Oxidative trifluoromethylation and difluoromethylation of unactivated olefins

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1. General information

All chemical reagents are obtained from commercial suppliers and used without further purification. All unknown compounds are characterized by $^1$H NMR, $^{13}$C NMR, MS and elemental analyses. Analytical thin-layer chromatography is performed on glass plates precoated with silica gel impregnated with a fluorescent indicator (254 nm), and the plates are visualized by exposure to ultraviolet light. Mass spectra are taken on a Thermo Scientific ISQ LT GC-MS instrument in the electron ionization (EI) mode. $^1$H NMR, $^{13}$C NMR and $^{19}$F NMR spectra are recorded on an AVANCE 500 Bruker spectrometer operating at 500 MHz, 125 MHz and 470 MHz in CDCl$_3$, respectively, and chemical shifts are reported in ppm. GC analyses are performed on an Agilent 7890A instrument (Column: Agilent 19091J-413:30 m × 320 μm × 0.25 μm, H, FID detection). GC-MS data was recorded on a 5975C Mass Selective Detector, coupled with a 7890A Gas Chromatograph (Agilent Technologies). High-resolution mass spectra data were obtained on Agilent mass spectrometer using ESI-TOF (electrospray ionization-time of flight) and Waters Micromass GCT Premier spectrometer (electrospray ionization: EI).

2. General procedure

General procedure for the preparation of olefins from corresponding aldehydes by wittig reaction: Compounds 1 were prepared according to literature. A benzaldehyde derivative (5 mmol) was added to potassium carbonate (1.1 g, 8 mmol) and methyltriphenylphosphonium bromide (2.1 g, 6 mmol) in anhydrous 1,4-dioxane (5 mL) and heated at reflux for 16 h. The reaction mixture was then cooled, filtered and washed with pentane and then concentrated in vacuo.

Two methods of isolation can be used:
1. The residue was dissolved in hot pentane, cooled to 0 °C, filtered (to remove triphenylphosphine oxide: sparingly soluble in cold pentane) and washed with cold pentane. The filtrate was dried (MgSO$_4$) and concentrated in vacuo to give the styrene derivative.
2. Isolate via silica gel column chromatography in 40% EtOAc/pentane (ensuring dioxane is removed prior to isolation). All styrene derivatives were then vacuum distilled (may require gentle heating) and degassed before transferring to the glove box.

General procedure for trifluoromethylation of styrenes: A 50 mL oven-dried Schlenk tube with a magnetic stirring bar was equipped with AgF (0.375 mmol), sealed with a septum, and degassed by alternating vacuum evacuation and oxygen backfill (three times). A solution of the olefin (0.25 mmol) and TMSCF$_3$ (0.25 mmol) in 1 mL anhydrous DMF was added immediately via syringe. Then another 0.25 mmol TMSCF$_3$ was added by syringe after 1 h. The mixture was stirred at room temperature for 2 h. Upon completion, the reaction mixture was diluted with Et$_2$O and filtered through a celite pad. Et$_2$O (20 ml) were added. The organic layer was washed
with water (3 × 5 ml). The combined organic layer was dried over MgSO₄, filtered and concentrated in vacuum. The residue was purified by flash chromatography using petrol ether/ethyl acetate as the eluent. The conditions for chromatography and data for characterization of the products are given below.

**General procedure for difluoromethylation of styrenes:** A 50 mL oven-dried Schlenk tube with a magnetic stirring bar was equipped with AgF (0.375 mmol), sealed with a septum, and degassed by alternating vacuum evacuation and oxygen backfill (three times). A solution of the olefin (0.25 mmol) and TMSCF₂R (0.25 mmol, R=CF₂COOEt or CF₃) in 1 mL anhydrous DMF was added immediately via syringe. Then another 0.25 mmol TMSCF₂R was added by syringe after 2 h. The mixture was stirred at room temperature for 4 h. Upon completion, the reaction mixture was diluted with ethyl acetate and filtered through a celite pad. Ethyl acetate (20 mL) were added. The organic layer was washed with water (3 × 5 ml). The combined organic layer was dried over MgSO₄, filtered and concentrated in vacuum. The residue was purified by flash chromatography using petrol ether/ethyl acetate as the eluent. The conditions for chromatography and data for characterization of the products are given below.

### The procedures of control experiments

![Scheme S1 Control experiments](image)

**Equation 1:** A 50 mL oven-dried Schlenk tube with a magnetic stirring bar was equipped with AgF (0.75 mmol), sealed with a septum, and degassed by alternating vacuum evacuation and oxygen backfill (three times). A solution of 2-Vinylnaphthalene (0.5 mmol) in 2 mL anhydrous DMF was added via syringe. To the resulting suspension, which was precooled to 0 °C was added TMSCF₂CF₃ (0.5 mmol) by syringe. Then another 0.5 mmol TMSCF₂CF₃ was added by syringe after 2 h. The mixture was stirred at 0 °C for 4 h. Then the mixture was allowed to warm up to room
temperature and stirring was continued for an additional 2 h. This procedure was monitored by GC-MS.

Oxidative perfluoromethylated intermediate 5c’ was generated in a 35% yield at 0 °C, comparing with a 5% yield when the reaction was warmed up to room temperature. Upon completion, the reaction mixture (equation 1) was diluted with ethyl acetate and filtered through a celite pad. Ethyl acetate (20 mL) were added. The organic layer was washed with water (3 × 10 ml). The combined organic layer was dried over MgSO₄, filtered and concentrated in vacuum. The residue was purified by flash chromatography. We found intermediate 5c’ and product 5c were hard to separate. The mixture of 5c’ and 5c was detected by ¹H NMR and ¹⁹F NMR.

Figure S1 ¹H NMR of the mixture
3. Characterization data

3,3,3-trifluoro-1-phenylpropan-1-one (3a)<sup>2</sup>

The title compound was isolated as a white solid after chromatography on silica with a Combiflash system (100:0-99:1 petrol ether/ethyl acetate). Yield: 89%. <sup>1</sup>H NMR (500 MHz, CDCl<sub>3</sub>) δ 7.95 (d, <i>J</i> = 7.8 Hz, 2H), 7.65 (t, <i>J</i> = 7.4 Hz, 1H), 7.52 (t, <i>J</i> = 7.7 Hz, 2H), 3.81 (q, <i>J</i> = 10.0 Hz, 2H). <sup>13</sup>C NMR (126 MHz, CDCl<sub>3</sub>) δ 189.87 (s), 135.94 (s), 134.34 (s), 129.08 (s), 128.48 (s), 124.15 (q, <i>J</i> = 277.8 Hz), 42.22 (q, <i>J</i> = 27.7 Hz). <sup>19</sup>F NMR (470 MHz, CDCl<sub>3</sub>) δ -62.17 (s).

1-(4-bromophenyl)-3,3,3-trifluoropropan-1-one (3b)<sup>2</sup>

The title compound was isolated as a slightly yellow solid after chromatography on silica with a Combiflash system (100:0-99:1 petrol ether/ethyl acetate). Yield: 83%. <sup>1</sup>H NMR (500 MHz, CDCl<sub>3</sub>) δ 7.79 (d, <i>J</i> = 8.6 Hz, 2H), 7.65 (d, <i>J</i> = 8.6 Hz, 2H), 3.77 (q, <i>J</i> = 9.9 Hz, 2H). <sup>13</sup>C NMR (126 MHz, CDCl<sub>3</sub>) δ 189.97 (s), 135.94 (s), 134.34 (s), 129.08 (s), 128.48 (s), 124.15 (q, <i>J</i> = 277.8 Hz), 42.22 (q, <i>J</i> = 28.1 Hz). <sup>19</sup>F NMR (470 MHz, CDCl<sub>3</sub>) δ -61.98 (s).

1-(4-chlorophenyl)-3,3,3-trifluoropropan-1-one (3c)<sup>2</sup>

The title compound was isolated as a white solid after chromatography on silica with a Combiflash system (100:0-99:1 petrol ether/ethyl acetate). Yield: 77%. <sup>1</sup>H NMR (500 MHz, CDCl<sub>3</sub>) δ 7.88 (d, <i>J</i> = 8.6 Hz, 2H), 7.49 (d, <i>J</i> = 8.6 Hz, 2H), 3.78 (q, <i>J</i> = 9.9 Hz, 2H). <sup>13</sup>C NMR (126 MHz, CDCl<sub>3</sub>) δ 188.97 (s), 141.03 (s), 134.24 (s), 129.89 (s), 129.45 (s), 123.96 (q, <i>J</i> = 278.0 Hz), 42.27 (q, <i>J</i> = 28.5 Hz). <sup>19</sup>F NMR (470 MHz, CDCl<sub>3</sub>) δ -61.96 (s).
3,3,3-trifluoro-1-(4-fluorophenyl)propan-1-one (3d)  

The title compound was isolated as a colorless liquid after chromatography on silica with a Combiflash system (100:0-99:1 petrol ether/ethyl acetate). Yield: 85%. ¹H NMR (500 MHz, CDCl₃) δ 7.99 – 7.96 (m, 2H), 7.19 (t, J = 8.5 Hz, 2H), 3.78 (q, J = 9.9 Hz, 2H). ¹³C NMR (126 MHz, CDCl₃) δ 188.28 (s), 166.49 (d, J = 258.3 Hz), 132.41 (s), 131.29 (d, J = 9.1 Hz), 124.00 (q, J = 277.2 Hz), 116.31 (d, J = 21.4 Hz), 42.24 (q, J = 28.5 Hz). ¹⁹F NMR (470 MHz, CDCl₃) δ -61.96 (s), -102.81 (s).

3,3,3-trifluoro-1-(p-tolyl)propan-1-one (3e)  

The title compound was isolated as a white solid after chromatography on silica with a Combiflash system (100:0-99:1 petrol ether/ethyl acetate). Yield: 87%. ¹H NMR (500 MHz, CDCl₃) δ 7.84 (d, J = 8.1 Hz, 2H), 7.31 (d, J = 8.0 Hz, 2H), 3.77 (q, J = 10.1 Hz, 2H), 2.44 (s, 3H). ¹³C NMR (126 MHz, CDCl₃) δ 189.44 (s), 145.42 (s), 133.58 (s), 129.73 (s), 128.64 (s), 124.19 (q, J = 276.2 Hz), 42.13 (q, J = 27.5 Hz), 21.82 (s). ¹⁹F NMR (470 MHz, CDCl₃) δ -61.98 (s).

1-(4-(tert-butyl)phenyl)-3,3,3-trifluoropropan-1-one (3f)  

The title compound was isolated as a slightly yellow liquid after chromatography on silica with a Combiflash system (100:0-99:1 petrol ether/ethyl acetate). Yield: 86%. ¹H NMR (500 MHz, CDCl₃) δ 7.89 (d, J = 8.5 Hz, 2H), 7.53 (d, J = 8.5 Hz, 2H), 3.78 (q, J = 10.1 Hz, 2H), 1.36 (s, 9H). ¹³C NMR (126 MHz, CDCl₃) δ 189.43 (s), 158.33 (s), 133.46 (s), 128.52 (s), 126.02 (s), 124.22 (q, J = 275.0 Hz), 42.12 (q, J = 27.5 Hz), 35.37 (s), 31.11 (s). ¹⁹F NMR (470 MHz, CDCl₃) δ -61.95 (s).

3,3,3-trifluoro-1-(4-methoxyphenyl)propan-1-one (3g)  

The title compound was isolated as a yellow solid after chromatography on silica with a Combiflash system (100:0-96:4 petrol ether/ethyl acetate). Yield: 75%. ¹H NMR (500 MHz, CDCl₃) δ 7.91 (d, J = 8.4 Hz, 2H), 6.97 (d, J = 8.4 Hz, 2H), 3.89 (s, 3H), 3.74 (q, J = 10.1 Hz, 2H). ¹³C NMR (126 MHz, CDCl₃) δ 188.28 (s), 164.49 (s), 140.67 (s), 130.94 (s), 124.26 (q, J = 275.6 Hz), 114.23 (s), 55.69 (s), 41.93 (q, J = 27.5 Hz). ¹⁹F NMR (470 MHz, CDCl₃) δ -61.94 (s).

4-(3,3,3-trifluoropropanoyl)phenyl acetate (3h)  

The title compound was isolated as a white solid after chromatography on silica with a Combiflash system (100:0-93:7 petrol ether/ethyl acetate). Yield: 90%. ¹H NMR (500 MHz, CDCl₃) δ 7.97 (d, J = 8.7 Hz, 2H), 7.24 (d, J = 8.8 Hz, 2H), 3.78 (q, J = 10.0 Hz, 2H), 2.33 (s, 3H). ¹³C NMR (126 MHz, CDCl₃) δ 188.64 (s), 168.81 (s), 155.31 (s), 133.44 (s), 130.18 (s), 124.00 (q, J = 277.6 Hz), 122.31 (s), 42.21 (q, J = 28.5 Hz), 21.23 (s). ¹⁹F NMR (470 MHz, CDCl₃) δ -61.97 (s).
**3,3,3-trifluoro-1-(4-nitrophenyl)propan-1-one (3i)**

The title compound was isolated as a slightly yellow solid after chromatography on silica with a Combiflash system (100:0-95:5 petrol ether/ethyl acetate). Yield: 70%.\(^1\)\(^\text{H}\) NMR (500 MHz, CDCl\(_3\)) δ 8.37 (d, \(J = 8.8\) Hz, 2H), 8.12 (d, \(J = 8.8\) Hz, 2H), 3.87 (q, \(J = 9.7\) Hz, 2H).\(^{13}\)C NMR (126 MHz, CDCl\(_3\)) δ 188.49 (s), 151.07 (s), 140.08 (s), 129.61 (s), 124.31 (s), 123.65 (q, \(J = 277.6\) Hz), 42.85 (q, \(J = 29.0\) Hz).\(^{19}\)F NMR (470 MHz, CDCl\(_3\)) δ -61.92 (s).

**4-(3,3,3-trifluoropropanoyl)benzonitrile (3j)**

The title compound was isolated as a slightly yellow liquid after chromatography on silica with a Combiflash system (100:0-96:4 petrol ether/ethyl acetate). Yield: 79%.\(^1\)\(^\text{H}\) NMR (500 MHz, CDCl\(_3\)) δ 8.04 (d, \(J = 8.4\) Hz, 2H), 7.84 (d, \(J = 8.5\) Hz, 2H), 3.83 (q, \(J = 9.7\) Hz, 2H).\(^{13}\)C NMR (126 MHz, CDCl\(_3\)) δ 188.66 (s), 138.66 (s), 132.94 (s), 128.91 (s), 123.70 (q, \(J = 277.5\) Hz), 117.67 (s), 42.61 (q, \(J = 29.0\) Hz).\(^{19}\)F NMR (470 MHz, CDCl\(_3\)) δ -61.92 (s).

**1-(3-bromophenyl)-3,3,3-trifluoropropan-1-one (3k)**

The title compound was isolated as a yellow liquid after chromatography on silica with a Combiflash system (100:0-99:1 petrol ether/ethyl acetate). Yield: 79%.\(^1\)\(^\text{H}\) NMR (500 MHz, CDCl\(_3\)) δ 8.07 (s, 1H), 7.86 (d, \(J = 7.8\) Hz, 1H), 7.77 (d, \(J = 7.9\) Hz, 1H), 7.41 (t, \(J = 7.9\) Hz, 1H), 3.78 (q, \(J = 9.8\) Hz, 2H).\(^{13}\)C NMR (126 MHz, CDCl\(_3\)) δ 188.56 (s), 137.58 (s), 137.19 (s), 131.50 (s), 130.63 (s), 126.99 (s), 123.88 (q, \(J = 276.3\) Hz), 123.45 (s), 42.34 (q, \(J = 28.8\) Hz).\(^{19}\)F NMR (470 MHz, CDCl\(_3\)) δ -62.00 (s).

**3,3,3-trifluoro-1-(3-(trifluoromethyl)phenyl)propan-1-one (3l)**

The title compound was isolated as a slightly yellow liquid after chromatography on silica with a Combiflash system (100:0-99:1 petrol ether/ethyl acetate). Yield: 86%.\(^1\)\(^\text{H}\) NMR (500 MHz, CDCl\(_3\)) δ 8.19 (s, 1H), 8.13 (d, \(J = 7.9\) Hz, 1H), 7.91 (d, \(J = 7.8\) Hz, 1H), 7.69 (t, \(J = 7.8\) Hz, 1H), 3.84 (d, \(J = 9.8\) Hz, 2H).\(^{13}\)C NMR (126 MHz, CDCl\(_3\)) δ 188.60 (s), 136.41 (s), 132.02 (s), 131.75 (s), 130.72 (s), 130.72 (s), 125.32 (s), 123.82 (q, \(J = 277.6\) Hz), 123.45 (s), 42.45 (q, \(J = 28.6\) Hz).\(^{19}\)F NMR (470 MHz, CDCl\(_3\)) δ -61.97 (s), -62.93 (s).

**3,3,3-trifluoro-2-methyl-1-(3-phenoxyphenyl)propan-1-one (3m)**

The title compound was isolated as a colorless liquid after chromatography on silica with a Combiflash system (100:0-96:4 petrol ether/ethyl acetate). Yield: 84%.\(^1\)\(^\text{H}\) NMR (500 MHz, CDCl\(_3\)) δ 7.65 – 7.63 (m, 1H), 7.56 (t, \(J = 5.0\) Hz, 1H), 7.48 (t, \(J = 7.5\) Hz, 1H), 7.41 – 7.37 (m, 2H), 7.29 – 7.26 (m, 1H), 7.20 – 7.16 (m, 1H), 7.05 – 7.03 (m, 2H), 3.76 (q, \(J = 9.9\) Hz, 2H).\(^{13}\)C NMR (126 MHz, CDCl\(_3\)) δ 191.74 (s), 189.24 (s), 158.34 (s), 156.33 (s), 137.61 (s), 130.45 (s), 130.20 (s), 124.32 (s), 124.03 (q, \(J = 278.0\) Hz), 123.01 (s), 120.71 (s), 119.55 (d, \(J = 16.5\) Hz), 117.94 (s), 42.38 (q, \(J = 28.6\) Hz).\(^{19}\)F NMR (470 MHz, CDCl\(_3\)) δ -62.02 (s). HRMS (EI) Calcd. For
280.0711, C₁₅H₁₁F₃O, found 280.0714.

1-(2,4-dichlorophenyl)-3,3,3-trifluoropropan-1-one (3n)²

The title compound was isolated as a slightly yellow liquid after chromatography on silica with a Combiflash system (100:0-97:3 petrol ether/ethyl acetate). Yield: 82%. \(^1\)H NMR (500 MHz, CDCl₃) δ 7.54 (d, \(J = 8.4\) Hz, 1H), 7.49 (d, \(J = 1.9\) Hz, 1H), 7.38 (dd, \(J = 8.4, 1.9\) Hz, 1H), 3.86 (q, \(J = 9.9\) Hz, 2H). \(^{13}\)C NMR (126 MHz, CDCl₃) δ 191.17 (s), 139.06 (s), 135.88 (s), 132.49 (s), 131.08 (s), 130.85 (s), 127.94 (s), 123.56 (q, \(J = 278.0\) Hz), 46.27 (q, \(J = 28.6\) Hz). \(^{19}\)F NMR (470 MHz, CDCl₃) δ -62.13 (s).

1-(2-bromophenyl)-3,3,3-trifluoropropan-1-one (3o)²

The title compound was isolated as a slightly yellow liquid after chromatography on silica with a Combiflash system (100:0-99:1 petrol ether/ethyl acetate). Yield: 81%. \(^1\)H NMR (500 MHz, CDCl₃) δ 7.68 – 7.64 (m, 1H), 7.47 – 7.41 (m, 2H), 7.39 – 7.36 (m, 1H), 3.85 (q, \(J = 10.0\) Hz, 2H). \(^{13}\)C NMR (126 MHz, CDCl₃) δ 193.40 (s), 140.14 (s), 134.06 (s), 132.82 (s), 129.30 (s), 127.90 (s), 123.58 (q, \(J = 277.2\) Hz), 45.98 (q, \(J = 28.1\) Hz). \(^{19}\)F NMR (470 MHz, CDCl₃) δ -62.09 (s).

1-(2-chlorophenyl)-3,3,3-trifluoropropan-1-one (3p)²

The title compound was isolated as a yellow liquid after chromatography on silica with a Combiflash system (100:0-99:1 petrol ether/ethyl acetate). Yield: 78%. \(^1\)H NMR (500 MHz, CDCl₃) δ 7.59 – 7.53 (m, 1H), 7.48 – 7.44 (m, 2H), 7.40 – 7.37 (m, 1H), 3.87 (q, \(J = 10.0\) Hz, 2H). \(^{13}\)C NMR (126 MHz, CDCl₃) δ 192.50 (s), 137.79 (s), 133.10 (s), 131.33 (s), 130.90 (s), 129.83 (s), 127.45 (s), 123.68 (q, \(J = 278.5\) Hz), 46.26 (q, \(J = 27.7\) Hz). \(^{19}\)F NMR (470 MHz, CDCl₃) δ -62.17 (s).

3,3,3-trifluoro-1-(naphthalen-2-yl)propan-1-one (3q)²

The title compound was isolated as a white solid after chromatography on silica with a Combiflash system (100:0-97:3 petrol ether/ethyl acetate). Yield: 85%. \(^1\)H NMR (500 MHz, CDCl₃) δ 8.41 (s, 1H), 8.03 – 7.96 (m, 2H), 7.93 – 7.89 (m, 2H), 7.68 – 7.63 (m, 1H), 7.62 – 7.57 (m, 1H), 3.94 (q, \(J = 10.0\) Hz, 2H). \(^{13}\)C NMR (126 MHz, CDCl₃) δ 189.78 (s), 136.11 (s), 133.35 (s), 132.48 (s), 130.68 (s), 129.84 (s), 129.34 (s), 129.06 (s), 128.00 (s), 127.34 (s), 125.36 (s), 124.26 (q, \(J = 277.2\) Hz), 123.59 (s), 42.28 (q, \(J = 28.5\) Hz). \(^{19}\)F NMR (470 MHz, CDCl₃) δ -61.86 (s).

3,3,3-trifluoro-1-(naphthalen-1-yl)propan-1-one (3r)²

The title compound was isolated as a slightly yellow liquid after chromatography on silica with a Combiflash system (100:0-96:4 petrol ether/ethyl acetate). Yield: 63%. \(^1\)H NMR (500 MHz, CDCl₃) δ 8.73 (d, \(J = 8.6\) Hz, 1H), 8.07 (d, \(J = 8.2\) Hz, 1H), 7.91 (d, \(J = 8.1\) Hz, 1H), 7.88 (d, \(J = 7.2\) Hz, 1H), 7.66 (t, \(J = 7.5\) Hz, 1H), 7.59 (t, \(J = 7.4\) Hz, 1H), 7.54 (t, \(J = 7.7\) Hz, 1H), 3.92 (q, \(J = 10.0\) Hz, 2H). \(^{13}\)C NMR (126 MHz, CDCl₃) δ 192.99 (s), 134.4 (s), 134.17 (s), 133.97 (s), 130.33 (s), 128.26 (q, \(J = 277.2\) Hz), 123.59 (s), 42.28 (q, \(J = 28.5\) Hz).
3,3,3-trifluoro-2-methyl-1-phenylpropan-1-one (3s)²

The title compound was isolated as a colorless liquid after chromatography on silica with a Combiflash system (100:0-99:1 petrol ether/ethyl acetate). Yield: 74%. ¹H NMR (500 MHz, CDCl₃) δ 7.97 (d, J = 8.1 Hz, 2H), 7.64 (dd, J = 10.7, 4.1 Hz, 1H), 7.52 (t, J = 7.8 Hz, 2H), 4.32 – 4.20 (m, 1H), 1.49 (d, J = 7.2 Hz, 3H).

13C NMR (126 MHz, CDCl₃) δ 194.53 (s), 135.83 (s), 134.11 (s), 129.04 (s), 128.73 (s), 125.43 (q, J = 281.0 Hz), 44.44 (q, J = 26.5 Hz), 11.81 (s).

19F NMR (470 MHz, CDCl₃) δ -61.90 (s).

3,3,3-trifluoro-1,2-diphenylpropan-1-one (3t)²

The title compound was isolated as a slightly yellow liquid after chromatography on silica with a Combiflash system (100:0-98:2 petrol ether/ethyl acetate). Yield: 60%. ¹H NMR (500 MHz, CDCl₃) δ 7.91 (dd, J = 8.4, 1.1 Hz, 2H), 7.55-7.52 (m, 1H), 7.50 – 7.44 (m, 2H), 7.45 – 7.34 (m, 5H), 5.29 (q, J = 8.2 Hz, 1H).

13C NMR (126 MHz, CDCl₃) δ 191.23 (s), 135.55 (s), 133.90 (s), 129.97 (s), 129.82 (s), 129.41 (s), 129.13 (s), 128.92 (s), 124.37 (q, J = 275.9 Hz), 56.70 (s, J = 26.5 Hz).

19F NMR (470 MHz, CDCl₃) δ -66.50 (s).

3,3,3-trifluoro-1-(thiophen-2-yl)propan-1-one (3u)⁵

The title compound was isolated as a colorless liquid after chromatography on silica with a Combiflash system (100:0-99:1 petrol ether/ethyl acetate). Yield: 89%. ¹H NMR (500 MHz, CDCl₃) δ 7.76 (dd, J = 4.9, 1.0 Hz, 1H), 7.74 (dd, J = 3.8, 0.8 Hz, 1H), 7.19 (dd, J = 4.9, 3.9 Hz, 1H), 3.72 (q, J = 10.1 Hz, 2H).

13C NMR (126 MHz, CDCl₃) δ 182.27 (s), 143.34 (s), 135.82 (s), 133.52 (s), 128.62 (s), 123.77 (q, J = 278.0 Hz), 43.21 (q, J = 29.0 Hz).

19F NMR (470 MHz, CDCl₃) δ -61.90 (s).

1,1,1-trifluoro-5-phenylpentan-3-one (3v)³

The title compound was isolated as a colorless liquid after chromatography on silica with a Combiflash system (100:0-99:1 petrol ether/ethyl acetate). Yield: 71%. ¹H NMR (500 MHz, CDCl₃) δ 7.31 (t, J = 7.5 Hz, 2H), 7.23 (t, J = 7.5 Hz, 1H), 7.19 (t, J = 7.3 Hz, 2H), 3.20 (q, J = 10.4 Hz, 2H), 2.95 (t, J = 7.2 Hz, 2H), 2.87 (t, J = 7.4 Hz, 2H).

13C NMR (126 MHz, CDCl₃) δ 199.31 (s), 140.26 (s), 128.76 (s), 128.42 (s), 126.53 (s), 123.68 (q, J = 277.6 Hz), 46.65 (q, J = 28.6 Hz), 45.09 (s), 29.34 (s).

19F NMR (470 MHz, CDCl₃) δ -62.32 (s).

3-(3,3,3-trifluoropropanoyl)benzaldehyde(3w)²

The title compound was isolated as a colorless liquid after chromatography on silica with a Combiflash system (100:0-97:3 petrol ether/ethyl acetate). Yield: 84%. ¹H NMR (500 MHz, CDCl₃) δ 10.11 (s, 1H), 8.41 (s, 1H), 8.22 (d, J = 7.8 Hz, 1H), 8.16 (d, J = 7.6 Hz, 1H), 7.73 (t, J = 7.7 Hz, 1H), 3.87 (t, J = 9.8 Hz, 2H).

13C NMR (126 MHz, CDCl₃) δ 191.10 (s), 189.00 (s), 136.98 (s), 136.65 (s), 134.87 (s), 133.79 (s), 130.06 (s), 129.31 (s), 123.89 (q, J = 278.04
ethyl (Z)-2-fluoro-4-oxo-4-phenylbut-2-enoate (4a)

The title compound was isolated as a colorless liquid after chromatography on silica with a Combiflash system (100:0-95:5 petrol ether/ethyl acetate). Yield: 85%. 1H NMR (500 MHz, CDCl3) δ 7.95 (d, J = 7.6 Hz, 2H), 7.63 (t, J = 7.4 Hz, 1H), 7.51 (t, J = 7.7 Hz, 2H), 7.13 (d, J = 30.8 Hz, 1H), 4.40 (q, J = 7.1 Hz, 2H), 1.40 (t, J = 7.2 Hz, 3H). 13C NMR (126 MHz, CDCl3) δ 188.33 (s), 160.29 (d, J = 34.0 Hz), 152.24 (d, J = 286.0 Hz), 136.82 (s), 134.17 (s), 128.95 (s), 128.92 (s), 112.22 (s), 63.00 (s), 14.20 (s). 19F NMR (470 MHz, CDCl3) δ -61.96 (s).

ethyl (Z)-4-(4-chlorophenyl)-2-fluoro-4-oxobut-2-enoate (4b)

The title compound was isolated as a slightly yellow liquid after chromatography on silica with a Combiflash system (100:0-95:5 petrol ether/ethyl acetate). Yield: 60%. 1H NMR (500 MHz, CDCl3) δ 7.88 (d, J = 8.6 Hz, 2H), 7.48 (d, J = 8.5 Hz, 2H), 7.07 (d, J = 30.6 Hz, 1H), 4.40 (q, J = 7.1 Hz, 2H), 1.40 (t, J = 7.1 Hz, 3H). 13C NMR (126 MHz, CDCl3) δ 187.10 (s), 160.13 (d, J = 34.0 Hz), 152.49 (d, J = 287.3 Hz), 140.76 (s), 135.17 (s), 130.28 (s), 129.35 (s), 111.77 (s), 63.08 (s), 14.19 (s). 19F NMR (470 MHz, CDCl3) δ -110.39 (s).

ethyl (Z)-2-fluoro-4-(4-fluorophenyl)-4-oxobut-2-enoate (4c)

The title compound was isolated as a colorless liquid after chromatography on silica with a Combiflash system (100:0-95:5 petrol ether/ethyl acetate). Yield: 75%. 1H NMR (500 MHz, CDCl3) δ 7.98 (dd, J = 8.7, 5.4 Hz, 2H), 7.18 (t, J = 8.5 Hz, 2H), 7.08 (d, J = 30.7 Hz, 1H), 4.40 (q, J = 7.1 Hz, 2H), 1.40 (t, J = 7.2 Hz, 3H). 13C NMR (126 MHz, CDCl3) δ 186.79 (s), 166.44 (d, J = 257.0 Hz), 160.18 (d, J = 34.8 Hz), 152.28 (d, J = 286.0 Hz), 133.26 (s), 131.68 (d, J = 8.9 Hz), 116.23 (d, J = 22.7 Hz), 112.01 (s), 63.05 (s), 14.18 (s). 19F NMR (470 MHz, CDCl3) δ -103.11 (s), -109.97 (s). HRMS (EI) Calcd. For C12H10ClFO3, found 256.0302.

ethyl (Z)-4-(4-(tert-butyl)phenyl)-2-fluoro-4-oxobut-2-enoate (4d)

The title compound was isolated as a slightly yellow liquid after chromatography on silica with a Combiflash system (100:0-95:5 petrol ether/ethyl acetate). Yield: 78%. 1H NMR (500 MHz, CDCl3) δ 7.89 (d, J = 8.4 Hz, 2H), 7.52 (d, J = 8.6 Hz, 2H), 7.12 (d, J = 31.0 Hz, 1H), 4.40 (q, J = 7.1 Hz, 2H), 1.40 (t, J = 7.1 Hz, 3H), 1.36 (s, 9H). 13C NMR (126 MHz, CDCl3) δ 187.92 (s), 160.39 (d, J = 35.3 Hz), 158.18 (s), 151.95 (d, J = 284.8 Hz), 134.28 (s), 128.94 (s), 125.96 (s), 112.46 (s), 62.92 (s), 35.40 (s), 31.15 (s), 14.20 (s). 19F NMR (470 MHz, CDCl3) δ -111.18 (s). HRMS (ESI) Calcd. For C16H19FO3 [M-H]+, found 279.1407.

ethyl (Z)-2-fluoro-4-oxo-4-(3-phenoxyphenyl)but-2-enoate (4e)

The title compound was isolated as a colorless liquid after chromatography on silica with a
ethyl (Z)-4-(3-bromophenyl)-2-fluoro-4-oxobut-2-enoate (4f)

The title compound was isolated as a yellow liquid after chromatography on silica with a Combiflash system (100:0-95:5 petrol ether/ethyl acetate). Yield: 65%. 

\[
\text{\(^1\)H NMR (500 MHz, CDCl}_3\) \delta 8.07 (s, 1H), 7.87 (d, J = 7.8 Hz, 1H), 7.76 (d, J = 7.0 Hz, 1H), 7.40 (t, J = 7.9 Hz, 1H), 7.08 (d, J = 30.3 Hz, 1H), 4.41 (q, J = 7.1 Hz, 2H), 1.41 (t, J = 7.1 Hz, 3H).
\]

\[
\text{\(^{13}\)C NMR (126 MHz, CDCl}_3\) \delta 186.96 (s), 160.10 (d, J = 34.0 Hz), 152.80 (d, J = 289.8 Hz), 138.57 (s), 136.96 (s), 131.76 (s), 130.55 (s), 127.42 (s), 123.31 (s), 111.49 (s), 63.15 (s), 14.19 (s).
\]

\[
\text{\(^{19}\)F NMR (470 MHz, CDCl}_3\) \delta -108.65 (s). HRMS (ESI) Calcd. For 300.9876, C\textsubscript{12}H\textsubscript{10}BrFO\textsubscript{3} [M-H]\textsuperscript{+}, found 300.9889.
\]

ethyl (Z)-4-(4-acetoxyphenyl)-2-fluoro-4-oxobut-2-enoate (4g)

The title compound was isolated as a colorless liquid after chromatography on silica with a Combiflash system (100:0-90:10 petrol ether/ethyl acetate). Yield: 70%. 

\[
\text{\(^1\)H NMR (500 MHz, CDCl}_3\) \delta 7.99 (d, J = 8.6 Hz, 2H), 7.25 (d, J = 8.7 Hz, 2H), 7.10 (d, J = 30.7 Hz, 1H), 4.39 (q, J = 7.2 Hz, 2H), 2.34 (s, 3H), 1.40 (t, J = 7.1 Hz, 3H).
\]

\[
\text{\(^{13}\)C NMR (126 MHz, CDCl}_3\) \delta 187.03 (s), 168.78 (s), 160.20 (d, J = 35.1 Hz), 155.21 (s), 152.33 (d, J = 287.3 Hz), 134.33 (s), 130.57 (s), 122.22 (s), 111.96 (s), 63.03 (s), 21.26 (s), 14.19 (s).
\]

\[
\text{\(^{19}\)F NMR (470 MHz, CDCl}_3\) \delta -109.98 (s). HRMS (ESI) Calcd. For 303.0645, C\textsubscript{14}H\textsubscript{13}FO\textsubscript{5} [M-Na]\textsuperscript{+}, found 303.0659.
\]

ethyl (Z)-2-fluoro-4-(naphthalen-2-yl)-4-oxobut-2-enoate (4h)

The title compound was isolated as a colorless liquid after chromatography on silica with a Combiflash system (100:0-95:5 petrol ether/ethyl acetate). Yield: 72%. 

\[
\text{\(^1\)H NMR (500 MHz, CDCl}_3\) \delta 8.44 (s, 1H), 8.03 (d, J = 8.6 Hz, 1H), 7.99 (t, J = 7.5 Hz, 1H), 7.93 (d, J = 8.5 Hz, 1H), 7.90 (d, J = 8.2 Hz, 1H), 7.64 (t, J = 7.4 Hz, 1H), 7.59 (t, J = 7.5 Hz, 1H), 7.28 (d, J = 30.0 Hz, 1H), 4.43 (q, J = 7.1 Hz, 2H), 1.43 (t, J = 7.1 Hz, 3H).
\]

\[
\text{\(^{13}\)C NMR (126 MHz, CDCl}_3\) \delta 188.16 (s), 160.41 (d, J = 35.3 Hz), 152.25 (d, J = 286.0 Hz), 136.14 (s), 134.23 (s), 132.57 (s), 131.37 (s), 129.88 (s), 129.23 (s), 129.02 (s), 128.03 (s), 127.20 (s), 123.85 (s), 112.39 (s), 63.04 (s), 14.23 (s).
\]

\[
\text{\(^{19}\)F NMR (470 MHz, CDCl}_3\) \delta -110.67 (s). HRMS (ESI) Calcd. For 273.0927, C\textsubscript{16}H\textsubscript{13}FO\textsubscript{3} [M-H]\textsuperscript{+}, found 273.0929.
\]
(Z)-3,4,4,4-tetrafluoro-1-phenylbut-2-en-1-one (5a) \textsuperscript{9}

The title compound was isolated as a colorless liquid after chromatography on silica with a Combiflash system (100:0-98:2 petrol ether/ethyl acetate). Yield: 80%. \textsuperscript{1}H NMR (500 MHz, CDCl\textsubscript{3}) $\delta$ 7.94 (d, $J = 7.4$ Hz, 2H), 7.66 (t, $J = 7.4$ Hz, 1H), 7.54 (t, $J = 7.8$ Hz, 2H), 6.73 (d, $J = 31.4$ Hz, 1H). $^{13}$C NMR (126 MHz, CDCl\textsubscript{3}) $\delta$ 186.65 (s), 136.39 (s), 134.50 (s), 129.13 (s), 128.88 (s), 107.92 (s). \textsuperscript{19}F NMR (470 MHz, CDCl\textsubscript{3}) $\delta$ -73.14 (d, $J = 10.0$ Hz), -116.89 (q, $J = 10.1$ Hz).

(3)-1-(4-(tert-butyl)phenyl)-3,4,4,4-tetrafluorobut-2-en-1-one (5b)

The title compound was isolated as a slightly yellow liquid after chromatography on silica with a Combiflash system (100:0-98:2 petrol ether/ethyl acetate). Yield: 78%. \textsuperscript{1}H NMR (500 MHz, CDCl\textsubscript{3}) $\delta$ 7.87 (d, $J = 8.4$ Hz, 2H), 7.54 (d, $J = 8.4$ Hz, 2H), 6.71 (d, $J = 31.7$ Hz, 1H), 1.36 (s, 9H). $^{13}$C NMR (126 MHz, CDCl\textsubscript{3}) $\delta$ 185.13 (s), 157.54 (s), 150.90 (q, $J = 39.9$ Hz), 148.65 (q, $J = 39.9$ Hz), 132.76 (s), 127.82 (s), 125.02 (s), 120.35-113.49 (m), 107.04 (s), 34.35 (s), 30.02 (s). \textsuperscript{19}F NMR (470 MHz, CDCl\textsubscript{3}) $\delta$ -73.15 (d, $J = 10.2$ Hz), -117.78 (q, $J = 11.0$ Hz). HRMS (EI) Calcd. For C\textsubscript{14}H\textsubscript{14}F\textsubscript{4}O\textsubscript{3}, found 274.0975.

(3)-3,4,4,4-tetrafluoro-1-(naphthalen-2-yl)but-2-en-1-one (5c)

The title compound was isolated as a slightly yellow liquid after chromatography on silica with a Combiflash system (100:0-98:2 petrol ether/ethyl acetate). Yield: 75%. \textsuperscript{1}H NMR (500 MHz, CDCl\textsubscript{3}) $\delta$ 8.41 (s, 1H), 8.01 (d, $J = 7.9$ Hz, 2H), 7.95 (d, $J = 8.6$ Hz, 1H), 7.92 (d, $J = 8.1$ Hz, 1H), 7.67 (t, $J = 7.3$ Hz, 1H), 7.61 (t, $J = 7.4$ Hz, 1H), 6.87 (d, $J = 31.3$ Hz, 1H). $^{13}$C NMR (126 MHz, CDCl\textsubscript{3}) $\delta$ 186.47 (s), 136.26 (s), 133.80 (s), 132.52 (s), 131.36 (s), 129.90 (s), 129.46 (s), 129.22 (s), 128.07 (s), 127.37 (s), 123.69 (s), 108.03 (s). \textsuperscript{19}F NMR (470 MHz, CDCl\textsubscript{3}) $\delta$ -73.04 (d, $J = 10.2$ Hz), -117.09 (q, $J = 11.0$ Hz).

Reference

(1) Gallagher, K. J.; Webster, R. L., Chem. Commun. 2014, 50 (81), 12109-12111..
(4) CAS: 1639446-64-2.


(10) CAS: 1214712-41-0

5. NMR Spectra of all products

\[ 1^1H \text{ NMR 3a} \]
**1H NMR 3d**

**13C NMR 3d**
$^{13}$C NMR 3g

$^{19}$F NMR 3g
$^{19}F$ NMR 3h

$^1H$ NMR 3i
$^{13}$C NMR 3i

$^{19}$F NMR 3i
$^{19}$F NMR 3j

$^1$H NMR 3k
$^{13}$C NMR 3k

$^{19}$F NMR 3k
$^{1}H$ NMR 3n

$^{13}C$ NMR 3n
$^1$H NMR 3p

$^{13}$C NMR 3p
$^{13}$C NMR 3q

$^{19}$F NMR 3q
$^{19}$F NMR 3t

$^{1}$H NMR 3u
\[ \text{C NMR 3u} \]

\[ \text{F NMR 3u} \]
$^{13}$C NMR 3v

$^1$H NMR 3v
$^{13}$C NMR 3w

$^{19}$F NMR 3w
$^{19}$F NMR 4c

$^1$H NMR 4d
$^{13}$C NMR 4d

$^{19}$F NMR 4d
$^1$H NMR 4e

$^{13}$C NMR 4e
$^{1}H$ NMR 4g

$^{13}C$ NMR 4g
$^{13}$C NMR 4h

$^{19}$F NMR 4h
$^1$H NMR 5a

$^{13}$C NMR 5a
$^{13}$C NMR 5b

$^{19}$F NMR 5b
$^1$H NMR 5c

$^{13}$C NMR 5c
$^{19}$F NMR 5c