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Lewis Acid-Controlled Regioselective Phosphorylation of 2-Indolylmethanols with Diarylphosphine Oxides: Synthesis of Highly Substituted Indoles

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Abstract

The Lewis acid-promoted phosphorylation of 2-indolylmethanols with diarylphosphine oxides is described. The regioselectivity of the reaction can be modulated by the choice of rare earth metal Lewis acid, offering a highly selective approach to structurally diverse indole derivatives in up to 97% yield for over 50 examples. This strategy features high selectivity, good functional group tolerance, and easy scalability. The utility of this method is further highlighted by facile modification of the products to access novel indole-based phosphine ligand.

Graphical Abstract

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Notes

The authors declare no competing financial interest.

Supporting Information

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Reaction condition optimization, NMR and LC–MS spectra (PDF)

Crystallographic data for compound **3la** (CIF)

Crystallographic data for compound **4ag** (CIF)

INTRODUCTION

The indole nucleus widely exists in natural products and pharmaceutical drugs.^{1–3} Specially, indole-based phosphines have attracted significant attention due to their unique synthetic applications and pharmacological properties.⁴ For example, 3-phosphoindoles represent novel second-generation NNRTIs (non-nucleoside reverse transcriptase inhibitors), which exhibit excellent potency against HIV-1 in vitro.⁵ Therefore, various methods have been developed to prepare indole-based phosphines.⁶ Very recently, the Lu group demonstrated a new approach to phosphorylate indoles, in which diaryl-((trifluoromethanesulfonyl)oxy) phosphines are generated in situ as electrophilic phosphination reagents from diarylphosphine oxides.⁷ Thereafter, the Li group reported carbonate-catalyzed direct phosphorylation of indoles in the presence of magnesium nitrate, affording both 2- and 3-phosphorylated indoles.⁸ However, these advances focus on the phosphorylation of the simple indole skeleton. The development of novel methods to generate highly functionalized indole-based phosphine oxides is still needed.

It is well established that direct activation of benzylic, propargylic, and allylic alcohols may be achieved through S_N1 reactions by the use of Brønsted or Lewis acids,⁹ among which, indolylmethanols have attracted much attention as important and versatile reactants in organic synthesis.¹⁰ In particular, 2-indolylmethanols show great potential in the construction of indole derivatives.¹¹ As shown in Scheme 1, in the presence of Brønsted acid (B–H), 2-indolylmethanols can be converted into their delocalized cation intermediates, which are stabilized by two Ar groups. Subsequently, the delocalized cation can be regioselectively attacked by nucleophiles at the C3-position because the two bulky Ar groups block the attack to the benzylic position.

On the basis of this strategy, the Shi group has made significant contributions to this research field. In their creative work, a series of nucleophiles including indoles, cyclic enaminones, pyrazol-5-ones, 2-naphthols et al. were successfully added to the C3-position of the indole moiety (Scheme 2a).¹² Notably, phosphine nucleophiles have not been studied in this transformation, nor have any processes been reported involve selective functionalization at the benzylic site. On the basis of our research interest in new synthetic methods to generate organophosphorus compounds,¹³ we detail our findings herein on both of these aspects. In particular, it was discovered that C3 or benzyl functionalization could be induced selectively by use of different Lewis acid catalysts (Scheme 2b).

RESULTS AND DISCUSSION

To begin, the reaction of 2-indolylmethanol **1a** and diphenylphosphine oxide **2a** in the presence of Lewis acids was investigated (Table 1). In an initial experiment, the reaction was performed in acetonitrile at 100 °C catalyzed by FeCl₃ (Table 1, entry 1). In contrast to a large number of reports with other nucleophiles,¹² regioisomers of the phosphine oxide adducts were generated with FeCl₃ affording **3aa** in 54% yield as well as rearranged product **4aa** in 15% yield. Further screening of Lewis acids including CuBr₂, AlCl₃, BF₃·OEt₂ and Brønsted acid TsOH (Table 1, entries 1–6) revealed that **3aa** could be obtained with complete selectivity in 85% with AlCl₃ (Table 1, entry 3). On the other hand, we discovered

that TsOH afforded solely the rearranged product **4aa** in 70% yield (Table 1, entry 4). Encouraged by these results, additional strong Lewis acids were examined including the rare earth triflates [RE(OTf)₃] and rare earth pentafluorobenzoates [RE(Pfb)₃] (Table 1, entries 7–15). Notably, the counterion (triflate, pentafluorobenzoate) of the lanthanide salt had significant impact on the regioselectivity of this transformation. RE(Pfb)₃ led to predominant formation of **3aa** while RE(OTf)₃ furnished predominantly **4aa**. Of the tested rare earth salts, Y(Pfb)₃ afforded **3aa** in the highest yield (87%, Table 1, entry 15) and Yb(OTf)₃ afforded **4aa** in the highest yield (76%, Table 1, entry 12). TfOH and pentafluorobenzoic acid, which might be generated from Yb(OTf)₃ and Y(Pfb)₃ with trace amounts of water, showed a poorer regioselectivity (Table 1, entries 16 and 17), indicating a key role of the rare earth cation. It should be noted that though AlCl₃ is cheap and works well, we then tested AlCl₃ in another two substituted examples (**1b**, **1e**). Still, Y(Pfb)₃ turned out to be the best. Variation of the amount of catalyst, solvent, temperature, and reaction time did not improve the yield of **3aa** or **4aa** further (see Supporting Information Table S1 for details). Also, it was found that the optimal reaction conditions employed in Moran's work (TfOH (10 mol %), HFIP as solvent, 100 °C, 24 h) led to the ratio of **4aa/3aa** is 69/19.¹⁴

Y(Pfb)₃, which was identified as the best catalyst for the benzylic phosphorylation of 2-indolylmethanols, was used to assess the scope of the reaction (Scheme 3). A number of 2-indolylmethanols **1** were subjected to the reactions with diphenylphosphine oxide **2a** (top of Scheme 3). Both electron-rich and electron-deficient aryl 2-indolylmethanols reacted well and with very high to complete selectivity.

The reaction of 2-indolylmethanols **1a–f** having substitution at the 4-position with methyl, methoxy, *tert*-butyl, chloro, and fluoro functional groups furnished the corresponding products **3aa–fa** in 65–87% yields. Similar results were observed with the substrates **1h–j** bearing substitution at the 3-position of the phenyl ring with methyl, fluoro, and trifluoromethyl groups, affording the corresponding products **3ha–ja** in 66–79% yields. Only trace of product **3ga** was observed for the 2-methyl substituted substrate **1g** most likely due to steric hindrance. In addition, 2-indolylmethanols bearing C-5 methyl and C-6 chloro groups gave the corresponding products **3ka**, **3la** in excellent yields. The structure of **3la** was confirmed by X-ray analysis.¹⁵ The *N*-ethyl-substrate **1m** afforded the corresponding product **3ma** in a low yield of 33%, and the *N*-methyl-protected substrate was also not effective with this protocol. Allylic strain interactions from the *N*-substituents are proposed to destabilize the planar carbocation intermediate (see below). In line with a carbocation intermediate, the transformation was less effective with ethyl (**3na** in 21% yield) vs the aryl substitution described above. Notably, the gram-scale synthesis of product **3ea** proceeded with comparable catalytic efficacy.

The scope of the phosphine oxide component was next examined (bottom of Scheme 3). Diarylphosphine oxides bearing substituents at 3- or 4-positions were all amenable to the reaction, and the yields ranged from 51 to 97%. It should be noted that the reaction of 2-indolylmethanol **1a** with **2c**, **2e** gave lower yields (51%, 57%) of corresponding products; the strong electron-donating group may limit the acidity of the phosphine oxide. Steric hindrance effect was found to be extremely detrimental, and no products were detected at all

for 2-substituted aryl derivatives **2k** and **2l**. The reaction proceeded well with bistiophenephosphine oxide **2m**, and phenyl(*p*-tolyl)phosphine oxide **2n**, furnishing the desired products in 67–94% yields. When one arene ring was replaced by ethoxy groups, the product **3ao** was obtained in 43% yield. However, diethyl phosphonate failed to give the targeted product under the current reaction conditions.

We next investigated the scope of Yb(OTf)₃-catalyzed C3-phosphorylation of 2-indolylmethanols (top of Scheme 4). Both electron-donating and electron-withdrawing substituents on the phenyl ring of 2-indolylmethanols were well tolerated. The corresponding C3-phosphorylation products were isolated in 41–79% yields (**4aa–4ja**). Notably, 2-methyl substituted **1g**, which was not active in Y(Pfb)₃-mediated reaction, successfully takes part in C3-phosphorylation, providing **4ga** in 60% yield. 2-Indolylmethanols bearing substituents on the indole ring were also well accommodated reaction (**4ka**, **4la**). Again, little or no product was observed when the *N*-ethyl substrate (**1m**) and the diethyl methanol substrate group (**1n**) were utilized.

Diarylphosphine oxides with various substituents at the 3- and 4-positions were suitable substrates for this reaction (**4ab–4aj**, **4an**). In contrast to the benzylic reaction, substrates with 2-substitution gave good reactivity for the C3-phosphorylation adduct. For example, corresponding products **4ak** and **4al** were obtained in 49% and 97% yields, respectively. We theorize that the steric hindrance of these substrates promotes rearrangement.

Bistiophenephosphine oxide **2m** was also well tolerated, giving the product **4am** in 54% yield. Ethyl phenylphosphinate failed to yield the desired product (**4ao**). Notably, this Yb(OTf)₃-catalyzed C3-phosphorylation was also executed successfully on gram-scale, delivering **4ag** with a slightly decreased 57% yield. The structure of **4ag** was secured by X-ray diffraction.¹⁵

To probe the requirements for reactivity, surrogates of the 2-indolylmethanols **1** and diarylphosphine oxides **2** were explored (Figure 1). Treatment of diphenylphosphine oxide **2a** with benzhydrol or 2-indolylphenylmethanol yielded none of the adducts under the standard reaction conditions. These results show that the indolyl ring and two phenyl groups are all necessary, consistent with the intermediacy of a delocalized carbocation. Treatment of 2-indolylmethanol **1a** with diphenylphosphine or diphenylphosphine sulfide under the standard reaction conditions resulted in no product formation.

To obtain further insight into the mechanism, a series of control experiments were performed (Scheme 5). When benzylic adduct **3aa** was treated with Yb(OTf)₃, 73% yield of rearranged product **4aa** was obtained (Scheme 5a). The same transformation did occur in the absence of Yb(OTf)₃ (**3aa** was recovered in over 90% yield) indicating that a thermal rearrangement is not responsible for the C3 adducts (Scheme 5b). However, rearranged product **4aa** was not converted to **3aa** in the presence of Y(Pfb)₃ (Scheme 5c). These results indicate the C3-phosphorylation of 2-indolylmethanols involves the benzylic phosphorylation product **3** as an intermediate. Finally, a crossover experiment was designed to distinguish whether the rearrangement was occurring via an intramolecular or intermolecular pathway (Scheme 5d). An equimolar mixture of **3ca** and **3ab** was treated with Yb(OTf)₃ in CH₃CN. Product **4ca**

was isolated in 11% yield, along with 20% of **4ab**, while no crossover products were observed, thus indicating that the rearrangement product arises from an intramolecular process.

On the basis of the experimental results and previous reports,¹² a reaction mechanism for the formation of **3** and **4** is proposed in Scheme 6. First, association of the hydroxyl group of 2-indolylmethanol **1** with the Lewis acid triggers ionization. The resultant carbocation is stabilized by resonance delocalization; allylic strain between the aryl groups and the R² group explains the lack of the reactivity of the *N*-methyl and *N*-ethyl congeners (see above).

With Y(Pfb)₃, we speculate that the perfluorobenzoate forms an ion pair such that the site with the greatest LUMO density is attacked (Figure 2). Thus, phosphine oxide **2** adds to the benzylic position cation (via path a) giving the kinetic product, benzylic adduct **3**. With Yb(OTf)₃, the more stable triflate anion¹⁶ will form a weaker ion pair, allowing reversible addition. Addition of nucleophile **2** to C3 (via path b) followed by tautomerization leads to a thermodynamic sink in the form of **4** due to the stronger vinyl-Nu bond. Resubjection of product **3** to Yb(OTf)₃ yields rearrangement product **4** (path c), providing further evidence that **4** is a thermodynamic adduct. Notably, the putative ion pair must not dissociate readily as crossover experiments (Scheme 5d) support an intramolecular transfer.

Indole-based phosphine ligands such as CMphos, amide CMPhos in combination with a palladium metal precursor have been found to be effective catalysts for Suzuki–Miyaura coupling of unactivated aryl chlorides¹⁷ and Buchwald–Hartwig amination.¹⁸ To show the utility of this method for generating useful building blocks, a number of further transformations were carried out on products obtained in the course of these studies (Scheme 7). Treatment of product **3aa** with 6 equiv of triethoxysilane and a catalytic amount of Ti(OiPr)₄ in refluxing toluene afforded corresponding phosphine **5** in 53% yield (Scheme 7a).¹⁹ Also, reduction of **4aa** using the same reagents gave phosphine **6** in 81% yield. The straightforward deprotonation of **6** by *n*-BuLi and trapping of the lithiated intermediate with PPh₂Cl afforded the indolyl bisphosphine **7** in 46% yield (Scheme 7b). *N*-Methylation of **6** using MeI gave corresponding phosphine **8** in 63% yield. Diphenylphosphine sulphides are alternative ligands that are stable to oxidation where the sulfur atom functions as a soft donor.²⁰ For this system, phosphine sulphide **9** was easily generated in 55% yield by oxidation of **6** with elemental sulfur. Thus, this strategy gives rise to novel structures for developing new indole-based phosphine ligands.

CONCLUDING REMARKS

In summary, we have developed a method for selective phosphorylation of 2-indolylmethanols with diarylphosphine oxides. The use of Y(Pfb)₃ as a catalyst provides benzylic phosphorylation products in good yields (up to 97% yield). In contrast, C3-phosphorylation products are isolated as the major product with Yb(OTf)₃ as the catalyst. A wide variety of 2-indolylmethanols and diarylphosphine oxides perform well in this process. This protocol represents the first catalyst-controlled regioselective phosphorylation of 2-indolylmethanols in a one-pot manner. The nature of the Lewis acid counterion appears to have the largest impact on the regiocontrol, where strong Lewis acids stabilize the cationic

intermediate allowing formation of the thermodynamic C3-phosphorylation product. Weaker Lewis acids, cause phosphorylation at the site of greatest positive charge, leading to the benzylic phosphorylation adduct. A number of transformations carried out on the reaction products illustrate the value that this method holds for the creation of highly functionalized indole-based phosphine ligands. Further studies of these novel phosphorus-containing molecules are underway in our laboratory.

EXPERIMENTAL SECTION

General Information

^1H NMR, ^{13}C NMR, ^{19}F NMR and ^{31}P NMR spectra were recorded at 400 MHz, 100 MHz, 376 and 162 MHz respectively using tetramethylsilane as an internal reference. Chemical shifts (δ) and coupling constants (J) were expressed in parts per million and hertz, respectively. Melting points were uncorrected. High-resolution mass spectrometry (HRMS) was performed on an ESI-TOF spectrometer. 2-Indolylmethanols compound substrates were prepared according to the literature procedure.¹² Substituted phenylphosphine oxides were synthesized according to the reported procedure.²¹ Chemicals were commercially available and used without purification. Chromatography: Column chromatography was performed with silica gel (200–300 mesh ASTM).

General Procedure A

2-Indolylmethanols **1** (0.25 mmol, 1 equiv), Diarylphosphine Oxides **2** (0.375 mmol, 1.5 equiv), $\text{Y}(\text{Pfb})_3$ (36.10 mg, 0.05 mmol, 0.2 equiv), dry CH_3CN (2 mL) and a stir bar were added to a sealed tube. After being stirred at 100 °C for indicated time, the mixture was evaporated under vacuum. The corresponding product **3** was isolated by silica gel column chromatography with a petroleum ether/ethyl acetate mixture as eluent.

((1H-Indol-2-yl)diphenylmethyl)diphenylphosphine oxide (3aa)—General procedure A was followed using **1a** (74.84 mg, 0.25 mmol), **2a** (75.82 mg, 0.375 mmol) and $\text{Y}(\text{Pfb})_3$ (36.10 mg, 0.05 mmol, 0.2 equiv) in CH_3CN (2 mL) at 100 °C for 12 h. Chromatography (20% EtOAc/hexane) afforded **3aa** (105.17 mg) in 87% yield as a white solid (mp 232–234 °C): ^1H NMR (400 MHz, $\text{DMSO}-d_6$) δ 10.59 (s, 1H), 7.57–7.49 (m, 3H), 7.44 (d, $J = 7.7$ Hz, 1H), 7.38–7.30 (m, 6H), 7.26 (dd, $J = 8.4$, 6.8 Hz, 4H), 7.12–7.02 (m, 9H), 7.01–6.96 (m, 1H), 6.29 (t, $J = 2.2$ Hz, 1H). $^{13}\text{C}\{^1\text{H}\}$ NMR (100 MHz, CDCl_3) δ 139.1, 136.3, 133.1 (d, $J_{\text{C-P}} = 8.4$ Hz), 132.1 (d, $J_{\text{C-P}} = 2.8$ Hz), 131.6, 131.0 (d, $J_{\text{C-P}} = 5.1$ Hz), 130.7, 128.3 (d, $J_{\text{C-P}} = 11.4$ Hz), 128.0, 127.7 (d, $J_{\text{C-P}} = 1.4$ Hz), 127.1 (d, $J_{\text{C-P}} = 1.3$ Hz), 122.2, 120.4, 119.7, 111.5, 105.8 (d, $J_{\text{C-P}} = 6.5$ Hz), 61.2 (d, $J_{\text{C-P}} = 61.8$ Hz). ^{31}P NMR (162 MHz, $\text{DMSO}-d_6$) δ 33.46. HRMS (ESI-TOF) m/z $[\text{M} + \text{H}]^+$ Calcd for $\text{C}_{33}\text{H}_{27}\text{NOP}$ 484.1830, found 484.1834.

((1H-Indol-2-yl)di-p-tolylmethyl)diphenylphosphine oxide (3ba)—General procedure A was followed using **1b** (81.86 mg, 0.25 mmol), **2a** (75.82 mg, 0.375 mmol) and $\text{Y}(\text{Pfb})_3$ (36.10 mg, 0.05 mmol, 0.2 equiv) in CH_3CN (2 mL) at 100 °C for 12 h. Chromatography (20% EtOAc/hexane) afforded **3ba** (127.90 mg) in 65% yield as a white solid (mp 240–242 °C): ^1H NMR (400 MHz, CDCl_3) δ 10.31 (s, 1H), 7.50 (d, $J = 7.9$ Hz,

1H), 7.46–7.41 (m, 3H), 7.29–7.24 (m, 4H), 7.22–7.16 (m, 5H), 7.09 (t, $J = 7.5$ Hz, 1H), 6.95 (d, $J = 8.1$ Hz, 4H), 6.87 (d, $J = 8.0$ Hz, 4H), 6.25 (d, $J = 2.4$ Hz, 1H), 2.30 (s, 6H). $^{13}\text{C}\{^1\text{H}\}$ NMR (100 MHz, CDCl_3) δ 139.3, 137.4, 136.3, 136.1, 133.1 (d, $J_{\text{C-P}} = 8.4$ Hz), 131.9 (m, $J_{\text{C-P}} = 2.7$ Hz), 130.9, 130.8 (d, $J_{\text{C-P}} = 5.1$ Hz), 128.6, 128.3 (d, $J_{\text{C-P}} = 11.4$ Hz), 127.2, 122.1, 120.4, 119.6, 111.5, 105.7 (d, $J_{\text{C-P}} = 6.5$ Hz), 60.6 (d, $J_{\text{C-P}} = 62.3$ Hz), 21.0. ^{31}P NMR (162 MHz, CDCl_3) δ 36.62. HRMS (ESI-TOF) m/z $[\text{M} + \text{Na}]^+$ Calcd for $\text{C}_{35}\text{H}_{30}\text{NNaOP}$ 534.1963, found 534.1970.

((1H-Indol-2-yl)bis(4-methoxyphenyl)methyl)diphenylphosphine oxide (3ca)—

General procedure A was followed using **1c** (89.86 mg, 0.25 mmol), **2a** (75.82 mg, 0.375 mmol) and Y(Pfb)_3 (36.10 mg, 0.05 mmol, 0.2 equiv) in CH_3CN (2 mL) at 100 °C for 12 h. Chromatography (20% EtOAc/hexane) afforded **3ca** (92.41 mg) in 68% yield as a white solid (mp 215–217 °C): ^1H NMR (400 MHz, CDCl_3) δ 10.32 (s, 1H), 7.50 (d, $J = 7.8$ Hz, 1H), 7.47–7.42 (m, 3H), 7.29–7.24 (m, 4H), 7.23–7.17 (m, 5H), 7.09 (t, $J = 7.4$ Hz, 1H), 6.90 (d, $J = 8.4$ Hz, 4H), 6.71–6.65 (m, 4H), 6.23 (d, $J = 2.5$ Hz, 1H), 3.75 (s, 6H). $^{13}\text{C}\{^1\text{H}\}$ NMR (100 MHz, CDCl_3) δ 158.8 (d, $J_{\text{C-P}} = 1.5$ Hz), 139.6, 136.3, 133.1 (d, $J_{\text{C-P}} = 8.5$ Hz), 132.0 (m, $J_{\text{C-P}} = 5.1$ Hz), 131.8, 131.2, 130.9, 128.4 (d, $J_{\text{C-P}} = 11.3$ Hz), 127.1, 122.1, 120.4, 119.6, 113.2, 111.5, 105.6 (d, $J_{\text{C-P}} = 6.5$ Hz), 59.8 (d, $J_{\text{C-P}} = 62.6$ Hz), 55.3. ^{31}P NMR (CDCl_3 , 162 MHz) δ 36.49. HRMS (ESI-TOF) m/z $[\text{M} + \text{Na}]^+$ Calcd for $\text{C}_{35}\text{H}_{30}\text{NNaO}_3\text{P}$ 566.1861, found 566.1871.

(Bis (4-(tert-butyl) phenyl) (1H-indol-2-yl) methyl)-diphenylphosphine oxide (3da)—

General procedure A was followed using **1d** (102.90 mg, 0.25 mmol), **2a** (75.82 mg, 0.375 mmol) and Y(Pfb)_3 (36.10 mg, 0.05 mmol, 0.2 equiv) in CH_3CN (2 mL) at 100 °C for 12 h. Chromatography (20% EtOAc/hexane) afforded **3da** (128.09 mg) in 86% yield as a white solid (mp 239–241 °C): ^1H NMR (400 MHz, CDCl_3) δ 10.15 (s, 1H), 7.52 (d, $J = 7.9$ Hz, 1H), 7.47–7.41 (m, 3H), 7.25 (d, $J = 3.3$ Hz, 1H), 7.24–7.19 (m, 4H), 7.16 (d, $J = 8.3$ Hz, 4H), 7.13–7.07 (m, 5H), 6.90 (d, $J = 8.1$ Hz, 4H), 6.33 (d, $J = 2.6$ Hz, 1H), 1.28 (s, 18H). $^{13}\text{C}\{^1\text{H}\}$ NMR (100 MHz, CDCl_3) δ 150.6 (d, $J_{\text{C-P}} = 1.7$ Hz), 139.2, 136.3, 136.0, 133.1 (d, $J_{\text{C-P}} = 8.5$ Hz), 131.9 (m, $J_{\text{C-P}} = 3.1$ Hz), 131.0, 130.5 (d, $J_{\text{C-P}} = 5.1$ Hz), 128.3 (d, $J_{\text{C-P}} = 11.4$ Hz), 127.2 (d, $J_{\text{C-P}} = 1.5$ Hz), 124.9, 122.1, 120.4, 119.6, 111.5, 105.8, 60.5 (d, $J_{\text{C-P}} = 62.5$ Hz), 34.5, 31.3. ^{31}P NMR (162 MHz, CDCl_3) δ 36.66. HRMS (ESI-TOF) m/z $[\text{M} + \text{H}]^+$ Calcd for $\text{C}_{41}\text{H}_{43}\text{NOP}$ 596.3082, found 596.3079.

(Bis(4-chlorophenyl)(1H-indol-2-yl)methyl)diphenylphosphine oxide (3ea)—

General procedure A was followed using **1e** (92.06 mg, 0.25 mmol), **2a** (75.82 mg, 0.375 mmol) and Y(Pfb)_3 (36.10 mg, 0.05 mmol, 0.2 equiv) in CH_3CN (2 mL) at 100 °C for 12 h. Chromatography (20% EtOAc/hexane) afforded **3ea** (117.39 mg) in 85% yield as a white solid (mp 264–266 °C): ^1H NMR (400 MHz, CDCl_3) δ 10.34 (s, 1H), 7.53–7.44 (m, 4H), 7.34–7.27 (m, 4H), 7.24–7.17 (m, 5H), 7.16–7.08 (m, 5H), 6.93 (d, $J = 8.2$ Hz, 4H), 6.18 (d, $J = 2.4$ Hz, 1H). $^{13}\text{C}\{^1\text{H}\}$ NMR (100 MHz, CDCl_3) δ 137.4, 136.3, 133.9 (d, $J_{\text{C-P}} = 2.2$ Hz), 133.0 (d, $J_{\text{C-P}} = 8.6$ Hz), 132.5 (d, $J_{\text{C-P}} = 2.7$ Hz), 132.3 (d, $J_{\text{C-P}} = 4.9$ Hz), 131.0, 130.0, 128.6 (d, $J_{\text{C-P}} = 1.3$ Hz), 128.2, 127.0, 122.6, 120.6, 120.0, 111.7, 105.8, 60.3 (d, $J_{\text{C-P}} = 61.2$ Hz). ^{31}P NMR (CDCl_3 , 162 MHz) δ 36.47. HRMS (ESI-TOF) m/z $[\text{M} + \text{H}]^+$ Calcd for $\text{C}_{33}\text{H}_{25}\text{Cl}_2\text{NOP}$ 552.1051, found 552.1046.

(Bis(4-fluorophenyl)(1H-indol-2-yl)methyl)diphenylphosphine oxide (3fa)—

General procedure A was followed using **1f** (83.84 mg, 0.25 mmol), **2a** (75.82 mg, 0.375 mmol) and Y(Pfb)₃ (36.10 mg, 0.05 mmol, 0.2 equiv) in CH₃CN (2 mL) at 100 °C for 12 h. Chromatography (20% EtOAc/hexane) afforded **3fa** (105.21 mg) in 81% yield as a white solid (mp 234–236 °C): ¹H NMR (400 MHz, CDCl₃) δ 10.30 (s, 1H), 7.55–7.43 (m, 4H), 7.33–7.26 (m, 4H), 7.25–7.16 (m, 5H), 7.12 (t, *J* = 7.5 Hz, 1H), 6.99–6.93 (m, 4H), 6.89–6.83 (m, 4H), 6.20 (d, *J* = 2.5 Hz, 1H). ¹³C{¹H}NMR (100 MHz, CDCl₃) δ 163.3 (d, *J*_{C-F} = 247.3 Hz), 136.3, 134.8, 132.9 (d, *J*_{C-P} = 8.4 Hz), 132.6 (q, *J*_{C-F} = 5.1 Hz), 132.4 (d, *J*_{C-P} = 2.7 Hz), 131.1, 130.2, 128.6 (d, *J*_{C-P} = 11.4 Hz), 127.0 (d, *J*_{C-P} = 1.6 Hz), 122.5, 120.5, 119.3, 115.1 (d, *J*_{C-F} = 21.0 Hz), 111.6, 105.7, 60.0 (d, *J*_{C-P} = 62.0 Hz). ³¹P NMR (162 MHz, CDCl₃) δ 36.63. ¹⁹F NMR (376 MHz, CDCl₃) δ -113.87. HRMS (ESI-TOF) *m/z* [M - H]⁻ Calcd for C₃₃H₂₃F₂NOP 518.1485, found 518.1475.

((1H-Indol-2-yl)di-m-tolylmethyl)diphenylphosphine oxide (3ha)—General

procedure A was followed using **1h** (81.86 mg, 0.25 mmol), **2a** (75.82 mg, 0.375 mmol) and Y(Pfb)₃ (36.10 mg, 0.05 mmol, 0.2 equiv) in CH₃CN (2 mL) at 100 °C for 12 h. Chromatography (20% EtOAc/hexane) afforded **3ha** (92.41 mg) in 66% yield as a white solid (mp 193–195 °C): ¹H NMR (400 MHz, CDCl₃) δ 10.34 (s, 1H), 7.52 (d, *J* = 7.8 Hz, 1H), 7.47–7.42 (m, 3H), 7.29–7.23 (m, 4H), 7.20–7.14 (m, 5H), 7.11 (d, *J* = 7.6 Hz, 1H), 7.07–7.01 (m, 4H), 6.79 (d, *J* = 9.1 Hz, 4H), 6.27 (d, *J* = 2.4 Hz, 1H), 2.10 (s, 6H). ¹³C{¹H}NMR (100 MHz, CDCl₃) δ 138.9, 137.2 (d, *J*_{C-P} = 1.1 Hz), 136.3, 133.1 (d, *J*_{C-P} = 7.9 Hz), 132.0 (d, *J*_{C-P} = 2.8 Hz), 131.8 (d, *J*_{C-P} = 5.1 Hz), 131.7, 130.8, 128.3 (d, *J*_{C-P} = 2.0 Hz), 128.2 (t, *J*_{C-P} = 2.6 Hz), 127.9, 127.2, 122.1, 120.4, 119.6, 111.6, 105.7 (d, *J*_{C-P} = 6.7 Hz), 61.1 (d, *J*_{C-P} = 61.8 Hz), 29.8, 21.6. ³¹P NMR (162 MHz, CDCl₃) δ 36.91. HRMS (ESI-TOF) *m/z* [M + H]⁺ Calcd for C₃₅H₃₁NOP 512.2143, found 512.2146.

(Bis(3-fluorophenyl)(1H-indol-2-yl)methyl)diphenylphosphine oxide (3ia)—

General procedure A was followed using **1i** (83.84 mg, 0.25 mmol), **2a** (75.82 mg, 0.375 mmol) and Y(Pfb)₃ (36.10 mg, 0.05 mmol, 0.2 equiv) in CH₃CN (2 mL) at 100 °C for 12 h. Chromatography (20% EtOAc/hexane) afforded **3ia** (102.61 mg) in 79% yield as a white solid (mp 240–242 °C): ¹H NMR (400 MHz, CDCl₃) δ 10.29 (s, 1H), 7.55–7.45 (m, 4H), 7.31 (td, *J* = 7.7, 3.3 Hz, 4H), 7.25 (s, 1H), 7.21 (d, *J* = 1.2 Hz, 1H), 7.19 (d, *J* = 2.8 Hz, 2H), 7.16 (dt, *J* = 4.6, 2.8 Hz, 2H), 7.14–7.09 (m, 2H), 6.99 (td, *J* = 8.3, 2.8 Hz, 2H), 6.80 (d, *J* = 8.0 Hz, 2H), 6.72–6.67 (m, 2H), 6.23 (d, *J* = 2.4 Hz, 1H). ¹³C{¹H}NMR (100 MHz, CDCl₃) δ 163.5 (d, *J*_{C-F} = 244.5 Hz), 141.2, 136.3, 133.0 (d, *J*_{C-P} = 8.6 Hz), 132.5 (d, *J*_{C-P} = 2.8 Hz), 130.9, 130.0, 129.4 (d, *J*_{C-P} = 7.5 Hz), 128.6 (d, *J*_{C-P} = 11.5 Hz), 127.0 (d, *J*_{C-P} = 1.5 Hz), 126.6 (q, *J*_{C-F} = 2.9 Hz), 122.6, 120.6, 120.0, 118.3 (d, *J*_{C-P} = 28.7 Hz), 115.0 (d, *J*_{C-F} = 22.3 Hz), 111.6, 106.1 (d, *J*_{C-P} = 6.3 Hz), 60.8 (d, *J*_{C-P} = 59.6 Hz). ¹⁹F NMR (376 MHz, CDCl₃) δ -111.75. ³¹P NMR (162 MHz, CDCl₃) δ 36.68. HRMS (ESI-TOF) *m/z* [M + H]⁺ Calcd for C₃₃H₂₅F₂NOP 520.1642, found 520.1640.

((1H-Indol-2-yl)bis(3-(trifluoromethyl)phenyl)methyl)-diphenylphosphine oxide (3ja)—General procedure A was followed using **1j** (108.84 mg, 0.25 mmol), **2a** (75.82 mg, 0.375 mmol) and Y(Pfb)₃ (36.10 mg, 0.05 mmol, 0.2 equiv) in CH₃CN (2 mL) at 100 °C for 12 h. Chromatography (20% EtOAc/hexane) afforded **3ja** (92.41 mg) in 71% yield as a

white solid (mp 224–226 °C): ^1H NMR (400 MHz, CDCl_3) δ 10.52 (s, 1H), 7.57–7.48 (m, 6H), 7.34 (d, J = 3.9 Hz, 4H), 7.33–7.29 (m, 4H), 7.27 (d, J = 7.9 Hz, 1H), 7.23–7.18 (m, 3H), 7.17–7.15 (m, 1H), 7.15–7.10 (m, 3H), 6.19 (d, J = 2.4 Hz, 1H). $^{13}\text{C}\{^1\text{H}\}$ NMR (100 MHz, CDCl_3) δ 139.7, 136.4, 134.4 (d, $J_{\text{C-P}}$ = 4.3 Hz), 133.0 (d, $J_{\text{C-P}}$ = 8.6 Hz), 132.7 (d, $J_{\text{C-P}}$ = 2.7 Hz), 130.3, 130.1 (d, $J_{\text{C-P}}$ = 7.5 Hz), 129.2, 128.9, 128.8 (d, $J_{\text{C-P}}$ = 12.5 Hz), 127.5 (q, $J_{\text{C-F}}$ = 4.1 Hz), 127.0 (d, $J_{\text{C-P}}$ = 1.4 Hz), 125.0 (d, $J_{\text{C-F}}$ = 271.0 Hz), 124.8 (q, $J_{\text{C-F}}$ = 1.6 Hz), 122.8, 120.7, 120.1, 111.7, 105.8 (d, $J_{\text{C-P}}$ = 6.3 Hz), 61.0 (d, $J_{\text{C-P}}$ = 60.2 Hz). ^{19}F NMR (376 MHz, CDCl_3) δ –62.81. ^{31}P NMR (162 MHz, CDCl_3) δ 36.97. HRMS (ESI-TOF) m/z $[\text{M} - \text{H}]^-$ Calcd for $\text{C}_{35}\text{H}_{23}\text{F}_6\text{NOP}$ 618.1421, found 618.1421.

((5-Methyl-1H-indol-2-yl)diphenylmethyl)diphenylphosphine oxide (3ka)—

General procedure A was followed using **1k** (78.35 mg, 0.25 mmol), **2a** (75.82 mg, 0.375 mmol) and $\text{Y}(\text{Pfb})_3$ (36.10 mg, 0.05 mmol, 0.2 equiv) in CH_3CN (2 mL) at 100 °C for 12 h. Chromatography (20% EtOAc/hexane) afforded **3ka** (120.66 mg) in 97% yield as a white solid (mp 262–264 °C): ^1H NMR (400 MHz, CDCl_3) δ 10.17 (s, 1H), 7.47–7.42 (m, 2H), 7.34 (d, J = 8.3 Hz, 1H), 7.30–7.26 (m, 5H), 7.24–7.22 (m, 2H), 7.19–7.12 (m, 8H), 7.07–6.99 (m, 5H), 6.27–6.10 (m, 1H), 2.45 (s, 3H). $^{13}\text{C}\{^1\text{H}\}$ NMR (100 MHz, CDCl_3) δ 139.2, 134.6, 133.1 (d, $J_{\text{C-P}}$ = 9.0 Hz), 132.0 (d, $J_{\text{C-P}}$ = 2.7 Hz), 131.7, 131.0 (d, $J_{\text{C-P}}$ = 5.1 Hz), 130.8, 128.8, 128.3 (d, $J_{\text{C-P}}$ = 11.4 Hz), 127.9 (d, $J_{\text{C-P}}$ = 0.5 Hz), 127.6 (d, $J_{\text{C-P}}$ = 1.6 Hz), 127.4, 123.9, 120.0, 111.2, 105.4 (d, $J_{\text{C-P}}$ = 6.6 Hz), 61.3 (d, $J_{\text{C-P}}$ = 61.9 Hz), 21.5. ^{31}P NMR (162 MHz, CDCl_3) δ 36.65. HRMS (ESI-TOF) m/z $[\text{M} + \text{H}]^+$ Calcd for $\text{C}_{34}\text{H}_{29}\text{NOP}$ 498.1987, found 498.1990.

((6-Chloro-1H-indol-2-yl)diphenylmethyl)diphenylphosphine oxide (3la)—

General procedure A was followed using **1l** (83.45 mg, 0.25 mmol), **2a** (75.82 mg, 0.375 mmol) and $\text{Y}(\text{Pfb})_3$ (36.10 mg, 0.05 mmol, 0.2 equiv) in CH_3CN (2 mL) at 100 °C for 12 h. Chromatography (20% EtOAc/hexane) afforded **3la** (123.02 mg) in 95% yield as a white solid (mp 249–251 °C): ^1H NMR (400 MHz, CDCl_3) δ 10.28 (s, 1H), 7.42–7.36 (m, 3H), 7.32 (d, J = 8.5 Hz, 1H), 7.23–7.16 (m, 6H), 7.10 (s, 2H), 7.09–7.04 (m, 6H), 6.99 (dd, J = 8.4, 1.9 Hz, 1H), 6.93–6.89 (m, 4H), 6.18 (d, J = 2.4 Hz, 1H). $^{13}\text{C}\{^1\text{H}\}$ NMR (100 MHz, CDCl_3) δ 139.9, 138.8, 136.6, 133.0 (d, $J_{\text{C-P}}$ = 8.5 Hz), 132.2 (d, $J_{\text{C-P}}$ = 2.8 Hz), 131.4, 131.0 (d, $J_{\text{C-P}}$ = 5.1 Hz), 130.5, 128.4 (d, $J_{\text{C-P}}$ = 11.5 Hz), 128.0, 127.8 (d, $J_{\text{C-P}}$ = 1.5 Hz), 125.6 (d, $J_{\text{C-P}}$ = 1.7 Hz), 121.3, 120.5, 111.4, 105.7 (d, $J_{\text{C-P}}$ = 11.5 Hz), 61.2 (d, $J_{\text{C-P}}$ = 61.6 Hz). ^{31}P NMR (162 MHz, CDCl_3) δ 36.74. HRMS (ESI-TOF) m/z $[\text{M} + \text{H}]^+$ Calcd for $\text{C}_{33}\text{H}_{26}\text{ClNOP}$ 518.1441, found 518.1440.

((1-Ethyl-1H-indol-2-yl)diphenylmethyl)diphenylphosphine oxide (3ma)—

General procedure A was followed using **1m** (81.86 mg, 0.25 mmol), **2a** (75.82 mg, 0.375 mmol) and $\text{Y}(\text{Pfb})_3$ (36.10 mg, 0.05 mmol, 0.2 equiv) in CH_3CN (2 mL) at 100 °C for 12 h. Chromatography (20% EtOAc/hexane) afforded **3ma** (42.21 mg) in 33% yield as a white solid (mp 247–249 °C): ^1H NMR (400 MHz, CDCl_3) δ 7.47 (d, J = 7.8 Hz, 1H), 7.30–7.21 (m, 7H), 7.19–7.11 (m, 6H), 7.07 (td, J = 7.8, 3.2 Hz, 4H), 7.01 (d, J = 4.0 Hz, 2H), 6.97–6.90 (m, 1H), 6.87–6.79 (m, 4H), 3.36 (q, J = 7.1 Hz, 2H), 1.14 (s, 3H). $^{13}\text{C}\{^1\text{H}\}$ NMR (100 MHz, CDCl_3) δ 138.1 (d, $J_{\text{C-P}}$ = 3.3 Hz), 136.4, 136.1, 133.7 (d, $J_{\text{C-P}}$ = 7.9 Hz), 131.9 (d, $J_{\text{C-P}}$ = 4.0 Hz), 131.6 (d, $J_{\text{C-P}}$ = 1.6 Hz), 131.0, 130.0, 128.0 (d, $J_{\text{C-P}}$ = 3.0 Hz), 127.7 (d,

$J_{C-P} = 11.3$ Hz), 127.4, 121.6, 121.1, 119.2, 109.5, 105.8 (d, $J_{C-P} = 4.7$ Hz), 60.5 (d, $J_{C-P} = 59.8$ Hz), 40.7, 12.1. ^{31}P NMR (162 MHz, CDCl_3) δ 33.81. HRMS (ESI-TOF) m/z $[\text{M} + \text{H}]^+$ Calcd for $\text{C}_{35}\text{H}_{31}\text{NOP}$ 512.2143, found 512.2150.

(3-(1H-indol-2-yl)pentan-3-yl)diphenylphosphine oxide (3na)—General procedure

A was followed using **1n** (50.82 mg, 0.25 mmol), **2a** (75.82 mg, 0.375 mmol) and $\text{Y}(\text{Pfb})_3$ (36.10 mg, 0.05 mmol, 0.2 equiv) in CH_3CN (2 mL) at 100 °C for 12 h. Chromatography (20% EtOAc/hexane) afforded **3na** (20.34 mg) in 21% yield as a white solid (mp 202–204 °C): ^1H NMR (400 MHz, CDCl_3) δ 11.28 (s, 1H), 7.98–7.89 (m, 2H), 7.88–7.81 (m, 2H), 7.58–7.42 (m, 8H), 7.15–7.08 (m, 1H), 7.06–6.99 (m, 1H), 6.25 (dt, $J = 2.1, 1.0$ Hz, 1H), 3.19–3.09 (m, 1H), 2.79–2.67 (m, 1H), 2.25–2.07 (m, 1H), 1.80–1.59 (m, 1H), 1.03–0.82 (m, 6H). $^{13}\text{C}\{^1\text{H}\}$ NMR (100 MHz, CDCl_3) δ 139.3, 136.4, 132.2, 132.0 (d, $J_{C-P} = 9.4$ Hz), 131.1 (d, $J_{C-P} = 8.5$ Hz), 129.0 (d, $J_{C-P} = 3.5$ Hz), 128.0, 120.9, 119.5, 118.9, 111.4, 100.1, 35.2 (d, $J_{C-P} = 75.1$ Hz), 25.3, 12.6. ^{31}P NMR (162 MHz, CDCl_3) δ 39.30. HRMS (ESI-TOF) m/z $[\text{M} + \text{H}]^+$ Calcd for $\text{C}_{25}\text{H}_{27}\text{NOP}$ 388.1830, found 388.1833.

((1H-Indol-2-yl)diphenylmethyl)di-p-tolylphosphine oxide (3ab)—General

procedure A was followed using **1a** (74.84 mg, 0.25 mmol), **2b** (86.34 mg, 0.375 mmol) and $\text{Y}(\text{Pfb})_3$ (36.10 mg, 0.05 mmol, 0.2 equiv) in CH_3CN (2 mL) at 100 °C for 12 h. Chromatography (20% EtOAc/hexane) afforded **3ab** (124.06 mg) in 97% yield as a white solid (mp 225–227 °C): ^1H NMR (400 MHz, CDCl_3) δ 10.35 (s, 1H), 7.51 (d, $J = 7.7$ Hz, 1H), 7.45 (d, $J = 8.0$ Hz, 1H), 7.28–7.25 (m, 2H), 7.23–7.19 (m, 2H), 7.18–7.11 (m, 5H), 7.09–7.03 (m, 7H), 7.00 (d, $J = 8.5$ Hz, 4H), 6.28 (t, $J = 2.4$ Hz, 1H), 2.32 (s, 6H). $^{13}\text{C}\{^1\text{H}\}$ NMR (100 MHz, CDCl_3) δ 142.5 (d, $J_{C-P} = 3.8$ Hz), 139.3, 136.3, 133.1 (d, $J_{C-P} = 9.0$ Hz), 131.1, 129.1 (d, $J_{C-P} = 11.8$ Hz), 128.5, 127.9, 127.5 (d, $J_{C-P} = 1.3$ Hz), 127.1 (d, $J_{C-P} = 7.7$ Hz), 126.9, 122.1, 120.4, 119.6, 111.6, 105.7, 61.2 (d, $J_{C-P} = 61.9$ Hz), 21.6. ^{31}P NMR (162 MHz, CDCl_3) δ 37.19. HRMS (ESI-TOF) m/z $[\text{M} + \text{H}]^+$ Calcd for $\text{C}_{35}\text{H}_{31}\text{NOP}$ 512.2143, found 512.2147.

((1H-Indol-2-yl)diphenylmethyl)bis(4-methoxyphenyl)phosphine oxide (3ac)—

General procedure A was followed using **1a** (74.84 mg, 0.25 mmol), **2c** (98.34 mg, 0.375 mmol) and $\text{Y}(\text{Pfb})_3$ (36.10 mg, 0.05 mmol, 0.2 equiv) in CH_3CN (2 mL) at 100 °C for 12 h. Chromatography (20% EtOAc/hexane) afforded **3ac** (77.46 mg) in 57% yield as a white solid (mp 237–239 °C): ^1H NMR (400 MHz, CDCl_3) δ 10.37 (s, 1H), 7.52 (d, $J = 7.8$ Hz, 1H), 7.45 (d, $J = 8.1$ Hz, 1H), 7.28–7.22 (m, 3H), 7.19–7.12 (m, 5H), 7.08–6.99 (m, 8H), 6.76 (dd, $J = 8.9, 2.6$ Hz, 4H), 6.29 (d, $J = 2.4$ Hz, 1H), 3.78 (s, 6H). $^{13}\text{C}\{^1\text{H}\}$ NMR (100 MHz, CDCl_3) δ 162.4 (d, $J_{C-P} = 2.9$ Hz), 139.5, 136.2, 134.9 (d, $J_{C-P} = 9.7$ Hz), 131.0 (d, $J_{C-P} = 5.0$ Hz), 127.9, 127.5, 127.2 (d, $J_{C-P} = 1.6$ Hz), 122.9, 122.1, 121.9, 120.4, 119.6, 113.9 (d, $J_{C-P} = 12.4$ Hz), 111.6, 105.6, 61.1 (d, $J_{C-P} = 62.8$ Hz), 55.3. ^{31}P NMR (162 MHz, CDCl_3) δ 36.92. HRMS (ESI-TOF) m/z $[\text{M} + \text{H}]^+$ Calcd for $\text{C}_{35}\text{H}_{31}\text{NO}_3\text{P}$ 544.2042, found 544.2052.

((1H-Indol-2-yl)diphenylmethyl)bis(4-(tert-butyl)phenyl)-phosphine oxide (3ad)

—General procedure A was followed using **1a** (74.84 mg, 0.25 mmol), **2d** (117.90 mg, 0.375 mmol) and $\text{Y}(\text{Pfb})_3$ (36.10 mg, 0.05 mmol, 0.2 equiv) in CH_3CN (2 mL) at 100 °C for

12 h. Chromatography (20% EtOAc/hexane) afforded **3ad** (92.34 mg) in 62% yield as a white solid (mp 226–228 °C): ^1H NMR (400 MHz, DMSO- d_6) δ 10.65 (s, 1H), 7.54 (d, J = 8.1 Hz, 1H), 7.45 (d, J = 7.9 Hz, 1H), 7.40–7.30 (m, 6H), 7.25 (t, J = 7.5 Hz, 5H), 7.12–7.03 (m, 5H), 7.02–6.95 (m, 4H), 6.29 (s, 1H), 1.23 (s, 18H). $^{13}\text{C}\{^1\text{H}\}$ NMR (100 MHz, DMSO- d_6 with CDCl_3) δ 138.8, 137.1 (d, $J_{\text{C-P}}$ = 1.1 Hz), 136.2, 133.0 (d, $J_{\text{C-P}}$ = 7.9 Hz), 132.0 (d, $J_{\text{C-P}}$ = 2.8 Hz), 131.7 (d, $J_{\text{C-P}}$ = 5.1 Hz), 130.8, 128.2 (d, $J_{\text{C-P}}$ = 2.0 Hz), 128.1 (d, $J_{\text{C-P}}$ = 2.6 Hz), 127.8, 127.1, 122.1, 120.3, 119.6, 111.5, 105.7 (d, $J_{\text{C-P}}$ = 6.7 Hz), 61.1 (d, $J_{\text{C-P}}$ = 61.8 Hz), 29.8, 21.5. ^{31}P NMR (162 MHz, DMSO- d_6) δ 33.59. HRMS (ESI-TOF) m/z $[\text{M} + \text{H}]^+$ Calcd for $\text{C}_{41}\text{H}_{43}\text{NOP}$ 596.3082, found 596.3084.

((1H-Indol-2-yl)diphenylmethyl)bis(4-(dimethylamino)phenyl)-phosphine oxide (3ae)—General procedure A was followed using **1a** (74.84 mg, 0.25 mmol), **2e** (108.12 mg, 0.375 mmol) and $\text{Y}(\text{Pfb})_3$ (36.10 mg, 0.05 mmol, 0.2 equiv) in CH_3CN (2 mL) at 100 °C for 12 h. Chromatography (20% EtOAc/hexane) afforded **3ae** (72.64 mg) in 51% yield as a white solid (mp 168–170 °C): ^1H NMR (400 MHz, CDCl_3) δ 10.61 (s, 1H), 7.52 (d, J = 7.7 Hz, 1H), 7.45 (d, J = 8.1 Hz, 1H), 7.24–7.19 (m, 3H), 7.17–7.10 (m, 5H), 7.08–7.01 (m, 4H), 6.97–6.89 (m, 4H), 6.47 (dd, J = 9.1, 2.6 Hz, 4H), 6.25 (t, J = 2.4 Hz, 1H), 2.94 (s, 12H). $^{13}\text{C}\{^1\text{H}\}$ NMR (100 MHz, CDCl_3) δ 152.0 (d, $J_{\text{C-P}}$ = 2.4 Hz), 140.3, 136.1, 134.3 (d, $J_{\text{C-P}}$ = 9.8 Hz), 131.1 (d, $J_{\text{C-P}}$ = 6.0 Hz), 127.6, 127.3, 127.1, 121.7, 120.3, 119.3, 116.8, 115.8, 111.6, 111.0 (d, $J_{\text{C-P}}$ = 12.2 Hz), 105.2, 61.1 (d, $J_{\text{C-P}}$ = 62.8 Hz), 39.9. ^{31}P NMR (162 MHz, CDCl_3) δ 38.42. HRMS (ESI-TOF) m/z $[\text{M} + \text{H}]^+$ Calcd for $\text{C}_{37}\text{H}_{37}\text{N}_3\text{OP}$ 570.2674, found 570.2681.

((1H-Indol-2-yl)diphenylmethyl)bis(4-fluorophenyl)phosphine oxide (3af)—General procedure A was followed using **1a** (74.84 mg, 0.25 mmol), **2f** (89.32 mg, 0.375 mmol) and $\text{Y}(\text{Pfb})_3$ (36.10 mg, 0.05 mmol, 0.2 equiv) in CH_3CN (2 mL) at 100 °C for 12 h. Chromatography (20% EtOAc/hexane) afforded **3af** (119.49 mg) in 92% yield as a white solid (mp 290–292 °C): ^1H NMR (400 MHz, CDCl_3) δ 10.02 (s, 1H), 7.53 (d, J = 7.9 Hz, 1H), 7.42 (d, J = 8.1 Hz, 1H), 7.31–7.27 (m, 2H), 7.25–7.21 (m, 5H), 7.19 (t, J = 7.7 Hz, 4H), 7.15–7.10 (m, 1H), 7.14–7.08 (m, 8H), 6.31 (t, J = 2.4 Hz, 1H). $^{13}\text{C}\{^1\text{H}\}$ NMR (100 MHz, CDCl_3) δ 163.1 (d, $J_{\text{C-F}}$ = 247.3 Hz), 138.7, 136.3, 134.8, 133.0 (d, $J_{\text{C-P}}$ = 8.4 Hz), 132.6 (q, $J_{\text{C-F}}$ = 5.0 Hz), 131.1, 130.2, 128.6 (d, $J_{\text{C-P}}$ = 11.5 Hz), 127.0 (d, $J_{\text{C-P}}$ = 1.6 Hz), 122.5, 120.5, 119.9, 115.1 (d, $J_{\text{C-F}}$ = 20.9 Hz), 111.6, 105.7, 60.0 (d, $J_{\text{C-P}}$ = 62.0 Hz). ^{19}F NMR (376 MHz, CDCl_3) δ –113.88. ^{31}P NMR (162 MHz, CDCl_3) δ 36.63. HRMS (ESI-TOF) m/z $[\text{M} - \text{H}]^-$ Calcd for $\text{C}_{33}\text{H}_{23}\text{F}_2\text{NOP}$ 518.1485, found 518.1481.

((1H-Indol-2-yl)diphenylmethyl)bis(4-chlorophenyl)phosphine oxide (3ag)—General procedure A was followed using **1a** (74.84 mg, 0.25 mmol), **2g** (101.65 mg, 0.375 mmol) and $\text{Y}(\text{Pfb})_3$ (36.10 mg, 0.05 mmol, 0.2 equiv) in CH_3CN (2 mL) at 100 °C for 12 h. Chromatography (20% EtOAc/hexane) afforded **3ag** (129.82 mg) in 94% yield as a white solid (mp 277–279 °C): ^1H NMR (400 MHz, CDCl_3) δ 10.03 (s, 1H), 7.53 (d, J = 7.9 Hz, 1H), 7.43 (d, J = 8.1 Hz, 1H), 7.32–7.23 (m, 7H), 7.19 (t, J = 7.7 Hz, 4H), 7.14–7.09 (m, 1H), 7.05–6.98 (m, 8H), 6.33 (t, J = 2.4 Hz, 1H). $^{13}\text{C}\{^1\text{H}\}$ NMR (100 MHz, CDCl_3) δ 139.0 (d, $J_{\text{C-P}}$ = 3.5 Hz), 138.7, 136.2 (d, $J_{\text{C-P}}$ = 9.2 Hz), 134.4, 130.9 (d, $J_{\text{C-P}}$ = 6.3 Hz), 129.8, 128.9, 128.8 (d, $J_{\text{C-P}}$ = 12.0 Hz), 128.2, 128.0 (d, $J_{\text{C-P}}$ = 1.5 Hz), 127.0 (d, $J_{\text{C-P}}$ = 1.7 Hz),

122.5, 120.6, 120.0, 111.5, 106.1 (d, J_{C-P} = 6.6 Hz), 61.3 (d, J_{C-P} = 63.4 Hz). ^{31}P NMR (162 MHz, CDCl_3) δ 35.49. HRMS (ESI-TOF) m/z $[\text{M} - \text{H}]^-$ Calcd for $\text{C}_{33}\text{H}_{23}\text{Cl}_2\text{NOP}$ 550.0894, found 550.0888.

((1H-Indol-2-yl)diphenylmethyl)bis(3-fluorophenyl)phosphine oxide (3ah)—

General procedure A was followed using **1a** (74.84 mg, 0.25 mmol), **2h** (89.32 mg, 0.375 mmol) and $\text{Y}(\text{Pfb})_3$ (36.10 mg, 0.05 mmol, 0.2 equiv) in CH_3CN (2 mL) at 100 °C for 12 h. Chromatography (20% EtOAc/hexane) afforded **3ah** (92.22 mg) in 71% yield as a white solid (mp 259–261 °C): ^1H NMR (400 MHz, CDCl_3) δ 10.01 (s, 1H), 7.54 (d, J = 7.8 Hz, 1H), 7.45 (d, J = 8.2 Hz, 1H), 7.34–7.27 (m, 3H), 7.24–7.16 (m, 8H), 7.12 (t, J = 7.4 Hz, 1H), 7.03 (d, J = 7.9 Hz, 4H), 6.99–6.91 (m, 2H), 6.82–6.74 (m, 2H), 6.33 (d, J = 2.6 Hz, 1H). $^{13}\text{C}\{^1\text{H}\}$ NMR (100 MHz, CDCl_3) δ 163.4 (d, J_{C-F} = 248.6 Hz), 138.5, 137.9, 136.3, 133.9, 130.9 (d, J_{C-P} = 5.3 Hz), 130.4 (q, J_{C-F} = 7.2 Hz), 128.8 (q, J_{C-F} = 3.2 Hz), 128.2, 128.0 (d, J_{C-P} = 1.5 Hz), 127.0 (d, J_{C-P} = 1.7 Hz), 122.6, 120.5, 120.1 (d, J_{C-P} = 9.6 Hz), 119.6 (d, J_{C-P} = 2.5 Hz), 119.4 (d, J_{C-P} = 2.5 Hz), 111.5, 106.1 (d, J_{C-P} = 6.7 Hz), 61.4 (d, J_{C-P} = 63.4 Hz). ^{31}P NMR (162 MHz, CDCl_3) δ 34.54. ^{19}F NMR (376 MHz, CDCl_3) δ –110.55. HRMS (ESI-TOF) m/z $[\text{M} - \text{H}]^-$ Calcd for $\text{C}_{33}\text{H}_{23}\text{F}_2\text{NOP}$ 518.1485, found 518.1484.

((1H-Indol-2-yl)diphenylmethyl)bis(3-chlorophenyl)phosphine oxide (3ai)—

General procedure A was followed using **1a** (74.84 mg, 0.25 mmol), **2i** (101.65 mg, 0.375 mmol) and $\text{Y}(\text{Pfb})_3$ (36.10 mg, 0.05 mmol, 0.2 equiv) in CH_3CN (2 mL) at 100 °C for 12 h. Chromatography (20% EtOAc/hexane) afforded **3ai** (133.97 mg) in 97% yield as a white solid (mp 216–218 °C): ^1H NMR (400 MHz, CDCl_3) δ 9.89 (s, 1H), 7.53 (d, J = 7.9 Hz, 1H), 7.47–7.41 (m, 3H), 7.32 (t, J = 7.4 Hz, 2H), 7.27–7.21 (m, 6H), 7.20 (s, 1H), 7.12 (t, J = 7.5 Hz, 1H), 7.08–7.00 (m, 6H), 6.95 (dt, J = 10.7, 1.8 Hz, 2H), 6.37 (d, J = 2.6 Hz, 1H). $^{13}\text{C}\{^1\text{H}\}$ NMR (100 MHz, CDCl_3) δ 138.4, 137.6, 136.3, 134.8 (d, J_{C-P} = 14.8 Hz), 133.4, 132.9 (d, J_{C-P} = 9.3 Hz), 132.5, 132.4 (d, J_{C-P} = 2.7 Hz), 131.0 (t, J_{C-P} = 8.7 Hz), 129.8 (d, J_{C-P} = 12.4 Hz), 128.2, 128.1 (d, J_{C-P} = 1.7 Hz), 127.0 (d, J_{C-P} = 1.9 Hz), 122.6, 120.5, 120.0, 111.5, 106.2 (d, J_{C-P} = 6.6 Hz), 61.5 (d, J_{C-P} = 63.0 Hz). ^{31}P NMR (162 MHz, CDCl_3) δ 34.53. HRMS (ESI-TOF) m/z $[\text{M} - \text{H}]^-$ Calcd for $\text{C}_{33}\text{H}_{23}\text{Cl}_2\text{NOP}$ 550.0894, found 550.0886.

((1H-Indol-2-yl)diphenylmethyl)bis(3-(trifluoromethyl)phenyl)-phosphine oxide (3aj)—

General procedure A was followed using **1a** (74.84 mg, 0.25 mmol), **2j** (126.82 mg, 0.375 mmol) and $\text{Y}(\text{Pfb})_3$ (36.10 mg, 0.05 mmol, 0.2 equiv) in CH_3CN (2 mL) at 100 °C for 12 h. Chromatography (20% EtOAc/hexane) afforded **3aj** (113.07 mg) in 73% yield as a white solid (mp 220–222 °C): ^1H NMR (400 MHz, CDCl_3) δ 9.82 (s, 1H), 7.74 (dd, J = 5.3, 3.5 Hz, 2H), 7.52 (d, J = 7.9 Hz, 1H), 7.49–7.42 (m, 5H), 7.33 (td, J = 7.4, 1.3 Hz, 2H), 7.26–7.19 (m, 7H), 7.12 (t, J = 7.5 Hz, 1H), 7.02 (d, J = 7.8 Hz, 4H), 6.38 (t, J = 2.5 Hz, 1H). $^{13}\text{C}\{^1\text{H}\}$ NMR (100 MHz, CDCl_3) δ 138.1, 136.3 (m), 132.3, 131.4, 131.0, 130.9, 130.8 (d, J_{C-P} = 5.4 Hz), 130.6, 129.9 (q, J_{C-F} = 3.8 Hz), 129.1 (q, J_{C-F} = 11.3 Hz), 128.4 (d, J_{C-P} = 0.6 Hz), 128.3 (d, J_{C-P} = 1.6 Hz), 127.0 (d, J_{C-P} = 1.9 Hz), 124.6 (q, J_{C-F} = 271.4 Hz), 122.8, 120.5, 120.1, 111.4, 106.2 (d, J_{C-P} = 7.0 Hz), 61.5 (d, J_{C-P} = 63.6 Hz). ^{31}P

NMR (162 MHz, CDCl₃) δ 34.01. ¹⁹F NMR (376 MHz, CDCl₃) δ -63.12. HRMS (ESI-TOF) m/z [M + H]⁺ Calcd for C₃₅H₂₅F₆NOP 620.1578, found 620.1578.

((1H-Indol-2-yl)diphenylmethyl)di(thiophen-2-yl)phosphine oxide (3am)—

General procedure A was followed using **1a** (74.84 mg, 0.25 mmol), **2m** (80.34 mg, 0.375 mmol) and Y(Pfb)₃ (36.10 mg, 0.05 mmol, 0.2 equiv) in CH₃CN (2 mL) at 100 °C for 12 h. Chromatography (20% EtOAc/hexane) afforded **3am** (116.46 mg) in 94% yield as a white solid (mp 303–305 °C): ¹H NMR (400 MHz, CDCl₃) δ 10.08 (s, 1H), 7.63 (t, J = 4.5 Hz, 2H), 7.56 (d, J = 7.8 Hz, 1H), 7.45 (d, J = 8.1 Hz, 1H), 7.32–7.25 (m, 3H), 7.21 (t, J = 7.8 Hz, 4H), 7.17–7.12 (m, 1H), 7.11–6.99 (m, 6H), 6.89–6.81 (m, 2H), 6.30 (s, 1H).

¹³C{¹H}NMR (100 MHz, CDCl₃) δ 138.5, 138.1 (d, J_{C-P} = 9.1 Hz), 136.3, 135.5 (d, J_{C-P} = 4.3 Hz), 132.7, 131.6, 130.8 (d, J_{C-P} = 5.3 Hz), 128.2 (m), 128.1, 128.0 (d, J_{C-P} = 1.6 Hz), 127.4 (d, J_{C-P} = 1.5 Hz), 122.5, 120.6, 120.0, 111.7, 106.5, 61.5 (d, J_{C-P} = 72.0 Hz). ³¹P NMR (162 MHz, CDCl₃) δ 29.18. HRMS (ESI-TOF) m/z [M + H]⁺ Calcd for C₂₉H₂₃NOPS₂ 496.0959, found 496.0958.

((1H-Indol-2-yl)diphenylmethyl)(phenyl)(p-tolyl)phosphine oxide (3an)—

General procedure A was followed using **1a** (74.84 mg, 0.25 mmol), **2n** (81.08 mg, 0.375 mmol) and Y(Pfb)₃ (36.10 mg, 0.05 mmol, 0.2 equiv) in CH₃CN (2 mL) at 100 °C for 12 h.

Chromatography (20% EtOAc/hexane) afforded **3an** (83.34 mg) in 67% yield as a white solid (mp 164–166 °C): ¹H NMR (400 MHz, CDCl₃) δ 10.29 (s, 1H), 7.51 (d, J = 7.9 Hz, 1H), 7.49–7.39 (m, 2H), 7.30–7.23 (m, 2H), 7.26–7.19 (m, 3H), 7.15 (td, J = 8.0, 4.6 Hz, 7H), 7.09–6.96 (m, 8H), 6.27 (t, J = 2.4 Hz, 1H), 2.33 (s, 3H). ¹³C{¹H}NMR (100 MHz, CDCl₃) δ 142.6 (d, J_{C-P} = 2.9 Hz), 139.3 (d, J_{C-P} = 11.9 Hz), 136.3, 133.1, 133.0 (d, J_{C-P} = 2.6 Hz), 131.9 (d, J_{C-P} = 3.2 Hz), 131.1 (d, J_{C-P} = 3.6 Hz), 131.0 (d, J_{C-P} = 3.5 Hz), 129.2 (d, J_{C-P} = 11.8 Hz), 128.3 (d, J_{C-P} = 8.4 Hz), 128.0, 127.9 (d, J_{C-P} = 1.7 Hz), 127.6, 127.3, 127.1 (d, J_{C-P} = 1.6 Hz), 122.2, 120.4, 119.6, 111.5, 105.7 (d, J_{C-P} = 4.8 Hz), 61.2 (d, J_{C-P} = 64.9 Hz), 21.5. ³¹P NMR (162 MHz, CDCl₃) δ 36.93. HRMS (ESI-TOF) m/z [M + H]⁺ Calcd for C₃₄H₂₉NOP 498.1987, found 498.1992.

Ethyl ((1H-indol-2-yl)diphenylmethyl)(phenyl)phosphinate (3ao)—

General procedure A was followed using **1a** (74.84 mg, 0.25 mmol), **2o** (63.81 mg, 0.375 mmol) and Y(Pfb)₃ (36.10 mg, 0.05 mmol, 0.2 equiv) in CH₃CN (2 mL) at 100 °C for 12 h.

Chromatography (20% EtOAc/hexanes) afforded **3ao** (48.54 mg) in 43% yield as a white solid (mp 200–202 °C): ¹H NMR (400 MHz, CDCl₃) δ 9.91 (s, 1H), 7.52 (d, J = 7.8 Hz, 1H), 7.49–7.45 (dt, J = 8.0, 1.6 Hz, 2H), 7.45–7.41 (m, 1H), 7.42–7.38 (m, 1H), 7.30–7.26 (m, 2H), 7.25–7.19 (m, 6H), 7.19–7.15 (m, 5H), 7.10–7.04 (m, 1H), 6.30 (dt, J = 2.8, 1.4 Hz, 1H), 4.18–3.85 (m, 2H), 1.20 (t, J = 7.0 Hz, 3H). ¹³C{¹H}NMR (100 MHz, CDCl₃) δ 140.0 (d, J_{C-P} = 4.4 Hz), 138.7, 136.1 (d, J_{C-P} = 7.2 Hz), 133.6 (d, J_{C-P} = 14.2 Hz), 132.5 (d, J_{C-P} = 2.7 Hz), 130.9 (d, J_{C-P} = 5.2 Hz), 130.0, 128.8, 128.1 (d, J_{C-P} = 12.5 Hz), 127.8, 127.4 (d, J_{C-P} = 1.8 Hz), 121.9, 120.4, 119.6, 111.2, 104.8 (d, J_{C-P} = 7.2 Hz), 62.2 (d, J_{C-P} = 7.2 Hz), 60.2 (d, J_{C-P} = 89.9 Hz), 16.4. ³¹P NMR (162 MHz, CDCl₃) δ 42.47. HRMS (ESI-TOF) m/z [M + H]⁺ Calcd for C₂₉H₂₇NO₂P 452.1779, found 452.1779.

General Procedure B

2-Indolylmethanols **1** (0.25 mmol, 1 equiv), Diarylphosphine Oxides **2** (0.375 mmol, 1.5 equiv), Yb(OTf)₃ (31.01 mg, 0.05 mmol), dry CH₃CN (2 mL) and a stir bar were added to a sealed tube. After being stirred at 100 °C for indicated time, the mixture was evaporated under vacuum. The corresponding product **4** was isolated by silica gel column chromatography with a dichloro-methane/ethyl acetate mixture as eluent.

(2-Benzhydryl-1H-indol-3-yl)diphenylphosphine oxide (4aa)—General procedure B was followed using **1a** (74.84 mg, 0.25 mmol), **2a** (75.82 mg, 0.375 mmol) and Yb(OTf)₃ (31.01 mg, 0.05 mmol, 0.2 equiv) in CH₃CN (2 mL) at 100 °C for 12 h. Chromatography (10% EtOAc/dichloromethane) afforded **4aa** (91.87 mg) in 76% yield as a white solid (mp 212–214 °C): ¹H NMR (400 MHz, DMSO-*d*₆) δ 11.70 (s, 1H), 7.63–7.55 (m, 7H), 7.49 (dd, *J* = 7.5, 2.6 Hz, 4H), 7.41 (d, *J* = 8.3 Hz, 1H), 7.31–7.26 (m, 4H), 7.23 (d, *J* = 7.1 Hz, 1H), 7.16–7.11 (m, 4H), 7.08–7.04 (m, 1H), 6.84–6.78 (m, 1H), 6.75 (s, 1H), 6.54 (d, *J* = 8.1 Hz, 1H). ¹³C{¹H}NMR (100 MHz, DMSO-*d*₆) δ 150.0 (d, *J*_{C-P} = 16.8 Hz), 148.6, 138.8, 136.9 (d, *J*_{C-P} = 6.5 Hz), 135.3, 134.2, 131.6 (d, *J*_{C-P} = 2.4 Hz), 131.2 (d, *J*_{C-P} = 10.1 Hz), 128.5 (d, *J*_{C-P} = 11.8 Hz), 128.3, 125.0, 121.6, 120.1, 119.5, 111.9, 100.6 (d, *J*_{C-P} = 124.8 Hz), 54.8. ³¹P NMR (162 MHz, DMSO-*d*₆) δ 21.95. HRMS (ESI-TOF) *m/z* [M + H]⁺ Calcd for C₃₃H₂₇NOP 484.1830, found 484.1831.

2-(Di-p-tolylmethyl)-1H-indol-3-yl)diphenylphosphine oxide (4ba)—General procedure B was followed using **1b** (81.86 mg, 0.25 mmol), **2a** (75.82 mg, 0.375 mmol) and Yb(OTf)₃ (31.01 mg, 0.05 mmol, 0.2 equiv) in CH₃CN (2 mL) at 100 °C for 12 h. Chromatography (10% EtOAc/dichloromethane) afforded **4ba** (52.43 mg) in 41% yield as a white solid (mp 244–246 °C): ¹H NMR (400 MHz, DMSO-*d*₆) δ 11.60 (d, *J* = 2.9 Hz, 1H), 7.62–7.59 (m, *J* = 1.2 Hz, 1H), 7.59–7.54 (m, *J* = 8.3 Hz, 5H), 7.49–7.43 (m, *J* = 7.4 Hz, 4H), 7.42–7.38 (m, 1H), 7.10–7.03 (m, 5H), 6.99 (d, *J* = 8.1 Hz, 4H), 6.82–6.77 (m, *J* = 8.1 Hz, 1H), 6.61 (s, 1H), 6.55 (d, *J* = 8.1 Hz, 1H), 2.25 (s, 6H). ¹³C{¹H}NMR (100 MHz, DMSO-*d*₆) δ 150.2 (d, *J*_{C-P} = 17.0 Hz), 138.8, 136.9 (d, *J*_{C-P} = 11.4 Hz), 135.5, 135.1, 134.0, 131.7 (d, *J*_{C-P} = 2.8 Hz), 131.2 (d, *J*_{C-P} = 10.2 Hz), 128.8, 128.5 (t, *J*_{C-P} = 7.5 Hz), 128.2 (d, *J*_{C-P} = 12.0 Hz), 121.7, 120.2, 119.6, 112.0, 100.5 (d, *J*_{C-P} = 125.1 Hz), 46.3, 20.5. ³¹P NMR (DMSO-*d*₆, 162 MHz) δ 22.25. HRMS (ESI-TOF) *m/z* [M + H]⁺ Calcd for C₃₅H₃₁NOP 512.2143, found 512.2140.

(2-(Bis (4-methoxyphenyl) methyl)-1H-indol-3-yl)-diphenylphosphine oxide (4ca)—General procedure B was followed using **1c** (89.86 mg, 0.25 mmol), **2a** (75.82 mg, 0.375 mmol) and Yb(OTf)₃ (31.01 mg, 0.05 mmol, 0.2 equiv) in CH₃CN (2 mL) at 100 °C for 12 h. Chromatography (10% EtOAc/dichloromethane) afforded **4ca** (77.46 mg) in 57% yield as a white solid (mp 177–179 °C): ¹H NMR (400 MHz, DMSO-*d*₆) δ 11.55 (d, *J* = 2.9 Hz, 1H), 7.54–7.47 (m, 7H), 7.41–7.37 (m, 4H), 7.34 (dd, *J* = 8.1, 1.6 Hz, 1H), 6.98–6.92 (m, 5H), 6.78–6.71 (m, 4H), 6.47 (d, *J* = 8.1 Hz, 1H), 6.42 (s, 1H), 3.63 (s, 6H). ¹³C{¹H}NMR (100 MHz, DMSO-*d*₆) δ 157.7, 136.9 (d, *J*_{C-P} = 11.5 Hz), 135.1, 134.1, 133.9, 131.7 (d, *J*_{C-P} = 2.3 Hz), 131.2 (d, *J*_{C-P} = 10.1 Hz), 130.3 (d, *J*_{C-P} = 11.4 Hz), 129.6, 129.0 (d, *J*_{C-P} = 12.4 Hz), 128.6 (d, *J*_{C-P} = 47.8 Hz), 121.7, 120.2 (d, *J*_{C-P} = 61.1 Hz), 113.7, 112.0, 100.3 (d, *J*_{C-P} = 125.1 Hz), 55.0, 45.5. ³¹P NMR (DMSO-*d*₆, 162 MHz) δ

22.05. HRMS (ESI-TOF) m/z $[M + Na]^+$ Calcd for $C_{35}H_{30}NNaO_3P$ 566.1861, found 566.1869.

(2-(Bis (4-(tert-butyl) phenyl) methyl)-1H-indol-3-yl)-diphenylphosphine oxide (4da)—General procedure B was followed using **1d** (102.90 mg, 0.25 mmol), **2a** (75.82 mg, 0.375 mmol) and $Yb(OTf)_3$ (31.01 mg, 0.05 mmol, 0.2 equiv) in CH_3CN (2 mL) at 100 °C for 12 h. Chromatography (10% EtOAc/dichloromethane) afforded **4da** (117.71 mg) in 75% yield as a white solid (mp 247–249 °C): 1H NMR (400 MHz, $DMSO-d_6$) δ 11.69 (d, $J = 2.9$ Hz, 1H), 7.62–7.55 (m, 6H), 7.49–7.44 (m, 4H), 7.43–7.39 (m, 1H), 7.31–7.26 (m, 4H), 7.10–7.03 (m, 5H), 6.82–6.77 (m, 1H), 6.66 (s, 1H), 6.55 (d, $J = 8.1$ Hz, 1H), 1.24 (s, 18H). $^{13}C\{^1H\}$ NMR (100 MHz, $DMSO-d_6$) δ 150.3 (d, $J_{C-P} = 16.9$ Hz), 148.6, 138.9, 137.0 (d, $J_{C-P} = 11.5$ Hz), 135.3, 134.3, 131.6, 131.2 (d, $J_{C-P} = 10.2$ Hz), 128.6 (d, $J_{C-P} = 11.8$ Hz), 128.3, 125.0, 121.6, 120.1, 119.6, 112.0, 100.7 (d, $J_{C-P} = 124.8$ Hz), 54.9, 34.1, 31.1. ^{31}P NMR (162 MHz, $DMSO-d_6$) δ 22.01. HRMS (ESI-TOF) m/z $[M + H]^+$ Calcd for $C_{41}H_{43}NOP$ 596.3082, found 596.3092.

(2-(Bis(4-chlorophenyl)methyl)-1H-indol-3-yl)diphenylphosphine oxide (4ea)—General procedure B was followed using **1e** (92.06 mg, 0.25 mmol), **2a** (75.82 mg, 0.375 mmol) and $Yb(OTf)_3$ (31.01 mg, 0.05 mmol, 0.2 equiv) in CH_3CN (2 mL) at 100 °C for 12 h. Chromatography (10% EtOAc/dichloromethane) afforded **4ea** (59.39 mg) in 43% yield as a white solid (mp 244–246 °C): 1H NMR (400 MHz, $DMSO-d_6$) δ 11.73 (d, $J = 2.9$ Hz, 1H), 7.60–7.53 (m, 6H), 7.49–7.44 (m, 4H), 7.43–7.39 (m, 1H), 7.37–7.32 (m, 4H), 7.14–7.05 (m, 5H), 6.84–6.79 (m, 1H), 6.76 (s, 1H), 6.49 (d, $J = 8.1$ Hz, 1H). $^{13}C\{^1H\}$ NMR (100 MHz, $DMSO-d_6$) δ 148.8 (d, $J_{C-P} = 16.8$ Hz), 140.1, 136.9 (d, $J_{C-P} = 11.3$ Hz), 134.7, 133.7, 131.8, 131.4, 131.1 (d, $J_{C-P} = 10.3$ Hz), 130.5, 128.6 (d, $J_{C-P} = 12.6$ Hz), 128.4, 122.0, 120.5, 119.5, 112.1, 101.1 (d, $J_{C-P} = 124.3$ Hz), 45.9. ^{31}P NMR (162 MHz, $DMSO-d_6$) δ 22.40. HRMS (ESI-TOF) m/z $[M - H]^-$ Calcd for $C_{33}H_{23}Cl_2NOP$ 550.0894, found 550.0908.

(2-(Bis(4-fluorophenyl)methyl)-1H-indol-3-yl)diphenylphosphine oxide (4fa)—General procedure B was followed using **1f** (83.84 mg, 0.25 mmol), **2a** (75.82 mg, 0.375 mmol) and $Yb(OTf)_3$ (31.01 mg, 0.05 mmol, 0.2 equiv) in CH_3CN (2 mL) at 100 °C for 12 h. Chromatography (10% EtOAc/dichloromethane) afforded **4fa** (66.24 mg) in 51% yield as a white solid (mp 272–274 °C): 1H NMR (400 MHz, $DMSO-d_6$) δ 11.76 (d, $J = 2.8$ Hz, 1H), 7.56–7.48 (m, 6H), 7.44–7.38 (m, 4H), 7.37–7.34 (m, 1H), 7.32–7.23 (m, 2H), 7.05–6.98 (m, 3H), 6.95–6.90 (m, 2H), 6.85–6.78 (m, 3H), 6.79–6.72 (m, 1H), 6.42 (d, $J = 8.1$ Hz, 1H). $^{13}C\{^1H\}$ NMR (100 MHz, $DMSO-d_6$) δ 163.3 (d, $J_{C-F} = 242.3$ Hz), 143.7 (d, $J_{C-P} = 6.8$ Hz), 134.9, 133.8, 131.8, 131.2 (d, $J_{C-P} = 10.2$ Hz), 130.5 (d, $J_{C-P} = 8.3$ Hz), 128.7 (d, $J_{C-P} = 11.8$ Hz), 124.8, 122.1, 120.5, 119.6, 115.4 (d, $J_{C-F} = 21.9$ Hz), 113.8 (d, $J_{C-F} = 20.7$ Hz), 112.1, 101.5 (d, $J_{C-P} = 123.5$ Hz), 46.5. ^{19}F NMR (376 MHz, $DMSO-d_6$) δ -112.76. ^{31}P NMR (162 MHz, $DMSO-d_6$) δ 22.13. HRMS (ESI-TOF) m/z $[M - H]^-$ Calcd for $C_{33}H_{23}F_2NOP$ 518.1485, found 518.1479.

(2-(Di-o-tolylmethyl)-1H-indol-3-yl)diphenylphosphine oxide (4ga)—General procedure B was followed using **1g** (81.86 mg, 0.25 mmol), **2a** (75.82 mg, 0.375 mmol) and

Yb(OTf)₃ (31.01 mg, 0.05 mmol, 0.2 equiv) in CH₃CN (2 mL) at 100 °C for 12 h. Chromatography (10% EtOAc/dichloromethane) afforded **4ga** (76.74 mg) in 60% yield as a white solid (mp 193–195 °C): ¹H NMR (400 MHz, DMSO-*d*₆) δ 11.11 (d, *J* = 2.9 Hz, 1H), 7.53–7.44 (m, 6H), 7.43 (d, *J* = 1.6 Hz, 1H), 7.41–7.34 (m, 4H), 7.15–7.11 (m, 4H), 7.08–7.01 (m, 3H), 6.99 (s, 1H), 6.85–6.79 (m, 1H), 6.72 (d, *J* = 7.5 Hz, 2H), 6.59 (d, *J* = 8.0 Hz, 1H), 2.09 (s, 6H). ¹³C{¹H}NMR (100 MHz, DMSO-*d*₆) δ 170.3, 149.2 (d, *J*_{C-P} = 16.7 Hz), 140.1, 136.5 (d, *J*_{C-P} = 11.4 Hz), 136.3, 135.0, 134.0, 131.4 (d, *J*_{C-P} = 2.4 Hz), 131.0 (d, *J*_{C-P} = 10.1 Hz), 130.1, 128.4 (m), 126.6, 125.8, 121.4, 120.3, 119.5, 112.3, 99.5 (d, *J*_{C-P} = 124.8 Hz), 42.5, 19.1. ³¹P NMR (162 MHz, DMSO-*d*₆) δ 21.82. HRMS (ESI-TOF) *m/z* [M + H]⁺ Calcd for C₃₅H₃₁NOP 512.2143, found 512.2133.

(2-(Di-*m*-tolylmethyl)-1H-indol-3-yl)diphenylphosphine oxide (4ha)—General procedure B was followed using **1h** (81.86 mg, 0.25 mmol), **2a** (75.82 mg, 0.375 mmol) and Yb(OTf)₃ (31.01 mg, 0.05 mmol, 0.2 equiv) in CH₃CN (2 mL) at 100 °C for 12 h. Chromatography (10% EtOAc/dichloromethane) afforded **4ha** (79.30 mg) in 62% yield as a white solid (mp 275–277 °C): ¹H NMR (400 MHz, DMSO-*d*₆) δ 11.57 (d, *J* = 3.0 Hz, 1H), 7.55–7.48 (m, 6H), 7.44–7.38 (m, 4H), 7.34 (d, *J* = 8.2 Hz, 1H), 7.10 (t, *J* = 7.6 Hz, 2H), 7.01–6.93 (m, 3H), 6.88 (d, *J* = 7.8 Hz, 2H), 6.81 (s, 2H), 6.73 (t, *J* = 7.6 Hz, 1H), 6.58 (s, 1H), 6.45 (d, *J* = 8.2 Hz, 1H), 2.12 (s, 6H). ¹³C{¹H}NMR (100 MHz, DMSO-*d*₆ with CDCl₃) δ 149.9 (d, *J*_{C-P} = 16.7 Hz), 141.6, 137.1, 136.9 (d, *J*_{C-P} = 11.8 Hz), 135.1, 134.0, 131.4, 131.2 (d, *J*_{C-P} = 10.2 Hz), 129.4, 128.2 (d, *J*_{C-P} = 11.9 Hz), 127.9, 126.9, 125.7, 121.4, 120.0, 119.6, 111.9, 99.2 (d, *J*_{C-P} = 125.5 Hz), 47.0, 21.1. ³¹P NMR (162 MHz, DMSO-*d*₆) δ 22.10. HRMS (ESI-TOF) *m/z* [M + H]⁺ Calcd for C₃₅H₃₁NOP 512.2143, found 512.2142.

(2-(Bis(3-fluorophenyl)methyl)-1H-indol-3-yl)diphenylphosphine oxide (4ia)—General procedure B was followed using **1i** (83.84 mg, 0.25 mmol), **2a** (75.82 mg, 0.375 mmol) and Yb(OTf)₃ (31.01 mg, 0.05 mmol, 0.2 equiv) in CH₃CN (2 mL) at 100 °C for 12 h. Chromatography (10% EtOAc/dichloromethane) afforded **4ia** (102.61 mg) in 79% yield as a white solid (mp 329–331 °C): ¹H NMR (400 MHz, DMSO-*d*₆) δ 11.82 (s, 1H), 7.59 (dd, *J* = 12.5, 7.3 Hz, 7H), 7.53–7.46 (m, 4H), 7.43 (d, *J* = 8.1 Hz, 1H), 7.36 (q, *J* = 7.5 Hz, 2H), 7.09 (t, *J* = 7.9 Hz, 3H), 7.00 (d, *J* = 7.8 Hz, 2H), 6.93–6.81 (m, 3H), 6.50 (d, *J* = 8.1 Hz, 1H). ¹³C{¹H}NMR (100 MHz, DMSO-*d*₆) δ 163.3 (d, *J*_{C-F} = 242.3 Hz), 148.2 (d, *J*_{C-P} = 16.6 Hz), 143.7 (d, *J*_{C-P} = 6.5 Hz), 137.0 (d, *J*_{C-P} = 12.6 Hz), 134.9, 133.8, 131.8 (q, *J*_{C-F} = 5.5 Hz), 131.2 (d, *J*_{C-P} = 10.2 Hz), 130.5 (d, *J*_{C-P} = 8.3 Hz), 128.7 (d, *J*_{C-P} = 11.6 Hz), 127.9, 124.8, 122.1, 120.5, 119.6, 115.4 (d, *J*_{C-F} = 21.8 Hz), 113.8 (d, *J*_{C-F} = 17.6 Hz), 112.1, 101.5 (d, *J*_{C-P} = 123.4 Hz). ¹⁹F NMR (376 MHz, DMSO-*d*₆) δ –108.01. ³¹P NMR (162 MHz, DMSO-*d*₆) δ 22.12. HRMS (ESI-TOF) *m/z* [M + H]⁺ Calcd for C₃₃H₂₅F₂NOP 520.1642, found 520.1641.

(2-(Bis(3-(trifluoromethyl)phenyl)methyl)-1H-indol-3-yl)-diphenylphosphine oxide (4ja)—General procedure B was followed using **1j** (108.84 mg, 0.25 mmol), **2a** (75.82 mg, 0.375 mmol) and Yb(OTf)₃ (31.01 mg, 0.05 mmol, 0.2 equiv) in CH₃CN (2 mL) at 100 °C for 12 h. Chromatography (10% EtOAc/dichloromethane) afforded **4ja** (109.97 mg) in 71% yield as a white solid (mp 275–277 °C): ¹H NMR (400 MHz, DMSO-*d*₆) δ

11.63 (d, $J = 2.9$ Hz, 1H), 7.54 (d, $J = 1.3$ Hz, 1H), 7.52–7.47 (m, 5H), 7.43–7.36 (m, 4H), 7.35–7.32 (m, 1H), 7.23–7.19 (m, 4H), 7.02–6.97 (m, 5H), 6.76–6.67 (m, 1H), 6.58 (s, 1H), 6.46 (d, $J = 8.0$ Hz, 1H). $^{13}\text{C}\{^1\text{H}\}$ NMR (100 MHz, DMSO- d_6) δ 150.3 (d, $J_{\text{C-P}} = 1.8$ Hz), 150.1, 148.6, 138.9, 136.9, 136.8, 135.2, 134.2, 131.7 (q, $J_{\text{C-F}} = 1.9$ Hz), 131.2 (d, $J_{\text{C-P}} = 10.2$ Hz), 128.6 (d, $J_{\text{C-P}} = 11.8$ Hz), 128.3, 128.0 (d, $J_{\text{C-F}} = 2.5$ Hz), 125.1, 121.7 (d, $J_{\text{C-F}} = 210.1$ Hz), 120.2, 119.6, 112.0, 100.6 (d, $J_{\text{C-P}} = 124.9$ Hz), 45.1. ^{31}P NMR (162 MHz, DMSO- d_6) δ 22.10. ^{19}F NMR (376 MHz, DMSO- d_6) δ -62.66. HRMS (ESI-TOF) m/z [M – H] $^-$ Calcd for $\text{C}_{35}\text{H}_{23}\text{F}_6\text{NOP}$ 618.1421, found 618.1431.

(2-Benzhydryl-5-methyl-1H-indol-3-yl)diphenylphosphine oxide (4ka)—General procedure B was followed using **1k** (78.35 mg, 0.25 mmol), **2a** (75.82 mg, 0.375 mmol) and $\text{Yb}(\text{OTf})_3$ (31.01 mg, 0.05 mmol, 0.2 equiv) in CH_3CN (2 mL) at 100 °C for 12 h. Chromatography (10% EtOAc/dichloromethane) afforded **4ka** (103.25 mg) in 83% yield as a white solid (mp 276–278 °C): ^1H NMR (400 MHz, DMSO- d_6) δ 11.61 (s, 1H), 7.65–7.52 (m, 6H), 7.52–7.43 (m, 4H), 7.34–7.17 (m, 7H), 7.12 (d, $J = 7.5$ Hz, 4H), 6.94–6.85 (m, 1H), 6.64 (s, 1H), 6.31 (s, 1H), 2.07 (s, 3H). $^{13}\text{C}\{^1\text{H}\}$ NMR (100 MHz, DMSO- d_6) δ 149.4 (d, $J_{\text{C-P}} = 17.0$ Hz), 141.7, 135.2 (d, $J_{\text{C-P}} = 1.5$ Hz), 135.1, 134.2, 131.6 (d, $J_{\text{C-P}} = 1.8$ Hz), 131.2 (d, $J_{\text{C-P}} = 10.1$ Hz), 128.7, 128.6, 128.5, 128.3, 126.5, 123.2, 119.4, 111.7, 100.5 (d, $J_{\text{C-P}} = 94.9$ Hz), 47.1, 21.3. ^{31}P NMR (162 MHz, DMSO- d_6) δ 22.17. HRMS (ESI-TOF) m/z [M – H] $^-$ Calcd for $\text{C}_{34}\text{H}_{27}\text{NOP}$ 496.1830, found 496.1825.

(2-Benzhydryl-6-chloro-1H-indol-3-yl)diphenylphosphine oxide (4la)—General procedure B was followed using **1l** (83.45 mg, 0.25 mmol), **2a** (75.82 mg, 0.375 mmol) and $\text{Yb}(\text{OTf})_3$ (31.01 mg, 0.05 mmol, 0.2 equiv) in CH_3CN (2 mL) at 100 °C for 12 h. Chromatography (10% EtOAc/dichloromethane) afforded **4la** (67.34 mg) in 52% yield as a white solid (mp 287–289 °C): ^1H NMR (400 MHz, DMSO- d_6) δ 11.82 (d, $J = 2.9$ Hz, 1H), 7.62–7.55 (m, 6H), 7.51–7.44 (m, 4H), 7.43 (d, $J = 2.0$ Hz, 1H), 7.31–7.25 (m, 4H), 7.25–7.20 (m, 2H), 7.14–7.09 (m, 4H), 6.87 (dd, $J = 8.6, 2.1$ Hz, 1H), 6.67 (s, 1H), 6.55 (d, $J = 8.7$ Hz, 1H). $^{13}\text{C}\{^1\text{H}\}$ NMR (100 MHz, DMSO- d_6) δ 150.6 (d, $J_{\text{C-P}} = 16.5$ Hz), 141.3, 137.4 (d, $J_{\text{C-P}} = 11.4$ Hz), 134.8, 133.7, 131.8 (d, $J_{\text{C-P}} = 2.4$ Hz), 131.2 (d, $J_{\text{C-P}} = 10.2$ Hz), 128.7 (d, $J_{\text{C-P}} = 11.8$ Hz), 128.6, 128.4, 127.0 (d, $J_{\text{C-P}} = 11.8$ Hz), 126.6, 121.0, 120.6, 111.6, 101.5 (d, $J_{\text{C-P}} = 123.3$ Hz), 47.0. ^{31}P NMR (162 MHz, DMSO- d_6) δ 21.55. HRMS (ESI-TOF) m/z [M + H] $^+$ Calcd for $\text{C}_{33}\text{H}_{26}\text{ClNOP}$ 518.1441, found 518.1440.

(2-Benzhydryl-1H-indol-3-yl)di-p-tolylphosphine oxide (4ab)—General procedure B was followed using **1a** (74.84 mg, 0.25 mmol), **2b** (86.34 mg, 0.375 mmol) and $\text{Yb}(\text{OTf})_3$ (31.01 mg, 0.05 mmol, 0.2 equiv) in CH_3CN (2 mL) at 100 °C for 12 h. Chromatography (10% EtOAc/dichloromethane) afforded **4ab** (92.09 mg) in 72% yield as a white solid (mp 225–227 °C): ^1H NMR (400 MHz, DMSO- d_6) δ 11.66 (d, $J = 2.9$ Hz, 1H), 7.50–7.43 (m, 4H), 7.42–7.39 (m, 1H), 7.30 (t, $J = 1.4$ Hz, 1H), 7.29–7.26 (m, 7H), 7.24 (d, $J = 1.4$ Hz, 1H), 7.22 (s, 1H), 7.17–7.12 (m, 4H), 7.07–7.01 (m, 1H), 6.84–6.79 (m, 2H), 6.62 (d, $J = 8.1$ Hz, 1H), 2.34 (s, 6H). $^{13}\text{C}\{^1\text{H}\}$ NMR (100 MHz, DMSO- d_6) δ 149.5 (d, $J_{\text{C-P}} = 16.7$ Hz), 141.8, 141.5 (d, $J_{\text{C-P}} = 2.7$ Hz), 136.9 (d, $J_{\text{C-P}} = 10.8$ Hz), 132.3, 131.2 (d, $J_{\text{C-P}} = 10.5$ Hz), 129.1 (d, $J_{\text{C-P}} = 12.1$ Hz), 128.7, 128.3, 128.1, 126.4, 121.7 (d, $J_{\text{C-P}} = 11.9$ Hz), 120.1,

119.8, 111.9, 101.2 (d, J_{C-P} = 124.0 Hz), 46.9, 21.1. ^{31}P NMR (162 MHz, DMSO- d_6) δ 22.03. HRMS (ESI-TOF) m/z [M + H] $^+$ Calcd for $\text{C}_{35}\text{H}_{31}\text{NOP}$ 512.2143, found 512.2142.

(2-Benzhydryl-1H-indol-3-yl)bis(4-methoxyphenyl)phosphine oxide (4ac)—

General procedure B was followed using **1a** (74.84 mg, 0.25 mmol), **2c** (98.34 mg, 0.375 mmol) and $\text{Yb}(\text{OTf})_3$ (31.01 mg, 0.05 mmol, 0.2 equiv) in CH_3CN (2 mL) at 100 °C for 12 h. Chromatography (10% EtOAc/dichloromethane) afforded **4ac** (44.85 mg) in 33% yield as a white solid (mp 299–301 °C): ^1H NMR (400 MHz, DMSO- d_6) δ 11.64 (d, J = 2.8 Hz, 1H), 7.53–7.45 (m, 4H), 7.43–7.38 (m, 1H), 7.32–7.26 (m, 4H), 7.25–7.19 (m, 2H), 7.17–7.13 (m, 4H), 7.06–6.98 (m, 5H), 6.86–6.80 (m, 2H), 6.62 (d, J = 8.1 Hz, 1H), 3.78 (s, 6H). $^{13}\text{C}\{^1\text{H}\}$ NMR (100 MHz, DMSO- d_6) δ 161.6 (d, J_{C-P} = 2.6 Hz), 149.3 (d, J_{C-P} = 16.3 Hz), 141.9, 136.9 (d, J_{C-P} = 11.5 Hz), 133.0 (d, J_{C-P} = 11.6 Hz), 128.7 (d, J_{C-P} = 38.2 Hz), 128.1 (d, J_{C-P} = 11.6 Hz), 126.9, 126.4, 125.8, 121.6, 120.1, 119.8, 114.1 (d, J_{C-P} = 12.8 Hz), 111.9, 101.7 (d, J_{C-P} = 124.6 Hz), 55.3, 46.8. ^{31}P NMR (162 MHz, DMSO- d_6) δ 21.23. HRMS (ESI-TOF) m/z [M + H] $^+$ Calcd for $\text{C}_{35}\text{H}_{31}\text{NO}_3\text{P}$ 544.2042, found 544.2043.

(2-Benzhydryl-1H-indol-3-yl)bis(4-(tert-butyl)phenyl)phosphine oxide (4ad)—

General procedure B was followed using **1a** (74.84 mg, 0.25 mmol), **2d** (117.90 mg, 0.375 mmol) and $\text{Yb}(\text{OTf})_3$ (31.01 mg, 0.05 mmol, 0.2 equiv) in CH_3CN (2 mL) at 100 °C for 12 h. Chromatography (10% EtOAc/dichloromethane) afforded **4ad** (110.22 mg) in 74% yield as a white solid (mp 260–262 °C): ^1H NMR (400 MHz, DMSO- d_6) δ 11.67 (d, J = 2.8 Hz, 1H), 7.57–7.50 (m, 4H), 7.49–7.44 (m, 4H), 7.43–7.39 (m, 1H), 7.29–7.24 (m, 4H), 7.23–7.18 (m, 2H), 7.15–7.11 (m, 4H), 7.06–7.01 (m, 1H), 6.81–6.75 (m, 1H), 6.73 (s, 1H), 6.65 (d, J = 8.1 Hz, 1H), 1.26 (s, 18H). $^{13}\text{C}\{^1\text{H}\}$ NMR (100 MHz, DMSO- d_6) δ 154.3 (d, J_{C-P} = 2.5 Hz), 149.3 (d, J_{C-P} = 16.8 Hz), 141.8, 137.0 (d, J_{C-P} = 11.4 Hz), 132.3, 131.1 (t, J_{C-P} = 6.4 Hz), 128.7, 128.3, 128.1 (d, J_{C-P} = 11.9 Hz), 126.4, 125.4 (d, J_{C-P} = 11.9 Hz), 121.7, 120.1, 119.8, 111.9, 101.5 (d, J_{C-P} = 124.0 Hz), 46.9, 34.6, 30.8. ^{31}P NMR (162 MHz, DMSO- d_6) δ 21.48. HRMS (ESI-TOF) m/z [M + H] $^+$ Calcd for $\text{C}_{41}\text{H}_{43}\text{NOP}$ 596.3082, found 596.3091.

(2-Benzhydryl-1H-indol-3-yl)bis(4-(dimethylamino)phenyl)-phosphine oxide

(4ae)—General procedure B was followed using **1a** (74.84 mg, 0.25 mmol), **2e** (108.12 mg, 0.375 mmol) and $\text{Yb}(\text{OTf})_3$ (31.01 mg, 0.05 mmol, 0.2 equiv) in CH_3CN (2 mL) at 100 °C for 12 h. Chromatography (10% EtOAc/dichloromethane) afforded **4ae** (49.85 mg) in 35% yield as a white solid (mp 303–305 °C): ^1H NMR (400 MHz, DMSO- d_6) δ 11.50 (s, 1H), 7.40–7.26 (m, 9H), 7.24–7.14 (m, 6H), 7.07–6.95 (m, 2H), 6.81 (t, J = 7.6 Hz, 1H), 6.77–6.65 (m, 5H), 2.93 (s, 12H). $^{13}\text{C}\{^1\text{H}\}$ NMR (100 MHz, DMSO- d_6) δ 150.1 (d, J_{C-P} = 16.3 Hz), 148.6, 138.6, 136.7 (d, J_{C-P} = 6.5 Hz), 135.3, 134.2, 131.6 (d, J_{C-P} = 2.5 Hz), 131.0 (d, J_{C-P} = 10.0 Hz), 128.3 (d, J_{C-P} = 11.9 Hz), 128.1, 125.0, 121.4, 120.1, 119.3, 111.9, 100.3 (d, J_{C-P} = 124.8 Hz), 54.9, 46.2. ^{31}P NMR (162 MHz, DMSO- d_6) δ 21.92. HRMS (ESI-TOF) m/z [M + H] $^+$ Calcd for $\text{C}_{37}\text{H}_{37}\text{N}_3\text{OP}$ 570.2674, found 570.2674.

(2-Benzhydryl-1H-indol-3-yl)bis(4-fluorophenyl)phosphine oxide (4af)—

General procedure B was followed using **1a** (74.84 mg, 0.25 mmol), **2f** (89.32 mg, 0.375 mmol) and $\text{Yb}(\text{OTf})_3$ (31.01 mg, 0.05 mmol, 0.2 equiv) in CH_3CN (2 mL) at 100 °C for 12 h.

Chromatography (10% EtOAc/dichloromethane) afforded **4af** (64.94 mg) in 50% yield as a white solid (mp 304–306 °C): ^1H NMR (400 MHz, DMSO- d_6) δ 11.79–11.75 (m, 1H), 7.69–7.58 (m, 4H), 7.47–7.41 (d, J = 8.2 Hz, 1H), 7.38–7.26 (m, 8H), 7.24 (d, J = 7.0 Hz, 2H), 7.14 (d, J = 7.5 Hz, 4H), 7.08 (t, J = 7.7 Hz, 1H), 6.86 (t, J = 7.6 Hz, 1H), 6.77 (s, 1H), 6.52 (d, J = 8.1 Hz, 1H). $^{13}\text{C}\{^1\text{H}\}$ NMR (100 MHz, DMSO- d_6) 165.3 (d, $J_{\text{C-F}}$ = 247.4 Hz), 150.1 (d, $J_{\text{C-P}}$ = 17.2 Hz), 141.5, 137.0 (d, $J_{\text{C-P}}$ = 11.7 Hz), 133.9 (q, $J_{\text{C-F}}$ = 19.2 Hz), 131.4, 130.4, 128.7 (d, $J_{\text{C-P}}$ = 29.1 Hz), 127.9 (d, $J_{\text{C-P}}$ = 12.2 Hz), 126.5, 121.9, 120.5, 119.3, 115.9 (d, $J_{\text{C-F}}$ = 13.0 Hz), 112.2, 100.4 (d, $J_{\text{C-P}}$ = 126.1 Hz), 47.1. ^{19}F NMR (376 MHz, DMSO- d_6) δ -102.83, -102.84. ^{31}P NMR (162 MHz, DMSO- d_6) δ 20.50. HRMS (ESI-TOF) m/z $[\text{M} - \text{H}]^-$ Calcd for $\text{C}_{33}\text{H}_{23}\text{F}_2\text{NOP}$ 518.1485, found 518.1480.

(2-Benzhydryl-1H-indol-3-yl)bis(4-chlorophenyl)phosphine oxide (4ag)—

General procedure B was followed using **1a** (74.84 mg, 0.25 mmol), **2g** (101.65 mg, 0.375 mmol) and $\text{Yb}(\text{OTf})_3$ (31.01 mg, 0.05 mmol, 0.2 equiv) in CH_3CN (2 mL) at 100 °C for 12 h. Chromatography (10% EtOAc/dichloromethane) afforded **4ag** (87.01 mg) in 63% yield as a white solid (mp 281–283 °C): ^1H NMR (400 MHz, DMSO- d_6) δ 11.78 (d, J = 2.9 Hz, 1H), 7.61–7.55 (m, 4H), 7.55–7.52 (m, 4H), 7.46–7.42 (m, 1H), 7.31–7.26 (m, 4H), 7.24–7.20 (m, 2H), 7.16–7.12 (m, 4H), 7.11–7.05 (m, 1H), 6.89–6.84 (m, 1H), 6.76 (s, 1H), 6.55 (d, J = 8.1 Hz, 1H). $^{13}\text{C}\{^1\text{H}\}$ NMR (100 MHz, DMSO- d_6) δ 150.3 (d, $J_{\text{C-P}}$ = 17.0 Hz), 141.5, 137.0 (d, $J_{\text{C-P}}$ = 2.8 Hz), 136.9, 133.7, 133.0 (d, $J_{\text{C-P}}$ = 11.3 Hz), 132.7, 128.9 (d, $J_{\text{C-P}}$ = 12.5 Hz), 128.7 (d, $J_{\text{C-P}}$ = 31.1 Hz), 127.8 (d, $J_{\text{C-P}}$ = 12.2 Hz), 126.5, 121.9, 120.6, 119.3, 112.2, 99.8 (d, $J_{\text{C-P}}$ = 126.9 Hz), 78.9 (t, $J_{\text{C-P}}$ = 33.0 Hz). ^{31}P NMR (162 MHz, DMSO- d_6) δ 20.87. HRMS (ESI-TOF) m/z $[\text{M} - \text{H}]^-$ Calcd for $\text{C}_{33}\text{H}_{23}\text{Cl}_2\text{NOP}$ 550.0894, found 550.0900.

(2-Benzhydryl-1H-indol-3-yl)bis(3-fluorophenyl)phosphine oxide (4ah)—General procedure B was followed using **1a** (74.84 mg, 0.25 mmol), **2h** (89.32 mg, 0.375 mmol) and $\text{Yb}(\text{OTf})_3$ (31.01 mg, 0.05 mmol, 0.2 equiv) in CH_3CN (2 mL) at 100 °C for 12 h.

Chromatography (10% EtOAc/dichloromethane) afforded **4ah** (83.13 mg) in 64% yield as a white solid (mp 270–272 °C): ^1H NMR (400 MHz, DMSO- d_6) δ 11.80 (d, J = 3.0 Hz, 1H), 7.59–7.52 (m, 2H), 7.48–7.41 (m, 5H), 7.34–7.27 (m, 6H), 7.26–7.22 (m, 2H), 7.14–7.07 (m, 5H), 6.90–6.35 (m, 1H), 6.62 (s, 1H), 6.55 (d, J = 8.1 Hz, 1H). $^{13}\text{C}\{^1\text{H}\}$ NMR (100 MHz, DMSO- d_6) δ 163.1 (d, $J_{\text{C-F}}$ = 263.1 Hz), 150.3 (d, $J_{\text{C-P}}$ = 17.5 Hz), 141.3, 137.4 (d, $J_{\text{C-P}}$ = 5.1 Hz), 137.0 (d, $J_{\text{C-P}}$ = 1.9 Hz), 136.4 (d, $J_{\text{C-P}}$ = 5.3 Hz), 131.4 (q, $J_{\text{C-F}}$ = 7.5 Hz), 128.6 (d, $J_{\text{C-P}}$ = 25.0 Hz), 127.7, 127.4 (d, $J_{\text{C-P}}$ = 3.0 Hz), 126.6, 122.0, 120.6, 119.3 (d, $J_{\text{C-P}}$ = 7.0 Hz), 119.0, 117.7 (q, $J_{\text{C-F}}$ = 11.2 Hz), 112.3, 99.6 (d, $J_{\text{C-P}}$ = 127.5 Hz), 47.3. ^{19}F NMR (376 MHz, DMSO- d_6) δ -111.31, -111.32. ^{31}P NMR (162 MHz, DMSO- d_6) δ 19.89. HRMS (ESI-TOF) m/z $[\text{M} - \text{H}]^-$ Calcd for $\text{C}_{33}\text{H}_{23}\text{F}_2\text{NOP}$ 518.1485, found 518.1480.

(2-Benzhydryl-1H-indol-3-yl)bis(3-chlorophenyl)phosphine oxide (4ai)—General procedure B was followed using **1a** (74.84 mg, 0.25 mmol), **2i** (101.65 mg, 0.375 mmol) and $\text{Yb}(\text{OTf})_3$ (31.01 mg, 0.05 mmol, 0.2 equiv) in CH_3CN (2 mL) at 100 °C for 12 h.

Chromatography (10% EtOAc/dichloromethane) afforded **4ai** (55.24 mg) in 40% yield as a white solid (mp 229–231 °C): ^1H NMR (400 MHz, DMSO- d_6) δ 11.83 (d, J = 3.0 Hz, 1H), 7.70–7.62 (m, 2H), 7.59–7.50 (m, 6H), 7.48–7.44 (m, 1H), 7.32–7.26 (m, 4H), 7.26–7.20

(m, 2H), 7.13–7.08 (m, 5H), 6.93–6.86 (m, 1H), 6.62–6.57 (m, 2H). $^{13}\text{C}\{^1\text{H}\}$ NMR (100 MHz, DMSO- d_6) δ 150.4 (d, $J_{\text{C-P}} = 17.4$ Hz), 141.2, 137.1, 137.0 (d, $J_{\text{C-P}} = 12.0$ Hz), 136.1, 133.8 (d, $J_{\text{C-P}} = 15.6$ Hz), 132.0 (d, $J_{\text{C-P}} = 2.2$ Hz), 131.0 (d, $J_{\text{C-P}} = 13.3$ Hz), 130.5 (d, $J_{\text{C-P}} = 11.0$ Hz), 129.8 (d, $J_{\text{C-P}} = 9.9$ Hz), 128.6 (d, $J_{\text{C-P}} = 23.0$ Hz), 127.8 (d, $J_{\text{C-P}} = 12.2$ Hz), 126.7, 122.1, 120.7, 119.2, 112.4, 99.4 (d, $J_{\text{C-P}} = 127.6$ Hz), 47.3. ^{31}P NMR (162 MHz, DMSO- d_6) δ 20.03. HRMS (ESI-TOF) m/z $[\text{M} - \text{H}]^-$ Calcd for $\text{C}_{33}\text{H}_{23}\text{Cl}_2\text{NOP}$ 550.0894, found 550.0892.

((2-Benzhydryl-1H-indol-3-yl)bis(3-(trifluoromethyl)phenyl)-phosphine oxide (4aj))—

General procedure B was followed using **1a** (74.84 mg, 0.25 mmol), **2j** (126.82 mg, 0.375 mmol) and $\text{Yb}(\text{OTf})_3$ (31.01 mg, 0.05 mmol, 0.2 equiv) in CH_3CN (2 mL) at 100 °C for 12 h. Chromatography (10% EtOAc/dichloromethane) afforded **4aj** (144.04 mg) in 93% yield as a white solid (mp 249–251 °C): ^1H NMR (400 MHz, CDCl_3) δ 8.83 (d, $J = 3.0$ Hz, 1H), 7.87 (d, $J = 12.4$ Hz, 2H), 7.75–7.62 (m, 4H), 7.47–7.41 (m, 2H), 7.30 (dd, $J = 8.3, 1.9$ Hz, 1H), 7.19–7.09 (m, 7H), 7.07–7.00 (m, 4H), 6.93 (t, $J = 7.6$ Hz, 1H), 6.68 (d, $J = 8.1$ Hz, 1H), 6.61 (s, 1H). $^{13}\text{C}\{^1\text{H}\}$ NMR (100 MHz, CDCl_3) δ 150.9 (d, $J_{\text{C-P}} = 17.6$ Hz), 140.9, 135.8 (d, $J_{\text{C-P}} = 11.4$ Hz), 135.5, 134.9 (d, $J_{\text{C-P}} = 10.6$ Hz), 134.4, 131.2 (q, $J_{\text{C-F}} = 12.5$ Hz), 129.1 (q, $J_{\text{C-F}} = 12.7$ Hz), 128.9, 128.6, 128.5 (d, $J_{\text{C-P}} = 4.8$ Hz), 127.1, 124.9 (q, $J_{\text{C-F}} = 270.6$ Hz), 122.7, 121.6, 120.0, 119.5, 111.7, 99.7 (d, $J_{\text{C-P}} = 128.9$ Hz), 48.5. ^{19}F NMR (376 MHz, CDCl_3) δ -62.67. ^{31}P NMR (162 MHz, CDCl_3) δ 21.52. HRMS (ESI-TOF) m/z $[\text{M} + \text{H}]^+$ Calcd for $\text{C}_{35}\text{H}_{25}\text{F}_6\text{NOP}$ 620.1578, found 620.1576.

((1H-Indol-2-yl)diphenylmethyl)dimesitylphosphine oxide (4ak))—

General procedure B was followed using **1a** (74.84 mg, 0.25 mmol), **2k** (107.38 mg, 0.375 mmol) and $\text{Yb}(\text{OTf})_3$ (31.01 mg, 0.05 mmol, 0.2 equiv) in CH_3CN (2 mL) at 100 °C for 12 h. Chromatography (10% EtOAc/dichloromethane) afforded **4ak** (69.54 mg) in 49% yield as a white solid (mp 219–221 °C): ^1H NMR (400 MHz, CDCl_3) δ 8.37 (s, 1H), 7.23 (d, $J = 8.3$ Hz, 1H), 7.18–7.13 (m, 7H), 7.10–7.05 (m, 4H), 6.84–6.79 (m, 1H), 6.72 (d, $J = 3.7$ Hz, 5H), 6.43 (d, $J = 8.2$ Hz, 1H), 2.24 (s, 6H), 2.13 (s, 12H). $^{13}\text{C}\{^1\text{H}\}$ NMR (100 MHz, CDCl_3) δ 149.2 (d, $J_{\text{C-P}} = 15.3$ Hz), 142.6 (d, $J_{\text{C-P}} = 10.1$ Hz), 141.3, 140.6 (d, $J_{\text{C-P}} = 2.4$ Hz), 135.7 (d, $J_{\text{C-P}} = 11.0$ Hz), 131.8, 131.1 (d, $J_{\text{C-P}} = 10.6$ Hz), 129.1, 128.3 (d, $J_{\text{C-P}} = 12.1$ Hz), 126.9, 126.4, 121.9, 120.9, 119.8, 111.1, 107.9 (d, $J_{\text{C-P}} = 119.7$ Hz), 58.4, 23.5, 21.0. ^{31}P NMR (162 MHz, CDCl_3) δ 20.88. HRMS (ESI-TOF) m/z $[\text{M} + \text{H}]^+$ Calcd for $\text{C}_{39}\text{H}_{39}\text{NOP}$ 568.2769, found 568.2768.

((1H-Indol-2-yl)diphenylmethyl)di(naphthalen-1-yl)phosphine oxide (4al))—

General procedure B was followed using **1a** (74.84 mg, 0.25 mmol), **2l** (113.37 mg, 0.375 mmol) and $\text{Yb}(\text{OTf})_3$ (31.01 mg, 0.05 mmol, 0.2 equiv) in CH_3CN (2 mL) at 100 °C for 12 h. Chromatography (10% EtOAc/dichloromethane) afforded **4al** (141.54 mg) in 97% yield as a white solid (mp 213–215 °C): ^1H NMR (400 MHz, CDCl_3) δ 8.90 (s, 1H), 8.70 (s, 1H), 8.51 (d, $J = 3.0$ Hz, 1H), 7.84 (d, $J = 43.9$ Hz, 4H), 7.55–7.27 (m, 6H), 7.24–7.21 (m, 1H), 7.21–7.10 (m, 7H), 7.08–6.94 (m, 6H), 6.85–6.76 (m, 2H), 6.53 (s, 1H). $^{13}\text{C}\{^1\text{H}\}$ NMR (100 MHz, CDCl_3) δ 148.8 (d, $J_{\text{C-P}} = 12.8$ Hz), 141.5, 137.8, 135.9, 135.8, 134.1, 133.9, 132.9, 129.7, 129.6, 129.1, 128.6, 127.7, 127.2, 126.9, 126.8, 126.4, 124.4, 122.4, 121.2 (d, $J_{\text{C-P}} =$

5.4 Hz), 111.1, 102.1 (d, J_{C-P} = 125.9 Hz), 48.0. ^{31}P NMR (162 MHz, CDCl_3) δ 31.01. HRMS (ESI-TOF) m/z $[\text{M} - \text{H}]^-$ Calcd for $\text{C}_{41}\text{H}_{29}\text{NOP}$ 582.1987, found 582.1992.

(2-Benzhydryl-1H-indol-3-yl)di(thiophen-2-yl)phosphine oxide (4am)—General procedure B was followed using **1a** (74.84 mg, 0.25 mmol), **2m** (80.34 mg, 0.375 mmol) and $\text{Yb}(\text{OTf})_3$ (31.01 mg, 0.05 mmol, 0.2 equiv) in CH_3CN (2 mL) at 100 °C for 12 h. Chromatography (10% EtOAc/dichloromethane) afforded **4am** (66.91 mg) in 54% yield as a white solid (mp 303–305 °C): ^1H NMR (400 MHz, $\text{DMSO}-d_6$) δ 11.80 (d, J = 3.4 Hz, 1H), 8.06–7.98 (m, 2H), 7.47–7.40 (m, 3H), 7.36–7.29 (m, 4H), 7.27–7.18 (m, 8H), 7.12–7.05 (m, 1H), 6.96 (s, 1H), 6.93–6.86 (m, 1H), 6.77 (d, J = 8.0 Hz, 1H). $^{13}\text{C}\{^1\text{H}\}$ NMR (100 MHz, $\text{DMSO}-d_6$) δ 150.0 (d, J_{C-P} = 19.0 Hz), 141.8, 137.5, 136.9 (d, J_{C-P} = 12.3 Hz), 136.3, 135.7 (d, J_{C-P} = 11.2 Hz), 134.4 (d, J_{C-P} = 5.2 Hz), 128.7, 128.4 (d, J_{C-P} = 5.6 Hz), 127.6 (d, J_{C-P} = 13.2 Hz), 126.6, 122.0, 120.4, 119.7, 112.0, 101.5 (d, J_{C-P} = 138.1 Hz), 46.7. ^{31}P NMR (162 MHz, $\text{DMSO}-d_6$) δ 5.73. HRMS (ESI-TOF) m/z $[\text{M} + \text{H}]^+$ Calcd for $\text{C}_{29}\text{H}_{23}\text{NOPS}_2$ 496.0959, found 496.0950.

(2-Benzhydryl-1H-indol-3-yl)(phenyl)(p-tolyl)phosphine oxide (4an)—General procedure B was followed using **1a** (74.84 mg, 0.25 mmol), **2n** (81.08 mg, 0.375 mmol) and $\text{Yb}(\text{OTf})_3$ (31.01 mg, 0.05 mmol, 0.2 equiv) in CH_3CN (2 mL) at 100 °C for 12 h. Chromatography (10% EtOAc/dichloromethane) afforded **4an** (79.61 mg) in 64% yield as a white solid (mp 290–292 °C): ^1H NMR (400 MHz, $\text{DMSO}-d_6$) δ 11.71 (d, J = 2.9 Hz, 1H), 7.63–7.54 (m, 3H), 7.52–7.44 (m, 4H), 7.41 (d, J = 8.2 Hz, 1H), 7.33–7.27 (m, 6H), 7.24–7.19 (m, 2H), 7.18–7.13 (m, 4H), 7.09–7.02 (m, 1H), 6.91–6.73 (m, 2H), 6.59 (d, J = 8.1 Hz, 1H), 2.34 (s, 3H). $^{13}\text{C}\{^1\text{H}\}$ NMR (100 MHz, $\text{DMSO}-d_6$) δ 149.6 (d, J_{C-P} = 16.8 Hz), 141.8 (d, J_{C-P} = 2.7 Hz), 141.7 (d, J_{C-P} = 3.7 Hz), 137.0 (d, J_{C-P} = 11.5 Hz), 135.5, 134.4, 132.0, 131.6, 131.3 (d, J_{C-P} = 10.9 Hz), 130.9, 129.2 (d, J_{C-P} = 12.3 Hz), 128.7 (d, J_{C-P} = 13.0 Hz), 128.4 (d, J_{C-P} = 11.1 Hz), 128.1 (d, J_{C-P} = 12.0 Hz), 126.5, 121.7, 120.2, 119.7, 112.0, 101.1 (d, J_{C-P} = 124.4 Hz), 46.9, 21.1. ^{31}P NMR (162 MHz, $\text{DMSO}-d_6$) δ 22.01. HRMS (ESI-TOF) m/z $[\text{M} + \text{H}]^+$ Calcd for $\text{C}_{34}\text{H}_{29}\text{NOP}$ 498.1987, found 498.1983.

General Procedure C

5 was made by using the known procedure.²² To a mixture of **3aa** (174.078 mg, 0.36 mmol, 1 equiv), $\text{Ti}(\text{OiPr})_4$ (51.16 mg, 0.18 mmol, 0.5 equiv) and $\text{HSi}(\text{OCH}_2\text{CH}_3)_3$ (354.82 mg, 2.16 mmol, 6 equiv) was added 5 mL of anhydrous toluene, under Ar atmosphere. The pale brown slurry was heated to reflux, the solid dissolved and the solution turned gray-green 12 h later. The reaction was stopped, cooled to r.t. and the solvent was removed in vacuo to afford a brown solid. The corresponding product **5** was isolated by silica gel column chromatography with a petroleum ether/ethyl acetate (50/1) mixture as eluent to afford **5** (89.21 mg) in 53% yield.

2-((Diphenylphosphanyl)diphenylmethyl)-1H-indole (5)—General procedure C was followed using **3aa** (174.078 mg, 0.36 mmol, 1 equiv), $\text{Ti}(\text{OiPr})_4$ (51.16 mg, 0.18 mmol, 0.5 equiv) and $\text{HSi}(\text{OCH}_2\text{CH}_3)_3$ (354.82 mg, 2.16 mmol, 6 equiv) in toluene (5 mL) at 120 °C for 12 h. Chromatography (2% EtOAc/petroleum ether) afforded **5** (89.21 mg) in 53% yield as a white solid (mp 90–92 °C): ^1H NMR (400 MHz, CDCl_3) δ 10.27 (s, 1H), 7.52 (d, J =

7.9 Hz, 1H), 7.49–7.42 (m, 3H), 7.30–7.23 (m, 7H), 7.21–7.10 (m, 9H), 7.01 (d, $J = 7.9$ Hz, 4H), 6.28 (d, $J = 2.3$ Hz, 1H). $^{13}\text{C}\{^1\text{H}\}$ NMR (100 MHz, CDCl_3) δ 137.4, 136.3, 133.9 (d, $J_{\text{C-P}} = 2.2$ Hz), 133.0 (d, $J_{\text{C-P}} = 8.6$ Hz), 132.5 (d, $J_{\text{C-P}} = 2.7$ Hz), 132.3 (d, $J_{\text{C-P}} = 4.9$ Hz), 131.0, 130.0, 128.6 (d, $J_{\text{C-P}} = 11.5$ Hz), 128.2, 127.0 (d, $J_{\text{C-P}} = 1.5$ Hz), 122.6, 120.6, 120.0, 111.7, 105.8 (d, $J_{\text{C-P}} = 6.1$ Hz), 60.3 (d, $J_{\text{C-P}} = 61.3$ Hz). ^{31}P NMR (162 MHz, CDCl_3) δ -16.13. HRMS (ESI-TOF) m/z $[\text{M} + \text{H}]^+$ Calcd for $\text{C}_{33}\text{H}_{27}\text{NP}$ 468.1881, found 468.1880.

2-Benzhydryl-3-(diphenylphosphanyl)-1H-indole (6)—General procedure C was followed using **4aa** (174.078 mg, 0.36 mmol, 1 equiv), $\text{Ti}(\text{OiPr})_4$ (51.16 mg, 0.18 mmol, 0.5 equiv) and $\text{HSi}(\text{OCH}_2\text{CH}_3)_3$ (354.82 mg, 2.16 mmol, 6 equiv) in toluene (5 mL) at 120 °C for 12 h. Chromatography (2% EtOAc/petroleum ether) afforded **6** (136.34 mg) in 81% yield as a white solid (mp 102–104 °C): ^1H NMR (400 MHz, CDCl_3) δ 8.00 (d, $J = 3.1$ Hz, 1H), 7.24–7.22 (m, 4H), 7.21–7.17 (m, 3H), 7.16 (d, $J = 4.9$ Hz, 3H), 7.12 (dd, $J = 5.8, 2.3$ Hz, 7H), 7.09–7.04 (m, 4H), 6.98 (t, $J = 7.5$ Hz, 1H), 6.91 (d, $J = 8.0$ Hz, 1H), 6.76 (t, $J = 7.6$ Hz, 1H), 6.46 (d, $J = 5.3$ Hz, 1H). $^{13}\text{C}\{^1\text{H}\}$ NMR (100 MHz, CDCl_3) δ 149.0 (d, $J_{\text{C-P}} = 43.4$ Hz), 142.1, 137.2 (d, $J_{\text{C-P}} = 6.1$ Hz), 136.7 (d, $J_{\text{C-P}} = 2.9$ Hz), 132.6 (d, $J_{\text{C-P}} = 18.0$ Hz), 130.1 (d, $J_{\text{C-P}} = 4.8$ Hz), 129.1, 128.7, 128.2 (d, $J_{\text{C-P}} = 6.3$ Hz), 127.7, 126.9, 121.9, 121.8, 120.2, 111.1, 103.8 (d, $J_{\text{C-P}} = 123.1$ Hz), 49.1 (d, $J_{\text{C-P}} = 15.8$ Hz). ^{31}P NMR (162 MHz, CDCl_3) δ -31.62. HRMS (ESI-TOF) m/z $[\text{M} + \text{H}]^+$ Calcd for $\text{C}_{33}\text{H}_{27}\text{NP}$ 468.1881, found 468.1886.

General Procedure D

To a stirred solution of **6** (935.10 mg, 2 mmol, 1 equiv) in THF (7 mL) under Ar atmosphere, was added *n*-BuLi (0.96 mL, 2.4 mmol, 1.2 equiv, 2.5 M) dropwise at -78 °C. The reaction was then slowly warmed to r.t. and then stirred for a further 2 h at room temperature. After the mixture cooled to -78 °C, PPh_2Cl (529.12 mg, 2.4 mmol, 1.2 equiv) in THF (5 mL) was added dropwise. The mixture was then warmed to rt and stirred for a further 2 h. It was then quenched with NH_4Cl solution at 0 °C. Chromatography (petroleum ether/ethyl acetate = 50/1) afforded **7** (599.59 mg) in 46% yield as a white solid.¹⁷

2-Benzhydryl-1,3-bis(diphenylphosphanyl)-1H-indole (7)—General procedure D was followed using **6** (935.10 mg, 2 mmol, 1 equiv), *n*-BuLi (0.96 mL, 2.4 mmol, 1.2 equiv, 2.5 M) and PPh_2Cl (529.12 mg, 2.4 mmol, 1.2 equiv) in THF (12 mL) at -78 °C for 2 h. Chromatography (2% EtOAc/petroleum ether) afforded **7** (599.59 mg) in 46% yield as a white solid (mp 121–123 °C): ^1H NMR (400 MHz, CDCl_3) δ 7.31 (dd, $J = 7.5, 1.7$ Hz, 4H), 7.29–7.21 (m, 5H), 7.19–7.11 (m, 12H), 7.05–6.93 (m, 10H), 6.84 (dd, $J = 7.3, 1.9$ Hz, 1H), 6.74 (dd, $J = 7.4, 1.7$ Hz, 1H), 6.66–6.57 (m, 2H). $^{13}\text{C}\{^1\text{H}\}$ NMR (100 MHz, CDCl_3) δ 156.7 (d, $J_{\text{C-P}} = 63.5$ Hz), 141.2, 141.2, 140.6 (d, $J_{\text{C-P}} = 9.3$ Hz), 137.2 (d, $J_{\text{C-P}} = 9.1$ Hz), 134.1 (d, $J_{\text{C-P}} = 17.0$ Hz), 132.6 (d, $J_{\text{C-P}} = 18.3$ Hz), 131.2 (d, $J_{\text{C-P}} = 20.1$ Hz), 130.0 (t, $J_{\text{C-P}} = 2.9$ Hz), 128.9, 128.5 (d, $J_{\text{C-P}} = 5.6$ Hz), 128.2 (d, $J_{\text{C-P}} = 5.5$ Hz), 128.0, 127.7, 126.3, 122.4, 121.6, 120.8, 115.4, 109.4 (d, $J_{\text{C-P}} = 8.2$ Hz), 60.5. ^{31}P NMR (162 MHz, CDCl_3) δ 36.24 (d, $J = 3.7$ Hz), -29.02 (d, $J = 2.7$ Hz). HRMS (ESI-TOF) m/z $[\text{M} + \text{H}]^+$ Calcd for $\text{C}_{45}\text{H}_{36}\text{NP}_2$ 652.2323, found 652.2330.

General Procedure E

To a THF (5 mL) solution of **6** (935.10 mg, 2 mmol, 1 equiv) was added NaH (120.00 mg, 5 mmol, 2.5 equiv) at 0 °C. The reaction mixture was stirred at the same temperature for 30 min. Then the corresponding iodide (312.268 mg, 2.2 mmol, 1.1 equiv) was added. The reaction mixture was stirred at room temperature until complete consumption of stirred material (detected by TLC). The reaction mixture was quenched with water. Chromatography (petroleum ether/ethyl acetate = 50/1) afforded **8** (606.79 mg) in 63% yield as a white solid.¹⁷

2-Benzhydryl-3-(diphenylphosphanyl)-1-methyl-1H-indole (8)—General procedure E was followed using **6** (935.10 mg, 2 mmol, 1 equiv), NaH (120.00 mg, 5 mmol, 2.5 equiv) and iodide (312.268 mg, 2.2 mmol, 1.1 equiv) in THF (12 mL) at –78 °C for 2 h. Chromatography (2% EtOAc/petroleum ether) afforded **8** (606.79 mg) in 63% yield as a white solid (mp 101–103 °C): ¹H NMR (400 MHz, CDCl₃) δ 7.35–7.27 (m, 3H), 7.21–7.10 (m, 18H), 7.10–7.05 (m, 1H), 7.03 (d, *J* = 10.9 Hz, 1H), 6.92 (d, *J* = 8.0 Hz, 1H), 6.82–6.77 (m, 1H), 3.33 (s, 3H). ¹³C{¹H}NMR (100 MHz, CDCl₃) δ 149.0 (d, *J*_{C–P} = 40.4 Hz), 139.5, 138.0 (d, *J*_{C–P} = 2.8 Hz), 136.4 (d, *J*_{C–P} = 6.6 Hz), 131.4, 131.2, 128.1, 127.4, 127.1 (d, *J*_{C–P} = 6.2 Hz), 126.5, 125.5, 120.9, 120.7, 119.0, 108.2, 103.4, 46.7, 30.9. ³¹P NMR (162 MHz, CDCl₃) δ –29.83. HRMS (ESI-TOF) *m/z* [M + H]⁺ Calcd for C₃₄H₂₉NP 482.2038, found 482.2035.

General Procedure F

6 (467.55 mg, 1 mmol, 1 equiv), S₈ (32.00 mg, 0.125 mmol, 0.125 equiv), dry CH₂Cl₂ (2 mL) and a stir bar were added to a sealed tube. After being stirred at 80 °C for 12 h, the mixture was evaporated under vacuum. The corresponding product **9** (274.79 mg, 55% yield) was isolated by silica gel column chromatography with petroleum ether/ethyl acetate (50/1) mixture as eluent.²³

(2-Benzhydryl-1H-indol-3-yl)diphenylphosphine sulfide (9)—General procedure F was followed using **6** (467.55 mg, 1 mmol, 1 equiv), S₈ (32.00 mg, 0.125 mmol, 0.125 equiv) in CH₂Cl₂ (2 mL) at 80 °C for 12 h. Chromatography (2% EtOAc/petroleum ether) afforded **9** (274.79 mg) in 55% yield as a white solid (mp 175–177 °C): ¹H NMR (400 MHz, CDCl₃) δ 8.23 (s, 1H), 7.78–7.67 (m, 4H), 7.45–7.35 (m, 2H), 7.33–7.27 (m, 5H), 7.20–7.14 (m, 6H), 7.14–7.09 (m, 1H), 6.98–6.92 (m, 4H), 6.88–6.82 (m, 1H), 6.60–6.54 (m, 2H). ¹³C{¹H}NMR (100 MHz, CDCl₃) δ 147.9 (d, *J*_{C–P} = 18.9 Hz), 141.1, 135.4 (d, *J*_{C–P} = 11.2 Hz), 134.2, 133.3, 132.1 (d, *J*_{C–P} = 11.0 Hz), 131.2 (d, *J*_{C–P} = 3.0 Hz), 129.3 (d, *J*_{C–P} = 9.9 Hz), 129.1, 128.5, 128.4 (d, *J*_{C–P} = 12.6 Hz), 126.9, 122.5, 121.1, 111.1, 101.9 (d, *J*_{C–P} = 105.8 Hz), 47.7. ³¹P NMR (162 MHz, CDCl₃) δ 30.55. HRMS (ESI-TOF) *m/z* [M + H]⁺ Calcd for C₃₃H₂₇NPS 500.1602, found 500.1609.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

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Figure 1.
Limited substrates under Yb(OTf)₃ or Y(Pfb)₃-catalyzed conditions.

Figure 2.
LUMO orbital of the cation from ionization of **1**.

Scheme 1.
C3-Functionalization of 2-Indolylmethanols with Nucleophile

(a) *Previous work: regioselective C3-position substitution (C-C bond formation)*

(b) *This work: Lewis acid-controlled regioselective phosphorylation (C-P bond formation)*

Scheme 2.
Regioselective Substitutions of 2-Indolylmethanols

Scheme 3. Regioselective Y(Pfb)₃-Catalyzed Benzylic Phosphorylation of 2-Indolylmethanols^a

^aReaction conditions: **1** (0.25 mmol), **2** (0.375 mmol), Y(Pfb)₃ (20 mol %), CH₃CN (2 mL) at 100 °C for 12 h. ^bConducted on a 5 mmol scale.

Scheme 4. Regiospecific Yb(OTf)₃-Catalyzed C3-Phosphorylation of 2-Indolylmethanols^a

^aReaction conditions: **1** (0.25 mmol), **2** (0.375 mmol), Yb(OTf)₃ (20 mol %), CH₃CN (2 mL) at 100 °C for 12 h. ^bConducted on a 5 mmol scale.

Scheme 5.
Mechanistic Probes

Scheme 6.
Proposed Mechanistic Profile

Scheme 7.
Derivatization of Products

Table 1

Optimization of the Reaction Conditions^a

entry	catalyst	solvent	temp (°C)	time (h)	3aa/4aa yield (%)
1	FeCl ₃	CH ₃ CN	100	12	54/15
2	CuBr ₂	CH ₃ CN	100	12	48/0
3	AlCl ₃	CH ₃ CN	100	12	85/0
4	TsOH	CH ₃ CN	100	12	0/70
5	BF ₃ ·OEt ₂	CH ₃ CN	100	12	18/26
6	Cu(OTf) ₂	CH ₃ CN	100	12	0/69
7	La(OTf) ₃	CH ₃ CN	100	12	28/31
8	Sc(OTf) ₃	CH ₃ CN	100	12	22/40
9	Nd(Pf ₆) ₃	CH ₃ CN	100	12	67/<5
10	Sc(Pf ₆) ₃	CH ₃ CN	100	12	31/<5
11	Yb(Pf ₆) ₃	CH ₃ CN	100	12	77/<5
12	Yb(OTf)₃	CH₃CN	100	12	<5/76
13	Y(OTf) ₃	CH ₃ CN	100	12	0/72
14	Dy(OTf) ₃	CH ₃ CN	100	12	12/53
15	Y(Pf₆)₃	CH₃CN	100	12	87/<5
16	TiOH	CH ₃ CN	100	12	35/43 (21/57) ^c
17	PFBA ^b	CH ₃ CN	100	12	53/27

^aReaction conditions: **1a** (0.25 mmol), **2a** (0.375 mmol), catalyst (20 mol %), CH₃CN (2 mL), 100 °C, 12 h, under air.^bPFBA: pentafluorobenzoic acid.^cRun 48 h.