Stereoselective defluorinative carboxylation of gem-difluoroalkenes with carbon dioxide

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1. General information

Reactions were monitored by thin layer chromatography using UV light or I$_2$ to visualize the course of reaction. Purification of reaction products was carried out by flash chromatography on silica gel. Chemical yields refer to pure isolated substances. $^1$H, $^{13}$C and $^{19}$F NMR spectra were obtained using a Bruker DPX-400 spectrometer. Chemical shifts were reported in ppm with TMS as the internal standard. The following abbreviations were used to designate chemical shift multiplicities: s = singlet, d = doublet, t = triplet, q = quartet, h = heptet, m = multiplet, br = broad.

CuI (anhydrous, 99.995% trace metals basis) was purchased from Aldrich. Xantphos, LiO'Bu and B$_2$Pin$_2$ was purchased from J&K Scientific. Anhydrous DMA was prepared by first pre-dried with anhydrous Na$_2$SO$_4$, then distilled from CaSO$_4$ into 4Å molecular sieves. CO$_2$ (99.999%) was commercially available and was dried by conc. H$_2$SO$_4$. The substrates 1a-d$^{[1]}$, 3a-d$^{[1]}$, 5a-d$^{[2]}$ and 7a-d$^{[3]}$ were synthesized according to literature methods.

List of abbreviation:

<table>
<thead>
<tr>
<th>Entry</th>
<th>Chemical name</th>
<th>Abbreviation</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>N, N-Dimethyl formamide</td>
<td>DMF</td>
</tr>
<tr>
<td>2</td>
<td>N, N-Dimethyl acetamide</td>
<td>DMA</td>
</tr>
<tr>
<td>3</td>
<td>Petroleum ether</td>
<td>PE</td>
</tr>
<tr>
<td>4</td>
<td>Ethyl acetate</td>
<td>EtOAc</td>
</tr>
<tr>
<td>5</td>
<td>Methanol</td>
<td>MeOH</td>
</tr>
</tbody>
</table>

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2. General procedure for the defluorinative carboxylation

In a glovebox under argon, a flame-dried Schlenk tube (10 mL) fitted with a stirring bar was charged with CuI (7.6 mg, 0.04 mmol), Xantphos (23.1 mg, 0.04 mmol), LiOtBu (96.1 mg, 1.2 mmol), bis(pinacolato)diboron (182.8 mg, 0.72 mmol) and gem-difluoroalkenes (0.4 mmol). The Schlenk tube was taken out of the glovebox and then evacuated and back-filled with CO₂ for three times. Subsequently, freshly anhydrous DMA (2.0 mL) was added via syringe under a positive CO₂ atmosphere. Once added, the reaction tube was sealed at atmospheric pressure of CO₂ (1 atm). The mixture was stirred at 60 °C for 24 h. After the tube was cooled to room temperature, the reaction mixture was diluted with EtOAc (3.0 mL), quenched by 2 N HCl (3.0 mL) and then extracted by EtOAc (3×5 mL). Finally, the combined organic phases were dried over Na₂SO₄, filtered and concentrated \textit{in vacuo}. The residue was purified by a silica gel flash column chromatography (petroleum ether/EtOAc 10/1, then EtOAc/MeOH 20/1 with 0.1% AcOH added) to give the desired product.
3. Characterization Data

84.0 mg, 97% yield, white solid. $^1$H NMR (400 MHz, DMSO-$d_6$): $\delta$ 8.26 (s, 1H), 7.99-7.93 (m, 3H), 7.84-7.81 (m, 1H), 7.61-7.55 (m, 2H), 7.20 (d, $J = 36.4$ Hz, 1H); $^{13}$C NMR (100 MHz, DMSO-$d_6$): $\delta$ 162.44 (d, $J = 34.4$ Hz, 1C), 147.87 (d, $J = 263.9$ Hz, 1C), 133.52 (d, $J = 1.9$ Hz, 1C), 133.22, 130.79 (d, $J = 7.8$ Hz, 1C), 129.01 (d, $J = 4.2$ Hz, 1C), 128.92 (d, $J = 2.5$ Hz, 1C), 128.04, 127.86, 127.23, 127.10 (d, $J = 8.1$ Hz, 1C), 117.13; $^{19}$F NMR (376 MHz, DMSO-$d_6$): $\delta$ -123.50; HRMS (ESI): Exact mass calcd for C$_{13}$H$_8$FO$_2^-$ [M-H]: 215.0514, found: 215.0514. The spectroscopic data correspond to those previously reported in the literature.$^4$

80.0 mg, 93% yield, white solid. $^1$H NMR (400 MHz, acetone-$d_6$): $\delta$ 8.16 (d, $J = 8.4$ Hz, 1H), 8.02-7.97 (m, 3H), 7.75 (d, $J = 33.6$ Hz, 1H), 7.68-7.58 (m, 3H); $^{13}$C NMR (125 MHz, acetone-$d_6$): $\delta$ 161.40 (d, $J = 35.9$ Hz, 1C), 148.20 (d, $J = 264.5$ Hz, 1C), 133.78, 131.34, 129.96 (d, $J = 1.6$ Hz, 1C), 128.80, 128.42 (d, $J = 10.5$ Hz, 1C), 127.23 (d, $J = 3.5$ Hz, 1C), 127.01, 126.23, 125.46, 123.51, 113.49 (d, $J = 5.9$ Hz, 1C); $^{19}$F NMR (376 MHz, acetone-$d_6$): $\delta$ -125.49; HRMS (ESI): Exact mass calcd for C$_{13}$H$_8$FO$_2^-$ [M-H]: 215.0514, found: 215.0517. The spectroscopic data correspond to those previously reported in the literature.$^5$

73.5 mg, 83% yield, yellow solid. $^1$H NMR (500 MHz, acetone-$d_6$): $\delta$ 8.00-7.98 (m, 1H), 7.93-7.91 (m, 1H), 7.80 (s, 1H), 7.51-7.41 (m, 3H); $^{13}$C NMR (125 MHz, acetone-$d_6$): $\delta$ 160.85 (d, $J = 33.9$ Hz, 1C), 146.83 (d, $J = 264.4$ Hz, 1C), 141.64 (d, $J = 8.5$ Hz, 1C), 138.89, 133.62 (d, $J = 6.0$ Hz, 1C), 128.81 (d, $J = 4.3$ Hz, 1C), 125.99, 124.91, 124.43 (d, $J = 2.1$ Hz, 1C), 122.27, 112.09 (d, $J = 8.0$ Hz, 1C); $^{19}$F NMR (376 MHz, acetone-$d_6$): $\delta$ -122.40; HRMS (ESI): Exact mass calcd for C$_{11}$H$_{9}$FO$_2$S$^-$ [M-H]: 221.0078, found: 221.0077.

59.0 mg, 72% yield, white solid. $^1$H NMR (500 MHz, acetone-$d_6$): $\delta$ 7.74 (dd, $J = 8.0$ Hz, $J = 1.5$ Hz, 1H), 7.58 (d, $J = 8.0$ Hz, 1H), 7.45-7.41 (m, 1H), 7.35-7.30 (m, 2H), 7.14 (d, $J = 30.0$ Hz, 1H); $^{13}$C NMR (125 MHz,

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acetone-$d_6$): $\delta$ 160.89 (d, $J = 33.5$ Hz, 1C), 155.17 (d, $J = 2.1$ Hz, 1C), 148.72 (d, $J = 4.9$ Hz, 1C), 147.77 (d, $J = 269.0$ Hz, 1C), 128.46, 126.22, 123.55, 121.90, 111.24, 111.13 (d, $J = 10.7$ Hz, 1C), 106.50 (d, $J = 7.5$ Hz, 1C); $^{19}$F NMR (376 MHz, acetone-$d_6$): $\delta$ -118.47; HRMS (ESI): Exact mass calcd for C$_{11}$H$_{6}$FO$_3$: [M-H]: 205.0306, found: 205.0311.

The spectroscopic data correspond to those previously reported in the literature.$[^5]$
7.6 Hz, 1C), 133.04 (d, J = 3.5 Hz, 1C), 130.27, 124.28 (d, J = 8.6 Hz, 1C), 123.88 (d, J = 1.8 Hz, 1C), 114.74; \(^{19}\)F NMR (376 MHz, acetone-\(d_6\)): \(\delta\) -121.67; HRMS (ESI): Exact mass calcd for C\(_9\)H\(_9\)FO\(_4\) [M-H]: 210.0208, found: 210.0200.

73.0 mg, 78% yield, white solid. \(^1\)H NMR (400 MHz, acetone-\(d_6\)): \(\delta\) 7.95 (d, \(J = 8.0\) Hz, 2H), 7.81 (d, \(J = 8.4\) Hz, 2H), 7.13 (d, \(J = 34.8\) Hz, 1H); \(^{13}\)C NMR (125 MHz, acetone-\(d_6\)): \(\delta\) 161.13 (d, \(J = 35.0\) Hz, 1C), 148.77 (d, \(J = 267.4\) Hz, 1C), 135.29, 130.60 (d, \(J = 8.1\) Hz, 1C), 130.42-129.92 (m, 1C), 125.65 (d, \(J = 4.1\) Hz, 1C), 124.17 (q, \(J = 269.8\) Hz, 1C), 115.26; \(^{19}\)F NMR (376 MHz, acetone-\(d_6\)): \(\delta\) -63.42, -121.77; HRMS (ESI): Exact mass calcd for C\(_{10}\)H\(_9\)F\(_4\)O\(_2\) [M-H]: 233.0231, found: 233.0230. The spectroscopic data correspond to those previously reported in the literature.\(^{[4]}\)

122.0 mg, 91% yield, white solid. \(^1\)H NMR (400 MHz, acetone-\(d_6\)): \(\delta\) 7.78-7.72 (m, 4H), 7.49 (d, \(J = 7.6\) Hz, 2H), 7.14 (d, \(J = 8.8\) Hz, 2H), 7.02 (d, \(J = 35.2\) Hz, 1H), 2.47 (s, 3H); \(^{13}\)C NMR (125 MHz, acetone-\(d_6\)): \(\delta\) 161.21 (d, \(J = 35.4\) Hz, 1C), 150.15 (d, \(J = 3.8\) Hz, 1C), 147.66 (d, \(J = 265.0\) Hz, 1C), 146.03, 132.28, 131.65 (d, \(J = 8.0\) Hz, 1C), 130.42 (d, \(J = 4.1\) Hz, 1C), 130.09, 128.41, 122.72, 115.57 (d, \(J = 4.5\) Hz, 1C), 20.71; \(^{19}\)F NMR (376 MHz, acetone-\(d_6\)): \(\delta\) -124.53; HRMS (ESI): Exact mass calcd for C\(_{10}\)H\(_{12}\)FO\(_5\)S [M-H]: 335.0395, found: 335.0386.

72.5 mg, 86% yield, white solid. \(^1\)H NMR (400 MHz, acetone-\(d_6\)): \(\delta\) 7.66 (d, \(J = 8.4\) Hz, 2H), 7.34 (d, \(J = 8.8\) Hz, 2H), 6.99 (d, \(J = 36.0\) Hz, 1H), 2.54 (s, 3H); \(^{13}\)C NMR (125 MHz, acetone-\(d_6\)): \(\delta\) 161.40 (d, \(J = 35.0\) Hz, 1C), 146.86 (d, \(J = 262.4\) Hz, 1C), 141.58 (d, \(J = 3.1\) Hz, 1C), 130.54 (d, \(J = 8.1\) Hz, 1C), 127.59 (d, \(J = 4.5\) Hz, 1C), 125.70, 116.75 (d, \(J = 4.6\) Hz, 1C), 13.87; \(^{19}\)F NMR (376 MHz, acetone-\(d_6\)): \(\delta\) -125.79; HRMS (ESI): Exact mass calcd for C\(_{10}\)H\(_8\)FO\(_2\)S [M-H]: 211.0235, found: 211.0235.

86.0 mg, 88% yield, white solid. \(^1\)H NMR (400 MHz, acetone-\(d_6\)): \(\delta\) 7.70-7.65 (m, 4H), 7.03 (d, \(J = 35.2\) Hz, 1H); \(^{13}\)C NMR (125 MHz, acetone-\(d_6\)): \(\delta\) 161.19 (d, \(J = 35.4\) Hz, 1C), 147.72 (d, \(J = 265.0\) Hz, 1C), 132.02, 131.89 (d,
\[ J = 8.4 \text{ Hz, 1C}, \quad 130.53 \text{ (d, } J = 4.1 \text{ Hz, 1C}), \quad 123.30 \text{ (d, } J = 3.8 \text{ Hz, 1C}), \quad 115.86 \text{ (d, } J = 4.5 \text{ Hz, 1C}); \]

\(^{19}\text{F NMR (376 MHz, acetone-}d_6\text{): } \delta -123.89; \text{ HRMS (ESI): Exact mass calcd for C}_9\text{H}_5\text{Br}^{79}\text{FO}_2^-\text{ [M-H]}^-: 242.9462, \text{ found: 242.9461.} \]

\[ \begin{array}{c}
\text{F} \\
\text{Br}
\end{array} \quad \begin{array}{c}
\text{CO}_2\text{H}
\end{array} \]

70.0 mg, 72% yield, white solid. \(^1\text{H NMR (400 MHz, acetone-}d_6\text{): } \delta 7.92 \text{ (dd, } J = 7.8 \text{ Hz, } J = 2.0 \text{ Hz, 1H}), \quad 7.75 \text{ (dd, } J = 8.4 \text{ Hz, } J = 1.2 \text{ Hz, 1H}), \quad 7.52-7.48 \text{ (m, 1H),}
\]

7.38-7.30 \text{ (m, 2H); } \(^{13}\text{C NMR (125 MHz, acetone-}d_6\text{): } \delta 148.38 \text{ (d, } J = 268.0 \text{ Hz, 1C}), \quad 133.17, \quad 131.23 \text{ (d, } J = 12.4 \text{ Hz, 1C}), \quad 131.11 \text{ (d, } J = 1.6 \text{ Hz, 1C}), \quad 130.91 \text{ (d, } J = 4.3 \text{ Hz, 1C}), \quad 128.06, \quad 124.08 \text{ (d, } J = 1.6 \text{ Hz, 1C}), \quad 114.84; \]

\(^{19}\text{F NMR (376 MHz, acetone-}d_6\text{): } \delta -124.41; \text{ HRMS (ESI): Exact mass calcd for C}_9\text{H}_5\text{Br}^{79}\text{FO}_2^-\text{ [M-H]}^-: 242.9462, \text{ found: 242.9460.} \]

\[ \begin{array}{c}
\text{F} \\
\text{Cl}
\end{array} \quad \begin{array}{c}
\text{CO}_2\text{H}
\end{array} \]

69.5 mg, 87% yield, white solid. \(^1\text{H NMR (400 MHz, acetone-}d_6\text{): } \delta 7.75 \text{ (d, } J = 8.8 \text{ Hz, 2H}), \quad 7.51 \text{ (d, } J = 8.4 \text{ Hz, 2H}), \quad 7.04 \text{ (d, } J = 35.2 \text{ Hz, 1H); } \]

\(^{13}\text{C NMR (125 MHz, acetone-}d_6\text{): } \delta 161.26, \quad 147.65 \text{ (d, } J = 264.8 \text{ Hz, 1C}), \quad 134.92 \text{ (d, } J = 3.6 \text{ Hz, 1C}), \quad 131.70 \text{ (d, } J = 8.3 \text{ Hz, 1C}), \quad 130.15 \text{ (d, } J = 4.1 \text{ Hz, 1C), 129.00, 115.79 \text{ (d, } J = 4.5 \text{ Hz, 1C); } \]

\(^{19}\text{F NMR (376 MHz, acetone-}d_6\text{): } \delta -124.27; \text{ HRMS (ESI): Exact mass calcd for C}_9\text{H}_5\text{Cl}^{35}\text{FO}_2^-\text{ [M-H]}^-: 198.9968, \text{ found: 198.9967.} \]

\[ \begin{array}{c}
\text{Cl} \\
\text{F}
\end{array} \quad \begin{array}{c}
\text{CO}_2\text{H}
\end{array} \]

64.0 mg, 80% yield, white solid. \(^1\text{H NMR (500 MHz, acetone-}d_6\text{): } \delta 7.75 \text{ (s, 1H), } \quad 7.68 \text{ (d, } J = 7.5 \text{ Hz, 1H), } \quad 7.51-7.45 \text{ (m, 2H), } \quad 7.04 \text{ (d, } J = 35.0 \text{ Hz, 1H); } \]

\(^{13}\text{C NMR (125 MHz, acetone-}d_6\text{): } \delta 161.25 \text{ (d, } J = 35.1 \text{ Hz, 1C}), \quad 148.15 \text{ (d, } J = 266.0 \text{ Hz, 1C}), \quad 134.19, \quad 133.33 \text{ (d, } J = 4.1 \text{ Hz, 1C), 130.53, 129.59 \text{ (d, } J = 8.5 \text{ Hz, 1C), 129.42 \text{ (d, } J = 2.5 \text{ Hz, 1C), 128.53 \text{ (d, } J = 8.1 \text{ Hz, 1C), 115.51 \text{ (d, } J = 4.2 \text{ Hz, 1C); } \]

\(^{19}\text{F NMR (376 MHz, acetone-}d_6\text{): } \delta -122.96; \text{ HRMS (ESI): Exact mass calcd for C}_9\text{H}_5\text{Cl}^{35}\text{FO}_2^-\text{ [M-H]}^-: 198.9968, \text{ found: 198.9965.} \]

\[ \begin{array}{c}
\text{Cl} \\
\text{F}
\end{array} \quad \begin{array}{c}
\text{CO}_2\text{H}
\end{array} \]

65.5 mg, 82% yield, white solid. \(^1\text{H NMR (400 MHz, acetone-}d_6\text{): } \delta 7.96-7.94 \text{ (m, 1H), } \quad 7.57-7.55 \text{ (m, 1H), } \quad 7.47-7.44 \text{ (m, 2H), } \quad 7.37 \text{ (d, } J = 34.0 \text{ Hz, 1H); } \]

\(^{13}\text{C NMR (125 MHz, acetone-}d_6\text{): } \delta 161.14, \quad 148.44 \text{ (d, } J = 268.0 \text{ Hz, 1C), 133.65 \text{ (d, } J = 1.9 \text{ Hz, 1C), 131.12 \text{ (d, } J = 12.88 \text{ Hz, 1C), 130.98 \text{ (d, } J = 1.8 \text{ Hz, 1C), 129.82, 129.10 \text{ (d, } J = 4.5 \text{ Hz, 1C), 127.51, 112.16 \text{ (d, } J = 3.8 \text{ Hz, 1C); } \]

\(^{19}\text{F NMR (376 MHz, acetone-}d_6\text{): } \delta -124.01; \text{ HRMS (ESI): Exact mass calcd for C}_9\text{H}_5\text{Cl}^{35}\text{FO}_2^-\text{ [M-H]}^-: 198.9968, \text{ found: 198.9965.} \]

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65.5 mg, 86% yield, white solid. $^1$H NMR (400 MHz, acetone-$d_6$): δ 7.93 (d, $J = 8.8$ Hz, 2H), 7.88 (d, $J = 8.8$ Hz, 2H), 7.13 (d, $J = 34.8$ Hz, 1H); $^{13}$C NMR (125 MHz, acetone-$d_6$): δ 160.94 (d, $J = 34.9$ Hz, 1C), 149.00 (d, $J = 268.0$ Hz, 1C), 135.81 (d, $J = 4.0$ Hz, 1C), 132.55, 130.70 (d, $J = 8.2$ Hz, 1C), 118.13, 115.18 (d, $J = 4.0$ Hz, 1C), 112.57 (d, $J = 3.1$ Hz, 1C); $^{19}$F NMR (376 MHz, acetone-$d_6$): δ -120.87; HRMS (ESI): Exact mass calcd for C$_{10}$H$_3$FNO$_2^-$ [M-H]: 190.0310, found: 190.0313. The spectroscopic data correspond to those previously reported in the literature. [4]

72.5 mg, 95% yield, white solid. $^1$H NMR (500 MHz, acetone-$d_6$): δ 8.09 (s, 1H), 8.05 (d, $J = 8.0$ Hz, 1H), 7.83 (d, $J = 7.5$ Hz, 1H), 7.71 (t, $J = 8.0$ Hz, 1H), 7.11 (d, $J = 33.5$ Hz, 1H); $^{13}$C NMR (100 MHz, DMSO-$d_6$): δ 162.00 (d, $J = 34.6$ Hz, 1C), 148.83 (d, $J = 267.0$ Hz, 1C), 134.74 (d, $J = 8.7$ Hz, 1C), 133.76 (d, $J = 7.2$ Hz, 1C), 133.34 (d, $J = 2.1$ Hz, 1C), 132.71 (d, $J = 3.6$ Hz, 1C), 130.66, 118.79, 114.99 (d, $J = 3.7$ Hz, 1C), 112.59; $^{19}$F NMR (376 MHz, DMSO-$d_6$): δ -120.91; HRMS (ESI): Exact mass calcd for C$_{10}$H$_3$FNO$_2^-$ [M-H]: 190.0310, found: 190.0312.

78.0 mg, 83% yield, white solid. $^1$H NMR (400 MHz, acetone-$d_6$): δ 7.92 (d, $J = 2.0$ Hz, 1H), 7.73-7.67 (m, 2H), 7.05 (d, $J = 34.4$ Hz, 1H); $^{13}$C NMR (125 MHz, acetone-$d_6$): δ 161.13, 148.43 (d, $J = 266.7$ Hz, 1C), 132.74 (d, $J = 3.4$ Hz, 1C), 132.28, 131.88 (d, $J = 3.9$ Hz, 1C), 131.61 (d, $J = 8.2$ Hz, 1C), 130.99, 129.80 (d, $J = 8.5$ Hz, 1C), 114.56 (d, $J = 4.1$ Hz, 1C); $^{19}$F NMR (376 MHz, acetone-$d_6$): δ -122.34; HRMS (ESI): Exact mass calcd for C$_9$H$_4$Cl$_2$F$_2$O$_2^-$ [M-H]: 232.9578, found: 232.9573.

80.5 mg, 82% yield, white solid. $^1$H NMR (400 MHz, acetone-$d_6$): δ 7.68 (s, 1H), 7.59 (d, $J = 8.4$ Hz, 1H), 7.40 (d, $J = 8.4$ Hz, 1H), 7.08 (d, $J = 34.8$ Hz, 1H); $^{13}$C NMR (125 MHz, acetone-$d_6$): δ 161.26, 147.42 (d, $J = 264.8$ Hz, 1C), 143.92 (d, $J = 3.1$ Hz, 1C), 143.79, 131.63 (t, $J = 252.1$ Hz, 1C), 128.03 (d, $J = 3.8$ Hz, 1C), 127.20 (d, $J = 7.3$ Hz, 1C), 115.81 (d, $J = 4.0$ Hz, 1C), 110.79 (d, $J = 7.9$ Hz, 1C), 110.15; $^{19}$F NMR (376 MHz, acetone-$d_6$): δ -51.27, -124.86; HRMS (ESI): Exact mass calcd for C$_{10}$H$_4$F$_3$O$_4^-$ [M-H]: 245.0067, found: 245.0062.
56.0 mg, 73% yield, white solid. $^1$H NMR (400 MHz, acetone-$d_6$): $\delta$ 7.64-7.61 (m, 2H), 7.43-7.33 (m, 3H), 7.21-7.07 (m, 2H), 6.90 (dd, $J =$ 31.4 Hz, $J =$ 10.4 Hz, 1H); $^{13}$C NMR (125 MHz, acetone-$d_6$): $\delta$ 161.04 (d, $J =$ 34.1 Hz, 1C), 146.87 (d, $J =$ 260.6 Hz, 1C), 139.10 (d, $J =$ 4.4 Hz, 1C), 136.30 (d, $J =$ 1.9 Hz, 1C), 129.03, 128.84, 127.24, 118.65 (d, $J =$ 8.9 Hz, 1C), 118.53 (d, $J =$ 2.4 Hz, 1C); $^{19}$F NMR (376 MHz, acetone-$d_6$): $\delta$ -128.60; HRMS (ESI): Exact mass calcd for $\text{C}_{11}\text{H}_8\text{FO}_2^-$ [M-H]: 191.0514, found: 191.0514.

56.0 mg, 67% yield, white solid. $^1$H NMR (500 MHz, acetone-$d_6$): $\delta$ 7.70-7.66 (m, 2H), 7.19-7.14 (m, 2H), 7.12-7.04 (m, 2H), 6.87 (dd, $J =$ 31.5 Hz, $J =$ 10.0 Hz, 1H); $^{13}$C NMR (125 MHz, acetone-$d_6$): $\delta$ 163.04 (d, $J =$ 246.1 Hz, 1C), 161.17 (d, $J =$ 34.2 Hz, 1C), 146.92 (d, $J =$ 260.5 Hz, 1C), 137.71 (d, $J =$ 4.5 Hz, 1C), 132.83 (dd, $J =$ 3.6 Hz, $J =$ 1.7 Hz, 1C), 129.29 (d, $J =$ 8.2 Hz, 1C), 118.53 (d, $J =$ 14.6 Hz, 1C), 118.50 (d, $J =$ 3.0 Hz, 1C), 115.70 (d, $J =$ 21.7 Hz, 1C); $^{19}$F NMR (376 MHz, acetone-$d_6$): $\delta$ -113.57 (d, $J =$ 2.6 Hz, 1F), -128.47 (d, $J =$ 2.3 Hz, 1F); HRMS (ESI): Exact mass calcd for $\text{C}_{11}\text{H}_7\text{F}_2\text{O}_2^-$ [M-H]: 209.0420, found: 209.0415.

52.0 mg, 63% yield, white solid. $^1$H NMR (400 MHz, acetone-$d_6$): $\delta$ 7.42-7.41 (m, 4H), 7.35-7.30 (m, 1H), 6.97 (s, 1H), 6.76 (d, $J =$ 35.6 Hz, 1H), 2.22 (dd, $J =$ 2.8 Hz, $J =$ 1.2 Hz, 3H); $^{13}$C NMR (125 MHz, acetone-$d_6$): $\delta$ 161.77 (d, $J =$ 34.9 Hz, 1C), 146.07 (d, $J =$ 262.7 Hz, 1C), 137.18 (d, $J =$ 6.1 Hz, 1C), 136.60, 131.09 (d, $J =$ 5.7 Hz, 1C), 129.37, 128.32, 127.64, 121.91 (d, $J =$ 4.0 Hz, 1C), 15.82 (d, $J =$ 7.1 Hz, 1C); $^{19}$F NMR (376 MHz, acetone-$d_6$): $\delta$ -127.49; HRMS (ESI): Exact mass calcd for $\text{C}_{12}\text{H}_{10}\text{F}_2\text{O}_2^-$ [M-H]: 205.0665, found: 205.0656.

75.0 mg, 70% yield, white solid. $^1$H NMR (500 MHz, acetone-$d_6$): $\delta$ 7.54-7.48 (m, 3H), 7.38 (s, 5H), 7.28-7.26 (m, 2H), 7.07 (d, $J =$ 11.5 Hz, 1H), 6.69 (dd, $J =$ 31.0 Hz, $J =$ 12.0 Hz, 1H); $^{13}$C NMR (125 MHz, acetone-$d_6$): $\delta$ 161.09 (d, $J =$ 34.4 Hz, 1C), 149.76 (d, $J =$ 5.2 Hz, 1C), 147.81 (d, $J =$ 263.0 Hz, 1C), 141.04, 138.52, 130.13, 128.82, 128.58, 128.51, 128.45, 127.94, 117.04 (d, $J =$ 1.7 Hz, 1C), 115.78 (d, $J =$ 7.4 Hz, 1C); $^{19}$F NMR (376 MHz, acetone-$d_6$): $\delta$ -127.59; HRMS (ESI): Exact mass calcd for $\text{C}_{17}\text{H}_{12}\text{FO}_2^-$ [M-H]: 267.0827, found: 267.0823.
34.2 mg, 87% yield, white solid. $^1$H NMR (400 MHz, acetone-$d_6$): $\delta$ 8.16 (s, 1H), 7.99-7.93 (m, 3H), 7.88-7.84 (m, 2H), 7.58-7.56 (m, 2H), 6.67 (d, $J = 16.0$ Hz, 1H); $^{13}$C NMR (125 MHz, acetone-$d_6$): $\delta$ 166.85, 144.55, 134.31, 133.49, 132.19, 129.79, 128.65, 128.54, 127.73, 127.72, 126.71, 123.71, 118.66; HRMS (ESI): Exact mass calcd for C$^{13}$H$^9$O$_2$-$[M-H]$: 197.0603, found: 197.0606.

18.4 mg, 57% yield, white solid. $^1$H NMR (500 MHz, DMSO-$d_6$): $\delta$ 12.4 (br, 1H), 7.58 (d, $J = 16.0$ Hz, 1H), 7.53 (dd, $J = 6.5$ Hz, $J = 2.0$ Hz, 2H), 7.18 (d, $J = 8.0$ Hz, 2H), 6.47 (d, $J = 16.0$ Hz, 1H), 2.29 (s, 3H); $^{13}$C NMR (125 MHz, DMSO-$d_6$): $\delta$ 168.22, 144.37, 140.54, 131.93, 129.93, 128.58, 118.52, 21.41. The spectroscopic data correspond to those previously reported in the literature.[6]

36.2 mg, 81% yield, white solid. $^1$H NMR (500 MHz, DMSO-$d_6$): $\delta$ 12.44 (br, 1H), 7.79-7.75 (m, 2H), 7.73-7.63 (m, 5H), 7.50-7.43 (m, 2H), 7.41-7.36 (m, 1H), 6.58 (dd, $J = 16.0$ Hz, $J = 9.5$ Hz, 1H); $^{13}$C NMR (100 MHz, DMSO-$d_6$): $\delta$ 168.08, 143.88, 142.17, 139.70, 133.84, 129.45, 129.29, 128.36, 127.52, 127.12, 119.66. The spectroscopic data correspond to those previously reported in the literature.[7]

25.2 mg, 70% yield, white solid. $^1$H NMR (500 MHz, DMSO-$d_6$): $\delta$ 12.49 (br, 1H), 7.64 (d, $J = 8.5$ Hz, 2H), 7.57 (d, $J = 16.5$ Hz, 1H), 7.38 (d, $J = 8.5$ Hz, 2H), 6.51 (dd, $J = 16.0$ Hz, $J = 5.5$ Hz, 1H); $^{13}$C NMR (125 MHz, DMSO-$d_6$): $\delta$ 167.91, 142.91, 135.18, 133.55, 130.19, 129.26, 120.42. The spectroscopic data correspond to those previously reported in the literature.[7]

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4. Product elaboration

In a flame-dried Schlenk tube (10 mL) containing a stirring bar, a solution of 2a (43.0 mg, 0.2 mmol, 1.0 equiv) and LiAlH₄ (15.0 mg, 0.4 mmol, 2.0 equivs) in Et₂O (2.0 mL) was stirred for 5 h at 0 °C and then quenched by water (0.5 mL). The solution was extracted with EtOAc (3×5 mL). The organic extracts were washed with water and brine, dried over anhydrous Na₂SO₄, filtered, and concentrated in vacuo. The residue was purified by chromatography on silica gel (petroleum ether/ethyl acetate 7/1 to 3/1) to give the product 8 (35.0 mg, 87% yield) as a white solid. 

\[\text{H NMR (500 MHz, CDCl}_3\text{: }\delta \text{ 7.93 (s, 1H), 7.82–7.79 (m, 3H), 7.69–7.67 (m, 1H), 7.47–7.45 (m, 2H), 5.94 (d, } J = 38.5 \text{ Hz, 1H), 4.33 (d, } J = 14.5 \text{ Hz, 2H); }^1\text{C NMR (125 MHz, CDCl}_3\text{: }\delta \text{ 158.43 (d, } J = 265.5 \text{ Hz, 1C), 133.37, 132.60 (d, } J = 1.9 \text{ Hz, 1C), 130.24 (d, } J = 3.0 \text{ Hz, 1C), 128.11, 128.09, 127.92 (d, } J = 7.0 \text{ Hz, 1C), 127.59, 126.52 (d, } J = 7.5 \text{ Hz, 1C), 126.24, 126.16, 107.66 (d, } J = 6.5 \text{ Hz, 1C), 62.02 (d, } J = 32.2 \text{ Hz, 1C); }^1\text{H NMR (376 MHz, CDCl}_3\text{: }\delta \text{ -112.99. The spectroscopic data correspond to those previously reported in the literature.}\] 

A flame-dried tube filled with nitrogen was charged with 2a (43.0 mg, 0.2 mmol, 2.0 equivs), 1,3,4-oxadiazole (0.1 mmol, 14.5 mg, 1.0 equiv), dppe (8.0 mg, 0.02 mmol), Pd(acac)₂ (3.0 mg, 0.01 mmol), CuCO₃ (77.5 mg, 0.35 mmol, 3.5 equivs), 4 Å MS (50.0 mg). After which, the tube was purged and back-filled with nitrogen (this operation was repeated three times), then anhydrous DMA (0.7 mL) and DMSO (0.3 mL) were added. The tube was sealed and heated at 140 °C for 12 hours then cooled to room temperature. The reaction mixture was poured into NH₄Cl (10 mL)/EtOAc (10 mL), then was filtered through a plug of celite (washed with EtOAc) and extracted with EtOAc (3×10 mL). The combined organic layer was dried over Na₂SO₄, filtrated and the solvent was removed under reduced pressure. The crude product was then purified by flash silica gel column chromatography (petroleum ether/EtOAc 15/1 to 10/1) affording the desired compound 9 in 75% yield (23.5 mg) as a white solid. 

\[\text{H NMR (500 MHz, CDCl}_3\text{: }\delta \text{ 8.17-8.15 (m, 3H),}\]

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7.92-7.85 (m, 4H), 7.63-7.52 (m, 5H), 7.07 (d, J = 37.0 Hz, 1H); $^{13}$C NMR (125 MHz, CDCl$_3$): $\delta$ 164.86, 159.40 (d, J = 37.2 Hz, 1C), 143.42 (d, J = 254.7 Hz, 1C), 133.49 (d, J = 2.0 Hz, 1C), 132.23, 130.34 (d, J = 7.6 Hz, 1C), 129.21, 128.76, 128.72, 128.69, 128.56, 127.72, 127.33, 127.17, 126.73, 126.56 (d, J = 8.1 Hz, 1C), 123.25, 114.71 (d, J = 4.1 Hz, 1C); $^{19}$F NMR (376 MHz, CDCl$_3$): $\delta$ -126.68. The spectroscopic data correspond to those previously reported in the literature.$^{[9]}$

6a

<Chemical Structure Image>

<NMR Spectrum Image>