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Visible-Light-Mediated [2+2+1] Carbocyclization Reactions of 1,7-Enynes with Bromofluoroacetate to Form Fused Monofluorinated Cyclopenta[*c*]quinolin-4-ones

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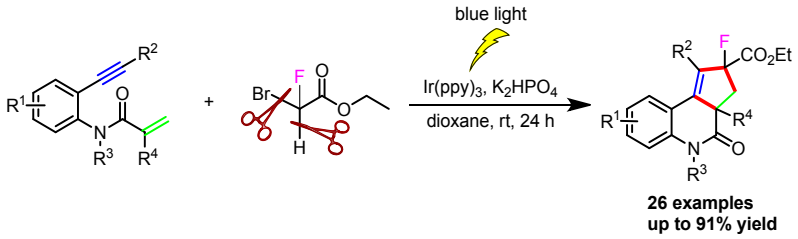


ABSTRACT: Herein we describe a new protocol for photoinduced radical [2+2+1] carbocyclization reactions of 1,7-enynes with bromofluoroacetate. These reactions, which proceed via a cascade involving fluoroalkylation, 6-*exo*-*dig* and 5-*endo*-*trig* cyclizations, H-transfer step, and oxidative dehydrogenation, provide an efficient and general route to a variety of fused monofluorinated cyclopenta[*c*]quinolin-4-one derivatives.

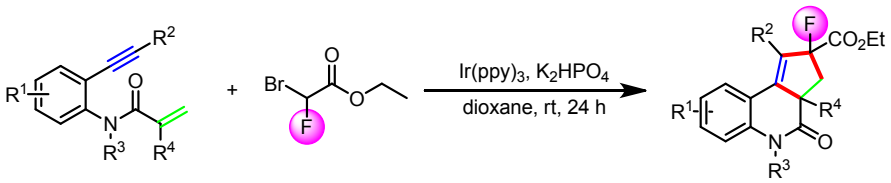
INTRODUCTION

Because complex heteroatom-containing polycyclic hydrocarbon motifs can be found in numerous bioactive molecules, including natural products and pharmaceuticals,[1] considerable research effort has been aimed at developing novel and efficient methods for their synthesis.[2] In addition, methods for incorporating fluorine atoms into carbocycles and heterocycles have attracted interest because fluorine-containing compounds show unique electronegativity, hydrophobicity, metabolic stability, and bioavailability.[3,4] In fact, approximately 20% of drugs and 30% of pesticides currently on the market contain fluorine atoms.[5] Recently, radical enabled bicyclization involved H-transfer of 1,*n*-enynes were used to synthesize heteroatom-containing polycyclic hydrocarbon motifs.[6] For example, Li group

reported a visible light-initiated C(sp3)-Br/C(sp3)-H functionalization of *a*-carbonyl alkyl bromides through hydride radical shift,[7a] and Xia group reported a visible-light-mediated 1,7-enyne bicyclizations protocol for synthesis of heteroatom-containing polycyclic compounds.[7b] In previous work, we developed a copper-catalyzed 1,7-enyne trifluoromethylation/bicyclization reaction with Togni's reagent, which serves as a method for the synthesis of CF_3-containing heterocycles such as indenes, dihydroquinolinones, and dihydrocoumarin-fused tetracyclic compounds.[8] In addition, Tang group reported an efficient and general method for photoredox-catalyzed atom transfer radical addition and cyclization reactions of perfluoroalkyl halides with 1,7-enynes.[9]

Although considerable progress has been made in the synthesis of fluorine-containing heterocycles, the use of 1,*n*-enynes for domino cyclizations initiated by radicals containing a single fluorine atom to afford polycyclic structures has never been reported. Inspired by recent developments in radical-triggered 1,*n*-enyne cyclization reactions, and as part of our ongoing work on the preparation of useful monofluorinated heterocycles, we designed a series of 1,7-enynes with the aim of preparing monofluorinated cyclopenta[*c*]quinolin-4-one derivatives via visible-light-mediated [2+2+1] carbocyclization (Scheme 1).

Scheme 1. Cyclization Reactions of 1,7-Enynes

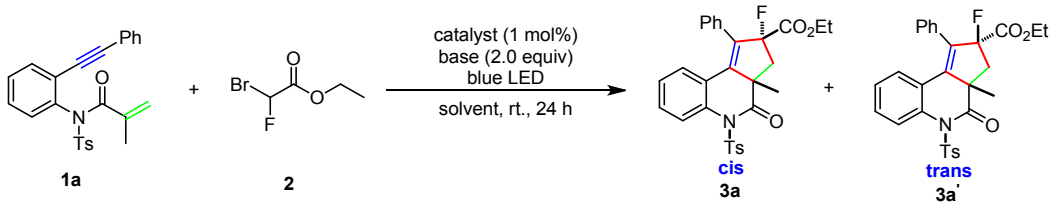


RESULTS AND DISCUSSION

We began our investigation by examining the reactions of 1,7-enyne **1a** (0.2 mmol) with ethyl bromofluoroacetate (**2**) (0.4 mmol) and K_2HPO_4 (0.4 mmol) in the presence of various catalysts in THF at room temperature with irradiation by a blue LED (approximately 2 cm away from the light source) (Table 1). To our delight, when *fac*-Ir(ppy)$_3$ (0.002 mmol) was used as the catalyst, reaction for 24 h afforded desired product **3a** in 94% yield (as determined by ^{19}F NMR spectroscopy, entry 1) with a diastereomeric ratio of 8:1. Attempting to improve the yield, we evaluated other bases (K_2CO_3, Na_2HPO_4, Na_2CO_3, Cs_2CO_3, 2,6-lutidine, and

1,4-diazabicyclo[2.2.2]octane; entries 2 – 7), but none of them performed better than K_2HPO_4. The other photoredox catalysts we tested (entries 8 – 11) failed to catalyze the desired reaction. We also evaluated solvents other than THF (entries 12 – 18) and found that dioxane was the most effective, increasing the yield of **3a** to 94%. The yield decreased when the amount of **2**, $Ir(ppy)_3$, or base was decreased (entries 19 – 21). The blue light and the argon atmosphere were necessary for the reaction (entries 22 and 23). In terms of both yield and diastereoselectivity, the combination of $Ir(ppy)_3$ as the catalyst, K_2HPO_4 as the base, and dioxane as the solvent was optimal (entry 18).

Table 1. Optimization of Reaction Conditions[a]



entry	catalyst	base	solvent	yield (%)[b]	dr[c]
1	*fac*-$Ir(ppy)_3$	K_2HPO_4	THF	90	8:1
2	*fac*-$Ir(ppy)_3$	K_2CO_3	THF	60	6:1
3	*fac*-$Ir(ppy)_3$	Na_2HPO_4	THF	54	10:1
4	*fac*-$Ir(ppy)_3$	Na_2CO_3	THF	67	8:1
5	*fac*-$Ir(ppy)_3$	Cs_2CO_3	THF	80	8:1
6	*fac*-$Ir(ppy)_3$	2,6-lutidine	THF	28	3:1
7	*fac*-$Ir(ppy)_3$	DABCO	THF	20	>25:1
8	Acid Red 87	K_2HPO_4	THF	N.R.	—
9	$Ru(bpy)_3PF_6$	K_2HPO_4	THF	N.R.	—
10	$Ru(bpy)_3Cl_2·6H_2O$	K_2HPO_4	THF	N.R.	—
11	$[Ir(dtppy)(ppy)_2]PF_6$	K_2HPO_4	THF	N.R.	—
12	*fac*-$Ir(ppy)_3$	K_2HPO_4	DMF	40	8:1
13	*fac*-$Ir(ppy)_3$	K_2HPO_4	DMSO	52	>25:1
14	*fac*-$Ir(ppy)_3$	K_2HPO_4	MeCN	28	10:1
15	*fac*-$Ir(ppy)_3$	K_2HPO_4	MTBE	17	>25:1
16	*fac*-$Ir(ppy)_3$	K_2HPO_4	DME	67	9:1

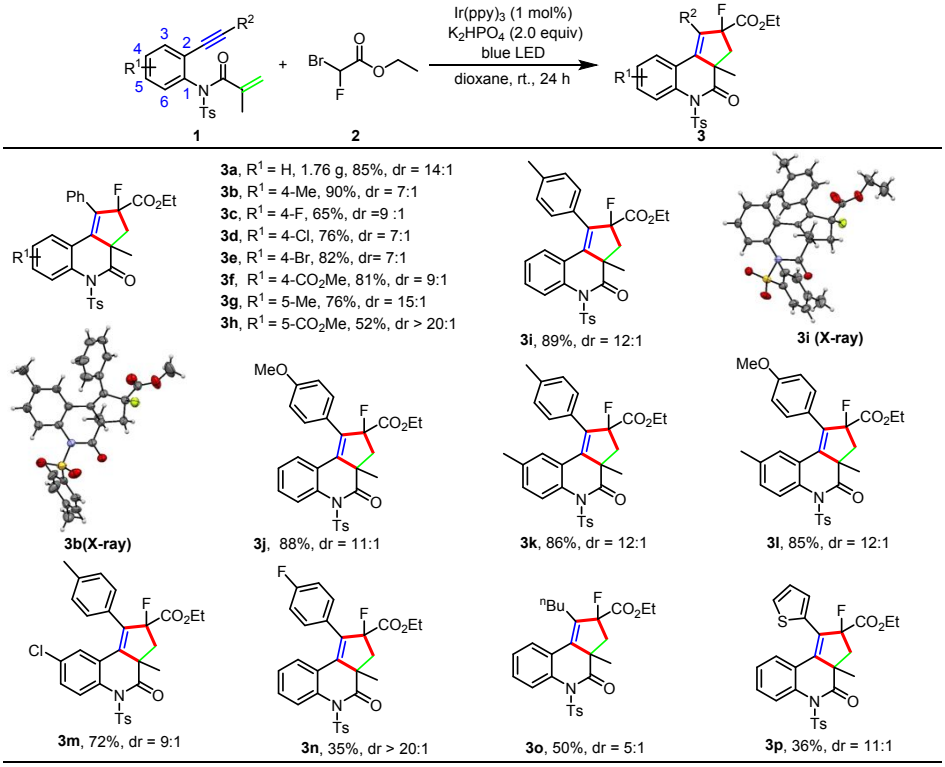
17	*fac*-Ir(ppy)$_3$	K_2HPO_4	DCM	44	12:1
18	*fac*-Ir(ppy)$_3$	K_2HPO_4	dioxane	94	14:1
19[d]	*fac*-Ir(ppy)$_3$	K_2HPO_4	dioxane	42	10:1
20[e]	*fac*-Ir(ppy)$_3$	K_2HPO_4	dioxane	77	12:1
21[f]	*fac*-Ir(ppy)$_3$	K_2HPO_4	dioxane	71	11:1
22[g]	*fac*-Ir(ppy)$_3$	K_2HPO_4	dioxane	N.R.	—
23[h]	*fac*-Ir(ppy)$_3$	K_2HPO_4	dioxane	N.R.	—

[a]Reaction conditions, unless otherwise noted: **1a** (0.2 mmol), *fac*-Ir(ppy)$_3$ (0.002 mmol), base (0.4 mmol), **2a** (0.4 mmol), solvent (anhydrous, 2 mL), 3 W blue LED (approximately 2 cm away from the light source), room temperature, under an Ar atmosphere. [b]Determined by ^{19}F NMR spectroscopy with (trifluoromethyl)benzene as an internal standard; N.R. = no reaction. [c]Diastereomeric ratio (dr) refers to the ratio of *cis* compound **3a** to *trans* compound **3a**. [d]The amount of *fac*-Ir(ppy)$_3$ was 0.001 mmol. [e]The amount of **2a** was 0.24 mmol. [f]The amount of base was 0.24 mmol. [g]The reaction was carried out in air. [h]The reaction was carried out in the dark.

To explore the generality of the protocol, we carried out reactions of various benzene-tethered 1,7-enynes **1** (Scheme 2). First, we evaluated the effect of the R^1 substituent on the benzene ring. These experiments showed that a variety of substituents were suitable for constructing cyclopenta[*c*]quinolin-4-ones **3b**–**3h** in moderate to excellent yields. Enynes with electron-donating substituents (**3b** and **3g**) showed higher yields than those with electron-withdrawing substituents (**3f** and **3h**); and the position of the substituent also affected the yield (compare **3b** with **3g** and **3f** with **3h**). Several substituents, namely, Me, Cl, and F, on the benzene ring were well-tolerated. We have tried to synthesize the substrate containing pyridine or cis alkenyl substrates, but we have difficult in synthesizing the alkenyl substrates, the substrate containing pyridine only can be obtained in trace which was difficult to separate. Second, we investigated the effects of the R^2 substituent on the terminal alkyne. When R^2 was an electron-rich aromatic group, the corresponding products (**3i**–**3m**) were obtained in good yields. In contrast, electron-deficient aromatic groups, alkyl groups, and heteroaryl groups showed lower reactivities (**3n–3p**). The structures of **3b** and **3i** were determined by X-ray crystallographic analysis.[10] In addition, the protocol was amenable to scale up: the reaction of **1a** with **2** carried out on a 4.0 mmol scale under standard conditions was complete within 48 h and gave **3a** in 85%

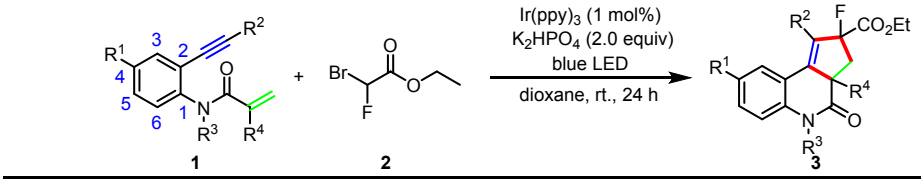
yield (1.76 g, Scheme 2).

Scheme 2. Reaction Scope with Respect to R^1 and R^2 of the 1,7-Enyne.

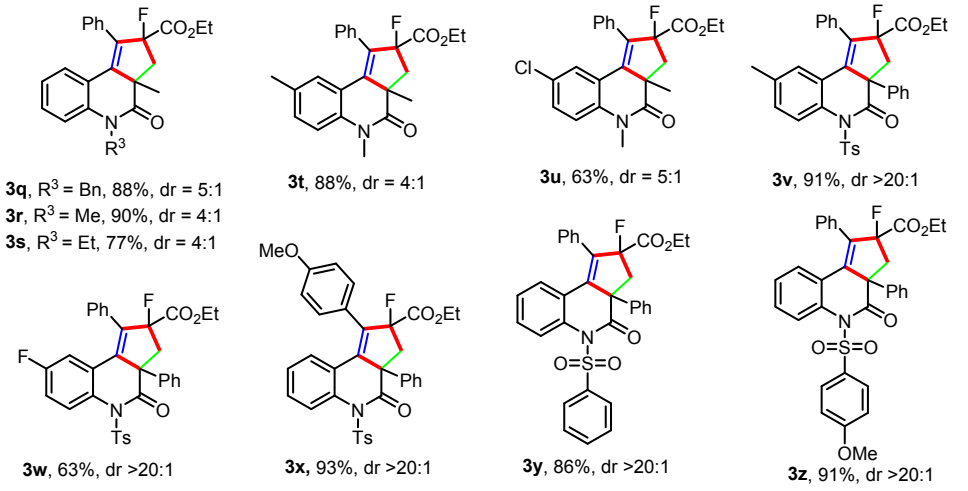


Various R^3 substituents (benzyl, methyl, and ethyl) on the nitrogen were also well-tolerated under the standard conditions (Scheme 3), affording the corresponding products (**3q**–**3u**) in good yields; but the diastereoselectivity of these reactions was somewhat lower than that observed with the *N*-Ts enynes. When R^4 was a phenyl group (**3v**–**3z**), the diastereoselectivity of the reaction was better than when R^4 was a Me group; the *cis*/*trans* ratio exceeded 20:1 in all cases, even when R^3 was changed from Ts to benzenesulfonyl (**3y**) or 4-methoxybenzenesulfonyl (**3z**), and the yields were high. We tried to use 2-bromo-*N*-ethyl-2-fluoroacetamide as the free radical precursor, but no desired product can be obtained under the standard conditions. Beta-substituted methacrylamide derivatives are not suitable to the reaction due to the steric hindrance and the complexity of products.

Scheme 3. Reaction Scope with Respect to R^3 and R^4 of the 1,7-Enyne



1 2 3



3q, R^3 = Bn, 88%, dr = 5:1
3r, R^3 = Me, 90%, dr = 4:1
3s, R^3 = Et, 77%, dr = 4:1

3t, 88%, dr = 4:1

3u, 63%, dr = 5:1

3v, 91%, dr >20:1

3w, 63%, dr >20:1

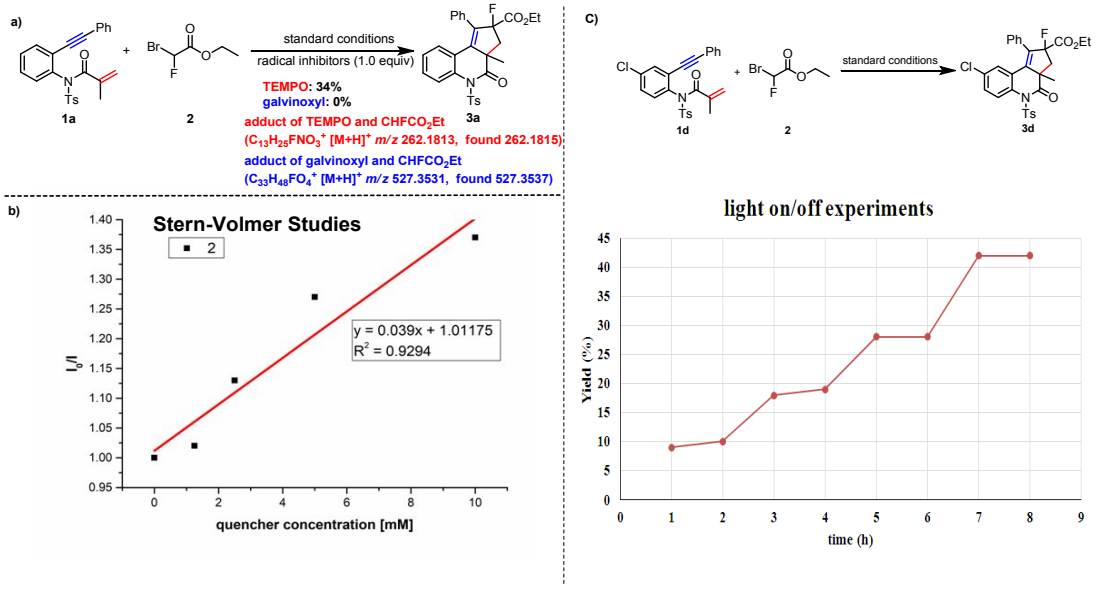
3x, 93%, dr >20:1

3y, 86%, dr >20:1

3z, 91%, dr >20:1

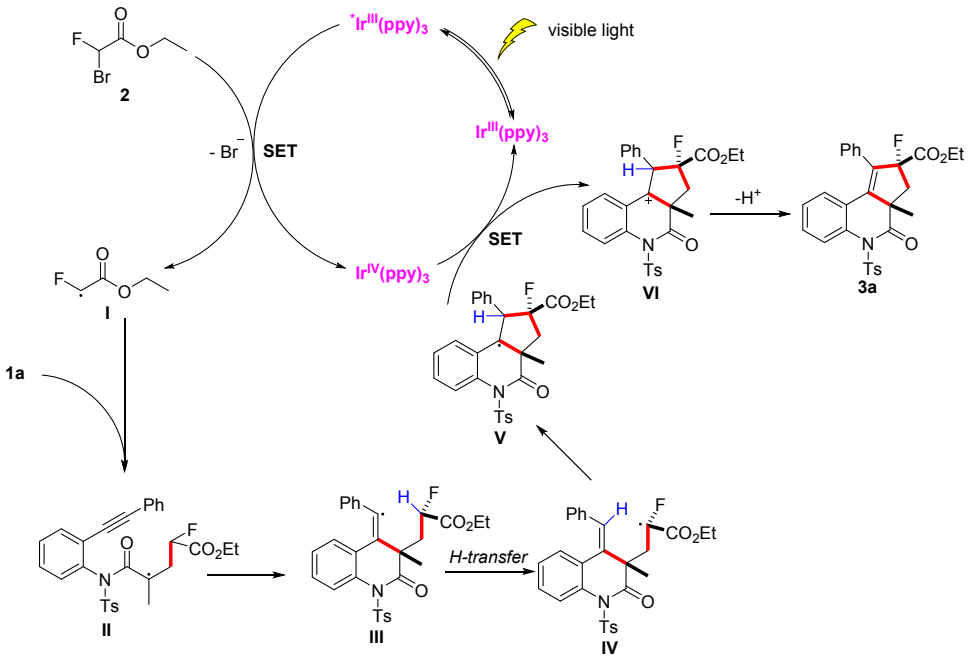
To gain insight into the reaction mechanism, we conducted some control experiments (Scheme 4). When the reaction **1a** and **2** was performed in the presence of 1 equiv of the radical inhibitor TEMPO (2,2,6,6-tetramethylpiperidine-1-oxyl), the yield decreased dramatically (to 34%); and none of the desired product formed in the presence of the radical scavenger galvinoxyl. Furthermore, TEMPO and galvinoxyl adducts of ethyl 2-fluoroacetate radical (generated in situ) were detected by LC-MS (see Supporting Information for details). These results indicate that the reaction may have proceeded through a radical pathway. Fluorescence quenching analysis revealed that **2** was an effective quencher of the excited state photocatalyst (see Supporting Information for details). To determine whether radical propagation was involved, we performed light on/off experiments with **1d** as a substrate, which showed the irradiation dependence of the reaction yield and thus ruled out the involvement of radical chain pathway.

Scheme 4. Control Experiments



On the basis of control experiments and literature precedents, we propose the mechanism outlined in Scheme 5. Irradiation of [*fac*-^{III}Ir(ppy)$_3$] by visible light generates the excited state [*fac*-^{III}Ir(ppy)$_3$]*, which is oxidized by ethyl bromoacetate **2** to generate radical **I**.[11] The radical of ethyl 2-fluoroacetate (I) is an electron-deficient radical, which tends to react with more electron-rich alkenes, therefore, radical **I** is captured by the C–C double bond of 1,7-enyne **1a**, and subsequent *6-exo-dig* cyclization with the C–C triple bond affords radical intermediate **III**. Then a H-transfer step shift generates radical intermediate **IV**, which undergoes a *5-endo-trig* cyclization to form intermediate **V**.[12] The substituents (R^2, R^3, and R^4) have synergetic effects on diastereoselectivity (Scheme 1). They achieve the diastereoselectivity mainly by influencing the most favorable spatial configuration of the intermediate **IV** to **V** for the *5-endo-trig* cyclization reaction. After oxidization by *fac*-^{IV}Ir(ppy)$_3$ and loss of a proton, intermediate **V** is converted to final product **3a**.

Scheme 5. Proposed Mechanism



CONCLUSIONS

In conclusion, we have developed a protocol for visible-light-mediated [2+2+1] carbocyclization reactions of 1,7-enynes with ethyl bromoacetate **2** for the synthesis of fused monofluorinated cyclopenta[*c*]quinolin-4-one derivatives. This novel mild protocol has good functional group tolerance and high yields. A study of the mechanism indicated that a radical fluoromethylation and sequential *6-exo-dig* and *5-endo-trig* cyclization processes are involved. The activity against of two representative compounds tobacco mosaic virus highlighted the potential utility of this protocol for the construction of bioactive functionalized polycycles.

EXPERIMENTAL SECTION

General Experimental Information. All solvents and chemicals were used as purchased unless stated otherwise. Blue light-emitting diode (LED) (3 W, max = 455 nm, intensity: 450 mW) purchased from JIADENG (LS) was used for blue light irradiation. A fan attached to the apparatus was used to maintain the reaction temperature at room temperature. The material of the irradiation vessel was borosilicate glass. ^{1}H, ^{13}C, and ^{19}F Nuclear Magnetic Resonance (NMR) spectra were recorded on Bruker Avance 400 Ultrashield NMR spectrometers. Chemical shifts (δ) were given in parts per million (ppm) and were measured downfield from internal tetramethylsilane. High-resolution mass spectrometry (HRMS) data were obtained on an FTICR-MS instrument with q-TOF mass analyzer (Ionspec 7.0 T). Single crystal

X-ray structure data were collected on Rigaku Saturn 70. The melting points were determined on an X-4 microscope melting point apparatus and are uncorrected. Conversion was monitored by thin layer chromatography (TLC). Flash column chromatography was performed over silica gel (200-300 mesh).

General procedures for the synthesis of 1

To a 100 mL flask were added 2-iodoaniline (10 mmol), $Pd(PPh_3)_2Cl_2$ (210 mg, 0.3 mmol), CuI (87 mg, 0.3 mmol), Et_3N (40 mL). After degassing with argon and four evacuation/backfill-cycles with argon, alkyne was added dropwise. The reaction mixture was heated with heating mantle and stirred at 45℃. When the reaction was complete as monitored by TLC, the resulting mixture was purified by column chromatography on silica gel to afford the product 2-ethynylaniline.

Method 1 (1a-1p, 1v-1z)： To a solution of 2-ethynylaniline (5 mmol) in chloroform/pyridine (30 mL, V/V=1:9) in 100 mL flask were added TsCl (953 mg, 5 mmol), the reaction mixture was stirred at room temperature. When the reaction was complete as monitored by TLC, concentrated under reduced pressure, dilute hydrochloric acid was added, the mixture was extracted with ethyl acetate for 3 times. The combined organic layer was dried over anhydrous Na_2SO_4, filtered, evaporated to afford the desired product *N*-(2-ethynylphenyl)benzenesulfonamides.

Method 2 (1q-1u)： To a solution of 2-ethynylaniline (5 mmol) in THF (30 mL) were added *n*-butyllithium (1.6 M in hexanes) (9.4 mL, 15 mmol) at -78℃ under argon atmosphere in a four-necked flask, R^3I was added 2 h later, and the mixture was warmed to room temperature. When the reaction was complete as monitored by TLC, water was added to quench reaction under ice bath, the mixture was extracted with ethyl acetate for 3 times. The combined organic layer was dried over anhydrous Na_2SO_4, filtered, evaporated, the resulting mixture was purified by column chromatography on silica gel to afford the product *N*-alkyl-2-ethynylanilines.

To a solution of *N*-(2-ethynylphenyl)benzenesulfonamides or *N*-alkyl-2-ethynylanilines (1 equiv) and Et_3N (2 equiv) in dichloromethane was added corresponding methacryloyl chloride (1.5 equiv) dropwise, then the mixture was allowed to warmed to room temperature, when the reaction was complete as monitored by TLC, water was added, the mixture was extracted with dichloromethane

for 3 times. The combined organic layer was dried over anhydrous Na_2SO_4, filtered, evaporated, the resulting mixture was purified by column chromatography on silica gel to afford the product **1**.

N-(2-(Phenylethynyl)phenyl)-N-tosylmethacrylamide (1a).[13a] White solid, 0.91 g, 86% yield; Mp 209–210 ºC, R_f = 0.40 (petroleum ether/EtOAc, 10:1); ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.92 (d, J = 8.0 Hz, 2H), 7.63 (d, J = 7.2 Hz, 1H), 7.51 – 7.36 (m, 3H), 7.29 (t, J = 7.6 Hz, 1H), 7.22 (t, J = 7.2 Hz, 2H), 7.09 – 7.01 (m, 4H), 5.24 (d, J = 4.8 Hz, 2H), 2.08 (s, 3H), 1.77 (s, 3H). ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 170.6, 144.7, 139.1 138.8, 136.2, 132.7, 132.6, 131.5, 130.0, 129.2, 128.9, 128.8, 128.7, 128.0, 123.8, 123.4, 121.9, 94.8, 85.5, 21.4, 19.2. HRMS (ESI) calcd for $C_{25}H_{21}NO_3S[M+H]^+$ 416.1315, found 416.1315.

N-(4-methyl-2-(phenylethynyl)phenyl)-N-tosylmethacrylamide (1b).[13a] White solid, 0.85 g, 80% yield; Mp 160–161 ºC, R_f = 0.40 (petroleum ether/EtOAc, 10:1); ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.92 (d, J = 8.4 Hz, 2H), 7.49 (d, J = 8.4 Hz, 1H), 7.40 – 7.17 (m, 5H), 7.04 (d, J = 7.6 Hz, 4H), 5.24 (s, 2H), 2.38 (s, 3H), 2.07 (s, 3H), 1.77 (s, 3H). ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 170.6, 144.7, 139.5, 139.1, 136.3, 136.2, 133.2, 132.3, 131.4, 130.0, 129.9, 128.9, 128.7, 128.0, 123.6, 123.0, 122.0, 94.4, 85.7, 21.4, 21.1, 19.2. HRMS (ESI) calcd for $C_{26}H_{23}NO_3S[M+H]^+$ 430.1471, found 430.1471.

N-(4-fluoro-2-(phenylethynyl)phenyl)-N-tosylmethacrylamide (1c). 0.74 g, 74%; White solid, Mp 173–174 ºC, R_f = 0.30 (petroleum ether/EtOAc, 10:1); ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.91 (d, J = 8.4 Hz, 2H), 7.59 (dd, J = 8.4, 5.2 Hz, 1H), 7.34 – 7.11 (m, 5H), 7.14 – 6.85 (m, 4H), 5.27 (s, 1H), 5.22 (s, 1H), 2.08 (s, 3H), 1.78 (s, 3H).^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 170.4, 162.2 (d, J = 249.5 Hz), 144.9, 139.0, 136.0, 135.0, 134.3 (d, J = 9.3 Hz) 131.6, 129.9, 129.1, 129.0, 128.1, 125.1(d, J = 10.5 Hz), 123.9, 121.4, 119.1(d, J = 24.1 Hz), 116.4 (d, J = 22.9 Hz), 95.8, 84.5, 21.4, 19.2. ^{19}F NMR (376 MHz, $CDCl_3$) δ -111.3 (dd, J = 13.2, 7.5 Hz). HRMS (ESI) calcd for $C_{25}H_{20}FNO_3S$ $[M+H]^+$ 434.1221, found 434.1220.

N-(4-chloro-2-(phenylethynyl)phenyl)-N-tosylmethacrylamide (1d).[13a] 0.68 g, 63% yield; White solid, Mp 185–186 ºC, R_f = 0.30 (petroleum ether/EtOAc, 10:1); ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.91 (d, J = 8.4 Hz, 2H), 7.55 (d, J = 8.8 Hz, 1H), 7.46 (d,

J = 2.4 Hz, 1H), 7.40 (dd, *J* = 8.4, 2.4 Hz, 1H), 7.34 – 7.19 (m, 3H), 7.10 – 7.00 (m, 4H), 5.29 (s, 1H), 5.23 (s, 1H), 2.07 (s, 3H), 1.78 (s, 3H). $^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$) δ 170.3, 144.9, 139.0, 137.4, 136.0, 135.1, 133.6, 132.3, 131.6, 129.9, 129.9, 129.1, 129.0, 128.1, 124.8, 124.1, 121.4, 95.9, 84.3, 21.4, 19.2. HRMS (ESI) calcd for $C_{25}H_{20}ClNO_3S$ $[M+H]^+$ 450.0925, found 450.0924.

N-(4-bromo-2-(phenylethynyl)phenyl)-N-tosylmethacrylamide (1e). 0.91 g, 74%; White solid, Mp 183–184 ºC, R_f = 0.30 (petroleum ether/EtOAc, 10:1); ^1H NMR (400 MHz, $CDCl_3$) δ 7.90 (d, *J* = 8.4 Hz, 2H), 7.62 (d, *J* = 1.6 Hz, 1H), 7.58– 7.53 (m, 1H), 7.51– 7.46 (m, 1H), 7.38 – 7.16 (m, 3H), 7.05 (t, *J* = 6.8 Hz, 4H), 5.29 (s, 1H), 5.23 (s, 1H), 2.07 (s, 3H), 1.78 (s, 3H).$^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$) δ 170.2, 144.9, 138.9, 137.9, 136.0, 135.2, 133.8, 132.1, 131.6, 129.9, 129.1, 129.0, 128.1, 125.1, 124.2, 123.0, 121.4, 96.0, 84.1, 21.4, 19.1. HRMS (ESI) calcd for $C_{25}H_{20}BrNO_3S$ $[M+H]^+$ 494.0420, found 494.0418.

Methyl (phenylethynyl)-4-(N-tosylmethacrylamido)benzoate (1f).[13e] 0.81 g, 69%; White solid, Mp 161–162 ºC, R_f = 0.40 (petroleum ether/EtOAc, 7:1); ^1H NMR (400 MHz, $CDCl_3$) δ 8.16 (d, *J* = 1.6 Hz, 1H), 8.07 (dd, *J* = 8.4, 2.0 Hz, 1H), 7.90 (d, *J* = 8.4 Hz, 2H), 7.72 (d, *J* = 8.4 Hz, 1H), 7.37 – 7.20 (m, 3H), 7.06 (d, *J* = 8.0 Hz, 4H), 5.27 (s, 1H), 5.22 (s, 1H), 3.96 (s, 3H), 2.08 (s, 3H), 1.78 (s, 3H). $^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$) δ 170.2, 165.5, 145.0, 142.5, 139.0, 136.0, 134.0, 132.7, 131.5, 130.8, 129.9, 129.6, 129.1, 129.0, 128.1, 124.4, 123.7, 121.5, 95.6, 84.6, 52.6, 21.4, 19.1. HRMS (ESI) calcd for $C_{27}H_{23}NO_5S$ $[M+H]^+$ 474.1370, found 474.1373.

N-(5-methyl-2-(phenylethynyl)phenyl)-N-tosylmethacrylamide (1g).[13e] 0.95 g, 87%; White solid, Mp 165–166 ºC, R_f = 0.30 (petroleum ether/EtOAc, 10:1); ^1H NMR (400 MHz, $CDCl_3$) δ 7.95 (d, *J* = 8.4 Hz, 2H), 7.47 (s, 1H), 7.39 (d, *J* = 7.9 Hz, 1H), 7.33 – 7.18 (m, 4H), 7.12 – 6.99 (m, 4H), 5.26 (d, *J* = 0.8 Hz, 2H), 2.47 (s, 3H), 2.10 (s, 3H), 1.80 (s, 3H). $^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$) δ 170.6, 144.7, 139.5, 139.1, 138.6, 136.3, 133.1, 132.4, 131.3, 130.2, 130.0, 128.9, 128.5, 128.0, 123.6, 122.1, 120.4, 94.1, 85.7, 21.5, 21.4, 19.3. HRMS (ESI) calcd for $C_{26}H_{23}NO_3S[M+H]^+$ 430.1471, found 430.1476.

Methyl 4-(phenylethynyl)-(N-tosylmethacrylamido)benzoate (1h). 0.89 g, 78%; White solid, Mp 148–149 ºC, R_f = 0.40 (petroleum ether/EtOAc, 7:1); ^1H NMR (400

MHz, $CDCl_3$) δ 8.27 (d, J = 1.6 Hz, 1H), 8.06 (dd, J = 8.4, 1.6 Hz, 1H), 7.92 (d, J = 8.4 Hz, 2H), 7.55 (d, J = 8.0 Hz, 1H), 7.35 – 7.29 (m, 1H), 7.24 (t, J = 7.6 Hz, 2H), 7.11 – 7.04 (m, 4H), 5.26 (d, J = 1.2 Hz, 1H), 5.22 (s, 1H), 3.97 (s, 3H), 2.09 (s, 3H), 1.77 (s, 3H). $^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$) δ 170.3, 165.5, 145.0, 139.0, 138.9, 136.1, 133.4, 132.7, 131.7, 130.5, 130.0, 129.3, 129.0, 128.1, 127.7, 124.3, 121.4, 97.7, 85.1, 52.6, 21.4, 19.2. HRMS (ESI) calcd for $C_{27}H_{23}NO_5S$ $[M+H]^+$ 474.1370, found 474.1369.

N-(2-(p-tolylethynyl)phenyl)-N-tosylmethacrylamide (1i).[13a] White solid, 0.86 g, 78% yield; Mp 184–185 ºC, R_f = 0.30 (petroleum ether/EtOAc, 10:1); ^1H NMR (400 MHz, $CDCl_3$) δ 7.92 (d, J = 8.0 Hz, 2H), 7.61 (d, J = 8.0 Hz, 1H), 7.51 – 7.34 (m, 3H), 7.04 (dd, J = 17.6, 8.0 Hz, 4H), 6.93 (d, J = 8.0 Hz, 2H), 5.22 (d, J = 6.8 Hz, 2H), 2.34 (s, 3H), 2.10 (s, 3H), 1.76 (s, 3H). $^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$) δ 170.5, 144.6, 139.1, 139.0, 138.7, 136.3, 132.6, 132.5, 131.4, 130.0, 129.1, 128.9, 128.8, 128.7, 123.7, 123.6, 118.9, 95.2, 85.0, 21.6, 21.4, 19.2. HRMS (ESI) calcd for $C_{26}H_{23}NO_3S$ $[M+H]^+$ 430.1471, found 430.1474.

N-(2-((4-methoxyphenyl)ethynyl)phenyl)-N-tosylmethacrylamide (1j).[13e] 0.75 g, 71%; White solid, Mp 170–171 ºC, R_f = 0.30 (petroleum ether/EtOAc, 10:1); ^1H NMR (400 MHz, $CDCl_3$) δ 7.93 (d, J = 8.0 Hz, 2H), 7.61 (dd, J = 8.0, 1.6 Hz, 1H), 7.48 – 7.34 (m, 3H), 7.08 (d, J = 8.4 Hz, 2H), 6.98 (d, J = 8.8 Hz, 2H), 6.74 (d, J = 8.8 Hz, 2H), 5.23 (d, J = 6.0 Hz, 2H), 3.81 (s, 3H), 2.13 (s, 3H), 1.76 (s, 3H). $^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$) δ 170.6, 160.0, 144.6, 139.1, 138.6, 136.3, 133.0, 132.5, 132.4, 130.0, 129.1, 128.9, 128.4, 123.8, 123.7, 114.1, 113.7, 95.1, 84.5, 55.3, 21.4, 19.2. HRMS (ESI) calcd for $C_{26}H_{23}NO_4S$ $[M+H]^+$ 446.1421, found 446.1420.

N-(4-methyl-2-(p-tolylethynyl)phenyl)-N-tosylmethacrylamide (1k). 1.10 g, 91%; White solid, Mp 197–198 ºC, R_f = 0.30 (petroleum ether/EtOAc, 10:1); ^1H NMR (400 MHz, $CDCl_3$) δ 7.85 (d, J = 8.4 Hz, 2H), 7.41 (d, J = 8.4 Hz, 1H), 7.17 (dd, J = 18.8, 7.6 Hz, 2H), 6.96 (dd, J = 18.8, 8.0 Hz, 4H), 6.85 (d, J = 8.0 Hz, 2H), 5.15 (s, 2H), 2.31 (s, 3H), 2.26 (s, 3H), 2.02 (s, 3H), 1.69 (s, 3H). $^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$) δ 170.7, 144.5, 139.4, 139.1, 138.9, 136.3, 136.1, 133.0, 132.2, 131.4, 130.0, 129.7, 128.9, 128.7, 123.5, 123.2, 119.0, 94.7, 21.5, 21.4, 21.1, 19.3. HRMS (ESI) calcd for $C_{27}H_{25}NO_3S$ $[M+H]^+$ 444.1628, found 444.1631.

N-(2-((4-methoxyphenyl)ethynyl)-4-methylphenyl)-N-tosylmethacrylamide (1l). 0.95 g, 84%; White solid, Mp 159–160 ºC, R_f = 0.30 (petroleum ether/EtOAc, 10:1); ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.93 (d, J = 8.0 Hz, 2H), 7.47 (d, J = 8.0 Hz, 1H), 7.26 (s, 1H), 7.22 (d, J = 8.0 Hz, 1H), 7.07 (d, J = 8.0 Hz, 2H), 6.97 (d, J = 8.8 Hz, 2H), 6.73 (d, J = 8.8 Hz, 2H), 5.23 (s, 2H), 3.80 (s, 3H), 2.38 (s, 3H), 2.12 (s, 3H), 1.76 (s, 3H). ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 170.7, 159.9, 144.5, 139.4, 139.1, 136.9, 136.0, 133.0, 132.8, 132.2, 130.0, 129.5, 128.9, 123.5, 123.4, 114.2, 113.6, 94.7, 84.6, 55.3, 21.4, 21.1, 19.2. HRMS (ESI) calcd for $C_{27}H_{25}NO_4S$ $[M+H]^+$ 460.1577, found 460.1585.

N-(4-chloro-2-(p-tolylethynyl)phenyl)-N-tosylmethacrylamide (1m).[13c] 1.01 g, 88%; White solid, Mp 212–213 ºC, R_f = 0.30 (petroleum ether/EtOAc, 10:1); ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.91 (d, J = 8.4 Hz, 2H), 7.54 (d, J = 8.4 Hz, 1H), 7.44 (d, J = 2.4 Hz, 1H), 7.38 (dd, J = 8.4, 2.4 Hz, 1H), 7.05 (dd, J = 14.0, 8.4 Hz, 4H), 6.93 (d, J = 8.0 Hz, 2H), 5.28 (s, 1H), 5.21 (s, 1H), 2.34 (s, 3H), 2.09 (s, 3H), 1.77 (s, 3H). ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 170.7, 159.9, 144.5, 139.4, 139.1, 136.4, 136.0, 133.0, 132.8, 132.2, 130.0, 129.5, 128.9, 123.5, 123.4, 114.2, 113.7, 94.7, 84.6, 55.3, 21.4, 21.1, 19.2. HRMS (ESI) calcd for $C_{26}H_{22}ClNO_3S$ $[M+H]^+$ 464.1082, found 464.1083.

N-(2-((4-fluorophenyl)ethynyl)phenyl)-N-tosylmethacrylamide (1n).[13a] White solid, 0.65 g, 84% yield; Mp 186–187 ºC, R_f = 0.30 (petroleum ether/EtOAc, 10:1); ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.91 (d, J = 8.4 Hz, 2H), 7.69 – 7.52 (m, 1H), 7.51 – 7.30 (m, 3H), 7.18 – 6.98 (m, 3H), 6.92 (t, J = 8.8 Hz, 2H), 5.39 – 4.89 (m, 2H), 2.13 (s, 3H), 1.76 (s, 3H). ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 170.6, 162.8(d, J =249.0 Hz), 144.6, 139.0, 138.9, 136.3, 133.5, 133.4, 132.5, 130.0, 129.1 (d, J =25.0 Hz), 128.9, 123.9, 123.3, 118.1 (d, J =3.5 Hz), 115.5, 115.2, 93.8, 85.3, 21.4, 19.2. ^{19}F NMR (376 MHz, $CDCl_3$) δ -139.4. HRMS (ESI) calcd for $C_{25}H_{20}FNO_3S$ $[M+H]^+$ 434.1221, found. 434.1217.

N-(2-(hex-1-yn-1-yl)phenyl)-N-tosylmethacrylamide (1o).[13e] 0.75 g, 78%; White solid, Mp 86–87 ºC, R_f = 0.40 (petroleum ether/EtOAc, 15:1); ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.92 (d, J = 8.4 Hz, 2H), 7.53 – 7.45 (m, 1H), 7.40 – 7.24 (m, 6H), 5.22 (d, J = 4.4 Hz, 2H), 2.43 (s, 3H), 1.93 (t, J = 6.4 Hz, 2H), 1.77 (s, 3H), 1.28 – 1.19 (m,

4H), 0.86 (t, J = 6.8 Hz, 3H). $^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$) δ 170.4, 144.4, 139.1, 138.7, 136.5, 133.0, 132.1, 130.0, 129.0, 128.9, 128.2, 124.4, 123.3, 96.8, 76.5, 30.1, 22.2, 21.7, 19.2, 19.0, 13.6. HRMS (ESI) calcd for $C_{23}H_{25}NO_3S$ $[M+H]^+$ 396.1628, found 396.1634.

N-(2-(thiophen-2-ylethynyl)phenyl)-N-tosylmethacrylamide (1p). 0.70 g, 65%; White solid, Mp 174–175ºC, R_f = 0.30 (petroleum ether/EtOAc, 10:1); ^1H NMR (400 MHz, $CDCl_3$) δ 7.90 (d, J = 8.4 Hz, 2H), 7.62 (d, J = 7.6 Hz, 1H), 7.49 – 7.34 (m, 3H), 7.26 – 7.21 (m, 1H), 7.11 (d, J = 8.0 Hz, 2H), 6.95 – 6.85 (m, 2H), 5.25 (d, J = 3.2 Hz, 2H), 2.20 (s, 3H), 1.79 (s, 3H). $^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$) δ 170.3, 144.7, 139.0, 138.5, 136.1, 133.0, 132.6, 132.3, 129.8, 129.2, 129.0, 128.0, 126.9, 123.9, 123.2, 121.7, 89.1, 88.3, 21.5, 19.2. HRMS (ESI) calcd for $C_{23}H_{19}NO_3S_2$ $[M+H]^+$ 422.0879, found 422.0881.

N-benzyl-N-(2-(phenylethynyl)phenyl)methacrylamide (1q).[13a] White solid, 0.55 g, 62% yield; Mp 77–78 ºC, R_f = 0.40 (petroleum ether/EtOAc, 15:1); ^1H NMR (400 MHz, $CDCl_3$) δ 7.57 – 7.46 (m, 3H), 7.39 – 7.32 (m, 3H), 7.31 – 7.14 (m, 7H), 6.86 (d, J = 7.6 Hz, 1H), 5.52 (d, J = 14.4Hz, 1H), 5.01 (d, J = 5.6 Hz, 2H), 4.58 (d, J = 14.4 Hz, 1H), 1.86 (s, 3H). $^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$) δ 172.0, 144.5, 140.5, 137.2, 132.9, 131.7, 129.4, 129.2, 128.8, 128.5, 128.3, 127.5, 127.4, 122.8, 122.6, 119.1, 94.9, 86.1, 52.4, 20.3. HRMS (ESI) calcd for $C_{25}H_{21}NO$ $[M+H]^+$ 352.1696, found 352.1700.

N-methyl-N-(2-(phenylethynyl)phenyl)methacrylamide (1r).[13d] White solid, 0.45 g, 69%; Mp 41–42 ºC, R_f = 0.40 (petroleum ether/EtOAc, 15:1); ^1H NMR (400 MHz, $CDCl_3$) δ 7.58 – 7.49 (m, 3H), 7.37 – 7.26 (m, 5H), 7.18 (d, J = 7.6 Hz, 1H), 5.01 (d, J = 11.5 Hz, 2H), 3.37 (s, 3H), 1.84 (s, 3H). $^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$) δ 172.3, 146.4, 140.5, 132.9, 131.7, 129.3, 128.8, 128.5, 128.2, 127.5, 122.6, 122.3, 119.1, 94.8, 85.8, 77.5, 77.1, 36.9, 20.2. HRMS (ESI) calcd for $C_{19}H_{17}NO$ $[M+H]^+$ 276.1383, found 276.1389.

N-ethyl-N-(2-(phenylethynyl)phenyl)methacrylamide (1s).[13e] 0.53 g, 74%; White solid, Mp 68–69 ℃, R_f = 0.30 (petroleum ether/EtOAc, 15:1); ^1H NMR (400 MHz, $CDCl_3$) δ 7.61 – 7.48 (m, 3H), 7.40 – 7.24 (m, 5H), 7.17 (d, J = 7.6 Hz, 1H), 4.98 (s, 2H), 4.07 – 3.73 (m, 2H), 1.84 (s, 3H), 1.19 (t, J = 7.2 Hz, 3H). $^{13}C\{^1H\}$ NMR (100

MHz, $CDCl_3$) δ 171.8, 144.7, 140.8, 132.9, 131.6, 129.2, 129.0, 128.7, 128.5, 127.4, 123.1, 122.7, 118.9, 94.7, 86.4, 44.4, 20.2, 12.8. HRMS (ESI) calcd for $C_{20}H_{19}NO$ $[M+H]^+$ 290.1538, found 290.1539.

N-methyl-N-(4-methyl-2-(phenylethynyl)phenyl)methacrylamide (1t). White solid, 0.47 g, 65%; Mp 81–82 ℃, R_f = 0.40 (petroleum ether/EtOAc, 15:1); ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.57 – 7.45 (m, 1H), 7.39 – 7.33 (m, 1H), 7.13 (d, J = 8.0 Hz, 1H), 7.06 (d, J = 8.0 Hz, 1H), 5.01 (d, J = 15.1 Hz, 1H), 3.35 (s, 1H), 2.36 (s, 1H), 1.83 (s, 1H).^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 172.5, 143.9, 140.6, 137.5, 133.3, 131.7, 130.1, 128.7, 128.5, 128.0, 122.7, 121.9, 118.8, 85.9, 37.0, 20.9, 20.2. HRMS (ESI) calcd for $C_{20}H_{19}NO$ $[M+H]^+$ 290.1538, found 290.1537.

N-(4-chloro-2-(phenylethynyl)phenyl)-N-methylmethacrylamide (1u). Yellow solid, 0.65 g, 84%; Mp 72–73 ºC, R_f = 0.30 (petroleum ether/EtOAc, 15:1); ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.62 – 7.46 (m, 3H), 7.40 – 7.28 (m, 4H), 7.12 (d, J = 8.4 Hz, 1H), 5.03 (d, J = 11.2 Hz, 2H), 3.34 (s, 3H), 1.85 (s, 3H). ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 172.2, 144.9, 140.2, 133.1, 132.6, 131.8, 129.4, 129.2, 128.6, 123.9, 122.1, 119.4, 95.9, 84.5, 36.9, 20.1. HRMS (ESI) calcd for $C_{19}H_{16}ClNO$ $[M+H]^+$ 310.0993, found 310.0997.

N-(4-methyl-2-(phenylethynyl)phenyl)-2-phenyl-N-tosylacrylamide (1v).[13b] White solid, 0.90 g, 74%; Mp 162–164 ºC, R_f = 0.30 (petroleum ether/EtOAc, 5:1); ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.98 (d, J = 8.3 Hz, 2H), 7.31 – 7.27 (m, 1H), 7.25 – 7.13 (m, 6H), 7.11 – 6.99 (m, 6H), 6.74 (d, J = 6.9 Hz, 1H), 6.62 (d, J = 8.2 Hz, 1H), 5.73 (s, 1H), 5.39 (s, 1H), 2.29 (s, 3H), 2.10 (s, 3H). ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 168.7, 144.2, 143.7, 138.3, 135.3, 135.0, 133.2, 131.53, 131.46, 130.5, 128.9, 128.0, 127.9, 127.5, 127.3, 127.2, 127.0, 125.1, 122.6, 121.1, 93.5, 85.0, 20.4, 20.0. HRMS (ESI) calcd for $C_{31}H_{26}NO_3S$ $[M+H]^+$ 492.1628, found 492.1638.

N-(4-fluoro-2-(phenylethynyl)phenyl)-2-phenyl-N-tosylacrylamide (1w).[13b] White solid, 0.71 g, 58%; Mp 123–124 ºC, R_f = 0.40 (petroleum ether/EtOAc, 5:1); ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.97 (d, J = 8.2 Hz, 2H), 7.32 (t, J = 7.4 Hz, 1H), 7.26 – 7.17 (m, 5H), 7.10 – 7.03 (m, 5H), 7.01 (d, J = 7.5 Hz, 2H), 6.71 – 6.57 (m, 2H), 5.75 (s, 1H), 5.42 (s, 1H), 2.09 (s, 3H). ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 168.5, 161.0 (d, J = 251.2 Hz), 144.2, 143.9, 135.1, 134.9, 133.7 (d, J = 9.8 Hz), 131.9 (d, J = 3.0 Hz),

130.6, 128.9, 128.0, 127.5, 127.4, 127.1, 125.1, 124.6 (d, J = 10.7 Hz), 121.9, 120.5, 117.3 (d, J = 24.3 Hz), 114.4 (d, J = 23.0 Hz), 94.9, 83.8, 20.4. HRMS (ESI) calcd for $C_{30}H_{23}FNO_3S$ $[M+H]^+$ 496.1377, found 496.1377.

N-(2-((4-methoxyphenyl)ethynyl)phenyl)-2-phenyl-N-tosylacrylamide (1x).[13b] White solid, 0.85 g, 67%; Mp 127–128 ºC, R_f = 0.30 (petroleum ether/EtOAc, 5:1); ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.99 (d, J = 8.3 Hz, 2H), 7.36 (d, J = 6.7 Hz, 1H), 7.24 – 7.12 (m, 4H), 7.10 (d, J = 8.1 Hz, 2H), 7.03 – 6.95 (m, 4H), 6.90 (t, J = 7.1 Hz, 1H), 6.79 – 6.70 (m, 3H), 5.72 (s, 1H), 5.38 (s, 1H), 3.83 (s, 3H), 2.15 (s, 3H). ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 169.7, 159.9, 145.3, 144.7, 136.5, 136.5, 136.0, 133.1, 132.9, 131.8, 129.9, 129.0, 128.9, 128.4, 128.2, 127.6, 126.2, 124.4, 122.4, 114.3, 113.7, 95.3, 84.9, 55.4, 21.5. HRMS (ESI) calcd for $C_{31}H_{26}NO_4S$ $[M+H]^+$ 508.1577, found 508.1585.

2-phenyl-N-(2-(phenylethynyl)phenyl)-N-(phenylsulfonyl)acrylamide (1y).[13b] White solid, 0.80 g, 71%; Mp 136–138 ºC, R_f = 0.40 (petroleum ether/EtOAc, 5:1); ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.17 – 8.07 (m, 2H), 7.40 (d, J = 7.6 Hz, 1H), 7.35 – 7.31 (m, 3H), 7.29 (d, J = 7.2 Hz, 1H), 7.23 (t, J = 7.6 Hz, 4H), 7.16 (t, J = 7.4 Hz, 2H), 7.06 (d, J = 7.5 Hz, 2H), 6.99 (d, J = 7.5 Hz, 2H), 6.95 (t, J = 7.9 Hz, 1H), 6.75 (d, J = 8.1 Hz, 1H), 5.74 (s, 1H), 5.40 (s, 1H). ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 168.7, 144.1, 138.3, 135.6, 134.8, 132.5, 131.8, 131.1, 130.5, 128.8, 128.1, 127.7, 127.4, 127.3, 127.2, 127.1, 127.0, 125.1, 123.0, 121.6, 120.9, 94.1, 84.8. HRMS (ESI) calcd for $C_{29}H_{22}NO_3S$ $[M+H]^+$ 464.1315, found 464.1321.

N-((4-methoxyphenyl)sulfonyl)-2-phenyl-N-(2-(phenylethynyl)phenyl)acrylamide (1z).[13b] White solid, 0.95 g, 78%; Mp 158–160 ºC, R_f = 0.40 (petroleum ether/EtOAc, 5:1); ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.04 (d, J = 8.9 Hz, 2H), 7.41 – 7.36 (m, 1H), 7.34 – 7.28 (m, 1H), 7.25 – 7.12 (m, 6H), 7.10 (d, J = 7.1 Hz, 2H), 7.00 (d, J = 7.0 Hz, 2H), 6.96 – 6.89 (m, 1H), 6.76 – 6.69 (m, 3H), 5.76 (s, 1H), 5.39 (s, 1H), 3.55 (s, 3H). ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 169.7, 163.6, 145.3, 136.9, 136.0, 133.0, 132.2, 132.1, 131.5, 130.6, 129.0, 128.6, 128.4, 128.2, 128.1, 126.2, 124.0, 122.4, 122.1, 113.5, 94.9, 86.0, 55.3. HRMS (ESI) calcd for $C_{30}H_{24}NO_4S$ $[M+H]^+$ 494.1421, found 494.1427.

General Procedures for the Synthesis of Monofluorosubstituted Quinoline

Derivatives

To an oven dried reaction tube was charged with substrate **1** (0.20 mmol), $Ir(ppy)_3$ (1 mol %) and K_2HPO_4 (0.40 mmol). The vial was evacuated and backfilled with argon (this process was repeated three times) and then 2 mL dioxane and ethyl bromofluoroacetate (0.40 mmol) were added. The reaction mixture was irradiated by a 3W blue LED bulb (approximately 2 cm away from the light source) at room temperature for 24 hours before concentrating in vacuo. The reaction mixture was quenched with water, and then extracted with EtOAc. The organic layers were washed with brine, dried over Na_2SO_4, filtered, and concentrated under reduced pressure. The crude mixture was purified by flash column chromatography to give the desired compound **3**.

2-Ethyl-2-fluoro-3a-methyl-4-oxo-1-phenyl-5-tosyl-3,3a,4,5-tetrahydro-2H-cyclopenta[c]quinoline-2-carboxylate (3a). White solid, 93 mg, yield 94%, dr = 14:1, R_f = 0.40 (petroleum ether/EtOAc, 10:1); ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.84 (t, J = 8.4 Hz, 3H), 7.37 (m, 6H), 7.21 (m, 2H), 7.15 – 7.05 (m, 2H), 4.46 – 4.11 (m, 2H), 2.63 (m, 2H), 2.43 (s, 3H), 1.43 – 1.21 (m, 6H).^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 174.0, 170.5(d, J = 32.4 Hz), 145.3, 141.4, 141.3, 136.9, 136.6, 136.3, 135.3, 131.5, 129.5, 129.1, 128.8, 128.7, 128.3, 127.5, 126.5, 124.4, 123.9, 103.1(d, J = 190.0 Hz), 62.4, 55.4, 45.6, 23.4, 21.7, 14.1. ^{19}F NMR (376 MHz, $CDCl_3$) δ -139.5 (dd, J = 27.1, 8.1 Hz). HRMS (ESI) calcd for $C_{29}H_{26}FNO_5S$ $[M+H]^+$520.1588, found 520.1582.

2-Ethyl-2-fluoro-3a,8-dimethyl-4-oxo-1-phenyl-5-tosyl-3,3a,4,5-tetrahydro-2H-cyclopenta[c]quinoline-2-carboxylate (3b). White solid, 96 mg, yield 90%, dr = 7:1, R_f = 0.30 (petroleum ether/EtOAc, 10:1); ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.81 (d, J = 8.4 Hz, 2H), 7.68 (d, J = 8.4 Hz, 1H), 7.41 – 7.33 (m, 3H), 7.29 (d, J = 8.0 Hz, 2H), 7.19-7.18 (m, 3H), 6.87 (s, 1H), 4.39 – 4.24 (m, 2H), 2.58-2.40 (m, 2H), 2.40 (s, 3H), 2.18 (s, 3H), 1.29-1.26 (m, 6H). ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 174.1, 170.6(d, J = 31.4 Hz), 145.2, 141.4, 136.5, 136.3, 132.9, 131.5, 129.9, 129.5, 128.7, 128.3, 127.7, 124.3, 123.8, 103.1 (d, J = 200.0 Hz), 62.4, 55.5, 45.5, 45.3, 23.4, 21.7, 20.9, 14.1. ^{19}F NMR (376 MHz, $CDCl_3$) δ -139.6 (dd, J = 27.6, 9.7 Hz). HRMS (ESI) calcd for $C_{30}H_{28}FNO_5S$ $[M+H]^+$534.1745, found 534.1747.

2-Ethyl-2,8-difluoro-3a-methyl-4-oxo-1-phenyl-5-tosyl-3,3a,4,5-tetrahydro-2H-c

yclopenta[c]quinoline-2-carboxylate (3c). White solid, 69 mg, yield 65%, dr = 9:1, R_f = 0.30 (petroleum ether/EtOAc, 10:1); ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.89 – 7.76 (m, 3H), 7.40 – 7.29 (m, 5H), 7.16 –7.11(m, 2H), 7.13 – 7.05 (m, 1H), 6.79 – 6.74 (m, 1H), 4.31– 4.25 (m, 2H), 2.60 – 2.41(m, 2H), 2.41 (s, 3H), 1.33 – 1.25 (m, 6H). ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 173.7, 170.2, 161.6, 159.2, 145.5 , 140.4, 138.2, 138.0, 135.9, 131.4, 130.9, 129.6, 129.2, 128.9, 128.6, 128.3, 126.4, 126.3, 125.9, 116.3, 116.1, 114.2, 114.0, 103.0(d, J = 200.0 Hz), 62.5, 55.3, 45.5, 45.3, 23.4, 23.3, 21.7, 14.1. ^{19}F NMR (376 MHz, $CDCl_3$) δ -114.0 (s), -139.7 (dd, J = 27.4, 10.1 Hz). HRMS (ESI) calcd for $C_{29}H_{25}F_2NO_5S$ $[M+H]^+$538.1494, found 538.1494.

2-Ethyl-8-chloro-2-fluoro-3a-methyl-4-oxo-1-phenyl-5-tosyl-3,3a,4,5-tetrahydro -2H-cyclopenta[c]quinoline-2-carboxylate (3d). White solid, 84 mg, yield 76%, dr = 7:1, R_f = 0.30 (petroleum ether/EtOAc, 10:1); ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.79-7.75 (m, 3H), 7.43 – 7.29 (m, 6H), 7.17 – 7.16 (m, 2H), 7.06 – 7.03 (m, 1H), 4.31 – 4.24 (m, 2H), 2.61 – 2.41 (m, 2H), 2.41 (s, 3H), 1.29 – 1.27 (m, 6H). ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 173.6, 170.2, 145.6, 145.3, 140.0, 138.2, 138.0, 135.9, 133.8, 132.2, 130.8, 129.6, 129.2, 128.9, 128.7, 128.3, 127.1, 125.7, 125.5, 103.0 (d, J = 190.0 Hz), 62.5, 61.7, 56.0, 55.3, 45.5, 45.3, 44.7, 24.1 23.3, 21.7, 14.1. ^{19}F NMR (376 MHz, $CDCl_3$) δ -140.3 (dd, J = 27.3, 9.1 Hz). HRMS (ESI) calcd for $C_{29}H_{25}ClFNO_5S$ $[M+H]^+$554.1199, found 554.1190.

2-Ethyl-8-bromo-2-fluoro-3a-methyl-4-oxo-1-phenyl-5-tosyl-3,3a,4,5-tetrahydro -2H-cyclopenta[c]quinoline-2-carboxylate (3e). White solid, 98 mg, yield 82%, dr = 7:1, R_f = 0.30 (petroleum ether/EtOAc, 10:1); ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.80 (d, J = 8.4 Hz, 2H), 7.71 (d, J = 8.4Hz, 1H), 7.54 – 7.51 (m,1H), 7.45 – 7.27 (m, 6H), 7.19 – 7.14 (m, 2H), 4.40 – 4.23 (m, 2H), 2.84 – 2.49 (m, 2H), 2.42 (s, 3H), 1.33 – 1.27(m, 6H). ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 173.5, 170.2, 145.6, 139.8, 138.2, 138.0, 135.9, 134.4, 132.1, 130.8, 130.0, 129.7, 129.3, 128.9, 128.7, 128.3, 126.0, 125.8, 120.0, 102.9 (d, J = 200.0 Hz), 62.5, 55.3, 45.5, 45.2, 23.4, 23.3, 21.7, 14.1, 13.7. ^{19}F NMR (376 MHz, $CDCl_3$) δ -144.6 (dd, J = 27.4, 10.0 Hz). HRMS (ESI) calcd for $C_{29}H_{25}BrFNO_5S$ $[M+H]^+$598.0694, found 598.0692.

2-Ethyl-8-methyl-2-fluoro-3a-methyl-4-oxo-1-phenyl-5-tosyl-3,3a,4,5-tetrahydro -2H-cyclopenta[c]quinoline-2,8-dicarboxylate (3f). White solid, 93 mg, yield 81%, dr

= 9:1, R_f = 0.40 (petroleum ether/EtOAc, 10:1); ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.04 (dd, J = 8.8, 2.0 Hz, 1H), 7.90 (d, J = 8.4Hz, 1H), 7.83 (d, J = 8.4 Hz, 2H), 7.77 (d, J = 1.2 Hz, 1H), 7.40 – 7.36 (m, 3H), 7.32 (d, J = 8.0 Hz, 2H), 7.20 – 7.18 (m, 2H), 4.40 – 4.23 (m, 2H), 3.83 (s, 3H), 2.76 – 2.51 (m, 2H), 2.43 (s, 3H), 1.30-1.27 (m, 6H).^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 173.7, 170.2, 165.7, 145.6, 140.2, 138.8, 138.2, 138.0, 136.0, 130.9, 130.1, 129.6, 129.1, 128.8, 128.3, 124.1, 123.9, 103.0 (d, J = 202.0 Hz), 62.5, 55.2, 52.4, 45.5, 23.4, 21.7, 14.1. ^{19}F NMR (376 MHz, $CDCl_3$) δ -139.5 (dd, J = 27.4, 10.1 Hz). HRMS (ESI) calcd for $C_{31}H_{28}FNO_9S$ $[M+H]^+$578.1643, found 578.1635.

2-Ethyl-2-fluoro-3a,7-dimethyl-4-oxo-1-phenyl-5-tosyl-3,3a,4,5-tetrahydro-2H-cyclopenta[c]quinoline-2-carboxylate (3g). White solid, 81 mg, yield 76%, dr = 15:1, R_f = 0.40 (petroleum ether/EtOAc, 10:1); ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.73 (d, J = 8.0 Hz, 1H), 7.54 (s, 1H), 7.32 – 7.19 (m, 3H), 7.15 – 7.05 (m, 1H), 6.95 – 6.71 (m, 1H), 4.32 – 3.88 (m, 1H), 2.66 – 2.38 (m, 1H), 2.45 (s, 4H), 1.50 – 1.06 (m, 4H). ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 174.2, 170.6 (d, J = 32.7 Hz), 145.2, 141.4, 139.7, 135.9 (d, J = 22.9 Hz), 135.3, 131.7, 129.5, 128.8, 128.7, 128.6, 128.2, 127.4, 127.2, 125.0, 121.0, 103.1 (d, J = 197.0 Hz), 62.4, 55.4, 45.6 , 45.3, 23.5 (d, J = 6.2 Hz), 21.7 (d, J = 6.8 Hz), 14.1. ^{19}F NMR (376 MHz, $CDCl_3$) δ -141.0 (dd, J = 27.1, 9.8 Hz). HRMS (ESI) calcd for $C_{30}H_{28}FNO_5S$ $[M+H]^+$534.1745, found 534.1741.

2-Ethyl-7-methyl-2-fluoro-3a-methyl-4-oxo-1-phenyl-5-tosyl-3,3a,4,5-tetrahydro-2H-cyclopenta[c]quinoline-2,7-dicarboxylate (3h). White solid, 60 mg, yield 52%, dr > 20:1, R_f = 0.40 (petroleum ether/EtOAc, 5:1); ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.34 (s, 1H), 7.73 (d, J = 8.0 Hz, 2H), 7.64 (d, J = 8.0 Hz, 1H), 7.23 -7.19 (m, 5H), 7.08 – 6.95 (m, 3H), 4.25 – 4.11 (m, 2H), 3.81 (s, 3H), 2.61-2.42 (m, 2H), 2.29 (s, 3H), 1.16 -1.14 (m, 3H). ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 173.6, 170.2 (d, J = 32.7 Hz), 165.8, 145.6, 140.4, 138.8, 136.0, 135.4, 131.0, 130.9, 130.8, 129.6, 129.2, 128.8, 128.7,128.4, 128.2, 127.5, 125.3, 103.0 (d, J = 200.0 Hz), 62.5, 55.3, 52.6, 45.7, 23.3, 21.7, 14.1. ^{19}F NMR (376 MHz, $CDCl_3$) δ -140.0 (dd, J = 27.5, 9.6 Hz). HRMS (ESI) calcd for $C_{31}H_{28}FNO_9S$ $[M+H]^+$578.1643, found 578.1644.

2-Ethyl-2-fluoro-3a-methyl-4-oxo-1-(p-tolyl)-5-tosyl-3,3a,4,5-tetrahydro-2H-cyclopenta[c]quinoline-2-carboxylate (3i). White solid, 95 mg, yield 89%, dr = 12:1, R_f

= 0.40 (petroleum ether/EtOAc, 10:1); ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.81-7.92 (m, 3H), 7.40 – 7.35 (m, 1H), 7.29 – 7.26 (m, 2H), 7.28 – 7.12 (m, 6H), 4.31 – 3.98 (m, 2H), 2.72 – 2.48 (m, 2H), 2.40 (s, 3H), 2.35 (s, 3H), 1.29 – 1.25 (m, 6H).^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) *δ* 174.1, 170.6, 145.3, 140.7, 138.7, 136.8, 136.7, 136.3, 135.3, 129.5, 129.4, 129.0, 128.6, 128.4, 128.3, 127.5, 126.5, 124.4, 124.1, 103.1 (d, *J* = 190.0 Hz), 62.4, 55.4, 45.6, 45.4, 23.4, 23.3, 21.7, 21.3, 14.1. ^{19}F NMR (376 MHz, $CDCl_3$) *δ* -139.7 (dd, *J* = 27.5, 9.6 Hz). HRMS (ESI) calcd for $C_{30}H_{28}FNO_5S$ $[M+H]^+$534.1745, found 534.1749.

2-Ethyl-2-fluoro-1-(4-methoxyphenyl)-3a-methyl-4-oxo-5-tosyl-3,3a,4,5-tetrahydro-2H-cyclopenta[c]quinoline-2-carboxylate (3j). White solid, 96 mg, yield 88%, dr = 11:1, R_f = 0.30 (petroleum ether/EtOAc, 10:1); ^{1}H NMR (400 MHz, $CDCl_3$) *δ* 7.91 – 7.77 (m, 3H), 7.39 – 7.37(m, 1H), 7.29 – 7.27 (m, 3H), 7.16 – 7.11 (m, 3H), 6.87 (d, *J* = 8.8 Hz, 2H), 4.39 – 4.24 (m, 2H), 3.83 (s, 3H), 2.58 – 2.41(m, 2H), 2.41 (s, 3H), 1.30 (t, *J* = 7.2 Hz, 3H), 1.24 (s, 3H).^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) *δ* 174.2, 170.6, 159.9, 145.3, 140.1, 136.5, 136.3, 135.3, 130.0, 129.5, 129.0, 128.2, 127.4, 126.5, 124.4, 123.5, 114.2, 103.0 (d, *J* = 200.0 Hz), 62.4, 55.3, 45.6,23.3, 21.7, 14.1. ^{19}F NMR (376 MHz, $CDCl_3$) *δ* -140.0 (dd, *J* = 27.4, 8.9 Hz). HRMS (ESI) calcd for $C_{30}H_{28}FNO_6S$ $[M+H]^+$550.1694, found 550.1686.

2-Ethyl-2-fluoro-3a,8-dimethyl-4-oxo-1-(p-tolyl)-5-tosyl-3,3a,4,5-tetrahydro-2H-cyclopenta[c]quinoline-2-carboxylate (3k). White solid, 94 mg, yield 86%, dr = 12:1, R_f = 0.30 (petroleum ether/EtOAc, 10:1); ^{1}H NMR (400 MHz, $CDCl_3$) *δ* 7.80 (d, *J* = 8.4 Hz, 2H), 7.68 (d, *J* = 8.4 Hz, 1H), 7.28 – 7.26 (m, 2H), 7.20 – 7.08 (m, 5H), 6.93 (d, *J* = 1.2 Hz, 1H), 4.39 – 4.22 (m, 2H), 2.64 – 2.50 (m, 2H), 2.36 (s, 3H), 2.32 (s, 3H) 2.20 (s, 3H), 1.29 (t, *J* = 7.2 Hz, 3H), 1.25 (s, 3H). ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) *δ* 174.16, 170.7, 145.2, 140.7, 138.7, 136.5, 136.3, 132.9, 129.9, 129.5, 129.4, 129.0, 128.8, 128.6, 128.4, 128.2, 127.7, 124.3, 124.1, 103.1 (d, *J* = 191.9 Hz), 62.3, 55.5, 45.5, 45.3, 23.3, 21.7, 21.4, 20.9, 14.1. ^{19}F NMR (376 MHz, $CDCl_3$) *δ* -139.9 (dd, *J* = 27.5, 9.5 Hz). HRMS (ESI) calcd for $C_{31}H_{30}FNO_5S$ $[M+H]^+$548.1901, found 548.1896.

2-Ethyl-2-fluoro-1-(4-methoxyphenyl)-3a,8-dimethyl-4-oxo-5-tosyl-3,3a,4,5-tetrahydro-2H-cyclopenta[c]quinoline-2-carboxylate (3l). White solid, 95 mg, yield 85%,

dr = 12:1, R_f = 0.30 (petroleum ether/EtOAc, 10:1); ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.96 – 7.74 (m, 3H), 7.68 (d, J = 8.4 Hz, 1H), 7.33 – 7.28 (m, 1H), 7.23 – 7.18 (m, 1H), 7.17 – 7.12 (m, 2H), 7.08 – 6.92 (m, 2H), 6.92 – 6.70 (m, 3H), 4.40 – 4.23 (m, 2H), 3.83 (s, 3H), 2.70 – 2.42 (m, 2H), 2.39 (s, 3H), 2.21 (s, 3H), 1.33 – 1.26 (m, 3H).^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 174.2, 170.8, 159.9, 145.2, 140.1, 139.1, 136.5, 136.2, 133.0, 132.2, 130.0, 129.8, 129.5, 128.8, 128.2, 127.7, 124.3, 123.6, 114.11, 113.63, 103.0 (d, J = 195.9 Hz), 67.1, 62.4, 55.3, 45.4, 23.2, 21.4, 19.2, 14.1. ^{19}F NMR (376 MHz, $CDCl_3$) δ -140.6 (dd, J = 18.3, 9.1 Hz). HRMS (ESI) calcd for $C_{31}H_{30}FNO_6S$ $[M+H]^+$564.1851, found 564.1842.

2-Ethyl-8-chloro-2-fluoro-3a-methyl-4-oxo-1-(p-tolyl)-5-tosyl-3,3a,4,5-tetrahydro-2H-cyclopenta[c]quinoline-2-carboxylate (3m). White solid, 81 mg, yield 72%, dr = 9:1, R_f = 0.30 (petroleum ether/EtOAc, 10:1); ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.78 – 7.74 (m, 3H), 7.37 – 7.28 (m, 3H), 7.18 (d, J = 8.0 Hz, 2H), 7.08 – 7.05 m, 3H), 4.39 – 4.23 (m, 2H), 2.58 – 2.48 (m, 2H), 2.40 (s, 3H), 2.31 (s, 3H), 1.37 – 1.25 (m, 6H).^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 173.7, 170.3, 145.5, 139.2, 139.1, 138.3, 138.0, 135.9, 133.8, 132.2, 129.6, 129.1, 128.8, 128.5, 128.3, 128.1, 127.7, 127.1, 125.8, 125.7, 102.9 (d, J = 191.9 Hz), 62.6, 55.2, 45.2, 23.2, 21.7, 21.4, 14.1.^{19}F NMR (376 MHz, $CDCl_3$) δ -140.9 (dd, J = 27.4, 9.6 Hz). HRMS (ESI) calcd for $C_{30}H_{27}ClFNO_5S$ $[M+H]^+$568.1355, found 568.1351.

2-Ethyl-8-chloro-2-fluoro-3a-methyl-4-oxo-1-(p-tolyl)-5-tosyl-3,3a,4,5-tetrahydro-2H-cyclopenta[c]quinoline-2-carboxylate (3n). Oil, 39 mg, yield 35%, dr >20:1, R_f = 0.30 (petroleum ether/EtOAc, 10:1); ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.90 – 7.75 (m, 3H), 7.45 – 7.28 (m, 3H), 7.22 – 6.97 (m, 6H), 4.40 – 4.17 (m, 2H), 2.82 – 2.48 (m, 2H), 2.42 (s, 3H), 1.37 – 1.15 (m, 6H). ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 173.9, 170.4, 162.9 (d, J = 274.0 Hz), 145.4, 136.2, 135.3, 132.6, 130.8, 130.7, 129.5, 129.3, 128.3, 127.3, 126.5, 124.4, 123.7, 116.0, 115.8, 103.1 (d, J = 194.0 Hz), 62.5, 55.4, 45.4, 23.4, 21.7, 14.1. ^{19}F NMR (376 MHz, $CDCl_3$) δ -111.6 (ddd, J = 14.3, 8.9, 5.4 Hz), -139.3 (dd, J = 28.3, 10.5 Hz). HRMS (ESI) calcd for $C_{29}H_{25}F_2NO_5S$ $[M+H]^+$538.1494, found 538.1493.

2-Ethyl-1-butyl-2-fluoro-3a-methyl-4-oxo-5-tosyl-3,3a,4,5-tetrahydro-2H-cyclopenta[c]quinoline-2-carboxylate (3o). Yellow oil, 49 mg, yield 50%, dr = 5:1, R_f =

0.40 (petroleum ether/EtOAc, 15:1); ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.00 – 7.66 (m, 3H), 7.49 – 7.20 (m, 5H), 4.34 – 4.20 (m, 2H), 2.58 – 2.37 (m, 5H), 1.46 – 1.19 (m, 8H), 1.19 – 1.01 (m, 3H), 1.01 – 0.83 (m, 4H).^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 174.5, 170.6 (d, J = 32.8 Hz), 145.1, 140.0 (d, J = 9.0 Hz), 138.1 (d, J = 21.0 Hz), 136.2, 135.0, 130.9, 129.4, 128.9), 128.2, 126.7, 124.4, 103.4 (d, J = 194.5 Hz), 65.6, 62.2, 55.2, 45.0 (d, J = 23.3 Hz), 30. 5, 25.1, 23.2 (d, J = 6.4 Hz), 23.0, 21.7, 19.2, 13.9 (d, J = 29.2 Hz). ^{19}F NMR (376 MHz, $CDCl_3$) δ -140.5 (dd, J = 26.4, 12.4 Hz). HRMS (ESI) calcd for $C_{27}H_{30}FNO_5S$ $[M+H]^+$500.1901, found 500.1900.

2-Ethyl-2-fluoro-3a-methyl-4-oxo-1-(thiophen-2-yl)-5-tosyl-3,3a,4,5-tetrahydro-2H-cyclopenta[c]quinoline-2-carboxylate (3p). White solid, 37 mg, yield 36%, dr = 11:1, R_f = 0.40 (petroleum ether/EtOAc, 10:1); ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.82 (d, J = 8.0 Hz, 1H), 7.72 (d, J = 8.0 Hz, 2H), 7.57 (d, J = 7.5 Hz, 1H), 7.47 (t, J = 7.7 Hz, 1H), 7.37 – 7.27 (m, 2H), 7.20 – 7.10 (m, 3H), 7.03 (t, J = 4.0 Hz,1H), 4.38 – 4.22 (m, 2H), 2.76 – 2.43 (m, 2H), 2.35 (s, 3H), 1.30 (t, J = 7.2 Hz, 3H), 1.18 (s, 3H). ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 173.7, 170.3, 145.3, 135.9, 135.3, 132.3, 129.6, 129.5, 128.5, 128.1, 127.6, 127.3, 126.9, 126.6, 125.1, 124.3, 102.7(d, J = 193.0 Hz), 62.5, 55.9, 45.0, 23.0, 21.7, 14.1. ^{19}F NMR (376 MHz, $CDCl_3$) δ -139.9 (dd, J = 27.7, 11.3 Hz). HRMS (ESI) calcd for $C_{27}H_{24}FNO_5S_2$ $[M+H]^+$526.1153, found 526.1150.

2-Ethyl-5-benzyl-2-fluoro-3a-methyl-4-oxo-1-phenyl-3,3a,4,5-tetrahydro-2H-cyclopenta[c]quinoline-2-carboxylate (3q). White solid, 80 mg, yield 88%, dr = 5:1, R_f = 0.30 (petroleum ether/EtOAc, 15:1); ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.71 (s, 1H), 7.40 – 7.31 (m, 5H), 7.29 – 7.20 (m, 6H), 7.13 – 7.05 (m, 1H), 6.98 – 6.93 (m, 2H), 6.82 – 6.76 (m, 1H), 5.58 (d, J = 16.4 Hz, 1H), 4.75 (d, J = 16.4 Hz, 1H), 4.18 – 4.05 (m, 2H), 1.52 (s, 3H), 1.14 (t, J = 7.2 Hz, 3H). ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 174.0, 171.2 (d, J = 23.1 Hz), 143.0, 139.7, 136.9, 136.0, 132.6, 130.0, 129.1, 128.9, 128.7, 128.4, 127.9, 127.3, 126.2, 122.8, 116.0, 103.7 (d, J = 194.8 Hz), 62.3, 52.7, 46.7, 45.6, 25.6 14.1. ^{19}F NMR (376 MHz, $CDCl_3$) δ -136.8 (dd, J = 29.4, 7.6 Hz). HRMS (ESI) calcd for $C_{29}H_{26}FNO_3$ $[M+H]^+$456.1969, found 456.1971.

2-Ethyl-2-fluoro-3a,5-dimethyl-4-oxo-1-phenyl-3,3a,4,5-tetrahydro-2H-cyclopenta[c]quinoline-2-carboxylate (3r). Yellow oil, 68 mg, yield 90%, dr = 4:1, R_f = 0.40 (petroleum ether/EtOAc, 15:1); ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.32 (dq, J = 11.3, 3.2

Hz, 4H), 7.22 – 7.15 (m, 2H), 7.12 – 6.98 (m, 2H), 6.82 (td, *J* = 7.6, 0.8 Hz, 1H), 4.42 – 4.27 (m, 2H), 3.48 – 3.39 (m, 3H), 3.18 – 2.68 (m, 2H), 1.44 (s, 3H), 1.35 – 1.16 (m, 3H). $^{13}C\{^{1}H\}$ NMR (100 MHz, $CDCl_3$) δ 173.7, 171.0, 143.1, 140.2, 135.6, 132.6, 129.9, 129.1, 128.6, 128.3, 127.8, 122.6, 119.8, 115.2, 103.6 (d, *J* = 194.2 Hz), 67.1, 62.2, 52.5, 45.6, 45.4, 30.0, 25.5, 14.1.^{19}F NMR (376 MHz, $CDCl_3$) δ -137.5 (dd, *J* = 29.6, 7.6 Hz). HRMS (ESI) calcd for $C_{23}H_{22}FNO_3$ $[M+H]^+$380.1656, found 380.1645.

2-Ethyl-5-ethyl-2-fluoro-3a-methyl-4-oxo-1-phenyl-3,3a,4,5-tetrahydro-2H-cyclo penta[c]quinoline-2-carboxylate (3s). Yellow oil, 60 mg, yield 77%, dr = 4:1, R_f = 0.30 (petroleum ether/EtOAc, 15:1); ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.58 – 6.94 (m, 9H), 6.81 (dd, *J* = 16.1, 8.5 Hz, 1H), 4.45 – 3.70 (m, 5H), 3.21 – 2.60 (m, 2H), 1.52 – 1.08 (m, 9H).$^{13}C\{^{1}H\}$ NMR (100 MHz, $CDCl_3$) δ 173. 2 171.1, 143.3, 143.2, 139.2, 135.6, 135.3, 133.3, 132.6, 131.6, 130.4, 130.0, 129.1, 129.0, 128.7, 128.6, 128.5, 128.3, 128.2, 122.4, 120.0, 115.1, 114.9, 103.6 (d, *J* = 194.1 Hz), 62.2, 52.4, , 45.4, 37.8, 25.37, 25.3, 14.1, 12.6.^{19}F NMR (376 MHz, $CDCl_3$) δ -137.5 (dd, *J* = 29.5, 7.4 Hz). HRMS (ESI) calcd for $C_{24}H_{24}FNO_3$ $[M+H]^+$394.1813, found 394.1806.

2-Ethyl-2-fluoro-3a,5,8-trimethyl-4-oxo-1-phenyl-3,3a,4,5-tetrahydro-2H-cyclop enta[c]quinoline-2-carboxylate (3t). Yellow oil, 69 mg, yield 88%, dr = 4:1, R_f = 0.30 (petroleum ether/EtOAc, 15:1); ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.38 – 7.27 (m, 4H), 7.23 – 6.88 (m, 4H), 4.42 – 4.27 (m, 2H), 3.45 – 3.35 (m, 3H), 3.17 – 2.97 (m, 1H), 2.78 – 2.67 (m, 1H), 2.07 (s, 3H), 1.41 (s, 3H), 1.33 (t, *J* = 7.2 Hz, 3H). $^{13}C\{^{1}H\}$ NMR (100 MHz, $CDCl_3$) δ 173.6, 170.9, 143.3, 137.9, 133.3, 132.7, 132.0, 131.0, 130.5, 129.1, 128.5, 128.4, 128.3, 119.7, 115.0, 103.6(d, *J* = 194.1 Hz), 62.2, 52.6, 45.6, 30.0, 25.5, 20.5, 14.1. ^{19}F NMR (376 MHz, $CDCl_3$) δ -138.8 (dd, *J* = 29.5, 6.5 Hz). HRMS (ESI) calcd for $C_{24}H_{24}FNO_3$ $[M+H]^+$394.1813, found 394.1813.

2-Ethyl-8-bromo-2-fluoro-3a,5-dimethyl-4-oxo-1-phenyl-3,3a,4,5-tetrahydro-2H -cyclopenta[c]quinoline-2-carboxylate (3u). Yellow oil, 57 mg, yield 63%, dr = 5:1, R_f = 0.30 (petroleum ether/EtOAc, 10:1); ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.43 – 6.89 (m, 8H), 4.46 – 3.81 (m, 2H), 3.42 (s, 3H), 3.19 – 2.39 (m, 2H), 1.40 (s, 3H), 1.33 (t, *J* = 6.3 Hz, 3H). $^{13}C\{^{1}H\}$ NMR (100 MHz, $CDCl_3$) δ 173.4, 170.8, 141.7, 138.8, 137.2, 131.8, 130.1, 129.7, 128.9, 128.71, 128.3, 128.0, 127.8, 121.3, 116.4, 103.4(d, *J* = 194.9 Hz), 62.3, 52.4, 45.5, 30.2, 25.4, 14.1. ^{19}F NMR (376 MHz, $CDCl_3$) δ -137.7 (d,

J = 29.9 Hz). HRMS (ESI) calcd for $C_{23}H_{21}ClFNO_3$ $[M+H]^+$414.1267, found 414.1262.

2-Ethyl-2-fluoro-8-methyl-4-oxo-1,3a-diphenyl-5-tosyl-3,3a,4,5-tetrahydro-2H-cyclopenta[c]quinoline-2-carboxylate (3v). White solid, 108 mg, yield 91%, dr > 20:1, R_f = 0.30 (petroleum ether/EtOAc, 5:1); ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.80 (d, *J* = 8.3 Hz, 2H), 7.49 (d, *J* = 8.4 Hz, 1H), 7.41 – 7.35 (m, 3H), 7.29 (dd, *J* = 13.3, 6.6 Hz, 4H), 7.12 (ddd, *J* = 8.2, 4.7, 2.4 Hz, 6H), 7.02 – 6.92 (m, 2H), 4.22 – 4.05 (m, 3H), 3.20 (dd, *J* = 27.0, 15.5 Hz, 1H), 2.66 (t, *J* = 15.0 Hz, 1H), 2.38 (d, *J* = 19.7 Hz, 3H), 2.12 (d, *J* = 8.5 Hz, 3H), 1.11 (t, *J* = 7.1 Hz, 3H). ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 171.2, 169.9, 145.2, 140.2, 140.1, 139.8, 139.6, 138.9, 138.8, 136.5, 136.2, 132.4, 131.4, 129.7, 129.5, 129.0, 128.7, 128.3, 127.7, 127.4, 126.3, 125.3, 124.5, 103.6 (d, *J* = 194.6 Hz), 64.3, 62.2, 47.5, 21.7, 20.9, 13.9. ^{19}F NMR (376 MHz, $CDCl_3$) δ -104.2 (dd, *J* = 27.0, 14.5 Hz). HRMS (ESI) calcd for $C_{35}H_{30}FNO_5S$ $[M+H]^+$596.1901, found 596.1899.

2-Ethyl-2,8-difluoro-4-oxo-1,3a-diphenyl-5-tosyl-3,3a,4,5-tetrahydro-2H-cyclopenta[c]quinoline-2-carboxylate (3w). White solid, 75 mg, yield 63%, dr > 20:1, R_f = 0.40 (petroleum ether/EtOAc, 5:1); ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.86 – 7.74 (m, 2H), 7.62 – 7.54 (m, 1H), 7.48 – 7.11 (m, 13H), 6.95 – 6.80 (m, 2H), 4.21 – 4.09 (m, 2H), 3.29 – 3.14 (m, 1H), 2.72 – 2.62 (m, 1H), 2.41 (d, *J* = 5.8 Hz, 3H), 1.19 – 1.00 (m, 3H). ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 170.8, 169.6, 160.4 (d, *J* = 246.9 Hz), 145.5, 138.4, 135.8, 130.8, 129.5, 129.4, 128.9, 128.8, 128.3, 127.9, 126.7, 126.7, 126.2, 116.1, 115.8, 113.8, 103.6 (d, *J* = 194.9 Hz), 64.2, 62.4, 47.5, 47.2, 13.9. ^{19}F NMR (376 MHz, $CDCl_3$) δ 136.0 (dd, *J* = 13.4, 7.9 Hz), 109.91 (dd, *J* = 26.9, 15.0 Hz). HRMS (ESI) calcd for $C_{34}H_{27}F_2NO_5S$ $[M+H]^+$ 600.1651, found 600.1647.

2-Ethyl-2-fluoro-1-(4-methoxyphenyl)-4-oxo-3a-phenyl-5-tosyl-3,3a,4,5-tetrahydro-2H-cyclopenta[c]quinoline-2-carboxylate (3x). White solid, 113 mg, yield 93%, dr > 20:1, R_f = 0.30 (petroleum ether/EtOAc, 5:1); ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.83 (t, *J* = 14.9 Hz, 2H), 7.61 (d, *J* = 8.2 Hz, 1H), 7.34 – 7.02 (m, 12H), 6.88 (dd, *J* = 22.6, 8.6 Hz, 2H), 4.24 – 4.11 (m, 2H), 3.89 – 3.78 (m, 3H), 3.28 – 3.12 (m, 1H), 2.65 (t, *J* = 14.7 Hz, 1H), 2.40 (s, 3H), 1.11 (t, *J* = 7.1 Hz, 3H). ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 171.2, 170.0, 160.1, 145.3, 139.7, 139.5, 138.7, 138.6, 136.2, 134.8, 130.3,

129.5, 128.8, 128.6, 128.4, 128.2, 127.7, 127.2, 126.6, 126.4, 125.8, 124.7, 123.4, 114.2, 103.6(d, J = 194.3 Hz), 64.0, 62.2, 55.3, 47.5, 21.7, 13.9. ^{19}F NMR (376 MHz, $CDCl_3$) δ -140.7 (dd, J = 27.1, 13.9 Hz). HRMS (ESI) calcd for $C_{35}H_{30}FNO_6S$ $[M+H]^+$612.1851, found 612.1845.

2-Ethyl-2-fluoro-4-oxo-1,3a-diphenyl-5-(phenylsulfonyl)-3,3a,4,5-tetrahydro-2H-cyclopenta[c]quinoline-2-carboxylate (3y). White solid, 97 mg, yield 86%, dr > 20:1, R_f = 0.30 (petroleum ether/EtOAc, 5:1); ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.95 (t, J = 14.0 Hz, 2H), 7.62 (t, J = 7.5 Hz, 2H), 7.57 – 7.47 (m, 2H), 7.44 – 7.34 (m, 3H), 7.28 (dd, J = 10.5, 7.2 Hz, 2H), 7.23 – 7.08 (m, 7H), 7.03 (t, J = 7.5 Hz, 1H), 4.19 – 4.08 (m, 2H), 3.21 (dd, J = 26.8, 15.5 Hz, 1H), 2.67 (t, J = 15.4 Hz, 1H), 1.10 (t, J = 7.1 Hz, 3H). ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 171.1, 169.8, 140.2, 140.0, 139.9, 139.1, 138.6, 138.6, 134.7, 134.1, 131.3, 129.0, 128.9, 128.7, 128.2, 127.8, 127.2, 126.7, 126.3, 125.4, 125.3, 124.7, 103.8(d, J = 195.3 Hz), 67.1, 64.2, 62.3, 47.3, 13.9. ^{19}F NMR (376 MHz, $CDCl_3$) δ -140.1 (dd, J = 26.7, 15.2 Hz). HRMS (ESI) calcd for $C_{33}H_{26}FNO_5S$ $[M+H]^+$ 568.1588, found 568.1585.

2-Ethyl-2-fluoro-5-((4-methoxyphenyl)sulfonyl)-4-oxo-1,3a-diphenyl-3,3a,4,5-tetrahydro-2H-cyclopenta[c]quinoline-2-carboxylate (3z). White solid, 108 mg, yield 91%, dr > 20:1, R_f = 0.30 (petroleum ether/EtOAc, 5:1); ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.88 (d, J = 8.9 Hz, 2H), 7.61 (d, J = 8.1 Hz, 1H), 7.37 (d, J = 2.5 Hz, 3H), 7.32 – 7.24 (m, 2H), 7.20 – 7.07 (m, 7H), 7.05 – 6.91 (m, 3H), 4.23 – 4.11 (m, 2H), 3.82 (s, 3H), 3.25 (dd, J = 27.0, 15.5 Hz, 1H), 2.69 (t, J = 15.1 Hz, 1H), 1.10 (t, J = 7.1 Hz, 3H).^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 171.1, 169.9, 164.1, 140.1, 139.9, 139.7, 138.8, 134.8, 131.4, 130.8, 130.3, 129.0, 128.9, 128.7, 127.7, 127.2, 126.5, 126.3, 125.4, 124.7, 114.0, 103.8 (d, J = 194.3 Hz), 64.2, 62.3, 55.8, 47.5, 13.9.^{19}F NMR (376 MHz, $CDCl_3$) δ 110.3 (dd, J = 26.9, 14.6 Hz). HRMS (ESI) calcd for $C_{34}H_{28}FNO_6S$ $[M+H]^+$598.1694, found 598.1689.

ASSOCIATED CONTENT

Investigations of the mechanism, crystal data and structure refinement of **3b** and **3i**, NMR spectra for compounds **1** and **3**.

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Notes

The authors declare no competing financial interest.

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