

Supporting Information for:

Synthesis of Aromatic Ketones by a Transition Metal-Catalyzed Tandem Sequence

Jing Zhao, Colin O. Hughes, and F. Dean Toste*

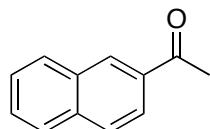
Department of Chemistry, University of California, Berkeley, CA 94720

General Information. Unless otherwise noted all commercial materials were used without purification. Small scale reactions (< 10mL) were carried out in Fisher Scientific disposable scintillation vials. Dichloromethane (CH_2Cl_2) and dichloroethane (DCE) were obtained from EMD. Silver trifluoromethanesulfonate (AgOTf), silver tetrafluoroborate (AgBF_4) and silver hexafluoroantimonate (AgSbF_6) were obtained from Aldrich Chemical Company and Strem Chemicals respectively. Triphenylphosphinegold(I) chloride (Ph_3PAuCl) and tri-*t*-butylphosphinegold(I) chloride ($t\text{-Bu}_3\text{PAuCl}$) were prepared according to the method of Bruce.¹ Tris(triphenylphosphinegold)-oxonium tetrafluoroborate ($[(\text{Ph}_3\text{PAu})_3\text{O}] \text{BF}_4$) was prepared according to the method of Sharp.² Thin-layer chromatography (TLC) analysis of reaction mixtures was performed using Merck silica gel 60 F_{254} TLC plates and visualized by UV and permanganate staining. Flash column chromatography was carried out on Merck 60 silica gel (32-63 mm). ^1H and ^{13}C NMR spectra were recorded with Bruker DRX-500, AVB-400, AVQ-400, and AV-300 spectrometers and referenced to CDCl_3 unless otherwise noted. Mass spectral and analytical data were obtained via the Micro-Mass/Analytical Facility operated by the College of Chemistry, University of California, Berkeley.

Representative procedure for Silver(I) catalyzed formal Myers-Saito reaction. To a small screw-cap scintillation vial equipped with a magnetic stir bar and charged with AgSbF_6 (5 mol%), PPh_3 (2 mol%), and MgO (1.5 equiv.) was added CH_2Cl_2 (0.2M). A solution of propargyl ester (~150 mg, 1 equiv.) in CH_2Cl_2 was added to the cloudy white suspension. The reaction mixture was then stirred at room temperature and monitored periodically by TLC. Upon completion, the reaction mixture was loaded directly on to a silica gel column and chromatographed with the appropriate mixture of hexanes and ethyl

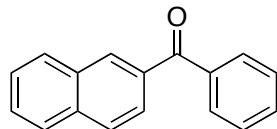
ether to give the Myers-Saito products described below.

Representative procedure for Gold(I) catalyzed formal Myers-Saito reaction. To a small screw-cap scintillation vial equipped with a magnetic stir bar and charged with $\text{AuCl}(\text{PPh}_3)$ or $\text{AuCl}(\text{P}^t\text{Bu}_3)$ (5 mol %) and AgSbF_6 (5 mol%) was added CH_2Cl_2 (0.2M). The cloudy white suspension solution was then added to a CH_2Cl_2 (or CH_3CN) solution of propargyl ester (~150 mg, 1 equiv.). The reaction mixture was stirred at room temperature and monitored periodically by TLC. Upon completion, the reaction mixture was loaded directly on to a silica gel column and chromatographed with the appropriate mixture of hexanes and ethyl ether to give the Myers-Saito products described below.



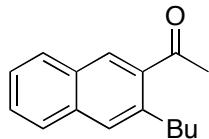
1-(Naphthalen-2-yl)ethanone (5a) was isolated as a light yellow solid by flash chromatography eluting with 4:1 hexanes:diethyl ether.

^1H NMR (400 MHz, CD_2Cl_2) δ 8.47 (s, 1H), 8.04 (d, 1H, J = 8.8 Hz), 7.97 (d, 1H, J = 8.0 Hz), 7.87-7.90 (m, 2H), 7.54-7.62 (m, 2H), 2.73 (s, 3H); IR (film): 1678 cm^{-1} ; ^{13}C NMR (100 MHz, CDCl_3) δ 198.08, 135.50, 134.37, 132.41, 130.14, 129.47, 128.40, 128.34, 127.70, 126.70, 123.80, 26.62; HRMS (EI) calc. for $[\text{C}_{12}\text{H}_{10}\text{O}_1]^+$ 170.0732, found 170.0730;



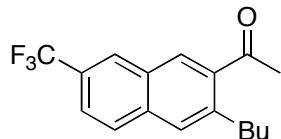
Naphthalen-2-yl(phenyl)methanone (5b) was isolated as a light yellow solid by flash chromatography eluting with 19:1 hexanes:diethyl ether.

^1H NMR (500 MHz, CD_2Cl_2) δ : 8.28 (s, 1H), 7.96 (s, 2H), 7.93 (d of d, 2H, J_1 = 8.0 Hz, J_2 = 2.5 Hz), 7.88 (d, 2H, J = 7.0 Hz), 7.62-7.65 (m, 2H), 7.51-7.59 (m, 3H); IR (film): 3058, 3027, 2919, 2851, 1656 cm^{-1} ; ^{13}C NMR (126 MHz, CD_2Cl_2) δ : 196.78, 137.88, 135.25, 134.79, 132.37, 132.23, 131.87, 130.09, 129.40, 128.33, 128.32, 128.29, 127.81, 126.78, 125.77; HRMS (EI) calc. for $[\text{C}_{17}\text{H}_{12}\text{O}_1]^+$ 232.0888, found 232.0890;



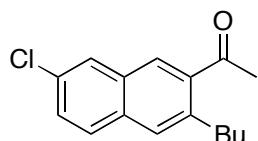
1-(3-Butylnaphthalen-2-yl)ethanone (7b) was isolated as a yellow oil by flash chromatography eluting with 19:1 hexanes:diethyl ether.

¹H NMR (400 MHz, CDCl₃) δ 8.18 (s, 1H), 7.87 (d, 1H, J = 8.0 Hz), 7.79 (d, 1H, J = 8.0 Hz), 7.68 (s, 1H), 7.56 (d of t, 1H, J₁ = 6.8 Hz, J₂ = 0.8 Hz), 7.49 (d of t, 1H, J₁ = 6.8 Hz, J₂ = 0.8 Hz), 3.04 (t, 2H, J = 8.0 Hz), 2.72 (s, 3H), 1.58-1.66 (m, 2H), 1.39-1.48 (m, 2H), 0.97 (t, 3H, J = 7.4 Hz); IR (film): 2955, 2929, 2869, 2860, 1684 cm⁻¹; ¹³C NMR (100 MHz, CDCl₃) δ 201.99, 139.16, 136.63, 134.59, 130.86, 130.12, 129.19, 128.38, 127.97, 127.05, 125.89, 33.90, 33.79, 29.84, 22.74, 13.97; HRMS (EI) calc. for [C₁₆H₁₈O₁]⁺ 226.1358, found 226.1361;



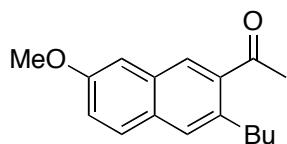
1-(3-Butyl-7-(trifluoromethyl)naphthalen-2-yl)ethanone (7c) was isolated as a yellow solid by flash chromatography eluting with 19:1 hexanes:diethyl ether.

¹H NMR (500 MHz, CD₂Cl₂) δ 8.23 (s, 1H), 8.20 (s, 1H), 7.92 (d, 1H, J = 8.5 Hz), 7.76 (s, 1H), 7.70 (d of d, 1H, J₁ = 8.5 Hz, J₂ = 1.5 Hz), 3.02 (t, 2H, J = 7.5 Hz), 2.69 (s, 3H), 1.57-1.63 (m, 2H), 1.39-1.43 (m, 2H), 0.95 (t, 3H, J = 7.5 Hz); IR (film): 2959, 2932, 2862, 1690 cm⁻¹; ¹³C NMR (126 MHz, CD₂Cl₂) δ 202.08, 142.31, 138.89, 136.19, 130.83, 130.34, 129.65, 128.86, 128.10 (q, J = 32.8 Hz), 126.68 (q, J = 5.0 Hz), 124.95 (q, J = 273.4 Hz), 123.80 (q, J = 3.8 Hz), 34.29, 34.24, 30.38, 23.30, 14.29; HRMS (EI) calc. for [C₁₇H₁₇O₁F₃]⁺ 294.1232, found 294.1236;



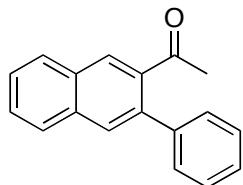
1-(3-Butyl-7-chloronaphthalen-2-yl)ethanone (7d) was isolated as a light brown solid by flash chromatography eluting with 19:1 hexanes:diethyl ether.

¹H NMR (500 MHz, CD₂Cl₂) δ 8.06 (s, 1H), 7.87 (d, 1H, J = 1.5 Hz), 7.75 (d, 1H, J = 9.0 Hz), 7.67 (s, 1H), 7.48 (d of d, 1H, J₁ = 8.5 Hz, J₂ = 6.0 Hz), 2.97 (t, 2H, J = 7.5 Hz), 2.67 (s, 3H), 1.55-1.61 (m, 2H), 1.36-1.43 (m, 2H), 0.94 (t, 3H, J = 7.0 Hz); IR (film): 2956, 2930, 2860, 1687 cm⁻¹; ¹³C NMR (126 MHz, CD₂Cl₂) δ 202.28, 140.05, 138.65, 133.25, 132.12, 132.01, 129.54, 129.34, 129.17, 129.14, 127.46, 34.33, 34.09, 30.38, 23.28, 14.30; HRMS (EI) calc. for [C₁₆H₁₇Cl₁O₁]⁺ 260.0968, found 260.0971;



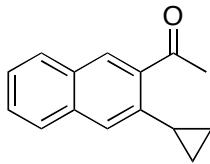
1-(3-Butyl-7-methoxynaphthalen-2-yl)ethanone (7e) was isolated as a light yellow solid by flash chromatography eluting with 19:1 hexanes:diethyl ether.

¹H NMR (400 MHz, CD₂Cl₂) δ 8.07 (s, 1H), 7.69 (d, 1H, J = 8.8 Hz), 7.60 (s, 1H), 7.20-7.22 (m, 2H), 3.92 (s, 3H), 2.97 (t, 2H, J = 8.0 Hz), 2.68 (s, 3H), 1.55-1.63 (m, 2H), 1.36-1.45 (m, 2H), 0.96 (t, 3H, J = 7.2 Hz); IR (film): 2956, 2931, 2869, 2859, 1682 cm⁻¹; ¹³C NMR (100 MHz, CD₂Cl₂) δ 202.57, 158.32, 137.95, 137.24, 132.66, 130.66, 129.47, 129.21, 129.09, 121.31, 106.64, 55.87, 34.56, 34.04, 30.32, 23.32, 14.36; HRMS (EI) calc. for [C₁₇H₂₀O₂]⁺ 256.1463, found 256.1464;



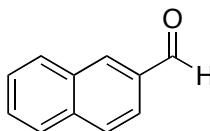
1-(3-Phenylnaphthalen-2-yl)ethanone (7f) was isolated as a light yellow oil by flash chromatography eluting with 4:1 hexanes:diethyl ether.

¹H NMR (300 MHz, CD₂Cl₂) δ 8.15 (s, 1H), 7.99 (d, 1H, J = 6.0 Hz), 7.92 (d, 1H, J = 6.0 Hz), 7.87 (s, 1H), 7.55-7.65 (m, 2H), 7.43-7.54 (m, 5H), 2.23 (s, 3H); IR (film): 3055, 3023, 2927, 2917, 1687 cm⁻¹; ¹³C NMR (100 MHz, CD₂Cl₂) δ 203.74, 141.63, 139.64, 138.07, 134.60, 132.26, 130.08, 129.47, 129.11, 129.06, 128.53, 128.31, 128.04, 127.33, 30.66. HRMS (EI) calc. for [C₁₈H₁₄O]⁺ 246.1045, found 246.1049.



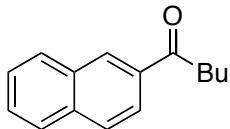
1-(3-Cyclopropylnaphthalen-2-yl)ethanone (7g) was isolated as a light yellow oil by flash chromatography eluting with 9:1 hexanes:diethyl ether.

¹H NMR (500 MHz, CD₂Cl₂) δ 8.09 (s, 1H), 7.88 (d, 1H, J = 8.0 Hz), 7.78 (d, 1H, J = 8.0 Hz), 7.55 (d of t, 2H, J₁ = 7.5 Hz, J₂ = 1.0 Hz), 7.48 (d of t, 1H, J₁ = 8.0 Hz, J₂ = 1.0 Hz), 2.72 (s, 3H), 2.50-2.55 (m, 1H), 1.01-1.05 (m, 2H), 0.76-0.80 (m, 2H); IR (film): 3063, 3013, 2998, 2920, 1685 cm⁻¹; ¹³C NMR (100 MHz, CD₂Cl₂) δ 202.93, 139.56, 139.52, 135.00, 131.38, 129.18, 128.86, 128.32, 127.71, 126.52, 125.71, 30.69, 14.50, 8.82; HRMS (EI) calc. for [C₁₅H₁₄O]⁺ 210.1045, found 210.1047.



2-Naphthaldehyde (7h) was isolated as a white powder by flash chromatography eluting with 19:1 hexanes:diethyl ether.

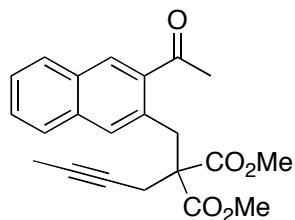
¹H NMR (400 MHz, CDCl₃) δ 10.17 (s, 1H), 8.35 (s, 1H), 7.91-8.03 (m, 4H), 7.58-7.68 (m, 2H); IR (film): 3062, 2846, 2830, 1693 cm⁻¹; ¹³C NMR (100 MHz, CDCl₃) δ 192.22, 136.41, 134.53, 134.06, 132.60, 129.49, 129.08, 129.06, 128.04, 127.05, 122.72; HRMS (EI) calc. for [C₁₁H₈O]⁺ 156.0575, found 156.0572.



1-(Naphthalen-2-yl)pentan-1-one (7i) was isolated as a light brown solid by flash chromatography eluting with 19:1 hexanes:diethyl ether.

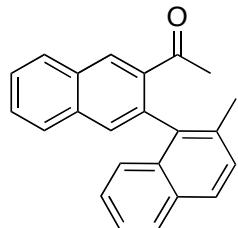
¹H NMR (400 MHz, CD₂Cl₂) δ 8.49 (s, 1H), 7.99-8.04 (m, 2H), 7.89-7.92 (m, 2H), 7.55-7.63 (m, 2H), 3.10 (t, 2H, J = 7.6 Hz), 1.73-1.80 (m, 2H), 1.41-1.51 (m, 2H), 0.99 (t, 3H, J = 7.6 Hz); IR (film): 3059, 2956, 2930, 2871, 1680 cm⁻¹; ¹³C NMR (100 MHz, CD₂Cl₂) δ 200.69, 136.02, 135.12, 133.17, 130.03, 128.84, 128.25, 127.27, 124.42,

38.90, 27.13, 23.07, 14.34; HRMS (EI) calc. for $[C_{15}H_{16}O_1]^+$ 212.1201, found 212.1200;



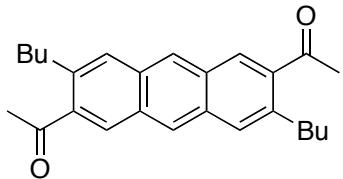
Dimethyl 2-(3-acetylphenyl)methyl-2-(but-2-ynyl)malonate (7j) was isolated as a colorless oil by flash chromatography eluting with 4:1 hexanes:diethyl ether.

1H NMR (500 MHz, CD_2Cl_2) δ : 8.20 (s, 1H), 7.91 (d, 1H, J = 8.5 Hz), 7.83 (s, 1H), 7.81 (d, 1H, J = 8.0 Hz), 7.59 (t, 1H, J = 8.0 Hz), 7.53 (t, 1H, J = 8.0 Hz), 3.91 (s, 2H), 3.69 (s, 6H), 2.69 (s, 3H), 2.52 (q, 2H, J = 2.5 Hz), 1.85 (t, 3H, J = 2.5 Hz); IR (film): 2951, 2920, 2849, 1734, 1684 cm^{-1} ; ^{13}C NMR (126 MHz, CD_2Cl_2) δ : 201.93, 171.20, 138.12, 134.57, 132.57, 132.33, 131.95, 130.68, 128.97, 128.78, 127.91, 127.26, 80.26, 74.40, 58.99, 53.08, 34.19, 29.92, 23.94, 3.80; HRMS (EI) calc. for $[C_{22}H_{22}O_5]^+$ 366.1467, found 366.1463;



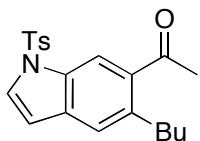
1-(2-Methyl-1,7'-binaphthyl-6'-yl)ethanone (9) was isolated as a light yellow oil by flash chromatography eluting with 9:1 hexanes:diethyl ether.

1H NMR (400 MHz, CD_2Cl_2) δ 8.41 (s, 1H), 8.06-8.09 (m, 1H), 7.84-7.89 (m, 3H), 7.72 (s, 1H), 7.62-7.65 (m, 2H), 7.47 (d, 1H, J = 8.4 Hz), 7.40-7.42 (m, 1H), 7.28-7.30 (m, 2H), 2.20 (s, 3H), 2.10 (s, 3H); IR (film): 3052, 2922, 1686 cm^{-1} ; ^{13}C NMR (100 MHz, CD_2Cl_2) δ 201.17, 139.08, 137.73, 135.64, 135.17, 134.22, 133.63, 132.61, 132.49, 131.40, 130.19, 129.46, 129.14, 128.80, 128.45, 128.20, 127.99, 127.44, 126.60, 126.23, 125.37, 29.38, 21.10; HRMS (EI) calc. for $[C_{23}H_{18}O]^+$ 310.1358, found 310.1353.



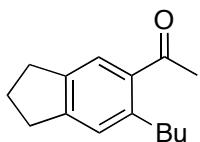
1,1'-(3,7-Dibutylanthracene-2,6-diyl)diethanone (11) was isolated as a light yellow solid by flash chromatography eluting with 4:1 hexanes:diethyl ether.

¹H NMR (500 MHz, CD₂Cl₂) δ: 8.40 (s, 1H), 8.35 (s, 1H), 7.82 (s, 1H), 3.03 (t, 2H, J = 8.0 Hz), 2.73 (s, 3H), 1.58-1.64 (m, 2H), 1.40-1.45 (m, 2H), 0.96 (t, 3H, J = 7.5 Hz); IR (film): 2956, 2928, 2870, 2860, 1682 cm⁻¹; ¹³C NMR (126 MHz, CD₂Cl₂) δ: 202.21, 138.82, 138.25, 132.65, 131.30, 131.27, 129.38, 126.96, 34.31, 34.19, 30.20, 23.32, 14.34; HRMS (EI) calc. for [C₂₆H₃₀O₂]⁺ 374.2246, found 374.2247;



1-(5-Butyl-1-tosyl-1H-indol-6-yl)ethanone (13) was isolated as a yellow solid by flash chromatography eluting with 4:1 hexanes:diethyl ether.

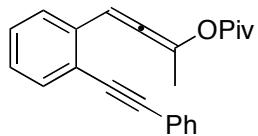
¹H NMR (500 MHz, CD₂Cl₂) δ: 8.27 (s, 1H), 7.77 (d, 2H, J = 8.5 Hz), 7.66 (d, 1H, J = 4.0 Hz), 7.40 (s, 1H), 7.27 (d, 2H, J = 8.0 Hz), 6.65 (d, 1H, J = 3.5 Hz), 2.87 (t, 2H, J = 7.5 Hz), 2.65 (s, 3H), 2.34 (s, 3H), 1.48-1.54 (m, 2H), 1.32-1.39 (m, 2H), 0.91 (t, 3H, J = 7.0 Hz); IR (film): 2956, 2927, 2869, 2858, 1682 cm⁻¹; ¹³C NMR (126 MHz, CD₂Cl₂) δ: 202.00, 146.18, 138.48, 135.54, 135.46, 133.46, 132.99, 130.58, 129.59, 127.25, 123.76, 114.93, 109.24, 34.80, 34.17, 30.46, 23.28, 21.86, 14.28; HRMS (FAB) calc. for [C₂₁H₂₃SNO₃]⁺ 369.1399, found 369.1392;



1-(6-Butyl-2,3-dihydro-1H-inden-5-yl)ethanone (15) was isolated as a colorless oil by flash chromatography eluting with 19:1 hexanes:diethyl ether.

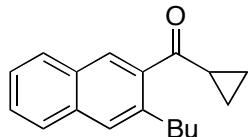
¹H NMR (400 MHz, CD₂Cl₂) δ: 7.50 (s, 1H), 7.11 (s, 1H), 2.88-2.92 (m, 4H), 2.78 (t, 2H, J = 7.6 Hz), 2.52 (s, 3H), 2.06-2.12 (m, 2H), 1.46-1.52 (m, 2H), 1.33-1.38

(m, 2H), 0.92 (t, 3H, $J = 7.2$ Hz); IR (film): 2955, 2931, 2869, 2857, 1682 cm^{-1} ; ^{13}C NMR (100 MHz, CD_2Cl_2) δ : 202.48, 148.63, 142.14, 141.61, 136.77, 127.46, 125.51, 34.87, 34.19, 33.41, 32.85, 30.34, 25.95, 23.36, 14.31; HRMS (EI) calc. for $[\text{C}_{15}\text{H}_{20}\text{O}_1]^+$ 216.1514, found 216.1513;



4-(2-(Phenylethynyl)phenyl)buta-2,3-dien-2-yl pivalate (16) was isolated as a colorless oil by flash chromatography eluting with 49:1 hexanes:diethyl ether.

^1H NMR (400 MHz, CD_2Cl_2) δ 7.69 (d, 1H, $J = 8.0$ Hz), 7.54-7.59 (m, 3H), 7.34-7.44 (m, 4H), 7.27 (d of t, 1H, $J_1 = 7.5$ Hz, $J_2 = 1.0$ Hz), 7.20 (q, 1H, $J = 3.0$ Hz), 2.08 (d, 3H, $J = 3.0$ Hz), 1.26 (s, 9H); IR (film): 2972, 1743, 1113 cm^{-1} ; ^{13}C NMR (100 MHz, CD_2Cl_2) δ 198.85, 176.43, 135.90, 132.90, 132.08, 129.18, 129.11, 129.02, 128.28, 128.21, 124.01, 123.59, 122.55, 101.63, 94.85, 87.67, 39.53, 27.43, 18.41; HRMS (FAB) calc. for $[\text{C}_{18}\text{H}_{13}\text{O}_1]^+$ ($M^+ - \text{CO-}t\text{-Bu}$) 245.0966, found 245.0971;



(3-Butynaphthalen-2-yl)(cyclopropyl)methanone (18) was isolated as a colorless oil by flash chromatography eluting with 9:1 hexanes:diethyl ether.

^1H NMR (400 MHz, CD_2Cl_2) δ : 8.19 (s, 1H), 7.90 (d, 2H, $J = 8.0$ Hz), 7.81 (d, 1H, $J = 4.0$ Hz), 7.69 (s, 1H), 7.47-7.56 (m, 2H), 2.96 (t, 2H, $J = 8.0$ Hz), 2.53-2.59 (m, 1H), 1.57-1.64 (m, 2H), 1.34-1.43 (m, 2H), 1.25-1.29 (m, 2H), 1.08-1.15 (m, 2H), 0.94 (t, 3H, $J = 7.2$ Hz); IR (film): 3056, 3007, 2956, 2928, 2869, 2859, 1673 cm^{-1} ; ^{13}C NMR (101 MHz, CD_2Cl_2) δ : 205.65, 139.57, 138.89, 134.84, 131.61, 129.13, 129.04, 128.78, 128.07, 127.66, 126.42, 34.55, 33.76, 23.24, 21.50, 14.31, 12.53; HRMS (EI) calc. for $[\text{C}_{18}\text{H}_{20}\text{O}_1]^+$ 252.1514, found 252.1517;

References:

- (1) Bruce, M. I.; Nicholson, B. K.; Bin Shawkataly, O., *Inorg. Syn.* **1989**, 26, 324.
- (2) Yang, Y.; Ramamoorthy, V.; Sharp, P. R., *Inorg. Chem.* **1993**, 32, (10), 1946.