Electronic Supplementary Information

Photoredox 1,2-Dicarbofunctionalization of Unactivated Alkenes via Tandem Radical Difluoroalkylation and Alknyl Migration

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1. General information

All reactions were carried out under argon atmosphere with dry solvents in Schlenk-tube unless otherwise noted. Dry solvents were purchased from J&K®. All other reagents were purchased from commercial sources and used as received. The luminescence quenching experiment was taken using a F-7000 FL Spectrophotometer (Hitachi, Japan). Thin layer chromatography (TLC) was performed on silica coated glass plates (GF 254) with detection by UV (λ = 254 and 366 nm). Flash chromatography was performed on silica (200-300 mesh) with the indicated eluent mixtures. 1H NMR, 13C NMR spectra and 19F NMR spectra were recorded on Bruker AVANCE 400 spectrometer. Chemical shifts (δ) are reported in ppm downfield from tetramethylsilane. Abbreviations for signal couplings are: s, singlet; d, doublet; t, triplet; m, multiplet. The configuration of product 3 were determined by NMR spectra (1H, 13C, 19F NMR). High resolution mass spectra were gained using an Agilent 6210 Series TOF LC-MS equipped with electrospray ionization (ESI) probe operating in positive ion mode.

The substrates alkynyl-substituted tertiary alcohols 1 were prepared by the addition of freshly prepared alkynyllithium to the precursor ketones referring to the reported procedures.[1-2]

2. General procedure for alkynyl migration of corresponding
In a 10 mL oven-dried Schlenk tube equipped with a stirring bar, alkyne-substituted tertiary alcohol 1 (0.2 mmol, 1.0 equiv), fac-Ir(ppy)$_3$ (0.004 mmol, 2 mol %), bromodifluoro reagents 2 (0.4 mmol, 2.0 equiv), 2,6-lutidine (0.1 mmol, 0.5 equiv) and anhydrous MeCN (2.0 mL) were successively added. The resulting reaction mixture was subjected to evacuation/flushing with argon for three times under -78 °C. Then it was allowed to warm to room temperature and irradiated with 3 W blue LEDs until the starting material was fully consumed (monitored by TLC). Removing the solvent in vacuo, the resulting residues were purified by preparative thin layer chromatography (PTLC; PE/EA) to afford the desired akynyl migration product 3.

3. Stern-Volmer plot (Luminescence quenching experiment)
The luminescence quenching experiment was taken using a F-7000 FL Spectrophotometer (Hitachi, Japan). The experiments were carried out in $3 \times 10^{-5}$ mol/L of $\text{fac-Irppy}_3$ in anhydrous CH$_3$CN at 25 °C. The excitation wavelength was 375 nm and the emission intensity was collected at 516 nm. The concentrations of quencher (bromodifluoroacetate) in anhydrous CH$_3$CN were 0 mol/L, $1.00 \times 10^{-2}$ mol/L, $2.7 \times 10^{-2}$ mol/L, $6.7 \times 10^{-2}$ mol/L, $1.00 \times 10^{-1}$ mol/L.

Luminescence quenching of $\text{fac-Irppy}_3$ by bromodifluoroacetate
4. Characterization of the products 3

ethyl 2,2-difluoro-7-oxo-7-phenyl-4-(phenylethynyl)heptanoate (3a)
(prepared according to the general procedure described above by using 1a and 2a as substrates.)

\[
\begin{align*}
\text{Yellow oil, yield 69\%.} & \quad \text{\textsuperscript{1}H NMR (400 MHz, Chloroform-\textit{d}) } \delta 8.00 - 7.97 (m, 2H), 7.59 - 7.53 (m, 1H), 7.48 - 7.43 (m, 2H), 7.39 - 7.35 (m, 2H), 7.30 - 7.27 (m, 3H), 4.23 (d, J = 7.2 Hz, 2H), 3.29 - 3.20 (m, 2H), 3.05 (hept, J = 4.8 Hz, 1H), 2.63 - 2.47 (m, 1H), 2.35 (m, 1H), 2.20 - 2.09 (m, 1H), 2.04 - 1.91 (m, 1H), 1.28 (t, J = 7.2 Hz, 3H). \text{\textsuperscript{13}C NMR (100 MHz, Chloroform-\textit{d}) } \delta 199.2, 163.9 (t, J = 32.3 Hz), 136.8, 133.2, 131.6, 128.6, 128.3, 128.1, 123.0, 115.4 (t, J = 249.2 Hz), 89.5, 83.7, 63.0, 40.0 (t, J = 23.2 Hz), 36.0, 29.7, 25.8, 13.8. \text{\textsuperscript{19}F NMR (376 MHz, Chloroform-\textit{d}) } \delta -101.1 (d, J = 262.8 Hz), -106.7 (d, J = 262.8 Hz). \text{HRMS (ESI) calcd for C}_{23}\text{H}_{22}\text{F}_{2}O_{3}\text{Na}[M+Na]^{+}: 407.1429, found: 407.1426.
\end{align*}
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ethyl 2,2-difluoro-7-oxo-4-(phenylethynyl)-7-(o-tolyl)heptanoate (3b)
(prepared according to the general procedure described above by using 1b and 2a as substrates.)

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\begin{align*}
\text{Yellow oil, yield 59%.} & \quad \text{\textsuperscript{1}H NMR (400 MHz, Chloroform-\textit{d}) } \delta 7.70 - 7.67 (m, 1H), 7.39 - 7.34 (m, 3H), 7.29 - 7.23 (m, 5H), 4.22 (q, J = 7.2 Hz, 2H), 3.21 - 3.14 (m, 2H), 3.04 (hept, J = 4.7 Hz, 1H), 2.63 - 2.45 (m, 4H), 2.34 (qd, J = 14.6, 4.7 Hz, 1H), 2.19 - 2.06 (m, 1H), 1.99 - 1.87 (m, 1H), 1.27 (t, J = 7.2 Hz, 3H). \text{\textsuperscript{13}C NMR (100 MHz, Chloroform-\textit{d}) } \delta 203.3, 163.9 (t, J = 32.5 Hz), 138.1, 137.8, 132.0, 131.6, 131.4, 128.5, 128.3, 128.1, 125.7, 123.0, 115.4 (t, J = 247.9 Hz), 89.5, 83.7, 63.0, 40.0 (t, J = 23.2 Hz), 38.8, 29.7, 25.7, 21.4, 13.8. \text{\textsuperscript{19}F NMR (376 MHz, Chloroform-\textit{d}) } \delta -101.1 (d, J = 262.7 Hz), -106.8 (d, J = 262.7 Hz). \text{HRMS (ESI) calcd for C}_{24}\text{H}_{24}\text{F}_{2}O_{3}\text{Na}[M+Na]^{+}: 421.1586, found: 421.1579.
\end{align*}
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ethyl 2,2-difluoro-7-oxo-4-(phenylethynyl)-7-(p-tolyl)heptanoate (3c)
(prepared according to the general procedure described above by using 1c and 2a as substrates.)
**Yellow oil, yield 59%**. \(^1\)H NMR (400 MHz, Chloroform-\(d\)) \(\delta 7.89 (d, J = 8.2 \text{ Hz}, 2\text{H}), 7.39 – 7.35 (m, 2\text{H}), 7.31 – 7.22 (m, 5\text{H}), 4.22 (q, J = 7.1 \text{ Hz}, 2\text{H}), 3.25 – 3.19 (m, 2\text{H}), 3.04 (hept, \(J = 4.7 \text{ Hz}, 1\text{H}), 2.63 – 2.47 (m, 1\text{H}), 2.42 – 2.28 (m, 4\text{H}), 2.19 – 2.07 (m, 1\text{H}), 2.03 – 1.89 (m, 1\text{H}), 1.27 (t, \(J = 7.1 \text{ Hz}, 3\text{H}). \(^{13}\)C NMR (100 MHz, Chloroform-\(d\)) \(\delta 198.9, 163.9 (t, J = 32.3 \text{ Hz}), 144.0, 134.3, 131.6, 129.3, 128.2 (t, \(J = 6.5 \text{ Hz}), 123.0, 115.4 (t, J = 248.0 \text{ Hz}), 89.6, 83.6, 63.0, 40.0 (t, \(J = 23.2 \text{ Hz}), 35.9, 29.8, 25.8, 21.7, 13.8. \(^{19}\)F NMR (376 MHz, Chloroform-\(d\)) \(\delta -101.1 (d, J = 262.7 \text{ Hz}), -106.7 (d, \(J = 262.7 \text{ Hz}). HRMS (ESI) calcd for C\(_{24}\)H\(_{24}\)F\(_2\)O\(_3\)Na [M+Na]\(^+\): 421.1586, found: 421.1583.

ethyl 2,2-difluoro-7-(4-methoxyphenyl)-7-oxo-4-(phenylethynyl)heptanoate (3d)
(prepared according to the general procedure described above by using 1d and 2a as substrates.)

**Faint yellow oil, 57% yield.** \(^1\)H NMR (400 MHz, Chloroform-\(d\)) \(\delta 8.00 – 7.93 (m, 2\text{H}), 7.38 (dd, \(J = 6.7, 3.1 \text{ Hz}, 2\text{H}), 7.28 (dd, \(J = 5.1, 1.8 \text{ Hz}, 3\text{H}), 6.97 – 6.90 (m, 2\text{H}), 4.22 (q, \(J = 7.2 \text{ Hz}, 2\text{H}), 3.87 (s, 3\text{H}), 3.28 – 3.11 (m, 2\text{H}), 3.04 (hept, \(J = 4.8 \text{ Hz}, 1\text{H}), 2.64 – 2.45 (m, 1\text{H}), 2.35 (qd, \(J = 14.6, 4.6 \text{ Hz}, 1\text{H}), 2.19 – 2.08 (m, 1\text{H}), 2.01 – 1.88 (m, 1\text{H}), 1.27 (t, \(J = 7.2 \text{ Hz}, 3\text{H}). \(^{13}\)C NMR (100 MHz, Chloroform-\(d\)) \(\delta 197.8, 163.9 (t, \(J = 33.0 \text{ Hz}), 163.5, 131.6, 130.3, 128.3, 128.1, 123.0, 115.4 (t, \(J = 251.9 \text{ Hz}), 113.8, 89.6, 83.6, 63.0, 55.5, 40.0 (t, \(J = 23.4 \text{ Hz}), 35.6, 29.9, 13.8. \(^{19}\)F NMR (376 MHz, Chloroform-\(d\)) \(\delta -101.1 (d, \(J = 262.6 \text{ Hz}), -106.8 (d, \(J = 262.6 \text{ Hz). HRMS (ESI) calcd for C\(_{24}\)H\(_{24}\)F\(_2\)O\(_4\)Na [M+Na]\(^+\): 437.1535, found: 437.1531.

ethyl 2,2-difluoro-7-oxo-4-(phenylethynyl)-7-(4-(trifluoromethyl)phenyl)heptanoate (3e)
(prepared according to the general procedure described above by using 1e and 2a as substrates.)

**Orange yellow oil, yield 64%**. \(^1\)H NMR (400 MHz, Chloroform-\(d\)) \(\delta 8.08 (d, \(J = 8.1 \text{ Hz}, 2\text{H}), 7.72 (d, \(J = 8.2 \text{ Hz}, 2\text{H}), 7.39 – 7.32 (m, 2\text{H}), 7.32 – 7.24 (m, 3\text{H}), 4.23 (q, \(J = 7.2 \text{ Hz}, 2\text{H}), 3.35 – 3.19 (m,
ethyl 7-(3-chlorophenyl)-2,2-difluoro-7-oxo-4-(phenylethynyl)heptanoate (3f)
(prepared according to the general procedure described above by using 1f and 2a as substrates.)

Faint yellow oil, yield 54%. 1H NMR (400 MHz, Chloroform-d) δ 7.95 (s, 1H), 7.85 (d, J = 7.8 Hz, 1H), 7.53 (d, J = 8.0 Hz, 1H), 7.42 – 7.35 (m, 3H), 7.30 – 7.26 (m, 3H), 4.23 (q, J = 7.2 Hz, 2H), 3.25 – 3.17 (m, 2H), 3.04 (hept, J = 4.8 Hz, 1H), 2.64 – 2.47 (m, 1H), 2.35 (qd, J = 14.8, 4.8 Hz, 1H), 2.20 – 2.10 (m, 1H), 2.02 – 1.91 (m, 1H), 1.28 (t, J = 7.2 Hz, 3H). 13C NMR (100 MHz, Chloroform-d) δ 197.9, 163.9 (t, J = 32.4 Hz), 138.6, 133.0, 132.8, 130.0, 128.5, 128.3, 128.2, 122.9, 115.3 (t, J = 249.5 Hz), 89.3, 83.8, 63.0, 40.0 (t, J = 23.2 Hz), 36.1, 29.5, 25.7, 13.8. 19F NMR (376 MHz, Chloroform-d) δ -101.1 (d, J = 262.9 Hz), -106.7 (d, J = 263.0 Hz). HRMS (ESI) calcd for C23H21F2O3Na [M+Na]+: 441.1039, found: 441.1043.

ethyl 2,2-difluoro-7-(naphthalen-2-yl)-7-oxo-4-(phenylethynyl)heptanoate (3g)
(prepared according to the general procedure described above by using 1g and 2a as substrates.)

Yellow oil, yield 56%. 1H NMR (400 MHz, Chloroform-d) δ 8.05 (dd, J = 8.6, 1.7 Hz, 1H), 7.62 – 7.51 (m, 2H), 7.40 – 7.37 (m, 2H), 7.30 – 7.26 (m, 3H), 4.23 (q, J = 7.2 Hz, 2H), 3.42 – 3.35 (m, 2H), 3.09 (hept, J = 4.8 Hz, 1H), 2.66 – 2.50 (m, 1H), 2.38 (qd, J = 14.5, 4.7 Hz, 1H), 2.25 – 2.16 (m, 1H), 2.08 – 1.98 (m, 1H), 1.28 (t, J = 7.2 Hz, 3H). 13C NMR (100 MHz, Chloroform-d) δ 199.2, 163.9 (t, J = 32.1 Hz), 135.6, 134.1, 132.5, 131.6, 129.8, 129.6, 128.5, 128.3, 128.2, 127.8, 126.8, 123.8, 115.4 (t, J = 249.4 Hz), 89.6, 83.7, 63.0, 40.0 (t, J = 23.2 Hz), 36.0, 29.9, 13.8. 19F NMR (376 MHz, Chloroform-d) δ -101.1 (d, J = 262.7 Hz), -106.8 (d, J = 262.8 Hz). HRMS (ESI) calcd for C27H24F2O3Na [M+Na]+: 457.1586, found: 457.1580.

ethyl 2,2-difluoro-7-oxo-4-(phenylethynyl)-7-(thiophen-2-yl)heptanoate (3h)
(prepared according to the general procedure described above by using 1h and 2a as substrates.)

**Yellow oil, yield 45%**. $^1$H NMR (400 MHz, Chloroform-$d$) $\delta$ 7.76 (dd, $J = 3.8, 1.1$ Hz, 1H), 7.63 (dd, $J = 4.9, 1.1$ Hz, 1H), 7.39 – 7.35 (m, 2H), 7.32 – 7.24 (m, 3H), 7.12 (dd, $J = 4.9, 3.8$ Hz, 1H), 4.22 (q, $J = 7.2$ Hz, 2H), 3.24 – 3.16 (m, 3H), 3.03 (hept, $J = 4.8$ Hz, 1H), 2.62 – 2.47 (m, 1H), 2.34 (qd, $J = 14.6, 4.7$ Hz, 1H), 2.21 – 2.09 (m, 1H), 2.02 – 1.91 (m, 1H), 1.27 (t, $J = 7.2$ Hz, 3H). $^{13}$C NMR (100 MHz, Chloroform-$d$) $\delta$ 192.2, 163.9 (t, $J = 32.4$ Hz), 144.1, 133.7, 132.0, 131.6, 128.3, 128.2, 128.1, 122.9, 115.3 (t, $J = 249.0$ Hz), 89.4, 83.8, 63.0, 39.9 (t, $J = 23.2$ Hz), 36.7, 29.8, 13.8. $^{19}$F NMR (376 MHz, Chloroform-$d$) $\delta$ -101.1 (d, $J = 262.9$ Hz), -106.7 (d, $J = 262.5$ Hz). HRMS (ESI) calcd for C$_{21}$H$_{20}$F$_2$O$_3$SNa [M+Na]$^+$: 413.0993, found: 413.0997.

ethyl 2,2-difluoro-7-oxo-8-phenyl-4-(phenylethynyl)octanoate (3i)

(prepared according to the general procedure described above by using 1i and 2a as substrates.)

**Yellow oil, 20 % yield.** $^1$H NMR (400 MHz, Chloroform-$d$) $\delta$ 7.34 – 7.24 (m, 8H), 7.21 – 7.18 (m, 2H), 4.20 (q, $J = 7.1$ Hz, 2H), 3.71 (s, 2H), 2.89 (hept, $J = 4.8$ Hz, 1H), 2.81 – 2.63 (m, 2H), 2.55 – 2.36 (m, 1H), 2.24 (qd, $J = 14.6, 4.7$ Hz, 1H), 1.98 – 1.88 (m, 1H), 1.81 – 1.70 (m, 1H), 1.26 (t, $J = 7.2$ Hz, 3H). $^{13}$C NMR (100 MHz, Chloroform-$d$) $\delta$ 207.4, 163.9 (t, $J = 32.5$ Hz), 134.1, 131.6, 129.4, 128.8, 128.2, 128.2, 127.1, 122.9, 115.3 (t, $J=248.0$ Hz), 89.3, 83.6, 63.0, 50.3, 39.8 (t, $J = 23.3$ Hz), 39.2, 29.0, 25.5, 13.8. $^{19}$F NMR (376 MHz, Chloroform-$d$) $\delta$ -101.2 (d, $J = 262.8$ Hz), -106.8 (d, $J = 262.8$ Hz). HRMS (ESI) calcd for C$_{24}$H$_{24}$F$_2$O$_3$Na [M+Na]$^+$: 421.1586, found: 421.1592.

ethyl 7-cyclohexyl-2,2-difluoro-7-oxo-4-(phenylethynyl)heptanoate (3j)

(prepared according to the general procedure described above by using 1j and 2a as substrates.)
Faint yellow oil, 65% yield. $^1$H NMR (400 MHz, Chloroform-$d$) δ 7.42 – 7.36 (m, 2H), 7.33 – 7.28 (m, 3H), 4.21 (q, $J = 7.1$ Hz, 2H), 2.92 (hept, $J = 4.8$Hz, 1H), 2.70 (t, $J = 7.3$ Hz, 2H), 2.58 – 2.43 (m, 1H), 2.41 – 2.21 (m, 2H), 2.00 – 1.90 (m, 1H), 1.87 – 1.72 (m, 5H), 1.68 – 1.64 (m, 1H), 1.39 – 1.16 (m, 8H). $^{13}$C NMR (101 MHz, Chloroform-$d$) δ 213.1, 163.9 (t, $J = 32.4$ Hz), 131.6, 128.3, 128.1, 123.1, 115.3 (t, $J = 249.4$ Hz), 89.5, 83.5, 63.0, 51.0, 39.9 (t, $J = 23.3$ Hz), 37.8, 29.1, 28.6, 28.5, 25.8, 25.7, 25.6, 13.8. $^{19}$F NMR (376 MHz, Chloroform-$d$) δ -101.1 (d, $J = 262.8$ Hz), -106.9 (d, $J = 262.8$ Hz). HRMS (ESI) calcd for C$_{23}$H$_{28}$F$_2$O$_3$Na [M+Na]$^+$: 413.1899, found: 413.1897.

ethyl 2,2-difluoro-7-oxo-7-phenyl-4-(p-tolylethynyl)heptanoate (3k) (prepared according to the general procedure described above by using 1k and 2a as substrates.)

Colorless oil, yield 57%. $^1$H NMR (400 MHz, Chloroform-$d$) δ 8.01 – 7.96 (m, 2H), 7.59 – 7.53 (m, 1H), 7.50 – 7.41 (m, 2H), 7.30 – 7.23 (m, 2H), 7.08 (d, $J = 7.9$ Hz, 2H), 4.22 (q, $J = 7.1$ Hz, 2H), 3.29 – 3.20 (m, 2H), 3.03 (hept, $J = 4.8$ Hz, 1H), 2.63 – 2.46 (m, 1H), 2.40 – 2.28 (m, 4H), 2.19 – 2.09 (m, 1H), 2.01 – 1.90 (m, 2H), 1.27 (t, $J = 7.1$ Hz, 3H). $^{13}$C NMR (100 MHz, Chloroform-$d$) δ 199.3, 163.9 (t, $J = 32.4$ Hz), 138.2, 136.8, 133.1, 131.5, 129.0, 128.6, 128.1, 119.9, 115.4 (t, $J = 246.1$ Hz), 88.7, 83.8, 63.0, 40.0 (t, $J = 23.0$ Hz), 36.0, 29.7, 25.8, 21.4, 13.8. $^{19}$F NMR (376 MHz, Chloroform-$d$) δ -101.0 (d, $J = 262.6$ Hz), -106.8 (d, $J = 262.7$ Hz). HRMS (ESI) calcd for C$_{24}$H$_{24}$F$_2$O$_3$Na [M+Na]$^+$: 421.1586, found: 421.1581.

ethyl 4-((4-ethylphenyl)ethynyl)-2,2-difluoro-7-oxo-7-phenylheptanoate (3l) (prepared according to the general procedure described above by using 1l and 2a as substrates.)

Yellow oil, yield 67%. $^1$H NMR (400 MHz, Chloroform-$d$) δ 8.01 – 7.97 (m, 2H), 7.59 – 7.52 (m, 1H), 7.49 – 7.42 (m, 2H), 7.31 – 7.24 (m, 2H), 7.11 (d, $J = 8.3$ Hz, 2H), 4.23 (q, $J = 7.2$ Hz, 2H), 3.32 – 3.17 (m, 2H), 3.03 (hept, $J = 4.7$ Hz, 1H), 2.62 (q, $J = 7.6$ Hz, 2H), 2.59 – 2.47 (m, 1H), 2.34 (qd, $J = 14.6$, 4.7 Hz, 1H), 2.21 – 2.09 (m, 1H), 2.01 – 1.90 (m, 1H), 1.28 (t, $J = 7.2$ Hz, 3H), 1.21 (t, $J = 7.6$ Hz, 3H). $^{13}$C NMR (100 MHz, Chloroform-$d$) δ 199.3, 164.0 (t, $J = 32.4$ Hz), 144.5, 136.8, 133.1, 131.6, 128.6, 128.1, 127.8, 120.1, 115.4 (t, $J = 244.0$ Hz), 88.7, 83.8, 63.0, 40.1 (t, $J = 23.3$ Hz), 36.0, 29.7, 28.8, 25.9, 15.4, 13.8. $^{19}$F NMR (376 MHz, Chloroform-$d$) δ -101.0 (d, $J = 262.5$ Hz), -106.8 (d, $J = 262.5$ Hz). HRMS (ESI) calcd for C$_{25}$H$_{32}$F$_2$O$_3$Na [M+Na]$^+$: 435.1742, found: 435.1737.
ethyl 2,2-difluoro-7-oxo-7-phenyl-4-(m-tolylethynyl)heptanoate (3m)
(prepared according to the general procedure described above by using 1m and 2a as substrates.)

Orange yellow oil, 57% yield. $^1$H NMR (400 MHz, Chloroform-$d$) $\delta$ 8.02 – 7.95 (m, 2H), 7.56 (t, $J$ = 7.4 Hz, 1H), 7.46 (t, $J$ = 7.6 Hz, 2H), 7.21 – 7.15 (m, 3H), 7.11 – 7.05 (m, 1H), 4.23 (q, $J$ = 7.1 Hz, 2H), 3.33 – 3.16 (m, 2H), 3.04 (hept, $J$ = 4.8 Hz, 1H), 2.62 – 2.46 (m, 1H), 2.41 – 2.28 (m, 4H), 2.19 – 2.10 (m, 1H), 2.01 – 1.90 (m, 1H), 1.28 (t, $J$ = 7.1 Hz, 3H). $^{13}$C NMR (100 MHz, Chloroform-$d$) $\delta$ 199.3, 163.9, 137.9, 136.8, 133.2, 132.2, 129.0, 128.6, 128.2, 128.1, 122.8, 115.4 (t, $J$ = 249.9 Hz), 89.1, 83.8, 63.0, 40.0 (t, $J$ = 23.2 Hz), 36.0, 29.7, 25.8, 21.2, 13.8. $^{19}$F NMR (376 MHz, Chloroform-$d$) $\delta$ -101.1 (d, $J$ = 262.5 Hz), -106.7 (d, $J$ = 262.5 Hz). HRMS (ESI) calcd for C$_{24}$H$_{24}$F$_2$O$_3$Na [M+Na]$^+$: 421.1586, found: 421.1585.

ethyl 4-([1,1'-biphenyl]-4-ylethynyl)-2,2-difluoro-7-oxo-7-phenylheptanoate (3n)
(prepared according to the general procedure described above by using 1n and 2a as substrates.)

Yellow oil, yield 53%. $^1$H NMR (400 MHz, Chloroform-$d$) $\delta$ 8.02 – 7.96 (m, 2H), 7.59 – 7.50 (m, 5H), 7.48 – 7.41 (m, 6H), 7.37 – 7.32 (m, 1H), 4.24 (q, $J$ = 7.1 Hz, 2H), 3.30 – 3.18 (m, 2H), 3.07 (hept, $J$ = 4.8 Hz, 1H), 2.66 – 2.48 (m, 1H), 2.37 (qd, $J$ = 14.5, 4.6 Hz, 1H), 2.21 – 2.10 (m, 1H), 2.05 – 1.93 (m, 1H), 1.29 (t, $J$ = 7.1 Hz, 3H). $^{13}$C NMR (100 MHz, Chloroform-$d$) $\delta$ 199.2, 163.9 (t, $J$ = 32.5 Hz), 140.9, 140.3, 136.8, 133.2, 132.0, 128.9, 128.7, 128.1, 127.7, 127.0, 126.9, 121.9, 115.4 (t, $J$ = 249.9 Hz), 90.2, 83.6, 63.1, 40.0 (t, $J$ = 23.2 Hz), 36.0, 29.7, 25.9, 13.9. $^{19}$F NMR (376 MHz, Chloroform-$d$) $\delta$ -101.1 (d, $J$ = 262.4 Hz), -106.7 (d, $J$ = 262.7 Hz). HRMS (ESI) calcd for C$_{29}$H$_{26}$F$_2$O$_3$Na [M+Na]$^+$: 483.1742, found: 483.1750.

ethyl 2,2-difluoro-4-((4-fluorophenyl)ethynyl)-7-oxo-7-(p-tolyl)heptanoate (3o)
(prepared according to the general procedure described above by using 1o and 2a as substrates.)
Yellow oil, 56% yield. $^1$H NMR (400 MHz, Chloroform-$d$) $\delta$ 7.88 (d, $J = 8.3$ Hz, 2H), 7.37 – 7.32 (m, 2H), 7.25 (d, $J = 8.5$ Hz, 2H), 7.02 – 6.93 (m, 2H), 4.22 (q, $J = 7.2$ Hz, 2H), 3.26 – 3.15 (m, 2H), 3.03 (hept, $J = 4.8$ Hz, 1H), 2.62 – 2.44 (m, 1H), 2.42 – 2.27 (m, 4H), 2.19 – 2.07 (m, 1H), 2.01 – 1.90 (m, 1H), 1.87 (t, $J = 7.2$ Hz, 3H). $^{13}$C NMR (100 MHz, Chloroform-$d$) $\delta$ 198.8, 163.9 (t, $J = 32.3$ Hz), 162.9 (d, $J = 247.5$ Hz), 144.0, 134.3, 133.4 (d, $J = 8.3$ Hz), 129.3, 128.2, 119.1 (d, $J = 3.2$ Hz), 115.5 (d, $J = 22.0$ Hz), 115.3 (t, $J = 243.6$ Hz), 89.3, 82.5, 63.0, 39.9 (t, $J = 23.2$ Hz), 35.8, 29.7, 25.8, 21.6, 13.8. $^{19}$F NMR (376 MHz, Chloroform-$d$) $\delta$ -101.3 (d, $J = 262.9$ Hz), -106.6 (d, $J = 262.9$ Hz), -111.2 (s). HRMS (ESI) calcd for C$_{24}$H$_{23}$F$_3$O$_3$Na [M+Na]$^+$: 439.1492, found: 439.1485.

ethyl 2,2-difluoro-4-((2-fluorophenyl)ethynyl)-7-oxo-7-(p-tolyl)heptanoate (3p)
(prepared according to the general procedure described above by using 1p and 2a as substrates.)

Yellow oil, 48% yield. $^1$H NMR (400 MHz, Chloroform-$d$) $\delta$ 7.90 (d, $J = 8.2$ Hz, 2H), 7.41 – 7.35 (m, 1H), 7.31 – 7.23 (m, 3H), 7.09 – 7.01 (m, 2H), 4.27 (q, $J = 7.2$ Hz, 2H), 3.34 – 3.18 (m, 2H), 3.09 (hept, $J = 4.8$ Hz, 1H), 2.65 – 2.48 (m, 1H), 2.42 – 2.30 (m, 4H), 2.23 – 2.10 (m, 1H), 2.02 – 1.90 (m, 1H), 1.31 (t, $J = 7.2$ Hz, 3H). $^{13}$C NMR (100 MHz, Chloroform-$d$) $\delta$ 199.0, 164.0 (t, $J = 16.2$ Hz), 163.5, 161.5, 143.9, 134.3, 133.5, 129.8 (d, $J = 7.9$ Hz), 129.3, 128.2, 123.9 (d, $J = 3.5$ Hz), 115.4 (d, $J = 21.1$ Hz), 115.3 (t, $J = 247.3$ Hz), 111.5 (d, $J = 15.7$ Hz), 95.1, 63.0, 39.8 (t, $J = 23.2$ Hz), 35.8, 29.7, 26.0, 21.6, 13.8. $^{19}$F NMR (376 MHz, Chloroform-$d$) $\delta$ -101.7 (d, $J = 262.8$ Hz), -106.3 (d, $J = 262.9$ Hz), -110.5 (s). HRMS (ESI) calcd for C$_{24}$H$_{23}$F$_3$O$_3$Na [M+Na]$^+$: 439.1492, found: 439.1482.

ethyl 2,2-difluoro-7-oxo-4-(thiophen-3-ylethynyl)-7-(p-tolyl)heptanoate (3q)
(prepared according to the general procedure described above by using 1q and 2a as substrates.)
Yellow oil, 33% yield. $^1$H NMR (400 MHz, Chloroform-$d$) $\delta$ 7.88 (d, $J = 8.2$ Hz, 2H), 7.36 (dd, $J = 3.0$, 1.1 Hz, 1H), 7.27 – 7.22 (m, 3H), 7.04 (dd, $J = 5.0$, 1.1 Hz, 1H), 4.23 (q, $J = 7.2$ Hz, 2H), 3.28 – 3.12 (m, 2H), 3.01 (hept, $J = 4.7$ Hz, 1H), 2.61 – 2.45 (m, 1H), 2.43 – 2.27 (m, 4H), 2.17 – 2.07 (m, 1H), 2.00 – 1.89 (m, 1H), 1.28 (t, $J = 7.2$ Hz, 3H). $^{13}$C NMR (100 MHz, Chloroform-$d$) $\delta$ 198.9, 163.9 (t, $J = 32.3$ Hz), 144.0, 134.3, 129.8, 129.3, 128.4, 128.2, 122.0, 115.4 (t, $J = 251.8$ Hz), 89.1, 78.7, 63.0, 39.9 (t, $J = 23.3$ Hz), 35.8, 29.7, 25.8, 21.7, 13.8. $^{19}$F NMR (376 MHz, Chloroform-$d$) $\delta$ -101.1 (d, $J = 262.7$ Hz), -106.9 (d, $J = 262.7$ Hz). HRMS (ESI) calcd for C$_{22}$H$_{22}$F$_{2}$O$_{3}$SNa [M+Na]$^+$: 427.1150, found: 427.1157.

2,2-difluoro-1-morpholino-7-phenyl-4-(phenylethynyl)heptane-1,7-dione (3s) (prepared according to the general procedure described above by using 1a and 2b as substrates.)

Colorless oil, yield 36%. $^1$H NMR (400 MHz, Chloroform-$d$) $\delta$ 8.02 – 7.98 (m, 2H), 7.59 – 7.53 (m, 1H), 7.46 (t, $J = 7.6$ Hz, 2H), 7.39 – 7.35 (m, 2H), 7.30 – 7.25 (m, 3H), 3.79 – 3.61 (m, 8H), 3.35 – 3.23 (m, 2H), 3.22 – 3.11 (m, 1H), 2.68 – 2.41 (m, 2H), 2.24 – 2.14 (m, 1H), 2.04 – 1.94 (m, 1H). $^{13}$C NMR (100 MHz, Chloroform-$d$) $\delta$ 199.5, 161.8 (t, $J = 28.9$ Hz), 136.9, 133.1, 131.6, 128.6, 128.2, 128.1, 128.0, 123.3, 118.8 (t, $J = 255.8$ Hz), 90.9, 82.8, 66.7 (d, $J = 9.0$ Hz), 46.6, 43.4, 39.9 (t, $J = 22.0$ Hz), 36.1, 29.8, 25.7. $^{19}$F NMR (376 MHz, Chloroform-$d$) $\delta$ -97.6 (d, $J = 282.3$ Hz), -98.9 (d, $J = 282.1$ Hz). HRMS (ESI) calcd for C$_{25}$H$_{25}$F$_{2}$NO$_{3}$H [M+H]$^+$: 426.1875, found: 426.1872.

2,2-difluoro-1-(indolin-1-yl)-7-phenyl-4-(phenylethynyl)heptane-1,7-dione (3t) (prepared according to the general procedure described above by using 1a and 2c as substrates.)

Brown oil, yield 36%. $^1$H NMR (400 MHz, Chloroform-$d$) $\delta$ 8.21 (d, $J = 7.9$ Hz, 1H), 8.03 – 7.98 (m, 2H), 7.59 – 7.53 (m, 1H), 7.46 (t, $J = 7.6$ Hz, 2H), 7.31 – 7.27 (m, 2H), 7.25 – 7.18 (m, 5H), 7.13 – 7.04 (m, 1H), 4.37 (t, $J = 8.3$ Hz, 2H), 3.33 – 3.25 (m, 2H), 3.23 – 3.14 (m, 3H), 2.80 – 2.46 (m, 2H), 2.28 – 2.17 (m, 1H), 2.10 – 1.95 (m, 1H). $^{13}$C NMR (100 MHz, Chloroform-$d$) $\delta$ 199.5, 161.2 (t, $J = 30.0$ Hz), 142.7, 136.9, 133.1, 131.7, 131.6, 128.6, 128.2, 127.9, 127.5, 125.1, 124.7, 123.2, 118.5 (t, $J = 255.9$ Hz), 118.0, 90.6, 83.0, 48.0, 39.6 (t, $J = 22.5$ Hz), 36.1, 29.8, 28.7, 25.8. $^{19}$F NMR (376 MHz, Chloroform-$d$) $\delta$ -101.3 (s). HRMS (ESI) calcd for C$_{29}$H$_{25}$F$_{2}$NO$_{2}$Na [M+Na]$^+$: 480.1746, found: 480.1738.
2,2-difluoro-N-(naphthalen-1-yl)-7-oxo-7-phenyl-4-(phenylethynyl)heptanamide (3u)
(prepared according to the general procedure described above by using 1a and 2d as substrates.)

**Khaki oil, 34% yield.** $^1$H NMR (400 MHz, Chloroform-$d$) $\delta$ 8.57 (s, 1H), 8.01 – 7.92 (m, 3H), 7.89 – 7.77 (m, 2H), 7.70 (d, $J = 8.3$ Hz, 1H), 7.59 – 7.50 (m, 1H), 7.52 – 7.35 (m, 5H), 7.27 – 7.20 (m, 3H), 7.22 – 7.16 (m, 1H), 7.18 – 7.09 (m, 2H), 3.30 – 3.20 (m, 2H), 3.15 (hept, $J = 4.8$ Hz, 1H), 2.84 – 2.65 (m, 1H), 2.63 – 2.47 (m, 1H), 2.30 – 2.13 (m, 1H), 2.07 – 1.95 (m, 1H). $^{13}$C NMR (100 MHz, Chloroform-$d$) $\delta$ 199.3, 162.3 (t, $J = 28.1$ Hz), 136.8, 134.0, 133.2, 131.6, 130.3, 128.8, 128.6, 128.1, 128.0, 126.7, 126.7, 126.2, 125.5, 122.8, 120.8, 120.1, 117.9 (t, $J = 255.7$ Hz), 89.5, 84.0, 39.1 (t, $J = 22.8$ Hz), 35.9, 29.7. $^{19}$F NMR (376 MHz, Chloroform-$d$) $\delta$ -100.7 (d, $J = 257.4$ Hz), -104.1 (d, $J = 257.4$ Hz). HRMS (ESI) calcd for C$_{31}$H$_{25}$F$_2$NO$_2$Na [M+Na]$^+$: 504.1746, found: 504.1741.

5. References
$^1$H, $^{13}$C, and $^{19}$F NMR spectra

ethyl 2,2-difluoro-7-oxo-7-phenyl-4-(phenylethynyl)heptanoate (3a)
ethyl 2,2-difluoro-7-oxo-4-(phenylethynyl)-7-(o-tolyl)heptanoate (3b)
ethyl 2,2-difluoro-7-oxo-4-(phenylethynyl)-7-(p-tolyl)heptanoate (3e)
ethyl 2,2-difluoro-7-(4-methoxyphenyl)-7-oxo-4-(phenylethynyl)heptanoate (3d)
ethyl 2,2-difluoro-7-oxo-4-(phenylethynyl)-7-(4-(trifluoromethyl)phenyl)heptanoate (3e)
ethyl 7-(3-chlorophenyl)-2,2-difluoro-7-oxo-4-(phenylethynyl)heptanoate (3f)
ethyl 2,2-difluoro-7-(naphthalen-2-yl)-7-oxo-4-(phenylethynyl)heptanoate (3g)
ethyl 2,2-difluoro-7-oxo-4-(phenylethynyl)-7-(thiophen-2-yl)heptanoate (3h)
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\text{O} & \quad \text{O} \\
\text{F} & \quad \text{F} \\
\text{S} & \quad \text{O}
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ethyl 2,2-difluoro-7-oxo-8-phenyl-4-(phenylethynyl)octanoate (3i)
ethyl 7-cyclohexyl-2,2-difluoro-7-oxo-4-(phenylethynyl)heptanoate (3j)
ethyl 2,2-difluoro-7-oxo-7-phenyl-4-(p-tolylethynyl)heptanoate (3k)
ethyl 4-((4-ethylphenyl)ethynyl)-2,2-difluoro-7-oxo-7-phenylheptanoate (3I)
ethyl 2,2-difluoro-7-oxo-7-phenyl-4-(m-tolylethynyl)heptanoate (3m)
ethyl 4-\([1,1'^{-}\text{biphenyl}]-4\text{-ylethynyl}\)-2,2-difluoro-7-oxo-7-phenylheptanoate (3n)
ethyl 2,2-difluoro-4-((4-fluorophenyl)ethynyl)-7-oxo-7-(p-tolyl)heptanoate (3o)
ethyl 2,2-difluoro-4-((2-fluorophenyl)ethynyl)-7-oxo-7-(p-tolyl)heptanoate (3p)

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\begin{align*}
\text{O} & \quad \text{O} \\
\text{F} & \quad \text{F} \\
\text{O} & \\
\end{align*}
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ethyl 2,2-difluoro-7-oxo-4-(thiophen-3-ylethynyl)-7-(p-tolyl)heptanoate (3q)
2,2-difluoro-1-morpholino-7-phenyl-4-(phenylethynyl)heptane-1,7-dione (3s)
2,2-difluoro-N-(naphthalen-1-yl)-7-oxo-7-phenyl-4-(phenylethynyl)heptanamide (3u)