Supporting Information

Unlocking Enhanced Reactivity of Hexafluoroisopropanol: A Sustainable Atom Economical Approach to Selective Cascade di-π-Functionalization of Allenamides

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1. General Considerations

Reagent information

Unless otherwise stated, all the reactions were carried out under air atmosphere in screw cap reaction tubes. [1,1,1,3,3,3]-Hexafluoro-2-propanol (HFIP) was bought from Merck CAS: 920-66-1] in sealed bottles. Other chemicals for synthesizing several allenamides were obtained from Sigma Aldrich and TCI chemicals and used without further purification. For column chromatography, silica gel (100-200 mesh) from Merck was used. A gradient elution using hexane and ethyl acetate was performed, based on Merck aluminium TLC sheets (silica gel $60F_{254}$). All the other reagents were purchased from commercial sources and used as received.

Analytical information

All the isolated compounds were characterized by ^{1}H NMR, ^{13}C NMR spectroscopy, and HRMS. Copies of the ^{1}H NMR, ^{13}C NMR can be found in the Supporting information. Unless otherwise stated, all the Nuclear Magnetic Resonance spectra were recorded on Bruker 400 MHz and 600 MHz instruments. Chemical shifts were quoted in parts per million (ppm) referenced to 0.0 ppm for TMS. All the ^{1}H NMR experiments were measured relative to signals for residual *d*1-chloroform ($CDCl_3$, 7.26 ppm) and dimethyl sulfoxide-*d*6 (DMSO-*d*6, 2.50 ppm), unless otherwise stated. All ^{13}C-NMR spectra were reported in ppm relative to residual carbon signals of $CDCl_3$ (77.16 ppm) and DMSO-*d*6 (39.52 ppm), unless otherwise stated, and all were obtained with ^{1}H decoupling. The following abbreviations (or a combination thereof) were used to explain multiplicities: s = singlet, d = doublet, t = triplet, q = quartet, p = pentet, m = multiplet, br = broad. Coupling constant, *J*, was reported in Hertz unit (Hz). All ^{1}H NMR analysis of the crude reaction mixtures were performed by using 1,3,5-trimethoxybenzene as the internal standard. High-resolution mass spectra (HRMS) were recorded on a micro-mass ESI TOF (time of flight) mass spectrometer.

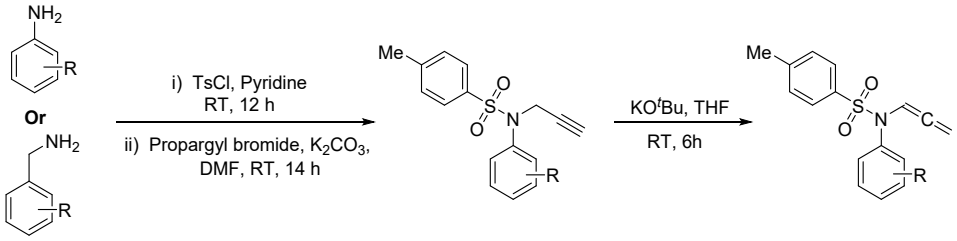
Description of Reaction Tube:

Pictorial description of reaction tube for cascade di-functionalization:

Fisher brand Disposable Borosilicate Glass tubes (16*125mm) with Threaded End (Fisher Scientific); Kimble Black Phenolic Screw Thread Closures with open tops (Fisher Scientific); Thermo Scientific National PTFE/Silicone Septa for Sample Screw Thread Caps (Fisher Scientific).

2. Experimental Section

2.1. General procedure (A) for synthesis of allenamides[1]:

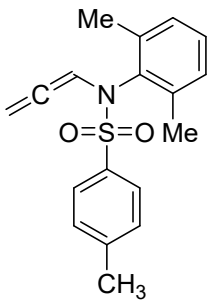


Scheme 1. Synthesis of allenamides

To a two necked flask was charged with substituted aniline or benzyl amine (5.0 mmol, 1 equiv) and pyridine (10 mL) at room temperature (rt). Then 4-methylbenzenesulfonyl chloride (TsCl) 1.0 gm (5.25 mmol, 1.05 equiv) was added slowly and resulting reaction mixture was stirred at 25 ^{o}C for 12 h. The progress of reaction was monitored by TLC. After completion, the reaction mixture was quenched with 1 (M) aqueous HCl solution (20 mL X 2)) and extracted with DCM (40 mL x 3). The combined organic phase was dried over anhydrous Na_2SO_4 and concentrated under reduced vacuum. The crude residue was used for the next step without further purification.

The whole crude residue was dissolved in DMF (15 mL), in two necked flaks. Then K_2CO_3 1.40 gm (10.0 mmol, 2.0 equiv) and propargyl bromide 0.6 mL (7.5 mmol, 1.5 equiv) were added at rt and stirred for 14 h. TLC showed the amide was consumed completely. The reaction mixture was quenched with water (30 mL) and extracted with ethyl acetate (30 mL x 3). Combined organic phase was dried over anhydrous Na_2SO_4 and concentrated under reduced vacuum. The crude residue was used for the next step without further purification.

A single necked flask was charged with dry THF (15 mL) and whole crude 4-methyl-*N*-phenyl-*N*-(prop-2-yn-1-yl) benzene sulfonamide. The solution was cooled at 0 ^{o}C and KO^{t}Bu 0.56 gm (5.0 mmol, 1.0 equiv) were added. The resulting reaction mixture was warmed to 25 ^{o}C and stirred for 6 h. TLC showed the starting material was consumed completely. The reaction was quenched with H_2O (10 mL) and extracted with ethyl acetate (20 mL x 3). Combined organic phases were dried over anhydrous Na_2SO_4 and concentrated under reduced vacuum. The residue was purified with silica gel column (Hex/EtOAc; 7/1) to give the desired allenamide as (60 – 75%) yield. All the allenamide compounds are known in literature. Some of representative compound's NMR spectra are given below.



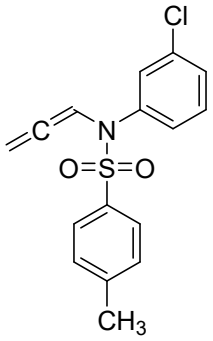
N-(2,6-dimethylphenyl)-4-methyl-N-(propa-1,2-dien-1-yl)benzenesulfonamide (**1b**):

Appearance: Light yellow solid.

Yield: 70% (438 mg, 2 mmol scale).

^{1}H NMR (400 MHz, $CDCl_3$) δ 7.72 (d, *J* = 8.2 Hz, 2H), 7.33 (d, *J* = 8.1 Hz, 2H), 7.22 – 7.13 (m, 2H), 7.04 (d, *J* = 7.5 Hz, 2H), 5.04 (d, *J* = 6.2 Hz, 2H), 2.47 (s, 3H), 1.99 (s, 6H).

^{13}C NMR (101 MHz, $CDCl_3$) δ 200.57, 143.91, 139.25, 137.82, 134.90, 129.89, 128.81, 128.68, 127.46, 101.26, 87.18, 21.71, 18.52.



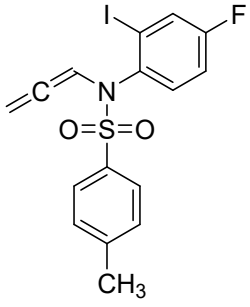
N-(3-chlorophenyl)-4-methyl-N-(propa-1,2-dien-1-yl)benzenesulfonamide (**1c**):

Appearance: Light yellow solid.

Yield: 69% (440 mg, 2 mmol scale).

^{1}H NMR (400 MHz, $CDCl_3$) δ 7.56 (d, *J* = 8.2 Hz, 2H), 7.30 (d, *J* = 8.1 Hz, 3H), 7.22 (t, *J* = 8.0 Hz, 1H), 7.05 (t, *J* = 6.3 Hz, 1H), 7.00 (s, 1H), 6.91 (d, *J* = 7.9 Hz, 1H), 5.07 (d, *J* = 6.3 Hz, 2H), 2.45 (s, 3H).

^{13}C NMR (101 MHz, $CDCl_3$) δ 201.15, 144.41, 138.55, 135.07, 134.26, 129.92, 129.81, 129.79, 129.04, 127.97, 127.86, 102.22, 88.01, 21.78.



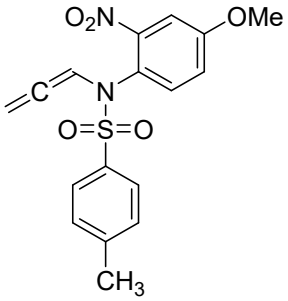
N-(4-fluoro-2-iodophenyl)-4-methyl-N-(propa-1,2-dien-1-yl)benzenesulfonamide (**1e**):

Appearance: white solid.

Yield: 60% (257 mg, 1 mmol scale).

^{1}H NMR (400 MHz, $CDCl_3$) δ 7.63 (d, *J* = 8.1 Hz, 2H), 7.44 (dd, *J* = 14.5, 9.0 Hz, 2H), 7.32 (d, *J* = 8.1 Hz, 2H), 7.08 (t, *J* = 6.2 Hz, 1H), 6.86 (t, *J* = 8.0 Hz, 1H), 5.12 (d, *J* = 6.2 Hz, 2H), 2.47 (s, 3H).

^{13}C NMR (101 MHz, $CDCl_3$) δ 200.70, 144.44, 135.58, 133.94, 133.91, 133.61, 133.60, 129.86, 127.70, 126.31, 126.09, 101.52, 94.57, 94.49, 88.35, 21.80.



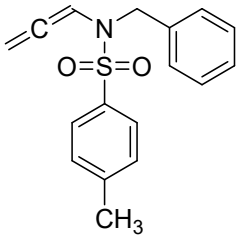
N-(4-methoxy-2-nitrophenyl)-4-methyl-N-(propa-1,2-dien-1-yl)benzenesulfonamide (**1f**):

Appearance: Orange solid.

Yield: 63% (454 mg, 2 mmol scale).

^{1}H NMR (400 MHz, $CDCl_3$) δ 7.58 (d, *J* = 8.1 Hz, 2H), 7.39 (d, *J* = 2.8 Hz, 1H), 7.29 (d, *J* = 8.1 Hz, 2H), 7.09 (t, *J* = 6.2 Hz, 1H), 6.97 (dd, *J* = 8.8, 2.9 Hz, 1H), 6.87 (d, *J* = 8.8 Hz, 1H), 5.09 (d, *J* = 6.2 Hz, 2H), 3.86 (s, 3H), 2.44 (s, 3H).

^{13}C NMR (101 MHz, $CDCl_3$) δ 201.08, 160.01, 144.53, 135.44, 133.09, 129.90, 129.68, 127.99, 127.83, 122.68, 118.71, 110.32, 102.45, 88.39, 56.20, 21.78.



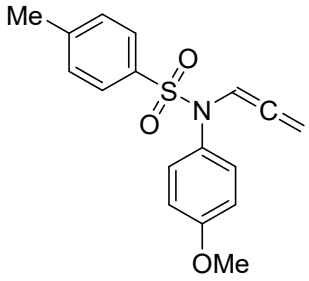
N-benzyl-4-methyl-N-(propa-1,2-dien-1-yl)benzenesulfonamide (**1g**)

Appearance: Light yellow solid.

Yield: 71% (420 mg, 2 mmol scale).

^{1}H NMR (400 MHz, $CDCl_3$) δ 7.74 (d, *J* = 8.0 Hz, 2H), 7.37 – 7.27 (m, 7H), 6.85 (t, *J* = 6.1 Hz, 1H), 5.16 (d, *J* = 6.1 Hz, 2H), 4.32 (s, 2H), 2.47 (s, 3H).

^{13}C NMR (101 MHz, $CDCl_3$) δ 202.35, 143.94, 136.34, 135.49, 129.92, 128.45, 128.02, 127.57, 127.39, 100.25, 88.19, 50.18, 21.74.



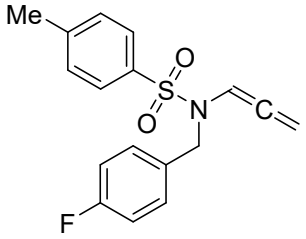
***N*-(4-methoxyphenyl)-4-methyl-N-(propa-1,2-dien-1-yl)benzenesulfonamide (1h):**

Appearance: Light brown solid.

Yield: 60% (378 mg, 2 mmol scale).

^{1}H NMR (600 MHz, $CDCl_3$) δ 7.55 (d, *J* = 8.1 Hz, 2H), 7.27 (d, *J* = 8.0 Hz, 2H), 7.12 (t, *J* = 6.3 Hz, 1H), 6.90 – 6.88 (m, 2H), 6.79 – 6.76 (m, 2H), 5.03 (d, *J* = 6.2 Hz, 2H), 3.79 (s, 3H), 2.44 (s, 3H) ppm.

^{13}C NMR (151 MHz, $CDCl_3$) δ 201.1, 159.6, 144.0, 135.4, 130.9, 129.6, 127.9, 114.0, 102.9, 87.6, 55.5, 21.8 ppm.



***N*-(4-fluorobenzyl)-4-methyl-N-(propa-1,2-dien-1-yl)benzenesulfonamide (1i):**

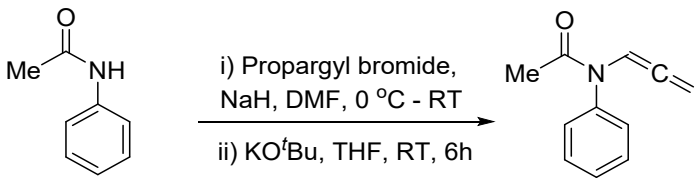
Appearance: Yellow solid.

Yield: 64% (406 mg, 2 mmol scale).

^{1}H NMR (600 MHz, $CDCl_3$) δ 7.72 – 7.69 (m, 2H), 7.33 (d, *J* = 8.0 Hz, 2H), 7.27 (dd, *J* = 8.5, 5.5 Hz, 2H), 6.97 (t, *J* = 8.7 Hz, 2H), 6.81 (t, *J* = 6.2 Hz, 1H), 5.15 (d, *J* = 6.2 Hz, 2H), 4.25 (s, 2H), 2.44 (s, 3H).

^{13}C NMR (151 MHz, $CDCl_3$) δ 202.2, 163.1 (d, $J_{C\text{-}F}$ = 244.4 Hz), 144.1, 135.3, 132.0 (d, $J_{C\text{-}F}$ = 2.7 Hz) , 130.0, 129.8 (d, $J_{C\text{-}F}$ = 8.1 Hz), 127.3, 115.4 (d, $J_{C\text{-}F}$ = 21.2 Hz), 100.1, 88.3, 49.5, 21.7.

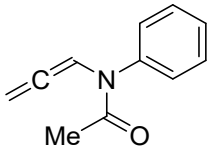
2.2. General procedure (B) for synthesis of allenamides (1l; from acetanilide**):**



Scheme 2. Synthesis of N-acetyl allenamide

A two necked flask was charged with DMF (15 mL) and acetanilide 0.675 gm (5.0 mmol, 1 equiv) under nitrogen environment. The solution was cooled at 0 °C and NaH 0.180 gm (7.5 mmol, 1.5 equiv) was added in small portion. The resulting reaction mixture warmed to 25 °C and stirred for 0.5 h. Then reaction was again cooled to 0 °C, propargyl bromide 0.6 mL (7.25 mmol, 1.5 equiv) was added dropwise and stirred for 10 h at room temperature. After completion, the reaction mixture was quenched with cold H_2O (30 mL) and extracted with ethyl acetate (40 mL X 3). Combined organic phases were dried over anhydrous Na_2SO_4 and concentrated under reduced vacuum. The residue was purified with silica gel column (Hex: EtOAc = 7:1) to give product as an off white solid 0.632 gm (73% yield).

A single necked flask was charged with dry THF (15 mL) and *N*-(phenyl)-*N*-(prop-2-yn-1-yl) acetamide 0.632 gm (3.6 mmol, 1 equiv). The solution was cooled at 0 °C and KO^{t}Bu 0.404 gm (3.6 mmol, 1.0 equiv) was added. The resulting reaction mixture was warmed to 25 °C and stirred for 6 h. TLC showed the starting material was consumed completely. The reaction was quenched with H_2O (20 mL) and extracted with ethyl acetate (40 mL x 3). Combined organic phases were dried over anhydrous Na_2SO_4 and concentrated under reduced vacuum. The residue was purified with silica gel column (Hex: EtOAc = 9:1) to give **1l** as a yellow solid 0.455 gm (70% Yield).

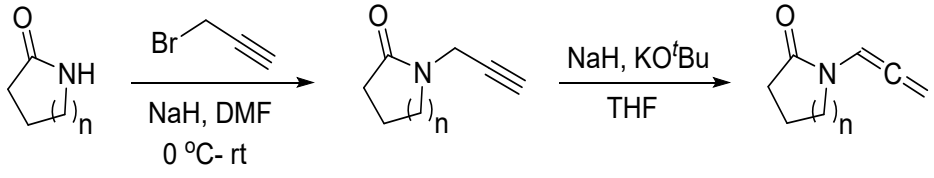


N-phenyl-N-(propa-1,2-dien-1-yl)acetamide (**1l**):

^{1}H NMR (400 MHz, $CDCl_3$) δ 7.47 – 7.37 (m, 3H), 7.22 – 7.16 (m, 2H), 6.70 (d, *J* = 7.6 Hz, 1H), 5.01 (d, *J* = 6.4 Hz, 2H), 1.92 (s, 3H).

^{13}C NMR (101 MHz, $CDCl_3$) δ 202.64, 168.53, 129.44, 129.28, 128.46, 115.09, 100.94, 86.39, 29.72.

2.3. General procedure (C) for synthesis of cyclic allenamides[2]**:**

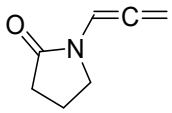


Scheme 3. Synthesis of cyclic allenamides

To a two necked round bottom flask was added dry DMF (15 mL), and desired lactame (10 mmol, 1 equiv) under nitrogen atmosphere. The reaction mixture was cooled to 0 °C and NaH was added (12 mmol, 1.2 equiv.) slowly and reaction mixture warmed up to room temperature and stirred for 45 mins. After 45 mins the reaction mixture again cooled to 0°C and added propargyl bromide (11

mmol, 1.1 equiv) dropwise. Subsequently, the reaction mixture slowly warmed up to room temperature and stirred for another 6 h. After completion, the reaction mixture was quenched with H_2O (20 mL) and extracted with ethyl acetate (30 mL X 3). The organic phase was dried over anhydrous Na_2SO_4 and dried over reduced pressure to get residue. The residue was purified on silica gel (100-200 mesh size) (Hex/EtOAc; 3/2) to afford desired product in 80 % yield.

To a dry two necked flask dry THF (20 mL) was added followed by 1-(prop-2-yn-1-yl)-lactame (6.6 mmol) under nitrogen atmosphere. Then NaH (11.2 mmol, 1.7 equiv) and ^{t}BuOK (3.3 mmol, 0.5 equiv.) were added to the flask at room temperature. The resulting reaction mixture was stirred for 6 h, and reaction progress was monitored by TLC. After completion, the reaction was quenched with H_2O (10 mL) and extracted with ethyl acetate (30 mL X 3). The combined organic phase was dried over Na_2SO_4 and concentrated under vacuum. The residue was purified with silica gel column (Hex/EtOAc; 3/2) to give cyclic allenamide**.** These compounds are known compounds, so we have added NMR data as representative examples.



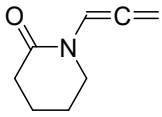
1-(propa-1,2-dien-1-yl) pyrrolidin-2-one (1n):

Appearance: Yellow oil.

Yield: 75% (0.92 g, 10 mmol scale).

^{1}H NMR (600 MHz, $CDCl_3$) δ 7.06 (t, *J* = 6.4 Hz, 1H), 5.36 (d, *J* = 6.4 Hz, 2H), 3.40 (t, *J* = 7.2 Hz, 2H), 2.45 (t, *J* = 8.1 Hz, 2H), 2.06 (dt, *J* = 15.9, 7.7 Hz, 2H).

^{13}C NMR (151 MHz, $CDCl_3$) δ 202.7, 173.0, 95.8, 86.6, 45.8, 31.2, 17.4.



1-(propa-1,2-dien-1-yl) piperidin-2-one (1o):

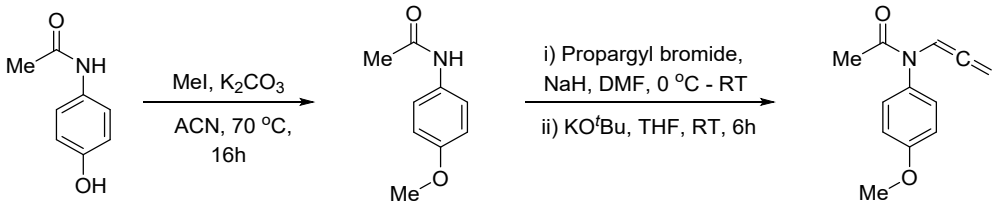
Appearance: Yellow oil.

Yield: 68% (0.89 g, 10 mmol scale).

^{1}H NMR (600 MHz, $CDCl_3$) δ 7.57 (t, *J* = 6.5 Hz, 1H), 5.34 (d, *J* = 6.5 Hz, 2H), 3.27 (t, *J* = 6.0 Hz, 2H), 2.42 (t, *J* = 6.6 Hz, 2H), 1.83 – 1.81 (m, 2H), 1.78 – 1.76 (m, 2H).

^{13}C NMR (151 MHz, $CDCl_3$) δ 202.3, 168.2, 99.0, 87.0, 46.0, 32.8, 22.7, 21.0.

2.4. General procedure (D) for synthesis of allenamide from paracetamol:

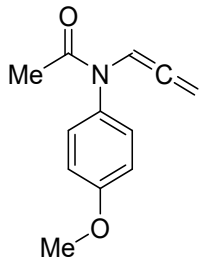


Scheme 4. Synthesis of allenamide **1q**

A single necked flask was charged with dry ACN (20 mL) and paracetamol 0.760 gm (5.0 mmol, 1 equiv). Then K_2CO_3 1.387 gm (10.0 mmol, 2 equiv) and MeI 0.34 mL (5.5 mmol, 1.1 equiv) were added. The resulting reaction mixture was heated to 70 °C and stirred for 16 h. TLC showed starting material was consumed completely. The reaction was quenched with H_2O (10 mL) and extracted with ethyl acetate (30 mL X 3). Combined organic phases were dried over anhydrous Na_2SO_4 and concentrated under reduced vacuum. The residue was purified with silica gel column (Hex/EtOAc; 3/1) to give product 0.660 gm (80% Yield).

A two necked flask was charged with DMF (10 mL) and *N*-(4-methoxyphenyl) acetamide 0.660 gm (4.5 mmol, 1 equiv) under nitrogen environment. The solution was cooled at 0 °C and NaH 0.130 gm (5.4 mmol, 1.2 equiv.) was added in small portion. The resulting reaction mixture warmed to 25 °C and stirred for 0.5 h. Then reaction was again cooled to 0 °C, propargyl bromide 0.5 mL (6.7 mmol, 1.5 equiv.) was added dropwise and stirred for 16 h at room temperature. After completion, the reaction mixture was quenched with cold H_2O (20 mL) and extracted with ethyl acetate (30 mL X 3). Combined organic phases were dried over anhydrous Na_2SO_4 and concentrated under reduced vacuum. The residue was purified with silica gel column (Hex/EtOAc; 3/1) to give product as an off white solid 0.685 gm (75% yield).

A single necked flask was charged with dry THF (20 mL) and *N*-(4-methoxyphenyl)-*N*-(prop-2-yn-1-yl) acetamide 0.685 gm (3.4 mmol, 1 equiv). The solution was cooled at 0 °C and KO^{t}Bu 0.191 gm (1.7 mmol, 0.5 equiv) was added. The resulting reaction mixture was warmed to 25 °C and stirred for 6 h. TLC showed the starting material was consumed completely. The reaction was quenched with H_2O (10 mL) and extracted with ethyl acetate (30 mL X 3). Combined organic phases were dried over anhydrous Na_2SO_4 and concentrated under reduced vacuum. The residue was purified with silica gel column (Hex/EtOAc; 4/1) to give **1q** as a yellow liquid 0.415 gm (60% Yield).



***N*-(4-methoxyphenyl)-N-(propa-1,2-dien-1-yl)acetamide (1p):**

Appearance: yellow liquid.

Yield: 60% (415 mg, 5 mmol scale).

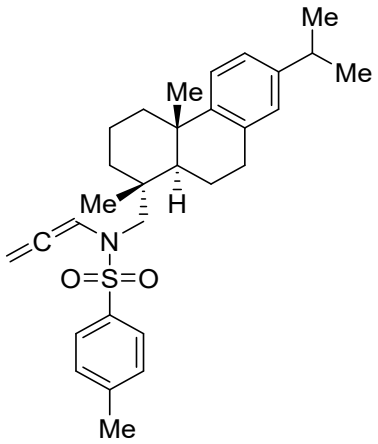
^{1}H NMR (600 MHz, $CDCl_3$) δ 7.60 (t, *J* = 6.4 Hz, 1H), 7.03 – 7.00 (m, 2H), 6.86 – 6.84 (m, 2H), 4.93 (d, *J* = 6.4 Hz, 2H), 3.82 (s, 3H), 1.88 (s, 3H).

^{13}C NMR (151 MHz, $CDCl_3$) δ 202.8, 169.1, 159.4, 133.0, 129.5, 114.6, 101.2, 86.4, , 55.5, 23.0.

LRMS m/z (EI) calc. for $C_{12}H_{13}NO_2$ [M^+] = 203.1, found 203.1

2.5. General procedure (E) for synthesis of allenamide from (±)dehydroabietyl amine (1r):

This molecule was synthesized following general procedure (A)



***N*-(((1R,4aS,10aR)-7-isopropyl-1,4a-dimethyl-1,2,3,4,4a,9,10,10a-octahydrophenanthren-1-yl)methyl)-4-methyl-N-(propa-1,2-dien-1-yl)benzenesulfonamide (1r):**

Appearance: Colorless sticky liquid.

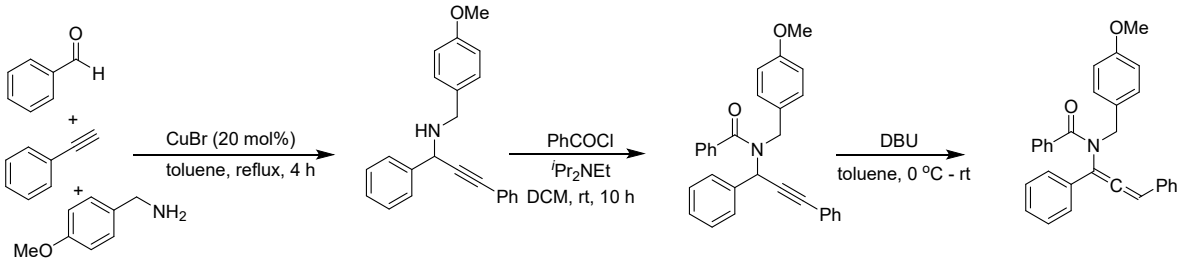
Yield: 46% (219 mg, 1 mmol scale).

^{1}H NMR (400 MHz, $CDCl_3$) δ 7.78 (d, *J* = 8.2 Hz, 1H), 7.68 (d, *J* = 8.2 Hz, 2H), 7.32 (d, *J* = 8.2 Hz, 2H), 7.18 (d, *J* = 8.2 Hz, 1H), 7.00 (d, *J* = 8.0 Hz, 1H), 6.66 (t, *J* = 6.2 Hz, 1H), 5.17 (d, *J* = 6.2 Hz, 2H), 3.07 – 2.95 (m, 2H), 2.91 (dd, *J* = 9.3, 5.4 Hz, 2H), 2.83 (dd, *J* = 13.9, 7.0 Hz, 1H), 2.45 (s, 3H), 2.31 – 2.20 (m, 2H), 2.06 (d, *J* = 9.7 Hz, 2H), 1.86 (d, *J* = 7.1 Hz, 2H), 1.71 (d, *J* = 9.2 Hz, 2H), 1.24 (d, 6H), 1.19 (s, 1H), 1.14 (s, 3H) ppm.

^{13}C NMR (101 MHz, $CDCl_3$) δ 204.2, 147.6, 134.8, 129.6, 128.8, 128.0, 127.8, 127.0, 124.1, 123.9, 103.0, 87.4, 57.4, 45.8, 38.6, 38.3, 33.6, 32.1, 31.4, 29.8, 25.9, 24.1, 22.8, 21.7, 18.7, 14.3 ppm.

LRMS m/z (EI) calc. for $C_{30}H_{39}NO_2S$ [M^+] = 477.3, found 477.3.

2.5. General procedure (F) for synthesis of *tri*-substituted allenamide (1s)[3] :

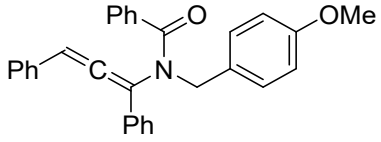


Scheme 5. Synthesis of tri-substituted allenamide

To a solution of benzaldehyde 0.5 mL (5.00 mmol, 1 equiv) and 4-methoxy benzylamine 0.98 mL (7.50 mmol, 1.5 equiv) in toluene (10 mL), phenylacetylene (0.82 mL, 7.50 mmol, 1.5 equiv) and CuBr (143 mg, 1.00 mmol, 0.2 equiv) were added and refluxed in argon atmosphere for 4 h. The progress of the reaction was monitored by TLC. After completion, the reaction was quenched with water (5 mL). The mixture was extracted with ethyl acetate (20 mL X 2). The organic layer was washed brine, dried over Na_2SO_4, filtered and concentrated in vacuo to give a crude product, which was purified by silica gel column chromatography (Hex/EtOAc; 98/2) to afford a propargylamine amine in 0.98 gm (60%) yield.

To a solution of propargylamine 0.65 gm (2 mmol, 1 equiv), *i*-Pr_2NEt (3 mL) and CH_2Cl_2 (15 mL), benzoyl chloride (0.35 mL, 3.0 mmol, 1.5 equiv) was added at room temperature in argon atmosphere and was stirred for 10 h. The progress of the reaction was monitored by TLC. After completion, the reaction was quenched with water (10 mL) was extracted with ethyl acetate (20 mL X 2). The organic layer was washed with brine and dried over Na_2SO_4, filtered and concentrated in vacuo to give a crude product, which was purified by silica gel column chromatography (hexane/EtOAc; 96/4) to afford a propargylamide 0.56 gm (65% yield).

To a solution of propargylamide 0.43 gm (1 mmol, 1.0 equiv) in toluene (10 mL), DBU 0.45 mL (3 mmol, 3.0 equiv) was added at 0 °C in argon atmosphere. The reaction mixture was stirred at room temperature for 2 h. The reaction was quenched with water (5 mL) and was extracted with ethyl acetate (20 mL X 2). The organic layer was dried over Na_2SO_4, filtered and concentrated in vacuo to give a crude product, which was purified by silica gel column chromatography (hexane/EtOAc; 98/2) to afford the corresponding allenamide (**1s**) 0.25 gm (58%) yield.



N-(1,3-diphenylpropa-1,2-dien-1-yl)-N-(4-methoxybenzyl)benzamide (1s).

Appearance: Pale yellow solid.

Yield: 58% (250 mg, 1 mmol scale).

^{1}H NMR (400 MHz, $CDCl_3$) δ 7.62 – 7.56 (m, 2H), 7.46 – 7.42 (m, 4H), 7.41 – 7.27 (m, 6H), 7.11 (dt, *J* = 26.0, 7.2 Hz, 3H), 6.81 (d, *J* = 8.7 Hz, 2H), 6.52 (d, *J* = 6.9 Hz, 2H), 5.81 (s, 1H), 5.36 (d, *J* = 12.6 Hz, 1H), 4.55 (d, *J* = 14.1 Hz, 1H), 3.77 (s, 3H) ppm.

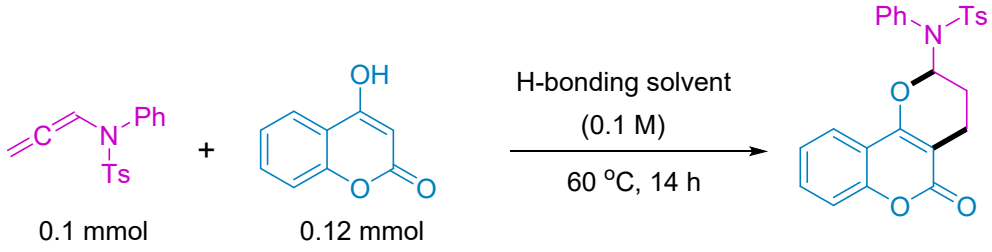
^{13}C NMR (100 MHz, $CDCl_3$) δ 209.1, 172.0, 171.1, 159.2, 139.1, 136.4, 133.2, 132.2, 130.7, 130.1, 129.6, 129.2, 128.7, 128.6, 128.5, 128.1, 128.0, 127.7, 127.6, 126.2, 125.7, 116.3, 114.0, 101.2, 55.3, 48.8, 20.8 ppm.

ESI-MS: m/z calculated for $[M+Na]^+$; $C_{30}H_{25}NO_2Na$: Calculated, 454.1783 & found 454.1778.

3.0 Optimization details for HFIP mediated di-functionalization of allenamides with 4-hydroxy coumarin

Condition A:

Table 1. Screening of H-bonded solvents[a]

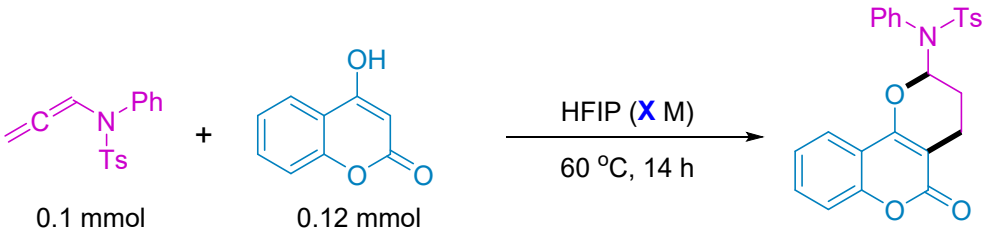


0.1 mmol 0.12 mmol

entry	Solvent	Yield
1	Toluene	0%
2	1,2-Dichloroethane (DCE)	trace
3	2,2,2-Trifluoroethanol	23%
4	**HFIP**	**96%**
5	THF	0%
6	*t*-AmOH	trace
7	1,4-dioxane	0%
8	H_2O	trace
9	Isopropanol	trace
10	MeOH	trace
11	EtOH	trace

[a] Yields are based on ^{1}H NMR of crude reaction mixture using 1,3,5-trimethoxybenzne as internal standard

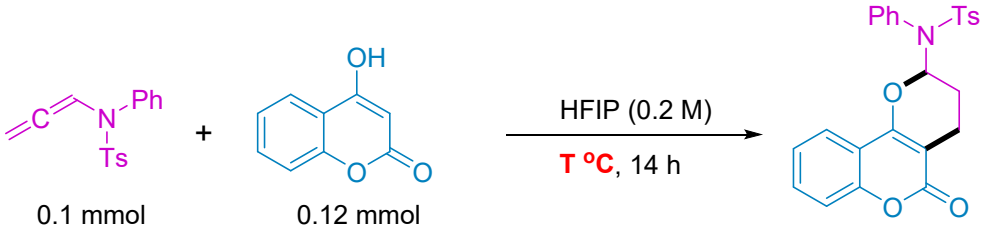
Table 2. Screening of concentration of HFIP[a]



entry	Concentration of HFIP (M)	Yield
1	0.1	96%
2	**0.2**	**97%**
3	0.3	96%

[a] Yields are based on ^{1}H NMR of crude reaction mixture using 1,3,5-trimethoxybenzne as internal standard

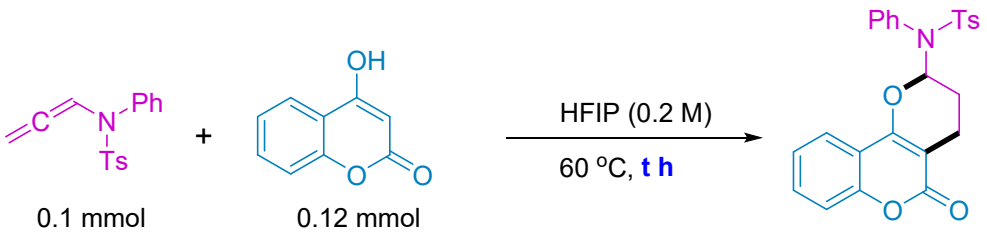
Table 3. Screening of reaction temperature[a]



entry	Temperature (° C)	Yield
1	**60**	**97%**
2	70	97%
3	40	60%
4	25	27%

[a] Yields are based on ^{1}H NMR of crude reaction mixture using 1,3,5-trimethoxybenzne as internal standard

Table 4. Screening of reaction time[a]

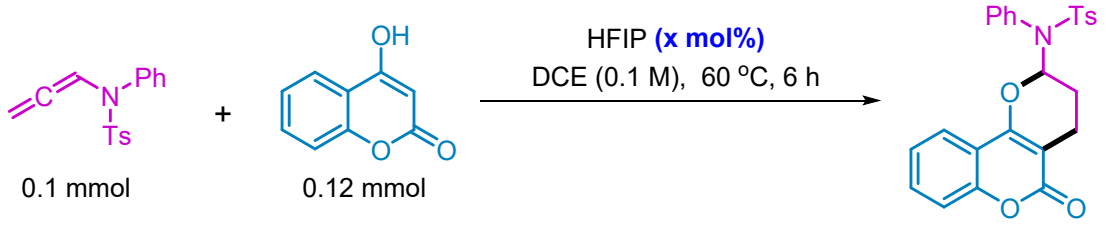


entry	Time (h)	Yield
1	**5**	**99%**
2	8	99%
3	12	97%
4	14	97%

[a] Yields are based on ^{1}H NMR of crude reaction mixture using 1,3,5-trimethoxybenzne as internal standard

Condition B: (Optimization for catalytic condition)

Table 5. Screening of HFIP amount[a]

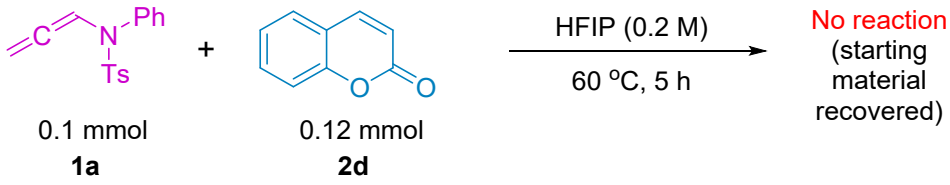


entry	Concentration of HFIP (mol %)	Yield
1	25	73%
2	**50**	**94%**
3	100	95%

[a] Yields are based on ^{1}H NMR of crude reaction mixture using 1,3,5-trimethoxybenzne as internal standard

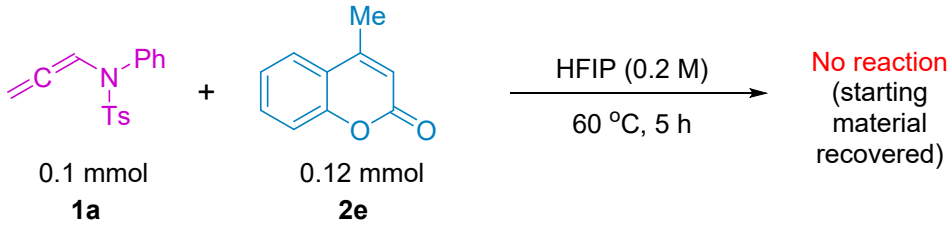
4. Mechanistic Studies:

a) Reaction with simple coumarin:



Selective C – H functionalization of coumarin is not feasible.

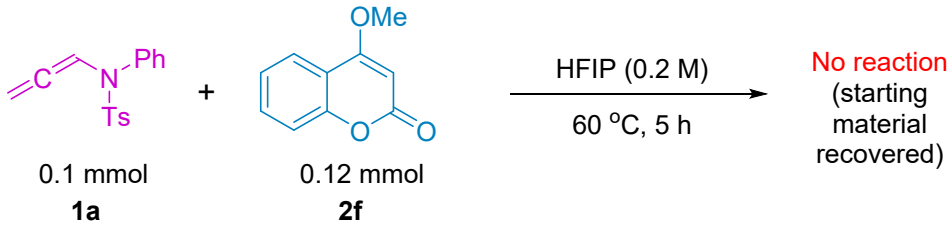
b) Reaction with 4-methyl coumarin:



0.1 mmol **1a** + 0.12 mmol **2e**

Methyl substitution at 4-position did not enhance the feasibility of C – H functionalization.

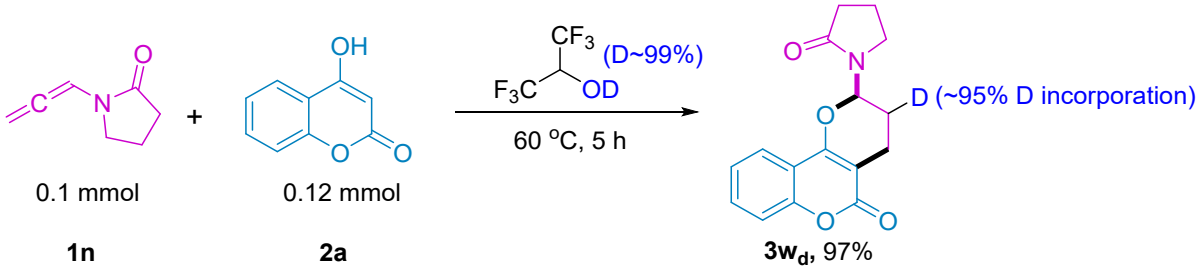
c) Reaction with 4-methoxy coumarin:



0.1 mmol **1a** + 0.12 mmol **2f**

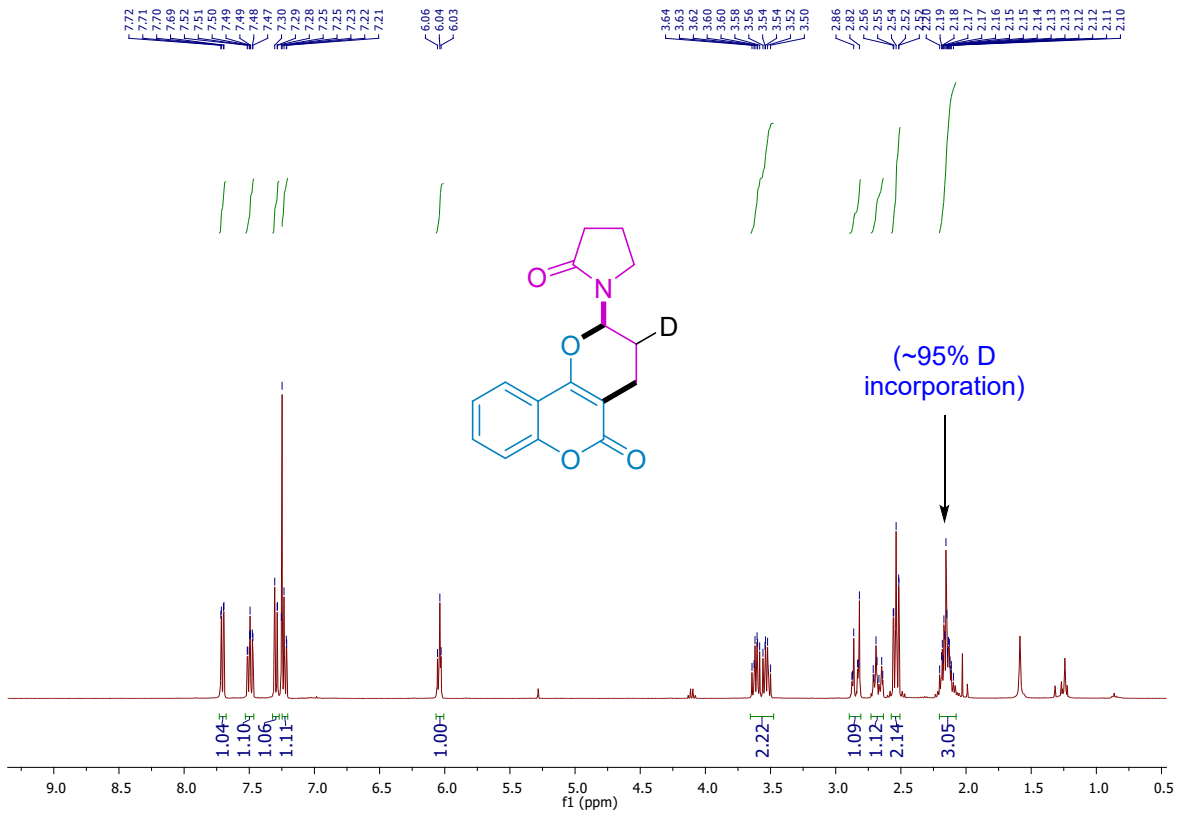
Methoxy substitution at 4-position also did not help the feasibility of di-functionalization. Even, a lone pair of oxygen (from -OMe group) could not participate in di-functionalization reaction.

d) Reaction in HFIP-OD

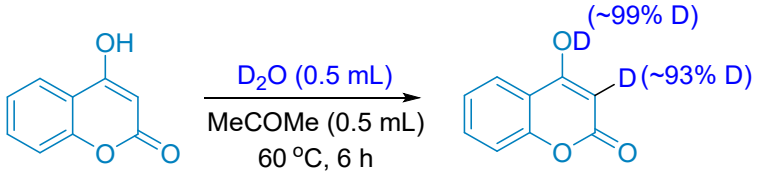


0.1 mmol **1n** + 0.12 mmol **2a**

3w$_d$, 97%

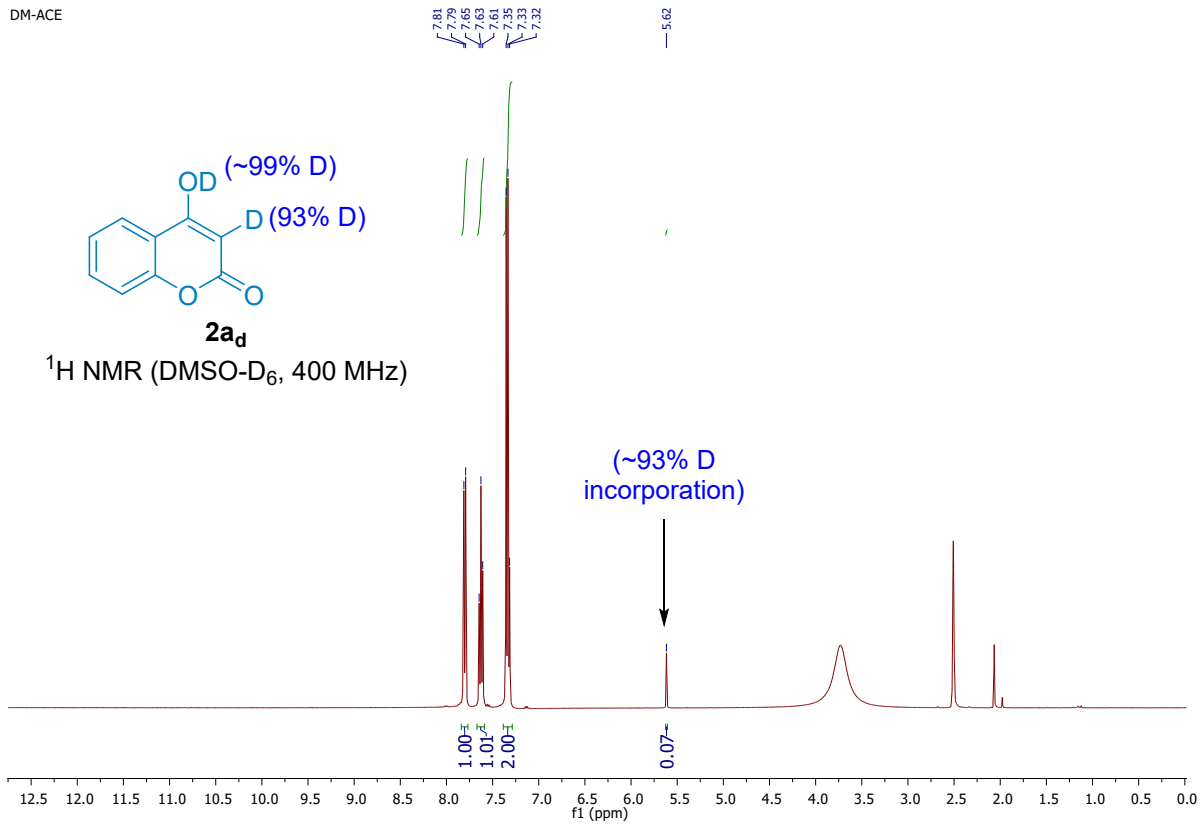


e) Synthesis of coumarin-D (**2a$_d$**)

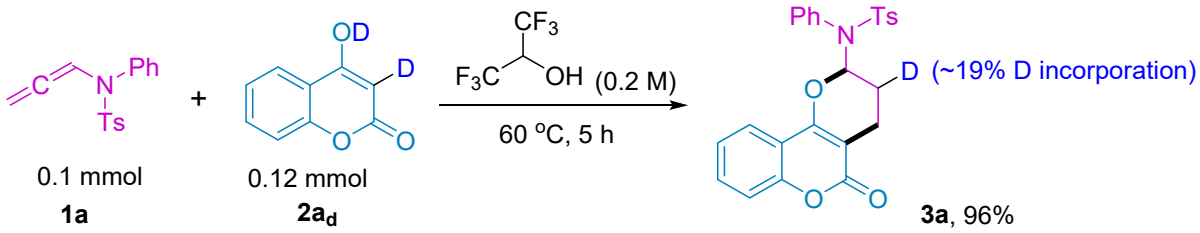


2a **2a$_d$**, 99%

In a reaction tube 4-hydroxy coumarin 100 mg (0.6 mmol) was dissolved in acetone (0.5 mL) and D_2O (0.5 mL). The reaction mixture was heated up to 60 °C and was stirred for 6 h. Then the reaction mixture was cooled and evaporated under vacuum to get dry white solid product 100 mg (99%). ^1H NMR of the product suggested the D-incorporation around 99% at (-OD) and 93% at C-D bond.



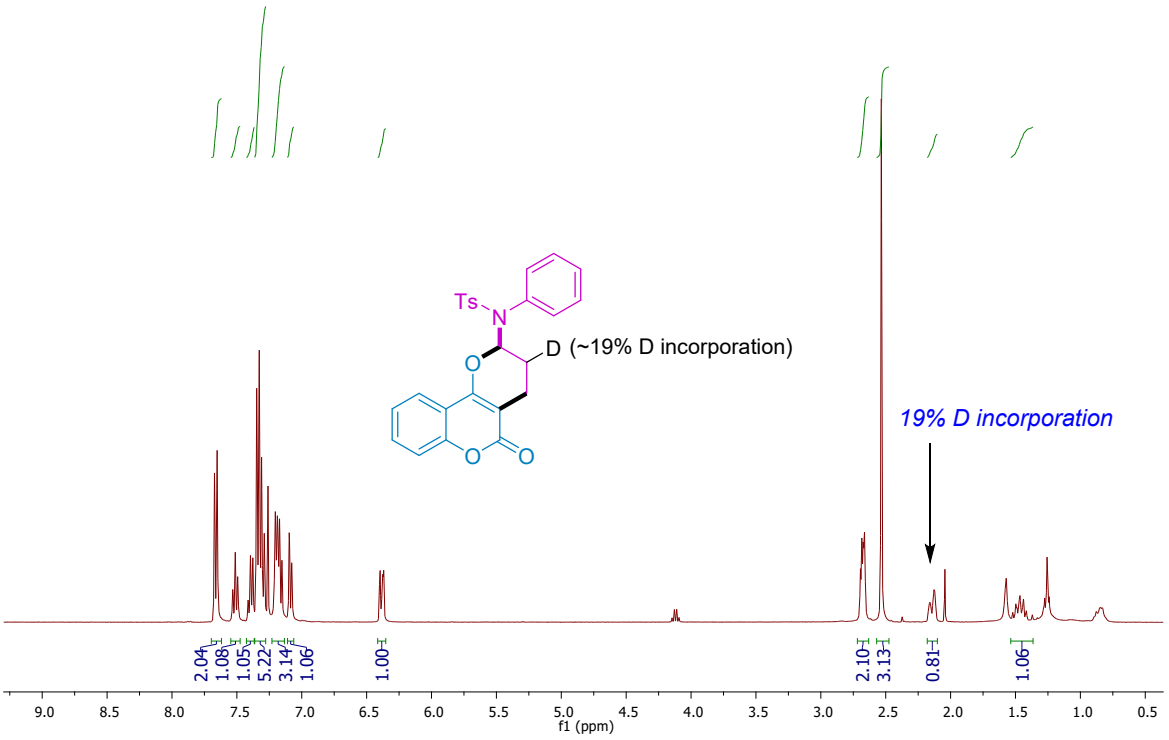
f) Reaction with coumarin-D (**2a$_d$**):



0.1 mmol
1a

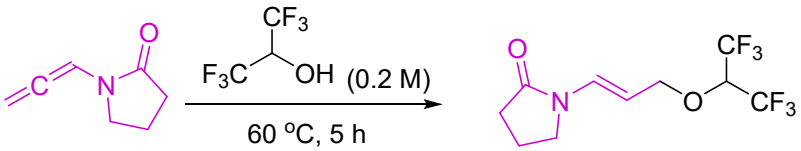
0.12 mmol
2a$_d$

3a, 96%



h) Stepwise reaction for path A:

Step 1:



1n 0.3 mmol **4**, 75%

(*E*)-1-(3-((1,1,1,3,3,3-hexafluoropropan-2-yl)oxy)prop-1-en-1-yl)pyrrolidin-2-one (5):

Appearance: white solid.

Yield: 75% (66 mg)

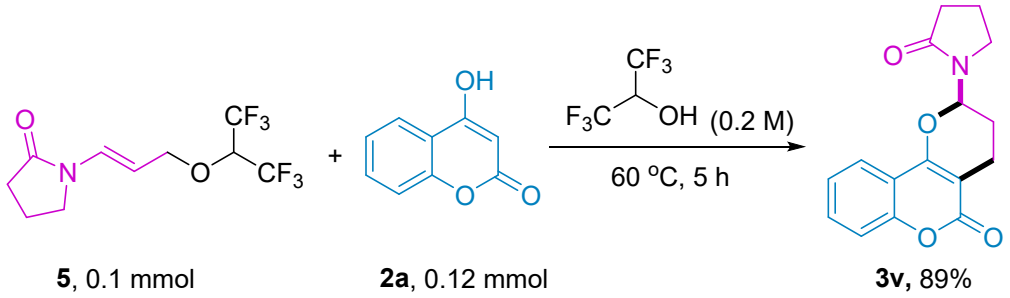
^{1}H NMR (400 MHz, $CDCl_3$) δ 7.16 (d, *J* = 14.4 Hz, 1H), 4.98 (dt, *J* = 14.6, 7.5 Hz, 1H), 4.37 (d, *J* = 7.5 Hz, 2H), 4.14 (dt, *J* = 12.1, 6.1 Hz, 1H), 3.57 – 3.51 (m, 2H), 2.51 (t, *J* = 8.2 Hz, 2H), 2.14 (dt, *J* = 15.8, 7.7 Hz, 2H) ppm.

^{13}C NMR (101 MHz, $CDCl_3$) δ 173.9, 130.2, 123.1, 120.3, 104.0, 73.6, 73.4, 73.3, 72.9, 4.17, 31.1, 17.5 ppm.

^{19}F NMR (151 MHz, $CDCl_3$) δ -73.82, -73.82 ppm.

HRMS (ESI): Calculated for $C_{10}H_{11}F_6NO_2$ [M^+], 291.0694; found, 290.9506 [M-H].

Step 2:



5, 0.1 mmol **2a**, 0.12 mmol **3v,** 89%

5. Computational studies

All calculations were performed employing a density functional theory (DFT) method implemented in the Gaussian 16 suite of programs.[4] For geometry optimization and frequency analysis, we adopted the BP86 functional[5] level of theory in combination with Grimme's D3 dispersion corrections with a Becke-Johnson damping scheme (D3BJ)[6,7] in the gas phase. During geometry optimization we used the split-valence plus single polarization basis set def2-SVP[8] for non-metals. The geometries were optimized without any symmetry constraints. For each transition state, in addition to analyzing the character of the normal mode associated with the imaginary frequency, intrinsic reaction coordinate (IRC) analysis[9] was performed to confirm that it connects the correct reactant and product on the potential energy surface. Furthermore, performed the thermal correction to Gibbs free energy at 333.15 K and 1 atm. To refine the computed energy, single point calculations were performed using the hybrid-meta-GGA M06 functional[10] by including the dispersion D3 with the def2-TZVP[8] basis set, for nonmetals. Solvation energies were evaluated implicitly by a self-consistent reaction field (SCRF) approach for all the intermediates and transitions states, in HFIP solvent, using the SMD continuum solvation model.[11] The free energies (ΔG), calculated at the M06-D3(SMD)/def2-TZVP//BP86-D3(BJ)/def2-SVP level are reported throughout the article unless otherwise mentioned. The ΔG value is obtained by augmenting the in solvent electronic energy (ΔE), calculated at M06-D3(SMD)/def2-TZVP, with the corresponding free energy corrections calculated at BP86-D3(BJ)/def2-SVP at 333.15 K in the gas phase.

Table 1. Cartesian coordinates (Å) of the optimized structures of all intermediates and transition states at BP86-D3(BJ)/def2-SVP at 333.15 K level of theory. E_e^S represents the absolute electronic energy in Hartree at M06-D3/def2-TZVP at 333.15 K level of theory in the HFIP solvent.

1n

E_e^S = -401.9746668

Frequency = 86.9803 cm^{-1}

C	-3.059616000	0.201321000	-1.962860000
C	-3.007472000	1.386094000	-0.971606000
C	-3.381610000	-1.014176000	-1.076879000
N	-2.638151000	0.747954000	0.287919000
C	-2.833218000	-0.635572000	0.302734000
H	-2.064100000	0.070460000	-2.435439000
H	-4.476677000	-1.180901000	-0.969190000
H	-3.990853000	1.901861000	-0.868541000
H	-2.259390000	2.158792000	-1.247194000
O	-2.624545000	-1.360921000	1.264723000
H	-2.940466000	-1.970356000	-1.418558000
H	-3.794173000	0.369647000	-2.774114000
C	-2.232045000	1.444696000	1.429711000
H	-2.036531000	0.772177000	2.285445000
C	-2.088467000	2.761805000	1.506697000
C	-1.942999000	4.067620000	1.611126000
H	-0.981690000	4.567973000	1.386627000
H	-2.773978000	4.723776000	1.933394000

HFIP

E_e^S = -789.8642827

Frequency = 39.873 cm^{-1}

C	0.023218000	-0.008813000	-0.523705000
H	1.002688000	0.392443000	-0.163130000
C	0.106225000	0.008144000	-2.067165000
F	0.004807000	1.309326000	-2.472010000
F	1.285100000	-0.467897000	-2.511457000
F	-0.885744000	-0.679261000	-2.657418000
C	-0.097362000	-1.424940000	0.072043000
F	0.011977000	-1.362450000	1.415620000
F	-1.272584000	-2.003294000	-0.227504000
F	0.899184000	-2.214214000	-0.393203000
O	-1.085185000	0.720859000	-0.074638000
H	-1.016714000	1.617622000	-0.455160000

IN1

E_e^S = -1191.877102

Frequency = 9.6268 cm^{-1}

C	-0.894048000	0.978953000	-1.619602000
C	-1.815610000	1.625295000	-0.560287000
C	-0.759279000	-0.481949000	-1.160098000
N	-1.591080000	0.807658000	0.629331000
C	-0.977804000	-0.427027000	0.353180000
H	0.098461000	1.474621000	-1.597338000
H	-1.552158000	-1.134736000	-1.588983000
H	-2.891502000	1.592806000	-0.851733000
H	-1.559148000	2.686007000	-0.356573000
O	-0.718186000	-1.276717000	1.190000000
H	0.212576000	-0.957712000	-1.393442000
H	-1.298502000	1.089446000	-2.644183000
C	-2.018756000	1.143120000	1.903812000
H	-1.740209000	0.376562000	2.647782000
C	-2.711700000	2.258995000	2.237242000
C	-3.138605000	2.536363000	3.640198000
H	-4.234694000	2.700100000	3.699529000
H	-2.891018000	1.684161000	4.309653000
H	-2.979794000	3.016371000	1.482686000
C	-3.137569000	4.664921000	4.863952000
H	-2.431811000	5.506216000	5.032775000
C	-3.506418000	4.159701000	6.281464000
C	-4.343141000	5.308631000	4.119873000
O	-2.435325000	3.725068000	4.113053000
F	-2.381186000	3.823247000	6.944440000
F	-4.140780000	5.123543000	6.989010000
F	-4.306673000	3.068686000	6.253685000
F	-4.048781000	5.440741000	2.808096000
F	-5.484670000	4.579851000	4.211879000
F	-4.605630000	6.536664000	4.615825000

2a

E_e^S = -572.1236043

Frequency = 91.288 cm^{-1}

C	0.269198000	2.382655000	-7.172572000
C	0.263329000	3.751337000	-7.033122000
C	0.265967000	2.180250000	-4.732013000
C	0.270647000	1.532066000	-5.995953000
C	0.276453000	0.118556000	-6.051592000
C	0.277675000	-0.632422000	-4.873343000
C	0.273093000	0.023339000	-3.622378000
C	0.267270000	1.420577000	-3.545945000
H	0.262055000	4.423015000	-7.905034000
H	0.263618000	1.951722000	-2.583198000
H	0.274054000	-0.567452000	-2.693142000
H	0.282238000	-1.731707000	-4.920402000
H	0.280030000	-0.368639000	-7.037215000
O	0.260274000	3.533781000	-4.611183000
O	0.273467000	1.740600000	-8.361414000
H	0.271885000	2.404242000	-9.079436000
C	0.258594000	4.405104000	-5.735528000
O	0.253903000	5.596708000	-5.514430000

IN2

E_e^S = -1764.020318

Frequency = 10.5018 cm^{-1}

C	-2.662886000	3.043383000	1.642730000
C	-3.992175000	2.288936000	1.882906000
C	-1.612064000	1.937698000	1.438162000
N	-3.563827000	0.967548000	2.346219000

C	-2.197635000	0.700209000	2.111365000
H	-2.420725000	3.644414000	2.540704000
H	-1.451461000	1.686786000	0.366020000
H	-4.602447000	2.180235000	0.957061000
H	-4.619212000	2.787268000	2.649974000
O	-1.646795000	-0.353112000	2.386274000
H	-0.617565000	2.159947000	1.870537000
H	-2.739891000	3.738688000	0.785294000
C	-4.390127000	0.027269000	2.917425000
H	-3.841018000	-0.889604000	3.195072000
C	-5.718294000	0.176639000	3.164373000
C	-6.472167000	-0.852862000	3.923824000
H	-7.503469000	-0.993348000	3.552416000
H	-5.952548000	-1.831733000	3.925863000
H	-6.243621000	1.109597000	2.907561000
C	-7.806483000	-0.274492000	5.976064000
H	-7.599121000	-0.105733000	7.053906000
C	-8.713661000	-1.535542000	5.934264000
C	-8.514742000	1.014784000	5.490246000
O	-6.559080000	-0.457227000	5.365888000
F	-7.955116000	-2.637437000	6.097373000
F	-9.622784000	-1.492612000	6.928530000
F	-9.385677000	-1.661852000	4.763746000
F	-7.745549000	2.085997000	5.783447000
F	-8.728946000	1.018603000	4.154710000
F	-9.703812000	1.168414000	6.108312000
C	-3.459232000	0.773019000	5.790954000
C	-4.172463000	1.941100000	5.607744000
C	-2.026066000	0.761604000	5.549142000
O	-4.009376000	-0.397826000	6.138328000
H	-5.261064000	1.970869000	5.740189000
C	-3.560556000	3.151777000	5.113639000
C	-1.425746000	1.971214000	5.117306000
C	-0.050028000	2.021858000	4.824819000
O	-2.149328000	3.111165000	4.936514000
C	-1.230293000	-0.401227000	5.659823000
C	0.132960000	-0.354449000	5.360812000
H	-1.716330000	-1.336772000	5.970350000
C	0.720567000	0.859599000	4.946153000
H	0.745586000	-1.265016000	5.436685000
H	1.794751000	0.896241000	4.706971000
H	0.384352000	2.978191000	4.498646000
H	-5.002446000	-0.352222000	6.029578000
O	-4.116974000	4.188244000	4.796833000

TS1

E_e^S = -1763.977416

Frequency = -160.3782 cm^{-1}

C	4.748115000	2.734773000	0.358511000
C	3.891319000	1.674573000	-0.363912000
C	3.739139000	3.533036000	1.197867000
N	2.559059000	2.301036000	-0.466265000
C	2.444978000	3.473267000	0.405162000
H	5.232688000	3.400409000	-0.385147000
H	3.539246000	3.044755000	2.178703000
H	3.791854000	0.730726000	0.211430000
H	4.276111000	1.423070000	-1.371562000
O	1.472946000	4.182326000	0.433328000
H	4.017600000	4.583296000	1.405028000
H	5.549399000	2.267193000	0.960736000
C	1.509354000	1.808525000	-1.130568000
H	0.534051000	2.347378000	-0.981664000
C	1.595602000	0.616243000	-1.887928000
C	0.465635000	-0.000889000	-2.368667000
H	-0.529552000	0.454115000	-2.244482000
H	0.530684000	-0.957649000	-2.902989000
H	2.563099000	0.104107000	-1.990175000
C	1.017288000	-2.542551000	0.200018000
H	0.622309000	-3.482343000	0.668369000
C	1.352898000	-1.627104000	1.407772000
C	2.292296000	-2.990748000	-0.553178000
O	0.132652000	-1.959484000	-0.671422000
F	0.252729000	-1.432747000	2.157967000
F	2.317544000	-2.144454000	2.204853000
F	1.785451000	-0.389623000	1.009452000
F	1.963085000	-3.624699000	-1.693033000
F	3.095200000	-1.935410000	-0.896632000
F	3.047077000	-3.830326000	0.189933000
C	-1.640332000	0.428713000	-0.019968000
C	-2.534279000	-0.655554000	0.074387000
C	-3.964239000	-0.307121000	0.110595000
O	-2.175931000	-1.894056000	0.119726000
H	-0.565998000	0.236012000	0.038687000
C	-2.046196000	1.772255000	-0.278772000
C	-4.339602000	1.052009000	-0.040506000
C	-5.696605000	1.427380000	0.004722000
O	-3.426208000	2.045423000	-0.256343000
C	-4.970480000	-1.280988000	0.294047000
C	-6.318379000	-0.912196000	0.341022000
H	-4.646805000	-2.327437000	0.399424000
C	-6.677087000	0.446070000	0.196587000
H	-7.097799000	-1.675520000	0.488503000
H	-7.737518000	0.741970000	0.231532000
H	-5.952971000	2.490086000	-0.116965000
O	-1.312620000	2.726346000	-0.561878000
H	-0.932852000	-1.974694000	-0.268846000

IN3

E_e^S = -1764.026514

Frequency = 6.5783 cm^{-1}

C	-10.537298000	1.796281000	2.869062000
C	-9.412931000	1.132819000	2.041628000
C	-10.255041000	3.303194000	2.750502000
N	-8.330617000	2.113110000	2.093980000
C	-8.747734000	3.390500000	2.503665000
H	-10.451177000	1.478770000	3.928679000
H	-10.764663000	3.760852000	1.873194000
H	-9.710711000	0.944027000	0.984084000
H	-9.076282000	0.165344000	2.469206000
O	-8.016011000	4.363428000	2.598510000
H	-10.536663000	3.902780000	3.637404000
H	-11.543287000	1.501443000	2.513275000
C	-7.025751000	1.855862000	1.710018000
H	-6.367251000	2.727411000	1.867518000

C	-6.582042000	0.686442000	1.187104000
C	-5.156830000	0.451346000	0.819181000
H	-4.569756000	1.393827000	0.813491000
H	-5.092488000	-0.008343000	-0.186744000
H	-7.266567000	-0.164204000	1.037197000
C	-5.943540000	-2.869908000	-1.496928000
H	-5.107667000	-2.654661000	-2.202480000
C	-7.097589000	-1.934494000	-1.915626000
C	-6.272061000	-4.370739000	-1.680099000
O	-5.627410000	-2.608315000	-0.166189000
F	-6.642942000	-0.654307000	-1.965804000
F	-7.582647000	-2.240714000	-3.138406000
F	-8.119721000	-1.966408000	-1.035713000
F	-5.250719000	-5.107676000	-1.188924000
F	-7.397827000	-4.728723000	-1.028999000
F	-6.420954000	-4.691907000	-2.987068000
C	-3.150306000	-1.021167000	1.154436000
C	-4.454228000	-0.596673000	1.792842000
C	-1.961695000	-0.271750000	1.571490000
O	-3.119686000	-1.887209000	0.261899000
H	-5.138348000	-1.464054000	1.861242000
C	-4.347000000	0.023873000	3.164316000
C	-2.050170000	0.616172000	2.674497000
C	-0.930344000	1.368525000	3.072741000
O	-3.187178000	0.763483000	3.427332000
C	-0.729753000	-0.403674000	0.886227000
C	0.381561000	0.344689000	1.275824000
H	-0.693059000	-1.105863000	0.039566000
C	0.273136000	1.233333000	2.369468000
H	1.335337000	0.247048000	0.736246000
H	1.146228000	1.827932000	2.680681000
H	-1.027463000	2.043793000	3.935024000
H	-4.634816000	-2.481306000	-0.072244000
O	-5.215992000	0.014994000	3.998212000

TS2

E_e^S = -1763.979205

Frequency = -1236.8952 cm^{-1}

C	0.817907000	-1.935585000	0.577363000
C	0.733036000	-0.692299000	1.351458000
C	3.255383000	-1.420265000	0.364292000
C	2.144643000	-2.204999000	-0.023961000
C	2.321758000	-3.225309000	-0.982119000
C	3.575373000	-3.451146000	-1.558484000
C	4.673658000	-2.653263000	-1.168889000
C	4.522137000	-1.644267000	-0.209776000
H	5.366001000	-1.017884000	0.114532000
H	5.664219000	-2.823865000	-1.619655000
H	3.707855000	-4.242790000	-2.311841000
H	1.434418000	-3.818844000	-1.251384000
O	3.170175000	-0.444805000	1.317528000
O	-0.163676000	-2.678152000	0.356828000
C	1.953196000	-0.129654000	1.952934000
O	2.011660000	0.623270000	2.905564000
C	-0.541511000	-0.466315000	2.165220000
H	-0.335001000	0.364885000	2.865415000
H	-0.769065000	-1.365447000	2.777980000
C	-1.771247000	-0.086340000	1.309584000
H	-2.366352000	0.768824000	1.690092000
C	-2.545488000	-1.144372000	0.739784000
H	-2.075269000	-2.147407000	0.624590000
C	-5.866861000	-0.101935000	-0.426579000
C	-5.623511000	-1.397574000	-1.218426000
C	-4.469125000	0.308666000	0.082536000
C	-4.411774000	-2.036885000	-0.562373000
N	-3.738145000	-0.967429000	0.174325000
H	-6.534783000	-0.305086000	0.435523000
H	-3.928589000	0.982861000	-0.616051000
H	-5.346319000	-1.192652000	-2.277428000
H	-6.471641000	-2.107871000	-1.237864000
O	-4.002822000	-3.169439000	-0.600055000
H	-4.491251000	0.807120000	1.072054000
H	-6.334465000	0.699328000	-1.028692000
H	0.495012000	0.155349000	0.203134000
C	0.220336000	1.984657000	-1.046164000
H	-0.156201000	2.237947000	-2.066738000
C	1.755731000	2.197251000	-1.119851000
C	-0.470245000	2.989675000	-0.095645000
O	-0.110804000	0.680323000	-0.716418000
F	2.321761000	2.265226000	0.104497000
F	2.324011000	1.172307000	-1.785892000
F	2.051100000	3.341927000	-1.779858000
F	-1.827094000	2.886059000	-0.254430000
F	-0.208791000	2.730704000	1.201962000
F	-0.133606000	4.268718000	-0.353045000
H	-1.314647000	0.363234000	0.313958000

IN4

E_e^S = -1764.04907

Frequency = 11.6707 cm^{-1}

O	0.741551000	3.143903000	-8.106252000
C	-0.272386000	4.123018000	-8.083585000
C	-0.577870000	4.722570000	-6.787259000
C	0.105440000	4.334474000	-5.655427000
C	1.205231000	3.388767000	-5.730378000
C	1.462128000	2.809126000	-7.001831000
C	2.483421000	1.853858000	-7.162830000
C	3.263151000	1.484265000	-6.061190000
C	3.040035000	2.070734000	-4.796916000
C	2.025939000	3.019402000	-4.635742000
O	-0.200120000	4.800197000	-4.411516000
H	1.863300000	3.482854000	-3.652855000
H	3.660249000	1.786362000	-3.934213000
H	4.060452000	0.735852000	-6.188354000
H	2.643150000	1.423244000	-8.161880000
O	-0.826267000	4.384611000	-9.132595000
C	-1.641011000	5.788398000	-6.744423000
H	-2.649066000	5.325255000	-6.846865000
H	-1.527459000	6.440033000	-7.635049000
C	-1.529920000	6.595772000	-5.447638000
H	-0.636684000	7.250535000	-5.445197000
C	-1.420365000	5.643330000	-4.260961000
H	-2.270726000	4.929759000	-4.257474000
H	-2.420449000	7.236846000	-5.290542000

N	-1.350472000	6.249499000	-2.973405000
C	-2.099979000	5.739003000	-1.810746000
H	-1.688715000	4.760687000	-1.481091000
H	-3.170144000	5.600101000	-2.068400000
C	-1.872488000	6.837097000	-0.753251000
H	-1.944739000	6.440020000	0.277494000
H	-2.638323000	7.633119000	-0.865217000
C	-0.484872000	7.392101000	-1.109326000
H	0.330812000	6.794966000	-0.643810000
C	-0.375272000	7.192982000	-2.623252000
O	0.419304000	7.713721000	-3.391469000
H	-0.312895000	8.451897000	-0.841236000
H	-0.021717000	3.858366000	-2.988324000
O	0.023834000	3.335450000	-2.143384000
C	-0.262940000	1.999653000	-2.437181000
C	0.383287000	1.140461000	-1.334405000
C	-1.784225000	1.782132000	-2.588911000
H	0.192063000	1.655694000	-3.396765000
F	-0.043536000	1.490149000	-0.105990000
F	1.725521000	1.299493000	-1.372794000
F	0.114524000	-0.171533000	-1.519416000
F	-2.244859000	2.615435000	-3.570038000
F	-2.465001000	2.075432000	-1.462910000
F	-2.085847000	0.522980000	-2.956325000

3v

E_e^S = -974.177216

Frequency = 29.8884 cm^{-1}

O	0.145677000	2.761787000	-7.843918000
C	-0.215632000	4.126787000	-7.863558000
C	-0.303150000	4.801905000	-6.574351000
C	-0.052301000	4.121109000	-5.399393000
C	0.321805000	2.718472000	-5.419871000
C	0.405984000	2.089816000	-6.688965000
C	0.761333000	0.731432000	-6.790595000
C	1.032373000	0.002489000	-5.626587000
C	0.948303000	0.614618000	-4.356628000
C	0.592964000	1.962557000	-4.255112000
O	-0.127827000	4.681721000	-4.171535000
H	0.511295000	2.461596000	-3.278883000
H	1.158238000	0.030071000	-3.448189000
H	1.310461000	-1.059891000	-5.707113000
H	0.815792000	0.276110000	-7.790034000
O	-0.417933000	4.636575000	-8.948906000
C	-0.632518000	6.272003000	-6.568360000
H	-1.724194000	6.422490000	-6.728753000
H	-0.136860000	6.759845000	-7.432539000
C	-0.191364000	6.898103000	-5.240211000
H	0.916847000	6.973882000	-5.204612000
C	-0.671320000	6.040057000	-4.070243000
H	-1.780845000	5.951787000	-4.060509000
H	-0.601017000	7.920818000	-5.115418000
N	-0.308977000	6.524629000	-2.781223000
C	1.060107000	6.844427000	-2.377304000
H	1.366421000	7.846352000	-2.758923000
H	1.770908000	6.093990000	-2.780101000
C	0.975982000	6.822865000	-0.833600000
H	1.711115000	7.505282000	-0.364967000
H	1.188851000	5.796458000	-0.469078000
C	-0.488858000	7.185429000	-0.537049000
H	-0.646399000	8.284945000	-0.468751000
C	-1.252891000	6.679352000	-1.765023000
O	-2.451872000	6.474148000	-1.880993000
H	-0.904953000	6.738167000	0.385688000

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7.0 General procedure for the HFIP mediated cascade di-functionalization of 4-hydroxy coumarin derivatives with allenamides.

Condition A:

An oven-dried screw cap reaction tube was charged with a magnetic stir-bar, allenamides **1** (0.2 mmol, 1.0 equiv) 4-hydroxy coumarin **2** (0.24 mmol, 1.2 equiv), and in HFIP (1 mL, 0.2 M). The resulting reaction mixture was stirred vigorously on a preheated aluminum block at 60 °C for 5 h. After the completion of the reaction (vide TLC), the desired product was isolated via precipitation technique.

Process: In the crude reaction mixture, 1 mL solvent mixture (EtOAc/Hexane; 9/1) was added and stirred for 10 mins. A white precipitation appeared and filtered through sintered glass funnel under vacuum.

A pictorial diagram was presented for the whole process [0.6 mmol scale] (Figure 1).

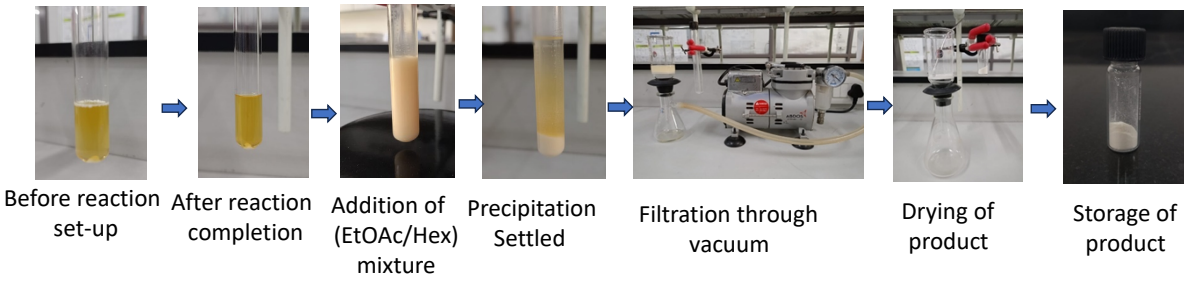
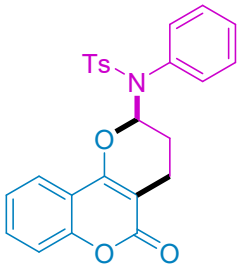


Figure 1. Pictorial diagram of process development

Condition B:

An oven-dried screw cap reaction tube was charged with a magnetic stir-bar, allenamides **1** (0.2 mmol, 1.0 equiv) 4-hydroxy coumarin **2** (0.24 mmol, 1.2 equiv) and DCE (2 mL, 0.2 M). Then HFIP (17 mg, 0.1 mmol) was added to the reaction tube and the resulting reaction mixture was stirred vigorously on a preheated aluminum block at 60 °C for 5 – 8 h. After the completion of the reaction (vide TLC), the desired product was isolated by column chromatography using silica gel (mesh size 100-200) and DCM/hexane as the eluent.

7.1. Characterization data of di-functionalized products.



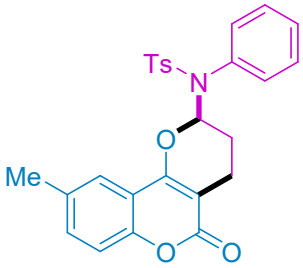
(*R*)-4-methyl-N-(5-oxo-3,4-dihydro-2H,5H-pyrano[3,2-c]chromen-2-yl)-N phenylbenzenesulfonamide **(3a):**
***Rf*:** 0.4 (DCM/Hexane, 95/5)
Appearance: white solid
Purification: Added 1 ml (EtOAc/Hex; 9/1) and filtered the product (**Condition A**)
Column chromatography (DCM/Hexane; 9/1) (**Condition B**)

Yield: 99% (88 mg; **A**); 94% (84 mg; **B**)

^{1}H NMR (400 MHz, $CDCl_3$) δ 7.66 (d, *J* = 8.2 Hz, 2H), 7.54 – 7.49 (m, 1H), 7.39 (d, *J* = 7.3 Hz, 1H), 7.36 – 7.29 (m, 5H), 7.23 – 7.16 (m, 3H), 7.09 (dd, *J* = 7.8, 1.3 Hz, 1H), 6.38 (dd, *J* = 11.0, 2.1 Hz, 1H), 2.68 (dd, *J* = 8.9, 3.8 Hz, 2H), 2.53 (s, 3H), 2.18 – 2.09 (m, 1H), 1.51 – 1.42 (m, 1H).

^{13}C NMR (101 MHz, $CDCl_3$) δ 162.50, 159.00, 152.70, 144.28, 136.97, 134.90, 131.76, 131.44, 129.67, 129.64, 129.37, 128.68, 123.68, 122.23, 116.90, 115.41, 100.92, 86.73, 26.03, 21.85, 20.29.

HRMS (ESI-MS): m/z calculated for $[M+Na]^+$; $C_{25}H_{21}NO_5SNa$: Calculated, 470.1038, found 470.1047.



(R)-4-methyl-N-(9-methyl-5-oxo-3,4-dihydro-2H,5H-pyrano[3,2-c]chromen-2-yl)-N-phenylbenzenesulfonamide (**3b**):

***Rf*:** 0.4 (DCM/Hexane, 95/5)

Appearance: white solid

Purification: Added 1 ml (EtOAc/Hex; 9/1) and filtered the product (**Condition A**)

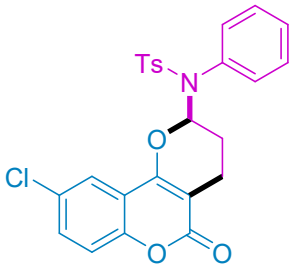
Column chromatography (DCM/Hexane; 9/1) (**Condition B**)

Yield: 97% (89 mg; **A**); 92% (85 mg; **B**)

^{1}H NMR (400 MHz, $CDCl_3$) δ 7.66 (d, *J* = 8.2 Hz, 2H), 7.43 – 7.37 (m, 1H), 7.33 (dd, *J* = 13.8, 6.0 Hz, 5H), 7.19 (d, *J* = 8.4 Hz, 3H), 6.93 (s, 1H), 6.40 (dd, *J* = 10.9, 1.8 Hz, 1H), 2.67 (dd, *J* = 8.8, 3.6 Hz, 2H), 2.52 (s, 3H), 2.39 (s, 3H), 2.16 – 2.07 (m, 1H), 1.49 – 1.40 (m, 1H).

^{13}C NMR (101 MHz, $CDCl_3$) δ 162.72, 159.00, 150.85, 144.08, 136.89, 134.86, 133.42, 132.76, 131.46, 129.66, 129.64, 129.38, 128.78, 121.71, 116.67, 115.14, 100.80, 86.75, 26.03, 21.90, 21.08, 20.32.

HRMS (ESI-MS): m/z calculated for $[M+H]^+$ $C_{26}H_{24}NO_5S$, calculated, 462.1375; found, 462.1390.



(R)-N-(9-chloro-5-oxo-3,4-dihydro-2H,5H-pyrano[3,2-c]chromen-2-yl)-4-methyl-N-phenylbenzenesulfonamide (**3c**):

***Rf*:** 0.4 (DCM/Hexane, 95/5)

Appearance: white solid

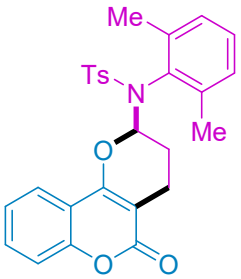
Purification: Added 1 ml (EtOAc/Hex; 9/1) and filtered the product (**Condition A**)

Yield: 96% (92 mg; **A**)

^{1}H NMR (400 MHz, $CDCl_3$) δ 7.66 (d, *J* = 8.2 Hz, 2H), 7.50 – 7.46 (m, 1H), 7.44 – 7.35 (m, 5H), 7.28 (s, 1H), 7.24 – 7.14 (m, 2H), 7.12 (d, *J* = 2.3 Hz, 1H), 6.43 (dd, *J* = 10.9, 1.8 Hz, 1H), 2.70 (dd, *J* = 8.9, 3.8 Hz, 2H), 2.56 (s, 3H), 2.22 – 2.12 (m, 1H), 1.54 – 1.43 (m, 1H).

^{13}C NMR (101 MHz, $CDCl_3$) δ 161.93, 157.98, 151.07, 144.75, 136.50, 134.80, 131.78, 131.35, 129.87, 129.76, 129.45, 129.40, 128.62, 121.64, 118.41, 116.65, 101.95, 87.14, 25.88, 21.98, 20.35.

HRMS (ESI-MS): m/z calculated for $[M+H]^+$ $C_{25}H_{21}ClNO_5S$, calculated, 482.0829; found, 482.0823.



(R)-N-(2,6-dimethylphenyl)-4-methyl-N-(5-oxo-3,4-dihydro-2H,5H-pyrano[3,2-c]chromen-2-yl)benzenesulfonamide (**3d**):

***Rf*:** 0.3 (DCM/Hexane, 95/5)

Appearance: white solid

Purification: Added 1 ml (EtOAc/Hex; 9/1) and filtered the product (**Condition A**)

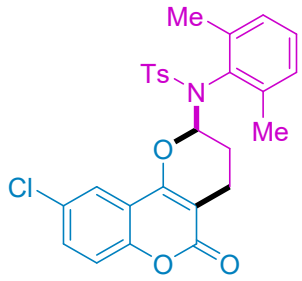
Column chromatography (DCM/Hexane; 93/7) (**Condition B**)

Yield: 96% (91 mg; **A**); 91% (86 mg; **B**)

^{1}H NMR (400 MHz, $CDCl_3$) δ 7.82 (d, *J* = 8.2 Hz, 2H), 7.52 – 7.48 (m, 1H), 7.36 (d, *J* = 8.1 Hz, 2H), 7.29 (d, *J* = 8.3 Hz, 1H), 7.21 – 7.12 (m, 4H), 7.05 – 6.96 (m, 1H), 6.42 (dd, *J* = 10.7, 1.5 Hz, 1H), 2.65 (dd, *J* = 8.3, 3.2 Hz, 2H), 2.52 (s, 3H), 2.43 (s, 3H), 2.03 – 1.96 (m, 1H), 1.92 (s, 3H), 1.42 – 1.32 (m, 1H).

^{13}C NMR (101 MHz, $CDCl_3$) δ 162.57, 158.91, 152.69, 144.30, 141.39, 139.25, 138.78, 133.77, 131.72, 129.78, 129.52, 129.33, 129.24, 128.56, 123.67, 122.41, 116.85, 115.41, 100.82, 87.95, 24.96, 21.83, 20.38, 20.29, 19.68.

HRMS (ESI-MS): m/z calculated for $[M+Na]^+$ $C_{27}H_{25}NNaO_5S$, calculated, 498.1351; found, 498.1346.



(R)-N-(9-chloro-5-oxo-3,4-dihydro-2H,5H-pyrano[3,2-c]chromen-2-yl)-N-(2,6-dimethylphenyl)-4-methylbenzenesulfonamide (**3e**):

***Rf*:** 0.4 (DCM/Hexane, 95/5)

Appearance: white solid

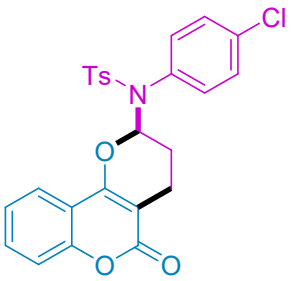
Purification: Added 1 ml (EtOAc/Hex; 9/1) and filtered the product (**Condition A**)

Yield: 95% (97 mg; **A**)

^{1}H NMR (400 MHz, $CDCl_3$) δ 7.83 (d, *J* = 8.3 Hz, 2H), 7.49 – 7.44 (m, 3H), 7.25 (d, *J* = 8.8 Hz, 1H), 7.22 – 7.19 (m, 3H), 7.02 (dd, *J* = 9.3, 3.9 Hz, 1H), 6.49 (dd, *J* = 10.9, 2.3 Hz, 1H), 2.66 (dd, *J* = 9.1, 4.1 Hz, 2H), 2.54 (s, 3H), 2.49 (s, 3H), 2.04 – 1.96 (m, 1H), 1.83 (s, 3H), 1.43 – 1.27 (m, 1H).

^{13}C NMR (101 MHz, $CDCl_3$) δ 161.89, 157.77, 151.03, 144.62, 141.50, 138.87, 138.59, 133.73, 131.69, 130.05, 129.49, 129.38, 129.33, 129.25, 128.37, 121.73, 118.33, 116.49, 101.79, 88.19, 21.88, 21.14, 20.38, 20.31, 19.54.

HRMS (ESI-MS): m/z calculated for $[M+H]^+$ $C_{27}H_{25}ClNO_5S$, calculated, 510.1142; found, 510.1136.



(R)-N-(4-chlorophenyl)-4-methyl-N-(5-oxo-3,4-dihydro-2H,5H-pyrano[3,2-c]chromen-2-yl)benzenesulfonamide (**3f**):

Rf**:** 0.4 (DCM/Hexane, 95/5)

Appearance: white solid

Purification: Added 1 ml (EtOAc/Hex; 9/1) and filtered the product (**Condition A**)

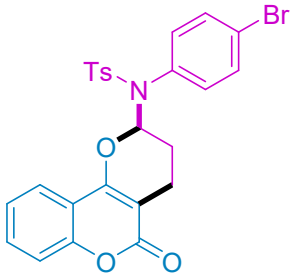
Column chromatography (DCM/Hexane; 9/1) (**Condition B**)

Yield: 97% (93 mg; **A**); 91% (87 mg; **B**)

^{1}H NMR (400 MHz, $CDCl_3$) δ 7.68 (d, *J* = 8.3 Hz, 2H), 7.57 – 7.53 (m, 1H), 7.38 (d, *J* = 8.3 Hz, 2H), 7.33 (d, *J* = 8.6 Hz, 3H), 7.24 – 7.11 (m, 3H), 7.07 (dd, *J* = 7.9, 1.7 Hz, 1H), 6.38 (dd, *J* = 11.1, 2.3 Hz, 1H), 2.76 – 2.67 (m, 2H), 2.56 (s, 3H), 2.21 – 2.10 (m, 1H), 1.55 – 1.45 (m, 1H).

^{13}C NMR (101 MHz, $CDCl_3$) δ 162.46, 158.89, 152.69, 144.58, 136.58, 135.91, 133.40, 132.64, 131.87, 129.78, 129.69, 128.66, 123.74, 122.08, 116.99, 115.28, 101.00, 86.60, 26.01, 21.88, 20.27.

HRMS (ESI-MS): m/z calculated for $[M+H]^+$ $C_{25}H_{21}ClNO_5S$, calculated, 482.0829; found, 482.0823.



(R)-N-(4-bromophenyl)-4-methyl-N-(5-oxo-3,4-dihydro-2H,5H-pyrano[3,2-c]chromen-2-yl)benzenesulfonamide (**3g**):

Rf**:** 0.4 (DCM/Hexane, 95/5)

Appearance: white solid

Purification: Added 1 ml (EtOAc/Hex; 9/1) and filtered the product (**Condition A**)

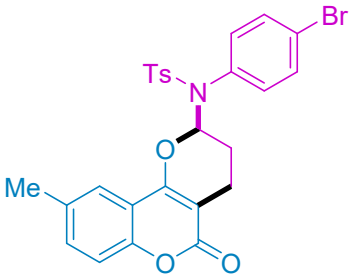
Column chromatography (DCM/Hexane; 9/1) (**Condition B**)

Yield: 97% (102 mg; **A**); 92% (96 mg; **B**)

^{1}H NMR (400 MHz, $CDCl_3$) δ 7.66 (d, *J* = 8.2 Hz, 2H), 7.52 (t, *J* = 7.8 Hz, 1H), 7.46 (d, *J* = 8.5 Hz, 2H), 7.33 (dd, *J* = 19.4, 8.2 Hz, 3H), 7.17 (t, *J* = 7.6 Hz, 1H), 7.06 (t, *J* = 8.4 Hz, 3H), 6.36 (dd, *J* = 11.0, 1.8 Hz, 1H), 2.71 – 2.67 (m, 2H), 2.54 (s, 3H), 2.15 – 2.11 (m, 1H), 1.53 – 1.41 (m, 1H).

^{13}C NMR (101 MHz, $CDCl_3$) δ 162.40, 158.85, 152.73, 144.58, 136.63, 133.99, 132.97, 132.71, 131.86, 129.79, 128.67, 124.11, 123.73, 122.08, 117.00, 115.30, 101.04, 86.58, 26.04, 21.88, 20.29.

HRMS (ESI-MS): m/z calculated for $[M+Na]^+$; $C_{25}H_{20}BrNO_5SNa$: Calculated, 548.0143; found 548.0149.



(R)-N-(4-bromophenyl)-4-methyl-N-(9-methyl-5-oxo-3,4-dihydro-2H,5H-pyrano[3,2-c]chromen-2-yl)benzenesulfonamide (**3h**):

***Rf*:** 0.5 (DCM/Hexane, 95/5)

Appearance: white solid

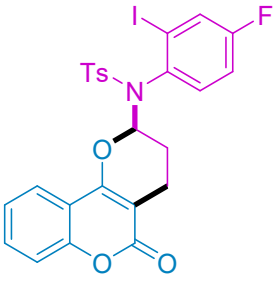
Purification: Added 1 ml (EtOAc/Hex; 9/1) and filtered the product (**Condition A**)

Yield: 96% (103 mg; **A**)

^{1}H NMR (400 MHz, $CDCl_3$) δ 7.66 (d, *J* = 8.2 Hz, 2H), 7.47 (d, *J* = 8.4 Hz, 2H), 7.34 (dd, *J* = 16.2, 8.3 Hz, 3H), 7.20 (d, *J* = 8.4 Hz, 1H), 7.06 (d, *J* = 8.0 Hz, 2H), 6.89 (s, 1H), 6.37 (dd, *J* = 11.0, 1.8 Hz, 1H), 2.73 – 2.61 (m, 2H), 2.52 (s, 3H), 2.38 (s, 3H), 2.15 – 2.11 (m, 1H), 1.51 – 1.41 (m, 1H).

^{13}C NMR (101 MHz, $CDCl_3$) δ 162.59, 158.84, 150.90, 144.37, 136.60, 133.98, 133.46, 132.99, 132.85, 132.72, 129.79, 128.78, 124.10, 121.57, 116.77, 115.05, 100.94, 86.60, 26.06, 21.92, 21.08, 20.33.

HRMS (ESI-MS): m/z calculated for $[M+H]^+$; $C_{26}H_{23}BrNO_5S$: Calculated, 540.0480; found 540.0467.



(R)-N-(4-fluoro-2-iodophenyl)-4-methyl-N-(5-oxo-3,4-dihydro-2H,5H-pyrano[3,2-c]chromen-2-yl)benzenesulfonamide (**3i**):

***Rf*:** 0.5 (DCM/Hexane, 95/5)

Appearance: white solid

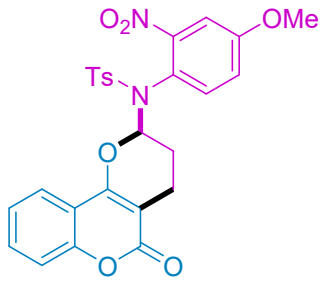
Purification: Added 1 ml (EtOAc/Hex; 9/1) and filtered the product (**Condition A**)

Yield: 95% (112 mg; **A**)

^{1}H NMR (400 MHz, $CDCl_3$) δ 7.73 (d, *J* = 8.0 Hz, 2H), 7.59 (d, *J* = 7.8 Hz, 1H), 7.50 (t, *J* = 7.9 Hz, 1H), 7.37 (d, *J* = 7.8 Hz, 3H), 7.29 (d, *J* = 8.3 Hz, 1H), 7.16 (t, *J* = 7.5 Hz, 1H), 7.05 (s, 1H), 6.71 (s, 1H), 6.34 – 6.27 (m, 1H), 2.71 – 2.67 (m, 2H), 2.53 (s, 3H), 2.32 – 2.21 (m, , 1H), 1.54 – 1.41 (m, 1H).

^{13}C NMR (101 MHz, $CDCl_3$) δ 162.33, 158.83, 152.70, 144.79, 136.75, 134.19, 134.15, 133.53, 133.47, 133.38, 131.86, 129.91, 128.63, 126.82, 126.59, 123.77, 122.04, 116.94, 115.20, 100.97, 95.90, 95.82, 86.40, 25.25, 21.87, 20.06.

HRMS (ESI-MS): m/z calculated for $[M+Na]^+$; $C_{25}H_{19}FINO_5SNa$: Calculated, 613.9910 & found 613.9911.



(R)-N-(4-methoxy-2-nitrophenyl)-4-methyl-N-(5-oxo-3,4-dihydro-2H,5H-pyrano[3,2-c]chromen-2-yl)benzenesulfonamide (**3j**):

***Rf*:** 0.2 (DCM/Hexane, 95/5)

Appearance: Yellowish white solid

Purification: Added 1 ml (EtOAc/Hex; 9/1) and filtered the product (**Condition A**)

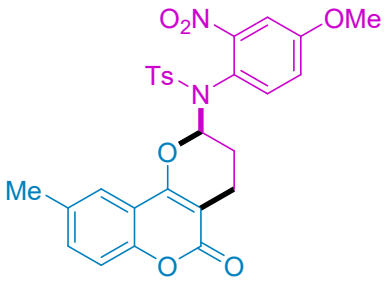
Column chromatography (DCM/Hexane; 96/4) (**Condition B**)

Yield: 94% (98 mg; **A**); 87% (91 mg; **B**)

^{1}H NMR (400 MHz, $CDCl_3$) δ 7.62 (d, *J* = 8.2 Hz, 2H), 7.54 – 7.47 (m, 2H), 7.35 (d, *J* = 8.1 Hz, 2H), 7.31 (d, *J* = 8.3 Hz, 1H), 7.14 (t, *J* = 7.5 Hz, 1H), 7.04 (d, *J* = 8.9 Hz, 1H), 6.97 – 6.88 (m, 2H), 6.45 – 6.38 (m, 1H), 3.88 (s, 3H), 2.74 – 2.67 (m, 3H), 2.54 (s, 3H), 1.55 – 1.47 (m, 1H).

^{13}C NMR (101 MHz, $CDCl_3$) δ 162.23, 160.47, 158.51, 152.58, 151.17, 144.64, 136.22, 132.77, 131.71, 129.73, 128.62, 123.49, 121.91, 120.31, 118.60, 116.88, 115.14, 110.97, 101.25, 87.46, 56.17, 24.63, 21.75, 19.95.

HRMS (ESI-MS):m/z calculated for $[M+Na]^+$; $C_{26}H_{22}N_2O_8SNa$: Calculated, 545.0995 & found 545.0999.



(R)-N-(4-methoxy-2-nitrophenyl)-4-methyl-N-(9-methyl-5-oxo-3,4-dihydro-2H,5H-pyrano[3,2-c]chromen-2-yl)benzenesulfonamide (**3k**):

***Rf*:** 0.2 (DCM/Hexane, 95/5)

Appearance: Yellowish white solid

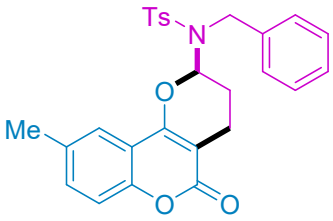
Purification: Added 1 ml (EtOAc/Hex; 9/1) and filtered the product (**Condition A**)

Yield: 92% (98 mg; **A**)

^{1}H NMR (400 MHz, $CDCl_3$) δ 7.62 (d, *J* = 8.1 Hz, 2H), 7.50 (d, *J* = 2.7 Hz, 1H), 7.36 – 7.31 (m, 3H), 7.21 (d, *J* = 8.4 Hz, 1H), 7.00 (d, *J* = 8.9 Hz, 1H), 6.94 (dd, *J* = 8.9, 2.8 Hz, 1H), 6.80 (s, 1H), 6.46 – 6.43 (m, 1H), 3.89 (s, 3H), 2.72 – 2.68 (m, *J* = 5.7 Hz, 3H), 2.52 (s, 3H), 2.37 (s, 3H), 1.54 – 1.46 (m, 1H).

^{13}C NMR (101 MHz, $CDCl_3$) δ 162.49, 160.45, 158.56, 151.13, 150.74, 144.40, 136.18, 133.28, 132.83, 132.72, 129.74, 128.71, 121.33, 120.26, 118.62, 116.68, 114.91, 111.02, 101.18, 87.40, 56.18, 24.64, 21.81, 20.93, 20.01.

HRMS (ESI-MS):m/z calculated for $[M+Na]^+$; $C_{27}H_{24}N_2O_8SNa$: Calculated, 559.1151; found 559.1156.



(R)-N-benzyl-4-methyl-N-(9-methyl-5-oxo-3,4-dihydro-2H,5H-pyrano[3,2-c]chromen-2-yl)benzenesulfonamide (**3l**):

***Rf*:** 0.5 (DCM/Hexane, 95/5)

Appearance: white solid

Purification: Added 1 ml (EtOAc/Hex; 9/1) and filtered the product (**Condition A**)

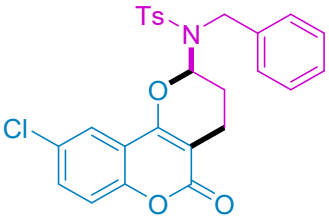
Yield: 98% (93 mg; **A**)

^{1}H NMR (400 MHz, $CDCl_3$) δ 7.92 (d, *J* = 8.1 Hz, 2H), 7.46 (d, *J* = 7.5 Hz, 2H), 7.42 (d, *J* = 8.0 Hz, 2H), 7.37 (t, *J* = 7.4 Hz, 2H), 7.34 – 7.29 (m, 2H), 7.19 (d, *J* = 8.4 Hz, 1H), 6.70 (s,

1H), 6.19 (d, *J* = 10.6 Hz, 1H), 4.81 (d, *J* = 16.9 Hz, 1H), 4.26 (d, *J* = 16.9 Hz, 1H), 2.68 (dd, *J* = 17.4, 5.0 Hz, 1H), 2.58 – 2.54 (m, 1H), 2.54 (s, 3H), 2.33 (s, 3H), 1.98 – 1.93 (m, 1H), 1.79 – 1.69 (m, 1H).

^{13}C NMR (101 MHz, $CDCl_3$) δ 162.60, 159.28, 150.80, 144.11, 137.65, 137.13, 133.22, 132.74, 130.02, 128.84, 128.38, 127.80, 127.23, 121.75, 116.56, 114.85, 100.86, 87.05, 47.07, 26.73, 21.85, 20.91, 20.57.

HRMS (ESI-MS):m/z calculated for $[M+H]^+$ $C_{27}H_{26}NO_5S$, calculated, 476.1532; found, 476.1531.



(R)-*N*-benzyl-*N*-(9-chloro-5-oxo-3,4-dihydro-2H,5H-pyrano[3,2-c]chromen-2-yl)-4-methylbenzenesulfonamide (**3m**):

***Rf*:** 0.4 (DCM/Hexane, 95/5)

Appearance: white solid

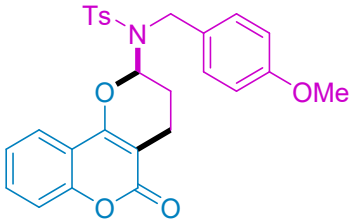
Purification: Added 1 ml (EtOAc/Hex; 9/1) and filtered the product (**Condition A**)

Yield: 96% (95 mg; **A**)

^{1}H NMR (400 MHz, $CDCl_3$) δ 7.88 (d, *J* = 8.3 Hz, 2H), 7.47 – 7.41 (m, 5H), 7.36 (t, *J* = 7.5 Hz, 2H), 7.32 – 7.27 (m, 1H), 7.22 (d, *J* = 8.8 Hz, 1H), 6.83 (d, *J* = 2.8 Hz, 1H), 6.17 (dd, *J* = 11.3, 2.3 Hz, 1H), 4.81 (d, *J* = 16.9 Hz, 1H), 4.20 (d, *J* = 16.9 Hz, 1H), 2.66 (dd, *J* = 17.7, 4.4 Hz, 1H), 2.58 – 2.51 (m, 4H), 2.01 – 1.91 (m, 1H), 1.82 – 1.68 (m, 1H).

^{13}C NMR (101 MHz, $CDCl_3$) δ 161.82, 158.27, 151.02, 144.86, 137.58, 136.81, 131.76, 130.23, 129.23, 128.91, 128.20, 127.88, 127.18, 121.69, 118.31, 116.37, 101.99, 87.43, 47.17, 26.60, 21.96, 20.60.

HRMS (ESI-MS):m/z calculated for $[M+H]^+$ $C_{26}H_{23}ClNO_5S$, calculated, 496.0985; found, 482.0980.



(R)-N-(4-methoxybenzyl)-4-methyl-N-(5-oxo-3,4-dihydro-2H,5H-pyrano[3,2-c]chromen-2-yl)benzenesulfonamide (**3n**):

***Rf*:** 0.3 (DCM/Hexane, 95/5)

Appearance: white solid

Purification: Added 1 ml (EtOAc/Hex; 9/1) and filtered the product (**Condition A**)

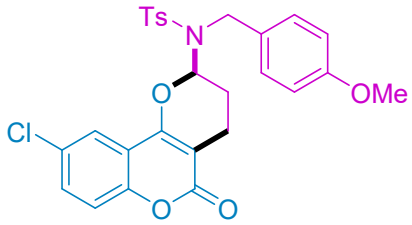
Column chromatography (DCM/Hexane; 96/4) (**Condition B**)

Yield: 94% (92 mg; **A**); 88% (86 mg; **B**)

^{1}H NMR (400 MHz, $CDCl_3$) δ 7.89 (d, *J* = 8.1 Hz, 2H), 7.50 (t, *J* = 7.8 Hz, 1H), 7.38 (dd, *J* = 14.1, 8.3 Hz, 4H), 7.31 (s, 1H), 7.09 (t, *J* = 7.6 Hz, 1H), 6.89 (d, *J* = 8.5 Hz, 2H), 6.78 (d, *J* = 7.8 Hz, 1H), 6.12 (d, *J* = 10.0 Hz, 1H), 4.79 (d, *J* = 16.5 Hz, 1H), 4.21 (d, *J* = 16.5 Hz, 1H), 3.83 (s, 3H), 2.70 (dd, *J* = 17.5, 5.2 Hz, 1H), 2.63 – 2.50 (m, 4H), 1.97 (dd, *J* = 13.7, 5.8 Hz, 1H), 1.87 – 1.76 (m, 1H).

^{13}C NMR (101 MHz, $CDCl_3$) δ 162.47, 159.33, 159.28, 152.65, 144.22, 137.30, 131.80, 130.04, 129.52, 128.62, 128.12, 123.44, 122.23, 116.80, 115.13, 114.23, 101.02, 87.09, 55.44, 46.76, 26.72, 21.79, 20.62.

HRMS (ESI-MS):m/z calculated for $[M+Na]^+$ $C_{27}H_{25}NNaO_6S$, calculated, 514.1300; found, 514.1295.



(R)-N-(9-chloro-5-oxo-3,4-dihydro-2H,5H-pyrano[3,2-c]chromen-2-yl)-N-(4-methoxybenzyl)-4-methylbenzenesulfonamide (**3o**):

***Rf*:** 0.3 (DCM/Hexane, 95/5)

Appearance: white solid

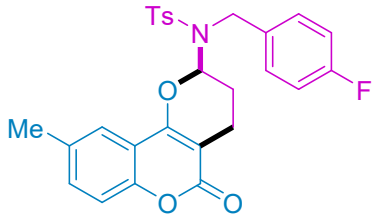
Purification: Added 1 ml (EtOAc/Hex; 9/1) and filtered the product (**Condition A**)

Yield: 91% (95 mg; **A**)

^{1}H NMR (400 MHz, $CDCl_3$) δ 7.87 (d, *J* = 8.1 Hz, 2H), 7.43 (d, *J* = 8.3 Hz, 3H), 7.34 (d, *J* = 8.5 Hz, 2H), 7.22 (d, *J* = 8.8 Hz, 1H), 6.88 (d, *J* = 8.5 Hz, 2H), 6.83 (d, *J* = 2.3 Hz, 1H), 6.15 (d, *J* = 9.8 Hz, 1H), 4.75 (d, *J* = 16.6 Hz, 1H), 4.15 (d, *J* = 16.5 Hz, 1H), 3.81 (s, 3H), 2.67 (dd, *J* = 17.6, 4.8 Hz, 1H), 2.59 – 2.49 (m, 4H), 1.95 (dd, *J* = 13.8, 5.8 Hz, 1H), 1.84 – 1.73 (m, 1H).

^{13}C NMR (101 MHz, $CDCl_3$) δ 161.89, 159.31, 158.32, 151.01, 144.79, 136.88, 131.76, 130.20, 129.45, 129.23, 128.56, 128.18, 121.70, 118.31, 116.38, 114.26, 101.98, 87.46, 55.44, 46.74, 26.62, 21.95, 20.66.

HRMS (ESI-MS): m/z calculated for $[M+Na]^+$ $C_{27}H_{24}ClNNaO_6S$, calculated, 548.0911; found, 548.0905.



(R)-N-(4-fluorobenzyl)-4-methyl-N-(9-methyl-5-oxo-3,4-dihydro-2H,5H-pyrano[3,2-c]chromen-2-yl)benzenesulfonamide (**3p**):

***Rf*:** 0.4 (DCM/Hexane, 95/5)

Appearance: white solid

Purification: Added 1 ml (EtOAc/Hex; 9/1) and filtered the product (**Condition A**)

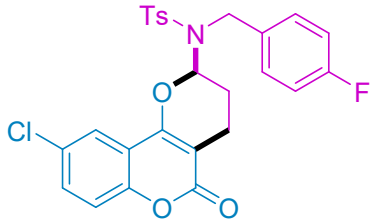
Column chromatography (DCM/Hexane; 93/7) (**Condition B**)

Yield: 95% (93 mg; **A**); 86% (84 mg; **B**)

^{1}H NMR (400 MHz, $CDCl_3$) δ 7.89 (d, J = 8.2 Hz, 2H), 7.41 (dd, J = 10.9, 6.9 Hz, 4H), 7.29 (d, J = 8.5 Hz, 1H), 7.18 (d, J = 8.4 Hz, 1H), 7.04 (t, J = 8.6 Hz, 2H), 6.66 (s, 1H), 6.15 (d, J = 9.6 Hz, 1H), 4.73 (d, J = 16.8 Hz, 1H), 4.22 (d, J = 16.8 Hz, 1H), 2.68 (dd, J = 17.5, 4.7 Hz, 1H), 2.62 – 2.53 (m, 1H), 2.51 (s, 3H), 2.31 (s, 3H), 1.95 (dd, J = 13.6, 5.8 Hz, 1H), 1.79 – 1.68 (m, 1H).

^{13}C NMR (101 MHz, $CDCl_3$) δ 162.63, 159.28, 150.83, 144.26, 137.01, 133.40 (d, $J_{C\text{-}F}$ = 3.03 Hz), 133.28, 132.83, 130.07, 129.03 (d, $J_{C\text{-}F}$ = 8.08 Hz), 128.38, 121.70, 116.63, 115.90, 115.69, 114.81, 100.89, 86.97, 46.43, 26.78, 21.87, 20.92, 20.57.

HRMS (ESI-MS): m/z calculated for $[M+H]^+$ $C_{27}H_{25}FNO_5S$, calculated, 494.1437; found, 494.1432.



(R)-N-(9-chloro-5-oxo-3,4-dihydro-2H,5H-pyrano[3,2-c]chromen-2-yl)-N-(4-fluorobenzyl)-4-methylbenzenesulfonamide (**3q**):

***Rf*:** 0.4 (DCM/Hexane, 95/5)

Appearance: white solid

Purification: Added 1 ml (EtOAc/Hex; 9/1) and filtered the product (**Condition A**)

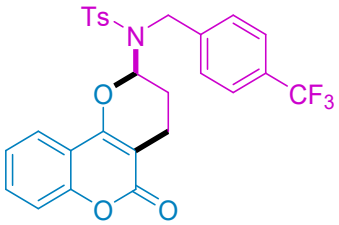
Yield: 93% (99 mg; **A**)

^{1}H NMR (400 MHz, $CDCl_3$) δ 7.85 (d, J = 8.2 Hz, 2H), 7.40 (dd, J = 12.3, 6.7 Hz, 5H), 7.20 (d, J = 8.8 Hz, 1H), 7.02 (t, J = 8.6 Hz, 2H), 6.79 (d, J = 2.3 Hz, 1H), 6.13 (d, J = 9.8 Hz, 1H),

4.73 (d, J = 16.8 Hz, 1H), 4.16 (d, J = 16.8 Hz, 1H), 2.66 (dd, J = 17.6, 4.6 Hz, 1H), 2.59 – 2.53 (m, 1H), 2.51 (s, 3H), 1.96 – 1.92 (m, 1H), 1.77 – 1.67 (m, 1H).

^{13}C NMR (101 MHz, $CDCl_3$) δ 161.62, 158.06, 150.87, 144.85, 136.51, 133.20 (d, J_{C-F} = 3.03 Hz), 131.67, 130.12, 129.12, 128.82 (d, J_{C-F} = 8.08 Hz), 128.03, 123.06, 121.48, 118.18, 116.16, 115.78, 115.57, 101.86, 87.16, 46.37, 26.49, 21.80, 20.44.

HRMS (ESI-MS): m/z calculated for $[M+Na]^+$; $C_{26}H_{21}ClFNO_5SNa$: Calculated, 536.0711; found 536.0718.



(R)-4-methyl-N-(5-oxo-3,4-dihydro-2H,5H-pyrano[3,2-c]chromen-2-yl)-N-(4-(trifluoromethyl)benzyl)benzenesulfonamide (**3r**):

***Rf*:** 0.4 (DCM/Hexane, 95/5)

Appearance: white solid

Purification: Added 1 ml (EtOAc/Hex; 9/1) and filtered the product (**Condition A**)

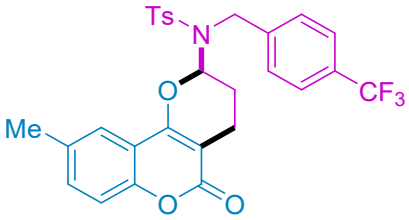
Yield: 92% (97 mg; **A**)

^{1}H NMR (400 MHz, $CDCl_3$) δ 7.89 (d, J = 8.1 Hz, 2H), 7.64 (d, J = 8.3 Hz, 2H), 7.59 (d, J = 8.2 Hz, 2H), 7.51 (t, J = 7.7 Hz, 1H), 7.41 (d, J = 8.1 Hz, 2H), 7.29 (d, J = 8.2 Hz, 1H), 7.09 (t, J = 7.6 Hz, 1H), 6.75 (d, J = 7.8 Hz, 1H), 6.15 (d, J = 9.9 Hz, 1H), 4.84 (d, J = 17.2 Hz, 1H), 4.34 (d, J = 17.2 Hz, 1H), 2.72 (dd, J = 17.6, 4.9 Hz, 1H), 2.66 – 2.56 (m, 1H), 2.55 (s, 3H), 2.01 (dd, J = 13.5, 5.7 Hz, 1H), 1.79 – 1.68 (m, 1H).

^{19}F NMR (377 MHz, $CDCl_3$) δ -62.52.

^{13}C NMR (101 MHz, $CDCl_3$) δ 162.28, 159.15, 152.66, 144.60, 141.82, 136.91, 131.91, 130.17, 128.15, 127.53, 125.92 (q, J = 4.04 Hz), 123.49, 122.11, 116.85, 114.99, 101.02, 86.81, 46.69, 26.70, 21.79, 20.45.

HRMS (ESI-MS): m/z calculated for $[M+H]^+$ $C_{27}H_{23}F_3NO_5S$, calculated, 530.1249; found, 530.1244.



(R)-4-methyl-N-(9-methyl-5-oxo-3,4-dihydro-2H,5H-pyrano[3,2-c]chromen-2-yl)-N-(4-(trifluoromethyl)benzyl)benzenesulfonamide (**3s**):

***Rf*:** 0.4 (DCM/Hexane, 95/5)

Appearance: white solid

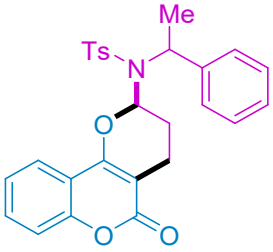
Purification: Added 1 ml (EtOAc/Hex; 9/1) and filtered the product (**Condition A**)

Yield: 89% (97 mg; **A**)

^{1}H NMR (400 MHz, $CDCl_3$) δ 7.89 (d, *J* = 8.2 Hz, 2H), 7.59 (q, *J* = 8.5 Hz, 4H), 7.40 (d, *J* = 8.2 Hz, 2H), 7.29 (dd, *J* = 8.4, 2.2 Hz, 1H), 7.16 (d, *J* = 8.4 Hz, 1H), 6.65 (d, *J* = 2.1 Hz, 1H), 6.17 (dd, *J* = 11.2, 2.2 Hz, 1H), 4.78 (d, *J* = 17.4 Hz, 1H), 4.31 (d, *J* = 17.4 Hz, 1H), 2.71 – 2.64 (m, 1H), 2.59 (dd, *J* = 12.0, 5.9 Hz, 1H), 2.51 (s, 3H), 2.30 (s, 3H), 2.02 – 1.92 (m, 1H), 1.75 – 1.66 (m, 1H).

^{13}C NMR (101 MHz, $CDCl_3$) δ 162.50, 159.15, 150.79, 144.43, 141.81, 136.72, 133.29, 132.84, 130.11, 128.39, 127.50, 125.88 (q, *J* = 3.03 Hz), 125.47, 122.77, 121.64, 116.61, 114.72, 100.85, 86.79, 46.57, 26.74, 21.86, 20.90, 20.45.

HRMS (ESI-MS): m/z calculated for $[M+H]^+$ $C_{28}H_{25}F_3NO_5S$, calculated, 544.1406; found, 544.1400.



4-methyl-N-((R)-5-oxo-3,4-dihydro-2H,5H-pyrano[3,2-c]chromen-2-yl)-N-(1-phenylethyl)benzenesulfonamide (**3t**): (Rotamers; 1:1)

***Rf*:** 0.4 (DCM/Hexane, 95/5)

Appearance: white solid

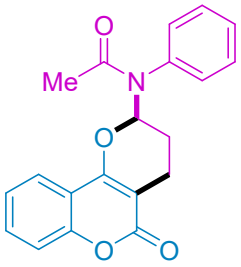
Purification: Added 1 ml (EtOAc/Hex; 9/1) and filtered the product (**Condition A**)

Yield: 86% (81 mg; **A**)

^{1}H NMR (400 MHz, $CDCl_3$) δ 7.80 (d, *J* = 8.3 Hz, 1H), 7.64 (d, *J* = 8.2 Hz, 1H), 7.41 (t, *J* = 7.8 Hz, 2H), 7.31 – 7.16 (m, 7H), 7.14 – 6.95 (m, 2H), 5.21 (s, 2H), 2.69 – 2.54 (m, 1H), 2.41 (d, *J* = 4.8 Hz, 3H), 2.36 – 2.18 (m, 1H), 1.81 (dd, *J* = 64.0, 10.4 Hz, 2H), 1.52 (t, *J* = 6.9 Hz, 3H).

^{13}C NMR (101 MHz, $CDCl_3$) δ 161.46, 161.37, 158.32, 158.03, 151.56, 151.52, 142.89, 142.74, 138.89, 138.84, 137.75, 137.20, 130.57, 128.71, 128.61, 127.60, 127.32, 126.93, 126.87, 126.78, 126.72, 126.27, 122.56, 122.50, 121.23, 121.08, 115.70, 115.60, 114.28, 114.23, 100.00, 99.79, 86.41, 86.03, 55.73, 53.58, 28.67, 25.67, 25.34, 20.60, 20.01, 19.92, 17.07, 16.93.

HRMS (ESI-MS): m/z calculated for $[M+H]^+$; $C_{27}H_{26}NO_5S$: Calculated, 476.1532; found 476.1528.



(R)-N-(5-oxo-3,4-dihydro-2H,5H-pyrano[3,2-c]chromen-2-yl)-N-phenylacetamide (**3u**): (Rotamers; 1:1)

***Rf*:** 0.5 (DCM/Hexane, 95/5)

Appearance: brown solid

Purification: Added 1 ml (EtOAc/Hex; 9/1) and filtered the product (**Condition A**)

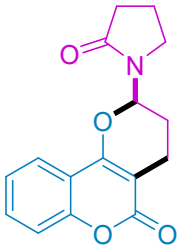
Column chromatography (EtOAc/Hexane;1/9) (**Condition B**)

Yield: 93% (62 mg; **A**); 86% (57 mg; **B**)

^{1}H NMR (400 MHz, $CDCl_3$) δ 7.81 (d, *J* = 7.8 Hz, 1H), 7.63 (bs, 2H), 7.52 (t, *J* = 8.1 Hz, 5H), 7.36 – 7.27 (m, 6H), 7.26 – 7.22 (m, 2H), 7.11 (t, *J* = 7.3 Hz, 2H), 6.75 (d, *J* = 8.3 Hz, 2H), 2.83 – 2.61 (m, 2H), 2.36 – 2.27 (m, 1H), 2.19 (s, 6H), 2.15 – 2.07 (m, 1H).

^{13}C NMR (101 MHz, $CDCl_3$) δ 168.51, 163.30, 160.55, 152.39, 146.84, 138.01, 131.40, 129.25, 128.95, 127.39, 124.24, 123.79, 122.55, 119.93, 116.50, 115.83, 115.04, 100.87, 79.58, 28.39, 24.55, 19.81.

HRMS (ESI-MS): m/z calculated for $[M+H]^+$ $C_{20}H_{18}NO_4$, calculated, 336.1236; found, 336.1230.



(R)-1-(5-oxo-3,4-dihydro-2H,5H-pyrano[3,2-c]chromen-2-yl)pyrrolidin-2-one (**3v**):

***Rf*:** 0.6 (DCM/Hexane, 95/5)

Appearance: white solid

Purification: Added 1 ml (EtOAc/Hex; 9/1) and filtered the product (**Condition A**)

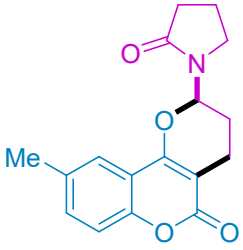
Column chromatography (EtOAc/Hexane;7/3) (**Condition B**)

Yield: 97% (55 mg; **A**); 92% (52 mg; **B**)

^{1}H NMR (400 MHz, $CDCl_3$) δ 7.71 (d, *J* = 7.8 Hz, 1H), 7.50 (t, *J* = 7.7 Hz, 1H), 7.29 (d, *J* = 8.4 Hz, 1H), 7.24 (t, *J* = 7.6 Hz, 1H), 6.05 (dd, *J* = 9.9, 3.4 Hz, 1H), 3.59 (qd, *J* = 15.7, 8.8 Hz, 2H), 2.90 – 2.80 (m, 1H), 2.73 – 2.64 (m, 1H), 2.55 (t, *J* = 8.2 Hz, 2H), 2.22 – 2.09 (m, 4H).

^{13}C NMR (101 MHz, $CDCl_3$) δ 176.08, 162.71, 159.86, 152.52, 131.73, 123.88, 122.52, 116.62, 115.30, 100.74, 79.82, 42.34, 31.24, 24.52, 19.95, 18.17.

HRMS (ESI-MS): m/z calculated for $[M+H]^+$; $C_{16}H_{16}NO_4$: Calculated, 286.1079; found 286.1083.



(R)-1-(9-methyl-5-oxo-3,4-dihydro-2H,5H-pyrano[3,2-c]chromen-2-yl)pyrrolidin-2-one (**3w**):

***Rf*:** 0.6 (DCM/Hexane, 95/5)

Appearance: white solid

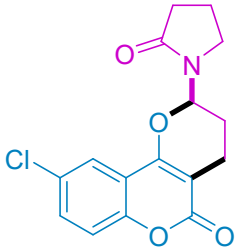
Purification: Added 1 ml (EtOAc/Hex; 9/1) and filtered the product (**Condition A**)

Yield: 95% (57 mg; **A**)

^{1}H NMR (400 MHz, $CDCl_3$) δ 7.48 (s, 1H), 7.30 (t, J = 6.6 Hz, 1H), 7.19 (d, J = 8.4 Hz, 1H), 6.04 (dd, J = 10.1, 3.2 Hz, 1H), 3.60 (qd, J = 15.1, 8.9 Hz, 2H), 2.90 – 2.78 (m, 1H), 2.73 – 2.64 (m, 1H), 2.59 – 2.54 (m, 2H), 2.39 (s, 3H), 2.27 – 2.06 (m, 4H).

^{13}C NMR (101 MHz, $CDCl_3$) δ 176.11, 162.92, 159.87, 150.68, 133.63, 132.73, 122.16, 116.39, 114.95, 100.61, 79.74, 42.37, 31.28, 24.56, 20.96, 19.98, 18.17.

HRMS (ESI-MS): m/z calculated for $[M+H]^+$ $C_{17}H_{18}NO_4$, calculated, 300.1236; found, 300.1238.



(R)-1-(9-chloro-5-oxo-3,4-dihydro-2H,5H-pyrano[3,2-c]chromen-2-yl)pyrrolidin-2-one (**3x**):

***Rf*:** 0.6 (DCM/Hexane, 95/5)

Appearance: white solid

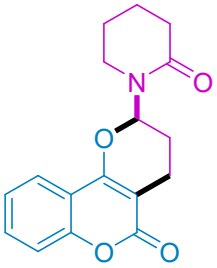
Purification: Added 1 ml (EtOAc/Hex; 9/1) and filtered the product (**Condition A**)

Yield: 94% (60 mg; **A**)

^{1}H NMR (400 MHz, $CDCl_3$) δ 7.70 (d, J = 2.3 Hz, 1H), 7.47 (dd, J = 8.8, 2.4 Hz, 1H), 7.28 (s, 1H), 6.07 (dd, J = 10.5, 2.8 Hz, 1H), 3.61 (qd, J = 15.0, 8.9 Hz, 2H), 2.94 – 2.83 (m, 1H), 2.76 – 2.67 (m, 1H), 2.62 – 2.52 (m, 2H), 2.28 – 2.08 (m, 4H).

^{13}C NMR (101 MHz, $CDCl_3$) δ 176.21, 162.20, 158.89, 150.97, 131.79, 129.55, 122.19, 118.23, 116.52, 101.78, 80.10, 42.39, 31.25, 24.51, 20.11, 18.19.

HRMS (ESI-MS): m/z calculated for $[M+H]^+$ $C_{16}H_{15}ClNO_4$, calculated, 320.0690; found, 320.0690.



(R)-1-(5-oxo-3,4-dihydro-2H,5H-pyrano[3,2-c]chromen-2-yl)piperidin-2-one (**3y**):

***Rf*:** 0.5 (DCM/Hexane, 95/5)

Appearance: white solid

Purification: Added 1 ml (EtOAc/Hex; 9/1) and filtered the product (**Condition A**)

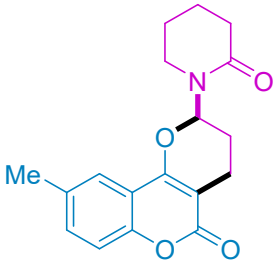
Column chromatography (EtOAc/Hexane;7/3) (**Condition B**)

Yield: 92% (55 mg; **A**), 89% (53 mg; **B**)

^{1}H NMR (400 MHz, $CDCl_3$) δ 7.73 (d, J = 7.9 Hz, 1H), 7.51 (t, J = 7.7 Hz, 1H), 7.34 – 7.22 (m, 2H), 6.61 (dd, J = 9.1, 4.4 Hz, 1H), 3.53 (dd, J = 11.4, 6.1 Hz, 1H), 3.40 – 3.34 (m, 1H), 2.93 – 2.80 (m, 1H), 2.78 – 2.64 (m, 1H), 2.57 (t, J = 6.2 Hz, 2H), 2.19 – 2.07 (m, 2H), 1.97 – 1.82 (m, 4H).

^{13}C NMR (101 MHz, $CDCl_3$) δ 170.92, 162.77, 160.15, 152.53, 131.71, 123.89, 122.49, 116.67, 115.39, 100.88, 81.23, 41.84, 32.72, 23.68, 23.09, 20.74, 20.13.

HRMS (ESI-MS): m/z calculated for $[M+H]^+$ $C_{17}H_{18}NO_4$, calculated, 300.1236; found, 300.1238.



(R)-1-(9-methyl-5-oxo-3,4-dihydro-2H,5H-pyrano[3,2-c]chromen-2-yl)piperidin-2-one (**3z**):

***Rf*:** 0.5 (DCM/Hexane, 95/5)

Appearance: white solid

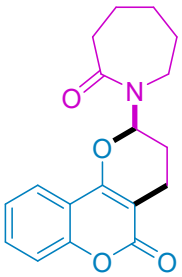
Purification: Added 1 ml (EtOAc/Hex; 9/1) and filtered the product (**Condition A**)

Yield: 90% (60 mg; **A**)

^{1}H NMR (400 MHz, $CDCl_3$) δ 7.49 (s, 1H), 7.34 – 7.27 (m, 1H), 7.20 (d, *J* = 8.4 Hz, 1H), 6.59 (dd, *J* = 9.2, 4.3 Hz, 1H), 3.53 (dd, *J* = 11.3, 5.8 Hz, 1H), 3.45 – 3.34 (m, 1H), 2.90 – 2.81 (m, 1H), 2.74 – 2.65 (m, 1H), 2.58 (t, *J* = 5.7 Hz, 2H), 2.41 (s, 3H), 2.18 – 2.06 (m, 2H), 1.97 (t, *J* = 8.7 Hz, 3H), 1.88 – 1.80 (m, 1H).

^{13}C NMR (101 MHz, $CDCl_3$) δ 170.95, 162.98, 160.16, 150.67, 133.61, 132.71, 122.11, 116.42, 115.03, 100.75, 81.17, 41.85, 32.74, 23.70, 23.09, 21.00, 20.74, 20.16.

HRMS (ESI-MS): m/z calculated for $[M+H]^+$ $C_{18}H_{20}NO_4$, calculated, 314.1392; found, 314.1395.



(R)-1-(5-oxo-3,4-dihydro-2H,5H-pyrano[3,2-c]chromen-2-yl)azepan-2-one (**3za**):

***Rf*:** 0.5 (DCM/Hexane, 95/5)

Appearance: white solid

Purification: Added 1 ml (EtOAc/Hex; 9/1) and filtered the product (**Condition A**)

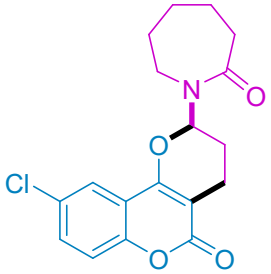
Column chromatography (EtOAc/Hexane;7/3) (**Condition B**)

Yield: 89% (55 mg; **A**); 82% (51 mg; **B**)

^{1}H NMR (400 MHz, $CDCl_3$) δ 7.70 (d, *J* = 7.8 Hz, 1H), 7.52 (t, *J* = 7.8 Hz, 1H), 7.37 – 7.21 (m, 2H), 6.52 (dd, *J* = 10.9, 2.5 Hz, 1H), 3.48 (d, *J* = 4.3 Hz, 2H), 2.86 (dd, *J* = 17.4, 4.2 Hz, 1H), 2.75 – 2.66 (m, 3H), 2.18 – 1.97 (m, 2H), 1.90 – 1.71 (m, 6H).

^{13}C NMR (101 MHz, $CDCl_3$) δ 176.54, 162.77, 160.05, 152.56, 131.71, 123.95, 122.38, 116.72, 115.44, 100.84, 82.10, 43.26, 37.52, 29.94, 29.81, 24.51, 23.51, 20.05.

HRMS (ESI-MS): m/z calculated for $[M+H]^+$ $C_{18}H_{20}NO_4$, calculated, 314.1392; found, 314.1387.



(R)-1-(9-chloro-5-oxo-3,4-dihydro-2H,5H-pyrano[3,2-c]chromen-2-yl)azepan-2-one (**3zb**):

***Rf*:** 0.5 (DCM/Hexane, 95/5)

Appearance: white solid

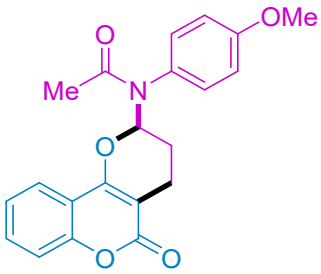
Purification: Added 1 ml (EtOAc/Hex; 9/1) and filtered the product (**Condition A**)

Yield: 88% (61 mg; **A**)

^{1}H NMR (400 MHz, $CDCl_3$) δ 7.61 (d, *J* = 2.2 Hz, 1H), 7.43 (dd, *J* = 8.8, 2.3 Hz, 1H), 7.23 (d, *J* = 8.8 Hz, 1H), 6.49 (dd, *J* = 11.0, 2.4 Hz, 1H), 3.53 – 3.38 (m, 2H), 2.83 (dd, *J* = 17.5, 4.8 Hz, 1H), 2.74 – 2.61 (m, 3H), 2.16 – 1.94 (m, 2H), 1.89 – 1.69 (m, 6H).

^{13}C NMR (101 MHz, $CDCl_3$) δ 176.61, 162.15, 159.02, 150.91, 131.69, 129.48, 122.00, 118.20, 116.57, 101.80, 82.30, 43.28, 37.49, 29.92, 29.76, 24.42, 23.48, 20.16.

HRMS (ESI-MS): m/z calculated for $[M+H]^+$ $C_{18}H_{19}ClNO_4$, calculated, 348.1003; found, 348.0997.



(R)-N-(4-methoxyphenyl)-N-(5-oxo-3,4-dihydro-2H,5H-pyrano[3,2-c]chromen-2-yl)acetamide (**3zc**): (Rotamer; 1:1)

***Rf*:** 0.5 (DCM/Hexane, 95/5)

Appearance: white solid

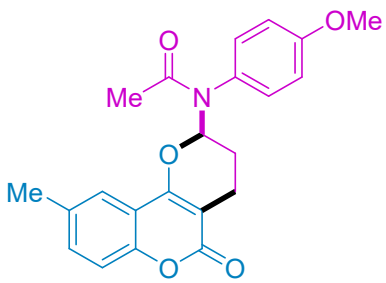
Purification: Added 1 ml (EtOAc/Hex; 9/1) and filtered the product (**Condition A**)

Yield: 90% (65 mg; **A**)

^{1}H NMR (400 MHz, $CDCl_3$) δ 7.85 (d, *J* = 8.0 Hz, 1H), 7.53 (t, *J* = 7.7 Hz, 1H), 7.41 (d, *J* = 8.8 Hz, 2H), 7.32 (t, *J* = 7.1 Hz, 3H), 7.15 (d, *J* = 7.9 Hz, 1H), 6.99 – 6.91 (m, 2H), 6.86 (d, *J* = 8.7 Hz, 2H), 6.71 (d, *J* = 10.5 Hz, 1H), 3.84 (s, 3H), 3.80 (s, 3H), 2.66 – 2.70 (m, 2H), 2.17 (s, 3H), 2.05 – 2.08 (m, 1H), 1.96 (s, 3H), 1.58 – 1.47 (m, 1H).

^{13}C NMR (101 MHz, $CDCl_3$) δ 172.35, 168.41, 162.85, 160.03, 159.94, 156.50, 152.59, 131.69, 131.15, 131.12, 130.96, 130.35, 124.00, 122.51, 122.00, 116.72, 115.58, 115.10, 114.83, 114.21, 100.62, 81.44, 55.62, 55.58, 25.23, 24.45, 23.51, 20.07.

HRMS (ESI-MS): m/z calculated for $[M+H]^+$ $C_{21}H_{20}NO_5$, calculated, 366.1341; found, 366.1336.



(R)-N-(4-methoxyphenyl)-N-(9-methyl-5-oxo-3,4-dihydro-2H,5H-pyrano[3,2-c]chromen-2-yl)acetamide (**3zd**):

***Rf*:** 0.4 (DCM/Hexane, 95/5)

Appearance: white solid

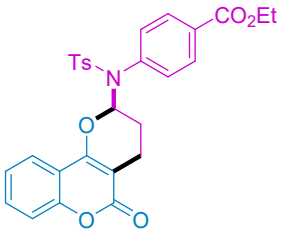
Purification: Added 1 ml (EtOAc/Hex; 9/1) and filtered the product (**Condition A**)

Yield: 87% (66 mg; **A**)

^{1}H NMR (400 MHz, $CDCl_3$) δ 7.60 (s, 1H), 7.33 (d, *J* = 8.1 Hz, 2H), 7.17 (dd, *J* = 20.5, 7.8 Hz, 2H), 6.96 (s, 2H), 6.68 (d, *J* = 10.8 Hz, 1H), 3.84 (s, 3H), 2.69 – 2.64 (m, , 2H), 2.46 (s, 3H), 2.06 – 2.03 (m, 1H), 1.97 (s, 3H), 1.57 – 1.47 (m, 1H).

^{13}C NMR (101 MHz, $CDCl_3$) δ 172.38, 163.03, 160.04, 159.94, 150.77, 133.70, 132.70, 130.90, 130.48, 122.14, 116.49, 115.25, 114.85, 100.52, 81.42, 55.63, 25.28, 23.55, 21.13, 20.10.

HRMS (ESI-MS): m/z calculated for $[M+H]^+$ $C_{22}H_{22}NO_5$, calculated, 380.1498; found, 380.1492.



ethyl (R)-4-((4-methyl-N-(5-oxo-3,4-dihydro-2H,5H-pyrano[3,2-c]chromen-2-yl)phenyl)sulfonamido)benzoate (**3ze**):

***Rf*:** 0.4 (DCM/Hexane, 95/5)

Appearance: white solid

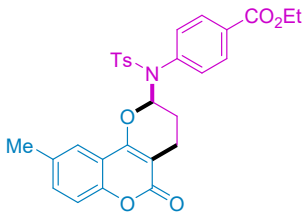
Purification: Added 1 ml (EtOAc/Hex; 9/1) and filtered the product (**Condition A**)

Yield: 91% (94 mg; **A**)

^{1}H NMR (400 MHz, $CDCl_3$) δ 8.03 (d, *J* = 8.6 Hz, 2H), 7.66 (d, *J* = 8.3 Hz, 2H), 7.57 – 7.51 (m, 1H), 7.41 – 7.24 (m, 5H), 7.19 (t, *J* = 7.6 Hz, 1H), 7.07 (dd, *J* = 7.9, 1.3 Hz, 1H), 6.40 (dd, *J* = 11.1, 2.4 Hz, 1H), 4.39 (q, *J* = 7.1 Hz, 2H), 2.76 – 2.64 (m, 2H), 2.56 (s, 3H), 2.21 – 2.11 (m, 1H), 1.57 – 1.42 (m, 1H), 1.39 (t, *J* = 7.1 Hz, 3H).

^{13}C NMR (101 MHz, $CDCl_3$) δ 165.68, 162.40, 158.82, 152.69, 144.60, 139.06, 136.63, 131.86, 131.60, 131.30, 130.60, 129.78, 128.62, 123.73, 122.09, 116.96, 115.26, 100.99, 86.62, 61.51, 25.98, 21.87, 20.28, 14.40.

HRMS (ESI-MS): m/z calculated for $[M+H]^+$ $C_{28}H_{26}NO_7S$, calculated, 520.1430; found, 520.1424.



ethyl (R)-4-((4-methyl-N-(9-methyl-5-oxo-3,4-dihydro-2H,5H-pyrano[3,2-c]chromen-2-yl)phenyl)sulfonamido)benzoate (**3zf**):

***Rf*:** 0.4 (DCM/Hexane, 95/5)

Appearance: white solid

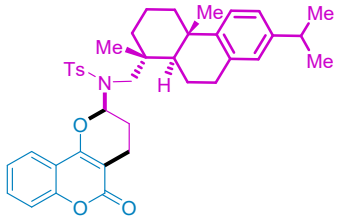
Purification: Added 1 ml (EtOAc/Hex; 9/1) and filtered the product (**Condition A**)

Yield: 89% (95 mg; **A**)

^{1}H NMR (400 MHz, $CDCl_3$) δ 8.04 (d, *J* = 8.6 Hz, 2H), 7.66 (d, *J* = 8.2 Hz, 2H), 7.43 – 7.25 (m, 5H), 7.22 (d, *J* = 8.4 Hz, 1H), 6.92 (s, 1H), 6.42 (dd, *J* = 11.1, 2.4 Hz, 1H), 4.39 (q, *J* = 7.1 Hz, 2H), 2.76 – 2.62 (m, 2H), 2.54 (s, 3H), 2.41 (s, 3H), 2.21 – 2.09 (m, 1H), 1.51 – 1.43 (m, 1H), 1.39 (t, *J* = 7.1 Hz, 3H).

^{13}C NMR (101 MHz, $CDCl_3$) δ 165.68, 162.60, 158.81, 150.83, 144.39, 139.04, 136.56, 133.48, 132.84, 131.58, 131.32, 130.60, 129.78, 128.72, 121.58, 116.71, 114.99, 100.86, 86.64, 61.50, 25.99, 21.90, 21.06, 20.31, 14.40.

HRMS (ESI-MS): m/z calculated for $[M+H]^+$ $C_{29}H_{28}NO_7S$, calculated, 534.1586; found, 534.1581.



N-(((1R,4aS,10aR)-7-isopropyl-1,4a-dimethyl-1,2,3,4,4a,9,10,10a-octahydrophenanthren-1-yl)methyl)-4-methyl-N-((R)-5-oxo-3,4-dihydro-2H,5H-pyrano[3,2-c]chromen-2-yl)benzenesulfonamide (**3zg**):

***Rf*:** 0.4 (DCM/Hexane, 95/5)

Appearance: white solid

Purification: Added 1 ml (EtOAc/Hex; 9/1) and filtered the product (**Condition A**)

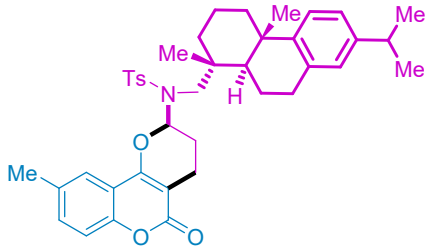
Yield: 83% (106 mg; **A**)

^{1}H NMR (400 MHz, $CDCl_3$) δ 7.76 (d, *J* = 8.1 Hz, 2H), 7.49 – 7.46 (m, 1H), 7.31 – 7.26 (m, 3H), 7.17 (dd, *J* = 17.2, 8.2 Hz, 1H), 7.08 (t, *J* = 7.5 Hz, 1H), 7.00 (dd, *J* = 16.9, 8.1 Hz, 1H), 6.89 (d, *J* = 19.5 Hz, 2H), 5.59 (dd, *J* = 25.0, 10.4 Hz, 1H), 3.71 – 3.47 (m, 1H), 3.34 – 3.18 (m, 1H), 3.01 – 2.92 (m, 1H), 2.87 – 2.79 (m, 2H), 2.58 – 2.49 (m, 1H), 2.42 (d, *J* = 9.8 Hz,

3H), 2.33 – 2.22 (m, 2H), 1.98 – 1.67 (m, 5H), 1.63 – 1.40 (m, 3H), 1.30 – 1.20 (m, 9H), 1.14 (s, 3H), 1.03 – 0.74 (m, 2H).

^{13}C NMR (101 MHz, $CDCl_3$) δ 162.55, 159.27, 152.60, 152.56, 147.45, 147.28, 145.80, 145.77, 143.96, 138.33, 134.60, 134.19, 131.71, 129.93, 127.80, 127.68, 126.94, 126.87, 124.00, 123.93, 123.48, 123.43, 122.41, 122.36, 116.60, 116.55, 115.02, 114.97, 101.02, 100.88, 89.60, 47.23, 45.88, 38.58, 38.27, 38.15, 37.96, 37.91, 37.89, 33.57, 33.50, 30.01, 29.89, 29.81, 25.88, 25.85, 25.71, 25.69, 24.09, 24.07, 21.65, 21.63, 21.61, 21.28, 21.20, 19.71, 19.66, 19.41, 18.88, 18.72, 18.65.

HRMS (ESI-MS): m/z calculated for $[M+H]^+$ $C_{39}H_{46}NO_5S$, calculated, 640.3097; found, 640.3094.



N-(((1R,4aS,10aR)-7-isopropyl-1,4a-dimethyl-1,2,3,4,4a,9,10,10a-octahydrophenanthren-1-yl)methyl)-4-methyl-N-((R)-9-methyl-5-oxo-3,4-dihydro-2H,5H-pyrano[3,2-c]chromen-2-yl)benzenesulfonamide (**3zh**):

***Rf*:** 0.4 (DCM/Hexane, 95/5)

Appearance: white solid

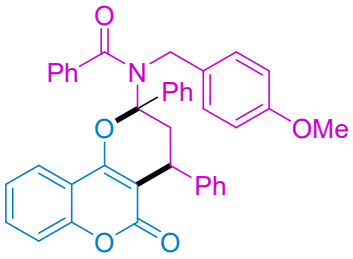
Purification: Added 1 ml (EtOAc/Hex; 9/1) and filtered the product (**Condition A**)

Yield: 80% (104 mg; **A**)

^{1}H NMR (400 MHz, $CDCl_3$) δ 7.85 – 7.69 (m, 2H), 7.30 (q, *J* = 6.4 Hz, 3H), 7.16 (dd, *J* = 16.3, 8.1 Hz, 2H), 6.99 (dd, *J* = 17.6, 8.1 Hz, 1H), 6.87 (d, *J* = 26.4 Hz, 1H), 6.73 (s, 1H), 5.58 (dd, *J* = 28.3, 9.9 Hz, 1H), 4.48 – 4.42 (m, 1H), 4.06 (d, *J* = 29.8 Hz, 1H), 3.67 – 3.46 (m, 1H), 3.24 (dd, *J* = 36.3, 15.4 Hz, 1H), 2.95 (d, *J* = 17.2 Hz, 1H), 2.87 – 2.73 (m, 2H), 2.61 – 2.44 (m, 1H), 2.42 (d, *J* = 9.7 Hz, 3H), 2.32 (s, 4H), 2.23 (s, 1H), 1.91 – 1.71 (m, 4H), 1.70 – 1.60 (m, 3H), 1.59 – 1.35 (m, 3H), 1.28 – 1.21 (m, 7H), 1.13 (s, 3H).

^{13}C NMR (101 MHz, $CDCl_3$) δ 162.78, 159.35, 150.85, 150.79, 147.50, 147.32, 145.86, 145.81, 143.87, 138.37, 134.18, 133.20, 132.74, 132.71, 129.87, 128.09, 127.94, 126.97, 126.86, 124.05, 124.00, 123.98, 123.92, 121.96, 116.47, 116.40, 114.75, 101.00, 100.84, 89.69, 45.76, 38.66, 38.34, 38.21, 37.96, 37.92, 33.61, 33.53, 30.02, 29.94, 29.86, 25.89, 25.75, 24.15, 24.10, 24.07, 21.71, 21.68, 21.40, 20.96, 19.78, 19.73, 19.53, 19.06, 18.77, 18.71.

HRMS (ESI-MS): m/z calculated for $[M+H]^+$ $C_{40}H_{48}NO_5S$, calculated, 654.3253; found, 654.3248.



N-(4-methoxybenzyl)-N-((2R,4S)-5-oxo-2,4-diphenyl-3,4-dihydro-2H,5H-pyrano[3,2-c]chromen-2-yl)benzamide (**3zi**):

***Rf*:** 0.5 (EtOAc/Hexane, 3/7)

Appearance: white solid

Purification: Column chromatography (EtOAc/Hexane, 1/5) (**Condition A**)

Yield: 80% (95 mg; **A**)

^{1}H NMR (400 MHz, $CDCl_3$) δ 7.87 (d, *J* = 7.3 Hz, 2H), 7.82 (d, *J* = 7.8 Hz, 1H), 7.58 (t, *J* = 7.8 Hz, 1H), 7.46 – 7.33 (m, 5H), 7.33 – 7.25 (m, 6H), 7.25 – 7.17 (m, 4H), 6.47 (d, *J* = 8.5 Hz, 2H), 6.37 (d, *J* = 8.5 Hz, 2H), 4.57 (d, *J* = 16.3 Hz, 1H), 4.41 – 4.29 (m, 2H), 4.23 (d, *J* = 16.3 Hz, 1H), 3.61 (s, 3H), 2.37 (dd, *J* = 14.1, 11.2 Hz, 1H).

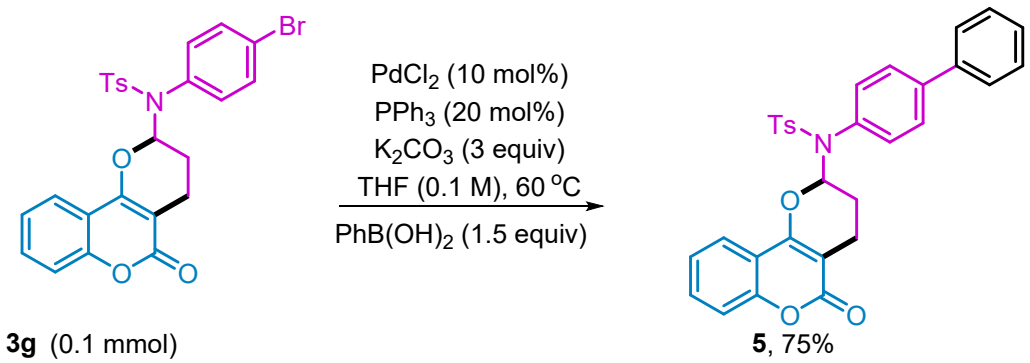
^{13}C NMR (101 MHz, $CDCl_3$) δ 174.21, 160.62, 158.24, 158.10, 152.94, 142.27, 140.87, 137.79, 131.74, 130.17, 129.03, 128.82, 128.59, 128.53, 128.05, 126.98, 126.66, 126.56, 125.82, 123.78, 122.43, 116.67, 115.18, 113.20, 106.54, 102.96, 93.87, 55.08, 50.40, 44.12, 36.70.

HRMS (ESI-MS): m/z calculated for $[M+Na]^+$ $C_{39}H_{31}NaNO_5$, calculated, 616.2100; found, 616.2100.

7.2 General procedure for gram scale reaction

An oven-dried screw cap reaction tube was charged with a magnetic stir-bar, allenamides **1d** (1.09 gm, 3 mmol, 1.0 equiv) 4-hydroxy coumarin **2a** (0.58 gm, 3.6 mmol, 1.2 equiv), and in HFIP (6 mL, 0.5 M). The resulting reaction mixture was stirred vigorously on a preheated aluminum block at 60 °C for 8 h. After the completion of the reaction (vide TLC), the desired product was isolated via precipitation technique (addition of 6 mL EtOAc/Hexane mixture, 9/1). The white solid was dried under vacuum, provided **3g** 1.4 gm product in 94% yield.

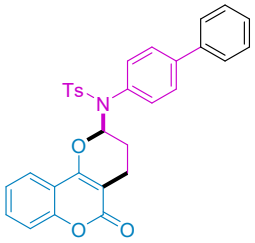
7.3 Synthesis compound 5



3g (0.1 mmol)

5, 75%

An oven-dried screw cap reaction tube was charged with a magnetic stir-bar, **3g** (53 mg, 0.1 mmol) and phenyl boronic acid (18 mg, 0.15 mmol). Then $PdCl_2$ (2 mg, 0.01 mmol), PPh_3 (5 mg, 0.02 mmol), K_2CO_3 (41 mg, 0.3 mmol) and THF (1 mL) were added to the reaction tube and the reaction mixture was stirred at 60 °C for 12 h. The reaction was monitored by TLC. After completion of the reaction, the desired product was purified by column chromatography (DCM/hexane, 7/3). The brown solid product **5** was isolated as 75% yield (39 mg).



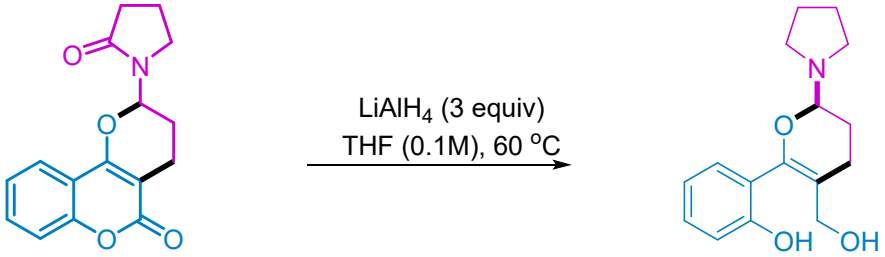
(R)-N-([1,1'-biphenyl]-4-yl)-4-methyl-N-(5-oxo-3,4-dihydro-2H,5H-pyrano[3,2-c]chromen-2-yl)benzenesulfonamide (**5**): (Rotamer, 1:1)

^{1}H NMR (400 MHz, $CDCl_3$) δ 7.73 (d, *J* = 8.2 Hz, 1H), 7.68 (d, *J* = 8.2 Hz, 1H), 7.51 (ddd, *J* = 23.8, 15.5, 7.5 Hz, 7H), 7.38 (dd, *J* = 7.8, 5.3 Hz, 3H), 7.32 (d, *J* = 8.3 Hz, 1H), 7.29 (d, *J* = 3.8 Hz, 1H), 7.23 – 7.16 (m, 1H), 7.13 – 7.05 (m, 2H), 6.41 (ddd, *J* = 20.5, 11.0, 2.3 Hz, 1H), 2.78 – 2.67 (m, 2H), 2.56 (s, 3H), 2.25 – 2.09 (m, 1H), 1.67 – 1.47 (m, 1H).

^{13}C NMR (101 MHz, $CDCl_3$) δ 162.35, 162.24, 158.87, 158.70, 152.59, 152.57, 144.45, 144.20, 142.39, 139.71, 136.88, 136.48, 133.85, 133.80, 132.83, 132.57, 131.71, 131.64, 131.54, 129.66, 129.57, 128.91, 128.58, 128.52, 127.91, 127.86, 127.11, 123.96, 123.59, 123.57, 122.10, 121.95, 116.83, 116.78, 115.29, 115.15, 100.88, 100.84, 86.68, 86.43, 25.95, 25.90, 21.73, 20.18, 20.15.

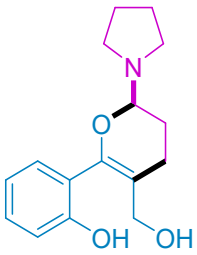
LRMS (ESI-MS): m/z calculated for $[M+H]^+$ $C_{31}H_{26}NO_5S$, calculated, 524.1; found, 524.1.

7.4 Synthesis compound 6



3v (0.1 mmol) **6**, 70%

An oven-dried screw cap reaction tube was charged with a magnetic stir-bar, 3v (29 mg, 0.1 mmol) and THF (1 mL). Then $LialH_4$ (12 mg, 0.3 mmol) was added to the reaction tube and the reaction mixture was stirred at 60 °C for 6 h. The reaction was monitored by TLC. After completion of the reaction, the desired product was purified by column chromatography (DCM/hexane, 95/5). The liquid product **6** was isolated as 70% yield (19 mg).



(R)-2-(5-(hydroxymethyl)-2-(pyrrolidin-1-yl)-3,4-dihydro-2H-pyran-6-yl)phenol (**6**):

^{1}H NMR (400 MHz, $CDCl_3$) δ 7.58 (s, 1H), 7.35 – 7.26 (m, 2H), 6.92 (d, *J* = 8.5 Hz, 1H), 3.56 (dd, *J* = 13.3, 6.6 Hz, 1H), 2.54 – 2.49 (m, 2H), 2.34 (s, 2H), 1.80 (s, 3H), 1.61 – 1.52 (m, 3H), 1.25 (d, *J* = 6.9 Hz, 4H).

^{13}C NMR (101 MHz, $CDCl_3$) δ 161.07, 137.33, 129.50, 127.86, 118.48, 118.30, 106.26, 103.00, 56.23, 54.06, 39.81, 31.56, 29.66, 23.38, 20.62, 17.81.

LRMS (ESI-MS): m/z calculated for $[M+H]^+$ $C_{16}H_{22}NO_3$, calculated, 276.1; found, 276.1.

8. X-Ray crystallographic data of 3v

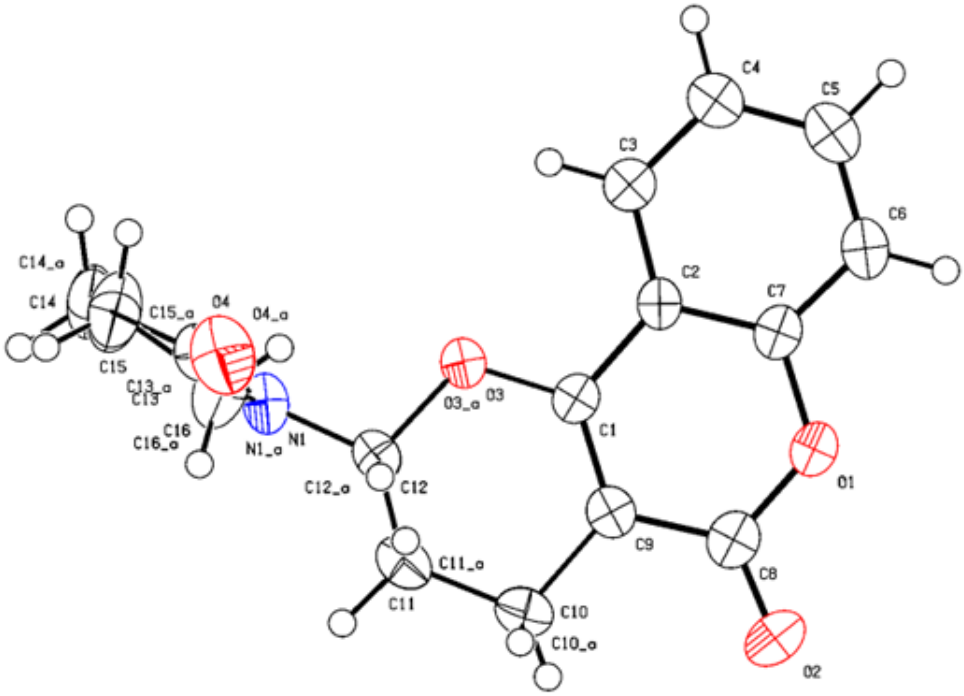


Figure 2. X-ray structure of **3v** (drawn at 50% thermal ellipsoid probability)

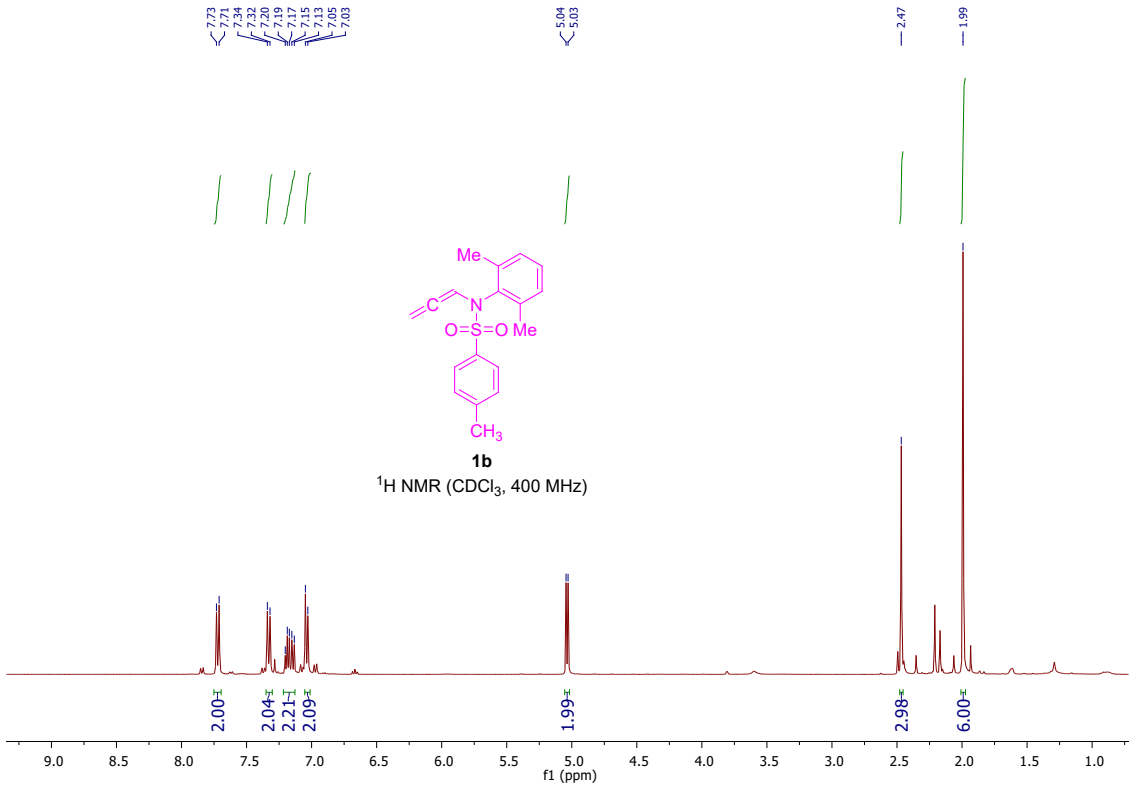
CCDC-2375035 contains the supplementary crystallographic data of compound (R)-1-(5-oxo-3,4-dihydro-2H,5H-pyrano[3,2-c]chromen-2-yl)pyrrolidin-2-one (**3v**). The crystals of **3v** were obtained by dissolving **3v** in dichloromethane and layering with pentane followed by slow evaporation. X-Ray crystallographic structure analysis of (R)-1-(5-oxo-3,4-dihydro-2H,5H-pyrano[3,2-c]chromen-2-yl)pyrrolidin-2-one (**3v**) was performed on Bruker APEX-II CCD diffractometer. The crystal was kept at 296.15K during data collection. Using Olex2, the structure was solved with the SHELXS structure solution program using Direct Methods and

refined with the SHELXL refinement package using Least Squares minimization. The non-hydrogen atoms were refined anisotropically. Hydrogen atoms were refined isotropically. The crystal data are mentioned below:

Compound	**3v**
CCDC NO	**2375035**
Empirical formula	$C_{16}\ H_{15}\ N\ O_4$
Formula weight	285.29
Temperature/K	173(2)
Crystal system	Orthorhombic
Space group	*C m c e*
a/Å	6.8069(15)
b/Å	18.566(5)
c/Å	20.810(4)
α/°	90
β/°	90
γ/°	90
Volume/Å^3	2629.9(10)
Z	8
ρ_{calc}g/cm^3	1.441
μ/mm^{-1}	0.104
F(000)	1200
Radiation	Mo*K*α
Data/restraints/parameters	1264/0/157
Goodness-of-fit on F^2	1.141
Final R indexes [all data]	R_1 = 0.0668, wR_2 = 0.1867

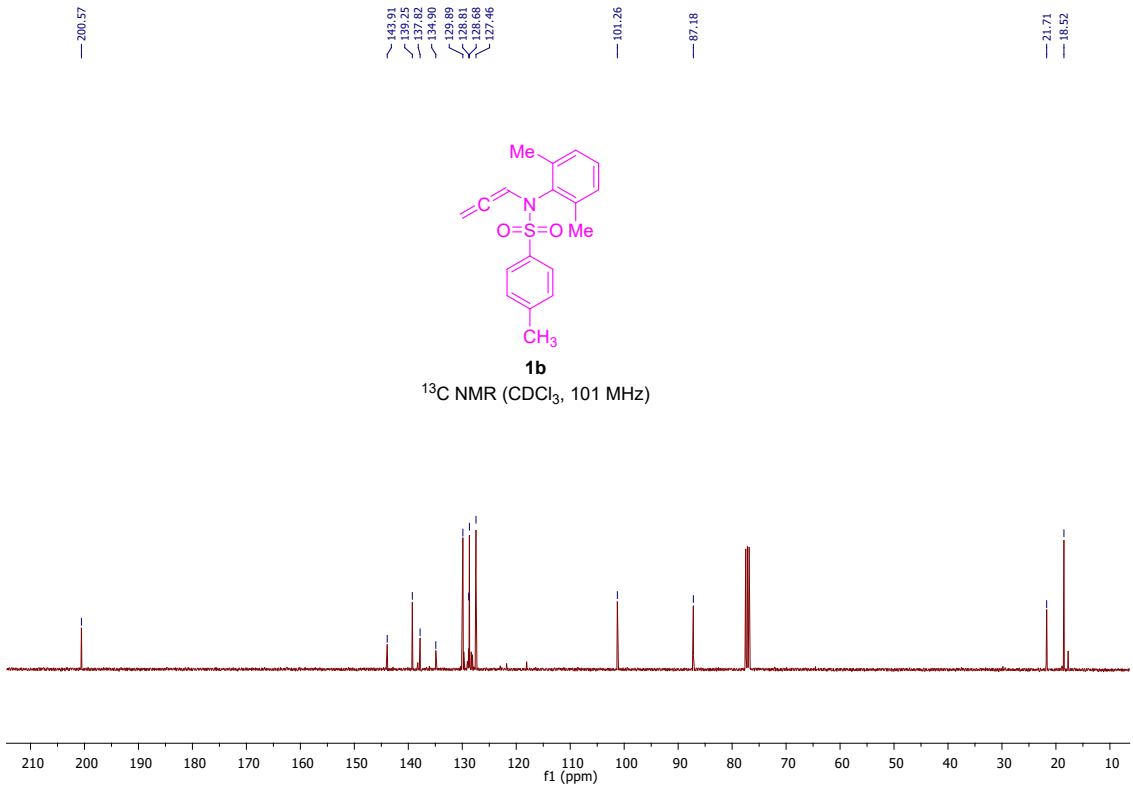
9. NMR spectra of allenamides

N-(2,6-dimethylphenyl)-4-methyl-N-(propa-1,2-dien-1-yl)benzenesulfonamide (**1b**):



1b

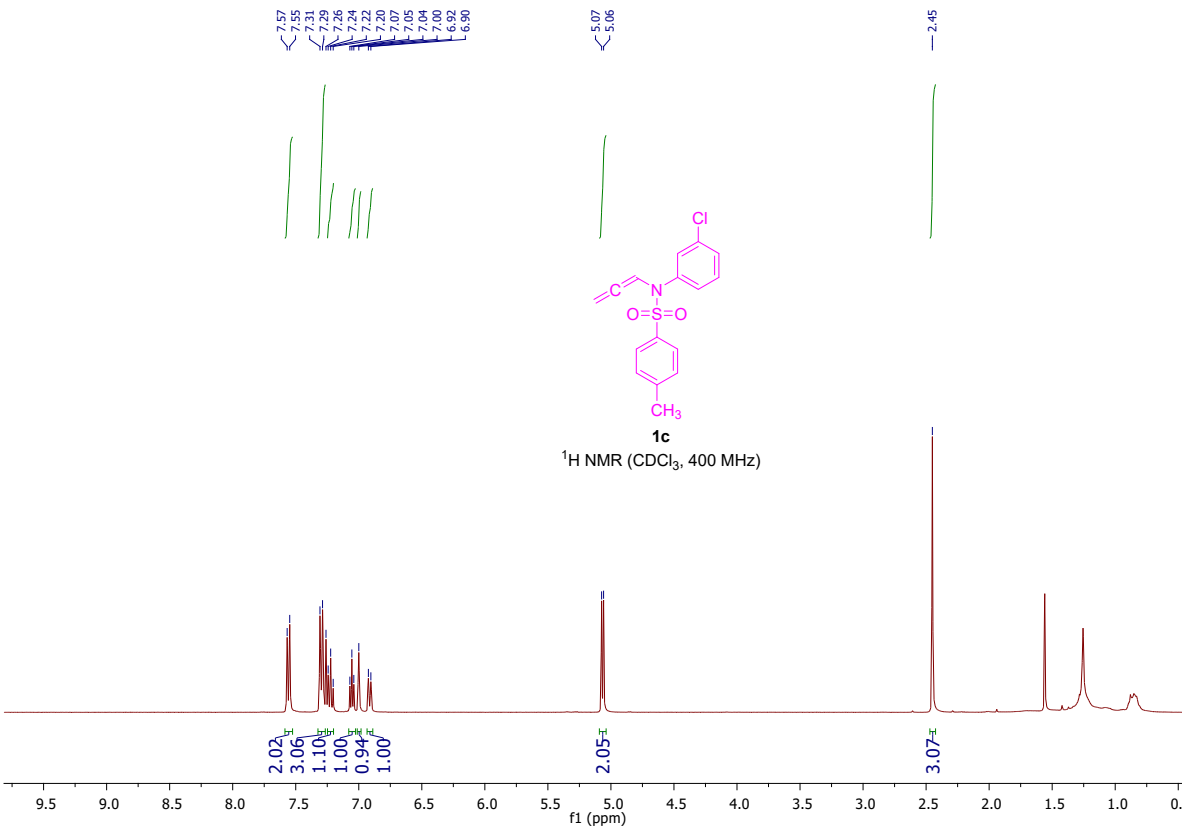
^{1}H NMR ($CDCl_3$, 400 MHz)



1b

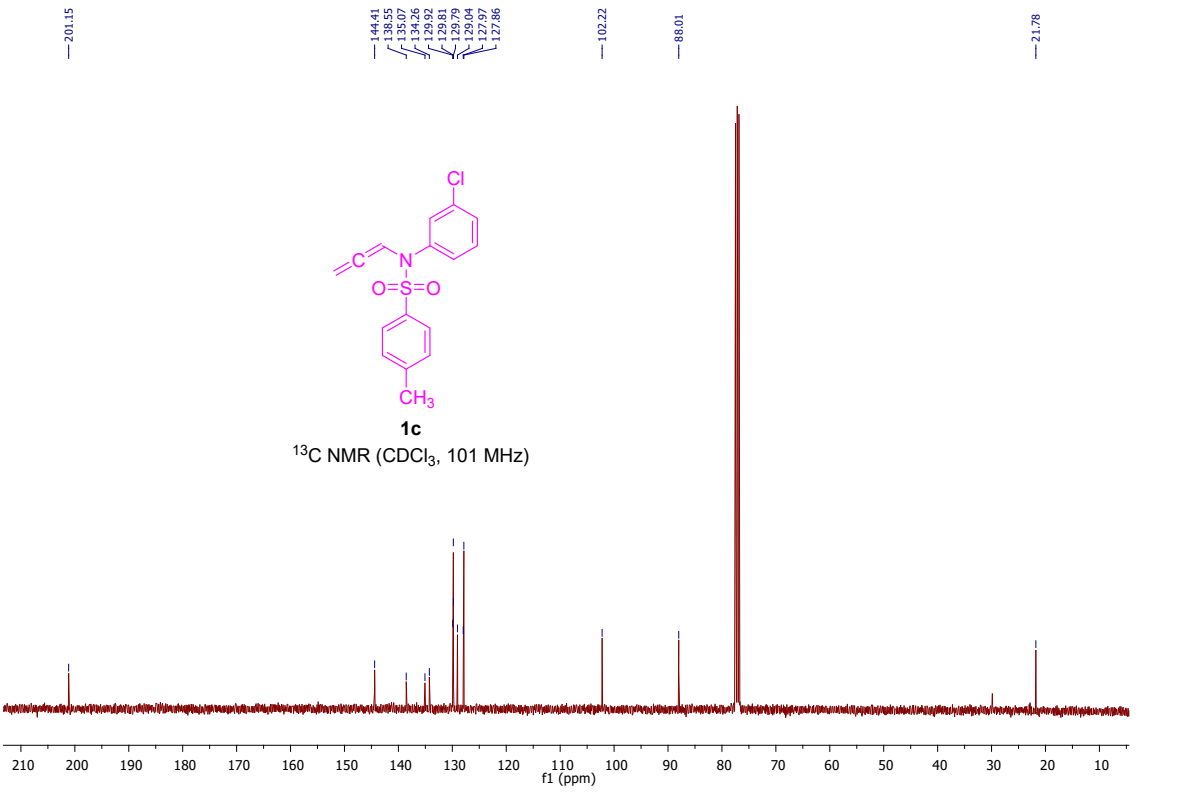
^{13}C NMR ($CDCl_3$, 101 MHz)

N-(3-chlorophenyl)-4-methyl-N-(propa-1,2-dien-1-yl)benzenesulfonamide (**1c**):



1c

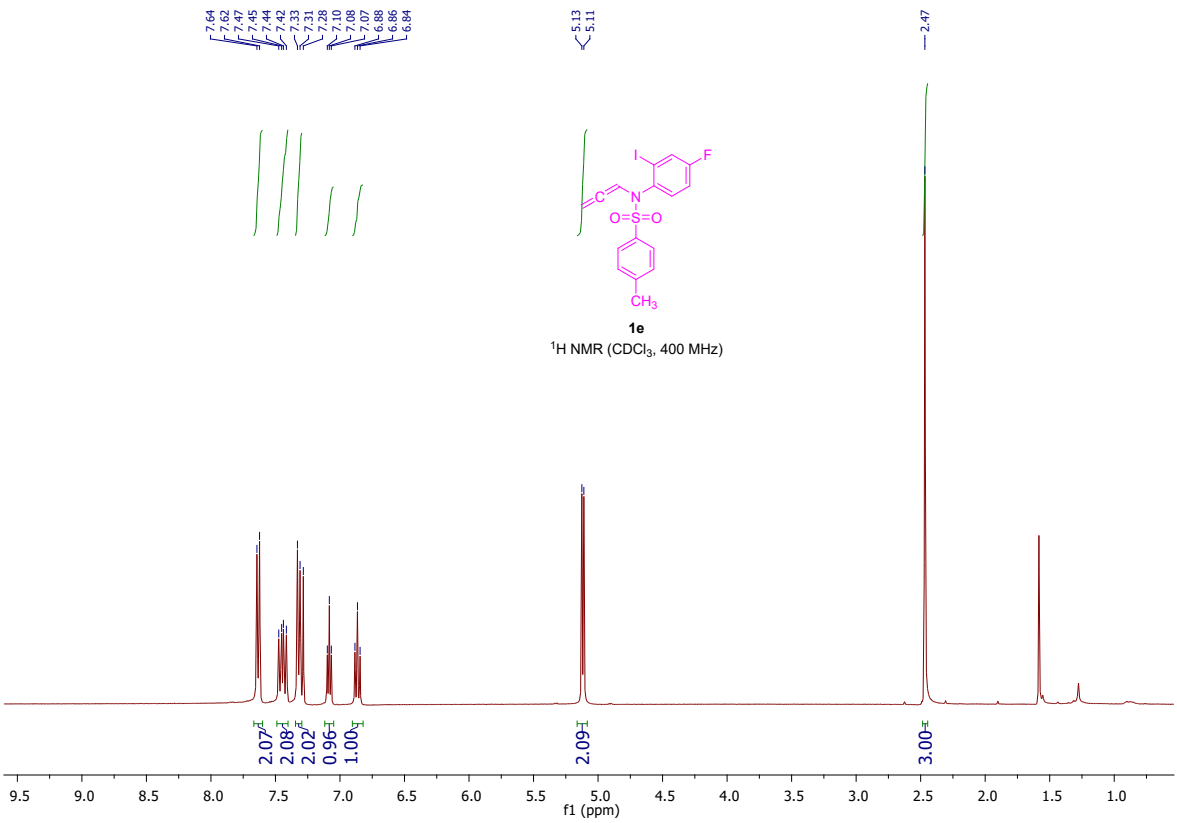
^{1}H NMR ($CDCl_3$, 400 MHz)



1c

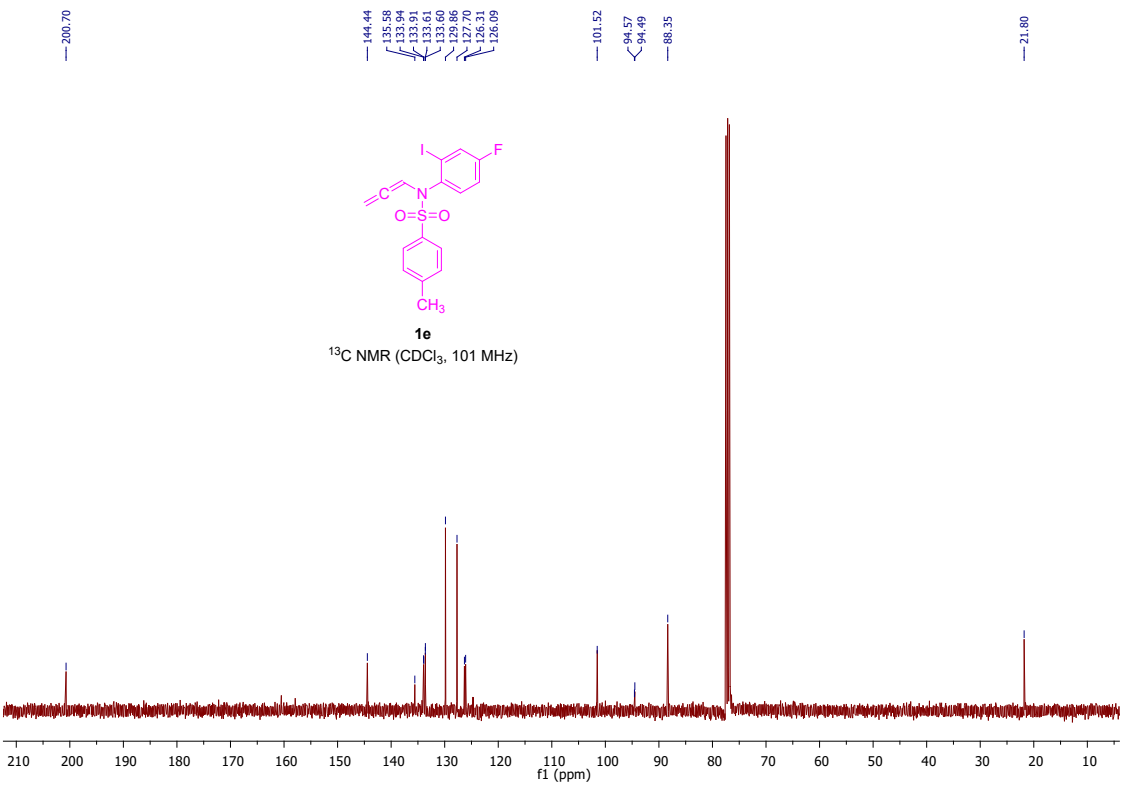
^{13}C NMR ($CDCl_3$, 101 MHz)

N-(4-fluoro-2-iodophenyl)-4-methyl-N-(propa-1,2-dien-1-yl)benzenesulfonamide (**1e**):



1e

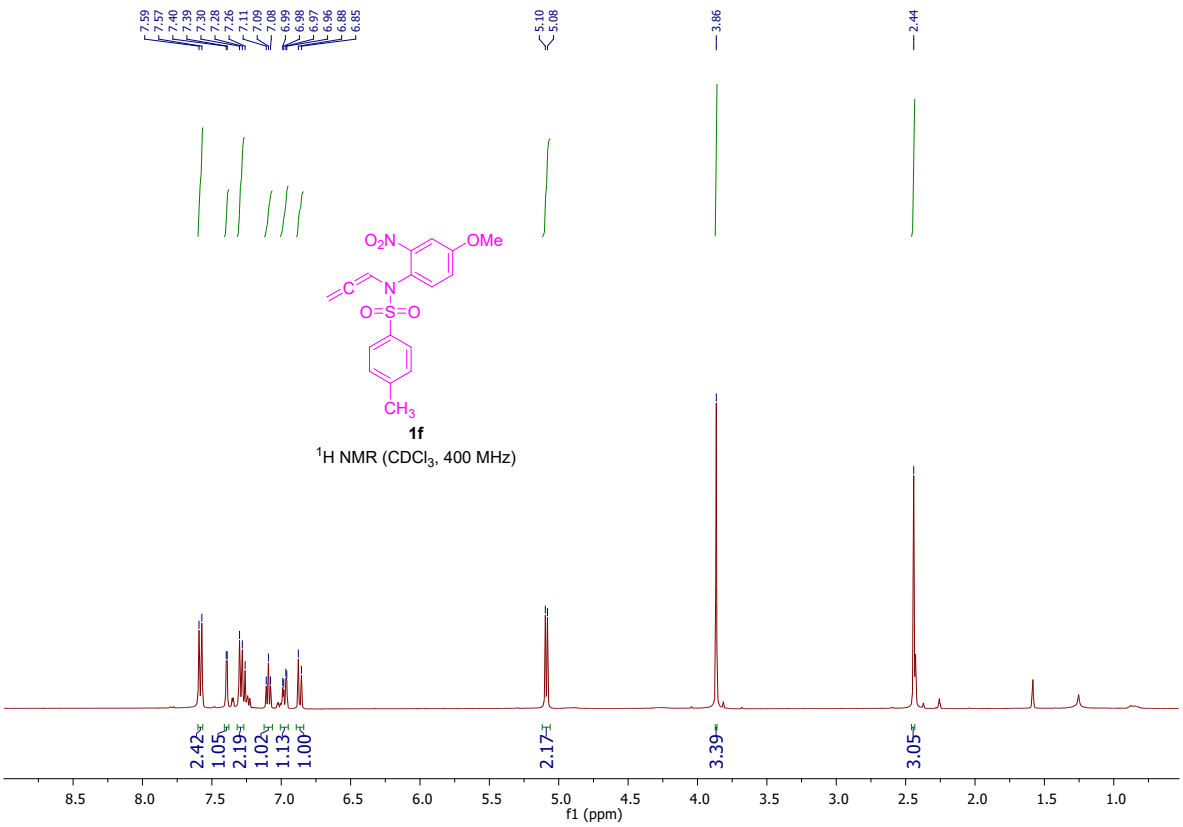
^{1}H NMR ($CDCl_3$, 400 MHz)

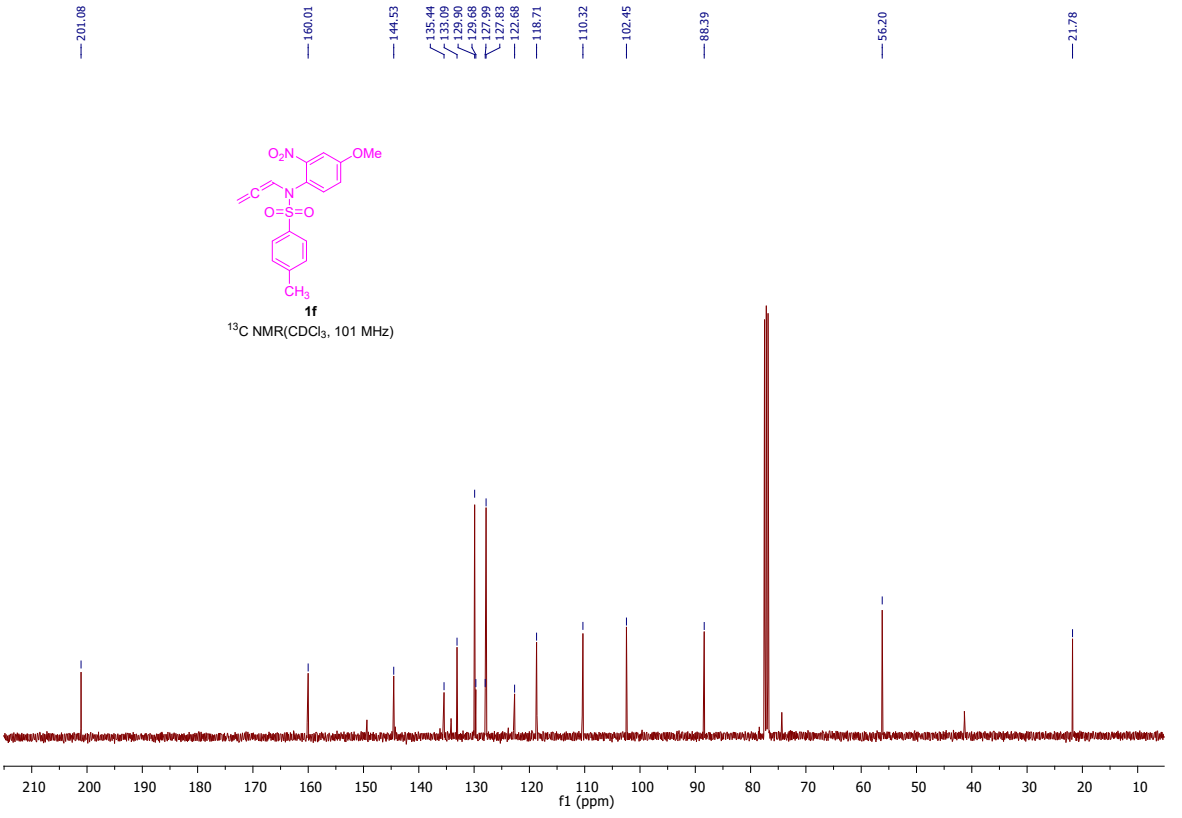


1e

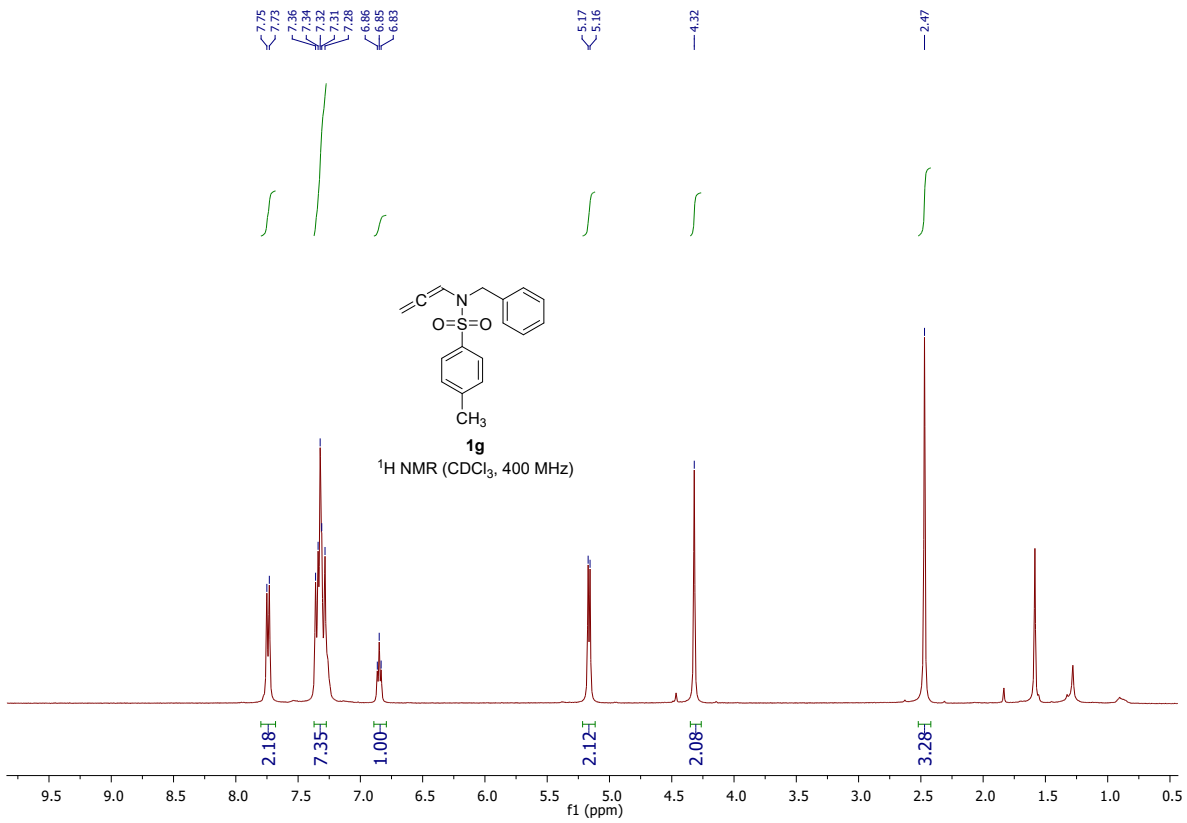
^{13}C NMR ($CDCl_3$, 101 MHz)

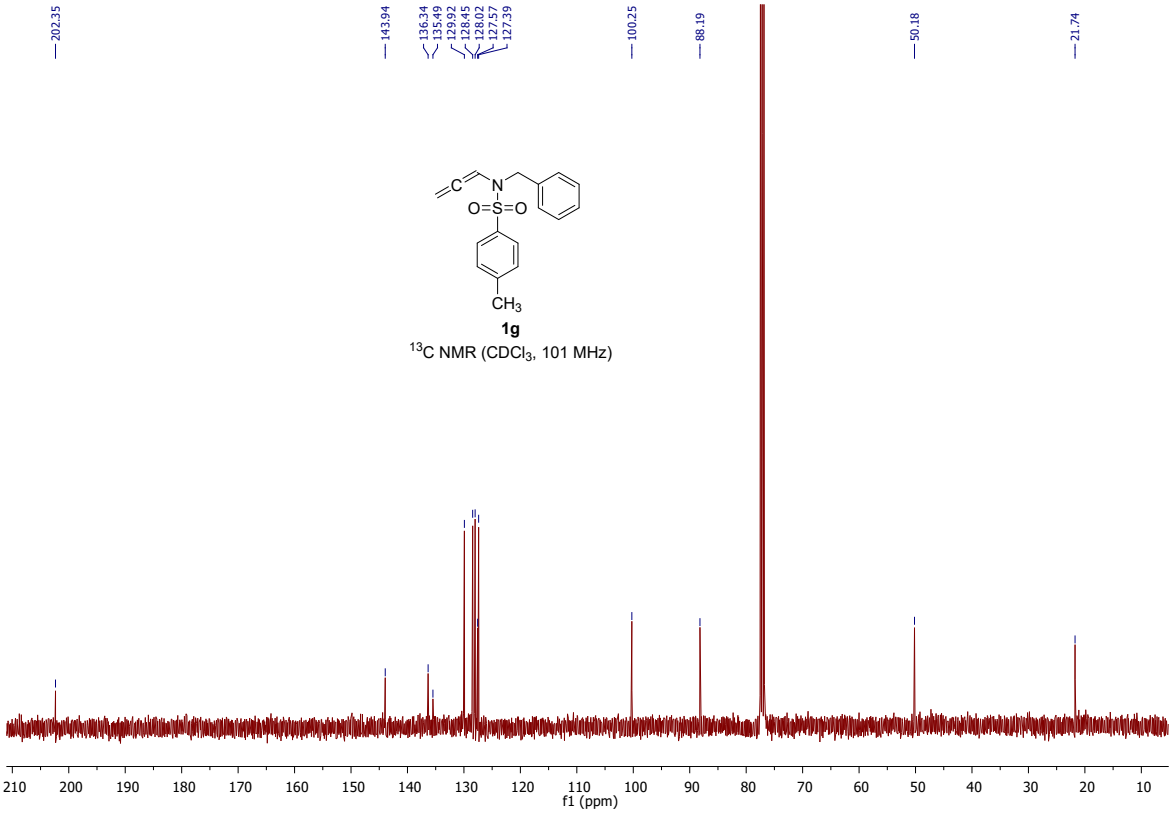
N-(4-methoxy-2-nitrophenyl)-4-methyl-N-(propa-1,2-dien-1-yl)benzenesulfonamide (**1f**):



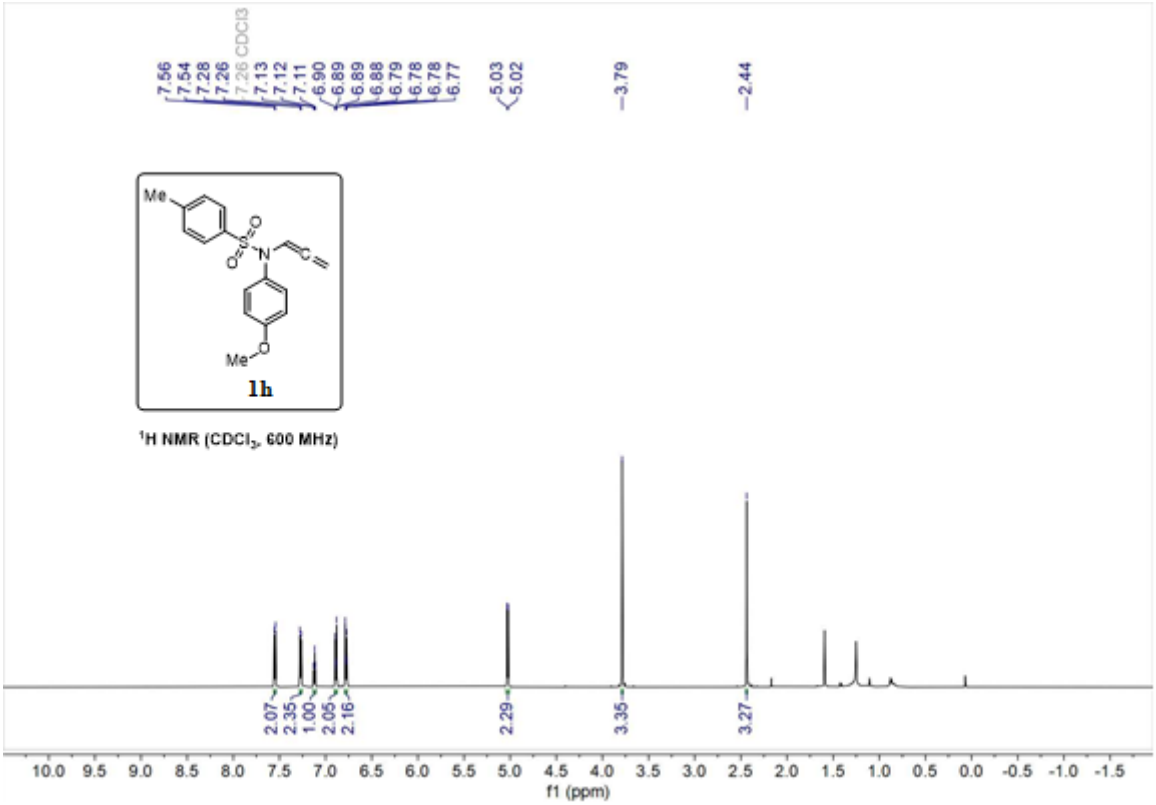


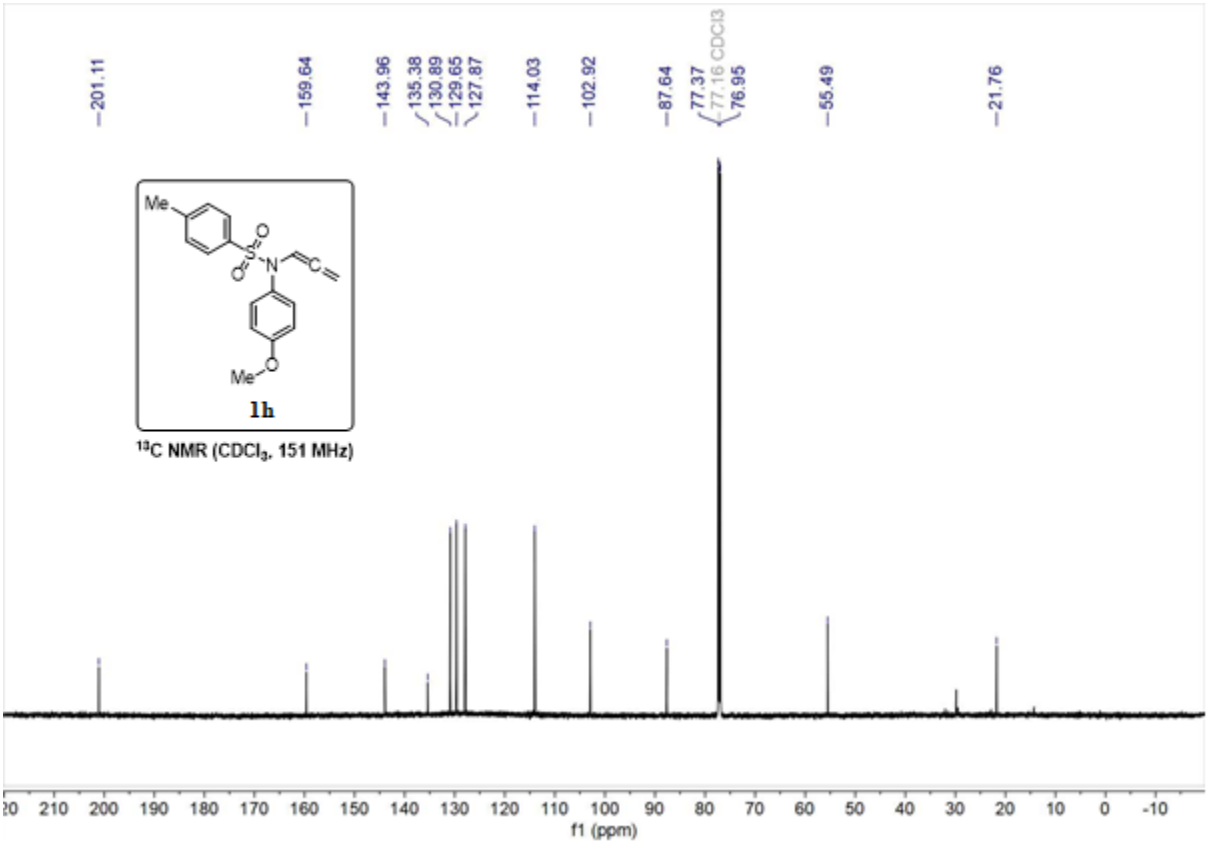
N-benzyl-4-methyl-N-(propa-1,2-dien-1-yl)benzenesulfonamide (**1g**):



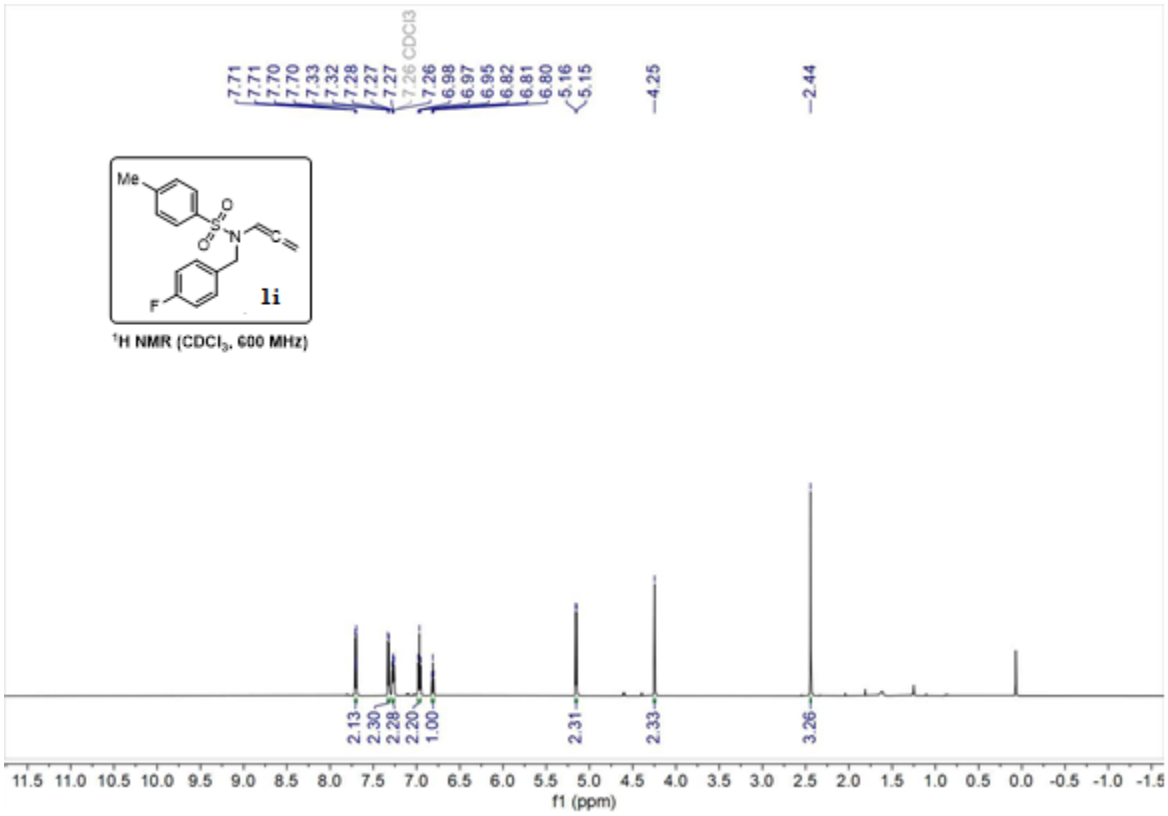


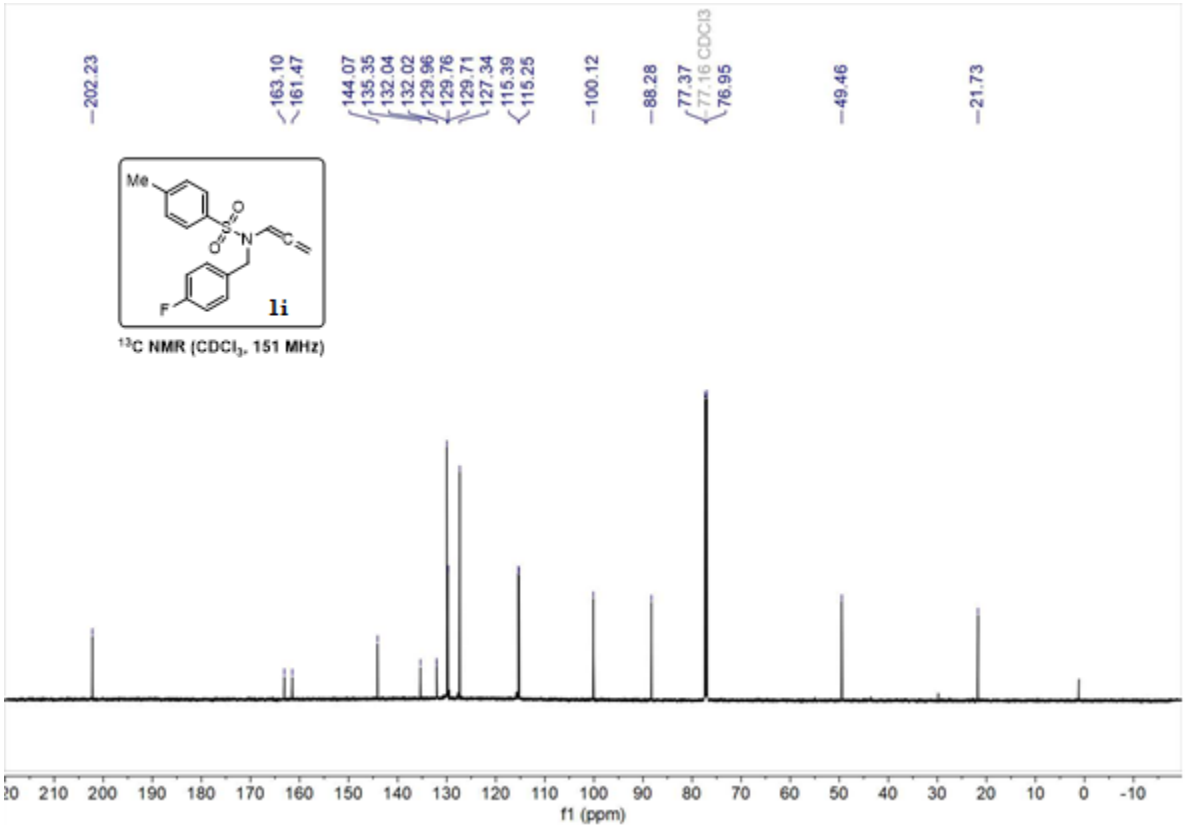
N-(4-methoxybenzyl)-4-methyl-N-(propa-1,2-dien-1-yl)benzenesulfonamide (**1h**):



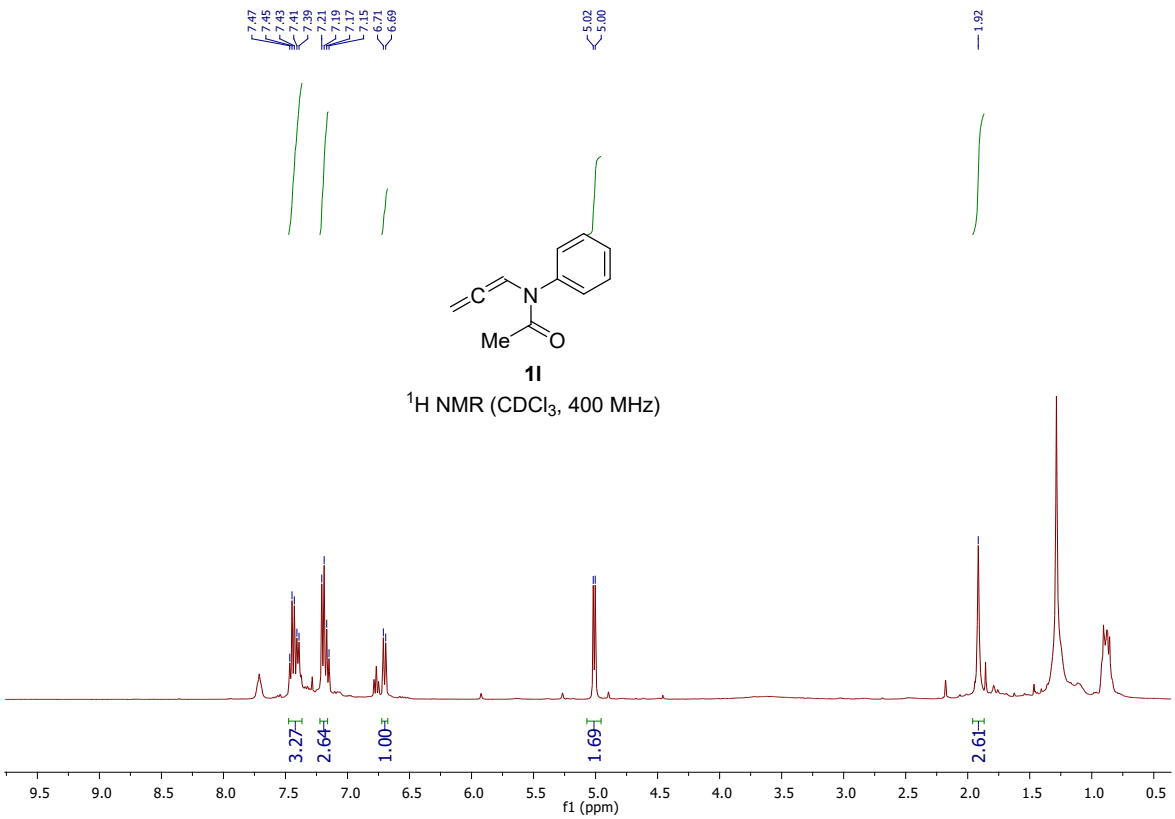


N-(4-fluorobenzyl)-4-methyl-N-(propa-1,2-dien-1-yl)benzenesulfonamide (**1i**):



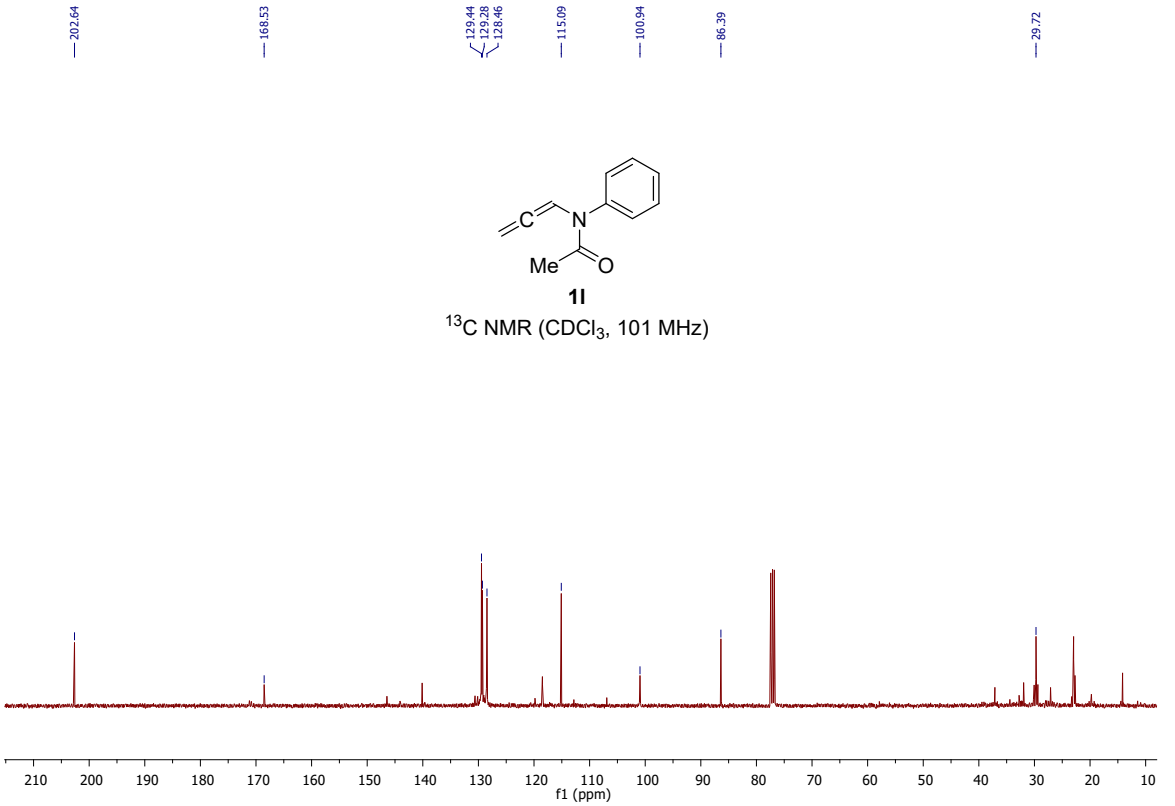


N-phenyl-N-(propa-1,2-dien-1-yl)acetamide (**1l**):



1l

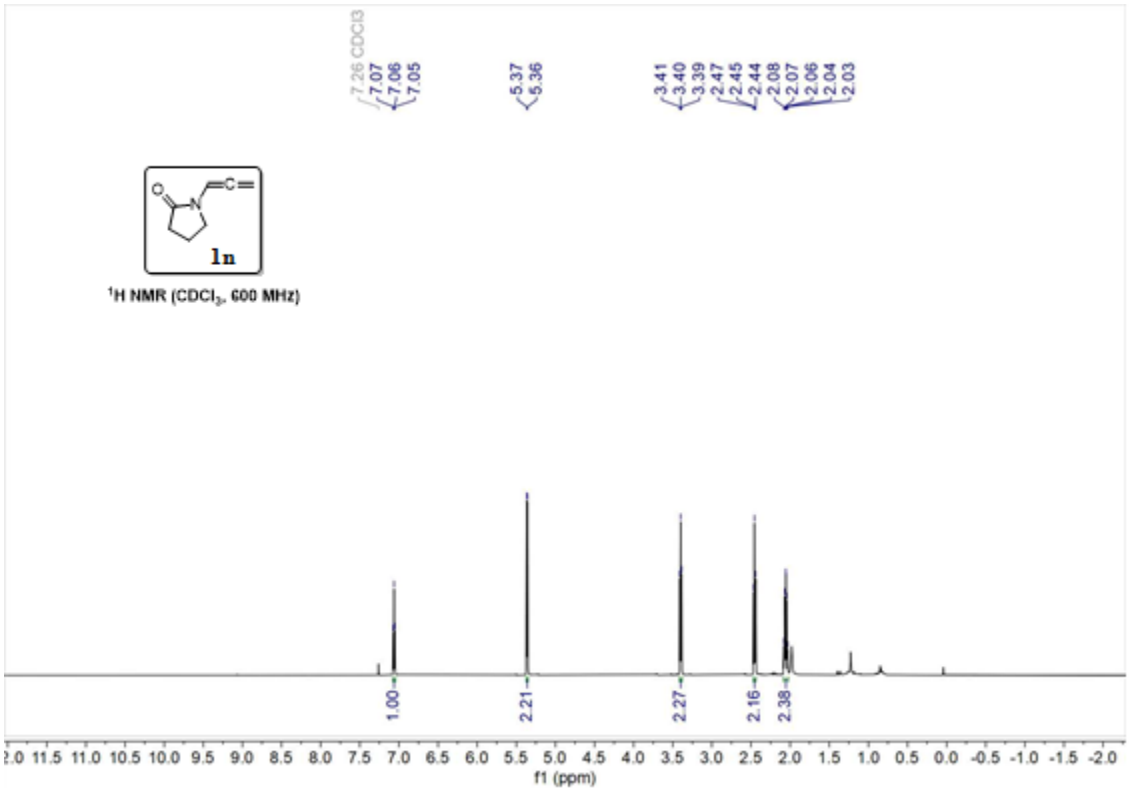
^{1}H NMR ($CDCl_3$, 400 MHz)

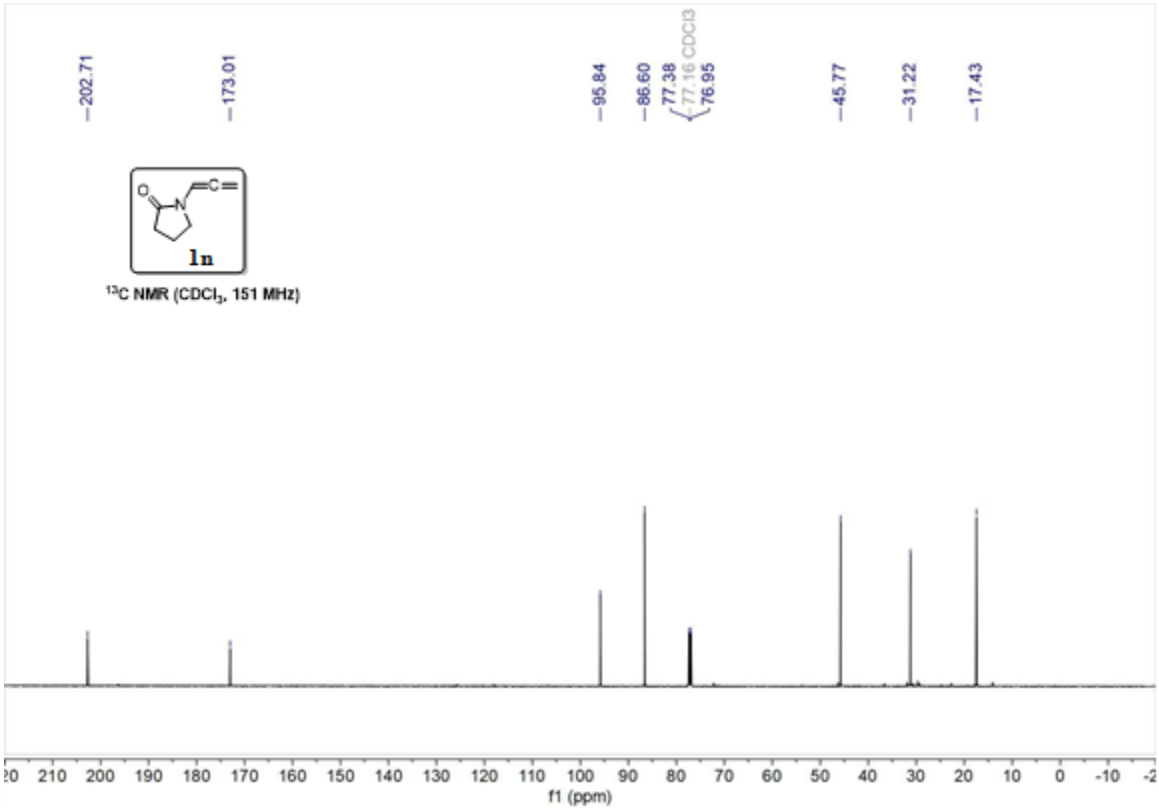


1l

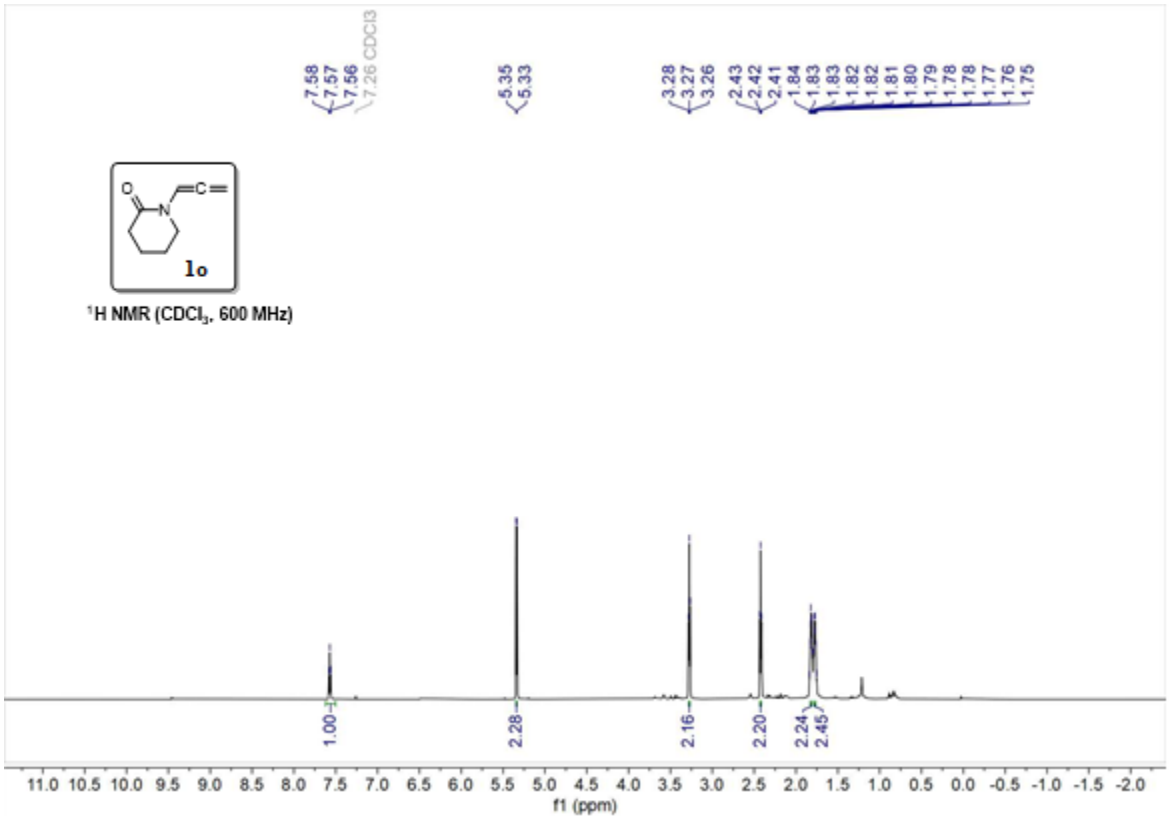
^{13}C NMR ($CDCl_3$, 101 MHz)

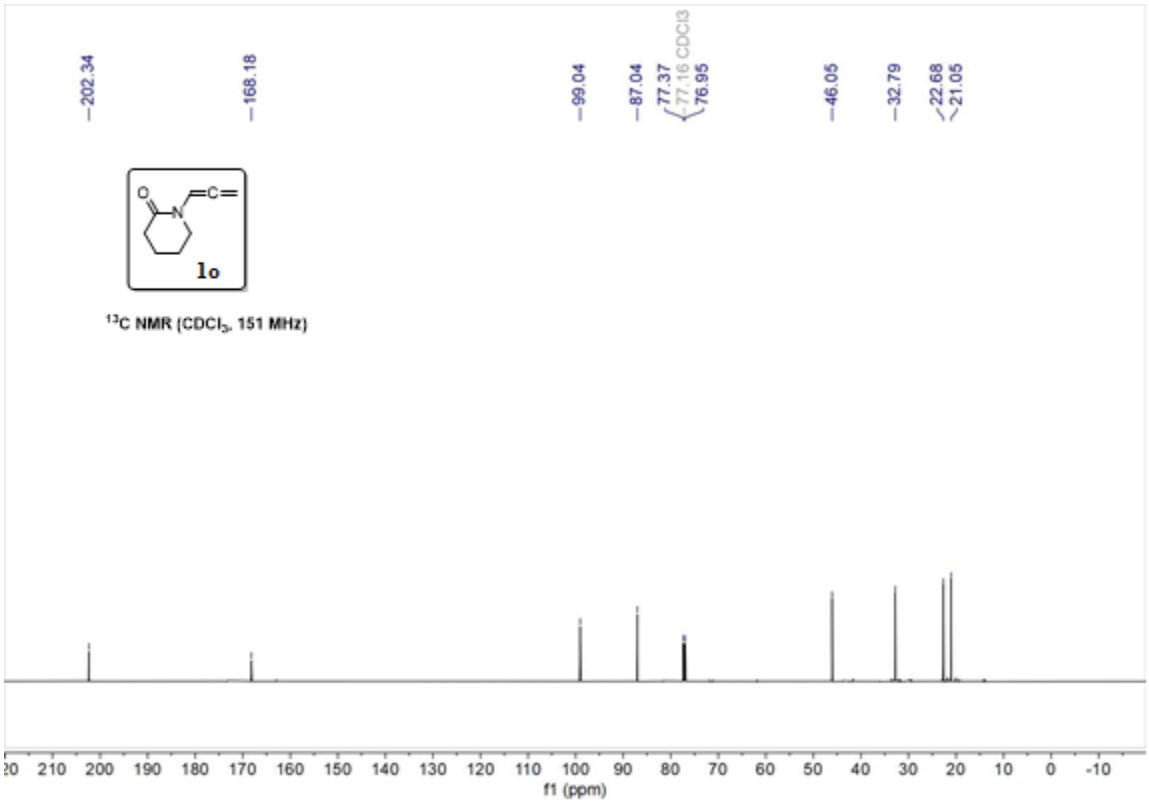
1-(propa-1,2-dien-1-yl)pyrrolidin-2-one (**1n**):



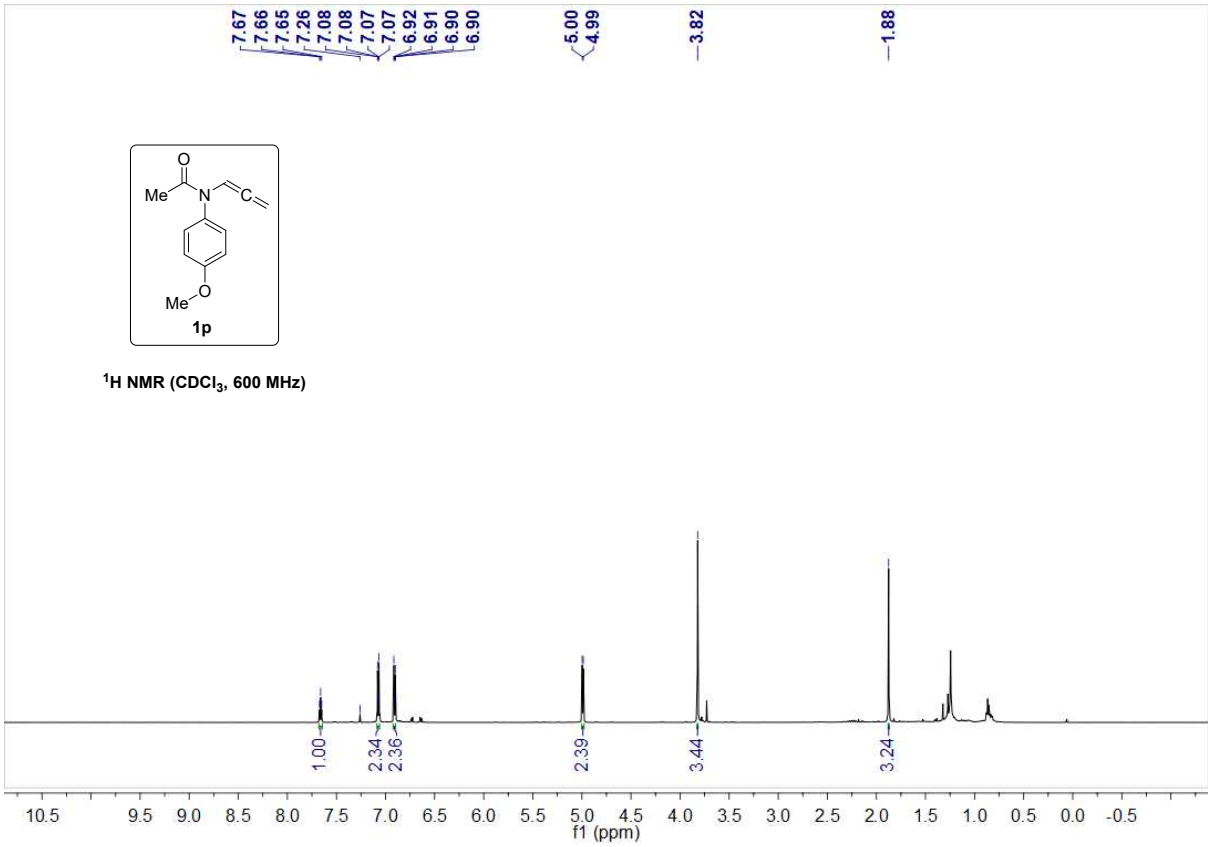


1-(propa-1,2-dien-1-yl)piperidin-2-one (**1o**):

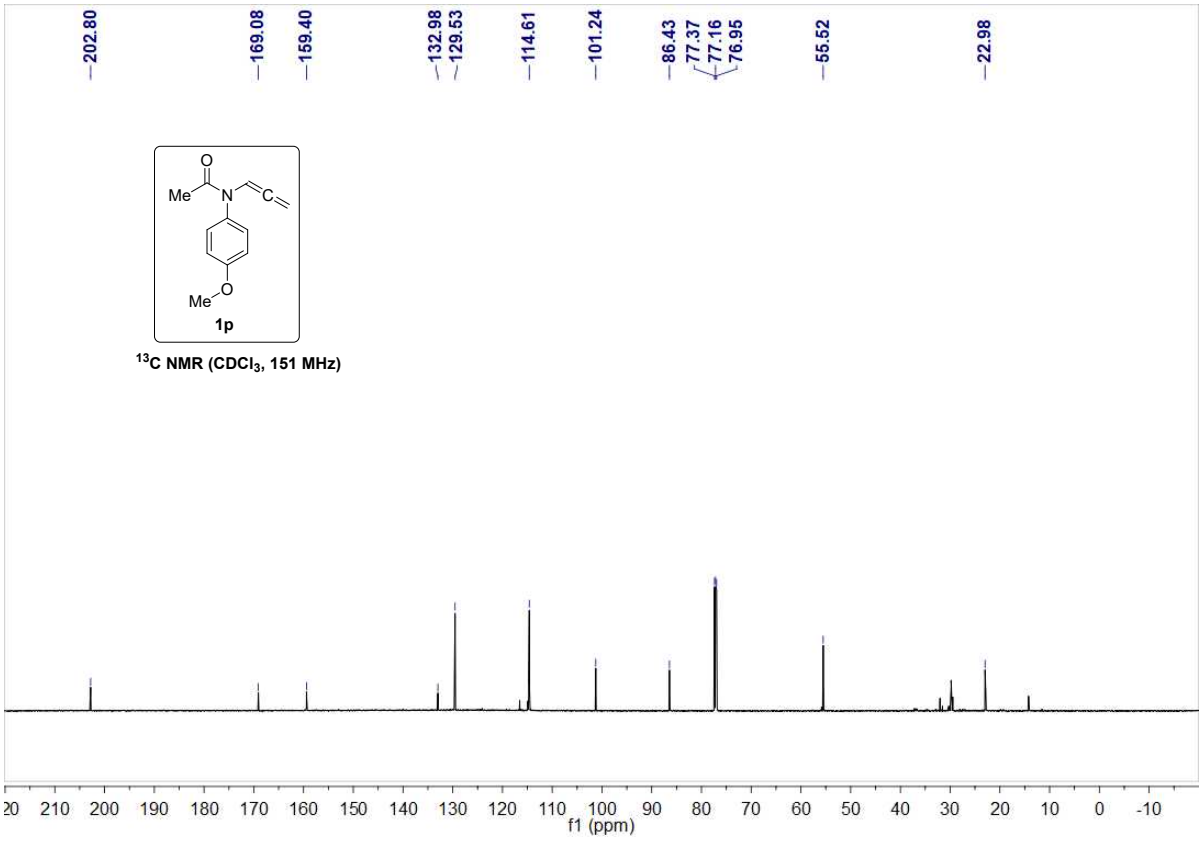




N-(4-methoxyphenyl)-N-(propa-1,2-dien-1-yl)acetamide (**1p**):

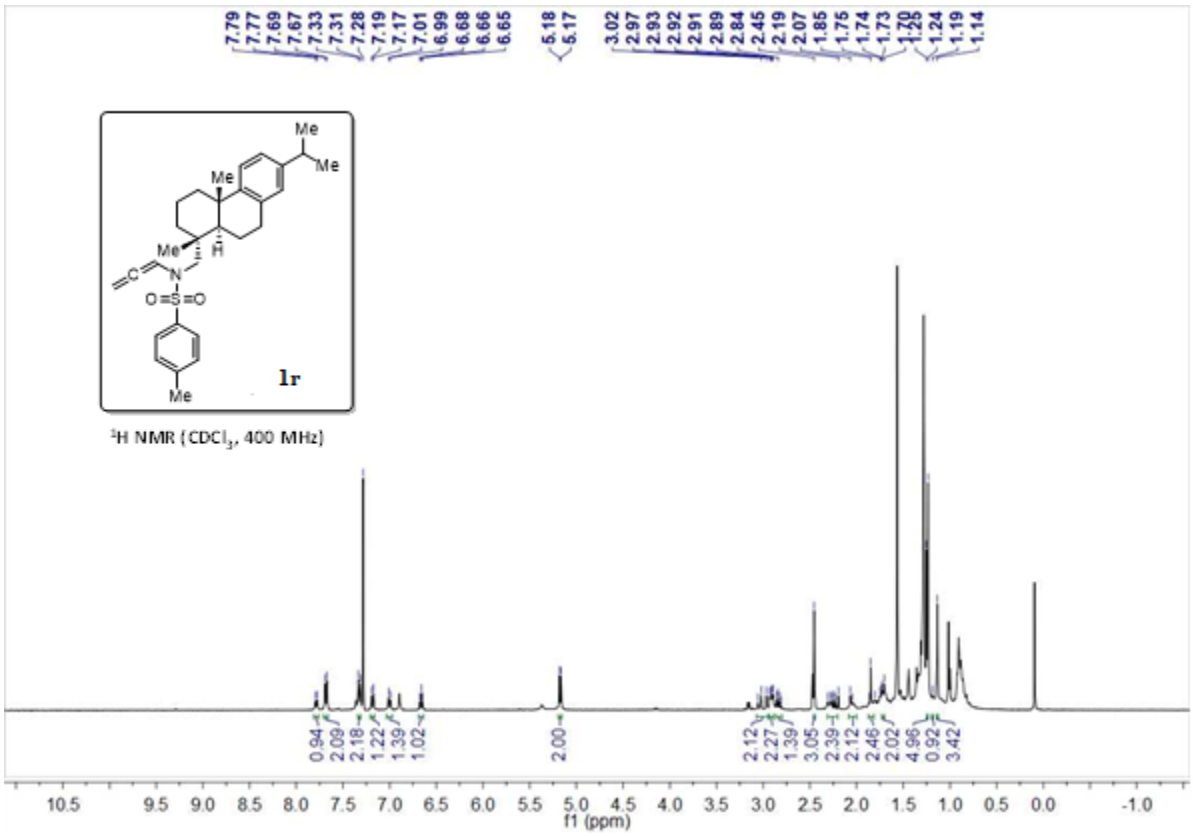


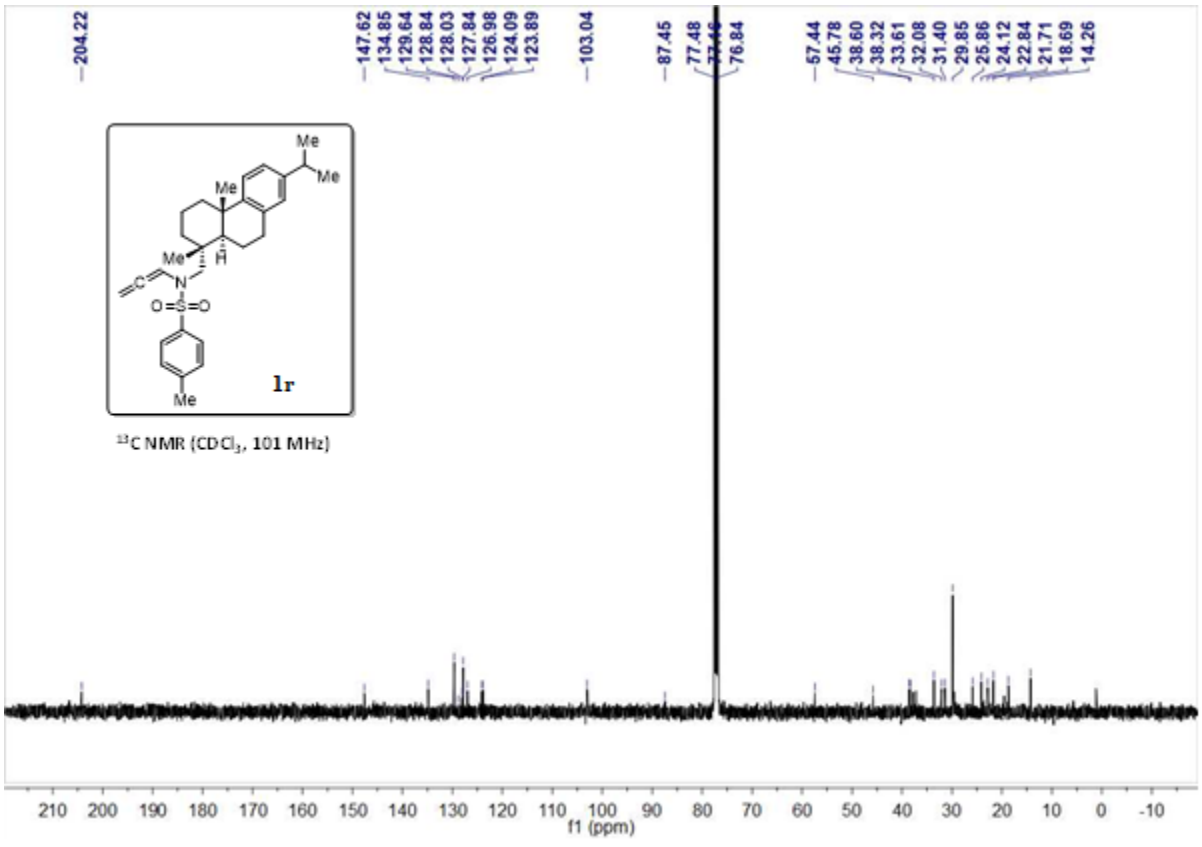
^{1}H NMR ($CDCl_3$, 600 MHz)



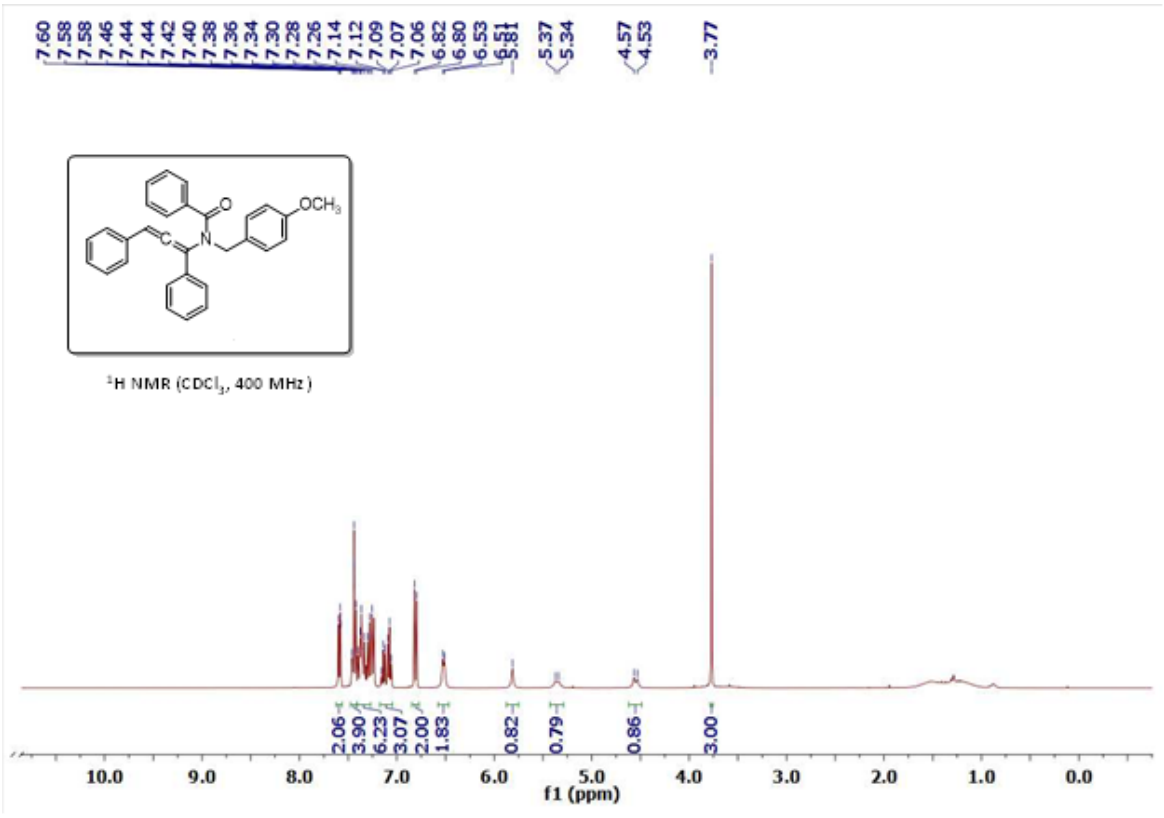
^{13}C NMR ($CDCl_3$, 151 MHz)

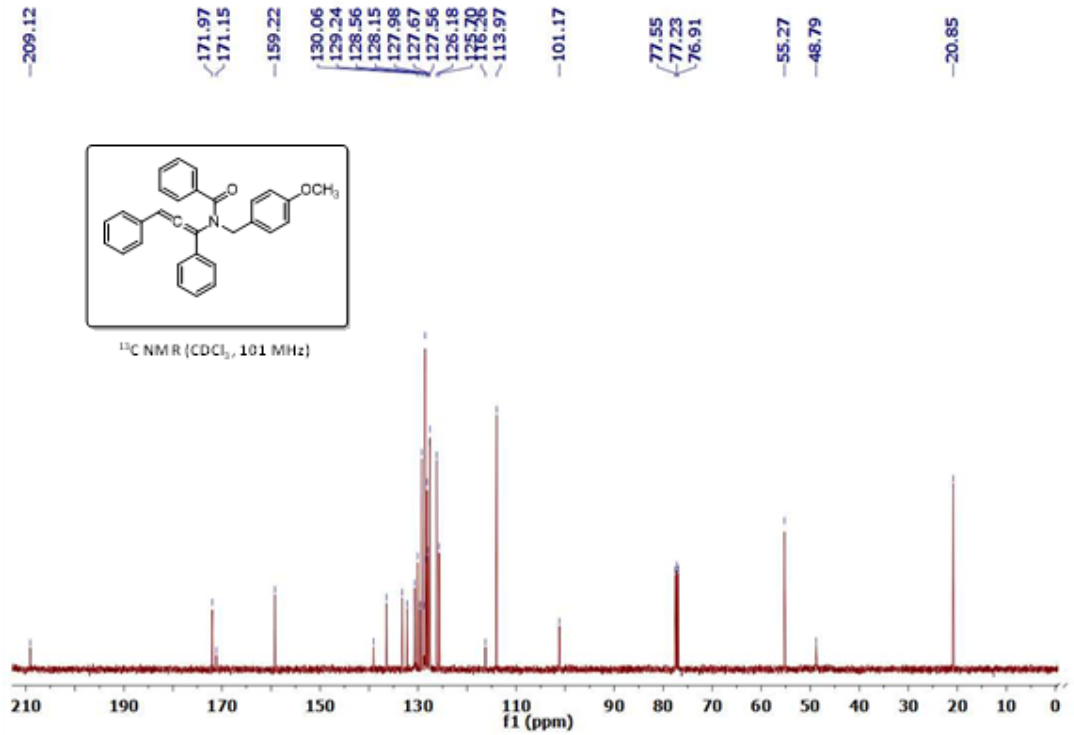
N-(((1R,4aS,10aR)-7-isopropyl-1,4a-dimethyl-1,2,3,4,4a,9,10,10a-octahydrophenanthren-1-yl)methyl)-4-methyl-N-(propa-1,2-dien-1-yl)benzenesulfonamide (**1r**):





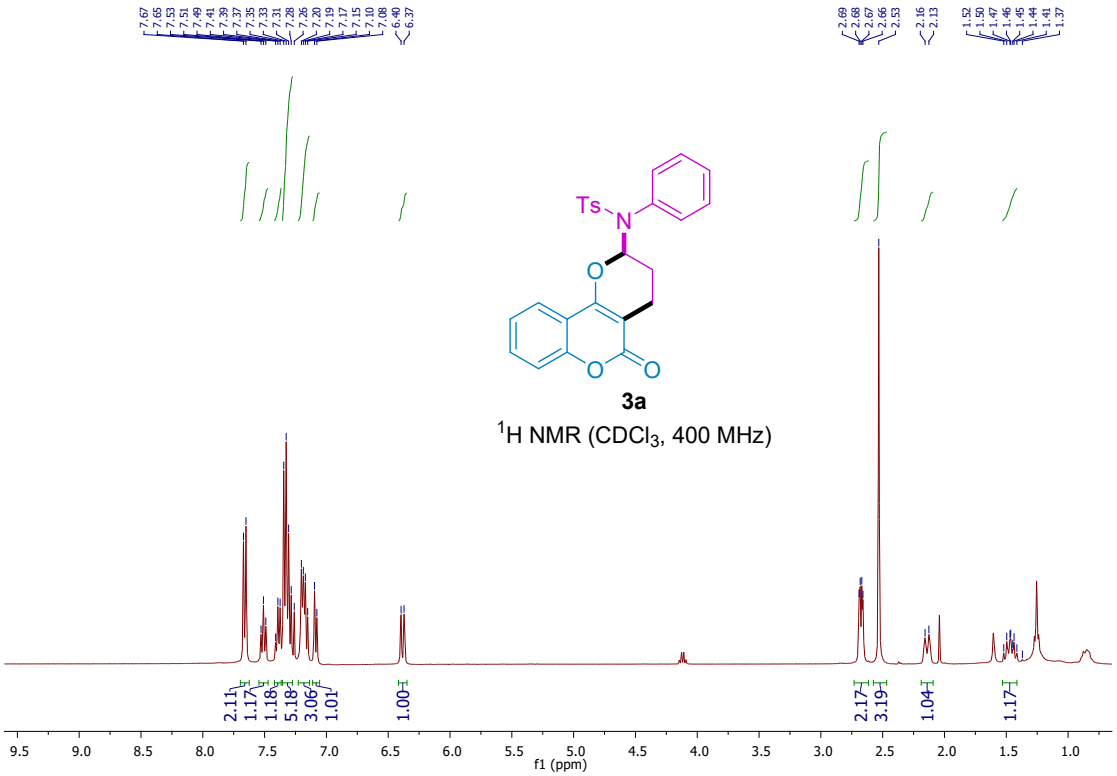
N-(1,3-diphenylpropa-1,2-dien-1-yl)-N-(4-methoxybenzyl)benzamide (**1s**):

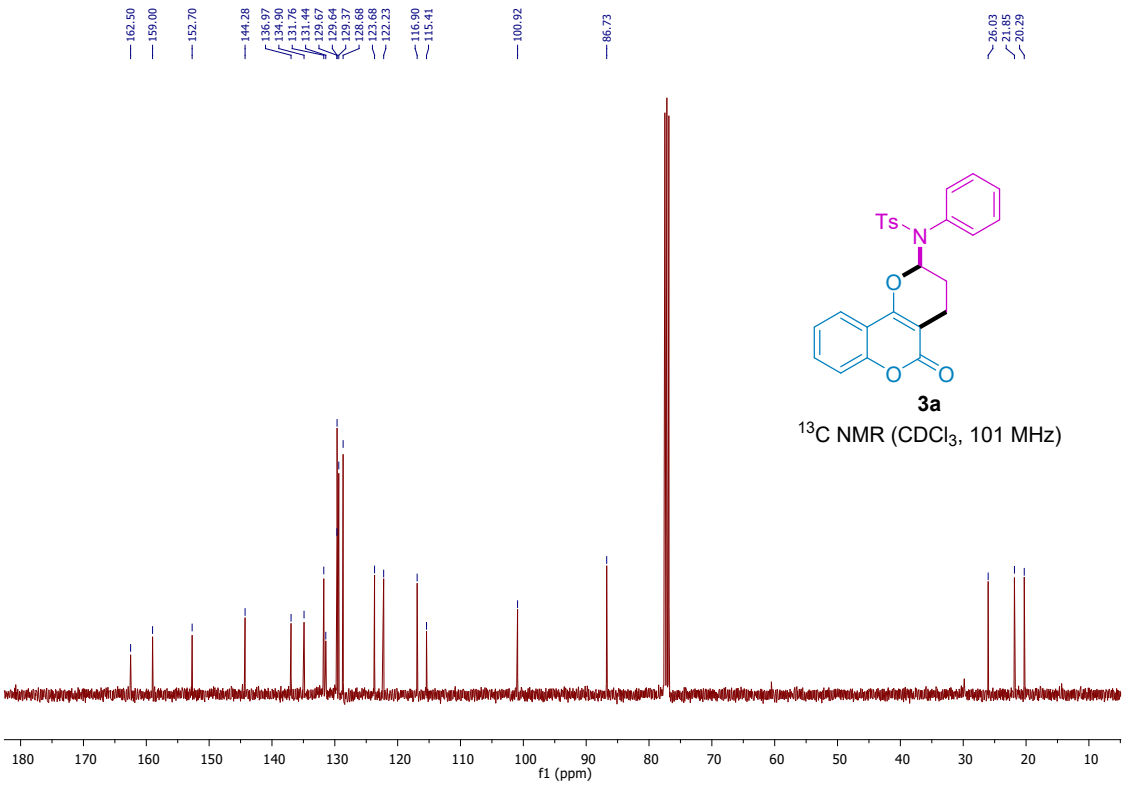




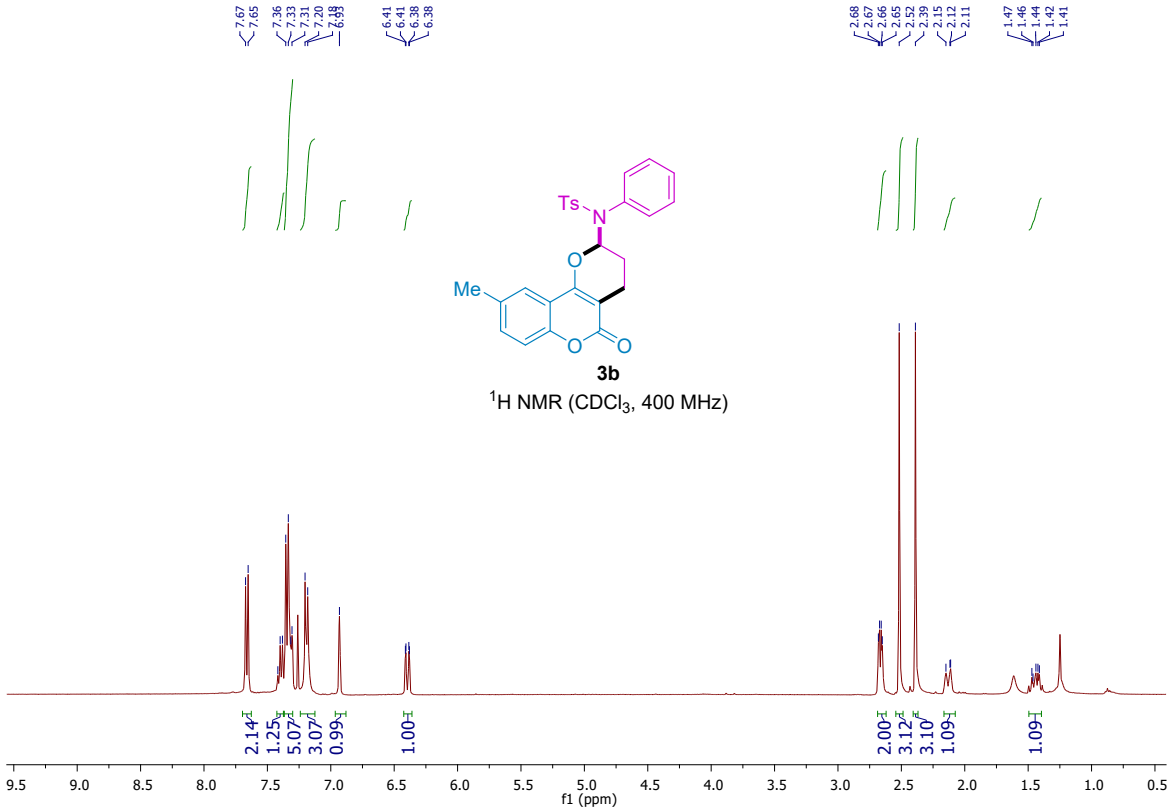
10. NMR spectra of di-functionalized product

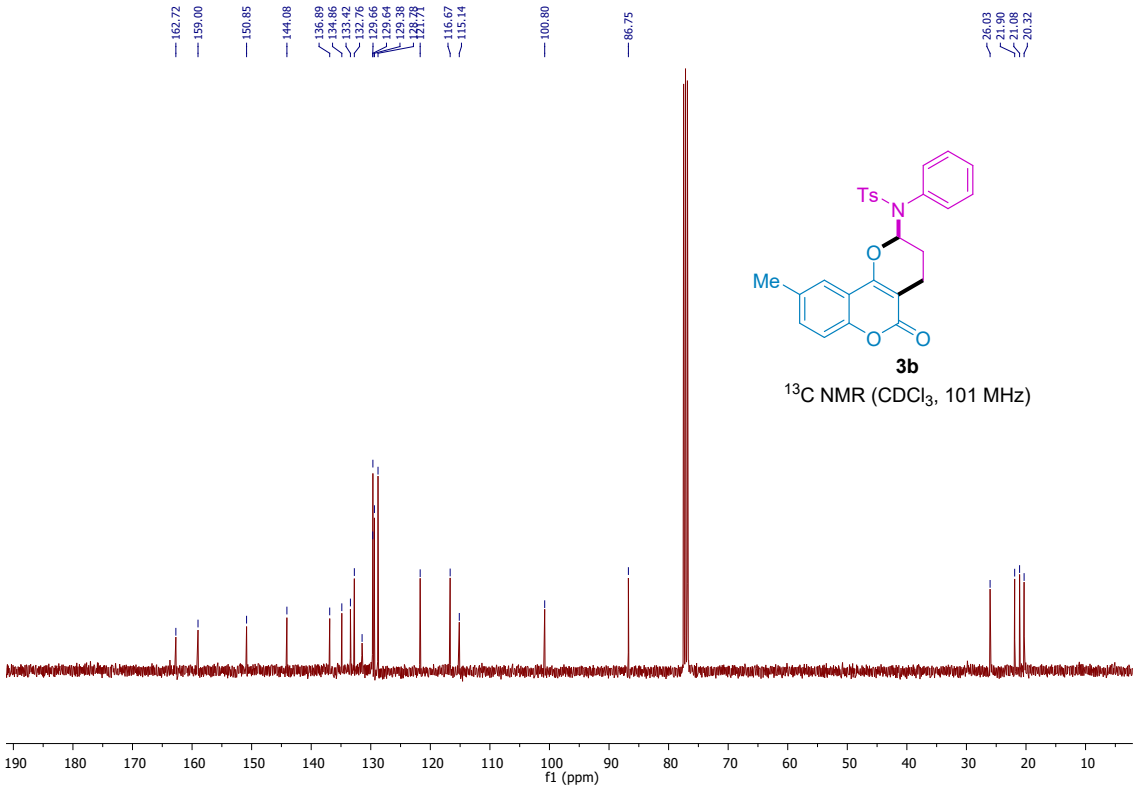
(R)-4-methyl-N-(5-oxo-3,4-dihydro-2H,5H-pyrano[3,2-c]chromen-2-yl)-N-phenylbenzenesulfonamide (**3a**):



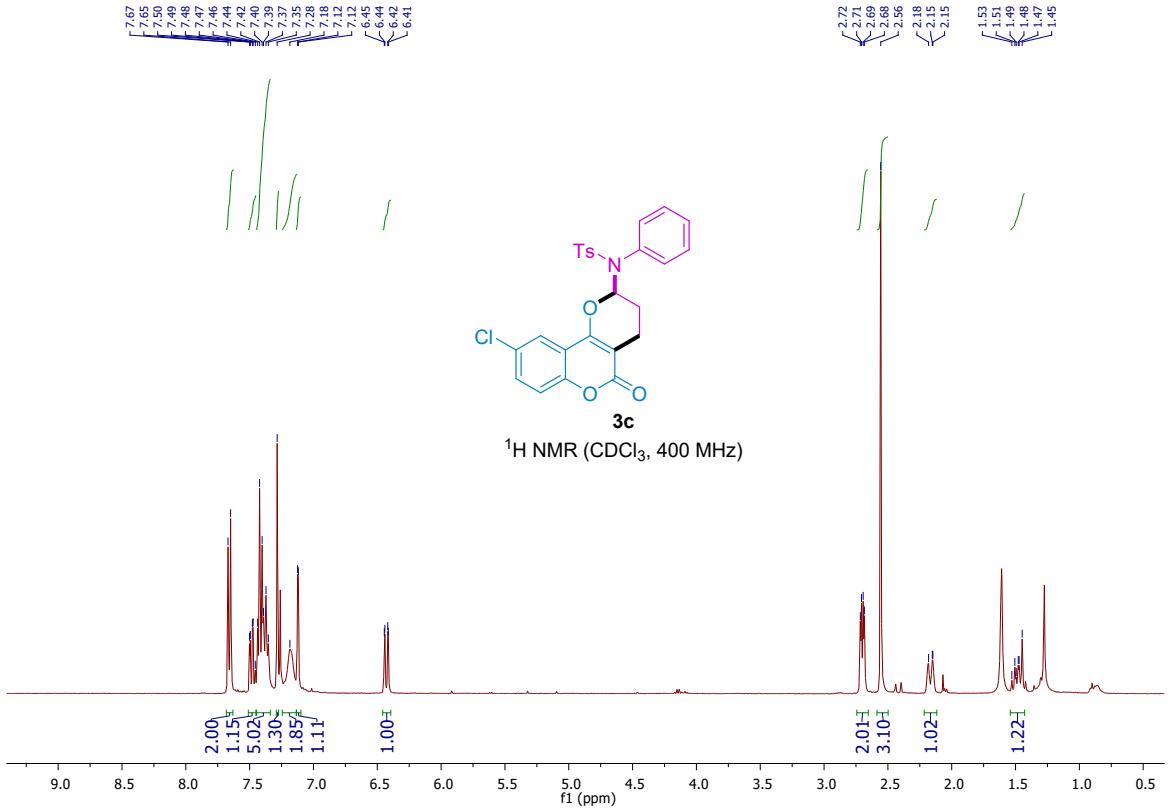


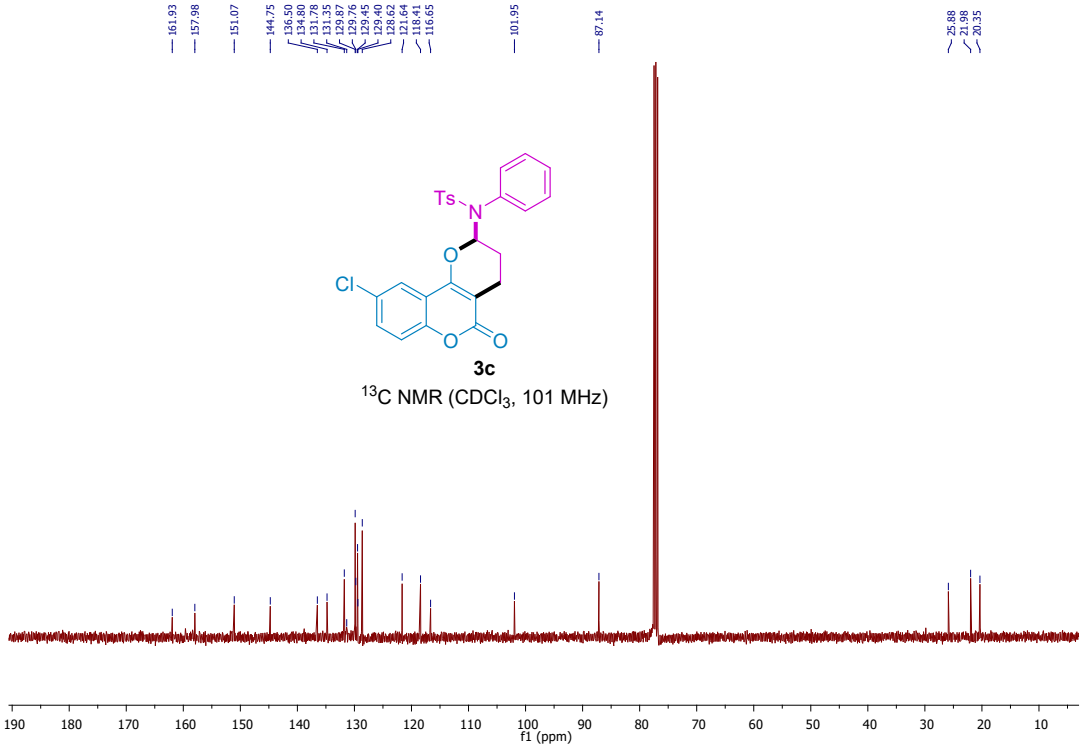
(R)-4-methyl-N-(9-methyl-5-oxo-3,4-dihydro-2H,5H-pyrano[3,2-c]chromen-2-yl)-N-phenylbenzenesulfonamide (**3b**):



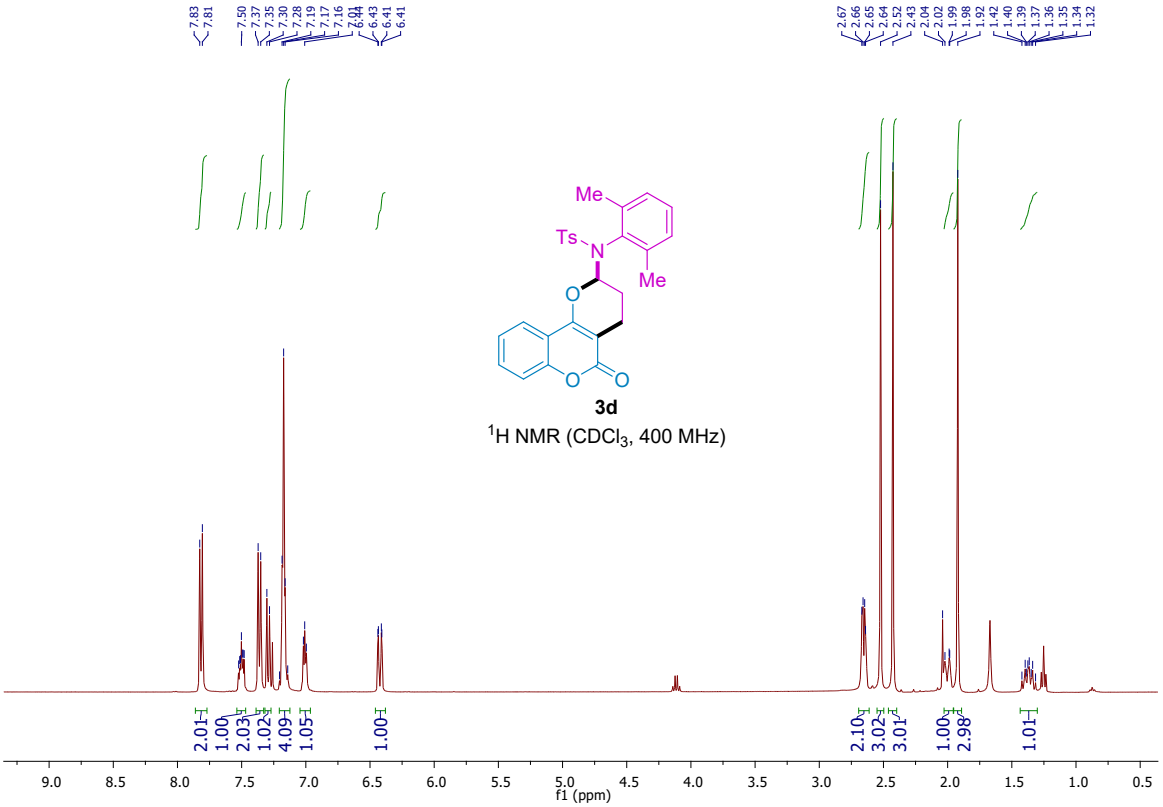


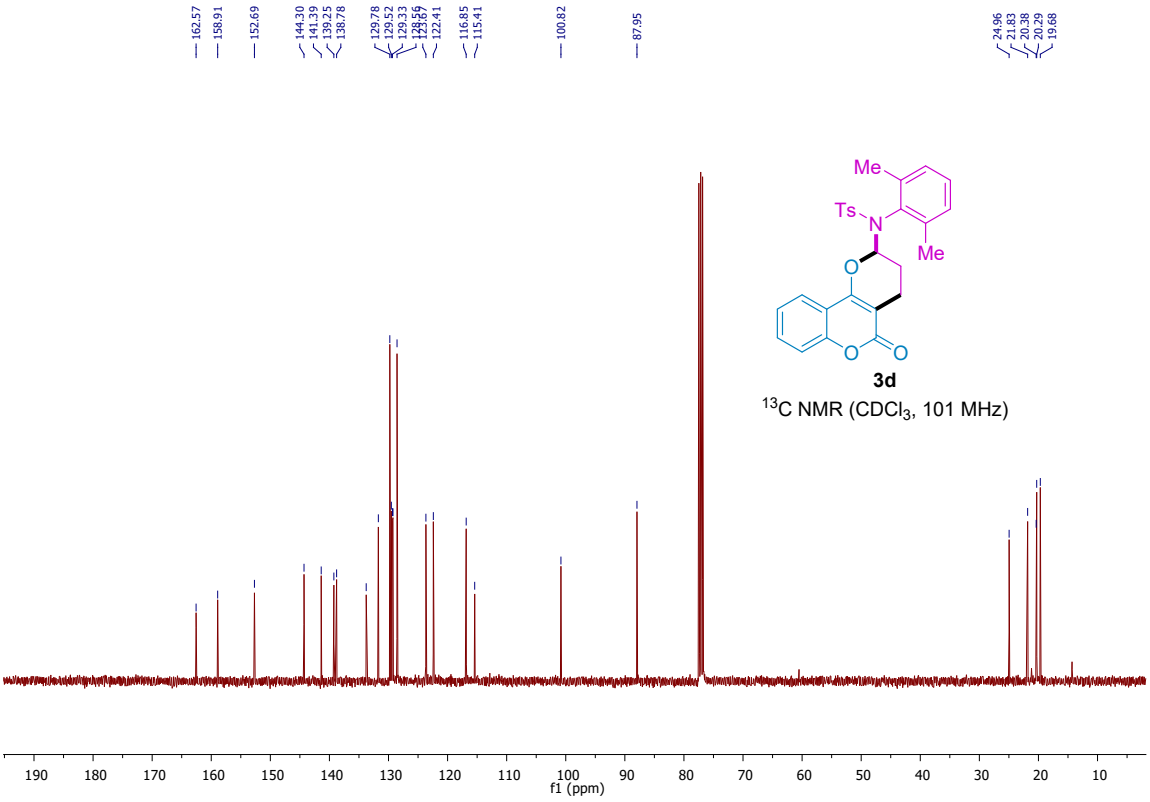
(R)-N-(9-chloro-5-oxo-3,4-dihydro-2H,5H-pyrano[3,2-c]chromen-2-yl)-4-methyl-N-phenylbenzenesulfonamide (**3c**):



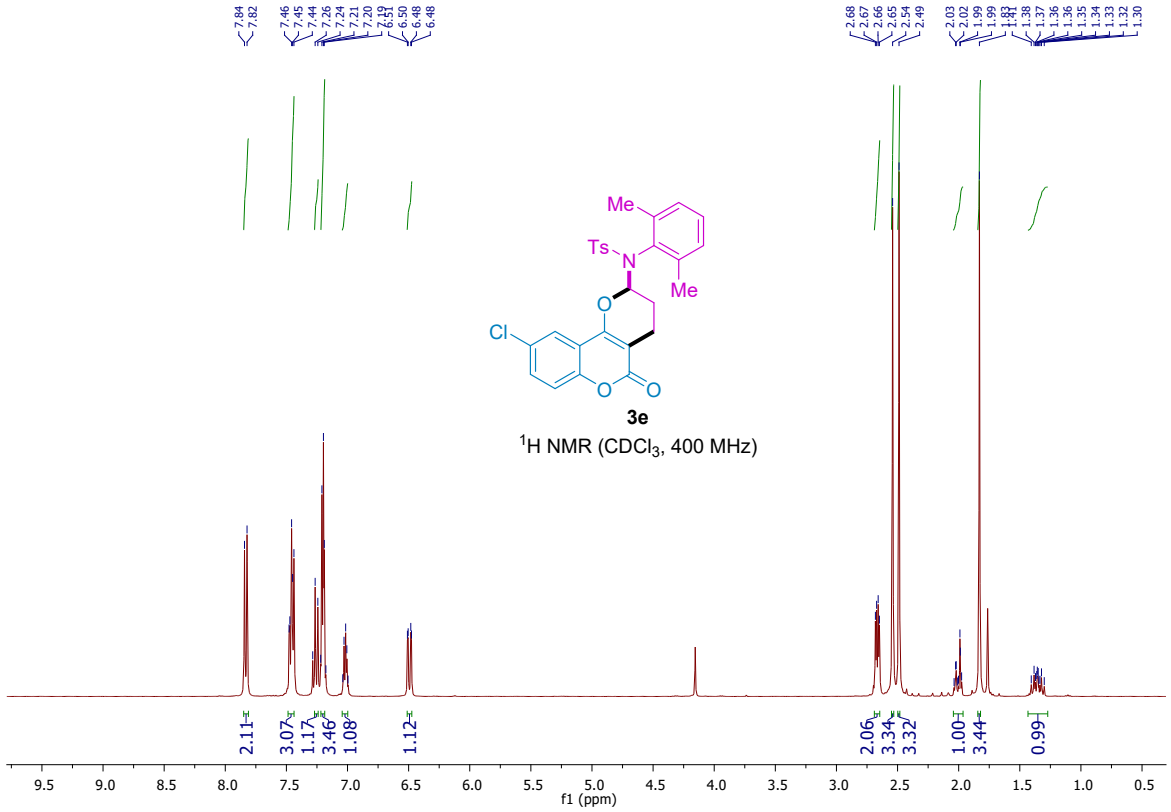


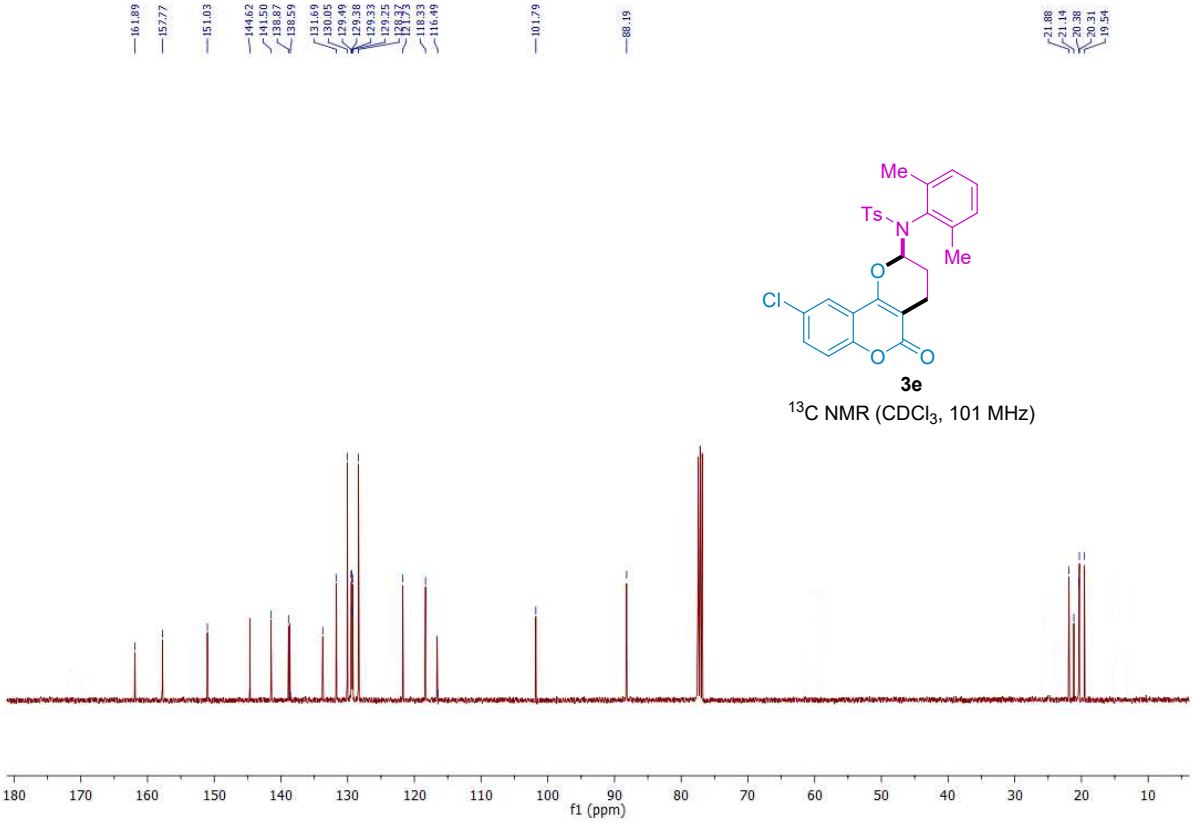
(R)-N-(2,6-dimethylphenyl)-4-methyl-N-(5-oxo-3,4-dihydro-2H,5H-pyrano[3,2-c]chromen-2-yl)benzenesulfonamide (**3d**):



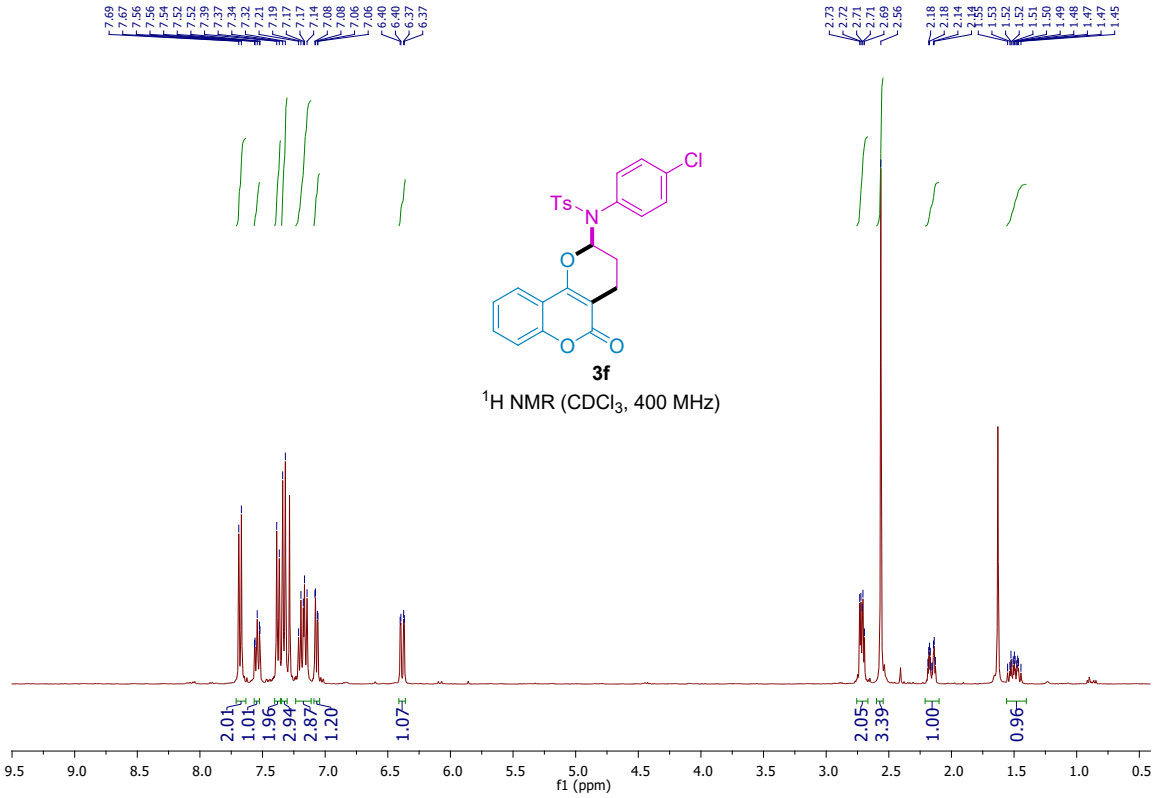


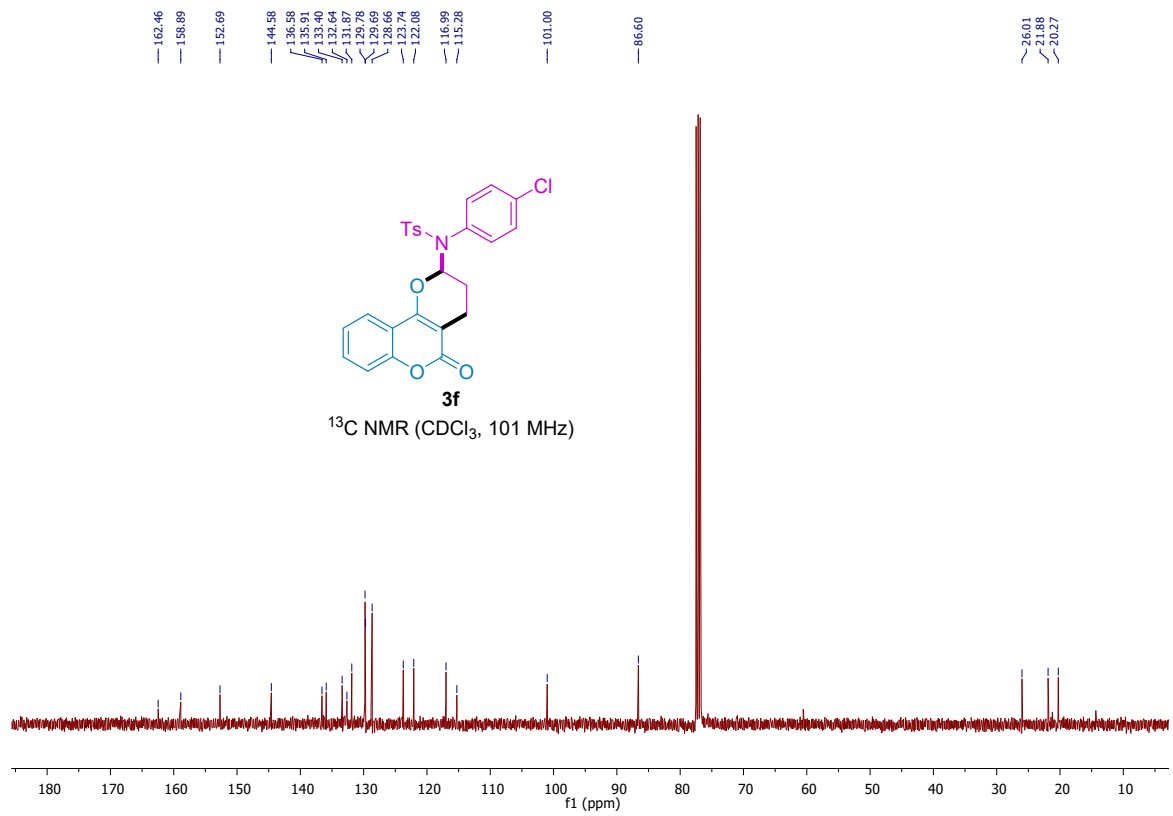
(R)-N-(9-chloro-5-oxo-3,4-dihydro-2H,5H-pyrano[3,2-c]chromen-2-yl)-N-(2,6-dimethylphenyl)-4-methylbenzenesulfonamide (**3e**):



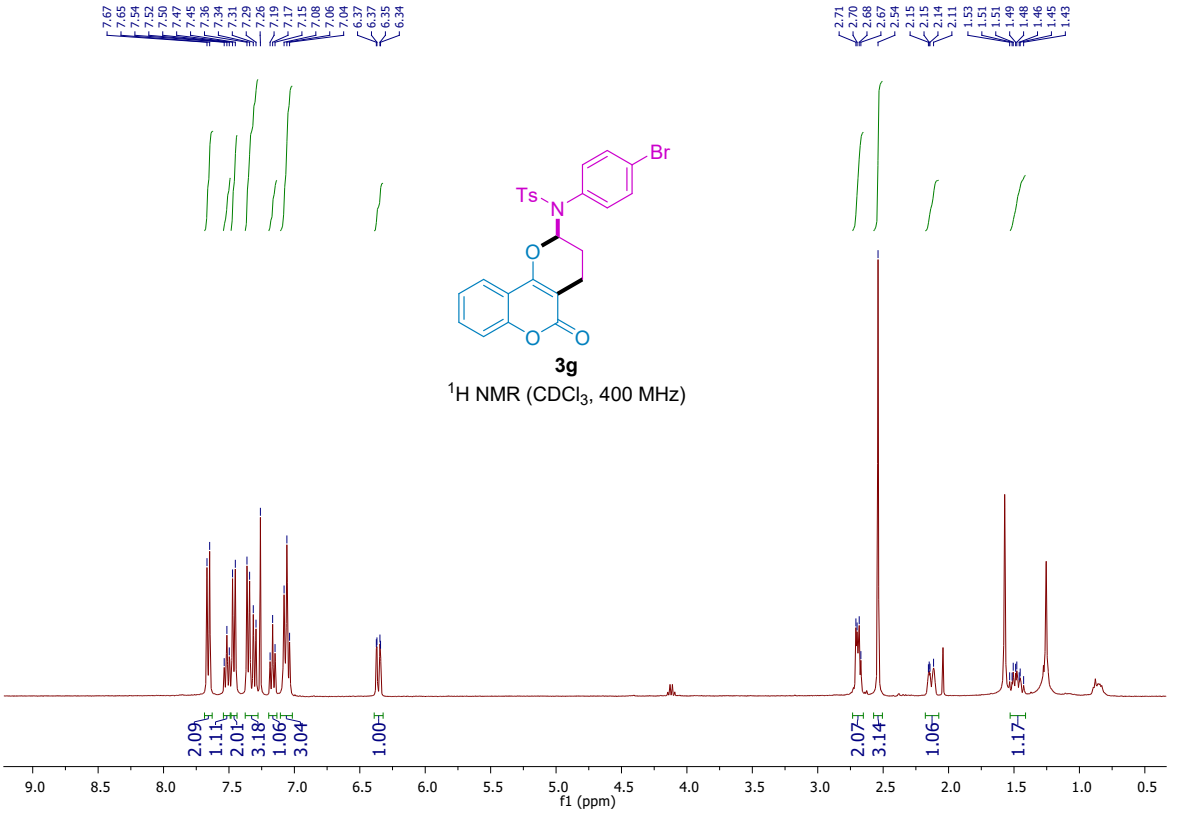


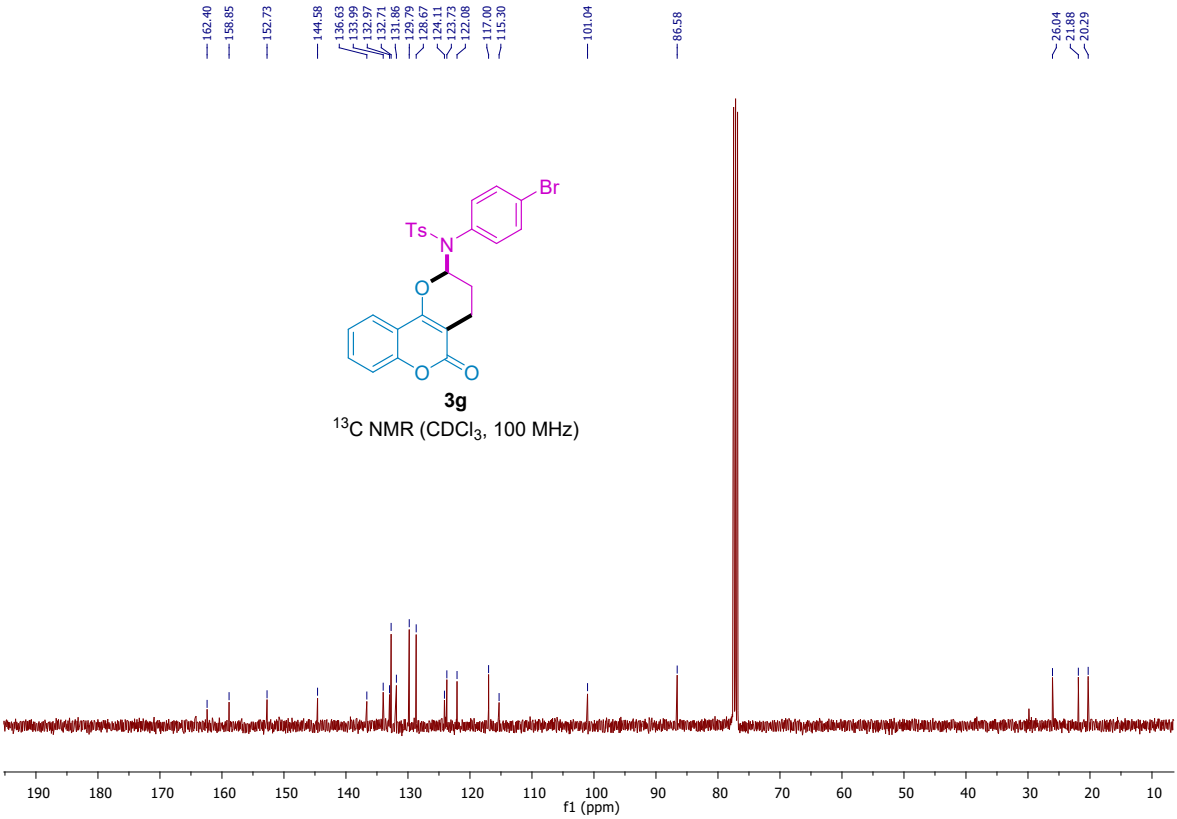
(R)-N-(4-chlorophenyl)-4-methyl-N-(5-oxo-3,4-dihydro-2H,5H-pyrano[3,2-c]chromen-2-yl)benzenesulfonamide (**3f**):



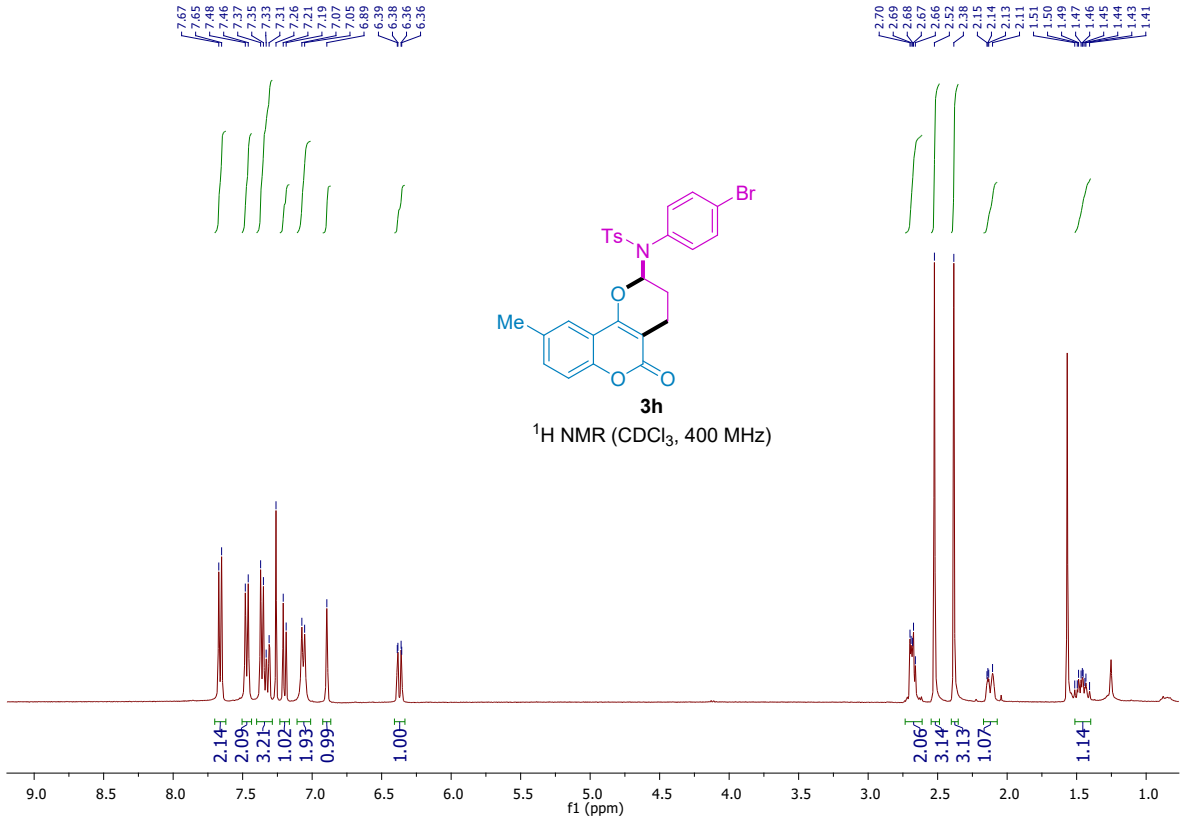


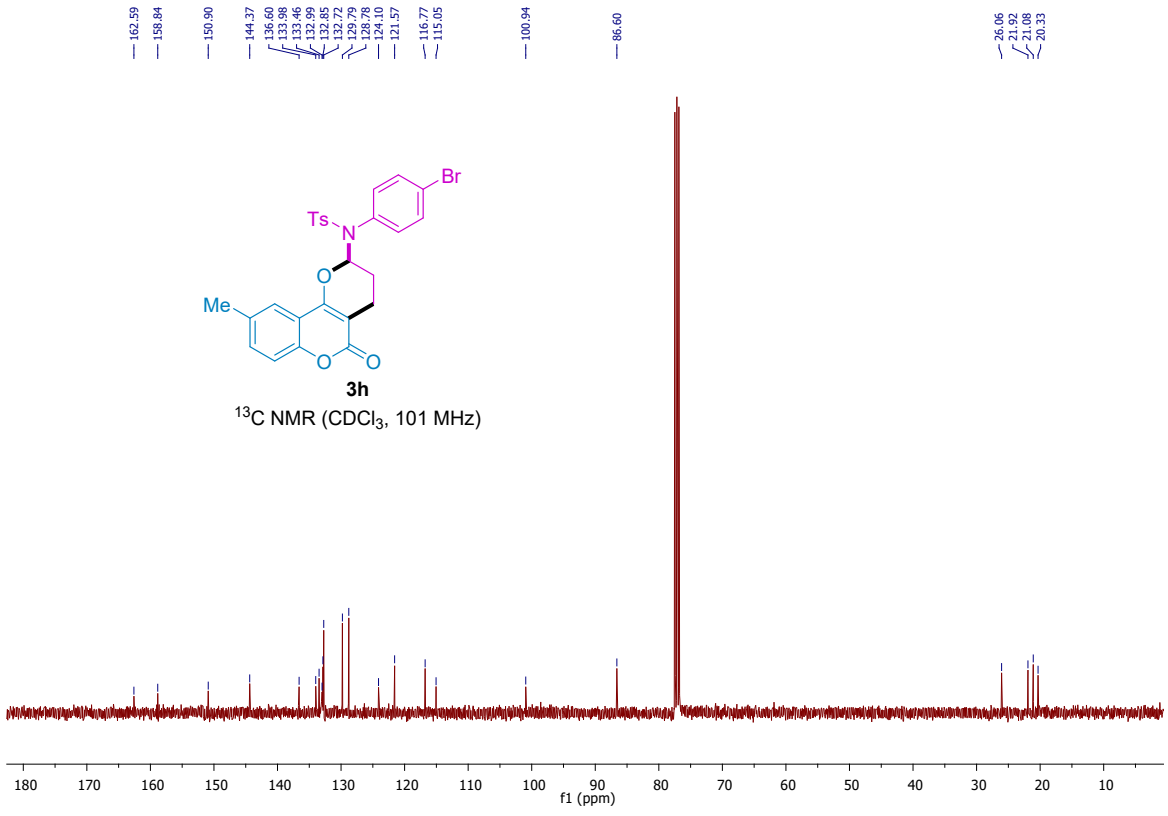
(R)-N-(4-bromophenyl)-4-methyl-N-(5-oxo-3,4-dihydro-2H,5H-pyrano[3,2-c]chromen-2-yl)benzenesulfonamide (**3g**):



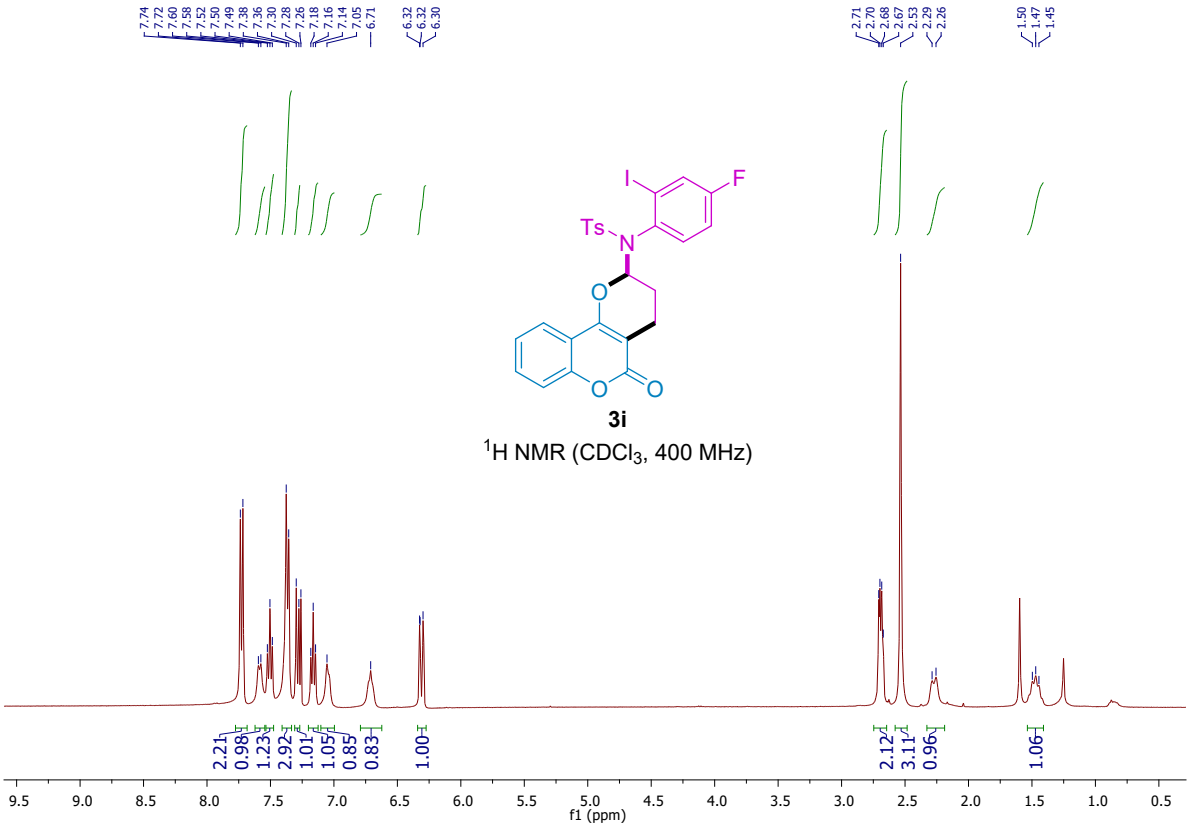


(R)-N-(4-bromophenyl)-4-methyl-N-(9-methyl-5-oxo-3,4-dihydro-2H,5H-pyrano[3,2-c]chromen-2-yl)benzenesulfonamide (**3h**):



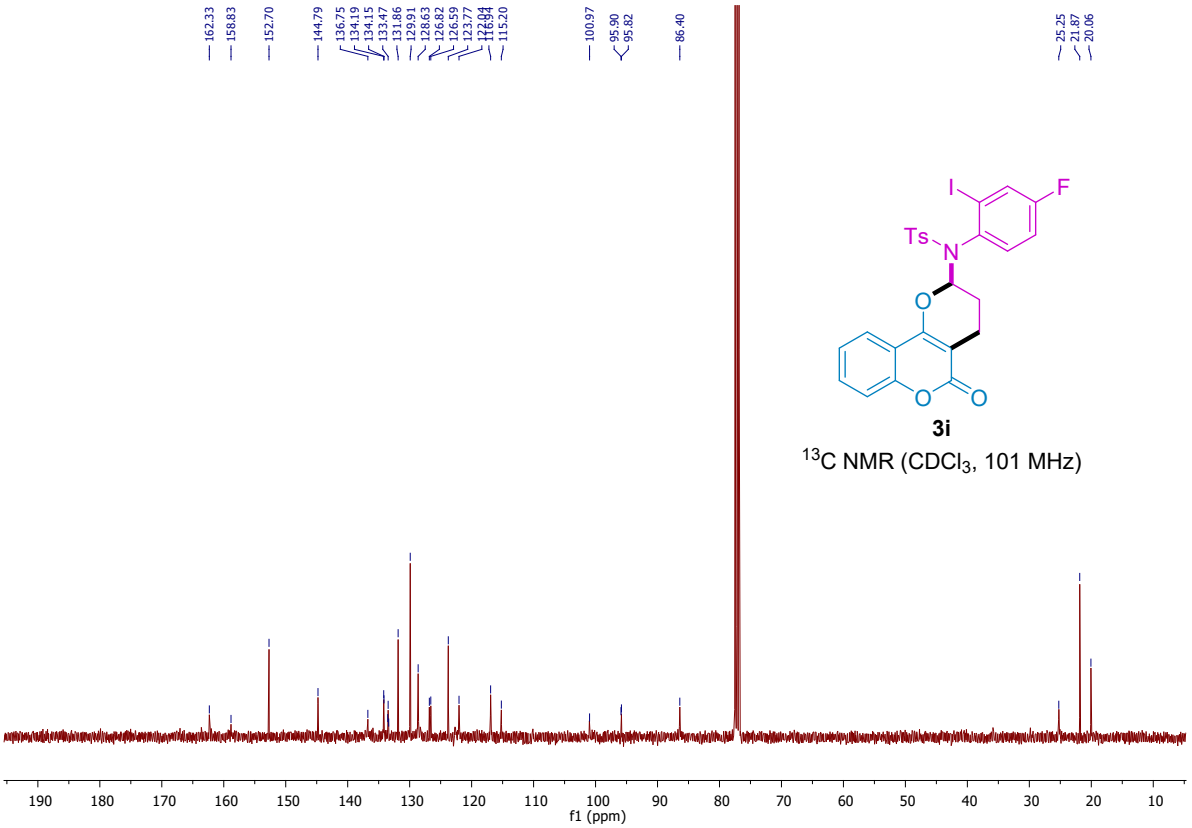


(R)-N-(4-fluoro-2-iodophenyl)-4-methyl-N-(5-oxo-3,4-dihydro-2H,5H-pyrano[3,2-c]chromen-2-yl)benzenesulfonamide (**3i**):



3i

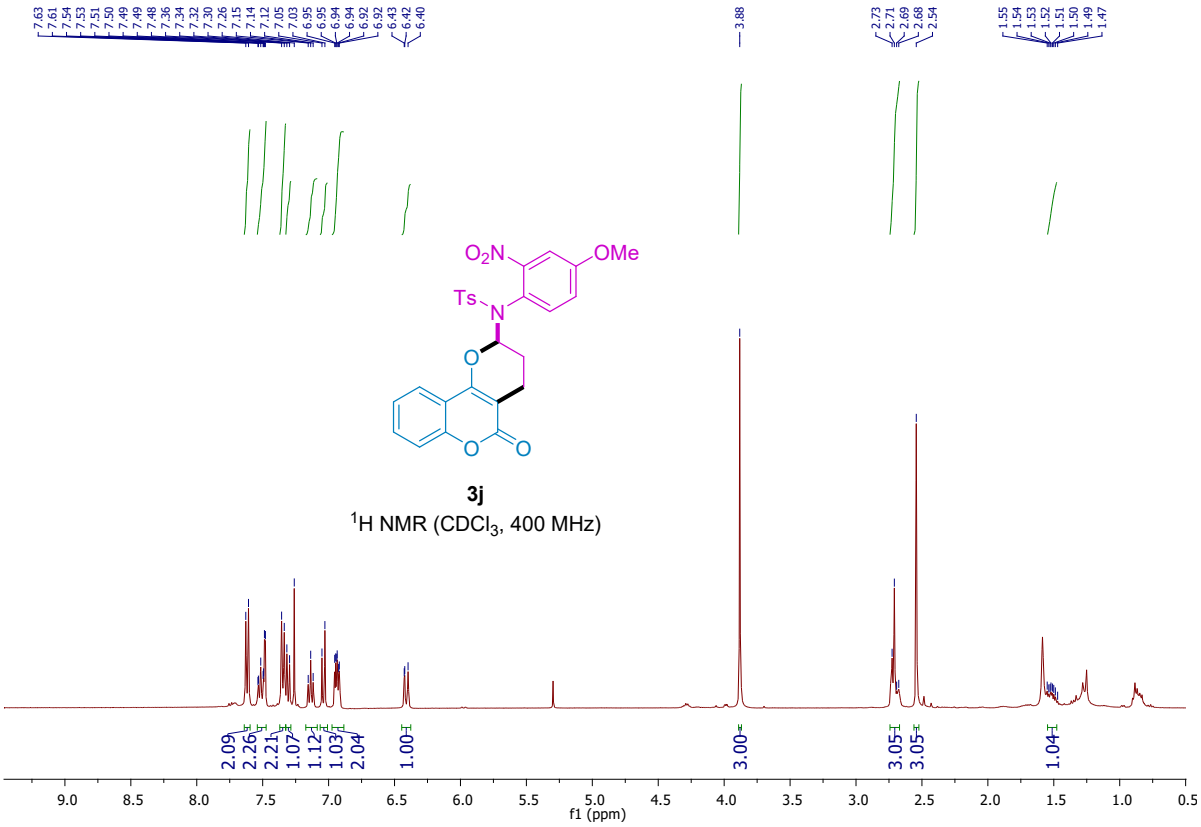
^{1}H NMR ($CDCl_3$, 400 MHz)



3i

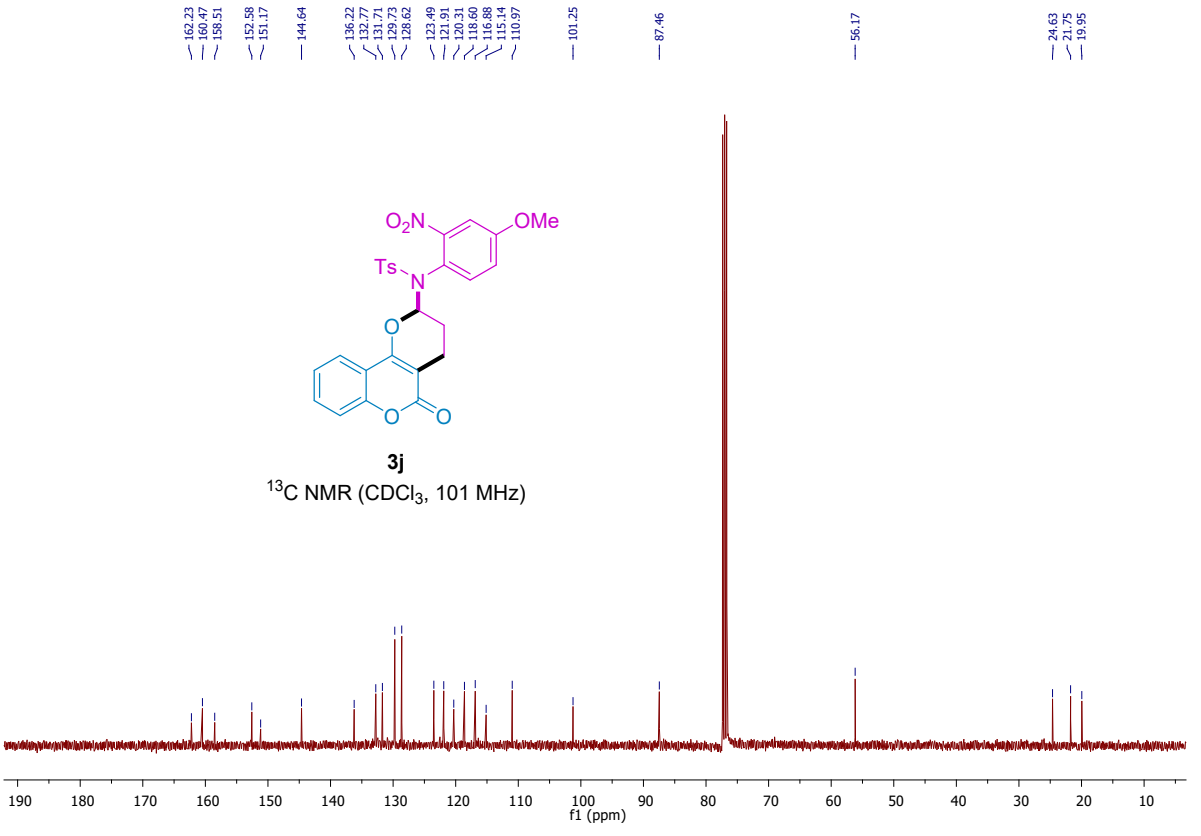
^{13}C NMR ($CDCl_3$, 101 MHz)

(R)-N-(4-methoxy-2-nitrophenyl)-4-methyl-N-(5-oxo-3,4-dihydro-2H,5H-pyrano[3,2-c]chromen-2-yl)benzenesulfonamide (**3j**):



3j

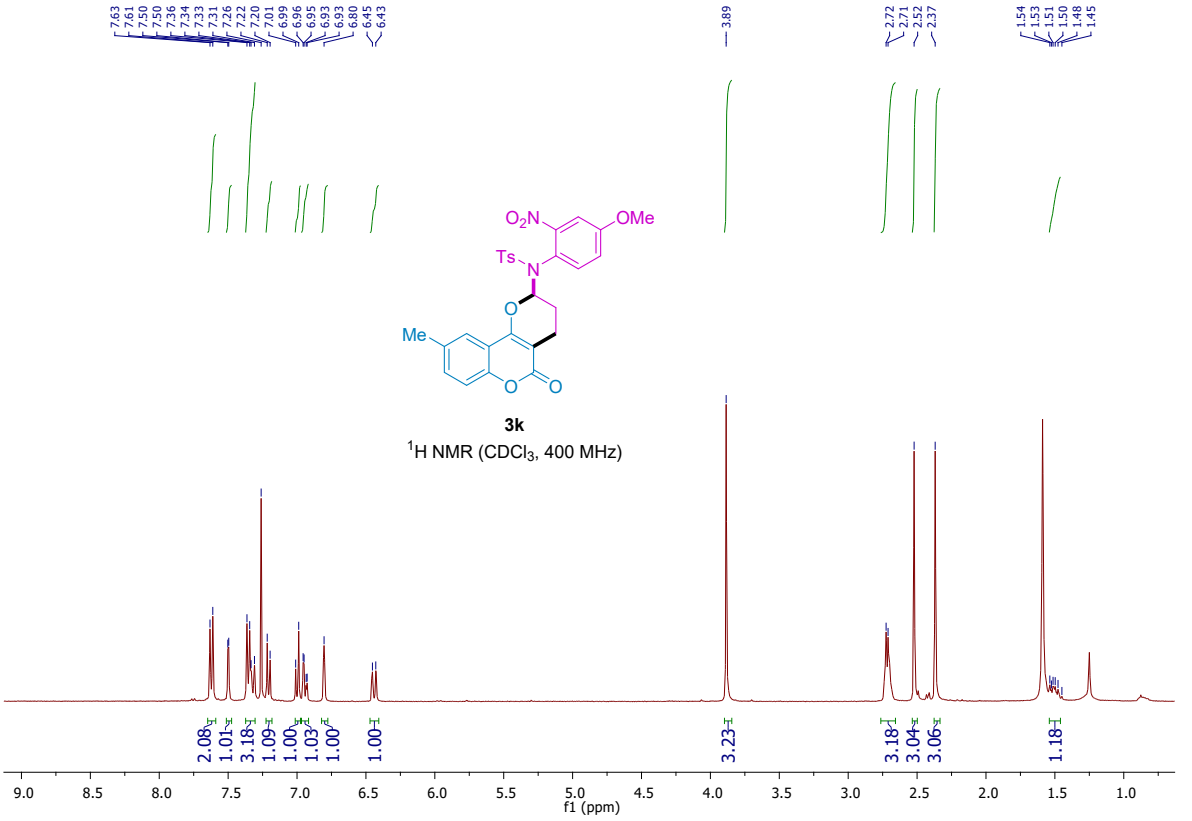
^{1}H NMR ($CDCl_3$, 400 MHz)

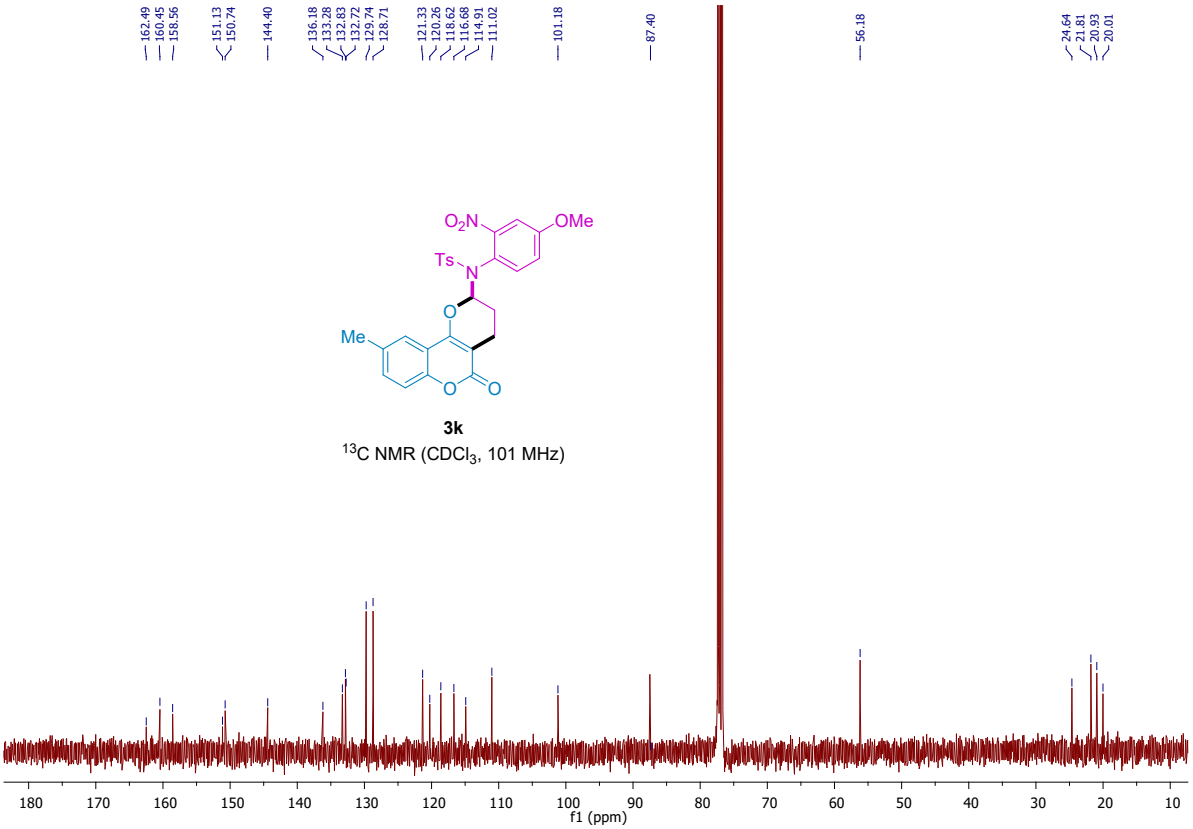


3j

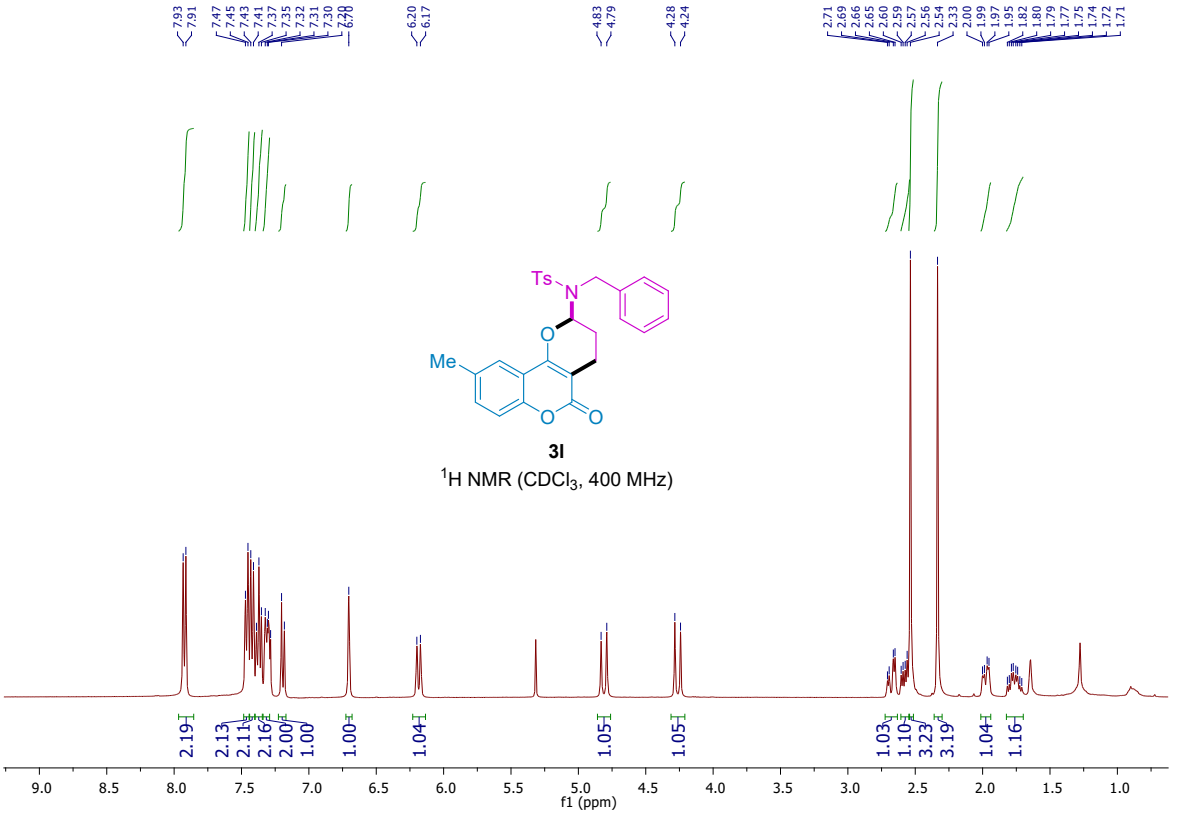
^{13}C NMR ($CDCl_3$, 101 MHz)

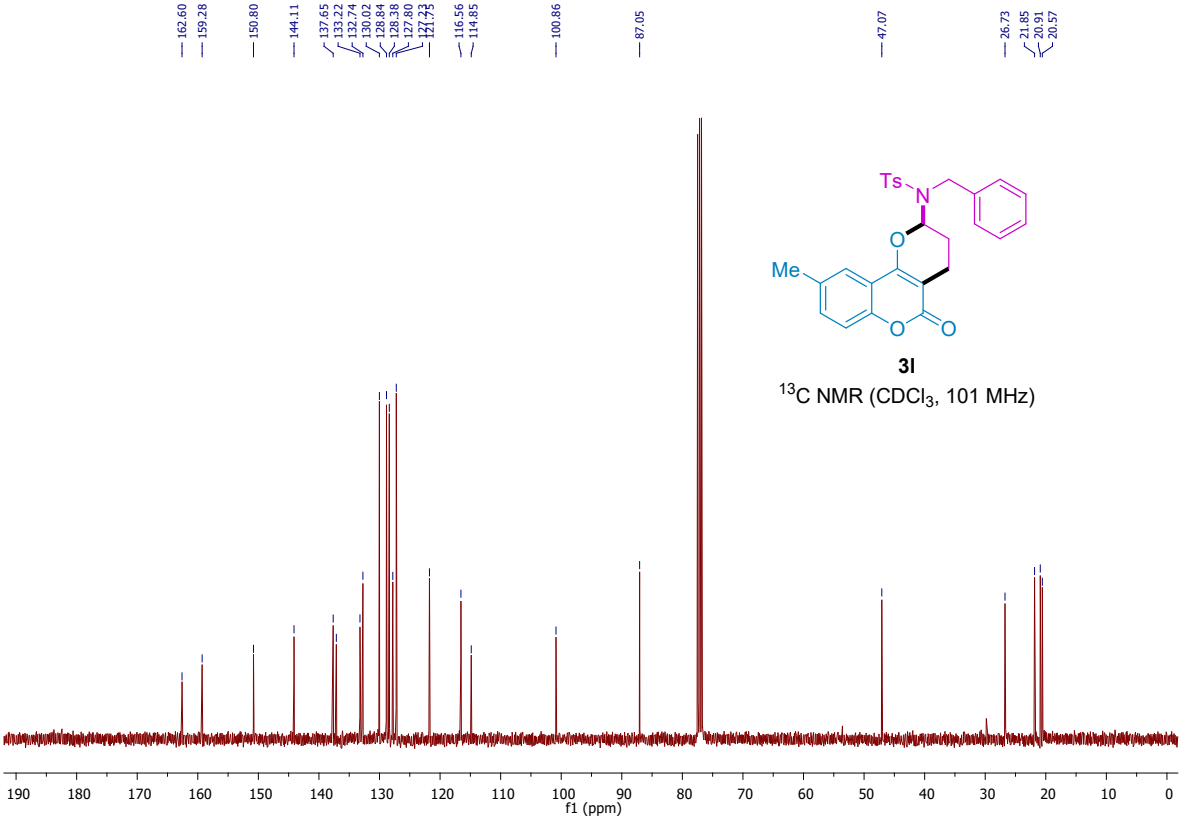
(R)-N-(4-methoxy-2-nitrophenyl)-4-methyl-N-(9-methyl-5-oxo-3,4-dihydro-2H,5H-pyrano[3,2-c]chromen-2-yl)benzenesulfonamide (**3k**):



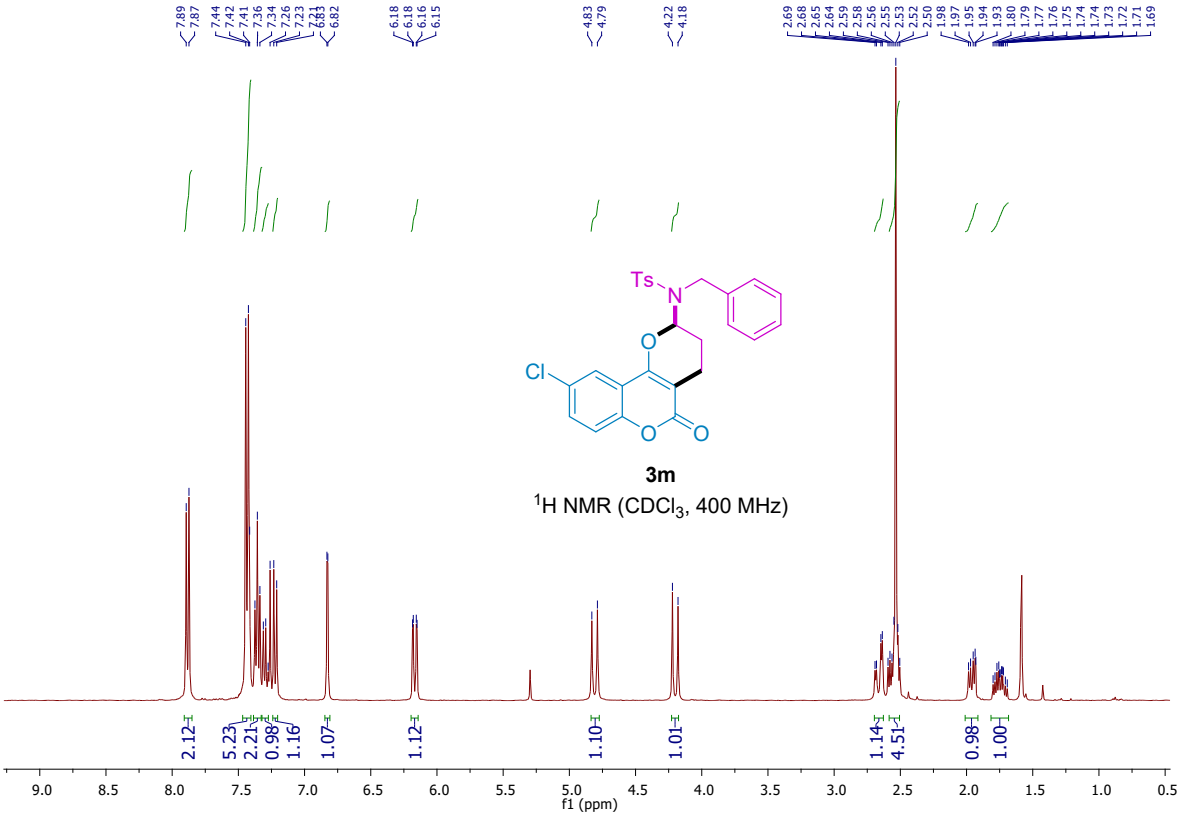


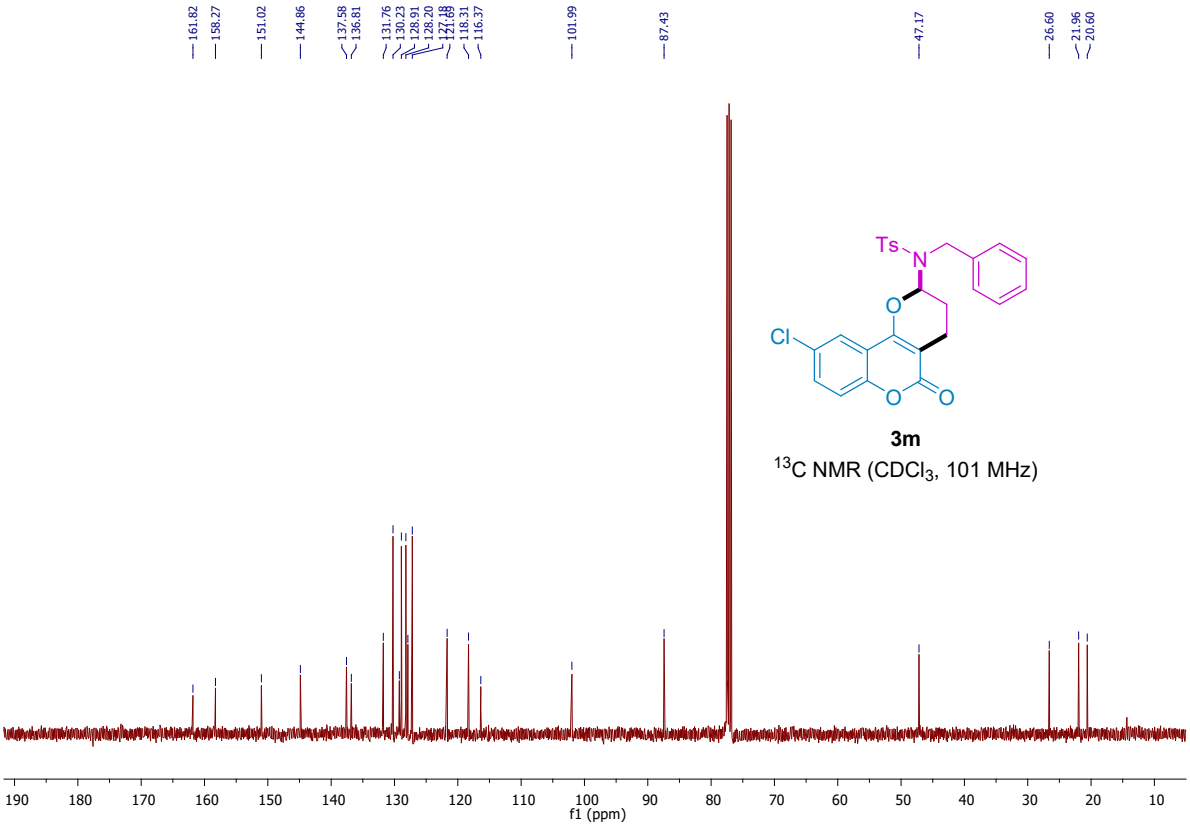
(R)-N-benzyl-4-methyl-N-(9-methyl-5-oxo-3,4-dihydro-2H,5H-pyrano[3,2-c]chromen-2-yl)benzenesulfonamide (**3l**):



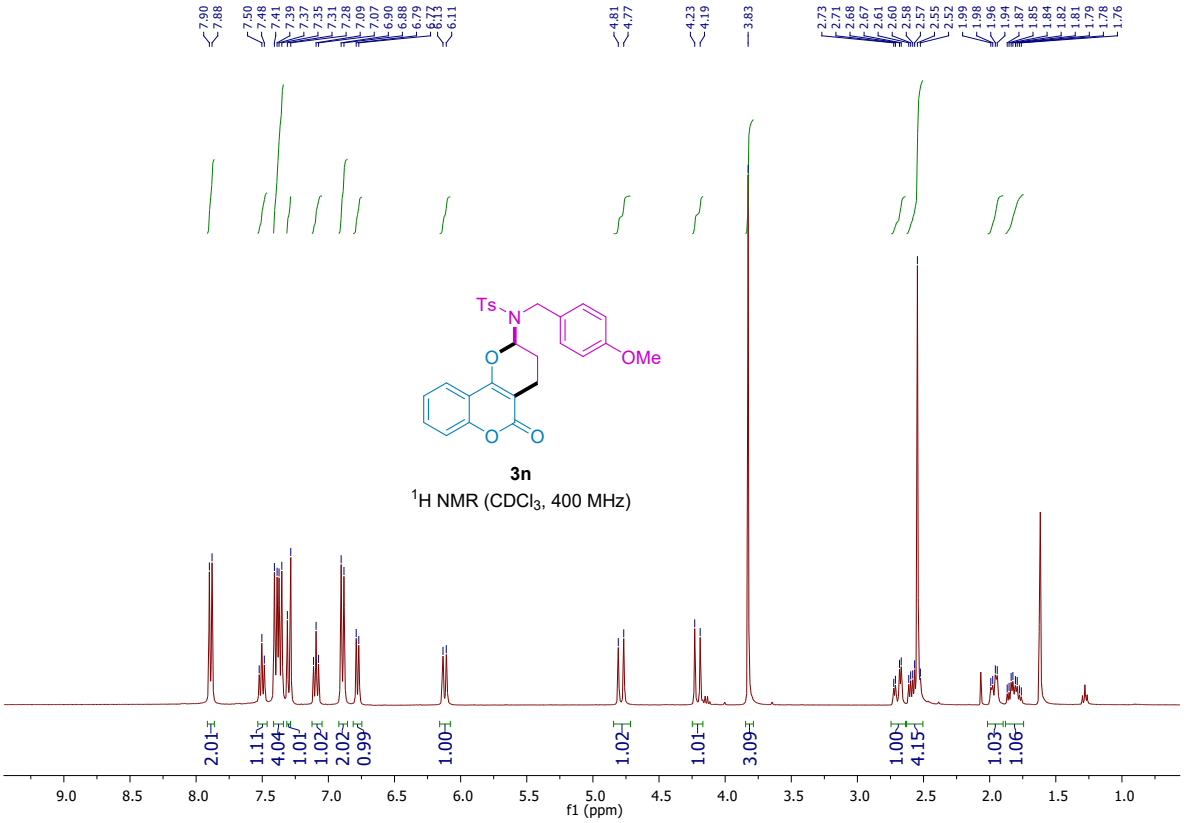


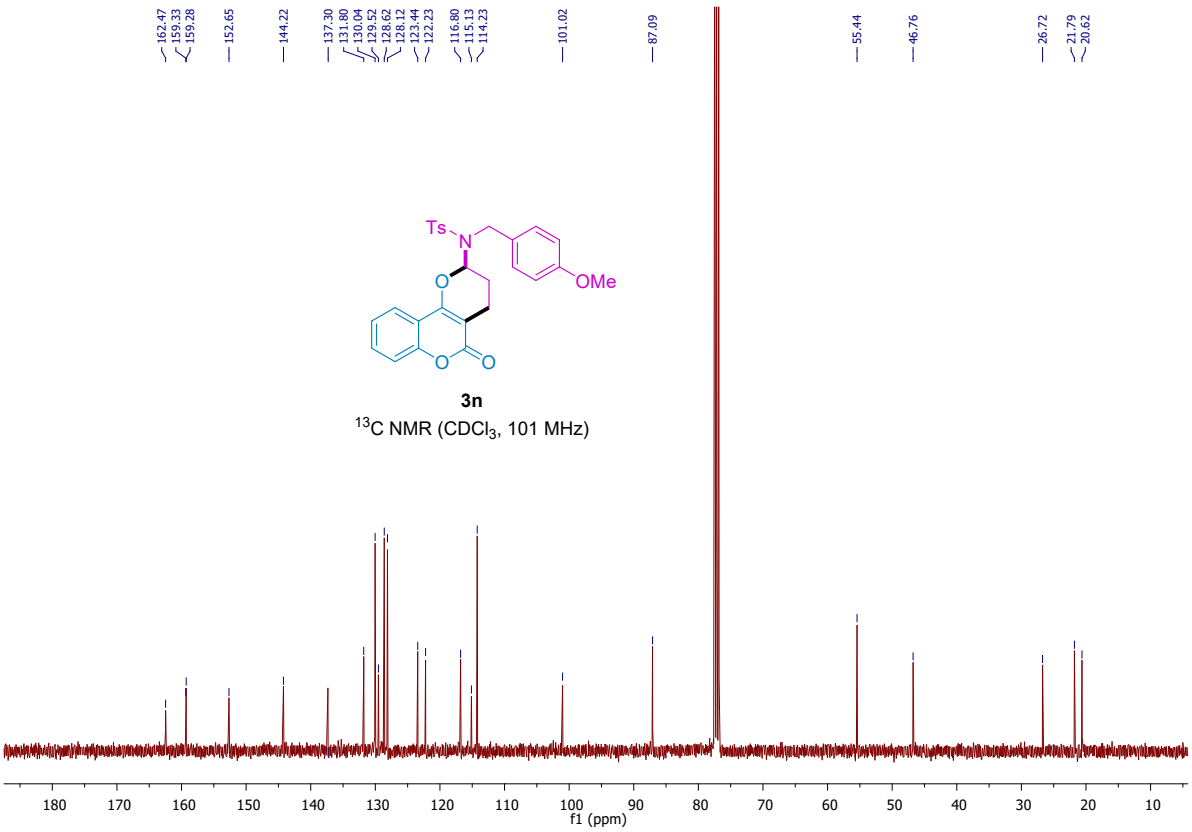
(R)-N-benzyl-N-(9-chloro-5-oxo-3,4-dihydro-2H,5H-pyrano[3,2-c]chromen-2-yl)-4-methylbenzenesulfonamide (**3m**):



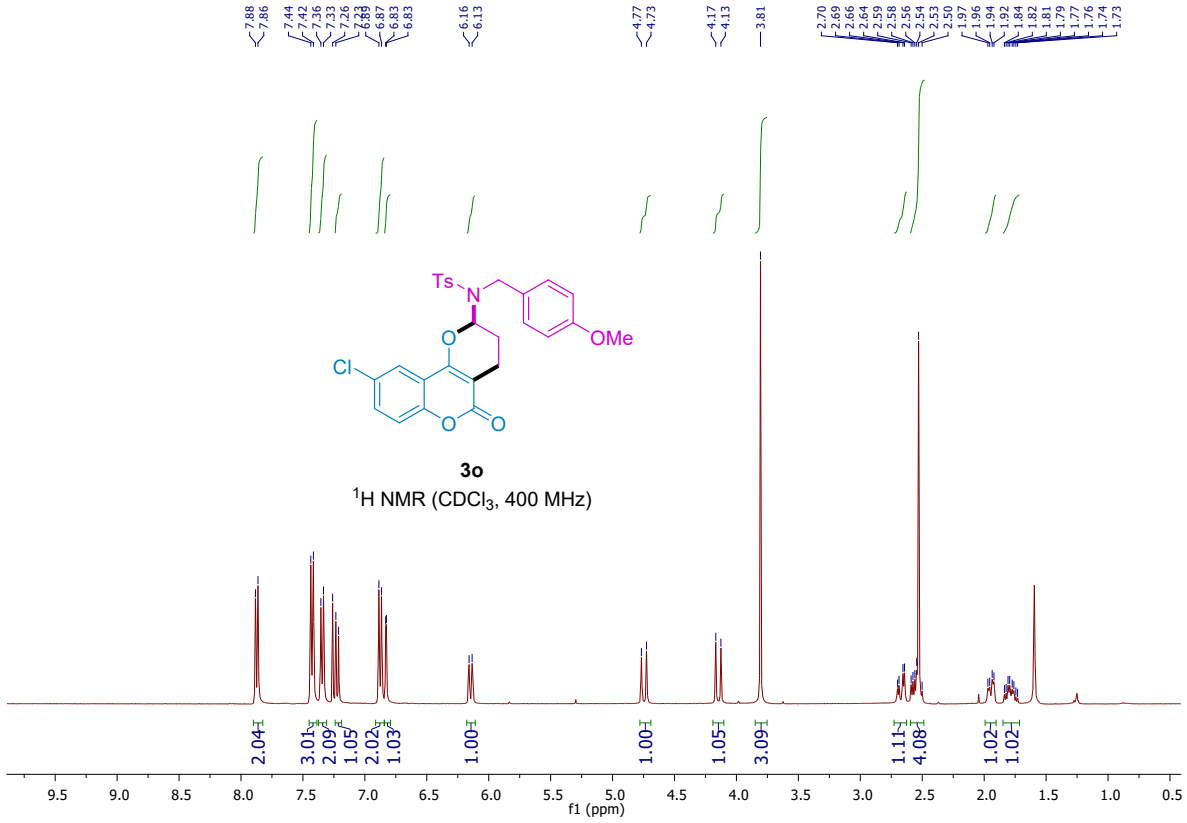


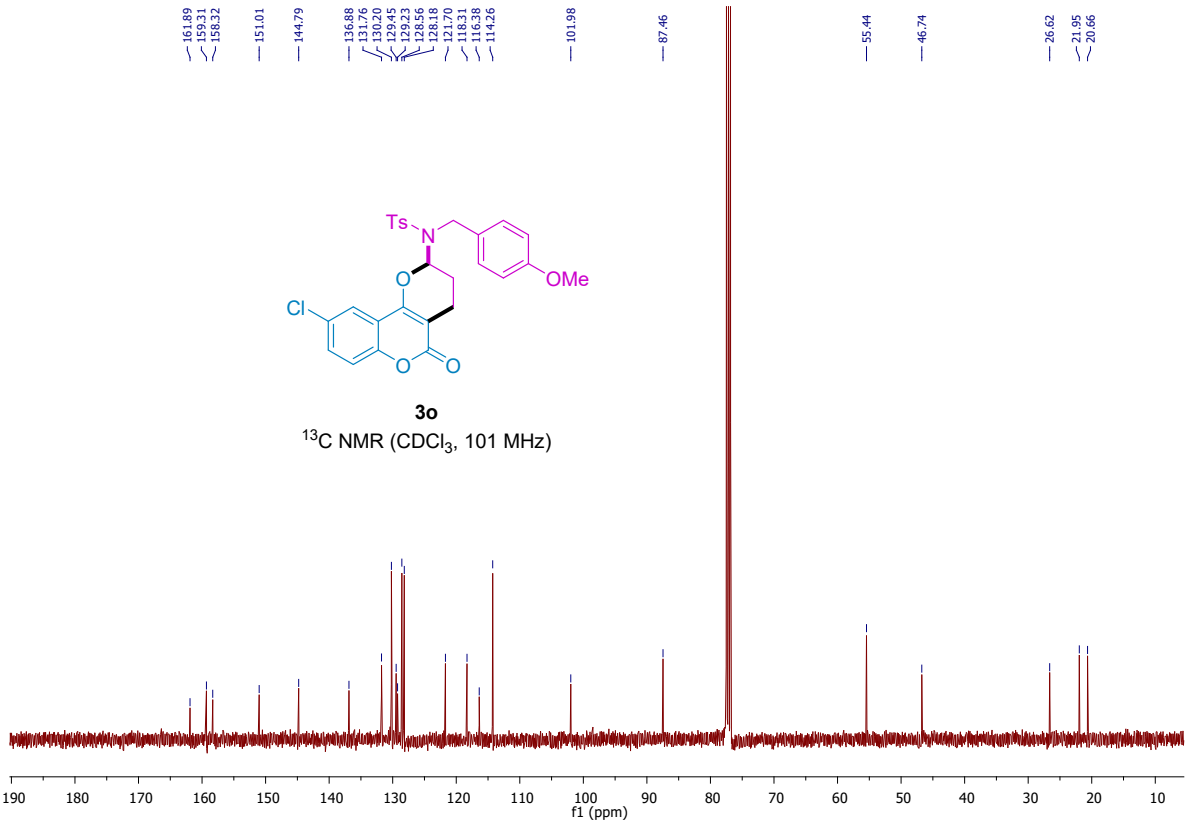
(R)-N-(3-methoxybenzyl)-4-methyl-N-(5-oxo-3,4-dihydro-2H,5H-pyrano[3,2-c]chromen-2-yl)benzenesulfonamide (**3n**):



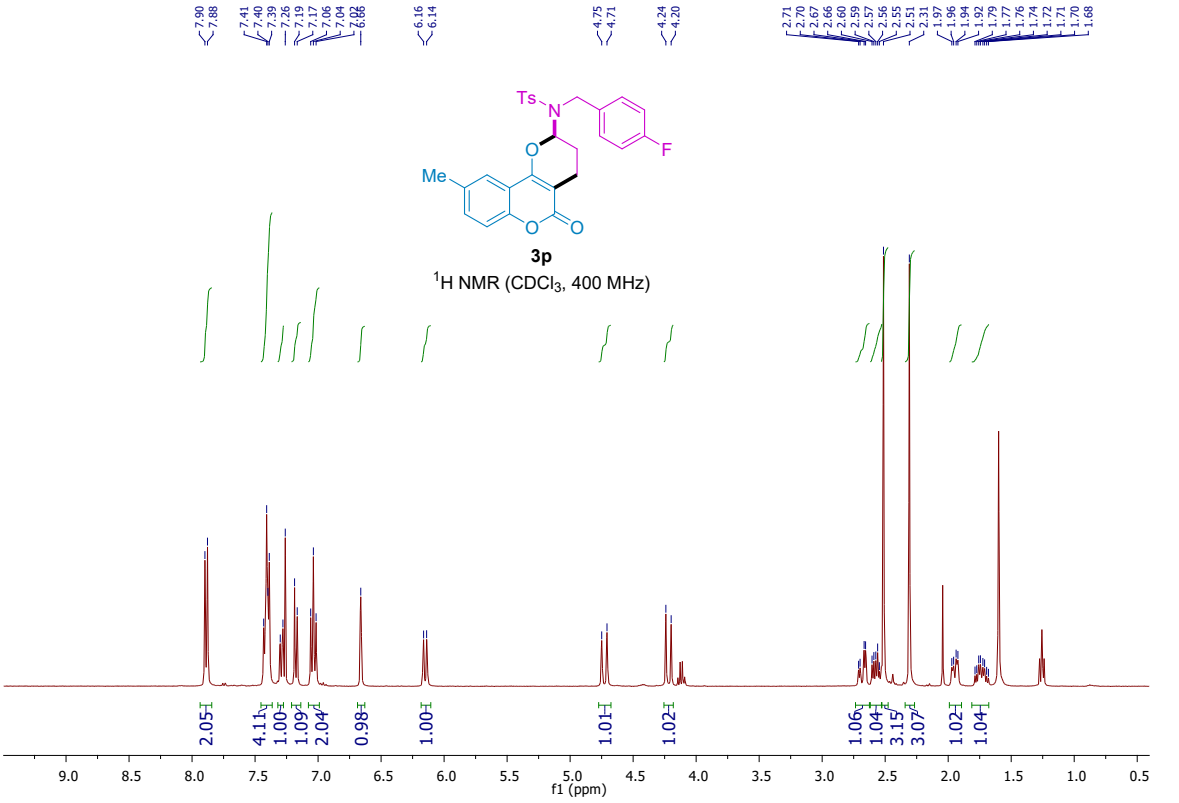


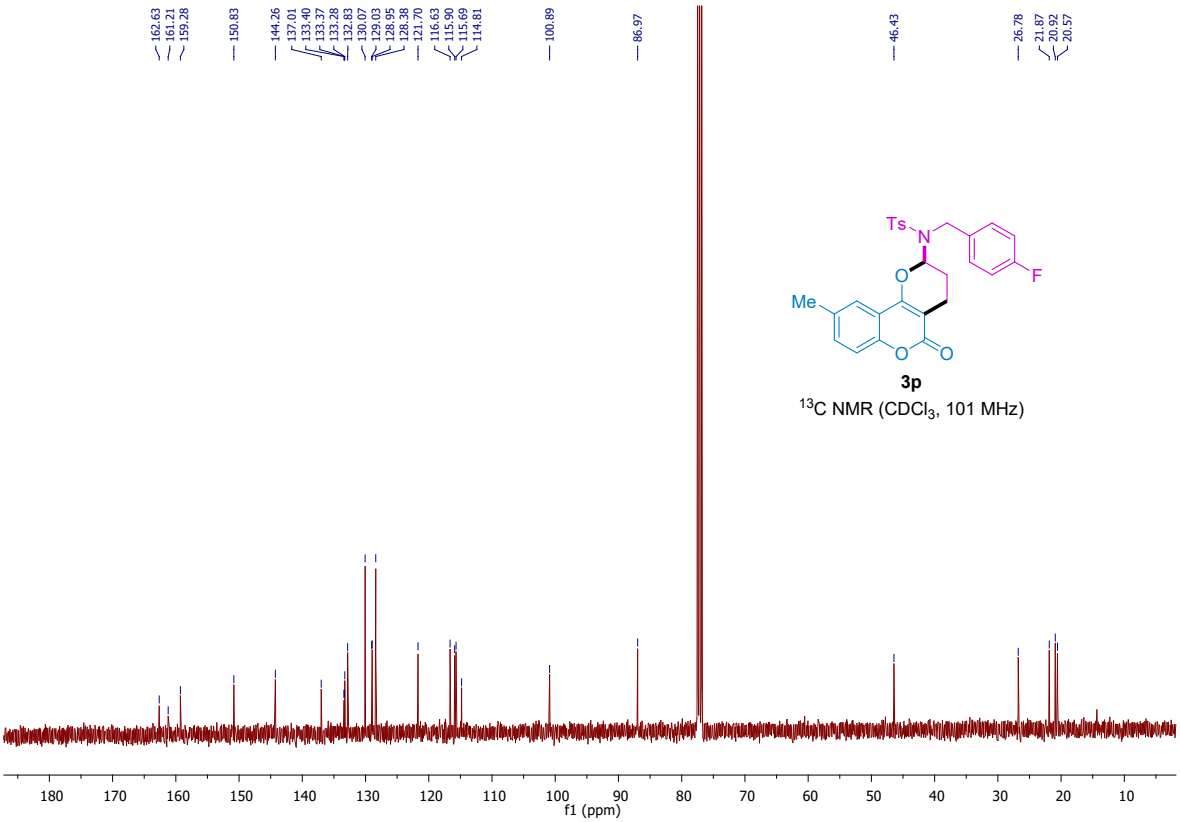
(R)-N-(9-chloro-5-oxo-3,4-dihydro-2H,5H-pyrano[3,2-c]chromen-2-yl)-N-(3-methoxybenzyl)-4-methylbenzenesulfonamide (**3o**):



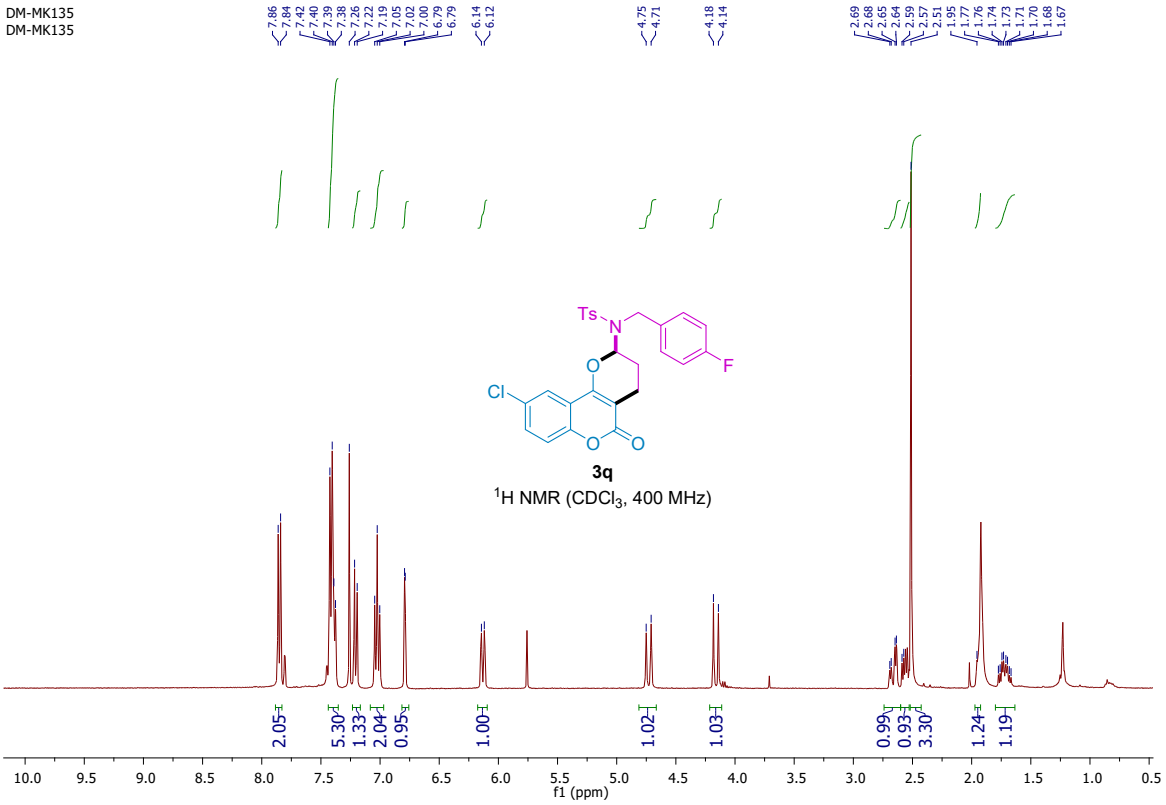


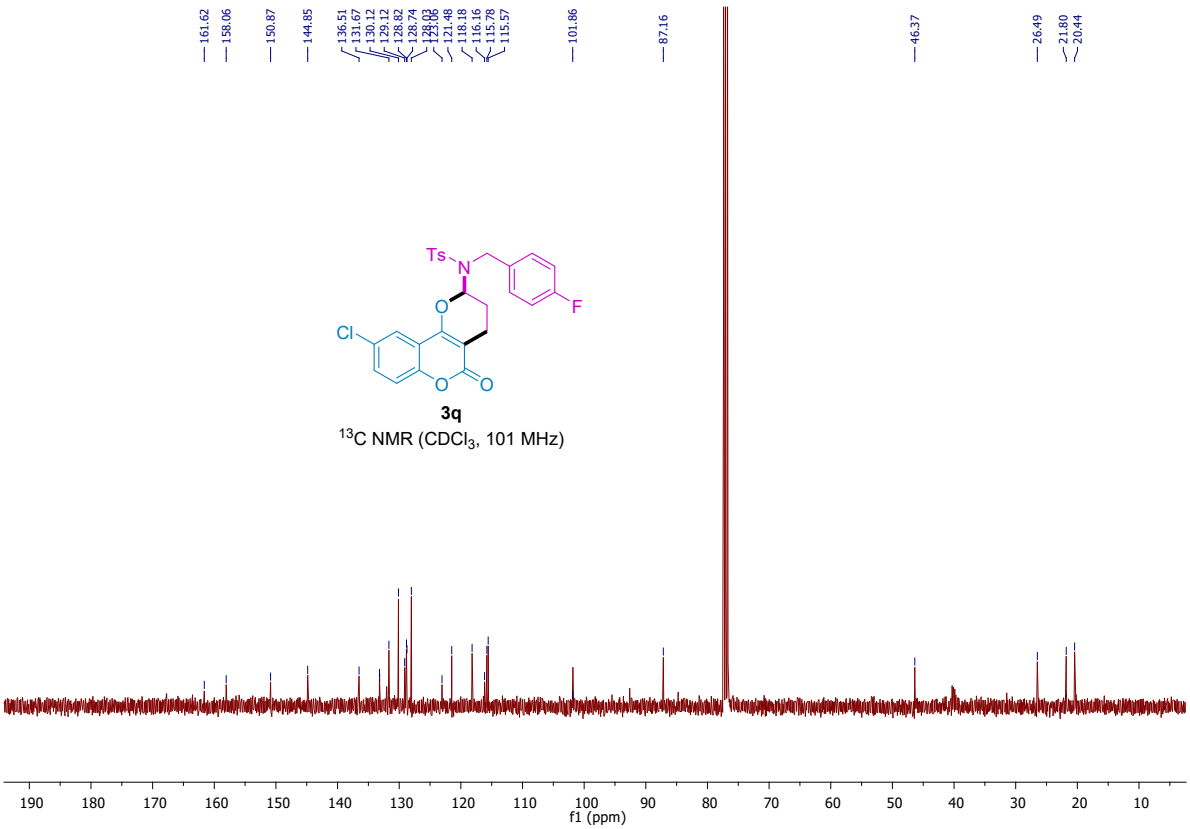
(R)-N-(4-fluorobenzyl)-4-methyl-N-(9-methyl-5-oxo-3,4-dihydro-2H,5H-pyrano[3,2-c]chromen-2-yl)benzenesulfonamide (**3p**):



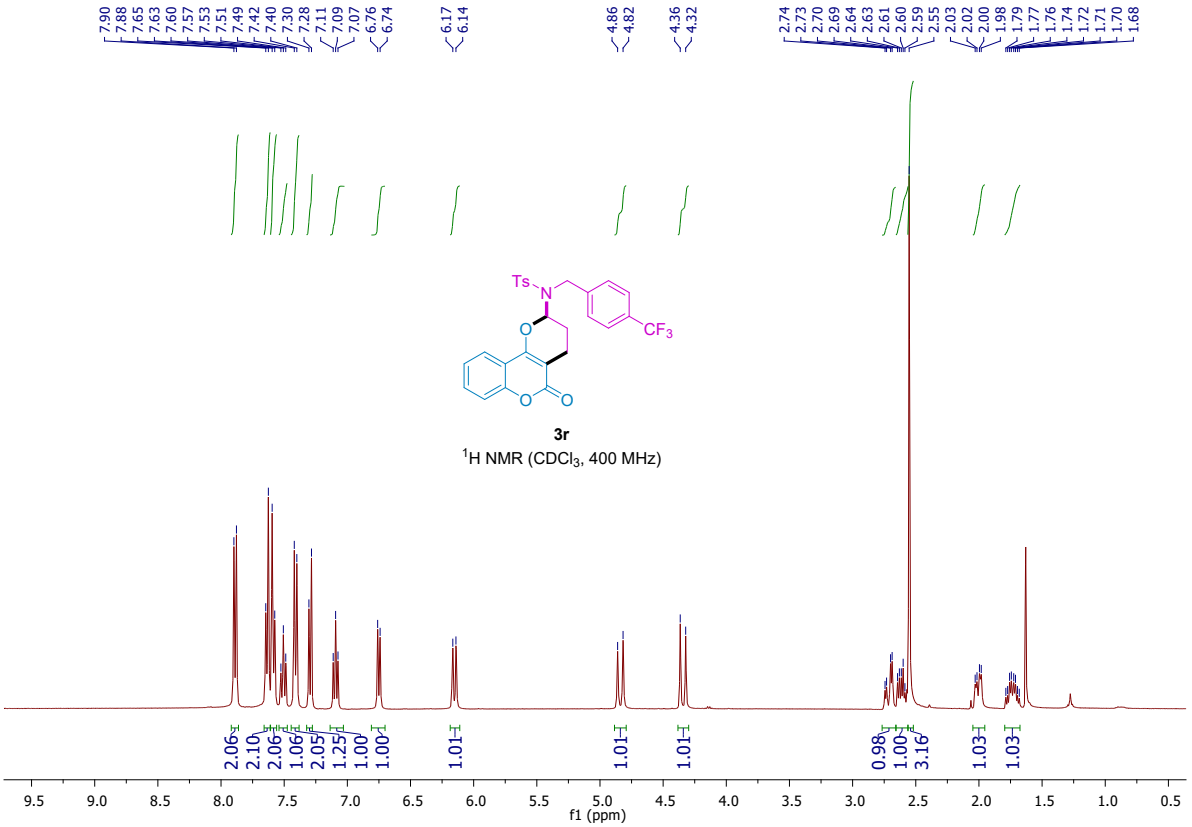


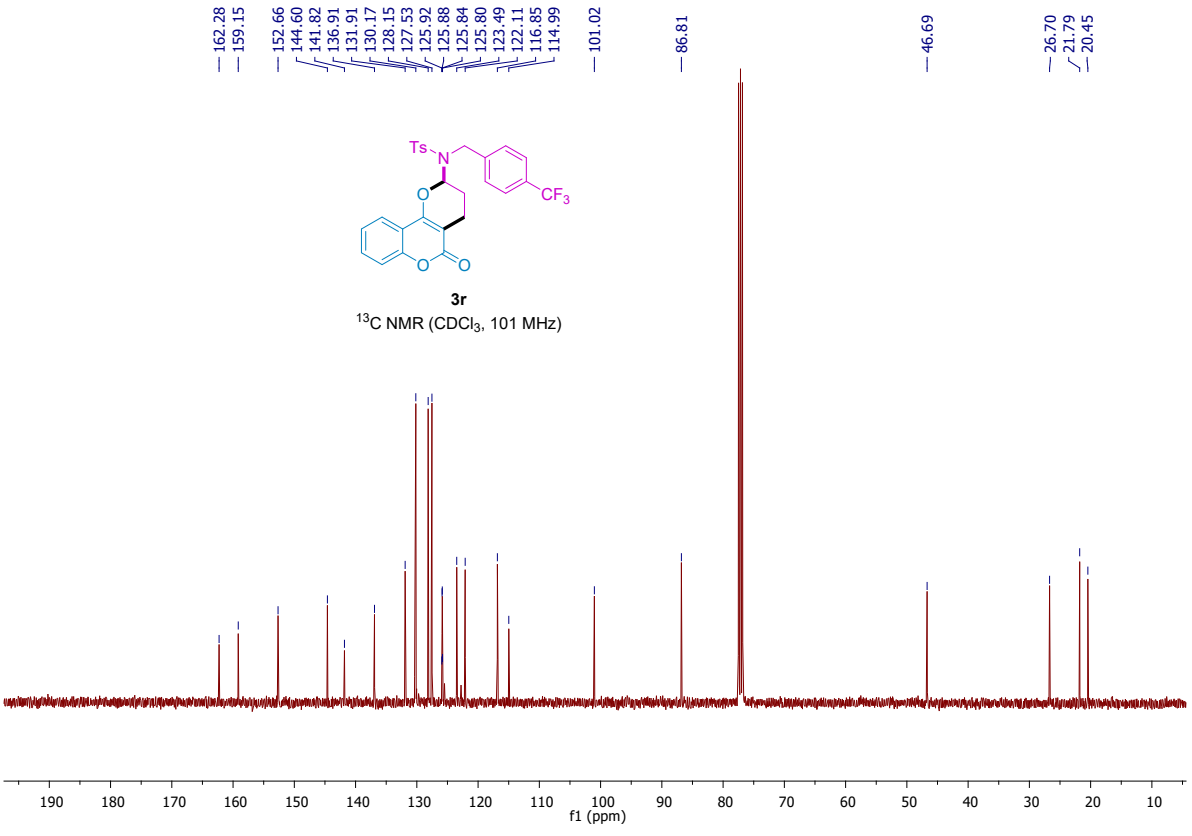
(R)-N-(9-chloro-5-oxo-3,4-dihydro-2H,5H-pyrano[3,2-c]chromen-2-yl)-N-(4-fluorobenzyl)-4-methylbenzenesulfonamide (**3q**):

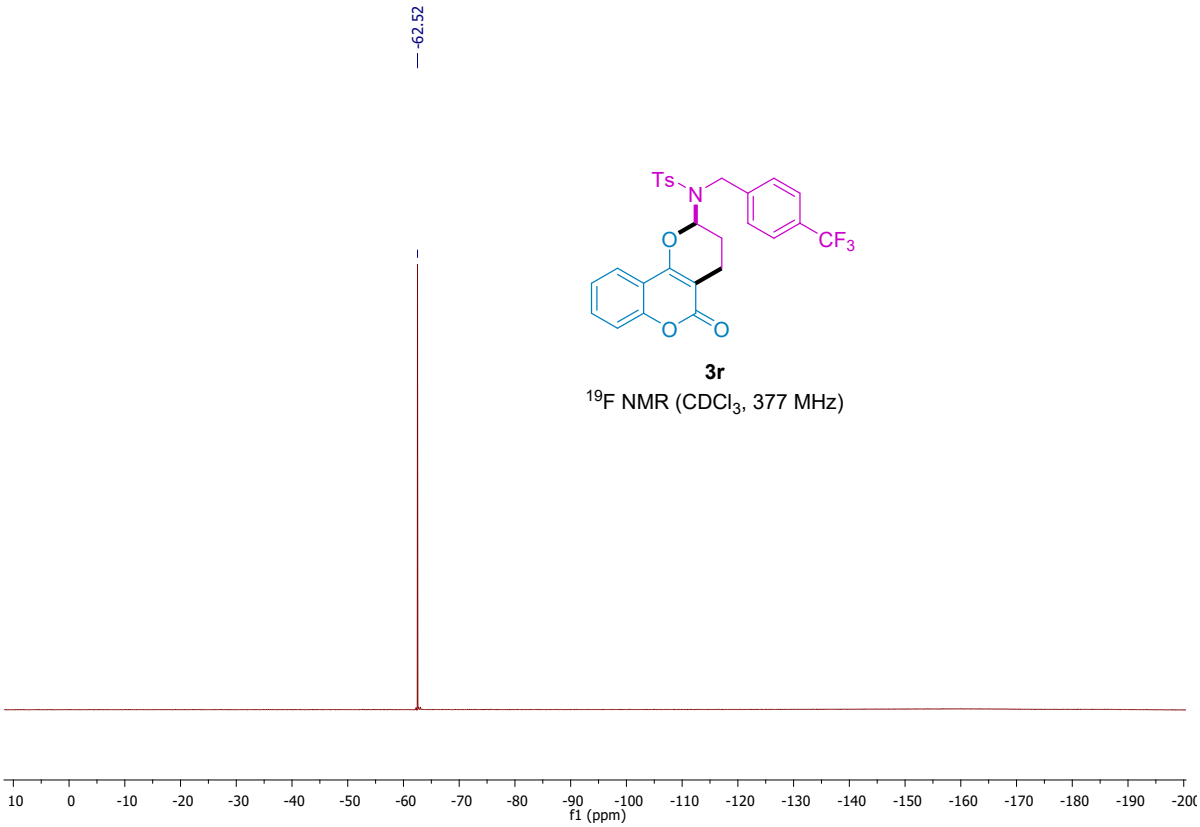




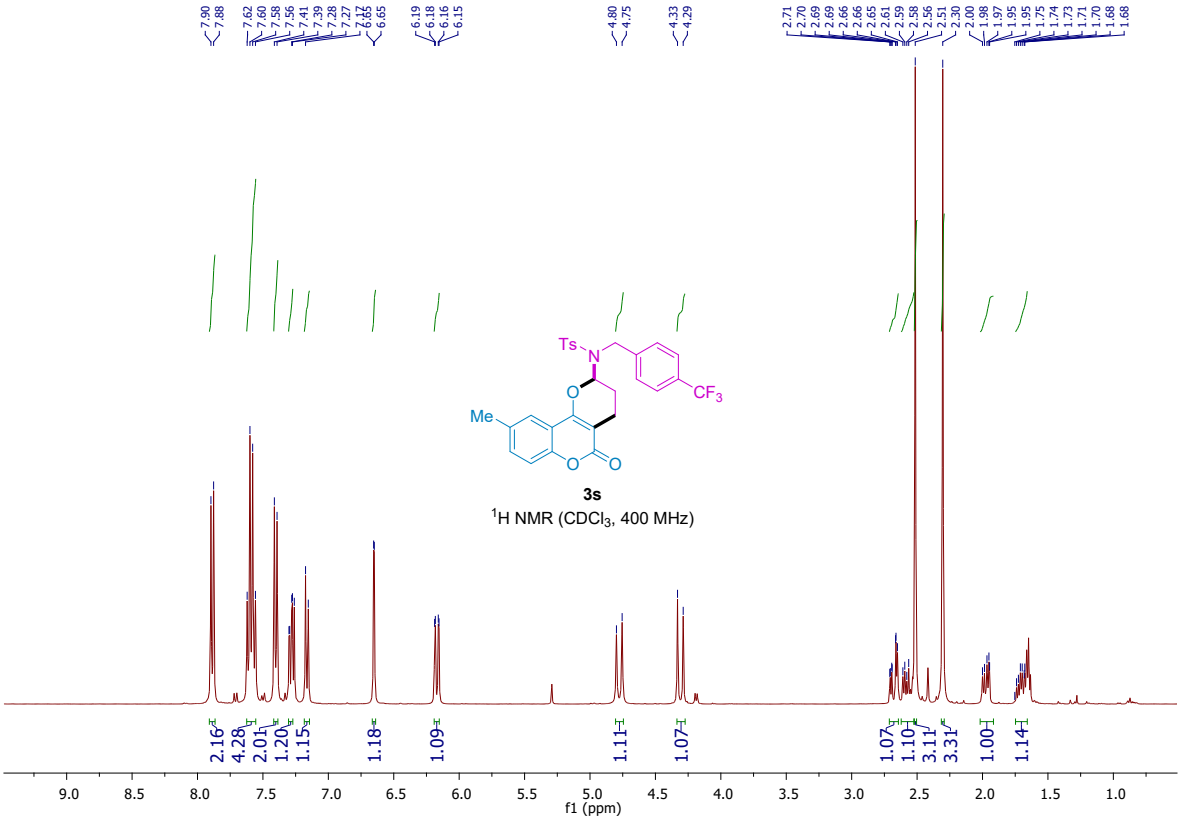
(R)-4-methyl-N-(5-oxo-3,4-dihydro-2H,5H-pyrano[3,2-c]chromen-2-yl)-N-(4-(trifluoromethyl)benzyl)benzenesulfonamide (**3r**):

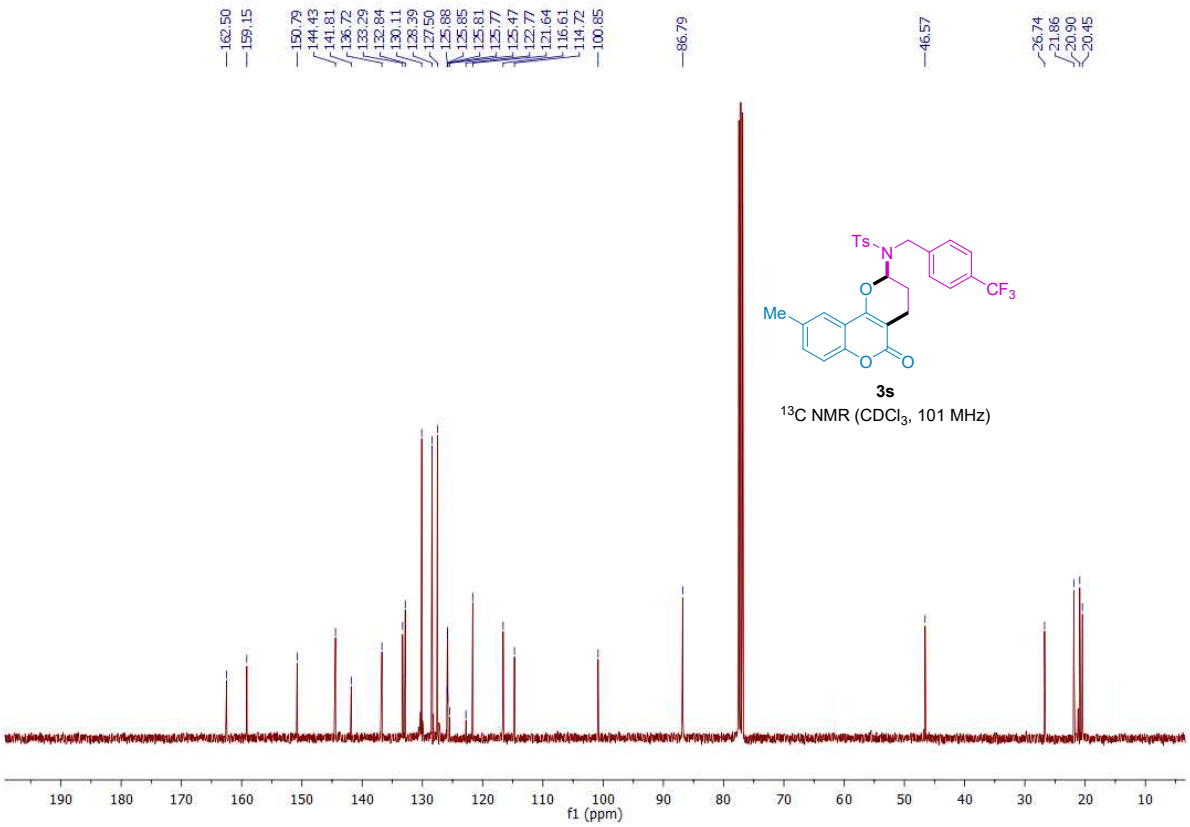




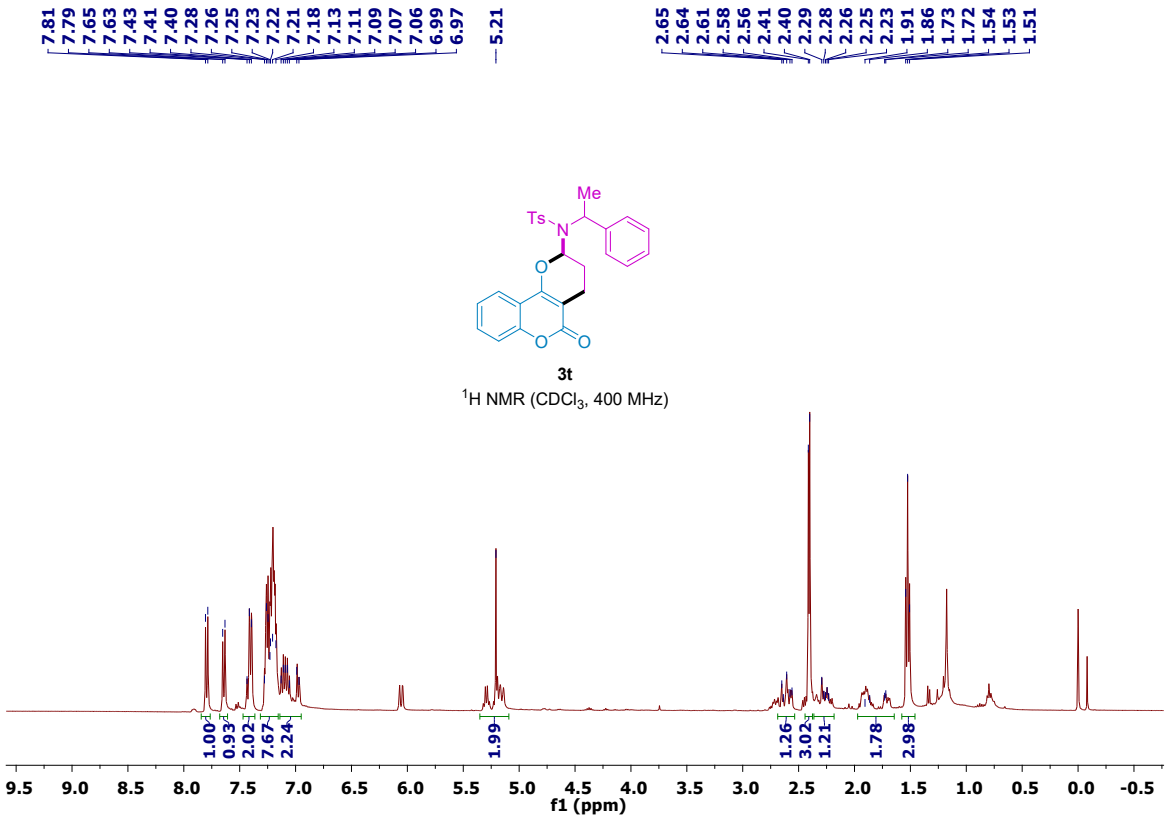


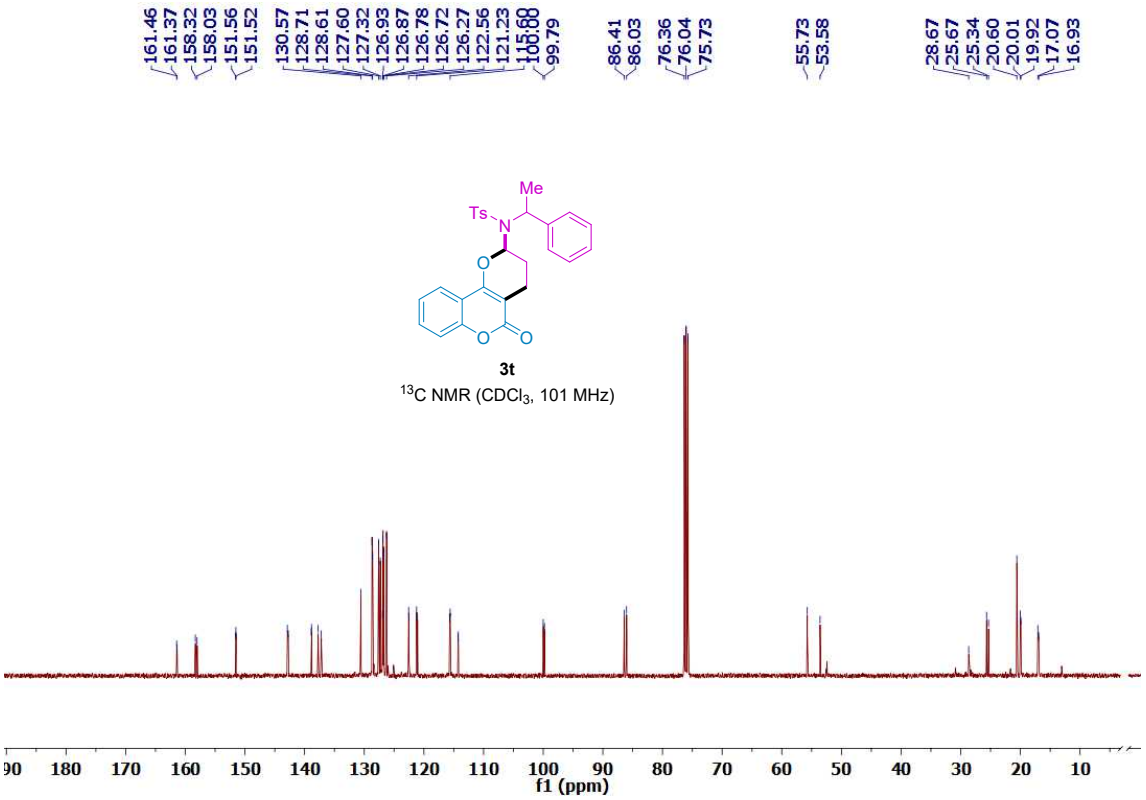
(R)-4-methyl-N-(9-methyl-5-oxo-3,4-dihydro-2H,5H-pyrano[3,2-c]chromen-2-yl)-N-(4-(trifluoromethyl)benzyl)benzenesulfonamide (**3s**):



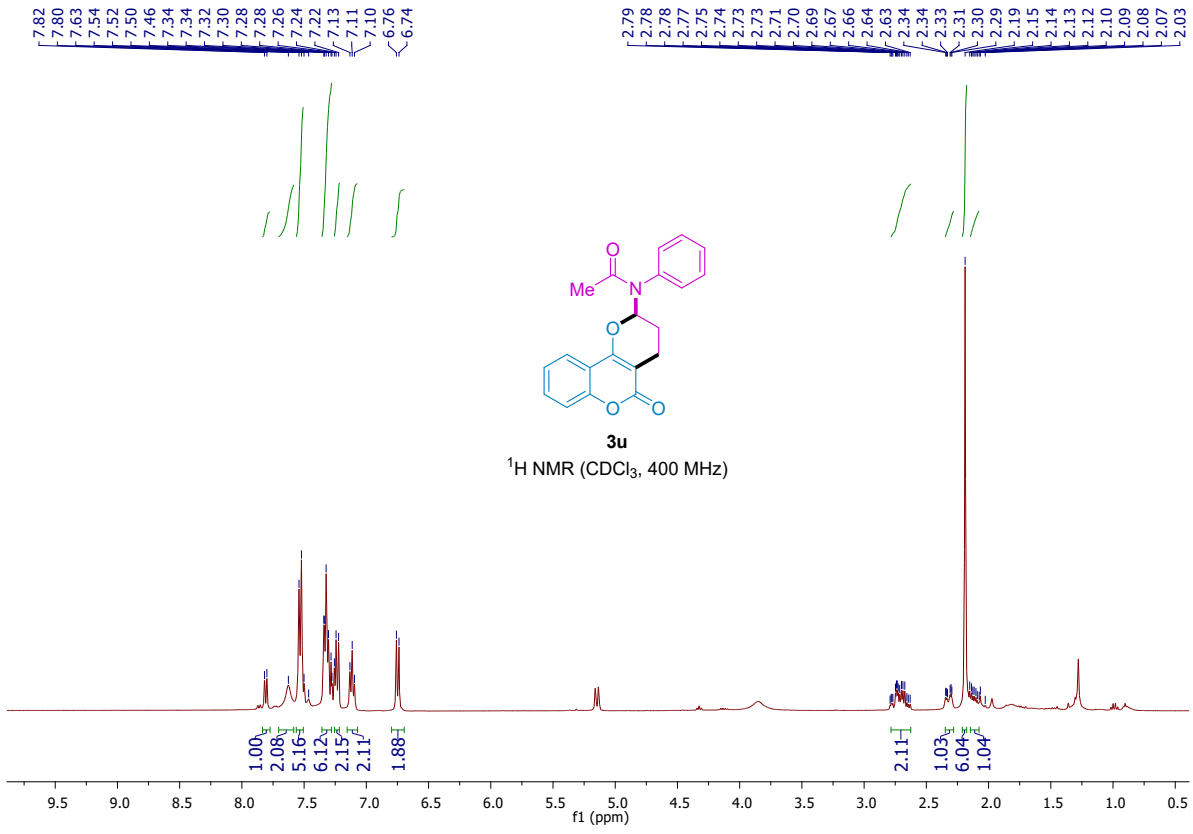


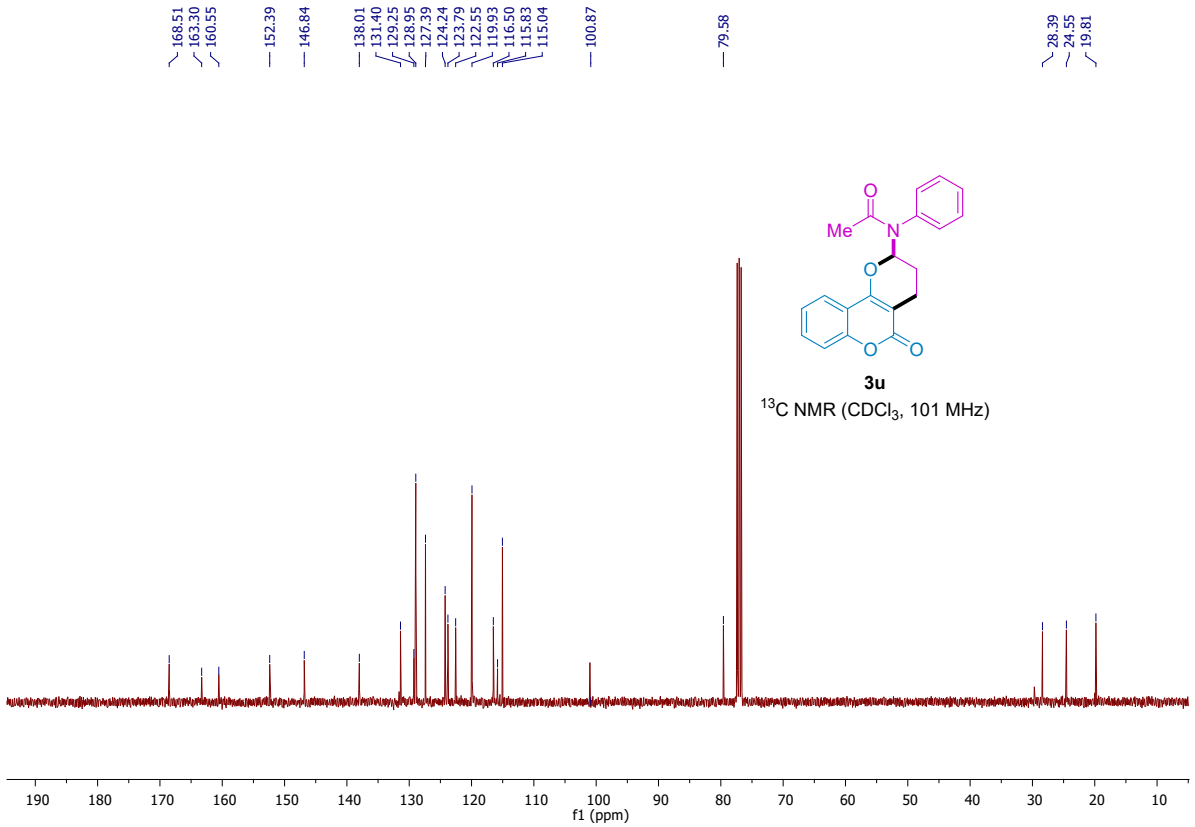
4-methyl-N-((R)-5-oxo-3,4-dihydro-2H,5H-pyrano[3,2-c]chromen-2-yl)-N-(1-phenylethyl)benzenesulfonamide (**3t**):



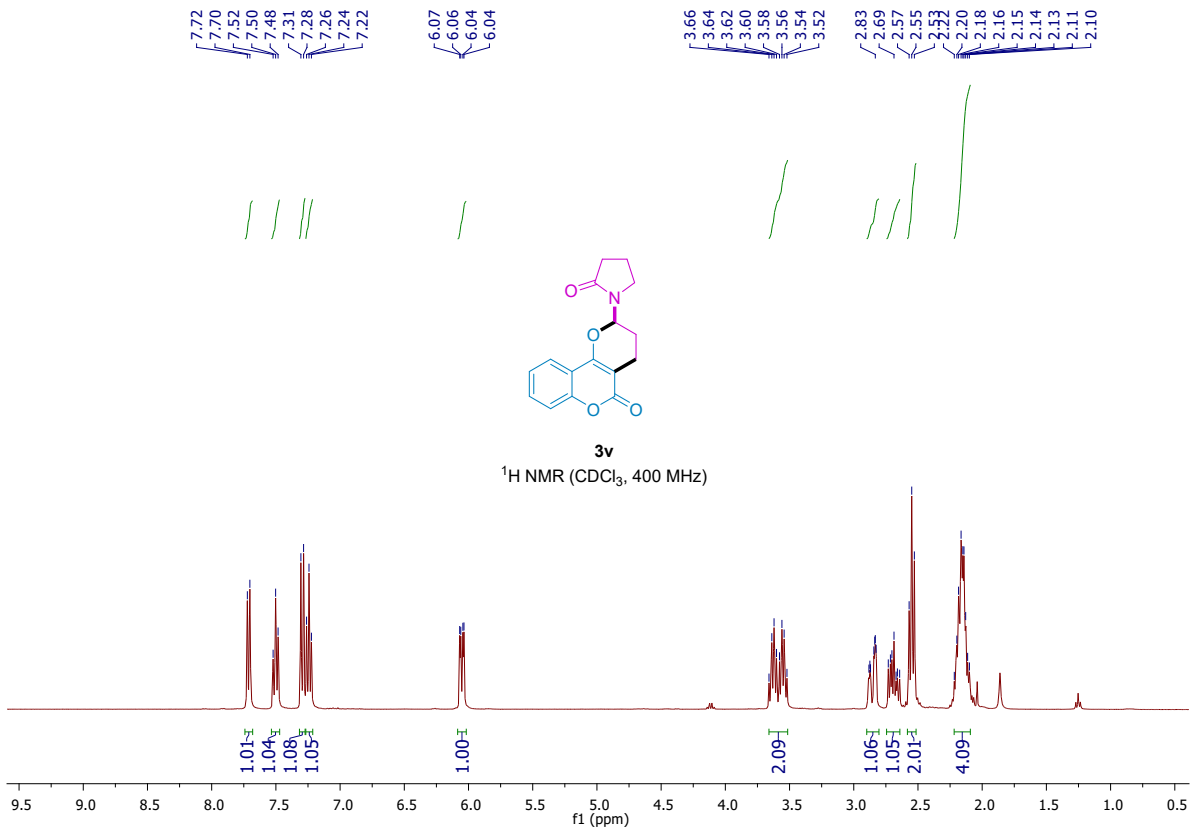


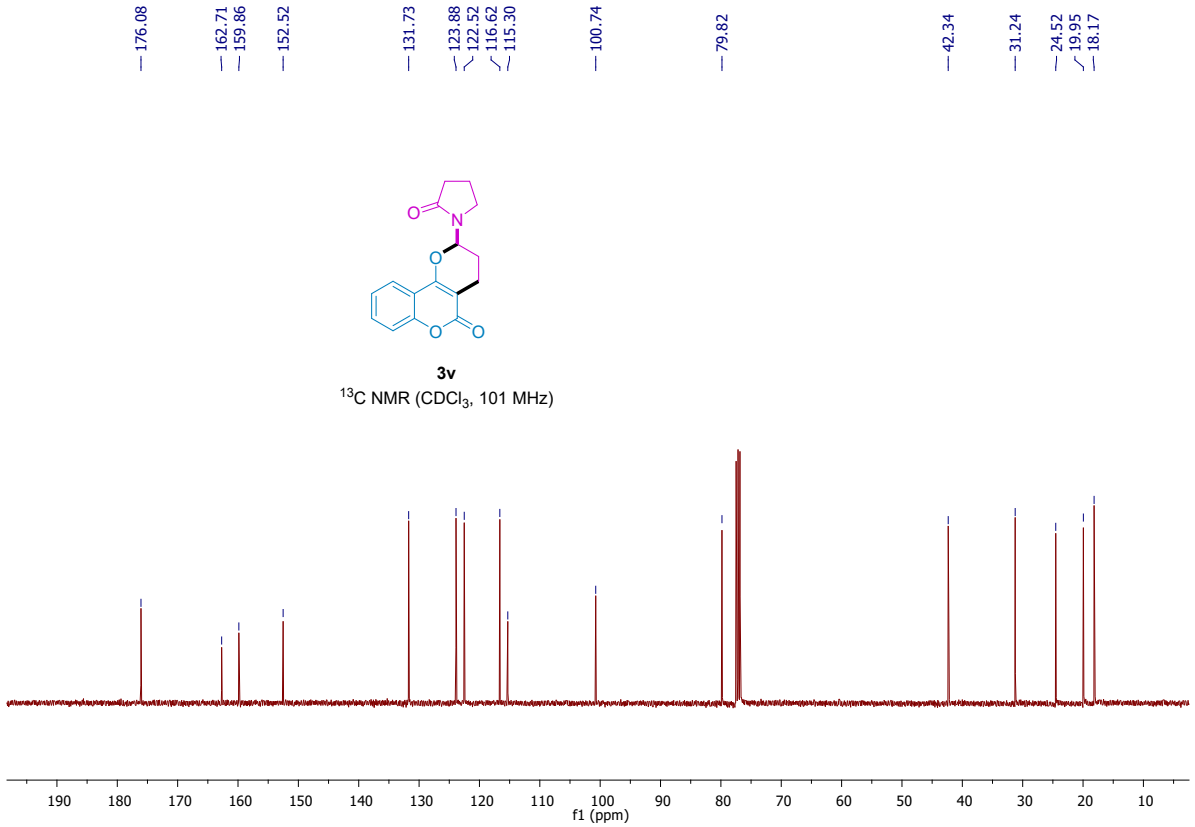
(R)-N-(5-oxo-3,4-dihydro-2H,5H-pyrano[3,2-c]chromen-2-yl)-N-phenylacetamide (**3u**) (Rotamer):



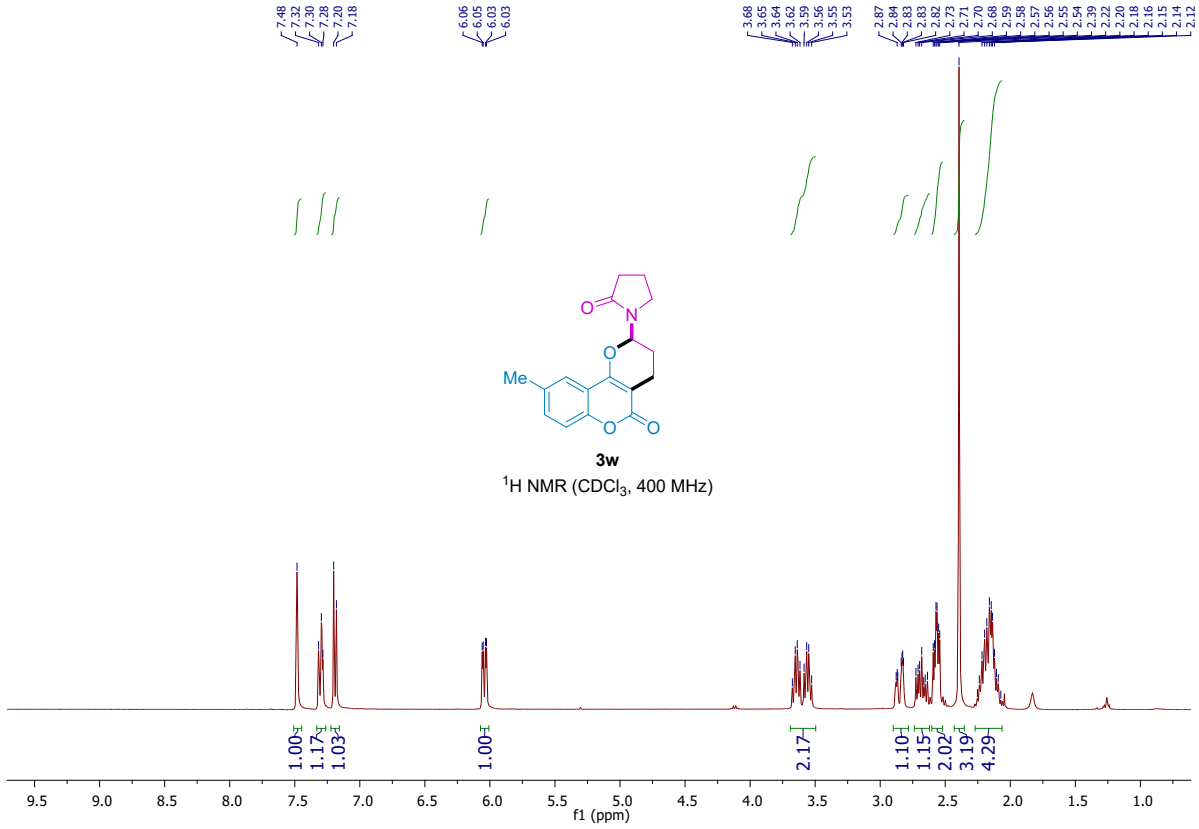


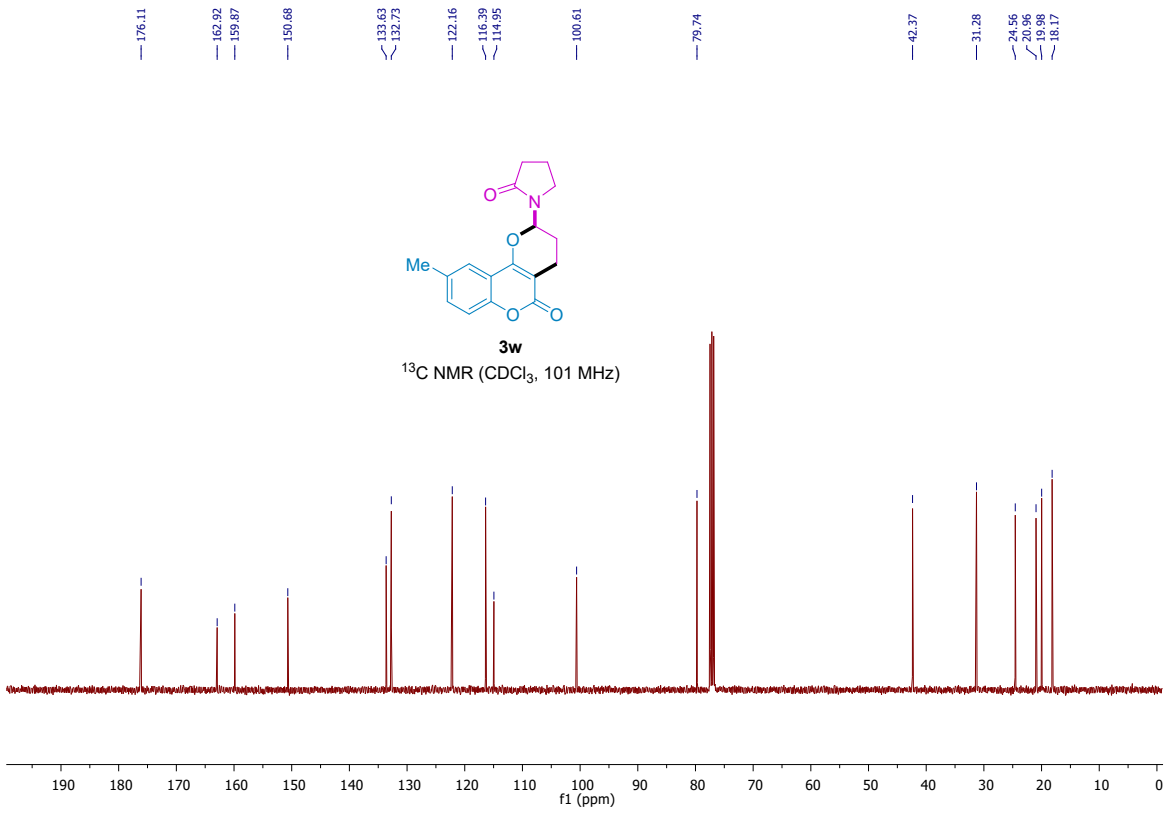
(R)-1-(5-oxo-3,4-dihydro-2H,5H-pyrano[3,2-c]chromen-2-yl)pyrrolidin-2-one (**3v**):



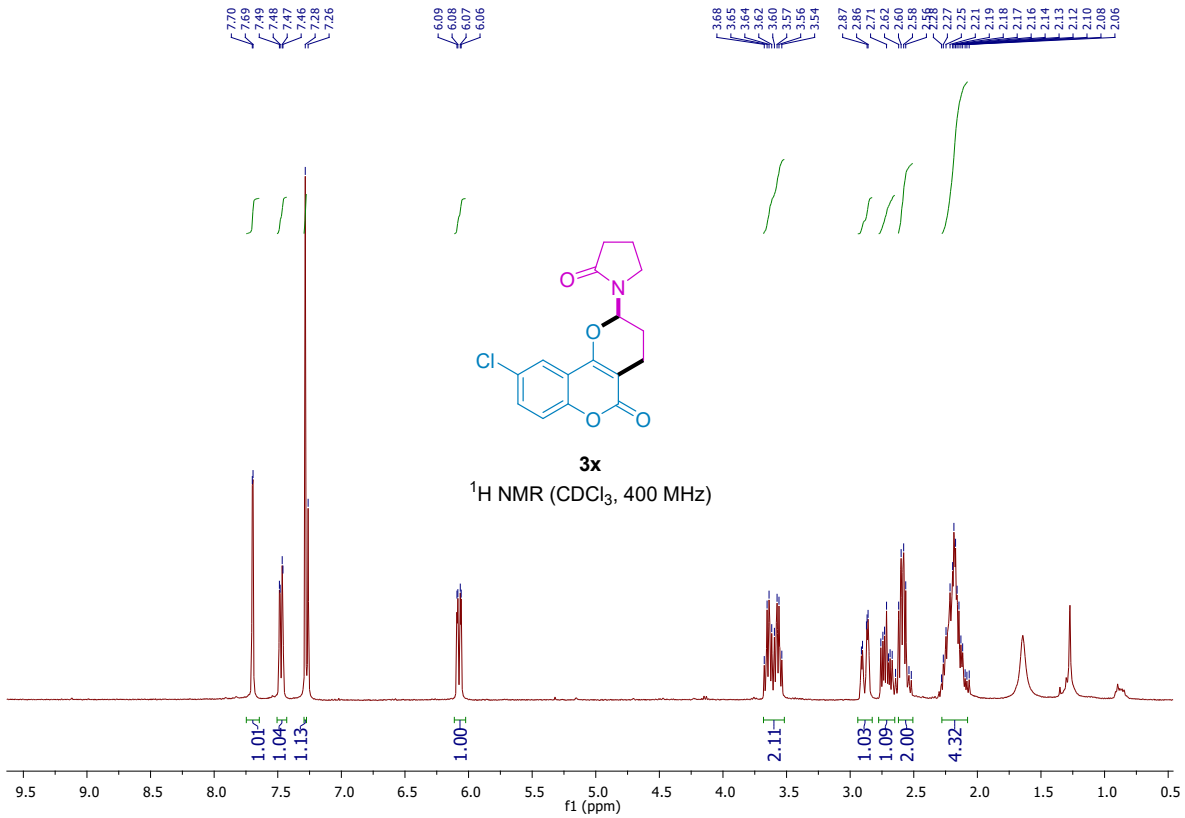


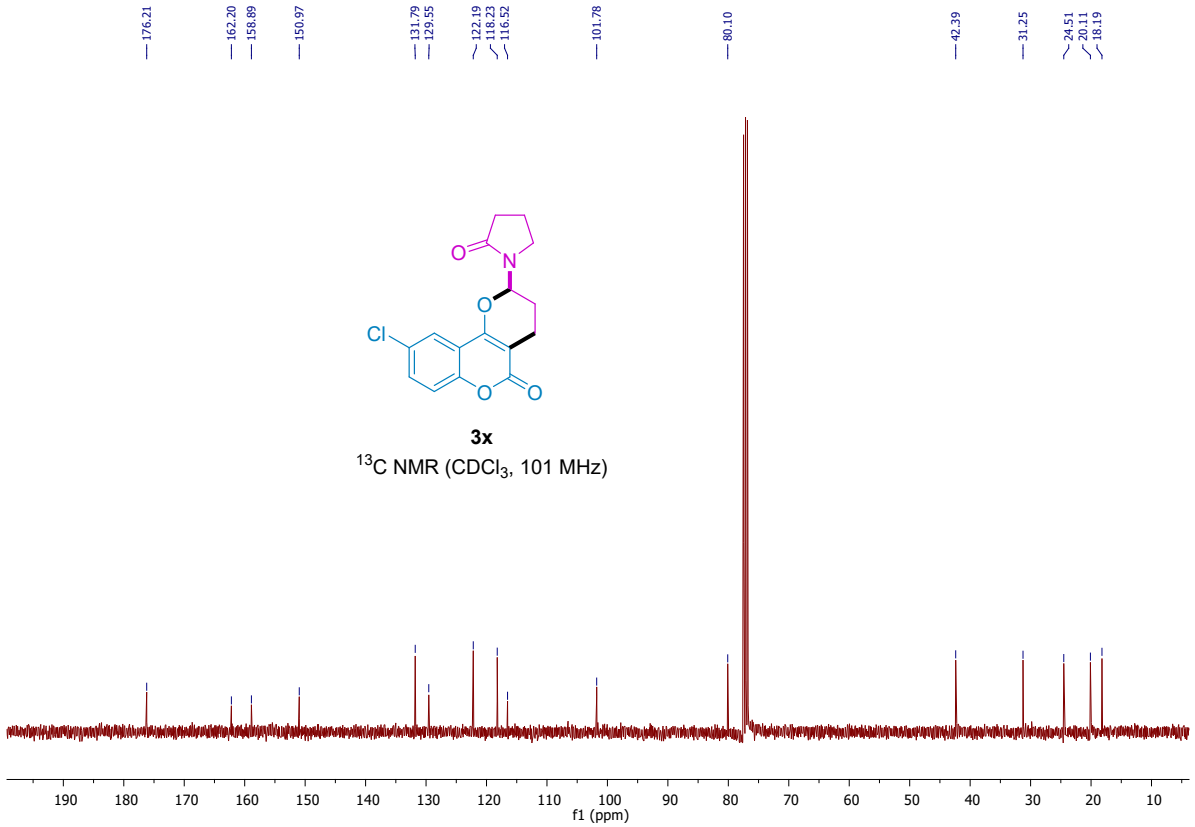
(R)-1-(9-methyl-5-oxo-3,4-dihydro-2H,5H-pyrano[3,2-c]chromen-2-yl)pyrrolidin-2-one (**3w**):



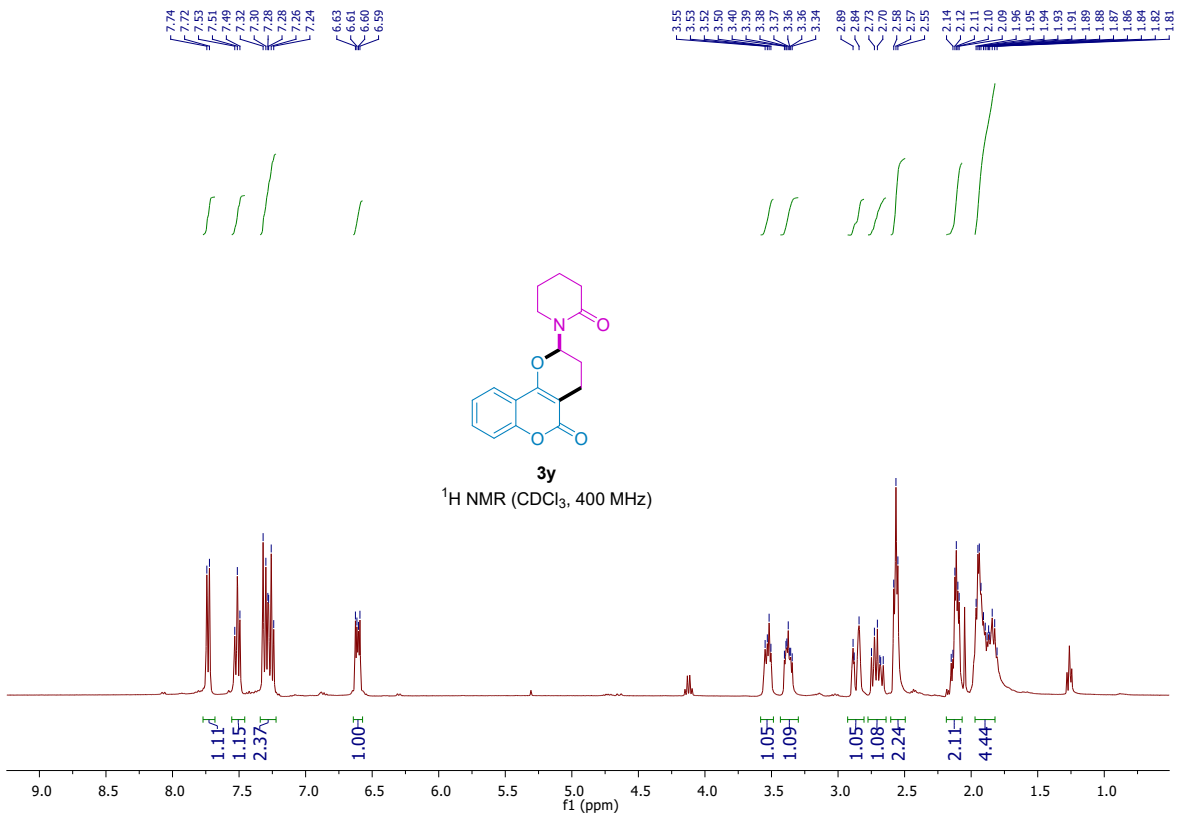


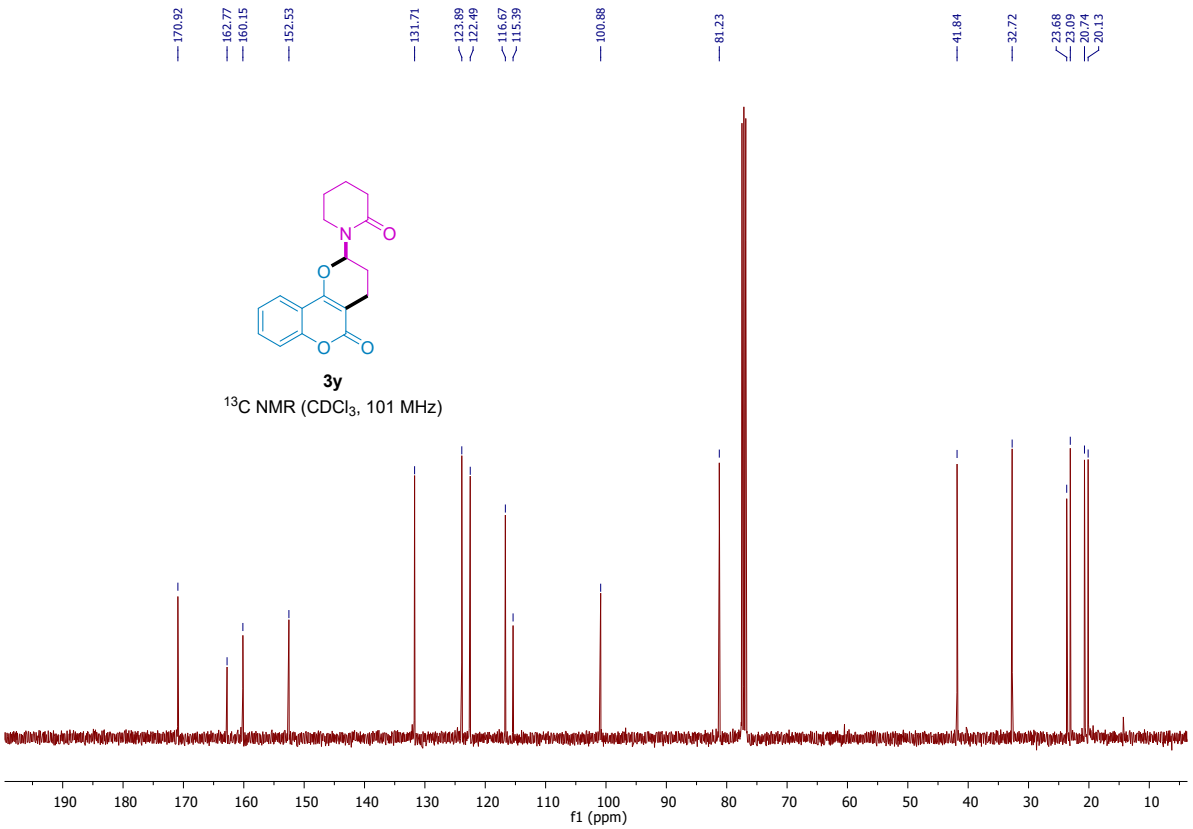
(R)-1-(9-chloro-5-oxo-3,4-dihydro-2H,5H-pyrano[3,2-c]chromen-2-yl)pyrrolidin-2-one (**3x**):



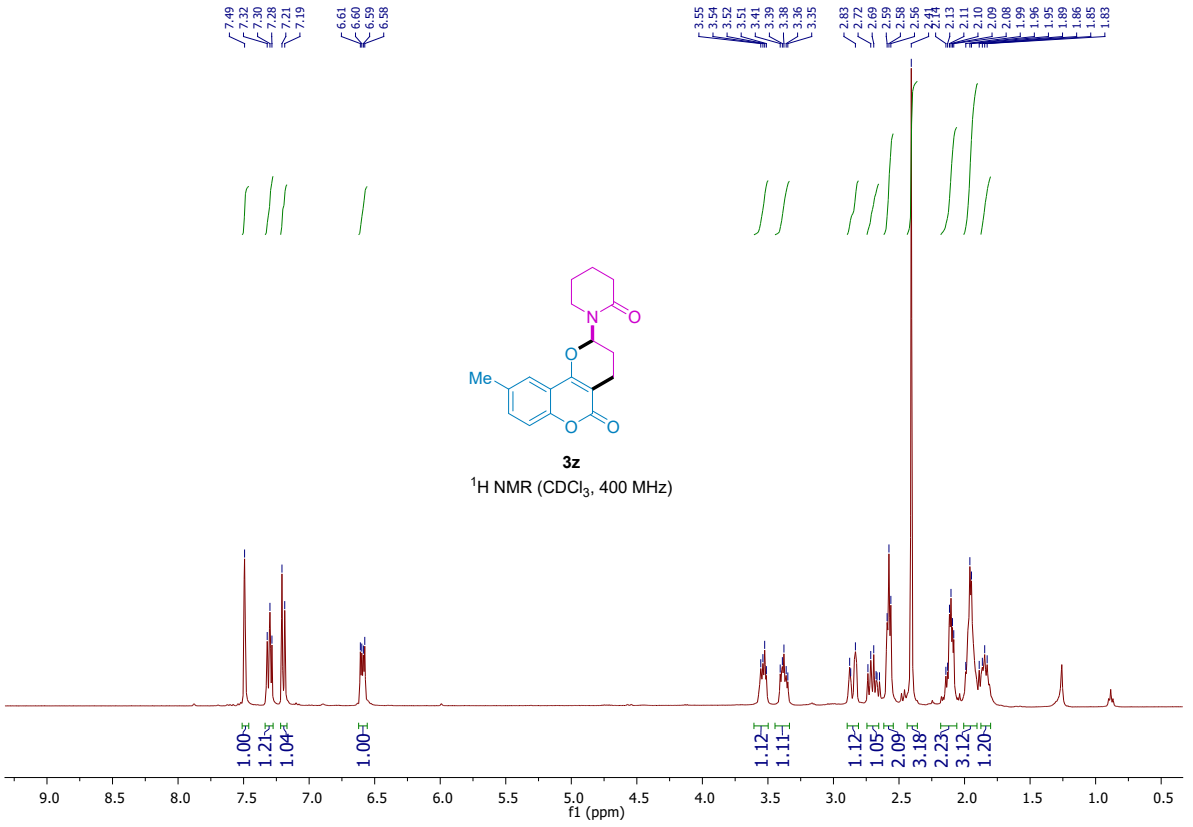


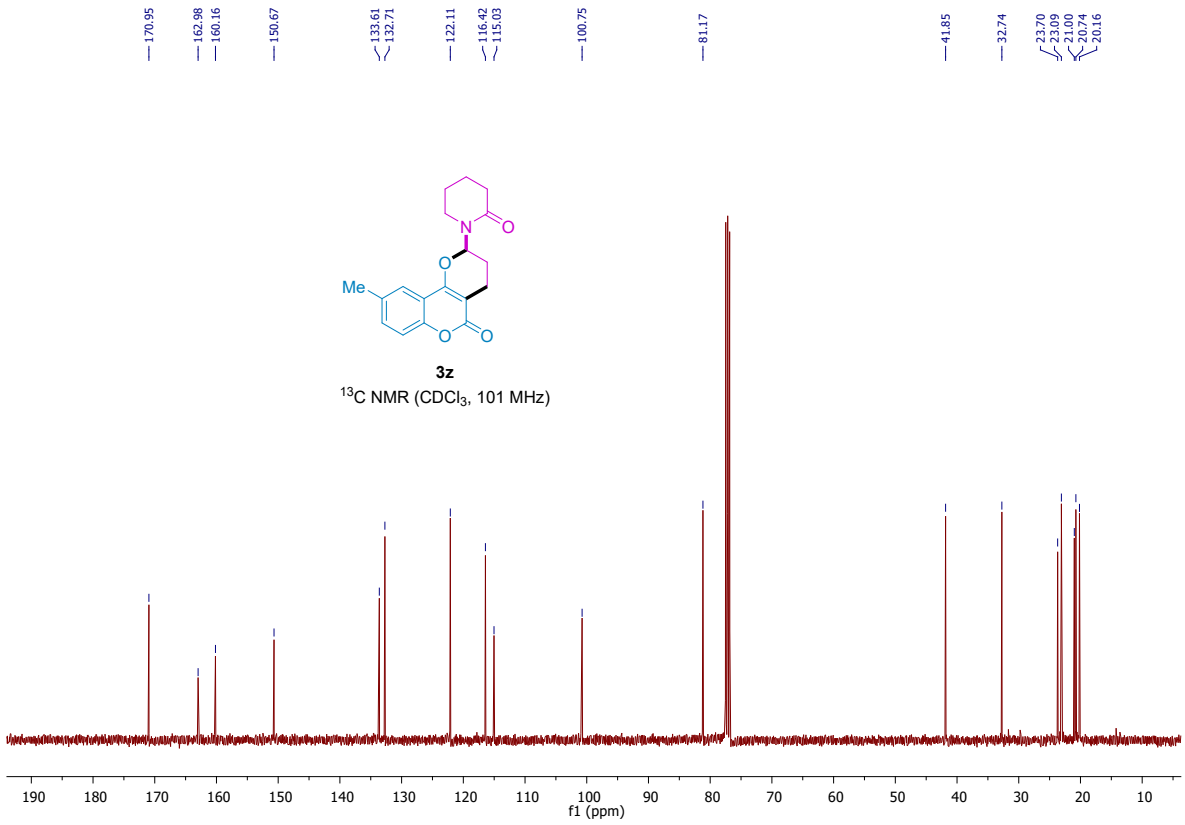
(R)-1-(5-oxo-3,4-dihydro-2H,5H-pyrano[3,2-c]chromen-2-yl)piperidin-2-one (**3y**):



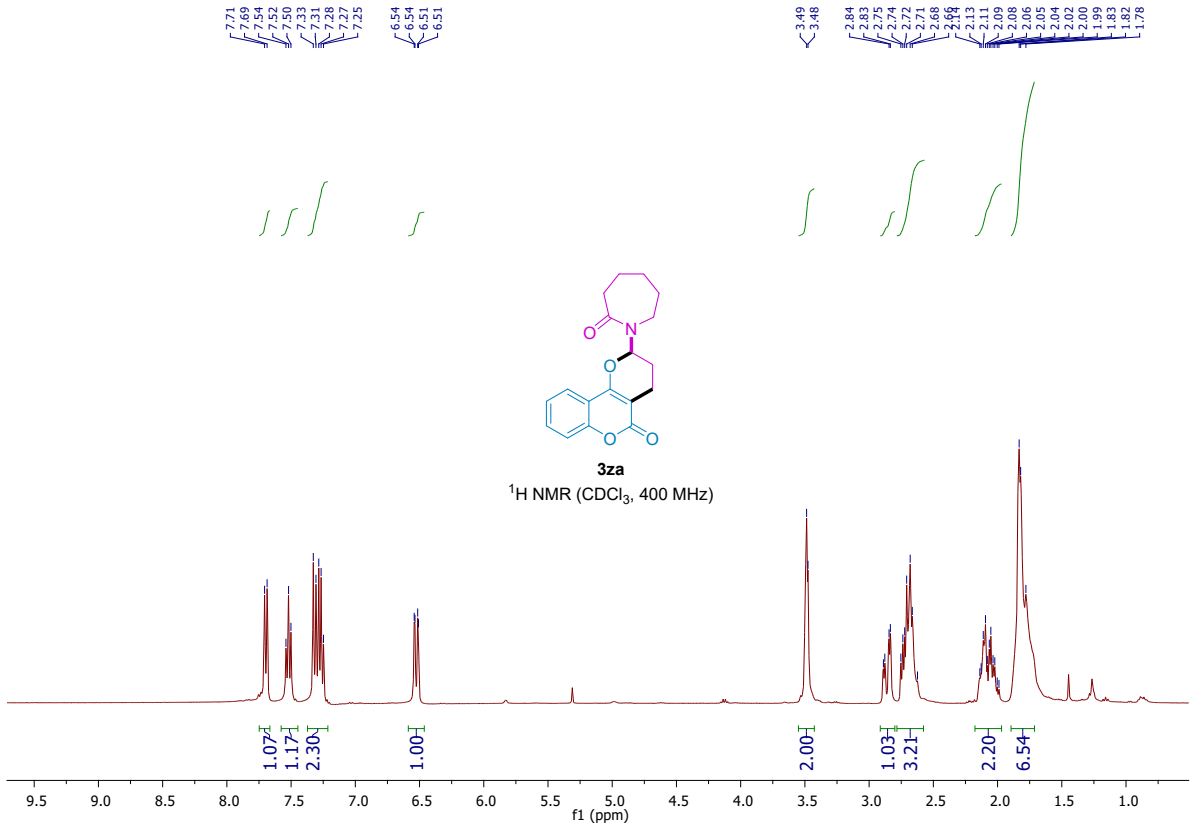


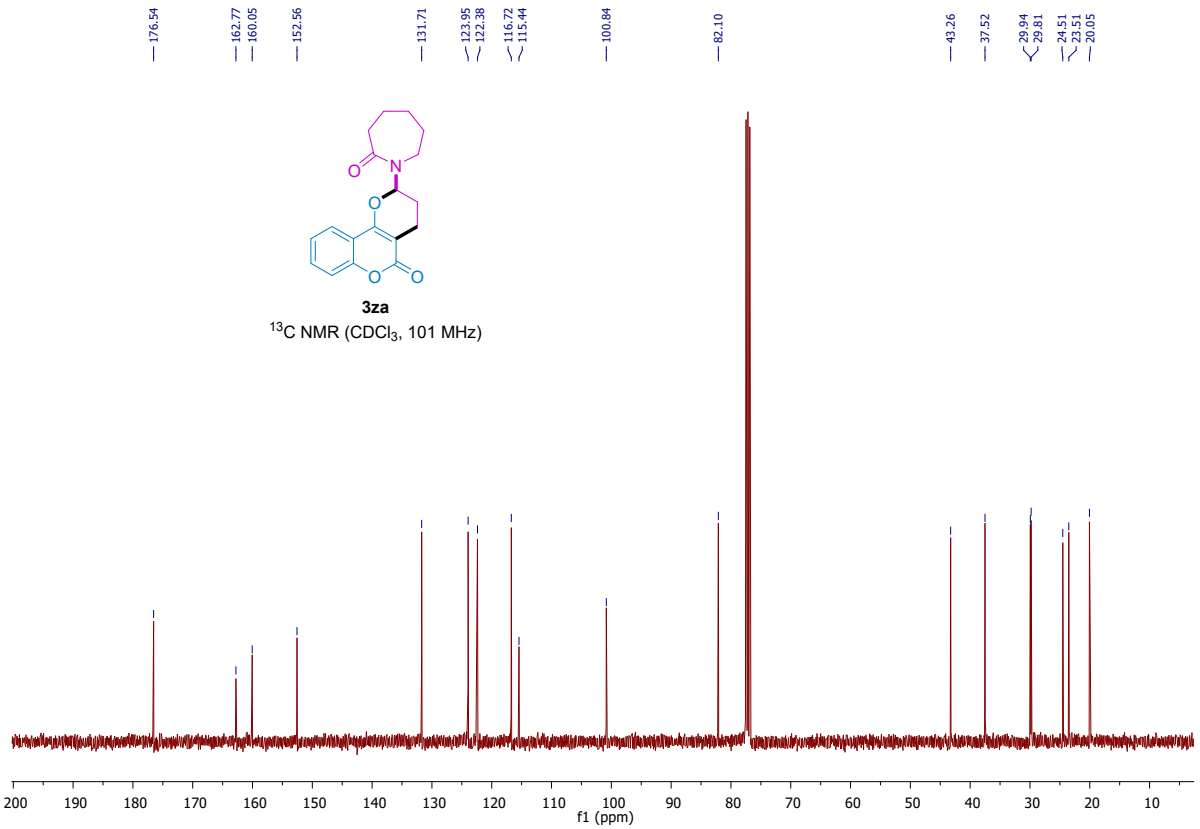
(R)-1-(9-methyl-5-oxo-3,4-dihydro-2H,5H-pyrano[3,2-c]chromen-2-yl)piperidin-2-one (**3z**):



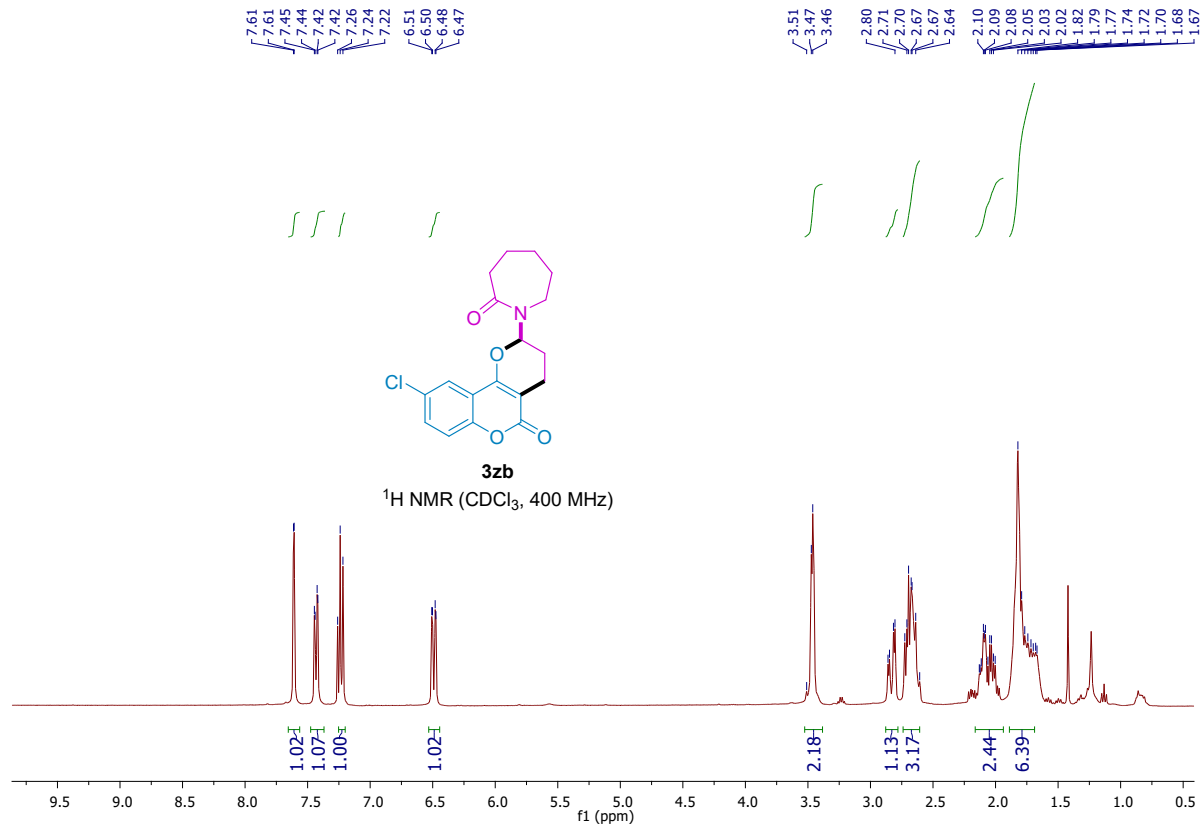


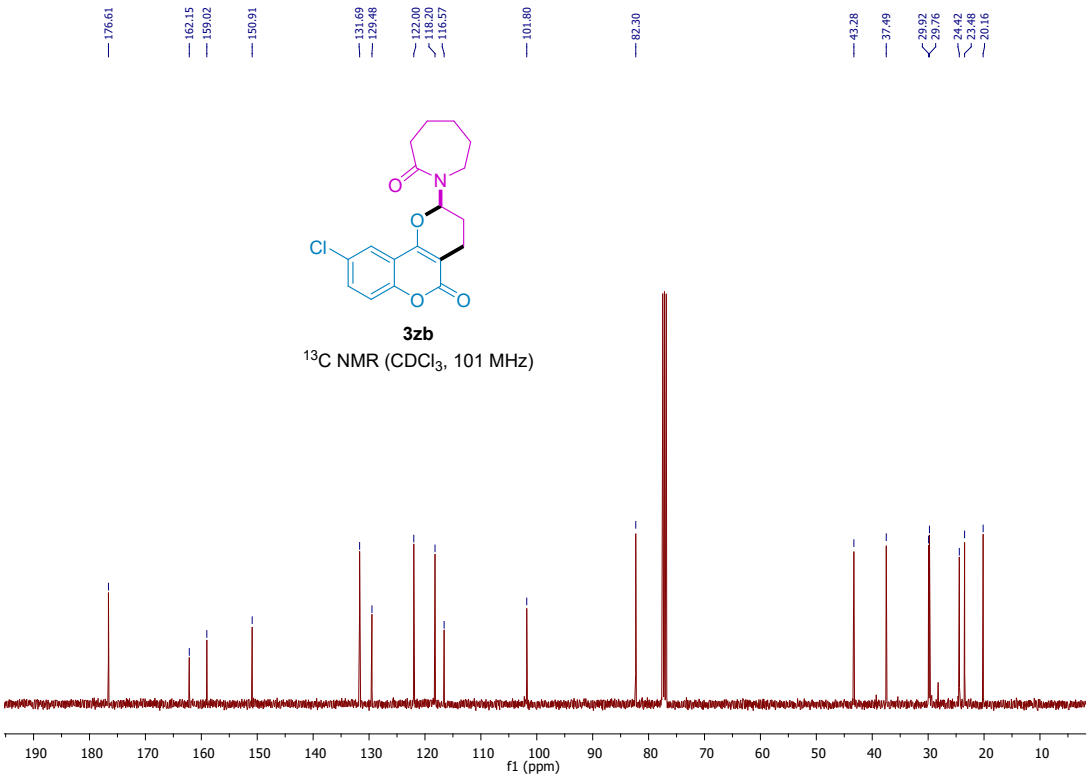
(R)-1-(5-oxo-3,4-dihydro-2H,5H-pyrano[3,2-c]chromen-2-yl)azepan-2-one (**3za**):



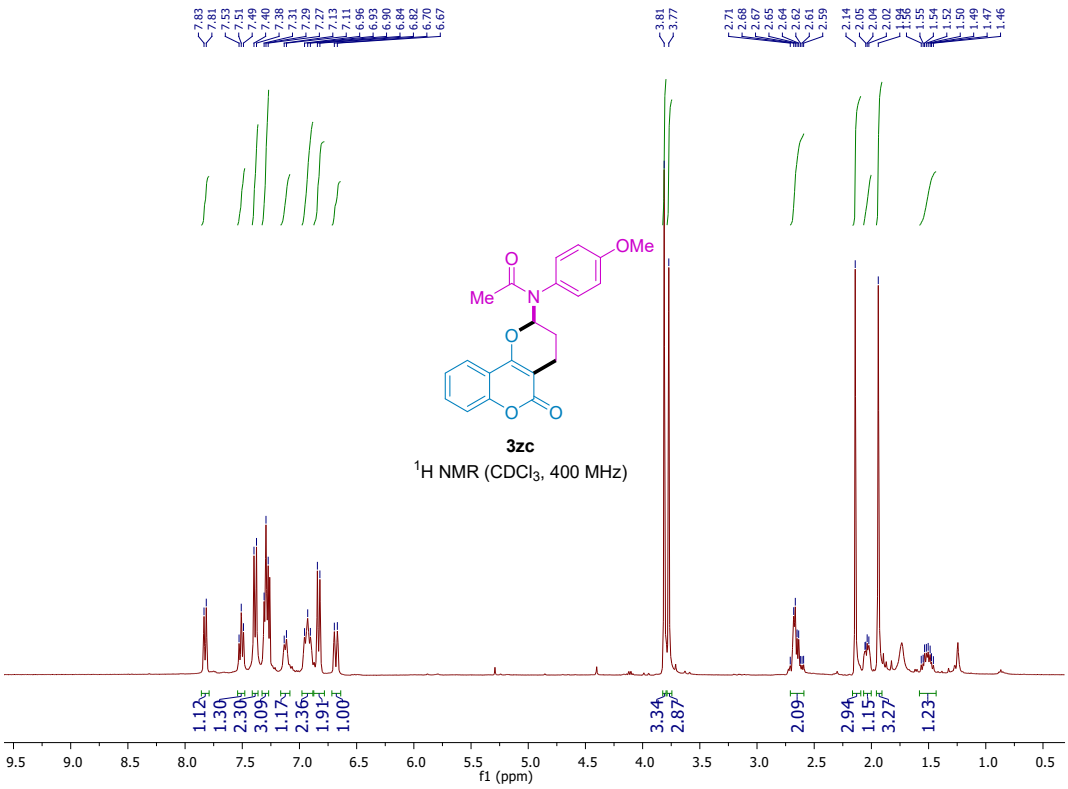


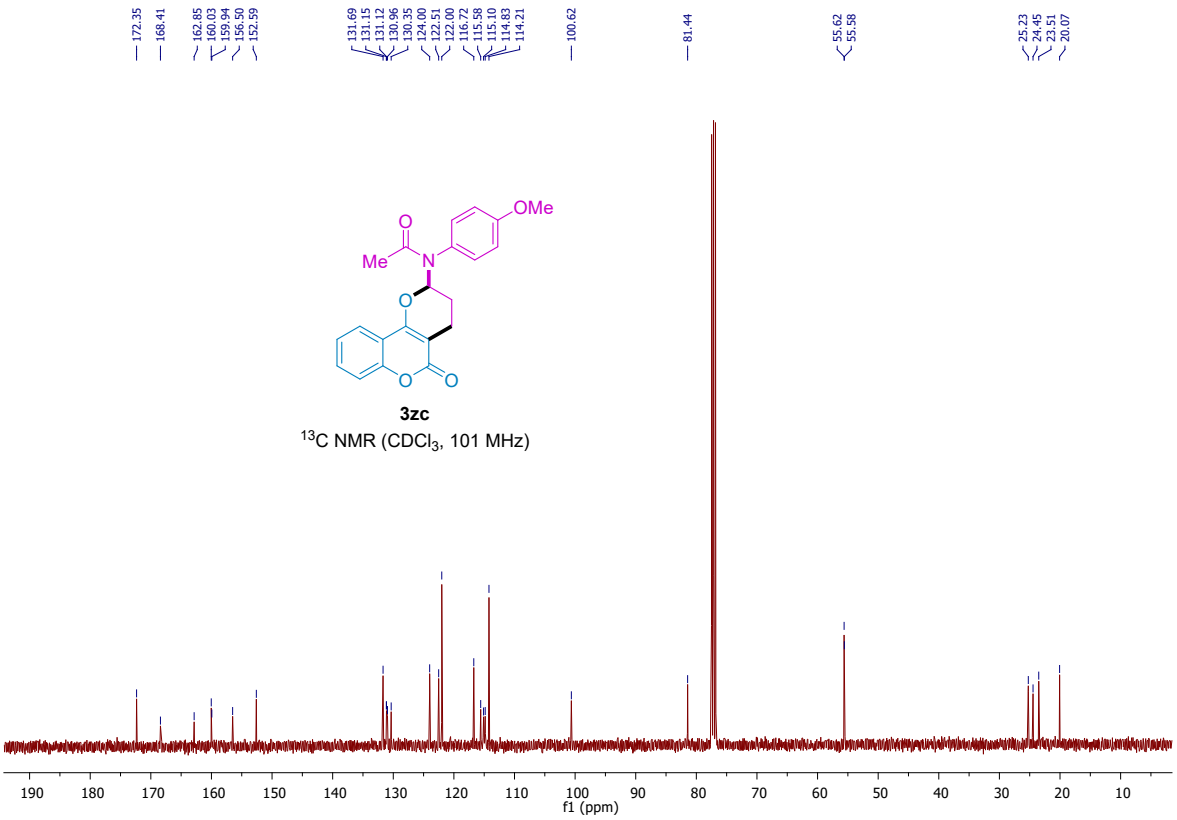
(R)-1-(9-chloro-5-oxo-3,4-dihydro-2H,5H-pyrano[3,2-c]chromen-2-yl)azepan-2-one (**3zb**):



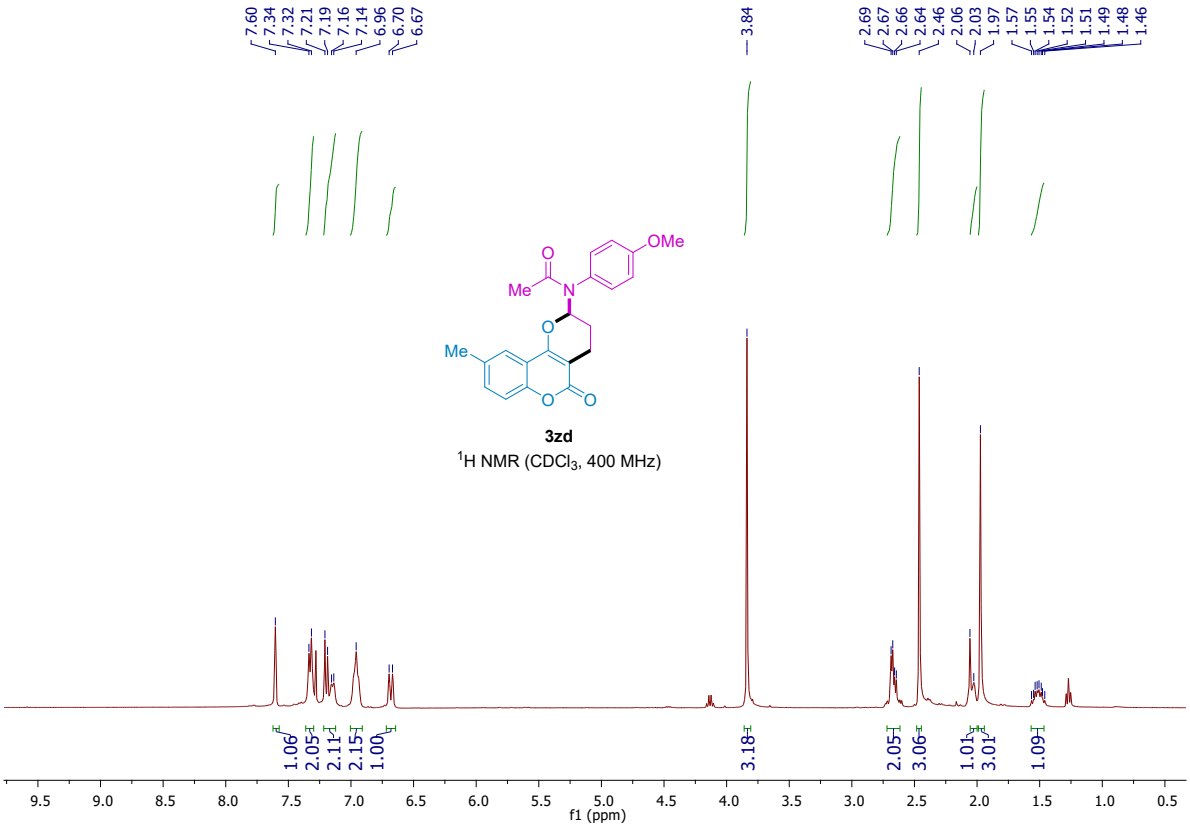


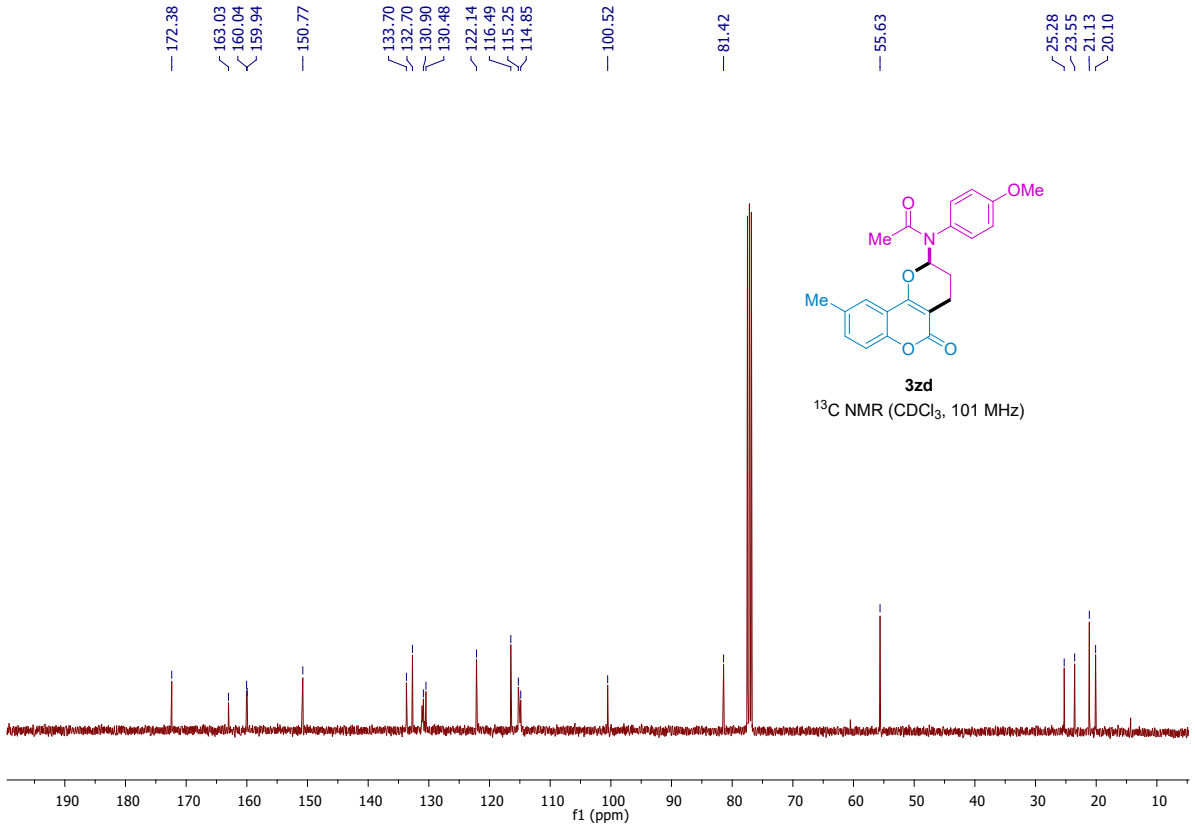
(R)-N-(4-methoxyphenyl)-N-(5-oxo-3,4-dihydro-2H,5H-pyrano[3,2-c]chromen-2-yl)acetamide (**3zc**, rotamer):



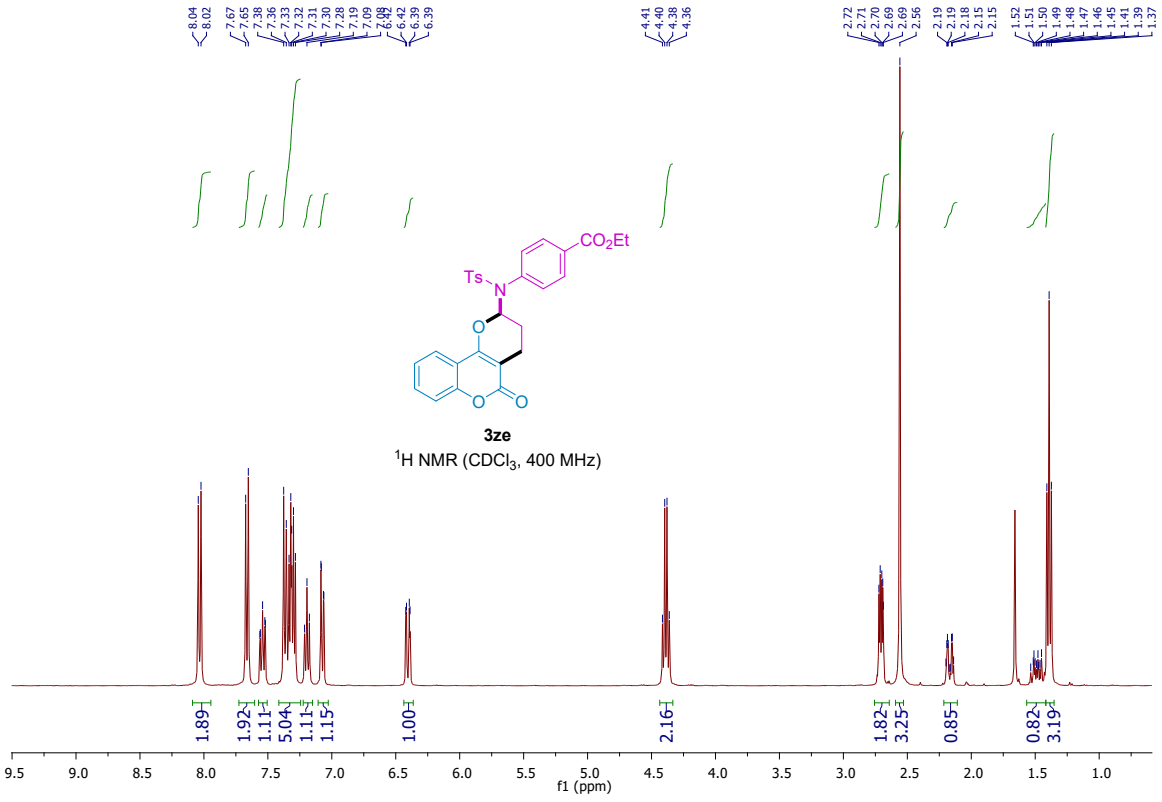


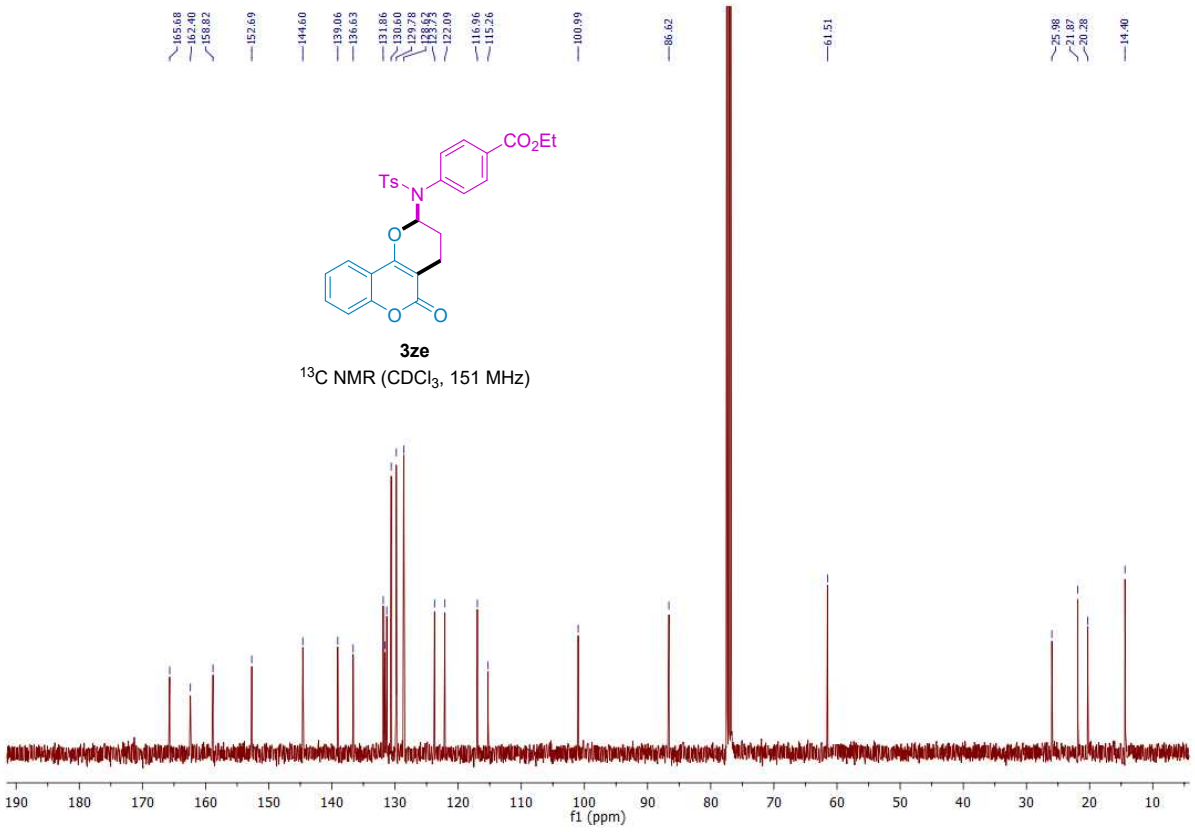
(R)-N-(4-methoxyphenyl)-N-(9-methyl-5-oxo-3,4-dihydro-2H,5H-pyrano[3,2-c]chromen-2-yl)acetamide (**3zd**):



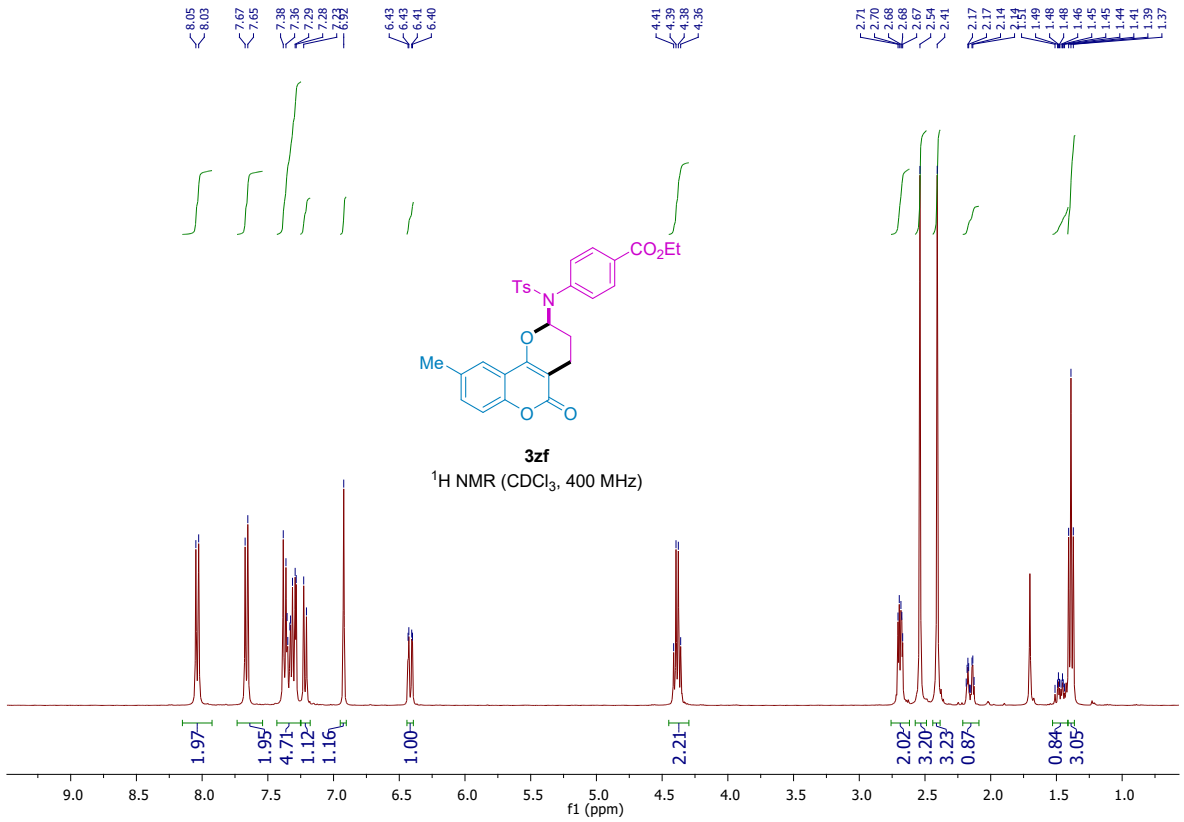


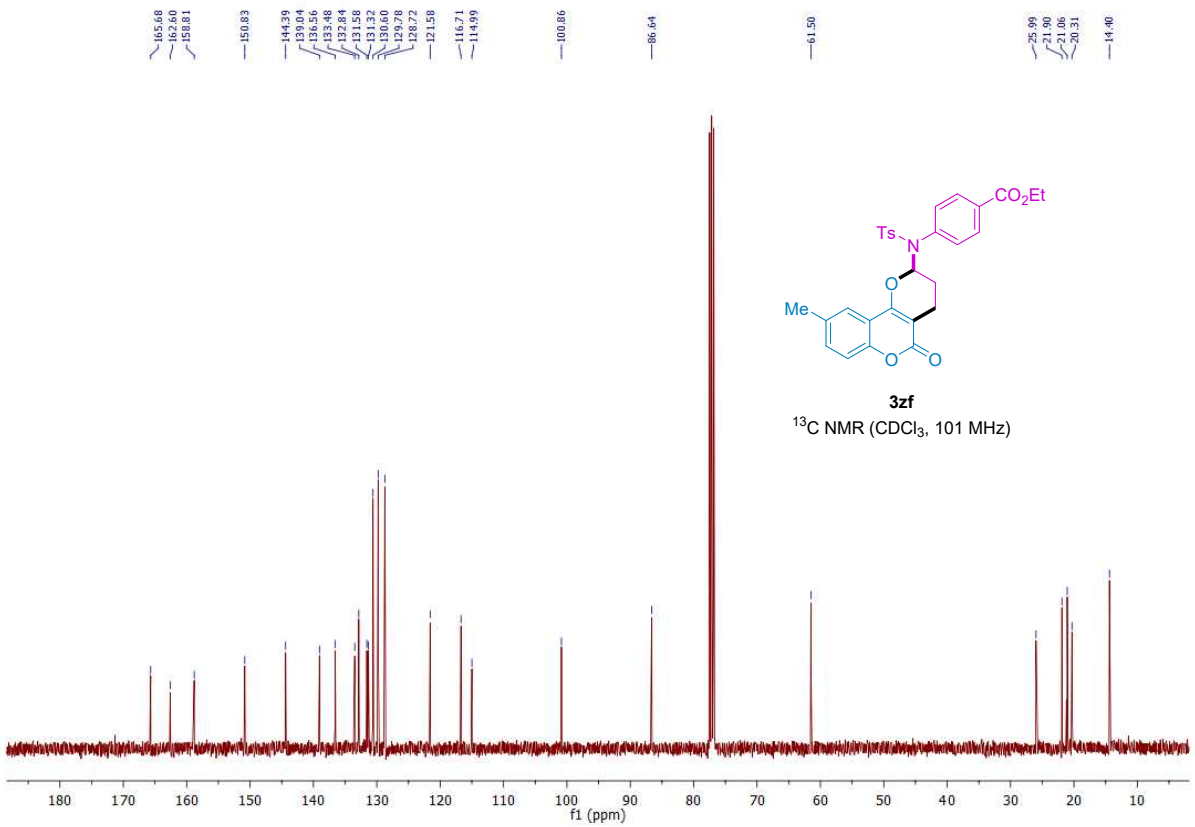
ethyl (R)-4-((4-methyl-N-(5-oxo-3,4-dihydro-2H,5H-pyrano[3,2-c]chromen-2-yl)phenyl)sulfonamido)benzoate (**3ze**):



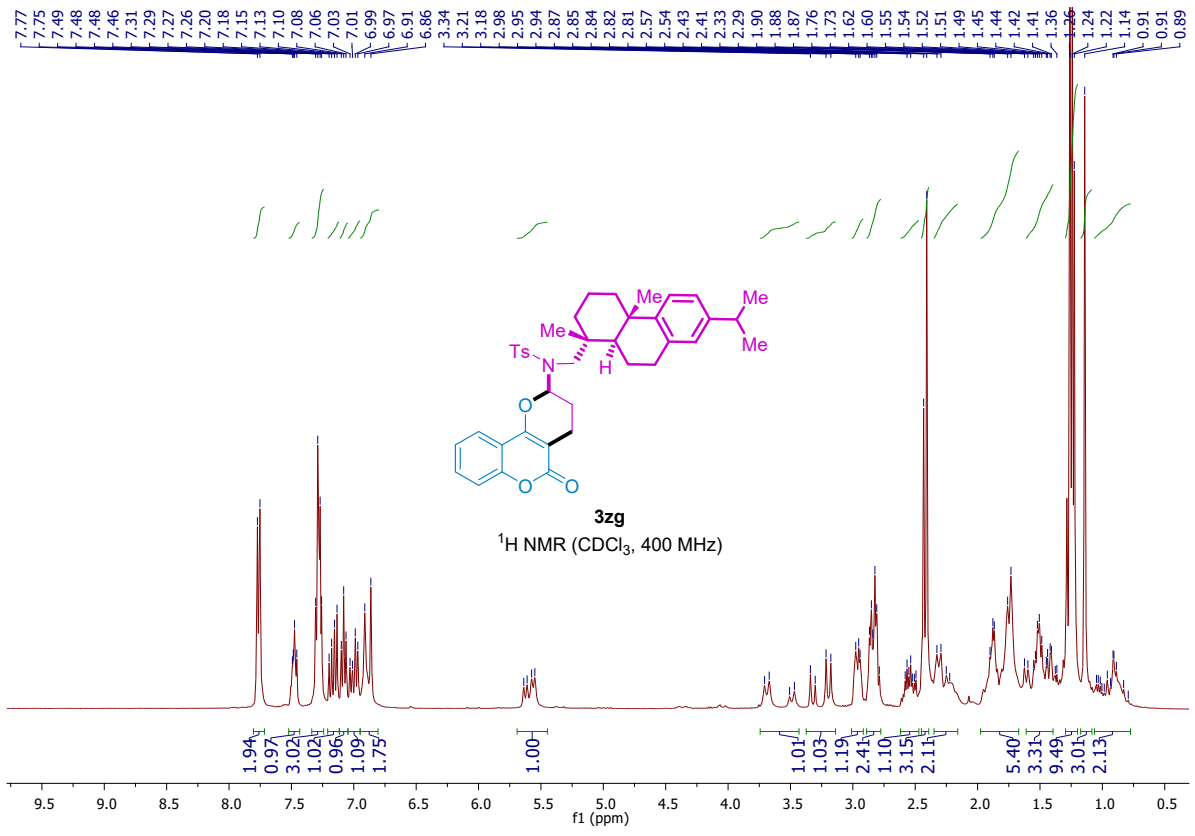


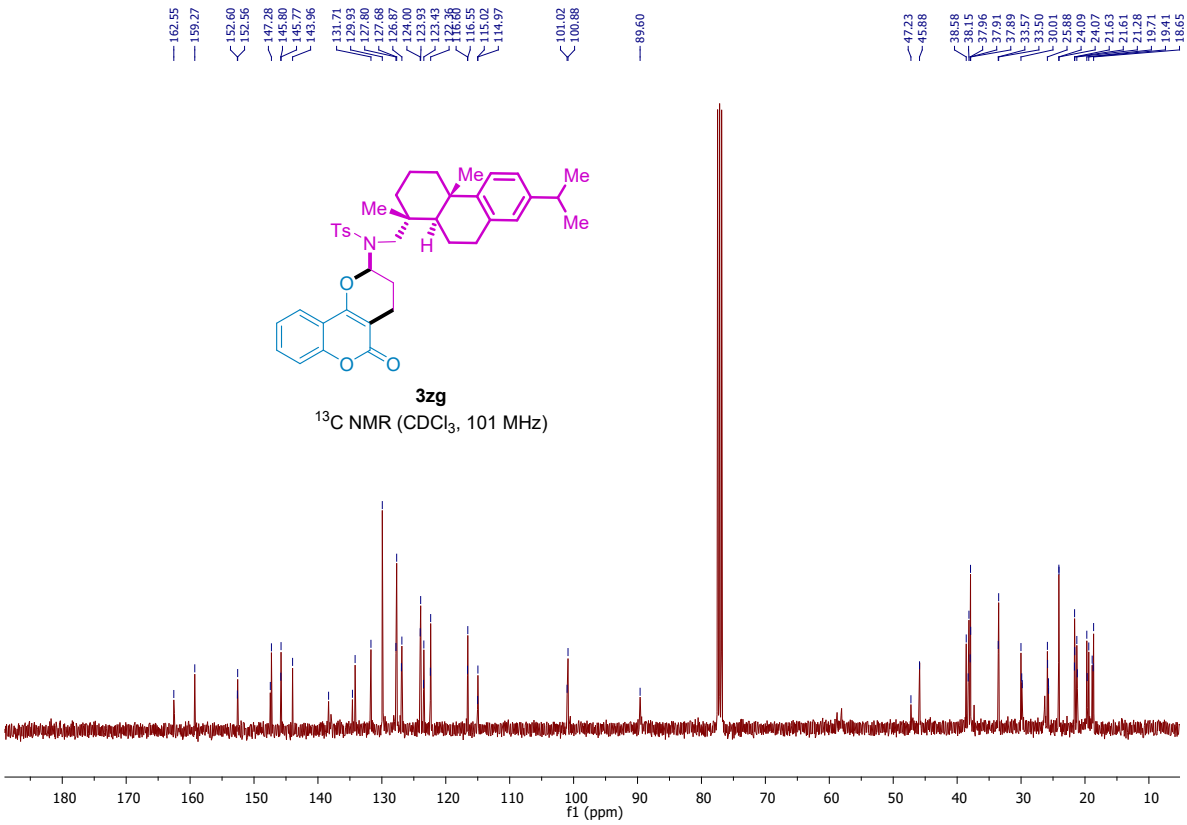
ethyl (R)-4-((4-methyl-N-(9-methyl-5-oxo-3,4-dihydro-2H,5H-pyrano[3,2-c]chromen-2-yl)phenyl)sulfonamido)benzoate (**3zf**):



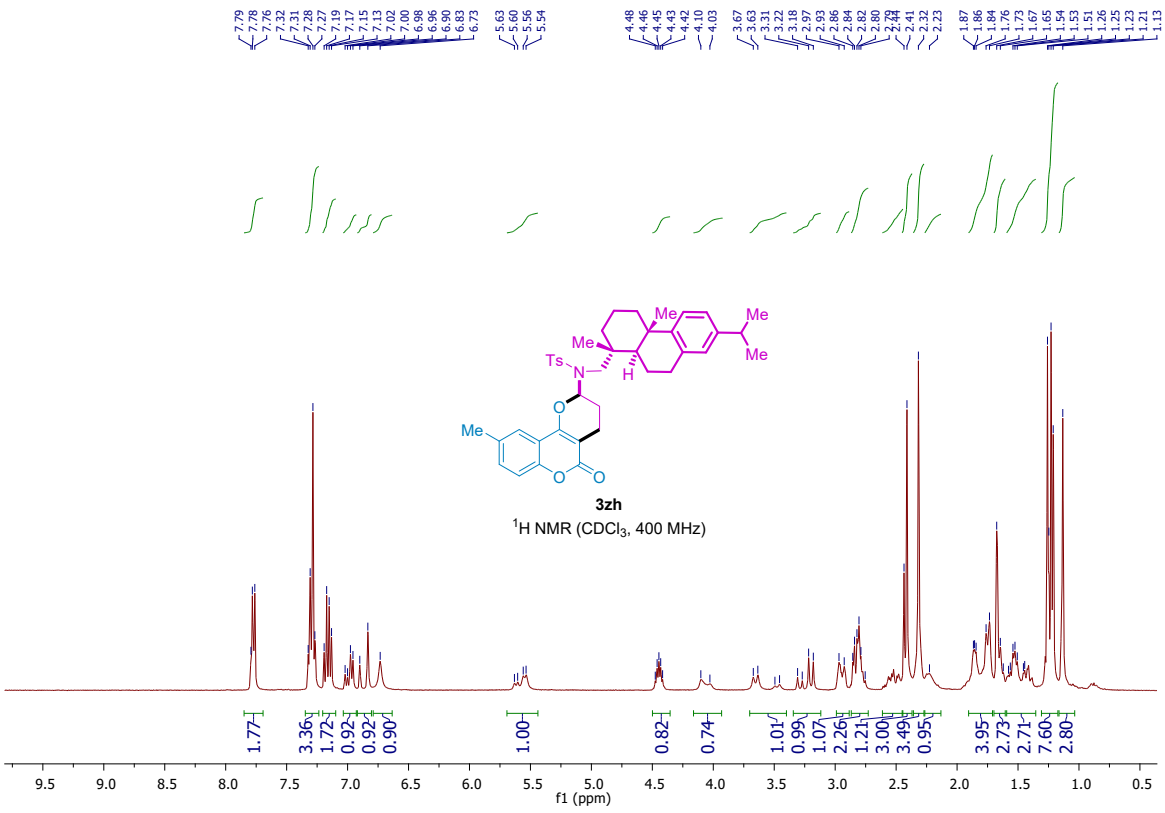


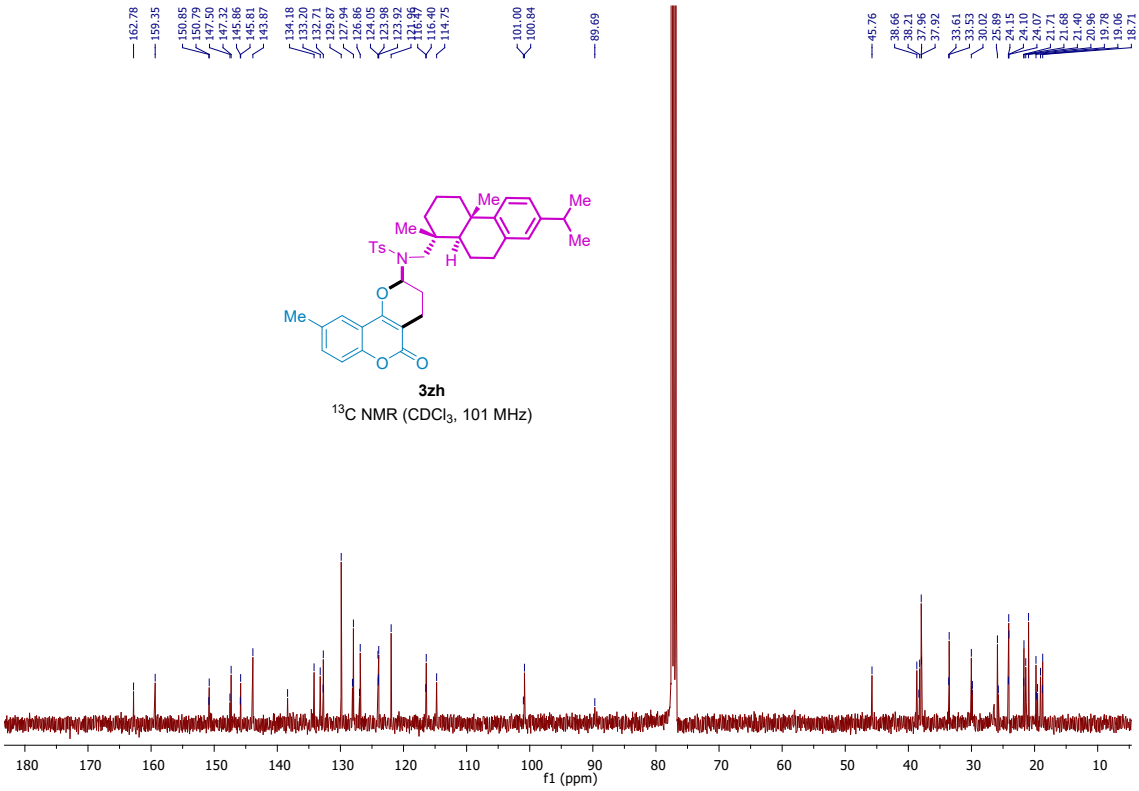
N-(((1R,4aS,10aR)-7-isopropyl-1,4a-dimethyl-1,2,3,4,4a,9,10,10a-octahydrophenanthren-1-yl)methyl)-4-methyl-N-((R)-5-oxo-3,4-dihydro-2H,5H-pyrano[3,2-c]chromen-2-yl)benzenesulfonamide (**3zg**):



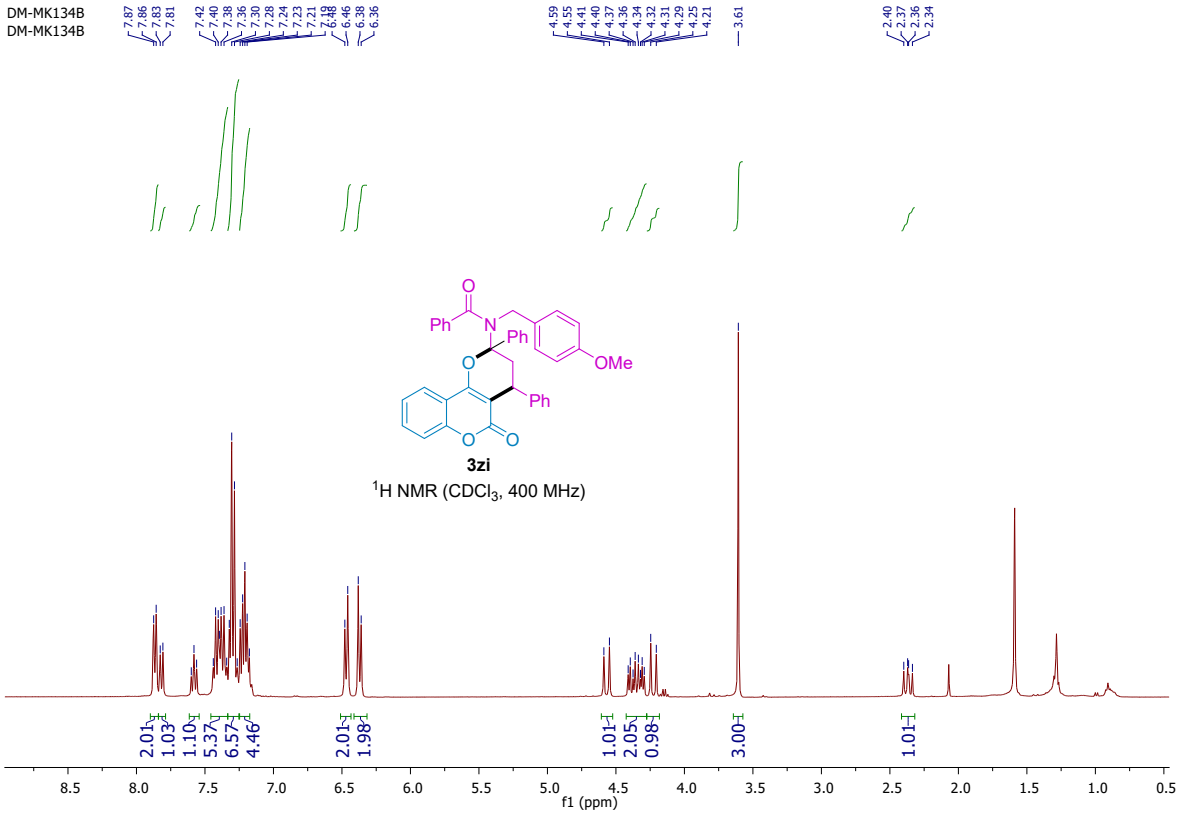


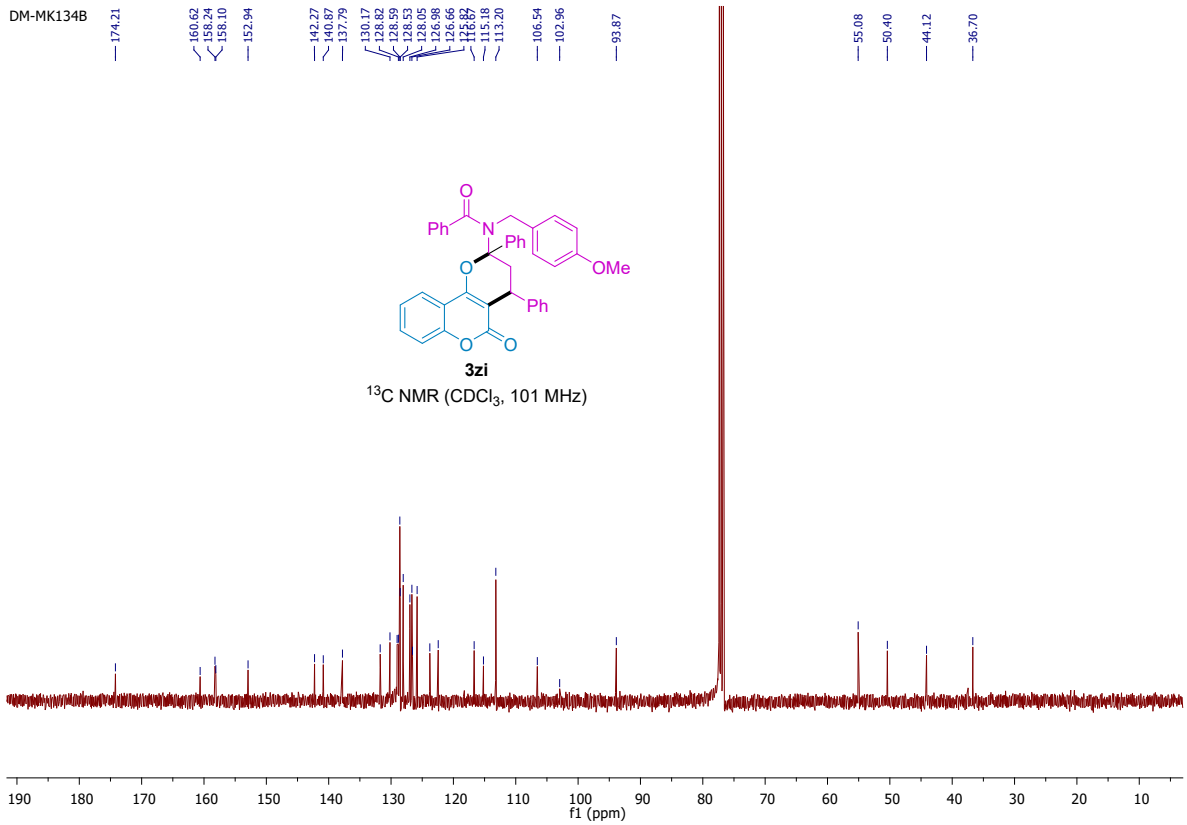
N-(((1R,4aS,10aR)-7-isopropyl-1,4a-dimethyl-1,2,3,4,4a,9,10,10a-octahydrophenanthren-1-yl)methyl)-4-methyl-N-((R)-9-methyl-5-oxo-3,4-dihydro-2H,5H-pyrano[3,2-c]chromen-2-yl)benzenesulfonamide (**3zh**):



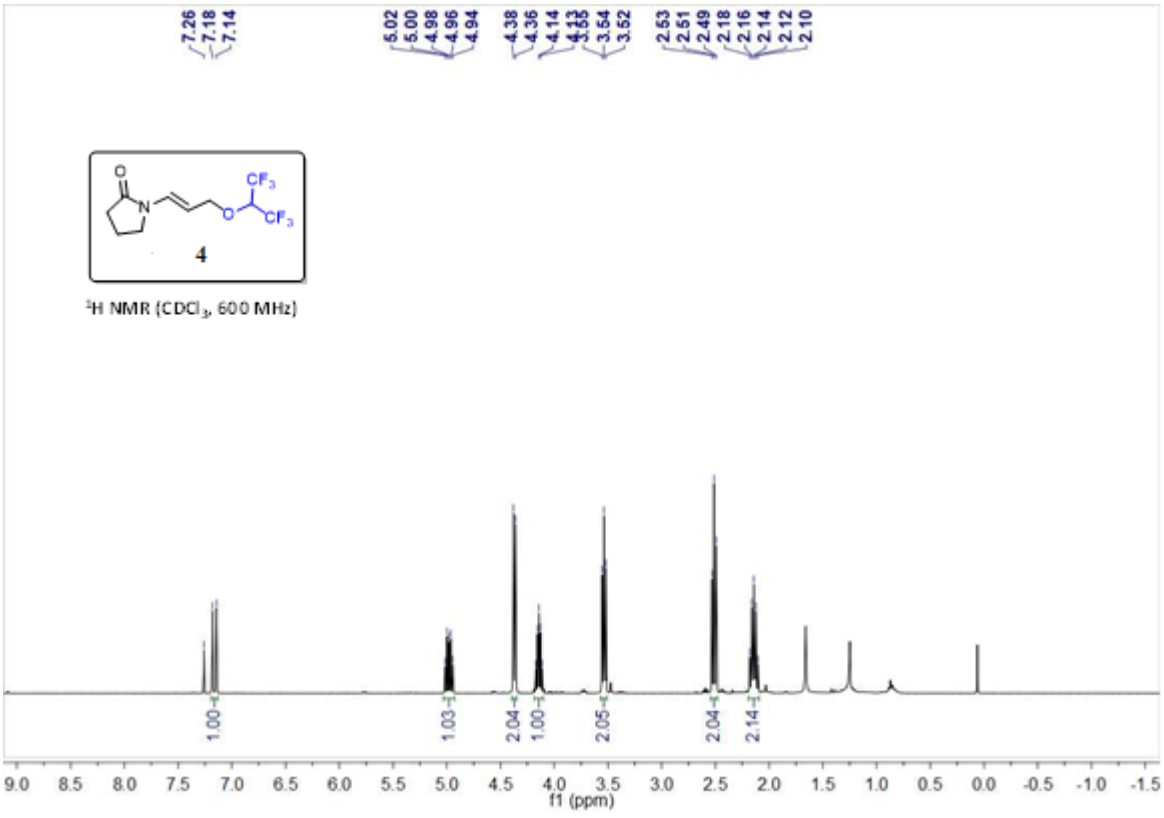


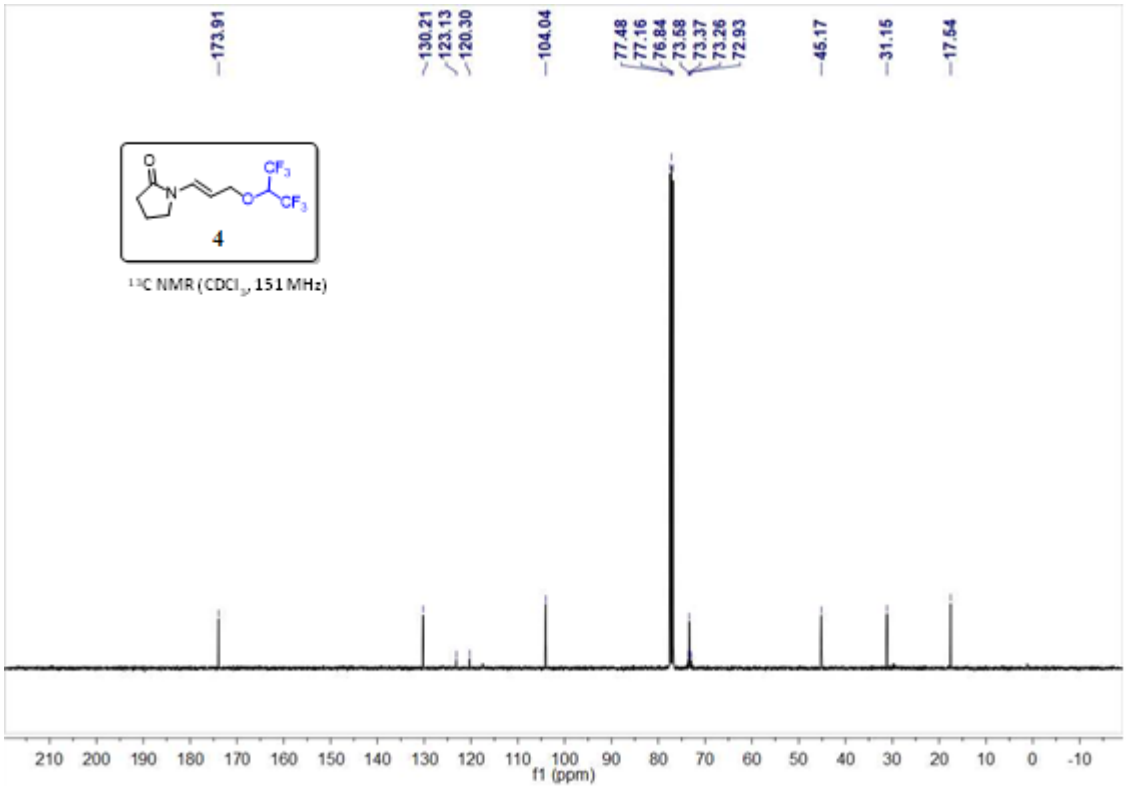
N-(4-methoxybenzyl)-N-((2R,4S)-5-oxo-2,4-diphenyl-3,4-dihydro-2H,5H-pyrano[3,2-c]chromen-2-yl)benzamide (**3zi**):

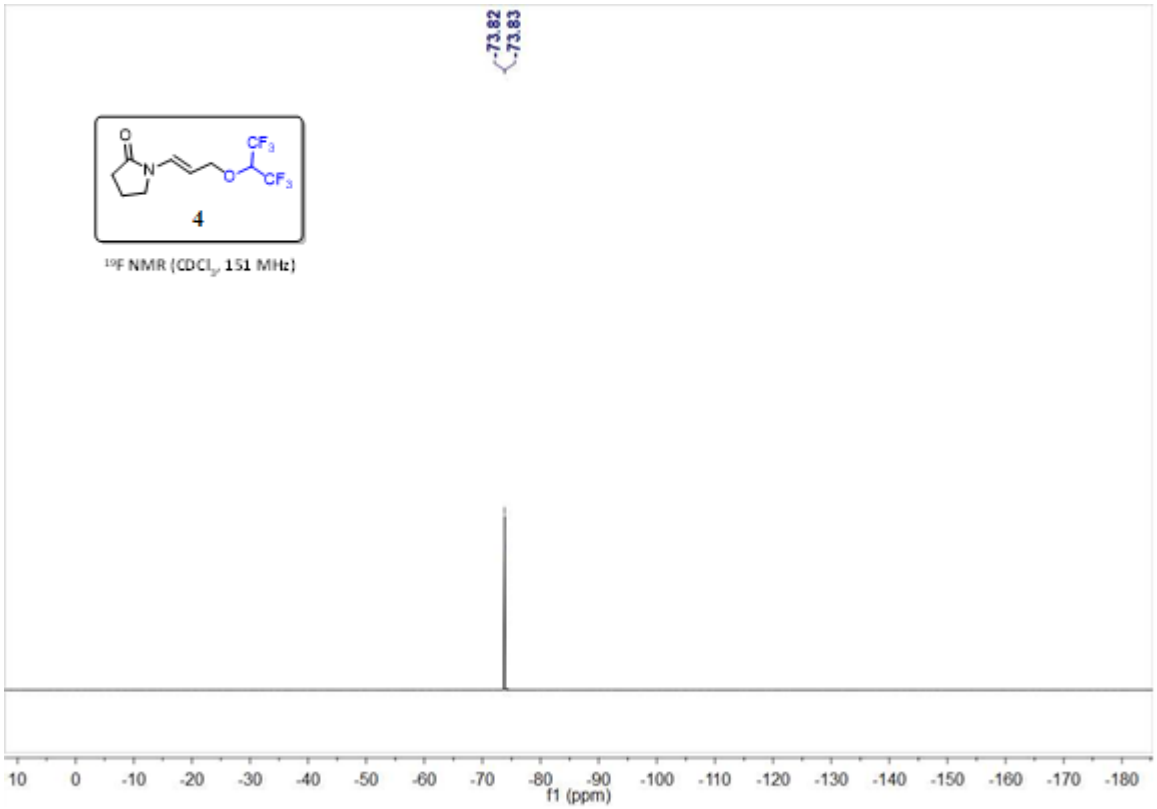




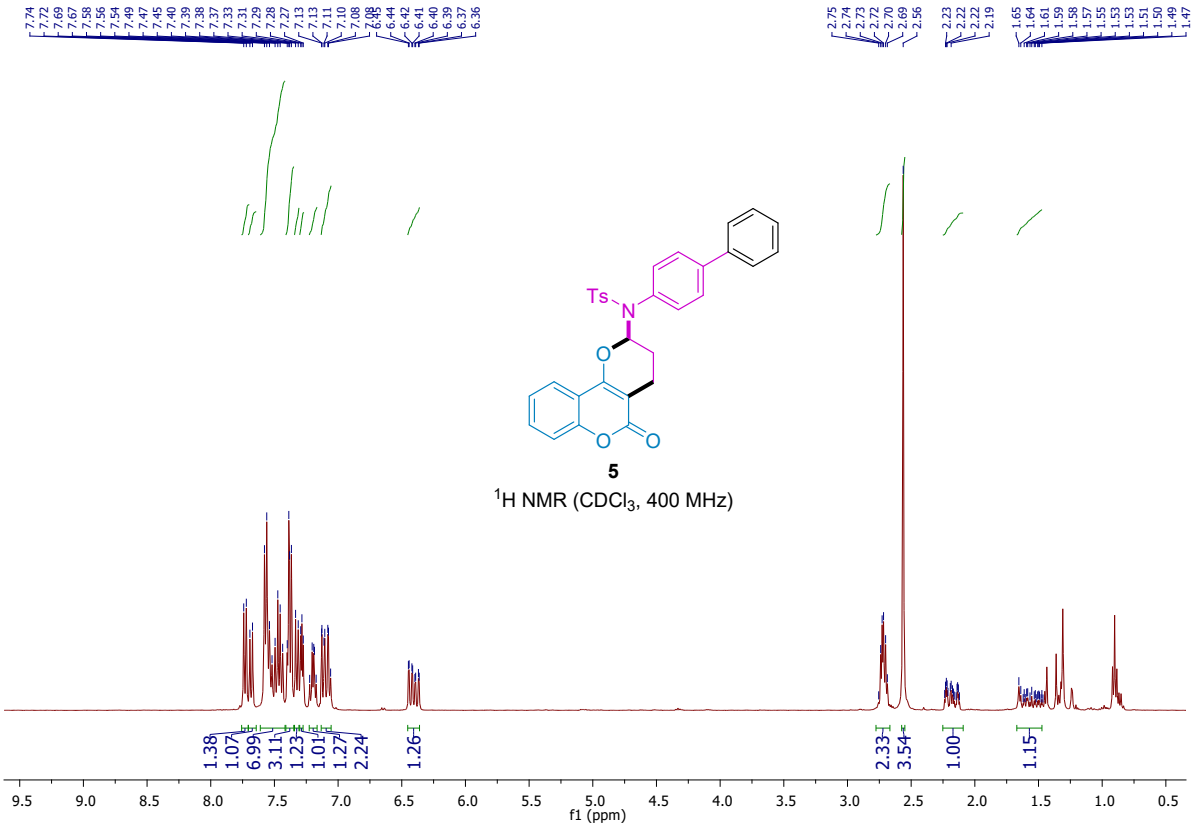
11. (E)-1-(3-((1,1,1,3,3,3-hexafluoropropan-2-yl)oxy)prop-1-en-1-yl)pyrrolidin-2-one (**4**):

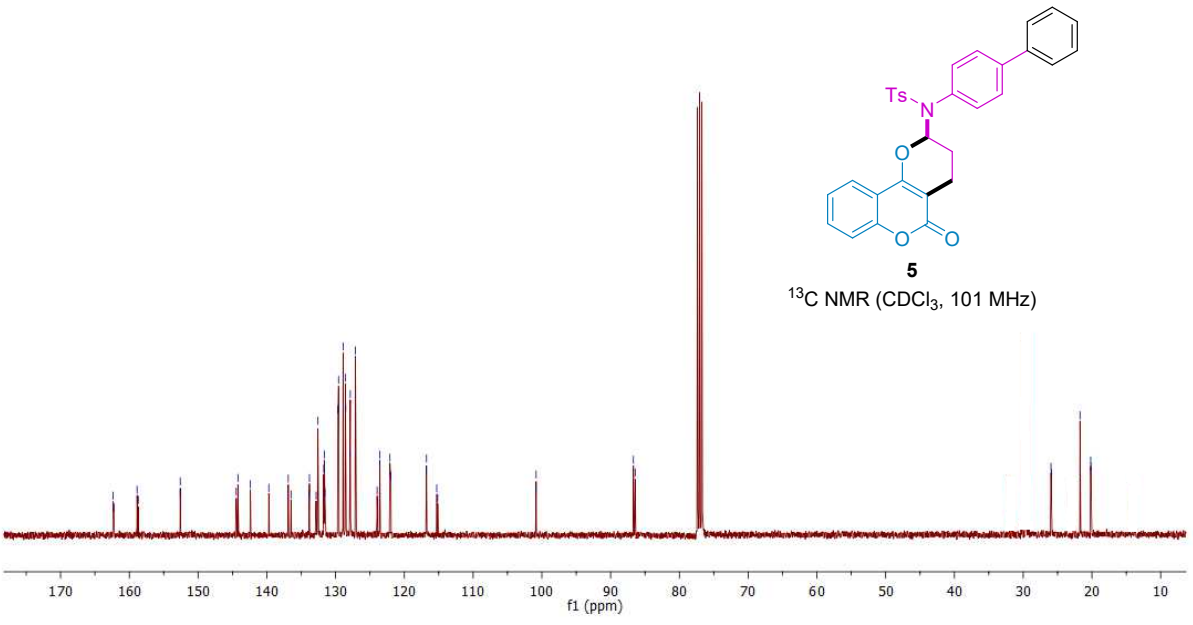



173.91
130.21
123.13
120.30
104.04
77.48
77.16
76.84
73.58
73.37
73.26
72.93
45.17
31.15
17.64
4
13C NMR (CDCl3, 151 MHz)
f1 (ppm)

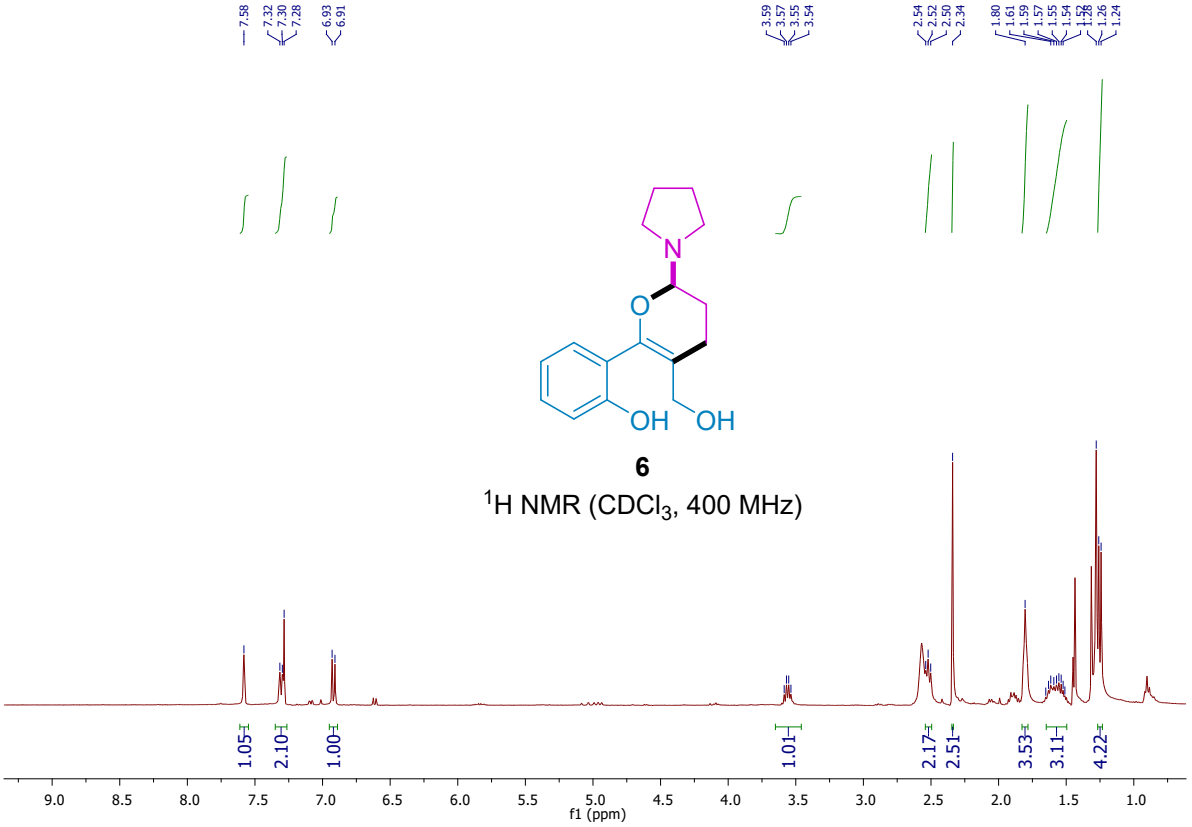

-73.82
-73.83
4
19F NMR (CDCl3, 151 MHz)
f1 (ppm)

12. (R)-N-([1,1'-biphenyl]-4-yl)-4-methyl-N-(5-oxo-3,4-dihydro-2H,5H-pyrano[3,2-c]chromen-2-yl)benzenesulfonamide (**5**): (Rotamer, 1:1)



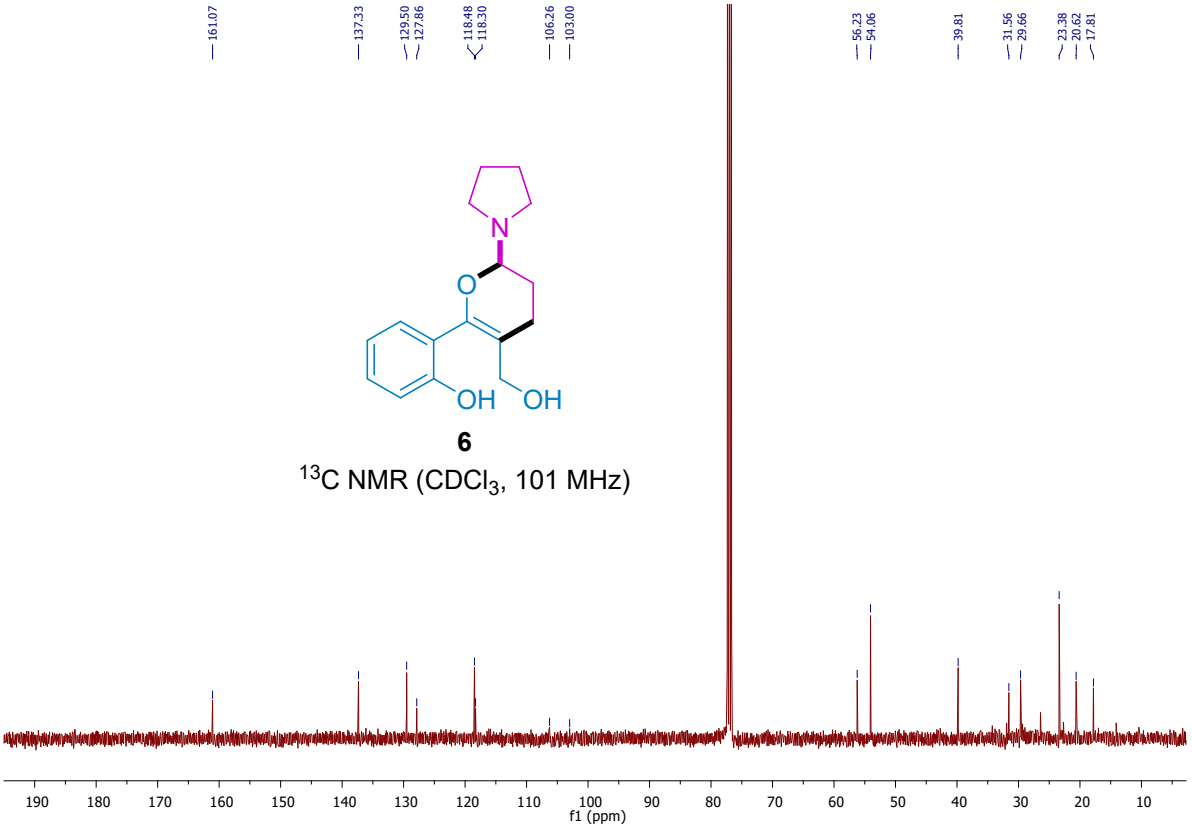


(R)-2-(5-(hydroxymethyl)-2-(pyrrolidin-1-yl)-3,4-dihydro-2H-pyran-6-yl)phenol (**6**)



6

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



6

^{13}C NMR ($CDCl_3$, 101 MHz)