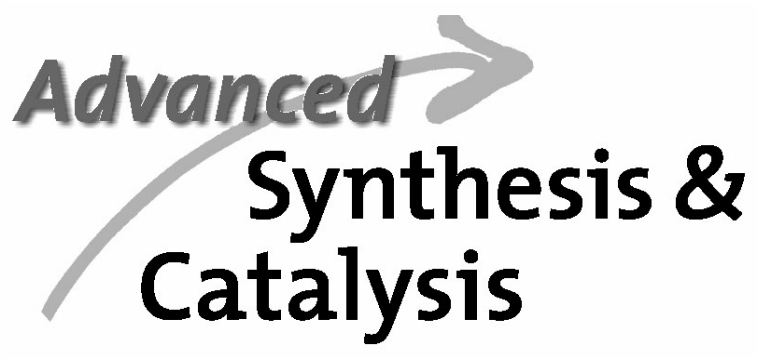

Supporting Information

Supporting Information

A Practical Transition Metal-Free Aryl-Aryl Coupling Method: Arynes as Key Intermediates

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Experimental Section

General Remarks

Starting materials, if commercial, were purchased and used as such, provided that adequate checks (melting ranges, refractive indices, and gas chromatography) had confirmed the claimed purity. When known compounds had to be prepared according to literature procedures, pertinent references are given. Air- and moisture-sensitive materials were stored in Schlenk tubes or Schlenk burettes. They were protected by and handled under an atmosphere of argon, using appropriate glassware. Diethyl ether and tetrahydrofuran were dried by distillation from sodium after the characteristic blue color of sodium diphenyl ketyl (benzophenone-sodium "radical-anion") had been found to persist.[42,43] Ethereal or other organic extracts were dried by washing with brine and then by storage over sodium sulfate. If no reduced pressure is specified, boiling ranges (b.p.) refer to ordinary atmosphere conditions (725 ± 25 Torr). Melting ranges (mp) given were found to be reproducible after recrystallization, unless stated otherwise ("decomp."), and were corrected using a calibration curve established with authentic standards. If melting points are missing, it means all attempts to crystallize the liquid at temperatures down to –75 °C failed. The temperature of dry ice/acetone baths is consistently indicated as –75 °C and "room temperature" (22 – 26 °C) as 25 °C. Silica gel (Merck Silica Gel 60, 40 – 63 μm) was used for column chromatography. The solid support was suspended in hexanes and, when all air bubbles had escaped, was washed into the column. When the level of the liquid was still 3 – 5 cm above the support layer, the dry powder, obtained by adsorption of the crude mixture to some 25 mL of silica and subsequent evaporation of the solvent, was poured on top of the column. ^{1}H and (^{1}H decoupled) ^{13}C nuclear magnetic resonance (NMR) spectra were recorded at 400 or 300 and

101 or 75 MHz, respectively. Chemical shifts are reported in d units, parts per million (ppm) and were measured relative to the signals for residual chloroform (7.27 ppm). Coupling constants *J* are given in Hz. Coupling patterns are abbreviated as, for example, s (singlet), d (doublet), t (triplet), q (quartet), quint (quintet), td (triplet of doublets) and m (multiplet).

Starting Materials

1-Bromo-3-fluoro-2-iodobenzene[29]

At –75 °C, butyllithium (0.10 mol) in hexanes (55 mL) and diisopropylamine (14 mL, 10 g, 0.10 mol) were added successively to tetrahydrofuran (0.20 L). After 15 min 3-bromofluorobenzene (11 mL, 18 g, 0.10 mol) was added. The mixture was kept for 2 h at –75 °C before a solution of iodine (25 g, 0.10 mol) in tetrahydrofuran (50 mL) was added. After addition of a 10% aqueous solution (0.10 L) of sodium thiosulfate the mixture was extracted with diethyl ether (3 × 0.10 L). The combined organic layers were dried over sodium sulfate before being evaporated to dryness. Distillation afforded a pure product; yield: 23.47 g (78%); bp 108–109 °C/10 mmHg; n_D^{20} = 1.6354; ^{1}H NMR (400 MHz, $CDCl_3$): *d* = 7.45 (td, *J* = 8.3, 1.3 Hz, 1 H), 7.22 (td, *J* = 8.3, 6.0 Hz, 1 H), 6.99 (ddd, *J* = 10.5, 7.5, 1.3 Hz, 1 H). – ^{13}C NMR (101 MHz, $CDCl_3$): *d* = 162. 4 (d, *J* = 248 Hz), 130.9 (d, *J* = 2 Hz), 130.6 (d, *J* = 9 Hz), 128.3 (d, *J* = 3 Hz), 113.8 (d, *J* = 25 Hz), 90.5 (d, *J* = 27 Hz); ^{19}F NMR (376 MHz, $CDCl_3$): *d* = –83.2 (t, *J* = 6.6 Hz); MS (CI): *m/z* (%) = 300 (94) [M^+], 94 (100); anal. calcd. for C_6H_3BrFI (300.89): C 23.95, H 1.00; found: C 24.07, H 1.08%.

1-Bromo-3-chloro-2-iodobenzene[29]

Analogously to 1-bromo-3-fluoro-2-iodobenzene starting from 1-bromo-3-chlorobenzene (12 mL, 19 g, 0.10 mol). Upon crystallization from ethanol, colorless needles were obtained; yield: 27.29 g (86%); mp 75 – 76 °C (after sublimation); ^{1}H NMR (400 MHz, $CDCl_3$): *d* = 7.52 (dd, *J* = 8.1, 1.3 Hz, 1 H), 7.38 (dd, *J* = 8.1, 1.3 Hz, 1 H), 7.14 (t, *J* = 7.9 Hz, 1 H); ^{13}C NMR (101 MHz, $CDCl_3$): *d* = 140.3, 131.6, 130.6, 130.0, 127.6, 106.6; anal. calcd. for C_6H_3BrClI (317.35): C 22.71, H 0.95; found: C 22.82, H 0.93%.

1,3-Dibromo-2-iodobenzene[29,40,41]

Analogously to 1-bromo-3-fluoro-2-iodobenzene starting from 1,3-dibromobenzene (0.12 L, 0.24 kg, 1.0 mol). Upon crystallization from ethanol (1.0 L), colorless platelets were obtained; yield: 0.33 kg (91%); mp 99-100 °C; ^{1}H NMR ($CDCl_3$, 400 MHz): *d* = 7.55 (d, *J* = 8.1 Hz, 2 H), 7.07 (t, *J* = 7.9 Hz, 1 H); anal. calcd. for $C_6H_3Br_2I$ (361.80): C 19.92, H 0.84; found: C 19.97, H 0.80%.

1-Bromo-2-iodo-3-trifluoromethoxybenzene

At –75 °C, butyllithium (0.10 mol) in hexanes (55 mL) and diisopropylamine (14 mL, 10 g, 0.10 mol) were added successively to tetrahydrofuran (0.2 L). After 15 min 1-bromo-3-trifluoromethoxy-benzene (13 mL, 20 g, 0.10 mmol) was added. The mixture was kept for 2 h at –75 °C before a solution of iodine (25 g, 0.10 mol) in tetrahydrofuran (50 mL) was added. After addition of a 10% aqueous solution (0.10 L) of sodium thiosulfate the mixture was extracted with diethyl ether (3 × 0.10 L). The combined organic layers were dried over sodium sulfate before being evaporated to dryness. Distillation afforded a pure product; yield: 31.92 g (87%); bp 65 – 67 °C/0.3 mmHg; n_D^{20} = 1.5494; ^{1}H NMR (400 MHz, $CDCl_3$): *d* = 7.58 (dd, *J* = 7.8, 1.5 Hz, 1 H), 7.32 (t, *J* = 8.0 Hz, 1 H), 7.18 (d, *J* = 8.0 Hz, 1 H); ^{13}C NMR (75 MHz, $CDCl_3$): *d* = 150.7, 131.8, 130.9, 130.2, 120.6 (q, *J* = 260 Hz), 118.9, 98.9; MS (CI): *m/z* (%) = 366 (100) [M^+]; anal. calcd. for $C_7H_3BrF_3IO$ (366.90): C 22.91, H 0.82; found: C 22.76, H 0.92%.

Disubstituted Biaryls by *Homo*-Aryl/Aryl Coupling

2-Bromo-2'-iodobiphenyl (4)[29]

At –75 °C, butyllithium (50 mmol) in hexanes (31 mL) was added to a solution of 1-bromo-2-iodobenzene (13 mL, 28 g, 0.10 mol) in tetrahydrofuran (0.20 L). The mixture was then warmed to 25 °C over a two hours period and hydrolyzed with a 1.0 M aqueous hydrochloric acid solution (0.10 L). After separation of the phases, the aqueous layer was extracted with diethyl ether (3 × 0.20 L). The combined organic layers were dried over sodium sulfate before being evaporated to dryness. Upon crystallization from ethanol, colorless needles were obtained; yield: 14.54 g (81%); mp 88.5 – 89 °C (ref.[44] 87.5 – 88 °C); ^{1}H NMR (400 MHz, $CDCl_3$): *d* = 7.94 (d, *J* = 7.9, 1 H), 7.66 (d, *J* = 8.0, 1 H), 7.39 (dt, *J* = 12.8, 7.5 Hz, 2 H), 7.2 (m, 3 H), 7.08 (dt, *J* = 7.6, 1.4 Hz, 1 H); ^{13}C-NMR (75 MHz, $CDCl_3$): *d* = 147.1, 144.2, 139.1, 131.8, 131.3, 131.2, 130.9, 130.0, 128.5, 126.4, 125.3, 99.1; anal. calcd. for $C_{12}H_8BrI$ (359.00): C 40.15, H 2.25; found: C 40.13, H 2.29%.

Disubstituted Biaryls by *Hetero*-Aryl/Aryl Coupling

2'-Bromo-2-methoxybiphenyl (5)

2-Bromoanisole (4.7 g, 25 mmol) was added to a –75 °C cold solution of *tert*-butyllithium (50 mmol) in pentanes (30 mL) and tetrahydrofuran (70 mL). After 5 min, the temperature was increased to –25 °C for 15 min. Then, a solution of 1,2-dibromobenzene (3.0 mL, 5.9 g, 25 mmol) in tetrahydrofuran (10 mL) was added dropwise, over a 10 min period. The mixture was allowed to reach room temperature before water (25 mL) was added followed by extraction with diethyl ether (3 x 20 mL). The combined organic layers were dried and evaporated. Column chromatography on silica gel (20 mL) using cyclohexane as eluent

afforded **5**. Crystallization from ethanol gave colorless needles; yield: 4.41 g (67%); mp 55 – 57 °C; ^{1}H NMR (300 MHz, $CDCl_3$): *d* = 7.65 (d, *J* = 7.9 Hz, 1 H), 7.3 (m, 4 H), 7.0 (m, 3 H), 3.73 (s, 3 H); ^{13}C NMR ($CDCl_3$ 75 MHz): *d* = 156.6, 139.9, 132.5, 131.6, 131.5, 130.3, 129.4, 128.7, 127.0, 124.3, 120.4, 111.1, 55.7; anal. calcd. for $C_{13}H_{11}BrO$ (263.13): C 59.34, H 4.21; found: C 59.51, H 4.29%.

2'-Bromo-2-trifluoromethoxybiphenyl (6)

Trifluoromethoxybenzene (4.1 g, 25 mmol) was added to a –75 °C cold solution of *sec*-butyllithium (25 mmol) in cyclohexane (20 mL) and tetrahydrofuran (30 mL). After 2 h at –75 °C, a solution of 1,2-dibromobenzene (3.0 mL, 5.9 g, 25 mmol) in tetrahydrofuran (5.0 mL) was added as described in the preceding paragraph. The reaction mixture was washed with brine (3 × 20 mL) and extracted with diethyl ether (3 x 20 mL). Column chromatography on silica gel (100 mL) using cyclohexane as eluent afforded a colorless oil; yield: 6.18 g (78%); ^{1}H NMR (300 MHz, $CDCl_3$): *d* = 7.59 (d, *J* = 8.5 Hz, 1 H), 7.38 (td, *J* = 8.1, 2.3 Hz, 1 H), 7.2 (m, 6 H); ^{13}C NMR (75 MHz ,$CDCl_3$): *d* = 146.4, 142.1, 137.7, 134.3, 132.6, 133.8, 131.6 (d, *J* = 33 Hz), 131.0, 129.4, 127.0, 126.5, 123.6, 120.4 (q, *J* = 258 Hz); anal. calcd. for $C_{13}H_8BrF_3O$ (317.06): C 49.24, H 2.54; found: C 49.61, H 2.62%.

2-Fluoro-3-chloro-2'-bromobiphenyl (7)

Prepared analogously to biphenyl **6** starting from 1-chloro-2-fluorobenzene (3.3 g, 25 mmol) affording a colorless oil; yield: 5.28 g (74%); ^{1}H NMR (300 MHz, $CDCl_3$): *d* = 7.61 (dd, *J* = 7.9, 1.1 Hz, 1 H), 7.37 (td, *J* = 7.6, 2.1 Hz, 1 H), 7.29 (dd, *J* = 7.9, 1.3 Hz, 1 H), 7.2 (m, 2 H), 7.1 (m, 2 H); ^{13}C NMR (75 MHz, $CDCl_3$): *d* = 158.4 (d, *J* = 250 Hz), 136.1, 133.4, 131.5, 130.4, 130.2, 129.9, 129.8, 127.7, 124.3 (d, *J* = 4 Hz), 123.5, 121.5 (d, *J* = 20 Hz); anal. calcd. for $C_{12}H_7BrClF$ (285.52): C 50.48, H 2.47; found: C 50.76, H 2.57%.

2-Chloro-6-trifluoromethyl-2'-bromobiphenyl (8)

Prepared analogously as biphenyl **6** starting from 1-chloro-3-trifluoromethylbenzene (1.8 g, 10 mmol) affording a colorless oil; yield: 2.01 g (60%); ^{1}H NMR (300 MHz, $CDCl_3$): *d* = 7.76 (s, 1 H), 7.70 (dd, *J* = 7.9, 1.1 Hz, 1 H), 7.59 (dd, *J* = 7.5, 1.3 Hz, 1 H), 7.41 (td, *J* = 7.5, 1.1 Hz, 2 H), 7.31 (dd, *J* = 7.5, 1.9 Hz, 1 H), 7.26 (td, *J* = 7.6, 2.0 Hz, 1 H); ^{13}C NMR (75 MHz, $CDCl_3$): *d* = 143.7, 139.2, 134.3, 132.9, 131.8, 130.9 (q, *J* = 33 Hz), 130.8, 130.1, 127.4, 126.6 (q, *J* = 4 Hz), 124.6 (q, *J* = 263 Hz), 123.5 (q, *J* = 4 Hz), 123.1; anal. calcd. for $C_{13}H_7BrClF_3$ (335.55): C 46.53, H 2.10; found: C 46.86, H 2.14%.

Trisubstituted Biaryls by *Homo*-Aryl/Aryl Coupling

2-Bromo-3',6-difluoro-2'-iodobiphenyl (9)[29]

At –75 °C, butyllithium (13 mmol) in hexanes (7.0 mL) was added to a solution of 1-bromo-3-fluoro-2-iodo-benzene (7.5 g, 25 mmol) in tetrahydrofuran (50 mL). After 45 min the mixture was allowed to reach 25 °C over a two hours period. Water (0.10 L) was added to the reaction mixture followed by extraction with diethyl ether (3 × 0.10 L). The combined organic layers were dried over sodium sulfate before being evaporated to dryness. Upon crystallization from ethanol, colorless needles were obtained; yield: 3.31 g (67%); mp 100 – 101 °C (after sublimation); ^{1}H NMR (400 MHz, $CDCl_3$): *d* = 7.50 (td, *J* = 8.1, 0.9 Hz, 1 H), 7.39 (dt, *J* = 7.9, 5.2 Hz, 1 H), 7.28 (dt, *J* = 8.2, 5.7 Hz, 1 H), 7.14 (dt, *J* = 8.6, 1.1 Hz, 1 H), 7.10 (dt, *J* = 8.0, 1.5 Hz, 1 H), 7.02 (dd, *J* = 7.5, 1.1 Hz, 1 H); ^{13}C NMR (101 MHz, $CDCl_3$): *d* = 162. 4 (d, *J* = 228 Hz), 160.0 (d, *J* = 234 Hz), 158.4, 143.0 (d, *J* = 2.1 Hz), 131.6 (d, *J* = 8.1 Hz), 131.1 (d, *J* = 8.9 Hz), 130.2 (d, *J* = 8.4 Hz), 128.7 (d, *J* = 3.5 Hz), 126.5 (d, *J* = 3.5 Hz), 125.0 (d, *J* = 3.2 Hz), 115.7 (d, *J* = 24.2 Hz), 115.3 (d, *J* = 22.5 Hz); ^{19}F-NMR (376 MHz, $CDCl_3$): *d* = –90.1 (dd, *J* = 6.0, 8.0 Hz), –109.1 (dd, *J* = 6.1, 8.7 Hz); MS (CI): *m/z* (%) = 394 (74) [M^+], 315 (100), 267 (26), 188 (96), 168 (18); anal. calcd. for $C_{12}H_6BrF_2I$ (394.98): C 36.49, H 1.53; found: C 36.50, H 1.29%.

2-Bromo-3',6-dichloro-2'-iodobiphenyl (10)[29]

Prepared analogously as biphenyl **9** starting from 1-bromo-3-chloro-2-iodobenzene (16 g, 50 mmol); colorless needles; yield: 8.34 g (78%); mp 136 – 138 °C (after sublimation); ^{1}H NMR (400 MHz, $CDCl_3$): *d* = 7.57 (dd, *J* = 8.0, 0.7 Hz, 1 H), 7.52 (dd, *J* = 8.1, 1.6 Hz, 1 H), 7.48 (dd, *J* = 8.0, 0.8 Hz, 1 H), 7.41 (t, *J* = 7.9 Hz, 1 H), 7.25 (t, *J* = 8.2 Hz, 1 H), 7.06 (dd, *J* = 7.5, 1.2 Hz, 1 H); ^{13}C NMR (101 MHz, $CDCl_3$): *d* = 146.9, 143.6, 139.6, 137.5, 131.2, 130.2, 129.4, 128.7, 128.6, 127.6, 124.6, 103.7; MS (CI): *m/z* (%) = 428 (100) [M^+], 347 (98), 301 (81), 266 (20), 220 (75), 185 (18), 150 (54); anal. calcd. for $C_{12}H_6BrCl_2I$ (427.89): C 33.68, H 1.41; found: C 33.80, H 1.27%.

Trisubstituted Biaryls by *Hetero*-Aryl/Aryl Coupling

2,2'-Dibromo-6-fluorobiphenyl (11)[29]

At –75 °C, butyllithium (50 mmol) in hexanes (24 mL) was added to a solution of 1-bromo-3-fluoro-2-iodo-benzene (7.5 g, 25 mmol) in tetrahydrofuran (50 mL). After 45 min 1,2-dibromobenzene (3.0 mL, 5.9 g, 25 mmol) was added to the mixture. After 2 h at –75 °C the mixture was allowed to obtain 25 °C over a two hours period. Water (0.10 L) was added to the reaction mixture followed by extraction with diethyl ether (3 × 0.10 L). Crystallization from ethanol afforded **11** as colorless needles; yield: 6.52 g (79%); mp 68 – 70 °C (after sublimation); ^{1}H NMR (400 MHz, $CDCl_3$): *d* = 7.70 (dd, *J* = 8.0, 1.2 Hz, 1 H), 7.48 (td, *J* = 7.9, 1.0 Hz, 1 H), 7.40 (dt, *J* = 7.8, 1.3 Hz, 1 H), 7.3 (m, 3 H), 7.13 (dt, *J* = 8.6, 1.1 Hz, 1 H);

^{13}C NMR (75 MHz, $CDCl_3$): *d* = 159.9 (d, *J* = 250 Hz), 136.1, 132.7, 131.4, 130.4, 130.3, 130.0, 128.2 (d, *J* = 3 Hz), 127.3, 124.7 (d, *J* = 3 Hz), 124.0, 114.7 (d, *J* = 23 Hz); ^{19}F NMR (376 MHz, $CDCl_3$): *d* = –109.1 (dd, *J* = 8.9, 6.5 Hz); MS (CI): *m/z* (%) = 330 (87) [M^+], 312 (26), 251 (100), 170 (99); calcd. for $C_{12}H_7Br_2F$ (329.99): C 43.68, H 2.14; found: C 44.00, H 2.10%.

2,2',6-Tribromobiphenyl (12)[29,40,41]

Prepared analogously as biphenyl **11** starting from 1,3-dibromo-2-iodobenzene (9.0 g, 25 mmol). The residue was purified by flash chromatography which afforded **12** as colorless needles;yield: 4.10 g (42%); mp 95 – 97 °C; ^{1}H NMR (400 MHz, $CDCl_3$): d = 7.69 (d, *J* = 8.1 Hz, 1 H), 7.64 (dd, *J* = 8.1, 0.7 Hz, 2 H), 7.42 (tt, *J* = 7.5, 0.9 Hz, 1 H), 7.29 (ddt, *J* = 7.8, 1.8, 0.7 Hz, 1 H), 7.18 (dd, *J* = 7.6, 1.6 Hz, 1 H), 7.12 (dd, *J* = 8.1, 0.7 Hz, 1 H); ^{13}C NMR (101 MHz, $CDCl_3$): *d* = 142.2, 141.9, 132.6, 131.4, 130.6, 130.3, 129.8, 127.4, 124.4, 123.3; anal. calcd. for $C_{12}H_7Br_3$ (390.70): C 36.87, H 1.81; found: C 36.82, H 1.66%.

2,2'-Dibromo-6-methoxybiphenyl (13)[40,41]

At –100 °C, *tert*-butyllithium (25 mmol) in pentane (18 mL) was added to a solution of 3-bromo-2-iodoanisole[45] (3.91 g, 12.5 mmol) in tetrahydrofuran (50 mL). After 45 min 1,2-dibromobenzene (1.5 mL, 3.0 g, 12.5 mmol) was added to the mixture. After 2 h at –100 °C the mixture was allowed to obtain 25 °C over a twelve hours period. Water (0.10 L) was added to the reaction mixture followed by extraction with diethyl ether (3 × 0.10 L). After crystallization from ethanol 2,2'-dibromo-6-methoxybiphenyl (**13**) was obtained as colorless cubes; yield: 2.05 g (48%); mp 93 – 95 °C; ^{1}H NMR ($CDCl_3$, 400 MHz): *d* = 7.67 (d, *J* = 8.0 Hz, 1 H), 7.38 (t, *J* = 7.5 Hz, 1 H), 7.3 (m, 4 H), 6.92 (d, *J* = 8.1 Hz, 1 H), 3.73 (s, 3 H); ^{13}C NMR ($CDCl_3$, 101 MHz): *d* = 157.9, 138.8, 132.3, 131.6, 131.4, 129.9, 129.1, 127.5, 127.1, 124.5, 124.2, 110.0, 56.1; anal. calcd. for $C_{13}H_{10}Br_2O$ (342.03): C 45.65, H 2.95; found: C 45.32, H 2.85%.

2,6-Difluoro-2'-bromo-3-methoxybiphenyl (14)

At –75 °C, 2,4-difluoroanisole (3.6 g, 25 mmol) was added to a solution of *sec*-butyllithium (25 mmol) in cyclohexane (15 mL) and tetrahydrofuran (35 mL). After 45 min, 1,2-dibromobenzene (3.0 mL, 5.9 g, 25 mmol) was added and the mixture was allowed to reach room temperature in the course of 12 h. Evaporation of the solvent followed by column chromatography on silica gel (100 mL) using cyclohexane as the eluent afforded **14** as colorless oil; yield: 6.06 g (81%); ^{1}H NMR (300 MHz, $CDCl_3$): *d* = 7.72 (dd, *J* = 8.1, 0.9 Hz, 1 H), 7.4 (m, 1 H), 7.3 (m, 2 H), 6.9 (m, 2 H), 3.93 (s, 3 H); ^{13}C NMR (75 MHz, $CDCl_3$): *d* = 153.4 (dd, *J* = 240, 5 Hz), 149.4 (dd, *J* = 249, 7 Hz), 144.3 (d, *J* = 7 Hz), 132.1, 131.9, 130.8,

130.4, 127.2, 124.3, 118.7 (dd, *J* = 22, 5 Hz), 113.1 (d, *J* = 10 Hz), 110.0 (d, *J* = 4 Hz), 56.7; anal. calcd. for $C_{13}H_9BrF_2O$ (299.11): C 52.20, H 3.03; found: C 52.41, H 3.13%.

2,6-Difluoro-2'-bromo-4-methoxybiphenyl (15)

Prepared analogously as biphenyl **14** from 3,5-difluoroanisole (3.6 g, 25 mmol) affording colorless needles; yield: 5.83 g (78%); mp 34 – 36 °C (from hexanes); ^{1}H NMR (300 MHz, $CDCl_3$): *d* = 7.61 (d, *J* = 7.9 Hz, 1 H), 7.29 (td, *J* = 7.3, 1.1 Hz, 1 H), 7.2 (m, 2 H), 6.47 (d, *J* = 9.2 Hz, 2 H), 3.76 (s, 3 H); ^{13}C NMR (75 MHz, $CDCl_3$): *d* = 161.0 (t, *J* = 14 Hz), 160.4 (dd, *J* = 247, 10 Hz, 2 C), 132.8, 132.5, 131.0, 129.9, 127.2, 125.1, 110.5 (t, *J* = 21 Hz), 97.9 (d, *J* = 10 Hz), 97.5 (d, *J* = 28 Hz), 55.6; anal. calcd. for $C_{13}H_9BrF_2O$ (299.11): C 52.20, H 3.03; found: C 52.10, H 3.10%.

2,6-Difluoro-3-chloro-2'-bromobiphenyl (16)

Prepared analogously as biphenyl **14** from 1-chloro-2,4-difluorobenzene (1.5 g, 10 mmol) affording a colorless oil; yield: 2.06 g (68%); ^{1}H NMR (300 MHz, $CDCl_3$): *d* = 7.76 (d, *J* = 7.9 Hz, 1 H), 7.4 (m, 2 H), 7.3 (m, 2 H), 7.0 (m, 1 H); ^{13}C NMR (75 MHz, $CDCl_3$): *d* = 158.8 (dd, *J* = 249, 6 Hz), 155.7 (dd, *J* = 251, 7 Hz), 133.3, 132.3, 130.9, 130.7, 130.6 (d, *J* = 3 Hz), 127.7, 124.7, 119.7 (t, *J* = 21 Hz), 117.3 (dd, *J* = 19, 4 Hz), 112.4 (dd, *J* = 23, 4 Hz); anal. calcd. for $C_{12}H_6BrClF_2$ (303.53): C 47.48, H 1.99; found: C 47.50, H 2.00%.

2,6-Difluoro-4-chloro-2'-bromobiphenyl (17)

Prepared analogously as biphenyl **14** from 1-chloro-3,5-difluorobenzene (1.5 g, 10 mmol) affording a colorless oil; yield: 2.22 g (73%); ^{1}H NMR (300 MHz, $CDCl_3$): *d* = 7.71 (d, *J* = 8.1 Hz, 1 H), 7.41 (td, *J* = 9.1, 1.3 Hz, 1 H), 7.3 (m, 2 H), 7.05 (symm. m, 2 H); ^{13}C NMR (75 MHz, $CDCl_3$): *d* = 159.9 (dd, *J* = 251, 9 Hz, 2 C), 133.0 (t, *J* = 13 Hz), 132.9, 132.0, 130.4, 129.9, 127.3, 124.4, 116.9 (t, *J* = 19 Hz), 112.7 (d, *J* = 28 Hz, 2 C); anal. calcd. for $C_{12}H_6BrClF_2$ (303.53): C 47.48, H 1.99; found: C 47.85, H 2.13%.

2'-Bromo-3,5,6-trimethoxy-2-methylbiphenyl (18)

Prepared analogously as biphenyl **11** starting from 3-bromo-1,2,5-trimethoxy-4-methylbenzene[46] (2.6 g, 10 mmol). The pure compound could be obtained column chromatography on silica gel using ethyl acetate/cyclohexane (1 : 9) as eluent. Crystallization from ethyl acetate/hexanes (1 : 5) afforded **18** as colorless needles; yield: 1.4 g (42%); mp 204 – 208 °C; ^{1}H NMR (400 MHz, $CDCl_3$): *d* = 7.70 (dd, *J* = 7.9, 1.1 Hz, 1 H), 7.3 (m, 4 H), 3.89 (s, 3 H), 3.60 (s, 3 H), 3.38 (s, 3 H), 2.32 (s, 3 H); ^{13}C NMR (75 MHz, $CDCl_3$): *d* = 149.3, 148.8, 144.9, 136.3, 132.4, 131.9, 129.7, 128.8, 126.8, 126.0, 124.8, 114.5, 60.7, 60.3, 56.1, 16.1; anal. calcd. for $C_{16}H_{17}BrO_3$ (337.21): C 56.99, H 5.08; found C 57.35, H 5.21%.

Tetrasubstituted Biaryls by *Homo*-Aryl/Aryl Coupling

10,10'-Dibromo-[9,9']biphenanthrenyl (19)[29]

At –75 °C, butyllithium (5.0 mmol) in hexanes (3.1 mL) was added to a solution of 9,10-dibromophenanthrene[47] (3.3 g, 10 mmol) in tetrahydrofuran (20 mL). The mixture was then warmed to 25 °C over a two hours period and hydrolyzed with a 1.0 M aqueous hydrochloric acid solution (0.10 L). After separation of the phases, the aqueous layer was extracted with dichloromethane (3 × 0.20 L). The combined organic layers were dried over sodium sulfate before being evaporated to dryness. Upon crystallization from ethanol, colorless needles were obtained; yield: 1.61 g (63%); mp 344 – 348 °C (dec.); ^{1}H-NMR (400 MHz, DMSO-d_6): d = 9.10 (d, J = 8.2 Hz, 2 H), 9.05 (d, J = 8.5 Hz, 2 H), 8.46 (d, J = 8.0 Hz, 2 H), 7.91 (symm. m, 4 H), 7.77 (t, J = 7.9 Hz, 2 H), 7.46 (t, J = 7.6 Hz, 2 H), 7.13 (d, J = 8.1 Hz, 2 H); anal. calcd. for $C_{28}H_{16}Br_2$ (512.24): C 65.65, H 3.15; found C 65.59, H 3.37%.

2-Bromo-4,5,2',6'-tetramethoxybiphenyl (20)

At 0 °C, butyllithium (5.5 mmol), in hexanes (3.6 mL) was added dropwise to a solution of 1,3-dimethoxybenzene (5.5 mmol, 0.8 g, 0.7 mL) in tetrahydrofuran (13 mL). Immediately after complete addition, the solution was allowed to reach 25°C. After 3.5 h, the reaction mixture was cooled to -78 °C and a solution of 1,2-dibromo-4,5-dimethoxybenzene[48] (5.0 mmol, 1.5 g) in tetrahydrofuran (2.5 mL) was added dropwise. The reaction mixture was allowed to reach 25 °C during a twelve hours period. Water (10 mL) was added, followed by extraction with ethyl acetate (4 × 10mL). The combined organic layers were dried over sodium sulfate, filtered and evaporated. The residue was purified by chromatography on silica gel and crystallization from methanol affording 2-bromo-4,5,2',6'-tetramethoxybiphenyl (**20**) as colorless cubes; yield: 1.0 g (55%); mp 70 - 72°C; ^{1}H NMR (300 MHz, $CDCl_3$): d = 7.25 (t, J = 8.4 Hz, 1 H), 7.05 (s, 1 H), 6.66 (s, 1 H), 6.57 (d, J = 8.4 Hz, 2 H), 3.82 (s, 3 H), 3.75 (s, 3 H), 3.68 (s, 6 H); ^{13}C NMR (75 MHz, $CDCl_3$): d = 157.9 (2C), 148.6, 148.1, 129.4, 127.9, 118.8, 115.2, 114.9, 104.2 (2C), 56.0 (4C); HR-MS: m/z = 375.0188, calcd. for $C_{16}H_{17}BrO_4Na$: 375.0202.

Synthesis of Mono- and Diphosphines

2',6-Bis(dicyclohexylphosphino)-2-methoxybiphenyl (21)[40,41]

At –75 °C, butyllithium (0.10 mol) in hexanes (63 mL) was added to a solution of 24 (17 g, 50 mmol) in tetrahydrofuran (0.25 L). After 15 min at –75 °C, the mixture was treated with a 2.0 M solution of chlorodicyclohexylphosphine (22 mL, 24 g, 0.10 mol) in toluene (50 mL). The mixture was allowed to reach 25 °C and treated with a saturated aqueous solution of ammonium chloride (0.10 L). The mixture was extracted with ethyl acetate (3 × 50 mL), and the combined organic layers were dried over sodium sulfate. The diphosphine **21** was

obtained after evaporation of the solvents and crystallization form methanol (0.10 L) as colorless cubes; yield: 43 g (74%); mp 220 – 221 °C (dec.); ^{1}H NMR (400 MHz, $CDCl_3$): *d* = 7.56 (symm. m, 1 H), 7.4 (m, 3 H), 7.16 (d, *J* = 7.5 Hz, 1 H), 7.08 (symm. m, 1 H), 6.88 (d, *J* = 7.8 Hz, 1 H), 3.66 (s, 3 H), 1.7 (m, 24 H), 1.2 (m, 20 H). 6.99 (ddd, *J* = 7.7, 2.9, 1.3 Hz, 1 H), 6.8 (m, 3 H), 6.63 (d, *J* = 8.6 Hz, 1 H), 3.01 (s, 3 H); ^{13}C NMR (101 MHz, $CDCl_3$): *d* = 157.5 (d, *J* = 9 Hz), 148.4 (d, *J* = 25 Hz), 141.7, 137.8 (d, *J* = 19 Hz), 136.2 (d, *J* = 18 Hz), 134.0, 132.4, 127.1, 125.0, 124.1, 108.9, 54.0, 35.9 (d, *J* = 16 Hz), 34.0 (d, *J* = 19 Hz), 32.5 (d, *J* = 16 Hz), 32.1 (d, *J* = 20 Hz), 31.7 (d, *J* = 16 Hz), 30.6, 29.7, 28.7 (d, *J* = 10 Hz), 28.0, 27.2, 26.4 (d, *J* = 13 Hz); ^{31}P NMR (162 MHz, $CDCl_3$): *d* = –9.9 (d, *J* = 12.1 Hz), –11.5 (d, *J* = 12.2 Hz); anal. calcd. for $C_{37}H_{54}OP_2$ (576.79): C 77.05, H 9.44; found: C 77.17, H 9.14%.

2,6-Difluoro-3-methoxy-2'-dicyclohexylphosphinobiphenyl (22)

Biphenyl **14** (1.5 g, 5.0 mmol) was added to a solution of *tert*-butyllithium (10 mmol) in pentanes (6.0 mL) and diethyl ether (15 mL) at –75 °C. After 15 min at –75 °C, a solution of chlorodicyclohexylphosphine (1.0 mL, 1.0 g, 5.0 mmol) in tetrahydrofuran (5.0 mL) was added to the reaction mixture. Evaporation of the solvent followed by column chromatography on silica gel (100 mL) using cyclohexane as the eluent gave a colorless oil. Crystallization from methanol afforded colorless needles; yield: 1.83 g (88%); mp 35 – 37 °C; ^{1}H NMR (300 MHz, $CDCl_3$): *d* = 7.65 (dd, *J* = 5.7, 2.9 Hz, 1 H), 7.44 (symm. m., 2 H), 7.25 (dd, *J* = 9.0, 3.4 Hz, 1 H), 6.96 (td, *J* = 8.9, 5.1 Hz, 1 H), 6.87 (td, *J* = 9.2, 1.7 Hz, 1 H), 3.92 (d, *J* = 2.1 Hz, 3 H), 1.81 (m, 12 H), 1.22 (m, 10 H); ^{13}C-NMR (75 MHz, $CDCl_3$) *d* 153.6 (dd, *J* = 240, 5 Hz), 151.0 (dd, *J* = 246, 7 Hz), 147.7 (d, *J* = 9 Hz), 144.0 (d, *J* = 33 Hz), 132.9 (d, *J* = 4 Hz), 130.8 (d, *J* = 6 Hz), 128.6, 127.8, 112.3 (dd, *J* = 9, 3 Hz), 109.4 (dd, *J* = 24, 5 Hz), 56.9, 34.2 (dd, *J* = 13, 3 Hz), 30.2 (d, *J* = 17 Hz), 28.7 (dd, *J* = 5, 3 Hz), 27.4, 27.2 (d, *J* = 8 Hz), 26.4 (d, *J* = 2 Hz); anal. calcd. for $C_{25}H_{31}F_2OP$ (416.48): C 72.10, H 7.50; found:L C 72.41, H 7.62%.

2,6-Difluoro-4-methoxy-2'-dicyclohexylphosphino-1,1'-biphenyl (23)

As described in the preceding paragraph, starting from biphenyl **15** (1.5 g, 5.0 mmol) afforded colorless needles of **23**; yield: 1.69 g (81%); mp 38 – 40 °C; ^{1}H-NMR (300 MHz, $CDCl_3$): *d* = 7.6 (m, 1 H), 7.4 (m, 2 H), 7.2 (m, 2 H), 6.49 (d, *J* = 8.7 Hz, 1 H), 3.87 (s, 3 H), 1.6 (m, 12 H), 1.1 (m, 10 H); ^{13}C-NMR (75 MHz, $CDCl_3$): δ = 160.5 (dd, *J* = 244, 12 Hz), 160.3 (t, *J* = 15 Hz), 137.7 (d, *J* = 33 Hz), 136.7 (d, *J* = 22 Hz), 132.9, 131.2 (d, *J* = 6 Hz), 128.5, 127.7, 112.1 (td, *J* = 21, 8 Hz) 97.4 (symm. m), 56.0 (s), 34.0 (d, *J* = 17 Hz), 30.3 (d, *J* = 24 Hz), 28.7 (d, *J* = 8 Hz), 27.3 (d, *J* = 13 Hz), 27.0 (d, *J* = 18 Hz); anal. calcd. for$C_{25}H_{31}F_2OP$ (416.48): C 72.10, H 7.50; found: C 72.33, H 7.58%.

6-Fluoro-2,2'-bis(dicyclohexylphosphino)biphenyl (24)[29]

Biphenyl **11** (1.6 g, 5.0 mmol) was added to a solution of butyllithium (10 mmol) in hexanes (6.3 mL) and tetrahydrofuran (20 mL) at –75 °C. After 15 min at –75 °C, a solution of chlorodicyclohexylphosphine (2.0 mL, 2.0 g, 10 mmol) in tetrahydrofuran (10 mL) was added to the reaction mixture. Evaporation of the solvent followed by column chromatography on silica gel (100 mL) using cyclohexane as eluent gave a colorless oil. Crystallization from ethyl acetate/hexanes (1:5) afforded colorless needles; yield: 2.23 g (79%); mp 184 – 186 °C; ^{1}H NMR (400 MHz, $CDCl_3$): *d* = 7.5 (m, 1 H), 7.3 (m, 4 H), 7.1 (m, 1 H), 1.7 (m, 24 H), 1.2 (m, 20H); ^{13}C-NMR (101 MHz, toluene-d_8): *d* = 162.7 (d, *J* = 11 Hz), 160.2 (d, *J* = 10 Hz), 143.8 (d, *J* = 5 Hz), 143.8 (d, *J* = 5.0 Hz), 139.6 (d, *J* = 22 Hz), 137.1 (d, *J* = 20 Hz), 133.6 (d, *J* = 5 Hz), 133.4, 133.1, 128.5 (d, *J* = 22 Hz), 128.2 (d, *J* = 12 Hz), 115.9 (d, *J* = 24 Hz), 37.8 (d, *J* = 18 Hz), 36.8 (d, *J* = 17 Hz), 34.6 (d, *J* = 17 Hz), 34.4 (d, *J* = 17 Hz), 31 (m), 30.9 (d, *J* = 14 Hz), 30.5 (d, *J* = 9 Hz), 30.4 (d, *J* = 8 Hz), 28 (m), 27.4; anal. calcd. for $C_{36}H_{51}FP_2$ (564.75): C 76.56, H 9.10; found: C 76.43, H 9.04.

Dicyclohexyl-(4,5,2',6'-tetramethoxybiphenyl-2-yl)phosphine (25)

At –78°C, *tert*-butyllithium (4.0 mmol) in pentane (2.3 mL) was added dropwise to a solution of 2-bromo-4,5,2',6'-tetramethoxy-biphenyl (**20**, 2.0 mmol, 0.7 g) in tetrahydrofuran (10 mL). After 1 h, a solution of chlorodicyclohexylphosphine (2.0 mol, 0.5 g, 0.5 mL) in toluene (2.0 mL) was added dropwise. One hour later, the mixture was allowed to reach 25 °C and was filtered on silica gel with diethyl ether as eluent. The organic layer was evaporated and the crude product was purified by chromatography on silica gel which afforded the monophosphine **25** as a white solid; yield: 0.07 g (7%); mp 133 – 135 °C; ^{1}H NMR (300 MHz, $CDCl_3$): *d* = 7.22 (t, *J* = 8.4 Hz, 1 H), 6.97 (s, 1 H), 6.60 (d, *J* = 3.0 Hz, 1 H), 6.50 (d, *J* = 8.4 Hz, 2 H), 3.85 (s, 3 H), 3.76 (s, 3 H), 3.61 (s, 6 H), 1.8- 1.4 (m, 13 H), 1.3- 0.8 (m, 12 H); ^{13}C NMR (75 MHz, $CDCl_3$): *d* = 157.7 (2C), 149.2, 147.1, 136.2 (d, *J* = 34 Hz), 126.8, 126.6 (d, *J* = 17 Hz), 119.8 (d, *J* = 7 Hz), 114.9 (d, *J* = 4 Hz), 114.8 (d, *J* = 7 Hz), 103.1 (2C), 56.1, 55.5, 55.2 (2C), 34.4 (d, *J* = 14 Hz), 30.1 (d, *J* = 17 Hz), 29.2 (d, *J* = 9 Hz), 27.6- 27.4 (m), 26.6; ^{31}P NMR (161 MHz, $CDCl_3$): *d* = –8.0; HR-MS: *m/z*=471.2637, calcd. for $C_{28}H_{39}O_4P$: 471.2659.

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