Note

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Concise synthesis of phospholene and its P-stereogenic derivatives

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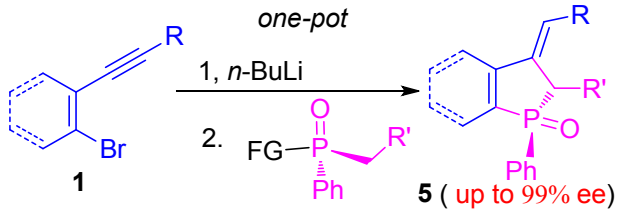
Supporting Information



ABSTRACT: A simple method to build phospholene derivatives has been achieved in a one-pot reaction with readily available *o*-alkynylarylbromides and alkylphosphine oxides. This method is also applicable to synthesize P-stereogenic phospholenes and the resulting chiral phosphine was utilized as a ligand for coordination chemistry.

Recent advanced studies on five-membered phosphacycles (Fig. 1), such as phosphole **A**,[1] phospholenes **C** and **D**,[2] and phospholane **E**,[3] have made possible a variety of novel electro-optic materials, [1] chiral ligands,[4] and organocatalysts.[2, 3] Hence, there is a constant quest for efficient synthetic methods to access these phosphacycles with diverse structural features from simple and readily available starting materials. It is well known that the electronic and stereochemical properties of these five-membered phosphorus heterocycles are directly related to their degree of unsaturation. Both the experiment and calculation results confirmed phospholene **B**,[5] a skeleton-rearranged phosphole, has even higher nucleophilicity and stability of the P-stereogenic center than the mother phosphole. In contrast to the rich chemistry and applications of phosphole **A**, phospholene **C**, **D**, and phospholane **E**, the substrate scope of phospholene **B** is significantly limited. We now report a convenient method to synthesize phospholene **B** from chloroalkylphosphine oxides and *α*-bromoarylacetylene, and its applications to the preparation of P-stereogenic phospholene.

Our group[6] and others[7,8] have demonstrated that *o*-alkynylphenylphosphanes are excellent precursors for the formation of phosphacycles. The *α*-lithiation and subsequent reaction with electrophiles is one of the convenient methods for the post-functionalization of alkylphosphine oxides.[9] This led us to hypothesize that intramolecular trapping of *α*-lithiated alkylphosphine oxide with the alkynyl group might occur to give 5-exo-dig and/or 6-endo-dig cyclization products (Scheme 1).

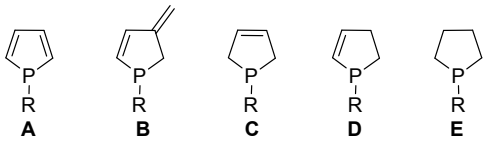
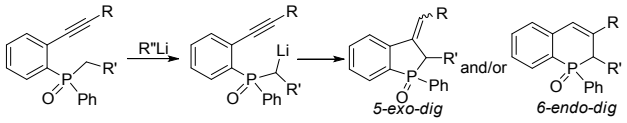


Figure 1. Five-membered phosphacycles.

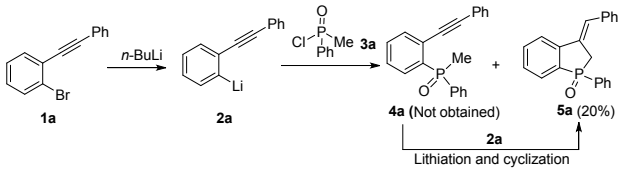
Scheme 1. A proposed ring-close reaction.



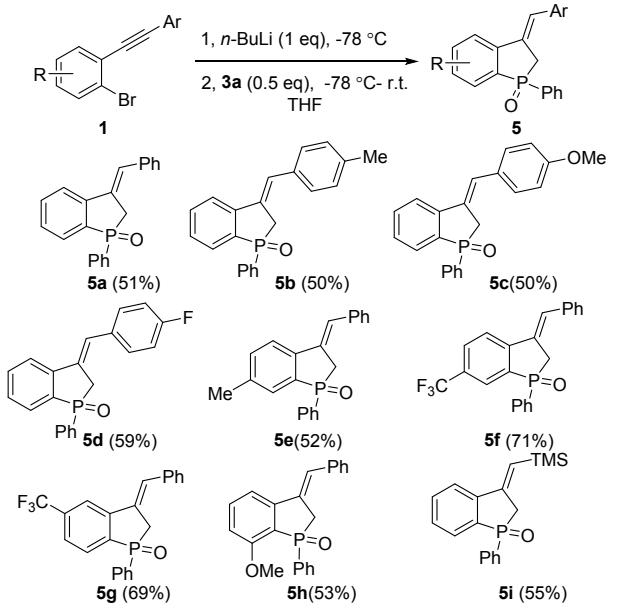
The study began with the synthesis of **4a** from *o*-alkynylbromobenzene **1a** and a methyl-substituted chlorophosphine oxide **3a**. First, one equivalent of bromide **1a** was treated with 1 equiv of *n*-BuLi in THF to give aryl lithium **2a**, then 1 equiv of **3a** was added to the reaction mixture at -78 °C, and stirred at the same temperature for 1 hour. Surprisingly, after warm up to room temperature and workup, the corresponding phosphine

oxide **4a** was not detected. We found a small amount (20 % isolated yield) of a new product **5a** was generated and its structure was tentatively assigned by NMR spectroscopy analysis. The stereochemistry of the exocyclic double bond was later confirmed by X-ray single-crystal analysis of **(S_P)-5c** (eq.4, Figure S1). This unexpected outcome indicated that a lithiation of the methyl group of the in-situ formed **4a** by aryl lithium **2a** and subsequent intramolecular nucleophilic cyclization of the carbon anion. Indeed, the reaction with 2 equiv of **2a** gave benzophospholene **5a** in fairly good yield (Scheme 2). Given that aryl lithium played dual roles in one reaction: a nucleophile (for coupling with chlorophosphine oxide) and a lithiation reagent (deprotonation of methyl group), the further research with this one-pot phospholene formation was carried out with 2 equiv of *o*-alkynylbromobenzenes (Scheme 2).

Scheme 2. **The unexpected direct formation of 5a**.

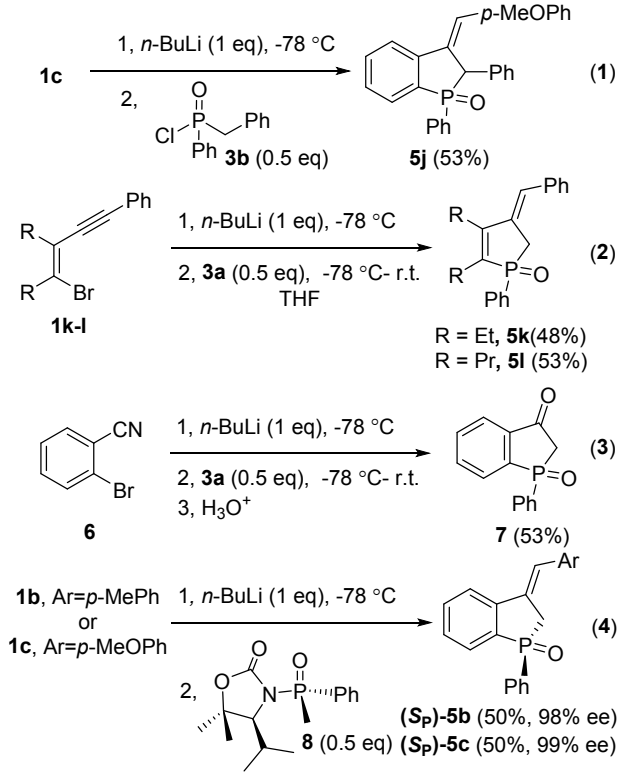


Scheme 3. Synthesis of annulated phospholenes.



In addition to Ar = Ph group (**5a**), Ar substrates bearing a methyl (**5b**) and methoxy (**5c**) were well compatible with this reaction (Scheme 3). A better result was obtained with electron-withdrawing fluorine-substituted **5d**. To further investigate the substituent's impact, we synthesized several anchor aryl moiety-containing substituents with varied electronic effects. When the anchor carried electronically neutral (Me, **5e**) or electron-donating (OMe, **5h**), the benzophospholenes (**5e** and **5h**) were isolated in around 50% yield. In contrast, when *meta* or *para* positions (to alkynyl) of the anchor was occupied by electron-withdrawing trifluoromethyl substituent, products **5g-f** were obtained in higher yield (69-71%). At the same time, we also obtained in fair yield with trimethylsilyl substituted **5i**. These suggest that substituents on the alkynyl moiety exert electronic effects on reaction efficiency.

Apart from methylchlorophosphine oxide **3a**, also benzylchlorophosphine oxide **3b**[10] was utilized. And an α-phenyl-substituted phospholene **5j** was obtained (eq. 1). Interestingly, bromoenynes **1k-l**[11] also underwent cyclization, which yielded the unfused phospholenes **5k** and **5l** smoothly in 48-53% yields (eq. 2). When *o*-bromoarylcyanide **6**[12] was used (eq. 3), phosphindole oxide **7** was isolated after hydrolysis.

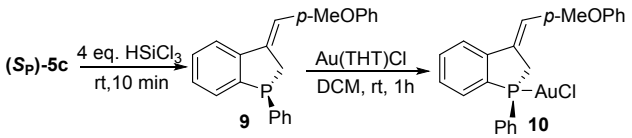


Gratifyingly, the highly efficient chiral auxiliary-based strategy was applicable to the asymmetric synthesis of P-stereogenic phospholenes. Replacing chloromethylphosphine oxide **3a** with P-

chiral oxazolidinone **8**[13] (eq.4), gave the P-stereogenic product **(S_P)-5b** or **(S_P)-5c** in excellent enantioselectivity ($\geqslant$ 98% ee).

The optically active phosphine oxide **(S_P)-5c** was reduced with chlorosilane[14] to give phosphine **9**. The reaction of this *in-situ* prepared and air-sensitive tertiary phosphine with Au(I) complex resulted in the efficient formation of the corresponding phosphine−Au(I) complex **10** in dichloromethane at room temperature. The absolute configuration of **9** was established by single-crystal X-ray diffraction analysis of its gold complex **10** (Scheme 4, Figure S2).

Scheme 4. **Preparation of chiral phosphine Au(I) complex 10**.



In summary, we developed a facile method for the one-pot synthesis of phospholenes from the readily available reagents. This finding also provides a practical and high stereoselective route to P-stereogenic phosphacycles. Further improving the reaction efficiency and expanding the potential of this chemistry and developing new asymmetric synthesis with this new kind of chiral phosphine are underway in our laboratories and will be reported in due course.

EXPERIMENTAL SECTION

General methods and materials: All reactions were performed under nitrogen using solvents dried by standard methods. ^{1}H NMR, ^{13}C NMR, and ^{31}P NMR spectra were recorded on 300, 75, and 121 MHz respectively with a Bruker AV 300 spectrometer. Chemical shifts are expressed in parts per million (ppm), coupling constants (J values) are reported in Hertz [Hz]. Chemical shift multiplicities are reported as follows: (s = singlet, d = doublet, t = triplet, m = multiplet, dd = doublet of doublet). HRMS spectra were obtained on an Agilent 1290-6540 UHPLC Q-Tof HR-MS spectrometer. X-ray crystallographic analyses were performed on an Oxford diffraction Gemini E diffractometer. Melting Point: heating rate: 4 °C/min, the thermometer was not corrected. Enantiomer excesses were determined by chiral HPLC analysis on Chiralcel IA/IB in comparison with the authentic racemates. Chiral HPLC analysis recorded on Shimadzu labtotal LC-20AT. Silica gel (200-300 mesh) was used for the chromatographic separations. All commercially available reagents were used without further purification. *o*-Bromoarylcyanide and chloro(tetrahydrothiophene)gold(I) are commercial reagents. Compounds **1**, **3**, **8** are known.[10,11,13,15]

General procedure for the synthesis of *o*-alkynylbromobenzenes (1a-1i): Palladium-catalyzed cross-coupling of substituted 2-bromoiodobenzene with an arylacetylene was performed following literature reports.[15] In 200 mL Schlenk bottle, 438 mg $PdCl_2(PPh_3)_2$ (2.5 mol%), 237 mg CuI (5 mol%) were added, and the bottle charged with nitrogen, 100 mL of Et_3N, bromoiodobenzene (25 mmol) and arylacetylene (27.5 mmol) were added sequentially in. After stirring at room temperature for 5 h, the reaction was quenched with 50 mL of saturated aqueous solution of NH_4Cl. The resulting mixture was then diluted with 100 mL of EtOAc, and washed with 2 × 30 mL of brine. The combined organic phase was dried over $MgSO_4$, filtered and the filtrate was concentrated in vacuo. The resulting residue was purified by column chromatography (hexanes) to afford the product**.**

1a: The general procedure was followed using 7.07 g of 2-bromoiodobenzene (25 mmol), 2.80 g of phenylacetylene (27.5 mmol). Purification by column chromatography (hexanes) afforded **1a** as yellow oil (6.36 g, 99% yield).

1b: The general procedure was followed using 7.07 g of 2-bromoiodobenzene (25 mmol), 3.19 g of 4-ethynyltoluene (27.5 mmol). Purification by column chromatography (hexanes) afforded **1b** as yellow solid (6.71 g, 99% yield).

1c: The general procedure was followed using 7.07 g of 2-bromoiodobenzene (25 mmol), 3.63 g of 4-ethynylanisole (27.5 mmol). Purification by column chromatography (hexanes) afforded **1c** as white solid (7.18 g, 99% yield).

1d: The general procedure was followed using 7.07 g of 2-bromoiodobenzene (25 mmol), 3.30 g of 4-fluorophenylacetylene (27.5 mmol). Purification by column chromatography (hexanes) afforded **1d** as yellow solid (6.53 g, 95% yield).

1e: The general procedure was followed using 7.42 g of 3-bromo-4-iodotoluene (25 mmol), 2.80 g of phenylacetylene (27.5 mmol). Purification by column chromatography (hexanes) afforded **1e** as yellow solid (6.71 g, 99% yield).

1f: The general procedure was followed using 8.77 g of 3-bromo-4-iodobenzotrifluoride (25 mmol), 2.80 g of phenylacetylene (27.5 mmol). Purification by column chromatography (hexanes) afforded **1f** as yellow solid (7.96 g, 98% yield).

1g: The general procedure was followed using 8.77 g of 4-bromo-3-iodobenzotrifluoride (25 mmol), 2.80 g of phenylacetylene (27.5 mmol). Purification by column chromatography (hexanes) afforded **1g** as yellow liquid (7.96 g, 98% yield).

1h: The general procedure was followed using 7.83 g of 2-bromo-3-iodoanisole (25 mmol), 2.80 g of phenylacetylene (27.5 mmol).

Purification by column chromatography (hexanes: EtOAc = 20: 1) afforded **1h** as yellow liquid (5.67 g, 79% yield).

1i: The general procedure was followed using 7.07 g of 2-bromoiodobenzene (25 mmol), 2.70 g of trimethylsilylacetylene (27.5 mmol) Purification by column chromatography (hexanes) afforded **1i** as yellow oil (6.26 g, 99 % yield).

General procedure for the synthesis of 1-bromo-1,3-enynes (1k,1l): These compounds were prepared following a known procedure.[11] To a mixture of $Pd(OAc)_2$ (224 mg, 1 mmol) and the appropriate internal alkyne (20 mmol), in CH_3CN (50 mL) was added the corresponding bromoalkyne (24 mmol). The reaction mixture was stirred for 20 h at r t and the solution was purified by column chromatography (hexanes) afforded product.

1k: The general procedure was followed using 1.64 g of 3-hexyne (20 mmol) and 4.34 g (bromoethynyl) benzene (24 mmol). Purification by column chromatography (hexanes) afforded **1k** as colorless oil (3.47 g, 66% yield).

1l: The general procedure was followed using 2.20 g of 4-octyne (20 mmol) and 4.34 g (bromoethynyl) benzene (24 mmol). Purification by column chromatography (hexanes) afforded **1l** as yellow oil (3.79 g, 65% yield).

Synthesis of 3a: This compound was prepared following a known procedure.[12] The title compound was obtained as colorless oil (12.6 g, 62% yield, over 3 steps).

Synthesis of 8: This compound was prepared following a known procedure.[12] **8** was recrystallized from ether to as white solid (15.5 g, 85% yield).

Synthesis of 3b: This compound was prepared following a known procedure.[10] **3b** was obtained as white solid (384 mg, 50% yield, over 4 steps).

General procedure for the synthesis of 5a-5l, 7: *o*-Alkynylbromobenzenes (2 mmol) was added in a 50 mL Schlenk bottle under nitrogen, 30 mL THF was added. *n*-BuLi (2.0 mmol, 1.6 M in hexane) was added dropwise at -78 °C under nitrogen. The reaction mixture was stirred for 1 h at this temperature, then **3a** (181 mg, 1 mmol) was added at -78 °C, then stirred at -78 °C for 1 h, after that the temperature was slowly raised to room temperature and stirred for 2 h. Water (30 mL) was added and the organic phase was extracted with EtOAc (3 × 40 mL), dried over anhydrous $MgSO_4$, filtered and the solvent was removed in vacuo, the resulting residue was purified by column chromatography (DCM: EA = 5: 1) to afford the product**.**

5a: The general procedure was followed using 514 mg **1a** (2 mmol), 1.25 mL *n*-BuLi (2.0 mmol, 1.6 M in hexane) and 181 mg **3a** (1 mmol). Purification by column chromatography (DCM: EA = 5: 1) afforded **5a** as white solid (161 mg, 51% yield). m p: 113.4-114.6 °C. ^{31}P $\{^1H\}$ NMR (121 MHz, $CDCl_3$) δ: 45.42. ^1H NMR (300 MHz, $CDCl_3$) δ: 7.95-7.85 (m, 1H), 7.78-7.52 (m, 4H), 7.52-7.35 (m, 8H), 7.34-7.23 (m, 2H), 3.60-3.30 (m, 2H). ^{13}C $\{^1H\}$ NMR (75MHz, $CDCl_3$) δ: 146.4 (d, $^2J_{PC}$ = 23.3 Hz, C), 136.6 (s, C), 133.2 (d, $^4J_{PC}$ = 2.2 Hz, CH), 133.1 (d, $^1J_{PC}$ = 97.5 Hz, C), 132.9 (d, $^1J_{PC}$ = 100.5 Hz, C), 132.5 (d, $^2J_{PC}$ = 7.1 Hz, C), 132.0 (d, $^4J_{PC}$ = 2.8 Hz, CH), 130.5 (d, $^2J_{PC}$ = 10.4 Hz, 2CH), 129.4 (d, $^2J_{PC}$ = 11.0 Hz, CH), 129.3 (d, $^3J_{PC}$ = 8.3 Hz, CH), 129.1 (s, 2CH), 128.7 (s, 2CH), 128.7 (d, $^3J_{PC}$ = 6.0 Hz, 2CH), 127.8 (s, CH), 125.7 (d, $^3J_{PC}$ = 10.6 Hz, CH), 121.6 (d, $^2J_{PC}$ = 12.1 Hz, CH), 34.9 (s, $^1J_{PC}$ = 71.1 Hz, CH_2). HRMS (ESI) m/z: $[M+H]^+$ Calcd for $C_{21}H_{18}OP$ 317.1090; Found 317.1092.

5b: The general procedure was followed using 542 mg **1b** (2 mmol), 1.25 mL *n*-BuLi (2.0 mmol, 1.6 M in hexane) and 181 mg **3a** (1 mmol), Purification by column chromatography (DCM: EA = 5: 1) afforded **5b** as white solid (165 mg, 50% yield). m p: 192.3-193.5 °C. ^{31}P $\{^1H\}$ NMR (121 MHz, $CDCl_3$) δ: 45.49. ^1H NMR (300 MHz, $CDCl_3$) δ: 7.91-7.83 (m, 1H), 7.76-7.65 (m, 1H), 7.65-7.33 (m, 9H), 7.32-7.16 (m, 3H), 3.58-3.29 (m, 2H), 2.36 (s, 3H). ^{13}C $\{^1H\}$ NMR (75 MHz, $CDCl_3$) δ: 146.6 (d, $^2J_{PC}$ = 24.0 Hz, C), 137.9 (s, C), 133.8 (s, C), 133.2 (d, $^4J_{PC}$ = 2.2 Hz, CH), 133.0 (d, $^1J_{PC}$ = 99.8 Hz, C), 133.0 (d, $^1J_{PC}$ = 101.2 Hz, C), 132.0 (d, $^4J_{PC}$ = 2.8 Hz, CH), 131.5 (d, $^2J_{PC}$ = 7.0 Hz, C), 130.5 (d, $^3J_{PC}$ = 10.4 Hz, 2CH), 129.4 (s, 2CH), 129.3(d, $^3J_{PC}$ = 2.3 Hz, CH), 129.1 (d, $^3J_{PC}$ = 5.0 Hz, CH), 129.0 (s, 2CH), 128.7 (d, $^2J_{PC}$ = 12.4 Hz, 2CH), 125.7 (d, $^3J_{PC}$ = 10.8 Hz, CH), 121.5 (d, $^2J_{PC}$ = 11.9 Hz, CH), 34.9 (d, $^1J_{PC}$ = 70.0 Hz, CH_2), 21.3 (s, CH_3). HRMS (ESI) m/z: $[M+H]^+$ Calcd for $C_{22}H_{20}OP$ 331.1246; Found 331.1249. The product was analyzed by HPLC to determine the enantiomeric excess: 0% ee (Chiralpak AD-H, *n*-hexane / i-propanol = 70: 30, flow rate 1.0 mL/min, λ= 254 nm); tr = 13.531 and 20.116 min.

5c: The general procedure was followed using 574 mg **1c** (2 mmol), 1.25 mL *n*-BuLi (2.0 mmol, 1.6 M in hexane) and 181 mg **3a** (1 mmol). Purification by column chromatography (DCM: EA = 5: 1) afforded **5c** as pain yellow solid (173 mg, 50% yield). m p: 128.7-131.4 °C. ^{31}P $\{^1H\}$ NMR (121 MHz, $CDCl_3$) δ: 45.87. ^1H NMR (300 MHz, $CDCl_3$) δ: 7.92-7.72 (m, 1H), 7.72-7.52 (m, 4H), 7.52-7.34 (m, 6H), 7.31-7.12 (m, 1H), 7.00-6.81 (m, 2H), 3.82 (s, 3H), 3.60-3.26 (m, 2H). ^{13}C $\{^1H\}$ NMR (75 MHz, $CDCl_3$) δ: 159.2 (s, C)**,** 146.8 (d, $^2J_{PC}$ = 24.7 Hz, C), 133.1 (d, $^4J_{PC}$ = 2.0 Hz, CH), 133.0 (d, $^1J_{PC}$ = 99.8 Hz, C), 132.7 (d, $^1J_{PC}$ = 99.0 Hz, C), 131.9 (d, $^4J_{PC}$ = 2.9 Hz, CH), 130.5 (d, $^3J_{PC}$ = 10.5 Hz, 2CH), 130.5 (s, 2CH), 130.3 (d, $^2J_{PC}$ = 6.8 Hz, C), 129.3 (s, C), 129.2 (d, $^3J_{PC}$ = 7.7 Hz, CH), 129.0 (d, $^3J_{PC}$ = 10.8 Hz, CH), 128.7 (d, $^2J_{PC}$ = 12.2 Hz, 2CH), 125.3 (d, $^3J_{PC}$ = 10.9 Hz, CH), 121.4 (d, $^2J_{PC}$ = 12.0 Hz, CH), 114.1 (s, 2CH), 55.3 (s, CH_3), 34.9 (d, $^1J_{PC}$ = 72 Hz, CH_2). HRMS (ESI) m/z: $[M+H]^+$ Calcd for $C_{22}H_{20}O_2P$ 347.1195; Found 347.1198. The product was analyzed by HPLC to determine the enantiomeric excess: 0% ee (Chiralpak AD-H, *n*-hexane / i-propanol = 70/30, flow rate 1.0 mL/min, λ= 254 nm); tr = 12.971 and 23.660 min.

5d: The general procedure was followed using 550 mg **1d** (2 mmol), 1.25 mL *n*-BuLi (2.0 mmol, 1.6 M in hexane) and 181mg **3a** (1 mmol). Purification by column chromatography (DCM: EA = 5: 1) afforded **5d** as white solid (197 mg, 59% yield). m p: 123.7-124.8 °C. ^{31}P $\{^1H\}$ NMR (121MHz, $CDCl_3$) δ: 45.20. ^1H NMR (300 MHz, $CDCl_3$) δ: 7.93-7.83 (m, 1H), 7.74-7.53 (m, 4H), 7.53-7.34 (m, 6H), 7.27 (s, 1H), 7.14-6.99 (m, 2H), 3.54-3.22 (m, 2H). ^{13}C $\{^1H\}$ NMR (75 MHz, $CDCl_3$) δ: 162.0 (d, $^1J_{FC}$ = 248.9 Hz, C), 146.2 (d, $^2J_{PC}$ = 24.5 Hz, C), 133.2 (d, $^4J_{PC}$ = 2.2 Hz, CH), 133.0 (d, $^1J_{PC}$ = 99.0 Hz, C), 132.7 (d. $^1J_{PC}$ = 100.0 Hz, C), 132.7 (d, $^2J_{PC}$ = 3.5Hz, C), 132.3 (dd, $^4J_{FC}$ = 6.9Hz, $^4J_{PC}$ = 1.8 Hz, C), 132.1 (d, $^4J_{PC}$ = 2.9 Hz, CH), 130.7 (d, $^3J_{PC}$ = 8.1 Hz, 2CH), 130.6 (d, $^2J_{PC}$ = 10.5 Hz, 2CH), 129.5 (d, $^3J_{PC}$ = 10.8 Hz, CH), 129.3 (d, $^3J_{PC}$ = 8.3 Hz, CH), 128.7 (d, $^3J_{FC}$ = 12.3 Hz, 2CH), 124.5 (d, $^3J_{PC}$ = 11.0 Hz, CH), 121.6 (d, $^2J_{PC}$ = 11.8 Hz, CH), 115.7 (d, $^2J_{FC}$ = 21.5 Hz, 2CH), 34.8 (d, $^1J_{PC}$ = 71.4 Hz, CH_2). HRMS (ESI) m/z: $[M+H]^+$ Calcd for $C_{21}H_{17}FOP$ 355.0996; Found 355.0997.

5e: The general procedure was followed using 542 mg **1e** (2 mmol), 1.25 mL *n*-BuLi (2.0 mmol, 1.6 M in hexane) and 181mg **3a** (1 mmol). Purification by column chromatography (DCM: EA = 5: 1) afforded **5e** as white solid (171 mg, 52% yield). m p: 155.6-

156.2 °C. ^{31}P {^{1}H} NMR (121 MHz, $CDCl_3$) δ: 45.47. ^{1}H NMR (300 MHz, $CDCl_3$) δ: 7.82-7.75 (m, 1H), 7.64-7.53 (m, 2H), 7.50-7.35 (m, 9H), 7.31-7.23 (m, 2H), 3.60-3.20 (m, 2H), 2.37 (s, 3H). ^{13}C {^{1}H} NMR (75 MHz, $CDCl_3$) δ: 143.9 (d, $^{2}J_{PC}$ = 24.6 Hz, C), 139.8 (d, $^{3}J_{PC}$ = 10.9 Hz, C), 136.7 (s, C), 134.4 (d, $^{4}J_{PC}$ = 2.5 Hz, CH), 133.7 (d, $^{1}J_{PC}$ = 98.0 Hz, C), 133.0 (d, $^{1}J_{PC}$ = 99.8 Hz, C), 132.5 (d, $^{2}J_{PC}$ = 7.0 Hz, C), 131.9 (d, $^{4}J_{PC}$ = 3.0 Hz, CH), 130.5 (d, $^{3}J_{PC}$ = 10.4 Hz, 2CH), 129.2 (d, $^{3}J_{PC}$ = 8.3 Hz, CH), 129.0 (s, 2CH), 128.7 (d, $^{2}J_{PC}$ = 12.0 Hz, 2CH), 128.7 (s, 2CH), 127.6 (s, CH), 124.6 (d, $^{3}J_{PC}$ = 10.9 Hz, CH), 121.5 (d, $^{2}J_{PC}$ = 12.9 Hz, CH), 35.0 (d, $^{1}J_{PC}$ = 71.1 Hz, CH_2), 21.3 (s, CH_3). HRMS (ESI) m/z: $[M+H]^+$ Calcd for $C_{22}H_{20}OP$ 331.1246; Found 331.1249.

5f: The general procedure was followed using 650 mg **1f** (2 mmol), 1.25 mL *n*-BuLi (2.0 mmol, 1.6 M in hexane) and 181 mg **3a** (1 mmol). Purification by column chromatography (DCM: EA=5:1) afforded **5f** as pain yellow solid (272 mg, 71% yield). m p: 132.9-134.7 °C. ^{31}P {^{1}H} NMR (121 MHz, $CDCl_3$) δ: 44.04. ^{1}H NMR (300 MHz, $CDCl_3$) δ: 8.04-7.91 (m, 2H), 7.88-7.80 (m, 1H), 7.66-7.53 (m, 2H), 7.53-7.39 (m, 7H), 7.36-7.28 (m, 1H), 3.64-3.38 (m, 2H). ^{13}C {^{1}H} NMR (75 MHz, $CDCl_3$) δ: 149.5 (d, $^{2}J_{PC}$ = 25.2 Hz, C)**,** 135.9 (s, C), 134.1 (d, $^{1}J_{PC}$ = 98.6 Hz, C), 132.4 (d, $^{4}J_{PC}$ = 3.0 Hz, CH), 132.0 (d, $^{1}J_{PC}$ = 100.5 Hz, C), 131.3 (d, $^{2}J_{PC}$ = 7.1 Hz, C), 131.2 (dd, $^{3}J_{FC}$ =33.0 Hz, $^{2}J_{PC}$ =11 Hz, C), 130.5 (d, $^{3}J_{PC}$ = 10.5 Hz, 2CH), 130.1-129.8 (m, CH), 129.3 (s, 2CH), 128.9 (d, $^{2}J_{PC}$ = 12.8 Hz, 2CH), 128.8 (s, 2CH), 128.5 (s, CH), 128.3 (d, $^{3}J_{PC}$ = 10.8 Hz, CH), 127.2 (q, $^{1}J_{FC}$ = 273.0 Hz, C), 126.9-126.2 (m, CH), 122.3 (d, $^{3}J_{PC}$ = 11.8 Hz, CH), 35.0 (d, $^{1}J_{PC}$ = 71.3 Hz, CH_2). HRMS (ESI) m/z: $[M+H]^+$ Calcd for $C_{22}H_{17}F_3OP$ 385.0964; Found 385.0960.

5g: The general procedure was followed using 650 mg **1g** (2 mmol), 1.25 mL *n*-BuLi (2.0 mmol, 1.6 M in hexane) and 181 mg **3a** (1 mmol). Purification by column chromatography (DCM: EA = 5: 1) afforded **5g** as pain yellow solid (265 mg, 69% yield). m p: 92.3-94.7 °C. ^{31}P {^{1}H} NMR (121 MHz, $CDCl_3$) δ: 44.17. ^{1}H NMR (300 MHz, $CDCl_3$) δ: 8.13 (s, 1H) 7.90-7.76 (m, 1H), 7.70-7.53 (m, 3H), 7.53-7.36 (m, 8H), 7.36-7.28 (m, 1H), 3.67-3.32 (m, 2H). ^{13}C {^{1}H} NMR (75 MHz, $CDCl_3$) δ: 146.9 (d, $^{2}J_{PC}$ = 25.0 Hz, C)**,** 137.0 (d, $^{1}J_{PC}$ = 96.9 Hz, C), 136.0 (s, C), 135.2 (dd, $^{2}J_{FC}$ = 32.4 Hz, $^{4}J_{PC}$ = 2.2Hz, C), 132.4 (d, $^{4}J_{PC}$ = 2.9 Hz, CH), 132.0 (d, $^{1}J_{PC}$ = 101.3 Hz, C), 131.7 (d, $^{2}J_{PC}$ = 6.1 Hz, C), 130.5 (d, $^{3}J_{PC}$ = 10.5 Hz, 2CH), 130.1 (d, $^{3}J_{PC}$ = 8.6 Hz, CH), 129.2 (s, 2CH), 128.9 (d, $^{2}J_{PC}$ = 12.0Hz, 2CH), 128.8 (s, 2CH), 128.4(s, CH), 127.4 (d, $^{2}J_{PC}$ = 10.7 Hz, CH), 127.2 (q, $^{1}J_{FC}$ = 271.5 Hz, C), 126.0-125.6 (m, CH), 118.9-118.4 (m, CH), 34.9 (d, $^{1}J_{PC}$ = 71.2 Hz , CH_2). HRMS (ESI) m/z: $[M+H]^+$ Calcd for $C_{22}H_{17}F_3OP$ 385.0964; Foun 385.0960.

5h: The general procedure was followed using 574 mg **1h** (2 mmol), 1.25 mL *n*-BuLi (2.0 mmol, 1.6 M in hexane) and 181 mg **3a** (1 mmol). Purification by column chromatography (DCM: EA = 5: 1) afforded **5h** as white solid (183 mg, 53% yield). m p: 144.5-145.7 °C. ^{31}P {^{1}H} NMR (121 MHz, $CDCl_3$) δ: 44.29. ^{1}H NMR (300 MHz, $CDCl_3$) δ: 7.69-7.52 (m, 3H), 7.51-7.31 (m, 8H), 7.31-7.20 (m, 2H), 6.85-6.74 (m, 1H), 3.75 (s, 3H), 3.57-3.24 (m, 2H). ^{13}C {^{1}H} NMR (75 MHz, $CDCl_3$) δ : 161.3 (d, $^{2}J_{PC}$ = 2.1 Hz, C), 148.7 (d, $^{2}J_{PC}$ = 22.0 Hz, C), 136.6 (s, C), 135.5 (d, $^{4}J_{PC}$ = 1.6 Hz, CH), 133.0 (d, $^{1}J_{PC}$ = 103.5 Hz, C), 132.5 (d, $^{2}J_{PC}$ = 7.0 Hz, C), 131.7 (d, $^{4}J_{PC}$ = 2.9 Hz, CH), 130.3 (d, $^{3}J_{PC}$ = 10.8 Hz, 2CH), 129.1 (s, 2CH), 128.6 (s, 2CH), 128.5 (d, $^{2}J_{PC}$ = 12.6 Hz, 2CH), 127.8 (s, CH), 126.0 (d, $^{3}J_{PC}$ = 11.7 Hz, CH), 120.6 (d, $^{1}J_{PC}$ = 99.4 Hz, C), 113.7 (d, $^{3}J_{PC}$ = 11.9 Hz, CH), 110.2 (d, $^{3}J_{PC}$ = 6.0 Hz, CH), 55.8 (s, CH_3), 35.3 (d, $^{1}J_{PC}$ = 72.5 Hz, CH_2). HRMS (ESI) m/z: $[M+H]^+$ Calcd for $C_{22}H_{20}O_2P$ 347.1195; Found 347.1198.

5i: The general procedure was followed using 506 mg **1i** (2 mmol), 1.25 mL *n*-BuLi (2.0 mmol, 1.6 M in hexane) and 181mg **3a** (1 mmol). Purification by column chromatography (DCM: EA = 5: 1) afforded **5i** as pain yellow solid (171 mg, 55% yield). m p: 70.4-72.3 °C. ^{31}P {^{1}H} NMR (121 MHz, $CDCl_3$) δ: 37.24. ^{1}H NMR (300 MHz, $CDCl_3$) δ: 7.79-7.65 (m, 2H), 7.64-7.53 (m, 3H), 7.53-7.36 (m, 4H), 5.92 (s, 1H), 3.58-3.07 (m, 2H), 0.25 (s, 9H). ^{13}C {^{1}H} NMR (75 MHz, $CDCl_3$) δ : 147.4 (d, $^{2}J_{PC}$ = 5.9 Hz, C), 145.4 (d, $^{2}J_{PC}$ = 20.4 Hz, C), 136.3 (d, $^{1}J_{PC}$ = 98.8 Hz, C), 132.6 (d, $^{1}J_{PC}$ = 99.0 Hz, C), 132.1 (d, $^{4}J_{PC}$ = 2.1 Hz, CH), 131.9 (d, $^{4}J_{PC}$ = 3.0 Hz, CH), 130.6 (d, $^{3}J_{PC}$ = 10.3 Hz, 2CH), 129.6 (d, $^{2}J_{PC}$ = 10.8 Hz, CH), 129.3 (d, $^{3}J_{PC}$ = 5.4 Hz, CH), 129.2 (d, $^{3}J_{PC}$ = 7.6 Hz, CH), 128.6 (d, $^{2}J_{PC}$ = 12.4 Hz, 2CH), 125.2 (d, $^{3}J_{PC}$ = 10.5 Hz, CH), 43.0 (d, $^{1}J_{PC}$ = 69.7 Hz, CH_2), 0.1 (s, $3CH_3$). HRMS (ESI) m/z: $[M+Na]^+$ Calcd for $C_{18}H_{21}OPSiNa$ 335.0991; Found 335.0995.

5j: The general procedure was followed using 574 mg **1c** (2 mmol), 1.25 mL *n*-BuLi (2.0 mmol, 1.6 M in hexane) and 250 mg **3b** (1 mmol). Purification by column chromatography (DCM: EA = 5: 1) afforded **5j** as white solid (248 mg, 53% yield). m p: 60.4-61.6 °C. This solid was recrystallized from the mixture of CH_2Cl_2/hexane before submitted to NMR analysis. ^{31}P {^{1}H} NMR (121 MHz, $CDCl_3$) δ: 52.59. ^{1}H NMR (300 MHz, $CDCl_3$) δ: 8.08-7.97 (m, 1H) 7.76-7.67 (m, 1H), 7.62-7.50 (m, 1H), 7.50-7.39 (m, 2H), 7.37-7.08 (m, 9H), 6.88-6.97 (m, 3H), 6.90-6.79 (m, 2H), 6.75-6.60 (m, 2H), 4.89 (d, $^{2}J_{PH}$ = 19.6 Hz, 1H), 3.75 (s, 3H). ^{13}C {^{1}H} NMR (75 MHz, $CDCl_3$) δ: 159.2 (s, C), 149.4 (d, $^{2}J_{PC}$ = 23.3 Hz, C), 149.0 (d, $^{1}J_{PC}$ = 93.0 Hz, C), 136.8 (d, $^{2}J_{PC}$ = 4.1 Hz, C), 133.8 (d, $^{2}J_{PC}$ = 7.6 Hz, C), 133.7 (d, $^{4}J_{PC}$ = 2.1 Hz, CH), 132.3 (d, $^{3}J_{PC}$ = 9.4 Hz, 2CH), 131.7 (d, $^{4}J_{PC}$ = 2.9 Hz, CH), 130.6 (s, 2CH), 130.5 (d, $^{1}J_{PC}$ = 96.0 Hz, C), 130.0 (d, $^{3}J_{PC}$ = 8.2 Hz, CH), 129.1 (d, $^{2}J_{PC}$ =11 Hz, CH), 129.0 (d, $^{3}J_{PC}$ =10.6 Hz, CH), 128.7 (s, CH), 128.6 (d, $^{4}J_{PC}$ = 3.0 Hz, 2CH), 128.0 (s, C), 127.6 (d, $^{2}J_{PC}$ = 12.3 Hz, 2CH), 126.3 (d, $^{3}J_{PC}$ = 3.4 Hz, CH), 121.6 (d, $^{3}J_{PC}$ = 11.5 Hz, CH), 113.8 (s, 2CH), 55.2 (s, CH_3), 52.9 (d, $^{1}J_{PC}$ = 66.0 Hz, CH). HRMS (ESI) m/z: $[M+H]^+$ Calcd for $C_{28}H_{24}O_2P$ 423.1508; Found 423.1511.

5k: The general procedure was followed using 526 mg **1k** (2 mmol), 1.25 mL *n*-BuLi (2.0 mmol, 1.6 M in hexane), and 181 mg **3a** (1 mmol). Purification by column chromatography (DCM: EA = 5: 1) afforded **5k** as yellow liquid (154 mg, 48% yield). ^{31}P {^{1}H} NMR (121 MHz, $CDCl_3$) δ: 51.07. ^{1}H NMR (300 MHz, $CDCl_3$) δ: 7.70-7.58 (m, 2H), 7.51-7.31 (m, 7H), 7.29-7.21 (m, 1H), 6.80 (s, 1H), 3.31-3.03 (m, 2H), 2.69-2.57 (m, 2H), 2.57-2.22 (m, 2H), 1.29-1.20 (m, 3H), 1.04-0.95 (m, 3H). ^{13}C {^{1}H} NMR (75 MHz, $CDCl_3$) δ: 158.3 (d, $^{2}J_{PC}$ = 22.6 Hz, C) 137.9 (d, $^{1}J_{PC}$ = 90.3 Hz, C), 136.9 (s, C), 135.1 (d, $^{2}J_{PC}$ = 12.7 Hz, C), 133.1 (d, $^{1}J_{PC}$ = 96.6 Hz, C), 131.7 (d, $^{4}J_{PC}$ = 3.0 Hz, CH), 130.6 (d, $^{3}J_{PC}$ = 10.2 Hz, 2CH), 129.0 (s, 2CH), 128.6 (d, $^{2}J_{PC}$ = 11.3 Hz, 2CH), 128.6 (s, 2CH), 127.5 (s, CH), 125.1 (d, $^{3}J_{PC}$ = 11.5 Hz， CH), 33.1 (d, $^{1}J_{PC}$ = 71.3 Hz. CH_2), 20.0 (d, $^{2}J_{PC}$ = 5.6 Hz, CH_3), 19.8 (s, CH_3), 13.9 (d, $^{3}J_{PC}$ = 2.2 Hz, CH_2), 13.7 (d, $^{3}J_{PC}$ = 1.5 Hz, CH_2). HRMS (ESI) m/z: $[M+H]^+$ Calcd for $C_{21}H_{24}OP$ 323.1559; Found 323.1562.

5l: The general procedure was followed using 582 mg **1l** (2 mmol), 1.25 mL *n*-BuLi (2.0 mmol, 1.6 M in hexane), and 181 mg **3a** (1 mmol). Purification by column chromatography (DCM: EA = 5: 1) afforded **5l** as colorless liquid (185 mg, 53% yield). ^{31}P {^{1}H} NMR (121 MHz, $CDCl_3$) δ: 51.57. ^{1}H NMR (300 MHz, $CDCl_3$) δ: 7.72-7.55 (m, 2H), 7.49-7.29 (m, 7H), 7.26-7.19 (m, 1H), 6.79 (s, 1H), 3.32-2.97 (m, 2H), 2.66-2.53 (m, 2H), 2.53-2.11 (m, 2H), 1.75-1.50 (m, 2H), 1.47-1.32 (m, 2H), 1.17-0.99 (m, 3H), 0.93-0.77 (m, 3H). ^{13}C {^{1}H} NMR (75 MHz, $CDCl_3$) δ: 157.0 (d, $^{2}J_{PC}$ = 22.9 Hz, C), 137.3 (d, $^{1}J_{PC}$=89.3 Hz, C), 136.9 (s, C), 135.5 (d, $^{2}J_{PC}$ = 13.0 Hz,

C), 133.1 (d, $^{1}J_{PC}$ = 96.3 Hz, C), 131.7 (d, $^{4}J_{PC}$ = 2.8 Hz, CH), 130.5 (d, $^{3}J_{PC}$ = 10.2 Hz, 2CH), 129.0 (s, 2CH), 128.6 (d, $^{2}J_{PC}$= 11.3 Hz, 2CH), 128.6 (s, 2CH), 127.5 (s, CH), 125.3 (d, $^{3}J_{PC}$ = 11.4 Hz, CH), 33.1 (d, $^{1}J_{PC}$ = 71.2 Hz, CH), 29.2 (d, $^{3}J_{PC}$ = 9.3 Hz, CH_2), 28.9 (d, $^{2}J_{PC}$ = 14.8 Hz, CH_2), 22.5 (d, $^{3}J_{PC}$ = 4.5 Hz, CH_2), 22.5 (s, CH_2), 14.6 (s, CH_3), 14.5 (s, CH_3). HRMS (ESI) m/z: $[M+H]^+$ Calcd for $C_{23}H_{28}OP$ 351.1872; Found 351.1871.

7: The general procedure was followed using 364 mg 2-bromobenzonitrile (2 mmol), 1.25 mL *n*-BuLi (2.0 mmol, 1.6 M in hexane), and 181 mg **3a** (1 mmol). Purification by column chromatography (DCM: EA = 5: 1) afforded **7** as pain yellow liquid (128 mg 53% yield). ^{31}P {^{1}H} NMR (121 MHz, $CDCl_3$) δ: 29.85. ^{1}H NMR (300 MHz, $CDCl_3$) δ: 8.13-8.01 (m, 1H), 7.95-7.74 (m, 3H), 7.68-7.52 (m, 3H), 7.52-7.41 (m, 2H), 3.43-3.07 (m, 2H). ^{13}C {^{1}H} NMR (75 MHz, $CDCl_3$) δ: 194.4 (d, $^{2}J_{PC}$ = 13.4 Hz, C), 141.7 (d, $^{1}J_{PC}$ = 90.8 Hz, C), 141.4 (d, $^{2}J_{PC}$ = 12.7 Hz, C), 135.9 (d, $^{3}J_{PC}$ = 10.9 Hz, CH), 133.7 (d, $^{4}J_{PC}$ = 2.2 Hz, CH), 132.6 (d, $^{4}J_{PC}$ = 3.1 Hz, CH), 130.9 (d, $^{1}J_{PC}$ = 105.0 Hz, C), 130.7 (d, $^{3}J_{PC}$ = 10.7 Hz, 2CH), 129.4 (d, $^{3}J_{PC}$ = 6.0 Hz, CH), 129.0 (d, $^{2}J_{PC}$ = 12.75Hz, 2CH), 124.7 (d, $^{2}J_{PC}$ = 11.3 Hz, CH), 40.2 (d, $^{1}J_{PC}$ = 72.0 Hz, CH_2). HRMS (ESI) m/z: $[M+H]^+$ Calcd for $C_{14}H_{12}O_2P$ 243.0569; Found 243.0567.

Synthesis of (S_P)-5b and (S_P)-5c: *o*-Alkynylbromobenzenes (2 mmol) was added in a 50 mL Schlenk bottle under nitrogen, 30 mL THF was added, 1.25 mL *n*-BuLi (2.0 mmol, 1.6 M in hexane) was added dropwise at -78 °C under nitrogen. The reaction mixture was stirred for 1 h at this temperature, then **8** (295 mg, 1 mmol) was added at -78 °C, then the temperature was slowly raised to room temperature and stirred for 2 h. Water (30 mL) was added and the organic phase was extracted with EtOAc (3 x 40 mL), dried over anhydrous $MgSO_4$, filtered and the solvent was removed in vacuo, the resulting residue was purified by column chromatography (DCM: EA = 5: 1) to afford the product.

(S_P)-5b: The general procedure was followed using 542 mg **1b** (2 mmol), 1.25 mL *n*-BuLi (2.0 mmol, 1.6 M in hexane), and 181 mg **3a** (1 mmol). Purification by column chromatography (DCM: EA = 5: 1) afforded **(S_P)-5b** as white solid (165 mg, 50% yield). m p: 192.3-193.5 °C. ^{31}P {^{1}H} NMR (121 MHz, $CDCl_3$) δ: 45.49. ^{1}H NMR (300 MHz, $CDCl_3$) δ: 7.91-7.83 (m, 1H), 7.76-7.65 (m, 1H), 7.65-7.33 (m, 9H), 7.32-7.16 (m, 3H), 3.58-3.29 (m, 2H), 2.36 (s, 3H). ^{13}C {^{1}H} NMR (75 MHz, $CDCl_3$) δ: 146.6 (d, $^{2}J_{PC}$ = 24.0 Hz, C), 137.9 (s, C), 133.8 (s, C), 133.1 (d, $^{4}J_{PC}$ = 2.2 Hz, CH), 133.0 (d, $^{1}J_{PC}$ = 99.8 Hz, C), 133.0 (d, $^{1}J_{PC}$ = 101.2 Hz, C), 132.0 (d, $^{4}J_{PC}$ = 2.8 Hz, CH), 131.5 (d, $^{2}J_{PC}$ = 7.0 Hz, C), 130.5 (d, $^{3}J_{PC}$ = 10.4 Hz, 2CH), 129.4 (s, 2CH), 129.2 (d, $^{3}J_{PC}$ = 8.3 Hz, CH), 129.2 (d, $^{3}J_{PC}$ = 10.5 Hz, CH), 129.0 (s, 2CH), 128.7 (d, $^{2}J_{PC}$ = 12.4 Hz, 2CH), 125.7 (d, $^{3}J_{PC}$ = 10.8 Hz, CH), 121.5 (d, $^{2}J_{PC}$ = 11.9 Hz, CH), 34.9 (d, $^{1}J_{PC}$ = 70.0 Hz, CH_2), 21.3 (s, CH_3). HRMS (ESI) m/z: $[M+H]^+$ Calcd for $C_{22}H_{20}OP$ 331.1246; Found 331.1249. The product was analyzed by HPLC to determine the enantiomeric excess: 98% ee (Chiralpak AD-H, *n*-hexane / *i*-propanol = 80: 20, flow rate 1.0 mL/min, λ= 254 nm); tr = 13.771 and 20.297 min.

(S_P)-5c: The general procedure was followed using 574 mg **1c** (2 mmol), 1.25 mL *n*-BuLi (2.0 mmol, 1.6 M in hexane), and 181 mg **3a** (1 mmol). Purification by column chromatography (DCM: EA = 5: 1) afforded **(S_P)-5c** as pain yellow solid (173 mg, 50% yield). m p: 128.7-131.4 °C. ^{31}P {^{1}H} NMR (121 MHz, $CDCl_3$) δ: 45.87. ^{1}H NMR (300 MHz, $CDCl_3$) δ: 7.92-7.72 (m, 1H), 7.72-7.52 (m, 4H), 7.52-7.34 (m, 6H), 7.31-7.12 (m, 1H), 7.00-6.81 (m, 2H), 3.82 (s, 3H), 3.60-3.26 (m, 2H). ^{13}C {^{1}H} NMR (75 MHz, $CDCl_3$) δ: 159.2 (s, C), 146.8 (d, $^{2}J_{PC}$ = 24.7 Hz, C), 133.1 (d, $^{4}J_{PC}$ = 2.0 Hz, CH), 133.0 (d, $^{1}J_{PC}$ = 99.8 Hz, C), 132.7 (d, $^{1}J_{PC}$ = 99.0 Hz, C), 131.9 (d, $^{4}J_{PC}$ = 2.9 Hz, CH), 130.5 (d, $^{3}J_{PC}$ = 10.5 Hz, 2CH), 130.5 (s, 2CH), 130.3 (d, $^{2}J_{PC}$ = 6.8 Hz, C), 129.3 (s, C), 129.3 (d, $^{3}J_{PC}$ = 8.3 Hz, CH), 129.0 (d, $^{3}J_{PC}$ = 10.7 Hz, CH), 128.7 (d, $^{2}J_{PC}$ = 12.2 Hz, 2CH), 125.3 (d, $^{3}J_{PC}$ = 10.9 Hz, CH), 121.4 (d, $^{2}J_{PC}$ = 12.0 Hz, CH), 114.1 (s, 2CH), 55.3 (s, CH_3), 34.9 (d, $^{1}J_{PC}$ = 72 Hz, CH_2). HRMS (ESI) m/z: $[M+H]^+$ Calcd for $C_{22}H_{20}O_2P$ 347.1195; Found 347.1198. The product was analyzed by HPLC to determine the enantiomeric excess: 99% ee (Chiralpak AD-H, *n*-hexane / i-propanol = 70 : 30, flow rate 1.0 mL/min, λ= 254 nm); tr = 13.044 and 23.873 min.

Synthesis of 10: 173 mg **(S_P)-5c** (0.5 mmol) was added in a 25 mL Schlenk bottle under nitrogen, 5 mL toluene was added, then 2 mL trichlorosilane (4 eq, 2 mmol) was added dropwise under nitrogen, the reaction mixture was stirred for 10 mim at room temperature, reaction completely. The solvent removed under reduced pressure, the crude residue was submitted to the next step without purification.

The product of the last step was added in a 25 mL Schlenk bottle under nitrogen, 5 mL distilled dichloromethane was added under nitrogen, 150 mg chloro (tetrahydrothiophene) gold (I) (0.5 mmol) was added, the reaction mixture was stirred for 1 h at room temperature, reaction completely, the solvent removed under reduced pressure. The resulting residue was purified by column chromatography (hexanes: dichloromethane = 1: 8) to afford the product **10** as white solid (267 mg, 95% yield). ^{31}P {^{1}H} NMR (121 MHz, $CDCl_3$) δ: 27.65. ^{1}H NMR (300 MHz, $CDCl_3$) δ: 7.81-7.49 (m, 1H), 7.44-7.31 (m, 11H), 6.97-6.89 (m, 2H), 3.83 (s, 3H), 3.81-3.38 (m, 2H). ^{13}C {^{1}H} NMR (75 MHz, $CDCl_3$) δ: 159.4 (s, C), 146.6 (d, $^{2}J_{CP}$ = 15.4 Hz, C), 133.1 (d, $^{2}J_{CP}$ = 8.3 Hz, C), 133.0 (d, $^{2}J_{CP}$ = 14.3 Hz, 2CH), 132.6 (d, $^{4}J_{CP}$ = 2.2 Hz, CH), 132.4 (d, $^{3}J_{CP}$ = 2.6 Hz, CH), 131.3 (d, $^{2}J_{CP}$ = 13.9 Hz, CH), 131.3 (d, $^{1}J_{CP}$ = 60.8 Hz, C), 131.0 (d, $^{1}J_{CP}$=55.5 Hz, C), 130.6 (s, 2CH), 129.3 (d, $^{3}J_{CP}$ = 12.2 Hz, 2CH), 128.8 (s, C), 126.4 (d, $^{3}J_{CP}$ = 7.5 Hz, CH), 122.1 (d, $^{3}J_{CP}$ = 8.9 Hz, CH), 114.2 (s, 2CH), 114.2 (s, CH), 55.4 (s, CH_3), 34.1 (d, $^{1}J_{CP}$ = 41.1 Hz, CH_2).

Procedure for Gram-Scale Preparation of 5c: **1c** (2.87 g, 10 mmol) was added in a 200 mL Schlenk bottle under nitrogen, 150 mL THF was added, 6.25 mL *n*-BuLi (2.0 mmol, 1.6 M in hexane) was added dropwise at -78 °C. The reaction mixture was stirred for 1 h at this temperature, then **3a** (905 mg, 5 mmol) was added at -78 °C, then the temperature was slowly raised to room temperature and stirred for 2 h. After that, H_2O (50 mL) was added and the organic phase was extracted with EtOAc (3 x 40 mL), dried over anhydrous $MgSO_4$, filtered and the solvent was removed in vacuo, the resulting residue was purified by column chromatography (DCM: EA = 5: 1) to afford **5c** as a white solid (865 mg, 50% yield).

X-Ray crystallography: Crystals suitable for X-ray crystallography were obtained by crystallisation from a mixture of *n*-hexane and dichloromethane (**(S_P)-5c, 10**). X-ray crystallographic analyses were performed on an Oxford diffraction Gemini E diffractometer. The data confirm the molecular configuration. Complete structural data have been deposited with the Cambridge Crystallographic Data Centre, and their CCDC numbers are 1978510 **(S_P)-5c**), 1978512(**10**).

ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available free of charge on the ACS Publications website at: X-ray diffraction data and spectroscopic data for all new compounds including ^{1}H and ^{13}C NMR spectra (PDF).

Accession Codes

CCDC 1978510 (**(S_P)-5c**), 1978512(**10**) contains the supplementary crystallographic data for this paper. These data can be obtained free of charge via www. ccdc.cam. ac. Uk /data_request/cif, or by emailing data_ request@ccdc.cam.ac.uk, or by contacting The CambridgeCrystallographic Data Centre, 12 Union Road, Cambridge CB21EZ, UK; fax: +44 1223 336033

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