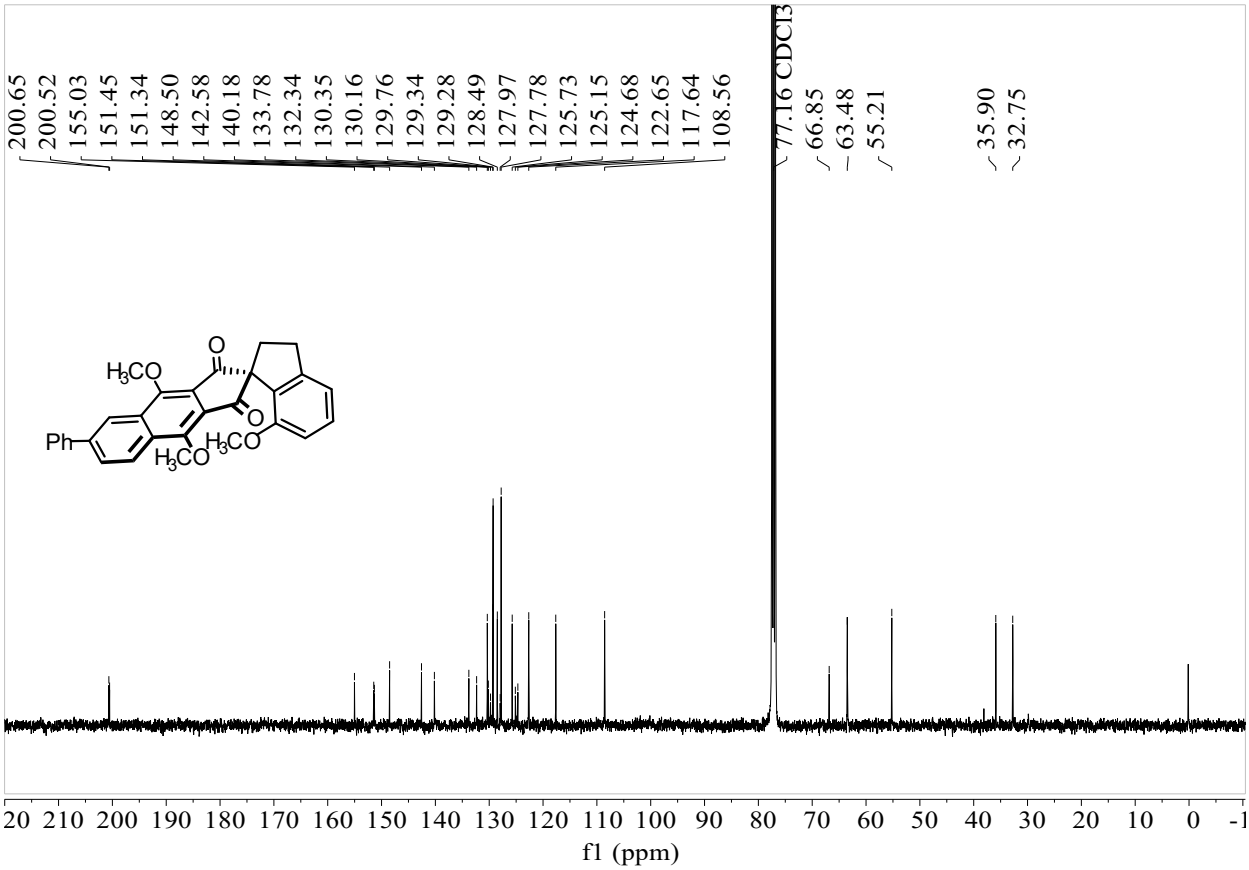
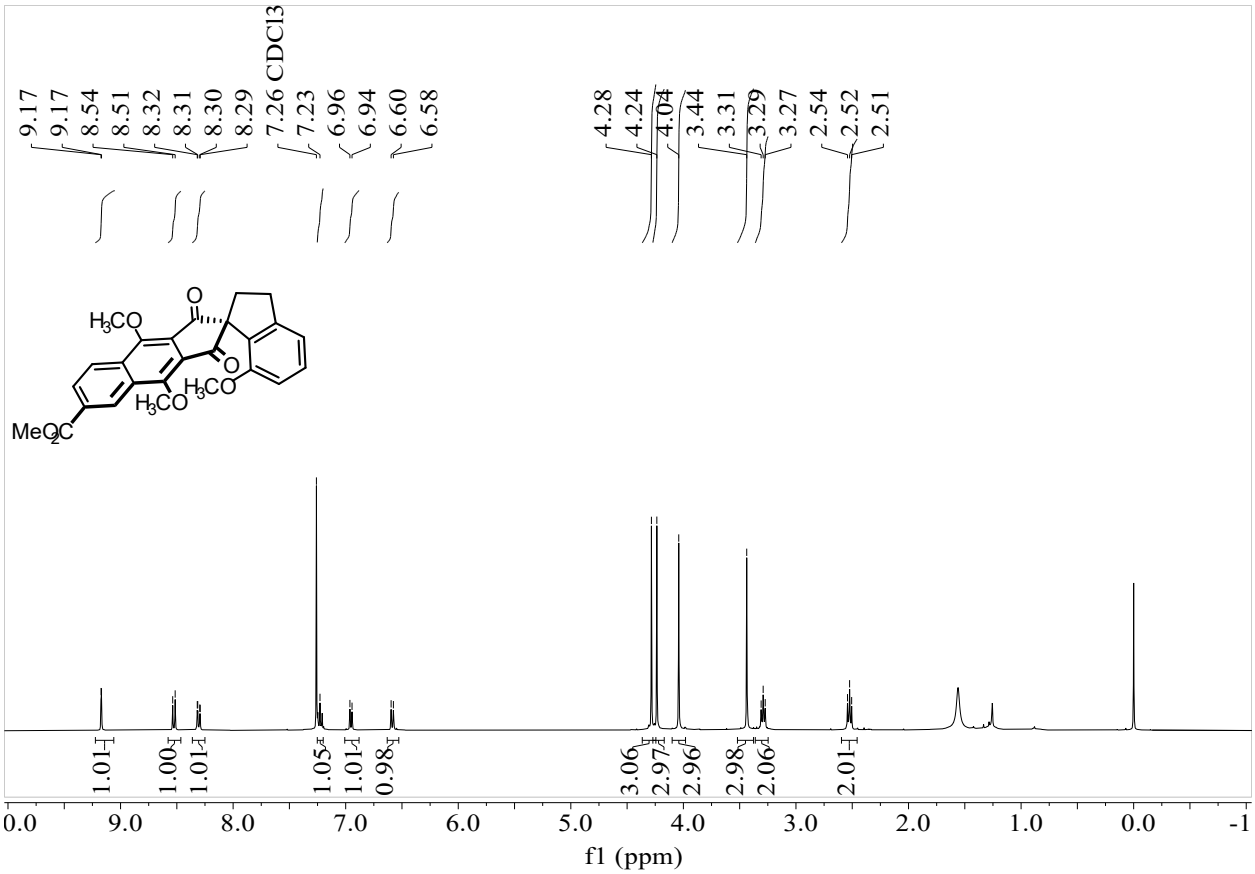


Fig. S31 ^{1}H NMR and ^{13}C NMR spectra of **3f**


9.17
9.17
8.54
8.51
8.32
8.31
8.30
8.29
7.26 CDCl3
7.23
6.96
6.94
6.60
6.58
4.28
4.24
4.04
3.44
3.31
3.29
3.27
2.54
2.52
2.51
1.01
1.00
1.01
1.05
1.01
0.98
3.06
2.97
2.96
2.98
2.06
2.01
f1 (ppm)

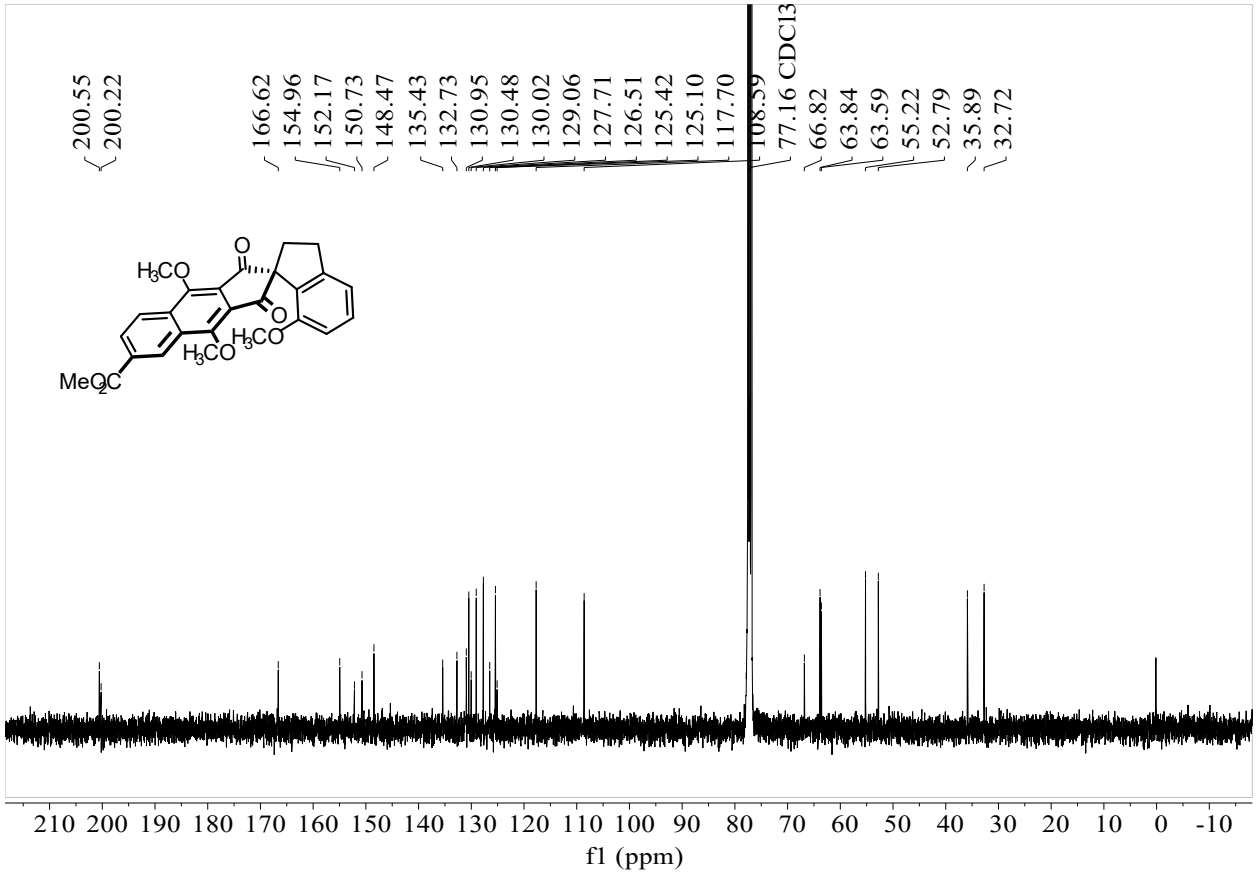
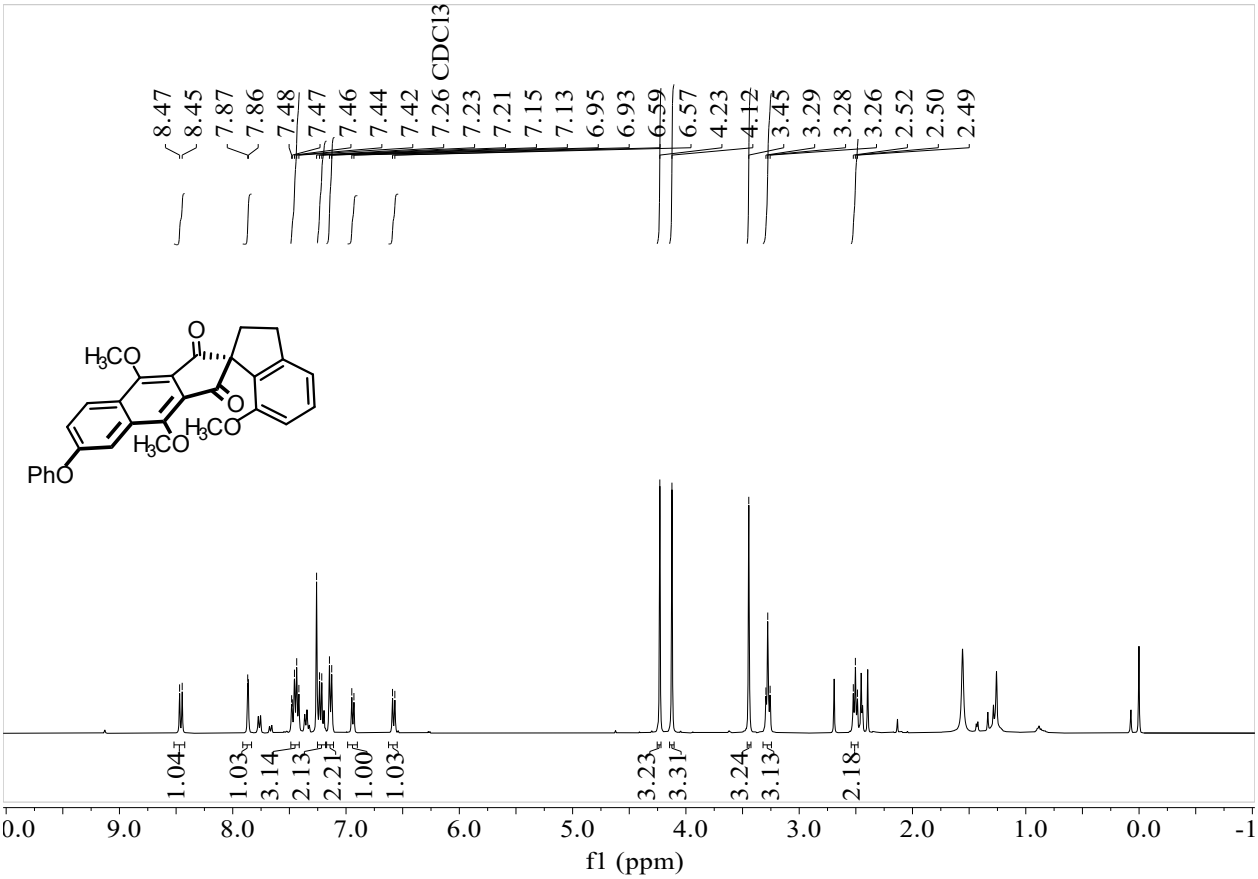
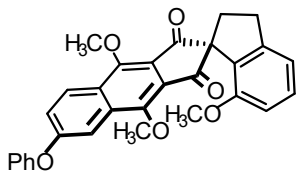

200.55
200.22
166.62
154.96
152.17
150.73
148.47
135.43
132.73
130.95
130.48
130.02
129.06
127.71
126.51
125.42
125.10
117.70
108.59
77.16 CDCl3
66.82
63.84
63.59
55.22
52.79
35.89
32.72
f1 (ppm)

Fig.

S32 ^{1}H NMR and ^{13}C NMR spectra of **3g**





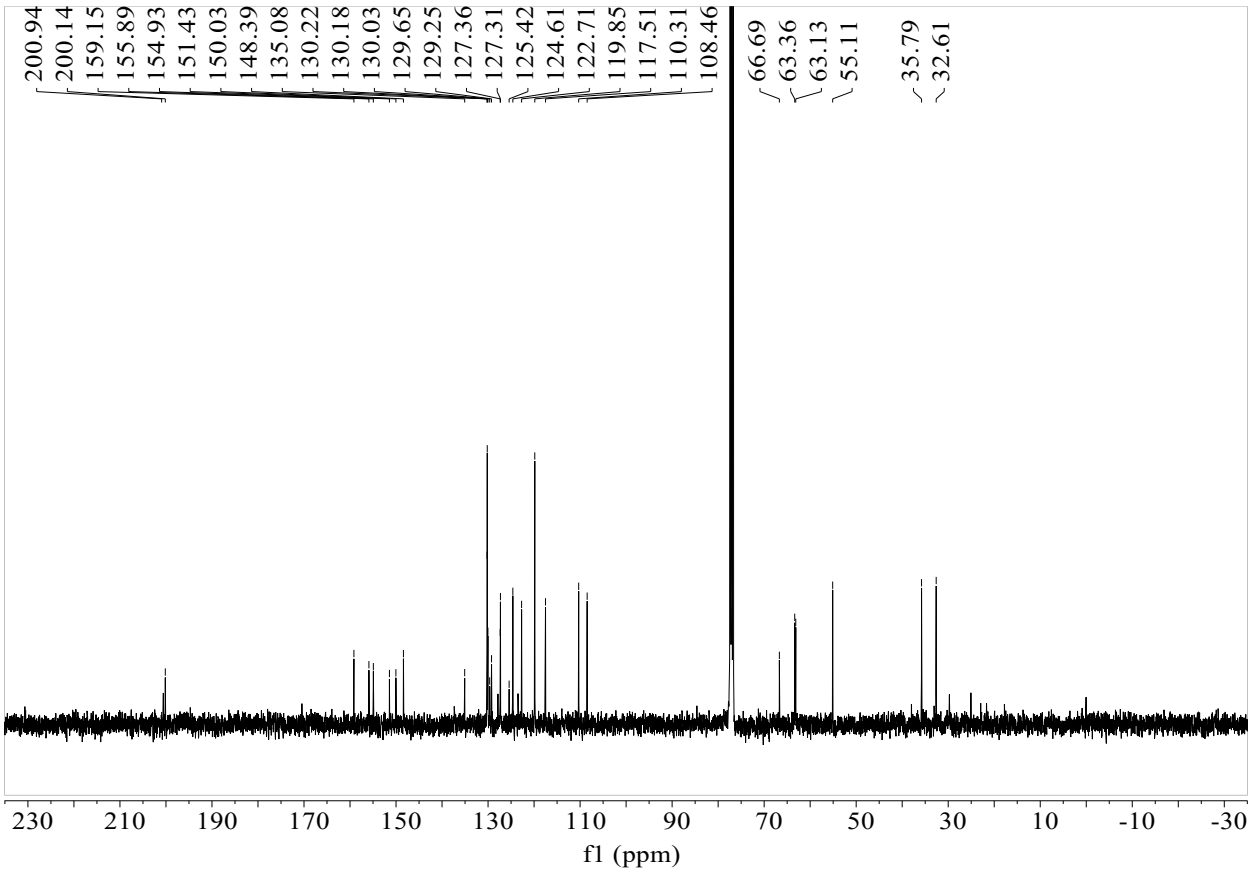
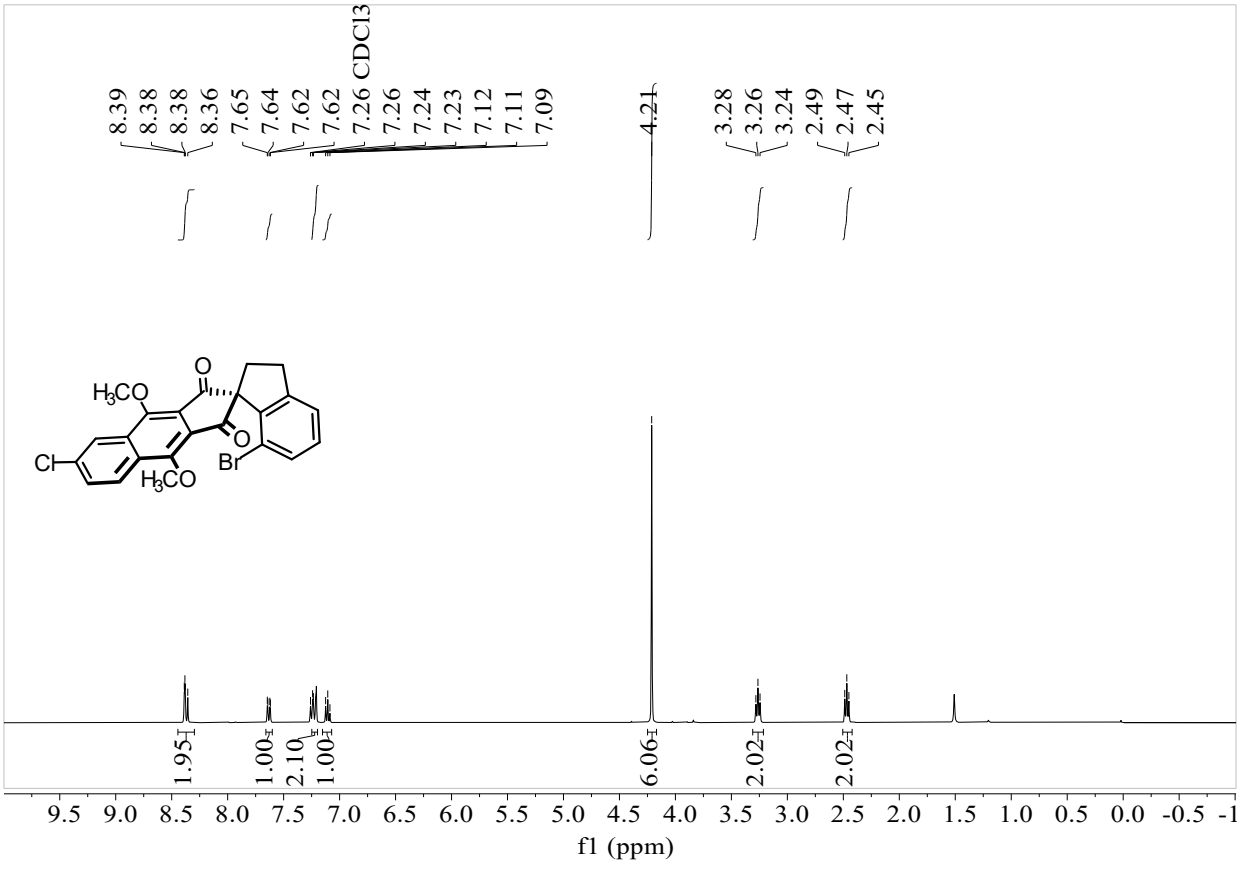


Fig. S33 ^{1}H NMR and ^{13}C NMR spectra of **3h**



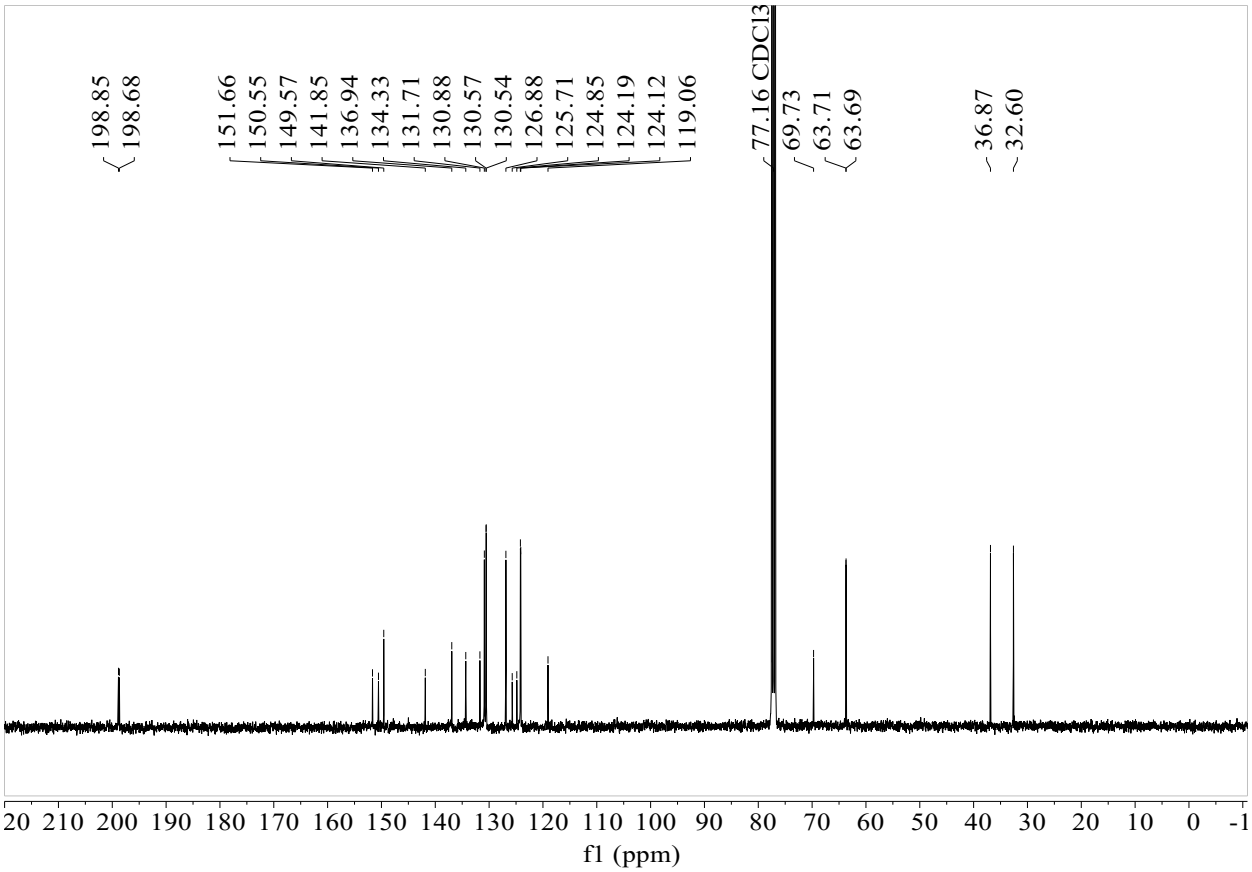
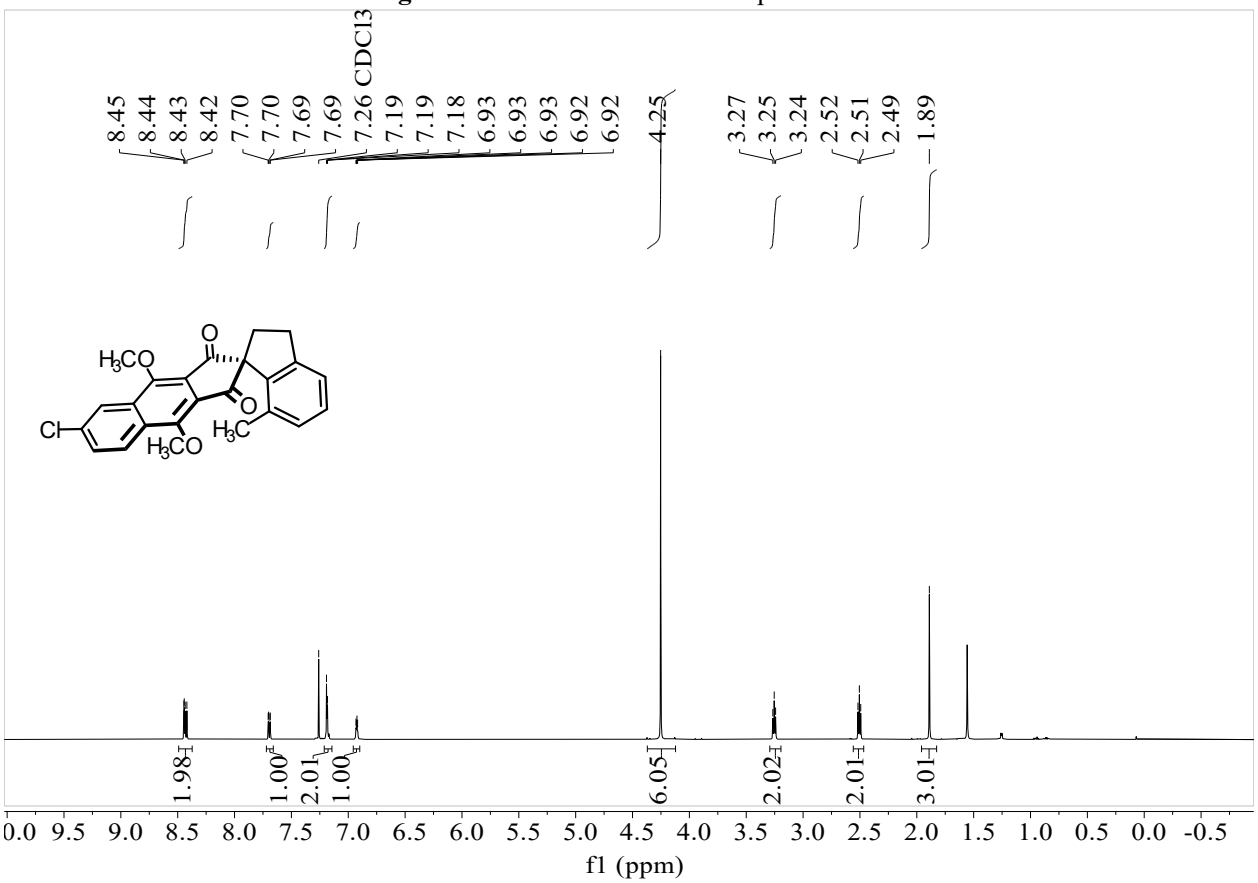


Fig. S34 ^{1}H NMR and ^{13}C NMR spectra of **3i**



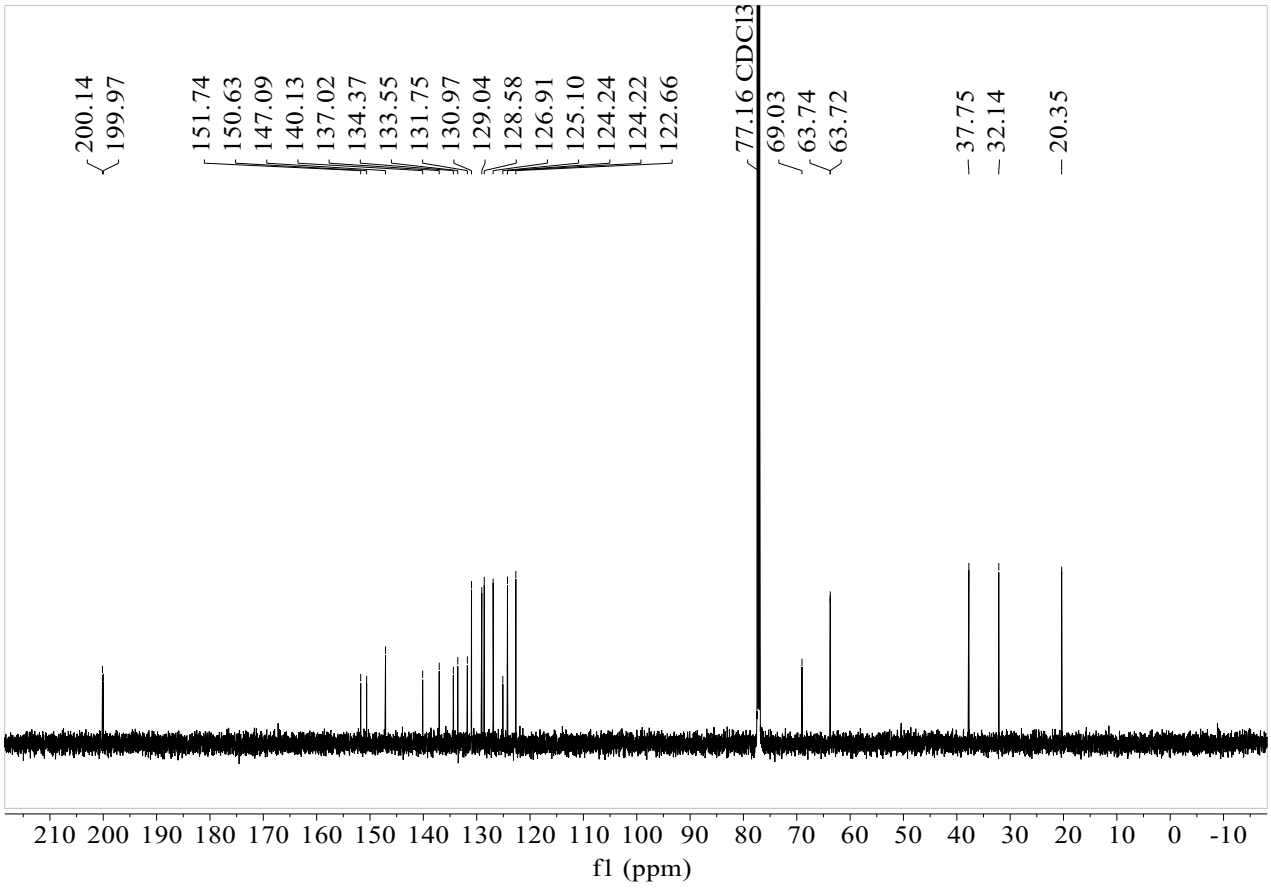
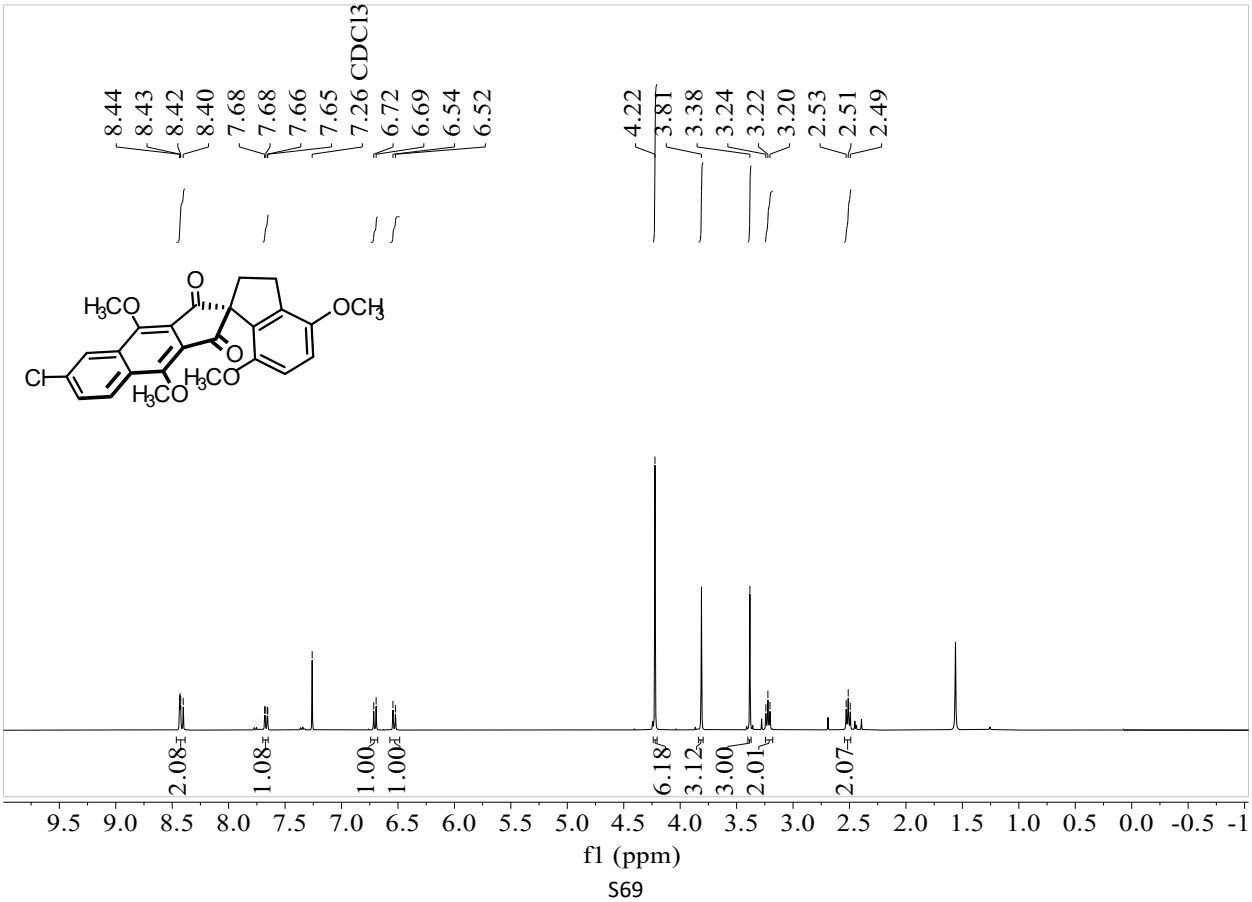


Fig. S35 ^{1}H NMR and ^{13}C NMR spectra of **3j**



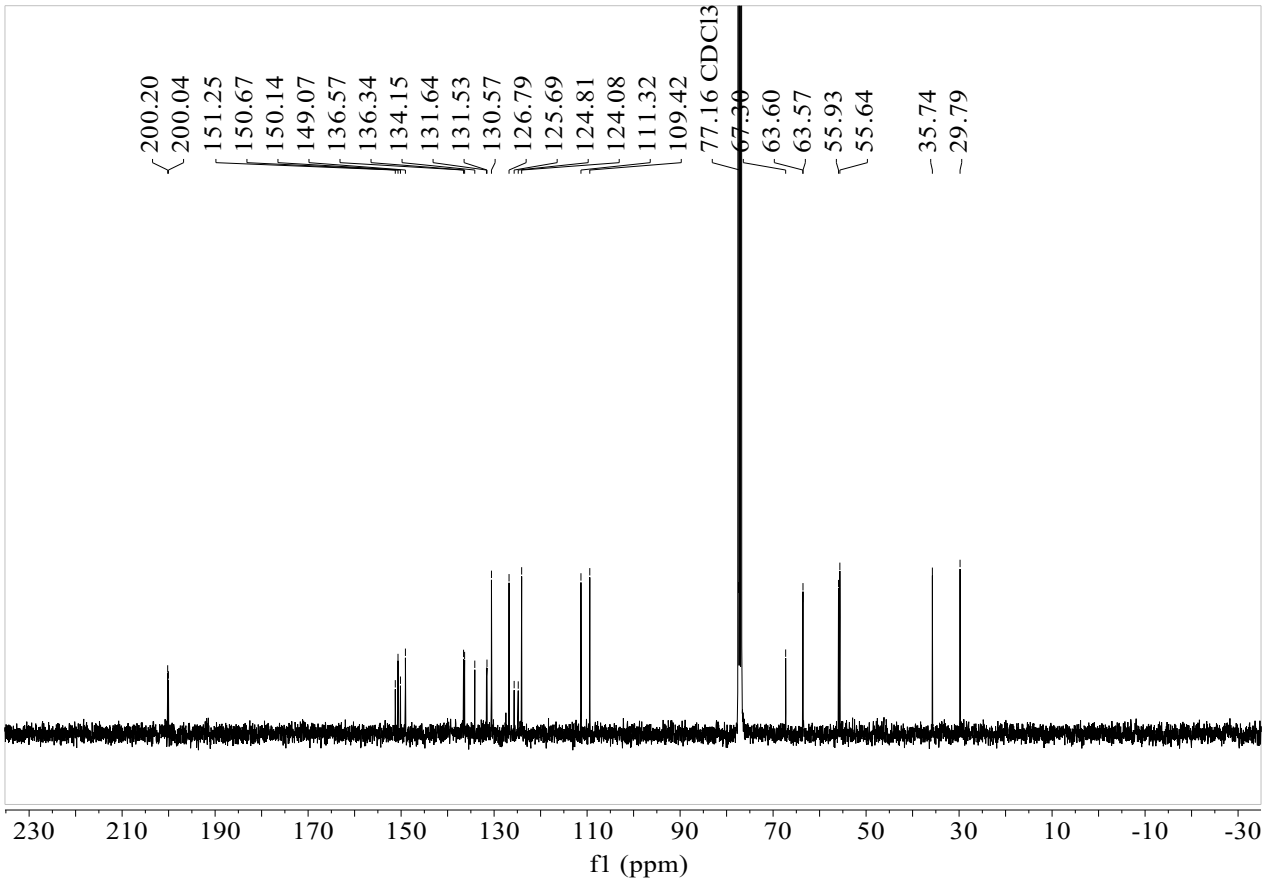


Fig. S36 ^{1}H NMR and ^{13}C NMR spectra of **3k**

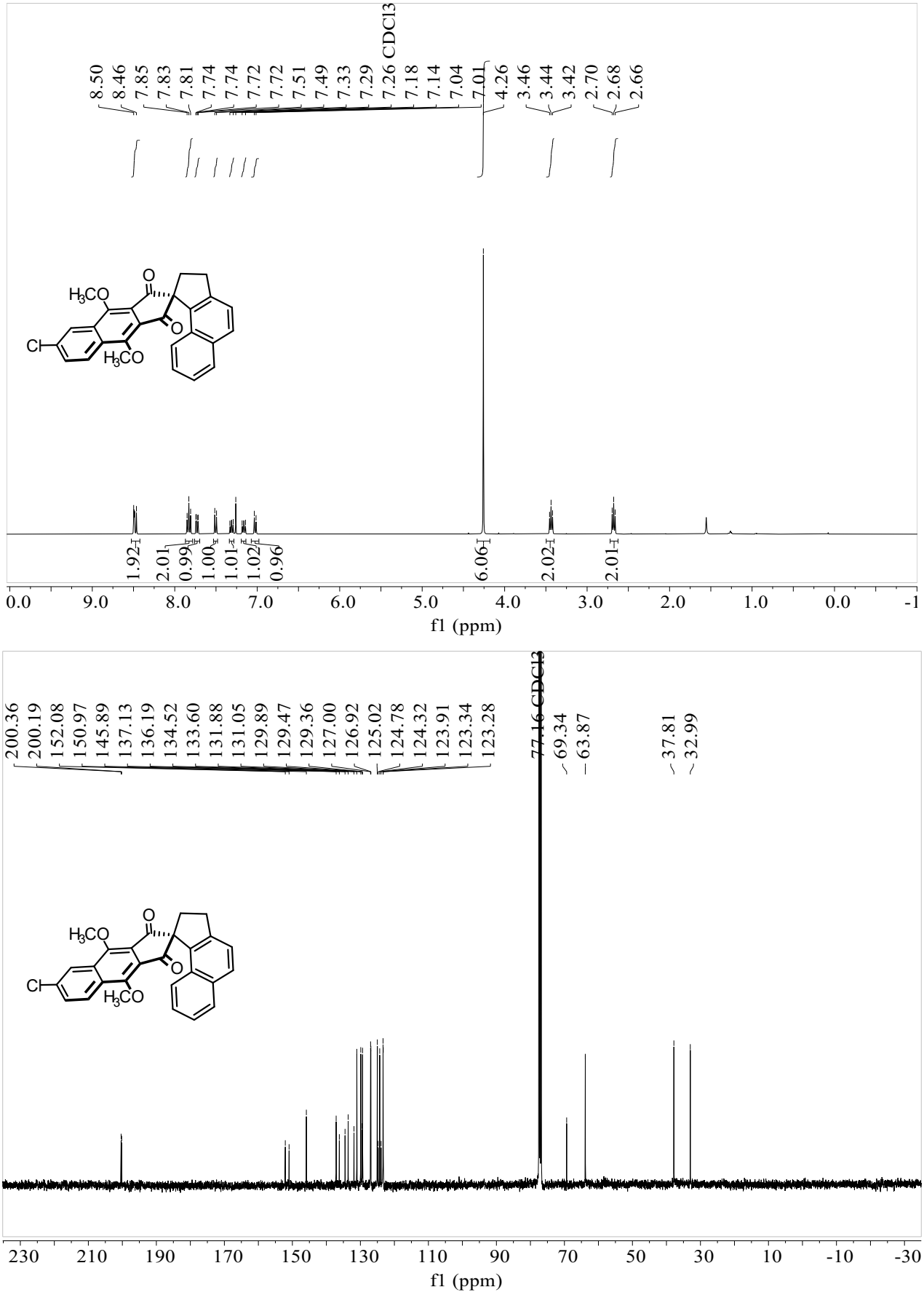
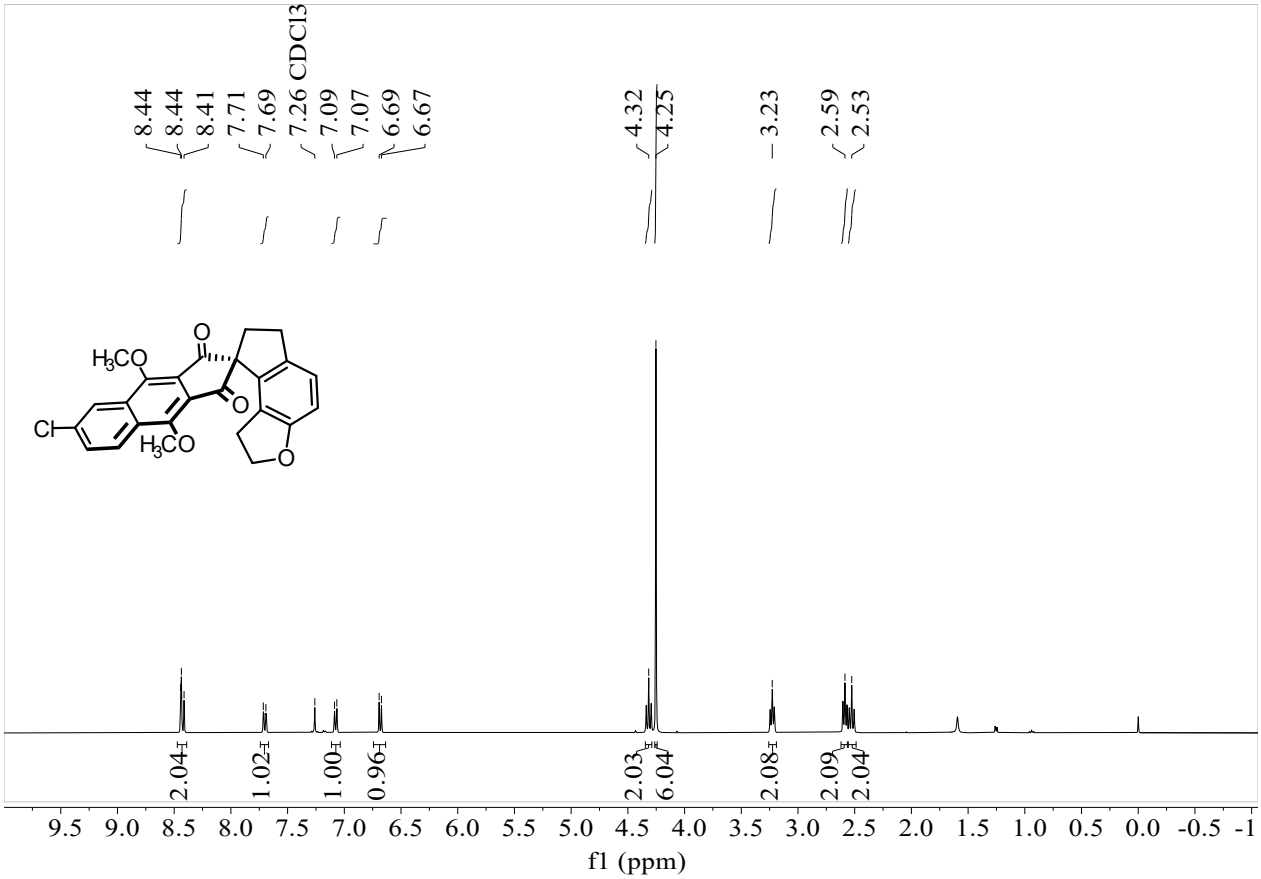


Fig. S37 ^{1}H NMR and ^{13}C NMR spectra of **3l**



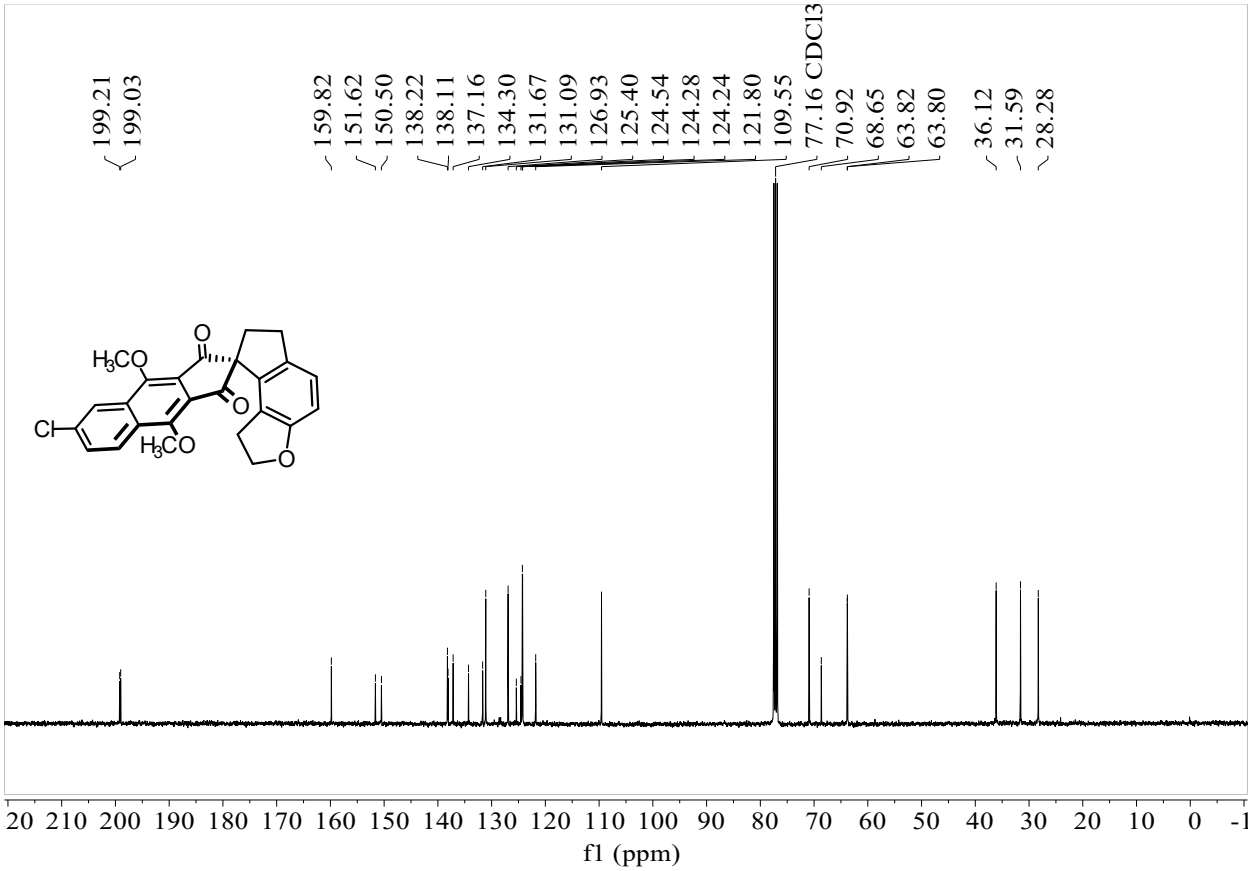
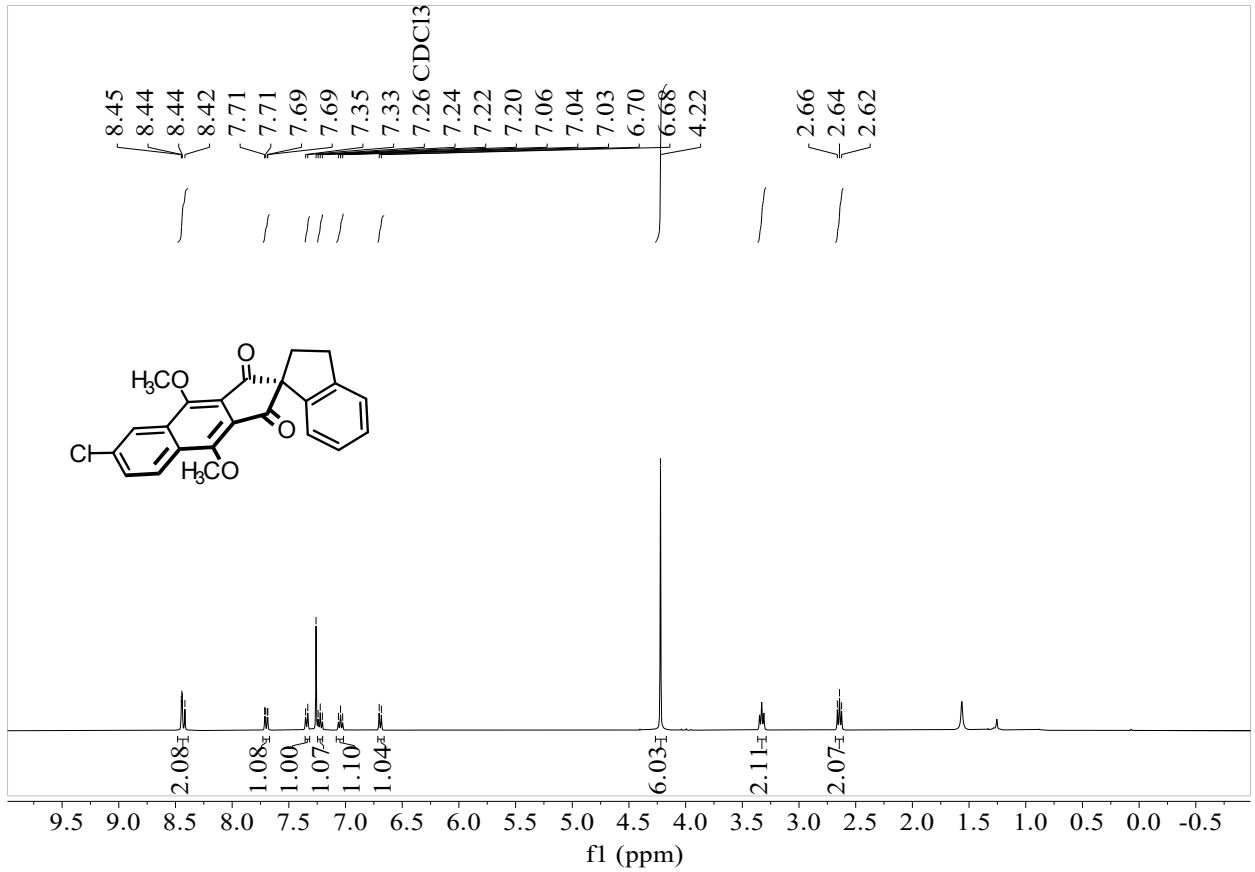


Fig. S38 ^{1}H NMR and ^{13}C NMR spectra of **3m**



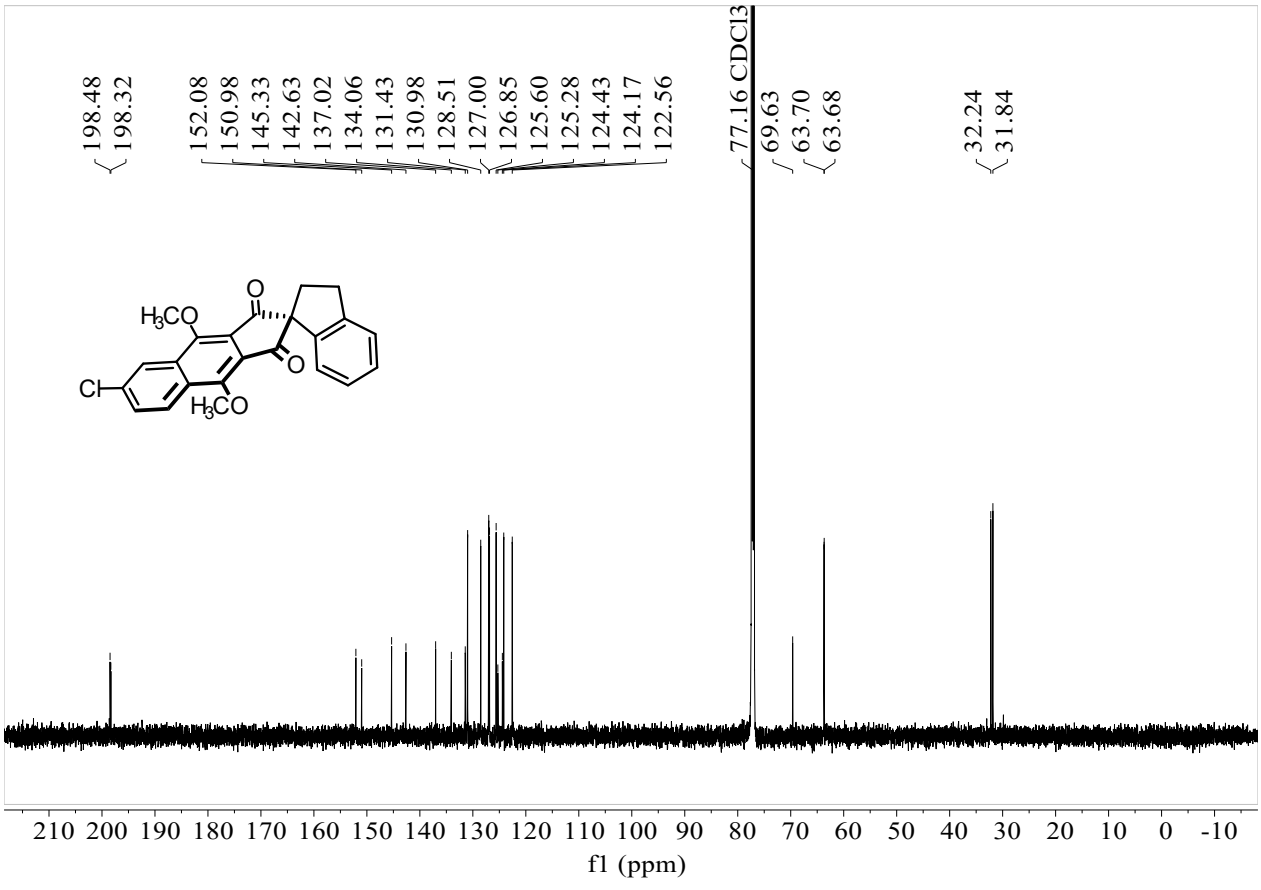
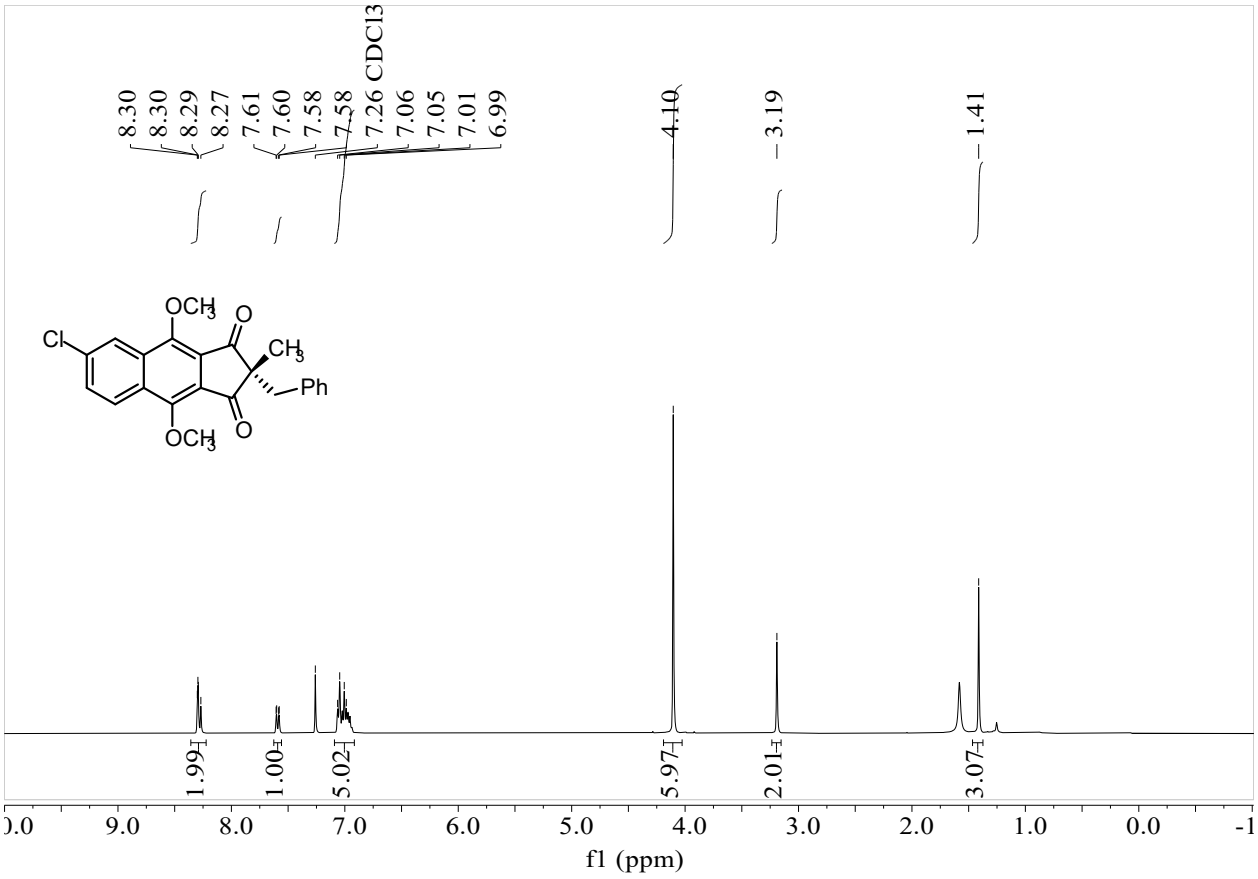


Fig. S39 ^{1}H NMR and ^{13}C NMR spectra of **3n**



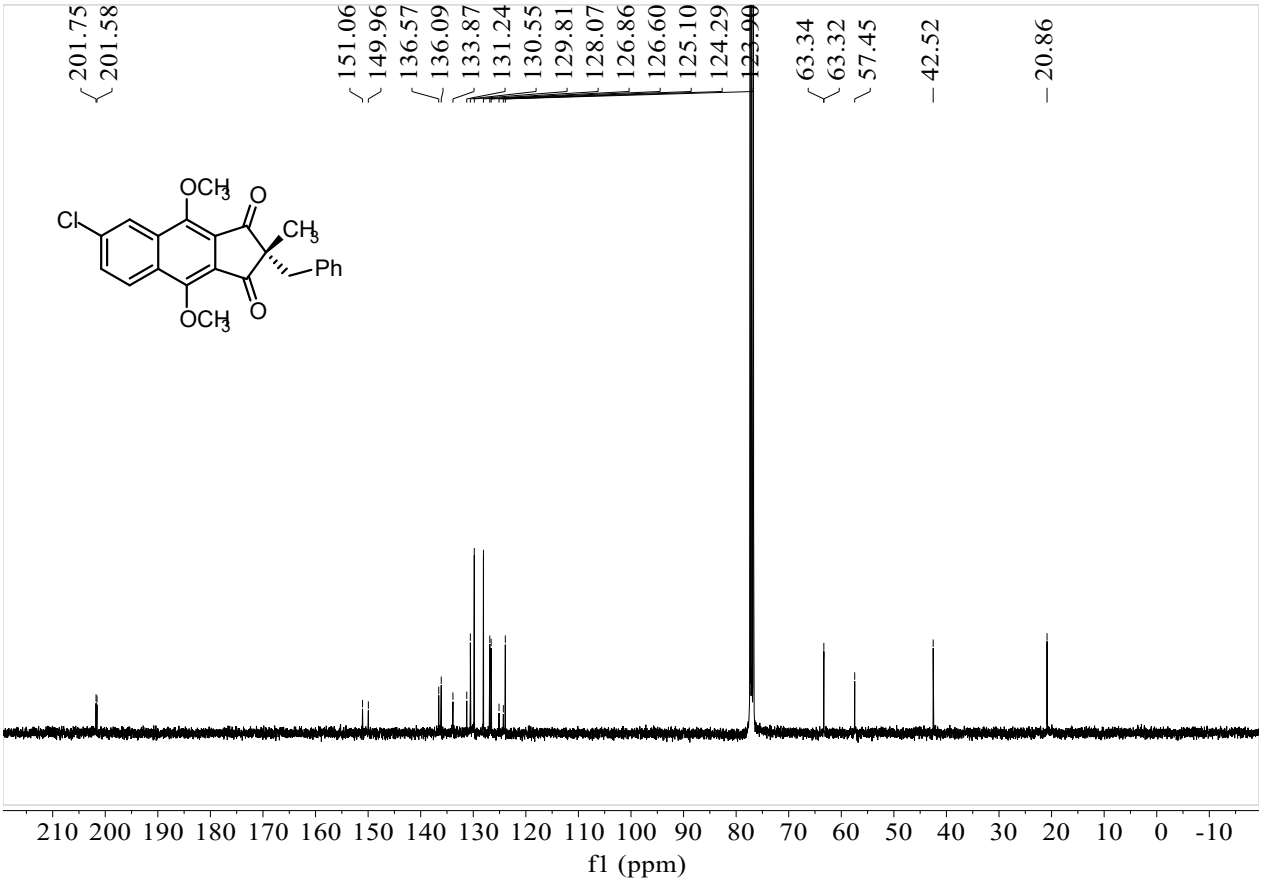
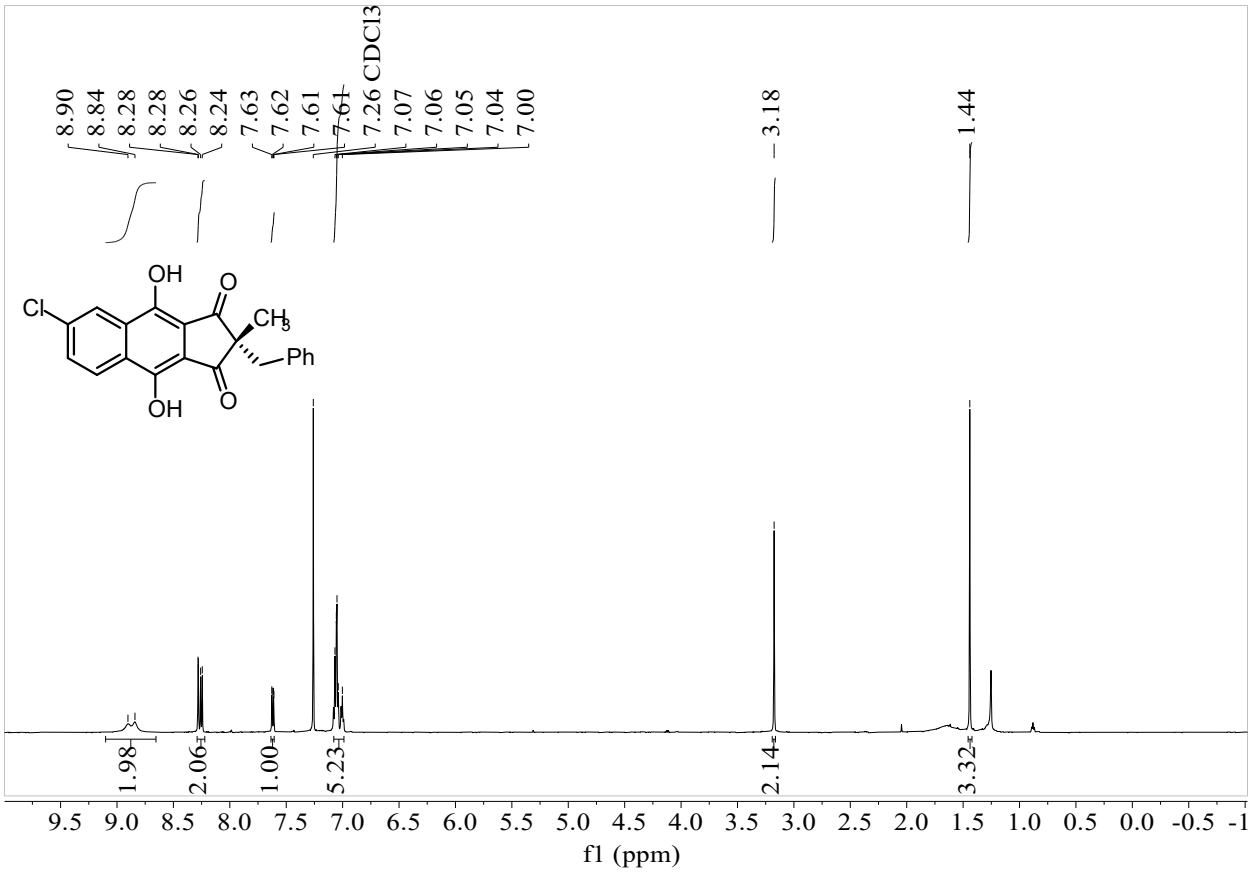


Fig. S40 ^{1}H NMR and ^{13}C NMR spectra of **3o**



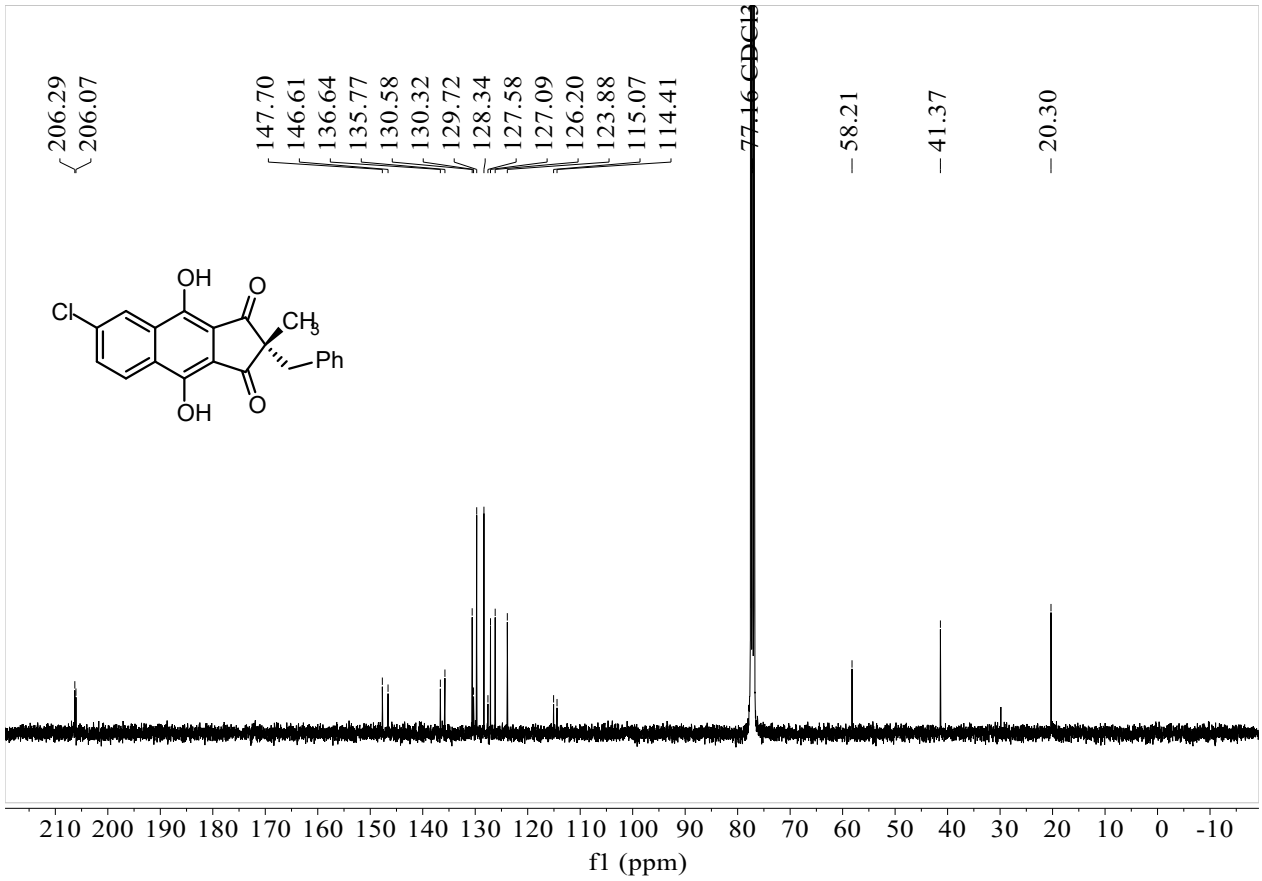
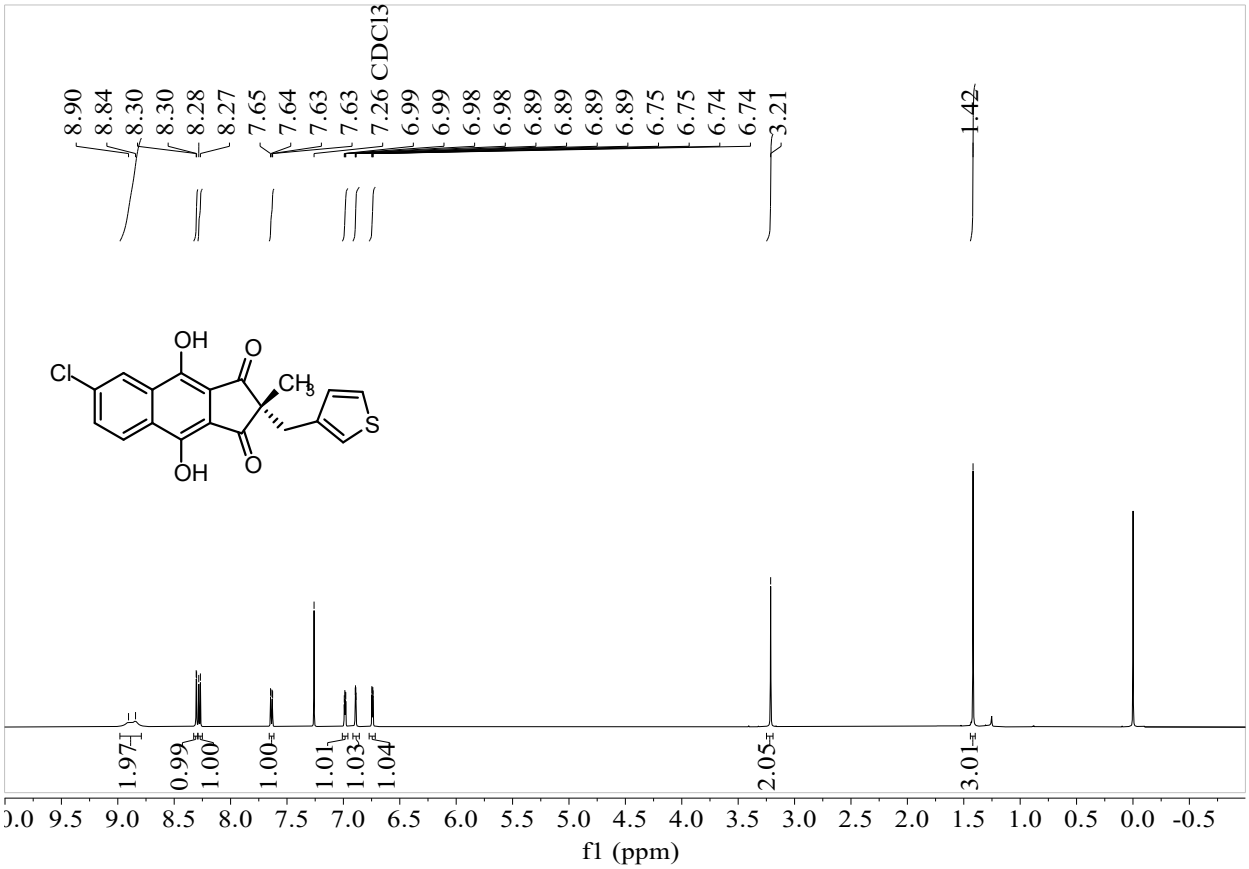


Fig. S41 ^{1}H NMR and ^{13}C NMR spectra of **3o'**



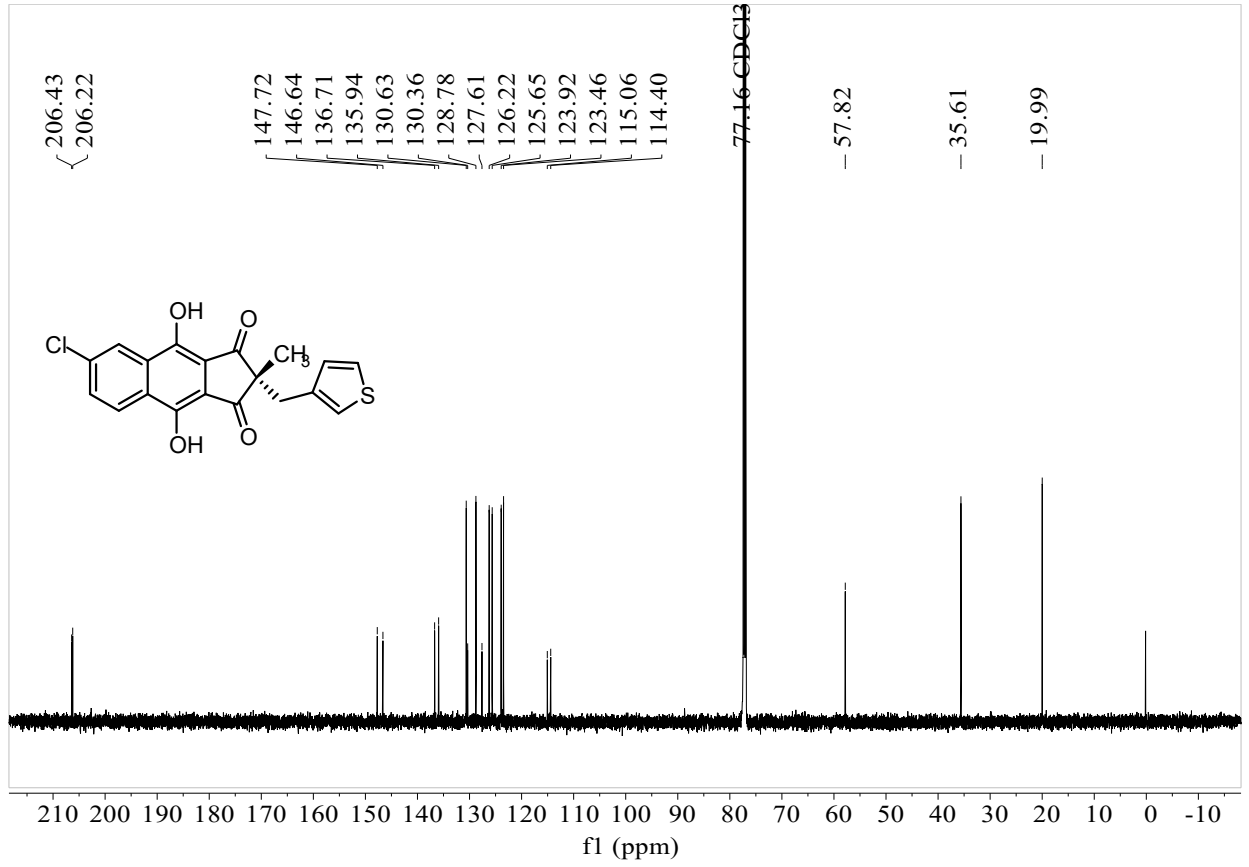
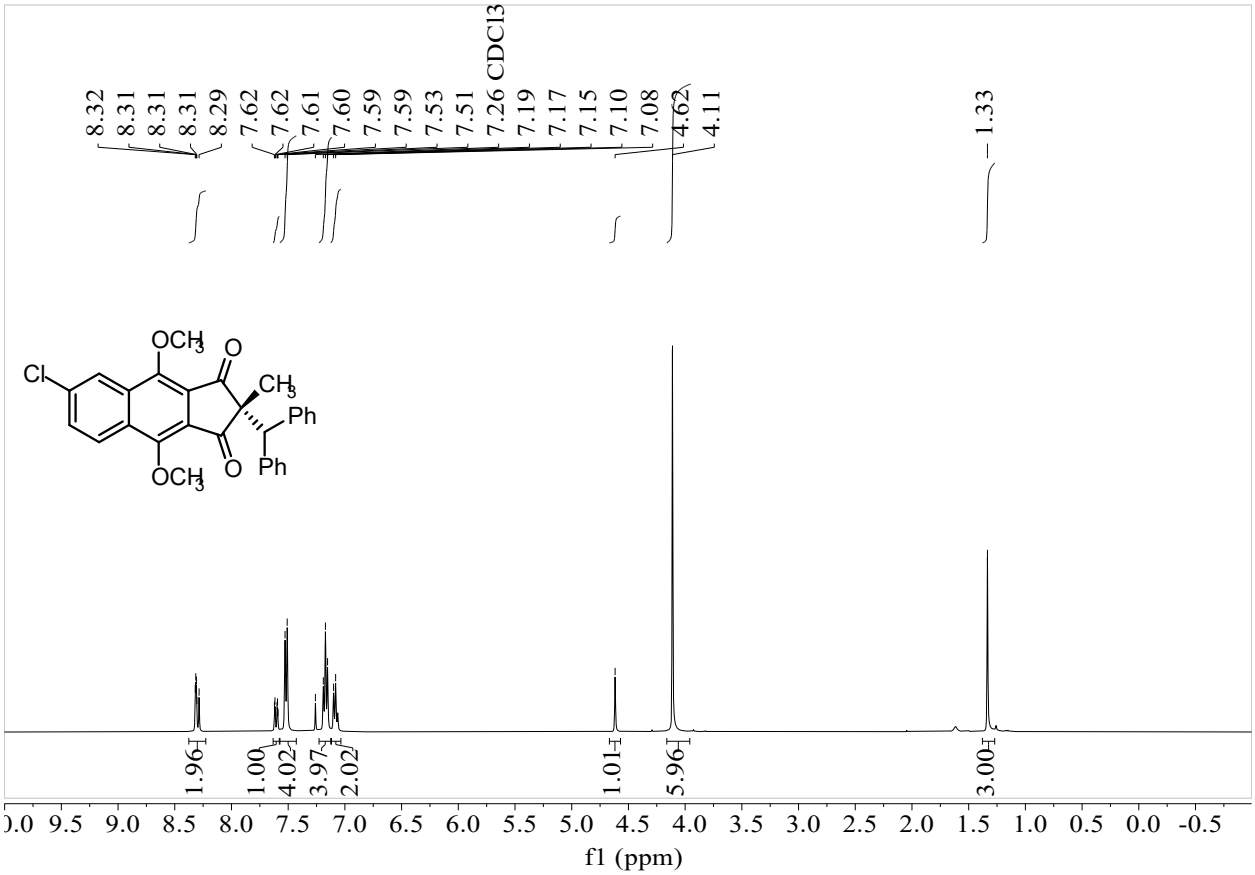


Fig. S42 ^{1}H NMR and ^{13}C NMR spectra of **3p**



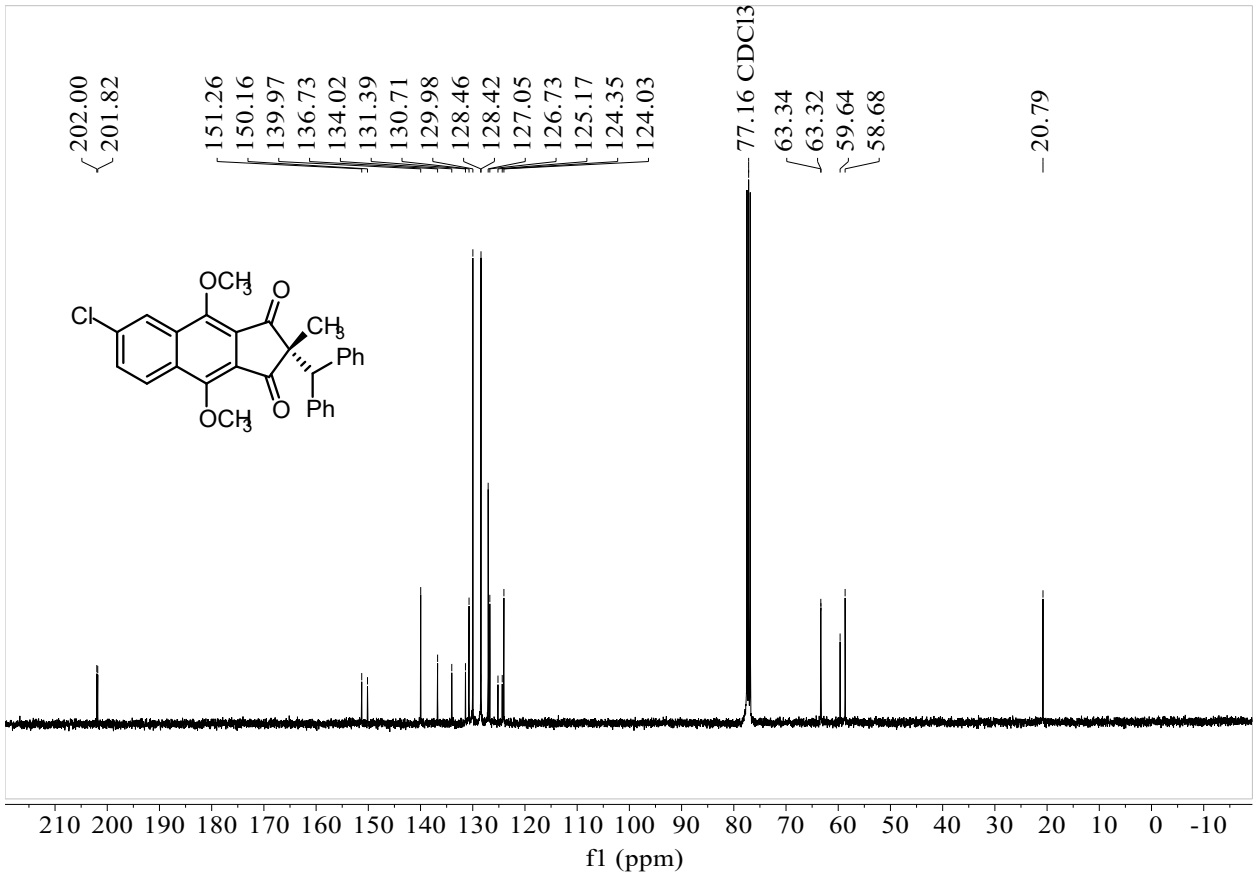
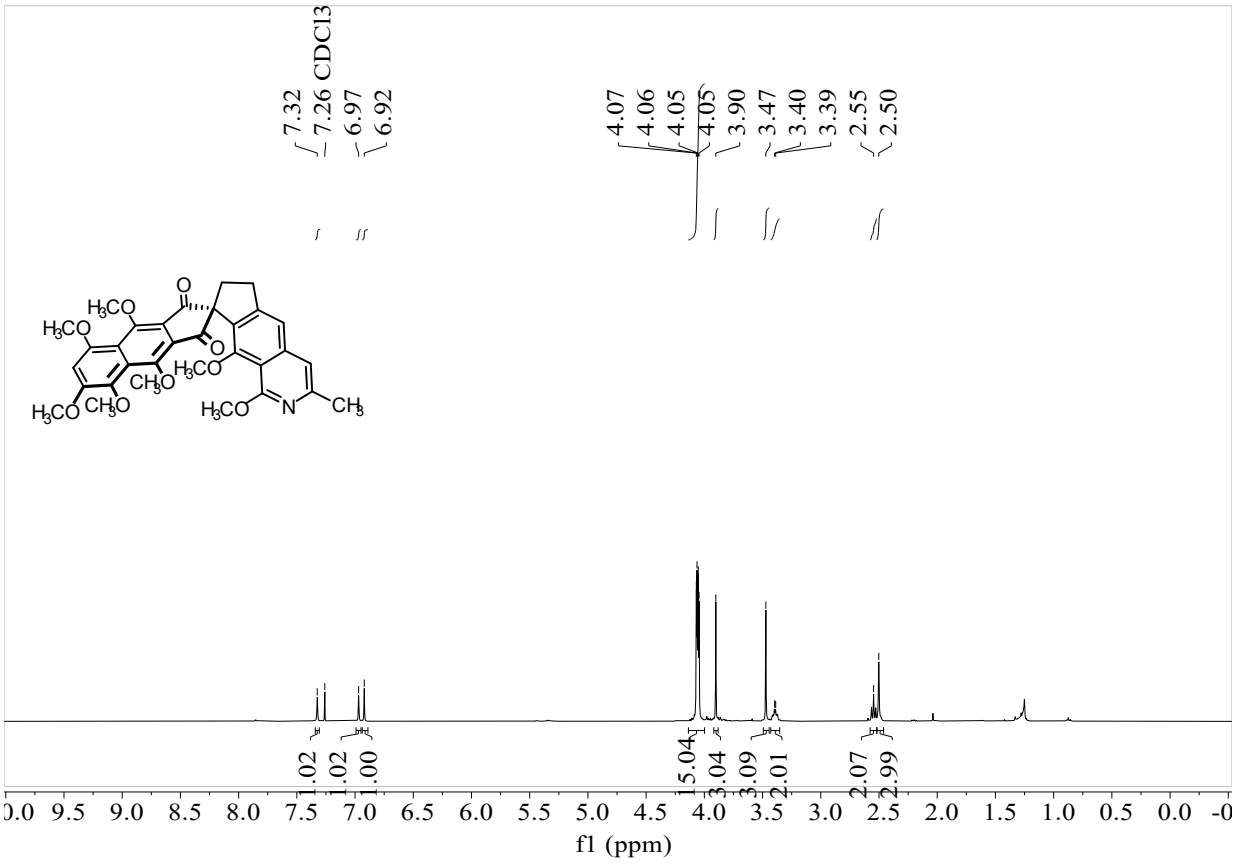


Fig. S43 ^{1}H NMR and ^{13}C NMR spectra of **3q**



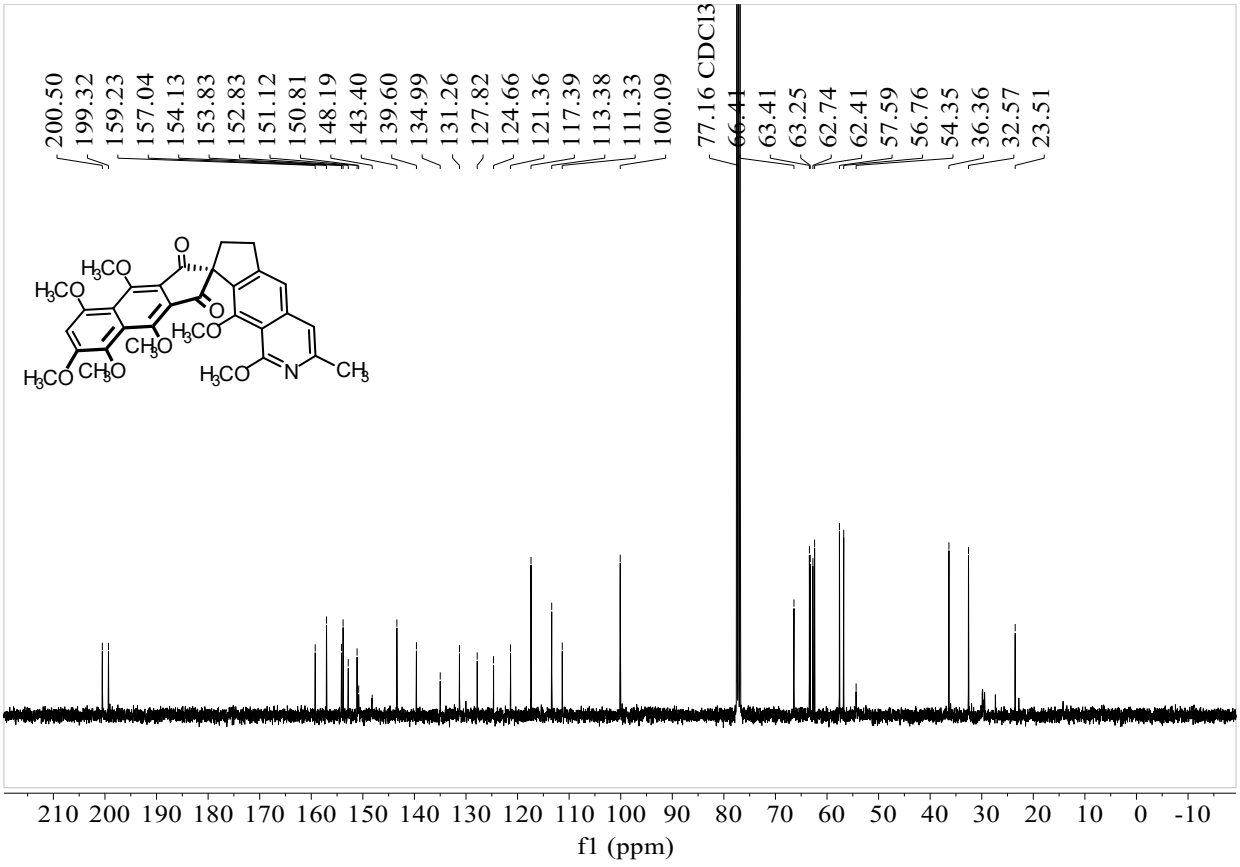
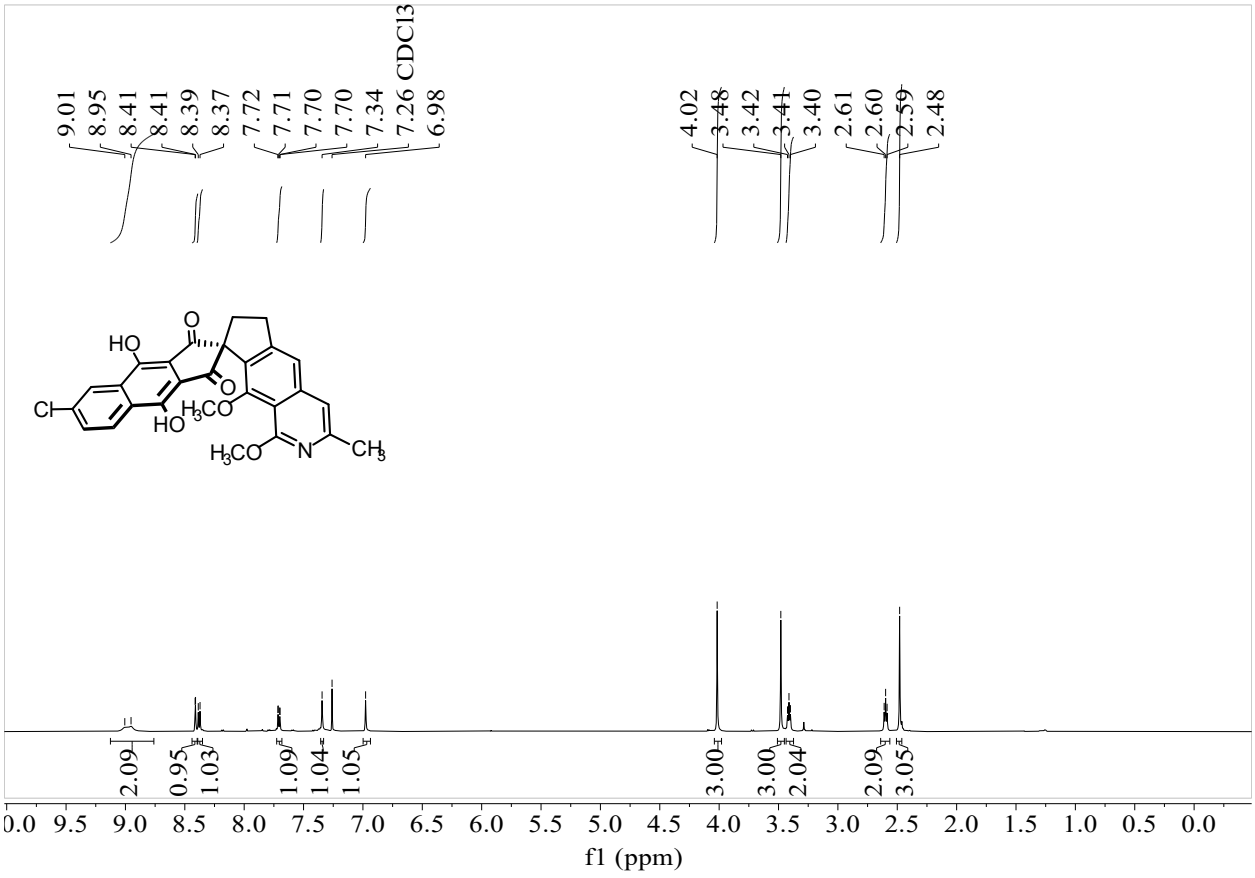


Fig. S44 ^{1}H NMR and ^{13}C NMR spectra of **3r**



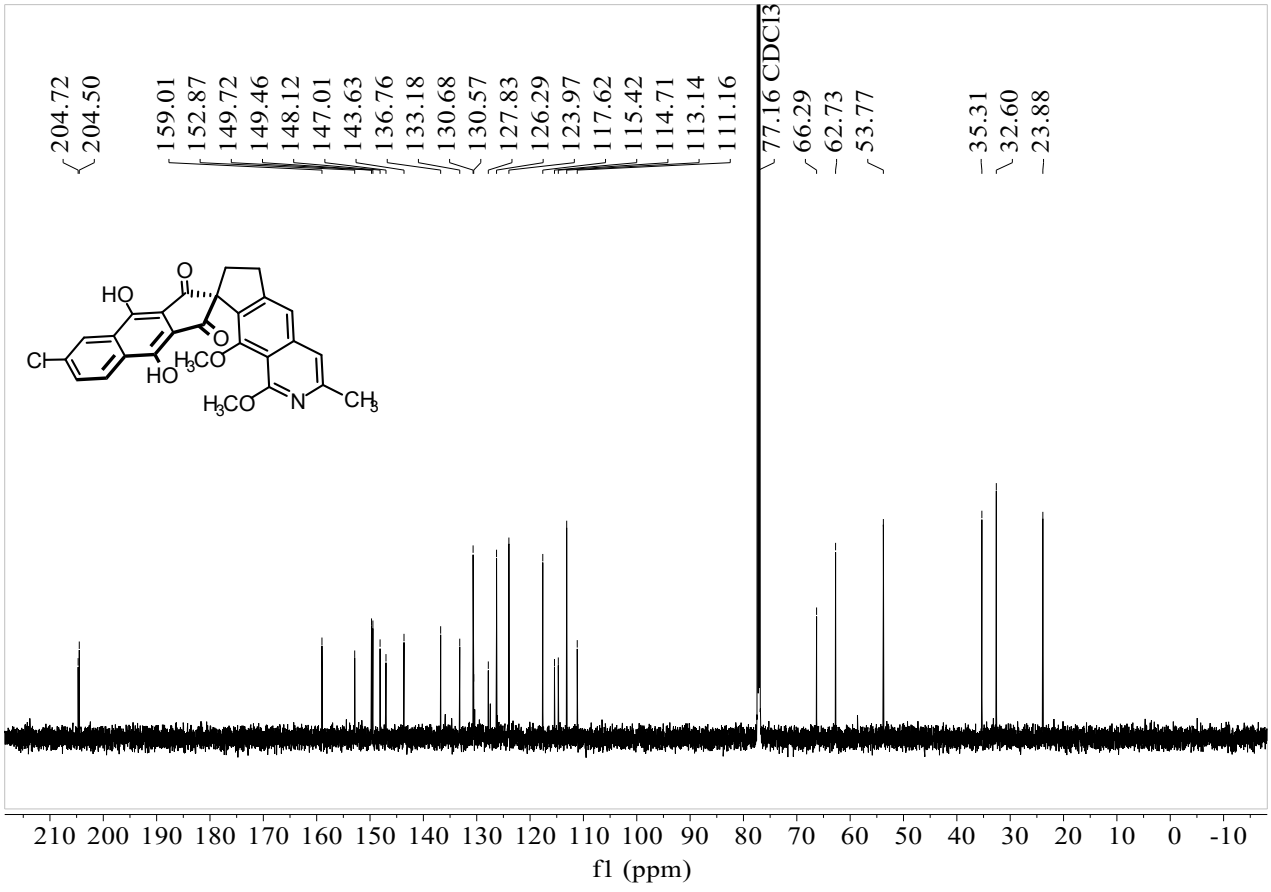
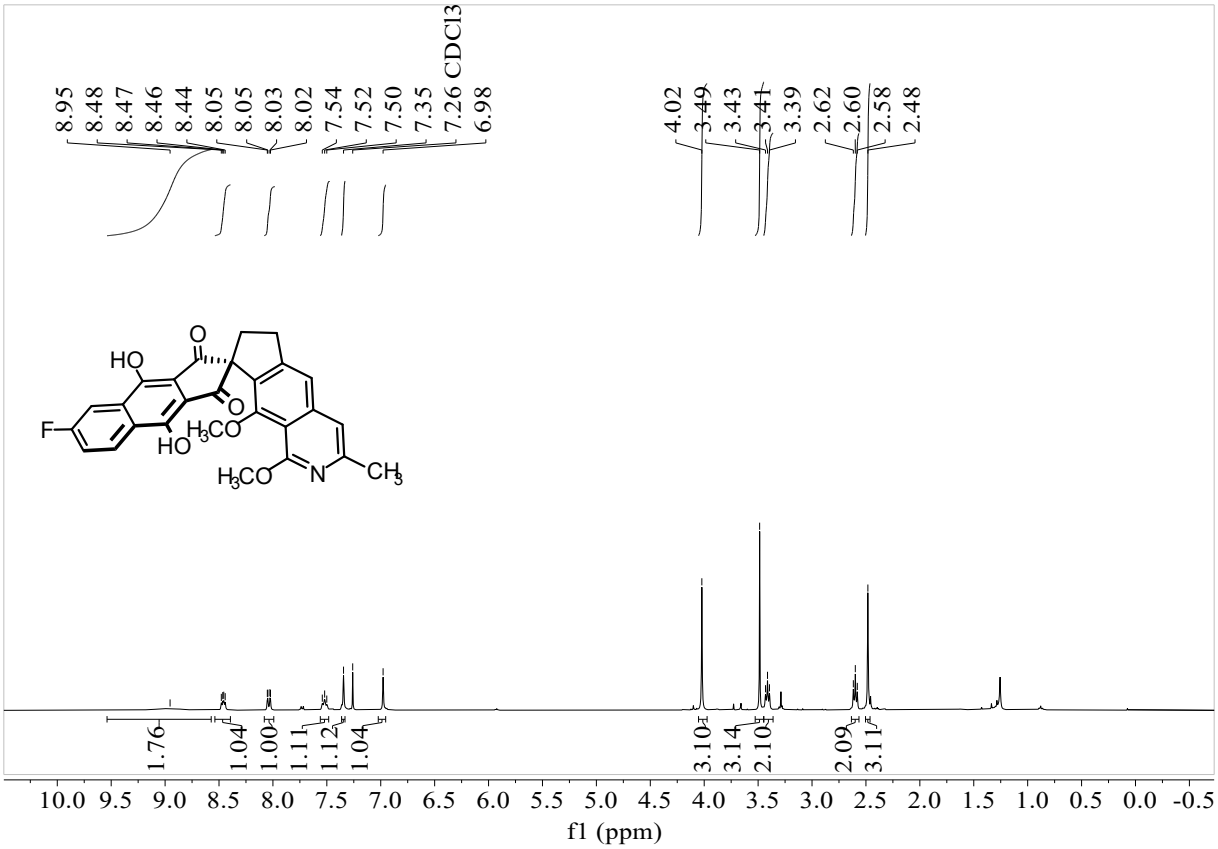


Fig. S45 ^{1}H NMR and ^{13}C NMR spectra of **3s**



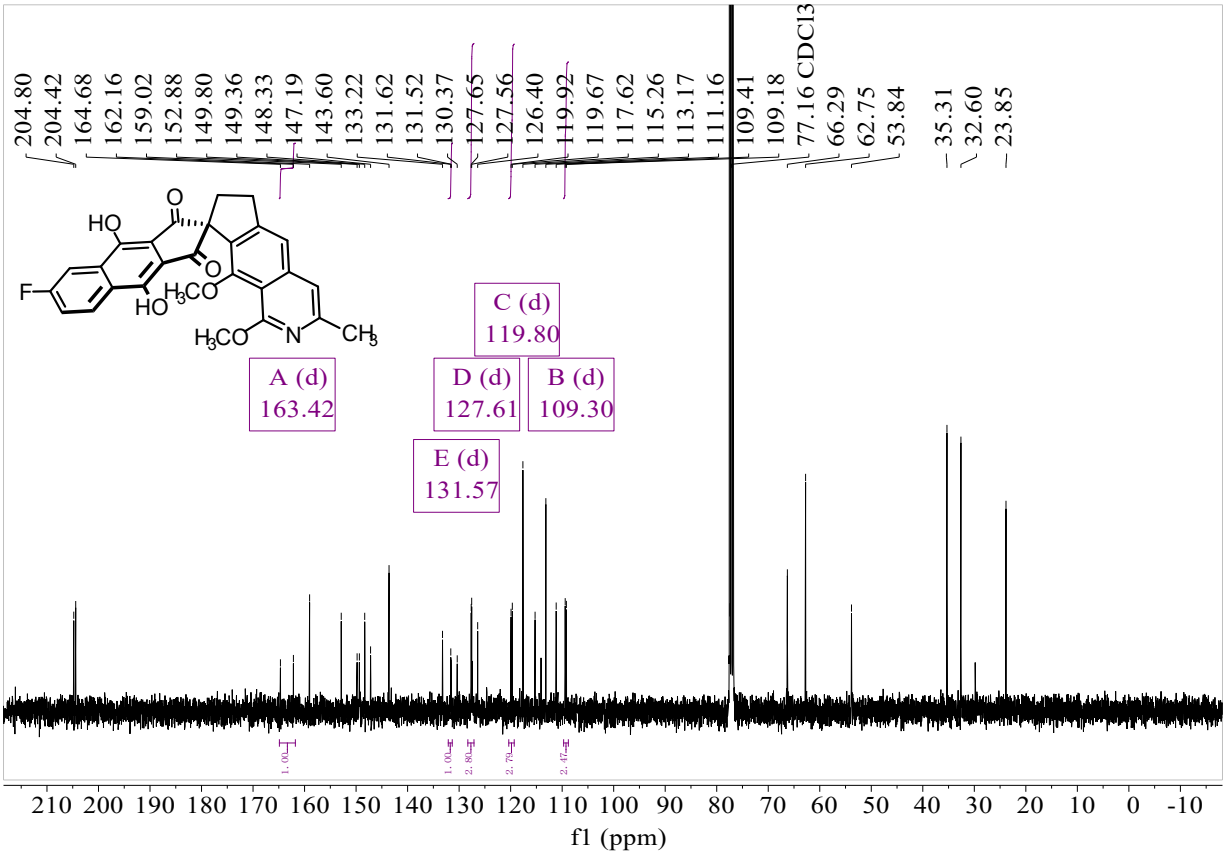


Fig. S46 ^{1}H NMR and ^{13}C NMR spectra of **3t**

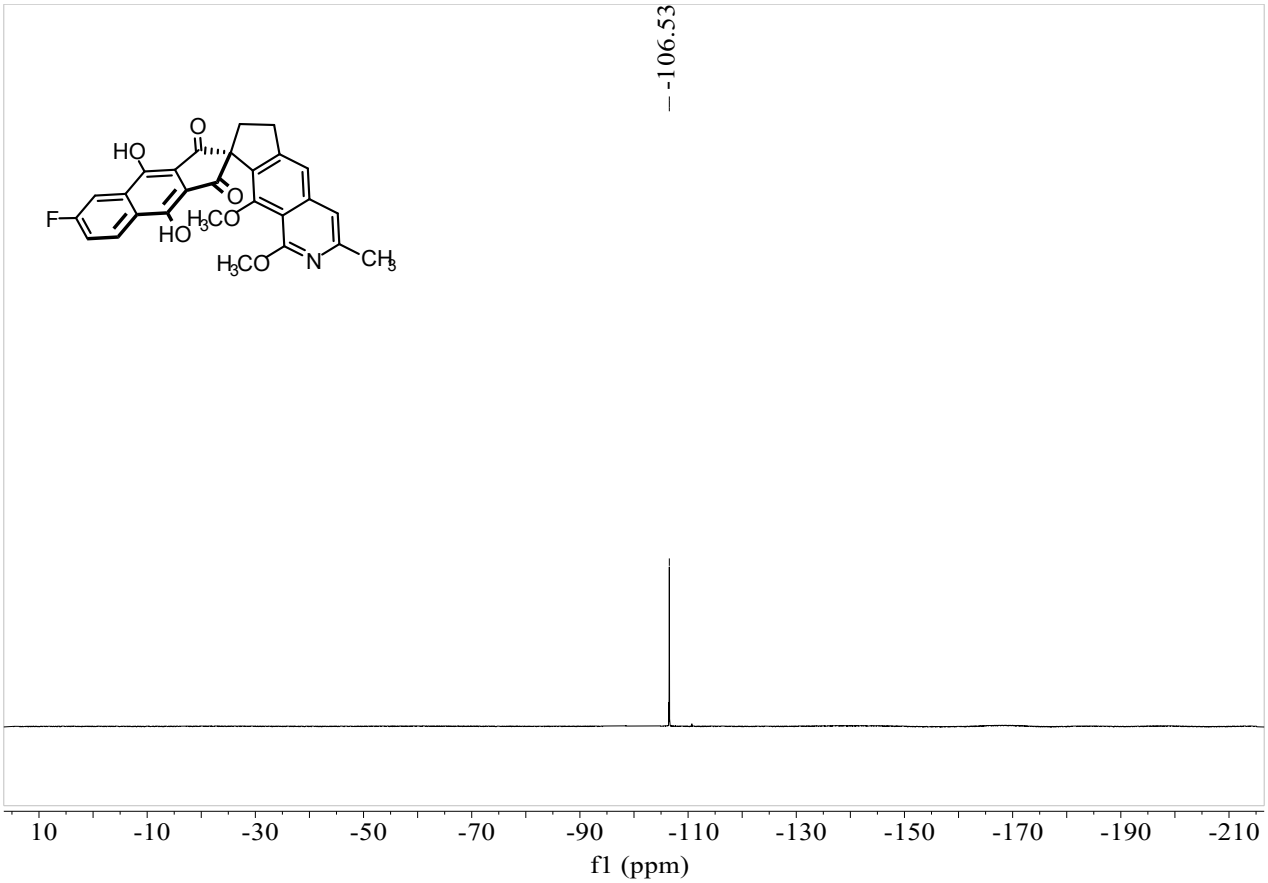
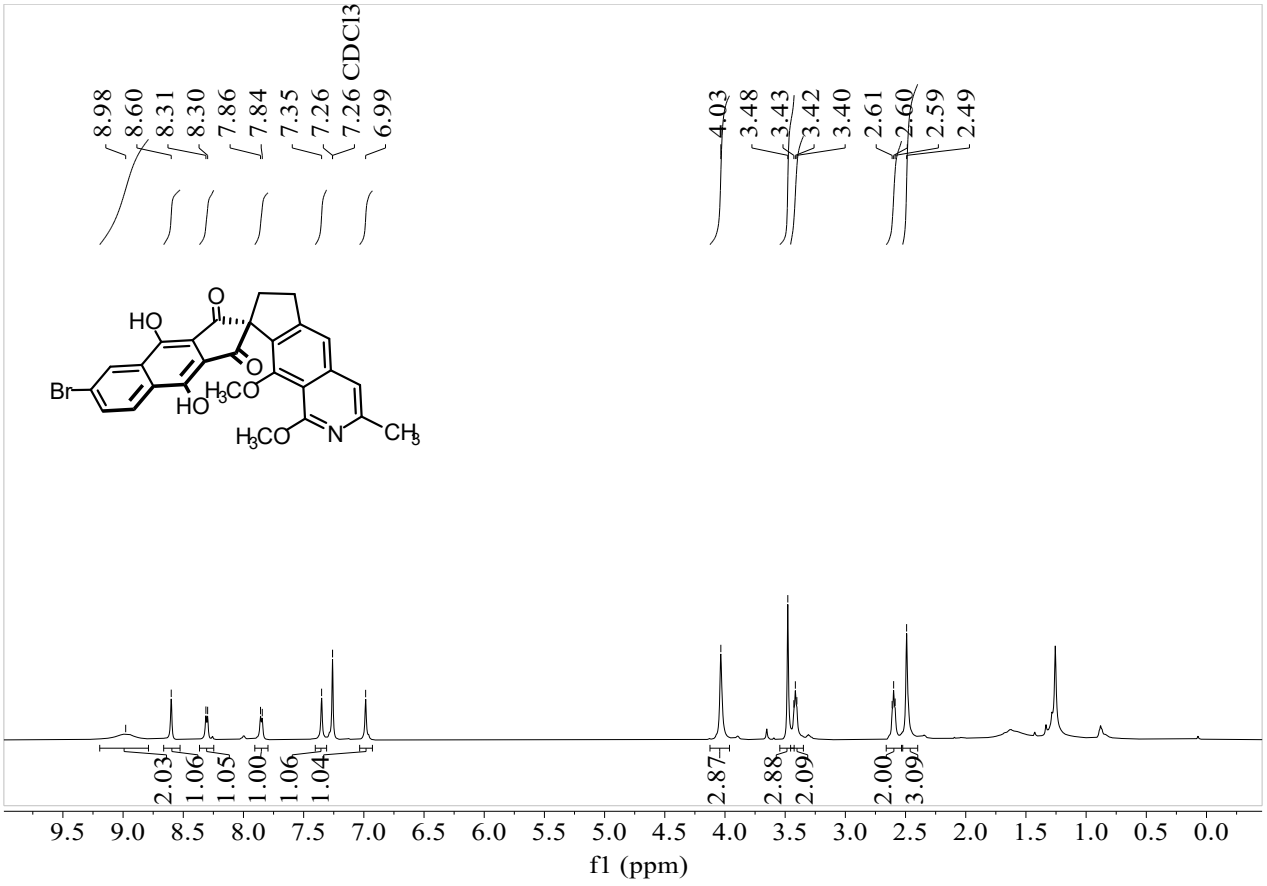


Fig. S47 ^{19}F NMR spectra of **3t**



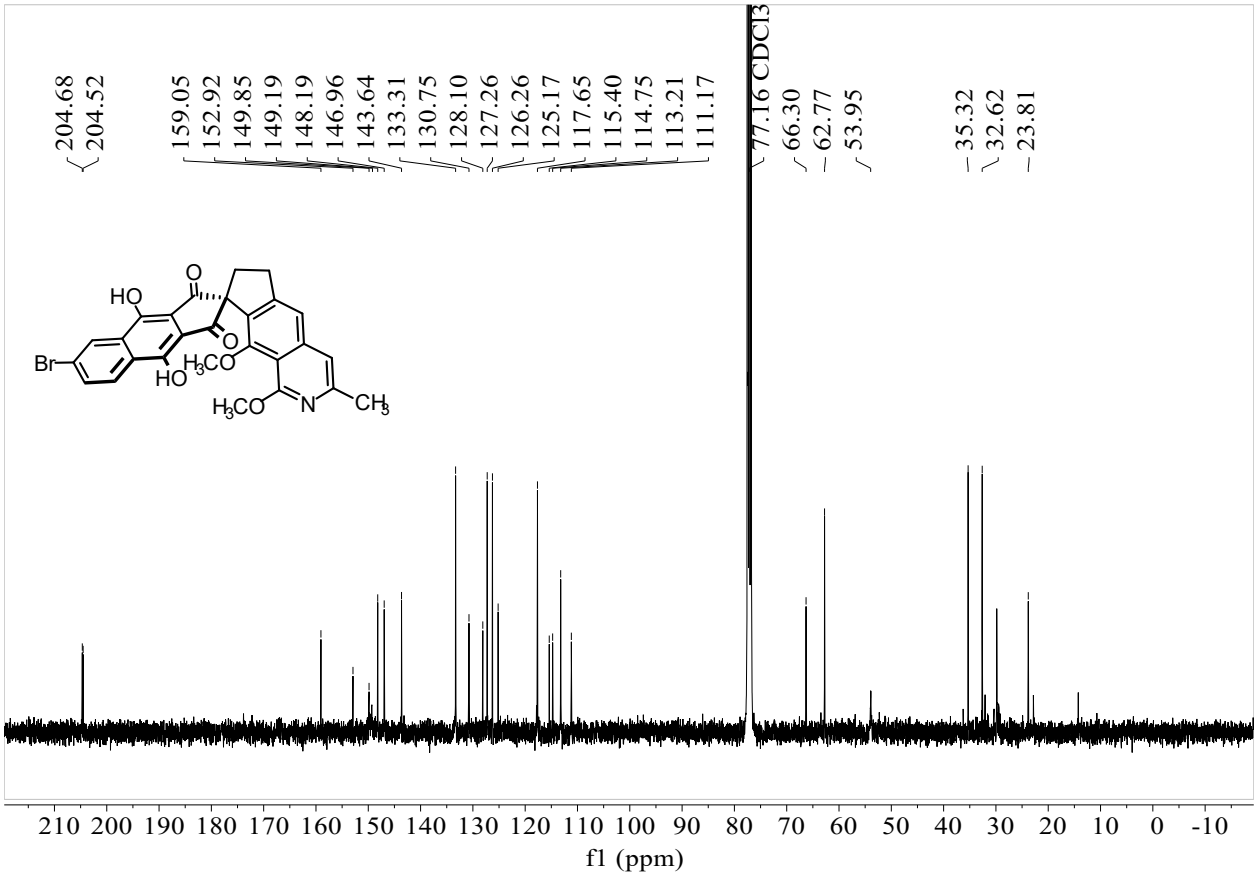
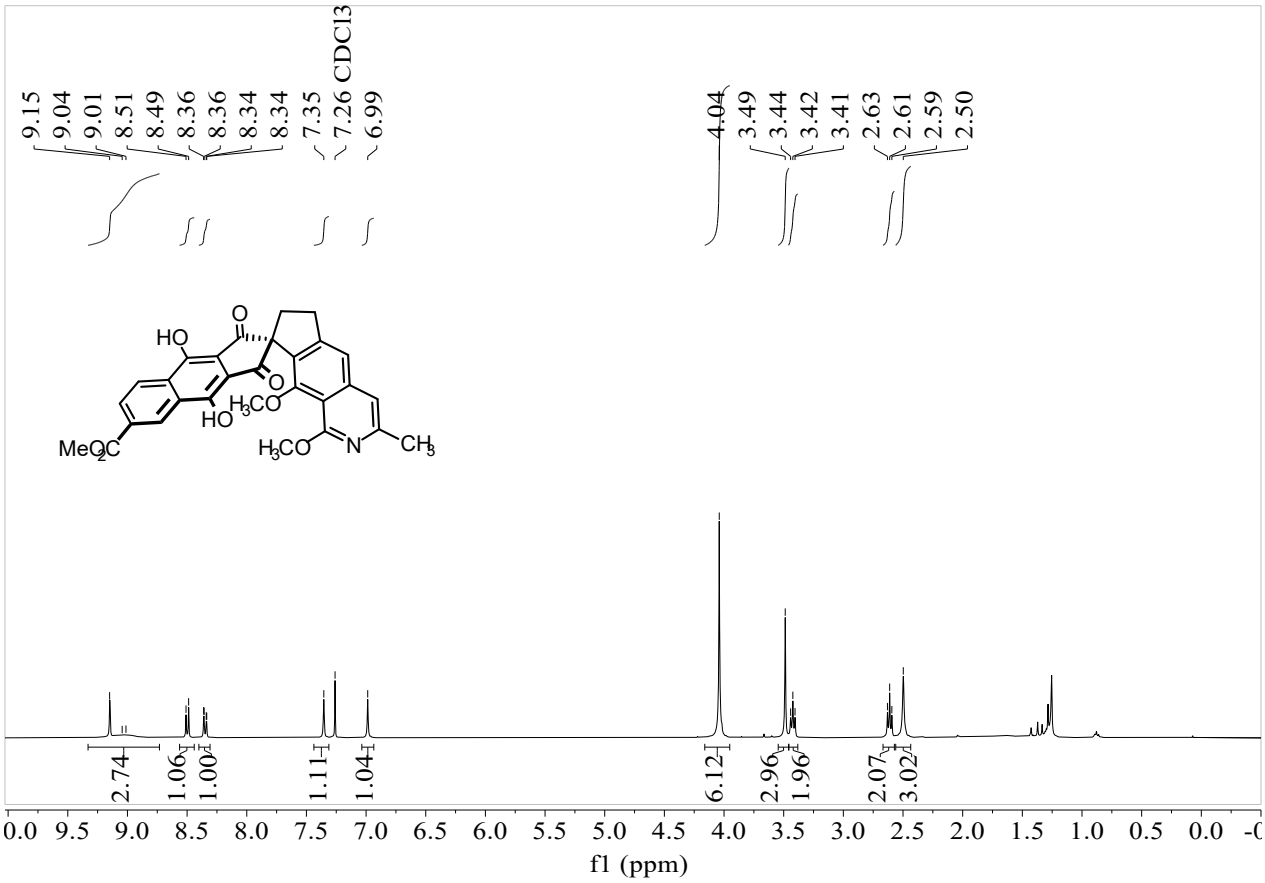


Fig. S48 ^{1}H NMR and ^{13}C NMR spectra of **3u**



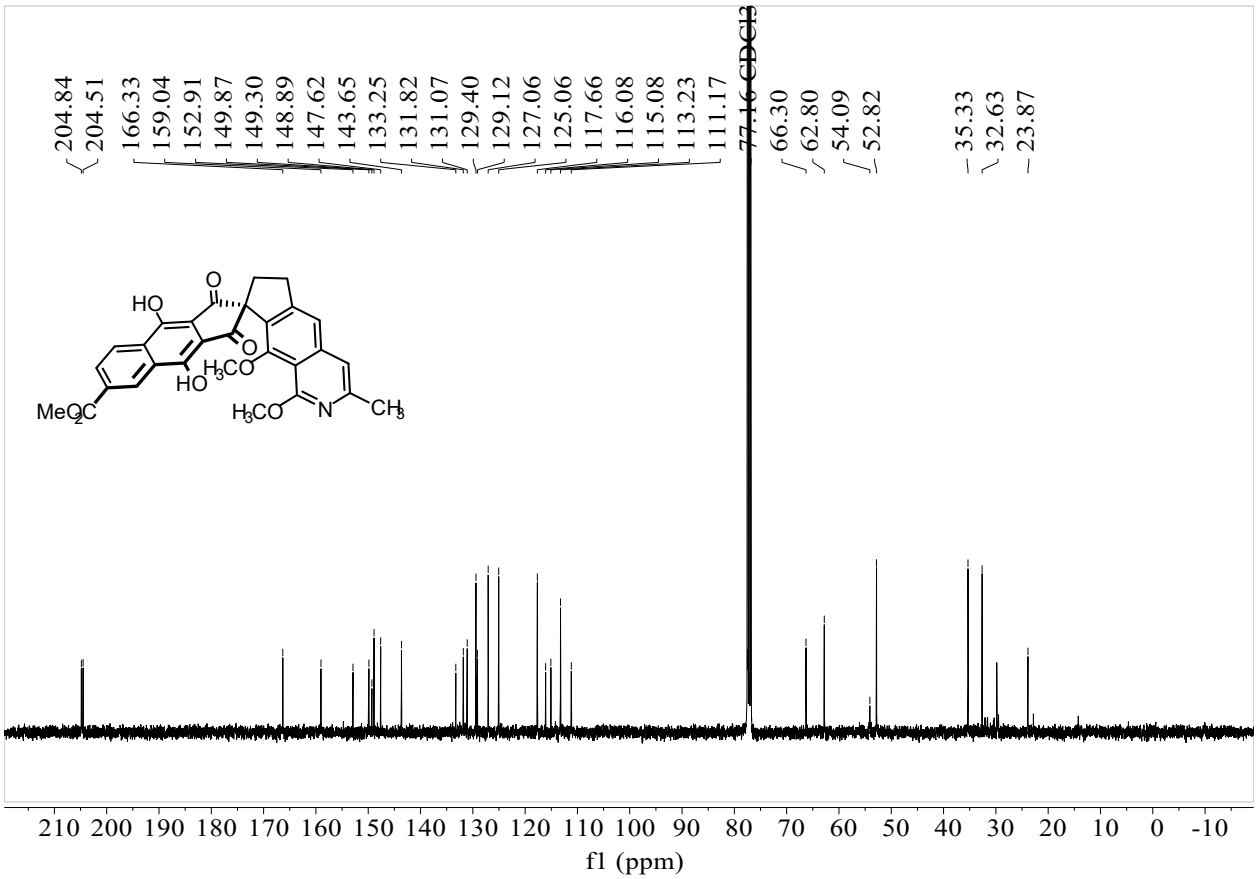


Fig. S49 ^{1}H NMR and ^{13}C NMR spectra of **3v**

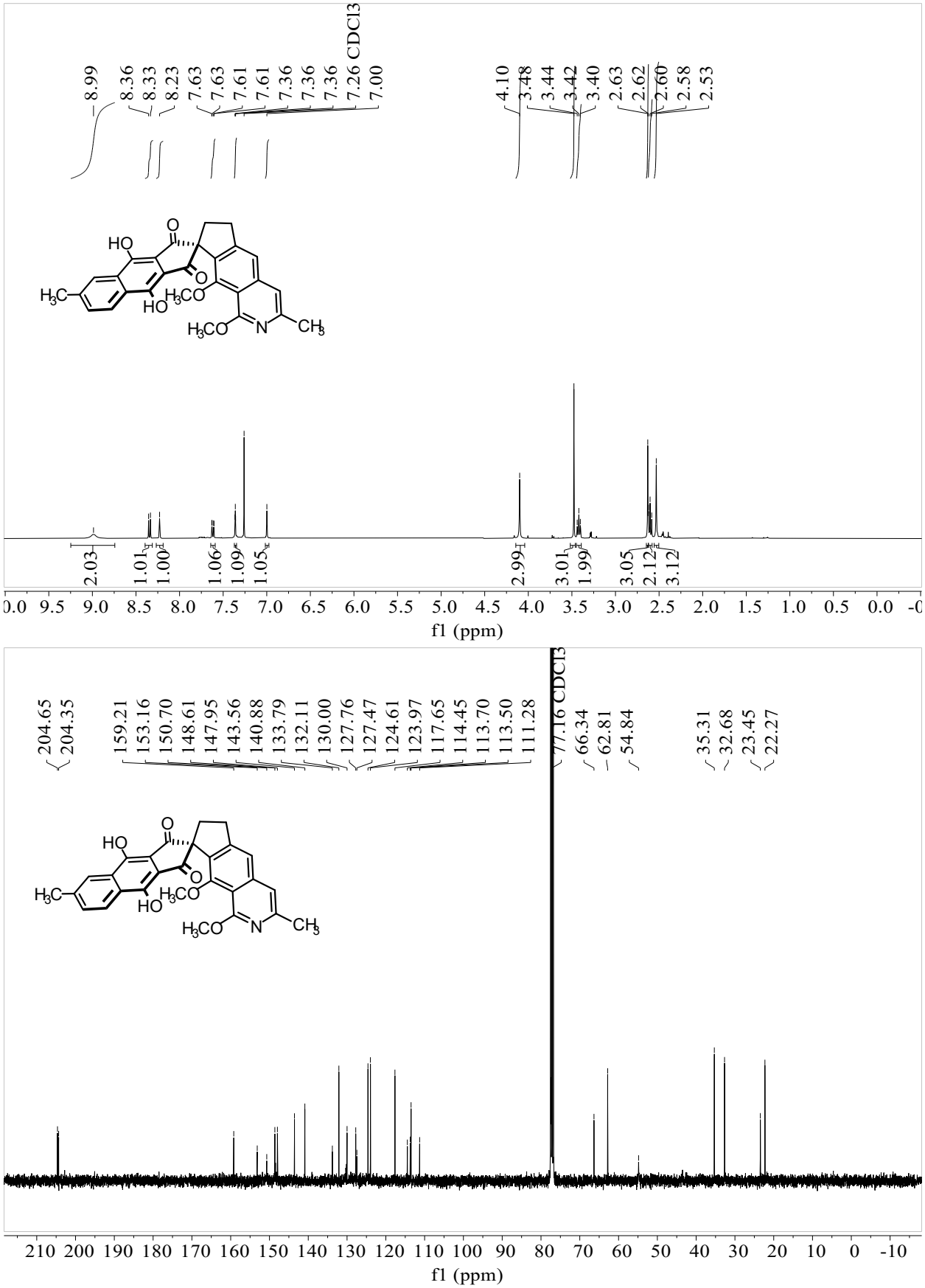
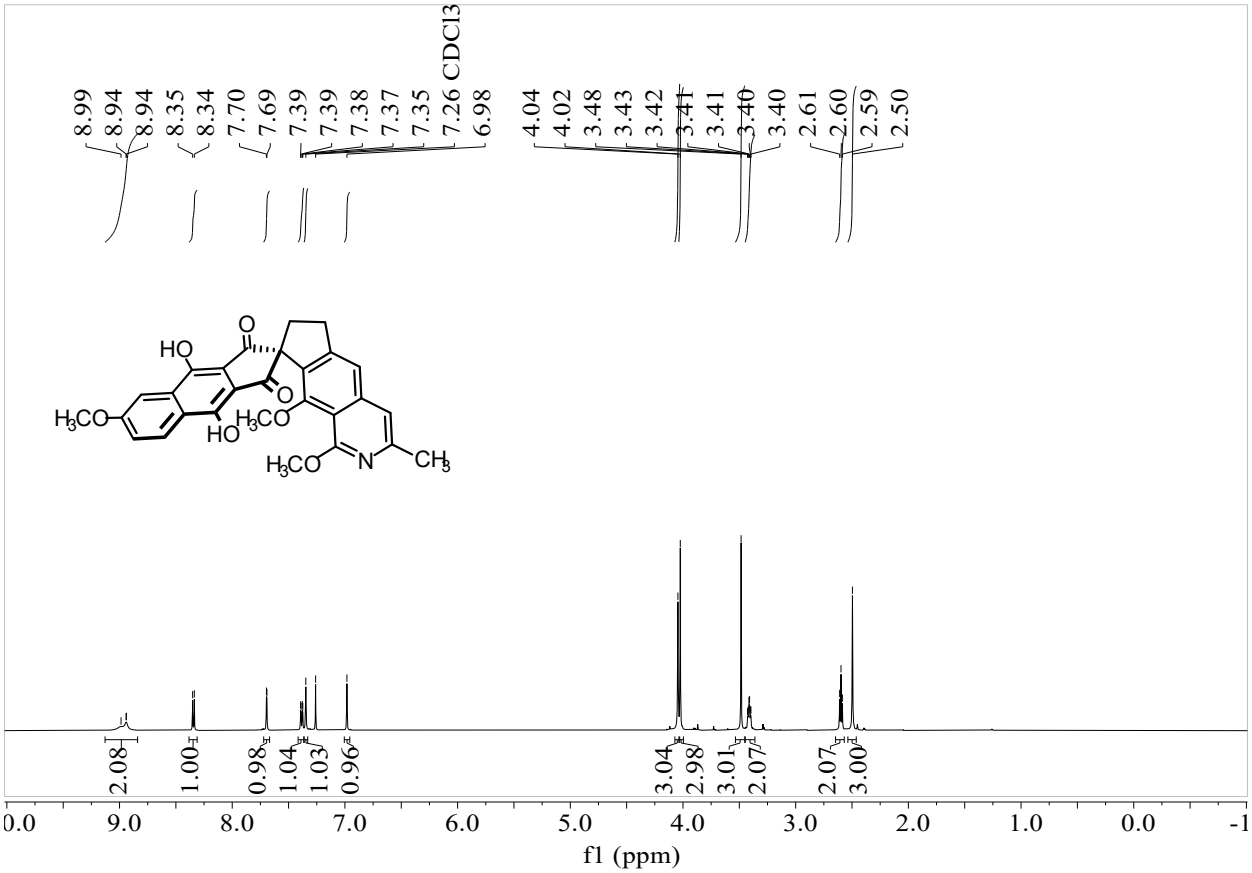


Fig. S50 ^{1}H NMR and ^{13}C NMR spectra of **3w**



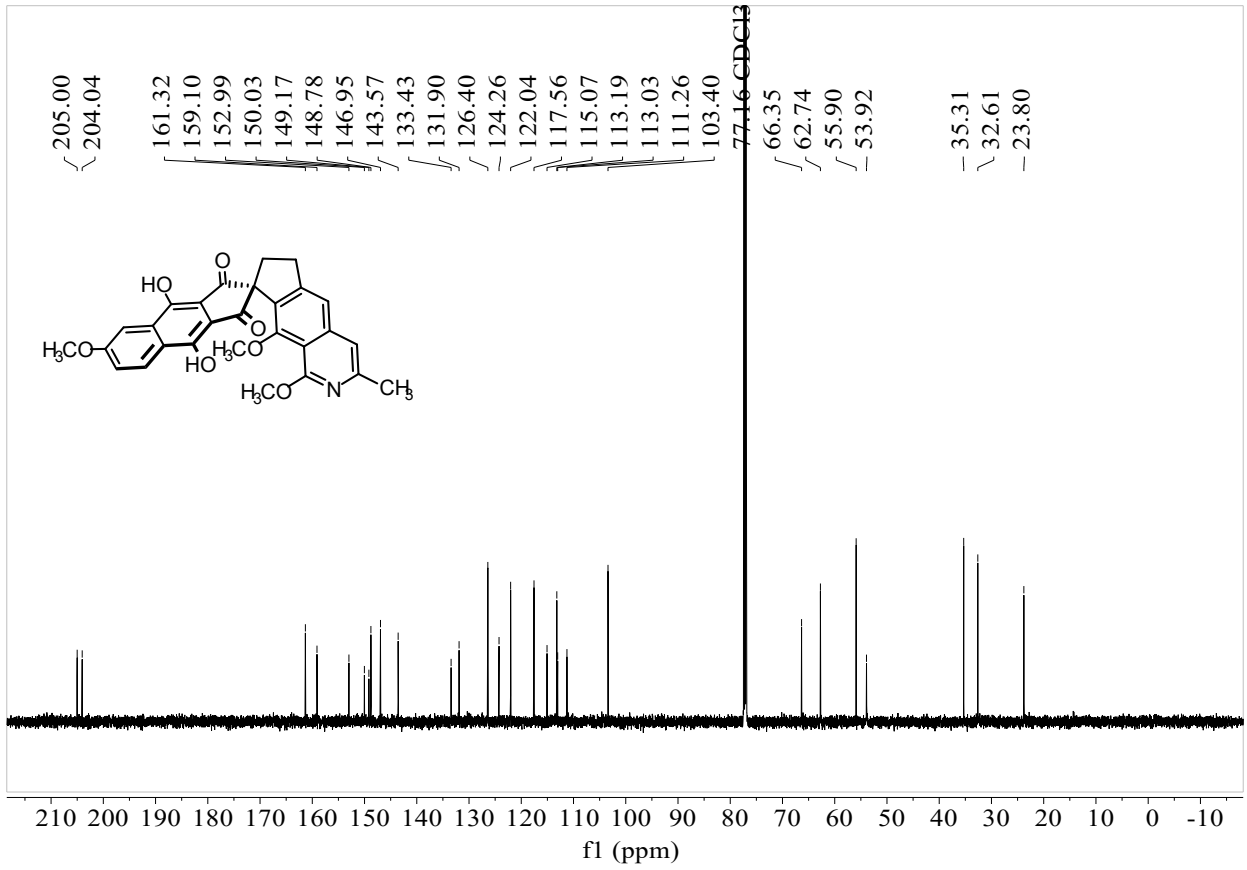
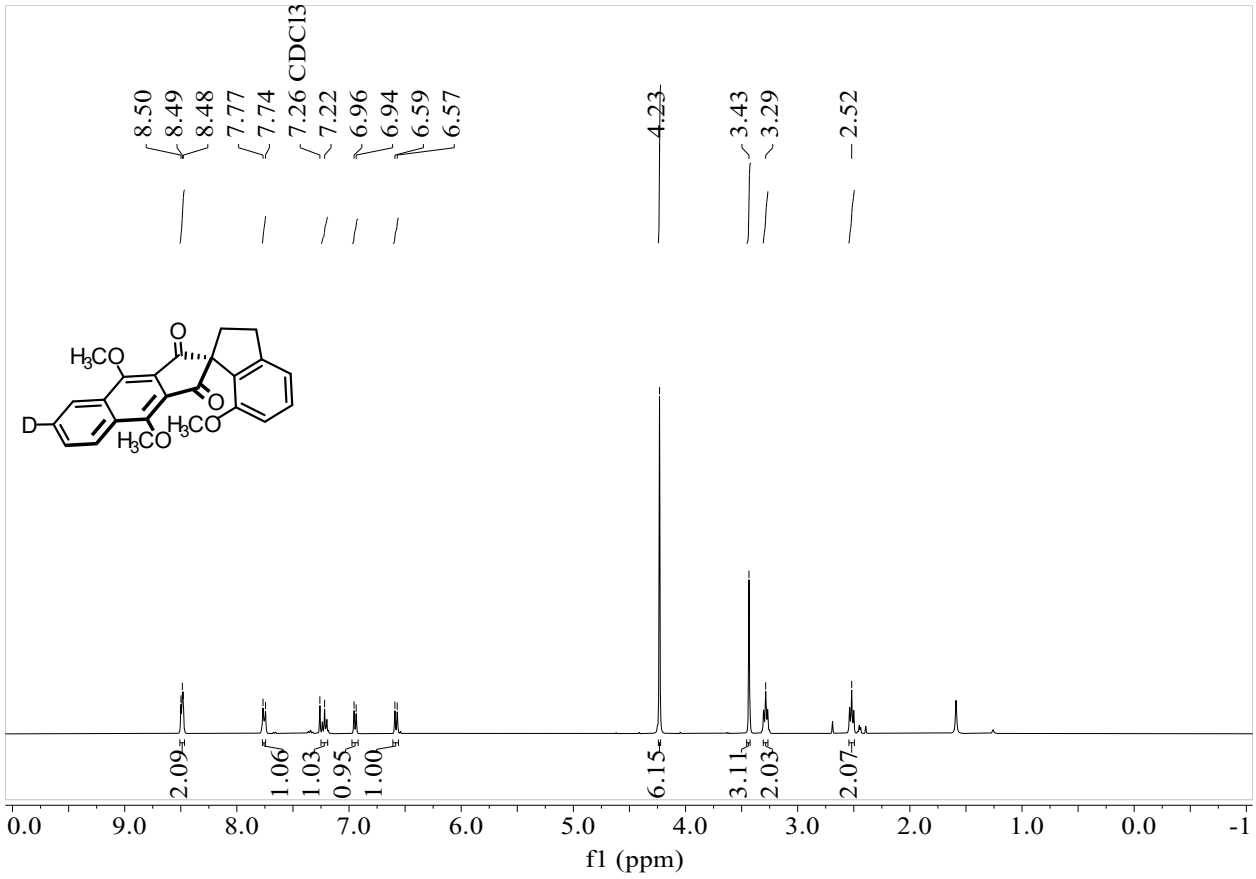


Fig. S51 ^{1}H NMR and ^{13}C NMR spectra of **3x**



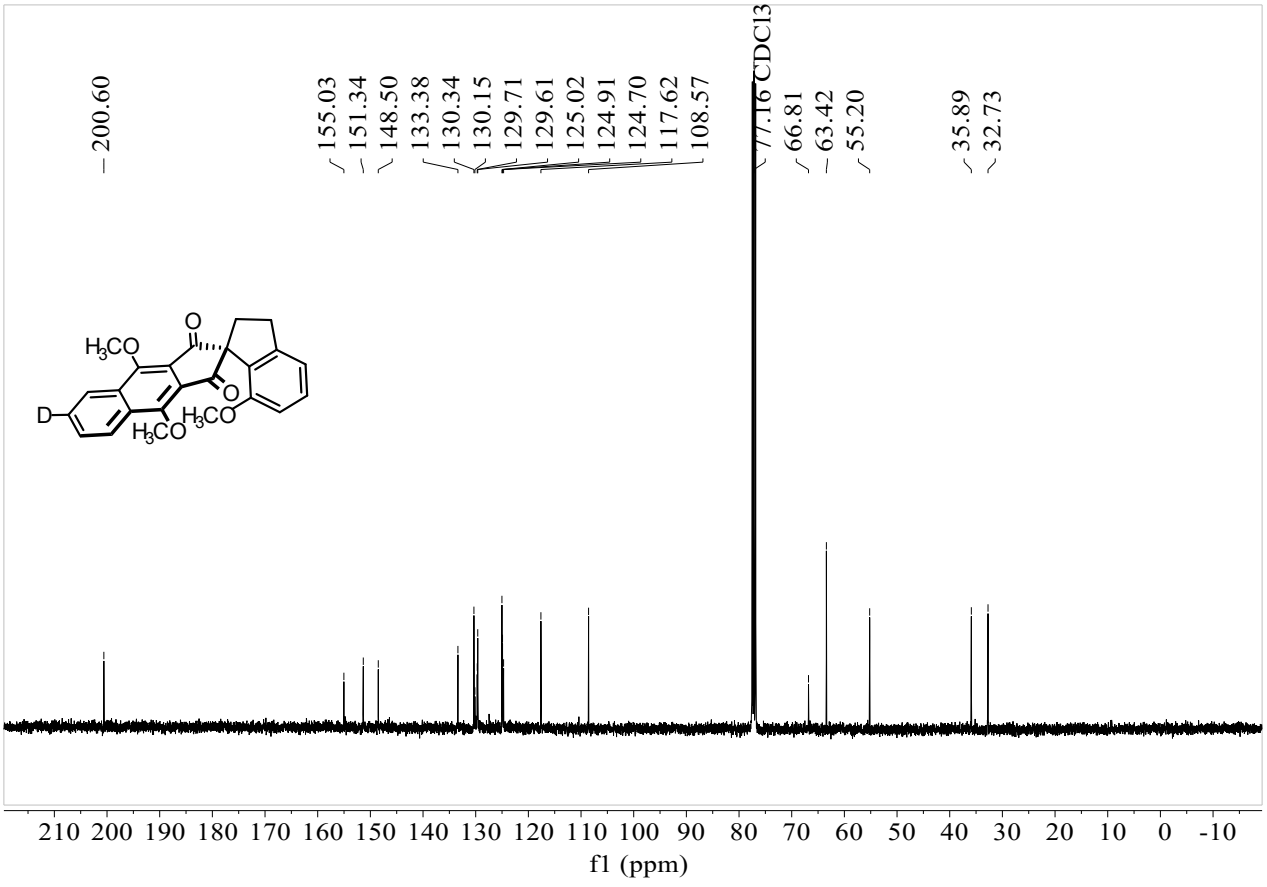


Fig. S52 ^{1}H NMR and ^{13}C NMR spectra of **3y**