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Sulfoximines as a Versatile Scaffold for Electrophilic Fluoroalkylating Reagents

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New electrophilic fluoroalkylating agents based on the sulfoximine skeleton as a common platform are described. We demonstrate the importance of the activating group, attached to the nitrogen, and its specificity for the fluorinated group to be delivered. As an application, a variety of unknown dichlorofluoro, bromodifluoro, and trifluoromethyl alkynes have been prepared using these reagents.

Introduction

The major progress recently realized in the domain of electrophilic introduction of fluoroalkylated groups into organic molecules has triggered the publication of noteworthy works, especially in the field of organo- or metal-assisted catalysis.[1] These important new developments are possible thanks to the availability of various fluorinated reagents which can be organized into three families. The first one, inspired by the pioneering work of Yagupolskii,[2] is based on the sulfonium skeletons. Many teams have contributed to the growth of this family which now covers not only the electrophilic trifluoromethylation reaction (Shreeve,[3] Umemoto,[4] Shibata,[5] and ourselves[6]), but also the mono- and difluoroalkylation (Prakash and Olah)[7] and pentafluoroethylation reactions.[8] The second series of molecules, hypervalent iodine(III)-CF_3 reagents, was proposed by Togni.[9] The third family of molecules is based on the sulfoximine functionality, as reported recently by Shibata for trifluoro- and monofluoromethylation[10] and Hu for difluoromethylation reactions (Figure 1).[11] In connection with this field, our research group recently unlocked access to the fluorinated sulfoximines[12] by discovering a versatile and safe preparation method, allowing the synthesis of a wide range of fluoroalkylated sulfilimines.[13] One principal advantage offered by sulfoximine reagents is their structural flexibility, potentially enabling a broader range of electrophilic fluorinated functional and activating groups than presently known. Although structurally similar, the sulfur(VI) derivatives described by Shibata and Hu exhibit three important differences, which make the comparison of their respective merits difficult: (1) the functionalization at the nitrogen (tosyl group or ammonium functionality), (2) the nature of the fluorinated group, and (3) the range of nucleophiles studied so far in electrophilic fluoroalkylation reactions. Although the reasons for choosing two different activating groups for different fluorinated substituents were not explicitly stated in the publications by the mentioned groups, it may be suspected that they were selected based on accessibility and/or reactivity considerations.

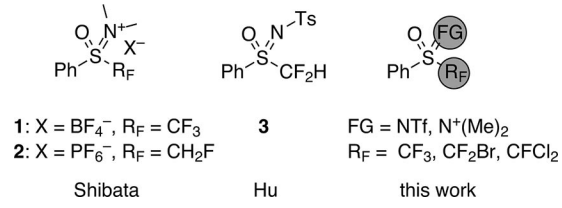

Figure 1. Electrophilic fluoroalkylating reagents based on sulfoximine skeleton.

Here, we take advantage of our knowledge in this area of chemistry to present a convergent synthesis of the fluorodichloro-, bromodifluoro-, and trifluoromethyl *NH*-sulfoximines. Our work provides easy access to a common scaffold allowing the functionalization "à la demande" of the nitrogen atom, and thus the introduction of either an *N*-triflyl group (other electron-withdrawing groups may be also introduced)[13] or a dimethylammonium functionality, as well as the use of various fluorinated groups (Figure 1). A comparison of the reactivity induced by these activating groups (neutral reagents vs salts) is then possible for various perfluoroalkylated chains with a common nucleophile.

Results and Discussion

Our previously described method for the direct transformation of acyl sulfilimines to the corresponding *NH*-sulfoximines[12] afforded the trifluoromethyl derivative **4c** in good yields, but was slightly less efficient for the fluoro-

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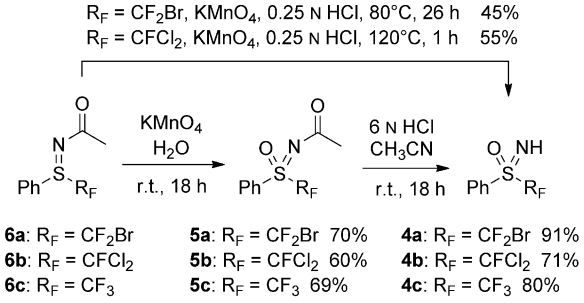
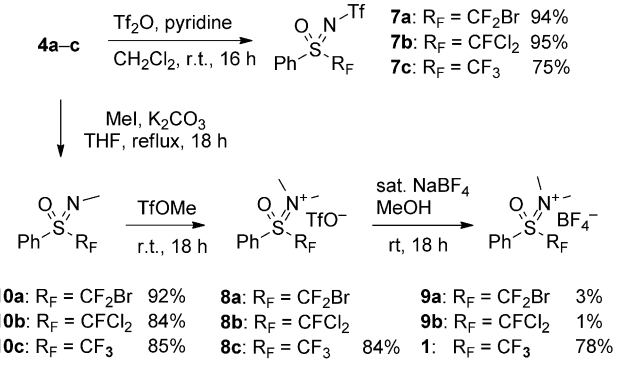
dichloro- and bromodifluorosulfilimines series. A reappraisal of the reaction conditions allowed us to describe an improved and secure two-step procedure (Scheme 1). In all cases, acyl sulfoximines **5** were easily isolated after smooth oxidation of the corresponding sulfilimines **6**. Previously deprotected under basic conditions, the nitrogen atom was now readily released by a simple acidic treatment at room temperature. A one-pot procedure has also been studied and developed. However, this more direct approach is somewhat substrate and condition dependent.



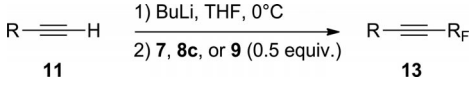
Scheme 1. Modified procedures for the synthesis of mono- and difluorinated sulfoximines from sulfilimines.

The next step involved the *N*-functionalization of sulfoximines **4a**–**c** by either the introduction of an electron-withdrawing group or the quaternarization of the nitrogen atom (Scheme 2). Sulfur derivatives **4a**–**c** were treated with trifluoromethanesulfonic anhydride to afford the derivatives **7a**–**c** in good to excellent yields. The preparation of the ammonium derivatives **8c** and **1**, previously published by Shibata and co-workers, was nicely reproduced. However, the same conditions did not permit the scalable synthesis of reagents **9a** and **9b**. The first methylation step gave the corresponding sulfoximines **10a** and **10b** with excellent yields. However, further treatment with neat methyl trifluoromethanesulfonate led to the formation of secondary compounds which were very difficult to separate from the ammonium triflates **8a** and **8b**.[14] A metathesis reaction finally allowed the isolation of nearly pure tetrafluoroborate salts **9a** and **9b**, but resulted in very low yields from *N*-methyl sulfoximines **10a** and **10b**, stressing the importance of the nature of the activating group in relation to the fluorinated substituent.



Scheme 2. Preparation of a set of electrophilic fluoroalkylating reagents.

The electrophilic perfluoroalkylating properties of these sulfoximines were then evaluated with acetylides as the common nucleophile. The justification for choosing these reagents was not only because of an interest in the compounds formed (vide infra), but also because of possibly comparing the reactivity with other electrophilic perfluoroalkylating agents, in particular sulfonium salts. First, a study of the best reaction conditions was conducted, resulting in the protocol summarized in Scheme 3.[15]



Scheme 3. Electrophilic fluoroalkylating reactions.

Interestingly, the distinction between the two trifluoromethyl compounds **7c** and **8c** was straightforward, giving a very clear conclusion. No reaction occurred with the triflyl derivative **7c**,[16] whereas ammonium **8c** readily transferred its trifluoromethyl group to the terminal acetylenic carbon (Table 1).[17]

Table 1. Electrophilic fluoroalkylation experiments.

Entry	R in Nucleophile **11**	Fluoroalkylation yield [%][a]		
		8c, CF_3[b]	**7a**, CF_2Br[b]	**7b**, $CFCl_2$[b]
1	6-MeO-2-naphthyl	51	48[c]	42[d]
2	Ph	53	47	41
3	*p*-tolyl	35	27	29
4	*p*-anisyl	43	15	21
5	4-CF_3Ph	12	14	31
6	methoxymethyl	2	33	17
7	2-phenylethyl	trace	36	11
8	butyl	trace	32	10
9	3-chloropropyl	trace	34	5
10	1-cyclohexenyl	16	17	3
11	cyclopropyl	6	12	7

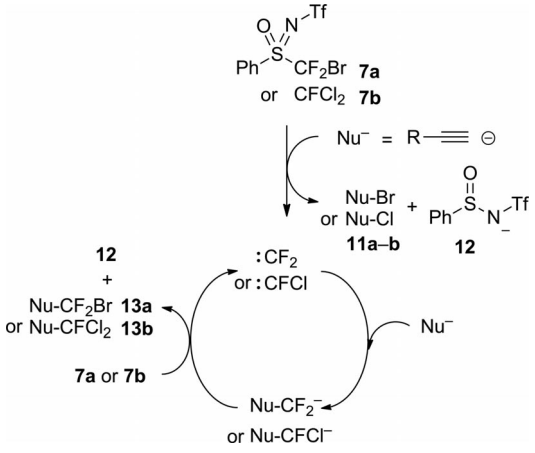
[a] Reported yields were estimated by ^{19}F NMR spectroscopic analysis of the crude mixture with an internal standard otherwise stated (see Supporting Information). [b] Fluorinated reagent and fluorinated group introduced. [c] Isolated in pure form. [d] Isolated as a mixture (8:2) with the corresponding chlorinated alkyne **11b**.

With ammonium reagent **8c**, the best yields were achieved in the aromatic series (Table 1, Entries 1–4). A decrease was observed in the presence of an electron-withdrawing group at the *para* position (Table 1, Entry 5). Reactions performed with aliphatic substituents proved unsuccessful (Table 1, Entries 6–9, 11), except in the presence of a conjugated bond (Table 1, Entry 10). These results are in line with those obtained with Umemoto's reagent,[4] affording an alternative way for the direct trifluoromethylation of alkynes.[18]

Extensive fluoroalkylation studies were not possible with ammonium salts **9a** and **9b**, because only small quantities were available. However, the few tests carried out with these reagents demonstrated their weak reactivity. We thus fo-

cused our attention on triflyl derivatives **7a** and **7b**. They are indeed easy to prepare with a reduced number of steps, soluble in THF (tetrahydrofuran) at low temperature, and proved to be efficient electrophilic fluoroalkylating reagents. With sulfoximine **7a**, the incorporation of the bromodifluoro moiety occurred with acceptable (Table 1, Entries 1, 2, 6–9) to lower yields in the case of some specific nucleophiles (Table 1, Entries 10, 11) or *para*-substituted aromatic derivatives (Table 1, Entries 3–5). Once again, our new reagent offers direct access to bromodifluoroacetylenes[19] with electrophilic properties similar to those of the sulfonium salt reagents.[8] Finally, reactions using dichlorofluorosulfoximine **7b** were fruitful, especially for aromatic acetylenic nucleophiles (Table 1, Entries 1–5). The aliphatic series gave moderate yields (Table 1, Entries 6–11). To the best of our knowledge, these results constitute the first direct synthesis of the unknown dichlorofluoromethylacetylenic compounds.[20]

With all the three reagents, the yields for fluoroalkylation were somewhat similar using acetylenic nucleophiles attached to an aromatic ring (Table 1, Entries 1–5), whereas the results from the three reagents differed in the aliphatic series (Table 1, Entries 7–9). In these latter cases, sulfoximines **7a** and **7b** allowed the desired transformation, whereas no reaction was observed with reagent **8c**. One possible explanation for this phenomenon may be that a different reaction mechanism is occurring for the two types of activating groups, that is, the *N*-triflyl group versus the ammonium salt. An electrophilic trifluoromethylation process with reagent **8c** has already been put forward by Shibata.[10a] The structure of the two new reagents **7a** and **7b** is similar to sulfoximine **3** which, as Hu describes, is proposed to undergo a carbenic pathway for its difluoromethylation reactions.[11a] In this present work, the isolation and characterization of side product **11a** (23% yield) from 2-ethynyl-6-methoxynaphthalene (Table 1, Entry 1), as well as the formation of chlorinated product **11b**,[21] also strongly suggest the intervention of a carbenic mechanism.[22] During the initiation step, the nucleophilic species generates a difluoromethyl (or chlorofluoro) carbene which is then able to start a catalytic cycle for the production of the fluoroalkylated material (Scheme 4). The significant amount of molecules **11a** and **11b** indicates that the initiation reaction competes efficiently with the catalytic cycle. The direct attack of the nucleophile on **7a** or **7b** then becomes a side reaction lowering the yields of fluoroalkylated compounds.



Scheme 4. Mechanistic proposal.

Conclusions

We have demonstrated that the sulfoximine functionality is a very efficient and adaptable scaffold for the design of dichlorofluoro-, bromodifluoro-, and trifluoromethyl-alkylating agents. We also showed the importance of the activating group bonded to the nitrogen, how the choice of the activating group depends on the fluorinated group to be transferred, and a way to tune the fluoroalkylating reagents. Ammonium reagents are best for the transfer of the trifluoromethyl group, whereas neutral triflates should be used for the introduction of CF_2Br or $CFCl_2$ substituents. New fluorohalomethyl groups bearing alkynes, especially dichlorofluoromethylated ones, were obtained during this study, opening the way to postfunctionalization through halogen substitution. The full potential of these new electrophilic perfluoroalkylating reagents is currently under development in our laboratory.

Experimental Section

General Methods: Each reaction was carried out under argon in a freshly distilled solvent, unless otherwise noted. All chemicals were purchased from Sigma–Aldrich, ABCR or Alfa Aesar and were used without further purification. Trifluoromethanesulfonic anhydride and sodium trifluoromethanesulfinate were purchased from Apollo Scientific. Organic solvents were purchased from Merck and Carlo Erba. Reactions were monitored by thin-layer chromatography on silica gel 60 F254, or by ^{19}F NMR spectroscopy. Unless otherwise noted, yields refer to materials purified by column chromatography. NMR spectra were recorded with a Bruker AC-200 spectrometer. Reported coupling constants and chemicals shifts were based on a first-order analysis. Internal reference was the residual peak of $CHCl_3$ (δ = 7.27 ppm) for ^1H (200 MHz), the central peak of $CDCl_3$ (δ = 77 ppm) for ^{13}C (50 MHz) spectra and internal $CFCl_3$ (δ = 0 ppm) for ^{19}F (282 MHz) NMR spectra. High-resolution electrospray mass spectra in the positive ion mode were obtained with a Xevo Q-Tof WATERS spectrometer. Melting points were determined with a Büchi melting point apparatus.

General Procedure for the Synthesis of Acyl Sulfoximines as Exemplified by the Preparation of *N*-Acetyl Bromodifluoromethyl Phenyl Sulfoximine (5a): A mixture of *N*-(acetyl) bromodifluoromethyl phenyl sulfilimine (**6a**, 2.00 g, 6.75 mmol; for the success of the reaction, the sulfilimine should be absolutely free of solvent) and potassium permanganate (1.06 g, 6.75 mmol, 1 equiv.) in water (75 mL) was stirred at room temperature for 18 h. $Na_2S_2O_4$ was added until there was discoloration, and then the mixture was diluted with water (65 mL) and extracted with CH_2Cl_2 (3 × 60 mL). The organic layer was dried with $MgSO_4$ and concentrated under reduced pressure. The residue was purified by column chromatography on silica gel (pentane/Et_2O, 7:3) to give **5a** as a white powder

(1.47 g, 70%); m.p. 76–78 °C. ^{19}F NMR (188 MHz, $CDCl_3$): δ = –56.7 and –54.9 (AB system, J_{AB} = 141 Hz, 2 F) ppm. ^1H NMR (200 MHz, $CDCl_3$): δ = 2.28 (s, 3 H), 7.67 (td, J = 8.8, 1.4 Hz, 2 H), 7.82 (t, J = 7.5 Hz, 1 H), 8.05 (d, J = 7.8 Hz, 2 H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 27.0, 121.1, (dd, J = 351, 347 Hz, CF_2), 125.8, 129.7, 129.9, 130.6, 135.9, 178.0 (d, J = 1.1 Hz, CO) ppm. MS (ESI+, for ^{79}Br): m/z = 334 $[M + Na]^+$. HRMS: calcd. for $C_9H_8{}^{79}BrF_2NO_2SNa$ $[M + Na]^+$ 333.9325; found 333.9334 (Δ = 2.7 ppm).

***N*-(Acetyl) Dichlorofluoromethyl Phenyl Sulfoximine (5b):** Brown powder; m.p. 80–82 °C. ^{19}F NMR (188 MHz, $CDCl_3$): δ = –60.5 (s, 1 F) ppm. ^1H NMR (200 MHz, $CDCl_3$): δ = 2.27 (s, 3 H), 7.64 (td, J = 8 Hz, J = 1.6 Hz, 2 H), 7.79 (t, J = 7.4 Hz, 1 H), 8.06 (d, J = 8.4 Hz, 2 H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 27.2, 123.4 (d, J = 338 Hz, CF), 129.6, 130.0, 131.1, 135.8, 177.7 ppm. MS (ESI+, for ^{35}Cl): m/z = 284 $[M + H]^+$. HRMS: calcd. for $C_9H_9{}^{35}Cl_2FNO_2S$ $[M + H]^+$ 283.9715; found 283.9703 (Δ = –4.2 ppm).

General Procedure for the Synthesis of *NH*-Sulfoximines as Exemplified by the Preparation of Bromodifluoromethyl Phenyl Sulfoximine (4a): HCl (6 M, 1.60 mL, 2 equiv.) was added to **5a** (1.47 g, 4.72 mmol) which was diluted in acetonitrile (4.70 mL). The reaction was stirred at room temperature for 18 h, and then water (50 mL) was added. The crude mixture was extracted with CH_2Cl_2 (3 × 50 mL) and washed with $NaHCO_3$ (10% solution). The organic layer was dried with $MgSO_4$ and concentrated under reduced pressure. The residue was purified by column chromatography on silica gel (pentane/Et_2O, 7:3) to give **4a** as a colorless oil (1.16 g 91%). ^{19}F NMR (188 MHz, $CDCl_3$): δ = –56.6 and –55.3 (AB system, J_{AB} = 135 Hz, 2 F) ppm. ^1H NMR (200 MHz, $CDCl_3$): δ = 3.69 (br. s, 1 H), 7.67 (td, J = 8.8, 1.4 Hz, 2 H), 7.82 (t, J = 7.5 Hz, 1 H), 8.15 (dd, J = 7.7, 0.5 Hz, 2 H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 124.1 (dd, J = 359, 352 Hz, CF_2), 129.3, 129.9, 131.0, 135.2 ppm. MS (ESI+, for ^{79}Br): m/z = 270 $[M + H]^+$. HRMS: calcd. for $C_7H_7{}^{79}BrF_2NOS$ $[M + H]^+$ 269.9400; found 269.9405 (Δ = 1.9 ppm).

Dichlorofluoromethyl Phenyl Sulfoximine (4b): Colorless oil. ^{19}F NMR (188 MHz, $CDCl_3$): δ = –59.4 (s, 1 F) ppm. ^1H NMR (200 MHz, $CDCl_3$): δ = 3.73 (br. s, 1 H), 7.61 (t, J = 7.5 Hz, 2 H), 7.76 (tt, J = 7.3, 2.4 Hz, 1 H), 8.18 (d, J = 8.2 Hz, 2 H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 124.4 (d, J = 342 Hz, CF), 129.0, 130.1, 131.4, 135.1 ppm. MS (ESI+, for ^{35}Cl): m/z = 242 $[M + H]^+$. HRMS: calcd. for $C_7H_7{}^{35}Cl_2FNOS$ $[M + H]^+$ 241.9609; found 241.9605 (Δ = –1.7 ppm).

General Procedure for the Synthesis of *N*-Triflyl Sulfoximines as Exemplified by the Preparation of Bromodifluoromethyl Phenyl *N*-Trifluoromethanesulfonyl Sulfoximine (7a): To a solution of **4a** (0.45 g, 1.67 mmol) and pyridine (0.40 mL, 5 mmol, 3 equiv.) in CH_2Cl_2 (5 mL) was added trifluoromethanesulfonic anhydride (0.42 mL, 2.50 mmol, 1.50 equiv.) at 0 °C. The mixture was stirred 7 h at room temperature. Water (20 mL) was added, and the crude mixture was extracted with CH_2Cl_2 (3 × 20 mL). The combined organic phases were washed with water, dried with $MgSO_4$, and evaporated under reduced pressure. Purification by column chromatography on silica gel (pentane/Et_2O, 7:3) afforded **7a** as an orange powder (0.5 g, 75%); m.p. 46–48 °C. ^{19}F NMR (188 MHz, $CDCl_3$): δ = –78.9 (s, 3 F), –57.8 and –54.8 (AB system, J_{AB} = 142 Hz, 2 F) ppm. ^1H NMR ($CDCl_3$, 200 MHz): δ = 7.77 (t, J = 7.4 Hz, 2 H), 7.96 (t, J = 7.5 Hz, 1 H), 8.13 (d, J = 7.9 Hz, 2 H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 118.9 (dd, J = 352, 346 Hz, CF_2), 120.8 (q, J = 317 Hz, CF_3), 128.3, 130.5, 131.1, 137.8 ppm. MS (ESI+, for ^{79}Br): m/z = 424 $[M + Na]^+$. HRMS: calcd. for $C_8H_5{}^{79}BrF_5NO_3S_2Na$ $[M + Na]^+$ 423.8712; found 423.8730 (Δ = 4.2 ppm).

Dichlorofluoromethyl Phenyl *N*-Trifluoromethanesulfonyl Sulfoximine (7b): Brown oil. ^{19}F NMR (188 MHz, $CDCl_3$): δ = –78.8 (s, 3 F), –60.8 (s, 1 F) ppm. ^1H NMR (200 MHz, $CDCl_3$): δ = 7.77 (t, J = 7.7 Hz, 2 H), 7.96 (tt, J = 7.4, 2.1 Hz, 1 H), 8.18 (d, J = 8.4 Hz, 2 H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 119.0 (d, J = 318 Hz, CF), 123.6 (q, J = 339 Hz, CF_3), 128.7, 130.3, 131.6, 137.7 ppm. MS (ESI+, for ^{35}Cl): m/z = 396 $[M + Na]^+$. HRMS: calcd. for $C_8H_5{}^{35}Cl_2F_4NO_3S_2Na$ $[M + Na]^+$ 395.8922; found 395.8921 (Δ = –0.3 ppm).

Trifluoromethyl Phenyl *N*-Trifluoromethanesulfonylsulfoximine (7c): Yellow oil. ^{19}F NMR (188 MHz, $CDCl_3$): δ = –79.0 (s, 3 F), –75.8 (s, 3 F) ppm. ^1H NMR (200 MHz, $CDCl_3$): δ = 7.79 (t, J = 7.8 Hz, 2 H), 7.98 (tt, J = 7.4, 1.2 Hz, 1 H), 8.14 (d, J = 8 Hz, 2 H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 118.9 (q, J = 318 Hz, CF_3), 119.9 (q, J = 326 Hz, CF_3), 128.4, 130.4, 130.8, 138.2 ppm. MS (ESI+): m/z = 364 $[M + Na]^+$. HRMS: calcd. for $C_8H_5F_6NO_3S_2Na$ $[M + Na]^+$ 363.9513; found 363.9515 (Δ = 0.5 ppm).

General Procedure for the Methylation of *NH*-Sulfoximines as Exemplified by the Preparation of *N*-Methyl-*S*-phenyl-*S*-bromodifluoromethylsulfoximine (10a): To a solution of bromodifluoromethyl phenyl sulfoximine (0.59 g, 2.18 mmol) and K_2CO_3 (1.50 g, 10.90 mmol, 5 equiv.) in THF (6 mL) was added CH_3I (0.67 mL, 2.18 mmol). The reaction mixture was heated to reflux for 7 h. After cooling to room temperature, the reaction media was filtered with Celite. The residue was concentrated under reduced pressure and purified by column chromatography on silica gel (pentane/Et_2O, 9:1) to give **10a** (0.57 g, 92%). ^{19}F NMR (188 MHz, $CDCl_3$): δ = –52.8 and –49.6 (AB system, J_{AB} = 142 Hz, 2 F) ppm. ^1H NMR (200 MHz, $CDCl_3$): δ = 3.13 (t, J = 1.8 Hz, 3 H), 7.51 (t, J = 7.5 Hz, 2 H), 7.65 (tt, J = 7.3, 2.4 Hz, 1 H), 8.04 (d, J = 7.6 Hz, 2 H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 29.5, 122.2 (dd, J = 363, 357 Hz, CF_2), 128.9, 130.2 (d, J = 7.4 Hz), 131.5, 134.5 ppm. MS (ESI+, for ^{79}Br): m/z = 284 $[M + H]^+$. HRMS: calcd. for $C_8H_9{}^{79}BrF_2NOS$ $[M + H]^+$ 283.9556; found 283.9556 (Δ = 0 ppm).

***N*-Methyl-*S*-phenyl-*S*-dichlorofluoromethylsulfoximine (10b):** Yellow oil. ^{19}F NMR (188 MHz, $CDCl_3$): δ = –55.7 (s, 1 F) ppm. ^1H NMR (200 MHz, $CDCl_3$): δ = 3.16 (d, J = 1.6 Hz, 3 H), 7.52 (t, J = 7.4 Hz, 2 H), 7.66 (tt, J = 7.4, 1.4 Hz, 1 H), 8.08 (d, J = 8 Hz, 2 H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 30.0, 124.2 (d, J = 347 Hz, CF), 128.7, 130.5 (d, J = 1.1 Hz), 131.8, 134.4 ppm. MS (ESI+, for ^{35}Cl): m/z = 256 $[M + H]^+$. HRMS: calcd. for $C_8H_9{}^{35}Cl_2FNOS$ $[M + H]^+$ 255.9766, found 256.9765 (Δ = –0.4 ppm).

General Procedure for the Methylation of *N*-Methylsulfoximines as Exemplified by the Preparation of *N*,*N*-(Dimethylamino)-*S*-phenyl-*S*-bromodifluoromethyloxosulfonium Trifluoromethanesulfonate (8a): A mixture of **10a** (617 mg, 2.17 mmol) and methyl trifluoromethanesulfonate (241 μL, 2.17 mmol) was stirred at room temperature for 6 h. The mixture was dissolved in water (5 mL) and then washed with Et_2O (3 × 5 mL). The aqueous layer was evaporated under reduced pressure to give the title product as a colorless oil, and the crude product was used as such in the next metathesis reaction.

General Procedure for the Metathesis Reaction as Exemplified by the Preparation of *N*,*N*-(Dimethylamino)-*S*-phenyl-*S*-bromodifluoromethyl Oxosulfonium Tetrafluoroborate (9a): To a stirred solution of **8a** (1.00 g, 2.30 mmol) in MeOH (280 mL) was added an aqueous saturated solution of $NaBF_4$ (28 mL) at room temperature. Af-

ter stirring for 13 h, MeOH was removed under reduced pressure, and the residue was dissolved in water (50 mL). The aqueous layer was extracted with CH_2Cl_2 (3 × 50 mL), and the combined organic layers were dried with $MgSO_4$ and concentrated under reduced pressure to furnish an oil which was washed with a pentane/Et_2O solution (85:15, 3 × 30 mL). Compound **9a** was obtained as a white solid (30 mg, 3%). ^{19}F NMR (188 MHz, $CDCl_3$): δ = –154.3 (s, 4 F), –49.7 and –46.4 (AB system, J_{AB} = 149 Hz, 2 F) ppm. ^1H NMR (200 MHz, $CDCl_3$): δ = 3.42 (s, 6 H), 8.05 (t, J = 8.5 Hz, 2 H), 8.27 (t, J = 7.1 Hz, 1 H), 8.40 (d, J = 8.3 Hz, 2 H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 35.4, 41.4 (d, J = 1.6 Hz), 126.4 (dd, J = 367, 340 Hz, CF_2), 126.9, 129.3, 130.4, 132.7, 133.3, 141.7 ppm. MS (ESI+, for ^{79}Br): m/z = 298 $[M]^+$. HRMS: calcd. for $C_9H_{11}{}^{79}BrF_2NOS$ $[M]^+$ 297.9713; found 297.9729 (Δ = 5.4 ppm).

***N*,*N*-(Dimethylamino)-*S*-phenyl-*S*-dichlorofluoromethyloxosulfonium Tetrafluoroborate (9b):** ^{19}F NMR (188 MHz, $CDCl_3$): δ = –154.4 (s, 4 F), –52.2 (s, 1 F) ppm. ^1H NMR (200 MHz, $CDCl_3$): δ = 3.46 (s, 6 H), 8.04 (t, J = 7.9 Hz, 2 H), 8.25 (t, J = 7.5 Hz, 1 H), 8.45 (d, J = 8.1 Hz, 2 H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 35.4, 41.7 (d, J = 1.6 Hz), 128.4 (d, J = 298 Hz, CF), 132.6 (d, J = 2.2 Hz), 133.1, 133.7, 141.5 ppm. MS (ESI+, for ^{35}Cl): m/z = 270 $[M + H]^+$. HRMS: calcd. for $C_9H_{11}{}^{35}Cl_2FNOS$ $[M + H]^+$ 269.9922; found 269.9908, (Δ = –5.2 ppm).

General Procedure for the Electrophilic Fluoromethylation as Exemplified by the Preparation of 2-(3-Bromo-3,3-difluoropropynyl)-6-methoxynaphthalene (13): Under an argon atmosphere, butyllithium (1.6 M solution, 0.15 mL, 1.0 equiv.) was added to a solution of phenylacetylene (44 mg, 0.24 mmol, 1.0 equiv.) in THF (1 mL) at 0 °C. After 15 min, the mixture was cooled to –78 °C, and **7a** (50 mg, 0.12 mmol, 0.50 equiv.) in THF (1 mL) was added. After 1 h, the mixture was gradually warmed to room over 1 h. Water was then added, and the product extracted with Et_2O (3 × 10 mL) and washed with a brine solution. The combined organic phases were dried with $MgSO_4$, and the solvents were evaporated under vacuum. Purification by PTLC (preparative TLC, pentane/CH_2Cl_2, 80:20) afforded **13** (16 mg, 43%) and **14** (8 mg, 23%).

2-(3-Bromo-3,3-difluoropropynyl)-6-methoxynaphthalene (13a): Yellow powder; m.p. 58–60 °C. ^{19}F NMR (188 MHz, $CDCl_3$): δ = –31.1 (s, 2 F) ppm. ^1H NMR (200 MHz, $CDCl_3$): δ = 3.95 (s, 3 H), 7.14 (d, J = 2.5 Hz, 1 H), 7.22 (dd, J = 9.0, 2.6 Hz, 1 H), 7.51 (dd, J = 8.5, 1.4 Hz, 1 H), 7.74 (d, J = 9.2 Hz, 2 H), 8.04 (s, 1 H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 55.4, 80.6 (t, J = 38 Hz), 90.0 (t, J = 6 Hz), 102.1 (t, J = 287 Hz), 105.8, 113.3, 120.1, 127.2, 128.0, 128.1 (t, J = 1.9 Hz), 129.7, 133.1 (t, J = 2.5 Hz), 135.4, 159.3 ppm. MS (ESI+, for ^{79}Br): m/z = 311 $[M + H]^+$. HRMS: calcd. for $C_{14}H_{10}O^{79}BrF_2$ $[M + H]^+$ 310.9883; found 310.9893 (Δ = 3.2 ppm).

2-(Bromoethynyl)-6-methoxynaphthalene (11a): Yellow powder; m.p. 94–96 °C. ^1H NMR (200 MHz, $CDCl_3$): δ = 3.93 (s, 3 H), 7.14 (m, 2 H), 7.45 (dd, J = 8.6, 1.6 Hz, 1 H), 7.66 (m, 2 H), 7.91 (s, 1 H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 49.1, 55.4, 80.6, 105.8, 117.5, 119.5, 126.9, 128.3, 129.0, 129.3, 132.0, 134.3, 158.5 ppm. MS (ESI+, for ^{79}Br): m/z = 260 $[M]^+$, 261 $[M + H]^+$. HRMS: calcd. for $C_{13}H_{10}O^{79}Br$ $[M + H]^+$ 260.9915; found 260.9930 (Δ = 5.7 ppm).

2-(3,3-Chloro-3-fluoropropynyl)-6-methoxynaphthalene (13b): ^{19}F NMR (188 MHz, $CDCl_3$): δ = –33.9 (s, 1 F) ppm. ^1H NMR (200 MHz, $CDCl_3$): δ = 3.93 (s, 3 H), 7.13 (m, 2 H), 7.44 (dd, J = 8.6, 1.5 Hz, 1 H), 7.68 (m, 2 H), 7.9 (s, 1 H) ppm. MS (ESI+, for ^{35}Cl): m/z = 282 $[M]^+$, 283 $[M + H]^+$. HRMS: calcd. for $C_{14}H_{10}O^{35}Cl_2F$ $[M + H]^+$ 283.0093; found 283.0095 (Δ = 0.7 ppm).

2-(Chloroethynyl)-6-methoxynaphthalene (11b): MS (ESI+, for ^{35}Cl): m/z = 216 $[M]^+$. HRMS: calcd. for $C_{13}H_9O^{35}Cl$ $[M]^+$ 216.0342; found 216.0343 (Δ = 0.5 ppm).

Supporting Information (see footnote on the first page of this article): Copies of the NMR spectra of all the compounds.

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[16] Sulfoximine **7c** was entirely recovered at the end of the process.
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