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Expanding the Scope of the Organocatalytic Addition of Fluoro-bis(phenylsulfonyl)methane to Enals: Enantioselective Cascade Synthesis of Fluoroindane and Fluorochromanol Derivatives

Young Sug Kim,[+a,b] Sun Min Kim,[+a,b] Bing Wang,[a,c] Xavier Companyó,[a] Jing Li,[c] Albert Moyano,[a] Seoyoung Im,[d] Zdeněk Tošner,[e] Jung Woon Yang,[b,*] and Ramon Rios[a,f,*]

[a] Department de Química Orgànica, Universitat de Barcelona, Martíi Franqués 1-11, 08028 Barcelona, Spain
[b] Department of Energy Science, Sungkyunkwan University, Suwon 440-746, Korea
E-mail: jwyang@skku.edu
[c] State Key Laboratory of Elemento-Organic Chemistry, College of Chemistry, Nankai University Tianjin, Tianjin 30007, People's Republic of China
[d] Department of Chemistry, Sungkyunkwan University, Suwon 440-746, Korea
[e] Laboratory of NMR Spectroscopy, Charles University in Prague, Faculty of Science, Albertov 6, 128 43 Praha 2, Czech Republic
[f] School of Chemistry, University of Southampton, Southampton, SO171BJ, U.K.
E-mail: R.Rios-Torres@southampton.ac.uk
[+] These authors contributed equally to this work.

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Abstract: Highly enantioselective cascade reactions for the synthesis of fluoroindanes and chromanols derivatives are described. The cascade reactions consisted of either a double Michael reaction or Michael–hemiacetal formation *via* the addition of fluorobis(phenylsulfonyl)methane (FBSM) to enals. The final products were obtained in good yields with excellent stereoselectivities.

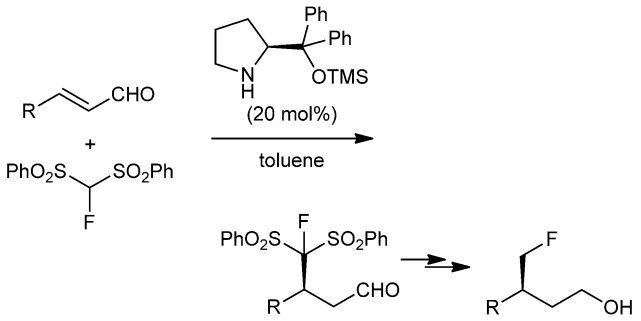
Keywords: enantioselectivity; fluorine; indanes; Michael reaction; organocatalysis

Introduction

Since the rediscovery of proline as a catalyst for aldol reactions by List, Barbas, and Lerner in 2000[1] and the subsequent development of iminium catalysis by MacMillan,[2] organocatalysis has emerged as a powerful tool in organic synthesis.[3]

Over the past few years, several research groups have worked to develop new and powerful methodologies for the syntheses of complex molecules in high yields with excellent enantioselectivity in a metal-free environment. Moreover, combining two or more organocatalytic reactions into a single protocol has been introduced as a challenging goal to alleviate the need for costly protecting groups and time-consuming purification procedures with individual reaction steps. To address these issues, tandem, domino, cascade, or multicomponent one-pot organocatalytic reactions have been utilized for the efficient diastereo- and enantioselective construction of complex molecules from readily available precursors *via* simple synthetic routes.[4] For example, a variety of tandem organocatalytic reactions for cyclopropanation[5] and aziridination,[6] as well as Michael–aldol,[7] Michael–Michael,[8] and Michael–α-alkylation reactions[9] have been developed with excellent results.

The success of fluorination to improve molecular properties has been convincingly demonstrated in a wide range of applications. In many cases, the small, highly electronegative fluorine atom is introduced following a particular rationale, based on our understanding of the effects of fluorination.[10] In the area of life sciences, well-known effects that include enhancement of metabolic stability, conformational stabilization, and modifications of reactive functional groups give rise to enhanced central nervous system (CNS) penetration or lipophilicity. Importantly, these effects cannot be considered individually as usually



Scheme 1. The formal fluoromethylation was reported in 2009.

a number of molecular properties are influenced simultaneously.[11] For example, fluorination of an amine-containing compound to increase its metabolic stability leads to a decrease in pK_a(H) and an increase in its lipophilicity, and thus, may induce strong conformational effects. For this reason, the development of new enantioselective methodologies that can deliver fluorinated compounds, a common moiety in drug candidates, would be of great interest not only for academia but also for the chemical industry.

In the realm of organocatalysis, several methodologies to access fluorine compounds have been developed such as α-fluorination[12] or α-trifluoromethylation of aldehydes.[13] In 2009, Rios, Wang, and Córdova independently developed an organocatalytic formal β-fluoromethylation of enals catalyzed by secondary amines with fluorobis(phenylsulfonyl)methane (FBSM),[14] resulting in the formation of fluorinated aldehydes with excellent results (Scheme 1).[15]

Intrigued by the highly enantioselective synthesis of fluorine compounds[16] and encouraged by our previous experience in the synthesis of fluorine compounds[17] and organocatalytic domino reactions,[18] we envisioned an organocatalytic domino reaction that would extend the synthetic applicability of our previously developed FBSM addition to enals.

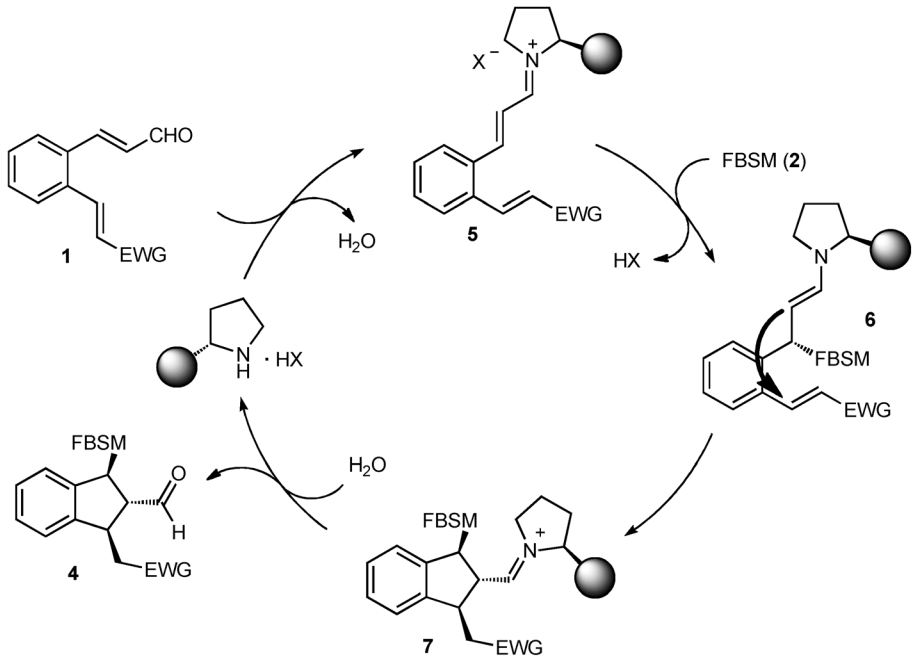
Results and Discussion

First, we focused on the development of a new Michael–Michael domino process, extending the synthetic utility of FBSM addition to enals.

Taking into account the underlying mechanism of this addition (Scheme 2), we realized that several synthetic protocols could be possible if the generated enamine intermediate **6** (*via* conjugated addition of FBSM to the α,β-unsaturated iminium ion) attacked an appropriate electrophile. The indane core would result from the domino Michael–Michael reaction sequence *via* the strategy shown in Scheme 2.

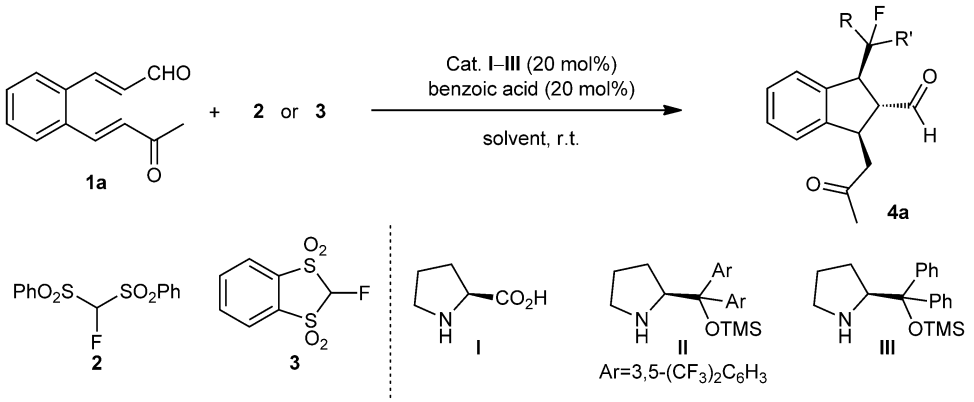
To determine the feasibility of this cascade process, we initially examined the efficacy of chiral organocatalysts **I–III** for the addition of FBSM **2** to enal-enone **1a** in toluene at room temperature. The results are summarized in Table 1.

Among the chiral pyrrolidine catalysts **I–III**, proline gave a complicated mixture (Table 1; entry 1), and no reaction occurred when diarylprolinol TMS ether **II** was employed as the organocatalyst (Table 1; entry 2). Gratifyingly, diphenylprolinol TMS ether **III** significantly increased both the chemical yield and enantio-



Scheme 2. Proposed catalytic cycle.

Table 1. Screening of reaction parameters.[a]



Entry	Fluorine source	Catalyst	Solvent	Yield [%][b]	*dr*[c]	*ee* [%][d]
1	**2**	**I**	toluene	C.M.	–	–
2	**2**	**II**	toluene	0	–	–
3	**2**	**III**	toluene	95	>20:1	>99
4	**2**	**III**	CH_2Cl_2	80	>20:1	>99
5	**2**	**III**	MeOH	0	–	–
6	**3**	**III**	toluene	C.M.	–	–

[a] *General reaction conditions:* **1a** (0.3 mmol), **2** or **3** (0.25 mmol), catalyst **I–III** (20 mol%), benzoic acid as additive (20 mol%), solvent (2.0 mL), room temperature.
[b] Isolated yield.
[c] Determined by ^{1}H NMR of the crude mixture.
[d] Determined by chiral-phase HPLC analysis. C.M. = complicated mixture.

selectivity of the desired product (Table 1; entry 3). To improve the catalytic activity, the reaction conditions were further optimized by examining the solvent and the fluorinating agent. Switching the solvent from toluene to CH_2Cl_2 or MeOH gave the desired products in 80% and 0% yields, respectively (Table 1; entries 4 and 5). Treatment with 2-fluoro-1,3-benzodithiole-1,1,3,3-tetraoxide **3**[19] as the fluorinating agent with enal-enone **1a** under the optimized conditions generated a complicated mixture (Table 1; entry 6).

After identifying suitable conditions for the Michael–Michael cyclization, we next explored the scope of this transformation, and the results are shown in Table 2. A variety of aromatic α,β-unsaturated aldehydes with different tethered Michael acceptors, including α,β-unsaturated ketone (Table 2; entries 1–3) and ester, were well tolerated in the intramolecular Michael–Michael cascade reaction. Extremely high levels of diastereoselectivity (>20:1) and enantioselectivity (99% *ee*) were obtained when enones were used (Table 2, entries 1–4), regardless of the nature of the substituents on the aromatic rings. With substrates bearing an unsaturated ester as electron-withdrawing group somewhat lower diastereo- and enantioselectivities were obtained (Table 2; entries 5 and 6).

The stereochemical assignment of adduct **4a** was made on the basis of a uniform reaction mechanism and specific NMR spectroscopy experiments (see the Supporting Information).

The Michael–Michael tandem reaction led to trisubstituted indane derivative **4**, which featured a *trans*,*trans* substitution pattern (Figure 1).[20]

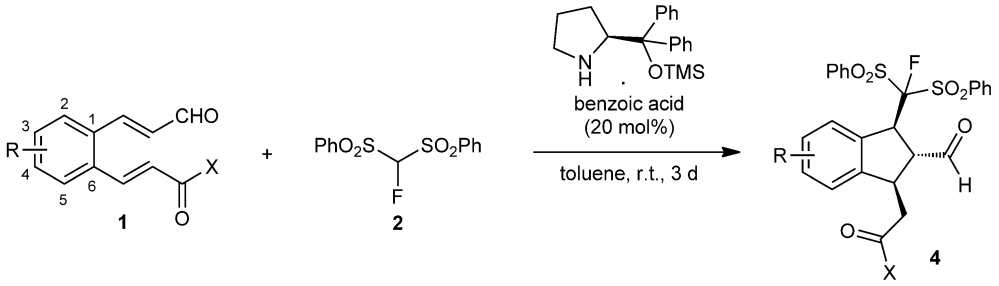
We have demonstrated that reductive desulfonylation of **4a** could be achieved with the Mg-MeOH-$NiBr_2$ system to deliver fluorinated compound **5a** in 71% yield (Scheme 3).

Next, we decided to study a related Michael–hemiacetal formation cascade reaction for the synthesis of fluorochromanol derivatives. Kim[21] and Wang[22] have recently reported the use of *ortho*-hydroxycinnamaldehydes as suitable starting materials for easy access to chiral chromanols *via* an iminium-catalyzed Michael addition, followed by intramolecular hemiacetal formation. Kim demonstrated the nucleophilic addition of malonates, nitroalkanes, and boronic acids to *ortho*-hydroxycinnamaldehydes **8** with excellent results.

A proposed catalytic cycle for the Michael–hemiacetal formation cascade reaction of *ortho*-hydroxycinnamaldehyde **8** and FBSM **2** with chiral organocatalyst **III**, similar to the mechanism suggested by the Kim group, is shown in Scheme 4.

The sequence of reactions begins with the activation of the cinnamaldehyde by the organocatalyst to form iminium ion **9**. Subsequently, the iminium ion

Table 2. Reaction scope with substrate **1**.[a]



Entry	R	Product	X	Yield [%][b]	*dr*[c]	*ee* [%][d]
1	–	**4a**	Me	65	>20:1	>99
2	3-F	**4b**	Me	69	>20:1	>99
3	4-MeO	**4c**	Me	58	>20:1	>99
4	3-F	**4d**	Ph	57	>20:1	>99
5	–	**4e**	OEt	65	5:1	94
6	3-F	**4f**	OEt	75	5:1	94

[a] *General reaction conditions:* **1** (0.3 mmol), **2** (0.25 mmol), catalyst **III** (20 mol%), benzoic acid as additive (20 mol%), solvent (2 mL), room temperature.
[b] Isolated yield.
[c] Determined by ^{1}H NMR of the crude mixture.
[d] Determined by chiral-phase HPLC analysis.

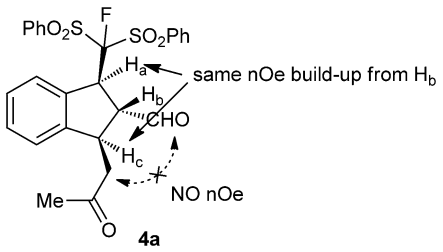
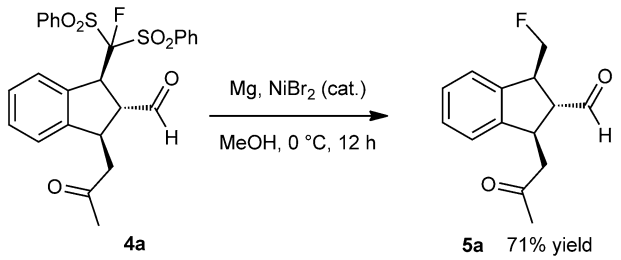


Figure 1. Relative configuration ascertained by nOe experiments.

quickly reacts with FBSM through a 1,4-addition pathway to give enamine intermediate **11**. After deprotonation of the hydroxy group of *ortho*-hydroxycinnamaldehyde by the resulting enamine species **11** and subsequent hydrolysis, cyclization provides the chroman-2-ol **13** and regenerates the organocatalyst. An important possible side product in this type of reaction, as previously reported by Wang, is the generation of aminal **10** from iminium ion **9** through the addition of a hydroxy group to the α,β-unsaturated iminium ion, thereby trapping the organocatalyst and decreasing the rate of the desired reaction.

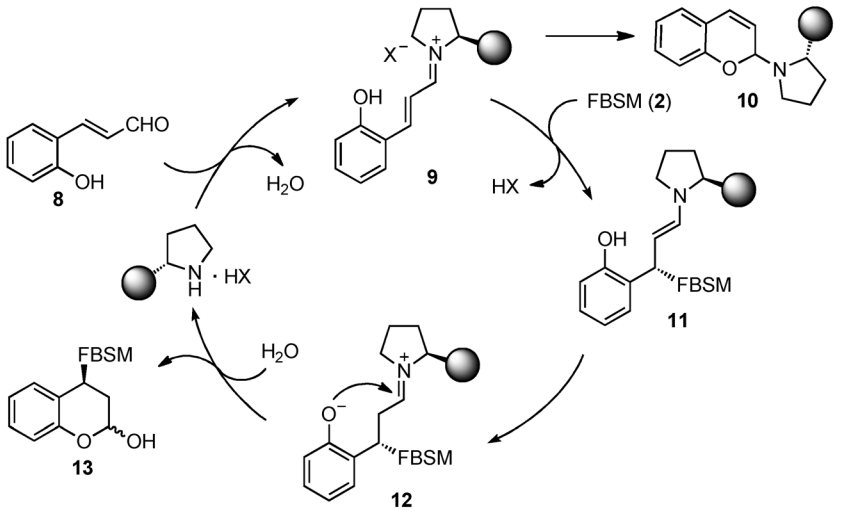


Scheme 3. Desulfonylation of **4a**.

We screened different reaction conditions in order to optimize the yield of the reaction and to avoid the formation of **10** (see the Supporting Information). To our delight, when *ortho*-hydroxycinnamaldehyde **8** was treated with FBSM **2** in the presence of catalyst **III** with benzoic acid as an additive in toluene at room temperature, the desired fluorinated chromanol **13** was produced in moderate to good yield and with excellent enantioselectivity.

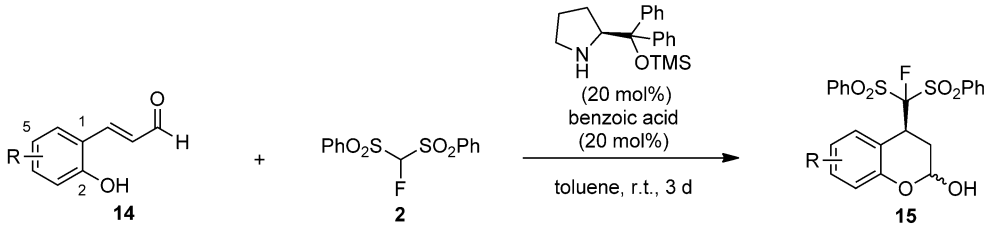
To explore the substrate scope of this transformation, various *ortho*-hydroxycinnamaldehydes were examined (Table 3). The reaction proceeded well with an electron-withdrawing substituent (Table 3; entry 4), electron-donating substituents (Table 3; entry 5) or with different halogen substituents (Table 3; entries 2, 3, 6–9). The desired products **15** were obtained in moderate to good yields (50–75%) with excellent enantioselectivities (92–96% *ee*) and good diastereoselectivities, regardless of the electronic nature and sites of substituents on the aromatic ring. A slight decrease in enantioselectivity (89% *ee*) was observed with 3,5-dichlorocinnamaldehyde as the substrate.

Moreover, we expanded this protocol for large-scale preparation of compound **15a**. The reaction of *ortho*-hydroxycinnamaldehyde was repeated on a 1.00 g (6.75 mmol) scale [27 times larger than the



Scheme 4. Proposed catalytic cycle for the Michael–hemiacetal formation cascade reaction.

Table 3. Reaction scope with substrate **14**.[a]

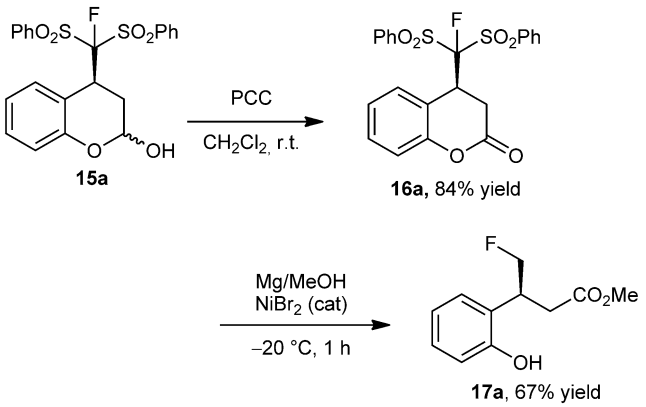


Entry	R	Product	Yield [%][b]	*dr*[c]	*ee* [%][d]
1	–	**15a**	75	4:1	92
2	5-Cl	**15b**	67	5:1	92
3	5-Br	**15c**	63	4:1	93
4	5-NO_2	**15d**	56	7:1	94
5	5-Me	**15e**	66	3:1	96
6	3-Br	**15f**	65	4:1	94
7	4-Br	**15g**	50	5:1	95
8	3,5-dichloro	**15h**	55	7:1	89
9	3,5-dibromo	**15i**	71	6:1	95

[a] *General reaction conditions:* **14** (0.25 mmol), **2** (0.25 mmol), catalyst **III** (20 mol%), benzoic acid as additive (20 mol%), solvent (1 mL), room temperature.
[b] Isolated yield.
[c] Determined by ^{1}H NMR of the crude mixture.
[d] Determined by chiral-phase HPLC analysis.

experiments described in Table 3], giving the product **15a** in 71% yield without any loss of enantioselectivity (92% *ee*) and diastereomeric ratio (4:1 *dr*) (see the Supporting Information).

As a brief demonstration of the utility of the developed methodology, we performed a simple oxidation of hemiacetal **15a** with PCC to furnish the corresponding lactone **16a** in 84% yield. Next, we proceed to eliminate the 1,1′-bis(sulfone) moiety by reductive desulfonylation with the Mg-MeOH-$NiBr_2$ system, which was further reductively ring-opened to give the fluorinated product **17a** in 67% yield (Scheme 5).



Scheme 5. Derivatization of **15a**.

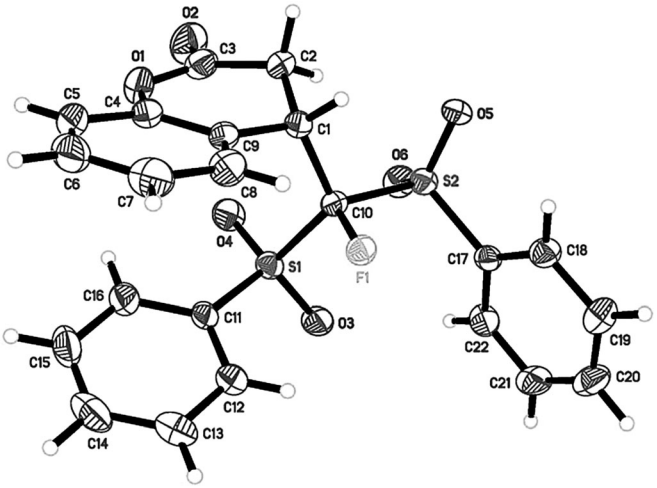


Figure 2. ORTEP drawing of compound **16a**.

In order to elucidate the absolute configuration of compound **16a**, an X-ray diffraction analysis was performed, shown in Figure 2.[23] From the X-ray structure of **16a**, the single stereogenic center was unambiguously established as having the (*R*)-configuration. The use of the (*S*)-configured catalyst **III** leads to the expected configuration of the product based on the proposed mechanism outlined in Scheme 4.

Conclusions

In summary, we have developed new cascade reactions for the synthesis of indanes and chromanols. Excellent stereoselectivities and moderate to good yields were observed in the addition of FBSM to enals *via* the Michael–Michael cascade reaction to afford indanes, as well as in the Michael–hemiacetal formation cascade reaction to afford chromanols. Importantly, these cascade reactions provide access to fluoro-substituted indane or chromanol derivatives in a one-pot process.

Experimental Section

General Procedure for the Michael/Michael Cascade Reaction

Catalyst **III** (16 mg, 0.05 mmol), fluorobis(phenylsulfonyl)-methane **2** (79 mg, 0.25 mmol), and benzoic acid (6.1 mg, 0.05 mmol) were added in 2 mL of toluene to a vial. Next, substrate **1** (0.30 mmol, 1.2 equiv.) was added and the reaction mixture was stirred at room temperature over 3 days. The crude product was purified by column chromatography on silica gel eluting with hexanes/ethyl acetate to afford the final compound **4**.

(1*S*,2*R*,3*R*)-1-[Fluorobis(phenylsulfonyl)methyl]-3-(2-oxopropyl)-2,3-dihydro-1*H*-indene-2-carbaldehyde (4a): yield: 83 mg (65%); dark yellow solid; $[\alpha]_D^{25}$: −194 (*c* 0.5, $CHCl_3$, 96% *ee*); ^{1}H NMR (400 MHz, $CDCl_3$): δ = 10.18 (br, 1H), 7.93 (m, 2H), 7.73 (m, 1H), 7.63 (m, 5H), 7.73 (m, 1H), 7.43 (m, 2H), 7.73 (m, 1H), 7.22 (m, 1H), 7.14 (m, 1H), 7.00 (m, 2H), 4.89 (m, 1H), 4.30 (m, 1H), 3.76 (m, 1H), 3.59 (m, 1H), 3.18 (m, 1H), 2.30 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ = 208.1, 200.0, 171.1, 143.9, 137.4, 135.3, 134.8, 131.4, 131.4, 130.7, 128.9, 128.5, 127.3, 124.0, 114.4, 110.8, 60.3, 55.2, 55.2, 50.1, 46.2, 46.1, 41.9, 30.9; ^{19}F NMR (376 MHz, $CDCl_3$): δ = −130.44; HR-MS (ESI): *m/z* = 532.1252, calcd. for $C_{26}H_{27}FNO_6S_2$ $(M+NH_4)^+$: 532.1264; enantiomeric excess: 99%, determined by HPLC (Daicel Chiralpak IA, *i*-PrOH/hexane = 10/90, UV 220 nm, flow rate 1 mL min^{-1}): major 35.7 min, minor 57.5 min.

(1*R*,2*R*,3*S*)-5-Fluoro-3-[fluorobis(phenylsulfonyl)-methyl]-1-(2-oxopropyl)-2,3-dihydro-1*H*-indene-2-carbaldehyde (4b): yield: 92 mg (69%); yellow foam; $[\alpha]_D^{25}$: −216 (*c* 0.5, $CHCl_3$, 96% *ee*); ^{1}H NMR (400 MHz, $CDCl_3$): δ = 10.15 (br, 1H), 7.91–7.26 (m, 1H), 7.01 (m, 1H), 6.83 (m, 1H), 6.69 (m, 1H), 4.83 (m, 1H), 4.31 (m, 1H), 3.76 (m, 1H), 3.59 (m, 1H), 3.10 (m, 1H), 2.31 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ = 207.7, 199.7, 187.1, 136.1, 135.4, 134.9, 134.5, 131.4, 130.6, 128.9, 128.6, 114.8, 114.6, 111.1, 110.9, 55.8, 55.7, 49.8, 45.7, 45.5, 41.7, 30.2; ^{19}F NMR (376 MHz, $CDCl_3$): δ = −113.68, −130.75; HR-MS (ESI): *m/z* = 550.1155, calcd. for $C_{26}H_{26}F_2NO_6S_2$ $(M+NH_4)^+$: 550.1170; enantiomeric excess: 99%, determined by HPLC (Daicel Chiralpak IA, *i*-PrOH/hexane = 10/90, UV 220 nm, flow rate 1 mL min^{-1}): major 28.9 min, minor 46.4 min.

(1*S*,2*R*,3*R*)-1-[Fluorobis(phenylsulfonyl)methyl]-5-methoxy-3-(2-oxopropyl)-2,3-dihydro-1*H*-indene-2-carbaldehyde (4c): yield: 79 mg (58%); yellow foam; $[\alpha]_D^{25}$: −173 (*c* 0.5, $CHCl_3$, 96% *ee*); ^{1}H NMR (400 MHz, $CDCl_3$): δ = 10.15 (br, 1H), 7.92 (m, 2H), 7.73 (m, 1H), 7.60 (m, 5H), 7.43 (m, 2H), 6.91 (m, 1H), 6.64 (m, 1H), 6.52 (m, 1H), 4.83 (m, 1H), 4.28 (m, 1H), 3.76 (s, 3H), 3.59 (m, 1H), 3.53 (m, 1H), 3.17 (m, 1H), 2.31 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ = 208.0, 200.0, 160.2, 145.6, 135.2, 134.7, 131.4, 131.4, 130.6, 130.5, 128.8, 128.5, 126.9, 126.8, 113.9, 108.7, 55.8, 55.7, 55.3, 49.9, 45.8, 45.6, 41.8, 30.3; ^{19}F NMR (376 MHz, $CDCl_3$): δ = −130.18; HR-MS (ESI): *m/z* = 562.1372, calcd. for $C_{27}H_{29}FNO_7S_2$ $(M+NH_4)^+$: 562.1364; enantiomeric excess: 99%, determined by HPLC (Daicel Chiralpak IA, *i*-PrOH/hexane = 10/90, UV 220 nm, flow rate 1 mL min^{-1}): major 40.1 min, minor 50.9 min.

(1*R*,2*R*,3*S*)-5-Fluoro-3-[fluorobis(phenylsulfonyl)-methyl]-1-(2-oxo-2-phenylethyl)-2,3-dihydro-1*H*-indene-2-carbaldehyde (4d): yield: 85 mg (57%); yellow foam; $[\alpha]_D^{25}$: −190 (*c* 0.4, $CHCl_3$, 99% *ee*); ^{1}H NMR (400 MHz, $CDCl_3$): δ = 10.27 (br, 1H), 8.07–8.04 (m, 2H), 7.92–7.88 (m, 2H), 7.80–7.45 (m, 11H), 7.12–7.05 (m, 1H), 6.90 (dd, J_1 = 2.3, J_2 = 8.7 Hz, 1H), 6.74 (td, J_1 = 8.6, J_2 = 2.3 Hz, 1H), 4.89 (t, J = 6.4 Hz, 1H), 4.40 (t, J = 5.0 Hz, 1H), 4.17 (dd, J_1 = 18.5, J_2 = 9.9 Hz, 1H), 4.01–3.96 (m, 1H), 3.62 (dd, J_1 = 18.5, J_2 = 3.9 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$): δ = 199.9, 199.1, 164.6, 137.5, 136.6, 135.4, 135.0, 133.5, 131.5, 131.4, 130.7, 130.7, 129.0, 128.7, 128.6, 128.2, 114.8, 114.6, 111.3, 111.1, 56.1 (d, $J_{C,F}$ = 6.1 Hz), 45.8 (d, $J_{C,F}$ = 17.2 Hz), 45.3, 42.1 (d, $J_{C,F}$ = 1.9 Hz); ^{19}F NMR (376 MHz, $CDCl_3$): δ = −112.6 (m, 1F) −130.3 (s, 1F); HR-MS (ESI): *m/z* = 612.6827, calcd. for $C_{31}H_{28}F_2NO_6S_2$ $(M+NH_4)^+$: 612.6834; enantiomeric excess: 99%, determined by HPLC (Daicel Chiralpak IB, *i*-PrOH/

hexane = 10/90, UV 220 nm, flow rate 1 mL min^{-1}): major 24.5 min, minor 39.4 min.

Ethyl 2-{(1*R*,2*R*,3*S*)-3-[fluorobis(phenylsulfonyl)methyl]-2-formyl-2,3-dihydro-1*H*-inden-1-yl}acetate (4e): yield: 88 mg (65%); yellow scum; $[\alpha]_D^{25}$: −134 (*c* 0.5, $CHCl_3$, 94% *ee*); ^{1}H NMR (400 MHz, $CDCl_3$): δ = 10.12 (m, 1H), 7.99–7.93 (m, 2H), 7.84–7.71 (m, 2H), 7.63–7.58 (m, 2H), 7.53–7.48 (m, 2H), 7.08–7.03 (m, 1H), 7.01–6.97 (m, 1H), 6.74–6.68 (m, 1H),, 5.15–5.10 (m, 1H), 5.0–4.95 (m, 1H), 4.85–4.75 (m, 1H), 4.47–4.40 (m, 2H), 3.08 (dd, J_1 = 17.2, J_2 = 5.2 Hz, 1H), 2.92 (dd, J_1 = 17.2, J_2 = 8.7 Hz, 1H) 1.48 (t, J = 7.2 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ = 200.7, 171.5, 147.2, 135.7, 135.3, 134.6, 131.5, 131.4, 130.1, 130.0, 130.0, 129.4, 128.8, 128.5, 114.8, 114.5, 110.6, 110.4, 61.1, 52.1 (d, $J_{C,F}$ = 6.5 Hz), 46.4 (d, $J_{C,F}$ = 17.8 Hz), 42.9 (d, $J_{C,F}$ = 2.3 Hz), 35.3, 14.1; ^{19}F NMR (376 MHz, $CDCl_3$): δ = −113.2 (m), 129.5 (d, $J_{H,F}$ = 9.9 Hz); HR-MS (ESI): *m/z* = 563.1009, calcd. for $C_{27}H_{25}F_2O_7S_2$ $(M+H)^+$: 563.1004; enantiomeric excess: 99%, determined by HPLC (Daicel Chiralpak IA, *i*-PrOH/hexane = 10/90, UV 220 nm, flow rate 1 mL min^{-1}): minor 27 min, major 35 min.

Ethyl 2-{(1*R*,2*R*,3*S*)-5-fluoro-3-[fluorobis(phenylsulfonyl)-methyl]-2-formyl-2,3-dihydro-1*H*-inden-1-yl}acetate (4f): yield: 105 mg (75%); white scum; $[\alpha]_D^{25}$: −142 (*c* 0.5, $CHCl_3$, 94% *ee*); ^{1}H NMR (400 MHz, $CDCl_3$): δ = 10.12 (m, 1H), 7.96–7.92 (m, 2H), 7.76–7.70 (m, 2H), 7.62–7.54 (m, 4H), 7.42–7.32 (m, 2H), 7.24–6.90 (m, 4H), 4.94–4.90 (m, 1H), 4.46–4.42 (m, 1H), 3.80 (s, 3H), 3.79–3.70 (m, 1H), 3.34 (dd, J_1 = 17.3, J_2 = 10.7 Hz, 1H), 3.05 (dd, J_1 = 17.3, J_2 = 4.1 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$): δ = 199.9, 173.2, 143.6, 137.4, 135.3, 134.8, 131.4, 131.4, 130.7, 128.9, 128.5, 127.3, 124.0, 117.0, 114.4, 55.4 (d, $J_{C,F}$ = 6.1 Hz), 51.9, 46.4 (d, $J_{C,F}$ = 16.9 Hz), 43.0, 40.1; ^{19}F NMR (376 MHz, $CDCl_3$): δ = −129.2 (d, $J_{H,F}$ = 10 Hz); HR-MS (ESI): *m/z* = 531.0945, calcd. for $C_{26}H_{24}FO_7S_2$ $(M+NH_4)^+$: 531.0942; enantiomeric excess: 94%, determined by HPLC (Daicel Chiralpak IA, *i*-PrOH/hexane = 10/90, UV 220 nm, flow rate 1 mL min^{-1},): major 27 min, minor 34 min.

Procedure for the Desulfonylation of 4a

To a well stirred solution of aldehyde (120 mg, 0.23 mmol) in anhydrous MeOH (5 mL), Mg turnings (195 mg, 8.1 mmol) and a catalytic amount of $NiBr_2$ were added at 0 °C under an argon atmosphere. After 12 h, the reaction mixture was filtered through Celite. The residue was washed thoroughly with MeOH. The filtrates were pooled, and the liquid was concentrated under reduced pressure. The resulting residue was dissolved in EtOAc, washed with saturated NH_4Cl solution, dried over anhydrous Na_2SO_4, and filtered. The filtrate was concentrated under reduced pressure to a residue, which was purified by column chromatography on silica gel using a gradient eluent system (hexanes/ethyl acetate = 8:1 to 5:1).

(1*S*,2*S*,3*S*)-5-Fluoro-3-(fluoromethyl)-1-(2-oxopropyl)-2,3-dihydro-1*H*-indene-2-carbaldehyde (5a): yield: 38 mg (71%); brownish liquid; $[\alpha]_D^{25}$: −16.20 (*c* 1.0, $CHCl_3$); ^{1}H NMR (700 MHz, $CDCl_3$): δ = 9.95 (s, 1H), 7.28–7.12 (m, 4H), 4.70 (d, J = 4.9 Hz, 1H), 4.64 (d, J = 4.9 Hz, 1H), 3.97–3.82 (m, 2H), 3.12–3.06 (m, 1H), 2.83–2.78 (m, 2H), 2.23 (s, 3H); ^{13}C NMR (175 MHz, $CDCl_3$): δ = 207.34, 201.34, 143.87, 139.96 (d, J = 5.25 Hz), 128.09, 127.76, 124.25, 123.89, 85.05 (d, J = 171.5 Hz), 60.13 (d, J = 1.75 Hz), 49.64, 45.43 (d, J = 19.25 Hz), 39.92, 29.98 (d, J = 92.56 Hz); ^{19}F NMR (376 MHz, $CDCl_3$): δ = −21.87 (td, J_1 = 94, J_2 = 23.03 Hz); HR-MS (ESI$^+$): *m/z* = 234.1272,calcd. for $[M+H]^+$ $C_{14}H_{15}O_2F$: 234.1056.

General Procedure for the Michael/Hemiacetal Formation Cascade Reaction

In a vial, catalyst **III** (16 mg, 0.05 mmol), fluorobis(phenylsulfonyl)methane **2** (79 mg, 0.25 mmol), and benzoic acid (6.1 mg, 0.05 mmol) were added in 1 mL of toluene. Next, substrate **14** (0.25 mmol, 1.0 equiv.) was added and the reaction mixture was stirred at room temperature over 3 days. The crude product was purified by column chromatography on silica gel eluting with hexanes/ethyl acetate to afford the final compound **15**.

(4*S*)-4-[Fluorobis(phenylsulfonyl)methyl]chroman-2-ol (15a): yield: 87 mg (75%); white solid; $[\alpha]_D^{25}$: +21.16 (*c* 0.5, $CHCl_3$, 93% *ee*); ^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.10–8.06 (m, 2H), 7.78–7.73 (m, 1H), 7.65–7.55 (m, 2H), 7.50–7.30 (m, 2H), 7.25–7.15 (m, 2H), 7.04–6.96 (m, 1H), 6.90–6.75 (m, 2H), 6.36 (t, J = 7.6 Hz, 1H), 5.84 (q, J = 3 Hz, 1H), 4.50–4.40 (m, 1H), 3.25–3.15 (m, 1H), 2.82–2.76 (m, 1H); ^{13}C NMR (100 MHz, $CDCl_3$): δ = 152.4, 135.0, 134.4, 131.6, 131.6, 130.1 128.6 128.5, 121.5, 121.0, 118.4, 118.3, 116.9, 116.9, 90.4, 34.2 (d, $J_{C,F}$ = 14.9 Hz), 27.5 (d, $J_{C,F}$ = 6.9 Hz); ^{19}F NMR (376 MHz, $CDCl_3$): δ = −127.0 (d, $J_{H,F}$ = 13.9 Hz); HR-MS (ESI): *m/z* = 463.0672, calcd. for $C_{22}H_{20}FO_6S_2$ $(M+H)^+$: 463.0680; enantiomeric excess: 93%, determined by HPLC (Daicel Chiralpak IA, *i*-PrOH/hexane = 10/90, UV 220 nm, flow rate 1 mL min^{-1}): major 28 min, minor 34 min.

(4*S*)-6-Chloro-4-[fluorobis(phenylsulfonyl)methyl]chroman-2-ol (15b): yield: 83 mg (67%); pale yellow solid; $[\alpha]_D^{25}$: +31.16 (*c* 0.5, CHI_3, 94% *ee*); ^{1}H NMR (500 MHz, $CDCl_3$): δ = 8.1–8.14 (m, 2H), 7.74–7.8 (m, 1H), 7.6–7.65 (m, 2H), 7.51 (tt, J_1 = 7.5, J_2 = 1.5 Hz, 1H), 7.3–7.35 (m, 2H), 7.24–7.27 (m, 1H), 7.19–7.24 (m, 1H), 6.93 (dd, J_1 = 9, J_2 = 3 Hz, 1H), 6.74 (broad s, 1H), 6.72 (d, J = 8.5 Hz, 1H), 5.83–5.87 (m, 1H), 4.39–4.47 (m, 1H), 3.19–3.26 (m, 1H), 2.96 (broad s, 1H), 2.82 (dddd, J_1 = 14, J_2 = 7.5, J_3 = 3, J_4 = 1 Hz, 1H); ^{13}C NMR (125 MHz, $CDCl_3$): δ = 151.3, 136.8, 136.2, 135.4, 135.2, 132.0, 130.0, 129.7, 129.4 129.3, 128.9, 128.8 (d, $J_{C,F}$ = 4.3 Hz), 126.0, 119.8, 118.9, 90.6, 34.1 (d, $J_{C,F}$ = 14.9 Hz), 27.3 (d, $J_{C,F}$ = 6.6 Hz); ^{19}F NMR (470 MHz, $CDCl_3$): δ = −127.17 (d, $J_{H,F}$ = 22.1 Hz); HR-MS (FAB$^+$): *m/z* = 496.0217, calcd. for $C_{26}H_{27}ClFNO_6S_2$: 496.0218; enantiomeric excess: 92%, determined by HPLC (Daicel Chiralpak IA, *i*-PrOH/hexane = 15/85, UV 220 nm, flow rate 1 mL min^{-1}): major 22 min, minor 27 min.

(4*S*)-6-Bromo-4-[fluorobis(phenylsulfonyl)methyl]chroman-2-ol (15c): yield: 85 mg (63%); pale yellow solid; $[\alpha]_D^{25}$: +35.24 (*c* 0.5, $CHCl_3$, 92% *ee*); ^{1}H NMR (500 MHz, $CDCl_3$): δ = 8.09–8.12 (m, 2H), 7.74–7.79 (m, 1H), 7.6–7.64 (m, 2H), 7.52 (tt, J_1 = 7.5, J_2 = 1.5 Hz, 1H), 7.29–7.34 (m, 2H), 7.23–7.28 (m, 1H), 7.2–7.22 (m, 1H), 7.06 (d, J_1 = 9, J_2 = 3 Hz, 1H), 6.88 (broad s, 1H), 6.67 (d, J = 9 Hz, 1H), 5.82–5.87 (m, 1H), 4.38–4.47 (m, 1H), 3.28 (broad s, 1H), 3.17–3.25 (m, 1H), 2.81 (dddd, J_1 = 14, J_2 = 7.5, J_3 = 3, J_4 = 1 Hz, 1H); ^{13}C NMR (125 MHz, $CDCl_3$): δ = 151.9, 136.7, 136.1, 135.4, 135.3, 132.3, 132.2, 131.9, 129.9, 128.9, 120.3, 119.4, 113.6, 90.6, 34.1 (d, $J_{C,F}$ = 14.9 Hz), 27.3 (d, $J_{C,F}$ =

6.8 Hz); ^{19}F NMR (470 MHz, $CDCl_3$): $\delta = -127.08$ (d, $J_{H,F} =$ 22.1 Hz); HR-MS (ESI): $m/z = 541.9692$, calcd. for $C_{22}H_{18}BrFNO_6S_2$ (FAB^+): 541.9692; enantiomeric excess: 92%, determined by HPLC (Daicel Chiralpak IA, *i*-PrOH/hexane = 15/85, UV 220 nm, flow rate 1 mL min^{-1}): major 24 min, minor 28 min.

(4*S*)-4-[Fluorobis(phenylsulfonyl)methyl]-6-nitrochroman-2-ol (15d): yield: 71 mg (56%); pale yellow solid; $[\alpha]_D^{25}$: +46.68 (*c* 0.5, $CHCl_3$, 94% *ee*); ^{1}H NMR (500 MHz, $CDCl_3$): $\delta = 8.11$ (d, $J = 8.5$ Hz, 2H), 7.83–7.86 (dd, $J_1 = 9$, $J_2 = 2.5$ Hz, 1H), 7.79 (t, $J = 7.5$ Hz, 1H), 7.71–7.76 (m, 1H), 7.61–7.66 (m, 2H), 7.44 (t, $J = 7.5$ Hz, 1H), 7.32–7.37 (m, 2H), 7.17–7.24 (m, 2H), 6.88 (d, $J = 9$ Hz, 1H), 5.95 (broad s, 1H), 4.47–4.57 (m, 1H), 3.16–3.26 (m, 1H), 2.89–2.97 (m, 1H); ^{13}C NMR (125 MHz, $CDCl_3$): $\delta = 159.5$, 140.8, 136.7, 136.4, 135.9, 135.7, 131.9, 130.1, 130, 126.2, 126.1, 125.6, 119.6, 118.0, 91.3, 34.5 (d, $J_{C,F} = 15.3$ Hz), 28.0 (d, $J_{C,F} =$ 6.8 Hz); ^{19}F NMR (470 MHz, $CDCl_3$): $\delta = -127.66$ (d, $J_{H,F} =$ 20.7 Hz); HR-MS (ESI): m/z = 530.0356, calcd. for $C_{22}H_{18}FNO_8S_2$ $(M+Na)^+$: 530.0356; enantiomeric excess: 92%, determined by HPLC (Daicel Chiralpak IA, *i*-PrOH/hexane = 15/85, UV 220 nm, flow rate 1 mL min^{-1}): major 28 min, minor 36 min.

(4*S*)-4-[Fluorobis(phenylsulfonyl)methyl]-6-methylchroman-2-ol (15e): yield: 79 mg (66%); dark yellow solid; $[\alpha]_D^{25}$: +25.16 (*c* 0.5, $CHCl_3$, 93% *ee*); ^{1}H NMR (500 MHz, $CDCl_3$): $\delta = 8.1$–8.14 (m, 2H), 7.73–7.78 (m, 1H), 7.58–7.63 (m, 2H), 7.43 (tt, $J_1 = 7.5$, $J_2 = 1.5$ Hz, 1H), 7.24–7.28 (m, 2H), 7.15–7.2 (m, 2H), 6.75–6.79 (m, 1H), 6.68 (d, $J =$ 8.5 Hz, 1H), 6.54 (broad s, 1H), 5.81 (q, $J = 3$ Hz, 1H), 4.37–4.47 (m, 1H), 3.21–3.29 (m, 1H), 2.77 (dddd, $J_1 = 14$, $J_2 = 7.5$, $J_3 = 3$, $J_4 = 1$ Hz, 1H), 1.79 (s, 3H); ^{13}C NMR (125 MHz, $CDCl_3$): $\delta = 145.8$, 132.5, 131.8, 130.5, 129.7, 127.2, 125.6, 125.5, 125.4, 125.3, 125.1, 124.0, 123.8, 113.6, 112.0, 85.9, 29.7 (d, $J_{C,F} = 14.8$ Hz). 23.0 (d, $J_{C,F} = 6.9$ Hz), 15.9; ^{19}F NMR (470 MHz, $CDCl_3$): $\delta = -127.74$ (d, $J_{H,F} = 23.5$ Hz); HR-MS (ESI): $m/z = 476.0764$, calcd. for $C_{23}H_{21}FO_6S_2$ (FAB^+): 476.0764; enantiomeric excess: 92%, determined by HPLC (Daicel Chiralpak IA, *i*-PrOH/hexane = 15/85, UV 220 nm, flow rate 1 mL min^{-1}): major 31 min, minor 38 min.

(4*S*)-8-Bromo-4-[fluorobis(phenylsulfonyl)methyl]chroman-2-ol (15f): yield: 88 mg (65%); pale yellow solid; $[\alpha]_D^{25}$: −74.40 (*c* 0.5, $CHCl_3$, 94% *ee*); ^{1}H NMR (500 MHz, $CDCl_3$): $\delta = 8.03$–8.08 (m, 2H), 7.72–7.77 (m, 2H), 7.56–7.61 (m, 3H), 7.48 (tt, $J_1 = 7.5$, $J_2 = 1$ Hz, 1H), 7.37–7.41 (m, 2H), 7.27–7.29 (m, 1H), 7.21–7.26 (m, 2H), 6.9–6.93 (m, 1H), 6.28 (t, $J = 8$ Hz, 1H), 5.91 (q, $J = 3$ Hz, 1H), 4.43–4.51 (m, 1H), 3.13–3.2 (m, 1H), 2.77 (ddd, $J_1 = 14.25$, $J_2 = 7.75$, $J_3 =$ 2.5 Hz, 1H); ^{13}C NMR (125 MHz, $CDCl_3$): $\delta = 149.4$, 136.9, 136.1, 135.8, 135.3, 134.8, 132.9, 131.7, 130.3, 130.2, 129.6, 128.8 (d, $J_{C,F} = 6.9$ Hz), 121.6, 119.3, 112.6, 91.3, 34.5 (d, $J_{C,F} = 15.1$ Hz), 27.9 (d, $J_{C,F} = 6.8$ Hz); ^{19}F NMR (470 MHz, $CDCl_3$): $\delta = -67.1$; HR-MS (ESI): $m/z = 564.9589$, calcd. for $C_{22}H_{18}BrFO_6S_2Na$ $(M+Na)^+$: 564.9592; enantiomeric excess: 94%, determined by HPLC (Daicel Chiralpak IA, *i*-PrOH/hexane = 15/85, UV 220 nm, flow rate 1 mL min^{-1}): major 20 min, minor 26 min.

(4*S*)-7-Bromo-4-[fluorobis(phenylsulfonyl)methyl]chroman-2-ol (15g): yield: 67 mg (50%); pale yellow solid; $[\alpha]_D^{25}$: −24.76 (*c* 0.5, $CHCl_3$, 95% *ee*); ^{1}H NMR (500 MHz, $CDCl_3$): $\delta = 8.07$–8.11 (m, 2H), 7.74–7.78 (m, 2H), 7.59–7.64 (m, 2H), 7.55 (tt, $J_1 = 7.5$, $J_2 = 1.5$ Hz, 1H), 7.3–7.35 (m, 2H), 7.25–7.28 (m, 1H), 7.2–7.24 (m, 1H), 6.93 (d, $J = 2$ Hz, 1H), 6.67 (ddd, $J_1 = 8.5$, $J_2 = 2.5$, $J_3 = 1$ Hz, 1H), 6.37 (dd, $J_1 = 8.5$, $J_2 = 2$ Hz, 1H), 5.83 (q, $J = 3$ Hz, 1H), 4.35–4.45 (m, 1H), 3.16–3.24 (m, 2H), 2.79 (dddd, $J_1 = 14$, $J_2 = 7.5$, $J_3 = 3$, $J_4 =$ 1 Hz, 1H); ^{13}C NMR (125 MHz, $CDCl_3$): $\delta = 153.5$, 137.1, 136.3, 135.8, 135.3, 134.5, 131.8, 130.9, 130.8, 130.3, 130.1, 129.6, 128.9 (d, $J_{C,F} = 12.3$ Hz), 124.2, 122.5, 121.5, 116.3, 90.8, 34.1 (d, $J_{C,F} = 15.1$ Hz), 27.5 (d, $J_{C,F} = 6.9$ Hz); ^{19}F NMR (470 MHz, $CDCl_3$): $\delta = -66.96$; HR-MS (ESI): $m/z =$ 564.9589, calcd. for $C_{22}H_{18}BrFO_6S_2Na$ $(M+Na)^+$: 564.9592; enantiomeric excess: 95%, determined by HPLC (Daicel Chiralpak IA, *i*-PrOH/hexane = 15/85, UV 220 nm, flow rate 1 mL min^{-1}): major 18 min, minor 25 min.

(4*S*)-6,8-Dichloro-4-[fluorobis(phenylsulfonyl)methyl]-chroman-2-ol (15h): yield: 73 mg (55%); white solid; $[\alpha]_D^{25}$: 35.36 (*c* 0.5, $CHCl_3$, 89% *ee*); ^{1}H NMR (500 MHz, $CDCl_3$): $\delta = 8.08$–8.13 (m, 2H), 7.96–8.01 (m, 2H), 7.75–7.8 (m, 1H), 7.59–7.64 (m, 3H), 7.52 (tt, $J_1 = 7.5$, $J_2 = 1.5$ Hz, 1H), 7.36–7.4 (m, 2H), 7.27–7.33 (m, 2H), 7.05 (d, $J = 2.5$ Hz, 1H), 6.73–6.76 (m, 1H), 5.95 (broad s, 1H), 4.4–4.5 (m, 1H), 3.4 (broad s, 1H), 3.17–3.27 (m, 1H), 2.85 (dddd, $J_1 = 14.25$, $J_2 =$ 7.75, $J_3 = 3$, $J_4 = 1$ Hz, 1H); ^{13}C NMR (125 MHz, $CDCl_3$): $\delta =$ 147.6, 136.8, 136.1, 135.8, 135.5, 135.3, 131.9 (d, $J_{C,F} = 2$ Hz), 130.3, 129.9, 129.6, 129.6, 128.8 (d, $J_{C,F} = 8.4$ Hz), 128 (d, $J_{C,F} = 12$ Hz), 125.7, 124.1, 120.5, 118.2, 116.1, 91.2, 34.3 (d, $J_{C,F} = 14.9$ Hz), 27.35 (d, $J_{C,F} = 6.4$ Hz); ^{19}F NMR (470 MHz, $CDCl_3$): $\delta = -66.95$; HR-MS (ESI): $m/z = 529.9828$, calcd. for $C_{22}H_{17}Cl_2FO_6S_2$ ($FAB+$): 529.9828; enantiomeric excess: 89%, determined by HPLC (Daicel Chiralpak IA, *i*-PrOH/hexane = 15/85, UV 220 nm, flow rate 1 mL min^{-1}): major 15 min, minor 19 min.

(4*S*)-6,8-Dibromo-4-[fluorobis(phenylsulfonyl)methyl]-chroman-2-ol (15i): yield: 110 mg (71%); white solid; $[\alpha]_D^{25}$: 33.48 (*c* 0.5, $CHCl_3$, 95% *ee*); ^{1}H NMR (500 MHz, $CDCl_3$): $\delta = 8.09$–8.13 (m, 2H), 7.96–8.01 (t, $J = 2.5$ Hz, 1H), 7.60–7.65 (m, 2H), 7.53 (t, $J = 7.5$ Hz, 1H), 7.29–7.4 (m, 5H), 6.9–6.92 (m, 1H), 5.93–5.98 (m, 1H), 4.41–4.56 (m, 1H), 3.35 (broad s, 1H), 3.2–3.29 (m, 1H), 2.8–2.87 (m, 1H); ^{13}C NMR (125 MHz, $CDCl_3$): $\delta = 148.9$, 136.8, 136.1, 135.5, 135.4, 135.2, 132.1, 131.9, 131.6, 131.5, 130.3, 129.9, 129.6, 128.9, 120.9, 113.5, 113.3, 91.3, 34.3 (d, $J_{C,F} = 14.8$ Hz), 27.4 (d, $J_{C,F} = 6.1$ Hz); ^{19}F NMR (470 MHz, $CDCl_3$): $\delta = -66.91$; HR-MS (ESI): $m/z = 619.8797$, calcd. for $C_{22}H_{17}Br_2FO_6S_2$ (FAB^+): 619.8798; enantiomeric excess: 95%, determined by HPLC (Daicel Chiralpak IA, *i*-PrOH/hexane = 15/85, UV 220 nm, flow rate 1 mL min^{-1}): major 16 min, minor 19 min.

Procedure for the Oxidation of 15a

PCC (323 mg, 1.5 mmol) was added to a well stirred solution of hemiacetal **15a** (231 mg, 0.5 mmol) in anhydrous CH_2Cl_2 (5 mL, 0.1 M) at room temperature. After 3 h, the reaction mixture was filtered through Celite. The resulting residue was dissolved in CH_2Cl_2, washed with saturated NH_4Cl solution, dried over anhydrous Na_2SO_4, and filtered. The filtrate was concentrated under reduced pressure to a residue, which was purified by column chromatography on silica gel eluting with hexanes/ethyl acetate (4:1) to afford **16a** as a white solid.

(*S*)-4-[Fluorobis(phenylsulfonyl)methyl]chroman-2-one (16a): yield: 193 mg (84%) white solid; $[\alpha]_D^{25}$: +53.08 (*c* 0.5, $CHCl_3$, 93% *ee*); ^{1}H NMR (500 MHz, $CDCl_3$): $\delta = 7.8$–7.87

(m, 2H), 7.71 (t, $J=7.5$ Hz, 1H), 7.48–7.54 (m, 5H), 7.27–7.3 (m, 2H), 7.22–7.26 (m, 1H), 7.05–7.08 (m, 1H), 6.96 (dd, $J_1=8$, $J_2=1$ Hz, 1H), 6.9 (td, $J_1=7.5$, $J_2=1$ Hz, 1H), 4.45 (dd, $J_1=12.5$, $J_2=9.5$ Hz, 1H), 4.01 (d, $J=18$ Hz), 3.1 (ddd, $J_1=18$, $J_2=9.5$, $J_2=2.5$ Hz, 1H); ^{13}C NMR (125 MHz, $CDCl_3$): $\delta=164.66$, 152.92, 135.66, 135.43, 135.26, 135.03, 131.39 (d, $J=3.9$ Hz), 131.16 (d, $J=2.1$ Hz), 130.82, 130.29 (d, $J=2.1$ Hz), 129.05, 128.77, 124.19, 117.92, 114.79, 37.86 (d, $J=18.1$ Hz), 29.3 (d, $J=7.5$ Hz); ^{19}F NMR (470 MHz, $CDCl_3$): $\delta=-158.37$ (td, $J_1=28.2$, $J_2=11.84$ Hz); HR-MS (EI^+): $m/z=460.0447$, calcd. for $C_{22}H_{18}FO_6S_2$ $(M+H)^+$: 460.0451.

Procedure for the Desulfonylation of 16a

Mg turnings (391 mg, 16.2 mmol) and $NiBr_2$ (11.8 mg, 0.054 mmol) were added to a well stirred solution of lactone (250 mg, 0.54 mmol) in anhydrous MeOH (20 mL) at −20 °C under an argon atmosphere. After 1 h, the reaction mixture was filtered through Celite, and the residue was washed thoroughly with MeOH. The filtrates were pooled, and the liquid was concentrated under reduced pressure. The resulting residue was dissolved in EtOAc, washed with saturated NH_4Cl solution, dried over anhydrous Na_2SO_4, and filtered. The filtrate was concentrated under reduced pressure to a residue, which was purified by column chromatography on silica gel eluting with hexanes/ethyl acetate (12:1) to give **17a** as a colorless liquid.

Methyl (*S*)-4-fluoro-3-(2-hydroxyphenyl)butanoate (17a): yield: 77 mg (67%); colorless liquid); $[\alpha]_D^{25}$: +27.48 (*c* 0.5, $CHCl_3$, 93% *ee*); ^{1}H NMR (500 MHz, $CDCl_3$): $\delta=7.07$–7.2 (m, 2H), 6.91 (t, $J=7.5$ Hz, 1H), 6.86 (d, $J=8.0$ Hz, 1H), 6.85 (s, 1H), 4.62–4.7 (m, 1H), 4.53–4.61 (m, 1H), 3.76–3.89 (m, 1H), 3.66 (s, 3H), 3.0 (dd, $J_1=17$, $J_2=5$ Hz, 1H), 2.77 (dd, $J_1=16.5$, $J_2=9$ Hz, 1H); ^{13}C NMR (125 MHz, $CDCl_3$): $\delta=174.31$, 153.96, 128.63, 128.03, 121.38, 117.39, 86.06, 84.69, 52.3, 36.29 (d, $J=4$ Hz), 35.86 (d, $J=19.5$ Hz); ^{19}F NMR (470 MHz, $CDCl_3$): $\delta=-158.37$ (td $J_1=28.2$, $J_2=11.8$ Hz); HR-MS (FAB^+): $m/z=235.0746$, calcd. for $C_{11}H_{13}FO_3Na$ $[M+Na]^+$: 235.0747.

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[23] CCDC 961044 contains the supplementary crystallographic data for this paper. These data can be obtained free of charge from The Cambridge Crystallographic Data Centre *via* www.ccdc.cam.ac.uk/data_request/cif.

