Ruthenium-Catalyzed C-H Amination of Aroylsilanes

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General Methods

Analytical thin layer chromatography (TLC) was performed using Merck 60 F254 precoated silica gel plate (0.2 mm thickness). Subsequent to elution, plates were visualized using UV radiation (254 nm) on Spectroline Model ENF-24061/F254 nm. Further visualization was possible by staining with basic solution of potassium permanganate or acidic solution of ceric molybdate. Flash column chromatography was performed using Merck aluminium oxide 90 active neutral with freshly distilled solvents. Columns were typically packed as slurry and equilibrated with the appropriate solvent system prior to use. Proton nuclear magnetic resonance spectra (1H NMR) were recorded on Bruker AMX400 and 500 MHz spectrophotometer (CDCl3 as solvent). Chemical shifts for 1H NMR spectra are reported as δ in units of parts per million (ppm) downfield from SiMe4 (δ 0.0) and relative to the signal of chloroform-d (δ 7.26, singlet). Multiplicities were given as: s (singlet), d (doublet), t (triplet), dd (doublets of doublet) or m (multiplets). The number of protons (n) for a given resonance is indicated by nH. Coupling constants are reported as a J value in Hz. Carbon nuclear magnetic resonance spectra (13C NMR) are reported as δ in units of parts per million (ppm) downfield from SiMe4 (δ 0.0) and relative to the signal of chloroform-d (δ 77.0, triplet). Mass spectrometry was performed by Waters Q-Tof Premier Micromass instrument, using Electro Spray Ionization (ESI) mode. IR spectra were recorded as thin films on KBr or NaCl plates on a Bio-Rad FTS 165 FTIR spectrometer and are reported in frequency of absorption (cm⁻¹). Other reagents, unless otherwise noted below, are commercially available from Alfa Aesar (China) Chemical Co., Ltd. and used without further purification. Acylsilanes were prepared by reported methods.¹²
General Procedure for Ru-Catalyzed C-H Amination

An oven-dried vial was charged with \([\text{Ru}(\mu\text{-cymene})\text{Cl}_2]_2\) (5 mol %, 0.005 mmol), \(\text{AgNTf}_2\) (20 mol %, 0.02 mmol), \(\text{Ag}_2\text{O}\) (50 mol %, 0.05 mmol), \(2\text{a}\) (0.2 mmol, 63.4 mg) and DCM (0.7 mL). Then, acylsilane \(1\) (0.1 mmol, 17.8 mg) was added into the solution. The vial was sealed under argon and heated to 90 °C with stirring for 18 hours. After cooling down, the mixture was directly applied to a flash column chromatography (ethyl acetate/petroleum ether mixtures) on silica gel to afford \(3\).

An oven-dried vial was charged with \([\text{Ru}(\mu\text{-cymene})\text{Cl}_2]_2\) (5 mol %, 0.005 mmol), \(\text{AgSbF}_6\) (40 mol %, 0.04 mmol), \(\text{Cu(OAc)}_2\text{·H}_2\text{O}\) (1.0 eq, 0.1 mmol), \(\text{NaOAc}\) (40 mol %, 0.04 mmol) and DCM (0.7 mL). Then, acylsilane \(1\) (0.1 mmol, 17.8 mg) and \(4\) (0.2 mmol, 39.4 mg) were added into the solution. The vial was sealed under argon and heated to 90 °C with stirring for 12 hours. After cooling down, the mixture was directly applied to a flash column chromatography (ethyl acetate/petroleum ether mixtures) on silica gel to afford \(5\).
Characterization Data

2-(2-((trimethylsilyl)carbonyl)phenyl)isoindoline-1,3-dione

Following the general experiment procedure, 3aa was obtained as a yellow solid (77%, 25.0 mg), m.p: 155.3 °C. $^1$H NMR (500 MHz, CDCl$_3$): δ = 11.53 (s, 1H), δ = 7.80 (dd, J = 7.5, 1.5 Hz, 1H), 7.70 (d, J = 8.5 Hz, 2H), 7.65 (dd, J = 8.5, 1.0 Hz, 1H), 7.41 (td, J = 10.5, 1.5 Hz, 2H), 7.21 (d, J = 8.0 Hz, 1H), 7.13 (td, J = 7.5, 1 Hz, 1H), 2.35 (s, 3H), 0.31 (s, 9H). $^{13}$C NMR (125 MHz, CDCl$_3$): δ = 240.21, 169.32, 141.48, 136.16, 133.96, 133.51, 131.86, 131.02, 130.34, 128.60, 125.58, 2.91. HR-MS (ESI): m/z calculated for C$_{20}$H$_{27}$NO$_3$Si: [M+H]$^+$: 324.1051, found: 324.1054. FTIR (KBr, cm$^{-1}$): 3384.70, 2945.79, 2828.04, 1647.66, 1534.23, 1403.74, 1028.83.

2-(5-methoxy-2-((trimethylsilyl)carbonyl)phenyl)isoindoline-1,3-dione

Following the general experiment procedure, 3ab was obtained as a yellow solid (60%, 21.2 mg), m.p: 137.9 °C. $^1$H NMR (500 MHz, CDCl$_3$): δ = 7.92 (dd, J = 5.0, 3.0 Hz, 2H), 7.84 (d, J = 8.5 Hz, 1H), 7.77 (dd, J = 5.5, 3.1 Hz, 2H), 7.06 (dd, J = 8.5, 2.5 Hz, 1H), 6.88 (d, J = 2.5 Hz, 1H), 3.89 (s, 3H), 0.31 (s, 9H). $^{13}$C NMR (125 MHz, CDCl$_3$): δ = 236.86, 169.10, 163.75, 135.81, 134.33, 133.83, 133.62, 130.62, 125.34, 118.07, 115.36, 57.32, 2.62. HR-MS (ESI): m/z calculated for C$_{19}$H$_{19}$NO$_4$Si: [M+H]$^+$: 354.1156, found:354.1156. FTIR (KBr, cm$^{-1}$): 3383.49, 2973.83, 2938.60, 2839.25, 1476.64, 1392.52, 1032.68, 1016.82.
2-(5-methyl-2-((trimethylsilyl)carbonyl)phenyl)isoindoline-1,3-dione

Following the general experiment procedure, 3ac was obtained as a yellow solid (62%, 21 mg), m.p: 133.2℃. $^1$H NMR (500 MHz, CDCl$_3$): $\delta$ = 7.92-7.89 (m, 2H), 7.78-7.74 (m, 2H), 7.71 (d, $J$ = 7.5 Hz, 1H), 7.36 (d, $J$ = 8.0 Hz, 1H), 7.18 (s, 1H), 2.45 (s, 3H), 0.31 (s, 9H). $^{13}$C NMR (125 MHz, CDCl$_3$): $\delta$ = 239.15, 169.38, 144.53, 138.47, 135.96, 133.95, 132.71, 131.85, 131.04, 128.58, 125.45, 23.23, 2.79. HR-MS (ESI): m/z calculated for C$_{19}$H$_{19}$NO$_3$Si: [M+H]$^+$: 338.1207, found: 338.121.

FTIR (KBr, cm$^{-1}$): 3731.69, 3627.12, 3383.79, 2922.90, 1734.58, 1557.44, 1403.00, 1026.47.

2-(5-ethyl-2-((trimethylsilyl)carbonyl)phenyl)isoindoline-1,3-dione

Following the general experiment procedure, 3ad was obtained as a yellow solid (70%, 24.5 mg), m.p: 155.0℃. $^1$H NMR (500 MHz, CDCl$_3$): $\delta$ = 7.92 - 7.89 (m, 2H), 7.78-7.73 (m, 3H), 7.39 (dd, $J$ = 8.0, 1.5 Hz, 1H), 7.20 (d, $J$ = 1Hz, 1H), 2.76 (q, $J$ = 7.5 Hz, 2H), 1.39 (t, $J$ = 7.5 Hz, 3H), 0.32 (s, 9H). $^{13}$C NMR (125 MHz, CDCl$_3$): $\delta$ = 239.11, 169.37, 150.54, 138.59, 135.94, 133.95, 131.56, 129.76, 128.64, 125.41, 30.39, 16.53, 2.77. HR-MS (ESI): m/z calculated for C$_{20}$H$_{21}$NO$_3$Si: [M+H]$^+$: 352.1363, found: 352.1364. FTIR (KBr, cm$^{-1}$): 3850.87, 3748.24, 3667.61, 3564.65, 2357.70, 1731.78, 1557.18, 1028.04.
2-(5-butyl-2-((trimethylsilyl)carbonyl)phenyl)isoindoline-1,3-dione

Following the general experiment procedure, 3ae was obtained as a yellow solid (65%, 23.8 mg), m.p: 165.4 °C. $^1$H NMR (500 MHz, CDCl$_3$): $\delta$ = 7.90 (dd, $J$ = 5.5, 3.0 Hz, 2H), 7.77-7.72 (m, 3H), 7.37 (dd, $J$ = 7.5, 1.5 Hz, 1H), 7.19 (d, $J$ = 1.5 Hz, 1H), 2.70 (t, $J$ = 7.0 Hz, 2H), 1.69-1.63 (ddd, $J$ = 9.5, 5.0, 2.0 Hz, 2H), 1.40 (dd, $J$ = 15.0, 7.5 Hz, 2H), 0.94 (t, $J$ = 7.5 Hz, 3H), 0.32 (s, 9H). $^{13}$C NMR (125 MHz, CDCl$_3$): $\delta$ = 239.10, 169.34, 149.37, 138.54, 135.93, 133.94, 132.00, 131.84, 130.25, 128.57, 125.39, 37.17, 34.68, 24.12, 15.64, 2.77. HR-MS (ESI): m/z calculated for C$_{22}$H$_{25}$F$_{3}$NO$_3$Si: [M+H]$^+$: 380.1676, found: 380.1673. FTIR (KBr, cm$^{-1}$): 3850.96, 3708.81, 3646.24, 3422.68, 2957.39, 1651.54, 1557.31, 1021.07.

2-(5-(tert-butyl)-2-((trimethylsilyl)carbonyl)phenyl)isoindoline-1,3-dione

Following the general experiment procedure, 3af was obtained as a yellow solid (80%, 30 mg), m.p: 196.0 °C. $^1$H NMR (500 MHz, CDCl$_3$): $\delta$ = 7.91 (dd, $J$ = 5.5, 3.0 Hz, 2H), 7.78- 7.75 (m, 3H), 7.57 (dd, $J$ = 8.0, 2.0 Hz, 1H), 7.35 (d, $J$ = 2.0 Hz, 1H), 1.37 (s, 9H), 0.32 (s, 9H). $^{13}$C NMR (125 MHz, CDCl$_3$) : $\delta$ = 238.97, 169.39, 157.48, 138.17, 135.89, 133.99, 131.80, 129.30, 128.45, 127.31, 125.38, 36.89, 32.77, 32.69, 2.75. HR-MS (ESI): m/z calculated for C$_{22}$H$_{25}$NO$_3$Si: [M+H]$^+$: 380.1676, found: 380.1673. FTIR (KBr, cm$^{-1}$): 3851.23, 3673.83, 3565.06, 3417.06, 2957.39, 1651.67, 1457.01, 1032.54.
2-(5-isopropyl-2-(((trimethylsilyl)carbonyl)phenyl)isoindoline-1,3-dione

Following the general experiment procedure, 3ag was obtained as a yellow solid (69%, 25 mg), m.p:143.8°C. \( ^1H \text{NMR} \) (500 MHz, CDCl\(_3\)): \( \delta = 7.91 \) (dd, \( J = 5.5, 3.0 \) Hz, 2H), 7.77-7.75 (m, 3H), 7.42 (dd, \( J = 8.0, 1.6 \) Hz, 1H), 7.22 (d, \( J = 1.5 \) Hz, 1H), 3.00 (dt, \( J = 14, 7.0 \) Hz, 1H), 1.31 (d, \( J = 6.9 \) Hz, 6H), 0.32 (s, 9H). \( ^{13}C \text{NMR} \) (125 MHz, CDCl\(_3\)): \( \delta = 239.01, 169.36, 155.10, 138.61, 135.91, 133.94, 132.02, 130.34, 128.65, 128.33, 125.39, 35.77, 25.29, 2.76. HR-MS (ESI): m/z calculated for C\(_{21}\)H\(_{23}\)NO\(_3\)Si: [M+H]\(^+\): 366.1520, found: 366.1522. FTIR (KBr, cm\(^{-1}\)): 3851.60, 3742.79, 3673.89, 3444.21, 1682.51, 1557.45, 1403.03, 1016.82.

2-(4-(((trimethylsilyl)carbonyl)-[1,1'-biphenyl]-3-yl)isoindoline-1,3-dione

Following the general experiment procedure, 3ah was obtained as a yellow solid (65%, 26 mg), m.p:159.0°C. \( ^1H \text{NMR} \) (500 MHz, CDCl\(_3\)): \( \delta = 7.93 \) (dd, \( J = 5.5, 3.0 \) Hz, 2H), 7.86 (d, \( J = 8.0 \) Hz, 1H), 7.79-7.76 (m, 3H), 7.65 -7.63 (m, 2H), 7.60 (d, \( J = 1.5 \) Hz, 1H), 7.47 (t, \( J = 7.5 \) Hz, 2H), 7.40 (t, \( J = 7.3 \) Hz, 1H), 0.36 (s, 9H). \( ^{13}C \text{NMR} \) (125 MHz, CDCl\(_3\)): \( \delta = 239.37, 169.28, 146.63, 140.83, 139.51, 136.07, 133.93, 131.99, 130.78, 130.72, 130.21, 129.16, 129.12, 128.75, 125.52, 2.80. HR-MS (ESI): m/z calculated for C\(_{24}\)H\(_{21}\)NO\(_3\)Si: [M+H]\(^+\): 400.1363, found: 400.1361. FTIR (KBr, cm\(^{-1}\)): 3868.36, 3742.97, 3471.24, 2359.32, 1681.31, 1557.66, 1398.11, 668.09.
2-(5-fluoro-2-((trimethylsilyl)carbonyl)phenyl)isoindoline-1,3-dione

Following the general experiment procedure, 3ai was obtained as a yellow solid (65%, 22.2 mg), m.p: 133.9°C. $^1$H NMR (500 MHz, CDCl$_3$): $\delta$ = 7.92 (q, $J$ = 3.0 Hz, 2H), 7.80 -7.75 (m, 3H), 7.26 -7.23 (m, 1H), 7.15 (dd, $J$ = 9.0, 2.5 Hz, 1H), 0.33 (s, 9H). $^{13}$C NMR (125 MHz, CDCl$_3$): $\delta$ = 238.54, 168.89, 165.47 (d, $J_{CF}$ = 252.6 Hz), 137.88 (d, $J_{CF}$ = 3.6 Hz), 136.34, 133.80, 133.02 (d, $J_{CF}$ = 9.7 Hz), 130.87 (d, $J_{CF}$ = 10.9 Hz), 125.74, 119.69 (d, $J_{CF}$ = 23.5 Hz), 117.23 (d, $J_{CF}$ = 21.1 Hz), 2.90. HR-MS (ESI): m/z calculated for C$_{18}$H$_{16}$NO$_3$Si: [M+H]$^+$: 342.0956, found: 342.0950. FTIR (KBr, cm$^{-1}$): 3667.90, 3564.88, 3472.93, 3383.78, 2358.15, 1731.78, 1684.11, 1403.01, 1028.04.

2-(5-chloro-2-((trimethylsilyl)carbonyl)phenyl)isoindoline-1,3-dione

Following the general experiment procedure, 3aj was obtained as a yellow solid (49%, 17.5 mg), m.p: 130.9°C. $^1$H NMR (500 MHz, CDCl$_3$): $\delta$ = 7.92 (dd, $J$ = 5.5, 3.0 Hz, 2H), 7.78 (dd, $J$ = 5.5, 3.5 Hz, 2H), 7.68 (d, $J$ = 8.5 Hz, 1H), 7.53 (dd, $J$ = 8.0, 2.0 Hz, 1H), 7.42 (d, $J$ = 2.0 Hz, 1H), 0.32 (s, 9H). $^{13}$C NMR (125 MHz, CDCl$_3$): $\delta$ = 239.11, 168.95, 139.82, 139.15, 136.41, 133.83, 132.21, 131.96, 130.51, 130.00, 125.79, 2.96. HR-MS (ESI): m/z calculated for C$_{18}$H$_{16}$ClNO$_3$Si: [M+H]$^+$: 358.0661, found: 358.0655. FTIR (KBr, cm$^{-1}$): 3851.10, 3742.44, 3646.24, 3184.11, 1651.56, 1557.28, 1504.96, 1402.83, 1036.45.
2-(5-bromo-2-((trimethylsilyl)carbonyl)phenyl)isoindoline-1,3-dione

Following the general experiment procedure, 3ak was obtained as a yellow solid (42%, 17 mg), m.p: 75.9°C. \(^1\)H NMR (500 MHz, CDCl\(_3\)): \(\delta = 7.91\) (dd, \(J = 5.0, 3.0\) Hz, 2H), 7.78 (dd, \(J = 5.5, 3.5\) Hz, 2H), 7.69 (dd, \(J = 8.0, 1.5\) Hz, 1H), 7.60 (d, \(J = 8.0\) Hz, 1H), 7.58 (d, \(J = 1.5\) Hz, 1H), 0.32 (s, 9H). \(^{13}\)C NMR (125 MHz, CDCl\(_3\)): \(\delta = 239.29, 168.95, 140.27, 136.43, 135.02, 133.83, 133.48, 132.01, 129.94, 127.20, 125.80, 2.96\). HR-MS (ESI): m/z calculated for C\(_{18}\)H\(_{16}\)BrNO\(_3\)Si: [M+H]\(^+\): 402.0156, found: 402.0150. FTIR (KBr, cm\(^{-1}\)): 3686.55, 3654.57, 3417.41, 3209.36, 2958.12, 1731.78, 1650.47, 1555.14, 1025.23, 500.24.

2-(5-(trifluoromethyl)-2-((trimethylsilyl)carbonyl)phenyl)isoindoline-1,3-dione

Following the general experiment procedure, 3al was obtained as a yellow solid (43%, 16.5 mg), m.p: 163.8°C. \(^1\)H NMR (500 MHz, CDCl\(_3\)): \(\delta = 7.92\) (dd, \(J = 5.5, 3.0\) Hz, 2H), 7.81 - 7.77 (m, 4H), 7.70 (s, 1H), 0.34 (s, 9H). \(^{13}\)C NMR (125 MHz, CDCl\(_3\)): \(\delta = 168.77, 144.55, 136.48, 135.0\) (d, \(J\(_{C,F} = 33.2\) Hz), 133.66, 130.31, 129.21, 128.68 (q, \(J\(_{C,F} = 3.7\) Hz), 127.06 (q, \(J\(_{C,F} = 3.7\) Hz), 125.78, 122.84 (q, \(J\(_{C,F} = 271.2\) Hz), 31.58, 2.90. HR-MS (ESI): m/z calculated for C\(_{19}\)H\(_{16}\)F\(_3\)NO\(_3\)Si: [M+H]\(^+\): 392.0924, found: 392.0921. FTIR (KBr, cm\(^{-1}\)): 3673.76, 3417.35, 3209.57, 2923.90, 1731.92, 1402.97, 1137.38, 854.21, 716.82.
2-(5-(trifluoromethoxy)-2-((trimethylsilyl)carbonyl)phenyl)isoindoline-1,3-dione

Following the general experiment procedure, 3am was obtained as a yellow solid (52%, 20.7 mg), m.p: 163.8 °C. $^1$H NMR (500 MHz, CDCl$_3$): $\delta$ = 7.92 (dd, $J$ = 5.5, 3.0 Hz, 2H), 7.80 - 7.76 (m, 3H), 7.39 (ddd, $J$ = 8.5, 2.5, 1.5 Hz, 1H), 7.29 (d, $J$ = 1.5 Hz, 1H), 0.34 (s, 9H). $^{13}$C NMR (125 MHz, CDCl$_3$): $\delta$ = 168.84, 152.53, 152.52, 139.79, 136.49, 133.79, 132.19, 130.56, 125.84, 124.15, 121.74, 2.97. HR-MS (ESI): m/z calculated for C$_{19}$H$_{16}$F$_3$NO$_4$Si: [M+H]$^+$: 408.0873, found: 408.0866. FTIR (KBr, cm$^{-1}$): 3851.39, 3673.79, 3564.97, 3417.87, 1737.38, 1455.50, 1398.00, 1028.04.

2-(2-((triethylsilyl)carbonyl)phenyl)isoindoline-1,3-dione

Following the general experiment procedure, 3an was obtained as a yellow solid (50%, 18.5 mg), m.p: 123.0 °C. $^1$H NMR (500 MHz, CDCl$_3$): $\delta$ = 7.91 (dd, $J$ = 5.5, 3.0 Hz, 2H), 7.79 - 7.75 (m, 3H), 7.62 - 7.55 (m, 2H), 7.37 (dd, $J$ = 7.5, 1.5 Hz, 1H), 0.97 (t, $J$ = 8.0 Hz, 9H), 0.88 - 0.83 (m, 6H). $^{13}$C NMR (125 MHz, CDCl$_3$): $\delta$ = 237.30, 166.71, 139.46, 133.42, 131.35, 130.94, 129.50, 128.58, 127.88, 125.85, 122.87, 6.48, 2.69. HR-MS (ESI): m/z calculated for C$_{21}$H$_{23}$NO$_3$Si: [M+H]$^+$: 366.1520, found: 366.1521. FTIR (KBr, cm$^{-1}$): 3667.53, 3626.59, 3585.11, 3564.58, 1682.33, 1633.72, 1402.94, 1028.04.
4-methyl-N-(2-((trimethylsilyl)carbonyl)phenyl)benzenesulfonamide

Following the general experiment procedure, 5aa was obtained as a yellow liquid (79%, 27 mg).

$^1$H NMR (500 MHz, CDCl$_3$): $\delta = 11.53$ (s, 1H), 7.80 (dd, $J = 7.5$, 1.54 Hz, 1H), 7.70 (d, $J = 8.5$ Hz, 2H), 7.65 (dd, $J = 8.0$, 0.5 Hz, 1H), 7.43-7.40 (m, 1H), 7.20 (d, $J = 8.0$ Hz, 2H), 7.13 (td, $J = 7.5$, 1.0 Hz, 1H), 2.35 (s, 3H), 0.31 (s, 9H).

$^{13}$C NMR (125 MHz, CDCl$_3$): $\delta = 241.44$, 145.23, 138.99, 138.12, 135.53, 135.36, 131.01, 128.68, 128.54, 124.08, 120.98, 22.93. HR-MS (ESI): m/z calculated for C$_{17}$H$_{21}$NO$_3$SSi: [M+H]$^+$: 348.1084, found: 348.1080.

FTIR (KBr, cm$^{-1}$): 3852.36, 3626.72, 3383.51, 1651.53, 1538.26, 1403.03, 1026.73, 963.73.

N-(5-methoxy-2-((trimethylsilyl)carbonyl)phenyl)-4-methylbenzenesulfonamide

Following the general experiment procedure, 5ab was obtained as a yellow liquid (65%, 25 mg).

$^1$H NMR (500 MHz, CDCl$_3$): $\delta = 12.10$ (s, 1H), 7.73 (dd, $J = 14.5$, 8.5 Hz, 3H), 7.23 (d, $J = 8.0$ Hz, 2H), 7.14 (d, $J = 2.5$ Hz, 1H), 6.58 (dd, $J = 9.0$, 2.5 Hz, 1H), 3.82 (s, 3H), 2.36 (s, 3H), 0.31 (s, 9H).

$^{13}$C NMR (125 MHz, CDCl$_3$): $\delta = 165.12$, 145.12, 142.00, 138.06, 137.51, 130.91, 128.62, 122.51, 110.01, 104.41, 56.92, 22.82, 2.34. HR-MS (ESI): m/z calculated for C$_{18}$H$_{23}$NO$_4$SSi: [M+H]$^+$: 378.1190, found: 378.1189.

FTIR (KBr, cm$^{-1}$): 3626.63, 3585.09, 3417.52, 2920.56, 1684.11, 1651.53, 1538.26, 1403.03, 1026.73, 963.73.

4-methyl-N-(5-methyl-2-((trimethylsilyl)carbonyl)phenyl)benzenesulfonamide

Following the general experiment procedure, 5ac was obtained as a yellow liquid (58%, 21 mg).

$^1$H NMR (500 MHz, CDCl$_3$): $\delta = 11.62$ (s, 1H), 7.61 (dd, $J = 20.0$, 7.0 Hz, 3H), 7.46 (s, 1H), 7.21
(d, J = 7.5 Hz, 2H), 6.92 (d, J = 8.0 Hz, 1H), 2.35 (d, J = 9.0 Hz, 6H), 0.30 (s, 9H). ^13^C NMR (125 MHz, CDCl\textsubscript{3}): δ = 240.17, 146.88, 145.06, 139.23, 138.25, 135.39, 130.93, 128.65, 126.53, 124.90, 121.20, 23.52, 22.89, 2.43. **HR-MS** (ESI): m/z calculated for C\textsubscript{18}H\textsubscript{23}NO\textsubscript{3}SSi: [M+H]^+: 362.1241, found: 362.1232. **FTIR** (KBr, cm\textsuperscript{-1}): 3851.29, 3742.57, 3646.43, 2358.46, 1651.56, 1455.31, 1028.04, 667.77.

![Image](5ad.png)

**N-(5-ethyl-2-((trimethylsilyl)carbonyl)phenyl)-4-methylbenzenesulfonamide**

Following the general experiment procedure, 5ad was obtained as a yellow liquid (60%, 23 mg).

^1^H NMR (500 MHz, CDCl\textsubscript{3}): δ = 11.64 (s, 1H), 7.71 (dd, J = 8.0, 2.5 Hz, 3H), 7.49 (d, J = 1.0 Hz, 1H), 7.20 (d, J = 8.5 Hz, 2H), 6.94 (dd, J = 8.0, 1.0 Hz, 1H), 2.63 (q, J = 7.5 Hz, 2H), 2.35 (s, 3H), 1.20 (t, J = 7.5 Hz, 3H), 0.30 (s, 9H). ^13^C NMR (125 MHz, CDCl\textsubscript{3}): δ = 240.15, 152.90, 145.05, 139.31, 138.18, 135.52, 130.87, 128.72, 126.62, 123.61, 120.00, 30.63, 22.87, 16.18, 2.41. **HR-MS** (ESI): m/z calculated for C\textsubscript{19}H\textsubscript{25}NO\textsubscript{3}SSi: [M+H]^+: 376.1397, found: 376.1393. **FTIR** (KBr, cm\textsuperscript{-1}): 3851.26, 3646.51, 3444.39, 2358.27, 1651.69, 1557.48, 1402.83, 1022.43.

![Image](5ae.png)

**N-(5-isopropyl-2-((trimethylsilyl)carbonyl)phenyl)-4-methylbenzenesulfonamide**

Following the general experiment procedure, 5ae was obtained as a yellow liquid (60%, 23 mg).

^1^H NMR (500 MHz, CDCl\textsubscript{3}): δ = 11.63 (s, 1H), 7.71 (dd, J = 8.0, 3.0 Hz, 3H), 7.51 (d, J = 1.5 Hz, 1H), 7.20 (d, J = 8.0 Hz, 2H), 6.94 (dd, J = 8.0, 1.5 Hz, 1H), 2.91-2.86 (m, 1H), 2.35 (s, 3H), 1.21 (d, J = 7.0 Hz, 6H), 0.30 (s, 9H). ^13^C NMR (125 MHz, CDCl\textsubscript{3}): δ = 240.15, 157.38, 145.08, 139.31, 138.06, 135.60, 130.84, 128.77, 126.64, 122.17, 118.61, 35.87, 24.71, 22.87, 2.41. **HR-MS** (ESI): m/z calculated for C\textsubscript{20}H\textsubscript{27}NO\textsubscript{3}SSi: [M+H]^+: 390.1550, found: 390.1544. **FTIR** (KBr, cm\textsuperscript{-1}): 3686.48, 3444.48, 3170.89, 1651.56, 1557.22, 1402.85, 1025.15, 449.20.
N-(5-(tert-butyl)-2-((trimethylsilyl)carbonyl)phenyl)-4-methylbenzenesulfonamide

Following the general experiment procedure, 5af was obtained as a yellow liquid (53%, 21 mg).

\(^1\text{H NMR}\) (500 MHz, CDCl\(_3\)): \(\delta = 11.62\) (s, 1H), 7.72 (dd, \(J = 8.5, 2.5\) Hz, 3H), 7.65 (d, \(J = 2.0\) Hz, 1H), 7.21 (d, \(J = 8.0\) Hz, 2H), 7.11 (dd, \(J = 8.5, 1.5\) Hz, 1H), 2.35 (s, 3H), 1.28 (s, 9H), 0.31 (s, 9H). \(^{13}\text{C NMR}\) (125 MHz, CDCl\(_3\)): \(\delta = 240.10, 159.59, 145.06, 139.07, 138.17, 135.25, 130.84, 128.86, 126.19, 120.94, 117.81, 36.88, 32.18, 22.86, 2.41. \(\text{HR-MS}\) (ESI): m/z calculated for C\(_{21}\)H\(_{29}\)NO\(_3\)SSi: [M+H\(^+\)]: 404.1710, found: 404.1702. \(\text{FTIR}\) (KBr, cm\(^{-1}\)): 3851.09, 3417.32, 3209.05, 2957.01, 1651.51, 1557.22, 1402.95, 1028.04.

N-(5-butyl-2-((trimethylsilyl)carbonyl)phenyl)-4-methylbenzenesulfonamide

Following the general experiment procedure, 5ag was obtained as a yellow liquid (62%, 25 mg).

\(^1\text{H NMR}\) (500 MHz, CDCl\(_3\)): \(\delta = 11.63\) (s, 1H), 7.71-7.67 (m, 3H), 7.46 (d, \(J = 1.0\) Hz, 1H), 7.20 (d, \(J = 8.0\) Hz, 2H), 6.91 (dd, \(J = 8.0, 1.5\) Hz, 1H), 2.59 (t, \(J = 7.5\) Hz, 2H), 2.35 (s, 3H), 1.58-1.52 (m, 2H), 1.30-1.26 (m, 4H), 0.91 (t, \(J = 7.5\) Hz, 3H), 0.30 (s, 9H). \(^{13}\text{C NMR}\) (125 MHz, CDCl\(_3\)): \(\delta = 240.14, 151.66, 145.02, 139.20, 138.13, 135.42, 130.85, 128.73, 126.60, 124.19, 120.53, 37.32, 34.18, 23.54, 22.85, 15.26, 2.40. \(\text{HR-MS}\) (ESI): m/z calculated for C\(_{21}\)H\(_{29}\)NO\(_3\)SSi: [M+H\(^+\)]: 404.1710, found: 404.1713. \(\text{FTIR}\) (KBr, cm\(^{-1}\)): 3850.83, 3673.41, 3606.00, 3444.07, 1684.11, 1557.15, 1402.95, 1171.03, 1028.04.

4-methyl-N-(4-((trimethylsilyl)carbonyl)-[1,1'-biphenyl]-3-yl)benzenesulfonamide
Following the general experiment procedure, **5ah** was obtained as a yellow liquid (60%, 25 mg).

$\text{H NMR (500 MHz, CDCl}_3\): } \delta = 11.65 \text{ (s, 1H), 7.91 (d, } J = 1.5 \text{ Hz, 1H), 7.85 (d, } J = 8.0 \text{ Hz, 1H), 7.74 (d, } J = 8.0 \text{ Hz, 2H), 7.58-7.56 \text{ (m, 2H), 7.48-7.41 \text{ (m, 3H), 7.34 (dd, } J = 8.0, 1.5 \text{ Hz, 1H), 7.21 (d, } J = 8.0 \text{ Hz, 2H), 2.35 \text{ (s, 3H), 0.33 (s, 9H). C NMR (125 MHz, CDCl}_3\): } \delta = 240.56, 148.01, 145.20, 140.58, 139.61, 138.21, 135.78, 131.00, 130.43, 130.16, 128.73, 128.69, 127.17, 122.53, 119.24, 22.89, 2.42. HR-MS (ESI): m/z calculated for C$_{23}$H$_{25}$NO$_3$SSi: [M+H]$^+$: 424.1397, found: 424.1395. FTIR (KBr, cm$^{-1}$): 3626.65, 3585.10, 1737.38, 1684.11, 1651.44, 1504.91, 1402.95, 1028.04.

![Chemical Structure of 5ai](image1)

**N-(5-fluoro-2-((trimethylsilyl)carbonyl)phenyl)-4-methylbenzenesulfonamide**

Following the general experiment procedure, **5ai** was obtained as a yellow liquid (64%, 24 mg).

$\text{H NMR (500 MHz, CDCl}_3\): } \delta = 11.96 \text{ (s, 1H), 7.82 (dd, } J = 8.5, 6.0 \text{ Hz, 1H), 7.76 (d, } J = 8.0 \text{ Hz, 2H), 7.37 (dd, } J = 11.0, 2.0 \text{ Hz, 1H), 7.26 (d, } J = 8.5 \text{ Hz, 2H), 6.77 (ddd, } J = 8.5, 8.0, 2.5 \text{ Hz, 1H), 2.38 (s, 3H), 0.33 (s, 9H). C NMR (125 MHz, CDCl}_3\): } \delta = 239.44, 167.89, 165.85, 145.57, 142.25 (d, $J_{C-F} = 12.5 \text{ Hz}), 137.95, 131.19, 128.72, 124.93 (d, $J_{C-F} = 2.5 \text{ Hz), 110.97 (d, } J_{C-F} = 22.4 \text{ Hz), 107.34 (d, } J_{C-F} = 26.8 \text{ Hz), 22.96, 2.45. HR-MS (ESI): m/z calculated for C$_{17}$H$_{20}$FNO$_3$SSi: [M+H]$^+$: 366.0990, found: 366.0992. FTIR (KBr, cm$^{-1}$): 3867.95, 3731.10, 3686.54, 2358.07, 1682.41, 1557.32, 1402.90, 1025.85.

![Chemical Structure of 5aj](image2)

**(2-amino-4-chlorophenyl)(trimethylsilyl)methanone**

Following the general experiment procedure, **5aj** was obtained as a yellow liquid (73%, 28 mg).

$\text{H NMR (500 MHz, CDCl}_3\): } \delta = 11.71 \text{ (s, 1H), 7.73 (t, } J = 8.0 \text{ Hz, 3H), 7.68 (d, } J = 2.0 \text{ Hz, 1H), 7.25 (d, } J = 8.0 \text{ Hz, 2H), 7.07 (dd, } J = 8.5, 2.0 \text{ Hz, 1H), 2.38 (s, 3H), 0.31 (s, 9H). C NMR (125 MHz, CDCl}_3\): } \delta = 240.56, 148.01, 145.20, 140.58, 139.61, 138.21, 135.78, 131.00, 130.43, 130.16, 128.73, 128.69, 127.17, 122.53, 119.24, 22.89, 2.42. HR-MS (ESI): m/z calculated for C$_{17}$H$_{20}$FNO$_3$SSi: [M+H]$^+$: 366.0990, found: 366.0992. FTIR (KBr, cm$^{-1}$): 3867.95, 3731.10, 3686.54, 2358.07, 1682.41, 1557.32, 1402.90, 1025.85.
MHz, CDCl\textsubscript{3}): \delta = 240.36, 145.64, 141.92, 140.49, 137.89, 136.47, 131.24, 128.75, 126.44, 124.16, 120.50, 23.02, 2.52. HR-MS (ESI): m/z calculated for C\textsubscript{17}H\textsubscript{20}ClNO\textsubscript{3}SSi: [M+H]\textsuperscript{+}: 382.0694, found: 382.0690. FTIR (KBr, cm\textsuperscript{-1}): 3813.78, 3673.59, 3417.25, 2957.01, 1651.54, 1557.26, 1402.91, 1022.43.

\[
\begin{array}{c}
\text{Br} \\
\text{TMS} \\
\text{NHTs} \\
(5ak)
\end{array}
\]

**N-(5-bromo-2-((trimethylsilyl)carbonyl)phenyl)-4-methylbenzenesulfonamide**

Following the general experiment procedure, *5ak* was obtained as a yellow liquid (65\%, 28 mg).

\textit{\textsuperscript{1}H NMR} (500 MHz, CDCl\textsubscript{3}): \delta = 11.64 (s, 1H), 7.85 (d, \textit{J} = 2.0 Hz, 1H), 7.73 (d, \textit{J} = 8.5 Hz, 2H), 7.63 (d, \textit{J} = 8.5 Hz, 1H), 7.24 (td, \textit{J} = 8.0, 1.5 Hz, 3H), 2.38 (s, 3H), 0.31 (s, 9H). \textit{\textsuperscript{13}C NMR} (125 MHz, CDCl\textsubscript{3}): \delta = 240.60, 145.63, 140.32, 137.93, 136.41, 131.24, 130.62, 128.78, 127.15, 126.79, 123.60, 23.03, 2.52. HR-MS (ESI): m/z calculated for C\textsubscript{17}H\textsubscript{20}BrNO\textsubscript{3}SSi: [M+H]\textsuperscript{+}: 426.0189, found: 426.0185. FTIR (KBr, cm\textsuperscript{-1}): 3852.36, 3627.65, 2358.90, 1682.44, 1651.59, 1505.11, 1455.34, 1393.47.

\[
\begin{array}{c}
\text{F}_3\text{C} \\
\text{TMS} \\
\text{NHTs} \\
(5ai)
\end{array}
\]

**4-methyl-N-(5-(trifluoromethyl)-2-((trimethylsilyl)carbonyl)phenyl)benzenesulfonamide**

Following the general experiment procedure, *5ai* was obtained as a yellow liquid (72\%, 29 mg).

\textit{\textsuperscript{1}H NMR} (500 MHz, CDCl\textsubscript{3}): \delta = 11.50 (s, 1H), 7.96 (d, \textit{J} = 1.0 Hz, 1H), 7.92 (d, \textit{J} = 8.0 Hz, 1H), 7.73 (d, \textit{J} = 8.0 Hz, 2H), 7.36 (dd, \textit{J} = 8.5, 1.5 Hz, 1H), 7.24 (d, \textit{J} = 8.0 Hz, 2H), 2.37 (s, 3H), 0.33 (s, 9H). \textit{\textsuperscript{13}C NMR} (125 MHz, CDCl\textsubscript{3}): \delta = 241.80, 145.89, 139.63, 137.84, 136.61 (q, \textit{J}_{\text{C-F}} = 32.9 Hz), 135.72, 151.36, 128.92, 124.60 (q, \textit{J}_{\text{C-F}} = 271.4 Hz), 120.52 (q, \textit{J}_{\text{C-F}} = 3.7 Hz), 117.99 (q, \textit{J}_{\text{C-F}} = 3.9 Hz), 23.10, 2.61. HR-MS (ESI): m/z calculated for C\textsubscript{18}H\textsubscript{20}F\textsubscript{3}NO\textsubscript{3}SSi: [M+H]\textsuperscript{+}: 416.0958, found: 416.0955. FTIR (KBr, cm\textsuperscript{-1}): 3851.56, 3627.65, 3555.22, 3384.07, 1682.44, 1651.59, 1505.11, 1455.34, 1393.47.
N-(4-fluoro-2-(((trimethylsilyl)carbonyl)phenyl)-4-methylbenzenesulfonamide

Following the general experiment procedure, 5am was obtained as a yellow liquid (75%, 27 mg).

\[ ^1H \text{ NMR} \ (500 \text{ MHz, CDCl}_3): \delta = 10.11 \ (s, 1H), 7.67 \ (d, J = 8.0 \text{ Hz, 2H}), 7.55-7.52 \ (m, 1H), 7.26-7.22 \ (m, 4H), 2.39 \ (s, 3H), 0.27 \ (s, 9H). \]

\[ ^{13}C \text{ NMR} \ (125 \text{ MHz, CDCl}_3): \delta = 241.04, 158.05 \ (d, J_{C-F} = 252.9 \text{ Hz}), 145.24, 138.76 \ (d, J_{C-F} = 1.8 \text{ Hz}), 135.26, 130.97, 129.48 \ (d, J_{C-F} = 3.2 \text{ Hz}), 129.04 \ (d, J_{C-F} = 0.88 \text{ Hz}), 127.25 \ (d, J_{C-F} = 7.6 \text{ Hz}), 126.27 \ (d, J_{C-F} = 12.1 \text{ Hz}), 122.58 \ (d, J_{C-F} = 20.9 \text{ Hz}), 23.20, 2.70. \]

HR-MS (ESI): m/z calculated for C_{17}H_{20}FNO_3SSi: [M+H]^+: 366.0990, found: 366.0993.

FTIR (KBr, cm^{-1}): 3853.37, 3675.46, 3422.43, 2360.84, 1560.75, 1454.21, 1397.85, 1025.23.

4-methyl-N-(5-(trifluoromethoxy)-2-(((trimethylsilyl)carbonyl)phenyl)benzenesulfonamide

Following the general experiment procedure, 5an was obtained as a yellow liquid (62%, 27 mg).

\[ ^1H \text{ NMR} \ (500 \text{ MHz, CDCl}_3): \delta = 11.81 \ (s, 1H), 7.84 \ (d, J = 8.5 \text{ Hz, 1H}), 7.76-7.74 \ (m, 2H), 7.53 \ (d, J = 1.5 \text{ Hz, 1H}), 7.25 \ (d, J = 8.0 \text{ Hz, 2H}), 6.92-6.89 \ (m, 1H), 2.37 \ (s, 3H), 0.33 \ (s, 9H). \]

\[ ^{13}C \text{ NMR} \ (125 \text{ MHz, CDCl}_3): \delta = 240.08, 154.14 \ (d, J_{C-F} = 1.5 \text{ Hz}), 145.74, 141.55, 137.78, 137.32, 131.23, 128.84, 125.99, 121.67 \ (q, J_{C-F} = 258.3 \text{ Hz}), 114.79, 111.68, 23.01, 2.51. \]

HR-MS (ESI): m/z calculated for C_{18}H_{20}F_3NO_4SSi: [M+H]^+: 432.0907, found: 432.0903.

FTIR (KBr, cm^{-1}): 3851.17, 3585.34, 3195.50, 1651.55, 1557.26, 1455.23, 1402.95, 1032.09.

4-methyl-N-(5-(methylthio)-2-(((trimethylsilyl)carbonyl)phenyl)benzenesulfonamide

Following the general experiment procedure, 5ao was obtained as a yellow liquid (36%, 14 mg).
\textbf{1H NMR} (500 MHz, CDCl\textsubscript{3}): $\delta = 11.86$ (s, 1H), 7.73 ($d$, $J = 8.5$ Hz, 2H), 7.65 ($d$, $J = 8.5$ Hz, 1H), 7.42 ($d$, $J = 1.5$ Hz, 1H), 7.23 ($d$, $J = 8.5$ Hz, 2H), 6.89 ($dd$, $J = 8.5$, 2.0 Hz, 1H), 2.47 (s, 3H), 2.37 (s, 3H), 0.30 (s, 9H). \textbf{13C NMR} (125 MHz, CDCl\textsubscript{3}): $\delta = 239.06$, 149.46, 145.26, 139.78, 138.10, 135.29, 131.00, 128.70, 124.86, 120.28, 115.32, 22.90, 15.91, 2.40. \textbf{HR-MS} (ESI): m/z calculated for C\textsubscript{18}H\textsubscript{23}NO\textsubscript{3}S\textsubscript{2}Si: [M+H]$^+$: 394.0961, found: 394.0954. \textbf{FTIR} (KBr, cm$^{-1}$): 3731.00, 3646.31, 3417.26, 2358.30, 1651.58, 1557.32, 1455.31, 1027.42.

![4-methyl-N-(5-(methylsulfonyl)-2-((trimethylsilyl)carbonyl)phenyl)benzenesulfonamide](image)

\textbf{4-methyl-N-(5-(methylsulfonyl)-2-((trimethylsilyl)carbonyl)phenyl)benzenesulfonamide}

Following the general experiment procedure, \textbf{5ap} was obtained as a yellow liquid (60%, 29 mg).

\textbf{1H NMR} (500 MHz, CDCl\textsubscript{3}): $\delta = 11.55$ (s, 1H), 8.21 ($d$, $J = 2.0$ Hz, 1H), 8.00 ($d$, $J = 8.0$ Hz, 1H), 7.78 ($d$, $J = 8.5$ Hz, 2H), 7.66 ($dd$, $J = 8.0$, 1.5 Hz, 1H), 7.28-7.26 (m, 2H), 3.07 (s, 3H), 2.37 (s, 3H), 0.35 (s, 9H). \textbf{13C NMR} (125 MHz, CDCl\textsubscript{3}): $\delta = 242.02$, 146.26, 140.02, 137.51, 136.19, 131.50, 129.96, 129.07, 128.03, 121.84, 119.32, 45.59, 23.14, 2.60. \textbf{HR-MS} (ESI): m/z calculated for C\textsubscript{18}H\textsubscript{23}NO\textsubscript{5}S\textsubscript{2}Si: [M+H]$^+$: 426.0860, found: 426.0857. \textbf{FTIR} (KBr, cm$^{-1}$): 3718.51, 3686.30, 3585.10, 1682.36, 1651.50, 1455.23, 1402.97, 1030.84.

![4-methyl-N-(2-((triethylsilyl)carbonyl)phenyl)benzenesulfonamide](image)

\textbf{4-methyl-N-(2-((triethylsilyl)carbonyl)phenyl)benzenesulfonamide}

Following the general experiment procedure, \textbf{5aq} was obtained as a yellow liquid (60%, 23.5 mg).

\textbf{1H NMR} (500 MHz, CDCl\textsubscript{3}): $\delta = 11.58$ (s, 1H), 7.78 ($dd$, $J = 8.0$, 1.5 Hz, 1H), 7.68 ($dd$, $J = 8.0$, 1.5 Hz, 3H), 7.43-7.40 (m, 1H), 7.18 ($d$, $J = 8.0$ Hz, 2H), 7.13 ($td$, $J = 7.5$, 1.0 Hz, 1H), 2.33 (s, 3H), 0.93-0.90 (m, 9H), 0.85-0.80 (m, 6H). \textbf{13C NMR} (125 MHz, CDCl\textsubscript{3}): $\delta = 239.25$, 142.70, 136.25, 135.70, 133.03, 132.61, 128.53, 127.03, 126.15, 121.75, 118.57, 20.44, 6.31, 2.87.
HR-MS (ESI): m/z calculated for C_{20}H_{27}NO_{3}S_{2}Si: [M+H]+: 390.1554, found: 390.1553. FTIR (KBr, cm⁻¹): 3384.70, 2945.79, 2828.04, 1647.66, 1403.74, 1028.83.

Deuterium-Labeled Experiments

An oven-dried vial was charged with [Ru(ρ-cymene)Cl₂]₂ (5 mol %, 0.005 mmol, 3.1 mg), AgNTf₂ (20 mol %, 0.02 mmol, 15.6 mg), Ag₂O (50 mol %, 0.05 mmol, 23.2 mg), 1a (0.1 mmol, 17.8 mg) and DCM (0.7 mL). Then, D₂O (10.0 eq, 1.0 mmol, 20.3 mg) was added into the solution. The vial was sealed under argon and heated to 90 °C with stirring for 6 hours. After cooling down, the mixture was directly applied to a flash column chromatography (ethyl acetate/petroleum ether mixtures), providing deuterium labeled 1a-d as a yellow oil (10 mg, 56% recovered). The D% was estimated by ^1H NMR.
An oven-dried vial was charged with [Ru(p-cymene)Cl2]2 (5 mol %, 0.005 mmol, 3.1 mg), AgSbF6 (40 mol %, 0.04 mmol, 13.6 mg), Cu(OAc)2•H2O (1.0 eq, 0.1 mmol, 20.0 mg), NaOAc (40 mol %, 0.04 mmol, 3.3 mg), 1a (0.1 mmol, 17.8 mg) and DCM (0.7 mL). Then, D2O (10.0 eq, 1.0 mmol, 20.3 mg) was added into the solution. The vial was sealed under argon and heated to 90 °C with stirring for 6 hours. After cooling down, the mixture was directly applied to a flash column chromatography (ethyl acetate/petroleum ether mixtures), providing deuterium labeled 1a-d as a yellow oil (12 mg, 68% recovered). The D% of 1a-d was estimated by 1H NMR.
An oven-dried vial was charged with $[\text{Ru}(p\text{-cymene})\text{Cl}_2]_2$ (5 mol %, 0.005 mmol, 3.1 mg), AgNTf$_2$ (20 mol %, 0.02 mmol, 15.6 mg), Ag$_2$O (50 mol %, 0.05 mmol, 23.2 mg), 1a (0.1 mmol, 17.8 mg), 2a (0.2 mmol, 63.4 mg) and DCM (0.7 mL). Then, D$_2$O (10.0 eq, 1.0 mmol, 20.3 mg) was added into the solution. The vial was sealed under argon and heated to 90 °C with stirring for 12 hours. After cooling down, the mixture was directly applied to a flash column chromatography (ethyl acetate/petroleum ether mixtures) on silica gel to afford 3aa (9.0 mg, 28% yield) and 1a-d (4.3 mg, 24% recovered). The D% of 1a-d and 3aa were estimated by $^1$H NMR.
An oven-dried vial was charged with \([\text{Ru}(\rho\text{-cymene})\text{Cl}_2]\) (5 mol %, 0.005 mmol, 3.1 mg), AgSbF$_6$ (40 mol %, 0.04 mmol, 13.6 mg), Cu(OAc)$_2$•H$_2$O (1.0 eq, 0.1 mmol, 20.0 mg), NaOAc (40 mol %, 0.04 mmol, 3.3 mg), 1a (0.1 mmol, 17.8 mg), 4a (0.2 mmol, 39.4 mg) and DCM (0.7 mL). Then, D$_2$O (10.0 eq, 1.0 mmol, 20.3 mg) was added into the solution. The vial was sealed under argon and heated to 90 °C with stirring for 12 hours. After cooling down, the mixture was directly applied to a flash column chromatography (ethyl acetate/petroleum ether mixtures) on silica gel to afford 5aa-d (11.6 mg, 33% yield) and 1a-d (7.3 mg, 41% recovered). The D% of 1a-d and 5aa-d were estimated by $^1$H NMR.
Deuterium Experiments

An oven-dried vial was charged with \([\text{Ru}(\mu\text{-cymene})\text{Cl}_2]_2\) (5 mol %, 0.005 mmol, 3.1 mg), AgNTf₂ (20 mol %, 0.02 mmol, 15.6 mg), Ag₂O (50 mol %, 0.05 mmol, 23.2 mg), 2a (0.3 mmol, 95.2 mg) and DCM (0.7 mL). Then, 1a (0.1 mmol, 17.8 mg) and 1a-d₅ (0.1 mmol, 18.3 mg) were added into the solution. The vial was sealed under argon and heated to 90 ℃ with stirring for 30 min. After cooling down, the mixture was directly applied to column chromatography for separation. The ratio of 3aa/3aa-d₄ (17.5 mg, 27% yield) was determined by ¹H NMR to be 2.0.

Competitive KIE Experiments

An oven-dried vial was charged with \([\text{Ru}(\mu\text{-cymene})\text{Cl}_2]_2\) (5 mol %, 0.005 mmol, 3.1 mg), AgNTf₂ (20 mol %, 0.02 mmol, 15.6 mg), Ag₂O (50 mol %, 0.05 mmol, 23.2 mg), 2a (0.3 mmol, 95.2 mg) and DCM (0.7 mL). Then, 1a (0.1 mmol, 17.8 mg) and 1a-d₅ (0.1 mmol, 18.3 mg) were added into the solution. The vial was sealed under argon and heated to 90 ℃ with stirring for 30 min. After cooling down, the mixture was directly applied to column chromatography for separation. The ratio of 3aa/3aa-d₄ (17.5 mg, 27% yield) was determined by ¹H NMR to be 2.0.
Parallel KIE Experiments

Parallel independent reactions of 1a or 1a-\(d_5\) with 2a were performed to determine the corresponding KIE value. Each 10 mL vial was charged with [Ru(p-cymene)Cl\(_2\)]\(_2\) (5 mol %, 0.005 mmol, 3.1 mg), AgNTf\(_2\) (20 mol %, 0.02 mmol, 15.6 mg), Ag\(_2\)O (50 mol %, 0.05 mmol, 23.2 mg), 2a (0.2 mmol, 63.4 mg) and DCM (0.7 mL). Then, 1a (0.1 mmol, 17.8 mg) and 1a-\(d_5\) (0.1 mmol, 18.3 mg) were added into the solution in sequence. The vials were sealed under Ar and heated to 90°C with stirring for 2, 4, 6, 8 or 10 minutes. After cooling down, the mixture was concentrated in vacuo and purified by column chromatography to determine the product yields. A KIE value was determined to be 2.30.

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Competitive KIE Experiments

An oven-dried vial was charged with [Ru(μ-cymene)Cl2]2 (5 mol %, 0.005 mmol, 3.1 mg), AgSbF6 (40 mol %, 0.04 mmol, 13.6 mg), Cu(OAc)2•H2O (1.0 eq, 0.1 mmol, 20.0 mg), NaOAc (40 mol %, 0.04 mmol, 3.3 mg) and DCM (0.7 mL). Then, 1a (0.1 mmol, 17.8 mg), 1a–d5 (0.1 mmol, 18.3 mg) and 4a (0.4 mmol, 79.0 mg) were added into the solution. The vial was sealed under argon and heated to 90 °C with stirring for 30 min. After cooling down, the mixture was directly applied to column chromatography for separation. The ratio of 5aa/5aa–d4 (34.5 mg, 50% yield) was determined by 1H NMR to be 2.6.

![Diagram showing competitive KIE Experiments](image-url)
Parallel KIE Experiments

Parallel independent reactions of 1a or 1a-d$_5$ with 4a were performed to determine the corresponding KIE value. Each 10 mL vial was charged with [Ru(p-cymene)Cl$_2$]$_2$ (5 mol %, 0.005 mmol, 3.1 mg), AgSbF$_6$ (40 mol %, 0.04 mmol, 13.6 mg), Cu(OAc)$_2$•H$_2$O (1.0 eq, 0.1 mmol, 20.0 mg), NaOAc (40 mol %, 0.04 mmol, 3.3 mg) and DCM (0.7 mL). Then, 1a (0.1 mmol, 17.8 mg), 1a-d$_5$ (0.1 mmol, 18.3 mg) and 4a (0.2 mmol, 39.4 mg) were added into the solution. The vials were sealed under Ar and heated to 90°C with stirring for 1.5, 2, 2.5 or 3.0 minutes. After cooling down, the mixture was concentrated in vacuo and purified by column chromatography to determine the product yields. A KIE value was determined to be 1.0.

<table>
<thead>
<tr>
<th>yield</th>
<th>1.5</th>
<th>2</th>
<th>2.5</th>
<th>3</th>
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<tr>
<td>ba</td>
<td>16%</td>
<td>21%</td>
<td>31.5%</td>
<td>37%</td>
</tr>
<tr>
<td>ba-d$_2$</td>
<td>10.3%</td>
<td>15.3%</td>
<td>22.6%</td>
<td>31.7%</td>
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</table>

![Graph](attachment:image.png)
Competitive Reaction

An oven-dried vial was charged with $[\text{Ru}(\rho\text{-cymene})\text{Cl}_2]_2$ (5 mol%, 0.005 mmol, 3.1 mg), AgNTf$_2$ (20 mol%, 0.02 mmol, 15.6 mg), Ag$_2$O (50 mol%, 0.05 mmol, 23.2 mg), 2a (0.2 mmol, 63.4 mg) and DCM (0.7 mL). Then, 1x (0.1 mmol, 20.8 mg) and 1y (0.1 mmol, 23.4 mg) were added into the solution. The vial was sealed under argon and heated to 90 °C with stirring for 12 hours. After cooling down, the mixture was concentrated in vacuo and purified by column chromatography to afford the product 3xa (26 mg, 37%).

An oven-dried vial was charged with $[\text{Ru}(\rho\text{-cymene})\text{Cl}_2]_2$ (5 mol %, 0.005 mmol, 3.1 mg), AgSbF$_6$ (40 mol %, 0.04 mmol, 13.6 mg), Cu(OAc)$_2$•H$_2$O (1.0 eq, 0.1 mmol, 20.0 mg), NaOAc (40 mol%, 0.04 mmol, 3.3 mg) and DCM (0.7 mL). Then, 1x (0.1 mmol, 17.8 mg), 1y (0.2 mmol, 39.4 mg) and 4a was added into the solution. The vial was sealed under argon and heated to 90 °C with stirring for 12 hours. After cooling down, the mixture was concentrated in vacuo and purified by column chromatography to afford the product 5ax (27 mg, 35%).
A suspension of 3aa (32.3 mg, 0.1 mmol) and hydrazine (5.0 eq), was stirred at ambient temperature for 4 h. At ambient temperature, the reaction mixture was diluted with CH$_2$Cl$_2$ and passed through celite with CH$_2$Cl$_2$. The organic layer was dried over Na$_2$SO$_4$. After evaporation of the solvent in vacuo, the crude product was purified by column chromatography on silica gel to yield 6 (10.0 mg, 52 %) as a yellow solid. $^1$H NMR (500 MHz, CDCl$_3$): $\delta$ = 7.06 (td, $J$ = 8.0, 1.5 Hz, 1H), 6.77 (dd, $J$ = 7.5, 1.5 Hz, 1H), 6.71 (t, $J$ = 7.4 Hz, 1H), 6.65 (d, $J$ = 8.0 Hz, 1H), 5.68 (s, 2H), 0.08 (s, 9H). $^{13}$C NMR (125 MHz, CDCl$_3$): $\delta$ = 160.80, 144.61, 130.93, 129.73, 123.10, 120.45, 117.57, 2.93. HR-MS (ESI): m/z calculated for C$_{10}$H$_{15}$NOSi: [M+H]$^+$: 194.0996, found: 194.0994. FTIR (KBr, cm$^{-1}$): 3851.10, 3646.24, 1651.56, 1557.20, 1504.96, 1404.83.

To a stirred mixture of 3aa (0.2 mmol, 64.7 mg) and azide (0.36 mmol, 46.5 mg) in CH$_2$Cl$_2$ (1 mL) was slowly added TfOH (2.0 equiv, 0.4 mmol). The reaction mixture was kept for 30 min at room temperature, then it was quenched with aqueous KOH (10%, 5 mL), extracted with CH$_2$Cl$_2$ (15 mL*3), washed with brine (15 mL), dried over Mg$_2$SO$_4$ and concentrated. The residue was purified by flash chromatography (MeOH/DCM mixture) to give 7 as a white sticky liquid (56.3 mg, 80% yield). $^1$H NMR (500 MHz, CDCl$_3$): $\delta$ = 7.95 – 7.89 (m, 2H), 7.79 – 7.74 (m, 2H), 7.74 – 7.71 (m, 1H), 7.64 – 7.59 (m, 1H), 7.54 – 7.48 (m, 1H), 7.43 – 7.36 (m, 1H), 6.67 (t, $J$ = 5.1 Hz, 1H), 4.16 (q, $J$ = 7.1 Hz, 2H), 4.05 (d, $J$ = 5.1 Hz, 2H), 1.24 (t, $J$ = 7.1 Hz, 3H). $^{13}$C NMR (125 MHz, CDCl$_3$) $\delta$ = 168.53, 166.48, 165.80, 133.26, 132.42, 131.07, 130.59, 129.03, 128.15, 127.29, 122.82, 60.53, 40.82, 13.08. HR-MS (ESI): m/z calculated for C$_{19}$H$_{16}$N$_2$O$_5$: [M+H]$^+$: 353.1132, found: 353.1130. FTIR (KBr, cm$^{-1}$): 3415.24, 3233.65, 1714.95, 1636.92, 1616.43, 1381.31, 1196.26, 619.44.
To a stirred mixture of 5aa (0.2 mmol, 69.5 mg) and azide (0.36 mmol, 46.5 mg) in CH₂Cl₂ (1 mL) was slowly added TfOH (2.0 equiv, 0.4 mmol). The reaction mixture was kept for 30 min at room temperature, then it was quenched with aqueous KOH (10%, 5 mL), extracted with CH₂Cl₂ (15 mL*3), washed with brine (15 mL), dried over MgSO₄ and concentrated. The residue was purified by flash chromatography (MeOH/DCM mixture) to give 8 as a light yellow solid (52.6 mg, 70% yield), m.p: 128.2 °C. ¹H NMR (500 MHz, CDCl₃): δ = 10.69 (s, 1H), 7.68 – 7.63 (m, 3H), 7.45 – 7.44 (m, 1H), 7.39 – 7.35 (m, 1H), 7.18 (d, J = 8.1 Hz, 2H), 7.05 – 7.00 (m, 1H), 6.74 (t, J = 5.1 Hz, 1H), 4.25 (q, J = 7.1 Hz, 2H), 4.07 (d, J = 5.1 Hz, 2H), 2.33 (s, 3H). ¹³C NMR (125 MHz, CDCl₃) δ = 169.53, 168.35, 143.73, 138.88, 136.37, 132.90, 129.53, 127.25, 127.10, 123.55, 121.00, 120.61, 61.86, 41.67, 21.49, 14.16. HR-MS (ESI): m/z calculated for C₁₈H₂₀N₂O₅S: [M+H]⁺: 377.1166, found: 377.1165. FTIR (KBr, cm⁻¹): 2914.95, 1748.60, 1616.82, 1543.93, 1412.15, 1207.48, 1154.21, 1084.11.

A screw-cap vial was charged with KF (1.0 equiv, 0.2 mmol), EtOH/H₂O = 3/1 (1.5 mL/ 0.5 mL). Then 5aa (0.2 mmol, 69.5 mg) were added into the solution in sequence. The vial was sealed under argon and heated to 50 °C with stirring for 16 h. After cooling down, the mixture was directly applied to a flash column chromatography (ethyl acetate/petroleum ether mixtures) to afford 9 as a white solid (43.4 mg, 79% yield), m.p: 146.1 °C. ¹H NMR (500 MHz, CDCl₃): δ = 10.80 (s, 1H), 9.90 – 9.76 (m, 1H), 7.80 – 7.74 (m, 2H), 7.68 (d, J = 8.4 Hz, 1H), 7.59 (dd, J = 7.6, 1.7 Hz, 1H), 7.50 (ddd, J = 8.7, 7.4, 1.7 Hz, 1H), 7.24 (d, J = 8.1 Hz, 2H), 7.16 (td, J = 7.5, 1.0 Hz, 1H), 2.36 (s, 3H). ¹³C NMR (125 MHz, CDCl₃) δ = 195.08, 144.24, 139.89, 136.33, 136.17, 135.83, 129.78, 127.26, 123.01, 121.87, 117.71, 21.55. HR-MS (ESI): m/z calculated for C₁₄H₁₃NO₃S: [M+H]⁺: 276.0689, found: 276.0682. FTIR (KBr, cm⁻¹): 3181.31, 1614.02, 1499.07, 1406.54, 1344.86, 1159.81, 1086.92, 927.10.
Gram-Scaled Synthesis

An oven-dried vial was charged with [Ru(ρ-cymene)Cl₂]₂ (5 mol %, 170 mg), AgSbF₆ (40 mol %, 769 mg), Cu(OAc)₂•H₂O (1.0 eq, 1.14 g), NaOAc (40 mol %, 184 mg) and DCM (40 mL). Then, 1a (1.0 eq, 1.02 g) and 4a (2.0 eq, 2.76 g) was added into the solution. The vial was sealed under argon and heated to 90 °C with stirring for 12 hours. After cooling down, the mixture was concentrated in vacuo and purified by column chromatography to afford the product 5aa (1.2 g, 60%).

References:

NMR Spectra

$^1$H NMR (CDCl$_3$, 500 MHz)

$^{13}$C NMR (CDCl$_3$, 125 MHz)
$\text{H NMR (CDCl$_3$, 500 MHz)}$

$\text{C NMR (CDCl$_3$, 125 MHz)}$
$^1$H NMR (CDCl$_3$, 500 MHz)

$^1$C NMR (CDCl$_3$, 125 MHz)
$^1$H NMR (CDCl$_3$, 500 MHz)

$^{13}$C NMR (CDCl$_3$, 125 MHz)
$^{1}H$ NMR (CDCl$_3$, 500 MHz)

$^{13}C$ NMR (CDCl$_3$, 125 MHz)
$^{1}H$ NMR (CDCl$_3$, 500 MHz)

$^{13}C$ NMR (CDCl$_3$, 125 MHz)
\[ ^1H\text{ NMR (CDCl}_3, 500\text{ MHz)} \]

\[ ^{13}C\text{ NMR (CDCl}_3, 125\text{ MHz)} \]
$^1$H NMR (CDCl$_3$, 500 MHz)

$^{13}$C NMR (CDCl$_3$, 125 MHz)
$^1$H NMR (CDCl$_3$, 500 MHz)

$^{13}$C NMR (CDCl$_3$, 125 MHz)
$^1$H NMR (CDCl$_3$, 500 MHz)

$^{13}$C NMR (CDCl$_3$, 125 MHz)
$^1$H NMR (CDCl$_3$, 500 MHz)

$^1$C NMR (CDCl$_3$, 125 MHz)
$^1$H NMR (CDCl$_3$, 500 MHz)

$^{13}$C NMR (CDCl$_3$, 125 MHz)
$^1$H NMR (CDCl$\text{$_3$}$, 500 MHz)

$^{13}$C NMR (CDCl$\text{$_3$}$, 125 MHz)
1H NMR (CDCl3, 500 MHz)

13C NMR (CDCl3, 125 MHz)
\[ \text{\textsuperscript{1}H NMR (CDCl\textsubscript{3}, 500 MHz)} \]

\[ \text{\textsuperscript{13}C NMR (CDCl\textsubscript{3}, 125 MHz)} \]
$^1$H NMR (CDCl$_3$, 500 MHz)

$^{13}$C NMR (CDCl$_3$, 125 MHz)
$^1$H NMR (CDCl$_3$, 500 MHz)

$^{13}$C NMR (CDCl$_3$, 125 MHz)
$^1$H NMR (CDCl$_3$, 500 MHz)

$^{13}$C NMR (CDCl$_3$, 125 MHz)
$^1$H NMR (CDCl$_3$, 500 MHz)

$^{13}$C NMR (CDCl$_3$, 125 MHz)
$^1$H NMR (CDCl$_3$, 500 MHz)

$^{13}$C NMR (CDCl$_3$, 125 MHz)
$^1$H NMR (CDCl$_3$, 500 MHz)

$^{13}$C NMR (CDCl$_3$, 125 MHz)
6

$^1$H NMR (CDCl$_3$, 500 MHz)

6

$^{13}$C NMR (CDCl$_3$, 125 MHz)
$^1$H NMR (CDCl$_3$, 500 MHz)

$^{13}$C NMR (CDCl$_3$, 125 MHz)